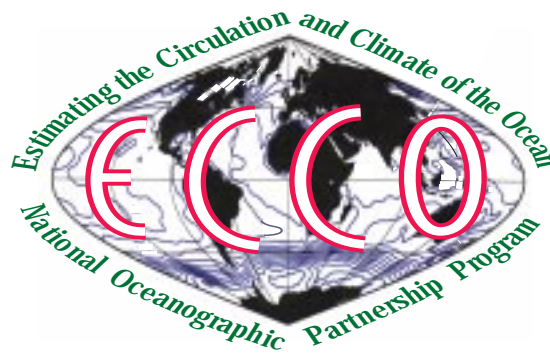


*The ECCO Report Series*¹

**Report of the 4. ECCO Meeting
May 31 and June 1
Green Building
Massachusetts Institute of Technology**



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Meeting Summary

The 4th ECCO meeting took place about 1.5 years into the project and represents the transition from previous exploratory work into sustained activities. This report will provide a summary of accomplishments and action items emerging from the meeting and will provide brief summaries of individual meeting contributions subsequently.

The central objective of ECCO is to produce a physically consistent 16+ year (1985 to present) analysis of the global ocean circulation at $1/4^\circ$ resolution using all available observations and to study the physical processes underlying the oceanic evolution. This is an ambitious goal driven by both scientific and practical requirements, and involves significant innovation and development in ocean modeling and estimation.

During its first two years, ECCO has focused on establishing the technical foundations of the project by developing and improving state estimation tools (parallel OGCM, its adjoint, automatic differentiation, and Kalman filter-RTS smoother). From those activities several results are now available that accomplish the first of their kind dynamically consistent ocean state estimates. Building upon these achievements, the ECCO project is now transitioning toward sustained product generation as envisioned in the ECCO proposal in support of CLIVAR and GODAE.

The next major goals of the ECCO Consortium are to produce two major analysis products: (1) A WOCE Synthesis of all of the available data during the WOCE field period, done to the highest resolution and with the nearest to optimal estimation method that are feasible. (2) A near-real time product, whose time delay is to be no longer than about two weeks, using most of the available continuing data, and an estimation method sensibly compromising the need for optimality with that for computational efficiency. Product (1) is the primary, but not sole, responsibility of SIO, (2) is the primary, but not sole responsibility of JPL. In addition, model development will continue, primarily at MIT, with scientific analysis, regional estimates, and experimental method studies taking place at all institutions.

1 Action Items

Several action items emerged from the meeting.

1. The next ECCO Meeting will take place January 24/25, 2002, in the Pasadena vicinity and will be hosted by JPL.
2. D. Stammer will prepare a detailed ECCO Report of the 4. Meeting. The report will be printed as part of the ECCO Report Series and will be send to all agency representatives.
3. From each group an ONR Report is due Sept. 28, 2001. D. Stammer will write one joint NOPP report at the end of the year for the entire consortium.

4. Several ECCO Live Access Servers (LAS) are in place and need to be completed. We will need to prepare one joint front page from where users can get to different model outputs.
5. With the new LAS in place the ECCO web page will be revised and will then contain a statement about or goals and products.
6. Interaction with other NOPP nodes: We need to enhance our interactions with other NOPP nodes. During the meeting several opportunities came up regarding the HYCOM and the FRONT NOPP nodes. In addition interaction with the virtual NOPP data hub are required to complete the ECCO LAS. All those interactions will be pursued over the next 6 months.
7. AGU Fall Session on estimation: a special session on estimation has been submitted and we expect 10 - 15 submission from the ECCO consortium to that session.
8. Highest priority in the near term needs to be on:
 - i) a completion of a new working version of the optimization build on the UV code. This new version needs to be completed over the next 3-6 weeks through interactions between Patrick, Ralf, Elisabeth and Detlef.
 - ii) A precise ECCO Work Plan and definition of ECCO Products will be required and needs to be completed over the next 6 weeks. First action will be taken by Ichiro and Detlef to merge the JPL and SIO activities in to one coherent ECCO activity. This activity needs to merge technical issues into production of core ECCO products for short-term and reanalysis purposes. The work statement also need to include next stages of ECCO model developments with deadlines.

