NCAR/AFWA Data Assimilation Program: Status And Future Plans

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Data Assimilation Testbed Center (DATC): Meral Demirtas, Hui Shao

National Center For Atmospheric Research

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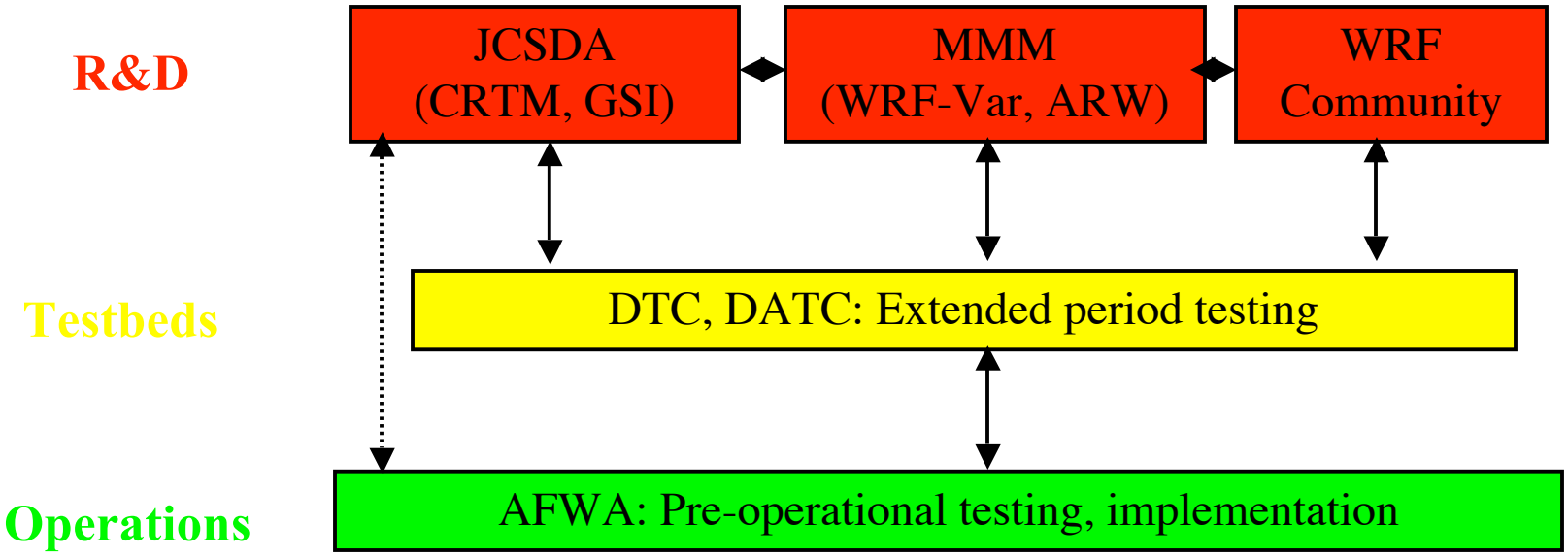
Taiwanese Central Weather Bureau, Civil Aeronautics Administration,
Beijing Meteorological Bureau,
Indian Met. Dept., National Center for Medium-Range Weather Prediction.

NCAR/AFWA DA Program Overview



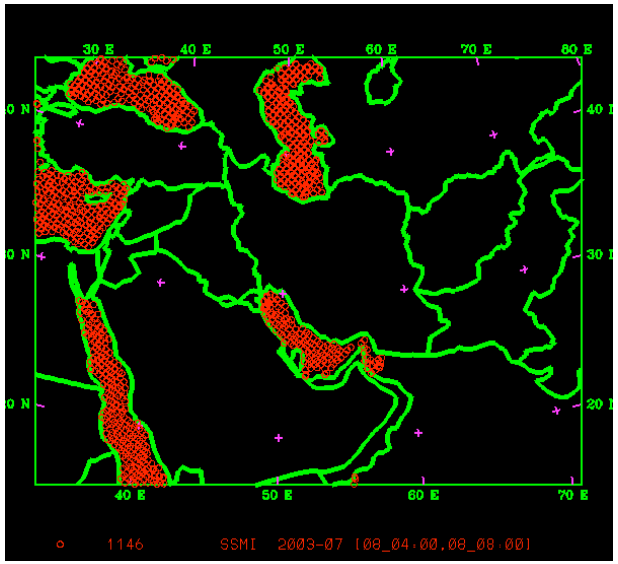
- NCAR/AFWA DA Program initiated in August 2006.
- MMM Division responsible for WRF-Var development and initial testing.
- JCSDA provides Community Radiative Transfer Model (CRTM), etc.
- WRF Community contributions include radar, radiance (RTTOVS).
- Data Assimilation Testbed Center (DATC) responsible for pre-release testing.

WRF-Var Data Assimilation Overview

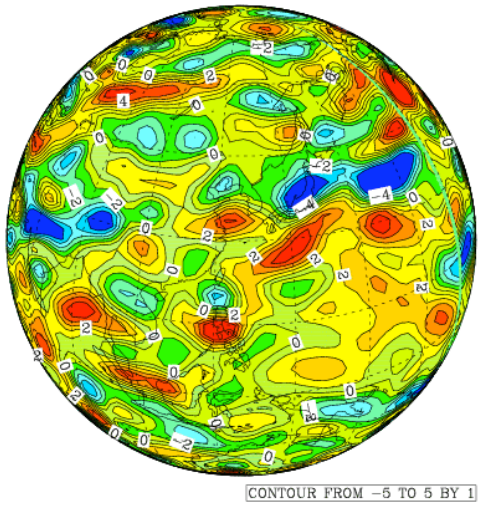
- **Techniques:** 3D-Var, 4D-Var (regional), Hybrid Variational/Ensemble DA.
- **Software Engineering:** WRF framework.
- **Multiple Models:** Runs with WRF, MM5, KMA global model, etc.
- **Domains:** Regional/global.
- **Applications:** Worldwide (AFWA), US, Korea, Taiwan, India, China (BMB), Israel, Antarctica, ….

  blue = unique contribution to JCSDA?

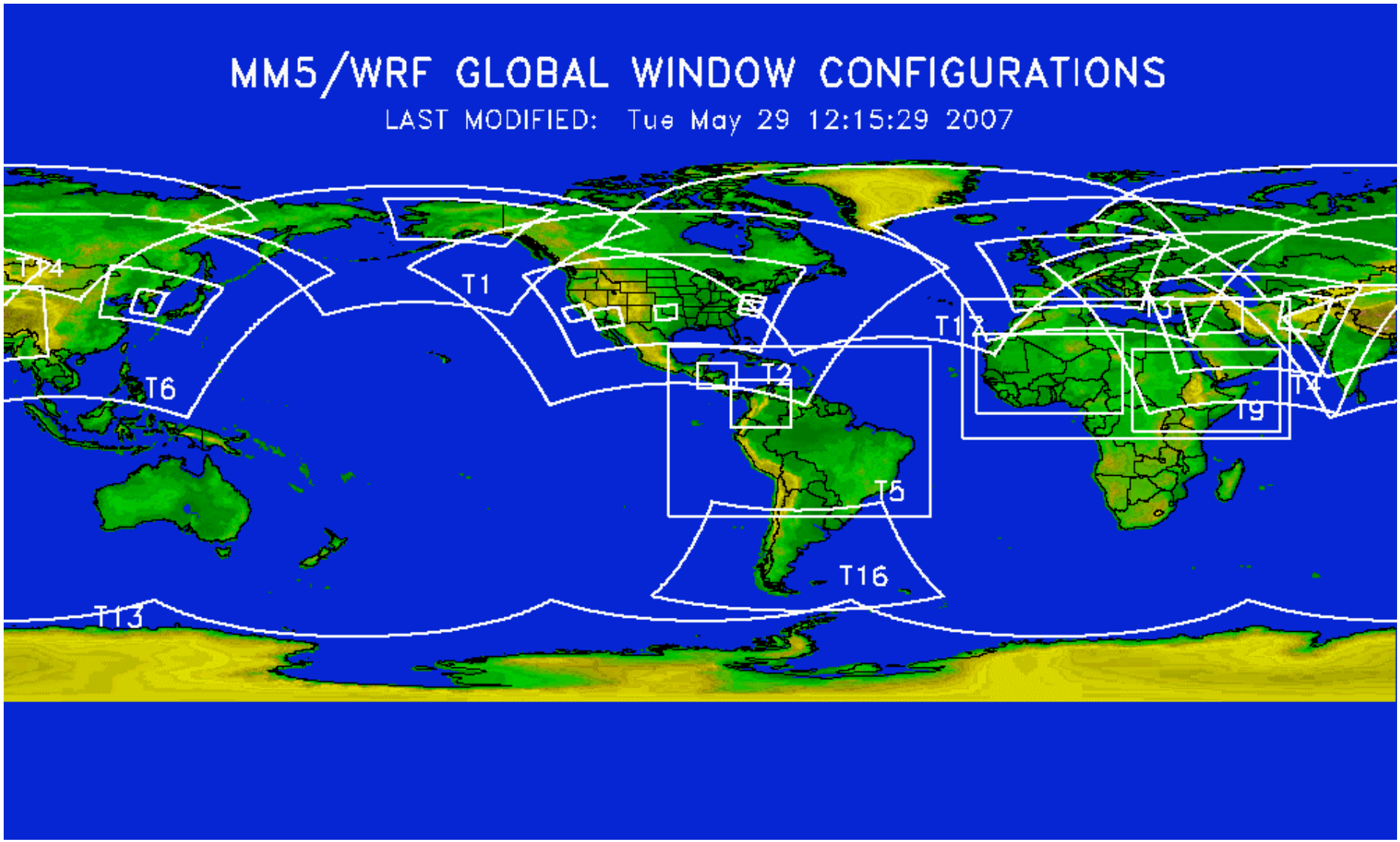
AFWA 15km S-W Asia:



KMA T213/426 Global:



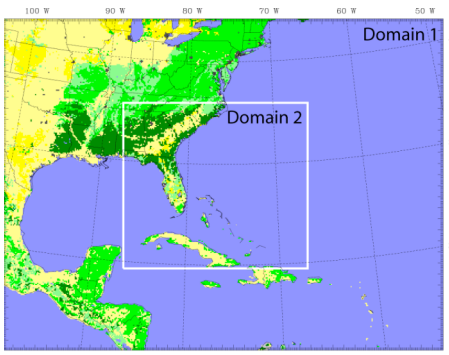
Worldwide AFWA MM5/WRF Theaters



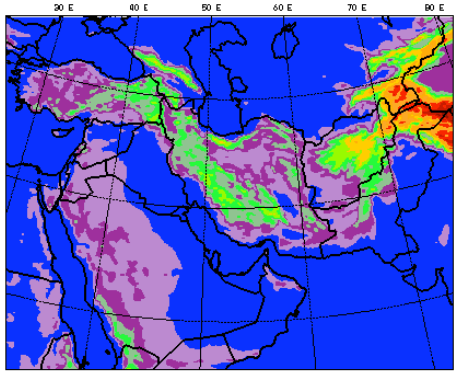
Courtesy Maj. Dan Pawlak (USAF)

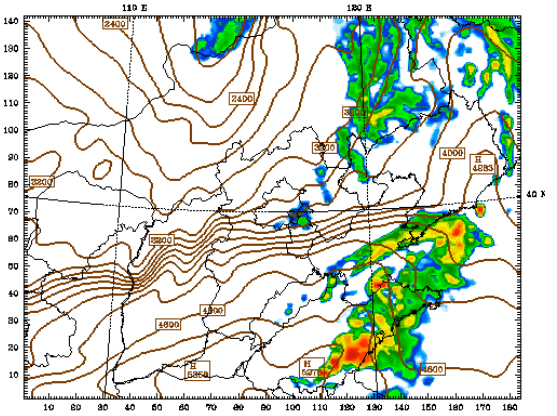
WRF-Var Resources

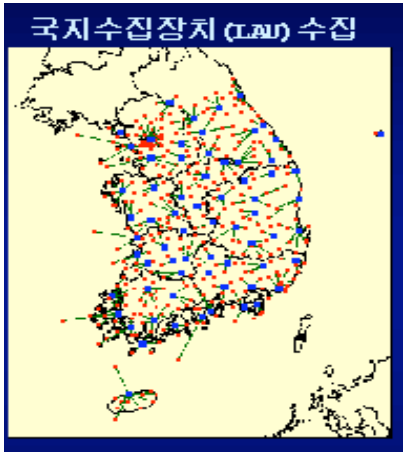
- NCAR staff: 23FTE, ~12 projects.
- Non-NCAR collaborators (AFWA, KMA, etc): ~10FTE.
- Community users: ~30 (more in 4000 general WRF downloads?).

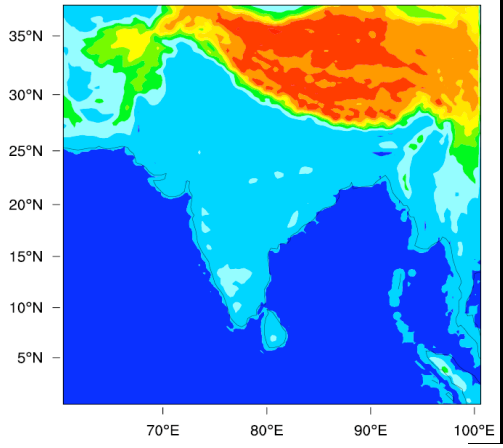


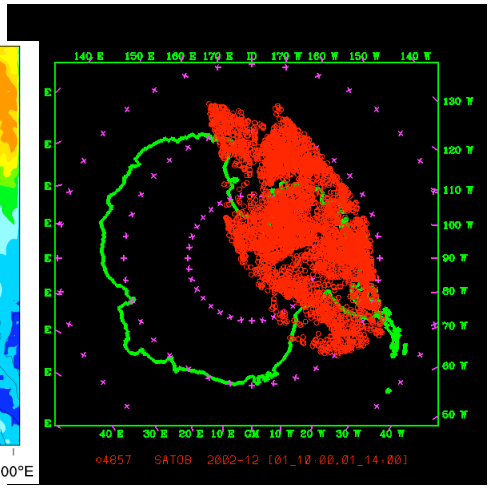
Domain1: 12km, 400X301X35
Domain 2: 4 km, 502X451X35

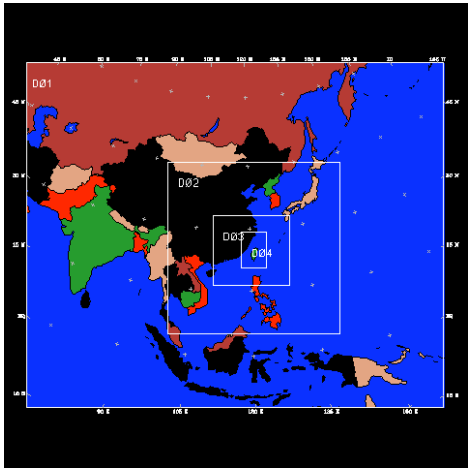


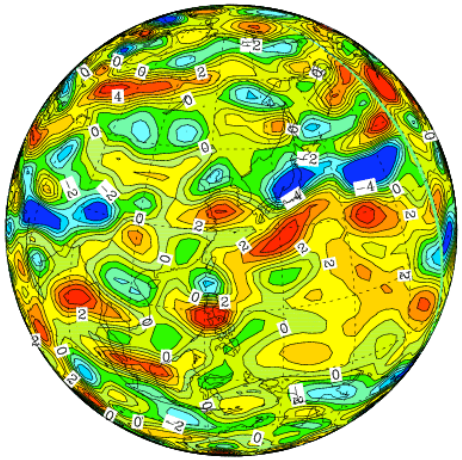










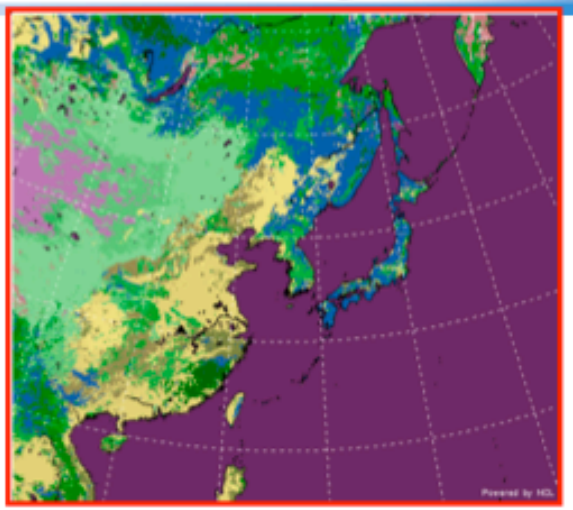


Korean WRF (KWRF) Implementation (S. W. Joo - KMA)

