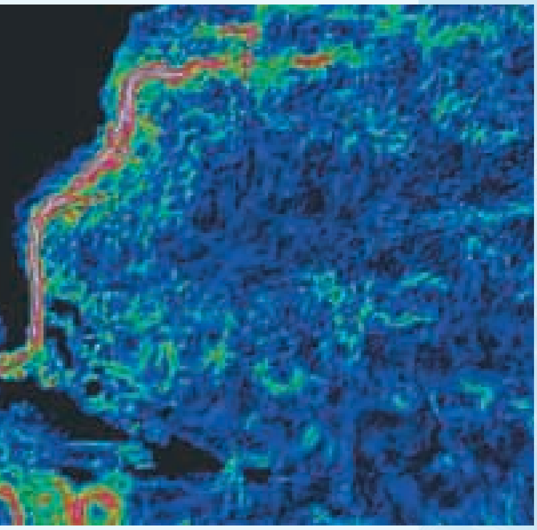

The ECCO Near-Real-Time

Global Ocean Data Assimilation System

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Data assimilation is the combination of observations and models. By combining the two, observations correct model errors, and models extrapolate observations in space/time and among different variables In the context of estimation, the combination is thus generally more accurate and more complete than either observations or models alone.

The Earth science community is most familiar with atmospheric data assimilation. This kind of assimilation has mainly been developed for numerical weather prediction, but its resulting analysis also provides invaluable means to study atmospheric circulation and to examine its impact on other components of Earth's climate system.

Data assimilation is also becoming increasingly common in oceanography. This trend has largely been motivated by satellite altimetry because of the nature of its measurements. On one hand, sufficient observations are necessary for assimilation to have an impact on models. On the other, assimilation is most relevant when observations by themselves do not observe the complete system. Satellite altimetry provides the largest volume of observations of ocean circulation compared to any other observing system, but it does not directly measure circulation at depth.

The consortium for "Estimating the Circulation and Climate of the Ocean" (ECCO) has established a series of assimilations to study ocean circulation [Stammer et al. 2002]. Results of these analyses are available on ECCO's Live Access Server at http://www.ecco-group.org/las/. Here, users may download or plot various properties of the assimilation products (Figure 1). Direct downloading of larger portions of the products, such as by rsync, is also possible.

One of the ECCO analyses is a near-real-time, near-global ocean data assimilation system called ECCO-2. Analyses of the ECCO-2 have continuously been extended approximately every 10 days since October 2002, and are available from 1993 to present. Latest results can be found on the ECCO data server above. images of the latest analysis can also be seen at http://ecco.jpl.nasa.gov/external/, as illustrated in Figure 2.

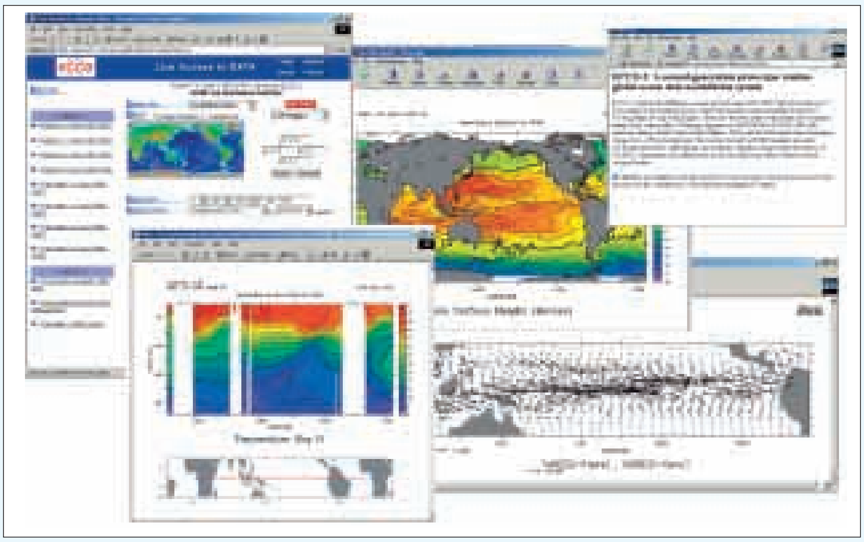
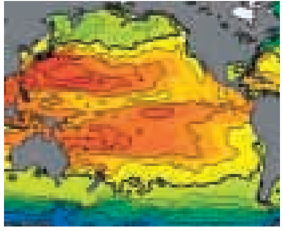


Figure1. ECCO Live Access Server (http://www.ecco-group.org/las) and examples of some of the plots that can be made. Example plots are sea-surface temperature, temperature zonal section, and surface current near the height of the 1997-98 El Niño event



Near-real-time analysis provides a tool for monitoring ocean circulation-similar to that of atmospheric data assimilation for the atmosphere-and contributes towards the goals of the Global Ocean Data Assimilation Experiment (GODAE), the aim of which is to "deliver regular, comprehensive information on the state of the oceans."

