WRF-Var: Current And Planned Capabilities

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National Center For Atmospheric Research

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Acknowledge:
NCAR Staff, NSF, NASA, JCSDA, EUMETSAT,
US Air Force Weather Agency, Korean Meteorological Administration,
Taiwanese Central Weather Bureau, Civil Aeronautics Administration,
Beijing Meteorological Bureau,
Indian Met. Dept., National Center for Medium-Range Weather Prediction.

WRF-Var Data Assimilation Overview

- **Techniques:** 3D-Var, 4D-Var (regional), Hybrid Variational/Ensemble DA.

- **Software Engineering:** WRF framework.

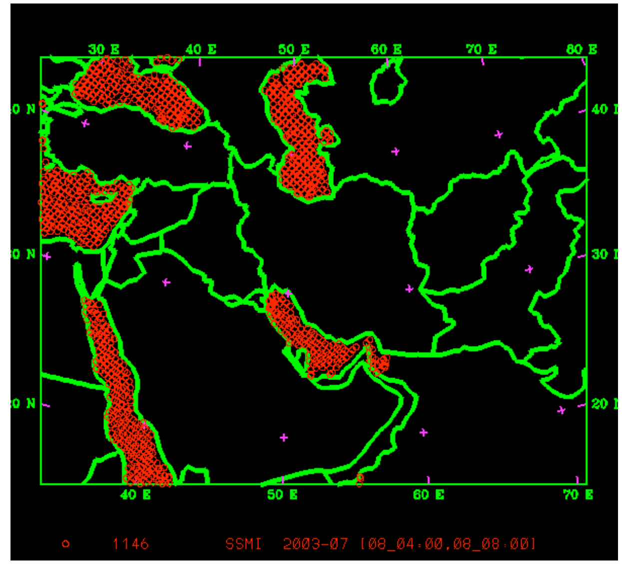
- **Multiple Models:** Runs with WRF, MM5, KMA global model, etc.

- **Domains:** Regional/global.

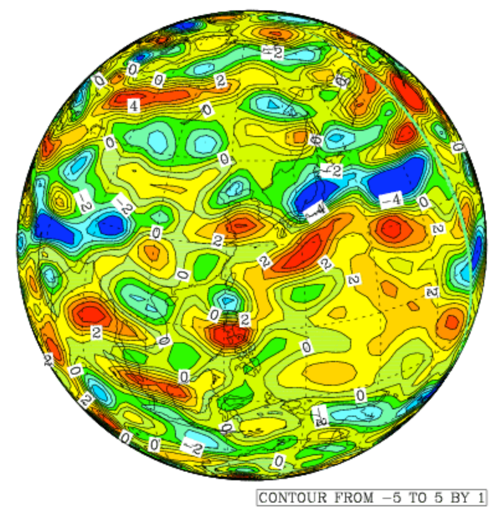
- **Applications:** Worldwide (AFWA), US, Korea, Taiwan, India, China (BMB), Israel, Antarctica, ….

blue = challenging areas for unification

AFWA 15km S-W Asia:

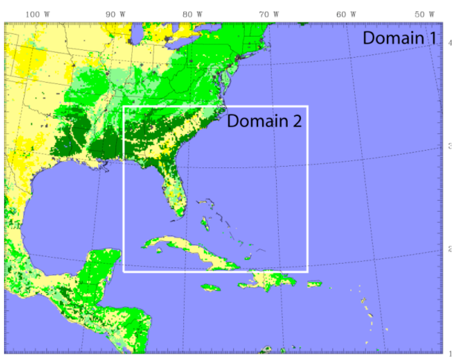


KMA T213 Global:

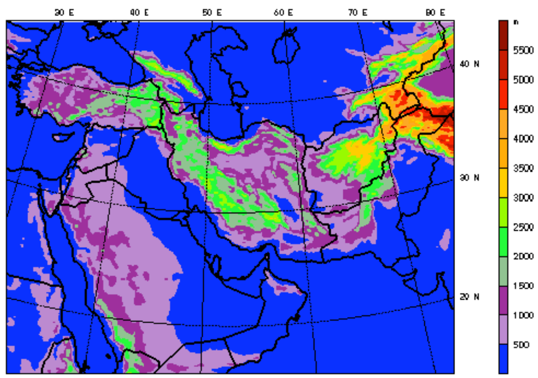


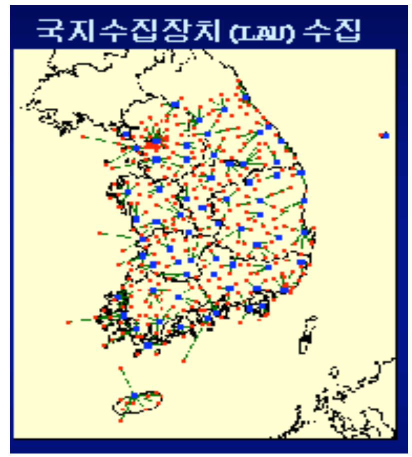
WRF-Var Resources

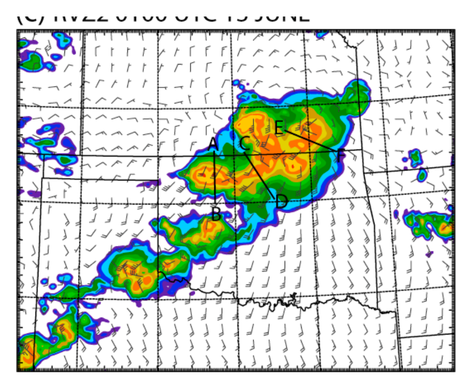
- NCAR staff: 23FTE, ~12 projects.
- Non-NCAR collaborators (AFWA, KMA, etc): ~10FTE.
- Community users: ~30 (more in 4000 general WRF downloads?).

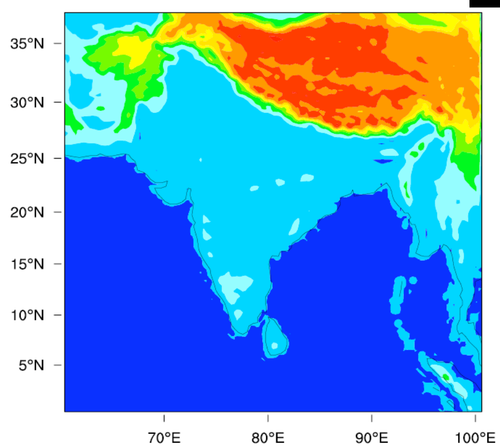


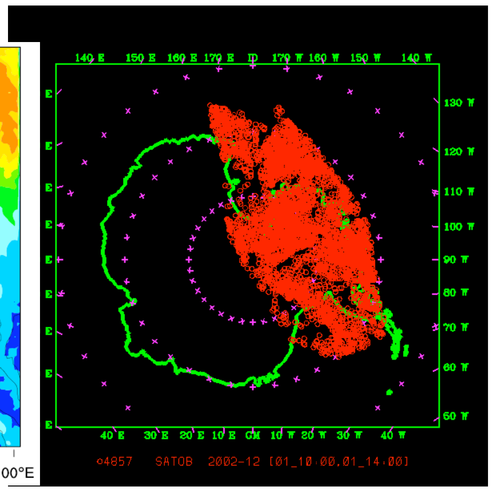
Domain1: 12km, 400X301X35
Domain 2: 4 km, 502X451X35

