Abstracts PMIP ocean workshop 2013 Corvallis

Southern Ocean as a key for understanding modelling uncertainties in simulating the Glacial AMOC

Ayako Abe-Ouchi, University of Tokyo

The reproduction of the change of AMOC by coupled AOGCMs is crucial for the future climate projection. Information from the paleo-proxy data shows a distinct change of the glacial ocean, i.e. a shoaling of the AMOC originated from the North Atlantic and different distribution of delta 13C from present day. It is shown by several studies that the Glacial AMOC is not well reproduced by several AOGCMs. Here we show that the improvement of simulating the sea surface temperature (SST) and seaice in the Southern ocean are required for reproducing the glacial AMOC by both multi-model analysis of PMIP/CMIP3 and 5 and a series of sensitivity experiment using MIROC AOGCM. If the warm bias in the modern Southern ocean is reduced, the sea ice at LGM around Antarctica is forming enough to reject brine. This leads to a sufficient strengthening of the AABW and results in weaker and shoaler AMOC at LGM, which simulates realistic pattern of delta 13C distribution. A series of additional experiments shows that the LGM Northern Hemisphere ice sheets are responsible for strengthening the AMOC, while low CO2 weakens the AMOC. This implies that the result of glacial AMOC depends critically on the subtle balance between the strengthening of the AABW formation caused by the CO2-induced cooling and the strengthening of AMOC by the growth of the northern hemisphere ice sheets.

Title: Mid-Holocene Tropical Pacific Climate State, Annual Cycle, and ENSO in PMIP2 and PMIP3

By Soon-Il An and Jung Choi
Yonsei University

Using the Paleoclimate Modeling Inter-comparison Project Phase 2 and 3 (PMIP2 and PMIP3), we investigated the tropical Pacific climate state, annual cycle, and El Niño-Southern Oscillation (ENSO) during the mid-Holocene period (6,000 years before present; 6ka run). When the 6ka run was compared to the control run (0ka run), the reduced sea surface temperature (SST) and the reduced precipitation due to the basin-wide cooling, and the intensified cross-equatorial surface winds due to the hemispheric discrepancy of the surface cooling over the tropical Pacific were commonly observed in both the PMIP2 and PMIP3, but the changes were more dominant in the PMIP3. The annual cycle of SST was weaker over the equatorial eastern Pacific, because of the orbital forcing change and the deepening mixed layer, while it was stronger over the equatorial western pacific in both the PMIP2 and PMIP3. The stronger annual cycle of the equatorial western Pacific SST was accompanied by the intensified annual cycle of the zonal surface wind, which dominated in the PMIP3 in particular. The ENSO activity in the 6ka run was significantly suppressed in the PMIP2, but marginally reduced in the PMIP3. In general, the weakened air-sea coupling associated with basin-wide cooling, reduced precipitation, and a hemispheric contrast in the climate state led to the suppression of ENSO activity, and the weakening of the annual cycle over the tropical eastern Pacific might lead to the intensification of ENSO through the frequency entrainment. Therefore, the two opposite effects are slightly compensated for by each other, which results in a small reduction in the ENSO activity during the 6ka in the PMIP3. On the whole, in PMIP2/PMIP3, the variability of canonical (or conventional) El Niño tends to be reduced during 6ka, while that of CP/Modoki El Niño tends to be intensified.

H. Bauch, Geomar, Kiel

Relationship between surface $\delta^{13}C$ in fossil calcite and past surface ocean properties

Traditionally, variations of stable carbon isotopes ($\delta^{13}C$) as found in fossil records of foraminifers are often used to infer past oceanic changes such as spatial water mass distribution and ventilation. While this inference seems quite well proven for deep-sea species with an epibenthic habitat and in relation with bottom water changes, the δ^{13} C signature in planktic foraminifers is less straight forward to understand due to strong biological effects inherent to the upper few hundreds meters of the ocean. Besides, species-dependent vital effects, the result is a complex of rapidly changing nutrients caused by a variable bioproductivity, the remineralization processes of organic matter, as well as the degree of surface stratification and exchange of the near-surface ocean with atmospheric CO2.

Many subpolar/polar North Atlantic $\delta^{13}C$ records measured on N. pachyderma (s) show a very strong similarity in their trends on glacial-interglacial timescales. Moreover, records from closer to the Arctic indicate the existence of a Mid-Pleistocene shift in $\delta^{13}C$ of this species which parallels with the onset of more intensified glacial-interglacial climate contrasts. Surface sediments from the Arctic ocean, which represent the past 2 ka or so, have extremely high $\delta^{13}C$ in N. pachyderma (s), indicating a thermodynamic relation between the carbon signature in this species and the ambient temperature of the water. In the Nordic Seas, and all along the main pathway of Atlantic surface water flow into the Arctic, such a thermodynamical relationship is further corroborated in detail by down core records covering the Holocene time interval.

Water Isotope Database: present and past archives

Timothé Bolliet[1], Valérie Masson-Delmotte[1], Franck Bassinot[2], Françoise Vimeux[1], Camille Risi[3], Jean Claude Dutay[1], Valérie Daux[1], Dominique Genty[1], Bruno Turcq[4], Bruno Malaize[5], Claire Waelbroeck[2], Laurence Gourcy[6], Catherine Pierre[7], Patrick Brockmann[1], Didier Roche[1], Laurent Bergonzini[8], Elisabeth Michel[2], Hans Christian Steen-Larsen[1], Pablo Ortega[1], Marlène Lavrieux[1], Amaelle Landais[1], Ulrich von Grafenstein[1], Jean Jouzel[1].

[1] Laboratoire des Sciences du Climat et de l'Environnement, IPSL/CEA-CNRS-UVSQ, UMR 8212, CEA Saclay, L'Orme des Merisiers, 91191 Gif-sur-Yvette Cedex, France.
[2] Laboratoire des Sciences du Climat et de l'Environnement/IPSL, CEA/CNRS/UVSQ, Avenue de la Terrasse, Bat. 12, 91198 Gif-sur-Yvette Cedex, France.
[3] Laboratoire de Météorologie Dynamique, PMC-CNRS-ENS/IPSL, Paris, France.
[4] LOCEAN-IPSL, IRD/Institut de Recherche pour le Développement, 32 av Henri Varagnat, Bondy, France.
[5] UMR CNRS 5805 EPOC, Université Bordeaux I, 33405 Talence, France.
[6] BRGM. 3 av. C. Guillemin, BP 36009, 45060, Orléans cedex 2, France.
[7] Laboratoire d'Océanographie et du Climat — Expérimentation et Approches Numériques (LOCEAN), CNRS UMR 7159, IPSL, Université Pierre et Marie Curie, CC 100, 4 place Jussieu, 75252 Paris cedex 05, France.
[8] IDES, Université Paris-Sud, UMR-CNRS 8148, Bât 504, F-91405 Orsay cedex, France

Paleoclimate data provide a good benchmark against which the realism of the processes simulated by climate models can be assessed. Within this framework, it is essential to minimize the introduction of uncertainties associated with transfer functions and therefore to operate with robust proxies. The implementation of stable isotopes of water or carbon inside climate models motivates a synthesis of the available data for their validation. Supported by the LABEX L-IPSL and involving a team of climate modelers and paleoclimatologists, this project aims at establishing a worldwide database of $d^{18}O$, dD, $d^{17}O$ and $d^{13}C$ from different proxy sources (e.g. oceanic microfossils, corals, ice cores, cave speleothems, lake sediments, tree rings, and higher plant leaf waxes). The ultimate goal is to provide a global vision of the hydrological cycle during the LGM and other selected key periods (last 200 years, Mid-Holocene, Dansgaard-Oeschger events, and the Eemian). It requires searching through hundreds of published oceanic and continental records, validating the selection of the data based on resolution and chronological information. As an example, we have extracted ~1200 $d^{18}O$ datasets out of ~650 marine sediment cores and corals, including ~700 $d^{18}O$ LGM records from 350 different sites. An additional aspect of this project consists in the construction of an online portal providing an intuitive and interactive platform allowing for the selection, visualization, and downloading of the records included in this database, thus improving the distribution and comparison of paleoclimatic records from various sites.

Greenland temperature response to climate forcing during the last deglaciation

Christo Buizert, Vasileios Gkinis, Jeffrey P. Severinghaus, Feng He,
Benoit S. Lecavalier, Philippe Kindler, Markus Leuenberger, Anders Carlson, Bo Vinther,
Valérie Masson-Delmotte, James W. C. White, Zhengyu Liu, Bette Otto-Bliesner and Edward J. Brook

Much of the regional and global climate variability during the last glacial termination (19-11 ka BP) can be explained as the superposition of two distinct modes (*1, 2*); a spatially uniform increase in global temperature correlated with greenhouse gas forcing, and a redistribution of heat associated with variability in the Atlantic meridional overturning circulation (AMOC) strength. The latter mode is expressed most clearly in the abrupt climate shifts recorded in the precipitation isotopic composition ($\delta^{18}O$) of Greenland ice cores, which are now widely used as a template for northern hemisphere abrupt change. Greenland $\delta^{18}O$ is influenced by many factors, including source temperature, moisture transport and origin and precipitation seasonality, complicating reconstruction of past temperatures. Here we use four non-$\delta^{18}O$ temperature reconstructions from three ice cores and a general circulation model (GCM) to elucidate the (often abrupt) Greenland surface temperature response to external (insolation) and internal (CO_2, AMOC, ice topography) climate forcings during the last termination.

Our reconstructions are based on $\delta^{15}N$ (NEEM, GISP2) and water isotope diffusion (NGRIP), both of which depend on physical processes in the firn column. The GCM and our reconstructions show excellent agreement on several key features. First, we find that the Younger Dryas (YD) period was 4-6°C warmer than the Oldest Dryas (OD) period in response to increased summer insolation and CO_2 forcing. By contrast, $\delta^{18}O$-based reconstrucions from Greenland summit suggest the YD to be the colder of the two periods. Our finding is consistent with non-ice core NH proxy reconstructions, as well as with East Greenland deglacial moraine sequences that suggest only a modest glacial re-advance during the YD. Second, the YD-OD temperature difference shows a northward enhancement, with warming being greatest at the northernmost NEEM site. By isolating different forcings in the GCM, we attribute this signal to retreat of the Laurentide ice sheet during this interval. Third, the abrupt Bølling and Holocene onset warmings and the YD cooling are largest in southeast Greenland, and decrease in magnitude upon going northwest. This spatial pattern is attributed to increased oceanic heat advection to the north-Atlantic upon AMOC resumption, and the associated sea ice retreat.

Last, we use the GCM to investigate the role of temperature seasonality, which supports existing hypotheses that abrupt climate change in Greenland is mostly a winter phenomenon, and that AMOC collapse leads to increased seasonality. Seasonality can be invoked to reconcile $\delta^{18}O$ records with NH ice sheet extent, and may explain the absence of a $\delta^{18}O$ response to increasing insolation and CO_2 forcing during the early deglaciation.

1. P. U. Clark *et al.*, Global climate evolution during the last deglaciation. *Proc. Natl. Acad. Sci. U. S. A.* **109**, E1134 (May, 2012).
2. J. D. Shakun *et al.*, Global warming preceded by increasing carbon dioxide concentrations during the last deglaciation. *Nature* **484**, 49 (2012).

