EUROPEAN SCIENCE FOUNDATION

FWF Der Wissenschaftsfonds.

universität innsbruck universitätszentrum obergurgl forschung • tagung • sport

**RESEARCH CONFERENCES**

ESF-FWF Conference in Partnership with LFUI

# Ocean Controls in Abrupt Climate Change

Universitätszentrum Obergurgl
(Ötz Valley, near Innsbruck) • Austria
19-24 May 2007


Chair: **Rainer Zahn**, Universitat Autònoma de Barcelona / ICTA / ICREA, ES
Vice-Chair: **Ian R. Hall**, Cardiff University, School of Earth, Ocean & Planetary Sciences, UK


**www.esf.org/conferences/07221**


With support from

The International Marine Past Global Change Study

Natural Environmental Research Council


# SCIENTIFIC REPORT

## ▪ Introduction (up to 2 pages)

Introduction on the topic in non-specialist terms (especially for highly technical subjects)

One of the most visible issues in climate research today relates to the future stability of the climatic regime. In particular, whether influences originating from human activities, potentially in combination with natural variations, are sufficient to result in a significant change of climate. The continuing buildup of industrial greenhouse gases in the atmosphere and concomitant increase in global temperatures has raised awareness that potentially decade to centuries of environmental change lie ahead and that these will have profound economic, political and societal impacts. Fundamental to this debate is the effect that future global warming will have on the ocean circulation because a reorganization of the globally connected system of ocean currents is the only known viable mechanism to induce substantial global-scale and notably, abrupt climate changes. Such changes necessarily involve the ocean circulation as it is the oceans that distribute vast quantities of heat around our planet, and thus influence atmospheric heat budgets and climatic patterns on a regional to hemisphere-wide scale.

Information on the climate's stability and variability during the past is contained in marine sediments and the polar ice caps. Data profiles from marine sediment cores and polar ice cores show that abrupt climate changes are not a new phenomenon but have occurred several times in the past. During such events the Atlantic Ocean circulation has undergone considerable slow-down, and even possibly complete collapse under the most extreme forcing. Resumption of a vigorous circulation at the end of such states likewise proceeded abruptly, sometimes within less than a decade. Modeling and climate reconstruction studies suggest that the consequences of such events would be global in extent. These effects of the past abrupt changes included a reduction in ocean currents carrying heat to the highlatitude North Atlantic thus causing substantial cooling in the region with sub-polar climates spreading throughout central Europe within a few decades. Concomitant with the changes in ocean circulation, major disruptions and widespread drought occurred in various regions of the northern hemisphere, while wetter conditions were observed in South America and Africa caused by a shift in atmospheric circulations pattern involving latitudinal displacement of the Intertropical Convergence Zone and greatly weakened monsoonal conditions. These findings highlight the wider impacts of ocean circulation changes on global climate. A shift of Atlantic Ocean circulation also forms an integral part of the *Intergovernmental Panel on Climate Change* predictions of future climate change in response to increasing atmospheric $CO_2$.

Enhancing the robustness of these predictions depends crucially on combining observations of past climate variability with computer models that simulate climate change. The ESF Research Conference focused directly on these issues by bringing together the international marine, terrestrial and atmospheric climatology and climate modeling communities. The aim of the conference was to present an integrated view on the significance of ocean-atmosphere-climate interactions in defining the state of global climate with a notable focus on the role of the ocean in stabilizing or destabilizing climate. This complex issue was approached from the perspectives of ocean field observations that document trends and shifts in ocean circulation under the current global warming; investigations into periods of accelerated ocean, atmosphere and climate changes during the past that are documented in data profiles from marine sediment cores and polar ice cores; and numerical climate modeling, some coupled with marine and terrestrial ecosystem models, that simulate a range of states of climate thereby providing plausible scenarios for climate variations and variability during the past. The multidisciplinary views presented at the conference produced a picture of the climate system as a fully dynamic entity that is highly sensitive to changes to any of its ocean, terrestrial and atmospheric sub-compartments. The marine and ice core database of past climate changes provided many examples illustrating that climate has changed repeatedly in the past on very fast time scales thereby alluding to the non-linear character of the forcing-response chain between the different climatic compartments. The retention of heat and salt in defined ocean regions in the past in particular received attention by the conference participants as it has acted as a threshold in global climate that when superseded destabilized the ocean circulation and stimulated accelerated climate changes. A series of plenary and round-table discussions concentrated on the implications to be drawn from these past changes about the future stability and behaviour of the ocean circulation under a continued human influence.

I hereby authorize ESF - and/or the Fonds zur Förderung der wissenschaftlichen Forschung in Österreich (FWF) and the Leopold-Franzens-Universität Innsbruck (LFUI) - to publish the above Introduction on a special page dedicated to ‘Conference Highlights’ within the Research Conferences website.

