"The ECCO High-Resolution Global Ocean Data Assimilation"

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Overview

The consortium for Estimating the Circulation and Climate of the Ocean (ECCO) has established a data assimilation system (**Fig 1**) providing global estimates of the full three-dimensional, time-varying oceanic state and of associated surface forcing fields required to bring the model into consistency with ocean observations. Remotely-sensed (sea level, winds, temperature, gravity) and in-situ (temperature, salinity, velocity) observations are assimilated with a state-of-the-art numerical ocean circulation model using advanced estimation methods (adjoint, Kalman filter, and Rauch-Tung-Striebel smoother). The data assimilated estimates are characterized by the physical consistency of their temporal evolution such as closed heat and property budgets (**Fig 2**). Estimates are available from 1992 to present in near real-time and are being used for a wide variety of scientific applications.

The present operational ECCO system is based on a primitive equation model (MITgcm) configured with relatively coarse resolutions in a near-global domain; e.g., 1° horizontal resolution that telescopes to 1/3° meridionally extending from 78°S to 78°N (360×224×46 grid points). To better resolve the diverse scales of ocean circulation, the ECCO assimilation system is being ported to an eddy-permitting model with higher spatial resolution. The figures below describe some of these results and illustrate the fidelity of the models and of the data assimilation estimates.

Eddy-Permitting Models

The operational ECCO model is reconfigured to a nominal 1/4° resolution that extends from 80°S to 80°N using an isotropic grid (1440x1080x50 grid points). Two separate integrations are carried out from 1992 to 2002; one is forced by NCEP reanalyses and another is integrated with operational ECCO-SIO estimated forcing corrections (Stammer et al., 2004, *J. Geophys. Res., in press*) in combination with NCEP estimates. The models are evaluated with respect to the Kuroshio and the Gulf Stream (**Fig 3**), the Equatorial Undercurrent (**Fig 4**), near-surface temperature distribution (**Fig 5**), and sea surface topography (**Fig 6**).

Results of the "SIO-forced" integration are generally in closer agreement with observations than the "NCEP-forced" integration. In particular, the "SIO-forced" solution has more accurate time-mean states than the "NCEP-forced" integration does (**Figs 3, 4, 5**). The "SIO-forced" solution results in some degradation in temporal variability (**Figs 5, 6**) especially in the western equatorial Pacific and the tropical North Pacific (**Fig 6**). The improvements illustrate the robustness of the assimilation estimate whereas the degradation in variability indicates either the estimate's model dependency and/or inadequate weights used in the optimization, especially the relative weights between the estimation's time-mean and time-variable constraints.

The ECCO Kalman filter/smoother assimilation system is presently being implemented on a global 1/6° cubed-sphere model (510x510x6x50 grid points) with an active sea ice model (**Fig 7**). The cubed sphere configuration permits global modeling without singularities often associated with spherical coordinates. In particular, this model allows inclusion of the Arctic Ocean.

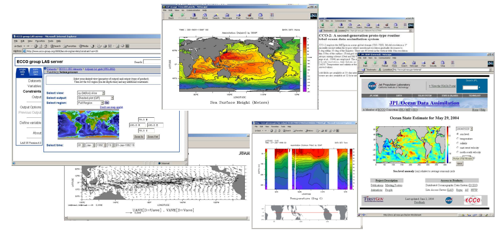

Fig 1: ECCO Live Access Server at http://www.ecco-group.org/las
ECCO products are updated regularly and are available via the Live Access Server (LAS) at http://www.ecco-group.org/las. Latest estimates are highlighted at http://ecco.jpl.nasa.gov/external.

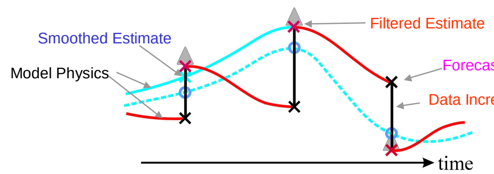

Fig 2: Schematic of Model State Evolution (e.g., Temperature).
*Data increments (**black line**) correct the consequence of model errors, but do not correct the source of errors. The **black** updates are inverted in the blue smoothed estimate, that explicitly corrects the state **and** model error sources (controls). The result (**blue curve**), in contrast to the **red** estimate, has a temporal evolution that can be physically accounted for.*

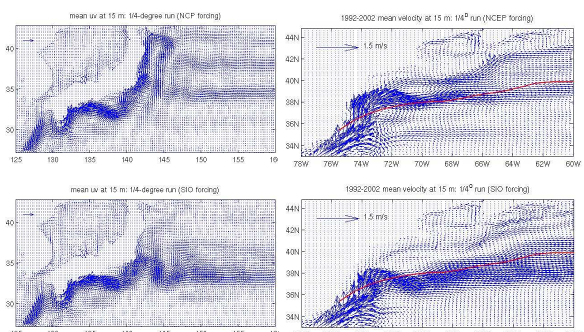

Fig 3: Time-Mean Near-Surface Circulation of Kuroshio (left) and Gulf Stream (right)
The "SIO-forced" solution (bottom) has more realistic pathways of Kuroshio and Gulf Stream than does the "NCEP-forced" model (top). The "NCEP-forced" solution has the Kuroshio and Gulf Stream separate too far north. The Slope Current, present in the "SIO-forced" model, is absent in the "NCEP-forced" solution. The red curve in the right panels is the mean path of the Gulf Stream north-wall position for the period of 1982-1998 digitized from AVHRR images.

