Flow-Adaptive Ocean Data Assimilation into a High-Resolution Global Coupled Model

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Data assimilation refers to the process of using a numerical model to interpolate in space and time between sparse and inexact observations. Under certain reasonable assumptions, the Kalman Filter can calculate the optimal weights with which to weigh the estimates of the state of a dynamical system (in our case, the climate system), provided on the one hand by the model and on other by the observations, to arrive at the optical state estimate.

One version of the GMAO ocean data assimilation system uses an ensemble Kalman Filter (EnKF) in which the time propagation of the background error covariance called for by the Kalman Filter is approximated using a relatively small number of model integrations. Our current system estimates background error covariances from the distribution of a relatively low resolution ensemble of MOM4 ocean models (at 1° horizontal resolution) coupled to an ensemble of GEOS-5 AGCMs (at 2° resolution) and uses this information to update the state of a higher-resolution coupled atmosphere-ocean model (AOGCM with 1/2° ocean and 1° atmosphere). While the use of an ensemble of lower resolution models to estimate the background covariances achieves very significant savings, the system still requires 1840 computer processors.

The dual resolution approach enables us to utilize the EnKF for a global assimilation of synoptic scale ocean data into the GEOS-5 AOGCM. However, the 1/2° ocean model is much too coarse to resolve the Western Boundary Currents or the ocean mesoscale. For this we will use a version of the AOGCM comprised of a 1/16° ocean with a 1/4° atmosphere. A minimum of 1920 processors will be required to run the high resolution AOGCM and the dual resolution EnKF will be too computationally expensive to use with it. Besides, assuming this approach could be used effectively, it would only provide large-scale background error covariance information and thus would not help constrain the mesoscale, assuming there are observations to do so.

We have developed a new spatially adaptive flow estimation (SAFE) methodology to function as a cost-effective flow-adaptive alternative to the EnKF. SAFE determines error covariance information from the local joint spatial distribution of model state variables and does not require that multiple model copies be run concurrently. The local covariance information is optionally complemented with temporal background error covariance estimates obtained by sampling the model state vector at regular intervals along a single model trajectory.

The SAFE methodology includes iterative data adaptive algorithms to optimally estimate the error of each assimilated observation and the geometry of the region which each observation is allowed to influence. The error estimates are a function of how well each observation can be explained by other nearby observations. The adaptively derived geometrical information reflects how well each observation explains neighboring data.

We have conducted the initial tests of the SAFE methodology with an AOGCM configuration of a 1/8° ocean and a 1° atmosphere. Following a cold start of the coupled model, we have assimilated surface temperature, salt and sea-ice extent into the coupled model daily. The upper panel in Figure 1 shows the details of the model surface temperature field in the Kuroshio region after 7 months. The middle panel shows the corresponding observations from Reynolds. The corresponding SST analysis from the 1/2° production ocean analysis is shown in the lower panel. (The production analysis starts in 1960 and assimilates *in situ* data in addition to the surface data processed here with the higher-resolution AOGCM.) Figure 2 shows the details over the eastern equatorial Pacific. Interestingly, tropical instability waves are adequately represented in the 1/8° SAFE analysis while they are smoothed out in the 1/2° analysis.

The rapid convergence of the 1/8° ocean analysis to the Reynolds analysis indicates that the SAFE methodology is working as expected and is ready to be applied with the 1/16° eddy-resolving ocean model.

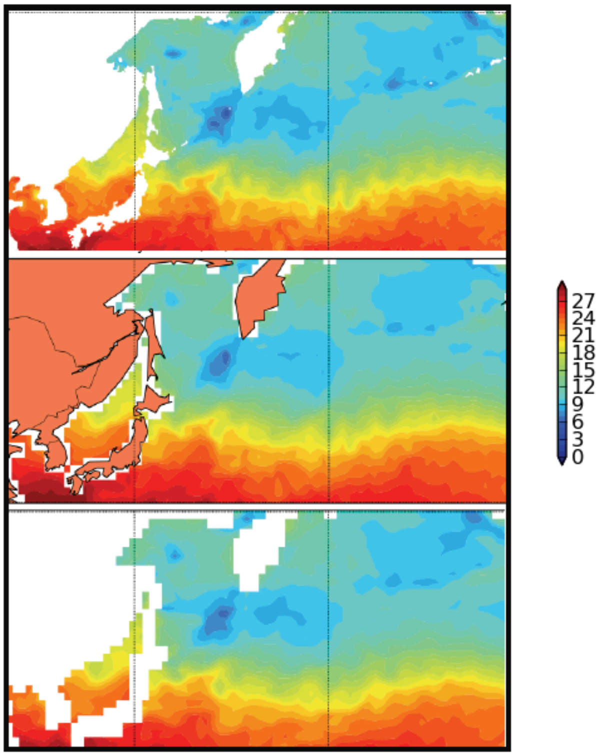

Figure 1: (Top panel) Detail of the 1/8° ocean analysis of SST on 1 August 2007 after 7 months of daily data assimilation. (Middle panel) The corresponding observed SST from Reynolds. (Bottom panel) The corresponding SST from our 1/2° ocean reanalysis.

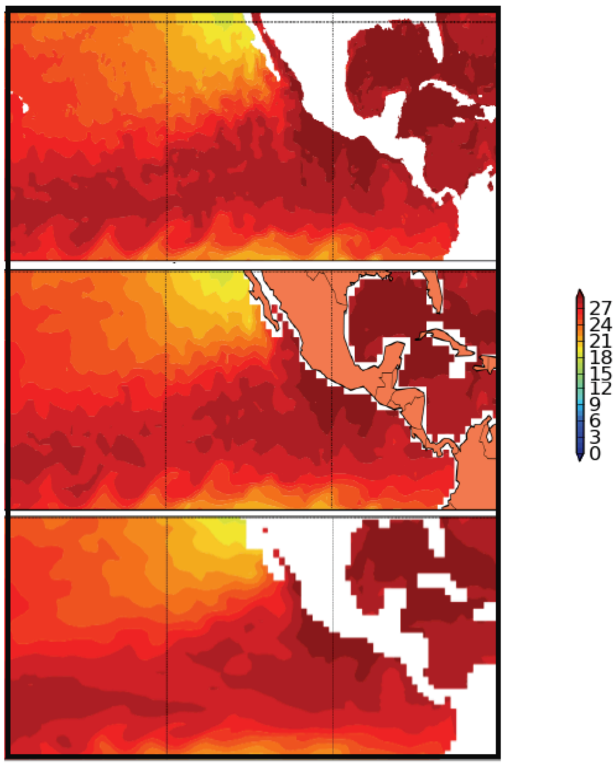

Figure 2: As for Figure 1, but for the eastern equatorial Pacific.