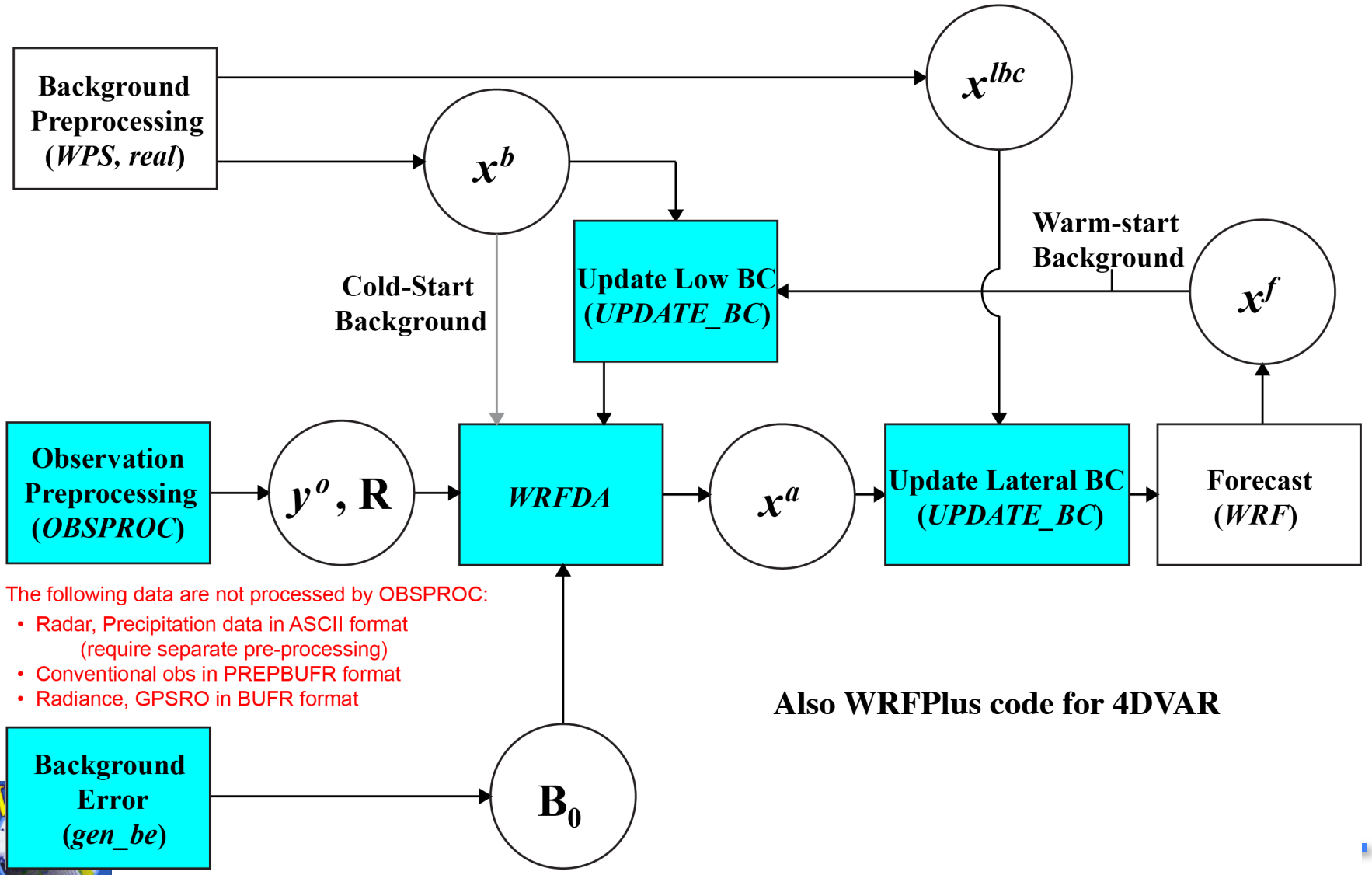
Introduction to WRFDA

Zhiquan (Jake) Liu

NCAR/MMM

WRFDA in the WRF Modeling System



The following data are not processed by OBSPROC:

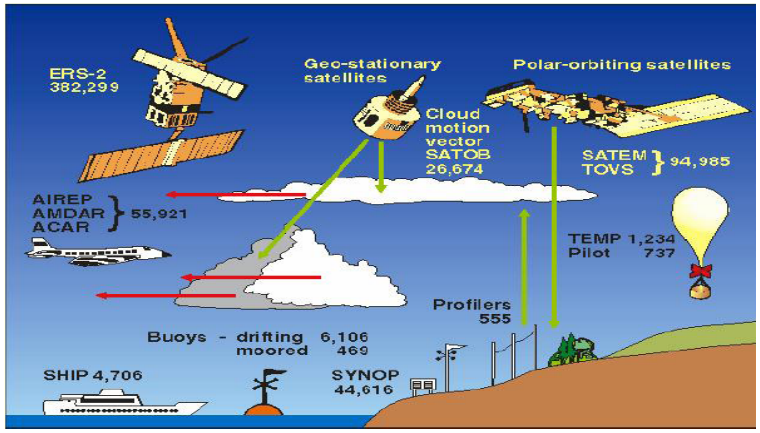
- Radar, Precipitation data in ASCII format (require separate pre-processing)
- Conventional obs in PREPBUFR format
- Radiance, GPSRO in BUFR format

Also WRFPlus code for 4DVAR

Why data assimilation?

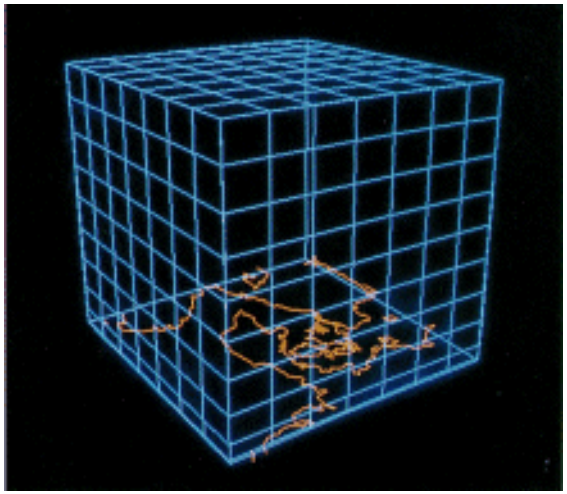
- Initial conditions
- Verification and validation of model forecasts
- Monitoring and assessment of observations
- Observing system design
- Reanalysis
- Better understanding:
  - Data assimilation methods
  - Model errors
  - Data errors
  - …