Radiocarbon and Overturning Circulation in the Glacial Southern Ocean

Andrea Burke
Andrew L. Stewart
Jess F. Adkins
Andrew F. Thompson
Raffaele Ferrari
Laura F. Robinson

Southern Ocean dynamics are thought to be important in driving glacial-interglacial atmospheric CO_2 change. Since the Southern Ocean is a region where the deep ocean is ventilated, changes in the upwelling and the overturning circulation in this region could substantially alter atmospheric CO_2. However, the mechanisms by which this can occur and how these oceanographic changes would be recorded in the paleo-record are not fully understood. Radiocarbon can be used as a tracer for understanding past circulation and carbon cycle changes because it is produced in the atmosphere, enters the ocean through air-sea gas exchange at the surface, and then decays away as it is isolated from the atmosphere. We present new and published radiocarbon data from the Southern Ocean over the last glacial and deglacial periods to investigate changes in circulation over these time periods. We have generated thirty new radiocarbon measurements of U-Th dated deep-sea corals from the Drake Passage and combine them with forty previously published deep-sea coral radiocarbon measurements from this region (1). These corals were dredged from water depths ranging between 328 and 1710 m, and grew between 9.9 and 27.2 thousand years ago. We compare this Drake Passage radiocarbon data with two deep South Atlantic radiocarbon records (2,3). These data show enhanced deep ocean stratification that is eroded away during the first half of the deglaciation. We use an idealized two-dimensional residual mean circulation model to further explore the mechanisms that could be used to explain the radiocarbon structure that is observed in the glacial Southern Ocean, and we consider the resulting implications for Southern Ocean overturning.

(1) Burke, A. and Robinson, L. F. (2012) *Science* 335 (6068): 557-561.

(2) Barker, S. et al. (2010) *Nature Geoscience* 3 (8): 567-571.

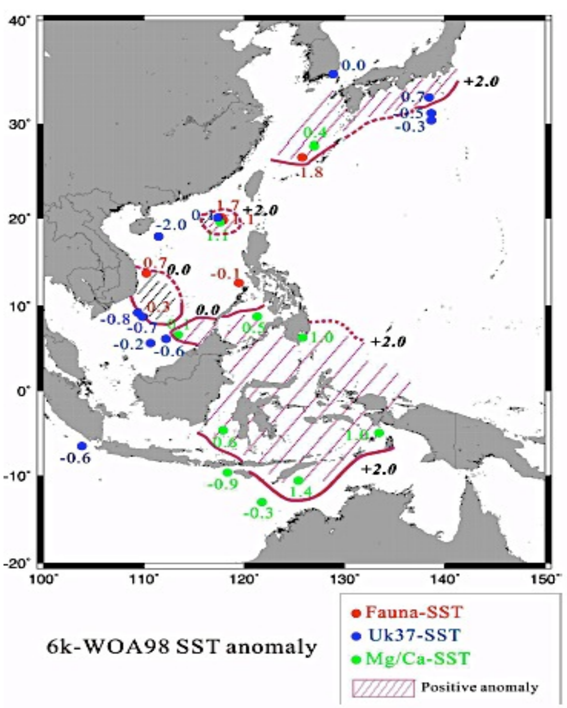
(3) Skinner, L. C. et al. (2010) *Science* 328 (5982): 1147-1151.

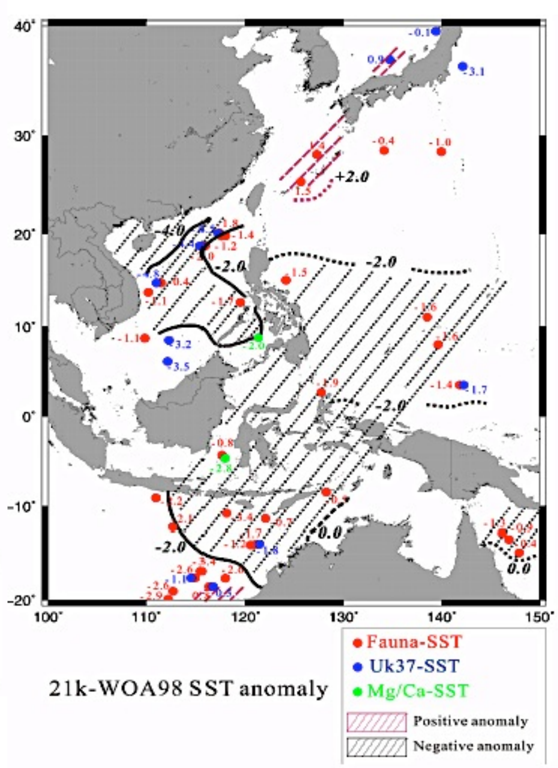
Western Tropical Pacific Temperature Changes During the Past 21,000 Years: Regional Time-Slice and Time Series Syntheses

Min-Te Chen[1], Da-Cheng Lin[1]

[1]Institute of Applied Geosciences, National Taiwan Ocean University, Keelung, Taiwan

Regional syntheses on past ocean climate changes form a basis by which deep understanding could be achieved on what key mechanisms have been responsible for driving the climate changes, for examples, since the Last Glacial Maximum (LGM). Here we present new data synthesis on western tropical Pacific sea surface temperature (SST) changes since the LGM. We adopted time slice and time series approaches and focused on the regional patterns of SST anomalies of 6K and 21K (see attached figures) by multiple SST proxies (Mg/Ca, alkenone, fauna) from GHOST (2004), MARGO (2009), Leduc et al. (2010), and MD core results published by Taiwan IMAGES groups (since 1997). Despite of proxy discrepancies, the 6K anomalies (6K SST minus WOA98 SST) show ~<1 to 2°C warming in the western Pacific warm pool (WPWP), southern and northern South China Sea (SCS), and the Pacific margin of Japan. The 21K anomalies show a more widespread cooling of ~<1-4°C in the WPWP and SCS, while a noticeable warming of ~1-1.5°C in the Kuroshio mainstream and the southern Japan Sea. Precisely AMS ^{14}C-dated foraminiferal Mg/Ca SST record from the East China Sea (ECS) (MD012404) exhibit two steps of warming since 21 ka --- at 14.7 ka and 12.8 ka, and a cooling (~1.5°C) during the interval of the Younger Dryas (YD), indicating a link to abrupt deglacial changes in the northern high latitudes. In the northern SCS, a high resolution, precisely AMS ^{14}C-dated alkenone SST record (MD972146) shows similar magnitude, near synchronous two steps of warming and YD cooling. However, the cooling during the H1 appears to be more pronounced in the SCS than ECS. We will discuss (1) the mechanisms that may have been responsible for these temperature patterns, (2) issues of proxy discrepancies and age model uncertainties, (3) further works that could be done with the uses of appropriate methods to compare model simulations with the observations.





Where has all the heat gone? Millennial-scale variability of the Brazil/North Brazil Currents during the last deglaciation

Chiessi, C.M., Mulitza, S., Silva, J.B., Prange, M., Groeneveld, J., Duleba, W.

Deglacial millennial-scale weakening events of the Atlantic meridional overturning circulation (AMOC) were supposedly associated with major changes in the surface hydrography of the western tropical Atlantic, i.e., in the Brazil/North Brazil Currents. It was suggested that the Brazil Current would strengthen (weaken) and the North Brazil Current would weaken (strengthen) during slowdown (speed-up) events of the AMOC. This antiphase pattern was claimed to be a necessary response to the decreased North Atlantic heat piracy during periods of weak AMOC. Part of the heat not transported to the Northern Hemisphere by the North Brazil Current would be deflected southward into higher latitudes of the Southern Hemisphere via the Brazil Current under a stalled AMOC. Nevertheless, direct sea-surface temperature (SST) and sea-surface salinity (SSS) comparisons of the Brazil/North Brazil Currents were not possible so far, mainly due to the lack of high temporal resolution records from the Brazil Current. Here we address this issue with new SST and SSS records based on foraminiferal Mg/Ca and stable oxygen isotopes from the Brazil Current covering the last deglaciation with appropriate temporal resolution (i.e., 65 yr between adjacent samples). Our records show high SST and SSS during Heinrich Stadial 1 (HS1) with a marked similarity to available records based on the same methods from the North Brazil Current. This argues against an anti-phase behavior of the Brazil/North Brazil Currents suggesting a remarkably synchronous SST and SSS evolution of the western tropical Atlantic during the last deglaciation.

Reevaluating last glacial tropical temperatures : updating MARGO

Thibault de Garidel-Thoron
CEREGE-CNRS, Aix-Marseille Université

Following the COMPARE meeting in 2012, we designed an updated database of planktonic foraminifera based sea surface temperature estimates for the last 32 ka. This database focuses on Mg/Ca temperature estimates obtained since MARGO. By constraining the set of records based on a number of criterion chosen as indicators of potential biases such as bioturbation, dissolution, living depth, we propose a new synthesis of tropical glacial surface temperature for the Last Glacial Maximum. In our new dataset (59 cores), the estimated SST for the LGM based on Mg/Ca in planktonic foraminifera is on the lower range of CLIMAP and MARGO datasets, i.e. SST are 3.1°C cooler than WOA modern SST. Those estimates are cooler than the ones based on foraminiferal transfer functions. LGM cooling based on alkenone estimates have been recently estimated to about 2.9°C (Bard, 2013) which is in the same range of Mg/Ca temperature based on the use of sigmoïdal calibrations in the upper thermal range. Using this database, which gathers both d18O and Mg/Ca analyses, we will discuss the choice of calibrations for the estimates of past salinity changes in the tropics.

The effect of sealevel on Indian Ocean circulation and climate during the LGM

Pedro DiNezio[1]*, Axel Timmermann[1], Jessica Tierney[2], David Lea[3], Weiqing Han[4]

[1]University of Hawaii / IPRC, [2]WHOI, [3]UCSB, [4]UC Boulder
*pdn@hawaii.edu

The sea level low stand during the Last Glacial Maximum (LGM) altered the geography of the Maritime Continent exposing the Sunda shelf and changing the circulation of the Indonesian Trough low (ITF). We explore theses effects using a series of comprehensive and idealized numerical simulations. We start studying changes in surface winds using a simulation of LGM climate performed with the HadCM3 coupled model. We use this simulation because it exhibits changes in rainfall and Walker circulation consistent with a multi-proxy synthesis. This simulation exhibits a reversal of the surface winds along the equatorial Indian Ocean, which shift to absolute easterlies in the LGM climate (from absolute westerlies in the pre-industrial climate). HadCM3's LGM simulation also exhibits a strengthening of the zonal sea-surface temperature (SST) gradient along the equator. We perform a series of idealized simulations with an atmospheric model to show that this response is initiated by reduced atmospheric deep convection over the exposed Sunda shelf, effectively reversing the Indian Ocean winds. However, this initial atmospheric response is amplified by the Bjerknes feedback as the easterly winds drive stronger upwelling off the coast of Sumatra, driving anomalously cool SSTs there and strengthening the zonal SST gradient. The altered ITF circulation also contributes to cooling of the eastern side of basin. Due to lowered sealevel, most of the ITF is routed through Timor straits, resulting in enhanced cooling off Java and Bali as the ITF's heat transport is routed southward.

We complete the study with an analysis of sea-surface salinity (SSS) changes. A salinity budget shows that the large-scale patterns of SSS change simulated by HadCM3 result from both changes in the fresh water fluxes, i.e. E-P, but also from changes in surface currents. One particularly interesting case is the salty conditions at the LGM seen in proxies and simulated by HadCM3 off India's Malabar Coast. This response is due to a reversal of the Eastern Indian Counter Current, which shuts down the seasonal transport of relatively fresher water from the Bay of Bengal. An ocean-only simulation shows that this reversal occurs in response to changes in remote winds over the Bay of Bengal. To conclude, we discuss strategies for using proxy data to test these mechanisms.

