# Status Report for WRF's Variational Data Assimilation System (WRF-Var)

WRF Workshop, June 20th 2006

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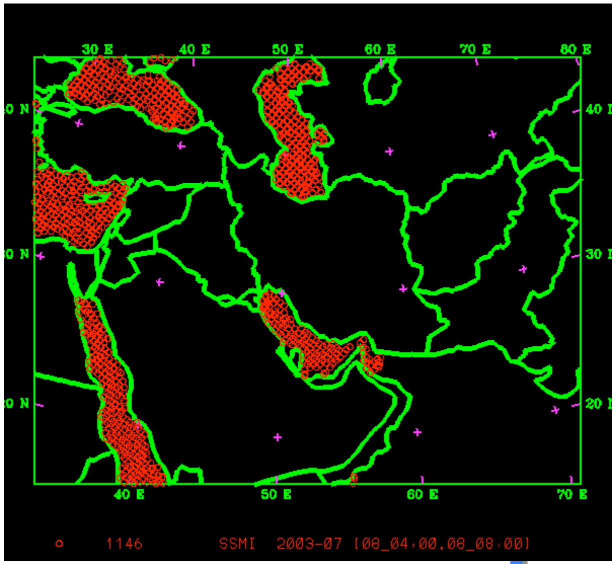
- Ops: US: AFWA, Korea: KMA, Taiwan: CAA, CWB, India: NCMRWF

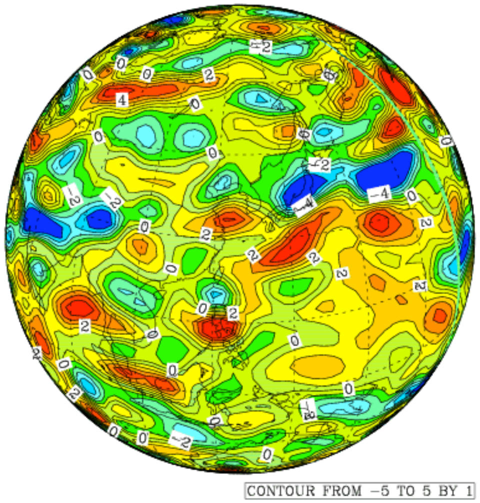
# WRF-Var: A “Unified” Model?

- Regional (worldwide applicability) / global.
- Run-time configurable 3/4D-Var.
- Single code (WRF-Var) for development, release. Supported by NCAR/MMM.
- Embedded within WRF framework.
- Multi-model: WRF/MM5/KMA/NFS/…
- WMO BUFR format adopted for obs. ingest.

AFWA 15km S-W Asia:




KMA T213 Global:



# WRF-Var Version 2.2
# (release September 2006?)

- Major new features/improvements (provisional):

  - Major software engineering reorganization.
  - Use of [PREP]BUFR for observation ingest.
  - Enhanced gen_be utility (EPS-based stats., efficiency).
  - Flow-dependent forecast error covariances.
  - Remove obsolete features (e.g. MM5/GFS-based errors).
  - Radiance data assimilation (See Liu's talk).

- NOT included: 4D-Var (under development, see Huang's talk).

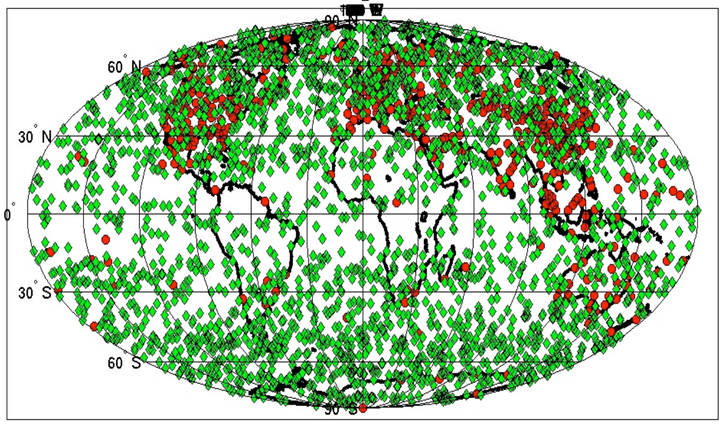
# WRF-Var Observations (May 2006)

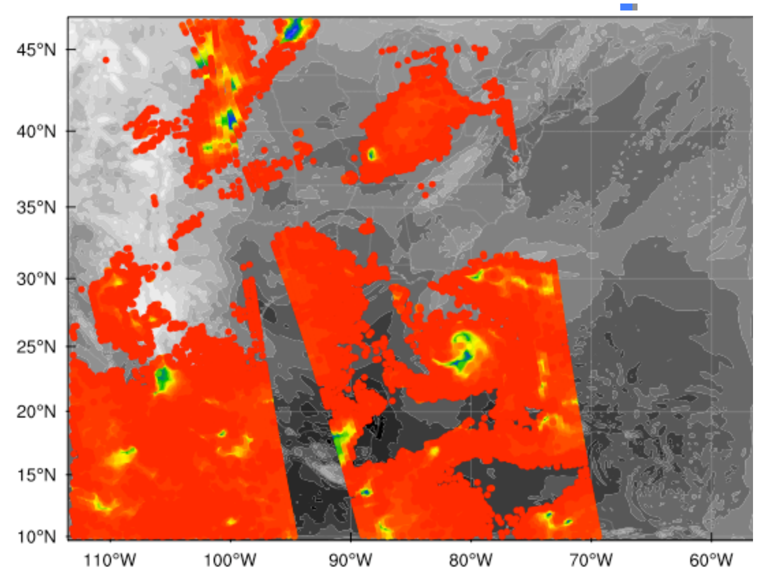
- Conventional:
  - Surface (SYNOP, METAR, SHIP, BUOY).
  - Upper air (TEMP, PIBAL, AIREP, ACARS).

- Remotely sensed retrievals:
  - Atmospheric Motion Vectors (geo/polar).
  - Ground-based GPS Total Precipitable Water.
  - SSM/I oceanic surface wind speed and TPW.
  - Scatterometer (Quikscat) oceanic surface winds.
  - Wind Profiler.
  - Radar radial velocity and reflectivity.
  - ATOVS/AIRS/MODIS temperature/humidities.
  - GPS refractivity (e.g. COSMIC).

