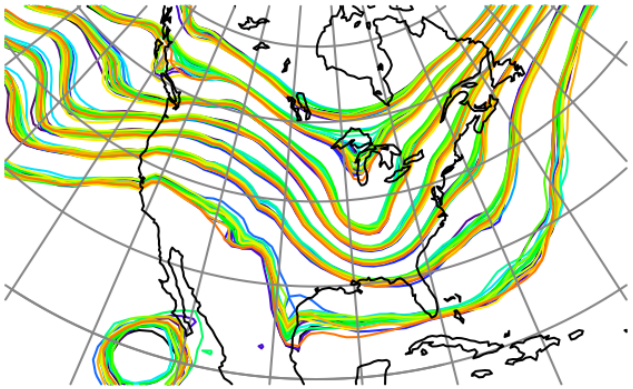
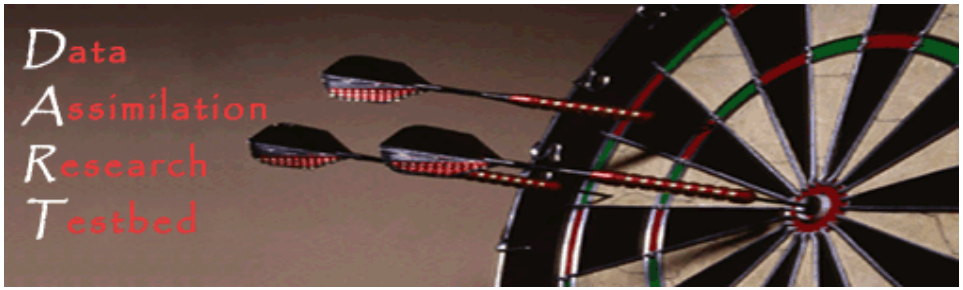


The Data Assimilation Research Testbed:
A Community Facility for Ensemble Data Assimilation

Jeff Anderson, Tim Hoar, Nancy Collins, Kevin Raeder, Hui Liu, Glen Romine,
Peter Lauritzen, Jennifer Kay, Chris Snyder, Alicia Karspeck, Steve Yeager



