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Design and experimentation of communication and of a teaching sequence on atmospheric physics

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Abstract

Weather and climate are topical issues widely present in the media, in the public culture, in political and socio-economic agendas and also in school guidelines. Having said that, confusion and a lot of misconceptions still exist with regards to issues such as climate change, greenhouse gases and the greenhouse effect, pollution, anthropogenic emissions, ozone hole, predictability of weather and climate, stationary processes, radiation fluxes and balances in the Earth system etc.

These themes are poorly addressed in the actual teaching practice in secondary schools, particularly from a quantitative point of view involving the underlying laws of physics, which are necessary for the understanding and construction of correct conceptual models of phenomena. Teachers often do not feel comfortable or lack the specific background for addressing such themes quantitatively, claiming for training initiatives which happen unfortunately only as a result of sporadic and local initiatives. For historical reasons, typical of the Italian context, these themes are usually addressed in subjects like geography or natural sciences for what concerns education in formal contexts such as primary and secondary schools and universities, but their treatment and significance would greatly benefit from an interdisciplinary approach, involving also the quantitative experimental approach of physics. At the same time, teaching physics from its general principles to their application in the context of weather phenomena and climate system, would improve the engagement and interest of students, fostering cooperation among teachers of different subjects, bridging boundaries and approaches characteristic of single disciplines. This would promote an integrated view of science as the result of a process, based on the application of the scientific method to the investigation and modeling of phenomena, where also technological advancement plays an important role, rather than as a mere collection of results and knowledge.

In this perspective the present work develops from the research in atmospheric physics, performed by the candidate during one year at Concordia station, Antarctica, presenting on one hand a series of physics communication initiatives designed and tested with innovative formats such as TEDx conferences, videoconferences with researchers working on the field, social platforms and traditional media, targeted to different audiences. On the other hand it presents the proposal of a teaching learning sequence based on quantitative experimental activities, demonstrations and simulations, targeted to secondary school students and pre-service teachers, integrating general physics with its applications to the atmosphere and to the climate system. The teaching learning sequence has been experimented with graduate students of the course: "Experimental physics laboratory at high school I", held at the Department of Physics of the University of Trento and in collaboration with IPRASE, it has been proposed in the form of a training course for physics and chemistry teachers and their technical assistants as a framework for the integration of physics and chemistry. The results of pre and post tests used as an evaluation tool of this preliminary experimentation will be presented, encouraging future developments of the sequence and further diffusion of weather and climate issues in the teaching practice through capillary pre-teachers' and teachers' training initiatives.

Contents

Introduction

Climate and *weather*, particularly with regards to the enhanced greenhouse effect and the associated global warming are current environmental topics widely present in the *media* and in the *public opinion*[29] [30]. These topics will involve and affect citizen, societies and economies of the future with their ability to mitigate and to adapt to changing global equilibria[31].

However from a scientific point of view, the explanations given by the same media are usually *inaccurate* or *misleading*[36] [37]. Such inaccuracy is typical for the vast majority of scientific knowledge regarding the climate and more in general the physics of the atmosphere.

One of the contributing factors could be the *complexity* of the involved phenomena, which require *cross-cutting* expertise in physics (from thermodynamics to optical physics and quantum mechanics)[173], [174], [176], but also in other scientific areas such as chemistry, technology, geography, biology etc.[178] [198] [179]. Another source of complexity results from the *many dimensions* involved in environmental issues, these being scientific, psychological-behavioral, societal, political, economic and ethical[328] [33].

The *physical processes* underlying the phenomenological manifestations of weather and climate in the Earth system are *poorly* addressed from a *quantitative*, experimental point of view, typical of the way physics and science proceed towards the understanding and mastering of structures and processes upon which nature works. The best environment for adopting such a point of view is traditionally represented by *formal education* in schools[157], but even if school guidelines suggest climate and weather as relevant issues to be taught at school[154] [155], their systematic introduction into the teaching practice is still far from being ubiquitous for a series of reasons, ranging from teachers lacking the necessary background and confidence to the history of the Italian meteorological service, to the lack of specific University courses educating professional figures in these fields in Italy[186] [184] [185] [188].

Many environmental and science educators and researchers have explored students' conceptual understandings, misconceptions, and knowledge of some issues, particularly greenhouse effect, global warming, and climate change but few have investigated the ways students conceptualize climate as a system or how components of the system influence climate and few have tried to integrate general physics traditionally taught at the secondary school level with its applications to the atmosphere, weather and climate[189] [191] [192].

After decades of climate change communication, many misconceptions about the physics of climate change and of the atmosphere are still present in students, teachers and textbooks [184] [190] [211] [214] [249] [216] [217] [268].

A more capillary diffusion of scientific knowledge and correct conceptual models about environmental issues is then urgent and necessary in front of the global planetary problems related to climate change which will require essential choices both from the side of political institutions and from the side of the single citizen[40] [41] [6].

For this reason an effective action of better scientific communication in informal contexts on one hand and of scientific education in formal contexts both for students and teachers on the other hand is becoming essential[35] [39].

The present work developed in a series of consequential steps. The research activities performed by the candidate in Antarctica, have been transformed, adapted and directed on one hand to an intense communication activity, experimenting with different and innovative media and formats and on the other hand to the design of a teaching sequence targeted at secondary school level, consisting of simple quantitative experimental activities bridging from general physics to its application to atmospheric phenomena and processes relevant for weather and climate, taking into account and addressing typical misconceptions.

The first chapter presents a general introduction to the field of research which the present work belongs to: physical science education and communication research, with a focus on environmental issues. Ideas, concepts, methods and good practices about physics education and communication research introduced here form the general framework which inspired and guided the design, implementation and experimentation of the communication initiatives, of the teaching sequence and of the training course for secondary school teachers which constitute the core of the present work and which will be presented in the following second and third chapter.

The second chapter introduces the scientific fields and the research activities performed by the candidate at the Italian and French station Concordia in Antarctica, together with the geographical, environmental and institutional context. Research activities presented more in detail will be the ones related to the radiometric and meteo-climatological observatories, funded by the Italian Antarctic Program (PNRA). The second part of the chapter will present the transformation and adaptation of these research activities into a series of innovative communication initiatives experimented by the candidate, addressing different audiences, experimenting with different media and innovative formats.

The third chapter constitutes the main and original part of the research, presenting the design and development of a teaching sequence targeted to secondary school level, consisting in a series of quantitative experimental activities and demonstrations integrating general physics with its application to some of the atmospheric phenomena related to climate and weather. This teaching sequence has been experimented with graduate students of the course "experimental physics laboratory at high school I" and has been adapted to a training course for physics and chemistry teachers and technical assistants in the framework of an experimentation on integrated sciences promoted by IPRASE. A preliminary evaluation of the first experimentation has been done using pre and post tests based on concept inventories which results will be discussed.

In the appendices there are a list of the communication initiatives performed by the candidate, the teaching materials produced and used for the experimentation of the teaching sequence, pre and post tests and a list of the research works published on peer reviewed journals.

Chapter 1

Physical science communication and education research

In this chapter it will be presented a general introduction to the field of research which the present work belongs to: *physics education research*, with a focus on *atmospheric* and *climate* physics and *environmental* issues[54] [72] [73]. The ideas, concepts and good practices introduced here, have inspired and guided the design, implementation and experimentation of the *communication initiatives*, of the *teaching sequence* and of the *training course for secondary school teachers* which constitute the core of the present work and which will be presented in the following chapters.

Physical science communication and education are two complementary aspects in the formation and in the diffusion of scientific culture within society, but they differ greatly with regards to their goals and methods.

Communication is usually done in *informal contexts* and aims at giving *information* to the public, to policy makers or to stakeholders, promoting awareness on certain scientific or technological issues which could also have potential impacts on society, production and economies. The public of those communication initiatives does not usually have a strong background in the subject being communicated and lacks of adequate tools for a deep understanding.

On the contrary, *education* is usually done in *formal contexts* (i.e. schools, universities etc.), teaching students contents and specific tools which are characteristic of science and of scientific thinking, helping them at forming a personal background of *knowledge*, *tools* and *methods*, which can then be applied in a professional context, and in real situations. For this reasons there are scientific careers which guide students to the formation of the necessary competencies for the acquisition of increasingly sophisticated tools, reasoning and argumentations.

How shall science being communicated? Researchers question themselves about that since many years and studies showed that there are many different and complementary approaches for catching the attention and engaging a vast public. In any case, given the heterogeneity of the recipients, it is impossible to discuss any of these approaches without taking into consideration the recipients of communication and at the same time different tools and strategies are needed for each of them, ranging from educational interventions, to traditional journalism, from face to face events, to the interaction through social media. From this point of view the present work will discuss in parallel actions of scientific communication directed towards a generic public (communication) and actions focused on students and teachers (education).

In general, for what concerns communication with the general public, there are many factors pushing scientists to be more involved in activities of communication and outreach. However, there are several cultural factors which contribute to the divide between science and society such as the declined authority of scientists, the diffusion of communication media, the increased complexity of the scientific production. Recent studies even showed that citizen do not believe that scientists are telling the truth about the more controversial issues related to science and technology[12]. The case of climate change and global warming and of their causes is probably one of the most symbolic and certainly one on which it is more necessary to intervene with effective actions.

For what concerns education, many recommendations have been done by the European Union about the need to innovate the basic science education. Among them the incorporation of environmental issues in science curricula and the promotion of schools as places of education for citizenship[162] [164].

The study of the physical mechanism underlying the greenhouse effect could foster the motivation and interest of students, stimulating a sensitivity and a proactive attitude with regards to the problem of global warming, promoting a deeper understanding of the physical concepts and laws being at the base of atmospheric science. Some research works[158] [267] claim that education and scientific knowledge about the problems related to global warming and the greenhouse effect could contribute to the formation and stimulation of virtuous behaviors, resulting in choices and actions towards the reduction or mitigation of climate change consequences[160] [161].

Weather and climate are common chat topics, being part of the daily experience of human beings and have a profound influence on life on Earth, being essential for health, food production and well being. Even if they are linked, it is important to distinguish their meaning.

Weather describes the conditions (state) of the atmosphere at a certain place and time in terms of temperature, pressure, humidity, wind, and other key parameters such as cloud cover and precipitation. These conditions, together with the conservation laws of physics in the form of dynamical equations, are responsible for the developing, manifestation and decaying of weather phenomena with different characteristic spatial and temporal scales and predictability. These weather phenomena range from waves in the westerlies to trade winds in the in the planetary scale, from mid-latitude low and high pressure systems with their associated frontal zones, showers in the synoptic scale, from local winds such as land and sea breezes, to convective systems, thunderstorms and tornadoes in the mesoscale, from turbulent exchanges to wind gusts and dust storms in the microscale. In this sense weather has only limited predictability since beyond a week or two individual weather systems are unpredictable.

Climate[316] in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The relevant quantities are most often surface variables such as temperature, precipitation and wind, classically averaged over 30 years, as defined by the World Meteorological Organization. Climate in a wider sense, is the state of the climate system including also all the associated statistics (mean, variability, frequency, magnitude, persistence, trends, etc.) often combining parameters to describe phenomena such as droughts. The climate system is complex and consists of five major components mutually interacting: the atmosphere, the hydrosphere, the cryosphere, the lithosphere and the biosphere. Its evolution in time depends both on its own internal dynamics and on external forcings such as volcanic eruptions, solar variations and anthropogenic forcings such as the atmospheric composition and land use changes.

Climate change refers to a change in the state of the climate system that can be detected (e.g., by the use of statistical tests) from changes in the mean and/or variability of its properties, and that persists for an extended period (i.e. decades or longer).

Three are the basic ingredients which determine the Earth's climate, and our environment:

- solar heating of the planet balanced by energy loss to space and emitted by the Earth
- atmosphere, ocean, land, and ice responses to heating which provide feedbacks mitigating or accentuating planetary temperature changes
- regional environmental systems, having innate patterns of climate variability dictated by their unique physical-chemical-biological conditions. These systems respond to the planetary energy balance and interact with each another via teleconnections.

Jarrett[323] identified a series of scientific concepts necessary to understand climate change such as: carbon cycle and fossil fuels, electromagnetic spectrum, interactions between greenhouse gases (GHG) and electromagnetic radiation, natural climate variability in the past and relationship to CO2 levels, difference between weather and climate, proportions of greenhouse and non-greenhouse gases in the atmosphere, radiative forcing capacity, feedback, stationary equilibrium of energy and conservation of energy.

Atmospheric physics is the application of physics to the study of the Earth's or of other planets' atmospheres. By using the principles and theory of mechanics, fluid dynamics, thermodynamics and statistical physics, electrodynamics and quantum physics in terms of interaction of the electromagnetic radiation with matter, it tries to model quantitatively characteristic atmospheric phenomena, processes and systems, which also play a relevant role in determining what we observe as weather or climate. At the same time, it applies the same physical and mathematical principles and theories with the help of technology to the study, design and construction of instruments for studying the atmosphere and at the same time for the analysis and interpretation of the data they provide. It is also concerned with the understanding of how these atmospheric processes tie into and are influenced by other parts of the climate system such as the hydrosphere, the cryosphere, the litosphere and the biosphere thus being closely interconnected with other disciplines such as chemistry, biology and geology[44].

1.1 Communication

Science communication is a new mission for science and the science communicator is a new job which is becoming more and more important for the survival of science itself[1]. It comprises two words: science and communication. This means on one hand that the science communicator must ideally know what science is, how science is done in laboratories (i.e. the scientific method) and have a good understanding of the subject he wants to communicate. On the other hand the science communicator must also know ideally, how to work with the media and especially understand the needs, interests and expectations of the public he wants to address. From this, a science communicator can be a researcher or a journalist. The first works with science but usually misses the the public's perspective (scientific understanding of the public). The second knows very well the media, the process of communication and the public's point of view but lacks of a background in science. Both have advantages and drawbacks and the researcher can choose to learn the basics of communication for doing it in first person or to work with journalists and other professionals of communication.

Science and society are in close relationship with each other[3] and as in a marriage, this relationship is good when it is based on mutual trust, listening and comprehension. Like two partners, science and society look for each other and they need each other, united by a non written contract but still binding. Society needs science as an engine for its social, economic and political well being, while science lives out of the resources, the talents and the freedom which society gives her. With the crisis of the authority of science, triggered by disasters following the use of technologies, made available by scientific discoveries, and by the increased voice of society thanks to the internet and the media, the relationship between science and society has come to a crisis.

Trying to solve this crisis, the first idea which dominated the majority of initiatives has been the "public understanding of science", the "standard model" for interpreting the relationship between science, technology and society[1]. Its basic assumption is the "deficit model" which states that at the origin of the controversies between science and society is the lack of understanding in citizen of scientific knowledge, theories and methodologies. But this interpretation has demonstrated to be a failure[4] since the public and so society cannot be considered as homogeneous and passive recipients of knowledge being translated just with a simplified language and transmitted by scientists as to fill the cultural and cognitive holes of the public.

The process of communication is more complex and it does not work if interpreted as a one way relationship. The paradigm has then changed from "public understanding of science" to "scientific understanding of public"[1]. This means that the researchers have to take into consideration the questions, interests, competences of their public. The relationship between science and society and so communication, works if it is a two ways interaction where a dialogue exists between the two parts and both respect each others needs, negotiating a mutual consensus through information and dialogue.

1.1.1 Why science communication matters

The National Permanent Conference of the directors of the Faculties of Sciences and Technologies is concerned with the cultural, social and economic underdevelopment which awaits Italy in the years to come; a country where the public perception of science is getting worse, research funding is one of the lowest in Europe and fundamental research is contracting. One of the essential and often neglected aspects to be considered in counteracting this situation is an adequate appreciation of the work of researchers. If citizens do not know or do not appreciate what is being done in research laboratories it is difficult to find social, political and economic support and at the same time talents and human resources, which are both necessary to let science and technology be further developed and to maintain our current well being.

Today, science is living a big paradox. As a matter of fact, it is a prevailing and fundamental building block of our contemporary societies, being able to deeply change our living habits, our way of producing goods and so our economies, our working habits and even our way of thinking, our ethics and our social interactions. On the other hand science is one of the less diffuse and shared cultures in our societies. With few exceptions (such as Finland and South Korea), international surveys are almost unanimous in reporting a lack of scientific culture in citizen, even in most advanced countries[1] [13] [12]. And this is getting even worse since scientific knowledge and its applications are continuously increasing and with increasing speed.

Presidents of the European governments who are willing to make the European Union the more competitive knowledge based society and economy in the world, are worried about the deficit in the competence of young people in STEM (Science, Technology, Engineering and Mathematics) subjects.

So since scientific research is more and more the true engine of cultural, social and economic dynamics, good scientific communication becomes an important factor of democracy and progress.

1.1.2 The advantage of being a researcher

Not all the researchers feel comfortable in the role of communicators, some of them can even have the feeling of "getting their hands dirty", others may feel useless the idea of adding their contribution to the amount of information which already overwhelms us. But nowadays not being well represented in the public arena exposes to the risks of loosing voice, resources, trust and often even freedom.

Communication with the general public has its risks by the way and among them, one is that better communication can prevail over the actual value of the content being communicated.

All the big institutions and private companies have had the need for public communication, having professionals devoted to this specific task. Science is starting to do it with decades of delay, but with science, the active involvement of researchers remains essential.

Science communication can be done by researchers, the experts of science or by journalists, the experts of communication, of the media and of the public. But since science is a very specialistic and specific field, it is difficult for a non expert to handle in depth scientific themes and see all the implications and long term consequences. The researcher, doing science everyday, is the person who has more and more appropriate tools to design correctly science communication. His big advantage, respect to the journalist, is that he is authentic when he speaks about science. He has the credibility and trust which derive from being the person who creates the knowledge, and not somebody who just tells about it as a second hand message.

1.1.3 The power of storytelling and emotions

Whereas in the communication with peers, the public is already interested in what is going to be said, in the communication with the generic public the researcher must compete for their attention and he should appeal and interest them. In this sense the information transmitted to the public should touch a fundamental human need or a theme which is already of public interest. The news which pass to the public should usually be connected to strong themes such as health, economic usefulness, wonder, national pride, fear etc.

Communication between scientists is neutral, cleaned from any emotional content, focused only on facts, quantitative data and reasoning, resulting in this way cold and detached. On the other hand, communication with the generic public should be spectacular and emotional (within certain limits) since an emotionally flat communication does not strike the public or is immediately forgot. The role of feelings and emotions in cognitive abilities has in fact been recognized by recent studies in neuroscience[1] [2].

The researcher can communicate for example his curiosity and wonder about nature, his passion for the research he is doing trying to answer unanswered fundamental questions, trying to solve a technological challenge, his pleasure for working in special uncommon environments, finding in this way the overlapping points with the emotions and feelings of his audience. Letting the passion and emotions coming on the surface, helps migrating from communicating something to communicating with somebody and so to the establishment of a relationship and an emotional contact, which is essential for the message to be received and fixed by the listener. The quality of communication depends largely on the quality of the relationship which has been established with the audience.

Another effective tool for catching the attention of the public is storytelling. The human mind seems to be built on purpose to assemble and remember stories, which are the most natural way of receiving information. Mental images created with stories are precious cognitive references, since they organize experiences in a coherent scheme and if a story is interesting and engaging, forces to listen, to continue and pay attention until the end. Whatever is the mean, the format, the goal and the content, communicating science to the public means being able to transform it into a story.

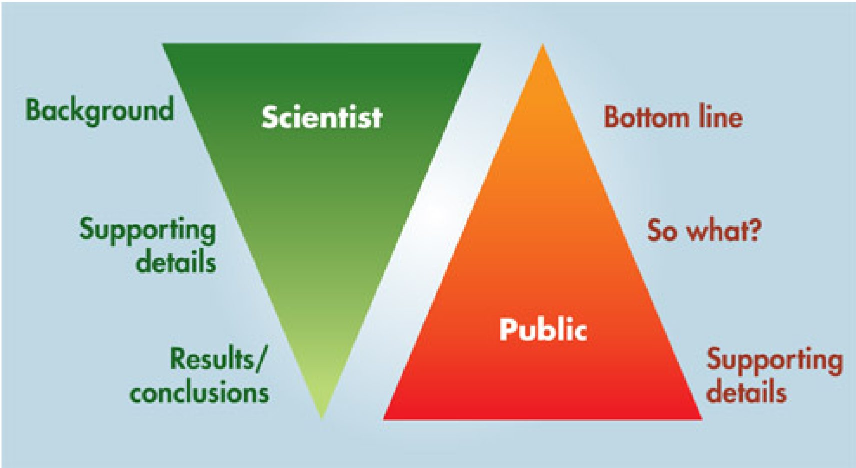

Figure 1.1: Two different kinds of communication are needed when addressing the scientist (a peer) or the lay public[35].

The narrator is close to both the public and the characters and should avoid abstraction. Ideas should be explained through facts and facts through people. The need for an involvement of the listener imposes the use of the reverse pyramid model (see fig. 1.1) which is opposite to the standard way in which scientific work is presented to peers. When addressing the general public, the incipit should strike emotionally the audience to catch its attention, then there should be the core of the story and only at the end the details, starting from the most important. Useful elements are also analogies, metaphors, flashbacks etc. The story should flow clear and concise as if it were spoken, but a clear explanation of the subject being told is essential, since comprehension is the core of knowledge.

1.1.4 The design of communication

Communication has to be planned and designed in advance, before any concrete action. It is not just a matter of intuition and creativity. There are many ways of communicating the same things and the choice should be the outcome of a careful reflection on five elements: the goal, the audience, the restrictions and opportunities of the subject and the message. Famous are also the 5 ”W” of anglosaxon journalism: what, who, when, where and why plus we can add an ”H” of how. Answering those questions is key to the design of a good story. It is a good practice to write at first a ”concept” which is a short page listing and justifying the choices made and to be submitted also to an external eye. This helps to check if everything is coherent and convincing.

Some guiding questions in this phase of design are: why I would like to do this? Who I would like to address? Which kind of audience? Which subset of society? Which change I would like to obtain in my audience (transfer information, visibility, awareness, debate, persuasion)? Who is my audience? What does my audience know already? What does the audience think about the subject? Which are their priorities, expectations, interests, motivations, needs and fears? Which are the constraints and the opportunities offered by the subject we want to communicate? Is it a news? Or can it be linked to a current event, news or discovery? Is it able to boost imagination and sense of surprise? How many people are interested in the subject? So what? How can the subject being communicated influence our way of living? What is it useful for? What will change with that? Which are possible future applications? Which new scenarios could consequently open? Which emotions and feelings can be stimulated by this subject? How close to the everyday life is the subject? How easily can this be understood? Is it possible to present the subject in a spectacular way? Which kind of service can be offered to the audience by communicating that particular subject in that particular way? Which is the message I would like to communicate? Which is the extreme synthesis of contents on which my communication should focus? Which is its connection with the needs of my audience?

Answering those questions helps defining the goal, the message, constraints and opportunities and the target of the communication, but another aspect to pay attention to is selecting the right tool.

The choice of the tool or medium to use for communicating the message to an audience is also key to communication. Media are not just technologies for transmitting information. Every message becomes different depending on the kind of media used to communicate it. The media address different kind of audiences, different numbers of people, they use different language, and transfer different amounts of information, they have their times and usage manners, function and values and moreover they demand different personal efforts. They are: television, radio, science museums and exhibitions, general press, specialized press, books, internet and public conferences. It is then clear the importance of knowing the main characteristics of the media before choosing which one to use and how to adapt the science to be communicated to it. Now a short summary of their characteristics.

Television speaks to almost everybody (98,5% of italian people watch it) and so it can be considered as a very generic media which could be used for letting people come closer to science and stimulate their interest. It uses mainly images which can be strong and have different meanings for different people, but uses very few words due to the very short time available and fast rhythm. It is then more effective at narrating facts about things which can be seen with the eyes, respect to explaining abstract concepts. Communication is elusive, the vision is distracted and it is considered as an entertainment by the audience. It is then useful to communicate the general sense of a subject, not to teach or explain something in depth but at the same time it is very effective at promoting interest and willingness to seek knowledge through other media such as books or press. It is also a mean which is more difficult to access and depends a lot on advertisement and auditel data. It can also be intimidating for the speaker, demanding uncommon personal and communication skills.

Radio is listened mainly in the early morning, by half of italian people who are usually younger than people watching television. It is purely made of words which are enhanced by background music and environment sounds. The communication is warm, immediate, and evocative, stimulating the imagination of the listener and inducing a more attentive state. There are less filters between the speaker and the listener, allowing the scientist to come in close contact with the audience, showing himself how he really is, away from stereotypes. Radio allows more freedom in the choice of subjects since it is less dependent on auditel data and words are more versatile. Conceptual and abstract themes, not directly linked to facts, can then find a place. Themes promoting discussion and reflection are usually preferred and the communication is usually made in the form of an interview by a conductor, which is also emotionally easier to handle by the speaker. The conductor promotes a dialogue between the speaker and the audience by asking questions and curiosities coming from the public. It is better to speak spontaneously and be passionate about the subject, starting with a captivating incipit, a synthetic summary with some elements of suspence. It is important to be concise and clear, spell words properly and repeat the concepts since the listener's attention can be discontinuous.

Press can be generic or specialized. Generic press is a very big world, diversified with very few studies about it. Science has usually little voice and it is present in an approximate way. Nowadays it is difficult to reach it, since the press offices are overwhelmed by news and press releases which determines a big competition for striking the attention of newspaper directors. There are less and less experts among journalists since news are usually just rewritten. Scientific journalists are usually external figures and there is a strong influence of marketing in the choice of news. So it would be important to know what is behind the choices of specific newspapers and to take care of relationships with people having a key role in that. Specialized press is easier to reach, it is usually read by young people and with attention, because they are usually polarized in their interests. There is place for fundamental sciences and for images, competition is less present and researchers can write articles without passing through an intermediary otherwise they can release interviews to a professional journalist.

Books are the most influent media for spreading culture and education and they are the best for transferring information and reasoning. They demand a big investment by the author in terms of time and self-discipline. They speak to a minority of people and they are difficult to promote to the public attention. It is important to prepare a concept of the book to be written to assess the writer's motivation and to synthesize the subject and the motivation of the book in a simple, clear idea. The writing can be done also with the help of a professional journalist.

Museums, science centers and exhibitions have grown a lot in the last 30 years around the world and they reach an audience which is quite big. In an epoch of mediated or even virtual experiences, it seems to be growing in citizen the need for real, personal, special and hands-on experiences, which can be offered only by these structures and events. They use different means like: objects to look at, photographic exhibitions, interactive exhibits, videoclips, theatrical performances, video projections, laboratories, animations and activities ranging from conferences to role plays. Depending on the theme, those means can be more or less effective. One of the first science centres has been the Exploratorium in San Francisco, opened in 1969. By the way they tend to attract children, kids and families, whereas they have difficulties in attracting adults. Concerning contents, museums and exhibitions have even more and stronger constraints respect to television and the cost of designing, producing, installing and maintaining an exposition is very high. An exhibition should communicate by using objects, not words. Spaces in museums are dense with information, but the majority of visitors tend to walk fast through them, in the same way an adult does while reading between the pages of a newspaper. They stop on this or that exhibit, depending on motivations often different from the ones imagined by the designers and even when they stop, it is only for half a minute on average. It is then very difficult to evaluate the educational effectiveness of museums and exhibitions. Generally speaking, excluding guided tours, people learn very little in terms of facts and theories. But science centres still have a big success because there, people can have a powerful emotional experience, which has the goal of giving to the visitor a mental map of the subject, fascinate, motivate his interest and encourage him to approach other media such as books for example or reinforce the motivation in a certain branch of studies at school.

Internet and social networks are the last media which have come to the scene but they have grown and are still growing in importance. They do not have many of the barriers of traditional media. Everybody can publish because of simplicity, low cost of the hardware, lack of costs for printing and distribution and there is space for everyone. Contents can remain archived and are free for the vast majority. It is accessible to everybody and almost everywhere, thanks also to the connectivity of smartphones. It can be used at the same time to communicate with the general public or with specific groups of interest. But the majority of websites are clicked by very few people or only rarely, maybe by chance. A website should offer interesting contents or useful services, but the most important thing is having the shortest link to other websites, the ones which constitute the hyperconnected web core worldwide. A big problem of the internet and of social media nowadays, is the fact that everybody can write about something and there are no information filters. This exposes citizen to fake news and facts which is dangerous especially when people do not have the knowledge and competences necessary to assess the authority and reliability of the sources of information. This exposes society to what has been called the "post truth" phenomenon, denoting circumstances in which objective facts are less influential in shaping public opinion than appeals to emotion and personal belief[14].

A last verification of the communication we have designed should be done considering the following considerations. Our success as communicators depends on what the public will do with our message. The public usually interprets messages in a way to feel more at ease and safe. When people's beliefs are attacked directly, they tend to defend and reinforce them. People pay more attention to messages which touch them or their opinions. People who do not feel safe in a relationship are bad listeners. It is more probable that people are

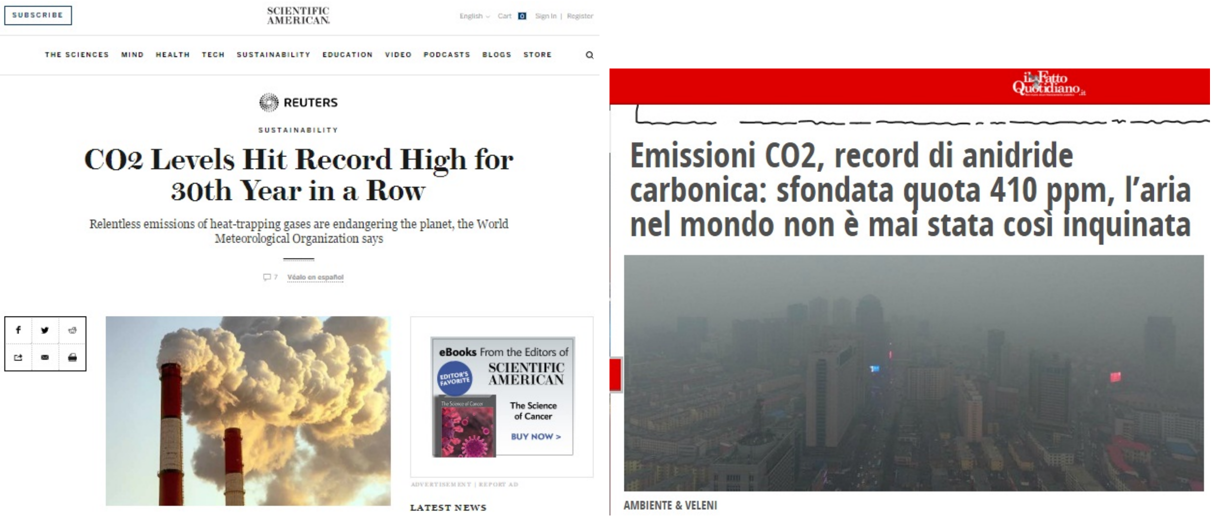

Figure 1.2: An example of climate science miscommunication in the news.

listening to you if you listen to them. People tend to change more easily as a response to a new experience plus a communication initiative. It is more probable that people will be more in favor of a change if they have been involved in a prior debate. A word enclosed message will be interpreted in light of how, when, where and who has pronounced it. The lack of self awareness and internal conflicts makes it more difficult to communicate with people.

1.1.5 Evaluating communication

Measuring the impact and the efficacy of an initiative of science communication is complex and difficult. What shall be measured? How much an audience clapped their hands? How satisfied seemed to be their faces during a conference? How much did they actively take part to experiments? Or how much did they score by answering a questionnaire. Sometimes it is very difficult and expensive to have a direct feedback from the public (i.e. statistical surveys on the audience when we communicate for example through television, radio or newspapers).

1.1.6 Communication about weather and climate

Despite a broad consensus amongst scientific experts that climate change is a serious issue needing the attention of policy communities and the public now, there is considerable public confusion about the related science, and a general apathy about the issue. The confusion about the science can be attributed to a combination of factors, including ineffective communication skills of the scientists involved, misinformation presented by contrarians and the failure of media to distinguish between scientific debate about detail versus significance.

In the mass media and in the internet, environmental issues and in particular climate change, weather extremes, daily weather forecasts and pollution are widely present[29]. The media are in fact one of the most important means by which lay people obtain information about science[37]. Unfortunately these media often report imprecise information and create confusion in the public opinion's understanding of such issues[36] [37] [38]. Media "miscommunication" has two sides: misreporting by the media and misunderstanding by the audience.

Typical inaccuracies from the side of the media involve confusing processes and phenomena such as pollution and air quality or ozone layer depletion with CO2 emissions, showing for example pictures of polluted cities or of smoky chimneys when reporting about CO2 atmospheric concentration or reporting about different phenomena (such as weather anomalies/extremes and climate change, air pollution and CO2 emissions, greenhouse effect and ozone depletion) in the same article (see fig. 1.2 for an example). Another typical inaccuracy is associating single weather extremes or exceptional temperatures for example as a proof/disproof of climate change or global warming, confusing the different domains of weather and climate. A vast misconception created by the media, also known as "balance as bias"[42] [28], is concerned with the communication of what is controversial and of what is well-established in climate science (such as global warming, and the anthropogenic greenhouse effect as a cause of it). From this point of view, media tend to balance statements with opposing views giving the public the erroneous concept of there being "two equal camps" in science and a false impression of a "debate" present about issues where none exists[37] [318] [45] [35]. A last but not least problem with good communication in the media about climate change science and environmental issues is represented by interests, ideological and political biases[43] [47].

Such inaccuracies and media mis-communication could also be at the origin of typical misconceptions present in the general public[49] and as pointed out in literature correct comprehension of scientific phenomena is decisive in fostering citizen actions and behaviors[48] [41]. From this point of view journalists, communicators, educators, teachers and scientists must work together more effectively, using even the latest research in psychology[32] to address these barriers through improved access to comprehensible and quality information and education, and to foster a learning environment of critical thinking amongst the general public and students facing climate change news and studies[33] [46].

1.2 Physics education research

Teaching is an intentional activity with the aim of producing a learning process by the student. Physics education research, studies teaching and learning processes in their specificity for the discipline. It is different from pedagogy and psychology of learning because it is concerned with phenomena and problems linked with the details of the disciplinary content to be taught and learnt[78] [54] (see fig.1.3).

At the center of its interest there is the education triangle student-teacher-knowledge with the sides epistemological (content elaboration and analysis), psychological (strategies

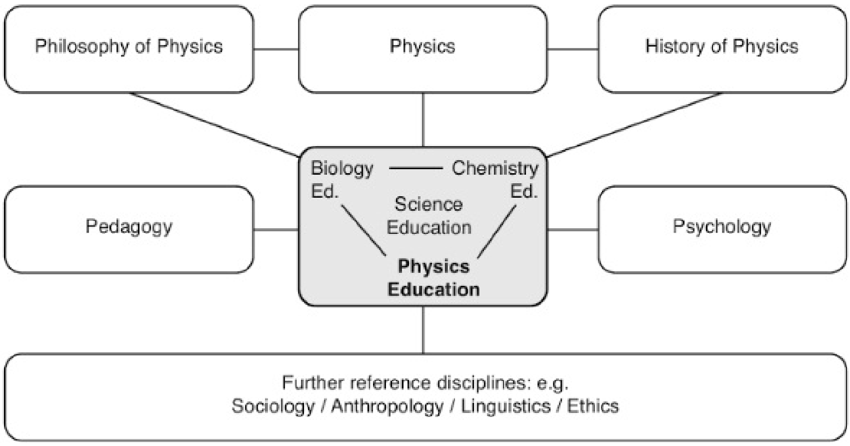

Figure 1.3: Reference disciplines for physics education[78].

of appropriation, conceptions and representations) and pedagogical (education interactions in the classroom). At the center there is the construction of the educational situation (see fig.1.4).

The disciplinary education was born in contrast with two widespread and opposite ideas on teaching: on one hand, the idea of a general education independent from contents, a general pedagogy where if one can teach, he can teach whatever. On the other hand the idea of education based only on contents, where if one knows the subject very well he can also be a good teacher. The disciplinary education is based instead on the idea that it is necessary to study problems and solutions related to the learning of specific content. This gives rise to a series of research lines concerning:

- a critical reflection on the conceptual organization and on the fundamentals of the content in view of a coherent reconstruction for teaching.
- the study of specific cognitive processes which are necessary for learning the content, with the obstacles, the difficulties, the mental models, the argumentation etc.
- the definition, based on the indications of the two preceding lines of research, of a cognitive path having specific goals scaled on the student's age
- the realization and experimentation of teaching-learning paths on particular segments of the study curricula indicating content, goals, methods, tools, cognitive strategies
- the design and experimentation of particular educational materials (learning materials, software, experiments, audiovisuals etc.)
- the organization of training courses for teachers coherent with the indications of the research at the previous points.

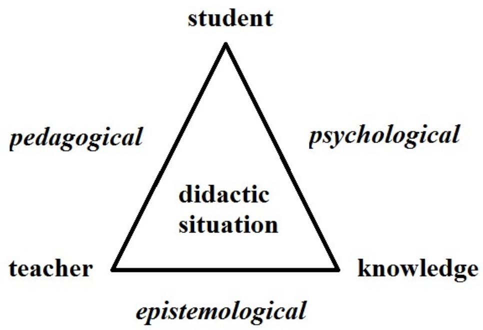

Figure 1.4: The education triangle.

In this way it is possible to consider six main fundamental research lines in physics education (see also fig.1.5):

- content analysis and explication of the methodological backbone of the discipline,
- study of the cognitive processes, obstacles and difficulties specific to the learning of a content,
- design of curricula,
- elaboration and experimentation of teaching sequences,
- production of educational materials,
- training of teachers.

Some of the specific themes of physics education research are: students' conceptions and reasoning, conceptual change strategies, the elaboration of teaching-learning sequences, interactions in the classroom, the role of linguistic facts, students' scientific language and reasoning, the practical laboratory activities, the use of information and communication technologies and audiovisuals, the analysis of disciplinary contents, problem solving, analysis of teachers' practices, the role of history and philosophy of science, the learning of the methods and nature of science, education in informal contexts and museums, the elaboration and analysis of guidelines and curricula, the interactions between similar disciplines, teachers' training etc.

1.2.1 Alternative conceptions

In the 1970s, started a wide and growing research movement on students' conceptions (representations, ideas etc.) about specific issues in physics and in other scientific disciplines. The terminology used varies from "preconceptions"[81] to "misconceptions"[79], while others prefer the terms "conceptual or alternative frameworks"[80].

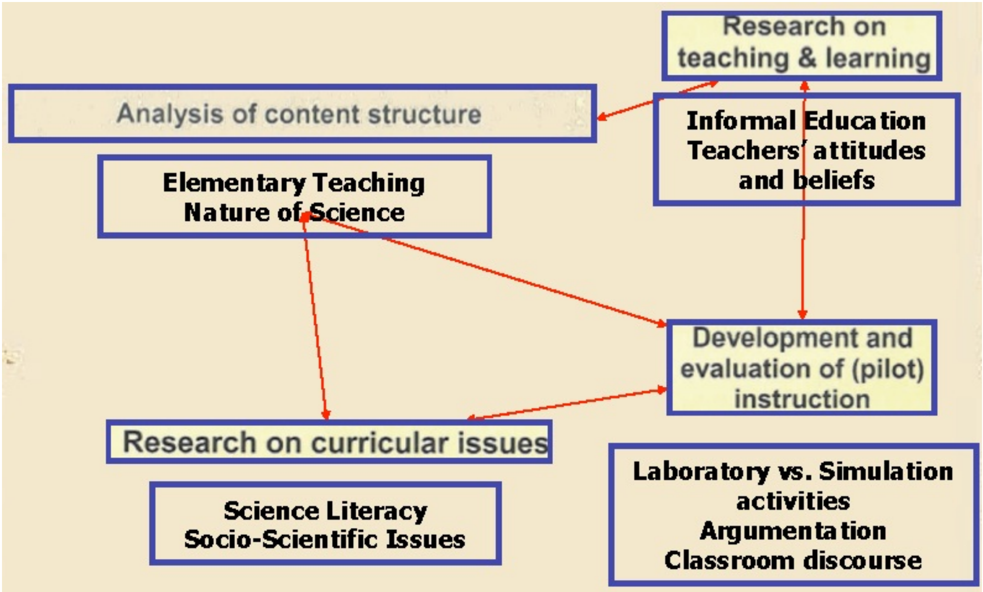

Figure 1.5: Research lines in physics education[60]

Research on student misconceptions and reasoning difficulties is based on the modern educational theory of constructivism, according to which, students do not receive knowledge, but they construct it on the base of their pre-existing ideas and experiences[65].

Humans in fact have a mental framework of knowledge that they actively created and built upon throughout life based on personal interpretations of experiences and interactions with the world. So students do not start any physics lesson with their mind free from any idea on the physical phenomena to be studied[69]. They already have interpretative schemes, personal ideas and conceptions on many physical situations. This fact is largely verified and accepted and the knowledge of those personal ideas constitutes one of the most important and relevant results of education research[54] [64] [66].

Similar conceptions have been found in different geographical and cultural contexts which suggests the existence of a sort of "spontaneous" physics[61]. By the way, for students at secondary school or university level, it is not correct thinking of truly spontaneous conceptions, but of a mixture of the ideas generated from the daily practical experience and of the ideas proposed by school education and by the mass media[54]. What is certainly true, is that a child in pre-scholar age forms already with his sensory and motor self-experience, personal interpretative and explicative models of the physical phenomena by which is surrounded. Those spontaneous conceptions do not constitute an organic and coherent ensemble for the single student, but still show a stability and efficacy in specific and limited situations and many of them still remain unchanged or only partly modified even after the study of the specific disciplines at school or at university[54]. From this point of view these often naive, incomplete, or inaccurate personal beliefs and ideas are strongly entrenched and resistant to change[63].

Some spontaneous and elementary explicative schemes seem deeply rooted and broadly used in different contexts, but are usually abandoned in secondary school, being substituted with other more complex and articulated conceptions which put together spontaneous ideas with rules and mental schemes learnt at school. This mix can show up as a personal reinterpretation of what has been taught in view of previous ideas or as a simple coexistence of two different explicative schemes which are alternatively activated by the student depending on his needs. The spontaneous conceptions which resist with time seem to be the ones which the students are able to coordinate with rules and concepts learnt at school. Some conceptions which are the cause of errors, seem to be produced, suggested or sustained by the same teaching which, at the pedagogical aim of simplifying or abbreviating, can sometimes foster wrong interpretations linked with students' and teachers' pre-conceptions[54].

Teaching/learning difficulties are usually related to conflicts between common sense and scientific knowledge (common vs scientific language), lack of experimental activities and phenomenological analysis, inadequate approaches and materials (frontal lesson, no use of ICT), poor learning environments (lack of peer interaction, unidirectional education) and ineffective teaching strategies, poor comprehension and use of mathematics[78]. These difficulties are common, robust, transverse to different contexts and resistant to traditional teaching methods. They should be pointed out and overcome with teaching activities based on research results but in service teachers are often even unaware of their existence. Questions with open ended answers requesting comments and/or explanations, multiple choice questionnaires with appropriate "distractors" from research, the use of the common language, of expressions, events or situations familiar to students helps uncovering these difficulties. The starting point to address alternative conceptions is pointing them out and recognize them (from our experience or from research in education), then understand why they were born (lack of integration between common sense and disciplinary knowledge), where they come from (experience, beliefs, familiar and cultural environment, social context), why they are so robust (the knowledge they come from is useful for interpreting reality) and in the end look for solutions to overcome them (activities, teaching sequences, specific experiments etc.). From this point of view it is important to remember to use questions which request qualitative reasoning and written answers, to discuss incorrect answers and possible origins, to ask students to synthesize concepts and mathematical relationships with their own words and that robust conceptual difficulties can be tackled from many points of view in different contexts.

There seems to exist a multiple coherence; the student preserves and applies more than an explicative model, maintaining the logic of each of them and the criteria of choice among them. Students are in general willing to modify or abandon their conceptions, if they are faced with contrasting reasoning, partly based on their spontaneous ideas and coherent with the explanations considered acceptable from them[75].

If we then want lasting learning and conceptual change to occur, students must actively engage and interact with information and experiences that challenge, confront, and conflict with their personal interpretations of reality. After challenging misconceptions, it is equally important that reasonable and more accurate explanations are given to students.

In any case students' ideas and conceptions even if incorrect or not exactly aligned with the ones of the scientific community should not only be considered as barriers to contrast and overcome, but they could constitute a useful background to work upon at the aim of building a more articulated knowledge structure, closer to the teaching objectives[54].

Many studies tried to unveil commonly held misconceptions related to various science topics[77]. Research into student alternative conceptions can help guide curricular choices, focus attention to key conceptual difficulties, and provide insight into the types of learning experiences and activities useful in addressing these misconceptions[67] [68] [250]. This effort is particularly important because, as mentioned above, misconceptions are deeply embedded within student's personal conceptual frameworks and are resistant to conceptual change[67] [63] [71].

Research-based assessments and concept inventories can be useful tools to investigate the presence of initial misconceptions (preconceptions) and their overcoming. Research-based assessments (RBAs) are standardized assessments that were rigorously developed and revised using student ideas and interviews, expert input, and statistical analysis. Concept inventories (CI) are RBAs instruments that probe students' understanding of particular physics concepts including both multiple-choice and open-ended assessments that were developed following a rigorous research process[139] [138].

RBAs and CI have had a major impact on physics and astronomy education reform by providing a universal and convincing measure of student understanding that instructors can use to assess and improve the effectiveness of their teaching. A review of the most relevant RBAs and CI in the different fields of physics can be found in[140] [141] [142].

1.2.2 Research based assessments on thermal and atmospheric physics

Environmental phenomena and processes related to weather and climate are complex, interdisciplinary and multidimensional[163]. Since the climate system is constituted of five different subsystems in interaction with each other (i.e. atmosphere, hydrosphere, cryosphere, lithosphere and biosphere); knowledge, methods and tools of different disciplines (mathematics, physics, chemistry, biology, geology etc.) are necessary to investigate its structure, processes and evolution. At the same time the study of climate and weather phenomena offers a natural framework for the integration of different disciplines which is greatly advocated in education[179] [162] [164] [182] [154] [155].

From the point of view of physics a good comprehension of thermal processes, thermodynamics, optics, electromagnetic radiation and its interaction with matter is essential and must be integrated for the elaboration of appropriate conceptual models of atmospheric physics phenomena such as for example ozone layer depletion, the greenhouse effect, winds, clouds and precipitation formation[173] [174] [191] [175]. Elements of the theory of dynamical systems (complexity, chaos, interactions and feedbacks, dynamic equilibrium) are also very important to understand climate and weather systems and their dynamics, being transversal and relevant to many different disciplines[165]. These segments of physics are usually taught separately at school and very few times students are confronted with their application to the explanation of complex real phenomena, facing the need of their integration. Again the context of climate and weather offers an interesting framework for such exercises.

Over the past two decades, many studies investigating students and teachers understanding of atmospheric phenomena and in particular of greenhouse effect and global warming, demonstrated that scientific knowledge and correct explanations about these phenomena and processes is still limited and that misconceptions are common across different ages and levels of education[222] [217] [228] [220] [218] [226] [229] [230] [339] [215] [214] [216] [211] [212] [249] [219] [248] [227] [250] [251].

Suggested reasons for this include problems with students' knowledge of the underlying scientific concepts or in applying knowledge learned in a different context[218] [216] [192]. Physics plays an important role for the understanding of phenomena and processes happening in the atmosphere and in the climate system[192], that's why misconceptions in climate and atmospheric science are often linked with misconceptions in general physics and a correct interpretation of phenomena related to atmosphere and climate should begin from a correct conceptual understanding of basic physics. In particular: physics of thermal phenomena, thermodynamics, physical optics, electromagnetic radiation and its interaction with matter, blackbody radiation.

A series of research based assessments and concept inventories have been developed, are available online[141] [142] and can be used to assess students and teachers' conceptual understanding of thermal phenomena, thermodynamics, the greenhouse effect and climate change and meteorology (TCE[146], TCS, TCI, HTCE[149], TTCI-T[147], GECI[145], CCCI[143], FMI[148]). Some of them are still under development or have been developed for specific contexts; only the ones which have been used in the assessment of the teaching sequence or which could be used will be introduced.

Even though testing is important and standardized tests have a place, they should not be the dominant culture of education. They should be diagnostic and help to determine if learning is taking place when one is teaching. A multiple-choice test is not the best for assessing deep conceptual understanding but if well developed, a concept inventory can flag conceptual issues (PRE-instruction), detect conceptual change (POST-instruction) and inform decisions about teaching strategies. In higher education (i.e. introductory physics), a concept inventory used as just described has proven to play an important role in transforming teaching practices among STEM faculty.

The Thermal Concept Inventory (TCE)[146] is a multiple-choice assessment of heat transfer, temperature change, and thermal properties of materials based on an inventory of students' alternative conceptions of thermodynamics from research literature. It was developed for third-year high school students and introductory college students in Australia. The multiple-choice answers allow students to choose from 'everyday physics' answers or 'classroom physics' answers. Many questions consist of a conversation between students and then statements about the opinions of the students involved in the conversation.

Thermal physics and thermodynamics present students with many conceptual and understanding difficulties[207] [208]. They do not differentiate between the concepts of heat and temperature, this causing difficulty in understanding processes as thermal conduction of thermal energy. Many of their conceptions are context-dependent and explanations are

TABLE IX. Thermodynamics Assessments

Title	Content	Intended Population	Research Validation	Purpose
Thermodynamic Conceptual Survey (TCS)	Temperature, heat Transfer, ideal gas law, 1st law of thermodynamics	Intro and Intermediate College	Silver	To assess students' understanding of heat and temperature, the ideal gas law, the first law of thermodynamics and processes.
Thermal Concept Evaluation (TCE)	Heat, temperature, heat transfer	Intro college and high School	Silver	To assess introductory college or 3rd-year high school students' understanding and application of thermodynamics concepts using common contexts that reflect students' own conceptions.
Heat and Temperature Conceptual Evaluation (HTCE)	Heat, temperature, specific heat capacity, phase changes	Intro College	Bronze	To assess students' understanding of heat and temperature concepts.

Figure 1.6: Thermodynamics assessments.[140]

related to single or isolated situations. Appropriate generalizations are often not recognized. Students are inconsistent in their explanations, using different conceptions to explain similar phenomena and generally not recognizing contradictions. They do not apply ideas learned in school to "everyday" situations but they are more likely to express alternative conceptions when explaining real-life situations. Students' knowledge frameworks often allow them to accept a statement of "what is" as a sufficient explanation of "why". For example, students believe that heat rises, but many accept this as a definitive explanation for convection currents. Even when students make correct statements, they often admit to being unclear about their ideas. Strongly held alternative conceptions also inhibit the development of more useful conceptions because students perceive no need to seek different explanations. Alternative beliefs arise through interaction with their physical and social environment, including the cultural use of imprecise language[209]. Hence, when using skin to judge the temperature of objects, children become accustomed to materials that usually feel warm or cool to touch and combine such experiences into a generalization that provides some explanation for that experience. Feeling warm or cold to touch are instead sensations produced by the interplay of complex processes involving different physics concepts such as temperature, thermal conductivity, heat capacity and latent heat. Common statements such as "to take one's temperature" lead to beliefs that may be in conflict with scientific views. Society's use of materials for heat-related purposes, for example using aluminum foil to keep things cold, leads to confusion about conductors, insulators, radiators, and reflectors and the mechanism by which they work in different situations. Naive beliefs are also developed though classroom instruction and reading textbooks. Belief is different from knowledge. In psychology, belief has a higher status than knowledge in that, for the believer, a belief is a taken-for-granted truth that requires no justification or proof. Beliefs lead the believer to talk or act or reason in particular ways, even though the believer may not be able to articulate that belief[91] [92]. Physics or science education research reports many incidents of discrepancies between what students learn, often for the purpose of assessment, and what they actually believe.

A review from literature of the most common misconceptions about climate change

	Categories		Students' misconceptions
Basic notions	a	Confusion about the kind and source of radiation involved in the greenhouse effect	• Sun rays in general[12] • Heat or thermal rays emitted from the sun[12] • UV radiation reflecting off the Earth's surface[12] • Increase in incoming UV or total solar radiation by the ozone layer depletion[4, 12]
	b	Confusion between UV and infrared radiation and surface temperature	• UV rays are "hot" [4, 12] • No distinction between UV and infrared radiation and between heat and surface temperature[4, 6, 10, 12, 14]
	c	Confusion about the kinds of greenhouse gases	• Considering air pollutants as greenhouse gases [4, 12] • Not considering ground-level ozone or natural emissions as a greenhouse gases[2, 7, 8] • Not considering CO_2 as a greenhouse gas[2, 4, 8, 15] • Not considering water vapor as a greenhouse gas[10]
	d	Involving concepts of a gas or dust layer that traps heat inside	• Greenhouse gases form a thin layer around the Earth and trap heat inside[1, 12, 16] • The greenhouse effect occurs where solar rays are trapped by the ozone layer[4, 12, 16] • Heat is trapped under a layer of dust created by pollution[15] • The atmospheric gases make a barrier bouncing back heat from the Earth[1]
	e	Confusion about the definition of greenhouse effect	• Do not know the definition[1, 15] • Confusion between the greenhouse effect and climate change[1] • Considering the greenhouse effect an environmental problem[12, 13]
	f	Confusion between weather and climate	• Able to sense warmer temperature as an indication of climate change[11, 16]
Causes	g	General environmentally harmful actions are not closely related to climate change	• Littering leads to climate change[2, 11] • Using environmentally unfavorable products/toxin cause climate change[2, 11]
	h	Pollution	Climate change is caused by • Acid rain [2, 7, 8, 15] • Nuclear waste[2, 7, 8] • Heat from car exhaust[5] • Air pollution or pollutants in general[1, 4, 10, 11, 12, 15, 16]
	i	Ozone hole	• Ozone holes let more solar energy to get into the Earth, causing global warming[1, 3, 4, 9, 12, 14, 16, 17] • Ozone holes let cooler air escape out of the Earth, increasing the global average temperature[4] • The ozone layer depletion (without further details)[2, 6, 7, 8, 10, 11, 15]
	j	Change in solar irradiation	• Increase in solar energy coming into the Earth[2, 7, 8, 16] • The Earth is getting closer to the sun[16] • Solar rays hit more areas of the Earth[16]
Effects	k	No change in my lifetime	• Nothing would happen in my lifetime[15, 16]
	l	Climate change claims are exaggerated	• Overestimates of the degree of global temperature change (e.g., about 7°F increase to date and 18.4°F in 50 years)[1, 11]
	m	Causes skin cancer	• Global warming causes skin cancer[2, 6, 7, 8, 16]
	n	Not understanding different feedbacks of climate change	• The expected climate change is only limited to warming in general[6, 11, 15]
	o	Depletion of ozone layer	• The greenhouse gases cause ozone layer to deplete[3, 9, 17] • The greenhouse effect causes air pollutants to go up to higher altitudes and attack the ozone layer[4]
	p	Increased air pollution	• Greenhouse gases are air pollutants and increased greenhouse gas concentration leads to air pollution[12]
Resolution/ mitigation	q	Proposing pro-environmental actions in general	• Proposing pro-environmental actions not closely related to climate change as a solution (e.g., protection of rare species, reduction of the global nuclear arsenal, the use of unleaded gas, pollute less, put waste in the trashcan, clean the streets)[2, 7, 8, 16]
	r	Unaware of the difficulties controlling CO_2 emissions	• Unaware of people's dependency on fossil fuel and the complexity of CO_2 control[1]
	s	Negative attitude toward taking action regarding climate change	• There is nothing that people can do about climate change[15] • People would not be willing to change their lifestyles[15, 16]

Figure 1.7: Most common misconceptions about climate change held by middle and high school students as reported by Choi et al.[268]

held by middle and high school students are reported in fig. 1.7.

The Greenhouse Effect Concept Inventory (GECI) is a 20 item multiple choice RBA developed by Keller[145] as an educational research tool designed to assess pre and post-instruction conceptual understanding of the greenhouse effect at secondary school and undergraduate level. It focuses primarily on the physics of energy flow through the Earth's atmosphere and it is offered to the science education community as a research tool for assessing instructional strategies on this topic.

Questions were developed after extensive research on students' beliefs about and models of the greenhouse effect; three versions of this multiple-choice instrument were administered to more than 2500 undergraduates as part of a development and validation iterative process which started from identifying common themes and trends in student beliefs and understanding through coding analysis of student-supplied written responses from six iteratively developed survey instruments administered to over 900 US undergraduate students of introductory science courses.

Its development confirmed that the study population subscribed to several beliefs and misconceptions previously identified in literature. These include correct understandings that carbon dioxide is an important greenhouse gas and the greenhouse effect increases planetary surface temperatures. Common association of the greenhouse effect with increased penetration of sunlight into and trapping of solar energy in the atmosphere. Intermixing of concepts associated with the greenhouse effect, global warming, and ozone depletion. Reinforcing the latter concept, the strong belief that the Sun radiates most of its energy as ultraviolet light. Inaccurate and incomplete description of trapping models, which include permanent trapping, trapping through reflection, and trapping of gases and pollution. Another reasoning difficulty involves the idea that Earth's surface radiates energy primarily during the nighttime[145].

The Climate Change Concept Inventory (CCCI)[143] is a 27 item multiple-choice diagnostic instrument developed by Jarrett as an educational research tool designed to assess pre and post-instruction conceptual understanding of the science of climate change at secondary school and undergraduate level. It focuses on seven conceptual areas: the carbon cycle and fossil fuels, the electromagnetic spectrum, interactions between greenhouse gases and electromagnetic radiation, proportions of greenhouse and non greenhouse gases in the atmosphere, feedback, equilibrium of energy and conservation of energy.

The concepts addressed were determined through a Delphi study of experts in secondary science teaching and climate science, and a review of research literature on students' understanding of the topic. A rigorous methodology has been applied for its iterative development and validation, including writing distractors based on known student misconceptions identified in literature and student focus group interviews, application of item-writing guidelines and statistical evaluation of item and test performance. Trial versions and and post trial assessments have been done with more than 250 high school students and with over 50 undergraduates, but this test is still under development.

Working on it there have been found common misconceptions such as: overestimation of human contributions to atmospheric carbon inputs, overestimation of the proportion of ultra violet radiation in sunlight, lack of awareness of the water solubility of carbon dioxide and the role of oceans in the global carbon cycle, overestimation of the proportion of greenhouse gases in the atmosphere, misidentification of greenhouse gases, lack of understanding of Earth's energy balance and black body radiation, misconceptions about the nature of interactions between electromagnetic radiation and atmospheric gases and limited understanding of carbon chemistry and the process of fossil fuel formation. The concept of feedback was reported as not being encountered in school education. The study's findings suggested that students in New South Wales aged thirteen to sixteen do not have the necessary accurate knowledge about the underlying concepts in order to comprehend the science of climate change[144].

Concerning weather and meteorology much less research work has been done on misconceptions, these being also probably more strongly related to basic thermal physics, thermodynamics and chemistry. A review of misconceptions, but mainly held by children has been done by Henriques[249], based also on previous works done by Aron[251], Dove[250], Spiropoulou[248], Rappaport[253], Malleus[254], Stepans[255] and Polito[252]. The idea of a first concept inventory on meteorology (FMI) has been proposed by Davenport[148] but it is still under development. There have been found that many undergraduate students, even after exposure to school science curricula have difficulty explaining simple atmospheric phenomena such as cloud and precipitation formation, the water cycle, the identification of water in its different states, the individuation of moisture sources in certain cases of cloud formation by incorporating fundamental principles of matter and energy. Other typical misconceptions are: the misidentification of cloud condensate as ”water vapor”, air as a sponge for water vapor, the idea that cold air cannot hold as much water vapor as warm air, the idea that raindrops are shaped like teardrops. Misconceptions fell into the following categories: properties of water, phase changes and the water cycle, cloud formation and precipitation, the atmosphere (gases), and greenhouse effect/global warming, the confusion distinguishing between weather and climate. Meteorology is an interdisciplinary subject where it is easy to use misconceptions gathered for other purposes especially in basic physics and relate them to the topic of weather[253] [256] [250] [249].

Other research studies have been carried out about students' ideas on thermal effects of radiation, but focusing on particular aspects such as: interaction between radiation and metals involving atomic models and quantum theory[265], the greenhouse effect and global warming[224] [229] [219] [216] [267] [225].

It was found, for example, that many students consider the ozone layer depletion and radioactivity as causes of global warming and the skin cancer as an effect of the latter, the idea of 'trapping' of sun rays by the atmosphere as explanation of the greenhouse effect. Specific studies on student conceptions and teaching proposals for secondary school about radiation-matter interaction are still lacking but there are suggestions that learning molecular behavior may improve student explanatory models of the greenhouse effect[246].

In previous research works focused on some aspects of the problem[325], it has been found a tendency to give absolute meaning to optical properties (i.e. transparency, absorptivity, emissivity) as intrinsic characteristics of bodies or materials, a lacking or incorrect consideration of infrared emission by bodies in the study of thermal balances and exchanges, a confusion between transitory phases and steady state situations, a difficulty in considering the interrelation of multiple factors and phenomena implied in energy balances. Concerning the greenhouse effect and its relationship with global warming diffuse students' ideas are: considering global warming and ozone hole as different aspects of the same problem, seeing ozone layer depletion as a cause of global warming, this causing cancer and skin diseases, the trapping of solar rays by the atmosphere as the mechanism for the greenhouse effect or interpreting it as the result of a non stationary situation in which more energy enters the system than leaves it[136] [197].

Other research efforts regarded the general physics principles fundamental to students for the understanding of the greenhouse effect. In a seminal paper on student beliefs about the greenhouse effect, Boyes and Stanisstreet[221] recommended that further research must be carried out regarding the manner in which children synthesize "the concepts of energy, heat, radiation, absorption, equilibrium, and photosynthesis, and others when thinking about global warming". Relevant to this pursuit are also previous studies regarding the concept of energy[237], the nature and interactions of light[236] [238], thermal energy and heat[239] [240] [241], gases, atmospheres, and weather[245] [244] [242] [250] [248] [249], and photosynthesis[243].

Research works[184] [190] [193] [191] [192] showed that many of the same misconceptions found in students have been found also in school teachers and pre-service teachers suggesting the necessity of addressing such issues in undergraduate and graduate courses and in teacher training courses. Many of them seem to be present even in textbooks[268] [326]. For a list of them in english and italian textbooks see fig. 1.8.

1.2.3 The educational transposition

The Model of Educational Reconstruction (MER) was developed in the mid 1990s on the basis of a continental European view of science education[77].

The idea of educational transposition or reconstruction is a key point in passing from academic scientific knowledge to scientific knowledge to be taught and to scientific knowledge actually taught, which then becomes learnt scientific knowledge or personal scientific knowledge, thanks to a process of personal construction by the student. There is a first external transposition by the "noosphere" (the ensemble of actors and decision makers who study and determine the educational functioning, school guidelines, disciplinary textbooks) and an internal transposition done by teachers (see fig.1.9)[54].

The whole research work is methodologically framed within two research strands: the Model of Educational Reconstruction[83] [84] [77] [85] and the design based research methods[86].

Teacher's physics is an intermediate construction in between the physicist's and the student's physics. A school subject is never a simplified reproduction of an academic subject, but the result of a process which brings to the elaboration of an original content, with its own context and range of application, goals, problems to solve and ensemble of allowed procedures.

This gives birth to scholastic contents which can be abandoned or brought back and be modified because of the influence of many factors which can be external or internal to the school system and to the class.

The transposition is unavoidable and necessary but has also some risks. In fact it has to be put under epistemological surveillance, the deviation or deformation with respect to the model of the academic physics must be accepted, but also checked and evaluated

Table 2. The Earth and environmental science textbooks' coverage of the scientific concepts corresponding to the students' misconceptions of climate change. Ad = Addison Wesley Longman; Pe = Pearson Education; Ho = Holt, Rinehart and Winston; MG = McGraw-Hill companies; MD = McDougal Littell; and De = Delmar Learning. N = Not covered and Y = Covered.

Scientific concepts corresponding to the students' misconceptions of climate change	The targeted students' misconceptions	Textbooks by subjects and publishers						
		Environmental science (N = 2)		Earth science (N = 6)				
		Ad	Pe	Pe	Ho	MG	MD	De
1) Distinction between weather and climate	f	**N**	Y	Y	Y	Y	Y	N
2) Distinction between global warming and climate change	n	Y	Y	Y	**N**	Y	Y	Y
3) Distinction between greenhouse effect and climate change	e	Y	Y	Y	Y	Y	Y	Y
4) The probable causes of climate change	g, h, i, and j	**N**	Y	Y	**N**	Y	Y	**N**
5) Distinction between pollution and greenhouse effects or climate change	h and p	**N**	**N**	**N**	**N**	**N**	**N**	**N**
6) The global temperature change so far	l	**N**	Y	Y	**N**	Y	Y	Y
7) Distinction between the ozone layer and greenhouse gases in terms of the interaction with radiation	d, i, m, and o	**N**	Y	Y	Y	**N**	**N**	**N**
8) Climate change is already under way	k	Y	Y	**N**	**N**	**N**	**N**	**N**
9) The major sources and the kinds of greenhouse gases	c and g	Y	Y	Y	Y	Y	Y	Y
10) Distribution of greenhouse gases in the atmosphere	d	**N**	**N**	**N**	Y	**N**	**N**	**N**
11) The mechanism of the greenhouse effect	a, d, and e	Y	Y	Y	Y	Y	Y	Y
12) Solar irradiation change and its possible impacts on current climate change	j	**N**	Y	**N**	**N**	**N**	**N**	**N**
13) Projections of future climate changes according to emission scenarios	s	**N**	Y	**N**	**N**	**N**	**N**	**N**
14) The dependency of human society on fossil fuel and barriers to reducing emission of greenhouse gases	r	Y	Y	**N**	**N**	**N**	**N**	**N**
15) How to mitigate climate change	q	Y	Y	Y	**N**	Y	Y	**N**
16) Distinction between incoming and outgoing solar radiation	a and b	Y	Y	Y	Y	Y	**N**	Y
17) Selective absorption of radiation in the atmospheric gases	c	**N**	**N**	Y	Y	Y	**N**	**N**
18) Distinction between the kinds of radiation and surface temperature	b	**N**	Y	Y	Y	**N**	**N**	Y

	Testi di Fisica				Testi di Chimica, Biologia, Geografia e Scienze della Terra									
	FISICA 2 - *Marazzini*	L'evoluzione della FISICA 2 – *Parodi et al.*	FISICA 1 - *Ohanian*	Manuale di FISICA 2 - *Miano*	Corso di CHIMICA - *Timberlake*	Chimica Società Ambiente - *Bargellini*	Dentro le scienze della Terra – *Gainotti et al.*	BIOGRAFIA delle cellule… - *Piseri et al.*	BIOGRAFIA Corso di Biologia… – *Piseri et al.*	BSCS VERDE 2 - *BSSC*	Temi di Geografia generale - *Mossudu*	BIOLOGY - *Starr*	OLTRE KYOTO – De *Marchi et al.*	LA TERRA, questa conosciuta – *Panizza et al.*
Misconception o imprecisioni nell'uso del termine "calore"		V	V		V	V	V	V	V	V	V	V	V	V
Spiegazione con riferimento ai soli effetti termici legati al calore					V									
Spiegazione con riferimento ai fenomeni radiativi	V	V		V		V				V		V		V
Spiegazione confusa tra fenomeni radiativi e calore			V				V	V	V		V		V	
Riferimento alla differenza dello spettro delle radiazione	V	V	V	V		V					V	V		V
Riferimento alla trasparenza e opacità dell'atmosfera	V	V	V	V		V					V			V
Spiegazione tramite il modello dell'intrappolamento	V		V	V	V	V	V	V	V	V	V	V	V	
Riferimento al bilancio energetico				V		V					V	V		V
Figura e didascalia corretta			-							-				V
Distinzione tra effetto serra ed effetto serra anomalo	V	V	V		V	V	V	V	V	V	V	V	V	V
Riferimento alle cause dell'aumento delle emissione di gas serra			V		V	V	V	V	V	V	V	V	V	
Riferimento alle conseguenze di un aumento della temperatura			V		V	V	V			V	V	V	V	V
Riferimento al dibattito scientifico sul global warming			V			V	V						V	

Figure 1.8: Misconceptions about climate change in english and italian textbooks as reported by Choi et al.[268] and by Tarantola et al.[326]

to avoid that it would remain only a terminological resemblance, sometimes even in a pseudo-scientific language.

The transfer of school knowledge implies a delimitation of the knowledge with the isolation from its epistemological and cultural context, the organization of thoughtful progressive sequences, the public definition of the knowledge to be transferred and of the kinds of examinations accepted.

The delimitation is both internal to the subject in relationship with other parts of the subject itself and external, in relationship with the cultural and methodological background, the context of problems in which the specific knowledge has been constructed. This de-contextualization of the scientific content from problems and cultural references in which acquires meaning, can create the so typical sensation of artificiality and loss of meaning which is common in the practice of teaching. Moreover teaching a subject at school needs it to be divided into fragments to be presented in succession, in a sequence of concepts which firstly have to be dissociated and isolated and secondly to be reconnected and linked in a structure and in a conceptual network[54].

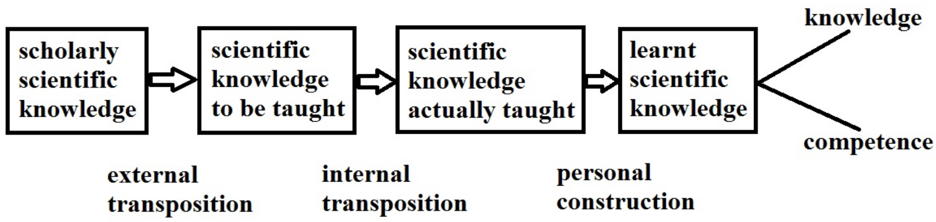

Figure 1.9: The educational transposition adapted from[54].

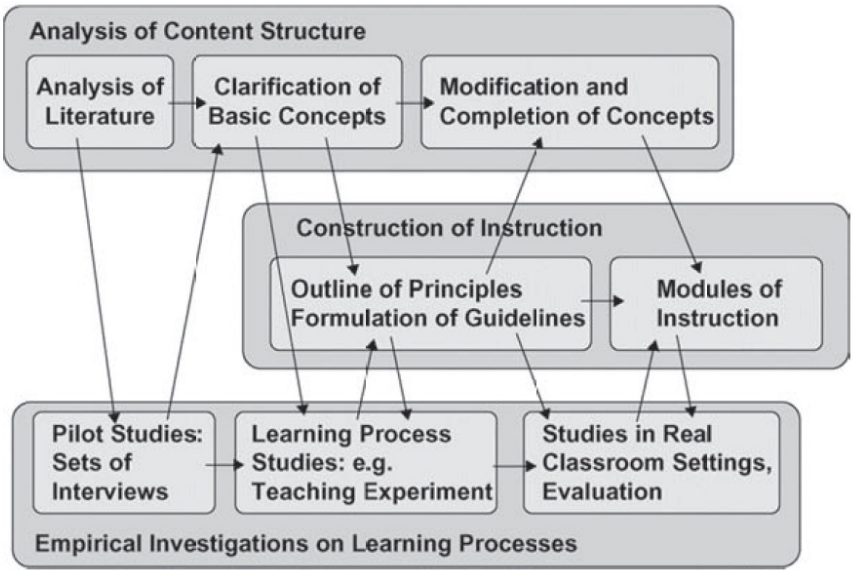

Figure 1.10: An example for the recursive process of educational reconstruction[83].

1.2.4 The design of a teaching learning sequence

The studies on alternative conceptions and on conceptual change, have contributed to investigate and put into light why students do not understand and which are the obstacles they face in the process of learning physics and more generally science[54].

There is then the problem of using the results of those studies to build educational proposals which can help students to understand and improve their learning process. Thus the research in education has been concentrating more and more on the elaboration and on the experimentation of teaching and learning sequences (TLS) based on the results obtained from the research of the last decades on common sense conceptions and on learning processes, relative to specific scientific content[76] [74] [111].

One of the lines of research which has greatly developed, studies ameliorative approaches to learning at microscopic and mesoscopic scales (i.e. relative to a single subject or theme,

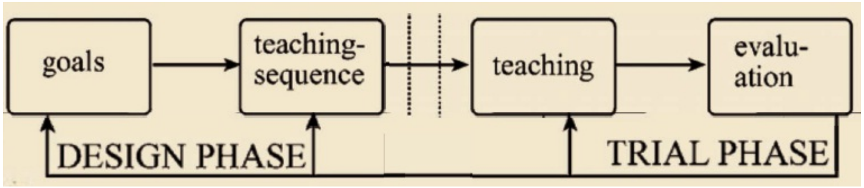

Figure 1.11: Curriculum design and development[112] [111].

treated in an educational sequence of several hours or weeks), while other research lines study solutions at a macroscopic level (i.e. of a whole curriculum of one or more years of studies), see fig.1.11.

Educational sequences can be developed with pure research purposes, to obtain results on specific aspects of the learning processes relative to a scientific subject, but also with innovation purposes, for example ameliorating the efficacy in teaching a specific subject or introducing new contents and methods in a determined segment of the school curriculum.

The design of a teaching-learning sequence involves many aspects and poses various methodological problems. With this aim, research in education has developed different approaches, methods and solutions such as education engineering, problem posing, education structures, the model of the educational reconstruction, the 3D approach and the core-clouds structure[54].

Another line of research develops instead longitudinal paths from elementary school to the beginning of the high school on physics and general science themes, with the aim of creating a learning progression centered on the development of reasoning strategies, transversal concepts and basic practices which characterize the process of constructing scientific knowledge.

An important method to be considered and applied in the development of teaching sequences is the "Inquiry Based Learning" (IBL) and many researchers have shown that Inquiry-Based approaches to learning are able to increase student motivation, interest, understanding and development[109] [108].

As defined in the National Science Education Standards[104], scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world (the scientific method).

Scientific inquiry reflects how scientists come to understand the natural world, and it is at the heart of how students learn. From a very early age, children interact with their environment, ask questions, and seek ways to answer those questions. Understanding science content is significantly enhanced when ideas are anchored to inquiry experiences.

Scientific inquiry is a powerful way of understanding science content. Students learn

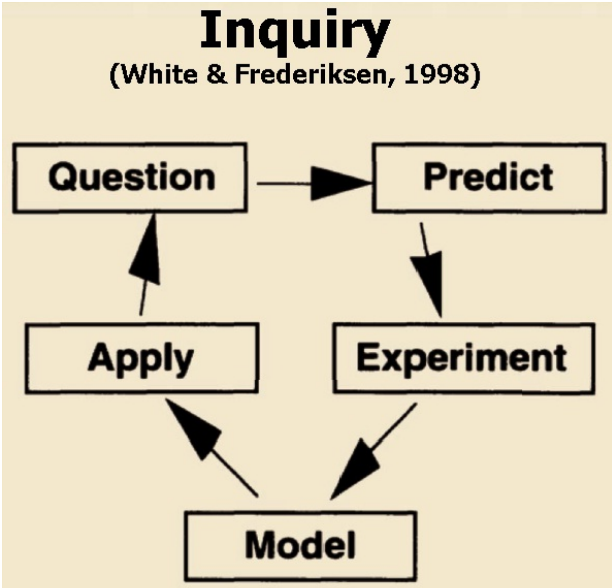

Figure 1.12: The process of learning through inquiry[112] [110].

how to ask questions and use evidence to answer them. In the process of learning the strategies of scientific inquiry, students learn to conduct an investigation and collect evidence from a variety of sources, develop an explanation from the data, and communicate and defend their conclusions. Phases in which students make a prediction and design an experiment are essential for the learning success. There are many levels of inquiry: from confirmation, structured, guided and open inquiry. In the latter case, which is the more authentic, students are engaged by a research question, they guess predictions, design and construct experiments (both in virtual environments and with concrete materials) to determine which of the predictions made is the best, they analyze results and summarize them in the form of scientific laws and/or models, they apply laws and models found to new situations, they think about the limitations of the same laws and models and on their path done, they go back to the initial question and revise their approach to the research (see fig.1.12).

The National Science Teachers Association (NSTA) recommends that all K-16 teachers embrace scientific inquiry and is committed to helping educators make it the centerpiece of the science classroom. The use of scientific inquiry will help ensure that students develop a deep understanding of science and scientific inquiry[100]

Students' education in fact should not consist merely in being able to repeat facts and memorised knowledge. From this point of view inquiry has an important role in developing understanding since it involves learners making sense through their own action, thinking and reasoning of different aspects of the world around. Inquiry-based science education promotes both conceptual understanding and the development of capabilities widely recognized as needed by everyone in the twenty-first century such as critical thinking, collaborative working, consideration of alternatives, effective communication. Rather than a superficial learning process in which motivation is based on the satisfaction of being rewarded, motivation when learning through inquiry comes from the satisfaction of having made sense of something that was not previously understood. Success requires teachers to have an understanding of the nature of science, seeing it not as a collection of facts to be learned but as a process of thinking, observation and experimentation[102].

The initial design of the activities of the teaching sequence is based on an approach of integration among a critical analysis of the scientific content in view of its reconstruction for the teaching activity, a reflection on what is already available (textbooks, online materials etc.) and an analysis of the results of the research in education focused on the specific issue.

Besson et al.[325] [136] pointed out that the introduction of a complex issue as is for example the physical basis of the greenhouse effect, requires a progressive conceptual construction with a sequence of cognitive steps necessary to attain a coherent explanation of the phenomenon. The accomplishment of these steps entails re-structuring the teaching of thermal phenomena and optics, and discussing the energy balances in stationary conditions of a system exposed to a constant source of energy. Thus in order to favor the students' acquisition of the basic physics concepts required to understand the greenhouse effect it is necessary to bridge two areas, optics and thermal phenomena, strictly connected from a conceptual, scientific and technological point of view, but often taught separately (with episodic connections) in introductory physics courses at university. Work with high school teachers, concerning a cycle of design, implementation, evaluation and redesign of a teaching learning sequence on this topics revealed to be also essential.

1.2.5 The role of laboratory in physics education

The laboratory is an essential part of physics because physics is inherently an experimental science, and there is an increasing awareness of the importance of the laboratory experience in physics and science education[93] [94] [95] [96] [97] [98]. From this point of view school guidelines and national standards of education focus more and more on authentic and engaging STEM educational experiences.

Physics is a way of approaching problem solving, requiring direct observation and experimentation. In this endeavor being successful requires synthesis and use of a broad spectrum of knowledge and skills, including mathematical, computational, experimental, and practical skills; and to develop particular habits of mind. "Thinking" like a physicist" and constructing knowledge of our physical universe pervade all of the recommended learning outcomes.

Learning outcomes of the physics laboratory (see fig. 1.13) are considered to be[97] [98]:

- Constructing knowledge: collect, analyze, and interpret real data from personal observations of the physical world to develop a physical worldview.

- Modeling: develop abstract representations of real systems studied in the laboratory, understand their limitations and uncertainties, and make predictions using models.

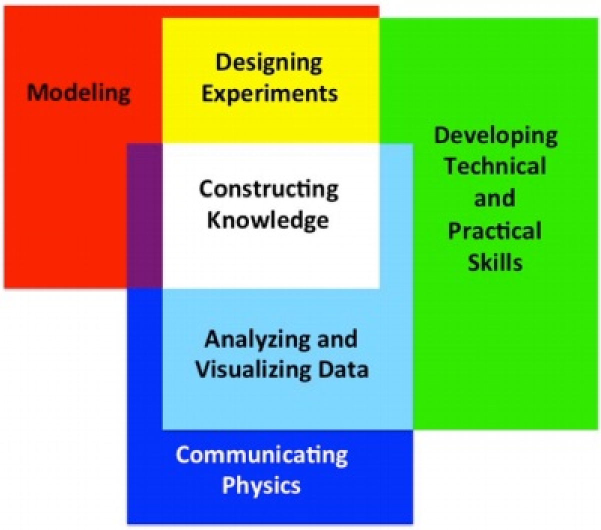

Figure 1.13: Role and outcomes of the laboratory and of experimental activities in physics education.[97]

Modeling the physical system, includes both understanding the main physics ideas and developing, using and revising a predictive model.

- Designing apparatus and experiments: develop, engineer, and troubleshoot apparatus and experiments to test models and hypotheses within specific constraints such as cost, time, safety, and available equipment. Carry out experiments.

- Developing technical and practical laboratory skills: become proficient using common test equipment in a range of standard laboratory measurements while being aware of device limitations.

- Analyzing and visualizing data: analyze and display data using statistical methods and critically interpret the validity and limitations of these data and their uncertainties.

- Communicating physics: present results and ideas with reasoned arguments supported by experimental evidence and utilizing appropriate and authentic written and verbal forms.

Moreover the physics laboratory prepares responsible scientists and fosters both a deeper understanding of natural processes and the development of a variety of transferable skills for the 21st century, providing for example a link to skills and habits valuable for innovation and entrepreneurship. The laboratory allows students to understand how physical ideas enable modern technologies and therefore to appreciate the role that physicists plays in developing practical solutions to societal problems[97].

1.2.6 The role of teachers and their training

While the research in education was elaborating multiple proposals of teaching-learning sequences and refined educational indications on specific learning problems, the factual school practice remained disconnected from those proposals, giving birth to a big divide between the products of the research in education and the school practice.

So it has been studied the problem of the large scale dissemination of teaching-learning sequences experimented in education research, and so the realization of sequences which could be used effectively in ordinary school environments and which could take into consideration the boundaries posed by the factual functioning of institutional school contexts of reference.

At this aim the importance of the role of the teacher has been underlined and much research has been concentrated on the study of the role of the teacher as a transformer of the education intentions of school guidelines or of researchers and on the elaboration of projects and of formative experiences for teachers[58] [59] [57].

Three are the fields of knowledge considered as founding building blocks of the competence of a teacher: subject matter knowledge, pedagogical knowledge and pedagogical content knowledge[54]. The last one is a defining component of recent approaches to teacher's education and is the subject of many studies. It is a special mixture of content and pedagogy, which is a specific form of teacher's professional understanding[55] [56]. Instructors develop pedagogical content knowledge as they gain exposure to helping students confront and resolve misconceptions and misconception research can support its development and implementation in the classroom quantifying, validating, and expanding its aspects[55].

Concerning the specificity of weather and climate, numerous research works[184] [185] [186] [187] [188] [190] [191] [192] [193] [194] [195] [196] showed that teachers of different subjects (from physics to chemistry, biology and natural science) and at different levels of lower education lack the necessary specific background and formation on atmospheric and environmental issues related climate and weather; this resulting in holding the same misconceptions of their students, "balance as bias"[185] in presenting climate change, and confusion among different issues, this constituting a strong barrier in the diffusion of such themes in the teaching practice at school, as advocated by school guidelines.

Chapter 2

Communication of Antarctic science

During the second year of Ph.D. program, the candidate participated to the 30th Italian expedition in Antarctica as a member of the 11th wintering team at the Italian and French research station Concordia in Antarctica. Covering the role of atmospheric physicist of the team, he has been in charge of the measurement campaigns of the Italian research projects[279] in the field of atmospheric physics, and operational meteorology for the institute of atmospheric sciences and climate of the national research council of Italy (ISAC-CNR) and for the Italian national agency for new technologies, energy and sustainable economic development (ENEA). Among his scientific tasks he managed for one year and autonomously instruments and measurements of the radiometric and of the meteo-climatological observatories.

These two observatories are important nodes of international global networks of measurements of the World Meteorological Organization (WMO). Their goal is to measure the fluxes of electromagnetic radiation at the Earth's surface (which at last play a big part in determining the temperature of the Earth's surface) and the physical quantities typical of the atmosphere (temperature, pressure, relative humidity, wind speed and wind direction). This quantitative information is useful both at research and operational level, for the characterization of the Antarctic regional and global meteorology and climatology, for the validation of remote sensed data (such as for example those measured from satellite radiometers), for monitoring and evaluating the impact of climate change and for the elaboration of weather forecasts[275] [279].

This chapter presents the science communication initiatives designed, performed and experimented during the Ph.D. program.

The first part will introduce the scientific fields and the research activities performed at Concordia station, together with the geographical, environmental and institutional context in which these are set. In particular there will be a general illustration of the research projects in the field of physics of the atmosphere, climate and meteorology, funded by the Italian Antarctic Program (PNRA).

The research activity performed in first person by the candidate has been rearranged, enriched and transformed by himself, designing, organizing and performing in first person, several science communication initiatives addressing different audiences, experimenting with different media, methods and innovative formats of communication both during his stay in Antarctica and later on. These initiatives will be presented and summarized in the second part of the chapter. For a detailed list of these see appendix A.

2.1 The Italian and French research station Concordia

The Antarctic continent holds a series of records. The last being discovered and visited, it is by all means the most isolated, most remote, the coldest, driest, windiest, most elevated and least explored continent of the Planet. Theater of many adventures and of both human and scientific challenges, such as the race for conquering the South Pole between Amundsen and Scott or the unfortunate attempt at crossing the continent by Shackleton, it is nowadays a continent entirely dedicated to scientific research[273]. In 1959, following the International Geophysical Year of 1957-1958, an international treaty has been ratified in Washington, to guarantee to all participant nations the right of using the Antarctic territory for scientific research, in the name of peace and international cooperation, respecting the endemic ecosystem. Today the Antarctic treaty has been signed by 46 nations worldwide and together with the environmental protocol of Madrid of 1991, preserves the continent from political claims, from the exploitation of natural resources and from military activities, at the aim of maintaining the continent as pristine and untouched as possible, an heritage devoted to science and mankind.

Its inhabitants are only technical and scientific temporary personnel, hosted in research stations, ranging from 4500 people during the summer period, to less than 1000 people during the winter period. During the summer there are connections via planes and ships with the rest of the world, while during wintertime the continent and people, remain completely isolated. Permanent research stations which host the personnel during the summer or year-round are almost 70, belonging to 30 different nations, signatory of the Antarctic treaty. Almost all these stations are situated on the coastal region of Antarctica, apart from the only three which are in the interior of the continent: the Russian Vostok, the American Amundsen-Scott at the geographic south pole and the Italian and French Concordia[280].

Concordia is an Italian and French research station, situated at Dome C (75°S of latitude, 123°E of longitude, 3233 m above sea level) on the Antarctic plateau. It is the only permanent and year-round European station in the interior of the continent, 1200 km far from the coast and Vostok is the nearest station at a distance of 600 km. This makes it one of the most remote, isolated and inhospitable places on Earth, being also referred to with the nickname "White Mars" by the European Space Agency which there studies human physiological and psychological adaptation to extreme environments[283].

The station has been built between 1999 and 2005 from an Italian and French collaboration for the purpose of constituting a platform for scientific research. Today it is jointly managed by the French Polar Institute (IPEV) and by the Italian Antarctic Program (PNRA), funded by MIUR. For what concerns Italy, the Antarctic National Scientific Commission (CSNA) defines the plans and strategies of Antarctic research and evaluates

Figure 2.1: Research stations on the Antarctic continent. The Italian and French station Concordia is situated at Dome C, on the east Antarctic plateau, at 3233 meters above sea level. (c) PNRA/IPEV

research projects, the Italian National Research Council (CNR) is responsible for the scientific planning and coordination and the Italian national agency for new technologies, energy and sustainable economic development (ENEA) is responsible for planning and carrying out the logistics[279].

At Dome C, it has been extracted an ice core, 3233 meters long, outcome of an European research project named EPICA (see fig.2.3). This ice core, allowed to reconstruct the climate of the last 800,000 years, particularly with regards to greenhouse gases concentration and temperature. The concentration of greenhouse gases like carbon dioxide and methane has been reconstructed by analyzing the composition of the tiny bubbles of fossil air, trapped in the ice. Past temperatures have been reconstructed independently from the analysis of the relative abundances of oxygen and hydrogen isotopes in the ice[284].

The landscape around the station consists of a white flat plateau of snow compacted by the action of wind. Temperatures during the summer period do not go above -25°C, and in winter they go below -80°C. The air is rarefied, with atmospheric pressure going down to 600 hPa in winter, making physical and cognitive activities more difficult. The climate is typical of a cold desert, with on average only 3 cm of precipitation per year and weak average winds. Until now no endemic form of life has been found, not even bacteria[305] [306]. The day and night cycle is altered, with 3 months of daylight for 24 hours during the summer period and 3 months without the sun during the winter period, whereas months with long dawn and dusk characterize intermediate periods.

The personnel living and working at the station is international, equally divided between scientific and logistic. It consists of around 60 people during the summer period which goes

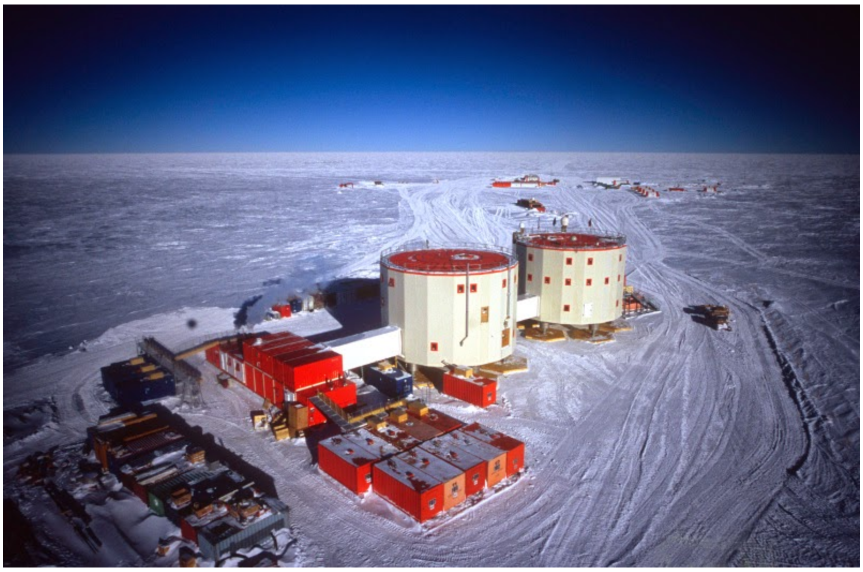

Figure 2.2: The Italian and French research station Concordia on the Antarctic plateau. (c) G. Dargaud.

from November to February, but reduces to only 13 people during the winter period which goes from February until the next November. Every year these 13 people pass the 9 months of the rigid Antarctic winter in complete isolation and autonomy. Apart from the strictly professional tasks, every team member participates to common activities related to the functioning of the station and to emergency procedures, having a specific and trained role in the fire-fighting, rescue and medical teams.

The station is made of two connected cylindrical towers, three floors each, separated from the ground with telescopic pillars as to maximize the thermal insulation and to minimize the accumulation of snow blown by the wind. Inside, there are the usual living facilities together with scientific laboratories and part of the instruments. A separate building made of containers, hosts the power plant (diesel generators) and the machines for recycling "greywater" and "blackwater". Drink water is produced by melting snow and heating is obtained with co-generation by recovering the heat taken away from the engines by the cooling systems. Food, materials, fuel and everything necessary for the winter period are all arriving from the French coastal station Dumont D'Urville with a raid of snow cats and snow tractors carrying containers and fuel tanks on special sledges driving for 10 days across the distance of 1200 km. The personnel instead arrives at the station and leaves only during the summer period, with special flights connecting Concordia with the coastal stations of Mario Zucchelli, Dumont D'Urville and Casey. They usually arrive on the Antarctic continent by icebreaker, or by plane.

The site of Dome C, where Concordia has been built, is a "dome" of ice, which is a site where the huge and thick ice cap covering Antarctica culminates and remains in stable conditions. It has been chosen because it has a series of unique geographical, environmental and logistical characteristics which satisfy a series of criteria necessary for performing certain scientific studies[274]. First of all the thickness of the ice cap, which has accu-

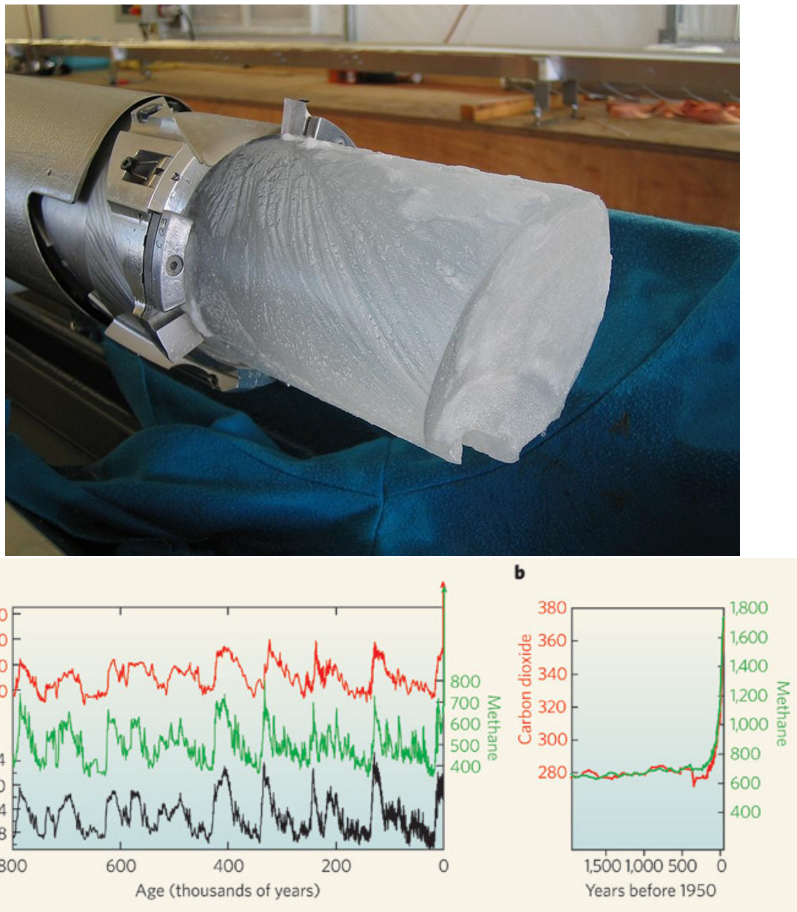

Figure 2.3: Above: the EPICA ice core, extracted at Dome C. Down on the left: concentrations of carbon dioxide (in p.p.m., red curve) and methane (in p.p.b., green curve) of the last 800,000 years, together with a reconstruction of the temperature (relative to the average of the last millennium), based on the ratio hydrogen-deuterium in the ice. Down on the right: methane and carbon dioxide concentrations of the last 2000 years[284]. (c) L. Augustin and Nature

mulated over more than one million years, opens the access to the archive of the Earth's climate through paleoclimatological studies[284] [285]. The rarefied, stable, pure and dry atmosphere is ideal for making astronomical and astrophysical observations[286] [287], as for example the research of exoplanets, the study of variable stars, the observation of the sky in the infrared band and in the microwave band for studying the cosmic radiation background and the origin of the Universe[288] [289]. At the same time, this kind of atmosphere is ideal for studies on the chemical composition of the lower and upper atmospheric layers (direct measurements of aerosols with air samplers and chemical analysis of filters and indirect measurements with the help of lidar techniques, studies on polar stratospheric clouds and on their role in the formation of the ozone hole)[301] [295] [302]. The position of the station, under the orbit of the majority of polar orbiting satellites, optimizes the possibilities of remote sensing for surface and atmospheric monitoring. The position under the polar vortex, allows the study of fluctuations in the concentration of stratospheric ozone above Antarctica (ozone hole) both with direct (stratospheric balloons) and indirect measurements (absorption of ultraviolet radiation through the atmosphere)[300] [295]. The fact of being very far away from any kind of disturbance and noise which are present instead on the coast, creates favorable conditions for monitoring and studying terrestrial magnetism and seismology[308] [309] [310]. At the same time, the distance from sources and anthropic emissions of pollutants and climate-altering substances, makes it an ideal site for making observations representative of the atmospheric background conditions[279]. An accurate characterization of the variability of such compounds, deriving from anthropic emissions and a deep comprehension of the processes and interactions which determine and regulate the changes which are happening, are fundamental to understand the actual state of the climate system and to predict future scenarios of our Planet, especially in areas where climate change is amplified by particular conditions and factors. For these reasons, the monitoring of the Earth-atmosphere system and the study of the causes/interactions among different components (cryosphere, atmosphere, hydrosphere, lithosphere and biosphere), has a primary role at Concordia station and more generally in Antarctica[280] [278].

Moreover the geophysical observatories (geomagnetism, seismology, physics and chemistry of the atmosphere, meteo-climatolgical, space weather) present at Dome C, have a primary role for their contribution to the global international networks of measurements and monitoring, because data coming from permanent manned measuring stations are very sparse in the Southern hemisphere and particularly in Antarctica. The scientific fields in which research activities are performed in Concordia are then: physics and chemistry of the atmosphere, particle physics, meteorology, climatology, glaciology, astronomy and astrophysics, seismology, geomagnetism and human biology. This last field of research is managed by ESA, with the study of physiological and psychological adaptation of small groups of individuals living and working in conditions similar to the ones present in long duration space missions or on the international space station or in more futuristic scenarios of colonization of other planets. The extreme environmental conditions, isolation, confinement, sensory deprivation and the alteration of the day-night cycle present in Concordia, make it a so called "space analog", which is a place you can find on Earth, with the most similar conditions to an extraterrestrial planet[283] [307].

Scientific instruments are installed outside Concordia station, inside a circular area of 2 km radius from the station (see fig.2.4). In the vicinity of the instruments, there are small remote laboratories, called "shelters", heated at about 8°C, which contain the electronic and IT acquisition systems, part of the instruments and spare parts. They are also emergency places to seek refuge and warm up during the routine operations which have to be done outside, often at prohibitive temperatures. On a daily basis, the scientific personnel walks to the instruments of their competence, does the necessary operations of maintenance, sampling, calibration, data acquisition and quality check and send them to the PI of the projects and to the servers of the international data networks.

Concordia and more generally Antarctica, represent then an immense scientific laboratory which is open air and multidisciplinary. A privileged platform for the observation

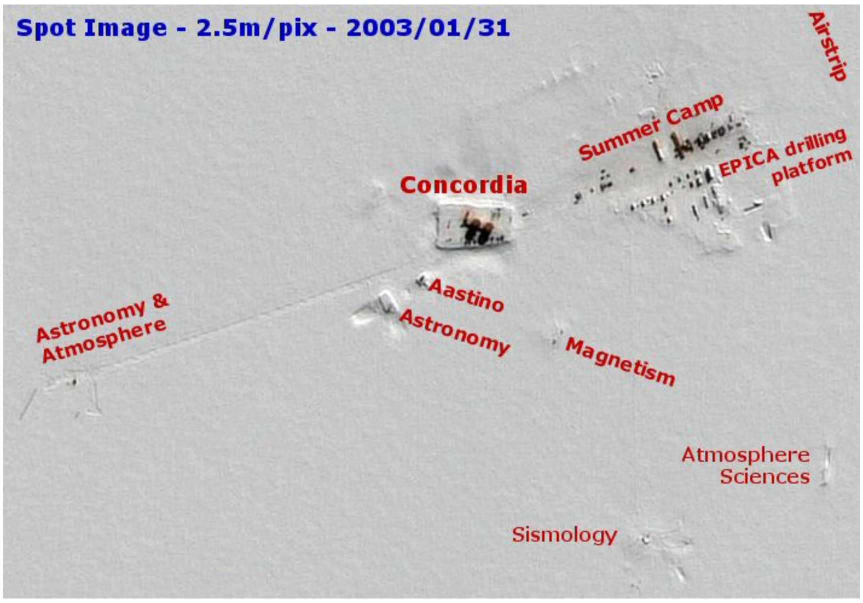

Figure 2.4: Aerial view of Dome C site. The Concordia facilities and the remote laboratories around the stations (shelters) where scientific instruments are installed. (c) Guillaume Dargaud - PNRA/IPEV

and for the scientific investigation of human adaptation, of Planetary equilibria and of the Universe[278] [280]. In these places, science and method, interdisciplinarity, adventure and inaccessibility, extreme conditions and extraordinary life stories of researchers are elements which mix together in a dimension which has almost been lost in our western societies, but which is still perceived as exotic, heroic and pioneering. This particular dimension which characterizes the process of performing research in Antarctica, at the southern edge of the World, stimulates and promotes a great interest and curiosity in the general public and in young students. For this reason it is an ideal context in which designing and experimenting science communication initiatives at many different levels.

2.2 The radiometric observatory (BSRN)

Among the research projects in the field of physics of the atmosphere, present at Dome C, one is concerned with the continuous and accurate measurement of the fluxes of electromagnetic radiation (solar and terrestrial, downwelling and upwelling) at the Earth's surface. These determine the radiation budget of the Earth-atmosphere system[319].

The radiative balance of the Earth-atmosphere system plays a fundamental role in determining the thermal condition and the circulation of the atmosphere and the ocean, shaping the main characteristics of the earth's climate[275] [324]. In fact, the irradiances (intensity of the electromagnetic radiation) at the earth's surface are important to understand the climate processes since the earth's surface transforms about 60% of the solar radiation absorbed by the planet. In polar areas they are even more important because on one hand snow-covered surfaces, ice sheets and glaciers typically reflect 75% to 95%

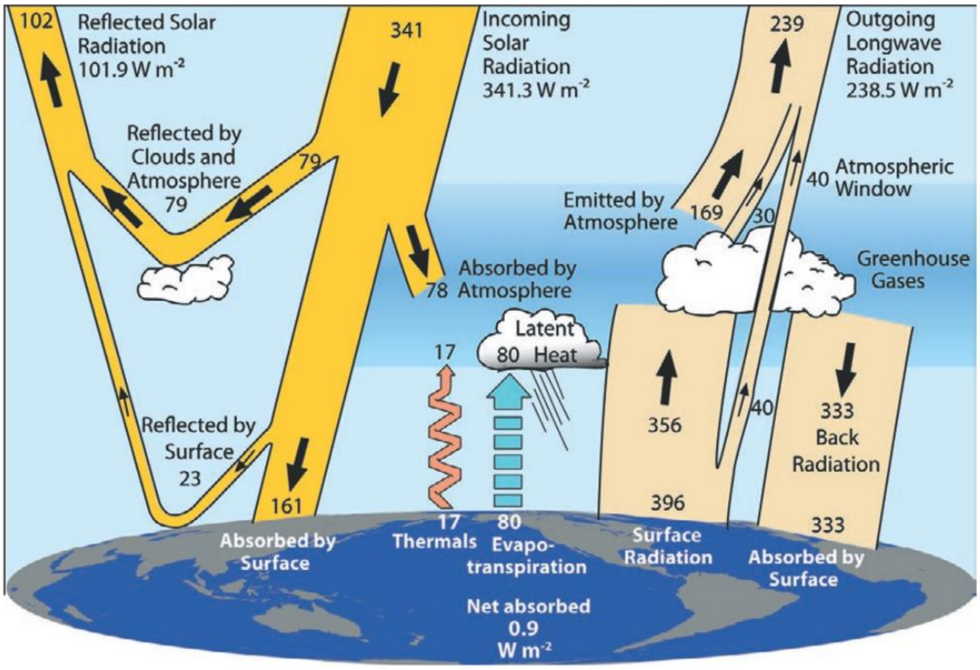

Figure 2.5: Global annual mean Earth's energy budget[?]. Solar and terrestrial radiation fluxes in the atmosphere and at the Earth's surface. (c) Kiehl and Trenberth (1997)

of the incoming solar radiation (mainly in the visible range), on the other hand snow has high longwave emissivity (around 0.98), which causes iced surfaces to loose heat very effectively in the form of thermal radiation (infrared range). For this reason, on the antarctic plateau, during most of the year, there is a pronounced radiation deficit at the surface. This heat loss is compensated by an average turbulent transport of sensible heat from the atmosphere to the surface (subsidence) making the antarctic ice sheet a major heat sink in the Earth's atmosphere (more energy is emitted to space in the form of infrared radiation than it is absorbed from sunlight), introducing in this way a strong coupling between the radiation balance and the near-surface climate. Due to the non linear couplings and feedback mechanisms between the different components of the climate system, even small changes in irradiance at the earth's surface (because of varied solar activity, astronomical parameters or atmospheric composition and characteristics) may cause profound changes in climate, and the amount of absorbed shortwave radiation (depending on the surface albedo) is very sensitive to these changes in irradiances. This is why the simulations of the past and future climate changes which would be induced by a change in the radiation budget are even more uncertain, requiring a radiometric network capable of very accurate and precise measurements, necessary for climate research[320].

Incoming (downwelling) and outgoing (upwelling) fluxes of shortwave ($0.3\mu m < \lambda < 3\mu m$) and longwave ($3\mu m < \lambda < 50\mu m$) electromagnetic radiation at the Earth's surface and in the atmosphere, can be modified by changes in chemical composition and features of the atmosphere (cloud cover, particulate content or aerosols and trace gases) and by

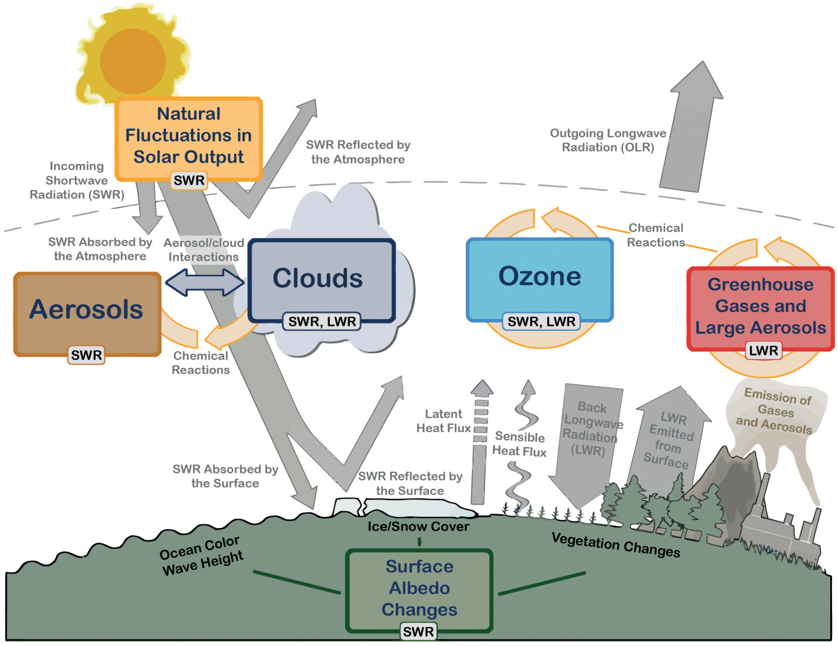

Figure 2.6: Main drivers of climate change [?]. The radiative balance between incoming solar shortwave radiation (SWR) and outgoing longwave radiation (OLR) is influenced by these global climate "drivers". (C) IPCC

changes in the properties of the surface (albedo). The peculiar characteristics of the polar regions emphasize the importance of the radiative balance and the sensitivity to changes of the climatic system of those areas.

So one very important thing is understanding the influence of global climate drivers (see fig.2.6). Natural fluctuations in solar output (solar cycles) can cause changes in the energy balance (through fluctuations in the amount of incoming SWR). Human activity changes the emissions of gases and aerosols, which are involved in atmospheric chemical reactions, resulting in modified O3 and aerosol amounts. O3 and aerosol particles absorb, scatter and reflect SWR, changing the energy balance. Some aerosols act as cloud condensation nuclei modifying the properties of cloud droplets and possibly affecting precipitation. Because cloud interactions with SWR and LWR are large, small changes in the properties of clouds have important implications for the radiative budget. Anthropogenic changes in greenhouse gases (GHGs: CO2, CH4, N2O, O3, CFCs) and large aerosols ($> 2.5\mu m$ in size) modify the amount of outgoing LWR by absorbing outgoing LWR and re-emitting less energy at a lower temperature. Surface albedo is changed by changes in vegetation or land surface properties, snow or ice cover and ocean color. These changes are driven by natural seasonal and diurnal changes (e.g., snow cover), as well as human influence (e.g., changes in vegetation types)[319].

The lack of measurements having the required accuracy for climate research, was the reason why the World Climate Research Programme (WCRP) of the World Meteorological Organization (WMO) proposed and initiated in 1988 the International Baseline Surface

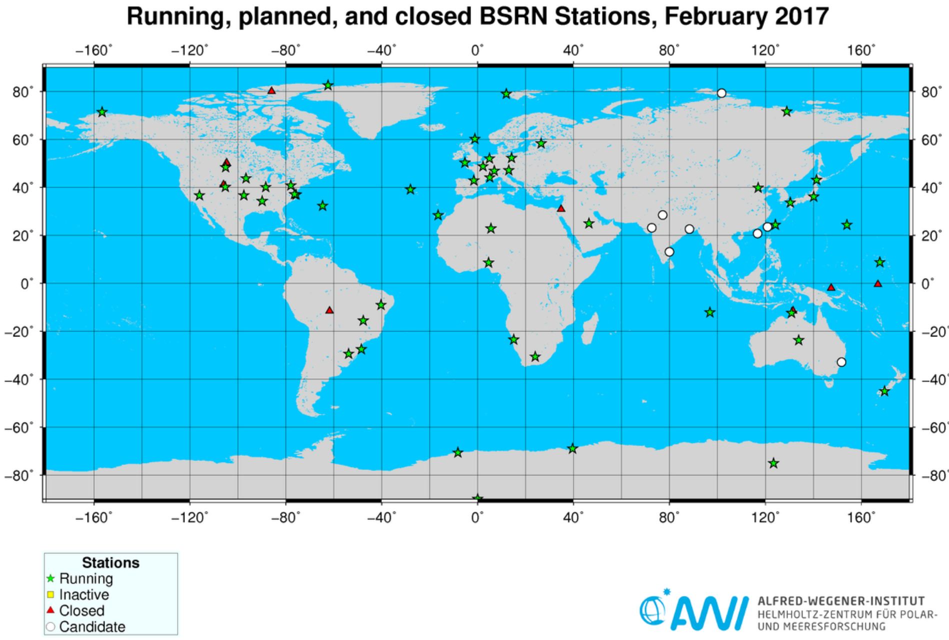

Figure 2.7: Radiometric observatories of the Baseline Surface Radiation Network (BSRN) of the World Climate Research Programme. Antarctica has only 4 running BSRN stations and only two are in the interior of the continent, one of which is installed at Dome C since 2006. (c) Alfred Wegener Institute

Radiation Network (BSRN), a new radiometric network of observatories to support climate research. Main goals of this network are: monitoring long-term changes in irradiances at the earth's surface, providing earth's surface irradiances for validating satellite-based estimates of the surface radiation budget and radiation transfer through the atmosphere and providing irradiances to validate and improve radiation codes of climate models.