KMA

WRF configuration

- WRF Version 2.1.2
- WRFSI
- KWRF 10km(574x514x31)
- 48 Hours forecast
- U3VR 6 hour cycle
- DFI



Model Physics

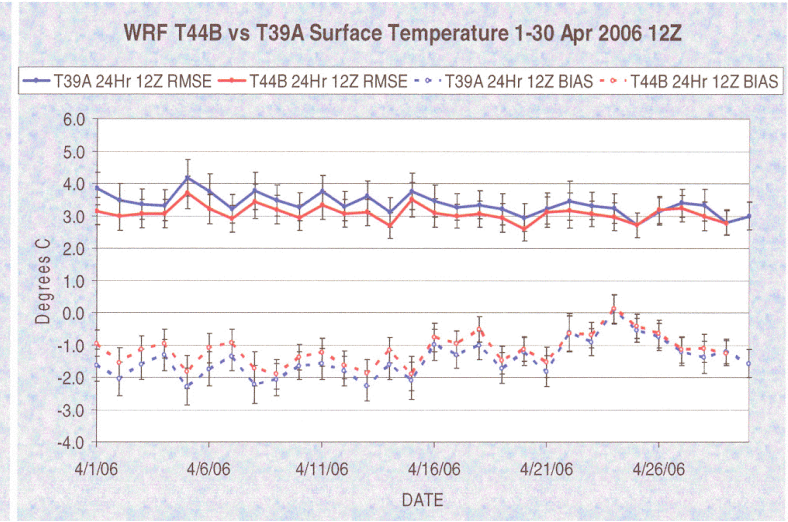
	RDAPS	KWRF
Microphysics Scheme	Mixed Phase	WSM6
Radiation Scheme	Cloud radiation	Dudhia/RRTM
Cumulus parameterization	New Kain-Fritsch	New Kain-Fritsch
Land-Surface model	5-layer soil	Noah LSM
PBL Scheme	MRF PBL	YSU PBL

KWRF Operational in May 2007

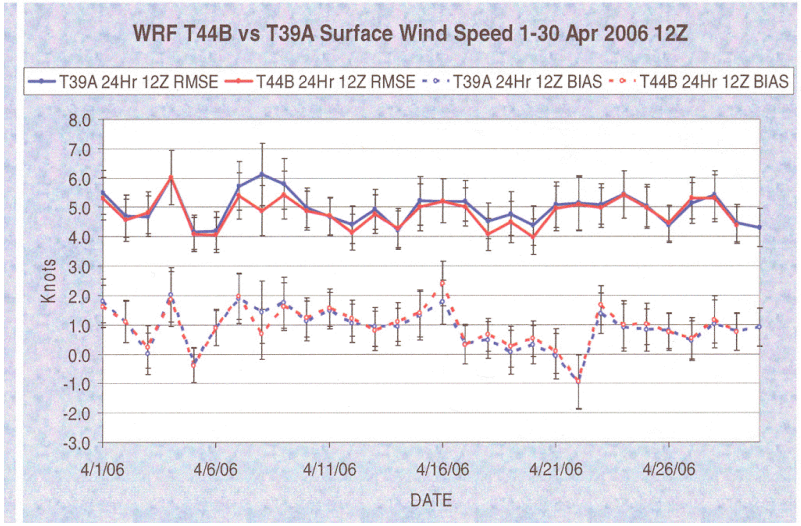
Impact of Tuned WRF-Var Forecast Errors for AFWA (S. W. Asia domain)

- WRF-ARW/WRF-Var operational at AFWA in July 2006.
- NMC-method used to estimate forecast errors.
- Re-tuning of forecast errors led to positive impact:

T+24 Surface Temperature Verif.



T+24 Surface Wind Verif.



Blue = WRF BE stats (1st version, fcsts from GFS)

Red = WRF BE stats (2nd version, fcsts from WRF-Var)

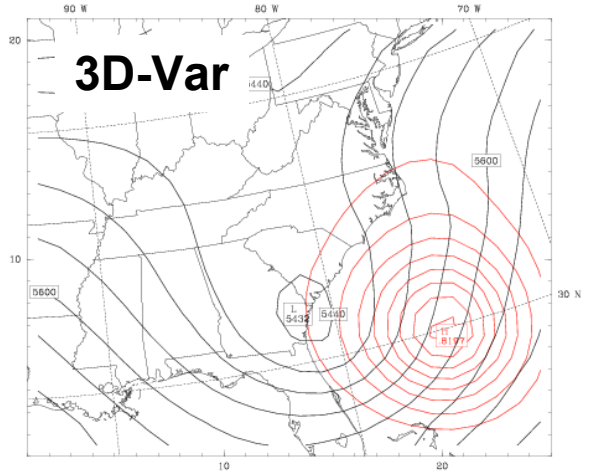
Courtesy: Robert Craig (AFWA)

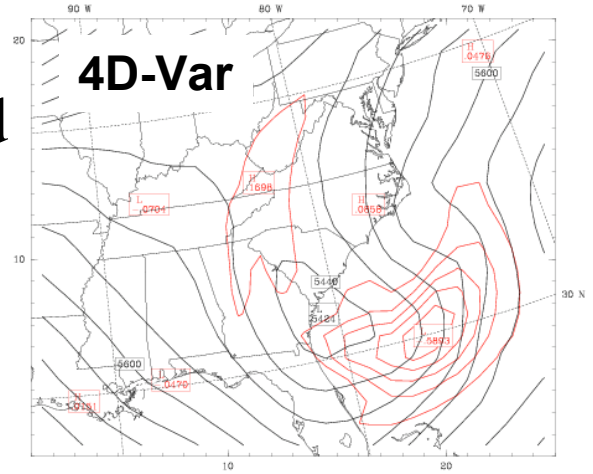
WRF-(4D)Var Summary

1. WRF-(4D)Var AFWA project: 2004-2007.

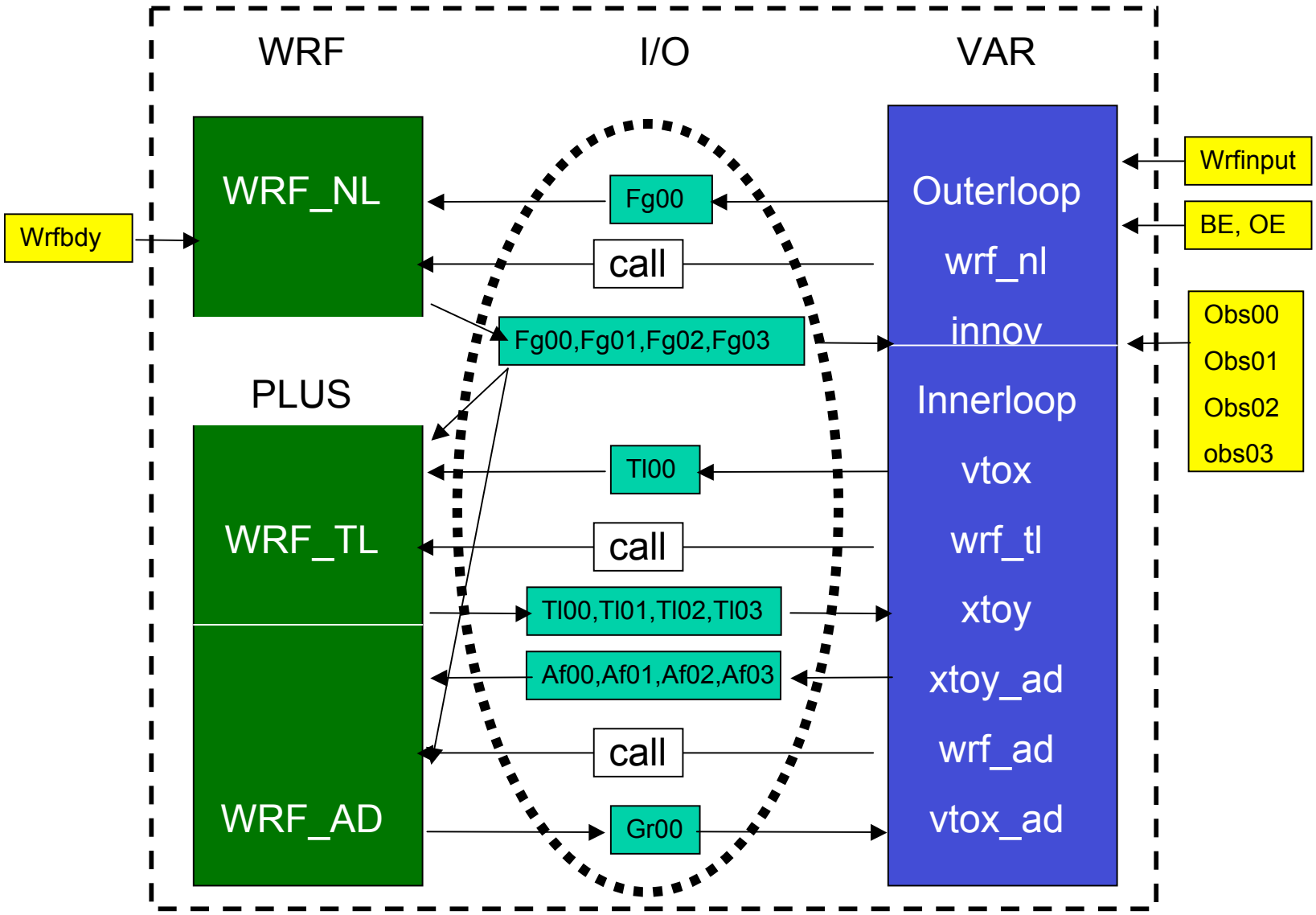
2. Formulation: Built within WRF-Var, using ARW dynamic core.

3. Status:
   - Prototype built (parallel, JcDFI, limited physics).
   - Prototypes delivered to AFWA in 2006 and 2007.
   - Current focus: Testing, more physics, optimization.





Basic system: 3 exes, disk I/O, parallel, simple phys, JcDF



Real Case: KMA Heavy Rain

Period: 12 UTC 4 May - 00 UTC 7 May, 2006

Assimilation window: 6 hours

Cycling

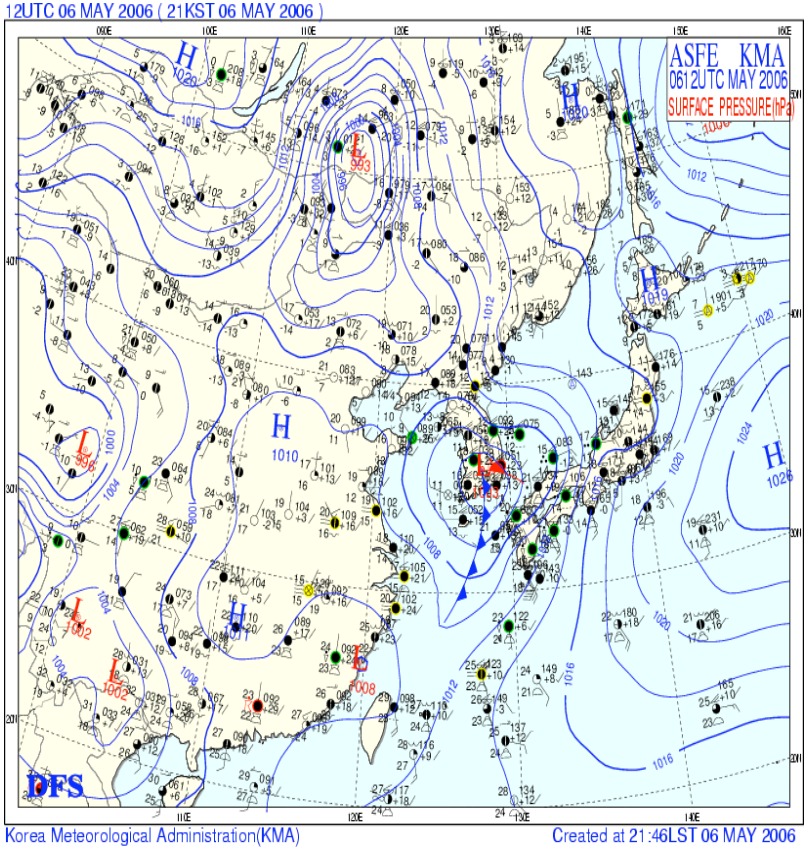
All KMA operational data except radar

Grid : 60x54x31

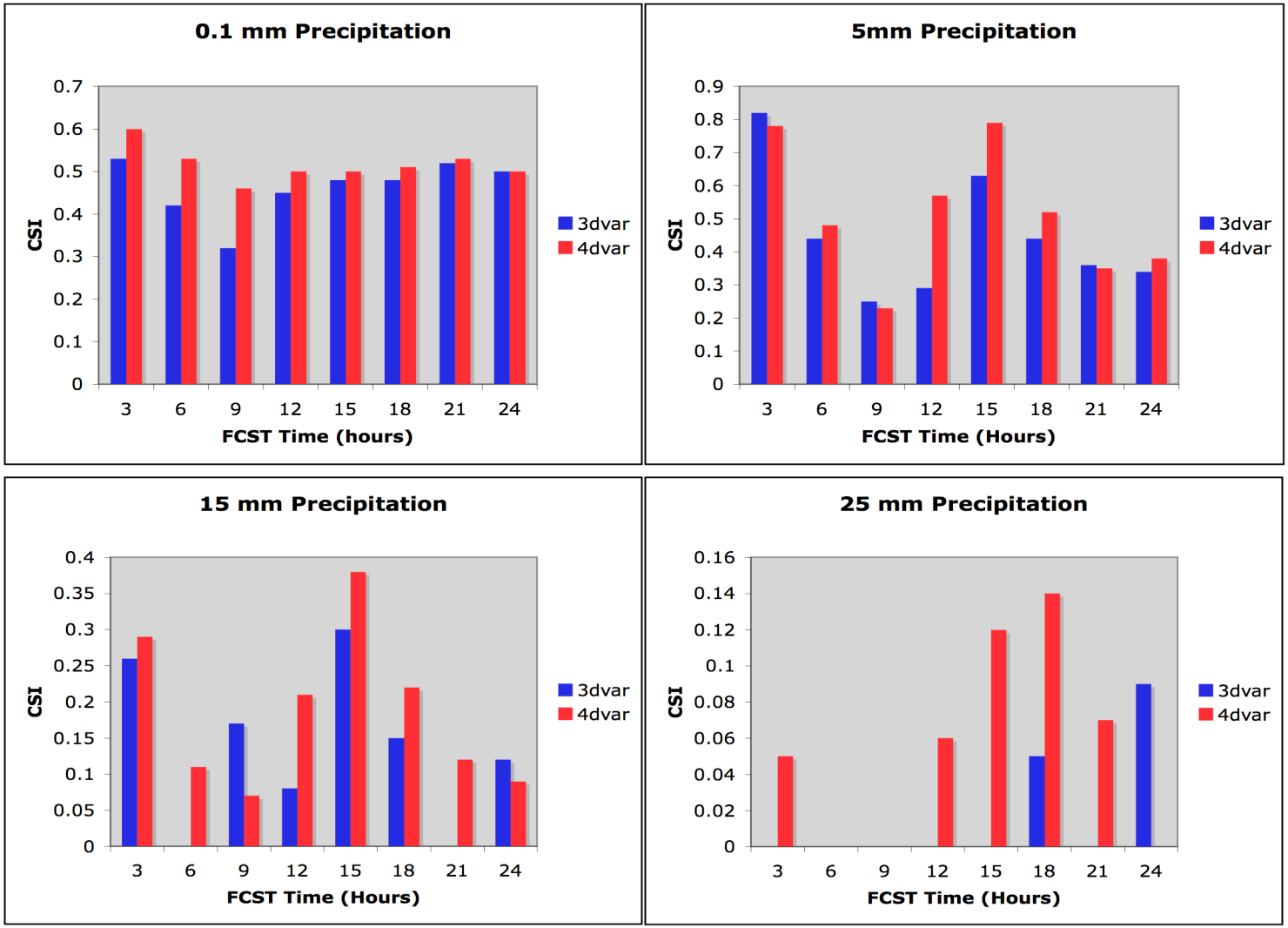
Resolution : 30km

Domain size: the same as the KMA operational 10km domain.