Overview of Data Assimilation

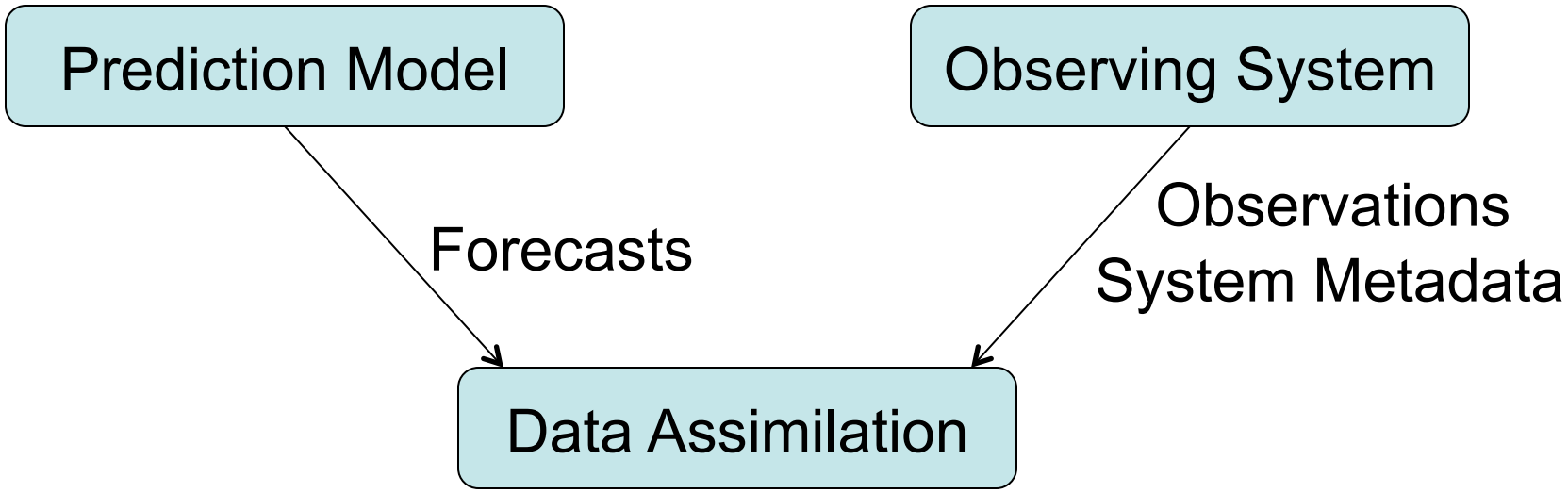
Prediction Model

Overview of Data Assimilation

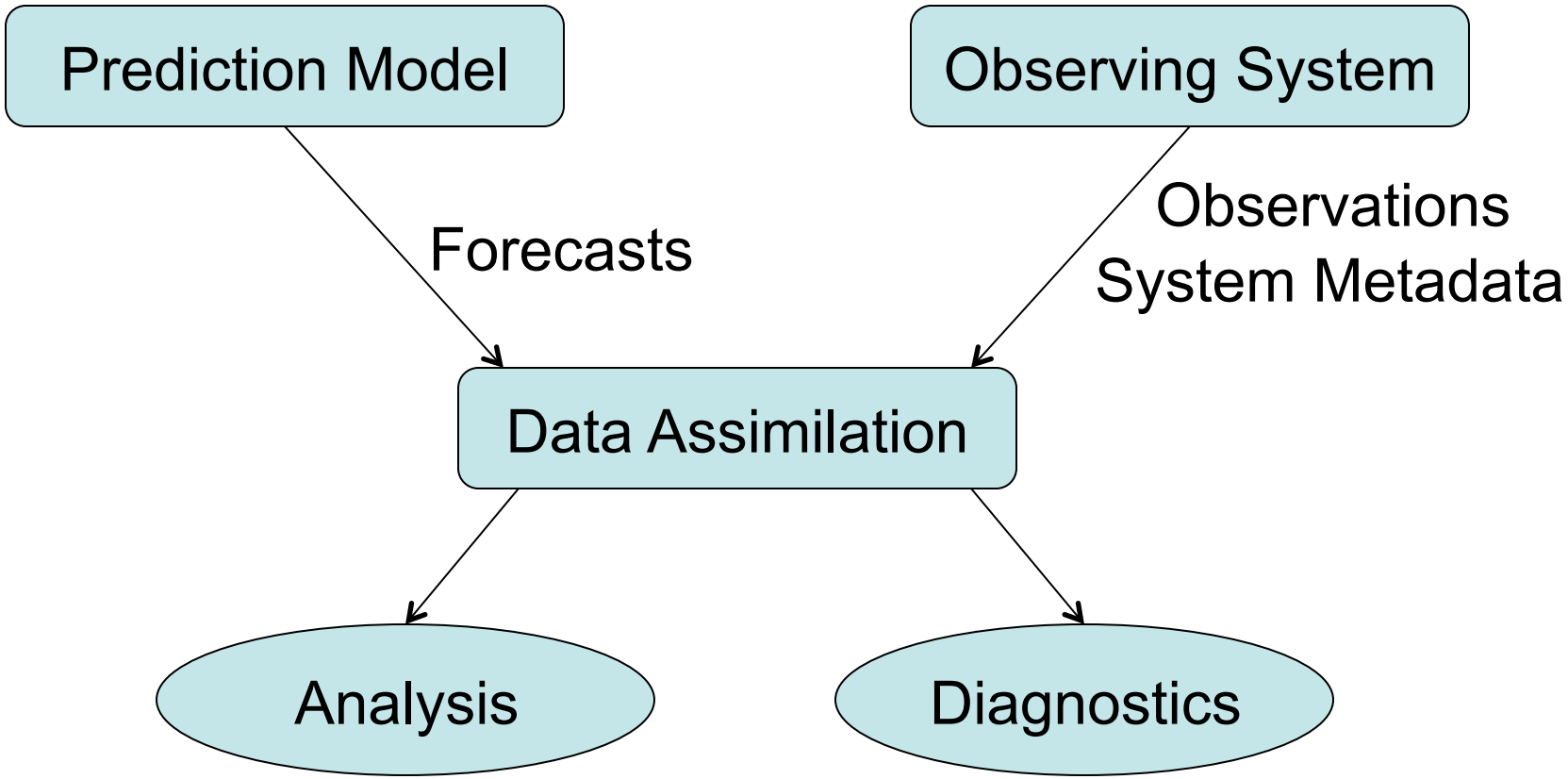
Prediction Model

Observing System

Overview of Data Assimilation



Overview of Data Assimilation



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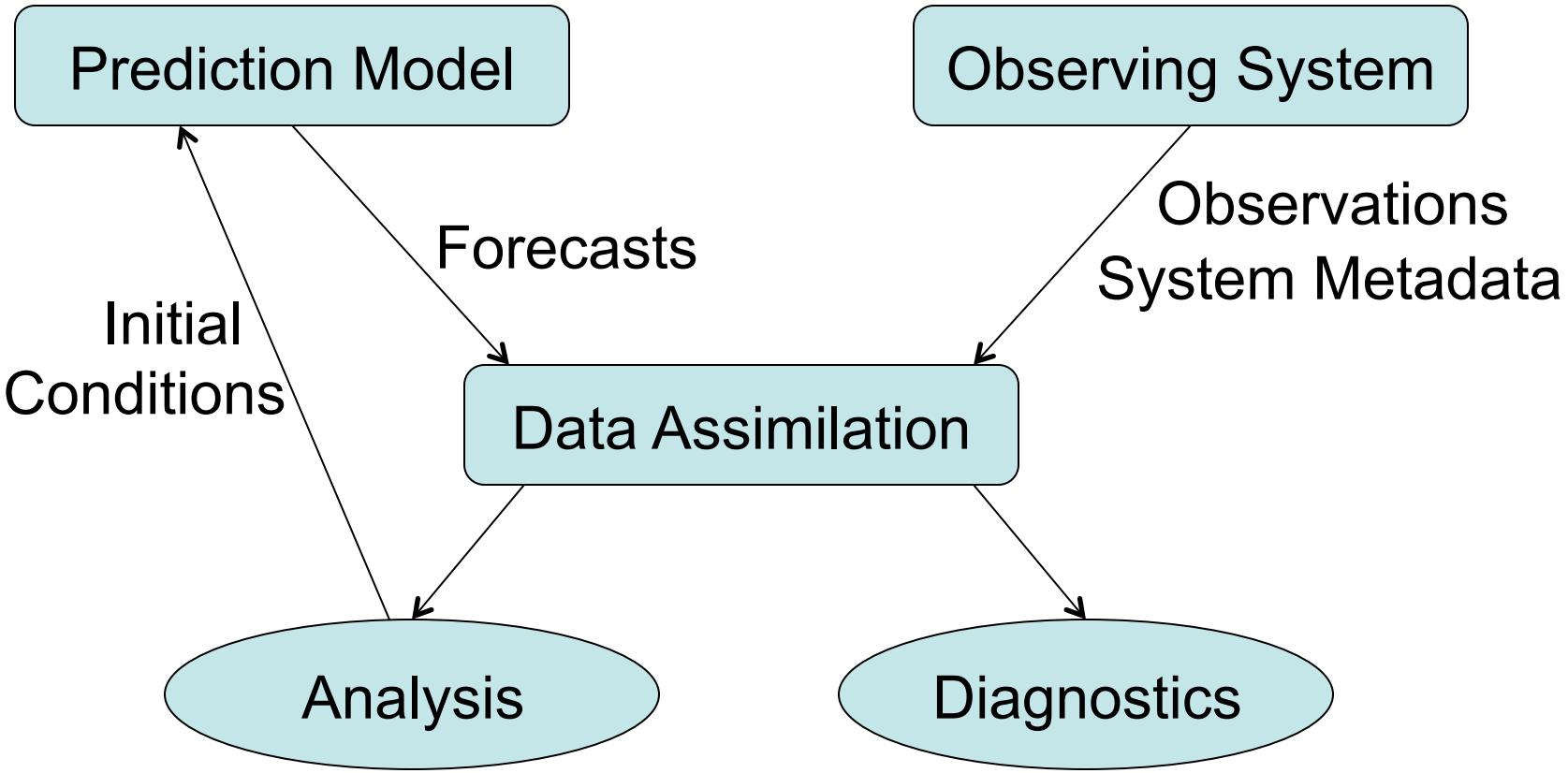
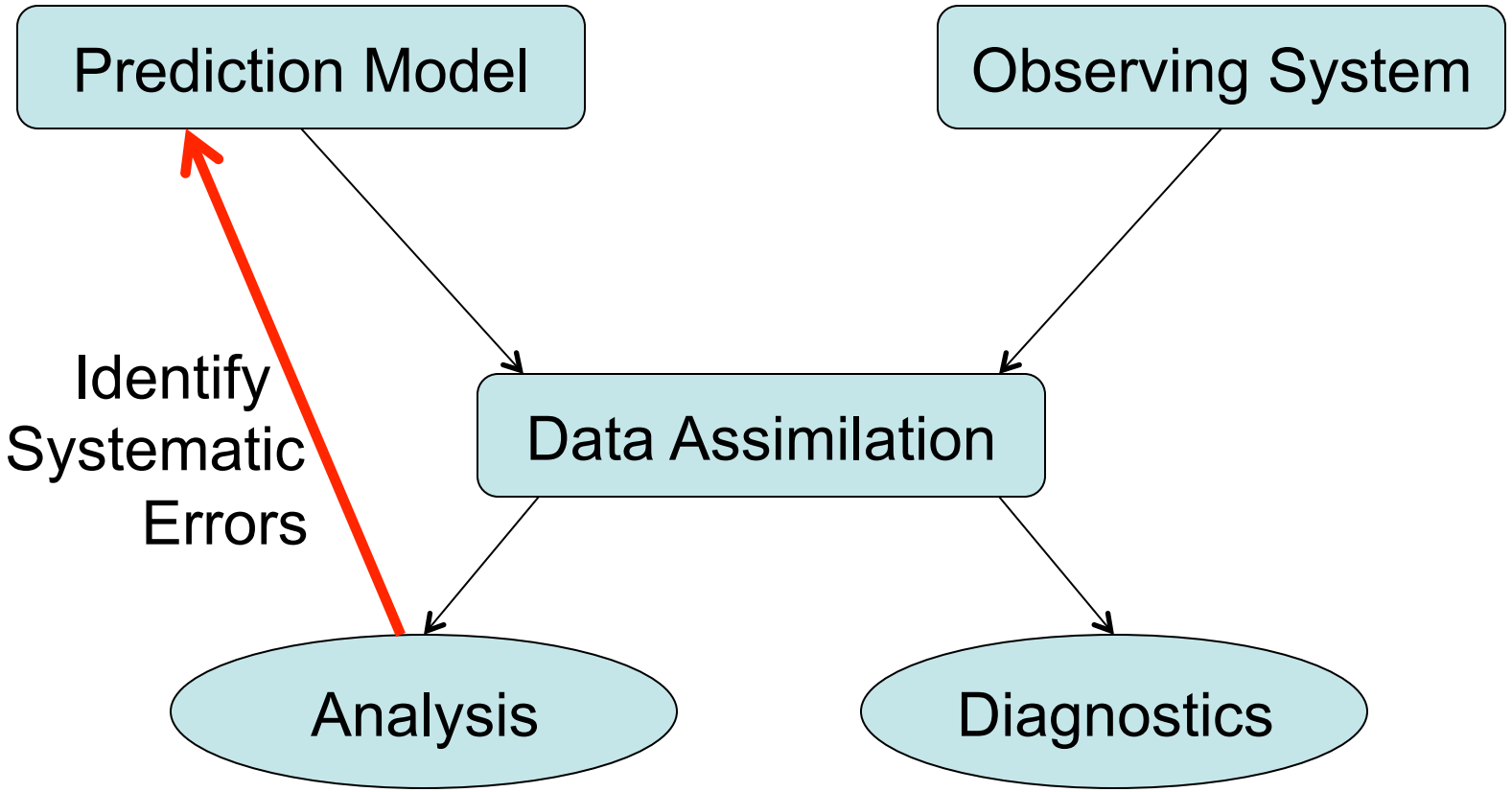


Overview of Data Assimilation



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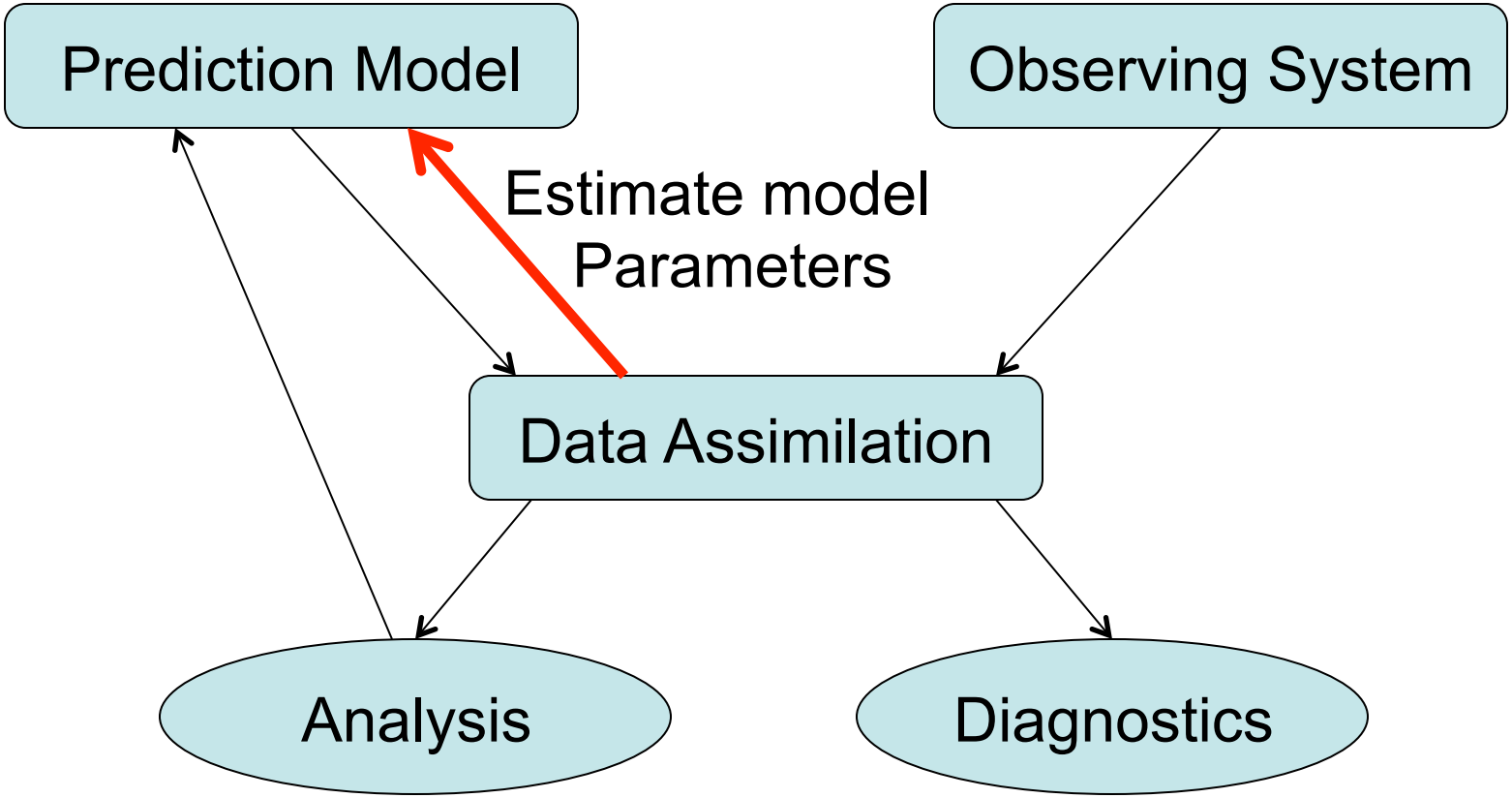
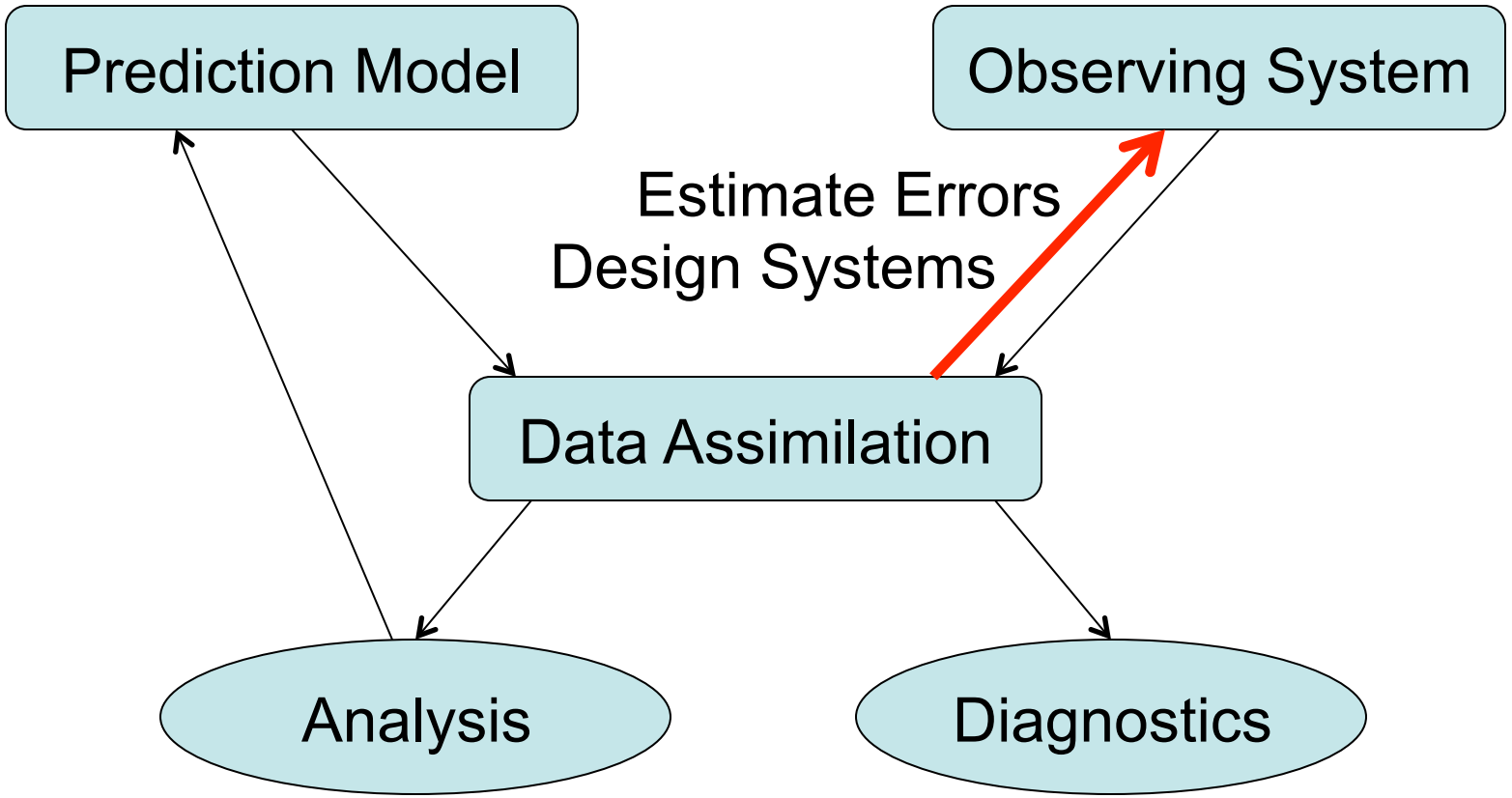
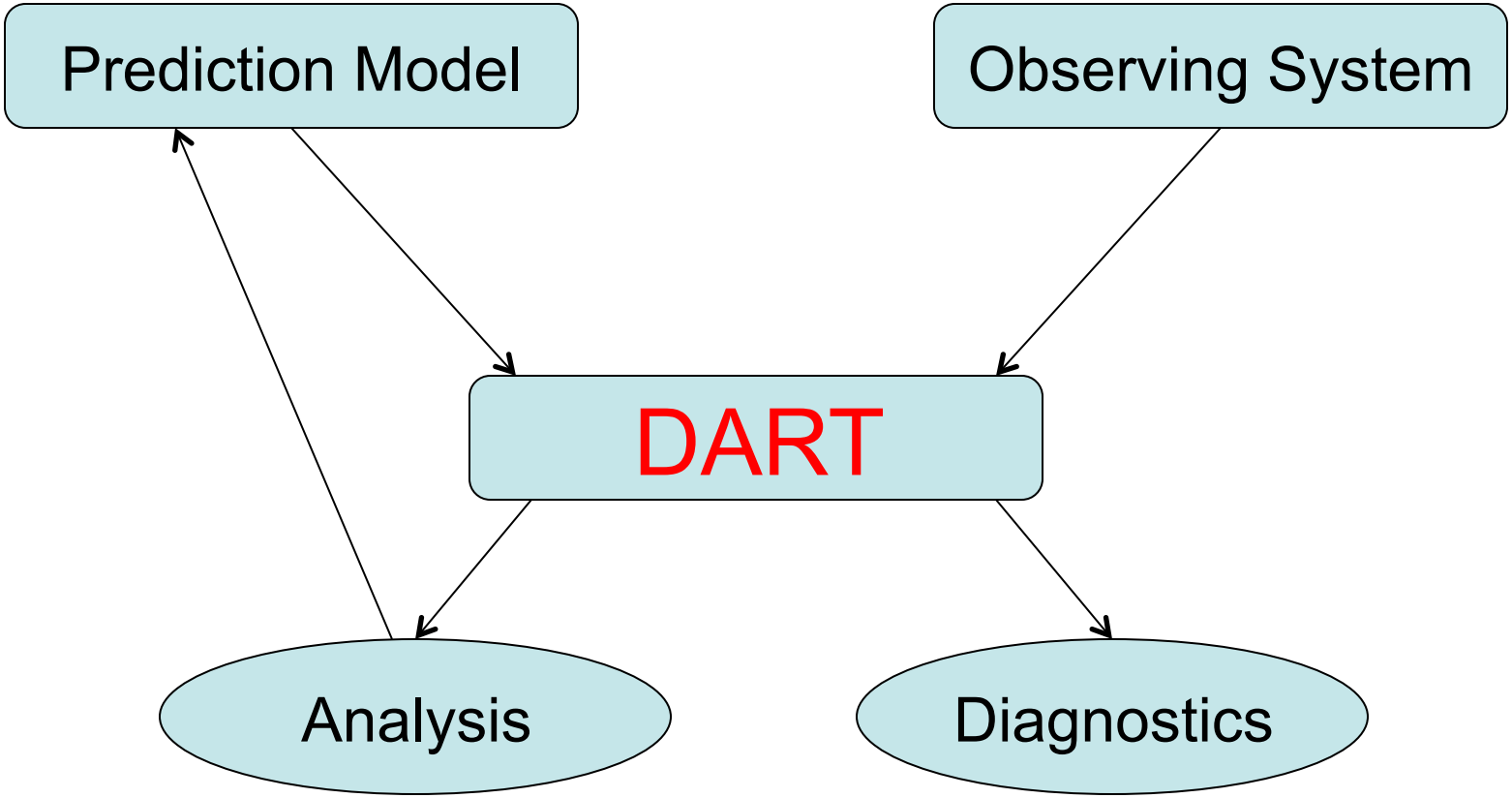


