The Ocean General Circulation

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SSH Variance, 9yrs.

T/P 1993–2001 ssh var

Cm^2
Eddy Velocity Variance (slope)


(cm/s)^2
Mean Kinetic Energy observed by Drifters (V*V/2g; cm)

Niiler, Maximenko et al.
Dynamically Balanced Mean Sea Level Derived from Joint Analysis of Drifter and Altimeter Data (1992 – 2002)
Large-scale Sea Level Changes:
Spectral Analysis of SSH and vel.: Energy on periods <150 days.
Changes in Eddy Variability

Fractional Changes of $\kappa$, 1993–2001
Determining Geostrophic Velocities

SSH gradients can be determined simultaneously in two directions from which the geostrophic surface flow field follows.
Timeseries of Velocity Anomalies

Arc 100

Time
Determining Geostrophic Velocities

Wide Swath Ocean Altimeter
Wide Swath Altimeter Concept
Ocean Data Assimilation

Goal:
Dynamic synthesis of all available data, including the marine goid and LOD and wobble observations.

Different Approaches:
• Simple (nudging, filters)
• Rigorous (smoothers) which preserve model dynamics.
“Estimating the Circulation and Climate of the Ocean”

http://www.ecco-group.org

- NOPP node to advance rigorous data assimilation into an operational tool.
- To describe the global ocean circulation at time scales of days to decades.
- To employ sustained ocean/data syntheses.
- **Global** pilot effort of GODAE and CLIVAR.
The ECCO Effort:

- Involves groups at MIT, JPL, and SIO.
- Employs all available observations as constraints: altimetry, SST, scatterometry, XBT, hydrographic sections, PALACE/ARGO, drifter, SSS, surface fluxes, etc.
- Uses ECCO ocean general circulation model employing advanced assimilation methods: adjoint model and Kalman filter/smoothing.
- Near-realtime estimates: 1-1/3 degree from 1992 to present; every week provided through ECCO LAS.
- The global synthesis (reanalysis): 1 degree, 11 yrs finished.
- 50 yrs with 1 degree resolution underway.
- Working toward goal of ¼ degree global near-real time smoother solution.
The Methodology

Cost Function

\[ J = \sum_{t} (y(t) - E(t)x(t))^T R^{-1}(t)(y(t) - E(t)x(t)), \quad (1) \]

Model

\[ x(t+1) = \mathcal{F}[x(t), q(t), u(t), \varepsilon(t), t], \quad (2) \]

Penalty-function type cost function

\[ J' = \sum_{t} \left[ (y(t) - E(t)x(t))^T R^{-1}(t)(y(t) - E(t)x(t)) + \varepsilon(t)^T Q^{-1} \varepsilon(t) \right], \quad (3) \]

The model can be imposed upon the objective function either by using Lagrange multipliers (constrained optimization), or in an unconstrained optimization form with a penalty-function type of formulation.
### ECCO 1 degree WOCE Synthesis, 1992 – 2002

#### Drifter 15m mean velocity
- WOCE and pre-WOCE hydrographic Sections
- TOGA TAO Temperature Profiles
- Global XBT Data Set
- RALACE and ARGO Temperature and Salinity Profiles
- SSS Observations

#### Monthly mean wind stress fields from ERS/NSCAT/QSCAT
- ERS-1 SSH
- ERS-2 SSH
- Daily TP SSH
- Mean TP SSH – EGM96

#### Monthly Reynolds/TM1SST Fields
- τ duncepp
- Hq_duncepp
- Hs_duncepp

#### Monthly T_lev
- Monthly S_lev

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### Controls

- T0_S0
  - τaut
  - Hqaut
  - Hsaut
The Mean Circulation, Atlantic:
Velocity and temperature, 160 m
The Mean Ocean Circulation, global

Niiler, Maximenko et al.
Global Ocean Heat and Freshwater Transports

Heat Transport

Freshwater Transports

Meridional Heat Transport

Meridional Freshwater Transport

Heat Storage
Surface Heat Flux Estimates

ECCO 1x1; delta HF; CI=20 W/m^2

LY03; delta HF; CI=20 W/m^2
Tropical-subtropical mass exchange: variability vs. mean

Counteracting changes of sea-level slope across LLWBC & interior

Anti-correlated pycnocline transports via LLWBC & interior

Variability: boundary & interior flow out of phase, the latter larger.
Mean: boundary & interior flow same direction, the former larger.

Steric SSH Changes and Mass-Induced SSH Changes

Steric Height Changes (cm/yr)  
Mass-induced Changes (cm/yr)
Abysal Temperature and Salt Drifts

![Temperature Trend](image1)

![Salinity Trend](image2)
Global Sea Level Rise:
GRACE: Gravity Change
Residual SSH values point toward inconsistencies in the EGM96 geoid errors. Ocean state estimation helps in determining geodetic information.
The Mean Ocean Circulation, global

Residual SSH values decrease significantly with use of GRACE geoid. New residuals do show dynamical structures. The ECCO estimate of a marine geoid is close to GRACE results.
Summary

Altimetry has proven invaluable for ocean circulation and climate studies.
Many new climate applications are expected.
Interannual to decadal variability looms large and needs to be a primary focus of a JASON-ARGO analysis.
New opportunities for studies of the mesoscale and its theory are available now or are anticipated.
Estimation has become a tool that provides a global syntheses of altimetry and other data in routine manner.
Pilot ¼ degree smoothing is anticipated to be available at the end of the 5 year ECCO project as a backbone of CLIVAR and GODAE.
First ECCO science applications include transport computations, surface fluxes, ocean variability, vorticity and energy budgets, angular momentum, etc.
Ocean data are being used to understand and estimate air-sea fluxes.
First interdisciplinary applications include CO2 sequestering, ocean mixing, seasonal prediction, climate observing system design.