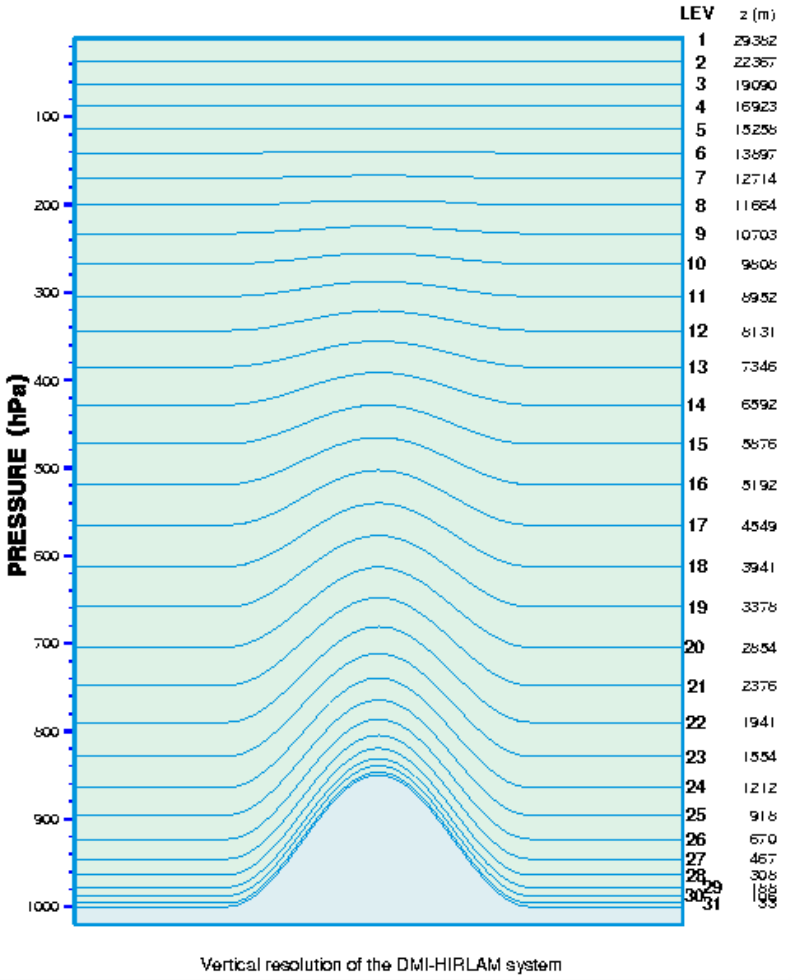
Data Assimilation: making bridge between model and observations



Observations
y^o, ~10^5-10^6

Model state
x, ~10^7





Vertical resolution of the DMI-HIRLAM system

WRFDA is a Data Assimilation system built within the WRF software framework, …

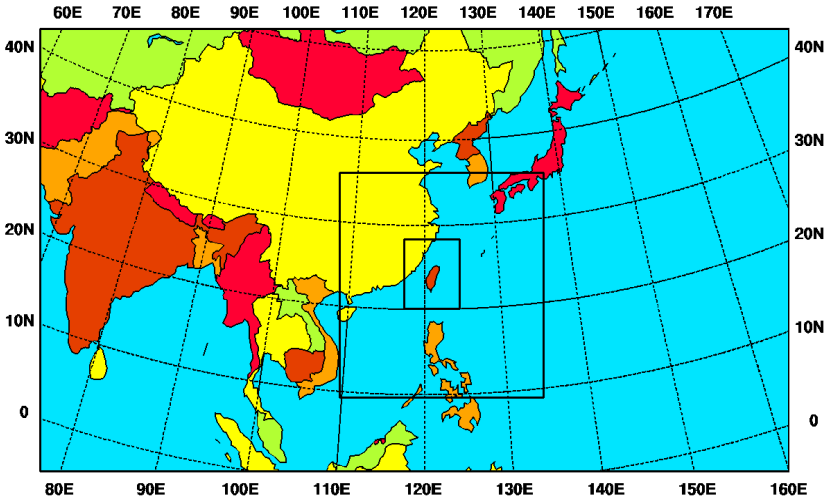
- **Goal:** Community WRF DA system for
  - research/operations, and
  - deterministic/probabilistic applications.

- **DA Techniques:**
  - 3D-Var
  - 4D-Var
  - Ensemble Transformed Kalman Filter
  - Hybrid-3DVAR.

- **Support:**
  - NCAR/MMM via wrfhelp@ucar.edu

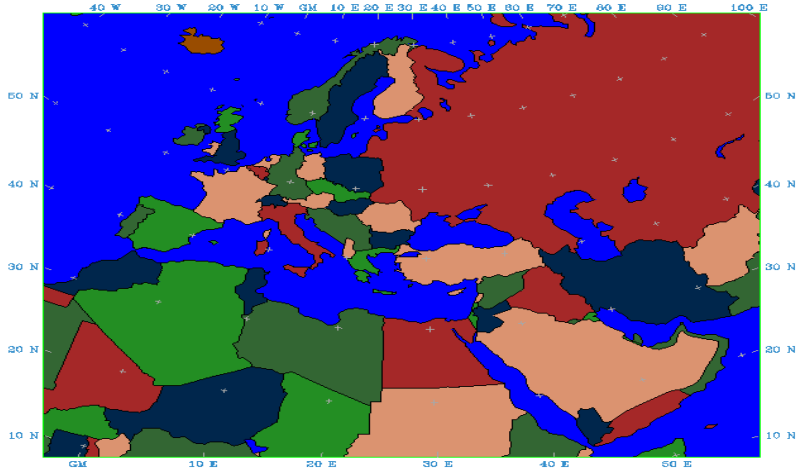
- **Observations:** Conv.+Sat.+Radar(+bogus)

Domain area of CWB WRF



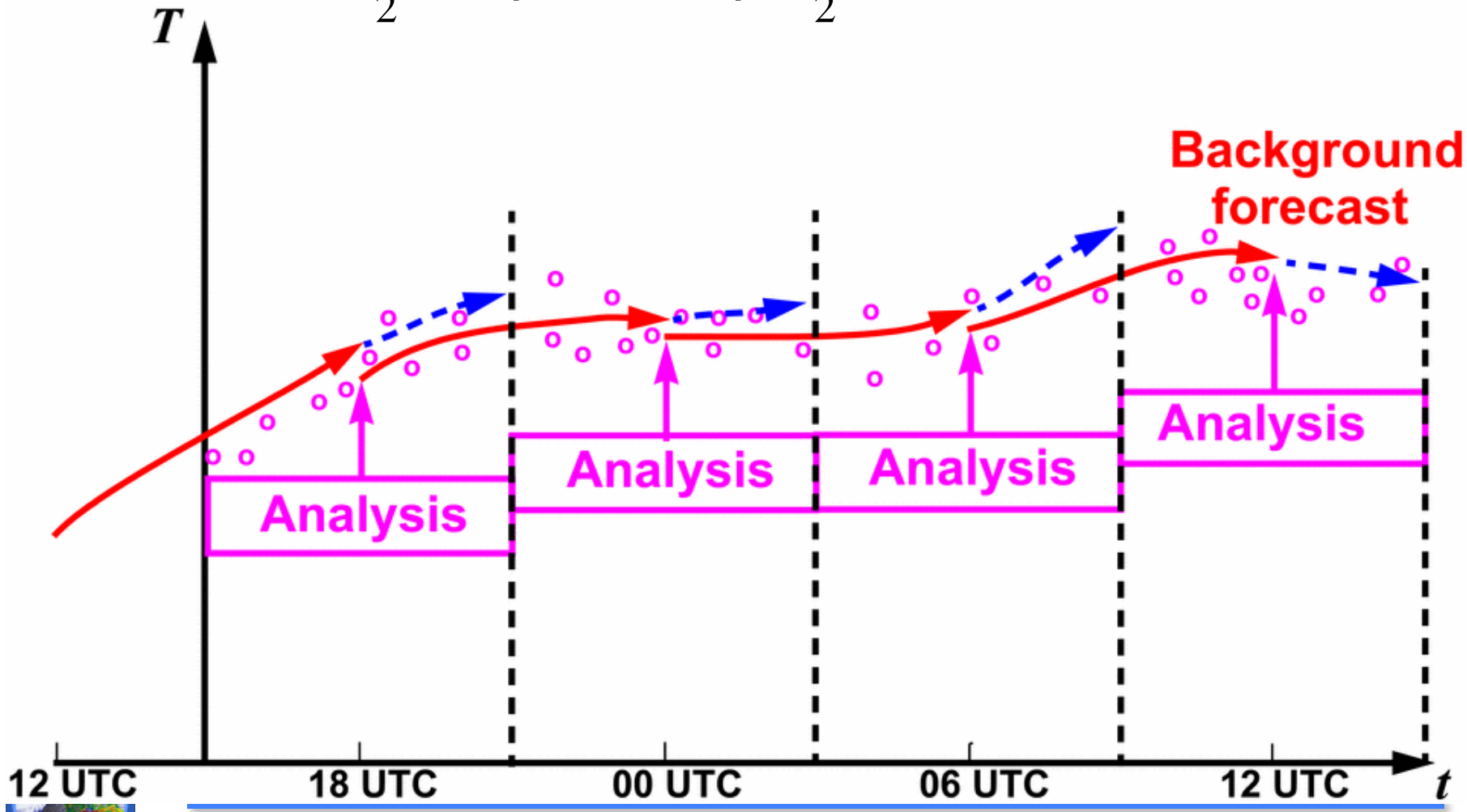
Both operations run in hybrid-3DVAR mode