Overview of Data Assimilation



Data Assimilation Research Testbed (DART)

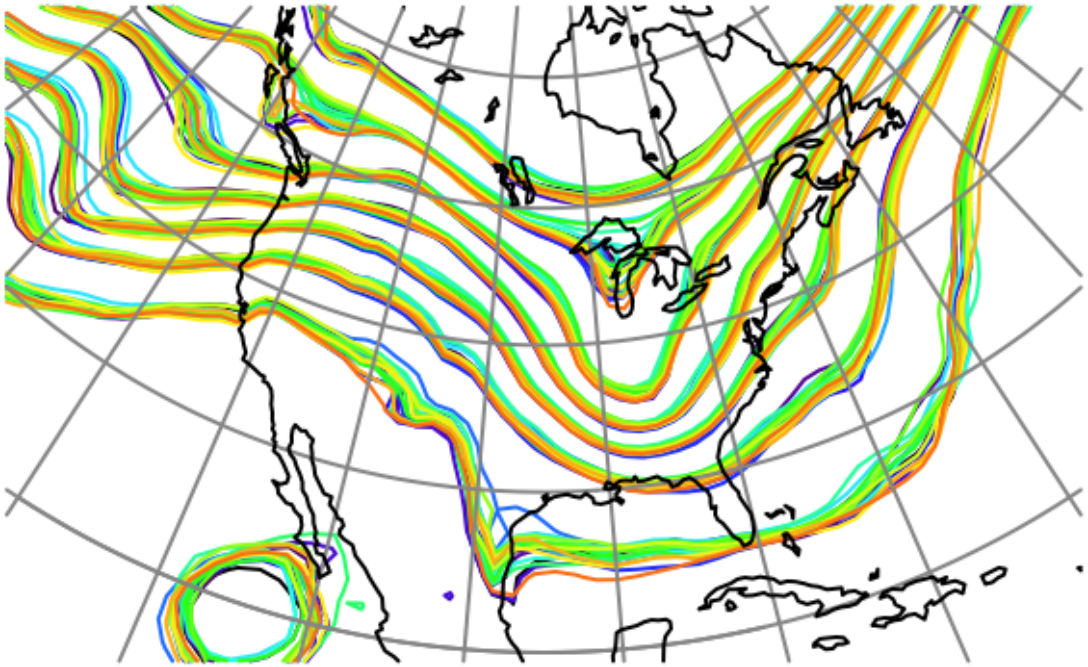


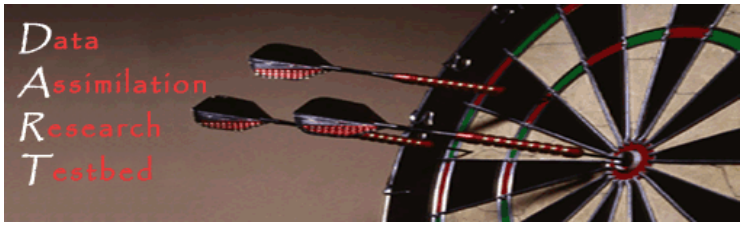
DART is a community ensemble assimilation facility.

What is Ensemble Data Assimilation?

Use an ensemble (set) of model forecasts.

Use sample statistics to get covariance between state and observations.





DART is used at:

48 UCAR member universities
More than 100 other sites

Public domain software for Data Assimilation

- Well-tested, portable, extensible, free!

Models

- Toy to HUGE

Observations

- Real, synthetic, novel

An extensive Tutorial

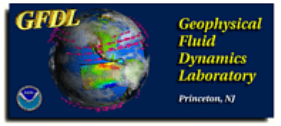
- With examples, exercises, explanations

People: The DAReS Team

UNIVERSITY OF WASHINGTON

CIRES

THE UNIVERSITY OF UTAH

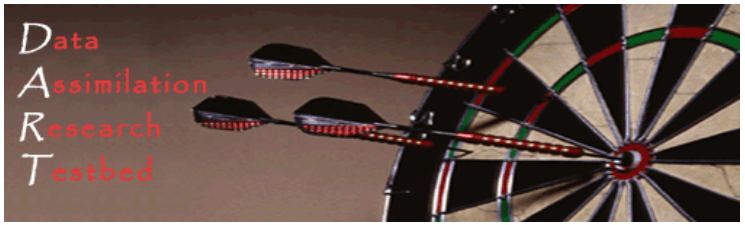


PENNSTATE

JPL
Jet Propulsion Laboratory
California Institute of Technology

NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

NSF



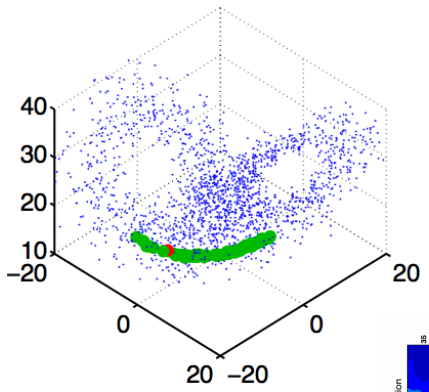
DART is:

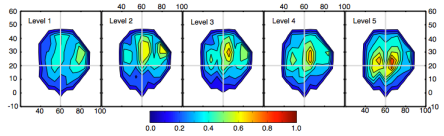
Education

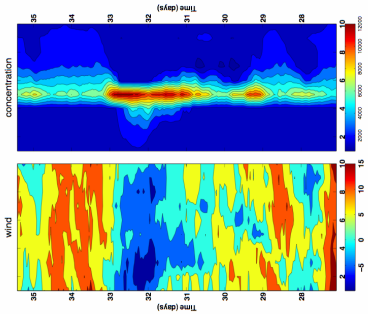
Exploration

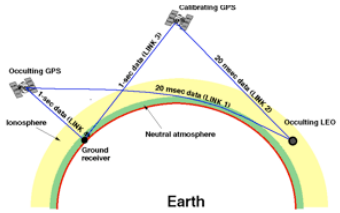
Research

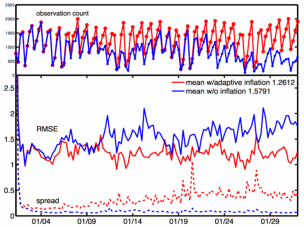
Operations

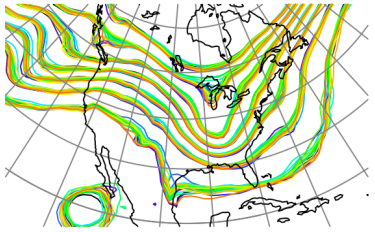


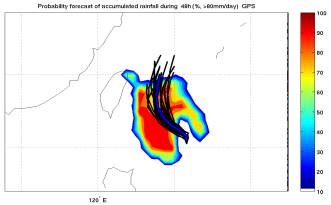


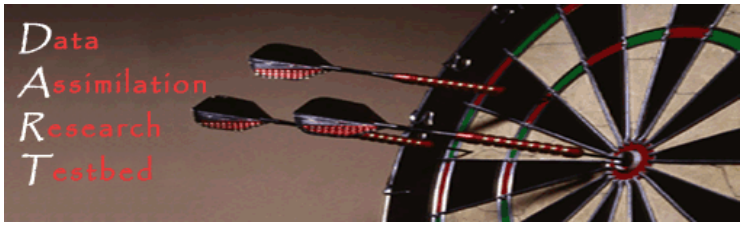










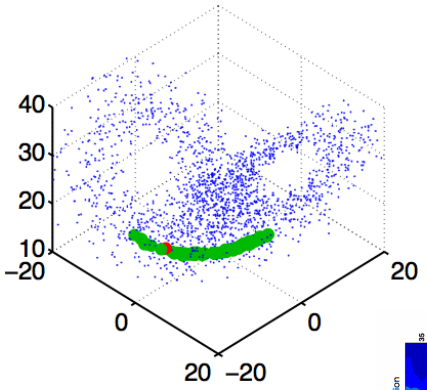


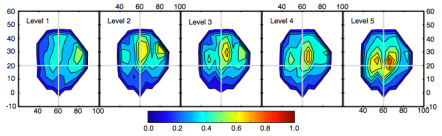
DART is:

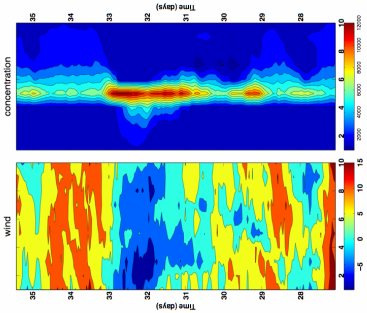
Education

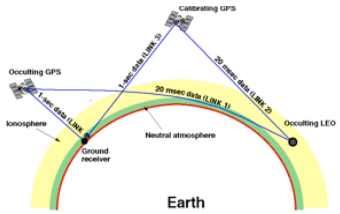
Exploration

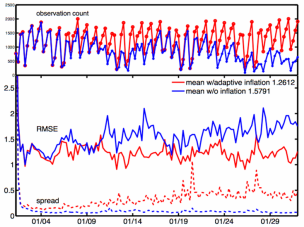
Research ↕ Operations

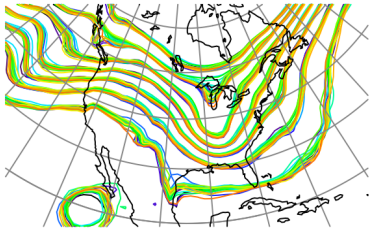


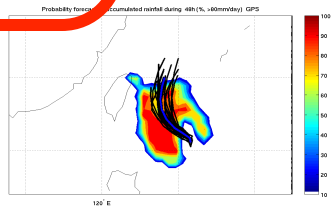












NCAR NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

NSF

AMS, Jan. 2013

DART works with many geophysical models

Global Atmosphere models:

CAM	Community Atmosphere Model; (all 3 dynamical cores)	NCAR
CAM/CHEM	CAM with Chemistry	NCAR
WACCM	Whole Atmosphere Community Climate Model	NCAR
AM2	Atmosphere Model 2	NOAA/GFDL
NOGAPS	Navy Operational Global Atmospheric Prediction System	US Navy
ECHAM	European Centre Hamburg Model	Hamburg
Planet WRF	Global version of WRF	JPL
MPAS	Model for Prediction Across Scales	NCAR/DOE

DART works with many geophysical models

Regional Atmosphere models:

WRF/ARW	Weather Research and Forecast Model	NCAR
WRF/CHEM	WRF with Chemistry	NCAR
NCOMMAS	Collaborative Model for Multiscale Atmospheric Simulation	NOAA/NSSL
COAMPS	Coupled Ocean/Atmosphere Mesoscale Prediction System	US Navy
CMAQ	Community Multi-scale Air Quality	EPA
COSMO	Consortium for Small-Scale Modeling	DWD

DART works with many geophysical models

Ocean models:

POP	Parallel Ocean Program	DOE/NCAR
MIT OGCM	Ocean General Circulation Model	MIT
ROMS	Regional Ocean Modeling System (under development)	Rutgers
MPAS	Model for Prediction Across Scales (Under development)	DOE/LANL

DART works with many geophysical models

Upper Atmosphere/Space Weather models:

ROSE		NCAR
TieGCM	Thermosphere Ionosphere Electrodynamic GCM	NCAR/HAO
GITM	Global Ionosphere Thermosphere Model	Michigan
Solar Dynamo	Dynamo/sunspot model	NCAR/HAO

DART works with many geophysical models

Land Surface models:

CLM	Community Land Model	NCAR
NOAH	Relatively simple land model	Community

DART users work with many observational datasets

Atmosphere Observations (1):

U,V,T,Q	NCEP: Radiosonde, AIRCRAFT (commercial), ACARS	BUFR
U,V	NCEP: Cloud Drift Winds from satellite	BUFR
U,V (ocean surface)	QUIKSCAT, including L2B (JPL)	HDF-4
T,Q,refractivity of the atmosphere	COSMIC Global Positioning Satellite radio occultation	NetCDF
T,Q,Tsurface	AIRS from Aqua/A-train satellite	HDF-4, HDF-EOS
U,V,T,Q,T, surface,pressure,altimeter	MADIS: ACARS, Marine and MESONET surface, METAR, radiosonde, satellite wind	NetCDF
Radar reflectivity, radial velocity	NCEP	Level2 (binary)

DART users work with many observational datasets

Atmosphere Observations (2):

U,V	MADIS; Wind Profilers, Atmospheric Motion Vectors (AMVs)	NetCDF, ASCII Text
U,V,T,Q,altimeter	OK mesonet (U. OK)	ASCII Text
Cloud Liquid Water Path, Cloud Top and Base Pressures	GOES satellite, CIMSS	NetCDF
U,V	SSEC (U Wisconsin): Cloud Drift Winds from satellite	ASCII Text
CO (carbon monoxide)	MOPITT	HDF
U,V	GOES CIMSS (U. WI); rapid-scan AMVs (Atmospheric Motion Vectors), satellite cloud winds	CIMSS ASCII

DART users work with many observational datasets

Atmosphere Observations (3):

T,Q,Total Precipitable Water	GOES CIMSS hyperspectral AIRS IR	CIMSS ASCII
Total Precipitable Water	AMSR, MODIS Microwave	ASCII Text
U,V	Operational typhoon bogus winds, Taiwan Central Weather Bureau	ASCII Text
U,V (at wind turbine hub height)	Seimens(?)	?
Electron density	COSMIC/FORMOSAT-3	LDM (UCAR/Unidata)
U,V,T	GTS	little-r
Chemical concentrations	IASI on EUMETSAT Polar System MetOp satellite	converted to ASCII intermediate format
Aerosol optical depth (AOD)	TERA and AQUA	HDF

DART users work with many observational datasets

Solar, Space Weather, Extraterrestrial Observations:

Radiances, Occultation on Mars	TES, limb sounder on Mars	?
Density, ion concentrations	CHAMP	NetCDF
Thermosphereic Mass Densities	CHAMP, GRACE	NetCDF
Electron densities	COSMIC	NetCDF
Total Electron Density	Garner GPS Archive	RINEX
Orbital element information	NORAD	ASCII
Solar Magnetic Fields	Wilcox, Mt Wilson, National Solar Observatories	?
Rotational, Meridional Circulation	Mt Wilson, SoHO, SDO, HMI	?

DART users work with many observational datasets

Ocean Observations:

T,Salinity	World Ocean Database: Argo floats, CTD(ships), XBT,moored thermistors, drifting buoys(GT-SPP)	packed ASCII
Surface U,V currents	CODAR	ASCII Text

DART users work with many observational datasets

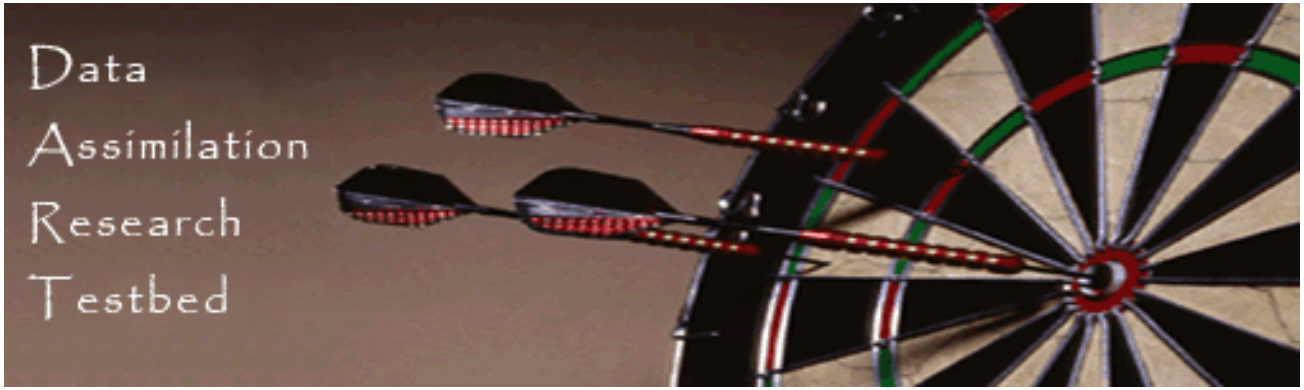
Land Observations:

Snow cover	MODIS	HDF
Heat Flux, Net Carbon	Ameriflux tower network	ASCII Text
Soil Moisture	COSMOS (neutron counter)	ASCII Text

Examples of Transitioning Research to 'Operations'

1. Convective scale prediction, nested mesoscale model,
2. Climate scenarios, global atmospheric GCM,
3. Decadal prediction, coupled ocean/atmosphere GCM.

