European Geosciences Union

GIFT – Geosciences Information For Teachers

GIFT WORKSHOP 2014

OUR CHANGING PLANET

Vienna, Austria, 27-30 April 2014

Dear Teachers,

Welcome to the 12th GIFT workshop of the European Geosciences Union!
This year the workshop will reunite 86 teachers from 19 different countries around the general theme "Our Changing Planet".

Numerous geological, geophysical, geochemical and geobiological data acquired over many years have documented that on geological time-scales, the Earth has continuously undergone significant changes. We know that plate tectonics have widely moved continents, that the chemistry of the atmosphere has changed, that the climate of the Earth has undergone hot and cold periods (the Earth has been so cold at some points that the term "Snowball Earth" has been used). The term "**natural variability"** is used to refer to this continuous evolution of our planet.

A new trend in variability has been progressively documented for the last 100-150 years of the Earth's history, since the industrial revolution started. Many studies have demonstrated that new factors of anthropogenic origin are becoming important in controlling the environment of the Earth's outer shells. These outer shells, containing air, water, ice, soil, plants and animals are precisely where we live. An impressive characteristic is that changes in the environment are occurring at a high rate and reaching values unprecedented in the Earth's history, to the point that the term "**Anthropocene**" has been proposed for this new era of the Earth's history.

Awareness that human activities may be responsible for irreversible changes in the Earth's environment, has led to the establishment of the Intergovernmental Panel on Climate Change (IPCC), that was created in 1988 by two United Nations Organizations: the World Meteorological Organization (WMO) and the United Nation Environmental Program (UNEP).

In September 2013, the IPCC published the first part of its Fifth Assessment Report (AR5), on the "*The Physical Science Basis*". In a worldwide press conference, its co-chairman Thomas Stocker announced that the IPCC has concluded that "*warming in the climate system is unequivocal*" and that "*it is extremely likely that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcing together".*

All model simulations of future climate changes depend crucially of the quantity of CO2 in the atmosphere, and predictions vary between 1.5 °C and 4.5 °C depending on the different gas emission scenarios. In conclusion, the Fifth Assessment affirms: "*Limiting climate change will require substantial and sustained reductions in greenhouse gas emissions".*

Given the major interest for human kind, there is no doubt that these questions will be discussed worldwide, in all the media. It therefore was clear to us that teachers needed to be provided with sound scientific information in order to answer the questions that will be asked by their students.

The GIFT-2014 workshop takes advantage of the presence of many IPCC lead authors at the General Assembly of EGU in Vienna. We have asked them to address you about the different aspects of climate change, in its most general form (changes in the atmosphere and surface ocean, including ocean acidification, cryosphere, information from paleoclimatic archives to quantify natural versus anthropogenic variability, carbon and other biogeochemical cycles, clouds and aerosols, evaluation of climate models to ensure projections and predictability, sea level change…). We will also ask scientists who are not IPCC lead authors to address the teachers, in their field of expertise.

The GIFT-2014 workshop will include hands-on activities led by science educators illustrating changing environmental factors, such as ocean acidification, and a parallel poster session “Science in tomorrow’s classroom” open to teachers and scientists attending the General Assembly of the European Geosciences Union.

We would like to continue to offer teachers the opportunity to attend GIFT and similar workshops, but this depends upon us being able to show our sponsors that teachers have used what they have learned at the GIFT workshops in their daily teaching, or as inspiration for new ways to teach science in their schools.
Therefore, **we would ask you**:

1. To fill out the evaluation form as soon as possible and send them back to us.

2. To make presentations of your experiences at GIFT to a group of your teaching colleagues soon after you return.

3. To send us reports and photographs about how you have used the GIFT information in your classrooms.

We also encourage you to write reports about the GIFT workshop in publications specifically intended for geoscience teachers. Very soon, a “Teachers’ Corner “ will be uploaded on our web page, where all teachers will be able to post their opinion.

Information on past and future GIFT workshops is available on the EGU homepage (http://www.egu.eu/education/gift/workshops/). At this link it is possible to download brochures (.pdf) of the workshops and the illustrated presentations given at the GIFT workshops for the last 8 years. Since 2009, web-TV presentations were also included, which may be freely used in your classrooms.

We hope you enjoy the workshop and your stay in Vienna!

Carlo Laj
On behalf of the Committee on Education of EGU

Acknowledgements

The GIFT-2014 workshop has been organized by the Committee on Education of the European Geosciences Union. EGU has supported the major share of the expenses, but the workshop has also benefited of the generous help of:

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William S. Goree Award

And we thank all the speakers who have contributed to this educational workshop and their institutions.

European Geosciences Union
Committee on Education

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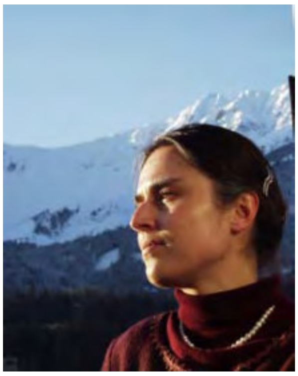
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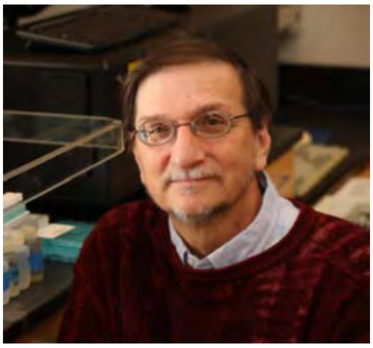
Steve Macko


Jean-Luc Berenguer


Phil Smith


Herbert Summesberger

Program

European Geosciences Union – General Assembly
GEOSCIENCE INFORMATION FOR TEACHERS (GIFT) WORKSHOP

Austria Center Vienna, 27-30 April 2014

'Our changing planet'

Sunday April 27, 2014

16:30 - 18:30 **GUIDED TOUR OF THE VIENNA MUSEUM OF NATURAL HISTORY**
and ice breaker reception
Herbert Summesberger and Mathias Harzhauser
Vienna Museum of Natural History

Monday April 28, 2014

08:30 - 08:45 **WELCOME!**
Günter Bloeschl
President of EGU

PRACTICAL INSTRUCTIONS FOR THE WORKSHOP
Carlo Laj
EGU Committee on Education

Chairperson: Carlo Laj

08:45 - 09:20 **IPCC FIFTH ASSESSMENT RELEASED – CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS**
Thomas Stocker
Co-Chair IPCC Working Group I
University of Bern, Switzerland

09:20 - 10:00 **CLIMATE INFORMATION FROM ICE CORES (PART 1)**
Thomas Blunier
Center for Ice and Climate
University of Copenhagen, Denmark

10:00 – 10:30 COFFEE BREAK

Chairperson: Phil Smith

10:30 – 11:15 **CLIMATE INFORMATION FROM ICE CORES (PART 2)**
Valérie Masson-Delmotte
Laboratoire des Sciences du Climat et de l'Environnement
Gif-sur-Yvette, France

11:15 - 11:30 **INSTRUCTIONS FOR THE POSTER SESSION EOS02**
Eve Arnold
Stockholm University, Sweden

11:30 - 12:00 **GENERAL DISCUSSION AND QUESTIONS**

12:00 – 14:00 LUNCH (SANDWICHES)

Chairperson: Francesca Cifelli

14:00 -18:00 **HANDS-ON ACTIVITIES**

Sally Soria-Dengg
GEOMAR Helmholtz Centre for Ocean Research
Kiel, Germany

Francesca Ugolini
Institute of Biometeorology-CNR
Firenze, Italy

Tuesday April 29, 2014

Chairperson: Stephen Macko

08:30 - 09:15 **SPACE FOR CLIMATE: OVERVIEW OF ESA EARTH OBSERVATION MISSIONS AND EXPLOITATION PROGRAMMES**
Francesco Sarti & Pierre-Philippe Mathieu
ESA-ESRIN, Frascati, Italy

09:15 - 10:00 **CLIMATE CHANGE, OCEAN WARMING, LAND ICE MELT, AND SEA LEVEL RISE**
Anny Cazenave
LEGOS-CNES, Toulouse, France

10:00 – 10:30 COFFEE BREAK

Chairperson: Annegret Schwarz

10:30 – 11:15 **THE GLOBAL CARBON CYCLE AND CLIMATE-CARBON COUPLING**
Laurent Bopp
CNRS
Gif-sur-Yvette, France

11:15 – 12:00 **OCEAN ACIDIFICATION AND ITS IMPACTS ON MARINE ORGANISMS AND ECOSYSTEMS**
James Orr
Laboratoire des Sciences du Climat et de l'Environnement
Gif-sur-Yvette, France

12:00 - 14:00 LUNCH (SANDWICHES)

Chairperson: Herbert Summesberger

14:00 – 15:00 **THE CARBON CAPER**
Phil Smith
John Innes Centre
Norwich, Great Britain

15:00- 15:30 COFFEE BREAK

Chairperson: Eve Arnold

15:30 – 19:00 **EOS2 – POSTER SESSION**

Wednesday April 30, 2014

Chairperson: Carlo Laj

08:30 - 09:15 **IMPACTS OF CLIMATE CHANGE ON AGRICULTURE**
Bernard Seguin
INRA
Avignon, France

09:15 - 10:00 **RECENT CHANGES IN ARCTIC ICE COVER FROM FIRST-HAND EXPERIENCE**
Larry Mayer
University of New Hampshire
Durham, N.H., USA

10:00 – 10:30 COFFEE BREAK

Chairperson: Angelo Camerlenghi

10:30 – 11:15 **IMPLICATIONS OF A CHANGING EARTH: OBVIOUS AND CASCADING**
Stephen Macko
Department of Environmental Sciences
University of Virginia, USA

11:15 - 11:45 **EDUCATIONAL ACTIVITIES AND PROJECTS OF EGU**
Carlo Laj
EGU Committee on Education

END OF THE WORKSHOP!

Speakers

Professor Thomas Stocker
Physics Institute, University of Bern, Switzerland
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Personal web page: http://www.climate.unibe.ch/stocker

EDUCATION

1987: PhD in Natural Sciences of ETH, Zürich.
1984: Dipl. Natw. (Umweltphysik), ETH, Zürich.

CARRER

Since 1993, Thomas Stocker is Professor of Climate and Environmental Physics, Physics Institute, University of Bern, Bern, Switzerland, Co-Director of the Physics Institute.
1991-1993: Associate Research Scientist at Lamont-Doherty Earth Observatory, Columbia University, Palisades New York, USA.
1989: Swiss National Science Foundation Research Fellow, Atmospheric and Oceanic Sciences, McGill University, Montreal, Canada.
1988-1989: SERC Visiting Research Fellow, Department of Mathematics, University College London.
1985-1988: Research Assistant, Laboratory of Hydraulics, Hydrology and Glaciology (VAW), ETH Zürich

RESEARCH INTERESTS

His research encompasses the development of climate models of intermediate complexity, modelling past and future climate change, and the reconstruction of the chemical composition of precipitation and greenhouse gas concentrations based on ice cores from Greenland and Antarctica.

PUBLICATIONS AND SERVICES

Thomas Stocker has authored or co-authored 180 peer-reviewed papers in the area of climate dynamics and paleoclimate modeling and reconstruction.
After more than 10 years of service in the UN Intergovernmental Panel on Climate Change (IPCC) he has been elected Co-Chair of Working Group I "The Physical Science Basis" of the IPCC in 2008.

AWARDS AND HONORS

Fellow of the American Geophysical Union, 2012
Hans Oeschger Medal of the European Geosciences Union, 2009
Descartes Prize for Transnational Collaborative Reserach, European Commission, Member of the EPICA Team, 2007
Doctor Honoris Causa, Université de Versailles, Saint-Quentin-En-Yvelines, 2006
National Latsis Prize of the Swiss National Science Foundation, 1993
Medal of ETH for excellent PhD Thesis, 1987
Medal of ETH for excellent Diploma Thesis, 1985

IPCC Fifth Assessment Released − Climate Change 2013: The Physical Science Basis

Thomas Stocker
University of Bern, Switzerland

CO_2 concentrations in the atmosphere are now unprecedented and 30% higher than during at least the last 800,000 years, and they rise more than 100 times faster than during the past 20,000 years. This is caused by anthropogenic emissions of greenhouse gases by burning coal, oil and gas, and by deforestation with consequent changes in the entire Earth System. The latest comprehensive scientific assessment *Climate Change 2013: The Physical Science Basis* by the Intergovernmental Panel on Climate Change documents a rapidly and profoundly changing Earth System and provides the latest scientific understanding of changes ahead of us. The full report is available at www.climatechange2013.org .

Based on multiple lines of independent evidence from the atmosphere, the ocean and the cryosphere, IPCC has concluded that *warming in the climate system is unequivocal*. There is no doubt that this warming and many of the consequent changes are caused by human activity. Since 1951 the Earth warmed by about 0.6 to 0.7°C which is one manifestation of a change in the energy balance of the Earth. It resulted from positive radiative forcing since 1750 AD caused by a large warming contribution by the increase in the greenhouse gas concentrations and a smaller cooling contribution by the increase in aerosols. The positive radiative forcing caused an uptake of energy by the Earth System, of which more than 90% is found in the ocean. For the first time scientists are able to link the accumulation of energy to the increase in radiative forcing in a quantitative manner; in other words, the climate system's energy budget is closed.

Therefore, *it is extremely likely that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings together*. In addition, many other changes have been detected over the past 50 years in all components of the climate system. The uptake of heat by the ocean, the rise in sea level, reductions in the Arctic sea ice cover, melting of the Greenland ice sheet, shrinking of glaciers worldwide, changes in the global water cycle, increases in the occurrence and strengths of extreme events such as the doubling in the frequency of heat waves, are among the many additional observations that can be causally linked to the increase in greenhouse gas concentrations since the mid 20th century. Based on this scientific evidence IPCC concludes: *Human influence on the climate system is clear*.

Based on a new set of future scenarios, comprehensive climate models are used to project the changes in the climate system during the 21st century and beyond. Global surface temperature will increase in all scenarios and by the end of the 21st century will *likely* exceed 1.5°C relative to 1850 to 1900 for all but the lowest emission scenario. This low emission scenario assumes effective policy intervention which results in aggressive emissions reductions of about 50% by mid 21st century. Conversely, a business-as-usual scenario would project temperature increases exceeding 4.5°C relative to 1850 to 1900 with profound changes in all components of the climate system. Sea level would rise between 0.52 to 0.98 m by 2100 with a rate of 8 to 16 mm per year, caused by increased ocean warming and loss of mass from glaciers and ice sheets. In this scenario a nearly ice-free Arctic Ocean in September is *likely* before mid-century. Furthermore, the contrast between wet and dry regions, and between wet and dry seasons will increase. Climate change will also affect carbon cycle processes in a way that will exacerbate the increase of CO2 in the atmosphere. Further uptake of carbon by the ocean will increase ocean acidification.

As the model simulations of future climate changes depend crucially on the emission scenario, this implies that the global society has a choice between a profoundly altered Earth System in which the two primary resources for human and eco systems, land and water, will be changed: land, through the increase in sea level, and water availability, through changes in the global water cycle, or alternatively, an Earth System with limited changes and in which adaptation appears still feasible in many regions.

An important new element of the latest IPCC assessment is the recognition that the total cumulative emissions of CO2 largely determine global mean surface warming by the late 21st century and beyond. In order to have a fair chance to keep global mean warming below 2°C the total amount of carbon emitted in the atmosphere since the late mid-19th century is about 1000 million tons of carbon of which by 2011 already 515 million tons have been emitted. Compatible with this target, therefore only 485 million tons of carbon can be emitted in the future. If the effect of additional greenhouse gases, such as methane and nitrous oxide emitted during food production, this amount reduces to only 275 million tons of carbon. This is equivalent to merely 29 years of 2012 emissions. Such a simple estimate, however, ignores the fact that emissions are still rising at about 2% per year, and that any decarbonization can evolve on rates that are limited by economic feasibility, estimated at no more than 5% per year reduction.

In conclusion the assessment affirms: *Limiting climate change will require substantial and sustained reductions in greenhouse gas emissions*. Therefore, we have a choice today whether we want to live in a world that is more than 4.5°C warmer than today, with an ice-free Arctic Ocean by the mid 21st century, substantially more extreme events, and an ocean which has become significantly more acid that marine organisms such as corals and plankton are seriously harmed, or whether we will manage to limit climate change below 2°C on global average. While it is our choice now, it is also clear that further delay and insufficient emissions reductions close the door on limiting global mean warming, and consequent impacts, permanently.

Professor Thomas Blunier
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EDUCATION

1995: Ph.D. in Physics, University of Bern.
1992: MS in Physics, University of Bern.

