Beyond the Conveyor: A Proposal for an inter-disciplinary SCOR Working to Advance Training and Research in 'Palaeo Physical Oceanography'

Abstract

The palaeoceanographic record is uniquely important for our understanding of the global climate system. Many insights into the special climatic role of the ocean circulation have come specifically from palaeoceanographic reconstructions that extend beyond historical observation. However, there remains a significant gap between modern oceanographic theory and the conceptual framework that underpins palaeoceanographic inference. This can limit the impact and relevance of palaeoceanographic findings, or even distort their interpretation. By bringing together a group of leading palaeoceanographers, fluid dynamicists and oceanographers, the proposed working group will begin the process of closing the gap between palaeoceanography and modern ocean physics.

The proposed working group will engage in two phases of action, to be carried out over the course of four years. The first phase will produce a document for peer-reviewed publication, providing: 1) a review of recent developments in palaeoceanography, identifying where the conceptual premises of palaeoceanographic inference have yet to be harmonised with modern oceanographic theory; 2) a description of the most important research questions in palaeoceanography where the involvement of fluid dynamicists and physical oceanographers is likely to be essential; and 3) a description of research problems in physical oceanography that will benefit significantly from a uniquely 'geological' perspective. The second phase of work will involve direct engagement with researchers in both disciplines to develop identified research questions into funded projects and studentships. Three workshops will serve to bring the working group together for these phases of action and a dedicated web site will serve to inform members and interested parties of actions to be taken, deadlines and opportunities for collaboration or student exchange.

Our ultimate goal will be to identify and address the main challenges involved in reconciling our interpretation of the past with modern ocean physics. This will sharpen the focus of palaeoceanographic research, while at the same time broadening the impact and contemporary relevance of geological research into global climate change.

Rationale

Understanding the ocean circulation is crucial to understanding the climate system, including in particular its response to natural or anthropogenic perturbations. Predictions of the rate of atmospheric CO_2 rise and global warming rely to a large extent on accurate estimates of the thermal inertia of the ocean and its approach to chemical equilibrium with the atmosphere, both of which rely to a large extent on knowledge of the large-scale ocean circulation and its stability under changing climatic conditions.

In order to understand how ocean and climate interact, we may employ fluid dynamical theory (in complex numerical models or simplified thought experiments), we may study empirical data (covering the last few decades), or we may look to the geological record. The last of these options is unique in allowing us to witness the behaviour of the ocean under conditions that differ significantly from today. In short, the geological record allows us to test our theories of ocean-climate interaction outside of the historical 'calibration sample'.

Currently there is a growing realisation of the potential that palaeoceanographic study holds for the advancement of our understanding of the climate system. At the same time, it has become clear that the special character of palaeoceanographic evidence (e.g. sparse geographical coverage, inherent chronological uncertainty, indirect 'proxy' observations) requires a special approach to its interpretation: arguably, one that has yet to become pervasive in the palaeoceanographic community. It is therefore particularly timely to set up a SCOR working group that will focus on closing the gap between the fundamental principles and methods of contemporary physical oceanography and those of the growing field of palaeoceanography. Indeed, the time for merely critically comparing palaeoceanographic and physical oceanographic methods has passed; it is time now to move the field of palaeoceanography forward, precisely so that it can contribute more incisively to the field of modern ocean science.

A SCOR working group represents the ideal mechanism for achieving this goal. This is primarily because SCOR support: 1) admits and encourages cross-disciplinary membership, which will be essential to the proposed endeavour; 2) permits a broad international participation, which in our case will be important for building adequate momentum to move the field forward; 3) is not beholden to any government directive or national science base, but rather exists to serve the interests of ocean research in general; and 4) permits the establishment of a team with a sufficiently long-term (4 year) mandate to ensure that real progress can be made. In contrast, other (national or charity) support structures could not accommodate the necessary international (especially trans-Atlantic) participation, or ensure the sort of long-term support that this type of endeavour requires.

