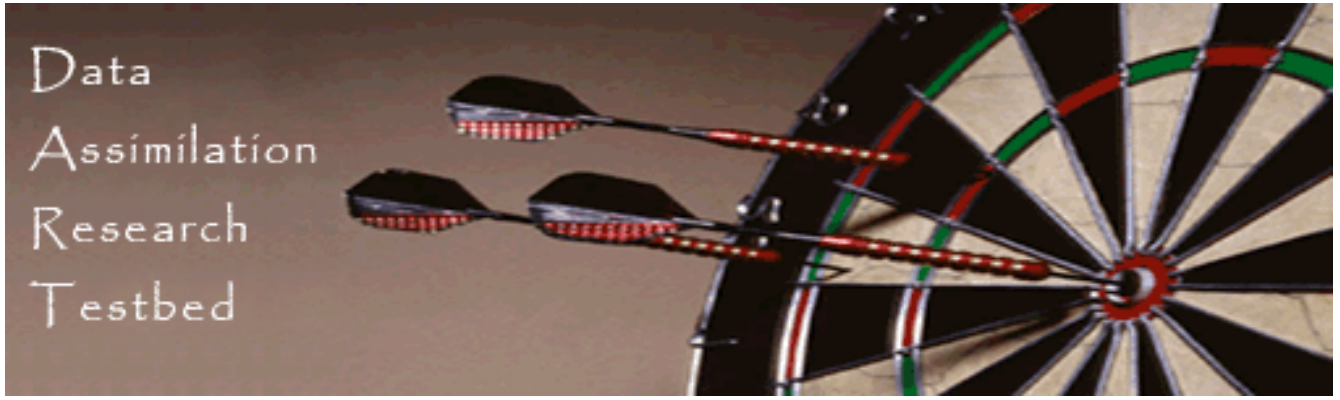
POP-DART; The Leading Edge of Coupled Ocean-Atmosphere Reanalyses



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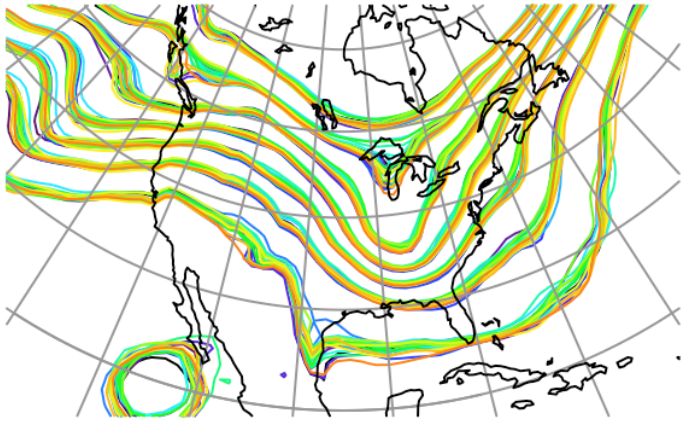
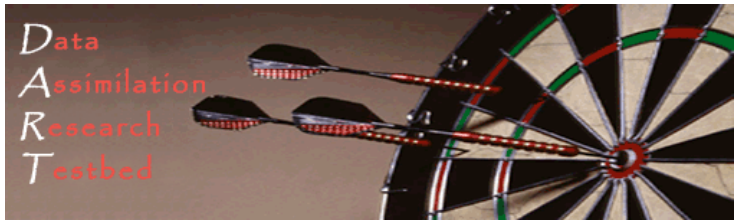
What is Data Assimilation?

Observations combined with a Model forecast…

…to produce an analysis
(best possible estimate).



DART is:



Public domain software for Data Assimilation

- Well-tested, portable, extensible, free!

Models

- Toy to HUGE

Observations

- Real, synthetic, novel

An extensive Tutorial

- With examples, exercises, explanations

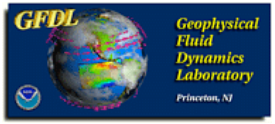
People: The DAReS Team

used at -

UNIVERSITY OF WASHINGTON

CIRES

THE UNIVERSITY OF UTAH



PENNSTATE

1855

JPL
Jet Propulsion Laboratory
California Institute of Technology

and many more.

...

NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

NSF

Ensemble Filter for Large Geophysical Models

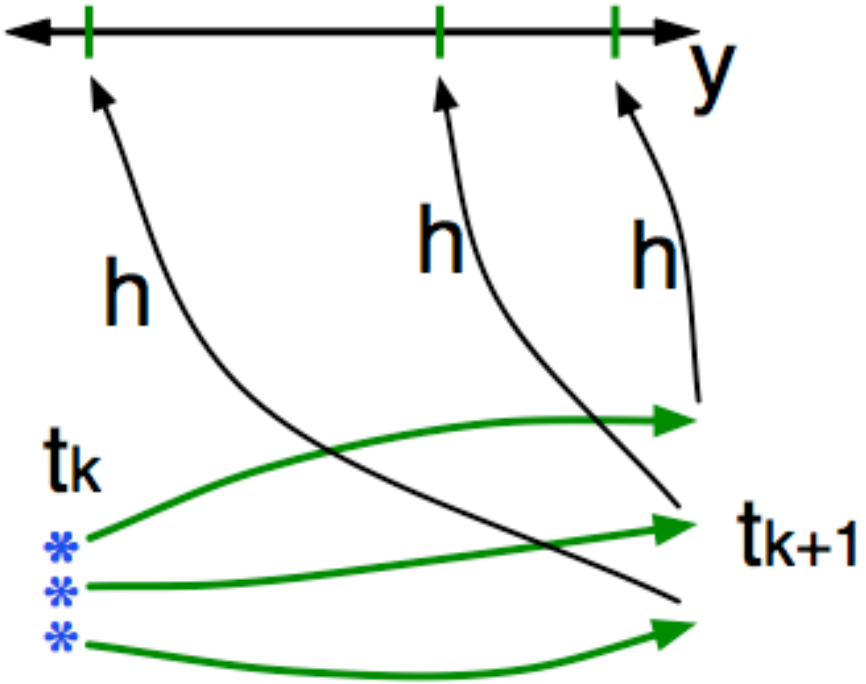
1. Use model to advance ensemble (3 members here) to time at which next observation becomes available.

