"A Prototype GODAE Routine Global Ocean Data Assimilation System: ECCO-2"

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ABSTRACT

A global ocean data assimilation system producing routine analyses has been established so as to monitor ocean circulation and to better understand processes underlying the seasonal-to-interannual changes. The system, ECCO-2, is a product of the consortium, "Estimating the Circulation and Climate of the Ocean (ECCO)." Analyses are regularly updated and are available via a Live Access Server at http://www.ecco-group.org/las. The modeling and assimilation systems are introduced and some of their applications are described.

Introduction

The consortium, "Estimating the Circulation and Climate of the Ocean" (ECCO), is a partnership between groups at the Jet Propulsion Laboratory (JPL), the Scripps Institution of Oceanography (SIO), and the Massachusetts Institute of Technology (MIT). ECCO's primary goal is to obtain physically consistent estimates of global ocean circulation for monitoring and understanding seasonal-to-interannual changes and the climate state of the ocean. The Consortium's activities and progress are described at http://www.ecco-group.org. Here we describe ECCO-2, a second-generation prototype, routine, global-ocean, data assimilation system. A discussion of ECCO-1, the first-generation system, is given in [7].

Model

The ECCO ocean state estimations are based on the MIT general circulation model (MITgcm; http://www.mitgcm.org). ECCO-2 employs the MITgcm in a near-global domain (78ºS~78ºN). Model resolution is 1º horizontally except within the tropics where meridional resolution gradually decreases to 0.3º within 10º of the Equator. There are 46 levels in the vertical with 10m-resolution within 150m of the surface. (Total grid dimension is $360\times224\times46 \approx 4\times10^6$.) The GM isentropic mixing scheme and the KPP mixed-layer formulation are employed. The model is forced by NCEP reanalysis products (time-mean replaced with those of COADS) with relaxation of temperature and salinity at the sea surface towards observed values.

Assimilation System

A hierarchy of assimilation methods is employed sequentially and individually to explore best strategies of assimilation with respect to the analyses' fidelity and to computational efficiency. The methods include a ***Green's functions*** approach (GF) [6], a ***partitioned Kalman filter*** and ***RTS smoother*** (PKF and PS) [1, 2], and the ***adjoint method*** [4]. All three approaches simultaneously estimate both the model state and the controls [2]. Table 1 summarizes the controls and observations that are assimilated. The assimilation results in a nearly universal model improvement (Figs 1 & 2).

	Control	d.o.f.	Data Assimilated	period
GF	mixing coefficients, initial TS, forcing	17	temperature (XBT, PALACE, WOCE, TAO, HOTS, BATS)	1993-2000
PKF/PS	time-varying wind	10^7	TOPEX/Poseidon, Jason-1, XBT	1993-present
Adjoint	forcing (wind and heat flux), initial TS	10^7	TOPEX/Poseidon, Levitus TS	1997-2001

Table 1: ECCO-2 Assimilation System
The hierarchy of data assimilation methods allows estimation of different elements of the model uncertainties in a computationally efficient manner.

The ***Green's function*** approach provides an efficient means to constrain gross characteristics of the model solution with a small number of parameters. The approach is the first step in the ECCO-2 assimilation system and is employed to minimize model bias and trend in stratification by assimilating hydrographic temperature observations (XBT, PALACE, WOCE, etc). See [6] for details.

Errors associated with inaccuracies in time-varying wind forcing are estimated next using a ***partitioned Kalman filter*** and a ***partitioned RTS smoother*** (PKF and PS) [1, 2]. By assimilating temporal anomalies of satellite sea surface height (TOPEX/Poseidon) and those of temperature (XBTs etc), the PKF and PS estimate large-scale adiabatic adjustments of the model state and associated corrections in wind forcing. The PKF and PS are computationally efficient (number of degrees of freedom estimated vis-à-vis computational requirements) and are employed in the continuous routine assimilation of the observations (presently at monthly intervals).

