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PAGES news

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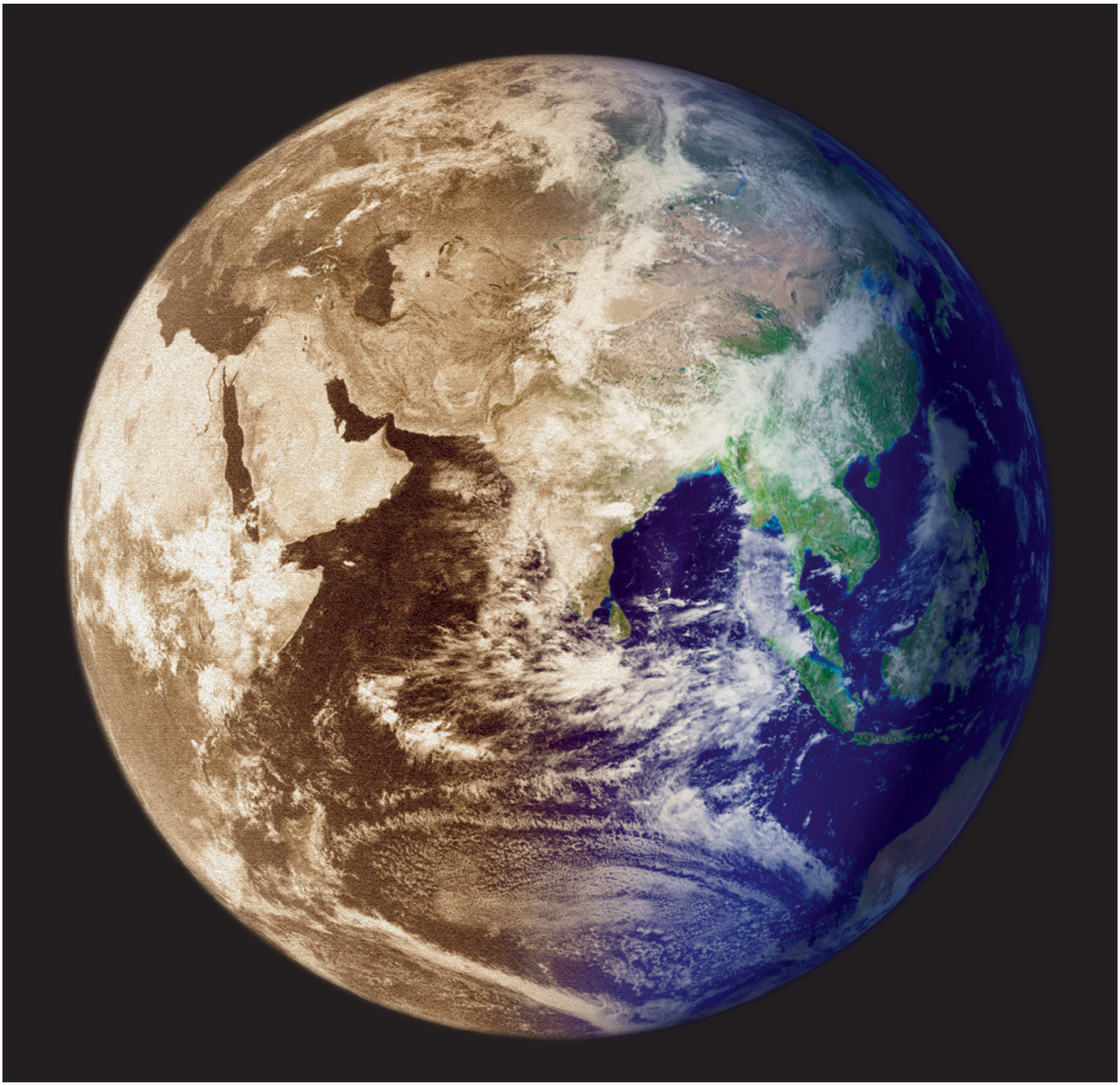
Paired Perspectives on Global Change

Editors:
Ninad R. Bondre, Thorsten Kiefer and Lucien von Gunten



Inside PAGES

New Working Groups

Three new PAGES Working Groups have been established since the last newsletter to help strengthen PAGES science.

The Sea Ice Proxies (SIP) was formed to critically assess and compare the different proxies for sea ice, in order to make recommendations about the reliability and applicability of each in the Arctic and the Antarctic setting. An extended objective will be to facilitate the production of new synthesis estimates of past sea ice extent based on the assessed proxies.

The Solar Forcing Working Group was created with the aim of bringing together scientists from the solar physics, climate modeling, and palaeoclimate reconstruction communities and contribute to a better mutual understanding and closer collaboration over open questions relating to solar-terrestrial interactions.

A new Ocean2k Working Group was created to complete the PAGES 2k Network that looks into the climate of the past two millennia. Ocean2k is also endorsed by CLIVAR and attempts to reconstruct and analyze the sea surface conditions and marine climate of the last two millennia. Paleoceanographic evidence is compiled from high-resolution archives, mostly sedimentary cores and corals (see page 4).

Staff updates

Michelle Kaufmann has relinquished her position as PAGES Finance and Office Manager. We wish her all the best and are grateful for her six years of dedicated service. Michelle has been replaced by Sonja Nyfeler and Francesca Baumgartner, who are sharing the duties between them. Sonja will stay on until her maternity leave in June after which Francesca will assume full charge of administrating PAGES finances.

New SSC members

Bette Otto-Bliesner, former PAGES co-chair, rotated off the Scientific Steering Committee (SSC) along with SSC members Cathy Whitlock and Zhongli Ding. Sadly, Mohammed Umer who was also scheduled to rotate off, passed away in November (page 3). PAGES is grateful for their commitment and stewardship all these years.

Alan Mix has replaced Bette as PAGES co-chair.

Four new members have been nominated to serve on the PAGES SSC from January 2012:

Janet Wilmshurst is a paleoecologist at Landcare research based in Lincoln, New Zealand. Her work focuses on applying paleoecological perspectives to current ecological issues. She is currently working on the effects of natural disturbance (volcanism, fire, storms, and earthquakes) on New Zealand's Holocene vegetation; the impacts of initial human settlement on pristine island ecosystems in South and East Polynesia; past diets of extinct avian herbivores; and the effects of introduced vertebrates on vegetation.

Liping Zhou is the Cheung Kong Professor of Physical Geography at Peking University in Beijing, China. He has mainly worked on chronology of geological and archaeological records in arid and semi-arid regions in northern mid-latitudes. His current research involves extensive use of ^{14}C and ^{10}Be in the study of biogeochemical dynamics on land and in the ocean. He is vice president of the Stratigraphy and Chronology Commission, INQUA.

Sheri Fritz is the George Holmes University Professor at the University of Nebraska – Lincoln, USA with appointments in both the Department of Earth and Atmospheric Sciences and the School of Biological Sciences. Her research uses lacustrine stratigraphic sequences to reconstruct past patterns of climate variation and of biotic and ecosystem evolution.

Immaculate Ssemmanda is a palynologist and lecturer in the Department of Geology at Makerere Univeristy in Kampala, Uganda and has been active in paleoclimate research in East Africa since the early 1990s. She is currently working on reconstructing past vegetation change in western Uganda as a part of a larger project on climatic and anthropogenic impacts on African ecosystems.

SSC nominations

PAGES invites nominations of scientists to serve on its SSC, which is responsible for overseeing PAGES activities. Scientists who serve on the SSC normally do so for a period of 3 years, with the potential for renewal for an additional term.

Up to 3 new members are sought to join in 2013. Deadline for sending in nominations is 5 March 2012. Please refer to the PAGES website for nomination guidelines (My PAGES > Get Involved).

OSM and YSM in 2013

The 4th PAGES Open Science Meeting (OSM) & 2nd Young Scientists Meeting (YSM) will be held on 13-16 Feb 2013 and 11-12 Feb 2013 respectively in Goa, India. With less than a year left, the local hosts and PAGES are working enthusiastically to ensure the meetings will be memorable and showcase the best in paleoscience. The theme for the OSM and YSM is The Past: *A Compass for Future Earth*. It was chosen to reflect the role of paleoscience in the recent shift towards sustainability and finding solutions.

Next newsletter issue

The forthcoming issue of *PAGES news* will showcase the latest work of PAGES-relevant science in Japan. Subsequently PAGES is preparing a newsletter with a special section on ENSO. Most of the articles are already in preparation but particularly fitting articles with new perspectives on ENSO are still welcome. Please send your contribution ideas to Pascal Braconnot (pascale.braconnot@lsce.ipsl.fr) before 31 May 2012.

You are also invited to submit at any time Science Highlights, Program News and Workshop Reports for the Open Section of *PAGES news*. Guidelines for authors can be found on the PAGES website (My PAGES > Newsletter).

Meeting support

The deadline for applying for PAGES meeting support is 5 March 2012. The subsequent deadline will be 30 September 2012.

PAGES offers meeting support for three categories of workshops that are relevant to PAGES Foci and Cross Cutting Themes: PAGES Working Group Meetings, Educational Meetings, and Open Call Meetings.

Application guidelines and online form can be found on the PAGES website (My PAGES > Meeting Support).

Eulogy: Mohammed Umer Mohammed

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The untimely death of Dr Mohammed Umer Mohammed, during fieldwork in the Afar on 27 November 2011, is a grievous loss to his numerous colleagues and friends in the international community of environmental geoscientists. Mohammed was Associate Professor at the Department of Earth Sciences, Addis Ababa University, for 19 years, where he initiated and led the Paleo-environment and Paleoanthropology Program. He served as a member of the PAGES Scientific Steering Committee, as co-leader of the PAGES Africa 2k Working Group, and of PAGES Science Focus 4 (Past Human-Climate-Ecosystem Interactions). He was a dedicated, inspiring and internationally recognized researcher, a truly dedicated mentor and educator, an ambassador for African science and for PAGES, and a much-valued friend to his students and colleagues.

Mohammed Umer, PAGES SSC member 2006-20011

Mohammed was born on 22 June 1959 in Robe, a small town in the Arsi Mountains, east of Ethiopia's Rift Valley. He graduated from Addis Ababa University with a BSc degree in Geology in 1981, and taught at Asmara University, Eritrea, for five years, before beginning research at the University of Aix-Marseille III. His PhD, on the vegetation history of the eastern Ethiopian highlands, was completed in 1992, despite the difficulties of undertaking fieldwork during a period of political transition. His subsequent research focused largely on the environmental history of Ethiopia, where he made significant contributions to knowledge of that country's place in the environmental, cultural and human evolutionary history of Africa. Mohammed took a full part in academic administration, as Associate Dean of the Faculty of Science of Addis Ababa University from 2005 to 2007, and was recently elected a member of the University Council.

Mohammed was a founding member of the East African Quaternary Research Association, and was elected its President in February 2011. He was a member of the executive committee of the International Association of Geomorphologists, and of the steering committee of the Hominid Sites and Paleolakes Drilling Project, supported by the International Continental Scientific Drilling Program. He was a key partner in the current Ethiopian Lakes Paleoenvironmental Reconstruction Project, led from Cologne University. These, and many other international scientific projects in Ethiopia, owe Mohammed a debt of gratitude: he was an essential and indefatigable colleague, making use of his wide-ranging network of friends to smooth the path of fieldwork and conferences, working with Ethiopian, French, American, German and British partners with tireless energy, great good-humor, and boundless enthusiasm.

Personally, I owe much to Mohammed for 18 years of fruitful collaboration and close friendship, during which we shared many memorable times – coring Rift valley lakes, surveying Lake Tana, exploring Mechara caves, and fieldwork on horseback in the mountains of south-western Ethiopia. Without his skills and enterprise, the work would have been almost impossible, and certainly far less enjoyable. He was a marvelous raconteur, with an inimitable style, and a vast store of amusing stories. Only a week before he died, Mohammed clearly enjoyed hosting a lunch party at his home for Ethiopian and international friends. That was just after fieldwork at the Dendi lakes, where he told me that he had now achieved two of his three "dream lakes", the others being Garba Guracha in the Bale Mountains, for which he published the vegetation history, and the sacred lake on Mt Ziqwala, which he held realistic hopes of investigating.

Hard as it is for us, his friends and colleagues, to know that we will not share more adventures with him, it must be so much harder for Hawsa, his wife, and his two young children to have lost such an inspiring husband and father. His legacy will be for us, his friends, colleagues and students, to continue the research that he so much valued, and to further the training of those who would follow in his path.

Ocean2k Working group – Call for participation

OCEAN2K

Reprint of PAGES e-news, vol. 2011, no. 3 from 5 December 2011

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Following a suggestion from the CLIVAR Scientific Steering Committee (SSC) and a meeting of the PAGES 2k network leadership in Bern, July 2011, the PAGES SSC endorsed the formation of a ninth 2k group focusing on the global oceans: Ocean2k. Motivating this project is an interest in placing observed historical marine conditions into the context of climatic variation over the past 2,000 years (Box 1). We plan to generate two outputs in time for consideration in the IPCC's Working Group I fifth assessment report, and contributing to the PAGES2K synthesis planned for 2014.

Box 1: Motivating questions

- What are the principal patterns of variation in ocean properties observed in both paleodata and paleomodeling simulations forced with realistic external forcings?
- What are the most likely underlying mechanisms?

The first goal is a metadatabase (Box 2) of Ocean2k-relevant proxy records and model output from publicly-accessible and citable sources, to be completed in January 2012. The metadatabase will comprise paleodata spanning the past 2000 years, as well as climate simulations from the fifth Coupled Model Intercomparison Project (CMIP5) and the third Paleoclimate Modeling Intercomparison Project (PMIP3). We hope that we can detect in the corresponding data and simulations the ocean imprint of large-scale variations in processes such as the Atlantic meridional overturning circulation, annular mode activity, monsoon circulations, and El Niño-Southern Oscillation (ENSO).

Box 2: Ocean2k matadatabase components and criteria

- Paleoproxy database of marine origin: from the public NOAA/WDC-A (http://www.ncdc.noaa.gov/paleo/) and PANGAEA (http://pangaea.de/) data portals
  - Variable: local interpretation of the measured proxy data
  - Time interval: any portion of the past 2000 years
  - Minimum time resolution: decadal to centennial
  - Minimum chronology resolution: 1 date per 50-500 years, as applicable
  - Uncertainty: internal and/or external reproducibility; interpretation, or bulk uncertainty
  - Reference: a citation in the peer-reviewed literature is available
  - Data link: A URL to the data source in a publicly accessible data repository

- Climate model output database: from the public CMIP5 (http://cmip-pcmdi.llnl.gov/cmip5/data_portal.html?submenuheader=3) and PMIP3 (http://pmip3.lsce.ipsl.fr/) data portals
  - Variable, time interval, uncertainty, reference
  - Data link: A URL to the model output in a publicly-accessible data repository

The second goal is a synthesis paper, based on the metadatabase, addressing the questions in Box 1, and submitted no later than July 2012. We will review the principal interpretable features in the data and simulations, discuss likely underlying mechanisms, identify leading uncertainties, and highlight areas for future research.

Given the short timeline, Ocean2k is currently not planning project meetings. Instead, we are dividing up the work and using the internet for regular communications. We need your help to achieve the group's ambitious goals (Box 3).

Box 3: Call for collaboration

- Have you developed data or modeling results that are not yet archived in a publicly-accessible archive? Please consider contributing it to an appropriate data portal (Box 2). We can then include your work in the paleometadatabase.
- Would you like to collaborate on the synthesis paper during the first half of 2012?

Please contact Mike Evans (mnevans@geol.umd.edu). The Ocean2k team is especially looking for a few highly motivated early-career scientists with the time and energy to lead the synthesis paper.

Further information on project goals is regularly updated at the Ocean2k webpages: http://www.igbp-pages.org/workinggroups/ocean2k/

We look forward to working with you.

PAGES Calendar 2012

3rd PAGES Varves Working Group workshop
21 - 23 Mar 2012 - Manderscheid, Germany

PALSEA Phase 5
4 - 8 Jun 2012 - Madison, USA

Paleofire reconstruction
21 - 22 Jun 2012 - Venice, Italy

4th PIGS workshop
2 - 5 Jul 2012 - Cambridge, UK

IPICS 2012 Open Science Conference
1 - 5 Oct 2012 - Giens, France

Holocene land-cover in Eastern Asia
9 - 10 Oct 2012 - Shijiahzuang, China

www.pages-igbp.org/calendar/upcoming

Scientific Ocean Drilling: Voyage of Discovery beyond 2013

Miyuki Otomo
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Scientific ocean drilling, one of the longest running and most successful international collaborations in Earth sciences, is now preparing for a seamless transition from the Integrated Ocean Drilling Program (IODP) to a new program phase. The current IODP, which shall terminate in September 2013, was built upon the accomplishments of the previous two legacy programs Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP), and has conducted cutting-edge investigations of the subseafloor since 2003. IODP employs three complementary types of drilling platforms, each with operational capabilities to support transformative science across a vast extent of Earth's oceans. The next phase of scientific ocean drilling, the International Ocean Discovery Program, is scheduled to start in October 2013 and will build on the new research plan "Illuminating Earth's Past, Present and Future". This science plan outlines the framework for the new IODP with four themes addressing fundamental questions about Earth's climate, deep-sea life, geodynamics and geohazards (IODP 2011). It will facilitate a long-term and global perspective on some of today's most pressing environmental issues. Planning for the new phase began in early 2009 with inputs solicited from the international community at the INVEST conference on new ventures in scientific drilling with over 600 scientists from 21 nations.

Multi-platform operations will also serve the science community for the post-2013 program (Fig. 1). Chikyu, the Japanese-operated riser type platform, will provide access to the deep ocean crust, Earth's mantle, seismogenic zones and hydrocarbon-prone regions. The US-supplied non-riser type vessel JOIDES Resolution, will continue to demonstrate its capabilities with the goal of operating with a full annual schedule. It will address a multitude of science objectives, in particular on climate history and the deep subseafloor biosphere. Finally, the mission-specific platforms provided by the European Consortium for Ocean Research Drilling (ECORD), will be deployed in challenging environments such as in shallow waters and ice-covered waters of the Arctic.

Subseafloor observatories developed within the ocean drilling community are another key feature of the new science plan. They will collect data at multiple depths along a borehole. These data can be combined with seabed and water-column studies. International collaboration has made it possible to link subseafloor observatories through cabled networks for real-time monitoring off the coasts of Japan, North America and Europe. China is currently developing plans for similar networks.

The new IODP program will continue to offer open access to all data and samples collected during expeditions after a scientific moratorium. Legacy cores collected since the start of the DSDP in 1968 through present are kept in three core repositories and are available for sampling by scientists and for educational purposes. The existing administrative structure of IODP will be maintained. In particular, the international IODP Science Advisory Structure will continue to guide proposal evaluation, scientific technology review, site characterization examination and safety assessment. The journal "Scientific Drilling", published jointly with ICDP, will continue without interruption.

The main features of the new IODP preserve the international, science-driven and multidisciplinary foundations of the program while providing new and exciting opportunities for oceanographic, microbiological and deep Earth discoveries. The results emerging from new IODP will provide benefits to society by advancing our understanding of geohazards, evolution of life and global climate change.

References

IODP (2011) *Illuminating Earth's Past, Present, and Future*. www.iodp.org/Science-Plan-for-2013-2023/

Schoof C (2010) *Nature Geoscience* 3: 450-451

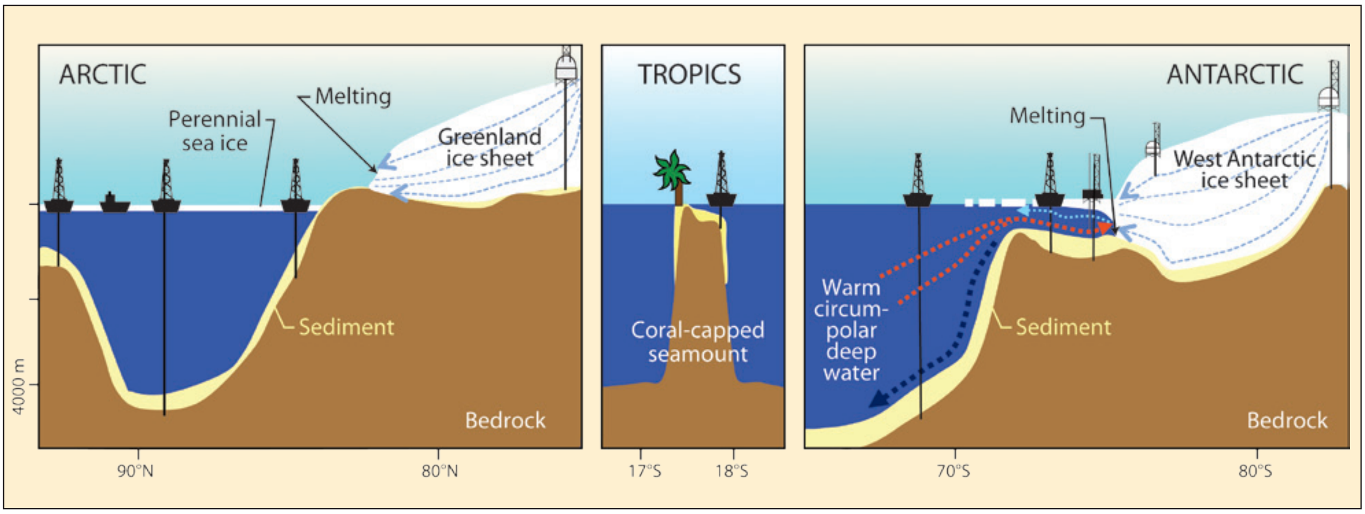

Figure 1: International Ocean Discovery Program (IODP) drilling strategy at the poles and tropics to collect records linking climate, ice sheet, and sea level histories on geologic time scales. Red arrows represent warm water flow beneath floating ice, recently recognized as a key factor in accelerating ice loss from West Antarctica. Elements of this figure were adapted from Schoof (2010).

SCOR/IGBP working group on modern planktonic foraminifera kicked off

Amsterdam, The Netherlands, 29 August - 2 September 2011

Gerald M. Ganssen[1] and Michal Kucera[2]

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Planktonic foraminifera have been the true heroes of paleoceanographic research since the birth of the discipline. The ornate shells of these microscopic amoebae are arguably the most important carriers of paleoclimate information available to scientists. Our ability to reconstruct past climate states and comprehend biotic responses to changing oceanic conditions depends on a complete understanding of their ecology, biology and physiology. The quantitative unravelling of the mechanisms by which they incorporate geochemical tracers into their shells is crucial for reconstructing oceanic temperature, pH and salinity.

In recent decades, research on these aspects of planktonic foraminifera has been lagging behind the rapid development of sophisticated geochemical tools and numerical ecological models and their application. To bridge this gap, the Scientific Committee on Oceanic Research (SCOR), together with the International Geosphere Biosphere Programme (IGBP), jointly established a new working group (WG) in 2011, with the aim to stimulate new research, benchmark the current knowledge and disseminate the results to a broad audience. For details of the proposed work of the group, please visit: www.scor-int.org/Working_Groups/SCOR_WG_Foraminifera_revised.pdf.

Figure 1: Light micrograph of a living Orbulina universa *caught off Southern California. This specimen illustrates the complex ecology and physiology of modern planktonic foraminifera, which need to be fully understood to make the most of the geochemical proxy signals, locked in their calcite shells. A dense network of calcite spines and rhizopodia surround a new spherical shell, providing a daytime habitat for thousands of dinoflagellate symbionts (yellow spots) that are distributed along the spines. Symbiont-derived nutrition is supplemented by feeding on crustaceans and other planktonic organisms. Here,* O. universa *has been fed a laboratory-grown* Artemia *nauplius whose tissue is digested in vacuoles inside the shell. The shell is approximately 0.5 mm across. Photo: Howard J. Spero, University of Calfiornia Davis.*

The first workshop of the SCOR/IGBP Working Group 138 on “Modern Planktonic Foraminifera and Ocean Changes" took place in a stimulating atmosphere of the medieval monastery environs of “Het Bethanienklooster” in Amsterdam. The participants (WG members and invited guests) of the kick-off workshop set the priorities for future work, specified the terms of reference and shaped and planned the deliverables. Specifically, the WG agreed to

a) set-up a Web-based network in cooperation with ongoing (inter)national research programmes and projects to guarantee an open-access, world-wide dissemination of results, data and research plans and

b) to synthesize the state of the science of modern planktonic foraminifera, from pioneering to ongoing research as an eBook or a special issue of an open-access journal. Contents for this foram compendium were drafted. The group decided that eForams (http://eforams.org) will be used as the Internet platform for the deliverables of the WG. The "WG138-eForams fusion" will thus represent an innovative experiment in developing new ways of science dissemination. In the same spirit of innovation in communication with its stakeholders, the WG has documented its aims in short video clips, which are freely available on the Internet (under: *A Foram's Tale* on YouTube).

In order to expose the aims of the WG to young researchers, the kick-off meeting was accompanied by a one-day focus symposium. It was attended by 18 early-career researchers from six countries and featured keynote presentations by Michal Kucera on genetic diversity and Howie Spero on calcification mechanisms and shell chemistry. The participants were briefed on the progress of the WG and engaged in discussions during the day, over posters and during the scenic canal boat trip in Amsterdam (*SCOR Amsterdam meeting* also on YouTube). On the morning of the following day, the participants including WG members, guests and young researchers reviewed the deliverables and considered the time plan and modalities to achieve the completion of the ambitious aims of the group.

This marked the closure of the workshop, where the pleasant and open atmosphere set the pace for the work of SCOR/IGBP WG 138. The workshop constituted an excellent opportunity for the group of experts, who met in this form and constellation for the first time, to review the current status and most recent developments in modern planktonic foraminiferal research and engage in exciting and stimulating discussions with the next generation of scientists.

Editorial: Harnessing the past and the present in the service of the future

Ninad R. Bondre[1] and Thorsten Kiefer[2]

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It is only in the present that we can study Earth processes as they occur. But sometimes due to a lack of information and sometimes due to an excess of it, we rarely know how those processes will unfold tens or hundreds of years from now. The finitude of the present precludes a comprehensive understanding of all Earth system processes and of the possible scenarios for the future, and it is the past that we must turn to in order to fill in the blanks. Past events are but traces of ancient processes frozen in time, affording us the luxury of knowing how it all ended. The present may very well be the key to the past, but the past represents a future that once was.

One of the achievements of the International Geosphere-Biosphere Programme (IGBP) and its projects has been to facilitate the movement from the present to the past and back to the present so as to build and refine our understanding of global change. As an uncertain future looms large, we rely more than ever on this approach. This issue of the Past Global Changes (PAGES) newsletter features paired perspectives that address the present and the past as two sides of the same coin, seeking to provide a window into the future. The topics cut across the research carried out in IGBP's projects and beyond on land, oceans, the atmosphere and their interfaces. The bringing together of communities, we feel, is timely in the context of the move towards the new *Future Earth* program by the International Council for Science (ICSU) and its partners.

We came up with a list of topics and one key question per topic after extensive consultation with the PAGES and IGBP communities. The topics do not cover Earth-system science comprehensively; instead, they reflect the lowest-hanging fruit, i.e. topics where substantial research is carried out on present as well as on past timescales alike. In principle, the article pairs were to address whether and how a particular process or phenomenon would change in the future. In practice, the articles reflect both the diversity of the topics and of the backgrounds and perspectives of the authors. Although dialogues developed between some of the authors of the complementary articles, we did not intentionally attempt to streamline the pairs of articles. This was because we wanted to maintain the duality of the perspectives.

The space restriction to one page for each article by no means allows a comprehensive response to the key questions. But the articles provide different yet complementary takes that also illuminate the questions themselves. There are indications in many articles regarding specific bits of information from the past or the present that could help enhance our process understanding and our projections of the future. Much in the articles remains inchoate, and we have no doubts that the active engagement of our readers will help make them more complete.

The communities studying the past and the present are by no means exclusive, but there can be a tendency for compartmentalization, primarily due to substantially different methods and approaches, but also due to the realities of today's academic environment. By placing side by side the perspectives on the future from the vantage points of the past and the present, we hope to both remind ourselves of the common ends and reaffirm the value of diverse perspectives and collaborations across time scales.

Earth System models - How well do Earth

PRESENT

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How well can Earth system models simulate the dynamics of global change? Well, if we wait long enough, we'll find out. But by then the models being judged will be deemed out-of-date and the latest models will be argued to be far superior! Recently models have under-predicted the rate of global warming and sea-level rise (Rahmstorf et al. 2007), and have failed to forecast the abruptness of Arctic sea-ice retreat (Stroeve et al. 2007) or the start of ocean de-oxygenation. This does not bode well.

When the dynamics of global change are basically linear – that is, the response is proportional to some forcing – and the forcing and response are accurately captured, the models should do a good job. Global warming in response to radiative forcing would be a great example, if only the radiative forcing effects of aerosols and the climate sensitivity to a given radiative forcing were not both highly uncertain (see pages 10/11 and 20/21 of this issue). The best way to reduce this uncertainty is to continue to reduce aerosol forcing and wait to see the climate response.

The prediction problem gets more difficult when the dynamics of change could be highly non-linear. Current global models struggle to capture potential climate "tipping points" at sub-continental scales (Fig. 1) (Lenton et al. 2008). For example, observations support the theory that the Atlantic meridional overturning circulation is "bi-stable" with an alternative collapsed state stable under the present climate, which it could conceivably be tipped into (Drijfhout et al. 2011). Yet the last generation of models were systematically biased, with just one stable ocean circulation state (Drijfhout et al. 2011), so it is no surprise that they did not forecast the possibility of future collapse (IPCC 2007).

Sometimes key processes or systems are simply missing from the models. Collective inability to put a number on the future contribution of ice sheets to sea-level rise (IPCC 2007) has provoked a welcome revolution in the modeling of ice-sheet dynamics. But we must be wary of the "kitchen sink" tendency to

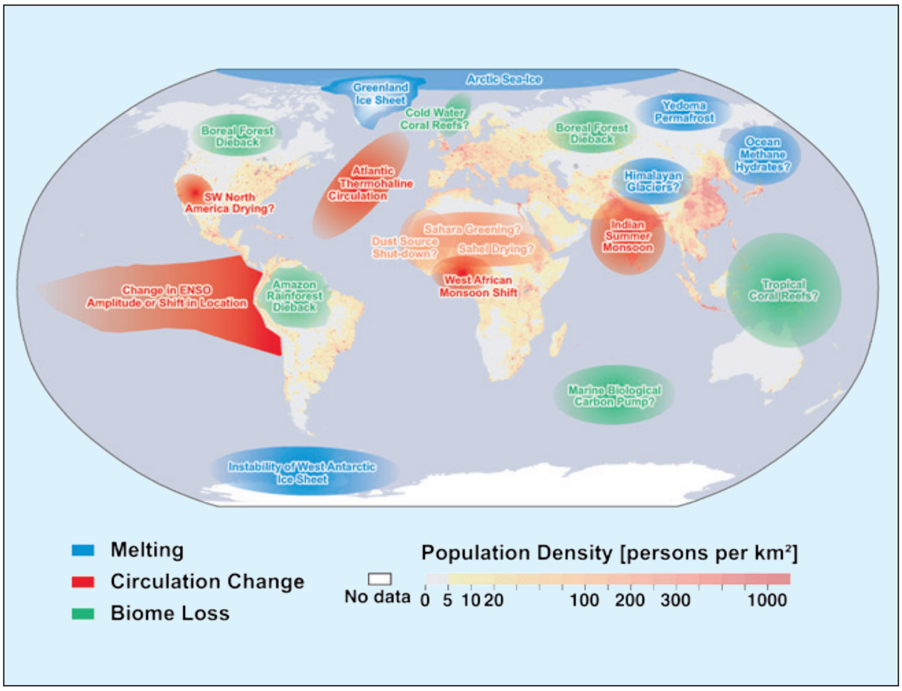

Figure 1: Map of potential policy-relevant tipping elements in the climate system, categorized into those involving ice melting, circulation changes, or biome losses – updated from Lenton et al. (2008) by Veronika Huber, Martin Wodinski, Tim Lenton and Hans-Joachim Schellnhuber.

keep putting more and more into Earth system models. Increasing complexity has been sold on the argument that it will reduce uncertainty in future projections, but it was never going to do that. Uncertainty has predictably increased as more forcing agents, couplings and feedbacks have been added to the models.

Century-scale runs with multiple simultaneous forcing agents and feedbacks are important for policymakers, but not the most scientifically informative if one wants to isolate the effects of a particular forcing or feedback, or attribute the causes of a particular change. What we need is a new way of using models together with available data to bridge the widening gap between predictive modeling and mechanistic understanding. The ocean overturning example highlights the need to recalibrate models using available data to get their stability properties right. But this is not just an initial condition problem; it will involve altering the parameters and even the processes in the models.

Earth system models are still at heart climate models with bits added on. This is of course sensible if – as many of us believe – climate change is the most dangerous global change that we as a species are driving. But it is worth considering the possibility that another global change might turn out to be more important. If, for example, our rampant mining of phosphates and fixing of nitrogen could ultimately trigger a global oceanic anoxic event, do we have a well-posed tool to assess this? Century-scale climate models are clearly inappropriate. Intermediate complexity models may be better posed. But I still see a need for truly "Earth system" models that can help define all of our planetary boundaries (Rockström et al. 2009).

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Drijfhout S, Weber S and van der Swaluw E (2011) *Climate Dynamics* 37: 1575-1586

Lenton TM et al. (2008) *PNAS* 105: 1786-1793

Rahmstorf S et al. (2007) *Science* 316: 709

Rockström J et al. (2009) *Nature* 461: 472-475

Stroeve J et al. (2007) *Geophysical Research Letters* 34, doi: 10.1029/2007GL029703

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Climate models, in particular the "big" general circulation models used for climate prediction, are first evaluated in comparison to present climate. This step is crucial, but does not warrant a correct sensitivity to external forcings or a realistic representation of the speed of climatic changes under time-dependent forcings. As underlined by Tim Lenton (this issue), it is unreasonable to just wait and see if the climate changes predicted by the current models have actually happened. But we can turn to the past and to the numerous paleo-records.

What do they tell us? That it is impossible to find a close analogue to the recent and probably future climate change in the paleo-record, in terms of forcing and in terms of the speed at which it occurs. But there *are* periods warmer than present and there *are* periods of abrupt climate changes. These past scenarios provide an endless list of challenges for climate – and more generally Earth System – modelers. The challenges fall into three categories. Are we able to model (and thus prove we understand) (1) the direction, (2) the amplitude and (3) the speed of the reconstructed climate changes?

For a long time, general circulation models have only been used to tackle the first two tasks, by considering simulations at equilibrium with external forcings and boundary conditions different from today. The Palaeoclimate Modelling Intercomparison Project (Braconnot et al. 2007) has led such comparisons for the Mid-Holocene (MH) and the Last Glacial Maximum (LGM). Very often, the models have proved to be able to simulate the sign of the reconstructed climate differences, but not their amplitude, e.g. in African monsoon amplification during the Holocene or for the European or Greenland cooling during the LGM. Does this prove the models have a too low sensitivity? Maybe, and there are many processes (e.g. vegetation, ice-sheets) that models do not account for yet. Their inclusion could increase model sensitivity to external forcing, at least regionally. On the other hand, we have to remember that the paleo-climatic reconstructions are also based on assumptions and associated with uncertainties. Direct ("forward") modeling of the paleo-climate indicators such as vegetation, oxygen isotopes or abundance of foraminifera offers a solution by accounting for multiple factors controlling the environmental indicators. Forward modeling has shown that formerly neglected processes needed to be considered in the interpretation of a record and that this can result in more satisfactory model-data comparisons than those between modeled and reconstructed climate variables (e.g. LeGrande et al. 2006).

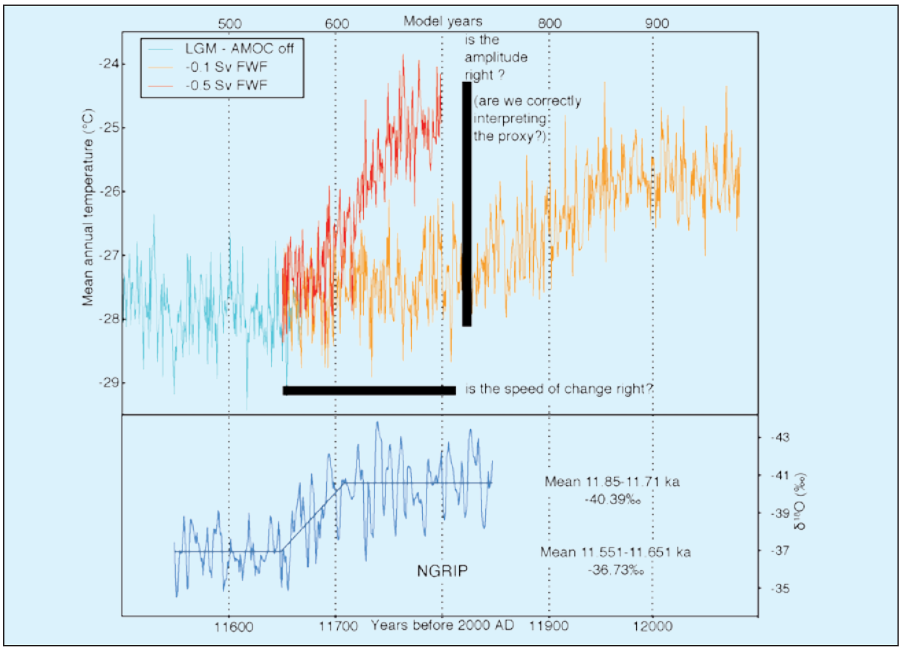

*Figure 1: Qualitative comparison of modeled warming events (**upper panel**) with a real event as recorded in the NGRIP ice core in Greenland between 11.6 and 11.8 ka BP (**lower panel**; Steffensen et al. 2009). The model results are for simulations using Last Glacial Maximum forcings. (blue) reference run, Atlantic Meridional Overturning Circulation (AMOC) "turned off", (orange) with a North Atlantic fresh water forcing of -0.1 Sv and (red) of -0.5 Sv (1 Sv = 10^6 m^3 s^{-1}).*

This is only a first step. As questions on the speed of future climate change and our ability to adapt to them arise, we can return to the paleo-record. On which timescales can climatic change occur? Our knowledge on this topic has greatly increased since a few decades ago, when climate history was considered to occur on tectonic and Milankovitch (ice age) timescales only. The discovery of abrupt climate changes in Greenland and elsewhere during the last glacial cycle has raised the challenge to understand changes that occurred over a few decades or even just a few years (Steffensen et al. 2009), much shorter than the time-scale at which the external forcings evolved (Fig. 1).

These short time-scales imply that "big" models can now be used to test our understanding of these fast climate changes, in addition to Earth System Models of Intermediate Complexity (EMICS). EMICS have the advantage of running fast and include representations of the slow components of the climate system. As such, they have been used extensively to study climate evolution, but the origin of the abrupt Dansgaard-Oeschger warmings is still elusive. So far, no model, neither EMIC nor GCM, has been able to simulate such transitions without imposing ad-hoc fresh water flux forcings. Are our models too simple? Are there missing processes in our understanding? Do we overinterpret the proxies? Are the very fast climatic shifts recorded in Greenland the result of a large change in interannual variability superimposed on a slower climate evolution? On this topic, big models, equipped with "proxy simulators" might bring new enlightening perspectives.

References

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Braconnot et al. (2007) *Climate of the Past* 3: 261-277

LeGrande et al. (2006) *PNAS* 103: 837-842

Steffensen et al. (2009) *Science* 321: 680-684

Climate

PRESENT

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The Climate Sensitivity (CS) is a key parameter for assessing future climate change, as is its counterpart the Transient Climate Response (TCR – see figure 1). The TCR is defined as the 20-year global, annual mean temperature change averaged around the time of CO_2 doubling, under a forcing scenario of CO_2 increasing at a rate of 1% per year compounded. Just like the CS, the TCR quantifies physical feedbacks in the climate system associated with the surface, clouds, water vapor, sea ice, etc., but it is more relevant for transient climate change in the near future and does not suffer from the "long tail" evident in estimates of the CS (Frame et al. 2005).

