

A National Oceanographic Partnership Program Award

A Consortium for Ocean Circulation and Climate Estimation

John Marshall

Department of Earth, Atmospheric, and Planetary Sciences, Room 54-1526
Massachusetts Institute of Technology, 77 Massachusetts Ave., Cambridge, MA 02139
Phone: (617) 253-9615 fax: (617) 253-4464 email: marshall@gulf.mit.edu

Carl Wunsch

Department of Earth, Atmospheric, and Planetary Sciences, Room 54-1520
Massachusetts Institute of Technology, 77 Massachusetts Ave., Cambridge, MA 02139
Phone: (617) 253-5937 fax: (617) 253-4464 email: cwunsch@pond.mit.edu

HTML link: <http://ecco-group.org/>
other sites closely linked to the project:

<http://mitgcm.lcs.mit.edu/>

<http://ecco.jpl.nasa.gov/odap/>

<http://ecco.ucsd.edu/>

Grant Number: N000149510967

Long-Term Goals

To bring ocean state estimation from its present experimental stage on to an operational footing in which global ocean circulation models are routinely constrained by remotely sensed and in-situ data to yield the evolving three-dimensional state of the ocean.

Objectives

To develop and apply ocean circulation models and state estimation techniques in support of global ocean state estimation.

Approach

The approach we are taking is to:

- (i) develop the MIT ocean circulation model in support of state estimation applications-improved algorithms and physical parameterizations of the forward model and maintenance and scientific application of its tangent linear and adjoint counterparts (J. Marshall and Carl Wunsch together with research scientists A. Adcroft, C. Hill and P. Heimbach).
- (ii) explore different estimation methods, including robust control approaches (C. Wunsch and postdoc M. Losch).
- (iii) analyze and scientifically explore the ECCO state estimates and produce products to test them (C. Wunsch, postdoc J. Scott, students X. Li, G. Gebbie).

Work Completed

The MITgcm that is at the heart of the ECCO data assimilation system has undergone continued improvement (Adcroft, Hill, and Marshall). The model has been documented and release 1 was made public at the end of September 2001-see <http://mitgcm.org/sealion/>. Papers are in

A National Oceanographic Partnership Program Award

preparation include (i) the deployment of MITgcm on 'the cubed sphere', our gridding solution for the sphere, (ii) atmosphere-ocean modeling using atmosphere-ocean fluid isomorphisms (iii) conservative treatments of the free surface in MITgcm and (iv) non-Boussinesq ocean modeling with MITgcm employing pressure as a vertical coordinate.

In Stammer et al. (2002a,b,c) we completed first overall discussions of ECCO results including tests of estimates against withheld data. Several other papers, listed in the References, describe aspects of the results. State estimates have been used to calculate global flux divergences (with S. Josey and W. Large) and energetics of the ocean circulation studied (with J. Scott) and compared to independent estimates, some of which were prepared by us. One student (G. Gebbie) has an eddy resolving version of the model in the subduction experiment region to understand eddy-resolving data assimilation. Another student (X. Li), using the offline code, has constrained the model with tritium and fluorocarbon data.

We have also been involved in 'outreach'- in August of 2002 the MIT group hosted a z-coordinate modeling meeting at MIT - see <http://ogcm.org/index.htm>. About 50 people attended the meeting from all over the world.

C. Wunsch co-directed the WOCE Young Investigator's Workshop at NCAR.

Results

In collaboration with Scripps and JPL, the ECCO assimilation system has been used to demonstrate that global ocean models can be meaningfully constrained by global observations to yield an estimate of the evolving state of the ocean (see figure 1). Moreover, we have shown that the resulting state estimates are better than that which would be obtained by using either observations or models alone. These are described in two submitted papers-Stammer et al. (2001 a,b).

Four manuscripts on ECCO state estimates and their scientific interpretation were completed or nearly so. We showed a clear importance of high energy, high latitude barotropic motions to sampling and modeling the ocean.

Our future goal is to continue to improve our models and assimilation schemes and make global state estimates at higher, and eventually, eddy-resolving resolutions.