The ***adjoint method*** is employed to periodically perform (presently annually) rigorous re-analyses of the preceding estimates. The approach utilizes the PKF/PS estimates as a first guess, that decreases the adjoint cost function by 40%, thereby reducing the computational requirements of the optimization. Sea level anomalies (T/P), climatological temperature and salinity, and NCEP re-analyses are assimilated, further optimizing the initial state and surface boundary conditions [4].

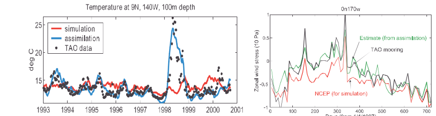

Fig 1: Validation of Assimilated Estimates
Assimilated estimates are in closer agreement with independent observations (subsurface temperature and wind) than prior estimates are.

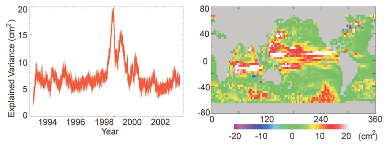

Fig 2: Explained Variance Relative to Simulation, Averaged in Space & Time
The assimilation improves the skill of the model nearly universally; 44% of T/P variance is explained by the assimilation relative to 32% for the simulation. The relative skill is simulation residual variance minus that of the assimilation.

ECCO Live Access Server and ECCO-2 Products

ECCO-2 products are updated periodically (with less than 1-month delay for routine PKF/PS estimates) and are available via the Live Access Server (LAS) at http://www.ecco-group.org/las. The LAS server allows convenient interactive display and downloading of model output in near real-time (e.g., Figs 3 & 4). ECCO-2 estimates are available at 10-day intervals (10-day averages) on the native model grid. Sea level and bottom pressure analyses are also available at 12-hour intervals that are useful for altimetric and satellite gravity de-aliasing and other high frequency applications. The Consortium invites analyses and application of these and other ECCO products.

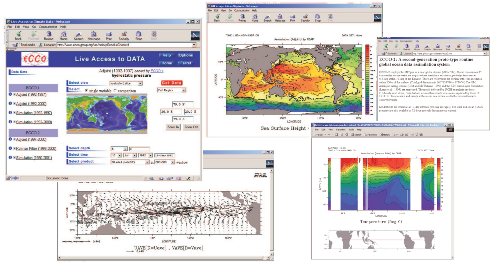

Fig 3: ECCO Live Access Server at http://www.ecco-group.org/las

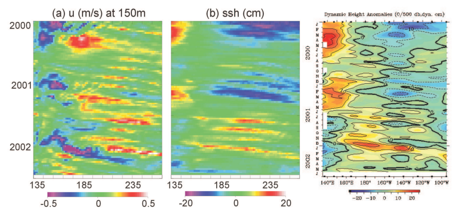

Fig 4: Zonal Velocity and Sea Level Anomalies along 0°N
The regular routine updates of ECCO-2 (left two) provide near real-time analyses of the complete state of the ocean that complement observations (e.g., TAO on right).

Examples of ECCO-2 Applications

ECCO assimilation products are characterized by their physical consistency, such as their closed tracer and energy budgets [2]. In Figs 5 & 6, a passive tracer and its adjoint are employed to identify the origin and pathway of Nino3 water. Seasonal-to-interannual variations of the subtropical-tropical exchange are found to be anti-correlated between the western boundary and interior (Fig 7). In [4], the upper-ocean heat balance is analyzed in select regions of the Pacific and Indian Oceans. ECCO-2 products are also being employed in studies of biogeochemical cycles (Fig 8), earth rotation (Fig 9), and earth deformation (Fig 10). The data assimilated solutions are generally more accurate than those of the unconstrained model, permitting better estimation of the effects of ocean circulation.

