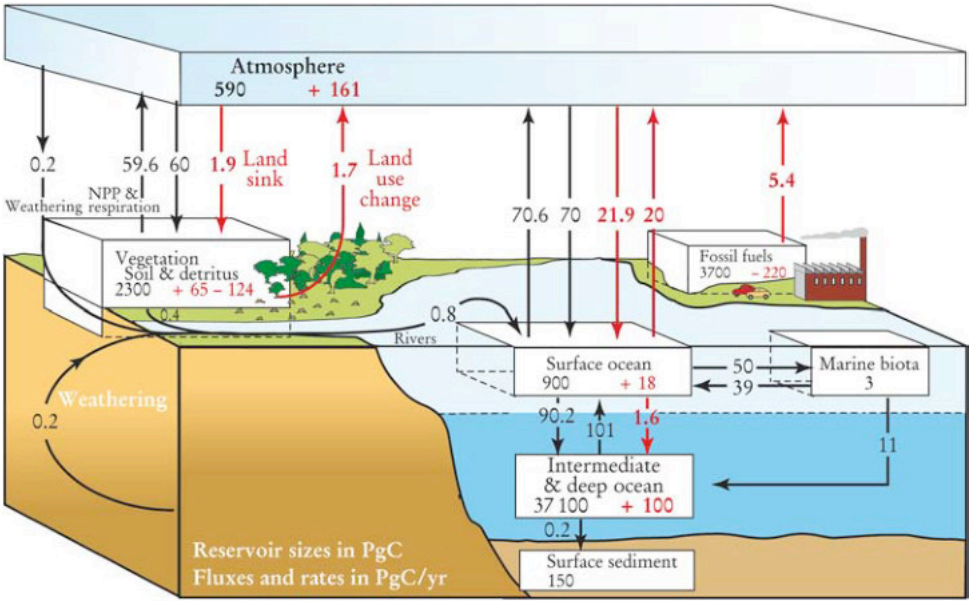
European Geosciences Union



GIFT - 2008
The Carbon Cycle

Geosciences Information for Teachers Workshop

Vienna, Austria, 14 - 16 April 2008

European Geosciences Union
GEOPHYSICAL INFORMATION FOR TEACHERS (GIFT) WORKSHOP
Austria Center Vienna
14-16 April 2008

The Carbon Cycle

Dear Teacher,

Welcome to the sixth EGU GIFT Workshop!

Seventy teachers from 19 countries will attend the GIFT-2008 workshop and we hope that this will result in international collaborations among teachers and schools in the different nations.

The general theme of the 2008 GIFT workshop is **"The Carbon Cycle"** – a theme that is central to the study of greenhouse gases and the topic of global warming. The carbon cycle is actually so important to our life that many European Community scientific research programs have been investigating its different aspects: CarboEurope, CarboOcean, EPOCA (European Project on Ocean Acidification), EPICA (European Project of Ice Coring in Antarctica) and the new project ICOS (Integrated Carbon Observation System) are significant examples.

In this GIFT-2008 workshop, all of our speakers are leading research scientists participating in these different projects. Their presentations will make the most recent developments regarding the atmospheric, biologic and oceanic aspects of the carbon cycle available to the teachers.

But, as in the preceding GIFT workshops, we have reserved time not only for scientists by also for poster and oral presentations by teachers to their fellow teachers. Don't be shy! If you have come to Vienna with an unscheduled presentation, tell us about it - we'll find a way to discuss it! This is the best way to start collaborations with your colleagues in other nations! A highlight on this argument will be the report by the 3 European teachers who have participated to the GIFT workshop in December 2007 at San Francisco, invited by the American Geophysical Union.

In addition, in collaboration with Philippe Saugier, educational coordinator of the CarboSchools program, we have invited 6 teachers already involved in CarboSchools to come and share their experience in this program with all the teachers present at the 2008 GIFT workshop. Thanks to the CarboSchools program, many teachers have already taken part in active collaborations with scientists from CarboEurope and CarboOcean and participated in workshops, field investigations and laboratory experiments dedicated to the carbon cycle. It appeared important to us to make all of the GIFT teachers aware of this educational program, and we thank CarboSchools for their involvement in GIFT-2008.

Alongside with oral presentations by scientists and teachers, Marc Jamous (IPSL) will introduce all the participants to a greenhouse experiment, suitable for classroom use. This experiment demonstrates different aspects of CO_2 – biosphere interactions over time with varying environmental conditions. All teachers will work in small groups to construct their

own classroom experiment, and the results of these different experiments will be presented by the groups to all of the workshop participants.

Finally, please, consider seriously the GIFT agreement we have asked you to endorse. The GIFT workshop is kindly sponsored by the EGU and several other science organizations. We would like to continue offering teachers the opportunity to attend EGU and the GIFT workshop, but this depends upon our being able to show our sponsors that teachers have used the new GIFT information and science didactics in their daily teaching, or as inspiration for new ways to teach science to students in their community schools. We ask that you make a presentation of your experiences at GIFT to a group of your teaching colleagues sometime soon after you return from EGU, and inform us of where, when and how many teachers attended your presentation, as well as telling us about how you have used the GIFT information in your classrooms.

Information on past and future GIFT workshop is now available on the EGU homepage. Look at:

http://www.copernicus.org/EGU/GIFT/gift_symposia.html

where you can find the brochure (pdf) and also the slides of the different presentations.

Also, look at "The Eggs", the EGU newsletters also on the EGU homepage. Kostas Kourtidis, the Editor of the newsletter invites all teachers to look at:

http://www.the-eggs.org/

with a dedicated Education column, where you can write reports on your own work and submit them at http://www.the-eggs.org/submit/ and also use the archive at http://www.the-eggs.org/archive.php to read about other teachers' work !

The Committee on Education of the European Geosciences Union welcomes you in Vienna for the GIFT-2008 workshop!

Carlo Laj
On behalf of the Committee on Education of EGU

Acknowledgements

The GIFT-2008 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:

The Direction des Sciences de la Matière of the "Commissariat à l'Energie Atomique" (CEA), in France

The American Geophysical Union, in the USA

The European Science Foundation (ESF) funded the participation of 10 teachers to GIFT-2008 under the EUROCORES Programme "EuroCLIMATE"

The National Science Foundation (USA)

The Carboschools Program

The Associazione per la Geofisica « Licio Cernobori » in Italy

The Bjerknes Centre for Climate Research in Bergen, Norway

The Institute of Geology and Geophysics, Cinese Academy of Sciences, Beijing China

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

European Geosciences Union
Committee on Education

http://www.copernicus.org/EGU/info/committee_on_education.html

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Steve Macko

Program

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

The Carbon Cycle

Sunday April 13, 2008

16:30 - **GUIDED TOUR OF THE VIENNA MUSEUM OF NATURAL HISTORY**
Herbert Summesberger
Vienna Museum of Natural History

Monday April 14, 2008

08:30 - 09:00 **OPENING OF THE WORKSHOP**
Carlo Laj
Laboratoire des Sciences du Climat et de l'Environnement
Gif-sur-Yvette, France

09:00 – 09:45 **TRENDS AND VULNERABILITIES IN THE GLOBAL CARBON CYCLE**
Philippe Ciais
Laboratoire des Sciences du Climat et de l'Environnement
Gif-sur-Yvette, France

09:45 – 10:00 **PRACTICAL INSTRUCTIONS FOR THE WORKSHOP**

10:00 – 10:30 **COFFEE BREAK**

10:30 – 11:15 NATURAL VARIATIONS OF ATMOSPHERIC CO_2 AND CH_4 FROM ICE CORES
Jérôme Chappellaz
Laboratoire de Géophysique et Géochimie de l'Environnement
Université Joseph Fourier
Grenoble, France

11:15 – 12:00 **HOW TO STUDY THE CARBON DIOXIDE CYCLE IN SECONDARY SCHOOLS: EXAMPLE OF A "HANDS-ON APPROACH", 1) INTRODUCTION**
Marc Jamous
Institut Pierre-Simon Laplace (IPSL)
Paris-France

12:00 – 13:30 **LUNCH** (SANDWICHES)

(13:00 - 13:30) LUNCHTIME VIDEO

SEARCHING FOR THE CARBON RESERVOIRS IN GAS HYDRATES AT THE BOTTOM OF THE OCEAN

Stephen Macko
University of Virginia
Charlottesville, VA 22903, USA

13:30 – 14:15 **THE ROLE OF THE BIOSPHERE FOR THE TERRESTRIAL CARBON CYCLE**

Markus Reichstein
Max Planck Institute for Biogeochemistry,
Jena, Germany

14:15 – 15:00 **Teacher – Scientist Collaborations**:

FROM TEACHER-AT-SEA TO AUTHENTIC SCIENCE IN THE CLASSROOM

Missy Holzer and Carlo Laj
Chatham High School, Chatham, NJ, USA, and
Laboratoire des Sciences du Climat et de l'Environnement (LSCE) (CEA-CRS-UVSQ), France.

15:00–15:30 **COFFEE BREAK**

15:30 – 17:30 **HOW TO STUDY THE CARBON DIOXIDE CYCLE IN SECONDARY SCHOOLS: EXAMPLE OF A "HANDS-ON APPROACH", 2) EXPERIMENTING**

Marc Jamous
CarboSchools and Geomon-Educ projects
IPSL (Institut Pierre-Simon Laplace) Paris-France

Tuesday, April 15, 2008

08:30 – 09:15 **THE OCEAN CARBON SINK, PROCESSES, TIMESCALES AND IMPACTS**

Christoph Heinze
Bjerknes Center for Climate Research
Bergen, Norway

9:15 – 10:00 **OCEAN ACIDIFICATION, THE OTHER HALF OF THE CO_2 PROBLEM: GETTING THE MESSAGE ACROSS TO POLICY MAKERS**

Carol Turley
Plymouth Marine Laboratory, Plymouth, UK

10:00 – 10:30 **COFFEE BREAK**

Teacher – to – teachers communications:

10:30 - 10:50 **ENERGY REDUCTION AT SCHOOL – EDUCATION OF SUSTAINABLE DEVELOPMENT IN PRACTICE**
Annegret Schwarz
Integrierte Gesamtschule,
Mainz, Germany

10:50 - 11:10 **REPORT ON THE AGU GIFT WORKSHOP IN SAN FRANCISCO**
Nicole Hermann, Lycée Roosevelt, Reims, France
Annegret Schwarz, Integrierte Gesamtschule, Mainz, Germany
Viola Wierzbicka-Klosiewicz , Zespol Szkol, nr.1, Swidnica, Poland