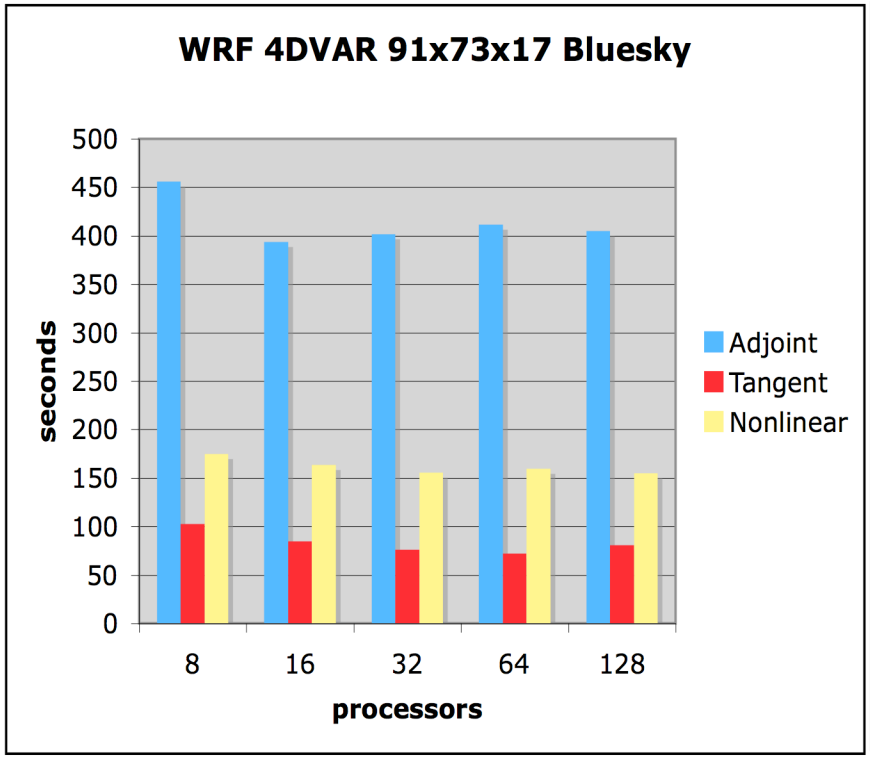
(from the KMA project)

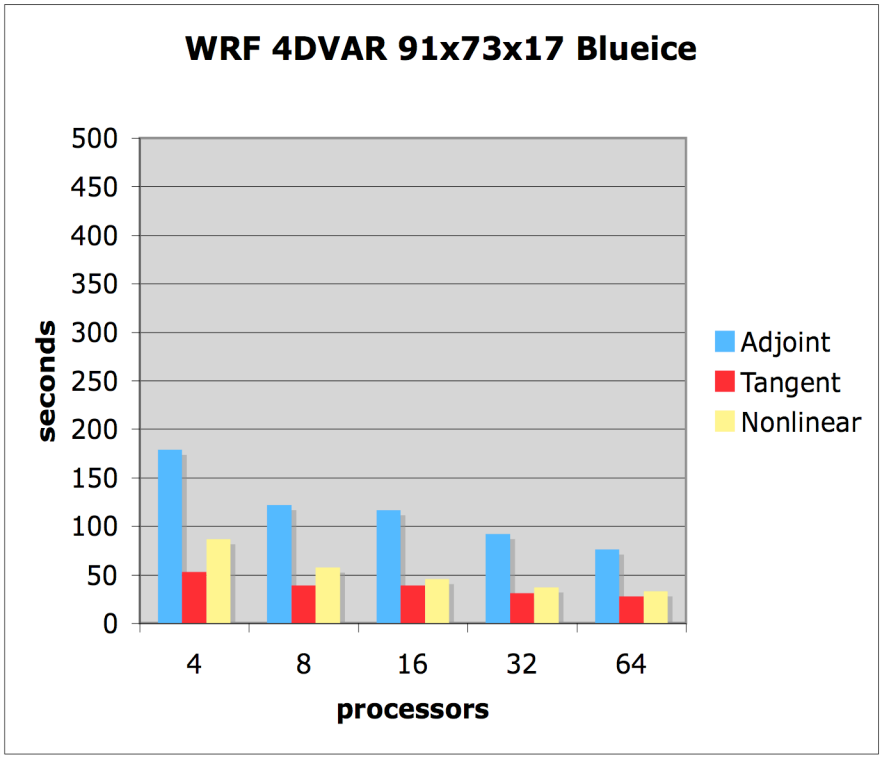


Precipitation Verification



Wall clock of 6 hours integration on Bluesky and Blueice



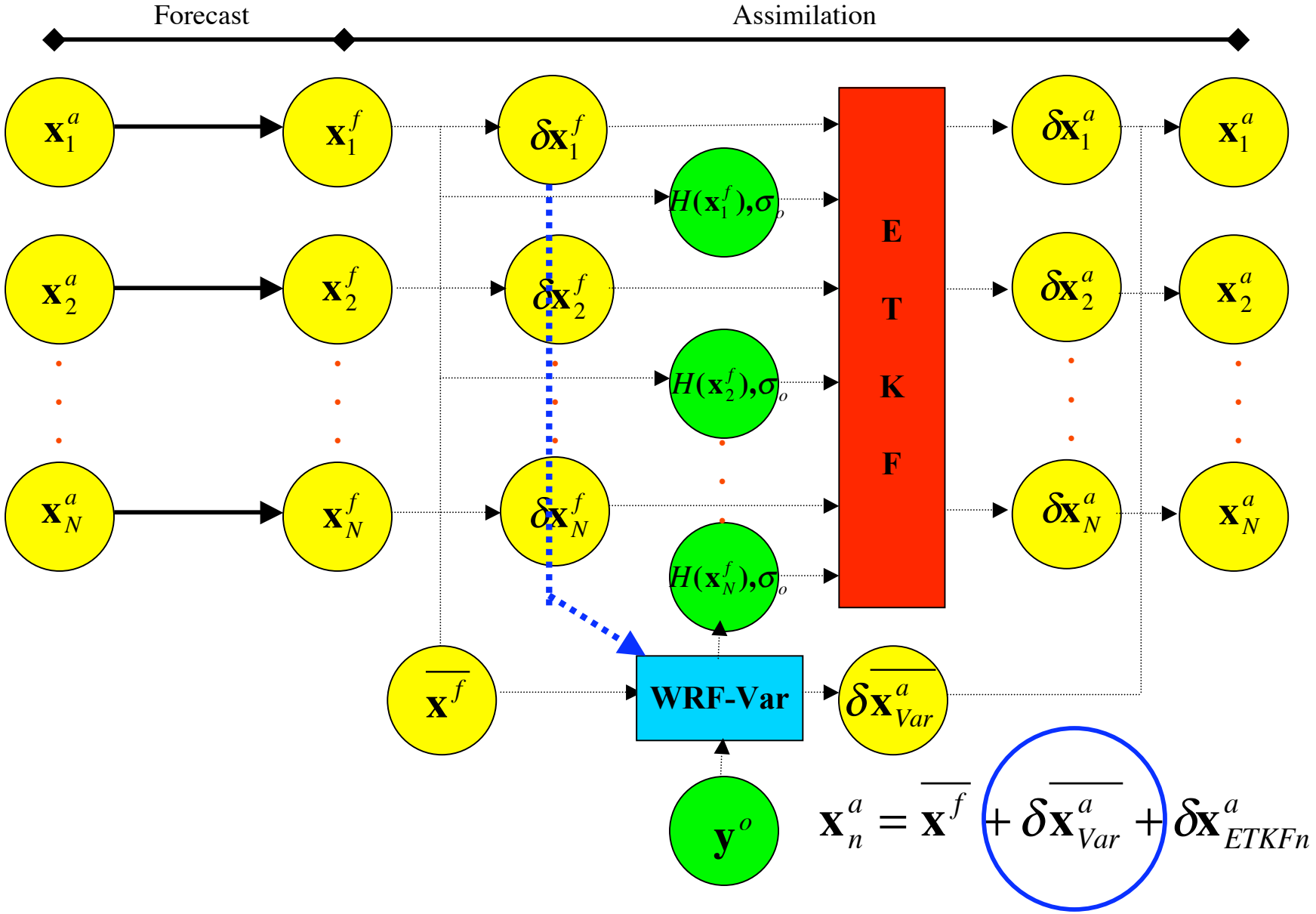


Bluesky: Old NCAR IBM

Blueice: New NCAR IBM

Note: Linear/adjoint models run with simplified physics

Cycling WRF/WRF-Var/ETKF System (Hybrid DA)



Subject of JCSDA and AFWA Seminars 2007

Hybrid DA Via Additional Control Variables

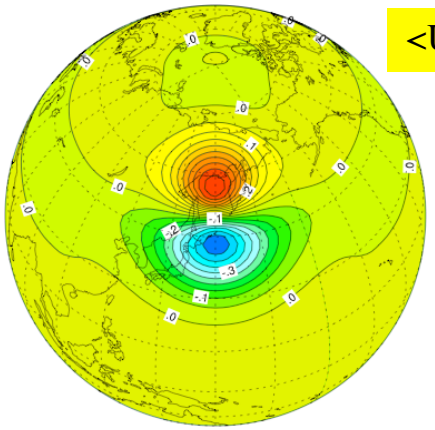
- Define the matrix of ensemble perturbations as

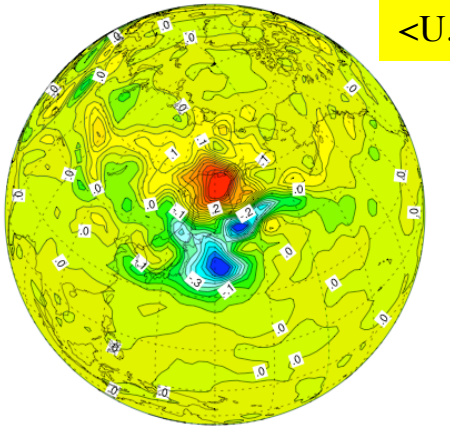
$$\delta \mathbf{X}_f = \left(\delta \mathbf{x}_{f1}, \delta \mathbf{x}_{f2}, ..., \delta \mathbf{x}_{fN} \right)$$

- Hybrid 3/4D-Var analysis increments given by

$$\delta \mathbf{x}_0 = \delta \mathbf{x}_{0d} + \delta \mathbf{X}_f \bullet \mathbf{a}$$

- Flow-dependence $\delta \mathbf{X}_f$ introduced via additional control variables



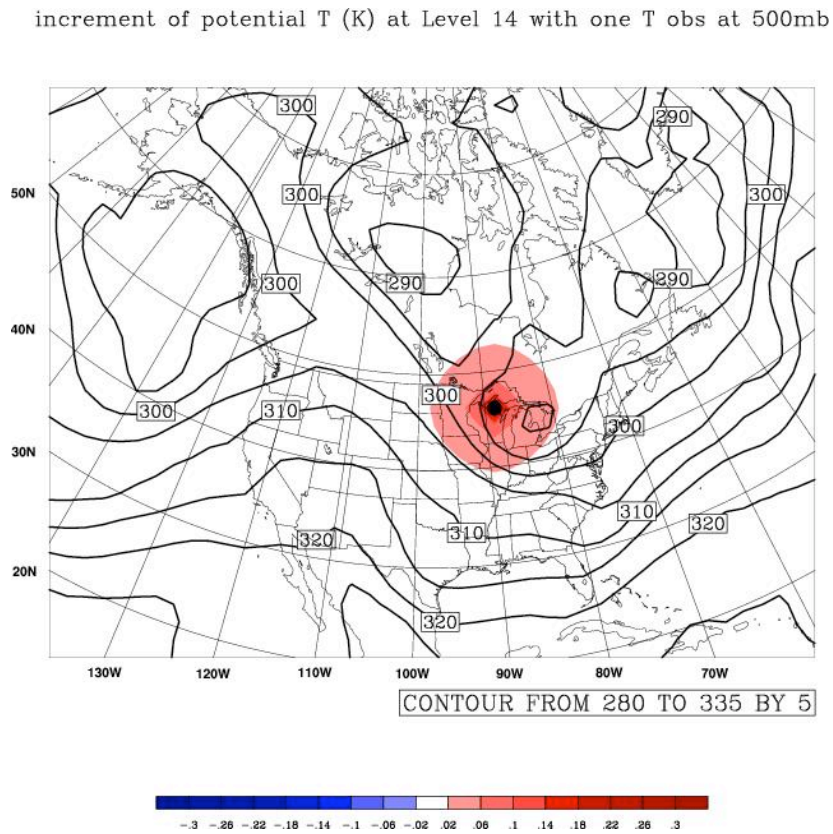


$$J = \frac{W_b}{2} \delta \mathbf{x}_0{}^T \mathbf{B}_o^{-1} \delta \mathbf{x}_0 + \frac{W_\alpha}{2} \mathbf{a}^T \mathbf{A}^{-1} \mathbf{a} + \frac{1}{2} \sum_{i=0}^{n} \left[\mathbf{H}_i \delta \mathbf{x}(t_i) - \mathbf{d}_i \right]^T \mathbf{R}_i^{-1} \left[\mathbf{H}_i \delta \mathbf{x}(t_i) - \mathbf{d}_i \right]$$

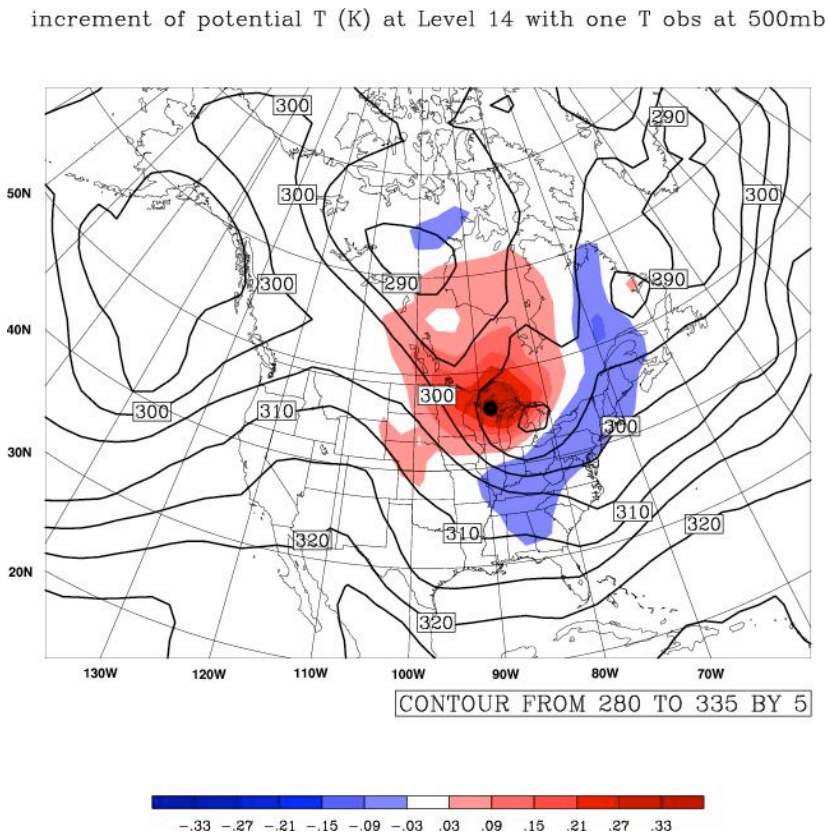
Hybrid DA (Regional) Single Observation Test