Panasonic Weather Solution European



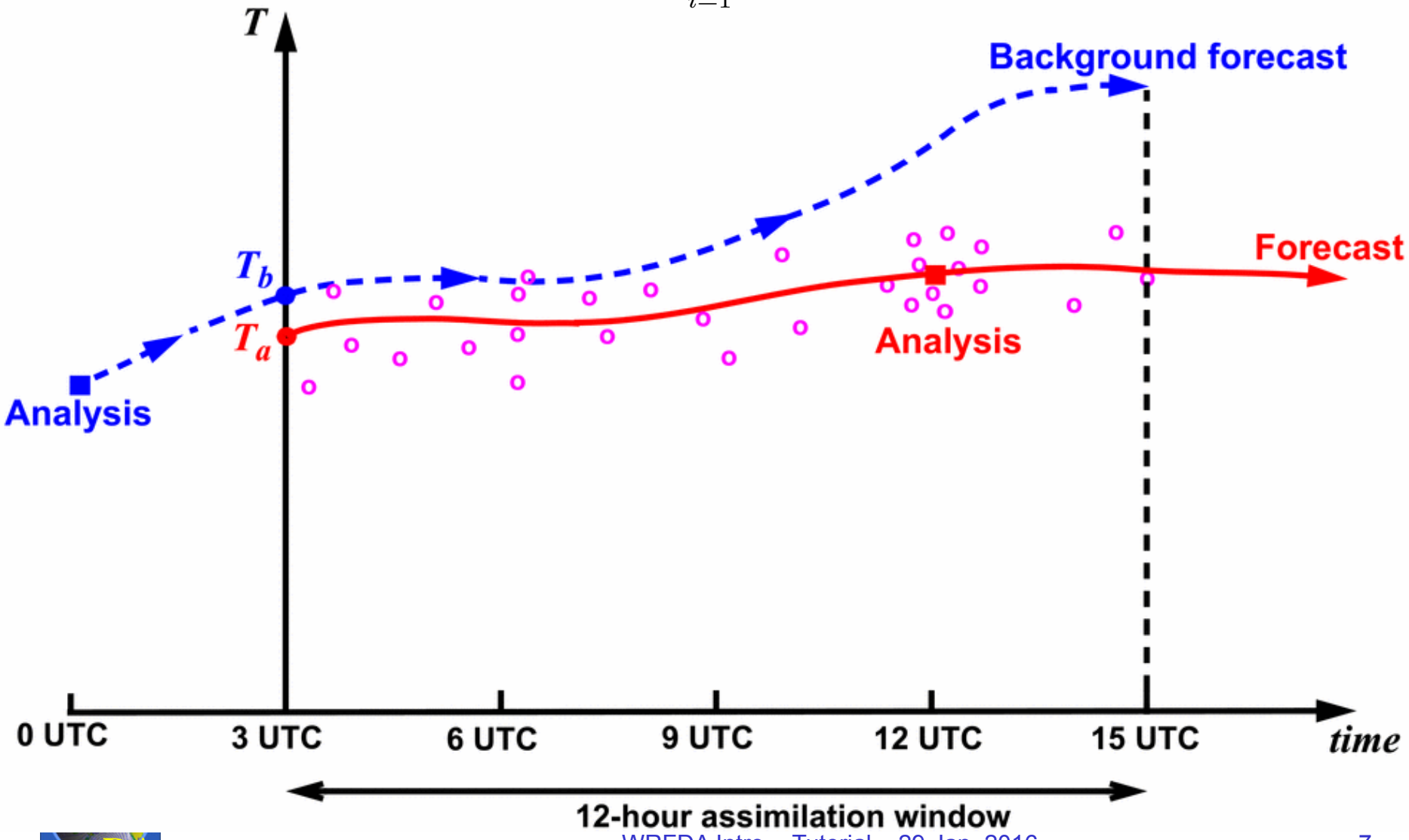
3DVAR (Barker et al. 2004)