- Radiances:
  - SSM/I brightness temperatures.
  - Direct radiance assimilation (SSM/I, TMI, AMSU, AIRS).

Occultation Locations for COSMIC, 6 S/C, 6 Planes, 24 Hrs



# WRF-Var Software Engineering Developments

- Subversion for code management:
  - Simplified directory structure and filenames
  - Start merge of WRF-Var and WRF repositories

- New compilation system:
  - Flat compilation structure
  - Automatic dependency analysis
  - G95 support

# More SE Developments

- New Test Environment
  - Namelist generation from environment variables
  - Flexible wrapper scripts (runs whole WRF system)
  - Extensive regression tests (month-long cycling trials)
  - Use of data assimilation system as verification tool.

- 4D-Var within WRF-Var
  - Automatic generation of TL/ADJ code (TAF)
  - Running parallel, but not fully coupled

# Background Error (BE) Estimation in WRF-Var

The number 1 question from WRF-Var users is

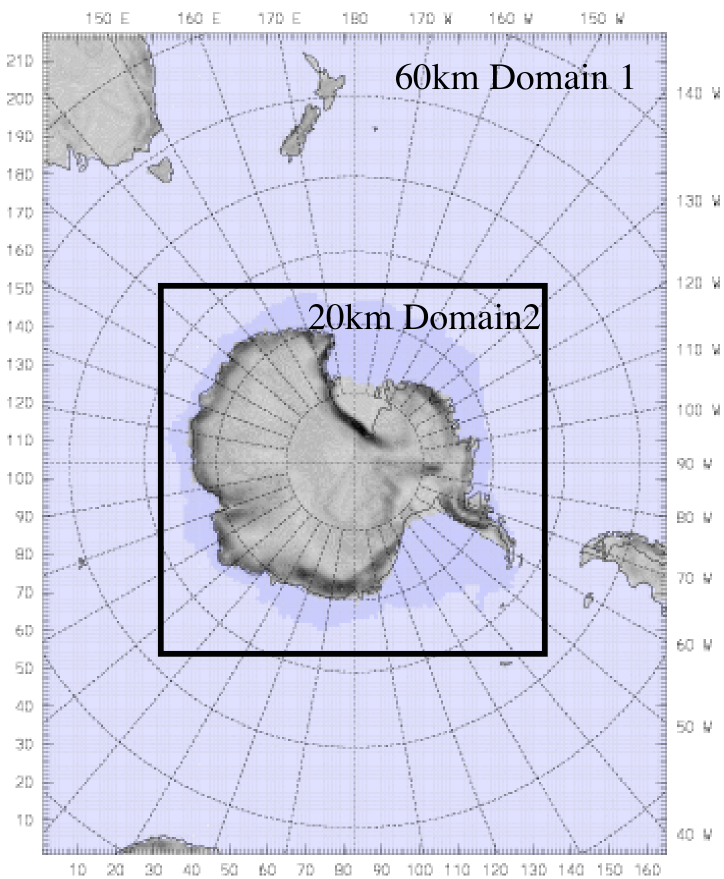
**"What background error covariances should I use?"**

Procedure:

1. Use default statistics files supplied (MM5, GFS-based).
2. Create you own, using WRF forecasts from your application.
3. Implement, iterate, tune.

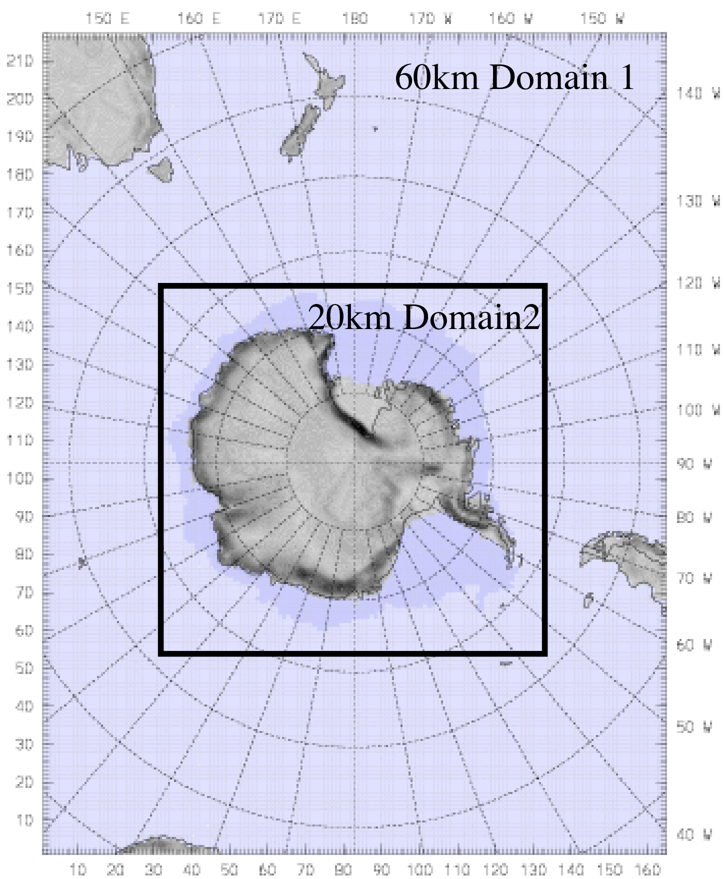
A utility *gen_be* has been developed at NCAR to calculate BEs.

