Coupled data assimilation in the CSIRO Climate Forecast System

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Coupled data assimilation

There are in general two ways through which observed information in the ocean can be transferred to the atmosphere and visa versa.

1) Via fluxes between the two through the coupled dynamics:

   • **Advantage**: Information is transferred between the ocean and atmosphere in a dynamically consistent way.

   • **Disadvantage**: the observational signal may be distorted through model error.

2) As the key to projecting observational information between the ocean and atmosphere are the coupled error covariances we can use these to directly project the observed information by coupling the error covariances.

   • **Advantages**: Despite model errors in the coupled error covariance, the observational signal can be transferred instantaneously between ocean and atmosphere.

   • **Disadvantage**: the time scales at which the flows vary are different. This is particularly true when the goal is to generate initial conditions suitable for predictions beyond seasonal.
Base Multi-year to decadal prediction system

**Completed:**

- Coupled models: GFDL CM2.1 – restoring below 2000m, +1000 year spinup + restoring to NCEP reanalysed large scales
  Data assimilation: EnKF-c variant ocean (u, v, T, S, eta)

- Ocean observations assimilated are T & S (Argo, XBT, CTD TAO etc), satellite products: altimetry, SSS, SST

- Atmosphere nudging to (NCEP, JRA-55) reanalysis (u, v, q, t, ps) – experimentation of e-folding times and nudging fields

- 2nd DA applied to generate appropriate Coupled covariances between ocean and atmosphere used in updates

- **Generalized** implementation of BV ensemble used to initialize forecasts i.e. flexible, relocatable etc

- Systematic sensitivity study carried out i.e. covariance localization, weighting of obs, BV rescaling periods and regions ~ about 20-30 ten year assimilation / reanalyses. Tendencies used for covariances.

**In progress:**

- BV ensemble used to update background covariances (40 members)
- Next stage will be 40 member ETKF + BV ensemble prediction system

- Idealised studies to explore covariant Lyapunov vectors continue.

- Parallel development of alternate methods for coupled DA: variants of ETKF, higher order moments etc in idealised systems e.g. coupled Lorenz attractors, closure models etc (Sakov & Sandery (BoM), Nadiga (LANL), Franzke (U. Hamburg))

Developing strategy and timeline for implementation into ACCESS (MOM+UM): Implementation into ACCESS CM2 to begin in January 2017
Example of global ocean assimilation statistics, SLA, SSS, SST, T & S
Scale localization (400-800km) and obs impact R-Factors (2).
Example of DA increments derived from ocean and coupled covariances
Dec 2015 (4000km localization R-Factor 64 .i.e. scaled to tendency)
Case 1: Coherent atmospheric response to upper ocean BVs out to 2 weeks dependent on disturbances getting into the midlatitude jets.
Case 2: At 1 month (30\(^{th}\) April year 7)

Note: we have projected onto the tropical ocean but there is a significant coherent response in the troposphere at the NH midlatitudes via modulation of the Hadley Cell.

Potential for longer timescales via Rossby wave breaking on PNA etc.
Difficulties
Where is the memory? Singular Spectral Analysis of CMIP5 pre-industrial control simulations.

SSH variances calculated from an ensemble average of the de-drifted pre-industrial control CMIP5 simulations. Relative explained variance range (normal font) as a fraction of the total variance are given on the Eurasian continent. Note that the shading is scaled to the explained variance range in each sub-plot.
Global ocean reanalyses 1990-2007: Ocean – Sea Ice model (MOM4p1)

Argo, CTD, XBT, SST, Altimetry

Argo period

Background innovation T(z) (Deg C)
Role of salinity

SSS 10S-10N

Figure 1. Time series of SSS values (psu) averaged between (180°E–180°W, 10°S–10°N) including reanalyses: ORAS4 (black), GECCO2 (blue), SODA (red), NCEP (thick purple), and CSIRO (thin purple with stars); forced ocean models: DRAKKAR (green), CORE2 (light blue). The NCEP ocean reanalysis uses only in situ data (D. Behringer, personal communication, 2014). An offset has been applied to all time series and referenced to the NCEP series, with values of 0.15 (ORAS4), 0.12 (DRAKKAR), 0.05 (SODA), —0.1 (GECCO2), 0.1 (CORE2), and 0.1 (CSIRO), respectively. A 13 month Hanning filter has also been applied to all time series.
Seasonal variations of the upper ocean salinity stratification in the Tropics

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Abstract

The salinity signature of the equatorial Pacific cold tongue as revealed by the satellite SMOS mission

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Figure 6. Independent vertical profiles of (left, in °C) temperature, (middle, in psu) salinity, and (right, in cph) $N^2(T,S)$ collected by two Argo floats near 14°S–118°W in the tropical Pacific during 2008. The profiles are shown by season, following the JFM, AMJ, JAS, and OND periods, from bottom to top, respectively. On each panel, the average seasonal profile (2001–2007) at this location from the present reanalysis is shown in red.

Figure S1–S4

Readme file

Describe its seasonal variations

Describe ocean salinity stratification (OSS)

Key Points: 

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Citation:
In the following, the ocean salinity stratification (OSS) is defined in terms of the difference between \( N^2(T, S) \) and \( N^2(T) \) thereby allowing the identification of the layer where the salinity stratification has its greatest impact on buoyancy in terms of stabilizing the water masses (Maes, 2008). Specifically, we define OSS as the vertical mean average of positive \( N^2(S) \) over the upper 300 m depth range, i.e.,

\[
\text{OSS} = \left\langle N^2(T, S) - N^2(T) \right\rangle_{0-300m}
\]

where

\[
N^2(T, S) = \frac{g}{\rho} \frac{\partial T}{\partial z} + g \frac{\partial S}{\partial z}
\]

\[
N^2(T) = \frac{g}{\rho} \frac{\partial T}{\partial z}
\]

\[
N^2_S(T, S) = N^2(T, S) - N^2(T)
\]

\[
\alpha = -\rho^{-1} \frac{\partial \rho}{\partial T}
\]

\[
\beta = \rho^{-1} \frac{\partial \rho}{\partial S}
\]

which typically occurs above the maximum of \( N^2(T, S) \). Importantly, the OSS measures the strength of the salinity stratification above the main thermocline and is independent of the position of the mixed layer.
How are the changes in the EAC dynamics related to the surface warming and atmospheric circulation?

Can the recent surface warming be regarded as simple linear trend?


Figure 13: (a) Global sea surface temperature (K) annual mean for the period 1870-2010 based on the HADISST dataset with the linear trend line; (b) composite states from cluster analysis; (c) regime transition toward +ve SAM - away from wave 3.
Ocean forecast initialization – from days to decades

What/where are the relevant low dimensional subspaces?

2060’s

[Map and diagrams showing ocean currents and temperature changes]

Decadal variability at Maria Island

Eddy resolving ensemble forecast

Sea Level Anomaly

1 week

1 month
Thanks!

References:
C. Franzke and T.J. O’Kane “Nonlinear and Stochastic Climate Dynamics” Cambridge University Press (in press December 2016)

- A.C.V. Freitas, J.S. Frederiksen, T.J. O’Kane and T. Ambrizzi (2016) Simulated austral winter response of the Hadley circulation and stationary Rossby wave propagation to warming climate (Climate Dynamics)