CARRER

Since 2007, Thomas Blunier is Professor at the Centre for Ice and Climate, Niels Bohr Institute, University of Copenhagen, Denmark.
2001-2007: Assistant Professor, Department of Climate and Environmental Physics, University of Bern, Switzerland.
1999-2001: Visiting Research Fellow, Department of Geosciences, Princeton University, USA.
1998: Invited Researcher, National Institute of Polar Research, Tokyo, Japan.
1996-1998: PostDoc Department of Climate and Environmental Physics, University of Bern, Switzerland.

RESEARCH INTERESTS

Reconstruction of climate records from ice cores from Greenland and Antarctica, specifically the composition of the past atmosphere. Links between climate change and atmospheric composition. Internal variability of the climate system, especially between the hemispheres.

PUBLICATIONS AND SERVICES

Thomas Blunier has authored or co-authored 73 peer-reviewed papers in the area of climate dynamics and paleoclimate modeling and reconstruction.
He is the current European Geosciences Union Division President Climate: Past, Present and Future.

Climate information from ice cores (part I)

Thomas Blunier
University of Copenhagen, Denmark

Introduction

Ice sheets are formed by the subsequent accumulation of past precipitation events. Accordingly, in the interior of polar ice sheets and on some high altitude glaciers, where dry snow prevails, a stratigraphically ordered sequence of precipitation events is archived. Using ice cores this climate archive can be accessed.

Drilling for ice cores started in the 1950s and several deep cores in Greenland and Antarctica were drilled since. In the early 1990s the longest ice cores were recovered from the summit of the Greenland ice sheet reaching bedrock at roughly 3200m. The oldest stratigraphically ordered ice to date is derived from the EPICA (European Project for Ice Coring in Antarctica) ice core at Dome C and is about 800,000 years old.

Top: NEEM field camp Greenland 2010
Left: NEEM drill trench.

Three different strains of information can be derived from ice cores:

- Information stored in the ice matrix itself (grain size, crystal orientation, snow accumulation, water isotopic composition).
- Particulate and dissolved tracers in the ice.
- Air in bubbles enclosures in the ice.

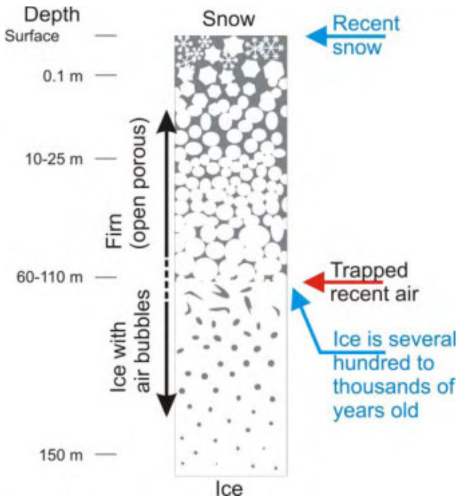
Transformation of snow to glacier ice

In the dry snow zones the top 60-110m of a glacier or an ice sheet in the accumulation zone consist of firn of increasing density with depth, formed by successive individual snow fall events. This firn column (Figure 1, left) is porous and air can diffuse through the pore space with decreasing effective diffusivity the smaller the pore space volume (the porosity) becomes. The transformation of fresh snow to glacier ice within the firn column takes place in several steps where the dominant process can be distinguished by the density.
Fresh snow has a typical density between 50-200 kg/m^3. Immediately after a snow fall event, recrystallization of the snow crystals by sublimation takes place very quickly ending up in round snow grains. Densification of the snow pack is achieved through settling and wind packing of the snow grains. Such aged snow has a density of typically 200-400 kg/m^3. Between the surface and a density of about 550 kg/m^3 the firn metamorphoses is dominated by the rearrangement of the firn grains in order to get to a closer packing. At 550 kg/m^3 the densest packing of spherical snow grains is reached. Geometrically the snow pack cannot further densify. Further down sintering and plastic deformation become the most important processes. Around a density of 800 kg/m^3 the pores are gradually pinched off and form bubbles in the ice. This zone is called firn-ice transition and spans

about the lowest 10% of the total firn column. The process of bubble enclosure is not instantaneous, i.e. not all bubbles are enclosed at the same time or density. Accordingly, also the depth and age of the enclosure of individual bubbles varies from one bubble to the other.

In the dry snow zones it typically occurs between 60-110 m. Higher temperature provides more energy for sintering and warmer ice can be more easily deformed. Thus, the close off depth is further up in the firn column for higher temperature. At the same time a smaller accumulation rate for a given temperature implies that a firn layer has more time to sinter and deform until it reaches a certain depth. Accordingly, higher accumulation rate tends to increase the close-off depth. Note that the temperature control is much stronger than the accumulation effect.

Glacier ice at the close off depth does not yet have the density of pure ice (e.g. made in a freezer). Deeper in the ice sheet under increasing hydrostatic pressure the air bubbles become smaller and smaller due to further deformation of the ice and the density increases slowly until all bubbles disappear. At this stage (at a depth between 700-1300m) a new ice-gas phase is formed (so-called clathrates or gas hydrates), where the gas molecules are incorporated into the ice matrix.



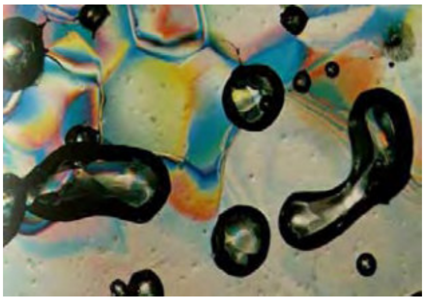


Figure 1 top: Picture of gas bubbles in an ice core.

Figure 1 left: Sketch of the top layers of the ice sheet. Snow is converted to ice over a longer time period. Therefore an open porous layer of roughly 60-110 meters exists. Only at the bottom of this layer is atmospheric gas occluded in bubbles.

Trace gases

On an absolute scale the most important greenhouse gas is water vapor. The amount of water vapor in the atmosphere depends on the temperature and cannot easily be influenced. Usually in a climate change context it is “disregarded” and it is frequently stated that CO2 is the most important greenhouse gas, which it is relative to the natural background.

Direct atmospheric records of greenhouse gases are restricted to the last few decades. In fact, most of what we know about changes of the atmospheric composition of the last centuries is derived from ice core measurements.

The last ~1000 years: Figure 2 left shows the concentration history of the major trace gases over the last 1000 years. While the concentrations were relatively stable up to about 1800 they increase dramatically afterwards.
The reason for the 100 ppmv increase of CO2 over the last 200 years is the input of fossil fuel burning emissions. This is clearly supported by the accompanying change in $d^{13}C$ (Figure 2 right). CO2 originating from fossil fuel is isotopically light as it is of organic origin. Adding light carbon with a signature of about -25‰ to the atmosphere decreases the atmospheric value from about -6.4 to -7.8‰ over the last 200 years. Direct systematic measurements of the atmospheric CO2 concentration started in 1958. Note, the very good agreement of ice core and direct atmospheric

measurements where they overlap, providing experimental proof of the reliability of ice core gas records.

In the case of methane the anthropogenic increase is even more dramatic starting from about 700 ppbv during preindustrial times to now reaching nearly 1800 ppbv. The reason for the increase rests in the anthropogenic output related to food and energy production. About 60% of today's emissions are human related. Half of that is from bacterial production in agricultural soil (e.g. rice production) and ruminants. The other half is from energy production, emission from landfills and biomass burning.
Nitrous oxide is also emitted by human activities such as fertilizer use and fossil fuel burning. Natural processes in soils and the oceans also release N_2O.

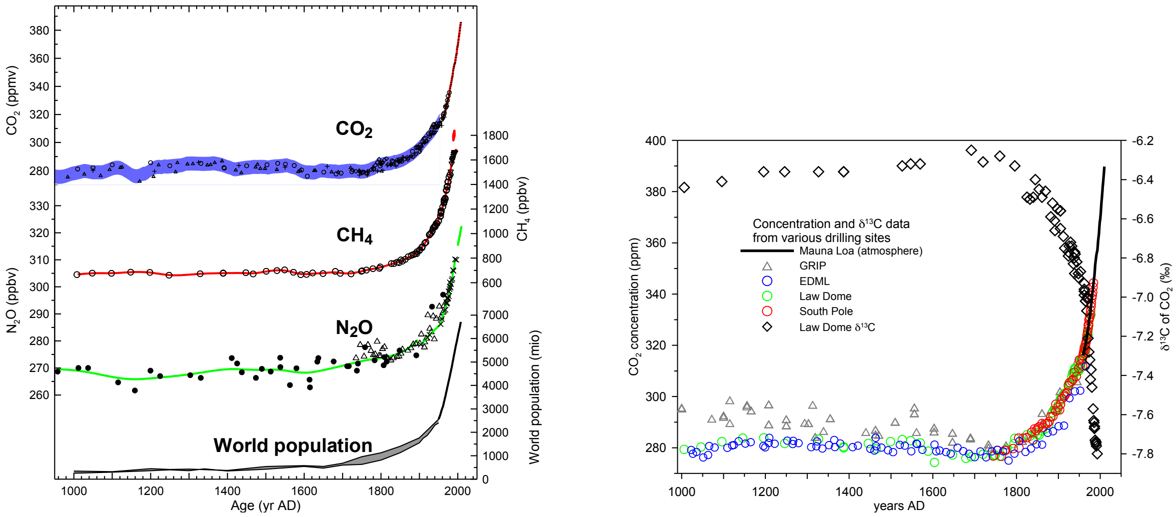


Figure 2: Left: CH_4 record from Law Dome, Antarctica, including firn measurements and direct atmospheric measurements (open triangles) from Cape Grim, Tasmania [*Etheridge et al.*, 1998]. N_2O measurements from ice cores [*Flückiger et al.*, 1999; *Machida et al.*, 1995] and firn air [*Battle et al.*, 1996]. CO2 data from Antarctic ice cores compiled by Barnola [1999]. The ice core measurements overlap with direct atmospheric measurements (solid line) [*Keeling and Whorf*, 2000]. World population [*McEvedy and Jones*, 1979].; Right: CO2 and $d^{13}C$ variations over the last 1000 years [*Etheridge et al.*, 1996; *Francey et al.*, 1998]

Longer timescales: Figure 3 shows the trace gas record over the last 800,000 years together with dD of H_2O, a proxy for the precipitation temperature. The vertical line to the right of the plot is the recent anthropogenic concentration increase. The natural band of concentrations over the last 800,000 years is 170 – 280 ppmv for CO2 and 350 – 700 ppbv for CH_4. The lower concentrations are associated with glacial conditions. CO2 concentrations are lower during glacial times mainly due to higher carbon storage in the deep ocean. In the case of CH_4, lower concentrations are mainly due to a decline in (boreal and tropical) wetland methane emissions. Generally there is a very high correlation between temperature and major trace gas content in the atmosphere. Essentially we find a linear relationship between the Antarctic temperature and the global CO2 record.

All major climate parameters show variations on the orbital frequencies. Globally only the eccentricity cycle 100,000 year cycle slightly changes the amount of incoming radiation. Precession and obliquity (20,000 and 40,000 years) affect the time during the year and the location energy is deposited on the globe. One might say that the cause of these climate changes is ultimately the Earth's orbit around the sun. However feedback mechanisms are necessary to translate the globally tiny variations into something like a glacial- interglacial change.

The climate system also experiences changes on time scales shorter than the orbital forcing. Those are internal to the climate system. In the northern hemisphere variations too short to be of orbital origin occur during the last glacial (Figure 3 inset), so called millennial scale oscillations. During that time both ocean and atmospheric circulation change and variations of climate parameters related to those events were termed Dansgaard-Oescher events and are found all over the world. Specifically the methane concentration is changing very much in parallel to the temperature oscillations found on top of the Greenland ice sheet. The reason is that changes in temperature and precipitation pattern affect methane emitting regions from the tropics to the high northern latitudes. Millennial scale oscillations are an intrinsic process of the present climate state. We find methane oscillations on millennial time scales during glacial times back to 800,000 years before present.

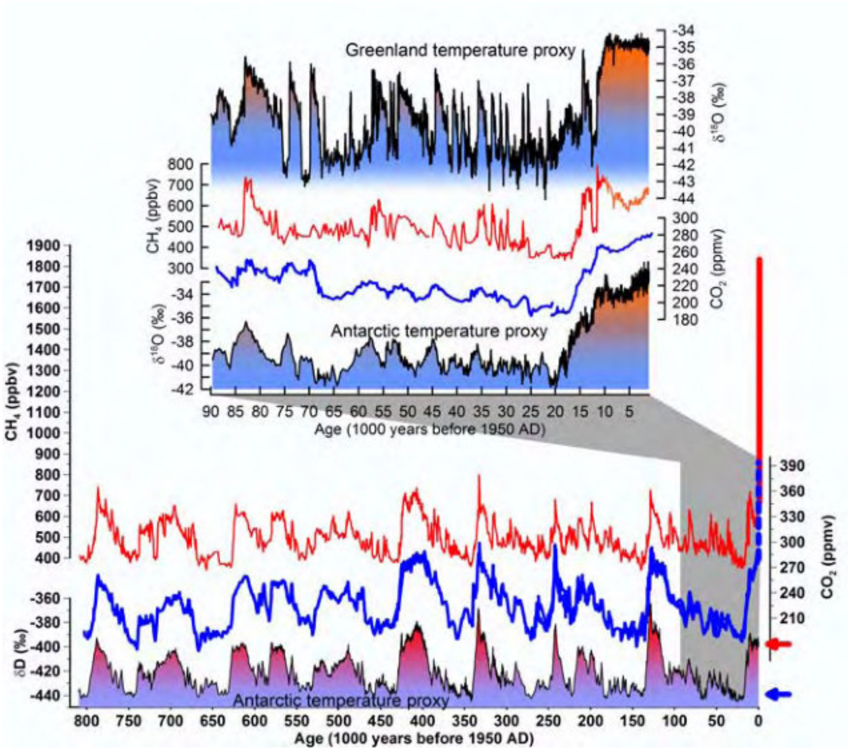


Figure 3: Main figure shows carbon dioxide and methane concentrations over the last 800,000 years from the Vostok and EPICA Dome C ice cores [Loulergue et al., 2008; Lüthi et al., 2008; Petit et al., 1999; Siegenthaler et al., 2005; Spahni et al., 2005] together with Antarctic dD of H_2O, a proxy for the local precipitation temperature. The vertical lines to the right of the plot show the recent anthropogenic increase. Blue and red arrows indicate levels of glacial and interglacial temperature in Antarctica, respectively.
The inset shows a zoom over the last 90,000 years adding a Greenland temperature proxy. [*Ahn and Brook*, 2008; *Blunier and Brook*, 2001; *Monnin et al.*, 2001]. $d^{18}O$ as dD of H_2O is a proxy for the local precipitation temperature.

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EDUCATION
1993: Engineer and master degree in fluid physics and energetics, Ecole Centrale de Paris.
1996: PhD in physics, Ecole Centrale de Paris.
2004: Habilitation to supervise scientific research, School of environment, Paris 6 University.

CAREER
1993-1996: PhD student, CEA/LMCE, Gif-sur-Yvette, paleoclimate modelling
Since 1996: scientist at LMCE (now LSCE), Gif-sur-Yvette, paleoclimate reconstructions from natural archives.
1998-2008: head of a research team working on continental paleoclimate.
2009- present: head of a research group (4 teams) working on past climate dynamics from natural archives.

RESEARCH INTERESTS
Quantification of past changes in climate and water cycle and mechanisms of climate changes. Relationships between water stable isotopes and climate based on modelling and present day monitoring data, in different areas (Greenland, Antarctica, Tibet). Climate reconstructions based on stable isotopes from ice cores and tree rings. Evaluation of climate models against paleoclimate data. Contributions of polar ice sheets to past sea level change.

PUBLICATIONS AND SERVICES
Co-author of about 150 peer-reviewed publications.
Co-author of several outreach books or book chapters in French and English for the general public and for children.
Member of steering committees of different international programmes focused on climate variability and on climate – cryosphere interactions.

AWARDS AND HONORS
Prix Etienne Roth (French Academy of Sciences) with FranÁoise Vimeux, 2002
Prix Louis D (Institute of France) with Jean Claude Duplessy, 2004
Descartes Prize (European Commission) with the EPICA project, 2008
Scientific excellence (University of Versailles), with my group, 2011
Felix of innovation (Ecole Centrale Paris), 2012
Prix Irëne Joliot Curie (Ministery of Research/Academy of sciences), woman scientist of the year 2013

Climate information from ice cores (part II)

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This extended abstract includes an introduction about the history of deep ice core drilling and the methodology used to retrieve temperature. It then provides a few key results of the IPCC AR5 report regarding past temperature changes over two timescales: the last millennium and glacial-interglacial changes.
Since the 1950s, numerous deep ice cores have been retrieved from polar ice sheets (Fig. 1). Efforts have been conducted in order to obtain both the oldest possible records, and to characterize the spatial variability. A first challenge has been to recover the oldest possible climatic records, allowing so far to reach 140,000 years back in time in Greenland (in the NEEM ice core) and 800,000 years in Antarctica (in the EPICA Dome C ice core). Older ice is known to exist in the deepest layers of central East Antarctica, which should in the future allow to extent the Antarctic climate records back to 1.2 million years ago. A second challenge lies in the characterization of regional climatic variations, thanks to the matrix of ice cores that have been obtained. This is motivated by the fact that past climatic changes involve reorganizations of ocean circulation, sea ice extent, and atmospheric circulation which leave different spatial fingerprints.

