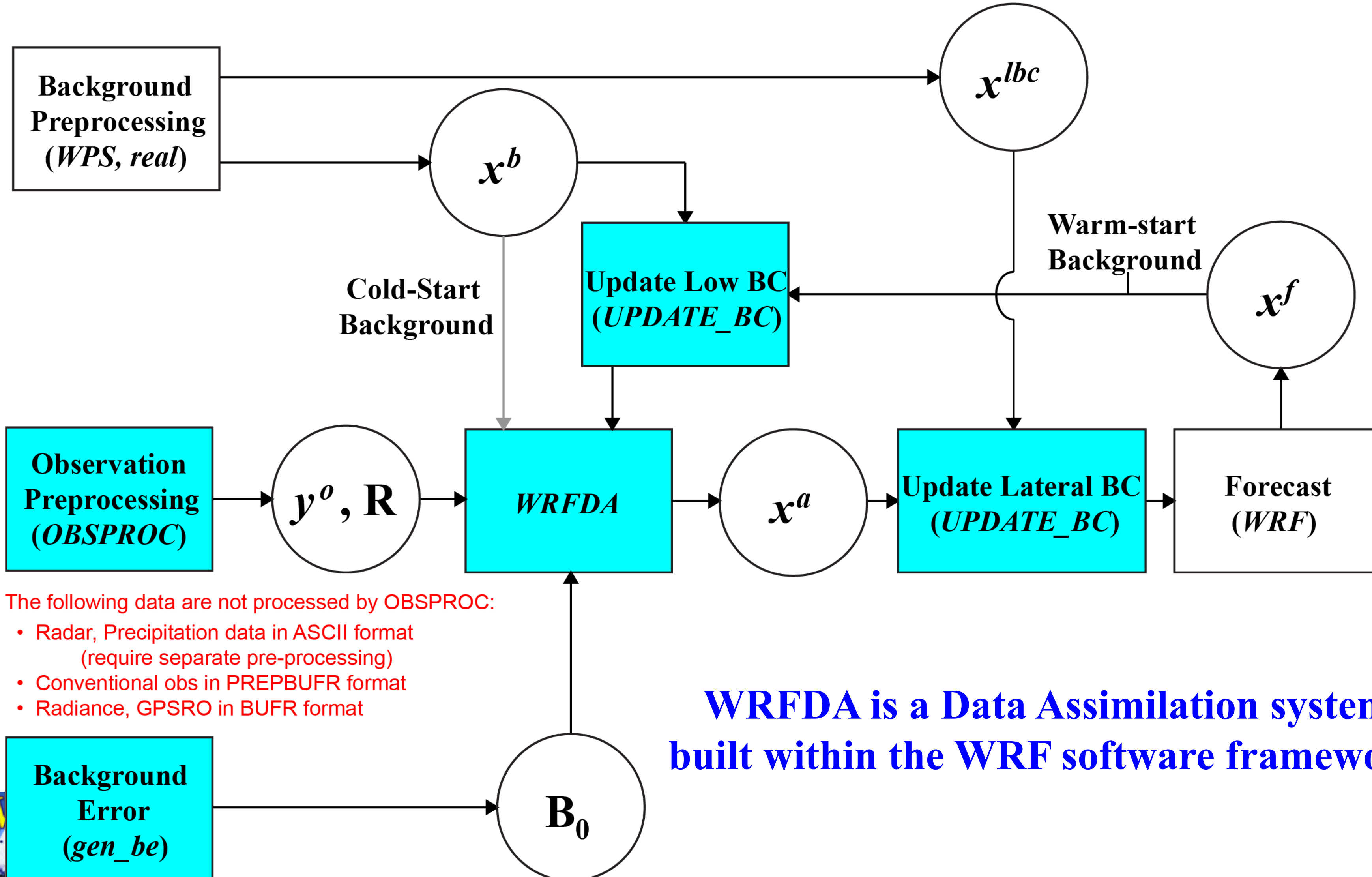
Introduction to WRFDA

Zhiquan (Jake) Liu

NCAR/MMM

WRFDA in the WRF Modeling System



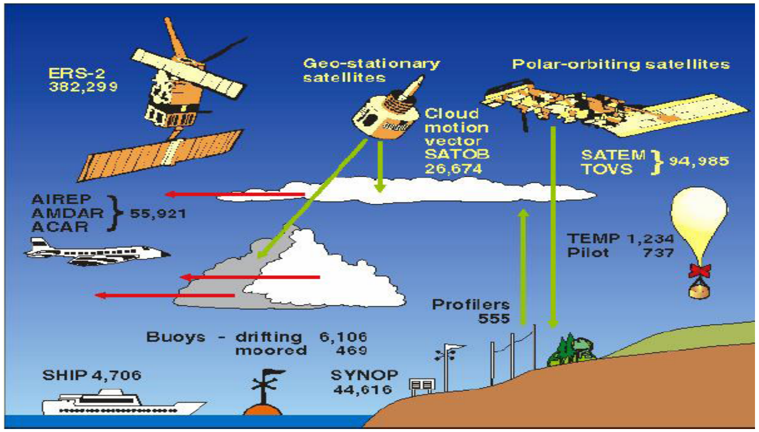
The following data are not processed by OBSPROC:

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

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

Why data assimilation?

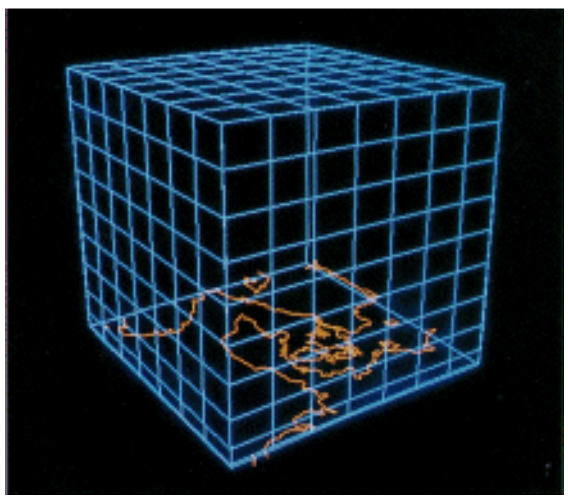
- Initial conditions for real-time forecast
- Verification and validation of model forecasts
- Monitoring and assessment of observations
- Observing system design
- Reanalysis
- Better understanding:
  - Data assimilation methods
  - Model errors
  - Data errors
  - …

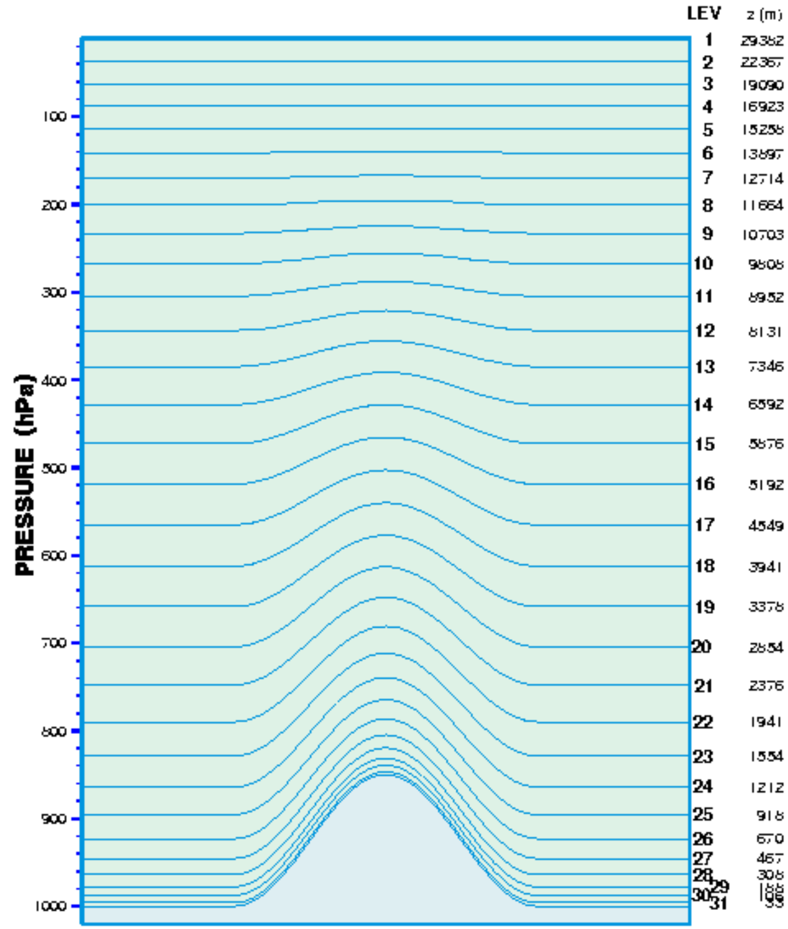


Data Assimilation: making bridge between model and observations

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

Model state
x, ~10^7





Vertical resolution of the DMI-HIRLAM system

DA algorithms currently available in WRFDA

- 3DVAR and FGAT
  - Different options for choice of control variables (e.g., Psi/Chi or U/V) and background error covariance modeling (e.g., vertical EOF or vertical recursive filter)
- 4DVAR
  - TL/Adjoint (i.e., WRFPlus code) of WRF up-to-date with WRF
  - Allow LBC control variable and Jc-DFI
- Hybrid-3DEnVar
  - Can run in dual-resolution mode
  - Can ingest ensemble from global or regional sources
- ETKF: for generating ensemble analysis

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 (reflectivity/retrieved rainwater, and radial-wind)**
  - Satellite temperature/humidity/thickness profiles
  - GPS refractivity (e.g. COSMIC)
  - **Stage IV precipitation/rain rate data (4D-Var only)**
- **Radiances:**

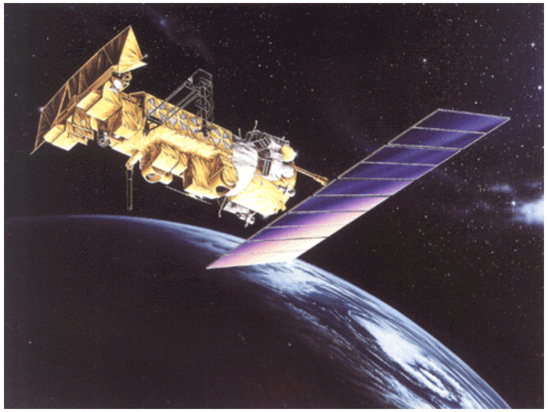
– HIRS	NOAA-16, NOAA-17, NOAA-18, NOAA-19, METOP-A
– AMSU-A	NOAA-15, NOAA-16, NOAA-18, NOAA-19, EOS-Aqua, METOP-A, METOP-B
– AMSU-B	NOAA-15, NOAA-16, NOAA-17
– MHS	NOAA-18, NOAA-19, METOP-A, METOP-B
– AIRS	EOS-Aqua
– SSMIS	DMSP-16, DMSP-17, DMSP-18
– IASI	METOP-A, METOP-B
– ATMS	Suomi-NPP
– MWTS	FY-3
– MWHS	FY-3
– SEVIRI	METEOSAT
– **AMSR2**	**GCOM-W1 (new in V3.8)**