11:10 – 11:20 **Questions to Inès Cifuentes (AGU-CEHR) and C.Laj**

11:20 - 11:35 **INTERNATIONAL COOPERATION BETWEEN SCHOOLS**

Vibeke Birkmann
Greve Gymnasium, Greve, Denmark

11:35 – 12:15 **PRESENTATION OF CARBOSCHOOLS PROJECTS: PART 1**

Vibeke Birkmann, Greve Gymnasium, Greve, Denmark
Daan Bosma, Maartenscollege, Groningen, Netherlands
Bente Færøvik, Bergen Katedralskole, Bergen, Norway
Mauricette Mesguich-Vidal, Lycée Max Linder, Libourne, France
Sabine Temming, Gymnasium Wellingdorf, Kiel, Germany
Hendrik Tzschaschel, Geschwister-Scholl-Realschule, Heidelberg, Germany

12:15 - 13:30 **LUNCH (Sandwiches)**

13:30 – 15 :00 **PRESENTATION OF CARBOSCHOOLS PROJECTS: PART 2**
Vibeke Birkmann, Greve Gymnasium, Greve, Denmark
Daan Bosma, Maartenscollege, Groningen, Netherlands
Bente Færøvik, Bergen Katedralskole, Bergen, Norway
Mauricette Mesguich-Vidal, Lycée Max Linder, Libourne, France
Sabine Temming, Gymnasium Wellingdorf, Kiel, Germany
Hendrik Tzschaschel, Geschwister-Scholl-Realschule, Heidelberg, Germany

15:00 – 15:30 **COFFEE BREAK**

15:30 – 17:30 **HOW TO STUDY THE CARBON DIOXIDE CYCLE IN SECONDARY SCHOOLS EXAMPLE OF A "HANDS-ON APPROACH", 3) EXPERIMENTING**
Marc Jamous
CarboSchools and Geomon-Educ projects
IPSL (Institut Pierre-Simon Laplace) Paris-France

Wednesday April 16 , 2008

08:30 - 09:15 **CAN WE REDUCE GLOBAL CO_2 EMISSIONS WITHOUT EARLY DEPLOYMENTOF CARBON CAPTURE AND SEQUESTRATION (CCS)?**
John Ludden
Vice-President EUG
British Geological Survey
Keyworth, Nottingham, U.K

09:15 – 10:00 **REPORT ON THE CARBON DIOXIDE CYCLE (GREENHOUSE) EXPERIMENT**
Teachers and Marc Jamous

10:00 – 10:30 **COFFEE BREAK**

10:30 - 10:50 **Teacher – to – teachers communication**
INTRODUCTION TO BIOREMEDIATION AT SECONDARY SCHOOLS
Maria Angels Hérnandez
IES Valldemosa
Barcelona, Spain

10:50 - 11:50 **CLIMATE CHANGE DUE TO CO_2 INCREASE**
Jean-Louis Dufresne
Laboratoire de Météorologie Dynamique
Paris, France

11:50 – 12:00 **Final remarks and Goodbye!**

END OF THE GIFT-2008 WORKSHOP

12:00 – 13:30 **LUNCH**

Speakers

Dr. Herbert Summesberger

Naturhistorisches Museum Wien
A-1010 Vienna, Austria

A Guided Tour of the Vienna Museum of Natural Sciences

Born in 1939 (Vienna, Austria), highschool (Baden; Austria). PhD (1966, University of Vienna; main subjects: geology, palaeontology, petrology). Thesis on structural geology, stratigraphy and palaeontology in the Northern Calcareous Alps. Since 1966 curator of the Museum of Natural History, Vienna. Retired in 2004. Research on mesozoic ammonites and stratigraphy. Studies in the United States, Oxford/UK. Organisation International Symposia "Cephalopods Present and Past", Vienna 1999; “Cretaceous Symposium Vienna 2000”. Leader of the Working Group on Geosciences, School and Public Relations of the Austrian Geological Society. Member of the Board of the Friends of the Museum of Natural History. Exhibitions, seminars for highschool teachers (Biology & Environmental Sciences). Highschool books. Vienna city guide fo building and decoration stones. Excursions for students, international specialists, teachers, Friends of the Museum. 1985 Installation of the P.R. department at the museum. 1999 Initiation of a volunteers’ system. 1999 Foundation of the museum’s magazine “Das Naturhistorische”.

Philippe Ciais

Laboratoire des Sciences du Climat et de l'Environnement (LSCE)
Unité Mixte CEA-CNRS-UVSQ
91190 Gif-sur-Yvette

Philippe.Ciais@lsce.ipsl.fr

Dr. Philippe Ciais is a carbon cycle researcher. He contributed 120 publications in peer-reviewed journals, including 13 in Science and Nature. He studied Physics at the Ecole Normale Supérieure and obtained a doctorate in 1991 in isotope glaciology. Appointed as a staff member of LSCE in 1994 by C. Laj, he developed carbon cycle research in this institute since then. Philippe Ciais is Associate Director of the LSCE, Lead Author of the IPCC, member of the Global Carbon Project (GCP) steering committee, chairman of the Integrated Global Carbon Observing Strategy (IGCO) in GEOSS. He coordinated several EU projects, and more recently the "Atmospheric component" of CARBOEUROPE-IP and the GEOMON-IP integrated project. He also coordinates the preparation of a large scale European Infrastructure to measure the carbon cycle, which is called ICOS.

Trends and vulnerabilities in the global carbon cycle

Philippe Ciais

Laboratoire des Sciences du Climat et de l'Environnement (LSCE)
Unité MixteCEA-CNRS-UVSQ
Gif-sur-Yvette
France

The natural carbon cycle currently absorbs on average half of man-made emissions. Emissions are caused by the burning of fossil fuels and by tropical deforestation. Natural sinks are in the ocean and in some terrestrial ecosystems. Over the recent period 2000-2006, an important acceleration has been observed in the rate at which emissions increased, which is driven by increasing economic activity and an increasing carbon intensity of economic development. On the other hand, over the past 40 years,one can detect a small, but persistent weakening of the natural sinks.

I will review how uncertainties can be reduced on regional carbon budgets and underlying processes. The potential contribution of hot spot regions which have started and may continue to loose carbon in the coming century will be discussed.

Jérôme Chappellaz

Laboratoire de Glaciologie et Géophysique de l'Environnement (CNRS - University of Grenoble), France
(jerome@lgge.obs.ujf-grenoble.fr)

Jérôme at Talos Dome (Antarctica) last winter

Jérôme Chappellaz has obtained his PhD in Geosciences in 1990 at Grenoble, France. He produced the first long-term record of atmospheric methane changes during glacial-interglacial cycles from the Vostok ice core (Antarctica). He then worked at the NASA / Goddard Institute for Space Studies (New York, USA) to develop quantitative estimates of the past CH4 budget based on modelling. He has pioneered the use of continuous-flow isotopic-ratio analyses on trace gases in the French community and he is responsible of a mass spectrometry laboratory at LGGE. One of his current activities concerns the reconstruction of the evolution of the stable carbon isotopic ratio of carbon dioxide through time, an important constraint on the natural carbon cycle dynamics.

CNRS Director of Research since 2002, he is also the Deputy Director of LGGE since 2003. He has been involved in several tens of research projects, including numerous European projects under the 4th, 5th and 6th frameworks. He is co-author of 101 publications, among them 68 in high-ranked scientific journals.

Jérôme Chappellaz is a member of the CNRS hiring committee in ocean and atmosphere sciences, and of two International Geosphere Biosphere

Programme scientific committees : PAGES (Past Global Changes) and AIMES (Analysis, Integration and Modelling of the Earth System). He was awarded the Bronze medal of CNRS in 1993 and the Jaffé Price of the french academy of science in 2001; the Institute for Scientific Information awarded him as a "Highly Cited Researcher" in 2006.

Natural variations of atmospheric CO2 and CH4 from ice cores

Jérôme Chappellaz

Laboratoire de Glaciologie et Géophysique de l'Environnement (CNRS - University of Grenoble), France

(jerome@lgge.obs.ujf-grenoble.fr)

Understanding the complex relationship between climate, biogeochemical cycles and greenhouse gas atmospheric mixing ratios requires observations at various time scales of all parameters and reservoirs involved. On this regard, past climatic changes experienced at the Earth surface over the last hundred of thousands of years are particularly relevant, as one can simultaneously access to spatial and temporal patterns of some climatic variables, to greenhouse gas mixing ratios in the atmosphere (based on ice core studies) and to a lesser extent to ecosystem distributions and characteristics. One very important aspect of paleoclimatic research including the carbon cycle is that it provides the ground to test Earth system models and their parameterizations under boundary conditions much different from the present, and thus to improve our confidence in their forecasts for the future.

In this presentation, we will go through the current state-of-the-art regarding the past evolution of carbon-bearing greenhouse gas mixing ratio, i.e. CO2 and CH4, as reconstructed in the course of the Holocene (last 11,500 yr), the last deglaciation, the abrupt climate changes during the last glaciation and the last eight climatic cycles as depicted by the EPICA / Dome C european ice core. We will first consider the role played by greenhouse gas changes in the sequence of climatic changes observed over these time scales. We will then discuss the possible causes considered to explain their variability, notably constrained from other climatic and biogeochemical records in the marine and terrestrial realms. We will conclude about the hints that the paleo-studies give to the climate community regarding possible natural retroactions in a warmed future.

Marc Jamous

Scientific popularizer
Institut Pierre-Simon Laplace (IPSL) (
Paris, France

Marc Jamous obtained a PhD in biology from the University Pierre et Marie Curie (Paris, France), in 1994. He worked at the University of Montreal (Canada) for three years (1995-1997).

Since 2000, Marc Jamous has been working on science education. He has produced many CDrom and websites for teachers, pupils and general public. He worked for four years with the well-known French project “La main à la pâte”. This project promotes and improves science education at the primary level according the "Hands-on" method, by encouraging pupils to participate in the discovery of natural objects and phenomena through observation and experimentation.

In April 2006, Marc Jamous began to work with secondary schools and laboratories to promote pedagogical projects on carbon cycle. Aims of these activities were to give a view of the research life to pupils from 11 to 18. During scholar year 2006-2007, ten French secondary schools worked with Marc Jamous. Pedagogical projects were thought and conducted by teachers, with the help from him. Some pupils visited laboratories. At the end of projects, all students made a presentation of their works during a meeting, as researchers used to do. For this scholar year, such pedagogical projects with French secondary schools had been launched, on the carbon cycle, but also on other near environmental topics.

How to study carbon dioxide cycle in secondary schools: example of a "hands-on approach"

Marc Jamous

Institut Pierre-Simon Laplace (IPSL)
Paris-France

Carbon dioxide (CO_2) is the mainly greenhouse gas implicated on the actual global warming. It is thus important to understand its cycle to have a good idea of processes relied to global changes. We have to keep on mind that global changes are in scholar programs of many European countries.

The evolution of carbon dioxide in atmosphere follows many complex processes, photosynthesises, respiration, dissolution in sea water, human production, that are not easy to understood by pupils from secondary schools. Invisibility and lack of odour of the gas add to the difficulty. Then, we think that study of carbon dioxide cycle must follow an experimental approach in secondary schools. Students, with the help from scientific documents, should imagine hypothesises, make experiments and tend to write conclusions, under, of course, the responsibility of their teachers.