A notable feature of the latest version of the Coupled Model Intercomparison Project (CMIP5) is that atmosphere models coupled to simple slab or mixed-layer oceans are not included in the design, limiting a direct comparison of the range of CSs with previous versions of CMIP (although the CS and TCR tend to be well correlated in models and the effective CS can be calculated from experiments included in CMIP5).

We may use modern observations to aid in building complex models of the climate system from "first principles" i.e. by solving the dynamical equations of the atmosphere and ocean and parameterizing sub-grid-scale processes in as much detail as possible. Multiple data sources may be used to evaluate both the individual building blocks and the emergent properties of the model; data from process-based observations, possibly gathered during dedicated field campaigns, historical in situ measurements, remotely sensed data, etc. We can then interpret measures such as the CS and TCR computed from complex modes as estimates that integrate our understanding of climate (embodied in the laws of physics) and modern day observations.

The range of CS and TCR has not changed much in successive generations of models. The example in the figure shows a range of 1.2-2.6°C for the CMIP3 models and 1.3-2.4°C for the CMIP5 models available at the time of writing.

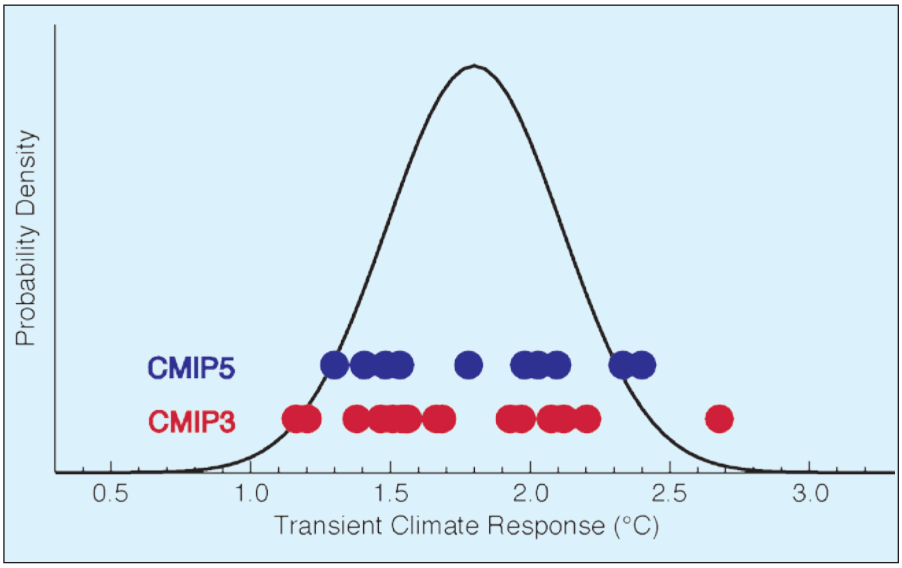

Figure 1: A comparison of estimates of the Transient Climate Response from complex models evaluated against modern observations from versions 3 and 5 of the Coupled Model Intercomparison Project (Meehl et al. 2007; Taylor et al. 2011) shown as red and blue dots respectively. A PDF of the TCR computed from a simple model with parameters constrained by observations is also shown (Gregory and Forster 2008).

An alternative approach comes from using simple climate models that may only simulate aggregate variables such as global mean temperature. Simple models can be run many times and statistical approaches can be used to formally estimate the parameters of the model based on constraints from observations/estimates of e.g. recent ocean heat uptake and radiative forcing. Measures such as CS and TCR then come with likelihood estimates and the uncertainty may be expressed as a probability density function (PDF – see Fig. 1).

Unfortunately, using different observational data sources from different modern (and paleo) time periods, have not produced tight constraints on variables such as the TCR. The 5-95% range in the example from the figure from (Gregory and Forster 2008) is 1.3-2.3°C, comparable with the ad hoc range from CMIPs. CMIP ranges of CS are also comparable with observationally constrained PDFs (Knutti and Hegerl 2008).

As the signal of climate change emerges from the noise of natural variability, PDFs based on simple-model constraints should narrow. Collection of new and more detailed modern observations, particularly of climate processes such as clouds, should allow us to better improve and evaluate our complex models. One recent approach combines complex modeling with formal parameter estimation to produce PDFs of global and regional change (Sexton et al., in press). This allows multiple modern observational records to be used to constrain projections, although the cost of implementation is high. There is still scope for much research in quantifying how sensitive Earth's climate is to CO_2 change using modern models and data.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Frame D et al. (2005) *Geophysical Research Letters* 32(9), doi:10.1029/2004GL022241

Gregory J and Forster P (2008) *Journal of Geophysical Research-Atmospheres* 113, doi:10.1029/2008JD010405

Knutti R and Hegerl G (2008) *Nature Geoscience* 1(11): 735-743

Meehl GA et al. (2007) *Bulletin of the American Meteorological Society* 88(9): 1383-1394

Sexton D, Murphy J, Collins M and Webb M (in press) *Climate Dynamics*, doi: 10.1007/s00382-011-1208-9

Taylor KE, Stouffer RJ and Meehl GA (2011) *A Summary of the CMIP5 Experiment Design*, http://cmip-pcmdi.llnl.gov/cmip5/experiment_design.html

sensitivity - How sensitive is Earth's climate to CO_2?

PAST

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The climate record definitively shows that the Earth's climate is sensitive to various drivers, including greenhouse gases, orbital variations and continental shifts. Unfortunately, there are no past analogs for the anticipated 21st Century climate changes, and so a principal challenge in applying these constraints to the future is to interpret these changes quantitatively.

At the global scale, the framework of radiative forcing and response is a powerful method to constrain sensitivity, however, there are many nuances. First, the system being described needs to be defined - what are the forcings, and what are the responses? This might seem clear at first glance, but actually depends on the availability of data and what timescales are being considered (Fig. 1). Second, there needs to be clarity in how the calculated sensitivity relates to either the "climate sensitivity" determined by models, or the related concept of the transient climate response.

The commonly used "Charney sensitivity" - the equilibrium surface temperature response to 2xCO_2 allowing most atmospheric processes to react, but holding ice sheets, vegetation, atmospheric composition and ocean circulation constant - is a useful climate model metric. Constraining this from paleo-data requires information on all the "constant" components, most notably for the Last Glacial Maximum (LGM), where many (though not all) the elements are available (Köhler et al. 2010; Schmittner et al. 2011), and perhaps the last millennium, where many aspects are not fundamentally different from today (Hegerl et al. 2006). However, while the Charney sensitivity is a useful characterization of the any particular atmospheric model, it is not the same as what would actually occur if 2xCO_2 were reached and maintained for a long time.

There are important nuances: climate sensitivity to cooler conditions might not be equivalent to climate sensitivity to warmer ones (indeed evidence suggests it is 80 to 90% smaller; Hargreaves et al. 2007; Crucifix 2006; Hansen et al. 2005) and some forcings just can't be fitted into a global forcing/response framework at all (such as orbital variations). Furthermore, there is often substantial uncertainty in the forcings - whether it is the size of ice sheets at the LGM, or solar forcing in medieval times, that must be taken into account in assessing the uncertainties in any estimates.

Constraining any sensitivities from the paleo-record is thus still a work in progress. Predominantly data-driven approaches (like Köhler et al. 2010 or Lorius et al. 1990, for the LGM) suggest a Charney sensitivity of around 3ºC (with a 2σ range of ~1-5ºC). Synthesis estimates that use a combination of intermediate models constrained by LGM paleo-data have given ranges of 1.2-4.3ºC (5-95%) (Schneider von Deimling et al. 2006) and 1.7-2.6ºC (17-83% range) (Schmittner et al. 2011). Note however, that the latter estimate includes a vegetation feedback, not included in the standard definition of the Charney sensitivity. A correction for this reduces the estimated sensitivity by about 0.2ºC. There is a large (and as yet barely quantified) sensitivity to model structure in these calculations since the models used to date do not give a very good fit to the regional details of the proxy data.

By expanding the framework to incorporate excluded fast and slow feedback elements, it is possible to estimate the long-term "Earth System Sensitivity" (ESS) (Lunt et al. 2010; Hansen et al. 2008), i.e. the temperature realized after all the feedbacks have worked themselves out. For instance, Lunt et al. (2010) found that the addition of ice sheet and vegetation responses (derived from Pliocene proxy data), increased their model sensitivity to CO_2 by ~50%. However, this will apply only at very long timescales (many tens of thousands of years or even longer). Intermediate definitions of the sensitivity might also be calculated - for instance, taking dust, aerosol and ozone changes (fast atmospheric responses) or ocean circulation changes as feedbacks as well, but still holding ice sheets and vegetation constant.

Linking estimates of climate drivers in the past, estimates of the climate response, and the prospects for future change is however a crucial task (Schmidt 2010). To a large extent it requires the use of climate models, and the incorporation of a paleo-climate modeling component in CMIP5 will serve as a good testbed for using the paleo-record to assess the credibility of many aspects of the future projections (not simply the global mean temperature sensitivity).

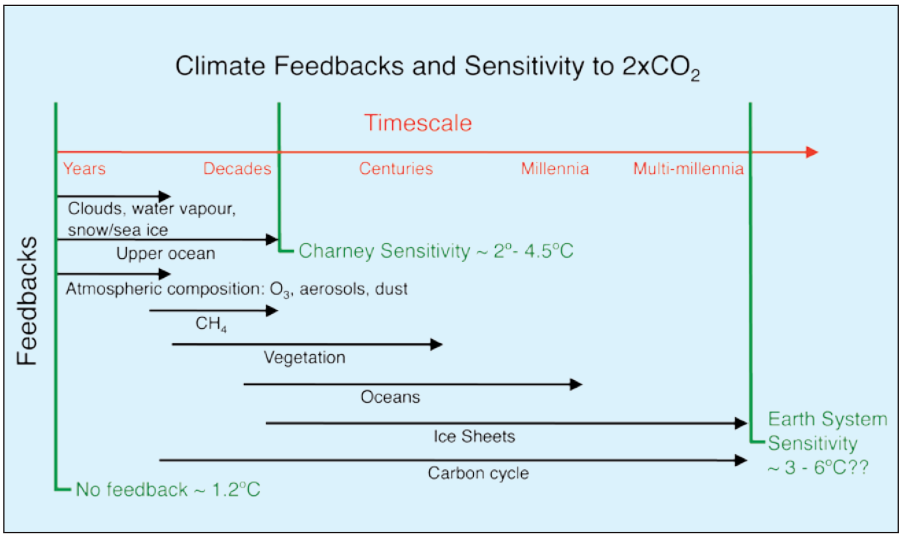

Figure 1: Climate sensitivities are a function of what feedbacks are included and what timescales are being considered.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Hargreaves JC, Abe-Ouchi A and Annan JD (2007) *Climate of the Past* 3(1): 77-87

Köhler P et al. (2010) *Quaternary Science Reviews* 29: 129-145

Lunt DJ et al. (2010) *Nature Geoscience* 3: 60-64

Schmittner A et al. (2011) *Science* 334: 1385-1388

Schneider Von Deimling T, Held H, Ganopolski A and Rahmstorf S (2006) *Climate Dynamics* 27(2-3): 149-163

Carbon cycle dynamics - How are major

PRESENT

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The entire Earth System, atmosphere, oceans, biology and geology are involved in the carbon cycle (Archer 2010). Carbon dioxide is taken up by the land biosphere through photosynthesis, and released through respiration and combustion (Schimel et al. 2001). The oceans take up carbon through closely coupled physical, chemical and biological processes (Sarmiento and Gruber 2006). They absorb carbon dioxide in regions where mixing and biological activity maintain low ocean carbon dioxide levels, allowing chemical diffusion from these active regions of the sea. In other regions, carbon-rich water mixes to the surface and releases carbon to the atmosphere. These processes are natural and have always occurred.

The anthroposphere, the sphere of human activities, transforms this cycle in two ways. First, humans burn carbon from geological reservoirs that would normally be stable over millions of years and introduce this additional carbon into the more active atmosphere-ocean-land system, increasing the total amount of carbon circulating in the Earth System (Archer 2010). Second, human land use converts biologically stored carbon in soils and plants to carbon dioxide in the atmosphere, changing the balance of stored and circulating carbon (Schimel 1995).

These human activities increase atmospheric carbon dioxide and thereby the trapping of heat in the atmosphere, leading to global climate change. As climate changes, it has consequences for the carbon cycle. The rates of many biogeochemical processes, such as photosynthesis, respiration, nitrogen cycling and wildfire increase in warmer conditions (Field et al. 2007). These higher process rates may speed up biological activity, producing potential positive and negative feedbacks to the carbon cycle. In some models, the feedback effects of the carbon cycle influence atmospheric CO_2 by tens to even hundreds of parts per million, corresponding to significant effects on temperature (Cox et al. 2000). Temperature effects may be largest in high latitude regions, where enormous post-glacial deposits of carbon in permafrost could be released as CO_2 and methane as these soils thaw (Koven et al. 2011).

Precipitation also changes as the warming atmosphere causes more evaporation. This intensification of the hydrological cycle will cause some regions to become wetter, but arid regions may become drier. Drier conditions in the tropics will decrease plant growth and reduce carbon storage in these regions (Fung et al. 2005). Warmer and wetter conditions in mid-latitude regions may actually increase carbon storage. Most evidence suggests the tropical effects are larger, leading to overall release of ecosystem carbon stores. This creates a global feedback increasing atmospheric carbon dioxide as temperatures warm.

When humans burn fossil fuels, they transform organic carbon compounds that last for millions of years into atmospheric carbon dioxide. The uptake and stabilization of carbon dioxide into long-lived carbon compounds – which defines the lifetime of carbon dioxide – takes a lot of time. While photosynthesis and air-sea gas exchange can draw CO_2 concentrations down quickly, i.e. within years, actually transferring that carbon into stable chemical forms, safe from recycling back to the atmosphere requires ten to thirty thousand years (Archer 2010).

Because of the long lifetime of changes to the carbon cycle, the paleo-perspective is critical. For example, paleorecords tell us that while atmospheric carbon dioxide concentrations can increase quite rapidly, it can take much, much longer for it to be locked into long-lasting forms and provides a timescale for these dynamics. During one well-documented event 55 million years ago, atmospheric carbon dioxide nearly doubled over about 20,000 years, with an accompanying increase in temperature of perhaps 6°C. While atmospheric carbon dioxide increased very rapidly, it took nearly 7-8 times longer to return to previous levels (Doney and Schimel 2007).

Carbon scientists are finding creative ways to combine paleodata, process studies and modern-day observations to model the "fast out-slow in" processes that determine the longevity and severity of climate change. The paleorecord provides an essential observational basis for assessing the reality of model-based scenarios of the long-term future.

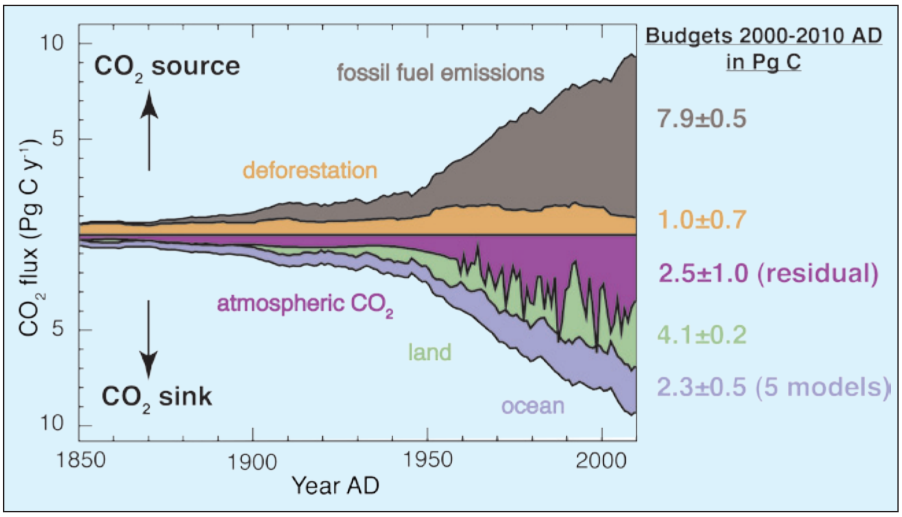

Figure 1: Human perturbation of the global carbon budget over the period 1850-2012 AD. The values on the right represent the amount of C emitted and absorbed during the last decade (2000-2010 AD). Figure modified from Global Carbon Project (2011), updated from Le Quéré et al. (2009) and Canadell et al. (2007).

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Archer D (2010) *The Global Carbon Cycle (Princeton Primers in Climate)*, Princeton University Press, 224 pp

Doney SC and Schimel DS (2007) *Annual Review of Environment and Resources* 32: 31-66

Cox PM et al. (2000) *Nature* 408: 184-187

Fung IY, Doney SC, Lindsay K and John J (2005) *PNAS* 102: 11201-11206

Koven CD et al. (2011) *PNAS* 108: 14769-14774

carbon sinks and sources varying with global change?

PAST

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Paleoclimate data are essential to gauge the magnitude and the speed of change in greenhouse gas concentrations, ocean acidification, and climate. These parameters co-determine the anthropogenic impacts on natural and socioeconomic systems and their capabilities to adapt.

Concentrations of the three major anthropogenic greenhouse gases were much smaller during at least the last 800 ka than modern and projected concentrations. The ice core record reveals that the average rate of increase in CO_2 and the radiative forcing from the combination of CO_2, CH_4, and N_2O occurred by more than an order of magnitude faster during the Industrial Era than during any comparable period of at least the past 16 ka (Joos and Spahni 2008). This implies that current global climate change and ocean acidification is progressing at a speed that is unprecedented at least since the agricultural period.

Ice, terrestrial and oceanic records reveal huge changes in climate during glacial periods on the decadal time scale (Jansen et al. 2007). These are linked to major reorganizations of the oceanic and atmospheric circulations, including a stop and go of the poleward Atlantic heat transport and shifts in the rain belt of the Inter Tropical Convergence Zone (ITCZ). These "Dansgaard-Oeschger" and related Southern Hemisphere climate swings demonstrate that the climate system can switch into new states within decades – a potential for unpleasant future surprise.

Surprisingly, variations in atmospheric CO_2 remained quite small during Dansgaard-Oeschger events. This indicates a certain insensitivity of atmospheric CO_2 to shifts in the ITCZ, changes in the ocean's overturning circulation, and abrupt warming of the boreal zone. Related variations in N_2O and CH_4 are substantial (Schilt et al. 2010), but the resulting radiative forcing is several times smaller than current anthropogenic forcing. Greenhouse gas concentrations react to climate change and amplify it, but the data may also indicate that such an amplification of man-made climate change may remain moderate compared to anthropogenic emissions. This is in line with results from Earth System Models and probabilistic analyses of the last millennium temperature and CO_2 records (Frank et al. 2010).

Theories and Earth system models must undergo the reality check to quantitatively explain the observations. For example, reconstructed and simulated spatio-temporal evolution of C-cycle parameters during the last 11 ka (Fig. 1) provide evidence that the millennial-scale CO_2 variations during the Holocene are primarily governed by natural processes (Menviel and Joos 2012), in contrast to previous claims of anthropogenic causes.

Paleoscience allows us to test hypothesis. Can we mitigate the man-made CO_2 increase by stimulating marine productivity and promoting an ocean carbon sink by artificial iron fertilization? Paleodata (Röthlisberger et al. 2004) and modeling suggest that we can't – past variations in aeolian iron input are not coupled to large atmospheric CO_2 changes.

Warming might set carbon free from permafrost and peat or CH_4 currently caged in clathrates in sediments, which would in turn amplify global warming and ocean acidification. However, soil, atmospheric CO_2 and carbon isotope data suggest a carbon sink, and not a source, in peatlands during periods of past warming (Yu 2010). Likewise, ice core data show no extraordinarily large CH_4 variations nor supporting isotopic signatures (Bock et al. 2010) for thermodynamic conditions potentially favoring CH_4 release from clathrates, i.e. during periods of rapid warming and sea level rise.

Yet, it is not always clear to which extent a comparison of the past with man-made climate change is viable. We need to improve our mechanistic understanding of the underlying processes to better assess the risk of ongoing greenhouse gas release and associated climate amplification and feedbacks in order to better guide emission mitigation and climate adaptation efforts. Paleoresearch, offering unique access to time scales and complex climate variations neither covered in the instrumental records nor accessible by laboratory studies, is the key to reach this policy-relevant goal, but its potential has barely been exploited.

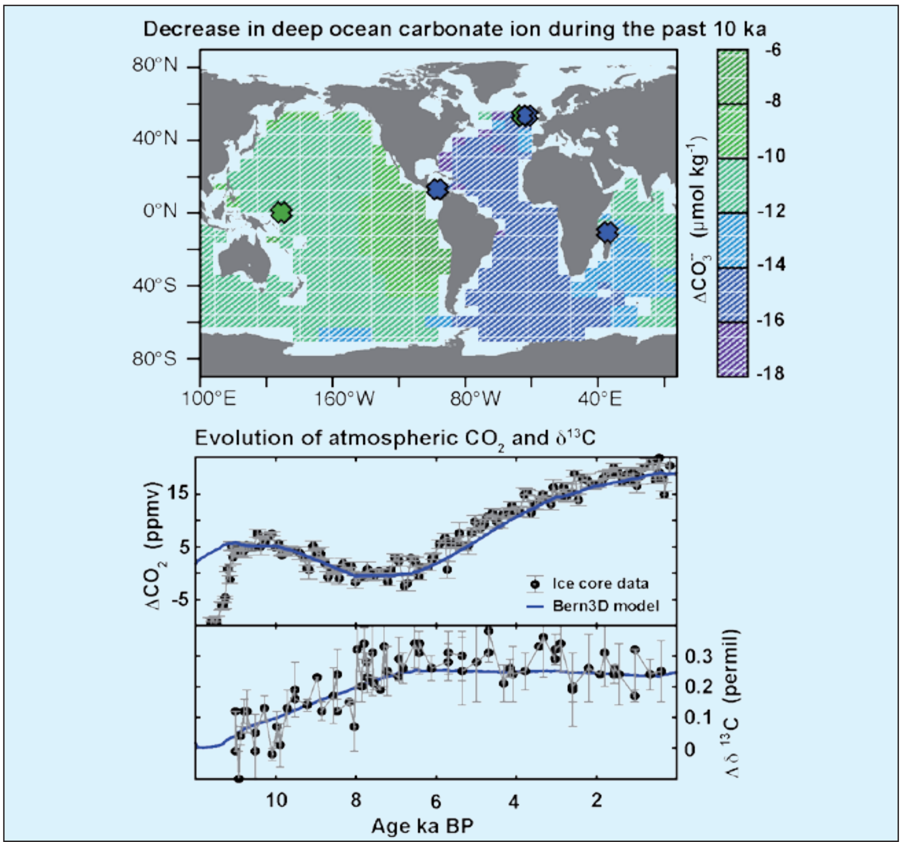

*Figure 1: Evolution of atmospheric CO_2 and $\delta^{13}C$ of atmospheric CO_2 (**lower panel**) and changes in deep ocean carbonate ion concentration (μmol kg^{-1}) over the last 10 ka (**upper panel**). Proxy data are shown by circles and crosses, and results from the Bern3D model by blue lines and color contours (after Menviel and Joos 2012).*

Selected references

Full reference list online under:

http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Frank DC et al. (2010) *Nature* 463: 527-530

Menviel L and Joos F (2012) *Paleoceanography* 27(1), doi: 10.1029/2011PA002224

Röthlisberger R et al. (2004) *Geophysical Research Letters* 31, doi: 10.1029/2004GL020338

Schilt A et al. (2010) *Quaternary Science Reviews* 29(1-2): 182-192

Yu Z (2010) *The Holocene* 21(5): 761-774

Ocean circulation - Does large-scale

PRESENT

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Earth's oceans undergo a relentless churning as water responds to the interplay of temperature, salinity and prevalent winds. In the Atlantic Ocean, roughly 18 Sv[1] of warm, saline near-surface water is carried northward by the Gulf Stream/North Atlantic Current system (Cunningham et al. 2007). An equivalent amount of cold, deep water from the Nordic and Labrador Seas is guided by topography to the Southern Ocean. Here, it returns to the upper ocean more slowly via the mixing of deeper and shallower waters and/or the upwelling of deeper water in response to the strong westerly winds. This global-scale Meridional Overturning Circulation (MOC) is responsible for the observed temperature contrast of 15°C at low-latitudes in the Atlantic between the upper ocean and the deep ocean. In contrast, the absence of deep water formation in the Northern Pacific and Indian Oceans means that oceanic northward heat transport is significantly less than in the North Atlantic (Lumpkin and Speer 2007).

In its fourth assessment report the Intergovernmental Panel of Climate Change considers it "very likely" that the MOC will have gradually slowed by the end of the 21st century as a consequence of global warming. Climate model projections predict a slowdown between 0 and 50% by the year 2100, although complete shutdown is considered "unlikely" for this time horizon. The reasons for the slowdown include factors that impede deep-water formation – warming of surface waters and salinity reduction at high latitudes due to the melting of continental ice sheets and the intensification of the hydrological cycle. Uncertainties regarding the freshwater fluxes and the locations of deep-water formation at high latitudes are the primary causes of the large uncertainties in the model projections.

Future changes to the MOC will also be determined by changes in the mechanisms leading to the upwelling of warmer waters. Winds have intensified by 30% over the Southern Ocean during the second half of the last century (Huang et al. 2006), possibly due to decreasing stratospheric ozone concentrations. This trend is expected to prevail until 2100 (Shindell and Schmidt 2004). Beyond the end of this century, in what will be a different climate, upwelling in the Southern Ocean might gain in importance relative to sinking in the North Atlantic. Other long-term influences on the overturning in the North Atlantic Ocean are related to increased surface saltwater exchanges between the Indian and South Atlantic Oceans in the Agulhas Current System.

At present, there is no convincing observational evidence for a long-term weakening of the Atlantic MOC. This absence of evidence should not be mistaken as evidence of absence of a slowdown, especially when there is a lack of adequate long-term and sustained monitoring. Discontinuous historic observations do not capture the large intraseasonal-to-interannual variations, thereby reducing the reliability of the projections of the long-term changes in the MOC. Continuous measurements spanning the past decade or so are not indicative of a "strong" MOC decline. But on decadal time scales, natural variations have considerably larger amplitudes than the anthropogenic signature (on the order of 0.5 Sv per decade). Thus, observations sustained over several decades are required to distinguish between natural and anthropogenic changes.

Monitoring of the MOC has improved since the beginning of this century (Kanzow et al. 2010; Send et al., in press). Methods include those based on ocean state estimates and those using numerical models to identify observable variables (indices) that correlate well with the MOC strength in the models. Careful validation against the existing direct observations is now required to establish the robustness of state-estimate-based and index-based changes to the MOC. In principle these methods could also be applied to paleo-oceanographic proxies, to open a window to ocean-induced changes in past climate.

[1] *1 Sv= $10^6 m^3s^{-1}$, unit for volumetric transport. For comparison, the Amazon River discharge in the Atlantic is about 0.2 Sv*

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Bingham RJ and Hughes CW (2009) *Journal of Geophysical Research* 114, doi: 10.1029/2009JC005492

Huang RX, Wang W and Liu LL (2006) *Deep Sea Research Part II* 53 (1-2): 31-41

Kanzow T et al. (2010) *Journal of Climate* 23: 5678-5698

Lumpkin R and K Speer (2007) *Journal of Physical Oceanography* 37: 2550-2562

Vellinga M, Wood RA and Gregory JM (2002) *Journal of Climate* 15: 764-780

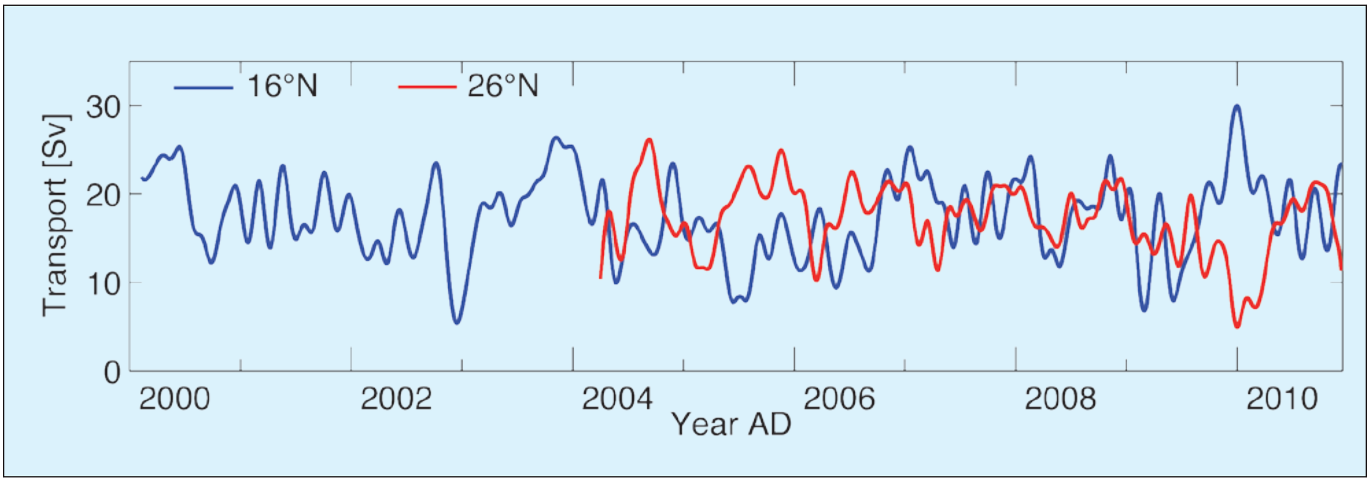

*Figure 1: Southward Deepwater Transport at 16°N (**blue** line) and Strength of Meridional Overturning at 26°N (**red** line) for the period 2000-2010 AD.*

ocean overturning circulation vary with climate change?

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A foundational geological concept that is attributed to James Hutton, the principle of "uniformitarianism", holds that *the present is the key to the past*. However, the observable present cannot capture the full dynamic range of the climate system, and it is therefore to the past that we must turn for a broader perspective on climate change. What is clear from the geological record is that the large-scale ocean circulation is not immutable; it has changed repeatedly in the past and in intimate connection with global and regional climate shifts. What is generally less clear, is exactly what aspect of the ocean circulation has changed in each instance (mass transport, interior mixing rates, transport pathways?), to what degree, and why. These ambiguities arise from two principle challenges in paleoceanography: first, the challenge of inferring hydrographic observations from "proxies"; and second, the challenge of inferring the ocean's large-scale circulation from sparse hydrographic observations, often with highly uncertain age-control. These difficulties become exacerbated when attempting to reconstruct analogues of the relatively subtle, high frequency or seasonally expressed changes in the ocean circulation that are likely to be most relevant to climate change in the decades to come.

Perhaps the most robust case study in past ocean-climate linkages comes from the last 60 ka. This time period has witnessed a succession of regional climate changes, with Greenland and the North Atlantic region exhibiting rapid warm/cold alternations in association with coupled but asynchronous changes in Antarctic temperature. The largest of these climatic perturbations also coincide with changes in the chemistry of waters filling the deep Atlantic (Fig. 1B). The latter are most easily attributed to shifts in the distribution of different water-masses, and therefore to changes in the ocean circulation; a view that is broadly consistent with some numerical model simulations (Ganopolski and Rahmstorf 2001; Liu et al. 2009).

The prevailing interpretation of the records shown in Figure 1 is that they represent the operation of a "thermal bipolar seesaw", resulting from changes in the "effectiveness" of the Atlantic overturning circulation as a heat pump from southern to northern latitudes (Schmittner et al. 2003).

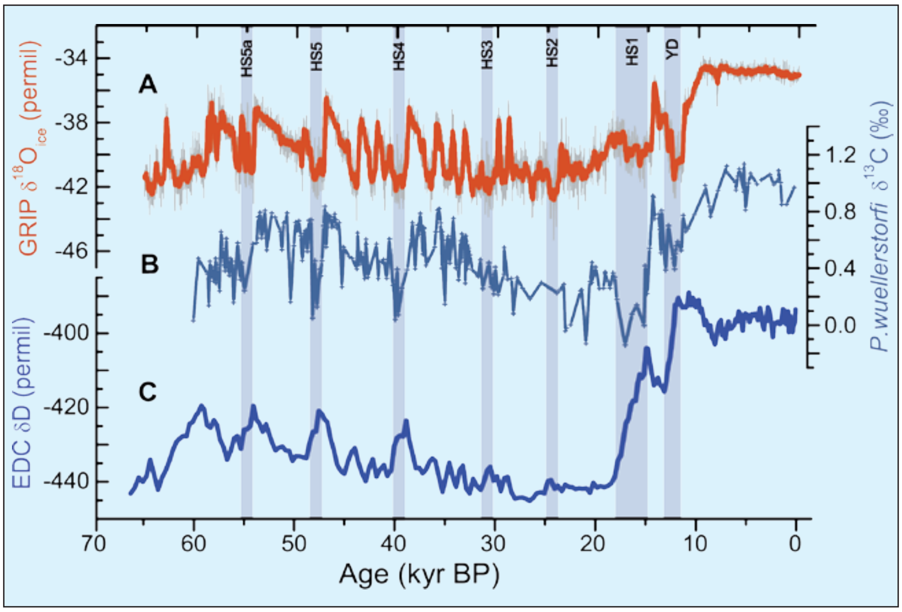

*Figure 1: Changes in the ocean-climate system over the past 60 ka, showing climate anomalies over Greenland (**A**) and Antarctica (**C**) (Lemieux-Dudon et al., 2010) compared with evidence for ocean circulation changes from the deep Northeast Atlantic (**B**) (Skinner et al. 2007). The evidence for circulation changes is derived from benthic foraminiferal stable carbon isotopes, which are interpreted here to represent primarily the preformed macro-nutrient content of deep waters, and therefore the relative dominance of northern- versus southern deep-waters in the deep North Atlantic. HS: Heinrich Stadial, YD: Younger Dryas.*

The hypothesized trigger for these overturning perturbations is anomalous meltwater supply to the North Atlantic: i.e. ice-sheet or ice-shelf surges that may well have been climatically driven (Alvarez-Solas et al. 2010; Flückiger et al. 2006). Interestingly, the patterns and associations of these rapid ocean-climate changes appear to be consistent with an overturning circulation that is conditionally stable, and that may respond non-linearly to relatively subtle perturbations, depending on the prevailing climate/forcing conditions (Margari et al. 2009; Rahmstorf et al. 2005). Indeed, through their inter-hemispheric teleconnections and their inferred impact on the carbon cycle (Anderson et al. 2009), such non-linear shifts in the ocean circulation are thought to have played a key role in tipping global climate out of its glacial state ca. 15-20 ka ago (Barker et al. 2011). Once this happened, ocean-climate variability appears to have become more subdued. Although this suggests a relative stabilization of the ocean circulation under interglacial conditions, it does not imply the complete elimination of ocean-climate variability during the Holocene. Indeed, evidence exists for centennial to millennial perturbations during the Holocene that are likely to have dwarfed those recorded in the instrumental record.

What can these impressive, if incompletely understood, changes in the past ocean-climate system teach us? In general, they question the paradigm of the ocean circulation as a millennially sluggish flywheel in the climate system. They suggest a capacity to respond sensitively to, and in turn impact significantly on regional and global climate, possibly in a non-linear fashion and with important ramifications for the carbon cycle and the global energy budget. However, the past does not provide an easy template for the future. If the geological record is to inform more directly on the stability properties of our modern circulation and its immediate future, paleoceanographers will need to focus on past ocean-climate variability in increasingly fine detail, and with a particular emphasis on relatively warm climate conditions.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Alvarez-Solas J et al. (2010) *Nature Geoscience* 3: 122-126
Anderson RF et al. (2009) *Science* 323: 1443-1448
Barker S et al. (2011) *Science* 334: 347-351
Margari V et al. (2009) *Nature Geoscience* 3(2): 127-131
Schmittner A et al. (2003) *Quaternary Science Reviews* 22: 659-671

Marine nutrient cycling - How will the

PRESENT

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The biological pump refers to a suite of biologically mediated processes that transport carbon from the ocean's surface layer to its interior. Its efficiency depends on the balance between the rates of carbon photo-assimilation, export and mineralization. Our knowledge of the biological carbon pump relies on our mechanistic understanding of factors structuring phytoplankton distributions and marine food webs, and the associated biogeochemical cycles. To assess the extent to which the strength and the efficiency of this pump will change in the future, we need to know how these factors – light, nutrients and temperature – might change in a warmer ocean. Models coupling an ecosystem module to a global circulation model provide important tools for understanding the dynamics of the carbon pump and its response to warming. But as pointed out by Sarmiento et al. (2004), existing tools are still not mature enough to allow this.

The last decade has seen increasing awareness of the relationship between key phytoplankton groups and their pivotal role in the functioning of the biological carbon pump (e.g. Boyd et al. 2010). Until recently, the picture was of a simple subdivision between efficient carbon export via a diatom-copepod-fish linear food chain in nutrient-rich waters and retention of surface carbon in nutrient-poor waters via a microbial network initiated by the ubiquitous pico/nano phytoplankton (Chisholm 2000). This picture has been recently complicated by the recognition of two additional small-sized players – the calcifying coccolithophores and the nitrogen-fixing cyanobacteria. These have a competitive advantage over diatoms in warm, well-illuminated surface waters supplied with imbalanced inorganic nitrogen and phosphorus nutrients. Their participation in carbon export is indirect and involves either aggregation with calcium carbonate liths acting as ballast particles or the release of nitrogen that sustains the growth of concomitant diatoms, thereby triggering carbon export (Chen et al. 2011)

Ocean warming affects the pelagic ecosystem both directly and indirectly, by increasing temperature and stratification. The latter tend to favor the dominance of small phytoplankton (e.g. Falkowski and Oliver 2007; Li et al. 2009) over large cells such as diatoms (Fig. 1). The resulting photo-assimilated carbon benefits the heterotrophic microbial food web, whose activity is stimulated by the warmer temperature (Sarmento et al. 2010), increasing the rate of carbon mineralization. Small phytoplankton cells also have low sinking rates. The spreading of such cells anticipated with increased ocean stratification will decrease the overall capacity of the biological pump, but the extent remains uncertain (Barber 2007).

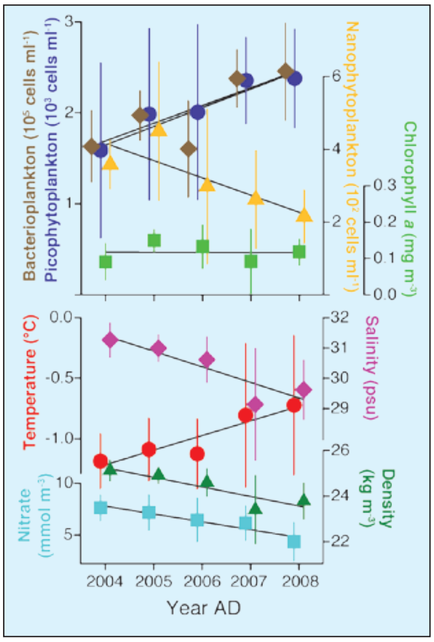

Figure 1: Summer conditions in the upper water layers of the Canadian Basin. The lower panel shows the physical water properties over the period 2004-2008, the upper the response of the plankton organisms during the same period. Figure modified from Li et al. 2009.

The prevalent view of the picophytoplankton carbon being totally remineralized in the surface waters has been recently challenged by data from the equatorial Pacific Ocean and Arabian Sea, which point to significant export of picophytoplankton-related carbon through indirect paths such as aggregation and fecal pellets (Richardson and Jackson 2007). The future latitudinal extent of coccolithophore blooms due to warming is unknown, however, particularly in light of the possible alteration of calcification rates by ocean acidification (Cermeño et al. 2008).