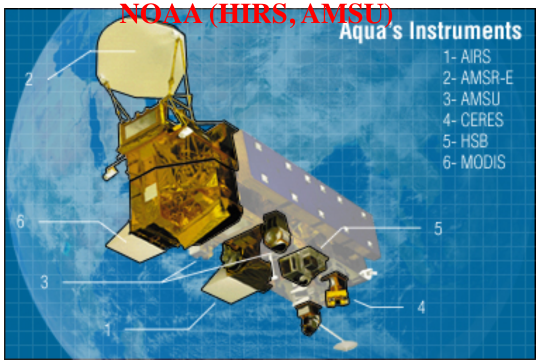
WRFDA is flexible to allow assimilation of different formats of observations:

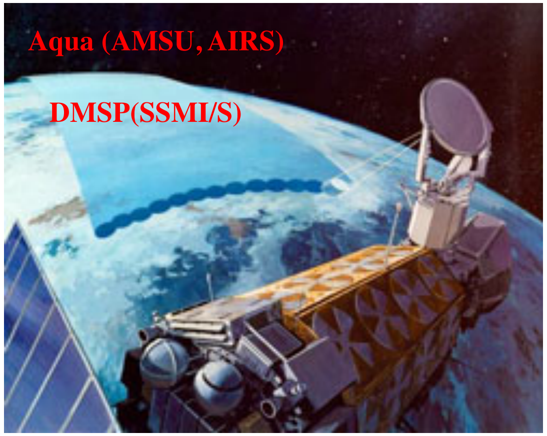
- **Little_r (ascii), HDF, Binary**
- **NOAA MADIS (netcdf),**
- **NCEP PrepBufr,**
- **NCEP radiance bufr**

WRFDA
Radiance Assimilation

- Two RTM interfaces
  - RTTOV or CRTM
- Variational Bias Correction
- Modular code design to ease adding new satellite sensors
- Capability for cloudy radiance DA

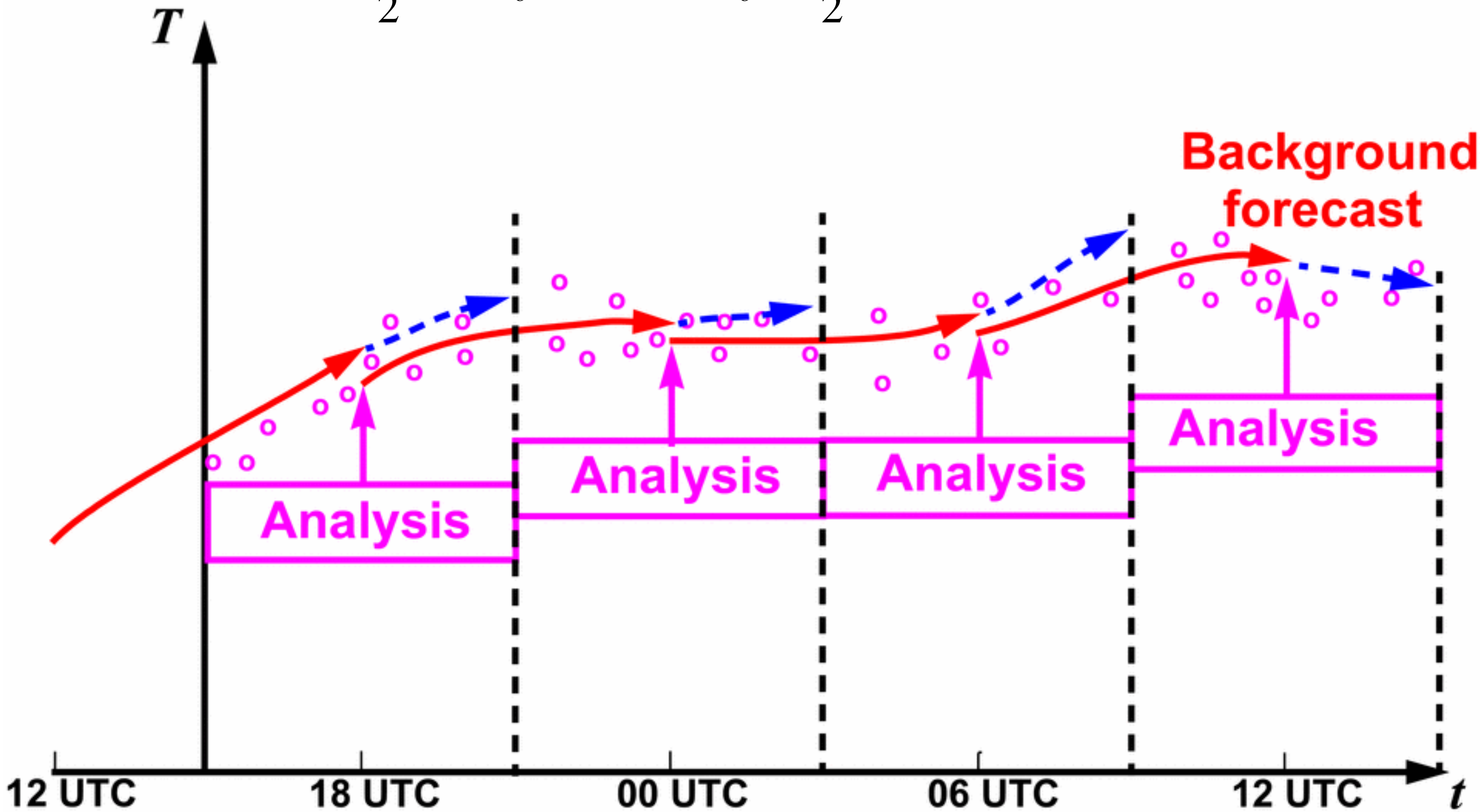






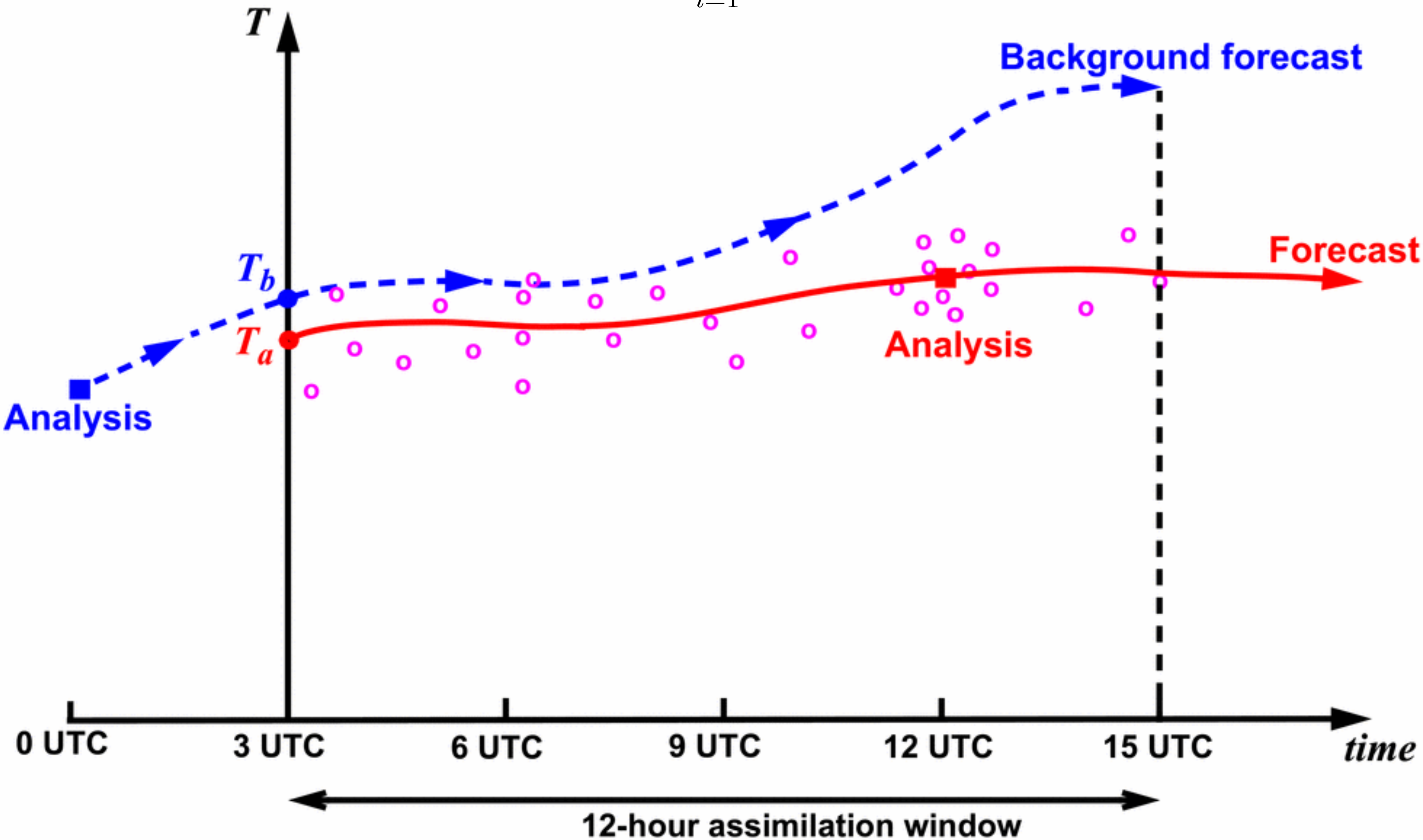
3DVAR (Barker et al. 2004)