In this workshop, we ask you to be like your pupils. By using simple apparatus, except a carbon dioxide sensor that could be bought by secondary schools, you will have to imagine and realise experimental protocols to study carbon dioxide cycle. You will work by groups and you will have access to scientific articles (from newspapers), as a help to find hypothesises and experiments. With the workshop, we hope to give you a better view of research world and we would like to see with you if this approach could raise your pupils a new attraction for scientific carriers.

Stephen Macko
Professor
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Stephen A. Macko is a Professor of Isotope and Organic Geochemistry in the Department of Environmental Sciences at the University of Virginia. He received his PhD from the University of Texas in Chemistry. His areas of interest include marine organic geochemistry, deep ocean communities, meteorites and the Origins of Life as well as K-12 education and outreach. He has authored over 250 refereed research papers and books; he was elected a Fellow of the Geochemical Society and European Association of Geochemistry in 2003 and id 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.

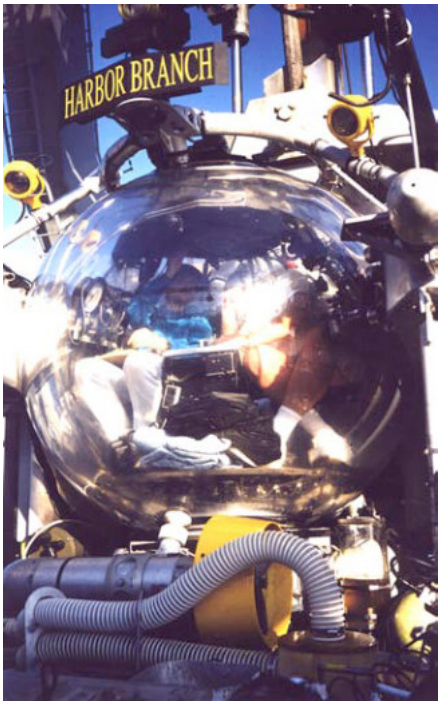
Recent projects of his include studies on chemosynthesis at cold seep sites and hot vents using the Johnson Sea Link and Alvin submersibles for sample acquisition; interpretation of ancient human diet; tracking fires and aerosols from sub-Saharan Africa, establishing the geochemical conditions of the Earth prior to the origins of life and pioneering the broadcast of live interactive classes between Africa and the USA.

He has been a scientist or chief scientist on numerous oceanographic expeditions, as well as a 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 a number of public and commercial radio and television interviews, including National Public Radio, about his research. His laboratory is featured in “King Corn”, a documentary on the influence of corn on the lives of North Americans, opened at Independent theaters in New York and Washington in October, 2007 and will appear on PBS in April, 2008.

Searching for the carbon reservoirs in gas hydrates at the bottom of the Ocean

Stephen Macko
University of Virginia
Department of Environmental Sciences
Charlottesville, VA 22903 USA

Gas hydrates represent one of the largest and most dynamic reservoirs of organic carbon, in particular methane, on Earth. Current estimates of the mass of carbon in global gas hydrate vary; however, the reservoir mass is probably between 10^{18} and 10^{19} g of carbon. Geochemical models, paleontological analyses and stable carbon isotopes suggest that large changes in global hydrate inventories have contributed to rapid shifts in global climate in past periods of Earth history .The largest fraction of the gas hydrate reservoir is buried beneath 200–300 m of sediment at the base of continental margins. Often these locations are also regions of petroleum seepage at which incredible communities of organisms have been found, and that base their existence on chemosynthesis through the utilization of the gas and oil seepage as a source of energy. This talk will be based around a video documentary of the speaker's dives in the Johnson Sea Link submersible to locations deep within the Gulf of Mexico. Highlights of the film are segments showing some of the exotic organisms such as tube worms and mussels that survive on symbiotic bacteria that consume oil and natural gas.



Stephen Macko (blue shirt) inside the Johnson Sea Link submersible about to dive in the Gulf of Mexico.

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Dr. Markus Reichstein
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Markus Reichstein is head of the Biogeochemical Model-Data Integration Group at the Max-Planck Institute for Biogeochemistry in Jena, Germany. Markus studied Landscape Ecology with complement subjects Chemistry, Botany and Mathematics/Information Science at the University of Münster, Germany. His master thesis was dedicated to analyzing and modelling microbial biomass and carbon mineralization of organic layers in the Alpine forest-tundra ecotone (finished 1998). Thereafter Markus went to the University of Bayreuth to work on a PhD thesis on "Drought effects on carbon and water exchange in three Mediterranean ecosystems" largely based on eddy covariance flux data and ecosystem-physiological modellling. With an Intra-European Marie-Curie fellowship Markus went to work in Riccardo Valentini's lab at the University of Tuscia, Viterbo Italy, from where the ecosystem component of the CARBOEUROPE project is coordinated. There he worked on integrating whole ecosystem CO_2 and H_2O gas exchange (FLUXNET eddy covariance) and remote sensing earth observation data with biogeochemical models of various complexities. This research is further pursued in the new Biogeochemical Model-Data Integration Group in Jena with focus on model-data synthesis, data mining, carbon-water interactions and soil process modeling.

The role of the biosphere for the terrestrial carbon cycle

Markus Reichstein
Biogeochemical Model-Data Integration Group, Max-Planck-Institute for Biogeochemistry, Jena, Germany

It is estimated that the terrestrial biosphere takes up globally 120 Pg C per year by gross photosynthesis and looses a slightly lower amount by autotrophic and heterotrophic respiration. These gross fluxes are more than 10 times higher than our annual fossil fuel emissions. The interannual variability of atmospheric CO_2 growth rates is strongly correlated with the activity of the terrestrial biosphere. These facts alone show the importance of the terrestrial biosphere for the global carbon cycle.
Compared to the gross fluxes the net sink (gross uptake minus respiration) is however very small. Moreoever, the sink function of the biosphere is highly variable and vulnerable, such that we currently think it will stop during the course of this century.
In this presentation I will review, explain and discuss the major components, processes, factors and feedbacks that constitute or influence the terrestrial carbon cycle and will present the current knowledge and speculations about how it will evolve under climate change conditions.

Some related publications of mine:

Ciais, P., M. Reichstein, N. Viovy, A. Granier, J. Ogée, V. Allard, N. Buchmann, et al. 2005. Europe-wide reduction in primary productivity caused by the heat and drought in 2003. Nature **437**:529-533.

Reichstein, M. 2006. Integration of FLUXNET and Earth observation data with biogeochemical modelling. iLeaps Newsletter **3**:32-34.

Reichstein, M., P. Ciais, D. Papale, R. Valentini, S. Running, N. Viovy, et al. 2007. A combined eddy covariance, remote sensing and modeling view on the 2003 European summer heatwave. Global Change Biology **13**:634–651.

Reichstein, M., D. Papale, R. Valentini, M. Aubinet, C. Bernhofer, A. Knohl, et al. 2007. Determinants of terrestrial ecosystem carbon balance inferred from European eddy covariance flux sites. Geophysical Research Letters **34**:L01402, doi:01410.01029/02006GL027880.

Heimann, M., and M. Reichstein. 2008. Terrestrial ecosystem carbon dynamics and climate feedbacks. Nature **451**:289-292.

Piao, S. L., P. Ciais, P. Friedlingstein, P. Peylin, M. Reichstein, S. Luyssaert, et al. 2008. Net carbon dioxide losses of northern ecosystems in response to autumn warming. Nature **451**:49-U43.

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Carlo Laj
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Missy and Carlo in Punta Arenas, touching the thumb of the Indian to have good weather !

Missy has been teaching high school science in the United States for over 20years and loves her job as much today as she did when she first started.Her philosophy in education includes using hands-on, minds-on inquiryactivities as a way to promote life-long learning in her students. Her students use real-time and original data and data tools in their pursuitof understanding Earth System Science. She enjoys field researchimmensely and has assisted in data collection in places such as Nicaragua,Kenya, Ecuador, Jamaica, 250 miles off the coast of Oregon and off the coast of Chile. Back in the classroom she uses her field experiences to develop units of study thatwill inspire students to get out and explore their natural world. Outsideher classroom she enjoys working with teachers and collaborating on ideasfor new and exciting educational materials. She is currently a doctoral student in science education at Rutgers University in New Jersey, USA.

Carlo has attended secondary school in Italy and the USA (American Field Service Exchange Student) and did his University studies at theUniversity of Paris, where he obtained his PhD in Solid State Physics. After his PhD he spent a few years working with critical phenomena (scattering of laser light by critical fluids) then moved into the field of geophysics.
His main interests in this new field have 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 excursions). In recent years he has used marine cores for attempting reconstructions of environmental and climatic changes on a global scale.
Carlo has published about 180 articles in international scientificjournals and is a Fellow of the American Geophysical Union (AGU).
He is the Chairman of Education Committee of the European Geosciences Union and a member of Committee on Education and Human Ressources , AGU

From Teacher-at-Sea to Authentic Science in the Classroom

Margaret Ann (Missy) Holzer and Carlo Laj

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and

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Research has shown that most teachers will teach the way they have been taught, unless a sustainable intervention has taken place. This has the greatest implications for teachers of science, where those who have been taught with inquiry approaches will employ inquiry approaches in their classrooms, and those who have been taught with lecture and note taking will teach primarily using lectures and note taking. If our children are to learn about the nature of science, they need to be taught using constructivist and inquiry methods. A teacher who only uses textbooks and lectures will not create students who can employ critical thinking skills indicative of the nature of science. There is a way to change the way our teachers teach science, and that is by exposing teachers to authentic inquiry. The Teacher at Sea Program sponsored by Institut Polaire Francais (IPEV) created such an opportunity for 4 teachers, who participated in the PACHIDERME deep sea sediment cruise on the R/V Marion Dufresne off the coast of Chile for 3 weeks in February, 2007. While onboard the teachers assisted research scientists from France, Germany, Norway, and Chile in their quest to gather and analyze sediment cores for clues to past climates. The teachers were immersed in the research projects right from the start. They all participated in a "watch" and assisted those on the watch with the processing of the cores, which included properly labeling and packaging each of the core segments. Prior to the packaging, preliminary analysis was done to identify the physical and biological attributes of the core. The scientists gave of their time to coach the teachers not only on the techniques they were using, but also on the process of science. Whether it's working on an unstable platform, coring into the unknown, or adjusting to the weather that Mother Nature brings, the nature and process of science out at sea is complicated. The teachers came to realize this as they sailed in and out of the fjord region and into the open ocean off the coast of Chile, and shared these experiences with colleagues and students from around the world. They sent daily logs via email, sent pictures, and answered questions sent by teachers and students from Europe, the United States, and Chile. Students kept journals as they followed the daily events of the teachers at sea. A powerpoint presentation documenting the scientific endeavors of the cruise was created and is being used by many teachers as a tool to show how scientific research is done at sea. Was this cruise effective in changing the teaching styles of those teachers on board? The teachers observed how scientists generate questions, propose study plans, and employ creative methods to answer those questions. Having witnessed the nature and process first hand, these teachers reassessed their teaching styles for scientific validity. They are employing a greater number of open/full inquiry projects where the students are constructing and

seeking to answer their own questions. These students will leave their classes knowing about the challenges of doing science, and the excitement in doing science. Whether it's out at sea, in the field, or in a lab, the participation of teachers in authentic inquiry is the best way to ensure our students are participating in authentic inquiry.