Analysis increment

Pure 3D-Var Covariance

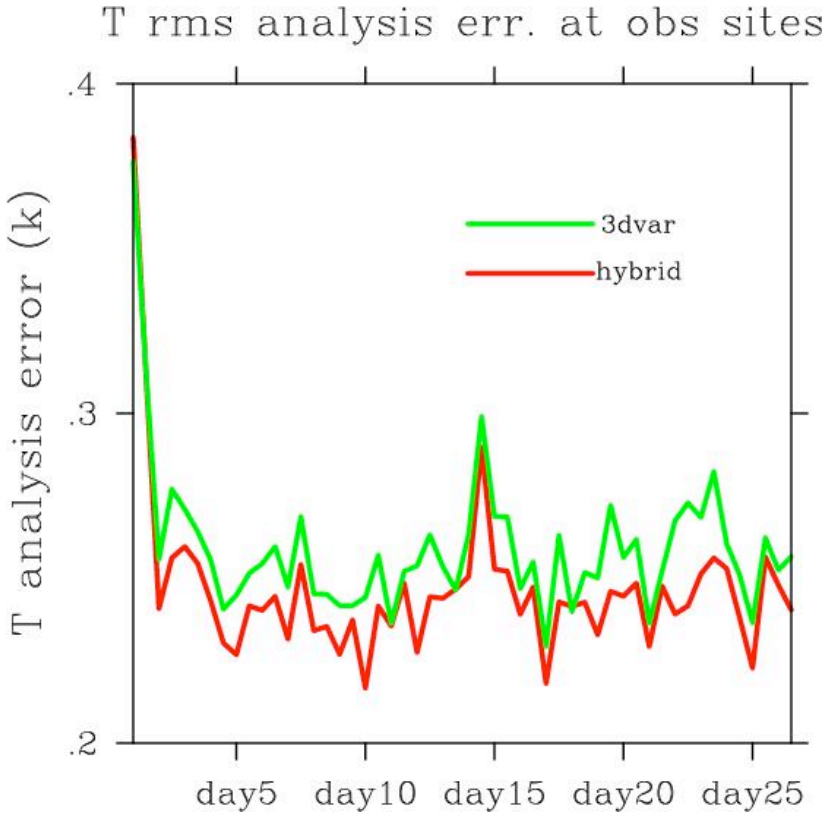


Pure Ensemble Covariance



Flow-dependent ETKF ensemble covariance is successfully incorporated in WRF-Var

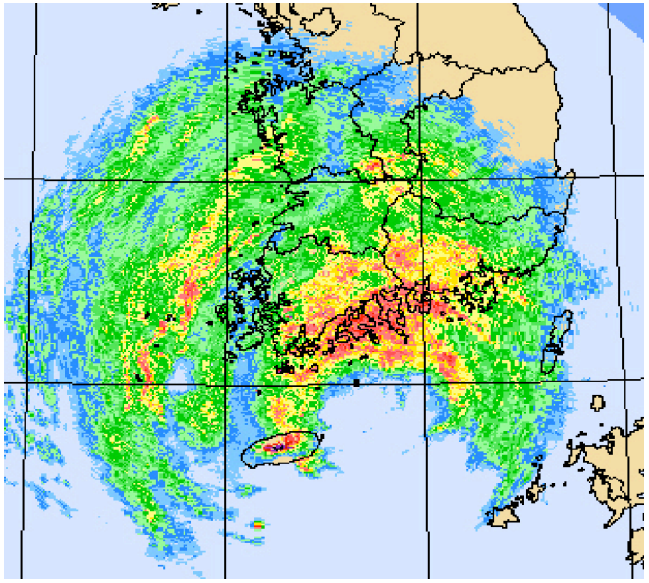
January 2003 OSSE Experiment (X. Wang)



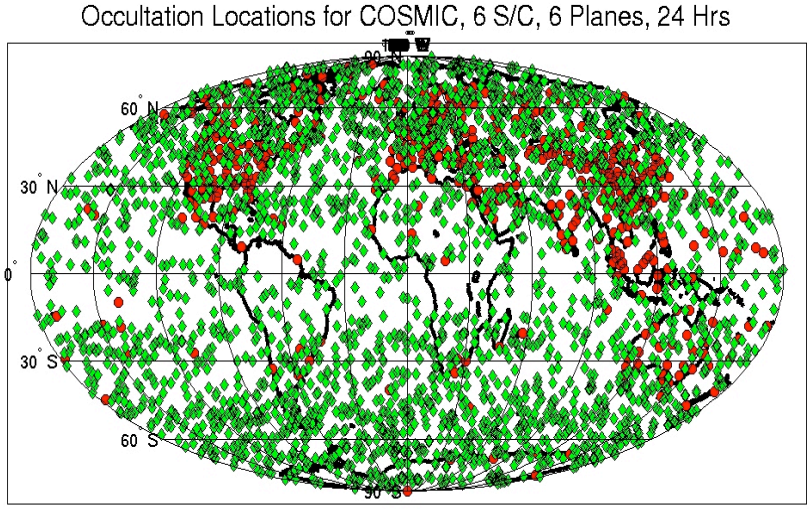
- Test hybrid with equal weight (0.5) on static/ensemble error covariances
- Hybrid analyses significantly better than the pure 3DVAR.
- Note yet cycling, nor tuned. Expect further improvements?

WRF-Var Observations

- 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 oceanic surface winds.
  - Wind Profiler.
  - Radar radial velocity and reflectivity.
  - Satellite temperature/humidities.
  - GPS refractivity (e.g. COSMIC).

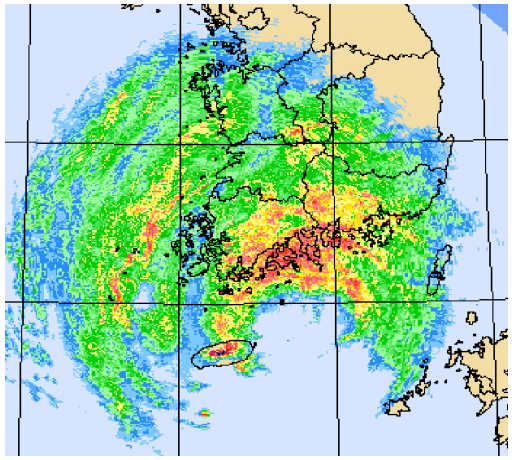


- Radiances:
  - SSM/I brightness temperatures.
  - Direct radiance assimilation(RTTOVS or CRTM).

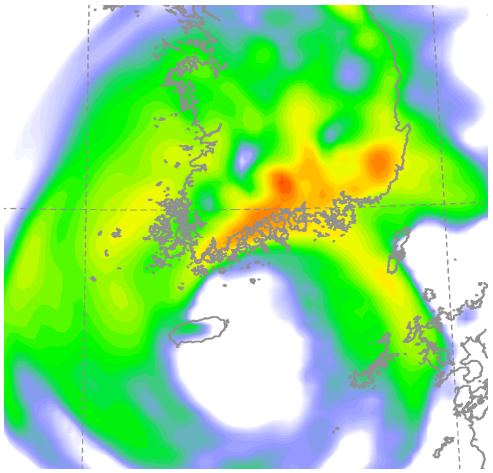
Korean Radar Data Assimilation in WRF-Var

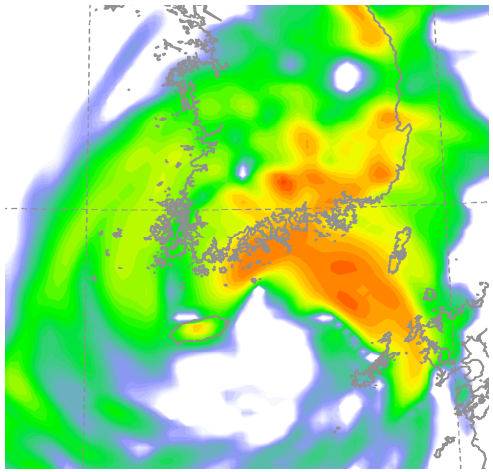
Typhoon Rusa Test Case 3hr Precip:

Obs (03Z, 31/08)

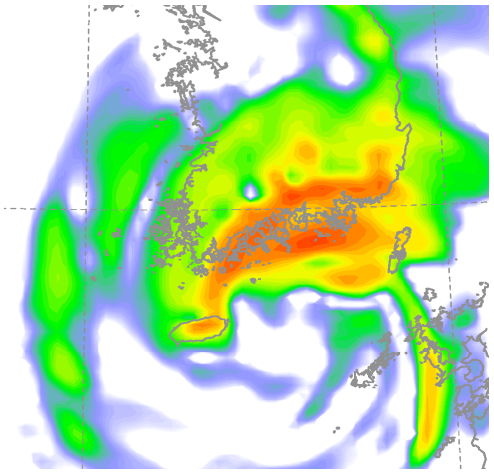


No Radar



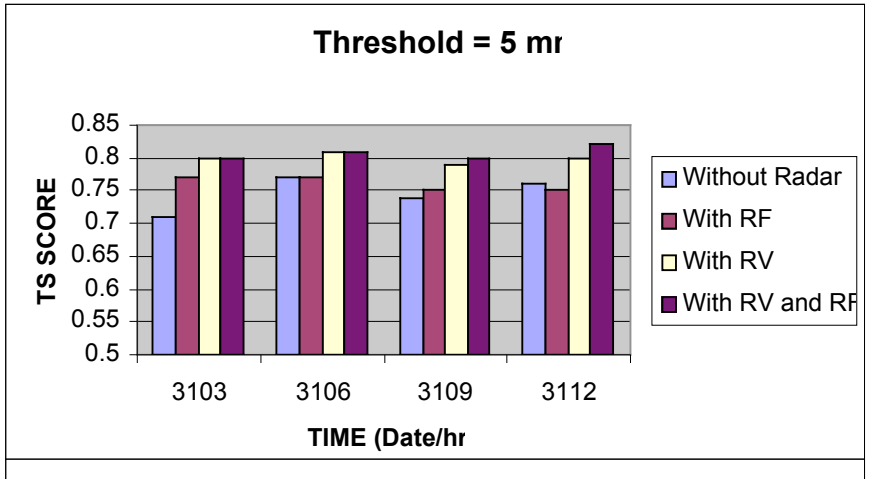


Radar RV

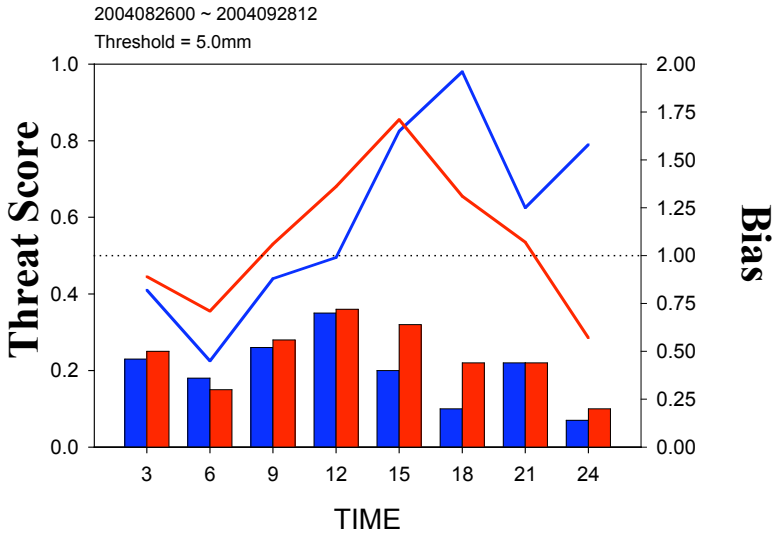


Radar RV+RF

Typhoon Rusa 3hr Precip. Verification:



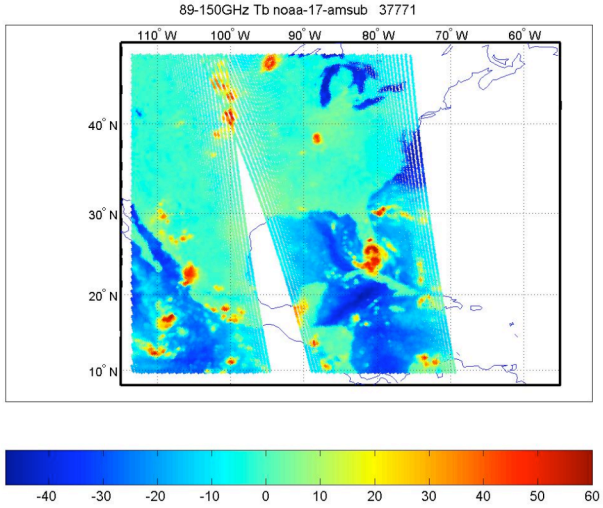
KMA Pre-operational Verification:
(no radar: blue, with radar: red)



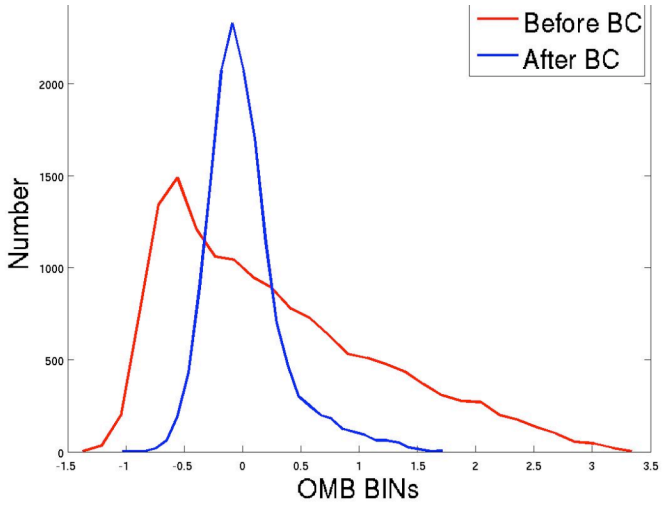
WRF-Var Radiance Assimilation Status

- Use NCEP BUFR libraries for all observations.
- NCEP BUFR 1b data ingested into WRF-Var.
- RTM interface: RTTOV8_5 or CRTM
- Currently only assimilating clear-sky radiances
- NESDIS Microwave surface emissivity model
- Range of monitoring diagnostics.
- Quality Control for AMSU-A/B, AIRS
- Bias Correction (Scan Angle + Air Mass)
- Thinning algorithm ported from GSI (Jianjun Xu
- Variational observation error tuning
- FGAT(First Guess at Appropriate Time)
- Parallel: MPI
- Flexible design to easily add new satellite sensor