Despite Antarctica's relevance to climate, it is still a relatively poorly characterized continent, especially in the interior. Only two BSRN stations are present in continental Antarctica, one at South Pole and one in Dome C, which has been installed in 2006[290].

The BSRN station operating in Dome C (see fig.2.8) is set at 1 km from the station and consists of a solar tracker pointing at the Sun, with a series of broadband radiometers mounted on it and facing the sky for measuring downwelling shortwave (global, direct and diffuse) and longwave incoming radiation (coming from the sun and from the atmosphere). On a fixed mast, at a height of 3 meters are mounted other broadband radiometers, facing the ground, for measuring upwelling shortwave and longwave outgoing radiation (reflected and emitted from the surface). These measurements are continuously acquired at a rate of one per minute. Typical radiometers used for measuring broadband surface irradiances are pyranometers, pyreliometers and pyrgeometers. Pyranometers are used to measure global solar radiation, so they respond both to the direct solar beam and to diffuse sky radiation from the whole hemisphere (field of view of 180°). The sensing element is a thermopile with a black coating, transforming the absorbed radiation via Seebeck effect into a voltage, which is proportional to the irradiance after calibration. It is covered

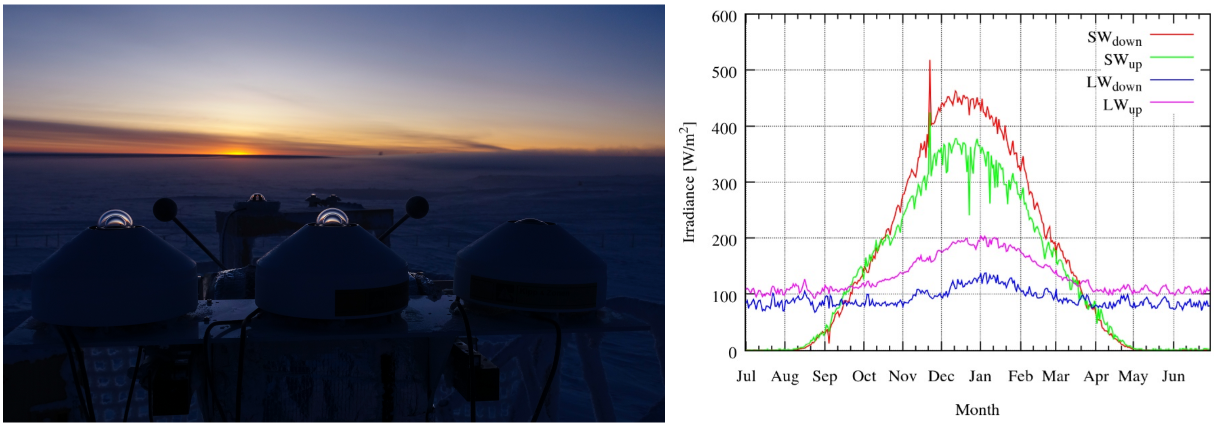

Figure 2.8: The BSRN station in Concordia and a typical yearly trend of the different irradiance components (shortwave and longwave upwelling and downwelling, daily averaged). (c) PNRA/IPEV

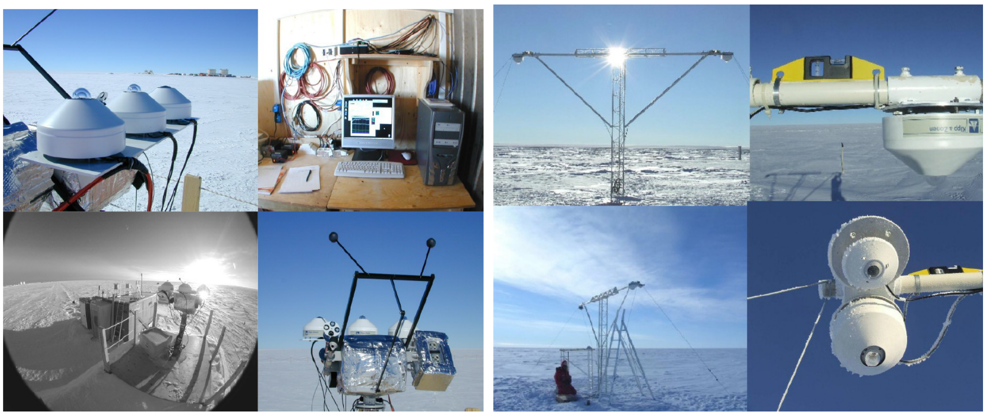

Figure 2.9: Pictures of the radiometric BSRN observatory setup of Concordia station. On the left solar tracker and devices for downwelling irradiance measurements, on the right albedo rack for upwnwelling irradiance measurements. (c) ISAC-CNR

with a quartz dome with transmittance approaching unity in the visible and near IR wavelength range ($0.3\mu m - 4\mu m$). The glass shield is necessary to isolate the sensor from the environment (wind, precipitation, etc.) and pyranometers are ventilated to avoid additional heating of the dome. With an appropriate shading of the solar disk they are used to measure diffuse sky radiation. Pyrgeometers are used to measure longwave (or thermal) radiation in the IR wavelength range ($3\mu m - 50\mu m$). Typically a silicon window is used to isolate the sensing element (thermopile) from the environment, and to filter only IR radiation. Pyrheliometers measure the direct solar beam. Their sensing element is a thermal detector which must be kept normal to the solar beam and therefore the pyrheliometer must be pointed at the Sun through a tracking mechanism. Its field of view should be small to exclude the scattered sky radiation[291] (see fig. 2.9).

All of the instruments and measurements are managed according to BSRN standard guidelines.

One aspect which is still poorly understood and considered to be relevant in the radiation budget over the Antarctic plateau is the effect of clouds[294] [293] [292]. They are responsible for two competing contributions to the surface radiation budget. On one hand they warm the surface by emitting longwave radiation while on the other hand they cool the surface by shading the incident shortwave radiation. Clouds are especially important in the antarctic longwave radiation budget because of the extremely dry antarctic atmosphere, respect to lower latitudes, which determines relatively less clear-sky atmospheric emission of radiation. Due to intense and persistent temperature inversions at the surface, antarctic clouds often emit radiation at warmer temperatures than the underlying surface. The balance of these shortwave and longwave effects of clouds is referred to as cloud radiative forcing with positive/negative values indicating that clouds warm/cool the surface relative to clear skies conditions.

It is then also important to carry out the radiometry concurrently with measurements of the relevant atmospheric characteristics, such as temperature, water vapor, ozone, aerosol, and clouds. These physical and chemical quantities are routinely measured by weather stations, radiosoundings of the meteo-climatological observatory, by ozonesoundings and by UV radiometry, by lidars through the scattering of light and by tropospheric particle counters and sizers[298] [297] [296] [365] [295].

2.3 The meteo-climatological observatory (RMO)

According to the scientific community[316] [278] [275], Polar regions are the most sensitive to climate variability, with potential and relevant impact on the rest of the Planet. For example, the response to climate change of the continental Antarctic ice cap, which is the main heat sink of Earth, could have big consequences on societies and economies around the world's coastlines, due to sea level rise. Climatic teleconnections [1] between Antarctica and other areas, appear to be well demonstrated from experimental data [316], but the physical mechanisms beyond these are not clear yet. Physical processes, balances and transport of properties that take place in Antarctica are key issues to understand such teleconnections. Their study relies on observation at various spatial and temporal scales, of meteo-climatological parameters.

The Italian (PNRA) project: "Meteo-Climatological Observatory" operates standard surface and upper-air measurements at the Italian Station "Mario Zucchelli" on the coastal region of the Ross Sea, Terra Victoria (since 1987) and at the Italian and French Station "Concordia" on the antarctic Plateau (since 2005). The main objective of the observatory is to describe the meteorology and climatology of the area, providing continuous data and information, according to standard and reliable procedures, using robust methodologies and testing new approaches[303].

[1] A teleconnection is a positive or negative correlation in the fluctuations of an atmospheric field, or fields, at widely separated points, and is mostly applied to variability that occurs on monthly or longer timescales[277]. Some examples of such teleconnections are: the El Nino Southern Oscillation (ENSO), the North Atlantic Oscillation (NAO), the Antarctic Oscillation (AAO) or Southern Annular Mode

Figure 2.10: On the left: picture of routine operations on the automatic weather station Milos 520 (Vaisala) installed at Concordia station since 2005. On the right picture of a daily launch of the meteorological radiosounding for retrieving vertical profiles of meteorological variables above Concordia station (c) PNRA/IPEV

The observatory operating at Dome C (WMO code 89625), is part of the Antarctic Observing Network (AntON) of surface and upper-air stations, contributing to different scientific and technical programmes of the World Meteorological Organization (WMO) such as the World Weather Watch (WWW) and the World Climate Programme (WCP). It consists of a weather station (AWS), and of a sounding station, both installed in 2005 for measuring standard meteorological variables such as air temperature, air pressure, relative humidity, wind speed and wind direction at the surface and in the upper atmosphere[304]. These physical quantities are measured by using standard and adapted to the antarctic conditions meteorological instruments[299].

A typical weather station (i.e. Vaisala AWS Milos520) is equipped with sensors for measuring wind speed and direction (cold and heated), temperature and relative humidity (thermocouple and capacitive), atmospheric pressure (solid state). Temperature and relative humidity sensors are shielded from radiation and the shield allows air circulation. Wind sensors must be kept clean from snow accumulation. These sensors must be installed at specific heights from the ground, as established by the WMO, to assure representativeness of the measurements acquired.

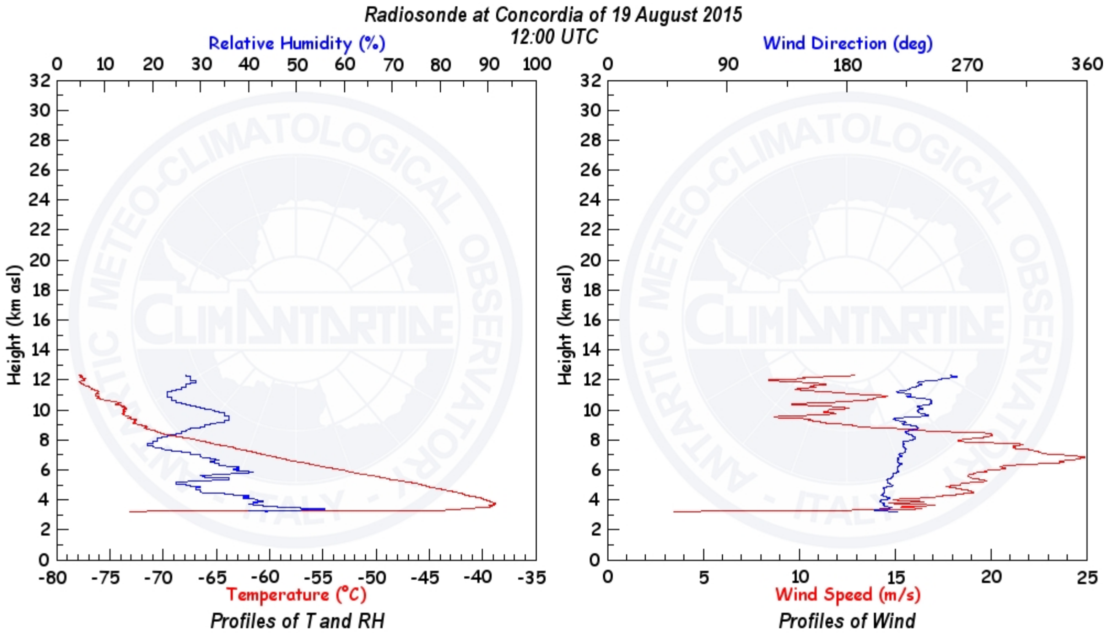

Figure 2.11: Typical vertical profiles of temperature, relative humidity, wind speed and wind direction from a radiosounding launched from Concordia station during the antarctic winter (c) PNRA/IPEV.

The radio sounding is used to monitor various atmospheric parameters along the vertical[299]. The measure is carried out with a radiosonde (VAISALA RS92) which is released into the atmosphere attached to a helium inflated balloon. At Concordia Station launches are performed once a day at 12 UTC all year round. Components of a radiosonde are a GPS receiver, a VHF transmitter, a barometer (Barocap silicon), a relative humidity sensor (F-Thermocap) and a sensor of temperature (H-Humicap). Pulled up by the balloon, the radiosonde rises up to 25-30 km above the ground, with a speed of about 2-5 m/s. As the radiosonde rises, sensors measure values of air pressure, temperature and relative humidity every two seconds, while the exact position of the radiosonde is tracked via GPS. These data are transmitted via a radio to a ground receiver system (VAISALA SPS311) managed by a specific software (DIGICORAIII) and stored. Horizontal and vertical components of the wind speed are calculated indirectly by the software by using differential GPS positions.

All these data are finally encoded (digital format and text) and assimilated in the Global Telecommunication System (GTS) of World Meteorological Organization (WMO) for initializing numerical models which, by integrating the physical equations of the atmosphere (conservation of mass, momentum and energy and thermodynamic state equation) allow numerical weather prediction and so the elaboration of meteorological maps and weather forecasts. At the same time these data are used for research purposes to characterize the local meteorology and climatology, to study characteristic weather phenomena of the Antarctic continent as well as to support other research projects and for flight and logistic operations.

A major effort is devoted to maintaining instruments and to collect, validate, archive and disseminate data.

2.4 Communication initiatives

The unusual, adventurous, extreme and engaging context of Concordia station and Antarctica has inspired and motivated the design, planning and realization of several communication initiatives about the scientific research performed there and about the life and work of researchers confined in such a place for such a long time. Different media and formats of communication have been experimented, adapting every time the content to the context and to the audience of the different events. These communication activity has been performed in first person and both from Antarctica and after coming back. Doing science communication from Antarctica, directly from the field, had the power of instilling into the audience (especially children) curiosity, a sense of privilege, the idea of having a unique opportunity and also gave more authenticity to the words and to the message communicated as a scientist, bringing a subject of research, like the studies conducted in Antarctica, closer to the audience's experience.

The science communication activity performed can be divided into the following macro-areas: conferences and videoconferences with the general public and with schools (AUSDA project of the PNRA, TEDxCNR, Festival of meteorology etc.), interviews released and articles written for generalized and specific press (La Stampa, Repubblica, Laboratory News etc.), interviews for TV shows and Radio broadcasts (Radio3Scienza etc.), a photographic exhibition (Paths in the ice), communication on social media platforms (Facebook, Twitter, Reddit). For a list of all the communication initiatives performed, see appendix A. In the following sections the ones which are considered to be particularly relevant in view of experimenting science communication with innovative formats and audiences will be considered more in detail.

2.4.1 The project: "Adopt a school from Antarctica"

During the stay in Antarctica a series of videoconferences have been organized with the aim of disseminating the science, environment and life at Concordia, promoting interest in the role played by Antarctica in our Planet and engaging students in a dialogue with the researchers working on the field. The majority of these videoconferences have been with single or multiple classes in the framework of the project: " adopt a school from Antarctica" (AUSDA) funded by the Italian Antarctic Program.

This project is based on the experimentation of an educational model in which students and teachers are involved in first person with the Antarctic continent, through a live and dialogic experience with the logistic and scientific personnel working in Antarctica. Every member of the team working at Concordia station has the possibility of adopt a class of students of a school across Italy from the elementary to upper secondary level and schools have the possibility to participate to the project asking to be adopted by a member of the team who will present Concordia's setting and manage the dialogue with the researchers

Figure 2.12: Picture of videoconferences with a series of schools in the framework of the AUSDA project of PNRA. (c) PNRA/IPEV

during the videoconference[22].

Goals of the project are: giving students a background of information and knowledge about Antarctica through a "live" learning experience. The student and the class are actively involved in the learning process, starting from reading material and web resources. They usually learn about the research projects developed during the Antarctic expedition (biology, glaciology, astronomy, geophysics etc.) with the help of their teacher and of a PNRA ambassador (usually a former member of the expedition), focusing on one particular topic of their interest. Students can then drive and deepen their learning depending on their interests, as if they were somehow "researchers", guided by the teacher and by the PNRA ambassador. At the end of the learning path, students have the opportunity of speaking directly with the researchers and technicians at Concordia station through a skype connection of about one hour. This allows students to connect live with what they studied and with the people who are on the field doing the research. After a first part in which the team introduces the class to the setting, the scientific and living challenges faced every day, the students have the opportunity to ask a series of questions they prepared during their previous learning experience and to satisfy their curiosities, allowing them to assume an active role and to observe and live the expedition in first person, through the words and the relationship established with the people working there. At the end of the project they have to present their work in the form of a report, of an article, or of a web page.

During one year almost 30 videoconferences have been organized with this format, involving students and classes from primary, lower secondary and upper secondary schools mainly from Italy, but some of them also from abroad (France, England, Martinique, USA). The communication style, the words, the expressions, the tones, the subject etc. had to be adapted to the different ages, knowledge and degree of intellectual maturity of the pupils, and the dialogic form with questions coming from pupils and answers coming from the team helped a lot with this task, helping pupils to express their interest and curiosities, helping researchers coming out from the "ivory tower" and challenging them to find appropriate words, metaphors, analogies and narrations to speak about the scientific issues which are present on the news and which will be relevant for their future lives such as climate and environmental studies. Students demonstrated a strong interest and curiosity in the majority of cases. Sometimes, especially with younger pupils this was directed more towards daily life in such extreme and isolated conditions, but this constituted also a strong leverage for engaging pupils into scientific issues.

2.4.2 TEDxCNR - "Beyond the known"

TED is a nonpartisan, nonprofit organization whose mission is synthesized by the motto: "ideas worth spreading" and who believes passionately in the power of ideas to spark conversation and debate, change attitudes, lives and, ultimately, the world. TED began in 1984 as a conference where Technology, Entertainment and Design converged, but today covers almost all topics from science, to business, to global issues — in more than 110 languages.

The TED (Technology, Entertainment, Design) conference taking place every year in Vancouver and the associated website of recorded conference presentations (TED Talks), which started in 2006, is a highly successful format for popularizing and disseminating among others, science-related ideas, claiming over two billions online views on its youtube channel[15] [16].

TED talks are targeted to a non specialist audience and are presented by invited speakers who are experts in their field, often top level academics or from important research institutes, but also people who have had remarkable experiences or accomplished remarkable things. Ideas have to be condensed by the speakers in the form of short, incisive talks of 18 minutes maximum. These talks are recorded, archived and published on the website ted.com and on the associated Youtube channel. A vital component of TED Talks is the entertainment aspect, so one of the challenges is enriching the talk with the methods used by professional "entertainers". For example the use of satire, humor, and other forms of comedy can help the public to connect and engage with science[21] [18].

In the same spirit of "ideas worth spreading", TED promotes the TEDx program, supporting independent organizers from all around the world who want to create and coordinate a TED-like event in their own community, under a free licence granted by TED. Modeled after the TED format, TEDx events feature a suite of live, short, carefully prepared talks, demonstrations and performances on a wide range of subjects to foster learning, inspiration and wonder, to spark conversations that matter and promote connections at the local level. The typical presentation should be again an up to 18-minute talk (since a generic audience is good at focusing on one subject at a time in relatively short chunks) by one or two speakers who are not payed. No panels or question and answer sessions

Figure 2.13: Picture during the talk: "Cosa abbiamo imparato vivendo un anno alla fine del mondo" held with dr. Giampietro Casasanta for the TEDxCNR event in Rome at Auditorium Parco della Musica - sala Sinopoli on the 8th october 2016. (c) CNR

with the audience are allowed after talks during the mainstage session. All original stage content (live talks, performances, etc.) is recorded and made accessible to TED and the public worldwide via the TEDx YouTube channel.

TEDxCNR - "Beyond the known" has been a global communication event, held in the Sinopoli theater at Auditorium Parco della Musica in Rome on the 8th October 2016. It has been the first TEDx event ever held by an Italian Research Institution and it could be a new interesting format for experimenting science communication. Curator and organizer of the event has been Michele Muccini, director of the Institute ISMN of the CNR, helped by his staff. Primary goal of the event has been sharing new visions and models across all fields of the cutting edge research activity developed by CNR (National Research Council of Italy) and its partners.

Candidate speakers (over 100) submitted a talk proposal to an open call published by CNR and underwent a selection process by an international panel of experts (Corrado Spinella, Enrico Bonatti, Alberto Sangiovanni Vincentelli, Maria Grazia Roncarolo e Michele Muccini). After passing this first step, there is a lot of time and effort going into talk and speaker preparation. Shaping, memorizing, and delivering a TED-like talk is a lot different from giving a speech or lecture as traditional formats used by researchers interacting with a public. In the phase of construction of the TEDx Talk, requiring a lot of discipline and creativity, speakers have been guided by Giovanni Carrada, author of the famous TV program Super Quark. In this phase speakers had to develop the core idea of the talk and put together an outline (throughline) and a script. The core idea could be new or surprising, or challenge a belief the audience already has. Or it can be a great basic idea with a compelling new argument behind it. A good idea should not be just a story or a list of facts, but should take evidence or observations and draw a larger conclusion. The structure of the talk should consist of an strong introduction, drawing in the audience members with something they care about, a body presenting the topic and all necessary evidence and a strong conclusion, leaving positive emotions, telling the audience how the idea might affect their lives if it would be implemented, or giving the audience a call to action. Every point within the talk should serve the purpose of proving the talk's main idea and its importance, making sure the audience understands why it matters to them. The talk should be relevant to the audience and make a connection with the guests.

Once the script of the talk is constructed in detail it comes the public speaking and rehearsal phase in which speakers are guided by experts in public speaking and coaching to work on body language, script and memorization, rehearsing to the point when the words feel like an integral and natural part of their being, on expressing emotions and developing a conversational tone. Speakers' should always keep the listener and what they might want or need to know in mind.

The final talk prepared and presented on stage by the candidate and Giampietro Casasanta has been: "*Cosa abbiamo imparato vivendo un anno alla fine del mondo*". The core idea has been about how one year of life in isolation and in close contact with a skeleton team of colleagues in Antarctica, changed our point of view on relationships. We decided to show this through the narration of the scientific and human challenges faced at Concordia. The structure of the talk was made of an initial "walk of wonder" with the silent projection of ten pictures of Concordia, of an introduction in which we introduced ourselves, where we have been and why, with a focus on the role of Concordia as an open air laboratory for multidisciplinary science and why the public should care about our message and in which way they could be affected. In the first part we narrated through typical routine operations, the physical challenges represented by the extreme environment faced to perform our scientific tasks such as taking samples, measurements and data necessary to reconstruct the climate of the past from ice-cores. In the second part we narrated the psychological, relational and human behavior performance challenges faced during such a long period of isolation in a small team and the analogies with the ones faced on one hand by astronauts during long duration missions and on the other hand by everyday life in the office or at home. We then concluded the talk by proposing some reflections about how to cope with difficult relationships and stress, underlining the importance of collaboration and cooperation between individuals, who by themselves have little value, going beyond personal emotions and beliefs and focusing only on the problem to be solved.

Alternating our voices in the presentation of the speech, contributed to give breaks in the pace of the narration, creating "a sense of teamwork", and a dialogic and conversational tone. The use of pictures greatly helped at picturing in the public's mind such an extreme environment, out of daily experience and imagination, and at awakening contrasting emotions[18] [19]. Science communication has not been the main backbone of the talk, but still it has been inserted in a broader perspective and in an unusual context where it is done[15], accessing to a much wider public respect to the public

Figure 2.14: Picture during the talk: "Diretta dall'Antartide: la stazione Concordia si presenta" held with Dr. Giampietro Casasanta at the Festival of Meteorology in Rovereto, at Trentino Sviluppo on the 21 november 2016 (c) UNITN

which could have been accessible with a traditional conference. The talk can be seen at: `http://www.tedxcnr.com/talks.html`.

2.4.3 Festival of meteorology

The Festival of Meteorology is a national event in Italy, organized for the first time in Rovereto in 2015 by Dino Zardi of the Department of civil, environmental and mechanical engineering of the University of Trento. After the success of the first edition, a second one has been organized on the 11th and 12th of November 2016, in collaboration with the University of Trento, "Comune di Rovereto", "Trentino Sviluppo" and "Fondazione Museo Civico di Rovereto". It has been an occasion for the different realities of Italian meteorology to meet, know each other and interact. The festival gathered together operators of the institutional and private weather services, experts and companies operating in the field, researchers, users of meteorological services and products, communication experts and meteorology enthusiasts, involving with different activities, ranging from conferences, exhibitions, workshops, live demonstrations of experiments, guided tours and panel discussion school teachers and students at every school level and the general public.

This festival goes under the broader category of science festivals among which one of the most famous in is the science festival of Genova. What distinguishes science festivals among other types of public engagement activities is the fact that they bring large amounts of people into direct contact with scientists and science communicators every year in a rich and diversified mix of activities. Science and technology which story and development are intimately linked, are showcased with the same freshness and style that would be expected from an arts or music festival. The core content is that of science and technology, but the style comes from the world of the arts[17].

Meteorology has always sparked the interest of humankind and with the advent and diffusion of fast and widespread portable devices with internet connection has become a mass and ”trendy” phenomenon, which influences the life of us all and is spoken by everybody. But meteorology with its instruments and measurements, numerical models and forecasts is based on physics and its methods. It is then an interesting subject to use for talking about and engaging the public in physics.

During both the first and second edition of the festival of meteorology, the candidate designed and held in first person with his antarctic colleague Giampietro Casasanta an intervention entitled: ”*Diretta dall'Antartide - La stazione Concordia si presenta*”. This was targeted at an audience of generic public and of people interested in meteorology, but not necessarily experts in the field or professionals. The concept of this conference has been introducing the setting of Concordia station in Antarctica and the meteorological activities and phenomenology present there as a station of the meteo-climatological observatory. This has been done also through the narration of the daily life and work of researchers, speaking in first person from Antarctica with the public with the use of a live skype-conference. An interesting experimentation has been showing and commenting live the profiles of the meteorological variables as they were acquired at that moment by the radiosounding being launched just before the videoconference. Questions coming from the audience demonstrated a strong participation and interest, and the efficacy of the methods used at least in terms of authenticity of the content being communicated and of the uniqueness of the opportunity to talk with the researchers and see live the meteorological measurements being acquired by the instruments, in a kind of ”live commentary” of a ”meteorological match”. There have been some difficulties during the videoconference due to the unstable internet connection which has been lost at times, but this contributed in a positive way to the engagement of the public, giving a sense of uniqueness, adventure and remoteness also to the process of communication itself.

Questions posed to the researchers on the field stimulated an active participation and engagement of the public allowing them to satisfy their curiosities. These questions enlightened and confirmed the presence of misconceptions about weather and climate. These misconceptions derive from the fact that the general public is exposed to weather and climate issues mainly through the mass media such as television, radio, newspapers which generally approach these subjects with strong emotional tones, incorrect information and confusion. Moreover these subjects are usually not systematically addressed in schools due to a lack of specific quantitative background in physics and natural science teachers which is partly the consequence of a lack of specific university courses tackling atmospheric sciences, weather and climate.

The conference, recorded and shared on the web can be seen on FestivalMeteorologia Youtube channel.

Figure 2.15: Manifesto of the photographic exhibition (c) PNRA/IPEV

2.4.4 A photographic exhibition: "Percorsi nel ghiaccio"

An interesting way to expose to and engage the general public into science, fostering their interest and inspiration to further deepen their knowledge through other means is by using photographic exhibitions in museums or in public places[172] [18] [19].

"*Percorsi nel ghiaccio - Due giovani ricercatori fra Antartide e Groenlandia*" is a photographic exhibition sponsored by "Comune di Cles (TN)" and designed by the candidate in collaboration with Alessandro Belleli and the cultural association "Sguardi". It is made of 46 pictures developing on two paths: "North" and "South". "South" narrates the experience of the physicist Lorenzo Moggio as a member of the Italian expedition in Antarctica and of the wintering team at the research station Concordia with some insights and a panel about the scientific research he performed in the field of atmospheric science. "North" narrates the experience of Alessandro Belleli, cultural anthropologist, during a period of 2 months in which he studied the artistic tradition of young Greenlanders of Kangerlussuaq and Sisimiut. The creative idea of the exhibition is narrating two opposite research experiences: human and scientific, happened at the opposite poles of the Earth, finding a point of contact in the themes of the extreme and of geographic, scientific and human

Figure 2.16: Picture during the inaugural conference of the photographic exhibition: ”Percorsi nel ghiaccio” held in Cles at Sala Borghesi Bertolla and in Genova at ”Castello D’Albertis - Museo delle Culture del Mondo” during the ”Festival della Scienza” 2014 (c) PNRA/IPEV

exploration. The exhibition and the introductory conferences are designed for the generic public and for what concerns the ”South” section, it aims at engaging the public into the scientific challenges of understanding planetary equilibria through the beauty of a pristine, remote and extreme environmental laboratory such as Antarctica.

The exhibition has been hosted in Cles at Sala Borghesi Bertolla and in Genova at ”Castello D’Albertis - Museo delle Culture del Mondo” during ”Festival della Scienza” 2014. The exhibition has been ”augmented” with two public conferences: ”South” and ”North” held by the curators of the exhibition (Lorenzo Moggio and Alessandro Belleli) during which they explained the idea of the exhibition and the details of their research activities. In the case of the conference ”South” together with a classical presentation, it has been used a combination of pictures and videos about the daily operations necessary to gather reliable data for the radiometric and meteo-climatological observatories.

2.4.5 A blog for Le Scienze and a Reddit - Science AMA

Scientific communication, traditionally conducted through print, radio, and television media, is increasing the experimentation of online web platform based solutions. While on one hand some sources merely create an online version of materials previously published in print, other venues actively aim to take advantage and experiment with the opportunities offered by web platforms, by their ability to reach a much larger audience and by the possibility of interaction and feedback from the audience[23] [24] [25] [26].

Figure 2.17: "365 giorni in Antartide" - a blog for Le Scienze - italian edition of Scientific American (c) Le Scienze

In this direction goes the online platform of Le Scienze with its blogs and the Reddit - science AMA series.

Le Scienze is the Italian edition of Scientific American of which it has been the first international edition. It was born in 1968 out of the initiative of Felice Ippolito, Alberto Mondadori and Carlo Caracciolo, and it is today directed by Marco Cattaneo. It comes out as a printed magazine and has also an online portal. Its subject is scientific discovery and technological innovation for the general public. Readers turn to it for a deep understanding of how science and technology can influence human affairs and illuminate the natural world. Its readers are not primarily scientists; to the extent that they have technical backgrounds, they read Scientific American for information about areas outside their expertise. The target is then more selected and biased with a strong interest in science in a broad sense and in its findings. On this magazine it is possible to find articles translated in italian from Scientific American and others where Italian leading scientists, inventors and engineers from various fields describe their ideas and achievements in clear and accessible prose, with rich graphics and visual style.

On the online platform Le Scienze experiments new forms of science communication and education such as blogs. These blogs are written by experts in the field and are intended to inform in an easy and curious way about subjects of current interest. During the antarctic mission the candidate experimented with this kind of communication media with the blog: "*365 giorni in Antartide*". The idea of this blog was narrating the life and science performed at Concordia station as in a monthly diary, through the everyday life and experiences of the researchers. Blog posts have been enriched with captivating pictures and stories of daily extreme life. The readers had the opportunity to write comments and give feedbacks on the posts allowing for a more interactive communication. Unfortunately due to the slow internet connection available at Concordia station and to some friction with other members of the team it has not been possible to complete the blog as it was intended. This demonstrates once again that science communication still finds difficulty

Figure 2.18: A reddit - Science AMA from Concordia station about the scientific research and life of Antarctica.

in being perceived as an important task to be done by the researchers, many of them still considering it as time "stolen" from the research, preferring and considering more important to remain in their "Ivory tower" as argued also by Giovanni Carrada in [1] and not considering that: "Today's scientists are no longer constrained simply by the laws of nature, as was generally the case in the past, but also by the laws (and attitudes) of the land" (cit. Norman Augustine).

Reddit is a social media platform for information worldwide, where people from all around the world can ask information and satisfy their curiosities. It is one of the most popular and influential websites on the internet, especially known in the USA. It gathers 174 million unique visitors per day, a high percentage of which being high school and college students, the perfect audience for science outreach.

One of the features of reddit is "Science AMA" (/r/Science AMA), or Ask Me Anything, which goal is to bring real researchers and knowledgable people to speak directly to reddit users about their area of expertise. Among them we cite only a few famous personalities who participated on a voluntary basis to one of these series: Barak Obama, Bill Gates, Stephen Hawking, Kerry Emanuel, Neil de Grasse Tyson and Bill Nye. On this platform scientists can answer in text format and interactively to questions done about their work by reddit users participating to the discussion. The use of this questions and answers format, allows scientists to communicate with an international audience of all ages and backgrounds. It is then an effective tool for scientific outreach, targeting different needs and publics thanks to the custom nature of its communication and to its flexibility.

On 22nd august 2015, when still based at Concordia station, the candidate together with colleagues Giampietro Casasanta and Beth Healey organized and participated with the support of the European Space Agency, to a science AMA about the research performed at Concordia station in first person in the fields of glaciology, climate science and human physiology. They offered their time (one day) for discussing and answering questions posed by visitors about the challenges faced while performing scientific research and living in Concordia. Feedback and interest demonstrated have been excellent with about 1800 answers given and 11541 positive feedbacks received (91%) from all around the world, even from other antarctic stations.


[redacted]

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GUEST BOOK

THE EXTREME SCIENCE OF 'WHITE MARS'

In one of the coldest, most isolated and remote places on Earth, a multicultural crew of 13 perform challenging research in a wide variety of fields and maintain the Italian-French station Concordia, on the Antarctic plateau. Here, Italian physicist **Lorenzo Moggio** tells us about this most extreme of research posts

Figure 2.19: An article written for Laboratory News, a specialized newspaper disseminating science to the general public.

Figure 2.20: The episode: "Antarctica's science seekers" in the show The Stream on Al Jazeera English Web TV, where the candidate participated as a guest speaking about research in climate science performed at Concordia station.

2.4.6 Traditional platforms: TV, Radio, newspapers and conferences

The candidate participated also to other science communication initiatives experiencing more traditional media such as radio, television, generic and specialized newspapers and public conferences.

Among these initiatives he wrote a short article entitled: "*The extreme science of white Mars*" for Laboratory News, a monthly magazine which goes out to scientists from across the scientific disciplines, covers a broad range of topics in both news and features, giving several opportunities to prominent and interesting scientists to contribute through comment sections and through a short blog style entry called "the Guest Book". The article and its extended version on the online platform of Laboratory News described shortly the setting and the fields of research present at Concordia station.

While in Antarctica he has been invited as a guest speaker in the episode: "*Antarctica's science seekers*" of the show The Stream on Al Jazeera English Web TV where

Figure 2.21: Interview for the episode: "A qualcuno piace freddo" for the famous Italian science communication broadcast Radio3Scienza on Radio3.

he discussed with Scott Borg Head of Antarctic Sciences at National Science Foundation, Slawek Tulaczyk, Glaciologist of the University of California-Santa Cruz and Carolyn Dowling, Geo-chemist at Ball State University, about his daily research work in Concordia and about the potential for research in one of the world's most inhospitable locations.

He has also been interviewed by Roberta Fulci for Radio3 in the program Radio3Scienza, one of the most known science communication programs on Italian Radio broadcast. The episode: "*A qualcuno piace freddo*" was about life and scientific challenges coming from being in such an extreme environment.

More standard communication initiatives performed by the candidate have been a number of conferences held at local secondary schools to young students, at two stages for young students in preparation to the mathematics olympic games and at local public conferences for the general public. The communication style chosen for these initiatives has been a mixture of pictures, videos, daily life operations and anecdotes, used for narrating about the research performed in the field of atmospheric science with the radiometric and meteo-climatological observatories.

2.4.7 Outcomes and reflections

These science communication activities in which the candidate took part actively, both in the design and in the realization used in many ways unconventional media for engaging people with science and physics. Their use has been more in a sense of science popularization, inspirational science and life of researchers and public engagement rather than in the sense of education which is better addressed in formal education environment such as schools and universities. The extreme and remote environment, life and challenges faced by the people living at Concordia station, Antarctica have been used as an inspirational hook to establish a connection with the public and to catch the audience's attention, interest and curiosity. This created a good platform for speaking about the science and the research performed among which the radiometric and of the meteo-climatological observatories allowed to speak about weather, climate and climate change and the role of Antarctica and more generally polar regions in determining our Planet's equilibria.

The interest showed by the public and especially by school students during videoconferences for these subjects was not enough and inspired the candidate in the development of a training course for teachers and of a teaching-learning sequence, based on quantitative laboratory activities to tackle some of the phenomena related to climate and weather (such as radiative balance, greenhouse effect and cloud formation) starting from the underlying basic physics.

Chapter 3

A teaching sequence from physics to atmospheric phenomena

This chapter presents a teaching sequence across basic physics and atmospheric phenomena related to weather and climate which has been developed during the Ph.D. program and which has been proposed as a training course for secondary school teachers promoted by IPRASE[1] and tested with graduate students.

The teaching sequence, designed taking into account typical misconceptions, concept inventories, previous attempts and recommendations present in education research literature, consists of a series of quantitative and qualitative experimental activities and demonstrations enriched by the use of applets and simulations which should guide the student through a series of steps and levels of understanding: from basic physics to its application to the analysis of some of the processes and phenomena typical of the atmosphere and relating to climate and weather.

A first step consists in the experimental investigation of relationships between physical quantities, inferring from the measurements and data collected some of the basic laws of physics.

In a second step students connect and use the knowledge and competences gained in the field of basic physics and apply them, also with the help of simulations and models, to the specific situations, phenomena and context of atmospheric science, elaborating a conceptual model of these phenomena based on the laws of physics. More specifically the focus is on two peculiar processes/phenomena having an important role in our climate and

[1]IPRASE is the Institute of Educational Research and Experimentation of the Autonomous Province of Trento, carrying out documented research in the pedagogical, methodological and training fields. Its goal is to support innovation and autonomy in schools and networks of schools, as well as promoting activities of the provincial committee of evaluation of the schools and the training system of the institutions involved in education. On request from the autonomous schools, of the networks of schools and of the Provincial Council, the Institute also carries out teacher training activities in schools, pre-schools, kindergartens and vocational training centers with activities that schools themselves are unlikely to offer. The Institute works in partnership with the University of Trento and with other Italian Universities, with Institutes of Research validated by the Italian Ministry of Education and with other Institutes of educational research across Europe[156].

weather, closely related with the measurements, activities and scope of the radiation and meteo-climatological observatories of Concordia station in Antarctica:

- *radiative equilibrium*, average global temperatures and the *greenhouse effect*,
- *thermodynamic* variables and transformations and the formation of *clouds* and *winds*.

These two "modules" build up onto a preliminary module on the physics of thermal phenomena and thermal equilibrium which allows to introduce the necessary physical quantities and the macroscopic and microscopic frameworks guiding the physical interpretation and modeling of such phenomena.

Following this sequence of experimental activities, data analysis and modeling the students should familiarize on one hand with the scientific process. Start from posing questions about relevant phenomena for their everyday life, investigate and discover through experimental activities, measurements and data analysis the necessary basic laws of physics and integrate them, also with the help of applets and simulations, in the construction of conceptual models for understanding the more complex phenomena questioned in the beginning, assessing validity and limitations of these models. On the other hand students should understand the physical basis of weather and climate change, the tools and methods used by researchers to investigate, model and predict the evolution of such complex systems, allowing them to understand the motivations of the challenges humanity will have to face relating to climate change, fostering engagement, participation and responsible behaviors of future citizen and wiser choices by politicians.

In the chapter there will be also a discussion about the motivations for such a teaching sequence, the methods used in its development and the educational strategies followed. Pre and post tests based on research literature have been used in the testing with graduate students as tools for a preliminary evaluation of how the the sequence performed in addressing typical misconceptions and incorrect conceptual models about basic physics and atmospheric phenomena.

Other proposal and tests done in the past on these themes such as the ones by Besson et al.[325] [326], Tasquier et al.[198] [332] [328], Borwne et al.[329], Lueddecke et al.[330], Corti et al.[336], Spiropoulou[340], Nucciotti et al.[348] or the one done in the framework of a collaboration between the Regional office for education of Emilia Romagna and the Institute of Atmospheric sciences and climate of the CNR[333] have been considered and further developed in our teaching sequence.

3.1 Motivation

Weather and climate and especially its change are issues having a broad and important resonance and impact in many contexts in the 21st century: from news and media, to public debate, from political agendas and international policies to discussions and planning of strategies for mitigation and adaptation of societies and economies. Weather and climate influence our lives and our choices from the perspective of the single citizen, but also from the perspective of companies, of insurance agencies, of policies and of their influence at a collective and global level. Despite public awareness and interest in weather and climate, most of the public only know what they have been fed by the media which are often not very good at communicating the scientific basis and issues underpinning weather extremes and climate change for example. They often tend to present news in a fashionable, emotional, uncritical and catastrophic way, attracting the attention of the public, but not letting the public understand or think about the processes and mechanisms which are at the basis of climate and weather dynamics and which are of importance to form correct mental models of the phenomena, to develop a critical attitude towards the news and to understand eventually which actions would be needed both at an individual and collective level to mitigate and counteract adverse impacts. Conceptual models of processes and phenomena about the atmosphere, weather and climate are essential to interpret correctly information and data and to become active and responsible citizens in the daily choices and behaviors which would be needed to implement and sustain successful policies for addressing and mitigating for example global warming, climate change and weather extremes[198] [41] [48] [199] [203].

As just said, climate change and weather extremes are broadly addressed by traditional media (news, TV and Radio broadcasts) which constitute the main and often only source of information for the vast majority of people, often leading to false alarmism, misleading beliefs and misconceptions[36] [200].

On the other hand, even if explicit reference to knowledge, abilities and competencies relating to "climate" and "meteorology" can be found in secondary school teaching guidelines[154] [155] [176], there seems to be little presence of these issues in the actual teaching practice in formal contexts, in particular with a quantitative, experimental approach showing and highlighting explicitly the connection with basic physics concepts, core backbone of such issues[186] [173] [174] [175] [180].

School guidelines[154] [155] also refer to climate and meteorology across different disciplines such as history, physics, natural science and geography, demonstrating how they can be considered as a conceptual box in which different disciplines can integrate, bridging their traditional boundaries and conceptual frameworks, promoting a multidimensional and integrated view of sciences and their founding backbone: the scientific method[179] [197] [198] [328].

But as pointed out in literature[184] [192], teachers may also have misconceptions and confusion about issues related to climate science and meteorology and then may not feel confident enough in teaching about such subjects to their students[185]. They may have never received proper formal education in these fields, for example at the University, or they may not find satisfactory training courses targeted to their specific needs. In fact, in Italy for example, climate science and meteorology courses are usually found across a broad spectrum of University courses ranging from geology, to environmental science, engineering, physics and natural science, but are often not compulsory. For historical reasons, scientific culture and learning about climate and meteorology has been confined to the context of the National Aeronautics, limiting its teaching to be diffused to citizen and civil society. Moreover in the anglo-saxon tradition and its academic system, geography (i.e.

physical geography), where climate is often taught, is considered as a scientific subject, whereas in Italy geography tends to belong to and to be taught from teachers having a background in humanistic studies. This can have implications in teachers' education and in their ability and confidence in teaching quantitatively about climate and meteorology to their students. For this reason an approach to these themes, with an integrated sequence involving teachers of different subjects (i.e. physics, chemistry, natural sciences, geography etc.) may positively impact the actual teaching practice about climate and weather, fostering cooperation among colleagues of different subjects, minimizing the impact in terms of teaching loads in the single subjects and promoting an interdisciplinary teaching of science, also advocated by school guidelines[154] [155] [176].

The science and processes of the atmosphere with its tangible manifestations in the weather and climate we have on our Planet, influencing our lives, offers an actual, concrete, motivating, inspiring and interdisciplinary context for students. In this context they can investigate natural phenomena by doing the work of the researcher, practicing the scientific method by asking questions and posing problems, building instruments, taking measurements, collecting and analyzing data, discovering laws and quantitative relationships, constructing conceptual models of the processes underlying the same natural phenomena, making predictions and verifying them, learning in this way a lot of physics. Climate, radiation and the greenhouse effect allow for example also the integration of modern physics with issues such as the blackbody radiation and the interaction of radiation with matter, as encouraged by school guidelines[154]. Learning about weather and climate and their quantitative processes, secondary school students can also gain a general idea and orientation with regards to their possible next studies in Master degrees in meteorology and environment such as the one which should start at the University of Trento in the next years.

A last motivation for the development of such a teaching sequence, is the active role which the citizen will be asked to assume with its behavior and with its life choices to meet the agreements and goals ratified by the governments of 143 nations at the Paris Climate Conference (COP21). These goals consist in limiting greenhouse gas emissions and achieving a balance between sources and sinks of greenhouse gases in the second half of this century, keeping global average temperature increase (global warming) well below 2°C (considered to be a critical threshold by climate scientists[316]) and pursuing efforts to limit it to 1.5°C respect to the time of the Industrial Revolution[204] [205].

3.2 Target

The teaching sequence has been designed to target secondary school students at the first two years or at the last two years of the school, when the fundamental physics necessary to speak about climate and weather is being taught as specified by the school guidelines[154].

As first trial, it has been experimented with graduate students of the course: "Experimental physics laboratory at high school I", held at the Department of Physics of the University of Trento for the Master in Mathematics and Physics with a focus on teaching and scientific communication.

A modified version of the same sequence has been proposed in the form of a training course, promoted by IPRASE for physics and chemistry teachers and their technical assistants. In this case the focus was more at proposing atmospheric science, phenomena and processes related to climate and weather as a framework for the integration of the physics and chemistry taught to students attending the first two common years at Buonarroti technical secondary school of Trento (`www.buonarroti.tn.it/`) and at Marconi technical secondary school (`www.marconirovereto.it/`), in the framework of a pilot experimentation towards the integration of physics and chemistry in technical secondary schools ongoing in the Autonomous Province of Trento.

3.3 Methodology and design guidelines

The design and implementation of the teaching sequence privileged the use of active learning methods[117] [118] [120], where experiments are based on research of the conceptual foundation needed to learn a particular topic area in physics and which demonstrated to work well in many different environments. There is evidence for example, that activity-based, computer-supported, interactive learning environments well serve the diversity of students studying physics and enhance their learning[119] [124] [115] [113] [116]. The design of the activities is based on a ”three-dimensional approach”, involving a synergic integration of a critical analysis of the scientific content in view of its reconstruction for teaching, an overview of current proposals (textbooks, common practice teaching), and an analysis of educational research on the topic.

We then identified a series of central themes: thermal phenomena and equilibrium, radiative equilibrium, average global temperatures and greenhouse effect, thermodynamic variables and transformations, phase changes and the formation of clouds and winds; which constitute the conceptual backbone for the development of the teaching sequence.

We then developed a series of activities integrated in the lessons, privileging, when possible a quantitative approach based on quantitative experiments and demonstrations. When this was not possible applets, visualizations and simulations have been used and helped explaining complex concepts and models such as the interaction between radiation and matter or at showing the impact of different processes and feedbacks in the climate system.

As general guidelines in the development and testing of the teaching sequence we tried to use as much as possible effective practices for teaching physics which have been demonstrated by PER to be useful at improving student learning such as using collaborative work and learning through development of problem-solving and critical thinking skills, keeping students actively involved by using activity-based guided-inquiry materials, using a learning cycle beginning with predictions (e.g. the PEC: prediction - experiment - comparison cycle), emphasizing conceptual understanding, letting the physical world being the authority, evaluating student understanding, making appropriate use of technology (e.g. spreadsheet for data analysis, smartphones, applets and simulations), beginning with the specific and moving to the general[127] [117] [132] [129] [124] [123] [132] [133] [199].

Concerning the testing of the teaching sequence with graduate students, our sources of data on students' progress and ideas included three questionnaires, discussions during and after the experiments, students' drawings, reports and explanations during the final exam of the course.

Two of the questionnaires (pre-tests) were given before the activities (the first before the thermal phenomena module and the second before the module on radiative equilibrium, greenhouse effect and climate), and the third (post-test) approximately two weeks after the end of the whole teaching sequence. Some questions have been taken and adapted from literature[145] [146] [147] [150], to allow for comparison (see appendix C). In the pre-test on the climate module we used open questions to investigate students' pre-knowledge with the least influence possible which can derive from the ways in which questions are posed or from having explicit alternatives among which to choose. This choice did not allow to use gain factor (or g-factor[115] [134] [139] [146]) for analyzing more quantitatively students' learning progress after the testing, leaving the evaluation process of the teaching sequence at a more qualitative and preliminary level.

3.4 The teaching sequence

The underlying idea of the teaching sequence is to start from simple quantitative experiments allowing to investigate and infer some of the basic laws of physics and then using these laws for constructing conceptual models and explanations about some of the phenomena observed or relevant in our climate and weather (for the details of the teaching sequence and of the single experimental activities, procedures and data see the teaching materials at appendix B).

As already said the teaching sequence has been built taking into consideration typical misconceptions held by students about thermal, climate and weather related atmospheric phenomena. These have been discussed and addressed in the testing with graduate students.

The teaching sequence (see fig. 3.1 for the conceptual structure) is divided into three modules strictly connected:

- a zero preliminary module with experimental activities on *basic physics* (i.e. thermal phenomena) which constitute the prerequisite for introducing physics principles and laws applied in the following modules in the context of the atmosphere
- a first module about *climate and atmospheric physics*, focusing on solar and terrestrial electromagnetic radiation, their interaction with the atmosphere, radiative equilibrium and global average temperature, greenhouse gases and the greenhouse effect (natural and anthropogenic), radiative forcing and global warming, feedback processes and chaotic behavior.
- a second module about *weather and meteorology*, focusing on states of matter, phase changes, ideal gases, thermodynamic variables and transformations (in particular

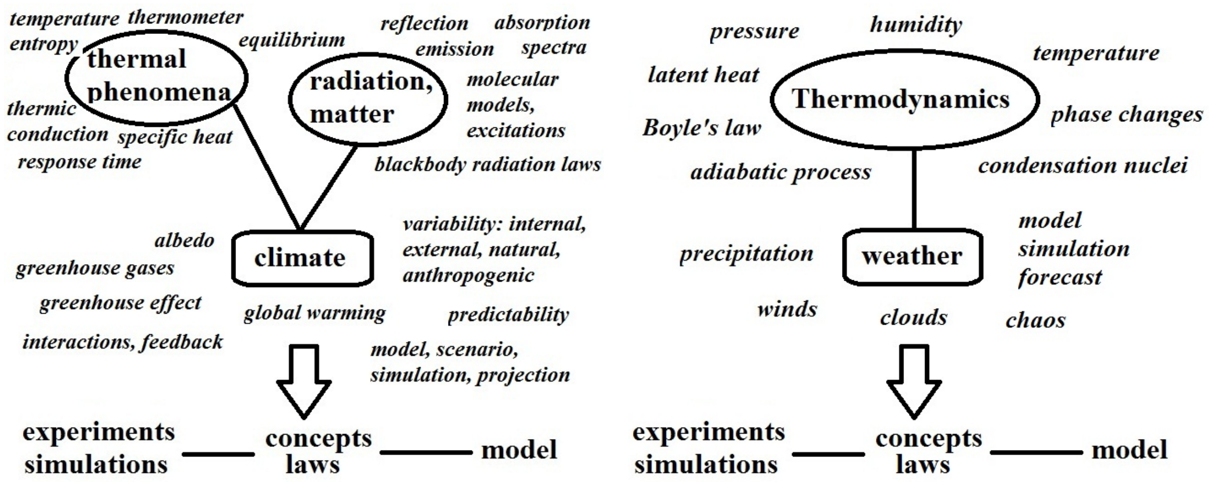


Figure 3.1: Conceptual structure of the teaching sequence.

temperature, pressure, adiabatic transformations) and the formation of winds, clouds, and precipitation.

These modules can be adapted to two different targets of students. On one hand the target could be students of the first two years of technical secondary schools (ITT) in the framework of the subject: integrated sciences (namely introductory physics and chemistry) in which they develop knowledge, abilities and competences characteristic of the ”hard” sciences such as quantities, instruments and the process of measure, together with a general background in physics and chemistry which will be useful as a starting point for the specific subjects they will study in the next years and both as informed, responsible and critic citizen, able to apply their knowledge and the scientific method in the practical contexts of real life and being informed about issues present in the news such as for example climate change.

On the other hand the target can be students of the last two years of secondary schools (typically ”Licei”) in the framework of a multidisciplinary module involving as subjects physics, and natural sciences (which include Earth sciences, biology and chemistry). In this case physics and natural science teachers could work in collaboration, leaving the quantitative experiments and physical conceptualization sections to the physics teacher and the more qualitative and phenomenological sections to the colleague of natural sciences. In this way it is also possible to minimize the impact in terms of hours spent in the economy of the teaching hours available for the single subjects which is an argument often used by secondary school teachers against the introduction of innovations and new issues in the teaching practice.

More in detail, the climate and atmospheric physics module can be treated at a higher level with students of the last year of scientific secondary schools (”Licei”), involving also modern physics as prescribed by the most recent school guidelines, with themes such as blackbody radiation, atomic and molecular absorption and emission spectra, interaction

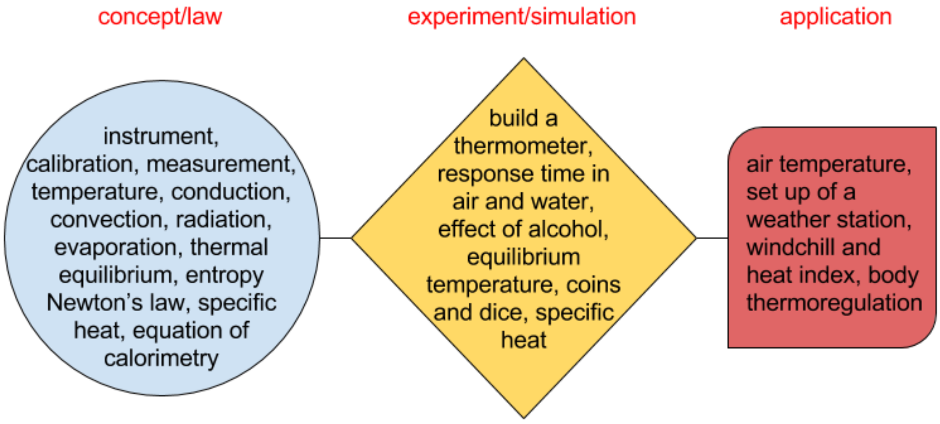


Figure 3.2: Structure of the thermal phenomena module in terms of: concepts/laws, experimental activities/simulations and applications.

of electromagnetic radiation with matter, non linear systems, chaotic behavior, statistical predictability etc. At the same time the same module can be treated at a lower, simplified and phenomenological level with students of the second year of secondary schools, discussing the concepts of the thermal effects of radiation, of the infrared emission of the Earth and of its interaction with the the atmosphere from a more qualitative point of view, closer to a classical optics approach.

The weather and meteorology module can be treated at higher level of detail, including quantitative modeling and derivations with a target of students attending the fourth year of scientific secondary schools ("Licei"), when addressing for example thermodynamics in physics or inorganic chemistry in natural sciences. At the same time the module can be adapted to target students of the first year of secondary schools, when addressing physical quantities and their measurements such as temperature, pressure, density, macroscopic properties of matter, microscopic models and phase changes.

3.4.1 Thermal phenomena

The sequence starts from traditional experiments about *thermal phenomena*, centered around the concept of thermal equilibrium. Students complete a pre-test (see appendix C) to asses their pre-conceptions. Physical quantities such as temperature are introduced at first from an operational and macroscopic point of view, together with the instruments used to measure them (i.e. thermometer). Students build a *thermometer* by calibrating a thermoscope in boiling water and melting ice.

Then an innovative experimental activity is proposed (see fig. 3.3 and appendix C), consisting in estimating the *response time* of a standard alcohol thermometer immersed in two different fluids: air and water, with the use of smartphones and video analysis techniques (i.e. time lapse and slow motion, video tracking). This activity allows to introduce some important aspects related to the problem of *measure*, *instruments*, their *calibration*

Figure 3.3: On the left, students measuring the response time of a thermometer with smartphones. On the right, students playing with dice and coins to investigate the microscopic approach to thermal equilibrium.

and characteristics, procedures, their limits and validity, the exponential function typical of decaying processes and the definition of the general concept of time constant of a process (in this case, response time of the thermometer), as well as mechanisms of *conduction* (Newton's cooling law $dT/dt = (T_2 - T_1)/\tau$), *convection* and *radiation* as means of transferring thermal energy between bodies at different temperatures. This experimental activity[366] has been developed and published as a part of the research activity performed by the candidate and has been tested with graduate students and teachers, allowing to discuss how time response is not an intrinsic property of the instrument itself, but it depends also on the environment and on the procedure followed. Another simple demonstration in this sense has been done by questioning students about what would have happened to the temperature if the thermometer would have got wet with alcohol, allowing for the introduction of the concepts of phase changes and latent heat, temperature vs feelings and the application to windchill and heat index and body thermoregulation.

Thermometers are then used to investigate the approach to *thermal equilibrium* and its dependence on differential temperature, mass and specific heat of bodies (two amounts of water at different temperatures in two different recipients and two metallic blocks at different temperatures in a polystyrene box), resulting in the fundamental *equation of calorimetry* ($Q = mc\Delta T$). The approach to thermal equilibrium is then revisited from a microscopic point of view establishing an analogy with an experimental activity with *coins and dice* developed and tested during the Ph.D. program[367], introducing the concept of *entropy* and its statistical interpretation. This activity showed the students that the de-

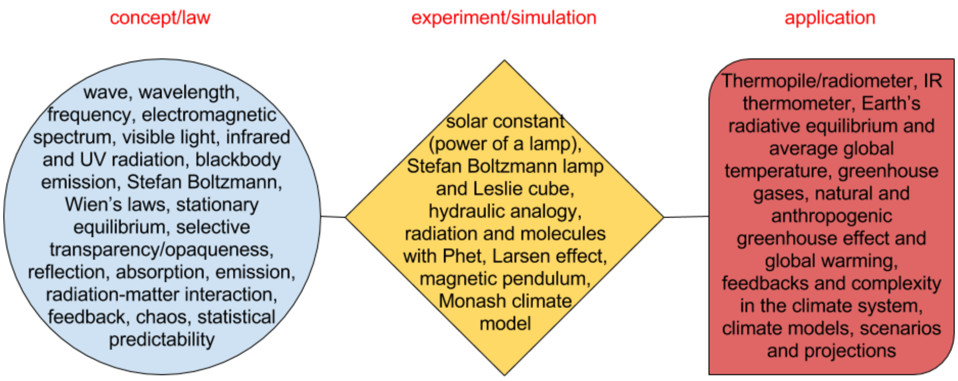


Figure 3.4: Structure of the climate module in terms of: concepts/laws, experimental activities/simulations and applications.

scription provided by thermodynamics is intrinsically probabilistic, and that macroscopic laws, such as the law of heat transfer, are based on microscopic phenomena which we interpret using a statistical description. Other classic experimental activities are: measuring the equivalent mass of the calorimeter and the *specific heat* of aluminum.

Before and after the experimental activities students have been asked to reason about typical *misconceptions*[146] [147] [206] [54] [150] [151] concerning temperature and heat, thermal conductivity, thermal capacity and specific heat which were contained in the form of questions in the pre-test. In this way, by facing *cognitive conflict* with their pre-knowledge they had to build new conceptual models which could give a better explanation of the phenomena and overcome the conflict, integrating their pre-existing knowledge with an improved one.

3.4.2 Radiation - climate module

After discussing thermal equilibrium, the concept of *electromagnetic radiation* and its *thermal effects* is introduced through the question of what would happen to the temperature of a black metal plate exposed to solar radiation or to a shining light bulb. Students discuss their pre-conceptions and engage in an experimental activity to verify their predictions. They use thermometers to measure the curve temperature vs time of aluminum plates of different colors (i.e. black and white), exposed to solar radiation or to a shining light bulb and then shadowed (light bulb off), they see that the *temperature* reaches a *stationary* value after some time, less in the case of the white metal plate and obtain in the case of the black metal plate an estimate of the *solar constant* (if exposed to solar radiation) or of the *power of a lamp* (if exposed to the light bulb), by balancing the energy fluxes during the heating and cooling phases. They then build a conceptual model of the phenomenon, understanding that the stationary temperature reached by the metal plate is the result of *radiative equilibrium* between the incoming *visible radiation* and the outgoing *infrared radiation* emitted by the body. By contrasting the principle of energy conservation and the fact of having a constant flux of energy being absorbed by the metal plate with the experimental fact of a stationary temperature, they must think of something being emitted by the metal plate which is not visible to our eyes, and face the need for infrared radiation being emitted by the body to establish equilibrium and conserve energy, resulting in a constant temperature. This experimental activity is used also to give insight into the working principle of a *thermopile* commonly used in radiometers to measure broadband integrated radiation fluxes as the ones used on BSRN stations. The case of the white metal plate exposed to visible radiation and warming up less compared to the black metal plate, offers the context to speak about the concept of surface *albedo* (fraction of the reflected over the incoming shortwave solar radiation arriving on a surface) which plays an important role in Earth's energy budget and in understanding the effects and feedback in terms of solar energy absorbed by the climate system (i.e. oceans with their low albedo compared to snow and ice), of a change of the surface albedo in polar regions, due to global warming and to the consequent melting of the Arctic sea-ice for example (*ice-albedo feedback*).

Students are then questioned on how the radiation emitted by bodies (blackbodies) depends quantitatively on their temperature (*Stefan Boltzmann law*) which they investigate with an experimental activity using the *Stefan Boltzmann lamp* (a tungsten filament lamp with its calibration curve of resistivity as a function of temperature, powered by a variable voltage) and a thermopile[349]. The concept of *blackbody* as a perfect absorber/emitter and that of *grey body*, having a lower *emissivity* is shown by using the *Leslie cube* (an aluminum cube heated inside by the radiation emitted by a light bulb, having on the outside surfaces of different emissivities), the thermopile and an infrared thermometer. By pointing the thermopile on different faces of the cube, students measure different amounts of radiation emitted even though the thermocouple indicates all faces having the same temperature, while the infrared thermometer indicates different temperatures of different faces. In this situation again the cognitive conflict is used to stimulate students to confront with their pre-knowledge and with their conceptual models, forcing them to integrate what they have learnt into a new conceptual framework. With the use of the spectroscope and a smartphone it is given also a *qualitative* demonstration of *Wien's law*, by observing the colors present in the *spectrum* and their intensity as the Stefan Boltzmann lamp is powered by a higher voltage (resulting in a higher temperature of the filament).

At this point the laws (i.e. Stefan Boltzmann) derived experimentally and the model used for explaining the radiation balance and the resulting stationary temperature in the case of the metal plate, are extended to the context of the *climate system*, identifying the Earth as a blackbody emitting thermal radiation and the average global temperature of the Earth as the radiative equilibrium temperature between the incoming solar radiation absorbed by the surface (solar constant diminished of the Earth's albedo) and the thermal radiation emitted by the *Earth's* surface, predicting a surface *temperature* much lower than the one observed (-18°C).

This balance between different kinds of radiation and the resulting *stationary condition* for the temperature are further stressed with a qualitative demonstration using a *hydraulic analogy* (i.e. glass with a hole at the bottom, water flowing in at a constant rate being the radiation absorbed coming from the sun, water flowing out from the hole being the thermal

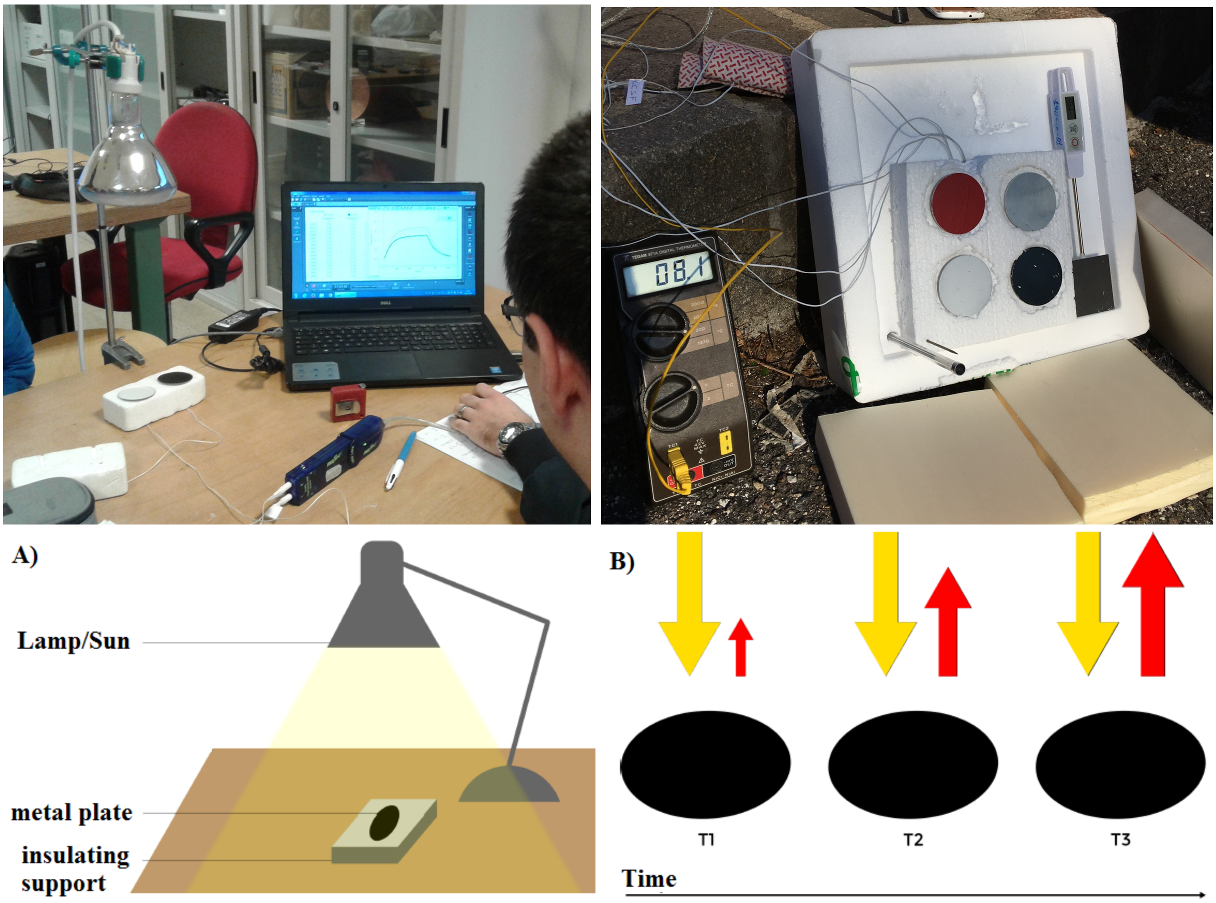


Figure 3.5: In the pictures above: on the left students measuring the power of a lamp and on the right, measuring the solar constant from the temperature of an absorbing aluminum plate. In the picture below: A) scheme of the experimental setup, B) approach to radiative equilibrium: yellow arrows represent the intensity of the radiation coming from the lamp (Sun), red arrows represent the intensity of the radiation emitted by the metal plate. T_i represent the temporal evolution of the temperature, with $T1 < T2 < T3$ and T_3 the equilibrium temperature.

radiation emitted by the Earth, stationary water level being the radiative equilibrium temperature)[336].

For younger students (first two years of secondary school) who may still not be familiar with the *electromagnetic spectrum* and at differentiating between visible and infrared radiation, it is possible to use some practical activities such as the construction of a *spectroscope* with cheap materials (cartoon and a diffraction grating sheet) which placed on a smartphone can show how the radiation coming from different sources of visible light is in fact composed of different "colors", corresponding to different wavelengths[342]. *Infrared* radiation, can be visualized by using cheap *smartphone thermocameras* for observing different objects or the IR pulsed light of remote controls with standard smartphone cameras.

Going back to the Earth's energy balance model, this is then modified and refined to account for the difference between the predicted and actual average temperature on Earth,

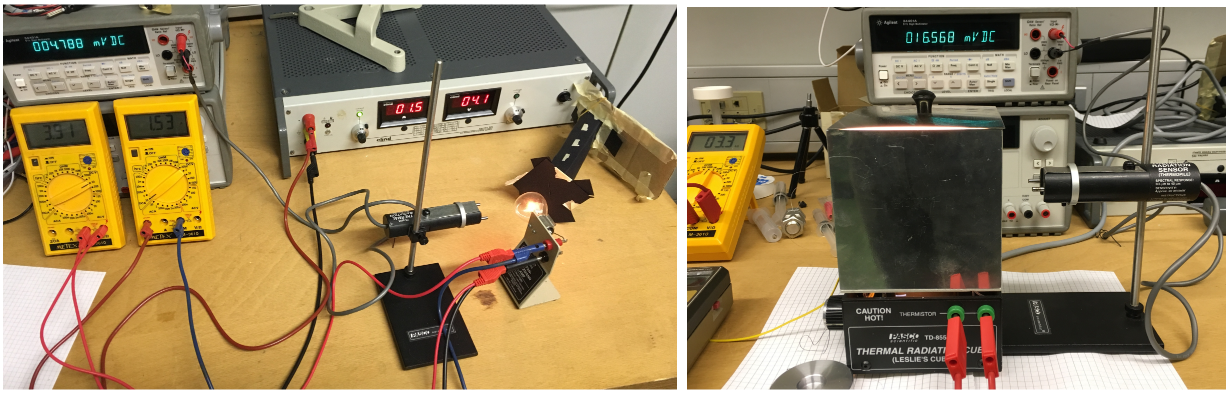


Figure 3.6: Measuring radiation emitted from the Stefan Boltzmann lamp on the left and from the Leslie cube on the right (Stefan Boltzmann law).

by taking into account the role of the *atmosphere* and of its gases. Again an analogy of the role played by the atmosphere is illustrated by showing the effect of interposing different materials (i.e. plexiglas, silica, aluminum) between a heated body (the Leslie cube) and the thermopile, showing students how concepts of bodies' *transparency* and *opaqueness* (in relationship with the optical processes of *absorption*, *diffusion* and *reflection*), are relative to the wavelength of the radiation used, as it is for the atmosphere, being almost transparent to solar radiation, mainly in the visible range (shortwave), but opaque to terrestrial radiation emitted by the Earth, mainly in the infrared range (longwave or thermal). This last, being absorbed and re-emitted by the so called *greenhouse gases*, naturally present in the atmosphere determines much higher temperatures than the ones calculated without any atmosphere.

Speaking of greenhouse gases and particularly of *water vapor* and *carbon dioxide*, is a good point for bridging to *chemistry*, speaking about atoms, their interaction forces and chemical *bonding* to form *molecules*, which can interact with the electromagnetic radiation by *absorbing* and *emitting photons*, and modifying their *vibrational, rotational or electronic energy state*. Here it is also possible to introduce some *modern physics* from a qualitative point of view, namely basic concepts of quantum mechanics such as the discrete nature of energy levels, atomic and molecular spectra and the interaction between radiation and gas molecules happening only in correspondence to specific photon energies. This is done from a qualitative point of view with the help of *Phet applets*[350] [339] asking the students to investigate the behavior of different molecules exposed to different kinds of electromagnetic radiation (photon energies).

With this activity students are also encouraged to investigate the behavior of the *ozone molecule*, with its different role in the troposphere (toxic for human health, constituting pollution and interacting with infrared radiation as a greenhouse gas, but having little effect since its very low concentrations) and in the stratosphere (forming the ozone layer, beneficial to life on Earth and interacting with UV light preventing the more energetic photons from reaching the ground and damaging cells and DNA).

Students of the last year of secondary school can further investigate the discrete nature

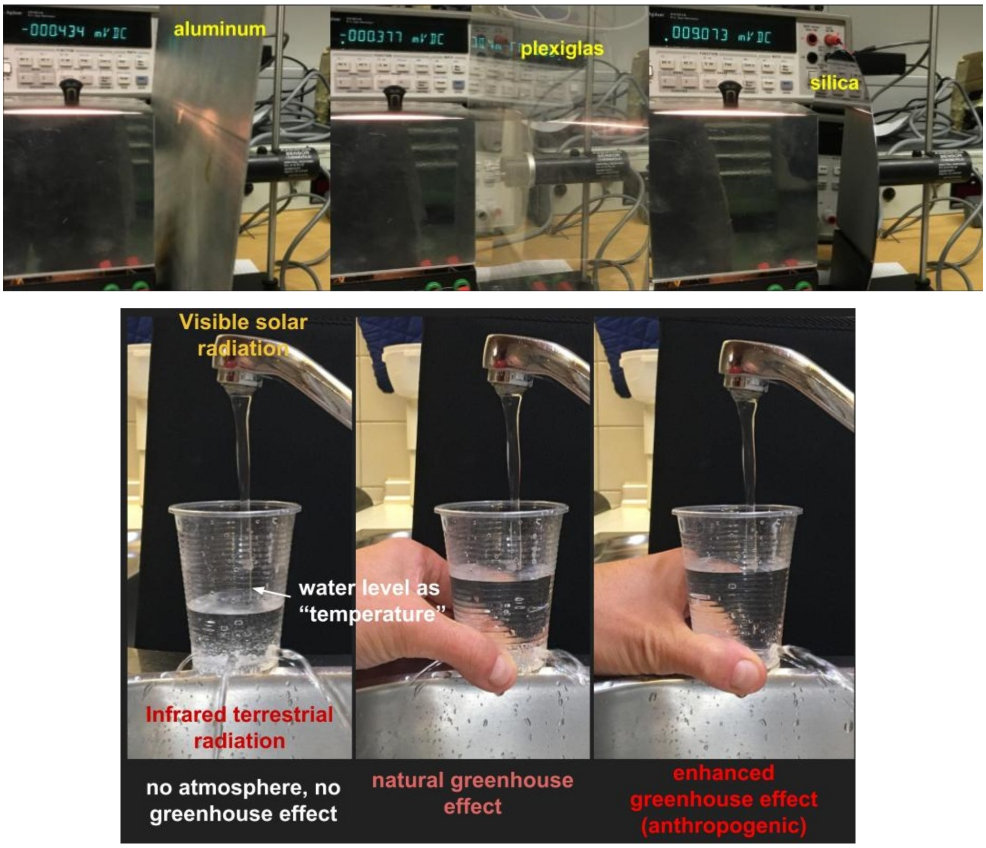


Figure 3.7: Above showing the different behavior of materials in terms of transparency and opaqueness (reflection, absorption and emission) with regards to visible and infrared radiation in analogy with what happens in the atmosphere due to the presence of greenhouse gases. Below the hydraulic analogy[336] used to illustrate the radiative equilibrium as being stationary and the effect of the natural and enhanced greenhouse effect.

of energy levels by seeing *hydrogen spectral lines* (Balmer series), with the use of a hydrogen lamp and smartphones with the home-made spectroscope mentioned above mounted on it and using a known spectrum for calibration.

After pointing out with these activities, the different behavior of greenhouse gases, naturally present in the atmosphere and of ozone to different kinds of radiation, students build a conceptual model of the atmosphere being almost transparent to visible light (no interaction between photons and greenhouse gases) and partially opaque to infrared radiation (absorption and re-emission of photons), this determining thermal radiation going back to the Earth's surface, being absorbed and then determining an increase in its temperature to re-establish radiative equilibrium. At this point students should have all the elements to build a coherent conceptual model of the physical basis of the greenhouse effect.

An important differentiation between the natural and enhanced or anomalous greenhouse effect is done: the first being beneficial and responsible of favorable conditions for life on Earth and the second, caused by increased anthropogenic emissions of carbon dioxide

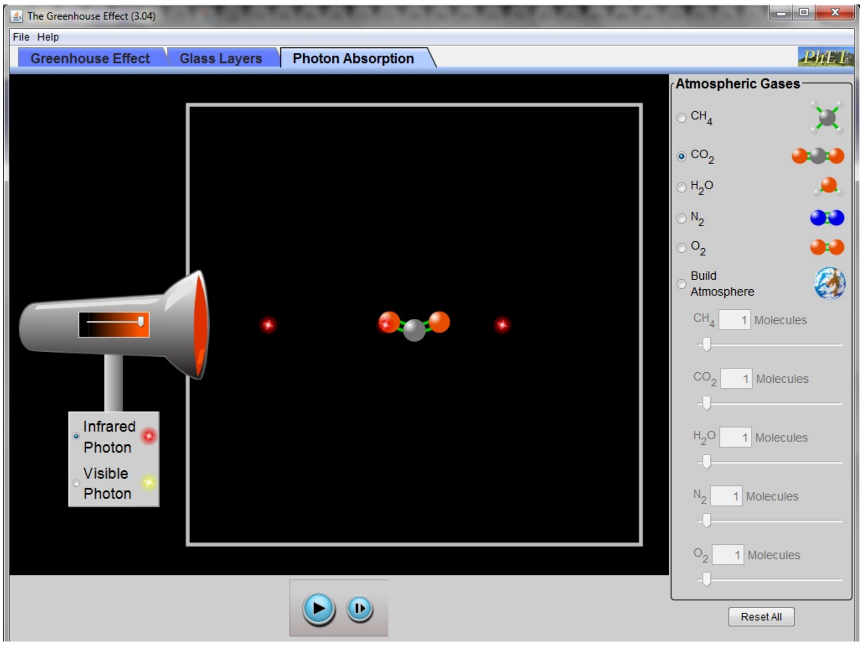


Figure 3.8: Investigating the interaction of different kinds of radiation with different molecules using Phet applets[350] [339].

since the industrial revolution and change in land use, being very likely the cause of global warming[316] [45]. This mechanism can be exemplified especially for younger students by using again the hydraulic analogy (glass with three holes), and letting them experiment what happens to the stationary water level (global average surface temperature in the analogy) when closing one hole of the plastic glass (natural greenhouse effect) and another smaller one (enhanced greenhouse effect). This analogy is also very clarifying with regards to a typical misconception related to the greenhouse effect which is the idea that greenhouse gases trap the radiation not allowing it to escape and so suggesting an unbalance in the radiative equilibrium which is not true in the end once the surface temperature has readjusted in response to the so called *radiative forcing* exerted by anthropogenic emission of greenhouse gases.

The effect of the atmosphere with greenhouse gases on the radiative balance of Earth has finally been modeled mathematically with some simple equations. Firstly considering the atmosphere as being transparent with regards to incoming solar radiation absorbed at the surface (taking into account also the planetary albedo) and as being totally opaque to the outgoing thermal radiation emitted by the Earth's surface which is completely absorbed and re-emitted both to space and back to Earth; this giving a too high estimate for the Earth's surface temperature. Secondly by considering the atmosphere as being only partially opaque to the thermal radiation which is what happens considering cumulative atmospheric (greenhouse gases molecules) absorption spectra.

From this more quantitative part on the thermal effects of radiation, blackbody emission and radiation and matter interaction, the sequence moves on illustrating some introductory

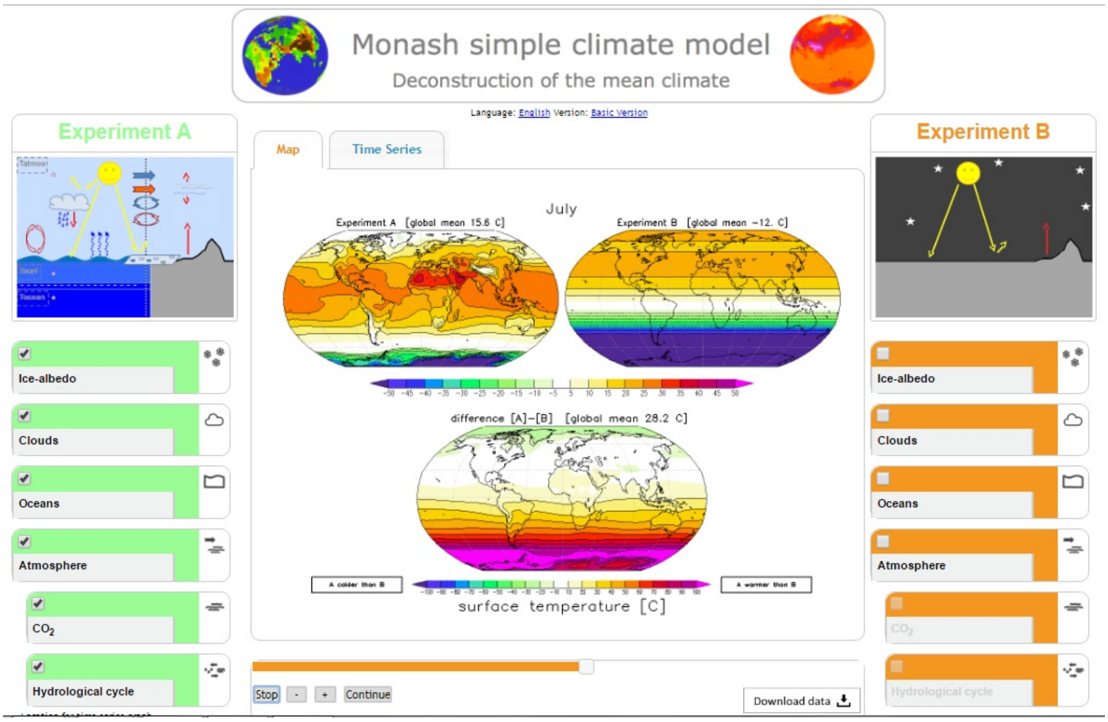


Figure 3.9: Investigating the effect on climate of different parameters and feedbacks using a simple climate model of the Monash University[337] [338].

information about the *climate system*, how *weather and climate* are two distinct but related concepts, which are the physical quantities used to characterize quantitatively the climate and how they have been reconstructed in the past thanks to proxies such as ice cores, how they are now measured thanks to global networks of observatories equipped with standard instruments and how they can be predicted thanks to numerical models and computer simulations based on the basic laws of physics. The main characteristics of the climate and of the climate system are illustrated such as its statistical nature, its variability in response to internal and external, natural and anthropogenic forcings, its subsystems, their interactions and feedback processes, being responsible for its nonlinear and chaotic behavior.

Some of these *interactions* and *feedbacks* are investigated by the students using simulations such as the *Monash simple climate model*[337] [338] and with a simple demonstration of positive feedback with the use of smartphones (*Larsen effect*). The concept of the *chaotic* behavior of the atmosphere and of the *statistical predictability* of climate is exemplified with a demonstration by using a *magnetic pendulum* and leaving the students observe and think about the effect of introducing a perturbation such as a wedge under the pendulum plane inclining it slightly on one side.

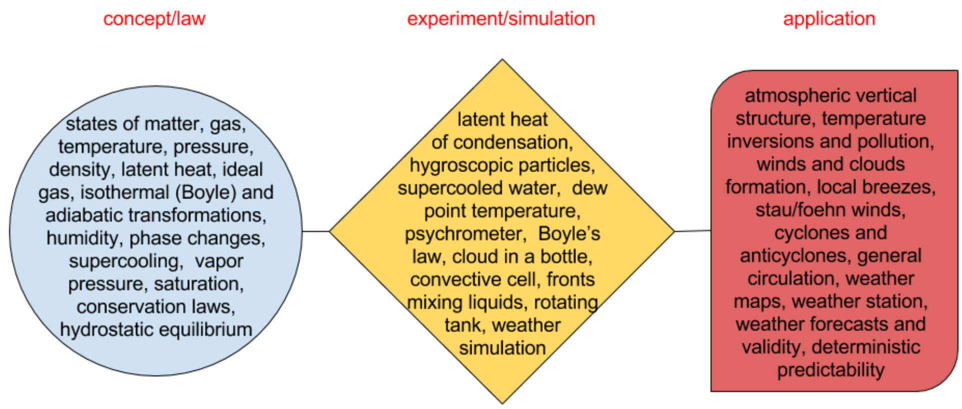


Figure 3.10: Structure of the weather module in terms of: concepts/laws, experimental activities/simulations and applications.

3.4.3 Thermodynamic - weather module

After the first module centered on radiation, its interaction with matter and its role in determining our global climate, the second module focuses more on thermodynamics and its application to weather phenomena. More specifically it starts from a general introduction on meteorology and its historical development, weather, its *phenomena* and their typical *spatial and temporal scales*. Questions, beliefs and proverbs used in daily discussions about weather phenomena are used as a starting point for promoting discussion among students, followed at the end of the sequence by their verification and explanation in light of the outcomes of the experiments, activities and conceptual models performed and constructed during the sequence.

A first exposition guided by some simple demonstrations (see appendix B for the details) presents the macroscopic properties and microscopic models for the solid, liquid and gaseous *states of matter*, and the ideal gas model.

Phase changes with a focus on water are introduced with some qualitative demonstrations (boiling water in a syringe) and quantitative experiments (measure of the *latent heat* of condensation and of fusion) followed by a conceptualization of what happens at the microscopic level. Concepts of *vapor pressure*, saturation vapor pressure, the Clausius-Clapeyron equation, absolute and relative *humidity*, are introduced focusing again on the concept of dynamic equilibrium and with an experimental activity: the measurement of the *dew point temperature* and a practical activity: the construction of a *psychrometer* for calculating relative humidity from the measure of wet and dry bulb temperatures.

Supercooling phenomena are introduced with a simple demonstration leaving a distilled water bottle in the freezer for some time and then making it freeze immediately by dropping a tiny piece of ice in it. A simple demonstration by using salt grains in a closed box with water is used to show the role of *hygroscopic particles*, the effect of *surfaces*, and of *molecular interactions* (adhesion and cohesion) at lowering the saturation vapor pressure, facilitating condensation of water vapor onto them. These demonstrations are very helpful

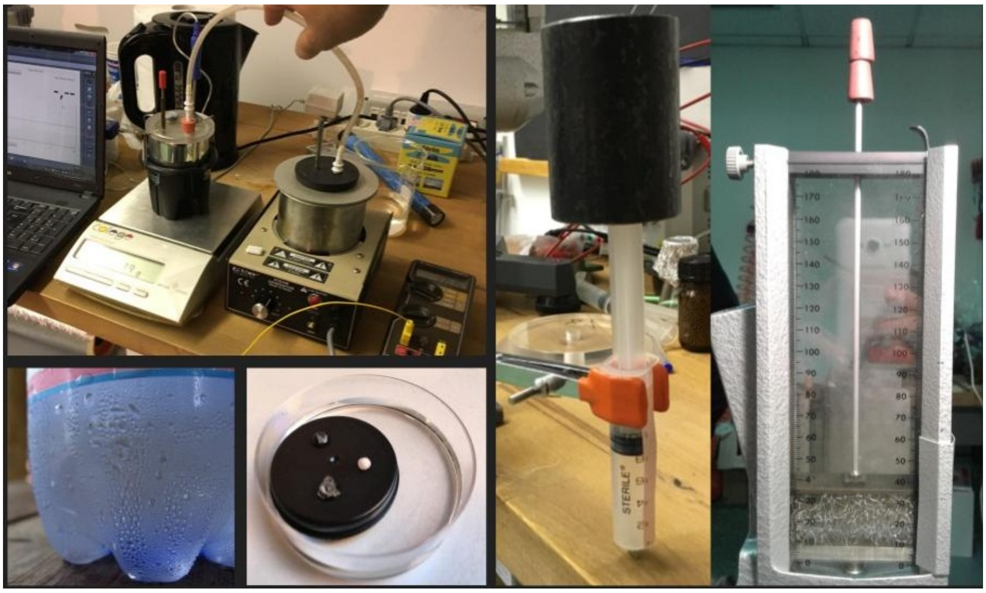


Figure 3.11: Some experimental activities: measuring the latent heat of condensation of water vapor, the dew point temperature, Boyle's law and a demonstrations of the role of hygroscopic particles and condensation nuclei.

for explaining the role of *condensation* and *freezing nuclei* in the formation of *water droplets* and *ice crystals* in clouds which would not form otherwise above -40°C.

The concept of *pressure* is then addressed through two experimental activities one aimed at verifying *Boyle's law* for isothermal transformations and the *macroscopic* concept of pressure with the use of a syringe and weights and another aimed at illustrating its *microscopic* interpretation in terms of average momentum transfer from the gas molecules to the recipient's walls with the use of an apparatus consisting in a chamber with a piston sustained by the agitation of tiny spherical balls put into motion from the vibration of the underlying bottom floor (see fig. 3.11 and appendix C for the details).

The *atmosphere* is then considered and modeled, starting from the *chemical composition* of air, the concept of *air parcel*, and its modeling as an *ideal gas*, the distinction between between dry and moist air (containing water vapor).

Physical quantities (temperature, pressure, humidity, wind speed and direction, precipitation and cloudiness) and conservation laws (mass, energy, momentum, state equation) used to characterize quantitatively the atmosphere and at the base of meteorological studies are introduced together with *instruments* and *observational networks* necessary to retrieve these data both from the surface and from the upper air, both with direct measurements and with remote sensing (i.e. weather stations and radiosoundings, satellites etc.)[357] [358].

It is then illustrated the *vertical average structure* of the atmosphere in terms of temperature, pressure and density explaining the physical processes and laws responsible for that structure (*hydrostatic equilibrium*, absorption of radiation at the surface and in the stratosphere, conduction and convection with the help of simple demonstrations) and the *forces* acting on air parcels (gravity, pressure gradient, friction, Coriolis and centrifugal). At the same time exceptions to these average structures are presented such as *thermal inversions*, the conditions for their formation and their effect on *pollution* and its stagnation.

Then a discussion about the factors influencing the latitudinal variation of the surface temperature, its effects on the formation of *low and high pressure centers* and so on the formation of *convective cells*, of *average winds*, and of the atmospheric *global circulation*, redistributing heat between the equator and the poles. Typical winds and the associated weather phenomena around low and high pressure systems at the surface and in the upper atmosphere are derived as a result of the balance between pressure gradient, Coriolis and friction forces, acting on the air parcels together with an interpretation of *weather maps.* Some simple demonstrations by using *rotating tanks*[344] [345] are used to introduce the concept of convective cell for speaking about valley winds, sea and mountain breezes and to show the formation of *cyclonic* and *anticyclonic* structures in a rotating system as a result of the Coriolis force (see fig. 3.12 and appendix C for the details).

Students investigate the process of clouds formation with a simple but clarifying demonstration: "*cloud in a bottle*" which allows to revisit and apply a lot of physics previously learned: from *adiabatic transformations* which characterize vertical movements of air parcels, to phase changes, from vapor pressure and saturation, to the role of *condensation nuclei.*

The notion of *air masses* and *fronts* is introduced with a demonstration using water at different temperatures and differently colored flowing one over another without mixing, the warmer and less dense flowing on top of the other. In the end, students can construct their own *weather station* with *arduino* and online resources freely available or they can decide to participate with their class or Institute to the *Globe project* taking part as responsible and active citizen in *citizen science* activities.

In conclusion, a rapid overview of how *weather forecasts* are made by using numerical models, how reliable they are in terms of *deterministic predictability* and a visualization of the outcomes of these models by using online visualization tools such as[354] [355] [362], allowing students to interpret data and guess what could imply from a phenomenological point of view in the atmosphere in view of the activities and conceptual models constructed during the sequence and verifying them with real time data coming for example from satellites or weather stations of the local weather service[359].

3.5 Preliminary results and discussion

Fifteen students of the course "Experimental physics laboratory at high school I" participated to the testing of the teaching sequence and answered pre and post tests (namely "pre test - termologia", "pre test - clima" and "post test - termologia&clima" see appendix C).

Twelve students are graduate students in mathematics and the other three graduate students in physics, the majority of them willing to pursue a career as secondary school teachers of mathematics and physics.

Figure 3.12: Some demonstrations of a convective cell, of fronts, of the formation of cyclones and anticyclones in a rotating tank and of the formation of a cloud.

Here we will summarize confront and discuss the results of these tests, of the discussions emerged during the sequence and the explanations and drawings they used in the final exam of the course.

”Pre test - termologia” has been constructed using multiple choice and open questions taken from literature: Thermal Concept Inventory (TCE)[146], Thermal and Transport Concept Inventory (TTCI)[147], Leiserowitz et al.[52], Leinonen et al.[151] and Loverude et al.[150].

”Pre test - clima” has been constructed mainly with open questions related to the climate concepts we wanted to address with the teaching sequence (i.e. difference between weather and climate, factors influencing climate and Earth’s average surface temperature, different radiation emitted by the sun and by the Earth and by the atmosphere, greenhouse gases and greenhouse effect, climate and equilibiria). Open questions have been used not to influence and constrict students’ answers, letting their conceptual reasoning coming out. Unfortunately this determined sometimes not very clear, too short or schematic explanations.

”Post test - termologia&clima” has been constructed by using multiple choice questions taken from the Thermal Concept Inventory (TCE)[146], Thermal and Transport Concept Inventory (TTCI)[147], the Greenhouse Effect Concept Inventory (GECI)[145], Tasquier et al.[328] open ended questions from Leinonen et al.[151] and Loverude et al.[150].

		Q10					tot
	PRE-TEST	a	b (correct)	c	d	e	
Q9	a	33%	7%				40%
	b			27%			27%
	c (correct)		27%		7%		33%
	d						0%
tot		33%	33%	27%	7%	0%	100%

		Q30					tot
	POST-TEST	a	b (correct)	c	d	e	
Q29	a	20%	7%				27%
	b		7%	20%			27%
	c (correct)		47%				47%
	d						0%
tot		20%	60%	20%	0%	0%	100%

		Q2					tot
	Nelson et al.	a	b (correct)	c	d	e	
Q1	a	41%	3%		2%	1%	47%
	b			17%			17%
	c (correct)	2%	20%	2%		2%	26%
	d		2%			8%	10%
tot		43%	25%	19%	2%	11%	100%

Figure 3.13: Above: pre and post test cross tabulation results comparing correlated answer pairs for the two questions related to ice melting, heat conduction and fundamental law of calorimetry (Q9, Q10 in ”pre-test termologia” and Q29, Q30 in ”post-test termologia&clima”). Below: results from literature[147]

3.5.1 Basic physics concepts

The pre-test on thermal phenomena (see appendix C, ”pre test - termologia” and results) allowed to investigate students’ conceptions in thermal physics and confirmed the presence of misconceptions and confusion between sensory experience and the physical interpretation and modeling of phenomena. For example in question 4 (Q4) we can see that few students do not recognize the dependence of boiling points of substances from pressure or that they have difficulty in applying what they learned in previous courses to real everyday situations (they say for example that in the mountains: ”the boiling point of water lowers” but ”water by itself is still at 100°C”). In Q5 5 students do not consider the possibility of supercooling states (answer e, ”you can’t have water at 0°C”) and 3 students consider heat as a quantity contained in bodies and not as just a transfer of energy between bodies (answer c ”both ice and water contain the same amount of heat”). Q6 shows 4 students again think heat as being a property contained in bodies (answer d, ”metal has less heat to loose respect to plastic”). From the answers given to Q7 we can see that 9 students (answers b, c and d) implicitly consider some bodies as containing heat because of their insulating properties (”tissue wrapped around the bottle warming it up even if room temperature is less than equilibrium temperature”), 4 students (answer d) forget to consider the role of phase changes and latent heat in the transfer of thermal energy (”room temperature being the same as the temperature of the water in the bottle wrapped with wet tissue”). Answers to Q8 shows 4 students consider heat as being a substance moving (answer a) and 4 students consider it as being contained, concentrated, as if it was an intrinsic property of bodies (answer b).

Confronting for example the results of Q6 (4 students choosing alternative d ”metal has less heat to loose respect to plastic”) and Q8 (4 students choosing alternative b ”metal

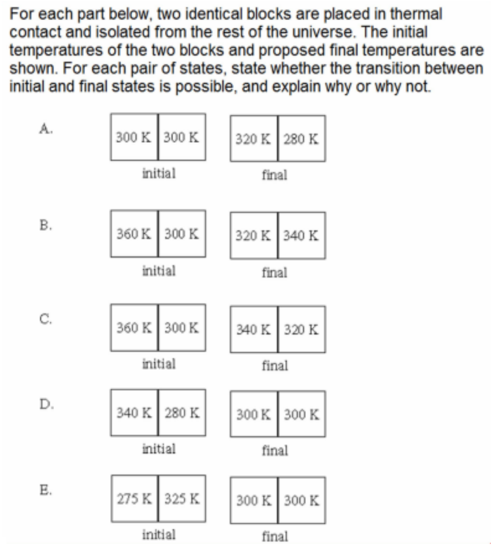


Figure 3.14: Approach to thermal equilibrium test item proposed to students' in both pre and post tests[150]

concentrates heat") of the pre-test with Q27 of the post test (no students choosing alternatives b "wood is a substance naturally warmer than metal" or c "wood contains more heat than metal"), we can see that the sequence had a qualitatively positive effect at fostering conceptual change, not considering anymore heat as a substance contained in bodies or concentrated differently by different materials or flowing between them or as an intrinsic property of different kinds of materials, determining our cold or warm feelings at touch, but considering these as just the result of processes of thermal conduction even if a few students wrongly choose the process of "'thermal radiation" as being involved instead of that of thermal conduction (Q27, 4 students choosing alternative d). Confronting instead Q7 (4 students choosing answer d) and Q5 (3 students choosing alternative c "both ice and water contain the same amount of heat") of the pre-test with Q28 of the post-test we can see an improvement in students' awareness of the role played by phase changes and latent heat as a powerful mean for thermal energy transfer (9 choose the correct answer c, 4 answer d and 2 answer a, but both answer c and d refer implicitly to evaporation and latent heat).

The results of Q9 and Q10 of the pre-test and of the same questions of the post-test (Q29 and Q30) are showed in fig. 3.13 together with the results obtained in literature on the same questions as reference. It is possible to see from the pre-test the presence of typical misconceptions (in similar proportions to Nelson et al.[147]) such as confusing transient and stationary situations, exchange of thermal energy and thermal equilibrium and thermal conduction. Confronting the results of pre and post tests we can see a net improvement, but the same misconceptions still resist for some of them, but for a percentage of students significantly lower compared to pre test and to Nelson et al.[147]

Considering the results of the test item Q11 of the pre-test and Q31, Q32 of the post-test (previously adopted in various studies on the same topics[150] [151] [368] [367], see fig.

3.14), since there could be ambiguities in evaluating students' answers, more weight has been given to the explanation provided than to the dichotomous yes/no verdict for each sub-item. Comparing the answers given to Q11 and Q32 what is interesting to point out is the evolution of students' conceptual explanations.

A significant change in perspective can be observed in about half the explanations provided by the students after the sequence, with the widespread use of terms connected to probability, the discussion of fluctuations and of the dynamical nature of thermal equilibrium. Five students explicitly describe the evolution of the system towards equilibrium as an approach to the state with the highest multiplicity in terms of microstates whereas such elements were mostly absent in the answers provided by students before the sequence, where most explanations were based on a deterministic idea of heat flow from hot to cold, and a static image of thermal equilibrium.

In order to justify the impossibility of an evolution away from equilibrium (case A in fig. 3.14) students often use variations of the following argument: "*No, because a system would perform a spontaneous transition to a state having a lesser number of accessible microstates*" or "*This is not possible because it implies going from a macrostate with a high number of microstates to one with a lower number of microstates, and thus less likely*". Some students also comment on the dynamical nature of the equilibrium state: "*at equilibrium the thermal energy flowing out of each system is equal to the thermal energy flowing in, because the number of microstates which realise the state is the maximum*". The analysis of case B prevalently induces students to reflect on fluctuations and, again, on the dynamical nature of equilibrium: "*In the case B it is useful to recall the microscopic model introduced in the lesson: the colder body can, to some degree, receive more thermal energy than what is necessary for reaching equilibrium. But afterwards, as time passes the process through which the hotter body cedes thermal energy reiterates, leading to an equilibrium situation*". Other students refer explicitly to the probability that "*it is extremely unlikely that after reaching thermal equilibrium at 330 K heat continues to flow from left to right*" or "*case B is not possible because when passing from one macrostate to another the system should have traversed the macrostate (300-300) which is the most likely because satisfied by a higher number of microstates, and thereby it should have stopped.*" The only student whose answer was judged incorrect in the post-test (because it was agreed that having a feeling for the order or magnitude of fluctuations is also important) however justifies his answer that B is possible in a way which is correct in a purely abstract sense: "*the situation shown could be a fluctuation around the equilibrium state*". In justifying the impossibility (or the possibility only as a transitory state) of case C, some students describe explicitly the process leading from the initial to the equilibrium state from a more microscopic point of view, "*the macrostate shown is more probable than the initial one, but not yet the most probable, so the system will continue evolving.*" Finally, we report almost integrally the conclusions expressed by one of the students who decided to write his final course report on this laboratory sequence: "*I believe that this teaching experience can be particularly instructive, allowing to consider various concepts starting from the following primary observation which is a cornerstone of thermodynamics: two bodies in thermal equilibrium have the same temperature. The mathematical tools used in the analysis of this phenomenon are fasci-*

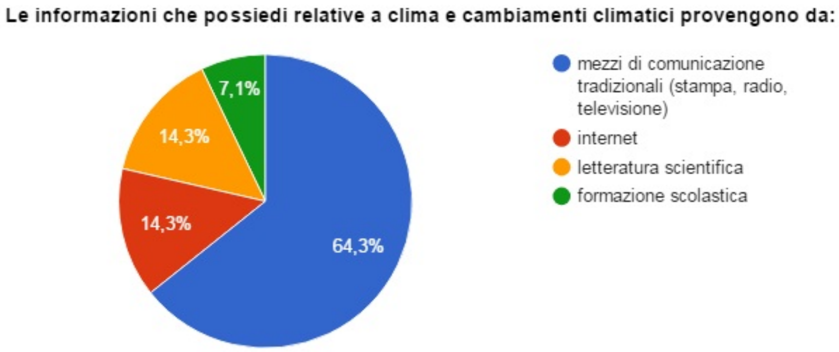


Figure 3.15: Students' source of information about climate and climate change (Pre-test). Out of 15 students 9 (64,3%) say their information comes mainly from traditional mass media (newspaper, TV, Radio broadcasts), 2 (14,3%) from scientific literature, 2 from the internet and only 1 (7,1%) from school education. None report having been exposed to climate issues at university.

nating and, regarding physics, several different topics can be highlighted: the exponential nature of various phenomena; the increase of entropy in an isolated system, the arrow of time emerging from the statistics of phenomena (...) We observe the great attention employed in this teaching approach in stimulating individuals who are forming their scientific thought to abstract and critical reasoning"[367].

Q1 of the pre-test seems to point out that 10 students recognize cyclones as being low pressure systems and the fact that the boiling temperature decreases if pressure decrease, but lack an idea of the order of magnitude of the typical drop in atmospheric pressure deriving from a cyclone. Q2 suggests that for 5 students does not seem clear that the boiling point is characterized by a fixed temperature if pressure does not change and that in the case of sea level atmospheric pressure, this corresponds to 100°C, whereas for lower pressures it is lower.

3.5.2 Climate and atmospheric physics concepts

Moving forward to pre and post tests related to climate issues ("pre test - clima" and "post test - termologia&clima"), answers to Q2 (pre test, see fig.3.15) show how even for graduate students prospecting a career in teaching mathematics and physics in secondary schools, information about climate science and climate change comes mainly from traditional mass media such as newspapers, television and radio as pointed out also in literature[52] [35], confirming also the minimal presence of such issues in the actual teaching practice, despite what school guidelines suggest. As pointed out in literature[213] [36], traditional media are likely to be a source of students' misconceptions and as many other surveys pointed out[184] [185] [186] [187] [188], there are confusion and barriers among school teachers with regards to teaching climate science as well as in textbooks as pointed out by [268] and [326]. All these arguments suggest and sustain the need of both the elaboration of teaching learning sequences about climate physics and their introduction into the teaching practice through teacher training courses and University courses with a focus on physics

Q3 pre - Difference between weather and climate (N=12)	
climate is a more global concept	
climate indicates a state of the atmosphere, weather is concerned with temperatures	
climate regards temperatures, weather relates to having a rainy or sunny day	
climate is used to describe regions, weather is the one of a single day	2
weather is relative to shorter times, climate to longer	2
weather is composed of directly observable phenomena in a short time. Climate is the tendency to manifest certain meteo events in a certain place together with data (i.e. temperatures, precipitation etc)	
climate is an ensemble of the typical weathers of a certain region	
weather varies in short times, is relative to a specific place and time. Climate describes vast areas with average quantities	
weather is about phenomena like rain, snow, wind. Climate regards many factors like latitude, altitude, season	
spatial and temporal scales	

Q2 post - Concerning weather and climate: (N=15)		
weather often changes from year to year	11	73%
climate represents the average weather conditions over a region	11	73%
climate often varies from year to year	2	13%
oceanic currents transport heat from the equator towards the poles	11	73%
weather represents the average climatic conditions over a region	2	13%
weather and climate are more or less the same thing	0	0%
the atmospheric circulation transports heat from the poles towards the equator	3	20%

Figure 3.16: Answers to pre and post test questions about differences between weather and climate.

and environmental science teaching.

Answers to Q3 (pre test) tended to be quite generic and confused but showed that students have a general sense of the difference between weather and climate at least in terms of spatial and temporal scales. On the other hand apart from one student saying: "*weather varies in short times, is relative to a precise place and time, while climate describes broad areas with average quantities*" there was not much explicit reference to climate in terms of statistics of weather conditions (measured with quantitative parameters) over long time periods. When addressing weather they tended to refer to specific weather phenomena, and they tended to address climate as something being related to "geographical areas" which is true in the case of regional climate, but this points out again the fact that climate science is rarely treated quantitatively from the point of view of the climate system with its processes[189] and it is taught in schools mainly from a phenomenological way, typically in geography courses. In the post test (see Q2 answers in fig.3.16 and Appendix C) the majority of students recognize climate as being related to weather through statistics ("*average*"), the fact that weather and climate are concepts related to different timescales (weather changes from year to year, but not climate) and the fact that motions in the atmosphere and in the oceans are caused by a different energy budget between the poles and the equator ("*oceanic currents transporting heat*"). However we can see that a few choices have been: "*the atmospheric circulation transports heat from the poles towards the equator*" (failing to apply the principles of thermodynamics in a concrete phenomenological situation), "*climate often varies from year to year*" and "*weather represents the average climatic conditions over a region*" but these last two answers could be the outcome of not carefully reading the text.

It is interesting to notice from Q4's answers (pre test, see Appendix C), that among the factors influencing the Earth's climate 3 students include pollution, confirming the confusion present among toxic or harmful chemical compounds, their relationship with public health, air quality problems in metropolitan regions and greenhouse gases emissions in relationship to the global climate change[145]. In Q5 (pre) some students even identified pollution as the main factor influencing temperature on Earth. Answers to Q4 and Q5 showed the presence of typical misconceptions[249] such as the "trapping of solar radiation" (i.e. "*radiations coming from the sun remaining trapped in the atmosphere*"), or the wrong identification of solar activity or geothermal heating or the Earth-Sun distance variation (wrong cause of the seasons) as main factors influencing Earth's average surface temper-

Q5 pre - Which is the main factor influencing the Earth's average surface temperature? (N=13)		
pollution	3	23%
latitude	2	15%
distance from the Sun (seasons)	2	15%
greenhouse effect	2	15%
geothermal	2	15%
solar activity	1	8%
Sun	1	8%
irradiation from the Sun	1	8%

Q13 post - Which of the following factors influences the most the average Earth's surface temperature? (N=15)			Q7 GECI.vC	
			pre (N=554)	post (N=399)
heat released from factories & human activities	0	0%	5%	4%
ozone hole letting in more light from the Sun	1	7%	44%	23%
flux & interaction of different kinds of radiation and the atmosphere	13	87%	20%	45%
air pollution trapped in the atmosphere by gases	0	0%	11%	10%
solar light amplified and concentrated by some gases in the atmosphere	1	7%	20%	18%

Q8 post - The Earth's atmosphere at the surface is warmer than it would be without GHE. Which radiation is absorbed by it and is the main cause of the increased surface temperature? (N=15)			Q2 GECI.vC	
			pre (N=556)	post (N=400)
radio	0	0%	1%	1%
infrared	12	80%	21%	59%
visible	2	13%	4%	8%
ultraviolet	1	7%	71%	32%
X rays	0	0%	2%	1%

Figure 3.17: Answers to pre and post test questions about the Earth's average surface temperature (Q5 pre test, Q13 and Q8 post test) and comparison with results from literature (GECI.vC)[145].

ature (i.e. the Earth's average surface temperature is mainly influenced by "*the thermal exchange with the Earth's nucleus*" or "*the distance from the Sun, the seasons*"). Only a few cited electromagnetic radiation and the greenhouse effect. Again students seem to be more aware of the regional climate than of the global climate, as referring to factors such as latitude, altitude, mountains, distance from water basins. Comparing these results with the answers given by students to Q13 and Q8 of the post test (see fig. 3.17 and Appendix C), we can see that the vast majority of them (13, 87%) identify fluxes of different kinds of electromagnetic radiation and their different interaction with the atmosphere as the main factor determining the Earth's average surface temperature and again that they (12, 80%) identify infrared radiation being absorbed in the atmosphere and having a major role with the greenhouse effect at warming up the Earth's surface. Very few of them still retain some misconceptions such as "ozone layer depletion being the cause of global warming", or "solar light interacting and being amplified by greenhouse gases" or visible and UV light being absorbed by the atmosphere in relationship with global warming and the greenhouse effect.

