Data Assimilation for Intra-Seasonal to Decadal Prediction

Issues for Discussion
Background

• Typically, but not always, the analysis is performed separately for atmosphere, ocean, land and ice
  – Some form “Coupled Data Assimilation” is Emerging
    • Best State Estimation vs. Initializing the Slow Manifold
• Ocean: Resolution is typically 1 degree with finer resolution in the deep tropics and 10 meters in the upper ocean
  – Quality Strongly depends on quality of surface fluxes
  – Surface fluxes typically come from operational weather forecast analyses
• SST is a key parameter. Most systems use subsurface temperature and, some, salinity (mainly from Argo)
• Improvements in data and models improve forecast skill
Dommenget and Stammer (2004) investigated the impact of ocean state estimates produced by the Estimating the Circulation and Climate of the Ocean (ECCO) project on seasonal forecasts. A series of seasonal hindcasts using the Massachusetts Institute of Technology (MIT) ocean model coupled to a statistical atmosphere showed that the anomaly correlation of SST forecasts was improved by assimilating data. However, it was thought that the impact of ECCO initial conditions in El Niño Southern Ocean (ENSO) forecasts was probably limited by the low quality of the statistical atmosphere. More recently, the impact of ocean data assimilation on El Niño forecasting has been tested using the ECCO-University of California, Los Angeles (UCLA) coupled system (Cazes-Boezio et al., 2008) by initializing ENSO hindcasts with the states obtained from the ECCO-Jet Propulsion Laboratory (JPL) ocean estimates (Fukumori, 2002) with and without data assimilation. The hindcasts initialized from the assimilation showed better skill in SST prediction.

Seasonal forecast skill can also be used to evaluate the ocean observing system. Fujii et al. (2008) evaluate the impact of the Tropical Atmosphere Ocean/Triangle Trans-Ocean Buoy Network (TAO/TRITON) array and Argo float data on the Japanese Meteorological Agency (JMA) seasonal forecasting system by conducting data-retention experiments. Figure 2 shows the increase in root mean square errors (RMSEs) of SST hindcasts resulting from the exclusion of Argo and TAO/TRITON from the ocean initial conditions. The results are for a range of one to seven months in the regions defined in Table 2. Results show that TAO/TRITON data improve the SST forecast in the eastern equatorial Pacific (NINO3, NINO4), and that Argo floats improve SST prediction in all the areas of the equatorial Pacific and also have

![Figure 1](image-url)
A positive (albeit modest) impact in the western Indian Ocean. Similar results have been obtained with the ECMWF seasonal forecasting system (Balmaseda and Anderson, 2009; Oke et al., 2009).

The term initialization shock refers to the adjustment process that takes place when the ocean and atmosphere initial conditions are not a solution of the coupled model. If the initialization adjustment is large, it can degrade the skill of seasonal forecasts. Separate initialization of ocean and atmosphere is prone to initialization shock, because it is not possible to impose balance constraints between the ocean state and the coupled model. Alternative strategies to avoid initialization shock are promising results and are currently being explored at different institutions.

Sugiura et al. (2008) demonstrate the feasibility of a four-dimensional variational coupled data assimilation system (4DVAR CDA) for a global coupled ocean-atmosphere model. Both initial conditions and parameters controlling the air-sea interaction can be modified by the analysis system. Several key events, such as El Niño, the Indian Ocean dipole, and the Asian summer monsoon, are successfully represented by 4DV AR CDA. Preliminary results suggest that the system has the potential for initialization of coupled ocean-atmosphere models for seasonal and interannual predictions.

Developments for assimilating ocean observations within a coupled model via an Ensemble Kalman Filter (EnKF CDA) are underway at NASA’s Global Modeling and Assimilation Office (GMAO) and at NOAA’s Geophysical Fluid Dynamics Laboratory (GFDL), aiming at the initialization of seasonal and decadal forecasts. A nice feature of EnKF CDA is that the ensemble of analyses can be used as initial conditions for the ensemble of coupled forecasts. An ocean analysis for the period 1979–2008 that used the GFDL CDA system (Zhang et al., 2007) may be found at http://data1.gfdl.gov/nomads/forms/assimilation.html. The coupled ocean-atmosphere balance can also be considered in the creation of initial perturbations for forecast ensembles. This approach is being pursued at GMAO using so-called coupled bred vectors (BV), which aim to capture the uncertainties related to slowly varying coupled instabilities, especially those related to ENSO. Yang et al. (in press) show that BVs improve ensemble mean SST forecasts. Their study also shows that BVs capture information on flow-dependent uncertainty that can be used for background error covariances in ocean assimilation, improving water mass distribution in the analysis.