The ECCO-2 analysis is based on the Massachusetts Institute of Technology general circulation model [MITgcm; Marshall et al., 1997]. ECCO-2 employs a model configuration of relatively high resolution with a 1° horizontal resolution telescoping to 1/3° within the Tropics and with 46 vertical levels (10-m layers in the top 150 m). The analysis assimilates satellite altimetry (Topex/Poseidon and Jason-1) and temperature profiles from the Global Telecommunication System (GTS).

One of the distinguishing features of ECCO assimilation is that its temporal evolution is physically consistent. For instance, budgets of heat and freshwater (salt) can be closed by explicit physical processes for the temporally evolving circulation. Such closure is particularly useful in diagnosing processes that underlie estimated temporal changes.

This consistency is achieved by the assimilations' estimation of model error sources, in addition to errors of the model state that result from these error sources [e.g., Fukumori, 2004]. The former are the assimilation's control variables, which include, for example, errors in wind, heat and freshwater fluxes, and mixing parameters. The latter includes errors of the model velocity, temperature, and salinity that define the modeled oceanic state.

ECCO assimilation products and tools are being used to analyze various aspects of ocean circulation and to study the ocean's impact on other processes (see http://www.ecco-group.org/publications.html for a full list of studies.) For instance, Fukumori et al. [2004] employed the adjoint of a simulated passive tracer using ECCO-2 estimates to identify the origin and pathway of surface water in the eastern tropical Pacific Ocean (Niño3 area; 150°~90°W 5°S~5°N) that plays a central role in El Niño. In particular, Figure 3 illustrates where this water mass was along the equator one year prior to reaching Niño3. The difference in distribution reflects the "normal" zonal flow and upwelling in a non-El Niño year (3a), and a zonal "sloshing" of the warm upper layer in an El Niño year (3b). Fluctuations in the circulation were found to stir the water mass and to significantly alter its pathway, illustrating the importance of resolving the ocean's temporal variability.

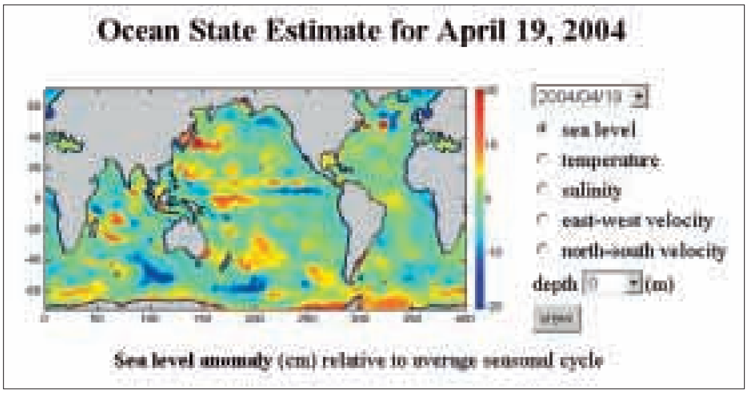


Figure 2. Plots of ECCO-2 Near Real-Time Analysis at http://ecco.jpl.nasa.gov/external. Near-surface anomalies from an average seasonal cycle are plotted to illustrate the state of the ocean in near-real time.