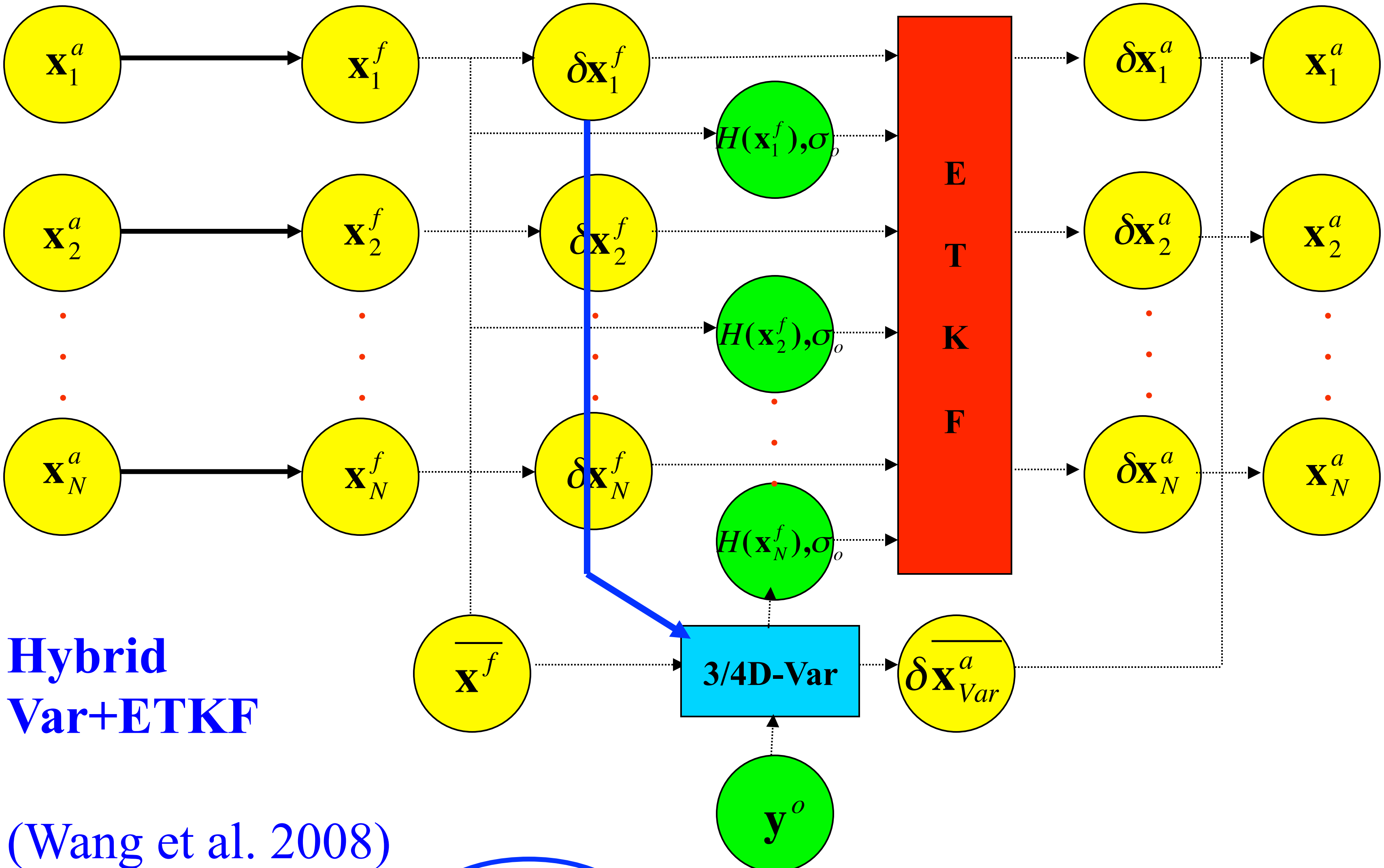
$$J(x) = \frac{1}{2}(x - x_b)^{\mathrm{T}} \mathrm{B}^{-1}(x - x_b) + \frac{1}{2}[H(x) - y]^{\mathrm{T}} \mathrm{R}^{-1}[H(x) - y]$$



4DVAR (Huang et al. 2009)

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

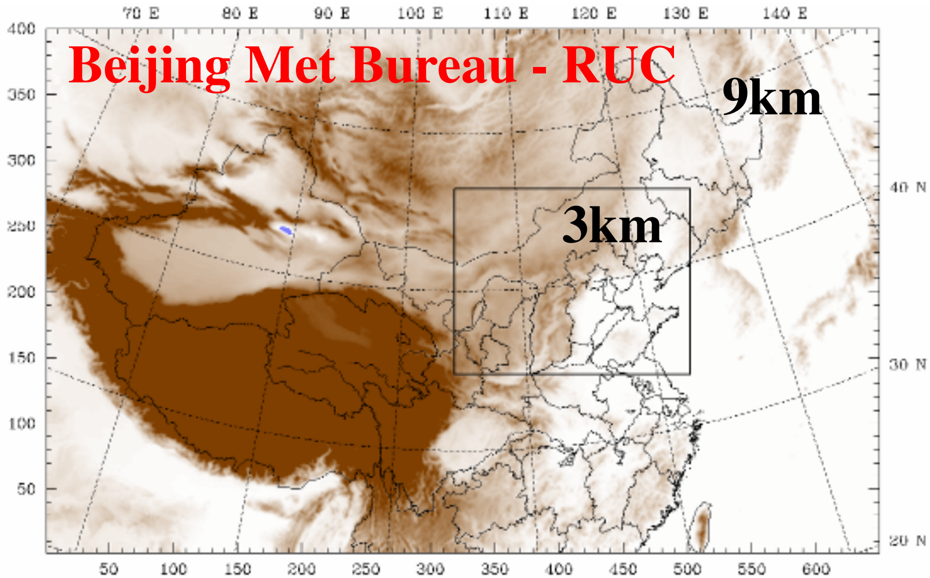


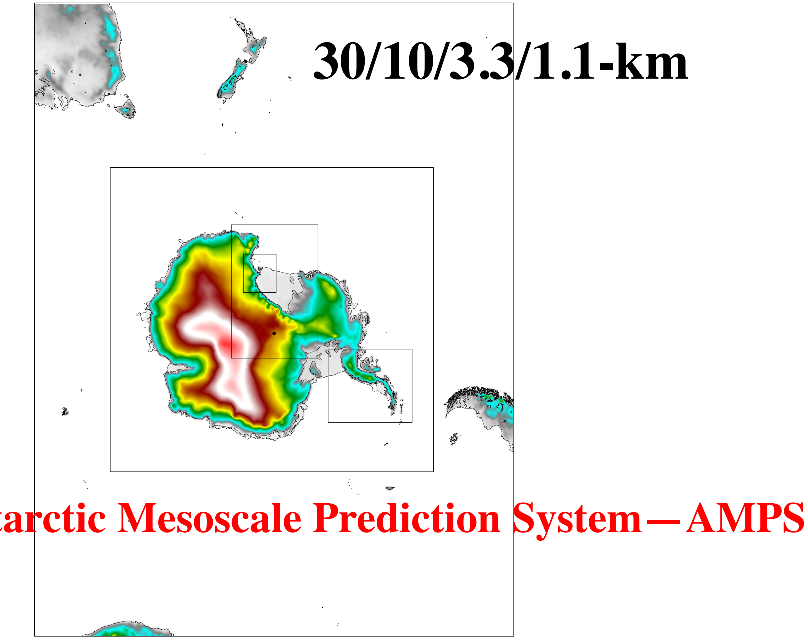


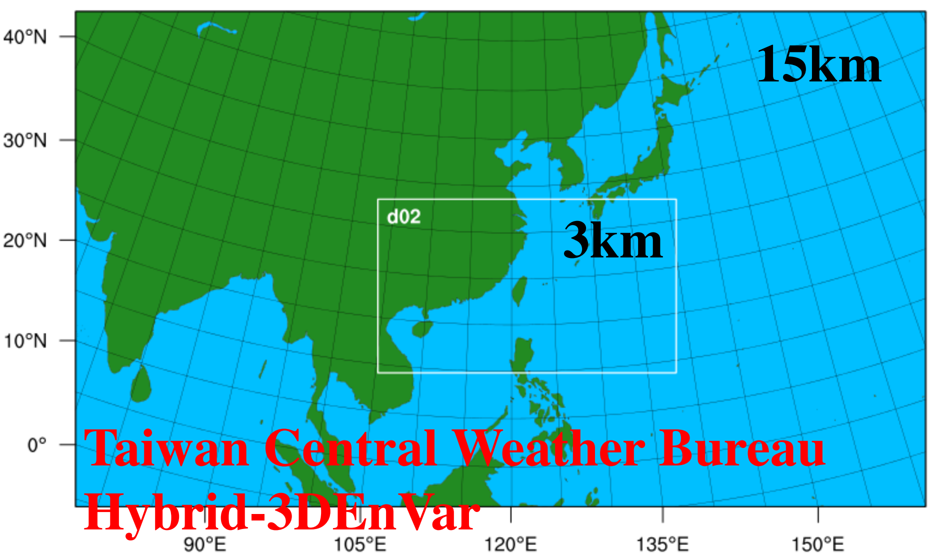
Hybrid Var+ETKF

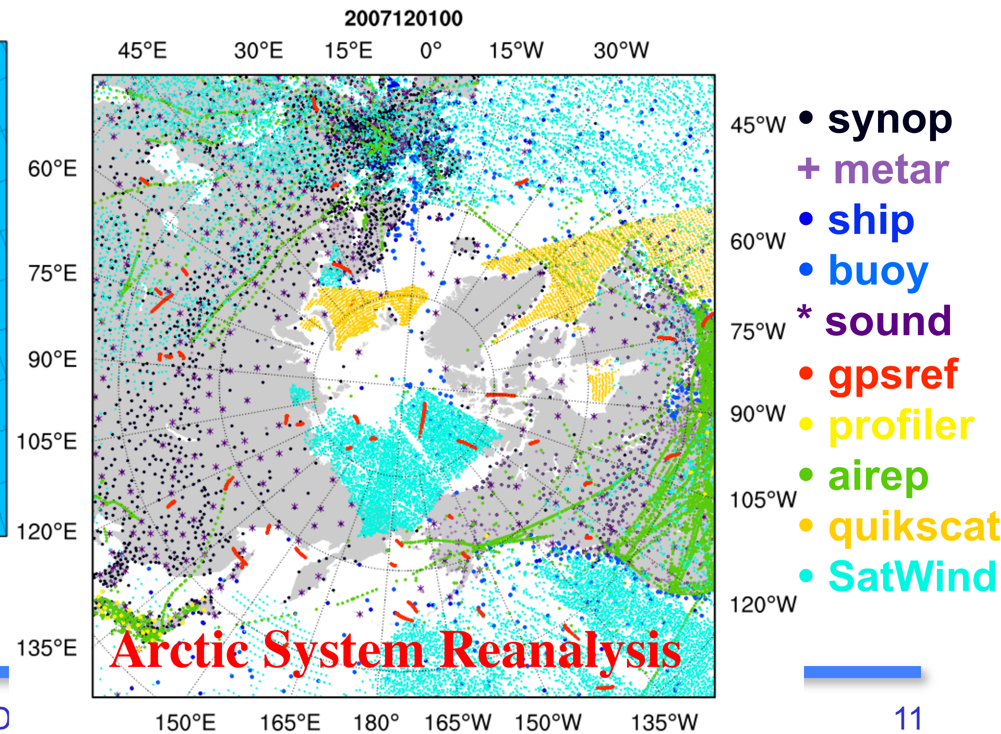
(Wang et al. 2008)

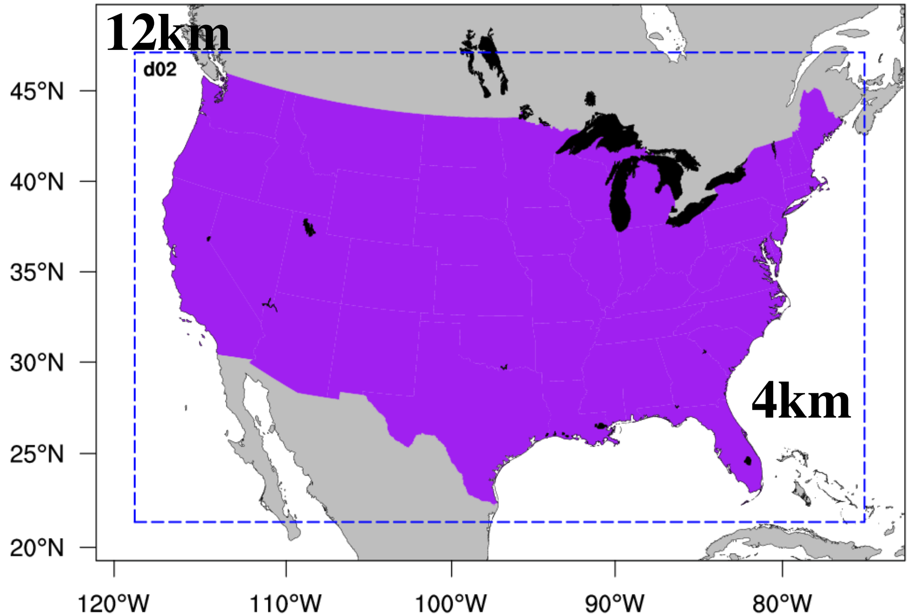
$$J = \frac{W_b}{2}\mathbf{v}^T\mathbf{v} + \frac{W_\alpha}{2}\mathbf{a}^T\mathbf{A}^{-1}\mathbf{a} + \frac{1}{2}\sum_{i=0}^{n}\left[\mathbf{d}_i - \mathbf{H}_i\mathbf{M}_i\mathbf{U}\mathbf{v}\right]^T \mathbf{R}_i^{-1}\left[\mathbf{d}_i - \mathbf{H}_i\mathbf{M}_i\mathbf{U}\mathbf{v}\right]$$

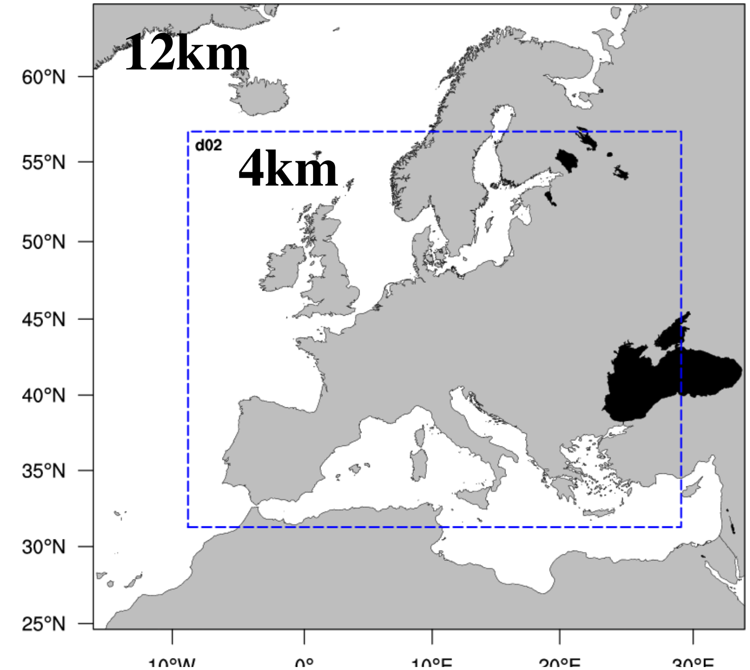

Beijing Met Bureau - RUC
9km
3km


30/10/3.3/1.1-km
Antarctic Mesoscale Prediction System—AMPS

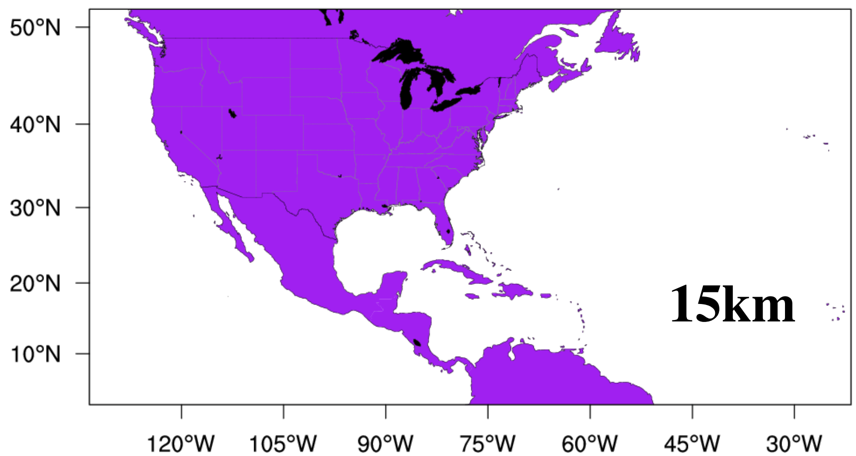

15km
d02
3km
Taiwan Central Weather Bureau
Hybrid-3DEnVar

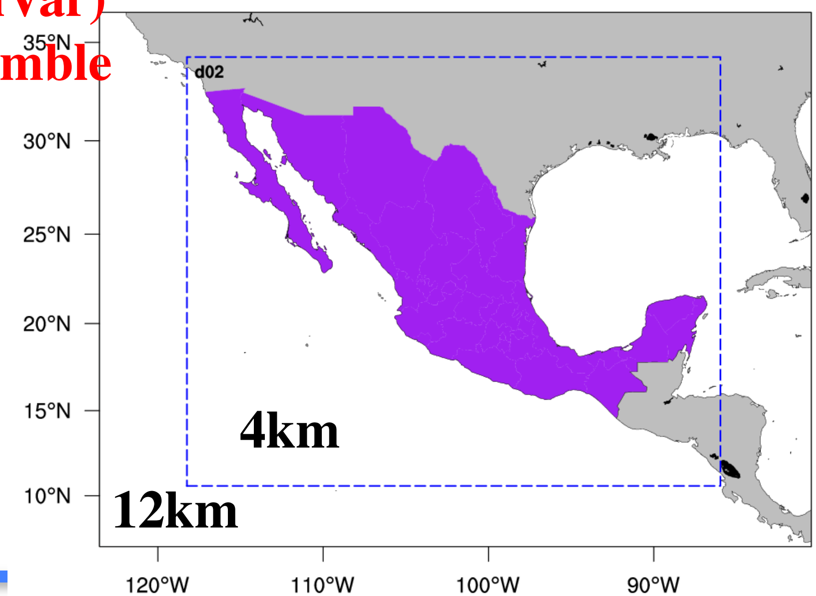

2007120100
Arctic System Reanalysis
• synop
+ metar
• ship
• buoy
* sound
• gpsref
• profiler
• airep
• quikscat
• SatWind





Operational domains by PWS (hybrid-3DEnVar)
Ensemble covariances from global GFS ensemble

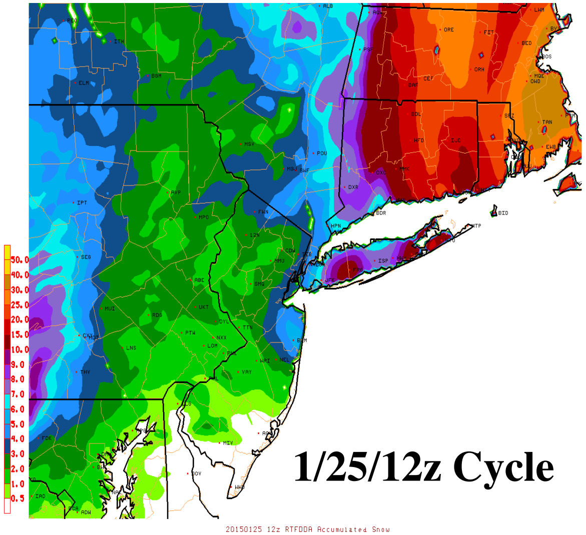




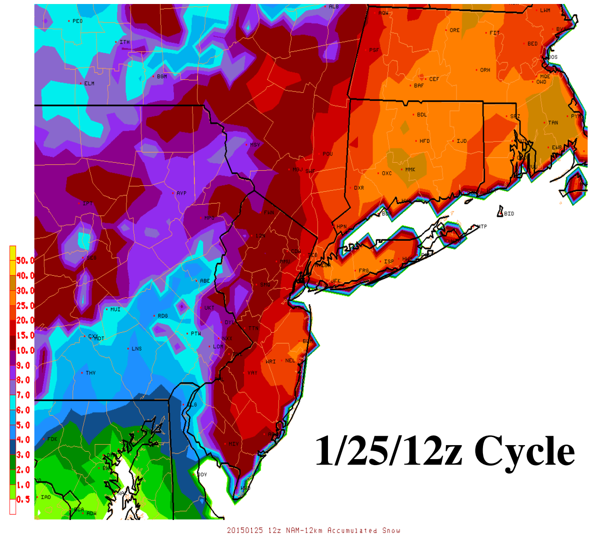
ntro -

January 26-27, 2015: Northeast “Blizzard?”

PWS 4km CONUS forecast



NCEP NAM forecast



ECMWF forecast

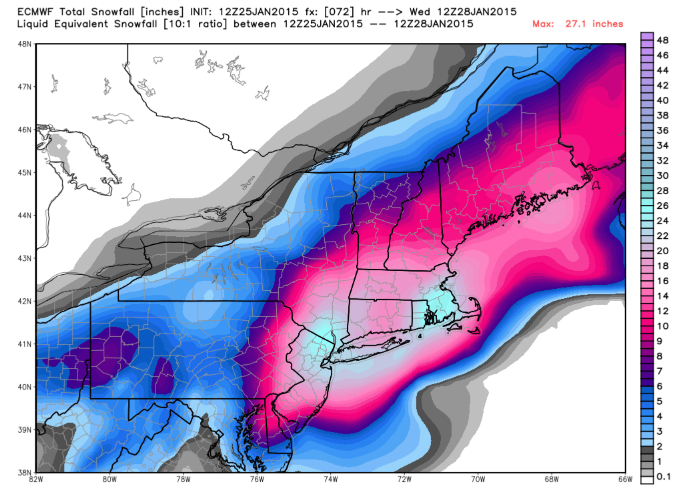
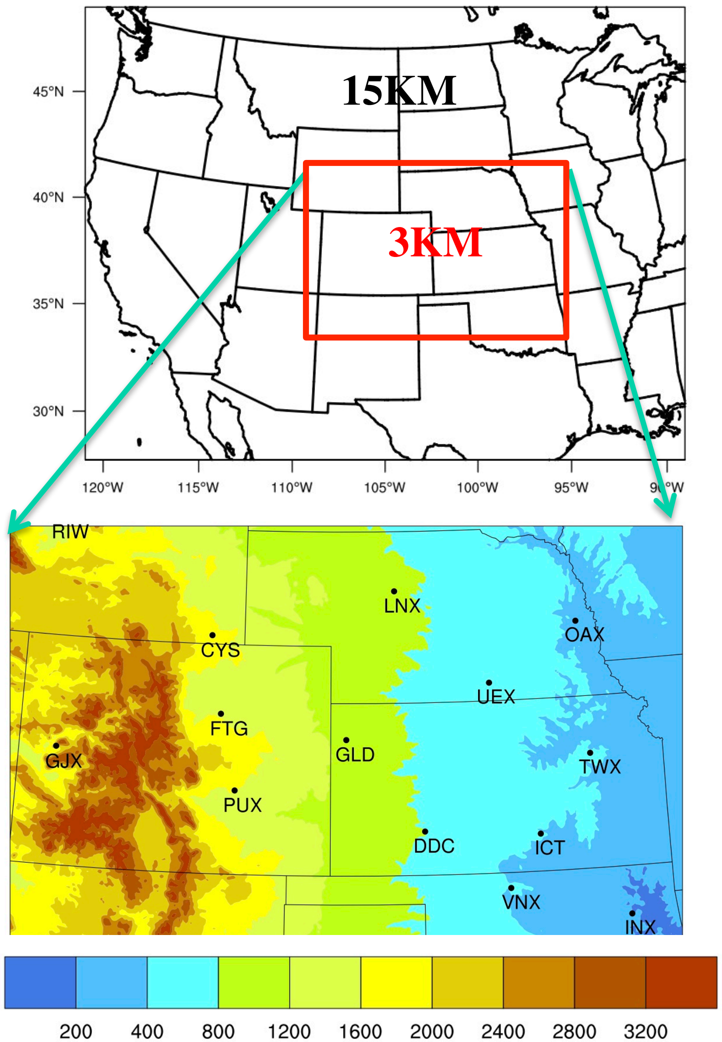


Table of average forecasted snowfall totals in inches, 48 hours in advance of storm

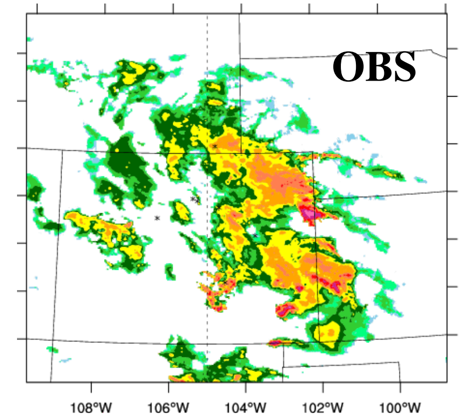
	ECMWF	NAM-12	NWS	PWS	Actual
PHL	13	8	10-15	3	1.2
LGA	21	21	20-25	8	11.0
EWR	21	18	20-25	6	6.5
BOS	23	22	25-30	28	24.6

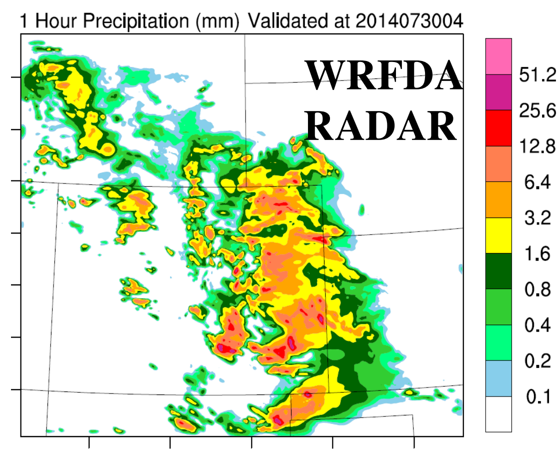
Radar DA for hydrological application

STEP Hydromet Real Time Exp. during spring time



- **The goal is to improve local-scale QPF in coupled hydromet system**
- **< 1 h rapid update**
- **Radar radial velocity and reflectivity assimilation**
- **High resolution vs. ensemble**
- **Impact of terrain**
- **Improved results in capturing localized storms**





Real-Time WRF/WRFDA-hybrid analysis/forecast over CONUS

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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:

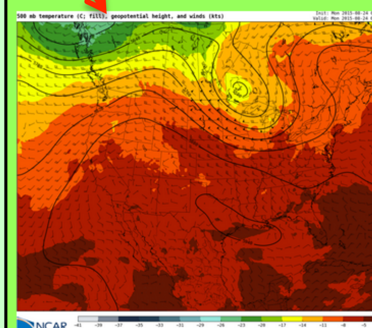
- WRF Software Framework (WSF)
- Advanced Research WRF (ARW) dynamic solver, including one-way, two-way nesting and moving nests, grid and observation nudging
- WRF Pre-Processing System (WPS)
- **WRF Data Assimilation System (WRFDA)** *(found on this site)*
- Numerous physics packages contributed by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

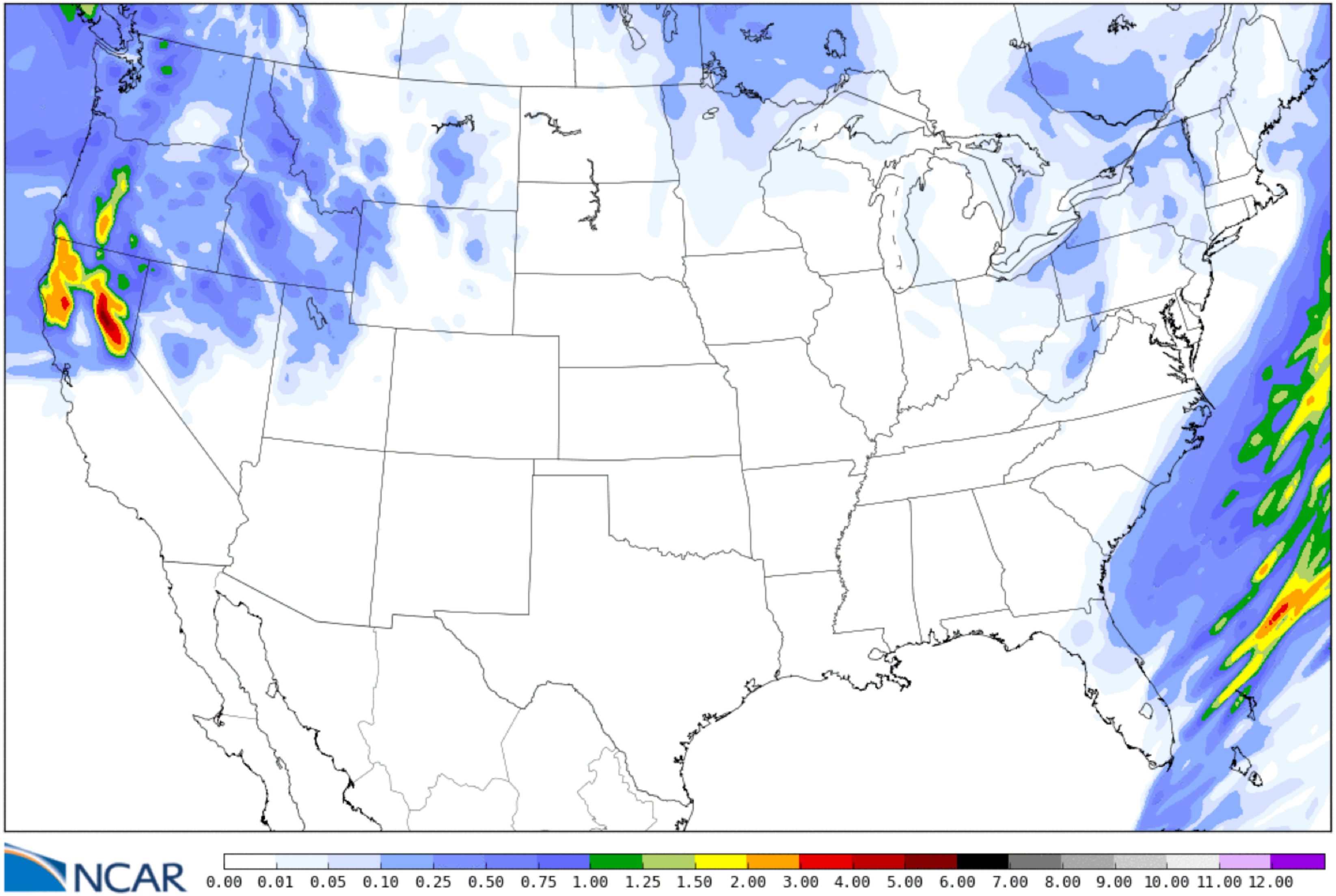
WHAT'S NEW

NCAR WRF/WRFDA Initialized: 00 UTC Fri 29 Jan 2016

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

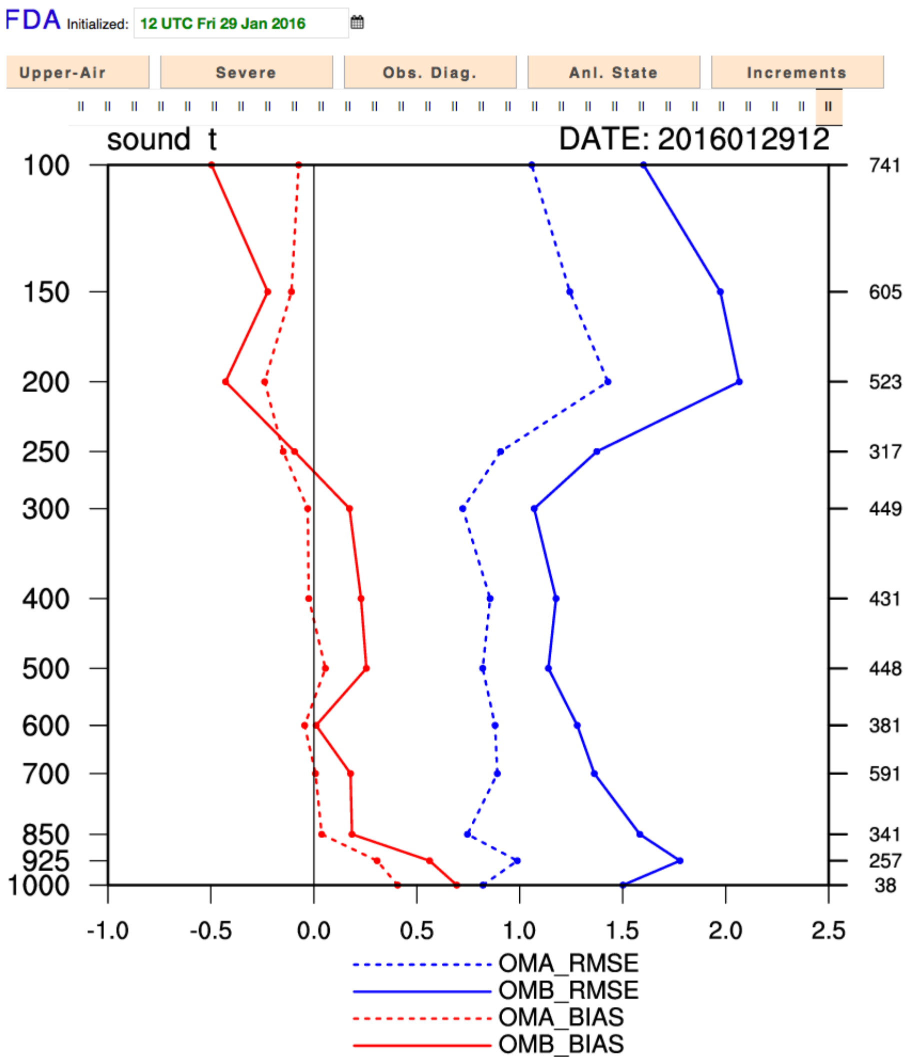
15-km ARW WRF 24-hr accumulated precipitation (in)

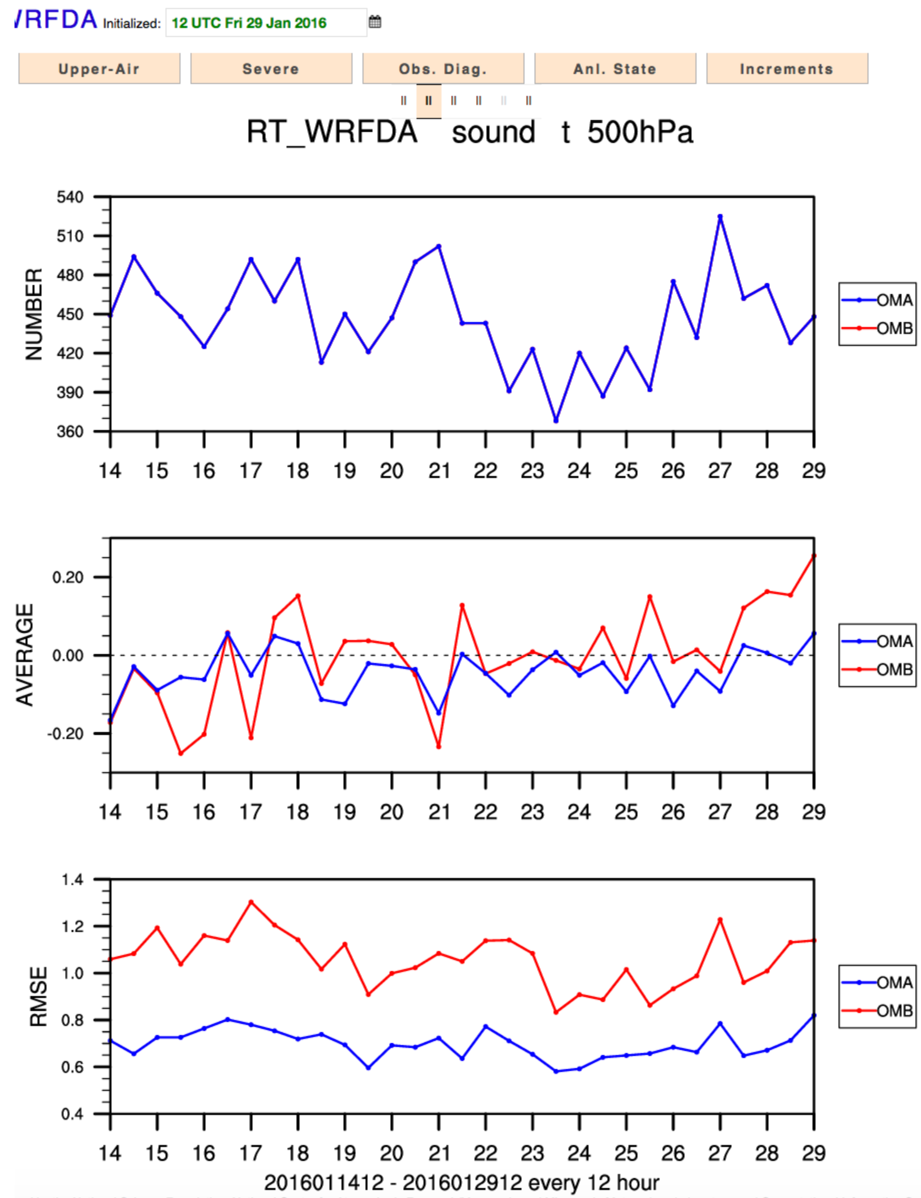
Init: Fri 2016-01-29 00 UTC
Valid: Sat 2016-01-30 00 UTC



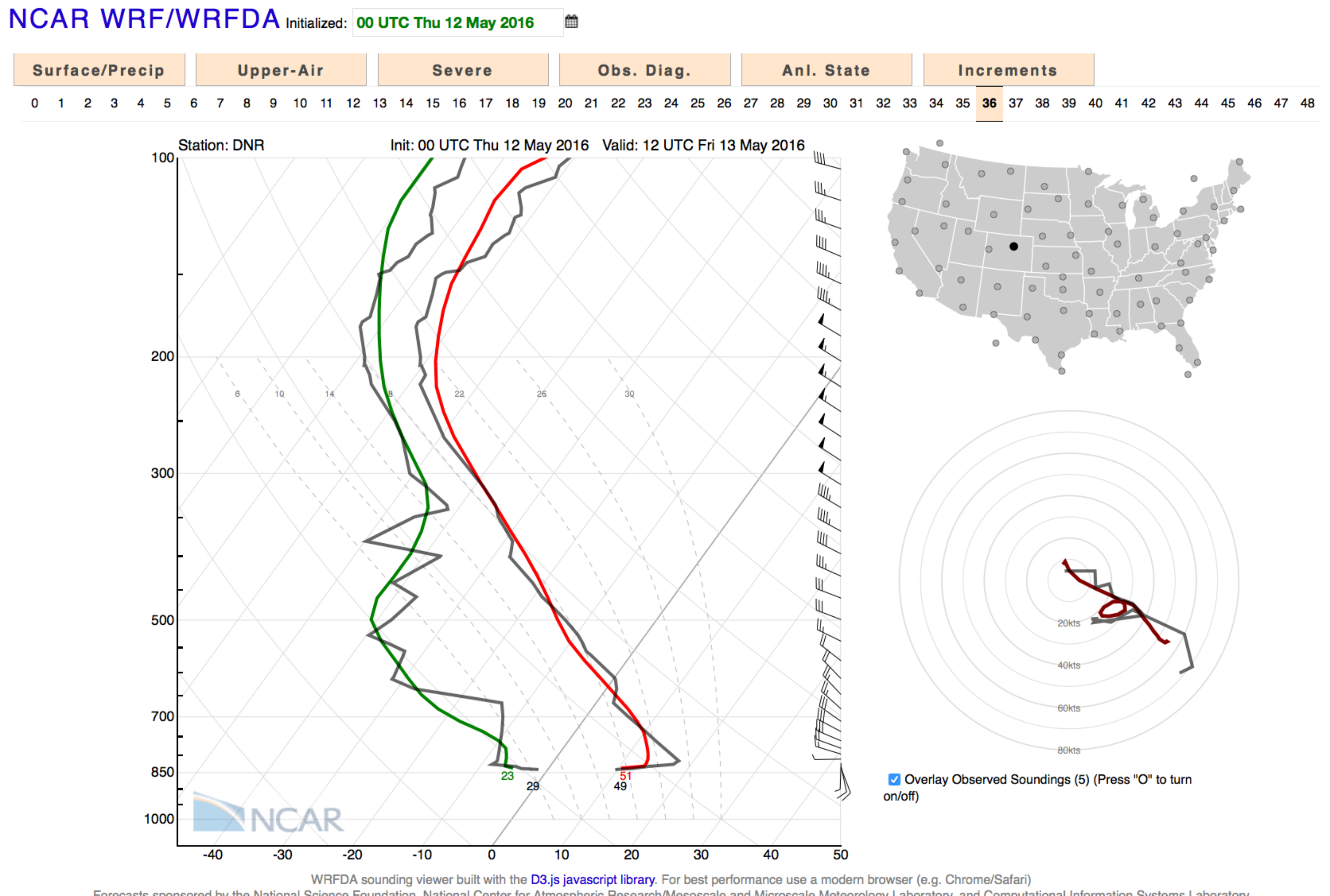
NCAR

Forecasts sponsored by the National Science Foundation, National Center for Atmospheric Research/Mesoscale and Microscale Meteorology Laboratory, and Computational Information Systems Laboratory

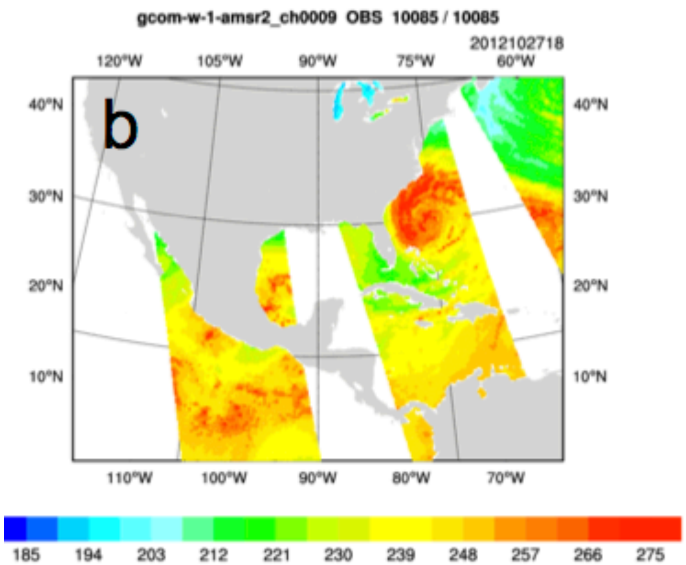

FDA Initialized: 12 UTC Fri 29 Jan 2016
Upper-Air
Severe
Obs. Diag.
Anl. State
Increments
sound t
DATE: 2016012912
100
150
200
250
300
400
500
600
700
850
925
1000
741
605
523
317
449
431
448
381
591
341
257
38
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
OMA_RMSE
OMB_RMSE
OMA_BIAS
OMB_BIAS

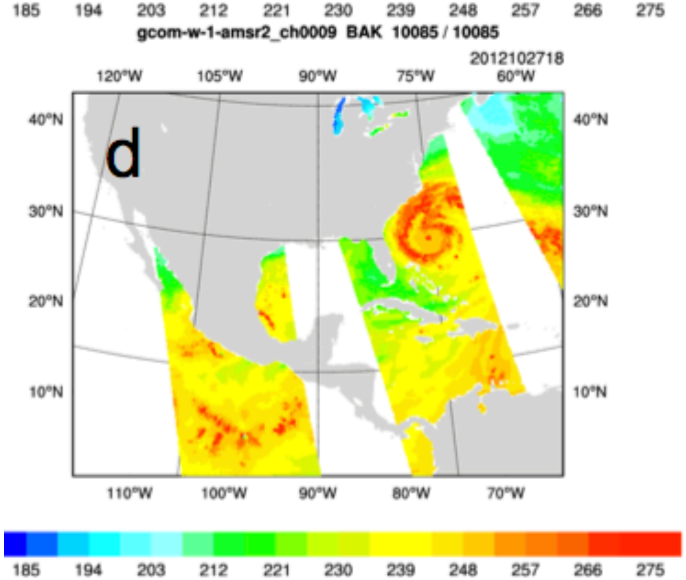

/RFDA Initialized: 12 UTC Fri 29 Jan 2016
Upper-Air
Severe
Obs. Diag.
Anl. State
Increments
RT_WRFDA sound t 500hPa
NUMBER
540
510
480
450
420
390
360
AVERAGE
0.20
0.00
-0.20
RMSE
1.4
1.2
1.0
0.8
0.6
0.4
14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
OMA
OMB
2016011412 - 2016012912 every 12 hour

Real-time WRF/WRFDA forecast

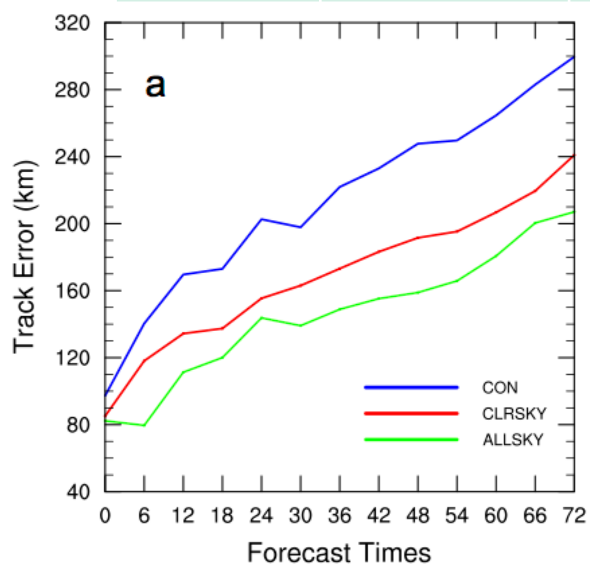


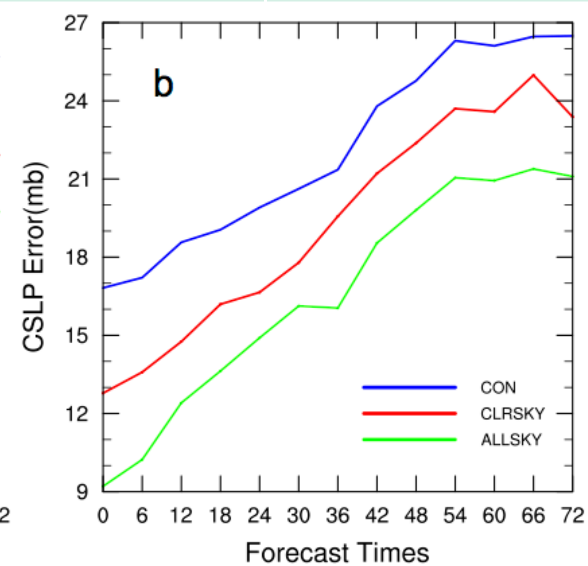
New in V3.8.1: all-sky radiance DA: AMSR2





Channel	Frequency (GHz)	Polarization	Footprint (along scan* along track)
1,2	6.925	V,H	35*61 km
3,4	7.3	V,H	35*61 km
5,6	10.65	V,H	24*41 km
7,8	18.7	V,H	13*22 km
9,10	23.8	V,H	15*26 km
11,12	36.5	V,H	7*12 km
13,14	89.0	V,H	3*5 km





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WRFDA beta releases

WRFDA: Beta releases

WRFDA is undergoing continuous development as more capabilities are added, both by NCAR scientists and community contributors. On this page you can find pre-release versions of new capabilities. As these capabilities are new and not fully tested, we appreciate any feedback you can offer us: contact us through wrfhelp or the WRFDA webmaster.

Below is a list of the current beta releases we have available.

AMSR2 CLOUDY RADIANCE ASSIMILATION

Typically, with radiance assimilation in WRFDA, pixels which are determined to have clouds in them are rejected. However, we have developed the ability to assimilate cloud-affected radiance observations with the JAXA GCOM-W1 AMSR2 instrument. This capability is described in this PDF guide, and in the following publication:

Chun Yang, Zhiquan Liu, Jamie Bresch, Syed R. H. Rizvi, Xiang-Yu Huang and Jinzhong Min, 2016: AMSR2 all-sky radiance assimilation and its impact on the analysis and forecast of Hurricane Sandy with a limited-area data assimilation system. *Tellus A*, **68**, 30917, doi:10.3402/tellusa.v68.30917.

Download pre-release code

To download beta release code:

Fill out the registration form by clicking **'New Users'** below, or select **'Returning Users'** if you have already registered to download WRF or WRFDA in the past. You will be redirected to a page where you can download a tar file with the code you are interested in.

New Users

Returning Users

New in V3.8: dynamic constraint capability

- A user-contributed new "weak penalty constraint" (WPEC) option has been added to WRFDA to enhance mass/wind balance (re-invented from MM5-3DVAR implementation).
- It can be used for hybrid-3DVAR, or for pure 3DVAR.
- The constraint is implemented as an additional cost function term,

$$J_d = G(\mathbf{x})^T \, \Gamma^{-1} G(\mathbf{x})$$

- Where $G(\mathbf{x})$ is the dynamic constraint, and Γ^{-1} is a namelist-controlled weighting factor. The non-linear operator G is steady state momentum equation:

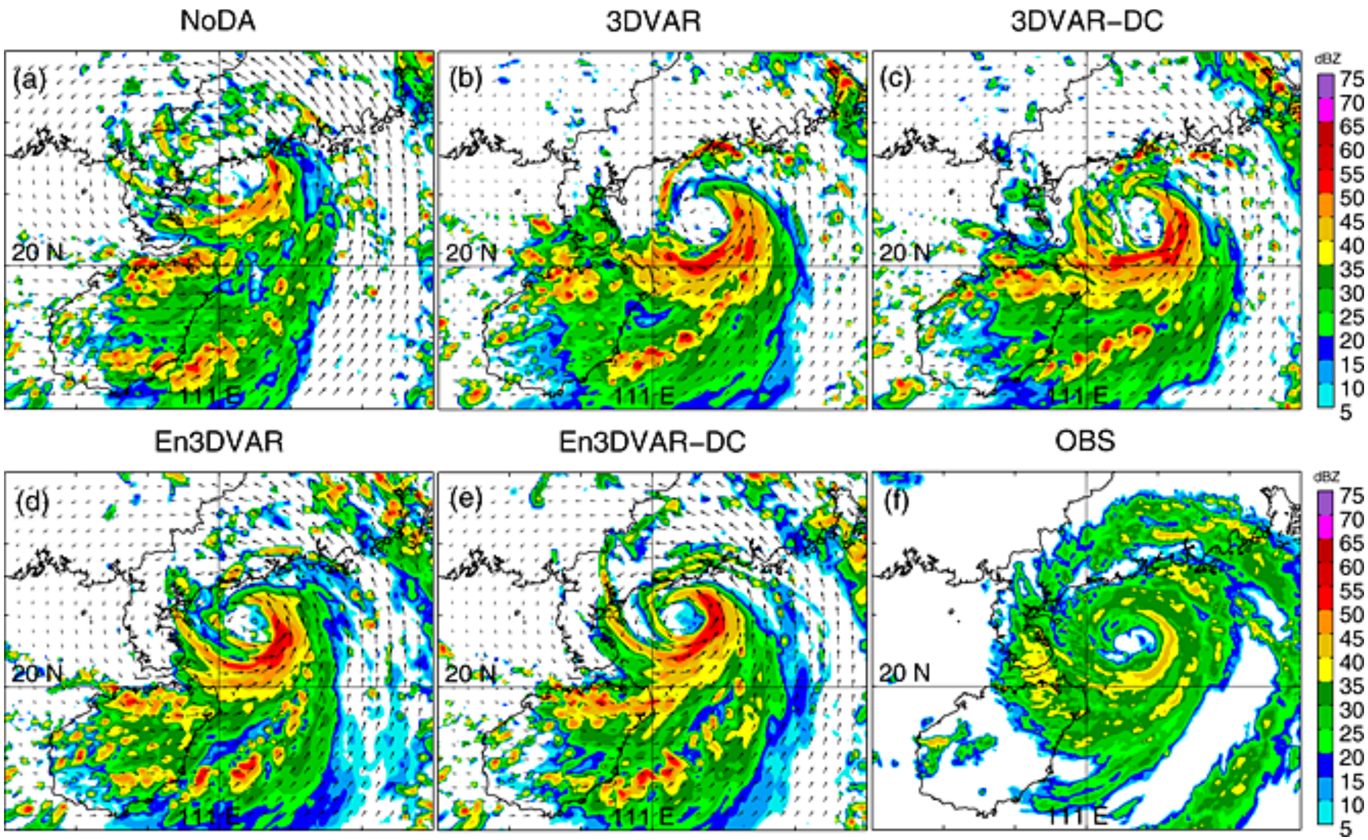
$$G = \vec{V} \cdot \nabla_\sigma \vec{V} + f\vec{k} \times \vec{V} + \nabla_\sigma \phi + \frac{1}{\rho} \nabla_\sigma p$$

Cyclostrophic term **Geostrophic term**

WRF DA

New dynamic constraint option

Li, Xin, Jie Ming, Ming Xue, Yuan Wang, and Kun Zhao, 2015: Implementation of a dynamic equation constraint based on the steady state momentum equations within the WRF hybrid ensemble–3DVar data assimilation system and test with radar T-TREC wind assimilation for tropical Cyclone Chanthu (2010). *JGR*, **120**, 4017–4039.



Analyzed reflectivity with and w/o the dynamic constraint

Ongoing work: Variational Bias Correction of Aircraft T

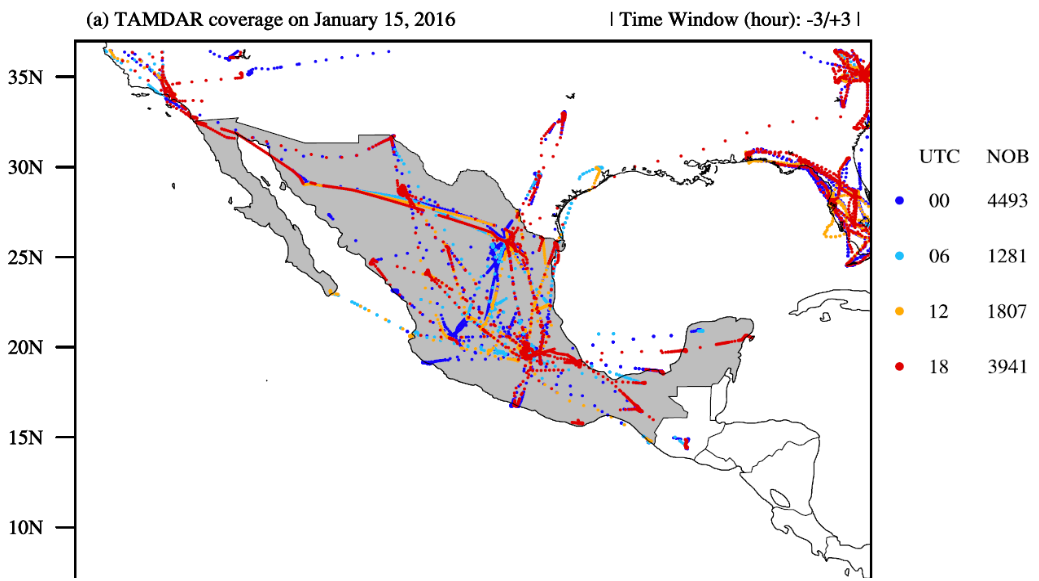
$$J(\mathbf{x},\boldsymbol{\beta}) = (\mathbf{x}-\mathbf{x}_b)^T \mathbf{B}_x^{-1}(\mathbf{x}-\mathbf{x}_b) + (\boldsymbol{\beta}-\boldsymbol{\beta}_b)^T \mathbf{B}_\beta^{-1}(\boldsymbol{\beta}-\boldsymbol{\beta}_b) + (\mathbf{y}-H[\mathbf{x},\mathbf{y},\boldsymbol{\beta}])^T \mathbf{R}^{-1}(\mathbf{y}-H[\mathbf{x},\mathbf{y},\boldsymbol{\beta}])$$

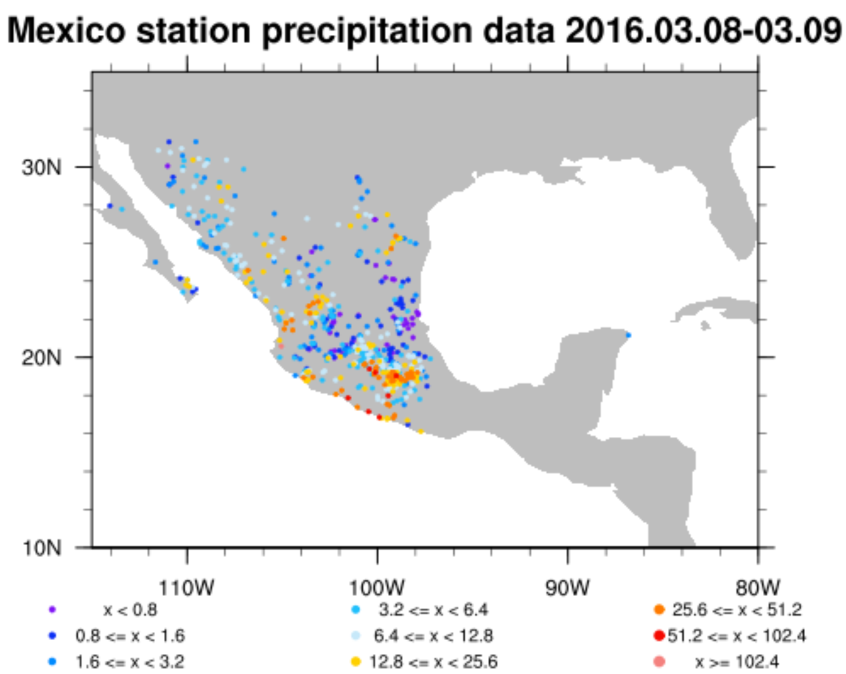
$$\tilde{H}(\mathbf{x},\mathbf{y},\boldsymbol{\beta}) = H(\mathbf{x}) - b(\mathbf{y},\boldsymbol{\beta})$$

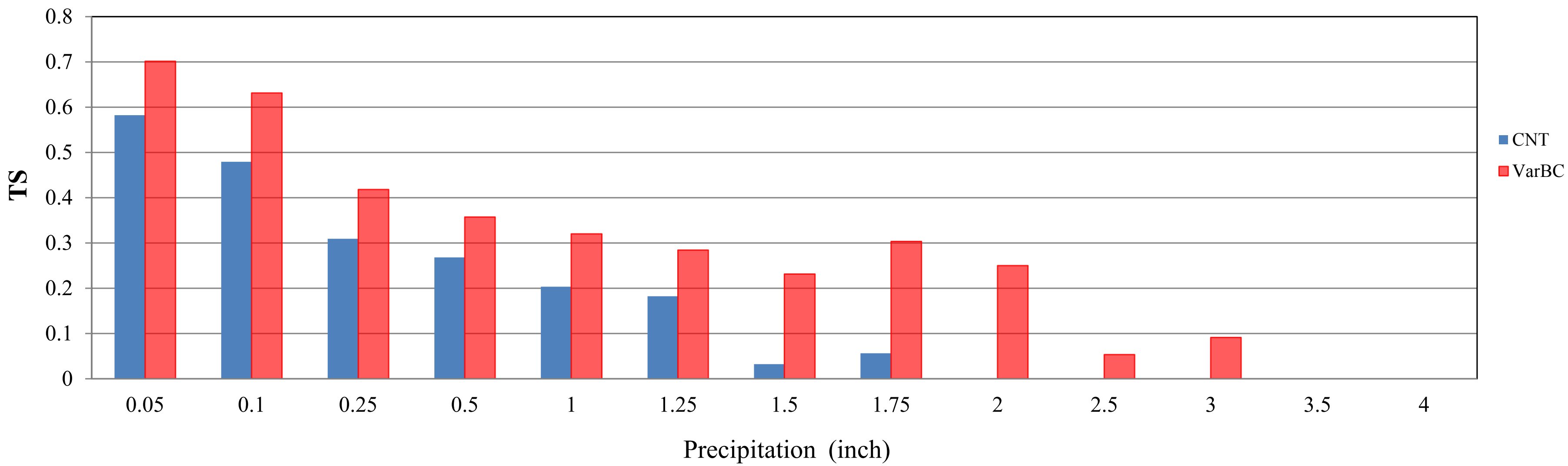
$$b(\mathbf{y},\boldsymbol{\beta}) = \sum_{n=0}^{N} \beta_n p_n(\mathbf{y}) = \begin{cases} \beta_{0+} + \beta_{1+} w & \text{if } \; w > 0 \\ \beta_{0-} + \beta_{1-} w & \text{if } \; w < 0 \end{cases}$$

$w = \dfrac{\mathrm{dp}}{\mathrm{dt}}$, β **is updated in cost function each cycle and written in parameter table.**

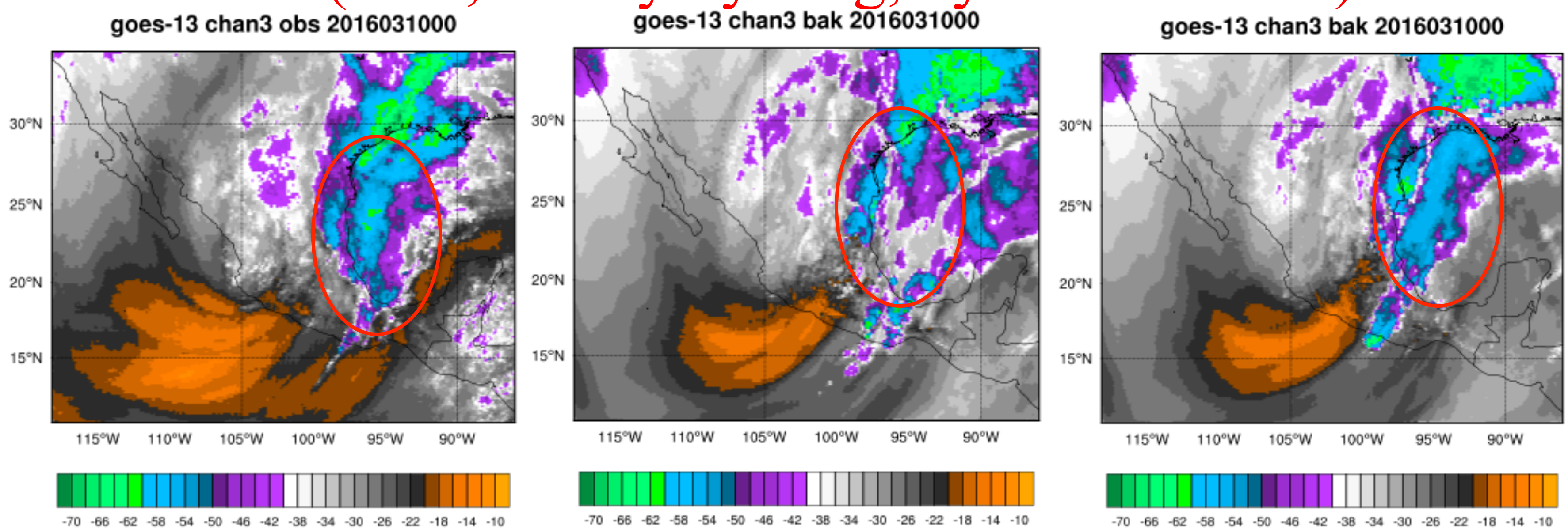
Impact of Aircraft T VarBC on rainfall forecast



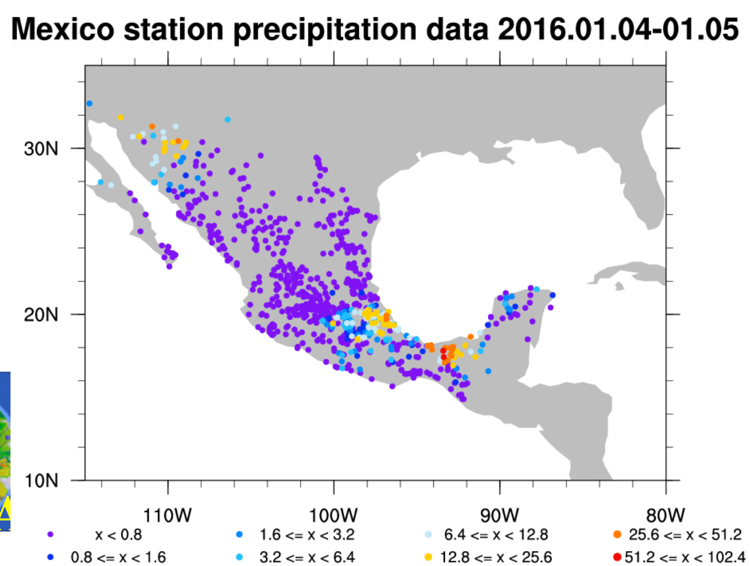


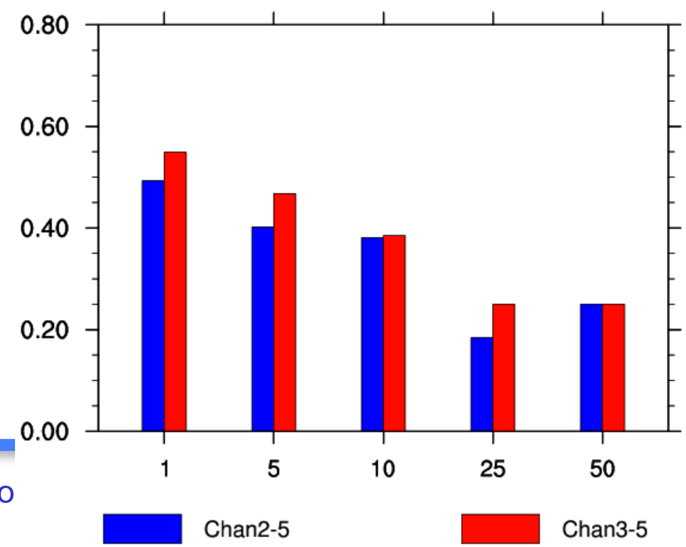


GEOS imager radiance DA at convection-permitting scale (4km, hourly-cycling, hybrid-3DVAR)



obs **No-GOES DA** **GOES-DA**





Other ongoing work

- Implemented Hybrid-4DEnVAR
  - Improving computing efficiency
- Continue developing Multi-Resolution Incremental 4DVAR (MRI-4DVAR)
- Continue developing cloudy radiance/product DA
- Improving surface data assimilation
- Improving radar DA
  - Adding divergence constraint
  - Assimilation of non-rain data
- WRFPlus-Chem & WRFDA-Chem
  - CU Boulder.

Last Remarks

- We welcome contributions from external users/developers.
  - Contact wrfhelp@ucar.edu or directly email to me liuz@ucar.edu for contributing back your code
- We maintain a WRFDA-related publications list, please inform us your papers to be included
  - http://www2.mmm.ucar.edu/wrf/users/wrfda/publications.html
- NCAR on-site WRFDA tutorial in Summer
  - This time will add some "developer guide".