In the pre test (Q6, see fig. 3.18 and Appendix C), when asked about the form of energy emitted with major intensity by the Sun, 5 students referred to electromagnetic radiation and 3 to just radiation, but only one explicitly referred to it as being in the visible range ("*If it is intended the energy arriving on Earth, luminous radiation of visible frequency.*"). One of them cited instead "*thermal energy*", others used imprecise or tautological definitions such as "*luminous energy*" or "*solar energy*". In the post test instead (Q20 and Q14, see fig. 3.18 and Appendix C), the majority of the students (73% and 87%) identify visible radiation as being the radiation emitted with most intensity by the Sun even if few of them refer to UV and infrared radiation.

When asked about the form of energy emitted with major intensity by the Earth in the pre test (see fig. 3.19 and Appendix C), only 4 of them (29%) referred correctly to *infrared* electromagnetic radiation and 3 of them (20%) again referred to the misconception of *geothermal energy*, 3 others referred again to generic "*electromagnetic radiation*",

Q6 pre - Which form of energy is emitted with the greatest intensity by the Sun? (N=13)		
electromagnetic	5	38%
radiation	3	23%
thermal	1	8%
luminous	1	8%
electromagnetic (visible)	1	8%
solar	2	15%

Q20 post - Form of energy (radiation) irradiated (emitted) with greatest intensity by the Sun (N=15)			Q14 GECI.vC	
			pre (N=556)	post (N=400)
radio	0	0%	3%	3%
infrared	1	7%	16%	20%
visible	11	73%	12%	31%
ultraviolet	3	20%	56%	38%
X rays	0	0%	13%	8%

Q16 post - Main two forms of energy (radiation) irradiated (emitted) by the Sun (N=15)		
UV, X rays	1	7%
UV, IR	1	7%
VIS, near IR	13	87%
radio, IR	0	0%

Figure 3.18: Answers to pre (Q6) and post test (Q20 and Q16) questions about energy (radiation) irradiated (emitted) by the Sun and comparison with results from literature (GECI.vC)[145].

one to "*radiations*" (maybe even meaning nuclear radiations such as alpha or beta but it could even be due to a typographic error since students filled the questionnaire using their smartphones), 2 of them referred to "*heat*" and one to "*thermal energy*". In the post test (Q26 and Q12, fig. 3.19), we can see that the majority identified infrared radiation as being emitted with major intensity by the Earth (both at daytime and at nighttime), but some of them (4, 27%), confuse in the daytime case, the emission of infrared radiation by the Earth's surface because of its temperature with the incoming radiation reflected by the Earth's surface, allowing us to see things and colors with our eyes during the day (see fig.3.19).

In the pre test, looking at answers to Q8 (see fig. 3.20 and Appendix C), the role of the atmosphere as a body emitting infrared radiation itself seems instead less evident since only 2 students (13%) correctly pointed this out. 4 of them refer generically to "*electromagnetic radiation*" or to "*radiation/radiations*" possibly hiding the same misconception discussed in the case of the Earth and related to the use of the term "radiations". 2 students refer to "*heat*" or "*thermal energy*". What is curious is that 3 of them (20%) say that the atmosphere emits mainly "*electrical energy*", probably referring to lightnings and pointing out a misconception which was not considered at the beginning and in GECI[145]. In the post test (Q23 and Q4) the majority of students (11, 73%) identified correctly infrared radiation as the one being emitted with the highest intensity by the atmosphere, but few of them still refer to "UV" and "visible" radiation and 2 of them do not recognize the atmosphere as being a body irradiating energy by virtue of its non zero absolute temperature ("*the atmosphere does not emit energy*"). 10 students identify correctly the selective transparency and opaqueness of the atmosphere ("*almost opaque to low frequency radiation and almost transparent to high frequency radiation*"), 4 of them probably confused "wavelength" and "frequency" concepts or did not associate the right part of the electromagnetic spectrum with the right kind of radiation playing a role in the climate system.

Summarizing, we can say the results of the post-tests showed that after the teaching

Q7 pre - Which form of energy is emitted with the greatest intensity by the Earth? (N=14)		
infrared	4	29%
geothermal	3	21%
heat/thermal	3	21%
electromagnetic	2	14%
radiation	1	7%
radiations	1	7%

Q26 & Q12 post - Form of energy (radiation) irradiated (emitted) with greatest intensity by the Earth during daytime/night-time (N=15)					Q20 GECI.vC (day)		Q6 GECI.vC (night)	
	daytime		nightime		pre (N=555)	post (N=399)	pre (N=556)	post (N=400)
radio	0	0%	0	0%	11%	5%	13%	7%
infrared	10	67%	15	100%	28%	61%	53%	79%
visible	4	27%	0	0%	35%	23%	7%	5%
ultraviolet	1	7%	0	0%	21%	10%	15%	5%
Earth's surface doesn't emit energy during daytime (night-time)	0	0%	0	0%	5%	2%	12%	4%

Figure 3.19: Answers to pre (Q7) and post test (Q26 and Q12) questions about energy (radiation) irradiated (emitted) by the Earth and comparison with results from literature (GECI.vC)[145].

Q8 pre - Which form of energy is emitted with the greatest intensity by the atmosphere? (N=11)		
electric	3	27%
heat/thermal	2	18%
infrared	2	18%
electromagnetic	2	18%
radiation	1	9%
radiations	1	9%

Q23 post - Main form of energy (radiation) irradiated (emitted) by the atmosphere (N=15)			Q17 GECI.vC	
			pre (N=555)	post (N=399)
radio	0	0%	15%	8%
infrared	11	73%	37%	63%
visible	1	7%	19%	14%
ultraviolet	1	7%	16%	9%
atmosphere doen't emit energy	2	13%	14%	6%

Q4 post - The atmosphere has to be considered as a body (N=15)			Q4 Tasquier post (N=25)
almost opaque to low freq. radiation and almost transparent to high freq.	10	67%	40%
almost opaque to high freq. radiation and almost transparent to low freq.	4	27%	28%
almost opaque to both high and low freq. radiation	1	7%	4%
almost transparent to both high and low freq. radiation	0	0%	28%

Figure 3.20: Answers to pre (Q8) and post test (Q23 and Q4) questions about energy (radiation) irradiated (emitted) by the atmosphere and comparison with results from literature (GECI.vC and Tasquier)[145] [328].

sequence, the majority of students differentiate between incoming radiation in the Earth system emitted by the Sun (mainly in the visible range of the spectrum) and outgoing terrestrial radiation emitted by the Earth and by the atmosphere (mainly in the infrared range of the spectrum) even if some students still forget to consider the Earth and its atmosphere as being themselves bodies emitting infrared radiation and confuse infrared radiation emitted by Earth and atmosphere and incoming solar radiation reflected by the surface or by elements in the atmosphere.

When asked to identify the main greenhouse gases in the pre test (Q9, see fig. 3.21), a majority of 12 students (86%) identified carbon dioxide, but only 2 (14%) included also water vapor. 5 of them also correctly identified methane. It is interesting to note that few of them even identified minor greenhouse gases, not having relevant effects on climate being short lived or concentrated locally such as CFC's, ozone and carbon monoxide.

Q9 pre - Which are the main greenhouse gases? (N=14)		
CO2	12	86%
CH4	5	36%
H2O	2	14%
O2	2	14%
Ne	2	14%
CFC	1	7%
CO	1	7%
NO2	1	7%
O3	1	7%

Q22 post - The two greenhouse gases more abundant in the Earth's atmosphere (N=15)			Q16 GECI.vC	
			pre (N=555)	post (N=400)
CO2, CH4	3	20%	18%	7%
O3, CO2	1	7%	20%	11%
N2, O2	0	0%	11%	6%
O2, CO2	0	0%	25%	17%
H2O, CO2	11	73%	26%	59%

Q14 post - Which of the following is not a greenhouse gas? (N=15)			Q8 GECI.vC	
			pre (N=556)	post (N=399)
CO2	0	0%	2%	1%
H2O	1	7%	20%	7%
CH4	0	0%	30%	38%
O2	12	80%	25%	25%
O3	2	13%	22%	29%

Figure 3.21: Answers to pre (Q9) and post test (Q22 and Q14) questions about the principal greenhouse gases and comparison with results from literature (GECI.vC)[145].

Q9 pre - A greenhouse gas is: (N=14)		
gas *amplifying the GHE*	1	7%
gas *blocking oxygen* at the surface	1	7%
gas causing the GHE	1	7%
blocks Earth's radiation from leaving the Earth	1	7%
blocks thermal energy from leaving the atmosphere	1	7%
no answer	9	64%

Q5 post - effect of greenhouse gases in the atmosphere: (N=15)			Q11 Tasquier post (N=24)
trap heat absorbed from the Earth producing extra warming	0	0%	58%
thinning of the high atmosphere increasing transparency to high freq radiation	0	0%	0%
increase the absorption of low frequency radiation in the atmosphere	3	20%	25%
trap a part of the IR radiation reflecting it down to Earth	12	80%	17%

Q10 post - Characteristic property of a greenhouse gas: (N=15)			Q4 GECI.vC	
			pre (N=556)	post (N=399)
destroy certain molecules in the atmosphere	1	7%	24%	10%
bend and amplify the sunlight entering the atmosphere	0	0%	21%	14%
trap certain molecules in the atmosphere	0	0%	44%	49%
reflect part of the radiation coming from the Earth's surface	12	80%	4%	10%
are transparent to some types of radiation but not to all	2	13%	8%	18%

Figure 3.22: Answers to pre (Q9) and post test (Q5 and Q10) questions about the action exerted by greenhouse gases and comparison with results from literature (GECI.vC and Tasquier)[145] [328].

One student probably intended nitrous oxide (N2O) but used the wrong chemical formula (”*NO2*”). 4 students wrongly identified oxygen (O2) and neon as being greenhouse gases (GHG). In the post test (Q22 and Q14), we can see that the majority of the students (11, 73%) identify CO2 and H2O as the more abundant greenhouse gases in the atmosphere and exclude oxygen (12, 80%) even if few of them still have difficulties at recognizing water vapor as the most abundant.

Looking at students' pre test answers on the role played by GHG in the atmosphere (Q9, see fig. 3.22 and Appendix C), we can note some of the typical misconceptions coming out such as: ”trapping” (A GHG ”*impedes the terrestrial radiation to leave the Earth*”), ”capping/greenhouse mechanism” (”*A GHG creates a shield in the atmosphere impeding to infrared rays coming from the Earth to disperse beyond the atmosphere*” or ”*impedes thermal energy to leave the atmosphere*”), ”blocking oxygen” (”*A GHG gas impedes oxygen flow on the Earth's surface*”) and 1 seems not to address the natural greenhouse effect to greenhouse gases naturally present in the atmosphere by saying: ”*A GHG is a gas which amplifies the greenhouse effect*”. In the post test (Q5 and Q10), we see that the

Q10 pre - Explain the greenhouse effect (N=14)		
gases causing an *increase of the temperature* on Earth	4	29%
cap of CO2, blocking of the flux of *oxygen*	3	21%
reflection, bouncing, trapping of *solar* radiation	2	14%
greenhouse gases *reflecting* back the *Earth's radiation* (energy)	2	14%
cap of gases, *greenhouse mechanism*	1	7%
greenhouse gases *absorbing* and *emitting atmospheric IR* radiation	1	7%

Q3 post - Physical process causing the greenhouse effect depends (N=15)			Q2 Tasquier post (N=25)
both from properties of radiation and of gases composing the atmosphere	13	87%	80%
only from properties of the incident radiation	0	0%	0%
only from properties of the gases composing the atmosphere	2	13%	8%
none of the preceding is correct	0	0%	12%

Q7 post - A planet with a greenhouse effect (N=15)			Q11 GECI.vC	
			pre (N=556)	post (N=400)
receives more UV from the Sun because does not have O3	0	0%	36%	12%
has an atmosphere absorbing and emitting certain forms of energy but not all	13	87%	36%	70%
receives more energy because it is closer to its central star	0	0%	4%	5%
has an atmosphere altered by living beings	1	7%	18%	12%
does not irradiate any form of energy to space	1	7%	6%	1%

Q19 post - If human civilization would not exist, would there be anyway the greenhouse effect on Earth? (N=15)			Q13 GECIv.C	
			pre (N=554)	post (N=400)
yes, GHE is caused by gases naturally present in the atmosphere	13	87%	37%	65%
yes, GHE is caused by plants releasing gases to the atmosphere	2	13%	17%	15%
no, GHE is caused by men burning fossil fuels and releasing pollutants	0	0%	28%	14%
no, GHE is caused by men reducing the ozone layer	0	0%	14%	7%
no, there is no definitive evidence of the existence of the GHE	0	0%	3%	1%

Figure 3.23: Answers to pre (Q10) and post test (Q3, Q7, Q19) questions about the greenhouse effect and comparison with results from literature (GECI.vC and Tasquier)[145] [328].

"IR trapping - reflecting" misconception remains strongly present even after the teaching sequence (12, 80%), while only some students recognize the process of absorption and selective transparency of GHGs, pointing out that only few of them understood correctly the details of the interaction between infrared radiation and the molecules of GHGs in terms of photon absorption and emission instead reflection. This suggests the need for a more in depth treatment of optical physics, of the molecular model and behavior of GHGs and of their interaction with radiation, as also sustained by Harris et al.[246]. From this point of view one of the difficult point for students is integrating the classical view of geometric optics and macroscopic models of matter (concepts like reflection, refraction, diffraction, transparency and opaqueness) with more complex views typical of optical and modern physics and microscopic models of matter (concepts like photon absorption, emission and diffusion, molecular energy levels etc.) which are by the way quite specialistic.

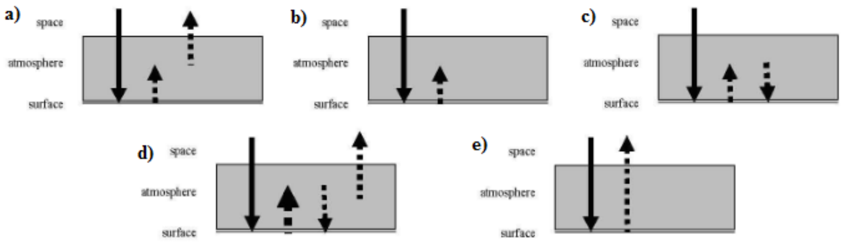
When asked in Q10 of the pre test (see fig. 3.23 and Appendix C), to give a detailed explanation of the greenhouse effect (GHE) only 1 student correctly explained the role of the atmosphere with greenhouse gases absorbing the majority of the infrared radiation emitted by the Earth and re-emitting infrared radiation themselves, also back to the Earth's surface. Instead typical misconceptions emerged[211] [212] [213] [145] [214] [249] [269] [144], such as the "*bouncing*" (reflection) of solar radiation between the Earth surface and the atmosphere, the "*trapping*" of solar radiation by greenhouse gases, "*not differentiating between solar and terrestrial radiation*" and the *different behavior* of greenhouse gases in their interaction with solar and terrestrial radiation, the "*reflection*" of infrared radiation by greenhouse gases instead of "*absorption*" and "*emission*" or the conceptual model of a "*capping layer*" formed by carbon dioxide "*blocking the passage of oxygen*" or in analogy to the wrong[210] heating "*mechanism of a greenhouse*" for growing plants. Some of them did not even try to explain the physical mechanism of the greenhouse effect. In the post test answers (Q3, Q7 and Q19), the majority of students (13, 87%) identify the dependence

Q25 post - Feel warm going from shadow to sunlight because: (N=15)			Q19 GECI.vC	
			pre (N=556)	post (N=400)
you absorb more UV radiation than emit in the VIS	1	7%	34%	20%
you absorb more VIS radiation than emit in the IR	13	87%	39%	52%
you reflect more UV than you emit in the IR	0	0%	17%	13%
you reflect more VIS radiation than you emit in the IR	0	0%	8%	11%
you reflect more IR than you emit in the VIS	1	7%	3%	6%

Q6 post - Temperature of an object exposed to a lamp increases reaching a constant value because (N=15)			Q10 Tasquier post (N=25)
reaches the equilibrium temperature with the lamp	1	7%	44%
temperature of that object cannot go over that value	0	0%	4%
energy emitted is equal to the absorbed by the object	14	93%	44%
the lamp cannot give more heat than that	0	0%	8%

Q9 post - On average total energy leaving Earth, going to space (N=15)			Q3 GECI.vC	
			pre (N=555)	post (N=399)
is more than the energy arriving from space (Sun)	0	0%	8%	5%
is less than the energy arriving from space (Sun)	5	33%	39%	26%
is almost equal to the energy arriving from space (Sun)	9	60%	22%	56%
depends from GHG concentration in the atmosphere	1	7%	16%	10%
depends from the O3 present in the atmosphere	0	0%	15%	3%

Q24 post - Because of greenhouse effect, Earth's average surface temperature depends mainly from (N=15)			Q18 GECI.vC	
			pre (N=556)	post (N=399)
increase in incoming energy from space	1	7%	16%	6%
decrease in the outgoing energy towards space	5	33%	18%	17%
increasing incoming and decreasing outgoing energy	2	13%	28%	21%
permanent trapping of energy in the atmosphere	3	20%	16%	14%
increase in absorbed and emitted energy between surface and atmosphere	4	27%	22%	43%



Q21 post - Radiative balance in the Earth system (N=15)			Q15 GECI.vC	
			pre (N=556)	post (N=400)
a	1	7%	16%	10%
b	0	0%	13%	8%
c	0	0%	22%	11%
d	13	87%	39%	55%
e	1	7%	11%	16%

Figure 3.24: Answers to post test questions (Q25, Q6, Q9, Q21, Q24) about radiative and energy balance of bodies exposed to sunlight and of the Earth's system and comparison with results from literature (GECI.vC and Tasquier)[145] [328].

of the greenhouse effect on both the properties of radiation and of gases composing the atmosphere. They also point out the selective absorption/emission processes involved and the natural presence of GHGs in the atmosphere being responsible for the natural greenhouse effect, beneficial to life but not caused by humans. By the way it is interesting to note a new misconception held by few students which is considering plants to have a role in causing the GHE, by releasing gases to the atmosphere. This misconception may be linked to the idea of oxygen being a GHG discussed before.

Post test questions number 25, 6, 9, 21 and 24 were related to the concept of radiative stationary balance. Looking at the students' answers (see fig. 3.24 and Appendix C) we can notice that the majority of them (13, 87%) correctly understood the process underlying the thermal effects of radiation observed in the experimental activity they performed with the metal plate exposed to a lamp (Sun), and the fact that temperature of an object increases when there is more energy being absorbed (i.e. in the visible range) than emitted (i.e. in the IR range) and reaches a stationary value in the case of balance between the two (14, 93%). When they applied this concept to the Earth's system and its energy budget, 9 students (60%) correctly say that the Earth system itself is in a condition of energy balance, but 5 students still say that on average the total energy leaving the Earth is less

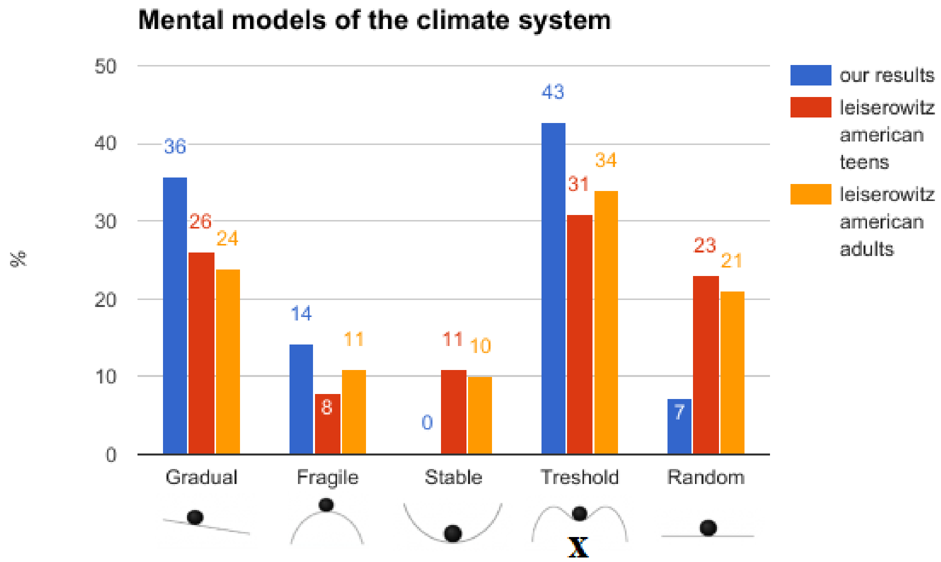


Figure 3.25: Mental models of the climate system confronted with the results for American teens and adults of Leiserowitz et al. From our results, most respondents chose the Threshold model (43%), followed by the Gradual (36%), Fragile (14%), Random (7%), and Stable (0%) models. Scientifically, at different temporal or spatial scales the climate system can exhibit each of these behaviors, but the best overall answer is the threshold model[52] [53].

then that arriving from space. Answers to Q21 show that the majority of students (13, 87%) recognize in the schematic drawing the correct processes leading to radiative balance in the Earth's system, having incoming solar energy passing through the atmosphere undisturbed but being absorbed at the Earth's surface and heating it up. The Earth's surface emitting then IR radiation back to space, a big part of which being absorbed by the atmosphere, heating it up. And finally the atmosphere itself emitting IR radiation both to space and back to Earth. The sum of the total incoming radiation being equal to the sum of the total outgoing radiation. Answers to Q24 anyway still show the difficulty of students at understanding stationary processes, the strongly held idea that greenhouse effect is related to the trapping of energy in the atmosphere or to a decrease in the outgoing energy from the Earth system. Only 4 of them identify the correct role of the atmosphere with GHG at increasing its absorbance with regards to IR radiation, this determining an increase in its temperature and so in the amount of energy it emits towards the Earth's surface.

Q11 (pre test), taken from the surveys made by Leiserowitz et al.[52] [53], gives instead a glimpse into students' mental models of the climate system. As we can see (fig. 3.25) the majority of them chose (most correctly) the threshold model, but there is also a considerable fraction of students choosing the gradual model which is more connected with ideas of a linear response of the climate system to changes and forcings while a more appropriate conceptual model involves thinking of nonlinear complex interactions in the system and feedbacks between its parts resulting in threshold model and the more correct concept of

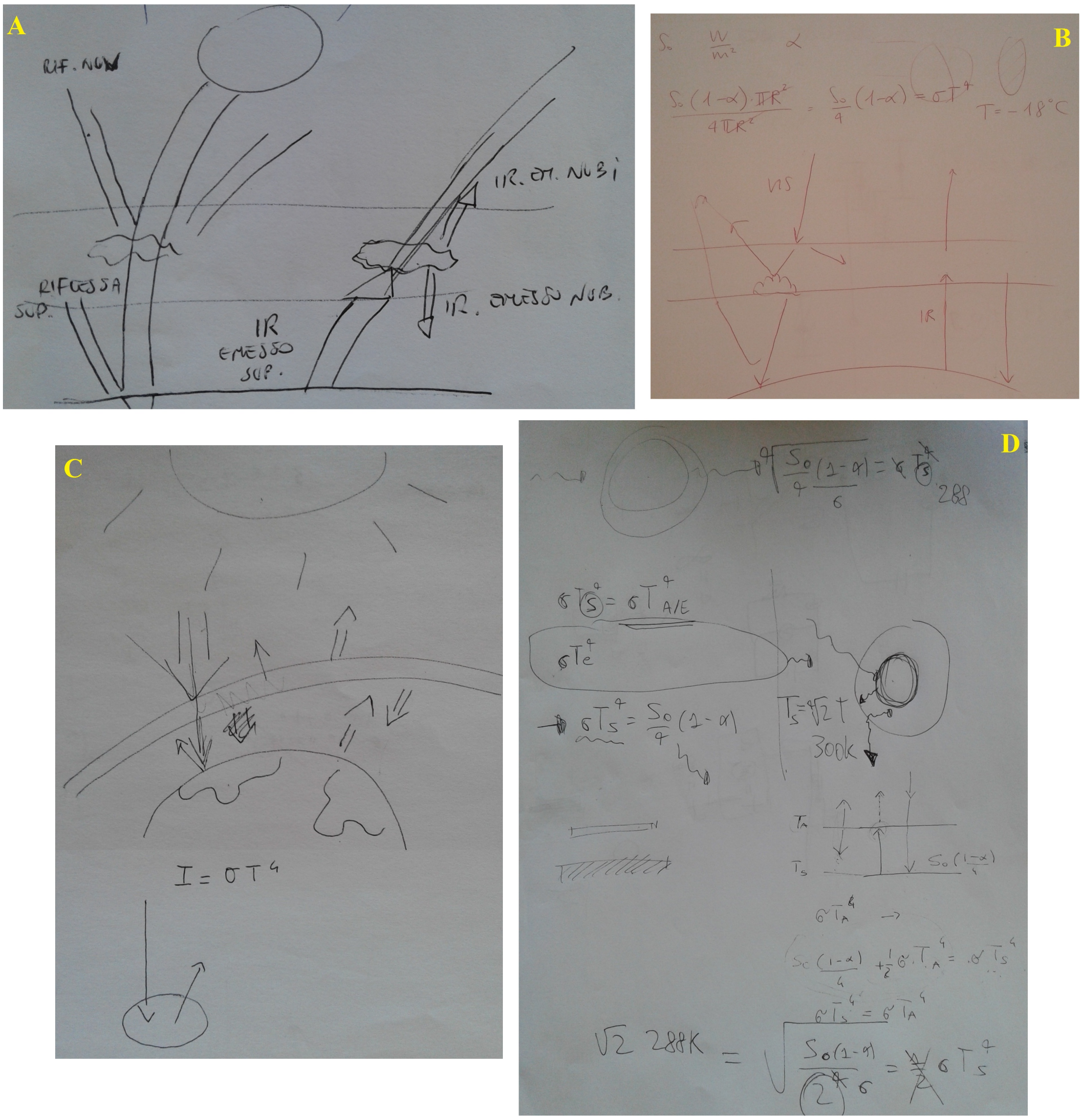


Figure 3.26: Drawings done by students during the final exam of the course.

abrupt climate change[317] [316]. Students' choosing the random model instead do not probably think it is possible to predict even in statistical terms future climate scenarios.

Giving a look at some of the drawings and graphical representations used by students during the final exam of the course (see fig. 3.26), we can have a glimpse on the conceptual models they developed after the teaching sequence and after a period of study and assimilation of what they learned.

With a generic look at fig. 3.26, we can see how different students prefer different approaches to the same problem: Earth's radiative balance, greenhouse effect and average surface temperature. The majority of them use drawings, but some prefer a more formal and mathematical approach (subfigures D and B) and one uses the analogies (i.e. between the metal plate exposed to the lamp and the Earth-Sun system).

Going into a more detailed, conceptual analysis we can see that:

- they all differentiated between incoming solar and outgoing terrestrial electromagnetic radiation, one of them explicitly indicating solar radiation being in the visible range and two of them indicating terrestrial as being in the infrared range (subfigures A, B)
- they pointed out the role of planetary and surface albedo, responsible of the reflection of the incoming solar radiation (A,B,C), recognizing for example an important role played by clouds.
- they recognized the different behavior of the atmosphere with regards to its interaction with solar radiation (almost transparent) and terrestrial IR radiation (almost opaque and absorbing the majority of the radiation emitted by the Earth)
- they all recognized the atmosphere (and clouds) as being a blackbody at a certain temperature and emitting itself both to space and towards the Earth's surface IR radiation
- one of them used the "metal plate conceptual model" as an analogy to explain the radiative balance between incoming visible and outgoing thermal radiation in the Earth's system (C)
- they recalled Stefan Boltzmann law and the dependence of the radiation intensity emitted by bodies on the fourth power of their absolute temperature, and applying this law to the case of the Earth and of the atmosphere (B, C, D)
- two of them modeled the problem of the radiative balance mathematically, recalling the calculations, done in the teaching sequence, of the radiative equilibrium temperature at the Earth's surface for two cases. The first case of a surface temperature resulting from a simple radiative equilibrium between the Sun (concepts of solar constant and albedo) and the Earth's radiation (no atmosphere, blackbody emitting following Stefan Boltzmann law), obtaining a value much less than the experimental one and so pointing out the role of the atmosphere and of greenhouse gases on the Earth at creating conditions favorable to life (C and D). The second case of a surface temperature resulting from the radiative equilibrium in the presence of an atmosphere (single layer) transparent to shortwave solar radiation but completely opaque to longwave terrestrial radiation with absorption and re-emission of infrared photons both to space and to the Earth's surface (C) obtaining a value higher than the experimental one and so suggesting a model atmosphere as being almost transparent to solar radiation and almost opaque to terrestrial.

Conclusions

Climate and weather are actual and multidimensional themes, present in the media and in the public discussion, which will involve and affect citizen, societies and economies of the future with their ability to mitigate and to adapt to changing global equilibria. On the other hand the physical processes underlying their phenomenological manifestations in the Earth system are poorly addressed from a quantitative point of view, typical of the ways physics and science proceed towards the understanding and mastering of the structures and processes upon which the World works. The best environment for adopting such a quantitative point of view is traditionally represented by formal education in schools, but even if Italian school guidelines suggest climate and weather as relevant issues to be taught at school, their systematic introduction into the teaching practice is still far from reality for a series of reasons, ranging from teachers lacking the necessary background to the history of the Italian meteorological service, to the lack of specific University courses educating professional figures in these fields.

The present work inscribes itself in this framework and developed both on the side of communication and on the side of education. Tools and methodologies used for the design of these experimentations have been the typical ones of Physics education research. A preliminary part focused for example on the analysis of the literature about typical mis-conceptions and mis-communications held by students and adults and reinforced or sometimes even created by the media.

New formats and media such as videoconferences, TEDx conferences, social media platforms (blog, Reddit, etc.), photographic exhibitions etc. have been explored and tested together with more traditional media (i.e. specialized magazines, radio, television, traditional conferences etc.) for communicating physics and engaging the general public and young students with the work and life of researchers in extreme environments such as Concordia station in Antarctica at the aim of monitoring, understanding and predicting climate and weather, but also trying to investigate the Universe and human beings. These initiatives allowed to address a considerable number of people compared to traditional conferences for example, of non experts and of youngsters, not necessarily interested in the specific subject. The role of Antarctica and of the extreme, remote and adventurous conditions faced by researchers there, together with the chance of connecting and speaking directly with them on the field and coming to know about their lives helped greatly at establishing an emotional contact with the audience, which is necessary for starting the process of communication and for engaging and interesting people about specific issues.

On the educational side, a teaching sequence targeted to secondary school students and based on quantitative experimental activities and demonstrations has been designed integrating basic physics and atmospheric science, taking into account and addressing typical misconceptions present in the literature and confirmed by pre-tests given to graduate students. The teaching sequence articulated in three modules strictly connected (basic physics, climate, weather), moving from thermal phenomena, electromagnetic radiation, radiative equilibrium, interaction of radiation with matter, blackbody emission, absorption and emission spectra of molecules, chaotic behavior and feedbacks, states of matter and phase changes, thermodynamic variables and processes to the Earth's energy balance and its average temperature, greenhouse gases and the greenhouse effect, to winds and the general circulation of the atmosphere, cyclones, anticyclones, fronts, sea and mountain breezes, stau and foehn winds, cloud formation and precipitation.

This teaching sequence has been proposed with the support of IPRASE, in the framework of an experimentation of integrated science teaching, as a training course for physics and chemistry teachers and technical assistants of two pilot secondary schools of Trentino (Buonarroti and Marconi Institutes) and has been tested with graduate students of the course "Experimental physics laboratory at high school I" (prospecting physics and mathematics teachers in secondary schools).

Pre-tests and post-tests based on literature have been prepared and used as tools for pointing out students' pre-conceptions, confronting them with the results from literature and for a preliminary assessment of the effectiveness of the teaching sequence, together with the analysis of drawings and explanations used by students during the final exam of the course. The experimental activities proposed and the teaching sequence itself, demonstrated promising both in terms of interest showed and expressed (see Appendix C, answers to questions 33, 34 and 35) by graduate students and teachers and in addressing part of the typical misconceptions.

In general the teaching sequence allowed students to ask themselves questions and investigate them with the help of scientific method especially in the case of experimental quantitative activities. The use of quantitative experiments, often proposed in the form of inquiry, characterized and differentiated from a methodological point of view the teaching sequence proposed from others present in literature. Students particularly appreciated the inquiry approach, learned to ask themselves questions and to investigate phenomena and common beliefs with the help of the scientific method, designing or executing guided (and not) quantitative experimental activities, retrieving and analyzing data, inferring quantitative relationships between physical quantities (i.e. physical laws), applying them to real phenomena constructing coherent physical models and in the end making predictions and confronting them with nature. In this way they learned to build more sophisticated conceptual models of phenomena and processes starting from basic physics and moving to atmospheric science allowing them to have a sound background and to exercise a critic ability confronting with phenomena talked about in the news and relevant to the World's present and future population such as the greenhouse effect and climate change.

The training course for teachers, resulted in a positive feedback from teachers who tested some of the activities proposed with their students and also from IPRASE and from the Autonomous Province of Trento which proposed to extend the training course to all the secondary technical schools of Trentino.

A part which should be further developed regards the design of the interaction of radiation with matter in terms of optical physics, modern physics, microscopic molecular models and spectra as well as building more quantitative and articulated experimental activities about the condition of stationary equilibrium, chaotic behavior, feedbacks and chemistry of the atmosphere. By the way students learned to differentiate among different kinds of radiation, to recognize the role of the Earth and of the atmosphere as bodies emitting infrared radiation following Stefan Boltzmann law, to understand the role played by greenhouse gases in the greenhouse effect being almost transparent to incoming solar radiation, while being almost opaque to IR terrestrial radiation, absorbing and emitting photons through excitation and relaxation of molecular motions, to discriminate between the natural and anthropogenic greenhouse effect and to understand its physical basis, recognizing the fundamental role played by water vapor. They learned the role played by phase changes, vapor pressure, surfaces and intermolecular forces in the formation of clouds and precipitation, the role of winds and the processes leading to their formation. They also learned to picture the approach to thermal equilibrium both from a macroscopic and microscopic point of view, grasping also the meaning of complex concepts such as entropy and statistical mechanics through simple experiments and analogies.

With this promising preliminary feedbacks received about the teaching sequence, it is then worth of amelioration in terms of further developing and better structuring the experimental activities and the educational materials in a way that these could also be spread in the community of teachers. At the aim of reaching the broadest possible teachers' community, ideally nationwide, it would be useful making the sequence and the experimental activities available online, taking advantage also of a dedicated youtube channel where the execution of the single experimental activities could be shown in detail, allowing at the same time for direct feedbacks from peers and students.

An interesting and necessary development and evaluation of the work would be testing the teaching sequence with a bigger number of students and teachers, promoting an integrated management of the sequence between physics for what concerns the experimental activities, and natural sciences for what concerns the more phenomenological and descriptive sections. In this sense testing a training course with natural science secondary school teachers would be illuminating.

Appendix A: List of communication initiatives

- 2015-2016 Organization and realization of more than 50 skype videoconferences from Concordia station, Antarctica with primary and secondary schools from Italy, France, UK and US, the majority of which have been part of the AUSDA communication project of the PNRA. During these skype conferences it has been presented the scientific research done in Concordia and by establishing a dialogue with students of single classes and by answering their questions and curiosities, they had the opportunity to learn about the daily work and life of researchers at Concordia, how Antarctica is relevant for the rest of the Planet and why science is done there.

- 8/10/2016 Speaker at the national event TEDxCNR organized by the National Research Council of Italy (CNR) in Rome at Auditorium Parco della Musica - Sinopoli theater. Title of the talk: ”Cosa abbiamo imparato vivendo per un anno alla fine del mondo”. This 18 minutes talk has been about a new perspective on how the scientific, physical and human challenges faced during one year of isolation at Concordia station, Antarctica changed our view on relationships.

- 17/10/2015 and 12/11/2016 Participation to the Festival of Meteorology of Rovereto, organized by prof. Dino Zardi with a conference about the Antarctic meteo-climatological observatory, the meteorological activities performed at Dome C and a live skype conference with the researchers on the field commenting data and graphs of a live radiosounding. Title of the conference: ”Diretta dall'Antartide - La stazione Concordia si presenta”. (2015 edition and 2016 edition)

- 28/4/2016 Seminar about the research activities which characterized the Ph.D. work of the candidate in the field of physical science education and communication. The seminar has been held for the students of the fourth and fifth year of the secondary school Liceo Scientifico Leonardo Da Vinci of Trento.

- 12/8/2016 Public conference about the scientific and human challenges faced during one year at Concordia station, Antarctica held at the Math Camp 2016, a stage of mathematical training for students of secondary schools, organized by Gabriele Dalla Torre and Elia Bombardelli in collaboration with DiCoMath Lab of the University of Trento.

- 27/8/2016 Public conference about the scientific and human challenges faced during one year at Concordia station, Antarctica held at the Summer Math Camp 2016, a stage in preparation to the mathematical olympic games, for secondary school students of Veneto, organized by the association Mathesis Vicenza at Istituti Filippin of Paderno del Grappa (TV).

- Public conferences about the climate and atmospheric physics research activities performed at Concordia station, Antarctica. The first held in Coredo (9/3/2016) and the second in Romallo (19/4/2016 Climountain project) in the framework of "Piano giovani di zona" of the "Politiche giovanili" of the Autonomous Province of Trento

- 25/8/2015 Reddit Science AMA: "We are living in Concordia station, Antarctica, researching glaciology, climate and physiology. We haven't seen the Sun for 4 months and 4 months to go before fresh supplies are flown in. The temperature outside is –67.8°C. AMA!" promoted by the European Space Agency.

- Interviews for local and national newspapers, for Italian and foreign Radio and TV broadcasts among which:

  La Stampa ("Le mie giornate tra i ghiacci a ottanta gradi sottozero", Federico Taddia),

  Repubblica.it - Le inchieste ("Lavorare alla fine del mondo", Veronica Ulivieri),

  Webmagazine unitn ("Un anno tra i ghiacci dell'Antartide", Sonia Caset),

  Corriere del Trentino ("A meno 30 gradi per amore della ricerca", Marta Romagnoli),

  Vice Motherboard ("The stars down to Earth", Daniel Oberhaus),

  Huffington Post (Stazione Concordia in Antartide: "Per amore della scienza viviamo nell'angolo più remoto del mondo, a -70 gradi"),

  Radio2 - Ettore ("Ettore@TEDxCNR", Michele Dalai),

  Radio3Scienza ("A qualcuno piace freddo", Roberta Fulci),

  Radio24 – L'altra Europa (3/1/2015 Podcast, Federico Taddia)

  Al Jazeera English - The Stream ("Antarctica's science seekers", 28/10/2015),

  Rai News 24 (6/1/2015 Podcast),

  Rai3 - TGR Trentino (Connection, Gabriele Carletti).

- Blog "365 giorni in Antartide" on the online platform of "Le Scienze". Posts written for ESA blog: "Chronicles from Concordia".

- "The extreme science of White Mars" an article written for Laboratory news.

Appendix B: Teaching materials and experiments

This Appendix reports in the form of slides, the teaching material, demonstrations, experimental activities and modelization relative to the three modules (basic physics - thermal phenomena, radiation - climate, thermodynamic - weather) which have been used during the experimentation of the teaching sequence. A first experimentation has been done with graduate students of the course: ”Experimental Physics Laboratory at High School Level I” held at the University of Trento for the ”Laurea Magistrale” in Mathematics and Physics with a focus on teaching and scientific communication. A second experimentation has been done in the form of a training course promoted by IPRASE for physics and chemistry teachers and their technical assistants at the aim of promoting atmospheric sciences and namely climate and meteorology as a framework for the integration of the physics and chemistry usually taught to students attending the first two common years at two technical secondary schools (ITT) of Trento (Buonarroti Institute) and Rovereto (Marconi Institute).

Esperimenti e attività di termologia di base

Esperimento 2: Raffreddamento di una tazza di tè

Questa esperienza si è ispirata ad una proposta dei lavoro tratta da "**IMOFI**" (**I**ntroduzione alla **MO**dellizzazione in **FI**sica): http://www.unipa.it/~sperande/IMOFI/IMOFI.html

Supponete di offrire a due amici, Mario e Carlo, una tazza di tè.
Mario decide di lasciare raffreddare il tè per alcuni minuti, poi aggiunge una certa quantità di latte e lo beve. Carlo aggiunge subito la stessa quantità di latte e poi aspetta gli stessi minuti di Mario prima di bere.
Chi dei due berrà il tè più freddo?

Dopo aver risposto alla domanda controllate la vostra risposta realizzando una esperienza con quanto avete a vostra disposizione. (Utilizzate il bicchiere di alluminio facendo attenzione a non superare i 200 g di acqua complessivi tra fredda e calda. Noi consigliamo 100 g di acqua calda a circa 70° e 50 di acqua fredda.)
Il risultato sperimentale rispecchia le vostre previsioni?

Esperimento 3: equilibrio termico

Riscaldate circa 200 g di acqua fino ad una temperatura di circa 80ºC e introducetevi un bicchiere di metallo contenente una massa d'acqua pari a 50 g e a temperatura ambiente.

Prima di eseguire le misure annotate le vostre risposte alle domande seguenti:

- Quale prevedete che sarà la temperatura massima misurata dal sensore all'interno del bicchiere?

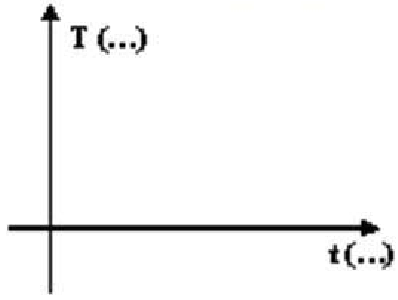
……

- Pensate che sarà maggiore la variazione di temperatura, rispetto al valore iniziale, per l'acqua al di fuori del bicchiere o per quella all'interno del bicchiere? Indicate il valore che prevedete di calcolare con i dati misurati

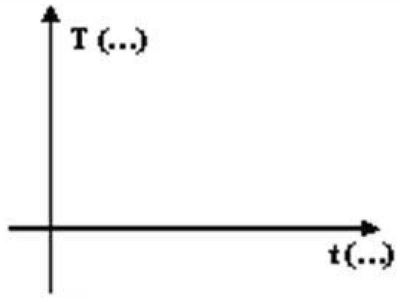
……

Fate una previsione dei grafici T(t) delle temperature dell'acqua all'interno e all'esterno del bicchierino in funzione del tempo, e riportateli nel grafico a lato, inserendo le unità di misura e le scale appropriate.

Fate la vostra previsione avvalendovi dell'apposito strumento disponibile nel software.



Ripetete l'esperienza descritta sopra, registrando i dati e disegnate il grafico ottenuto nello spazio a lato:



I grafici Temperatura-tempo sono in accordo con le vostre previsioni?

____

Schema dell'esperimento: La "*velocità*" di evaporazione

Si avvolgano le estremità delle sonde con pochissimo cotone idrofilo fissandolo con il filo metallico ricoperto. Successivamente, si bagni in alcol l'estremità della prima sonda e con altri liquidi (esempio acqua) l'estremità della seconda sonda

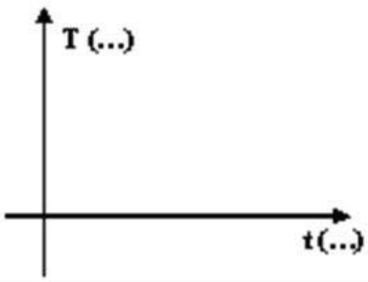
- Cosa prevedete che misurino i due sensori?

……

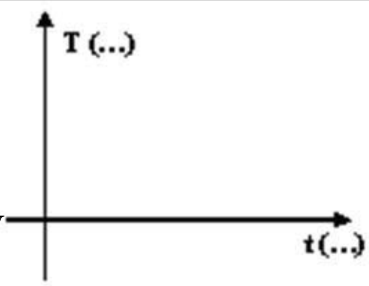
- Perché?

……

Fate una previsione del grafico T(t) della temperatura misurata dalle sonde 1 e 2…in funzione del tempo, e riportatela nel grafico a lato (inserendo le unità di misura e le scale appropriate).



Ripetete l'esperienza, registrando i dati e disegnate il grafico ottenuto nello spazio a lato:



Il grafico Temperatura-tempo sperimentale rispecchia le vostre previsioni?

____

____

Scheda: Equilibrio Termico 3
Nome:...
Scuola:..Data:...

Laboratorio 	**Materiali**	Calorimetro con coperchio acqua fornello elettrico (piastra riscaldante) recipienti 2 termometri bilancia
	Obiettivo	Prevedere la temperatura di equilibrio raggiunta quando si mescolano in un calorimetro una massa d'acqua, inizialmente a temperatura ambiente, e una massa d'acqua a temperatura più alta.

Esperimento: equilibrio termico 3

Inserire in un recipiente circa 150 g di acqua a temperatura ambiente e in un altro circa 150 g di acqua sempre a temperatura ambiente. Misurare le masse con una bilancia, introdurre l'acqua di uno dei recipienti a temperatura ambiente nel calorimetro (m_{fredda}=........±......) e tapparlo con l'apposito coperchio forato. Inserire il termometro nel foro, attendere che il sistema calorimetro-acqua-termometro abbia raggiunto l'equilibrio termico e misurarne la temperatura (T_{fredda} =.........±......).
Riscaldare la massa di acqua contenuta nell'altro recipiente (m_{calda}=......±.........) fino ad una temperatura di circa 70° C.

PREVISIONI

Prima di introdurre nel calorimetro la massa di acqua calda rispondi alle seguenti domande:

- Quale prevedi che sarà la temperatura di equilibrio raggiunta dal sistema?

....

- Pensi sia maggiore la variazione di temperatura, rispetto al valore iniziale, per l'acqua calda o per quella che all'interno del calorimetro si trovava a temperatura ambiente?

....

- Pensi che il calorimetro possa influenzare il valore della temperatura di equilibrio?

....
....

RISULTATI

Dopo aver annotato la temperatura dell'acqua calda (T_{calda} =……±……..), introdurre nel calorimetro la massa di acqua calda, rimettere velocemente il coperchio con il termometro e agitare l'acqua in modo da uniformare la temperatura. Attendere che il sistema raggiunga la nuova temperatura di equilibrio e annotarla (T_E=………±……).

La tua previsione è in accordo con il dato sperimentale? Se no, quale pensi sia la ragione della differenza riscontrata fra i due valori?

……

……

CALCOLO DELLA TEMPERATURA DI EQUILIBRIO

Chiamata Q_A la quantità di calore assorbita e Q_C la quantità di calore ceduta, per raggiungere l'equilibrio termico deve essere Q_A=Q_C. Supponendo che lo scambio di calore avvenga solamente tra le due masse di acqua, si hanno le seguenti relazioni:

$Q_A = cm_{fredda}(T_E - T_{fredda})$ (1)

$Q_C = cm_{calda}(T_{calda} - T_E)$ (2)

Uguagliando i due termini si può scrivere:

$$T_E = \frac{m_{calda}T_{calda} + m_{fredda}T_{fredda}}{m_{calda} + m_{fredda}} \qquad (3)$$

Confrontare la temperatura ricavata con questa formula e la temperatura misurata con il termometro.

Le due temperature coincidono?

……

In realtà il calore ceduto dall'acqua calda è assorbito anche dal calorimetro (contenitore-termometro-eventuale agitatore): nel processo termico è quindi necessario tener conto anche del del calorimetro.

EQUIVALENTE IN ACQUA DEL CALORIMETRO m_e

Quando versiamo l'acqua fredda nel calorimetro, dopo un certo tempo, l'acqua, il termometro, l'eventuale agitatore e le pareti del recipiente si trovano alla stessa temperatura, che indicata sopra con T_{fredda}. Versando successivamente l'acqua calda, si raggiunge una nuova temperatura di equilibrio, che abbiamo chiamato T_E.

Perché il sistema raggiunga l'equilibrio è necessario che la quantità di calore assorbita eguagli la quantità di calore ceduta. In questo caso a cedere calore è la massa m_{calda} di acqua a temperatura T_{calda}, ad assorbirlo non è la sola massa m_{fredda} di acqua a temperatura ambiente, ma l'intero sistema acqua-calorimetro-termometro.

Quindi, anche se il calorimetro è un contenitore isolato dall'esterno, esso partecipa comunque agli scambi termici che avvengono al suo interno, cedendo o assorbendo calore.

Per descrivere questa proprietà del calorimetro si utilizza il concetto di ***equivalente in acqua del calorimetro*** $\boldsymbol{m_e}$, detto anche massa equivalente, cioè quella massa di acqua che, nelle stesse condizioni di scambio termico, cederebbe o assorbirebbe la stessa quantità di calore che viene realmente ceduta o assorbita dal sistema calorimetro-termometro che si sta utilizzando.

DETERMINAZIONE DI m_e

Nel processo considerato è necessario tener conto anche dell' equivalente in acqua del calorimetro m_e.

Chiamata Q_A la quantità di calore assorbita e Q_C la quantità di calore ceduta, si hanno le seguenti relazioni:

$Q_A = c\,(m_{fredda} + m_e)\,(T_E - T_{fredda})$

$Q_C = c\,m_{calda}\,(T_{calda} - T_E)$

Dovendo risultare $Q_A = Q_C$, possiamo ricavare la relazione che permette di determinare m_e:

$$m_e = m_{calda}\frac{T_{calda}-T_E}{T_E-T_{fredda}} - m_{fredda}$$

Utilizzando i dati raccolti, il valore della massa equivalente relativa al calorimetro utilizzato è la seguente:

m_e = ... ± ....

dove possiamo calcolare l'errore nella misura a partire dalle indeterminazioni sulla misura della temperatura (ΔT) e della massa (Δm)

$$\Delta m_e = \Delta m\left(\left|\frac{T_{calda}-T_E}{T_E-T_{fredda}}\right|+1\right) + m_{calda}\frac{2\Delta T}{\left|T_E-T_{fredda}\right|}\left(\left|\frac{T_{calda}-T_E}{T_E-T_{fredda}}\right|+1\right)$$

Il grafico riportato in figura 22 riporta l'andamento atteso. L'inizio riporta la situazione prima dell'immersione, si rilevi al temperatura ogni 15" e si prenda come T'_o, quella osservata come andamento limite subito prima dell'immersione. Si inseriscano circa 20 ml di acqua calda. Attenzione, si ribadisce, a misurare il contenitore con l'acqua prima e dopo l'inserimento, per sottrazione si ottiene direttamente m'_a. Dopo l'inserimento dell'acqua calda, la temperatura tenderà a salire, si provi a rilevare la temperatura ogni 5 secondi, poi una volta osservato un andamento decrescente si rilevi la temperatura ogni 15" per qualche minuto. Quello che bisogna ottenere è la retta MP, prima dell'inserimeto dell'acqua calda e la retta RN dopo linserimento. Dal prolungamento della linea RN e la sua intersezione, con la parallela all'asse delle ordinate a partire dal punto P, si può ottenere la temperatura di equilibrio, da utilizzare nel calcolo, estrapolazione dall'andamento della retta RN. Dalla relazione 33si ottiene così la massa equivalente in acqua del calorimetro.

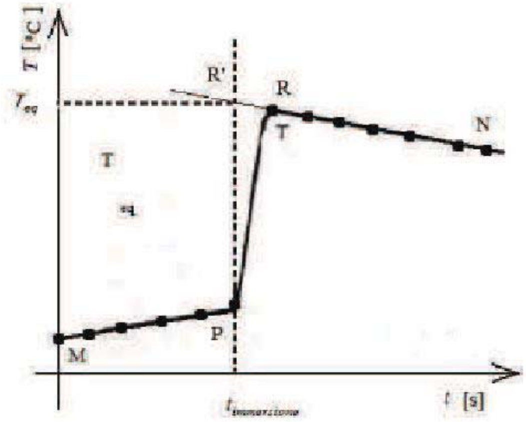
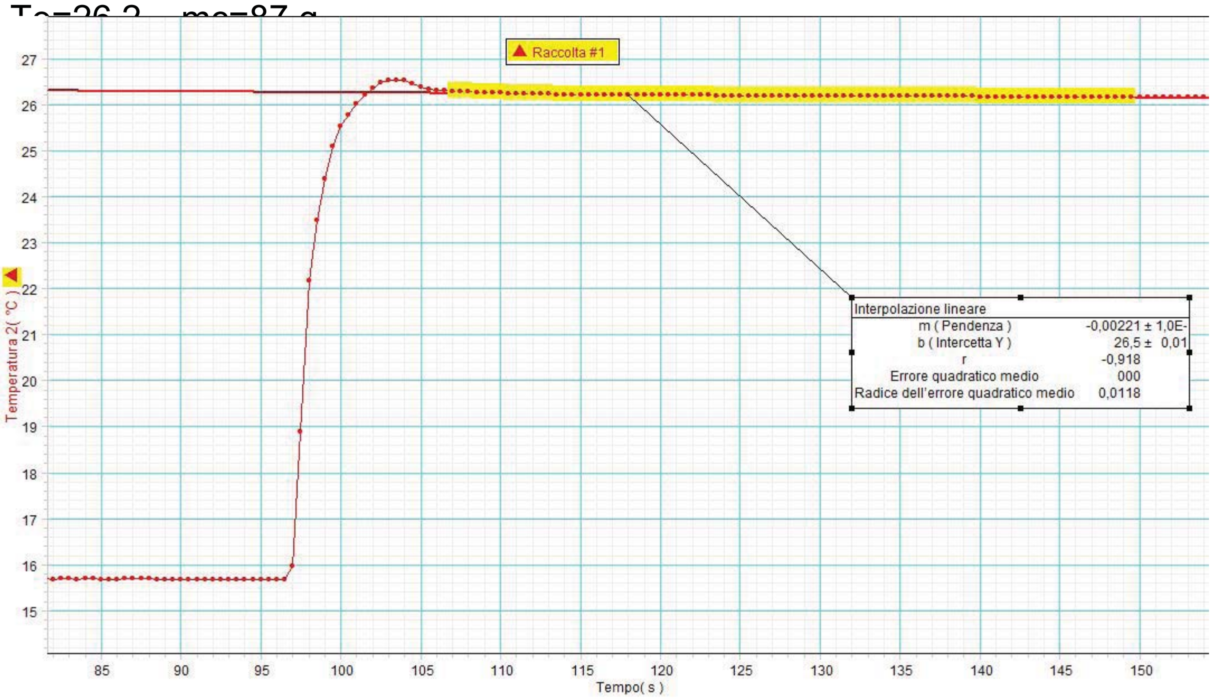


Figura 22: Andamento della temperatura del bagno termico nel calorimetro in funzione del tempo.

Tf=15.7 mf=428 g



Tf=15.7 mf=428 g

Te=26.2 mc=87 g

Tc=80.2

mc	87	tc	80,2
mf	428	tf	15,7
Te	26,2		

$$m_e = m_{calda}\frac{T_{calda} - T_E}{T_E - T_{fredda}} - m_{fredda}$$

me	19,42857

Laboratorio

Materiali	calorimetro acqua fornello elettrico (piastra riscaldante) recipienti oggetto di metallo 1 termometro bilancia
Obiettivo	Determinare il calore specifico di metalli diversi, sfruttando il principio dell'equilibrio termico.

Esperimento: Calore specifico

PREMESSA

Il calore specifico C di una sostanza è la quantità di calore necessaria per innalzare di un grado centigrado la temperatura dell'unità di massa della sostanza. Nel Sistema Internazionale il calore specifico si misura in $\frac{J}{kg\,K}$ ma è molto comune che il suo valore venga espresso in calorie per grammo per grado centigrado.

Dalla definizione di caloria segue che il calore specifico dell'acqua è *esattamente* uguale a 1 caloria per grammo per grado solo nell'intervallo di temperatura compreso tra 14,5 e 15,5 °C, e a pressione pari a 1 atmosfera.

Il valore del calore specifico di alcune sostanze in condizioni normali di temperatura e pressione $(T = 0°C,\ p = 1\,atm)$, sono riportati nella tabella che segue, nelle unità di misura sopra indicate, ricordando che è 1 cal = 4,186 J.

PROCEDIMENTO

Versate nel calorimetro una massa nota di acqua a temperatura ambiente (si consiglia di usarne circa 350g). Misurate la massa con la bilancia (m_{acqua}=.........±.........), coprite il calorimetro con il coperchio forato e misurate con il termometro la temperatura di equilibrio del sistema calorimetro-acqua (T_{acqua}=.........±.........).

In un pentolino scaldate dell'acqua fino alla temperatura di ebollizione. Misurate la massa del corpo metallico di cui si vuole misurare il calore specifico ($m_{metallo}$ =.........±.........) e immergetelo completamente nell'acqua bollente. Aspettate qualche minuto per permettere al corpo di portarsi all'equilibrio termico con l'acqua, misurate la temperatura del sistema acqua-metallo ($T_{metallo}$=.........±.........), poi spostate rapidamente il corpo metallico nel calorimetro. Richiudete immediatamente il coperchio e, tramite il termometro, leggete la temperatura di equilibrio raggiunta dal sistema (T_E=.........±.........).

ESPERIMENTO E OSSERVAZIONI

In questo caso il corpo metallico cede calore, mentre ad assorbirlo è l'intero sistema acqua-calorimetro (quindi si deve tenere conto della massa equivalente del calorimetro m_e).

Chiamata Q_A la quantità di calore assorbita e Q_C la quantità di calore ceduta, si possono scrivere le seguenti relazioni:

$Q_A = c_{acqua}(m_{acqua} + m_e)(T_E - T_{acqua})$

$Q_C = c_{metallo} m_{metallo}(T_{metallo} - T_E)$

dove $c_{metallo}$ è il calore specifico del metallo, cioè la nostra incognita e c_{acqua} è il calore specifico dell'acqua.

Dovendo risultare $Q_A = Q_C$, la relazione che permette di ricavare $c_{metallo}$ è la seguente:

$$c_{metallo} = \frac{(m_{acqua} + m_e)(T_E - T_{acqua})}{m_{metallo}(T_{metallo} - T_{acqua})} c_{acqua}$$

L'errore relativo può essere stimato come

$$\frac{\Delta c_{metallo}}{c_{metallo}} = \frac{(\Delta m_{acqua} + \Delta m_e)}{(m_{acqua} + m_e)} + \frac{2\Delta T}{(T_{metallo} - T_{acqua})} + \frac{2\Delta T}{(T_E - T_{acqua})} + \frac{\Delta m_{metallo}}{m_{metallo}}$$

Ne consegue che il valore del calore specifico misurato è:

$c_{metallo}$=.........±.........

Confrontate il risultato ottenuto con il valore noto per il metallo utilizzato: sono in accordo nel limite dell'errore sperimentale?

PASSAGGI DI STATO

 Laboratorio	Materiali	calorimetro acqua fornello elettrico (piastra riscaldante) recipienti ghiaccio a cubetti 2 termometri bilancia carta assorbente
	Obiettivo	Determinare il calore latente di fusione del ghiaccio.

Esperimento: Calore latente

Misurate la massa del calorimetro vuoto ($m_{calorimetro}$=.........±.........).

Prendete alcuni cubetti di ghiaccio in modo che la massa sia di circa 60 grammi e riponeteli in un recipiente isolante contenente una piccola quantità di acqua a temperatura ambiente. Attendete che inizi il processo di fusione, in modo che il ghiaccio si possa considerare ad una temperatura $T_{ghiaccio}$ = 0°C.

In un pentolino riscaldate circa 300 grammi di acqua fino a raggiungere una temperatura intorno ai 40°C, e introducetela nel calorimetro. Chiudete il calorimetro con il coperchio munito di termometro e attendete che venga raggiunto l'equilibrio termico.

Misurate la massa del calorimetro con l'acqua e sottraete la massa del calorimetro in modo da ricavare con una migliore precisione la massa dell'acqua calda (m_{acqua}=.........±..........)

Annotate la temperatura di equilibrio del sistema acqua più calorimetro (T_{acqua}=.........±.........).

A questo punto immergete i cubetti di ghiaccio nel calorimetro asciugandoli con la carta assorbente, quindi chiudete rapidamente il coperchio.
Quale pensate che sia la temperatura di equilibrio? Giustificate la vostra previsione.

____

____

____

Attendete ancora qualche minuto affinché il sistema si porti all'equilibrio termico e misurate la temperatura di equilibrio (T_E=………±………)
Il valore della temperatura di equilibrio è in accordo con le vostre previsioni?

____

____

____

Misurate la massa totale finale ($m_{tot}=m_{calorimetro}+m_{acqua}+m_{ghiaccio}$=………±………) e per differenza ricavate $m_{ghiaccio}=m_{tot}-m_{calorimetro}-m_{acqua}$=………±………

RICHIAMO TEORICO

Nel bilancio energetico di un processo termico in cui avviene un passaggio di stato bisogna tener conto del calore assorbito (o ceduto) perché avvenga il cambiamento di stato.
Il **calore latente** (di trasformazione) è la quantità di energia per unità di massa necessaria per ottenere una transizione di fase di una sostanza (ad esempio il calore necessario per far passare l'acqua dallo stato solido (ghiaccio) a quello liquido a pressione atmosferica).
Durante la transizione di fase la sostanza si presenta con due diverse fasi (acqua e ghiaccio), l'energia fornita (assorbita) alla sostanza non va ad aumentare (o diminuire) la temperatura della stessa, bensì agisce sui legami intermolecolari.

Nel nostro caso il passaggio di stato da considerare è la fusione del ghiaccio in acqua. Il suddetto processo si può schematizzare come segue: il ghiaccio, che si trova già alla temperatura di fusione ($T_{ghiaccio}$=0°C), deve assorbire una certa quantità di calore (Q_f) per fondere completamente alla temperatura di 0°C e alla pressione di 1 atmosfera; successivamente la massa di acqua proveniente dalla fusione del ghiaccio ($m_{ghiaccio}$), inizialmente a 0°C, deve assorbire una ulteriore quantità di calore (Q_A) per raggiungere la temperatura di equilibrio (T_E).

DETERMINAZIONE DEL CALORE LATENTE DI FUSIONE DEL GHIACCIO λ_f.

I termini che intervengono nel bilancio energetico sono i seguenti:

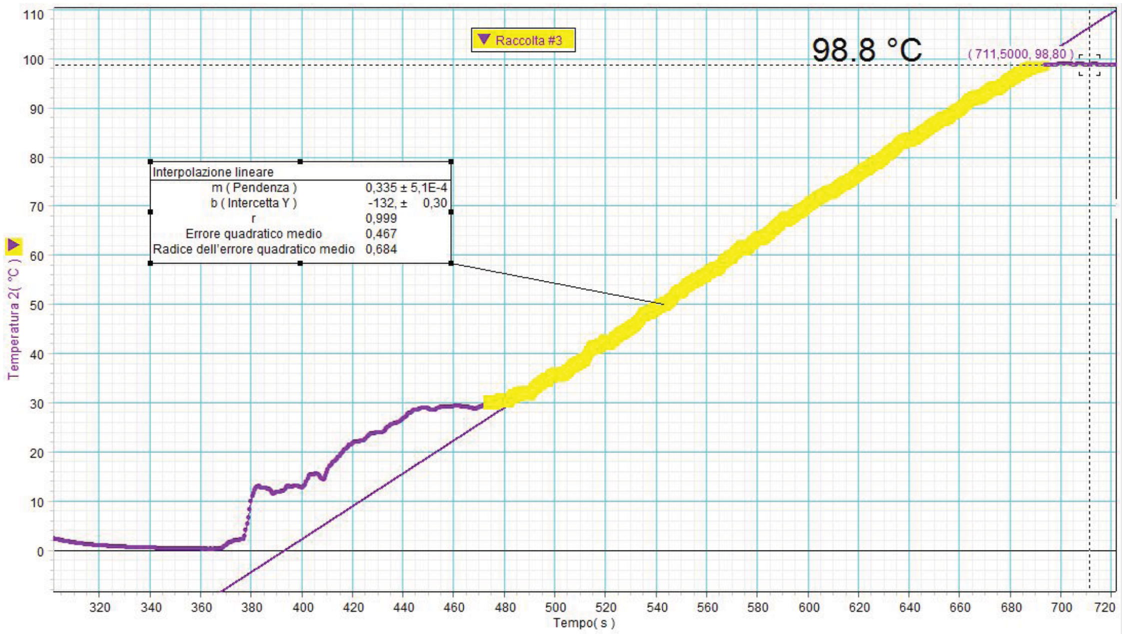
- Calore necessario al passaggio di stato $Q_f = m_{ghiaccio}\,\lambda_f$
- Calore assorbito dal ghiaccio fuso $Q_A = m_{ghiaccio} c_{acqua} (T_E - T_{ghiaccio})$
- Calore ceduto $Q_C = (m_{acqua} + m_e) c_{acqua}(T_{acqua} - T_E)$

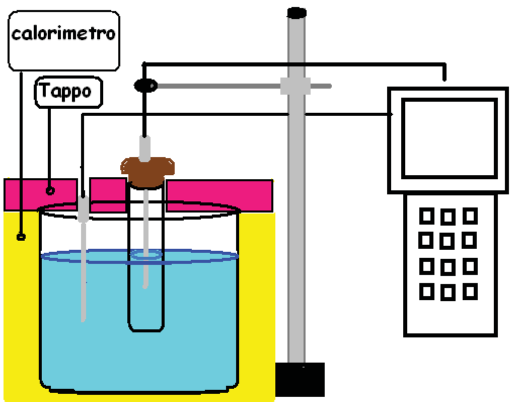
dove m_e indica l'equivalente in acqua del calorimetro e il valore di c_{acqua} è 1 kcal/kg
L'equazione del bilancio termico risulta, quindi, essere $Q_A + Q_f = Q_C$.
Sfruttando tale equazione la relazione che permette di ricavare λ_f è la seguente:

$$\lambda_F = \frac{(m_{acqua} + m_e) c_{acqua}(T_{acqua} - T_E) - m_{ghiaccio} c_{acqua}(T_E - T_{ghiaccio})}{m_{ghiaccio}} = \ldots\ldots\ldots$$

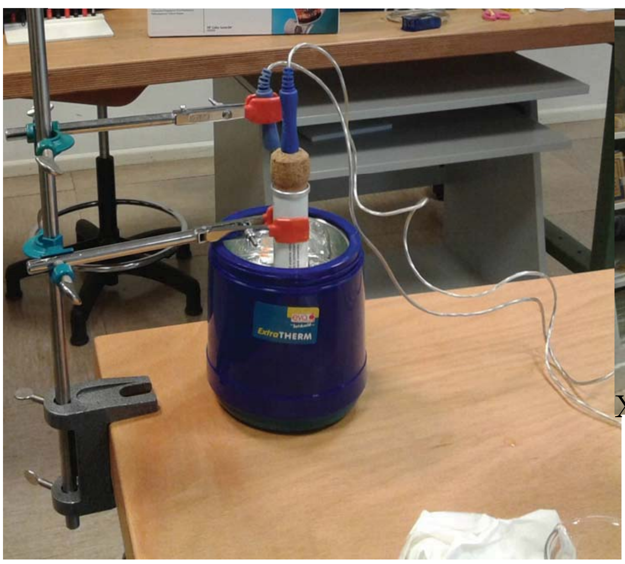
Confrontate il risultato ottenuto con il valore teorico di 80 kcal/kg (335 kJ/kg): sono in accordo?

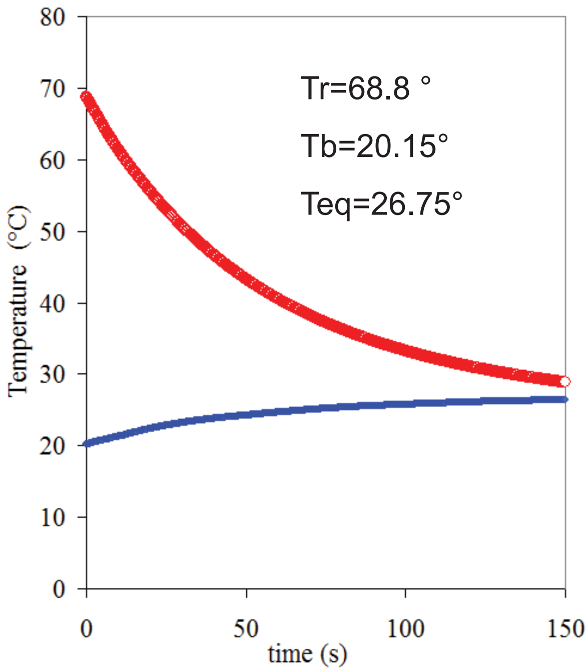
____

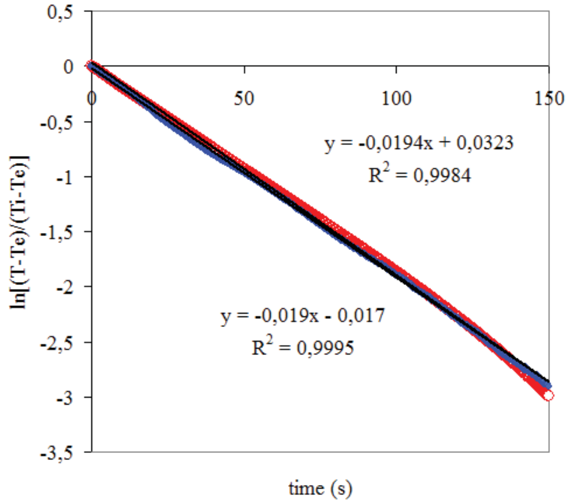




lo stato di equilibrio termico si raggiunge quando cessa lo scambio netto di energia e le temperature si eguagliano mentre più in generale tutte le grandezze termodinamiche macroscopiche restano invariate.







Masse	[g]	errore [g]
Termos	342,48	0,01
AF	397,82	0,02
Cilindro	10,98	0,01
AC	73,44	0,02

$$m_\alpha (T_\alpha - T_{eq}) \approx m_\beta (T_{eq} - T_\beta)$$

$$\tau_\alpha = 51.6s$$

$$\tau_\beta = 52.5s$$

Risultato ottenuto al 85%

Masse	[g]	errore [g]
Termos	342,48	0,01
AF	507,9	0,1
Cilindro	10,98	0,01
AC	50,27	0,02

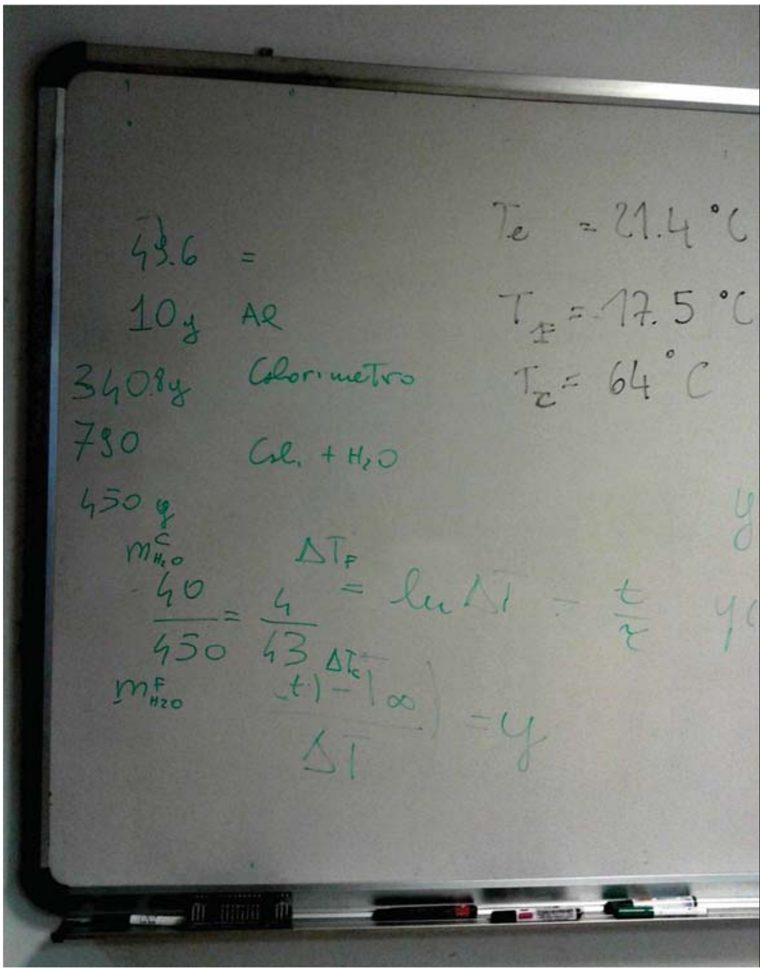
Temperature	[°C]	errore [°C]
AC iniziale	38,95	0,01
AC finale	20,31	0,01
AF iniziale	18,42	0,01
AF finale	20,31	0,01

Sigle

Acqua calda	AC
Acquafredda	AF

$$m_\alpha (T_\alpha - T_{eq}) \approx m_\beta (T_{eq} - T_\beta)$$

Risultato ottenuto al 98%



Tr=64 °

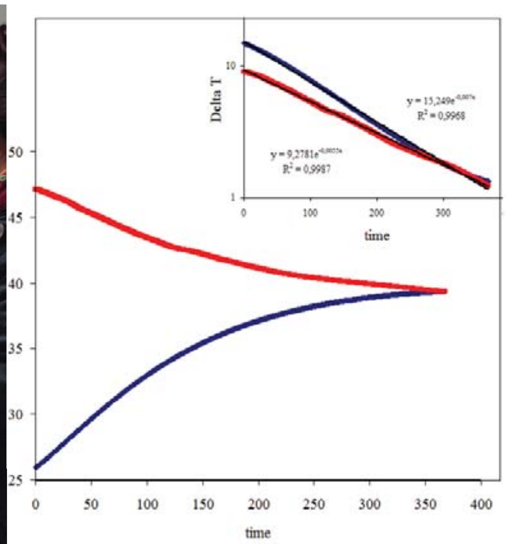
Tb=17.5°

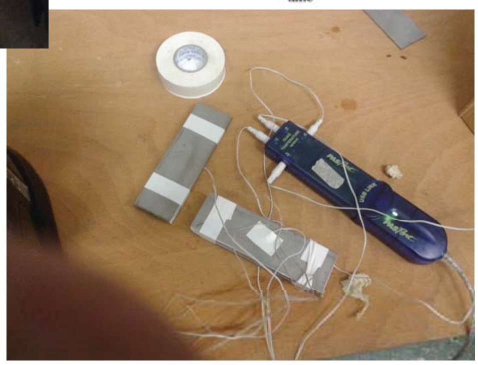
Teq=21.4°

Masse	**[g]**	**errore [g]**
Termos	341	1
AF	450	1
Cilindro	11	1
AC	40	1

0,0894 rapporto delta T

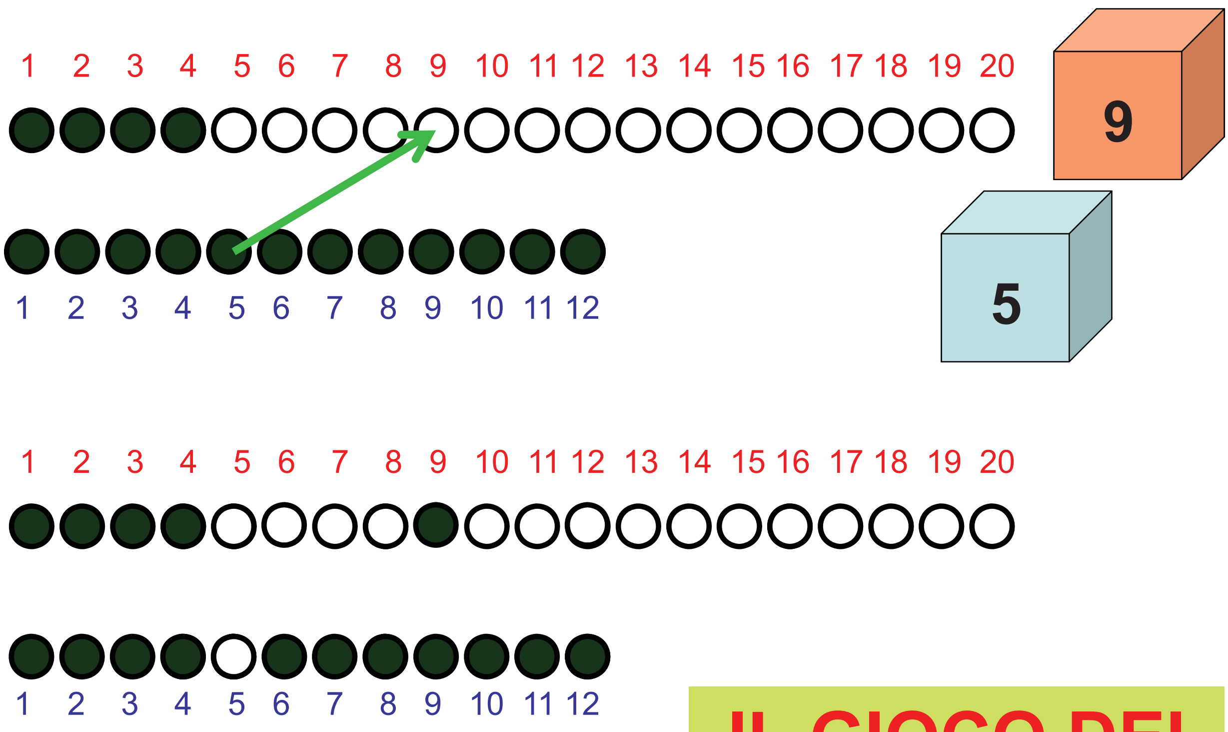
0,0889 rapporto masse





I tau ottenuti dal fit differiscono di 34 s su 175 s (20%) o meno (7%) a seconda del fit che usiamo
Le variazioni di temperatura dovrebbero essere in proporzione 3 a 2 (ottengo 15.5 ° e 9.3 ° ovvero rapporto 1,66 o 1.75 a seconda del fit che differisce dall'altro di un 10%-15%)

Discussione dei principali problemi sperimentali

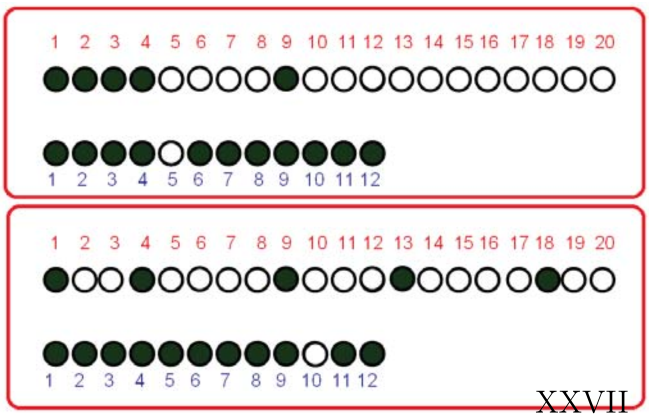


IL GIOCO DEI DADI

MACROSTATI E MICROSTATI

Se noi specifichiamo per ogni moneta dove essa è collocata allora stiamo definendo un particolare microstato del sistema.

Un modo di specificare un macrostato per il nostro sistema è determinare il numero di monete contenute in uno dei due sottosistemi ($\alpha\beta$). Questo macrostato ci dice come le monete si distribuiscono tra i sottosistemi tra le combinaioni possibili ma non ci fornisce informazioni circa la posizione specifica che assumono le monete.



Esempio di due microstati corrispondenti allo stesso macrostato

LA TAMPARATURE

Quindi definiamo le quantità macroscopiche (termodinamiche) del sistema. La proprietà che caratterizza il macrostato, che definiamo Tamparature, Ta, è definita come

$$kTa_\alpha = \frac{n_\alpha}{N_\alpha} \qquad kTa_\beta = \frac{n_\beta}{N_\beta}$$

e assume valori tra 0 e 1/k.
Quindi lo stato termodinamico di un corpo è definito dalla sua tamparture, grandezza **intensiva**, e dal suo volume/massa N, **grandezza estensiva,**
Un'altra quantità estensiva è

$$Ua = n_B$$

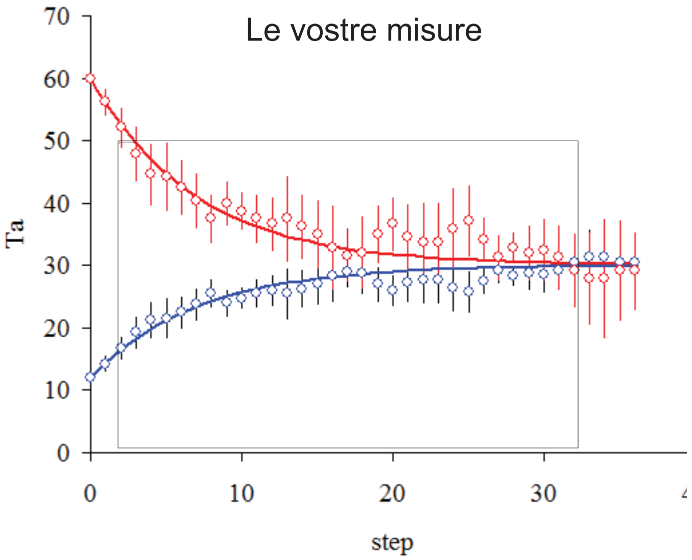
Possiamo osservare che la quantità Ta che ci dice il numero medio di monete è una quantità *intensiva* mentre Ua è una corrispondente quantità estensiva.

Noi abbiamo scelto k=1/60 (60 minimo comune multiplo di Na e Nb)

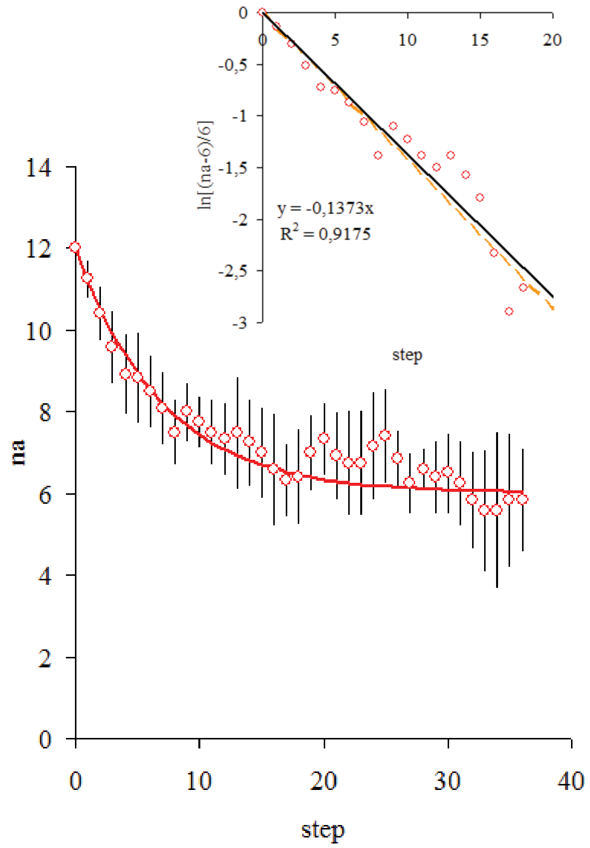
Domande?

- Esiste un macrostato di equilibrio del sistema? Quale è? Perché?
- Cosa c'entra la probabilità? Come posso calcolarla?

- Cosa sono le monetine nell'analogia tra i corpi a contatto e il gioco delle monete?
- Quale principio posso ottenere?
- Quali leggi fisiche posso ottenere? Come posso verificarle sperimentalmente?
- Quale grandezza termodinamica è legata alla probabilità?



Esiste un macrostato di equilibrio del sistema?
E' statico o dinamico?
Quanto tempo impiego a raggiungerlo?

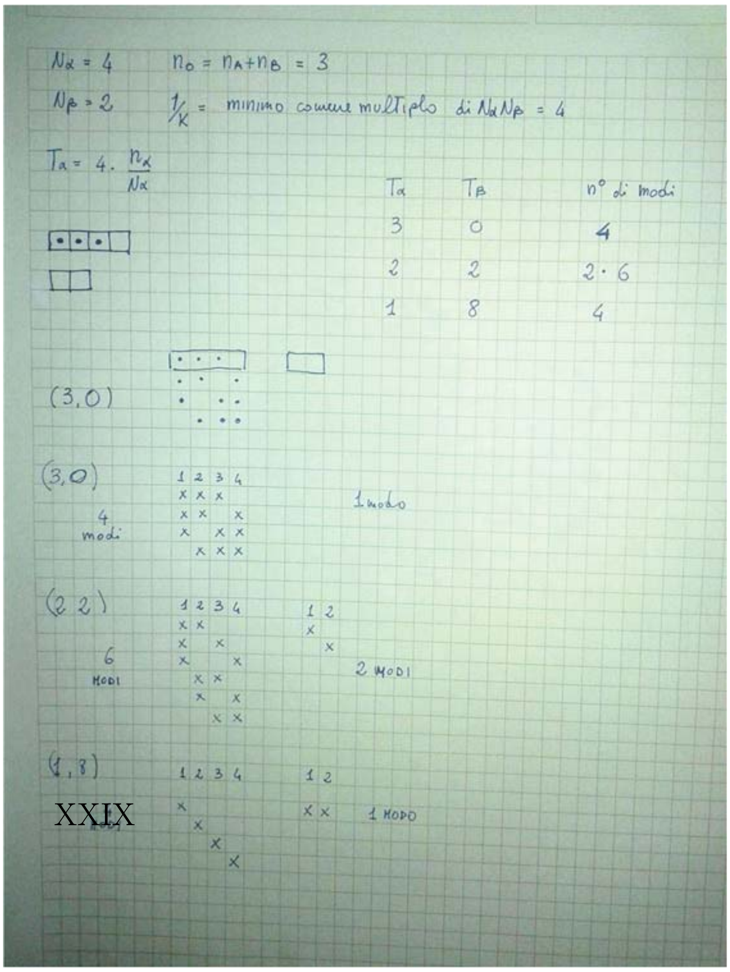


Dal tempo di dimezzamento $\tau = \frac{4 \pm 1}{\ln(2)} \approx 5.8 \pm 1.4$

Dal fit logaritmico $\tau = 7.3 \pm 0.3$

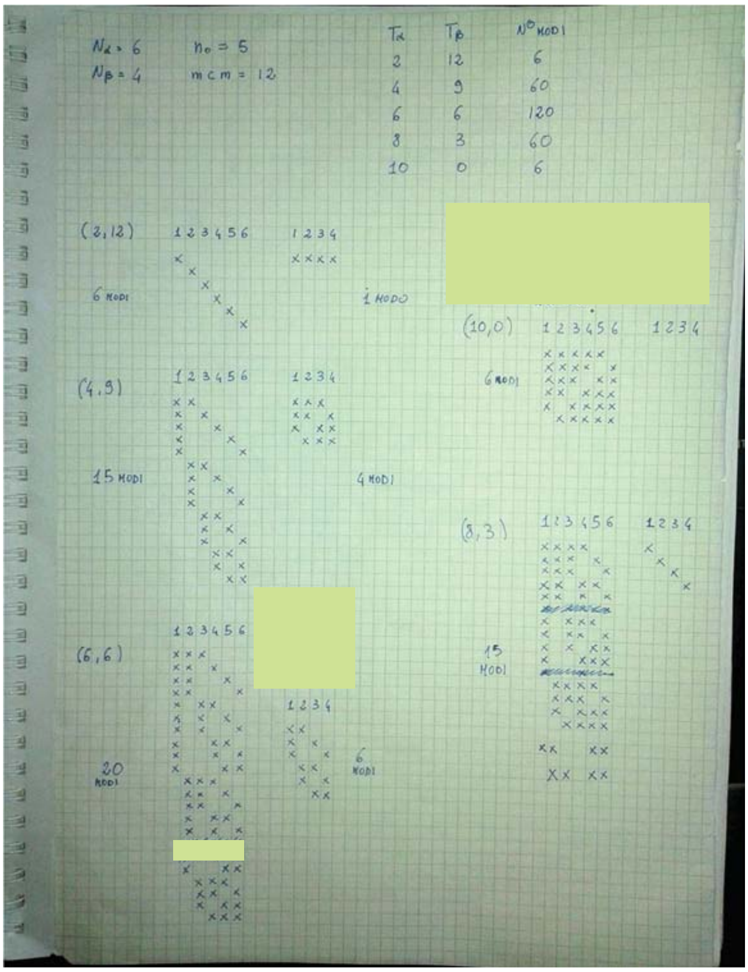
Molteplicità del macrostato e Probabilità

- Esempio

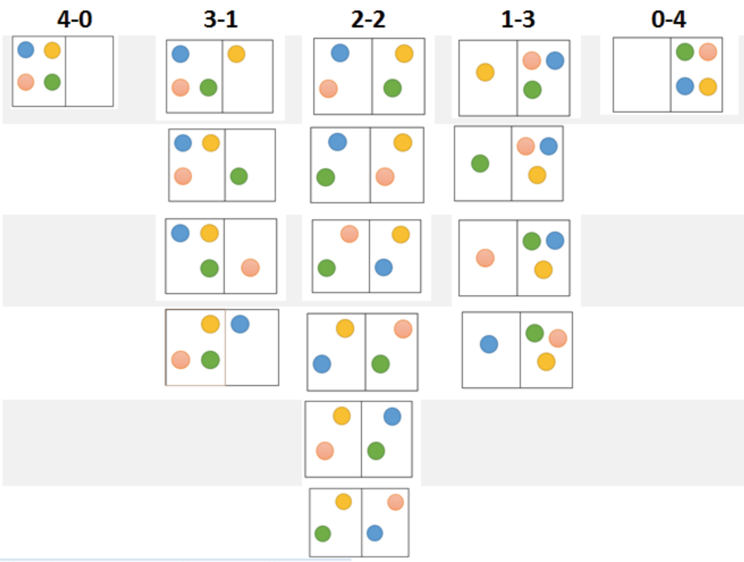


Molteplicità del macrostato e Probabilità

- Esempio



Molteplicità del macrostato e Probabilità



Il primo esempio che si può considerare è quello in cui 4 palline devono essere disposte all'interno di un contenitore diviso in due parti. Individuando le palline in base al loro colore, le situazioni che si possono presentare sono quelle rappresentate nella tabella seguente.

Come si può notare ci sono 16 situazioni possibili. Questi sono i microstati: le palline sono distinguibili e ogni caso può essere differenziato dagli altri. Se invece eliminiamo la distinguibilità delle palline, otteniamo solo 5 casi possibili. Tali casi corrispondono ai macrostati (ad esempio dire che ci sono 3 palline a destra e 1 a sinistra significa individuare il macrostato, mentre dire *quali* palline sono a destra o a sinistra significa specificare il microstato). Al macrostato 3-1 corrispondono 4 microstati: si tratta quindi di un macrostato con molteplicità 4. A questo punto si può ragionare su quale sia il macrostato più probabile, utilizzando la definizione di probabilità

$$P = \frac{numero\ casi\ favorevoli}{numero\ casi\ possibili} = \frac{n°\ microstati\ corrispondenti\ a\ quel\ macrostato}{numero\ totale\ dei\ microstati}$$

A differenza dei macrostati, i microstati sono tutti equiprobabili, in quanto la probabilità di realizzazione di ciascuno di essi è

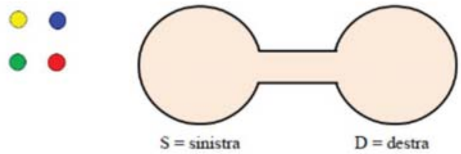
$$P = \frac{numero\ casi\ favorevoli}{numero\ casi\ possibili} = \frac{1}{numero\ totale\ dei\ microstati}$$

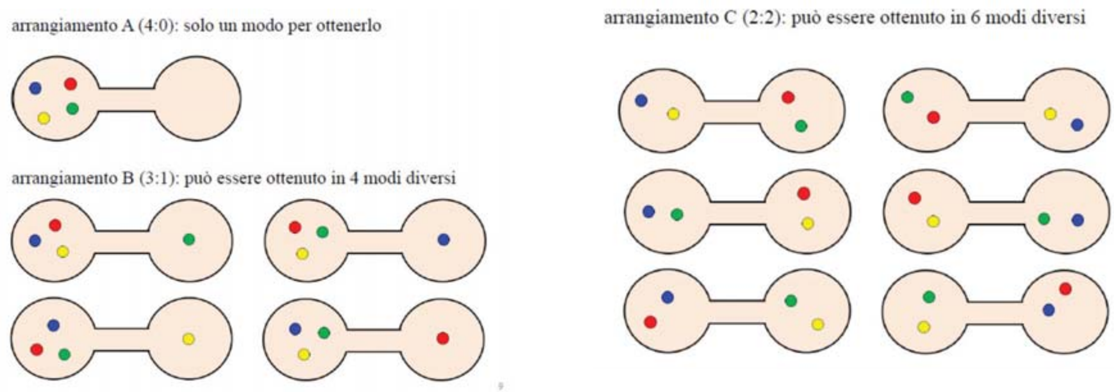
Microstati e macrostati

- la termodinamica classica classifica gli stati in base alle caratteristiche macroscopiche
- la termodinamica statistica utilizza i microstati (stati microscopici)
  - microstato: posizione e momento di ogni molecola
  - macrostato: (P,V,T)
- molteplicità: il numero di microstati corrispondenti ad un unico macrostato

Microstati e probabilità

Consideriamo 4 molecole da distribuire in due recipienti collegati





Molteplicità del macrostato e Probabilità

- non tutti i macrostati sono equivalenti. Infatti la molteciplicità di un macrostato per un corpo fatto di N caselle ad una data tamparatura, ovvero contenente un numero n di monete è espresso formalmente in termini di coefficienti binomiali

$$W(n_B, N) = W(Ta, N) = \frac{N!}{n_B!(N-n_B)!} = \frac{N!}{(TaN)!(N(1-Ta))!}$$

- Quale è la probabilità di scegliere uno qualsiasi dei microstati associati a un dato macrostato se noi scegliamo casualmente tra tutti i microstati possibili? Questa probabilità si calcola dividendo la molteplicità del macrostato per il numero totale dei possibili microstati.

capacità

Cosa accade alle proprietà termodinamiche, cioè al macrostato, quando scambiamo casualmente due pedine tra le due righe? Se hanno colori uguali nulla, altrimenti la temperatura del corpo a si modificherà di una quantità

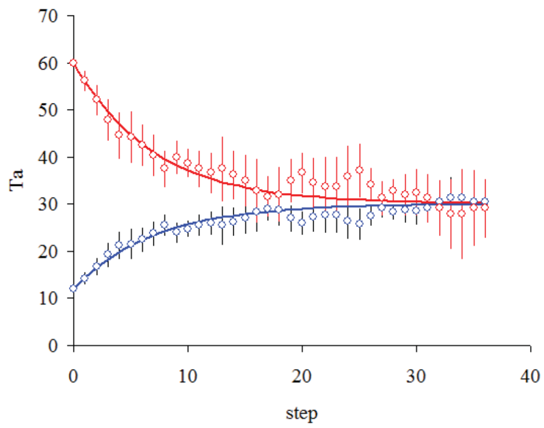
$$\Delta Ta_{\alpha} = \pm \frac{1}{kN_{\alpha}}$$

Attribuendo allo scambio bianco-nero il significato di passaggio di energia è evidente che *stiamo di fatto ipotizzando un insieme di quanti di energia(pedine nere), tutti identici, che possono distribuirsi liberamente all'interno di un sistema isolato* $\alpha + \beta$. Quindi possiamo identificare l'energia infinitesima scambiata, con $\delta q = \pm 1$ a seconda che lo scambio sia $(\alpha - W, \beta - B)$ o $(\alpha - B, \beta - W)$. Ne consegue che

$$\Delta Ta_{\beta} = +\frac{\delta q}{kN_{\alpha}} \text{ e } \Delta Ta_{\beta} = -\frac{\delta q}{kN_{\beta}}$$

Quindi definiamo Hat capacity come il rapporto tra la variazione di energia e la corrispondente variazione di tamparatura, $C_{\alpha} = \frac{\Delta Ua}{\Delta T} = kN_{\alpha}$.

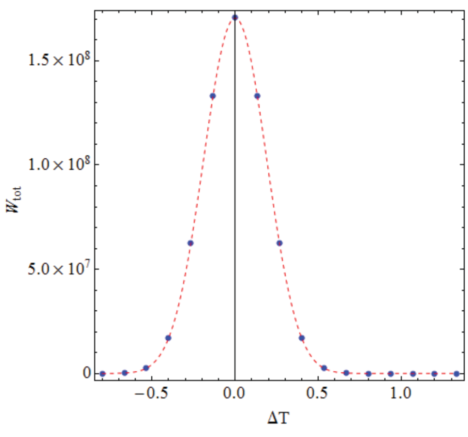
Dinamica verso l'equilbrio termico



Cosa farà il sistema dopo vari scambi casuali? Oscillerà tra diversi macrostati o tenderà verso un macrostato particolare? Quale?

I risultati ottenuti da voi mostrano che il sistema evolve verso il macrostato con molteplicità più alta, laddove la molteplicità in del sistema a contatto in funzione dei parametri termodinamici è

$$W_{tot}(Ta_{\alpha}, Ta_{\beta}) = W(N_{\alpha}, Ta_{\alpha})W(N_{\beta}, Ta_{\beta})$$



Possiamo rappresentare in funzione della differenza di tamparatura le molteplicità di ciascun macrostato

Osserviamo che l'equilibrio termico non è una condizione statica ma una condizione dinamica in cui sarebbe meglio parlare di stazionarietà. Infatti continuano ad esserci scambi di energia tra i corpi anche se il flusso netto in media (temporale su un numero sufficiente di lanci) è nullo. Quindi il sistema oscilla tra vari microstati appartenenti al macrostato di equilibrio e alcuni microstati appartenenti a macrostati prossimi all'equilibrio.
IL calcolo della temperatura di equilibrio è ottenuto applicando la conservazione di n_0

$$\frac{n_B^\alpha}{N_\alpha} = \frac{n_B^\beta}{N_\beta} = \frac{n_0 - n_B^\alpha}{N_\beta}$$

Quale principio posso ottenere?

- Il sistema evolve verso lo stato di massima probabilità
- Se pongo due corpi con tamparture diverse a contatto vi sarà un passaggio netto di energia dal corpo a tampartura maggiore a quello a tampartura minore che si frmerà quando i due corpi raggiungeranno la stessa tamparatura ovvero la condizione di equilibrio termico

Sappiamo che se due oggetti a diverse temperature sono posti in contatto termico (in modo che l'energia termica possa essere trasferita dall'uno all'altro), i due oggetti raggiungeranno prima o poi la stessa temperatura. Questi oggetti sono detti all'**equilibrio termico**. Per esem-

•Quali leggi fisiche posso ottenere?

Legge di conduzione del calore

Indichiamo con B le caselle piene e con W quelle vuote per ciascuna tabella

La probabilità che in ciascuno scambio vi sia un passaggio di δq può essere calcolata come

$$P(\alpha \to \beta) = P_\alpha(B)P_\beta(W) - P_\alpha(W)P_\beta(B) = \frac{n_B^\alpha}{N_\alpha}\frac{n_W^\beta}{N_\beta} - \frac{n_W^\alpha}{N_\alpha}\frac{n_B^\beta}{N_\beta} = \frac{n_B^\alpha}{N_\alpha}\left(1-\frac{n_B^\beta}{N_\beta}\right) - \left(1-\frac{n_B^\alpha}{N_\alpha}\right)\frac{n_B^\beta}{N_\beta}$$

$$= \frac{n_B^\alpha}{N_\alpha} - \frac{n_B^\beta}{N_\beta} = k(Ta_\alpha - Ta_\beta)$$

Questa è la legge di trasmissione del calore che stabilisce che la quantità di energia scambiata da due corpi a contatto è proporzionale alla differenza di temperatura tra i corpi.
Se identifichiamo l'intervallo di tempo tra due lanci come infinitesimo dt, utilizziamo il limite termodinamico e per la legge dei grandi numeri consideriamo che la Probabilità di scambio coincida con il numero di scambi nell'unità di tempo, la legge di trasmissione del calore assume la sua forma usuale

$$\frac{dn_B^\alpha}{dt} = N_\alpha k\frac{dTa_\alpha}{dt} = \frac{n_B^\alpha}{N_\alpha} - \frac{n_B^\beta}{N_\beta} = k(Ta_\alpha - Ta_\beta) \qquad \frac{dTa_\alpha}{dt} = \frac{1}{C_\alpha}(Ta_\alpha - Ta_\beta)$$

$$\frac{dn_B^\beta}{dt} = N_\beta k\frac{dTa_\beta}{dt} = -k(Ta_\alpha - Ta_\beta) \qquad \frac{dTa_\beta}{dt} = -\frac{1}{C_\beta}(Ta_\alpha - Ta_\beta)$$

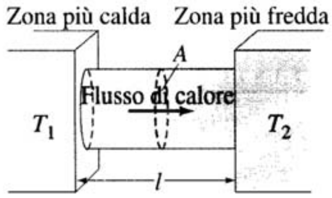
Conseguenza della legge di conduzione del calore è la condizione di equilibrio termico infatti la probabilità di avere uno scambio si riduce a 0 quando le temperature sono uguali.

La conduzione del calore ha luogo solo se è presente una differenza di temperatura. Infatti, si trova sperimentalmente che la velocità di flusso di calore attraverso una sostanza è proporzionale alla differenza in temperatura tra le sue estremità. La velocità di flusso di calore dipende anche dalla forma e dalla dimensione dell'oggetto e, per esaminare tutto ciò quantitativamente, consideriamo il flusso di calore attraverso un oggetto uniforme, come mostrato in figura 14-5. Si trova sperimentalmente che il flusso di calore ΔQ diviso per l'intervallo di tempo Δt è dato dalla relazione

$$\frac{\Delta Q}{\Delta t} = kA\frac{T_1 - T_2}{l} \qquad \textbf{(14–3)}$$

Velocità di flusso di calore per conduzione

dove A è l'area della sezione trasversale dell'oggetto, l è la distanza fra le due estremità, che sono mantenute a temperatura T_1 e T_2, e k è una costante di proporzionalità chiamata **conduttività termica**, che è caratteristica del materiale. Dall'eq. 14-3 vediamo† che la velocità di flusso di calore (misurato in J/s) è direttamente proporzionale alla sezione e al gradiente di temperatura $(T_1 - T_2)/l$.



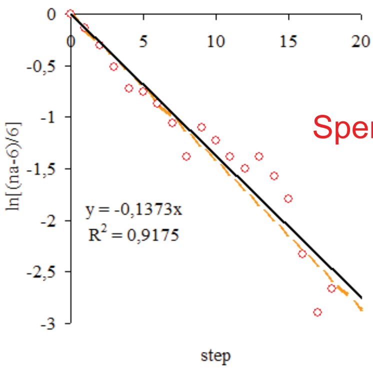
•Come posso verificarle sperimentalmente?

Come conseguenza della legge di trasmissione del calore possiamo calcolare i tipici andamenti esponenziali che si osservano macroscopicamente quando i corpi a contatto si portano all'equilibrio a partire dall'equazione differenziale (***)

$$\frac{d(Ta_\alpha - Ta_\beta)}{dt} = -\left(\frac{1}{N_\alpha}+\frac{1}{N_\beta}\right)(Ta_\alpha - Ta_\beta) = -\left(\frac{1}{\tau}\right)(Ta_\alpha - Ta_\beta).$$

Quindi

$$\Delta Ta\ (t) = \Delta Ta\ (0)e^{-t/\tau_H} \text{ e } \tau = \left(\frac{N_\alpha N_\beta}{N_\alpha + N_\beta}\right) = 7.5$$

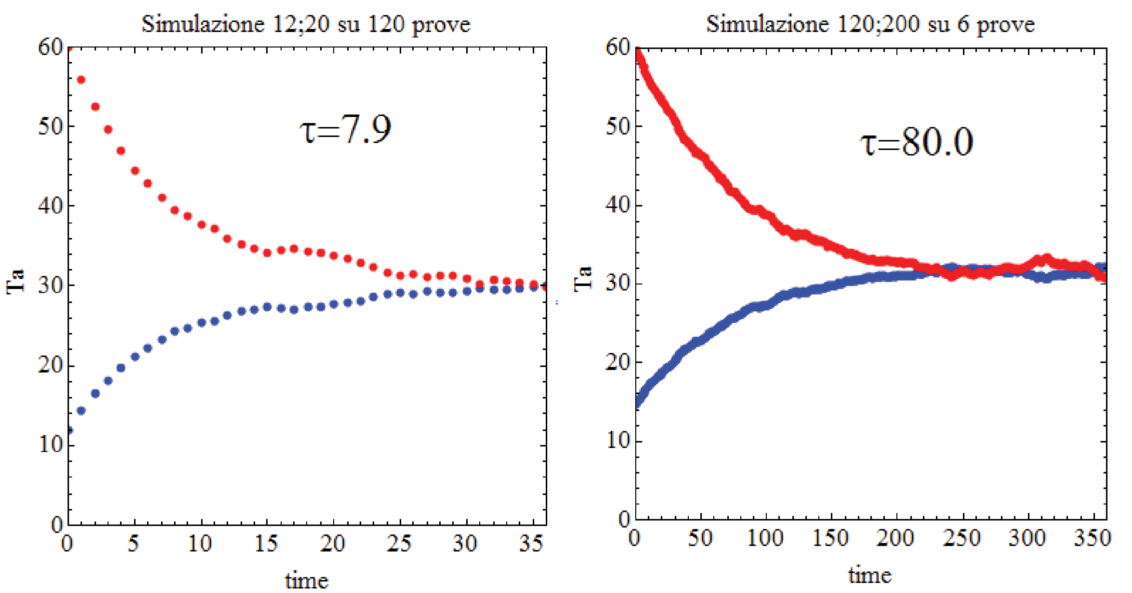


Sperimentalmente τ≈7.3

MATEMATICA

IL caso discreto non è uguale al caso continuo!!!

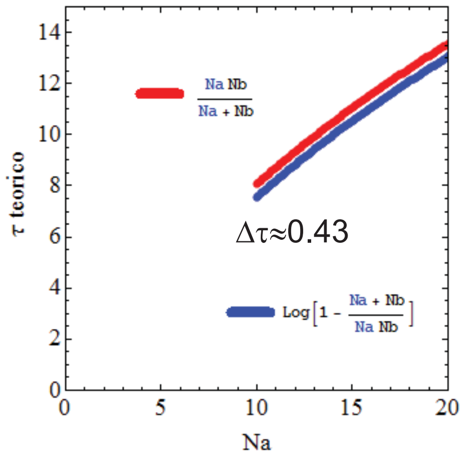
SIMULAZIONE

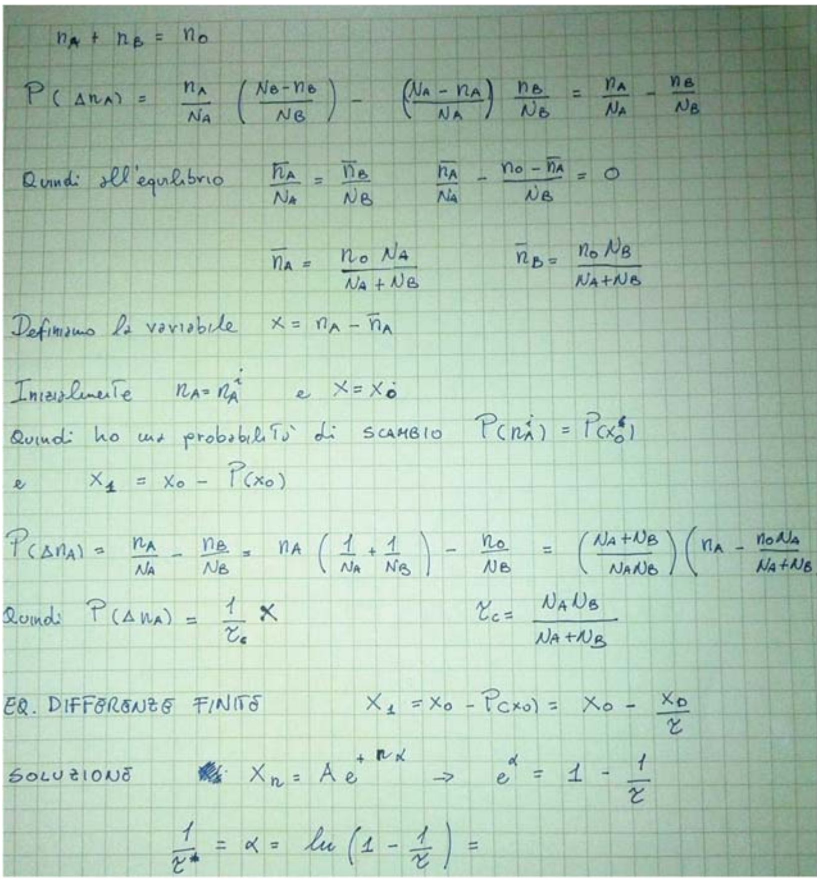


MATEMATICA

XXXV

IL caso discreto non è uguale al caso continuo!!!





•Quale grandezza termodinamica è legata alla probabilità?

L'entropia S

Termine coniato da R. Clausius (dal greco *εν*, "dentro", e da *τροπή*, "cambiamento").
L'irreversibilità del calore:

- il calore passa in maniera naturale dal caldo al freddo, mai dal freddo al caldo.
- l'attrito converte il movimento meccanico in calore, ma in natura non esiste un processo comparabile per trasformare il calore in movimento meccanico" .

Clausius individuò in queste classi di fenomeni spontanei due tipi di cambiamento:

- cambiamento di temperatura (energia termica che passa dal caldo al freddo)
- cambiamento di energia (energia meccanica che si trasforma in energia termica).

Suppose che questi due tipi di cambiamento dovessero avere la stessa natura, essere cioè due aspetti diversi di uno stesso fenomeno: variazioni di entropia. Le trasformazioni naturali che avvengono spontaneamente in natura dovevano produrre un aumento dell'entropia.
La variazione di entropia subita da un sistema in seguito ad una trasformazione è data da:

$$\Delta S = \frac{Q}{T}$$

XXXVI

Definita molteplicità (w) il numero di microstati equivalenti, per N molecole, la molteplicità di una configurazione è data da:

$$w = \frac{N!}{n_D! n_S!}$$

Le configurazioni con una maggiore molteplicità (più probabili) sono quelle ad **entropia** più alta.

