Coupled Data Assimilation with CESM-DART:
System Design and Evaluation

Abhishek Chatterjee
A. R. Karspeck, J. L. Anderson, N. Collins, G. Danabasoglu,
T. J. Hoar, K. D. Raeder, J. J. Tribbia, S. G. Yeager

National Center for Atmospheric Research

Ocean Model Working Group Meeting
January 16th - 17th 2014
Existing DART setups for CESM components

- **CAM-DART**
  - atmosphere component
  - Raeder et al. (2012), *J. Climate*

- **POP-DART**
  - ocean component
  - Karspeck et al. (2013), *J. Climate*
Defining the Terminology for the Coupled Framework

**Ideal Target**

**Cross-component**

**Coupled model DA**

“Assimilation into a coupled model where observations in one medium are used to generate analysis increments in the other”

(from M. Rienecker, WMO CAS Workshop, Dec. 2010)
Motivation for a CDA Framework

- **“Seamless prediction”** – days to decades
  - better and more balanced ocean-atmosphere states - consistent surface fluxes, mass and energy budgets
  - reduce forecast initialization shocks

- **Accurate representation of coupled phenomena, or processes linked by strong air-sea interactions**
  - short-term – MJO
  - extreme events – tropical cyclones

- **Improve use of near surface observational data**
  - let observations in boundary layers influence both fluids
  - capture the diurnal cycle in atmosphere-ocean interactions
Existing/Planned CDA Frameworks

- CESM-DART
- OMWG 2014
- ECMWF
- Met Office
- NCEP CFSR
- Canadian Met Service Systems
- BMRC
- JAMSTEC
- JMA-MRI
- GFDL
- NRL
Multi-component Coupled Model Data Assimilation

- Coupler exchanges fluxes and other necessary information between component models
- CESM 1_1_1 B-compset: several other models (e.g. sea/land-ice) that are active
Evaluating Performance in Observation Space

- Ensemble analysis provides an estimate of analysis and forecast uncertainty
  - (Top Panel) evolution of prior and posterior RMS error
  - (Bottom Panels) profile of time-averaged prior and posterior RMS error, total spread and bias relative to the actual radiosonde T observations
Multi-component (MuC) CDA

- Initial Conditions
  - 30 member ensemble
  - 20th century control run from ~1° CESM

- Atmosphere (CAM)
- Land (CLM)
- Ocean (POP)

- Ensemble members

- DART Atm. Obs.

- Time:
  - 00Z
  - 06Z
  - 12Z
  - 18Z
  - 24Z
Ocean-component (Ocean-only) CDA

Initial Conditions
- 30 member ensemble
- 20th century control run from ~1° CESM

Atmosphere (CAM)
- COUPLER
- ensemble members

Land (CLM)
- COUPLER

Ocean (POP)
- COUPLER

00Z 06Z 12Z 18Z 24Z

DART
Ocean Obs.
No-Assim. (Free) Coupled Model Run

Initial Conditions
- 30 member ensemble
- 20th century control run from ~1° CESM

Ocean (POP)
- Initial Conditions
- 30 member ensemble
- 20th century control run from ~1° CESM

Atmosphere (CAM)
- Initial Conditions
- 30 member ensemble
- 20th century control run from ~1° CESM

Land (CLM)
- Initial Conditions
- 30 member ensemble
- 20th century control run from ~1° CESM

ensemble members

00Z 06Z 12Z 18Z 24Z

Time
SST Evaluation (2004 Annual Mean)

<table>
<thead>
<tr>
<th></th>
<th>Mean Diff.*</th>
<th>RMSE**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free-run-HSST</td>
<td>+ 0.82</td>
<td>0.93</td>
</tr>
<tr>
<td>Ocean-only -HSST</td>
<td>+ 0.82</td>
<td>0.93</td>
</tr>
<tr>
<td>MuC - HSST</td>
<td>+ 0.93</td>
<td>1.06</td>
</tr>
</tbody>
</table>