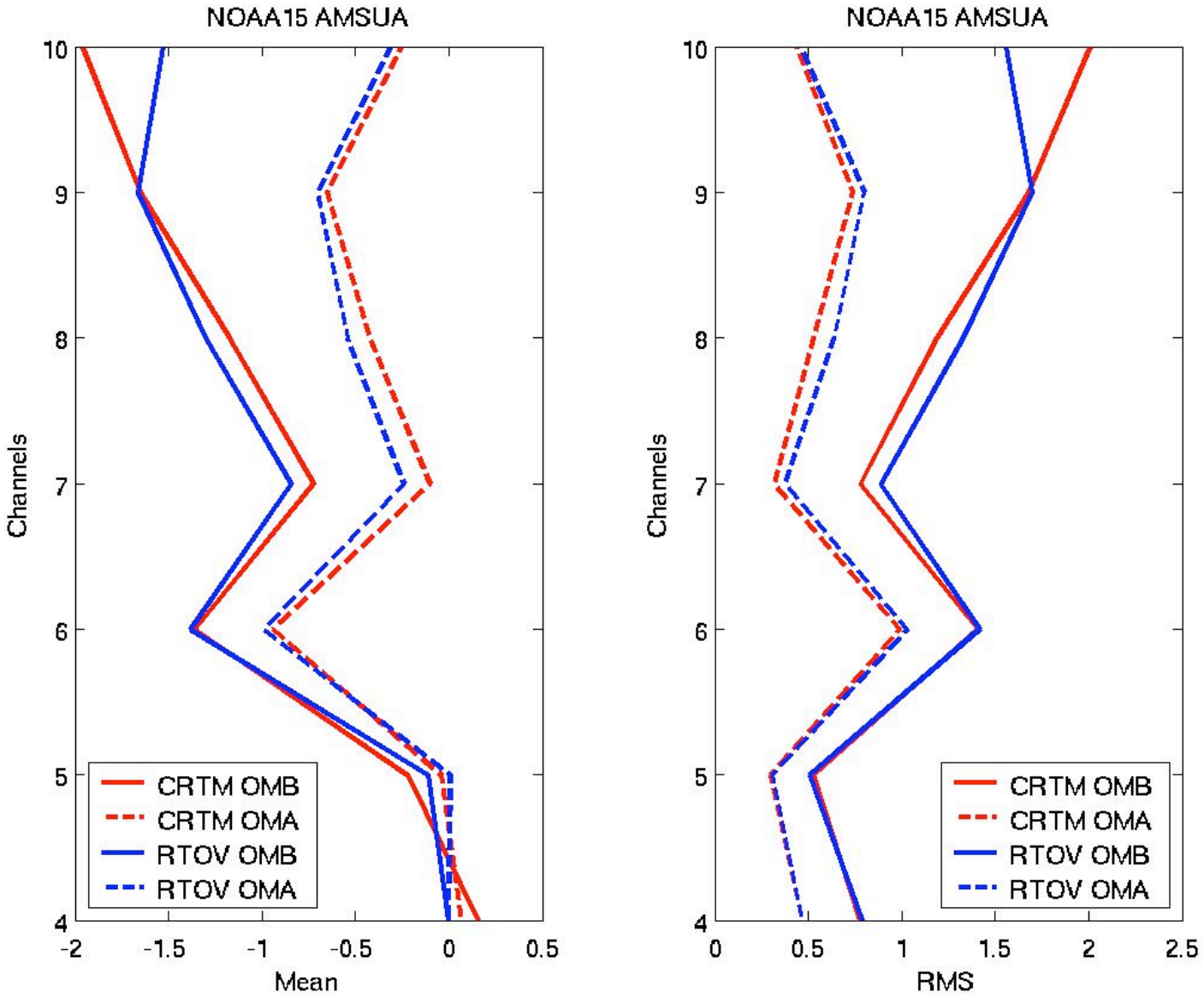
AMSU-B Scatter Index > 3K

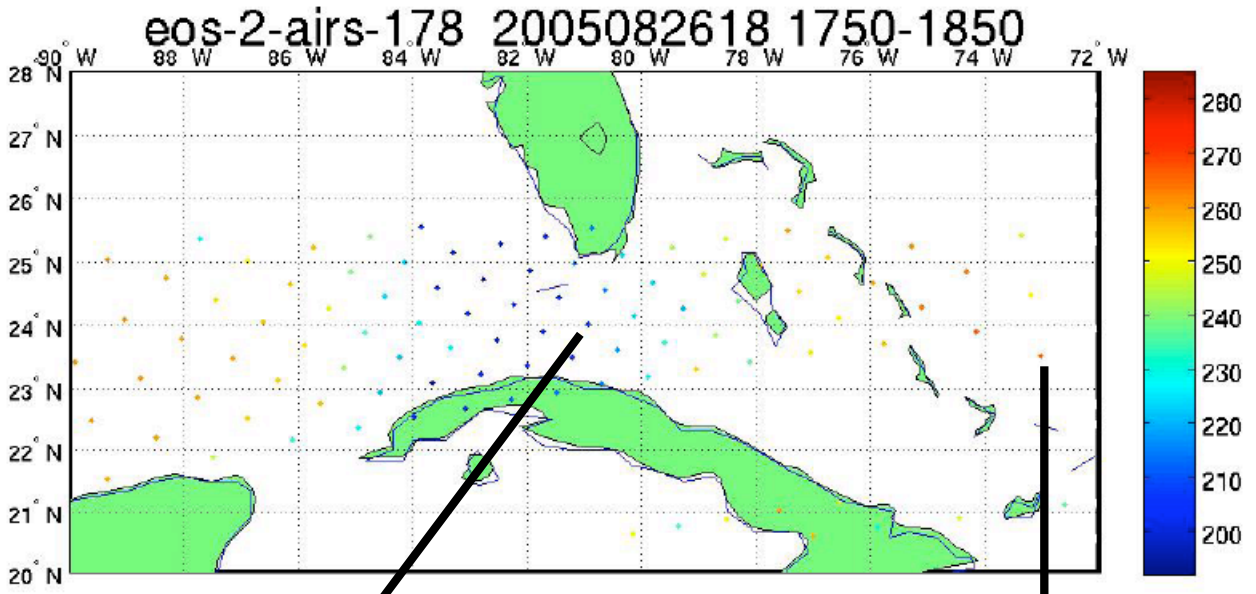


Air Mass Bias Correction: AMSU-A

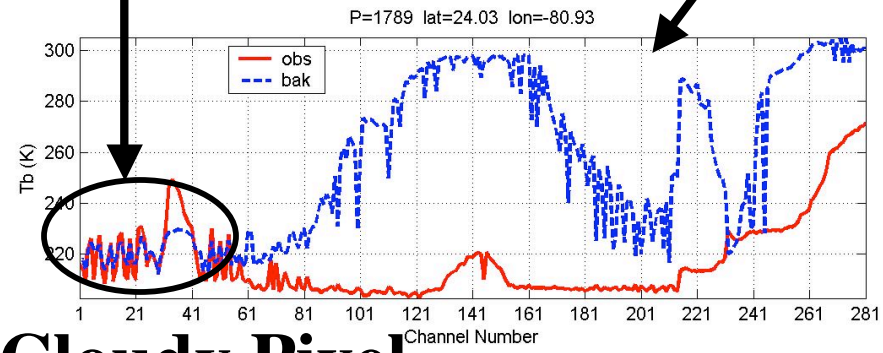


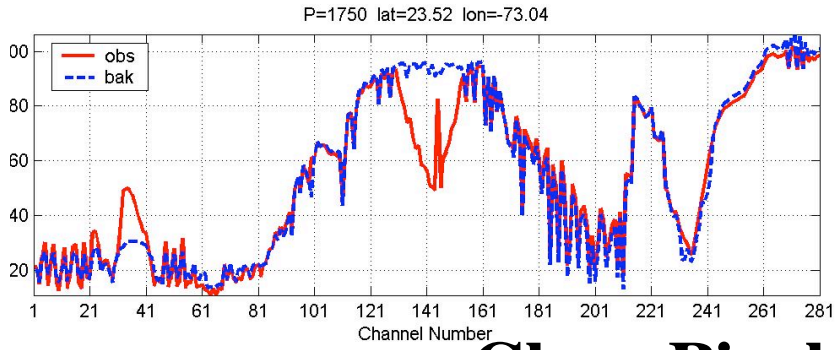
CRTM vs. RTTOVS Case Study Comparison



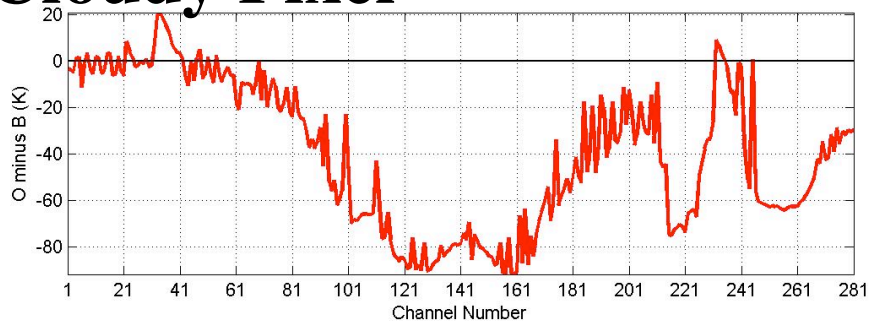


Can be used
Above cloud

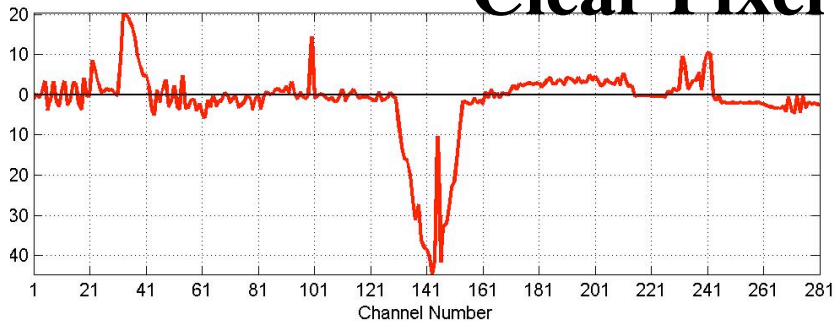




Cloudy Pixel

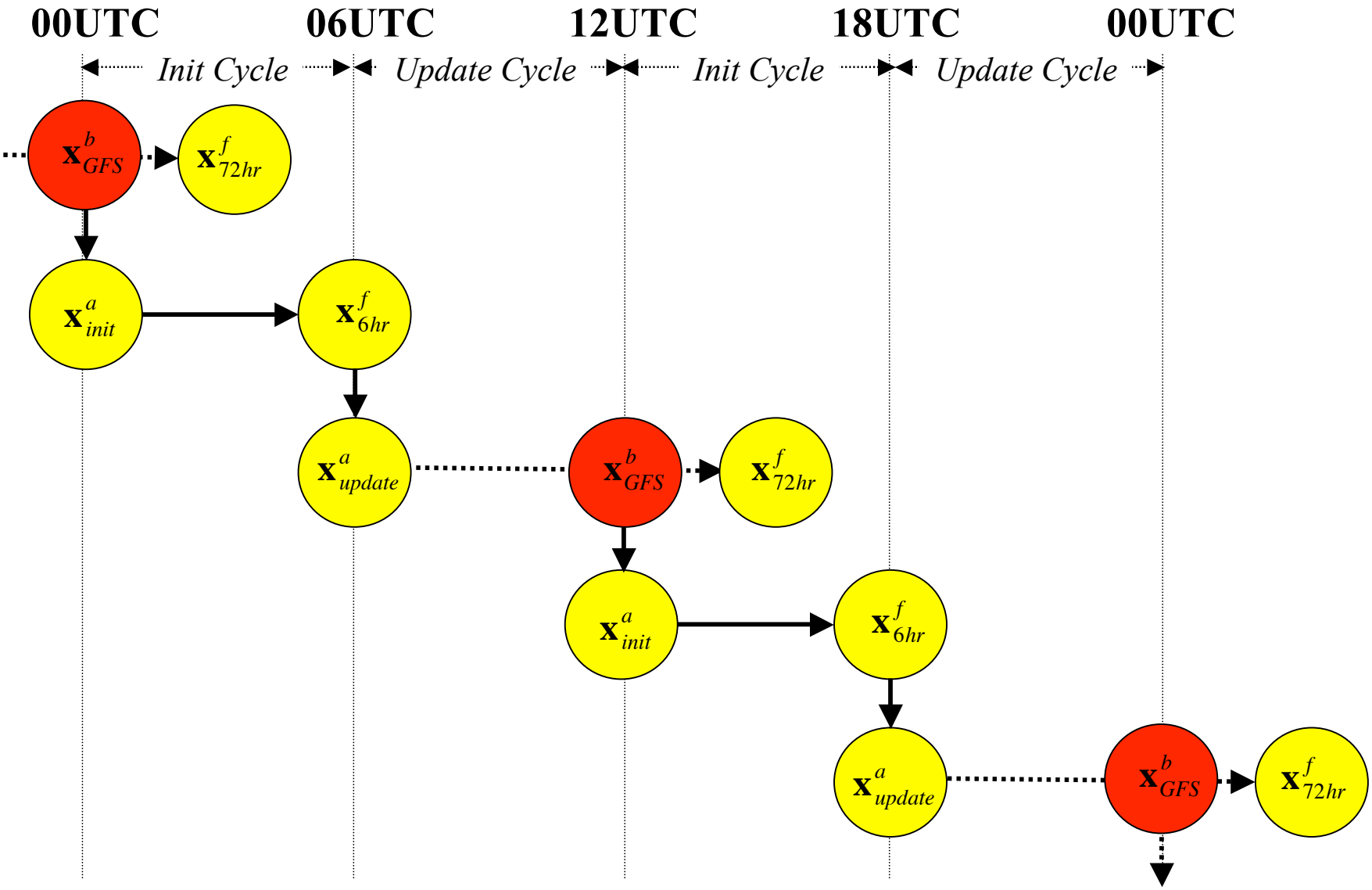


Clear Pixel



DATC AFWA Testbed (Update/Init)

Goal of DATC Testbeds is to provide an "operational-like" environment for researchers to test new capabilities of interest to sponsors, e.g. AFWA.



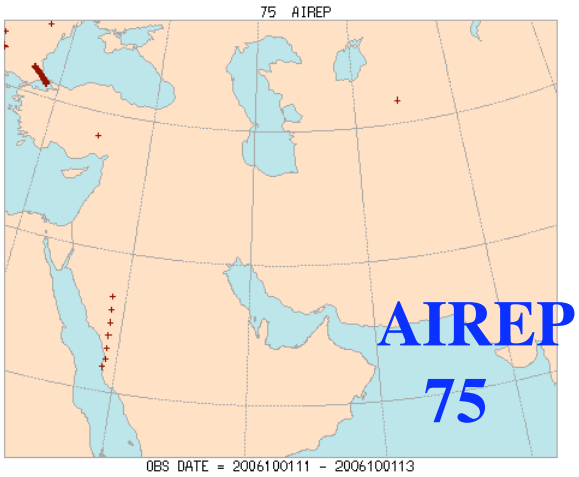
Global Radiance Data For October 2006

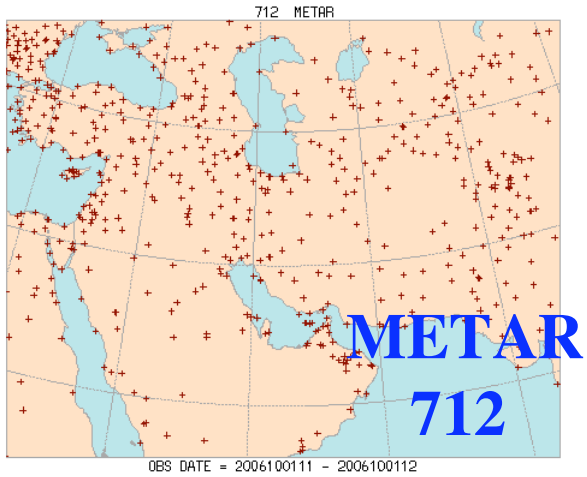
- WRF-Var ingests global BUFR radiance files.

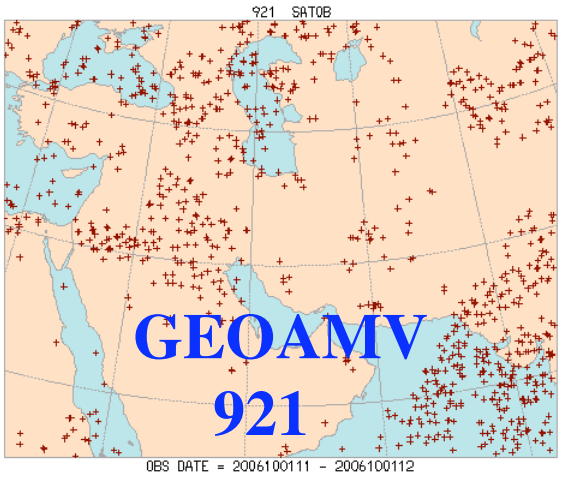
- Initial sensors studied: (Total: 12 from 5 satellites)
  - **HIRS** from NOAA16~18 (3)
  - **AMSU-A** from NOAA15,16,18, Aqua (4)
  - **AMSU-B** from NOAA15~17 (3)
  - **MHS** from NOAA18 (1)
  - **AIRS** from EOS-Aqua (1)

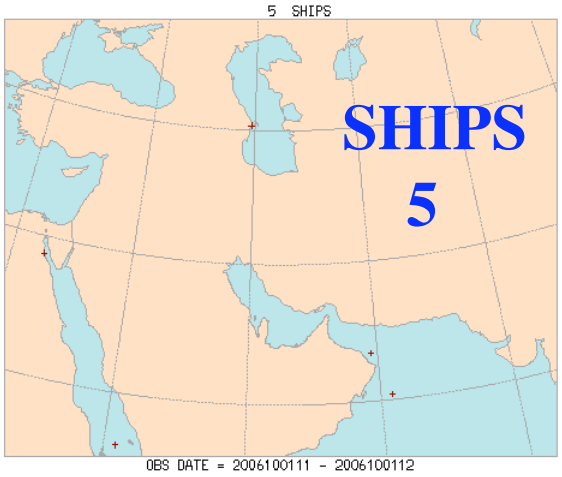
- AFWA producing BUFR radiance data locally.