11

L'equazione dell'entropia di Boltzmann

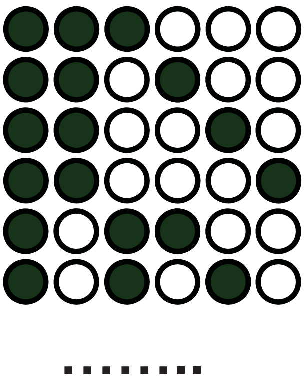
Ludwig Boltzmann sviluppò l'idea di considerare la distribuzione dell'energia nei vari livelli energetici come un modo per calcolare l'entropia

$$S = k \cdot \log w$$

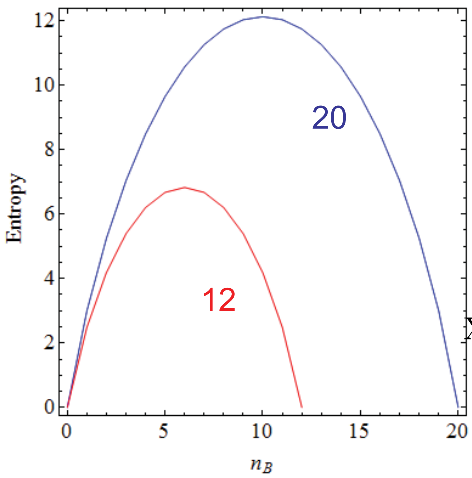
$k = 1.3807 \cdot 10^{-16}$ J/mol   costante di Boltzmann

w = il numero dei differenti modi in cui l'energia può essere distribuita nei livelli energetici disponibili

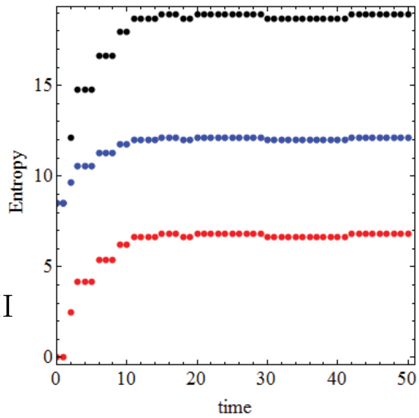
Zentralfriedhof, Vienna



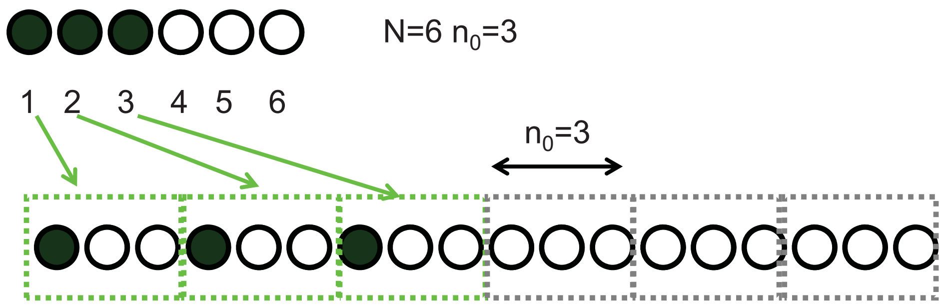
Se consideriamo l'entropia di un sistema (corpo) utilizzando le definizioni discusse sopra otteniamo che il massimo di S si ottiene in ogni caso ad half-filling cosa in contrasto con il nostro desiderio di modellizzare un corpo la cui temperatura può aumentare indefinitamente e W sia monotonamente crescente con il numero di palline nere/energia. Conseguenza di ciò è che nel raggiungere lo stato stazionario l'entropia dei singoli corpi cresce indipendentemente dal fatto che il corpo aumenti o diminuisca la propria temperatura



Entropia verso l'equilibrio per il modello giocattolo



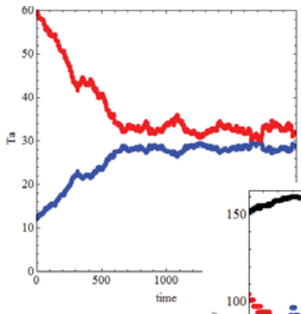
CORREZIONE AL MODELLO GIOCATTOLO

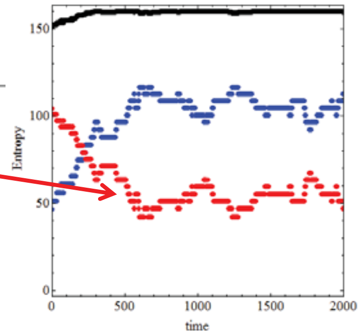


$$\tilde{N}_A = N_A n_0$$

Una rielaborazione basata su modelli di termodinamica più complessi può essere realizzata incrementando i siti possibili e questo fa sì che ciascuno dei sistemi sia sempre lontano da half-filling anche se computazionalmente il numero di stati possibili cresce notevolmente e il numero di lanci per raggiungere l'equilibrio anche

$$\tilde{N}_A = N_A n_0$$





L'entropia del corpo caldo diminuisce, cresce quella del corpo freddo. L'entropia complessiva cresce

•EQUIVALENZA CLAUSIUS BOLTZMANN

Siamo nel limite termodinamico poiché $\tilde{N} = N\ n_0 >> n_0$

DEFINIAMO

$$\Delta S = K \frac{\Delta W}{W} \qquad \frac{K}{\varepsilon_0} Ta = \frac{n}{\tilde{N}}$$

QUINDI CALCOLIAMO PER UN SISTEMA DI $\tilde{N} = N \cdot n_0$ CASELLE COSA ACCADE PER LO SCAMBIO DI UNA MONETINA (QUANTO DI ENERGIA $K \cdot 1 = \delta q$)

$$= \frac{\Delta W(N,Ta)}{W(N,Ta)} = \frac{W(N,Ta+\Delta Ta) - W(N,Ta)}{W(N,Ta)} = \frac{n_B!(N-n_B)!}{n_B+1!(N-n_B-1)!} - 1 = \frac{(N-1)}{(n_B+1)} \approx \frac{1}{Ta} = \frac{\delta q}{Ta}$$

POICHÉ $W = \frac{\tilde{N}!}{(\tilde{N}-n)!\ n!} \Rightarrow W(\tilde{N},n+1)/W(\tilde{N},n) = \frac{n!\ (\tilde{N}-n)!}{(n+1)!\ (\tilde{N}-n-1)!} = \frac{\tilde{N}-n}{n+1}$

SE, COME SAPPIAMO $\tilde{N} >> n$ $\quad W(\tilde{N},n+1)/W(\tilde{N},n) \simeq \frac{\tilde{N}}{n+1} = \frac{\varepsilon_0}{K} \frac{1}{Ta^+}$

con Ta^+ indico la Temperatura dopo lo scambio

$$\frac{\Delta W}{W} \simeq \frac{\tilde{N}}{n+1} - 1 \simeq \frac{\tilde{N}}{n+1} = \frac{\varepsilon_0}{K} \frac{1}{Ta}$$

Quindi $\Delta \bar{S} \simeq \frac{\varepsilon_0}{T_a} \Leftarrow$ $\varepsilon_0 \equiv$ QUANTO DI ENERGIA SCAMBIATO PER CONTATTO $\equiv \delta Q$

ENTROPIA DI CLAUSIUS $\Delta S = \frac{\Delta Q}{T}$

LIMITE CONTINUO $dS = K \frac{dW}{W} \Rightarrow S = S_0 + K \ln W$ ENTROPIA DI BOLTZMANN

•EQUIVALENZA CLAUSIUS BOLTZMANN

Prendiamo DUE CORPI A CONTATTO (A e B)

$$\Delta S_{A+B} = \frac{\Delta (W_A W_B)}{W_A W_B} = \frac{\Delta W_A}{W_A} + \frac{\Delta W_B}{W_B}$$

Se ε_0 passa dal corpo B al corpo A $(T_{a_B} > T_{a_A})$

$$\Delta S_{A+B} \simeq \frac{\tilde{N}_A}{n_{A+1}} - \frac{\tilde{N}_B}{n_B} \simeq \varepsilon_0 \left(\frac{1}{T_A} - \frac{1}{T_B} \right) \geqslant 0$$

($\tilde{N}_A$: Prende δq; $\tilde{N}_B$: Cede δQ)

L'entropia dell'intero sistema aumenta anche se $\Delta S_B \leq 0$

Domande?

- Esiste un macrostato di equilibrio del sistema? Quale è? Perché?
- Cosa c'entra la probabilità? Come posso calcolarla?

- Cosa sono le monetine nell'analogia tra i corpi a contatto e il gioco delle monete?
- Quale principio posso ottenere?
- Quali leggi fisiche posso ottenere? Come posso verificarle sperimentalmente?
- Quale grandezza termodinamica è legata alla probabilità?

Si ringrazia Pasquale Onorato per gran parte del materiale presente in questa presentazione.

Preconcezioni comuni

Questionario clima: https://goo.gl/forms/HlbTVUPXy3Qys5I22

Alcune misconcezioni

- meccanismo dell'effetto serra vs meccanismo della serra agricola
- confusione tra buco dell'ozono ed effetto serra
- intrappolamento della radiazione
- non equilibrio (entra più energia nel sistema o ne esce meno)
- ruolo del vapore acqueo
- non distinguere tra effetto serra naturale e anomalo
- non distinguere tra radiazione solare e terrestre e interazione con atmosfera
- linearità vs non linearità nelle risposte del sistema
- confusione tra tempo e clima e tra previsione deterministica e statistica

Alcuni video:

- https://www.youtube.com/watch?v=vqDbMEdLiCs
- www.youtube.com/watch?v=OWXoRSIxyIU
- www.youtube.com/watch?v=eNx9tvCrvv8
- www.youtube.com/watch?v=tVZUYJ_uAfY
- www.youtube.com/watch?v=xrQ-LFBLaO0
- www.youtube.com/watch?v=ffjIyms1BX4

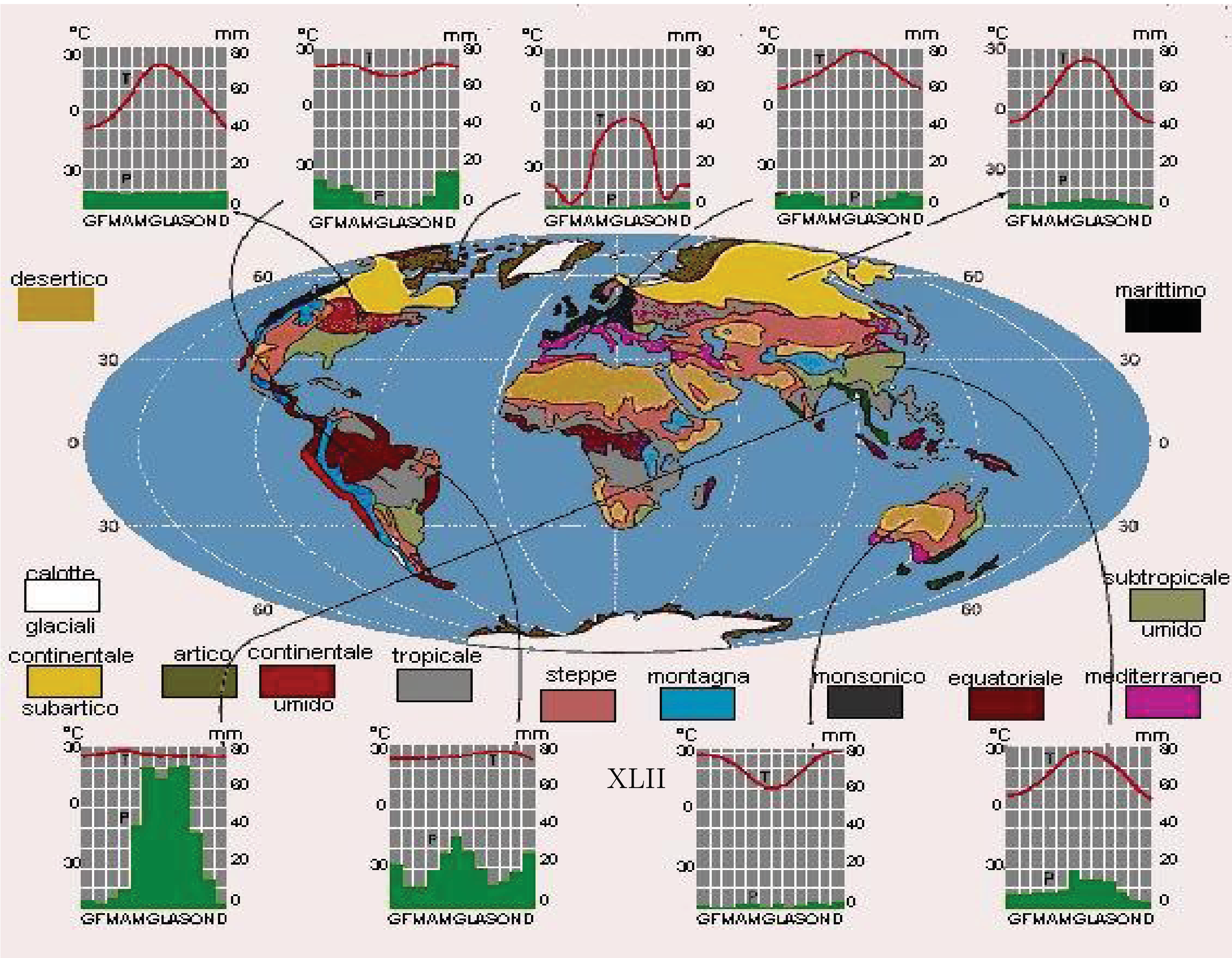
Che cos'è il clima

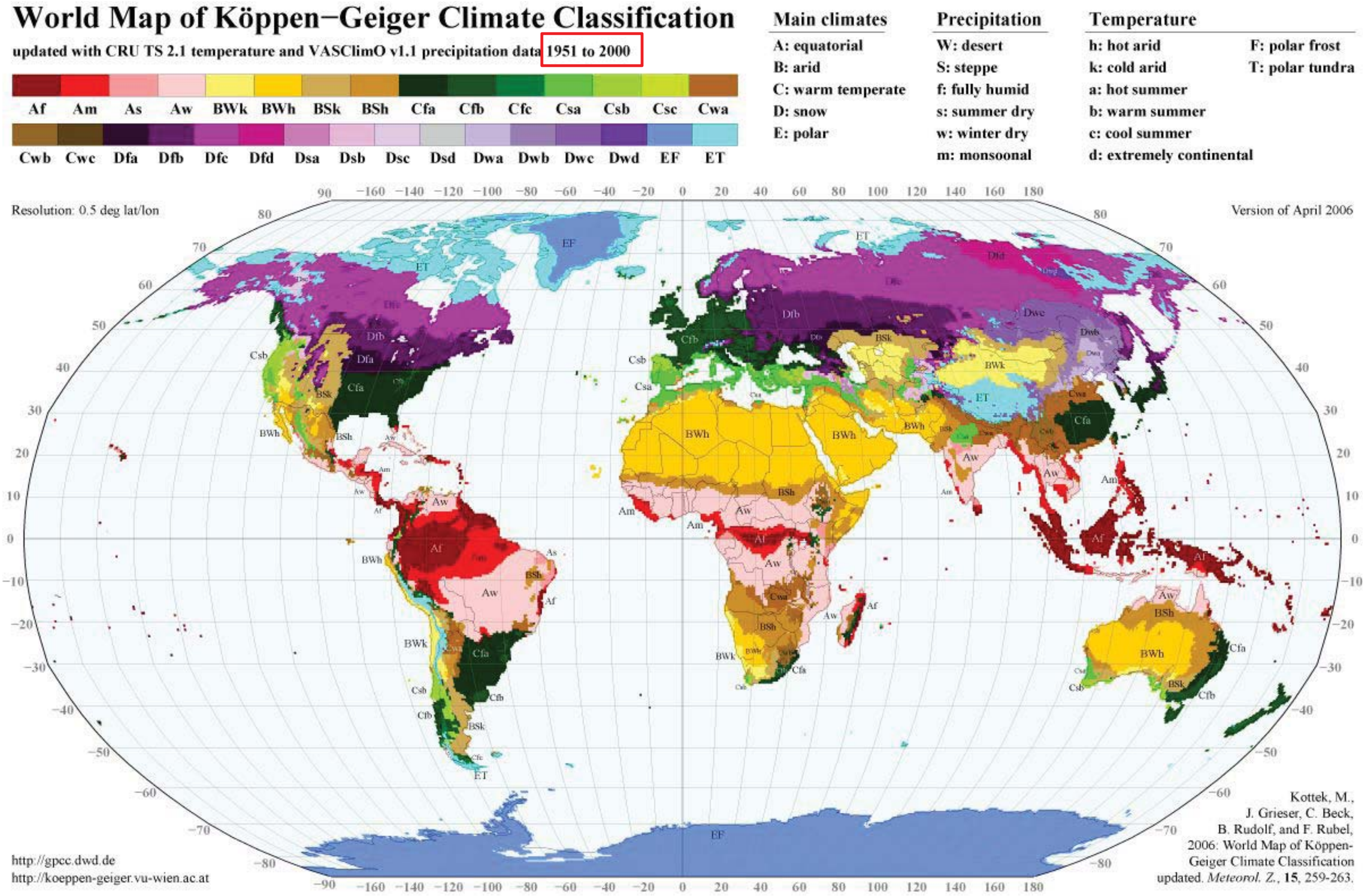
- dal greco **κλίμα -ματος** - inclinazione (raggi solari sulla superficie, latitudine e stagioni)
- varietà di significati a seconda dei contesti

Definizione - **IPCC AR5 2013** (Intergovernamental Panel on Climate Change)

*"The **climate system** is the highly complex dynamical system consisting of five major components: the **atmosphere**, the **hydrosphere**, the **cryosphere**, the **lithosphere** and the **biosphere,** and the **interactions** between them"*

La comprensione del sistema climatico richiede un approccio **multidisciplinare** e una batteria di strumenti che includono le **osservazioni** da terra e da satellite e lo sviluppo di **modelli** concettuali (o di **processo**), e di modelli **numerici** più complessi in grado di descrivere la **dinamica** di tutto il sistema.





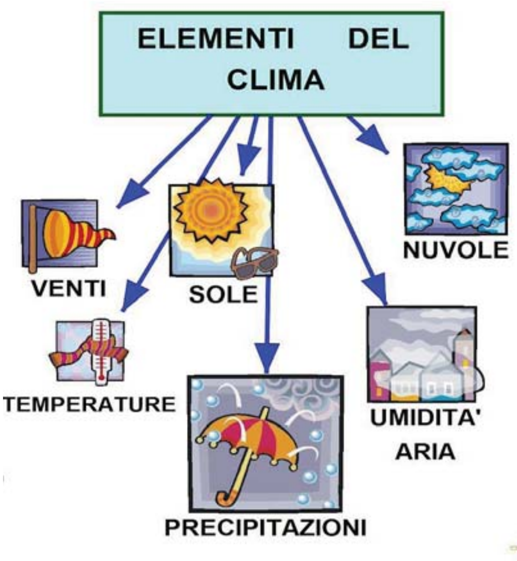
- 1900 Vladimir Köppen, **prima classificazione dei climi** (**vegetazione** tipica e medie annue o mensili di **temperature** e **precipitazioni**)
- **empirica**, scopi geografici. Non tiene conto delle cause del clima in termini di **processi fisici, chimici e biologici**. Molto più interessante!

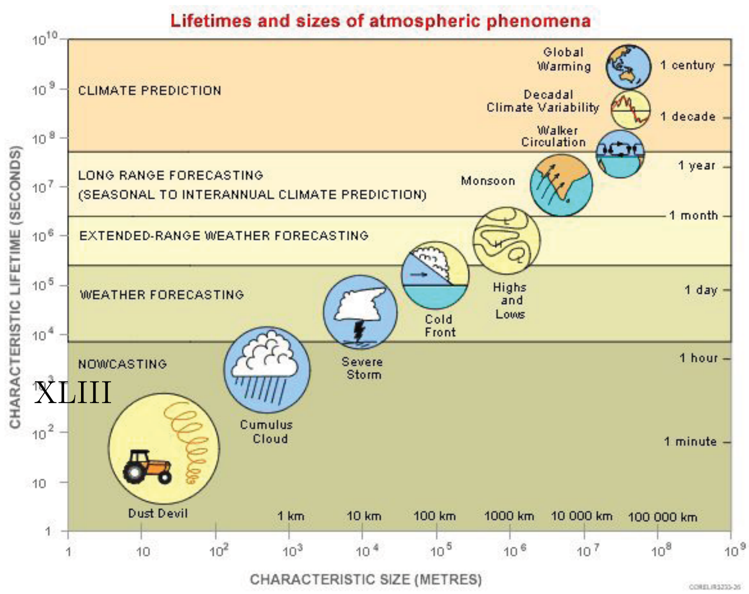
Parametri climatici e scale spazio-temporali

PER STUDIARE IL CLIMA E LE SUE VARIAZIONI DEVO DEFINIRE:

Quali **grandezze fisiche** sono più adatte a rappresentare il clima

Su quale **scala temporale** (anni, decenni, secoli) analizzare il fenomeno





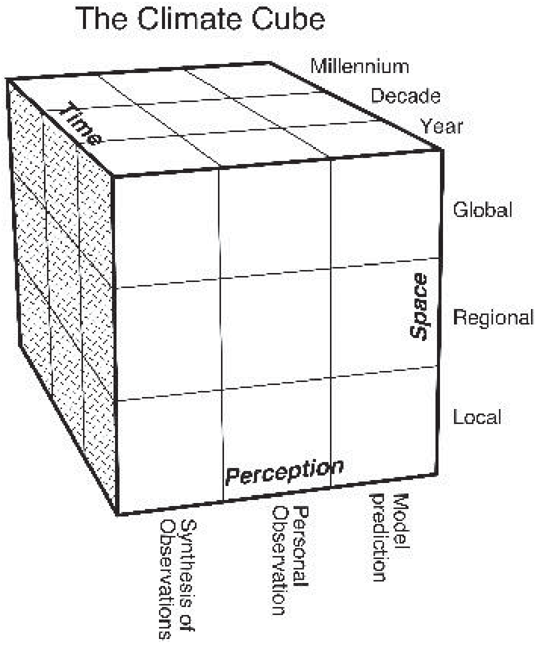
Clima e tempo meteorologico

Clima: analisi **statistica**, in termini di **valori medi** e "**variabilità**", delle condizioni meteorologiche medie di una determinata regione, effettuata su dati disponibili per un periodo di tempo sufficientemente lungo (tradizionalmente almeno **30 anni**, WMO).

La definizione del Clima richiede quindi una **media** nello **spazio** (l'estensione della regione considerata, o il globo) e nel **tempo** (su quale periodo temporale vengono mediate le variabili di interesse)

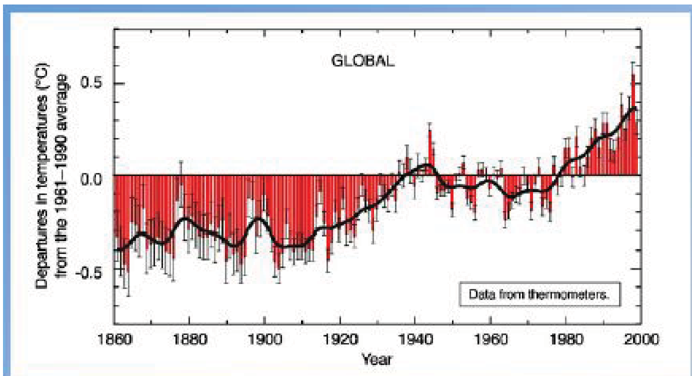
Tempo meteorologico: definito dalle **condizioni istantanee** (o mediate su periodi brevi, dal minuto alla settimana) e **locali** (in un preciso luogo geografico) delle variabili atmosferiche (temperatura, pressione, precipitazione, umidità, venti, nuvolosità etc)

"Climate is what you expect, weather is what you get"



Il cubo climatico. Il clima si può pensare esistere in almeno 3 dimensioni (arbitrarie e non univoche): nel tempo, nello spazio e nella percezione umana. Storicamente singole discipline si sono occupate di singole celle, ma complessità e interazioni!

Ricostruzione del clima del passato



DATI STRUMENTALI

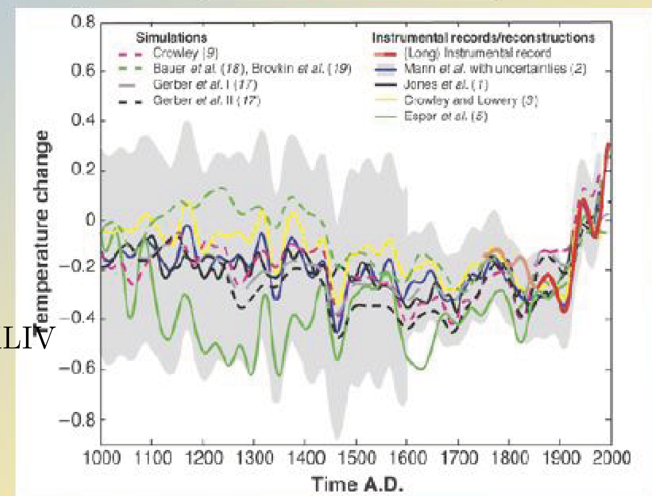
- **Ricostruzione più precisa** delle variazioni a breve termine (dopo omogeneizzazione!)
- **Limitati nel tempo** (le serie sono disponibili da quando esistono gli strumenti)

Adatti per studiare le **variazioni climatiche a breve e medio termine**

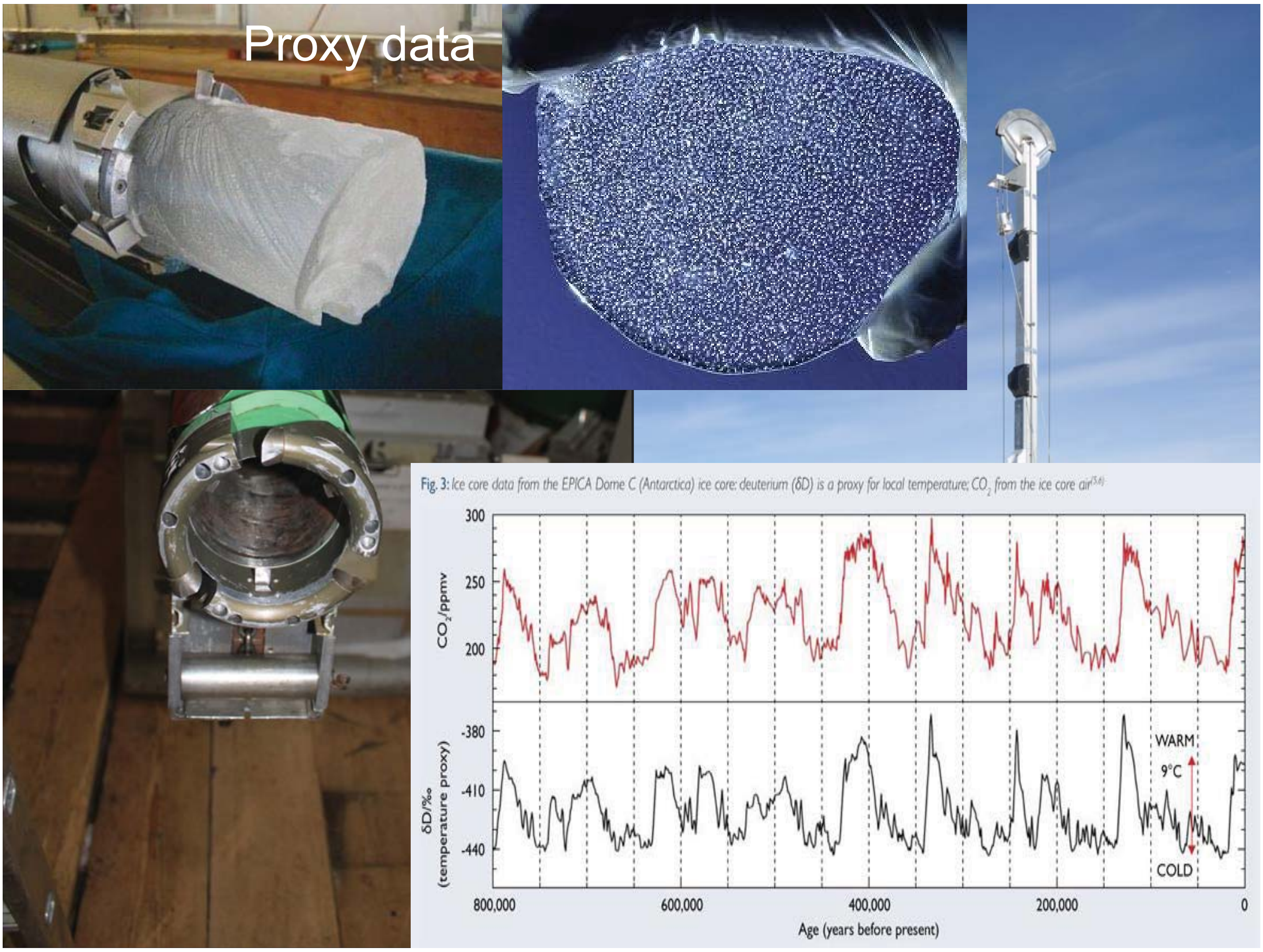
Adatti per studiare le **variazioni climatiche a lungo periodo** (fino a scale geologiche)

- Permettono di risalire al clima in **epoche remote**
- Hanno un'incertezza **maggiore** dei dati strumentali

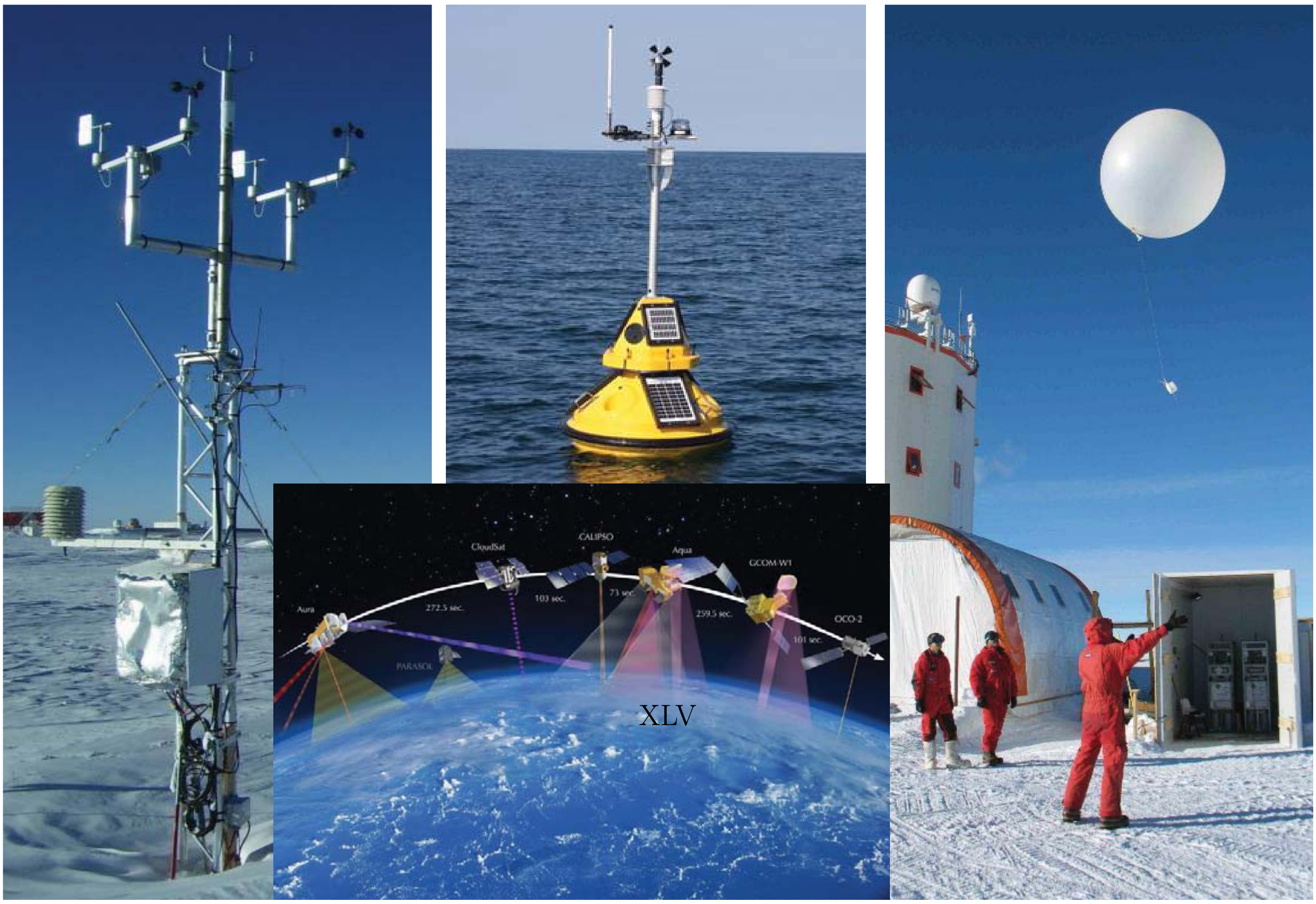
PROXY DATA



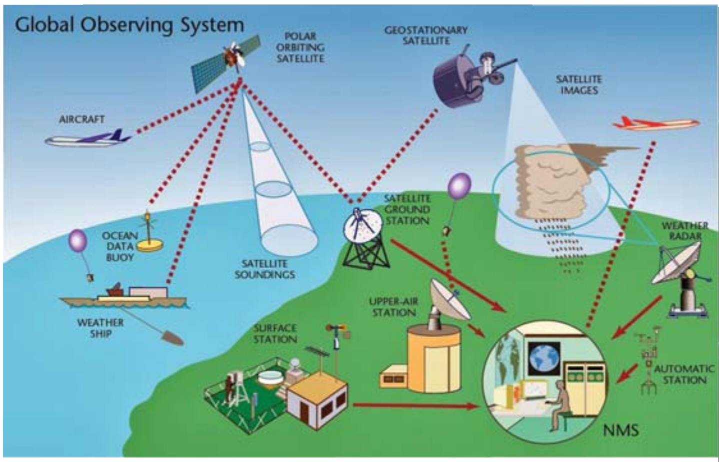
Proxy data

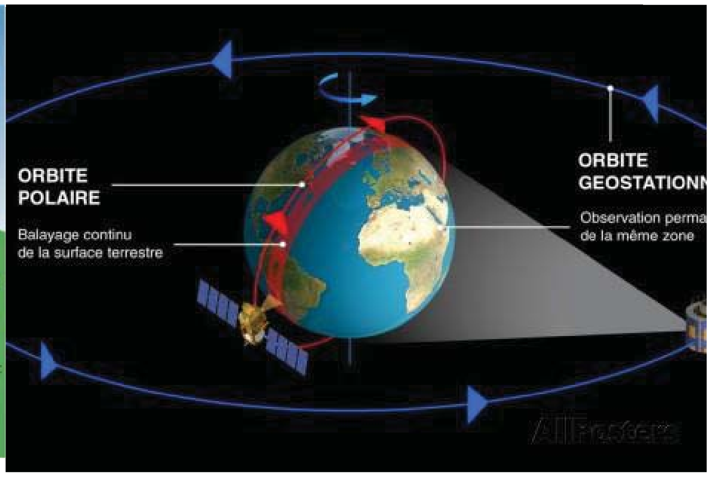


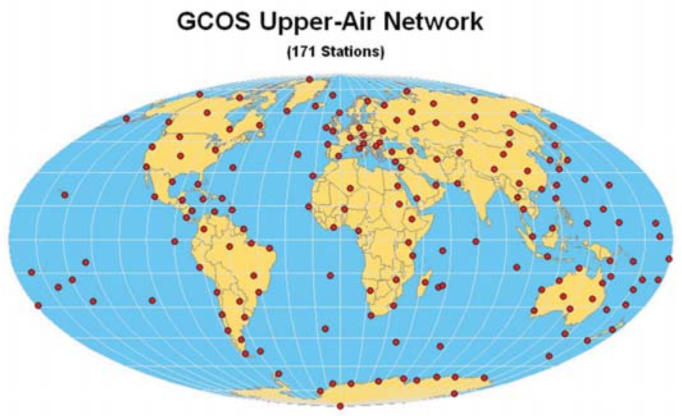
Dati strumentali

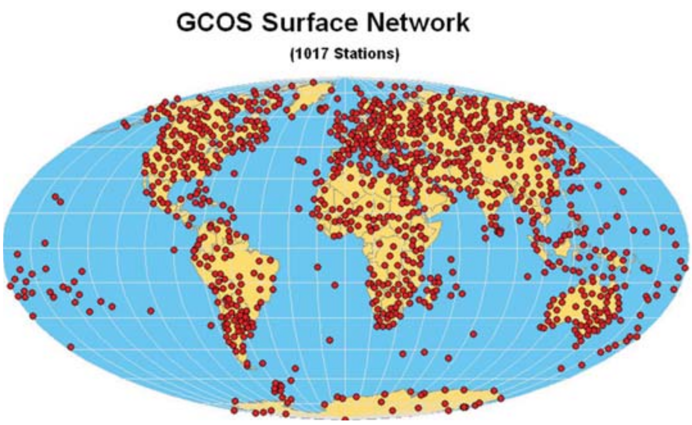


Una rete di osservazione mondiale (GCOS-WMO)

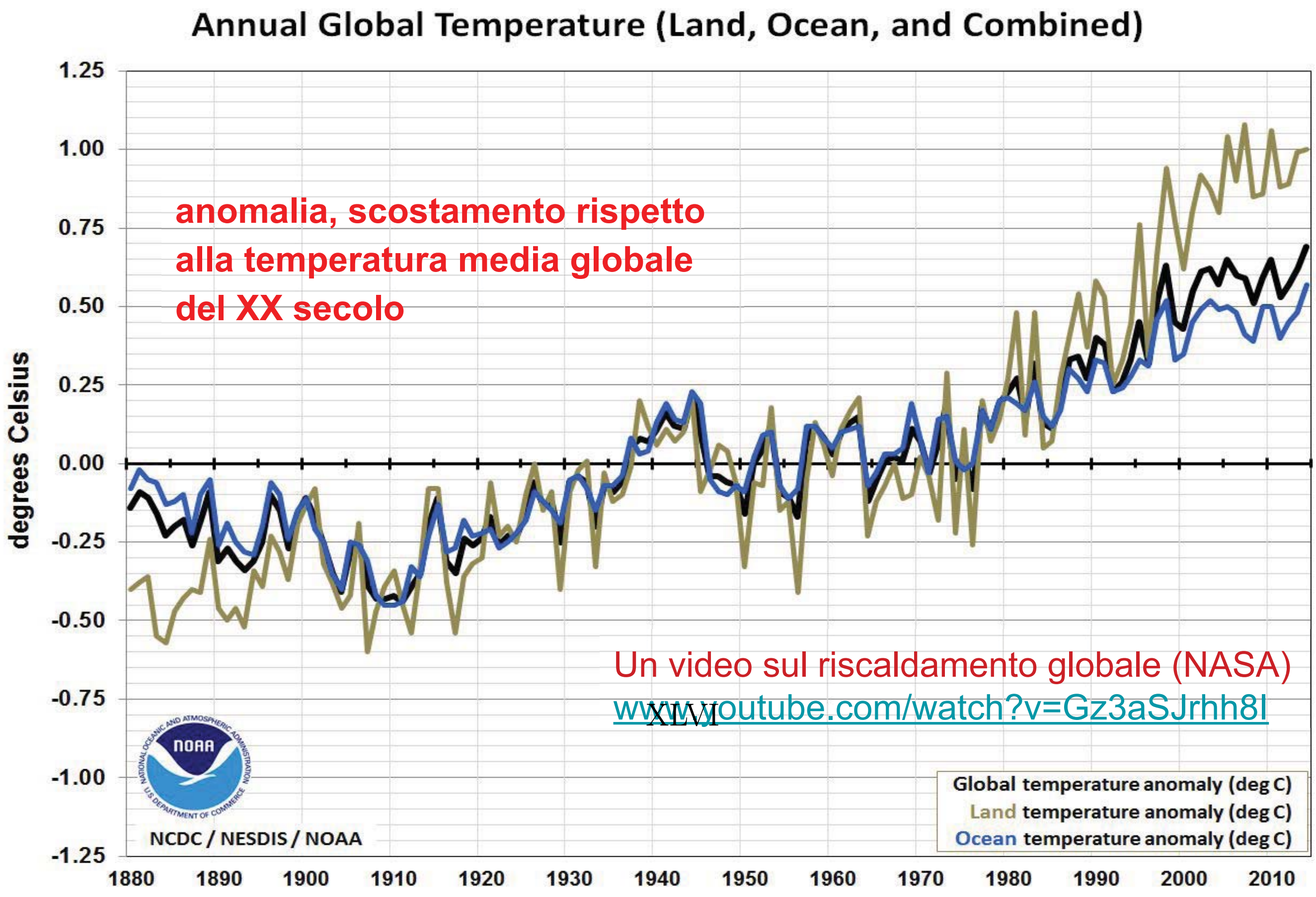






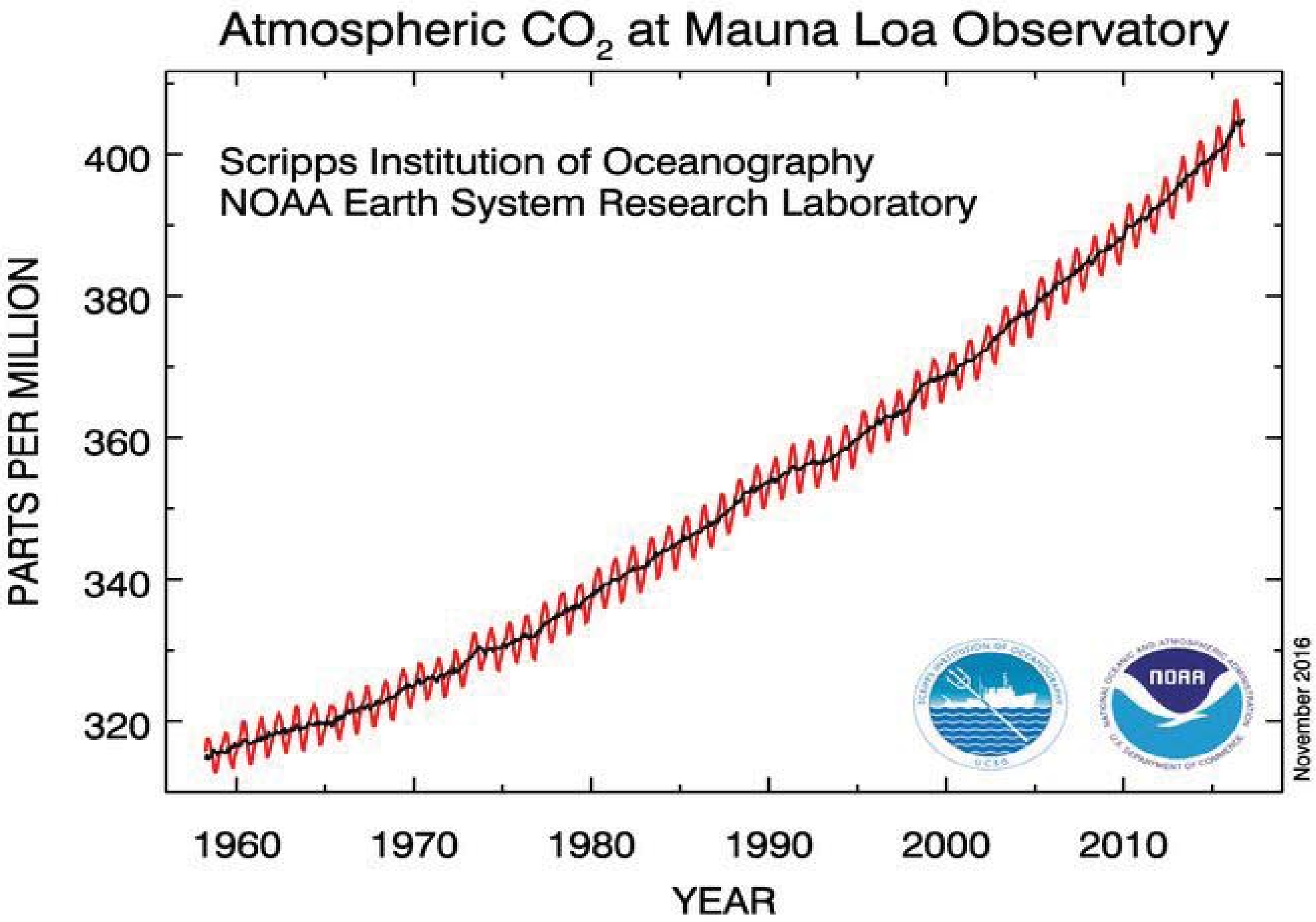


Riscaldamento globale nell'ultimo secolo



Un video sul riscaldamento globale (NASA)
www.youtube.com/watch?v=Gz3aSJrhh8I

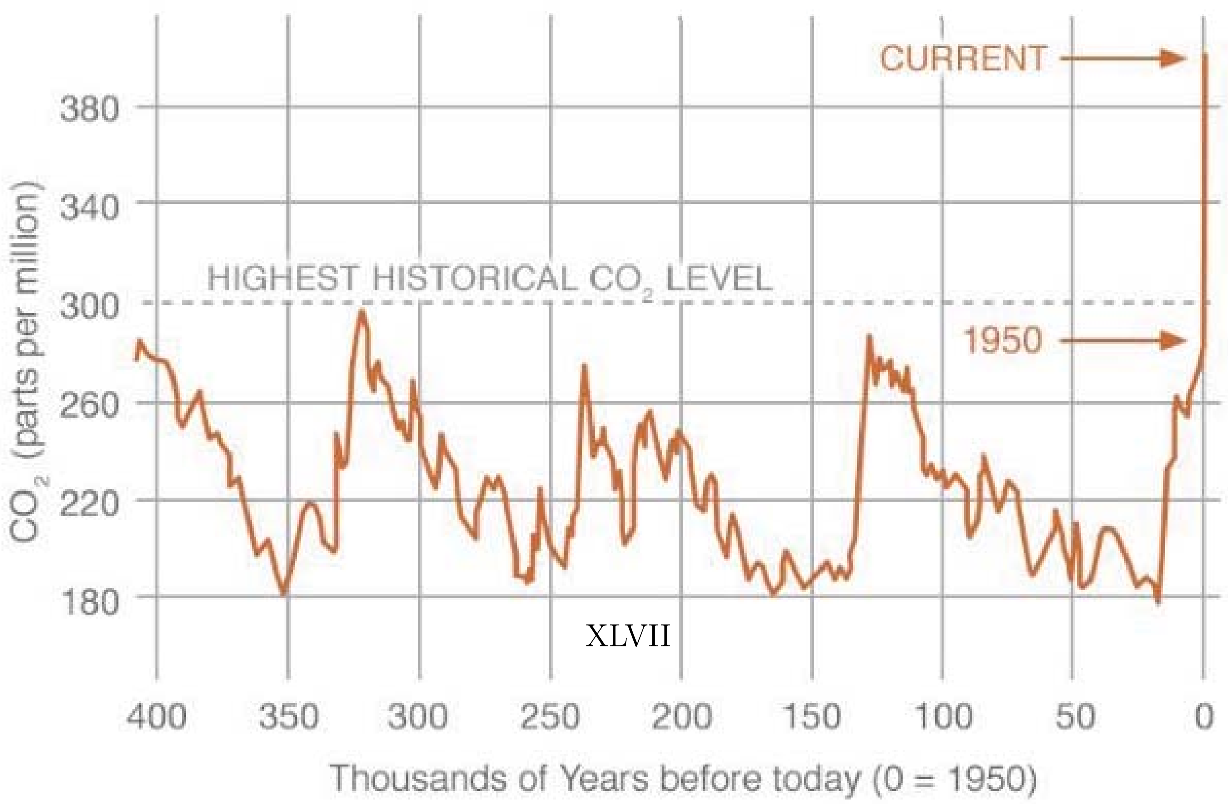
Concentrazione di anidride carbonica in atmosfera



PROXY (INDIRECT) MEASUREMENTS

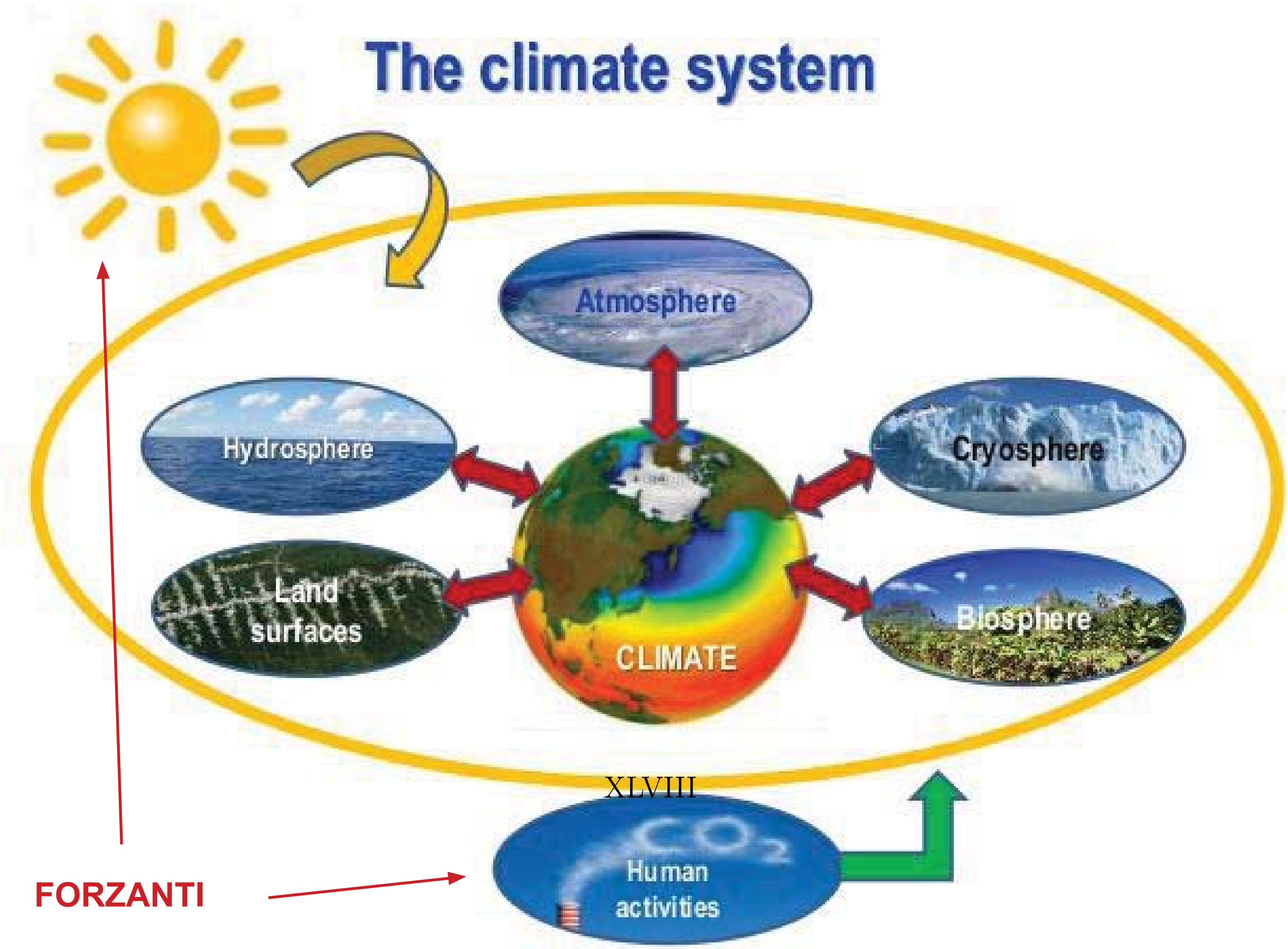
Data source: Reconstruction from ice cores.
Credit: NOAA

Video sulla concentrazione di CO2
www.youtube.com/watch?v=gH6fQh9eAQE
www.youtube.com/watch?v=ikGLNs3nYlc

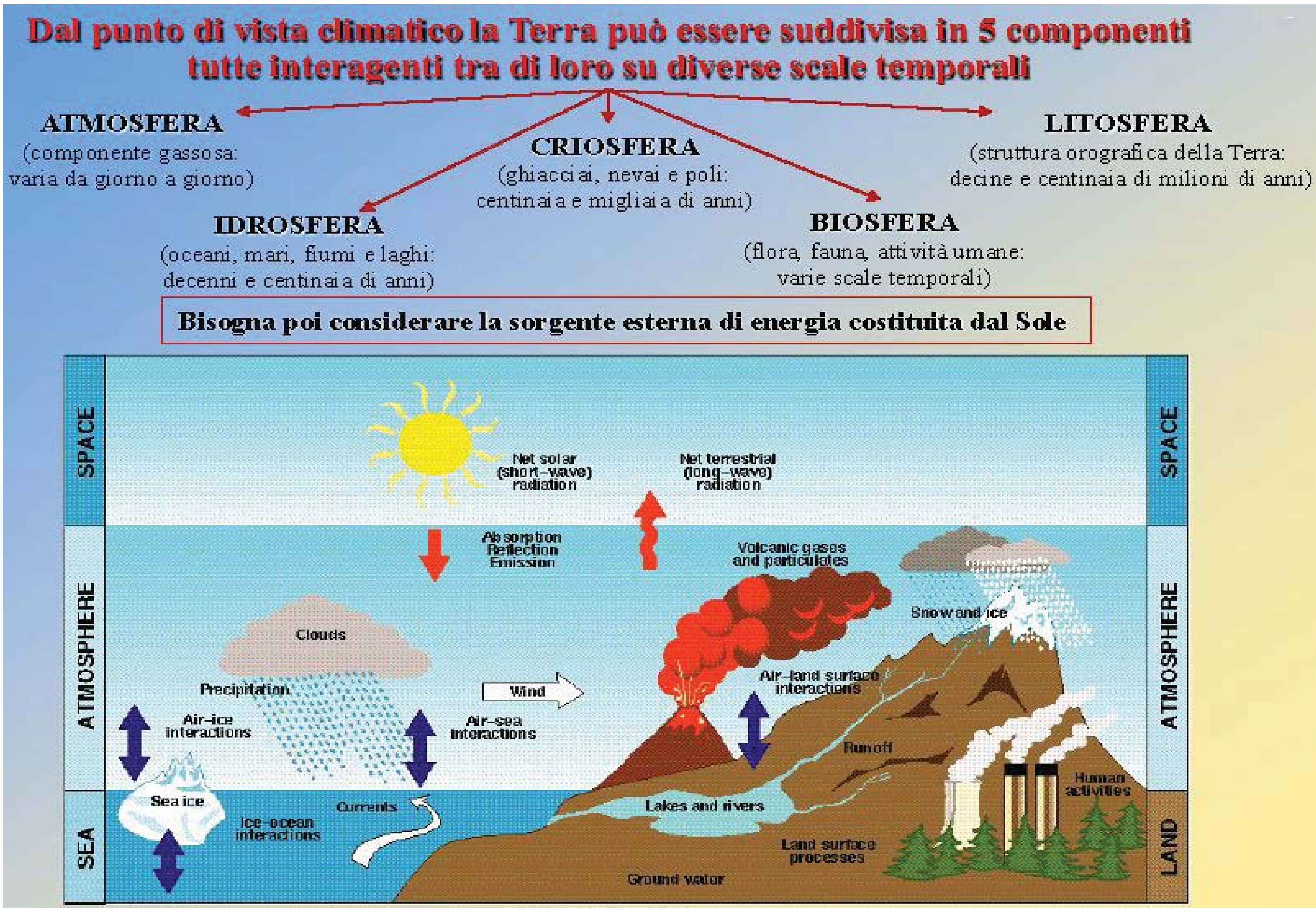


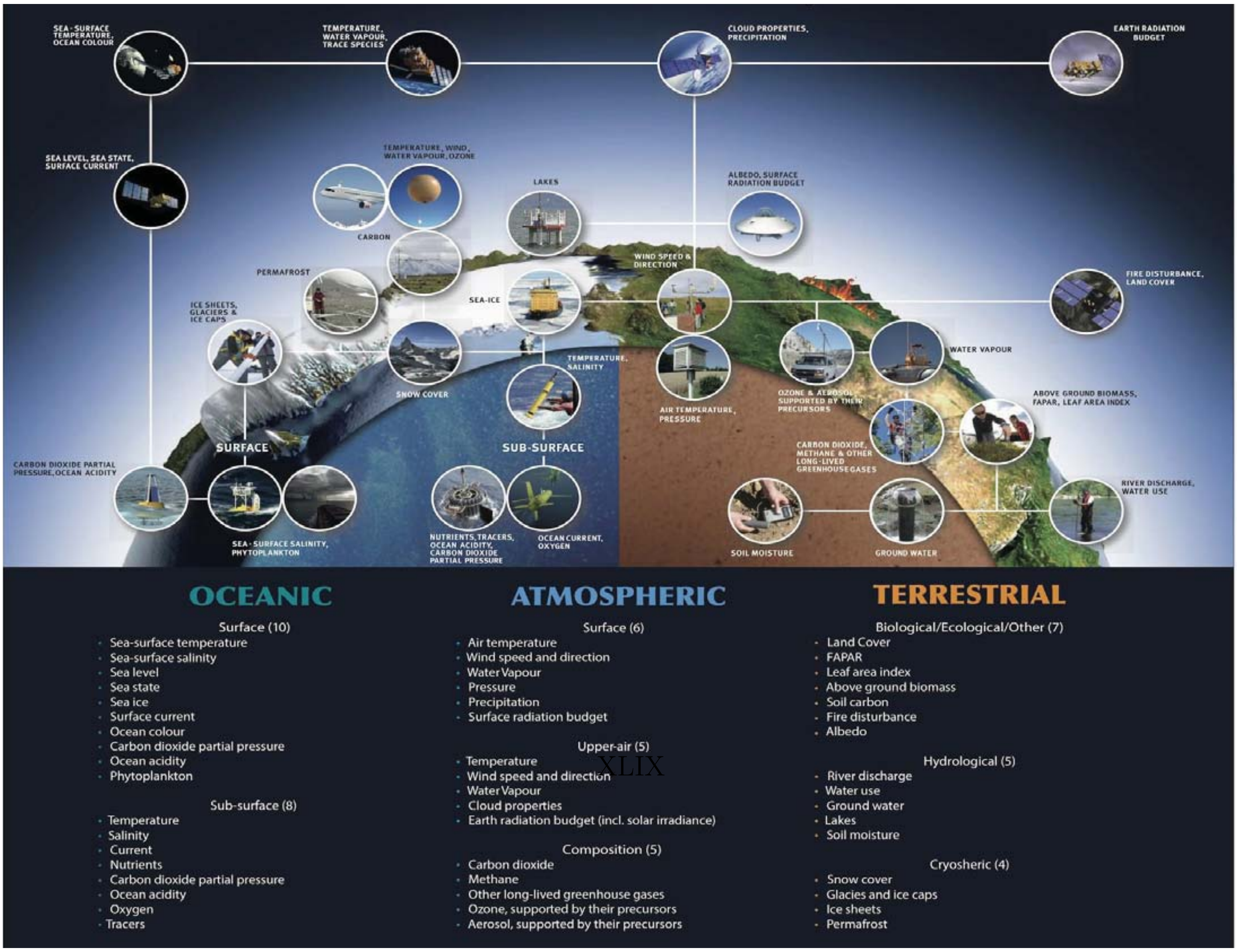
Alcuni siti per la visualizzazione di dati climatici

- NASA - Earth observations: http://neo.sci.gsfc.nasa.gov/
- NASA Global climate change - Vital Signs of the Planet: http://climate.nasa.gov/
- NOAA ESRL - Global monitoring: http://www.esrl.noaa.gov/gmd/dv/iadv/
- NOAA - Science on a Sphere: http://sos.noaa.gov/What_is_SOS/
- Il clima in Trentino http://www.climatrentino.it/clima_trentino/



Il sistema climatico





Proprietà del sistema climatico

- sottosistemi e interazioni (feedback)
- caos, non linearità, equilibri
- variabilità
- forzanti (naturali e antropogeniche)
    - esterne
    - interne
- predicibilità in senso statistico

Variabilità del clima della Terra

Il clima della terra ha contemporaneamente due proprietà apparentemente in contrasto:

Non è mai fisso ma le variabili "importanti" rimangono comunque in un intervallo limitato.

Perchè il clima sulla terra varia, e perchè non varia troppo?

L

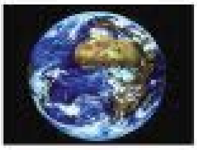
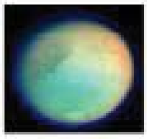
Specificità del clima della Terra

- Possiede un **inviluppo fluido che la circonda** (atmosfera + oceano). Questo consente una ridistribuzione del calore (venti e correnti oceaniche). L'atmosfera contiene dei **gas** (e in **giusta quantità**) che hanno reso possibile la vita (su altri pianeti dove ci sono altri gas e/o in diverse concentrazioni la vita come la conosciamo non sarebbe possibile es. Venere o Marte)

- le condizioni del nostro pianeta sono prossime a quelle del **punto triplo dell'acqua**, in cui fase solida, liquida e vapore coesistono, dando luogo a continui passaggi di fase con conseguente rilascio e assorbimento di grandi quantità di calore latente e tutta la termodinamica che ne consegue. L'acqua nelle sue varie forme circola attraverso il sistema dando luogo al **ciclo idrologico, che influenza ed è influenzato dal clima** stesso

- pianeta popolato di **organismi viventi** (tra cui l'uomo) => interazione clima-biosfera

ATMOSFERE E ALTRE CARATTERISTICHE DEI PIANETI DI TIPO TERRESTRE

		Venere	Terra	Marte	Titano
oggetto	u.misura				
N_2	% in atmosfera	3,5	78	2,7	98,4
O_2			20,7		
H_2O			0		
Ar			0,9	1,6	
CO_2		96,5	0,04	95,32	
NH_4					1,6
Temperatura al suolo	°C	460	15	-63	-179
Pressione al suolo	Bar	92	1,01	0,01	1,5
Gravità al suolo	g	0,9	1	0,38	0,14
Distanza media dal sole	Mln. km	108	150	225	1200
Raggio	km	12000	12600	3400	2500

Variabilità - sistema climatico

Si intende la **variazione** nello **stato medio** e in altre **statistiche** (deviazione standard, occorrenza degli estremi, etc.) che descrivono il clima su tutte le scale al di là di quelle dei singoli eventi meteorologici (def. IPCC)

Il clima evolve e cambia **a causa di:**

Propria **dinamica Interna**:

ad es. le circolazioni atmosferica e oceanica, i pattern di teleconnessione, meccanismi di retroazione (feedback)

Variazioni di **fattori esterni** al sistema (**forzanti**)

Origine naturale: es. variazioni nell'energia che arriva dal sole, eruzioni vulcaniche

Origine antropica: emissioni di gas a effetto serra, cambiamenti nell'uso del suolo, emissioni di aerosol

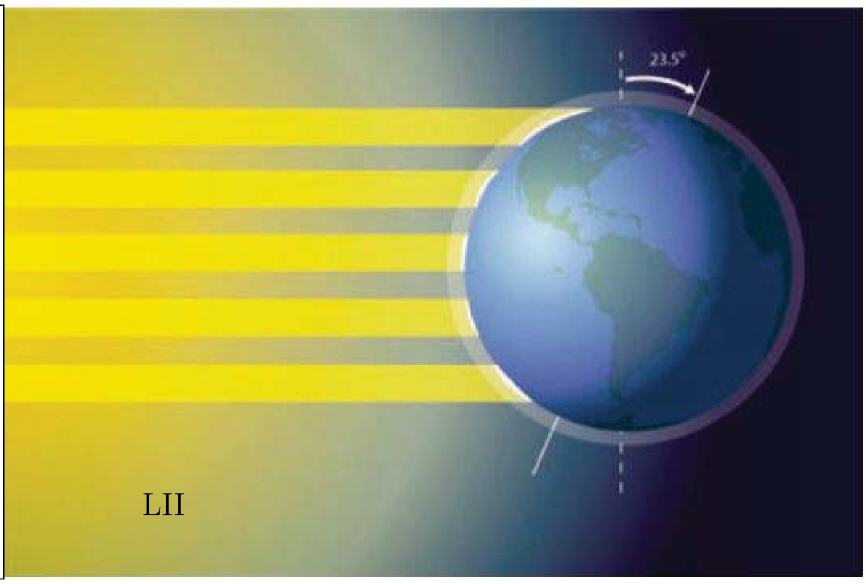
Variabilità - sistema climatico

Variabilità interna del clima - Circolazioni

Distribuzione geografica della radiazione solare

Nella zona equatoriale e tropicale, i raggi solari arrivano in modo quasi perpendicolare alla superficie, mentre spostandosi verso i poli l'inclinazione aumenta.

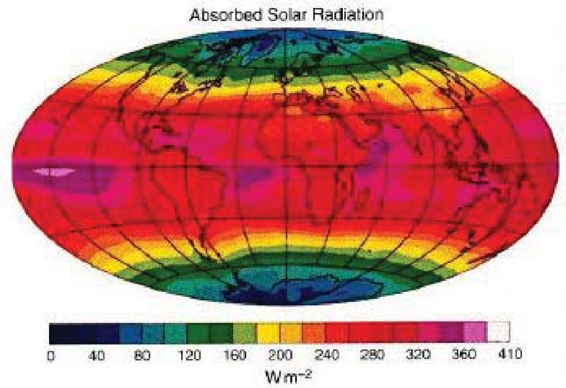
Questo fa si che e zone equatoriali si scaldino molto di più di quelle polari



Perchè le stagioni? http://astro.unl.edu/naap/motion1/animations/seasons_ecliptic.html

Variabilità - sistema climatico

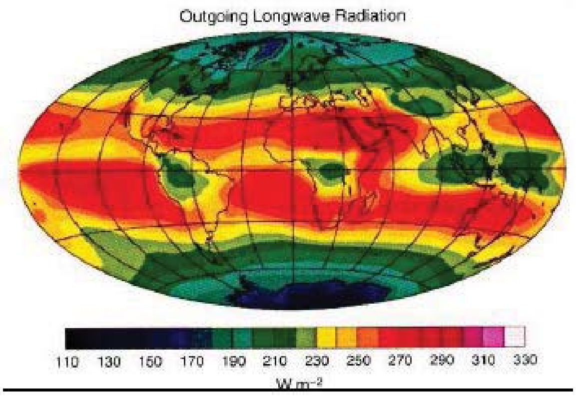
Variabilità interna del clima - Circolazioni



Radiazione solare assorbita

Forte gradiente latitudinale

- anti-correlata con l'albedo
- alta ai tropici (piccolo angolo solare zenitale, presenza degli oceani grandi assorbitori)
- bassa alle alte latitudini (minore insolazione, grandi angoli solari zenitali, presenza di nuvole e ghiaccio)

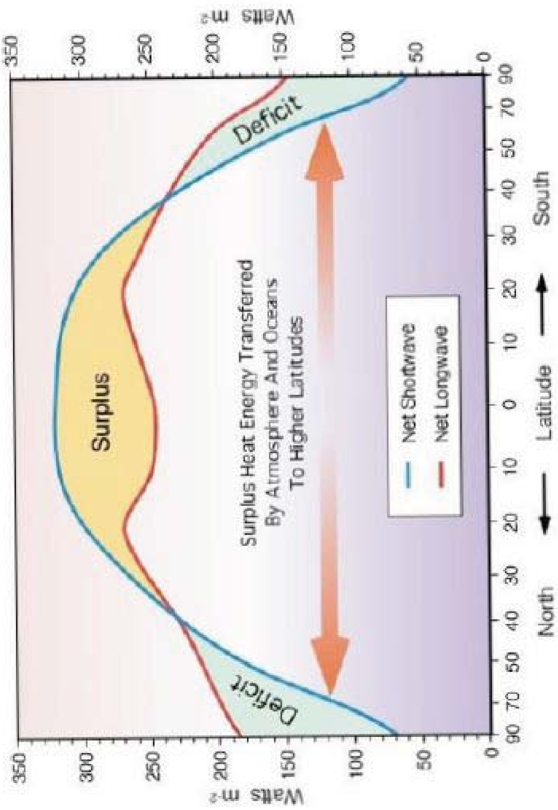


Radiazione infrarossa emessa

Funzione della temperatura superficiale (Legge di Stefan Boltzmann). I valori più bassi ai poli, i più alti sopra le aree molto secche e calde come i deserti sub-tropicali. Le aree equatoriali umide emettono minor radiazione IR che le aree tropicali secche.

Variabilità - sistema climatico

Variabilità interna del clima - Circolazioni



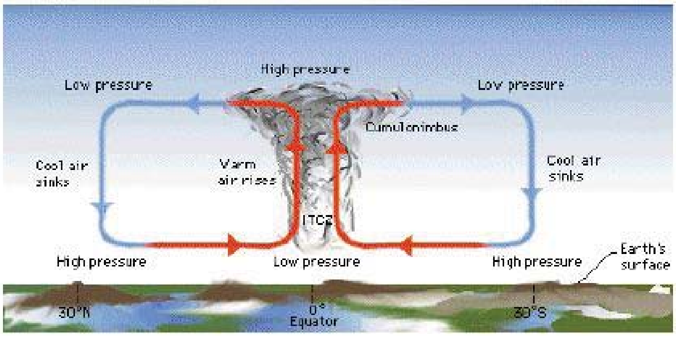
- Surplus di radiazione nelle regioni tropicali ed equatoriali
- Deficit nelle regioni polari.

I processi di trasporto nell'atmosfera (venti) e nell'oceano (correnti) ridistribuiscono l'energia sulla terra da dove si accumula a dove ce n'è meno.

Come risultato, il calore viene ridistribuito e le differenze di temperatura tra equatore e poli sono molto più limitate di quello che sarebbero in assenza di atmosfera e oceani

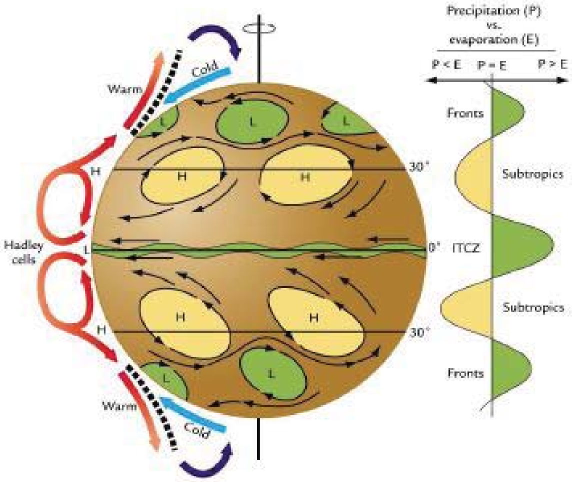
Variabilità - sistema climatico

Variabilità interna del clima - Circolazione atmosferica

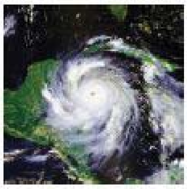


La maggior parte del trasporto di calore nella regione tropicale è ad opera della **Cella di Hadley.**

Alisei (superficiali), correnti a getto (subtropicali in quota), forza di Coriolis, piogge tropicali, ITCZ, deserti subtropicali.

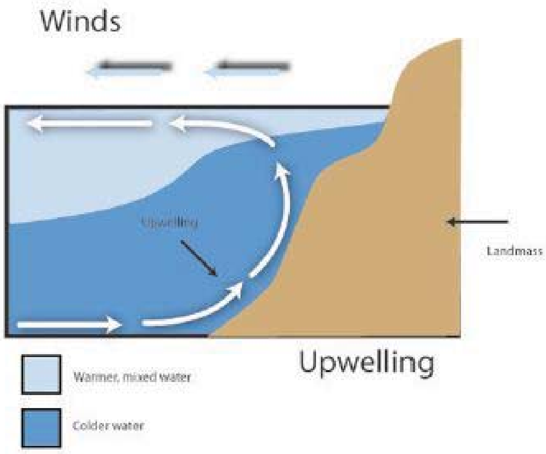


Alle medie e alte latitudini, invece, la quasi totalità del trasporto è ad opera dei cicloni o anticicloni.



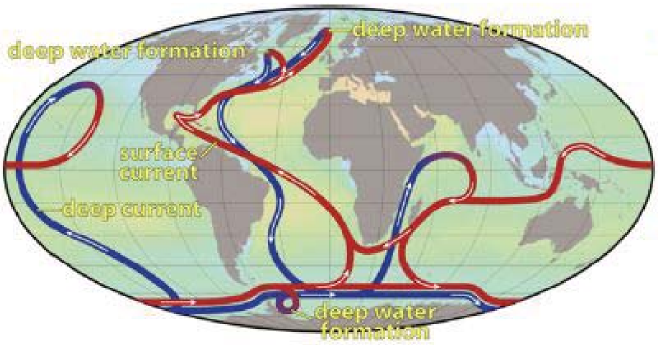
Variabilità - sistema climatico

Variabilità interna del clima - Circolazione oceanica



Correnti superficiali

- guidate dai venti; il loro pattern è determinato dalla direzione del vento, forza di Coriolis, e dalla posizione delle terre emerse.
- sono calde, e si muovono verso le alte latitudini (es., corrente del Golfo)



Correnti profonde

- guidate da variazioni nella DENSITA' dell'acqua; la densità varia in funzione della temperatura e della salinità (Circolazione Termoalina)
- caratterizzate da scale di tempo lunghe, dalle decine alle migliaia di anni

Variabilità - sistema climatico

Forzanti esterne al sistema

Il clima della Terra è interamente forzato dall'energia che arriva dal Sole.

Il contributo del calore geotermico e delle maree è sostanzialmente trascurabile nel bilancio energetico del clima terrestre.
(*Questi possono essere responsabili di alcuni aspetti importanti, per es. il calore geotermico di parte del riscaldamento degli strati profondi del ghiaccio continentale antartico; le maree della creazione di turbolenza oceanica*)

Variabilità - sistema climatico

Forzanti esterne al sistema

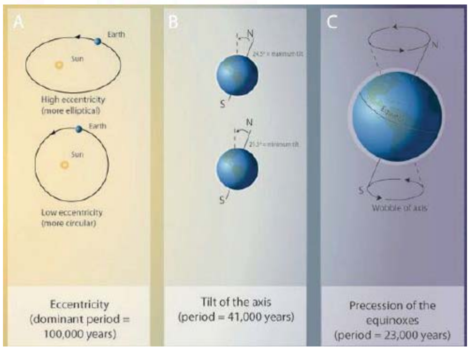
E' quindi chiaro che variazioni nella quantità di energia solare in arrivo sulla Terra possono modificare il clima.

Queste variazioni possono essere dovute a cambiamenti nella **quantità di energia emessa dal Sole**, a causa della dinamica interna della nostra stella, e a cambiamenti nei parametri dell'orbita terrestre, che possono modificare la quantità totale di energia solare che arriva sul pianeta o la sua distribuzione stagionale e geografica.

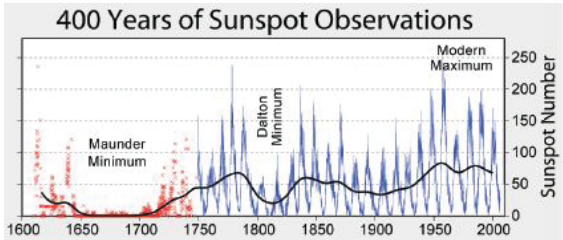
Variabilità - sistema climatico

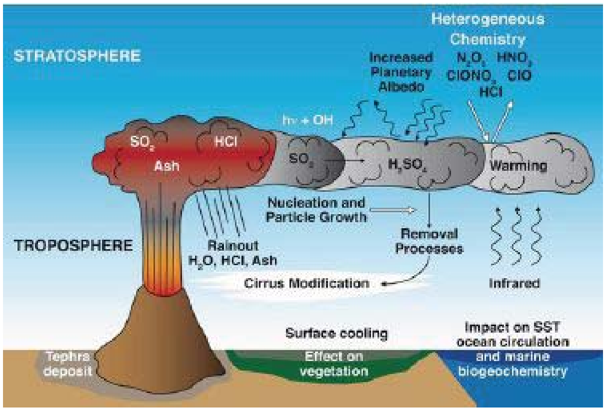
Forzanti esterne al sistema - naturali

- **Cicli di Milankovich:** variazioni cicliche parametri astronomici



- **Attività solare (macchie solari)**

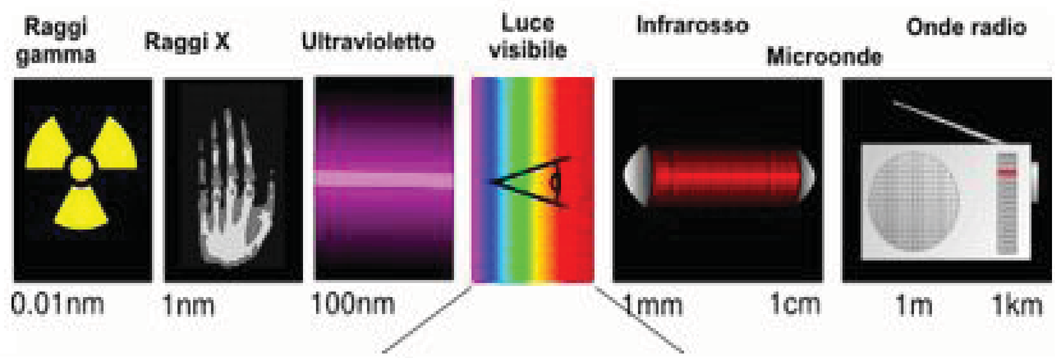




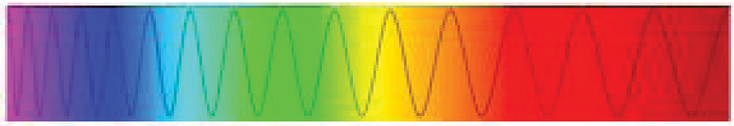
- **Eruzioni vulcaniche**

effetti termici della radiazione e misura della costante solare

Lo spettro della radiazione elettromagnetica



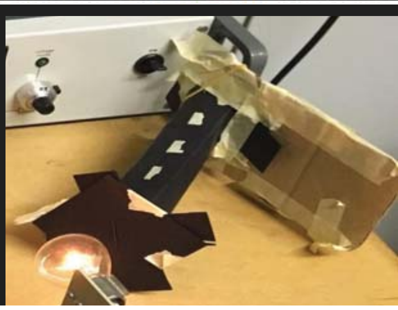
Radiazioni visibili: radiazioni ottiche a lunghezza d'onda compresa tra **380** e **780** nm.



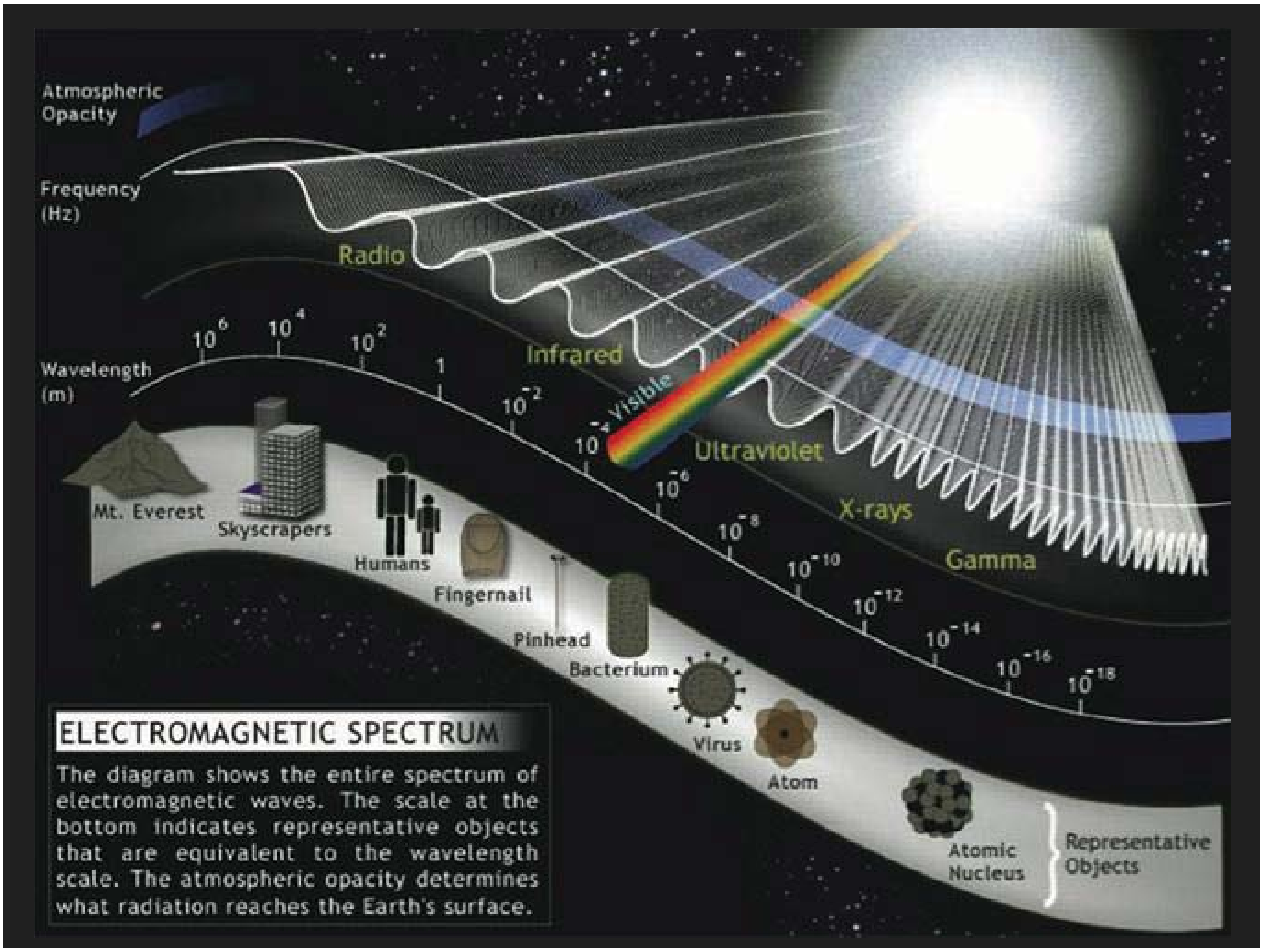
Radiazioni ultraviolette: radiazioni ottiche a lunghezza d'onda compresa tra **100** e **400** nm.
La banda degli ultravioletti è suddivisa in **UVA (315-400** nm), **UVB (280-315** nm) e **UVC (100-280** nm)

Radiazioni infrarosse: radiazioni ottiche a lunghezza d'onda compresa tra **780** nm e **1** mm.
La regione degli infrarossi è suddivisa in **IRA (780-1400** nm), **IRB (1400-3000** nm) e **IRC (3000 nm-1 mm)**

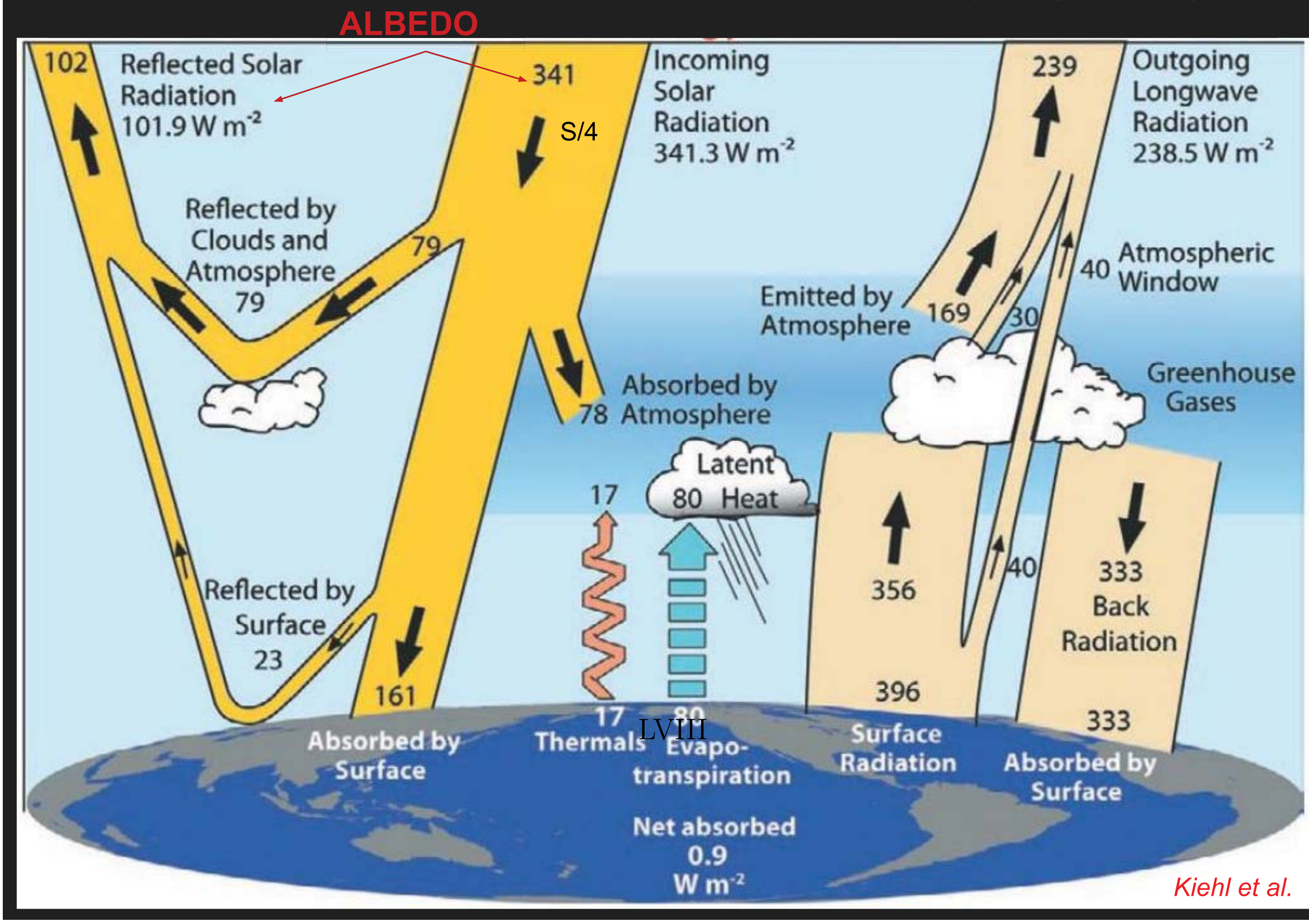
spettroscopio e smartphone!
cartoncino nero, fenditura, reticolo 500 righe/cm



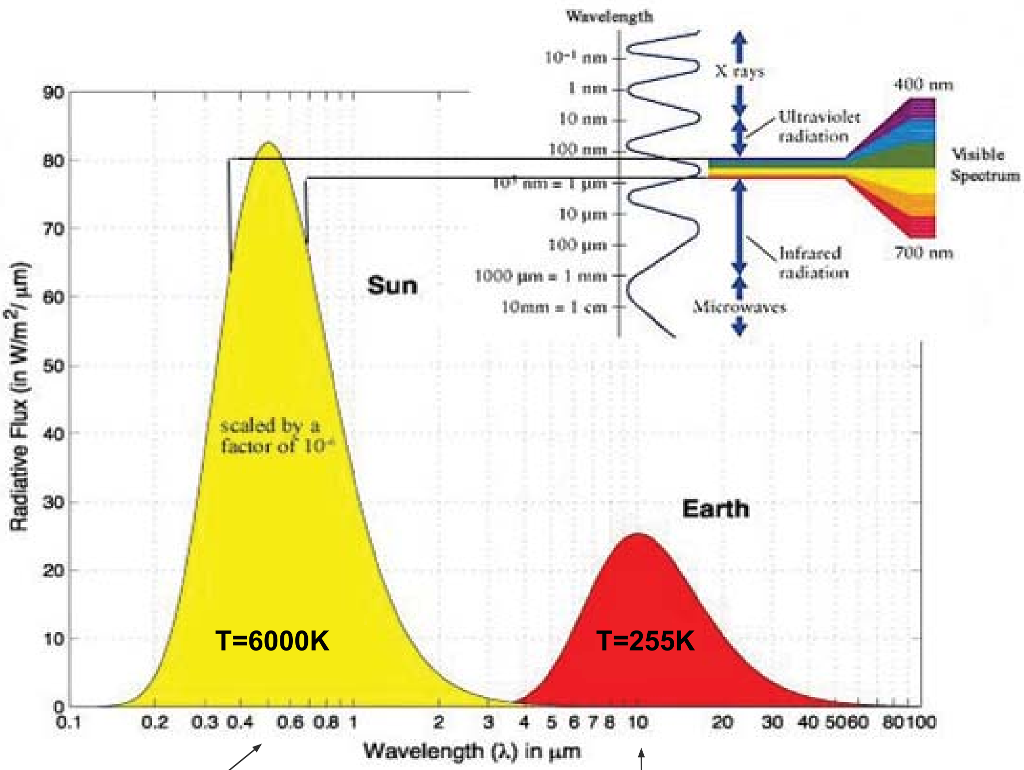
Dal sole (lampada) ci arriva energia sotto forma di radiazione elettromagnetica (irraggiamento)!



Flussi di radiazione e bilancio di energia (medi!)



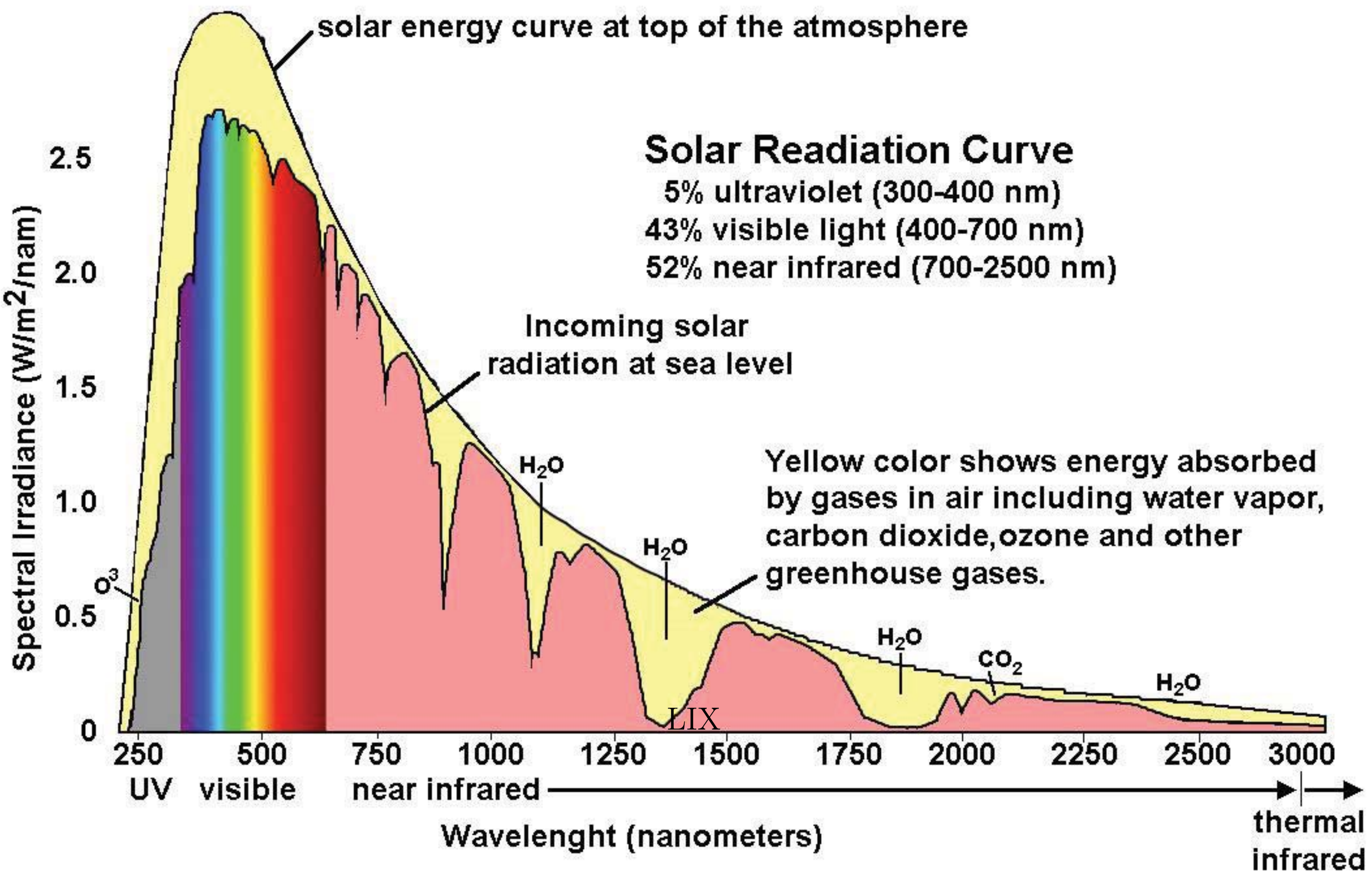
Radiazione solare e radiazione terrestre (disgiunte)



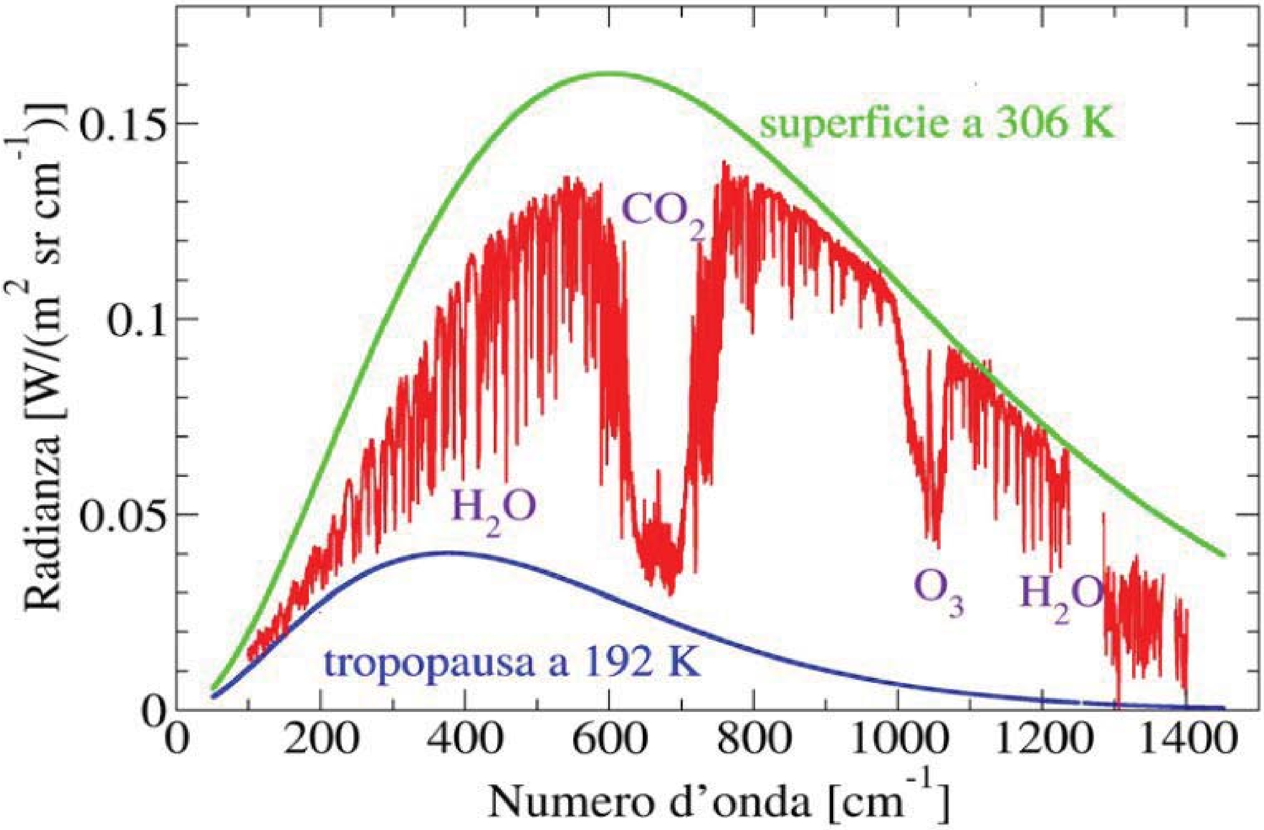
Radiazione solare (onda corta): ƛ<4μm

Radiazione terrestre (onda lunga o termica): ƛ>4μm

Lo spettro della radiazione solare - top vs superficie



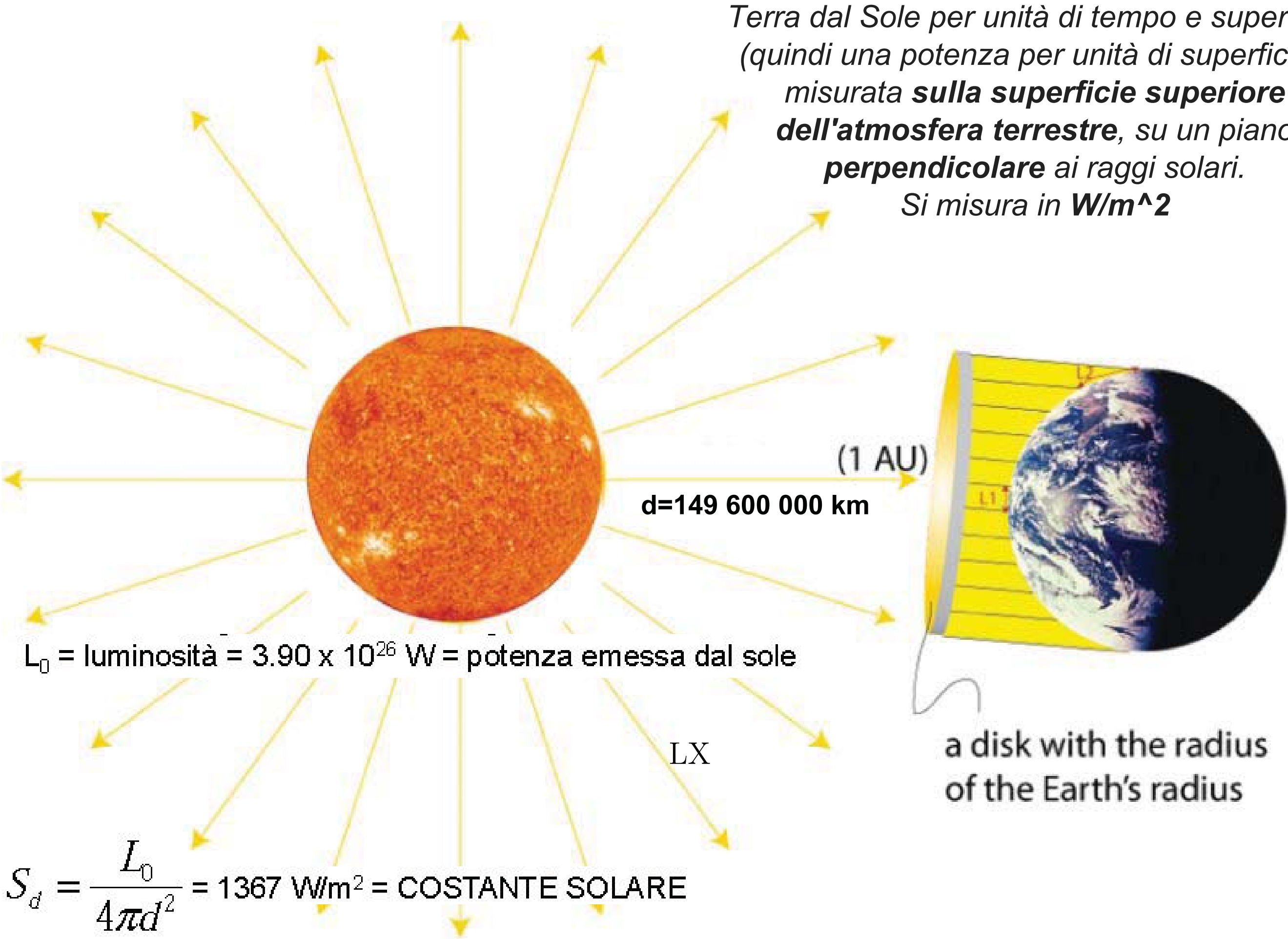
Lo spettro della radiazione terrestre - top vs superficie



Modello emissione terrestre: http://climatemodels.uchicago.edu/modtran/modtran.html

La costante solare

*Quantità di energia radiante che arriva sulla Terra dal Sole per unità di tempo e superficie (quindi una potenza per unità di superficie), misurata **sulla superficie superiore dell'atmosfera terrestre**, su un piano **perpendicolare** ai raggi solari.*
*Si misura in **W/m^2***



L_0 = luminosità = 3.90 x 10^{26} W = potenza emessa dal sole

$$S_d = \frac{L_0}{4\pi d^2}$$ = 1367 W/m^2 = COSTANTE SOLARE

Misura costante solare

MATERIALE:

- sole
- lastrina di alluminio annerita
- sensore di temperatura
- righello o metro
- supporto orientabile e stuzzicadenti
- bilancia

MISURARE:

- **massa** lastrina
- **superficie** lastrina
- **calore specifico** alluminio (896J/KgK)
- **temperatura** lastrina nel tempo T(t) (ogni 30 s) prima sotto il sole, poi mettendola in ombra

N.B. orientare superficie lastrina perpendicolare ai raggi solari

DOMANDE:

cosa succederà alla temperatura? Far ipotizzare curva T(t)

Stima potenza lampada - temperatura lastrine

MATERIALE:

- lampada (100W o 150W)
- lastrina di alluminio annerita
- sensore di temperatura
- righello o metro
- bilancia

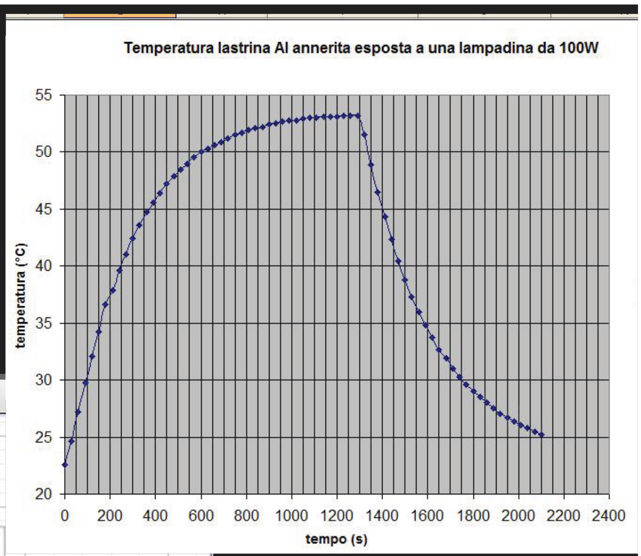
MISURE:

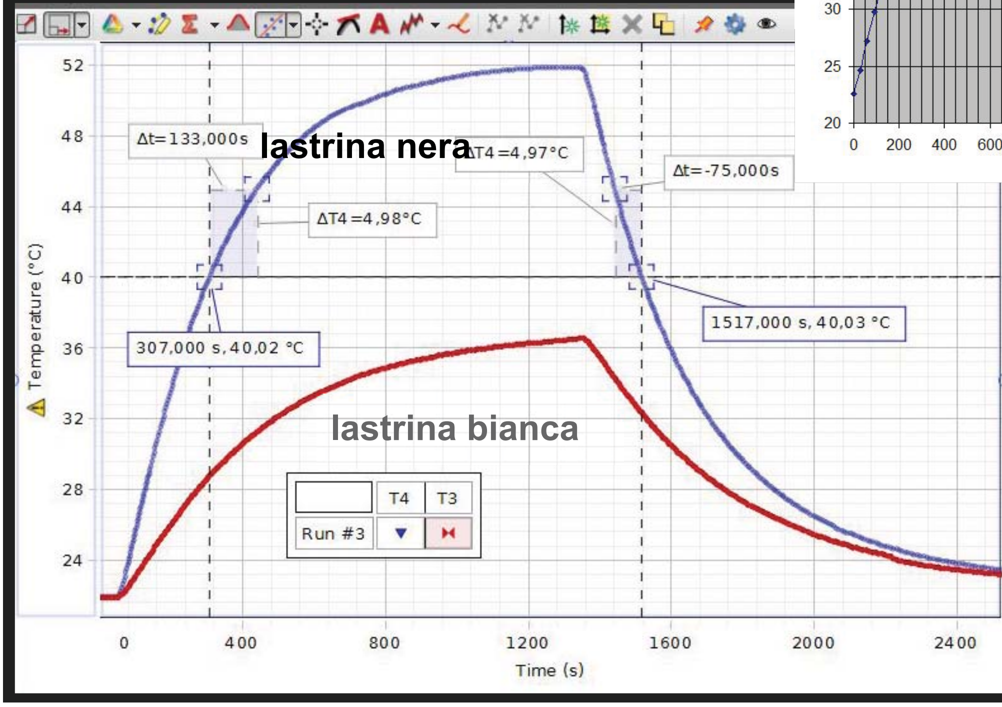
- **massa** lastrina
- **superficie** lastrina
- **distanza** lampada - lastrina (25cm)
- **calore specifico** alluminio (880J/KgK)
- **temperatura** lastrina nel tempo T(t) (ogni 30 s) lampada accesa, stazionarietà e poi spenta

N.B. lampada non emette su tutto l'angolo solido! Una stima potrebbe essere un solo emisfero

Dati - lampada

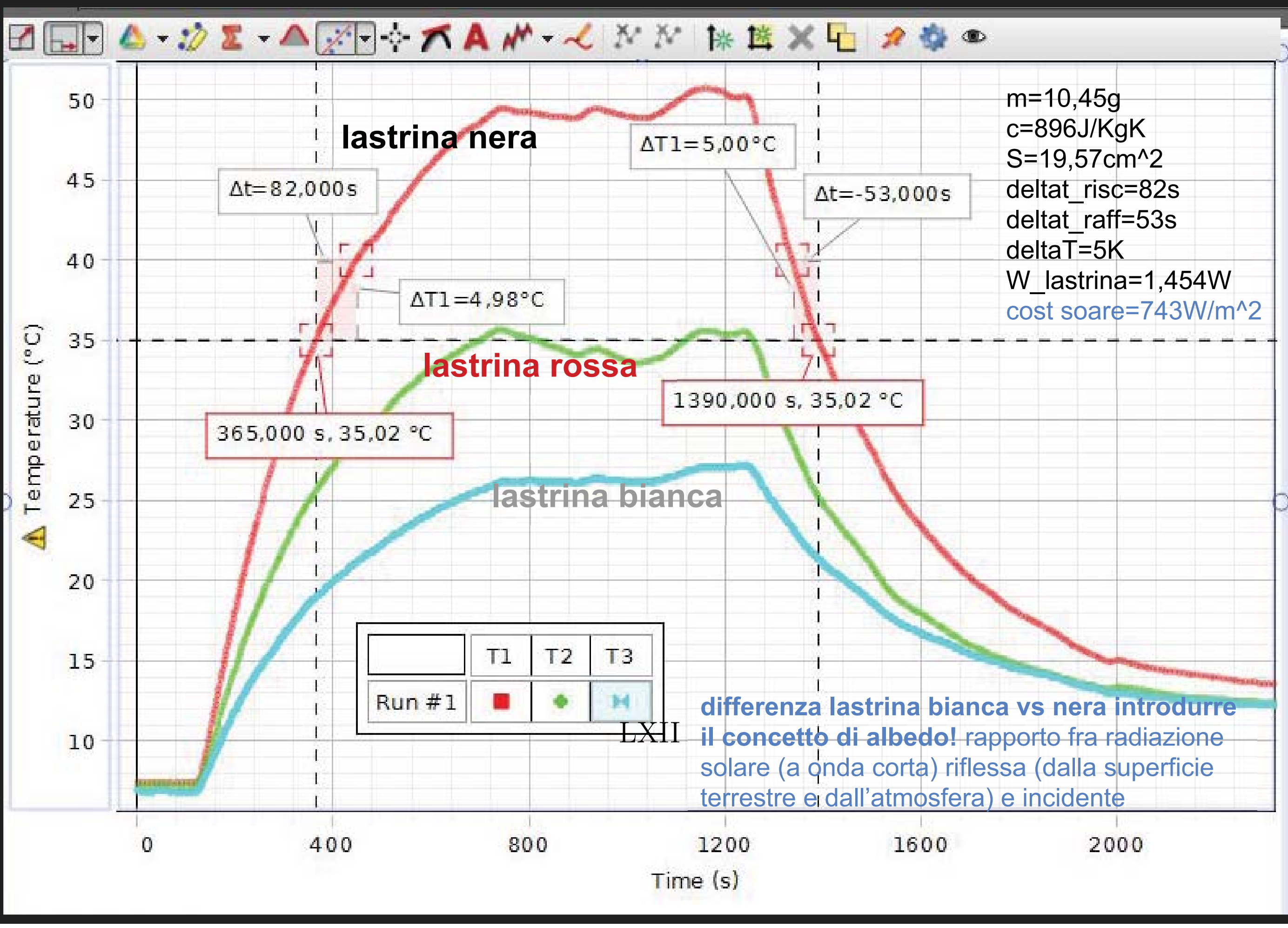
m=10,08 g
c=896 J/KgK
S=25 cm^2
d_lamp=20 cm
deltat_risc=110 s
deltat_raff=75 s
deltaT=4,98 K
W_lampada=1,013 W
W_totale=102 W





m=10,08 g
c=896 J/KgK
S=25 cm^2
d_lamp=20 cm
deltat_risc=133 s
deltat_raff=75 s
deltaT=4,98 K
W_lampada=0,938 W
Angolo solido: mezza sfera
W_totale=94 W

Dati - sole



m=10,45g
c=896J/KgK
S=19,57cm^2
deltat_risc=82s
deltat_raff=53s
deltaT=5K
W_lastrina=1,454W
cost soare=743W/m^2

differenza lastrina bianca vs nera introdurre il concetto di albedo! rapporto fra radiazione solare (a onda corta) riflessa (dalla superficie terrestre e dall'atmosfera) e incidente

LXII

Discussione qualitativa

3 FASI

1. accendo la lampada => temperatura lastrina **aumenta**
2. lampada accesa => temperatura lastrina **costante** (**stazionarietà**)
3. spengo la lampada => temperatura lastrina **diminuisce**

perchè?

com'è possibile che pur continuando a fornire energia (sole/lampada) la temperatura della lastrina ad un certo punto non aumenti più?

ci dev'essere dell'energia che viene dissipata, emessa dalla lastrina!