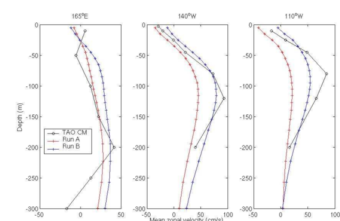

Fig 4: Vertical Profile of Time-Mean Equatorial Undercurrent
*The "SIO"-forced solution (blue) has a substantially stronger time-mean Equatorial Undercurrent that is closer to TAO current meter data (**black**) than the "NCEP"-forced solution (**red**)at all three longitudes; 165°E, 140° W, 110° W.*

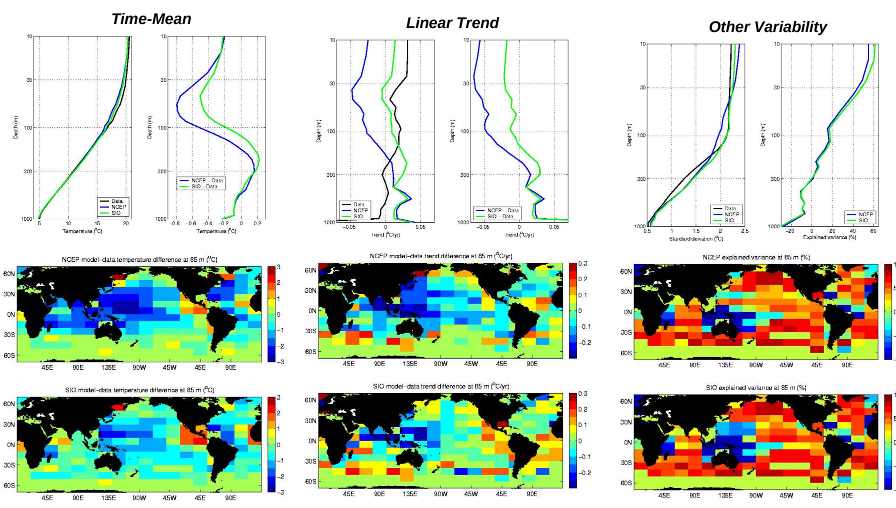

Fig 5: Near-Surface Temperature
Near-surface temperature is compared with available temperature profiles (mostly XBTs). Figures compare differences between the models and observations in terms of the time-mean (left), linear trend (middle), and variability about the mean & trend (far right); vertical profiles (top panel), horizontal distribution at 85m depth (middle & bottom panels for "NCEP" and "SIO", respectively). The mean (left) and linear trend (middle) of the "SIO-forced" solution (green curves at top & the bottom panels) are closer to observations than are those of the "NCEP-forced" estimates (blue curves at top & the middle panels). The temporal variability of the "SIO-forced" solution is also generally closer to observations except for a notable exception in the western Equatorial Pacific Ocean.

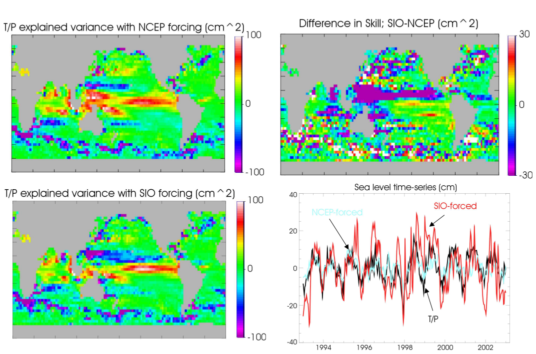

Fig 6: Sea Level Variability
*The "SIO-forced" solution has sea level variability closer to TOPEX/POSEIDON measurements than does the "NCEP-forced" model in the eastern Equatorial Pacific and the eastern subtropical South Pacific. However, there is a sizable degradation in the "SIO-forced" solution in the western tropical Pacific and the equatorial Indian Oceans. Time-series at 180° 10°N (right) shows the "SIO-forced" solution (**red**) having excessive variability than observations (**black**).*

Fig 7: Cubed-Sphere Model
The figures at right are perspectives of the cubed sphere model and show near-surface current speed and sea ice thickness in the Arctic Ocean in January 1999. (See authors for animations of these fields.) The cubed sphere model projects the sphere onto six faces of a cube. On each face a Cartesian coordinate system is used, thus eliminating the polar singularities associated with spherical coordinates. The ECCO operational partitioned Kalman filter is presently being implemented to this model. A regional high-resolution filter will further augment the system.