A National Oceanographic Partnership Program Award

A Consortium For Ocean Circulation And Climate Estimation

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http://www.jpl.nasa.gov/odap

Long-Term Goals

To bring, in the collaborative ECCO effort together with groups at JPL and MIT, ocean state estimation from its current experimental status to a practical and quasi-operational tool for studying large-scale ocean dynamics, designing observational strategies and examining the ocean's role in climate variability.

Objectives

We will improve the ocean general circulation models upon which assimilation is based, evaluate and improve assimilation techniques, and confront the practical problems of marshaling large data sets and carrying out routine assimilation runs. Our central technical goal is a complete global-scale ocean state estimation over at least the 15 year period 1985-2000 at 1/4 resolution with a complete error description and regional refinements to support CLIVAR and GODAE needs. We will combine all available and anticipated large-scale data sets —including TOPEX/POSEIDON, TOGA-TAO, high-resolution VOS XBT/XCTD, profiling floats, and drifters —with the dynamics embodied in a general circulation model to estimate the time-evolving, three-dimensional physical state of the full oceanic circulation. We will supplement the global state-estimates with high-resolution regional studies in support of CLIVAR's Basin-wide Extended Climate Studies (BECS) in the North Atlantic and the North Pacific. Global and regional results will be evaluated using available high-quality data sets and estimate covariance functions for processes and errors in data and models.

Approach

Our focus is on the state estimation of the global ocean in its entirety combining together all suitable data sets. Our interest is to draw models and observations together over decades of time to arrive at a complete (i.e., including aspects not directly measured) dynamical description of ocean circulation, such as insights into the natures of climate-related ocean variability, major ocean transport pathways, heat and freshwater flux divergences (similar for tracer and oxygen, silica, nitrate), location and rate of ventilation, and of the ocean's response to atmospheric variability.

The ECCO activities are performed in three groups located at MIT (J. Marshall, and C. Wunsch), JPL (I. Fukumori, L.-L. Fu, T. Lee, D. Menemenlis, and V. Zlotnicki) and SIO (D. Stammer (PI), R. Davis, P. Niiler). Each institution has its own task within the entire approach, covering model development, estimation activities, data preparation and scientific analyses. The ongoing ocean state estimations are based on the MIT GCM (*Marshall, et al.,* 1997) and two parallel optimization efforts: MIT and SIO use the adjoint method (Lagrange multipliers or constrained optimization method), exploiting the Tangent-linear and Adjoint Compiler (TAMC) of *Giering and Kaminski,* (1997) as described in *Marotzke et al*. (1999), while JPL's focus is primarily on a reduced state Kalman filter, e.g., *Fukumoriet al.,* (1999). Those data assimilation activities can be summarized as finding a rigorous solution of the time-varying model state over time that minimizes in a least-squares sense a sum of model-data misfits and deviations from model equations while taking into account the errors in both.

This report will focus on activities at SIO; the activities at JPL and MIT are being summarized in separate reports.

Work Completed

At SIO, activities by D. Stammer and his group are centered around performing a global ocean data synthesis estimate on a 1 spatial grid over the 10-year period 1992 through 2001 using the MIT adjoint model. This run is about to converge and a considerable analysis of the model output will be presented at the WOCE final conference in San Antonio in November 2002 (see http://www.ecco-group.org/posters.html for a complete list of poster presentation). Analyses will be done with respect to the solutions realism of the time-varying ocean circulation and transports. This systhesis is the most complete WOCE sythesis available and uses all WOCE data sets as constraints, including altimetry, the global WOCE hydrography, the global XBT data set (including the TAO data) and the preparation of the global surface drifter data set (P. Niiler) and float fields (R. Davis). Other large-scale or local data sets were processed for a comparison as independent data.

Several papers have been submitted or are in press (e.g., *Stammer et al.*, 2001a,b,c,d; *Lu and Stammer*, 2002; *K¨ase et al.* 2001; *Ponte et al.*, 2001; Wunsch and Stammer, 2002) and several others are in preparation (e.g., *Dommenget and Stammer*, 2002; *K¨ohl and Stammer*, 2002; *Thierry et al.*, 2002; Leeuwenburgh et al., 2002; *Stammer*, 2002).

Results

The most outstanding result of the ongoing and continuing work is that we were able to obtain a complete global ocean data synthesis that provides an estimate of the time-varying circulation over the 10-year time interval 1992 through 2001. Data employed include the entire suit of in situ data, altimetry, SST and scatterometry; in particular we use already all available ARGO and PALACE temperature and salinity profiles as constraints. Moreover, we use time-varying NCEP reanalysis fluxes of momentum, heat, freshwater, and NSCAT estimates of wind stress errors. Monthly means of the model state are required to remain within assigned bounds of the monthly mean *Levitus et al.* (1994) climatology and a drift of the model over the 10 year period is penalized to bring the model hydrography into a stable equilibrium with surface fluxes. To bring the model into consistency with the observations, the initial potential temperature () and salinity (S) fields are modified, as well as the surface forcing fields and internal model mixing coefficients. Changes in those fields (often referred to as "control" terms) are determined as a best-fit (in a least-squares sense) of the model state to the observations and their uncertainties over the full data period. We use this model-based synthesis now for a first dynamical

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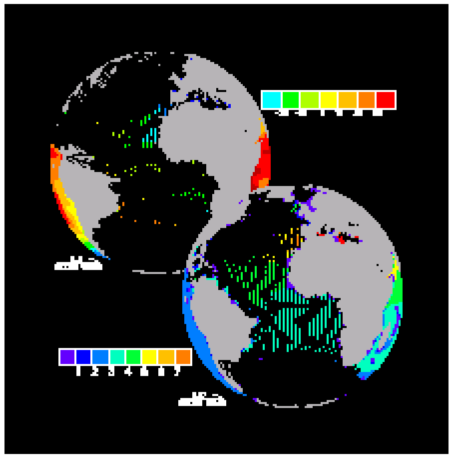

description of the time-evolving ocean circulation, its major ocean transport pathways, heat and freshwater flux divergences and of the ocean's response to atmospheric variability.