Anche la lastrina emette energia - (radiazione IR)

per ora ci basti sapere che la lastrina dissipa energia nell'ambiente circostante in modo da equilibrare l'energia in ingresso proveniente dal Sole (lampada)

- **fase 1 (riscaldamento)** $W_{Lampada} - W_{dissipata} = W_{misurataRISC}$
- **fase 2 (stazionarietà)** $W_{Lampada} = W_{dissipata} = W_{misurataEQUI}$
- **fase 3 (raffreddamento)** $W_{dissipata} = W_{misurataRAFF}$

Come risaliamo alle potenze dalle variazioni di temperatura? (legge termologia)

$$W_{RISC} = m_{lastrina} c_{lastrina} \frac{\Delta T}{\Delta t_{RISC}}$$

$$W_{RAFF} = m_{lastrina} c_{lastrina} \frac{\Delta T}{\Delta t_{RAFF}}$$

$$W_{Lampada} = m_{lastrina} c_{lastrina} \left(\frac{\Delta T}{\Delta t_{RISC}} + \frac{\Delta T}{\Delta t_{RAFF}}\right)$$

LXIII

N.B. angolo solido lampada / inclinazione lastrina

c_{Al}=896.9 J/kgK

$$W_{totale} = \frac{S_{sfera}}{S_{lastrina}} W_{lampada}$$

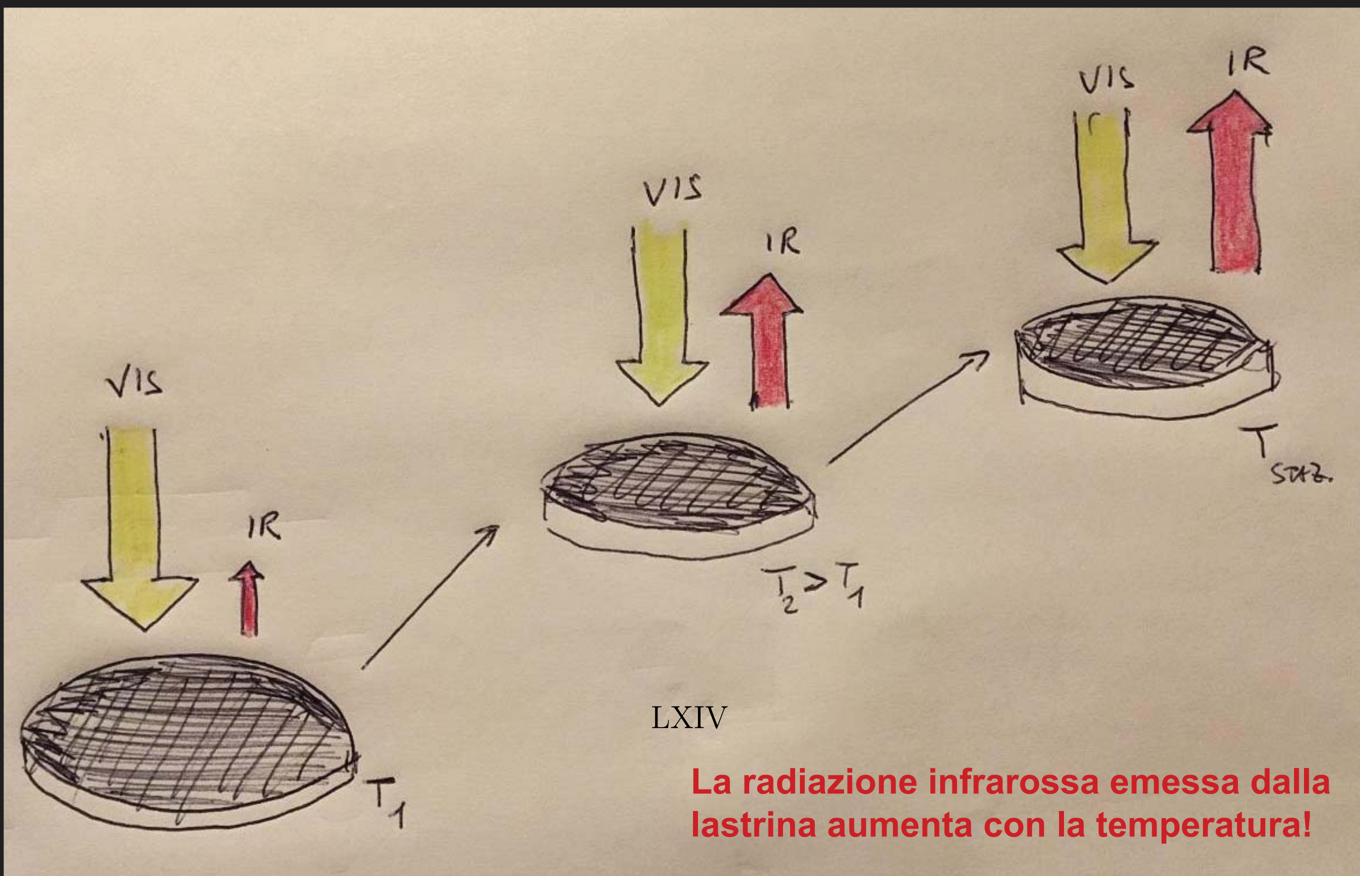
Criticità

- angolo solido di emissione della lampada
- filamento della lampadina non puntiforme
- perpendicolarità della lastrina rispetto ai raggi solari (lampada)

- In ogni caso si riesce a stimare l'ordine di grandezza della potenza della lampada (o della costante solare)

- N.B. Il valore tabulato della costante solare si riferisce al top dell'atmosfera!

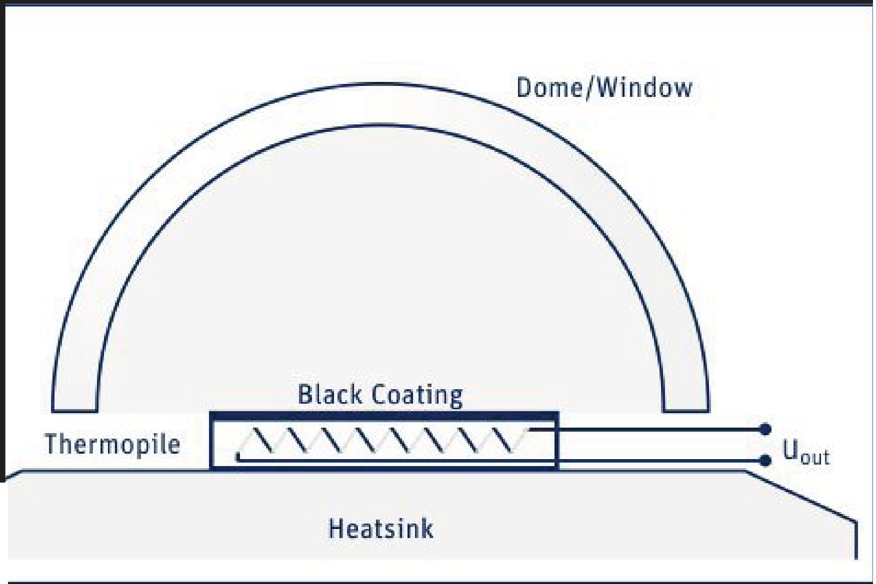
Un ragionamento qualitativo - radiazione infrarossa!



La radiazione infrarossa emessa dalla lastrina aumenta con la temperatura!

Principio di funzionamento di un radiometro

In genere per misurare la radiazione solare e terrestre si usano dei **radiometri** (**termopile**).



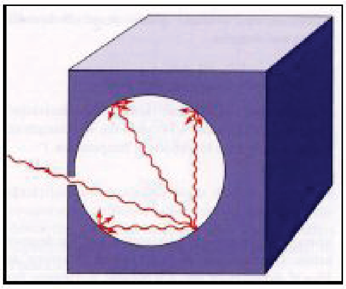
l'elemento sensibile è un **corpo nero** che assorbe la radiazione incidente, aumentando la sua temperatura. La differenza tra questa e la temperatura di un elemento di riferimento viene trasformata in una tensione. Dopo la **calibrazione**, questa tensione è proporzionale alla radianza

Un esempio: la stazione BSRN in Antartide

- **l’emissione di radiazione dipende dalla temperatura dell’oggetto, ma come?**
- **Quale legge di dipendenza dalla temperatura?**

“Vedere” la radiazione infrarossa

- **Fuoco** lo vedo (occhi), ma lo sento anche (recettori della pelle, caldo)
- sensore IR **telecomando** non lo vedo con gli occhi, ma attraverso la fotocamera smartphone
- osservo oggetti con la **termocamera** dopo aver spento la luce… oppure dietro ad un vetro. Cosa succede?
- La radiazione infrarossa emessa dai corpi viene misurata e trasformata in colori visibili corrispondenti a una determinata temperatura (legge di Stefan-Boltzmann). Il vetro riflette e assorbe parte della radiazione infrarossa.
- Termocamera e valutazioni di dispersione energetica degli edifici.



CORPO NERO

E' per definizione un assorbitore perfetto. A una data temperatura T, emette la massima quantità possibile di energia per quella T.

LEGGE DI CORPO NERO (o di PLANK)

Descrive la quantità ed il tipo (λ) di energia emessa da un corpo nero, funzione solo della **temperatura**. L'intensità della radiazione a una data lunghezza d'onda (**radianza monocromatica,** ovvero l'energia per unità di tempo, di area, di angolo solido) emessa da un corpo nero alla temperatura T è (ottenuta sperimentalmente):

$$B_\lambda(T)d\lambda = \frac{2hc^2}{\lambda^5\left(e^{\frac{hc}{k\lambda T}} - 1\right)}$$

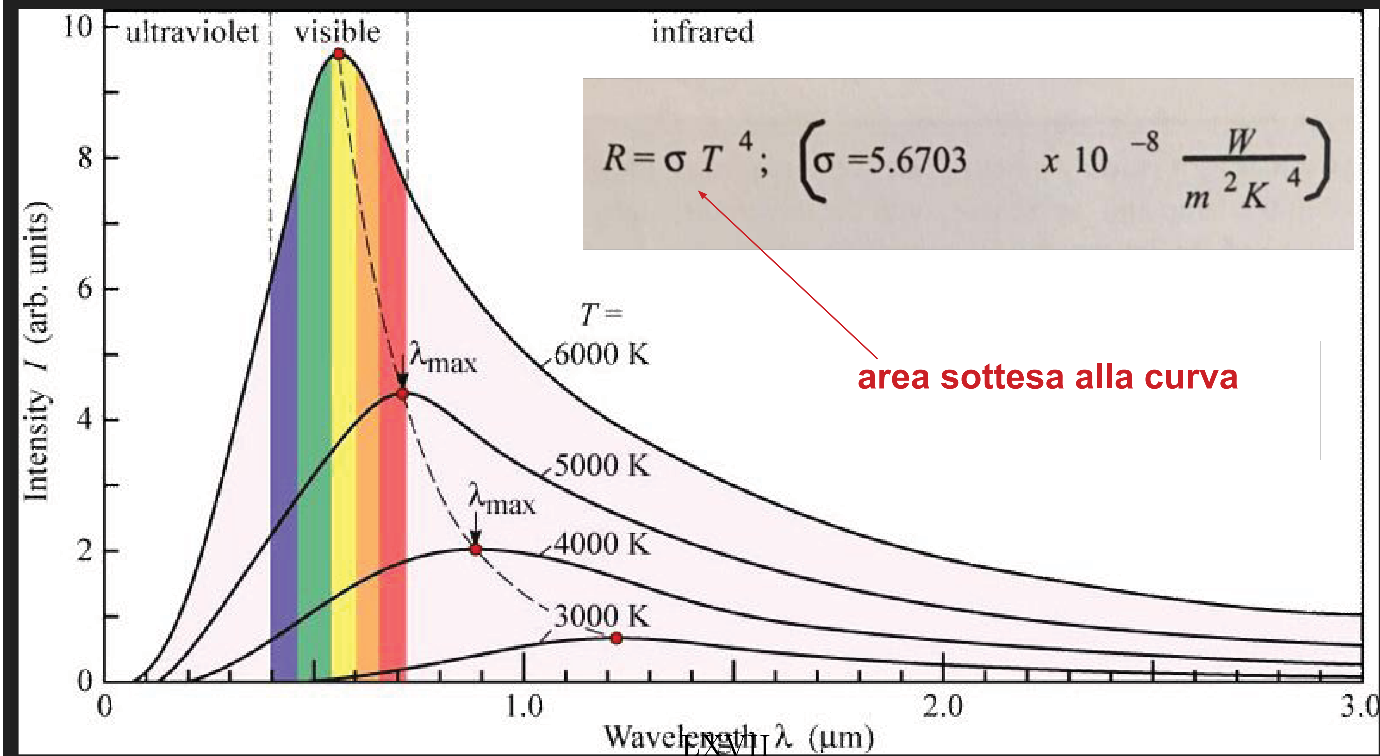
h= costante di Plank= 6.63 10^{-34} Js

k= costante di Boltzmann= 1.38 10^{-23} J/k

La **radiazione di corpo nero è isotropa**, ovvero è emessa uniformemente in tutte le direzioni. Ne consegue che l'intensità è indipendente dalla direzione.

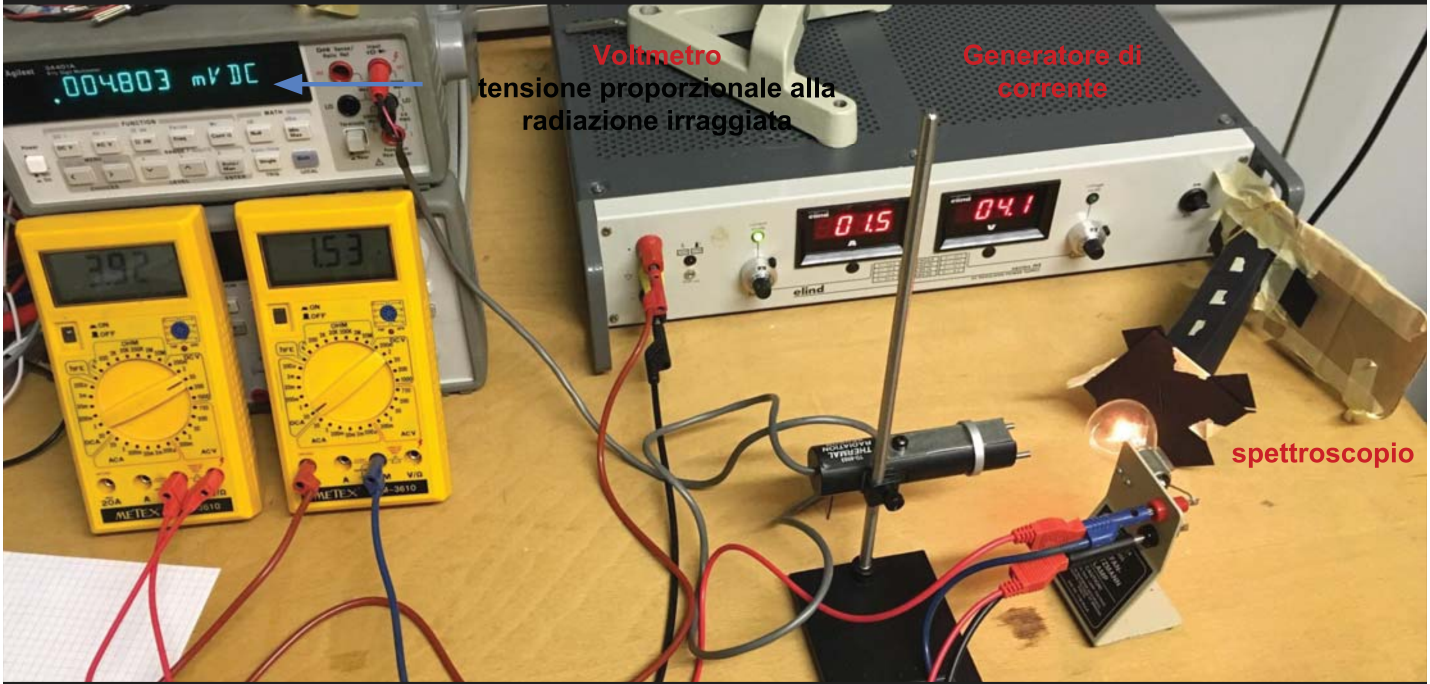
In realtà i corpi reali sono corpi grigi! e hanno un'emissività inferiore a 1

Legge di Stefan Boltzmann



Maggiore è la temperatura, maggiore è la quantità di energia emessa (**Legge di Stefan-Boltzmann**)

La lampada di Stefan Boltzmann

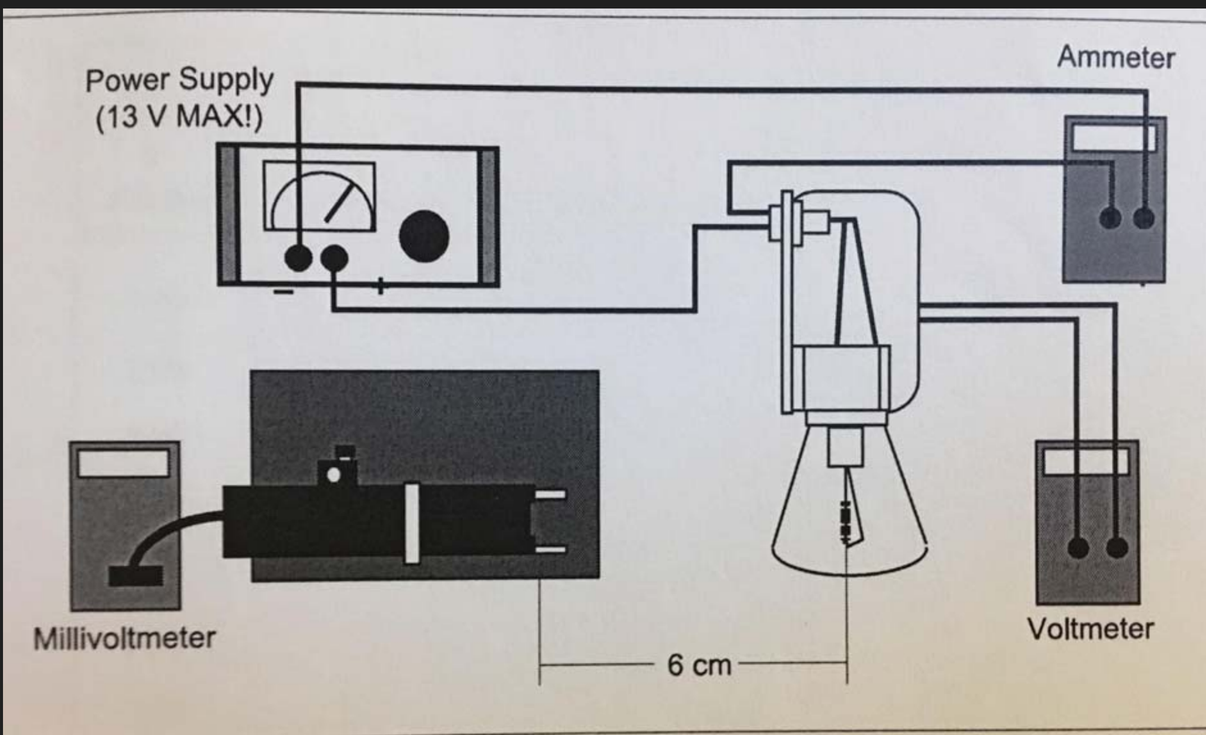


Amperometro
corrente alla lampadina

Voltmetro
tensione alla lampadina

radiometro (termopila)
risponde con una tensione proporzionale alla potenza irraggiata (W/m^2)

Lampada di SB (filamento tungsteno - resistenza nota in funzione della temperatura**)**



MISURE:

- **resistenza del filamento a temperatura ambiente (300K circa)**
  - N.B. devo stare attento alla resistenza dei fili (da sottrarre-serie)
- **tensione e corrente ai capi lampada => (resistenza dalla legge di Ohm)**
- **tensione ai capi del radiometro (termopila)**

Dalla resistenza ricavo la temperatura del filamento

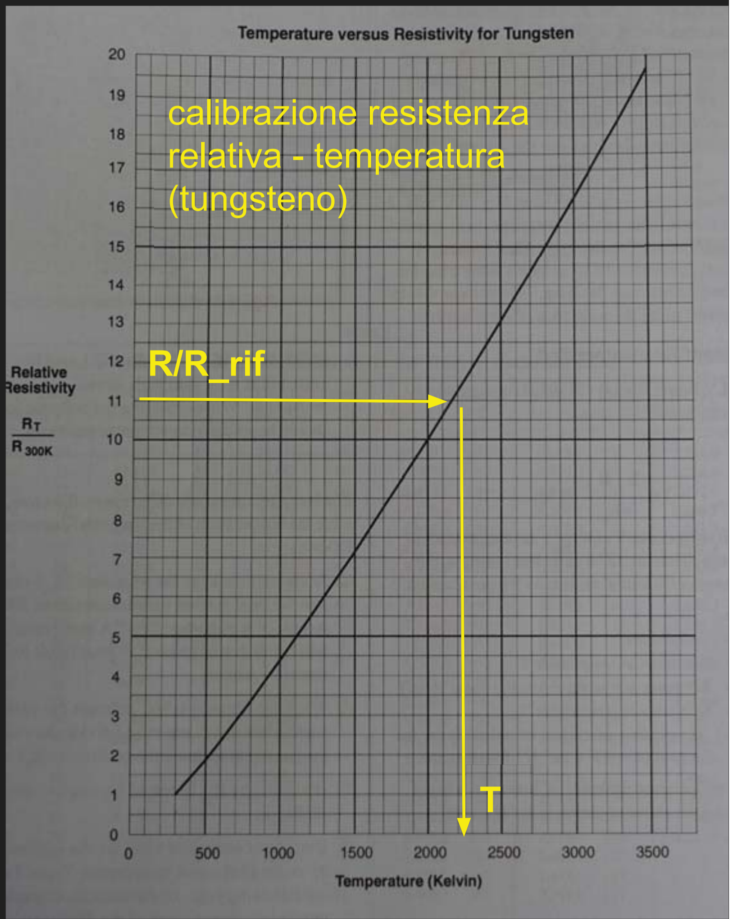
Data			Calculations		
V (Volts)	I (Amps)	Rad (mV)	R (Ohms)	T (K)	T⁴ (K⁴)
1.00					
2.00					
3.00					
4.00					
5.00					
6.00					
7.00					
8.00					
9.00					
10.00					
11.00					
12.00					

$$\rho = \rho_0[1+\alpha\cdot(T-T_0)]$$

$$R = \rho\frac{l}{S}$$

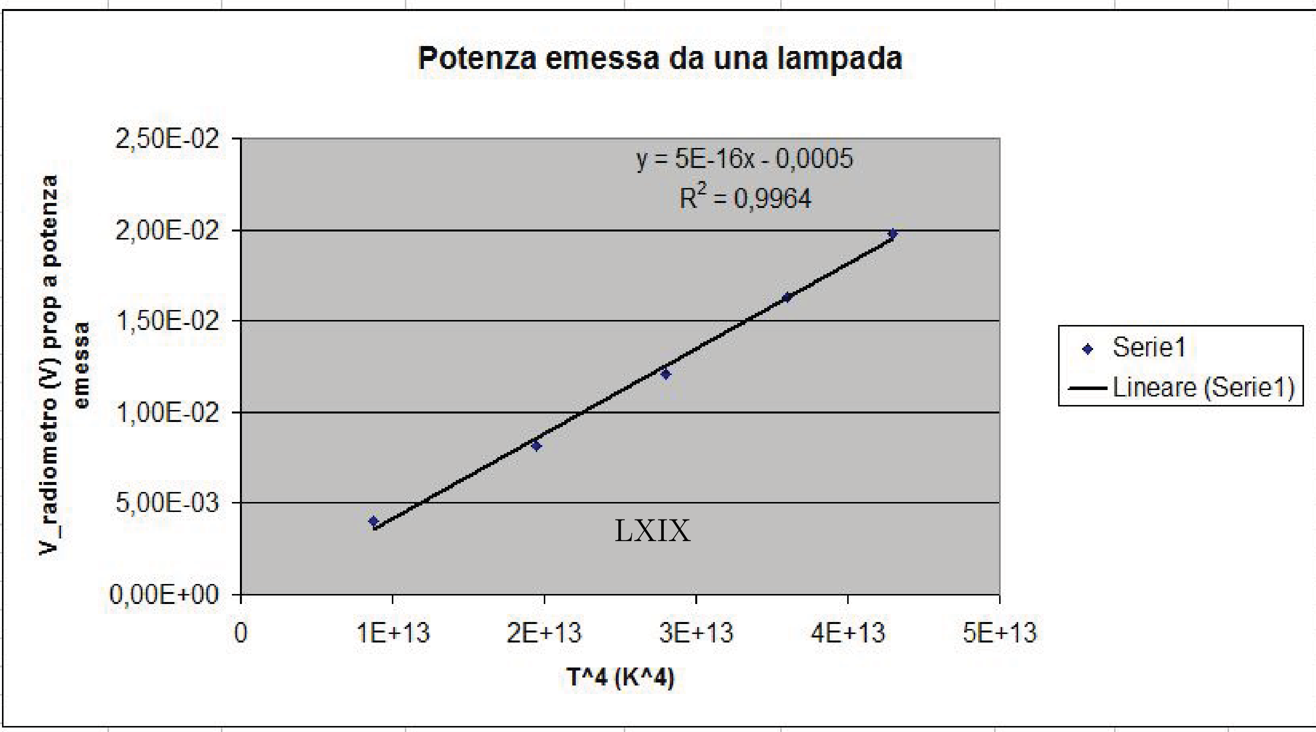
la resistività e quindi la **resistenza** dei conduttori elettrici dipende dalla **temperatura** (assumo non si modifichino lunghezza o sezione)

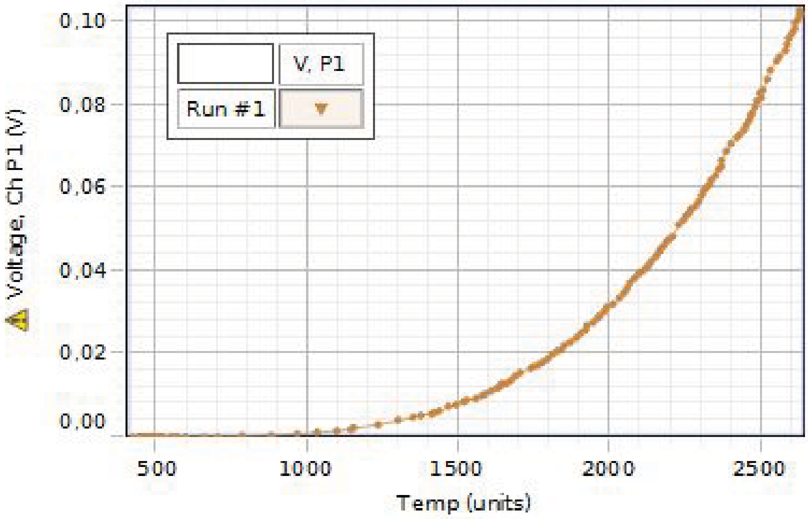
dal rapporto tra la resistenza calcolata e quella alla temperatura ambiente risalgo alla temperatura del filamento



Analisi dati 1

	A	B	C	D	E	F	G	H	I
1									
2	V_lamp (V)	I_lamp (A)	V_radiometro (V)	R_riferimento (Ohm)	R_lamp (Ohm)	R/R_ref	T_lamp (K)	T_amb (K)	T^4
3	4,51	1,64	4,00E-03	3,25E-01	2,75E+00	8,46E+00	1720	293,15	8,75E+12
4	6,88	2,02	8,17E-03	3,25E-01	3,41E+00	1,05E+01	2100	293,15	1,94E+13
5	8,68	2,28	1,21E-02	3,25E-01	3,81E+00	1,17E+01	2300	293,15	2,8E+13
6	10,31	2,49	1,63E-02	3,25E-01	4,14E+00	1,27E+01	2450	293,15	3,6E+13
7	11,62	2,65	1,98E-02	3,25E-01	4,38E+00	1,35E+01	2560	293,15	4,29E+13

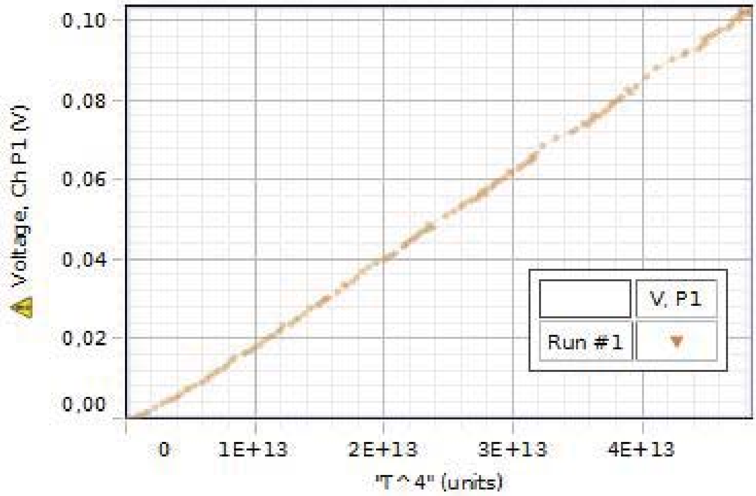




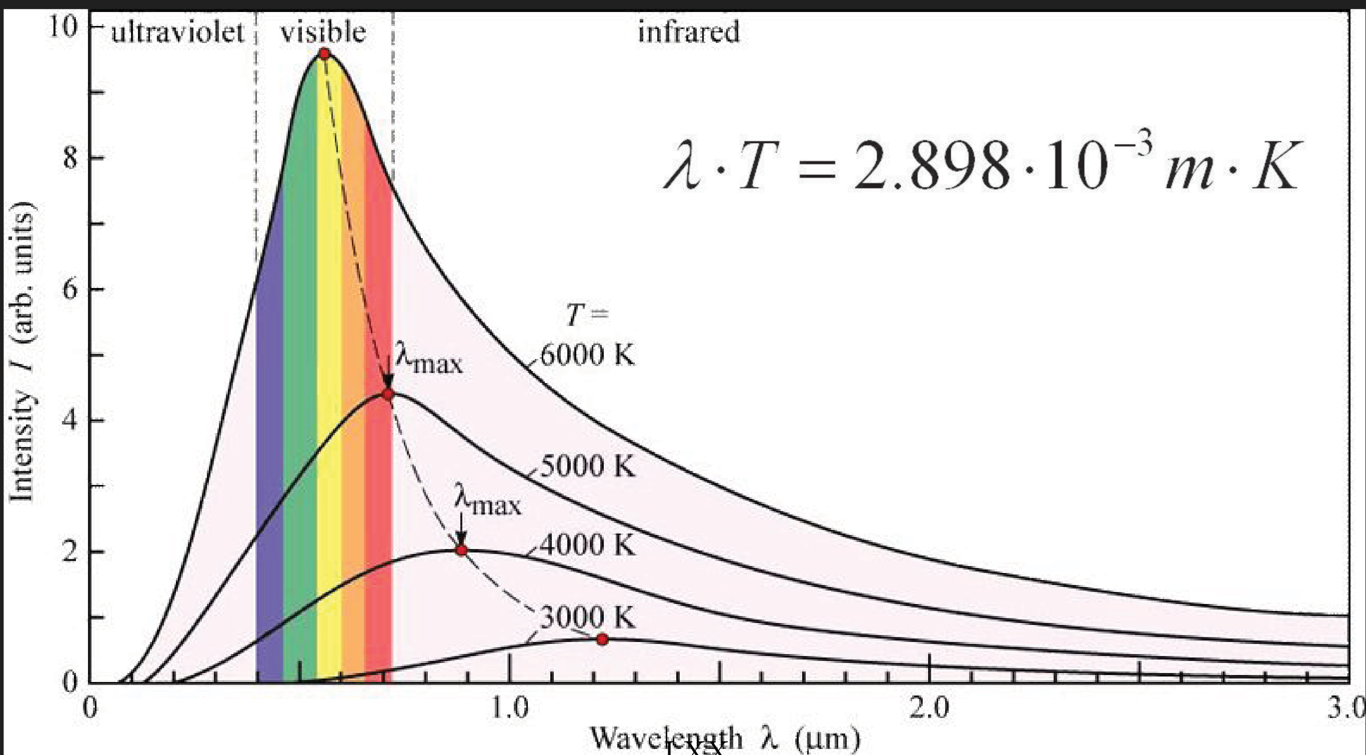
Analisi dati 2

N.B. a rigore dovrei sottrarre anche l'energia emessa dall'ambiente σTa^4, ma è trascurabile rispetto alla temperatura del filamento.

l'energia emessa sotto forma di radiazione elettromagnetica è proporzionale alla quarta potenza della temperatura del corpo emittente!



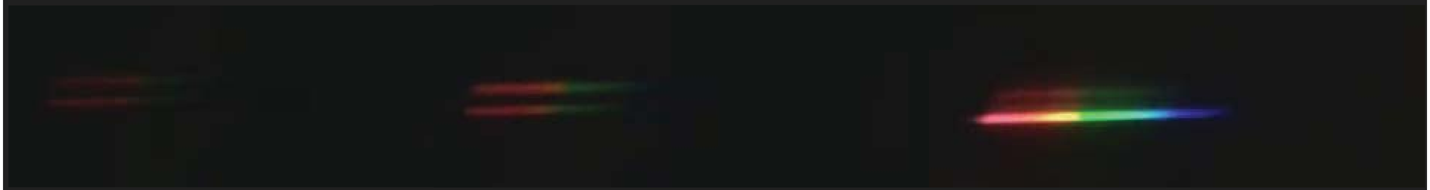
Legge di Wien



LXX

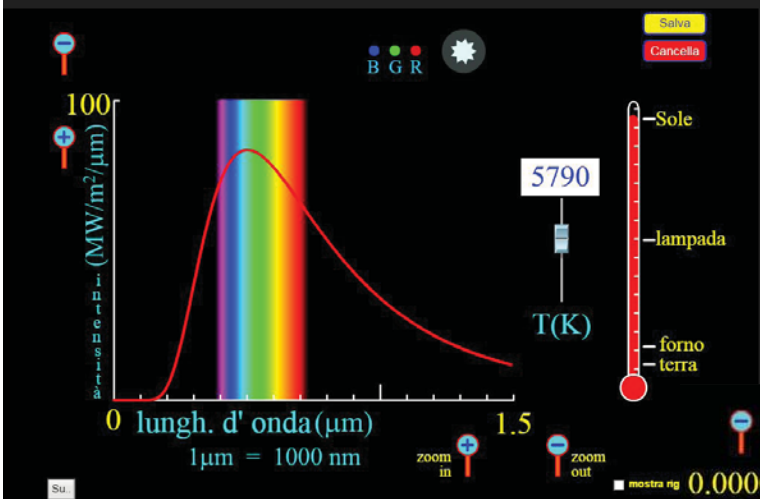
Maggiore è la temperatura, minore è la lunghezza d'onda corrispondente al picco di emissione (**Legge di Wien**).

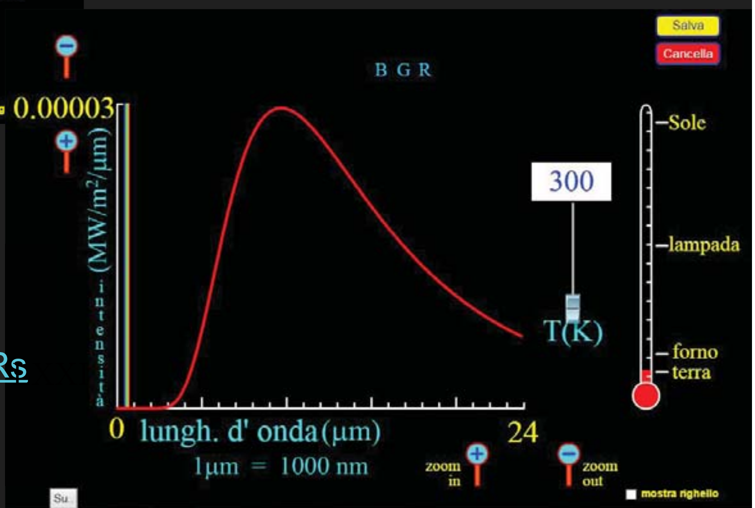
La legge di Wien qualitativa con lo spettroscopio



- Osservo con lo spettroscopio la lampada di stefan boltzmann mentre aumento la corrente che fornisco alla lampada.
- Qualitativamente vedo che cambia il colore della luce (massimo dell'intensità di emissione) e vedo che nello spettro compaiono colori diversi (dal rosso al violetto).
- In chimica questo si potrebbe collegare con la combustione di diverse sostanze, i colori della fiamma e il potere calorifico.

Lo spettro di corpo nero di sole e terra con un'applet

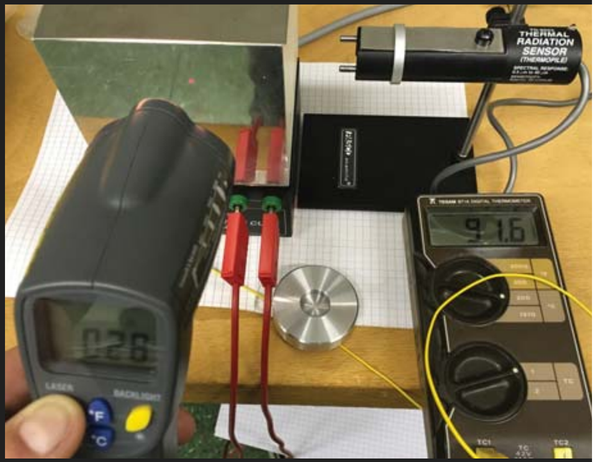




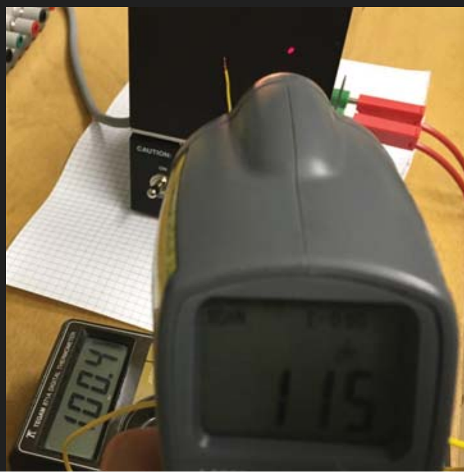
Un video su radiazione solare e terrestre (NASA)
www.youtube.com/watch?v=nNzDXXUiqRs

Applet Phet: https://phet.colorado.edu/it/simulation/blackbody-spectrum

Corpi grigi, emissività e cubo di Leslie



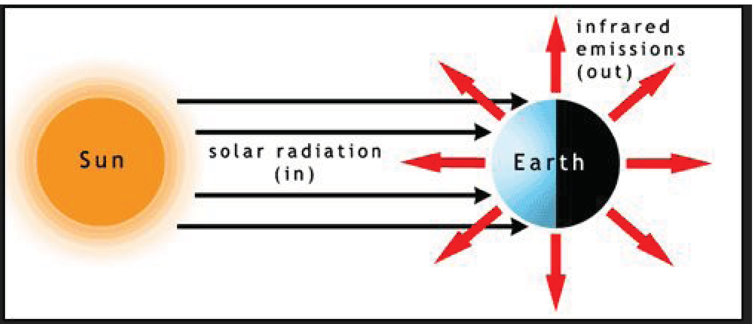
- **Cubo di Leslie** fatto dello stesso materiale, ma 4 facce diverse (superficie esterna nera, bianca, riflettente e ruvida opaca), all'interno una lampadina ad incandescenza.
- misuro la **temperatura** delle pareti del cubo con **termocoppia** esterna (oppure attraverso la misura della resistenza (boccole verdi) di una termoresistenza immersa nell'alluminio delle pareti.
- misuro la temperatura delle facce esterne con una **pistola a IR** (qualitativamente accosto la **mano** alle diverse facce).
- *come mai le temperature misurate dalla pistola IR sono diverse per le diverse facce?*
- La pistola IR misura la radiazione emessa e attraverso la **legge di Stefan** calcola la temperatura corrispondente
- Ma le **facce** sono diverse! Non sono corpi neri, ma **corpi grigi**! Hanno **diversa emissività**! Conferma
- Osservando la tensione in uscita dalla termopila affacciata sulle diverse facce.



Emissività dei corpi grigi e proprietà delle superfici

- le diverse facce sono tutte alla **stessa temperatura**, ma **irraggiano** radiazione elettromagnetica con **diversa** intensità (tensione ai capi della termopila)
- sono **corpi grigi** e hanno diversa emissività (o emittanza)!
- l'emissività dipende dalle proprietà delle **superfici**
- Intensità irraggiata dai corpi grigi: **$I=\varepsilon\sigma T^4$** con **ε emissività**

Un’analogia idraulica



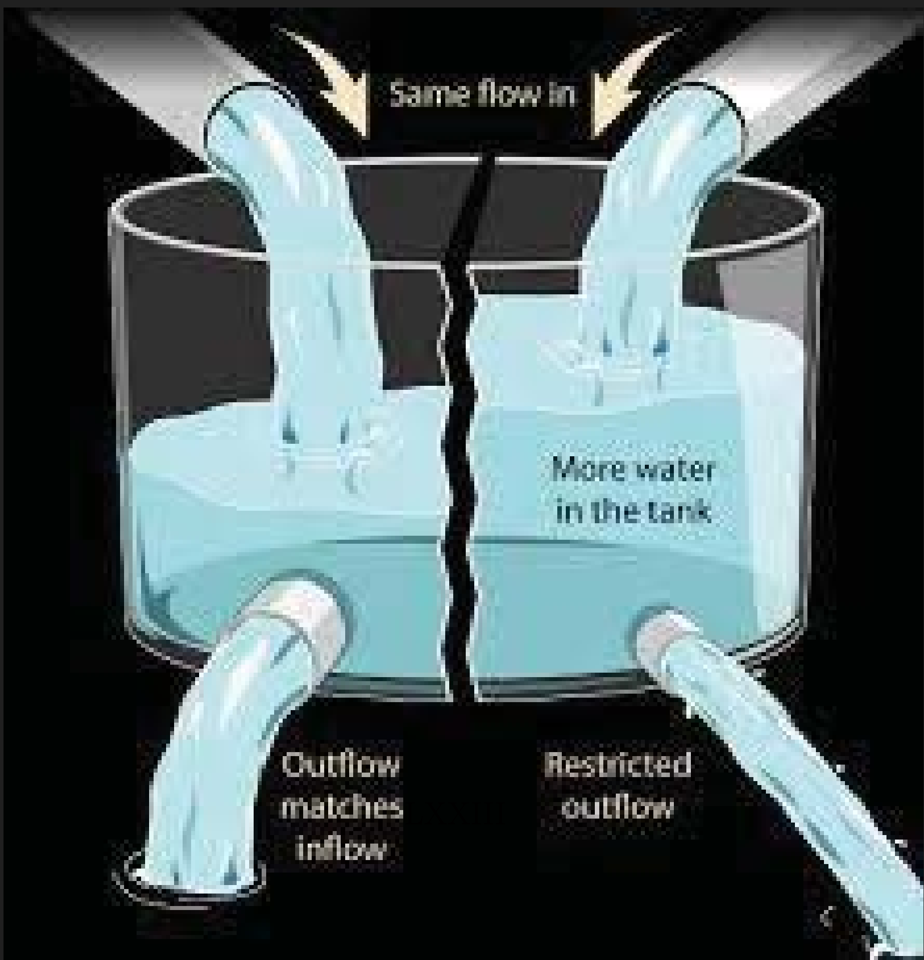
MATERIALE:

- bicchiere con 3 fori di diverso diametro
- rubinetto acqua o bottiglia di Mariotte (flusso cost)

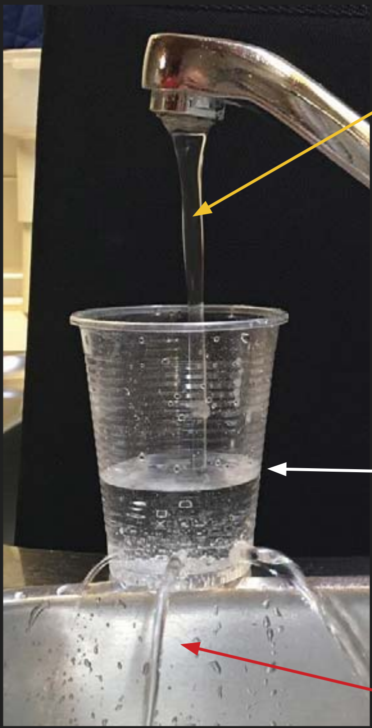
ATTIVITA’

- **equilibrio statico:** tappare tutti i fori e riempire con un tot di acqua
- **equilibrio dinamico:** ricerca di diversi equilibri con
  - tutti i fori aperti e vario apertura rubinetto
  - flusso rubinetto costante e tappo diversi fori

N.B. proponibile anche come **attività IBSE**, lasciando sperimentare agli studenti che cosa succede guidati solo da alcune domande guida.



Bilancio di flussi di radiazione e temperatura



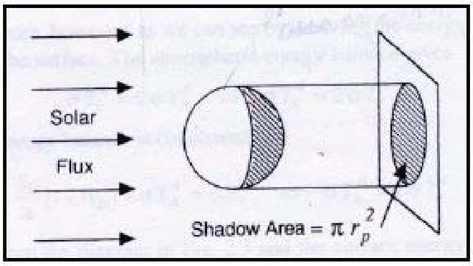
COSTANTE SOLARE - energia solare in ingresso (radiazione solare per lo più visibile)

Un video sull'equilibrio radiativo (NASA)
https://www.youtube.com/watch?v=DOAqECd70Ww

livello ⇔ "temperatura"

Energia emessa dalla Terra sotto forma di radiazione infrarossa (proporzionale alla temperatura alla quarta)

Radiazione solare assorbita



L'energia incidente sul pianeta è data dal prodotto della **costante solare** per l'**area che il pianeta espone alla radiazione incidente** perpendicolarmente ad essa. Tale superficie si chiama "**shadow area**".

La radiazione solare assorbita si calcola poi moltiplicando ulteriormente **per la frazione che non viene riflessa.**

costante solare!

$$S_0(1-\alpha_p)\pi R_p^2$$

Albedo = αp = frazione di radiazione riflessa dal pianeta.

Neve fresca	0.9
Oceano	0.1
Prato	0.2
Deserto	0.4
Valore medio terrestre	0.3

Nell'arco dell'intera giornata, a causa della rotazione terrestre, questa potenza è distribuita su tutto il globo terrestre, quindi occorre dividere per la superficie della sfera $4\pi R_p^2$ ottenendo la potenza media assorbita

$$\frac{S_0}{4}(1-\alpha_p)$$

Albedo

L'albedo indica la frazione di radiazione incidente che viene riflessa da una superficie. Misura quindi il "potere" riflettente di una superficie. La frazione di energia riflessa viene rimandata nello spazio e non contribuisce a scaldare il pianeta.

Type of surface	Albedo (%)
Ocean	2 – 10
Forest	6 – 18
Cities	14 – 18
Grass	7 – 25
Soil	10 – 20
Grassland	16 – 20
Desert (sand)	35 – 45
Ice	20 – 70
Cloud (thin, thick stratus)	30, 60 – 70
Snow (old)	40 – 60
Snow (fresh)	75 – 95

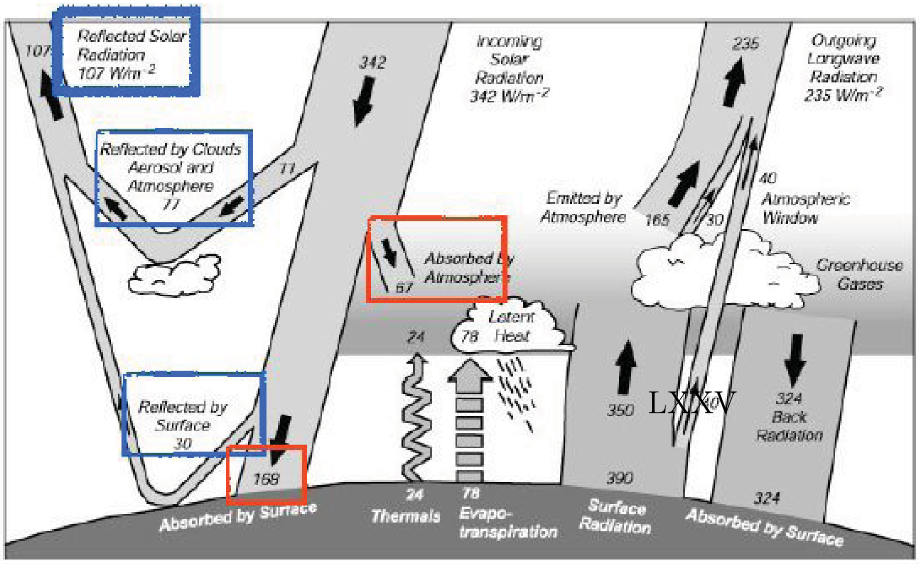
Neve fresca, nubi, ghiaccio, deserti, oceani, vegetazione, etc., hanno valori diversi di albedo (con una diretta influenza sulla temperatura della superficie)

L'esatto valore della frazione dipende, a parità di superficie, dalla lunghezza d'onda della radiazione incidente

Bilancio globale di energia

Albedo: 30% *
2/3 nubi, aerosol
1/3 neve, ghiacci, deserti
342-107 =235 W/m²

Assorbiti dal sistema terra-atmosfera:
atmosfera (67 W/m²)
superficie (168 W/m²)



$$E = \sigma T^4$$

$$(1-\alpha_p)\frac{S_0}{4} = \sigma T^4$$

$$T = \sqrt[4]{\frac{S_0}{4}\frac{1-\alpha_p}{\sigma}}$$

T~255 K=-18°C

T?

Bilancio globale di energia

T=255 K (-18°C) è di circa 30°C più bassa della temperatura media globale superficiale osservata, pari a Ts=288 K (15°C)

1. Questa **differenza è spiegata tenendo conto dell'effetto serra**

2. Nella trattazione abbiamo trascurato la presenza dell'atmosfera, quindi la temperatura T trovata non è quella reale, ma quella di un **pianeta terra senza atmosfera in equilibrio radiativo (Te=Tempertura di Emissione).**

$$Ts = Te+\Delta T$$

3. Il sistema terra-atmosfera non è assimilabile ad un corpo nero che emette alla T della superficie (Ts), ma alla temperatura **Te, che è in buon accordo con la temperatura a una qualche livello nell'alta troposfera** a cui avviene la massima emissione

4. **L'effetto netto dell'atmosfera (dell'effetto serra) è quello di riscaldare la superficie planetaria e raffreddare gli strati alti dell'atmosfera**

Variabilità - sistema climatico

Forzanti esterne al sistema - antropiche

Gas a effetto serra

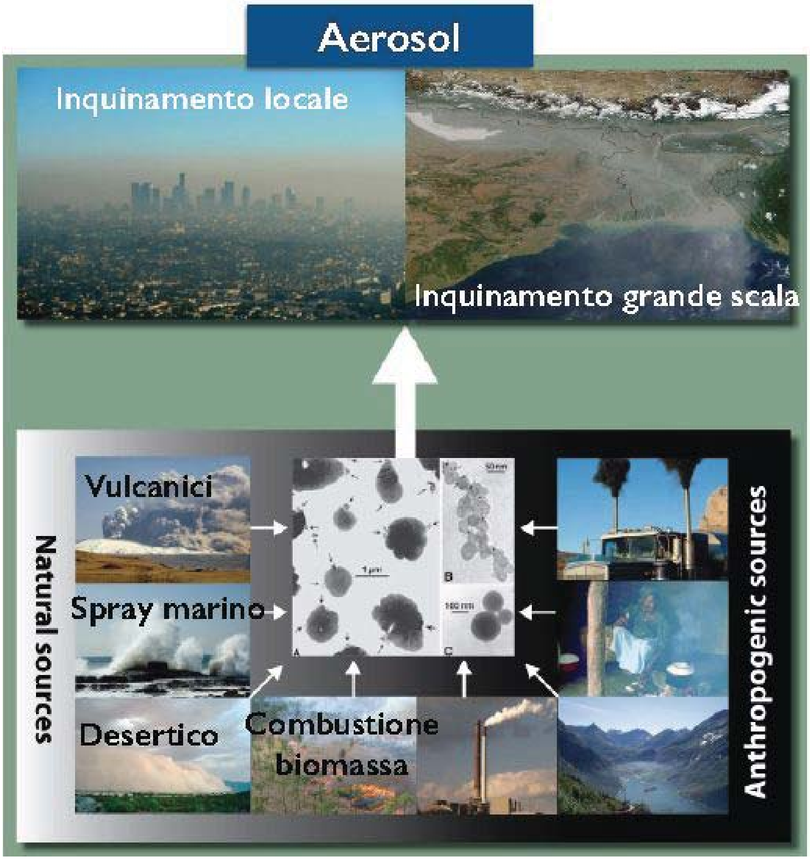
Aerosol troposferici

Uso del suolo

Operano su scale relativamente brevi ma tali da dar luogo a cambiamenti significativi e apprezzabili

Variabilità - sistema climatico

Forzanti esterne al sistema - antropiche



Gli aerosol atmosferici sono sospensioni di particelle **liquide, solide, o in fase mista caratterizzati da una composizione chimica e distribuzione dimensionale estremamente variabile**
0.001 mm < d < 0.01 mm

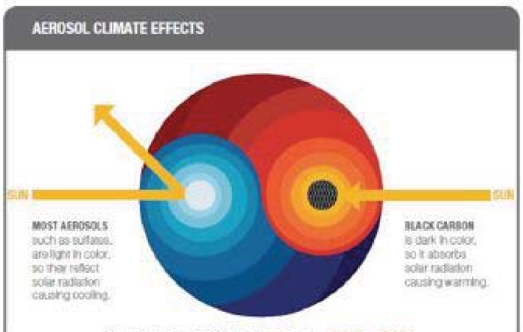
Questa variabilità è dovuta alla variabilità delle possibili **sorgenti** e ai diversi **meccanismi di formazione.** Le particelle di aerosol possono essere emesse direttamente in atmosfera (**aerosol primari**) o prodotti da gas precursori (**aerosol secondari**).

Variabilità - sistema climatico

Forzanti esterne al sistema - antropiche

Qual è l'effetto degli aerosol sul clima?

Il **Black Carbon** (BC, fuliggine) e , in misura minore, Organic Carbon (OC) e polvere minerale, contribuiscono al riscaldamento dell'atmosfera perchè **assorbono direttamente la radiazione solare incidente.**
BC si deposita anche sulle superfici innevate e ghiacciate rendendole più scure, più capaci di assorbire la radiazione solare e quindi accelerando la fusione delle stesse.



A quick look of black carbon, IGSD, 2009.

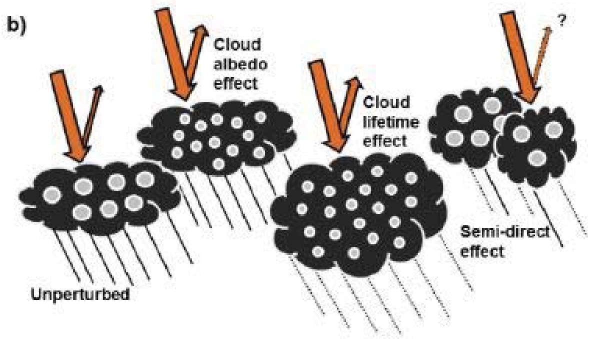
Gli aerosol solfati (in misura minore l'Organic Carbon e altri) possono invece causare un raffreddamento del sistema perchè **riflettono la luce del sole.**

EFFETTO DIRETTO
Interazione diretta con la radiazione solare

Variabilità - sistema climatico

Forzanti esterne al sistema - antropiche

Qual è l'effetto degli aerosol sul clima?



Gli aerosol possono agire come nuclei di condensazione (CCN) per le nubi.

Il principale effetto è quello di creare nubi costituite da più goccioline, di più piccole dimensioni, e con le seguenti caratteristiche:

1. Maggior riflettività (*Cloud Albedo o Twomey effect*)
2. Tempo di vita più lungo e minor precipitazione (*Cloud lifetime effect*)

Complessivamente, si ritiene che l'effetto principale delle nubi sia quello di raffreddare il clima, per i due punti sopra. Tuttavia, ciò dipende molto anche dalla composizione chimica degli aerosol che agiscono come CCN. **In generale, gli aerosol possono cambiare una serie di attributi delle nubi, come la loro formazione, dissipazione, riflettività, e tasso di precipitazione.**

EFFETTO INDIRETTO
Interazione tra aerosol e nubi

Variabilità - sistema climatico

Forzanti esterne al sistema - antropiche

Cambiamenti nell'uso del suolo

Cambiamenti nella riflettività della superficie terrestre sono dovuti anche a cambiamenti nell'uso del suolo e nella sua copertura.

Processi importanti: deforestazione, riforestazione, desertificazione, urbanizzazione possono alterare il bilancio idrico e di calore su scala locale, cambiando le caratteristiche della superficie.

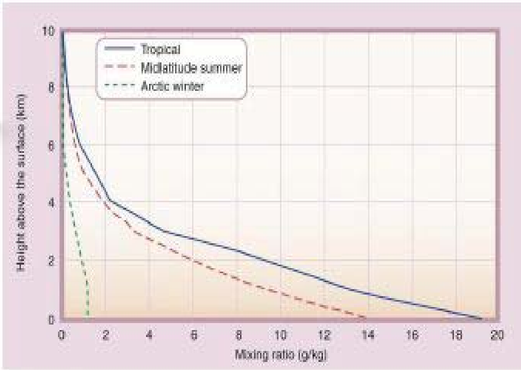
Gas a Effetto Serra (NATURALE)- Vapore Acqueo

- **Il vapore acqueo è il gas a effetto serra più abbondante e più importante in termini di contributo all'effetto serra naturale (60%),** nonostante sia caratterizzato da una vita media piuttosto breve e soggetto a molte trasformazioni
- Su scala **globale, la concentrazione di vapore acqueo è controllata dalla temperatura attraverso la legge di** Clausius-Clapeyron: +1°C => +7% H_2O; questo influenza anche i tassi di **evaporazione e precipitazione.**
- **La concentrazione globale di vapore acqueo non è affetta in modo DIRETTO dalle emissioni di origine antropica (lo è in modo indiretto e determina feedback).**

Atmosfera

Vegetazione

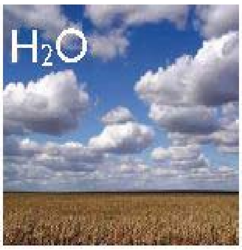
Criosfera

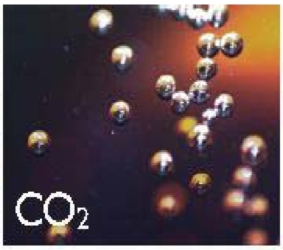


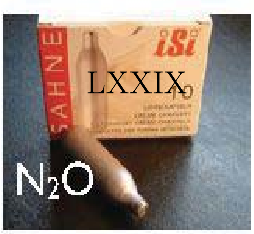
Gas a Effetto Serra

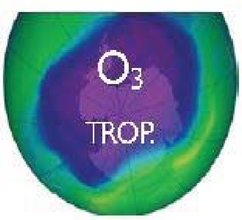
I principali gas a effetto serra di origine antropica includono **CO_2, CH_4, nitrous oxide (N_2O)**; le attività umane amplificano le concentrazioni di questi gas naturalmente presenti in atmosfera.

Molecule con tre o più atomi capaci di indurre moti vibrazionali che cambiano la struttura dipolare delle molecole, rendendole capaci ad assorbire la radiazione IR emessa dalla superficie della Terra.

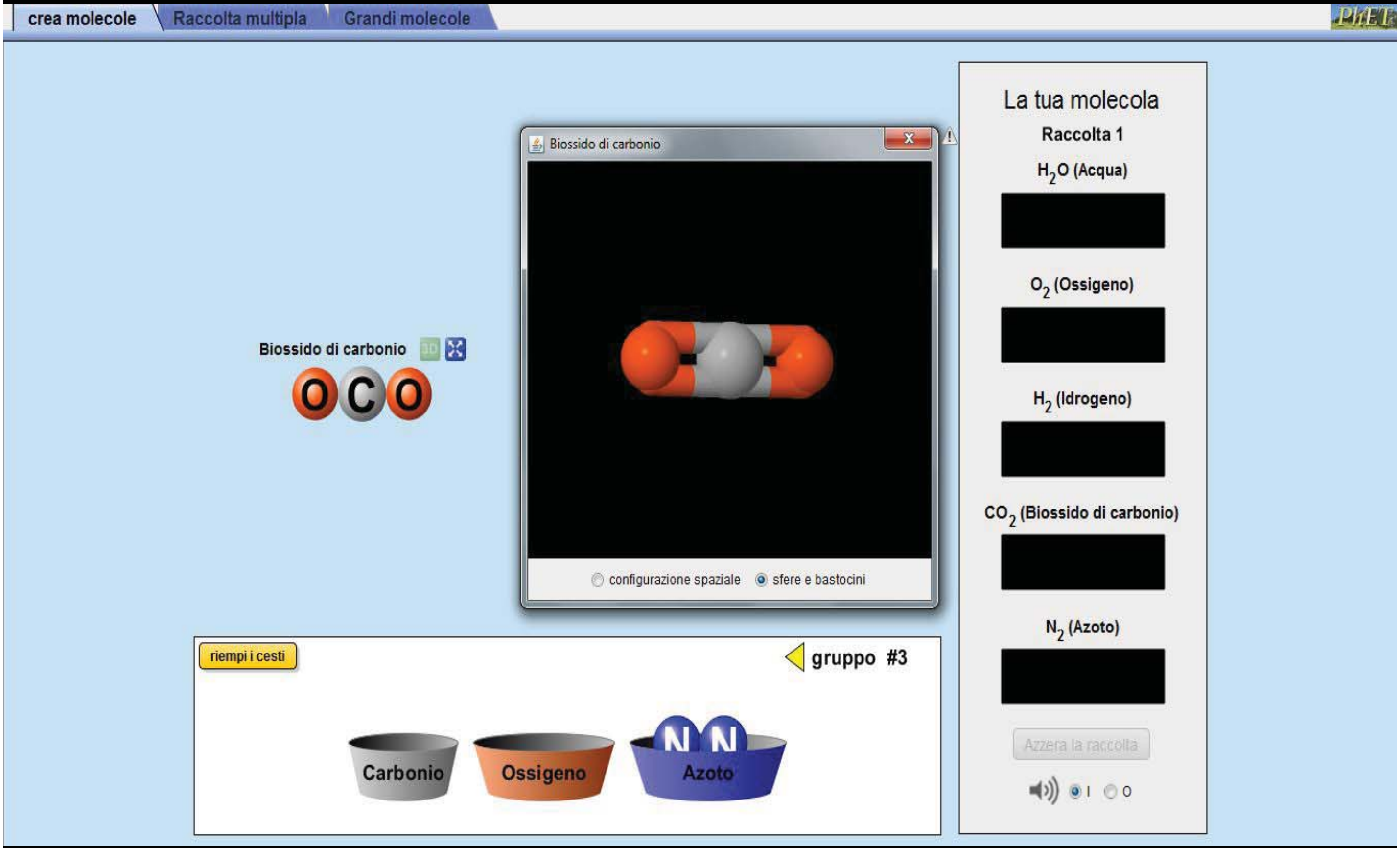






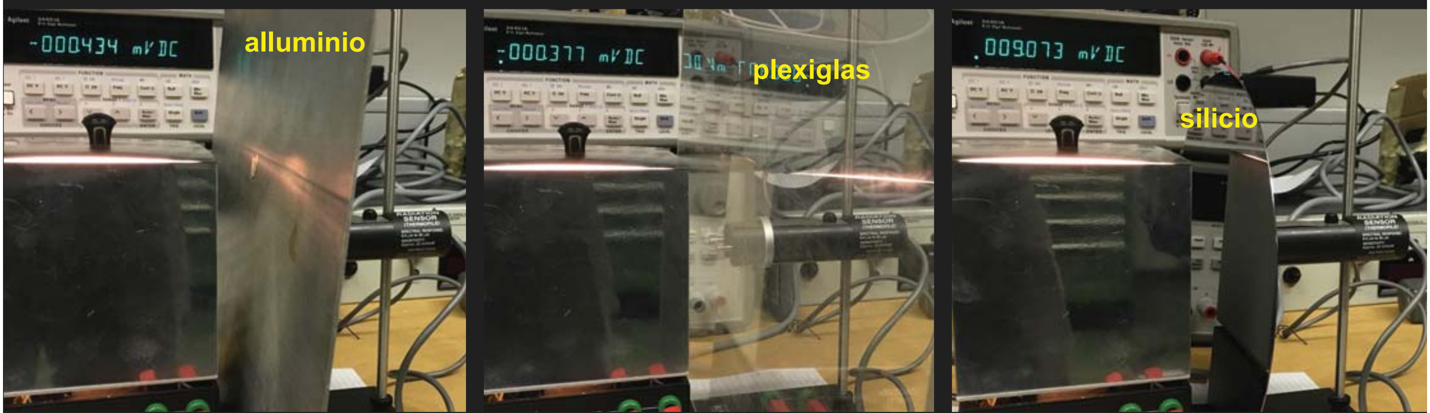


Costruire le molecole dei gas serra



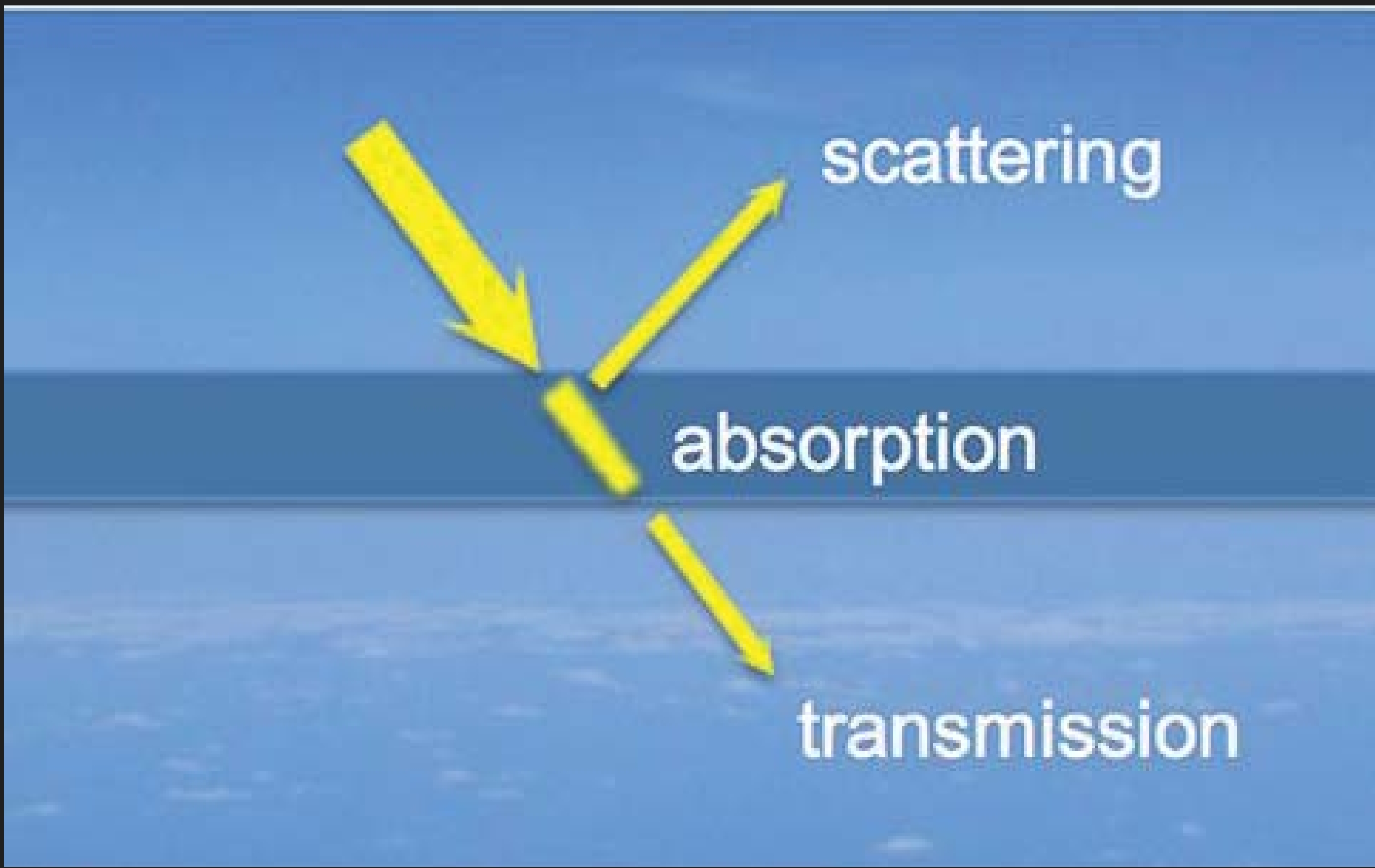
Applet Phet: https://phet.colorado.edu/it/simulation/build-a-molecule

Materiali opachi e trasparenti...
Rispetto a quale tipo di radiazione elettromagnetica?

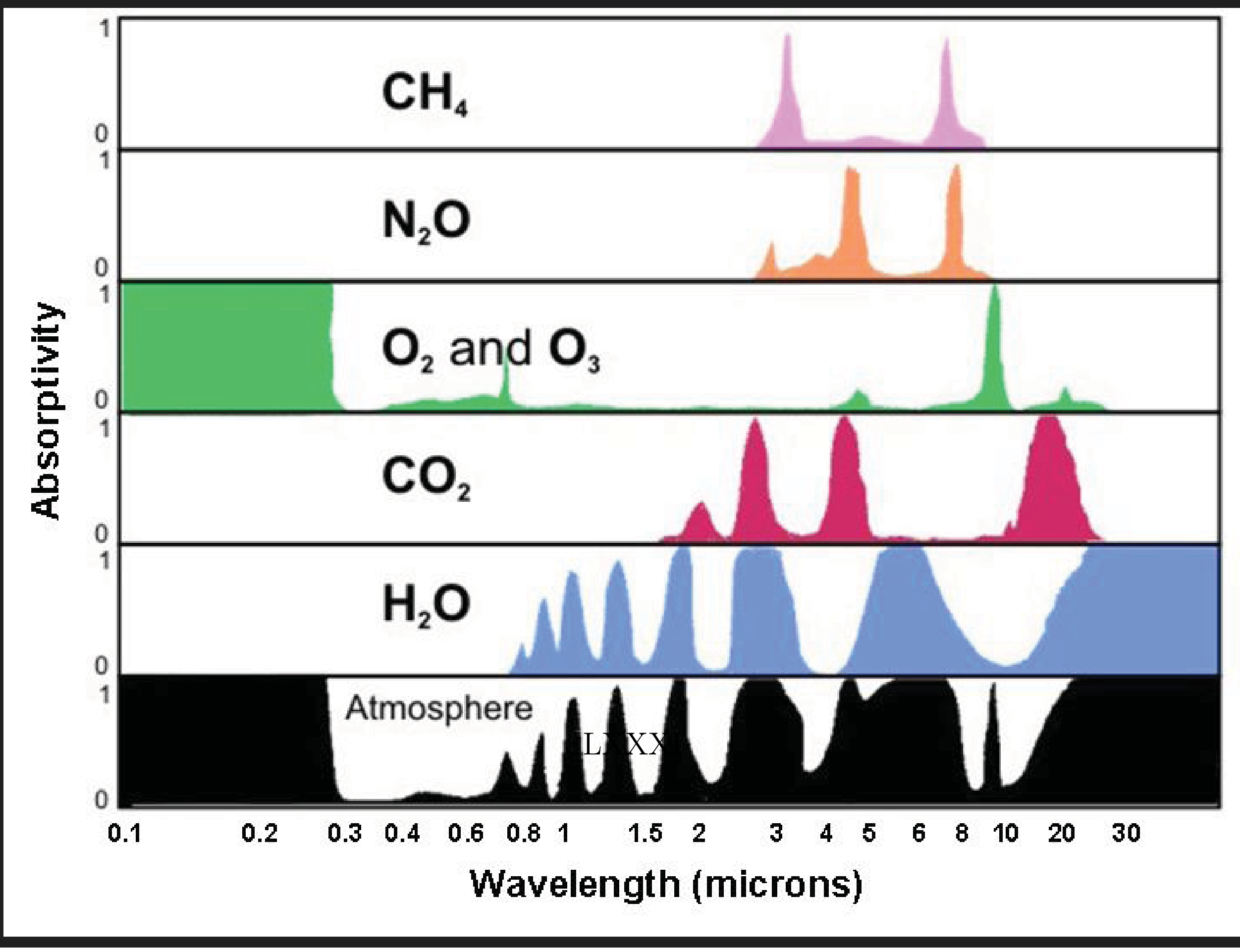


- tra il cubo di Leslie e il radiometro (termopila), interpongo delle lastre di **diversi materiali** (vetro, plexiglas, wafer di silicio ecc.)
- osservo come varia la tensione ai capi termopila (intensità emessa o irradianza)
- concetto di **opacità** e **trasparenza** è **relativo** al **tipo di radiazione**!
- Similmente **l'atmosfera** è quasi trasparente per la radiazione solare, mentre non lo è per la radiazione terrestre (assorbimento e riemissione da parte dei gas serra)

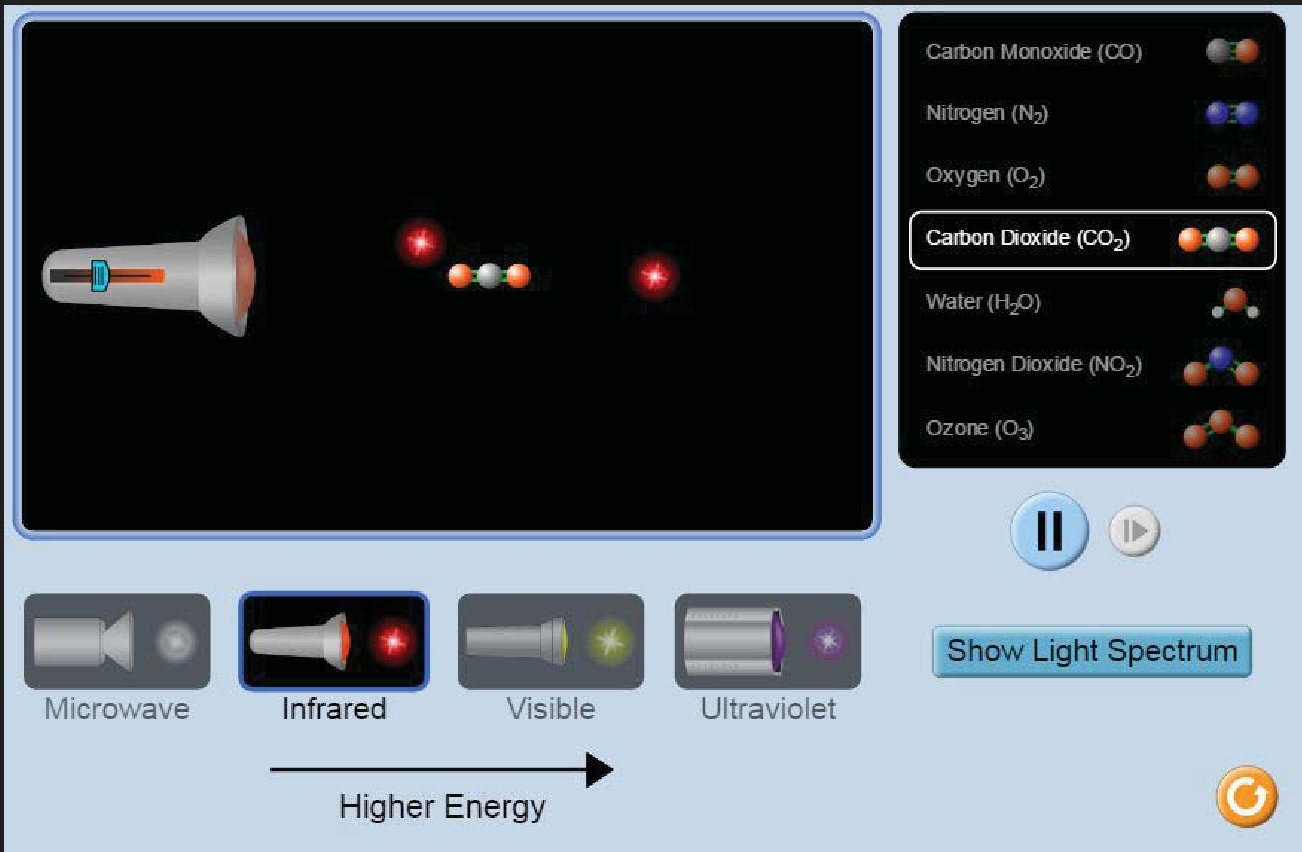
Diffusione, assorbimento, trasmissione in atmosfera



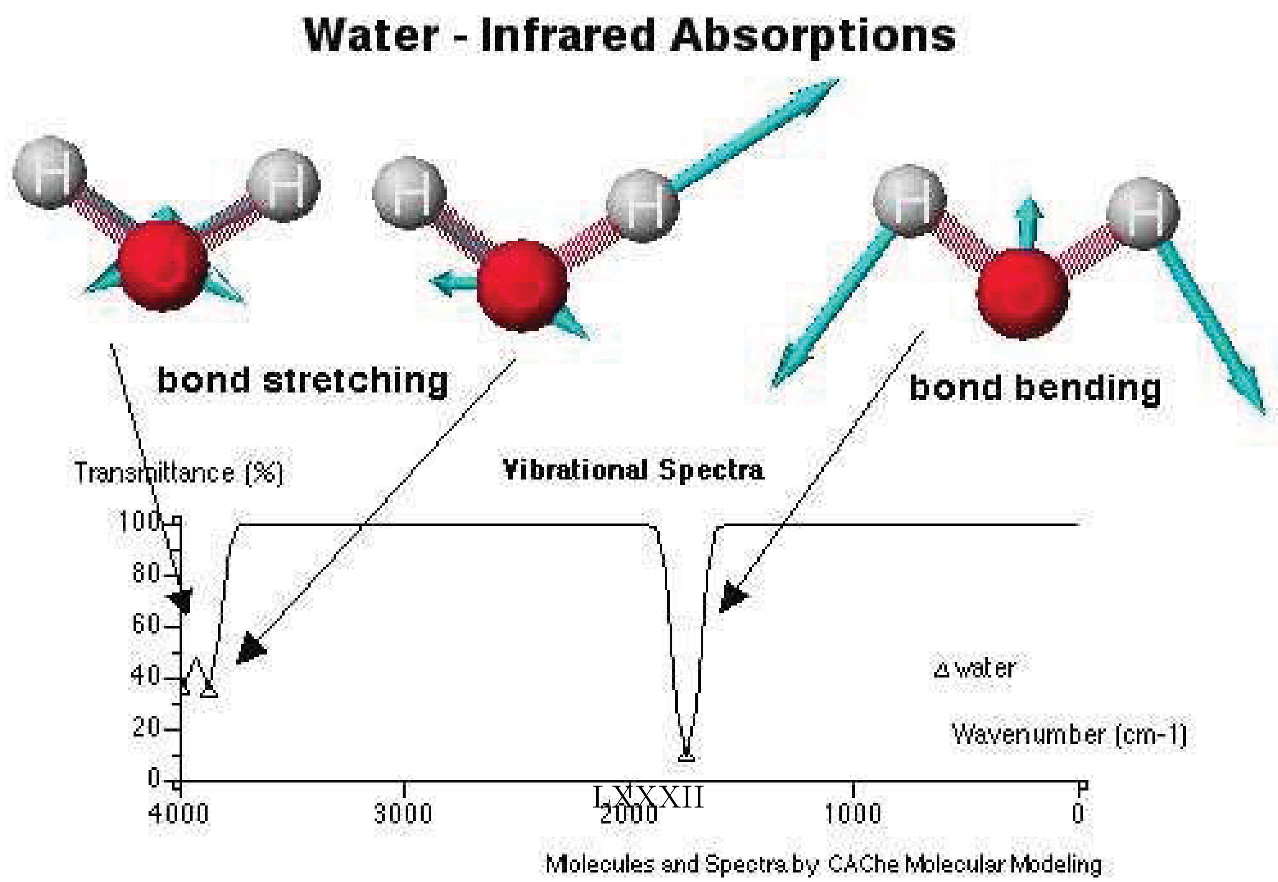
i gas serra e la radiazione elettromagnetica



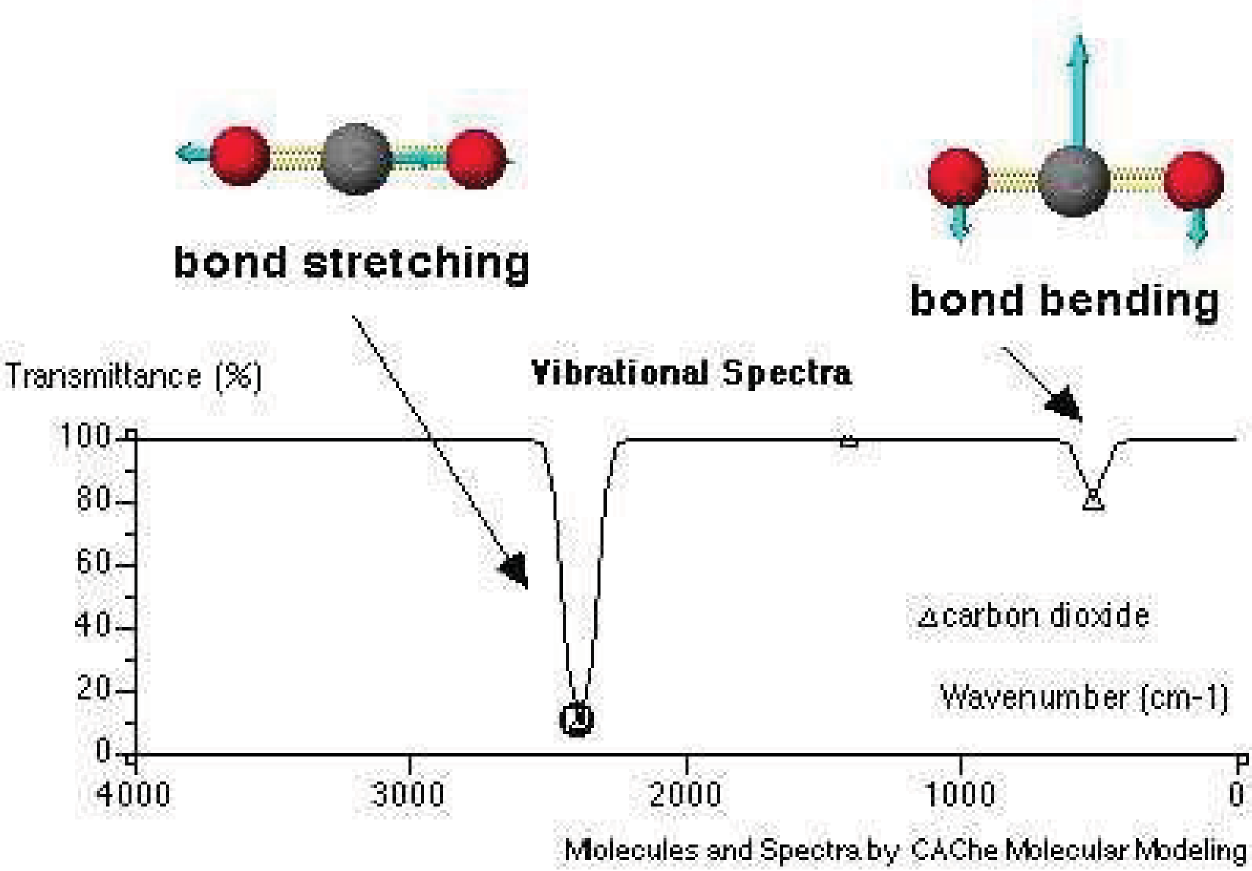
Interazione molecole e radiazione elettromagnetica



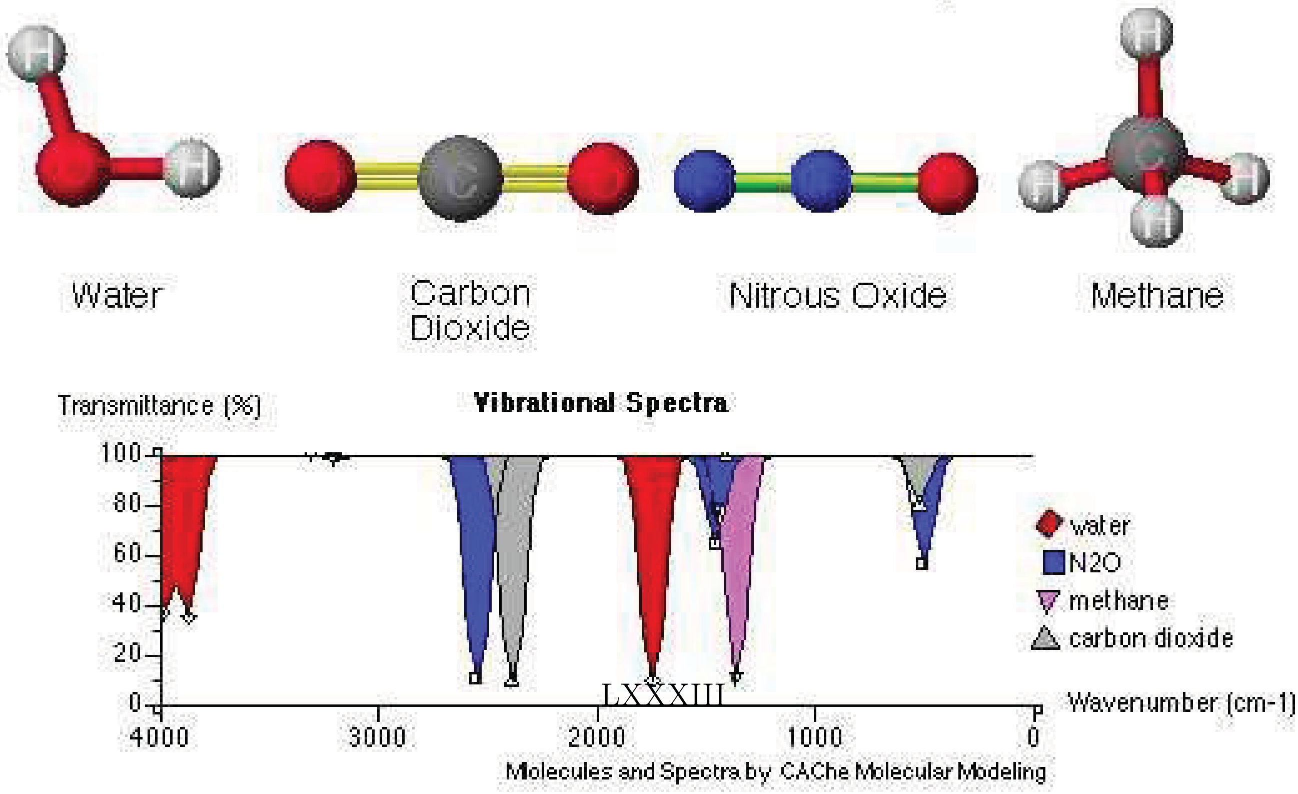
Applet Phet - https://phet.colorado.edu/en/simulation/molecules-and-light



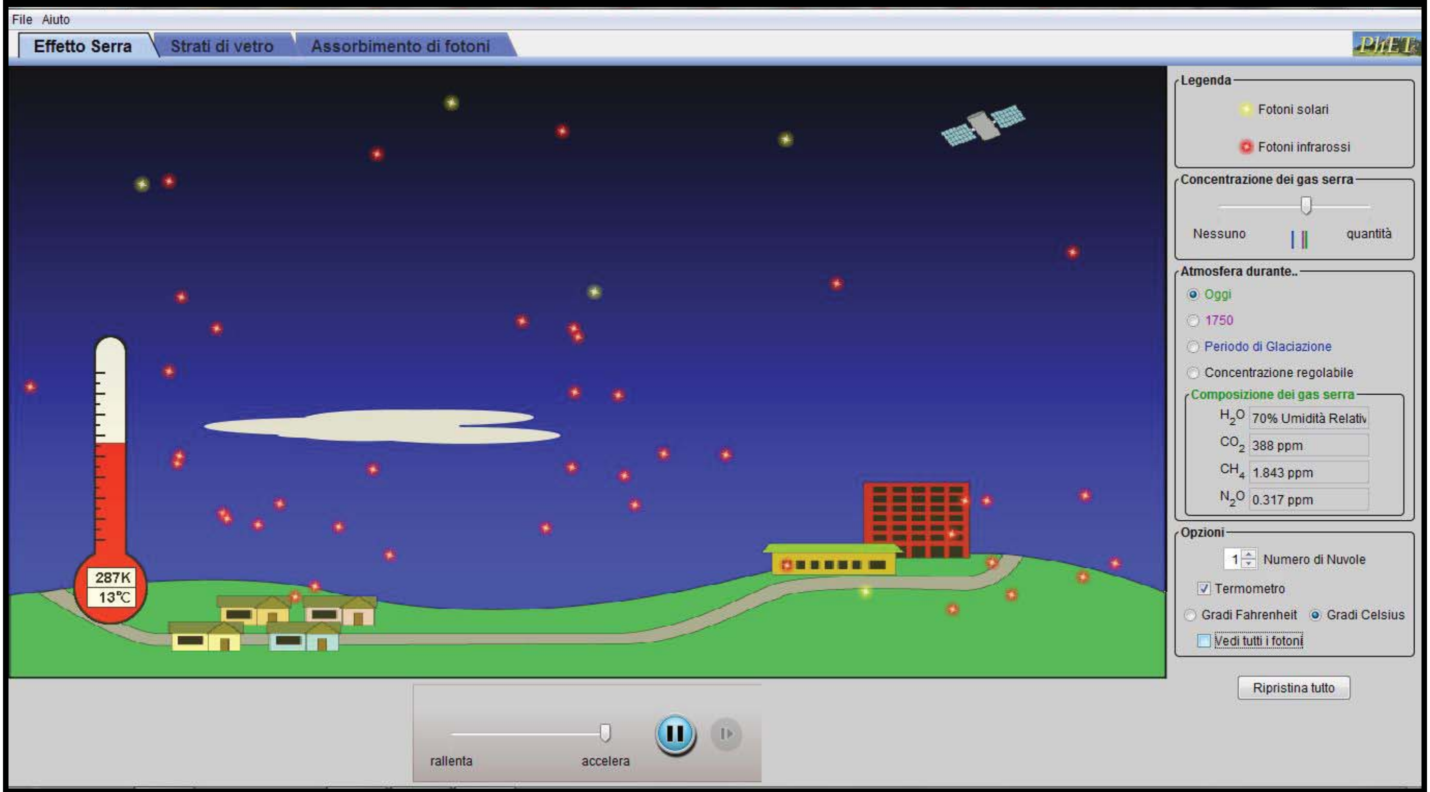
Carbon Dioxide - Infrared Absorption



Greenhouse Gases - All Infrared Absorptions

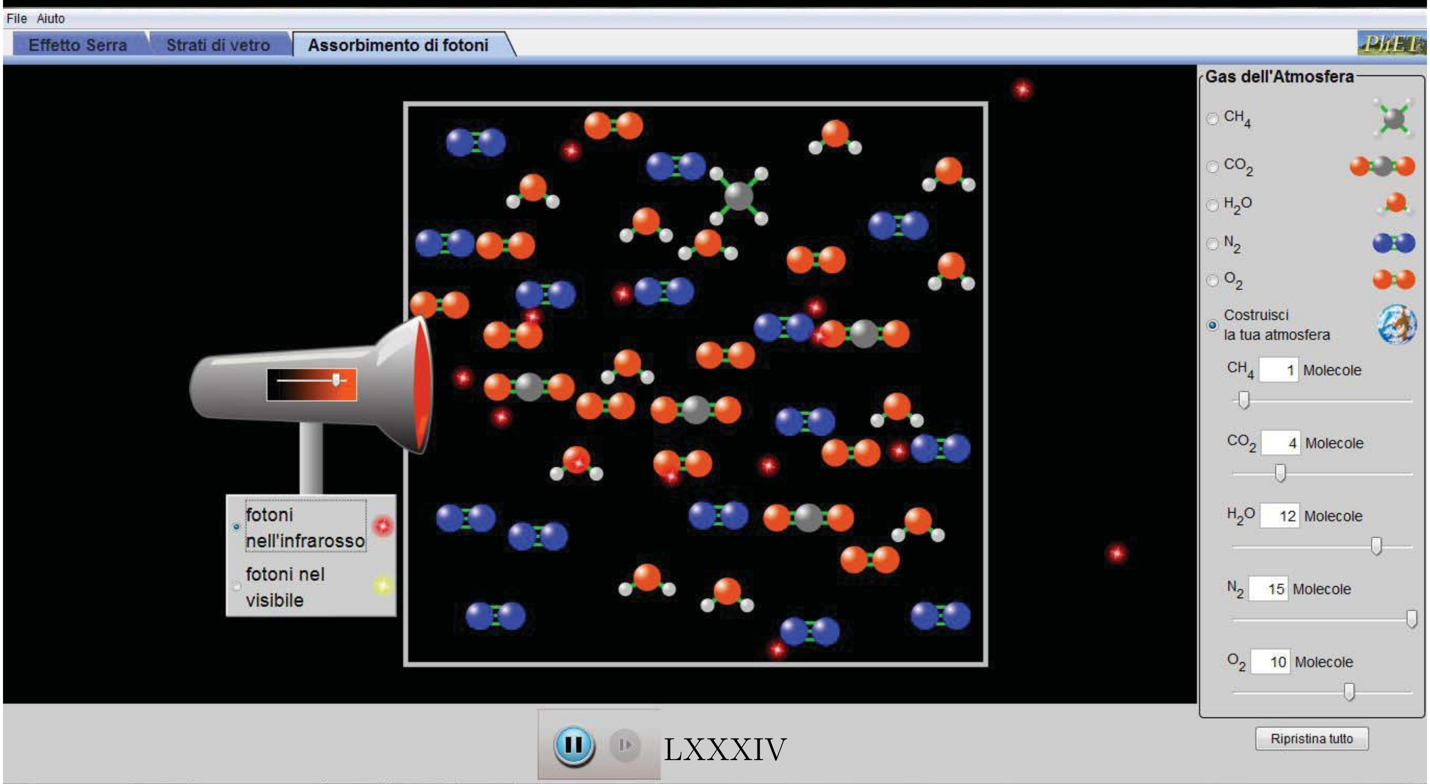


Effetto serra con un'applet



Applet effetto serra: https://phet.colorado.edu/it/simulation/greenhouse

Effetto serra con un'applet

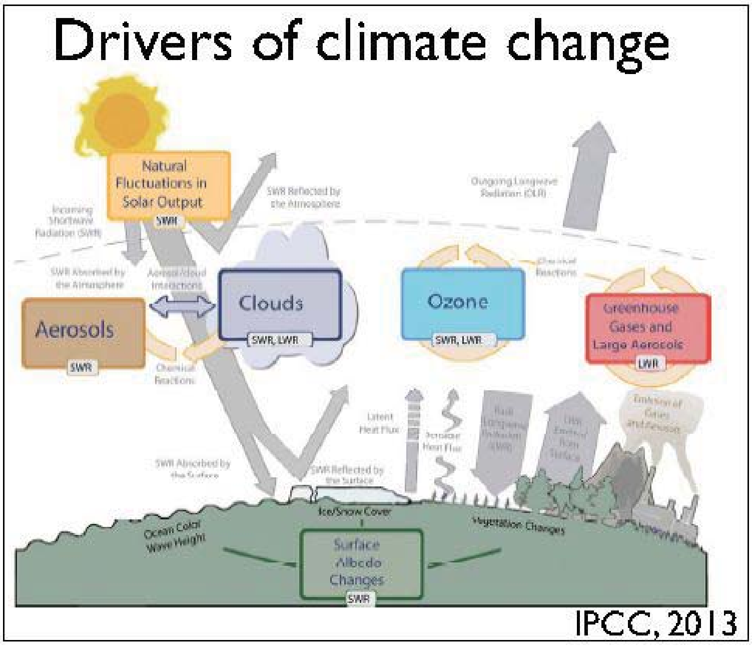


Applet effetto serra: https://phet.colorado.edu/it/simulation/greenhouse
Un video: www.youtube.com/watch?v=sTvqIijqvTg&t=7s

Variabilità - sistema climatico

Forzanti esterne al sistema

RF è una misura del cambio netto nel bilancio energetico in risposta a una perturbazione esterna (causando cambiamenti in variabili climatiche come la temperatura: effetti di raffreddamento o riscaldamento).



Gli elementi possono causare cambi nel clima includono
- cambiamenti nell'irradianza solare;
- cambiamenti nelle concentrazioni atmosferiche di gas in traccia e aerosol;
- ...

Una volta che un forzante è applicato, sono i meccanismi di retroazione che determinano la risposta (non lineare) finale del sistema

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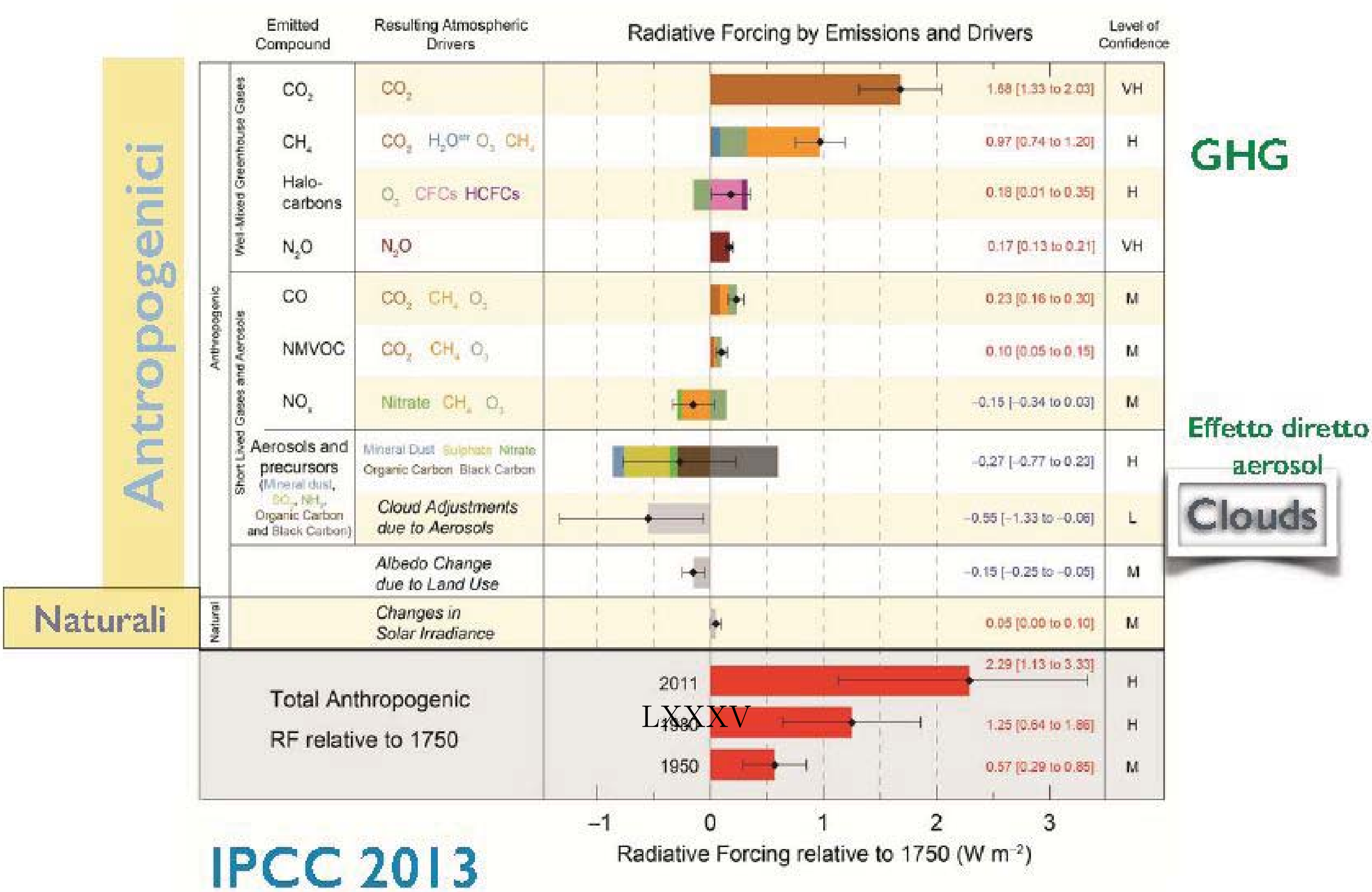
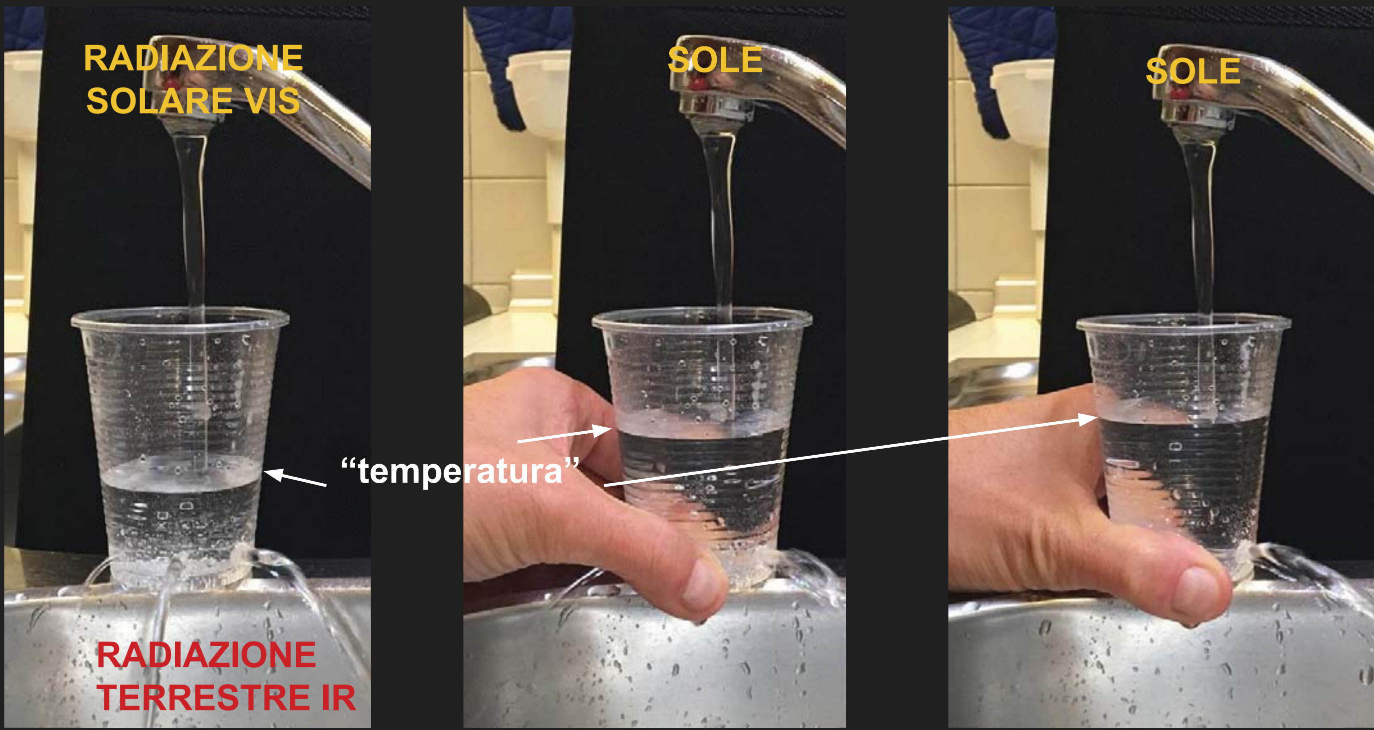
Forzanti esterne al sistema



IPCC 2013

L'effetto serra in un bicchiere



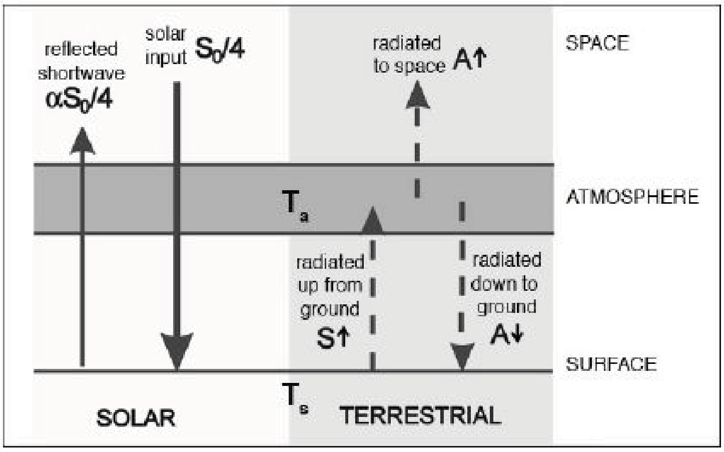
no effetto serra

effetto serra naturale

effetto serra anomalo (emissioni umane / suolo)

Un video sull'effetto serra (NASA) https://www.youtube.com/watch?v=ZzCA60WnoMk

Modello di effetto serra - I



Assunzioni

Consideriamo un solo strato di atmosfera:
- trasparente alla radiazione solare
- totalmente opaco alla radiazione IR terrestre

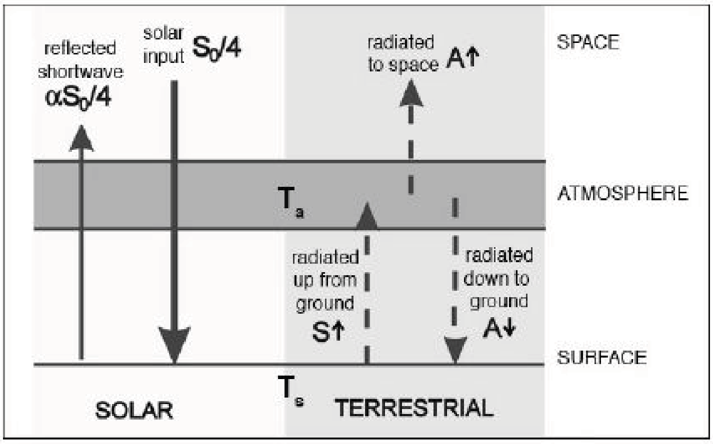
$$A \uparrow = \sigma T_a^4$$

TOA $$\sigma T_a^4 = \frac{1}{4}(1-\alpha_p)S_0 = \sigma T_e^4$$

LXXXVI

Alla superficie $$\underbrace{\frac{1}{4}(1-\alpha_p)S_0}_{\sigma T_a^4} + \underbrace{A\downarrow}_{\sigma T_a^4} = \underbrace{S\uparrow}_{\sigma T_s^4}$$

Modello di effetto serra -1



Assunzioni

Consideriamo un solo strato di atmosfera:

- trasparente alla radiazione solare
- totalmente opaco alla radiazione IR terrestre

$$A\uparrow = \sigma T_a^4$$

$$\sigma T_a^4 = \frac{1}{4}(1-\alpha_p)S_0 = \sigma T_e^4$$

$$\underbrace{\frac{1}{4}(1-\alpha_p)S_0}_{\sigma T_a^4} + \underbrace{A\downarrow}_{\sigma T_a^4} = \underbrace{S\uparrow}_{\sigma T_s^4}$$

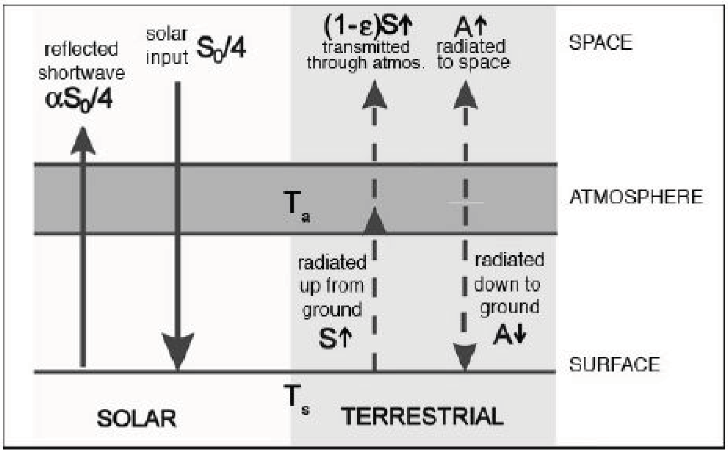
$$2\sigma T_e^4 = \sigma T_s^4$$

$$T_s = \sqrt[4]{2}T_e$$

$$T_e = 255K$$

$$T_s = 303K$$

Modello di effetto serra -2



Assunzioni

Consideriamo un solo strato di atmosfera:

- trasparente alla radiazione solare
- parzialmente opaco alla radiazione IR terrestre

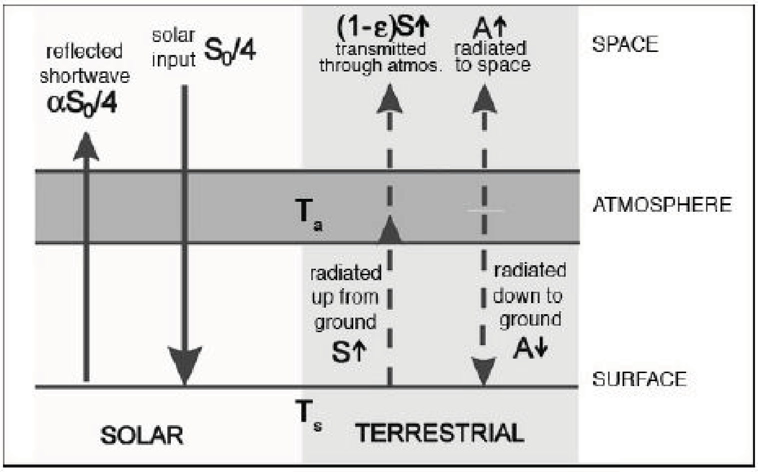
Una frazione ε della radiazione terrestre è assorbita dall'atmosfera, il resto (1-ε) è trasmessa

TOA $$\frac{1}{4}(1-\alpha_p)S_0 = (1-\epsilon)S\uparrow + A\uparrow$$

Surface $$\frac{1}{4}(1-\alpha_p)S_0 + A\downarrow = S\uparrow$$

Equilibrio $$A\uparrow = A\downarrow \qquad S\uparrow = \sigma T_s^4 = \frac{2}{2-\epsilon}T_e^4 \qquad T_s = \sqrt[4]{\frac{2}{2-\epsilon}}T_e$$

Modello di effetto serra -2



$$T_s = \sqrt[4]{\frac{2}{2-\epsilon}}T_e$$

$$T_a = \sqrt[4]{\frac{\epsilon}{2-\epsilon}}T_e$$

$$T_a < T_s$$

	Ta	Ts	Ts-Ta
ε=1	255	303	48
ε=0.77	227	288	61

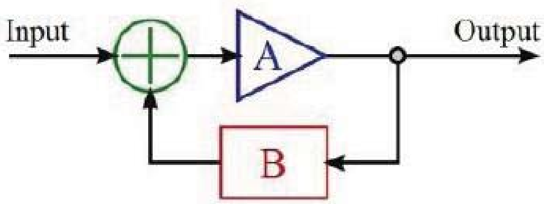
Atmosfera **totalmente opaca** alla radiazione IR

Atmosfera **parzialmente opaca** alla radiazione IR (diminuisce sia Ta sia Ts)

Variabilità - sistema climatico

Variabilità interna del clima - Retroazioni

"An interaction mechanism between processes in the climate system is called a climate feedback when the result of an initial process triggers changes in a second process that in turn influences the initial one (IPCC 2013, glossary)".

