A National Oceanographic Partnership Program Award

A Consortium for Ocean Circulation and Climate Estimation – JPL

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Long-Term Goals

The project's goal is to advance ocean data assimilation into a quasi-operational tool for studying ocean circulation. Observing the complete state of the ocean is difficult owing to its turbulent nature and the sparse and limited measurements. This project will establish a routine description of the global ocean by optimally combining available observations using a general circulation model, to monitor, to assess, and to understand ocean circulation. The effort further aims to demonstrate the practical utility of ocean observing systems by developing applications of such syntheses.

Objectives

The project's central technical goal is to establish a complete global ocean state estimation over the 16-plus year period from 1985 to present at 1/4º resolution with complete error descriptions, combining all available large-scale data sets with a state-of-the-art general circulation model. Of particular interest is understanding processes underlying the recent 1997-99 El Niño/La Niña event and the possible shift in the Pacific Decadal Oscillation in 1999. Tools necessary for such synthesis will be advanced, including improvements in models and assimilation techniques, with an emphasis on devising practical solutions in marshaling diverse data sets and large numerical models on a routine basis. The effort will exploit existing and ongoing oceanographic experiments (e.g., WOCE) and satellite missions (e.g., TOPEX/POSEIDON) and will support planned experiments including the Climate Variability and Predictability Program (CLIVAR) and the Global Ocean Data Assimilation Experiment (GODAE).

Approach

Advanced data assimilation schemes and state-of-the-art numerical ocean general circulation models are employed to analyze global oceanographic observations. The model is based on a parallel version of the MIT ocean general circulation model (Marshall et al., 1997) that exploits massively parallel supercomputers. The present model extends from 80°S to 80°N with a fairly high resolution (1° by 0.3° within the tropics, with 10m near surface layers) and employs advanced mixing schemes to best simulate diabatic processes. A hierarchical assimilation system is devised for computational efficiency that consists of a Kalman filter and smoother (KFS), the adjoint method, and a Green's function method. The approach is characterized by the physical consistency of its solution's temporal evolution (Figure 1). I.Fukumori, T.Lee, and D.Menemenlis are technical leads in the KFS, adjoint, and Green's function assimilations, respectively. L.Fu is responsible for programmatic oversight, and V.Zlotnicki is investigating high-frequency ocean bottom pressure variations. This project is part of a larger consortium formed under the National Oceanographic Partnership Program (NOPP). The synergistic efforts of the consortium elements are described below ("RELATED PROJECTS.")

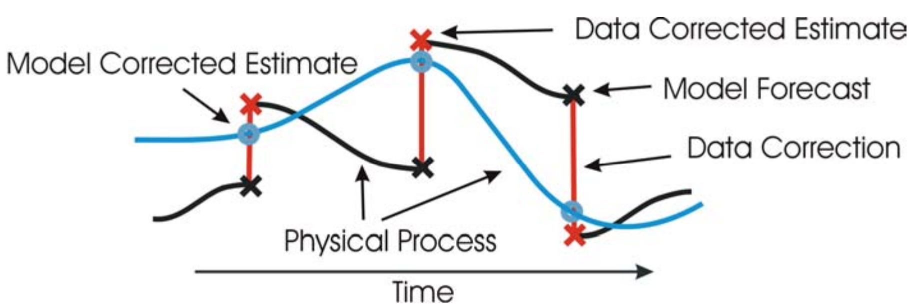

Figure 1: Schematic of data assimilation. [Typical sequential assimilation corrects the model state periodically by observations (from black to red crosses), resulting in changes (red line) that are not accounted for by physical processes (black curve). A physically consistent evolution is achieved by correcting model error sources (blue circle and blue curve).]