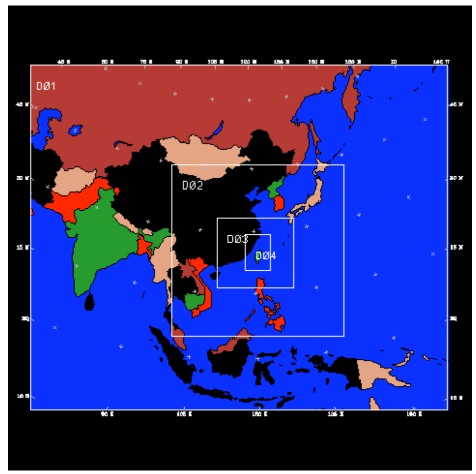


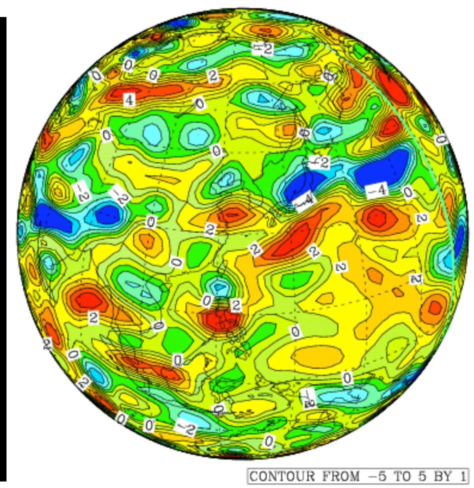






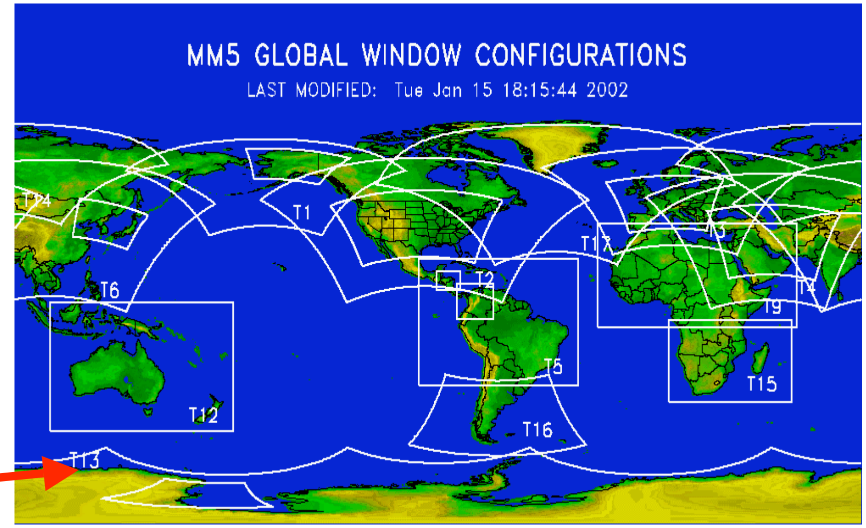


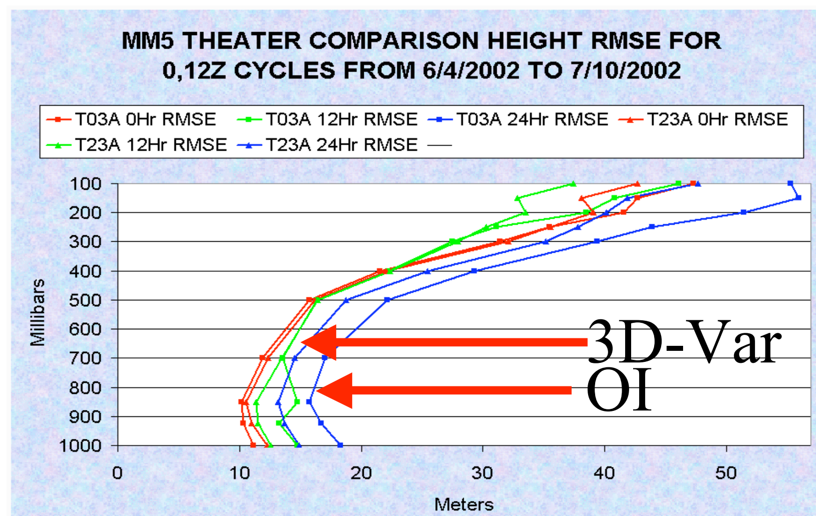




WRF Variational Data Assimilation (WRF-Var) History

- **June 2001:** MM5-3DVar adopted as starting point for WRF 3D-Var.
- **May 2002:** MM5/WRF 3D-Var operational in Taiwan.
- **September 2002:** MM5/WRF 3D-Var operational in 45km domains at AFWA.
- **June 2003:** First public release of WRF-Var.
- **July 2006:** WRF-Var/ARW operational in AFWA 15km domains.
- **May 2007:** WRF-Var/ARW operational in Korea 10km domain
- **Summer 2007:** Next release of WRF-Var?

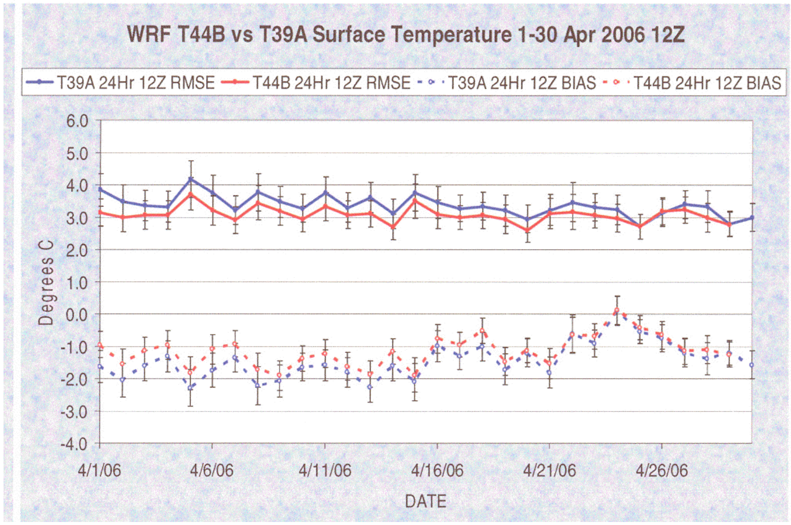




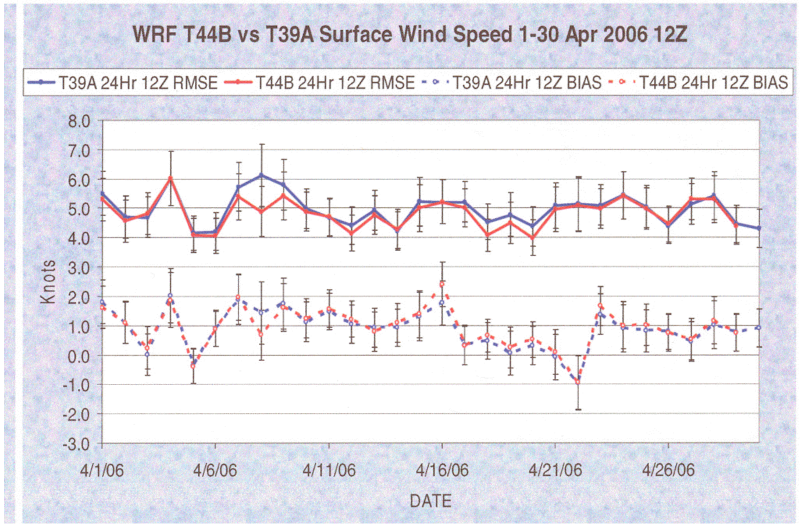
Impact of Tuned WRF-Var Forecast Errors for AFWA (S. W. Asia domain)

- 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.



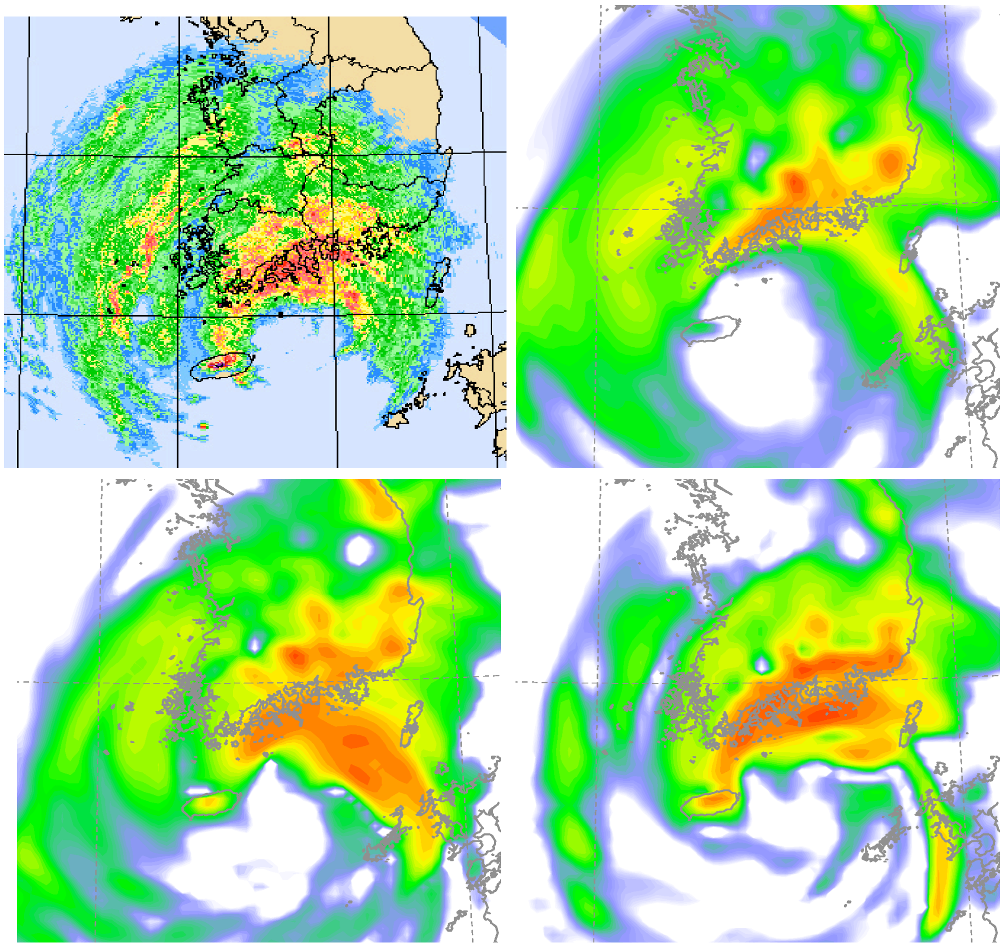
Blue = WRF BE stats (1st version, fcsts from GFS)

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

Korean Radar Data Assimilation in WRF-Var

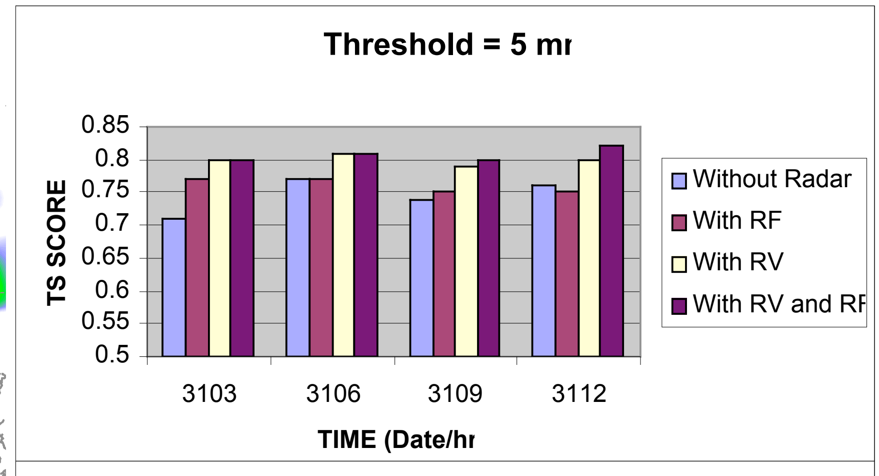
Typhoon Rusa Test Case 3hr Precip:

Obs (03Z, 31/08) No Radar



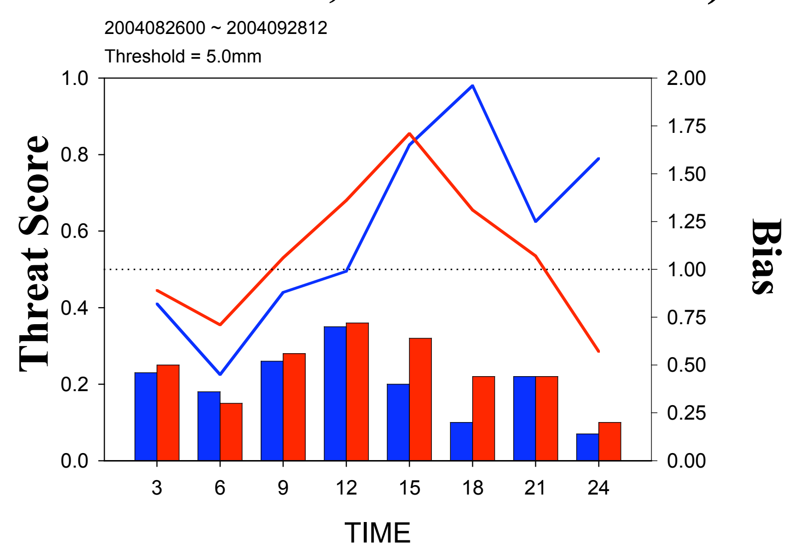
Radar RV Radar RV+RF

Typhoon Rusa 3hr Precip. Verification:



KMA Pre-operational Verification:

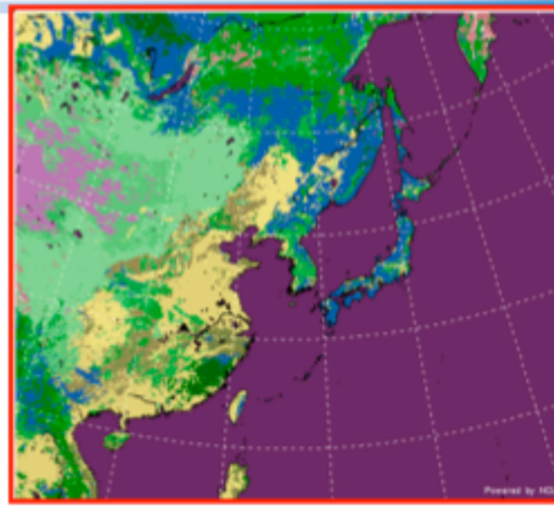
(no radar: blue, with radar: red)



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

KMA

WRF configuration

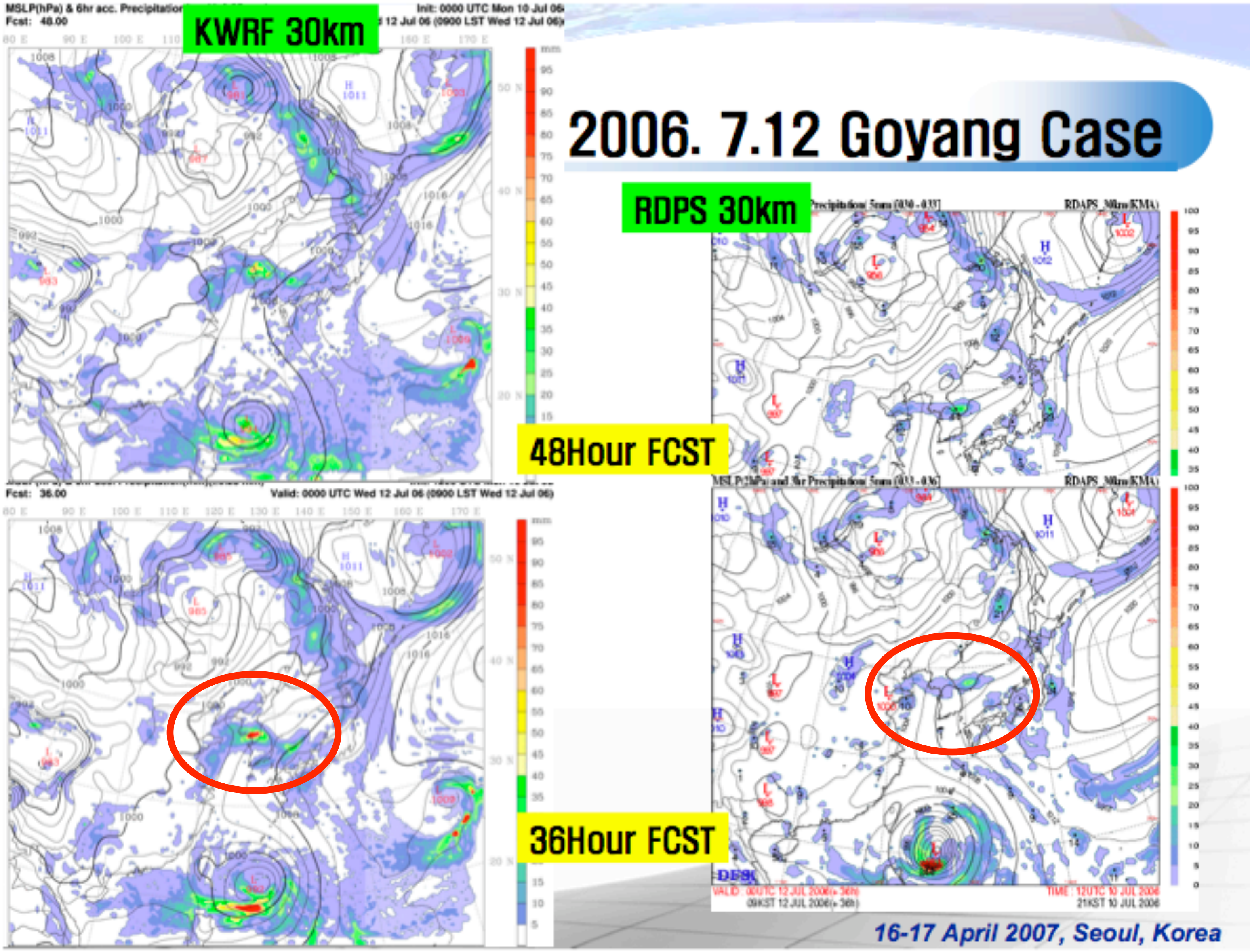


- WRF Version 2.1.2
- WRFSI
- KWRF 10km(574x514x31)
- 48 Hours forecast
- U3VR 6 hour cycle
- DFI

