Proposal for a Joint SCOR/IMAGES Working Group to Investigate the Reconstruction of Past Ocean Circulation

Abstract

Here we propose to form a working group, jointly supported by IMAGES and SCOR, which will (1) Assess currently available methods and data for assessing past ocean circulation and (2) Devise a plan for field and analytic studies which will lead to a better undertanding of past ocean circulation on millennial time scales over the last 120,000 years. This plan will outline a coordinated international project which we will refer to as the Paleocean Circulation Experiment (PACE).

Rationale

Investigations of past climate over the last several tens of millennia have shown that climate can change quite rapidly. For example, at the end of the Younger Dryas temperature jumped about two-thirds of the way from glacial to interglacial values in only a decade. Because of their ability to store and transport heat, the oceans are an integral part of the climate system. It has been postulated that the rapid climate changes inferred from the paleo-climate data result from changes in the Atlantic ocean circulation [e.g. *Alley and Clark*, 1999; *Rahmstorf*, 2002; *Sarnthein et al.*, 1994].

This hypothesis was driven by data from shell chemistry of foraminifera from deep sea sediments which suggested that nutrients were arrayed differently in the Atlantic over the course of these climate changes. However, even for the Last Glacial Maximum the existing nutrient data is insufficient to quantify an alternative ocean circulation state [*Legrand and Wunsch*, 1995; *Winguth et al.*, 1999]. When we turn to the rapid climate change events that occurred during the last glaciation and over the course of the deglaciation, the circulation scenarios based on nutrient reconstructions only become more poorly constrained.

However, there are several less widely applied methods for assessing rates of paleo-ocean circulation. These methods include assessing deep water residence times from Pa/Th ratios in sediments, assessing deep ocean ventilation from radiocarbon measurements in benthic corals and foraminifera, reconstructing geostrophic flows using density gradients inferred from oxygen isotope measurements and reconstructing the strength of near bottom current speed from physical properties of deep sea sediments.

The work of this group will be to bring together experts in these fields along with physical oceanographers and ocean modellers to come up with an effective and realistic research plan which will lead to a robust reconstruction of past ocean circulation. We will focus our effort on two timescales. The first is the last 120,000 years (covering an entire glacial cycle, along with most of the millennial scale climate changes during the last ice age), and the second is a higher resolution look at the period covering the deglaciation (the last 20,000 years).

Scientific Background

Several decades ago it was realized that chemistry of the shells of benthic foraminifera (carbon isotope and Cd/Ca ratios) carried an imprint of the nutrient content of deep water masses [*Boyle*, 1981; *Broecker*, 1982; *Shackleton*, 1977]. This led rapidly to the recognition that the water masses in the Atlantic Ocean were arrayed differently during the last glacial maximum than they are today, and the hypothesis that the glacial arrangement reflected a diminished contribution of low-nutrient North Atlantic Deep Water [*Boyle*, 1992; *Curry and Lohmann*, 1982]. More detailed spatial reconstructions indicated a shallow nutrient depleted water mass overlying a more nutrient rich water mass in the glacial Atlantic, which led to suggestions of the vigorous formation of a shallower water mass also originating in the North Atlantic. These findings spurred advances not only in geochemistry but in oceanography and climatology as well, as workers in these fields attempted to simulate the inferred glacial circulation patterns and assess the vulnerably of the modern ocean to such circulation changes.

While the nutrient distributions in the glacial Atlantic Ocean were consistent with a diminished flow of North Atlantic deep water, they also could have reflected an increase in inflow from the South Atlantic and/or a shallower yet undiminished deep water mass. Clearly tracers capable of giving information on deepwater flow rate, rather than nutrient content alone, were needed to more fully constrain the glacial ocean circulation. Differences between surface water (measured on planktonic foraminifera) and deep water (measured on coexisting benthic foraminifera) radiocarbon concentrations provided the first rate constraint [e.g. *Adkins and Boyle*, 1997; *Broecker et al.*, 1988; *Shackleton et al.*, 1988] Reduced amounts of Pa relative to the more particle-reactive Th in the glacial Atlantic suggested that deep water was exported from the Atlantic during glacial times [*Marchal et al.*, 2000; *Yu et al.*, 1996]. More recently density gradients (geostrophic shear) in upper waters have been used to infer changes in the upper ocean return flow that compensates the deep water export [*Lynch-Stieglitz*, 2001; *Lynch-Stieglitz et al.*, 1999a; *Lynch-Stieglitz et al.*, 1999b].