2 ECCO Accomplishments

Past efforts have largely been oriented towards technology building and have capitalized on the strength of individual institutions. They have produced initial ECCO products that now need to be improved and sustained. The future ECCO work builds upon these past achievements that include (1) model development, (2) preliminary WOCE-type synthesis, (3) prototype routine high-resolution analysis, and (4) exploratory process studies applying these tools.

1. A parallel version of the MIT model and its adjoint have been developed so as to model the ocean circulation using state-of-the-art massively parallel supercomputers. This model development effort has been led primarily by the MIT group. The parallel model, named MITgcmUV (MIT general circulation model, ultra versatile) is a complete re-write of the earlier serial vector version of the code (now called "MITgcm Classic"). Reflecting the parallel architecture, previous data infrastructures were re-coded and many new numerical and physical improvements have been implemented. A significant development was also

undertaken of the automatic adjoint compiler with regards to processing message passing commands used in the parallel program. At this time, the MITgcmUV version C40 is near completion and will be the basis for future product generation and the first ECCO code release to the public community.

2. A global synthesis on a 2° global grid for the period 1992 through 2000 was made using a major subset of the WOCE data and the adjoint of MITgcm Classic (the solution is called “ECCO-1”). Control terms included initial temperature and salinity fields and daily surface momentum, heat and fresh water fluxes. This computation, led by the SIO team, is the most comprehensive model-data synthesis to date with respect to the amount and type of observations used, the duration, and the complexity and sophistication of the model and assimilation methodology.
3. A global data synthesis employing a combination of the adjoint and a Kalman filter/smoothing has been used experimentally at JPL on a telescoping grid with 1° resolution in latitude and longitude in mid and high latitudes and a meridional resolution decreasing to $1/3^\circ$ near the equator. This analysis, referred to as “ECCO-2”, focuses on the seasonal-to-interannual variability of the ocean. It assimilates TOPEX/Poseidon sea level anomalies, climatological mean temperature and salinity, and surface flux data from 1993 to present. This effort helped early development of the parallel MITgcmUV and spearheaded the creation and application of its adjoint. ECCO-2 has achieved advanced data assimilation at the highest global resolution to date (1×0.3 -deg grid in the tropics with 46 vertical levels, 10-m layers in the upper 150 m). The analysis employs an approximate Kalman filter/smoothing and the adjoint method separately to explore the synergy of the two approaches (e.g., accuracy, computational requirements, error estimates). A combined approach will capitalize on their respective merits and will facilitate future ECCO product generation.
4. Numerous process studies have been carried out at all three institutions using the old and new model codes, their adjoints, and existing assimilation products. Firstly, a nested estimation approach was established at MIT by using a regional model with enhanced resolution that builds on the global optimization by using the initial and boundary conditions (lateral and surface) as input for an improved regional estimate which then also optimizes the open boundary conditions. This procedure was tested at MIT in the North Atlantic Ocean and separately in the subtropical subduction Region and is being adopted now in the tropical Pacific at SIO.

Many of our global science foci are related to ocean variability, and associated interaction of the ocean with the atmosphere. Accordingly phenomenological studies on basin to global scale will include the calculation of meridional fluxes and flux divergences of heat, fresh water, carbon and nutrients so as to determine the basic oceanic climate state and its interaction with the atmosphere.

Results of both ECCO-1 and ECCO-2 are now being analyzed for various studies and applications with particular foci in estimating transports and budgets of mass, heat, freshwater, and energy across various regions of the global domain. They are also being examined to assess improvements in air-sea fluxes of momentum, heat, and freshwater, to quantify the relative impact of different observing systems, to study barotropic dynamics, and to improve forecasting skills. The output from the optimizations are also being used beyond the traditional realm of physical oceanography such as applications to the Earth's angular momentum budget and to studies of biogeochemical tracer transport and distribution.

To enable the wide community to use ECCO results, Live Access Servers were created by the project which are now in place. The output of the two assimilation efforts are available to the wider community via the central ECCO data server at <http://www.ecco-group.org/las>). In addition to these model products, the first MIT ECCO model release (C40) and its adjoint are also available at <http://www.ecco-group.org>. The ECCO server has been established to support a general user community of the ECCO products and its tools. The server also carries the input observations as they were used during the various experiments for reference.