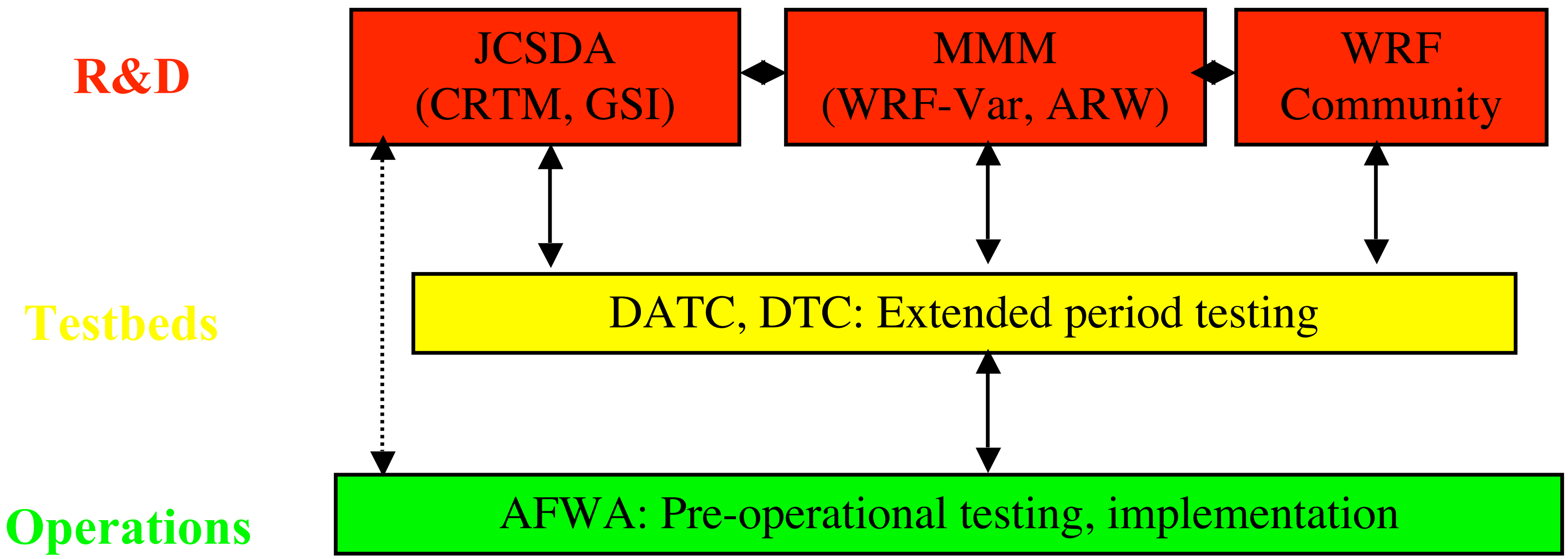
Model Physics

	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

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



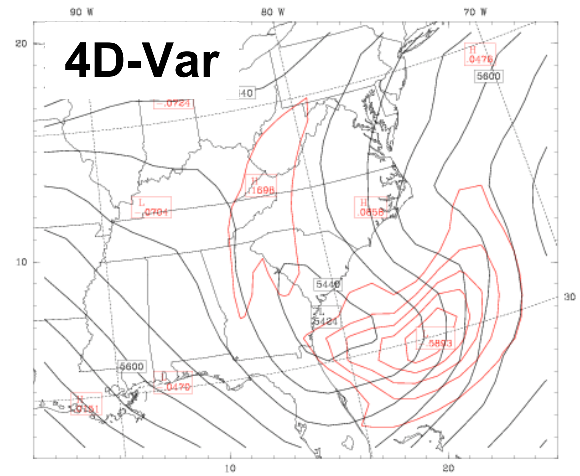
NCAR/AFWA DA Program Overview



- 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 provided e.g. initial radiance (RTTOVS), radar capabilities.
- Data Assimilation Testbed Center (DATC) responsible for pre-release testing.

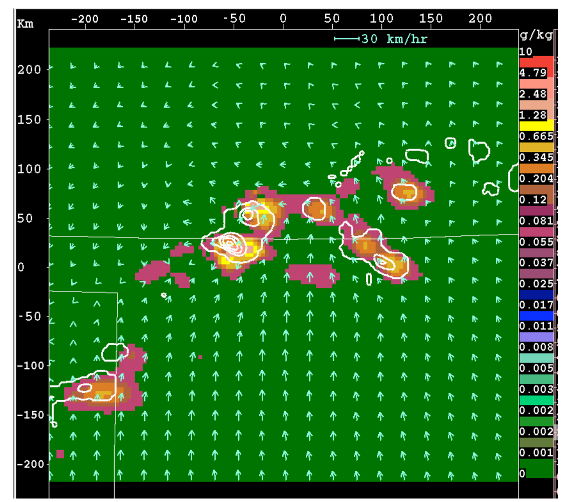
4D-Var Summary

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



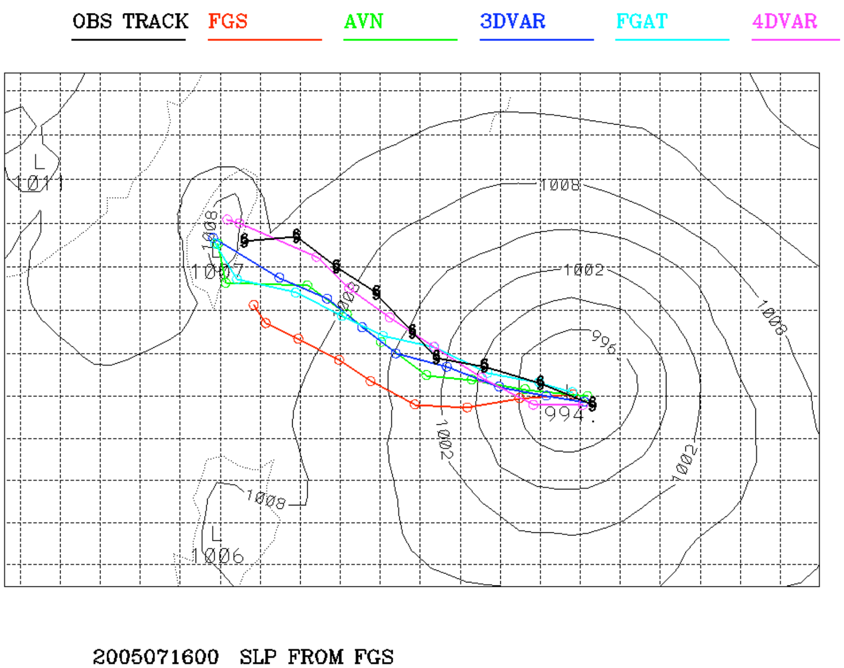
2. Formulation: Built within WRF-Var, using ARW core.

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



Typhoon Haitang 3/4D-Var Study

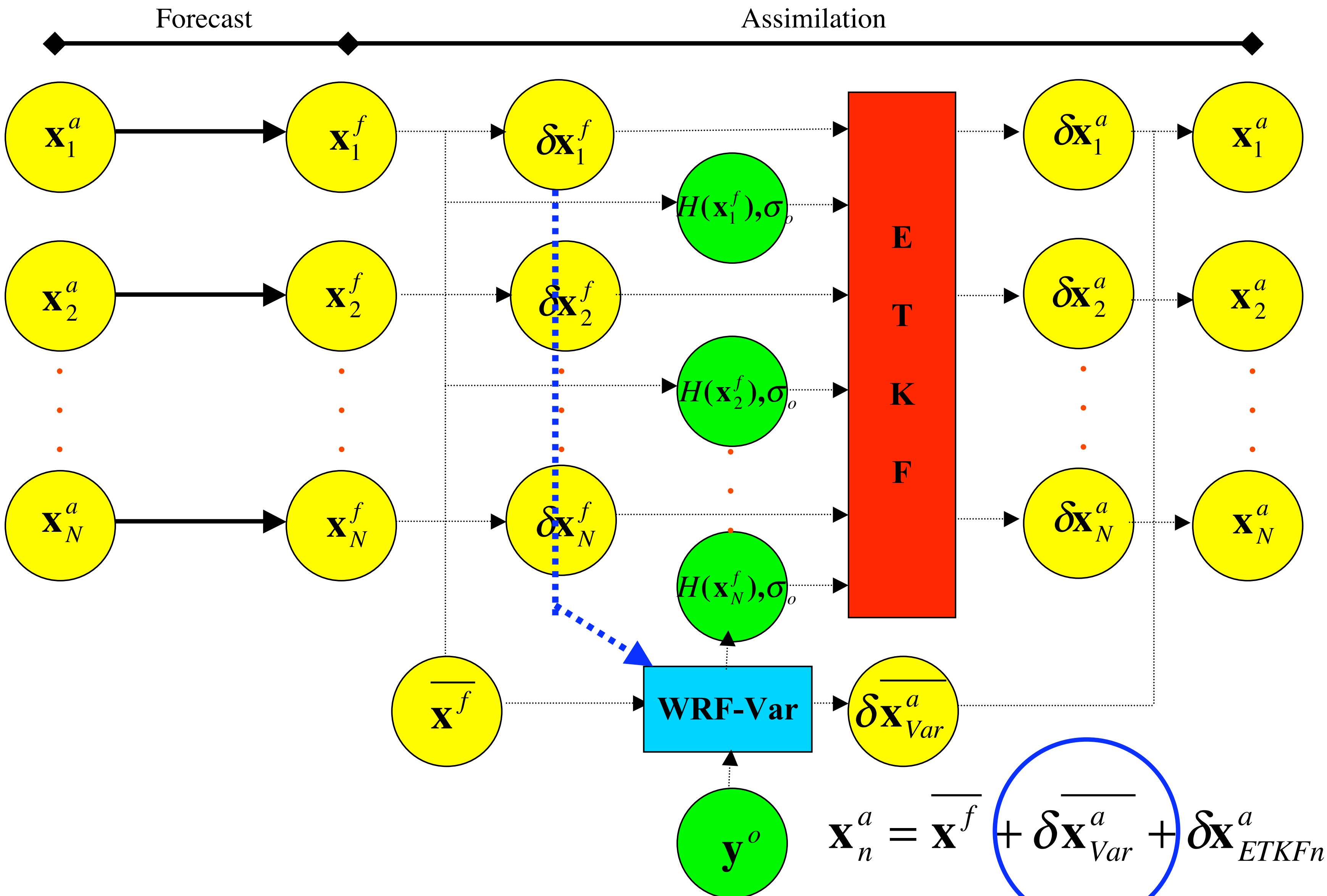
- Domain configuration: 91x73x17, 45km
- Observations from Taiwan CWB operational database.
- Experiments are conducted before Haitang's landfall at 0000 UTC 18 July 2005.