Ensemble state estimate, $x(t_k)$, after using previous observation (analysis)

Ensemble state at time of next observation (prior)

Ensemble Filter for Large Geophysical Models

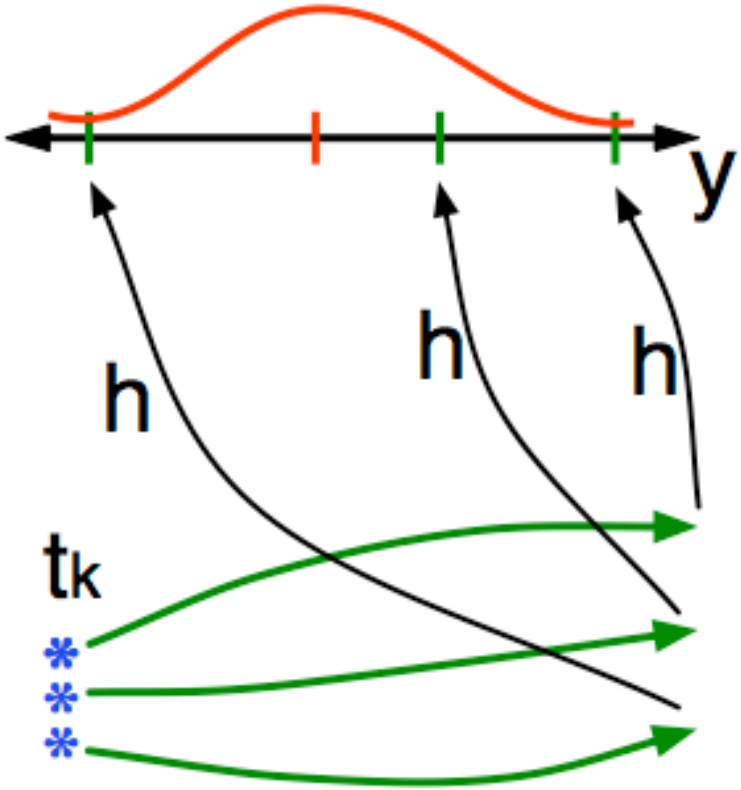
2. Get prior ensemble sample of observation, y = h(x), by applying forward operator **h** to each ensemble member.



Theory: observations from instruments with uncorrelated errors can be done sequentially.

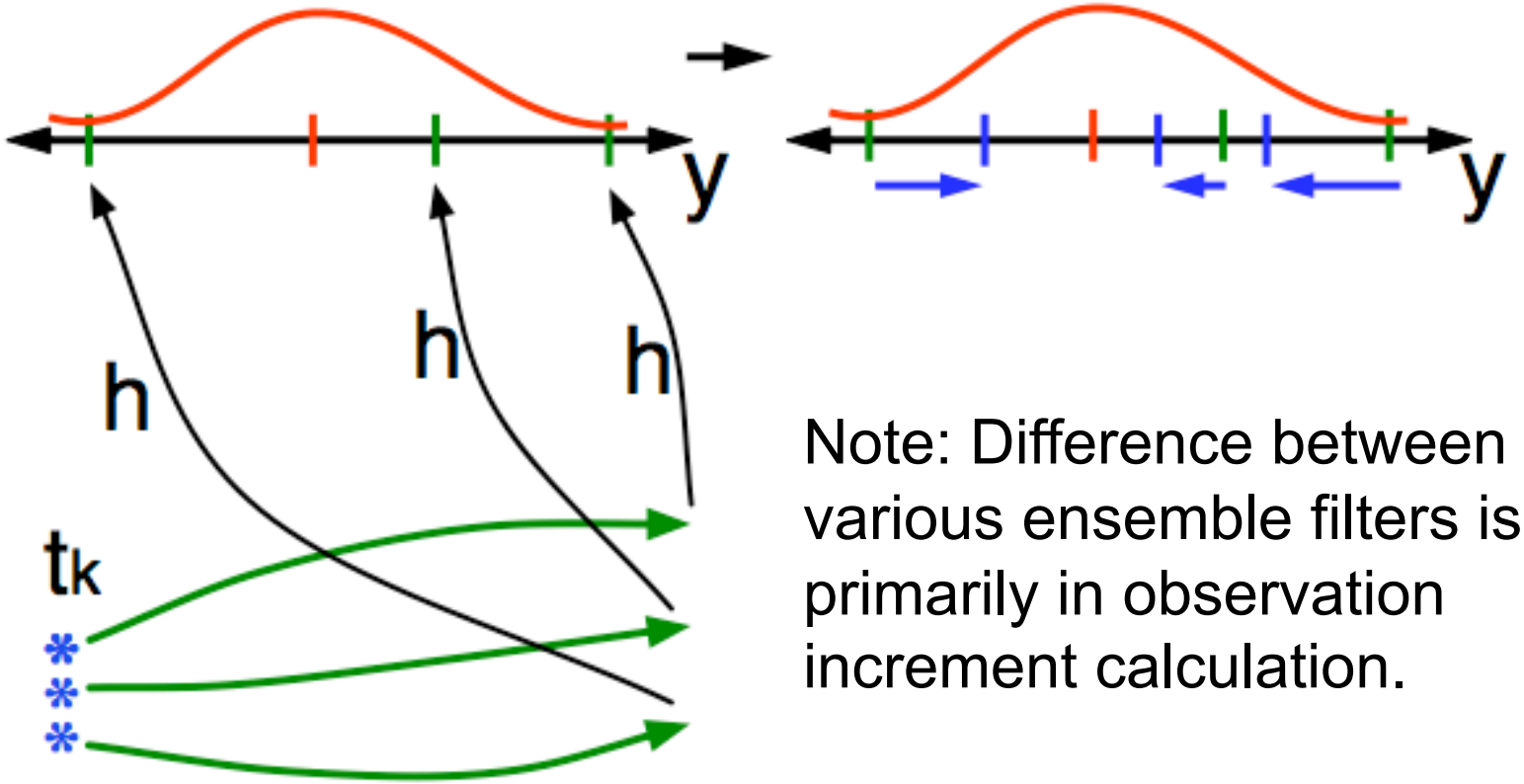
Ensemble Filter for Large Geophysical Models