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Christoph Heinze was born in Cologne, Germany and received most of his academic education from studies at the University of Hamburg (Institute for Oceanography) and the Max Planck Institute of Meteorology under guidance of Ernst Maier-Reimer and Klaus Hasselmann. Being by definition a "physical oceanographer" he already in his master thesis became interested in oceanographic tracers. This interest was deepened during his PhD work about the glacial CO_2 reduction in the atmosphere where he extended his view to the modelling and interpretation of marine sediment core data. He also worked for 2 years in Denmark at the National Environmental Research Institute. Since 2004 he is professor in chemical oceanography in Bergen, where he is currently coordinating the biggest European collaborative research project on the oceanic uptake of anthropogenic CO_2 so far. He was a lead author of chapter 7 on climate-biogeochemistry couplings for the 4th IPCC Assessment Report (Working Group I) published in 2007.

Primary research interests:
_ Marine biogeochemistry
_ Prognostic 3-D simulations of marine biogeochemical cycles
_ Quantification of the global carbon cycle
_ Feedback processes between climate and biogeochemical cycles
_ Understanding, interpretation, and simulation of the climatic paleo-record

Present position:
Professor in chemical oceanography at the Geophysical Institute of the University of Bergen (*Universitetet i Bergen*), Norway.
Leader of the Research Group 4 "Biogeochemical Cycles" at the Bjerknes Centre for Climate research, Bergen, Norway.
Project director ("co-ordinator") of the EU FP6 *Integrated Project* CARBOOCEAN – Marine carbon sources and sinks assessment. http://www.carboocean.org

Academic degrees:
Habilitation (1999, Thesis: "Das marine Sediment als Klimazeuge und Komponente des Klimasystems – eine Modellstudie [The marine sediment as a climate record and component of the climate system - a model study]").
PhD (1990, Thesis: "Zur Erniedrigung des atmosphärischen Kohlendioxidgehalts durch den Weltozean während der letzten Eiszeit [On the reduction of the atmospheric carbon dioxide concentration by the world ocean during the last glaciation]").

Diploma (1987, Thesis: “Diskussion der Tiefenwassererneuerung im Europäischen Nordmeer und im Eurasischen Becken unter Zuhilfenahme anthropogener Spurenstoffe [Discussion of the deep water renewal in the Nordic Seas and the Eurasian Basin by use of anthropogenic tracers]“).

The oceanic carbon sink - processes, timescales, and impacts

Christoph Heinze

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The ocean is a large natural carbon reservoir and will be the major ultimate sink for anthropogenic carbon. During the past decade, the ocean has taken up each year about 25% of the annual anthropogenic CO_2 emissions from fossil fuel burning and land use change.

The major reason for the considerable carbon storage in the ocean is the ability of seawater to dissociate CO_2. Only about 1 % of the inorganically dissolved carbon in the ocean is available as CO_2 (or – if hydrated with water H_2O – as carbonic acid H_2CO_3) while the remainder is dissociated into bicarbonate HCO_3^- (90 %) and carbonate CO_3^{2-} (9 %). The atmosphere and the ocean are linked through air-sea gas exchange processes. Water which has taken up anthropogenic carbon from the atmosphere is mixed into deeper layers of the ocean. CO_2 additions to the ocean lower the pH value of seawater and decrease the saturation for $CaCO_3$ (calcium carbonate). The upper ocean is at present everywhere oversaturated with respect to $CaCO_3$. Therefore, $CaCO_3$ sediment is found on topographic highs in the ocean like snow on the mountains. Anthropogenic CO_2 in the ocean will shallow the $CaCO_3$ saturation horizon and by and by dissolve the top layer of $CaCO_3$ sediment. Thus additional amounts of anthropogenic CO_2 can be neutralised to a considerable degree on very long time scales. Biological production of organic carbon at the sea surface lowers the surface CO_2 concentration locally, while production of shell material consisting of $CaCO_3$ increases the CO_2 concentration. Sinking biogenic particles are degraded in the water column or reach the sediment depending among other factors on the conditions in the water column, the size of particle aggregates, and the topography. The removal of biogenic particles is approximately balanced by input from the continents through rivers (and through Aeolian deposition). The biological carbon pump is intimately coupled to the nutrient cycling. Therefore, to first order, the biological carbon cycling does not directly contribute to the uptake of anthropogenic CO_2 itself, though it can locally influence the surface CO_2 concentration. However, changes in climatically induced ecosystem shifts, processes dependent on the CO_2 concentration in the surface layer, changes in nutrient supply from the continents, and ocean circulation changes can also induce changes in the biological carbon cycling with respective feedbacks to the atmosphere. It is possible, that marine biological processes contributed significantly to the natural glacial-interglacial shift in atmospheric CO_2 concentration.

Current observations indicate that the oceanic sink for anthropogenic carbon is at work indeed. It also shows that this sink regionally and temporally undergoes considerable changes, including a potential decrease in CO_2 sink strengths in the important deep water production areas of the North Atlantic and the Southern Ocean.

The timescale for the global overturning of the ocean in total is ca. 1500 years. Therefore, efficient oceanic buffering of anthropogenic carbon takes time. Neutralisation of human made CO_2 through $CaCO_3$ sediment dissolution takes even longer – several 10,000 years. Because of these long time scales for efficient ocean CO_2 buffering, reductions in CO_2 emissions are indeed helpful, as they give the ocean more time to mix waters carrying a high anthropogenic CO_2 load with more pristine waters.

The ocean does a major service to human societies by taking up large amounts of the CO_2 which is being emitted. However, the pH lowering of sea water (termed "ocean acidification" though the ocean is slightly alkaline) due to the human carbon additions may alter oceanic ecosystems. There is strong evidence that the pH change combined with the increase in water temperature will have detrimental effects to corals and other organisms which produce calcareous shell material. The impact of ocean acidification on life in the ocean and potentially the marine food chain is one of the hottest study fields of contemporary oceanography. Increasing CO_2 loads in the ocean will in addition reduce the oceanic CO_2 buffering ability so that lower percentages of CO_2 emissions to come will be taken away from the atmosphere through the marine carbon sink. Future scenarios therefore predict a positive net oceanic carbon cycle feedback to climate change for most model systems available at present. In summary one can state: The oceans are very efficient carbon sinks on long timescales. The pH lowering of seawater and the expected positive carbon cycle climate change are important factors which have to be taken into account in attempts to limit human induced CO_2 emissions to the atmosphere.

Carol Turley
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Dr Carol Turley's is a senior scientist at Plymouth Marine Laboratory in the UK with over 30 years research experience in marine science. Her interests have centred on the role of microbes in the ocean's biogeochemical cycles looking at habitats from deep-sea sediments, estuaries, frontal systems to large enclosed waters such as the Mediterranean to the open waters of the North Atlantic. She currently works on the impacts of climate change, ocean acidification and mitigation technology on marine ecosystems. She has produced over eighty peer reviewed publications and a similar number of reports and other publications. She was an author of the Royal Society and OSPAR Reports on ocean acidification. She has given advice to policy makers and other stakeholders and sits on senior committees for NERC (Strategy Panel on Climate Change; Advisory Committee on 2007SR on Energy), EPSRC (Energy Science Advisory Committee; Strategic Advisory Team), DEFRA (Marine Assessment Policy Committee), The Royal Society (Marine Advisory Network; Climate Change Advisory Network), the EU (FP7 Science Advisory Committee) and is a member of the IMBER (Integrated Marine Biogeochemical and Ecosystem Research) Scientific Steering Committee (an International Global Biosphere Programme). In the last year she has given invited key note presentations at international conferences held by the EU, the European Science Foundation, the Royal Society, and the Royal Society of Medicine and at the UK Parliamentary and Scientific Committee. She was Lead Author on the Intergovernmental Panel on Climate Change 4th Assessment Report, WGII, for Chapter 4 – Ecosystems, Their Properties, Goods and Services.

Ocean Acidification, the other half of the CO_2 problem: getting the message across to policy makers

Carol Turley
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The World's oceans play a vital role in the Earth's life support system through regulating climate and global biogeochemical cycles through their capacity to absorb atmospheric carbon dioxide. Oceans have already absorbed nearly half of the CO_2 produced by burning fossil fuels over the last 200 years and through this they have been buffering climate change.

However, when carbon dioxide reacts with water it produces carbonic acid, so when more CO_2 is taken up by the surface of our oceans the more surface ocean pH decreases (pH is a measure of acidity). Surface ocean pH has already declined by about 0.1 since pre-industrial times which may not sound much but as pH is measured on a logarithmic scale and measures the amount of hydrogen ions (H+) in the water it means that the amount of H+ has increased by 30%. If this trend continues and we burn all available fossil-fuel reserves, ocean pH will fall further (and acidity increase) by as much as 0.4 units from its current level of around pH 8.1 by the year 2100 and 0.67 by 2300. This is called "ocean acidification" and is happening at a rate that has not been experienced for at least 400,000 years and probably for the last 20 million years.

Changes to CO_2 concentrations in seawater also affects the rest of the carbonate cycle, with increased CO_2 resulting in a decrease in the amount of carbonate ions in seawater. Carbonate ions are used by calcifying organisms to make calcium carbonate shells, skeletons and liths (small platelets). Currently most surface waters of the world's oceans are saturated with carbonate ions. However, the lower the concentration of carbonate ions, the harder it will be for calcifying organisms like corals to make their shells or skeletons. In waters undersaturated in carbonate ions the unprotected shells of calcifying organisms will dissolve.

The effect of ocean acidification on marine ecosystems and organisms that inhabit them has only recently been recognised and is of growing concern to scientists and policy makers involved in climate change, biodiversity and the marine environment. Early findings imply that continued ocean acidification could lead to potentially significant changes to species biogeography, biodiversity loss, radical alteration of the ocean carbon cycle, changes to nutrient and trace metal speciation and trace gas flux, alteration of food webs, ecosystem and their services, including fisheries and shellfisheries but uncertainties are great and research is urgently need to reduce uncertainties.

As ocean acidification emerges as a key research issue for the future there is a need to bring together research scientists from many disciplines to address its complexity and to predict future impacts at different CO_2 emissions and stabilization scenarios. Additionally, it is important that scientists in this field bring this information to policy makers and other stakeholders, especially those involved in climate stabilization negotiations. I will be discussing some of the approaches scientists have taken to do this. As IPCC (2007) has recognized ocean acidification, for the first time, as a potentially serious climate change issue let us hope that this feeds into the future negotiations on

climate change – because the only way of reducing ocean acidification on a global scale is the urgent and substantial reduction of our emissions of CO_2.

