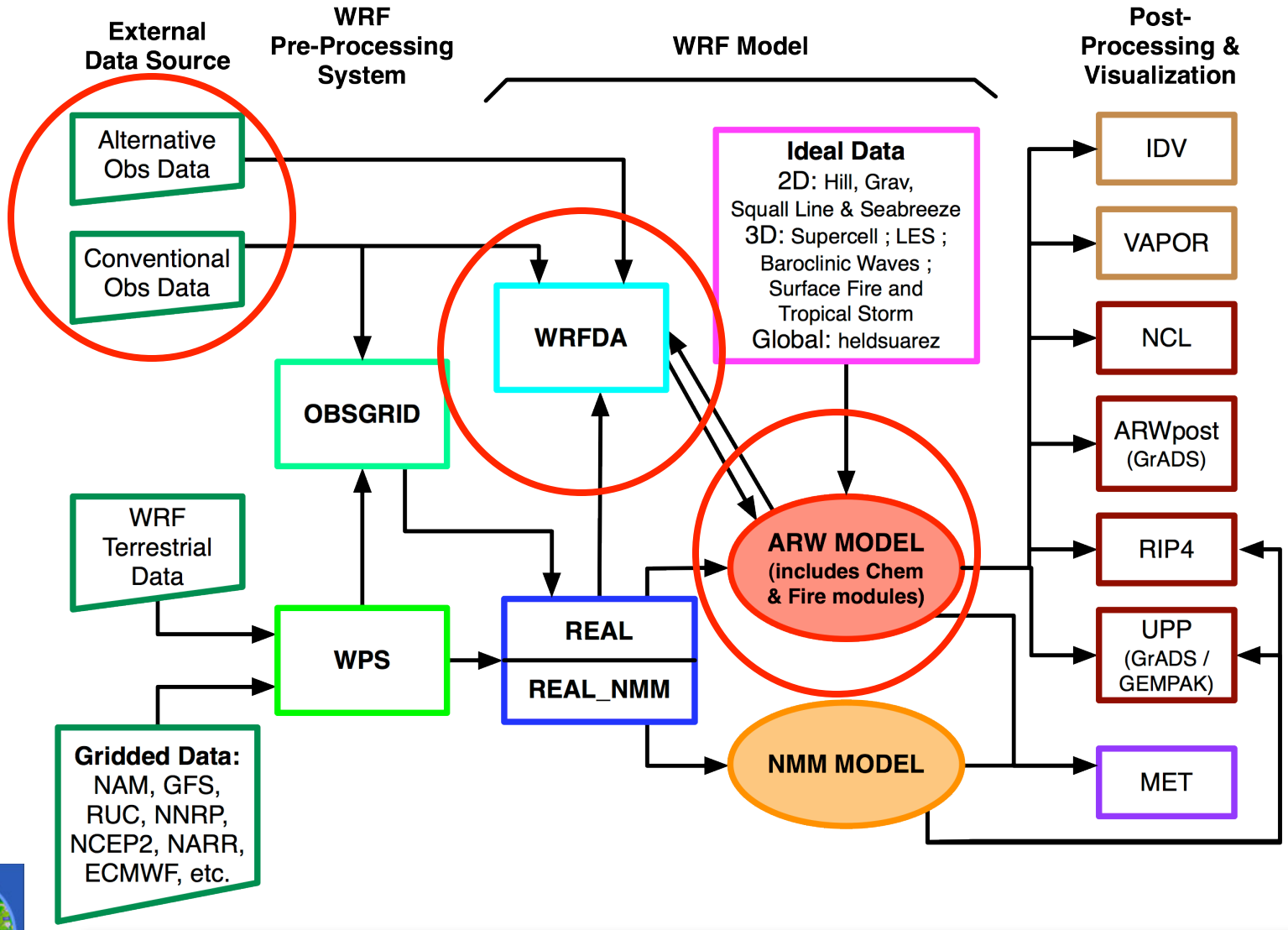
Introduction to WRFDA

Zhiquan (Jake) Liu

NCAR/MMM

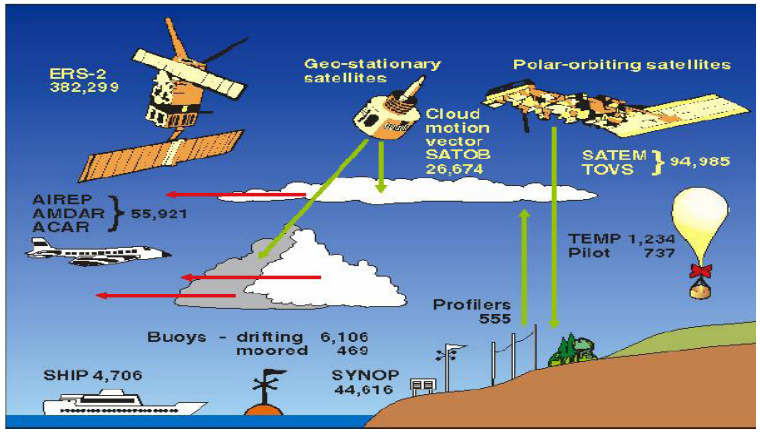
WRFDA is a Data Assimilation system built within the WRF software framework, used for applications in both research and operational environments….

