"A Kalman Filter and 3DVAR Intercomparison with NCEP's New Operational Forecasting System"

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Introduction

A Kalman filter is developed for the Modular Ocean Model (MOM4) employed in a new operational ocean analysis system under development at the National Centers for Environmental Prediction (NCEP). This study compares the ocean state estimates of this Kalman filter and those of NCEP's 3DVAR system in analyzing and forecasting seasonal-to-interannual variabilities of the ocean.

NCEP Global Ocean Data Assimilation System (GODAS)

The new NCEP model is based on MOM4 and employs a tripolar grid with a nominal 0.5° resolution that spans the entire globe including the Arctic Ocean. In situ temperature profiles (e.g., Argo, XBTs, TAO) and sea surface temperature measurements (Reynolds analysis) are assimilated employing a 3DVAR estimation method. Synthetic salinity profiles based on a local TS relationships are employed to retain realistic density stratification.

ECCO Kalman Filter

The Kalman filter employs a time-asymptotic, reduced-state, partitioned approximation (Fig 1) to estimate errors associated with uncertainties in wind forcing; $\hat{\mathbf{x}}^a = \hat{\mathbf{x}}^f + \sum \mathbf{K}_i \left(\mathbf{y} - \mathbf{H}\hat{\mathbf{x}}^f \right)$ $\mathbf{K}_i = \mathbf{B}_i \mathbf{P}'_{i,a} \mathbf{B}_i^T \mathbf{H}^T \mathbf{R}^{-1}$

The $\mathbf{H}^T$ operation uses the adjoint of the observation operator. The horizontal state reduction utilizes spatial interpolation based on diffusive distances (Fig 2). Satellite sea level observations (T/P, Jason-1) are assimilated intermittently.

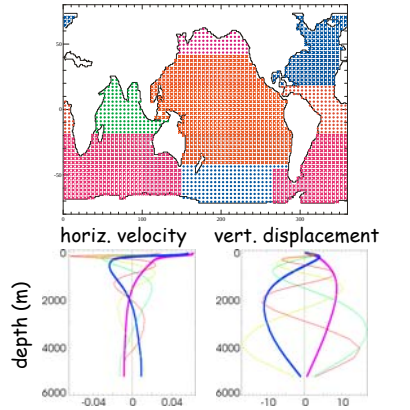

Fig 1: Horizontal partition is employed in the filter. State reduction is achieved horizontally by a coarse grid and vertically by a few dynamic modes.

Analyses

Model sea level is improved by the MOM4 filter similar to those of the ongoing ECCO near real-time analysis using MITgcm (Fig 3). However, globally averaged, the MOM4 3DVAR analysis has less improvement largely due to degradations in the extra-tropics (Fig 4). In the equatorial Pacific (TAO measurements), the 3DVAR estimate provides more accurate estimates of sea surface temperature and the 20° isotherm depth but less accurate velocity estimates (Figs 5 & 6).

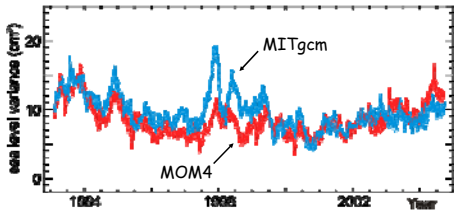

Fig 3: Improvements in model-explained observed altimetric sea level variance averaged globally.

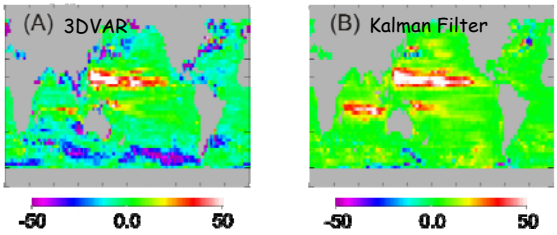

Fig 4: Improvements in model-explained observed altimetric sea level variance (cm²) averaged in time.

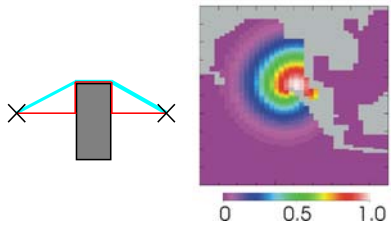

Fig 2: Objective mapping is employed using distances around land masses derived using diffusive distances of a passive tracer.

