The Use of the Data Assimilation Research Testbed for Initializing and Evaluating IPCC Decadal Forecasts.

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Outline

- Loosely coupled ocean-atmosphere data assimilation.
- Comparing model forecasts to observations (and analyses).
  - Ocean; conventional + surprising, but sparse
  - Atmosphere; old standbys and exciting newcomers
  - Tools for exploration
- Other uses of analyses and short forecasts.
  - Comparison with model output in model space
  - Initial conditions for forecasts
  - Identification of model formulation errors
A Loosely Coupled, Ocean-Atmosphere, Data Assimilation System

Obs used by NCAR-NCEP reanalyses

Hadley + NCEP-OI2 SSTs

DART/CAM assimilation system

CESM1 coupler history files: atmospheric forcing

World Ocean Database Observations

POP/DART assimilation system

CAM analyses:
- CAM4 initial files; posterior ensemble mean of state variables
- prior ensemble mean of all other variables
- CLM restart files; prior ensemble mean of all variables
- CICE restart files; prior ensemble mean of all variables

POP analyses:
- temperature, salinity, velocities, surface height

CAM state variables = PS, T, U, V, Q, CLDLIQ, CLDICE
Prior = values before assimilation (but after a short forecast)
Posterior = values after the assimilation of observations at that time
Observations for 1998-1999

Temperature and salinity from World Ocean Database.

FLOAT_SALINITY  68200
FLOAT_TEMPERATURE  395032
DRIFTER_TEMPERATURE  33963
MOORING_SALINITY  27476
MOORING_TEMPERATURE  623967
BOTTLE_SALINITY  79855
BOTTLE_TEMPERATURE  81488
CTD_SALINITY  328812
CTD_TEMPERATURE  368715
STD_SALINITY  674
STD_TEMPERATURE  677
XCTD_SALINITY  3328
XCTD_TEMPERATURE  5790
MBT_TEMPERATURE  58206
XBT_TEMPERATURE  1093330
APB_TEMPERATURE  580111

Observations of ocean currents are also available.
Exploring in Observation Space: MATLAB linked windows
Typical Daily Atmospheric Observation Set Coverages
(e.g. 12/6/2006)

Observations of moisture and pressure are also available.
Exploring in Observation Space: **Bias**, **RMS Error**, and **Obs Count**

**Radiosonde Temperature**
Northern Hemisphere

- **# of obs (o=pos, +=used)**
- **rmse pr=1.575**
- **rmse po=1.0868**
- **bias pr=0.040565**
- **bias po=0.096684**

**Aircraft Temperature**
Northern Hemisphere

- **# of obs (o=pos, +=used)**
- **rmse pr=1.672**
- **rmse po=1.3742**
- **bias pr=-0.68234**
- **bias po=-0.32104**

01-Dec-2006 03:00:01 through 01-Jan-2007 03:00:00
GPS occultation forward operators

Local refractivity:

- Interpolate model pressure, temperature and moisture to tangent point.
- Calculate density, then atmospheric refractivity.
- Compare refractivity from COSMIC DAAC.
- Max of 15 tangent points below 13 km per profile.
Exploring in Observation Space: Time series of RMS Error, Total Spread and Obs Count

GPS Radio Occultation Refractivity ~1000m

- **Southern Hemisphere**
  - rmse pr=6.6609, po=5.3202
  - totalspread pr=7.725, po=7.265

Radiosonde Specific Humidity ~925 hPa

- **Southern Hemisphere**
  - rmse pr=1.5098, po=1.5545
  - totalspread pr=2.4986, po=2.3751
DART-CAM Specific Humidity Analyses (and more) @ 992 hPa

Ensemble Mean, 0-21 g/kg

Member 1, 0-21 g/kg

Ensemble Spread (Analysis Uncertainty!), 0-4 g/kg

Prior Ensemble Inflation (time+space varying), 0-7
CCSM4 (POP+CAM4) Decadal Prediction Initial Conditions

Figures and analysis thanks to Alicia Karspeck

1. POP/DART ICs, Jan 1, 2000

2. ICs from hindcast, Jan 1, 2000

3. Hindcast error, Jan 1, 2000

Analysis (avg T in top 250m of N. Atlantic) from POP/DART assimilation.

ICs from a hindcast forced by CORE2 historical surface fluxes.

Difference of 2 from 1:
- Gulfstream fails to turn north @ 45W
- Gulfstream too broad off east coast
- North Atlantic drift eastward and southward is too weak
2 Year Lead Forecast; Monthly Means

Hindcast ICs

POP/DART ICs

Benefit of improved ICs lasts at least 2 years.
Other results imply benefit to at least 5 years.
Improving Climate AGCMs with Data Assimilation

- 6-hour forecasts from analysis ICs.
- Instantaneous meridional velocity (VS).
- Default (CESM 1.0) damping; 2 dy and 2 dx noise O(several m/s).
- Masked by time averaging or regridding.
- $\nabla^4$ damping (Peter Lauritzen); reduced noise; not perfect.

Examination of climate model output in a data assimilation framework helps identify model deficiencies.
CAM4’s cloud response to sea ice loss; July 2006 to 2007

24-hour forecasts started from DART/CAM analyses identified erroneous cloud response to disappearing sea ice. Jen Kay found that low clouds were only diagnosed over open water, not ice, and the low cloud scheme should have required a well mixed boundary layer.

Short forecasts with a climate model from analyses, compared against observations, point to model improvements.
Data Assimilation; not just for experts anymore

- DART has been engineered to minimize the effort to incorporate new models.
- Full complexity models have been interfaced to DART in less than a week.
- Many geophysical models already included: CAM (several versions), POP (CESM1), MITgcm_ocean, AM2, COAMPS, ROSE, WRF, NOGAPS, NCOMMAS.
- New observation sets can be incorporated with similar ease.
- Model interfaces are independent from observation interfaces, so that any model can assimilate any relevant observations without additional coding.
Summary

DART provides a flexible, convenient, rigorous environment for:

- Identifying model deficiencies and biases relative to real observations, both in model space and in observation space;
- Generating analyses for use as forecast initial conditions and for evaluating forecasts;
- Evaluating the forecasting skill of models.

Learn more at [www.image.ucar.edu/DARES/DART](http://www.image.ucar.edu/DARES/DART)
Contact us at dart@ucar.edu
However, prediction tests show that upper ocean bias reduction persists for 5+ years, especially with data assimilation initialization (red).
Physical Space Detail: SST Anomaly from HadOI-SST

Coupled Free Run

DART 23x1

DART 48x48

POP-CICE restored at surface to HadOI-SST

OMWG – 29 June 2010
CCSM4 (POP+CAM4) Decadal Prediction Initial Conditions

Figures and analysis thanks to Alicia Karspeck

Illustration: average T in top 250m of N Atlantic from:

1. POP/DART analysis (used as ICs for “POP/DART” forecast),
2. ICs from a “hindcast” forced by CORE2 historical surface fluxes,
3. Difference of 2 from 1.
Year 2 forecasts (to be continued...)

Ocean State Estimate w/ assimilation
Dec 2001

CCSM4 forecast from ocean state w/ assimilation
Dec 2001

RMS error in forecast of midlatitude–Atlantic upper ocean temperature

Difference from ocean state:
CCSM4 forecast from ocean state w/ assimilation
Dec 2001

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