Impact and Applications

National Security

NOPP funding has supported the development of high performance numerical code and software support for massively parallel computation that would have wide, although not direct application to national defense and homeland security

Economic Development

Possible commercialization of ocean state estimation products produced by ECCO

Quality of Life

A National Oceanographic Partnership Program Award

ECCO provides estimates of the evolving state of the ocean and so could be used to monitor pollution, climate change in the ocean, ice cover etc.

Science Education and Communication

ECCO could have a huge impact on science education by providing estimates of the evolving state of the ocean

Related projects

ECCO is a close collaboration between Scripps (Professor Detlef Stammer) (<http://ecco.ucsd.edu/>), JPL (Drs. Lee Fu and Ichiro Fukumori) (<http://ecco.jpl.nasa.gov/odap>) and MIT.

The FRONTS project, led by Professor Jim O'Donnell and Dr Chris Edwards (<http://nopp.uconn.edu>), also makes use of the models and techniques developed here.

Publications

The following publications made direct use of the models developed and run with ECCO support.

Bugnion, V. and C. Hill (2001a) The climatological sensitivity of thermohaline overturning strength, an adjoint study. Part I-The idealized behavior of decadal to centennial thermohaline sensitivity, submitted to *Journal of Climate*.

Bugnion, V. and C. Hill (2001b) The climatological sensitivity of thermohaline overturning strength, an adjoint study. Part II-Thermohaline overturning sensitivity in the contemporary climate, submitted to *Journal of Climate*

Dutay, J.-C., J. Bullister, S. Doney, J. Orr, R. Najjar, K. Caldeira, J.-M. Champin, H. Drange, M. Follows, Y. Gao, N. Gruber, D. Hecht, A. Ishida, F. Joos, K. Lindsay, Madec, E. Maier-Reimer, J. Marshall, R. Matear, P. Monfray, Plattner, J. Sarmiento, R. Schlitzer, R. Slater, I. Totterdell, M.F. Weirig, Y. Yamanaka, , and A. Yool (2001) Evaluation of ocean model ventilation with CFC-11: Comparison of 13 global ocean models, *Ocean Modeling*, 4, 89-120.

Ganachaud , A. and C. Wunsch (2002) Large-scale ocean heat and freshwater transports during the World Ocean Circulation Experiment, *J Climate*, in press.

Li, X. (2002) *Constraining the North Atlantic Circulation with Transient Tracer Observations*. PhD Thesis, MIT/WHOI, 194pp.

Losch, M. and C. Wunsch (2002) Bottom topography as a control variable in an ocean model, submitted for publication.

McKinley, G., M.J. Follows, and J.C. Marshall (2002) "Impact of Interannual Variability in Air-Sea O₂ Fluxes on the Determination of Global CO₂ Sinks Using Atmospheric O₂/N₂" to appear in *Geophys. Res. Lett.*, 27: 2933-2936

A National Oceanographic Partnership Program Award

Stammer, D., K. Ueyoshi, W. B. Large, S. Josey and C. Wunsch (2002) Global sea surface flux estimates obtained through ocean data assimilation. *J. Climate*, in press.

Stammer, D., C. Wunsch, R. Giering, C. Eckert, P. Heimbach, J. Marotzke, A. Adcroft, C.N. Hill, and J. Marshall (2002a) Volume, heat and freshwater transports of the Global Ocean Circulation 1992-1997, estimated from a general circulation model constrained by WOCE data, *J. Geophys. Res.*, DOI: 10.1029/2001JC000088

Stammer, D., C. Wunsch, R. Giering, C. Eckert, P. Heimbach, J. Marotzke, A. Adcroft, C.N. Hill, and J. Marshall (2002b) The global ocean circulation during 1992-1997, estimated from ocean observations and a general circulation model, *J. Geophys. Res.*, in press.

Stammer, D., C. Wunsch, I. Fukumori, and J. Marshall (2002c) State estimation in modern oceanographic research, *EOS*, 83(34), 289 and 294-295.

Stammer, D. and C. Wunsch (2002) Global ocean data assimilation and geoid measurements, *Space Science Revs.*, in press.

Wunsch, C. (2002) Oceanic age and transient tracers. Analytical and numerical solutions, *J. Geophys. Res.*, 107(C6), 1-1 to 1-16 DOI: 10.1029/2001JC000797.

Wunsch, C. (2002) Does the ocean have a "thermohaline circulation," and if so, what is it? To be published.