# Sensitivity to Forecast Error Covariances in Antarctica

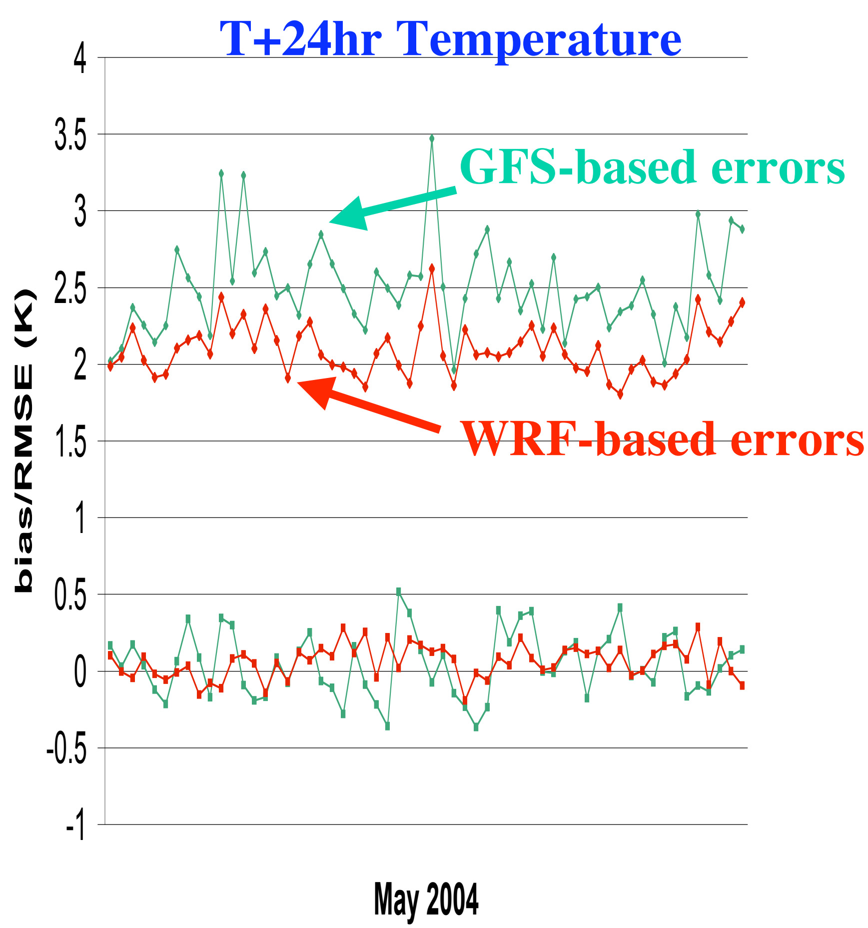



- Application: Antarctic Mesoscale Prediction System (AMPS).
- System: WRF-ARW/WRF-Var V2.1.
- Resolution: 60/20km resolution.
- Observations: Conventional, MODIS, 6-hourly cycling through May 2004.
- Assess impact of default and WRF-based forecast error covariances.

# Sensitivity to Forecast Error Covariances in Antarctica




**60km Verification (vs. radiosondes)**



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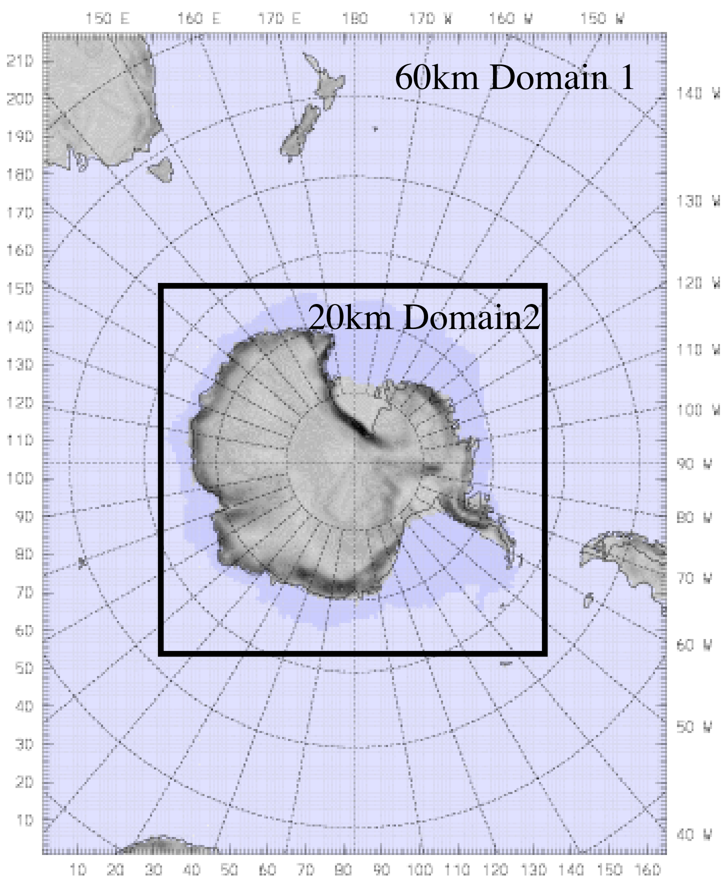
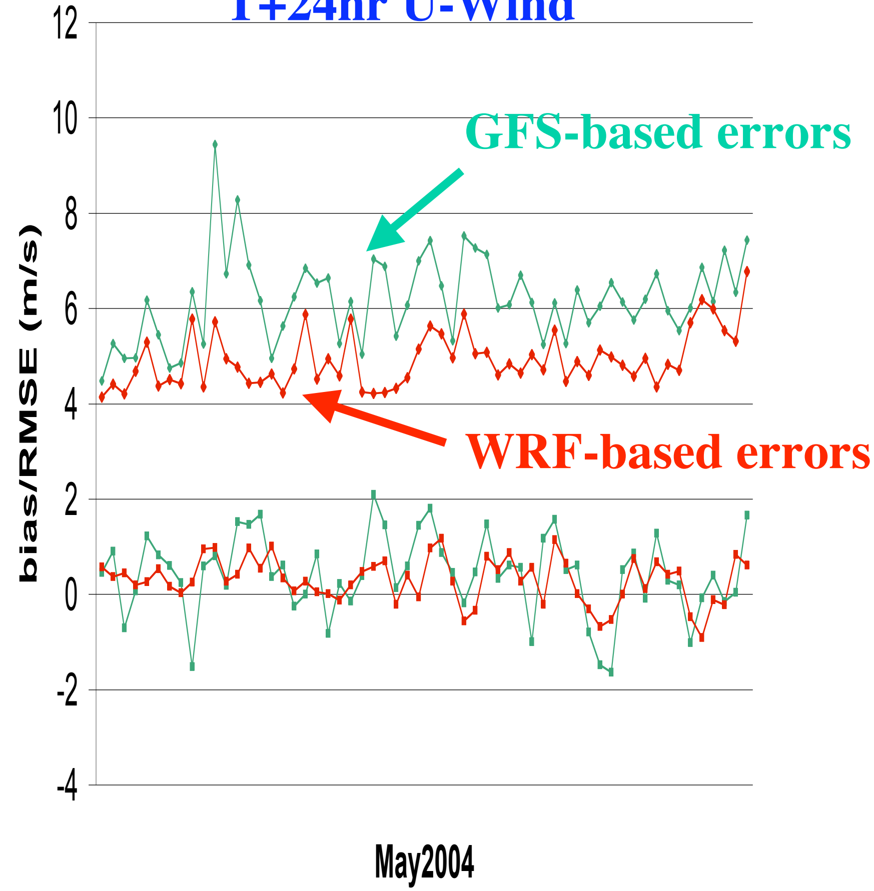