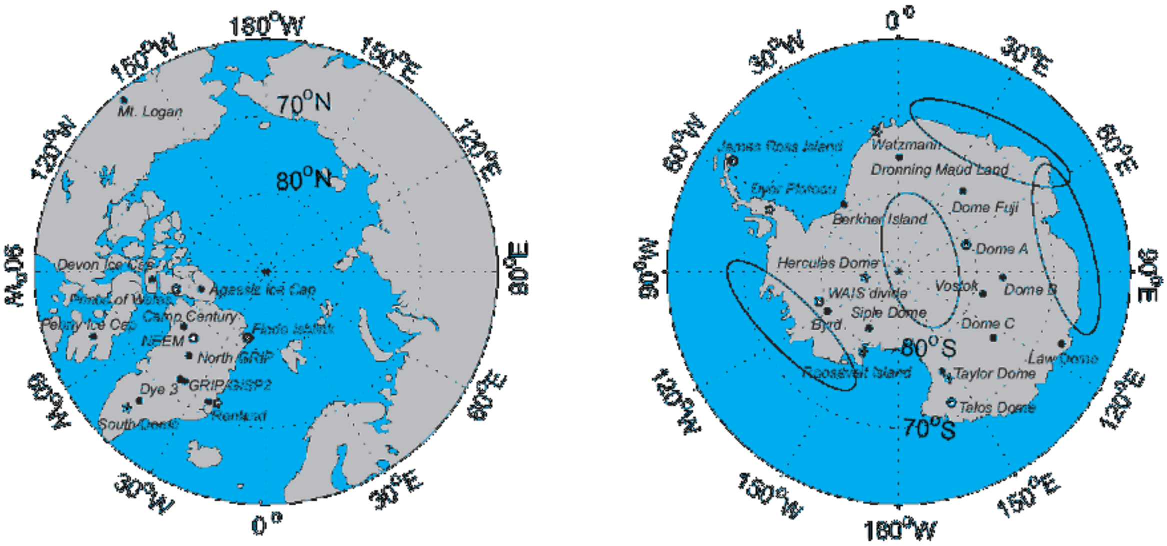


Figure 1. Map of the Arctic (left) and Antarctic (right) showing the location of deep ice cores covering tens of thousands of years. Filled circles indicate completed projects, open circles indicate recent or ongoing projects (e.g. NEEM, Dome A, WAIS) and stars indicate future projects. Large ovals (right) indicate poorly documented areas which should be explored for identifying suitable drilling sites.

Quantifying past climatic changes

Ice cores provide a wealth of climatic information related to local, regional and global climate. We will focus here on polar climate.
Several methods provide quantitative information on past changes in polar temperature, using three main tools. The first method takes advantage of physical processes relating changes in condensation

temperature to the ratio of heavy to light water molecules in polar precipitation ($HD^{16}O$/ $H_2{}^{16}O$, $H_2{}^{18}O$/ $H_2{}^{16}O$). These ratios are expressed in d units, expressed in ‰:

$$\delta^{18}O = \left(\frac{\left(\frac{H_2{}^{18}O}{H_2{}^{16}O}\right)_{sample}}{\left(\frac{H_2{}^{18}O}{H_2{}^{16}O}\right)_{mean\ ocean\ water}} - 1 \right) \times 1000$$

Accurate and continuous records of the isotopic composition of polar ice can be measured using mass spectrometers or more recently laser spectrometers.

Along the atmospheric water cycle, from evaporation at the ocean surface and during transportation to polar regions, air mass cooling leads to condensation. Due to fractionation processes related to each phase change, successive condensation leads to a gradual depletion of water vapour in heavy isotopes. Today, a linear relationship is observed between the spatial distribution of the isotopic composition of precipitation and temperature, providing the basis for an isotope thermometer. The application of this tool is however limited by processes which can alter this isotope thermometer such as changes in evaporation conditions (changes in moisture sources) or changes in deposition (seasonal timing of polar snowfall). Second-order parameters (deuterium excess and ^{17}O-excess) allow to characterize past changes in moisture sources and evaporation conditions (sea surface temperature, relative humidity at sea surface) and therefore to quantify their impacts on temperature reconstructions.

Alternative paleothermometry methods are available thanks to the measurements and inversion of borehole temperature profiles, and thanks to the impact of changes in firn temperature on the fractionation of gas molecules prior to their enclosure in air bubbles. The first method allows to estimate temperature trends during the last decades, the magnitude multi-centennial or multi-millennial changes. The second method mostly applies to Greenland and specifically to the quantification of abrupt temperature changes, leading to thermal fractionation of firn air. These alternative methods are used to calibrate past isotope-temperature relationships. Moreover, a growing number of regional and global atmospheric circulation models include the explicit simulation of the different water stable isotopes. Simulations of past climates also allow to identify the processes leading to changes in isotope-temperature relationships through time, both for Greenland and Antarctica.

Measurements of water stable isotopes also form the basis to estimate past changes in the annual snow accumulation (which is for central ice sheet locations the net result between precipitation and sublimation). For coastal Antarctic areas and Greenland, the identification of seasonal cycles in water stable isotopes and other ice core parameters forms the basis for annual layer counting which plays a key role for ice core chronologies over centuries to tens of thousand years. After deconvolution from layer thinning due to ice flow, measurements of layer thickness provide estimates of annual accumulation. In central Antarctica, accumulation is modeled based on the relationships between water stable isotopes, temperature, and saturation vapour pressure.

Understanding past climatic changes

Temperature reconstructions from ice cores are combined with temperature estimates from other natural archives (e.g. tree rings, deep sea sediment cores, lake sediments…) in order to provide a detailed spatio-temporal description of past regional to global temperature changes. Within the climate system, different processes act as feedbacks and therefore contribute to the response of the climate system to external perturbations on different time scales (Fig. 3).

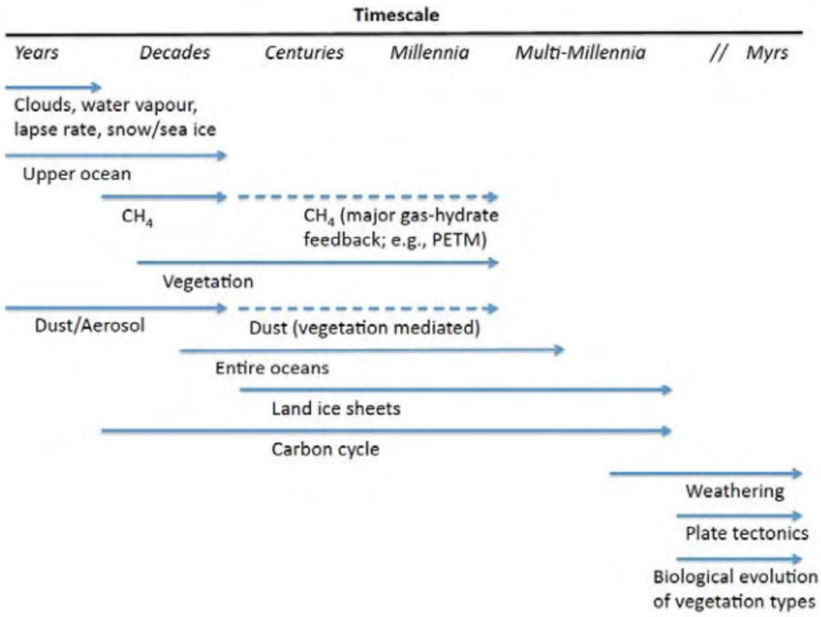


Figure 2. Timescales of climate feedbacks affecting the response of global mean surface temperature to radiative perturbations. From PALEOSENS (Nature, 2012).

During the last million years, when geological factors can be considered to be constant, the knowledge of external climate forcings (changes in incoming solar radiation due to changes in the astronomical configuration of the Earth's orbit; changes in solar and volcanic activity) and internal climate processes affecting the radiative fluxes (e.g. changes in atmospheric greenhouse gas composition and ice sheets), can be combined with temperature reconstructions in order to estimate climate sensitivity (that is, the response of global mean surface temperature to radiative forcing, translated to the climate response to a doubling of the atmospheric CO2 concentration).
Temperature reconstructions are also particularly important for processes involved in polar amplification, especially in the Arctic. They provide a benchmark against which the ability of climate models to qualitatively and quantitatively simulate past observed changes can be assessed. Long temperature estimates from ice core data and other natural archives provide a documentation of natural climate variability related to changes in ocean and atmospheric circulation, including sea ice extent. They have revealed the importance of abrupt changes in ocean circulation during glacial climates, and leading to a bipolar see-saw between Greenland and Antarctic climate. Finally, past changes in temperature at the surface of ice sheets is also related to changes in ice sheet thickness and therefore the contribution of Greenland or Antarctic ice sheets to sea level rise.
The following illustrations are extracted from the IPCC AR5 chapter on "information from paleoclimate archives" (chapter 5), and combine temperature reconstructions from ice cores and other archives, with results from simulations.

The last ~1000 years:
Figure 3 shows the first regional temperature reconstructions spanning the last 1000 years, together with climate simulations. We note a large long-term cooling trend in the Arctic, which is also recorded in Greenland ice core data, and attributed to the response of Arctic climate to the long term decrease in summer insolation, due to changes in the Earth's orbital parameters. Some of the centennial variations are captured by climate model simulations, showing that they are driven by external forcing (solar and volcanic forcing). Recent changes in Arctic surface temperature and sea ice extent (not shown), and in northern hemisphere mean surface temperature appear exceptional in a millennial context. Reconstructions of Antarctic climate show a much larger uncertainty.

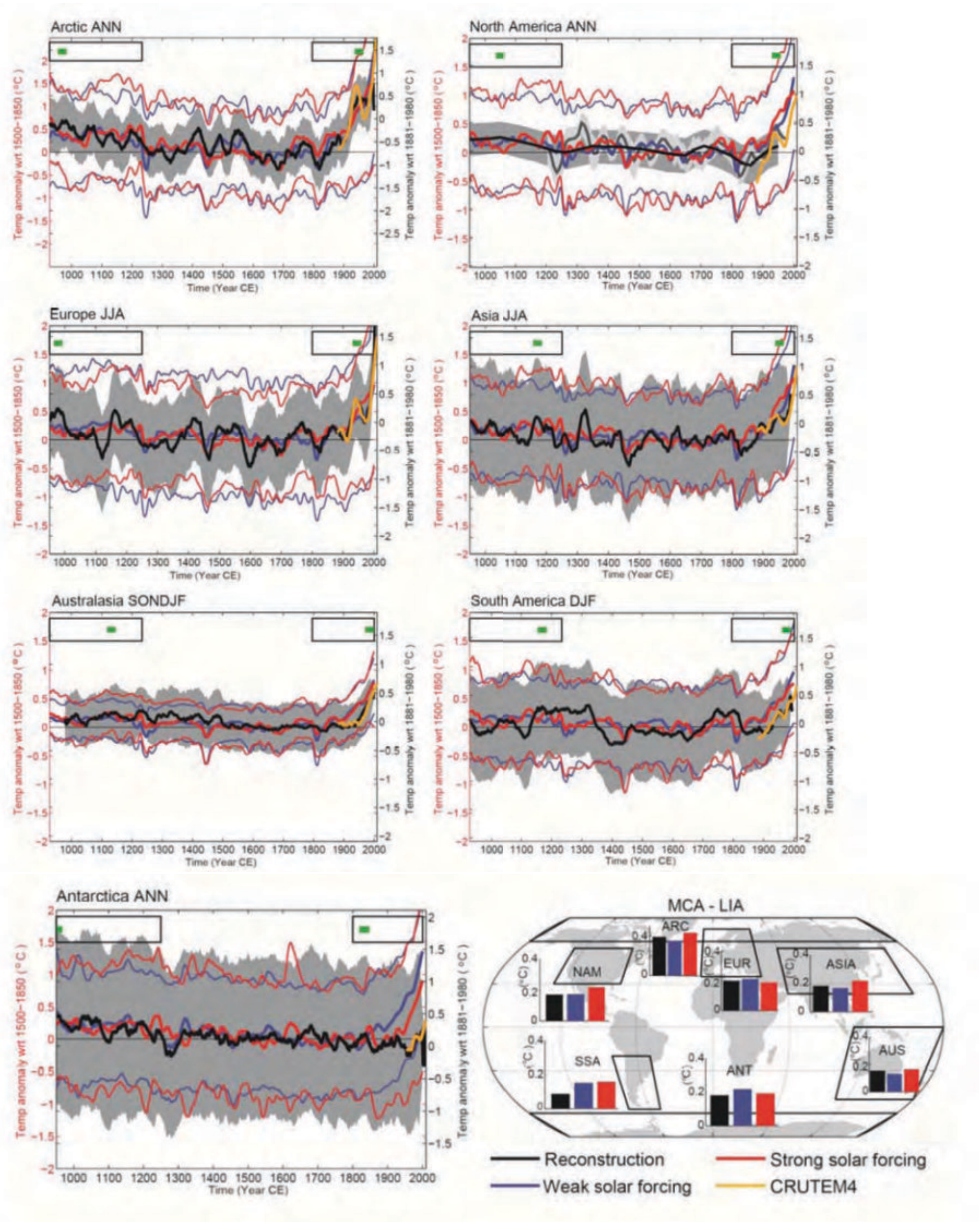


Figure 3. Comparison between temperature reconstructions for selected areas (black lines, grey shading indicating the associated uncertainty range) with simulations (multi-model average, with simulations conducted in response to weak or strong solar forcing) and instrumental temperature data (CRUTEM4, yellow). All datasets are smoothed using a 30 year running average. The green boxes in the upper lines indicate the warmest 30-year periods in the last centuries and during the medieval period. Different reconstructions are provided for different seasons (DJF, December-January-February; ANN, annual mean; JJA, June-July-August; SONDJF, September-February). In the map, bars show the reconstructed or simulated temperature changes between the Medieval Climate Anomaly (years 950 to 1250) and the Little Ice Age (period from 1450 to 1850). From IPCC AR5, Chapter 5.

Glacial-interglacial variations:

Figure 4 illustrates glacial-interglacial changes in Antarctic temperature (purple), based on an ensemble of ice core reconstructions. There is high confidence that changes in atmospheric CO2 concentration play an important role in glacial-interglacial cycles. While their primary driver lies in the seasonal and latitudinal distribution of incoming solar energy due to changes in the geometry of the Earth's orbit around the Sun, reconstructions and simulations show that the full magnitude of glacial-interglacial temperature and sea level (ice volume) changes cannot be explained without accounting for changes in atmospheric CO2 content and associated climate feedbacks.

During the last deglaciation, global mean temperature increased by 3 to 8°C. The mean rate of global warming was 0.3°C to 0.8°C per thousand years, with two periods marked by faster global warming, estimated at 1 to 1.5°C per thousand years, although regionally and on shorter time scales, higher rates have occurred.

In Antarctica, glacial cooling is associated with a larger magnitude (8 to 10°C), which is captured by glacial climate simulations. In Antarctica, the warmest temperatures were encountered during two past interglacial periods, including the last interglacial period about 130,000 to 115,000 years ago. The next section focuses specifically on this period.