The potentially large ocean deoxygenation due to the increased temperature and stratification projected for a warmer ocean (Keeling et al. 2010) will have direct consequences for marine biota, but only an indirect effect on ocean productivity and nutrient and carbon cycling. An expansion of suboxic/anoxic conditions would increase the release of phosphate and iron from sediments while some reactive nitrogen would be eliminated by denitrification or anaerobic ammonia oxidation. The subsequent shift in the ocean nitrate-to-phosphate balance will affect the composition and productivity of marine organisms, notably diazotrophic cyanobacteria, with uncertain consequences for the efficiency of the biological pump.

On the whole, the smallest phytoplanktons seem to have a competitive advantage in a warmer ocean. In contrast, diatoms are at an advantage in surface waters with transient nutrient pulses. In particular, they will benefit in coastal regions from stronger wind-driven upwelling events that are expected from increased storm and frequency resulting from climate warming. Improving the evaluation of changes to the biological carbon pump via ocean models is currently hampered by several uncertainties on mechanisms controlling phytoplankton dominance and food-web structures. Also, many global circulation models remain coarse in resolution and don't serve high frequency forcing. To be able to predict better the efficiency of the pump under future conditions, the complexity in biology needs to be matched with an appropriate complexity in the representation of the physical and chemical environment in ocean models.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Boyd PW, Strzepek R, Fu F and Hutchins D (2010) *Limnology and Oceanography* 55(3): 1353-1376

Chen Y-L L, Tuo S-H and Chen H-Y (2011) *Marine Ecology Process Series* 421: 25-38

Keeling RF, Kortzinger A and Gruber N (2010) *Annual Reviews of Marine Science* 2: 199-229

Richardson TL and Jackson GA (2007) *Science* 315: 838-840

Sarmento H et al. (2010) *Philosophical Transactions of the Royal Society* B 365: 2137-2149

ocean's capacity of biological carbon pumping change?

PAST

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Changes in oceanic carbon storage have been hypothesized to be the cause of the ~100 ppm variations in atmospheric CO_2 between glacials and interglacials (Sigman and Boyle 2000). If the ocean stores more carbon in colder than in warmer climates this implies that a positive feedback exists: as climate warms the ocean releases carbon, which increases atmospheric CO_2 and amplifies the original warming. However, presently we don't know how much ocean carbon storage changed in the past and why.

Carbon isotope data from Last Glacial Maximum (LGM, 19-22 ka) sediments indicate that more carbon was stored in the deepest ocean layers, particularly in the Atlantic (Fig. 1). $\delta^{13}C$ is fractionated during carbon uptake by phytoplankton, which favors the light isotope ^{12}C. Its distribution in the deep ocean is therefore determined to a large degree by the efficiency of the biological carbon pump, with lower values indicating more respired carbon.

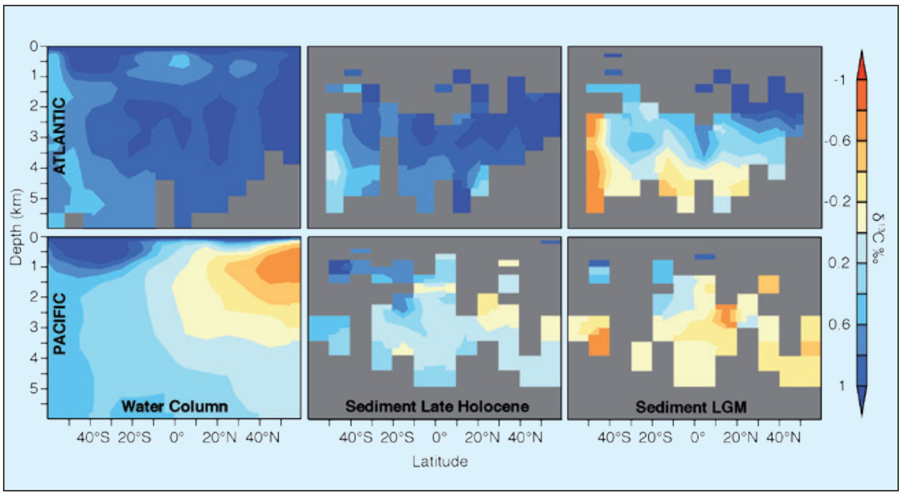

*Figure 1: Latitude-depth distribution of zonally averaged δ¹³C in the Atlantic (**top**) and Pacific (**bottom**). **Left**: modern water-column measurements from WOCE and CLIVAR cruises (Schmittner et al., unpublished data). Middle: Late Holocene sediment data. **Right**: LGM sediment data. Sediment data from Hesse et al. (2011) and Matsumoto et al. (2002).*

In the modern ocean deep waters in the North Atlantic are high (+1‰) in $\delta^{13}C$ and quite homogenous, corresponding to sinking of low nutrient, high oxygen surface waters. $\delta^{13}C$ values are lower in the Southern Ocean (+0.5‰) and decrease towards the North Pacific (−0.6‰), reflecting today's ocean's oldest waters with high nutrients and carbon and low oxygen.

During the LGM, the deep Atlantic had much larger vertical gradients than today, $\delta^{13}C$ values measured on microfossil shells of benthic foraminifera were up to 1‰ lower below 2-3 km depth, but similar above 2 km in the north (e.g. Curry and Oppo 2005). The deep Pacific Ocean was also higher in $\delta^{13}C$ particularly in the south (Matsumoto et al. 2002). In contrast to the North Atlantic, however, the North Pacific did not exhibit larger vertical gradients. The coherent large-scale differences in $\delta^{13}C$ suggest that biological carbon storage in the glacial ocean was most likely higher than today. But how much higher was it and why?

Biological, physical and chemical processes determine biological carbon storage in the ocean. It is likely that more than one process must be invoked to explain glacial to interglacial changes (Köhler et al. 2005). Increased solubility of CO_2 in colder water explains less than 20 ppm of the full glacial-interglacial difference. The increase in the vertical gradient of $\delta^{13}C$ in the Atlantic may require changes in the circulation such as a shoaling of the southward flowing deep waters or a change in the rate of northward flowing bottom waters. Furthermore, in a simple model of Bouttes et al. (2009) increased brine rejection from sea ice around Antarctica and its effect on deep ocean stratification lowered atmospheric CO_2 by ~42 ppm, but the effect will need to be reproduced with more realistic models. Large changes in the contributions of northern versus southern sources to the global deep water can also change the efficiency of the biological pump (Martin 1990), but did not contribute much to the glacial-interglacial atmospheric CO_2 changes.

The efficiency of plankton to use nitrate and phosphate may have been enhanced by more iron input to the surface ocean by higher dust deposition (Brovkin et al. 2007, estimate 37 ppm). A glacial dust plume from Patagonia may partly explain lower $\delta^{13}C$ in South Atlantic bottom waters but the increase in aeolian iron input may have been counteracted by a decrease in sedimentary sources due to lower sea level (Moore and Braucher 2008). It is also possible that the biologically available (fixed) nitrogen inventory of the glacial ocean was overall higher than today because denitrification was lower due to higher dissolved oxygen concentrations in the colder glacial ocean and reduced continental shelf area due to the sea level drop. However, these processes have not been quantified yet with a realistic 3-dimensional model.

Some or all of the processes that controlled changes in the glacial-interglacial ocean carbon storage may also be important for our warming planet. Decreased CO_2 solubility in a warming ocean will certainly occur. However, how important some of the other processes will be in the future is more uncertain. Better understanding of how and why ocean carbon storage varied in the past and in the future may now be possible due to coordinated international modeling projects and efforts to synthesize and increase the spatial coverage of paleoclimate data.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Bouttes N, Roche DM and Paillard D (2009) *Paleoceanography* 24, doi: 10.1029/2008PA001707

Brovkin V, Ganopolski A, Archer D and Rahmstorf S (2007) *Paleoceanography* 22, doi: 10.1029/2006PA001380

Martin JH (1990) *Paleoceanography* 5(1): 1-13

Matsumoto K, Oba T, Lynch-Stieglitz J and Yamamoto H (2002) *Quaternary Science Reviews* 21: 1693-1704

Moore JK and Braucher O (2008) *Biogeosciences* 5: 631-656

Arctic sea ice - When will the Arctic

PRESENT

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It seems inevitable that the Arctic will lose its summer sea ice cover as air temperatures continue to rise in response to increased concentrations of atmospheric greenhouse gases. Over the last 33 years for which we have high quality records from satellite remote sensing, the September (end-of-summer) sea-ice extent has declined at a rate of 13% per decade. The five lowest September extents in the satellite record have all been in the past five years; average extent for this period represents a 35% reduction compared to conditions in the 1980s. Although there will likely be winter sea ice for centuries to come, the ice that forms in winter will be too thin to survive the summer melt season.

Emerging results from the latest generation of coupled global climate models indicate that essentially ice-free conditions (with some residual ice surviving in favored locations) could be realized as early as 2030. However, we may get to an essentially ice free Arctic Ocean, only to see temporary recovery. Modeling work argues for both decadal-scale periods of especially rapid ice loss in the future and periods of increasing ice extent. This implies that concern over a tipping point in ice thickness that, when crossed results in a rapid slide to an ice-free state, is likely unfounded.

Given that environmental impacts of ice loss will be realized well before one gets to a truly ice-free state, the year at which we first see a blue Arctic Ocean is not as important as when the bulk of the ice is gone. Some within-Arctic impacts of sea-ice loss are already here. This includes loss of species habitat, northward migration of marine species, and increased coastal erosion along the Beaufort Sea coasts and elsewhere due to increased wave action and thermal erosion of permafrost-rich coastal bluffs (Overeem et al. 2011). The observed greening of the Arctic coastal tundra, as determined from satellite measurements of photosynthetic activity, is at least in part a response to loss of the local chilling effect of coastal ice (Bhatt et al. 2010).

Simulations with the first generation of global climate models projected

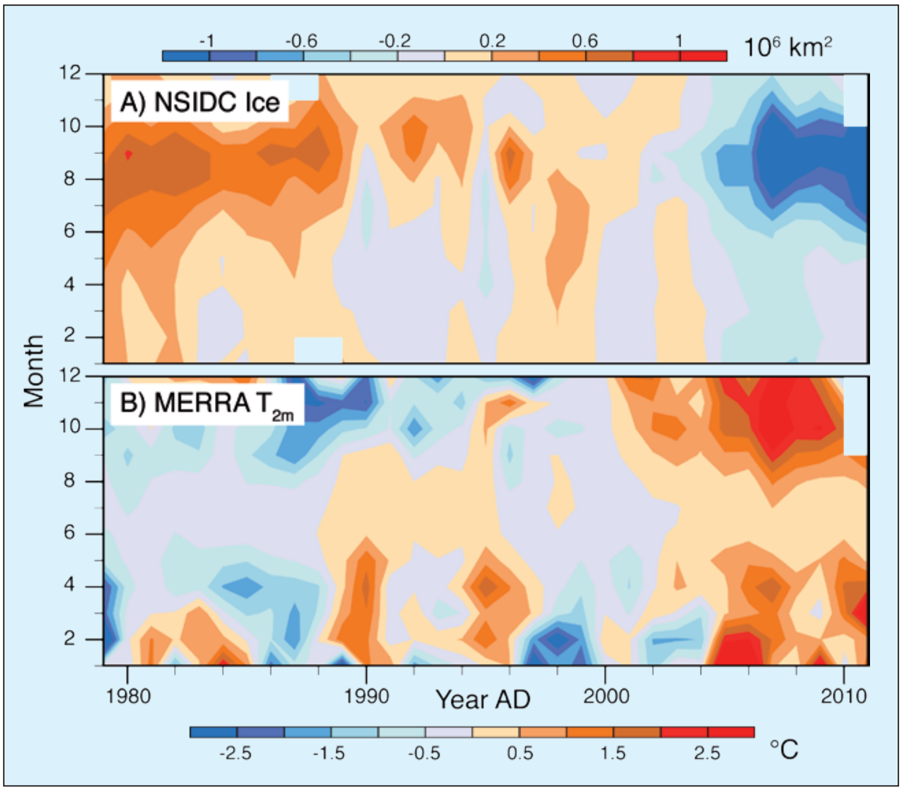

Figure 1: Time series by month (y-axis) and year (x-axis) of (top) anomalies in Arctic sea ice extent based on the satellite passive microwave record and (bottom) corresponding anomalies in 2-meter air temperate for the Arctic Ocean based on the NASA Modern Era Retrospective-Analysis for Research and Applications (MERRA). Anomalies are calculated with respect to the period 1979-2010.

that as the climate system responds to an increased level of carbon dioxide, there would be an outsized warming of the Arctic compared to the globe as a whole (Manabe and Stouffer 1980), a phenomenon termed Arctic amplification. While a number of processes can lead to Arctic amplification, summer sea-ice loss is a major driver: as the ice retreats in summer, there are ever larger areas of open water that readily absorb solar radiation and add heat to the ocean mixed layer. When the sun sets in autumn, this heat is released upwards, warming the overlying atmosphere. Arctic amplification has emerged strongly over the past decade of anomalously low summer sea-ice conditions.

There is growing recognition that Arctic amplification, through altering the static stability of the atmosphere, water vapor content and horizontal temperature gradients, will influence the character of weather patterns within and beyond the Arctic. Observational evidence suggests that high-latitude atmospheric circulation is already responding to ice loss, and a variety of studies indicate that these effects will become more pronounced in the coming decades (Serreze and Barry 2011). At least one modeling study finds that the warming effects of sea-ice loss will extend far inland, contributing to warming of the tundra soil column, hastening permafrost thaw and the release of stored carbon to the atmosphere (Lawrence et al. 2008). In short, there seem to be many reasons why we should care about losing the summer Arctic sea-ice cover.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Bhatt US et al. (2010) *Earth Interactions* 14: 1-20

Lawrence DM et al. (2008) *Geophysical Research Letters* 35, doi: 10.1029/2008GL033894

Manabe S and Stouffer RJ (1980) *Journal of Geophysical Research* 85: 5529-5554

Overeem I et al. (2011) *Geophysical Resesearch Letters* 38, doi: 10.1029/2011GL04681

Serreze MC and Barry RG (2011) *Global and Planetary Change* 77: 85-96

Ocean become ice-free and what will be the effects?

PAST

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As Arctic sea ice is shrinking at an accelerating speed for the fourth decade in a row and summer ice extent numbers are falling well below the range of historical observations, much attention is placed on paleoclimatic reconstructions based on long-term time series. This situation necessitates a clear understanding of the nature and limitations of paleo records that can be employed in the Arctic Ocean. The most direct long-term records of sea-ice changes could be derived from seafloor sediments. Not surprisingly, Arctic paleoceanographic research is currently on the rise (Polyak and Jakobsson 2011). However, very low sedimentation rates in the central Arctic Ocean and the predominant lack of deposits older than the last deglaciation (last ca. 15 ka) on the continental shelves narrow the application of paleo data from these sedimentary archives for evaluating future changes (Polyak et al. 2010, and references therein). Useful information is also derived from coastal records and related paleoclimatic archives such as continental ice cores at the Arctic Ocean periphery (e.g. Macias-Fauria et al. 2009; Funder et al. 2011; Kinnard et al. 2011); but none of them can provide a continuous long-term record.

Due to these limitations one should not expect too accurate predictions of the future course and rate of ice retreat from paleo records; nevertheless, they contain a plethora of information on the state of the Arctic system at different climatic conditions of a much wider range than that of the recent centuries (Fig. 1). Notably, paleo data could shed light on the functioning of the seasonally mostly ice free Arctic and its role in the global climatic ensemble, which is essential for predicting environmental change in the very near future (e.g. Serreze and Barry 2011). One critical set of questions relates to the fate of Arctic biota, from microscopic organisms to polar bears, uniquely adapted to live in or in connection with a perennially ice-covered ocean. Disruption of habitats and life cycle of many Arctic species with shrinking sea ice and increasing temperatures is already underway, along with a northward migration of lower-latitude biota from both the Atlantic and Pacific oceans (Wassmann 2011, and references therein). Striking examples are the penetration of the Pacific diatom *Neodenticula seminae* via the Arctic into the North Atlantic (Reid et al. 2007) and the distribution of the coccolithophore *Emiliania huxleyi* from the Atlantic to the northern edge of the Barents Sea (Hegseth and Sundfjord 2008). Stratigraphic data indicate that these migrations likely happen for the first time since the end of the Early Pleistocene (ca. 800 ka) and the Last Interglaciation (ca. 130 ka), respectively.

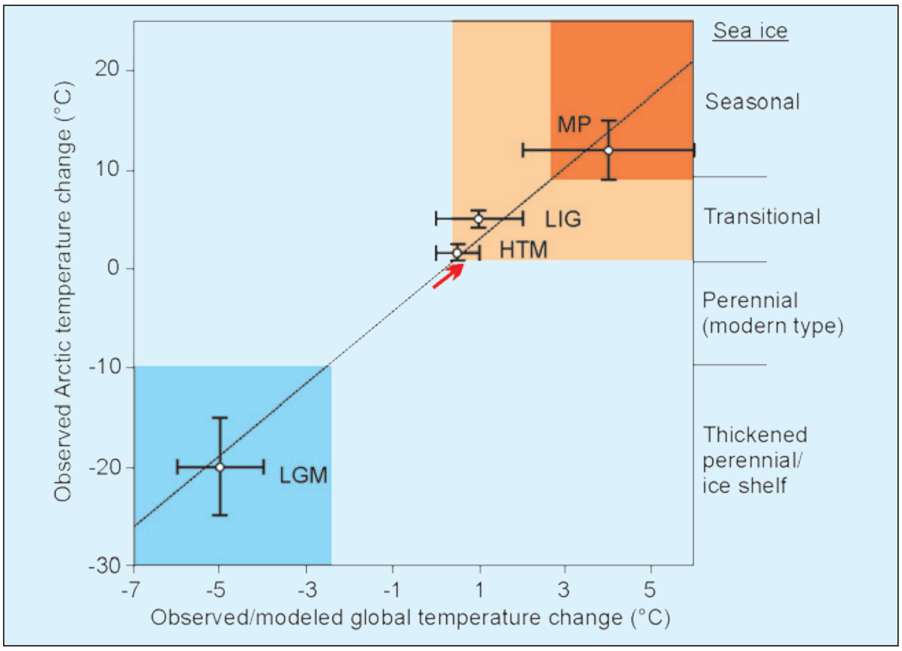

Figure 1: Schematic representation of Arctic sea-ice conditions inferred from paleoclimatic data (e.g. Polyak et al. 2010; Funder et al. 2011; Polyak and Jakobsson 2011). Paleo-temperature anomalies are shown for Last Glacial Maximum (LGM; ~20 ka), Holocene Thermal Maximum (HTM; ~8 ka), Last Interglaciation (LIG; ~130 ka), and middle Pliocene (MP; ~3.5 Ma) (from Miller et al. 2010). Punctured trend line represents the Arctic Amplification. Red arrow shows instrumentally observed temperature change, consistent with observed loss of sea ice approaching the "transitional" state with increasingly large seasonally ice-free areas (see accompanying paper by Serreze and Stroeve).

Investigation of these and other relatively warm, low-ice time intervals of the past few million years, from the current interglaciation (Holocene) to Pliocene, when the Arctic paleogeography was generally similar to modern, has a potential to clarify questions related to the survival of Arctic biota and other impacts of reduced sea ice. This task, however, is complicated by the paucity of paleobiological/biogeochemical proxies in Arctic sediment records because of low marine primary production, overwhelming inputs of terrigenous organic matter, and widespread dissolution of both calcareous and siliceous material, as well as problems with reconstructing sea-ice conditions, which cannot yet be definitively evaluated by any known single proxy. Another complication arises from difficulties with establishing age constraints for Arctic Ocean sediments due to various adverse impacts of the ice cover. Recent achievements in developing sea-ice proxies and improving age controls are encouraging (Polyak and Jakobsson, 2011, and references therein), but much more needs to be done. Promising steps in this direction are underway such as the ESF program Arctic Paleoclimate and its Extremes (APEX) and the newly created PAGES working group on Sea Ice Proxies (SIP), and we can hope for exciting breakthroughs in the near future.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Miller GH et al. (2010) *Quaternary Science Reviews* 29: 1779-1790

Polyak L el al. (2010) *Quaternary Science Reviews* 29: 1757-1778

Polyak L and Jakobsson M (2011) *Oceanography* 24: 52-64

Serreze MC and Barry RG (2011) *Global and Planetary Change* 77: 85-96

Wassmann P (2011) *Progress in Oceanography* 90: 1-17

Aerosols and climate - PRESENT

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Solids or liquids suspended in the atmosphere – aerosols – influence Earth's climate by interacting directly with radiation, by modifying clouds and by perturbing biogeochemical cycles and atmospheric chemistry. Aerosols consist of sulfates, organic carbon, black inorganic carbon, sea spray, mineral dust, ammonia and nitrates, and are emitted either directly or are formed from gaseous precursors. They are released by fossil fuel combustion, biomass burning or by emissions from the land and ocean surfaces. Aerosols reside in the troposphere for less than a day to a few weeks, and up to a few years in the stratosphere (Mahowald et al. 2011).

We monitor aerosols today using ground-based and satellite-borne remote sensing devices, and by in situ sampling on the ground and via aircraft, both at local and global scales (for example, the NASA Global Aerosol Climatology Project). But, despite the large number of observations of aerosols, there are large uncertainties in their distribution in space and time and their characteristics, because of their variability in space, time and composition (Mahowald et al. 2011; Formenti et al. 2011). In addition, aerosol deposition can be studied using passive natural or human-made collectors, such as snow pits or marine sediment traps (Kohfeld and Harrison 2001). Increasingly complex atmospheric transport and chemistry models and Earth-system models complement the set of tools for the study of the aerosol-climate interactions (Stier et al. 2006).

In its fourth assessment report, the Intergovernmental Panel on Climate Change estimated that anthropogenic aerosols had a net cooling effect on climate, partly offsetting the warming from greenhouse gases. But this conclusion is tempered by the large uncertainties involved. Aerosol-climate interactions thus constitute one of the major sources of uncertainty in assessing the global average radiative forcing (RF; Forster et al. 2007), and contribute to the large uncertainty in climate sensitivity (globally averaged surface temperature change at equilibrium) of between 2 and 4.5°C for doubling of CO2 (IPCC 2007).

Aerosols affect the climate in multiple ways. The direct effect – by scattering and absorption of solar and terrestrial radiation – leads to an RF value of -0.50±0.40 Wm^{-2} compared to the +1.7±0.1 Wm^{-2} estimated for rising CO_2 levels (Forster et al. 2007). Similarly, this interaction of aerosols with radiation also appears to be contributing to the observed "dimming" or reduction in the amount of incoming solar radiation that reaches the surface (e.g. Haywood et al. 2011). Aerosols interact with clouds by modulating albedo (the "cloud albedo" effect), which causes RF of -0.7 (-0.3 to -1.8) Wm^{-2}, and by modifying cloud lifetime (Forster et al. 2007). Aerosols also modify biogeochemical cycles by providing nutrients that limit primary production (e.g. Martin et al. 1990) and by producing climate alterations, which in turn enhance carbon uptake, affecting climate indirectly with an estimated RF of -0.50±0.40 Wm^{-2} (Mahowald 2011). In addition, deposition of black carbon and dust modify the albedo of snow (Hansen and Nazarenko 2004).

Natural aerosols are a potent source of feedbacks to the climate (Carlsaw et al. 2010). The impact of stratospheric aerosols on climate is seen in the response of the surface cooling to large volcanic events (e.g. Mt. Pinatubo), which can be as large as -0.2°C globally averaged (Robock 2000). Because of the potency of aerosols for climate perturbation, they are also being considered for tools in geoengineering the climate (e.g. Shepherd et al. 2009).

Humans have significantly increased the amount of aerosol in the atmosphere over the last 130 years. In the future, because of public health concerns as well as efforts to reduce combustion of fossil fuels, it is likely that emissions of anthropogenic aerosols will decrease (Fig. 1). This reduction in aerosols in the future is likely to both increase the rate of warming (Andreae et al. 2005), as well as make reductions in carbon dioxide harder to achieve (Mahowald 2011), because of the complicated and central role of aerosols in modulating climate and biogeochemistry.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Andreae MO, Jones CD and Cox PM (2005) *Nature* 435: 1187-1190

Carslaw KS et al. (2010) *Atmospheric Chemistry and Physics* 10: 1701-1737

Haywood JM et al. (2011) *Journal of Geophysical Research* 116, doi: 10.1029/2011JD016000

Mahowald N (2011) *Science* 334, 794-796

Mahowald N et al. (2011) *Annual Reviews of Environment and Resources* 36: 45-74

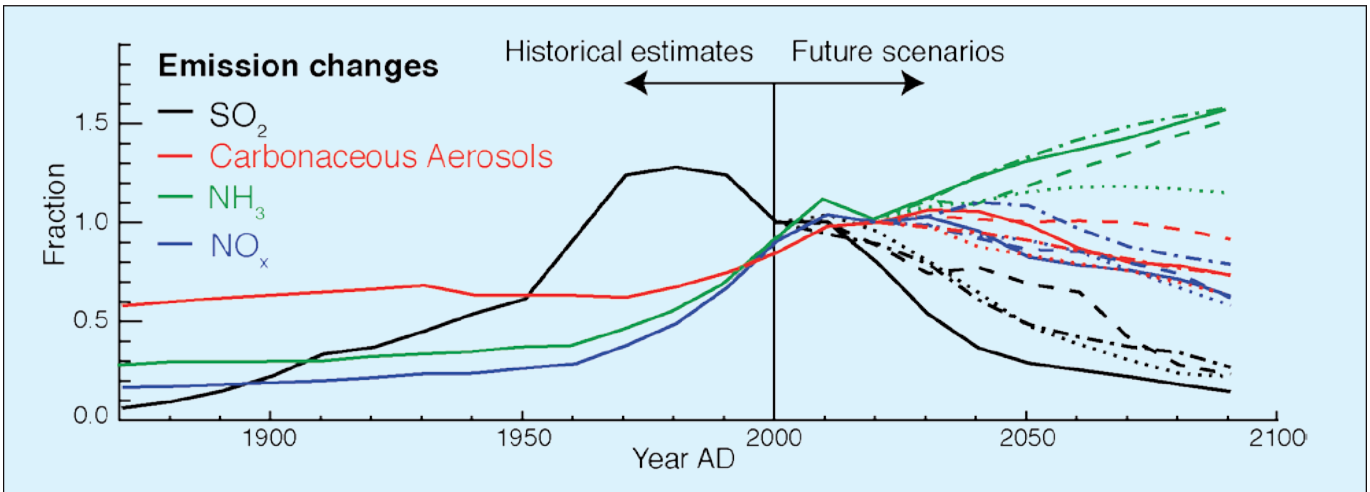

Figure 1: Historical and projected aerosol emissions relative to 2000 AD emissions. Sulfur dioxide forms sulfate aerosols, while about half the ammonia and nitrogen oxides form nitrogen-based aerosols in the atmosphere. Carbonaceous aerosols include both black and organic carbon and the estimated emissions here do not include secondary aerosol formation in the atmosphere. Calculations based on Mahowald (in press).

How sensitive is earth's climate to atmospheric aerosols?

PAST

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Paleoclimate records spanning the past several million years reveal large variability in the deposition of aeolian dust and other natural aerosols. Understanding this variability represents both a challenge and a useful test for Earth system models. The production, transport and deposition of natural aerosols are controlled by numerous physical and biogeochemical processes that are still not well understood. On the other hand, aerosols affect the climate via a number of physical and biogeochemical processes (see the accompanying article by Albani and Mahowald). On short time scales (several years), sulfur aerosols from volcanic eruptions play a significant role in forcing climate. On longer time scales, it is believed that climate-aerosol feedbacks amplify climate changes caused by other factors, such as changes in Earth's orbital parameters and concentrations of greenhouse gases.

Variability of the dust cycle is especially significant at glacial-interglacial time scales (Fig. 1). Paleoclimate data and model simulations suggest that during the Last Glacial Maximum (ca. 21,000 years before present) dust deposition in tropics was several times higher than at present and over Antarctica and Greenland the dust deposition rates increased by more than an order of magnitude. Such large increase in atmospheric dustiness cannot be explained without invoking a large increase in dust sources during glacial times (Mahowald et al. 2006). There are a number of processes via which variations in atmospheric dust loading and deposition rates may contribute as amplifiers and modifiers of the orbitally forced glacial cycles. First, an increase in atmospheric dustiness leads to increased reflection of incoming solar radiation and thus contributes to global cooling. This effect can be additionally enhanced by the effect of natural aerosols on cloud albedo (the so-called indirect effect), but partly offset by the additional absorption of outgoing long-wave radiation by dust particles (Takemura et al. 2009). The net simulated climatic effect of dust on climate during glacial times is sensitive to the poorly known optical properties of dust and is therefore model-dependent but typically of a comparable magnitude (1-2 W/m²) to other climatic factors, such as a lowering of the atmospheric CO_2 concentration and increased surface albedo due to ice sheet growth. At the same time, enhanced dust deposition over snow and ice leads to a reduction of surface albedo and thus enhances ice melt. This effect may have played a role in both preventing the ice sheets from spreading into lower latitudes (Krinner et al. 2006) and accelerating the retreat of the ice sheets during glacial terminations (Ganopolski et al. 2010).

In addition to the physical effect, enhanced deposition of dust over ocean areas where plankton growth is limited by the availability of iron can enhance biological production and thus lead to the drawdown of atmospheric CO_2 (Martin et al. 1990). Recent modeling experiments suggest that the iron fertilization effect in the Southern Ocean alone can explain a significant fraction of glacial CO_2 reduction (Brovkin et al. 2007). Further progress in understanding the role of dust and other natural aerosols in climate change therefore requires the incorporation of these processes into the new generation of Earth system models.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Brovkin V, Ganopolski A, Archer D and Rahmstorf S (2007) *Paleoceanography* 22, doi: 10.1029/2006PA001380

Ganopolski A, Calov R and Claussen M (2010) *Climate of the Past* 6: 229-244

Krinner G, Boucher O and Balkanski Y (2006) *Climate Dynamics* 27(6): 613-625

Mahowald N et al. (2006) *Journal of Geophysical Research* 111, doi: 10.1029/2005JD006653

Takemura T et al. (2009) *Atmospheric Chemistry and Physics* 9: 3061-3073

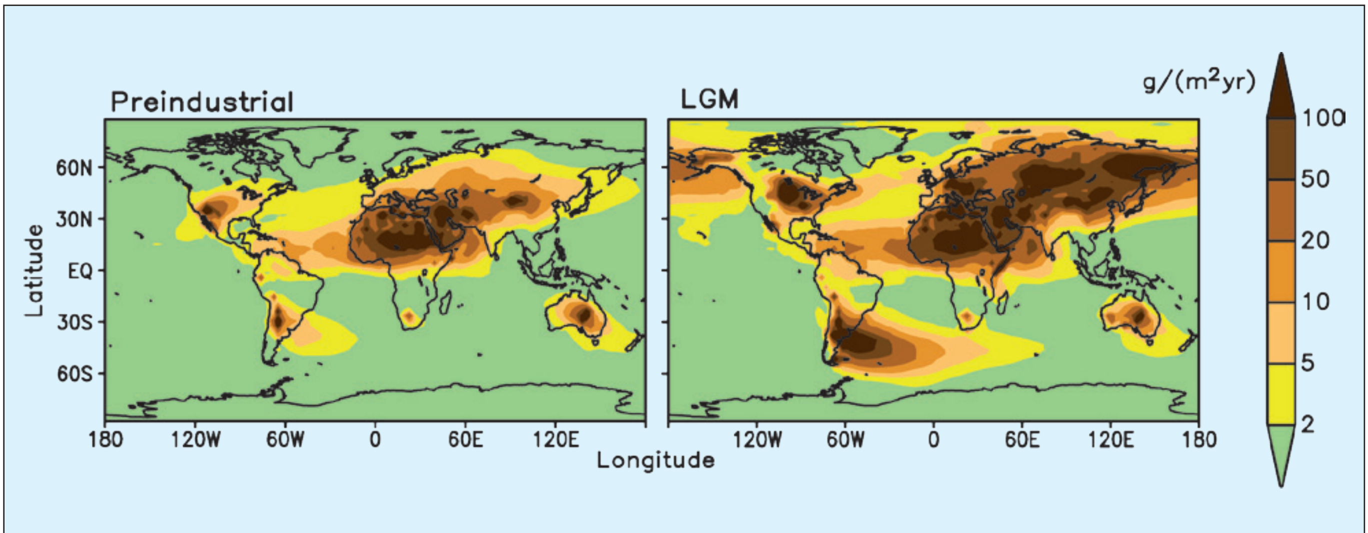
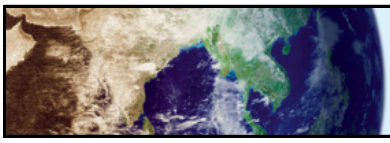


Figure 1: Modeled dust deposition under preindustrial climate conditions (left) and Last Glacial Maximum (right) based on Mahowald et al. (2006).



Land cover change - To what degree

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Historic changes in land use have altered the land surface significantly. For example, since the early 19th century, there has been a substantial increase in the area of cropland in the middle latitudes of the Northern Hemisphere. The pronounced tropical deforestation during the 20th century has paralleled the large-scale development of urban settlements and irrigated agriculture. The land-cover changes have resulted in a number of alterations in the regional and global climate system, primarily by: 1) Changing the surface albedo; 2) Changing the surface evapotranspiration; 3) Modifying winds, heat wave resilience, vulnerability to floods and other such factors in the proximity of human settlements; and 4) Modifying atmospheric CO_2 uptake.

Changes in the albedo and evaporation have likely had a discernible effect on global mean temperatures since the late 19th century, although models show varying results of the net effects on climate (Pitman et al. 2009). Decreased forest cover has generally increased the surface albedo, thereby reducing the net energy available at the surface. This has possibly led to a downward modulation of the global mean warming rate (approximately 0.7°C since instrumental measurements began; IPCC 2007) by 0–0.1°C (de Noblet-Ducoudré et al., in press). Local land-atmosphere feedbacks generate large spatial variability of the land-use effects. In general, land-use-induced temperature changes are relatively small in the tropics, but increase significantly while moving to the equator. In areas with large deforestation (e.g. USA, central Eurasia) the local cooling has likely more than compensated for the global mean warming induced by elevated greenhouse gas concentrations (de Noblet-Ducoudré et al., in press; Fig. 1), although this finding needs to be balanced with the fact that deforestation itself has significantly contributed to the increase in CO_2 (Pongratz et al. 2010). Net effects of land use on evaporation are more uncertain than those on albedo. Higher evaporation may be alternatively found over forests or grassland depending on the local conditions (Teuling et al. 2010).

Apart from the direct impacts on the physical climate system, large-scale deforestation has resulted in a significant release of carbon to the atmosphere, adding to the CO_2-perturbation caused by fossil fuel burning. On top of the estimated 9.1±0.5 Gt carbon released from fossil resources in 2010, another estimated 0.9±0.7 Gt carbon was released by land-use change (Peters et al. 2011). Through the combination of CO_2 and biophysical effects, deforestation is expected to lead to a net climate warming in tropical regions, but possibly to a net cooling in boreal regions (Betts et al. 2007, Bonan 2008). However, human management could also play a role, because areas that are deforested tend to have higher carbon content and less snow cover (Pongratz et al. 2011). Another marked effect of land-use change on climate is an increase in vulnerability to climate extremes, both because of the potential inability of forest areas to dampen temperature extremes during the early heatwave stages, and because of the increased exposure to extreme events like floods.

In the context of the 5th Coupled Model Intercomparison Project (CMIP5), many Global Circulation Model projections have been carried out for a number of future socio-economic scenarios, including land-use change. Early results indicate that the overall magnitude of projected land-use change (that is, the conversion of natural vegetation to cropland) is generally smaller than observed during the 20th century in all future scenarios. The regional differences, however, are pronounced. Sub-Saharan Africa is projected to experience a significant increase in agricultural area in most of the scenarios, even in the low-emission scenario targeted to meet the 2-degree global warming criterion. The local expression of land-use interaction with climate and the large spatial variability of the nature and degree of land-use change calls for an increasing focus on assessing impacts of land-cover change at a regional level.

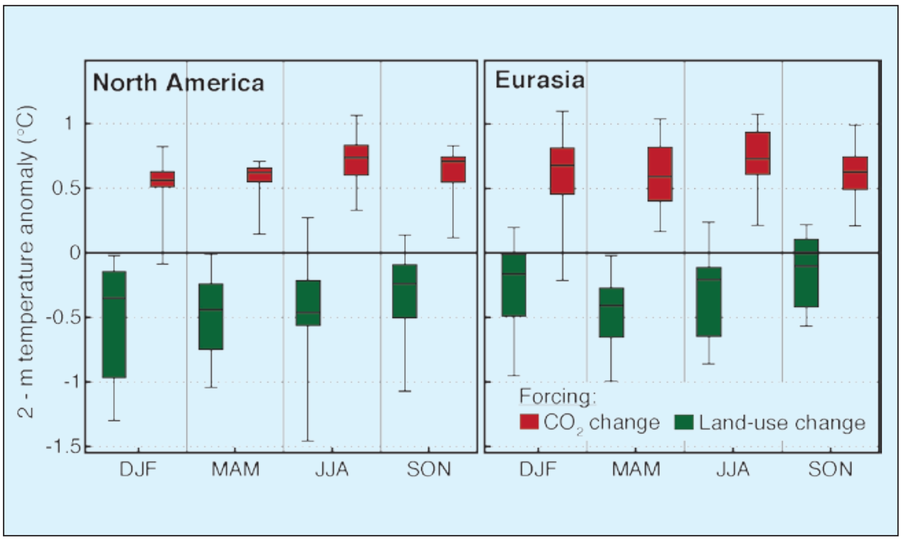

Figure 1: Effects of land use and CO_2 forcings on temperature change from pre-industrial to present-day in two heavily deforested areas (central North America and central Eurasia) as simulated with seven atmosphere-land models (de Noblet-Ducoudré et al., in press). Most simulations suggest that the propagating land use resulted in significant regional cooling, which approximately counteracted the concurrent CO_2-related warming in these regions.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Bonan GB (2008) *Science* 320: 1444

de Noblet-Ducoudré N et al. (in press) *Journal of Climate*, doi: 10.1175/JCLI-D-11-00338.1

Peters GP et al. (2011) *Nature Climate Change* 2: 2-4

Pitman AJ et al. (2009) *Geophysical Research Letters* 36, doi:10.1029/2009GL039076

Pongratz J et al. (2011) *Geophysical Research Letters* 38, doi: 10.1029/2011GL047848

Teuling AJ et al. (2010) *Nature Geoscience* 3: 722-727

do human land cover dynamics affect climate change?

PAST

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During the 12,000 years preceding the Industrial Revolution, melting ice sheets, stabilizing sea level, and changes in temperature and precipitation patterns influenced global land cover. Over the same period, humans adopted agriculture, domesticated animals, developed metallurgy and other technologies, and evolved in their social and cultural systems. These changes led to exponential growth in human populations, urbanization, and the expansion of human settlements to the entire ice-free area of the world. Both human-induced and natural environmental change over the Holocene resulted in the transformation of the Earth's system by modifying land cover and through emissions of greenhouse gases and aerosols.

Preindustrial anthropogenic activities, mainly deforestation, rice cultivation, and domestication of ruminants, resulted in substantial emissions of CO_2 and CH_4 to the atmosphere. This change in greenhouse gas concentrations could have affected global climate to the point of precluding the inception of a new glacial period (Ruddiman 2003; Ruddiman et al. 2011). Ruddiman based his analysis on orbital forcing, thought to be the ultimate cause of ice age inception, and atmospheric CO_2 and CH_4 concentrations measured in ice cores. He concluded that greenhouse gas concentrations in the Holocene showed anomalous trends when compared to previous interglacials. Ruddiman's analysis has been criticized on the alignment between orbital forcing and greenhouse gas records, and because most previous interglacials show a time trend in orbital forcing that is not completely analogous to the Holocene. There is one undisputed feature of the Holocene, however, that we know makes this epoch different from the rest of Earth history: the existence of behaviorally modern humans.