**60km Verification (vs. radiosondes)**

**T+24hr U-Wind**



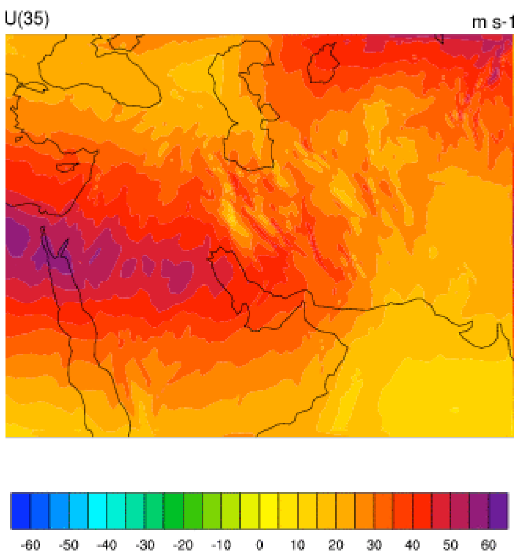
# Background Error Estimation - S.W. Asia

- Apply NMC-method to AFWA T4B (300x237x41 15km WRF-ARW)

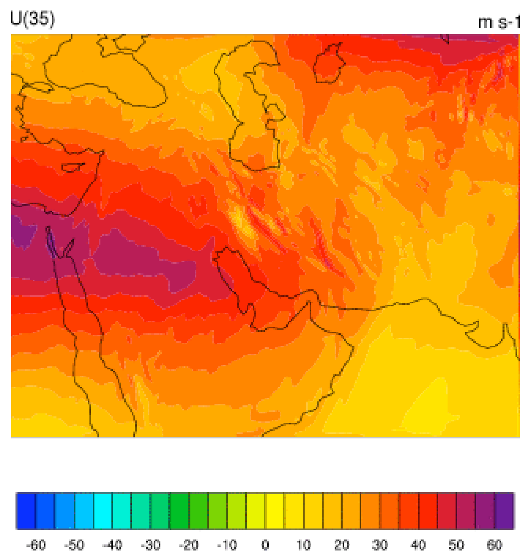
$$\mathbf{P}_f = \overline{\boldsymbol{x}'\boldsymbol{x}'^T} \approx A\overline{(\boldsymbol{x}^{t2} - \boldsymbol{x}^{t1})(\boldsymbol{x}^{t2} - \boldsymbol{x}^{t1})^T} \approx UU^T$$

- Example: 12 UTC February 4th 2006 error estimation for U-wind (level 35):

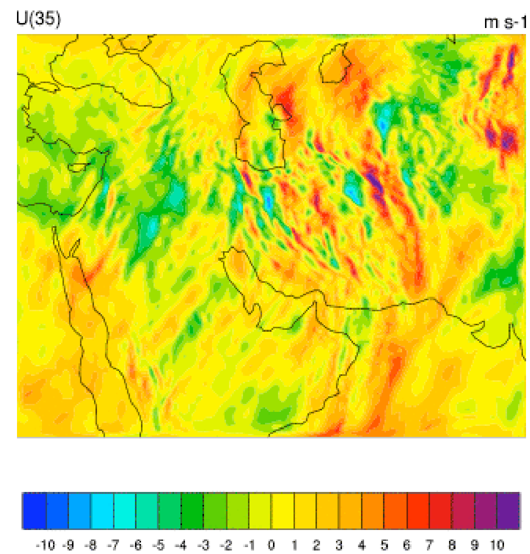
**t2 = 24hr WRF forecast**




**t1 = 12hr WRF forecast**




**2006020412 (“Error”)**




- WRF forecasts courtesy of Roy Peck (AFWA).

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2. Create you own, using WRF forecasts from your application.
3. Implement, iterate (i.e. recalculate BEs), tune.

A utility *gen_be* has been developed at NCAR to calculate BEs.