* Hurrell SST used as a ‘reference’ set
** Caveat - only 12 data points
SST Evaluation (2004 Time Series)

Gulf Stream

Kuroshio Region

Tropical Pacific (5N–5S, 80–100W)

Southern Ocean

Legend:
- NOAA Highres
- Hurrell
- MuC
- Ocean-only
- Free Run
SST Difference between the two DA Experiments

- Pronounced differences in phase/amplitude in Tropical Pacific, western boundary currents
- Corrections (biases?) in SH
- Differences related to
  - Forcing fields
  - Ensemble spread

2004 Annual Mean
Multi-Component (minus) Ocean-only

Multi-component CDA estimates a higher SST
Impact of Changes in Forcing fields

- Differences in SST corresponds to differences in surface heat flux, sea surface height → changes in wind fields
Impact of Changes in Forcing fields (contd.)

September 2004

Lower wind-stress in MuC

Shallower MLD in MuC
Impact of an Unconstrained Atmosphere

Evaluation in observation space of the prior and posterior RMS error and the ensemble spread for float temperatures

- Tropical Pacific (5S-5N, 80-100W)
Ongoing/Planned Activities

- 4 different experiments covering January – December 2004
  - multi-component (MuC) CDA ✓
  - ocean-component (ocean-only) CDA ✓
  - atmosphere-component CDA
  - no-assimilation (free) run ✓

- Planned prediction experiments
  - short-term: MJO, seasonal forecasting (e.g. ENSO)
  - long-term: decadal forecasting (e.g. AMOC)

- Improving/initiating new schemes for CESM-DART
  e.g. for POP-DART
  - accounting for representativeness error (A. Karspeck)
  - inclusion of BGC tracers (very initial discussions with K. Lindsay)
Summary

- Successful implementation of coupled DA with CESM-DART
  - multi-component coupled model framework
  - test-bed for transitioning to cross-component coupled model scheme

- Results from initial implementation-
  - demonstrates differences in multi-component vs. single-component frameworks
  - demonstrates strong impact of boundary forcing fields, esp. changes to wind fields when atmospheric observations are assimilated
  - part of the differences can be attributed to the response of the ensemble filter to constrained vs. unconstrained atmosphere

- Multiple configurations have been setup to explore-
  - potential strategies for initializing near-term climate prediction
Acknowledgements

- NOAA Climate and Global Change Postdoctoral Program, Visiting Scientists Program, UCAR
- CESM project is supported by the National Science Foundation and the Office of Science (BER) of the U.S. Department of Energy
- Frank Bryan, Tony Craig, Clara Deser, Brian Eaton, Jim Edwards, Peter Gent, Michael Levy, Keith Lindsay, Mitch Moncrieff, Nancy Norton, Chris Snyder, Mariana Vertenstein, and others
- Funding sources:
QUESTIONS?

abhishek@ucar.edu
CESM Model Components

- All active components (B COMPSET)
- Present day with CAM5 physics (CAM5 FV core)
- Horizontal Res: Nominal ~1°
- Vertical Discretization:
  - CAM – 30 levels
  - POP – 60 levels with 10 m resolution in the upper 200 m, gradually expanding to 250 m resolution below 3000 m depth

CESM Components – High Level Diagram

The coupler is in the middle and communicates with all other components

(adapted from - https://summerofhpc.prace-ri.eu)
CESM Model Bias

### SST

**b40_20th_1d_b08c5cn_139jp (yrs 1981-2000)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.11</td>
<td></td>
</tr>
</tbody>
</table>

### Surface Stress

**b40_20th_1d_b08c5cn_139jp (yrs 1981-2000)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.06</td>
<td></td>
</tr>
</tbody>
</table>
Estimated Atmospheric Model States

- **Suite of variables from atmosphere, ocean, land and other model components**
- **Quantitative examination ongoing**
  - need a larger timespan of runs to assess any systematic drifts
  - qualitatively fields for the first set of runs look ok!