The earliest significant impact humans probably had on large-scale land cover is the application of fire for the improvement of hunting and gathering opportunities. Even extremely low population densities can radically change land cover using fire (Bowman 1998; McWethy et al. 2009). Where an obvious anthropogenic trend is not identified in synthesis of charcoal records from sedimentary archives (Marlon et al. 2008) this may be a result of the fact that we have no appropriate baseline without human influence with which to assess the data, e.g. from previous interglacials.

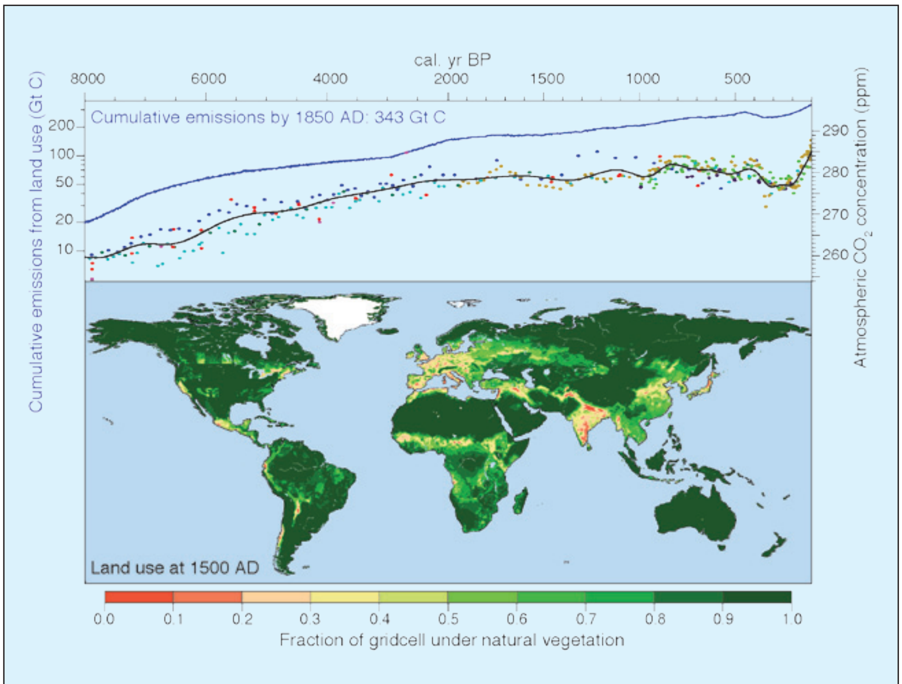

*Figure 1: **Top:** Preindustrial Holocene atmospheric CO_2 concentrations measured in Antarctic ice cores (dots, black line), and carbon emissions as a result of anthropogenic land cover change (blue line). **Bottom:** Global land use at 1500 AD, before the collapse of the indigenous populations of the Americas following European contact. For details and data sources, see Kaplan et al. 2011.*

With the Neolithic revolution, the human interaction with the landscape changed completely, with large areas of natural vegetation converted to cropland and pasture. Outside of river floodplains, early agriculture was inefficient, and meant that early farmers used much more land per capita than observed even in late preindustrial societies. Deforestation for agricultural land use and exploitation of forest resources for fuel, construction materials, and nutrients meant that human impact on the global carbon cycle could have been substantial (Fig. 1; Kaplan et al. 2011). Furthermore, beginning in the mid-Holocene, the spread of wet rice cultivation in Asia (Fuller et al. 2011) and the production of charcoal for metal smelting would have led to large increases in CH_4 emissions over natural levels. Thus, anthropogenic activities could have caused the increases in atmospheric CO_2 and CH_4 concentrations observed over the last 6 ka.

While anthropogenic activities may have stabilized or increased greenhouse gas concentrations leading to a warmer global climate than would have occurred otherwise, the biogeophysical impact of deforestation and increases in aerosols could have had contrasting effects. Cooling could have occurred as a result of increased surface and atmospheric albedo, though climate-modeling experiments have shown that these effects are limited to the region where land cover change occurred. Furthermore, preindustrial human activities affected the global hydrological balance: deforestation leads to reductions in evapotranspiration and increases in runoff; these alterations could also have led to seasonally contrasting changes in regional climate. Anthropogenic activities probably had an influence on regional and global climate over the Holocene, long before the Industrial Revolution.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Fuller DQ et al. (2011) *The Holocene* 21(5): 743-759
Kaplan JO et al. (2011) *The Holocene* 21(5): 775-791
McWethy DB et al. (2010) *PNAS* 107(50): 21343-21348
Marlon JR et al. (2008) *Nature Geoscience* 1: 697-702
Ruddiman WF, Kutzbach JE and Vavrus SJ (2011) *The Holocene* 21(5): 865-879

Fire -

PRESENT

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Large wildfires in a diverse array of forests are typically associated with drought during the fire season (Krawchuk and Moritz 2011). Drought occurrence is driven by variability in both temperature and precipitation. Climate change is expected to increase temperature over land, with greater increases in continental interiors and high northern latitudes. However, precipitation is more varied and uncertain, with increases projected in the tropics and high latitudes, and decreases in mid-latitudes (Dai 2010). Warming combined with changes in precipitation is projected to produce permanent severe drought conditions by mid-to-late century for much of the Americas, Africa, Southern Europe, Central and Southeast Asia, and Australia, although uncertainty is high (Dai 2010). Changes of this magnitude could substantially alter ecosystems, with wildfire constituting a mechanism effecting abrupt changes in response to more gradual climate forcings. The lack of analogues for transitions of this speed and magnitude limit the capacity to robustly model climate-fire-vegetation interactions in coming decades.

Ecosystems highly sensitive to recent climate trends include cool, moist forests with infrequent, stand-replacing fire where warming has led to longer fire seasons and/or increased evapotranspiration. Examples include substantially increased fire in mid-elevation Rocky Mountain forests of the USA (Westerling et al. 2006) and Canadian and Alaskan boreal forests (Soja et al. 2007) (Fig. 1). High-severity burned area in Siberian boreal forests may also have increased, but historical baseline data are less reliable (Soja et al. 2007). Fire is likely to further increase in these forests with continued warming (e.g. Krawchuk et al. 2009; Wotton et al. 2010; Westerling et al. 2011). However, as climate shifts and fire becomes more frequent, changes in regeneration and productivity for forest species could transform vegetation assemblages and the fire regimes they can support (Soja et al. 2007; Krawchuk et al. 2009; Westerling et al. 2011). An additional uncertainty for these ecosystems is how fire may interact with other disturbance types such as bark beetle outbreaks that alter the structure of forest fuels.

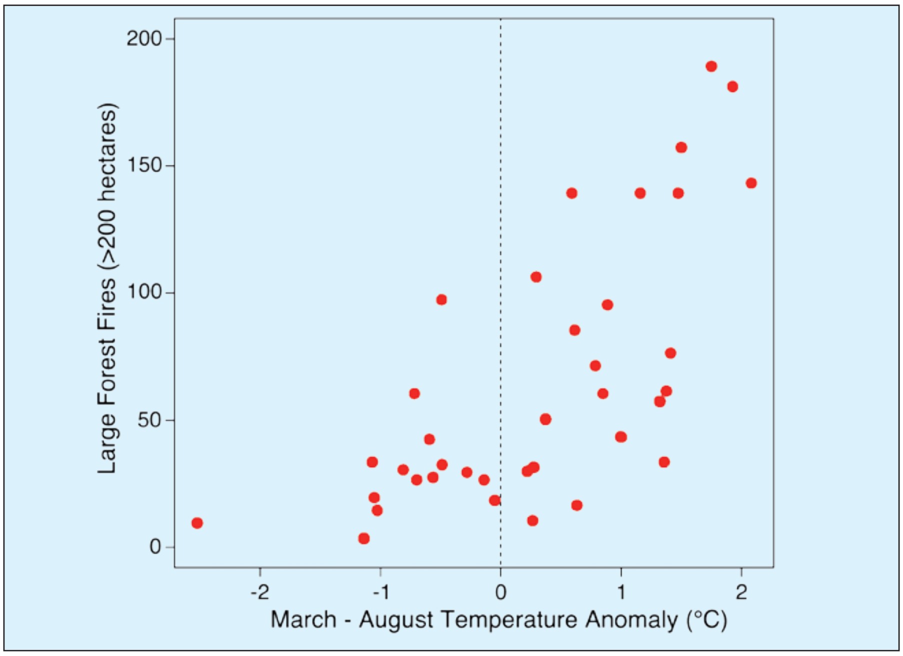

Figure 1: The number of large forest wildfires (vertical axis) versus average March through August temperature anomalies (horizontal axis) for 1972-2008 in Western US forests. Anomalies were constructed subtracting the long-term mean for 1972-1990. Fires are all large (> 200 ha) fires reported by the United States' Bureau of Indian Affairs, National Park Service, and Forest Service as burning in forests. All fires were classified as "action" fires on which suppression was attempted (fires used to manage vegetation were excluded). See Westerling et al. 2006 and Westerling et al 2011 for data and methodology.

Dry, warm forests may still be sensitive to warming that exacerbates periodic drought. Large areas burned in conjunction with recent drought and warming in mountain forests of the southwestern United States (Williams et al. 2010). The largest fires there coincided with reduced precipitation, higher temperatures and earlier spring snowmelt (Westerling et al. 2006). Land use and fire suppression in southwestern forests also led to fuel accumulation and changes in fuel structure. The interaction of fuel changes with climate change and variability likely contributed to increased fire and fire severity, but the relative importance of these causes is not known (Williams et al. 2010). Recurrent severe drought could convert large portions (>50%) of Southwestern U.S. forests to non-forest vegetation due to fire, beetles and other climate-related dieoff (Williams et al. 2010), substantially altering fire regimes.

As in higher latitude forests, drought-driven increases in fuel flammability drive increased fire in tropical forests. However, short-term reductions in precipitation, rather than elevated temperatures, are the dominant influence on wildfire in tropical forests due to their higher temperatures (Goldammer and Price 1998). While on average increased aridity is projected for Amazon, Mexico and Congo forests across many climate models, the greater uncertainty associated with projected patterns of precipitation make future fire predictions in these tropical forests more uncertain as well.

Diverse forests in many regions of the globe have the potential for increased fire in the coming decades due to changes in temperature, precipitation or both. Changes in climate and disturbance may substantially alter vegetation in ways that feed back to or limit changes in forest wildfire.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Dai A (2011) Wiley Interdisciplinary Reviews: *Climate Change*, 2(1): 45-65
Krawchuk M and Moritz M (2011) *Ecology* 92(1): 121-132
Soja A et al. (2007) *Global and Planetary Change* 56: 274-29
Westerling A et al. (2011) *PNAS* 108(32): 13165-13170
Williams A et al. (2010) *PNAS* 107(50): 21289-21294

Are we facing an increase in wildfires?

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Wildfire, the most widespread form of vegetation disturbance, has multiple influences on climate, and places an increasingly large socio-economic burden on society. Remote-sensing and historical records provide insights into how climatic, environmental and human factors influence the incidence of wildfire. These sources only cover the last few decades – a period when climate variations were much smaller than the changes expected during the 21st century and, globally, there were no radical changes in human activities. Luckily, there are other sources of information about changes in regional wildfire regimes in response to both large climatic changes and fundamental shifts in human activities. These sources include measurements of the isotopic composition of atmospheric gases trapped in ice cores, fire scars on living and fossil trees, and biomarkers and charcoal preserved in sediments. Of these, the most abundant are sedimentary charcoal: there are well over 800 site records worldwide, some providing high-resolution data for the last few millennia and some records spanning several glacial-interglacial cycles (Fig. 1).

Globally, fire is low during cold, glacial intervals and high during warm, interglacial intervals (Daniau et al. 2010a). The incidence of fire tracks the shift in global temperature during the last deglaciation (Power et al. 2008). It also tracks the rapid temperature changes (Dansgaard-Oeschger cycles) during the last glaciation with a lag of <50-100 years (Daniau et al. 2010a; Mooney et al. 2011). On centennial to multi-millennial time-scales and regional to global space-scales, temperature is the major driver of changes in biomass burning: increasing temperature leads to increased fire through increasing plant productivity and hence fuel production (Daniau et al., unpublished data). The effect of precipitation change is more complex. Fire peaks at intermediate precipitation levels at all temperatures: fire is low in dry environments because of lack of fuel and in wet environments because the fuel is too damp to burn. The impact of a precipitation change will depend on whether a site lies in a dry "fuel-limited" or a wet "drought-limited" environment. These climate-fire relationships are not unique to the paleorecord: similar relationships are found in global analyses of remotely sensed burnt area (Daniau et al., unpublished data).

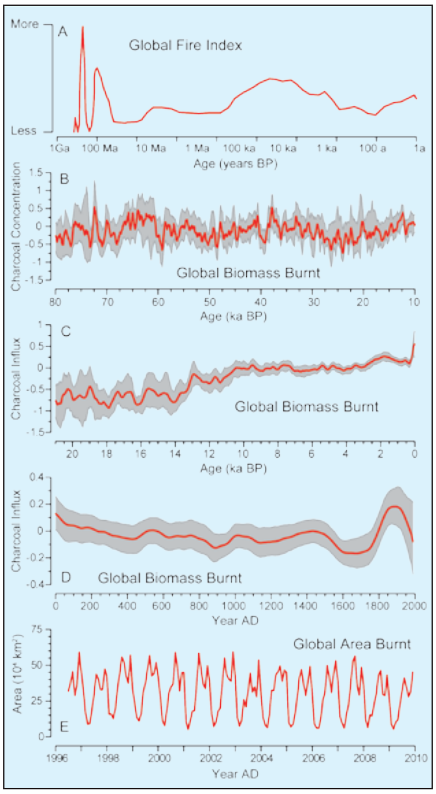


*Figure 1: The incidence of wildfire varies on multiple timescales. The record for the past billion years (1 Ga) (**A**) is a qualitative index of global fire based on discontinuous sedimentary charcoal records (Bowman et al. 2009). The record for the past 80 ka (**B**) is a global composite of 30 sedimentary charcoal records (Daniau et al. 2010a), that for the past 21 ka (**C**) is a global composite of ca. 700 sedimentary charcoal records (Daniau et al., unpublished data) and that for the past 2 ka is a global composite of ca. 400 sedimentary charcoal records (**D**; Marlon et al. 2008). The biomass burnt record in B, C and D is expressed as z-score anomalies from a long-term mean. Global area burnt from 1997 to 2009 (**E**) is derived from satellite-based remote sensing (GFED v3.1; Giglio et al. 2010).*

The paleorecord shows surprisingly little evidence of human impact on regional fire regimes. Colonization of uninhabited islands, such as New Zealand, may be marked by an increase in fire, as may cultural transitions, such as the European colonization of Australia (Mooney et al. 2011). However, there are examples of both colonization and cultural transition that are not accompanied by changes in fire. The transition from Neanderthal to Modern Humans in Europe was not accompanied by a change in fire regime (Daniau et al. 2010b); similarly, changes in fire regimes in the Americas are not synchronous with the dramatic collapse of indigenous populations after European colonization (Power et al., unpublished data). The largest human impact occurred around the end of the 19th century – the expansion of industrial-scale agriculture in many parts of the world, which resulted in substantial landscape fragmentation, coincides with decreases in fire in the affected regions and a large global decrease in biomass burning (Marlon et al. 2008; Wang et al. 2010).

Direct extrapolation of paleo-evidence to predict the future would be unreliable: the past is not an analogue for future climate and environmental changes because the combination of causal factors is different and regional land-use patterns have changed radically. But paleorecords show there are predictable relationships between climate and natural fire regimes. These relationships mean we can draw lessons from the paleorecord that have implications for fire in the 21st century. The paleorecord indicates that *global* warming will result in a *global* increase in fire; this will be mitigated in some regions by precipitation changes which either reduce fuel loads (warmer and drier climates) or increase fuel moisture (monsoonal climates). Human activities resulting in continued landscape fragmentation (e.g. urbanization, tropical deforestation) could reduce the influence of climate – but mitigation measures involving afforestation may lead to an increase in wildfires.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

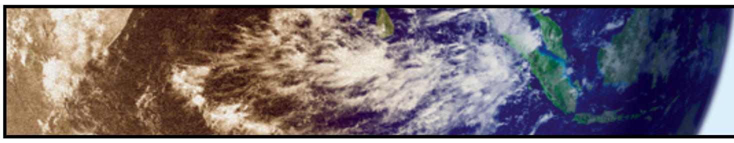
Daniau A-L, d'Errico F and Sánchez Goñi MF (2010b) *PloSONE* 5, doi: 10.1371/journal.pone.0009157

Marlon J et al. (2008) *Nature Geoscience* 1: 697-702

Mooney S et al. (2011) *Quaternary Science Reviews* 30: 28-46

Power MJ et al. (2008) *Climate Dynamics* 30: 887-907

Wang Z, Chappellaz J, Park K and Mak JE (2010) *Science* 330: 1663-1666



Monsoon climate - Will

PRESENT

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In physical essence, monsoon is a forced response of the coupled climate system to the annual cycle of insolation. Land-sea thermal contrast, moisture processes, topography and Earth's rotation are critical in determining monsoon rainfall patterns and vigor. Integrated regional monsoons generate a global-scale seasonally varying overturning circulation throughout the tropics (Trenberth et al. 2000). Global monsoon (GM) represents the dominant mode of annual variation of the tropical precipitation and circulation (Wang and Ding 2008), thus a defining feature of seasonality and a major mode of variability of the Earth's climate system.

Monsoon climate features an annual reversal of surface winds and contrasting rainy summer and dry winter. The monsoon domains defined by precipitation characteristics are shown in Figure 1, which include all regional monsoons over South Asia, East Asia, Australia, Africa and the Americas (Wang and Ding 2008).

Monsoonal interannual-interdecadal variations have been studied primarily on regional scales due to their indigenous characteristics associated with specific land-ocean configuration and differing feedback processes. However, global observations over the past three decades reveal a cohesive interannual variation across regional monsoons driven by El Niño-Southern Oscillation (ENSO). Thus, regional monsoons are coordinated not only by external (e.g. orbital) forcing but also by internal feedback processes, such as ENSO.

To what extent the regional monsoons vary in a cohesive manner on interdecadal time scale remains elusive. So far no uniform trend or coherent variation pattern has been found over the global monsoon domain. The total amount of global land monsoon rainfall during 1948-2003 exhibits an interdecadal fluctuation with a decreasing trend mainly due to weakening West African and South Asian monsoons (Zhou et al. 2008; Wang et al. 2011). But, since 1980 the global land monsoon rainfall has no significant trend, while the global oceanic monsoon precipitation shows an increasing trend (Wang et al. 2011).

A millennial simulation with the coupled climate model ECHO-G forced by changes in solar radiation, volcanic aerosols and greenhouse gas (GHG) concentration provides useful insight to GM rainfall variability. The leading pattern of centennial variability (wet Medieval Climate Anomaly, dry Little Ice Age, and wet present warming period) is characterized by a nearly uniform increase of precipitation across all regional monsoons, which is a forced response to the changes in external solar-volcanic and GHG forcing (Liu et al., unpublished data). The increase of GSMP is sensitive to warming pattern and determined by enhanced (a) land-ocean thermal contrast, (b) east-west thermal contrast between Southeast Pacific and tropical Indian Ocean, and (c) circumglobal southern hemisphere subtropical highs, which contribute to the hemispherical thermal contrast (Lui et al., unpublished data).

Will summer monsoon rain increase or decrease in the future? Based on the IPCC AR4 (Meehl et al. 2007), during austral summer the rainfall in all SH monsoon regions tends to increase (Fig. 1) and during boreal summer the rainfall in NH monsoon regions will also increase except for North America where it will decrease (Fig. 1). Thus, an overall intensification of summer monsoon rainfall is projected, signifying an amplifying annual variation of the hydrological cycle. Meanwhile the precipitation in the global subtropical desert and trade wind regions will decrease due to a monsoon-desert coupling mechanism. The annual mean monsoon precipitation is projected to increase in Asian-Australian monsoon but decrease in Mexico and Central America. However, the uncertain role of aerosols in general and carbon aerosols in particular, complicates future projections of monsoon precipitation over land, particularly for Asia. Further understanding of the driving mechanisms behind monsoon changes holds a key for their reliable prediction.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Trenberth KE, Stepaniak DP and Caron JM (2000) *Journal of Climate* 13: 3969-399

Wang B and Ding QH (2008) *Dynamics of Atmospheres and Oceans* 44: 165-1833

Wang B et al. (2011) *Climate Dynamics*, doi: 10.1007/s00382-011-1266-z

Zhou T, Zhang L and Li H (2008) *Geophysical Research Letters* 35, doi: 10.1029/2008GL034881

Meehl GA et al. (2007) Global Climate Projections. In: Solomon S et al. (Eds) *Climate Change 2007: The Physical Science Basis*, Cambridge University Press, 747-846

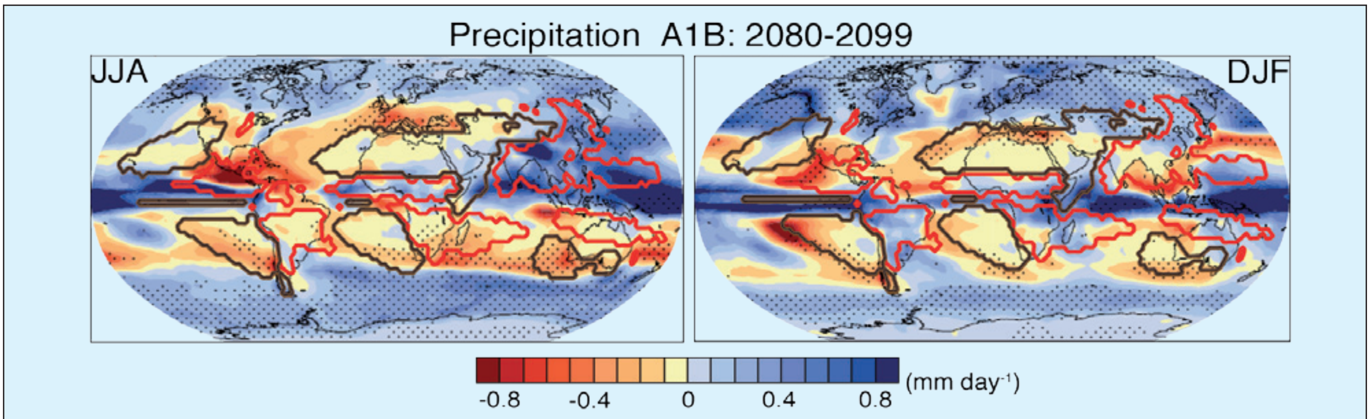

Figure 1: Multi-model mean changes in precipitation for boreal winter (DJF) and summer (JJA). Changes are given for the SRES A1B scenario, for the period 2080 to 2099 relative to 1980 to 1999. Stippling denotes areas where the magnitude of the multi-model ensemble mean exceeds the inter-model standard deviation. In the global monsoon domain (red contours) the summer-minus-winter precipitation exceeds 2.5 mm/day and the summer precipitation exceeds 55% of the annual total (Wang and Ding 2008). The dry regions with summer precipitation <1 mm/day are outlined in gray. The merged Global Precipitation Climatology Project/Climate Prediction Center Merged Analysis of Precipitation data were used to determine the monsoon and arid regions.

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Arab sailors, who traded extensively along the coasts of Arabia and India, used the word *mausim*, which means "seasons", to describe the large-scale changes in the winds over the Arabian Sea. The word "monsoon" likely originated from *mausim* and today it is applied to describe the tropical-subtropical seasonal reversals in the atmospheric circulation and associated precipitation over Asia-Australia, the Americas, and Africa.

The regional monsoons have long been viewed as gigantic, thermally-driven, land-sea breezes (Wang 2009). With the advent of satellite-based observations, a holistic view of monsoon has emerged which considers regional monsoons to be interactive components of a single global monsoon (GM) system. The GM is coordinated primarily by the annual cycle of solar radiation and the corresponding reversal of land-sea temperature gradients, along with the seasonal march of the Intertropical Convergence Zone (ITCZ).

A vast body of data describing "paleomonsoons" (PM) has been assembled from proxy archives, such as ice cores, marine and lake sediments, pollen spectra, tree-rings, loess, speleothems, and documentary evidence. Different archives record different aspects of the PM, and most are subject to complications such as thresholds in the climate or recording systems. In most cases it is difficult to extract detailed paleo-seasonality information (e.g. length or precipitation amounts of the summer rainy season) from such archives. Nonetheless, the proxy records describe PM variations on the time scales permitted by sample resolutions and chronologic constraints.

The PM phenomenon can be traced back to the deep time (10^6 to 10^8 years) (Wang 2009), but much focus has been put on reconstructing PM on orbital to decadal scales. Although the mechanisms driving PM oscillations are quite distinct on different time scales, the spatial-temporal patterns of PM variability are indeed comparable to the observed annual variations of the modern GM. For example, glacial-interglacial PM variability has been shown to be driven primarily by changes in summer insolation and global ice volume, and was possibly modulated by cross-equatorial pressure gradients (An et al. 2011). On orbital scales, PMs oscillated between strong states (during high summer insolation) and weak states (during low summer insolation), respectively, hence exhibiting an anti-phase relationship between the two hemispheres (Fig. 1, left panel).

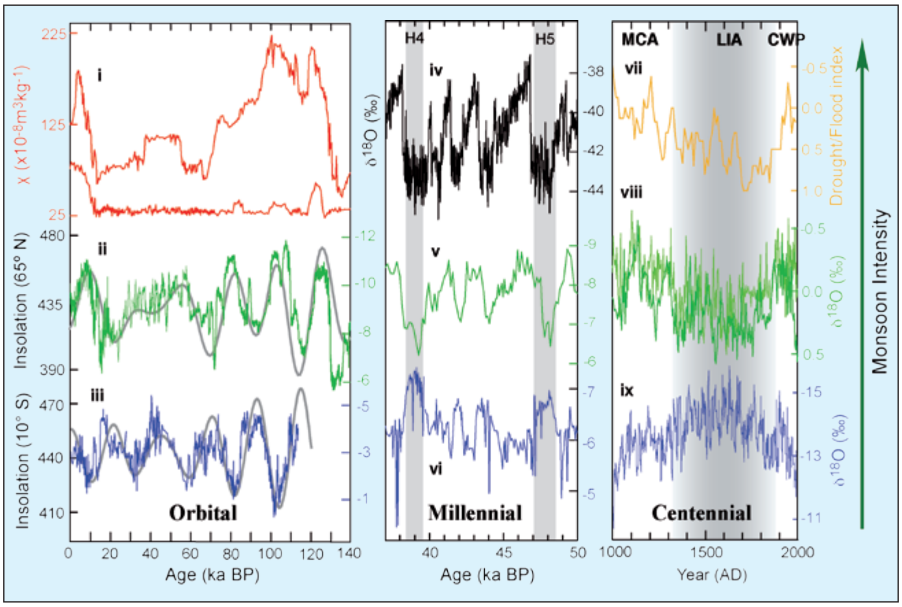

*Figure 1: Paleo-monsoon variability on orbital (**left**), millennial (**middle**) and centennial (**right**) time scales. (**i**) Chinese loess magnetic susceptibility (Sun et al. 2006) reflects AM glacial-interglacial variablility. (**ii**) Speleothem oxygen isotope ($\delta^{18}O$) records from China (Wang et al. 2008) and (**iii**) SE Brazil (Cruz et al. 2005) illustrate precessional cyclicity that follows summer insolation in their respective hemispheres (gray curves; Berger 1978) and anti-phasing between the AM and the SAM. (**iv**) Greenland ice core $\delta^{18}O$ as a temperature approximation (Svensson et al. 2008). (**v**) Speleothem $\delta^{18}O$ for AM (Wang et al. 2008) and (**vi**) SAM from northern Peru (Cheng et al., unpublished). Periods of Greenland warmth correspond with intense AM but are anti-phased with SAM intensity. (**vii**, **viii**) AM records from the summer monsoon fringes in China. (**vii**) Longxi Drought/Flood index based on historical literatures (Tan et al. 2011). (**viii**) Wangxiang (Zhang et al. 2008) and Huangye (Tan et al. 2011) speleothem records. (**ix**) Pumacocha lake record from Peru (Bird et al. 2011). MCA=Medieval Climate Anomaly; LIA=the Little Ice Age; CWP=Current Warm Period; H4 and H5 = Heinrich stadials.*

A number of proxy records of PM from both hemispheres reveal characteristic millennial-centennial length variability (Fig. 1, middle and right panel). On these time scales, PM oscillated between two contrasting states, with weak PM in the Northern and strong PM in the Southern Hemisphere and *vice-versa*. This pattern conforms remarkably well to climate model simulations that link changes in PM with changes in the Atlantic Meridional Overturning Circulation, which result in changes in interhemispheric temperature contrast and in turn, the mean latitudinal location of the ITCZ.

Human cultural history in monsoon regions is rich with accounts of severe climatic impacts related to changes in monsoon rainfall. Indeed, annually-resolved proxy records of PM covering the last few millennia reveal marked decadal-scale changes in spatiotemporal patterns of rainfall that are clearly outside the range of instrumental measurements of monsoon variability (e.g. Zhang et al. 2008; Bird et al. 2011; Tan et al. 2011; Sinha et al. 2011).

Most proxy studies indicate that PM strength across a range of time scales was modulated by near-surface land-sea thermal contrasts. However, the Asian Monsoon (AM) at its fringes and the South American Monsoon (SAM) seem to have waned over the past 50-100 years (Fig. 1, right panel). This is anomalous in the context of global warming, which presumably increases summer land-sea thermal contrasts and thus intensifies summer monsoons. If the observed waning trend of summer monsoon in fringe regions is linked to global warming over the last century and the total moisture evaporated from ocean increases in a future warmer world, one may expect persistent weaker summer monsoons in fringe areas of the monsoon, along with increased rainfall at lower latitudes. However, this inference must be weighed against the considerable uncertainty in future monsoon behavior that may stem from continued anthropogenic impacts such as aerosol loading and land-use change.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Sinha A et al. (2011) *Quaternary Science Reviews* 30: 47-62
Sun YB et al. (2006) *Geochemistry, Geophysics, Geosystems* 7, doi: 10.1029/2006GC001287
Tan L et al. (2011) *Climate of the Past* 7: 685-692
Wang PX (2009) *Chinese Science Bulletin* 54: 1113-1136
Wang YJ et al. (2008) *Nature* 451: 1090-1093

El Niño-Southern

PRESENT

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Climate variability in the tropical Pacific is dominated by the El Niño/Southern Oscillation (ENSO), which has global impacts, most notably in drought-prone regions such as the southwestern USA and Australia. How will the tropical Pacific fluctuate in the coming decades to century? A first-order answer from both paleoclimate records and climate models is that the Pacific will continue to be characterized by large seasonal and interannual variability during the coming century. Seasonally resolved tropical-Pacific paleoclimate records from periods in the Earth's history that were both warmer and colder than today point to interannual variability (Watanabe et al. 2011; Scroxton et al. 2011; Koutavas and Joanidis 2009; Tudhope et al. 2001). And models too have thus far not been able to rid the tropical Pacific of ENSO variability by either warming (Huber and Caballero 2003; Galeotti et al 2010; von der Heydt et al. 2011) or cooling the climate (Zheng et al. 2008).

This result may seem somewhat surprising given our textbook understanding of ENSO. One might conclude that the positive Bjerknes feedback between the winds, surface temperature gradient and thermocline on the equator would cause the Pacific to run away to one state or another, resulting in what is referred to in the literature as a "permanent El Niño" state. However, a recent analysis by DiNezio et al. (unpublished data) of model simulations of the climate response to doubled CO_2 shows that this does not happen because the winds and thermocline actually have opposing effects on ENSO. A warming climate would, on its own, weaken the Walker circulation and hence reduce ENSO variability. However, weaker trade winds would result in a less tilted but *shallower* thermocline, which would strengthen ENSO variability. These competing effects probably explain some changes in the past too. So it seems that ENSO is here to stay.

There are of course a number of other higher-order and important questions about the tropical Pacific that are still wide open. For example, can ENSO have long periods of quiescence? What causes decadal and multidecadal variability in the tropical Pacific? Are these behaviors of the tropical Pacific predictable on seasonal, interannual and decadal timescales? Are they influenced by greenhouse-gas forcing?

Limitations of the instrumental record do not allow us to fully address the question of decadal variability in the Pacific (Fig. 1). Annually resolved paleoclimate proxies are key to filling in the low-frequency part of the spectrum. Some paleoclimate proxies suggested that the Pacific climate has natural variability on timescales of centuries and even millenia (T. Ault, pers. comm.). We do not yet know of an appropriate mechanism, though feedbacks involving low-level clouds, among others, have been invoked (Clement et al. 2011). Current climate models, being deficient in their representation of low-level clouds (Clement et al. 2009), might not simulate Pacific decadal variability properly. Detection and attribution of anthropogenic change in the tropical Pacific may thus remain an extremely challenging problem for the foreseeable future.

As to predictability, one of the great achievements in the late 20th century was the development of a monitoring and prediction system that can predict ENSO a season in advance. However, despite improving modeling capabilities and increased observations over the past two decades, our predictive skill has not improved significantly. Further, there is now an ongoing international effort coordinated through the Coupled Model Intercomparison Project 5 (CMIP5) to attempt to make decadal or so-called "near-term" climate predictions. But our confidence in these prediction systems is limited by our ability to put them to the test of hindcasting past climate fluctuations. Here again, the observation record is simply too short, and the only way around this is to extend the record further back in time with paleoclimate data.

Of course, paleoclimate data are always going to be sparse, but it has been shown that predictions can be made with a relatively few set of the modes (e.g. Kirtman and Schopf 1998). It is encouraging that only a few records from key places in the Pacific over the last several centuries can provide a means to answering the questions about how the tropical Pacific climate will vary during the coming century.

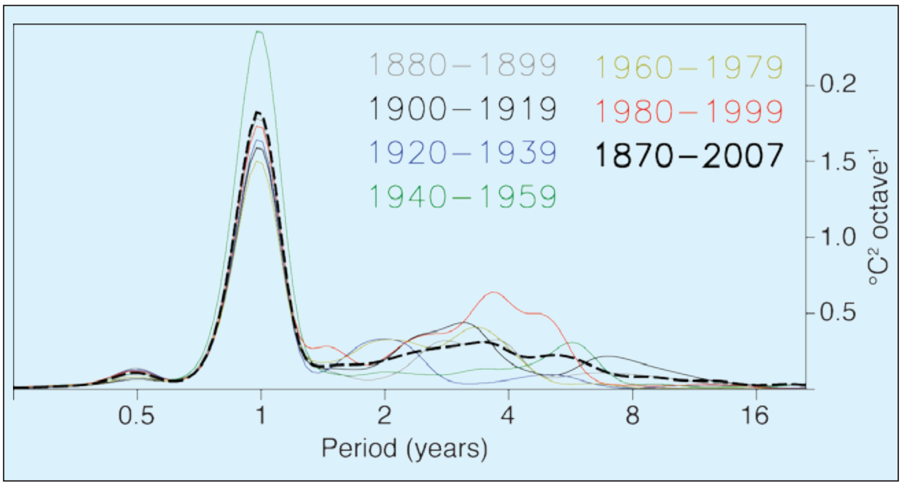

Figure 1: Power spectra of NINO3 SSTs from the ERSST.v3 historical reconstruction (Smith et al. 2008), as a function of the period in octaves of the annual cycle. The area to the left of each curve represents the spectral power within a frequency band. Figure after Wittenberg (2009).

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Clement AC, DiNezio P and Deser C (2011) *Journal of Climate* 24: 4056-4072

Huber M and Caballero R (2003) *Science* 299: 877-881

Scroxton N et al. (2011) *Paleoceanography* 26, doi: 10.1029/2010PA002097

Watanabe et al (2011) *Nature* 471: 209-211

Wittenberg AT (2009) *Geophysical Research Letters* 36, doi: 10.1029/2009GL038710

Oscillation - What is the outlook for ENSO?

PAST

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Despite considerable progress in understanding the El Niño-Southern Oscillation (ENSO) over recent decades, several mysteries remain:
- How irregular is ENSO?
- What causes its decadal modulation?
- How does radiative forcing (in particular anthropogenic forcing) influence this system?

The paleoclimate record can shed light onto some of these questions. As recounted by A. Clement (this issue) there is now strong evidence that ENSO has been active since the Pliocene warm epoch and through glacial cycles, suggesting that the phenomenon is rather impervious to external influences. The details are far thornier, for even a small change in the character of ENSO or its teleconnections can have far-reaching societal impacts (e.g. Hsiang et al. 2011). Since very few high-resolution archives take ENSO's pulse from the heart of the tropical Pacific, one must rely on archives from remote sites, which are vulnerable to interferences from local effects or changing teleconnections.

High-resolution sedimentary and coral records have suggested a rise in ENSO activity since the mid-Holocene (Moy et al. 2002; Tudhope et al. 2001). Emerging evidence from longer coral records from this period suggests that this situation is more nuanced (Cobb, McGregor and Tudhope, pers. comm.). This is consistent with a numerical experiment (Wittenberg 2009), which underscores that long observational windows are needed to characterize ENSO's nonstationary behavior.

The wealth of detailed paleoclimate archives spanning the past millennium provides a unique opportunity to test this idea. Li et al. (2011) [L11] took advantage of interannual signals embedded in drought-sensitive tree rings from North America to suggest a link to various indicators of its low-frequency behavior. A recent multiproxy study (Mann et al. 2009 [M09]) argued that the Little Ice Age (~1500-1800 AD) saw enhanced ENSO variability and a warmer eastern equatorial Pacific compared to the "Medieval Climate Anomaly" (~900-1300 AD), consistent with previous studies (Cobb et al. 2003; Mann et al. 2005;

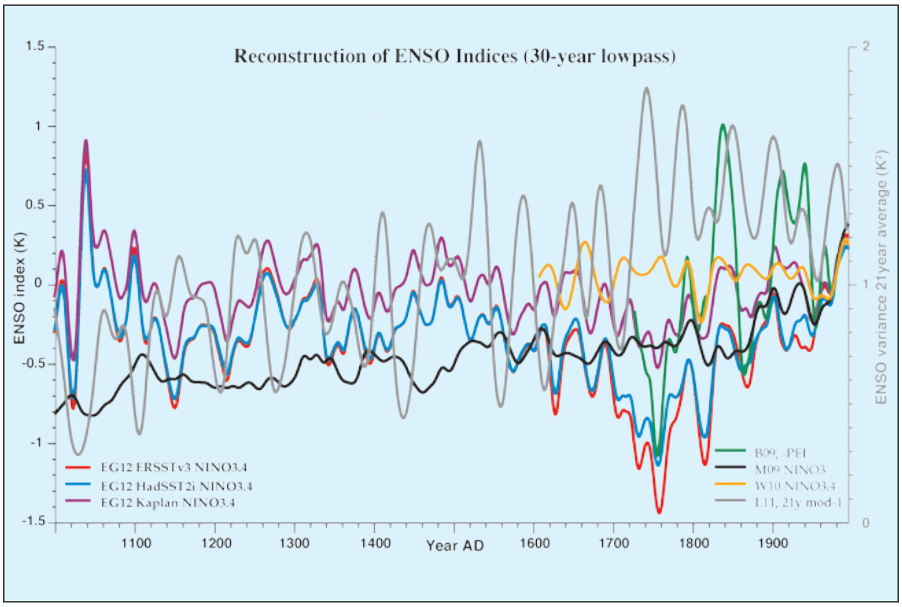


*Figure 1: Comparison of recent ENSO reconstructions. (**left axis**) NINO3.4 from, W10 and EG12, NINO3 from M09, Proxy ENSO index from B09 (inverted scale), (**right axis**) 21-year running ENSO variance from L11 All series have been 30-year lowpass-filtered. See text for details.*

Graham et al. 2010). Yet a multiproxy reconstruction based on the latest observations (Emile-Geay et al. 2012 [EG12]) suggests a more granular picture, with no clear dichotomy between the two periods (Fig. 1). This reconstruction and those of Wilson et al. (2010) [W10] and Braganza et al. (2009) [B09] contain considerable decadal and centennial variability - an important benchmark for climate models to reproduce. Nonetheless, the divergence between these estimates exposes considerable uncertainties, due in part to proxy errors and to the short calibration period that the instrumental record condemns us to. Adding to this uncertainty is the divergence between instrumental products over the tropical Pacific (e.g. Deser et al. 2010), which propagates beyond instrumental times [EG12].