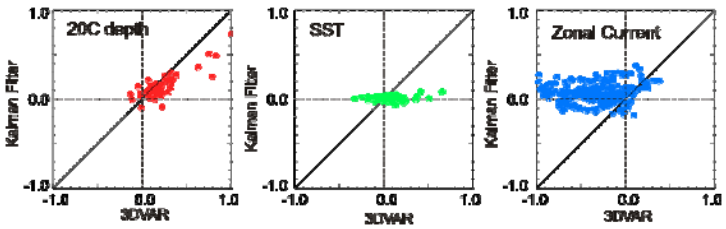

Fig 5: Improvements in model-explained TAO variance normalized by data variance.

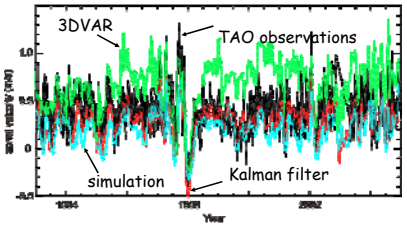

Fig 6: Zonal velocity@110°W 0°N 155m.

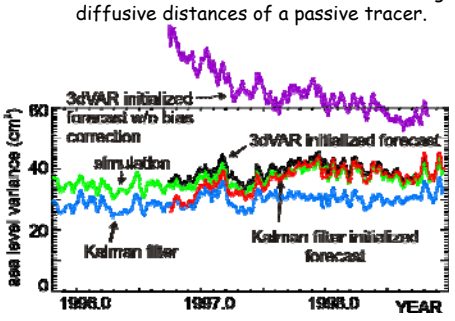

Fig 7: Model-data residual sea level variance.

Forecasts

The data assimilated estimates are used to initialize model simulations to assess their relative impact on the model's forecasting skill of anomalies. Globally averaged, the filter-initialized model retains its skill over a year (Fig 7), but a model bias leads to a significant deviation in the 3DVAR-initialized simulation (Figs 7 & 8). Operational forecasts are therefore bias corrected. Similarly corrected 3DVAR-initialized variations evaluated relative to the evolution of this bias are comparable to those of the filter-initialized model except in the extra-tropics (Figs 9, 10, 11).

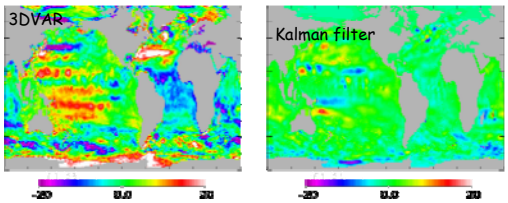

Fig 8: Sea level bias (cm) relative to simulation.

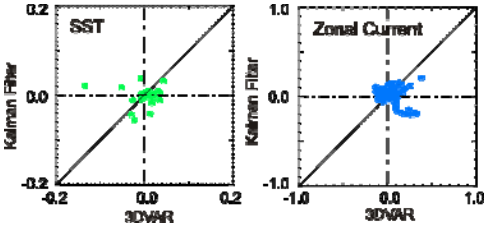

Fig 10: Same as Fig 5 but for forecasts.

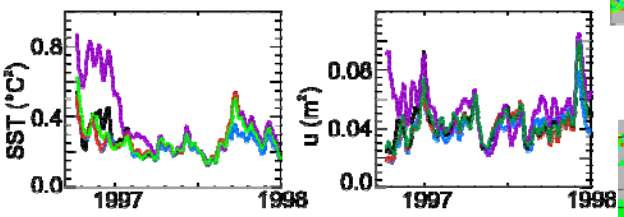

Fig 11: Modal-data residuals. cf Fig 7 for legend.

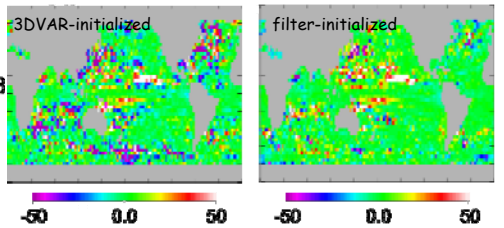

Fig 9: Forecast improvements in sea level residual (cm²)

Summary & Outlook

The ECCO Kalman filter has been ported to the MOM4 model of NCEP's next generation Climate Forecast System (CFS). The filter estimates are comparable in analysis and forecast skills to the 3DVAR estimates in the tropics but appear to be more skillful in the extra-tropics. The coupled CFS model will be initialized next to explore the impact of the analyses on forecasting the coupled evolution of the ocean and atmosphere system.