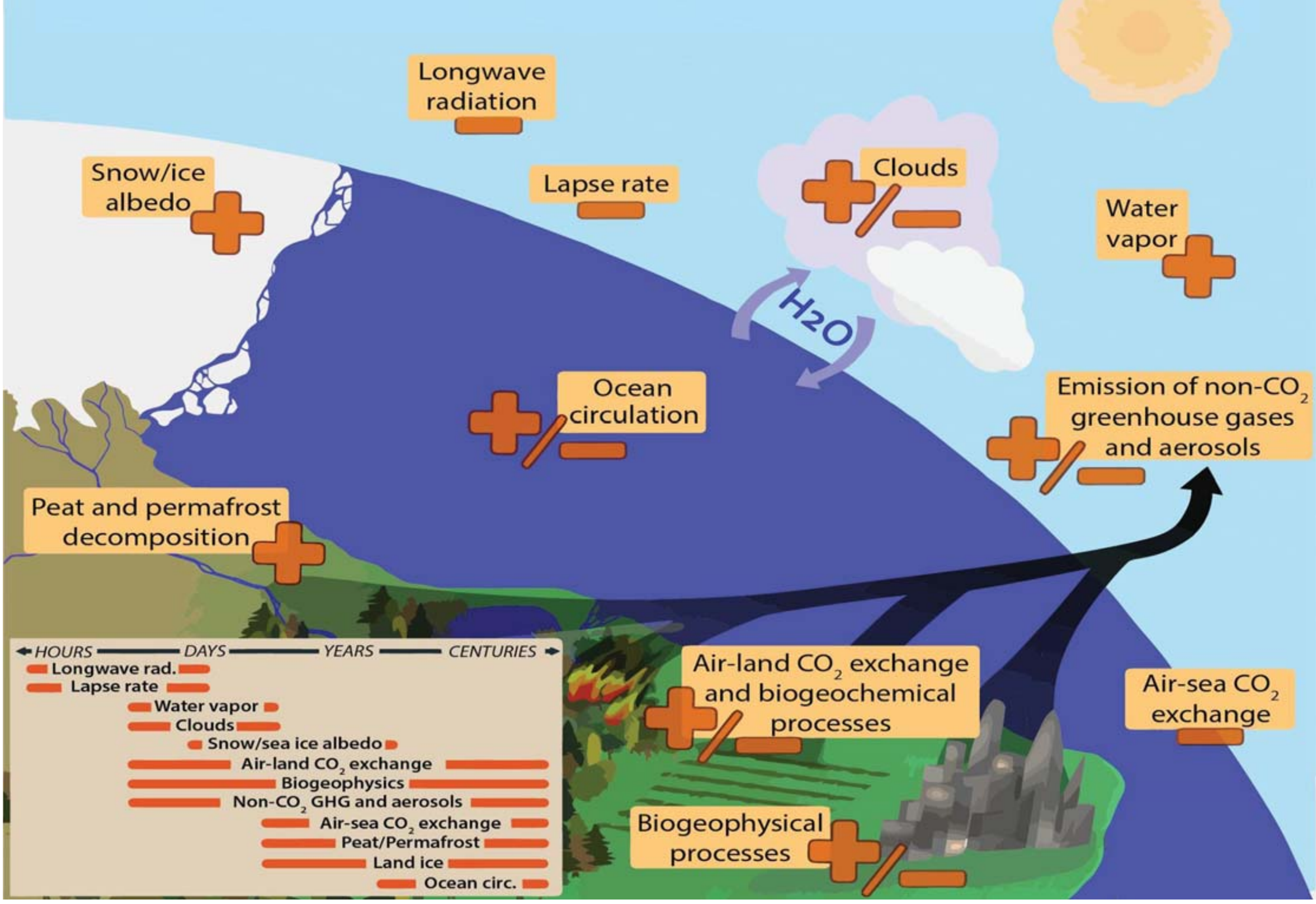


Processi che **amplificano (feedback positivi)** o **riducono (feedback negativi)** una forzante iniziale, ovvero una forza esterna persistente nel tempo.
Le amplificazioni o gli smorzamenti possono essere molti intensi.

Feedback **POSITIVI**: **amplificano**

Feedback **NEGATIVI**: **riducono**, **stabilizzano**

Interazioni e feedback nel sistema climatico



Variabilità - sistema climatico

Variabilità interna del clima - Retroazioni

Feedback POSITIVI		Feedback NEGATIVI
Ghiaccio-albedo (es: feedback fisico)		
Vapore acqueo	⟷	Lapse rate Temperatura
	NUBI	
Oceani		Oceani
Permafrost-metano		
Albedo-precipitazione-vegetazione (es: feedback biogeofisico)		
Amplificazione		Stabilizzazione

Variabilità - sistema climatico

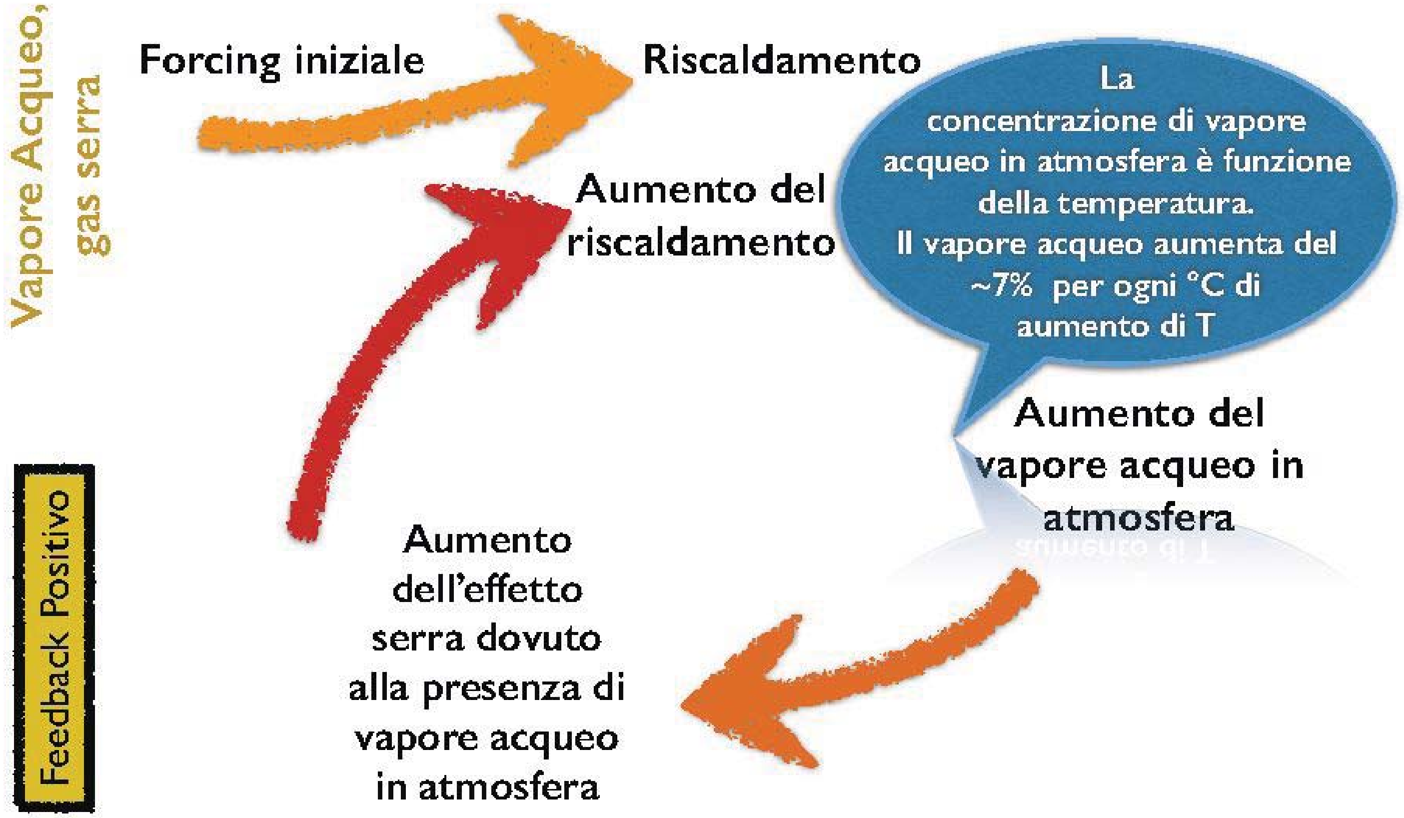
Un semplice esperimento qualitativo (albedo feedback)

- Due piastre (una nera e una bianca) sotto una lampada con una lastra di latte ghiacciato sopra. Misuro tempo di scioglimento e il volume di latte sciolto nel tempo raccolto da ciascuna lastra.

- Altri esempi:
  - www.youtube.com/watch?v=xHFrnVvDS8rQ
  - www.youtube.com/watch?v=u7tdI5NdX44
- Effetti in Artico: www.youtube.com/watch?v=SxqWgoR5Xrg

Variabilità - sistema climatico

Variabilità interna del clima - Retroazioni



Variabilità - sistema climatico

Variabilità interna del clima - Retroazioni

Vapore Acqueo, gas serra

Feedback Positivo

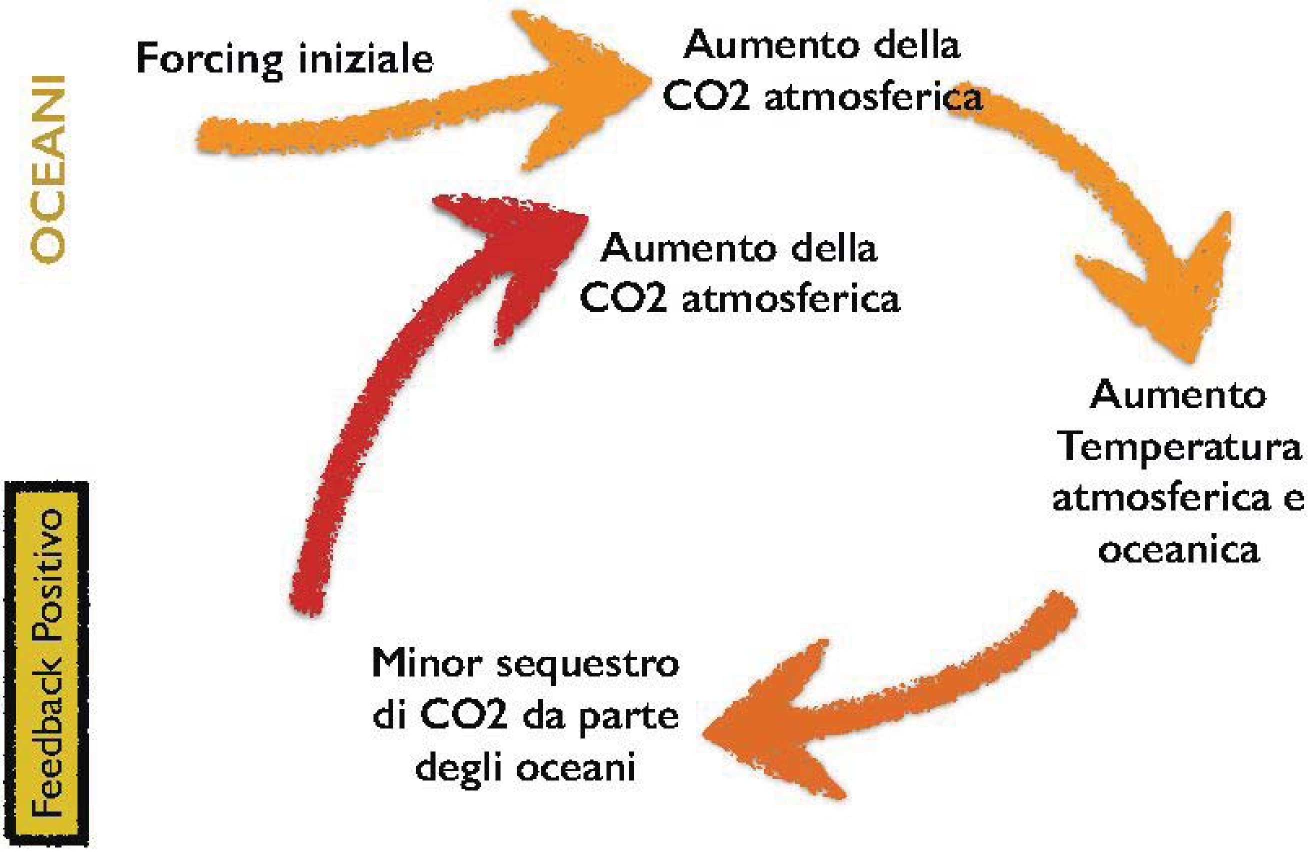
Poichè il **vapore acqueo è direttamente legato alla temperatura, esso rappresenta uno dei meccanismi di retroazione più forti nel sistema climatico,** in grado di amplificare il riscaldamento dovuto ad altri forzanti esterni, come l'aumento di CO2.

In assenza di altri feedbacks, il raddoppio della concentrazione di CO2 in atmosfera farebbe aumentare la Temperatura di poco più di 1 °C. La retroazione positiva associata al vapore acqueo singolarmente fa grosso modo raddoppiare il riscaldamento dovuto all'aumento di CO2 e il riscaldamento risulta ulteriormente amplificato includendo altri meccanismi di retroazione.

GLI EFFETTI DEI FEEDBACKS SI COMBINANO (in maniera non lineare)

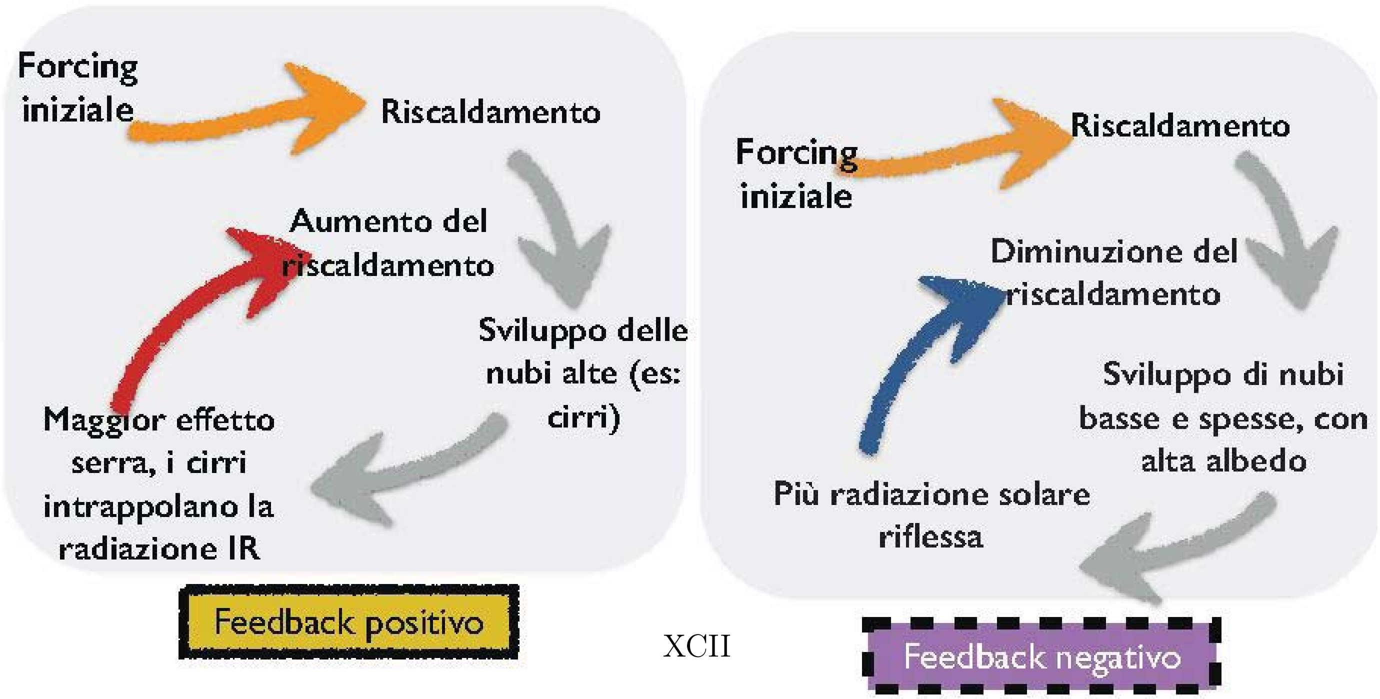
Variabilità - sistema climatico

Variabilità interna del clima - Retroazioni



Variabilità - sistema climatico

Variabilità interna del clima - Retroazioni



NUBI

una delle caratteristiche ancora meno conosciute del sistema climatico e fonte di incertezza nei modelli che simulano il clima

Variabilità - sistema climatico

Variabilità interna del clima - Retroazioni

OCEANI

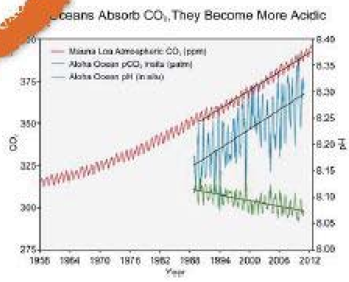
Feedback Positivo

Forcing iniziale

Riscaldamento

Aumento acidificazione degli oceani (diminuzione del pH)

Una proposta sperimentale: misura del pH di acqua frizzante e naturale



In un ambiente più acido il fitoplancton rilascia meno solfuro dimetile, sostanza che genera aerosol raffreddanti in atmosfera

Aumento del riscaldamento

Variabilità - sistema climatico

Variabilità interna del clima - Retroazioni

Albedo-preciptazione

Feedback Positivo

Forcing iniziale

Diminuzione della copertura vegetale

Albedo più elevata

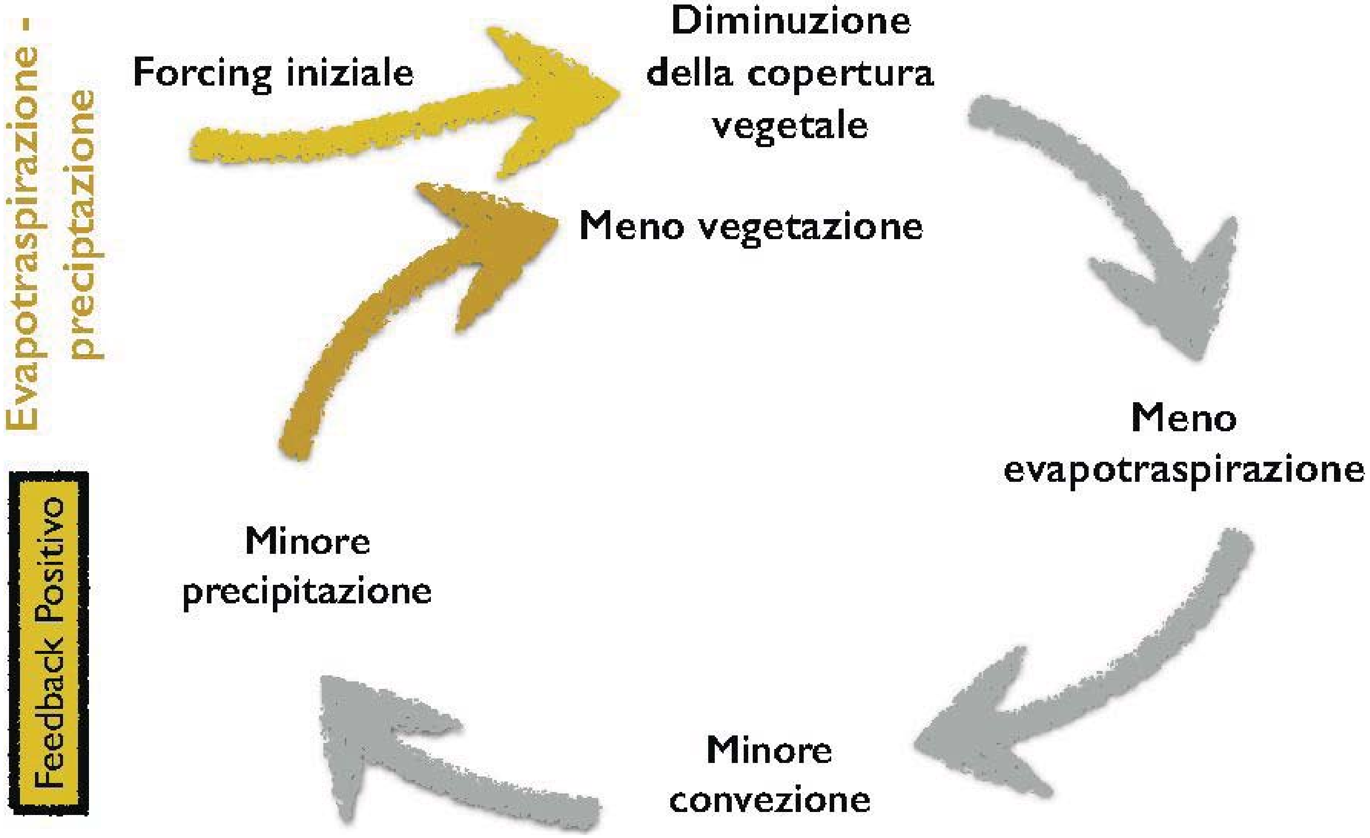
Abbassamento della Temperatura del suolo

Minore convezione e minore precipitazione

Meno vegetazione

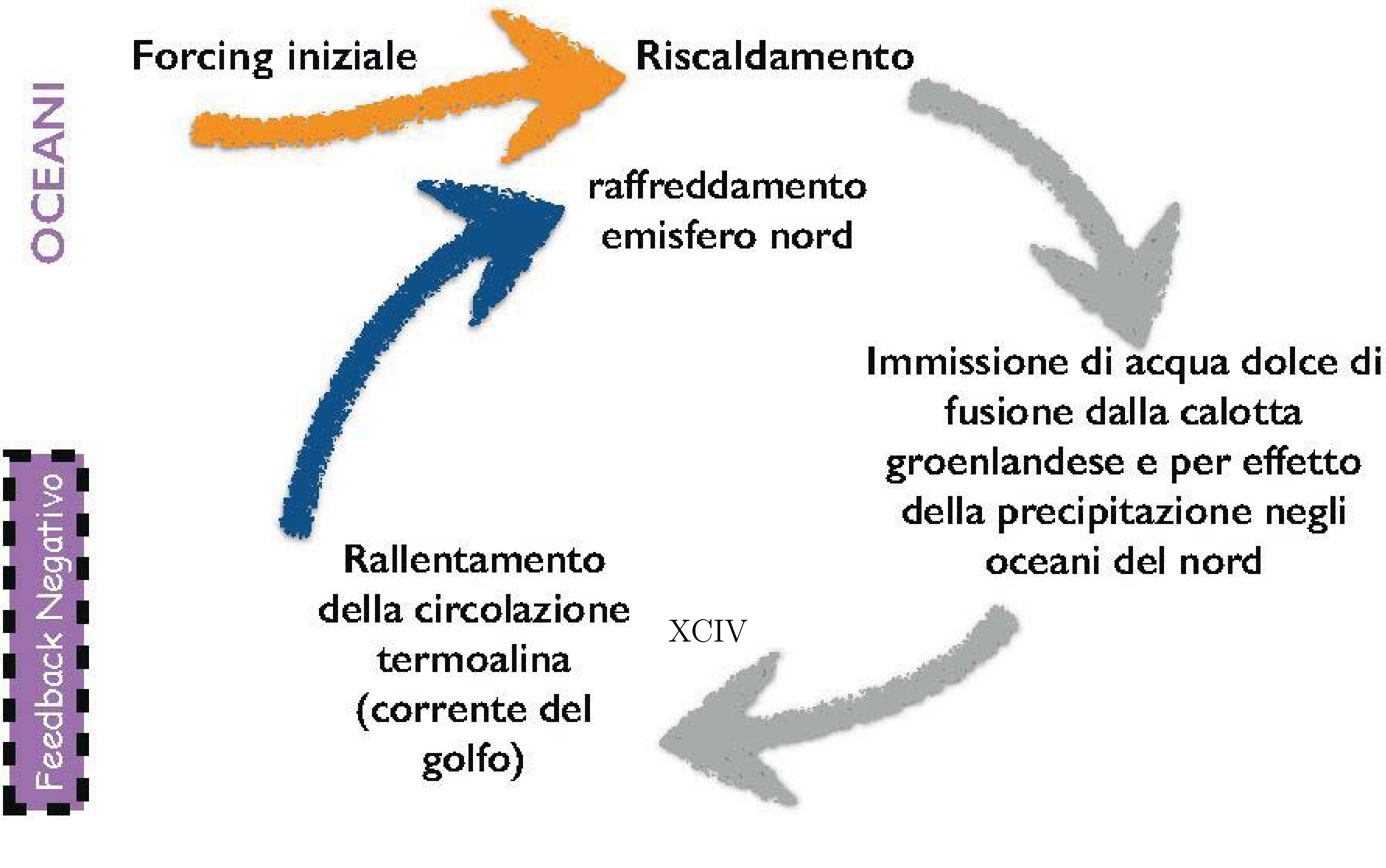
Variabilità - sistema climatico

Variabilità interna del clima - Retroazioni



Variabilità - sistema climatico

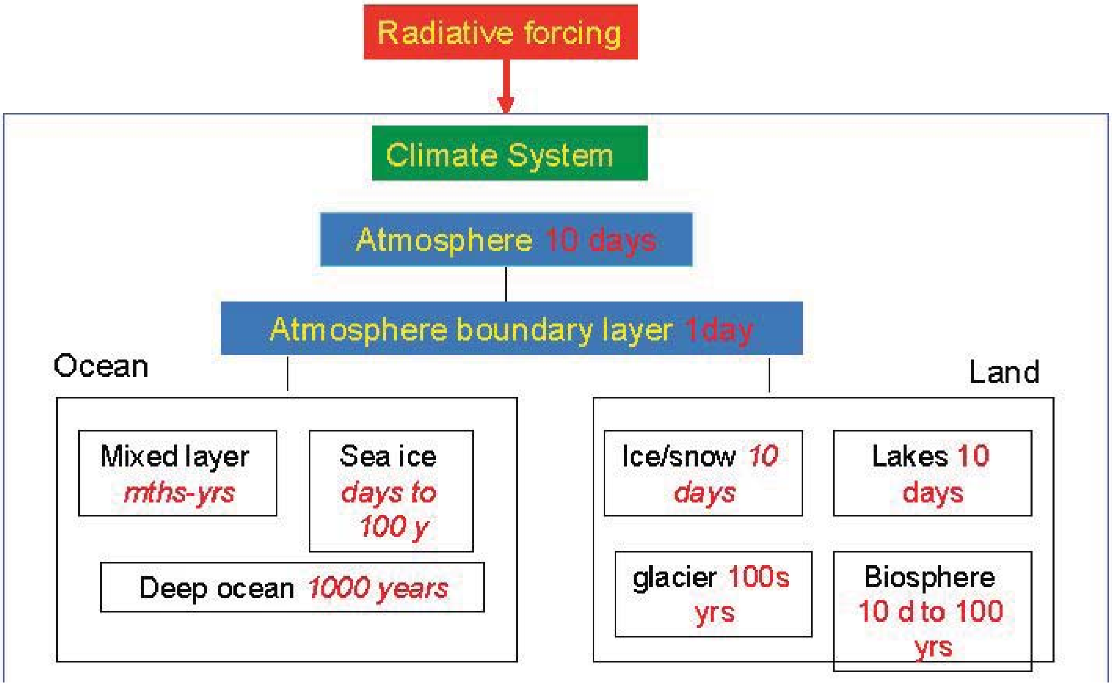
Variabilità interna del clima - Retroazioni



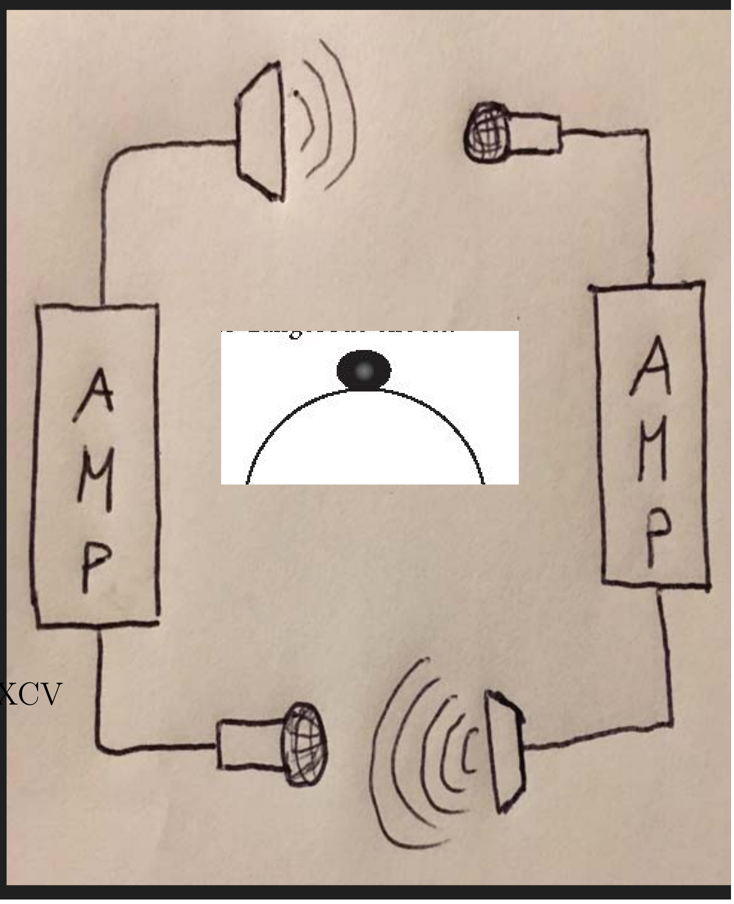
Variabilità - sistema climatico

Variabilità interna del clima - Retroazioni

L'importanza di un meccanismo di retroazione dipende dalle scale di tempo con cui i sottosistemi interessati "rispondono" al processo e impiegano per riequilibrarsi in seguito alla perturbazione che su essi ha agito.

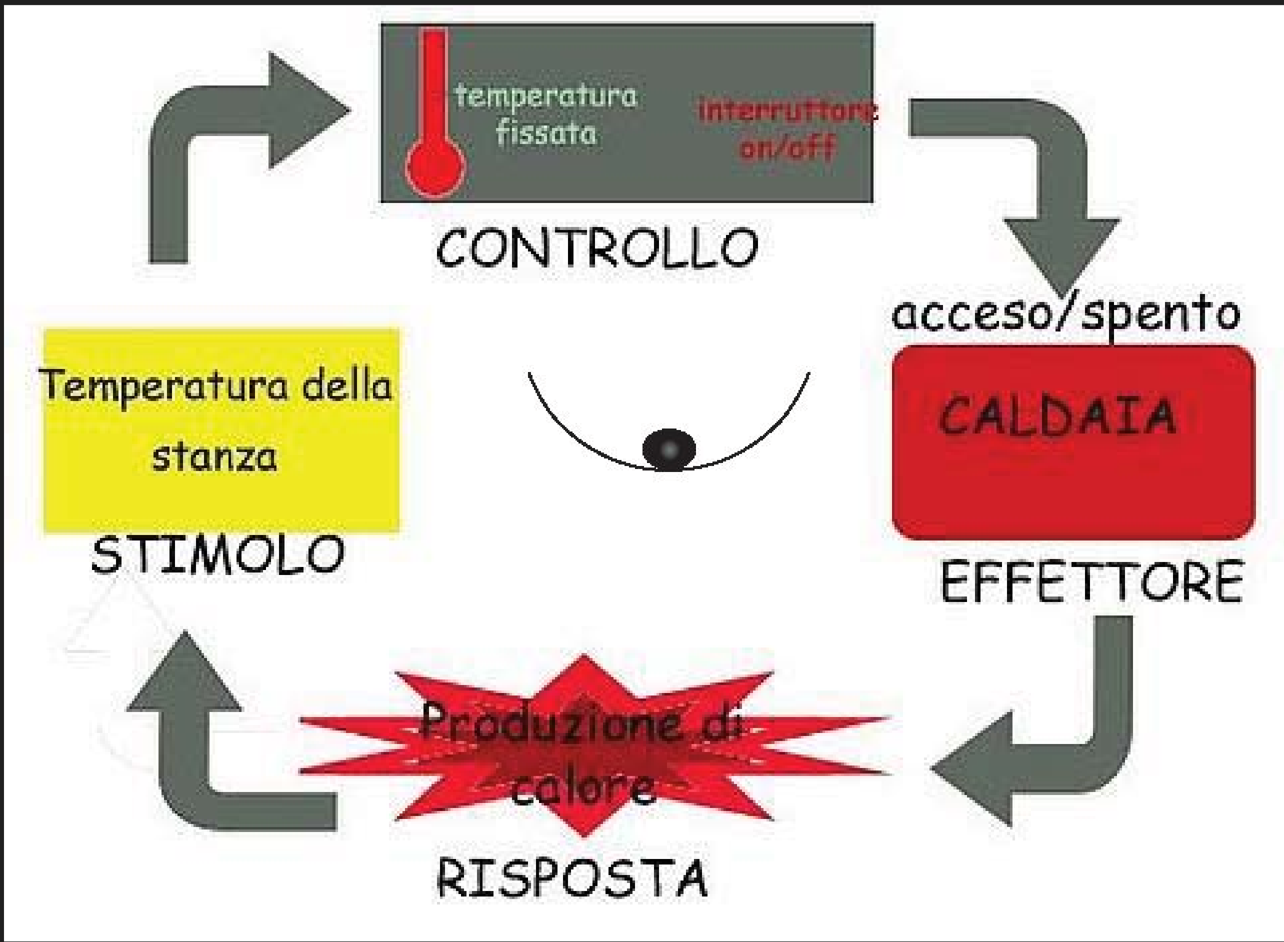


Un esempio di feedback positivo - effetto Larsen

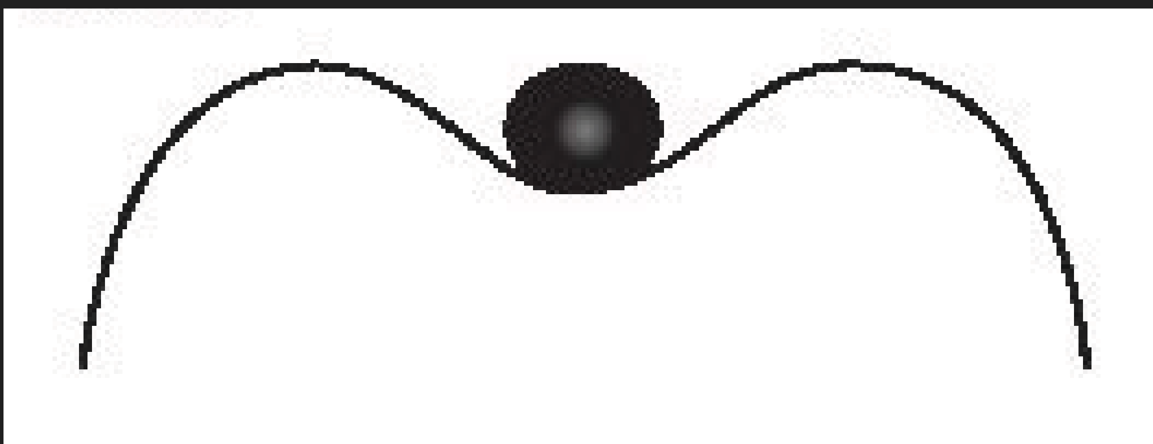


- ***chiamarsi con lo smartphone e accostarli (altoparlante a microfono)*** *- un piccolo rumore viene amplificato sempre di più fino a saturare il sistema*
- *lo stesso tra microfono e altoparlanti*

Un esempio di feedback negativo - il termostato



E il clima?

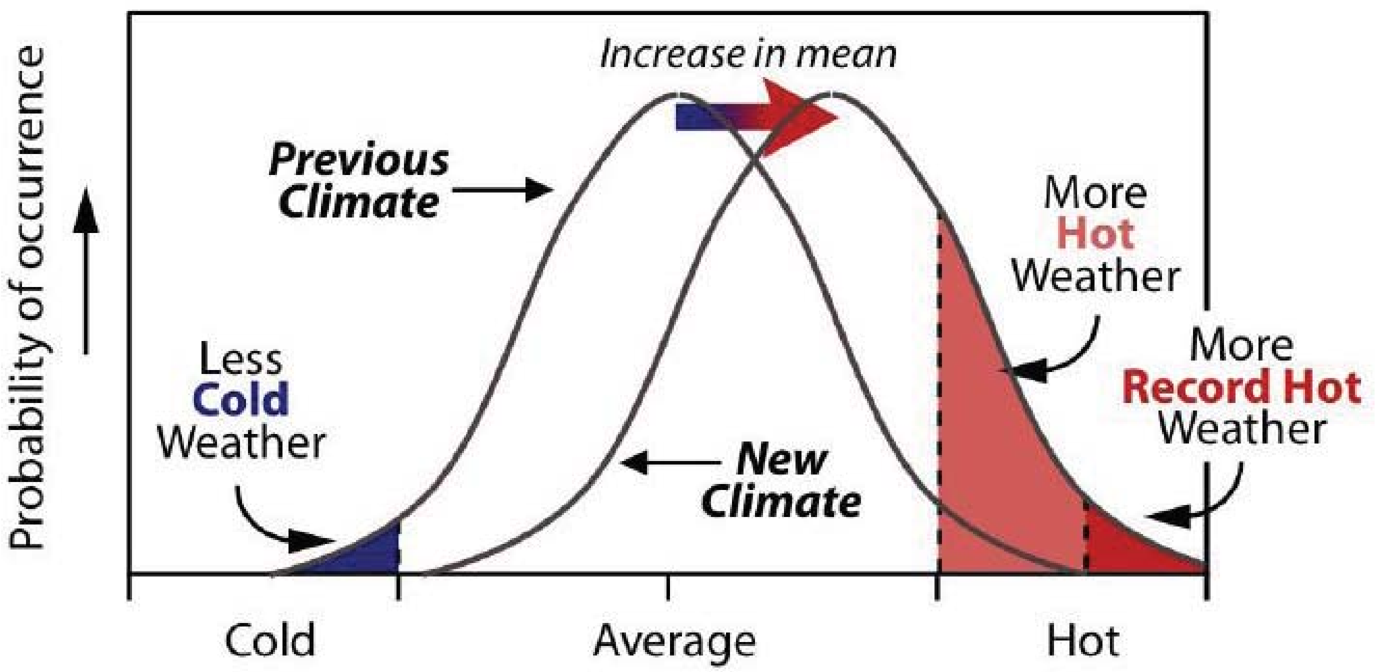


Il sistema climatico è in delicato equilibrio. Variazioni di alcune **forzanti** (come ad esempio le **emissioni di gas serra** nell'atmosfera) anche **piccole** possono **amplificarsi** con i meccanismi di **feedback** e **spostare** in maniera improvvisa e notevole **l'equilibrio** del sistema con conseguenze potenzialmente catastrofiche sulla vita

Il clima di domani

- Da un punto di vista **quantitativo** il clima può essere descritto come un **sistema dinamico di equazioni differenziali** non lineari
- L'evoluzione del sistema climatico può essere descritta nello **spazio delle fasi** a livello di **statistica** delle **traiettorie** sull'attrattore del sistema.

- **Modelli climatici** servono per calcolare l'andamento di queste traiettorie e la loro statistica
- Elaborazione di uno **scenario ipotetico** (società ed emissioni di gas serra ad esempio)
- **Proiezione climatica** (statistica): come si modifica la statistica delle traiettorie sull'attrattore del sistema (ad esempio come varierà in media la temperatura media del pianeta nel prossimo secolo in risposta allo scenario ipotizzato).



Al momento si ritiene impossibile "prevedere" la temperatura o la precipitazione su un dato luogo in un giorno preciso nel futuro (ad esempio il 23 settembre 2047), mentre si possono ottenere **proiezioni statistiche** e **probabilistiche** sulle caratteristiche tipiche delle variabili climatiche nel futuro.

A tal scopo si usano i **modelli climatici**, che prevedono come cambia la **statistica del clima**.

Previsioni di primo e secondo tipo: meteo e clima

Previsione di primo tipo: previsione dell'evoluzione temporale delle **singole "traiettorie"** percorse da un sistema (nello spazio delle fasi).

Sono **problemi ai valori iniziali** che prevedono la conoscenza dello stato del sistema ad un certo istante iniziale fissato, e una qualche legge del moto deterministica per far evolvere le traiettorie nel tempo.

Es:
- *Atmosfera: previsioni meteorologiche*
- *Oceano: previsioni stagionali dello stato di El Nino*

Previsione di secondo tipo: previsione di come variano le **proprietà statistiche** di un sistema al variare di un qualche parametro esterno (**forzante**).

Sono **problemi ai valori al contorno**, meno dipendenti dalle condizioni iniziali di un sistema soggetto a variazioni della forzatura esterna

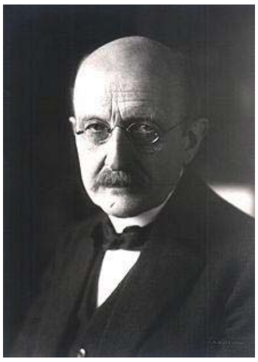
Ad es: *previsioni delle variazioni climatiche dovute a fattori esterni di origine naturale o antropica*

Dalla previsione meteorologica alla simulazione climatica

Nei modelli **meteorologici** il sistema che viene **descritto dinamicamente è l'atmosfera.**
Tutto ciò che sta alla sua interfaccia e che può influenzarne il comportamento è trattato come condizioni al contorno (es: *la quantità di radiazione emessa dal Sole, la temperatura media superficiale del mare*) che si ritengono invarianti per il periodo della previsione meteorologica (tipicamente 7-10 giorni).

Una simulazione climatica riguarda periodi più lunghi di quelli che caratterizzano la previsione meteorologica, durante i quali le condizioni al contorno non possono più essere considerate costanti, ma seguono una loro dinamica propria che interagisce con la dinamica atmosferica.

I modelli climatici globali si basano sulle leggi fondamentali della fisica ad es.



F=ma

E=hf

δQ=T*dS

Scale spaziali e temporali

$$\rho \frac{D\mathbf{u}}{Dt} = -\nabla p + \rho \mathbf{g} - \rho \Omega \wedge \mathbf{u} + \mathbf{F},$$

$$\frac{D\rho}{Dt} = -\rho \nabla \cdot \mathbf{u},$$

$$c_p \frac{D}{Dt} \ln \theta = \frac{Q}{T},$$

$$p = \rho RT.$$

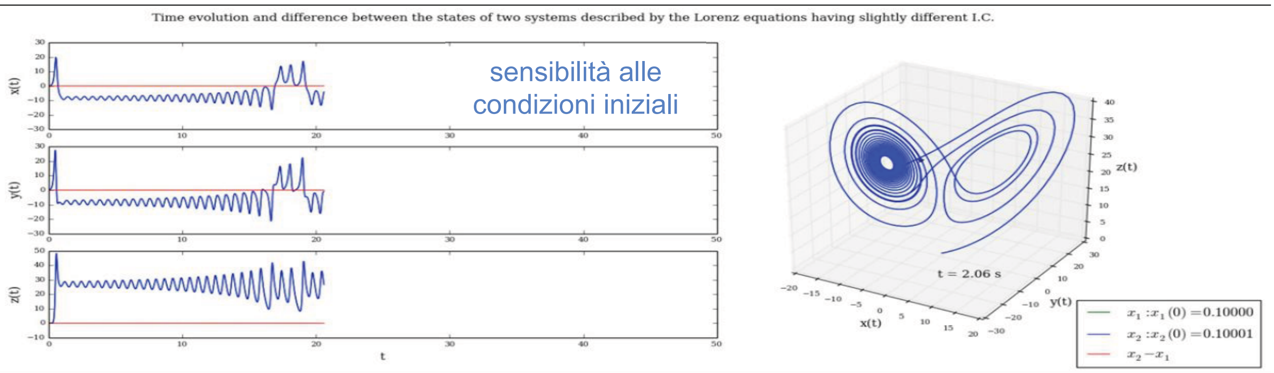
10000km

<100km

risorse di calcolo limitate! Al di sotto di una certa scala non risolvo dinamicamente i processi fisici, ma li includo indirettamente attraverso delle "parametrizzazioni" di tipo statistico

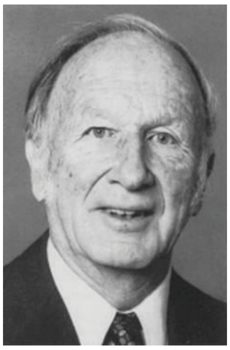
Caos deterministico - “l’effetto farfalla”

“Anche un battito d’ali di una farfalla in Brasile può provocare un uragano in Texas”



Evoluzione sistema di Lorenz: https://it.wikipedia.org/wiki/Attrattore_di_Lorenz

E.N. Lorenz



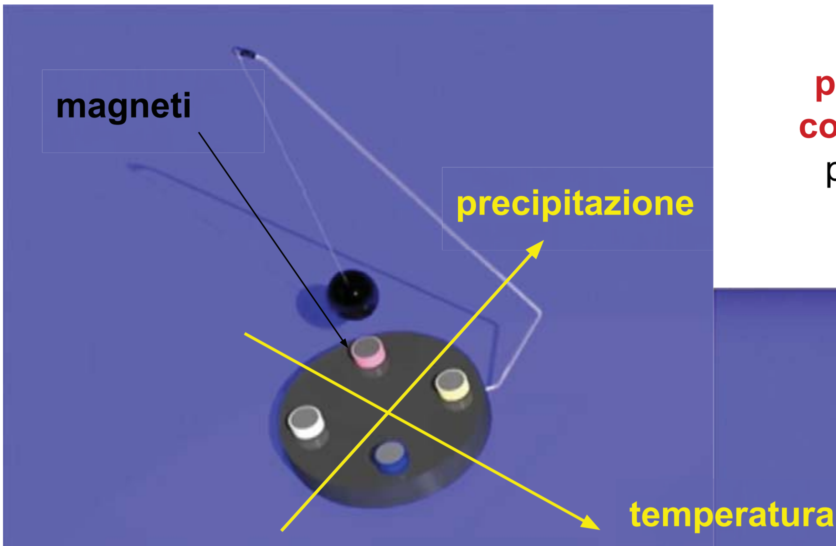
$$\frac{dx}{dt} = \sigma(y - x)$$

$$\frac{dy}{dt} = rx - y - xz$$

$$\frac{dz}{dt} = xy - bz$$

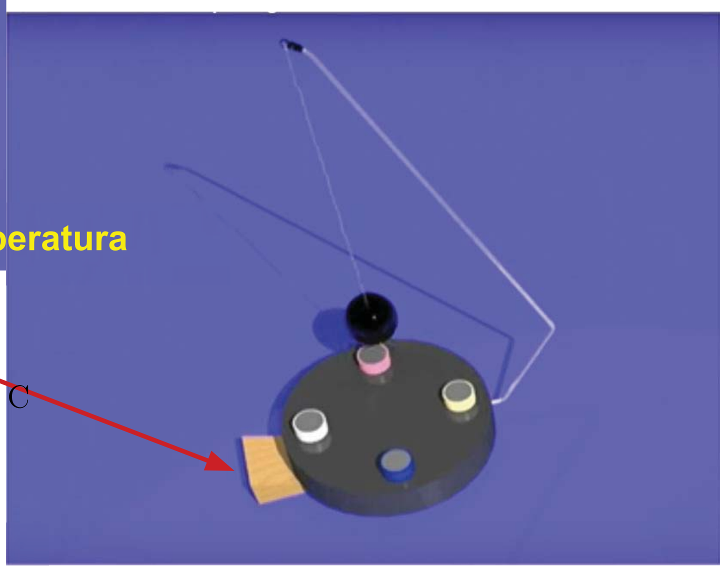
Attrattore di Lorenz

Caos, sistema dinamico, attrattore e predicibilità - una semplice attività: il pendolo magnetico

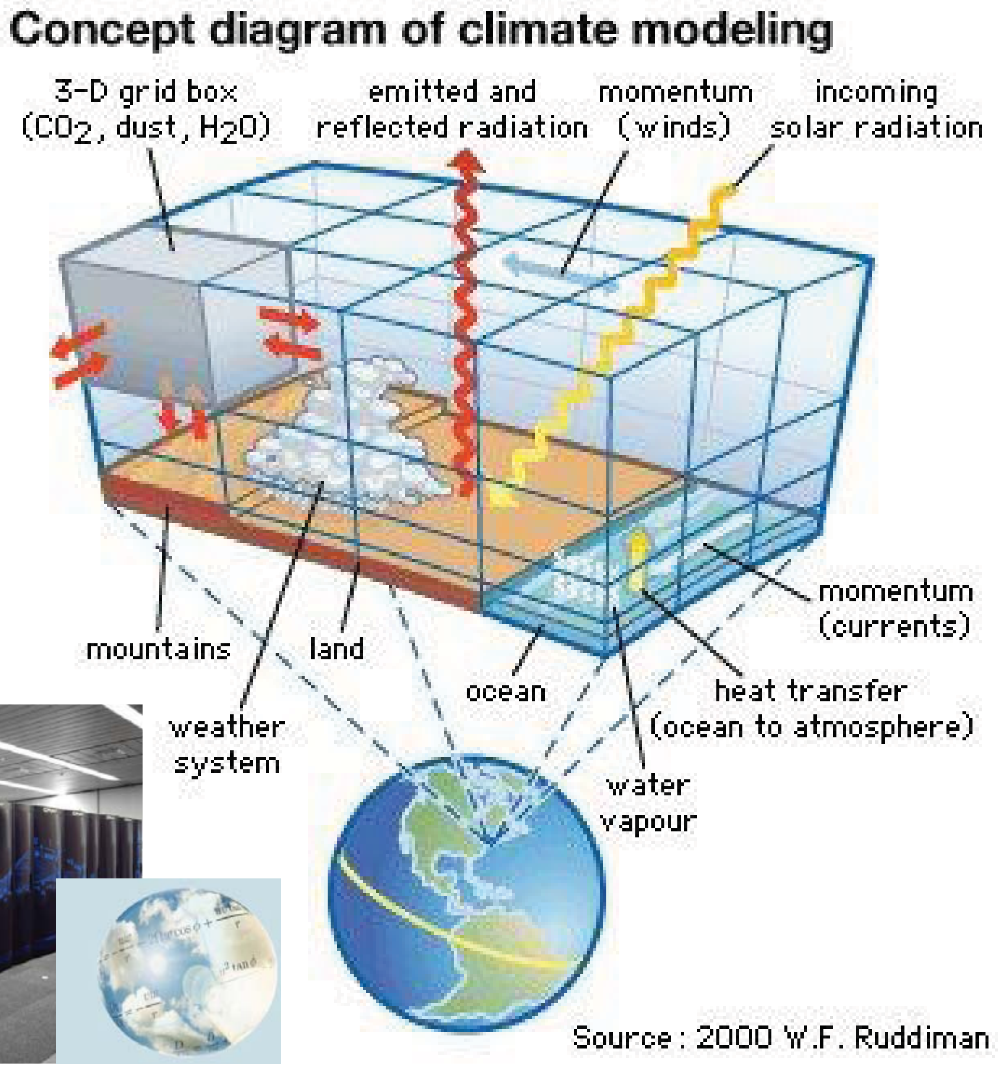


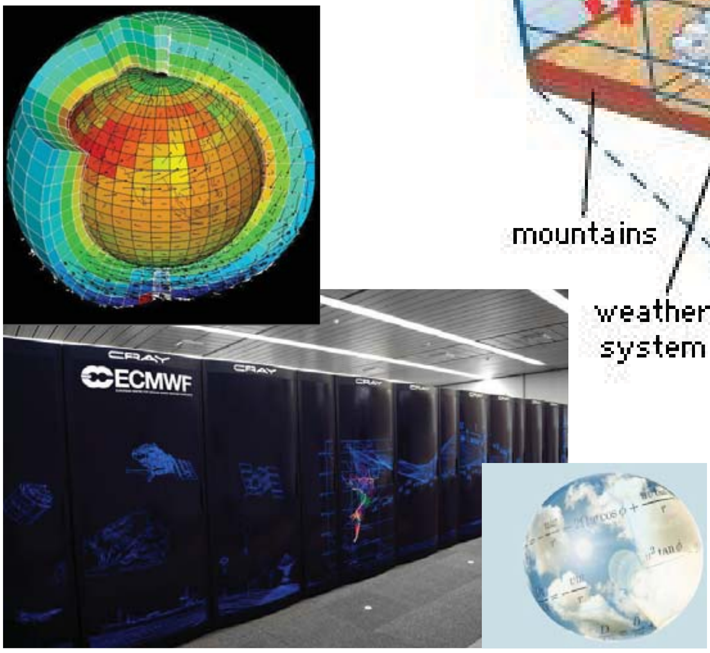
pendolo caotico, sensibilità alle condizioni iniziali (pur partendo da posizioni molto vicine, raggiunge equilibri molto diversi)

FORZANTE (ad es. raddoppio CO_2)! => modifica la statistica delle traiettorie (clima)
N.B. possibilità di farne il tracking!

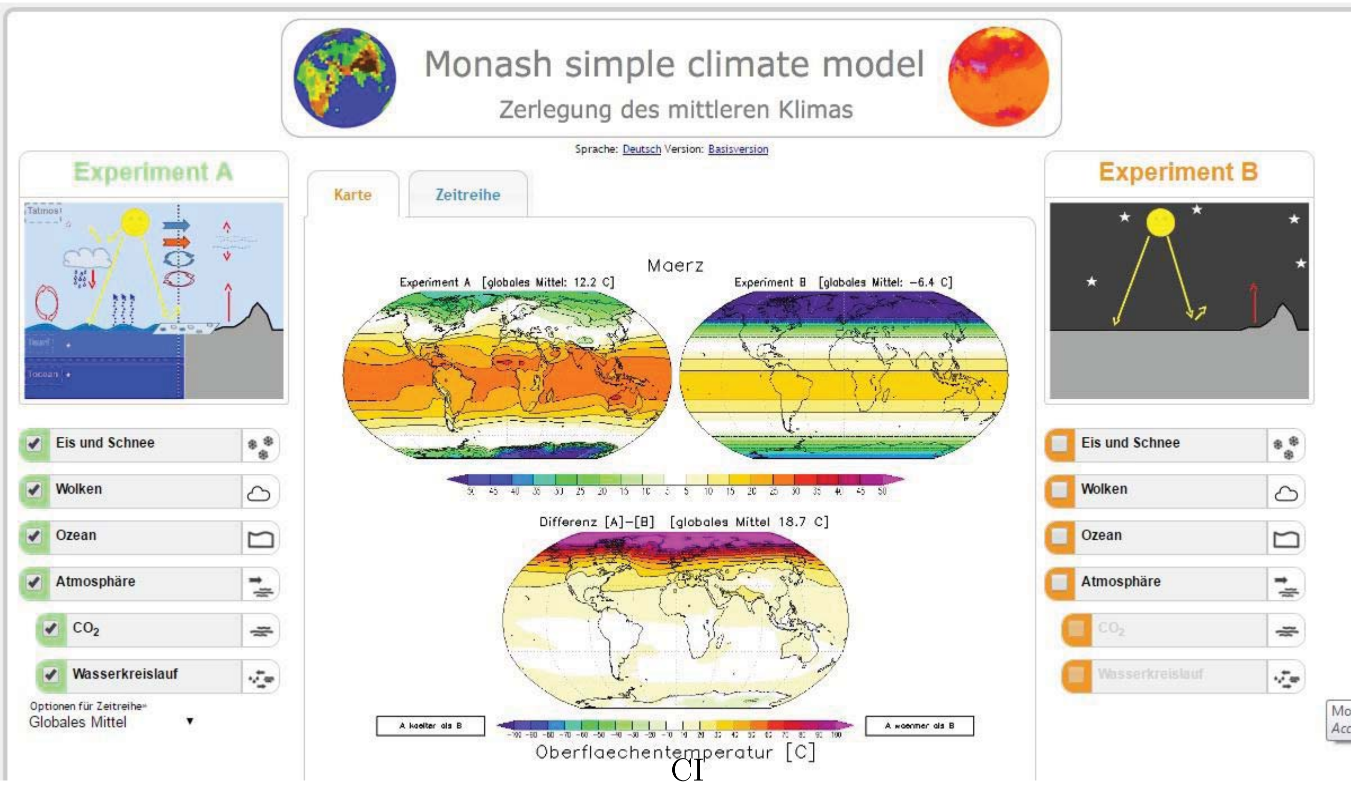


Qui: costruzione di un pendolo magnetico





Un semplice modello climatico per la didattica

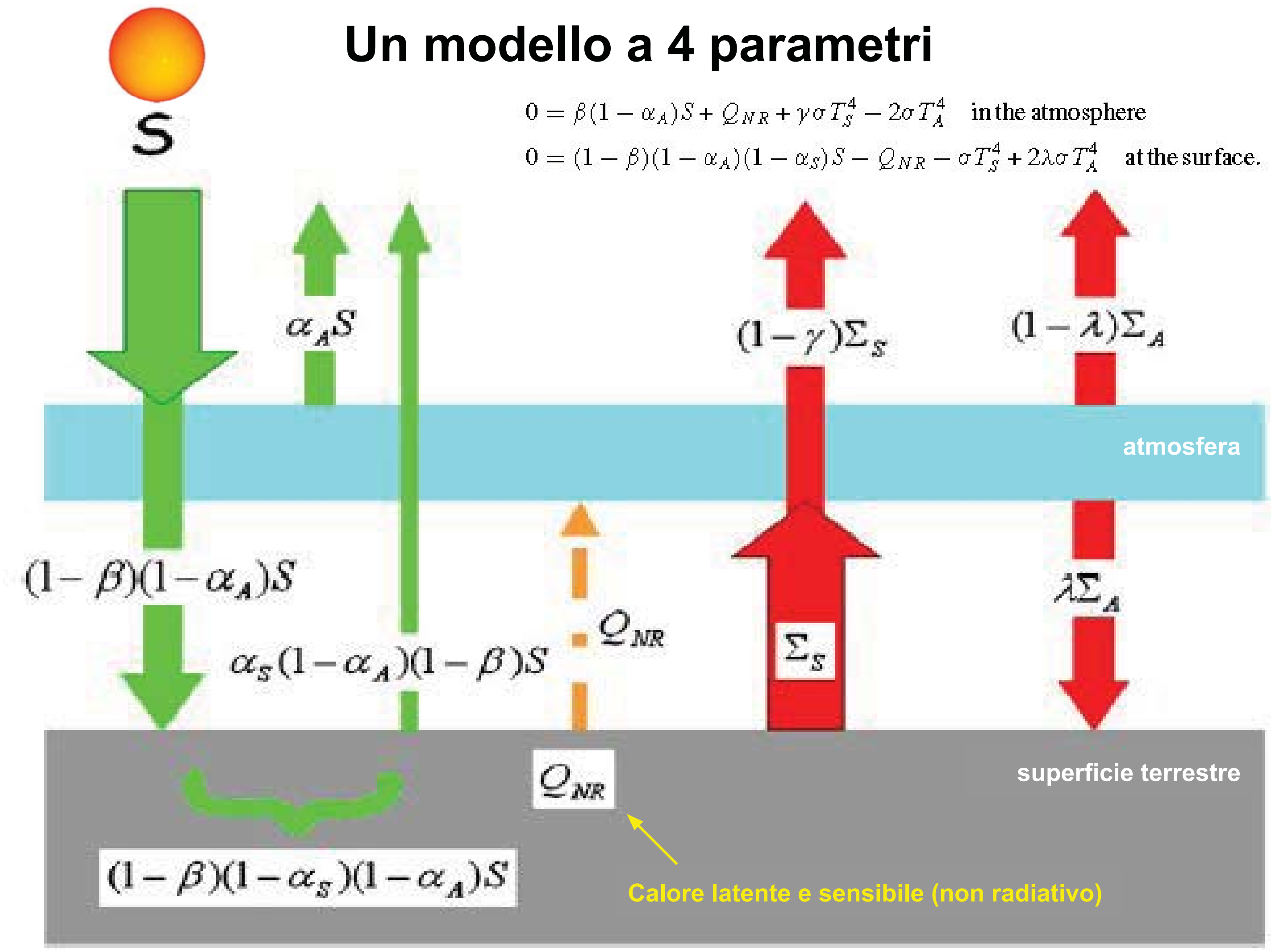


- Monash climate model: https://monash.edu/research/simple-climate-model/mscm
- Visualizzazione dati dal modello GFS (NCEP): https://earth.nullschool.net/
- Altri modelli interessanti: http://climatemodels.uchicago.edu/models.html

Un modello a 4 parametri

$$0 = \beta(1-\alpha_A)S + Q_{NR} + \gamma\sigma T_S^4 - 2\sigma T_A^4 \quad \text{in the atmosphere}$$

$$0 = (1-\beta)(1-\alpha_A)(1-\alpha_S)S - Q_{NR} - \sigma T_S^4 + 2\lambda\sigma T_A^4 \quad \text{at the surface.}$$



modello a 2 parametri: a (albedo), g (feedback)

$$S(1-a) = (1-g)\sigma T_S^4. \qquad T_{S\text{mean}} = \left(\frac{S(1-a)}{(1-g)\sigma}\right)^{1/4}$$

Planets	Average distances form the sun (10^6 km)	Average distances from the sun (u.a.)	Average solar energy intercepted by unit area of the planet's sufaces (W m^{-2})	Planet albedos (%)	Averaged surface temperatures without greenhouse effect (K)	Feedback factor g (%)	Actual averaged surface temperatures (K)
Mercury	579	0387	2280	5	~440	~0	~440
Venus	1082	0723	653	~75	230	~99	738
Earth 1700	1496	1	341	30	255	37.80	286.9
Earth 1900	1496	1	341	CIβ0	255	38.00	2871
Earth 2000	1496	1	341	30	255	38.35	287.5
Mars	2279	152	147	~15	216	~17	227

Table 2. Change of the contribution to feedback radiation due to the change of the concentration: examples for two greenhouse gases [27].

Greenhouse gas	CO_2	CH_4
Microscopic contribution to the feedback radiation ($W\ m^{-2}\ ppmv^{-1}$) [26]	1.68×10^{-2}	4.59×10^{-1}
Lifetime (years)	50–200	12
Concentration (Pre-industrial ~1700) (ppmv)	277	0.67
Total contribution to feedback radiation ($W\ m^{-2}$)	4.6	0.30
Contribution to feedback radiation%	3.2%	021%
Concentration (1900) (ppmv)	295	0.86
Total contribution to feedback radiation ($W\ m^{-2}$)	4.9	0.39
Contribution to feedback radiation%	3.4%	0.27%
Concentration (2000) (ppmv)	370	1,74
Total contribution to feedback radiation ($W\ m^{-2}$)	6.2	0.80
Contribution to feedback radiation%	4.2%	053%

$$g \approx g_0 + g_{CO_2}[CO_2]_{ppm} + g_{CH_4}[CH_4]_{ppm}.$$

Bibliografia essenziale e spunti

- Qui - una valida dispensa su clima e cambiamenti climatici (ISAC-CNR)
- Qui - Il clima in Trentino
- Schede: costante solare, radiazione termica e legge SB, apparato
- Qui - valido ipertesto della NASA sul bilancio energetico del pianeta (inglese)
- Qui - attività per gli studenti sull’effetto serra
- Qui - IPCC - Climate change 2013 - The physical science basis: (FAQ brochure)
- Qui - CLEAN - principi base di clima e risorse didattiche (inglese)
- Qui - NOAA - risorse per l’insegnamento del clima (inglese)
- Qui - Peixoto, J.P.; Oort, A.H. - Physics of Climate - American Institute of Physics
- Qui - un articolo sulle problematiche di riprodurre l’effetto serra in laboratorio
- Qui - un possibile esperimento sull’effetto serra
- Qui - P Onorato et al 2011 Eur. J. Phys. 32 363
- Qui - NASA climate kids
- Qui - approfondimento sull’effetto serra
- Video: www.youtube.com/watch?v=MEX2J_sAdGs

Si ringraziano Elisa Palazzi ricercatrice dell’ISAC-CNR, Gigi Gratton e Pasquale Onorato dell’Università di Trento per parte del materiale utilizzato in questa presentazione e per le utili discussioni.

Preconcezioni degli studenti

Questionario termologia: https://goo.gl/forms/28yV7DuJ5bARFcDa2

I proverbi legati alla saggezza popolare valgono?

Alcune misconcezioni:

- percezione di caldo e freddo e temperatura
- conducibilità termica e calore
- vapore acqueo nuvoletta bianca visibile
- aria scaldata dal sole
- foehn: bel tempo => alta pressione

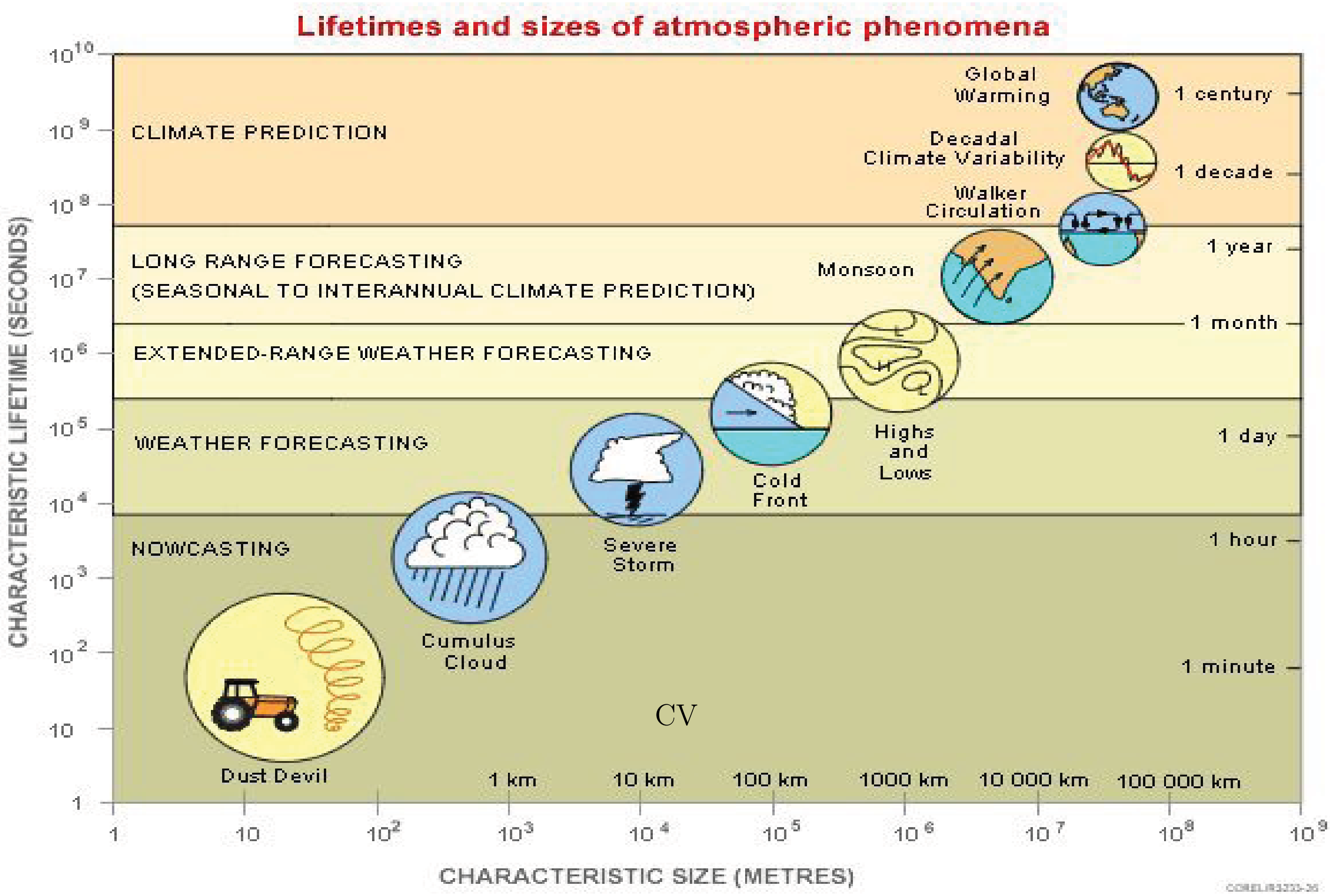
Alcuni video:

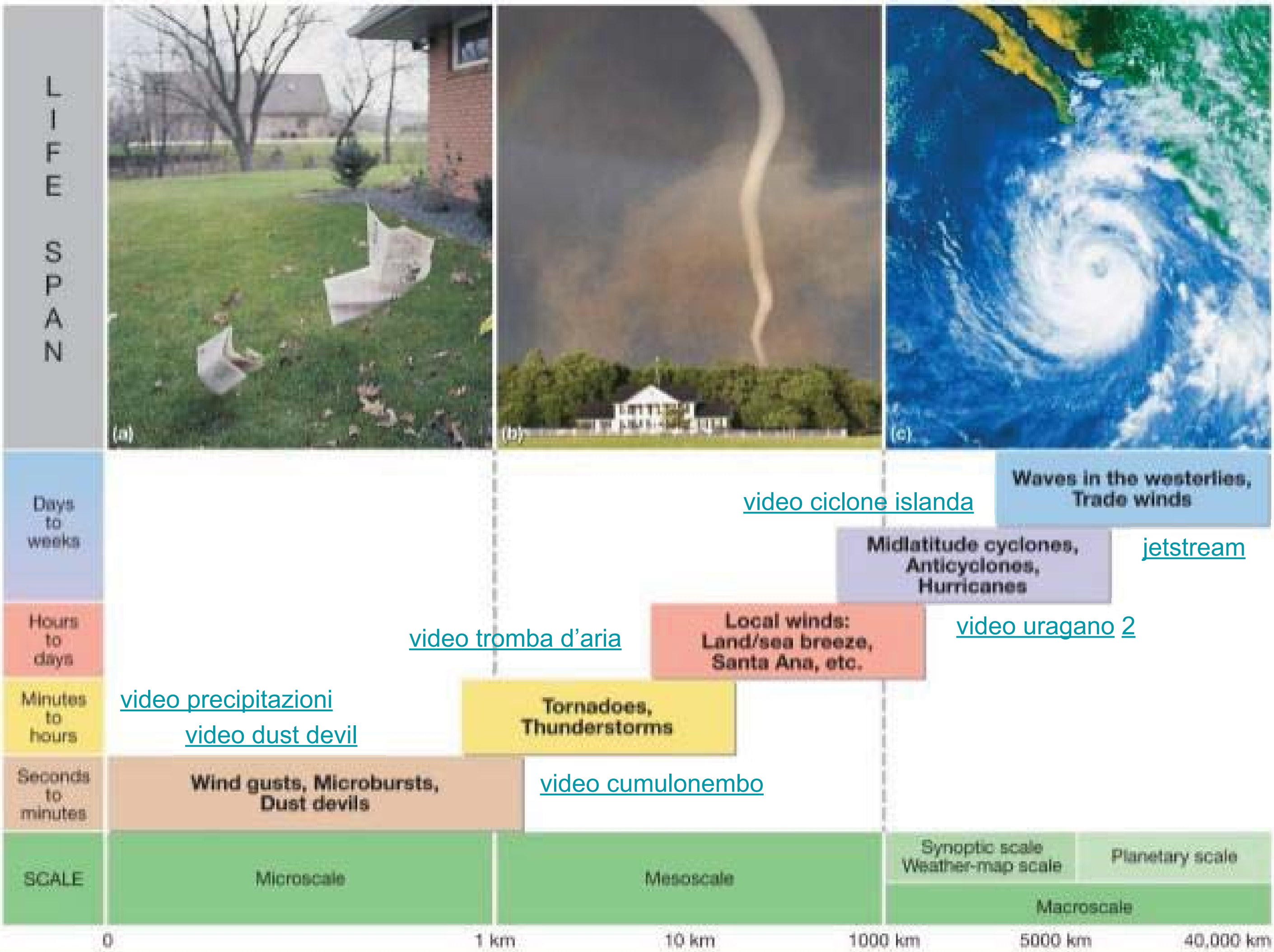
- https://www.youtube.com/watch?v=ISZxOl7G2J8
- https://www.youtube.com/watch?v=UFbZVb2kgJE
- https://www.youtube.com/watch?v=UtgFHHhm1xU
- https://www.youtube.com/watch?v=zz_CRzcIT-Q
- https://www.youtube.com/watch?v=mgrqvnuzeKM

Meteorologia e tempo meteorologico

- **meteorologia** (*meteoros* - oggetti alti nel cielo): studio di **atmosfera** e suoi **fenomeni**
  - mitologia, **divinità**
  - **osservativa** e **speculativa**
  - rivoluzione scientifica: strumenti e metodo => **scienza naturale**
  - progressi in **matematica**, **fisica**, **chimica** e **tecnologia**
    - **osservazioni** (grandezze fisiche, strumenti accurati e precisi anche a costi inferiori, tecniche di validazione e analisi dati, rete mondiale, trasferimento e gestione),
    - **modelli** (processi fisici e chimici, equazioni matematiche diagnostiche e prognostiche, supercomputer, modelli numerici e previsioni, tecniche probabilistiche e numeriche)
  - Oggi **disciplina scientifica quantitativa** (basata su dati ed equazioni!), lontana dalle derive pseudoscientifiche di “cipolle”, proverbi e “stregoni” interpreti di segni del cielo.
- **Tempo meteorologico:** insieme delle condizioni atmosferiche che si verificano in un determinato istante in un certo luogo. Più precisamente è costituito dalle **condizioni istantanee** (o mediate su periodi brevi, dal minuto alla settimana) e **locali** (in un preciso luogo geografico) delle variabili (**grandezze**) **atmosferiche** principe (temperatura, pressione, umidità, velocità e direzione del vento, precipitazioni e nuvolosità).

Scale spaziali e temporali





Un po' di storia - 1

- da sempre fenomeni meteo **curiosità** e fascino per **l'uomo**
- 380a.c. **Aristotele** (*Meteorologica*), **Teofrasto** (*Libro dei segni*): filosofico-speculative 2k anni!
- Medioevo e **almanacchi** (tavole astronomiche, previsioni per agricoltori)
- 1600 **Rivoluzione scientifica** - **strumenti** e **metodo** scientifico (**Bacon**) => **scienza naturale**

  Galileo: **termometro** ad acqua, **Torricelli**: **barometro** a mercurio, **Hooke**: **anemometro**, **Wren**: **pluviometro** basculante, **de Saussure** (1780): **igrometro** a capelli, **Ferdinando II de Medici** Accademia fiorentina del Cimento e prima **rete** di osservazione europea, Giovanni **Poleni**, **serie** di Padova (la più lunga!)

- 1686 **Halley**: venti **alisei** (tropicali) e monsoni: **origine termica** (sole) dei **moti atmosferici**
- 1735 **Hadley**: studia alisei e spiega la **circolazione atmosferica globale** (**rotazione** terrestre)
- 1738 **Bernoulli**: **teoria cinetica gas**, 1752 **Franklin:** natura **elettrica fulmini** (aquilone, parafulmine), 1772 **Lavoisier**: **aria miscela di gas**, 1834 **Clapeyron: equazione di stato** gas
- 1803 **Howard**: **classificazione nubi**, **Beaufort**: scala forza del **vento**
- 1835 **Coriolis:** gradiente pressione e deflessione - moto lungo le isobare ("**forza**" di **Coriolis**) 1856 **Ferrel**: **cella** a latitudini **intermedie** (venti occidentali)

Un po' di storia - 2

- 1843 **Marconi** e il **telegrafo**: scambio informazioni velocemente - le carte bariche
- 1873 **Organizzazione meteorologica internazionale** (tempesta Mar Nero), 1951 ONU: **WMO**
- '800 meteo in Italia: religiosi Angelo **Secchi** e Francesco **Denza** (Società meteorologica italiana => Regio ufficio centrale di meteorologia)
- 1920 scuola norvegese - **Bjerkenes**: **masse d'aria** e **fronti**, teoria **cicloni** extratropicali, **Rossby**: **flusso** atmosferico su **larga scala**, **Bergeron**: meccanismo **formazione pioggia**
- 1930 **Molchanov**: radiosonda e primi **radiosondaggi** (con pallone sonda), dati in tempo reale
- aerei militari scoprono **correnti a getto** (tempo a medie latitudini e trasporto aereo)
- 1950 **Richardson**, **Charney**, **Von Neumann:** ENIAC e la prima **previsione numerica**
- '60: **Lorentz**: natura caotica atmosfera, teoria del **caos**, **limite di predicibilità** dell'**atmosfera**
- 1960 **satelliti**: TIROS-1 (diffusione globale info meteo e telerilevamento - radiometri)
- '70 **radar** (Seconda Guerra mondiale): precipitazioni e vento (effetto doppler)
- 1975 **ECMWF:** centro operazionale previsioni numeriche a medio termine (supercomputer)
- **Tecniche** statistiche e numeriche: ensemble forecasting (**previsione probabilistica**): dare un grado di affidabilità alle previsioni
- Oggi in **Italia**: servizio **nazionale** (Aeronautica), **regionali** (Arpa, MeteoTN) e **privati** (Epson)

Fenomeni, domande, curiosità, proverbi...

- *come si forma una nube?*
- *come si formano le precipitazioni (pioggia, neve, grandine)?*
- *cosa determina i venti?*
- *come mai al mattino si forma sul terreno rugiada o brina?*
- *come mai in questi giorni la pianura padana è avvolta da una spessa nebbia mentre in montagna è sereno?*
- *perché a parità di temperatura sopportiamo meglio il caldo secco rispetto al caldo umido?*
- *in cosa consistono il cosiddetto foehn e la cosiddetta ora del garda?*
- *che cosa sono cicloni (o depressioni) e anticicloni?*
- *perché fa più freddo in montagna, ma non sempre?*
- *perchè il cielo è azzurro, rosso al tramonto e le nuvole sono bianche?*
- *come vengono fatte le previsioni meteorologiche?*
- *proverbi? (Rosso di sera bel tempo si spera, rosso di mattina la pioggia si avvicina; sta per piovere, lo sento nelle ossa; Luna con l'anello non porta tempo bello; fredda è la notte in cui la luna e le stelle brillano in tutta la loro bellezza; cielo a pecorelle, acqua a catinelle)*

L’atmosfera è materia

OBIETTIVO: dimostriamo che l’atmosfera (l’aria nel parlare comune) e’ fatta di qualcosa.

MATERIALE: una bottiglia di plastica vuota possibilmente grande (1,5 l).

ESECUZIONE: mostriamo la bottiglia d’acqua. Domandiamo agli alunni che cosa c’e’ dentro la bottiglia. Se rispondono niente aspiriamo dalla bottiglia l’aria fino a farla deformare e discutiamo su che cosa avete aspirato (si puo’ anche fare con un palloncino).

Il peso dell’aria

MATERIALE:

- una bottiglia di plastica vuota con valvola da bicicletta sul tappo.
- pompa da bicicletta
- bilancia di precisione

ESECUZIONE: peso la bottiglia a pressione atmosferica, comincio a pompare aria (dovrebbero bastare una ventina di pompate) e peso di nuovo la bottiglia sulla bilancia. N.B. se voglio posso anche provare a stimare quanta aria ho aggiunto nella bottiglia dalle dimensioni della pompa e quindi risalire alla massa d’aria inserita e stimarne la densità.

L’atmosfera è un gas - solido liquido e gas: prop macro

OBIETTIVO: Quali sono le differenze principali tra gli stati di aggregazione della materia?

MATERIALE: siringa di plastica più grande possibile (meglio se 3 una per stato di aggregazione), oggetti solidi di cui alcuni che possano entrare nella siringa (da apertura stantuffo), acqua in un bicchiere.

ESECUZIONE:

- **stato solido** - metto oggetti in siringa: entrano o no? (alcuni) Riesco ad eliminare l’aria tra di loro in modo da avere dentro solo materiale solido? (No) Riesco a comprimere spingendo lo stantuffo? (no) => solidi hanno forma e volume proprio.

- **stato liquido** - aspiro acqua dal bicchiere, lascio anche aria. Acqua entra dal piccolo buco anche se diametro bicchiere maggiore! Riesco a eliminare l’aria e a far occupare tutto il volume! Chiudo l’uscita, spingo stantuffo, riesco a comprimere? (no) => liquidi prendono la forma del recipiente ma non cambia il volume.
- **stato gassoso** - aspiro aria da bicchiere (o palloncino), riesco a riempirla senza problemi. Chiudo e spingo lo stantuffo. Vedo che più spingo più il volume occupato diminuisce => gas prende la forma del recipiente, lo occupa tutto e lo puo' variare (si puo' comprimere) nè forma nè volume propri

solido liquido e gas - proprietà microscopiche

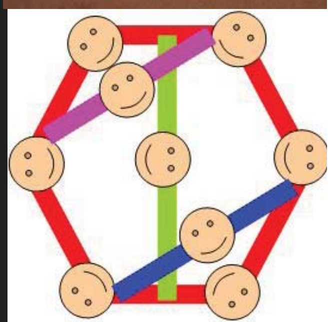
OBIETTIVO: spiegare le proprietà macroscopiche degli stati di aggregazione appena osservate con un modello microscopico

MATERIALE: corda (10m), 3 gruppi di studenti (atomi o molecole)

ESECUZIONE: Chiedere alle molecole (studenti) di rappresentare i tre stati di aggregazione (uno per gruppo). Disegnare con la corda sul pavimento un perimetro aperto, apertura piccola (contenitore).

solido: molecole a creare forma geometrica chiusa (es. esagono, braccia sovrapposte - legami). Chiedere di muoversi mantenendo la figura geometrica creata. Chiedere al solido di entrare nel contenitore senza modificare né la sua struttura né la forma del contenitore. Non ci riescono => allargare apertura, entra. Cosa succede se tiro gli estremi della corda (restringo il “volume”?). pareti toccano il solido non si puo’ piu’ restringere. => solido: molecole in struttura precisa connesse tra di loro (legami - molle) in modo che non si possa dargli una forma diversa (a meno di distruggere tale struttura)

liquido: molecole di raggrupparsi e muoversi indipendentemente, sempre toccandosi tra di loro (braccia abbassate). Riesco ad entrare se imboccatura stretta? (puo’ assumere diverse forme! molecole in contatto ma non legate, possono scivolare). Se restringo il perimetro? Toccate le molecole non posso comprimere (no spazio tra le molecole).



gas: molecole muoversi liberamente, occupando in maniera omogenea porzione di spazio (riempire gli spazi). Entrano? (no pbm se apertura fa passare una molecola). Posso restringere perimetro, ma se non escono e si muovono alla stessa velocità, urti tra loro e con corda con maggiore frequenza (pressione). Al limite stringendo al massimo => caso del liquido (bombole gpl vs ossigeno, gas compresso ne trasporto maggiore quantità). => Gas: molecole non legate tra loro, tendenza ad occupare tutto lo spazio a disposizione

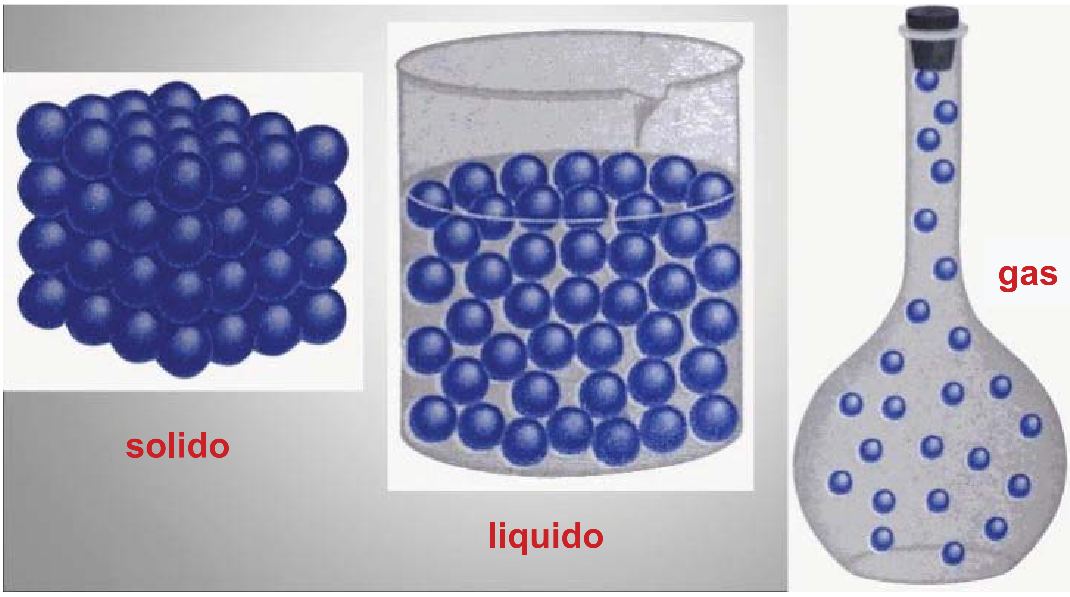
N.B. caso gas: moto in linea retta e cambio direzione solo se urto molecola o pareti!!

Perchè se molecole non legate tra loro e spazio vuoto non se ne vanno nello spazio? Gravità (che diminuisce con la quota)!

Stati di aggregazione della materia

- la materia è costituita da atomi e molecole, può presentarsi allo stato:

Un'applet Phet



FORMA	*costante, rigida, fissa*	*variabile (del contenitore)*	*variabile (del contenitore)*
VOLUME	*costante*	*costante*	*variabile (del contenitore)*
MOTO MOLECOLE (T) e INTERAZIONI	*vibrano attorno a posizioni fisse*	*particelle si muovono e interagiscono tra loro*	*ogni particella si muove indipendentemente*

Atmosfera (aria) = miscela di gas (e non solo) - Lavoisier

gas	concentrazione (% o parti per milione in volume ppmv)
Azoto (N_2)	78,084%
Ossigeno (O_2)	20,946%
Argon (Ar)	0,934%
Anidride carbonica (CO_2)	0,004% (400 ppm)
Neon (Ne)	0,001818% (18 ppm)
Elio (He)	0,000524% (5 ppm)
Metano (CH_4)	0,000179% (2 ppm)
Krypton (Kr)	0,000114% (1,1 ppm)
Idrogeno (H_2)	0,00005% (0,5 ppm)
Xeno (Xe)	0,0000087% (0,09 ppm)
Vapore acqueo (H_2O)	0,001% - 5% **molto variabile** in dipendenza dalla località
Ozono (O_3)	0,04 ppm (2-8 ppm in stratosfera! OMS: limite 0,1 ppm)
ossidi di azoto, monossido di carbonio, ammoniaca, biossido di zolfo, solfuro di idrogeno	tracce

Aerosol: particelle in sospensione, composizione chimica, dimensioni e concentrazione molto variabili

Un’idea per un’attività pratica - atmosfera in un vaso

- Comporre un modello di atmosfera in un vaso con legumi di diverso tipo (ad es. lenticchie, soia, ceci, fagioli) in modo tale che ciascuno rappresenti uno specifico gas componente l’atmosfera terrestre e sia presente nelle corrette proporzioni rispetto agli altri.
- Proponibile come attività IBSE
- percentuali, conversioni ppm, % ecc.

L’atmosfera - un fluido (gas)

- posso trattarla come un **gas ideale**, vale quindi la legge dei gas perfetti
- **particella di aria**: sufficientemente grande da contenere un grandissimo numero di molecole (N avogadro), ma sufficientemente piccola rispetto al mondo macroscopico da poter ignorare la natura discreta della materia.
- **aria secca**: N_2(78%)+O_2(21%)+Ar(1%) massa molare media M=28,96 u.m.a.
- **aria umida**: contiene vapore acqueo H_2O => massa inferiore! a parità di numero di molecole (H_2O: 18 u.m.a. O_2 : 32 u.m.a. N_2: 28 u.m.a)
- grandezze termodinamiche: **temperatura**, **pressione**, **densità** (volume),
- **forze** agenti, da cui dipendono la struttura dell’atmosfera e i suoi moti:
  - **gravità**
  - **gradiente di pressione**
  - **attrito**
  - **coriolis** (apparente)
  - **centrifuga** (apparente)
- **Atmosfera standard** (ICAO)

Grandezze fisiche atmosferiche e strumenti

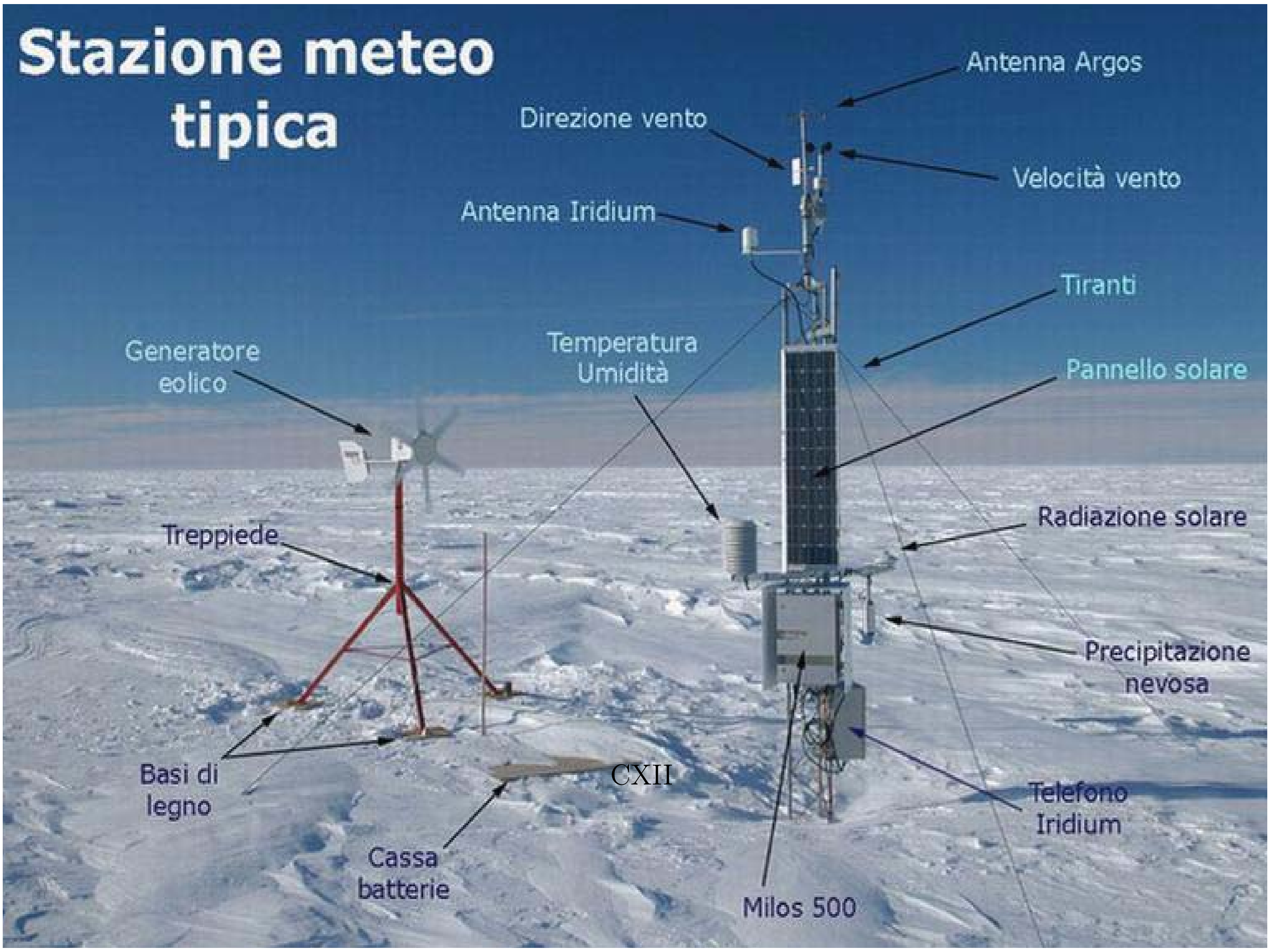
- **temperatura** (massima, minima, media) - termometro
- **pressione** - barometro
- **umidità** (assoluta e relativa) - igrometro a capello o psicrometro
- **vento** (modulo e direzione) - anemometro (a coppelle o sonico), banderuola, radar

========================

- **precipitazioni** - pluviometro, radar
- **nuvolosità** - osservazioni, cielometro, satellite (banda VIS e IR)

=========================

- **al suolo** e **in quota** (libera atmosfera),
- **dirette** e **indirette** (telerilevamento)
- tipicamente agli **orari sinottici**: 00-06-12-18 UTC (fuso di Greenwich)



Necessità di fare manutenzione per dati affidabili!

Una tipica stazione di radiosondaggio

[video radiosonda]

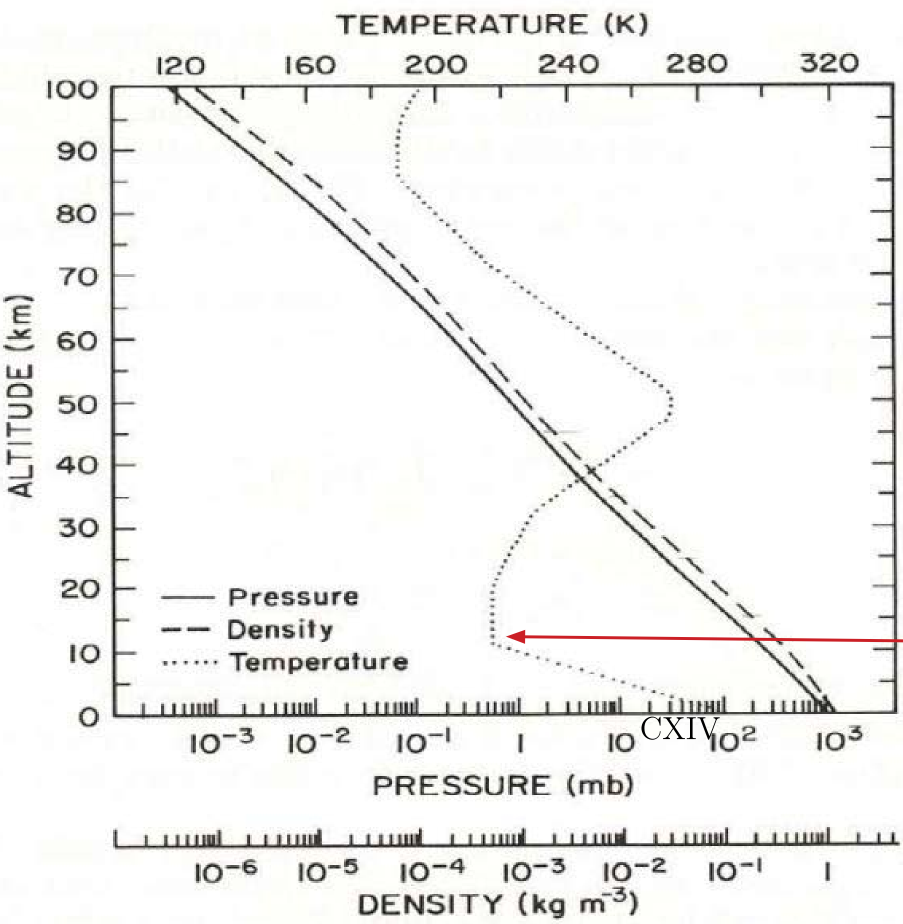
Atmosfera standard (ICAO)

- da **media climatologica**
  - **Aria secca** (umidità relativa: 0%) e priva di impurità
  - **Temperatura** media al livello del mare: T = 15°C (288,15 K)
  - **Pressione** atmosferica media al livello del mare: P = 1 atm = 101325 Pa
  - **Densità** dell'aria al livello medio del mare: ρ = 1,225 kg/m^3.
  - **Gradiente barico verticale**: −1 hPa ogni 9 m di altitudine (valido solo fino a 1500 m, perchè P(z) non è una legge lineare, ma di potenza!).
  - **Gradiente termico verticale**: 6,5°C ogni 1000 m di altitudine fino a 11km

Equazioni costitutive:

- legge di Stevino (**equilibrio idrostatico**): $dP=-\rho\, gdz$
- legge di stato per i **gas ideali**: $PV=nRT$ *($P=\rho R^*T$ $R^*=R/M$ costante specifica!)*
- **gradiente verticale di temperatura**: $dT=-\Gamma dz$ ($T=T_0-\Gamma z$)

Struttura verticale dell’atmosfera standard (T, P, ρ)

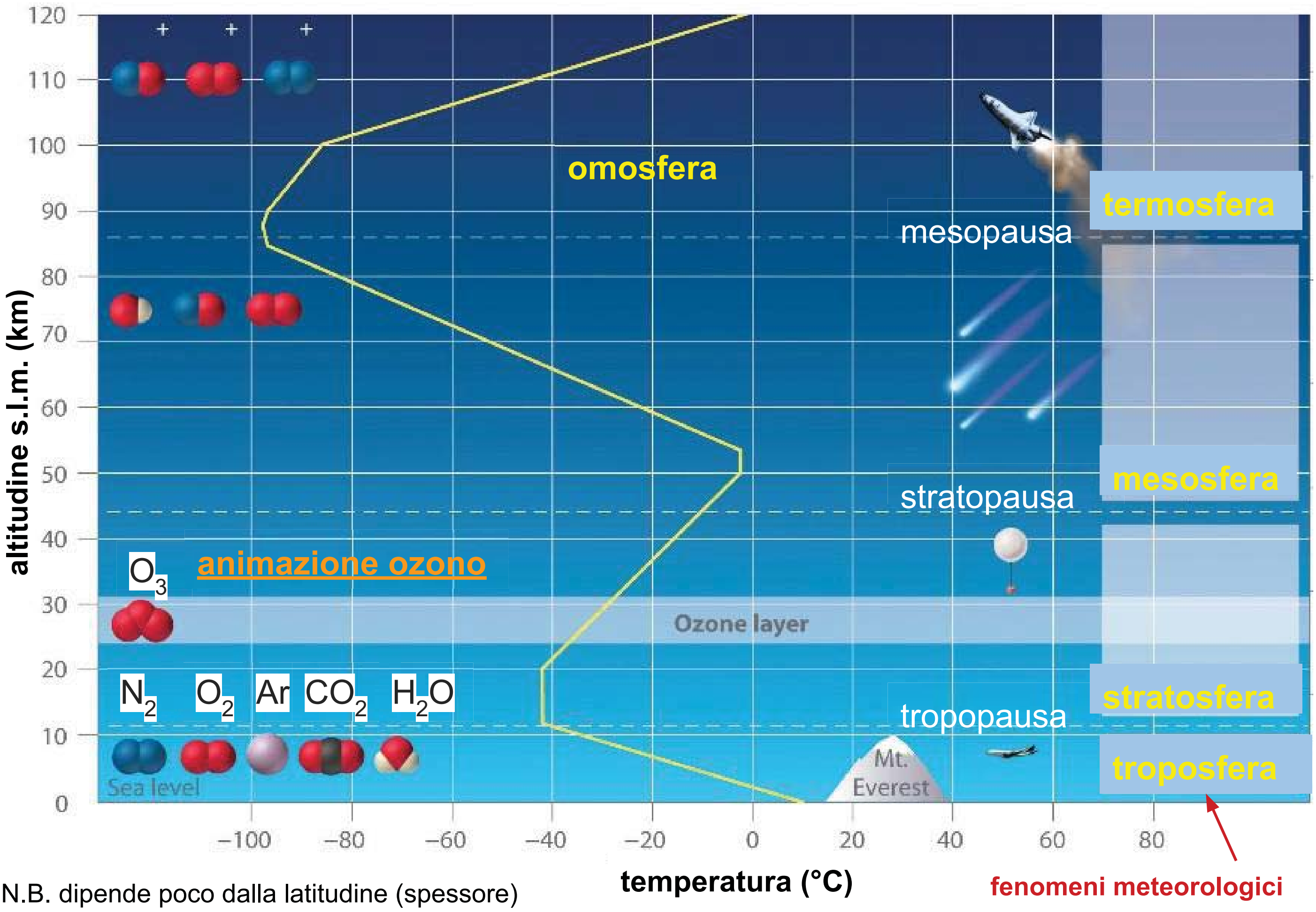


In troposfera:

- **temperatura** decresce linearmente con la quota
- **pressione** e **densità** diminuiscono esponenzialmente (in realtà legge di potenza)

tropopausa
fenomeni meteo avvengono in gran parte sotto!

Struttura termica verticale media dell'atmosfera

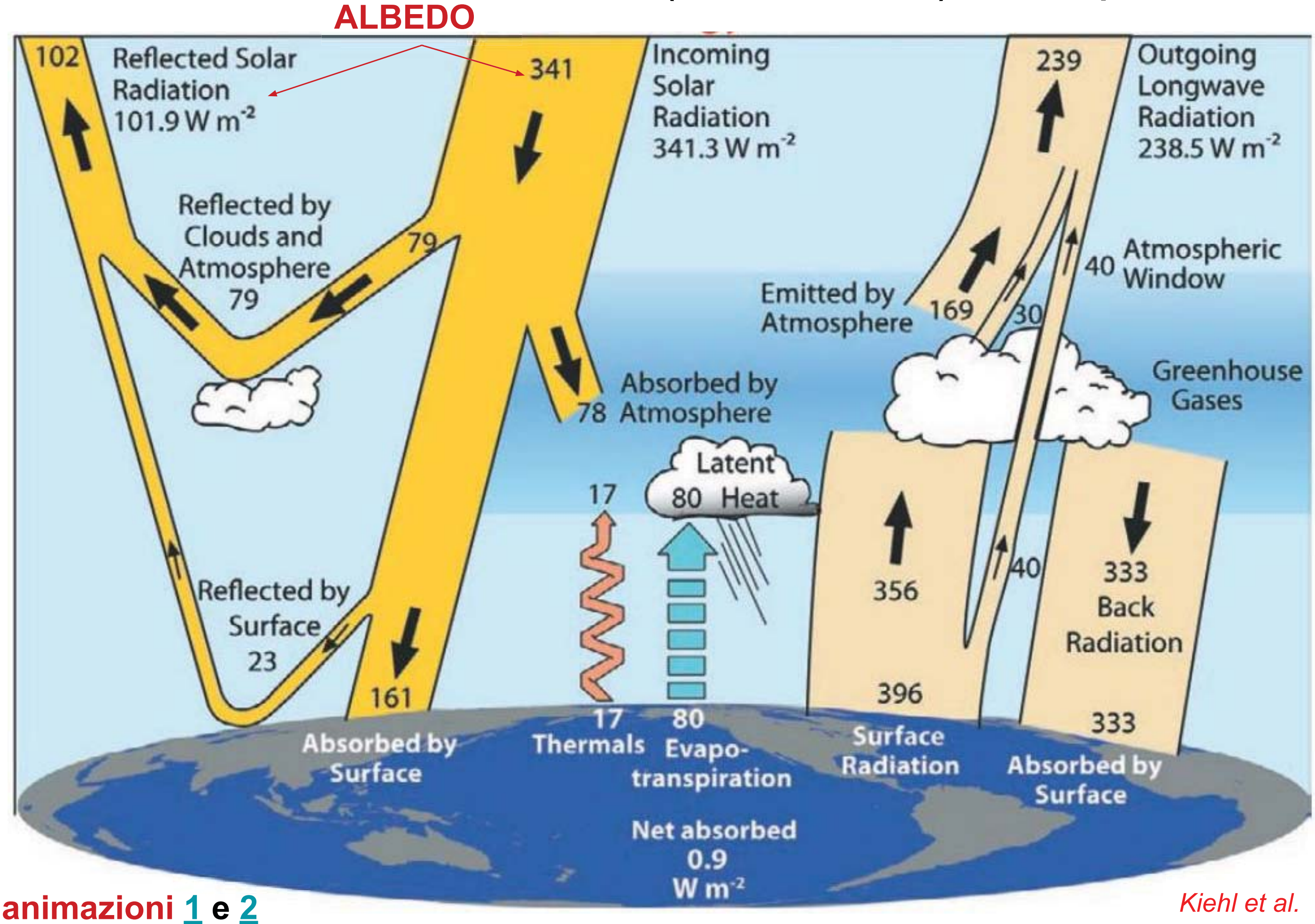


N.B. dipende poco dalla latitudine (spessore)

Variazione verticale di temperatura (gradiente) - cause

- La **radiazione solare** (irraggiamento) viene assorbita dal **terreno scalda**ndolo. Questo poi per **conduzione** scalda lo strato di aria immediatamente sovrastante che a sua volta per mezzo di moti turbolenti e **convezione** (trasporto di materia) riscalda l'aria più in alto, in troposfera (metafora della **pentola d'acqua**)
- normalmente in **troposfera** la **temperatura diminuisce con la quota - 6,5°C/km** per l'atmosfera standard (in montagna fa mediamente più freddo!)
- In **stratosfera** la temperatura aumenta per **l'assorbimento** della radiazione **UV** da parte dell'**ozono** (animazione)

Bilancio flussi di radiazione (sole e terra) e temperatura



animazioni 1 e 2

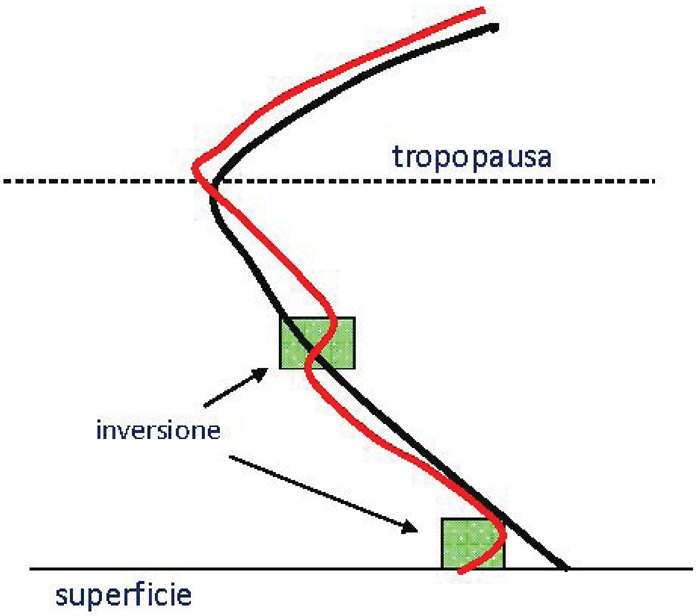
Kiehl et al.