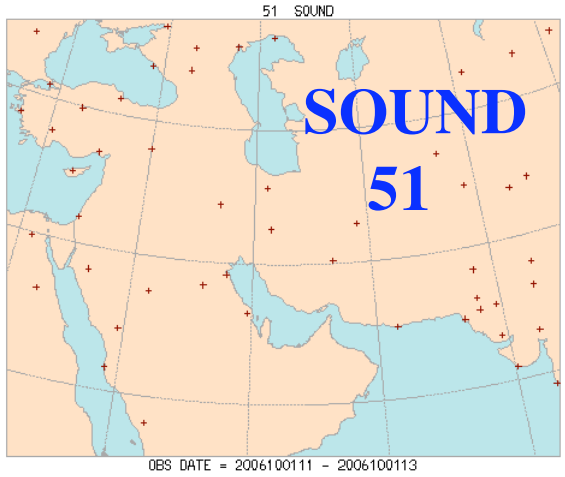
Conventional Data Coverage (2006100112)

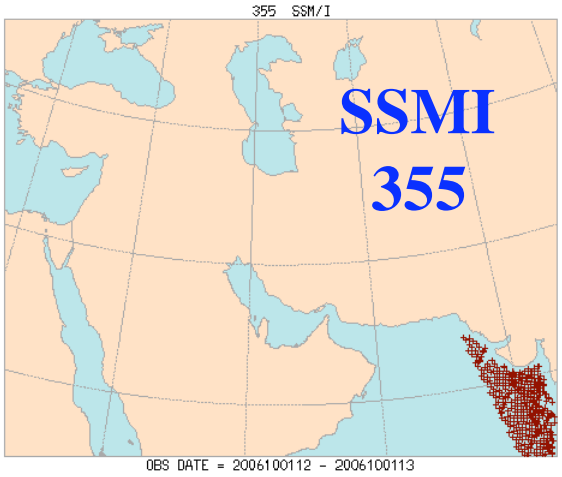




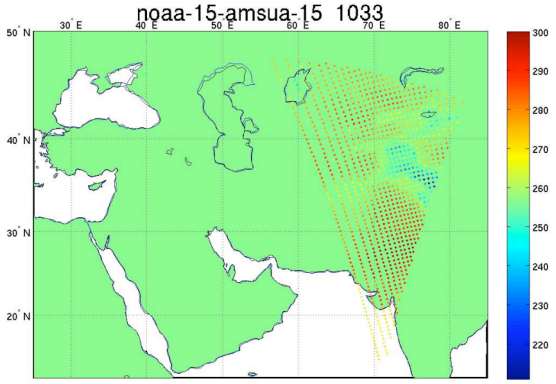


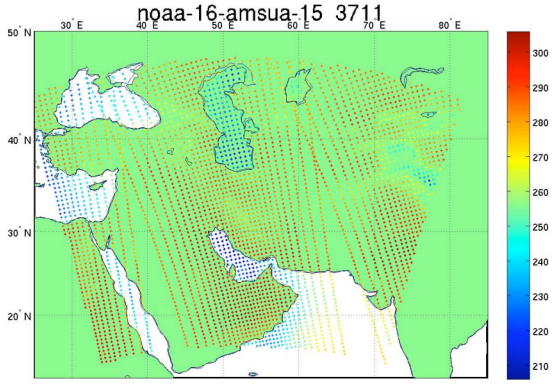


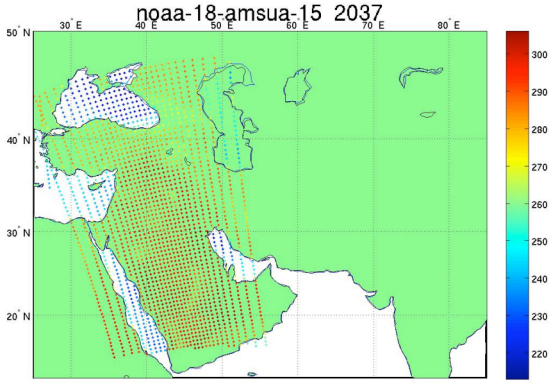


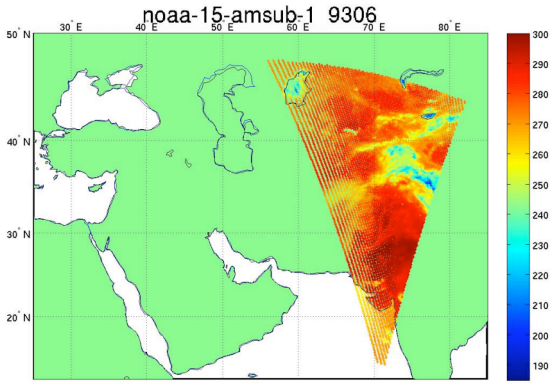


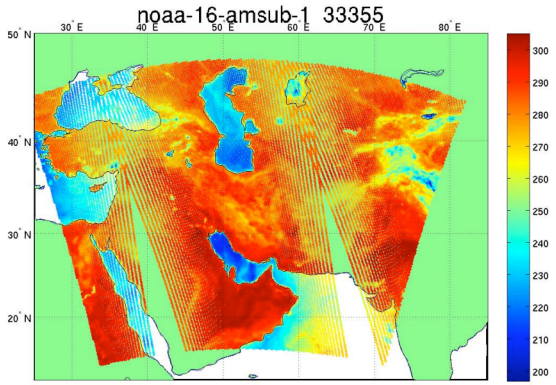
Radiance Data Coverage (2006100112)

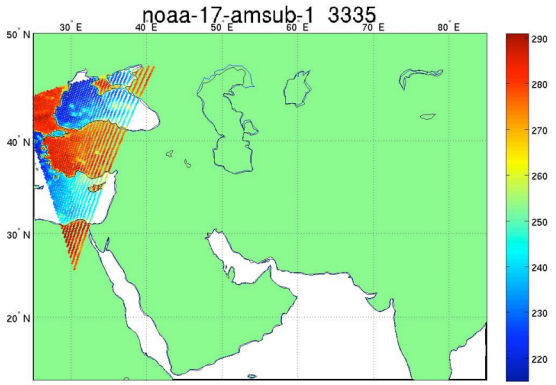


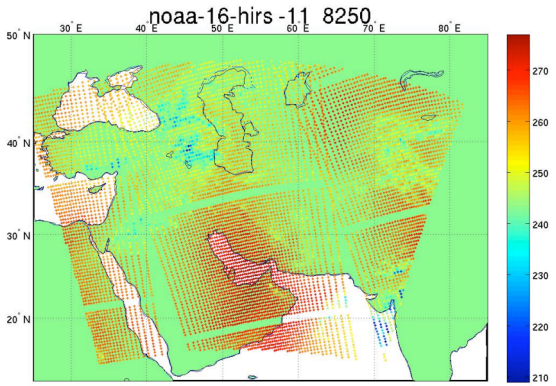


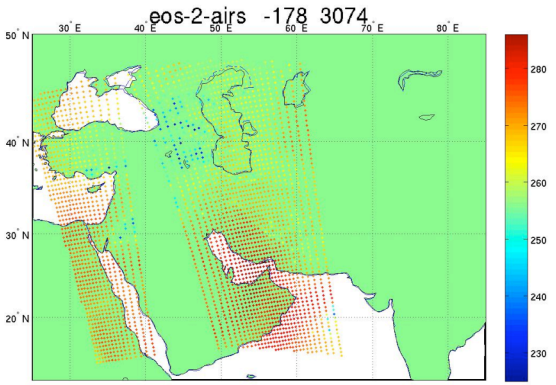


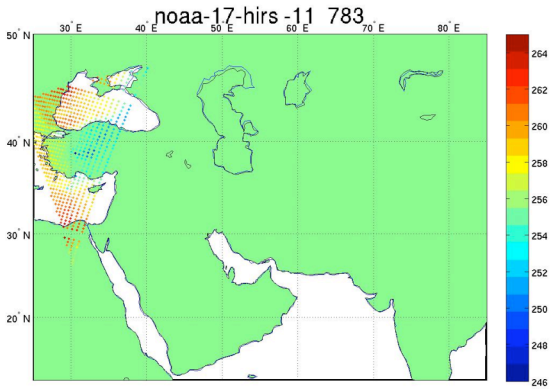






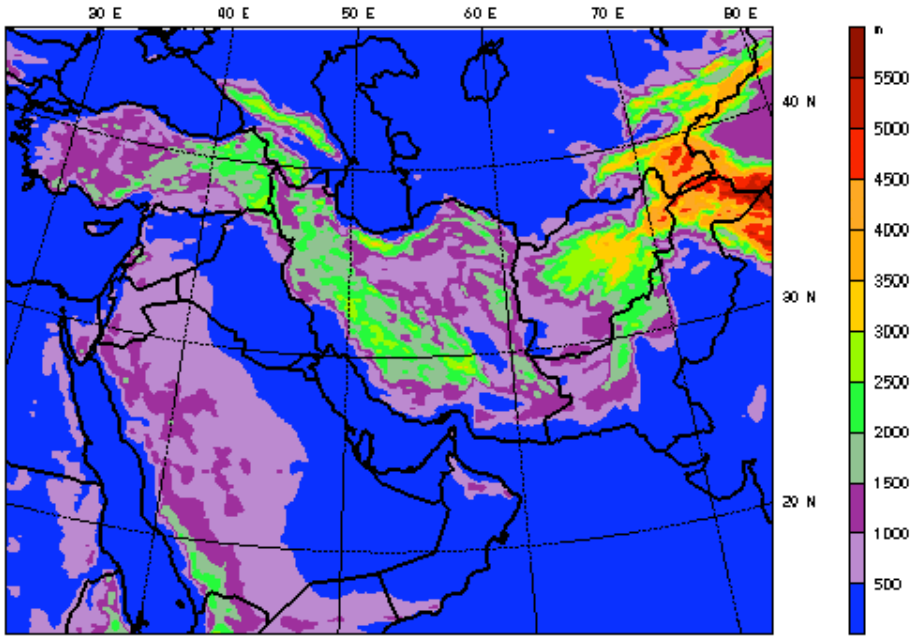




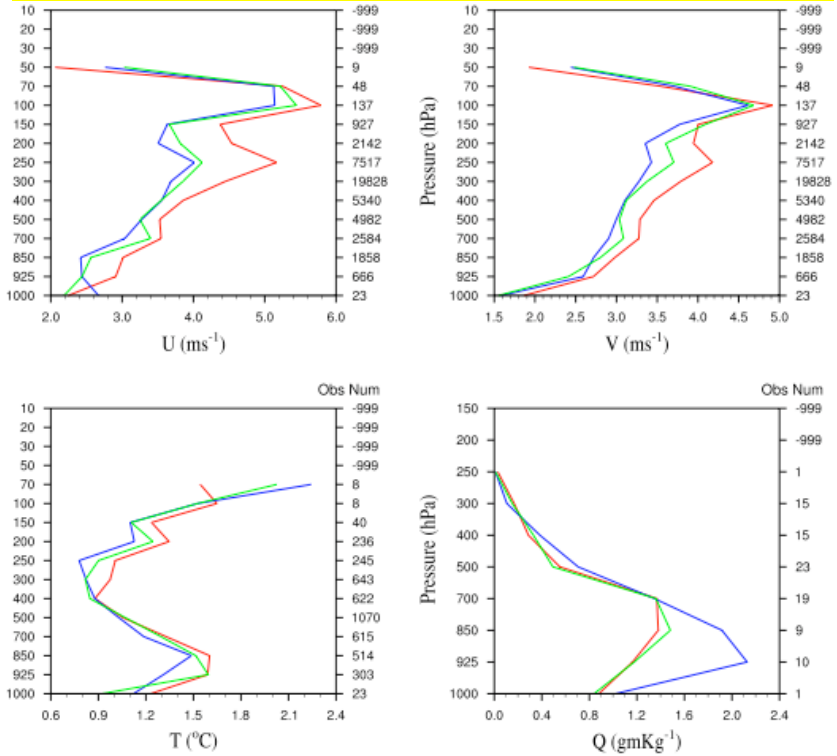


DATC AFWA Testbed: S. W. Asia (T4B Theater)

- Initial testbeds using October 2006 global data archived at NCEP (Jianjun Xu).
- Initial tests: Impact of DA configuration (noda, “update”-cycling, full-cycling)
- 2007 plans: AMSU/AIRS/4D-Var impact, expanded verification (with DTC).



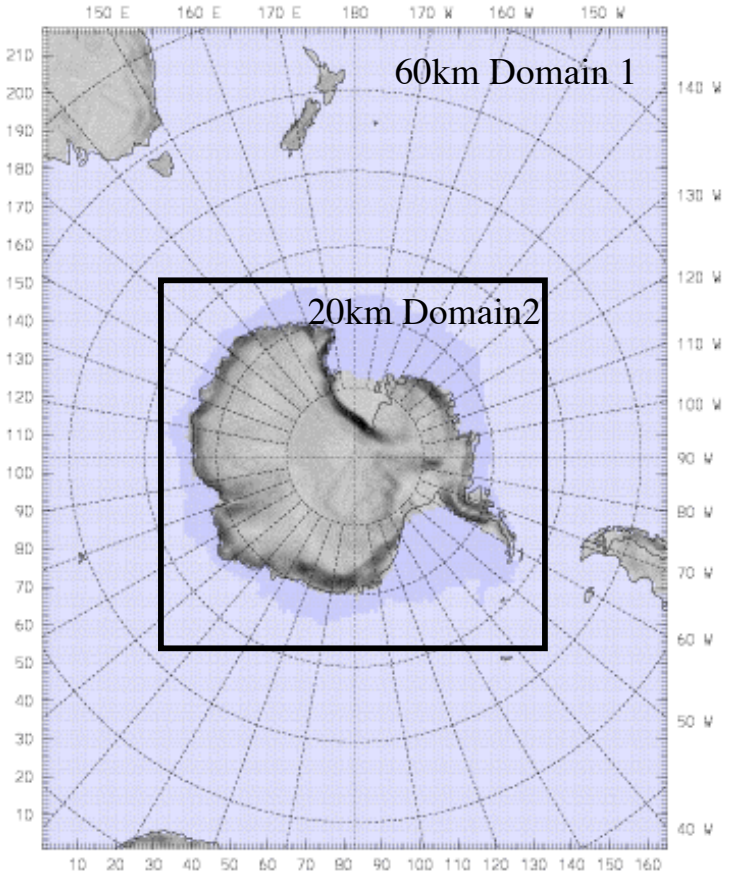
24hr Fcst Verif. Vs. Obs (Oct. 2006)

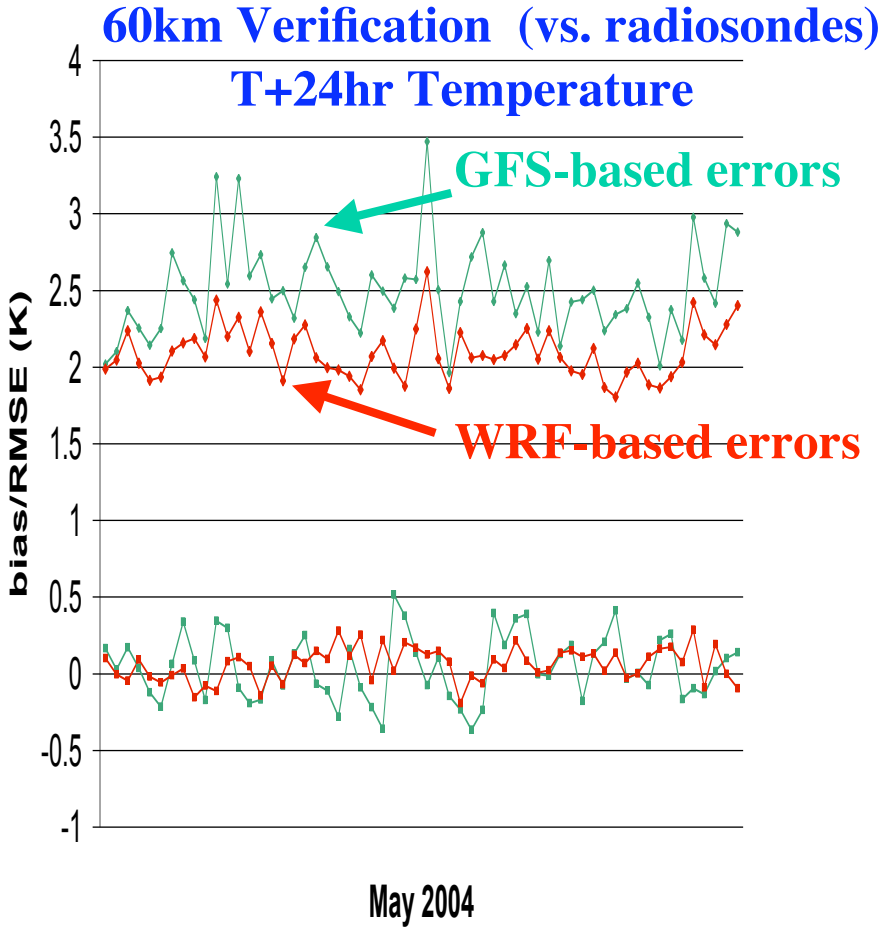


Preliminary Conclusion: Update-cycling best, but full-cycling results encouraging.

DATC Antarctica Testbed

- Part of a NSF-OPP/NASA-funded testbed for high-latitude DA studies.
- Testing DA within real-time Antarctic Mesoscale Prediction System (AMPS).
- Initial studies: Full-cycling, polar error covariances, COSMIC.