ENSO's response to external forcing over the last millennium is thus poorly constrained. Despite original suggestions of an El Niño-like response to explosive volcanism (Adams et al. 2003), the latest data from Palmyra Island do not appear to support this notion (Cobb 2011). Difficulties in reconstructing low-frequency variability further beset a tie to solar forcing. To establish a clear link between natural radiative forcing and the low-frequency modulation of ENSO, one would need more long and accurately dated tropical Pacific records than are presently available.

Were such a link eventually to be elucidated by new proxy observations, there is no guarantee that ENSO will react similarly to greenhouse forcing as it did to a changing Sun: greenhouse forcing has a very different vertical structure from solar forcing; it is differently impacted by clouds and aerosols, and acts 24 hours a day, unlike the Sun. These differences limit the extent to which natural forcings can serve as analogs for anthropogenic ones. Therefore, one should not view ENSO's past as a set of prophecies, but, rather, as a rich laboratory in which to test the models used to predict its future. The PAGES-sponsored PMIP3 data/model intercomparison effort is expected to bring much insight into this problem.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

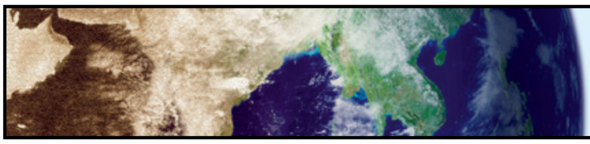
Braganza K et al. (2009) *Journal of Geophysical Research* 114, doi: 10.1029/2008JD010896

Deser C, Phillips AS and Alexander MA (2010) *Geophysical Research Letters* 37, doi: 10.1029/2010GL043321

Li J et al. (2011) *Nature Climate Change* 1(2): 114-118

Mann ME et al. (2009) *Science* 326(5957): 1256-1260

Wilson R et al. (2010) *Journal of Quaternary Science* 25(1): 62-78



Sea level rise - How much and

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Sea level is a sensitive indicator of climate change and responds to global warming both directly and indirectly. It rises as oceans warm up and seawater expands, and also as mountain glaciers and ice sheets melt in response to increasing temperature. Tide gauge measurements available since the late 19th century indicate that the global mean sea level has risen by an average of 1.7-1.8 mm $year^{-1}$ during the 20th century (Church and White 2011), marking the end of the relative stability of the past three millennia. Satellite data available since 1993 point to a higher mean rate of sea-level rise of 3.2±0.4 mm $year^{-1}$ during the past two decades (Cazenave and Remy 2011)

Ocean temperature data suggest that ocean thermal expansion has significantly increased during the second half of the 20th century, accounting for about 30% of the sea-level rise observed since 1993 (Cazenave and Remy 2011; Church et al. 2011a). Numerous observations have reported a worldwide retreat of glaciers during recent decades, with a significant acceleration of this retreat during the 1990s: this also contributes to about 30% of the sea-level rise. Change in land water storage due to natural climate variability contributes negligibly to sea level rise. Human activities (mostly underground water mining and dam building along rivers) have had large effects on sea level during the past six decades or so, but have mostly canceled each other out (Church et al. 2011a).

Little was known before the 1990s on the mass balance of the ice sheets because of inadequate and incomplete observations. But remote sensing techniques available since then suggest that the Greenland and West Antarctic ice sheets are losing mass at an accelerated rate, mostly from rapid outlet glacier flow and further iceberg discharge into the surrounding ocean (Steffen et al. 2010; Pfeffer 2011). For the period 1993-2003, less than 15% of the rate of global sea-level rise was due to the ice sheets. But their contribution has increased to ~70% since 2003-2004. Although not constant through time, mass loss from the ice sheets explains ~25% of the rate of sea-level rise since the early 1990s (Cazenave and Remy 2011; Church et al. 2011a).

There is little doubt that global warming will continue and even increase during the future decades as greenhouse gas emissions, the main contributor to anthropogenic global warming, are likely to keep growing. Projections from the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC 2007) indicate that sea level in the year 2100 should be higher than today's value by ~40 cm (within a range of ±15 cm due to model results dispersion and uncertainty on emissions). More recently it has been suggested that this value could be a lower bound. This is because the climate models at the time accounted for ocean warming and glacial melting (plus a surface mass balance component for the ice sheets) (IPCC 2007), but not for the recently observed dynamical processes that became quite active during the last decade (Steffen et al. 2010; Pfeffer 2011).

Thus, mass loss from ice sheets could eventually represent a much larger contribution to future sea-level rise than previously expected (Pfeffer 2011). Yet, despite much recent progress in process understanding and modeling, the ice sheet contribution to 21st century sea-level rise remains highly uncertain. Values around 30-50 cm by 2100 cannot be ruled out for the total land ice (glaciers plus ice sheets) contribution. If we add the ocean-warming component (in the range 20-30 cm; IPCC 2007), global mean sea level at the end of this century could eventually exceed present-day elevation by 50-80 cm (e.g. Church et al. 2011b).

Providing realistic sea-level projections remains a high priority in the climate modeling community given their importance to developing realistic coastal management and adaptation plans. But sustained and systematic monitoring of sea level and other climate parameters causing sea-level rise – for example, ocean heat content and land ice melt – is also needed. The better we understand present-day sea-level rise and its variability, the better we will be able to project changes in future sea level.

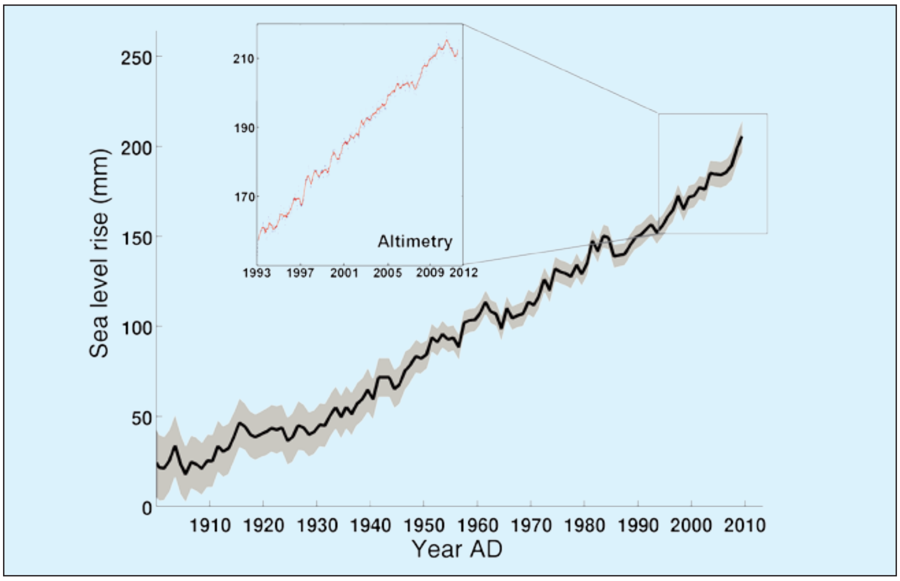

Figure 1: Twentieth century sea level curve (in black and associated uncertainty in light gray) based on tide gauge data and additional information (data from Church and White 2011). Box: altimetry-based sea level curve between 1993 and 2011 (data from AVISO; www.aviso.oceanobs.com/en/data/products/sea-surface-height-products/global/msla/index.html). Blue points represent data at 10-day intervals, the red curve their 4-month smoothing (from Meyssignac and Cazenave, unpublished data).

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Cazenave A and Remy F (2011) *Interdisciplinary Reviews: Climate Change* 2(5): 647-662

Church JA and White NJ (2011) *Surveys in Geophysics* 32(4-5): 585-602

Church JA et al. (2011a) *Geophysical Research Letters* 38, doi:10.1029/2011GL048794

Pfeffer WT (2011) *Oceanography* 24(2): 94-111

Steffen K et al. (2010) In: Church et al. (Eds) *Understanding sea level rise and variability*, Blackwell Publishing, 177-225

how fast will sea level rise over the coming centuries?

PAST

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The time scales of major West Antarctic Ice Sheet (WAIS) growth and retreat are centuries to millennia. Instrumental records around West Antarctica are only a few decades long and can therefore only offer a single snapshot of a moving target. The recent observed breakup of some Peninsula ice shelves, and accelerated flow and thinning of their upstream glaciers and Pine Island-Thwaites glaciers (e.g. Shepherd et al. 2003; Pritchard and Vaughan 2007; Jenkins et al. 2010), may be harbingers of future retreat, but by themselves shed little light on potential progression into a full collapse of central WAIS. If anything, contemporary observations indicate ever more pressingly that paleo data are uniquely placed to understand the collapse of the WAIS. Sub-ice shelf warming of part of the WAIS (Jenkins et al. 2010) indicates oceanographic phenomena bringing warm water masses onto the shelf next to the WAIS that may well turn out to be analogous to past collapse events once we understand more fully the processes behind them. It is critical to understand, not just the ice sheet itself, but the oceanography of the Antarctic shelves and sub-ice shelf systems. Oceanic modeling of these systems is challenging, and studies of past and future changes are in early stages of development (e.g. Holland et al. 2008; Olbers and Hellmer 2010; Dinniman et al. 2011). This is where studies such as ANDRILL (Naish et al. 2009) that span the relevant time periods truly come into their own. Such studies have provided substantial evidence from different climate states implying that drastic collapses of marine-based WAIS occurred during the warmest intervals of the Pleistocene and Pliocene. Coupled with related modeling studies (e.g. Pollard and DeConto 2009), these data represent among the best opportunities to understand the potential collapse of the WAIS during past warm periods.

Because of the availability of data, the Last Interglacial (LIG) has become an important target for the question of WAIS stability (e.g. Siddall and Valdes 2011). Estimates of eustatic sea level based on glacio-isostatic modeling of relative sea-level data for the LIG indicate that sea levels approached around 8-9 m above modern (Kopp et al. 2009). At the same time, a number of model-data syntheses have concluded that the maximum contribution to sea level from Greenland was only several meters at most (see Colville et al. 2011 for a recent review) and the contribution from thermal expansion was only in the tens of centimeters (McKay et al. 2011). The gap between the eustatic sea-level rise and plausible Greenland and steric contributions lead to the unavoidable conclusion that the WAIS did indeed reduce dramatically for LIG conditions. Further careful studies may well show more precisely by how much and under what oceanographic conditions this collapse occurred, and whether collapses occurred in earlier Pleistocene interglacials (Scherer et al. 2008; Hillenbrand et al. 2009).

For human populations this issue does not end with the question as to under what conditions will the WAIS begin to reduce dramatically. Two other questions arise – at what rate will it reduce and how will the ice-volume be redistributed in the ocean? Multiple studies of relative sea level during the LIG tentatively suggest rates of sea-level rise of the order of one meter per century resulting from ice sheet reduction beyond that which we have observed in the late Holocene (Rohling et al. 2008; Kopp et al. 2009; Thompson et al. 2011). Glacial isostatic adjustment (GIA) modeling of scenarios regarding the WAIS collapse indicate a 50% variability in local sea-level rise resulting from the collapse of the WAIS (Mitrovica et al. 2009). GIA models have been constructed largely to explain GIA responses since the Last Glacial Maximum and therefore paleo data is crucial to understand if the WAIS will collapse in the coming century, the rate of sea-level rise and its global distribution.

Given the complexity of ice sheet behavior it would be easy to become focused entirely on modern observations and state of the art deterministic models. Here we have argued for the careful, focused use of paleo data to understand the potential for the collapse of the WAIS in the next century and its implications for local populations.

Visite the PALSEA web site for more details: http://eis.bris.ac.uk/~glyms/working_group.html

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Colville EJ et al. (2011) *Science* 333: 620-623
Mitrovica JX, Gomez N and Clark P (2009) *Science* 323: 753
Naish T et al. (2009) *Nature* 458: 322-328
Pollard D and DeConto RM (2009) *Nature* 458: 329-332
Siddall M and Valdes PJ (2011) *Nature Geosciences* 1: 299-300

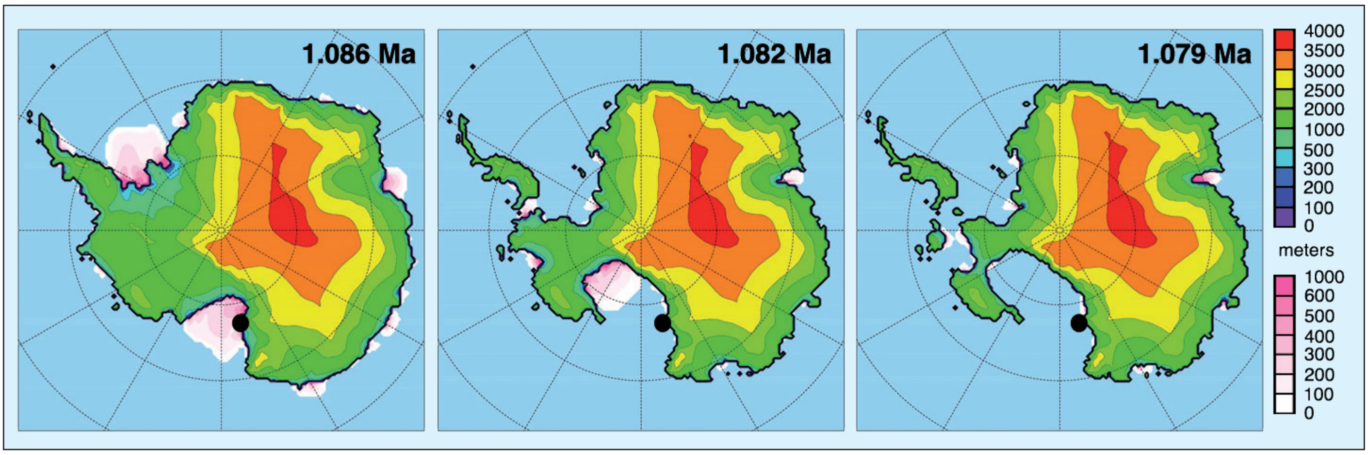

Figure 1: Snapshots of modeled ice distribution, essentially as in Pollard and DeConto 2009, showing collapse of WAIS marine ice leading into Marine Isotope Stage 31, a major interglacial event ca. 1.08 to 1.06 Ma (Scherer et al. 2008; DeConto et al., unpublished data). Grounded ice elevations (m) are shown by the rainbow scale, and floating ice thicknesses (m) by the pink scale. The approximate location of Cape Roberts and ANDRILL sediment cores (Scherer et al. 2008; Naish et al. 2009) is shown by a black dot.

Hurricanes and Typhoons - Will

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The human and economic costs of Hurricane Katrina in 2005 or Tropical Cyclone Nargis in 2008, coupled with growing coastal populations, highlight the need to know how tropical cyclone activity will respond to human-induced climate warming. This is not easy given the complexity of the processes that go into the making of a cyclone and the fact that we have a relatively poor handle on long-term (century-scale) variations in tropical cyclone activity around the globe. In the Atlantic some recent efforts have been made to quantify the uncertainty in long-term records of tropical cyclone counts (e.g. Vecchi and Knutson 2011).

A recent review (Knutson et al. 2010) points to a growing consensus regarding how tropical cyclone activity – particularly the globally averaged frequency, intensity and rainfall rates associated with cyclones – will behave during the 21st century. Models suggest that when averaged globally, the frequency of tropical cyclones is likely to remain the same or decrease through the 21st century: the decreases in the most compelling modeling studies to date span -6 to -34%. Confidence in this projection is buttressed by the ability of several of the recent climate models or regional downscaling models to reproduce past tropical cyclone variability in several basins when forced with historical variations in boundary conditions (e.g. Emanuel et al. 2008; Zhao et al. 2009). Proposed mechanisms include a weakening of the time averaged tropical circulation (Sugi et al. 2002; Held and Zhao 2011) or changes in the time averaged vertical profile of moisture in the middle and lower troposphere (Emanuel et al. 2008). Projections for individual regions are far less certain than global averages because of the uncertainties in estimating the regional climate response (for example, patterns of sea-surface temperature response). In the Atlantic basin, for example, 21st century hurricane activity projections depend, to first order, on the rate of warming of the tropical Atlantic compared to the rest of the tropical ocean, which is not well constrained by current climate models.

In contrast to tropical cyclone frequency, theoretical considerations and high-resolution models support the plausibility of an increase in globally averaged intensity of tropical cyclones through the 21st century, with a range of 2-11% among different studies (Knutson et al. 2010). Interestingly, recent high-resolution modeling studies suggest that the frequency of the strongest storms – for example Atlantic Category 4 and 5 hurricanes – will increase throughout the 21st century (e.g. Bender et al. 2010). In the model projections, there is a competition between the effect of fewer storms overall and an increase in the intensity of the storms that do occur. On balance, the latter effect dominates in this study for the case of very intense storms, but this very competition implies that we have less confidence in this projection. Existing studies unanimously project an increase in the rainfall rate associated with tropical cyclones during this century (Knutson et al. 2010), although the range is considerable (3 to 37%) and depends on such details as the averaging radius about the storm center that is used in constructing the storm precipitation measure.

In our view, more confident projections of 21st century tropical cyclone activity, including projections for individual basins, will require that climate modelers first reduce the uncertainty in projected sea-surface temperature patterns. This is challenging as it likely involves such difficult to model influences as cloud feedback and the climate response to changes in atmospheric aerosols (IPCC 2007). The potential importance of the latter is suggested by a recent study that concludes that aerosols have led to the recent increase in the intensity of Arabian Sea cyclones (Evan et al. 2011).

The attribution of tropical cyclone changes to anthropogenic forcing, which has not yet been convincingly demonstrated, requires long, homogeneous records of tropical cyclone activity and reliable estimates of the role of natural variability in observed tropical cyclone activity changes, among other things. Paleoclimate proxy records of tropical cyclone activity (e.g. Donnelly and Woodruff 2007; Nyberg et al. 2007) could help. For example, if a number of such reconstructions convincingly showed that the most recent 50-year period was highly unusual compared with the previous 1,000 years, this would be very suggestive of a detectable anthropogenic influence. However, such a clear signal remains to be demonstrated.

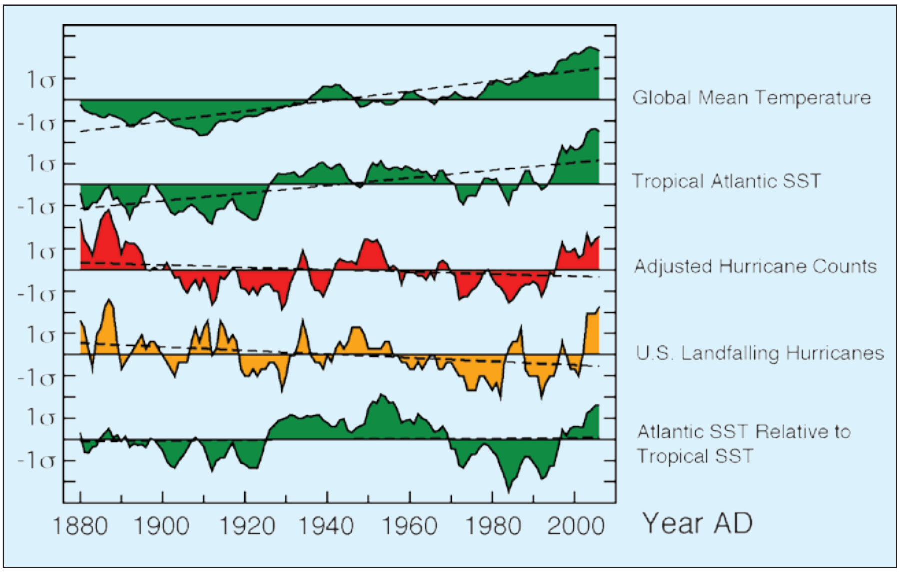

*Figure 1: Normalized anomalies relevant to Atlantic tropical cyclone activity changes: Global mean temperature (**green**, **top**); August-October sea surface temperature (SST) in the tropical Atlantic main development region (MDR; 10-20°N, 80-20°W; **green**, **second from top**); hurricane counts adjusted for missing hurricanes based on ship-track density (**red**); US landfalling hurricanes (no adjustments; **orange**), and MDR SST minus tropical mean SST (**green**, **bottom**). Vertical axis tick marks denote one standard deviation intervals. Curves are five-year running means; dashed lines are linear trends. Only the top three series have significant linear trends (p<0.05). Source: Vecchi and Knutson (2011).*

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Emanuel K, Sundararajan R and Williams J (2008) *Bulletin of the American Meteorological Society* 89: 347-367

Evan A, Kossin JP, Chung C and Ramanathan V (2011) *Nature* 479: 94-97

Knutson TR et al. (2010) *Nature Geoscience* 3: 157-163

Vecchi GA and Knutson TR (2011) *Journal of Climate* 24: 1736-1746

Zhao M, Held I, Lin S-J and Vecchi GA (2009) *Journal of Climate* 22: 6653-6678

tropical cyclones become stronger and more frequent?

PAST

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Paleohurricane reconstructions extend storm records further into the past to improve our understanding of the relationship between tropical cyclones and climate. Though several types of tropical cyclone proxies are under development, sediment-based records, which can span millennia, have thus far provided the longest storm reconstructions and have revealed the coarse centennial to millennial-scale features of hurricane climate (e.g. Donnelly and Woodruff 2007). New, high-resolution sediment records developed from coastal ponds along the Northeastern Gulf of Mexico and in the Northeastern USA document statistically-significant changes in storm activity in response to the modest climate variations of the late Holocene (Fig. 1A). These records provide evidence both for intervals with significantly elevated and depressed storm activity relative to the historic, instrumental period. The largest variability in these paleohurricane records occurs on multi-centennial and millennial timescales, which suggests that Atlantic hurricane activity is poorly constrained by the relatively short instrumental record.

Late Holocene variations in storm activity have been dominated by changes in the frequency of intense hurricanes rather than the overall number of landfalling tropical cyclones (e.g. Lane et al. 2011). A comparison between a 4500-year storm surge record from the Florida Panhandle (Fig. 1A) and reconstructions of SSTs and Loop Current migration within the northeastern Gulf (Richey et al. 2007) suggests that intense storms were most frequent in the region not when Gulf SSTs were warmest but rather when the high ocean heat content of the Loop Current was closest to the study site. Future, intense hurricane activity may similarly respond more sensitively to upper ocean thermal structure rather than SST. Larger-scale factors also may have driven basin-scale variability in Atlantic hurricane intensities, with more (less) intense events occurring more often during periods of reduced (increased) ENSO variability (Conroy et al. 2008; Fig. 1B) and warmer (cooler) SSTs in the western North Atlantic (Keigwin 1996; Fig. 1C). This is consistent with the idea that the relative warmth of the tropical North Atlantic may be a good, aggregate indicator of Atlantic hurricane activity on greater than inter-annual timescales.

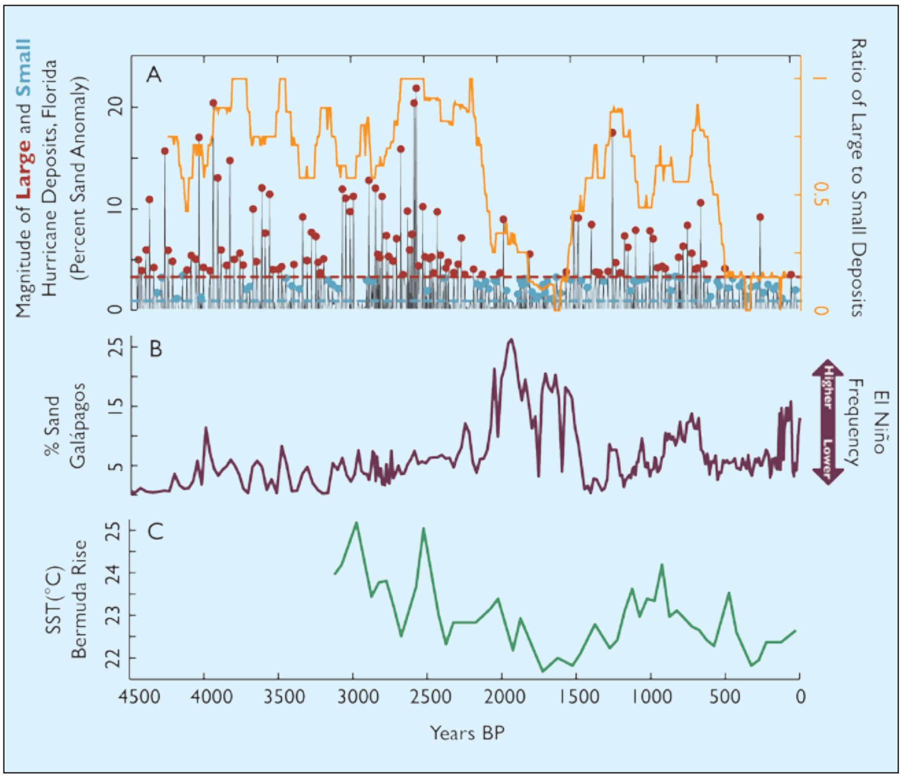


Figure 1: ***A****) shows a 4500-year record of hurricane storm surges at Mullet Pond, Florida. Blue and red dots represent chronologies of small and large storm deposits as defined by the dashed blue and red threshold lines, respectively. The orange curve is the ratio of intense to total activity found by applying a 157-year sliding window to the chronologies of discrete events.* ***B****) shows a proxy record of El Niño frequency based on lake level inferred from sand content in the crater lake El Junco in the Galapágos (Conroy et al. 2008).* ***C****) shows a time series of foraminiferal $\delta^{18}O$ (sea surface density) from the Bermuda Rise, inferred SST is shown on the y-axis, though a portion (estimated to be about one third) of the variability in $\delta^{18}O$ is thought to be related to changes in salinity also (Keigwin 1996).*

Given the stochastic nature of hurricane landfalls at a given location, any trend in basin-wide hurricane activity during the late 20th century would not be detectable in a single-site paleohurricane record. Further, given the possible disconnect between landfalling and basin-wide activity as well as high-frequency regional variability in the occurrence of landfalling storms, multi-site compilations of paleohurricane records may also fail to capture centennial or shorter scale trends or variability. However, on long timescales, North Atlantic paleohurricane records are fairly coherent revealing multi-centennial to millennial-scale intervals with either frequent or few intense hurricanes.

Though the Earth's climate state at the end of the 21st century may lack a Holocene analogue, hurricane proxies remain illustrative if not predictive. These records demonstrate that the climate system, on its own, can and has given rise to long-lived storm regimes much more active than anything experienced by vulnerable coastal cities and communities along the US Gulf and East Coasts. Paleo records of climate and hurricanes archive data from an experiment conducted in the laboratory of Earth's climate system, and reproducing the findings of that experiment would improve our understanding of the dynamical controls on hurricane activity. Forcing statistical and dynamical models of tropical cyclone climate with the boundary conditions of past millennia and comparing the results with paleohurricane records may provide a pathway to evaluate the predictive power of these emerging techniques and to identify the climatic causes of both the extremely active and very quiet storm regimes of the late Holocene.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

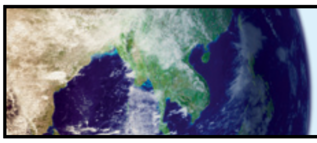
Conroy JL et al. (2008) *Quaternary Science Reviews* 27: 1166-1180

Donnelly JP and Woodruff JD (2007) *Nature* 447: 465-468

Keigwin LD (1996) *Science* 274(5292): 1504-1508

Lane P, Donnelly JP, Woodruff JD and Hawkes AD (2011) *Marine Geology* 287: 14-30

Richey JN, Poore RZ, Flower BP and Quinn TM (2007) *Geology* 35(5): 423-426



Vulnerability of coastlines - How do

PRESENT

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Most coastal zones of the world are ephemeral or sensitive to change, an exception being rocky shorelines that respond quite slowly to perturbations. Under the influence of long-term trends in Holocene sea level, coastlines have retreated, advanced or changed the nature of their land-sea interaction. But the human footprint is very large and growing in many places. For example the ocean volume is increasing due to human-induced global warming of the ocean (the steric effect) and the melt of our mountain and polar ice masses.

These modern trends are superimposed on regionally variable sea-level changes put in place prior to when humans began to have a significant impact. For coastlines undergoing uplift and where sea level continues to fall, for example those in the Pleistocene ice sheet zones, the rate will have slowed due to the more recent anthropogenic impact. For coastlines that were largely stable over the past few millennia, sea-level rise has begun to accelerate coastal retreat and is expected to do so in the foreseeable future.

In many of the world's deltas, human-induced subsidence – by water and petroleum mining, for example – now overwhelms the eustatic (global) sea level rise signal. In a study of 33 global deltas, relative sea-level rise was found to be four times larger on average than that for nearby bedrock shorelines (Syvitski et al. 2009). Tens of millions of hectares are flooded every year, and future flooding is only expected to get worse (Nicholls 2004; Syvitski et al. 2009).

Human activities further compound the problem of shoreline retreat (Fig. 1). For example, protective coastal mangrove forests or wetlands are removed, often to make room for shrimp farms (Woodroffe et al. 2006), accelerating coastal retreat from meters/year to kilometers/year. Coastal retreat in the arctic is also extremely high due to a combination of reduced summer sea-ice cover – which leads to increased wave energy – and a warmer coastal ocean. Together these processes combine to physically and thermally destroy thousands of kilometers of arctic coastal bluffs (Forbes 2010).

The great reduction in the sediment delivery to the world's coastal oceans is an important factor (Blum and Robert 2009) in coastal retreat. On average, there has been 1 major dam (>15 m in height) built every day for the last 110 years, sequestering hundreds of gigatons of sediment and carbon in reservoirs and greatly limiting the transport of sediment to the coast (Syvitski et al. 2005). Without this "fresh" sediment for tides and waves to rework, shoreline sediment is consumed and coastal retreat is accelerated.

The combination of decreased vegetation, reduced coastal sediment delivery and higher sea levels makes coastlines more susceptible to tropical storms and their surges: latest research shows that the frequency of the most intense storms will increase throughout this century (Knutson et al. 2010; Tom Knutson, this issue). The result is an ever-increasing reliance on engineering structures to protect infrastructure (e.g. cities, industry, transportation facilities, agriculture) that is found increasingly at elevations below sea level. These engineering structures can be overwhelmed with devastating consequences, as in the case of Hurricane Katrina and the Sendai Tsunamis.

Human activity has also lead to the formation of many coastal features: for example the deltas of rivers such as the Po and Rhone were formed due to anthropogenic acceleration of soil erosion by deforestation and farming activities. The deltas were inherently unstable. When soil erosion was reduced or sediment delivery was reduced with the proliferation of dams, these unstable deltas were the first to enter the destructive phase affecting much of the world's coastlines. A combination of modern and historical perspectives can help understand the global footprint of humans on our world's coastlines. And this can help us develop effective policies and protocols for learning to live in such transient environments.

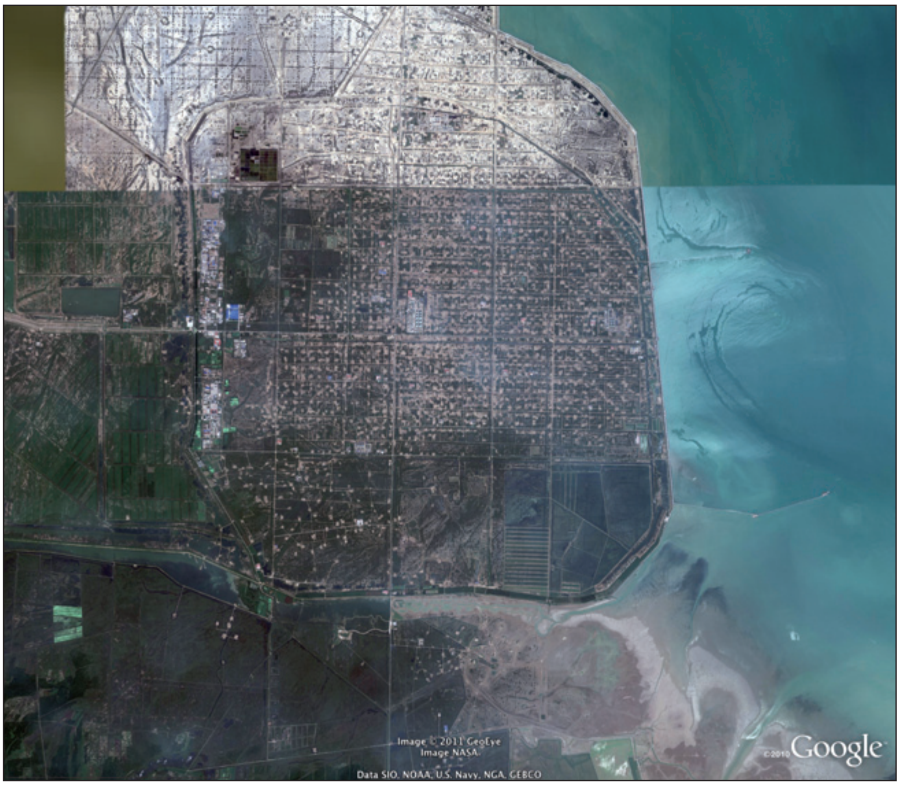

Figure 1: GEO-EYE satellite image of the Yellow River (Huanghe) delta. Each year 33.6 Mt of crude oil are extracted from the delta. The Gudong Seawall, built 1985-1988 to protect the oil fields from inundation, is 10 m thick at its top and 38 m at its bottom. The oilrigs are laid out on a grid pattern. The field is presently below sea level by 1 to 2 m, protected from the sea by the Seawall. Image from Google Earth Pro; pixel resolution is ~1 m.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Blum MD and Roberts HH (2009) *Nature Geoscience* 2: 488-491
Knutson et al. (2010) *Nature Geoscience* 3: 157-163
Nicholls RJ (2004) *Global Environmental Change* 14: 69-86
Syvitski JPM et al. (2009) *Nature Geoscience* 2: 681-689
Syvitski JPM, Vörösmarty C, Kettner AJ and Green P (2005) *Science* 308: 376-380

environmental changes affect coastlines and river deltas?

PAST

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Coastal changes have occurred throughout geological time due to tectonic and isostatic processes as well as sea level changes induced (primarily) by climatic changes. During the Quaternary, one of the main controls on coastal evolution was sea-level changes through the exchange of mass between ice sheets and oceans. However, local and regional changes are superimposed on the global signal. These local/regional changes become more important as the temporal scale resolution increases, producing substantial spatial and temporal variability in sea-level changes, even when localities lie close to each other. This becomes even more complex as humans occupied the coastal zone (e.g. Syvitski, this issue).

Furthermore, it seems that the overall warming and sea-level rise of the Holocene was punctuated by climatic events and, apparently, impacted the coastal evolution. In fact, a correlation between marsh evolution and rapid climatic changes (RCCs) in the Delaware Bay has been established at a millennial scale. The idea of coastal evolution linked to climatic changes is supported by stratigraphic sequences occurring simultaneously with RCCs recognized in the western Gulf of Mexico, in the Trinity/Sabine River incised valley system and in northern Spain. Among the RCCs identified during the Holocene, an event at 750-950 AD was characterized by polar cooling, tropical aridity and major atmospheric circulation changes. Although this event was global in scale, records of it are poorly correlated due to its different behavior between regions (Mayewski et al. 2004).

Concomitant with these reported RCC events, major coastal geomorphological changes have been identified. For instance, recent work undertaken in the US North Carolina estuaries and barrier islands suggests that the period ca. 750-1400 AD was characterized by a high degree of barrier island segmentation and open marine influence in areas now occupied by the modern estuaries. Figure 1B shows the interpretation of the environmental change that occurred in the southern part of the Pamlico Sound at 850 AD, reflecting the destruction of large segments of the barriers compared to the current situation (Fig. 1A) (Grand Pre et al. 2011). Estuaries along the southern Bay of Biscay reflect similar changes associated with RCCs. These changes might have impacted the tidal frame, currents and sediment transport. In fact, dramatic changes in the tidal frame have been modeled for the Bay of Fundy in response to the catastrophic breakdown of a barrier system (Shaw et al. 2010). Also, tidal changes have been recorded in Delaware Bay over the last 4000 years in response to the change of the basin shape during the late Holocene sea-level rise (Leorri et al. 2011).

Over the Holocene, coastal environments have moved across the landscape. However, accelerated rates of climate change and sea-level rise could affect coastal environments by overcoming the natural mechanisms of self-maintenance. The impact of these changes might be considered significant since there are more than 20,000 km of barrier islands along the world's open ocean coast, and they represent the front line to impacts of projected climate change. This may alter coastal systems from current conditions in a number of ways by: 1) increasing salt water intrusion landward, producing more rapid salinization; 2) altering the species composition through modified migration and other mechanisms; 3) enhancing tidal erosion, potentially forcing a coastal retreat; and 4) increasing the potential impact of future storms.

In the case of North Carolina, it has been suggested that hurricanes impacted the barrier islands at ca. 850 AD, causing the destruction of large segments of barriers. These barrier destruction events are essentially synchronous with intervals of RCCs at 750-950 AD and are coincident with transgressive surfaces in Delaware Bay, highlighting the importance of environmental changes in coastal evolution and suggesting their potential impact for future coastal evolution.

Acknowledgements
NSF (OCE-1130843); MICINN (CGL2009-08840), FCT (PTDC/CTE/105370/2008). IGCP Project 588.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Grand Pre C et al. (2011) *Quaternary Research* 76, 319-334
Leorri E, Mulligan R, Mallinson D and Cearreta A (2011) *Journal of Integrated Coastal Zone Management* 11(3): 307-314
Mayewski PA et al. (2004) *Quaternary Research* 62: 243-255
Shaw J et al. (2010) *Canadian Journal of Earth Science* 47: 1079-1091

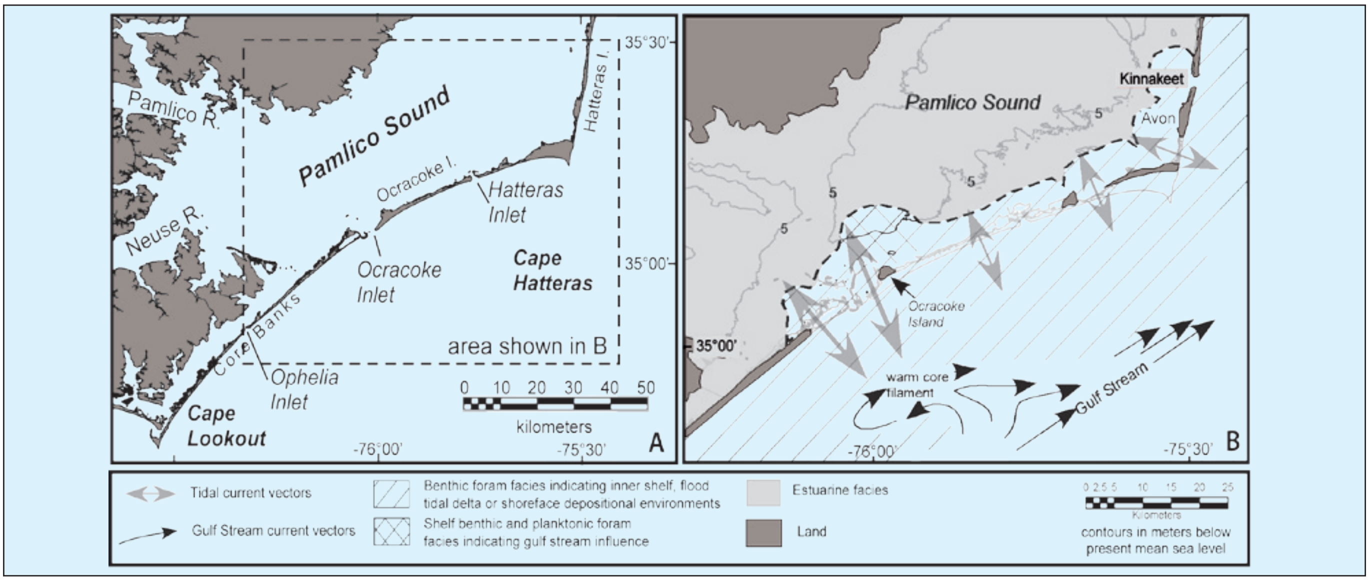

*Figure 1: **A**) Map of the Pamlico estuarine system in North Carolina showing the location of the main active inlets. **B**) Paleoenvironmental reconstruction of the southern Pamlico Sound region ca. 850 AD (modified from Grand Pre et al. 2011). Barrier island destruction along the southern Outer Banks resulted in a shallow, submarine sand shoal and localized deeper tidal channels over which normal marine waters were advected. The Cape Hatteras region exhibited several inlets with large flood-tide deltas.*

Ocean Acidification - PRESENT

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Ocean acidification, an expression coined in the early 2000s, describes changes in the chemistry of seawater generated by the uptake of anthropogenic carbon dioxide (CO_2). Among those changes is an increase in the concentration of dissolved inorganic carbon as well as a decrease in pH and the saturation state of calcium carbonate (Ω). Evidence for ocean acidification and its consequences for marine organisms and ecosystems have only recently begun to be investigated (Gattuso and Hansson 2011).

