Final Report

Title: Exploration of advanced ocean data assimilation schemes at NCEP
PIs: James Carton, Eugenia Kalnay, David Behringer, Hendrik Tolman
Grant #: NA13OAR4310108
Report Year: Year 1 (2013/14)
Grant Objective: explore the relative merits of different assimilation schemes: 3DVar, LETKF, and a hybrid filter in the context of NCEP's GODAS ocean analysis

The purpose of this grant is to provide the first major upgrade to the NCEP seasonal ocean data assimilation system (GODAS) since it was implemented in the early 1990s. The upgrade includes implementation of an ensemble Kalman Filter and associated hybrid filter as well as model and forcing improvements. To document the impact of this upgrade the grant also supported a set of intercomparisons between the current operational system (3DVar GODAS) and the upgraded system (Hybrid-GODAS). These intercomparisons are carried out with both idealized data and real data.

2. Results and Accomplishments

2.1) Local Ensemble Transform Kalman Filter (LETKF) was implemented in the new NCEP MOM4.1 global ocean (LETKF-GODAS).
2.2) A hybrid filter (combining 3DVar with the LETKF) was developed (Penny, 2014) with funding from a related project.
2.3) The hybrid filter has been implemented in GODAS (hybrid-GODAS).
2.4) To compare the filters two sets of experiments have been conducted.

First a set of observing system simulation experiments (OSSEs) have been carried out comparing the performance of the operational 3DVar Global Ocean Data Assimilation System (3DVar-GODAS), both with and without the use of Incremental Analysis Updates (IAU), with Hybrid-GODAS with the empirical scaling parameter (which effectively determines the relative impact of LETKF) α = 0.0, 0.5, and 1.0. The experiments, which span the eight year period 1991-1998, use the historical observation locations and times of sampling of XBT/CTD temperature and salinity profile data as appear in the historical archive and a 28-member ensemble for the Hybrid. However, the samples are taken from a previous 'nature run' so that we know what the truth is for this system. The observations as well as surface forcing and initial conditions were then contaminated with representativeness and instrument errors. In particularly, surface forcing was constructed by re-centering the 56-member 20^{th}-century analysis surface forcing around the NCEP R2 surface forcing, and choosing the first 28 members to drive the ocean ensembles. The results, summarized in Penny et al (2015), document the improvements by the switch to Hybrid-GODAS.

Finally, the experiment was repeated using the full historical set of ocean

observations for the 21-year period beginning January, 1992. The results, a few of which are shown in **Figs. 1** and **2**, also confirm the superiority of Hybrid-GODAS over the older 3DVar GODAS system. In **Fig. 1** the RMS and spatial mean errors of temperature and salinity are compared for the two systems. In **Fig. 2** we specifically target sea surface salinity (SSS) in the tropical Pacific. The first figure clearly demonstrates an improvement in the errors, while the second shows that Hybrid-GODAS has realistic SSS variations which were previously lacking. These SSS variations are important because they affect the stability of the equatorial thermocline and thus air-sea interaction. The research described in these figures is currently being written up for publication in the refereed literature.

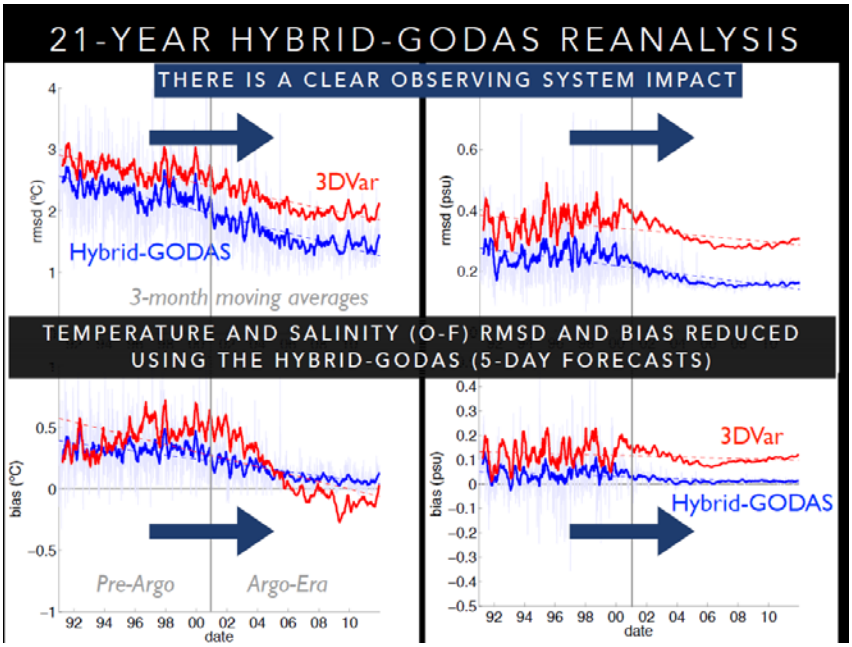

Figure 1. Global temperature (left), salinity (right) errors for 21-year experiments using the current 3DVar GODAS (red) and the new Hybrid-GODAS (blue) developed and implemented by this grant. The experiments are conducted assimilating the full historical data set for the 21-year period 1992-2012. Upper panels show monthly RMS errors with time. Lower panels show monthly mean errors (bias) with time. The new system reduces both RMS error and bias.