Date & Signature:

10 July 2007

## ▪ Scientific Content

### ▪ Summary of the conference sessions focusing on the scientific highlights

Conference sessions produced a series of highlights that can be clustered into four thematic themes.

**1) Ocean thermohaline circulation – modern observations**

Presentations on current trends in ocean circulation were focused on the water circulation in the Atlantic as this is considered an ocean region particularly sensitive to the influences of global warming. Over the past decade a multitude of studies have been conducted to probe the deep convection in the northern North Atlantic and Nordic Seas both possibly playing a pivotal role in drawing warm waters from the tropical-subtropical Atlantic to the North, in the Gulf Stream or so-called North Atlantic Drift. Current projections of future convection under continued global warming predict a slowdown of the North Atlantic overturning circulation in the coming century thus affecting poleward marine heat transports and ultimately, climate in Europe and beyond. The new data presented at the conference are of a unprecedented fine temporal resolution and included direct observational measurement of the overturning circulation strength that, for the first time, document the high degree of variability of the Atlantic deep water circulation. While the measurements confirm a net southward transportation at depth they reveal temporal variability of the water transports at nearly atmospheric timescales. Variability at such high frequency has remained undetected in previous studies because of aliasing of lower frequency variations due to lower sampling rates. With the full scale of variability visible in the new time series the trends towards slower rates of transportation that have been predicted by ocean circulation models and have been thought to exist in earlier observational time series are not thought robust. At such high temporal resolution it has become somewhat a philosophical task to distinguish any recent trend from what may appear to be natural oscillations. The point was made that such observations and considerations do not directly fit with the need and demand by front-line science journals and the public media for “break-through” scientific achievements that at times contain a flavour of sensationalism.

### 2) Marine palaeo-data, past ocean circulation

The palaeoceanography and palaeoclimate theme of the conference aimed at providing a global perspective of past ocean circulation changes by thematically integrating regional aspects into a global picture of a changing ocean. Several aspects were presented that focused on long-distance (far-field) connection pathways in the ocean along which climate signals propagate. Evidence was presented for the existence of subsurface channelling or “tunnelling” between the Southern Ocean and the low-latitude open ocean. The close structural similarity between palaeoclimatic signals documented in Antarctic ice cores and data profiles from sediment cores in the subtropical Pacific was presented as a clear indication of a direct linking between climate variability at high southern latitudes and ocean thermocline (upper 100 m water depths) changes at low latitudes. Such connection may constitute a possible pathway for signal transfer across long distances, up to interhemispheric, in circumvention of the atmosphere. A multitude of proxy data profiles were presented that all combine into a picture of ocean variability not dissimilar from atmospheric variability at high latitudes. Long-distance communication between the ocean basins has been demonstrated to the point of mapping water mass end-member chemical compositions and the influence of marine biochemical cycles in changing them through time. While the past years have seen a large community effort to demonstrating the sequence of processes and events that lead to a perturbed slowed ocean circulation, several conference presentations have targeted episodes in the past that encompass slowed states of ocean circulation coming to an end and the overturning circulation accelerating back towards a vigorous mode. These studies, in conjunction with numerical modelling studies (see below) have demonstrated that anomalous perturbation at high southern latitudes are likely to be as influential in changing ocean circulation globally as perturbations originating in the North Atlantic. This finding suggests that thermohaline water overturning in the south directly impacts deep convection in the north by way of altering the subsurface architecture of water mass layering and associated latitudinal transports of salt across entire ocean basins. From this and related presentations it has become clear that the retention of salt in the low-latitude surface ocean and its subsequent release to the high latitudes potentially constitutes a missing link in our understanding of the initiation of a strong and vigorous ocean overturning circulation at the end of a slowed circulation state. Such mechanism also bears the potential to stabilize the ocean circulation at low levels of perturbation. The palaeo-evidence likewise made it clear that while such scenarios hold implications for the future ocean and climatic developments they do not bear good resemblance with the current and prospective future boundary conditions under which the ocean will operate. Scenarios of past ocean and climate variations provide test cases against which to assess physically plausible scenarios of ocean and climate variability while they are not true analogues for future ocean circulation and climates.