Real-time WRF/DART Mesoscale Explicit Convection Forecasts



Glen Romine, Chris Snyder,
Craig Schwartz

NCAR/MMM

2012 Realtime analysis and forecast exercise

Operations period: 30 April to 30 June 2012

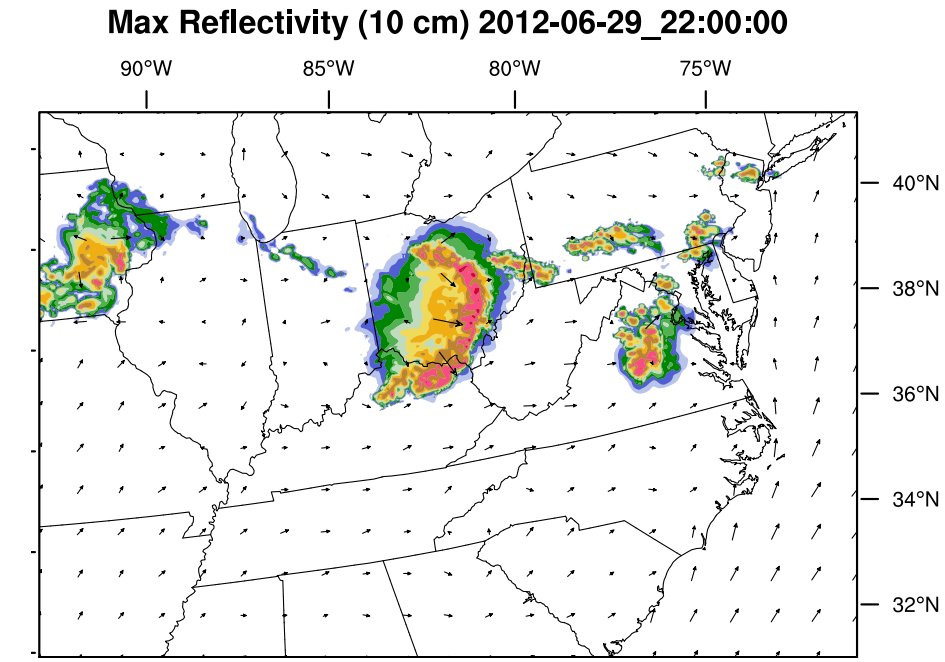
WRF model changes from 2011:

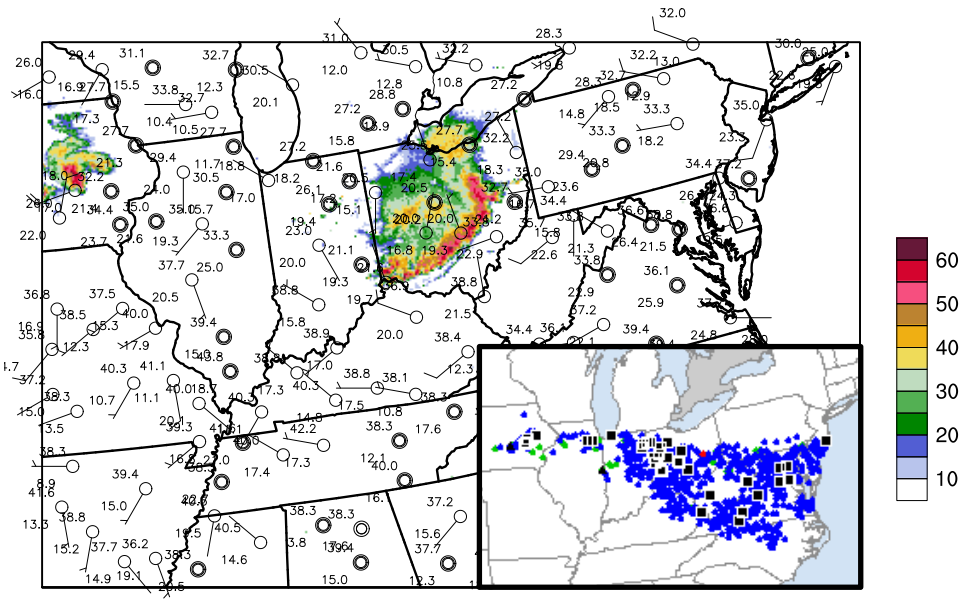
- Additional 5 vertical levels, now 40
- Raise Ptop to 50 mb (from 65 mb)
- Version 3.3.1 (3.2.1)
- Tiedtke CP, **RRTMG +aerosol and ozone climatology** for LW&SW radiation, Morrison microphysics (with mods)

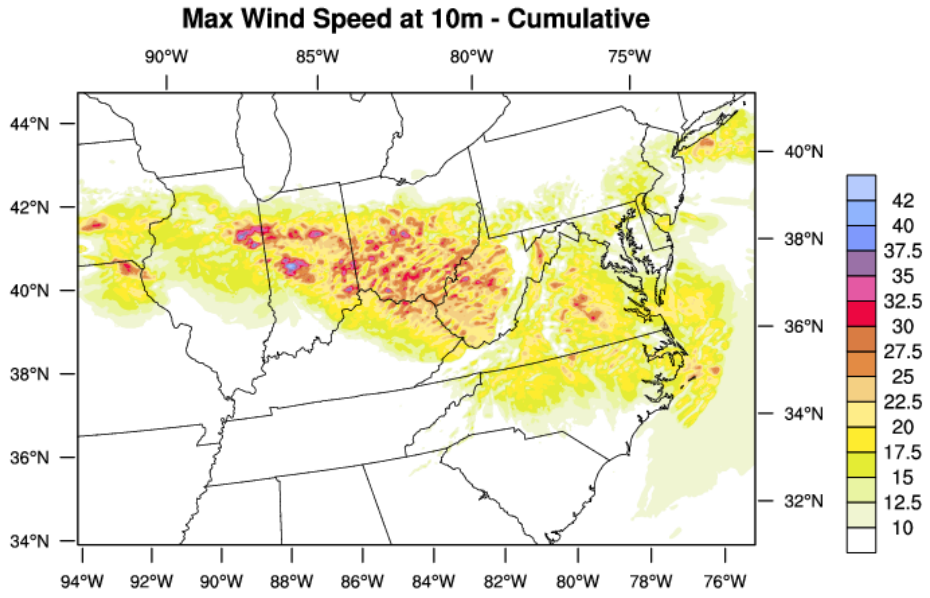
Key DART changes from 2011:

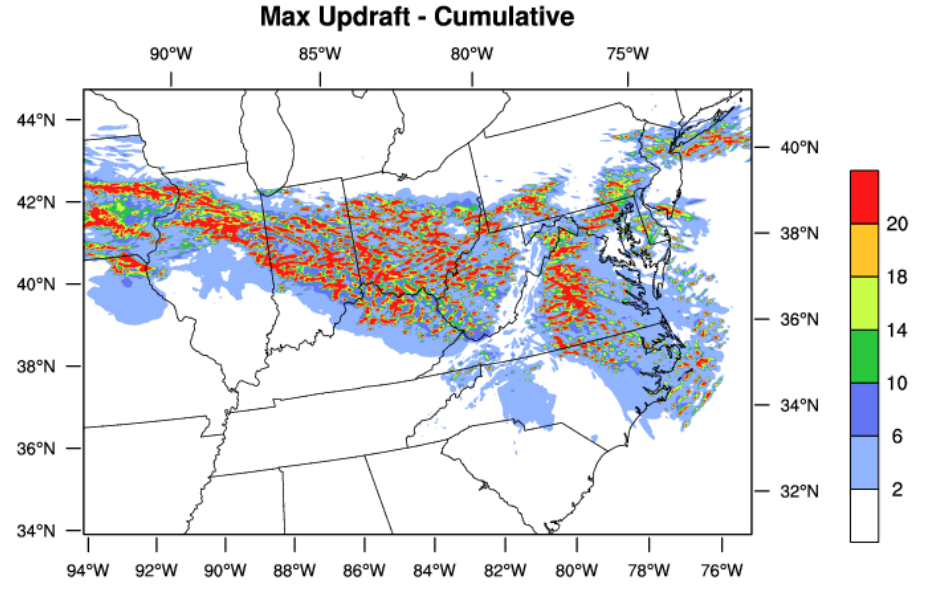
- Slightly reduced localization (larger spatial influence)
- More aggressive adaptive inflation
- Added **significant level radiosonde obs**
- Further **tuning of observation error assignments**