Scientific Background

Physical oceanographers and palaeoceanographers focus much of their attention on precisely the same phenomena (heat/material transports, deep western boundary currents, wind-driven upwelling, deep convection etc…). However, the types of observations available and the analytical approaches adopted differ substantially in each field. The skills and approaches required in palaoeceanography and in physical oceanography are not completely commensurate, and could not usefully replace each other. Nevertheless, it is clear that the analysis and interpretation of palaeoceanographic data could benefit greatly from the specialist insights of fluid dynamics or the methodological approaches of physical oceanography. Similarly, the reconstruction of past ocean/climate states may provide a unique 'palaeo-laboratory' for the investigation of phenomena that have yet to find consensus in physical oceanography. Cross-disciplinary research, with '*palaeo physical oceanography*' as its focus, has much to offer the fields of palaeoceanography and physical oceanography alike.

Twenty years ago, W. Broecker first described the large-scale ocean circulation system as '*The Great Ocean Conveyor*' (*1*). This pioneering metaphor has proven immensely influential and useful in ocean research. It condenses many important facts about the global overturning circulation, including the existence of localised regions of deep-water formation, the transport of water from the surface to the abyss and back again, and the fact that transports of water around the globe are highly connected and act to move a variety of climatically and biologically important chemical species both laterally and vertically. These important aspects of the overturning circulation, and the conveyor metaphor, have become explanatory pillars

in many areas of palaeoclimatology. Thus for example, the role of the global overturning circulation in glacial-interglacial carbon cycle change or the role of the Atlantic meridional overturning circulation (AMOC) in past abrupt climate change, are often explained in the palaeoceanographic literature in terms of the 'strength' of the conveyor circulation (*2-4*). At times this may represent a form of shorthand, providing a parameterisation of a more specific aspect of the ocean circulation that cannot yet be inferred from the existing palaeoceanographic data. However, as palaeoceanographic data become more varied and more detailed, our ability to go beyond this type of explanation becomes warranted, or even necessary. In this case it is important to ensure that our interpretations are not limited to the scope of the explanatory metaphor that happens to be at our disposal.

It is widely recognized that the 'conveyor' metaphor, although an immensely useful schematic, does not capture some key aspects of the ocean circulation system, and is therefore inherently limited as an explanatory metaphor (*5*). For many palaeoceanographic research questions, for example concerning glacial-interglacial CO_2 change or abrupt climate variability, it is becoming increasingly apparent that an enhanced conceptual model of the ocean circulation is required if significant progress is to be made. For example, it is now clear that our interpretation of the past must admit a broad range of transport timescales and pathways in the ocean (*5, 6*), as well as the importance of deep-water source regions outside of the North Atlantic (*7*). It has also been suggested that in considering the role of the ocean circulation in past abrupt high-latitude climate change, disproportionate attention has been focused on the role of deep circulations, relative to upper ocean transports (*8*). Similar questions have been raised concerning the energy budget of the ocean, and the relative importance of thermohaline density gradients *versus* wind-driven momentum transfers or turbulent mixing for the maintenance of the deep ocean circulations (*9*). Indeed, one of the main blind spots of the conveyor paradigm is with regard to relatively small-scale turbulent mixing processes (e.g. internal gravity wave breaking) that are important for both material and energy transfers in the ocean interior. It is possible that such processes could prove to be crucially important for transitions between different ocean and climate states in the past.

All of the above refinements of the 'great ocean conveyor' metaphor are active areas of research in physical oceanography, but they are also of direct relevance to a number of key research questions in palaeoceanography. In order to advance both of these fields together, it will be necessary to design research projects that specifically target 'post-conveyor' hypotheses, and that draw on cross-disciplinary expertise. This will require that new analytical (statistical, inverse, assimilation) methods be adapted specifically to palaeoceanographic datasets, which carry both drawbacks and significant advantages over contemporary observations. The interpretation of existing palaeoceanographic data will thus be improved, as will the design of future palaeoceanographic analysis programmes and the state of ocean research in general.

Statement of Work and Terms of Reference

The proposed working group will engage in two phases of action. The first phase of will:

1. ***Review recent key developments*** in palaeoceanography, and identify where the conceptual premises of palaeoceanographic inference have yet to be harmonised with modern oceanographic theory.

2) ***Identify the most important research questions in palaeoceanography***, specifically where the involvement of fluid dynamicists and physical oceanographers is essential.