3 Ongoing Activities

Our central technical goals for the future will be:

- To incorporate all available data types, develop associated error covariances, and to continue to improve models in support of the global estimate.
- A complete global-scale ocean state estimation over the 15 year period 1985-2000 at the highest possible resolution along with a complete error description.
- To develop near-real time capabilities in support of community needs.
- A 50 year long global synthesis on 1° resolution.

Related ongoing activities over the next few months will include:

1. At JPL: A Kalman Filter/Smoother for the period 1992 - 2000 on a variable grid and an adjoint run on the similar grid over various periods that will establish the near-real time effort (I. Fukumori, T. Lee).
2. At SIO: a 2° global adjoint run with KPP, a drift constraint and kappa and viscosity as controls.
3. At SIO: a 1° global adjoint full WOCE synthesis (E. Remy) This activity needs to be finished and analysed before the final WOCE conference end of 2002.

4. At LEGOS/CNRS/SIO: Higher-res. North Atlantic nested in global result (N. Ayoub).
5. At SIO: a $1/6^\circ$ Sub-polar North Atlantic to test high-resolution capabilities (A. Koehl).
6. At MIT/SIO: Subduction box, nested (P. Heimbach, O. Leeuwenbourgh, G. Gebbi).
7. At SIO: A high-resolution tropical Pacific box, nested (V. Thierry, B. Cornuelle).

Ongoing parameter estimations include air/sea fluxes and viscosity and diffusion coefficients as part of the control space. New eddy transfer parameterizations and extensions of the forward model to relax the Boussinesq parameterization are on their way. Both forward and adjoint models are being used for observing system design studies.

4 Ongoing Collaborations

ECCO representatives are members of various CLIVAR and GODAE steering teams and ensure that ECCO activities comply with community needs.

During this meeting representatives from two other NOPP nodes were present and reported about their work. Both reports suggested enhanced collaborations in the near future to fertilize the work of individual nodes by those from the others. Other specific interest for the FRONT node is technology and data transfer. The FRONT uses already the MIT forward model code. In the future the adjoint code and the boundary conditions provided from the global ECCO estimates will be required as well.

The HYCOM consortium is active in the Atlantic and on global scale. Of specific interest for the HYCOM consortium is a comparison of results with the goal to define metrics of goodness and to investigate uncertainties obtained from the different model runs.

Other ongoing interdisciplinary interactions include:

1. Tracer and/or biology: here M. Follows, P. Falkowsky, R. Weiss use the estimated physical model state to simulate bio-geochemical processes in the ocean. The next step will be to include some of those computations online into the estimation procedure, to investigate, e.g., the effect of tracers on the estimate of the physical circulation.
2. Earth angular momentum: in collaboration with R. Ponte we have demonstrated that estimates of the Earth's angular momentum can be improved using the constrained simulation of the ocean circulation.
3. Climate model initialization: P. Stone, T. Barnett (ACPI) have begun to use the estimated ocean state as initial conditions for coupled ocean climate runs. However, as a first step one has to assure that the estimated ocean state and related surface fluxes are compatible with coupled ocean-atmosphere models. Ultimately we intend to constrain coupled models by ocean data.

5 ECCO Computer Support

Computer support is of central importance for reaching ECCO goals. Here we list available and anticipated source of computational allocations in support of ECCO activities.

1. at SIO: ECCO, mermaid, atlas.
2. NPACI (T3E, IBM SP2, SV1)
3. NCAR (IBM SP2)
4. ONR (T3E, Origin 2000, SV1, IBM SP3)
5. LANL (Origin 2000)
6. JPL

6 ECCO-funded Personal

The following provides a list of researchers, postdocs and students supported directly through the ECCO grant.

JPL:

B.Cheng, B.Tang, Z.Xing, D.Menemenlis.