Some aspects of ocean acidification, such as the changes in the carbonate chemistry, are known with a high degree of certainty. It is also well established that three areas of the global ocean are more susceptible to ocean acidification than others, either because ocean acidification will be more severe (e.g. polar regions and the deep sea) or because it acts synergistically with another major stressor (e.g. coral reefs which are also strongly affected by global warming). Most biological, ecological and biogeochemical effects are much less certain. Calcification, primary production, nitrogen fixation and biodiversity will all be affected, but the magnitude of the projected changes remains unclear.

Although some studies indicate no effect or a positive effect of ocean acidification on the rate of calcification of some organisms (Andersson et al. 2011; Riebesell et al. 2011), meta-analyses reveal an overall significant, negative effect (e.g. Hendriks et al. 2010; Kroeker et al. 2010). In general, corals experience particularly adverse effects, whereas crustaceans, for example, grow thicker shells. Whether or not calcification decreases in response to elevated CO_2 and lower Ω, the deposition of calcium carbonate is thermodynamically less favorable under such conditions. Some organisms could up-regulate their metabolism and calcification to compensate for lower Ω, but this would have energetic costs that would divert energy from other essential processes, and thus may not be sustainable in the long term. Full or partial compensation may be possible in certain organisms if the additional energy demand required to calcify under elevated CO_2 can be supplied.

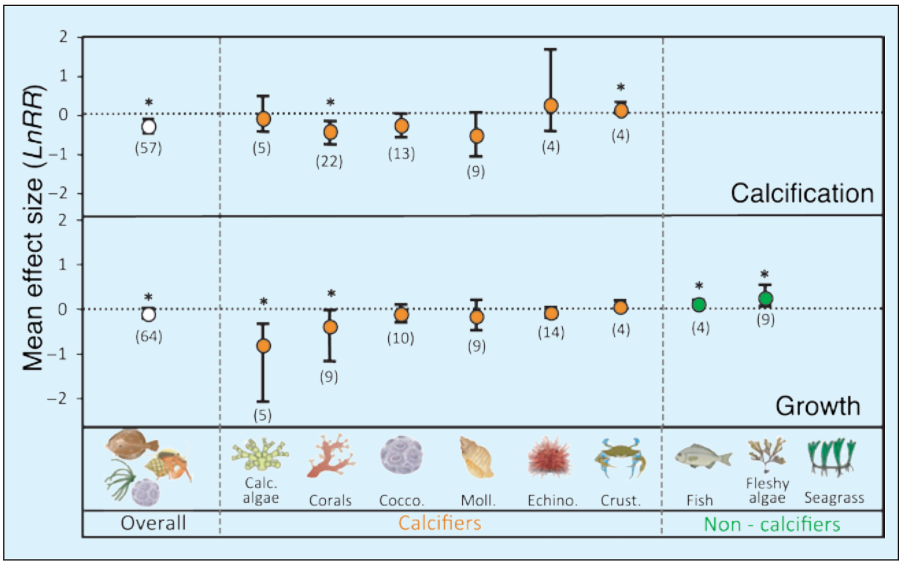

Figure 1: Effects of ocean acidification on marine organisms. Mean effect size and 95% bias-corrected bootstrapped confidence interval are shown. The number of experiments used to calculate mean effect sizes are shown in parentheses. Asterisks (*) mark significant mean effect sizes (95% confidence interval does not overlap zero). Figure adapted from Kroeker et al. (2010).

We need to know much more about the molecular and physiological processes involved in calcifying marine organisms to better understand the response of calcification to ocean acidification.

Ocean acidification is expected to affect not only single organisms but whole populations and thus ecosystems. There is mounting evidence, especially for benthic communities, suggesting that their composition will change as the oceans acidify. For example, the structure of an ecosystem around submarine CO_2 vents in the Mediterranean Sea appears to be governed by the concentration gradient around the vents (Barry et al. 2011). Non-calcareous algae replace calcareous ones closer to the vents, and no juvenile calcifiers are found close to the vents.

We know considerably less about the effects on composition of pelagic communities. Experiments on natural phytoplankton assemblages consistently show a modest increase in carbon fixation at elevated pCO_2 (Riebesell and Tortell 2011). The increased CO_2 levels would aid the growth of some groups of phytoplankton such as cyanobacteria, and decrease the competitiveness of others (e.g. some calcifiers). The combined effects of acidification and other global changes on ecosystems are uncertain but deserve more scrutiny, especially because of potential economic consequences on, for example, the fishing and tourism industry.

Ocean acidification and its impacts on marine ecosystems could provide an additional reason for reducing CO_2 emissions, but we need to reduce the uncertainties and offer a prognosis despite the sometimes conflicting observations. Synthetic studies will be key to make sense of the many dimensions of ocean acidification and its interactions with other stressors such as warming, coastal eutrophication and deoxygenation. There is reason to be optimistic, at least on the research front: the coming years will witness the launch of major research initiatives, in addition to IPCC and other assessments, which are expected to considerably improve our level of understanding.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Gattuso J-P et al. (2011) Ocean acidification: knowns, unknowns and perspectives. In: Gattuso J-P and Hansson L (Eds) *Ocean acidification*, Oxford University Press, 291-312

Gattuso J-P and Hansson L (2011) Ocean acidification: background and history. In: Gattuso J-P and Hansson L (Eds) *Ocean acidification*, Oxford University Press, 1-20

Hendriks IE, Duarte CM and Alvarez M (2010) *Estuarine, Coastal and Shelf Science* 86:157-164

Kroeker K, Kordas RL, Crim RN and Singh GG (2010) *Ecology Letters* 13: 1419-1434

Riebesell U and Tortell PD (2011) Effects of ocean acidification on pelagic organisms and ecosystems. In: Gattuso J-P and Hansson L (Eds) *Ocean acidification*, Oxford University Press, 99-121

How will ongoing ocean acidification affect marine life?

PAST

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Scientists use the geological record to "look back into the future", i.e. to evaluate effects of ocean acidification on whole marine ecosystems during carbon cycle-climate perturbations (Pelejero et al. 2010). Fortuitously, calcifying organisms, affected most immediately by decreased carbonate saturation (Fig. 1), have left a fossil record: planktic foraminifera and calcareous nannoplankton (coccolithophores) provide information on the effects of ocean acidification on calcifiers in surface oceans, benthic foraminifera and ostracodes in the deep sea, and corals, calcareous algae, echinoderms, bivalves and gastropods in shelf environments (Kiessling and Simpson 2011).

Where in the past can we find clues about future ocean acidification? To look at a world with CO_2 levels higher than today (>389 ppm) we need to go back into "Deep Time" (Kump et al. 2009; NRC 2011). During transitions from glacial to interglacial periods over the last 2.6 million years (Ma), atmospheric CO_2 levels increased by ~90 ppm over a few thousand years, but from ~175 to ~185 ppm, i.e. well below present levels. Atmospheric CO_2 levels may not have been above ~400 ppm for the last 35 Ma, the time since when ice sheets existed on Antarctica. The Deep Time warm worlds are not perfect analogs for the near future, among other reasons because life has evolved since then, but nevertheless may provide useful insights.

The long-term high pCO_2 and low pH levels in Deep Time did not result in low carbonate saturation states (Ω) in sea water, because on time scales of 10-100 ka the burial of $CaCO_3$ in marine sediments balances the cations released by rock weathering on land, and deep-sea carbonate dissolution buffers the oceans' Ω. This buffering has been possible only since ~180 Ma, when open-ocean calcifiers evolved and their remains started accumulating as deep-sea carbonates. Since then, only particularly rapid addition of CO_2 (over centuries, as during fossil fuel burning) results in a coupled decline of pH and saturation state. Studying past ocean acidification thus requires recognition of times when atmospheric CO_2 levels increased rapidly, e.g. from dissociation of methane hydrates from seafloor sediments, methane buildup and release from intrusion of magma into organic-rich sediments, volcanic outgassing, or rapid oceanic turnover of CO_2-rich deep waters.

Such climate - carbon cycle perturbations are recognized in the geological record by the co-occurrence of a negative carbon isotope excursion (CIE), which reflects the release of large amounts of isotopically light carbon into the ocean-atmosphere system, combined with proxy evidence for global warming and sea floor carbonate dissolution (Kump et al. 2009). During the 543 Ma of Earth history when animals existed (the Phanerozoic), perturbations occurred at the Permo-Triassic (P/Tr) boundary (~250 Ma), the Triassic-Jurassic (Tr/J) boundary (~200 Ma), during Oceanic Anoxic Events (OAEs) between ~183 and 93 Ma (Jurassic-Cretaceous), during the Paleocene-Eocene Thermal Maximum (PETM) (~55 Ma) and during smaller "hyperthermals" in the Paleogene (~65-40 Ma) (McInerney and Wing 2011). All these events resemble our possible future, with a CIE, global warming, ocean acidification and deoxygenation, thus various stressors affecting the biota. Severe extinctions (including reef biota) occurred at the P/Tr and Tr/J boundaries, i.e. before the evolution of ocean buffering. These early geological events are well suited to provide insight in processes following C-release at rates too rapid for buffering. Later acidification episodes were not associated with severe net extinction of oceanic calcifiers, although coralgal reefs and deep-sea benthic foraminifera suffered extinction during some OAEs and the PETM. Rates of speciation and extinction of calcareous nannoplankton and planktic foraminifera accelerated at or near the OAEs and across the PETM, and "deformed" nannoplankton has been reported, although these could be due to dissolution during or after deposition on the seafloor. The transient floral and faunal changes typically took at least several 10 ka to recover.

The best approximations of CO_2 emission rates during past carbon cycle perturbations indicate that emissions were considerably slower than the ongoing anthropogenic CO_2 emission. The geological record suggests that the human "grand geophysical experiment" is unprecedented, with the high rates of emission potentially having severe and long-term effects on oceanic biota.

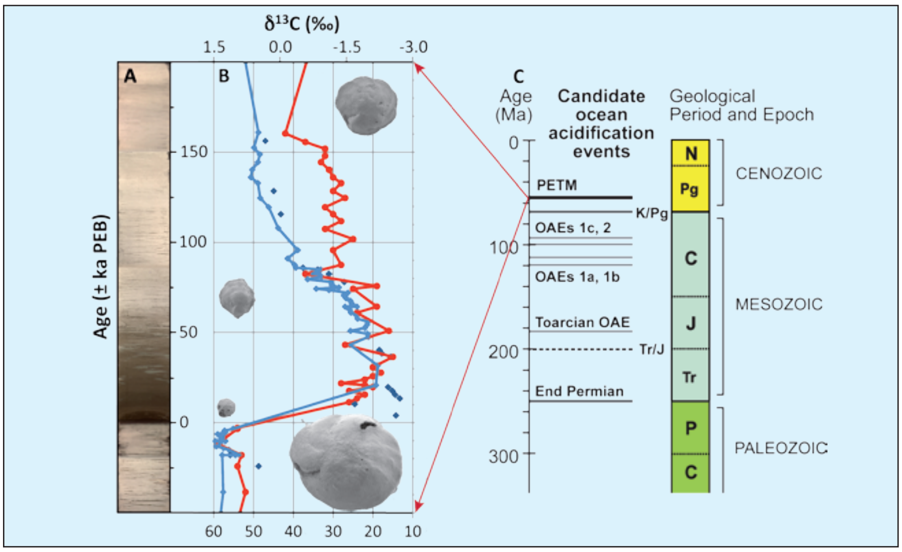


Figure 1: The Paleocene-Eocene Thermal Maximum at Walvis Ridge in the southeastern Atlantic Ocean, off Namibia. Paleo-water depth ~1500 m. ***A****) Core image shows carbonate ooze (light colors) and clay (dark colors), where carbonate has been dissolved during ocean acidification (Zachos et al. 2005). Sediment is plotted on an age scale in ka relative to the Paleocene-Eocene Boundary (PEB) (Hönisch et al., in press).* ***B****) Blue curve and blue dots show carbon isotope excursion (CIE) in shells of deep-sea benthic foraminifera (McCarren et al. 2008). Red curve shows decrease in number of species of deep-sea benthic foraminifera during extinction coeval with CIE (Thomas, unpublished data). Pictures show specimens of the benthic foraminifer* Nuttallides truempyi*, used for isotope analysis, survivor of the extinction. All at the same magnification, showing severe decrease in size during ocean acidification, placed at the location where they occurred in the sediment.* ***C****) Climate-carbon cycle disturbance in the oceans during the last 300 Ma of Earth history (modified after Kump et al. 2009).*

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

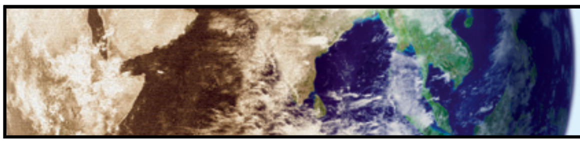
Hönisch B et al. (in press) *Science*

Kiessling W and Simpson C (2011) *Global Change Biology* 7: 56-67

Kump LR, Bralower TJ and Ridgwell A (2009) *Oceanography* 22(4): 94-107

McCarren H et al. (2008) *Geochemistry, Geophysics, Geosystems* 9, doi: 10.1029/2008GC002116

McInerney FA and Wing SL (2011) *Annual Reviews of Earth and Planetary Sciences* 39: 489-516



Water resources - How severe

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The terrestrial water budget is at the heart of many environmental issues. Water is crucial to agricultural production, the healthy functioning of biogeochemical cycles, biodiversity, industrial production and human health. Extremes play an important role: floods and droughts provide pressure points on water scarcity and environmental damage. Increasing population and wealth in many regions of the world are increasing the pressure on available water, a situation likely to be exacerbated by human activities including climate change.

As yet it is difficult to discern an increase in rainfall globally despite its likelihood in a warmer world, partly because changes in precipitation in different regions tend to cancel out. With increasing precipitation at high latitudes, decreasing precipitation in the subtropical regions and possibly changing distribution of precipitation in the tropics by the shifting position of the Intertropical Convergence Zone (see e.g. Zhang et al. 2007).

Extremes of rainfall have increased in Europe and worldwide (e.g. Zolina et al. 2010) and these are likely to be linked with increased greenhouse gases (Pall et al. 2011). Overall droughts have also increased through the 20th century and are predicted to increase further in the 21st century. However, the projected changes in rainfall patterns depend on atmospheric circulation patterns, which are not always represented well in the climate models. And the basin-scale response of river flows also depends on the regional-scale basin characteristics and human interventions, besides the warming induced by greenhouse gases.

In fact many of the observed trends in the hydrological cycle can be attributable to human activities beyond increasing CO_2. A decrease in groundwater, particularly noticeable in mid-western USA and northern India can be inferred from GRACE satellite data (e.g. Rodell et al. 2009), almost certainly due to over extraction for irrigation. Terrestrial evaporation has increased through the 1980s and 90s, most probably due to decreasing aerosols (Jung et al. 2011). Increasing runoff and increasing high flows linked to the melting of glaciers have been observed in the Alpine region. Flows in the northern rivers have increased, but it is unclear whether this is due to land-cover change, increasing precipitation or increasing CO_2 levels (see Gerten et al. 2008).

It is very likely that global warming has influenced river flows, but often either the long-term river-flow data are not available or the changes are masked by changes in land cover or extraction. Collaboration between climate, hydrological and water resource scientists working across a wide variety of scales is thus essential. In recent years this has been achieved with the bringing together of a wide variety of data sets and models (see e.g. Weedon et al. 2011; Haddeland et al. 2011).

Climate models continue to suggest decreases of rainfall in the semi-arid regions of the world, such as the Mediterranean region, southern USA and Central America, southern Australia and southern Africa. When translated into river flows and available water we predict increasing water scarcity in these regions but also in China, India and the Middle East, where populations and water consumption are rising fast (Fig. 1).

There is considerable variation in the both the global hydrology and climate models (Haddeland et al. 2011). Also regional analyses require the incorporation of many additional processes, such as irrigation and groundwater (and the interactions between them). At present the best approach seems to be to use an ensemble of available hydrological models in tandem with the ensemble of climate models used by the Intergovernmental Panel on Climate Change.

There has been considerable progress on quantifying the global and regional terrestrial water balance in recent years. Considerable uncertainties, however, remain particularly at the regional scale where in situ data on rainfall and runoff are limited. Satellite products and modeling can to an extent fill these gaps, but there remains a need to maintain surface based networks and the free flow of data.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Flörke M and Eisner S (2011) *The development of global spatially detailed estimates of sectorial water requirements, past, present and future.* WATCH Technical report number 46

Gerten D, Rost S, von Bloh W and Lucht W (2008) *Geophysical Research Letters* 35, doi: 10.1029/2008GL035258

Haddeland I et al. (2011) *Journal of Hydrometeorology* 12(5) 869-884

Zhang X et al. (2007) *Nature* 448: 461-465

Zolina O, Simmer C, Gulev SK and Kollet S (2010) *Geophysical Research Letters* 37, doi: 10.1029/2010GL042468

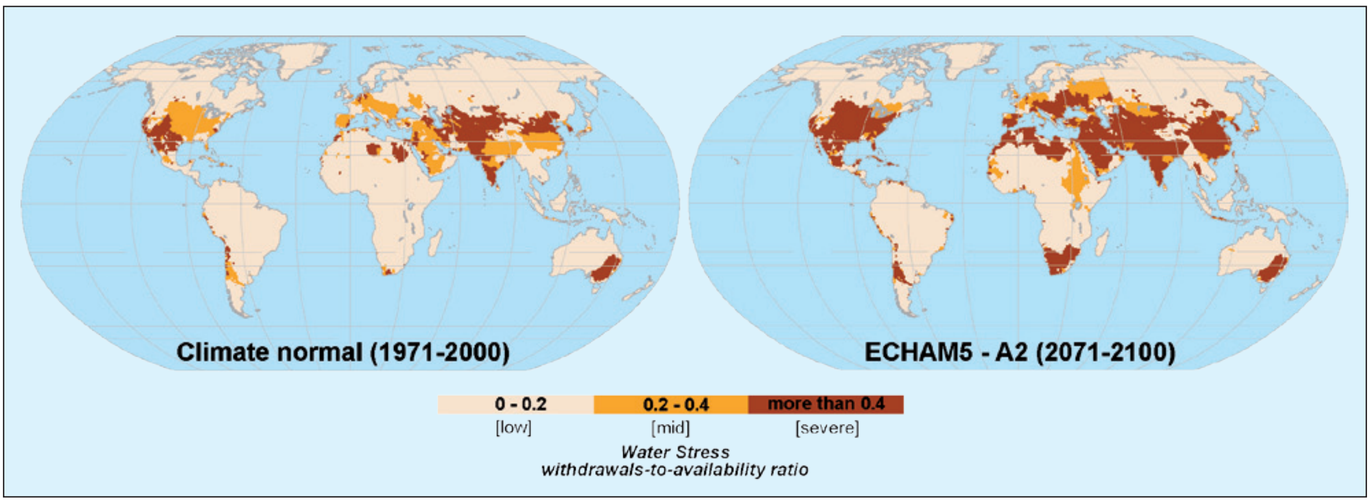

Figure 1: Water stress, calculated as the ratio between water withdrawals and availability, for the late 20th and 21st centuries (see Flörke and Eisner 2011).

PAST

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Climate model projections of future hydroclimatic change associated with increasing atmospheric greenhouse gas concentrations are sobering and, depending on where you live, very alarming. For example, southwestern North America is projected to enter into a long-term drying trend in the sub-tropics to mid-latitudes, and this trend in increasing aridity may have already begun (Seager et al. 2007a). Thus, the unprecedented 2011 Texan drought (www.ncdc.noaa.gov/sotc/drought/2011/8) is an example of what might happen with increasing frequency and duration in the future. Independent of whether or not model projected radiatively forced drying is actually happening now, there is abundant paleoclimate evidence for the occurrence of past "megadroughts" in North America (Stine 1994; Woodhouse and Overpeck 1998; Cook et al. 2004, 2007; Stahle et al. 2011), Asia (Buckley et al. 2010; Cook et al. 2010a), and Europe (Helama et al. 2009; Büntgen et al. 2011) that dwarf any periods of drought seen in instrumental climate records over the past century. The seminal property of megadroughts that differentiates them from even the most severe droughts observed today is duration (Herweijer et al. 2007), with the former often lasting several decades to a century or more compared to just a few years to a decade or so for the latter. Figure 1 shows three such megadroughts reconstructed from tree rings (Cook et al. 2010b) that hit the Mississippi Valley of the United States during early, middle, and late medieval times. These megadroughts lasted 46, 148, and 61 years, respectively, and are ominously located in the American "bread basket" where similar droughts in the future would have catastrophic consequences on agricultural production. This also means that water resources planning and infrastructure design based on observed hydroclimatic data are unlikely to be resilient enough to handle the possible return of megadroughts that we now know have happened in the past.

The cause of past megadroughts is still not fully understood, but persistent patterns of cold La Niña-like sea surface temperatures in the eastern equatorial Pacific ENSO region have been strongly implicated in North America (Herweijer et al. 2006; Seager et al. 2007b; Graham et al. 2007), along with the possible influence of the Atlantic Ocean there as well (Feng et al. 2008). Perhaps more importantly, the paleoclimate record indicates that megadroughts occurred more often during an earlier period of generally above average temperatures called the Medieval Warm Period (MWP), approximately 700 to 1,200 years ago. It is not important to know whether or not the MWP was as warm as today (cf. Crowley and Lowery 2000; Bradley et al. 2003; Mann et al. 2009; Ljungqvist et al. 2011). Rather, the paleoclimate record of past megadroughts simply tells us that 1) they are a natural part of the climate system with no need for anthropogenic greenhouse gas forcing to ignite and sustain them, and 2) rather ominously they appear to "like" warmer climates such as that which occurred during the MWP. Given the climate model projections of future drying and the high likelihood that global warming will continue throughout the 21st century (IPCC 2007), we may therefore be entering into a new era of megadroughts with potentially catastrophic consequences to water supplies needed for human consumption, agriculture, energy production, and for maintaining the aquatic environment. The degree to which any future megadroughts caused by human-induced global warming will resemble those in the past is unclear because the climate forcings operating today are different from the past. Regardless, the stage appears to be set now for some possibly radical future changes in hydroclimatic variability if the past is any guide.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Bradley R S, Hughes MK and Diaz HF (2003) *Science* 302: 404-405

Cook ER, Seager R, Cane MA and Stahle DW (2007) *Earth Science Reviews* 81: 93-134

Cook ER et al. (2010a) *Science* 328(5977): 486-489

IPCC (2007) *Climate Change 2007: The Physical Science Basis.* Solomon S et al. (Eds) Cambridge University Press, 996 pp

Seager R et al. (2007a) *Science* 316: 1181-1184

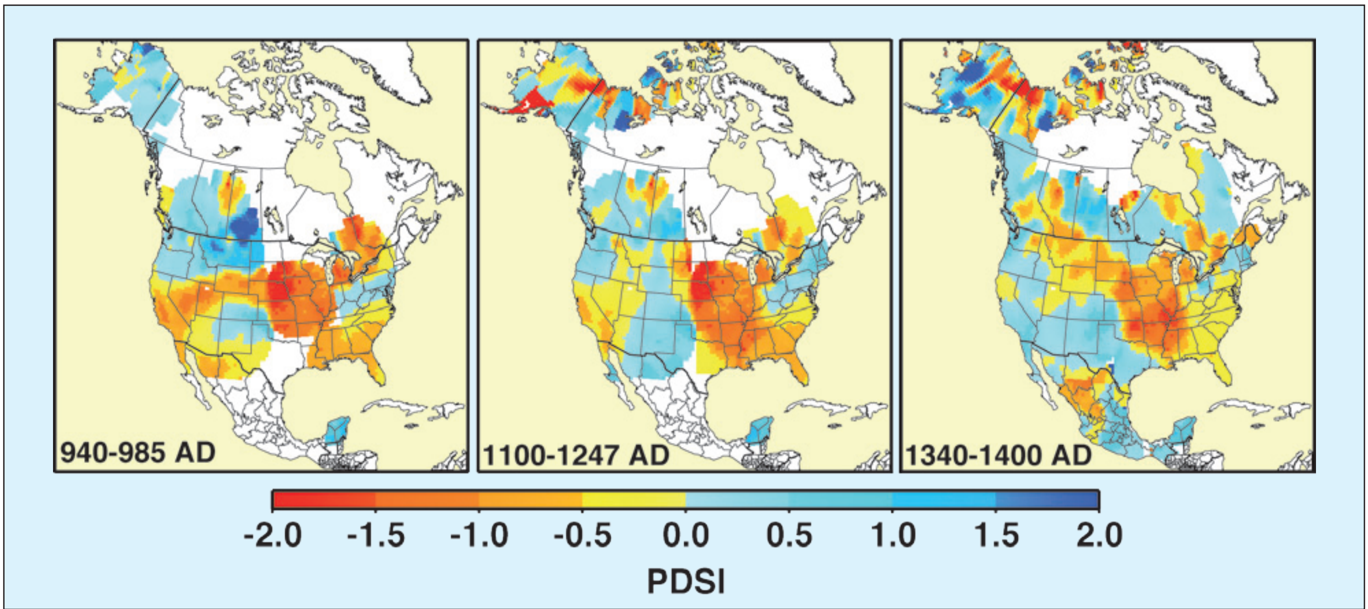
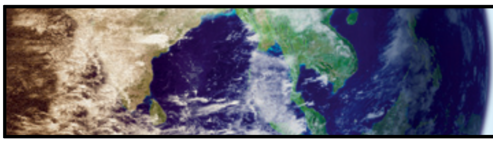


Figure 1: Examples of three megadroughts reconstructed from tree rings that hit the central Mississippi Valley of the United States during early, middle, and late medieval times. See Cook et al. (2010b) for details.



Ecosystems - How do ecosystems

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Ecosystem services, the benefits humans derive from the biodiversity and functioning of ecosystems, provide a direct link between society and the modifications to the biosphere in response to climate change. Examples of services include crop and forest products, climate regulation through carbon fixation, crop and wild plant pollination by native insects, and recreational, esthetic or religious values. In some regions, the prospect of a warming climate portends a change for the positive: it will allow the production of new crops including cereals or wines of high market value, increased production of some forest species or more enjoyable weather for tourism. However, such positive changes and associated opportunities are not the rule: abrupt changes in ecosystem services associated with climate change are already being observed, and many more are expected (Mooney et al. 2009).

The destruction of entire ecosystems is the most extreme manifestation of the effect of a changing climate. Consider the case of coral reefs, which serve as nurseries for many fish species. As water temperatures rise, bleaching of reefs deprives local populations of important resources from fishing (Hoegh-Guldberg et al. 2007). Coral reef loss also exposes local populations to increased risks from storm damage. Furthermore, income from tourism is lost and thereby an important incentive for sustainable coastal management. Finally, we lose an irreplaceable cultural asset at a global level.

Another example comes from the southwestern United States. A regional-scale tree die-off in semiarid woodlands following the drought in the year 2000 has been referred to as an ecosystem crash (Breshears et al. 2011). The death of trees cascaded to widespread mortality of other species, from pinyon to juniper woodlands. This abrupt event likely altered most ecosystem services fundamentally, with both positive and negative effects. There were short-term effects on grass availability for ranchers (positive), culturally important products such as pinyon nuts (negative) and overall cultural landscape value (negative). Longer-term effects concerned soil erosion and regional climate through changed albedo.

At the planetary scale, although model projections remain conflicting, the shrinking of the Amazon rainforest due to climate change and ensuing land-atmosphere feedbacks has been shown to have potential dramatic consequences for global climate (Mahli et al. 2009). Seemingly less striking changes can entail equally dramatic consequences. Because biotas are the providers of ecosystem services, shifts in the distribution of functionally important species have the potential to disrupt ecosystem services. The distributions of plants and their pollinators can be modified independently from each other, either because of different response speeds or because they are driven by different climatic variables.

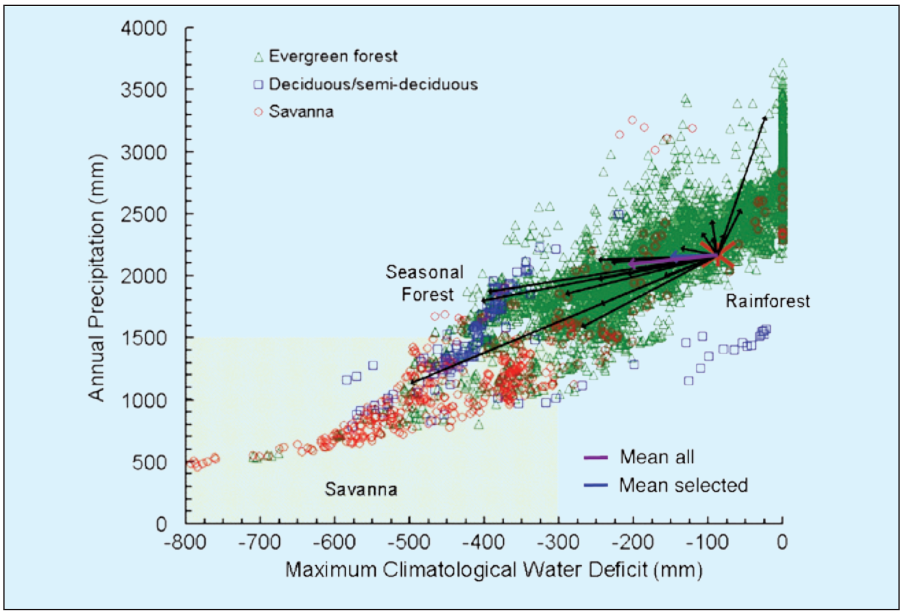

Figure 1: Type of vegetation in relation to rainfall in the Amazon region. The overlaid arrows show the trajectories of change as simulated by the 19 general circulation models used in the IPCC AR4 forced to start from the averaged observed climate over the period 1970-1999 AD (red star). The tips of the arrows represent the simulated late 21st-century (2070-2099 AD) rainfall regime. The purple arrow shows the mean of all model trajectories and the blue arrow the mean of all models that simulate the late 20th century adequately. Figure modified from Mahli et al. (2009).

Even before the changes in distributions, the subtle matching in phenologies between plants and pollinators is lost and so is the service of pollination, with costly consequences for food production and for culturally important rare species. Conversely, climate change is a golden opportunity for some pest species when their phenology or their distribution synchronizes with those of host plants. Several such cases have already been observed in forest species, such as the altitudinal expansion of the common mistletoe and of the pine processionary moth in the European Alps.

A spectacular case is that of the mountain pine beetle in North America (Kurz et al. 2008). With warming climate this species has been expanding northwards, affecting millions of hectares of coniferous forest. Compounded with increasing fire risk during warmer and drier summers, highly flammable beetle damaged forests have contributed to dramatic increase in burned areas, with considerable effects on regional carbon budgets (expected average emissions for western Canada: 36 g C m^{-2} yr^{-1}) and potential positive climate feedbacks. The same type of dynamics applies to invasive species, when the climate-driven expansion of exotics such as C_4 grasses into shrubby ecosystems (Australia, Cape Region of South Africa) profoundly modifies long-term fire regimes.

Such abrupt changes in ecosystem services are serious challenges to adaptive capacity. Learning from past events, detecting early warning signals and fostering resilience of socio-ecosystems will be essential.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Breshears DD, Lopez-Hoffman L and Graumlich LJ (2011) *Ambio* 40: 256-263

Hoegh-Guldberg O et al. (2007) *Science* 318(5857): 1737-1742

Kurz WA et al. (2008) *Nature* 452: 987-990

Mahli Y et al. (2009) *PNAS* 106(49): 20610-20615

Mooney H et al. (2009) *Current Opinion in Environmental Sustainability* 1: 46-54

and associated services respond to climatic change?

PAST

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Although "ecosystem services" is a relatively new term, the concept has a long history. For example, the 1895 New York State Constitution designated the Adirondack Forest Preserve to be "forever wild" in order to maintain water quality and supply in the Hudson River watershed. Ancient societies utilized such ecological goods as fuels, fibers, and foods deriving from natural or lightly managed ecosystems, and many came to recognize the ecological services provided by vegetated watersheds and floodplains. Such recognition often came the hard way, just as it does for modern societies.

Studies of the past play important roles in assessing risks and vulnerabilities for ecosystem services in two ways: by providing records of interactions among environmental change, ecosystem services, and societal activities, and by showing how ecosystem properties that underlie ecosystem services have been affected by climatic changes. Because human activities have affected ecosystems for centuries to millennia, it is particularly important to establish baselines for ecosystem properties and services, and to determine how those baselines have already been altered by humans. Teams of marine biologists and paleobiologists have documented history of human impacts on North American fisheries (Jackson et al. 2001; Jackson 2001). Although Native Americans harvested fish and shellfish, often intensively, estuarine ecosystems were little affected. However, introduction of European technologies led to rapid size decline of fish at the top of the food chain, and intensive oyster harvesting resulted in estuarine eutrophication. Both trends accelerated with industrial fishing of the 20th century, with multiple consequences for ecosystem goods and services.

In another example, alpine lake sediments in the western United States record a five-fold increase in dust deposition concurrent with intensive cattle and sheep grazing in the 19th century (Neff et al. 2008). Modeling studies reveal that the dust emissions, caused by breakup of soil crust and reduction of vegetation cover at low elevations, were sufficient to reduce snow albedo, shortening high-elevation snow-cover by several weeks and altering seasonal and total stream discharge (Painter et al. 2010). The sediment studies also show that federal grazing regulations introduced in the 1930s had mitigating effects on dust deposition (Neff et al. 2008).

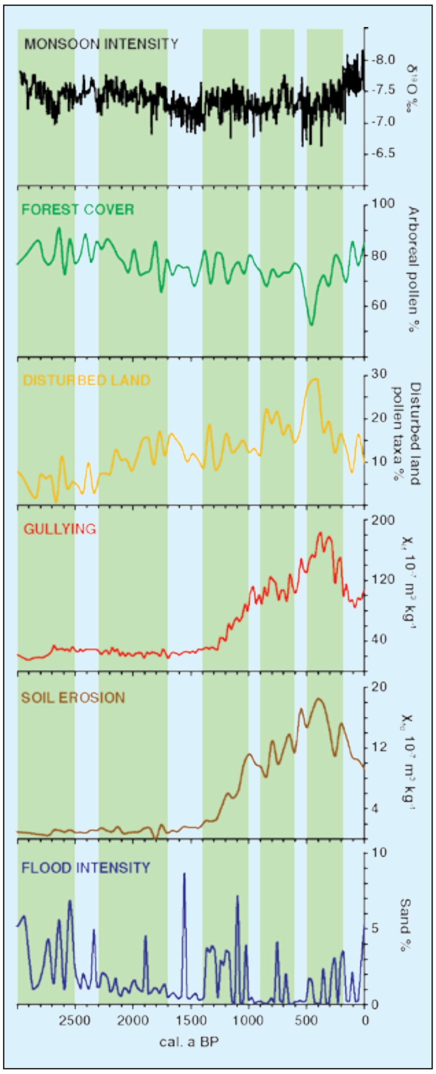

Figure 1: Geohistorical records of temporal changes in ecosystem properties and services. This 3000-year composite record of regional ecosystem attributes (land cover, erosion, flood intensity) inferred from sediments of Lake Erhai and monsoon intensity inferred from a speleothem shows ecosystem responses to changes in human population, cultural practices, and climate. The five green bands show primary periods of human effects on the regional environment (left to right): Bronze-Age culture, Han irrigated period, Nanzhao Kingdom, Dali Kingdom, and late Ming/early Qing environmental crisis. (From Dearing 2008).

These studies focus on impacts during the historical period, but ancient societies also provide object lessons on interactions among cultural practices, climate change, and ecosystem services (Costanza et al. 2007; Büntgen et al. 2011). Sediments from Lake Erhai in southwestern China show vividly how a succession of late Holocene cultures influenced land-cover, soil erosion, and flooding (Fig. 1), culminating in a peak of land clearance and soil erosion in the 17th and 18th centuries (Dearing 2008; Dearing et al. 2008). Consequences of land-use practices may have interacted with increasing monsoon intensity, leading to a well-documented environmental crisis that began to abate only in the 20th century.

Studies of environmental and ecological changes, even without direct links to cultural practices or consequences, play important roles in assessing ecosystem services. Ecosystem services ultimately derive from structural, functional, and compositional properties of ecosystems, and understanding how those properties have responded to past climate changes can provide insight into vulnerability of ecosystem services to ongoing and future climate change (Williams et al. 2004; Jackson 2006; Jackson et al. 2009). North American mid-continental droughts in the Holocene provide a series of case studies. Most recently, multidecadal droughts associated with the Medieval Climate Anomaly led to widespread changes in fire regime and vegetation composition in the central and western Great Lakes region (Shuman et al. 2009; Booth et al. 2012). In the mid-Holocene, a severe and persistent drought (ca. 4200-4000 a BP) resulted in forest disturbance and compositional change in the western Great Lakes as well as dune mobilization in the Upper Mississippi Valley (Booth et al. 2005). In the early Holocene, the mid-continent experienced a gradual, time-transgressive drying, punctuated by a rapid, region-wide drying associated with final collapse of the Laurentide ice sheet. Ecosystem responses show both gradual and time-transgressive trends and a step-change associated with the rapid event (Williams et al. 2009, 2010). Timing varied widely among individual sites, suggesting different thresholds and sensitivities of local systems. All these case studies indicate that ecosystem properties, and ultimately ecosystem services, are vulnerable to climatic change, whether transient or persistent, and that sensitivity varies substantially among ecosystems and regions.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Costanza R, Graumlich LJ and Steffen W (2007) *Sustainability or Collapse? An Integrated History and Future of People on Earth*, MIT, 520 pp

Dearing JA (2008) *The Holocene* 18: 117-127

Jackson JBC et al. (2001) *Science* 293: 629-638

Neff JC et al. (2008) *Nature Geoscience* 1: 189-195

Williams JW et al. (2010) *Geology* 38: 135-138

Abrupt changes - To what extent are

PRESENT

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Tipping points have entered common discourse in a range of applications: the uprisings of the Arab Spring, the narrative of sporting events, the evolution of consumer sectors, the rhythm of political campaigns, the threat of space junk, and the collapse of financial systems. An increasingly frequent application concerns the changing climate (Russill and Nyssa 2009). Some climate tipping points irreversibly change social structures, and the form of this change determines the ultimate effect on climate damages.