3. Get observed value and observational error distribution from observing system.



Ensemble Filter for Large Geophysical Models

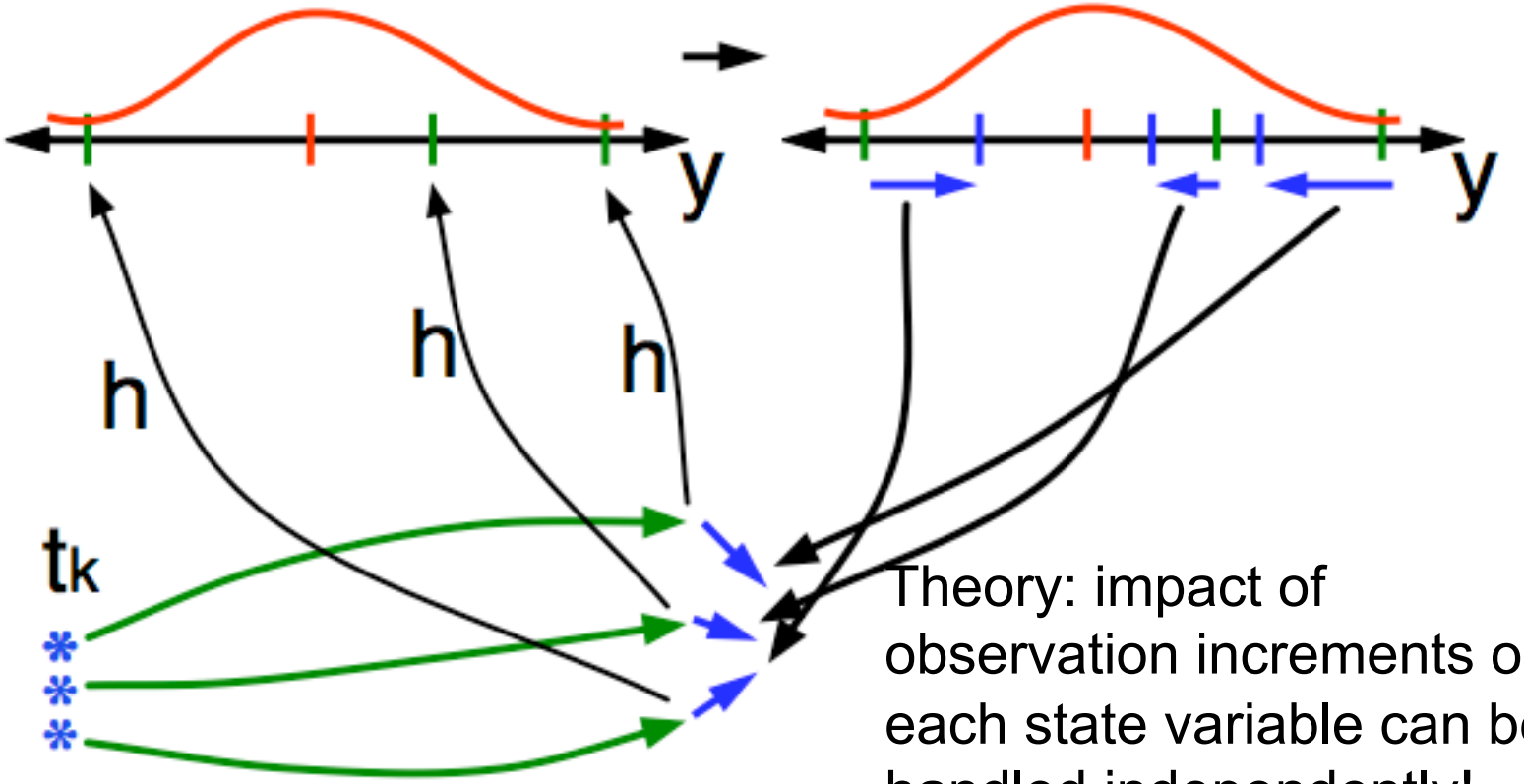
4. Find the increments for the prior observation ensemble (this is a scalar problem for uncorrelated observation errors).



Note: Difference between various ensemble filters is primarily in observation increment calculation.

Ensemble Filter for Large Geophysical Models

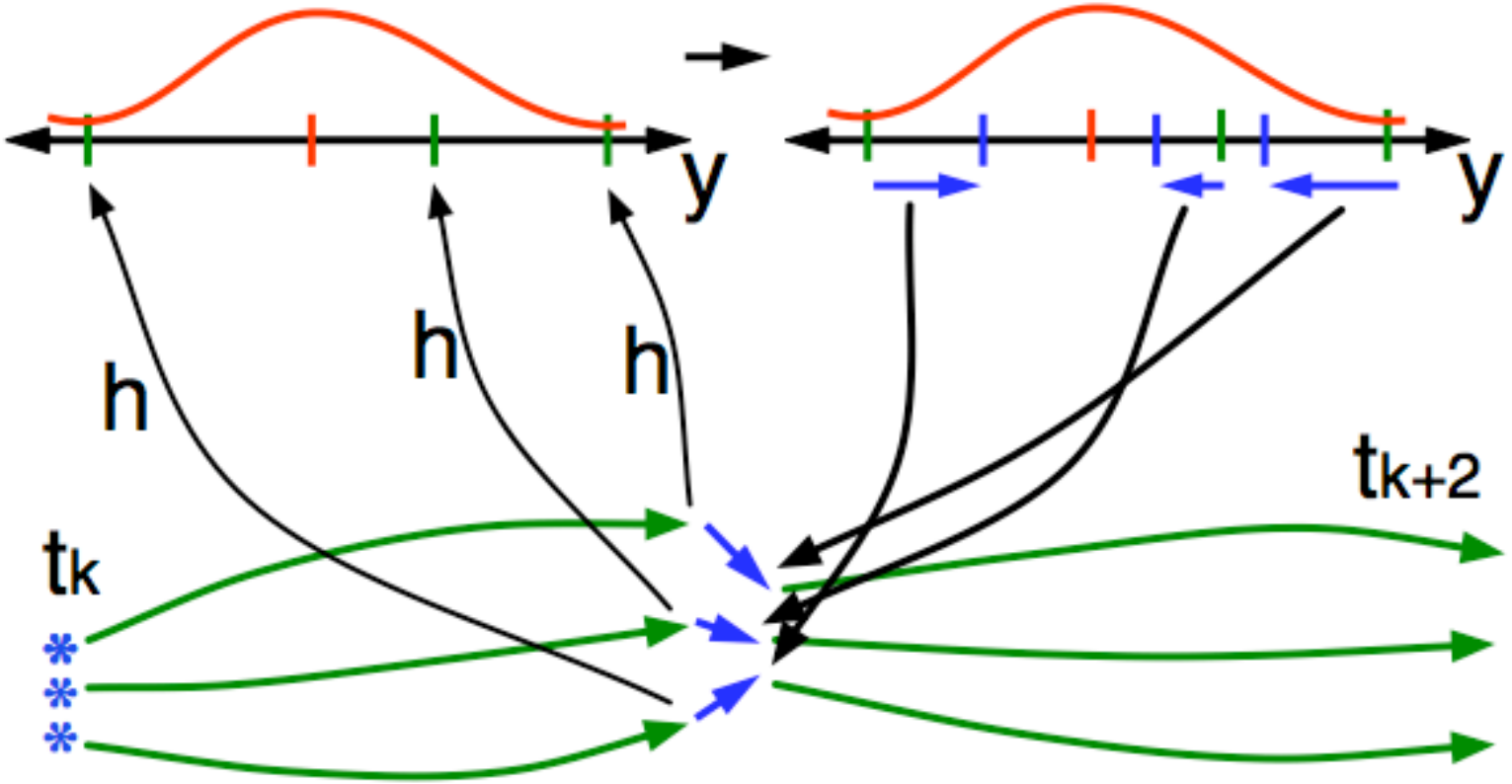
5. Use ensemble samples of **y** and each state variable to linearly regress observation increments onto state variable increments.



Theory: impact of observation increments on each state variable can be handled independently!