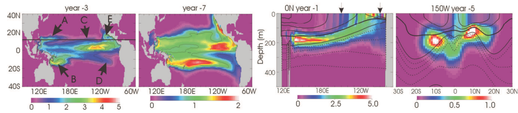

Fig 5: Origin and Pathway of Nino3 Water *Surface water in Nino3 is traced backwards in time by a passive adjoint tracer; Depth-integrated plan view at years -3 and -7 (units in arbitrary tracer unit; ATU), and zonal (0N) and meridional (150W) sections at years -1 and -5 (ATU/m²). The water mass travels in the thermocline through distinct pathways (A, B, C, D, E in left-most panel).*

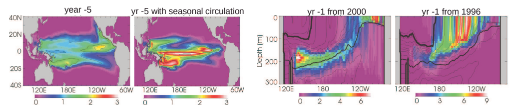

Fig 6: Time Dependence of Origin and Pathway of Nino3 Water *The time-dependent pathway is significantly different from the seasonal average (left). The adjoint tracer nicely illustrates the "sloshing" water of ENSO (right).*

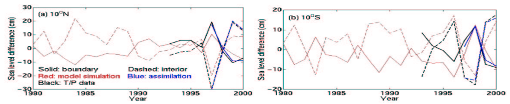

Fig 7: Meridional Transport Anomaly (sea level difference) in Pacific Ocean
The interannual-to-decadal variability of tropical-subtropical mass exchange tends to be anti-correlated between boundary and interior pathways in both hemispheres. (East-west sea level difference separated at 130°E at 10°N and 158°E at 10°S.)

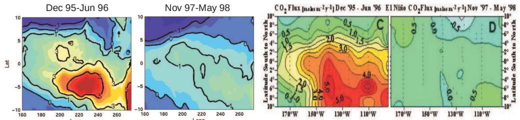

Fig 8: Sea-Air CO2 Flux [5] *The large efflux in the Equatorial Pacific during normal conditions are suppressed during '97-'98 ENSO. The ECCO-2 based estimates (left two) are comparable with independent observations [right; Chavez, 1999].*

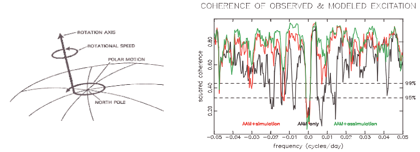

Fig 9: Polar Motion [3] *Observed polar motion excitation is most coherent with ocean-atmosphere estimates based on ECCO-2 assimilation (green) than either atmosphere alone (black) or without ocean data assimilation (red). Left panel shows schematic of Polar Motion.*

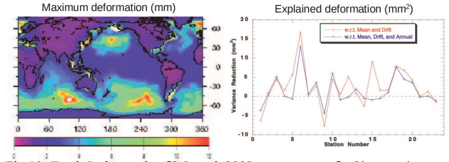

Fig 10: Earth Deformation [S.Desai, 2002, pers. comm.] *Changes in ocean circulation contribute to earth's surface deformation (left). ECCO-2 based estimates explain observed deformation at many coastal GPS stations (right).*

Conclusion

A prototype, GODAE, routine, global-ocean, data assimilation system has been established. The assimilation system, ECCO-2, regularly assimilates satellite sea level observations (TOPEX/Poseidon, Jason-1) and hydrographic temperature data (XBTs, ARGO etc) using a high-resolution global ocean general circulation model. The system employs a hierarchy of advanced data assimilation methods that consists of a Green's function approach that adjusts gross characteristics of the model, an approximate Kalman filter and smoother providing routine estimation, and an adjoint method that periodically performs rigorous optimization of the preceding analyses. Planned future upgrades include incorporation of additional observation types, expansion of the control space, and migration to a higher resolution model (1/4°).

The ECCO-2 state estimates are available at 10-day intervals (12-hourly for sea level and bottom pressure, daily for optimized surface forcing) via Live Access Servers at http://www.ecco-group.org/las and at http://eyre.jpl.nasa.gov/las. The estimates are characterized by their optimality (e.g., nearly universal improvement over unconstrained model) and physical consistency (e.g., closed heat and tracer budgets). Results are being used in studies of the ocean's heat balance and mechanisms of interannual change. Products are also being applied in studies of biogeochemical cycle and geodesy. Further analyses and applications of these estimates are welcomed.

References

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