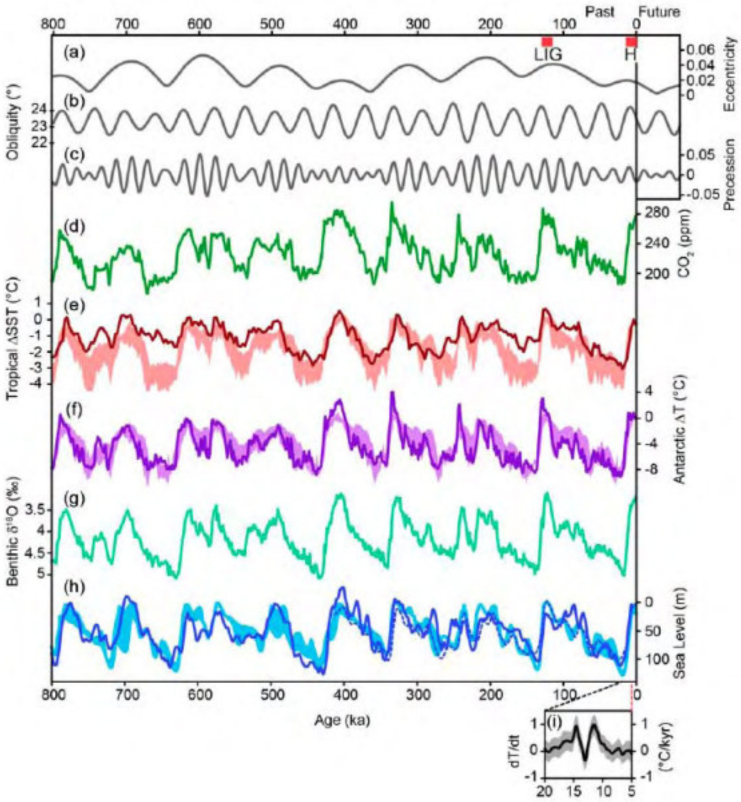
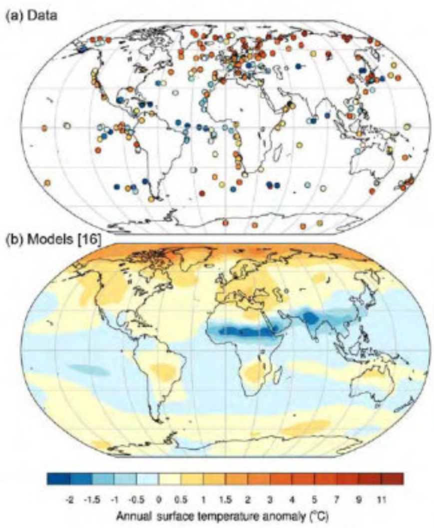


Figure 4. For the past 800,000 years, changes in the Earth's orbital parameters (eccentricity, obliquity and precession) together with changes in atmospheric CO2 concentration, tropical sea surface temperature, Antarctic temperature, deep sea sediment benthic foraminifera isotopic composition and inferred changes in sea level. Lines represent reconstructions from natural archives; shaded areas display ensemble of climate simulations. The lower insert shows the rate of global temperature change during the last deglaciation, estimated from a synthesis of paleoclimatic reconstructions. From IPCC AR5, Chapter 5.

Last interglacial climate and sea level:

Figure 5 illustrates reconstructed and simulated temperature changes during the last interglacial period (about 125,000 years ago). This period is marked by greenhouse gas concentrations close to pre-industrial values, but large changes in the orbital configuration of the Earth's orbit around the Sun (Figure 4). Changes in the Earth's obliquity induce reduced annual mean insolation in low latitudes, and increased annual mean insolation at high latitudes. Changes in the orbit's eccentricity and orbital precession induce a higher summer insolation in the northern hemisphere. Both reconstructions and simulations show temperature patterns due to these changes in insolation, such as cooler sea surface temperatures in several tropical areas and warmer sea surface and surface air temperatures in mid and high latitudes of the northern hemisphere. Greenland temperature estimates from the NEEM ice core suggest peak warming of more than 4°C above pre-industrial for several millennia. Antarctic temperature estimates show an earlier peak warming of at least 5°C and multi-millennial warming at least 2°C above pre-industrial. The Greenland warming simulated by climate models is smaller than reconstructed, possibly because feedbacks due to changes in boreal vegetation and Greenland topography are not taken into account. In response to orbital forcing, climate models do not capture the magnitude of the reconstructed Antarctic warming. Current works investigate the roles of changes in global ocean circulation and changes in Antarctic ice sheet topography. Altgother, it is estimated that global mean temperature was within 2°C of pre-industrial temperature, during the warmest millennia of the last interglacial period (as for the current interglacial period).

During the last interglacial period, the maximum global mean sea level was at least 5 m higher than present, and less than 10 m above present; the current best estimate is at 6 m above present level. Based on ice sheet model simulations consistent with elevation changes inferred from the NEEM ice core, the Greenland ice sheet very likely contributed between 1.4 and 4.3 m sea level equivalent, implying a contribution from the Antarctic ice sheet. The ice core data therefore also allow to place constraints on past ice sheet response to climate change. The state of the West Antarctic ice sheet during this period remains undocumented. Based on differences between different ice core records of East Antarctica (between Talos Dome and Dome C), changes in the topography of some coastal areas of East Antarctica cannot be excluded.



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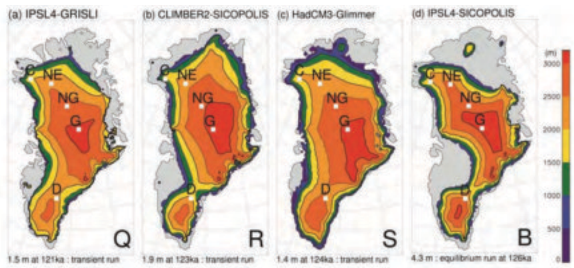

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Figure 5. For the past 800,000 years, changes in the Earth's orbital parameters (eccentricity, obliquity and precession) together with changes in atmospheric CO2 concentration, tropical sea surface temperature, Antarctic temperature, deep sea sediment benthic foraminifera isotopic composition and inferred changes in sea level. Lines represent reconstructions from natural archives; shaded areas display ensemble of climate simulations. The lower insert shows the rate of global temperature change during the last deglaciation, estimated from a synthesis of paleoclimatic reconstructions. From IPCC AR5, Chapter 5.

Take-home messages:
Polar ice cores offer a wealth of information on past climate, past changes in atmospheric composition, past climate forcings (e.g. volcanic and solar activity). When combined with climate information obtained from archives, a global picture of the magnitude and structure of past temperature changes is emerging, throughout different time scales. This local, regional and global picture allows to test the ability of climate and ice sheet models to resolve the key mechanisms at play, in response to external perturbations or arising from internal climate variability. These information also allow to place current or projected changes in the broader perspective of past climate dynamics.

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Web sites and books about ice core studies:

- *NEEM Greenland deep drilling: neem.dk*
- *PAGES (Past Global Changes)/ IPICS (International Partnership for Ice Core Science) www.pages-igbp.org/ipics*
- Antarctica, Global Science from a Frozen Continent, D. Walton, Cambridge U. Press, Cambridge, 2013 (352 pages)
- The white planet: the future of our frozen world, J. Jouzel, C. Lorius et D. Raynaud, Princeton University Press, 2013 (336 pages)
- IPCC AR5, chapter 5 (paleoclimate) : www.climatechange2013.org

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EDUCATION

B.Sc. and M.Sc. from the University of the Philippines
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Post-Doc at GEOMAR, Kiel, Germany

CAREER

Sally Soria-Dengg was awarded her Bachelor and Master of Science in Zoology from the University of the Philippines in Quezon City. While doing her Masters thesis, she taught undergraduate courses in Vertebrate Anatomy and Physiology at the same university. After her Masters studies she went to Germany to pursue doctoral studies on a scholarship grant from the Konrad-Adenauer-Foundation. She received her Ph.D. in Marine Biology from the Christian-Albrechts University in Kiel with a dissertation on the heavy metal uptake of mussels and oysters. After her Ph.D. she returned to her old university in the Philippines where she continued research on toxicity of metals on juvenile mussels and on seagrass. While there she also taught graduate and undergraduate courses on marine science. After one and a half years she went back to Kiel to work at the then Leibniz Institut für Meereskunde, now GEOMAR Helmholtz Centre for Ocean Research Kiel. She did research on the uptake of iron by marine phytoplankton focusing on the role of bacterial siderophores as iron carriers and on phytoplankton-bacteria interactions.
In 1995 she went to the USA and did some research work at the Princeton University. She returned to Germany in 1997 and devoted her time to her two daughters. She resumed her career going into an entirely different field. She is now involved in the school co-operations programme of GEOMAR, acting as a conduit between research and schools in Kiel and neighbouring towns. She worked as the regional coordinator for Kiel in the EU-funded CarboSchools project, where she designed and tested experiments on climate change and ocean acidification for pupils. Presently, she coordinates the school projects of the Collaborative Research Centres, SFB 574 and 754, at GEOMAR dealing with “Volatiles and Fluids in Subduction Zones” and “Climate - Biogeochemistry Interactions in the Tropical Ocean“, respectively. Sally gives teacher-training courses in Kiel and suburbs regularly and has also classroom experience through the different after-school courses she offers for interested and motivated pupils. She organises and teaches in summer schools on different marine science topics for pupils in the upper level secondary schools. She also supervises different group and individual research projects of pupils and has initiated and taken part in international teacher and school co-operations.

Some Experiments on Ocean Acidification and the Role of the Ocean in the Carbon Cycle

Sally Soria-Dengg
GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany

Five experiments concerning the effects of increased atmospheric carbon dioxide on the oceans and an activity showing a quick way to construct a solar cooker will be introduced in the workshop. Most of the experiments are described in a brochure each participant will receive. A lesson plan about the carbon cycle where the experiments are integrated can be found in Soria-Dengg and Jamous (2010).

Experiment 1: How do gases (CO2) get into the ocean?
With this simple experiment the diffusion of CO2 into the water from the atmosphere is demonstrated. The pupils will see that this process occurs at the air-water interface and without vertical mixing, dissolved CO2 remains only on the surface of the water. The experiment will be demonstrated using salad bowls and floating candles, materials which can be easily bought from the supermarket. The diffusion of CO2 from the air to the water is made visible by using a universal indicator to show the acidification of the water surface. Below is a description of the experiment in pictures (Figure 1-3):

Figure 1. Lighted floating candles are placed in a bowl filled with distilled water with an indicator solution (green- basic; yellow-acidic). The bowl is covered with another bowl with the same diameter.

Figure 2. The burning candles release CO2 inside the bowl. After some minutes the candles burn out. Take note of the colour of the water at the surface!

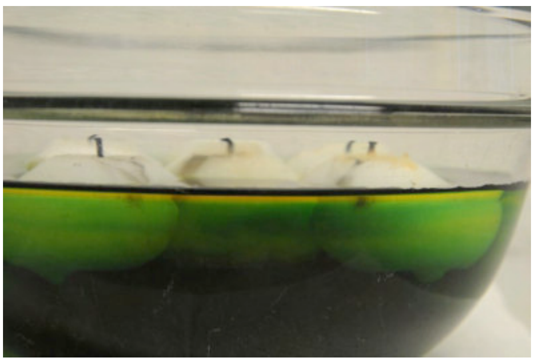

Figure 3. The surface of the water in contact with the air turns yellow, indicating acidification. This layer stays on the surface as long as no mixing occurs.

Experiment 2: How does temperature affect the solubility of gases in liquids?
One of the more relevant factors which influences the solubility of gases is temperature. Gases dissolve better in water at lower than at higher temperatures. This is true for both carbon dioxide and for oxygen. Oceans at higher latitudes have a higher capacity to dissolve gases and this capacity decreases as one nears the equator, where even degassing may occur. In Figure 4 the parts of the world oceans, which act as sinks or sources of CO2 is shown.

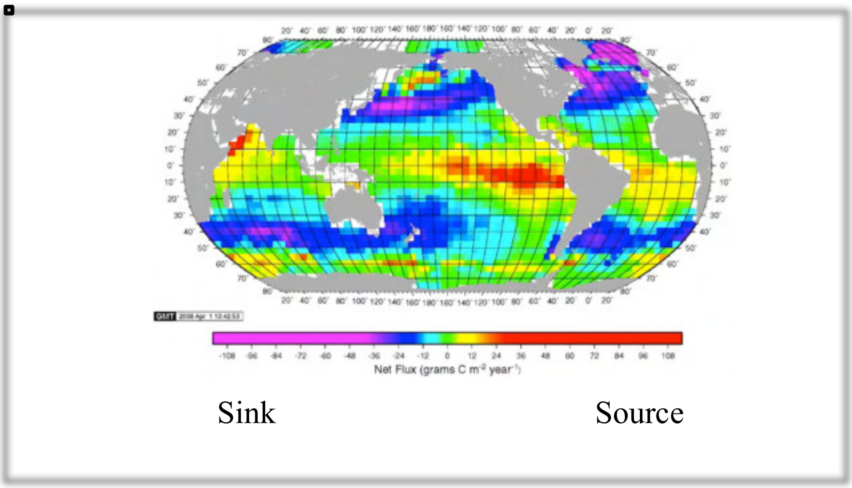

Figure 4
Sea-air CO2 flux in the world oceans (source: Takahashi et.al. 2009)

Ocean CO2 "sinks" are the regions where the CO2 are taken up by the ocean and subsequently transported to the deep, thus effectively removing CO2 from the atmosphere. CO2 "sources" are regions where CO2 is released from the ocean into the atmosphere.

In the following experiment, the volume of carbon dioxide generated by a fizz tablet in warm and cold water is compared. A fizz tablet dissolved in water releases CO2. A given volume of warm water given to a graduated cylinder is more easily saturated with CO2 than the same volume of cold water. Once water is saturated with gas, the excess escapes to the overlying air. Using this principle, the following experiment demonstrates how temperature affects the solubility of gases (Figure 5).

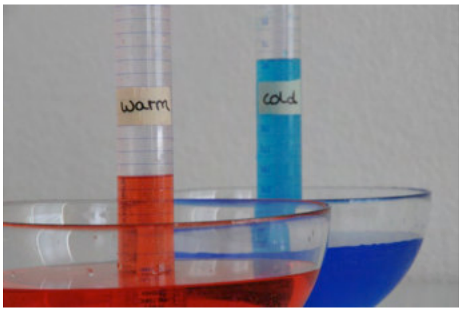

Figure 5. Experimental set-up demonstrating how temperature affects the solubility of gases

Experiment 3: How do the oceans act as a sink for CO2?
In the first experiment it was shown that CO2 from the atmosphere dissolves only in the water surface and that it stays there if no mixing occurs. According to Henry's Law at a given constant temperature, the solubility of a gas in a liquid is directly proportional to the partial pressure of the gas above the liquid. That means that after sometime, the concentration of

CO_2 in the water will equilibrate with that in the air. If that is the case, then the ocean will not be capable of taking up more CO_2 from the atmosphere once equilibrium is attained. However, this is not the case. There are processes in the ocean, which ensure that the CO_2 taken up in the surface is transported to the deep. This is mainly attained by thermal convection, where in specific parts of the oceans CO_2-rich surface waters are transported down. Once the CO_2 is removed from the surface, it is temporarily stored in the ocean (for a period of at least a thousand years), effectively removing this CO_2 from the atmosphere, thus it is a sink for CO_2. However, there are some areas in the oceans where the CO_2-rich bottom waters resurface, and because they have a higher concentration of CO_2 that the atmosphere and because of prevailing temperatures, these areas become “sources” of CO_2 (Figure 4).

In this experiment, the mechanism how CO_2 is transported to the deep by convection will be demonstrated. Carbon dioxide is generated in a test tube connected to another test tube containing water with indicator solution (Figure 6). The CO_2 produced in the right test tube is

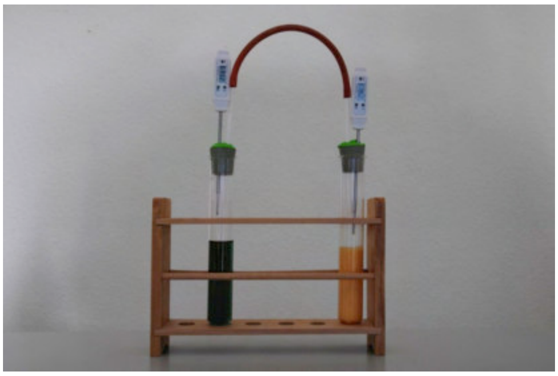

Figure 6. CO_2 is generated in the right test tube and transferred to the left, which contains water with an indicator solution.

transferred to the left. The amount of CO_2 produced in the right test tube can be dosed, so that this experiment can also be used to demonstrate how the ocean reacts to increasing CO_2 concentrations in the atmosphere. Once the CO_2 is dissolved in the surface of the water, it is cooled with ice cubes to show how convection occurs and how the CO_2-rich water is transported to the bottom of the test tube (Figure 7).

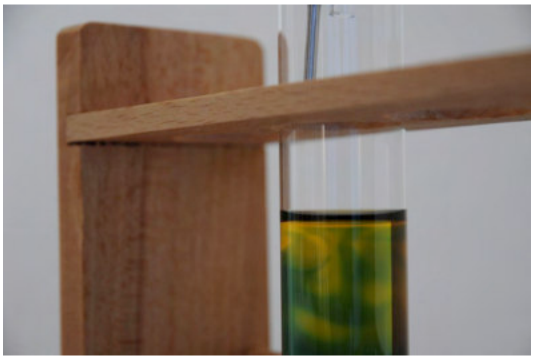

Figure 7. The CO_2-rich surface water starts to be transported to the bottom of the test tube after cooling.

Experiment 4: Where have all the ice gone?