WRFDA in WRF Modeling System



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
  - …

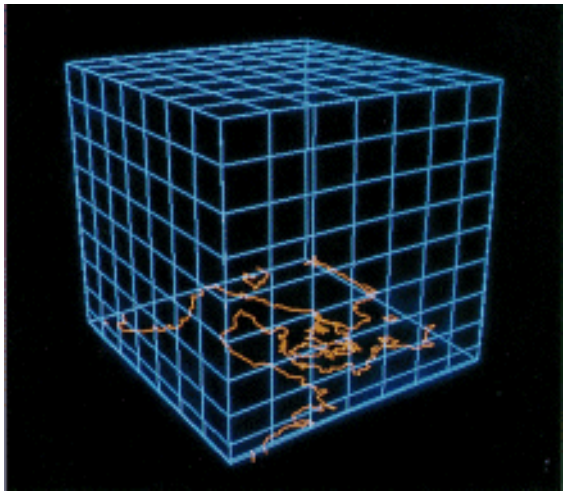


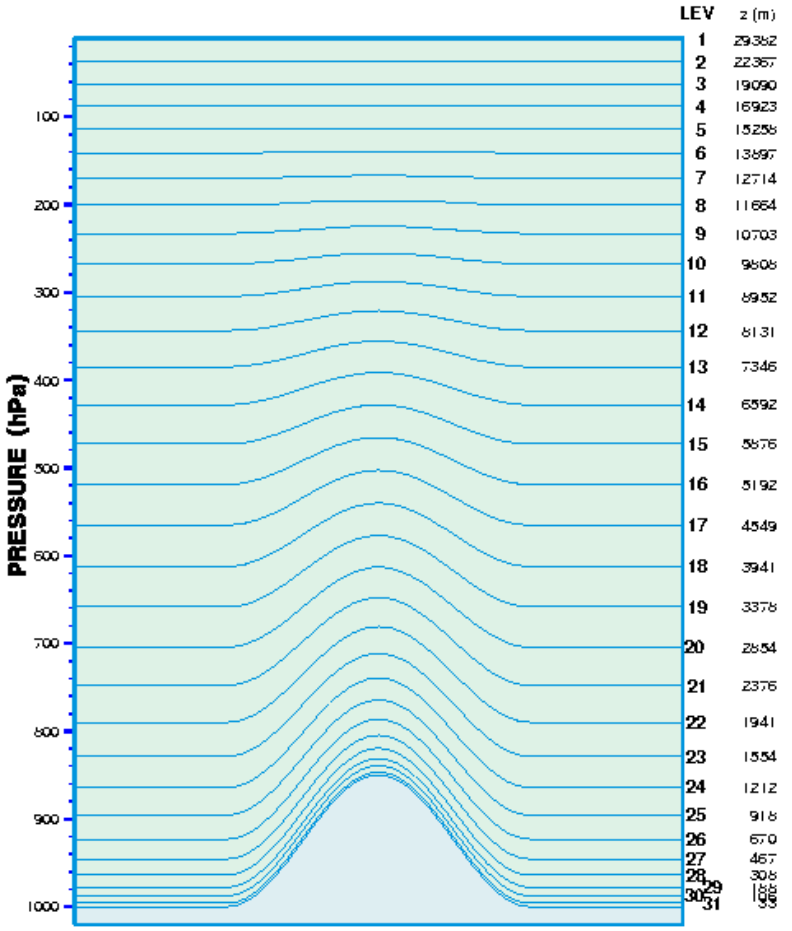
Observations

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

Model state

x, ~10^7





Vertical resolution of the DMI-HIRLAM system

Radiance impact on Hurricane forecasts (Liu et al. 2012)

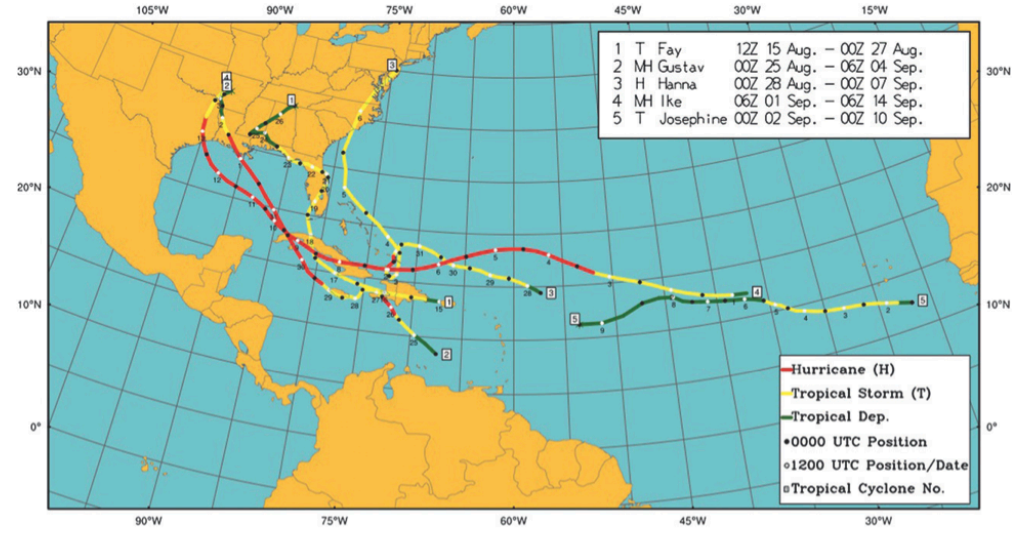


FIG. 1. NHC best track for the five named storms during 11 Aug–13 Sep 2008. See legend for meanings of colors and symbols used in the

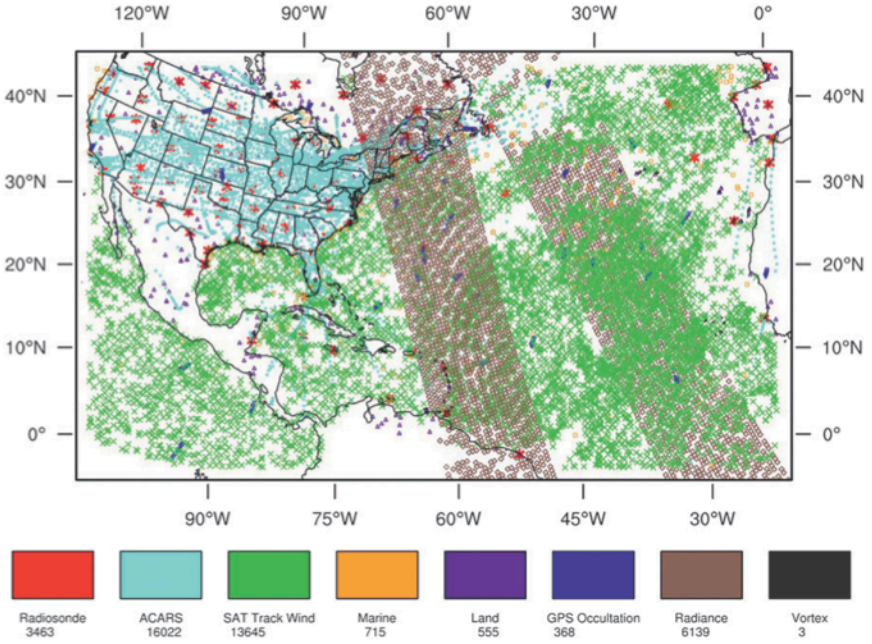


FIG. 2. Snapshot of observations assimilated at 0000 UTC 16 Aug 2008.

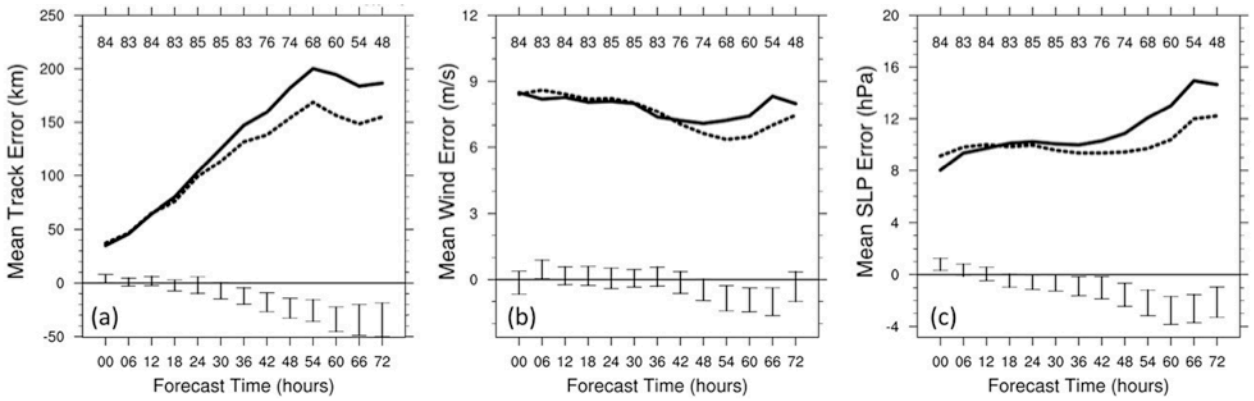
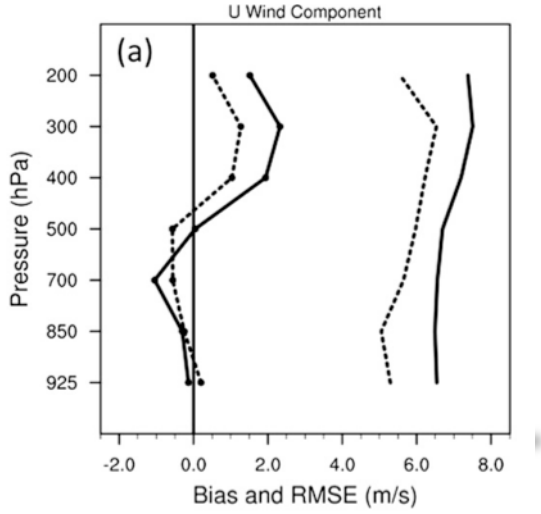
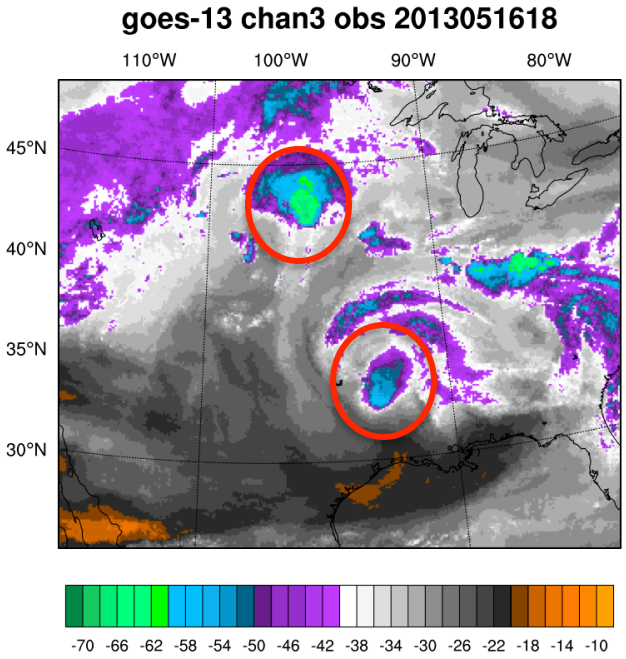


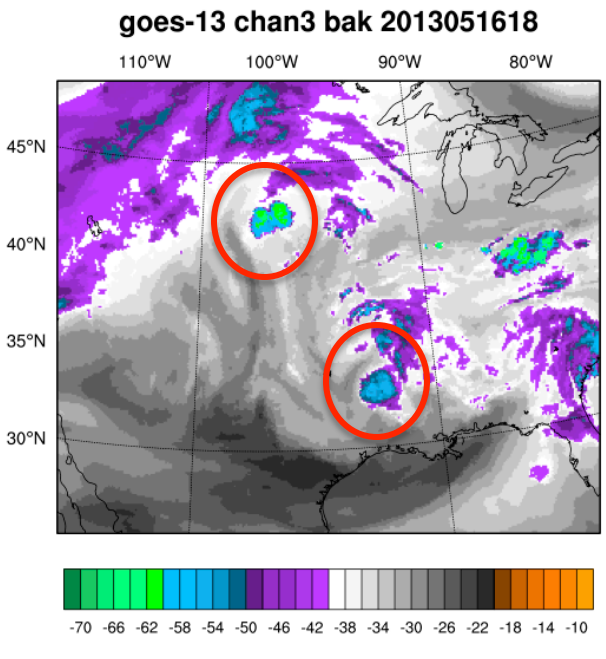
FIG. 5. Mean absolute errors as a function of forecast lead time for (a) track, (b) maximum wind speed, and (c) minimum sea level pressure for all storms. Solid lines denote the results from the NoAMA experiment and dashed lines denote the results from the AMA experiment. Bounds of the 90% confidence interval based upon differences between the two experiments' errors (see section 6b) are also shown.



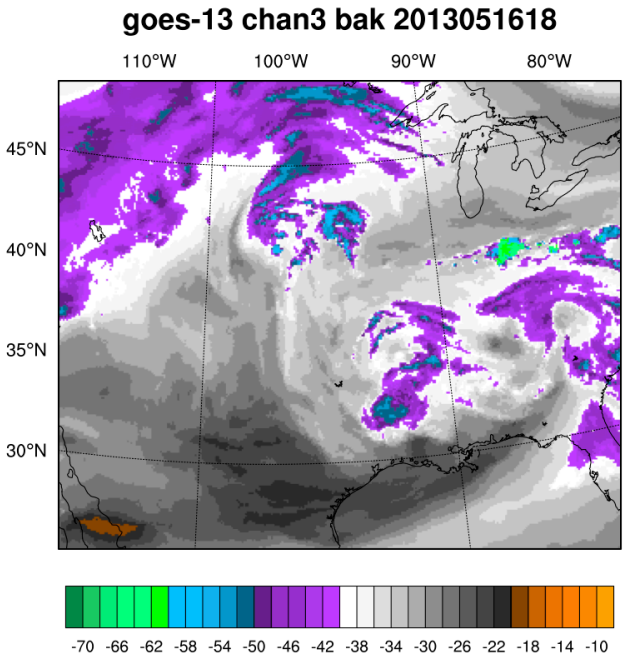
New radiance data assimilation: GOES-Imager



GOES-13 WV Obs



WRF 24-h Forecast with assimilation of GOES-13 clear-sky WV Obs



WRF 24-h Forecast w/o assim. of GOES-13 WV Obs

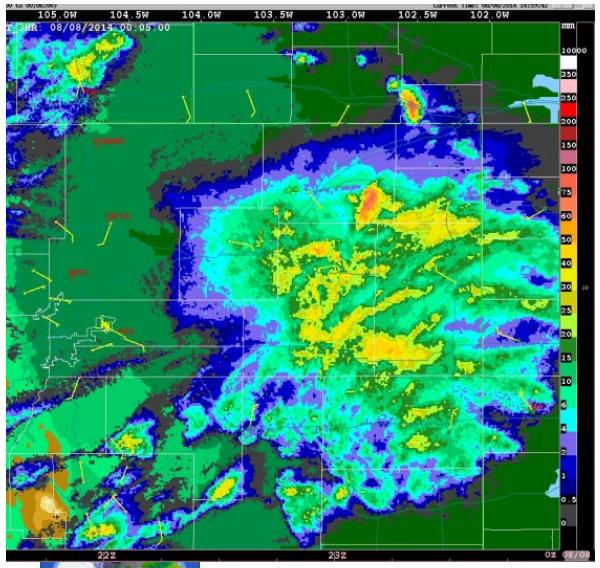
WRF configured at 3-km with hourly cycling 3DVAR assimilation

New capabilities in WRFDA 3.7 for radar DA

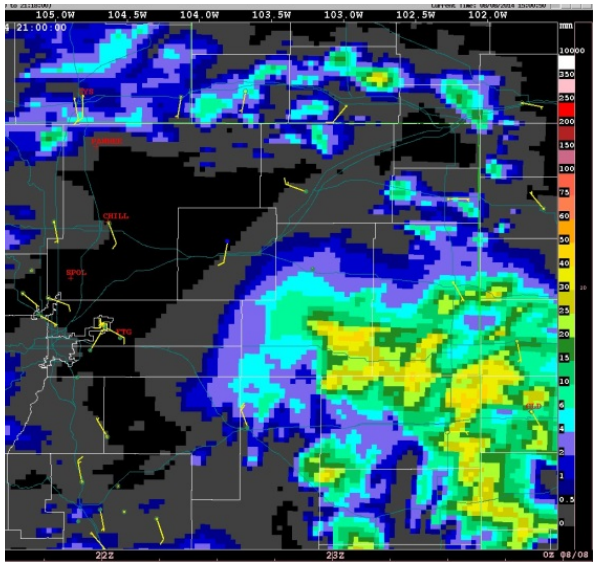
- Added separate cloud analysis variables Qc and Qr (vs. existing total water analysis variable)
- A new scheme to indirectly assimilate reflectivity by converting reflectivity to rainwater
- Added the assimilation of estimated humidity (from reflectivity) within cloud
- Making 4DVar radar DA fully compatible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

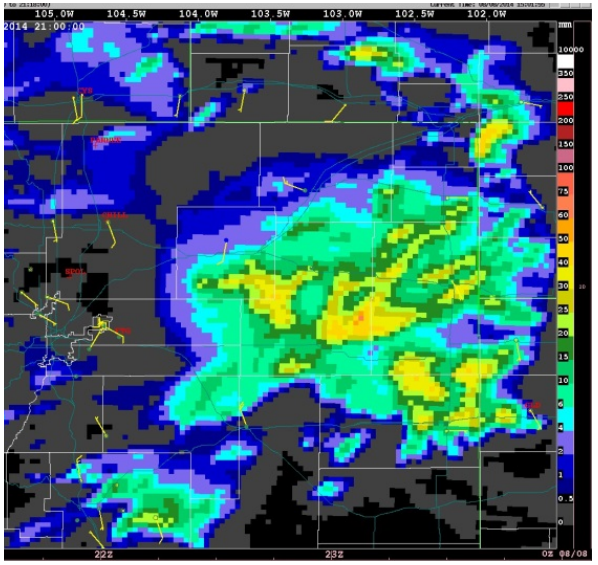
OBS



3DVar without radar

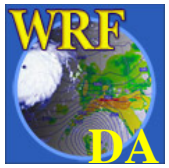


3DVar with radar



Assimilation methods

- Empirical methods
  - Successive Correction Method (SCM)
  - Nudging
  - Physical Initialisation (PI), Latent Heat Nudging (LHN)
- Statistical methods
  - Optimal Interpolation (OI)
  - 3-Dimensional VARiational data assimilation (3DVAR)
  - 4-Dimensional VARiational data assimilation (4DVAR)
- Advanced methods
  - Extended Kalman Filter (EKF)
  - Ensemble Kalman Filter (EnFK)
  - Hybrid VAR/Ens DA



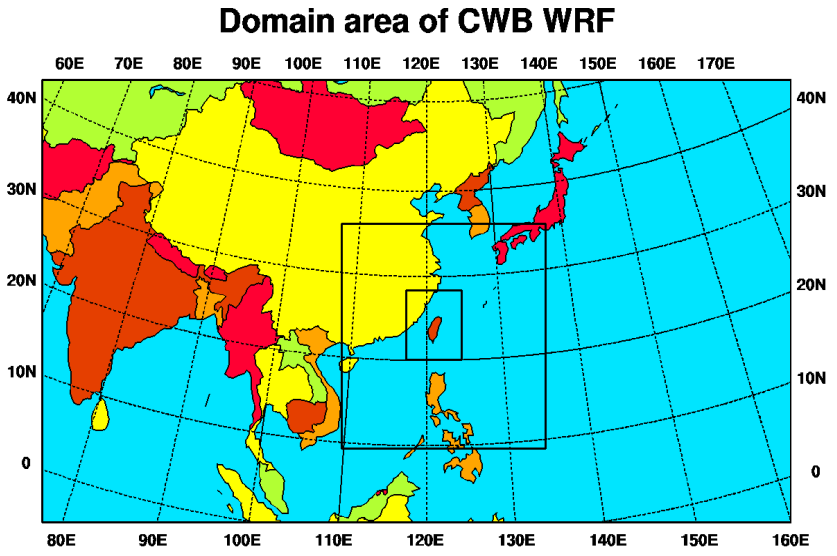
WRFDA is a Data Assimilation system built within the WRF software framework, …

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

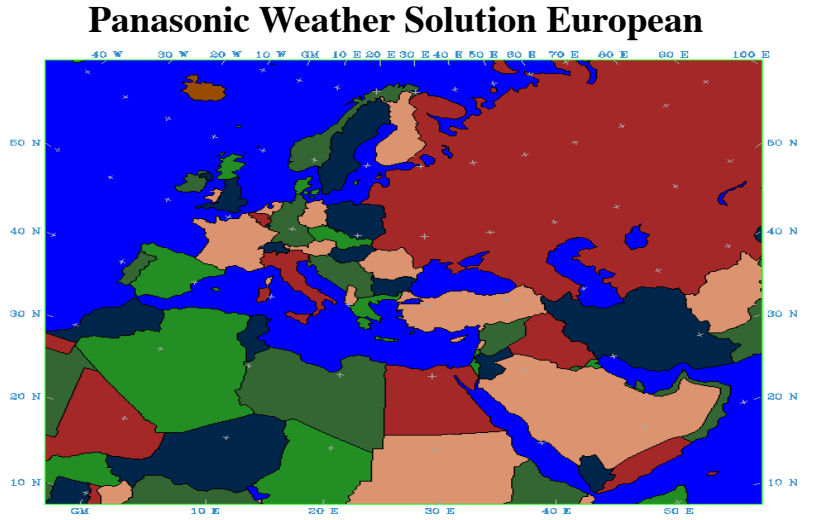
- **DA Techniques:**
  - 3D-Var
  - 4D-Var
  - Ensemble Transformed Kalman Filter
  - Hybrid-3DVAR.

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

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

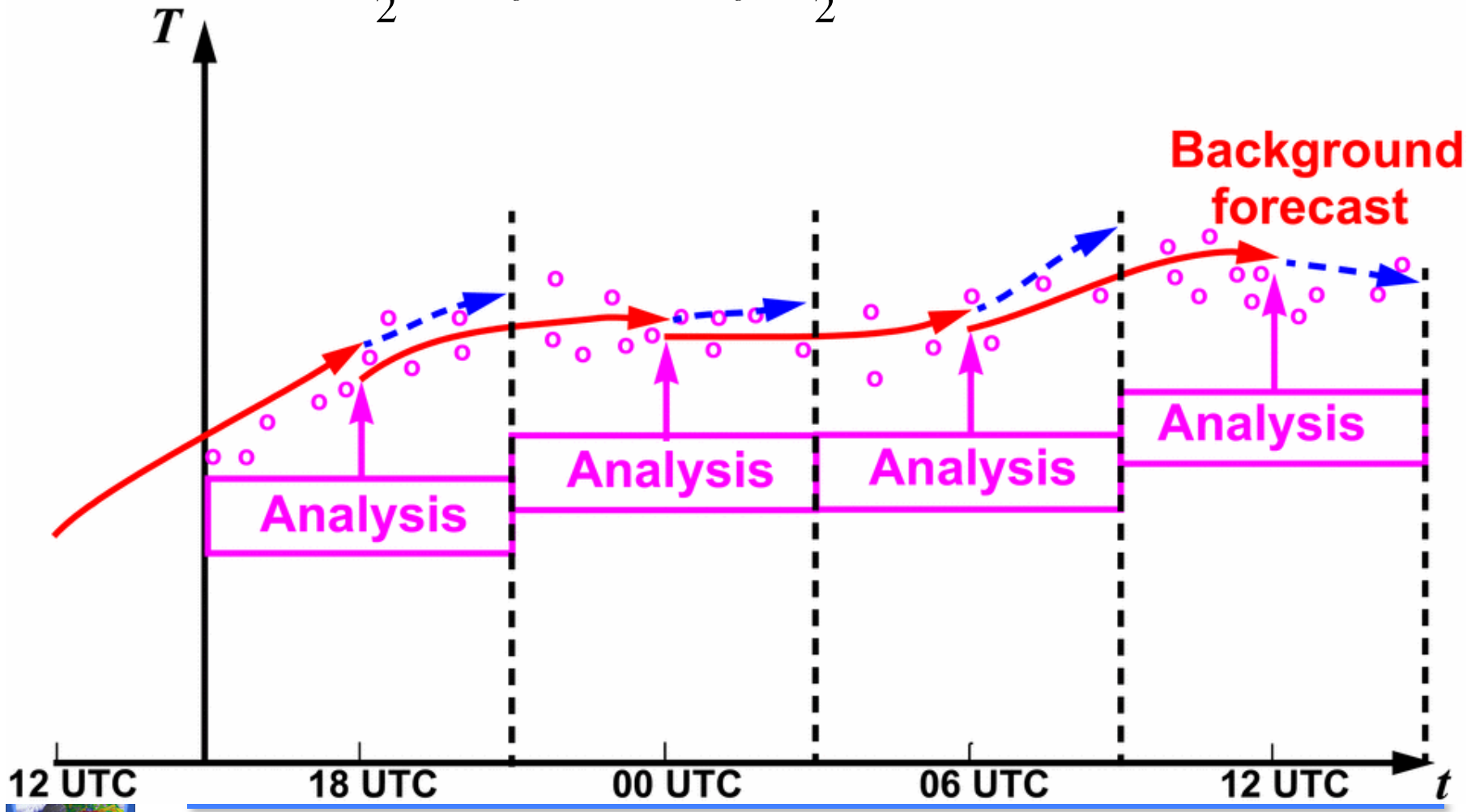


Both operations run in hybrid-3DVAR mode

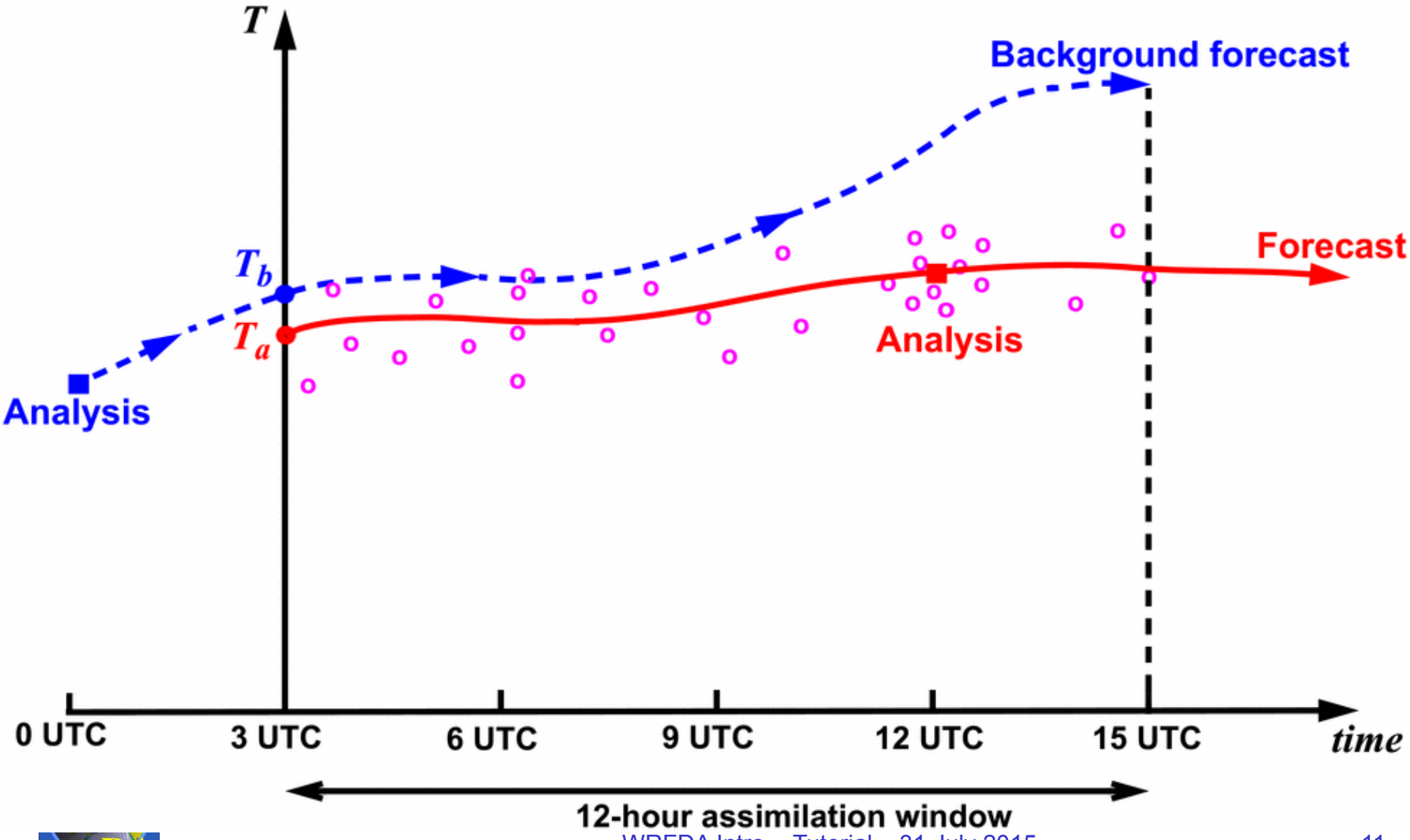


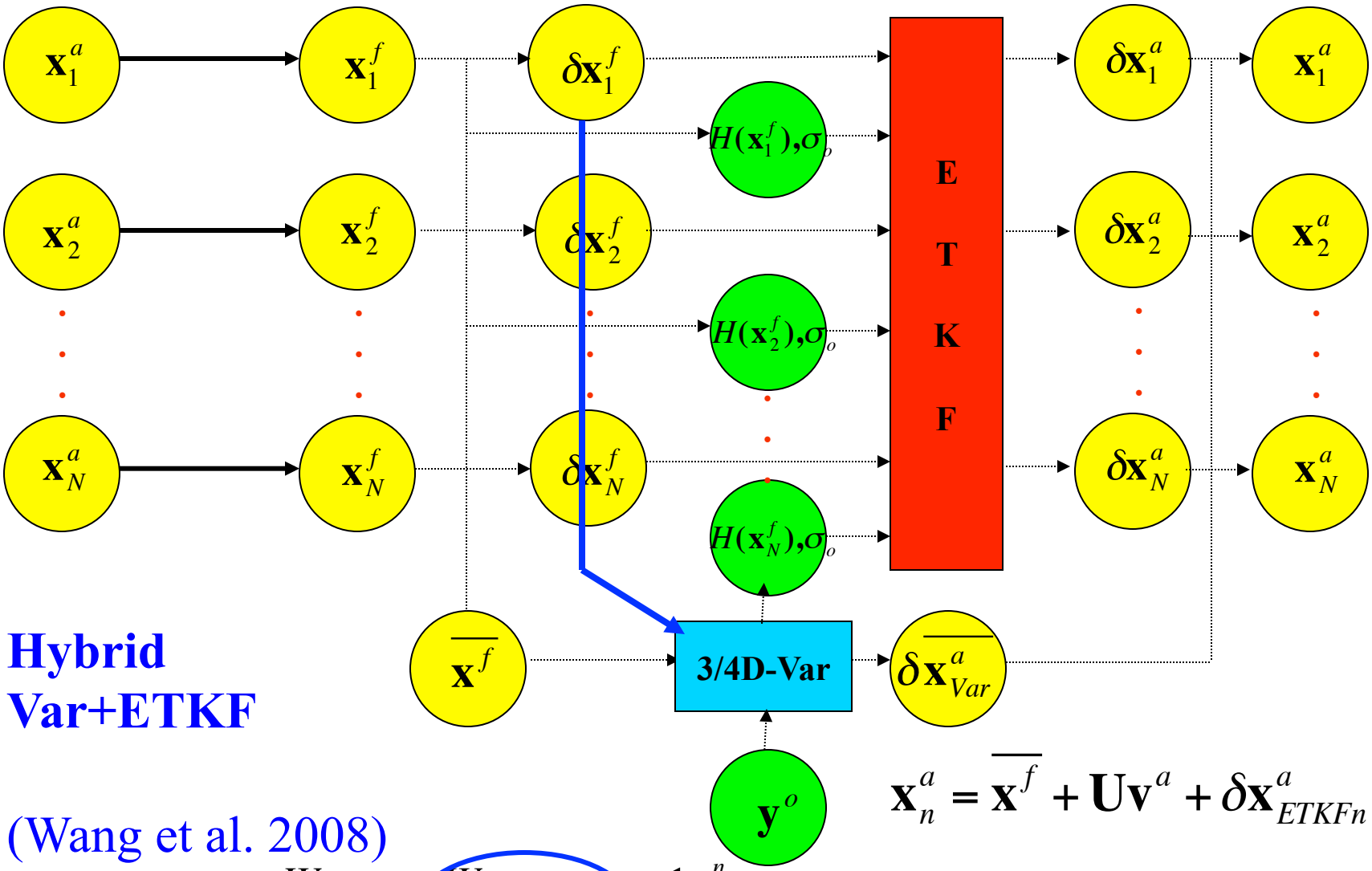
3DVAR (Barker et al. 2004)

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



4DVAR (Huang et al. 2009)





Hybrid Var+ETKF

(Wang et al. 2008)

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

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

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)

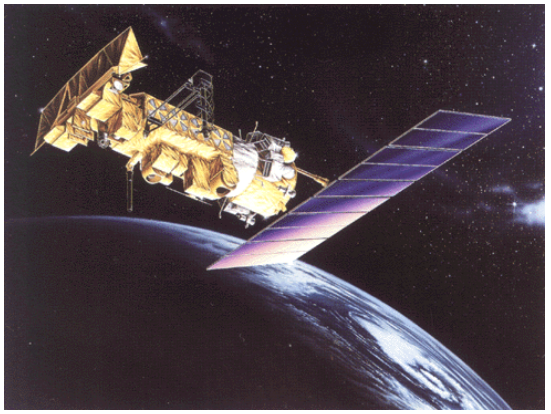
- **Radiances: can use RTTOV_11.1 or 11.2 (new in V3.7) or CRTM_2.1.3:**

– 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

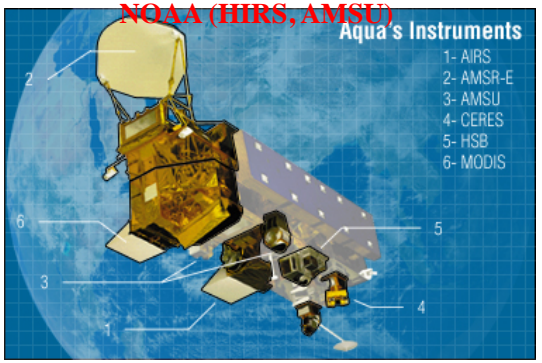
WRFDA is flexible to allow assimilation of different formats of observations:

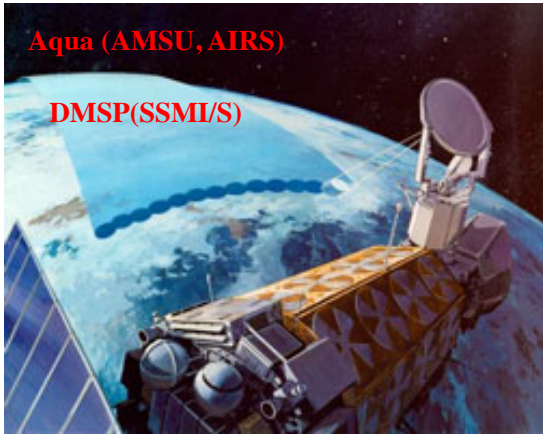
- **Little_r (ascii), HDF, Binary**
- **NOAA MADIS (netcdf),**
- **NCEP PrepBufr,**
- **NCEP radiance bufr**

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





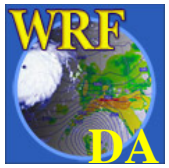
Past WRFDA tutorials

21-22 July 2008. NCAR.
02-04 Feb 2009. NCAR.
20-22 July 2009. NCAR.
03-05 Aug 2010. NCAR.
20-21 July 2011. NCAR.
23-25 July 2012. NCAR.
24-26 Jul 2013. NCAR.
28-30 Jul 2014. NCAR

18 April 2009. South Korea.
15-31 Oct 2009. Nanjing, China.
10 April 2010. Seoul, South Korea.
16 April 2011. Busan, South Korea.
10-20 Oct 2011. Bangkok, Thailand.
21 April 2012. Seoul, South Korea.
22-24 Sept 2013. Chengdu, China
14-25 Oct 2013. Vienna, Austria.

WRFDA online tutorial and user guide

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



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	Advanced practice session (WRF/WRFDA cycling, FGAT, FSO, advanced lessons)	

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