Work Completed

A hierarchical assimilation system has been established for producing routine analysis of ocean circulation. A series of Green's function are computed to correct gross errors in the model's time-mean state; a Kalman filter and smoother (KFS) are employed to produce near real-time, routine analysis of the time-evolving state; the adjoint method is utilized to periodically optimize the state estimates. Satellite and in situ observations are assimilated covering the period from 1993 to present (September 2002) that include sea level (satellite altimetry), temperature and salinity profiles (hydrography), and sea surface winds (satellite scatterometry). These results constitute one of the largest data assimilated model estimates of the ocean to date. A data server has been established (Live Access Server at http://www.ecco-group.org) that makes these results available to the general oceanographic community. A novel approximation of the KFS has been developed and implemented termed the Partitioned Kalman filter and smoother (Fukumori,

2002) that permits scaling the assimilation system to ultra high-resolution models. Analyses and additional information are provided at the JPL-ECCO server, http://ecco.jpl.nasa.gov/external/.

Results

Data assimilated global ocean circulation estimates are being analyzed to study mechanisms of seasonal-to-interannual changes of the ocean. In particular, water mass exchange between subtropical and tropical regions of the Pacific Ocean has been hypothesized as being part of a mechanism controlling inter-decadal changes in the nature of El Niño (Gu and Philander, 1997). The pathway of this exchange is analyzed based on the model estimates using a simulated passive tracer and its adjoint (Figure 2), the evolution of which describe, respectively, where the tracer-tagged water mass goes to and where it comes from. Over ten years, on average, water mass of the Nino3 region can be traced back (Figure 2a) to eastern subtropical thermocline waters of the northern (27%) and southern hemispheres (39%). The circulation towards the equator occurs along distinct pathways (Figure 2b); along the western boundary ("WB"), interior of the ocean ("Interior"), and along the seaboard of North America ("Coastal"). The Nino3 water subsequently returns to these subtropical latitudes in the upper ocean (Figure 2c). But in contrast to the hypothesized "Subtropical Cell" (STC; McCreary and Lu, 1994), this circulation is an open-circuit with water returning, not to the source region of the exchange, but to the western regions of the two hemispheres (subtropical gyres) and to the Indian Ocean.

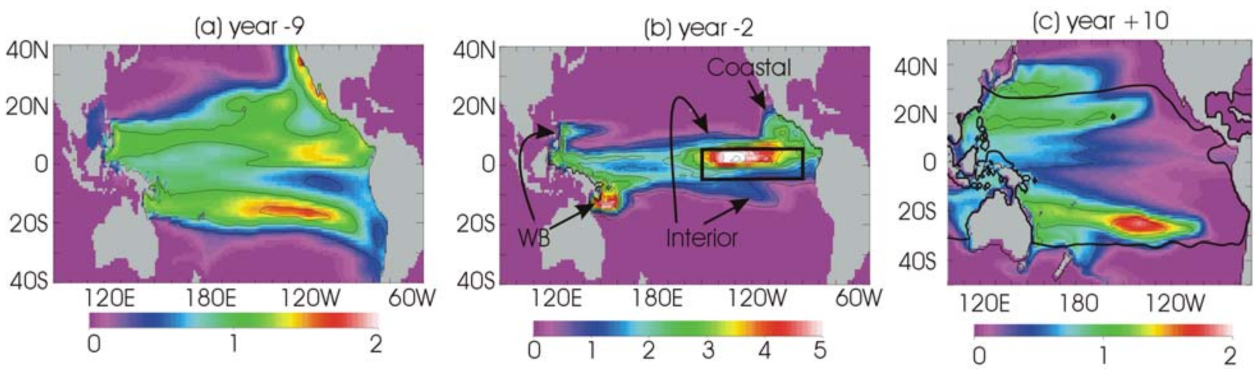

Figure 2: Horizontal distribution of Niño3 water mass at year -9 (a), year -2 (b), and year +10 (c) from reaching the surface of the eastern equatorial Pacific (Niño3 area boxed in (b); 150ºW~80ºW, 5ºS~5ºN). Figure displays integrated content normalized to 10 in Niño3. [The water mass flows equatorwards from the eastern subtropics, and returns poleward to the western subtropics.]