Track Error

Time	FGS	AVN	3DREF	4DREF
1512	84	82	73	66
1518	82	130	71	85
1600	138	83	92	68
1606	92	83	77	78
1612	96	90	74	61
1618	95	67	101	96
1700	100	86	88	84
1706	111	104	97	116
1712	126	134	131	133
1718	144	126	126	127
1800	150	159	169	156
Average	110.7	104.0	99.9	97.3

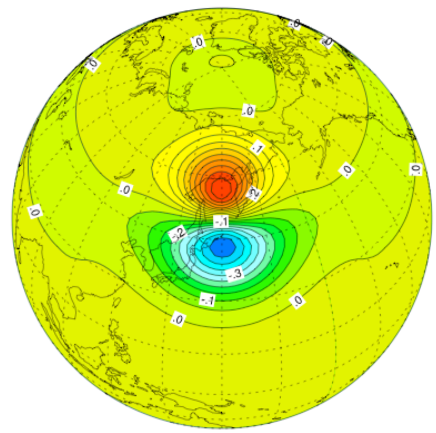
Cycling WRF/WRF-Var/ETKF System (Hybrid DA)



$$\mathbf{x}_n^a = \overline{\mathbf{x}^f} + \delta\overline{\mathbf{x}^a_{Var}} + \delta\mathbf{x}^a_{ETKFn}$$

Subject of JCSDA and AFWA Seminars 2007

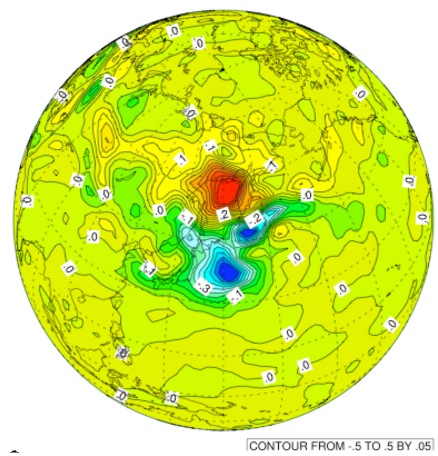
Hybrid DA Via Additional Control Variables



- Define the matrix of ensemble perturbations as

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

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

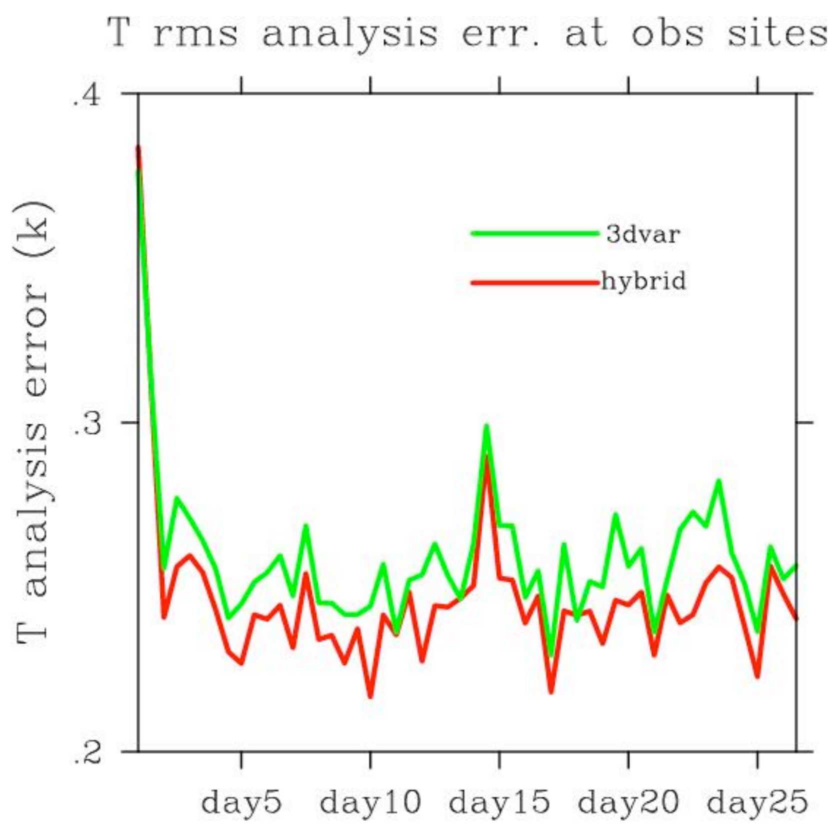


$$\delta\mathbf{x}_0 = \delta\mathbf{x}_{0d} + \delta\mathbf{X}_f \bullet \mathbf{a}$$

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

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

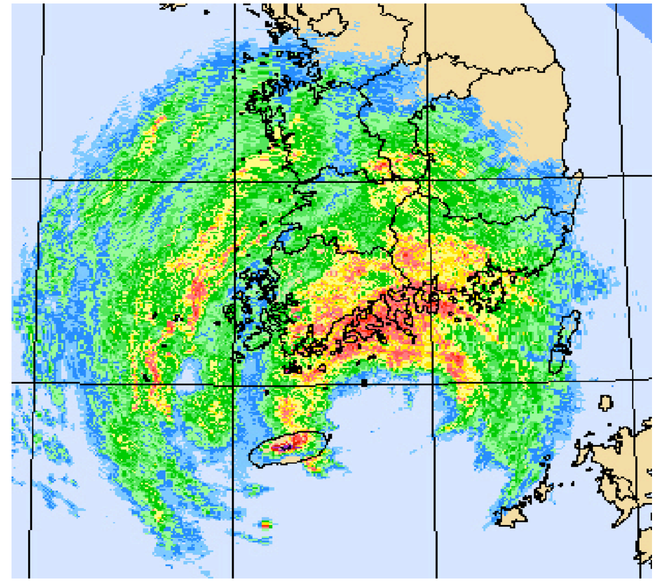
January 2003 OSSE Experiment (X. Wang)



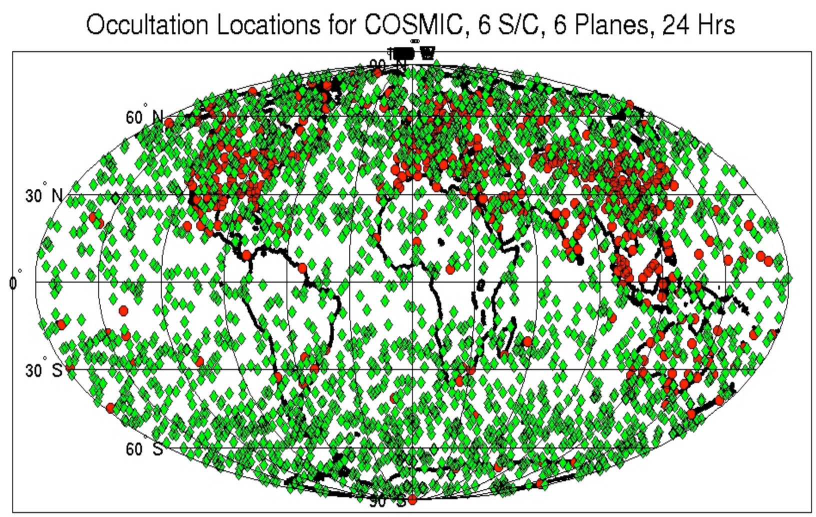
- Test hybrid with equal weight (0.5) on static/ensemble error covariances
- Hybrid analyses significantly better than the pure 3DVAR.
- Note yet cycling, nor tuned. Expect further improvements?

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).

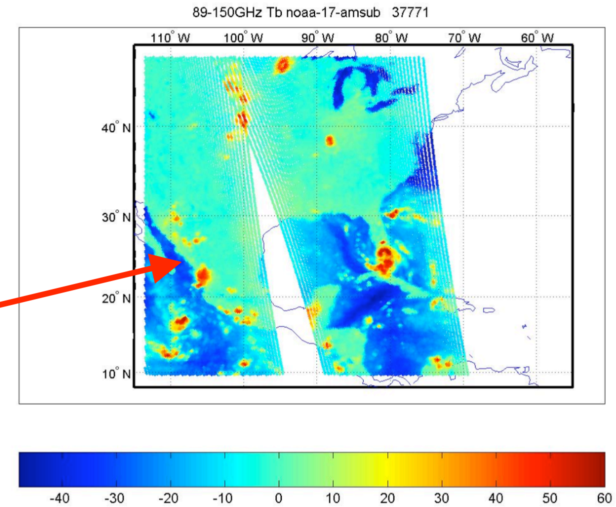


- Radiances:
  - SSM/I brightness temperatures.
  - Direct radiance assimilation.

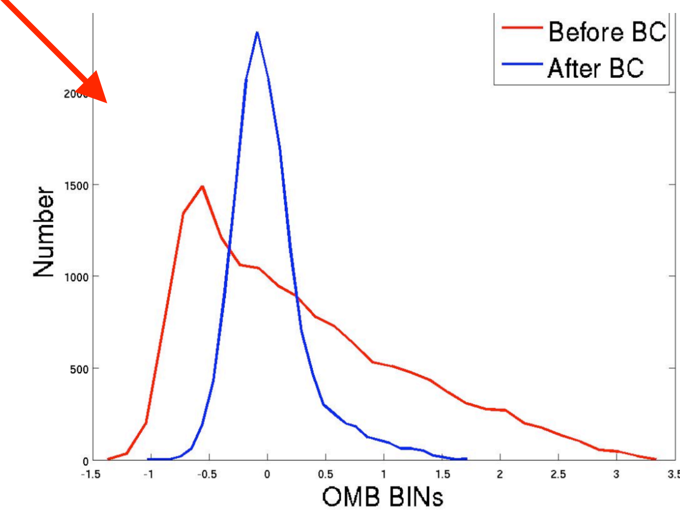
WRF-Var Radiance Assimilation Status

- BUFR Data interface for a number of satellites
- RTM interface: RTTOV8_5 or CRTM
- Currently only assimilating clear-sky radiances
- NESDIS Microwave surface emissivity model
- Quality Control for AMSU-A/B, AIRS
- Bias Correction (Scan Angle + Air Mass)
- Innovation output and Statistics Diagnosis
  - O-B, O-A, counting number of observation
- Variational observation error tuning
- FGAT(First Guess at Appropriate Time)
- Parallel: MPI (regional, not yet global)
- Flexible design to easily add new satellite sensor