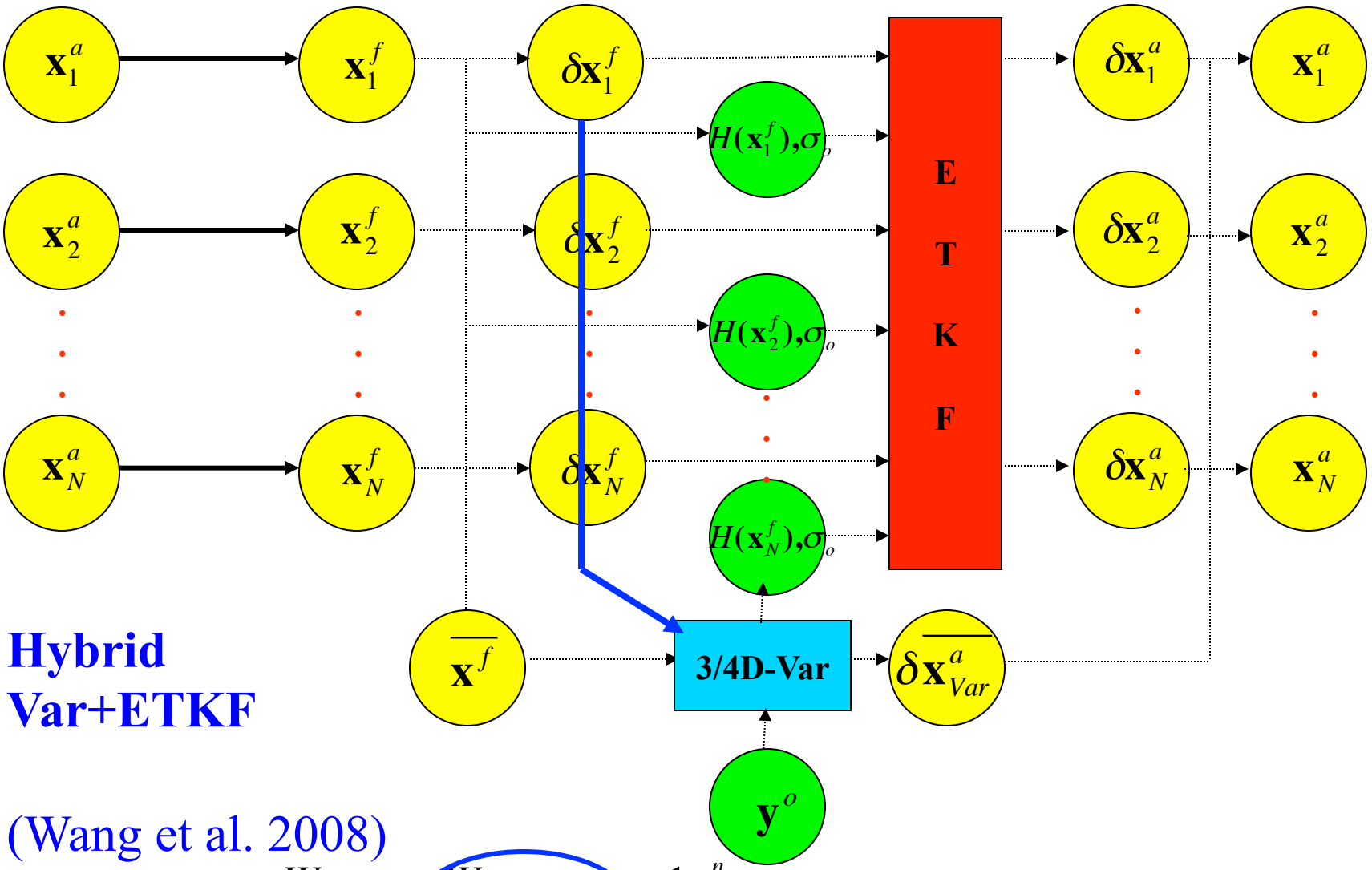
$$J(x) = \frac{1}{2}(x - x_b)^{\mathrm{T}} \mathrm{B}^{-1}(x - x_b) + \frac{1}{2}[H(x) - y]^{\mathrm{T}} \mathrm{R}^{-1}[H(x) - y]$$



4DVAR (Huang et al. 2009)

$$J(\mathbf{x}_0) = \frac{1}{2}(\mathbf{x}_0 - \mathbf{x}_0^b)^{\mathrm{T}}\mathbf{B}^{-1}(\mathbf{x}_0 - \mathbf{x}_0^b) + \frac{1}{2}\sum_{i=1}^{N}[H_i(M_i(\mathbf{x}_0)) - \mathbf{y}_i]^{\mathrm{T}}\mathbf{R}_i^{-1}[H_i(M_i(\mathbf{x}_0)) - \mathbf{y}_i]$$





Hybrid Var+ETKF

(Wang et al. 2008)

$$J = \frac{W_b}{2}\mathbf{v}^T\mathbf{v} + \frac{W_\alpha}{2}\mathbf{a}^T\mathbf{A}^{-1}\mathbf{a} + \frac{1}{2}\sum_{i=0}^{n}\left[\mathbf{d}_i - \mathbf{H}_i\mathbf{M}_i\mathbf{U}\mathbf{v}\right]^T \mathbf{R}_i^{-1}\left[\mathbf{d}_i - \mathbf{H}_i\mathbf{M}_i\mathbf{U}\mathbf{v}\right]$$

WRFDA Observations

- **In-Situ:**
  - SYNOP
  - METAR
  - SHIP
  - BUOY
  - TEMP
  - PIBAL
  - AIREP, AIREP humidity
  - TAMDAR
- **Bogus:**
  - TC bogus
  - Global bogus

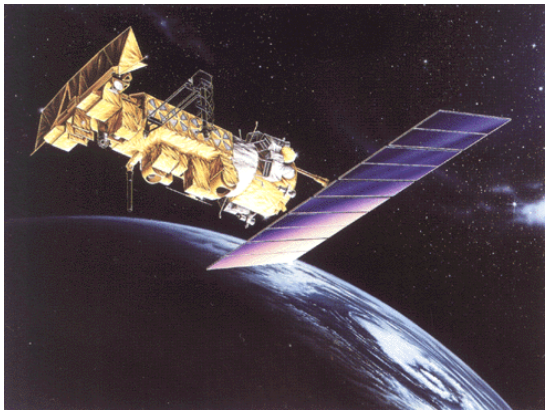
- **Remotely sensed retrievals:**
  - Atmospheric Motion Vectors (geo/polar)
  - SATEM thickness
  - Ground-based GPS TPW or ZTD
  - SSM/I oceanic surface wind speed and TPW
  - Scatterometer oceanic surface winds
  - Wind Profiler
  - **Radar data (enhancements in V3.7)**
  - Satellite temperature/humidity/thickness profiles
  - GPS refractivity (e.g. COSMIC)
  - Stage IV precipitation/rain rate data (4D-Var)

- **Radiances: can use RTTOV_11.1 or 11.2 (new in V3.7) or CRTM_2.1.3:**
  - HIRS NOAA-16, NOAA-17, NOAA-18, NOAA-19, METOP-A
  - AMSU-A NOAA-15, NOAA-16, NOAA-18, NOAA-19, EOS-Aqua, METOP-A, METOP-B
  - AMSU-B NOAA-15, NOAA-16, NOAA-17
  - MHS NOAA-18, NOAA-19, METOP-A, METOP-B
  - AIRS EOS-Aqua
  - SSMIS DMSP-16, DMSP-17, DMSP-18
  - IASI METOP-A, METOP-B
  - ATMS Suomi-NPP
  - MWTS FY-3
  - MWHS FY-3
  - SEVIRI METEOSAT

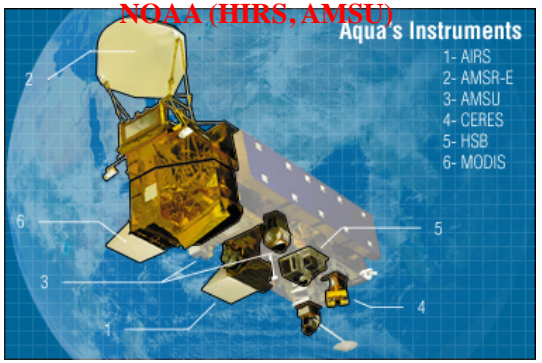
WRFDA is flexible to allow assimilation of different formats of observations:

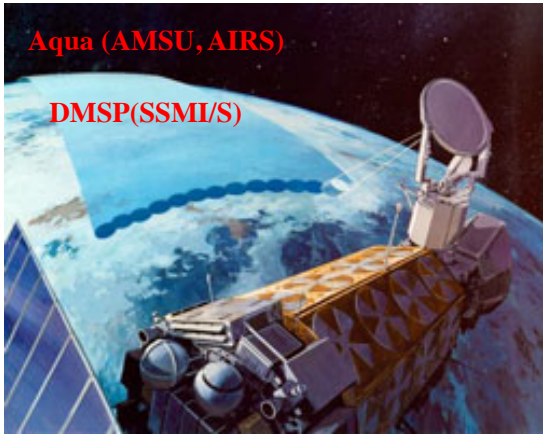
- **Little_r (ascii), HDF, Binary**
- **NOAA MADIS (netcdf),**
- **NCEP PrepBufr,**
- **NCEP radiance bufr**