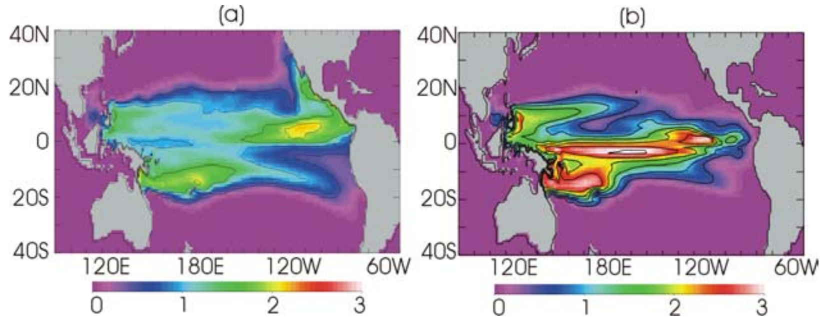

Figure 3: Depth-integrated horizontal distribution of Niño3 water mass at year –5 for different circulation estimates; time-variable circulation (a), time-mean circulation (b). [The interior and North American coastal pathways of subtropical-tropical exchange is much weaker in the absence of intra-annual variability in the circulation.]

Temporal variability causes the tropical circulation inferred from a time-mean state to differ significantly from the average circulation. In particular, non-seasonal, intra-annual variability stirrs the water mass meridionally, significantly enhancing the magnitude of the so-called interior pathway relative to that of the circuitous western boundary pathway (Figure 3). Such short-circuit in the subtropical-tropical exchange can help better explain observed tracer distributions, such as the tritium maximum in the central instead of the western equatorial Pacific (Fine et al., 1981) and the diffusion of observed thermal anomalies as they approach the equator (Deser et al., 1996).

The ocean circulation estimates are also utilized beyond traditional bounds of physical oceanography. For instance, ocean circulation is found to have a major impact on Earth's Polar Motion (Figure 4). Polar motion is the movement of the Earth's rotation axis relative to solid earth (Figure 4a). While angular momentum of the entire Earth system is conserved in the absence of external forcing, relative changes in atmospheric and oceanic circulation can alter the Earth's rotation axis relative to solid earth. Indeed, the combined effects of changes in the atmosphere and ocean is found to explain a larger fraction of observed Polar Motion than that of the atmosphere alone. Moreover, the data assimilated ocean model is found to have higher coherence with observed changes than that without assimilation, demonstrating the fidelity of the ocean data assimilation. The increased accuracy of the ocean estimate allows more accurate assessment of the mechanisms of Polar Motion and other geodetic processes.

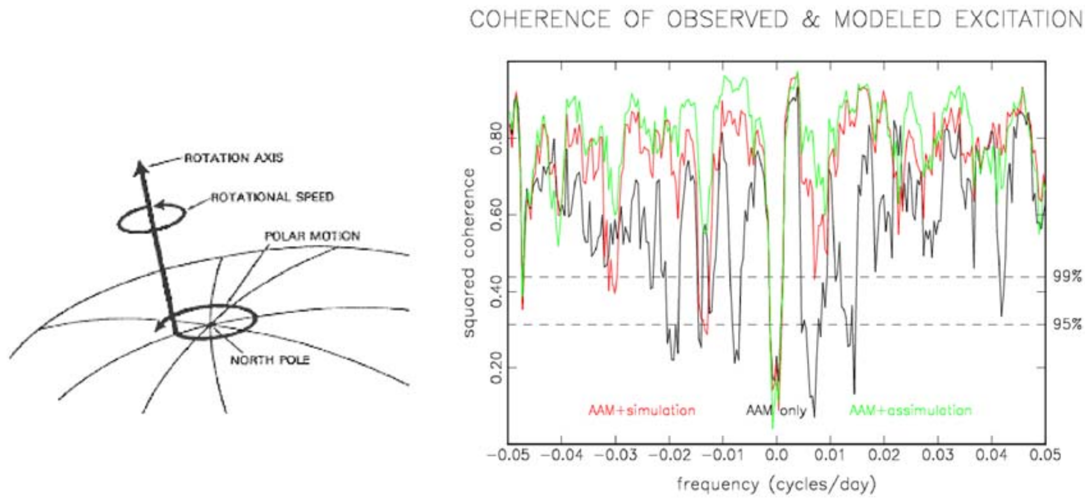

Figure 4: A schematic diagram of Polar Motion (left) and the coherence between observed excitation of Polar Motion and that estimated by models of the atmosphere and ocean (right); atmosphere only (black), atmosphere plus ocean simulation (red), atmosphere plus data assimilated ocean model (green). [The combined atmosphere and data assimilated ocean model has the highest coherence with observed excitation of Polar Motion across practically all analyzed frequencies from –0.05 cycles/day to 0.05 cycles/day.]

Impact and Applications

The project concerns estimation of the ocean state combining ocean observations and models. The process is known as data assimilation. Description of the ocean state and its variabilities, such as the flow field and thermal structure, will be improved. The project's impact consists of applications of these descriptions and the know-how of ocean data assimilation.

National Security

The thermal field description and the know-how of its estimation can lead to improvements in estimating the acoustic structure of the ocean that is critical to anti-submarine warfare and general naval operations.

Economic Development

Identification of fronts can aid in locating potential fishing grounds that will increase the efficiency of commercial fishing. Monitoring the near surface flow field can aid in ship routing, reducing shipping time and fuel consumption. Increased accuracy of sea surface temperature and near surface heat content, can lead to improvements in weather forecasting, which has a wide range of economic implications of its own. The data assimilation methodology itself developed by this project has the potential of improving weather and climate prediction that employ assimilation techniques to initialize their respective forecasting models.

Quality of Life

The project can lead to a means for monitoring the state of the ocean and the coastal environment that can aid in identifying changes that occur and the cause and origin of the changes. The monitoring will aid in mitigating potential harm to the environment and to efficient resource management.

Science Education and Communication

Data assimilation combines all available observations into a coherent and complete description of the ocean. The synthesis product will provide an efficient and simple basis for the general community to study the ocean, to analyze its circulation, and to exploit the observations without having to access and to examine unprocessed data from diverse sources.

Transitions

Products of this investigation are being incorporated as a contribution to the Global Ocean Data Assimilation Experiment (GODAE). GODAE is an international research program aimed at demonstrating the practical utility of ocean observations and data assimilation. GODAE is a developmental program and its applications include naval operations, weather and climate monitoring and forecasting, fisheries, ocean resource exploration, search and rescue, and shipping.

National Security

Contributions are made in the context of GODAE described above.

Economic Development

In addition to producing analyses for GODAE, planning is underway to test and to transition the know-how of ocean data assimilation to operational climate forecasting at the National Centers for Environmental Prediction (NCEP).

Quality of Life

Contributions are made in the context of GODAE described above.

Science Education and Communication

Ocean analyses are produced experimentally in near real-time every 10-days and are made available to GODAE and the general oceanographic community via the web (http://www.ecco-group.org/las). Products are used to investigate the nature of ocean circulation and its changes. These studies are not only conducted as part of this investigation, but are also being pursued by several research groups that are not directly associated with the present project or with GODAE. These external studies include, for example, investigations of the North Equatorial Countercurrent (Z.Yu, Univ. Hawaii), of air-sea carbon flux (G.McKinley, MIT), and of Earth's gravity field (J.Dickey, JPL).

Related Projects

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This project is part of a larger consortium formed under the National Oceanographic Partnership Program (NOPP). The consortium, entitled "Estimating the Circulation and Climate of the Ocean" (ECCO; http://www.ecco-group.org/) consists of groups at the Scripps Institution of Oceanography (SIO; D. Stammer, PI), Massachusetts Institute of Technology (MIT; J. Marshall, PI), and the present effort at JPL. The MIT group is the lead in forward model development, while SIO and JPL are leads in data assimilation. Assimilation efforts at SIO and JPL are closely linked and synergistic. The focus of the SIO group is on optimal assimilation utilizing a comprehensive set of observations whereas the JPL group is focusing on high resolution near real-time analyses. The trade-off between optimality and scope is justified given present limitations in computational resources. The two approaches will merge as knowledge and experience is gained by the complementary studies and as additional computational resources become available.

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