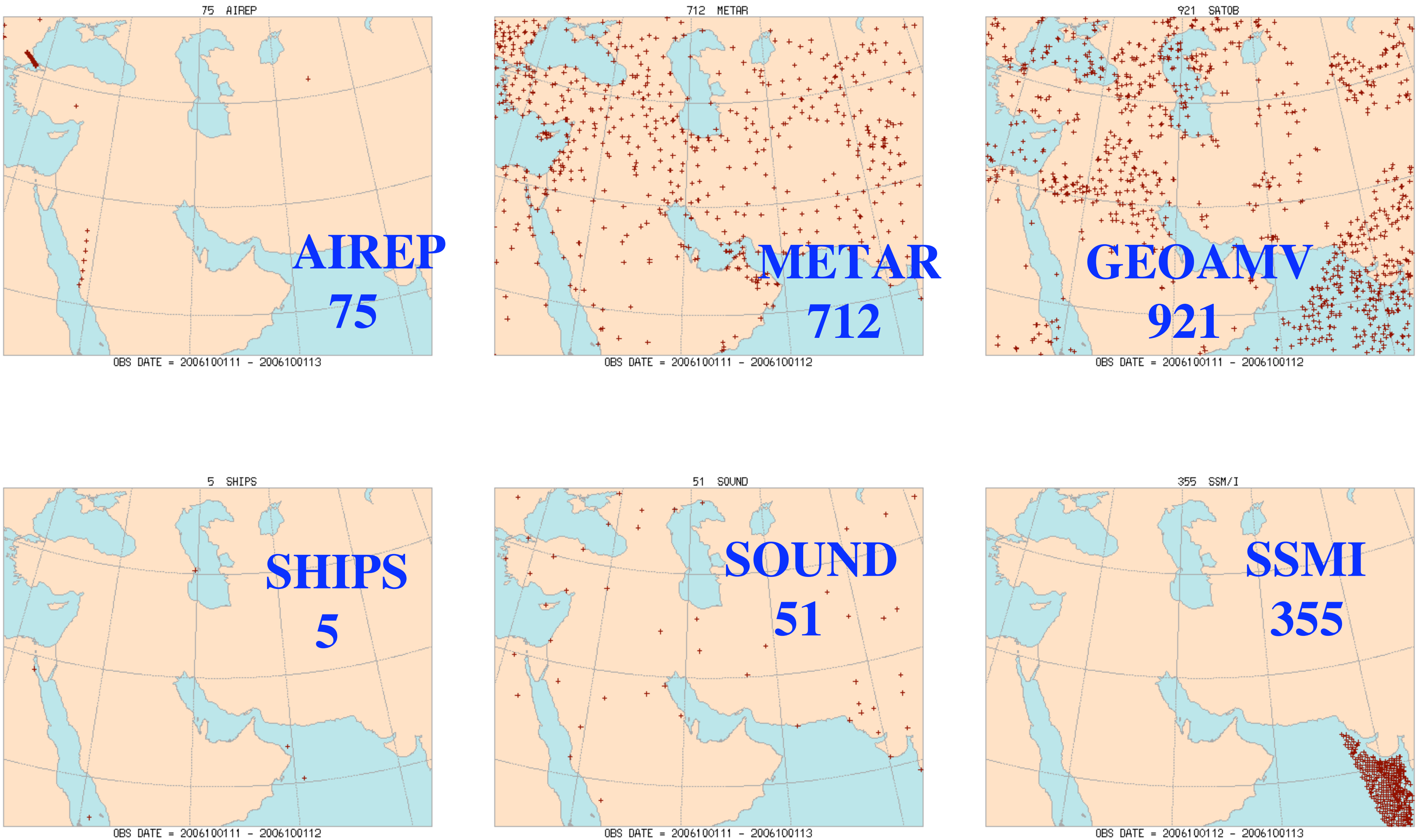
AMSU-B Scatter Index > 3K



Air Mass Bias Correction: AMSU-A



Coverage of conventional data for 2006100112



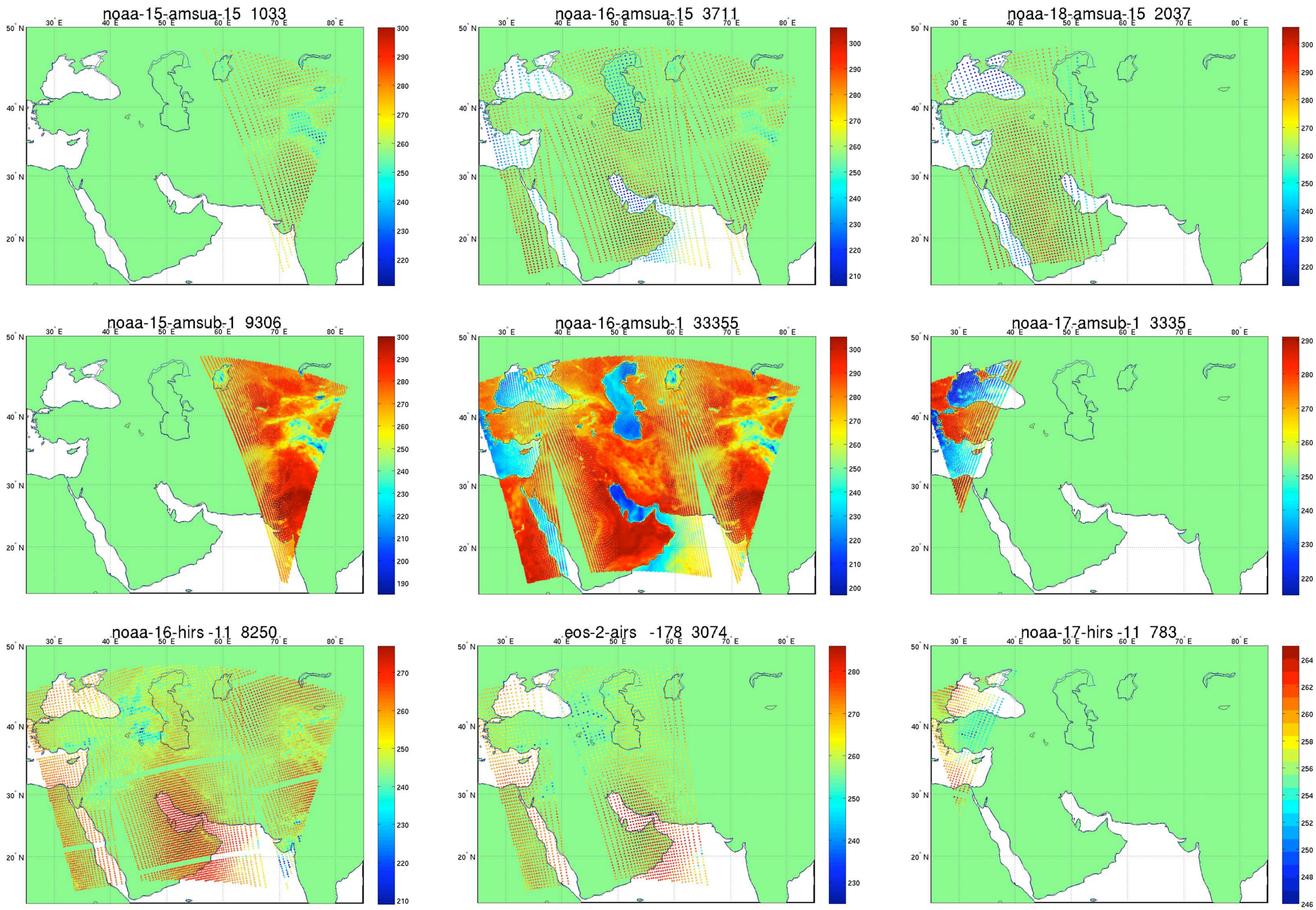
Global Radiance Data For October 2006

- 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 locally producing BUFR radiance data.