WRFDA
Radiance Assimilation



- BUFR 1b radiance ingest.
- **RTM interface (v3.5.1):**
  RTTOV (v11.1 or 11.2) or CRTM (v2.1.3)
- NESDIS microwave surface emissivity model
- Range of monitoring diagnostics.
- Quality Control for HIRS, AMSU, AIRS, SSMI/S.
- **Bias Correction:**
  Adaptive or Variational
- Variational observation error tuning
- Parallel: MPI
- Flexible design to easily add new satellite sensors
- Cloudy Radiance DA



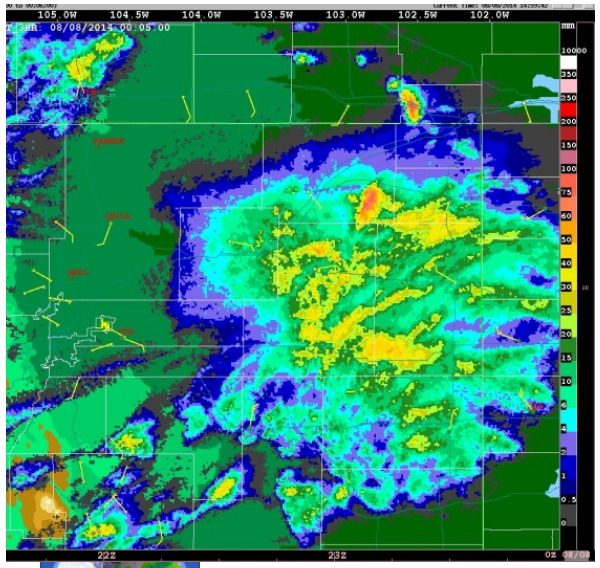


New capabilities in WRFDA 3.7 for radar DA

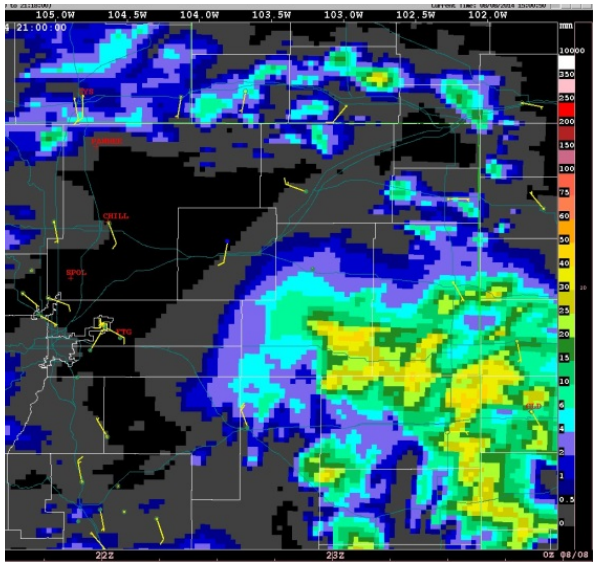
- Added separate cloud analysis variables Qc and Qr (vs. existing total water analysis variable)
- A new scheme to indirectly assimilate reflectivity by converting reflectivity to rainwater
- Added the assimilation of estimated humidity (from reflectivity) within cloud
- Making 4DVar radar DA fully compatible with 3DVar
- The new CV option CV7 is recommended for radar DA

3H accumulated rainfall in northeastern Colorado
during STEP 2014 Hydromet summer real time experiment at t = 3h