Due to increasing atmospheric temperatures the polar ice caps have started to melt. A very dramatic evidence of this is the decreasing size of the arctic ice and the melting glaciers in Greenland. In this experiment, the pupils will see how the melting of the ice leads to a pronounced layering of the ocean, which in turn affects the transport of gases to the deep, consequently influencing the capacity of the ocean to act as a sink for carbon dioxide as well as how the oxygenation of the oceans occur.

This experiment starts as a guessing game for the pupils. Ice cubes will be allowed to melt in beakers containing saltwater and tap water (Figure 8. left). The pupils will be asked to guess in which beaker the ice cube will melt faster. The ice cube in the beaker with tap water melts faster (Figure 8, right). The experiment is then repeated using either coloured ice cubes or coloured seawater or tap water in the beakers. After the ice has melted, the students will see a layer of fresh water in top of the seawater (Figure 9) and conversely, no such layer in the beaker containing tap water.

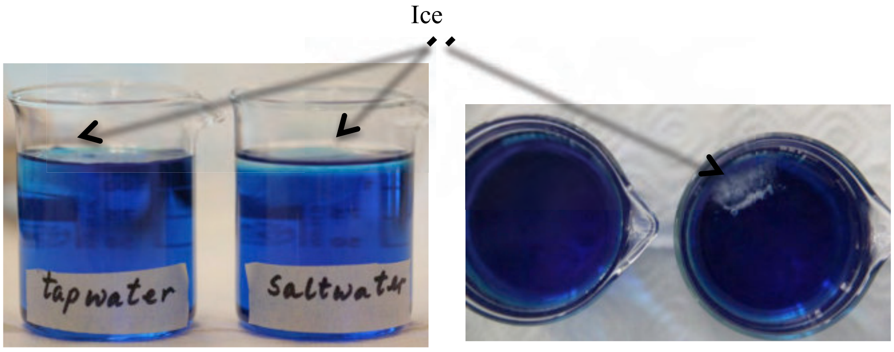

Figure 8. Ice cubes are allowed to melt in beakers containing tap water and seawater (left). The ice cube melts faster in the beaker with tapwater (right).

Figure 9. In the beaker containing saltwater, the melt water forms a thin layer on the surface.

If one observes closely and if coloured ice cube is used in uncoloured water, the cold melt water from the ice cube in the beaker containing tap water sinks to the bottom. This is due to the higher density of cold water. The cold melt water mixes with the surrounding warmer water, so the ice cube here melts faster. In the beaker with saltwater, the cold melt water stays in the surface, so that the ice cube melts slower.

The melting of the ice caps and of the Greenland ice leads to the formation of a diluted less dense layer of water which floats on the surface of the ocean. This results to a decreased capacity of the ocean to transport dissolved CO2 to the deep. This is reinforced further by increasing atmospheric temperatures causing warming of the oceans surface and further decreasing the density of the surface water. It should be noted that not only the transport of CO2 to deeper waters is affected but also of other gases especially oxygen leading to de-oxygenation of the oceans (Keeling, et. al. 2010).

Experiment 5: Around the world in a thousand years

The part of the ocean circulation patterns, which is driven by density gradients resulting from temperature (thermo) and salinity (haline) differences, is called the thermohaline circulation.

This is also termed as the global conveyor belt. This is responsible for the exchange of energy and materials including gases between the different ocean basins. In the following experiment, the thermohaline circulation, specifically the Gulf Stream, will be simulated using a 2-D tank model (Figure 10). On its way to the north, the Gulf Stream transports warm salty waters from the subtropics to the sub-polar regions of the Greenland and Labrador seas. When it reaches these regions, the Gulf Stream is cooled thus increasing in density. It sinks to the bottom and then flows southwards. A detailed description of the experiment can be found in the link below.

Figure 10. Simulating the Gulf Stream with a 2-D tank model. The left side of the tank represents the subtropics and the left side the sub-polar regions. The left side is cooled with ice due to decreased density the Gulf Stream (blue water) sinks to the bottom.

Activity: Constructing a solar cooker in 1 minute

This is a fun activity which teachers can do with their pupils, like staging a lunch cook-out in the school. A solar cooker is easily constructed and can be set-up in a matter of minutes. The solar cooker consists of a windshield sunshade available for a couple of Euros from department stores, a cake rack, a black pot and a transparent plastic bag. The windshield sunshade is shaped into a funnel and placed on a garden chair or on the ground facing the sun. The food is prepared by placing all ingredients in the black pot (with or without the addition of water depending on the recipe). The pot is covered and placed inside the transparent plastic bag on top of the cake rack (Figure 11). This is then placed in the sunshade and can be left unattended for the duration of the cooking period. Depending on where you are in Europe, the solar cooker may have to be turned towards the sun every once in a while. The duration of cooking depends on the intensity of the sun.

Figure 11. Different models of solar cookers used in a school lunch cook-out.

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Links:

1. detailed descriptions for the experiments can be found here:

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2. a detailed description of the tank experiment on Gulf Stream simulation

ftp://ftp.geomar.de/downloads/NaT/Dokumente/ExpDescriptionGulfStream.pdf

3. more experiments on the carbon cycle from the CarboSchools project can be found here:

http://www.carboeurope.org/education/libraryHome.php

4. recipes for the solar cooker can be found in the internet

Dr. Francesca Ugolini
Institute of Biometeorology-CNR (Italy)
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EDUCATION

She graduated in Forestry and Environmental Sciences with honours in 2003, at the University of Florence.

In 2004-05 she attended the Professional Master in Geomatics and Natural Resources Evaluation at the Istituto Agronomico per l'Oltremare, Ministry of Foreign Affairs.

In 2013 she got the PhD at the School 'Ubaldo Montelatici' (Faculty of Agriculture, University of Florence), investigating the physiological effects of deficit irrigation on two ornamental species at nursery stage.

CAREER

Since 2007 she works at the Institute of Biometeorology of CNR (Italian National Research Council). She works on carbon balance and greenhouse gas fluxes in natural ecosystems (grasslands) and on plant physiology. Since 2008, she has been also working on science dissemination projects that involve secondary schools in inquiry science projects (Carboschools, Teacher Scientist Partnership, Acariss). These projects aim to connect research laboratories with experiences at school.

RESEARCH INTERESTS

She is interested in studying plant response mechanisms to stressful environmental conditions. She's also interested in exchanging experiences and methodologies in the field of science dissemination, due to the belief that the scientist's commitment toward civil society is to transmit new knowledge.

PUBLICATIONS AND SERVICES

Ugolini F., Massetti L. 2013. Teaching the carbon cycle using IBL in the secondary schools. In: Dincer I. Colpan C.O., Kadioglu F. (Eds.) Causes, Impacts and Solutions to Global Warming - 2013, XII, 942 Springer. p. 472. ISBN 978-1-4614-7588-0.

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Ugolini F., Tognetti R., Bussotti F., Raschi A., Ennos A.R. Wood hydraulic and mechanical properties induced by low water availability on two ornamental species *Photinia x fraseri* var. Red Robin and *Viburnum opulus* L. Urban Forestry & Urban Greening. (in press).

AWARDS AND HONORS

2003. Degree with honour in Forestry and Environmental Sciences at the University of Florence.

2013. Winner of a Short Term Student Mobility under the European Cost Action 1204, for the proposal to investigate the knowledge transfer and collaboration between researchers and other stakeholders of green infrastructure.

The Carbon Cycle Through The 5e Model: Game And Experiment

Francesca Ugolini
CNR-IBIMET, Firenze, Italy

In this laboratory we introduce carbon cycle to teachers through a methodological teaching approach of Inquiry Based Learning: the 5E Instructional Model. The Instructional Model articulates the lessons in five steps or 'E':

1E. Engagement: initiates the learning process and exposes students' current conceptions.
2E. Exploration: students gain experience with phenomena or events.
3E. Explanation: the teacher may give an explanation to guide students toward a deeper understanding.
4E. Elaboration: students apply their understanding in new situations or contexts.
5E. Evaluation: student understanding is assessed.

This model has been developed and tested by the Biological Science Curriculum Study in the United States (Bybee et al., 2006) and was also applied by a sample of Italian teachers in almost 70 classes in Tuscany through the Acariss project. In there, the model was the guideline of structured didactic modules on environmental issues. It approaches pupils in a way that stimulates curiosity and investigation spirit, afterwards experimental activities are carried out to reproduce a phenomenon discussed or to deepen curiosity and to find explanations. Hands-on activities are generally very much appreciated by the students, as the former European project Carboschools documented (Carboschools consortium, 2010), therefore, a structured teaching plan might be highly worthy and useful for teachers who are not used to inquiry. The Italian pilot test of the 5E Instructional Model was successful in students, stimulating a positive attitude towards science, higher career decision-making self-efficacy (Di Fabio et al., in press), but also it obtained a positive evaluation on effectiveness by teachers (Ugolini et al., in press). The 5E Instructional model enables teachers to guide the class to questioning and experimenting when concepts come out.

This laboratory will present the methodology of the 5E Instructional Model on the matter of the carbon cycle. The activities proposed for each step will be presented and then discussed with participants.

Learning more about the Carbon Cycle is of great importance for it is a central issue necessary for understanding climate change. Carbon atom can link with other carbon atoms but also with other molecules, forming compounds of diverse forms, present everywhere on Earth, in all spheres (atmosphere, hydrosphere, lithosphere, biosphere). Moreover, molecules and substances can be transformed or degraded so that carbon atoms can move from one sphere to another.

1st E: Engagement (30 minutes)

The first part of the module engages the participants in the game 'the incredible journey through the carbon cycle' (Burnes, 2010).

The game involves the whole class: players (~30, even more) play the role of carbon atoms while the classroom corners represent the four Earth spheres. The game has a duration of about 15 minutes.

Firstly, players are divided into 4 groups (spheres) and each is assigned a corner of the room. The number of atoms is equal in each group. Each sphere has its own die which represents the probability of the carbon atom to sink or to move into another sphere. On each die face, a command and its motivation are described.

The game starts and players simultaneously roll their die and perform the command.

After 15 minutes, the game stops and discussion begins after having noted the number of atoms in each sphere.

Afterwards, one of the carbon movements from one sphere to another is reproduced in experimental way.

2^{nd} E: Exploration (30 minutes)

Atmosphere and biosphere. Carbon is in the atmosphere as molecule of carbon dioxide, methane, other volatile molecules. On the other hand, biosphere is the sphere of all living organisms.

The atmospheric concentration of carbon dioxide changes with location: environmental features, living organisms, anthropogenic activities etc. How much do living organisms affect the atmospheric concentration of carbon dioxide? How much carbon moves from the atmosphere to the biosphere?

A gas analyzer for carbon dioxide will be used in the experimental phase whose aim is to demonstrate respiration by living organisms and photosynthesis.

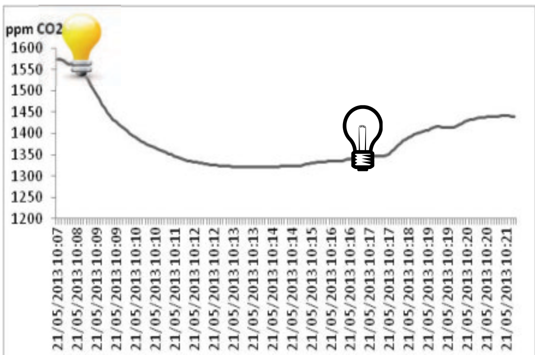
A small plant is placed in a simple greenhouse connected to the gas analyzer. Then, the system is exposed to sunlight (or artificial light) and carbon dioxide starts to be detected by the device. Values are recorded for 15 minutes afterwards nighttime is reproduced. Carbon dioxide values are recorded.

This experiment allows also to note inconsistencies due to environmental stress factors, so that some tips and explanations on the plant photosynthesizing capacity will be given.

The process is observed in real time and real measurements are taken and elaborated.

3^{rd} E: Explanation (20 minutes)

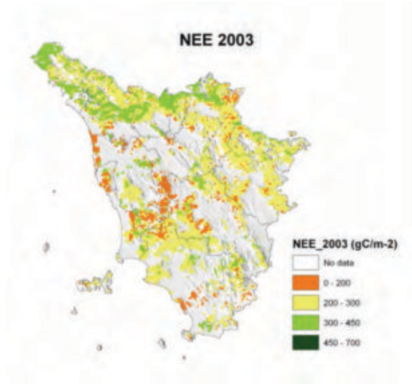
In this phase the data are elaborated and the results explained. The relation between variables involved in the experiment is discussed especially when data trends are different than expected.

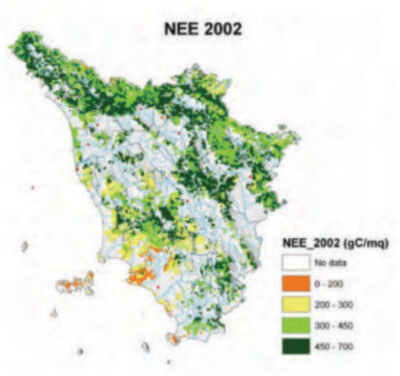


4th E: Elaboration (10 minutes)

In this phase the concepts raised during the previous phases are extended. The closed system of the experiment is compared to a terrestrial ecosystem (woodland, orchard, grassland etc.). Therefore, how does it happen in nature?

In nature the ecosystems can either be sinks or sources of carbon depending on their capacity to store. This depends not only on the type of soil cover but also on the photosynthesizing capacity of the species, which is connected to the climate conditions and its variations. So far, carbon fluxes have been monitored in several ecosystems in order to evaluate their carbon storage capacity. Some results from the latest national and European projects will be shown.





5th E: Evaluation (10 minutes)

Open discussion about teachers' evaluation on knowledge transfer and student's skills (field work, responsibility in carrying on the activities, data elaboration, ability to synthesize and present the work).

Final Discussion (20 minutes)

REFERENCES

Bybee, R.W., Taylor, J.A., Gardner, A., Van Scotter, P., Carlson Powell, J., Westbrook, A., Landes, N., 2006. The BSCS 5E Instructional Model: Origins and Effectiveness, BSCS Colorado Springs.

Burnes, R. The incredible journey: a trip through the carbon cycle. NAAEE's 39th Annual Conference. 7th Annual research symposium. September 29 - October 2, 2010. Buffalo-Niagara, New York.

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Di Fabio A., Palazzeschi L., Ugolini F., Massetti L., Cecchi F., Buselli E., Francini A., Minnocci A., Lanini M., Pellegrino L., Rossini G., Screti C., Tagliaferri G., Sebastiani L., Raschi A. (in press). Evaluation of the effectiveness of ACARISS project: New perspectives for developing talents in the field of science. Proceedings of the International Workshop "Science Education and Guidance in schools: the way forward". 21-22 October 2013, Florence, Italy.

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Dr. Francesco Sarti
PhD, Scientific Coordinator of the Education
and Training Activities
Directorate of Earth Observation Programmes
ESA/ESRIN
V.Galileo Galilei, C.P. 64
00044 Frascati (Italy)

After his Master Degree in Electrical Engineering at the University of Rome *La Sapienza*, he was hired in 1990 at the Operation Center of the European Space Agency in Germany (ESA/ESOC) in the area of mission analysis and orbit control manoeuvre optimization. He then moved to precise orbit determination and to orbit and attitude control and continued his career at ESA/ESTEC in The Netherlands.

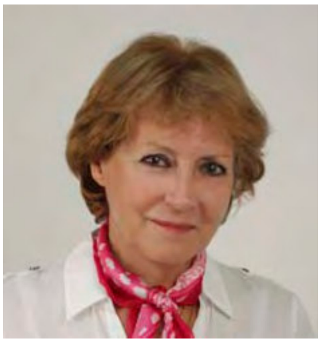
He moved to Toulouse, France, in 1997, where he got a Post-graduate Master in Applied Remote Sensing and Image Processing followed by a PhD on the subject of optical-radar remote sensing for the monitoring of surface deformation (University of Toulouse *Paul Sabatier*). In France, he was first employed by CESBIO (1998) and later by CNES (1999-2001), working as a Project Manager for the *International Charter on Space and Major Disasters*, conducting R&D activities for remote sensing applications to disaster management and natural risk monitoring, interferometric monitoring of several seismic areas and providing training courses in Earth Observation.

After a short period at Italian Space Agency (2001) as a technical interface ASICNES for the cooperation COSMO-SkyMed / Pléiades, he joined ESA/ESRIN, in Italy, working in Earth Observation applications; since 2007, he coordinates the Education and Training Activities in Earth Observation. In his spare time (unfortunately not much) he enjoys painting, playing piano and open-air sport like swimming and kayaking.

Space for Climate:
Overview of ESA Earth Observation Missions and Exploitation Programmes

Francesco Sarti & Pierre-Philippe Mathieu
ESA-ESRIN, Frascati (Italy)

Europe's capability for monitoring of our global environment from space is rapidly expanding. The European Space Agency (ESA) is developing a wealth of new Earth Observation (EO) missions. This includes a series of Earth Explorer missions (e.g. GOCE, SMOS, Cryosat-2 recently launched, and Swarm, ADM-Aeolus, EarthCARE) addressing specific scientific issues in global change research, the new generation of geostationary and polar Meteorological missions (e.g. MSG-2/3, MTG & EPS) in joint undertaking with EUMETSAT, as well as a family of 5 Sentinel missions responding to European policy needs within the framework of the Global Monitoring for Environment & Security (GMES) programme in partnership with the European Commission (EC). This expanding EO capability, capitalizing on 30+ years of investment in the space sector, will ensure the continuity of long-term high-quality records of environmental and meteorological data, which have been gathered in Europe through a variety of missions, including for example Envisat (since 2002), ERS (since 1991), and the family of meteorological satellites (since 1977). These European EO missions, in full synergy with national missions, provide Europe with a very powerful tool to contribute to the monitoring of climate system at the global scale, thereby paving the way towards a new ESA programme referred as the "Climate Change Initiative" (CCI). This presentation will describe in more details the "Climate Change Initiative" (CCI) programme, which aims to "systematically generate, preserve and give access to long-term data sets of some of the Essential Climate Variables (ECVs) required to meet the needs of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC)". In particular, this talk will discuss the opportunities of the programme, how it can foster interactions between EO data communities and climate research communities, and provide the foundation for climate science, modelling and also climate services. Finally, it will discuss some of the specific challenges it raises for the EO community in order to generate accurate and stable long-term climate data records (e.g. issue of error characterization, validation, quality assessment) and accelerate their uptake in climate models.



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Laboratoire d'Etudes en Géophysique et Océanographie Spatiale (LEGOS)
Centre National d'Etudes Spatiales
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EDUCATION

1975: Ph.D Thesis (Doctorat d'Etat) in Geophysics - University of Toulouse

CARRER

Director for Earth Sciences at the International Space Science Institute (ISSI), Bern, Switzerland.
Invited professor at the Collège de France, 2012-2013, annual chair 'Developpement Durable- Environnement, Energie et Société'.
Senior Scientist at the 'Laboratoire d'Etudes en Géophysique et Océanographie Spatiale' (LEGOS), Centre National d'Etudes Spatiales (CNES), Toulouse, France.
Head of the group 'Geophysique, Océanographie et Hydrologie Spatiale' at LEGOS (until 2009).
Deputy Director of LEGOS between 1996 and 2007.

RESEARCH INTERESTS

Satellite geodesy and space research in Earth sciences : Gravity field and marine geoid; Earth rotation and polar motion; Tides; Precise positioning by space geodesy techniques and applications to tectonic motions, vertical crustal motions, geocenter motions; Temporal changes of the Earth gravity field and global mass redistributions among the surface fluid envelopes of Earth (oceans, atmosphere, land); Sea level variations at regional and global scales (observation from satellite altimetry and tide gauges; study of climatic causes: ocean thermal expansion and salinity effects, mass balance of the ice sheets, land water storage change, etc.); Water cycle and land hydrology from space; Climate research.

PUBLICATIONS AND SERVICES

190+ articles in international journals (listed in annex); Several Monograph chapters**;** Editor of 5 books, among them : 'Satellite Altimetry and Earth Sciences. A handbook of Techniques and Application, Lee-L. Fu & A. Cazenave Editors, Academic Press, International Geophysics Series, Vol. 69, San Diego, USA, 463 pages, 2001'.
Member: IPCC (*Intergovernmental Panel on Climate Change*) Working Group I and lead author of the 5th Assessment Report (*Sea Level* chapter); Joint Scientific Committee (JSC) of WCRP (*World Climate Research Programme*); 'C. Whitten Medal' committee (*American Geophysical Union*) and 'Nansen Medal' committee (*European Geosciences Union*).

AWARDS AND HONORS

Bronze Medal of CNRS (1980), Prize Doisteau-Blutet of the *French Academy of Sciences* (1979; 1990), Prize Kodak-Pathé-Landucci of the *French Academy of Sciences* (1996), Vening-Meinesz Medal of the *European Geophysical Society* (1999), Arthur Holmes Medal of the *European Geosciences Union* (2006), Prize Manley Bendall, Medal 'Albert 1er de Monaco' of the *Institut Océanographique de Monaco* (2008), Prize 'Emile Girardeau' of the '*Academie de Marine*' (2010). Bowie Medal of the *American Geophysical Union* (2012).
Ordre National du Merite (Commandeur : 2007, Officier: 1997, Chevalier : 1981), Legion d'Honneur (Officier : 2010, Chevalier: 2000).

Climate change, ocean warming, land ice melt and sea level rise

Anny Cazenave
LEGOS-CNES, Toulouse, France

It is now well established that the Earth's climate is warming and that the main reason is the accumulation inside the atmosphere of green house gases produced by anthropogenic fossil fuel combustion and change in land use (mostly deforestation) (IPCC AR5, 2013). Global warming has already several visible consequences, in particular increase of the Earth's mean temperature and of ocean heat content, melting of glaciers, and ice mass loss from the Greenland and Antarctica ice sheets. Ocean warming causes thermal expansion of sea waters, hence sea level rise. Similarly, land ice melt that ultimately reaches the oceans, also causes sea level to rise. Sea level rise induced by global warming and its impacts in coastal zones has become a question of growing interest for in the scientific community, and the media and public. In this presentation, we summarize the most up-to-date knowledge about climate change and associated impacts on ocean warming, land ice melt and sea level rise. We also present sea level projections for the 21^{st} century under different warming scenarios, highlighting the regional variability that superimposes the global mean rise. Finally, we address the question of the sea level rise impacts. We discuss the many factors (due to natural phenomena and direct anthropogenic forcing) causing adverse effects in coastal zones and show that climate-related sea level rise will generally amplify the vulnerability of these regions.

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EDUCATION

1998-2001 : **PhD** Environmental Sciences (LSCE – Paris 6)
1997-98 : **Master Degree** Océano, Météo and Environment (Paris 6)
1996-97 : **Agrégation** des Sciences de la Vie et de la Terre
1994-96 : **Graduate Student in Earth Sciences** (University of Paris 6)
1994-98 : Ecole Normale Supérieure Paris, France.

CARRER

2012-present : Directeur de Recherche CNRS à IPSL/SCE, Paris, France
2012 (5 months) : Post- doctoral stage at the University of Cape Town, South Africa
2007 (6 months) : Post Doctoral Stage at the University of East Anglia, Norwich, UK.
2002-2003: Post-doc position at LSCE, Paris, France
2000-2001: Coopérant Service National (Scientifique Chercheur) at MPI Biogeochemie, Jena,
1998-2001: PhD position at LSCE, Paris, France.
1996 (6 months) : stage at MIT, Boston, United States.

RESEARCH ADMINISTRATION:

Responsable de l'équipe BIOMAC au LSCE (12 personnes) (depuis 2010)
Membre du Scientific Steering Commitee de IGBP/IMBER (depuis 2013)
Membre du Conseil Scientifique de l'IPSL (depuis 2009)
Membre du Conseil Scientifique du Pôle de Modélisation de l'IPSL (depuis 2005)
Membre du CNU Section 37 (2009-2011)
Membre du Scientific Steering Commitee de IGBP/AIMES (2005-2008)
Membre du Conseil de Laboratoire du LSCE (2004-2008)
PI de plusieurs projets européens (FP6-CARBOOCEAN, FP6-Euroceans, FP6-GreenCycles, FP7 EPOCA, FP7 MEECE, FP7-GreenCyclces2, FP7-CarboChange, FP7-Past4Future)
Editeur associé pour Biogeosciences.

TEACHING ACTIVITY :

2005-2013 : Cours et Responsable Modélisation à l'Ecole d'Eté SOLAS
2011-2013 : cours de thèse ED129 (Paris VI / UVSQ), cours de M1/M2 (Paris VI, Paris XI)

AWARDS AND HONORS

2011 : Médaille de la Société d'Océanographie de France

The Global Carbon Cycle And Climate-Carbon Coupling

Laurent Bopp
CNRS, Gif-sur-Yvette, France

Global carbon cycle modeling aims at quantifying the carbon exchanges between reservoirs involved in its global cycle and their changes over time. The major issues that carbon cycle modeling has contributed to in recent years are varied, but can be summarized as (1) understanding the past variations of atmospheric CO_2 for different time scales, and (2) estimating the evolution of atmospheric CO_2 in response to anthropogenic carbon emissions over the next decades and centuries.
Several observations have shown a strong link between climate variability and atmospheric CO_2. CO_2 contributes to the greenhouse effect and thus affects the energy balance of our planet, but in return, climate controls the storage of carbon in different reservoirs and therefore influences atmospheric CO_2. Changes in atmospheric CO_2 of about 100 ppm between glacial and interglacial period, for instance, are explained by the response of the ocean carbon cycle to climate variations. On shorter time scales, the interannual variations in the growth rate of atmospheric CO_2 between 0.5 and 3 ppm per year depending on the year, are linked to interannual climate variability: El Niño years are marked by a strong release of carbon by the terrestrial biosphere related to the particular climatic conditions of those years. These two time scales illustrate the strong links between the climate system and the carbon cycle. For decades, the evolution of CO_2 in the atmosphere depend on the evolution of anthropogenic emissions, but it will also depend on the capacity of carbon sinks to store a portion of anthropogenic carbon and thus to their responses to anthropogenic climate change. This question of the interaction between climate and the carbon cycle has led to the development of models of the global carbon cycle coupled to climate models that are used to estimate climate change in response to anthropogenic forcing.
For the terrestrial biosphere, carbon cycle models have been developed from surface models used in climate models, that represent the exchange of water and energy between the atmosphere and land surfaces. They usually detail the exchanges of carbon between the atmosphere, the above ground biomass and soil by calculating explicitly the main carbon fluxes (photosynthesis, autotrophic and heterotrophic respirations). Their complexity has increased significantly in recent years and many processes have been added: representation of different types of plants, taking into account the anthropisation of surfaces, incorporation of the nitrogen cycle in vegetation and soils, role of fire. In the ocean, carbon cycle models incorporate the essential aspects of this cycle: air-sea exchange of CO_2, the chemistry of inorganic carbon and a simplified representation of the ocean ecosystem and its role in the transfer of carbon from the surface to the deep ocean. The ecosystem is often represented by some functional groups of phytoplankton and zooplankton. Are also represented cycles of major nutrients, nitrogen, phosphorus, iron and silica. Finally, these models are intimately related to ocean circulation models. These models have also been incorporated into climate models to simulate the co-evolution of climate and the carbon cycle.

Conducted by teams from the Hadley Centre and from IPSL, the first coupled climate-carbon simulations date back from the early 2000s. They suggest the existence of a positive feedback between climate and the carbon cycle: anthropogenic climate change decreases the capacity of natural sinks, the ocean and the terrestrial biosphere to absorb anthropogenic carbon. The mechanisms involved are the following: in the ocean, rising temperatures decrease the solubility of CO_2 and vertical stratification prevents the penetration of anthropogenic carbon. For the terrestrial biosphere, warming stimulates heterotrophic respiration and the degradation of soil organic matter ; vegetation changes in response to climate change will also lead to carbon release.

In the last intercomparison exercise of climate models produced for the last IPCC report, coupled climate-carbon simulations play an important part. They allow to consider this feedback in climate change projections and they also allow to compute trajectories of allowable fossil fuel emissions for a given atmospheric CO_2 trajectory. Recent results using this last generation of climate-carbon coupled models will be presented in this talk.

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James Orr
Laboratoire des Sciences
du Climat et dl'Environnement
(CEA-CNRS-UVSQ)
Gif-sur-Yvette France
&
International Atomic Energy Agency
Environment Laboratories
Monaco

Education:
Ph.D., Chemical Oceanography, Texas A&M University, 1988
B.S., Chemistry, Mathematics Minor, Central Washington University, 1978

Scientific Interests:
Carbon cycle and biogeochemistry.
Ocean acidification;
Ocean circulation and tracers;

Research Experience:
Research Director (Ocean carbon-cycle modeling), LSCE/CEA, Gif-sur-Yvette, France, 1998—present
Research Scientist, Marine Environment Lab / IAEA, Monaco (secondment from LSCE), 2006—2009
Research Scientist, Atmospheric and Oceanic Sciences, Princeton University, 1988—1992

Research Projects:
Coordinator, Ocean Acidification International Coordination Centre, International Atomic Energy Agency (IAEA) Environment Laboratories, Monaco.
Chair, SOLAS-IMBER Ocean Acidification Working Group (SIOA).
Leader, Work package on intercomparison of ocean and earth system models, CarboOcean-2 EU Proposal (7th Framework), 2009
Leader, Theme on Modeling Ocean Acidification, EPOCA EU Project (7th Framework), 2006—present
Principal Investigator, EurOceans NoE, EU Project (6th Framework), 2005—2008
Coordinator, NOCES (Northern Ocean Carbon Exchange Study) Project, EU Project, 2002—2005
Coordinator, GOSAC-EC (Global Ocean Storage of Anthropogenic Carbon) Project, European component of OCMIP-2, EC Environment and Climate Programme, 1998—2002
Principal Investigator, ESCOBA-Ocean project (European Study of Carbon in the Ocean, Biosphere, and Atmosphere: Ocean Section) of the EC Environment and Climate Programme, 1996—1998.

Fellow, University Marine Fellowship, U.S. Sea Grant Program, awarded twice for Ph.D. research on marine radiochemistry

Ocean acidification and its impacts on marine organisms and ecosystems

Lina Hansson
IAEA Environment Laboratories, Monaco, France
&
James Orr
Laboratoire des Sciences du Climat et de l'Environnement
Gif-sur-Yvette, France

What is ocean acidification?

The consequences of man's use of fossil fuels (coal, oil and natural gas) in terms of global warming have not escaped anyone's attention. *Ocean acidification* is another, and much less known, result of the approximately 96 million tons of carbon dioxide (CO_2) released into the atmosphere every day, not only as a result of fossil fuel burning but also of deforestation and production of cement (1). Since the beginning of the industrial revolution, about one third of the CO_2 released into the atmosphere by anthropogenic activities has been absorbed by the world's oceans, which play a key role in moderating climate change (2). Without this capacity of the oceans, the CO_2 content in the atmosphere would have been much higher and global warming and its consequences more dramatic. The impacts of ocean acidification on marine ecosystems are still poorly known but one of the most likely consequences is the slower growth of organisms forming calcareous skeletons or shells, such as corals and mollusks.

The chemical process of ocean acidification

As CO_2 dissolves in the ocean it generates dramatic changes in sea water chemistry. CO_2 reacts with water molecules (H_2O) and forms the weak acid H_2CO_3 (carbonic acid). Most of this acid dissociates into hydrogen ions (H^+) and bicarbonate ions (HCO_3^-). The increase in H^+ ions reduces pH (measure of acidity) and the oceans acidify, i.e. they become more acidic or rather less alkaline since although the ocean is acidifying, its pH is still greater than 7 (that of water with a neutral pH). The average pH of today's surface waters is 8.1, which is approximately 0.1 pH units less than the estimated pre-industrial value 200 years ago (3,4).

Projections of future changes

Modelling demonstrates that if CO_2 continues to be released at the same pace as today, ocean average pH could reach 7.8 by the end of this century, corresponding to 0.5 units below the pre-industrial level, a pH level that has not been experienced for several millions of years (5). A change of 0.5 units might not sound as a very big change, but the pH scale is logarithmic meaning that such a change is equivalent to a threefold increase in acidity. The current rate of acidification may be unprecedented in Earth's history; it is estimated to be 10 to 100 times faster than any time in the past 50 million years (6). Several marine species, communities and ecosystems may not have the time to acclimate or adapt to these fast changes in ocean chemistry.

Possible consequences for marine organisms

The dissolution of carbon dioxide in sea water not only provokes an increase in hydrogen ions and thus a decline of pH, but also a decrease in a very important form of inorganic carbon: the carbonate ion (CO_3^{2-}). Numerous marine organisms such as corals, mollusks, crustaceans and sea urchins rely on carbonate ions to form their calcareous shells or skeletons in a process known as calcification. The concentration of carbonate ions in the ocean largely determines whether there is dissolution or precipitation of aragonite and calcite, the two natural polymorphs of calcium carbonate ($CaCO_3$), secreted in the form of shells or skeletons by these organisms. Today, surface waters are supersaturated with respect to aragonite and calcite, meaning that carbonate ions are abundant. This supersaturation is essential, not only for calcifying organisms to produce their skeletons or shells, but also to keep these structures intact. Existing shells and skeletons might dissolve if pH reach lower values and the oceans turn corrosive for these organisms. Calcifying organisms play an important role in the food chain and form diverse habitats for many species.

The magnitude of ocean acidification can be predicted with a high level of confidence since the ocean chemistry is well known. But the impacts of the acidification on marine organisms and their ecosystems are much less predictable. Not only calcifying organisms are potentially affected by ocean acidification. Other main physiological processes such as reproduction, growth and photosynthesis are susceptible to be impacted, possibly resulting in an important loss in marine biodiversity. But it is also possible that some species, like sea grasses that uses CO_2 for photosynthesis, are positively influenced by ocean acidification. Syntheses of recent studies show that organisms react differently, some species will be affected, others not, others will benefit (7). The variety of responses within and between taxa suggests that ocean acidification is a driver for substantial change in ocean ecosystems this century, potentially leading to long-term shifts in species composition.

Resources:

- The ***web site of the IAEA Ocean Acidification International Coordination Centre (OA-ICC)*** lists resources on ocean acidification according to audience and language: iaea.org/ocean-acidification

- The ***OA-ICC news stream*** offers a digest of daily media coverage, scientific articles, jobs, meeting announcements on ocean acidification news-oceanacidification-icc.org

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Phil Smith
Coordinator, Teacher Scientist Network (TSN)
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ACTIVITIES:

Dr. Phil Smith has for the last 9 years run a highly successful independent science education charity, the Teacher Scientist Network (TSN), that works closely with science teachers across Norfolk in the East of England. TSN is recognised as an exemplar activity linking the science and education communities.

Trained as a plant pathologist with a specific interest in fungal diseases of cereal crops, Phil started engaging with schools during his PhD. This led to a highly successful partnership with a primary school teacher which continued after Phil ‘hung-up’ his lab-coat. Phil regularly runs courses for teachers and coordinates the Networks activities which all focus upon linking real science with the school community. Phil received an MBE, a national order of merit, for services to science education in recognition of both his own science communication endeavours and those of TSN as a whole in Summer 2008. Phil has been a member of the EGU Committee of Education since 2004.

“The Carbon Caper”

Phil Smith
John Innes Centre, Colney Lane, Norwic, UK

The element Carbon is the present in all living organisms. It's recycled through various processes, which are described in the Carbon Cycle. Carbon is also a part of the ocean, air, and even rocks. Because the Earth is a dynamic place, carbon does not stay still. It is on the move! When we learn about the carbon cycle in school it is often in a very static way – not any more! This presentation will involve all the GIFT teachers becoming a part of the carbon cycle and looking at where we find Carbon, in what form and the influence of the Industrial revolution.

The original activity was developed by educators at the Science Museum in London (UK) and will be presented by Phil as an energetic and stimulating way to teach the basics of the Carbon Cycle: central to our understanding of the many components of Climate Change and the role Carbon plays. Through this activity students will understand the carbon cycle, how it has been affected by our use of fossil fuels since the Industrial Revolution, and how this underlies current concerns about climate change.

Bernard SEGUIN
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EDUCATION

Diplom of 'ingénieur agronome' from the Institut National Agronomique de Paris obtained in 1968, completemented by a PhD thesis (fluid mechanics/atmospheric physics) obtained in 1971 at the 'Université de Provence' in Marseille.

CAREER

Bernard SEGUIN, now retired, has been working for INRA (Institut National de la recherche agronomique) in France since 1967. He started in Versailles, then joined Avignon (south-east of France) in 1968 as a researcher in bioclimatology until 1998. He has acted as chief of the laboratory (station de bioclimatologie) during 12 years, before being involved in the scientific management within INRA as deputy -chief of department « Environnement et Agronomie » (1998-2002). Later on, he was named as coordinator of the INRA research work on climate change and greenhouse effect, until his retirement in 2011.

RESEARCH INTERESTS

The research work during about 30 years (1968-1998) at the 'Station de bioclimatologie' of INRA in Avignon has mostly concerned the fields of micrometeorology, climatology and remote sensing applied to agriculture and continental biosphere. Since 2002, it has been orientated towards the main topic of the impact of climate change on human and natural services

PUBLICATIONS AND SERVICES

He has published 60 papers in international journals concerning the above-described research fields.
Apart from numerous scientific actions and contributions to various committees in France, he has participated in European COST actions (77 and 718 COST actions on agrometeorology and remote sensing, then 725 on phenology and 734 on agriculture and climate change). Around the years 90, he has been involved in EU funded projects linking several countries of South America, among them Chile, with Netherlands, Spain and France on the use of agroclimatology and remote sensing for the monitoring of agriculture and hydrology. On a larger international point of view, he has been involved in several working groups of the Commission for Agricultural Meteorology of the World Meteorological Organization (WMO).

AWARDS AND HONORS

Within IPCC, honoured by the Nobel Prize for peace in 2007, he has acted as a lead-author LA for the 4th report (WG II on impacts, chapter 1 observed changes) and as a review editor for the forthcoming 5th report (also WG II, chapter 18 detection and attribution of observed impacts) to appear in April 2014. He has also contributed to IPCC as member (2004-2008) of the IPCC Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA).

Impacts of climate change on agriculture

Bernard Seguin

INRA, site Agroparc, 84914 Avignon cedex 9, France

Climate change will impact and has already impacted a large range of physical/biological systems and sectors of the human activity, among them agriculture (including livestock) and its main output as food production. Several other driving forces, especially in the economical and societal domain, will determine the evolution along the present century. But climate change has to be considered as a major factor in the context of the enormous challenge of furnishing food for about 9 billions of people instead of about 6 now. The main lines of the foreseen impacts have been established in the years 1990, when considering at this date the simple assumption of a doubling of CO_2 concentration. Recent studies have added more detailed estimates of the consequences for global food production, mainly confirming the previous lines. They differ above all by considering a range of emission scenarios (as the family of SRES defined by IPCC around 2000, or the new set of RCP trajectories recently proposed for the AR5 of the same IPCC to be published in 2014).

Expected effects on crop functioning

For assessing changes in the eco-physiological functioning of vegetal production, it is firstly necessary to consider the stimulation of photosynthesis by the elevation of atmospheric CO_2 concentration. It will concern as well pastures, forests and natural vegetation as annual crops. For these, even if there is some controversy about the results of experiments with free-air enrichment, the well-established curves of photosynthesis enrichment on an instantaneous basis (fig1) lead to consider a possible increase of about 10-20% with 550 ppm for C_3 temperate species as wheat, rice, soybean, whilst it seems to be limited to 0-10% for C_4 tropical species as maize, sorghum. This increase of potential production is a first component, on which direct effects of changes in the climatic variables have to be superposed.

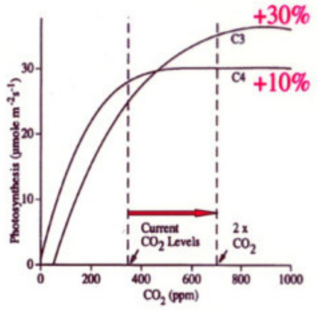

Fig.1. Typical increase of photosynthesis with increase in carbon dioxide concentration

They firstly involve temperature, whose effects may be quite variable: higher temperatures are generally favourable for growth in cold and temperate climates, except however when they exceed the optimum and even attain detrimental thresholds in the case of extreme events. On the contrary, they are generally unfavourable for warm areas, where the optimal ranges for the elementary physiological processes could be seriously exceeded. Another important component for the elaboration of the final yield will be significantly changed by the acceleration of the development calendar, leading to significant advances in the time of the phenological stages. At the end, the maturation and then the final harvest will occur

earlier, so that the total time during which the plant has worked with photosynthesis will be reduced. In the specific case of fruit trees, an other potentially negative impact of this advance in phenology could be faced with an increase of the risk of spring frost at the time of flowering: in spite of globally warmer conditions at the same period, because flowers will appear some weeks earlier and be finally exposed to more dangerous temperatures. On the contrary, for indeterminate cycle species like grass or forests, as warmer conditions will speed the budburst at spring and delay the browning in autumn, we can forecast a significant increase of the duration of growth season and then of the elaborated biomass.
Rainfall on a first place and other water balance components like potential evapotranspiration will also seriously modulate the potential changes in plant resulting from the above-described foreseen effects of temperature increase. Tendencies towards drier conditions may fully cancel the positive potential impact with higher CO_2 or milder temperatures. More generally, we also have to state that this general figure only considers the continuous effect of mean values for the climatic conditions, but that their variability and the occurrence of extreme events (frosts and heat-waves, droughts or torrential rainfall) would totally confirm or inverse this mean tendency. On the whole, the combination of these various influences leads to a variety of contrasted effects, depending upon the crop production and the geographical zone.

Expected and observed effects on crop production

Resulting effects on crop production may be grossly estimated by setting some in-field experiments or using empirical tools like climatic indices, but there is a general agreement for considering that only the use of well-defined and validated deterministic crop models is able to give valuable predictions. A synthetic view of the obtained projections with these crop models is available from the IPCC AR4 report, as depicted in fig 2

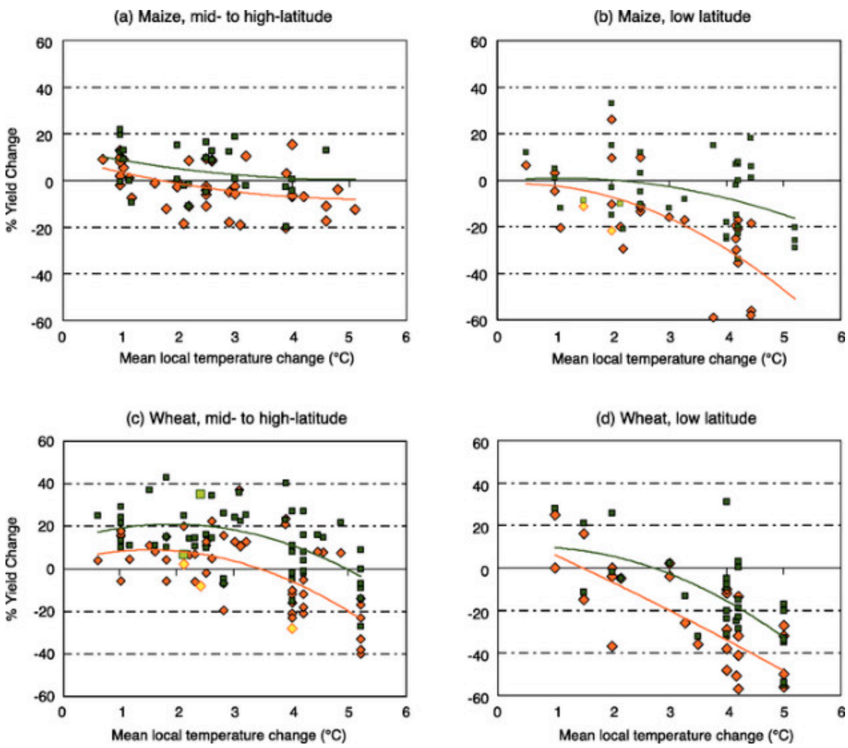

Fig.2. Effects of temperature change on wheat and maize, without adaptation in red and considering adaptation solutions in black (from Easterling et al 2007)

The final statement given in IPCC (2007) states that 'temperate regions, moderate to medium increases in local mean temperature (1° to 3°), along with associated CO_2 increase and rainfall changes, can have small beneficial impacts on crop yields. At lower latitudes, especially the seasonally dry tropics, even moderate increases are likely to have negative yield impacts for major cereals. Further warming has increasingly negative impacts in all regions".

Observed changes in agriculture and livestock resulting from the recent warming are still hardly detectable, except for advances in phenology (i.e flowering of fruit trees, harvest dates of vines and cereals) and the case of wine production in terms of quality, with a noticeable increase in sugar and alcohol content and a simultaneous decrease in acidity. The effect of warming is difficult to isolate from other driving forces in the evolution of regional yield and global production, still mainly sensitive to the climate variability. However, recent studies at a global scale have detected a first small, but significant decrease (of the order of 3%) of wheat, barley and maize yields since 1981. Also, among recent events, both in Europe and in Australia, severe droughts have confirmed the high sensitivity of pasture production, with large-scale losses of 50% and more.

Consequences for the global food production

Having a full viewing of the future would also need to incorporate an assessment of the future adaptation by geographical displacement of production zones. It seems easy to give a general idea of possible shifts, like the potential extension of grain maize or vine towards the north or the east in Europe. But it is much more difficult to quantitatively assess the large-scale consequences. Also, the forcing function of the market on the agricultural production is such that it is only possible to give the main tendencies caused by the component of the climate change alone. When these are aggregated up to the scale of the global trade market, it is confirmed that most of the increase in production will come from the agriculture of developed countries, which mostly benefit from climate change. It will have to compensate for declines projected, for the most part, in developing countries: the reduction of agricultural productivity could approach 20 to 25 % for some countries like Mexico, Nigeria or South Africa. The resulting increase of the number of people at risk of hunger marginally could grow from 380 millions up to 1300 millions in 2080, depending upon the future emission scenarios. It could even be underestimated in the case of unexpected surprises due to increased frequency and severity of extreme events.

Conclusion

Even if there are large uncertainties subsisting, we may consider that there is a sufficient amount of work and knowledge for starting the adaptive process.Some productions like fruit-trees and vine need at least 20 to 40 years of anticipation, due to the duration life of planting and the corresponding delay in plant breeding. For annual crops, the time scale seems to be less constrained, but there are many questions about the medium-term (2020-2040).

Adaptation may be thought in terms of genetics or cultural practices, but it will also include geographical movements along the landscape, both in latitude and altitude. Potential changes are significant, as illustrated by studies delimitating the northern expansion of grain maize, sunflower or soybean. They will raise specific questions for the productions directly linked to local specificities, generally in terms of quality as in the well-known case of 'terroirs' for the wine production. In any case, we have to underline that these climate change impacts will be combined with other significant drivers, some being of technical character but others surely predominant concerning the economical and sociological aspects.

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EDUCATION

1979 Ph.D. Scripps Institution of Oceanography, University of California, San Diego
1973 B.S. University of Rhode Island, magna cum laude, Honors program Geology.

CAREER

2013 -	Director, School of Marine Science and Ocean Engineering, UNH
2002 -	Adjunct Scientist – Woods Hole Oceanographic Institution
2000 -	Professor and Director Center for Coastal and Ocean Mapping, UNH
1991- 99	Professor and NSERC Chair in Ocean Mapping, Univ. of New Brunswick
1988- 89	Visiting Professor, Dept. de Geologie Dynamique, Univ. of Paris.
1986- 91	Associate Professor of Oceanography, Dalhousie University.
1986	Visiting Professor Chair, University of Kiel, W. Germany

RESEARCH INTERESTS

Sonar imaging and remote characterization of the seafloor as well as advanced applications of 3-D visualization to ocean mapping problems and applications of mapping to Law of the Sea issues, particularly in the Arctic.

RECENT RELEVANT PUBLICATIONS

Jakobsson, M., Mayer, L.A., Coakley, B. et al., 2013, The International Bathymetric Chart of the Arctic Ocean (IBCAO) Version 3.0, Geophysical Research Letters, Vol. 39, No. 12, L12609, doi:10.1029/2012GL052219

Mayer, L.A., 2012, Arctic Marine Research: A U.S. Practitioner's Perspective, in: S Wasum-Rainer, I. Winkelmann, and K. Tiroch, eds., *Arctic Science, International Law and Climate Change*, Max-Planck-Institut fur auslandisches offentliches Recht und Volkerrect, v. 235, Springer Heidleberg, pp. 83-95.

Mayer, L.A., 2012, The Continental Shelf and Changing Sea Level, in, M. Nordquist and J. Norton Moore, eds,. *Maritime Boundary Diplomacy*, Center for Oceans Law and Policy Series, Martinus Nijhoff Publishers, Leiden, pp. 197-212.

AWARDS AND HONORS

Superior Honor Award – Department of State 2013
Class of 1944 Professorship – University of New Hampshire – 2013-2016
Vice-Chair Consortium of Ocean Leadership Board of Trustees 2013-
Chair – National Academy of Sciences Committee on Effects of Deepwater Horizon Spill on Ecosystem Services in the Gulf of Mexico – 2011 -- 2013
University of Rhode Island – School of Oceanography Distinguished Alumni Award - 2007
University of New Hampshire Excellence in Research Award - 2007
Chair- Nat. Academies Committee on National Needs for Coastal Mapping and Charting , 2003
Member of U.S. Presidential Panel on Ocean Exploration – 2000
Doctor of Philosophy *honoris causa* – University of Stockholm, 1999
Geological Assoc. of Canada's Michael J. Keen Medal for contributions to marine geoscience – 1998
President -- Canadian Geophysical Union -- 1997 - 1999
Lansdowne Visiting Appointment -- University of Victoria 1991-1992
Selected as Astronaut Candidate finalist for the NASA Space Shuttle Program

Recent Changes in Arctic Ice Cover From First-Hand Experience

Larry A. Mayer
Professor of Earth Science and Ocean Engineering
Director, School of Marine Science and Ocean Engineering
Director, Center for Coastal and Ocean Mapping
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The vast expanses of ice that cover the Arctic Ocean serve humankind in many ways. The ice plays a critical role in regulating climate, ocean circulation, ocean chemistry and gas exchange as well as providing a unique habitat for a number of plant and animal species. On the down side, the ice has prevented access to the Arctic, making it the least known of all our ocean basins, limiting our knowledge of things as fundamental as the depth and shape of the seafloor (bathymetry). The fact that a deep ocean basin lies beneath the Arctic ice was not established until Fridtjof Nansen published a chart in 1903 that was based on eight sounding measurements carried out over the course of his three year drift through the Arctic Basin on the *Fram*. Through the early 20th Century, access to the Arctic was gained by taking advantage of thick and stable ice to establish ice-stations or man drifting "ice-islands". From these stations and individual measurements made from aircraft that would land on the ice, thousands of measurements (of many parameters) were made but given the expanse of the Arctic they were sparse and still only provided a very rough picture of the nature of the seafloor, the ice, and ocean water properties of the Arctic.