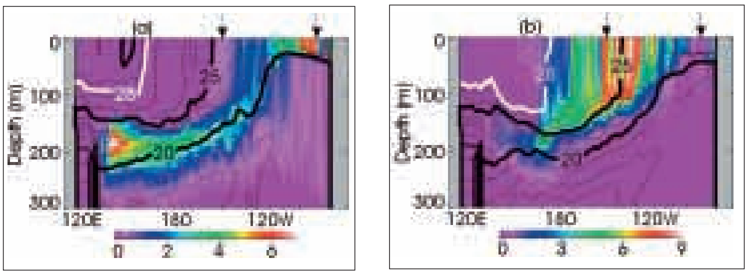
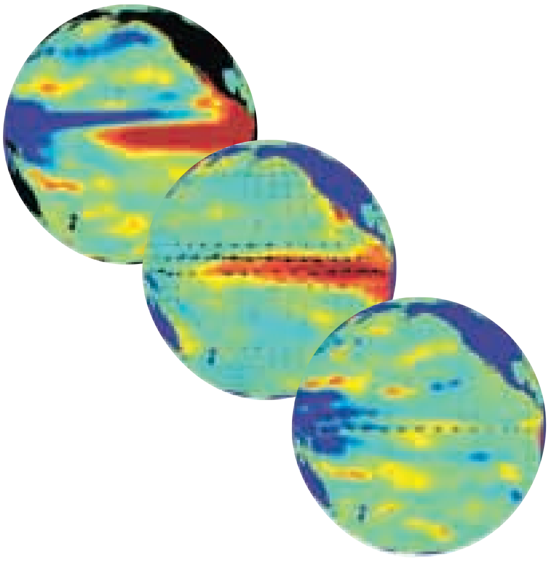


Figure 3. Zonal distribution of water along the Equator one year prior to reaching the surface of Niño3 (150°W~90°W, 5°S~5°N); (a) December 2000 Niño3 water in December 1999, (b) December 1997 Niño3 water in December 1996. Colored region describes fractional content of water (in an arbitrary tracer unit) that will be in the surface layer of Niño3 (arrow) one year later. Contours are temperature. [From Fukumori et al. 2004].



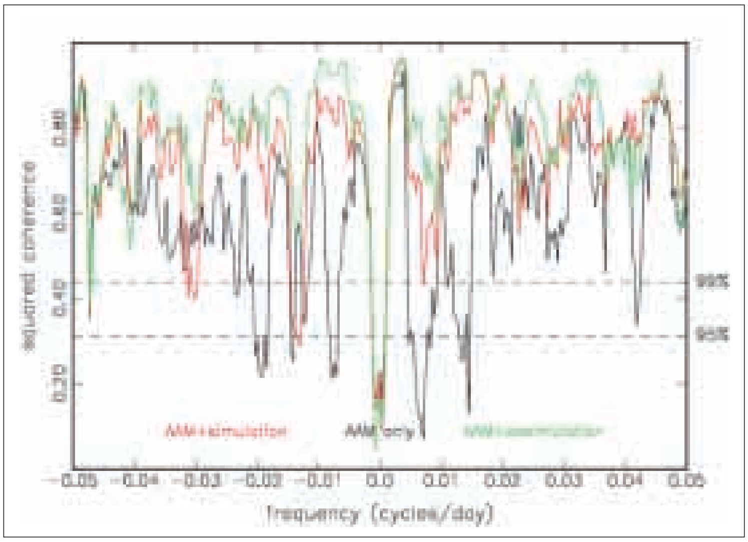


Figure 4. Coherence between observed and modeled excitation of Earth's wobble (polar motion); NCEP atmosphere model (AAM, black), ECCO-2 simulation plus NCEP atmosphere (red), ECCO-2 assimilation plus NCEP atmosphere (green).

The assimilation products are also useful outside the traditional bounds of oceanography. For instance, Gross et al. [2003] employed the analysis to assess the impact of ocean circulation on polar motion, i.e., the wobble of Earth's rotation axis relative to the terrestrial frame. Figure 4 shows the coherence between observed excitation of polar motion and that due to changes in atmospheric and oceanic circulation, as estimated by the National Centers for Environmental Prediction (NCEP) atmospheric analysis and ECCO-2 ocean analysis, respectively. Adding the impact of ocean circulation (red) significantly improves the coherence over that of the atmosphere alone (black) at almost all frequencies. Moreover, the ocean assimilation (green) further improves the coherence, illustrating the impact of ocean data assimilation in improving estimates of ocean circulation. Satellite navigation employs estimates of polar motion and thus would benefit from forecasts as well as near-real-time ocean analysis systems such as ECCO-2.

We invite further exploitation of these and other ECCO products for various investigations. Improvements in the assimilation system are also being pursued and will be available in due course. These include a higher-resolution analysis system (global 1/4°~1/6° resolution) and an expansion of the assimilation's suite of controls.

Acknowledgements

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