<u>Evaluation of modelled past ocean circulation with Neodymium Isotopic composition simulations</u>

Jean-Claude Dutay
LSCE, IPSL

Nd isotopic composition (Nd IC) behaves quasi-conservatively in the open ocean, apart from any lithogenic inputs. The evolution in ε_{Nd} along the modern day THC, from negative values in the north Atlantic, to positive values in the Pacific, makes ε_{Nd} a good candidate as a tracer of paleocirculation. For example, Piotrowski et al. (2004) measured the ε_{Nd} preserved in Fe-Mn oxides from LGM to mid Holocene in the South Atlantic, providing the first determination of circulation variations using Nd isotopic data at LGM. The temporal variations observed are interpreted as changes in circulation and the relative contribution of North Atlantic and North Pacific end-members. However Nd oceanic cycle is far from being completely constrained and uncertainties remain concerning the ability of ε_{Nd} to trace paleo-circulation.
Simulating explicitely Nd IC in ocean models allow to better understand the oceanic Nd cycle, and interpret the climatic signal it registers. We present two approaches for simulating ND IC in ocean model. A first simplified version that only simulates the ND IC and that has been applied for both present (Arsouze et al, 2007) and LGM climate (Arsouze et al, 2008). A second approach where both isotopes (ND-143 , Nd-144) are simulated as well as the explicit sources of these tracer in the ocean (Rivers, Boundary exchange at the continental margin, atmospheric dust) (Arsouze et al, 2009) (Rempfer et al , 2011, 2012a, 2012b).

Arsouze, T., Dutay J-C, Lacan F., Jeandel C., modelling the neodymium isotopic compsition with a global ocean general circulation model, Chemical Geology 239, pp165-177, 2007

Arsouze, T., Dutay, J.-C., Kageyama, M., Lacan, F., Alkama, R., Marti, O., Jeandel, C., 2008. A modelling sensitivity study of the Influence of the Atlantic meridional overturning circulation on neodymium isotopic composition at the Last Glacial Maximum. Climate of the Past 4, 191-203

Arsouze, T., Dutay, J.-C., Lacan, F., Jeandel, C., 2009. Reconstructing the Nd oceanic cycle using a coupled dynamical-biogeochemical model, Biogeosciences, 6, 2829-2846

Piotrowski, A. M., Goldstein, S. L., Hemming, S. R., and Fairbanks, R. G.: Intensification and variability of ocean thermohaline circulation through the last deglaciation, Earth Planet. Sc. Lett., 225, 205– 220, 2004.

Rempfer J., T. Stocker, F. Joos, J-C Dutay, M Siddall, 2011, Modelling Nd-isotopes with a coarse resolution ocean circulation model: Sensitivities to model parameters and source/sinks distributions, Geochimica et Cosmochimica Acta, 5927-5950

Rempfer J., Stocker T.F., Joos F**.,** Dutay J.C**.,** 2012, Sensitivity of Nd isotopic composition in seawater to changes in Nd sources and paleocanographic implications, Journal of Geophysical Research, vol 117, C12010, doi: 10.1029/2012JC008161

Rempfer J., Stocker T.F., Joos F**.,** Dutay J.C**.,** 2012. On the relationship between Nd isotopic composition and ocean overturning circulation in idealised freshwater discharge events. *Paleoceanography, Vol27, doi:10.1029/2012PA002312.*

How much did Glacial North Atlantic Water shoal?: Analysis of an LGM model constrained by observations

Geoffrey (Jake) Gebbie
Dept. of Physical Oceanography
Woods Hole Oceanographic Institution

Abstract:
Observations of d13C and Cd/Ca from the Last Glacial Maximum have been inferred to reflect a shoaling of northern source waters by about 1000 meters, with the degree of shoaling being significant enough for the water mass to be renamed Glacial North Atlantic Intermediate Water. These nutrient tracers, however, are influenced by many factors and may not solely record changes in water mass distributions. To quantify the extent and location of North Atlantic-derived waters at the LGM, we constrain a steady-state circulation model with observations. The method takes into account geometrical constraints and the interior sources and sinks of nonconservative tracers. Under the assumption that the glacial sources of remineralized material are similar to the modern-day, we find a steady solution consistent with 205 d13C, 87 Cd/Ca, and 174 d18O observations and their respective uncertainties. In this model scenario, the core of Glacial North Atlantic Water shoals and southern source water extends in greater quantities into the abyssal North Atlantic, as previously inferred. The depth of the interface between northern and southern source waters and the volume of North Atlantic Water, however, are not appreciably different from the modern-day. Under this scenario, the increased vertical range of d13C and Cd/Ca is due to remineralized nutrients in the intermediate-depth Southern Ocean that are then transported to the deep Atlantic, rather than a major water-mass reorganization. Thus, small changes in the circulation of mass may yield large changes in the circulation of nutrients. In a second scenario where d13C is modeled as a conservative tracer, the deep glacial northern-southern source interface does shoal by 1000 meters, but it is unrealistic for remineralization to have completely ceased during the LGM.

Dynamical perspective of proxy-indicated extreme sea-surface conditions in the Nordic Seas during the Last Glacial Maximum

Xun Gong1,2 (GongX1@cardiff.ac.uk), Michael Stärz2 (Michael.Staerz@awi.de) and Gerrit Lohmann2 (Gerrit.Lohmann@awi.de)

1School of Earth and Ocean Sciences, Cardiff University, Cardiff, UK
2Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany

Ocean dynamics in the Nordic Seas are sensitive to global climate change, and inversely play a crucial role in regulating the Atlantic and global climate system. In the studies of the Nordic Seas during the Last Glacial Maximum (LGM), the proxy records used in compilations show extremely different sea surface conditions and sea ice cover in the Nordic Seas, which might be related to large differences in the ocean circulation or different proxies and distinct methodology of proxy reconstruction. Additionally, different Earth System Model (ESM) simulations exhibit large spreads in simulating the dynamical processes of the glacial Nordic Seas. Due to their coarse resolution, they fail in representing the underlying dynamics and are therefore limited in their ability for model-data comparisons. Based on existing ESM simulations for the LGM, we apply a high-resolution North Atlantic/Arctic Ocean-Sea Ice Model with a horizontal resolution of 0.25 x 0.25 degree to understand the underlying physical processes in the Nordic Seas during the LGM. Our simulations are forced by different reconstructions based on cold and warm surface oceans associated with winds and thermohaline fluxes. The resulting ocean circulation nevertheless shows that the Nordic Seas experienced temperature conditions intermediate between the cold and warm reconstructions, with strong seasonal sea ice cover of the eastern part of the Nordic Seas. The results are in line with the conclusions of project of Multiproxy Approach for the Reconstruction of the Glacial Ocean surface (MARGO). This feature of the Nordic Seas during the LGM is robust, and is not related to our choices in surface salinity and applied fluxes in the regional model.

Can we ever hope the use MH SSTs for model evaluation?

Sandy P. Harrison, Ines Hessler, Michal Kucera, Stefan Mulitza, Claire Waelbroeck

The PMIP MH simulations show year-round warming in the Arctic, winter cooling and summer warming in the mid-latitude Atlantic, year round cooling in the tropics, Pacific Ocean and SH mid-latitudes, and year round warming in the Southern Ocean. The largest changes are the ca 2°C summer cooling in the tropics and the ca 2°C summer warming in the Arctic. The area of summer cooling in the tropics is more extensive in the CMIP5 ensemble than the PMIP2 ensemble, but conversely the area of summer warming in the Arctic is more extensive in PMIP2 than CMIP5. We use a new compilation of reconstructions of MH sea-surface temperatures (SSTs) to examine whether it is possible to test the signals emerging from the simulations. We use transfer function reconstructions of summer, winter and annual SST from planktonic foraminifera assemblages, modern analogue reconstructions of summer and winter SST from dinoflagellate cysts, summer and annual reconstructions based on Mg/Ca and summer reconstructions based on alkenone palaeo-thermometry. There is a high degree of variability in the reconstructed temperatures within the 5.5-6.5 ka BP window traditionally used for data-model comparison target datasets, both between samples from individual cores, between different sensors and within regions. Thus, between-sample variability in summer temperature in the tropics varies from 0.25° to 3°C, and can be >3°C in the Arctic. Between-sensor variability in regional reconstructions of summer SSTs varies from 0.75°C (alkenones vs foraminifera in the North Pacific) to <3°C (alkenones vs forams in the Mediterranean Sea). This variability is not reduced if the window-width is reduced to e.g. 500 years, the minimum that would yield sufficient reconstructions to produce a global map. Although there are patterns apparent in the maps of 5x5° gridded SST reconstructions, these are largely determined by the geographic distribution of different sensors. Application of the MARGO reliability index (which takes age and methodological reconstruction uncertainties into account) suggests that <5 grid cells have reconstructions falling into the "most reliable" category. These analyses suggest that a considerable effort is required to improve our understanding of the relationships between sensors and ocean climate, and thus to derive more reliable reconstructions, before the MH SST data can be used for model evaluation.

Towards quantifying uncertainties in sea surface temperature proxies ($U^{K'}_{37}$, TEX_{86}, Mg/Ca of foraminifera)

Sze Ling Ho, Thomas Laepple

Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Am Handelshafen 12, 27570 Bremerhaven, Germany.

Quantitative interpretation of proxy temperature records, especially during the time interval of small climatic changes such as the Holocene, can be compromised by inherent uncertainties in the proxies. Constraining and understanding the sources of the uncertainties may help to reconcile the mismatch, in terms of amplitude in temperature trends and variability, between model outputs and proxy records. Here, we report on two complementary pieces of our systematic efforts in quantifying proxy uncertainties.

We analyzed multiple sea surface temperature (SST) proxies on three short sediment cores from the same multicoring deployment. Our results allow to quantify and attribute the errors to the instrument, the work-up procedure and the spatial heterogeneity of proxies in sediments, providing some insights into how to best control for the noise sources. In the case of TEX_{86}^{L} and TEX_{86}^{H}, the spatial variability is as large as the downcore variability, suggesting that any interpretation of temporal changes in these proxies is highly uncertain at this study site.

Geochemical proxies often suggest different amplitudes of glacial-interglacial (G-IG) SST variations for a given site. In many cases, these differences in G-IG amplitude are explained by invoking differences in seasonal production and habitat depth of the source organism of proxies. To further look into this issue, we compile published SST records from global sites with multi-proxy records. Analyzing the modern and simulated glacial seasonal and vertical temperature distributions allows us to test simple explanations such as systematic season and depth habitat difference. Comparing the modern-day spatial relationship between proxies (based on published global surface sediments data) and downcore / temporal relationship between proxies suggest that the modern spatial relationship might not always hold over time.

Carbon isotopes in the ocean model of the CESM

Alexandra Jahn, NCAR

In order to improve comparisons with paleo records and present-day isotope data, carbon isotopes have been implemented into the ocean model of the Community Earth System Model (CESM). Both abiotic and biotic radiocarbon and biotic 13C tracers have been implemented and spun-up for present-day conditions in the stand-alone ocean model of the CESM1.2, at 3 degree resolution. I will present results from these present day spin-up simulations as well as from sensitivity simulations, compare them to observational data, and discuss the differences. I will also discuss the status of the ongoing implementation of additional ocean tracers (Pa/Th) to the ocean model and of the coupling the isotope-enabled ocean model to other parts of the CESM. Our goal is to include these new tracers in simulations for the last glacial maximum, and ultimately in an isotope enabled version of a transient simulation from the LGM to present day (i!"#$%). This simulation will be used for comparisons with observations, in order to better understand the ocean circulation changes during this period.

Flavio Justino
Brazil

A coupled global atmosphere-ocean model is used to study the influence of the Antarctica ice sheet in a configuration that mimics that of the early Miocene on the atmospheric and oceanic circulations. Based on different climate simulations of the present day (CTR) and conducted with distinct Antarctic ice sheet topography (AIS-EXP), it is found that the reduction of the Antarctic ice sheet topography (AIS) induces warming of the Southern Hemisphere and reduces the meridional thermal gradient. Consequently, the atmospheric transient low level eddy heat flux and the eddy momentum flux are reduced causing the reduced transport of heat from the mid-latitudes to the pole. The stationary flow and transient wave anomalies generate changes in the SSTs which modify the rate of deep water formation, strengthening the formation of the Antarctic Bottom Water. Substantial changes are predicted to occur in the atmospheric and oceanic heat transport and a comparison between the total heat transport of the atmosphere-ocean system, as simulated by the AIS-EXP and the CTR runs, shows that the reduction of the AIS height leads to reduced Southern Hemisphere poleward and increased equatorward heat transport. These results are in agreement with reduced storm track activities and baroclinicity.

Comparing Earth System Model results to oceanic data for the Last Glacial Maximum: new possibilities with the IPSL_CM5 model

Masa Kageyama, Véronique Mariotti, Tilla Roy, Laurent Bopp, Priscilla Le Mézo
Laboratoire des Sciences du Climat et de l'Environnement/IPSL
CE Saclay, L'Orme des Merisiers, bât. 701, 91191 Gif-sur-Yvette France

Contact author : Masa.Kageyama@lsce.ipsl.fr

The IPSL_CM5 Earth System Model (Dufresne et al, 2013) is the latest version of the IPSL atmosphere-ocean coupled model and has been used for the CMIP5 modelling exercise, for present, future and PMIP3 mid-Holocene and LGM simulations. It is equipped with the PISCES ocean biogeochemistry module, which is now run online. This feature allows for new comparisons with oceanic data, which we have illustrated for the LGM in Kageyama et al (2013a and b):
1- the simulated marine export production has been compared to the compilation of LGM paleo-productivity of Kohfeld et al (2005) and Kohfeld and Chase (2011);
2- the results from PISCES have been used to run the FORAMCLIM model (Lombard et al, 2011), which computes the growth rates and abundances of eight common and widely distributed foraminifer species.

This complements the traditional comparison to SST data, such as compiled by the MARGO group (MARGO, 2009). Here we will present comparisons between our LGM modelling results and the reconstructed SST, paleo-productivity and foraminifer distribution.

The PISCES results will also allow us to study the potential role of changes in the vertical distribution and seasonal cycle of productivity, between LGM and present, on SST reconstructions. The FORAMCLIM results will be used to analyse the importance of factors, such as nutrient availability, other than temperatures on the foraminifer distribution.

References :

Dufresne, J.-L. et al, 2013. Climate change projections using the IPSL-CM5 Earth System Model: from CMIP3 to CMIP5. Climate Dynamics, 40, 2123-2165.
Kageyama, M., P. Braconnot, L. Bopp, A. Caubel, M.-A. Foujols, E. Guilyardi, M. Khodri, J. Lloyd, F. Lombard, V. Mariotti, O. Marti, T. Roy, M.-N. Woillez, 2013a. Mid-Holocene and Last Glacial Maximum climate simulations with the IPSL model. Part I: comparing IPSL_CM5A to IPSL_CM4. Climate Dynamics, 40, 2447-2468.
Kageyama, M., P. Braconnot, L. Bopp, V. Mariotti, T. Roy, M.-N. Woillez, A. Caubel, M.-A. Foujols, E. Guilyardi, M. Khodri, J. Lloyd, F. Lombard, O. Marti, 2013b. Mid-Holocene and Last Glacial Maximum climate simulations with the IPSL model. Part II: model-data comparisons. Climate Dynamics, 40, 2469-2495.
Kohfeld, K. E., Le Quéré, C, Harrison, S., Anderson, R., 2005. Role of marine biology in glacial-interglacial CO_2 cycles. Science, 308, 74-78
Kohfeld, K. E. and Chase, Z., 2011. Controls on deglacial changes in biogenic fluxes in the north Pacific ocean, Quat. Sci. Rev. 30, 3350-3363

Lombard, F., Labeyrie, L., Michel, E., Bopp, L., Cortijo, E., Retailleau, S., Howa, H., and Jorissen, F., 2011. Modelling planktic foraminifer growth and distribution using an ecophysiological multi-species approach. Biogeosciences, 8, 853–873, 2011.
MARGO project members: (2009) Constraints on the magnitude and patterns of ocean cooling at the last glacial maximum. Nat. Geosci., 2, 127-132.

Paleoclimatic Changes Recorded in the Sediment Cores from the Eastern Arabian Sea

PRATIMA M. KESSARKAR and V. PURNACHANDRA RAO
[1]*CSIR-National Institute of Oceanography, Council of Scientific and Industrial Research, Dona Paula- 403 004 Goa, India*

The monsoons play an important role in controlling the physical and biogeochemical processes in the eastern Arabian Sea. Here, upwelling during the Indian summer monsoon (ISM) time induces high productivity in the surface waters. Oxygen minimum zone (OMZ) with perennial denitrification zone are important features of this region. Organic rich sediments are found here and have been extensively debated basically around two hypotheses: (a) higher productivity and (b) better preservation of organic matter. Ten sediment cores studied for organic carbon (OC) content from this area exhibit decreases in OC content from south to north in all the cores located within (286 m - 340 m) or below (1380 m - 2650 m) the OMZ, that support's more of productivity hypothesis. Detailed studies were carried out on four AMS dated cores for isotopic, sedimenotogical, geochemical and environmental rock magnetic parameters. Core SK126/39 containing record of past 70 ka shows large glacial-interglacial amplitude, $\Delta\delta^{18}O$ (planktonic foraminifera) of ~2.6‰, suggesting changes relating to monsoonal precipitation/runoff. Productivity proxy (OC and $CaCO_3$) and denitrification proxy ($\delta^{15}N$) indicate higher primary productivity and reduced denitrification intensity during last glacial maximum (LGM) and marine isotope stage (MIS) 4. Higher denitrification intensity was observed during MIS 1 and MIS 3 and reduced productivity and denitrification intensity during MIS 1/2, LGM and mid-MIS 3. Changes in productivity and denitrification intensities seem to be controlled by circulation, climate changes and hydrographic conditions in this area. Higher resolution core AAS62/1 that has past 16 ka record exhibit events like Bølling-Ållerød (B-A), Younger Dryas in the $\delta^{18}O$ and $\delta^{15}N$ profiles. The B-A event is characterized by higher water column denitrification rates similar to the present day. Comparing this data with that of Asian monsoon region of that from Timta cave of the western Himalayas and Hulu caves form China and that of warming signatures in Atlantic (Greenland Ice Sheet Project 2) indicate tele-connections through Intertropical Convergence Zone (ITCZ). Abrupt ISM event is observed in $\delta^{18}O_C$ values at ~ 11.8 ka BP is associated with June solar insolation maximum at 30° north supporting increase in ISM intensity episodes associated with warmer climate.

Quantifying uncertainties in Globigerinoides ruber Mg/Ca paleothermometry

Khider, D.1,2*, Jackson, C.1, Emile-Geay, J.2, Stott, L.D.2

1Institute for Geophysics, Jackson School of Geosciences, The University of Texas at Austin, Austin
2 Department of Earth Science, University of Southern California, Los Angeles

Evaluating paleoclimate models against existing paleoceanographic data requires a proper treatment of the uncertainties associated with these proxy records. In most studies, the errors in the reconstructed parameters are often assumed to be normally distributed, random, and independent. However, these assumptions need to be carefully verified as systematic errors can seriously bias the interpretation of proxy records. Here, we evaluate the uncertainties associated with reconstructing past sea surface temperatures (SSTs) variability from the Mg/Ca of the planktonic foraminifer Globigerinoides ruber.

Our approach to uncertainty quantification entails Monte-Carlo ensembles of possible realizations of the time series, which take simultaneously into account the errors in abscissa (the age model) and in the ordinates (SST). Although the analytical uncertainties associated with the radiocarbon and Mg/Ca measurements are random and independent, the errors associated with the preferred interpolation scheme for the age model and the Mg/Ca-SST calibration are dependent. This last point is important in assessing the magnitude of SST changes between two time periods as the uncertainty in the difference cannot be assessed through the commonly used approach of σdifference=(σt12+σt22)1/2, which requires independent samples. Furthermore, recent studies have found that the G. ruber Mg/Ca does not only co-vary with temperature, but also depends on sea surface salinity (SSS) and dissolution at the seafloor. In combination, these factors can introduce large systematic errors in reconstructions based on Mg/Ca measurements. In applying our uncertainty quantification scheme to a published Mg/Ca record for the Indonesian Seas (core MD98-2181), we find that the magnitude of the systematic error introduced by ignoring secondary effects on G. ruber Mg/Ca is of ~0.8°C at the Last Glacial Maximum, resulting from the ~1psu change associated with changes in global ice volume. The implications of this result for LGM-based estimates of equilibrium climate sensitivity will be discussed.

M. Kienast & N. Dubois

The glacial tropical Pacific: A synthesis of proxy reconstructions

The tropical Pacific Ocean is a critical region for the global climate system. It comprises the warmest region of the oceans, the Western Pacific Warm Pool (WPWP), which is the principal source of heat and water vapor to the atmosphere and plays an important role in the development of ENSO events. On the other side of the basin, the East Equatorial Pacific (EEP) is a critical region for the understanding of past global climate changes, because it receives Atlantic-derived moisture through cross isthmus atmospheric transport and is a major region of upwelling of waters sourced around Antarctica. As a result, the EEP is the most important oceanic source of CO2 and a significant source region for N2O. In spite of the best efforts of many paleoceanographers, the dynamics of the ancient tropical Pacific still remain elusive and controversial.

This paper provides a regional synthesis of paleoceanographic data bearing on the surface and thermocline ocean conditions in the tropical Pacific during the LGM. We will review and synthesize available reconstructions of sea surface temperatures and salinities, surface ocean productivity, and thermocline depth across the entire equatorial Pacific. The aim of this contribution is to provide a data set that can be compared and contrasted with model simulations of LGM conditions in this ocean region.

TITLE: The thermal and hydrological response of the tropical Indian Ocean during the LGM and deglaciation

AUTHORS (FIRST NAME, LAST NAME): David W Lea1, Rajeev Saraswat2, Pedro N Di Nezio3, Jessica E Tierney4, Jeremy D Shakun5, Maarten Blaauw6

INSTITUTIONS (ALL): 1. Earth Science, UCSB, Santa Barbara, CA, United States.
2. Micropaleontology Laboratory, National Institution of Oceanography, Goa, India.
3. SOEST, University of Hawaii, Honolulu, HI, United States.
4. Marine Geology and Geophysics, WHOI, Woods Hole, MA, United States.
5. Earth and Environmental Sciences, Boston College, Chestnut Hill, MA, United States.
6. School of Geography, Archaeology and Palaeoecology, Queen's University Belfast, Belfast, United Kingdom.

ABSTRACT BODY: The thermal and hydrological response of the tropical Indian Ocean during the last deglaciation is of special interest because of the broad impact of the Indian monsoon and the observation from many archives of an association between "weak monsoon intervals" and millennial scale events in the North Atlantic. Here we extend our studies of a core from the SE Arabian Sea, Malabar Coast (Saraswat et al., EPSL, 2013), in combination with GCM results, to establish the timing and probe the cause of temperature and hydrological shifts in the IO during the LGM and deglaciation.

The LGM section of the Malabar core indicates that SST, as estimated from Mg/Ca in *G. ruber*, was 2.7 ± 0.5 °C colder than Recent conditions. This cooling is larger than the MARGO estimate of LGM average annual cooling of 1.4±0.7 °C for the tropical Indian Ocean. The Malabar record reveals a brief ~500 year SST minimum after the LGM followed by deglacial warming starting at 18.6 kyr BP. Warming was interrupted by a plateau between 15.7 kyr and 13.2 kyr BP, after which SSTs rose to their maximum value at 9.2 kyr BP.

The Malabar core has two foraminiferal-based hydrological proxy records available, in the form of O18w calculated from Mg/Ca based SSTs and measured O18 and Ba/Ca. These two proxies record different aspects of hydrological change, because O18w primarily responds to E/P shifts and changes in rainfall composition, whereas Ba/Ca reflects changes in Indian subcontinent runoff. Both proxies can be precisely linked to the SST and C13 records derived from the same material. During the LGM, both the O18w and Ba/Ca proxies from the Malabar core indicate higher salinity. This regional signal contrasts with the basin scale freshening of the Arabian Sea inferred from a multiproxy synthesis (DiNezio and Tierney, 2013, Nature Geoscience).

In the present day climate, the Malabar region exhibits seasonal freshening due to advection of Bay of Bengal waters by the East Indian Coast Current (EICC). We explore this process in a simulation of the LGM climate performed with HadCM3; a coupled climate model that simulates the EICC realistically, but that also simulates LGM changes in the Walker circulation in agreement with proxy data. HadCM3 simulates a reversal of

the EICC at the LGM, leading to saltier conditions in the Malabar region in agreement with the proxy data.

The most remarkable aspect of the Malabar records during the deglaciation is the strong O18w maximum, indicating high salinity, at 15.9 (95% CI 16.3 to 15.0) kyr BP, coeval with H1. This very clearly defined feature corresponds almost exactly to a maximum in the Hulu Cave O18 record at 15.9 kyr BP. The Ba/Ca-based runoff record is at a minimum at this time, but barely lower than its LGM value, suggesting monsoonal runoff was low throughout the early deglacial, from 19 to 15.1 kyr BP, and that a further weakening of the EICC relative to its LGM state is unlikely to be the cause of the H1 salinity maximum. Thus the Malabar and Hulu
O18 maxima likely result from a large regional shift in either E/P and/or rainfall composition. An important clue in this regard, however, is that Malabar SSTs were not depressed and were still rising during the regional H1 O18w maximum at 15.9 kyr BP. If the Malabar SST record applies broadly, the tropical Indian Ocean did not cool during H1, and therefore cold SSTs could not have been the main cause of the weak monsoon interval centered on H1, as hypothesized by Pausata et al., 2011.

This talk will analyze the fidelity of the proxy records from the Malabar core and explore the implications of these regional thermal and hydrological shifts in the context of the global changes that occurred during the LGM and last deglaciation.

High Resolution CO_2 Reconstructions from the WAIS Divide Ice Core.

Shaun A. Marcott, Thomas K. Bauska, Christo Buizert, Michael Kalk, and Edward J. Brook.

We will present a carbon dioxide record from 60-35 and 28-9 ka from the last glacial and deglacial periods from a new ice core from West Antarctica with an average sampling resolution of 25-150 yrs. Our record shows that CO_2 variations during the glacial period have a clear relationship with abrupt climate changes in the Northern Hemisphere that continues into the deglacial period. In addition, instead of being gradual (several millennia), nearly half of the ~85ppm rise in CO_2 during the deglaciation occurred in three abrupt 10-15ppm steps that took place in less than 100-200 yrs and were followed by concentration plateaus. Each transition was synchronous with abrupt changes in methane (CH_4), suggesting a rapid reorganization of the carbon cycle. These rapid changes in atmospheric CO_2 and CH_4 concentrations are also recorded during the Heinrich Stadials of MIS 3, demonstrating an important mechanism that operates on centennial time scales during the glacial and deglaciation, which may point to important thresholds in the global carbon cycle. We will present our most recent results and newest interpretation.

The evolution of the Atlantic Ocean's thermohaline structure triggered by the a meltwater pulse in a transient simulation study

Juliana M. Marson and Ilana Wainer
jmarson@usp.br

The vertical distribution of the North Atlantic Deep Water (NADW) acquires its present day distribution and structure after the timing of an event that could be thought of as meltwater pulse 1A (MWP-1A). Most part of this event was represented in the simulation as a massive melting of glacial ice in Antarctica and associated freshwater flux into the Southern Ocean. Results show that spreading of the freshwater of southern origin into the Atlantic contributed to a process of erosion of the salt barrier at intermediate depths, which was characteristic of a glacial ocean. This weakens the ocean's vertical stratification without decreasing the density of the NADW source water, allowing this water mass to form and develop. The formation of the NADW marks a transition between the shallower (Last Glacial Maximum) and the deeper (present day) Atlantic Meridional Overturning Circulation.

Comparison of late Quaternary productivity variation in two contrasting basins of northern Indian Ocean using geochemical proxies.

Ishfaq Ahmad Mir[1, 2]
[1]Geological Survey of India, J&K, India, [2]National Institute of Oceanography, Goa, India.
geoishfaq@gmail.com, +91-09596879056

Abstract: A 4.1m long sediment core (SK-117/GC-08) raised from a water depth of 2500 m in the Eastern Arabian Sea (EAS) (Lat: 15˚29' N; Long: 72˚51' E) is studied for variation of productivity during the last 100 ka utilizing geochemical proxies. The temporal variation in element concentration and fluxes of $CaCO_3$, organic carbon (C_{org}) and Barium excess (Ba_{exc}) together in general indicate a higher productivity during the cold climate and highest during the Last Glacial Maximum in particular. This cold climate-increased productivity coupling may be attributed to the shoaling of nutricline due to enhanced convective mixing resulting from the intensified winter monsoon during cold periods.

A radiocarbon dated sediment core (SK-218/1) covering the past 45 ka is collected from the western Bay of Bengal (Lat: 14° 02′N; Long: 82° 00′E) at a water depth of 3307 m and is studied for variation of productivity utilizing geochemical proxies. The temporal variation in concentration and fluxes of $CaCO_3$, organic carbon (C_{org}) and Barium excess (Ba_{exc}) together in general indicate a higher productivity during interglacials. This warm climate intensified productivity may be attributed to stronger SW monsoon during interglacial's thereby bringing more fresh water and nutrients from nearby landmass than glacial period.

In both of the basins under same forces of monsoon driving mechanism there doesn't seem similar influence on productivity, EAS productivity is controlled more by local mechanism of convective mixing while as WBOB productivity is more controlled by Indian monsoon forcing mechanism.

Ocean Circulation During the Last Glacial Maximum Simulated by PMIP3 Climate Models

J. Muglia, A. Schmittner
College of Earth, Ocean, and Atmospheric Sciences, Oregon State University, Corvallis, USA

Computer simulated meridional streamfunction data were obtained from the GISS, MIROC, CCSM4, CNRM, Fgoals, MPI and MRI PMIP3 models, from the LGM and the Pre-Industrial Control data sets. We evaluated the difference between both time periods, by taking 50 year averages, and subtracting, for
each model, the averaged values of the LGM and Pre-Industrial Control streamfunction. We observe an increase in the intensity of the Atlantic Meridional Overturning Circulation (AMOC) in all the models studied, which averaged over all of them gives a 40% increase. This result contradicts some previous inferences based on paleoclimate data from the sea floor (McManus, Francois, Gherardi, Keigwin, & Brown-Leger, 2004). To investigate the processes governing the contrast found between the LGM and Control streamfunctions, we study the simulated density gradient across the Florida Straits, motivated by the observational results of (Lynch-Stieglitz, Curry, & Slowey, 1999) who suggest a reduction in that variable for the LGM.
Furthermore, we study the response of the UVic Model to changes in different forcings according to the range of estimates for the LGM, in order to infer the relevance of the different variables as drivers of change in the AMOC.

References:

Lynch-Stieglitz, J., Curry, W., & Slowey, N. (1999). Weaker Gulf Stream in the Florida straits during the last glacial maximum. Nature, 402 (December).

McManus, J. F., Francois, R., Gherardi, J.-M., Keigwin, L. D., & Brown-Leger, S. (2004). Collapse and rapid resumption of Atlantic meridional circulation linked to deglacial climate changes. Nature, 428(6985), 834–7.

A GUI-based synthesis toolbox for the collection, homogenization and visualization of foraminiferal stable isotope data

Stefan Mulitza and André Paul
(MARUM – Center for Marine Environmental Sciences, University of Bremen)

The PMIP-MARUM-PAGES Workshop on Comparing Ocean Models with Paleo-Archives 2012 (COMPARE 2012, Bremen, Germany, 18-21 March 2012) highlighted the need for comparisons of model simulations with paleoceanographic data. Stable carbon and oxygen isotope distributions allow for a direct comparison to models and an assessment of the changes in biogeochemistry and climate, which makes foraminiferal stable isotopes an important target for data compilations. Although foraminiferal stable isotope data are available in vast quantities, only very few quality-controlled data compilations have been published so far. The main reason for this is that stable isotope data are usually highly inhomogeneous with respect to the applied stratigraphic method (i.e. the used radiocarbon calibration curve), the used species and the data structure. The complexity of handling the paleoceanographic database in general calls for the development of a software package that allows the interactive exploration, analysis and visualization of paleoceanographic data. We will present a prototype of a software that allows to import (i.e from Excel) and manage foraminiferal stable isotope data. The basic functionality includes (1) the interactive radiocarbon calibration (2) graphic correlation with standard curves (3) the comparison with modern oceanographic data and (4) the extraction and visualization of time slices and time series with an error estimate. This tool will allow constantly maintaining and updating a synthesized stable isotope database, similar to comparable oceanographic software tools (i.e Ocean Data View, Schlitzer, R., http://odv.awi.de, 2012) and products (i.e., the World Ocean Atlas). The presented concept can also be transferred to other paleoceanographic proxy compilations.

Vector diagram analysis of ocean carbon pumps during the Last Glacial Maximum

Akira Oka (Atmosphere and Ocean Research Institute, University of Tokyo)

Using ocean carbon cycle model simulations of present-day and glacial climates, this study discusses the glacial responses of the ocean carbon pumps: organic matter, calcium carbonate, gas exchange, and freshwater pumps. The vector diagram presented here quantifies their individual impact on the glacial atmospheric pCO2 reduction; the strengthening of the organic matter pump contributes to 40-ppm reduction of atmospheric pCO2, most of which is cancelled by the weakening of the gas exchange pump. The response of the gas exchange pump is involved in various processes. Here, they are systematically revealed through analysis of additional sensitivity simulations. The analysis suggests that changes in the ocean deep circulation significantly affect the response of the gas exchange pump; the above-mentioned strong cancelation between the organic matter pump and the gas exchange pump is related to the glacial weakening of the Atlantic deep circulation. As in previous studies, the model used here fails to reproduce the observed magnitude of the glacial pCO2 reduction. Reduced ventilation in the glacial Southern Ocean is a possible mechanism for explaining this difference since this has the potential to significantly modify the glacial response of the gas exchange pump but may not accurately be reproduced in the model. Although the gas exchange pump has often been implicitly incorporated into other processes, this study suggests that its response is a key to understanding glacial changes in atmospheric pCO2. It is also demonstrated that the vector diagram is a useful tool for its investigation.

Mechanisms of glacial-interglacial CO_2 change examined by model-data comparison of an LGM hypercube ensemble

Kevin Oliver
National Oceanography Centre, Southampton, UK

A hypercube ensemble, with the Earth system model GENIE, is used to explore the potential of hypothesised causes of glacial-interglacial CO_2 cycles to simultaneously explain observed changes in atmospheric CO_2 and in marine proxies. The response of CO_2 to changes in physical (but not biogeochemical) processes, is strongly non-linear, suggesting that traditional Perturbation vs Control experiments alone are insufficient to explore the problem. Many ensemble members with low CO_2, typically associated with reduced ventilation of the deep Southern Ocean, are broadly consistent with changes in d13C at the last glacial maximum (LGM). A subset of these, typically associated with strong ice export from the Antarctic margin, are consistent with strong salinity gradients indicated by pore-water measurements. However, weak ventilation leading to low CO_2 is also associated with low global export production, which (outside of the high latitude Southern Ocean) is not consistent with LGM reconstructions. Export production therefore presents the most challenging observational target. This target is only met by simulations with increased energy available for diapycnal mixing in the deep ocean, consistent with tide models with LGM bathymetry, which acts to increase global ocean ventilation but not atmospheric CO_2.

What does a quantitative and "intelligent" model-data comparison mean?

André Paul, Stefan Mulitza and Michal Kucera
(MARUM – Center for Marine Environmental Sciences, University of Bremen)

An important conclusion reached at the PMIP-MARUM-PAGES Workshop on Comparing Ocean Models with Paleo-Archives 2012 [COMPARE 2012, Bremen, Germany, 18-21 March 2012 – see also PAGESnews 20(2):102, 2012] was that future model-data comparisons needed to be quantitative and "intelligent" (that is, diagnostic and process-oriented).

Following up on the discussion at that workshop, we will address the following questions: how to quantify model-data misfit and model error, and what "metrics" can paleo-ocean data provide? Inverse methods that aim at the optimization of the parameters of a particular model usually require the model-data misfit to be distilled in a single value of a cost function. By contrast the benchmarking of different models allows for multiple metrics that may go beyond comparing model and data on a point-by-point basis and, for example, assess gradients or patterns.

We will provide examples of comparing a model to data using a range of different metrics. The comparison is based on simulations of stable carbon and oxygen isotope distributions with the MIT general circulation model (MITgcm) with stable isotope data from the GEOSECS period (1972-1978) and the WOCE period and beyond (1990-2005), as well as with foraminiferal stable isotope data.

Deglacial whole-ocean $\delta^{13}C$ change estimated from 480 benthic foraminiferal records

Carlye D. Peterson[1], Lorraine E. Lisiecki[1], and Joseph V. Stern[1]
[1]Department of Earth Science, University of California, Santa Barbara, California, USA.

Abstract

Terrestrial carbon storage is dramatically decreased during glacial periods due to cold temperatures, increased aridity, and the presence of large ice sheets on land. Most of the carbon released by the terrestrial biosphere is stored in the ocean, where the light isotopic signature of terrestrial carbon is observed as a 0.32-0.7‰ depletion in benthic foraminiferal $\delta^{13}C$. The wide range in estimated $\delta^{13}C$ change results from the use of different subsets of benthic $\delta^{13}C$ data and different methods of weighting the mean $\delta^{13}C$ by volume. We estimate the glacial-interglacial $\delta^{13}C$ change of marine Dissolved Inorganic Carbon (DIC) using benthic *Cibicidoides* spp. $\delta^{13}C$ records from 480 core sites (more than three times as many sites as previous studies). We divide the ocean into eight regions to generate linear regressions of regional $\delta^{13}C$ versus depth for the Late Holocene (0-6 ka) and Last Glacial Maximum (19-23 ka) and estimate a mean $\delta^{13}C$ decrease of 0.38 ± 0.08‰ (2σ) for 0.5-5 km. Estimating large uncertainty ranges for $\delta^{13}C$ change in the top 0.5 km, below 5 km, and in the Southern Ocean, we calculate a whole-ocean change of 0.34 ± 0.16‰. This implies a terrestrial carbon change that is consistent with recent vegetation model estimates of 330-694 Gt C.

THE EQUATORIAL SEA SURFACE TEMPERATURE VARIABILITY DURING THE LAST MILLENNIUM

Luciana Figueiredo Prado and Ilana Wainer

The study of the variability patterns of the South Atlantic Basin is necessary to understand and predict the global climate because of its fundamental role in global climate control through heat transport to the North. As early as 330 years ago, the importance of the continental heat budget on the equatorial Atlantic Ocean, driving the the trade winds in the Gulf of Guinea was identified. However, only five decades ago studies started to understand the effects of these air-sea interaction processes over the Atlantic sector. More specifically, changes in continental rainfall are linked to the interannual variability of the equatorial Atlantic sea surface temperature, which is related to the Atlantic Niño. Here we aim to examine air-sea interaction processes in the tropical Atlantic region during abrupt events within the Last Millennium (LM, 850 to 1,850 Common Era, C.E.). This will be achieved by computing an index to the variability of the equatorial Atlantic sea surface temperature during the LM. This variability pattern will be obtained from the the National Center for Atmospheric Research – Community Climate Syste Model, version 4 (NCAR-CCSM4.0) transient run. We expect to use this index to identify possible differences in the sea surface field between the Little Medieval Climate Anomaly (MCA, 950 to 1,250 C.E.) and the Little Ice Age (LIA, 1,400 to 1,700 C.E.).

Key-words: Last Millennium; equatorial Atlantic Ocean; NCAR-CCSM4.0

Climate response to changes in orbital forcing around the first Pliocene Time Slice

Caroline Prescott, Alan Haywood, Julia Tindall, Aisling Dolan, Stephen Hunter, James Pope, Steven Pickering

Global annual mean temperatures (MAT) during the mid-Pliocene warm period (~3 to 3.3 Ma) were on average 2 to 3°C higher than the pre-industrial era. This combined with near modern continental configurations, orography and atmospheric CO_2 concentrations of 80 to 120 ppmv higher than the pre-industrial, make the mid-Pliocene warm period one of the best intervals in Earth history to investigate the potential long term future response of climate to near future concentrations of atmospheric carbon dioxide.

Existing data/model comparisons for the mid-Pliocene have identified specific regions of concordance and discord between climate models and proxy data. One reason for site-specific disagreement is likely related to the time (warm peak) averaged nature of the mid-Pliocene ocean temperatures provided within existing proxy syntheses. To facilitate improved data/model comparisons in the future new proxy sea surface temperature reconstructions must focus on specific time slices within the Pliocene epoch. Haywood et al. (2013) have identified an initial time slice for environmental reconstruction and climate and environmental modelling centred on Marine Isotope Stage KM5c (3.205 Ma BP). Critically, this interval displays a very near to modern orbital configuration simplifying the interpretation of proxy data and the experimental design used within climate models. It is also within a warmer period as identified by a negative benthic oxygen isotope excursion of significant duration (thousands of years) in the LR04 stack. . Nevertheless, current limitations of chronology and correlation make it likely that new proxy records will be attributable to a time range around the time slice, and may not always represent the time slice specifically. This introduces an element of uncertainty through orbital forcing around the time slice which can be investigated and quantified within a numerical climate modelling framework.
Using the Hadley Centre Coupled Climate Model Version 3 (HadCM3) we have performed a series of orbital forcing sensitivity tests around the identified time slice at MIS KM5c. Simulations every 2 Kyr either side of the time slice to a range +/- 20 kyr have been performed. The model results indicate that +/- 20 kyr either side of the time slice, orbital forcing exerts a less than 1°C change on global MAT. Seasonally, temperature variations exceed this value locally. One exception to this relative stability in climate to modest changes in orbital configuration is seen in the North Atlantic (a region noted for disagreement in existing Pliocene data/model comparisons). Here ocean surface temperature variations of up to 6°C are predicted by the model. These model responses are currently under investigation but appear related to variations in the strength of the Atlantic Meridional Overturning Circulation over relatively short timescales (geologically).

Glacial-interglacial changes in ocean carbon chemistry, constrained by boron isotopes, radiocarbon, trace elements, and modelling

James W.B. Rae[1], Jess F. Adkins[1], Christopher Charles[2], Tim Elliott[3], Alan Foreman[2], Gavin L. Foster[4], Laura C. Foster[3], Pieter Grootes[5], Andy Ridgwell[3], Michael Sarnthein[5], Daniela N. Schmidt[3]

Deep ocean carbon storage and release is commonly invoked to explain glacial-interglacial CO_2 cycles, but records of the carbonate chemistry of the glacial ocean have, until recently, been scarce. Here we show how the boron isotope composition ($\delta^{11}B$) of benthic foraminifera can be used to record deep ocean carbonate chemistry, and discuss the importance of foraminiferal morphotype in obtaining clean trace element records. We then present new $\delta^{11}B$ data from detailed depth profiles and time series, that record the pH of the deep ocean at the last glacial maximum (LGM), and how it evolved over the deglaciation. These data are explored using a recently-developed tracer fields modelling approach [1], and an earth system model, allowing us to constrain the roles of circulation, the biological pump, and carbonate compensation, in setting deep ocean carbon storage at the LGM. Finally, we show how deep ocean carbon storage evolved over the deglaciation, and describe the initially counter-intuitive signals of stratification breakdown. We show that pulses of stratification breakdown in the Southern Ocean and North Pacific likely caused CO_2 release from the deep ocean to the atmosphere, and discuss the role of atmospheric freshwater as a potential driver of deepwater formation.

[1] Lund, D. C., J. F. Adkins, and R. Ferrari (2011), Abyssal Atlantic circulation during the Last Glacial Maximum: Constraining the ratio between transport and vertical mixing, *Paleoceanography*, 26, PA1213, doi:10.1029/2010PA001938.

Abstract title: Effect of habitat variability on the climate signal recorded by marine temperature proxies.

Contributors: Tilla Roy, Thomas Laepple, Ling Ho, Fabian Lombard, Laurent Bopp   Affiliations of lead author: LOCEAN, UPMC, Paris France and Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Am Handelshafen 12, 27570 Bremerhaven, Germany.

Climate models consistently simulate less marine temperature variability over decadal and longer timescales than recorded in marine proxy records. One possible contributor to this discrepancy is the temporal variability in the habitat of the planktonic proxy species. Here we compare and contrast the influence of both depth and time-weighted habitat variability on the climate signal recorded by coccolithophores (Uk37) and foraminifer-based proxies (e.g. Mg/Ca), and on the accuracy of the core-top calibrations. Climate variability is simulated in a 1000 year control simulation of the IPSL Earth system model (ESM). Coccolithophores are simulated online as a small planktonic calcifying group in the PISCES biogeochemical module. The distributions of eight common foraminifer species are simulated in an offline ecophysiological foraminifera model (FORAMCLIM) based on temperature, phytoplankton concentration and light from the IPSL ESM. Based on the ESM simulations, we locate the geo   graphical regions where the effect of habitat weighting on the recorded temperature is expected to produce the largest discrepancies between surface ocean temperatures and proxy-based records, estimate the time-scales of variability over which these discrepancies dominate and assess their potential physical and biogeochemical drivers.

Deglacial 14C plateau suites recalibrated by Suigetsu atmospheric 14C record – Revised 14C reservoir ages from three ocean basins corroborate extreme surface water variations

M. Sarnthein1), S. Balmer1), and P.M. Grootes2)

1)Institute of Geosciences, University of Kiel, D-24098 Kiel, Germany
2)Institute of Ecosystem Research, University of Kiel, D-24098 Kiel, Germany

Radiocarbon (14C) reservoir/ventilation ages (**Δ**14C) provide unique insights into the dynamics of ocean water masses over LGM and deglacial times. The 14C plateau-tuning technique enables us to derive both an absolute chronology for marine sediment records and a high-resolution record of changing **Δ**14C values for deglacial surface and deep waters (Sarnthein et al., 2007; AGU Monogr. 173, 175). We designate as 14C plateau a sediment section in the age-depth profile with several almost constant planktic 14C ages – variation less than ±100 to ±300 yr – which form a plateau-shaped scatter band that extends over ~5 to 50 and up to 200 cm in sediment cores with sedimentation rates of >10 cm/ky. Previously, a suite of >15 plateau boundary ages were calibrated to a joint reference record of U/Th-dated 14C time series measured on coral samples, the Cariaco sediment record, and speleothems (Fairbanks et al., 2005, QSR 24; Hughen et al., 2006, QSR 25; Beck et al., 2001, Science 292). We now used the varve-counted atmospheric 14C record of Lake Suigetsu (Ramsey et al., 2012, Science 338, 370) to recalibrate the boundary ages and average ages of 14C plateaus and apply the amended plateau-tuning technique to ~14 **Δ**14C records from the Atlantic and Indo-Pacific. Main results are: (1) The Suigetsu atmospheric 14C record reflects all 14C plateaus, their internal structures and relative length previously identified, but implies a rise in the average plateau age by <200 14C yr during the LGM, >700 yr at its end, and <200 yr in the Bølling-Allerød. (2) Based on different 14C ages of coeval atmospheric and planktic 14C plateaus surface water **Δ**14C may have temporarily dropped to an equivalent of 20 yr in low-latitude stratified waters, such as in the Cariaco Basin, and in turn reached values corresponding to an age difference of >2500 14C yr in stratified subpolar regions and upwelled waters such as in the South China Sea, values that differ significantly from a widely assumed constant planktic **Δ**14C age of 400 yr. (3) Suites of deglacial planktic **Δ**14C ages are closely reproducible in 14C records measured on neighbor core sites. (4) Apparent deep-water 14C ventilation ages (benthic **Δ**14C), obtained from the sum of planktic **Δ**14C and coeval benthicplanktic **Δ**14C age differences, vary from an equivalent of <1000 to 5000 yr in LGM and deglacial ocean basins.

Biology and air–sea gas exchange controls on the distribution of carbon isotope ratios ($\delta^{13}C$) in the ocean

A. Schmittner[1], N. Gruber[2], A. C. Mix[1], R. M. Key[3], A. Tagliabue[4], and T. K. Westberry[5]
[1]College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, Oregon, USA
[2]Institute of Biogeochemistry and Pollutant Dynamics, ETH Zürich, Zürich, Switzerland
[3]Department of Geosciences, Princeton University, Princeton, New Jersey, USA
[4]School of Environmental Sciences, University of Liverpool, Liverpool, UK
[5]Department of Botany and Plant Pathology, Oregon State University, Corvallis, Oregon, USA

Abstract. Analysis of observations and sensitivity experiments with a new three-dimensional global model of stable carbon isotope cycling elucidate processes that control the distribution of $\delta^{13}C$ of dissolved inorganic carbon (DIC) in the contemporary and preindustrial ocean. Biological fractionation and the sinking of isotopically light $\delta^{13}C$ organic matter from the surface into the interior ocean leads to low $\delta^{13}C_{DIC}$ values at depths and in high latitude surface waters and high values in the upper ocean at low latitudes with maxima in the subtropics. Air–sea gas exchange has two effects. First, it acts to reduce the spatial gradients created by biology. Second, the associated temperature-dependent fractionation tends to increase (decrease) $\delta^{13}C_{DIC}$ values of colder (warmer) water, which generates gradients that oppose those arising from biology. Our model results suggest that both effects are similarly important in influencing surface and interior $\delta^{13}C_{DIC}$ distributions. However, since air–sea gas exchange is slow in the modern ocean, the biological effect dominates spatial $\delta^{13}C_{DIC}$ gradients both in the interior and at the surface, in contrast to conclusions from some previous studies. Calcium carbonate cycling, pH dependency of fractionation during air–sea gas exchange, and kinetic fractionation have minor effects on $\delta^{13}C_{DIC}$. Accumulation of isotopically light carbon from anthropogenic fossil fuel burning has decreased the spatial variability of surface and deep $\delta^{13}C_{DIC}$ since the industrial revolution in our model simulations. Analysis of a new synthesis of $\delta^{13}C_{DIC}$ measurements from years 1990 to 2005 is used to quantify preformed and remineralized contributions as well as the effects of biology and air–sea gas exchange. The model reproduces major features of the observed large-scale distribution of $\delta^{13}C_{DIC}$ as well as the individual contributions and effects. Residual misfits are documented and analyzed. Simulated surface and subsurface $\delta^{13}C_{DIC}$ are influenced by details of the ecosystem model formulation. For example, inclusion of a simple parameterization of iron limitation of phytoplankton growth rates and temperature-dependent zooplankton grazing rates improves the agreement with $\delta^{13}C_{DIC}$ observations and satellite estimates of phytoplankton growth rates and biomass, suggesting that $\delta^{13}C$ can also be a useful test of ecosystem models.

Emerging constraints on ocean 'ventilation' changes since the last glacial period: implications for marine carbon cycling and the deglacial process.

L.C. Skinner

Godwin Laboratory for Palaeoclimate Research
Department of Earth Sciences
University of Cambridge
Cambridge, UK
CB2 3EQ

Radiocarbon represents an invaluable carbon cycle tracer that is well suited to the investigation of past ocean circulation changes and their impacts on the marine carbon cycle. Here I present an overview of existing and emerging radiocarbon data spanning the last deglaciation, demonstrating significant changes in the extent of equilibration between the atmospheric and marine carbon pools over this time, with a direct bearing on the mechanisms of deglacial atmospheric CO_2 and $\Delta^{14}C$ change. Three perspectives on radiocarbon and carbon cycling since the last glacial period are presented: 1) a view of the LGM marine radiocarbon distribution and its implications for the ocean circulation at this time; 2) a deglacial history of radiocarbon ventilation change in the high latitude shallow sub-surface, the deep ocean, and the intermediate ocean, and its implications for the evolution of the ocean circulation during deglaciation; and 3) an assessment of the implications of the LGM and deglacial radiocarbon changes for marine CO_2 sequestration during the last glacial period, as well as the mechanisms that led to its release during deglaciation. An attempt is made to link these emerging observations with canonical theories of deglacial climate and carbon cycle change, and to delineate possible tests for numerical models striving to emulate or to simulate the deglacial process.

The last glacial cycle: transient simulations with an AOGCM

Robin Smith and Jonathan Gregory

A number of transient climate runs simulating the last 120 kyr have been carried out using FAMOUS, a fast atmosphere--ocean general circulation model (AOGCM). This is the first time such experiments have been done with a full AOGCM, providing a three-dimensional simulation of both atmosphere and ocean over this period. Atmospheric greenhouse gases, northern hemisphere ice sheets and variations in solar radiation arising from changes in the Earth's orbit are treated as forcing factors, and we find that their influences on mean climate and ocean variability combine in a linear fashion. The use of two different ice-sheet reconstructions in our experiments shows the sensitivity of the glacial climate system to ice-sheet forcing. The long-term temperature changes on Antarctica match well with reconstructions derived from ice-core data, as does variability on timescales longer than 10 kyr. Last Glacial Maximum (LGM) cooling on Greenland is reasonably well simulated, although our simulations, which lack ice-sheet meltwater forcing, do not reproduce the abrupt, millennial scale climate shifts seen in northern hemisphere climate proxies or their slower southern hemisphere counterparts. The spatial pattern of sea surface cooling at the LGM matches proxy reconstructions reasonably well. Although the model is fast, computational restrictions mean that the rate of change of the forcings has been increased by a factor of 10, making each experiment 12 kyr long. While this does not appear to distort the simulated evolution in general, it is almost certainly to blame for the slow rate of warming in the southern hemisphere during deglaciation.

Improving paleoceanographic chronologies of the last 40 kyr: ^{14}C-dated regional d^{18}O stacks and North Atlantic reservoir ages

Authors: Lorraine E. Lisiecki and Joseph V. Stern

Compilations of paleoceanographic data are powerful tools which can greatly benefit from improved age models. Here we combine two classic tools for age model development, benthic d^{18}O alignment and planktonic radiocarbon ages, to develop state-of-the-art regional age models for the intermediate North and South Atlantic, the deep Atlantic, the intermediate and deep Pacific, and the Indian Ocean. Collectively, these age models are constrained by 776 planktonic radiocarbon dates from 61 cores. We also construct regional benthic d^{18}O stacks using these radiocarbon age models and data from 252 cores. The stacks reveal differences of up to 4000 yr in the regional timing of the start of Termination 1, with the intermediate South Atlantic responding first at 18.5 kyr BP (95% CI: 17.7 – 19.0 kyr BP) and the deep Indian responding last at 14.5 kyr BP (95% CI: 14.3 – 14.8 kyr BP). The termination onset is 17.5 kyr BP in both the deep Atlantic and deep Pacific stacks, but the deep Pacific lags the deep Atlantic by as much as ~1700 yr during the middle of the termination. Diachronous regional d^{18}O responses suggest that data compilations based on the assumption of synchronous benthic d^{18}O change may have significant chronological errors. Radiocarbon-dated regional d^{18}O chronologies also improve our ability to compare paleoceanographic proxy records with LGM and deglacial model simulations and with well-dated proxy records from ice cores, speleothems, and corals.

North Atlantic Circulation and Radiocarbon Reservoir Ages

Authors: Joseph V. Stern and Lorraine E. Lisiecki

The high-latitude North Atlantic is an especially critical region for reconstructing deglacial climate responses and the interactions between climate and Atlantic Meridional Overturning Circulation (AMOC). However, AMOC changes also affect surface reservoir age, creating uncertainties of up to 2000 years in ^{14}C ages during Heinrich Stadial 1 (HS1). We address this key uncertainty with a comparison of high- and low-latitude deep North Atlantic records that yields a continuous record of high-latitude North Atlantic reservoir ages for the last 40 kyr. Our reconstruction reveals reservoir ages of >1000 ^{14}C yr from 18.5-16.5 kyr BP. Increased reservoir ages clearly precede HS1 ice-rafted debris (IRD) and suggest early weakening of the AMOC caused by the first deglacial melting event at 19 kyr BP. We also observe a rapid decrease in reservoir ages coincident with the 16 kyr BP IRD peak. We propose that this shift was caused by extreme North Atlantic stratification that allowed surface waters to equilibrate with the atmosphere, thus indicating severe weakening of the AMOC triggered by ice rafting at 16 kyr BP.

What kind of temperature is recorded in the composition of planktonic foraminifera assemblages?