Ensemble Filter for Large Geophysical Models

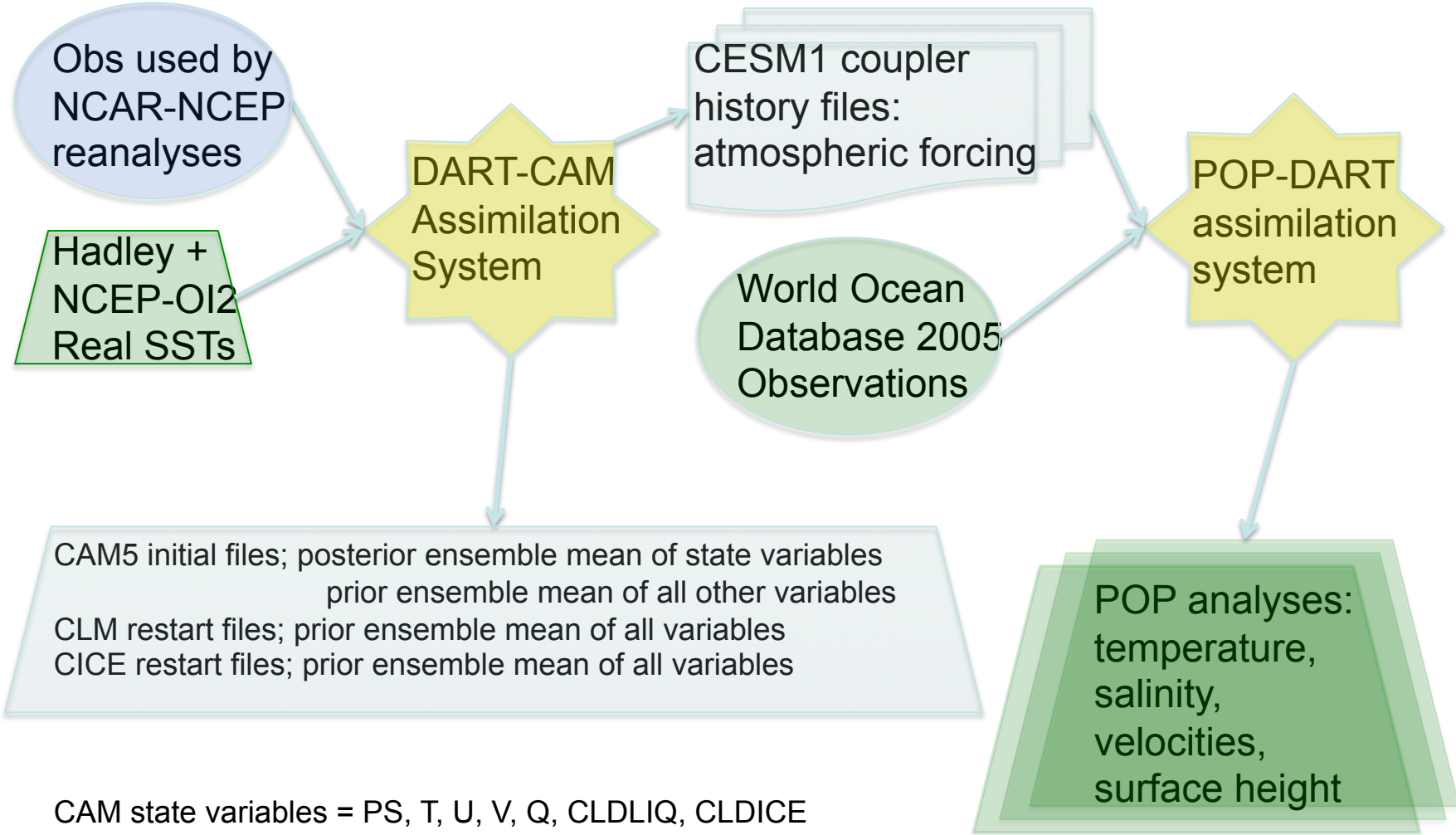
6. When all ensemble members for each state variable are updated, there is a new analysis. Integrate to time of next observation …



Motivation for Ocean Data Assimilation

- Climate change over time scales of 1 to several decades has been identified as very important for mitigation and infrastructure planning.
- The ocean plays a crucial role by providing a source or sink (and system memory) for the atmosphere of many quantities, such as heat, moisture, CO2, etc.
- Increasing numbers of observations from larger regions of the oceans are making state-of-the-art data assimilation a promising possibility.
- High fidelity ocean states will be needed by the IPCC decadal prediction program.

Reanalyses from a Mostly Coupled Ocean-Atmosphere System



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

POP-DART Assimilation System

Uses the CESM1 software framework; ocean, atmosphere, and other components communicate through the coupler. A few minor script changes and use of the interactive ensemble capability permit each member of an ensemble of POPs to be forced by a different CAM atmosphere.

```
# ------------------------------------------------------------------
# See if CSM finishes correctly (pirated from ccsm_postrun.csh)
# ------------------------------------------------------------------
# DART assimilation operating on restarts
# ------------------------------------------------------------------

grep 'SUCCESSFUL TERMINATION' $CplLogFile
if ( $status == 0 ) then
   ${CASEROOT}/assimilate.csh
endif
```

POP-DART Assimilation Design

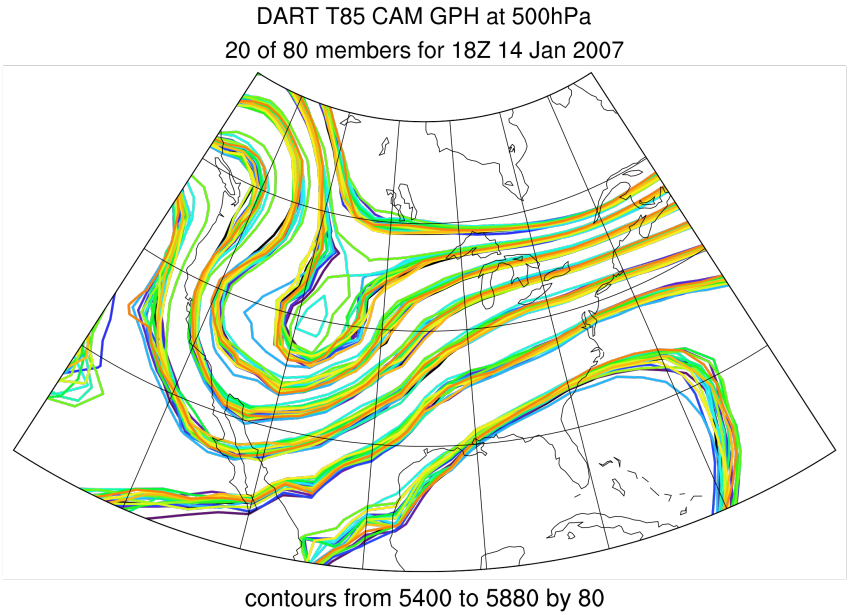
1. POP 1-degree displaced pole;
2. 48 Ensemble members;
3. Start from ‘climatological’ ocean ensemble;
4. Start from a ‘converged’ ensemble of atmospheric analyses;
5. Assimilate observations once per day;
6. Use all observations in a midnight +/- 12 hour window;
7. January 1998 through ~August 1999 (done) . . . present.