By the 1980's, satellite-derived measurements began to give a new perspective on the extent of Arctic sea ice. These measurements have shown large seasonal and inter-annual variability but the long-term trends have been disturbing. The most recent report of the IPCC (AR5) has shown that between 1979 and 2012 the annual mean sea ice extent in the Arctic has decreased about 4% per decade with the summer sea ice minimum decreasing between about 9.4 to 13.6%. Of even greater concern is the steady loss of old, thick, multiyear ice. Newer sensors on satellites and aircraft as well as upward-looking sonar data from submarines are providing estimates of the thickness (typically related to age) of Arctic sea ice. These data indicate that the extent of ice that survives through a summer (perennial ice) and the ice that survives through at least two summers (multiyear ice) has also rapidly declined with rates of approximately 11.5% per decade for the perennial ice and 13.5% per decade for multiyear ice. Thus beyond just the extent of the ice decreasing, the overall thickness and thus volume of ice in the Arctic has been drastically decreasing over the past 30 – 40 years. Projected into the future (through a number of modeling scenarios used by the IPCC) these trends indicate that the Arctic may have a nearly ice-free September (meaning sea ice extent of less than 1 million sq km for five consecutive years – for comparison the 1980 minimum sea ice extent was more than 7 million sq. km and the 2013 minimum was 3.4 million sq. km) by the middle of this century. The extensive loss of ice in the Arctic will change the amount of light reflected from the earth's surface (albedo), will change the rate at which heat is lost from the ocean (the ice acts as an insulator for heat loss), will affect the exchange of carbon dioxide and other gasses between the ocean and the atmosphere, and will change the density structure of Arctic Ocean waters. All of these factors will have significant impact on global climate and must now be incorporated into global climate models.

There are potential long-term benefits of decreased ice including much more efficient shipping routes between Europe and Asia and access to new sources of resources, though whether these are long-term benefits to the health of the planet is an important question. A short-term benefit of diminishing ice in the Arctic is that it has allowed greater access for exploration and study. Prompted by the recognition that the Arctic Ocean falls under the auspices of the Law of the Sea Treaty the five coastal states that border on the Arctic (Canada, Denmark [through Greenland], Norway, Russia and the United States) have all undertaken major mapping programs in the Arctic. The Treaty provides that if certain criteria of the shape and character of the continental margin of a coastal state are met, the state is entitled to sovereign rights over the resources of the seafloor and subsurface beyond the 200 nautical-mile Exclusive Economic Zone afforded to all coastal states. The coastal state is also responsible to extend its environmental protection to these regions. U.S. efforts in support of the Law of the Sea have led to eight cruises (four of them in collaboration with Canada) to the high Arctic over the past ten years. These cruises have discovered uncharted, 4000 m high submarine mountains, have found evidence of past ice sheet activity in regions not previously thought to have grounded ice, and have radically changed our view of the bathymetry (and perhaps the geologic origins) of the Arctic. They have taken place in the context of the remarkably changing Arctic ice cover described above and have offered a close-up and first-hand look and the nature of these changing conditions and their ramifications on Arctic operations. The presentation will present examples from these operations that highlight both the rapid decline in Arctic sea ice thickness and extent but also indicate that even with diminishing ice-cover, operations still require access to large and powerful icebreakers.

Professor Stephen A. Macko

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University of Virginia

Charlottesville, VA 22901

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ACTIVITIES:

Stephen A. Macko is a Professor of Isotope and Organic Geochemistry in the Department of Environmental Sciences at the University of Virginia. His areas of interest include marine organic geochemistry with special applications to climate change and deep ocean communities. He also works on meteorites with a focus on the Origins of Life. He has authored over 300 refereed research papers and books which have over 7000 citations and an H-index of 52; he was elected a Fellow of the Geochemical Society and of the European Association of Geochemistry in 2003 and was the Corresponding Education Editor for EOS. He received the All University Teaching Award at UVA and was a finalist for the State of Virginia Faculty of the Year award in 2007. He recently held the position of Program Officer for Geobiology and Low Temperature Geochemistry at the US National Science Foundation.

At the University of Virginia, he teaches classes on Oceanography, Geochemistry, Isotope Geochemistry and Organic. He has been a scientist or chief scientist on numerous oceanographic expeditions, including dives to depths of over 500m in the submersible Johnson Sea Link. He was a research scientist on the high Arctic Canadian Ice Island during five different years. He has been featured on Discovery and National Geographic television channel programs (*The Ultimate Guide to Mummies, The Moche Murder Mystery, The Mummy Road Show*) as well as the Peabody Award winning *King Corn*, a documentary on the influence of corn on the lives of North Americans.

Implications of a Changing Earth: Obvious and Cascading

Stephen A. Macko
Department of Environmental Sciences, University of Virginia, USA

The ocean influences nearly all activities on the planet, serving as a source of nutrition, energy and pathway for transport of resources while buffering the scale of variations in climate. It is also the portion of the planet that is perhaps in greatest need of data to address issues of the dramatic changes that are happening globally. Some of the changes are clearly the result of human inaction and lack of foresight. Fisheries, on which one sixth of human protein nutrition is derived, are in a state of near collapse for some species in the near term, owing to overfishing and mismanagement of a sustainable infrastructure. Lack of cautious application of new technologies and oversight has led to increasing levels of pollutants, sometimes catastrophically, as was evidenced in the recent Deepwater Horizon oil spill in the Gulf of Mexico. Global warming is influencing many aspects of the ocean system and will have collateral impacts beyond simply raising the temperature of the planet. Navigation and influence on transport are chief in our envisioning eventual impacts, and need to be anticipated, based on the best of models and data. Sea level rise and the associated coastal erosion, modifying waterways and ports, call for adaptive planning. Climate change could easily be seen to affect ocean circulation, wind dynamics, storm production and associated storm surges. Loss of sea ice in the Arctic will open new avenues which are economically and energetically more efficient for transport. With warming, and heightened destruction of ice sheets will likely come increased hazards from sea ice in shipping lanes. The rate of loss of the ice sheets such as that of Greenland is only beginning to be understood, and appears to be increasing. Sea ice coverage in the Arctic was the lowest on record in the summer of 2012, and the area of surface melt on the Greenland Ice Sheet was recorded at the highest, at 97%, since satellite images have documented its status. Diminishing ice cover will also influence an increase of fishing efforts and exploration for fossil fuels in the high Arctic. Without precise data on the sizes of fish stocks, the effects on commercial fisheries are complex, and begs for fundamental knowledge. Additionally, with the loss of sea ice, diminishing ice-based productivity may lead to a loss of diversity and modification of sustainable trophic structure in Arctic food webs. As a consequence of increased fossil fuel exploration, extraction and transport, the risk of contamination is heightened and at present only minimal preparation for impact and cleanup exists for this eventuality in fragile Arctic environments. The addition of massive amounts of carbon dioxide to the atmosphere and oceans, has changed the ocean chemistry, increasing the acidity or lowering the pH. Sound propagation in a more acid ocean may affect navigation as well as migration patterns of marine mammals and fish. Acidification influence on calcareous organisms at primary production levels could lead to catastrophic effects on the higher organisms of the food chains. The collateral impacts of the changing ocean in a period of global warming urgently require further study in order to enable adaptation and reduce vulnerability. Only through an appreciation for the past and a comprehensive understanding of the present, can we anticipate the future. The potential for that vision of the ocean lies with the cooperation among all nations.

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Education:

Secondary school in Italy and the USA (American Field Service Exchange Student.)
University studies at the University of Paris, PhD in Solid State Physics.

Career

I have done all my scientific career as an employee of the French Atomic Energy Commission, first as a researcher in the Physics Department than in the field of geophysics.

In 1985, I was appointed as Deputy Director of the Centre des Faibles Radioactivités and Head of the Department of Earth Sciences. I created and was first director of the Laboratoire de Modélisation du Climat et de l'Environnement, which was later united with the Centre des Faibles Radioactivités to form the present Laboratoire des Sciences du Climat et de l'Environnement (LSCE).

After 3 terms as Head of Department (12 years) I stepped down to a researcher position again, until I retired. I have been an "emeritus" researcher since then, and gradually reoriented my activities towards education.

I founded the Committee on Education of EGU, and have been its Chairman in the last 11 years.

Research Interests:

After my PhD I spent a few years working with critical phenomena (scattering of laser light by critical fluids) then moved into the field of geophysics.

My main interests in this new field has always been linked to the magnetic properties of sediments and igneous rocks (paleomagnetism), used with several objectives: geodynamical reconstructions (particularly in the Eastern Mediterranean and the Andean Cordillera), reconstruction of the history of the Earth's magnetic field (including the morphology of field reversals) and more recently reconstructions of environmental and climatic changes on a global scale.

I have published about 200 articles in international scientific journals and a few general popular articles in different journals.

Fellow of the American Geophysical Union (AGU).
F. Holweck prize of the French Academy of Science
Supervisor of 12 PhD students, and 8 Masters of Science

Educational activities:

Chairman, Education Committee of the European Geosciences Union
Participant to different National and International Education Committees
Union Service Award for creating the Committee on Education of EGU
Excellence in Geophysical Education Award of the American Geophysical Union

THE EDUCATIONAL ACTIVITIES OF THE EUROPEAN GEOSCIENCES UNION

Best practice for the science–teaching interface

C. Laj
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Abstract

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Introduction

In 2002 in Nice, France, EGU Executive Secretary Arne Richter announced a collaboration between scientists and schools all over Europe. The aim was to bring state-of-the-art science via high school teachers into tomorrow's classrooms.
Carlo Laj was appointed chair of the EGU Committee on Education (CoE) and, in 2003, the first GIFT workshop took place at the General Assembly, featuring 42 teachers from seven European countries. Since then, more than 1000 teachers have attended these workshops, which are a mixture of presentations by worldwide known scientists, hands-on experiences for the classroom and presentations by the teachers themselves to their fellow teachers

The Committee on Education of EGU has progressively developed programs and educational materials mainly aimed at secondary school teachers and pupils along 5 main axes:

1) Geosciences Information for Teachers (GIFT) workshops at EGU General Assemblies and more recently at Alexander von Humboldt topical Conferences
2) Educational sessions at EGU General Assemblies (teachers and scientists and science educators)
3) Gift Distinguished Lectures series
4) Teachers at sea
5) EGU-UNESCO-ESA Collaboration for GIFT workshops in Africa

These activities are briefly described below.

1) The GIFT workshops at the EGU General Assemblies

The program of each workshop is focused on a unique general theme, which changes every year, and which combines scientific presentations on current research in the Earth and Space Sciences, given by prominent scientists attending EGU General Assemblies, with hands-on, inquiry-based activities that can be used by the teachers in their classrooms to explain related scientific principles or topics. Also, teachers are welcomed to present to their colleagues some aspects of their own « out-of-the program » classroom activities.

The main objective of these workshops is to spread first-hand scientific information to science teachers of primary and secondary schools, significantly shortening the time between discovery and textbook, and to provide the teachers with material that can be directly transported into the classroom. In addition, the full immersion of science teachers in a truly scientific context (EGU General assemblies) and the direct contact with world leading geo-scientists are expected to stimulate curiosity towards scientific research that the teachers will transmit to their pupils.

The value of bringing teachers from several nations together includes the potential for networking and collaborations, the sharing of experiences, and an awareness of science education as it is presented outside their own countries. At all previous EGU GIFT workshops teachers mingled with teachers from outside their own country and had lunch together with the scientists, which provided rich dialogue for all those who participated since the dialogue included ideas about learning, presentation of science content, curriculum ideas… We, therefore, believe that, in addition to their scientific content, the GIFT workshops are of high societal value.

The workshop quickly became known amongst teachers all over the European continent and, in the following years, the number of participants doubled. Due to the importance of the valuable hands-on activities, which require an intimate setting, and the limited space at the conference venue, the maximum number of participants had to be limited to 85.

Today a GIFT workshop typically includes :

- Two and a half days of workshop
- 80 participants from 20 countries (selected from 250-300 applicants)
- 8-9 conferences by worldwide known scientists present at the General Assembly
- 1 half-day practical works with specialized educators
- 1 poster session "Science in tomorrow's classroom" where teachers are encouraged to present their out-of-the-official-program school activities and which is open to non-teachers participants (in 2012 we have had about 50 posters from the teachers attending the GIFT workshop out of a total of about 65)

1 visit to local institutions in Vienna (UNOOSA, IAEA…)

And each GIFT workshops starts with a visit and an ice-breaker reception at the Vienna Museum of Natural History on the Sunday preceding the workshop.

In the last 5 years these different themes were addressed: Natural Hazards (2013), Water! (2012), Evolution and Biodiversity (2011), Energy and Sustainable Development (2010), The Earth from Space (2009) this last one in collaboration with the European Space Agency (ESA°.

All the expenses for the selected teachers (travel, lodging and registration at the GA) are met by the organization.

The year 2009 brought further additions to the GIFT concept. For the first time, recordings were made available as web streams and are openly accessible free of charge via the EGU website
(http://www.egu.eu/outreach/gift/workshops/).

Also, in 2010, the Committee on Education decided to hold a « local » GIFT workshop associated with EGU Alexander von Humboldt Topical Conferences. These are a series of meetings held outside of Europe, in particular in South America, Africa or Asia, on selected topics of geosciences with a socio-economic impact for regions on these continents, jointly organized with the scientists and their institutes/institutions of these regions.

The first GIFT-AvH took place in Merida (Yucatan), the second in Penang (Malay) the third in Cusco (Peru). Each time we have had a participation of 40-45 « local » teachers. Noticeably, in the three cases it was the first workshop of the kind organized ever.

2) Educational sessions at the EGU General Assembly.

We regularly organize 8-10 educational sessions during the General Assembly. One of these sessions, mentioned above, « Sciences in tomorrow's classroom » is open to both teachers attending the GIFT workshop and to scientists with an interest in education attending the General Assembly. A growing interest has been shown in Vienna, with over 60 posters presentations, 2/3 by teachers and 1/3 by scientists.

3) The **GIFT Distinguished Lecture Series**

In 2011, the EGU Committee on Education has inaugurated an annual series of Geosciences Information for Teachers (GIFT) Distinguished Lectures, to be given by top scientists who have previously participated as speakers in GIFT workshops during EGU General Assemblies. High school teachers, high school directors and educators for teachers from the European area are welcome to ask for a GIFT distinguished Lecture!
Distinguished lectures have been given in Spain, Poland and next (2013-2014) in France, Italy and Spain.

4) The « Teachers at Sea » Program

"Teachers at sea" is an Educational Program making it possible for high school teachers to participate to oceanographic cruises together with the scientists.
3 editions of this program have taken place on board the Marion Dufresne during cruises PACHIDERME in 2007 (along the Coast and in the fiords of Southern Chile), AMOCINT in 2008 (in the North Atlantic Ocean) and CIRCEA (in the South China Sea in 2012).
On board, teachers participate to the « watches » which is really absolutely necessary for them to be in direct contact with the scientists and students and to be totally immerged in the different activities taking place on board, not only for watching the different coring operations, but also to actively participate personally to the first steps of treatment of the cores: cutting, opening, archiving, measurements of some of their physical properties and of their sedimentological description.
Part of the sediments is saved for the schools, and can be mailed to the different teachers asking for them.

2014: GIFT goes to Africa! (An EGU-UNESCO-ESA Program)

2014 brings new and fascinating prospects for GIFT. The EGU has teamed up with UNESCO to take the GIFT workshop idea to Africa. ESA has more recently joined this program. The scope is to disseminate the latest findings in science to the teachers there, to support the development of the next generation of Earth scientists in Africa. The opportunities and challenges in the Earth sciences there are great, starting with traditional mineral extraction and extending into environmental management such as climate change adaptation, prevention of natural hazards, and ensuring access to drinking water.

(http://www.egu.eu/outreach/gift/)