Further information and references can be found in:

Raven et al. (2005) Ocean Acidification. A Report by The Royal Society Working Group on Ocean Acidification. There is a summary for policy makers and contains a very useful review of ocean acidification and the potential impacts. http://www.royalsoc.ac.uk/document.asp?id=3249

IGBP-SCOR Fast Track Initiative "Ocean Acidification" Workshop (2006): Ocean acidification—modern observations and past experiences. A useful summary of what can be learnt from the geological record of past acidification events: http://igbp-scor.pages.unibe.ch/firstworkshop.html

Haugan et al. (2006) Effects on the marine environment of ocean acidification resulting from elevated levels of CO2 in the atmosphere, DN-utredning 2006-1. This is a science rich report of potential impacts on the OSPAR region (N Atlantic). http://www.ospar.org/documents/dbase/publications/p00285_Ocean%20acidification.pdf

Joan A. Kleypas et al. (2006) Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers: A Guide for Future Research. A report summarising impacts on calcifiers from a workshop sponsored by the National Science Foundation, the National Oceanic and Atmospheric Administration, and the U.S. Geological Survey. http://www.ucar.edu/communications/Final_acidification.pdf

Schubert et al. (2006) The Future Oceans – Warming Up, Rising High, Turning Sour. A report by the German Advisory Council on Global Change (WBGU) on climate impacts on oceans. http://www.wbgu.de/wbgu_sn2006_en.html.

Fischlin et al. (2007) Ecosystems, their properties, goods, and services. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, 211-272. This is the chapter in the IPCC report that deals with impact of climate change on the oceans but there are many other interesting chapters http://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-chapter4.pdf

The SCOR UNESCO ocean acidification website provides a central source of information for ocean scientists on research activities in this area, including resources, links to blogs, research programmes and information on the latest publications. http://www.ocean-acidification.net/

The EUR-OCEANS Fact Sheet on ocean acidification, a useful quick guide. http://www.eur-oceans.eu/WP9/Factsheets/FS7/FS7_web.pdf

Annegret Schwarz

http://rfb.bildung-rp.de/rfb/schwarz-dr-annegret.html
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Activities:

- Geography teacher
- Project manager of KESCH (= energy reduction at school for the purpose of protecting the global climate)
- Head of the Geography Department at school
- Regional Adviser for the Geography teachers of secondary education schools in the area
- Secretary for Education of Sustainable Development at the Federal Department of Education and Cultural Affairs in Mainz, Rhineland-Palatinate

The presentation:
Energy Reduction at School – Education of Sustainable Development in Practice

The Education of Sustainable Development (ESD) is very valuable in strengthening the capacity of students to make judgements and choices in favour of a safer, healthier and more prosperous world, thereby improving the quality of life in general. This learning process can provide a critical reflection and greater awareness in the younger generation, which leads to a change of lifestyle, including the patterns of consumption and production.

Facing today's global problems, the importance of ESD, the motto of the UN-decade 2005 – 2014, is well known and broadly accepted. Teaching sustainable development is, however, quite a challenge for the teachers who try to implement the topic in regular lessons at school. One of the reasons could be that the term sustainability, as such, is rather abstract and hardly conceivable for the young individuals in class. Therefore, several ideas how to teach ESD successfully are given in the presentation.

In addition, the government of Rhineland-Palatinate, a federal state in Germany, has established an ESD network of schools. All the participating schools regularly take part in conferences and teachers' training programs in order to put ESD into practice successfully. This network is coordinated by the federal department of education and the federal department of environmental affairs, which have several advisors of ESD to support the schools in their objectives toward sustainable education.

NICOLE, VIOLETTA AND ANNEGRET (left to right) **IN SAN FRANCISCO !**

REPORT ON THE AGU GIFT WORKSHOP IN SAN FRANCISCO

NICOLE HERMAN has been a teacher for nearly 40 years : first a primary school teacher, then a Mathematics or Technology teacher in a junior high school and now an Applied Physics teacher to post-baccalaureat students in the Lycée Roosevelt in Reims, France. She has been a member of different research teams implemented by the ministry of Education since 1987 (pedagogical uses of satellites images, computer assisted experiments in Science, location by satellite…) and has organized workshops for students in her school on all the subjects linked with satellite data: local satellite images, oceanographic measurements using drifting buoys... and recently a workshop on atmospheric studies.(nicole.herman@wanadoo.fr)

VIOLETTA WIERZBICKA-KLOSIEWICZ is a graduate of University of Wroclaw (master's degree in physics and in philosophy) and now ateacher of Physics and Philosophy at the Zespol Szkol Nr1 in Swidnica, Poland. She has School Festivals of Physics, and she is an author and coordinator of the Socrates Comenius project "About birds in English" (six schools, six countries); She also organizes School Festivals of Science, during which students can have direct access to University scientists and their work. Coordinator all pro-ecological activities taken by school. (violettawierzbicka@gazeta.pl)

ANNEGRET SCHWARZ, is a teacher at the Integrierte Gesamtschule Mainz, Germany. See her curriculum in the previous page!

REPORT ON THE AGU GIFT WORKSHOP IN SAN FRANCISCO

A Presentation of the European teachers

Nicole Herman (France), Viola Wirzbicka (Poland), Annegret Schwarz (Germany)

The AGU Fall Meeting in San Francisco (Dec. 10-14, 2007) was an outstanding experience for the three of us. Thanks to the invitation of the American Geophysical Union (AGU), we had the wonderful opportunity to participate in the conference with a widespread range of sessions, incorporating atmospheric sciences, hydrology, biogeosciences, ocean sciences, seismology, geophysics, geodesy and many more.

The essential meeting for the American teachers and for we European teachers was the GIFT-workshop, which took place on two days as part of the AGU Fall Meeting.

This provided an excellent occasion to get information on current scientific issues, such as the climate change science or the IPCC report, as well as practical studies on activities for the classroom. In the course of this outstanding program it was exciting for us to work together with the American colleagues and to have the opportunity to exchange our different ideas and experiences. Contacts with teachers and researchers were made. Since then relations have intensified between the participants. Now we are thinking about mutual projects for the near future. On the whole, this event has been an invaluable and very memorable experience for us European teachers.

Vibeke Birkmann

Senior teacher (biology and English) and pedagogical inspector,
Greve Gymnasium,
Denmark

INTERNATIONAL COOPERATION BETWEEN SCHOOLS

A description and evaluation of possible joint projects. The overall outline is planned in advance by the teachers, but the students take part in the details of the plan. The subject is chosen in advance by teachers and could be "global warming, local changes" . The actual project comprises e-mail contact between students, and the compilation of joint reports, and perhaps even student exchange.
The official framework could be Carbo Schools or Young Reporters for the Environment and there is a possibility to apply for a Comenius grant.

PRESENTATION AND DISCUSSION OF CARBOSCHOOLS PROJECTS

Project on Global Warming

An interdisciplinary cross-curricular project based on the film "An Inconvenient Truth"

The idea of the project is to fulfil the obligation of introducing students to interdisciplinary based problem solving and to the various theories of knowledge (epistemology, theory of scientific research) that is a part of the Danish Baccalaureate exam giving entrance to universities.

The students chose the subject "global warming". They worked on the scientific aspects of this subject and especially the possible consequences for Denmark in their biology lessons in the weeks leading up to the project week.
These biology studies also included lab work and field investigations with visits to research sites

Students doing lab work

The actual week the students worked in groups. The traditional school timetable was suspended.

The project was based on an evaluation and discussion of Al Gore's film "An Inconvenient Truth"
At the end of the week the students should give an oral presentation (in small groups) and start a debate. The teachers gave them the following points to consider:

- What artistic effects are being used in the film to underline Al Gore's point of view?
- Discuss the scientific focus of the film. Are all the consequences presented scientifically sound, and is anything left out?
- Give an account of the rhetorical patterns of speech used in the film
- Give an analysis of the film and genre to which the film belongs
- How are the basic values of the American society reflected in the film?
- Give an analysis of the relationship between facts and beliefs in the film

The subjects involved were biology, Danish, history and ancient history (rhetoric).

English was also associated to the project. The students read English articles and played the climate board game “Keep Cool” that is played in English.

Students doing field work

Students playing ”Keep Cool” – a climate board game

Vibeke Birkmann, senior teacher (biology and English) and pedagogical inspector,
Greve Gymnasium,
Denmark

Daan Bosma,

Maartenscollege
Postbus 6105
9702 HC Groningen

Daan Bosma completed his study of Biology at the University of Groningen in 1975. He is teaching Biology and Computer science at a school in the same town, where both secondary and pre-academic education are given.

Local CO2 trapped in our school web

Al Gore's "*An Inconvenient Truth*" has made CO_2 reduction one of the hottest news items today. Ever since the documentary came out, the daily news is dominated by alarming predictions and ambitious reduction plans. However, all this attention is focused mainly on global and average CO_2 concentrations. The great dynamics of atmospheric CO_2 levels on a local scale and the complexities of measuring CO_2 have managed to escape from media attention.

We want to let pupils work with CO_2 in their own environment instead of global average levels. In our project, pupils interpret local atmospheric CO_2 levels, measure CO_2 in an experimental setup to monitor combustion or photosynthesis, and make calculations on the CO_2 emission of human activities.

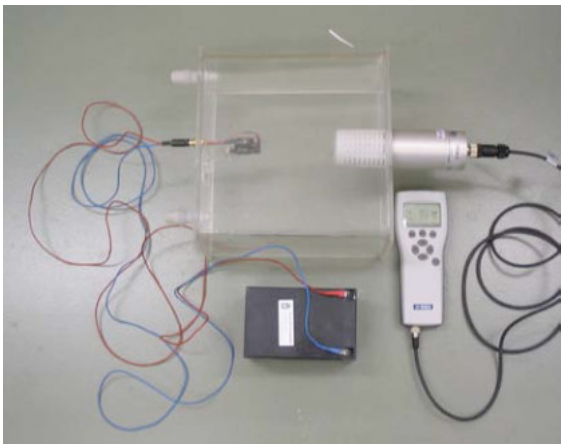
To make monitoring local CO_2 levels possible, a network of science teachers ("Studiestijgers") and the Faculty of Mathematics and Natural Sciences of the University of Groningen (Centre for Isotope Research (CIO) and Department of Education) collaborate in a project on measuring atmospheric CO_2 on the roofs of schools. This project is called the SchoolCO_2-web.

Currently, three schools in the northern part of the Netherlands are equipped with semi-professional CO_2-sensors (Vaisala GMP 343) and weather stations (Davis Vantage Pro). The first school is located in an urban area, the second in the countryside and the third in a suburb. The measurements are permanently collected on a central computer and will be available on a website for public use. Teachers and pupils are invited to analyze these data and interpret the results.