# Background Error Estimation - S.W. Asia

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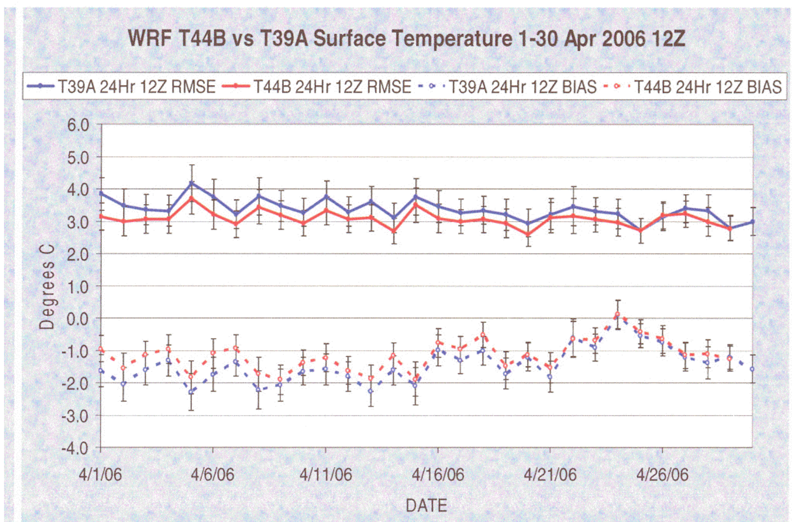
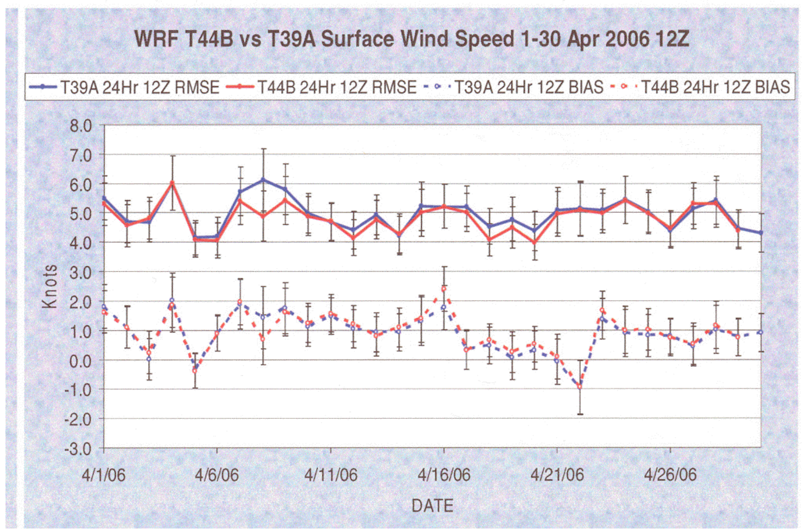
- 24hr forecast verification (courtesy Steve Rugg, AFWA).



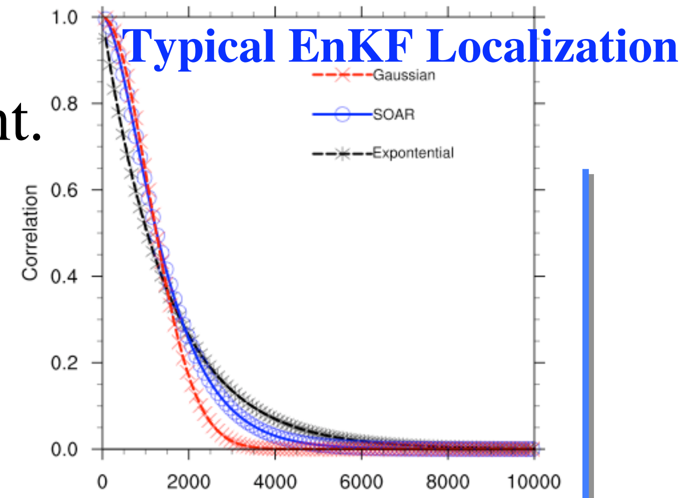



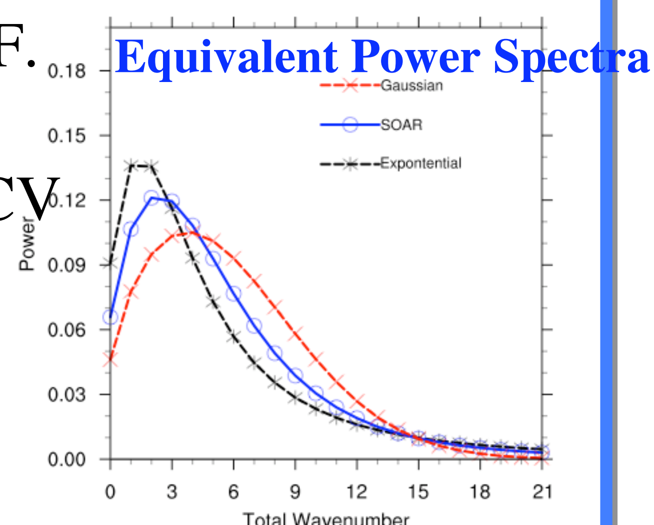

Blue = WRF BE stats (1st generation)

Red = WRF BE stats (2nd generation)

# Flow-Dependent Error Covariances in WRF-Var

- Forecast errors are typically flow-dependent.
- Numerous methods applied in 3/4D-Var in past decade.
- Adopt “alpha control variable” (ACV) method (Barker and Lorenc, 1999) in WRF.
- Lorenc (2003) suggests equivalence of ACV with covariance localization in EnKF.
- ACV “resolution” ~T42. Negligible cost.



# The "Alpha" Control Variable

• WRF-Var includes a "control variable" transform:

$$\boldsymbol{x}' = U\boldsymbol{v} = U_p U_v U_h \boldsymbol{v}$$

• Include additional operations in WRF-Var's $U_p$ transform (1 member example):

$$\psi' = \psi' + \alpha\psi'_e, \quad \chi_u' = \chi_u' + \alpha\chi_{ue}', \quad T_u' = T_u' + \alpha T_{ue}',$$