Postdocs:

M.Nakamura

MIT:

A. Adcroft, D. Jamous, D. Spiegel

Postdocs:

F. Condi, J. Scott

Students:

Shin, Bolton

SIO:

Y. Lu, K. Ueyoshi

Postdocs:

A. Koehl, E. Remy, D. Dommenget

Students:

S. Grimes, B. Hodges

7 ECCO Publications

- Adcroft, A (2001) Implementation of a unified atmosphere/ocean model on the expanded spherical cubic grid. In preparation.
- Ayoub, N., D. Stammer, and C. Wunsch, 2000: A dynamically consistent combination of TOPEX/POSEIDON observations and the MIT OGCM in the North Atlantic, ECCO Report Series, Report 10, in press.
- Biastoch, A., R. Käse and D. Stammer, The sensitivity of the Denmark-Scotland Ridge Overflow to forcing changes, to be submitted.
- Bugnion and Hill: The climatological sensitivity of thermohaline overturning strength, an adjoint study. Part I - The idealized behavior of decadal to centennial thermohaline sensitivity. To be submitted to Journal of Climate.
- Bugnion and Hill: The climatological sensitivity of thermohaline overturning strength, an adjoint study. Part II - Thermohaline overturning sensitivity in the contemporary climate. To be submitted to Journal of Climate
- Campin, J-M Adcroft, A., Hill, C and Marshall, J (2001) On the treatment of the non-linear free surface in ocean models: in preparation
- Cheng, B., 2001. Some performance comparisons for an ocean model on the SGI Origin 2000 and the HP V-class 2500, Proceedings of the Cray Users Group Summit 2001, Indian Wells, CA.
- Czaja, Herbaut and Marshall (2001) Modeling the role of ocean circulation in middle-latitude air-sea interaction: in preparation
- Dommenges, D. and D. Stammer, 2001: Improving seasonal forecast skills through ocean state estimation, in preparation.
- ECCO Group, The, 2001: Ocean State Estimation as new Paradigm of Modern Oceanographic Research, in preparation.
- Fieguth, P., D. Menemenlis, I. Fukumori, and L.-L. Fu, 2001. Mapping and Pseudo-Inverse Algorithms for Ocean Data Assimilation, (in preparation).
- Fukumori, I., 2001. A partitioned Kalman filter and smoother, Monthly Weather Review, (submitted).

- Fukumori, I., B. Tang, D. Menemenlis, Z. Xing, T. Lee, B. Cheng, and L.-L. Fu, 2001. Evolution of the global oceanic state from 1993 to 2000 estimated by altimetric data assimilation, (in preparation).
- Hirose, N., I. Fukumori, and R. Ponte, 2001. A non-isostatic global sea level response to barometric pressure near 5-days, *Geophysical Research Letters*, 28, 2441-2444.
- Hirose, N., I. Fukumori, V. Zlotnicki, and R. Ponte, 2000. High-frequency barotropic ocean response to atmospheric disturbances: Sensitivity to forcing, topography, and friction, *Journal of Geophysical Research*, (in press).
- Käse, R.H., A. Biastoch and D. Stammer, 2001, On the Circulation in the Labrador and Irminger Seas, *Geophysical Res. Letter*, in press.
- Kohl, A., and D. Stammer, 2001: An adjoint approach for designing an ocean observing system, in preparation.
- Lee, T., D. Menemenlis, I. Fukumori, 2000: Effects of interior mixing on the mean and variability of tropical circulation in an ocean general circulation model. In preparation.
- Lee, T., I. Fukumori, D. Menemenlis, Z. Xing, and L.-L. Fu, 2001. Effects of the Indonesian Throughflow on the Pacific and Indian Oceans, *J. Phys. Oceanogr.*, (submitted for publication).
- Lee, T., R. Giering, and B. Cheng, 2001. Adjoint sensitivity of Indonesian throughflow transport to wind stress: application to interannual variability, (in preparation).
- Lee, T., 2000: Interannual variation of the Indonesian Throughflow transport estimated from wind stress and adjoint sensitivity. In preparation.
- Lu, Y. and D. Stammer, 2001: Vorticity balance in a global ocean circulation model, to be submitted.
- Marotzke, J., R. Giering, Q. K. Zhang, D. Stammer, C. N. Hill, and T. Lee, 1999: Construction of the adjoint MIT ocean general circulation model and application to Atlantic heat transport sensitivity, *newblock J. Geophys. Research*, 104, 29,529 - 29,548, 1999.
- Marshall, J, Adcroft, A. Campin, J-M, Hill, C and A.A. White (2001) Atmosphere-Ocean fluid isomorphisms: in preparation.
- Marshall, J. and D. Jamous (2001) Formulation and implementation of an ocean model based on the residual circulation: in preparation