June 29 2012 DC derecho event: Forecast from 12 UTC

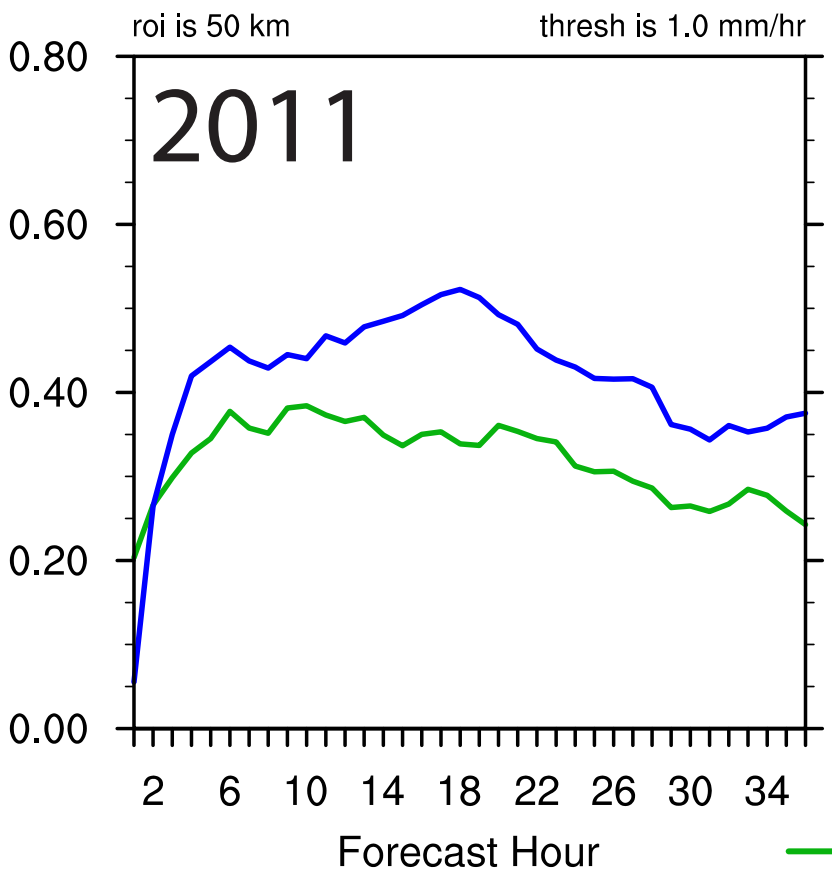


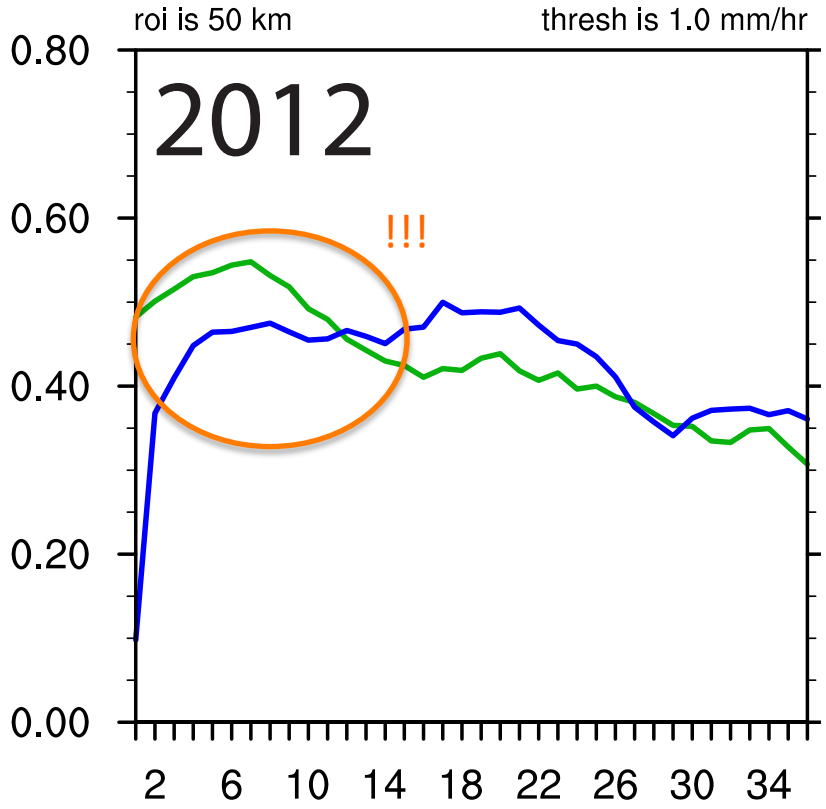






Realtime forecast skill EKF vs. GFS IC from 00 UTC





WRF-DART IC

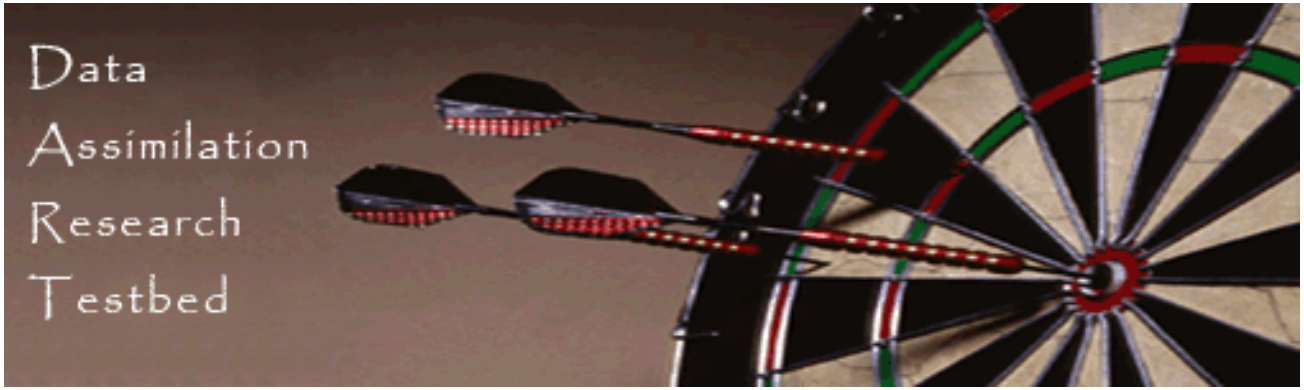
GFS IC

Retrospective tests and further improvements in WRF physics (esp. radiation, microphysics) for both analysis and forecast model led to increased forecast skill during the 2012 realtime experiment

Examples of Transitioning Research to 'Operations'

1. Convective scale prediction, nested mesoscale model,
2. Climate scenarios, global atmospheric GCM,
3. Decadal prediction, coupled ocean/atmosphere GCM.

Diagnosing and Correcting Errors in the CAM Finite Volume core with DART



Kevin Raeder*

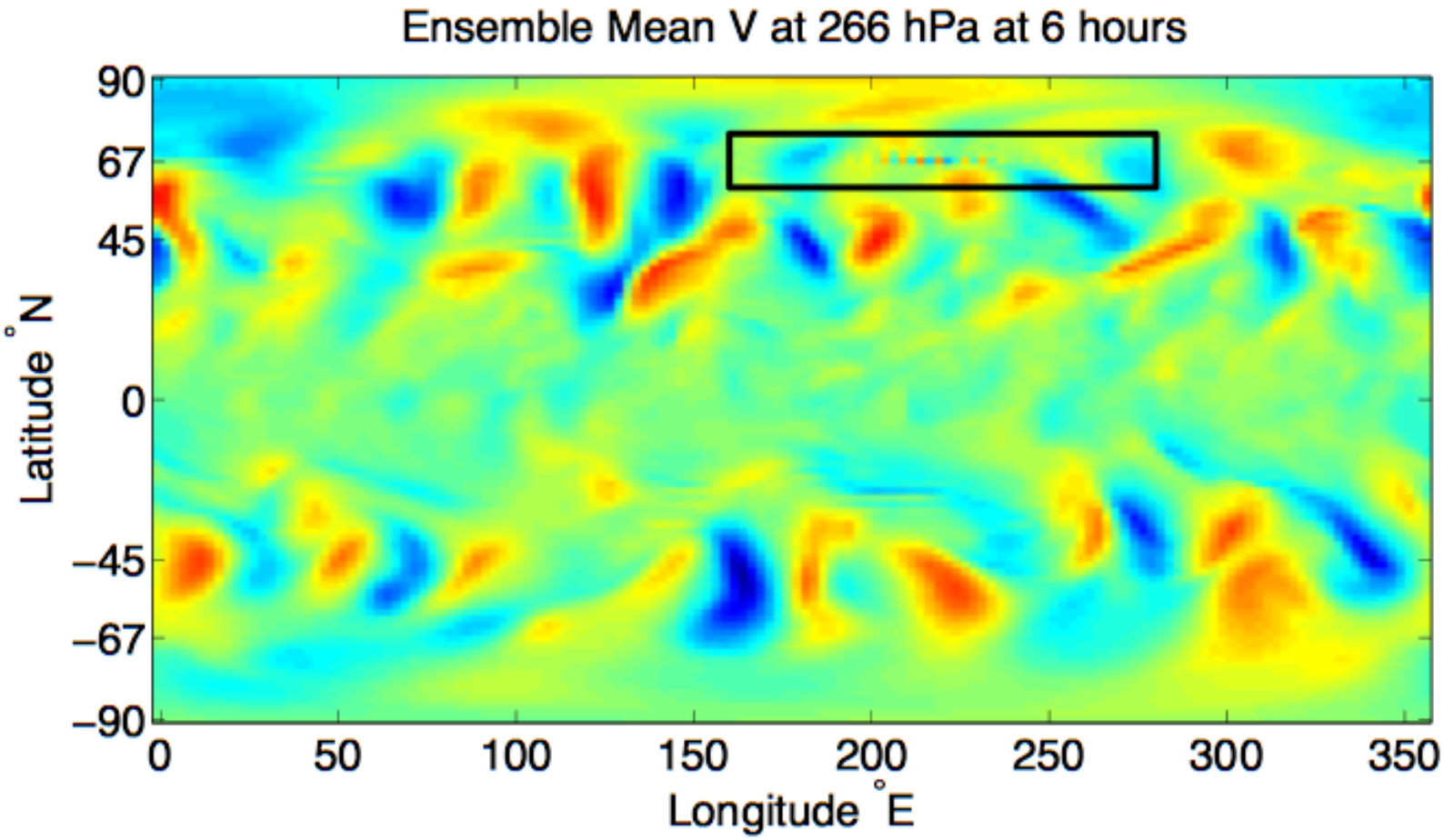
Jeff Anderson*

Peter Lauritzen+

Tim Hoar*

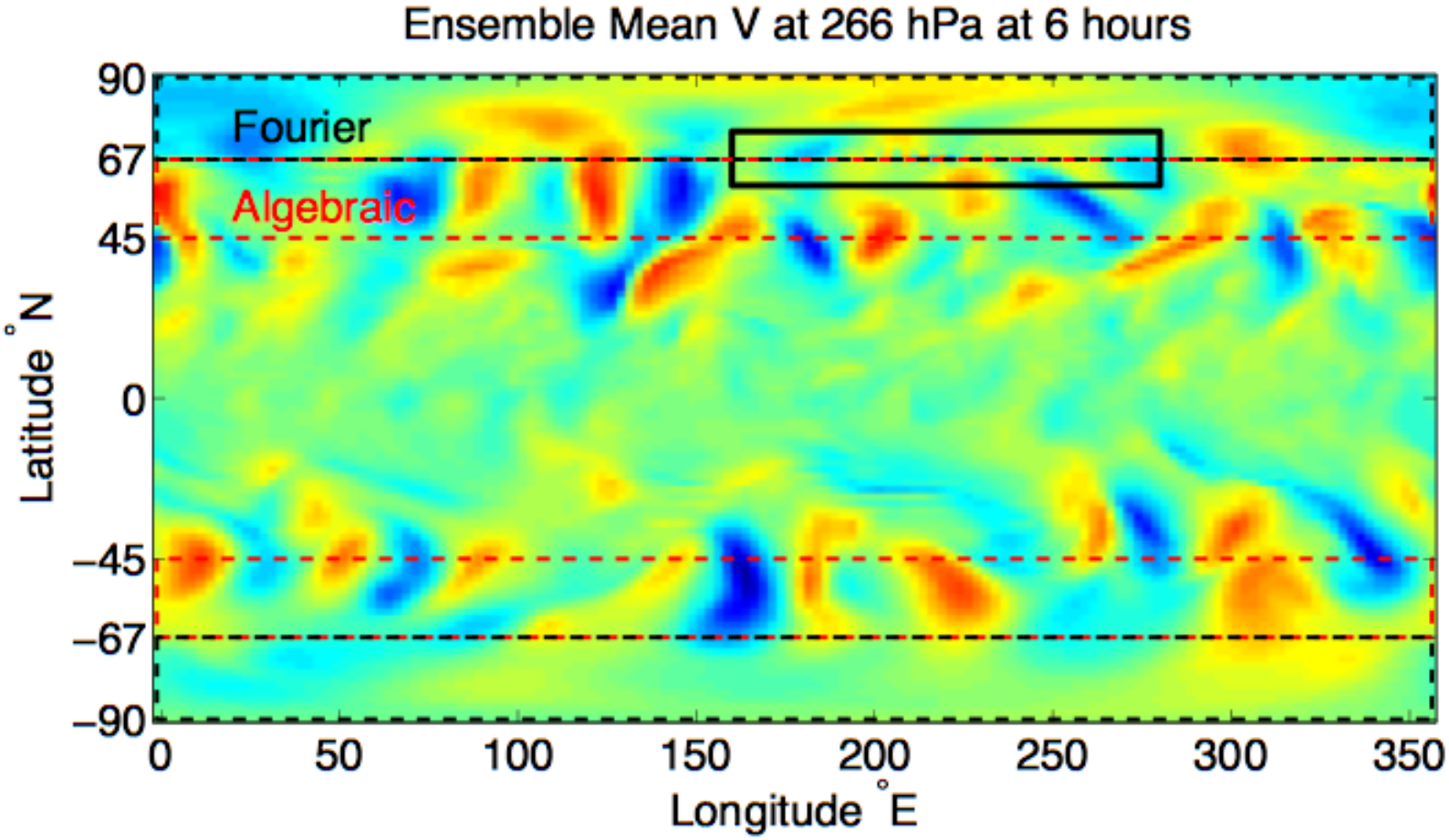
*NCAR/CISL/IMAGe/DAReS
+NCAR/ESSL/CGD/AMPS