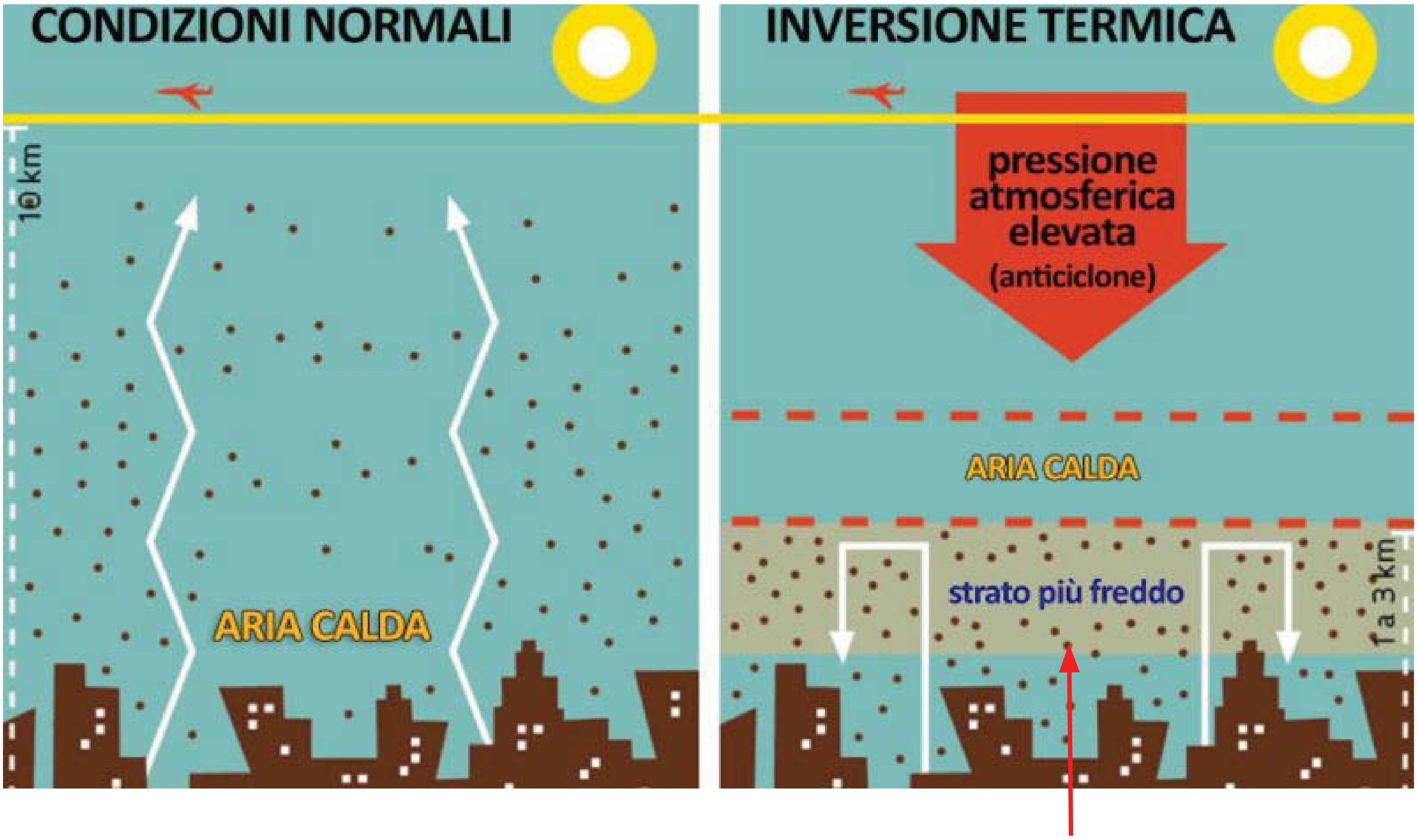
Non sempre però è così...

Inversioni termiche

Zone dell'atmosfera dove il **gradiente di temperatura si inverte** rispetto all'andamento usuale (ovvero nel caso della troposfera, la **temperatura aumenta** con la **quota** invece di diminuire)

- tipiche della troposfera, ma frequenti anche in stratosfera
- possono essere **al suolo** o **in quota**
- impediscono all'aria calda di salire, **inibiscono i moti verticali**
- si formano tipicamente in autunno e inverno (**raggi solari più obliqui**, scaldano meno il fondovalle rispetto ai versanti), intensificate se c'è **copertura nevosa** nel fondovalle (riflessione radiazione solare).
- fenomeni: **foschia, nebbia, ristagno inquinanti**

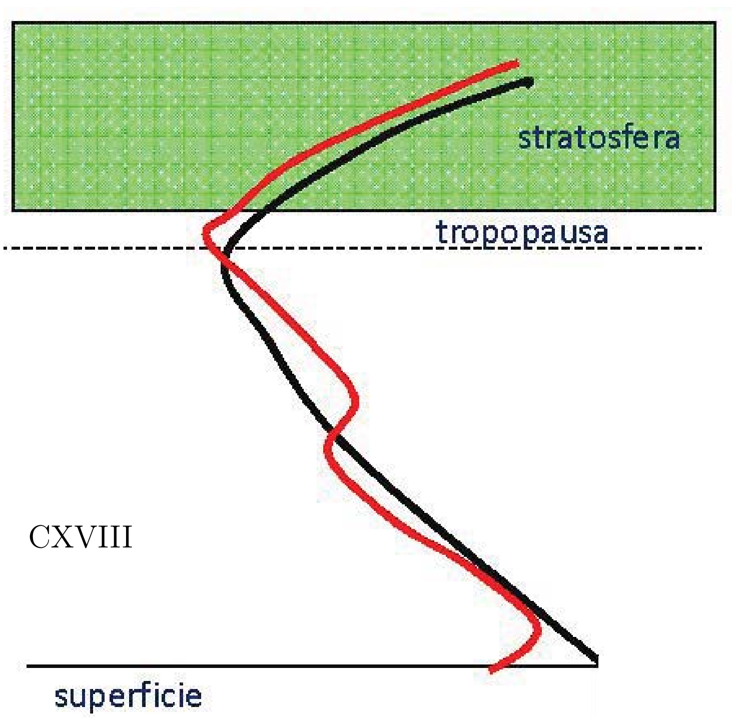




ristagno inquinanti!

Stratosfera

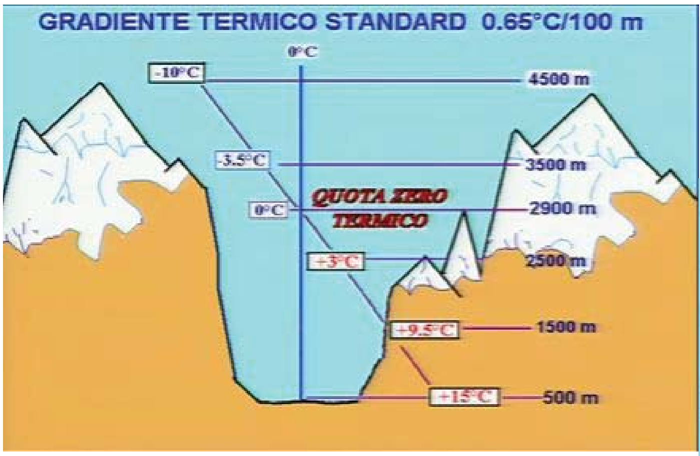
La stratosfera è l'inversione più importante perché intrappola tutto il **vapore nei bassi strati** (inibizione dei moti verticali) e per questo i **fenomeni meteorologici** sono quasi tutti confinati nella **troposfera**.

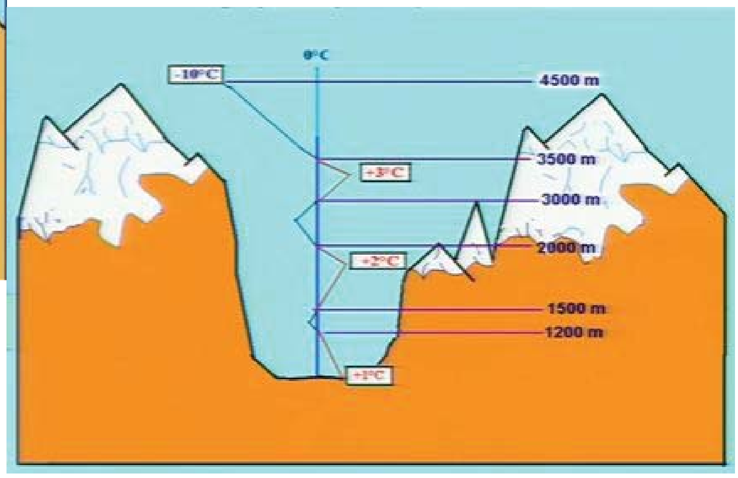


un possibile esperimento

Zero termico

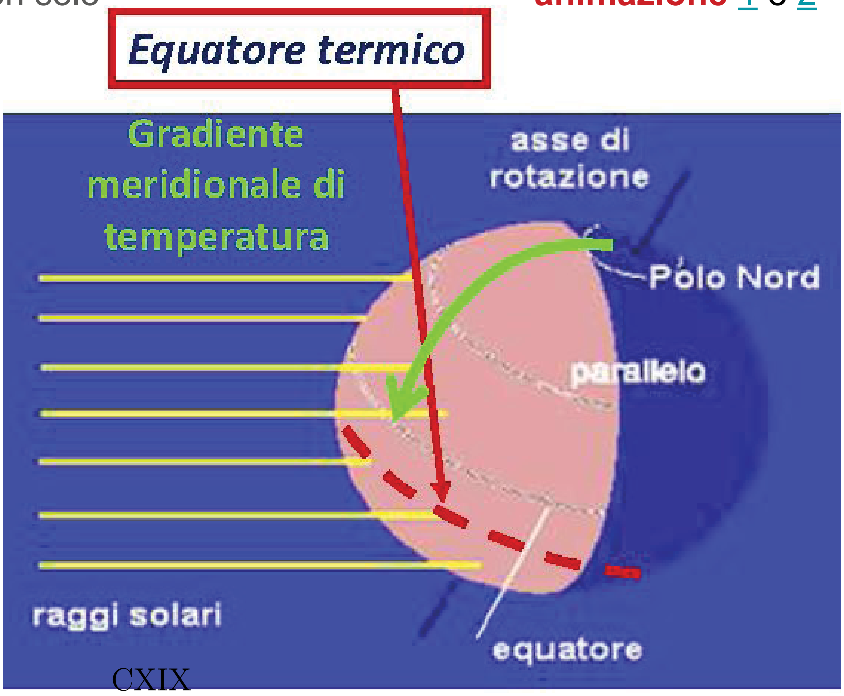
- La **quota** dello **zero termico** nella **libera atmosfera** corrisponde all'ultimo passaggio fra temperatura positiva e negativa (non tiene conto di eventuali strati sottostanti a temperatura negativa). Al di sopra di quella quota la temperatura è sempre sotto zero!
- previsione del **limite delle nevicate!** (200-500 m al di sotto di tale quota)





Variazioni orizzontali della temperatura - cause

Tipicamente con **latitudine** ma non solo **animazione** 1 e 2



Dipendono da:

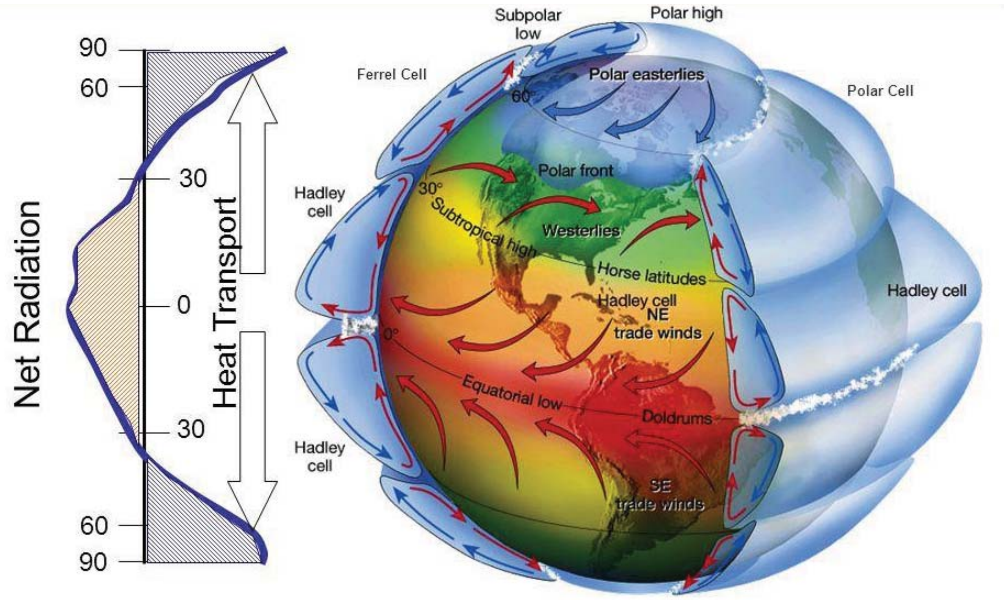
- inclinazione asse terrestre
- ora del giorno
- stagione
- anno
- distribuzione mare/terra
- tipologia del suolo (albedo)
- capacità termica
- orografia (versanti)
- scambi di calore

Escursione termica: variazione temperatura tra max diurno e min notturno in 24 ore.

N.B. insolazione e stagioni con mappamondo + cella fotovoltaica + proiettore

Conseguenze delle variazioni di temperatura

- La superficie terrestre **non** è **uniformemente riscaldata**
- principio zero della termodinamica: corpi a temperatura diversa messi a contatto si portano all'**equilibrio termico** (stessa temperatura)
- In atmosfera deve esserci quindi un meccanismo per **redistribuire il calore** in eccesso e annullare i gradienti di temperatura => così si innesca la **dinamica** dell'atmosfera (**moti dell'aria e circolazione** generale dell'atmosfera)



La propagazione del calore

Processi che regolano trasferimento di energia (calore) tra corpi a diversa temperatura:

- **conduzione**: contatto tra corpi, scambiato dalle molecole che vibrano attorno alla loro posizione di equilibrio
- **convezione**: moto macro di materia da regione più calda a più fredda (tipico di fluidi e gas)
- **irraggiamento**: con onde elettromagnetiche (pacchetti di energia che dipendono da T corpo)
- **avvezione (calda o fredda)**: trasporto attraverso il vento.

N.B. Questi processi non sono indipendenti, ma **legati** tra loro!

Un’idea di esperimento sulla conduzione

OBIETTIVO: mostrare come nel caso della conduzione il calore si propaga in maniera uniforme rispetto al punto scaldato

MATERIALE: lamiera, cera (colorata), candela (fornelletto), molletta per tenere la lamiera.

ESECUZIONE: spalmare della cera sulla lamiera sfregandola o squagliandola in modo il piu' possibile uniforme. Mettere la lamiera su una candela o accendino tenendola con la molletta. La cera si squaglia in maniera uniforme (cerchio con centro la posizione della candela).

COSA SUCCEDE: nell'esperimento si e' propagato del calore (energia) in un solido (la lamiera) con il meccanismo della conduzione. In un solido atomi o molecole non possono muoversi dalla loro posizione (altrimenti cambierebbe forma) ma possono agitarsi intorno alla loro posizione. Più si agitano più trasmettono l'energia ai vicini che a loro volta la trasmetteranno ad altri vicini. Non essendoci una direzione preferenziale alla fine il calore risulterà propagarsi in maniera 'circolare' (ugualmente in tutte le direzioni).

Un’idea di esperimento sulla convezione

OBIETTIVO: mostrare che se il calore è propagato per convezione (possibile nei fluidi aria e acqua) non si propaga in maniera uniforme ma tende a propagarsi verso l'alto

MATERIALE: phon, provettone, 2 cubetti di ghiaccio + peso (rondella), colorante alimentare, tubo forato

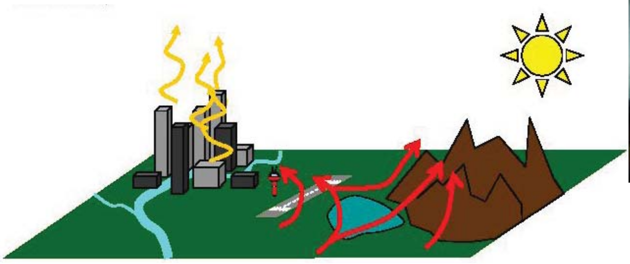
ESECUZIONE: nella provetta un ghiaccio con un peso per farlo affondare, un secondo pezzo di ghiaccio (uguale) e riempire con acqua. Accendo asciugacapelli. Quale dei 2 ghiacci si scioglierà per primo? (se come conduzione => allo stesso modo). Qui riscaldo un fluido => conduzione + convezione (più efficiente) che trasporterà il calore verso l'alto (acqua calda è meno densa) => ghiaccio galleggiante si scioglie per primo. Si può aggiungere goccia di colorante senza troppa spinta che si distribuisce nella meta' superiore della colonna d'acqua.

COSA SUCCEDE: fluido scaldato ha densità minore (esperimenti di espansione di aria e acqua) => la parte scaldata, meno densa galleggia rispetto al resto e si propaga verso l'alto.

video di un altro esperimento

Altri fattori che modificano la temperatura

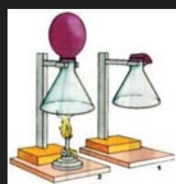
- **land use** => isola di calore urbana (può modificare la dinamica atmosferica a qualunque scala)
- **sconvolgimenti climatici** (forti esplosioni vulcaniche, catastrofi naturali di grande impatto)
- **copertura nuvolosa** (schermano la radiazione solare diminuendo massime diurne e aumentando le minime notturne)
- **precipitazioni** (mentre cade la precipitazione evapora parzialmente sottraendo calore all'atmosfera)



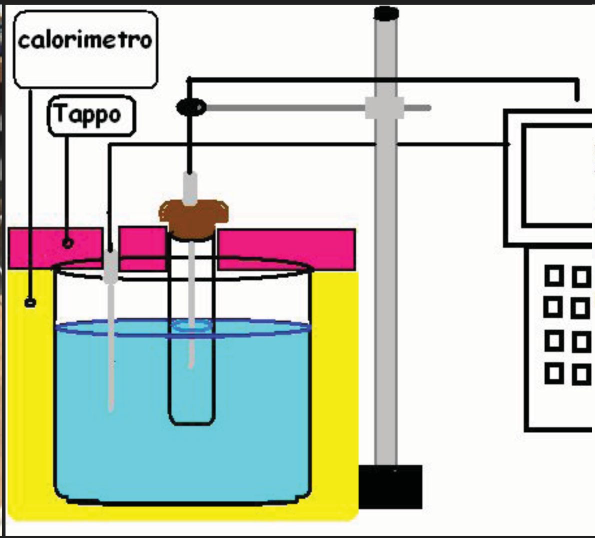
Temperatura

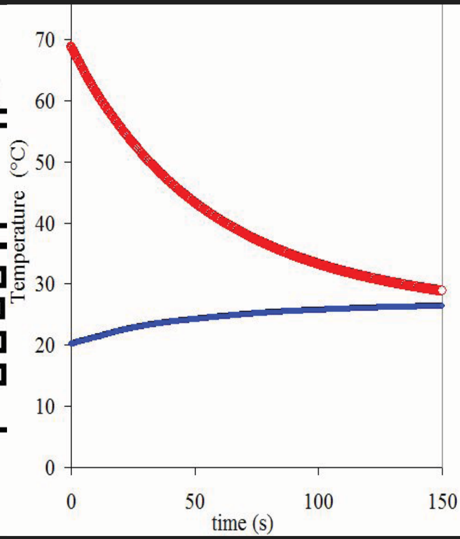
- **dilatazione termica**
  - solidi - anello di gravesande o sbarretta metallica riscaldati
  - liquidi - bottiglia con cannuccia piena fino all'orlo riscaldata
  - gas - palloncino al caldo/freddo
- **volume** dipende dalla **temperatura**
- uso questa proprietà per costruire uno strumento che riveli variazioni di temperatura - il **termoscopio**
- operazione di **taratura** e **termometro**
  - punti fissi (acqua e ghiaccio e acqua in ebollizione)
  - confronto con un altro strumento (curva di calibrazione)
- **scale** termometriche (°C, K)






Equilibrio termico (andamento temporale)





$$m_\alpha (T_\alpha - T_{eq}) \approx m_\beta (T_{eq} - T_\beta)$$

- lo stato di **equilibrio termico** si raggiunge quando **cessa lo scambio netto di energia** e le **temperature si eguagliano**
- **principio zero della termodinamica**: due corpi a contatto con diversa temperatura tenderanno ad uniformare le loro temperature

Prontezza di un termometro

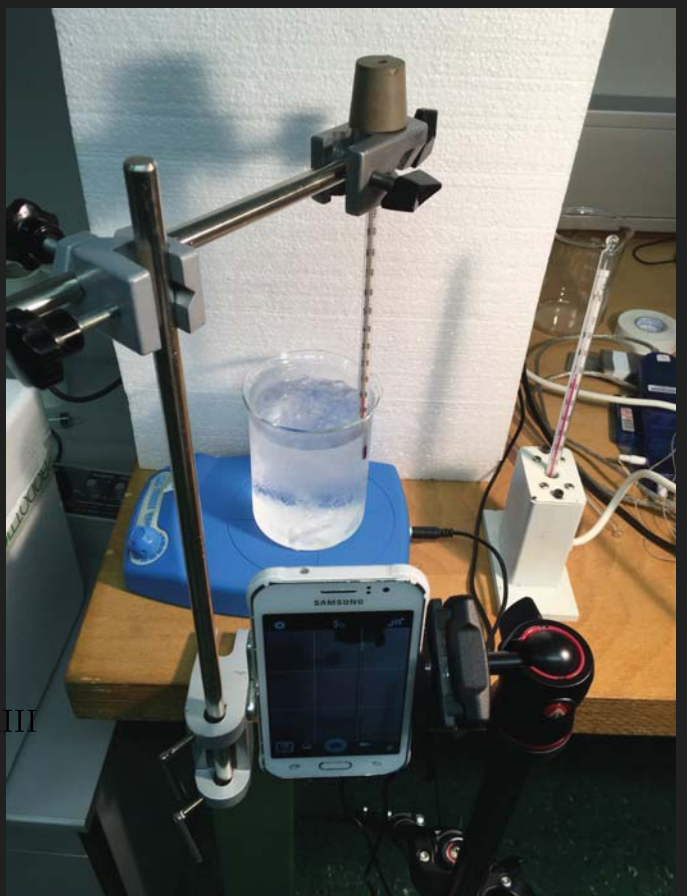
MATERIALE:

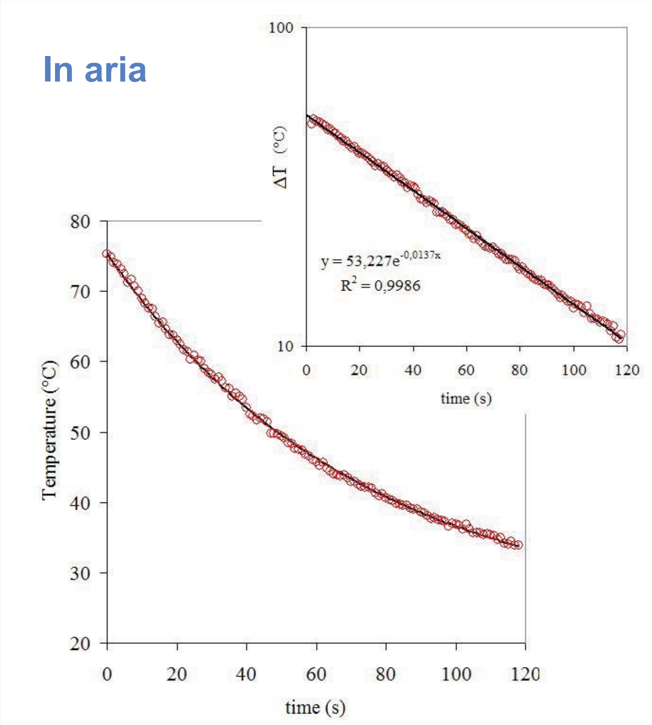
- termometro
- fornetto
- supporto
- beker + acqua
- smartphone + tracker o cronometro

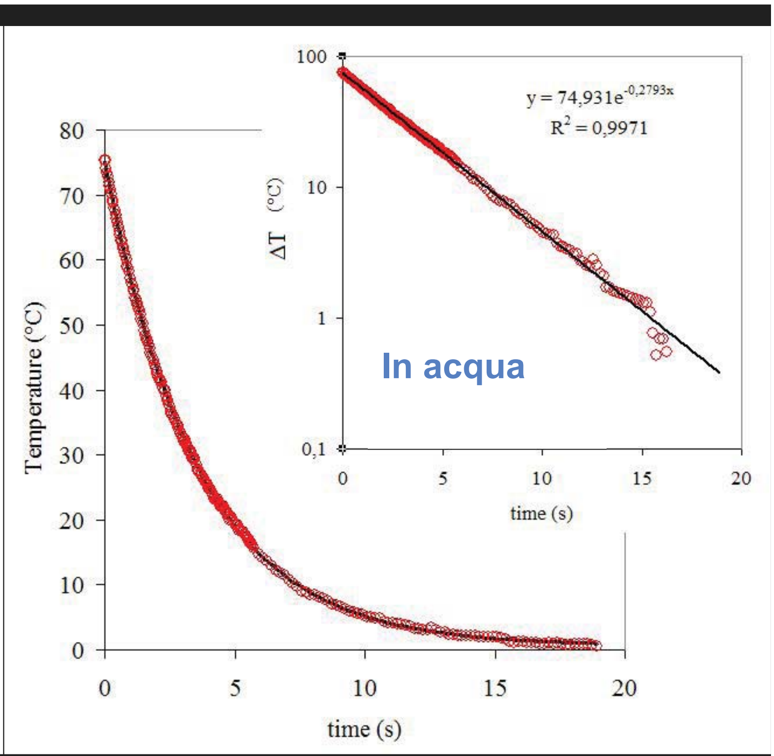
ESECUZIONE:

riscaldare termometro con fornetto e misurare l'andamento della temperatura nel tempo nel caso in cui il termometro sia in aria e poi ripetere immerso immergendo in acqua. Stimare la costante di tempo (tempo di dimezzamento).

Extra: fare la stessa cosa con il termometro esposto ad un ventilatore!







- andamento **esponenziale** decrescente **Temperatura - tempo**
- i due tempi di risposta (costante di tempo) differiscono di un **fattore 20**! (73-3,58 s)
- l'aria è 20 volte meno efficiente dell'acqua nei processi convettivi di trasferimento dell'energia
- **il tempo di risposta (prontezza) non è caratteristica solo dello strumento!**

Capannina meteorologica

- voglio misurare la **temperatura dell'aria**! Non di altre cose.
- **posizionamento**
- bianco riflette la luce per minimizzare gli effetti dell'**irraggiamento** (sole)
- fessure per permettere la **ventilazione** (passaggio aria)
- **standard di acquisizione** dei dati meteo => protocolli **WMO** (ad es. frequenza, orario, **altezza** dal suolo **2 m**)
- In molti casi misure di temperatura errate! Temperatura del bulbo, non dell'aria.

Esperimenti di approfondimento

- Alcool e acqua a temperatura ambiente. Chiedo agli studenti cosa succederà alla temperatura se **mescolo acqua e alcool**… La temperatura aumenta! Principio zero sì, ma se sistema isolato e se non avvengono **reazioni chimiche**!
- Prendo un **termometro**, e lo **bagno con alcool** (o acqua) a temperatura ambiente. Chiedo agli studenti cosa succederà alla temperatura indicata dal termometro… Scende! Perchè c'è evaporazione dell'alcool e di conseguenza sottrazione di calore latente!
- Poi posso anche **agitarlo** e mostrare che il calo di temperatura è ancora più rapido (effetto **vento**)
- Bicchiere con **acqua a temperatura ambiente** e chiedo agli studenti se temperatura di aria e acqua sono **veramente** le stesse (in realtà l'acqua è leggermente più fredda per via dell'evaporazione sempre presente).
- **sudorazione** e **termoregolazione**
- **effetto windchill**

Temperatura percepita ed effetto windchill

Wind chill chart (Celsius) — temperature (°C) — click here for Fahrenheit chart

wind speed (kph) \ calm	5	0	−5	−10	−15	−20	−25	−30	−35	−40
10	3	−3	−9	−15	−21	−27	−33	−39	−45	−51
20	1	−5	−12	−18	−24	−31	−37	−43	−49	−56
30	0	−7	−13	−20	−26	−33	−39	−46	−52	−59
40	−1	−7	−14	−21	−27	−34	−41	−48	−54	−61
50	−2	−8	−15	−22	−29	−35	−42	−49	−56	−63
60	−2	−9	−16	−23	−30	−37	−43	−50	−57	−64
70	−2	−9	−16	−23	−30	−37	−44	−51	−59	−66
80	−3	−10	−17	−24	−31	−38	−45	−52	−60	−67
90	−3	−10	−17	−25	−32	−39	−46	−53	−61	−68
100	−3	−11	−18	−25	−32	−40	−47	−54	−61	−69

wind chill (°C) = $13.12 + 0.6215T - 11.37(V^{0.16}) + 0.3965T(V^{0.16})$ — T = air temperature (°C)

frostbite times: 30 minutes, 10 minutes, 5 minutes — V = wind speed (kph)

Con **venti forti** e **basse temperature**, la temperatura percepita dalle parti del **corpo esposte all'aria** è **più bassa** rispetto a quella misurata perché il vento aumenta l'**evaporazione** del sudore e rimuove lo **straterello** di **aria calda** a contatto con la pelle (sottrazione calore)

Pressione

- punto di vista **macroscopico**: forza per unità di superficie
- legge di Boyle in siringa
- Punto di vista **microscopico**: urti delle molecole contro le pareti del recipiente
- legge di Boyle e palline di vetro
- un applet Phet - proprietà dei gas
- sperimentare con bottiglia di plastica con valvola di bicicletta e palloncino
- Esperimento di approfondimento (pressione e tensione superficiale!)

Pressione 1

- pressione come **frequenza degli urti delle molecole del gas contro i confini dello spazio che occupa** (interne ed esterne)
- **calpesto** una bottiglia, da un'altra **aspiro** aria, soffiandoci dentro posso farla tornare come prima: cosa succede?
- pareti di plastica, facilmente deformabili, soggette ad urti con la stessa frequenza da dentro e da fuori in quanto il gas, tende ad occupare omogeneamente tutti gli spazi dove può andare. Se gli urti in media sono gli stessi da entrambi i lati la parete della bottiglia non si muove.
- Nel caso schiaccio la bottiglia con il piede, all'inizio ci sono un ugual numero di molecole che urtano da entrambi i lati ma come poso il peso sopra agli urti delle molecole si aggiungerà il peso del corpo e quindi la parte si sposta in quanto dall'altra parte le molecole non ce la fanno a controbilanciare il peso.
- Nel caso sia aspirata l'aria dalla bottiglia, nella parte interna della parete non ci saranno molecole che urtano per controbilanciare quelle esterne e quindi quest'ultime deformano la parete.
- chiedere a qualcuno che va in montagna di chiudere una bottiglia in montagna e portarla poi a scuola

Pressione 2

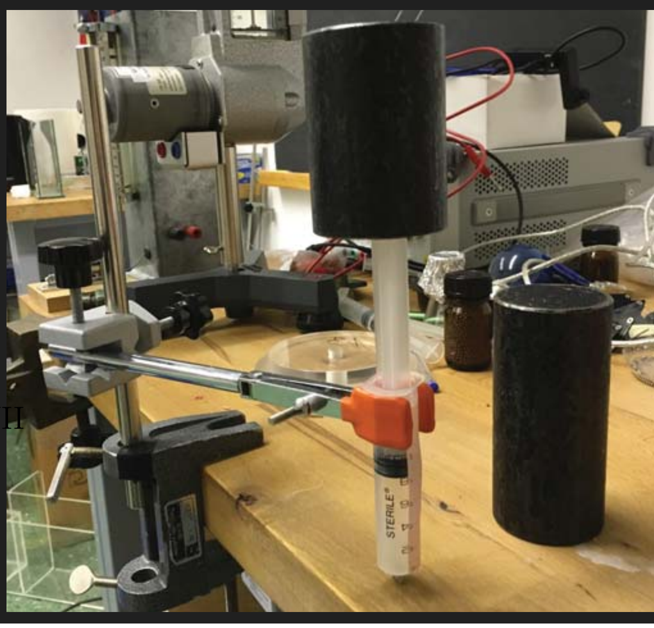
- Barattolo/bottiglia con valvola di bicicletta, palloncino, pompa per bicicletta
- gonfia un **palloncino nella bottiglia** toccando un po' le pareti e chiudo ermeticamente. Palloncino resta fermo in quanto tocca le pareti. Pompo aria nel barattolo e si vede come il volume occupato dal palloncino diminuisce e quindi si muove liberamente dentro la bottiglia. Svuoto e il palloncino si gonfiera' nuovamente.
- Quando si gonfia il palloncino introduco molecole d'aria al suo interno. Il volume che occupera' il palloncino dipende da quanto 'spingono' le molecole all'interno rispetto alla pressione esterna. Quando il palloncino e' all'esterno del barattolo il volume dipendera' dall'**equilibrio tra le molecole al suo interno e quelle esterne** data la pressione atmosferica. Quando mettiamo il palloncino dentro il barattolo e cominciamo a pompare aria, all'interno del palloncino le molecole sono sempre le stesse mentre all'esterno pompando aria ne aggiungo sempre di più e si spingono di piu' di prima dall'esterno e il palloncino comincia a ridurre il suo volume (e anche la sua superficie) fino a che il numero di urti (pressione) per unita' di superficie all'interno del palloncino eguaglia quelli esterni.
- Quando faccio uscire l'aria dalla valvola diminuiscono le molecole che urtano dall'esterno mentre sono sempre le stesse quelle all'interno del palloncino e quindi il palloncino si espande.

Trasformazioni isoterme - Legge di Boyle in siringa

MATERIALE:

- siringa, bava da pescatore, masse, bilancia, supporto, carta millimetrata, calibro, barometro, supporto, scotch

ESECUZIONE:

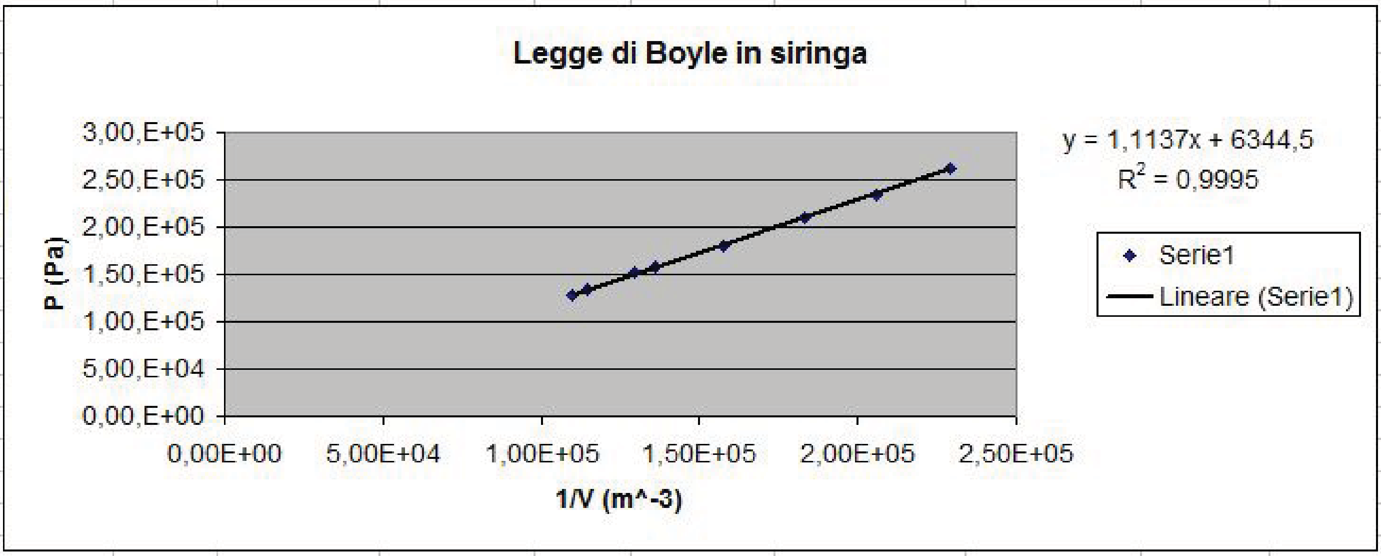


1. bava nella siringa e faccio in modo che la pressione iniziale dentro la siringa sia uguale a quella atmosferica, peso le masse, misuro la sezione interna della siringa e la pressione atmosferica.
2. aggiungo varie masse e misuro il volume corrispondente
3. Stima incertezza: metà scarto tra volume massimo e volume minimo (dalla posizione di equilibrio raggiunta spingo ulteriormente e rilascio). N.B. aspettare un po' che termalizzi
4. grafico P_tot = P_masse + P_atm vs 1/V

Analisi dati - proporzionalità inversa P-V

masse	m0 (g)	m1 (g)	m2 (g)	m3 (g)	P_atm (Pa)	diametro (mm)	delta d	r (mm)	S (m^2)
	123	602,9	1089,4	1665,1	98100	15,9	0,1	7,95	1,98E-04

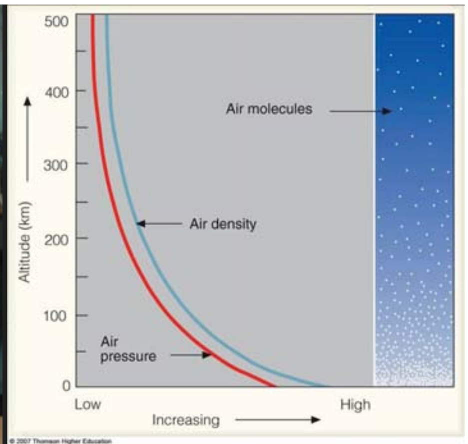
massa (g)	delta m	h_max (mm)	h_min (mm)	h (mm)	delta h	V (m^3)	P_masse (Pa)	P_tot (Pa)	1/V
602,9	0,1	47	45	46	1	9,13E-06	29802	1,28,E+05	1,10E+05
725,9		45	43	44		8,73E-06	35882	1,34,E+05	1,15E+05
1089,4		40	38	39		7,74E-06	53851	1,52,E+05	1,29E+05
1212,4		38	36	37		7,34E-06	59931	1,58,E+05	1,36E+05
1665,1		33	31	32		6,35E-06	82309	1,80,E+05	1,57E+05
2268		28	27	27,5		5,46E-06	112111	2,10,E+05	1,83E+05
2754,5		25	24	24,5		4,86E-06	136159	2,34,E+05	2,06E+05
3330,2		22	22	22		4,37E-06	164617	2,63,E+05	2,29E+05



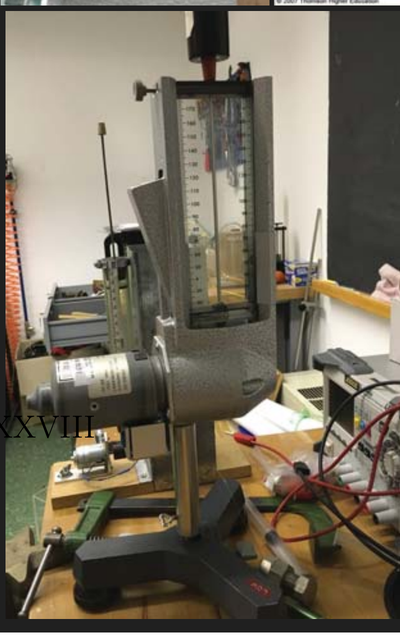
Analogia microscopica

MATERIALE:

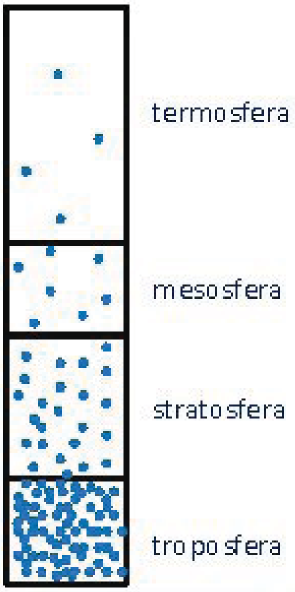
- simulatore modello gas perfetto (palline, motorino + base vibrante + stantuffo)

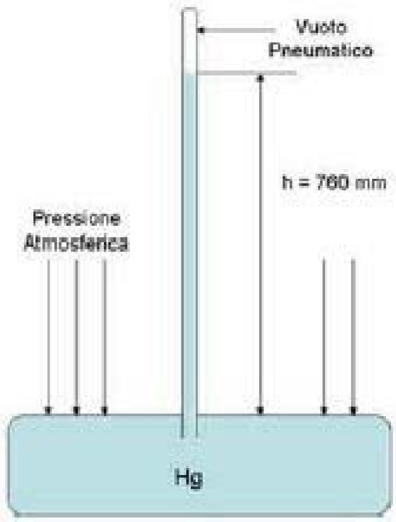


- l'azione della forza peso è rilevante (si può parlare di equilibrio idrostatico e di legge di Stevino) e visibile a livello di stratificazione delle palline (densità che diminuisce con la quota) e delle loro traiettorie paraboliche (modello di atmosfera)
- concetto microscopico di pressione come numero medio di urti delle palline (molecole)
- si può ricavare sperimentalmente una proporzionalità inversa tra pressione (atmosferica + masse aggiunte) e volume occupato dalle palline



La pressione atmosferica





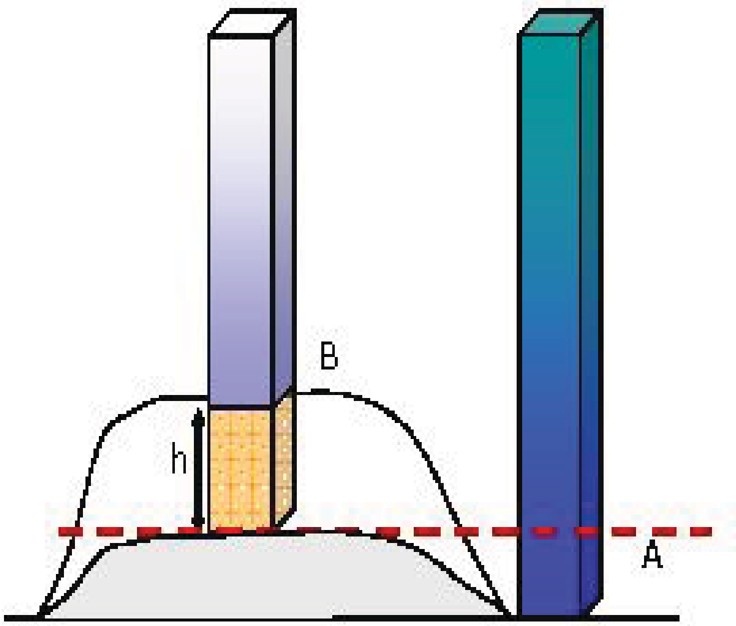
- **forza per unità d'area** dovuta al peso (forza di gravità) di una colonna di atmosfera
- i gas atmosferici si **rarefanno** quindi salendo (minore densità) e la **pressione diminuisce** con la **quota** (non esistono inversioni bariche)
- dall'equilibrio tra gradiente di pressione e gravità si ottiene l'**equilibrio idrostatico** (Stevino), ma in atmosfera la densità dipende dalla temperatura che dipende dalla quota!
- Si misura con un **barometro** (torricelli, o aneroide) **unità** di misura: mmHg (Torr), Pa, bar

Bicchiere capovolto e pressione atmosferica

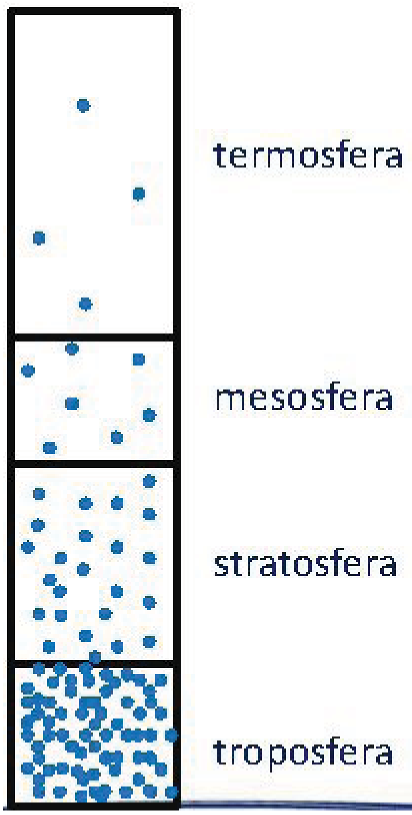
- la **pressione** atmosferica agisce in **tutte le direzioni**
- all'interno del bicchiere il volume dell'aria si espande leggermente (esce un po' d'acqua o la superficie della carta si bomba un po') e si crea quindi una **lieve depressione** rispetto alla pressione esterna atmosferica, sufficiente a sostenere il peso del foglio di carta
- interessante poi usare invece della carta una calza o una **retina a maglie fine** (ruolo della **tensione superficiale**!)

Riduzione della pressione a livello del mare

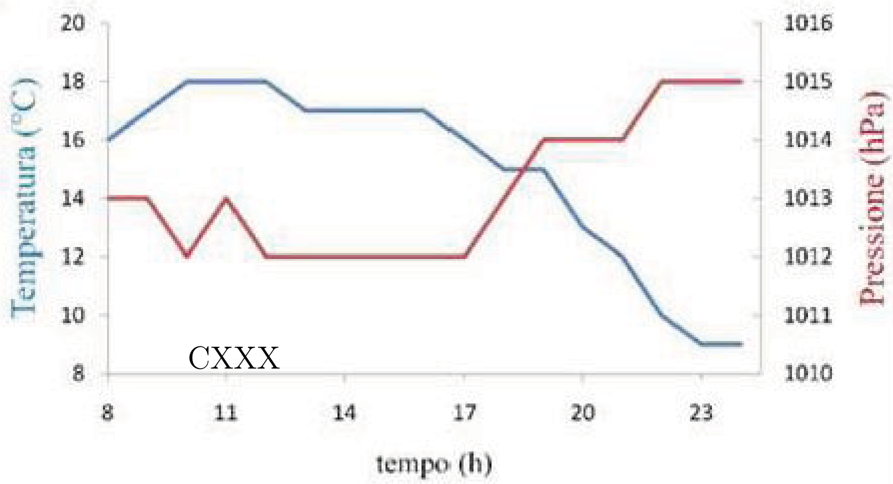
- Dove esiste **l'orografia**, occorre "rimuoverla" e sostituirla con un **volume equivalente di atmosfera** (calcolato usando i parametri dell'**atmosfera standard**)
- Questa operazione si chiama **riduzione della pressione ad un dato livello**
- Ciò che viene fatto regolarmente per elaborare le **carte bariche al suolo**



Pressione e temperatura in atmosfera



La pressione dipende da quanta massa atmosferica si trova nella colonna



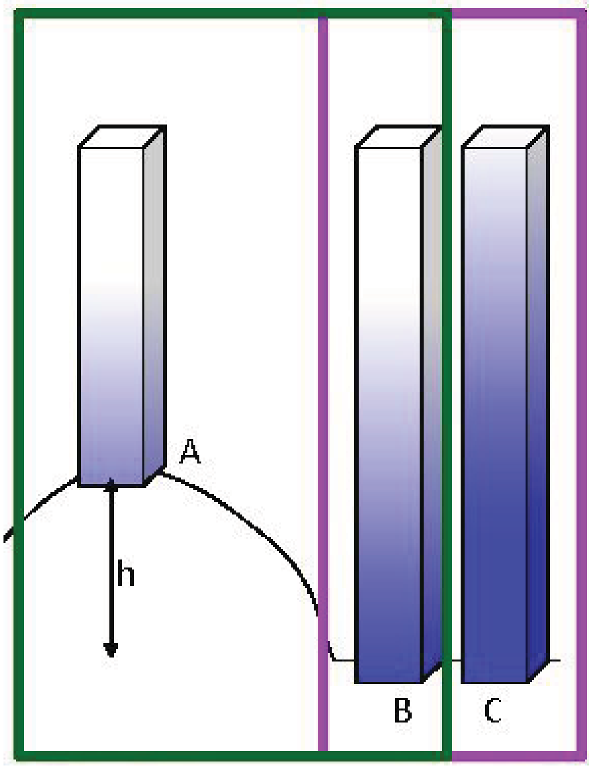
Perchè varia la pressione atmosferica?

Colonne alla stessa quota

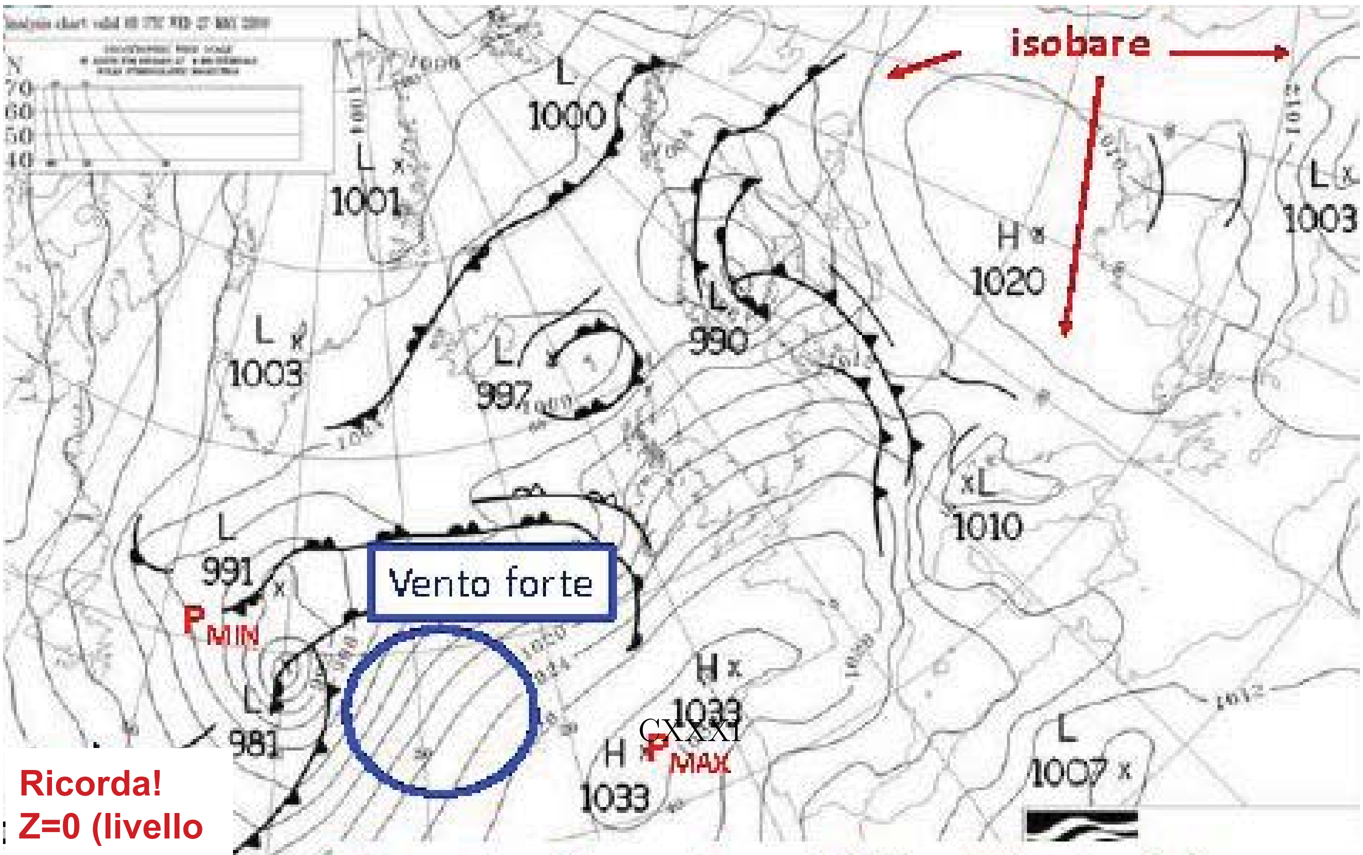
- **la densità dell'aria è diversa**

Colonne a quote diverse

- **"manca l'aria"**



Mappe di pressione - isobare e venti - animazione



Esempio di pressione ridotta al livello del mare

Il vento

- **vettore** (modulo, direzione e verso) - campo vettoriale di velocità del fluido
- nasce dalle **differenze di pressione** per **uniformare la densità** dell'atmosfera
- spostamento di aria **da** zone ad **alta pressione** verso zone **a bassa** pressione

Rosa dei venti (direzione di provenienza)

Scala Beaufort (intensità e condizioni)

Grado Beaufort	Velocità del Vento (Km/h)	Descrizione	Icona	Condizioni sul Territorio
0	0	Calmo		Il fumo sale verticalmente.
1	1 -6	Bava di Vento		Movimento del vento visibile dal fumo.
2	7 - 11	Brezza Leggera		Si sente il vento sulla pelle nuda. Le foglie frusciano.
3	12 - 19	Brezza Tesa		Foglie e rami più piccoli in movimento costante.
4	20 -29	Vento Moderato		Sollevamento di polvere e carta. I rami sono agitati.
5	30 - 39	Vento Teso		Oscillano gli arbusti con foglie. Si formano piccole onde nelle acque interne.
6	40 - 50	Vento Fresco		Movimento di grossi rami. Difficoltà ad usare l'ombrello.
7	51 - 62	Vento Forte		Interi alberi agitati. Difficoltà a camminare contro vento.
8	63 - 75	Burrasca		Ramoscelli strappati dagli alberi. Generalmente è impossibile camminare contro vento.
9	76 - 87	Burrasca Forte		Leggeri danni alle strutture. Camini e tegole asportati.
10	88 - 102	Tempesta		Sradicamento di alberi. Considerevoli danni strutturali.
11	103 - 117	Tempesta Violenta		Vasti danni strutturali.
12	> 118	Uragano		Danni ingenti ed estesi alle strutture.

Da quali forze è determinato?

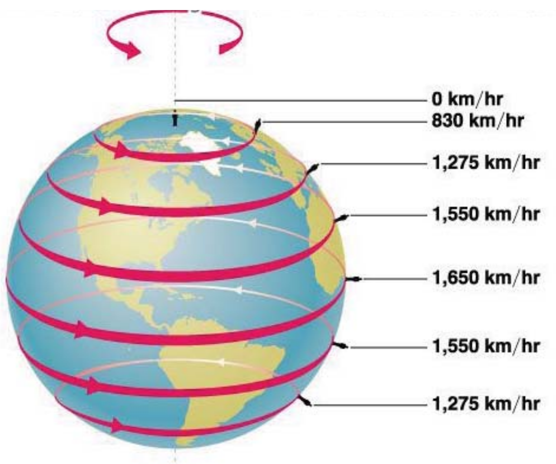
CXXXII

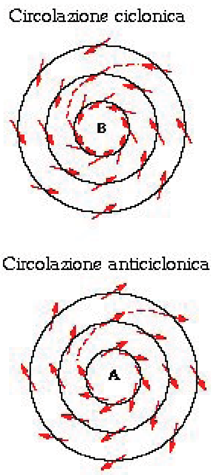
animazioni: Newton, attrito, Coriolis

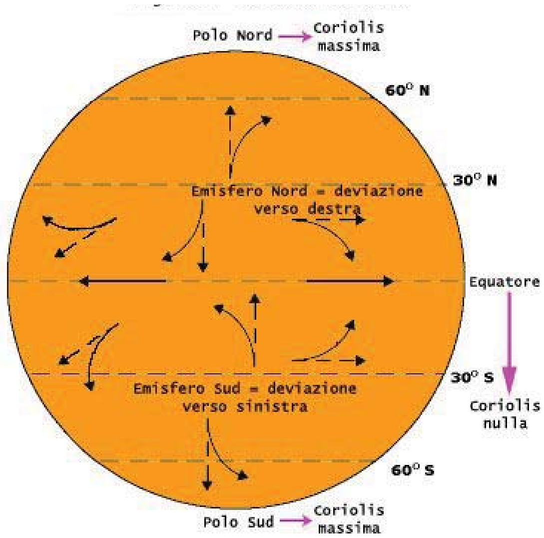
Forza di Coriolis

$$\mathbf{F}_C = m a_C = -2m\,\boldsymbol{\omega} \times \mathbf{v}$$

- forza **apparente** (moto in sistema di riferimento non inerziale - rotazione)
- **ortogonale** alla **velocità**, nello stesso piano del moto
- massima ai poli, minima all'equatore
- **devia verso destra** vento nell'emisfero **boreale** (lo fa ruotare in senso **antiorario** attorno a un **ciclone**, orario anticiclone), verso sinistra in quello australe
- esperimento: provare a lanciarsi una palla su una giostra o far tracciare una linea dritta mentre si ruota il foglio

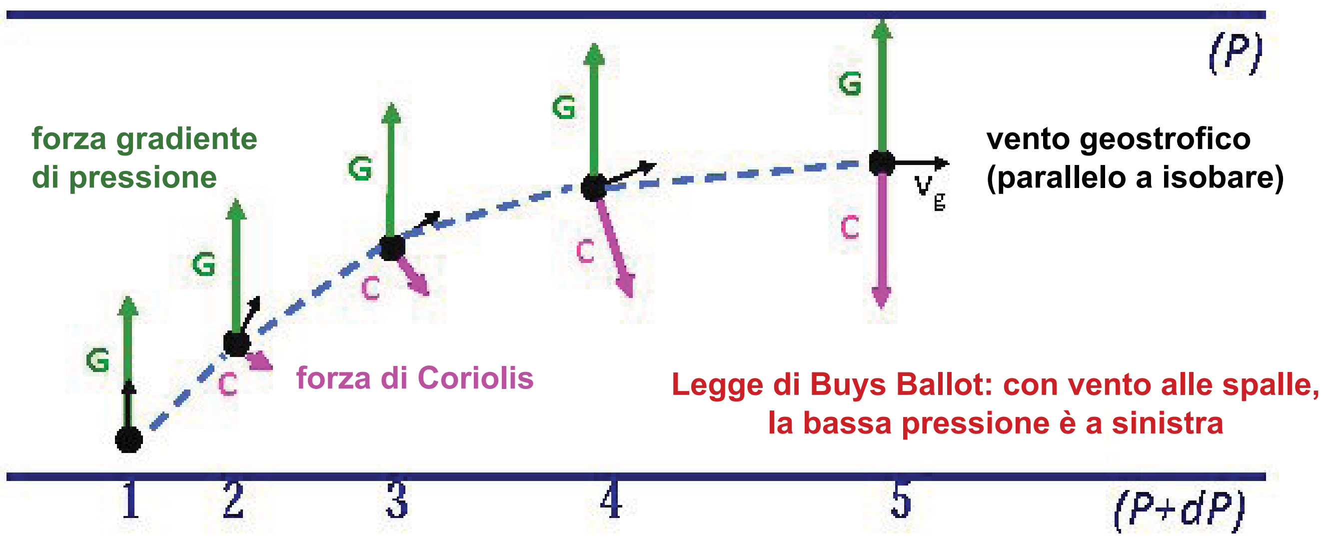






Vento in quota: parallelo alle isobare

http://www.mesoscale.iastate.edu/agron206/animations/Geostrophic_Gradient_Flow.swf

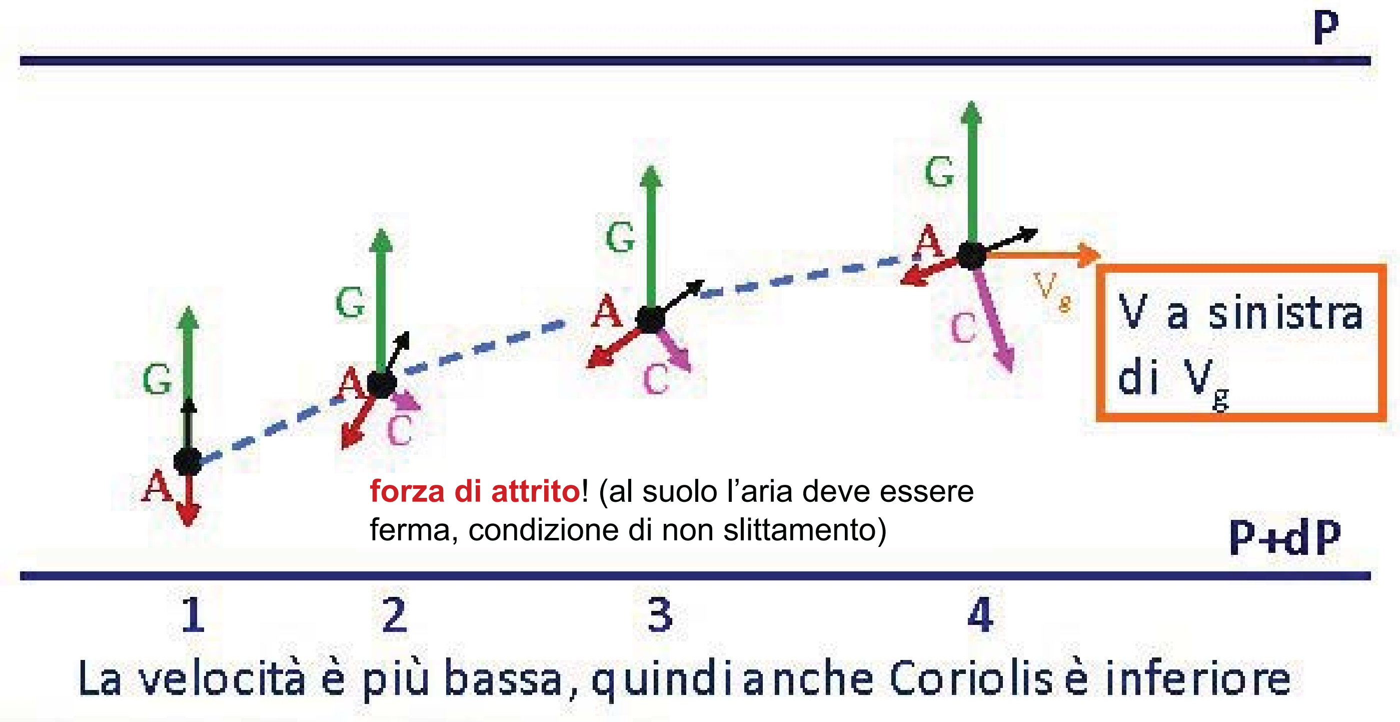


Condizioni

- Niente attrito
- isobare/isoipse rettilinee e parallele
- isobare invarianti nel tempo

Vento al suolo: bassa pressione e convergenza, alta pressione e divergenza

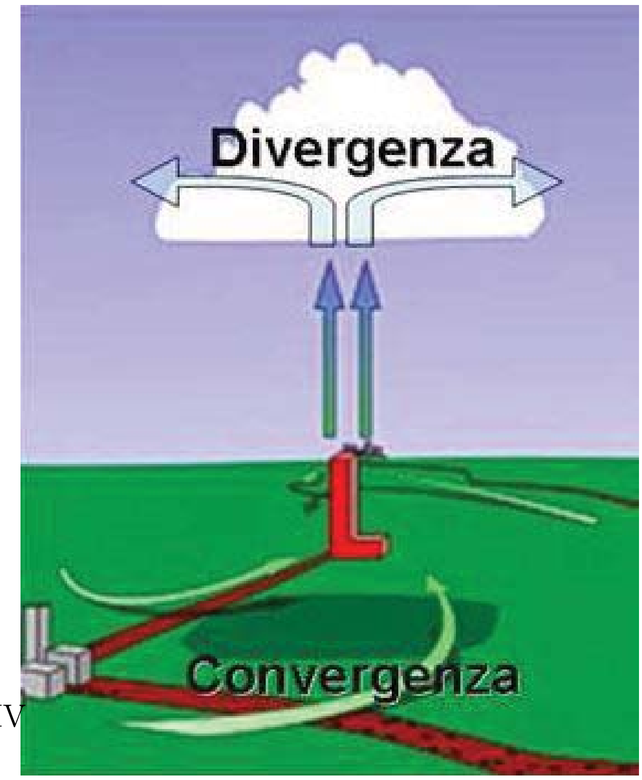
http://www.mesoscale.iastate.edu/agron206/animations/PGF_Coriolis_Friction.swf



Bassa pressione e cicloni (o depressioni) - es: Islanda

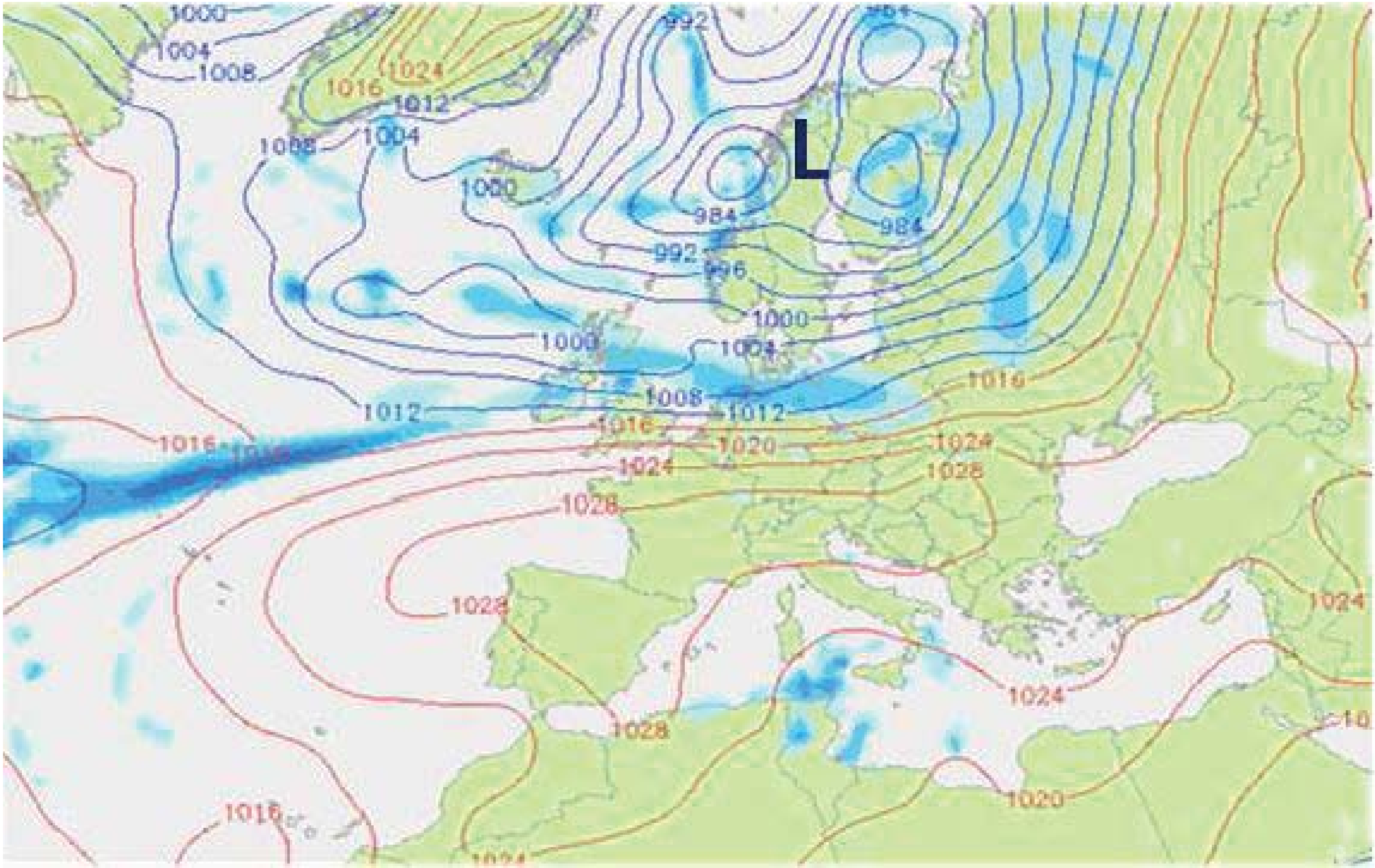
Nel **ciclone**

- l'**aria sale** (moti ascendenti)
- la pressione diminuisce verso il centro (**bassa pressione al suolo**)
- i **venti** ruotano in senso **antiorario** (Coriolis) e sono **forti**
- associato a **nubi stratiformi e convettive, e a precipitazioni**



http://www.mesoscale.iastate.edu/agron206/animations/12_CycAntiCyc.swf
http://www.mesoscale.iastate.edu/agron206/animations/Cyclone_Form_Movement.swf

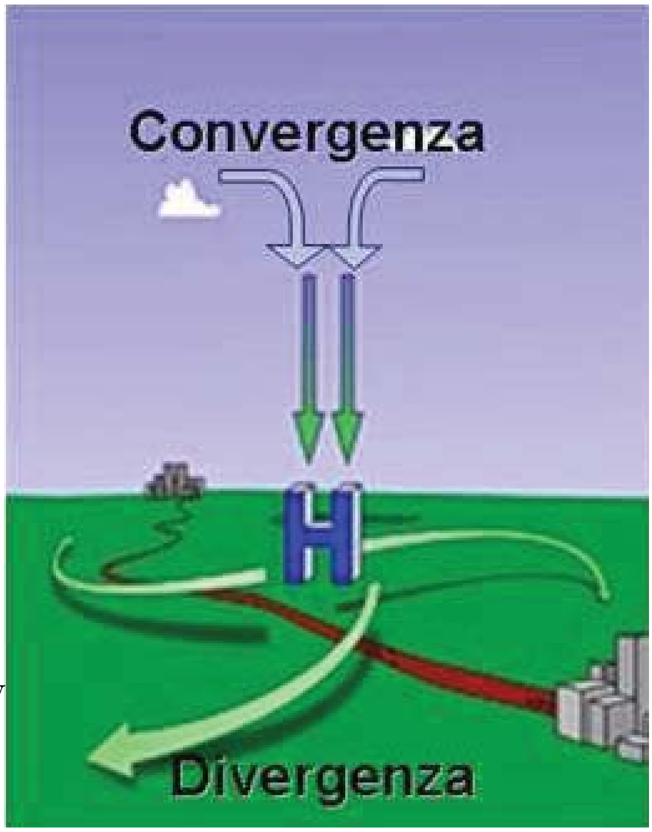
Un esempio: ciclone e mappa di pressione al suolo



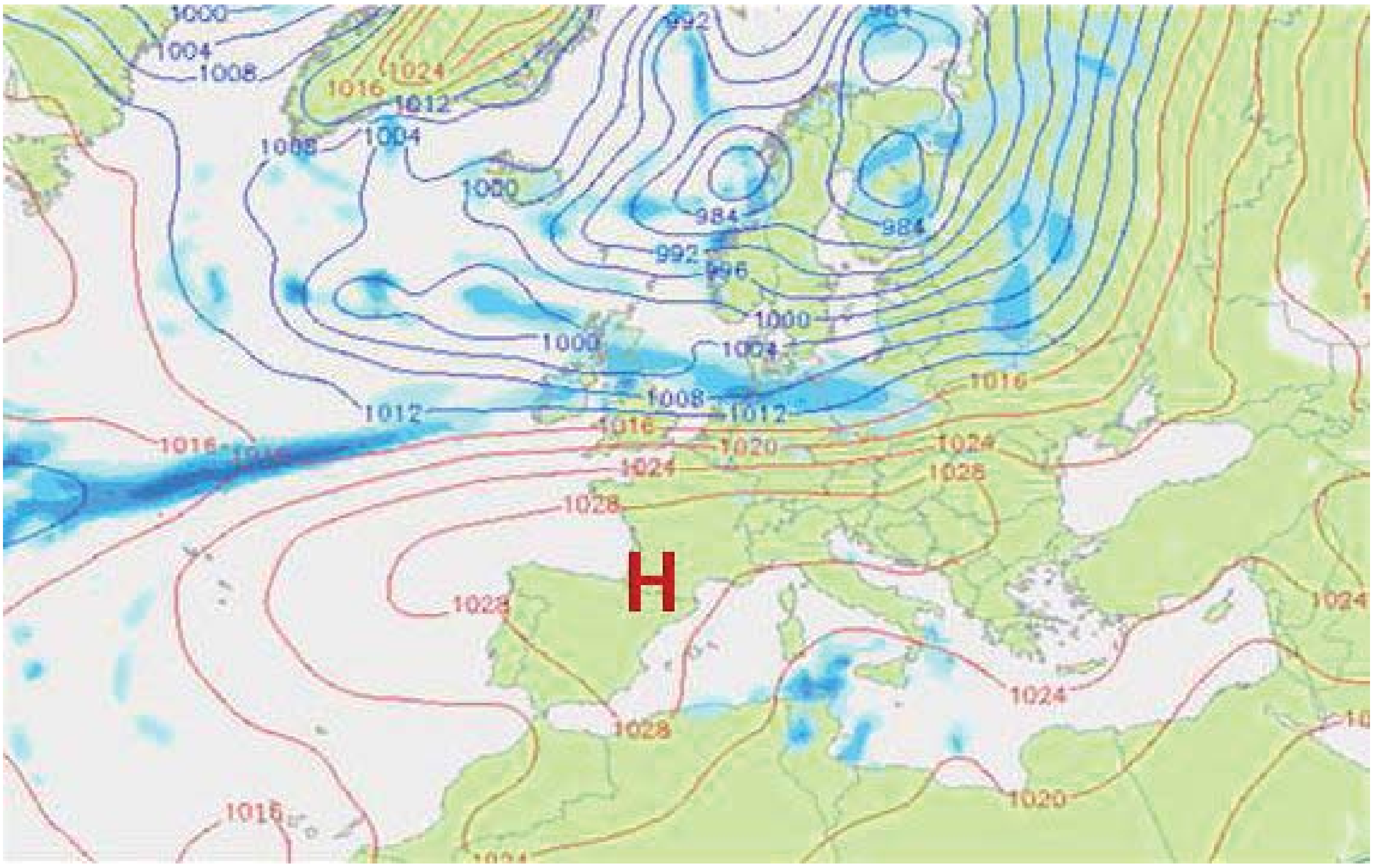
Alta pressione e anticicloni - es: Azzorre

Nell'**anticiclone**

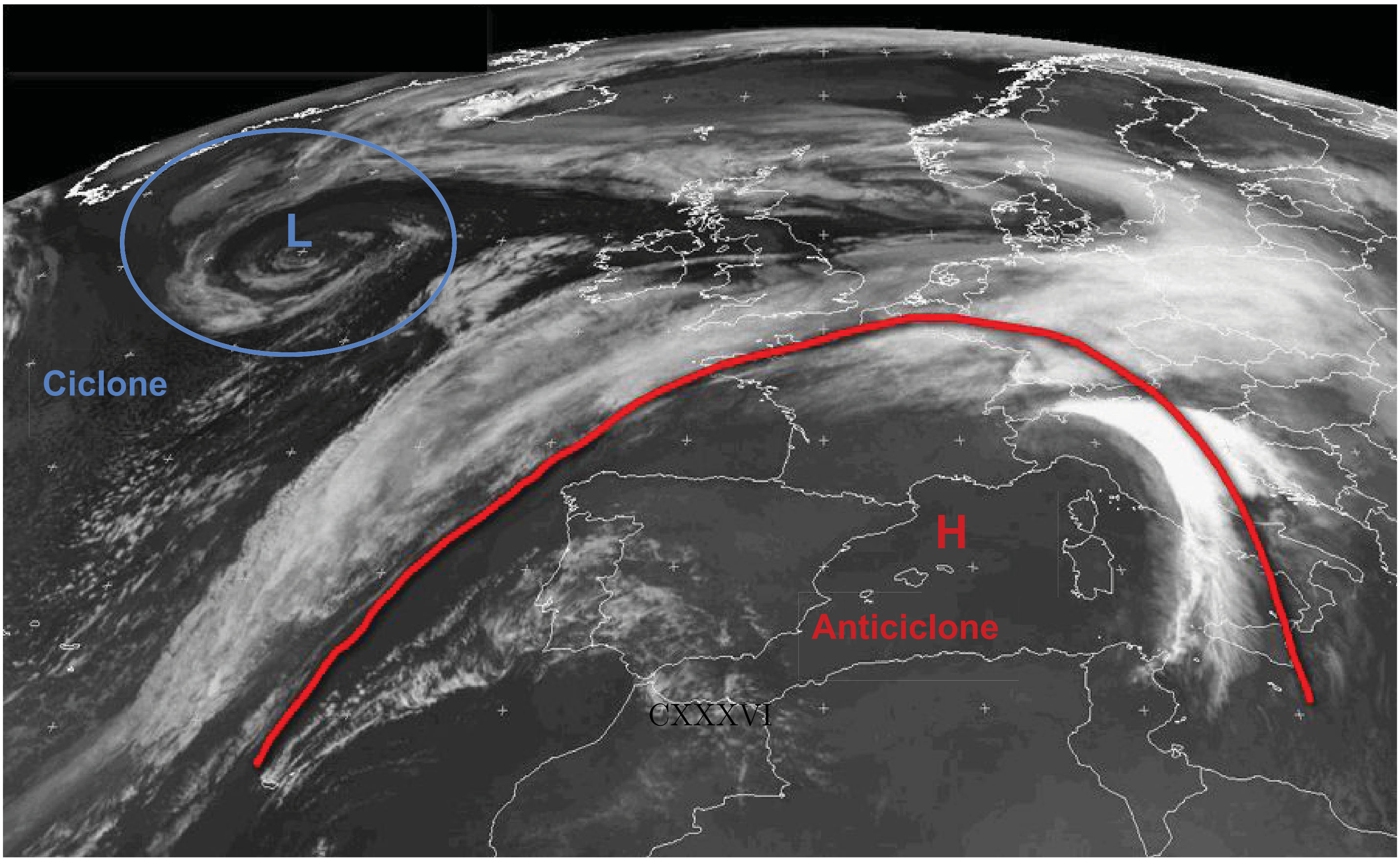
- l'aria scende (**subsidenza**)
- la pressione aumenta verso il centro (**alta pressione al suolo**)
- i **venti** ruotano in senso **orario** (Coriolis) e sono **calmi**
- condizioni di **sky clear** o **nubi basse**
- blocca la convezione negli strati bassi favorendo **smog** e **nebbia**



Un esempio: anticiclone e mappa di pressione al suolo



da satellite: circolazione ciclonica vs anticiclonica



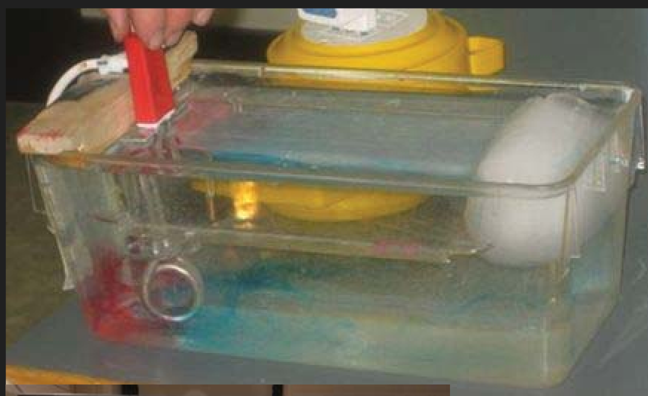
Cicloni e anticicloni in padella

MATERIALE:

- supporto rotante (tagliere, ruota di bicicletta, giradischi), contenitore (padella), tubetto aspirine bucato, latte o colorante
- variante con gradiente di temperatura: lattina tagliata con ghiaccio e acqua calda

Video MetOffice

Cella convettiva: una dimostrazione

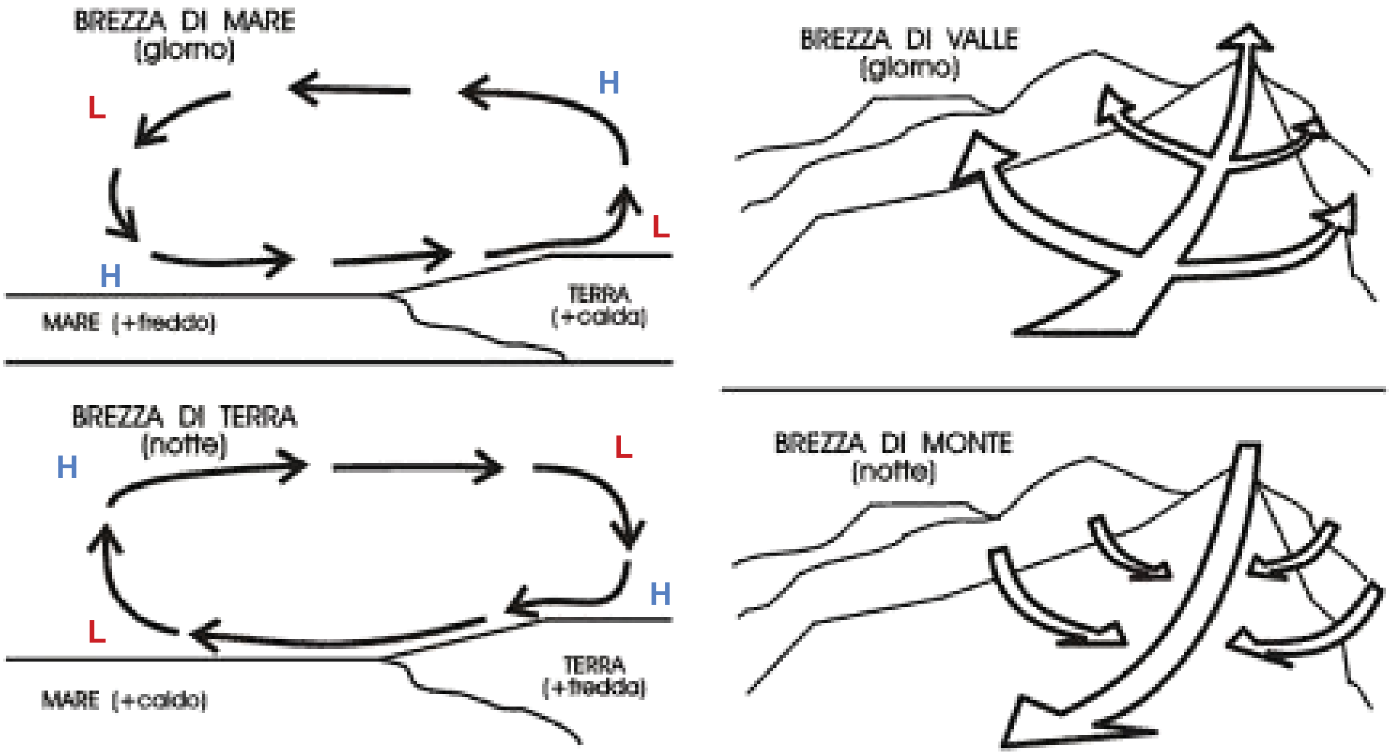


- recipiente (che conduca il calore sul fondo), due bicchieri, acqua bollente (in alternativa resistenza) e ghiaccio, coloranti alimentari.

- variante su piatto rotante con latina con ghiaccio al centro

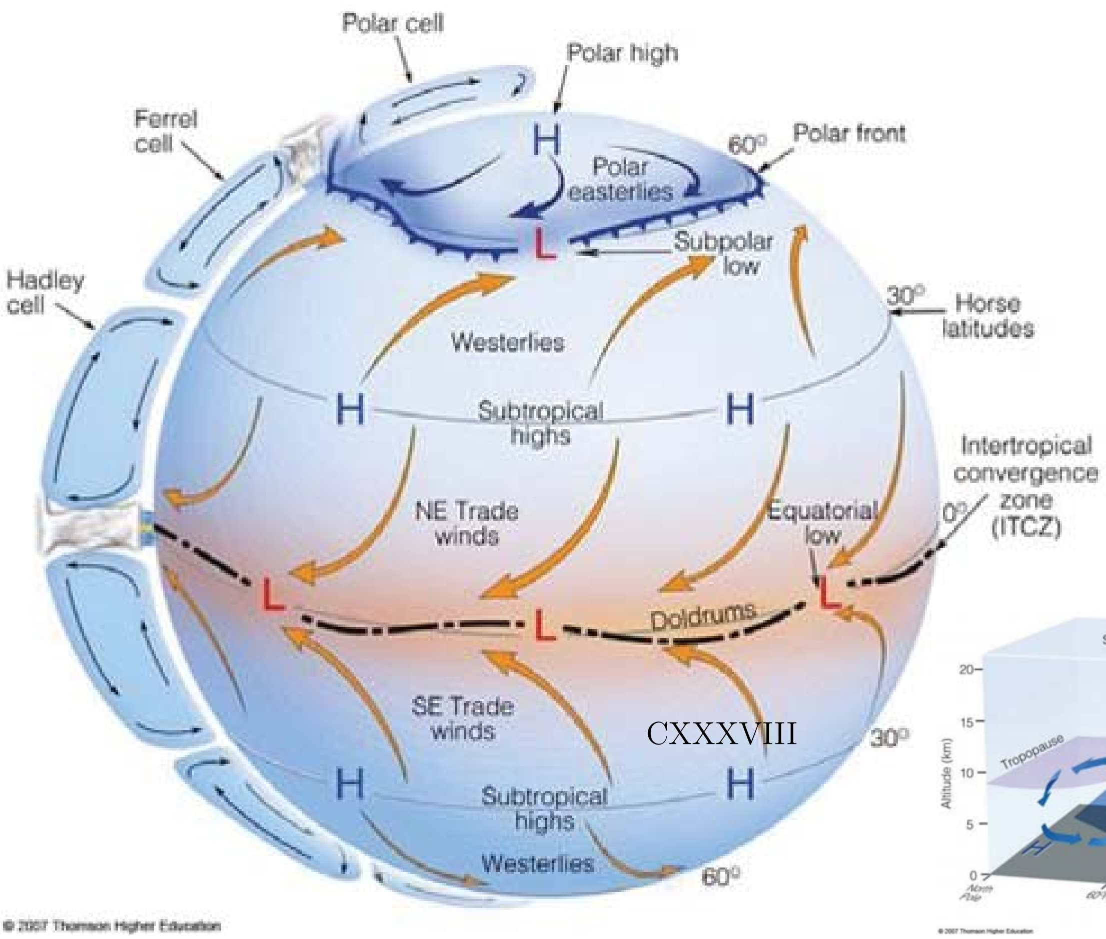
Video weather in a tank (MIT)
Video SPINlab (UCLA)

Brezze e venti locali (mesoscala)

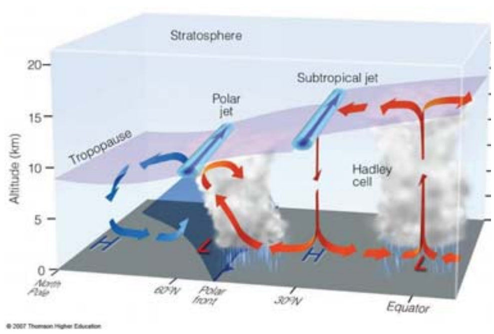


es: **pelér/ora del garda**, aria che tira **in su di giorno e in giu la sera** (montagna)

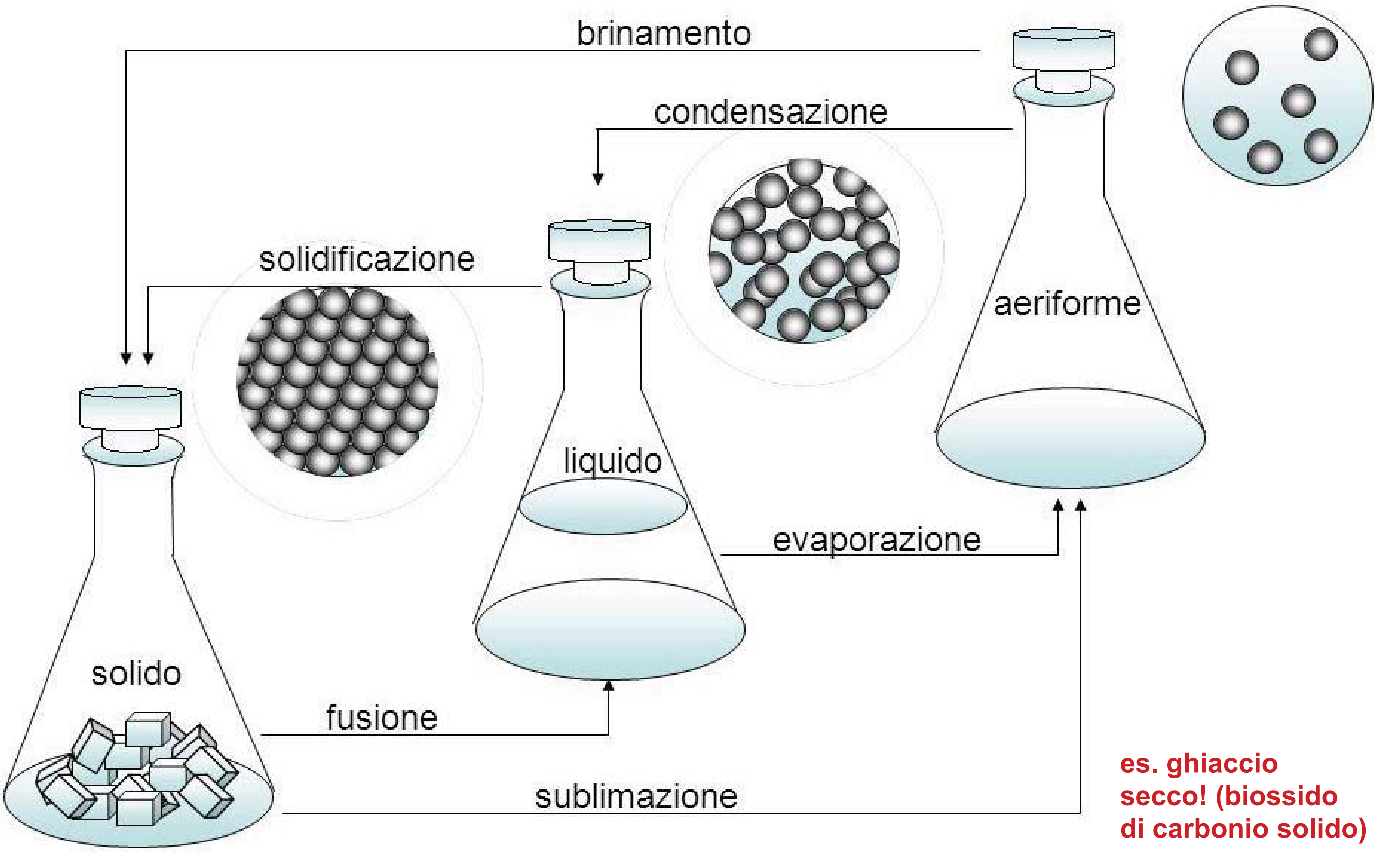
La circolazione generale dell'atmosfera



[un video](#)

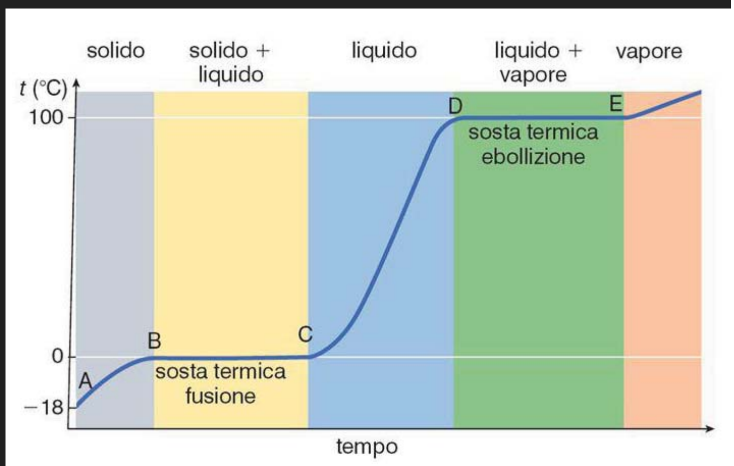


Passaggi di stato



es. ghiaccio secco! (biossido di carbonio solido)

Temperatura e passaggi di stato



MATERIALE:

- bollitore
- ghiaccio
- termometro

ESECUZIONE:

- metto nel bollitore ghiaccio dal congelatore, accendo e misuro la temperatura al variare del tempo, fare grafico T(t) e notare i due punti fissi: fusione ed ebollizione (sosta termica) in cui T resta costante.

COSA SUCCEDE:

- continuo a fornire energia ma T non aumenta!
- L'energia che fornisco sotto forma di calore viene impiegata per rompere i legami tra le molecole ("allentare" le interazioni)

N.B. **quando l'acqua bolle posso abbassare il gas!**

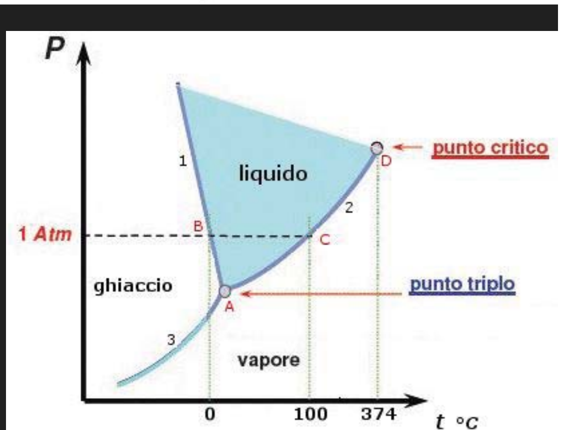


diagramma di fase P-T

Calore latente di condensazione (vaporizzazione)

MISURE:

- massa e temperatura acqua in calorimetro (ambiente)
- massa e temperatura (iniziale) del vapore
- temperatura di equilibrio

$m_{vapore} = 6{,}9\ g$

$m_{H2O} = 202{,}52\ g$

$m^* = 10{,}2\ g$

$T_{H2O} = 21{,}89°C$

$T_{vapore} = 97{,}7°C$

$T_{eq} = 37{,}23°C$

dalle misure ƛ=412,4 cal/g
valore di rif. ƛ=541 cal/g

$$Q_{condensazione} + Q_{ceduto\ H2O} = Q_{assorbito\ H2O}$$

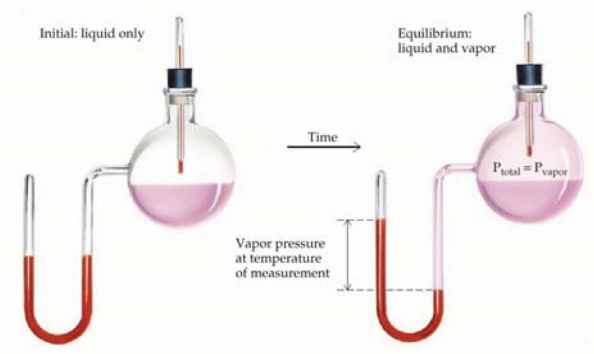
$$m_{vapore} \cdot \lambda_{condensazione} + m_{vapore} \cdot c_{H2O}(T_{vapore} - T_{eq}) = (m_{H2O} + m^*) \cdot c_{H2O}(T_{eq} - T_{H2O})$$

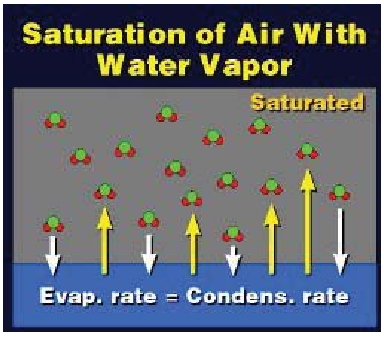
$$\lambda_{condensazione} = c_{H2O}(T_{eq} - T_{vapore}) + (m_{H2O} + m^*) \cdot c_{H2O}(T_{eq} - T_{H2O}) / m_{vapore}$$

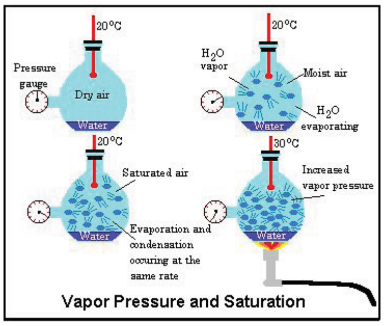
Ebollizione in siringa o in campana a vuoto

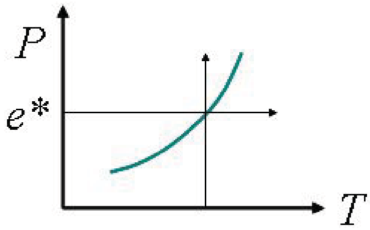
- **MATERIALE:** siringa con tappo o campana a vuoto, acqua, termometro
- **Punti fissi** (temperatura di ebollizione o in generale dei passaggi di stato) **dipendono dalla pressione**!
- in montagna l'acqua non bolle a 100°C! Difficile cuocere la pasta!

Pressione di vapore e tensione di vapore saturo









- vapore acqueo è un gas => **legge di Dalton** (pressioni parziali)
- **pressione di vapore**
- **saturazione**: **equilibrio dinamico** - evaporazione = condensazion
- alla saturazione P_vapore = **tensione** (o pressione) di **vapore saturo**
- P_vapore_saturo **cresce** esponenzialmente **con la temperatura**! Clausius Clapeyron
- N.B. il **vapore acqueo coesiste con l'aria**, non è contenuto o assorbito da questa (spugna)

Umidità assoluta e relativa

- **aria secca** e **umida** (contiene o meno vapore acqueo)
- **umidità assoluta**: m_vapore/V_aria (g/m^3) concentrazione assoluta di vapore
- **umidità relativa**: RH = 100*P_vapore/P_vapore_saturo (%)
- N.B. alla **saturazione** RH=100% (T=T_rugiada, P=P_vapore_saturo)
- da un punto di vista del **benessere fisico** (evapotraspirazione) è l'umidità relativa quella che conta (caldo secco, caldo umido, afa)
- **rapporto di mescolamento**: rapporto tra massa di vapore e la massa di aria secca - concentrazione relativa all'aria secca
- **umidità specifica**: q=m_vapore/m_aria (g/Kg) m_aria = m_secca + m_umida

Temperatura di rugiada (o dew point)

OBIETTIVO: dimostrare che l'**aria contiene vapore acqueo**

MATERIALE: recipiente lucido e buon conduttore di calore (ad esempio in acciaio inox), acqua, ghiaccio, termometro

ESECUZIONE:

Verso acqua a temperatura ambiente in recipiente lucido e aggiungendo ghiaccio a pezzetti (mescolare) abbasso la temperatura dell'acqua fino a quando non noto che all'esterno del recipiente si forma della condensa. La temperatura a cui questo avviene si dice **temperatura di rugiada**.

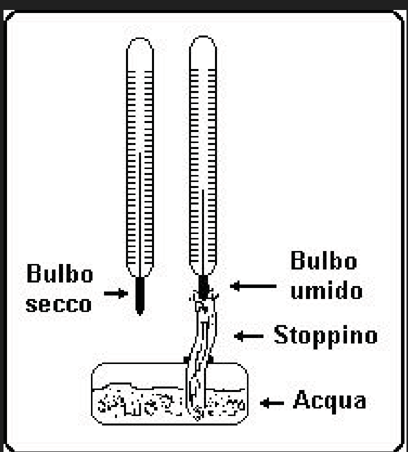
COSA SUCCEDE:

L'aria contiene vapore acqueo che è trasparente (non lo vediamo). Alla temperatura di rugiada il vapore acqueo condensa allo stato liquido formando delle piccolissime goccioline sulla parete esterna del recipiente. A quella temperatura si dice che l'aria è **satura** (di vapore acqueo) ovvero ho raggiunto il valore della **pressione di vapore saturo** per l'acqua.

N.B. in presenza di stazione meteo posso confrontare il valore ottenuto con quello di riferimento. In inverno, quando l'aria è molto secca (poca umidità) potrebbe essere difficile vedere la patina di condensa che si forma all'esterno.

Costruzione di uno psicrometro

- 2 termometri, uno con il bulbo avvolto in una garza bagnata con acqua distillata.
- un termometro misura la temperatura dell'aria, l'altro la **temperatura di bulbo bagnato**
- il **tasso di evaporazione** dalla garza che avvolge il termometro a bulbo bagnato e quindi il **raffreddamento** dello stesso dipende dall'**umidità relativa** (vicinanza alla o lontananza dalla saturazione)
- Dalla differenza tra due queste temperature si può risalire all'umidità relativa con **tabelle psicrometriche**.



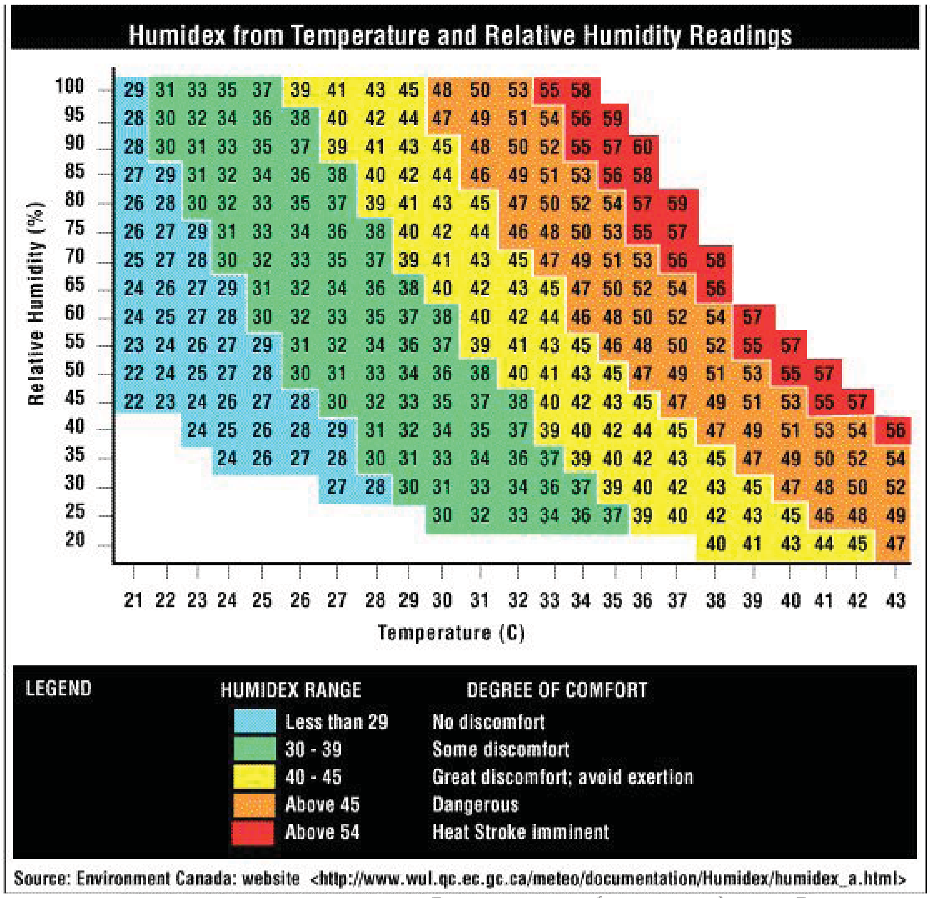
T. del bulbo umido	Differenza tra le temperature dei due bulbi											
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
2	90	83	75	67	61	54	47	42	36	31	26	23
3	90	83	76	69	63	56	49	44	39	34	29	26
4	91	84	77	70	64	57	51	45	41	36	32	28
5	91	85	78	71	65	59	54	48	43	39	34	30
6	92	85	78	72	66	61	56	50	45	41	35	33
7	92	86	79	73	67	62	57	52	47	43	39	35
8	92	86	80	74	68	63	58	54	49	45	41	37
9	93	86	81	75	70	65	60	55	51	47	43	39
10	94	87	82	76	71	66	61	57	53	48	45	41
11	94	88	82	77	72	67	62	58	55	50	47	43
12	94	88	82	78	73	68	63	59	56	52	48	44
13	94	89	83	78	73	69	64	61	57	53	50	46
14	94	89	83	79	74	70	66	62	58	54	51	47
15	94	89	84	80	75	71	67	63	59	55	52	49
16	95	90	84	80	75	72	67	64	60	57	53	50
17	95	90	84	81	76	73	68	65	61	58	54	52
18	95	90	85	81	76	74	69	66	62	59	56	53
19	95	91	85	82	77	74	70	66	63	60	57	54
20	95	91	86	82	78	75	71	66	64	61	58	55
21	95	91	86	83	79	75	71	68	65	62	59	56
22	95	91	87	83	79	76	72	69	65	63	60	57
23	96	91	87	83	80	76	72	69	66	63	61	58
24	96	92	88	84	80	77	73	70	67	64	62	59
25	96	92	88	84	81	77	74	70	68	65	63	59
26	96	92	88	84	81	77	74	71	68	65	63	59
27	96	92	88	84	81	77	74	71	68	65	63	59
28	96	92	88	84	81	77	74	71	68	65	63	60
29	96	92	88	84	81	77	74	72	69	66	63	60
30	97	93	89	85	82	78	75	72	69	66	64	60
31	97	93	89	85	82	78	75	72	69	66	64	61
32	97	93	89	85	82	78	75	72	70	67	64	61
33	97	93	89	85	82	78	75	72	70	67	64	62
34	97	93	89	85	82	78	75	72	70	67	65	62
35	97	93	89	85	82	78	75	72	70	67	65	62
36	98	94	90	86	83	79	76	73	71	68	65	63
37	98	94	90	86	83	79	76	73	71	68	66	63
38	98	94	90	86	83	79	76	73	71	68	66	63
39	98	94	90	87	83	80	77	74	72	69	67	64

Temperatura percepita e indice di calore (humidex)

L'umidità dell'aria combinata a **elevate temperature**, è fonte di disagio poiché limita la perdita di calore corporeo attraverso l'**evaporazione del sudore** sulla pelle. (bassa umidità permette un maggiore raffreddamento per evaporazione cutanea, umidità più elevate la ostacolano)

Altri indici anche (**Heat index**)

calcolatore



Humidex from Temperature and Relative Humidity Readings

Relative Humidity (%) \ Temperature (C)	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
100	29	31	33	35	37	39	41	43	45	48	50	53	55	58									
95	28	30	32	34	36	38	40	42	44	47	49	51	54	56	59								
90	28	30	31	33	35	37	39	41	43	45	48	50	52	55	57	60							
85	27	29	31	32	34	36	38	40	42	44	46	49	51	53	56	58							
80	26	28	30	32	33	35	37	39	41	43	45	47	50	52	54	57	59						
75	26	27	29	31	33	34	36	38	40	42	44	46	48	50	53	55	57						
70	25	27	28	30	32	33	35	37	39	41	43	45	47	49	51	53	56	58					
65	24	26	27	29	31	32	34	36	38	40	42	43	45	47	50	52	54	56					
60	24	25	27	28	30	32	33	35	37	38	40	42	44	46	48	50	52	54	57				
55	23	24	26	27	29	31	32	34	36	37	39	41	43	45	46	48	50	52	55	57			
50	22	24	25	27	28	30	31	33	34	36	38	40	41	43	45	47	49	51	53	55	57		
45	22	23	24	26	27	28	30	32	33	35	37	38	40	42	43	45	47	49	51	53	55	57	
40			24	25	26	28	29	31	32	34	35	37	39	40	42	44	45	47	49	51	53	54	56
35				24	26	27	28	30	31	33	34	36	37	39	40	42	43	45	47	49	50	52	54
30							27	28	30	31	33	34	36	37	39	40	42	43	45	47	48	50	52
25										30	32	33	34	36	37	39	40	42	43	45	46	48	49
20																		40	41	43	44	45	47

$$\text{Humidex} = T_{\text{air}} + 0.5555\left[6.11e^{5417.7530\left(\frac{1}{273.16}-\frac{1}{T_{\text{dew}}}\right)} - 10\right]$$

Aerosol e nuclei di condensazione

video: https://www.youtube.com/watch?v=87v_9Bud7vw

MATERIALE:

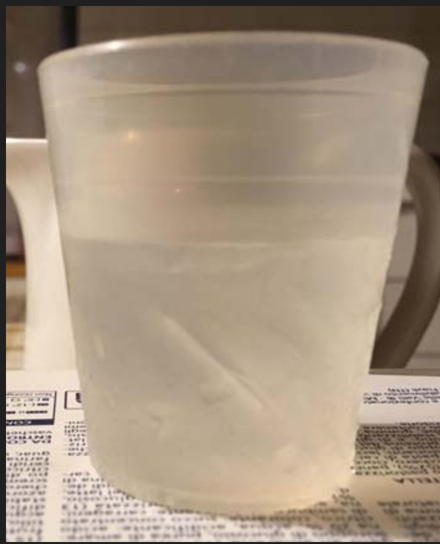
- acqua, contenitore (tipo piatto di petri), supporto, sale grosso e polistirolo

Riempiendo il contenitore di acqua e posizionando sopra al supporto galleggiante dei granelli di sale e delle palline di polistirolo noto che dopo un po' di tempo attorno al granello di sale il vapore acqueo condensa formando delle goccioline, cosa che non avviene invece per le palline di polistirolo.

Questo è analogo a quello che succede nelle nubi quando sono presenti nuclei di condensazione (aerosol di determinati tipi) che abbassando la pressione di vapore saturo in corrispondenza delle loro superfici facilitano la formazione di micro goccioline da cui poi originano le precipitazioni.

Acqua sopraffusa e nuclei di congelamento

vaschetta, sale da cucina (60g), acqua (0,5l), bicchierino, pezzetto di ghiaccio, freezer



raffreddo vaschetta in freezer (-20°C), immergo un bicchierino con acqua del rubinetto e aspetto finché la temperatura non raggiunge quella della vaschetta. In questo modo se sto attento a non urtare il bicchierino ci sarà ancora acqua liquida (sopraffusa). Solo aggiungendo un piccolo granello di ghiaccio l'acqua solidificherà istantaneamente (formazione nubi!)

