FRIDAY

CLIMATE STABILITY AND INSTABILITY — TRANSITION FROM FLYWHEEL TO DRIVER

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My assigned task is to explore to what extent the ocean “merely” serves as a long-term memory of the climate system, responding to atmospheric perturbations, and to what extent oceanic processes can trigger climate transitions. The focus will be on the Atlantic’s meridional overturning circulation (MOC). First, I will draw some general conclusions about the dynamics of the MOC from basic observational facts. Then, I will discuss the intricacies of deciding between “driver” and “flywheel” with the example of ocean mixing. Moreover, I will show examples demonstrating how conclusions about the role of ocean mixing and surface forcing fundamentally depend on the timescales considered.

Ultimately, our views of the MOC as “driver” or as “flywheel” must be decided by continuous observations of the MOC itself and the factors influencing it. I will present a concept for observing the MOC on a continuous basis, and will argue that the philosophy behind this concept could serve as a case study for long-term ocean observations within CLIVAR.

THE FUTURE OF CLIMATE OBSERVATIONS IN THE GLOBAL OCEAN

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A central part of the WOCE and TOGA legacy is the global ocean observing system for climate. The scientific basis for such a system is to a significant extent defined by WOCE’s results and by WOCE’s limitations. While the global hydrographic survey in the 1990’s was the first of its kind, providing the patterns of ocean heat transport and revealing decadal variability in large-scale property distributions, WOCE also demonstrated the importance of ocean-climate variability on timescales faster than the shutter-speed of this “snapshot”. TOPEX/POSEIDON was enormously successful in measuring global variability in sea-surface height and it stimulated efforts to match its global scope with subsurface datasets. WOCE produced revolutionary new technologies for observing the ocean, such as profiling floats and moored profilers. It made improvements to existing technologies for more accurate measurements of CTD/O_2 /Nutrients/ Geochemical tracers, plus ocean currents and marine meteorology. It devised new observational strategies such as the High Resolution XBT Network to document time variability from the mesoscale to the basin-scale, and it discovered new value in existing sampling modes such as Time-Series Stations. These WOCE advances, along with parallel TOGA contributions such as the Tropical Moored Buoy Network, have now been incorporated into the design of global ocean observations for climate (Koblinsky and Smith, 2001, *Observing the Oceans in the 21st Century*). New funding has become available through a partnership of research and operational users. We now have the opportunity to build an enduring ocean observing system (OS)—one having great value to mankind and society—that could not be imagined at WOCE’s outset. The design of an OS for climate is not finished or frozen. Major challenges remain, including:

- The boundary currents (BCs), western and eastern. The Argo Project will observe the global ocean in near-real time, but its 3° resolution will not be adequate for BCs. A BC counterpart to Argo is needed. Autonomous gliders can fill this gap, but there are technical, design, logistical, and political challenges.
- Biogeochemical measurements. Autonomous technologies have evolved rapidly for cost-effective global physical measurements (T,S,v). A practical strategy is needed for enhancement of the OS with biogeochemical measurements, including autonomous, moored, VOS and R/V-based elements. Development of stable, low power sensors is a requirement.
- Observations and models. Observations must fill many roles in relation to model initialization and data assimilation. The evolution of the OS must be harmonized with the state of modeling

and data assimilation and the results used to demonstrate value of the OS. Testing and improvement of model and assimilation parameterizations is also a key role.

- The research/operations partnership. The evolution of the OS has been inspired by scientific knowledge and technical progress. The present close integration of research and observation must be maintained. The research-application partnership provides further opportunities for investment and efficiency and a measure of long-term surety.
- Data and information management. Technical innovation and improved techniques are needed if the effectiveness of data management (quality control, assembly, distribution) is to match the evolution in observation and modeling and assimilation. The extension into multi-disciplinary partnerships and broader and more sophisticated use of data demands such change.

WOCE, THE OCEANS, AND THE WCRP

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The oceans play a mayor role in the climate system because of their large heat capacity, heat transport, moisture supply and gas storage. The World Ocean Circulation Experiment has, therefore, become a substantial and important component of the World Climate Research Programme. WOCE has grown into the largest oceanographic experiment ever undertaken. It has changed our view of the oceans, and it provided a strong foundation for future oceanic research within the WCRP and the wider global change community. A view on this role of WOCE and future ocean research from a WCRP perspective is presented.

AFTER WOCE WHAT ARE THE REMAINING CHALLENGES AND HOW SHOULD WE SET ABOUT MEETING THEM?

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The main focus of WOCE has been on a quantitative description of the large-scale ocean circulation, both through observations and models, with the objective to better understand the role of the oceans in the physical climate system. It is my view that past-WOCE research should go beyond ocean physics and also investigate the interactions of ocean physics with other aspects of the global environment, including but not limited to climate issues. The objective should be to develop and validate the ocean component of earth system models suitable for the simulation of the present environmental state, for a dynamical understanding of past environmental changes and for the prediction of future anthropogenically caused changes.

Among the scientific issues discussed are

- the role of small-scale physical processes for the circulation. This concerns e.g. the turbulent diapycnal mixing in the ocean and its role for circulation dynamics, high-latitude convection, flows through narrow straits which crucially determine watermass properties and large-scale transports, and the interaction of eddies with mean circulation.
- describing and understanding the dynamics of ocean circulation variability at all time scales. A reconstruction of the ocean circulation during much of the 20th century, through combination of oceanic and atmospheric observations with models, could help to focus on the question to which degree the observed deep ocean state is in equilibrium with the forcing over that period. On longer time scales, proxy data need to be utilized to develop concepts on the dynamics of observed variability.
- the controversial role of the extratropical ocean circulation for climate variability. While atmospheric model results suggest a rather passive role of extrattropical ocean dynamics scales and challenge the traditional view of oceanographers regarding the importance of ocean meridional heat transport, paleoceanographic results suggest that on centennial-to-millenial scales climate variability is controlled by thermohaline circulation changes.
- the interaction of ocean circulation with biogeochemical cycles. This includes the role of circulation changes for biogeochemical processes such as biological production and the

cycling of carbon and other relevant tracers, in particular those that can serve as proxies for paleo studies, and also the question how (and on what time scales) changes in biogeochemistry can feed back on the physical state.

Other issues adressed are the contributions to the development of an ocean observing system including operational applications, the necessities for the development of ocean model development, and the international organisation of past-WOCE research.