Gridpoint noise detected in CAM/DART analysis



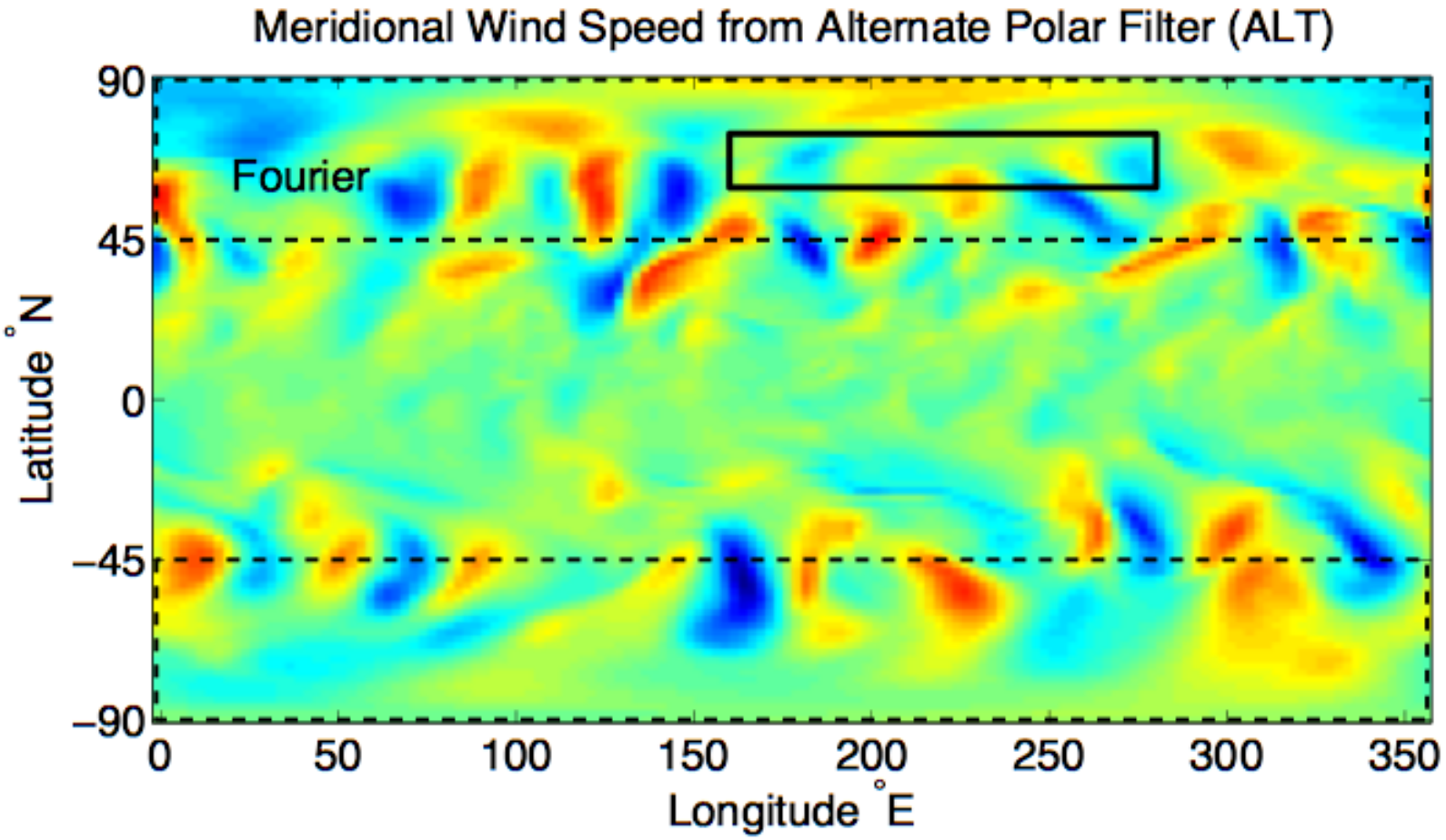
CAM FV core - 80 member mean - 00Z 25 September 2006

Suspicions turned to the polar filter (DPF)

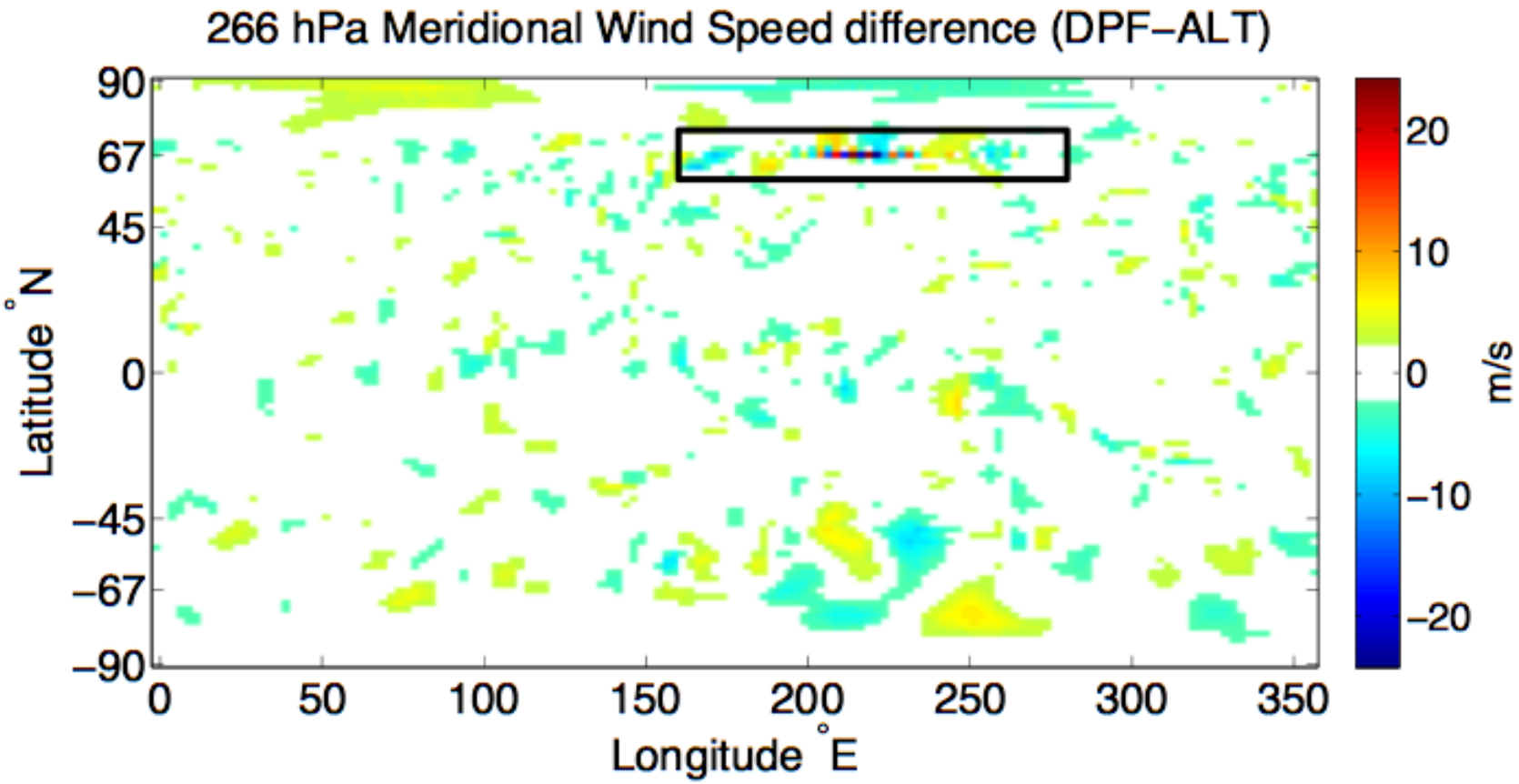


CAM FV core - 80 member mean - 00Z 25 September 2006

Continuous polar filter (alt-pft) eliminated noise.



Differences mostly in transition region of default filter.



Diagnosing and Correcting Errors in the CAM Finite Volume core with DART

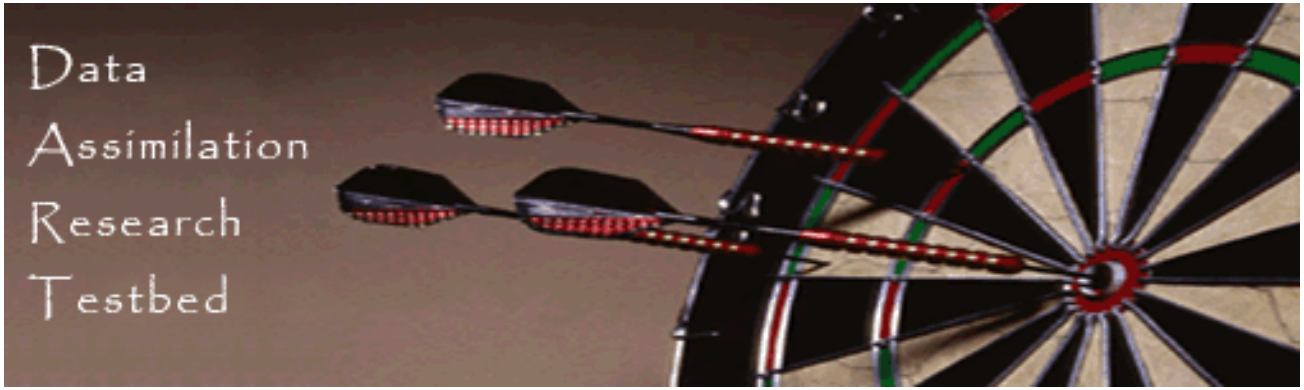
The use of DART diagnosed a problem that had been unrecognized (or at least undocumented).

Could have an important effect on any physics in which meridional mixing is important.

The problem can be seen in ‘free runs’ - it is not a data assimilation artifact.

Without assimilation, can’t get reproducing occurrences to diagnose.

Cloud response to the 2007 Arctic sea ice loss in CAM3.5 and CAM4



Jennifer E. Kay

National Center for Atmospheric Research (NCAR)

Colorado State University (CSU)

Collaborators: Julienne Stroeve (NSIDC),

Andrew Gettelman, Kevin Raeder, Jeff Anderson (NCAR),

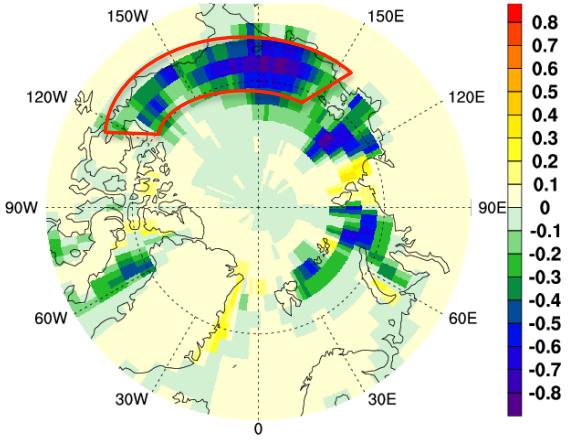
Graeme Stephens, Tristan L'Ecuyer, Chris O'Dell (CSU)

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.

