Ensemble data assimilation using the CESM model
Integrating the CESM with the DART ensemble filter

*CESM Tutorial*

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Why do data assimilation with the CESM?

Climate (re)analysis
- Want to generate a historical record of the climate system (or its components)
  e.g.: “Has the ocean warmed in the last 50 years?”
- Want to understand physical processes in a data-constrained system

Initializing forecasts
- Time scales of days to decades (atm + ocean + land + ice)

Model improvement
- Using DA increments to diagnose and try to understand(?) the biases/errors in the models

Assess an observational platform
Data Assimilation Research Testbed
Fortran code
developed/maintained in CISL

Data assimilation capabilities for CESM are based on the DART ensemble filter

We have working systems for
+ CAM assimilation
+ POP assimilation
+ CLM assimilation
** Greenhouse gases, manmade aerosols, volcanic eruptions, solar variability
Community Earth System Model
“multi-instance”

** Greenhouse gases, anthropogenic aerosols, volcanic eruptions, solar variability
DART is a model-agnostic ensemble filter for data assimilation; Necessary Ingredients:

- **Model forecasts**
  - Model state can be defined independently for each component or jointly across components.
- **Forward operators** to map from the model state vector to the observation space
- **Observations**

(http://www.image.ucar.edu/DAReS/DART)
Frameworks for data assimilation

Schematic courtesy of A. Chatterjee
Community Earth System Model interfacing with DART in a “single-component” DA uncoupled framework

- Atmosphere (CAM)
- Ocean (POP)
- PRESCRIBED ice fields
- COUPLER
- PRESCRIBED runoff
- ocn obs
- DART
Community Earth System Model interfacing with DART in a “multi-component” DA coupled framework

- ATM obs ↔ DART → Atmosphere (CAM)
- OCN obs ↔ DART → Ocean (POP)
- Land (CLM) ↔ DART → Land (CLM)
- SEA ICE (CICE) ↔ DART → SEA ICE (CICE)
- River-Runoff ↔ DART

What are the existing resources?
- DART
CESM-DART

coupled data assimilation (time-view)

- Coupler exchanges fluxes and other necessary information between component models at equal or higher frequency than assimilation update.

- Multi-component: assimilation of observations independently in each component.
POP/CAM/CESM-DART: experimental climate reanalyses

1. CAM4-DART (2° atm-only)
2. POP-DART v1: ocean-only
3. POP-DART v2
4. CESM-DART_1 coupled
5. CESM-DART_2 coupled (w/CAM5, POPDART v2)

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All methods use the “model agnostic” DART implementation of the Ensemble Adjustment Kalman Filter
Some ocean results: SST variability

1970-1979 Monthly SST correlation

cesm_6hr_1970b_Hadley-OI SST

<table>
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<th>60°N</th>
<th>30°N</th>
<th>Eq</th>
<th>30°S</th>
<th>60°S</th>
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<td>-0.7</td>
<td>-0.5</td>
<td>-0.3</td>
<td>0.2</td>
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SST anomalies in the Nino 3.4 region (5N-5S, 120W-170W)

$r = 0.95$

1972-73 El Nino event simulated

Plots courtesy of S. Karol

Generally high correlation with HADISST
More early results from the CESM-DART coupled assimilation atm

6hr snapshots of sea level pressure from CAM5

[Images of maps showing sea level pressure comparisons between NCAR CESM-DART and NCEP for different dates and locations, highlighting Hurricane "Eloise".]
end

How to learn more:

DART website:

- http://www.image.ucar.edu/DARES/DART
- Examples/papers/tutorials/etc.
Early results are promising, but we need more eyes on the data!


Contact: aliciak@ucar.edu

- Ocean/land/ice (monthly history files available)
- Atm (6 hourly history files available)
- Ocean (data assimilation increments available)
- Atm (data assimilation increments available)

Also more diagnostics available (ask me)
DART jurisdiction:
- Implementation of DA algorithms
- Efficiency of the software
- Definition of protocols
  - observation format
  - common time/distance protocol
  - protocol for passing state vector between the model and DART
- Library of “use cases” (commonly used model interfaces, observational data sets, forward operators, diagnostic routines)

User jurisdiction:
- Definition of the “state”
- Observations
- Mapping from the model state to the observations (‘forward operators’)

Model/use/obs specific interfaces

CESM jurisdiction:
- The best way to run an ensemble of simulations (speed)
- How to stop (or pause) and restart (resume) a simulation
- What model fields diagnostics are output/saved/archived