- McKinley, G., M.J. Follows and J.C. Marshall (2000) Interannual variability of oxygen fluxes in the North Atlantic. *Geophys. Res. Lett.*, 27, 2933-2936.
- McKinley, G., M.J. Follows and J.C. Marshall (2001) Interannual variability of global carbon fluxes. in preparation
- Menemenlis, D., 2001. Vertical Mixing and Sea-Ice Parameterizations in the MIT Ocean Circulation Model, (in preparation).
- Nakamura, M., I. Fukumori, T. Lee, and D. Menemenlis, 2001. Source and sink of anomalous heat for ENSO simulated by an ocean GCM, (in preparation).
- Ponte, R., D. Stammer and C. Wunsch, 2000: Improved ocean angular momentum estimates using an ocean model constrained by large-scale data. *Geophys. Res. Lett.*, 28, 1775-1778.
- Remy, E. and D. Stammer, 2001: Dynamics of long-period fluctuations in the North Pacific, in preparation.
- Scott, J., and C. Wunsch, Energetics, in preparation.
- Stammer, D. and E. P.Chassignet, 2000: Ocean State Estimation and Prediction in Support of Oceanographic Research, *Oceanography*, 13, 51–56.
- Stammer, D., C. Wunsch, R. Giering, C. Eckert, P. Heimbach, J. Marotzke, A. Adcroft, C.N. Hill, and J. Marshall, 2001, The global ocean circulation during 1992 –1997, estimated from ocean observations and a general circulation model, submitted for publication.
- Stammer, D., C. Wunsch, R. Giering, C. Eckert, P. Heimbach, J. Marotzke, A. Adcroft, C.N. Hill, and J. Marshall, 2001: Volume, Heat and Freshwater Transports of the Global Ocean Circulation 1992 –1997, Estimated from a General Circulation Model Constrained by WOCE Data, submitted for publications.
- Stammer. D., K. Ueyoshi, W. Large and C. Wunsch, 2001: Estimates of Surface Momentum, heat and freshwater fluxes, obtained from combining an ocean circulation model with global ocean data sets, to be submitted for publications.
- Walker, S., D. Stammer and R. Weiss, 2001: Tracer distributions simulated and estimated using ocean state estimation, in preparation.
- Wunsch, C., 2000: Ocean Observations and the Climate Forecast Problem, *Quarterly J. of the Royal Meteorological society*, submitted for publication.
- Wunsch, C., 2001: Oceanic Age and Transient Tracers. *Analytical and Numerical Solutions*. submitted for publication.

8 Meeting Agenda

May 31: 8:30 - 5:30

8:30 - 12:00 General Discussion:

8:30 - 8:45 Introduction and Agenda review (D. Stammer)

8:45 - 9:00 Message from Agency Representatives

9:00 - 9:30 ECCO Accomplishments: Now and projected (D. Stammer)

9:30 - 10:00 Progress and plans in model development (J. Marshall)

10:00 - 10:30 Coffee Break

10:30 - 11:00 Data Assimilation: long-term goals (C. Wunsch)

11:00 - 11:30 First Kalman Filter results and beyond for the Pacific Ocean (Ichiro Fukumori)

11:30 - 12:00 Computing support (I. Fukumori, D. Stammer, Ch. Hill)

12:00 - 1:30 Lunch in Walker Hall

1:30pm - 3:10 Programmatic Context:

1:30 - 1:50 Summary of HYCOM NOPP node activities (E. Chassignet, HYCOM NOPP Node)

1:50 - 2:10 Block Island Sound NOPP node activity (C. Edward, UConn)

2:10 - 2:30 Impact of state estimation on tracer model studies (M. Follows, MIT)

2:30 - 2:50 Applying estimated fields for angular momentum studies (R. Ponte, AER)

2:50 - 3:10 High-res. adjoint results for the Pacific (T. Lee, JPL/NASA)

3:10 - 3:30 Coffee Break

3:30 - 5:30 Science Discussions I:

3:30 - 3:45 The next global optimization (E. Remy, SIO)

3:45 - 4:00 Surface flux comparison (K. Ueyoshi, D. Stammer, SIO)

4:00 - 4:20 A North Atlantic Assimilation Experiment (N. Ayoub, CNES, France)

4:20 - 4:35 Subduction Experiment (P. Heimbach, O. Leeuwenburgh, J. Gebbie, MIT/SIO)

4:35 - 4:50 Can ocean state estimation improve predictions? (D. Dömmenget, SIO)

4:50 - 5:05 Energetics (J. Scott, MIT)

5:05 - 5:20 Barotropic Dynamics (Y. Lu, SIO)

5:30 Adjourn

6:00 - 8:00 Dinner around Harvard Square.