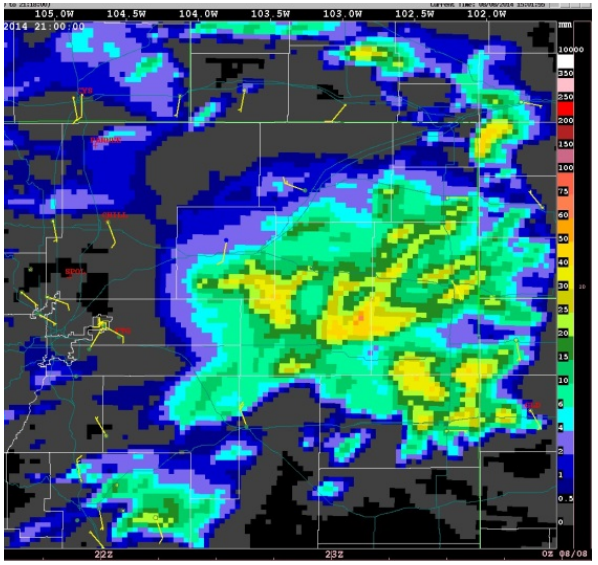
OBS



3DVar without radar

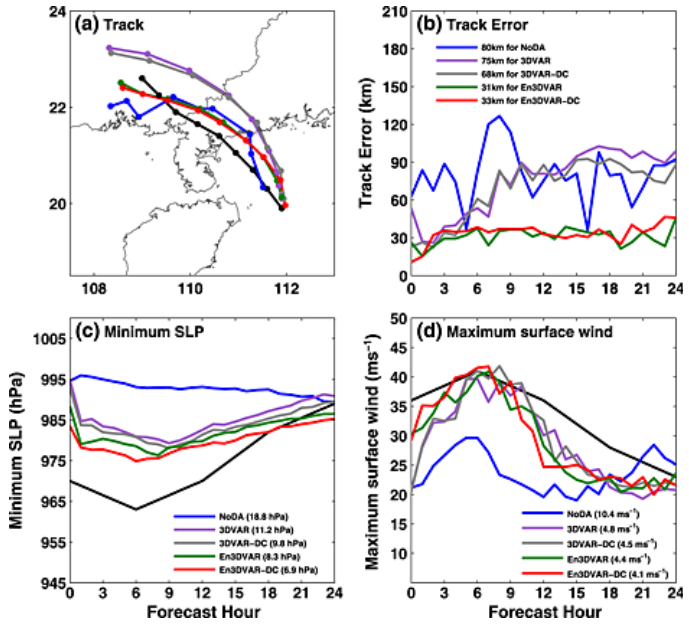


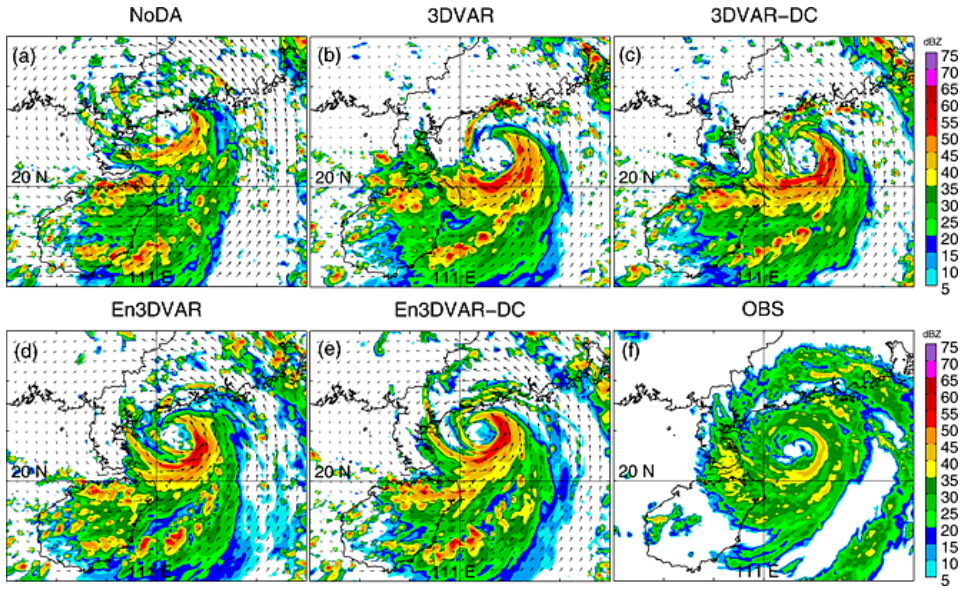
3DVar with radar



Next release: dynamic constraint option

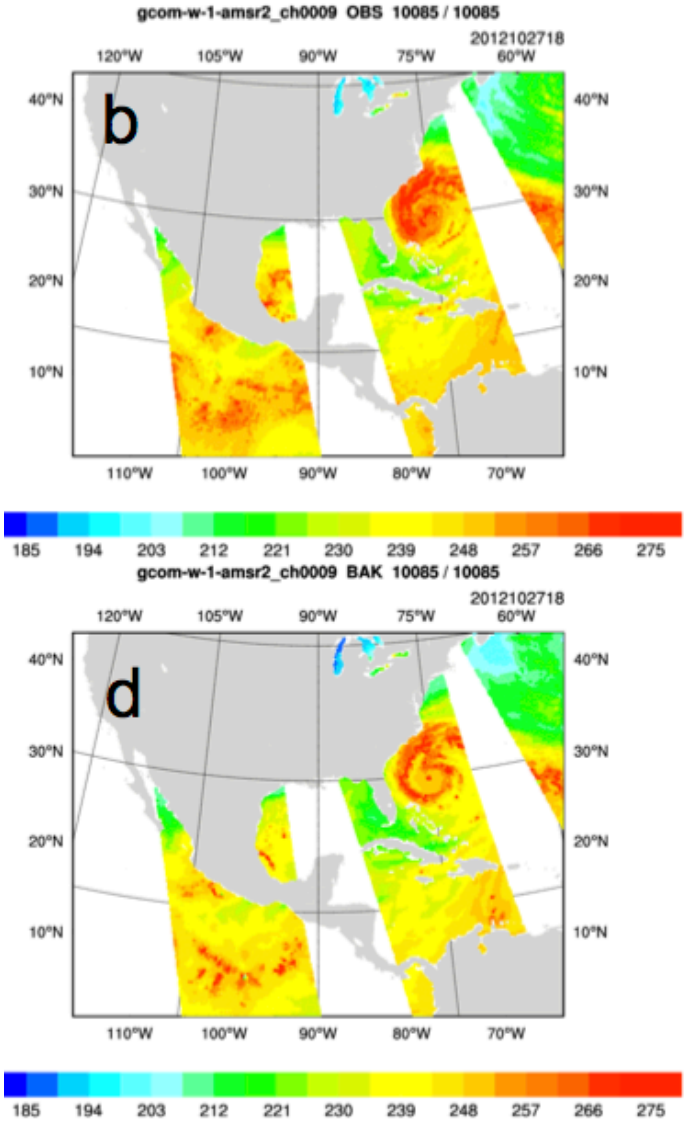
User contributed: Li et al., 2015 *JGR* (doi:10.1002/2014JD022706)

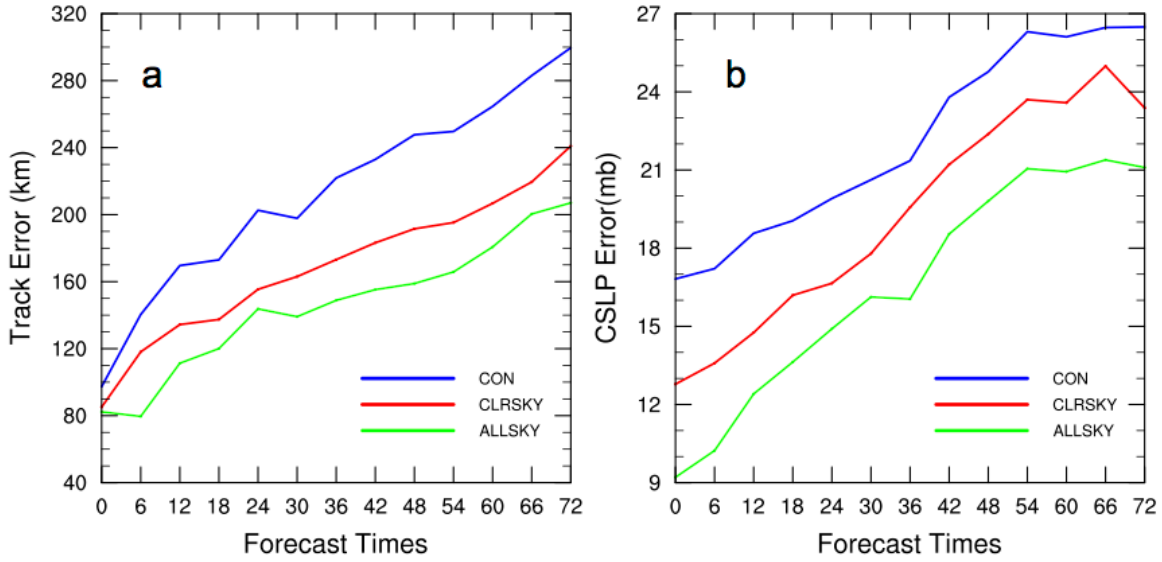




- Left: plots showing TC track and intensity with (gray and red) and without (purple and green) the dynamic constraint. Best track is in black
- Right: changes in initial analyzed reflectivity with and without the dynamic constraint

Next release: AMSR2 radiance DA





Applied to Hurricane Sandy forecast with clear-sky and all-sky AMSR2 radiance DA

Yang et al., 2016

www2.mmm.ucar.edu/wrf/users/wrfda

WRFDA *USERS* PAGE

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Have questions? Try our FAQ first!

WRF Data Assimilation System Users Page

Welcome to the page for users of the Weather Research and Forecasting (WRF) model data assimilation system (WRFDA). The WRFDA system is in the public domain and is freely available for community use. It is designed to be a flexible, state-of-the-art atmospheric data assimilation system that is portable and efficient on available parallel computing platforms. WRFDA is suitable for use in a broad range of applications, across scales ranging from kilometers for regional and mesoscale modeling to thousands of kilometers for global scale modeling.