Undesirable tipping points involve climate change impacts. First, consider New Orleans or Bangladesh. The infrastructure in these regions are increasingly stressed due to higher sea levels and disappearing wetland buffers. Changing conditions have made them more vulnerable to future storms that could trigger a tipping point for the local culture and economy. Or consider a climate-induced drought that shifts a livestock-based economy to less water-intensive activities. These changes become partially irreversible as economic activity, infrastructure, and communities reorganize under new constraints.

Second, and perhaps more troublingly, climate change might induce large-scale migrations due to higher sea levels, water stress, crop failures, or extreme weather events (de Sherbinin et al. 2011). Shifting populations have triggered massive changes throughout world history, and future migrating populations could trigger internal or external conflicts and bring new challenges of assimilation and adjustment. For example, climate change could enhance water scarcity in South Asia, and recent conflicts in Darfur and other parts of Africa might have been exacerbated by environmental problems.

Other societal tipping points are desirable. First, a breakthrough in low-carbon technology might be necessary to change the dynamics of the energy system (Hoffert et al. 2002). If solar cells or batteries become cheap enough, electrical and transportation systems could begin shifting to less carbon-intensive structures even without a direct policy spur. Second, enacting a greenhouse gas emission policy should create constituencies for further policy. Ambitious policies currently lack clearly defined winners to lobby for their enactment, but moderate policies could develop this constituency by coining valuable property rights in tradable permits or by nurturing low-carbon industries. Third, on the international level, a climate coalition that includes enough countries might be able to raise remaining countries' cost of holding out (Barrett 2003).

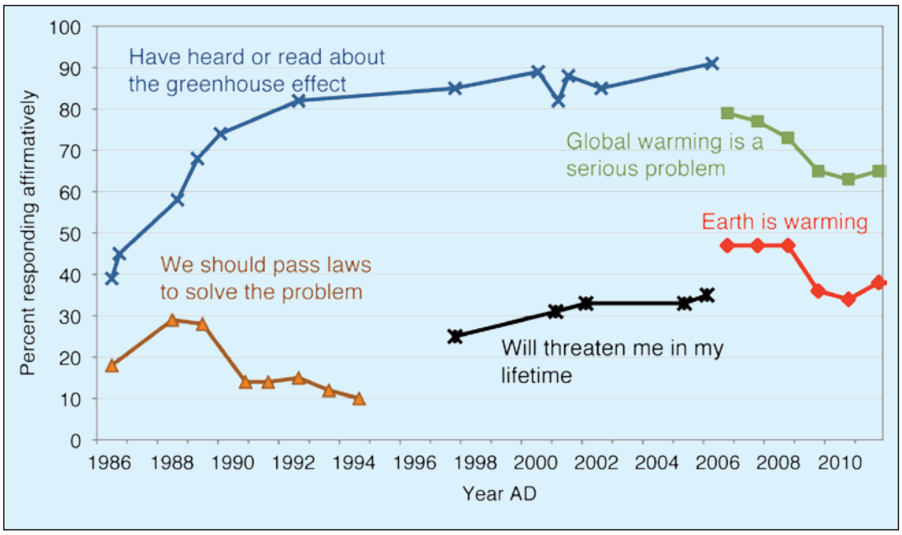

Figure 1: The response of the U.S. public to surveys' questions about global climate change (Pew Research Center for the People & the Press; Nisbet and Myers 2007).

Finally, we may still reach a further tipping point in climate awareness (see figure 1). Drawing on examples ranging from the diffusion of rumors to trends in smoking, some argue that social networks allow beliefs and behaviors to spread quickly once they reach a critical mass (Gladwell 2000). Incurring undesirable tipping points could raise public concern about the climate to such a threshold. Similar to how the first exposure to the horror of nuclear weapons has so far kept the world from further nuclear warfare, reaching the first undesirable climate tipping point may end up making future tipping points less likely by spurring preventive action.

From economic analysis of tipping points in the physical climate system, we have shown that the best policy response to a tipping possibility depends on two questions: (1) Can we affect whether a tipping point occurs? (2) If we knew a tipping point were about to occur, would we want to pursue a different policy? The first question captures our ability to prevent or spur a tipping point, while the second captures our desire to hedge against the possibility that it occurs. Because the undesirable tipping points depend on our present and future emission decisions, they provide additional incentive to reduce emissions. These undesirable tipping points also increase the payoffs to adaptation policies that reduce society's exposure to a changing climate. In contrast, desirable tipping points favor policies that make them more likely: funding research into low-carbon technology, pricing carbon sooner rather than later, and building climate awareness. If these desirable tipping points end up spurring significant emission reductions, they might even hold the key to avoiding undesirable ones.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Barrett S (2003) *Environment and Statecraft: The strategy of environmental treaty-making*, Oxford University Press, 437 pp

de Sherbinin A et al. (2011) *Science* 334(6055): 456-457

Gladwell M (2000) *The tipping point: How little things can make a big difference*, Little Brown, 288 pp

Hoffert M et al. (2002) *Science* 298(5595): 981-987

Russill C and Nyssa Z (2009) *Global Environmental Change*, 19(3): 336-344

tipping points a concern in coping with global change?

PAST

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Paleoclimatic records can provide information on the operation of the climate system, including the occurrence of tipping points and the risk of abrupt changes. The deep Greenland and Antarctic ice cores are particularly well suited to study abrupt changes, because they provide a detailed and well-dated record of past climate. Prominent examples of abrupt changes are the 25 Dansgaard-Oeschger (DO) events (NGRIP 2004) that occurred during the last glacial cycle (Fig. 1).

The DO events are characterized by abrupt warming followed by a gradual cooling. The isotopic composition of the nitrogen (N_2) in air bubbles trapped in Greenland ice and the stable water isotopes of oxygen (^{18}O) and hydrogen (deuterium, D) of the ice itself show that the abrupt warmings represent surface temperature changes in the order of 10-15°C (Landais et al. 2005). Annually dated ice core sections covering the two most recent DO events reveal the actual rapidity of the changes. Some proxies, like the deuterium excess ($d=\delta D-8*\delta^{18}O$), changed level over just a few years (Steffensen et al. 2008). The deuterium excess reflects the temperature at the moisture uptake region for the precipitation. Its step-like changes in Greenland ice cores suggest that the atmospheric circulation regime shifted substantially and irreversibly basically from one year to the next (Masson-Delmotte et al. 2005). Following the atmospheric regime shift, temperatures over Greenland warmed more gradually over some decades by 10-15°C, as shown by the $\delta^{18}O$ record (Steffensen et al. 2008). These observations prove that the climate system did, and therefore can, tip and reorganize internally within years and cause strong and fast regional temperature changes.

How and why did the abrupt climate changes happen? Studies from all latitudes based on ice cores from Polar Regions, marine sediments, stalagmites, corals and other paleoclimatic archives allow us to piece together a broader picture of the DO events and to deduce a sequence of causes and effects. During the cold phases preceding the abrupt warmings, vast volumes of ice were discharged into the ocean from the large glacial ice sheets including the North American Laurentide ice sheet, causing sea level to rise by several tens of meters (Siddall et al. 2003). The overturning circulation and associated northward heat transport in the Atlantic slowed down. This warmed the South and cooled the northern polar region further and may have resulted in a southward shift of the Intertropical Convergence Zone (ITCZ; Partin et al. 2007).

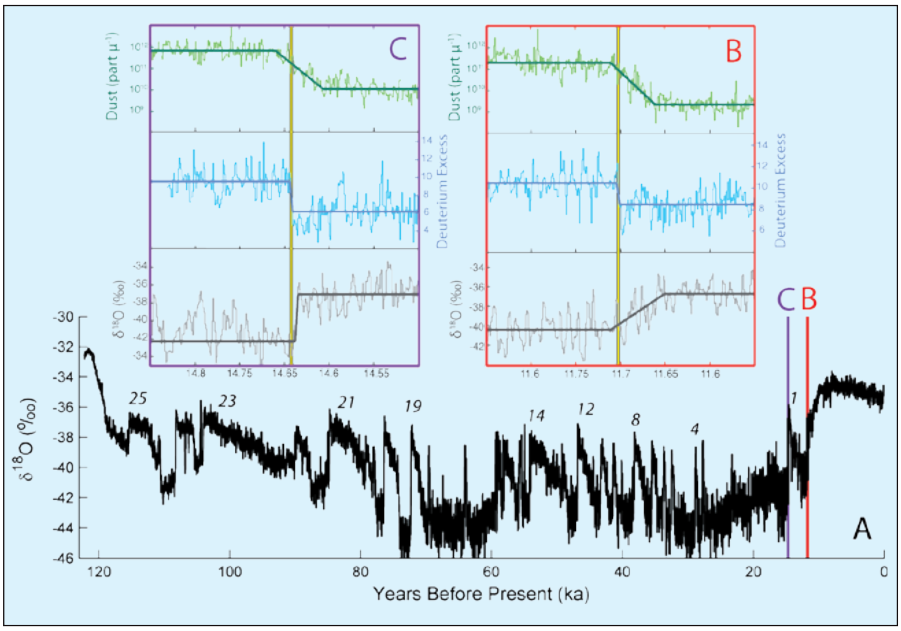

*Figure 1: High-resolution records from the Greenland ice core NGRIP. Panel **A** shows stable water isotopes ($\delta^{18}O$) in 20-year resolution. Numbers mark the most prominent of the 25 Dansgaard-Oeschger events. Panels **B** and **C** zoom in on two 300-year intervals during the transition from the last glacial to the Holocene. Shown are records of $\delta^{18}O$, deuterium excess and the unsolvable dust at 1-year resolution. The solid lines highlight the transitions in the records; the vertical yellow lines mark the steps in deuterium excess over just a few years. (Figure based on Steffensen et al. 2008).*

What caused the abrupt warmings? This is less well understood and requires investigation of the (very sparse) near-annually dated records. The studies from the Greenland ice cores suggest that the sudden rearrangement of the northern atmospheric circulation might have been initiated by a sudden shift of the ITCZ in the low latitudes. A sudden decrease of the dust concentration in the ice indicates that the wetness of the source area for the dust (related to the position of the ITCZ) had shifted (Steffensen et al. 2008). Perhaps the warming of the south finally pushed the ITCZ north again?

Can such tipping points of temperature and sea level change happen in the coming decades and centuries? The DO events during the last glacial seemed to be initiated by surges from big glacial ice sheets. Such large Ice sheets are not present nowadays, but other triggers that could cause the system to tip are plausible. Increased precipitation and melting of ice sheets and glaciers could increase the fresh water supply to the Arctic and the North Atlantic Ocean and alter the intensity of the ocean circulation. This would tip the energy distribution between the North and South in a similar way as happened during the glacial DO events. Rapid mass loss of the West Antarctic Ice Sheet, of which major parts lie more than 1 km below the present sea level, could cause an abrupt sea level rise of several meters.

State-of-the-art simulations with complex Earth System models do not project abrupt climate changes for this century. However, based on our understanding of the past DO events we conclude that abrupt changes of temperature and sea level cannot be ruled out entirely for our future world.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Partin JW et al. (2007) *Nature* 449: 452-455

Landais AA, Jouzel J, Masson-Delmotte V and Caillon N (2005) *Comptes Rendus Geosciences* 337: 947-956

Masson-Delmotte V et al. (2005) *Science* 309: 118-121

Siddall M et al. (2003) *Nature* 423: 853-858

Steffensen JP et al. (2008) *Science* 321: 680-684

Is there a global Holocene climate mode?

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The two main millennial-scale Holocene climate patterns or submodes are also significant at the multidecadal to century-scale level.

Large-scale climate patterns and modes are important instruments to characterize prevalent teleconnections and their related processes. Their correlation with forcing factors constitutes an important element of climate diagnostics. The increasing number of data and modeling studies referring to Holocene climate provokes the question whether or not global patterns or modes predominated.

The millennial-scale pattern

The Holocene spans the time period of the last 11.7 ka. During the first 5 ka a reorganization of the hydrographic system due to the melt of the large ice sheets took place (Carlson et al. 2008; Renssen et al. 2007). Apart from the recent decades being influenced by anthropogenic forcing climate change during the period of the last 7 ka was dominated by the decreasing solar insolation in the Northern Hemisphere during boreal summer (Berger 1978; Wanner et al. 2008). Due to this redistribution of solar energy the global climate system experienced rearrangements, which are represented in Figure 1a and b for the Holocene Thermal Maximum (HTM) and the so-called Neoglacial (Wanner et al. 2008).

During the HTM the enhanced heating of the Northern Hemisphere during boreal summer led to a warming generating intensified heat lows and a higher activity of the Afro-Asian summer monsoon systems transporting more moisture to the corresponding continental areas. Positive temperature anomalies in the area of the Indo-Pacific Warm Pool (IPWP) and negative ones in the eastern Pacific area predominated (Xu et al. 2010; Marchitto et al. 2010) and, correspondingly, the El Niño frequency was low (Clement et al. 2000; Rein et al. 2005). For the North Atlantic area some studies (e.g. Rimbu et al. 2003) show that positive North Atlantic Oscillation/Arctic Oscillation (NAO/AO) indices dominated during the early Holocene. No information is available for the Atlantic Multidecadal Oscillation (AMO; Schlesinger and Ramankutty 1994). Even more uncertainties exist in the Southern Hemisphere subtropics and midlatitudes.

An almost opposite pattern existed during the Neoglacial (Fig. 1b). The Intertropical Convergence Zone (ITCZ) shifted to a more southerly position, the Afro-Asian summer monsoon systems were less active, and the corresponding continental areas were exposed to an increasing dryness (Gasse et al. 2000; Haug et al. 2001; Wang et al. 2005). A warmer eastern tropical Pacific and a higher El Niño frequency coincided with predominantly neutral or negative NAO/AO indices and likely led to a more humid climate in the Great Plains and southwestern North America.

A multi-decadal to century-scale Holocene mode explaining climate shifts?

In addition to the orbitally driven solar insolation changes the patterns in Figure 1 were also determined by internal variability, which strongly depends on specific physical boundary conditions, such as land-ocean and sea-ice distribution and topography. In concert with the two other natural forcings (solar, volcanic) characteristic temperature and humidity patterns may have occurred, which could be interpreted as climate modes (Stephenson et al. 2004). One possible way to study long-term global climate variability and change is to investigate the dynamical modes with an annular structure on both hemispheres, expressed by the indices describing the strength of the Westerlies, namely the Antarctic Oscillation (AAO; Thompson and Wallace 2000) and the AO/NAO (Hurrell et al. 2003). The focus of the maps on Figures 1a and b is more directed towards the dynamics in the Atlantic and Pacific areas. The most important mode is located in the Pacific, the area with the highest sea surface temperatures. Its orientation is mostly zonal, and it encompasses the IPWP and the ENSO system, including its connections with the Indian/East Asian monsoon as well as with the Pacific North American Pattern and the Pacific Decadal Oscillation. The orientation of the second mode (NAO/AMO) is rather meridional, including the Atlantic Ocean with the Arctic sea ice and the adjacent continental areas.

How far are ENSO and NAO coupled, and which processes determine the dominating patterns in Figure 1? A first option is to investigate whether or not the two modes are correlated and interact in a systematic manner on short time scales, and then extend the analysis to long time scales. Recent studies (Brönnimann 2007) suggest that a coupling exists, and that it most likely operates through an alteration of the flow over the Pacific-North American-Atlantic sector. However, the coupling is statistically weak and has not been addressed for longer time scales.

A second option is to study the influence of the two major non-orbital natural forcing factors (Shindell et al. 2003): solar and volcanic activity. In case of large tropical volcanic eruptions (Robock and Mao 1995; Fischer et al. 2006) the lower stratosphere is heated more over the tropical regions than near the poles, which accelerates the wintertime polar vortex. Through downward propagation, this can affect the circulation near the ground. Therefore, despite an overall annual mean global surface cooling, the strengthening of the Westerlies (with positive NAO indices) causes higher winter temperatures mainly along the west coasts of the major continents. So-called Grand Solar Minima (GSM; Steinhilber et al. 2009) cause a major cooling especially in the large continental areas of the Northern Hemisphere. Due to their inertia the oceans show a delayed SST response, and negative AO/NAO indices predominate (Shindell et al. 2003; Mann et al. 2009). Whether or not the two forcings affect global climate via altering ENSO is debated (Adams et al. 2003; Mann et al. 2005; Meehl et al. 2009). At least during the early Holocene periods of low solar activity corresponded with El-Niño-like (warm) conditions, weak Asian monsoons and low SSTs in the North Atlantic (Marchitto et al. 2010).

A third option is to study the frequency and the strength of important modes during periods with predominating warm or cold temperature anomalies. On the basis of petrologic tracers in the North Atlantic, Bond et al. (1997 and 2001) postulated a "1500 year" cycle that is sup-

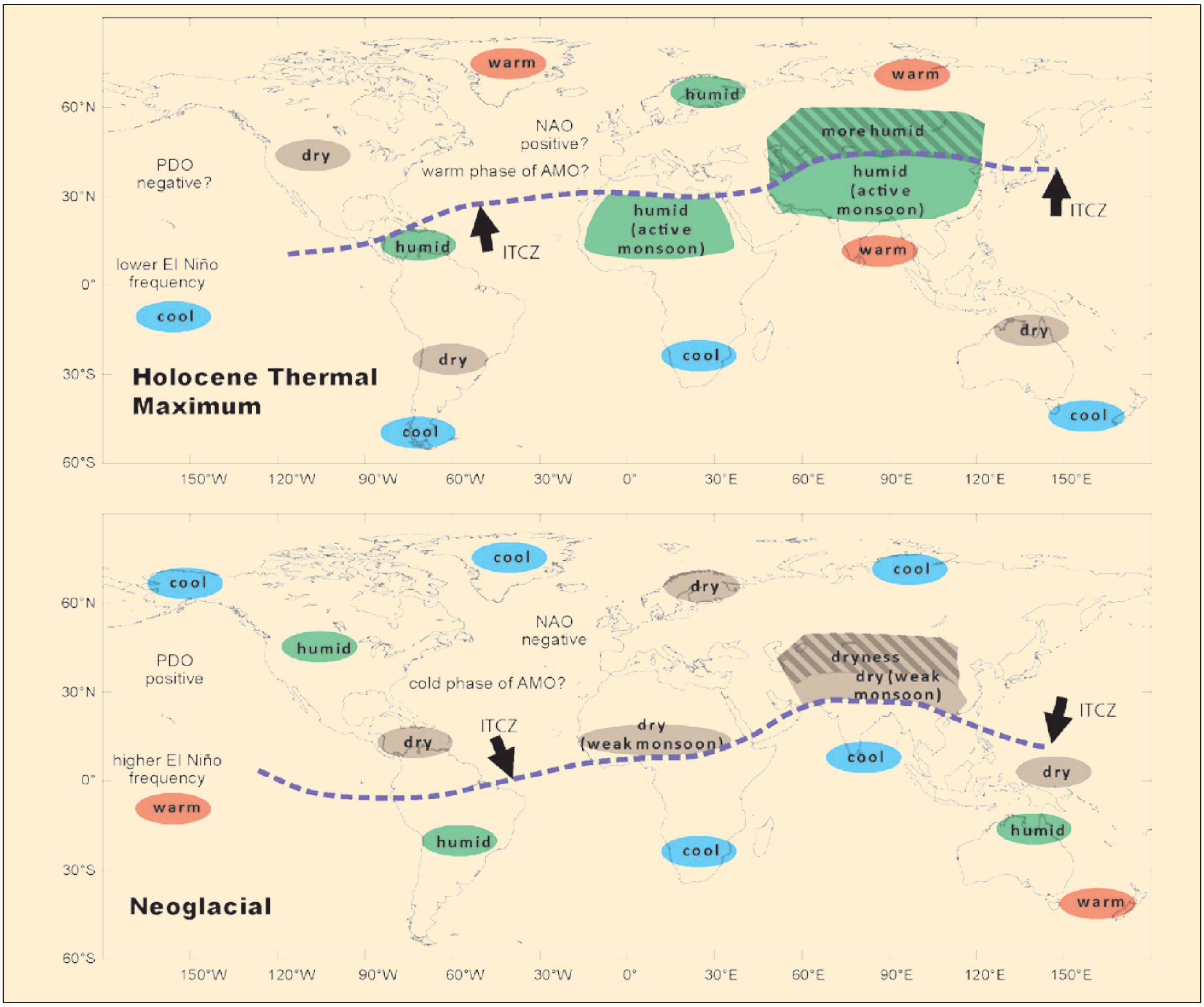

Figure 1: Climate patterns of the Holocene Thermal Maximum (~7-4.5 ka BP; Ljungqvist 2011), and the Neoglacial, which started around 4.2 ka BP and ended with the modern industrialization in the 19th century. Both Figures were outlined based on existing Holocene proxy time series (Wanner et al. 2011).

posed to have persisted throughout the Holocene. These cycles were thought to be the Holocene equivalents of the Pleistocene Dansgaard-Oeschger cycles (Alley 2005). Several authors (e.g. Hong et al. 2003; Gupta et al. 2005; Wang et al. 2005) speculated that a link existed between the weak Indian/Asian summer monsoon and the cool North Atlantic climate, which was possibly triggered by solar influence. Recent studies show that different dynamical processes were likely responsible for the existence of the Bond cycles (Wanner and Bütikofer 2009). Prior to the modern warm period with anthropogenic forcing, the last 2 ka included two warmer (Roman Warm Period RWP, Medieval Climate Anomaly MCA) and two cooler periods (Migration Period Cooling MPC, Little Ice Age LIA). It is still debated whether or not those phenomena were global. The solar activity was obviously higher and the volcanic forcing weaker during the RWP and the MCA (Steinhilber et al. 2009), and a shift from positive to negative NAO indices might have occurred during the MCA-LIA transition (Trouet et al. 2009; Mann et al. 2009). Similar to the pattern in Figure 1a multidecadal droughts occurred in southwestern North America during the RWP (Routson et al. 2011) and during the MCA (Seager et al. 2007), possibly linked with La Niña-like conditions and positive NAO indices.

Interestingly, a rapid shift to more humid conditions was observed during the LIA, mainly in the tropics (Wanner and Ritz 2011). Gagan et al. (2004) postulate that the tropical Pacific played a role as a source region of water vapor during the expansion of the LIA glaciers. The LIA was characterized by a coincidence of large explosive volcanic events and strong solar minima (Breitenmoser et al. 2011). While during the MPC a remarkable GSM took place around AD 650 (Steinhilber et al. 2009) the RWP shows neither strong volcanic events nor a GSM. On the other hand the oscillations in the early Holocene (Marchitto et al. 2010) as well as the MCA-LIA transition were exposed to stronger forcings and show patterns similar to the millennial scale ones in Figure 1a and b.

We could therefore pose the question whether or not these patterns represent the features of a characteristic multidecadal to century scale climate mode. If the two patterns in Figure 1 represent two specific submodes of Holocene climate, the question can be asked whether one of them could dominate in the future under the influence of anthropogenic climate change.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Bond G et al. (2001) *Science* 278: 1257-1266

Brönnimann S (2007) *Reviews of Geophysics* 45, doi: 10.1029/2006RG000199

Marchitto TM et al. (2010) *Science* 330: 1378-1381

Stephenson DB, Hannachi A and O Neill A (2004) *Quarterly Journal of the Royal Meteorological Society* 130: 583-605

Wanner H et al. (2008) *Quaternary Science Reviews* 27: 1791-1828

2nd PAGES 2k Network Meeting: Review of status and plans for synthesis

Bern, Switzerland, 28 July 2011

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The 2nd PAGES 2k Network Meeting took place in Bern one day after the XVIII INQUA Congress and was attended by 31 participants. The PAGES 2k coordinator Heinz Wanner gave an introduction on the scientific objectives, the concept, and the schedule of the PAGES 2k project. This was followed by presentations from all regional groups and from associated guests. The meeting wrapped up with strategic and scientific discussions.

All 2k regional groups (Fig. 1) agreed that the 2k Network should work towards a consortium paper for the IPCC AR5 manuscript submission deadline. It was agreed that drafts of the regional time series and accompanying explanatory text sections should be completed by January 2012 to provide enough time for the writing team to produce a meaningful synthesis. The two main aspects discussed in this regard were whether the firm timeline is realistic to produce reliable temperature reconstructions, and the difficulties of producing a temperature record for some regions, such as Africa, where natural archives appear to be sensitive mainly to precipitation. The plenary decided to attempt producing a first set of reconstructions to retain the current momentum of the 2k initiative and to focus on paleotemperatures because they were considered most useful for IPCC AR5. A stronger emphasis on precipitation and climate modes will be set for the final 2k synthesis.

Representatives of the eight regional 2k groups summarized recent activities, the results achieved since the first meeting in Corvallis in July 2009, and their possible contributions to the planned PAGES 2k consortium paper. Despite the difficulties encountered by several groups in identifying and processing a significant number of high-resolution proxies, the participants were impressed by the progress made within each group. Not surprisingly, the discussion was centered on how to include and compile the best proxy records in the available time, and how to organize the rapidly growing global data set.

Figure 1: The nine regional groups of the PAGES 2k Network on 2000-year climate reconstructions.

Eugene Wahl from NOAA in Boulder, USA offered support to the 2k climate reconstruction process by way of hosting the 2k datasets. The NOAA Paleoclimatology branch will adapt a section of its Paleoclimate data bank to cater to the needs of the 2k groups. The plenary decided that each regional group would appoint a data manager in charge of the regional groups' contributions to the 2k data collections and archiving.

Eugene Wahl also shed light on the revised concept and first available datasets of the PAGES-CLIVAR Paleoclimate Reconstruction (PR) Challenge. He (along with fellow PR Challenge co-leader Nicholas Graham) also invited all colleagues interested in paleoclimate reconstructions to participate in the PR Challenge. Incidentally, a report on the PR Challenge was published in the last issue of PAGES news (Graham and Wahl 2011).

Hugues Goosse (Louvain, Belgium) shared information on the existing/planned simulations being carried out by the PMIP3 community and by groups working with EMICs. He and Bette Otto-Bliesner (NCAR, Boulder) also expressed their interest in collaborating with the 2k-reconstruction community. The modeling community will be an integral part of the final 2k synthesis.

Realizing that the ocean regions are still insufficiently covered by the existing regional groups, the plenary suggested initiating a working group on high-resolution paleoceanographic reconstructions of the last 2k. A lead team has since formed around Mike Evans (Univ. Maryland, USA) and started the process (page 4). Finally, the plenary discussed the schedule and the goals for the final 2k-reconstruction synthesis. Collaboration with modeling activities will be intensified and a strong effort will be made to generate regional precipitation reconstructions and to analyze past circulation patterns and climate modes.

Reference

Graham N and Wahl E (2011) *PAGES news* 19(2): 71-72

1st Workshop of the PAGES Antarctica2k Working Group

ANTARCTICA2K

Bern, Switzerland, 19-20 July 2011

TAS VAN OMMEN[1] AND THE ANTARCTICA2K STEERING COMMITTEE

[1]Australian Antarctic Division (AAD), Kingston, Australia; tas.van.ommen@aad.gov.au

The first Workshop of the PAGES Antarctica2k meeting at the University of Bern was a successful start to the tasks of building a community for reconstructing Antarctic climate and the development of a plan to undertake such reconstructions within the PAGES 2k Network timeframe. The meeting resolved to make reconstructing Antarctic temperature a priority. At present, the best available reconstruction for the continent is that of Schneider et al. (2006) in Figure 1. Now, some five years later, additional records, new methodologies, and a longer meteorological calibration period are available. This last point is significant, as the very short extent of the high quality instrumental record in Antarctica (3-4 decades) makes even a 5-10 year extension in overlap with the proxy records valuable. The intention is to push the 200-year record back towards the 2000-year goal of the PAGES 2k Network.

This undertaking has some unique challenges attached to it. Beyond the short nature of the calibration period, the meteorological data are also spatially sparse and there is concern that the period of observations is coincident with the period of anthropogenic disturbance. On the proxy side, the high-resolution data network will presently be limited to ice core records. While ice cores are generally well suited to reconstruct climate, the Antarctica2k database will nevertheless be much less heterogeneous in proxy types than other geographic regions in the PAGES 2k Network. However, lower resolution proxy records will be incorporated for validation of decadal and centennial scale variability. In addition, the group has acknowledged the potential for high-resolution marine based records (Expedition 318 Scientists, 2010) that will be used at later stages of the project.

The work plan developed for the temperature reconstruction is organized around three groups: a data group (led by Mark Curran, AAD Australia) is assembling the input records and dealing with dating and quality control, a synthesis group (led by Tas van Ommen) will derive the actual high resolution reconstruction and a "non-ice" proxy group (led by Dominic Hodgson, BAS Cambridge) is working on the complementary lower resolution records.

At the meeting, good initial progress was made by the data group. Initial comparison of volcanic records from Law Dome (Eastern Antarctica), the West Antarctic Ice Sheet and Greenland confirmed the potential of a common volcanic-tie chronology to underpin the 2000-year record. Law Dome and Greenland volcanic marker ages agree within 4 years at 168 AD. The data group will assemble the ice core records (water isotope and associated volcanic data) with chronological and quality control to ensure consistent dating. This phase is expected to be completed by November 2011. The synthesis will then take place and an initial reconstruction product is expected for early 2012. Discussion at the workshop around the analysis issues acknowledged that the unique challenges noted above might lead to problems with some of the statistical reconstruction methods. Therefore the group will investigate a range of reconstruction approaches.

Later in the PAGES 2k Network timeframe, the Antarctica2k group will investigate reconstructions for other variables including precipitation.

The steering committee for the Working Group comprises Tas van Ommen (leader), Hubertus Fischer, Dominic Hodgson, Mark Curran, Valérie Masson-Delmotte, Bo Vinther and Liz Thomas. We welcome participation from the Antarctic paleoclimate community.

References

Expedition 318 Scientists (2010) *IODP Preliminary Report* 318, doi: 10.2204/iodp.pr.318.2010

Schneider et al. (2006) *Geophysical Research Letters* 33, doi: 10.1029/2006GL027057

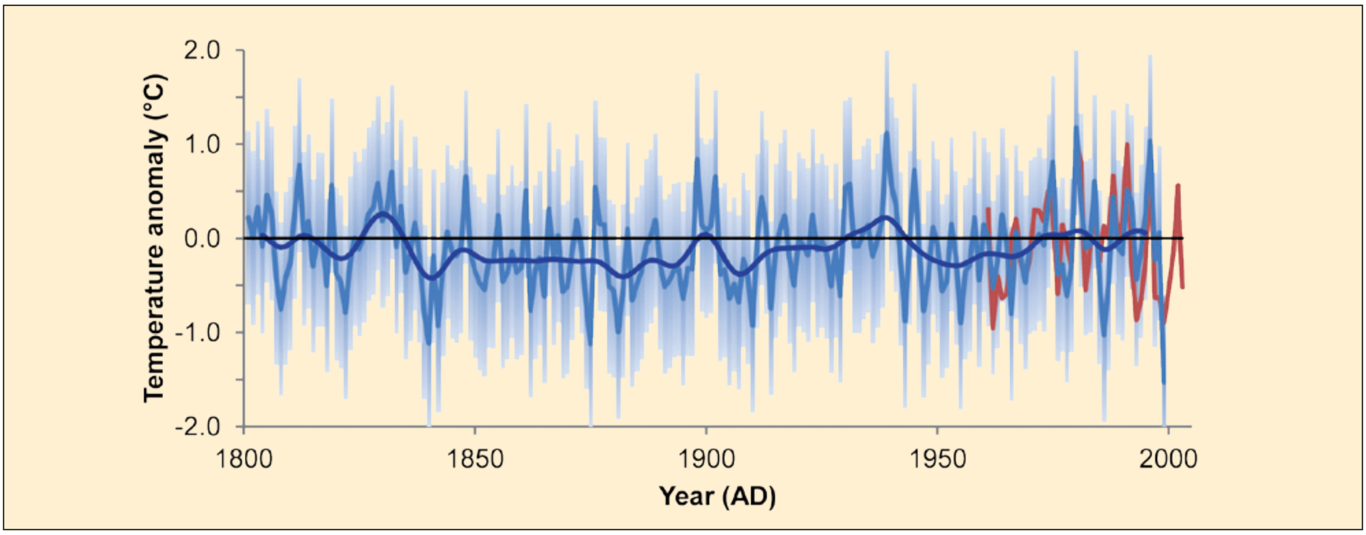

Figure 1: Antarctic temperature reconstruction from AD 1800-2000 based on five ice core sites (adapted from Schneider et al. 2006). ***Blue curves*** *are the annual reconstruction and a decadal smooth (Gaussian with σ=3 years). Error shading shows 95% confidence interval.* ***Red curve*** *is calibration temperature target. The zero reference is the 1961-1990 climatological mean.*

The nitrogen cycle in the ocean, past and present

2nd NICOPP meeting, Halifax, Canada, 8-10 June 2011

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Discussions among the 21 scientists attending the NICOPP 2011 meeting confirm that this is an exciting time to be studying nitrogen (N) cycling in the past and present oceans. For example, measurements of the N isotopic composition ($\delta^{15}N$) of marine nitrate and nitrite (the most widely available forms of marine N) are now relatively commonplace and sedimentary reconstructions of past N cycling processes are becoming increasingly sophisticated through the use of microfossil-bound and compound-specific $\delta^{15}N$. These new techniques allow us to identify isotopic distinctions between sedimentary and species size fractions, which promise to provide an even more detailed look at past N cycling and related ocean conditions. Furthermore, the laboratory-based data provide crucial benchmarks for computer-based simulations of the marine N cycle. All of these approaches provide insight to ocean productivity and the biogeochemical processes associated with both N and carbon cycling, such as nitrate assimilation by phytoplankton and denitrification in oxygen-deficient zones.

Past N cycling was a dominant topic for two themes of the meeting: the global sediment $\delta^{15}N$ database (proposed at NICOPP 2010, Galbraith et al. 2010) and the impact of diagenesis on whole sediment $\delta^{15}N$ (total combustible sedimentary N; also known as "bulk").

Global sediment $\delta^{15}N$ database

To date, 138 records of whole sediment $\delta^{15}N$ variability covering the last ca. 2.5 Ma have been compiled into a database, which will be described in a publication and made available to the community shortly (Fig. 1). The compilation is promising but also highlights the need for enhanced geographical coverage in particular in the largely neglected subtropical gyres and most of the Southern Hemisphere. This sediment $\delta^{15}N$ database will be a powerful tool for reconciling marine N cycling with past changes in the mean climate state.

The influence of diagenesis

Even with significant developments in the use of alternate sedimentological $\delta^{15}N$ records such as microfossil-bound and compound-specific $\delta^{15}N$, much of our knowledge of past N cycling processes will continue to rely on whole sediment $\delta^{15}N$, given that it can be measured in any sediment at relatively low cost. However, at some sites, coretop whole sediment $\delta^{15}N$ is elevated relative to the expected export from the modern surface ocean. The underlying cause of the $\delta^{15}N$ enrichment is assumed to be the preferential loss of ^{14}N during the remineralization of freshly deposited organic matter or "diagenetic fractionation".

This issue was a major concern of NICOPP 2011 with several presentations dedicated to using the global sediment $\delta^{15}N$ database and whole sediment / microfossil $\delta^{15}N$ measurements to discuss why and where diagenetic fractionation is important. Among these discussions, several investigators independently converged on the finding that coretop whole sediment $\delta^{15}N$ in the deep-sea, which ranges from 1-17‰, is on average 2 ± 2‰ higher than values from sediment trap time series at the same sites. However, where coretop sediments were measured for both whole sediment and microfossil-bound $\delta^{15}N$ (assumed to be resistant to diagenetic alteration) they generally agreed. These findings suggest that coincident measurements of whole sediment and microfossil-bound / compound-specific $\delta^{15}N$ will help answer why deep-sea coretop sediment $\delta^{15}N$ is elevated, by illuminating the molecular transformation of sedimentary organic matter. Furthermore, where the fidelity of whole sediment $\delta^{15}N$ is assured (i.e. in the case of little terrigenous input and minimal diagenetic fractionation) differences with microfossil-bound $\delta^{15}N$ could provide new insight to surface ocean N cycling processes.

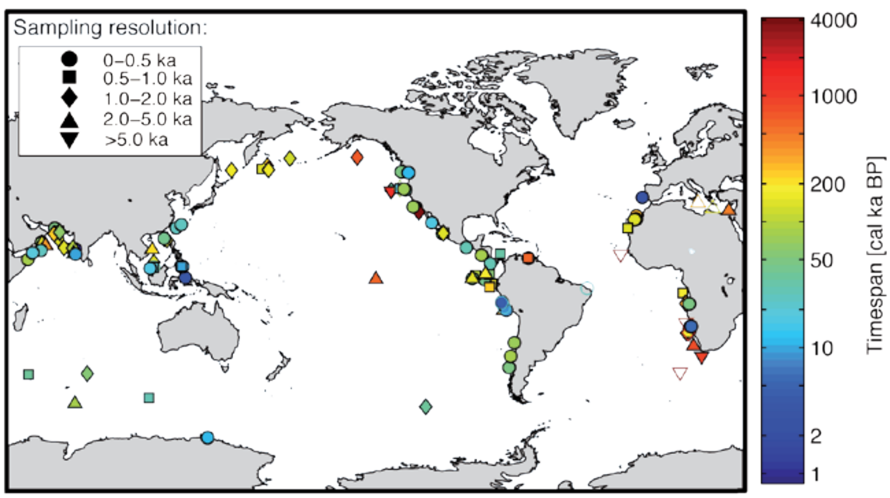

Figure 1: Global distribution of available sedimentary $\delta^{15}N$ records, together with their respective temporal coverage and resolution. Cores that do not cover the last glacial cycle are marked by an open symbol.

Interlaboratory calibration

On a different note, a laboratory intercalibration was proposed to optimize comparison between whole sediment $\delta^{15}N$ records. Laboratories interested in joining the effort should please contact Mark Altabet (maltabet@umassd.edu).

Reference

Galbraith E, Kienast M and Kiefer T (2010) *PAGES news* 18(2): 92-93

Open PHAROS workshop on "Sediment and carbon fluxes under human impact and climate change"

LUCIFS Workshop, Bern, Switzerland, 28-30 July 2011

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Sediment-burden carbon fluxes represent a considerable yet insufficiently understood component of the global carbon (C) cycle. The contribution of soil erosion and sediment transport on hillslopes and in channels to greenhouse gas emission and/or long-term C storage remains largely unknown. The major aim of the workshop was to bring together leading and early-career scientists focusing on C and sediment fluxes from different viewpoints (e.g. soils, hillslopes, fluvial and limnic systems). Perspectives for unravelling long-term sediment-burden C fluxes and the prospects of establishing the relationships between C and sediment fluxes were discussed. In addition, concepts, methods and regions that are best suited for establishing Holocene sediment-carbon fluxes were identified. The workshop was organized by the PAGES working group LUCIFS (Land Use and Climate Impacts on Fluvial Systems) under the Focus 4 Themes "Sediment" and "Carbon". A total of 19 researchers from different disciplines (ecology, geology, geomorphology and limnology) and countries (Belgium, Ethiopia, Germany, Japan, Switzerland, The Netherlands, UK and USA) contributed to the workshop.

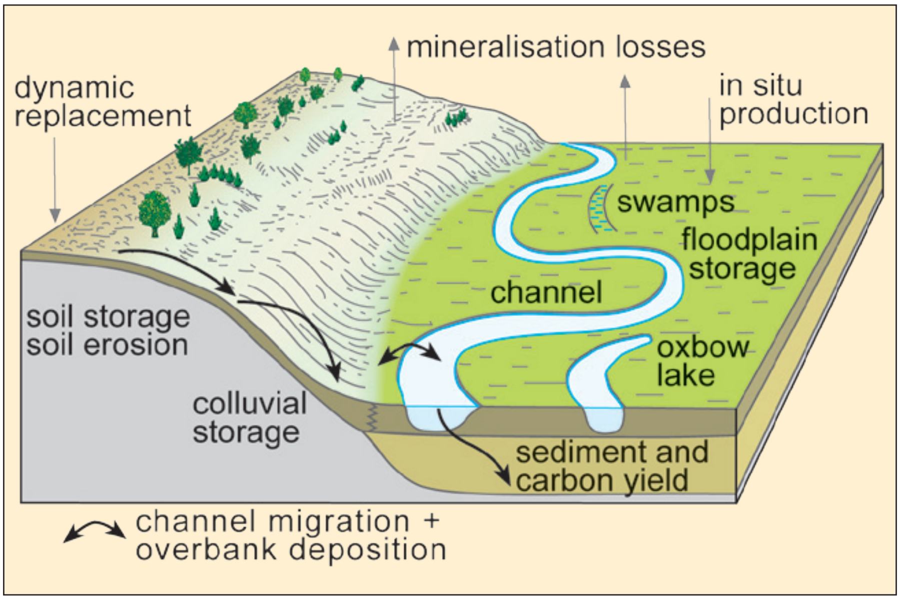

Figure 1: Sediment-burden carbon fluxes on hillslopes and in floodplains; representing key mechanisms as mentioned in the text.