Telford, Richard[1,2]; Li, Camille[2,3]; Kucera, Michal[4]
[1]Department of Biology, University of Bergen, Bergen, Norway
[2]Bjerknes Centre for Climate Research, Bergen, Norway
[3]Geophysical Institute, University of Bergen, Bergen, Norway
[4]MARUM & Fachbereich Geowissenschaften, Universität Bremen, Bremen, Germany
Email: mkucera@marum.de

Analysis of planktonic foraminifera assemblages has been a key method to reconstruct sea surface temperatures since the LGM. In this approach, the composition of a fossil assemblage is converted to an absolute temperature using one or several transfer functions - mathematical algorithms calibrated on modern surface sediment samples and long-term instrumental SST averages. In the past decades, large calibration datasets have been generated and sophisticated regression techniques used to optimally extract the relationship between assemblage composition and SST. Recent research indicates that the potential of these avenues to improve transfer functions is largely depleted and that the crux to constrain the uncertainty of transfer-function based SST reconstructions lies elsewhere. Despite the fact that planktonic foraminifera inhabit a broad depth range in the upper ocean and that species flux varies through the year, transfer functions have been usually calibrated against a uniform SST definition and the resulting reconstructions have been interpreted to represent such uniform SST. This praxis has been justified by the assumption of high covariance among SST at all depths and seasons, both in the modern ocean and presumably in the past. Recent work has shown that this assumption may not be valid and that new approaches are needed to constrain the sensitivity of planktonic foraminifera assemblages to SST. The problem at hand is analogous to that faced by geochemical paleothermometers: an objective change in the chemical composition is observed, but it remains uncertain how this change can be attributed to a change in the thermal structure of the habitat of the signal carrier. Here we show that in the case of foraminifera transfer functions, SST reconstructions based on shallow SST calibrations often do not explain as much variance in a time series of fossil data as do reconstructions based on subsurface temperature. We show that this mismatch is likely to have a geographical structure and is most pronounced in the tropics, with potentially significant consequences for interpreting reconstructed LGM SST patterns.

Variability in glacial Atlantic meridional overturning circulation in response to Laurentide Ice-Sheet topographic uncertainty

David J. Ullman[1,2], Allegra N. LeGrande[3], Anders E. Carlson[1,2], Faron S. Anslow[4], Joe M. Licciardi[5]

[1]College of Earth, Ocean, and Atmospheric Sciences, Oregon State University
[2]Department of Geoscience, University of Wisconsin-Madison
[3]NASA Goddard Institute for Space Studies
[4]Pacific Climate Impacts Consortium
[5]Department of Earth Sciences, University of New Hampshire

During the last glacial maximum (LGM) and subsequent deglaciation, the Laurentide Ice Sheet (LIS) was a large orographic obstacle to general atmospheric flow. Such a barrier led to large shifts in both mesoscale and downstream atmospheric circulation, which in turn impacted ocean overturning. Here, we use 2 separate LIS topographic reconstructions as boundary conditions in the NASA GISS ModelE2-R to explore the connections between ice-sheet topography and ocean circulation at the LGM. These LIS reconstructions provide an upper and lower bound to the current PMIP3 boundary conditions for LIS elevation and express a range of uncertainty in our understanding of LIS topography and its impact on modeled climate. While both simulations indicate enhanced Atlantic Meridional Overturning Circulation (AMOC) relative to the 0 ka control simulation, the higher-elevation LIS simulation results in stronger AMOC compared to that of the lower LIS simulation. A second comparison at 14 ka with a smaller difference between LIS elevations confirms the resulting difference in AMOC with stronger circulation again associated with the higher LIS. These results indicate that the range of LIS topographic reconstructions provide a significant source of uncertainty in the simulation of LGM and deglacial ocean circulation. Such resulting uncertainty should be considered in PMIP3 model-data comparisons with kinematic tracers and other water mass proxies.

A numerical study of the impact of meltwater pulses of polar origin on the Western Indian Ocean circulation since the Last Glacial Maximum .

Ilana Wainer & Juliana Marson

Changes in the Western Indian Ocean tropical circulation are examined using a transient simulation of the last 21,000 years with the Coupled Climate System Model v3 of the National Center for Atmospheric Research (NCAR-CCSM3). This simulation includes prescribed meltwater pulses in agreement to what has been identified with sea level records during this period. The purpose of the study is to isolate northern and southern hemisphere impacts considering that the Indian Ocean geometry is open in the South and occupied by continents to the north.
Results show how melt water pulses of northern hemisphere origin impact the western Indian Ocean through the atmosphere, while the impacts of a large meltwater pulse of southern origin, timed in the model at ~14,000 years ago to coincide with meltwater pulse 1A (MWP-1A) affect the ocean directly. In other words, the monsoonal regime in the model fluctuates with Greenland temperatures (as in Hong *et al.*, 2003) while the ocean responds to the meltwater flux coming from the Antarctica Ice Sheet freshening the usually high salinity waters that come from Red Sea and Persian Gulf.

The Labrador Sea at the Last Glacial Maximum

Kelsey Winsor[1], Anders Carlson[2], Alan Mix[2]
[1]*Dept. of Geoscience, University of Wisconsin-Madison*
[2]*College of Earth, Ocean, and Atmospheric Sciences, Oregon State University*

The Labrador Sea plays an important role in North Atlantic climate and Atlantic meridional overturning circulation. However, little is known about its response to greenhouse gas lowering and the growth of continental ice sheets at the Last Glacial Maximum (LGM). Here, we assess the temperature change of the Labrador Sea at the LGM relative to present. Planktic $\delta^{18}O$ records in the south, north, east, and west Labrador Sea show a consistent ~2 per mil increase at the LGM relative to the Holocene, of which 1 per mil is attributable to the growth of continental ice sheets. Planktic Mg/Ca measurements from the northeast Labrador Sea indicate ~3°C of near-surface Labrador cooling to ~1°C at the LGM (relative to the late Holocene), which would explain ~0.75 per mil of the $\delta^{18}O$ change. An increase in the fraction of Arctic foraminifera in the southern Labrador Sea suggests a similar 3-4°C of cooling at the LGM. The remaining <0.25 per mil $\delta^{18}O$ increase at the LGM could therefore reflect slightly saltier and enriched surface waters from reduced inflow of fresh Arctic waters. Because near surface waters were above freezing with calcifying foraminifera, we suggest that the Labrador Sea was seasonally sea-ice free at the LGM. Additional Mg/Ca analyses will further constrain the response of the Labrador Sea to LGM climate forcing.

Simulating δ 18O in CESM ocean model and its application to understanding meltwater events during Last Deglaciation

Jiaxu Zhang
University of Wisconsin-Madison

Earth System Models (ESMs) have been used to understand paleoclimate evolution as an independent line of evidence beside past proxy records. However, one great challenge for model-data comparison is that ESMs usually do not directly simulate geochemical variables that can be compared directly with proxies. We meet this challenge by developing the simulation capability of a series of major geotracers, including water isotopes, in a state-of-art ESM, the Community Earth System Model (CESM). Here we focus on the δ18O simulation in the ocean component of CESM. A surface isotopic flux forcing is introduced into the ocean model to represent the fractionation process and concentration change. We then evaluate the model performance in simulating δ18O based on the comparison with observations. We also show the simulated δ18O during the Last Glacial Maximum and the sequent deglaciation, and its potential application on constraining timing, location and strength of major meltwater events.

Different ocean states and transient characteristic in LGM simulations and implications for deglaciation

X. Zhang*, G. Lohmann, G. Knorr and X. Xu
Alfred Wegener Institute for Polar and Marine Research, Bussestrasse 24, D-27570, Bremerhaven, Germany
*Correspondence to: X. Zhang (xu.zhang@awi.de)

Abstract:
The last deglaciation is one of the best constrained global-scale climate changes documented by climate archives. Nevertheless, understanding of the underlying dynamics is still limited, especially with respect to abrupt climate shifts and associated changes in the Atlantic meridional overturning circulation (AMOC) during glacial and deglacial periods. A fundamental issue is how to obtain an appropriate climate state at the Last Glacial Maximum (LGM, 21,000 years before present, 21ka BP) that can be used as an initial condition for deglaciation. With the aid of a comprehensive climate model, we found that initial ocean states play an important role on the equilibrium time scale of the simulated glacial ocean. Independent of the initialization the climatological surface characteristics are similar and quasi-stationary, even when trends in the deep ocean are still significant, which provides an explanation for the large spread of simulated LGM ocean states among the Paleoclimate Modeling Intercomparison Project phase 2 (PMIP2) models. Accordingly, we emphasize that cautions must be taken when allegedly quasistationary states on the basis of surface properties are used as a reference for both model inter-comparison and data model comparison. The simulated ocean state with most realistic AMOC is characterized by a pronounced vertical stratification, in line with reconstructions. Hosing experiments further suggest that response of the glacial ocean is distinctly dependent on the ocean background state, i.e. only the state with robust stratification shows an overshoot behavior in the North Atlantic. We propose that the salinity stratification represents a key control on the AMOC pattern and its transient response to perturbations. Furthermore, additional experiments
suggest that the stratified deep ocean formed prior to the LGM during a time of minimum obliquity (~27ka BP). This indicates that changes in the glacial deep ocean already occur before the last deglaciation. In combination, these findings represent a new paradigm for the LGM and the last deglaciation, which challenges the conventional evaluation of glacial and deglacial AMOC changes based on an ocean state derived from 21ka BP boundary conditions.

Analysis of the ENSO stability in the mid-Holocene simulations of PMIP models

Zheng W.*, Chen L., Yu Y.

State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics (LASG), Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, 100029, CHINA

Abstract

The Bjerknes stability (BJ) index (Jin et al., 2006) is used to access the stability of El Niño – Southern Oscillation (ENSO) in the mid-Holocene simulations of the Paleoclimate Model Intercomparison Project (PMIP) models. The models show a large spread in ENSO stability defined by BJ index, which may be associated with the different representation of the mean climate and the air-sea interactions. Comparisons of the respective components in the BJ index with those derived from the observation show that all the PMIP models underestimated the positive effect of the thermocline feedback in the pre-industrial simulations, while others are inconsistent among models. For the mid-Holocene, most of the models show a positive correlation between the changes in BJ index and in ENSO amplitude (the larger BJ index the stronger ENSO amplitude, or vice verse). The changes of thermocline feedback are most important in the components of BJ index; however, no consistent change (increased or decreased) can be concluded among models. Therefore, the relationship between the changes in the mean state and the ENSO stability needs further study.

* Corresponding to Dr. Zheng Weipeng, Email: zhengwp@mail.iap.ac.cn

Coupled ice sheet – climate modeling of the LGM and the deglaciation

Florian A. Ziemen, Christian B. Rodehacke, Uwe Mikolajewicz

September **5**, **2013**

With a coupled ice sheet model – AOVGCM system, simulations were performed under steady-state last glacial maximum (LGM) and under transient glacial-deglacial boundary conditions. The model shows Heinrich-events as internal oscillations under steady state LGM boundary conditions as well as under transient forcings. The deep water formation areas and ocean circulation depend on the state of the ice sheets. We show results from the simulations and discuss the impact of the time-varying ice sheets on the climate system with focus on the ocean circulation.

For the experiments, we coupled a modified version of the Parallel Ice Sheet Model (mPISM) bidirectionally with the AOVGCM ECHAM**5**/MPIOM/LPJ. ECHAM**5** and LPJ were run in T**31** resolution (_ 3.75_), MPIOM on a grid with a nominal resolution of 3_ and poles over Greenland and Antarctica, mPISM on a **20**km grid covering most of the northern hemisphere. In the models, as well as in the coupling, no flux correction or anomaly maps are applied. The ice sheet surface mass balance is computed using a positive degree day scheme with lapse rate correction and height desertification effect.

Most experiments were performed with an **1**:**10** asynchronous coupling between the climate and the ice sheets. This allows covering the long time spans while still being able to study the interactions between the ice sheets and the climate system. One Heinrich event was modeled with a synchronous coupling. The steady state simulations were performed under LGM boundary conditions. The transient simulations were started **10 000** to **20 000** years before the LGM and reach into the Holocene.

The simulations show recurring ice sheet surges as consequences of an internal instability mechanism. We discuss these surges and their consequences for the ocean circulation. For the same orbital and greenhouse gas forcings, the transient simulations show different ice sheet configurations and ocean circulation states, including different locations of the deep water formation areas. We analyze these ocean circulation states and their implications for the climate.