Fig. 1 shows the mean flow field at 27m and 1975 m depth from the 1 WOCE synthesis calculation, together with the mean sea surface height and the temperature field at 1975 m. All major circulation structures are simulated, but are smooth due to the present low model resolution.

Figure 1: ***Example of the ongoing WOCE synthesis on 1 resolution for the near surface and the deep circulation. The figure shows the estimated mean sea surface height and near-surface velocity field (top) as well as the flow and temperature fields in about 2000 meter depth. See Stammer et al. (2002a,b,c) for details.***

Impact and Applications

The ECCO activities are performed in three groups located at MIT (J. Marshall, and C. Wunsch), JPL (I. Fukumori, L.-L. Fu, T. Lee, D. Menemenlis, and V. Zlotnicki) and SIO (D. Stammer (PI), R. Davis, P. Niiler). Each institution has its own task within the entire approach, covering model development, estimation activities, data preparation and scientific analyses.

At SIO, activities by D. Stammer and his group were centered during 2002 around performing a global ocean data synthesis on a 1 degree spatial grid over the 10-year period 1992 through 2001 using the MIT adjoint model. A considerable analysis of the model output was presented at the WOCE Final Conference in San Antonio in November 2002 (see http://www.ecco-group.org/posters.html for a complete list of poster presentation) as an example of one of the most complete global ocean data syntheses that uses all WOCE data sets as constraints, including altimetry, scatterometry, sea surface temperature, the global WOCE hydrography, the global XBT data set (including the TAO data) and a preparation of the global surface drifter data set (P. Niiler) and float fields (R. Davis).

Most of our synthesis applications are oriented toward physical oceanography. However, many interdisciplinary applications are now under way or have begun recently, including our studies which show the ocean's impact on the earth angular momentum budget and the importance of ocean state estimation for those studies (Ponte et al., 2000). Other applications include simulations of tracer and carbon distribution as they began already at MIT and SIO. Moreover, the ECCO consortium will be in close contact with the recently formed NOPP node lead by L. Rothein on physical/biological modeling in the North Atlantic. The ECCO consortium is already in close collaboration with the NOPP FRONT node and the HYCOM NOPP node in terms of technology transfer and interchange of scientific results.

The ECCO estimated time-varying model state and consistent surface flux fields from the entire estimation period can be accessed via the project's Live-Access-Server (LAS) http://www.ecco-group.org/las .

National Security

The existence of the new ECCO infrastructure allows the community now to perform tglobal ocean data syntheses routinely in support of a wide range of scientific and non-scientific applications, the most prominent of which will be in the near term the support of climate research. However, application have started to use the ocean synthesis results to improve ocean-atmosphere flux fields of momentum, heat and freshwater and thus to improve atmospheric models. First applications are on their way to use those estimated fields to initialize coupled ocean-atmosphere models to improve forecast on seasonal to decadal timescale. They are now also being used to improve our regional simulations and forecasts, such as the tropical Pacific or the California Current system. All those applications have an immediate impact on predicting climate shifts over the US continent. They will also be available for initializing regional coastal models which can be used to predict currents and the distribution of discharges in coastal regions as they are of concern for military applications or pollution management.

Transitions

The development of the ECCO infrastructure and the availability of its global and regional syntheses of the time-evolving ocean is a major mile stone within the evolution of oceanography. It will impact the development and maintenance of a global ocean observing system as well as the way how climate research will be performed in the future. It is anticipated that, in two to three years, the project will be able to address the US CLIVAR and GODAE related objective of depicting the time-evolving ocean state with spatial resolution up to ¼ degree globally and in parallel 50-year long reanalysis effort. In addition we will be able to provide initial conditions for coupled climate forecast models.

Economic Development

The ECCO infrastructure eventually will be transitioned into national laboratories such as the National Center for Environmental Prediction, and used there in support of seasonal to interannual and longer-term forecasts. It is anticipated that over the next 2-3 years this transition will take place to assure best-possible attempts to improve our national and regional forecast on seasonal cycle. This will effect positively several economic aspects similar to the impact of previous improvements in ENSO forecasting. In addition, this transition will assure the optimal use of NASA's satellite remote sending data in physical oceanography and climate research through their melding with in situ ocean data and the dynamics embedded in general circulation models.

RELATED PROJECTS

1 - HYCOM Consortium for Data-Assimilative Ocean Modeling: it is anticipated that the ECCO and HYCOM results will be inter compared to identify model-related agreements and uncertainties in both estimation approaches.

2 - Front Resolving Observational Network with Telemetry makes use of the models and techniques developed as part of ECCO. It is anticipated that the FRONT modeling activity will be embedded into the ECCO estimation results.

3 - NOPP Virtual Ocean Data Hub: this activity is essential for setting up the ECCO live access server.

4 - Rothstein et al NOPP Node this recently funded NOPP activity will heavily rely on our estimated physical states.

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