Vaisala GMP 343 on suburb school Maartenscollege

On the short term, day-night, seasonal and local fluctuations of CO2-levels and fluctuations induced by atmospheric turbulence and inversion (dependent on weather circumstances) can be determined. On the longer term, and by using proper data selection schemes, the seasonal cycle of CO2 will become visible (already after 18 months), and after two-three years, the raising of the carbon dioxide background level can be observed and even quantified. Moreover, effort has been made to choose equipment that can provide us with measurements which could be accurate enough to be used within scientific research.

Currently, the teacher network is working on designing new projects and educational material. One of the goals is to produce a module within the framework of a new science subject "Nature, Life and Technology". This module will focus on the art of measuring and interpretation of data, in which CO_2-measurements and the data of the SchoolCO_2-web will serve as the central context. In this way we encourage pupils to think about the carbon cycle and factors influencing carbon dioxide levels.



CO_2 box for measuring photosynthesis and respiration in the classroom

Besides this module, the teacher network is working on a number of smaller projects. Some of these will be designed around the measurements of the SchoolCO_2-web. But another way in which teachers want pupils to work with CO_2 is to let them do measurements themselves. The idea is to design a CO_2 box. This will basically consist of a big transparent plastic box with an opening for a CO_2 meter. Inside this box, you can put plants, insects or burn material. With the CO_2 meter you can measure the effects of respiration and combustion. This could show pupils for example how long grass needs to fix the amount of CO2 which is being released by burning a match.

A third kind of projects will focus on calculations on the CO_2 emission of human activities and the efficiency of our current solutions. These projects will build around questions like: how many trees do I need to plant to compensate my flight to New York and how much CO_2 is emitted for production of the meat I eat? By working on these calculations, we hope that pupils get insight in the relative effect of different human activities on CO_2 emission and reduction.

The SchoolCO_2-web will participate in the Carboschools+ project. This means that the SchoolCO_2-web will expand, not only in the Netherlands, but also with several new schools in European countries being connected in 2008 and 2009. In these countries initiatives will also being taken to start identical teacher networks. This will bring the opportunity to compare data collected at schools all over Europe and to organize international discussions between students.

Bente Færøvik,
Biology, Scienceand ICT (Information, Communication Technology)
Coordinator for the science subjects at Bergen Katedralskole and contact person towards Carboschools.

Bergen Katedralskole
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The Norwegian branch of Carboschools/Carbonordic/Carboocean

The sea outside our door

This project is a cooperation between Bergen Katedralskole (an upper secondary school in Bergen, Norway) and Bjerknes Centre for Climate Research in Bergen. So far 26 students, 4 teachers and 4 scientists/technicians have been involved in the project.

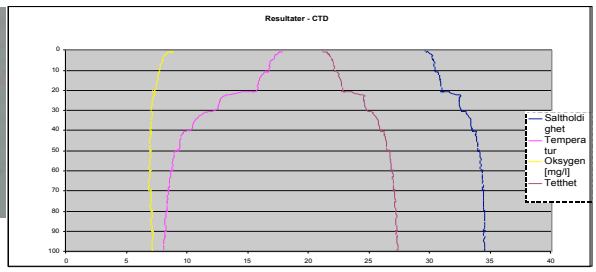
In the initial phase scientists from BCCR gave a lecture about the carbon cycle to the science teachers and to the students. The students also had lectures at school about the greenhouse effect.

Students from Bergen Katedralskole were then invited by BCCR to take part in 4 science expeditions with RV Hans Bratstrøm to explore the fjords in our local area outside Bergen.

In august 2006 26 students (age 17) and 3 science teachers from Bergen Katedralskole were on board to investigate sea water in Hjeltefjorden. 2 scientists /technicians from BCCR joined us and explained how to use the scientific equipment on board and how to do the sampling. They had to explain the scientific background, what is measured, and demonstrate experiments. They helped the students to analyse samples and calculate marine carbon cycle

RV Hans Brattstrøm is equipped with a plankton net, seabed grabsampling equipment, a water sampler and a sensor for hydrography measurements. The students investigated depth, temperature, salinity, and did oxygen measurements and investigation of plankton. They also learned about life and security on board.
In april 2007 the same group of students had a new cruise to 2 new locations (Vatlestraumen depth 50m and Korsfjorden depth 500m). The students' work was to take new samplings from the two locations and compare them. The students did seabed grab-sampling surveys and

compared the species found at the seabed of the two locations. To analyze the Carbon-samplings, 5 of the students visited the laboratories at Bjerknes Centre for Climate Researsh using their equipment.

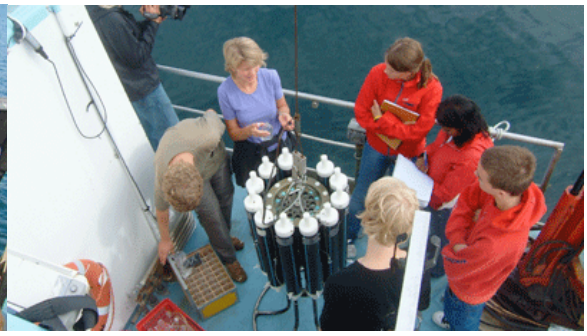


Zooplankton

Results from the CTD measuring

The students' work consisted in collecting all relevant data, analyze the data and write a report from the work on board with pictures of all relevant equipment.

Plankton



Watersampling

This project is part of a subject called Science. The students have to do a scientific investigation in one of the science items. They may use 2 teaching hours every week. It has been possible to change the schedule for one special week or day so that we may join the cruise. Work hours used by the students: 4 hours learning about the greenhouse effect, 4 hours visiting the laboratories at BCCR and have a lecture about the marine carbon cycle, 2 hours to prepare the cruise, 4 days at cruise and 10 –12 hours work after the cruise.

Positive aspects of this project: The students were very interested and worked very hard. The scientists from BCCR were motivated and helpful.
Negative aspects: Because of matters outside our control, it was difficult to fulfill the report from the last cruise. Exams were close and other excursions had to be made. This subject is not evaluated by grading. It is just approved. I think it is better with evaluation by grade. It can also be difficult to change the schoolschedule to get one day at cruise.

CARBOSCHOOLS project in Bordeaux *: school year:* 2007 2008

This is a collaboration between our high school "L*ycée* Max Linder" and the EPHYSE research unit from INRA Bordeaux.
34 pupils 16 year-old
8 teachers are involved with the following disciplines: physics and chemistry, biology and geology, economics and ECJS, English, Spanish, mathematics, two documentation assistants.

Mauricette Mesguisch-Vidal
Lycée Max-Linder Bordeaux

Assessment of the actions carried out since the beginning of the year:
Collective actions:

- Conference by a scientist from INRA on the climate, carbon cycle and role of forests. Nearly 100 pupils attended this conference.
- Visit of the experimental site " Le Bray" in October 2007 by all the pupils accompanied by 5 teachers and a laboratory assistant: discovery of plant species of the forest, observation of the sensors on the site with a researcher (see photograph). This maritime pine forest has been studied since 1987 by INRA for the CARBOEUROPE and previous projects.

- The pupils produced a slide show report of their visit. It shows what they have learnt about different sensors and their understanding of how researchers study the interaction between the atmosphere and forest vegetation.

Multi disciplinary actions:

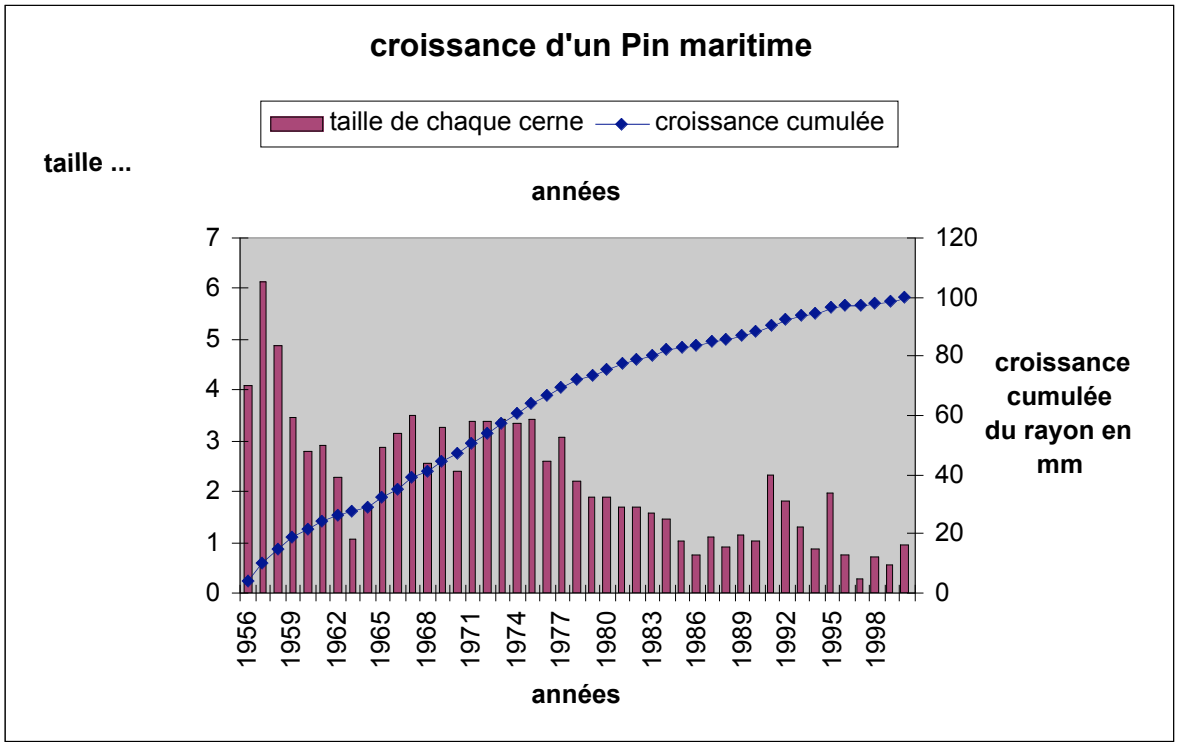
- In MPI (physical measurements and computing):

we study the mechanics of some sensors from their physics and electrical points of view and twos was combined with the exploitation of the data measured by the sensor. Data are exploited in the form of files provided by the INRA.

For example, we study the diameter growth of trees. First we study the principle of the physical sensor: the potentiometer then data measured by this sensor. Then we can see the growth of the tree over one year.

We also study ring width and dendrochronology.

A picture of the work produced by 2 pupils on the growth of the trees: see picture enclosed



The next sensor to be studied is an infra red CO_2 analyser.

- In ECJS (civic, law and social education) and economics: various research topics were chosen by the pupils: the forest, the ecological footprint, Grenelle of the environment – a governmental forum organised last September, the various aspects of sustainable development...
- In SVT (biology and geology): the greenhouse effect, action of the human being on the environment (in progress)
- In English and Spanish: work on the vocabulary related to the climate change starting from texts or video documents.