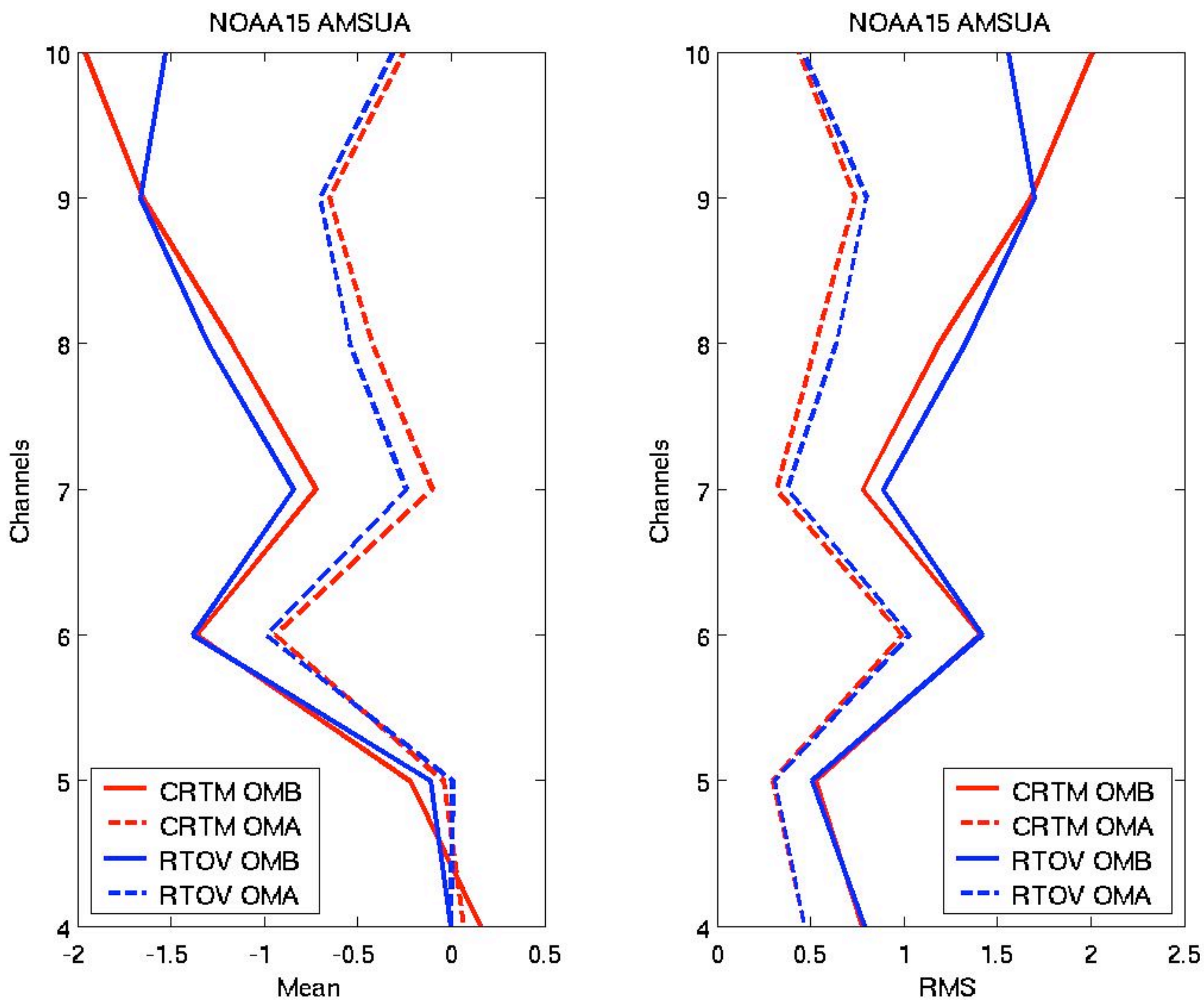
Satellite Coverage (over 60000 pixels)



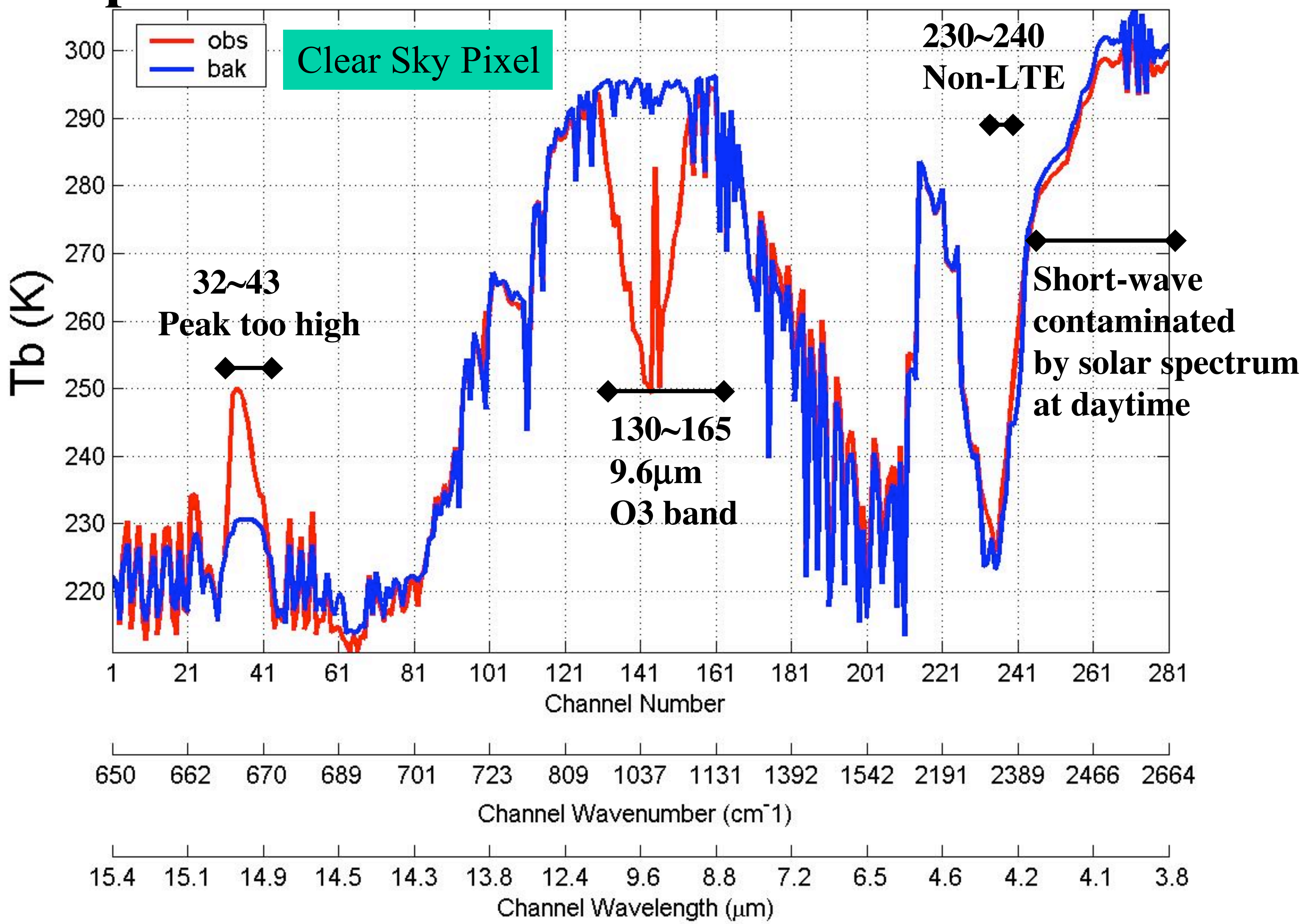
Implementation of CRTM in WRF-Var

- RTTOVS radiance capability introduced in 2005 (KMA project).
- Zhiquan Liu visited JCSDA in November 2006.
- Forward, TL, and adjoint models of CRTM coupled with WRF-Var.
- Currently using 2006/12/20 Beta Release
- Initial tests comparing CRTM with RTTOVS.
- Improved speed of CRTM through optimization of horizontal interpolation in WRF-Var.

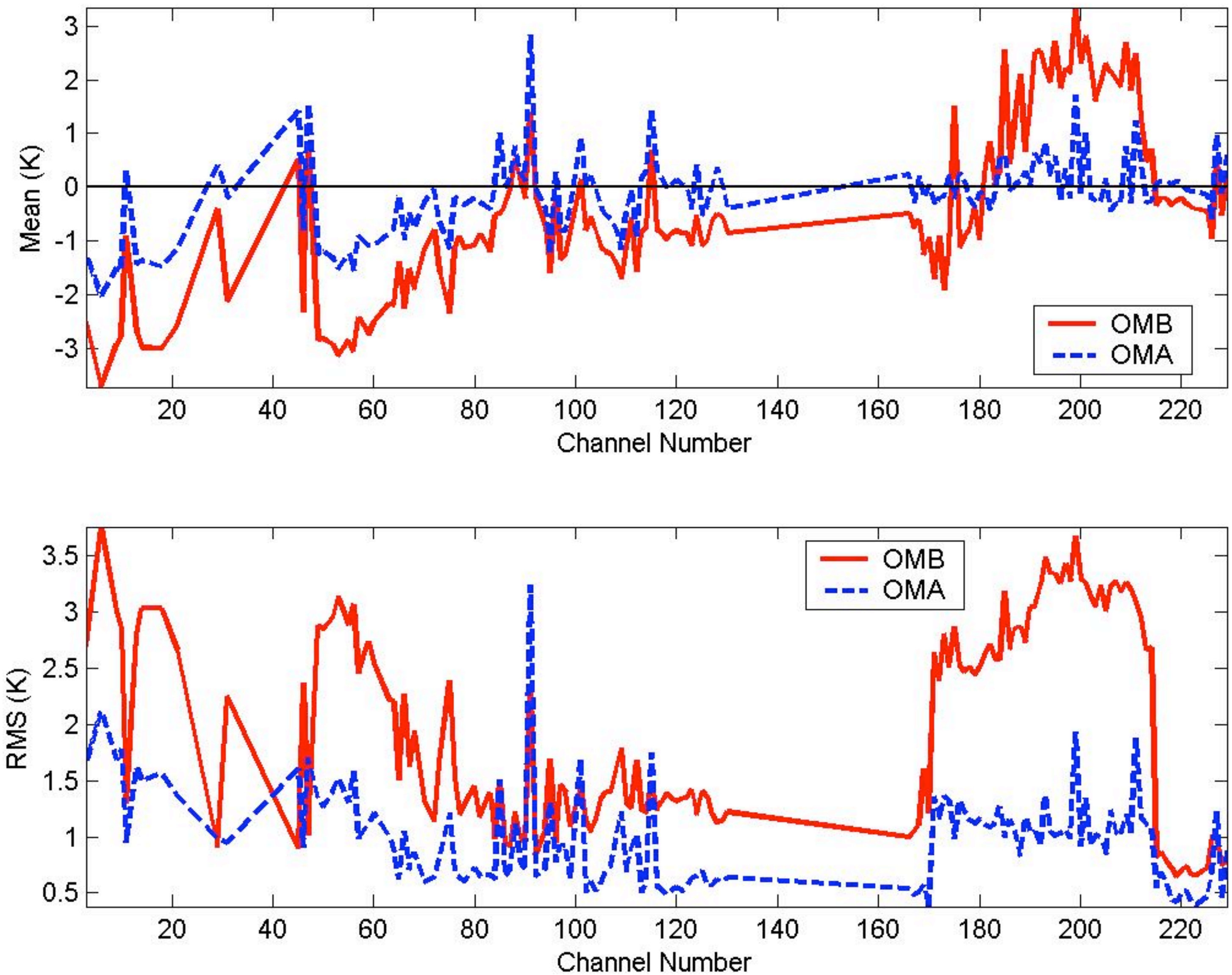
Comparison of CRTM and RTTOVS in WRF-Var



Comparison of AIRS Observed/Calculated B. T.