Assimilation of ocean observations into models is now commonly used to estimate ocean conditions, which are in turn used to initialize seasonal forecasts. Modelers at several institutions around the world produce routine ocean reanalyses to initialize their operational seasonal forecasts. These ocean reanalyses are reconstructions of ocean history that provide a valuable resource for climate variability studies, having the advantage of being continuously actualized with the latest (real-time) ocean state. They are being used experimentally for the initialization of decadal forecasts.

The first generation of ocean initialization systems was univariate and assimilated only temperature data. These systems were able to reduce uncertainty. The bars show the relative increase in root mean square errors of one- to seven-month forecasts of monthly sea surface temperature resulting from withholding TAO/TRITON and Argo data from the initialization of seasonal forecasts. The regions are defined in Table 2. From Fujii et al. (2008)
May Initial Conditions
3-Months Lead

Improved Correlation Due to Model Improvement
May Initial Conditions
3-Months Lead

Improved Correlation Due to Model Improvement and Better Initial Condition?
Initialization

• Not necessarily the same thing as assimilation
  – Shock and/or Coupled Model Biases

• Anomaly Initialization vs. Full Initialization

• Coupled Data Assimilation
  – Slow Manifold vs. Best State Estimations
Figure 3: Assessment of hindcast skill for predictions of near surface temperature. Colours show the uncentred correlation of the full-field (left column) and anomaly (middle column) hindcasts, and their difference (full-field minus anomaly, right column). Stippling denotes skill or differences exceeding the 5±95% confidence interval. The rows show the skill for different forecast periods (see text, Section 2.5). Skill is assessed over the total hindcast set except for longer forecast periods where verifying observations are not available for the later hindcasts. Bias adjustment was applied with cross validation (Eq. 2) for full-field hindcasts and using the fixed period transient simulations (Eq. 4) for anomaly hindcasts.
What do we mean by “coupled data assimilation”?

• Assimilation into a coupled model where observations in one medium are used to generate analysis increments in the other [minimization of a joint cost function with controls in both media].

or

• Loosely (weakly) coupled: the first guess (background) for each medium is generated by a coupled integration.

or

• Reduced systems: atmosphere with corrections in ocean mixed layer model; ocean with correction of surface fluxes
ECDA - Fully-coupled data assimilation system

GHG + NA radiative forcing

Atmospheric model

\[ u^0, v^0, t^0, q^0, ps^0 \]

\[ u, v, t, q, ps \]

Land model

Sea-Ice model

Ocean model

GHG + NA radiative forcing

Atm Obs

ADA

LDA

Sea-Ice model

(IDA)

Atmospheric model

\[(Q_t, Q_q)\]

\[(\tau_x, \tau_y)\]

\[(u, v)^{obs}, \eta^{obs}\]

Sea-Ice model

\[(T, S)^{obs}\]

Ocean model

\[T, S, U, V\]

Ocn Obs

ODA

Courtesy Zhang & Rosati
Climate predictions – from SI to decadal time scales
ENSO forecast: NINO3 SSTA skills

Courtesy Zhang & Rosati
Precipitation - SST relation improved by coupled nature of CFSR
Tropical western Pacific - 10°S-10°N, 130°-150°E, Nov-Apr
Intraseasonal signal (20-100 days)

From Saha et al., BAMS 2010
Spatial Resolution
Perturbations

- Standard Techniques
  - Lagged Ensemble
  - Wind Perturbations
- Ensemble Systems (e.g., EnKF, Perturbed Physics, Stochastic Physics) include perturbations
- Bred Vectors
- Stochastic Optimals