We have planned an exhibition in our high school during the week for sustainable development from 1st to April 7 08.

Sabine Temming

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- Secondary school teacher (grade 5 to 13) in Biology, German and Drama
- Head of Biology Department, Gymnasium Wellingdorf in Kiel
- NaT-Working Marine Research: Project member and school representative
  in cooperation with IFM-GEOMAR (Leibniz Institute for Marine Sciences),
  the University of Kiel and the Cluster of Excellence "The Future Ocean"
- CarboSchools EU Project: Pedagogical Advisor

NaT-Working Marine Research, Kiel, Germany:
Students, Teachers, and Researchers Study the Ocean

Concept:

Using the specific example of marine sciences, NaT-Working *Marine Research* attempts to convey the fascination of natural sciences and the complexity of the climate system to students from secondary schools. Supplementary to work in the classroom, opportunities are provided for practical studies on current research issues in direct contact with researchers. The students obtain hands-on experience with scientific methods and insights into research on topics as diverse as deep-sea ecosystems and CO_2-induced ocean acidification.

Research vessels: Polarfuchs and ALKOR

Contributors:

The project is funded by the NaT-Working Program of the Robert Bosch Foundation and through its participation in the Kiel Cluster of Excellence "The Future Ocean" by the German Research Foundation. Scientists of the Leibniz-Institute of Marine Sciences and the Christian-Albrechts-University in Kiel contribute their knowledge in biological, chemical, physical, meteorological, geological, economical and legal aspects of oceanography. Together with the teachers of the participating schools, this network provides the necessary background for the complex topics in geosciences and ecology.

Practical Implementation:

Grade 10 – 13: Together with their teachers and marine scientists the students work individually or in groups. The projects range from short- (days) to long-term (months) and are conducted within the schools as well as at the Institute of Marine Sciences. Wherever possible, the projects are designed to be

interdisciplinary, linked to actual research and integrated into the school curriculum. Results are presented by the students, and the work of the students is usually graded.

These research projects are supplemented by a "Rent-a-Scientist" program, exhibitions at the institute such as the "Day of Marine Research", teacher training seminars and field trips on the Baltic Sea. The projects are presented to the public in exhibitions, symposia, on the web and as posters and exhibits at the schools.

Preparing a scientific poster

Dicscussing results during an exibition

Young Scientists

Grade 5 – 8: Young Marine Scientists:
In a Student Science Club, an interdisciplinary afternoon activity, younger pupils obtain their first exposure to scientific work. Through various experiments in topics ranging from osmoregulation in marine organisms to simulation of the Gulf Stream in tanks, the pupils acquire the basic skills for “learning by research”.

Examples for current projects:

_ Single student projects:
→ *Mnemiopsis – an “alien species” in the Baltic Sea*

_ Course projects:
→ *Ecology of the Kiel Fjord*
→ *Fertilizing the Oceans with Iron - Ecological and Legal Aspects of Engineering a CO_2 drawdown.*

student experiment:
seastars preference of specific salinities

→ *The Effects of Changing Salinity on Organisms*

_ Student Science Club:
→ *Young Marine Scientists: Monitoring the Kiel Fjord*
→ *Ocean Experiments in the Classroom*


"Open day" at IFM-GEOMAR

Investigating the Effects of Changing Salinity on Organisms -
A Course Project in a 12th Grade Ecology Class

I will mainly report about the collaboration between my Advanced Biology class and scientists of IFM-GEOMAR. We have been pursuing this 6 month project to investigate the effects of changing salinity on organisms in the estuary of a local river. Students developed their own research questions and designed experiments to find answers. They were working in groups together with scientists and presented the results as written reports, posters and talks at school. In addition they presented their work to the public during a an "Open Day" at IFM-GEOMAR. In a final step, the students are preparing a web presentation on the project.
I will show examples for the various results of the groups, and the different types of collaboration with scientists.

Hendrik Tzschaschel
Geschwister-Scholl-Realschule in
Mannheim, Germany

Teacher of Mathematics and Science – especially chemistry and physics

Lead teacher for science teaching in Baden-Württemberg

EU-procject TSP: Teacher – scientist – Partnership

Overall aim and specific objectives

Overall aim is to identify the needs of science teachers to prepare them for teaching authentic science, according to national and local conditions. Specifically, we devise bottom-up approaches and identify evidence-based practice for integrating teacher development, student learning and school development into innovative project work with research institutions.

Another important fact is improving student learning by involving them in practical tasks in authentic research environments as well as improving teaching methodology of teachers and designing innovative learning environments. Integrating external learning into schooling on regular basis is essential.

The project is an innovative systemic approach to teaching and learning of science and professional teacher development. It focused on improving teachers' abilities to use authentic external learning as a tool for development.

There has to be a professional partnership between teacher education, science research and schools.

Our Geschwister-Scholl-Realschule cooperates with the University of Education Heidelberg and the University of Applied Sciences Mannheim.

Geschwister-Scholl-Realschule – PH Heidelberg

The new curriculum in science of year 10 (students aged 16) implicates teaching in groups. Every group organizes their own program for three months. All projects in science are designed to be interdisciplinary and integrated in the general school program.

Four teachers of the school are involved in the special project TSP working together with scientists of the PH Heidelberg and the University of Applied Sciences Mannheim.

Two teachers planned with students to organize their projects and used authentic external learning places.

First group

19 students were involved in this group. 6 teams worked on different projects about using solar energy. The motto was: “If we use new forms of energy, we will reduce the output of carbon dioxide”.

The students worked together in teams of 3 – 5 students started in September with their own ideas and finished their projects in December.

In cooperation with tutors of the laboratory “science-live!” the students were devoted to the topic climate and energy.

The students developed their own ideas:

-to build a catamaran, which uses solar power.
-to discuss using solar energy in the universe
- to use solar energy with a collector
- to build a solar mobile ….. →

The second group

20 students were involved in this group. 5 teams worked on different projects about climate change and global warming together with the institution science live! and scientists of the University of Applied Sciences Mannheim.

Students attend a workshop activity in science one afternoon per week, learning the basics skills for researching. The students investigate different forms of new energy, using external learning places. A model for a water pump driving with solar power is planned.	

Next we will find out about climate change. We install different sensors for CO2 and weather data on the roof of the school and would like to communicate with other people who measure the data about CO2 production.

Prof. John Ludden
Executive Director of the British Geological Survey
Vice-President of EGU

Professor John Ludden is the Executive Director of the British Geological Survey. In this role he oversees all of the activities of the BGS in the UK and internationally. The BGS employs 800 people at three principal sites (Keyworth-Nottingham, Edinburgh, and Wallingford) across the UK, and involves a budget of about £55 million.
Before taking the post at the BGS, he was Director of the Earth Sciences Division at the CNRS, the French National Centre for Scientific Research. He has also served as Director of Research for the CNRS in Nancy, France, where he also taught at the French National School of Geology (ENSG-Nancy). Prior to this, Professor Ludden worked at the University of Montreal, Columbia University and with Woods Hole Oceanographic Institution in the USA. He holds a doctorate in Igneous Petrology from the University of Manchester, UK. Professor Ludden is currently Past-President of the European Geosciences Union. He is appointed as a Visiting Professor in Earth Sciences at the University of Oxford and University of Leicester, UK.

Can we reduce global CO_2 emissions without early deployment of Carbon Capture and Sequestration (CCS)?

John Ludden,
Executive Director, British Geological Survey, UK.

There is no doubt that conventional oil is definitely on the way out and despite the massive advances in exploration technology over the last three decades the world is not replacing reserves with discoveries. This means that oil products from conventional oil will be replaced by:

- Unconventional oil produced from tar sands and oil shales
- Gas to liquids technology based on natural gas
- Coal pyrolysis

This will accelerate emissions growth on top of the emissions from projected energy demand growth. What's more many natural gas fields with associated CO_2 will be produced as gas prices rise. Currently anthropogenic emissions are about 30Gt/year and volcanic emissions~0.3Gt. Anthropogenic emissions are rising at more than 2.5%/annum (~750Mt/annum)

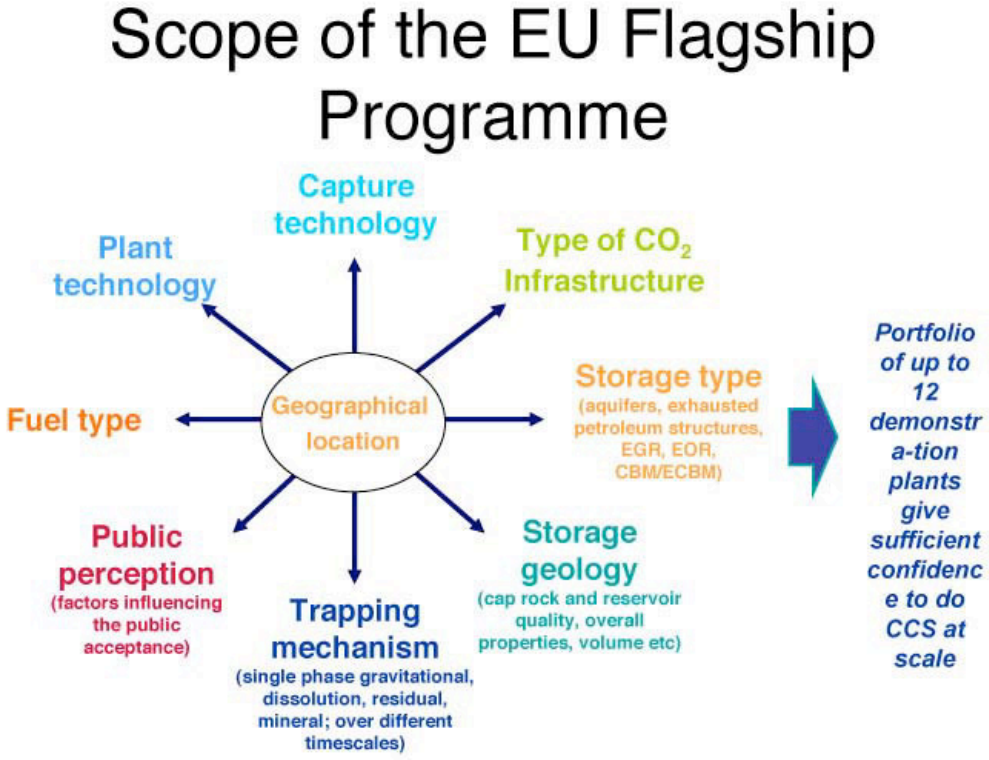
Current atmospheric CO_2 concentrations are 383ppm (CO_2equivalent is ~ 375ppm) . It is likely that 2ºC above pre-industrial (1750, 278ppm CO2) global average temperature will be reached when CO_2eq (Total) is ~450ppm provided emissions peak no later than 2015 (IPCC 2007). A 2º C rise is defined by policymakers (e.g., EU member states) as the threshold above which warming is classed as "dangerous". Achieving peak CO_2eq (Total) before 2015 seems highly unlikely as global policy is failing to be effective in reducing emissions.