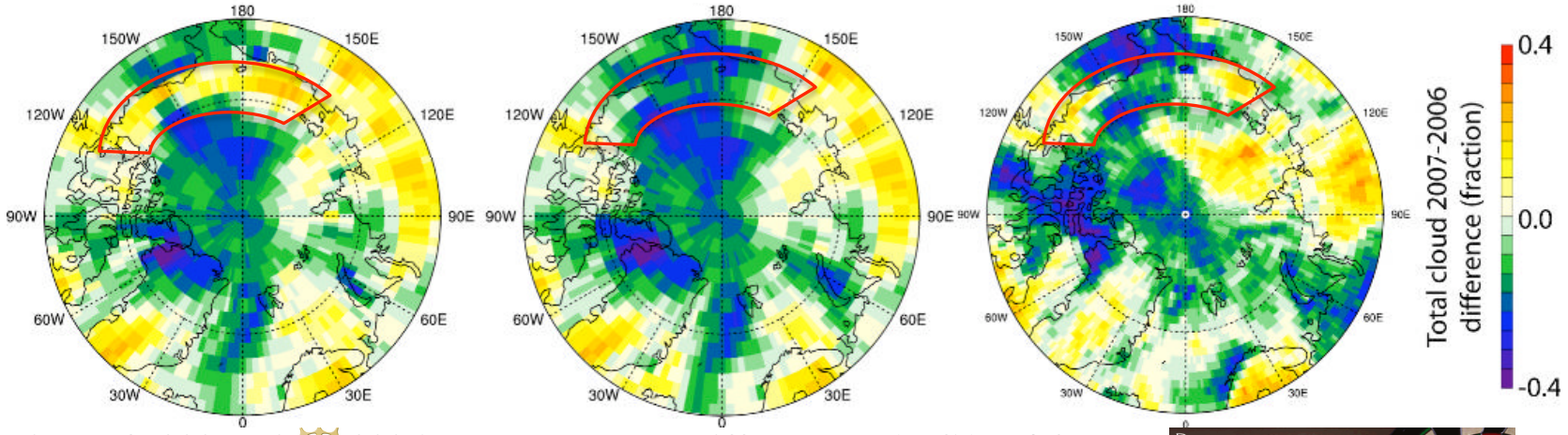
Observed ice fraction loss



July CAM4 Forecasts

July CAM4 Forecasts with CLDST_MIXBL

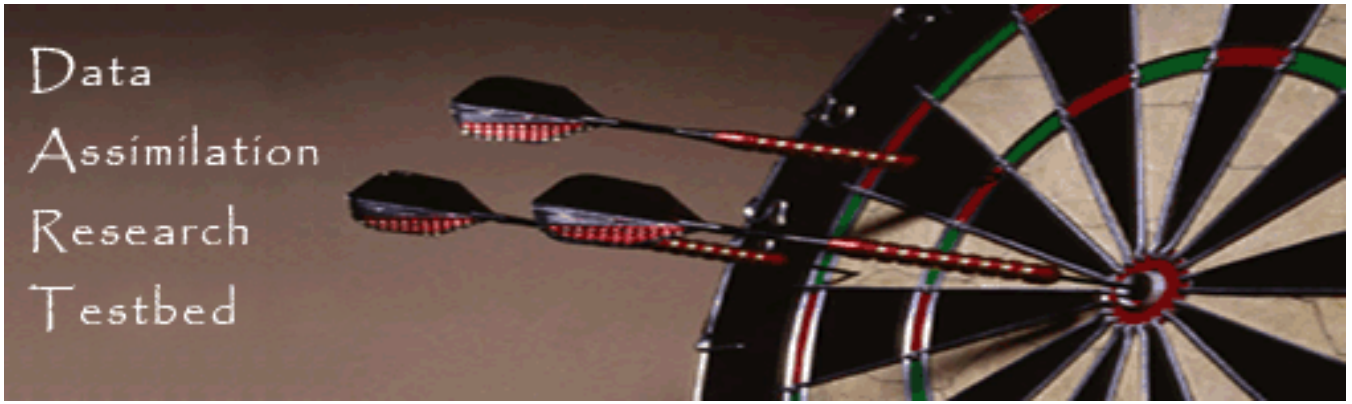
July Observed



Examples of Transitioning Research to 'Operations'

1. Convective scale prediction, nested mesoscale model,
2. Climate scenarios, global atmospheric GCM,
3. Decadal prediction, coupled ocean/atmosphere GCM.

Moving towards coupled assimilation for earth system models.



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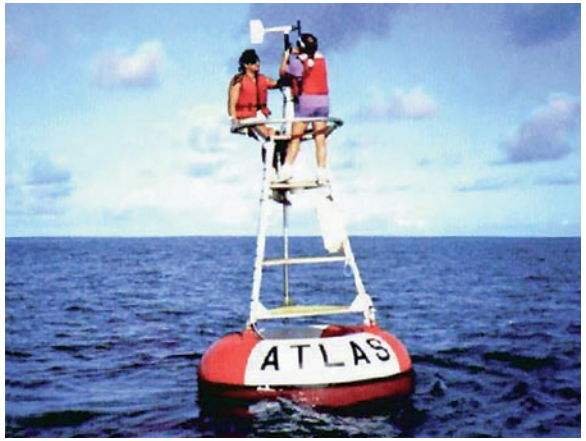
Ocean Data Assimilation with DART/POP

- Climate change over time scales of 1 to several decades is important for mitigation and infrastructure planning.
- DART has been used with the POP ocean model to generate initial conditions for coupled model predictions.
- These initial conditions have been used by NCAR to make coupled model decadal predictions for the next IPCC.

World Ocean Database T,S observation counts

These counts are for 1998 & 1999 and are representative.

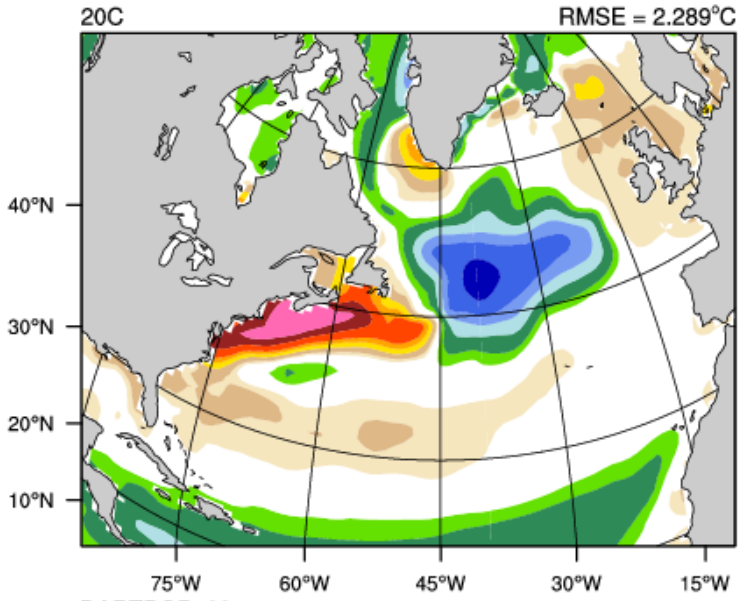
FLOAT_SALINITY	68200
FLOAT_TEMPERATURE	395032
DRIFTER_TEMPERATURE	33963
MOORING_SALINITY	27476
MOORING_TEMPERATURE	623967
BOTTLE_SALINITY	79855
BOTTLE_TEMPERATURE	81488
CTD_SALINITY	328812
CTD_TEMPERATURE	368715
STD_SALINITY	674
STD_TEMPERATURE	677
XCTD_SALINITY	3328
XCTD_TEMPERATURE	5790
MBT_TEMPERATURE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

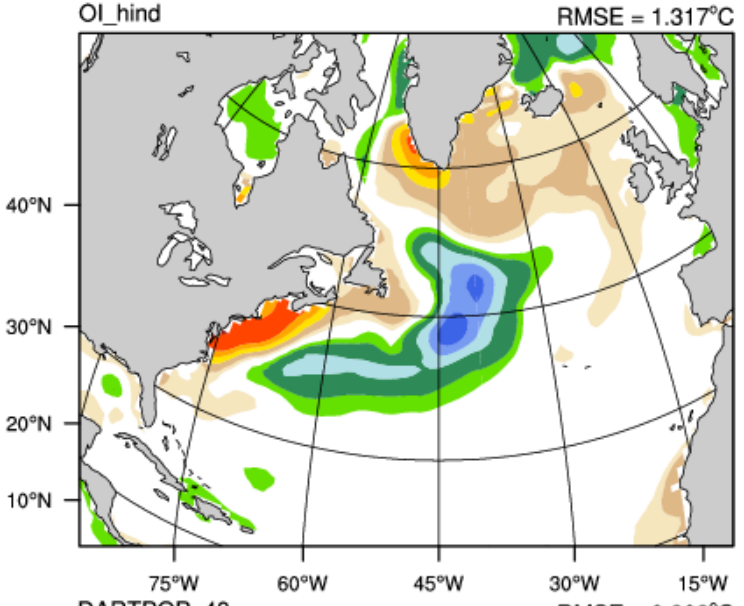


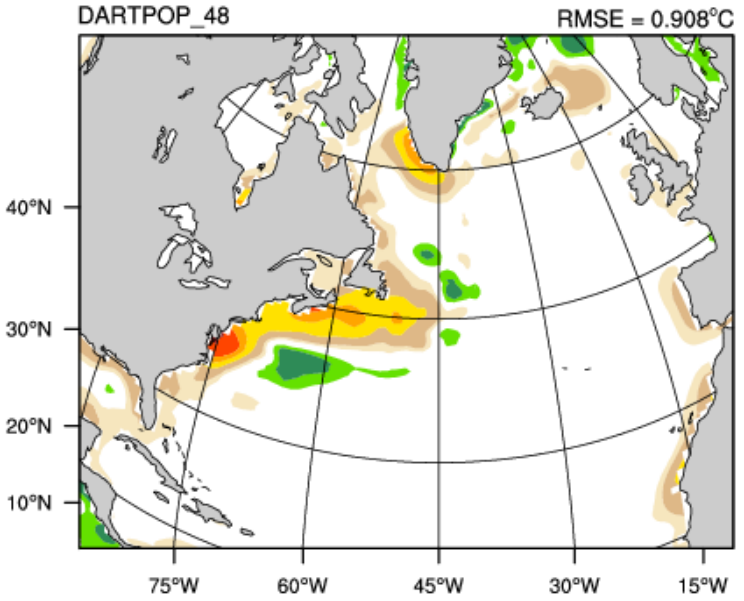
- temperature observation error standard deviation == 0.5 K.
- salinity observation error standard deviation == 0.5 msu.

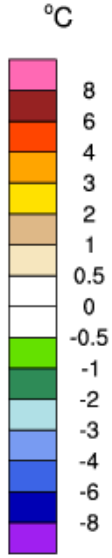
Physical Space: 1998/1999 SST Anomaly from HadOI-SST

Coupled Free Run





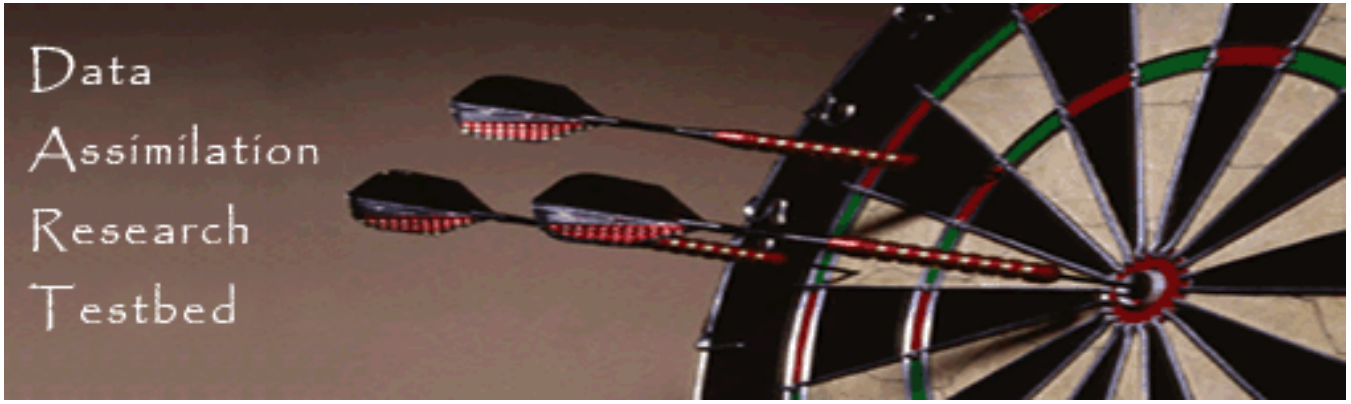




POP forced by observed atmosphere (hindcast)

Ensemble Assimilation
48 POP oceans
Forced by 48 CAM reanalyses

Learn more about DART at:



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

Anderson, J., Hoar, T., Raeder, K., Liu, H., Collins, N., Torn, R., Arellano, A., 2009: *The Data Assimilation Research Testbed: A community facility.* BAMS, **90**, 1283—1296, doi: 10.1175/2009BAMS2618.1