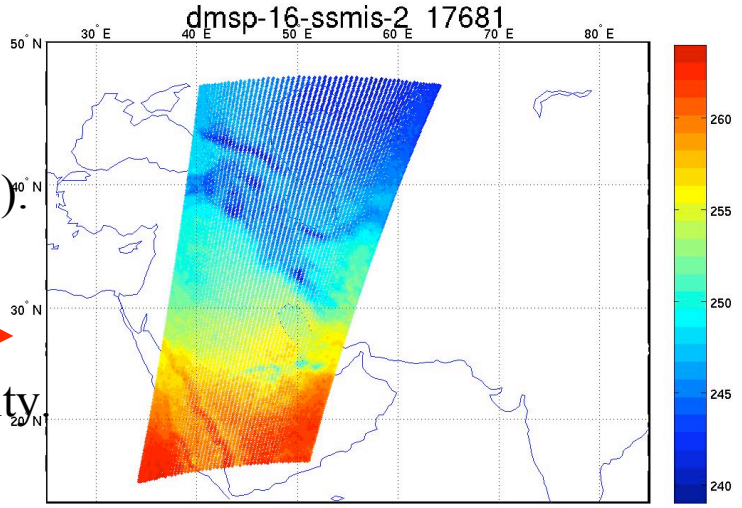




NCAR/AFWA DA Program Plans

General Goals:

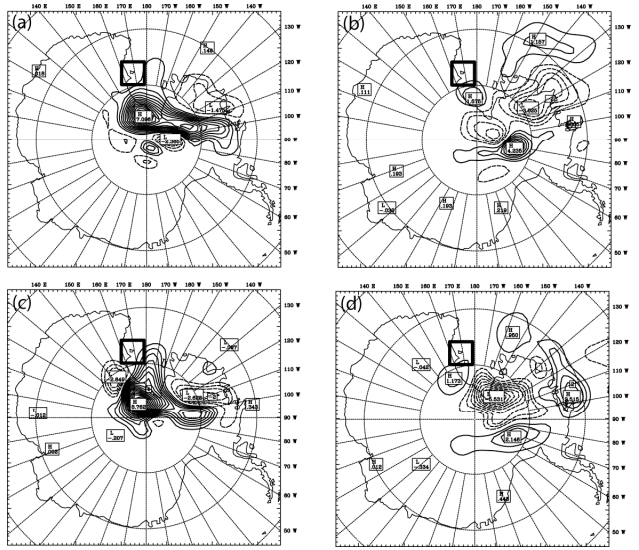
- Research: Focus on very high-resolution (1-10km).
- Development: Unified DA system (3/4D-Var, EnKF).
- Community Model: Flexibility is a key requirement.
- Leverage international WRF community efforts.
- Work with JCSDA to eliminate **unnecessary** diversity.



LAS: 52.8GHz,V,38*38,SSM/T1-2,800mb

WRF-Var Development (MMM Division):

- 4D-Var (physics, optimization).
- Adjoint Sensitivities.
- EnKF within WRF-Var.
- Instrument-specific radiance QC, bias correction.

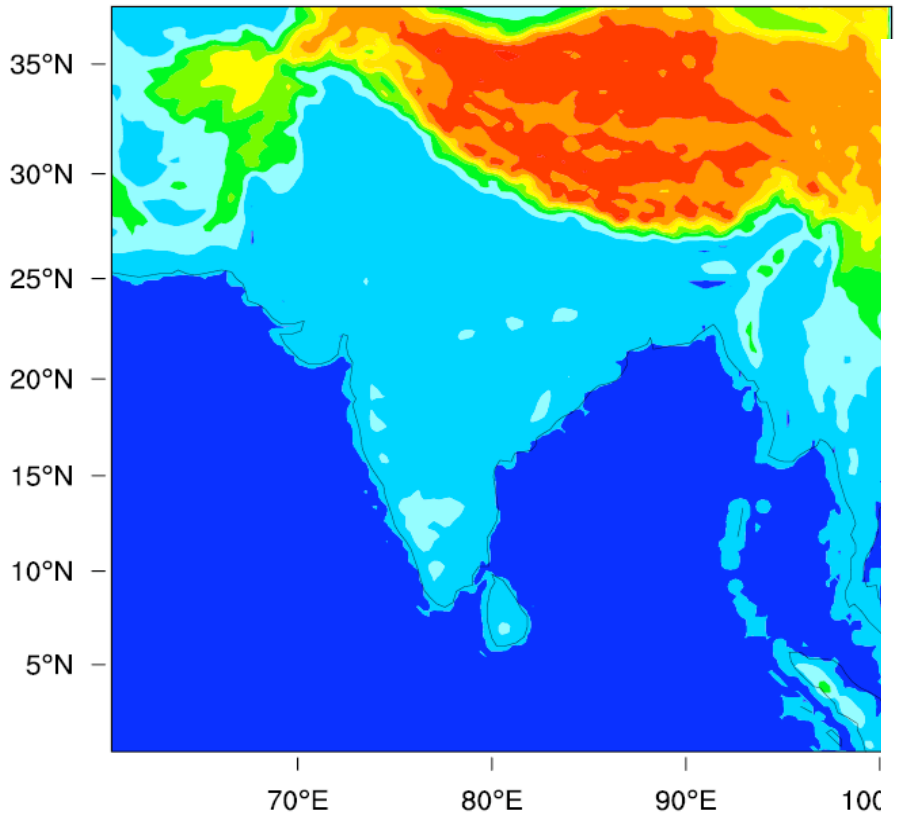


Data Assimilation Extended-Period Testing (DATC):

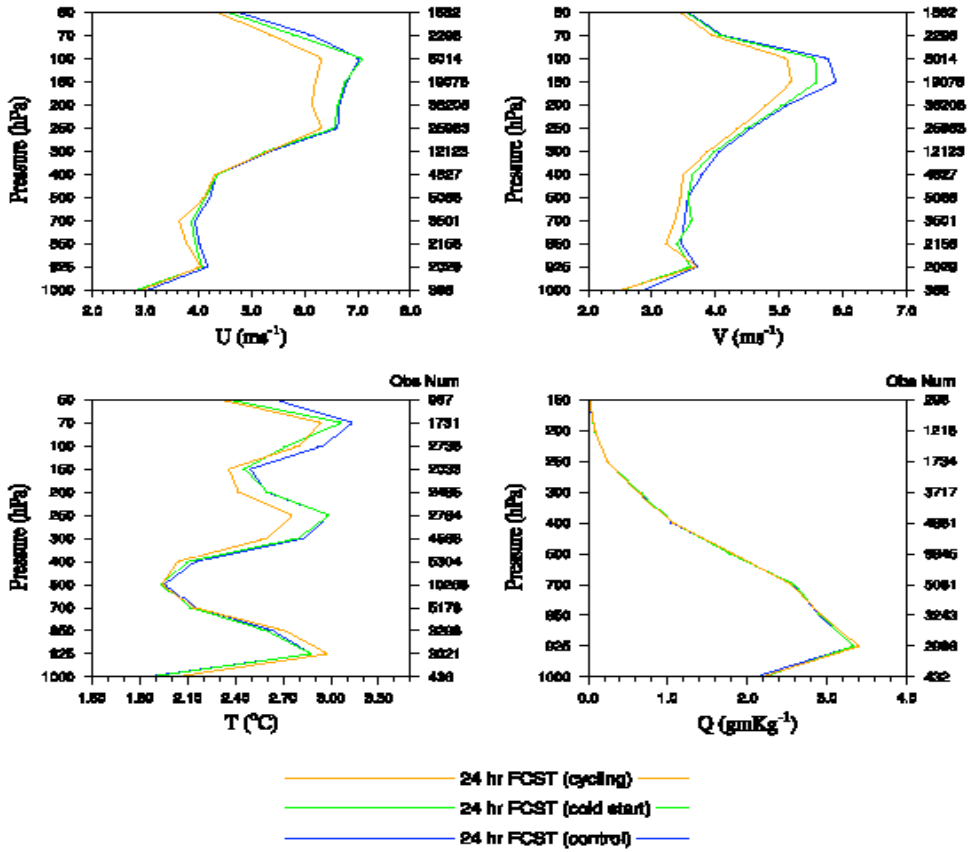
- Technique intercomparison: 3/4D-Var, EnKF, Hybrid
- System studies: WRF-Var, GSI, DART.
- Obs. impact: AMSU, AIRS, COSMIC, SSMI/S.
- New Regional testbeds: Korea, India, JME, CONUS.

DATC India Testbed

- Community-funded testbed for tropical DA studies.
- 3 long-term visitors from India to NCAR in 2006-2007.
- Permits leveraging for e.g. AFWA's India/Pakistan theater.



24hr Fcst Verif. Vs. Obs (Aug. 2005)



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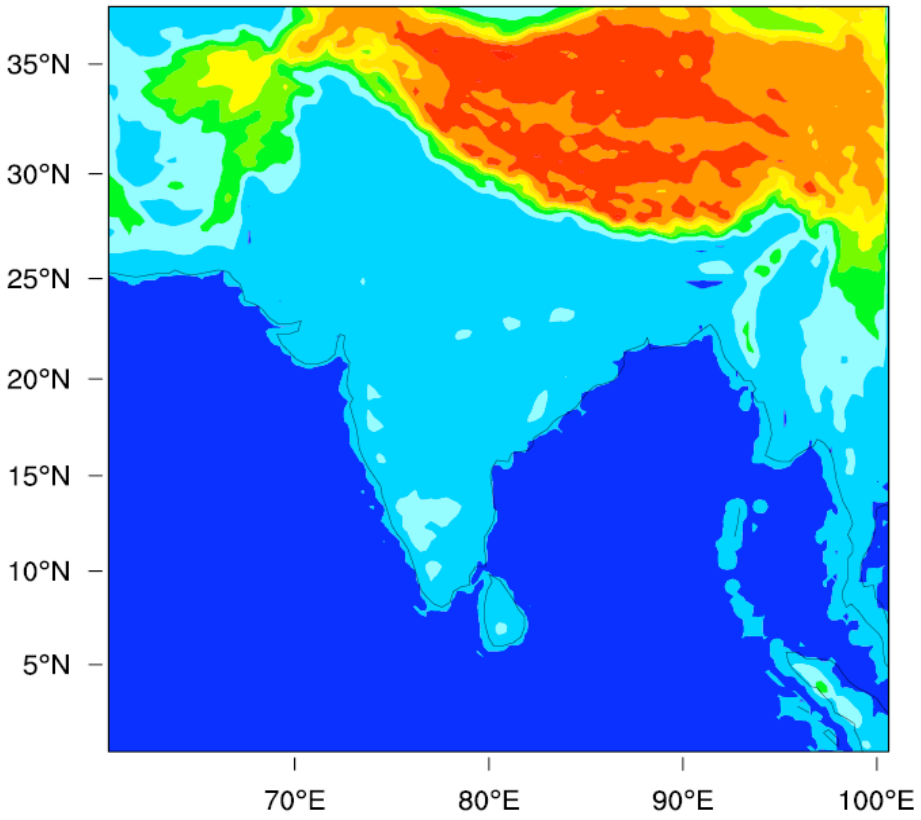

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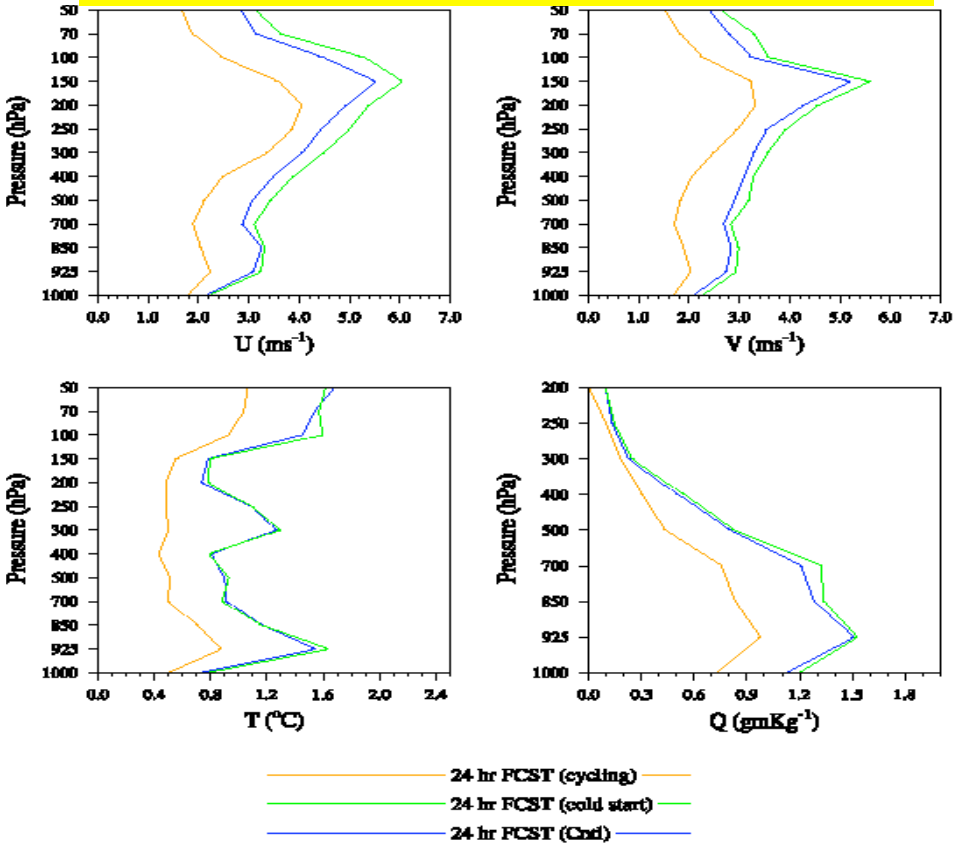

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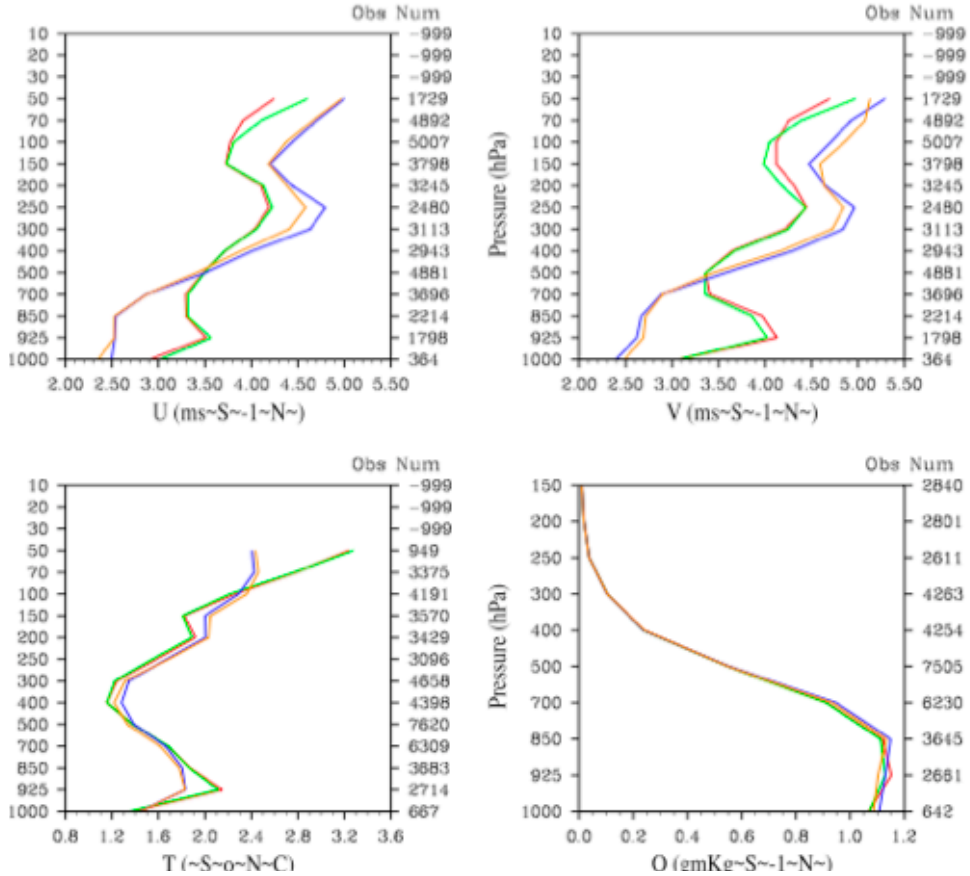
12hr Fcst Verif. Vs. Obs (Oct. 2006)