Discussions on the first day focused on the contribution and importance of single system components along the sediment/carbon flow path (e.g. hillslopes, floodplains and lakes) and their interconnections. Kristof van Oost (Louvain, Belgium), Rolf Aalto (Exeter, UK), and John Boyle (Liverpool, UK) gave keynotes speeches on organic C storage and erosion on hillslopes, floodplains and lakes. The second day's session focused on the wider implications of environmental changes (including climate change and human impacts) on sediment-burden C fluxes. Simon Mudd (Edinburgh, UK) and Jed Kaplan (Lausanne, Switzerland) presented ideas on quantifying long-term soil production and biogeochemistry to use as baseline information for modern soil processes. They also discussed Holocene C flux and land use changes. Jane Willenbring (Pennsylvania, USA) gave a presentation on quantifying long-term C loading from anthropogenic erosion. On the third day, Fritz Schlunegger and Fabian Van den Berg (Bern, Switzerland) led a fieldtrip to showcase subglacial erosion, the formation of inner valley gorges and knickpoint retreat in glacial hanging valleys.

All presentations highlighted the current overly simplistic consideration of hillslopes and channels in models of the global C cycle; hillslopes are often represented as simple engines that release C through soil formation and subsequent erosion, and fluvial channels are often viewed as pipes that passively transport carbon from the hillslopes to the oceans. During the workshop it became clear that sediment-burden C fluxes are altered by various processes at different spatial and temporal scales. Sediments eroded at hillslopes may be stored several times under different environmental conditions along the flow path to the oceans. During storage, organic C can either decompose or build up depending on the specific environmental conditions. Four key mechanisms determine the coupled sediment/carbon flux: i) dynamic replacement of eroded C due to soil formation, ii) increased mineralization of C due to aggregate breakdown during transport, iii) protection of eroded organic material through burial and iv) organic matter complexation (Fig. 1). On short timescales (ca. 50 years) soil erosion seems to have only limited effects on atmospheric CO_2-concentrations, while on longer timescales (centuries to millennia) the C protection through burial dominates. This shows the clear need to define the relative importance of each key mechanism for specific timescales and environmental conditions. Furthermore, the discussion groups identified major gaps in understanding of feedback mechanisms between soil erosion and C fluxes, such as interdependence of soil productivity and ecological diversity. Such feedbacks may irreversibly alter the C cycling and might even be more important than direct fluxes. The participants of the workshop stressed the need for comparative studies on direct and indirect effects of soil erosion on the C cycle. These are needed to evaluate the effects of human-induced soil erosion in areas with different geology, climate and land use history.

Ice sheet modeling, sea level and isostasy

PALSEA

PALSEA PAGES/IMAGES workshop, Harvard, USA, 25-27 August 2011

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This 4th PALSEA workshop was hosted and co-sponsored by the Harvard Centre for the Environment and was an opportunity for a wide-ranging discussion amongst scientists active in the collection and analysis of relevant sea level and ice sheet data sets, and the modeling and development of theory for representing changes in the oceans and cryosphere.

Anders Carlson presented results on geochemical fingerprinting of ocean sediment to differentiate areas of Greenland where the ice sheet had retreated during the Last Interglacial (LIG) (Colville et al. 2011). Bob Kopp presented efforts to extend his Bayesian analysis of the Glacial Isostatic Adjustment (GIA) response during the LIG using relative sea level (RSL) data to attribute sea-level rise (Kopp et al. 2009). Maureen Raymo presented exploratory work looking at Mid-Pliocene Warm Period (MPWP) RSL indicators alongside GIA modeling from Jerry Mitrovica (Raymo et al. 2011). Early modeling results indicate that the GIA response globally varies by the order of ten meters and can plausibly explain much of the divergence of the RSL data for this period.

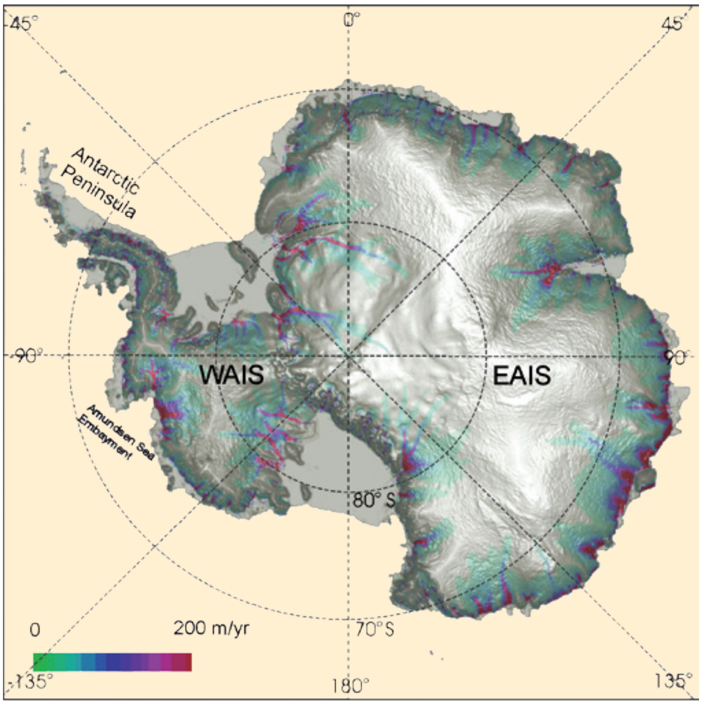

Figure 1: Surface topography derived from satellite radar altimetry and steady-state ice flow rates for the Antarctic ice sheet for the present-day (Bamber et al. 2007). Reprinted with permission from Elsevier.

Andrea Dutton and Bill Thompson presented two methodologies for interpreting fossil coral indicators of RSL for the LIG. Their results show differences but also similarities, most particularly that there is at least one period during which sea level appears to fall and then rise again by up to several meters (for full discussion see PALSEA website: http://eis.bris.ac.uk/~glyms/working_group.html).

Christian Schoof presented his work on grounding line stability (e.g. Schoof 2007), which has been incorporated into ice sheet models. Richard Hindmarsh talked about validation of the marine ice-sheet instability theory. A fresh look at the theoretical underpinnings by Schoof (2007) emphasizes the importance of the boundary layer near the grounding line. He presented evidence from an analogous flow situation, the ice shelf calving front, to show that the boundary layer theory operates as expected. The Weertman instability hypothesis (1974) suggests that there is a positive feedback causing the collapse of a marine ice sheet sitting on a bed that slopes down inlands. Natalya Gomez coupled a 1D dynamic ice-sheet model to a sea-level model with viscoelastically deforming Earth model and found that the sea-level fall predicted during periods of ice-sheet reduction could stabilize ice sheets, reducing the effectiveness of the Weertman instability mechanism and slowing down ice sheet retreat (Gomez et al., in press).

David Pollard discussed the complications for modeling the Antarctic ice sheet posed by sequence stratigraphy data of the ice sheet. In particular, records from the New Jersey margin (Miller et al. 2005) show large fluctuations in sea level, which are not easily captured by the model. Ayako Abe-Ouchi presented challenges in coupled ice sheet-climate modeling, especially in simulating rapid changes (Abe-Ouchi et al. 2007). For example, the model does not currently simulate the precise timing and character of the termination of the last glacial period and the glacial inception at the conclusion of the LIG.

Glenn Milne presented results of GIA modeling of RSL data from the Greenland coast (Long et al. 2010). Reconciling these data with existing GIA models of the Laurentide ice sheet collapse is an ongoing challenge.

Shawn Marshall led a discussion on observed processes that may drive rapid ice sheet responses in the present day. Discussion centered on the effect of melt ponds on the albedo of the ice sheets and in particular the multi-year accumulation of heat in the ice sheet. This effect increases the scope for the formation of melt channels to move fluid to the base of the ice sheet, where it reduces friction with the bed. Ben Horton presented a new RSL record from the east cost of the USA covering the last two millennia (Kemp et al., in press) demonstrating that modern sea-level rise is anomalous compared to the pre-industrial period. Finally, Jonathan Bamber presented preliminary results of an elicitation exercise, which asked experts on ice sheet dynamics to assess the likelihood of several scenarios regarding ice sheet and ice shelf stability in the next centuries. For example, the question was posed "how much will the WAIS contribute to sea-level rise in the twenty first century". There was broad agreement between experts, though the opinion of some experts acted as clear outliers.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Colville EJ et al. (2011) *Science* 333: 620-623
Gomez N et al. (in press) *Journal of Geophysical Research*
Kemp AC et al. (in press) *PNAS*, doi: 10.1073/pnas.1015619108
Long AJ et al. (2010) *Quaternary Science Reviews* 29(3-4): 367-383
Raymo ME et al. (2011) *Nature Geoscience* 4: 328-332

Tropical Climate Variability with a focus on Last Millennium, Mid-Holocene and Last Glacial Maximum

Paleoclimate Modelling Intercomparison Project PMIP3

PMIP3 Workshop, Villefranche-sur-Mer, France, 21-23 September 2011

Pascale Braconnot[1], S.P. Harrison[2], S. Tudhope[3] and C. Michaut[4]

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Twenty scientists assembled at Villefranche-sur-Mer, southern France to foster analyses of past climate variability from model and observations. They included scientists representing a diversity of high-resolution climate archives and climate modelers focusing on the analysis of short-term variability in paleoclimate simulations. The Observatory of Haute Provence served as the workshop venue thanks to support from the staff of that institute. The charming location, perfect Mediterranean weather, excellent food, and enthusiasm of the participants all contributed to make this a stimulating and productive workshop. WCRP, PAGES, INQUA/PALCOMM and IPSL supported this meeting.

The El-Niño/Southern Oscillation (ENSO) is the major mode of climate variability in tropical regions. ENSO monitoring, understanding, and prediction have received a lot of attention in recent decades because it strongly affects the economy of tropical regions and beyond (McPhaden et al. 2006). However, there remain major uncertainties regarding the fluctuations and future evolution of ENSO. The increasing number of records from natural archives (corals, mollusk shells, varved sediments, speleothems, tree rings, etc.) with annual or sub-annual resolution now available finally enables us to draw a consistent picture of past changes in tropical climate variability. On the modeling side, the Last Millennium, the Mid-Holocene (6 ka) and the Last Glacial Maximum (21 ka) are the three main foci of the CMIP5/PMIP3 project for multi-model ensemble paleoclimate simulations (Taylor et al. 2011). These paleo-simulations are run with the same model version that each modeling group is using for future climate projections in CMIP5. This allows us to test how the simulated variability is affected by changes in the climate background state. However, to evaluate how well these models reproduce observed changes in ENSO variability, it is first necessary to produce a pan-tropical synthesis of past changes in ENSO variability that includes all the possible types of record and a critical evaluation of these records. Furthermore, specific criteria and new methodologies need to be developed to facilitate data-data and data-model comparisons.

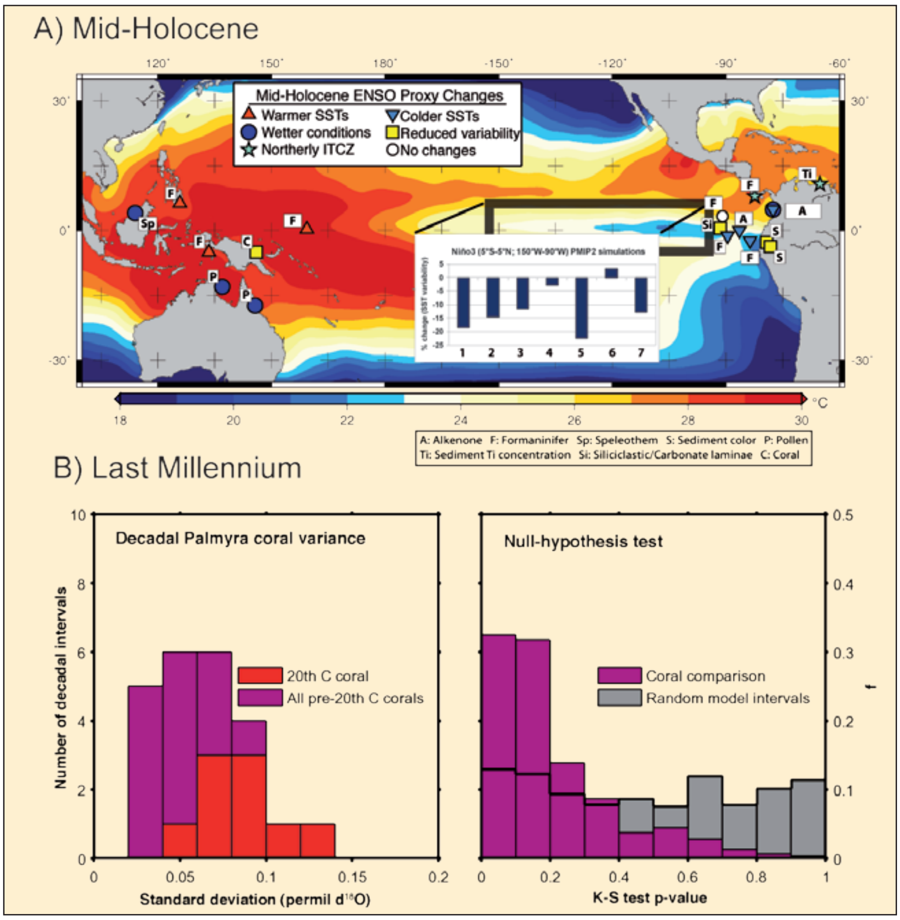

Figure 1: Analyses of ENSO and model-data comparison for the mid-Holocene and the Last Millennium. ***A****) Map showing a synthesis of the Pacific state during the mid-Holocene (from Braconnot et al. 2011), together with the change in El-Niño variability (%) as simulated by PMIP2 simulations #1-7 (inset, Zheng et al. 2008). Coral data (Tudhope et al. 2001, "C") indicate a 60% reduction in ENSO, suggesting that simulations underestimate the observed changes (Brown et al. 2008). The background shows SSTs during the La Niña event of December 1998. The results in (****B****) are from Russon et al. (unpublished data).* ***Left panel****: Distribution of decadal standard deviations of stable oxygen isotope records from modern and fossil corals (Cobb et al. 2003). Variance was relatively lower before than during the 20th century.* ***Right panel****: Kolmogorov-Smirnov test of the null hypothesis that the two probability density functions shown in the left panel are drawn from the same distribution. For the coral comparison (purple bars) p-values are generally <0.2, suggesting rejection of the null hypothesis, whereas an equivalent comparison of randomly sampled control run data of the HadCM3 climate model (gray bars) is consistent with the null hypothesis. Thus, the differences between the decadal variance properties of ENSO in the 20th Century and the pre-20th Century are likely to represent forced ENSO variability.*

In this context, the objectives of this meeting were to determine the best way to produce a "synthetic" product on short-term (interannual to decadal) climate variability in tropical regions and to design analyses of the CMIP5/PMIP3 simulations.

On the first day, participants presented the modeling tools, summarized available paleodata and discussed the difficulties inherent in the analysis and interpretation of these records including how to overcome them. Thereafter, two working groups (focusing on the Last Millennium and the mid-Holocene) discussed interpretative issues and determined the best way to include information from different archives within a common framework. The working groups also discussed the analyses of model experiments and observations to characterize variability for each time period. Several plenary sessions allowed discussion of cross-cutting methodological issues.

A plan for a multi-authored publication in a high-profile journal of the current state-of-knowledge about changes in tropical variability based on data analysis, model experiments and data-model comparisons emerged from the working group efforts. The meeting participants produced a draft outline for this paper, including key results and design of the figures.

These three intensive days of meeting are only the beginning. Work will continue in the coming months with the aim of completing the synthesis paper early next year. In addition, several participants agreed to contribute to a PAGES (or PAGES/CLIVAR Intersection) newsletter focused on past ENSO.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Braconnot P, Luan Y, Brewer S and Zheng W (2011) *Climate Dynamics*, doi: 10.1007/s00382-011-1029-x

Brown J, Tudhope AW, Collins M and McGregor HV (2008) *Paleoceanography* 23(3), doi: 10.1029/2007pa001512

Cobb KM, Charles CD, Cheng H and Edwards RL (2003) *Nature* 424: 271-276

Tudhope AW et al. (2001) *Science* 291: 1511-1517

Zheng W et al. (2008) *Climate Dynamics* 30: 745-762

North American Dendroclimatic Data: Compilation, Characterization, and Spatiotemporal Analysis

NAM2k Workshop, Tucson, USA, 26-28 October 2011

Valerie Trouet[1], D. Stahle[2] and H. Diaz[3]

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During the first meeting of the PAGES North American 2k Working Group (NAM2k) in Flagstaff, USA, in May 2011, a task group was assigned to collaborate on the assimilation of available data sources and exploration of spatiotemporal analysis tools. Considering the numerical dominance of tree-ring data within the climate proxy data pool for North America, this task group focuses in first instance on compiling and analyzing tree-ring data, with the goal of producing a high-resolution reconstruction of key climate variables for North America (including Canada, USA, and Mexico). The necessary steps towards achieving this goal were discussed by 12 paleoclimatologists from the USA and Canada in a workshop held at the University of Arizona in Tucson. The workshop was supported by the University's Institute of the Environment and by PAGES.

The participants first discussed available tree-ring data and their characteristics, including time-series length, seasonality, climate parameter calibration, and geographic representation (Fig. 1). The North American Drought Atlas (NADA, Cook et al. 2004) was generally accepted as a spatially explicit, high-resolution drought reconstruction for North America that can likely not be improved upon without extensive new data collection. The working group will therefore aim to complement the NADA with a continental-scale temperature reconstruction equivalent.

Two general approaches to the development of such a gridded temperature reconstruction were suggested: (1) compilation of all available tree-ring data, regardless of the strength of their temperature-sensitivity and extraction of the best possible temperature signal out of this extended data set or (2) a priori selection of best qualified tree-ring data and reconstruction development based on this limited data-set. The workshop participants decided to adopt the second approach and defined a set of selection criteria including a minimum time-span covered by the tree-ring series (AD 1650-1990) and strength (r>0.316), sign (positive), and seasonality (summer) of the temperature signal in the tree-ring series. Tree-ring chronologies from the International Tree-Ring Database (ITRDB) will be screened according to these criteria and complemented by chronologies from individual researchers, which have not yet been contributed to the ITRDB. The raw ring-width data contributing to the selected chronologies will be detrended using a signal-free approach before implementation in the reconstruction algorithm.

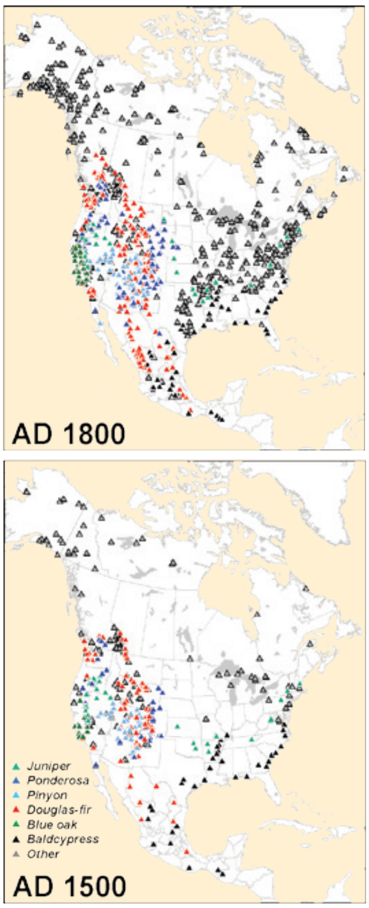

Figure 1: Species-specific tree-ring chronologies available for the North American continent that extend back to AD 1800 and AD 1500.

The task group aims to first apply a nested empirical orthogonal functions (EOF) based methodology. In a first step, only the tree-ring data covering the time-period AD 1200-1990 will be included. The next phase will include all previously selected tree-ring data. In addition to this EOF-based approach for spatial reconstruction, a Bayesian Hierarchical Model (BHM) will be used to extract climate information from the tree-ring time-series. Both methodologies will initially be run on annual time-scales, but also decadal-scale reconstructions will be developed that allow for inclusion of other, decadal-resolution proxies, including pollen data. For this purpose, the NAM2K working group will collaborate closely with the Arctic working group and a joint workshop will be organized.

Reference

Cook ER et al. (2004) *Science* 306(5698): 1015-1018

3rd Polar Marine Diatom Taxonomy and Ecology Workshop

Sydney, Australia, 4-8 July 2011

Amy Leventer[1], L. Armand[2], D. Harwood[3] and R. Jordan[4]

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Diatoms are key organisms at the base of high-latitude communities throughout the late Paleogene and Neogene. Their fossil remains serve as a fundamental basis for age determination and paleoenvironmental reconstruction, and are key indicators of marine paleotemperatures, presence/absence of sea ice, and the advance and retreat of ice sheets and shelves - all important geological data that can feed into ice-sheet and climate models.

The workshop was attended by 27 diatomists from 11 countries and was hosted by Leanne Armand at the Department of Biological Sciences, Macquarie University. International participation (especially at the graduate student and post-doctoral level) was instrumental in the transfer of sound taxonomic skills and the exchange of knowledge relative to modern and fossil diatom records of the polar regions. These skills are key to understanding the ecologic and micropaleontologic records of the poles. This meeting was timely for the hands-on transfer of results from the successful Antarctic Drilling (ANDRILL) project (Ross Sea), several recent Integrated Ocean Drilling Program (IODP) Legs (Wilkes Land, Campbell Plateau, and Bering Sea), and a suite of polar marine-based projects hosted at the national level (such as the US NSF-sponsored Larsen Ice Shelf System – Antarctica LARISSA project).

The two primary goals of the workshop were: (1) to provide the international community of polar diatom research with an opportunity to exchange data, discuss taxonomic issues toward standardization of terminology and identifications, and to explore new techniques and approaches, and (2) to allow students to receive training and advice from leaders in the field.

Mornings were devoted to taxonomic work at the microscope and based on participants' slide sets that highlighted particular genera and species. These sessions focused on identification of key extant and extinct paleoenvironmental indicators in both the Antarctic and Arctic regions, understanding the environmental implications of morphological variability within single species, and recognition of important biostratigraphic markers ranging back to the Eocene (ca. 56-34 Ma). In the afternoons, advances in the field were discussed. These included the application of biomarker and stable isotopic studies to biosiliceous sediments, the role of dissolution in altering the diatom paleo-record, and lessons learned through studies of modern phytoplankton.

In addition, two keynote speakers shared their expert knowledge with participants: Diana Krawczyk (University of Szczecin, Poland) spoke about her paleoclimatic research off West Greenland, addressing the local implications of ocean-climate forcing and the expression of late Holocene climatic events (such as the Little Ice Age and the Medieval Climate Anomaly) in the marine diatom sedimentary record. Simon Wright (Australian Antarctic Division and Antarctic Climate and Ecosystems Cooperative Research Centre) provided a larger scale framework for diatom studies through his work on the responses of Southern Ocean phytoplankton to climate change.

One of the intended objectives of this workshop was to bring together students and early career researchers with the intention that the weeklong conversations and discussions would lead to future research collaborations. The next Polar Marine Diatom workshop is planned for 2013 and will be hosted by Jenny Pike (Cardiff

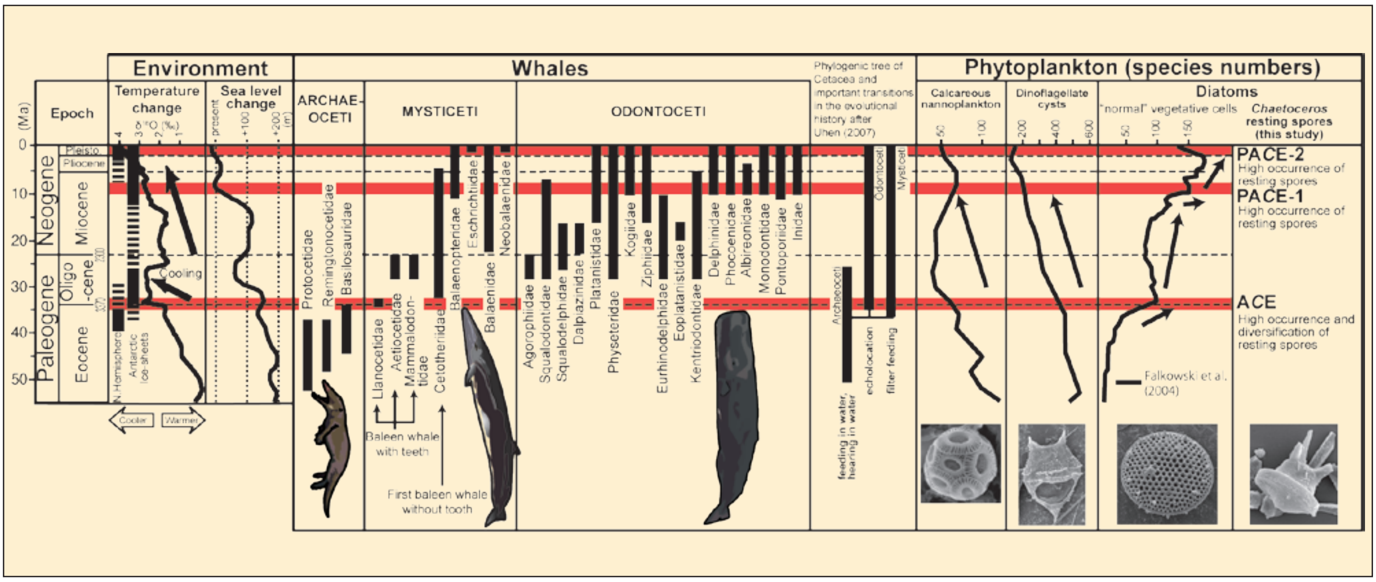

Figure 1: Comparison of marine phytoplankton species-richness curve indicated by Falkowski et al. (2004) with chronologic ranges of cetacean families worldwide by Uhen (2007), and sea-level change. Global deep-sea oxygen record and paleo-temperature change are by Zachos et al. (2001) and the presence data of sea ice and ice sheets were compiled by St. John (2008) and Stickley et al. (2009). The Atlantic Chaetoceros Explosion (ACE) event occurred across the E/O boundary in the North Atlantic, and is characterized by resting spore diversification that occurred as a consequence of upwelling activation following changes in thermohaline circulation through global cooling in early Oligocene. Pacific Chaetoceros Explosion events-1 and -2 (PACE-1 and PACE-2) are characterized by relatively higher occurrences of iron input following the Himalayan uplift and aridification at 8.5 Ma and ca. 2.5 Ma in the North Pacific regions. From Itsuki Suto, Nagoya University, Japan.

University, UK). Previous workshop accomplishments are reported by Armand (2006), Assmy (2008) and Leventer et al. (2007).

In addition to PAGES, the workshop was also supported by the ARC Research Network for Earth System Science, the Australian Marine Geoscience Office, Geoscience Australia, the Australian Biological Resources Study, Macquarie University, ATA Scientific and ANDRILL.

Selected references

Full reference list online under:

http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Falkowski PG et al. (2004) *Science* 305: 354-360

St. John K (2008) *Paleoceanography* 23, doi:10.1029/2007PA001483

Stickley et al. (2009) *Nature* 460: 376-379

Uhen MD (2007) *The Anatomical Record* 290: 514-522

Zachos J et al. (2001) *Science* 292: 686-693

Climate change in the Carpathian-Balkan region during the Late Pleistocene and Holocene

1st International Workshop, Suceava, Romania, 9-12 June 2011

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The Carpathian Mountains are considered as one of Europe's last "wilderness" areas, but are nevertheless under heavy pressure from human activities. Examples range from large-scale activities (e.g. sulfur mines in Calimani), ecological disasters (e.g. tailing dam failures in the Toroiaga and Baia Mare areas) to cross-border pollution (e.g. Chernobyl nuclear accident). The current political thrust for development is accelerating the pace of industrial activities, exploitation of natural resources and tourism.

Romania has just recently been integrated into the European Union and many community-based projects were initiated to evaluate problems related to climatic and anthropogenic impacts. However, the Carpathian Mountains remain the least studied mountain range in Europe. This paucity of research projects in the region is reflected by the low number of well-dated and high-resolution paleo-records (e.g. Buczkó et al. 2009, Fig. 1). Rose et al. (2009) published a pollution history study from a lake in the Retezat Mountains at the western extremity of the Southern Carpathians, but no similar studies exist for the rest of the mountain range, despite the abundance of lakes (Akinyemi et al., in press).

The purpose of this workshop was to bring together an international group of scientists interested in the Carpathian-Balkan region to discuss research results and promote opportunities for interdisciplinary and international collaboration. The workshop was co-sponsored by the University of Suceava, the Applied Geography Association (GEOCONCEPT), the Mountain Research Institute (MRI) and PAGES.

The program centered on oral and poster presentations as well as open discussions on the climatic and environmental dynamics during the Pleistocene and Holocene in the Carpathian and Balkan mountains. The workshop featured 36 talks and 15 posters. The 70 participants were from Romania, Hungary, Germany, United Kingdom, Bulgaria, Slovenia, Ukraine, Poland, Switzerland, Czech Republic and Belgium. The entire workshop was webcast and it was educational for young researchers and students by providing them a platform to present their results to an international audience and discuss their research in a multidisciplinary community.

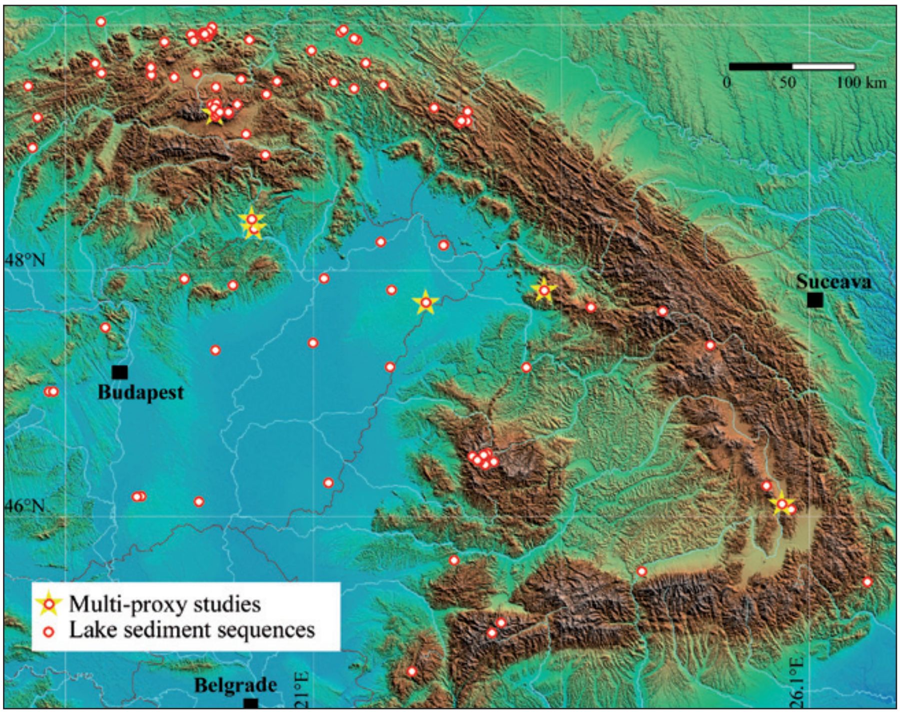

Figure 1: Map showing all sedimentary sequences identified in the Carpathian mountain range by Buczkó et al. (2009) in their review of dated Late Quaternary paleolimnological records. Despite the relative density of records listed in that study, the authors conclude that only very few records can be used for modern environment or climate studies, and that large areas of the Carpathian mountains remain under-investigated. Figure modified from Buczkó et al. (2009).

A post-symposium field trip was organized to the formerly glaciated alpine ranges of the Northern Romanian Carpathians (Rodna Mountains), as well as to several large peat-bog accumulations and wetland ecosystems (Iezer lake and Poiana Stampei peat bog).

The organizers of the workshop offered to lead publication of the more advanced workshop contributions in a special issue of the journal Quaternary International and 29 author groups committed themselves to contribute papers.

In order to promote follow-up activities in the region, the "Suceava working group" was created under the lead of Marcel Mindrescu, Angelica Feurdean, Enikő Magyari and Dan Veres. A group website is currently being set up (http://atlas.usv.ro/www/climatechange/) and grant proposals will be prepared. The group will also coordinate the organization of a second regional workshop in 2013 or 2014. Further activities, such as summer camps or meetings in the field will also be considered.

References

Akinyemi FO, Hutchinson SM, Mindrescu M and Rothwell JJ (in press) *Quaternary International*, doi: 10.1016/j.quaint.2012.01.022

Buczkó K, Magyari EK, Bitušík P and Wacnik A (2009) *Hydrobiologia* 631: 3-28

Rose NL et al. (2009) *Advances in Limnology* 62: 319-350

International conference of young scientists "Land-Ocean-Atmosphere Interactions in the Changing World"

Vistula Spit, Russia, 5-10 September 2011

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Vistula Spit, a sandy stretch of land between the Baltic Sea and the Vistula Lagoon, was a perfect place to discuss interactions between land, ocean and atmosphere. The Young Scientists Meeting was initiated under the umbrella of the International Geosphere-Biosphere Programme (IGBP) and co-sponsored by PAGES and the Scientific Committee on Oceanic Research. The conference organization was a joint effort of three institutions within the Russian Academy of Sciences: the Institute of Geography, the P.P. Shirshov Institute of Oceanology and the A.M. Obukhov Institute of Atmospheric Physics. The conference was hosted by the Institute of Oceanology at the Field Research Station "Baltic Spit".

The conference attracted 79 early career and 11 established scientists from 10 countries interested in climatic, environmental and socioeconomic aspects of global change on modern and paleo timescales. It provided a great opportunity for extensive discussion and international networking between young scientists and high-level experts.

Land-Ocean-Atmosphere interactions in the context of global changes were discussed in four sessions on (1) monitoring changes and (2) understanding the mechanisms of interaction, (3) social problems in the changing world, and (4) reconstruction and forecast of climate and environmental changes. The sessions started with invited lectures from senior scientists and were followed by oral and poster presentations of young scientists. Additionally to the scientific lectures, the directors of two international projects T. Kiefer (PAGES) and A. Reissel (iLEAPS) presented overviews of their projects' activities and the opportunities for young scientists.

In the paleoscience session, A. Pospieszyńska presented optical density analyses of wood from living trees and historical buildings, and characterized pre-instrumental climate in Poland. O. Maksimova reported on tree-ring research from the upper tree line in Tien Shan Mountains. Maximum density correlates with summer temperatures and allowed reconstructing June-August temperatures for 1650-1995 AD. V. Matskovsky presented two new absolutely dated tree-ring width chronologies from the Vologda region (1195-2009 AD, Fig. 1) and the Solovki islands (1187-2008 AD). Both chronologies correlate significantly with European Russian high-resolution temperature reconstructions from pollen and historical data, and with Northern Hemisphere summer temperatures.

I. Bushueva presented high-resolution reconstructions of mountain glacier variations in the Caucasus over the last 400 years. I. Sokolov discussed changes of glaciers on the Franz Josef Land archipelago. U. Pączek aimed to identify short-term climatic oscillations in sediments from the Gulf of Gdańsk (southern Baltic Sea). The data reveal great variability in sediment composition that indicates sensitivity to regional climatic and local hydrodynamic conditions. A. Dolgikh described his work on soil horizons in the habitation deposits of ancient cities of European Russia. E. Kotlovanova and colleagues inverted 87 borehole temperature profiles (67 from Urals, 20 from Eastern Europe) into ground surface temperature histories. Temperature minima between 1700 and 1900 AD were followed by climate warming.

R. Przybylak and P. Wyszyński compared the meteorological conditions in the Arctic during the 1st International Polar Year (1882/83) with data from the period 1961-1990 AD. Meteorological conditions during the early instrumental period were not significantly different from the later 20th century.

Further presentations were given on geological evidence from Sicily about the Messinian salinity crisis (A. Rybkina), coastal dynamics of Cheleken peninsula (R. Kurbanov), alongshore currents at the eastern Pacific margin (M. Kladovschikova) and fluctuations of Baltic Sea level (E. Kochetkova).

The plenum of young scientists awarded the most enthusiastic young scientist Igor Kozlov (Russia) with a "dream house" candlestick. His presentations were dedicated to using Synthetic Aperture Radar satellite data for oceanographic studies. Aleksandra Pospieszyńska (Poland, see above) received the same gift as an award for her excellent presentation from the established scientists.

Reference

Mann ME and Jones PD (2003) *Geophysical Research Letters* 30(15), doi: 10.1029/2003GL017814

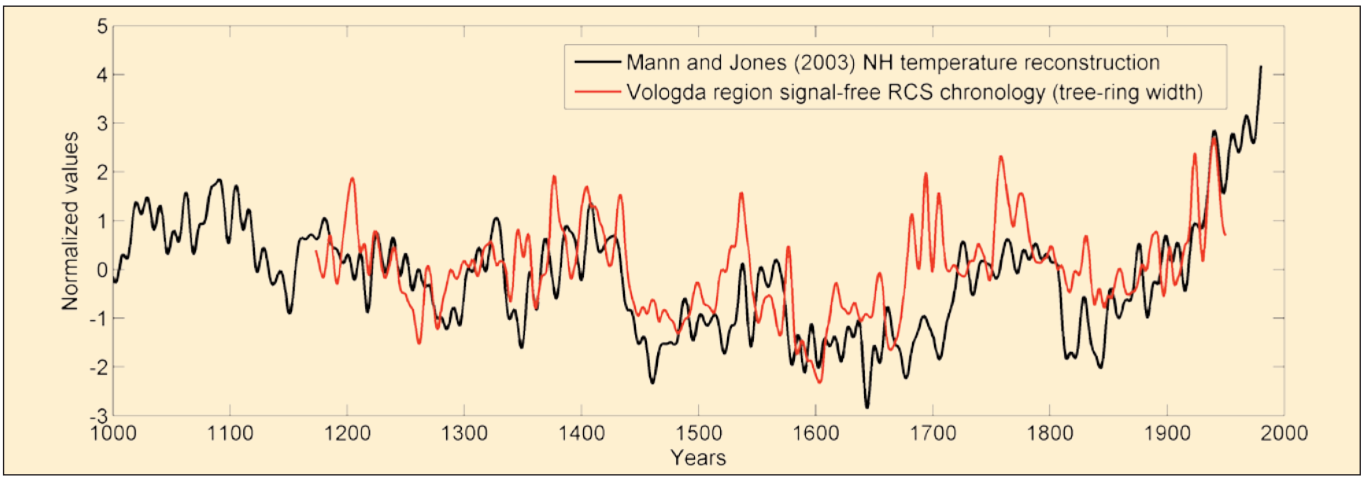

Figure 1: Comparison of Vologda region (60°N, 38°W) signal-free Regional Curve Standardization (RCS) tree-ring width chronology (red) with the Mann and Jones (2003) northern Hemisphere (NH) temperature reconstruction (black) (Correlation R=0.59). The Little Ice Age is well pronounced during 1450-1660 AD.

Contents

Announcements

Special Section: Paired Perspectives on Global Change

Open Section:

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