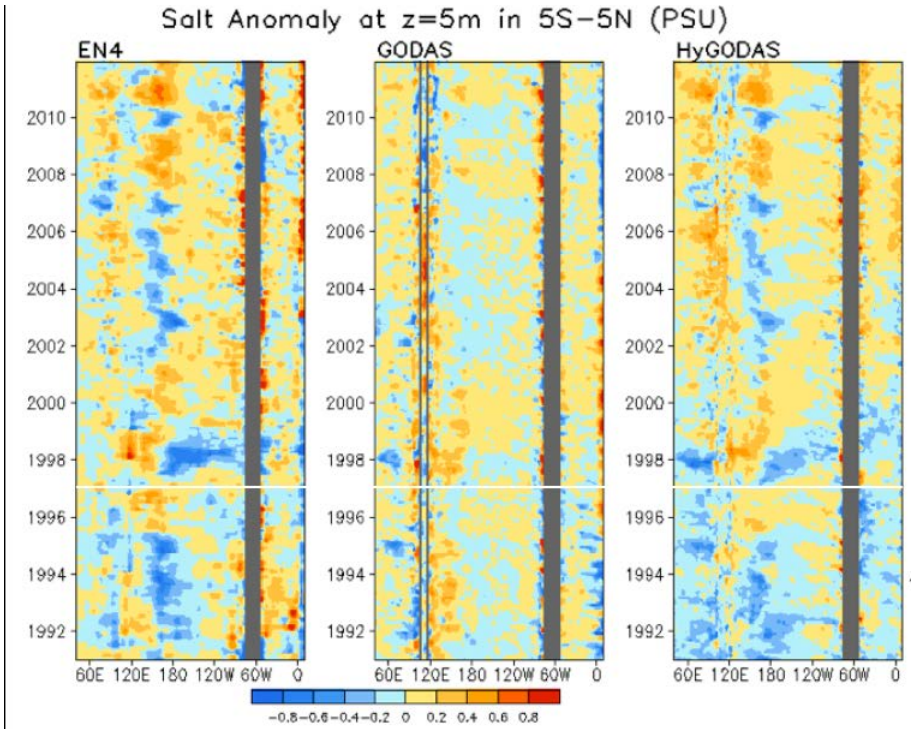

Figure 2. Hovemuller diagram of sea surface salinity (SSS') anomaly from its monthly climatology at 0N, with time for the two experiments shown in **Fig. 1**. Lefthand panel shows SSS' from an independent analysis. Note the eastward shift of convection during El Nino. Central panel shows SSS' for the 3DVar GODAS with little ENSO variation. This ENSO variation, in contrast is striking in the SSS' from the new Hybrid –GODAS.

3. Highlights of Accomplishments

The system upgrade has proceeded in a number of steps.

- The LETKF-GODAS and Hybrid-GODAS data assimilation codes have completed and debugged.
- The LETKF-GODAS and Hybrid-GODAS data assimilation codes have been ported to the NOAA Gaea computing system. Scripts have been written to run with identical data as the operational 3DVar-GODAS.
- In the process of porting these codes, the observation operator formerly coded within LETKF has been extracted to facilitate operational implementation and later incorporation into a coupled ensemble data assimilation system like the next-generation CFS.
- 3DVar-GODAS, LETKF-GODAS, and Hybrid-GODAS experiments have been run for multi-year experiments with synthetic temperature and salinity profile data (described above).
- The results show that the Hybrid-GODAS is significantly outperforming the 3DVar-GODAS in synthetic observation experiments (not shown) and experiments with actual data (**Figs. 1 & 2**).

4. Publications related to the Project

Penny, S.G., The Hybrid Local Ensemble Transform Kalman Filter, Mon. Wea. Rev., 142, 2139-2149.

Penny, S.G., D. Behringer, J. Carton, E. Kalnay, 2015: A Hybrid Global Ocean Data Assimilation System at NCEP, Mon. Wea. Rev., 143, 4660-4677.

Penny, S.G., and collaborators, 2016: Performance of the NCEP Hybrid Global Ocean Data Assimilation System, in preparation.

5. PI Contact Information.

Professor James Carton

University of Maryland

Department of Atmospheric and Oceanic Science

Room 3413 Computer and Space Sci. Bldg. -- West wing

Stadium Dr.

College Park, MD 20742-0001

(301)-405-5391 carton@atmos.umd.edu