### 3) Ice core palaeo-data, past atmospheric circulation and climate forcings

Ice core palaeoclimatology has been instrumental in refining our insight into atmospheric chemical variations and their role in climate changes. A series of ice core presentations have shown that age modelling is an issue, notably when comparing ice core profiles with marine palaeoclimatic profiles. While ice flow modelling provides some guidance the potential error bars are considerable. Annual layer counting probably still provides the most robust framework for developing age models for ice cores and is considered accurate to within 5-10% of the absolute age. But layer counting is particularly difficult in Antarctica where ice accumulation is very low and therefore ice layer thinning with depth tends to make it difficult to unambiguously identify varves. New data were presented from the Antarctic Dome C ice core that verify the temporal pattern observed previously between atmospheric $CO_2$ changes and climate. Detailed inspection of both entities confirms that during the last deglaciation the onset of $CO_2$ increase was delayed until some 720 ± 320 years after the onset of deglacial warming in Antarctica. This supports earlier notions that while $CO_2$ increase was involved in the demise of the last glacial it did not act as a primary forcing in initiating the warming. Observations of isotopic and chemical composition patterns in precipitation (snowfall) and ice cores at coastal sites in western Antarctica were presented that demonstrate that signals from extra-polar climatic regimes such as the el Nino Southern Oscillation invade Antarctica via an interaction with local atmospheric systems i.e., Southern Annular Mode and Antarctic Circumpolar Wave. This pattern makes a strong case that coastal sites receive extra-Antarctic signals while regions deeper in Antarctica remain disconnected from lower-latitude climate influences. Data from such coastal settings will play an increasingly prominent role to assess the significance of oceanic vs. atmospheric forcing at polar latitudes and will guide the positioning of future ice core drilling sites that will enable such research.

Solar input as a potential climate forcing mechanism was tested using cosmogenic isotope abundance variations along Greenland ice cores. While the data were suggestive that some solar variability existed during the last glacial period the amplitude of the estimated radiation changes were not sufficiently high to exert control on the climate changes indicated in the ice core palaeoclimatic data. It was noted, however, that this does not constitute a final rejection of the solar forcing hypothesis but rather that other locations may be better suited to test this hypothesis.

**4) Numerical climate modeling: probing the past to predict the future**

The past 10 years have seen impressive advances in numerical climate modeling to the extent that today a hierarchy of models is available to the climate and paleoclimate community to address our need to quantitatively examine climate mechanisms across a range of space and time scales as well as providing a climate prediction capability. These range from Earth System Models of Intermediate Complexity to General Circulation Models (GCM) that separately model ocean and atmosphere circulation, and on to fully-coupled 3D global Atmosphere-Ocean General Circulation Models (AOGCM). During the conference results of model simulations have been presented that demonstrate the models' capacity to detect in fine detail evolving temporal and spatial patterns of climatic variables such as temperature and precipitation in different regions. For instance when simulating abrupt climate events temperature changes in the wider North Atlantic region seem centered about the winter season while for Eurasia largest temperature changes are predicted for the spring season. Abrupt changes of climate under glacial conditions appear to cause an asymmetric response of sea ice extent in different sectors of the North Atlantic. When used as analogues for past abrupt climatic events such spatial patterns bear implications for the correlation between and synchronization of palaeoclimatic records on regional to global scales. The models also demonstrate the interlinking between freshwater injection, altered ocean circulation and subsequent changes in atmospheric circulation leading locally to anomalously stronger vertical mixing of the surface ocean. This facilitates the transfer of ocean heat to the surface thereby potentially counterbalancing the climatic cooling effects caused by a slowed thermohaline overturn. Coupling AOGCMs with marine and terrestrial ecosystem models enables assessing the impacts of the simulated climate changes on marine biological production and continental vegetation. Transports of nutrient rich surface waters are predicted to change in the course of abrupt climate events from polar regions to lower latitudes where photosynthesis is less light-limited. This stimulates changes in primary production and importantly, the export of carbon from the surface to the deep ocean on a hemisphere-wide basis. On the continents the extent of forests changes with consequences for the amount of carbon stored in soils. These simulations suggest that about half of the total atmospheric $CO_2$ changes that are associated with past abrupt climate events were potentially derived from changes in the terrestrial carbon reservoir. This compellingly reveals that while the oceans constitute the largest carbon reservoir by far the role of the terrestrial carbon reservoir in modulating abrupt climate changes is not to be underestimated. These and similar model results demonstrate that substantial progress has been made with model performance and resolution, and that the models' capacity to capture many of the details of past climate changes that are documented in palaeoclimatic records has significantly improved.