3) ***Identify key research problems in physical oceanography*** that will benefit specifically from 'geological' observations.

4) ***Summarize the above findings for publication*** in a widely accessible scientific periodical.

5) ***Establish a web-based forum*** to facilitate the management of the working group's activities (e.g. by informing members of required actions and deadlines) and to advertise opportunities for inter-disciplinary exchange via studentships or post-doctoral projects.

The second phase of work will involve direct engagement with researchers in both disciplines to develop the research questions identified previously into nationally/internationally funded projects and studentships.

In order to meet these terms of reference, the working group will need to meet at least three times. Prior to the first meeting, informal gatherings of working group members will be convened at the 2010 AGUT Fall Meeting (San Francisco, USA) and again at the 2011 European Geosciences Meeting (Vienna, Austria). These informal meetings will serve to lay the groundwork and clarify the agenda for the first formal meeting. The first formal meeting is proposed for the autumn of 2011, and will serve to accomplish the bulk of the first phase of work, in preparation for the writing of the preliminary 'summary/recommendation' report. The second meeting will take place one year later in 2012, and will involve a sub-set of the working group membership. This second meeting will have as its aim the finalisation of the summary/recommendation report for publication. The third and final meeting will take place two years later in 2014, and will take the form of an open science meeting. Funding for this meeting will be sought independently, through the European Science Foundation (ESF) or the Royal Society (UK) for example. The goal of this final meeting will be to share the working group's activities and momentum with the wider ocean research community.

It is intended that the working group proposed here will build upon two preceding SCOR working groups in particular: the IAPSO/SCOR WG 121 on Ocean Mixing (chaired by R. Muench), and the SCOR/IMAGES WG 123 on Reconstruction of Past Ocean Circulation (PACE; chaired by J. Lynch-Stieglitz). In order to ensure synergies between these working groups and their outputs we have nominated members/associate members who have been closely involved in WG 121 and WG 123. Whereas these previous working groups have engaged in detailed reviews within their respective fields (palaeoceanography and physical oceanography), our proposed working group aims, in effect, to bring their findings together to motivate new and incisive research at the juncture of these two disciplines.

Working Group Membership

Membership of the proposed working group should be internationally inclusive and with roughly equal participation of palaeoceanographers (P in the list below) and physical oceanographers (or fluid dynamicists, numerical modellers, statisticians; O in the list below). It is proposed that the group be chaired by an early career research scientist who will be able to direct the working group's activities without dominating

its discussions. A chair and a co-chair are nominated below, representing each of the main research fields. The chair of the group will be responsible for convening the meetings and drawing up the draft reports. The working group membership proposed below is provisional and it is expected that a final list of participants will be obtained through consultation with the SCOR steering committee.

Proposed Full Members

Luke Skinner (chair)	GB (P; deep-water temperature/radiocarbon)
Peter Huybers (co-chair)	USA (O; state estimation inverse methods)
Eric Galbraith	CAN (P; biogeochemical cycling)
Helen Johnson	GB (O; AMOC stability and theory)
Francois Primeau	USA (O; transit time/pathway distribution methods)
Benedicte Lemieux-Dudon	France (O; Bayesian statistics, chronology modelling)
Trond Dokken	Norway (P; North Altantic water properties)
Stefan Mulitza	Germany (P; East Atlantic properties, global database)
Cristiano Chiessi	Brazil (P; South Atlantic water properties)
(To be named)	Asia/Pacific region (O/P)

Proposed Associate Members

Olivier Marchal	USA (O; state estimation techniques)
Axel Timmermann	USA (O; palaeoclimate modelling)
Carl Wunsch	USA (O; inverse methods, modern hydrography)
Michael McIntyre	GB (O; fluid dynamical theory)
Jean Lynch-Stieglitz	USA (P; stable isotopes, palaeo-densities)
Jody Klymak	CAN (O; turbulent mixing processes)
*Chris Garret	CAN (O; turbulent mixing processes)
Jess Adkins	USA (P; global water properties, ventilation timescales)
Andy Watson	GB (O; Southern Ocean mixing processes)

**Chris Garret is proposed as a link with the IAPSO/SCOR WG 121 on Ocean Mixing, though this link might also be provided by Jody Klymak.*

References

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