The Mesoscale and Microscale Meteorology (MMM) Laboratory of NCAR currently maintains and supports a subset of the overall WRF code (Version 3) that includes:

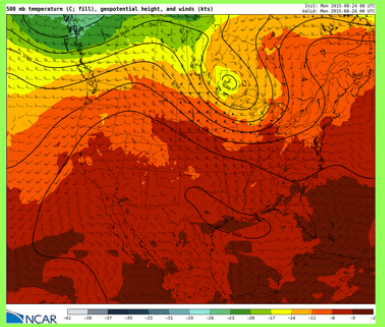
- WRF Software Framework (WSF)
- Advanced Research WRF (ARW) dynamic solver, including one-way, two-way nesting and moving nests, grid and observation nudging
- WRF Pre-Processing System (WPS)
- **WRF Data Assimilation System (WRFDA)** *(found on this site)*
- Numerous physics packages contributed by WRF partners and the research community

Other components of the WRF system will be supported for community use in the future, depending on interest and available resources.

LATEST WRFDA RELEASE

WRFDA Version 3.7.1
(Released August 14, 2015)

WRF / WRFDA REALTIME FORECAST



Click here for latest 48-hr forecast

UPCOMING EVENTS

June, 2016

2016 WRF Workshop, NCAR Center Green Campus, Boulder, CO, USA.

WHAT'S NEW

NCAR WRF/WRFDA

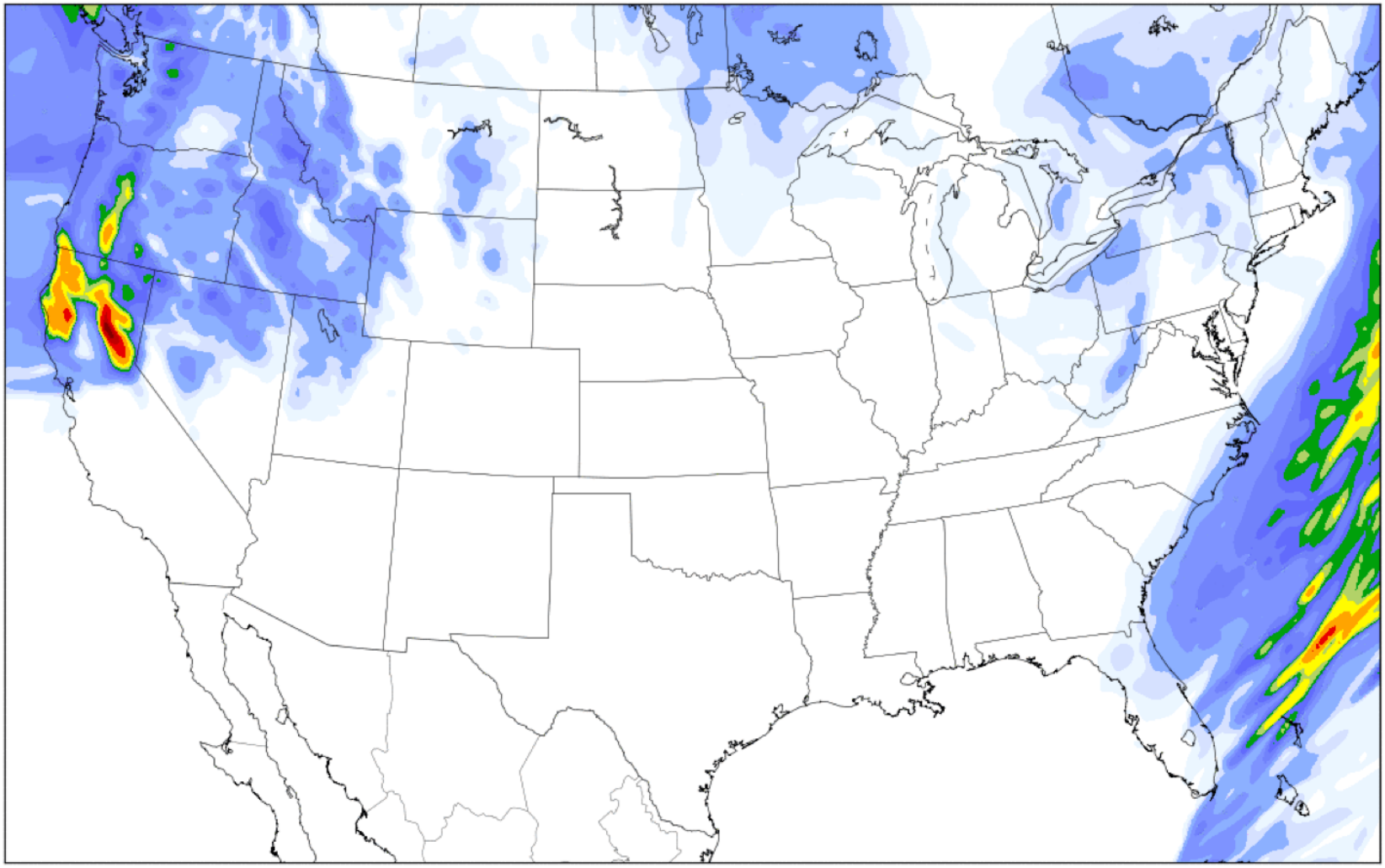
Initialized: 00 UTC Fri 29 Jan 2016

Surface/Precip | Upper-Air | Severe | Obs. Diag. | Anl. State | Increments

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 **24** 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48

15-km ARW WRF 24-hr accumulated precipitation (in)

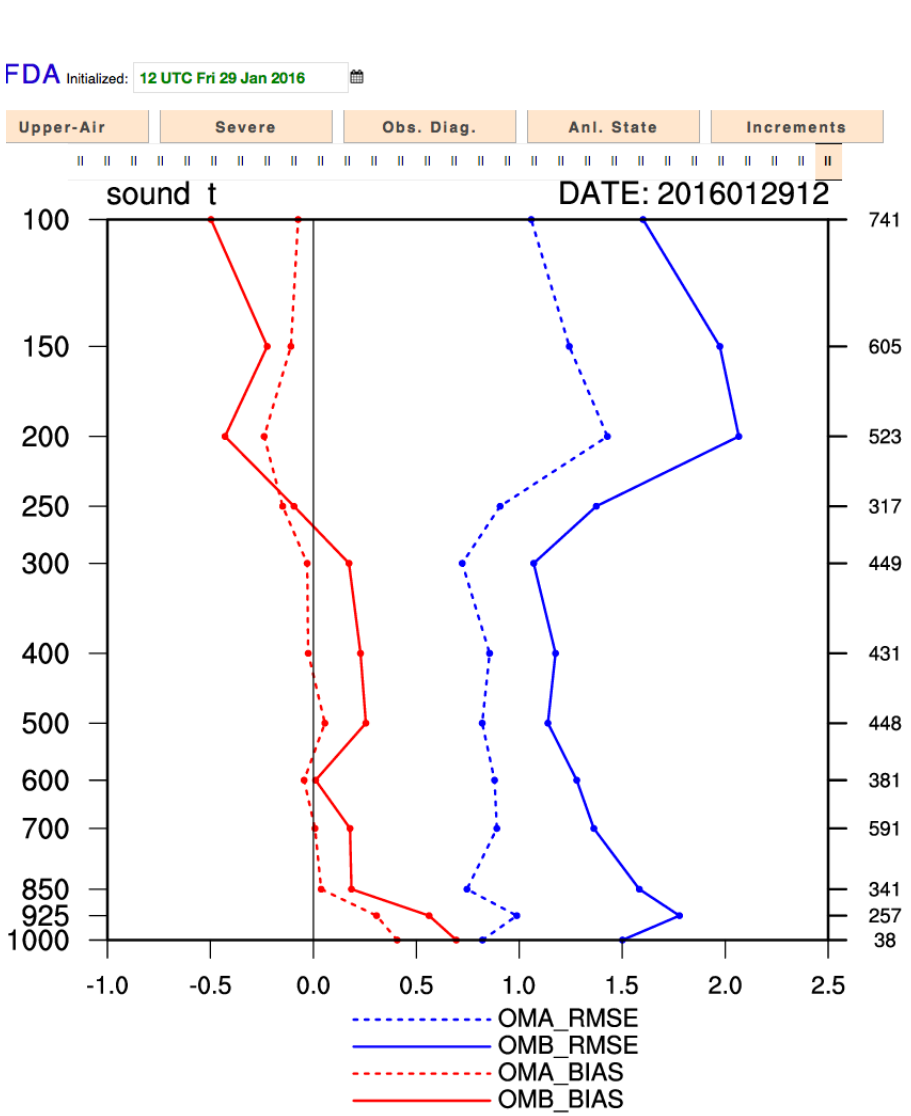
Init: Fri 2016-01-29 00 UTC
Valid: Sat 2016-01-30 00 UTC