However, even for the relatively well studied last glacial maximum, the existing data are not sufficient to constrain Atantic Ocean circulation [e.g. *Broecker*, 2002; *Legrand and Wunsch*, 1995; *Winguth et al.*, 1999; *Wunsch*, 2003]. The lack of rate tracer data from many locations, inherent limitations in the nutrient tracer proxies, and insufficient chronological constraint probably all contribute to this inadequacy. Needless to say, the nature of last glacial maximum ocean circulation in the relatively data poor Pacific, Indian and Southern Oceans is even more poorly known than for the Atlantic. Again, while there is good evidence that the water masses were arrayed differently in these oceans, the data appears to be insufficient to quantitatively constrain the circulation changes. And, perhaps most importantly, even for the Atlantic Ocean, the time history of circulation changes over the millennial scale abrupt climate changes are also very poorly constrained. Evidence from carbon isotopes in benthic foraminifera is difficult to interpret, with carbon isotope excursions not related in a consistent one-to-one fashion with the millennial-scale variability observed in the surface ocean and ice cores. These inconsistencies are evident both for different events within individual sediment cores [*Elliot et al.*, 2002; *Oppo and Lehman*, 1995] and between different core locations for the same event [e.g. *Curry et al.*, 1999]. It is possible that the complex patterns seen in the carbon isotope records stem from the concurrent changes in deep water density as well as rates and location of formation. Adequate chronologic constraints are also necessary to reconstruct past ocean circulation states on these millennial time scales. For ages greater than 40,000 years before present, radiocarbon dating must be supplemented by other methods. As more attention focuses on the possibility that the meridional overturning circulation plays a primary role in sub-Milankovitch scale climate variability, it is crucial that we know how the strength of the overturning circulation changed on these time scales.

Understanding how ocean circulation changed in association with the abrupt climate changes during and since the last ice age is of prime importance to a broad scientific community. There is no theoretical reason why the mass circulation of the glacial ocean cannot be reconstructed from a well designed data base of tracer distributions and measurements of paleo-geostrophic shear [*Wunsch*, 2003]. A systematic assessment of the methods of reconstruction of past ocean circulation, along with a well thought out plan for a substantial data gathering effort are clearly needed if the paleoceanographic community is to make substantial progress on this problem. Our effort will focus on the last 120,000 years, with a special focus on the last 20,000 years. The former time period covers an entire glacial cycle, and all of the millennial scale climate variability during the last ice age. The chronology for this interval is currently improving with innovations in U/Th dating as well as detailed work in paleomagnetism of sediments. The latter time period encompasses the last glacial maximum, the most recent Heinrich event, the Younger Dryas climate reversal on the deglaciation, as well as the Holocene and is entirely within the range of radiocarbon dating.

Terms of Reference

This working group will undertake the following tasks:

(1) *Assess the existing paleoceanographic methods for reconstructing the history ocean circulation over the past 120,000 years.* Are the existing methods sufficient for a robust reconstruction of past ocean circulation? Are existing chronological tools sufficient to reconstruct distinct ocean circulation states? If not, what developments are necessary?

(2) *Assess the available paleoceanographic data for reconstructing the history ocean circulation over the past 120,000 years.* Can robust conclusions on past ocean circulation be drawn from the existing data? For what time periods and locations?

(3) *Develop an effective and realistic implementation plan to quantitatively assess the hypothesized changes in ocean circulation during over this same timescale.* The group would identify a minimum array of global locations and data types which would help to constrain changes in ocean circulation linked to major climatic changes, bearing in mind the potential for collecting appropriate geologic material as well as the size of the expected circulation signal relative to the uncertainties in the methods. Through international cooperation within IMAGES and ODP existing cores would be identified and plans for new coring to meet these objectives would be discussed.

Relationship to SCOR Objectives

This working group is particularly relevant to SCOR for several reasons. (1) Any research plan for progress in reconstructing past ocean circulation will require the full coordination of efforts of the international community. SCOR has the experience and support to mount international working and operational groups. (2) In addition, this will be an interdisciplinary group which will draw on the full expertise of members of all fields of modern and paleo-oceanography (numerical analysis and modeling, physics, chemistry, biology, geophysics, geochemistry, sedimentology). (3) Ultimately any research plan will involve extensive sampling along the continental margins of the world ocean. The sampling will take place in the EEZ of many countries, including developing countries. It will be particularly valuable if young scientists from these countries are incorporated into the research program as Ph.D. students and post-doctoral scientists.

Relationship to IMAGES-PAGES-IGBP Objectives

A robust reconstruction of past ocean circulation is vital if we are to understand how ocean circulation is linked to the dramatic changes in climate that have occurred over the past 120,000 years, as well as to understand the role that changes in ocean circulation could play as the climate changes in the future. IMAGES strives to better understand the role of ocean circulation in climate through coordination of research on past climate from ocean sediments. This working group will link closely with other IMAGES working groups such as EPILOG which is re-evaluating last glacial maximum climate reconstructions and with the ice and continental paleoclimatologists working through PAGES. IMAGES has the experience with field programs involving international action, high sampling resolution and multi-proxy analysis, and the data quality assessment, distribution and archiving needs of such programs. It is anticipated that IMAGES will provide longer term support for the Paleocean Circulation Experiment (PACE) through working group meetings and workshops at the conclusion of the four year working group proposed here.

Meetings and Schedule of Work

Year 1: Meeting of Working Group at AGU December 2003. The first formal meeting will take place during December 2003 in San Francisco, California, USA in association with the fall meeting of the American Geophysical Union. At this meeting the goals and agenda of the working group will be laid out. Planning for the Year 2 workshop (goals, agenda, list of invited speakers) will be discussed.

Year 2: Workshop at Lamont-Doherty Earth Observatory, Palisades, New York, USA November 2004. This workshop will bring together experts in various methods of paleoceanographic reconstruction with inverse modelers who have worked on constraining past and present ocean circulation using sparse data sets. Talks will be given in these areas, as well as reviews of existing data sets. Ample time will be allotted to discussion. Additional funds will be secured from U.S funding agencies to bring in a diverse group of researchers in addition to the Working Group members. The workshop will conclude with a working group meeting outlining work assignments and schedule toward producing the planning document.

Year 3: Meeting at EGS April 2005. Finalize recommendations for planning document.

Year 4: By the end of Year 4, the planning document will be completed.

Products

(1) The primary product of this working group will be a comprehensive planning document for a large, coordinated international program to reconstruct past ocean circulation (PACE, Paleocean Circulation Experiment). This report will incorporate the results from the above assessments and be distributed as a pdf and printed document.

(2) A report to EOS, the newsletter of the American Geophysical Union, documenting the tasks and results of the working group.

(3) A set of papers in a specialized journal resulting from the presentations and discussions of the workshop.

(4) A set of downloadable overheads (pdf) for the IMAGES/PAGES website summarizing the results and plans of the working group.

Working Group Membership

The proposed membership attempts to strike a balance between experts in ocean modeling and inverse methods and experts on paleoceanographic reconstruction, between experts of various nationalities and between various SCOR membership categories.

Proposed Members:

Jean Lynch-Stieglitz (Chair)	USA	Stable isotopes/geostrophic shear
Catherine Kissel (vice-Chair)	France	Paleo-current from sediment properties and chronology
Jess Adkins	USA	Radiocarbon, porewaters
Gideon Henderson	UK	Pa/Th and chronology
Juan Carlos Herguera	Mexico	Stable isotopes
Olivier Marchal	USA	Inverse modelling
Jochem Marotzke	UK	Ocean modeling
Stefan Mulitza	Germany	Upper ocean temperature
Ein-Fen Yu	Taiwan	Pa/Th
Rainer Zahn	Spain	Stable isotopes, trace metals

Corresponding Members (or alternate members):

Eduard Bard	France	Chronology, sea surface temperature
Thierry Fichefet	Belgium	paleo-ocean modeling
Jerry McManus	USA	Pa/Th
Ulysses Ninneman	Norway	Stable isotopes
Andrew Weaver	Canada	Paleoclimate modeling

References

Adkins, J.F., and E.A. Boyle, Changing atmospheric Δ14C and the record of deep water paleoventilation ages, *Paleoceanography*, *12* (3), 337-344, 1997.

Alley, R.B., and P.U. Clark, The deglaciation of the northern hemisphere: A global perspective, *Annual Review of Earth and Planetary Sciences*, *27*, 149-182, 1999.

Boyle, E.A., Cadmium, zinc, copper, and barium in foraminifera tests, *Earth and Planetary Science Letters*, *53*, 11-35, 1981.

Boyle, E.A., Cadmium and δ13C paleochemical ocean distributions during the stage 2 glacial maximum, *Annu. Rev. Earth Planet. Sci.*, *20*, 245-287, 1992.

Broecker, W.S., Glacial to interglacial changes in ocean chemistry, *Prog. In Oceanography*, *11*, 151-197, 1982.

Broecker, W.S., Constraints on the glacial operation of the Atlantic Ocean's conveyor circulation, *Israel Journal of Chemistry*, *42*, 1-14, 2002.

Broecker, W.S., M. Klas, N. Raganobeavan, G. Mathieu, A. Mix, M. Andree, H. Oeschger, W. Wolfli, M. Suter, G. Bonani, H. Hofmann, M. Nessi, and E. Morenzoni, Accelerator mass spectrometry radiocarbon measurements on marine carbonate samples from deep-sea cores and sediment traps, *Radiocarbon*, *30*, 261-295, 1988.

Curry, W.B., and G.P. Lohmann, Carbon isotopic changes in benthic foraminifera from the western South Atlantic: Reconstructions of glacial abyssal circulation patterns, *Quaternary Research*, *18*, 218-235, 1982.

Curry, W.B., T.M. Marchitto, J.F. McManus, D.W. Oppo, and K.L. Laarkamp, Millennial-scale changes in ventilation of the thermocline, intermediate and deep waters of the glacial North Atlantic, in *Mechanisms of Global Climate Change at Millennial Time Scales*, edited by P. Clark, R. Webb, and L. Keigwin, pp. 59-76, American Geophysical Union, Washington, D.C., 1999.

Elliot, M., L. Labeyrie, and J.C. Duplessy, Changes in North Atlantic deep-water formation associated with the Dansgaard-Oeschger temperature oscillations (60-10 ka), *Quaternary Science Reviews*, *21* (10), 1153-1165, 2002.

Legrand, P., and C. Wunsch, Constraints From Paleotracer Data On the North-Atlantic Circulation During the Last Glacial Maximum, *Paleoceanography*, *10* (6), 1011-1045, 1995.

Lynch-Stieglitz, J., Using ocean margin density to constrain ocean circulation and surface wind strength in the past, *Geochemistry Geophysics Geosystems*, *2*, art. no.-2001GC000208, 2001.

Lynch-Stieglitz, J., W.B. Curry, and N. Slowey, A geostrophic transport estimate for the Florida Current from the oxygen isotope composition of benthic foraminifera, *Paleoceanography*, *14* (3), 360-373, 1999a.

Lynch-Stieglitz, J., W.B. Curry, and N. Slowey, Weaker Gulf Stream in the Florida Straits during the Last Glacial Maximum, *Nature*, *402*, 644-648, 1999b.

Marchal, O., R. Francois, T.F. Stocker, and F. Joos, Ocean thermohaline circulation and sedimentary Pa-231/Th-230 ratio, *Paleoceanography*, *15* (6), 625-641, 2000.

Oppo, D.W., and S.J. Lehman, Suborbital Timescale Variability of North-Atlantic Deep-Water During the Past 200,000 Years, *Paleoceanography*, *10* (5), 901-910, 1995.

Rahmstorf, S., Ocean circulation and climate during the past 120,000 years, *Nature*, *419* (6903), 207-214, 2002.

Sarnthein, M., K. Winn, S.J.A. Jung, J.C. Duplessy, L. Labeyrie, H. Erlenkeuser, and G. Ganssen, Changes in East Atlantic Deep-Water Circulation Over the Last 30,000 Years - 8 Time Slice Reconstructions, *Paleoceanography*, *9* (2), 209-267, 1994.

Shackleton, N.J., Tropical rainforest history and the equatorial Pacific carbonate dissolution cycles, in *Fate of Fossil Fuel CO2 in the Oceans*, edited by N.R. Anderson, and A. Malahoff, pp. 401-427, 1977.

Shackleton, N.J., J.-C. Duplessy, M. Arnold, P. Maurice, M.A. Hall, and J. Cartlidge, Radiocarbon age of the last glacial Pacific, *Nature*, *335*, 708-711, 1988.

Winguth, A.M.E., D. Archer, J.C. Duplessy, E. Maier-Reimer, and U. Mikolajewicz, Sensitivity of paleonutrient tracer distributions and deep-sea circulation to glacial boundary conditions, *Paleoceanography*, *14* (3), 304-323, 1999.

Wunsch, C., Determining paleoceanographic circulations, with emphasis on the Last Glacial Maximum, *Quaternary Science Reviews*, *22* (2-4), 371-385, 2003.

Yu, E.F., R. Francois, and M.P. Bacon, Similar rates of modern and last-glacial ocean thermohaline circulation inferred from radiochemical data, *Nature*, *379* (6567), 689-694, 1996.