$$r' = r' + \alpha r_e', \qquad p_{su}' = p_{su}' + \alpha p_{sue}'$$

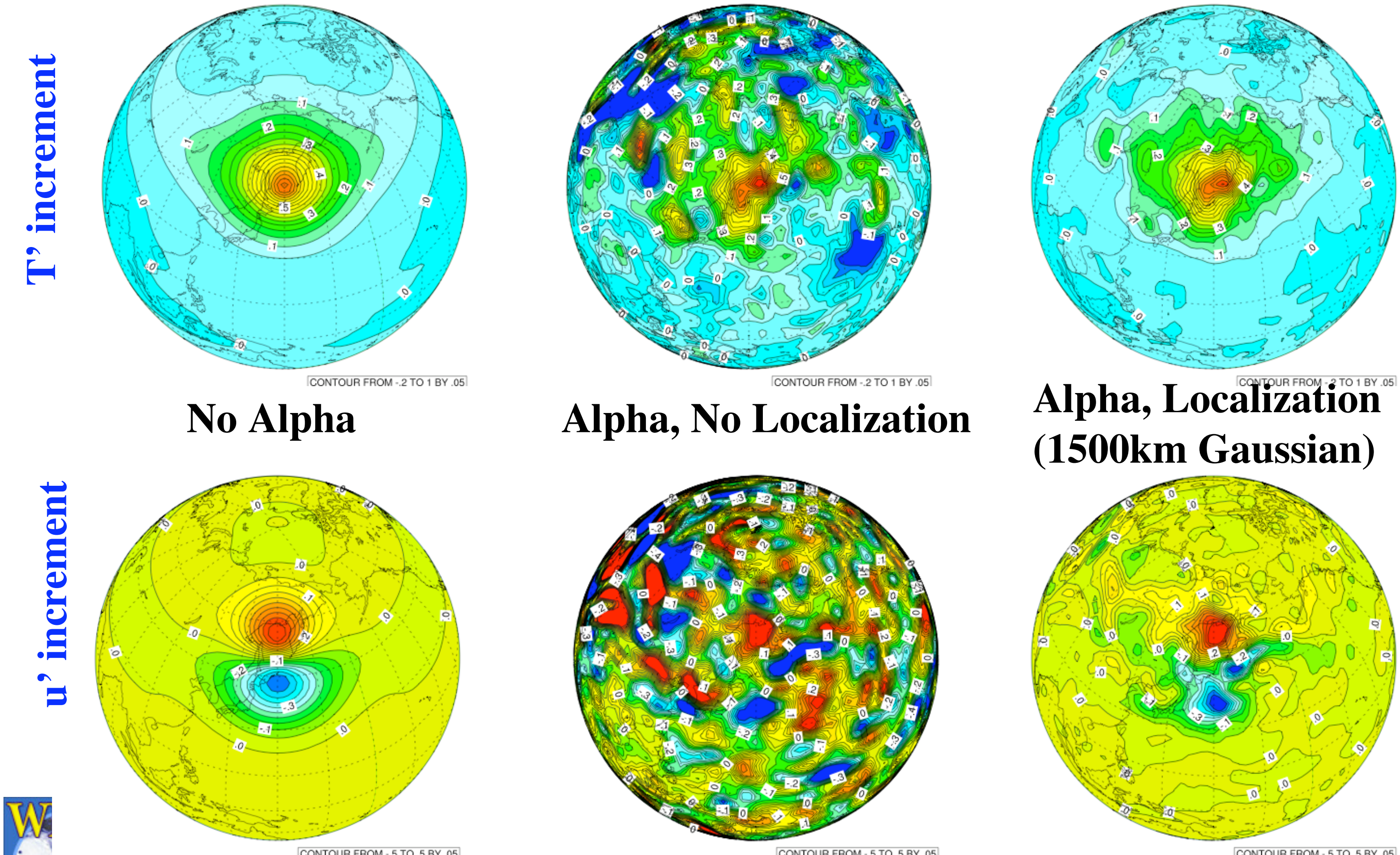
•Subscript e indicates flow-dependent predictors (e.g. from ETKF-based EPS).

•Flow-dependence applied before statistical balance (so balance unaffected).

•Additional term in the cost function to constrain alpha.