## ▪ Assessment of the results and their potential impact on future research or applications

see below

## ▪ Forward Look Plenary Discussion

### ▪ State-of-the-art in the field

A primary issue discussed related to the question of lessons to be learned from studies into the past ocean and climate variability and the underlying dynamics that drives this variability. Specifically it was discussed if palaeoclimatic research can contribute to formulating, improving and refining climate projections into the future. Spontaneous consensus existed that the primary benefit of palaeoclimate research relates to probing the sensitivity of climate under natural forcing conditions and an array of climatic boundary conditions. Palaeoclimate research has provided timeseries of climate-related variables that reach back in time far beyond any instrumental record and therefore provides the only means for climatic observations on long timescales. It also was reiterated that the current knowledge of the full scale of natural climate variability, including amplitude and speeds of change, is derived directly from long palaeo-time-series and would have gone unnoticed without such data profiles. The principal potential of palaeoclimate research lies with the discovery and identification of the processes, feedback mechanisms, response times etc., that drive climate between different states. Such insight ultimately aids our understanding of the roles that different compartments of the climate system play in conditioning climate for change. Pitfalls are that the data (“proxies”) generated and used in palaeoclimatic research are far from perfect in that they are not uniquely linked with one single climate-relevant parameter but typically are influenced by a range of parameters, including post-depositional alteration by variations in the environment or matrix in which they are stored. It was likewise noted that there are a range of parameters that are beyond the reach of palaeoclimatic research such as cloud formation that is highly relevant in climatic developments but for which direct proxies do not exist.

### ▪ Emerging topics

Development of a robust framework for age modeling and time scale construction was highlighted as but one task that will substantially benefit the research into palaeoclimatic variability on an interhemispheric to global scale. Synchronization of time scales is an ultimate prerequisite in the core-to-core comparison of palaeoclimatic time series from marine sediment and polar ice cores and specifically, in synthesizing these data into synoptic maps of ocean and climate variables. This will involve the combined use of radiogenic isotope decay series, fine-scale and globally synchronous stratigraphy from geomagnetic palaeo-intensity variations, and mapping of proxy marker events. The wider use of existing, and the development of new proxies that are linked to ocean dynamical processes and parameters such as rate of overturn, flow speed and seawater density are needed as well as an improved proxy validation/calibration and insight into uncertainties associated with routinely applied traditional proxies. This will entail fine-scale (seasonal) calibrations using mooring, sediment trap and seafloor surface sediment data from a range of ocean climatic regimes. The need for an improved spatial coverage of the global network of sediment cores was recognized with a particular emphasis on the Southern and Arctic Oceans and the Pacific. Ultimately, the data must be synthesized into a dynamic database that facilitates interoperable access by the palaeo-data and the climate modeling communities.

### ▪ Visions for the future of the research field – identification of issues in the 5-10 years & timeframe

There was a clear consensus in the discussion that for making progress in climate and palaeoclimatic research alike there is no alternative other than the palaeo-data and climate modeling communities joining forces. A main task in future palaeoclimate research therefore lies with the integration of palaeo-data into climate models. The recent years have seen a surge of fine-scale quantitative palaeodata generation involving both ultra-high temporal resolution of the data profiles and establishing extensive multi-proxy databases along individual sediment cores. This has greatly benefited the advancement of palaeoceanographic reconstruction but as yet has not yielded a great improvement of our understanding of the ocean and climate dynamics that ultimately shaped the data profiles. At the same time the quality and capacity of climate models has greatly improved to the point that today a hierarchy of models exists ranging from low-resolution simulations of full climatic cycles to fully coupled atmosphere-ocean models. Yet, the models remain largely under-constrained because of the lack of precise information from palaeo-databases that enable stringent model testing. To overcome the boundaries between the hands-on analytical palaeo-data community and the climate modeling community they both must learn to speak a common language and to acknowledge that palaeo-proxies and climate models are far from perfect. One task will be for the palaeo-data community to clearly communicate the degree of robustness of the proxy data and levels of uncertainty involved with their conversion into quantitative estimates of past ocean and climate variables. The other task will rest with the modeling community to communicate their specific needs with respect to data input for the testing and further constraining their models.

## ▪ Is there a need for a foresight-type initiative?

## ▪ The reaction of the participants to the location and the organization, including networking, and any other relevant comments

The conference venue was received extremely well by all participants. It was felt a great benefit of the Obergurgl conference centre that the party of participants stayed together throughout the day, including socializing in the evening which allowed to carry on with the discussions and personal communication of the day. The implementation of up to one hour long plenary discussions at the end of the morning and afternoon sessions involving all speakers was likewise received very positively as it gave all participants and speakers ample time to raise and elaborate on questions more comprehensively than is possible during the five minute discussion time typically allocated at the end of individual talks. Two moderated evening discussions were held in a social and relaxed atmosphere and resulted in exchanges of views and perspectives well beyond what is normally achieved in more formal discussion rounds. Several participants specifically commented that for future meetings they will adopt similar schemes for the discussions as they provide a common ground for all to participate. The overall impression communicated to the conference chairs by many participants was “best conference for quite some time”.

Date & Signature:

10 July 2007