

Towards A Unified Variational/Ensemble Data Assimilation System for WRF

Hans X.-Y. Huang,

D. Barker, Z. Liu, X. Zhang, Y. Chen, Q. Xiao, T. Auligne, H. Shao,
Y.-R Guo, M. Demirtas, S. Rizvi, H.-C. Lin, M. Duda, H. Wang, Z. Ma, J. Sun,
C. Snyder and Y.-H. Kuo

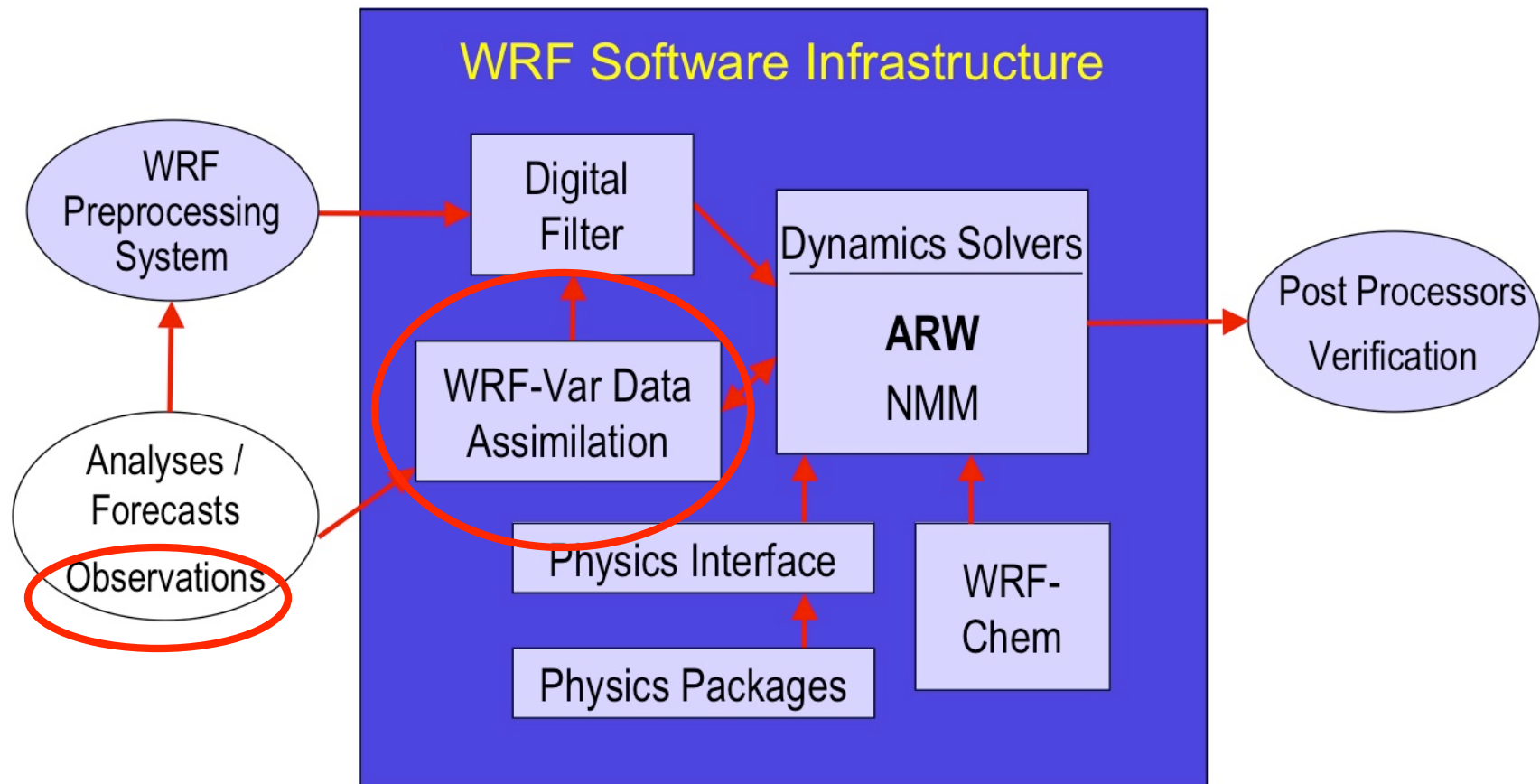
NCAR

S. Rugg, AFWA

Acknowledge:

AFWA, NCAR Staff, NSF, NASA, JCSDA,
EUMETSAT,
Korean Meteorological Administration,
Taiwanese Central Weather Bureau, Civil Aeronautics Administration,
Beijing Meteorological Bureau,
Indian Institute of Technology, Indian Meteorological Department.

WRF Modeling System



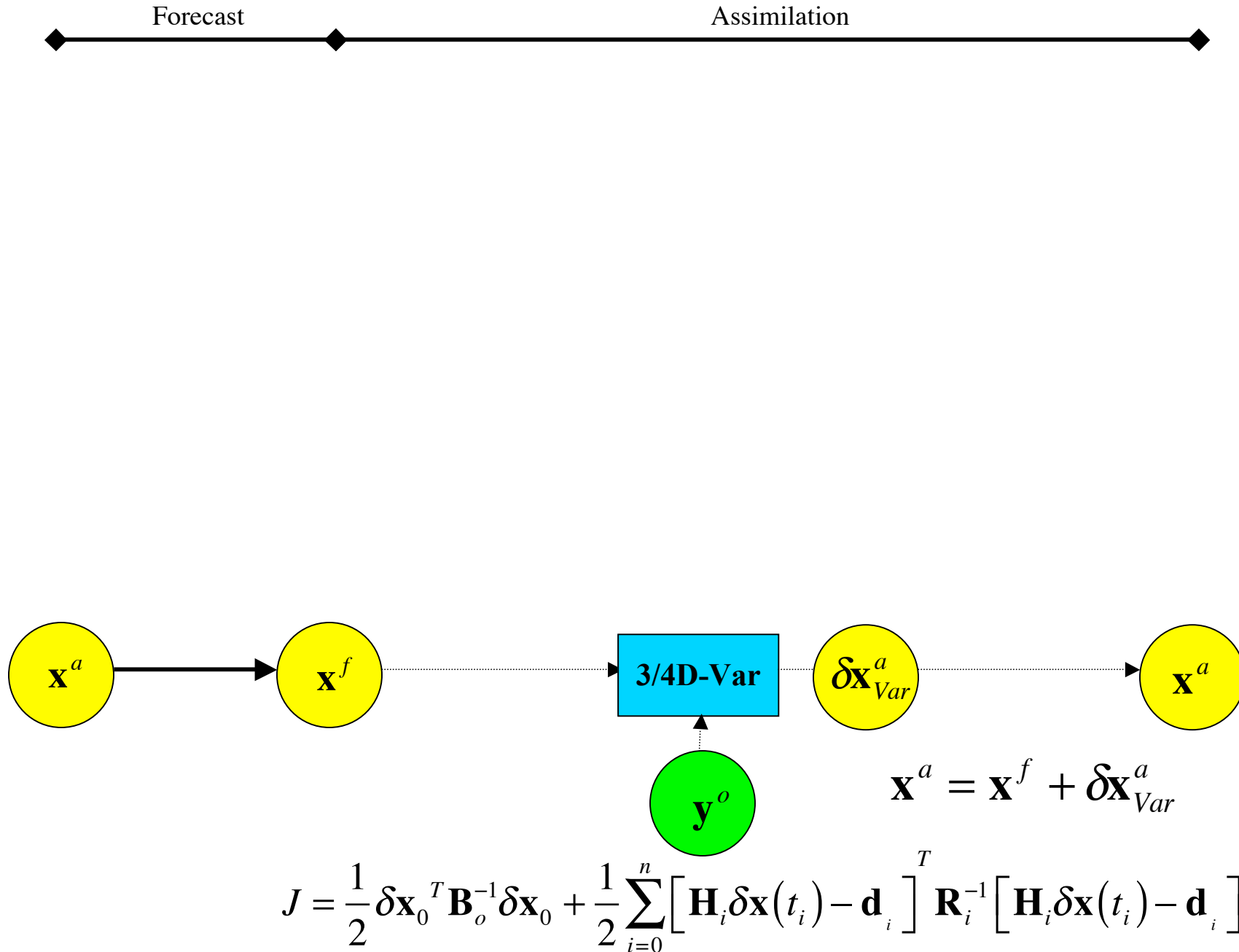
ARW = Advanced Research WRF (NCAR) Core

NMM = Nonhydrostatic Mesoscale Model (NCEP) Core

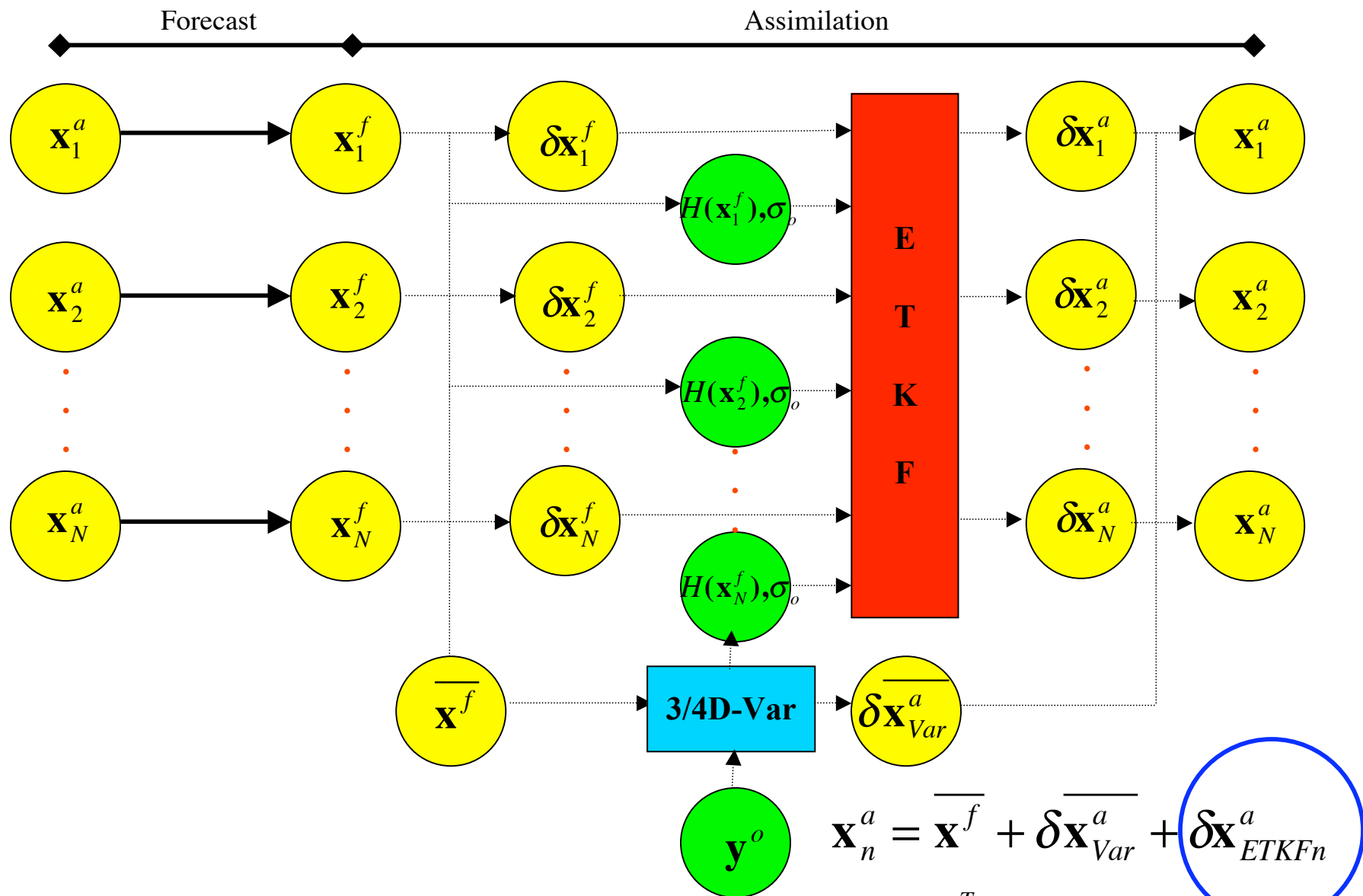
WRF-Var Version 3.0

- Major new features:
 - Ensemble Transform Kalman Filter (ETKF).
 - Enhanced forecast error covariances (e.g. ensemble-based).
 - Hybrid variational/ensemble DA.
 - Major software engineering reorganization.
 - Remove obsolete features (e.g. MM5/GFS-based errors).
 - Unified WRF/WRF-Var code repository.
- Available for download from <http://www.WRF-model.org>
- **NOT included in public release. Collaborators welcome!**
 - 4D-Var.
 - Radiance data assimilation via CRTM/RTTOVS.

1. Deterministic Cycling NWP System

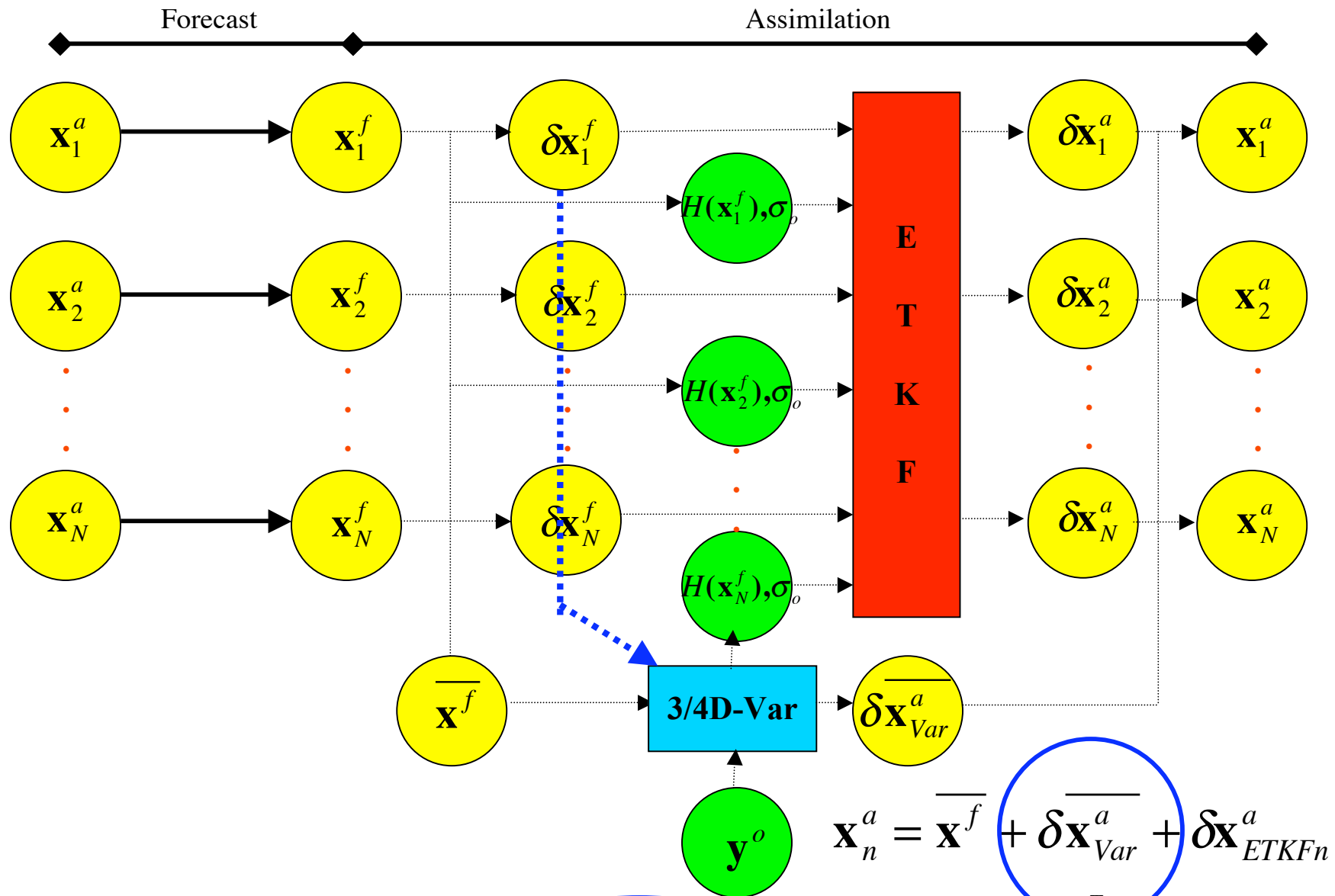


2. Cycling WRF/WRF-Var/ETKF System



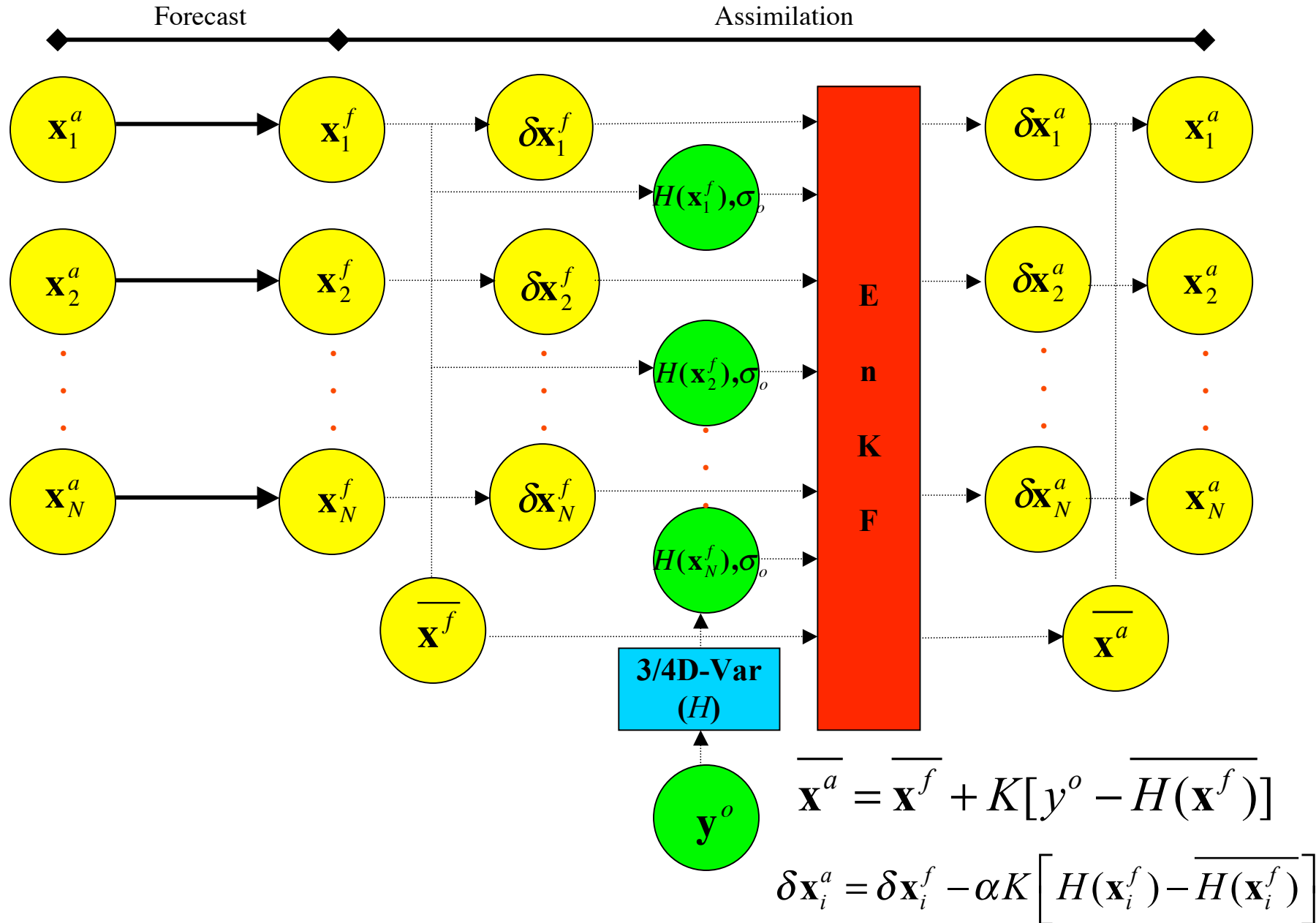
$$J = \frac{1}{2} \delta \mathbf{x}_0^T \mathbf{B}_o^{-1} \delta \mathbf{x}_0 + \frac{1}{2} \sum_{i=0}^n \left[\mathbf{H}_i \delta \mathbf{x}(t_i) - \mathbf{d}_i \right]^T \mathbf{R}_i^{-1} \left[\mathbf{H}_i \delta \mathbf{x}(t_i) - \mathbf{d}_i \right]$$

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



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

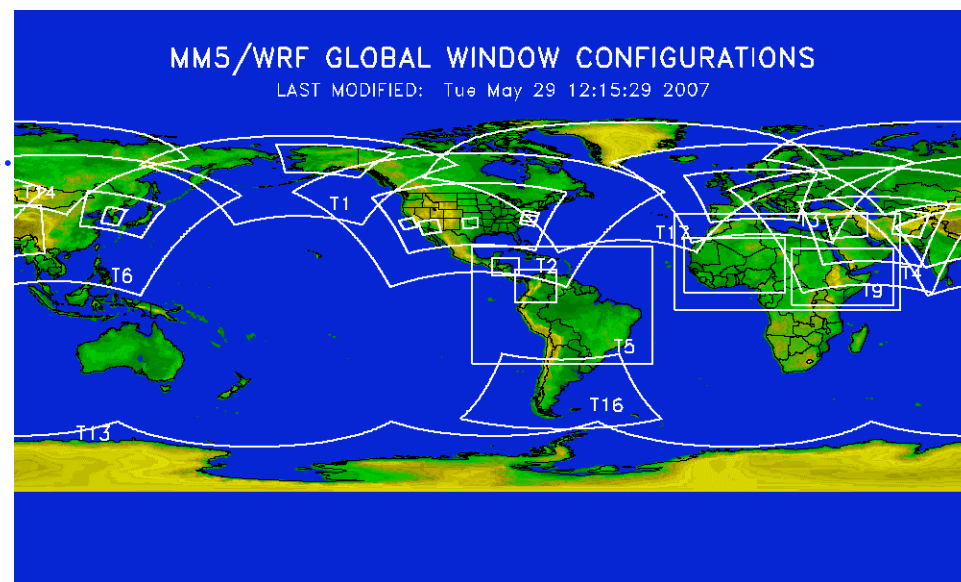
4. Cycling WRF/EnKF System



WRF-Var (WRFDA) Data Assimilation Overview

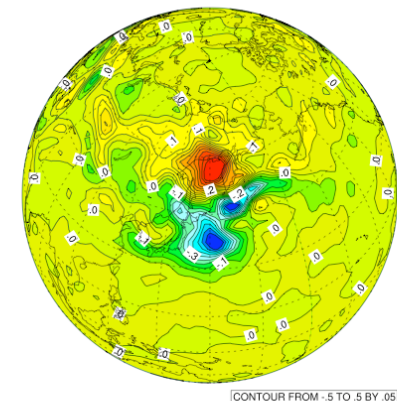
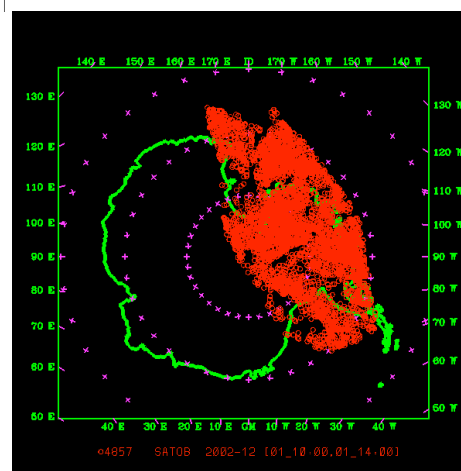
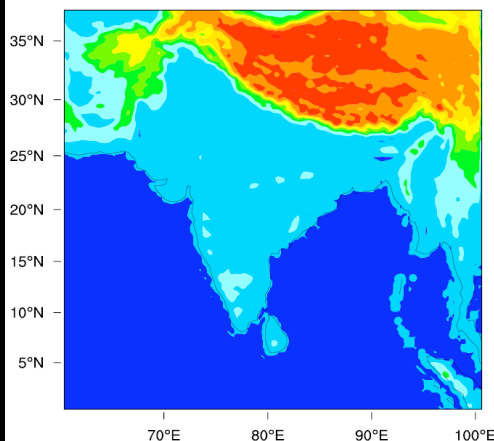
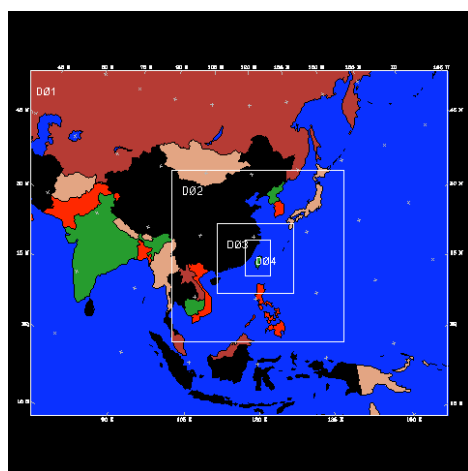
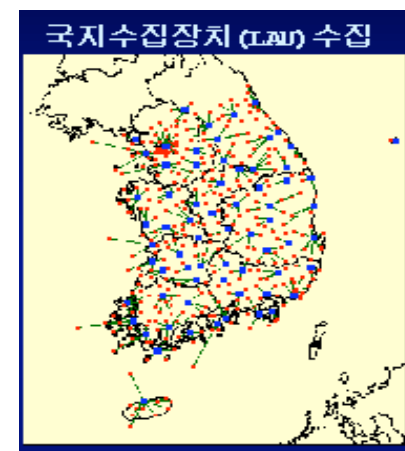
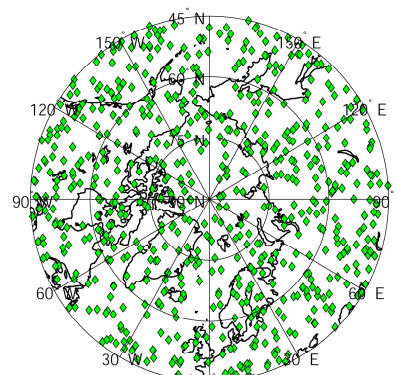
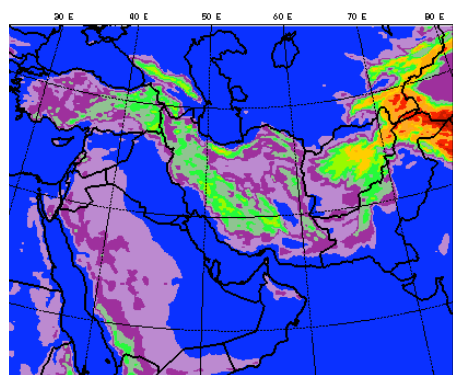
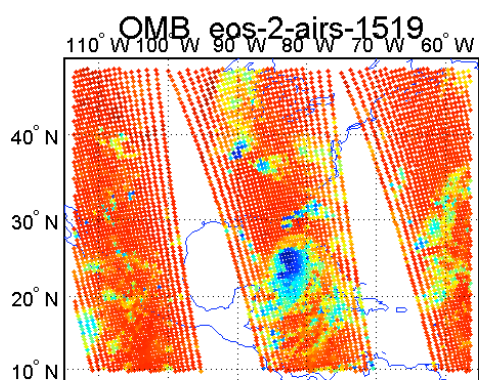
- **Goal:** Community WRF DA system for regional/global, research/operations, and deterministic/probabilistic applications.
- **Techniques:**
 - 3D-Var
 - 4D-Var (regional)
 - Ensemble DA,
 - Hybrid Variational/Ensemble DA.
- **WRFDA Team:**
 - NCAR/ESSL/MMM/DAG
 - NCAR/RAL/JNT/DATC
- **Observations:** Conv.+Sat.+Radar

AFWA Theaters:



WRFDA Overview

- NCAR staff: ~20FTE, ~12 projects.
- Non-NCAR collaborators (AFWA, KMA, CWB, BMB, IMD, etc): ~10FTE.
- Community users: ~30 (more in 7500 general WRF downloads?).



Ongoing work

5.1 TOWARD A UNIFIED WRF DATA ASSIMILATION SYSTEM:

WRFDA. X.-Y. Huang, D. Barker, Z. Liu, X. Zhang, Y. Chen, Q. Xiao, T. Auligne, H. Shao, Y.-R Guo, M. Demirtas, S. Rizvi, H.-C. Lin, M. Duda, H. Wang, Z. Ma, S. Thomas, W. Huang, J. Sun, C. Snyder, Y.-H. Kuo and S. Rugg

5.2 PERFORMANCE OF WRF 4D-VAR SYSTEM: SCIENTIFIC AND SOFTWARE ENGINEERING. Xin Zhang, X.-Y. Huang and H. L. Wang

5.3 IMPACT OF AIRS OBSERVATIONS OVER THE ANTARCTIC REGION. Thomas Auligne, Hui Shao, Dale Barker, Zhiquan Liu and Hui-Chuan Lin

5.6 APPLICATIONS OF WRF DATA ASSIMILATION SYSTEM AT THE NCAR DATA ASSIMILATION TESTBED CENTER

(DATC) X.-Y. Huang, **Hui Shao**, Meral Demirtas, Zhiquan Liu, Rizvi Syed, Thomas Auligne and Dale Barker

Ongoing Work: Research and Development

- ❑ **P5.1 RADIANCE DATA ASSIMILATION FOR WRF MODEL: OVERVIEW AND RESULTS.** **Zhiquan Liu**, Tom Auligne, Hui-Chuan Lin, Dale Barker, Xiaoyan Zhang, Xin Zhang, Hui Shao and Xiang-Yu Huang (NCAR) and Dongliang Wang (Shanghai Typhoon Institute)
- ❑ **P5.5 DOPPLER RADAR DATA ASSIMILATION WITH WRF 3D-VAR: IHOP RETROSPECTIVE STUDIES.** **Qingnong Xiao**, Eunha Lim, Xiaoyan Zhang, Juanzhen Sun and Zhiquan Liu
- ❑ **P5.6 ASSIMILATION OF DOPPLER RADAR DATA WITH WRF 4D-VAR FOR A CONVECTIVE CASE.** **Y.-R. Guo**, and J. Sun (NCAR, USA), E. Lim (KMA, S. Korea), X.-Y. Huang, and X. Zhang (NCAR, USA), and S. Sugimoto (Central Research Institute of Electric Power Industry, Japan)
- ❑ **P5.3 IMPACT OF OUTER LOOP FOR WRF DATA ASSIMILATION SYSTEM (WRFDA).** **Syed Rizvi**, Y.-R Guo, H. Shao, M. Demirtas and X.-Y. Huang
- ❑ **P5.13 AN ENSEMBLE-BASED FOUR-DIMENSIONAL VARIATIONAL DATA ASSIMILATION SCHEME.** **Chengsi Liu** (LASG and NCAR, USA), Qingnong Xiao (NCAR, USA) and Bin Wang (LASG)

Ongoing Work: Applications

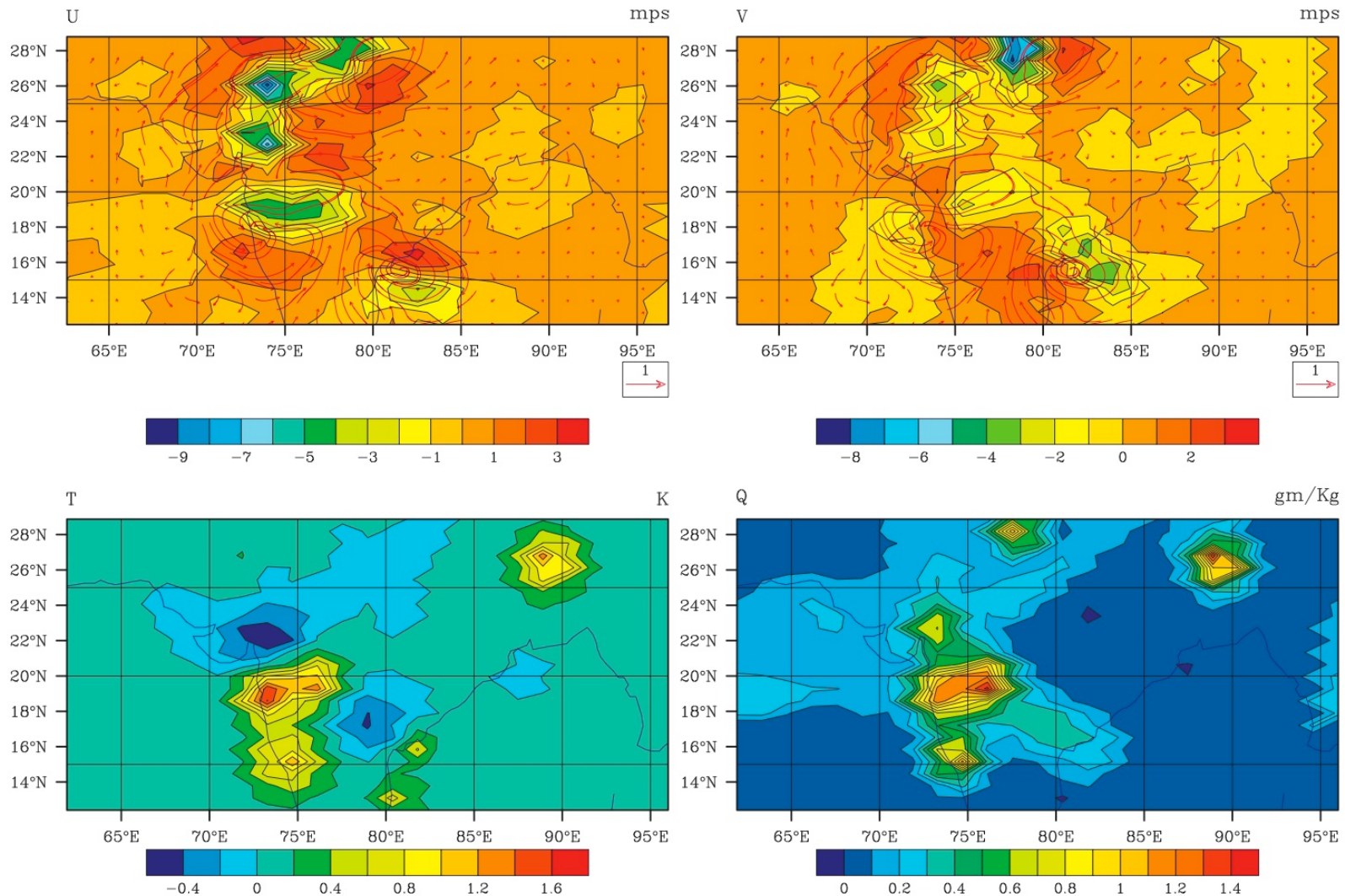
- ❑ **P5.4 IMPACT STUDIES OF SATELLITE OBSERVATIONS IN THE ANTARCTIC MESOSCALE PREDICTION SYSTEM: AMSU-A RADIANCE MEASUREMENTS.** **Hui Shao**, Zhiquan Liu, Thomas Auligne, Dale Barker, Jordan Powers and Xiang-Yu Huang
- ❑ **P5.15 HIGH-RESOLUTION SHORT-RANGE NWP OF HIGH-IMPACT WEATHER EVENTS ON THE KOREAN PENINSULA.** **Meral Demirtas**, Dale Barker, Jimy Dudhia, and Dave Gill (NCAR, USA), Ji-Hyun Ha (SNU, S. Korea), Seung-On Hwang (KMA, S. Korea) and Eunha Lim (NCAR, USA)
- ❑ **P5.11 ASSIMILATION OF AMSU-A RADIANCE FOR IMPROVING KATRINA FORECAST.** **Dongliang Wang** and Zhiquan Liu (NCAR, USA)
- ❑ **P5.12 AN OBSERVING SYSTEM SIMULATION EXPERIMENT (OSSE) FOR METEOSAT THIRD GENERATION INFRA-RED SOUNDING RETRIEVALS USING BOTH MM5 AND WRF.** Xiang-Yu Huang, **Hongli Wang**, Yongsheng Chen, and Xin Zhang (NCAR, USA), Stephen A. Tjemkes, and Rolf Stuhlmann (EUMETSAT)
- ❑ **P6.7 A MULTI-YEAR ARCTIC SYSTEM REANALYSIS.** **David. H. Bromwich** (The Ohio State University, USA), Dale M. Barker (NCAR, USA), John E. Walsh (University of Illinois at Urbana-Champaign, USA), Mark C. Serreze (University of Colorado, USA), Ying-Hwa Kuo, and Fei Chen (NCAR, USA), Keith M. Hines, Le-Sheng Bai, and Sheng-Hung Wang (The Ohio State University, USA), Andrew G. Slater (University of Colorado, USA), William L. Chapman (University of Illinois at Urbana-Champaign, USA), Hans Huang, and Michael Barlage (NCAR, UCA), Tae-Kwon Wee (UCAR, USA), Paul R. Berger, and Lin Li (Ohio Supercomputer Center, USA)

Ongoing Work: GSI and NMM

- ❑ **P5.7 IMPACT OF THE GSI DATA ASSIMILATION ON WRF-NMM FORECAST OF TROPICAL CYCLONES OVER NORTH INDIAN OCEAN.** K. Naga Ratna (India Meteorological Department, India), Ming Hu (NOAA, USA), Xiang-Yu Huang, and S.R.Rizvi (NCAR, USA) and S. Pattnayak (ITT, India)
- ❑ **P8.4 A COMPARATIVE STUDY ON PERFORMANCE OF MM5 AND WRF (ARW & NMM) MODELS IN SIMULATION OF TROPICAL CYCLONE OVER BAY OF BENGAL.** S. Pattanayak and U. C. Mohanty (ITT, India), S. R. Rizvi, and X. Huang (NCAR, USA) and K. Naga Ratna (India Meteorological Department, India)

WRF-Var and NMM (Pattanayak and Rizvi) Analysis increments

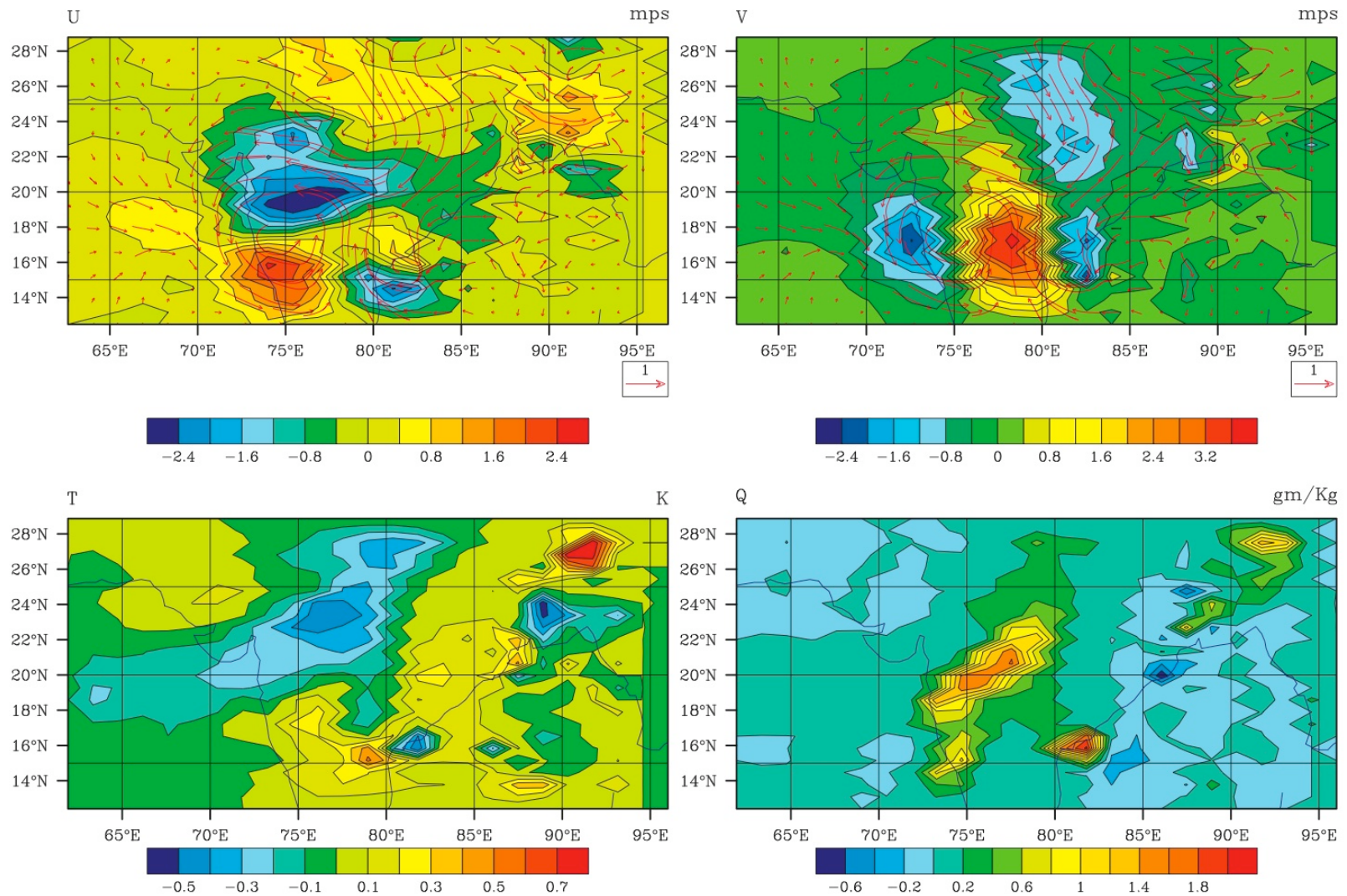
Difference of 00 hours forecast from NMM at Sigma level=25



WRF-Var and NMM (Pattanayak and Rizvi)

Impact on 12h forecasts

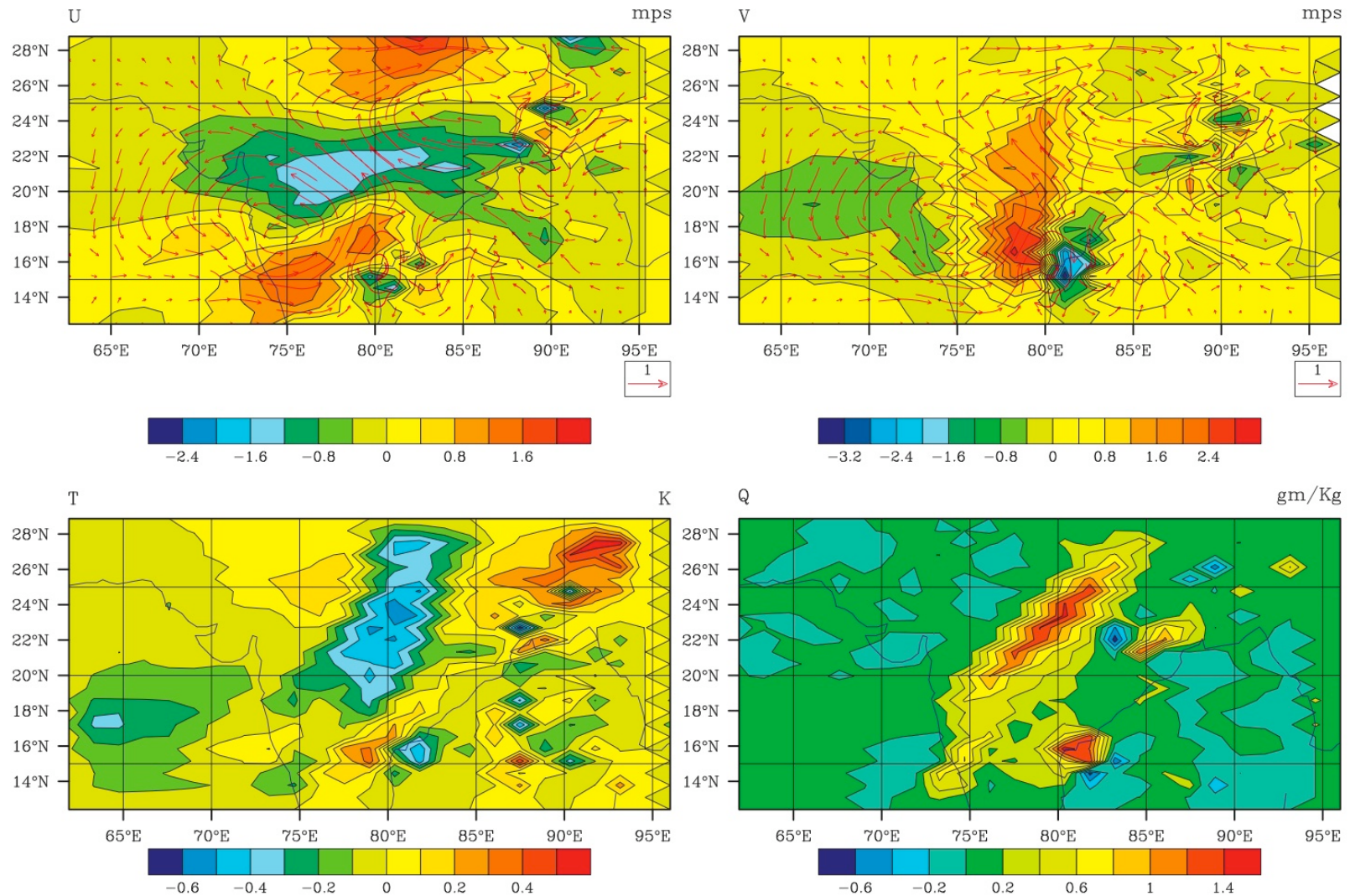
Difference of 12 hours forecast from NMM at Sigma level=25



WRF-Var and NMM (Pattanayak and Rizvi)

Impact on 24h forecasts

Difference of 24 hours forecast from NMM at Sigma level=25

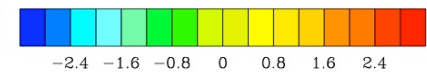
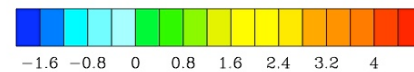
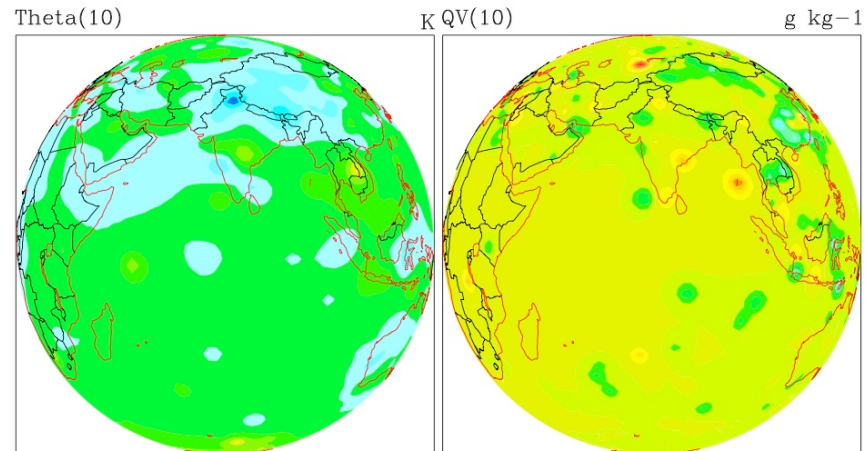
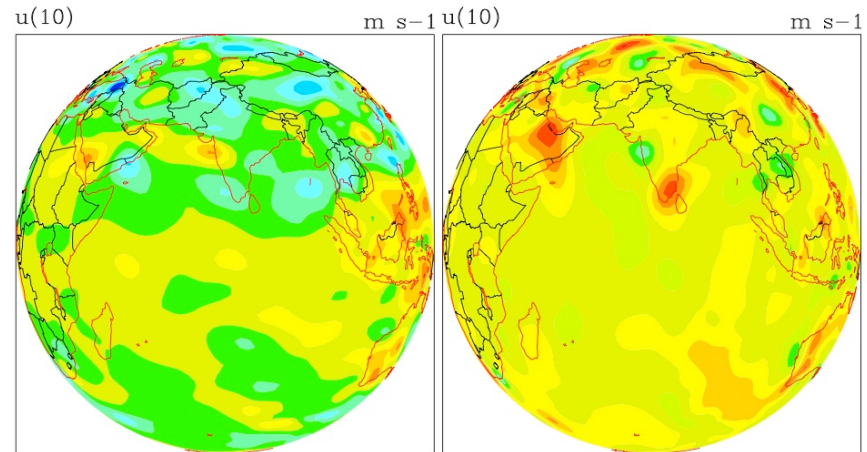


Global WRF-Var (Rizvi and Duda)

Analysis increments

Analysis – FG

Date 2008060500 Level 10



Summary

- WRFDA:
 - 3D-Var
 - 4D-Var
 - ETKF
 - Hybrid Var/ETKF
- Ongoing work:
 - Further research and development in satellite data assimilation
 - Further research and development in radar data assimilation
 - Optimization of WRF 4D-Var
 - Systematic test of hybrid Var/ETKF
 - Incorporate EnKF in WRFDA
 - Ensemble-based 4D-Var
 - WRFDA for WRF-NMM
 - WRFDA for global ARW
- Applications:
 - Operations and real time applications
 - DATC activities
 - High impact weather

Yong-Run Guo

The first radar data assimilation experiment using WRF 4D-Var (OSSE)

TRUTH ----- Initial condition from TRUTH (13-h forecast initialized at 2002061212Z from AWIPS 3-h analysis) run cutted by ndown, boundary condition from NCEP GFS data.

NODA ----- Both initial condition and boundary condition from NCEP GFS data.

3DVAR ----- 3DVAR analysis at 2002061301Z used as the initial condition, and boundary condition from NCEP GFS. Only Radar radial velocity at 2002061301Z assimilated (total # of data points = 65,195).

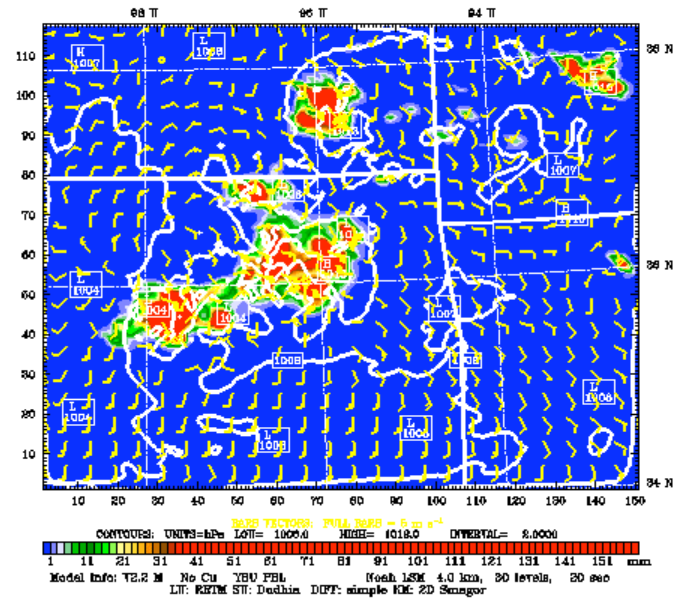
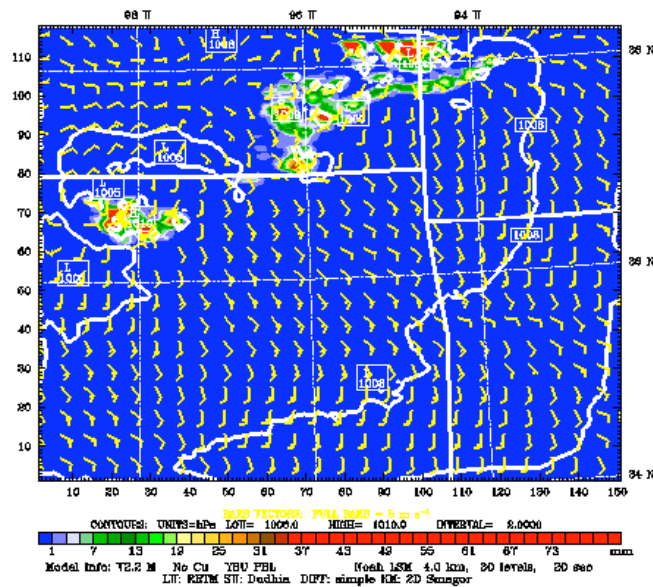
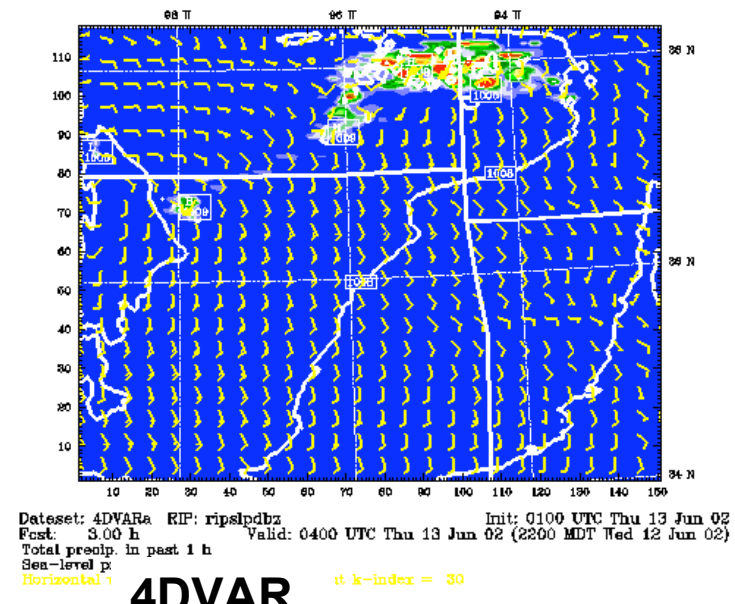
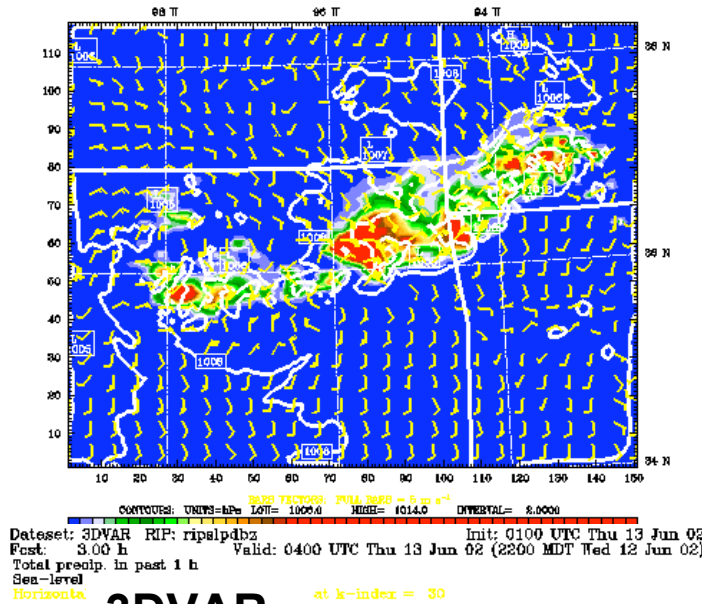
4DVAR ----- 4DVAR analysis at 2002061301Z used as initial condition, and boundary condition from NCEP GFS. The radar radial velocity at 4 times: 200206130100, 05, 10, and 15, are assimilated (total # of data points = 262,445).

Yong-Run Guo: Radar 4D-Var

Hourly precipitation ending at 03-h forecast

TRUTH

NODA



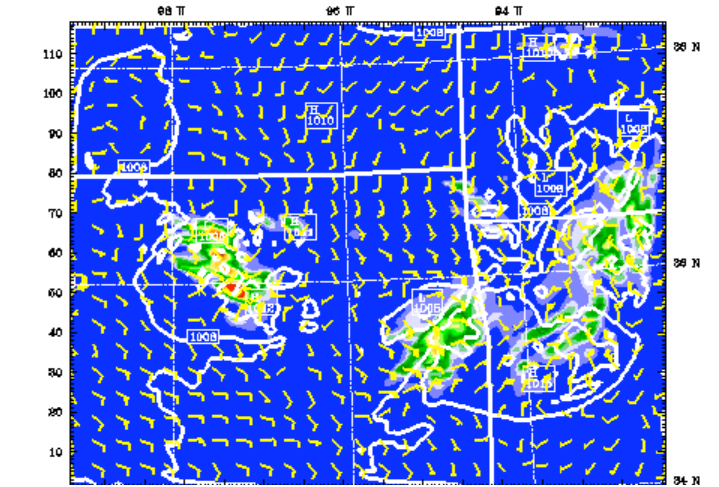
Yong-Run Guo: Radar 4D-Var

Hourly precipitation ending at 06-h forecast

Sea-level pressure
Horizontal wind

TRUTH

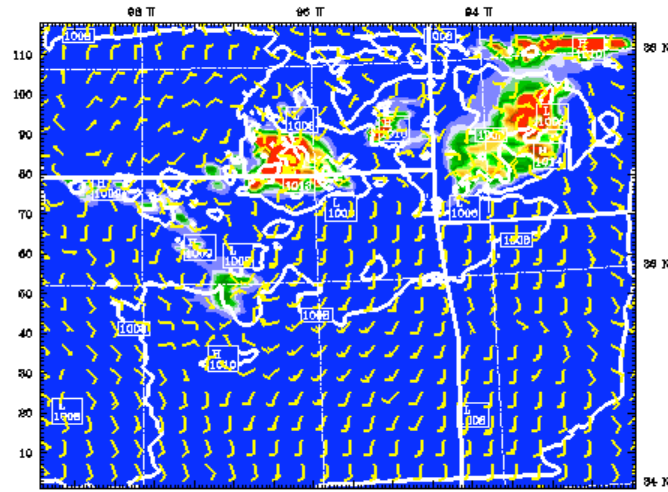
at k-index = 30



Dateset: 3DVAR RIP: ripaldbz Init: 0100 UTC Thu 13 Jun 02
Fest: 6.00 h Valid: 0700 UTC Thu 13 Jun 02 (0100 MDT Thu 13 Jun 02)
Total precip. in past 1 h
Sea-level pressure
Horizontal wind

3DVAR

at k-index = 30

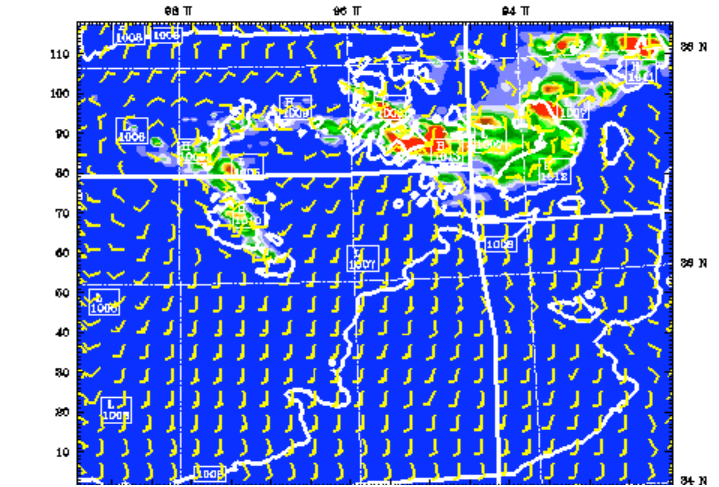


CONTOURS: UNITS=hPa LOT= 1000.0 HIGR= 1018.0 DIVERG= 8.0000
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121 129
Model Info: T2.2 M No Cu YBU PBL (Fesh LSM 4.0 km, 30 levels, 20 sec
LIT: RRTM ST: Dudhia DEPT: simple KMC 2D Sengor

Sea-level pressure
Horizontal wind

NODA

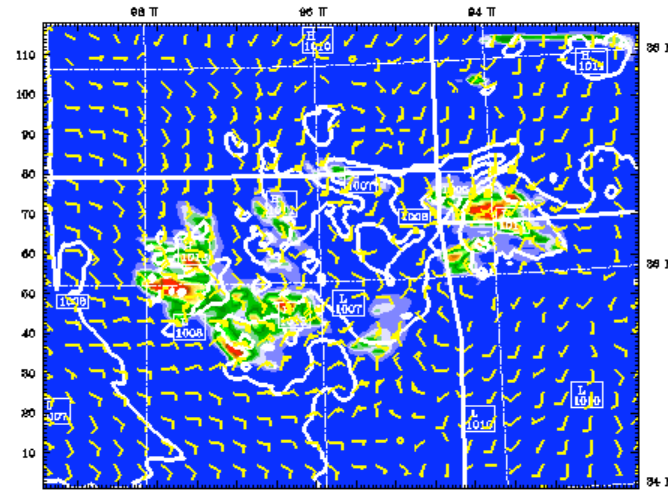
at k-index = 30



Dateset: 4DVARa RIP: ripaldbz Init: 0100 UTC Thu 13 Jun 02
Fest: 6.00 h Valid: 0700 UTC Thu 13 Jun 02 (0100 MDT Thu 13 Jun 02)
Total precip. in past 1 h
Sea-level pressure
Horizontal wind

4DVAR

k-index = 30



CONTOURS: UNITS=hPa LOT= 1000.0 HIGR= 1014.0 DIVERG= 8.0000
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69
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LIT: RRTM ST: Dudhia DEPT: simple KMC 2D Sengor