If we go for staying within a 3ºC threshold above pre-industrial then we need to peak CO_2eq (Total) no later than 2030 (IPCC 2007). This is still achievable provided we deploy CCS on a global scale over the next two decades. But is 3ºC acceptable given that at high latitudes this may mean >5ºC rise because the Arctic is warming at twice global average?

EC intends to have all new European fossil power-plant build fitted with CCS after 2020 with existing plant progressively retrofitted. UK intends to demonstrate retrofit on commercial scale by 2014.

So the challenge is political. We can already deliver CCS technology and constantly improve on this. Rapid political progress has been made in the last 5 years. EC will issue a Directive on CCS (January 2008)

There is no agreement yet on CCS in Kyoto phase 1 & 2 or post Kyoto agreements and this will be vital if CCS is to be deployed in the BRICS.



The figure above demonstrates the aims of the ETP-ZEP European Technology Platform for Zero Emission Power-plants Flagship Programme. It is instructive in that it shows that a combination of technologies and of geological repositories is possible for CCS. The ZEP has been lobbying the EC to help fund research and technology in this area so that different energy producers can test and optimise technology.

Various geological media are envisaged. These are oil and gas fields, saline aquifers, coal seams. It will be important to match CO2 sources and geological storage sites and to undertake experimental studies of flow and transport, thermodynamic and kinetic processes and geochemical interactions.

An important consideration is storage safety. The EC has funded a project CO2 GeoNet is looking at natural analogues and conducting controlled release experiments. Indications are that leakage has only local ecological effects. People who live on natural CO2 seeps are being interviewed by about how they live with the hazard and their views on CO2 storage as a technology. The highest risk of leakage is with the engineered infrastructure, not the the geology. We know where boreholes are so they can be monitored and fixed if needed. Thorough geological characterisation and operation of storage with due diligence are essential to minimise leakage risk.

There is no single technology/strategy that can reduce emissions to the level required and global emissions are still rising despite the focus on renewables, energy efficiency etc. CCS is the only technology that deals with fossil fuels directly and can deliver deep cuts in fossil fuel emissions. Its looks like its already too late to prevent global emissions peaking before 2015, hence we are on the trajectory for a >2ºC rise above pre-industrial (contrary to EU policy). If we are to cut and reverse CO2 emissions no later than 2030 we must deploy CCS now. Or we will be on the trajectory for a >3ºC global temperature rise and risk ocean acidification.

Acknowledgements: BGS CCS team Drs Nick Riley, Sam Holloway and Andy Chadwick and the ETP-ZEP European Technology Platform for Zero Emission Powerplants.

Maria Angels Hérnandez

IES Valldemossa, Barcelona
Spain

M.Àngels Hernández. Biologist. Biology and Earth Sciences teacher. Teaches in a state run public secondary school in Barcelona, Spain, both compulsory 12-16 and non-compulsoty 16-18. Teacher trainer involved in teaching science in foreign languages and particularly through international projects. Has published several educational books and DVDs on Biodiversity, the Origin of Life, Applications of Science and Technology , the very latest on The Energy of the Future.

Introduction to Bioremediation at secondary schools

Workshop on **Bioremediation** : Presentation of a science lab practical experience

The goal of the experience is to demonstrate that bioremediation may occur in nature spontaneously given enough time.

To illustrate the process the presentation to teachers will deal with different facts according to the living being biotype involved in bioremediation (whether it is a bacterium, a fungus or a plant).
At present we are setting an experience studying bioremediation of petroleum hydrocarbons. The material needed is easily available at any gas station (polluted soil with petroleum hydrocarbon contaminants). Natural degradation shall take place at different rates according to bacterial features and limiting nutrients. The set includes 8 beakers (4 pairs) with oil, soil, bacteria (in some cases well known oil-degrading ones) and a variety of inorganic nutrients undergoing a range of temperatures and light expositions.
We shall record the process at different stages and assess the best conditions and biotypes for bioremediation in our particular case.

Jean-Louis Dufresne

Laboratoire de Météorologie Dynamique
IPSL
Paris, France

Dr. J.L. Dufresne is "Chargé de Recherche" at CNRS, in the Laboratoire de Météorologie Dynamique, where he is the leader of the **"Climate modeling and global change"** team.

He participates to the development of the IPSL climate model, to the realization of climate change simulations and to their analysis.

His main research topics during the last 10 years are radiative transfer computations, development of model coupling, studies of global climate and climate change, cloud feedbacks and climate-carbon cycle feedbacks analysis.

He also participates to different educational workshop, such as the GIFT workshop in 2004, and promotes various simple experiments that illustrate climate physical processes.

Main research Topics :

- Radiative transfer in gazes
- Climate change studies
- Climate feedbacks and climate / carbon feedback
- Atmosphere / sea-ice / ocean coupling and interactions
- Atmosphere - ocean coupled GCM development
- Radiative transfer in planetary atmosphere (Earth, Mars, Venus)
- Airborne ultra sonic anemometer thermometer

Climate change due to CO_2 increase

Jean-Louis Dufresne
Laboratoire de Météorologie Dynamique - Isntitut Pierre Simon Laplace
CNRS - UPMC
Paris, France

The earth surface is heated by solar radiation and is cooled by convection, evaporation of water and emission of longwave radiation (also called infra-red radiation). At thermal equilibrium, the power received by the surface should be balanced by the power lost by the surface. This law, called heat budget law at equilibrium, has been first established by Joseph Fourrier, a French physicist, in 1824. Although many of these heat exchanges were not quantified, he correctly deduced that a change of the solar radiation or of the surface characteristics will impact the earth surface temperature.

If we now consider the earth and its atmosphere as a whole, radiation is the only possible heat exchange between the earth and space. The earth is heated by absorption of solar radiation and cooled by emission of longwave radiation and at equilibrium this two radiative fluxes have the same value. The longwave radiation emitted by the earth to space is much lower than the longwave radiation emitted by the surface, and the difference between these two longwave fluxes is due the "green house effect". Since the end of the 19th century, it has been recognized that water vapour (H_2O) and carbon dioxyde (CO_2) are the two major greenhouse gazes of the atmosphere.

The hypothesis that a change of CO_2 concentration may change the greenhouse effect and therefore the global mean surface temperature was first made by Svante Arrhenius, a Swedish chemist, in 1896. He made a first estimate of the absorption of the longwave radiation by the water vapor and the carbon dioxide of the atmosphere. Using a very simple model, he estimates the impact of a change of the CO_2 concentration on the global mean surface temperature. But these computations contained some important errors.

During the 20th century very strong progress was made in our understanding of the physical laws that describe the emission and absorption of radiation. Since 1970-1980 radiative transfer in the atmosphere is accurately computed and it is possible to estimate how much any change of the H_2O or CO_2 concentration modify the heat budget of the earth. One can for instance obtains that a doubling of the CO_2 concentration increases the radiative budget of the earth by almost 3.7 $W.m^{-2}$, to be compared to the 240 $W.m^{-2}$ of the solar radiation absorbed, on global average, by the earth. If nothing else that the temperature may change (i.e. if the water vapor, the clouds... do not change), the heat imbalance due to a doubling of the CO_2 concentration would lead to a global warming of almost 1.2°C. But this hypothesis is very crude. When the temperature change, the water vapor, the clouds, the snow cover, and many other climate variables are also modified. These changes affect the heat budget and therefore the global mean temperature. They are called feedbacks, and are positive if they amplify the initial temperature change and negative if they damp it.

It appears that there are many strong positive feedbacks in the climate system. To illustrate this, we show in figure1 the mean surface temperature increase due to a doubling of the CO_2 concentration as computed by 12 models that participate to the

preparation of the IPCC fourth assessment report that was published in 2007.

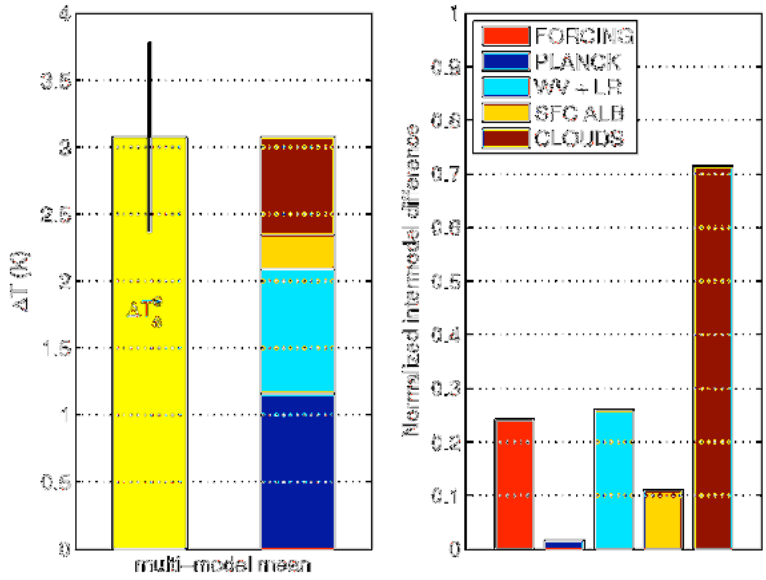


Figure 1: For a CO2 doubling, **(a, left)** multi-model mean ± 1 standard deviation of the equilibrium temperature change (DT^e_s) and contributions to this temperature change associated with the Planck response, combined water vapor and lapse rate (WV+LR) feedback, surface albedo feedback and cloud feedback. **(b, right)** inter-model standard deviation of the temperature change estimates associated with the radiative forcing, the Planck response and the various feedbacks normalized by the inter-model standard deviation of the equilibrium temperature change DT^e_s as reported in (a). (*Dufresne et Bony, 2008)*

On the left of this figure, it is shown that the multi-model global warming is about 3°C, with a standard deviation of 0.7°C. The temperature increase if all but the temperature were constant (the "Planck response") is 1.2°C. The water vapor feedback increase this temperature by 0.9°C. When the temperature increase, the atmosphere may hold more water vapor, and the increase of the water vapor amount increase the greenhouse effect, and therefore the temperature. An other feedback is called the "surface albedo" feedback and increases the temperature by 0.3°C. It is due to a change of the snow and the sea-ice cover. When the temperature increases, the snow and the sea-ice cover is reduced. As they reflect the solar radiation, the reduction of the snow and the sea-ice surface leads to an increase of the absorbed solar radiation, and therefore an increase of the heat absorbed by the surface. The last feedback involves clouds. Clouds reflect solar radiation, which cools the surface, and they absorbed longwave radiation, which enhances the greenhouse effect and heats the surface. How the balance between these two opposite effects change with climate is difficult to assess. It appears that in current climate models the cloud feedback increases the temperature by 0.7°C. This value is a multi-model mean and may be very different from one model to another. On the right of figure 1, one can observed that the cloud feedback is currently the main cause of spread of the temperature increase estimate.