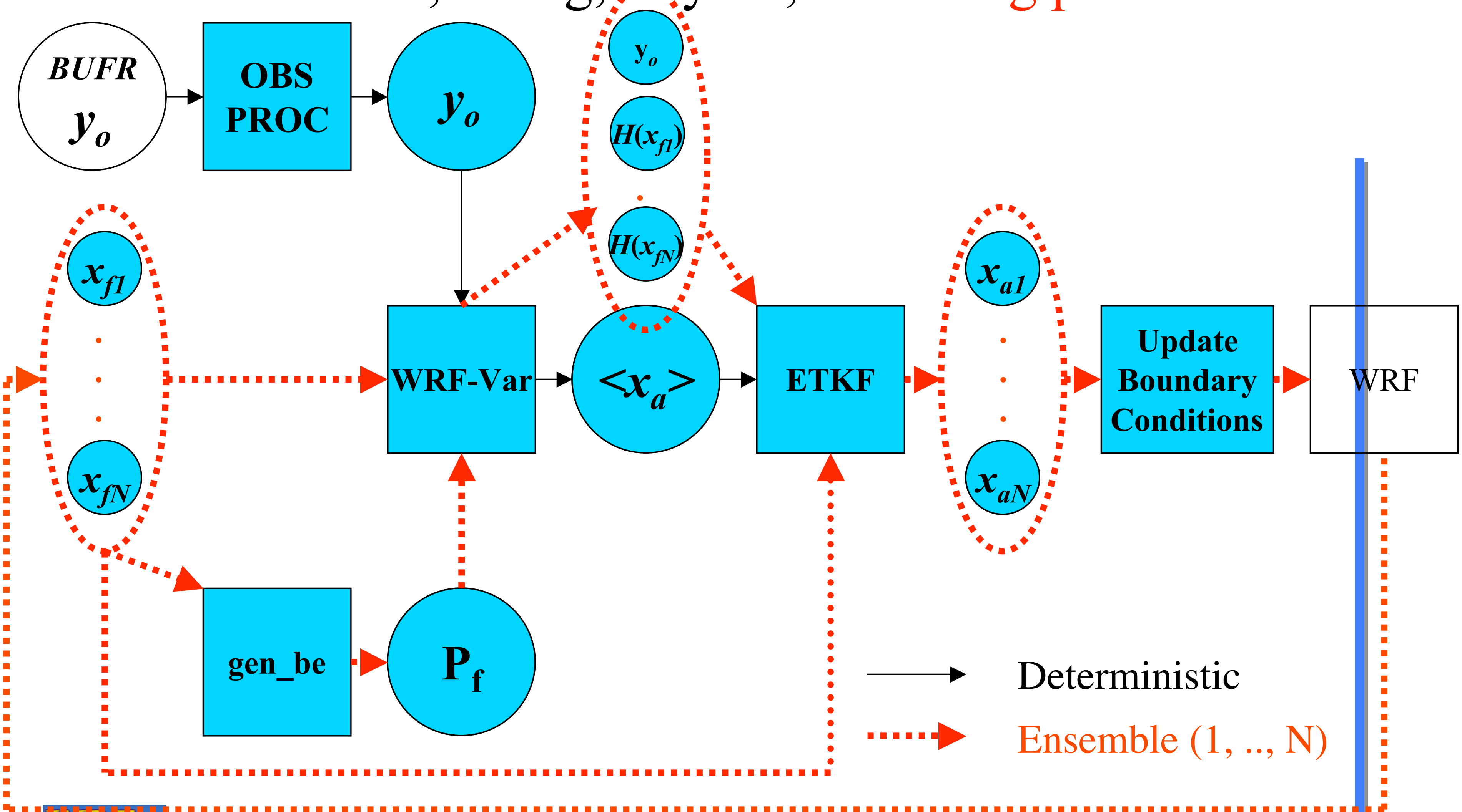
# Single Observation Test - Alpha CV

- Specify single T observation (O-B, $\sigma_o$=1K) at 50N, 150E, 500hPa.
- Example: Flow-Dependence given by 1 member of KMA's EPS.



# WRF Hybrid Variational/Ensemble Data Assimilation

Barker, Wang, Snyder, see Wang poster

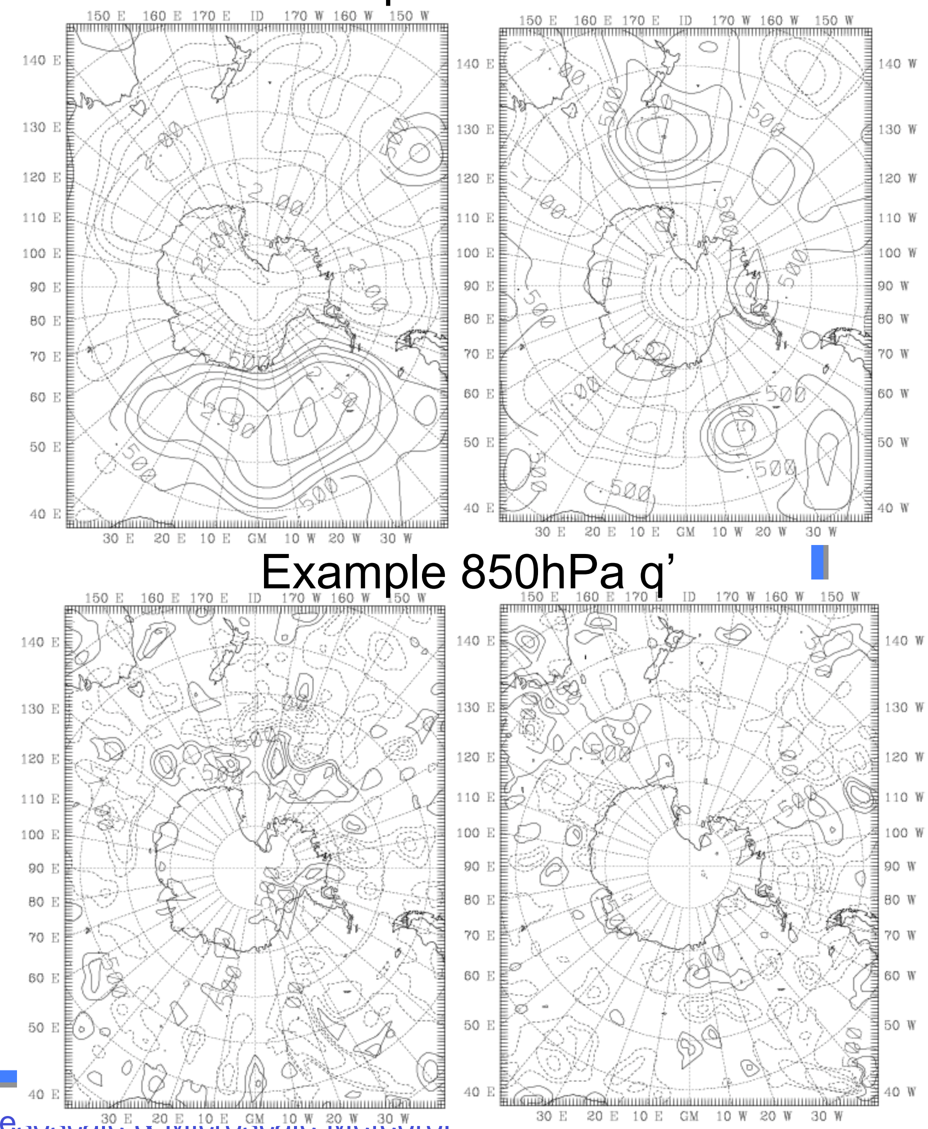


# General Uses of WRF-Var

- Obs QC and reformatting (e.g. little_r to PREPBUFR).
- DA Diagnostics (e.g. observation error tuning).
- Observation-based verification systems.
- Initialization of initial/lateral BCs in limited- area ensemble forecasting system,
  - Create ensemble of analysis perturbations: x'=Uv (v = R(0,1)) ("randomcv").
- Use of parts of code in other systems (e.g. RAMDAS, DART).

Example 500hPa T'

Example 850hPa q'



Random Seed 1 Random Seed 2

# RAB Document: Data Assimilation

- Data assimilation components of "Research-Community Priorities for WRF-System Development:

  - 2. Convective Resolving NWP:
    - Needs: Remotely sensed obs (e.g. radar, high. Res satellite), advanced techniques.
    - Action: DA training, efficient/flexible DA system.
  - 3. Hurricane Research and Prediction:
    - Needs: Remotely-sensed obs (radar, satellite), dropwindsonde, advanced DA.
  - 5. Air Quality and Chemistry Modeling:
    - Needs: Chemical DA testbeds, Advanced/Efficient DA, Adjoints for AQ models, Targeting chemical obs, Field Campaigns.
    - Action plan: Initiate coordinated effort between DA/AQ communities.
  - 9. Forecast Verification Capabilities:
    - Needs: Use parts of DA system for verification (e.g. observation minus fcst diffs.)
    - Actions: Couple verification to 3D-Var to maximize use of observations.