Forcing by Atmospheric Ensemble

1. Force each POP ensemble member with a different member of an atmospheric ensemble reanalysis;

2. Atmospheric reanalyses are 2-degree FV CAM5, forced by the same real ocean (Hadley+NCEP-OI2, not POP). In principle could also use GFDL's AM2, or NCEP GFS;

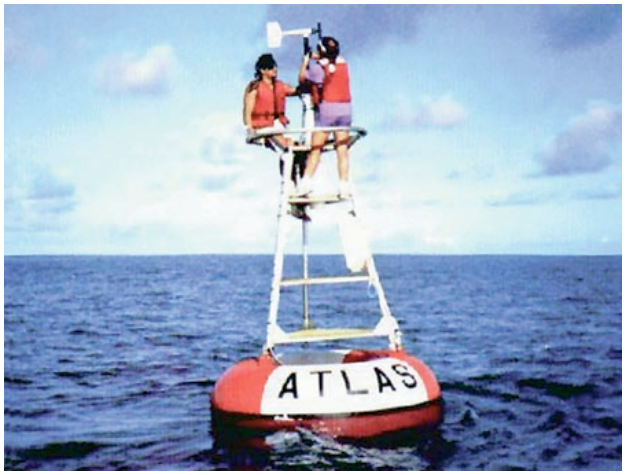
3. Generates additional ocean spread;



Observations for 1998-1999

Temperature and salinity from World Ocean Database 2005.

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 for 1998-1999

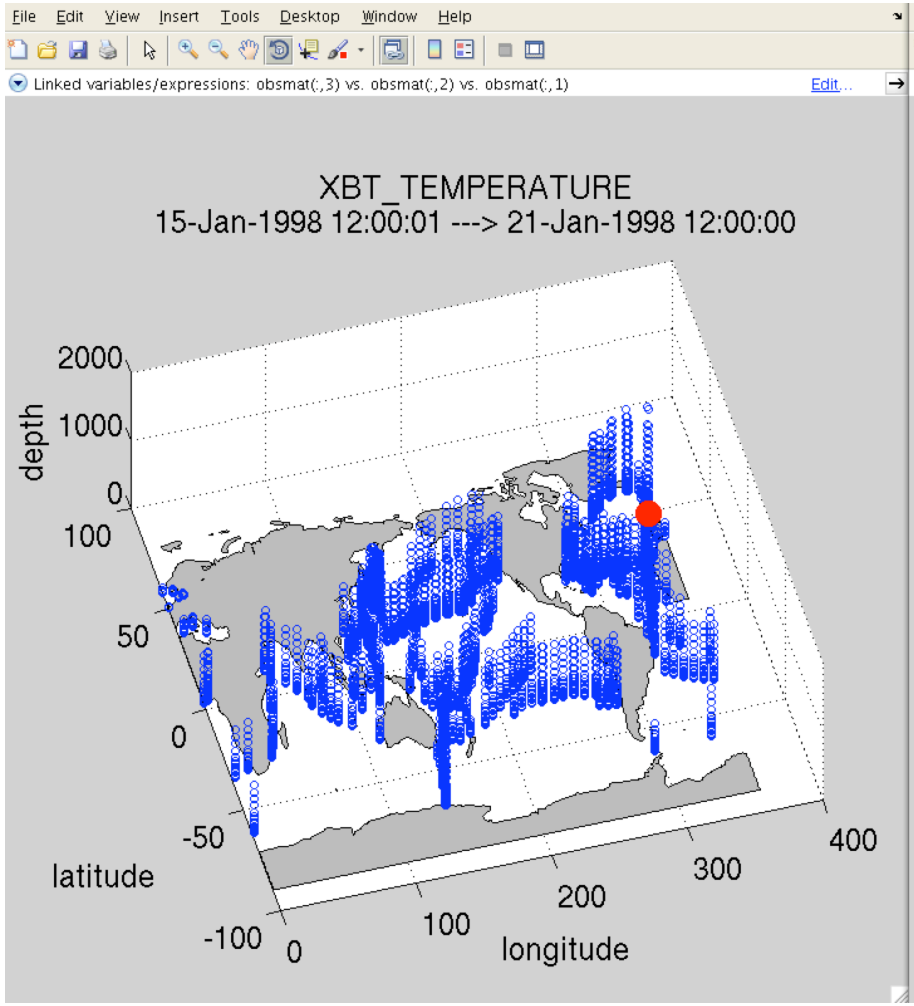
Temperature observation error standard deviation 0.5 K;
Salinity observation error standard deviation 0.5 msu.

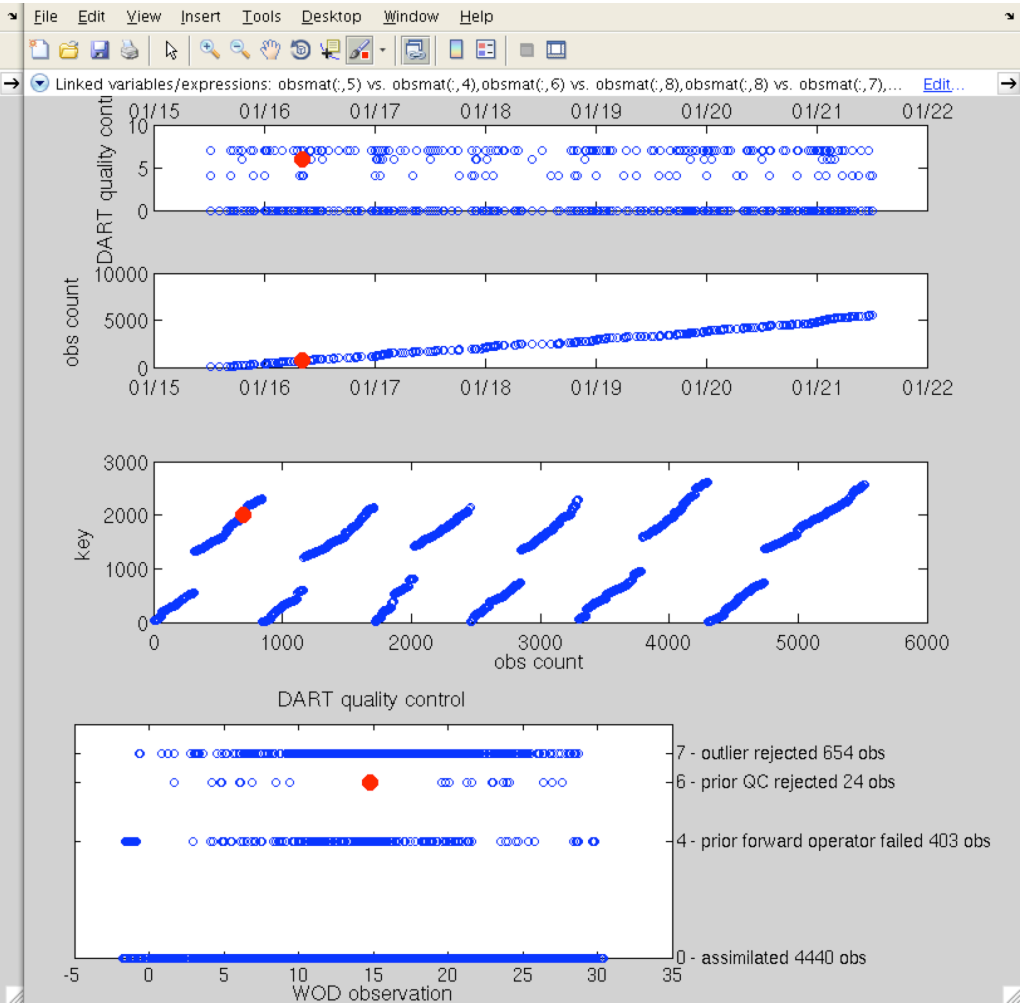
System is also ready to assimilate:

U, V;

Sea surface height.

Observation Visualization Tools





Observation Space Diagnostics (Jan-Feb1998)

10m Mooring Temperature

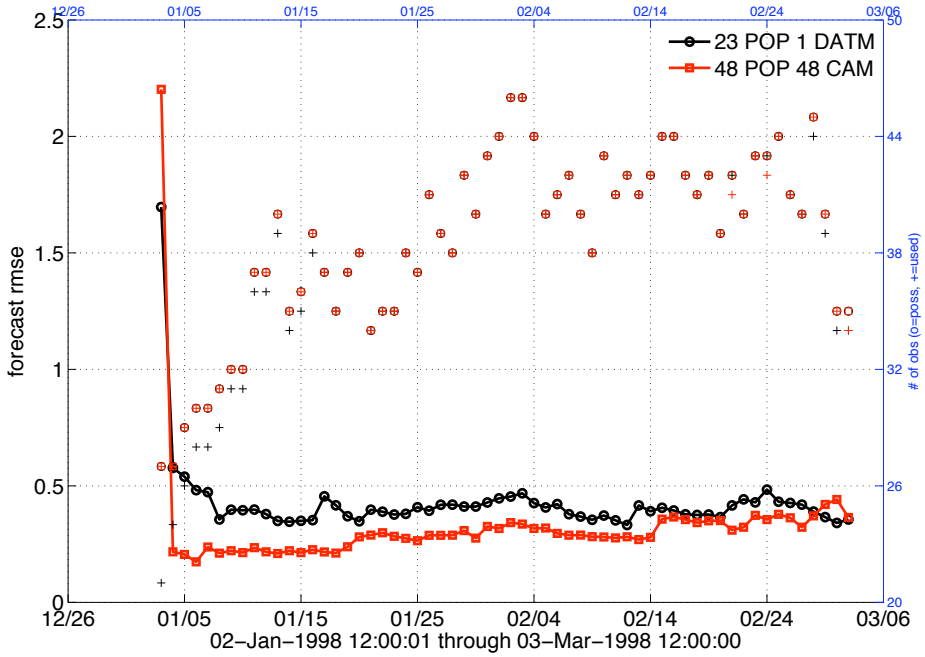
- 1.Ensemble mean analysis difference from obs.

2.Ensemble mean 1-day forecast difference from obs.

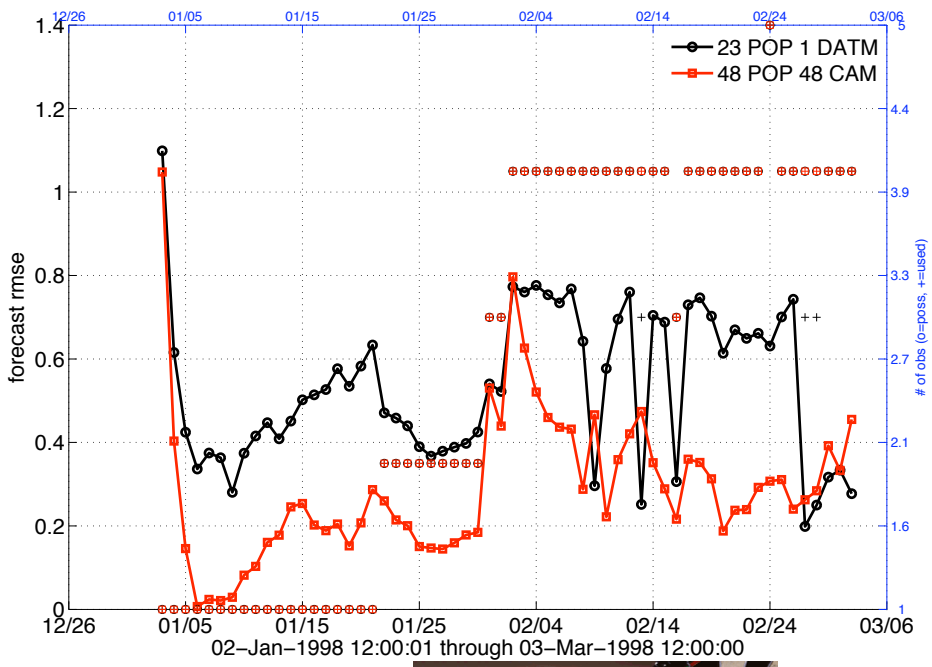
3. ☐ is # observations available. + is # assimilated.

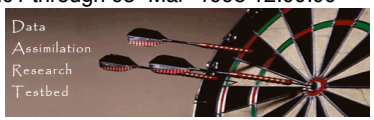
4. Obs. are rejected if they are too far from ensemble mean (3 standard deviations here).