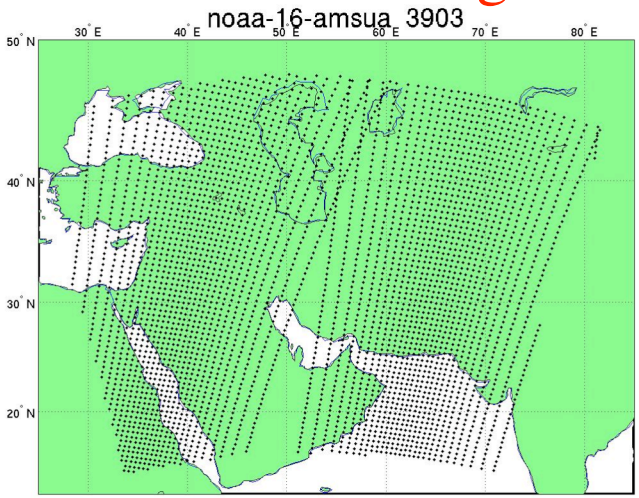


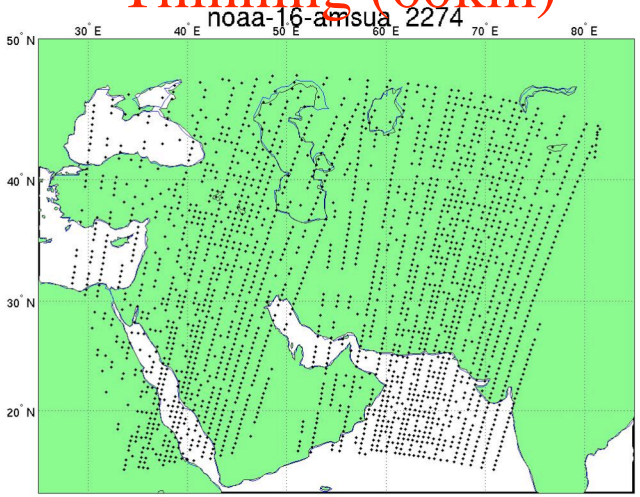
Impact of Thinning in WRF-Var

NO Thinning

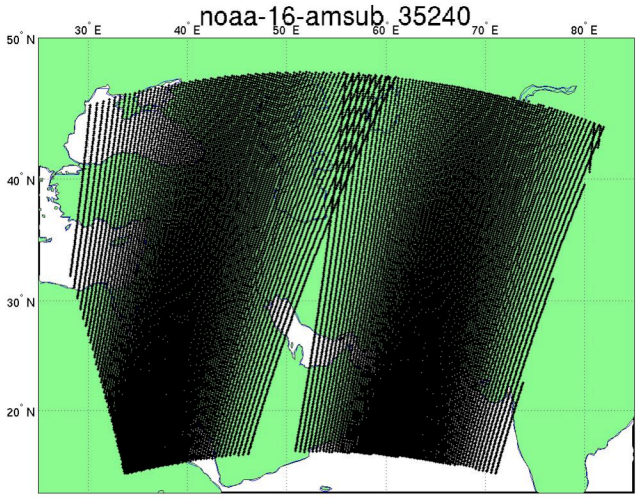
Thinning (60km)

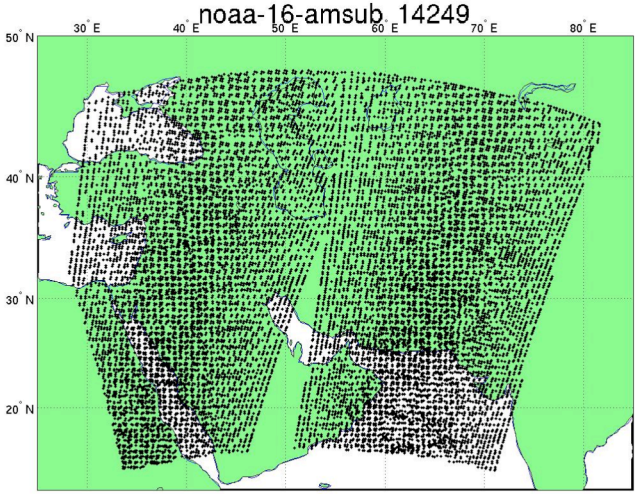
AMSU-A





AMSU-B





Courtesy of Zhiquan Liu (NCAR), Jianjun Xu (JCSDA)

Included in WRF-Var (r2522) delivered to AFWA this month

Hybrid Variational/Ensemble Data Assimilation

- Hybrid 3/4D-Var analysis increments updated in minimization by

$$\delta \mathbf{x}_0 = \delta \mathbf{x}_{0d} + \delta \mathbf{X}_f \bullet \mathbf{a}$$

- Flow-dependence is constrained by an additional cost-function $J_{\alpha,}$ i.e.

$$J = \frac{W_b}{2} \delta \mathbf{x}_0{}^T \mathbf{B}_o^{-1} \delta \mathbf{x}_0 + \boxed{\frac{W_\alpha}{2} \mathbf{a}^T \mathbf{A}^{-1} \mathbf{a}} + \frac{1}{2} \sum_{i=0}^{n} \left[\mathbf{H}_i \delta \mathbf{x}(t_i) - \mathbf{d}_i \right]^T \mathbf{R}_i^{-1} \left[\mathbf{H}_i \delta \mathbf{x}(t_i) - \mathbf{d}_i \right]$$

- W_b and W_α are weights of climatological/flow-dependent errors in hybrid.

- Forecast error variance conservation:

$$\frac{1}{W_b} + \frac{1}{W_\alpha / \sigma_\alpha^2} = 1$$

- Define empirical alpha covariance matrix

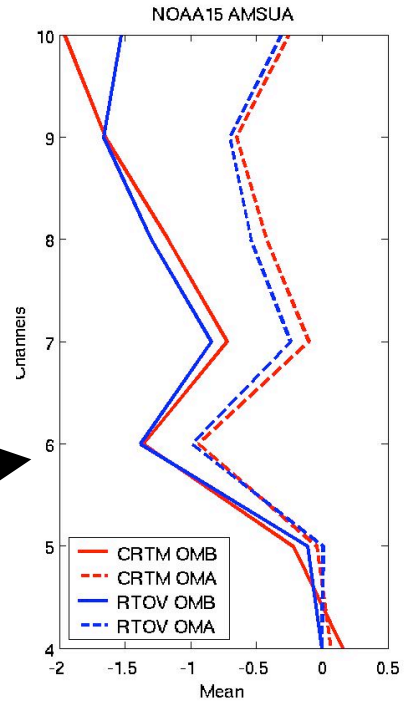
$$\mathbf{A} = \sigma_\alpha^2 \mathbf{A}_c$$

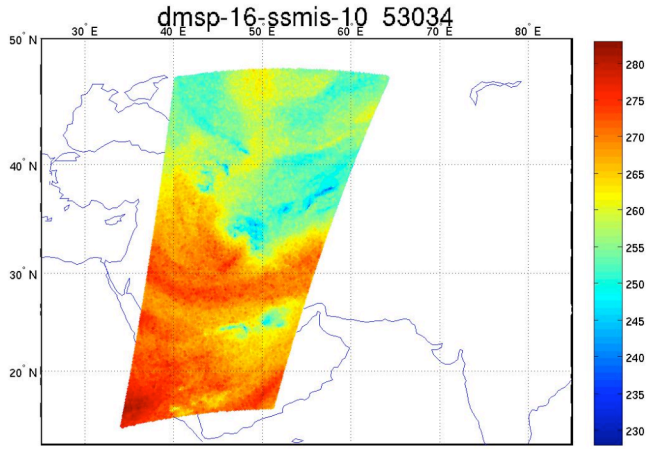
WRF-Var Interactions With JCSDA

- Exchange of visitors:
  - Dale Barker (NCAR) -> JCSDA (July 2004).
  - Jianjun Xu (AFWA/JCSDA) -> NCAR (2*2006, 2007).
  - Zhiquan Liu (NCAR) -> JCSDA (Nov. 2006).

- Development and testing:
  - Use of CRTM in WRF-Var (NCAR, NESDIS).
  - Radiance bias correction (NCAR, AFWA, CSU)
  - Intercomparison of WRF-Var, GSI (NCAR, AFWA).
  - SSMI/S Evaluation (NCAR, AFWA).
  - COSMIC testing (NCAR, NCEP).

- Scientific Meetings:
  - GPS (COSMIC) Workshops (Boulder, D.C.).
  - JCSDA Invited Seminars (Barker, Huang).
  - JCSDA Science Meeting (1-2 May 2007).

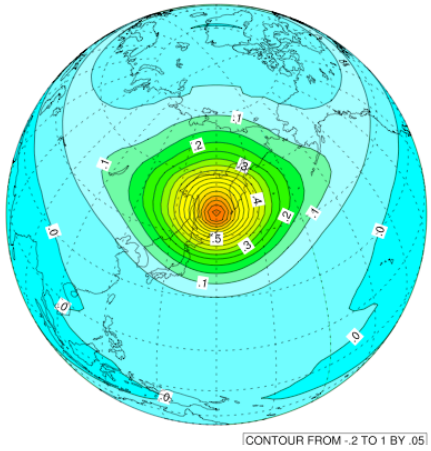




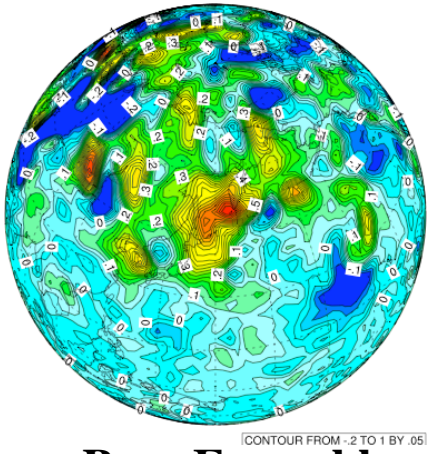
Hybrid DA (Global) Single Observation Test

- Temperature observation (O-B, σ_o=1K) at 50N, 150E, 500hPa.
- Worst case scenario: Ensemble size *N*=1 (taken from KMA's error breeding system).

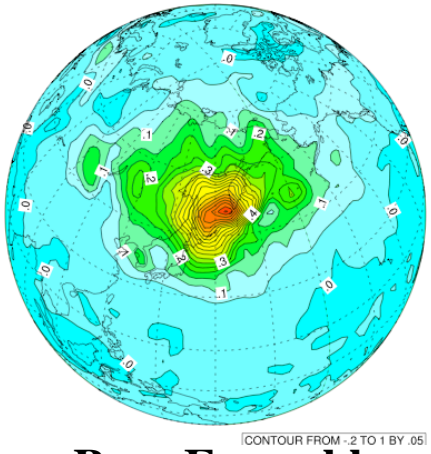
T increment



Pure 3D-Var

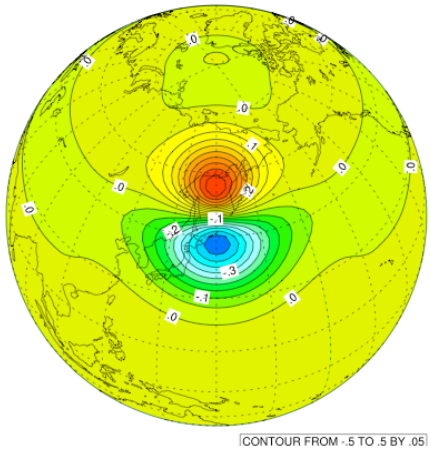


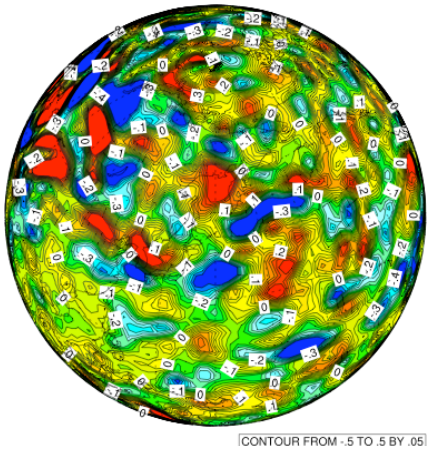
Pure Ensemble, No Localization

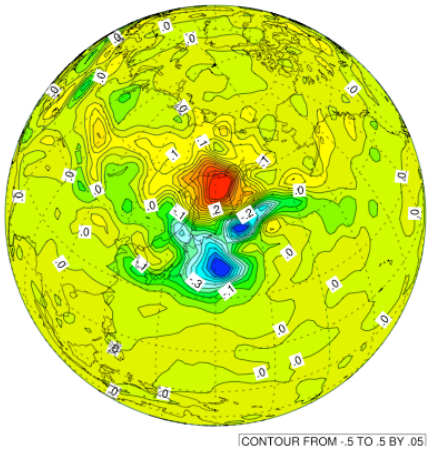


Pure Ensemble, With Localization

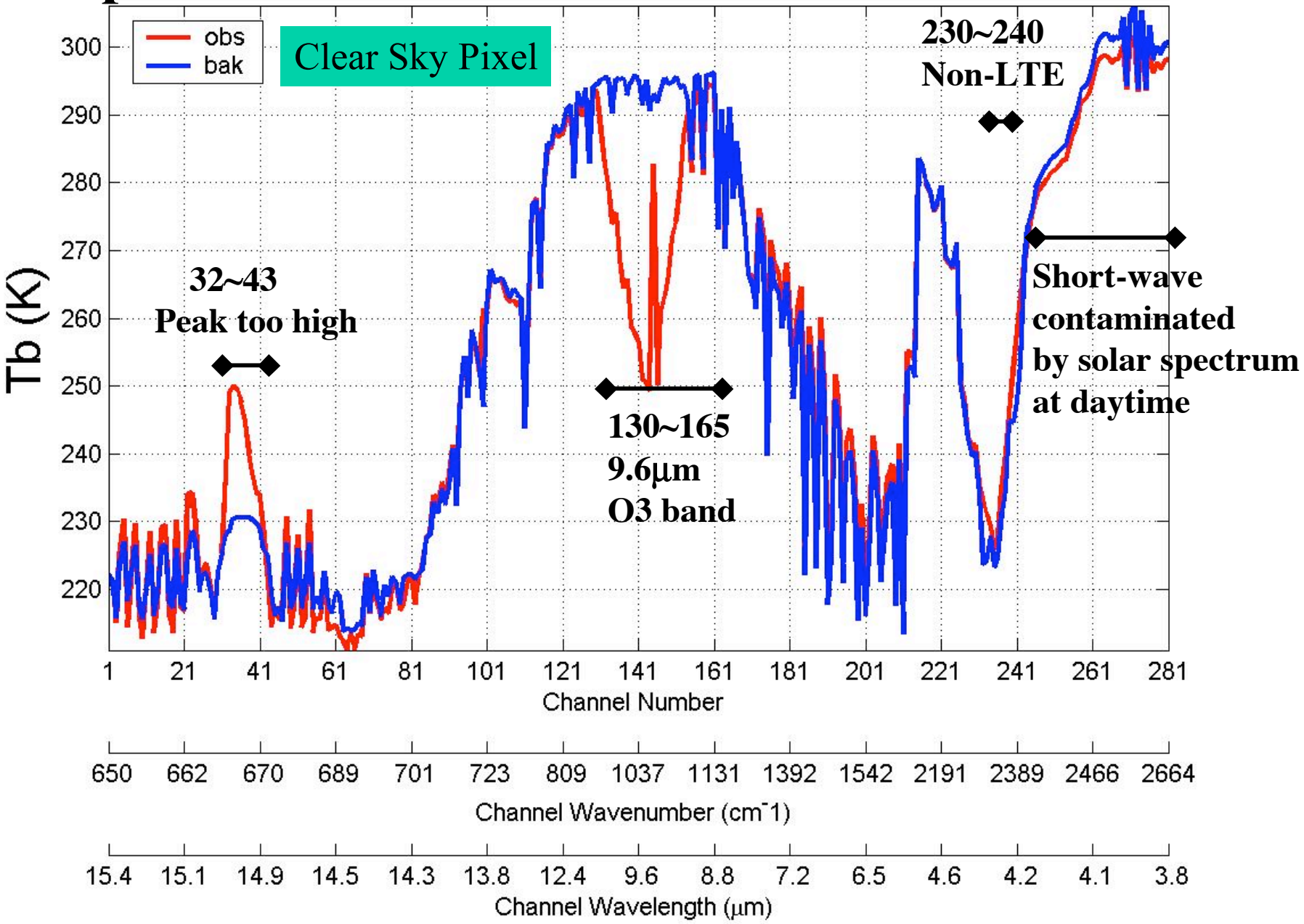
u increment







Comparison of AIRS Observed/Calculated B. T.



Current AIRS QC

- Ocean pixels only
- Cloud detection
  - Long-wave window channel 10.6 μm
    - Reject pixel if Tb(129) < 271K
  - Short-wave near IR channel 3.8 μm
    - Reject channels 257~281 if Tb(272) > 307K (to avoid impact of Solar contamination)
    - Reject Pixel if Tb(272)<307K and abs[SST-Tb(272)] > 2K
- Innovation max difference 15K
- Innovation not larger than 3*obs_error