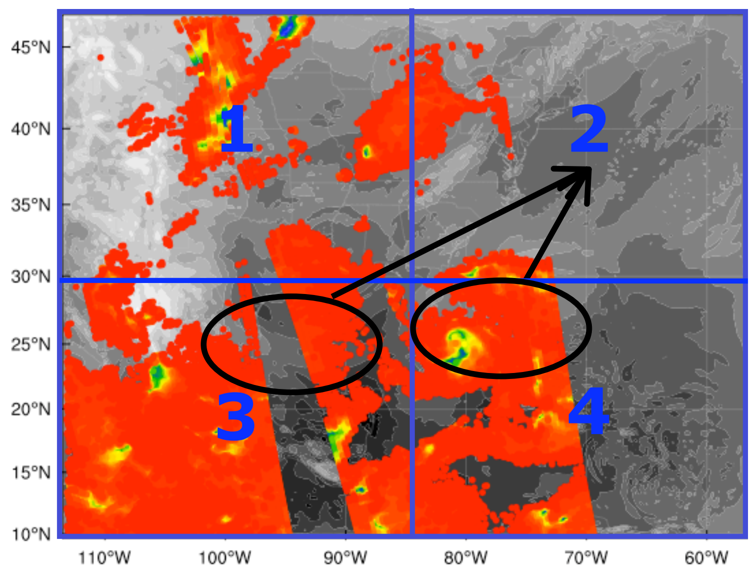
WRF-Var AIRS Assimilation Test



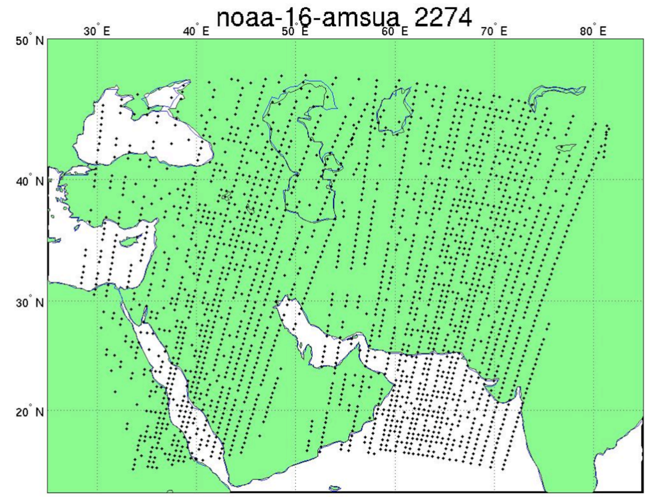
Preliminary result: Ocean only, no bias correction applied.

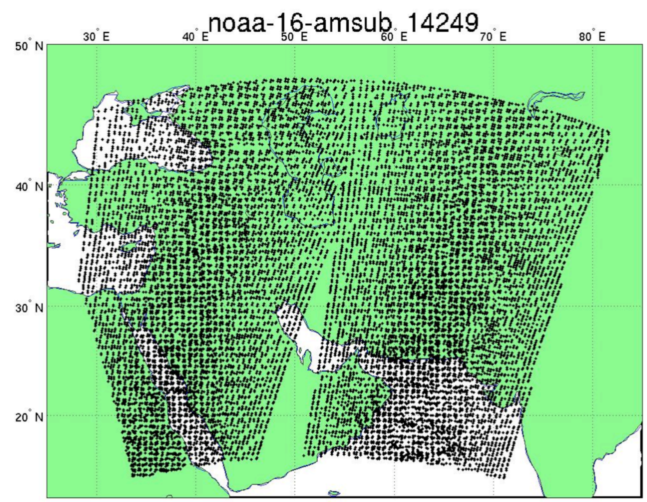
Radiance Assimilation Efficiency Improvements

Load Balancing



Thinning (60km)





Load Balancing Impact On Regional Case

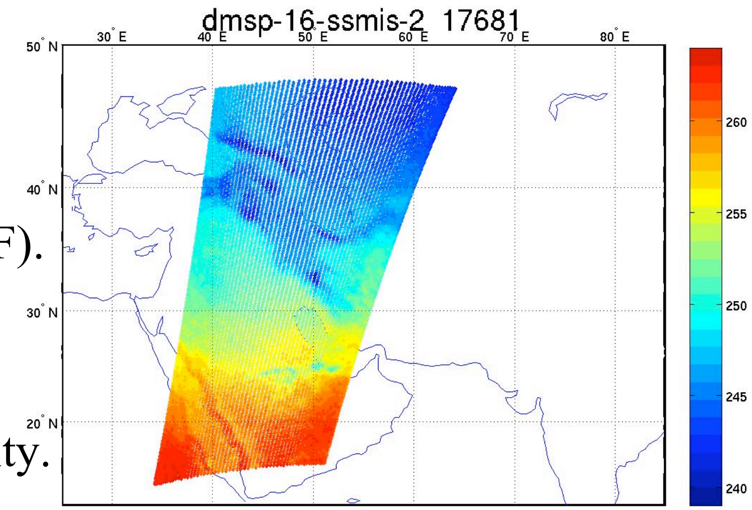
Original Code

	Calls	Elapsed Time (seconds)				CPU Time (seconds)				Speed up
	per PE	Average per PE	%	Minimum	Maximum	Total	%	Minimum	Maximum	32 PE
wrfvar	1.0	349.94	97.8	347.4 on 14	354.1 on 27	9553.59	2822.2	285.0 on 3	349.4 on 24	27.30
da_wrfvar_run	1.0	268.65	75.1	265.8 on 4	273.1 on 27	8240.70	2434.4	254.6 on 30	268.6 on 24	30.67
da_wrfvar_interface	1.0	268.65	75.1	265.8 on 4	273.1 on 27	8240.70	2434.4	254.6 on 30	268.6 on 24	30.67
da_solve	1.0	268.62	75.1	265.7 on 4	273.1 on 27	8240.68	2434.4	254.6 on 30	268.6 on 24	30.68
da_minimise_cg	1.0	217.33	60.7	216.2 on 12	218.6 on 31	6895.48	2037.0	212.4 on 3	217.7 on 31	31.73

Optimized Code

	s	Elapsed Time (seconds)				CPU Time (seconds)				Speed up
	per PE	Average per PE	%	Minimum	Maximum	Total	%	Minimum	Maximum	32 PE
wrfvar	1.0	137.31	96.4	0.0 on 0	142.0 on 25	3962.43	2939.1	0.0 on 0	140.1 on 16	28.86
da_wrfvar_run	1.0	109.49	76.9	0.0 on 0	113.4 on 25	3365.62	2496.4	0.0 on 0	111.7 on 16	30.74
da_wrfvar_interface	1.0	109.49	76.9	0.0 on 0	113.4 on 25	3365.62	2496.4	0.0 on 0	111.7 on 16	30.74
da_solve	1.0	109.49	76.9	0.0 on 0	113.4 on 25	3365.57	2496.3	0.0 on 0	111.7 on 24	30.74
da_minimise_cg	1.0	88.72	62.3	88.4 on 11	89.1 on 0	2807.65	2082.5	87.2 on 20	88.4 on 24	31.65

NCAR/AFWA DA Program Plans



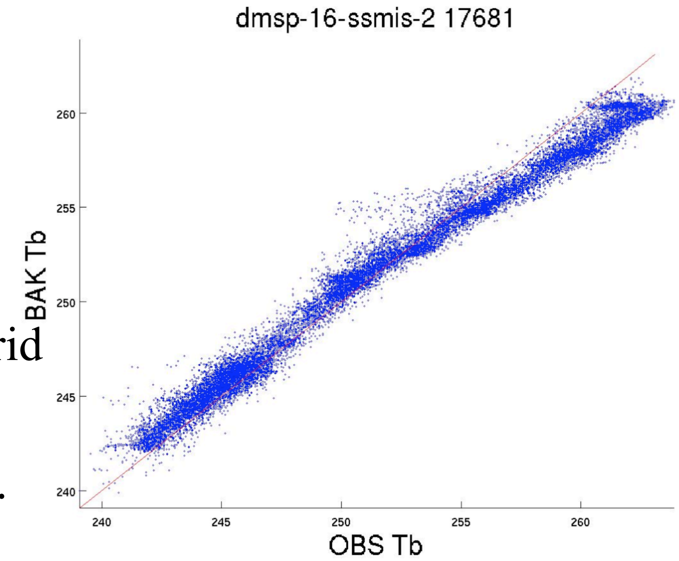
General Goals:

- Research: Focus on very high-resolution (1-10km).
- Development: Unified DA system (3/4D-Var, EnKF).
- Community Model: Flexibility 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).
- 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.
- COSMIC, AMSU, AIRS impact in AFWA theaters.