Pacific



Atlantic



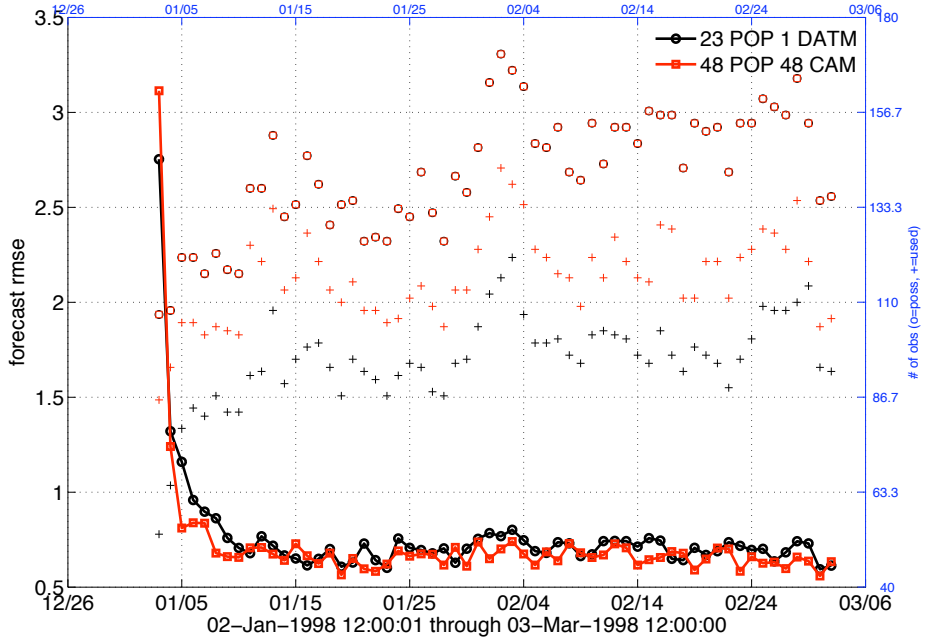


Observation Space Diagnostics (Jan-Feb 1998)

100m Mooring Temperature

1. ☐ is # observations available. + is # assimilated.
2. Obs. are rejected if they are too far from ensemble mean (3 standard deviations here).
3. About 1/3 of obs. rejected by 48 member assimilation in the Pacific.
4. Model bias in thermocline?

Pacific



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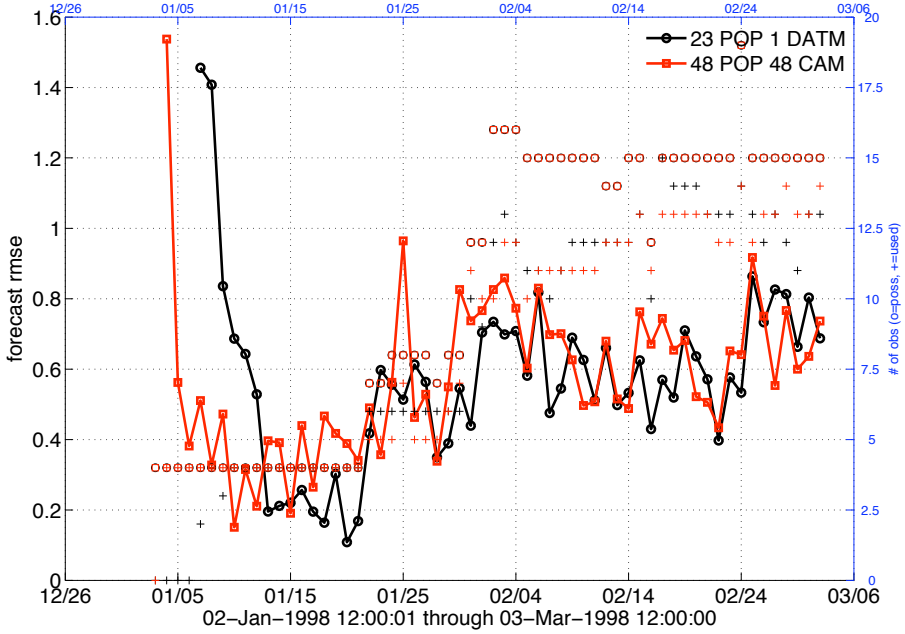
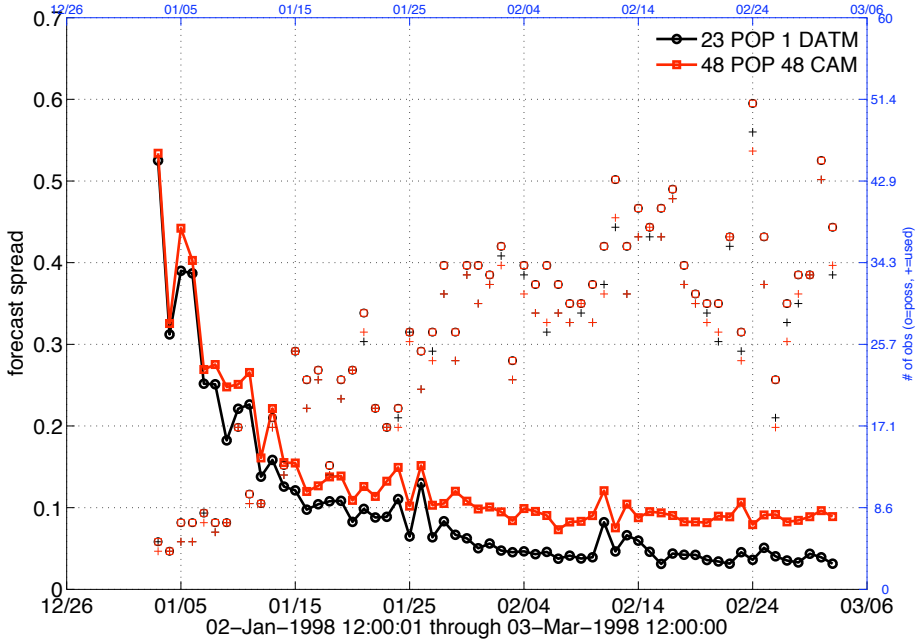


Observation Space Diagnostics: Ensemble *Spread* for 100m Expendable Bathythermograph (XBT)

1. Spread contracts too much for the 23 member/single atmosphere assimilation;
2. Model bias adds to the problem;
3. Using single atmospheric forcing is also part of the problem;
4. Adaptive spread inflation tools in DART won't work with POP (yet).
5. Statistical Sampling Error Correction does work.