Friday June 1: 8:30 - 5:00

8:30 - 11:20 Technical Discussions

8:30 - 9:00 Model Development: status of forward and adjoint model and next required improvements (C. Hill, P. Heimbach, MIT)

9:00 - 9:20 News about TAMC and TAF (R. Giering, FastOpt/SIO)
 9:20 - 9:40 ECCO Servers (P. Heimbach, Z. Xing, Y. Lu, MIT, JPL, SIO)
 9:40 - 10:00 New Eddy parameterization (J. Marshall, MIT)
10:00 - 10:20 Coffee Break
 10:20 - 10:35 Bottom Pressure, Boussinesque Approximation (Y. Lu, A. Adcroft, MIT/SIO)
 10:35 - 10:50 Status of ice model development (D. Menemenlis, JPL)
 10:50 - 11:20 Presentation of the MIT Ocean Model Documentation
 (J. Marshall, C. Hill, MIT)
11:20 - 4:30 Science Discussions II
 11:20 - 11:35 Labrador Sea, Denmark Strait Overflow (A. Biastoch, SIO)
 11:35 - 11:50 Sensitivities and Observing System Design (A. Koehl, SIO)
12:00 - 1:30 Lunch in Walker Hall
 1:30 - 1:50 High-res. Atlantic forward runs (A. Adcroft, MIT)
 2:10 - 2:25 Nested high-res. tropical Pacific estimations: first steps
 (V. Thierry, B. Cornuelle, T. Lee, SIO/JPL)
 2:25 - 2:50 Li, Losch (MIT)
2:50 - 3:10 Coffee Break
 3:10 - 3:20 Model-data comparison studies (P. Niiler and R. Davis, SIO)
 3:20 - 3:50 Low-frequency Transport Variability in the ECCO results across
 the WOCE Section A2 (Katja Lorbacher, BSH, Germany)
 3:50 - 4:10 Interpolation and Decimation Algorithms for Ocean Data Assimilation
 (D. Menemenlis, JPL)
 4:10 - 4:30 New algorithmic approaches for state estimation (C. Wunsch, MIT)
4:30 - 5:00 Next Steps:
 Summer Workshop 2002 (C. Wunsch, D. Stammer, I. Fukumori, J. Marshall)
 Next meeting? (all)
 Meeting summary and closing (D. Stammer)
5:00pm Closing the Meeting

List of Participants

Arne Biastoch, SIO
Nadia Ayoub, LEGOS/CNRS
Alistair Adcroft, MIT
Goeran Bronstrom, Göteborg University
Jean-Michel Campin, MIT
Eric Chassignet, U. of Miami/RSMAS
Bruce Cornuelle, SIO
Dietmar Dommenges, SIO
Stephanie Dutkiewicz, MIT
Chris Edwards, UConn
Ichiro Fukumori, JPL
Lee Lueng Fu, JPL
Mick Follows, MIT
RALf Giering, SIO
Patrick Heimbach, MIT
Chris Hill, MIT
Daniel Jamous, MIT
Eric Itsweire, NSF
Armin Koehl, SIO
Katja Lorbacher, DHI (Germany)
Tony Lee, JPL
Martin Losch, MIT
Youyu Lu, SIO
John Marshall, MIT
Dimitris Menemenlis, JPL
Terri Paluszkiwicz, ONR
Rui Ponte
Elisabeth Remy, SIO
Jeff Scott, MIT
Raj Kumar Sharma, SIO
Detlef Stammer, SIO
Virginie Thierry, SIO
Kyozo Ueyoshi, SIO
Carl Wunsch, MIT
Zhangfan Xing, JPL