NCAR

0.00 0.01 0.05 0.10 0.25 0.50 0.75 1.00 1.25 1.50 2.00 3.00 4.00 5.00 6.00 7.00 8.00 9.00 10.00 11.00 12.00

Forecasts sponsored by the National Science Foundation, National Center for Atmospheric Research/Mesoscale and Microscale Meteorology Laboratory, and Computational Information Systems Laboratory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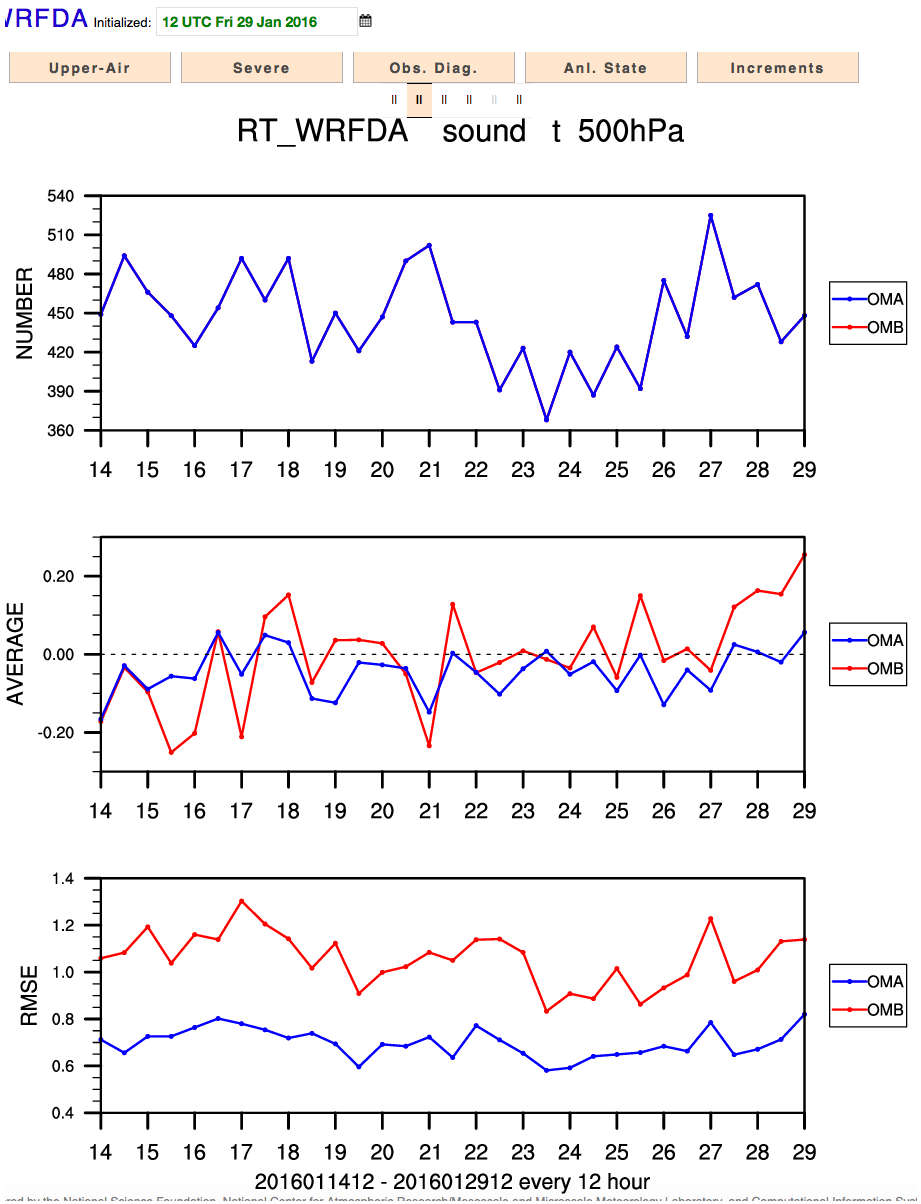
OMB_BIAS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OMA
OMB
2016011412 - 2016012912 every 12 hour

Learn WRFDA from online tutorial presentations and practice

WRFDA Tutorial: 2015 Agenda

Click the links in the agenda below to download the slide presentations and view the practice exercises

2015 WRFDA Tutorial Agenda

Wednesday - August 5, 2015

08:00-08:30	Registration	
08:30-09:00	**Welcome and Participants' Introduction**	Zhiquan Liu
09:00-10:00	**Overview of WRF Data Assimilation**	Zhiquan Liu
10:00-10:20	Coffee Break	
10:20-11:10	**WRFDA Software and Compilation**	Michael Kavulich
11:10-12:00	**Observations (1): Conventional Obs Pre-Processing**	Jamie Bresch
12:00-13:00	Lunch	
13:00-14:00	**Algorithm (1): 3DVAR Setup, Run and Diagnostics**	Craig Schwartz
14:00-15:00	**Algorithm (2): Background Error Modeling and Estimation**	Syed Rizvi
15:00-15:20	Coffee Break	
15:20-15:30	**Introduction to practice sessions**	Michael Kavulich
15:30-18:00	**Practice Session 1 (OBSPROC, 3DVAR, GEN_BE, single-ob tests)**	

Thursday - August 6, 2015

09:00-10:00	**Observations (2): Radiance data assimilation**	Jamie Bresch
10:00-10:20	Coffee Break	
10:20-11:00	**Algorithm (3): 4DVAR**	Zhiquan Liu
11:00-12:30	**Practice Session 2 (Radiance, 4DVAR)**	
12:30-13:30	lunch	
13:30-14:20	**Algorithm (4): Hybrid Variational/Ensemble**	Craig Schwartz
14:20-15:10	**Observations (3): Radar Data Assimilation**	Jenny Sun
15:10-15:30	Coffee Break	
15:30-16:10	**WRFDA Tools and Verification Package**	Michael Kavulich
16:10-16:30	**Wrap-up discussion**	Zhiquan Liu
16:30-18:00	**Practice Session 3 (hybrid, radar, tools)**	

Friday - August 7, 2015

08:00-12:00	**Practice Session 4 (WRF/WRFDA cycling, FGAT, FSO, other exercises)**	