Pacific



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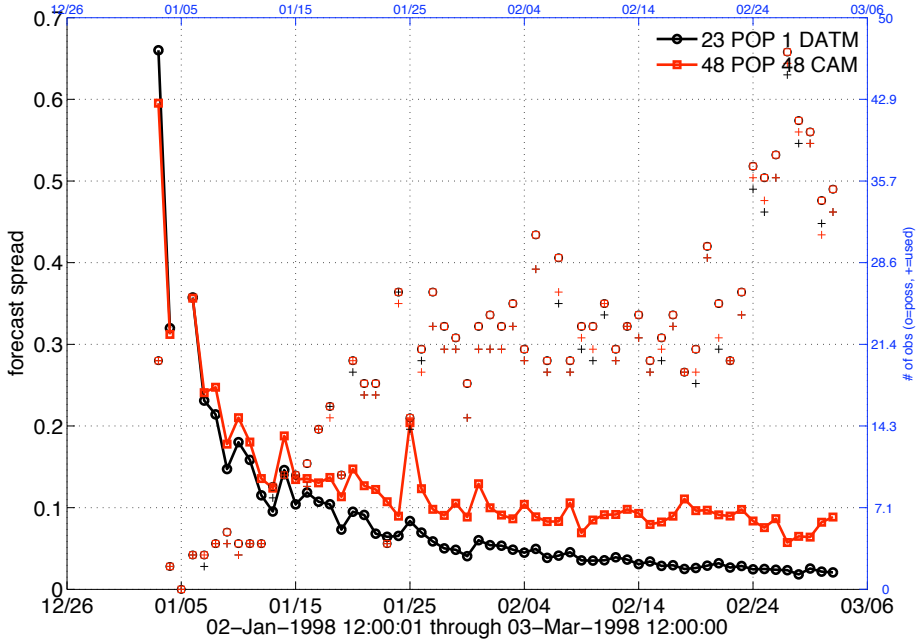
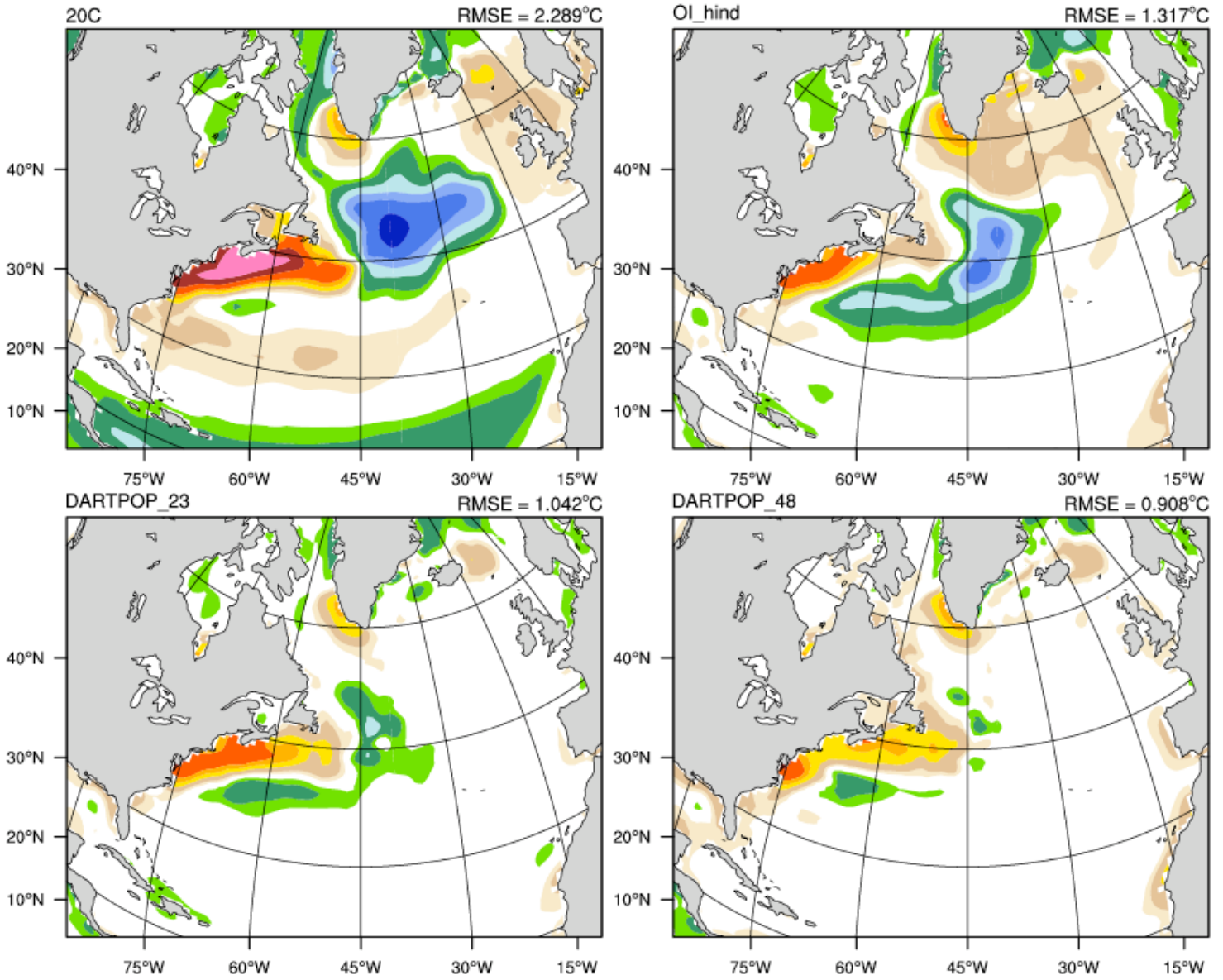


Physical Space Detail: SST Anomaly from HadOI-SST

Coupled Free Run

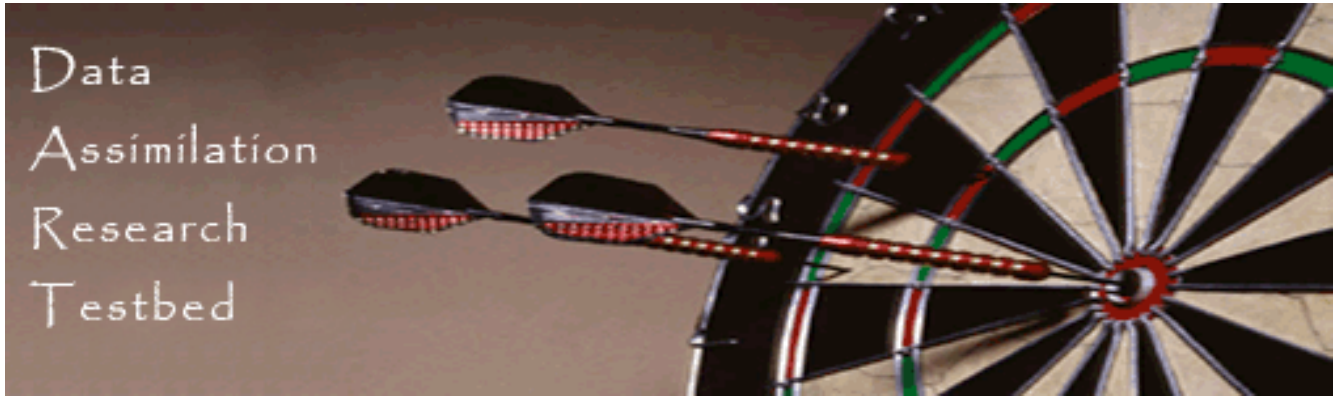
DART 23x1



POP-CICE restored at surface to HadOI-SST

DART 48x48

Learn about ensemble assimilation and DART tools at:



http://www.image.ucar.edu/DAReS/DART/