Trasformazioni adiabatiche secche e sature

- **trasformazione adiabatica**: in cui **non c'è scambio di calore** tra il sistema considerato (es. particella d'aria) e l'ambiente esterno (es. atmosfera circostante)
- aria: buon isolante (piumini, vetri case ecc.)
- In atmosfera **moti delle particelle aria** sono troppo **veloci** perchè ci sia scambio di calore => **processi adiabatici**
- Dal primo principio della termodinamica (conservazione dell'energia):
    - DQ=DU+DW => DU+DW=0
- Quando l'**aria non satura** sale di quota si raffredda secondo un gradiente **adiabatico secco** (perde **9,8°C/km**)
- Quando l'**aria è satura** (raggiungo la temperatura di rugiada e comincia ad esserci condensazione) si raffredda secondo un gradiente **adiabatico saturo** (perde solo **5°C/km** per via della liberazione di calore latente nella condensazione!)

http://www.mesoscale.iastate.edu/agron206/animations/Bouyancy_Lapse_Rates.swf
http://www.mesoscale.iastate.edu/agron206/animations/Enviromental_Lapse_Rates.swf

Nube in bottiglia (e autocombustione)

MATERIALE:

- bottiglia PET + tappo con valvola camera d'aria, fiammifero, pompa bicicletta

ESECUZIONE:

1. chiudo bottiglia, metto in pressione, apro il tappo e non vedo nulla
2. accendo un cerino e lo butto nella bottiglia (introduco nuclei di condensazione), chiudo, metto in pressione, apro il tappo e vedo formarsi una nube bianca evidente

COSA SUCCEDE:

pompando nella bottiglia aggiungo aria e aumento la pressione interna. Svitando il tappo la pressione diminuisce bruscamente (espansione adiabatica) e la temperatura cala drasticamente aumentando l'umidità relativa. Il fumo del cerino aggiunge nella bottiglia particelle microscopiche sulla cui superficie la pressione di vapore saturo è più bassa, facilitando la condensazione del vapore acqueo presente nell'aria (ruolo degli aerosol - nuclei di condensazione nelle nubi).

apparato PASCO: inserendo un piccolo pezzo di carta e comprimendo rapidamente l'aria all'interno si raggiunge la temperatura di autocombustione della carta.

Nube gassosa di CO2 in acqua frizzante

MATERIALE: bicchiere con acqua frizzante, sale da cucina, anacardi (o uvetta)

ESECUZIONE:

- verso acqua frizzante in un bicchiere, noto che le bollicine di anidride carbonica gassosa non si formano allo stesso modo in tutti i punti del bicchiere (tendono a formarsi maggiormente sul bordo interno). Aggiungendo sale da cucina, il numero delle bollicine aumenta notevolmente. Se inserisco un'uvetta noto che dapprima tende a scendere verso il fondo, poi si formano sulla sua superficie bollicine e risale a galla.

COSA SUCCEDE:

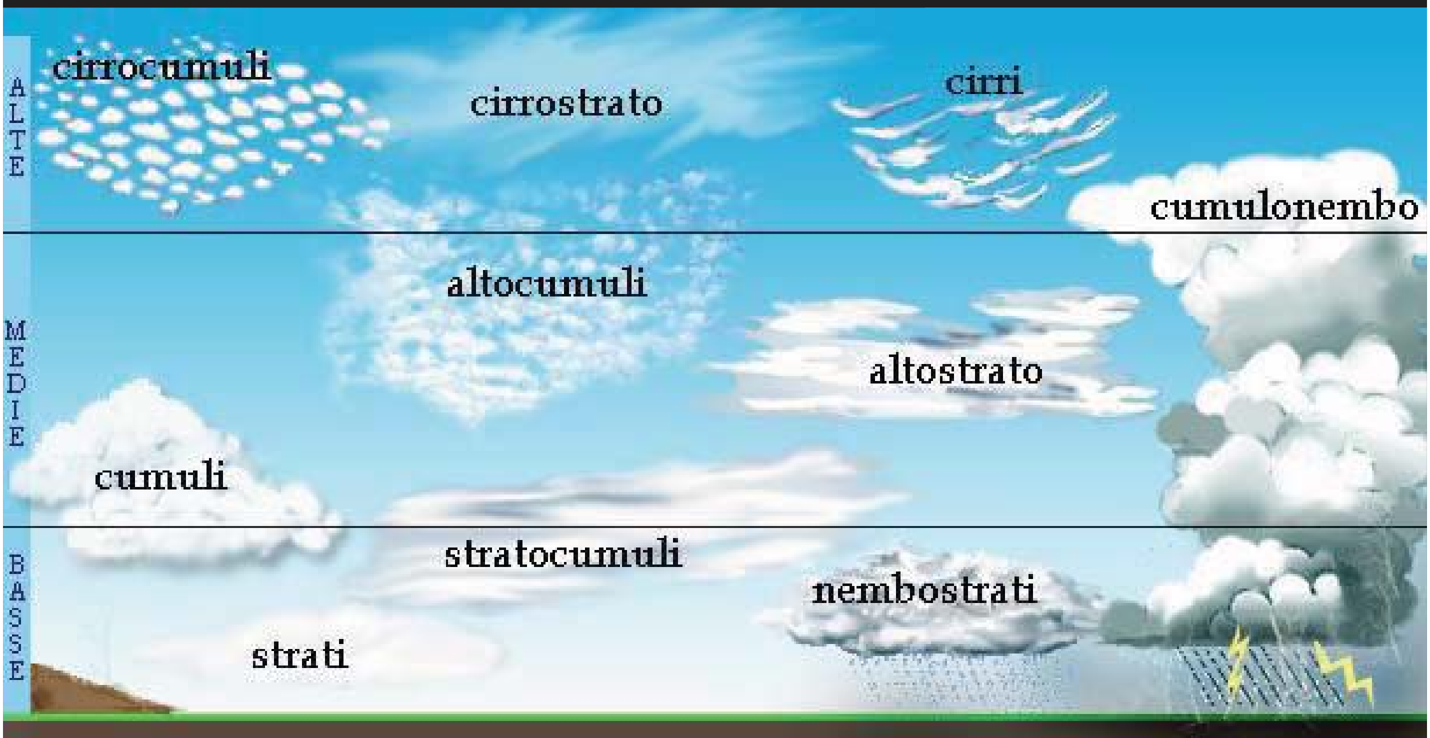
- l'acqua frizzante contiene disciolta anidride carbonica in condizioni di supersaturazione. Le bollicine sono costituite da anidride carbonica che passa allo stato gassoso e si formano in corrispondenza di imperfezioni o sporco della superficie del bicchiere. Aggiungendo sale da cucina fornisco nuclei di "vaporizzazione"

Nubi e precipitazioni

- **aria umida**
- **sollevamento** massa d'aria
  - **convezione** (termico - radiazione, conduzione e convezione - galleggiamento)
  - **orografia** (ostacolo)
  - **convergenza** (dinamico)
  - **fronti** (dinamico)
- **raffreddamento (adiabatico secco)** a temperatura di rugiada, **saturazione** => **base nube**
- a seconda delle **correnti verticali** e dell'**instabilità** dell'aria sollevamento e raffreddamento (**adiabatico saturo**) prosegue o no (più lentamente, per via della condensazione, liberazione calore latente!) => più o meno **sviluppo verticale della nube**
- **Precipitazione**
  - presenza **nuclei di condensazione** (**congelamento**) - aerosol: polvere, fuliggine, sale marino ecc. o minuscoli cristalli di ghiaccio
  - **crescita goccioline**:
    - nubi fredde - **Bergeron-Findeisen** (cristalli di ghiaccio e migrazione vapore, dove pressione di vapore saturo inferiore - superfici!),
    - nubi calde - **Langmuir** (coalescenza gocce acqua liquida)
  - precipitano se **raggiungere massa** tale da non essere più sostenute dai moti verticali
  - arrivano **al suolo se non evaporano** completamente nel tragitto
  - **solida** o **liquida** a seconda delle **temperature degli strati** di aria sottostanti

Tipi di nuvole

un video



- **Classificazione** nubi in base alla **quota** (basse, medie, alte, sviluppo verticale) e al **pattern** (isolata, pattern ripetuto o strato)

Atlante delle nubi: http://www.astrogeo.va.it/nuvole2/nuvole.htm
Riconoscere le nubi: http://www.metlink.org/observations-and-data/cloudkey/

Masse d'aria e loro caratteristiche

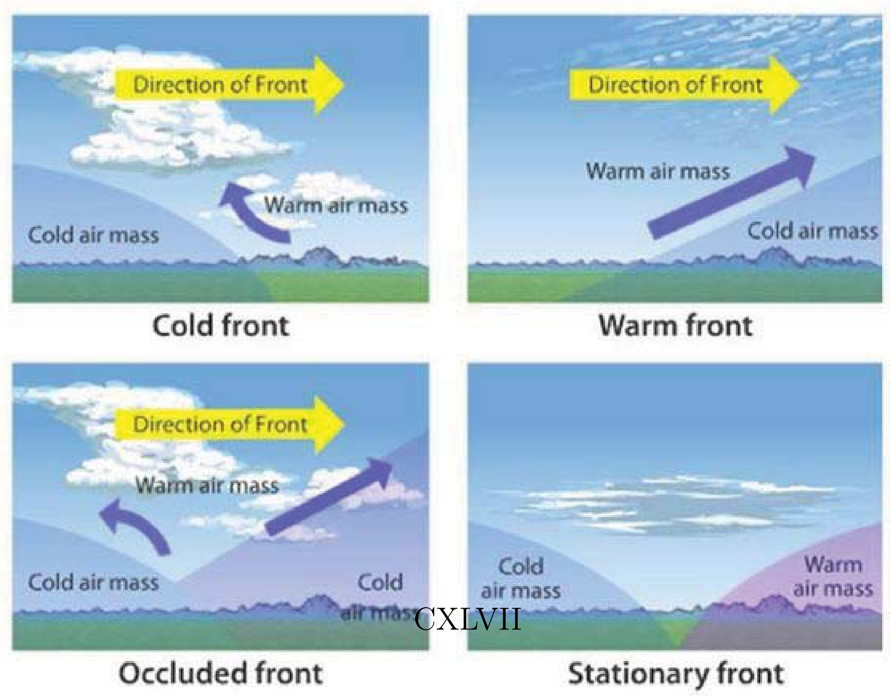
- Masse d'aria diverse a seconda di
  - **temperatura** (calda, fredda)
  - **umidità** (secca, umida)

- Caratteristiche **dipendenti** principalmente **da dove si origina** la massa d'aria

ARTICA	continentale
	marittima
POLARE	continentale
	marittima
TROPICALE	continentale
	marittima

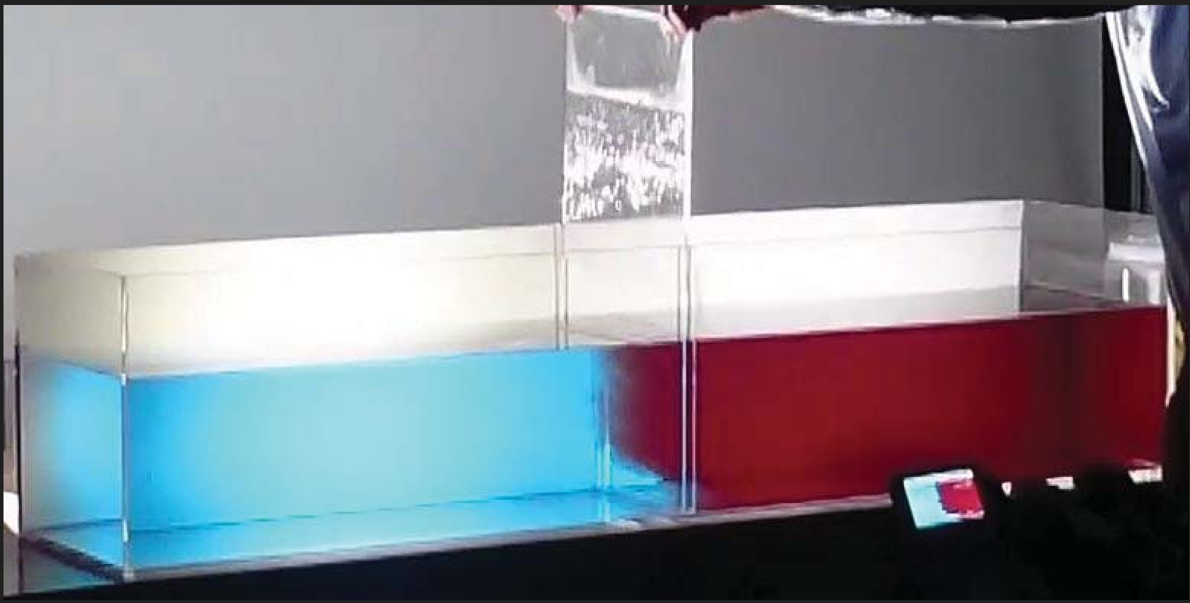
Fronti meteorologici

- **Fronte**: superficie di **separazione** tra due **masse d'aria** con caratteristiche **diverse** (temperatura e umidità)



http://www.mesoscale.iastate.edu/agron206/animations/05_cnWfronts.html
http://www.mesoscale.iastate.edu/agron206/animations/Cyclone_Form_Movement.swf

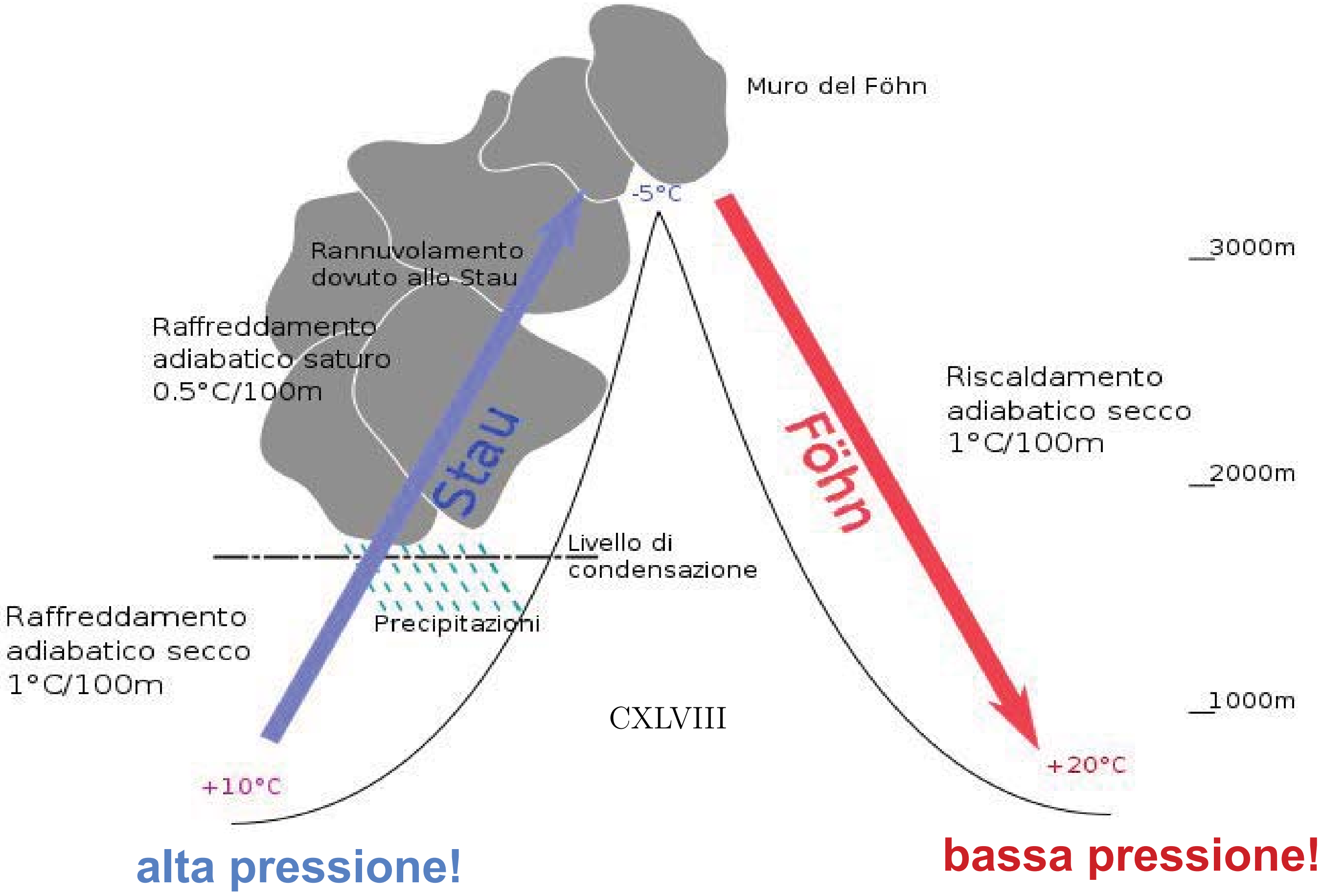
Fronte - un esperimento dimostrativo

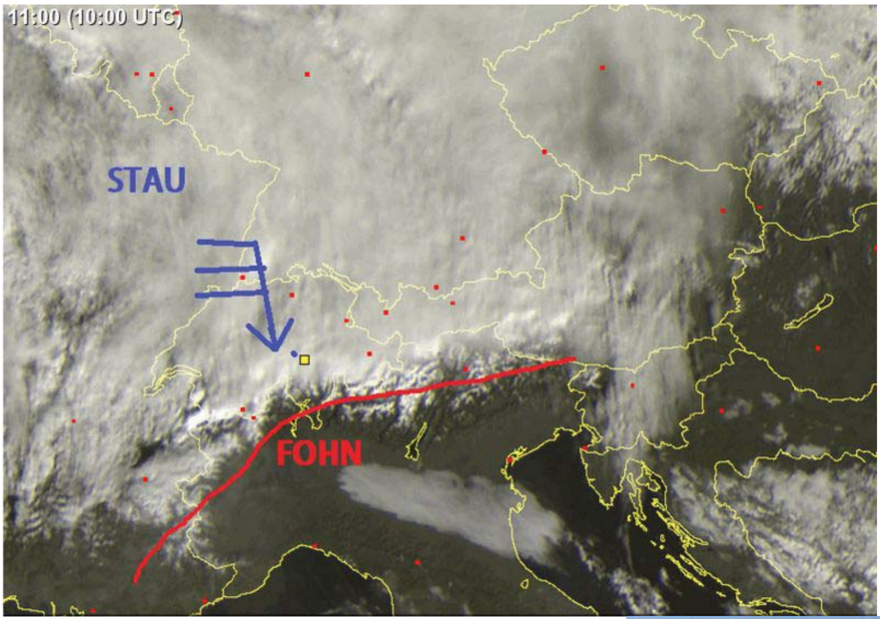


MATERIALE: recipiente lungo e stretto con setto di separazione, acqua a temperatura ambiente e calda, 2 coloranti

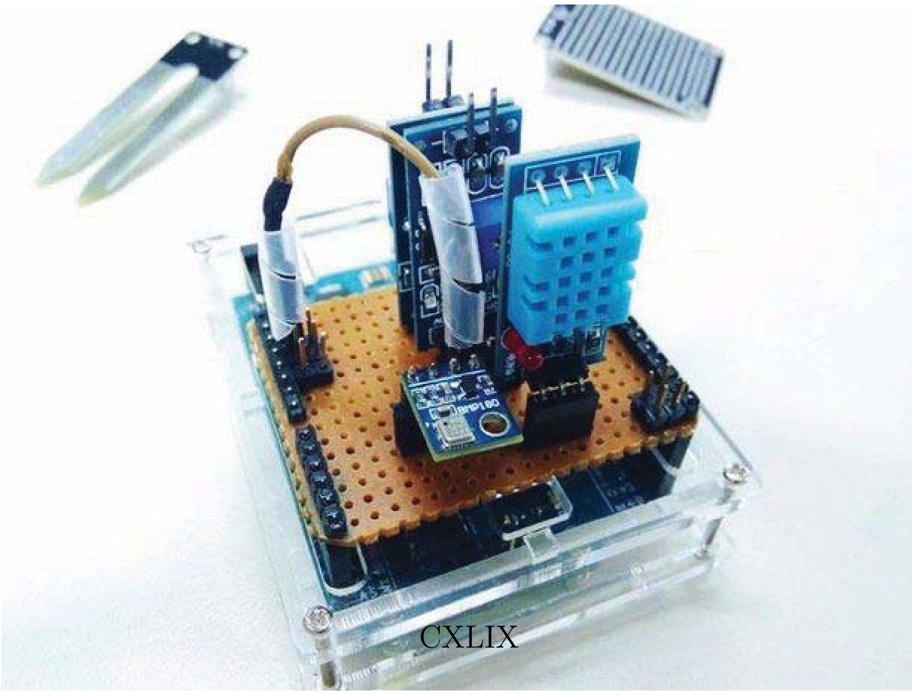
- chiedo agli studenti di fare delle previsioni su cosa succederà togliendo il setto
- le masse d’aria scorrono una sull’altra, l’acqua calda (meno densa) sopra l’acqua fredda (più densa), il fronte è la superficie di separazione tra le due

Stau e foehn





Costruire una stazione meteorologica con arduino o raspberry



http://www.instructables.com/id/Arduino-Weather-Station-AWS/

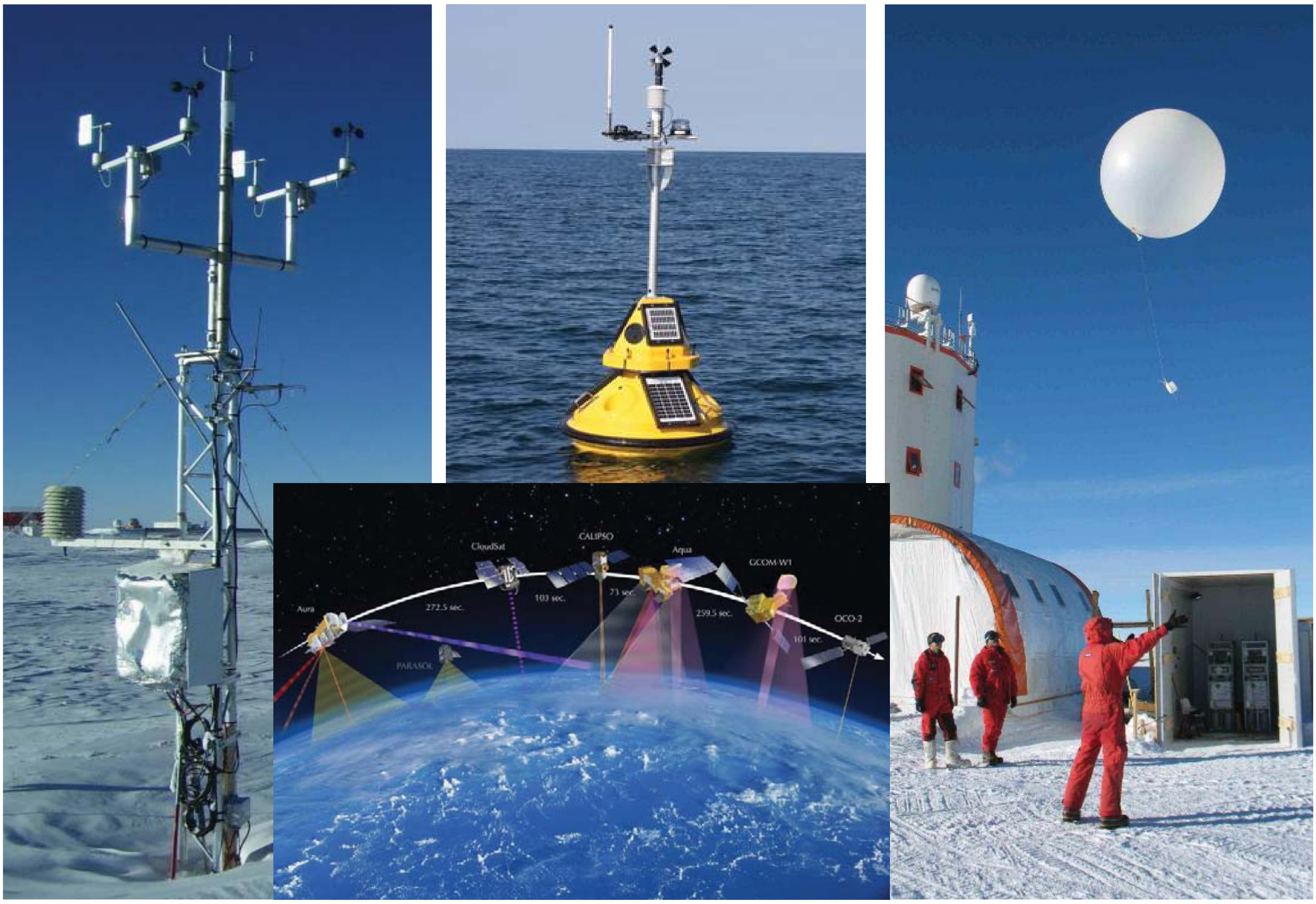
Il progetto GLOBE

- 1994 **GLOBE**: Global Learning and Observations to Benefit the Evironment
- programma mondiale di educazione scientifica basato su attività pratiche gestite da scuole primarie e secondarie.
- promuove e sostiene la collaborazione tra studenti, insegnanti e scienziati impegnati in indagini basate su domande condotte sull'ambiente e sul sistema Terra in stretta cooperazione con NASA, NOAA and NSF Earth System Science Projects (ESSP's) impegnati in studi e ricerche sulle dinamiche del sistema Terra.
  - promuovere l'insegnamento e l'apprendimento della scienza, aumentare l'alfabetizzazione e le gestione ambientale, nonché promuovere la scoperta scientifica
  - Migliorare i risultati degli studenti attraverso il curriculum con un focus sulla ricerca degli studenti in scienze ambientali e sul sistema Terra;
  - Potenziare la consapevolezza e supportare le attività delle persone in tutto il mondo a beneficio dell'ambiente;
  - Contribuire alla comprensione scientifica della Terra come un sistema
  - Collegare e ispirare la prossima generazione di scienziati a livello mondiale.
- Sito Web ufficiale - Sito web - GLOBE Italia (molto materiale e protocolli di misura tradotti)

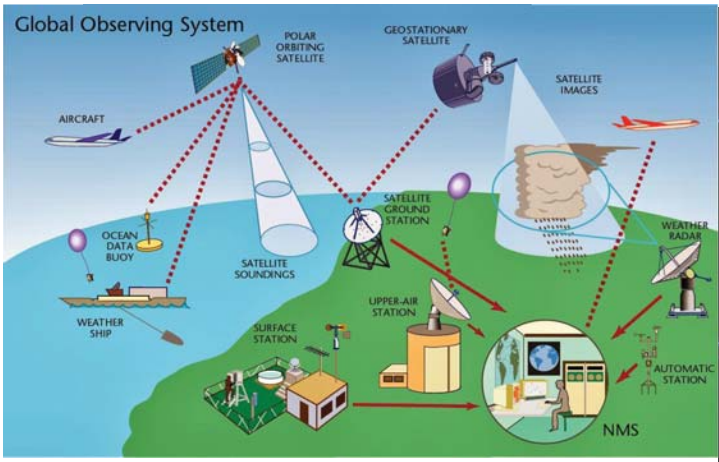
La previsione meteorologica numerica

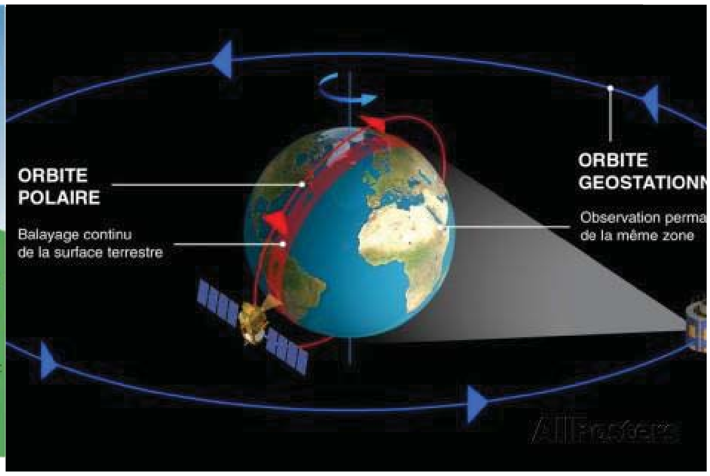
- **rete globale** di **osservazioni** (strumenti e misure) per conoscere lo stato iniziale atmosfera (campi 3D di temperatura, pressione, umidità, vento)
- rete **telecomunicazioni** per trasmettere e raccogliere dati in un archivio mondiale
- batteria di **supercomputer** e **modelli numerici dell'atmosfera** per:
  - elaborare lo **stato iniziale** dell'atmosfera da dati disomogenei (**assimilazione**, omogeneizzazione spaziale e temporale)
  - risolvere **equazioni** della dinamica dell'atmosfera, calcolare l'**evoluzione temporale** dei campi 3D delle grandezze meteo e indirettamente altre quantità (nuvolosità, precipitazioni ecc. attraverso parametrizzazioni)
- un **bravo meteorologo** che conosca le peculiarità locali, capisca quando il modello è affidabile e quando no e che **interpreti,** traduca l'output dei modelli in un prodotto comprensibile e usufruibile dal cittadino (il **bollettino meteorologico**).
- N.B. **previsioni automatiche** (località): agganciano al punto di griglia del **modello** più vicino mentre bollettino meteo e meteorologo previsore: usa tantissime fonti differenti e interpreta alla luce delle conoscenze del territorio locale

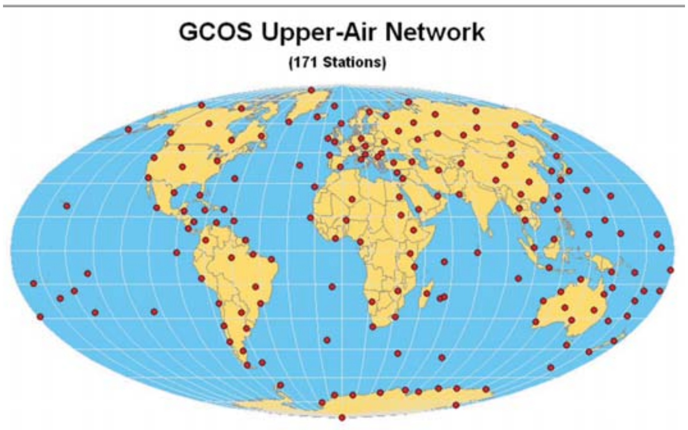
Dati strumentali



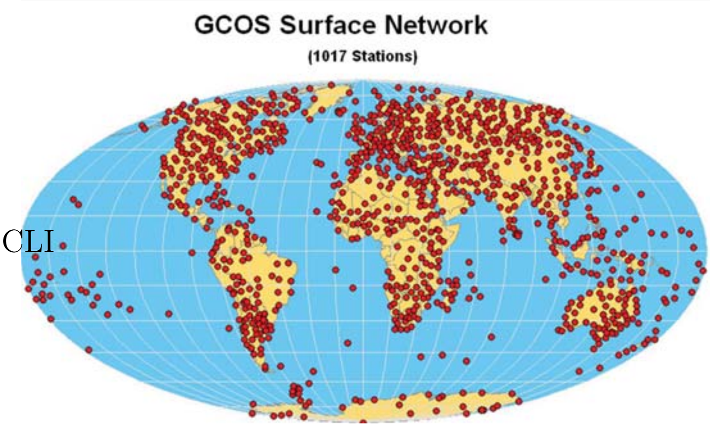
Una rete di osservazione mondiale (GCOS-WMO)







CLI



I principi fisici e le equazioni dell'atmosfera

- atmosfera come fluido continuo: visione lagrangiana o euleriana
  - Conservazione della quantità di moto: equazioni di Navier-Stokes

$$\frac{D\mathbf{u}}{Dt} = -\frac{1}{\rho}\nabla p - 2\,\mathbf{\Omega}\times\mathbf{u} + \mathbf{g}_a + \mu\nabla^2\mathbf{u} \qquad \frac{D}{Dt} \doteq \frac{\partial}{\partial t} + \mathbf{u}\cdot\nabla$$

  - Conservazione dell'energia: primo principio della termodinamica

$$c_v\frac{DT}{Dt} + p\frac{D\alpha}{Dt} = J \qquad \alpha \doteq 1/\rho$$

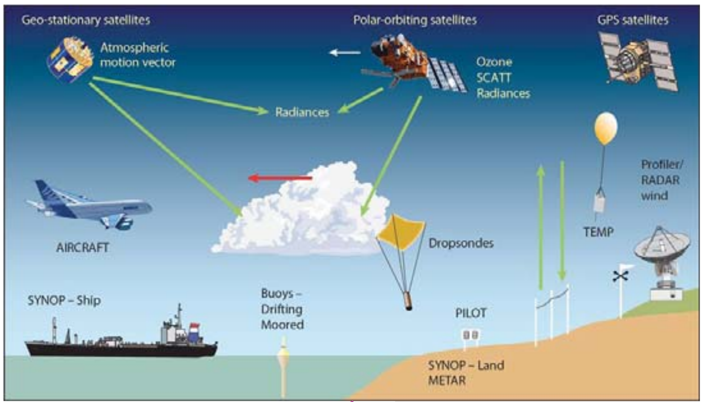
  - Conservazione della massa: equazione di continuità

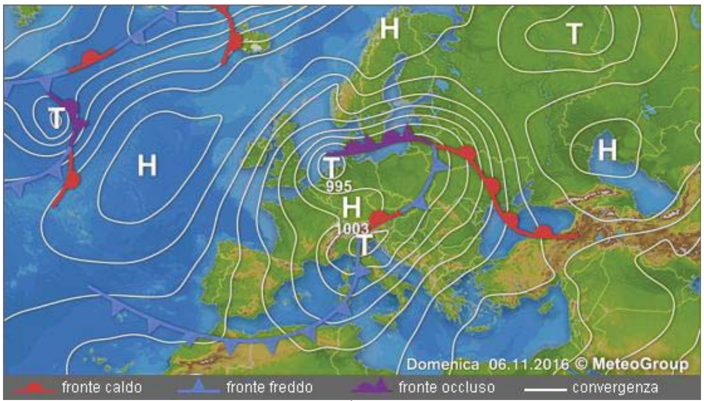
$$\frac{1}{\rho}\frac{D\rho}{Dt} + \nabla\cdot\mathbf{u} = 0$$

  - Equazione di stato

$$f(\rho, p, T) = 0$$

- sistema di equazioni differenziali alle derivate parziali: determinano l'evoluzione dei campi meteorologici (temperatura, pressione, vento)

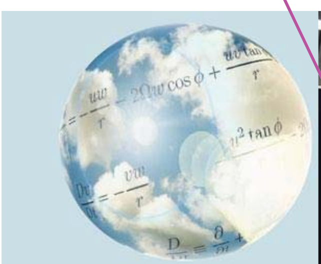


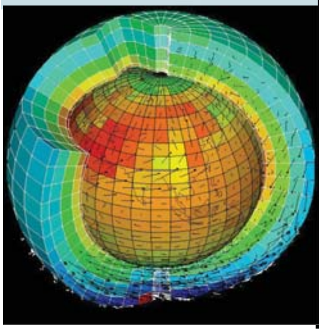


osservazioni (stato)

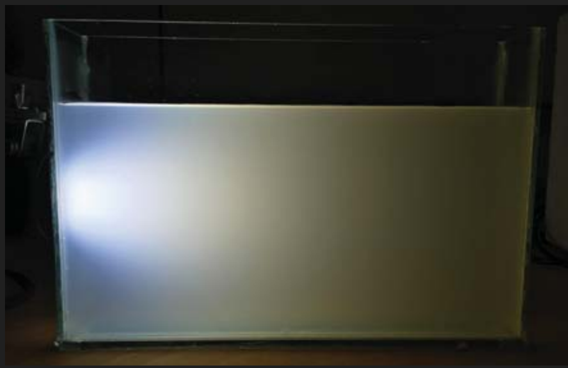
modelli numerici (dinamica)

mappe meteo

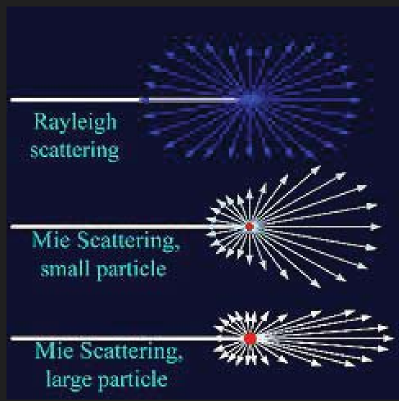




Cielo azzurro, rosso al tramonto, nubi bianche



Aggiungendo latte (poco) nella vaschetta con acqua e illuminata con un fascio di luce vedo che nella prima parte del tragitto viene diffusa maggiormente la componente a onda corta (colore blu), mentre nella parte finale rimane solo la componente a onda lunga (colore rosso) da diffondere. Questo in regime di diffusione alla Rayleigh (dimensione molecole di latte inferiori alla lunghezza d'onda della luce visibile, diffusione proporzionale alla frequenza alla quarta). Nelle nubi invece la dimensione delle goccioline è dell'ordine o maggiore rispetto alla lunghezza d'onda della luce visibile e si è quindi in regime di diffusione alla Mie (indipendente dalla frequenza della luce) per cui tutte le lunghezze d'onda vengono diffuse ugualmente (colore bianco)



Alcuni siti interessanti

- Applet meteo: http://www.mesoscale.iastate.edu/agron206/animations/
- Mappe meteo ECMWF (Meteogroup): http://www.meteoearth.com/
- Immagini da satellite Eumetsat: http://eumetview.eumetsat.int/mapviewer/
- Sat24: http://it.sat24.com/it
- Meteosat aeronautica: http://www.meteoam.it/meteosat
- ISAC modelli meteorologici: http://www.isac.cnr.it/dinamica/projects/forecasts/
- Radar Monte Macaion: http://www.meteotrentino.it/dati-meteo/radar/loop/loop_radar.aspx?ID=144
- Radar Teolo: http://www.arpa.veneto.it/bollettini/meteo/radar/radar.php
- Wetterzentrale: http://www.wetterzentrale.de/
- Radiosondaggi Uni Whyoming: http://weather.uwyo.edu/upperair/sounding.html
- http://www.meteoindiretta.it/satelliti_pressione.php
- Stazioni meteo e dati Meteotrentino: http://www.meteotrentino.it/dati-meteo/stazioni/mappe/gmapstz.aspx?ID=205
- GFS - NCEP earth nullschool: https://earth.nullschool.net/#current/wind/
- SOS - NOAA: http://sos.noaa.gov/Datasets/dataset.php?id=55
- Wisconsin SSEC data: http://www.ssec.wisc.edu/data/
- Festivalmeteorologia: http://www.festivalmeteorologia.it/index.php/it/
- MetLink: http://www.metlink.org/experimentsdemonstrations/

Ulteriori risorse/bibliografia

- Progetto GLOBE: http://www.globe.gov/do-globe/globe-teachers-guide
- MetOffice - MetLink: http://www.metlink.org/
- COMET Program (NCAR - NCEP): http://www.comet.ucar.edu/
- Weather in a tank (MIT): http://paoc.mit.edu/labguide/
- Spin Lab UCLA: https://www.youtube.com/user/spinlabucla
- PSSC: https://www.youtube.com/playlist?list=PLAA7AA6B0E433653C
- Corso IBSE meteorologia (NASA): https://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Meteorology_Guide.html
- NASA:
  - https://www.nasa.gov/audience/foreducators/topnav/materials/listbysubject/Meteorology_landingpage.html
  - https://earthengine.google.com/timelapse/
  - http://world.time.com/timelapse/
  - https://www.nasa.gov/topics/earth/index.html
  - http://climate.nasa.gov/
  - https://www.youtube.com/watch?v=dqpFU5SRPgY
- Manuale di Meteorologia - Centro Epson
- Clouds in a glass of beer - Craig F. Bohren
- Meteorology Today - C Donald Ahrens

Si ringraziano Luigi Liberti (ISAC-CNR Roma), Claudia Faccani (ENAV academy) per parte del materiale utilizzato in questa presentazione e per le utili discussioni

Appendix C: Pre and post tests: questions and answers

Pre test - termologia

Questo questionario è volto a stabilire la tua comprensione circa alcuni concetti fisici di termologia. Si tratta di un questionario anonimo che non verrà utilizzato per scopi di valutazione. Serve unicamente come indicazione sulla situazione di comprensione e apprendimento in relazione alla sperimentazione didattica in corso. Rispondi al meglio delle tue conoscenze e competenze.

1. **Su una stufa in una casetta sulle coste della Scozia durante un intenso ciclone c'è una pentola piena d'acqua. L'acqua ha cominciato a bollire velocemente. La temperatura più probabile dell'acqua è circa:**
   Contrassegna solo un ovale.

   - 88°C
   - 98°C
   - 110°C
   - Nessuna delle risposte precedenti può essere corretta.

2. **Cinque minuti dopo, l'acqua nella pentola sta ancora bollendo. Adesso la temperatura più probabile dell'acqua è circa:**
   Contrassegna solo un ovale.

   - 88°C
   - 98°C
   - 110°C
   - 120°C

3. **Marco prende due bicchieri di acqua a 40°C e li mescola con un bicchiere d'acqua a 10°C. Qual è la temperatura più probabile della miscela? I bicchieri contengono tutti la stessa quantità di acqua.**
   Contrassegna solo un ovale.

   - 20°C
   - 25°C
   - 30°C
   - 50°C

4. **Francesca crede di dover utilizzare acqua che bolle per fare una tazza di tè. Dice allora al suo amico Franco: "non potrei fare il tè se fossi in campeggio in alta montagna perché l'acqua non bolle in alta quota". Con chi dei seguenti amici di Francesca sei più d'accordo?**
   Contrassegna solo un ovale.

   - Marco dice: "Sì che bolle, ma l'acqua in ebollizione non è semplicemente così calda come lo è qui".
   - Lisa dice: "Questo non è vero. L'acqua bolle sempre alla stessa temperatura".
   - Federico dice: "Il punto di ebollizione dell'acqua si abbassa, ma l'acqua di per sé è ancora a 100°C".
   - Sara dice: "Sono d'accordo con Francesca. L'acqua non riesce mai a raggiungere il suo punto di ebollizione".

5. **Serena chiede a un gruppo di amici: "se metto nel freezer 100 grammi di ghiaccio a 0°C e 100 grammi di acqua a 0°C, chi dei due perderà alla fine la maggior quantità di calore?" Con quale delle seguenti risposte degli amici sei più d'accordo?**

Contrassegna solo un ovale.

- Samuele dice: "i 100 grammi di ghiaccio"
- Sara dice: "i 100 grammi di acqua"
- Paolo dice: "nessuno perché contengono entrambi la stessa quantità di calore"
- Davide dice: "non c'è risposta perché il ghiaccio non contiene alcun calore"
- Matteo dice: "non c'è risposta perché non puoi avere acqua a 0°C"

6. **Serena annuncia che non le piace sedersi sulle sedie di metallo nella stanza perché "sono più fredde di quelle di plastica". Con chi dei seguenti amici di Serena sei più d'accordo?**

Contrassegna solo un ovale.

- Marco è d'accordo e dice: "Sono più fredde perché il metallo è naturalmente più freddo della plastica"
- Karen dice: "Non sono più fredde, sono alla stessa temperatura".
- Olga dice: "Non sono più fredde, semplicemente percepiamo più fredde quelle di metallo perché sono più pesanti".
- Jim dice: "Sono più fredde perché il metallo ha meno calore da perdere rispetto alla plastica".

7. **Daniela prende due bottiglie di vetro contenenti acqua a 20°C e le avvolge con due pezze: una asciutta e una umida. 20 minuti più tardi misura la temperatura dell'acqua in ciascuna bottiglia. L'acqua nella bottiglia avvolta dalla pezza bagnata è a 18°C, mentre l'acqua nella bottiglia avvolta dalla pezza asciutta è di 22°C. La temperatura più probabile della stanza in cui avviene questo esperimento è:**

Contrassegna solo un ovale.

- 26°C
- 21°C
- 20°C
- 18°C

8. **Patrizia crede che Luca cucini le torte sul ripiano superiore dentro al forno elettrico perché è più caldo in alto che sul fondo. Quale dei seguenti amici ha ragione?**

Contrassegna solo un ovale.

- Gloria dice che è più caldo in alto perché il calore sale verso l'alto.
- Samuele dice che è più caldo perché le teglie di metallo concentrano il calore.
- Ruggero dice che è più caldo in alto perché più l'aria è calda, meno è densa.
- Ugo è in disaccordo con tutti e dice che non è possibile che sia più caldo in alto.

9. **Sei nel business di sciogliere il ghiaccio a 0°C usando dei blocchetti di metallo caldi come sorgente di energia. La prima opzione consiste nell'uso di un blocchetto di metallo alla temperatura di 200°C, la seconda consiste nell'uso di due blocchetti di metallo alla temperatura di 100°C. I singoli blocchetti di metallo sono fatti dello stesso materiale e hanno lo stesso peso e la stessa superficie. Quale delle due opzioni farà sciogliere più ghiaccio?**

Contrassegna solo un ovale.

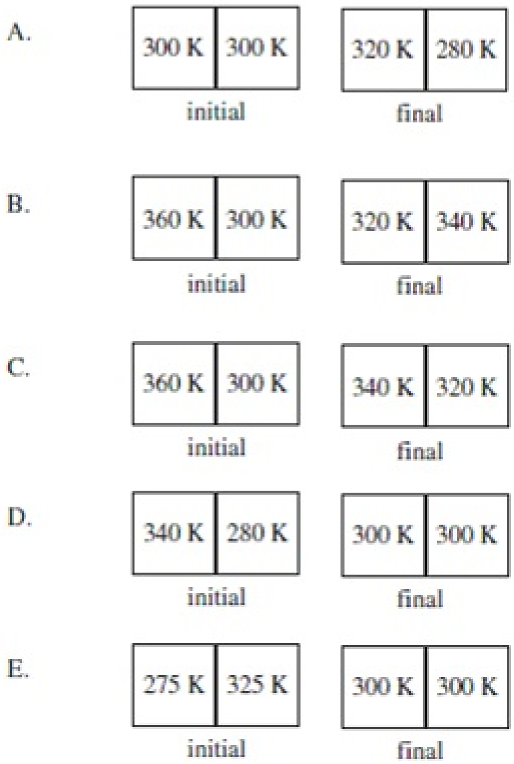
- i blocchetti a 100°C
- il blocchetto a 200°C
- entrambe le opzioni faranno sciogliere la stessa quantità di ghiaccio
- non si può dire con le sole informazioni fornite

10. **perché:**

Contrassegna solo un ovale.

- i due blocchetti hanno il doppio della superficie rispetto al blocchetto singolo e quindi il tasso di trasferimento dell'energia è più elevato quando si usano più blocchetti.
- l'energia trasferita è proporzionale alla massa dei blocchetti utilizzati e alla variazione di temperatura della temperatura dei blocchetti durante il processo.
- usare un blocchetto a temperatura più elevata farà sciogliere il ghiaccio più velocemente in quanto la maggiore differenza di temperatura aumenterà il tasso di trasferimento dell'energia.
- la temperatura del blocchetto più caldo diminuirà più velocemente man mano che l'energia è trasferita al ghiaccio.
- la capacità termica del metallo è una funzione della temperatura.

11. **Due blocchi identici sono posti in contatto termico tra di loro e isolati dal resto dell'universo. Qui sotto sono raffigurate le temperature iniziali e finali ipotetiche dei due blocchi. Per ogni coppia di stati, specifica se la transizione tra stato iniziale e finale è possibile e spiega perché sì o perché no.**



Pre test - clima

Questo questionario ha lo scopo di sondare le tue pre-conoscenze circa fenomeni e tematiche inerenti il clima. Si tratta di un questionario anonimo, che verrà utilizzato solo per scopi di ricerca. Rispondi al meglio delle tue conoscenze e competenze.

1. **A quale corso di laurea/laurea magistrale sei iscritto?**
   Contrassegna solo un ovale.

   - ◯ fisica
   - ◯ matematica
   - ◯ Altro: ______________________________

2. **Le informazioni che possiedi relative a clima e cambiamenti climatici provengono da:**
   Seleziona tutte le voci applicabili.

   - ☐ mezzi di comunicazione tradizionali (stampa, radio, televisione)
   - ☐ corsi universitari
   - ☐ letteratura scientifica
   - ☐ internet
   - ☐ formazione scolastica
   - ☐ non sono particolarmente informato a riguardo
   - ☐ Altro: ______________________________

3. **Che differenza c'è tra tempo meteorologico e clima?**

   ____
   ____
   ____
   ____
   ____

4. **Quali fattori influenzano il clima? Fai qualche esempio.**

   ____
   ____
   ____
   ____
   ____

5. **Quale fattore influenza maggiormente la temperatura media superficiale della Terra?**

6. **Quale forma di energia emette con maggiore intensità il Sole?**

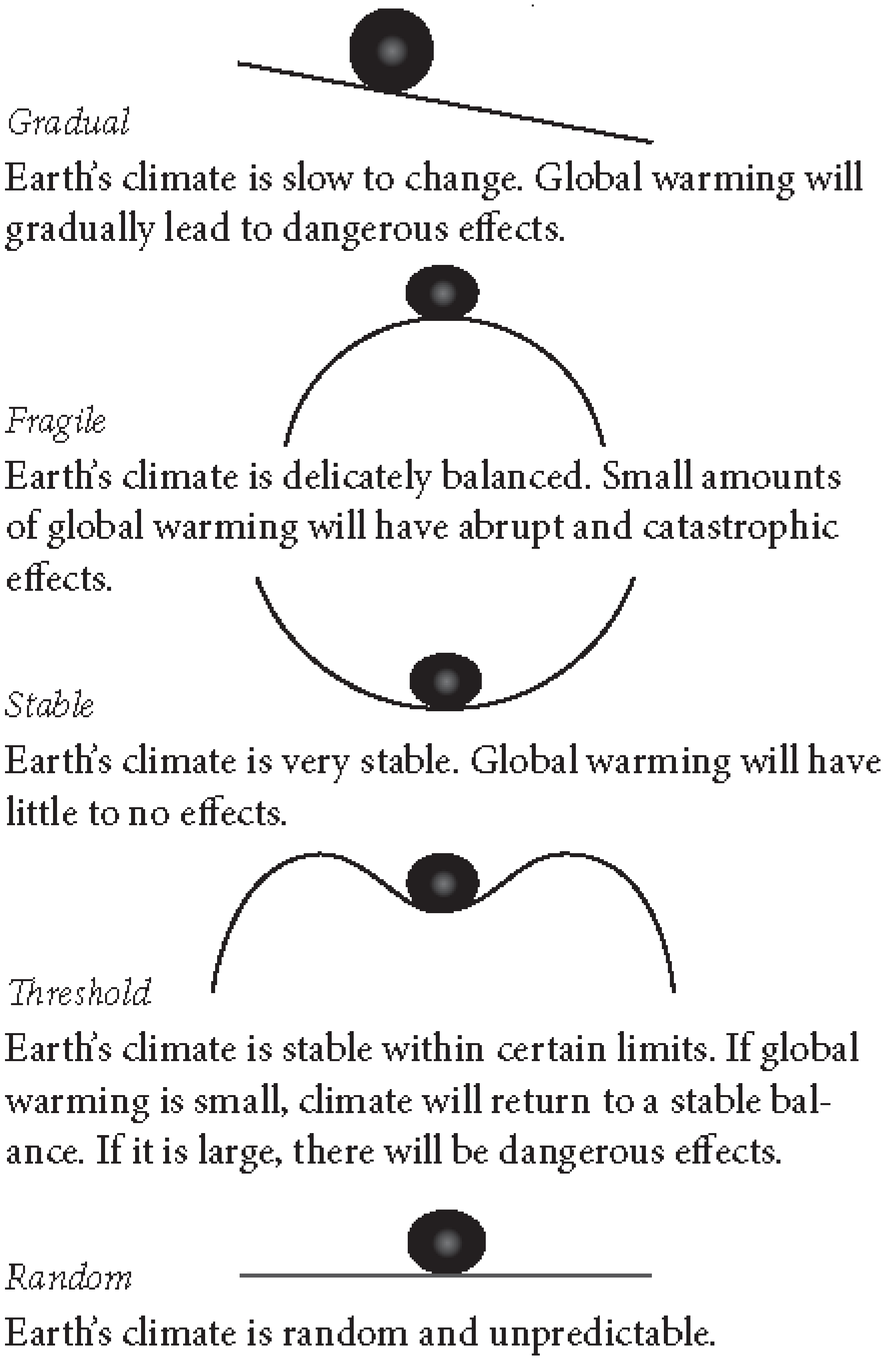
7. **Quale forma di energia emette con maggiore intensità la Terra?**

8. **Quale forma di energia emette maggiormente l'atmosfera terrestre?**

9. **Che cos'è un gas serra? Elenca i principali gas serra presenti in atmosfera.**

10. **Dai una spiegazione il più precisa possibile e al meglio delle informazioni in tuo possesso dell'effetto serra.**

11. **Scegli tra le seguenti figure quale rappresenta in maniera più calzante il funzionamento del sistema climatico in base alle tue conoscenze. Ogni figura rappresenta il clima della Terra come una palla in equilibrio su una linea eppure ognuna ha una diversa capacità di sopportare il riscaldamento globale causato dall'uomo.**



Contrassegna solo un ovale.

- ◯ Graduale
- ◯ Fragile
- ◯ Stabile
- ◯ A soglia
- ◯ Casuale

Post test - termologia&clima

Questo questionario ha lo scopo di ottenere un feedback a seguito del percorso didattico circa fenomeni e tematiche inerenti termologia, clima e atmosfera. Si tratta di un questionario anonimo, che verrà utilizzato solo per scopi di ricerca. Rispondi al meglio delle tue conoscenze e competenze.

1. **A quale corso di laurea/laurea magistrale sei iscritto?**

   Contrassegna solo un ovale.

   - ◯ matematica
   - ◯ fisica
   - ◯ Altro: ____________________

2. **Tra le seguenti affermazioni scegli quelle che ritieni tendenzialmente vere**

   Seleziona tutte le voci applicabili.

   - ☐ Il tempo meteorologico spesso cambia di anno in anno
   - ☐ Il clima rappresenta le condizioni meteorologiche medie in una regione
   - ☐ Il clima spesso varia di anno in anno
   - ☐ Le correnti oceaniche trasportano calore dall'equatore verso i poli nord e sud
   - ☐ Il tempo meteorologico rappresenta le condizioni climatiche medie in una regione
   - ☐ Clima e tempo meteorologico sono più o meno la stessa cosa
   - ☐ La circolazione atmosferica trasporta calore dai poli nord e sud verso l'equatore

3. **Il fenomeno fisico che provoca l'effetto serra dipende:**

   Contrassegna solo un ovale.

   - ◯ sia dalle proprietà della radiazione che dalle proprietà dei gas che compongono l'atmosfera
   - ◯ solo dalle proprietà della radiazione elettromagnetica incidente
   - ◯ solo dalle proprietà dei gas che compongono l'atmosfera terrestre
   - ◯ nessuna delle risposte precedenti è corretta

4. **L'atmosfera è da considerarsi:**

   Contrassegna solo un ovale.

   - ◯ un corpo quasi completamente opaco per la radiazione a bassa frequenza e un corpo quasi trasparente per la radiazione ad alta frequenza
   - ◯ un corpo quasi completamente opaco per la radiazione ad alta frequenza e un corpo quasi trasparente per la radiazione a bassa frequenza
   - ◯ un corpo quasi completamente opaco per la radiazione sia ad alta che a bassa frequenza
   - ◯ un corpo quasi completamente trasparente per la radiazione sia ad alta che a bassa frequenza

5. **Qual è l'effetto dei gas serra in atmosfera?**
Contrassegna solo un ovale.

- Intrappolano il calore assorbito dalla Terra, producendo un ulteriore riscaldamento
- causano una diminuzione di spessore dell'alta atmosfera aumentando così la trasparenza rispetto alla radiazione ad alta frequenza
- provocano un incremento dell'assorbimento dell'atmosfera nei confronti della radiazione a bassa frequenza
- Intrappolano una parte della radiazione infrarossa riflettendola verso il basso.

6. **La temperatura di un oggetto esposto ad una lampada aumenta fino a raggiungere dopo un certo tempo un valore costante. Perché da quel momento in poi la temperatura non aumenta più?**
Contrassegna solo un ovale.

- Perchè l'oggetto raggiunge la temperatura di equilibrio con la lampada
- Perchè la temperatura di quell'oggetto non può oltrepassare quel valore
- Perchè in quella situazione l'energia emessa è uguale a quella assorbita dall'oggetto
- Perchè la lampada non può fornire più calore di quello

7. **Un meccanismo di feedback consiste nel:**
Contrassegna solo un ovale.

- l'azione di un disturbo continuo e prolungato che produce effetti sempre maggiori sul sistema
- l'azione combinata di molti fattori che producono perturbazioni sempre maggiori nel sistema
- fatto che gli effetti prodotti da una perturbazione di un sistema diventino la causa di successive perturbazioni che possono amplificare o smorzare la perturbazione iniziale
- fatto che un fenomeno che ha raggiunto il suo massimo sviluppo ritorni spontaneamente alla situazione iniziale

8. **L'atmosfera terrestre a livello del suolo è più calda di quanto sarebbe senza effetto serra. Quale forma di radiazione viene assorbita dall'atmosfera ed è la causa principale della maggiore temperatura al suolo?**
Contrassegna solo un ovale.

- radio
- infrarossa
- visibile
- ultravioletto
- raggi X

9. **In media, l'ammontare totale dell'energia che abbandona il sistema Terra e va nello spazio**
Contrassegna solo un ovale.

- è maggiore della quantità di energia che arriva dallo spazio (in particolare dal Sole)
- è minore della quantità di energia che arriva dallo spazio (in particolare dal Sole)
- è circa uguale alla quantità di energia che arriva dallo spazio (in particolare dal Sole)
- dipende dalla concentrazione dei gas serra presenti nell'atmosfera
- dipende dall'ozono presente in atmosfera

10. **Quale delle seguenti è una proprietà caratteristica dei gas serra?**
Contrassegna solo un ovale.

- possono distruggere certe molecole presenti nell'atmosfera
- piegano e amplificano la luce proveniente dal Sole che entra in atmosfera
- possono intrappolare certe molecole in atmosfera
- possono riflettere una parte della radiazione proveniente dalla superficie terrestre
- sono trasparenti ad alcune forme di radiazione, ma non a tutte

11. **Completa la seguente frase con l'opzione corretta: L'effetto serra è un processo molto ... causato molto probabilmente ...**
Contrassegna solo un ovale.

- recente - dall'utilizzo di combustibili fossili, l'industria, l'agricoltura e altre attività umane
- vecchio - dalle piante che aumentano l'umidità e creano condizioni simili a quelle presenti in una serra per le piante
- recente - dalla riduzione dello strato di ozono che permette ad una maggiore quantità di radiazione ultravioletta di raggiungere la superficie terrestre
- vecchio - dalle interazioni in atmosfera tra gas presenti in natura e varie forme di radiazione

12. **Quale forma di energia (radiazione) irraggia (emette) principalmente la superficie della Terra di notte?**
Contrassegna solo un ovale.

- radio
- infrarossa
- visibile
- ultravioletta
- la superficie della Terra non emette energia durante la notte

13. **Quale dei seguenti fattori influenza maggiormente la temperatura media superficiale della Terra?**
Contrassegna solo un ovale.

- il calore rilasciato dalle industrie e da altre attività umane
- la distruzione del buco dell'ozono, facendo entrare così in atmosfera più luce solare
- il flusso di diversi tipi di radiazione attraverso l'atmosfera e la loro interazione con essa
- l'inquinamento dell'aria, intrappolato in atmosfera dai gas
- il fatto che la luce del sole venga amplificata e concentrata da alcuni gas presenti nell'atmosfera

14. **Quale dei seguenti non è un gas serra?**
Contrassegna solo un ovale.

- anidride carbonica
- vapore acqueo
- metano
- ossigeno
- ozono

15. **Quale delle seguenti affermazioni descrive meglio la relazione tra effetto serra e riscaldamento globale?**

Contrassegna solo un ovale.

- Effetto serra e riscaldamento globale sono la stessa cosa
- un incremento dell'effetto serra può causare il riscaldamento globale
- il riscaldamento globale potrebbe causare un incremento dell'effetto serra
- L'effetto serra e il riscaldamento globale non sono probabilmente correlati
- Non esiste alcuna chiara prova che l'effetto serra e il riscaldamento globale esistano

16. **Quali sono le due forme di energia (radiazione) irraggiate (emesse) principalmente dal sole?**

Contrassegna solo un ovale.

- ultravioletti e raggi X
- ultravioletti e infrarossi
- visibile e vicino infrarosso
- radio e infrarossi

17. **Un pianeta che ha un effetto serra**

Contrassegna solo un ovale.

- riceve più radiazione ultravioletta dal sole perché non contiene ozono nella sua atmosfera
- possiede un'atmosfera che assorbe ed emette certe forme di energia, ma non tutte
- riceve più energia perché è più vicino alla sua stella centrale
- possiede un'atmosfera alterata a causa degli esseri viventiì
- non irradia alcuna forma di energia nello spazio

18. **Da quali due forme di energia la superficie terrestre è riscaldata maggiormente?**

Contrassegna solo un ovale.

- ultravioletta e raggi X
- ultravioletta e infrarossa
- visibile e ultravioletta
- infrarossa e visibile
- radio e infrarossa

19. **Se la civiltà umana non si fosse mai sviluppata sulla Terra, ci sarebbe stato comunque l'effetto serra?**

Contrassegna solo un ovale.

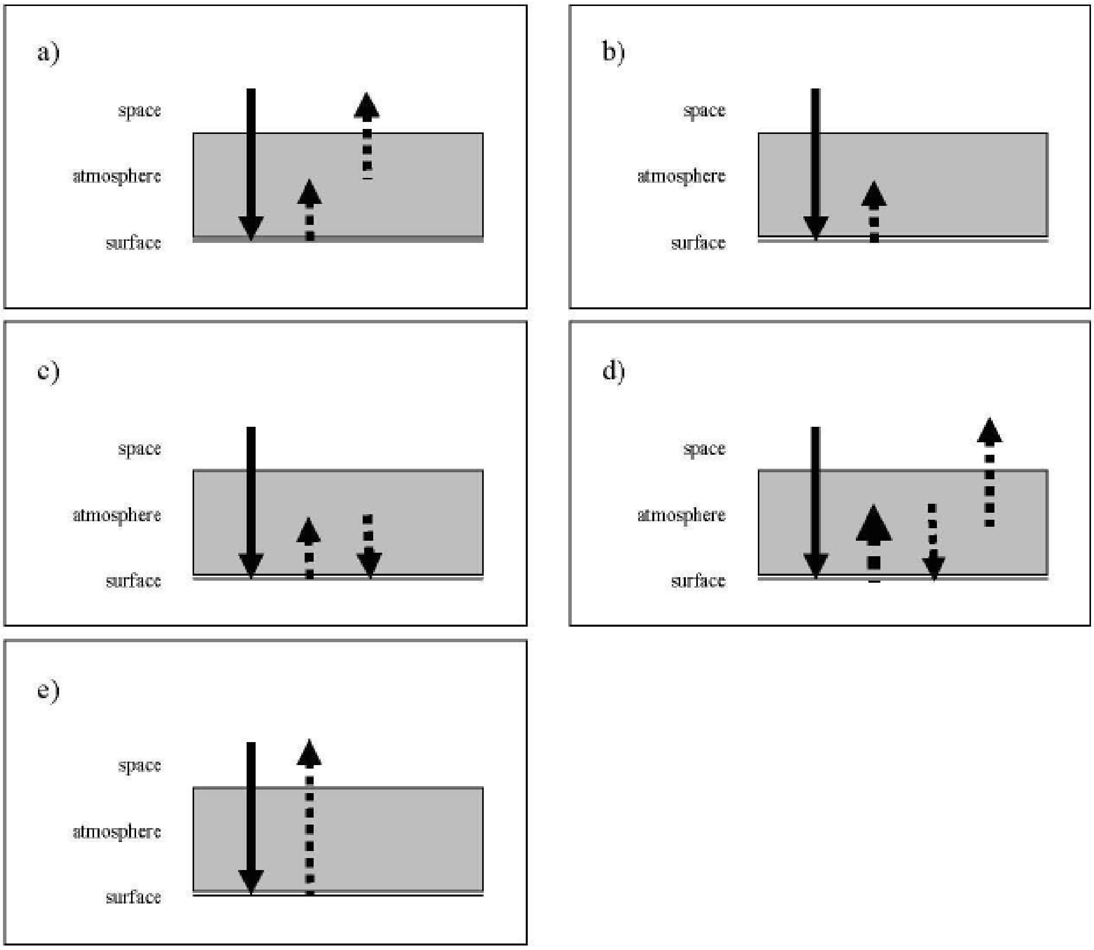
- Sì, l'effetto serra è causato da gas che sono presenti naturalmente in atmosfera
- Sì, l'effetto serra è causato da piante che rilasciano gas nell'atmosfera
- No, l'effetto serra è causato dall'uomo bruciando combustibili fossili e rilasciando inquinanti
- No, l'effetto serra è causato dall'uomo riducendo lo strato di ozono nell'atmosfera
- No, non c'è alcuna evidenza conclusiva che l'effetto serra esista

20. **Quale delle seguenti forme di energia (radiazione) irraggia (emette) il sole con maggiore intensità?**

Contrassegna solo un ovale.

- radio
- infrarossa
- visibile
- ultravioletta
- raggi X

21. **Ognuno dei diagrammi qui sotto raffigura la superficie della terra, l'atmosfera e lo spazio. La freccia piena rappresenta l'energia (radiazione) proveniente dal sole che viene assorbita dalla superficie terrestre. La freccia tratteggiata rappresenta l'energia (radiazione) che viene irraggiata (emessa) dalla superficie terrestre e dall'atmosfera. Lo spessore delle frecce rappresenta approssimativamente la quantità di energia (radiazione). Scegli il diagramma che rappresenta meglio il bilancio di energia (radiazione) nel sistema Terra.**



Contrassegna solo un ovale.

- a
- b
- c
- d
- e

22. **Tra i seguenti, quali sono i due gas serra più abbondanti nell'atmosfera terrestre?**
Contrassegna solo un ovale.

- anidride carbonica e metano
- ozono e anidride carbonica
- azoto e ossigeno
- ossigeno e anidride carbonica
- vapore acqueo e anidride carbonica

23. **Quale forma di energia (radiazione) irraggia (emette) maggiormente l'atmosfera terrestre?**
Contrassegna solo un ovale.

- radio
- infrarossa
- visibile
- ultravioletta
- l'atmosfera terrestre non emette energia

24. **A causa dell'effetto serra, la temperatura media superficiale della Terra dipende principalmente**
Contrassegna solo un ovale.

- da un aumento dell'energia in ingresso, proveniente dallo spazio
- da una diminuzione dell'energia in uscita verso lo spazio
- da un aumento sia dell'energia in ingresso che da una diminuzione dell'energia in uscita verso lo spazio
- da un intrappolamento permanente dell'energia nell'atmosfera
- da un aumento nella quantità di energia assorbita ed emessa tra la superficie terrestre e l'atmosfera

25. **Cammini da una zona all'ombra a una zona esposta alla luce solare diretta e cominci a sentire più caldo. Quale delle seguenti frasi descrive più correttamente la causa dell'aumento di temperatura?**
Contrassegna solo un ovale.

- Assorbi più radiazione ultravioletta di quanta tu ne emetti sotto forma di radiazione visibile
- Assorbi più radiazione visibile di quanta ne emetti sotto forma di radiazione infrarossa
- Rifletti più radiazione ultravioletta di quanta ne emetti sotto forma di radiazione infrarossa
- Rifletti più radiazione visibile di quanta ne emetti sotto forma di radiazione infrarossa
- Rifletti più radiazione infrarossa di quanta ne emetti sotto forma di radiazione visibile

26. **Quale forma di energia (radiazione) emette (irraggia) maggiormente la superficie terrestre durante il giorno?**
Contrassegna solo un ovale.

- radio
- infrarossa
- visibile
- ultravioletta
- la superficie terrestre non emette energia durante il giorno

27. **Francesca prende dal suo astuccio un righello di metallo e uno di legno. Afferma di percepire più freddo quello di metallo rispetto a quello di legno. Qual è la spiegazione che ritieni più corretta?**

Contrassegna solo un ovale.

- Il metallo conduce l'energia via dalla sua mano più rapidamente del legno.
- Il legno è una sostanza naturalmente più calda del metallo.
- Il righello di legno contiene più calore di quello di metallo
- I metalli irradiano meglio il calore rispetto al legno
- Il freddo fluisce più facilmente da un metallo

28. **Marco sta leggendo una domanda a risposta multipla da un libro di testo: "sudare ti rinfresca perché il sudore presente sulla tua pelle:**

Contrassegna solo un ovale.

- inumidisce la superficie della pelle e superfici umide estraggono più calore rispetto alle superfici secche
- drena il calore dai pori e lo sparpaglia all'esterno, sulla superficie della pelle
- è alla stessa temperatura della tua pelle, ma evapora e quindi porta via calore
- è leggermente più freddo della tua pelle per via dell'evaporazione e quindi il calore è trasferito dalla tua pelle al sudore

29. **Sei nel business di sciogliere il ghiaccio a 0°C usando dei blocchetti di metallo caldi come sorgente di energia. La prima opzione consiste nell'uso di un blocchetto di metallo alla temperatura di 200°C, la seconda consiste nell'uso di due blocchetti di metallo alla temperatura di 100°C. I singoli blocchetti di metallo sono fatti dello stesso materiale e hanno lo stesso peso e la stessa superficie. Quale delle due opzioni farà sciogliere più ghiaccio?**

Contrassegna solo un ovale.

- i blocchetti a 100°C
- il blocchetto a 200°C
- entrambe le opzioni faranno sciogliere la stessa quantità di ghiaccio
- non si può dire con le sole informazioni fornite

30. **perché:**

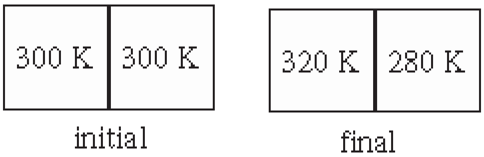
Contrassegna solo un ovale.

- i due blocchetti hanno il doppio della superficie rispetto al blocchetto singolo e quindi il tasso di trasferimento dell'energia è più elevato quando si usano più blocchetti.
- l'energia trasferita è proporzionale alla massa dei blocchetti utilizzati e alla variazione della temperatura dei blocchetti durante il processo.
- usare un blocchetto a temperatura più elevata farà sciogliere il ghiaccio più velocemente in quanto la maggiore differenza di temperatura aumenterà il tasso di trasferimento dell'energia.
- la temperatura del blocchetto più caldo diminuirà più velocemente man mano che l'energia è trasferita al ghiaccio.
- la capacità termica del metallo è una funzione della temperatura.

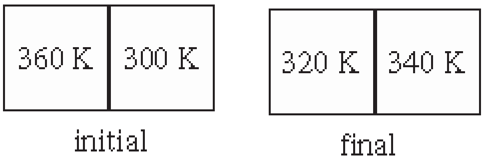
31. **Due oggetti A e B sono posti in un recipiente isolato e sono collegati tra loro tramite una sottile barra metallica. L'oggetto A è a una temperatura maggiore di B quindi l'energia è trasferita spontaneamente da A a B. Cosa succede al numero di microstati accessibili (aumenta, diminuisce o rimane invariato) durante il processo per il sistema A, per il sistema B e per il sistema A+B? Motiva le tue risposte.**

32. **Per ognuno dei casi presentati successivamente, due blocchi di metallo di massa uguale sono posti in contatto termico e sono isolati dal resto dell'universo. Le temperature iniziali dei due blocchi e quelle finali sono mostrate nelle figure. Per ogni coppia di stati, stabilisci se la transizione tra lo stato iniziale e quello finale è possibile e spiega perché o perché no anche alla luce del modello microscopico visto a lezione.**

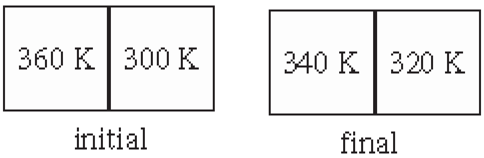
A.



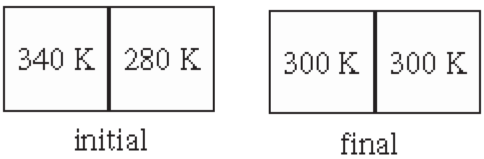
B.



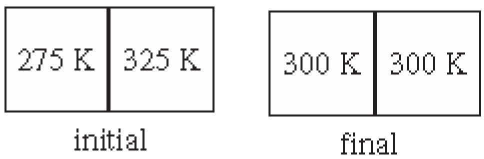
C.



D.



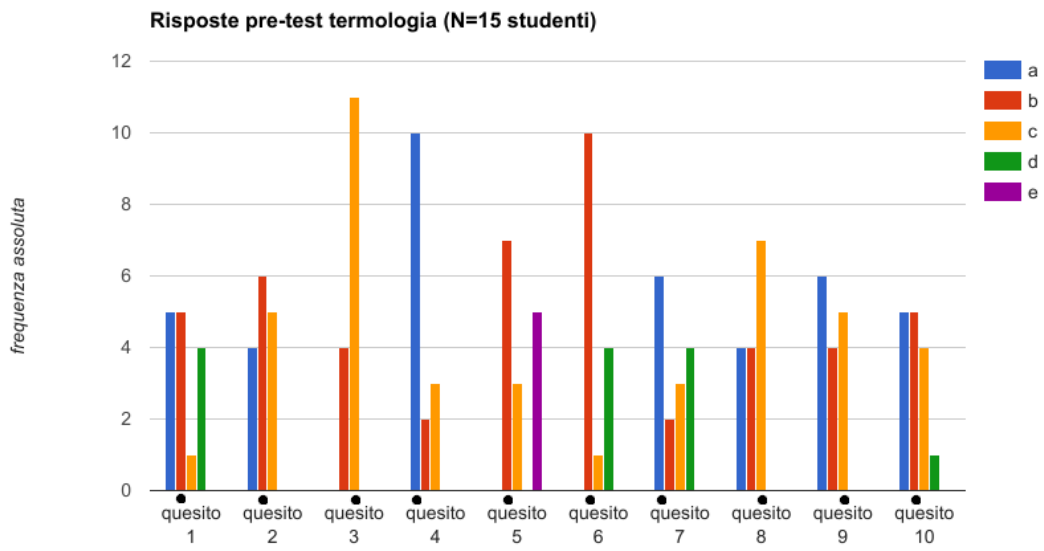
E.



33. **Quali momenti (esperimenti quantitativi, dimostrazioni o lezioni frontali) del percorso didattico pensi abbiano contribuito maggiormente a chiarirti le idee e a farti elaborare un modello concettuale dei processi fisici sottostanti ai processi termici, ai flussi di radiazione sulla Terra e all'effetto serra?**

34. **Ritieni che le attività sperimentali proposte risultino più interessanti e possano motivare maggiormente uno studente di scuola superiore se inserite in un percorso didattico in cui l'obiettivo finale sia la comprensione di alcuni dei meccanismi del clima e dell'atmosfera? Se ne avrai la possibilità pensi di utilizzare alcune idee/esperimenti a scuola con gli studenti?**

35. **Il percorso didattico è stato di tuo gradimento? Sentiti libera/o di esprimere le tue considerazioni per poterlo rendere più efficace e interessante. Grazie per la tua collaborazione.**



Q11

La b, c ed e sono possibili perché raggiungo un equilibrio tra le due temperature proporzionale. Per la a no perché ho già equilibrio e la d non risulta proporzionale.

La b, c ed e sono possibili perché raggiungo un equilibrio tra le due temperature proporzionale. Per la a no perché ho già equilibrio e la d non risulta proporzionale.

A. No perché esce da uno stato di equilibrio
B. No perché passa da uno stato di equilibrio e ne esce
C. Si perché la differenza tra le temperature di partena è uguale per entrambi
D. No perché dovrebbero avere la media delle temperature di partenza (310 K)
E. Si, stesso motivo della C.

a) non è possibile perchè il calore tende a passare dal blocco più caldo al più freddo per cercare di raggiungere uno stato di equilibrio
b) non è possibile perchè è passato più del calore necessario all'equilibrio
c) possibile anche se non è ancora uno stato "finale"
d) non possibile perchè la somma dei calori dellos stato iniziale e finale non è uguale
d) possibile

A. no, perché sono in equilibrio.
B. no, perché il primo deve avere temperatura maggiore del secondo.
C. si.
D. no, le differenze di temperatura sono diverse.
E. si.

A.non è possibile (infatti sono già in equilibrio termico nello stato iniziale)
B. non è possibile (il blocco di 360K cede calore, ma non così tanto, l'equilibrio termico viene raggiunto prima)
C.è possibile (c'è stato uno scambio di calore in virtù di una variazione di temperatura, il blocco di 360K ha ceduto calore)
D.non è possibile (essendo il sistema isolato, non è possibile che ci sia stata una 'creazione' di energia)
E.è possibile (c'è stato uno scambio di calore in virtù di una variazione di temperatura, il blocco di 325K ha ceduto calore)

A. non è possibile perché sono in equilibrio all'inizio.
B. Non è possibile perché il secondo avrà temperatura minore o uguale del primo.
C. È possibile perché le differenze di temperatura sono uguali e si stanno avvicinando all'equilibrio.
D. Non è possibile perché le differenze di temperatura sono diverse per il primo e il secondo.
E. È possibile perché sono arrivati all'equilibrio termico.

C ed E sono possibili, le altre no. A prevede spostamento di calore da corpi freddi a corpi caldi. B "supera" l'equilibrio. In D non si sposta tanto calore uguale.

A. No, perché il temperatura cambia verso l'equilibrio, così che l'entropia sia massima. Inoltre avrei creazione di energia dal nulla, il che implica la non
conservazione dell'energia.
B. No, perché prima raggiungono entrambe 330K e poi tornerei nelle condizioni del caso A.
C.Sì, in quanto la temperatura si avvia verso l'equilibrio. In seguito le temperature raggiungeranno l'equilibrio.
D. No, Perché prima raggiungono i 310K entrambe, e poi avrei energia che viene distrutta, il che va contro il principio di conservazione dell'energia
E.Sì: lo scambio di calore avviene sempre dal corpo più caldo al più freddo fino al raggiungimento dell'equilibrio, e quindi è analogo al caso C, anche se in quello non raggiunge il completo equilibrio all'istante finale considerato

A) Non è possibile perché la situazione di partenza è di equilibrio termico, quella finale no;
B) Non è possibile perché anche se le differenze di energia termica dei due blocchi sono uguali e opposte, il punto di equilibrio termico (T = 330 K) viene raggiunto e superato;
C) E' possibile perché l'energia termica di entrambi i blocchi varia in ugual misura, e il calore scorre dal corpo più caldo al più freddo. La situazione finale non è però di equilibrio;
D) Non è possibile perché la differenza di energia termica dei due blocchetti dovrebbe essere uguale, e quindi, siccome i blocchetti sono identici, dovrebbe essere uguale il loro DELTAT: in questo caso invece non lo è;
E)E' possibile per lo stesso motivo di B), e inoltre in questo caso la situazione finale è di equilibrio termico

A no! B no! C lo stato finale non è all'equilibrio termico, la variazione di temperatura è uguale per entrambi i blocchi :) D no! E sì

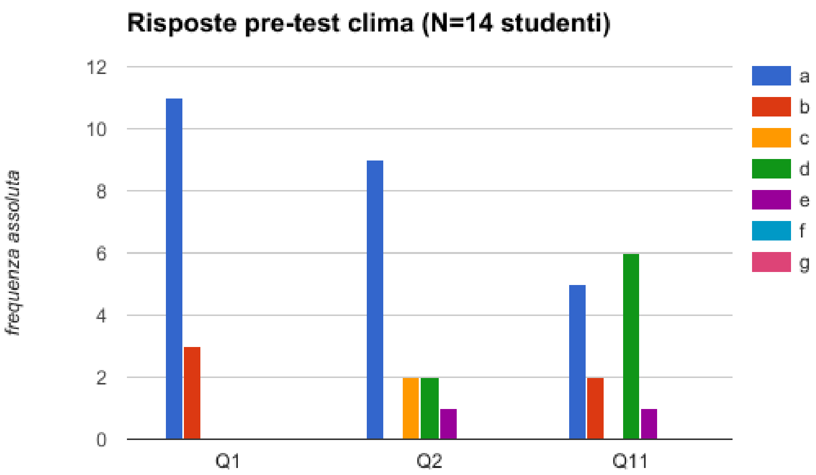
D

A: no perché per equilibrio termico la temperature devono stare nell'intervallo tra le temperature iniziali
B: no perché il secondo non può essere più caldo del primo
C: si (idem di sopra)
D: no, l'equilibrio tra i due non è 300 perché è troppo basso
E: si (idem della D)

A e B no perché al massimo si può raggiungere la temperatura di equilibrio, non si può trasferire piu calore. C si, potrebbe essere uno stato intermedio prima di raggiungere la temperatura di equilibrio, D e E si perche hanno raggiunto la temperatura di equilibrio

E è l'unica possibile perché alla fine i due blocchi avranno la stessa temperatura. Dato che i blocchi sono identici, la temperatura finale è la media aritmetica delle temperature iniziali

Figure 3.27: Students' answers to pre tests termologia. The correct answer is marked with a black dot on the x axis of the graph.



Q3

Il tempo metereologico riguarda eventi metereologici come pioggia, neve, vento,...mentre quando si parla di clima si considerano molti fattori come la latitudine, l'altezza, stagione, ...
Il tempo metereologico riguarda eventi metereologici come pioggia, neve, vento,...mentre quando si parla di clima si considerano molti fattori come la latitudine, l'altezza, stagione, ...
Il clima è un concetto più globale
Il clima indica lo stato dell'atmosfera terrestre, il tempo metereologico è relativo alle temperature
Clima si intende la temperatura, tempo meteorologico si intende il fatto che un giorno ci sia una giornata soleggiata, piovosa.
Clima a zone, tempo indica quello di un giorno.
Il tempo meteorologico è relativo a tempi più brevi, il clima a tempi più lunghi
Il tempo metereologico si compone dei fenomeni direttamente osservabili in un breve arco di tempo Il concetto di clima è invece legato alla tendenza a manifestare un certo tipo di eventi metereologici in un dato luogo, unitamente a dati quali (per esempio) precipitazioni, temperature etc
Il tempo meteorologico è quello del giorno, il clima è un modo per descrivere le zone
Tempo meteorologico si riferisce a tempi brevi, il clima a tempi più lunghi
Il clima è un insieme di tempi metereologici tipici di una zona
Il tempo meteorologico varia in tempi rapidi, riguarda un preciso luogo in un preciso tempo. Il clima descrive aree ampie con delle quantità medie.
Le scale spaziale e temporale

Q4

Inquinamento
Inquinamento
Giorno/notte, latitudine,
Giorno/notte, latitudine,
Insolazione, eruzioni vulcaniche, attività umane
Inquinamento, effetto serra
Pressione, Temperatura
Latitudine, altitudine, vicinanza al mare
Latitudine Vicinanza o meno a grandi masse d'acqua Presenza o meno di correnti (es. Corrente del golfo) Altitudine
Temperatura, pressione, inquinamento
CO2, latitudine, morfologia (mari e monti)
Emissioni di gas nell'atmosfera, radiazioni provenienti dal sole che rimangono intrappolate nell'atmosfera
Gli oceani, le montagne e soprattutto il Sole
il bilancio radiativo terrestre e le nubi, innanzi tutto.

Q5

Inquinamento
Inquinamento
Latitudine (essere all'equatore é diverso da essere al polo nord)
Latitudine (essere all'equatore é diverso da essere al polo nord)
Sole
Distanza dal Sole, le stagioni
Effetto serra
Inquinamento
Lo scambio termico con il nucleo terrestre
La temperatura proveniente dal nucleo della Terra insieme all'irraggiamento proveniente dal sole
L'effetto serra combinato alla radiazione solare
La vicinanza al sole (stagioni)
L'attività solare.

Q6

Radiazione
Radiazione
Radiazione
Energia solare
Energia solare
Elettromagnetica
Elettromagnetica
Radiazioni elettromagnetiche
Energia termica
Radiazione elettromagnetica
Luminosa
Energia elettromagnetica
Se si intende quella che arriva sulla terra, radiazione luminosa nelle frequenze del visibile.

Q7

Energia geotermica
Energia geotermica
Calore
Calore
Radiazione
Radiazioni
Radiazione infrarossa
Termica
Energia geotermica
Elettromagnetica (nell'infrarosso)
Infrarosso
Energia elettromagnetico
Elettromagnetica
Radiazione infrarossa.

Q8

Energia elettrica
Energia elettrica
Energia elettrica
Elettromagnetica
Elettromagnetica
Radiazione
Radiazioni
Termica
Infrarosso
Calore
Radiazione infrarossa

Q9

Anidride carbonica, ossigeno, metano
Anidride carbonica, ossigeno, metano
Un gas che amplifica l'effetto serra. Vapor acqueo, metano, co2
Anidride carbonica, neon, gas delle bombolette spray
Il gas serra è un gas che impedisce il passaggio di ossigeno sulla superficie terrestre. Un esempio è l'anidride carbonica
È un gas che provoca l"effetto serra. Anidride carbonica
E' un gas che impedisce alla radiazione terrestre di lasciare la Terra. Anidride carbonica
Un gas serra è un gas presente nell'atmosfera terrestre e che impedisce all'energia termica di lasciare l'atmosfera stessa
Anidride carbonica
CO2 CO
Un gas che crea uno schermo nell'atmosfera impedendo ai raggi infrarossi provenienti dalla Terra di disperdersi oltre l'atmosfera, aumentando la temperatura dell'atmosfera e modificando il clima. Esempio: CO2
Anidride carbonica, metano
Neon
Vapor d'acqua, C02, CH4, NO2, O3.

Q10

Insieme di gas che porta all'innalzamento della temperatura sulla terra.
Insieme di gas che porta all'innalzamento della temperatura sulla terra.
L'effetto per cui la radiazione riflessa dalla terra viene in parte riflessa nuovamente verso il suolo
Ci sono dei gas che non permettono alle radiazioni solari di uscire dall'atmosfera e quindi vi è un aumento delle temperature
Il gas serra crea una cappa di anidride carbonica e impedisce il passaggio dinossigeno
Troppa emissione di anidride carbonica che crea una cappa
I gas serra riflettono verso l'interno la radiazione emessa dalla Terra causando un aumento della temperatura
L'effetto serra è un effetto naturalmente presente sul pianeta Terra il quale impedisce eccessive escursioni termiche tra il giorno e la notte, impedendo un eccessivo raffreddamento della superficie terrestre. Negli ultimi anni si è associato il termine al fenomeno di surriscaldamento globale dovuto alle attività umane, le quali, rilasciando grandi quantità di gas serra ne stanno andando ad intensificare l'effetto.
La grande emissione di anidride carbonica crea una cappa che impedisce l'ingresso all'ossigeno
Letture personali su internet, programma delle superiori
La dispersione di CO2 nell'atmosfera come altri gas serra aumentano la temperatura terrestre modificando in modo radicale il clima globale e provocando conseguenze come lo scioglimento dei ghiacci al polo e desertificazione.
L'atmosfera impedisce a una buona parte di energia emessa dalla terra di essere dispersa, rispedendola verso la terra
Una cappa di gas che si comporta come una serra e fa aumentare la temperatura della terra
I gas serra assorbono larga parte della radiazione infrarossa emessa dall'atmosfera, riscaldandola. Di conseguenza, l'atmosfera emette a sua volta radiazione infrarossa, riscaldando la superficie terrestre.

Figure 3.28: Students' answers to pre tests clima.

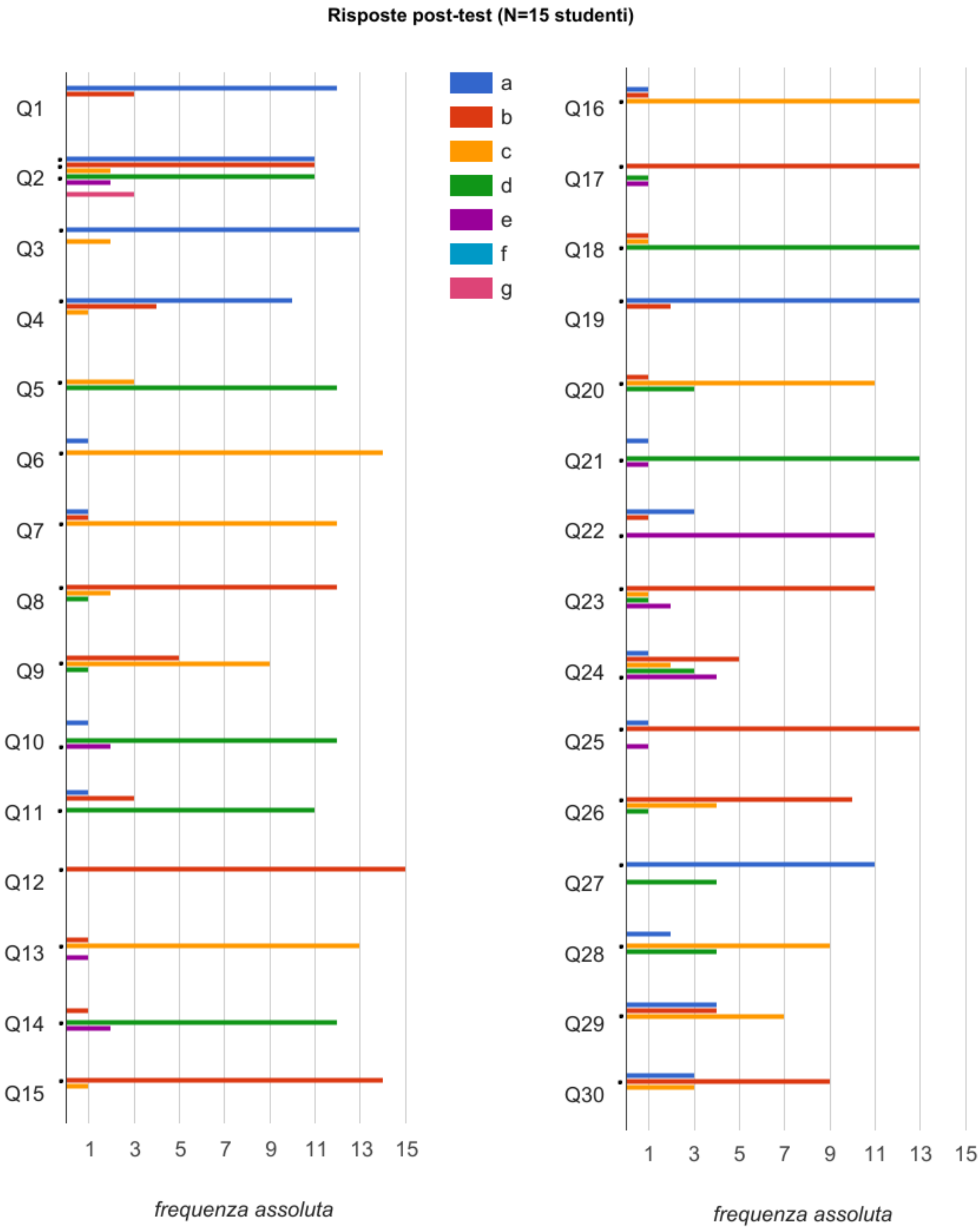


Figure 3.29: Students' answers to post test termologia&clima. The correct answer is marked with a black dot on the x axis of the graph.

Q31

Rimane invariato

Il numero di microstati accessibili per il sistema A+B dovrebbe aumentare, quindi l'aumento di microstati per il sistema B è maggiore della diminuzione di microstati per il sistema A.

Ricordando l'esperimento della "Tamparatura" svolto in classe si può pensare che:
> per i corpi A e B visti come sistemi separati i microstati aumentino, perché è possibile ora per loro perdere e/o acquistare calore
> il numero invece di incrostati accessibile per il sistema A+B invece non cambia

Il numero di microstati accessibili del sistema A+B dovrebbe aumentare, quindi l'aumento di microstati per il sistema B è maggiore della diminuzione per il sistema A

Per il sistema A+B il numero di microstati rimane invariato, per A diminuisce e per B aumenta perche diminuisce e aumenta rispettivamente la temperatura.

Il numero di microstatia accessibili al sistema isolato A+B aumenta per raggiungere il punto d'equilibrio... (*microstati). Dovendo raggiungere il massimo suppongo che anche il numero di microstati accessibili singolarmente da a e b potrebbe aumentare. ... Ma non è necessario, ciò che conta è massimizzare i microstati accessibili totali.

Aumenta per il corpo B, perché passa da una temperatura più bassa a una più alta e la temperatura è direttamente proporzionale al numero di microstati. Analogamente, il numero di microstati disponibili per A diminuisce.
Il sistema A+B viene portato per il secondo principio della termodinamica a una condizione di entropia più alta, e cioè a un numero più alto di microstati.

Il numero di microstati che realizzano A diminuisce e il numero di microstati che realizzano B aumenta. Il numero di microstati che realizzano il sistema resta invariato. Ciò succede perché il numero di microstati che realizzano un macrostato posso essere interpretati come una misura della temperatura del macrostato stesso; quindi calando la temperatura di A e aumentando quella di B succede quando detto sopra per questi due. Il sistema è isolato quindi il numero di microstati non varia.

Per il sistema A il numero dei Microsoft diminuisce, per B aumenta eper A più B rimane invariato..questo perché A è a temperatura maggiore di B quindi cede parte del suo calore per raggiungere l'equilibrio e non puo aumentare nel totale perché l'energia si conserva in un sistema isolato.

A diminuisce, B aumenta, A+B resta uguale.

Aumenta in tutti e 3 i casi.

Per A diminuisce, per B aumenta, per A+B rimane invariato

Q32

A. No, perché un sistema passerebbe spontaneamente ad avere un numero minore di microstati accessibili
B. No
C. Sì
D. No
E. Sì

A) non possibile. I corpi sono in equilibrio termico. Anche se consideriamo una loro interazione termica essa non sarà in grado di essere tanto significativa da produrre quel risultato
B e C) possibili.
Nel caso C non si è atteso a sufficienza che l'equilibrio si stabilizzasse tra i due corpi per cui il più caldo non ha ancora ceduto tutto il calore possibile.
Nel caso B è utile ricordare il modello microscopico visto a lezione: il corpo più freddo può in una certa misura ricevere più calore di quello necessario per giungere all'equilibrio. Successivamente con il trascorrere del tempo il processo tramite cui il corpo più caldo cede calore continua ad iterarsi, conducendo ad una situazione di equilibrio
D) impossibile: la temperatura del sistema è cresciuta
E) possibile

I due blocchetti convergono ad una temperatura d'equilibrio che dev'essere compresa tra le due temperature iniziali. Perciò sicuramente non sono possibili i casi a e b e sono plausibili invece i casi d ed e. Per quanto riguarda il caso c, è una temperatura possibile solamente se il caso finale non è stato calcolato fino allo stato d'equilibrio che impone la stessa temperatura per entrambi i blocchetti (tralaltro dello stesso materiale quindi non ci sono problemi di calore specifico)

A. No, perché un sistema passerebbe spontaneamente ad avere un numero minore di microstati accessibili;
B. No, perché i due sistemi superano il punto di equilibrio, corrispondente alla situazione con il maggior numero di microstati accessibili;
C. Sì, perché i due sistemi variano in modo simmetrico il numero di microstati;
D. No, perché il numero di microstati di un sistema varia più del numero di microstati per l'altro sistema
E. Sì, per lo stesso motivo di C, con la differenza che i sistemi qui raggiungono il punto di equilibrio.

A no, Bno, perche il sistema evolve verso una temperatura di equilibrio e una volta raggiunta non la supera, C si, potrebbe essere uno stato di transizione verso lo stato con temperatura di equilibrio, D no perche la temperatura di equilibrio é 310, E si perche ha raggiunto la temp di equilibrio. La temperatura di equilibrio in questo caso é la temperatura intermedia in quanto massa e calore specifico con uguali per entrambi i blocchetti.

A) no, il flusso netto di calore all'equilibrio termico è nullo b)è improbabile che dopo aver raggiunto l'equilibrio a 330 K il calore continui a fluire da sx a dx. C) la transizione è possibile, però lo stato raffigurato non è quello all'equilibrio, avendo i corpi temperatura differente d)no, è stata persa l'energia corrispondente a 20 gradi e)sì, questo funziona, raggiunge l'equilibrio

A non è possibile perché passo da un macrostato con tanti microstati a uno con meno microstati, e quindi meno probabile. B non è possibile perché nel passare da un macrostato all'altro ha dovuto attraversare il macrostato (300-300) che è il più probabile perché soddisfatto da più microstati, e lì avrebbe dovuto fermarsi. C non va bene perché il macrostato di arrivo è più probabile di quello di partenza ma non è ancora il più probabile, quindi il sistema evolverà ancora.
D non va bene perché il macrostato finale non è consentito dalle energie cinetiche del macrostato iniziale (avrei perso energia nel contatto). E invece va bene.

A, B e D no; C ed E sì. A no perché all'equilibrio il calore uscente è uguale a quello entrante, ovvero il numero di microstati che realizzano il sistema è massimo; negli esperimenti non si osservavano spostamenti di calore tra corpi sí da avere temperature diverse dopo aver raggiunto l'equilibrio. B no perché il numero di microstati varia fino all'equilibrio a 330 e poi è come il caso A. D no perché il numero di microstati non varia essendo il sistema isolato, come si vede nella domanda precedente; negli esperimenti calava solo perché il sistema non era isolato perfettamente. C sí per la domanda precedente, visto che il calore viene ceduta ai corpi più freddi. E sì per il punto precedente e perché 300 è la temperatura di equilibrio.

La d e la e sono corrette in quanto da un certo stato iniziale raggiungo una temperatura di equilibrio.

A. No perché sono in equilibrio termico.
B. No perché si è oltrepassato il valore di equilibrio termico.
C. Si.
D. No perché 340-20=320 e calore ceduto=calore assorbito.
E. Si.

Suppongo che i due blocchi siano fatti dello stesso metallo.
A. Possibile, i due blocchi sono già in equilibrio termico, perciò se sono isolati vi restano.
B. Lo stato finale è impossibile, per raggiungerlo i due blocchi devono passare per lo stato di equilibrio a 330 K e rimanerci.
C. Possibile, i due blocchi stanno convergendo all'equilibrio termico a 330 K e, nello stato finale, le rispettive differenze di temperatura con lo stato iniziale sono uguali (hanno stessa massa e stesso calore specifico).
D. Impossibile, l'equilibrio termico è (340+280)/2=310 K.
E. Possibile, i due blocchi hanno raggiunto l'equilibrio termico.
Nel caso in cui i due blocchi siano fatti di metalli diversi il caso D diventa possibile se il calore specifico del blocco di sinistra è il doppio di quello di destra.

A non è possibile perché il sistema parte dall'equilibrio. B non è possibile perché il sistema ha già passato l'equilibrio. C è possibile perché il calore fluisce da quello a temperatura maggiore a quello con temperatura minore. D non è possibile perché con la differenza di temperatura iniziale non si può arrivare allo stato finale in figura. E è possibile perché arrivano all'equilibrio.

A: si, perché l'equilibrio termico è una situazione instabile.
B: si, c'è stato scambio di calore da corpo caldo a corpo più freddo e questa situazione potrebbe essere una oscillazione attorno all'equilibrio
C: si, c'è stato scambio di calore da corpo caldo a corpo più freddo
D: no, il sistema è isolato
E: si, c'è stato scambio di calore da corpo caldo a corpo più freddo

Figure 3.30: Students' answers to post test termologia&clima.

Q33

Esperimenti quantitativi e lezioni frontali

Esperimenti quantitativi e lezioni frontali

L'esperimento della piastrina sotto la lampada e il cubo di Leslie

L'esperimento dell'irraggiamento della lampada sulla lastra annerita e il modello sull'effetto serra con il bicchiere bucato.

Esperimento con la lampada e lastrina, esperienza del bicchiere per il concetto di equilibrio (radiazione che "entra" e che "esce"). É stato importante anche poi rivedere le cose spiegate complessivamente con la lezione frontale.

È stato importante osservare la temperatura letta dal termometro bagnato dall'alcol e interessanti gli esperimenti riguardanti l'irraggiamento, con le due differenti lastrine e con il sensore e la lampadina a tensione variabile

Le lezioni sono necessarie per capire i temi proposti, ma la fase sperimentale è quella più adatta a chiarire le idee e assimilare al meglio i concetti proposti con un'esperienza che rimane impressa più a lungo delle parole o delle slide.

L'esperimento con le lastrine

L'esperimento sul calore specifico e la lezione sul clima.

L'esperimento sulle piastrine accompagnato dalle slide e dall'esempio del bicchiere.

L'esperimento sull'irraggiamento. Abbiamo posto due corpi di diverso colore sotto la stessa lampada accesa e abbiamo misurato le temperature a intervalli di tempo fissati. Inoltre l'analogia del bicchiere bucato in cui il livello di acqua varia in base alla dimensione del buco lasciato libero è servito a capire l'effetto serra e l'effetto dell'aumento dell'effetto serra sulla temperatura media globale.

L'esperimento con la lampada e i dischetti e l'esempio del bicchiere con l'acqua e i tre buchi.

Esperimento con lampada e lastrine nera (un corpo caldo emette radiazioni con intensità dipendente dalla sua temperatura, legge di Stefan-B.), il cubo di Leslie (concetto di trasparenza che va riferito ad una specifica radiazione, abbiamo utilizzato silicio e plexiglas per spiegare ciò)

Sicuramente gli esperimenti sono fondamentali, ma anche le slide commentate sono utili.

Q34

Sì ad entrambe le domande.

Penso che le attività didattiche proposte possano risultare più interessanti se focalizzate al comprendere i fenomeni del clima.
Allo stesso tempo però penso che se anche dovessi progettare un corso di fisica che non preveda questo discorso esplicitamente le utlizzerei (magari dando dei semplici richiami al loro parallelismo con i concetti del clima) perché penso siano dei modi semplici e chiari per fissare i concetti

Si penso siano molto interessanti ed alcuni facilmente riproducibili e penso che li utilizzerò non solo con il fine di intendere i fenomeni climatici, ma (soprattutto quelli che usano Excel) anche per far comprendere la differenza tra valore incognito e valore costante nelle situazioni di dipendenza diretta in una formula.

Sì, ad entrambe le domande

Penso che avere un obbiettivo (come spiegare o capire certi fenomeni) sia importante per un percorso didattico per interessare lo studente. Se avro la possibilità penso che sfrutterò l'esperimento della lampada, magari usando il sole!

Sicuramente il percorso è interessante, ma non sono in grado di sapere se si può proporre né se lo userò. Spero in entrambi i casi che sì, possa funzionare.

Sì, specie quelle attività che si possono svolgere in gruppetti con del materiale facile da reperire e da utilizzare praticamente. L'uso degli esperimenti secondo me si può estendere a tutti gli ambiti in cui essi siano utili, praticabili senza pericolo anche in autonomia (o semiautonomia) dagli studenti e non ricoprano tempi eccessivamente lunghi, che spesso nelle scuole non abbiamo a disposizione. Quindi ne farei uso decisamente volentieri ove possibile.

Sì. Sì.

Sì mi piacerebbe utilizzare molto alcune esperienze di laboratorio proposte soprattutto la lezione sul clima

Sì.

Penso che la comprensione dei meccanismi alla base di fenomeni "quotidiani" è in generale un buon incentivo e solletica la curiosità di conoscere. Oltre a ciò, il riscaldamento globale e l'effetto serra sono fenomeni che vengono studiati (almeno nel mio caso) in Geografia e tra qualche anno probabilmente anche in Storia, vederli dal punto di vista della fisica è fondamentale per fornire un quadro più completo e corretto. Se ne avrò l'occasione userò sicuramente l'analogia del bicchiere.

si penso che potrebbero essere interessanti e anche molto utili nel giusto contesto didattico e mi piacerebbe utilizzare queste idee.

Ho trovato le attività laboratoriali proposte molto utili e fondamentali per la comprensione di alcuni fenomeni climatici e quindi molto adatte in una scuola superiore. Un esempio è fornito dall'attività della 'nuvola in bottiglia', che fornisce una spiegazione esaustiva del ruolo degli aerosol nell'atmosfera (introducendoli nella bottiglia, usando un fiammifero, e poi aprendo la bottiglia precedentemente messa in pressione abbiamo assistito alla formazione di una nube bianca). Quindi ritengo che, se ne avrò la possibilità, proporrei quasi sicuramente questa attività ed altre ai miei studenti.

Sicuramente sì.

Q35

Sì, soprattutto per quanto riguarda la parte sperimentale.

Si, il percorso mi è piaciuto.
Forse cercherei di rendere la parte di "teoria" leggermente più schematica in modo da non perdere il filo del discorso tra un'esperienza e l'altra.

Il corso mi è piaciuto molto, soprattutto la parte finale quando abbiamo ripreso esperimenti superficialmente non molto inerenti al clima cucendoli insieme e svelando l'obiettivo a posteriori.
L'unica cosa che mi è un po' dispiaciuta è stata il fatto che (credo per ragioni di tempo) non abbiamo ripercorso proprio tutte le risposte che avevamo provato a dare nel primo questionario. Non nel senso che avrei voluto facessimo più esperimenti, perché capisco non fosse possibile, ma almeno andare a sottolineare i misconcetti che abbiamo anche sul resto degli argomenti.

Sì, soprattutto la parte sperimentale

Penso che il percorso sia stato interessante per l'argomento trattato. Penso però che si potrebbero migliorare le parti di lezione frontale per poter comprendere piu a fondo gli argomenti trattati e per essere quindi piu efficaci.

Certo! Forse sarebbe stato opportuno, anche se forse impegnativo, fare delle relazioni sugli esperimenti svolti.

Decisamente si, soprattutto la parte inerente la messa in atto, analisi e discussione degli esperimenti proposti.

È stato interessante, anche perché non avevo mai fatto una cosa simile

Questo corso mi è piaciuto molto e mi ha dato molti suggerimenti per presentare, in un futuro, delle esperienze di laboratorio di fisica.

Ritengo che una maggiore spiegazione degli argomenti prima dell'esecuzione dell'esperimento ne avrebbe agevolato la comprensione. Ho trovato difficile soprattutto trovare il fine ultimo di quanto stavo facendo durante gli esperimenti; spesso mi sembrava di procedere un po' a caso.

La parte sul clima è stata sicuramente interessante, mi sarebbe piaciuto aver avuto più tempo per andare con più calma e più in profondità.

È stato molto interessante. Penso che per interiorizzarlo del tutto sarebbe stato meglio fare in ogni lezione sia l'esperimento sia la parte di teoria specifica all'esperimento, piuttosto che fare una presentazione riassuntiva in un singolo giorno.

Certo, ho trovato questo percorso didattico ricco di spunti e fondamentale per la comprensione di alcuni fenomeni di cui non ero a conoscenza. Le spiegazioni sono state molto comprensibili e ho trovato molto utili anche le slides, ben fatte.

Molto interessante

Figure 3.31: Students' feedback about the teaching sequence.

Appendix D: Peer reviewed publications

P. Ricaud, P. Grigioni, R. Zbinden, J.-L. Attié, L. Genoni, A. Galeandro, L. Moggio, S. Montaguti, I. Petenko and P. Legovini, 2015, *Review of tropospheric temperature, absolute humidity and integrated water vapour from the HAMSTRAD radiometer installed at Dome C, Antarctica, 2009–14*, Antarctic Science 7(6), 598-616

Abstract

The HAMSTRAD (H2O Antarctica Microwave Stratospheric and Tropospheric Radiometers) instrument is a microwave radiometer installed at Dome C (Antarctica, 75°06'S, 123°21'E, 3233 m a.m.s.l.) dedicated to the tropospheric measurements of temperature, absolute humidity and integrated water vapour (IWV). The aim of the present paper is to review the entire HAMSTRAD dataset from 2009 to 2014 with a 7-minute integration time from 0 to 10 km by comparison with coincident radiosondes launched at 12h00 UTC at Dome C. Based upon an extensive evaluation of biases and time correlation coefficients (r), we can state: i) IWV is of excellent quality (r>0.98) and can be used without retrieving significant bias, ii) temperature is suitable for scientific analyses over 10 km with a high time correlation with radiosondes (r>0.80) and iii) absolute humidity is suitable for scientific analyses over 4 km with a moderate time correlation against radiosondes (r>0.70). The vertical distribution of temperature (10 km) and absolute humidity (4 km) is subject to biases that need to be removed if the analyses require the use of vertical profiling. The HAMSTRAD dataset is provided in open access to the scientific community.

L. Moggio, P. Onorato, L. M. Gratton and S. Oss 2017, *Time-lapse and slow-motion tracking of temperature changes: response time of a thermometer*, Physics Education 52(2)

Abstract

We propose the use of a smartphone based time-lapse and slow-motion video techniques together with tracking analysis as valuable tools for investigating thermal processes such as the response time of a thermometer. The two simple experimental activities presented

here, suitable also for high school and undergraduate students, allow one to measure in a simple yet rigorous way the response time of an alcohol thermometer and show its critical dependence on the properties of the surrounding environment giving insight into instrument characteristics, heat transfer and thermal equilibrium concepts.

P. Onorato, M. Malgieri, L. Moggio, and S. Oss 2017, *Microscopic and probabilistic approach to thermal steady state based on a dice and coin toy model*, European Journal of Physics 38(4), 045102

Abstract

In this article we present an educational approach to thermal equilibrium which was tested with a group of 13 undergraduate students of the University of Trento. The approach is based on a stochastic toy model, in which bodies in thermal contact are represented by rows of squares on a cardboard table, which exchange coins placed on the squares based on the roll of two dice. The discussion of several physical principles, such as the exponential approach to equilibrium, the calculation of the equilibrium temperature, and the interpretation of the equilibrium state as the most probable macrostate, proceeds through a continual comparison between the outcomes obtained with the toy model and the results of a real experiment on thermal contact of two masses of water at different temperature. At the end of the sequence, a re-analysis of the experimental results in view of both the Boltzmann and Clausius definitions of entropy allows for a critical discussion of the concepts of temperature and entropy. In order to provide the reader with a feeling of how the sequence was received by students, and how it helped them understand the topics introduced, we discuss some excerpts from their answers to a conceptual item given at the end of the sequence.

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