# 8. WRF Data Assimilation Development (Chris Snyder)

- 1) Further development of advanced assimilation algorithms:
  - Variational needs: Background error covariances suitable for mesoscale, adjoints for additional physical parameterizations (e.g. microphysics, PBL), control of lateral boundary conditions, suppression of gravity waves.
  - Ensemble DA needs: Ameliorate effects of sampling error.
- 2) Assimilation of new observation types:
  - Needs: Radar , high-res satellite data in presence of cloud/precipitation.
- 3) Assessment of model error (major limitation for 4D-Var, EnKF).
- **Proposed Action plan: Testbeds.**

# Data Assimilation Testbed Center

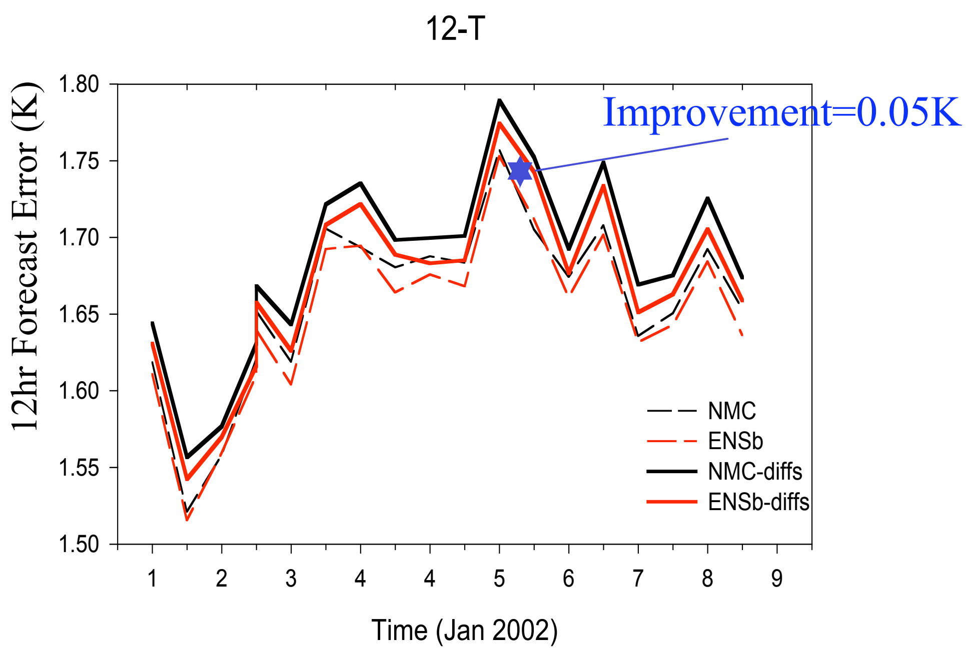
- Potential Role for Data Assimilation TestBed Center (DATC):
  - Collect/quality control/preprocess/archive observations.
  - Maintain (but not develop) DA codes for use in DTC/DATC experiments.
  - Provide computational resources for DATC activities.
  - Supply training in the use of supported DA systems.
  - Information point for community DA activities.
- Sample DATC experiments (extended period, cycling):
  - Pre-release tests (e.g. WRF 2.1 vs. WRF 2.2).
  - Observation impact studies (e.g. radar reflectivities, COSMIC).
  - DA system tuning (e.g. error covariances).
  - Technique intercomparison (e.g. nudging, 3D-Var, 4D-Var, EnKF).
  - System intercomparison (e.g. WRF-Var, GSI, NAVDAS).

## Importance of Data Assimilation For General WRF Development/Testing

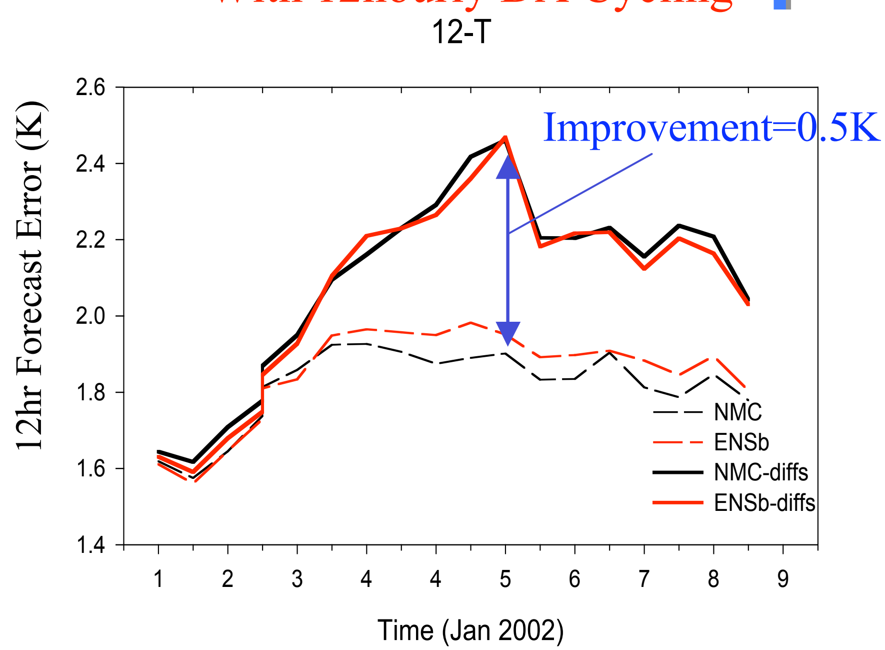
Experiment:

- Test undisclosed change to WRF modeling system.
- 40km WRF CONUS application. Solid = Control, Dashed = Test.
- Use January 2002 conventional data for cycling.

Without DA Cycling




With 12hourly DA Cycling



# Data Assimilation Needs

- Advanced DA for NWP requires significant resources:
  - System complexity (QC, monitoring, tuning, etc).
  - No "one size fits all" solution to NWP DA, requires flexible approach.
  - Computational expense (CPU, memory, bandwidth, archiving, etc).
  - Training/education for next-generation DA experts.
- Too bi a problem for all but the Advanced DA for NWP requires significant resources: