



Introduction to WRFDA

Hans Huang

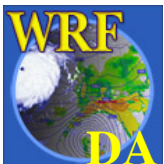
WRFDA is a **Data Assimilation** system built within the **WRF** software framework, used for application in both research and operational environments....

Acknowledge:

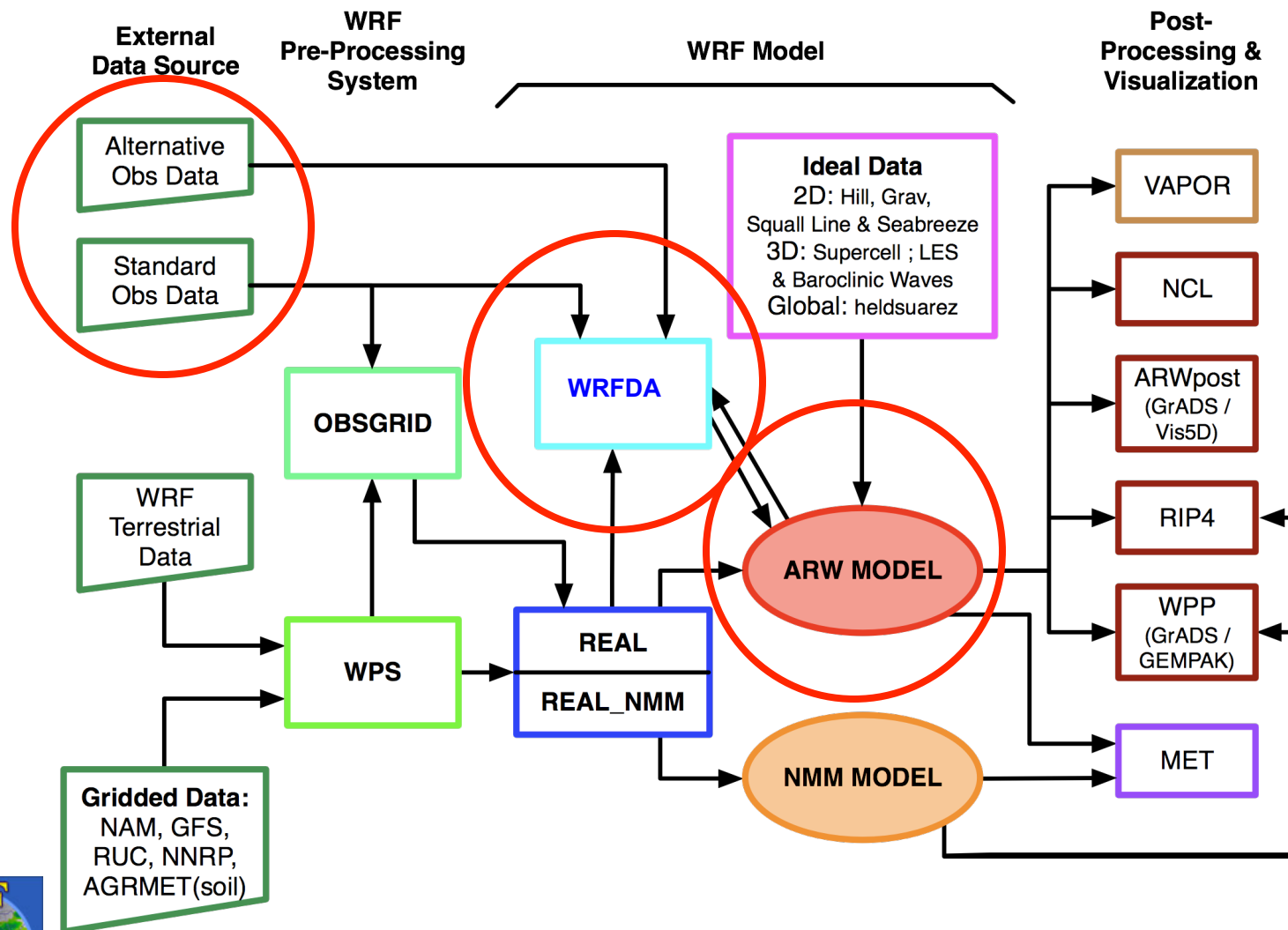
NCAR/MMM/DAS

NCAR/RAL/JNT/DATC

NCAR, AFWA, USWRP, NSF-OPP, KMA, CWB, CAA, EUMETSAT, BMB,
AirDat

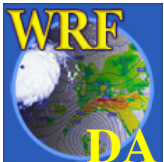


WRFDA in WRF Modeling System



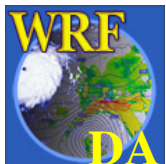
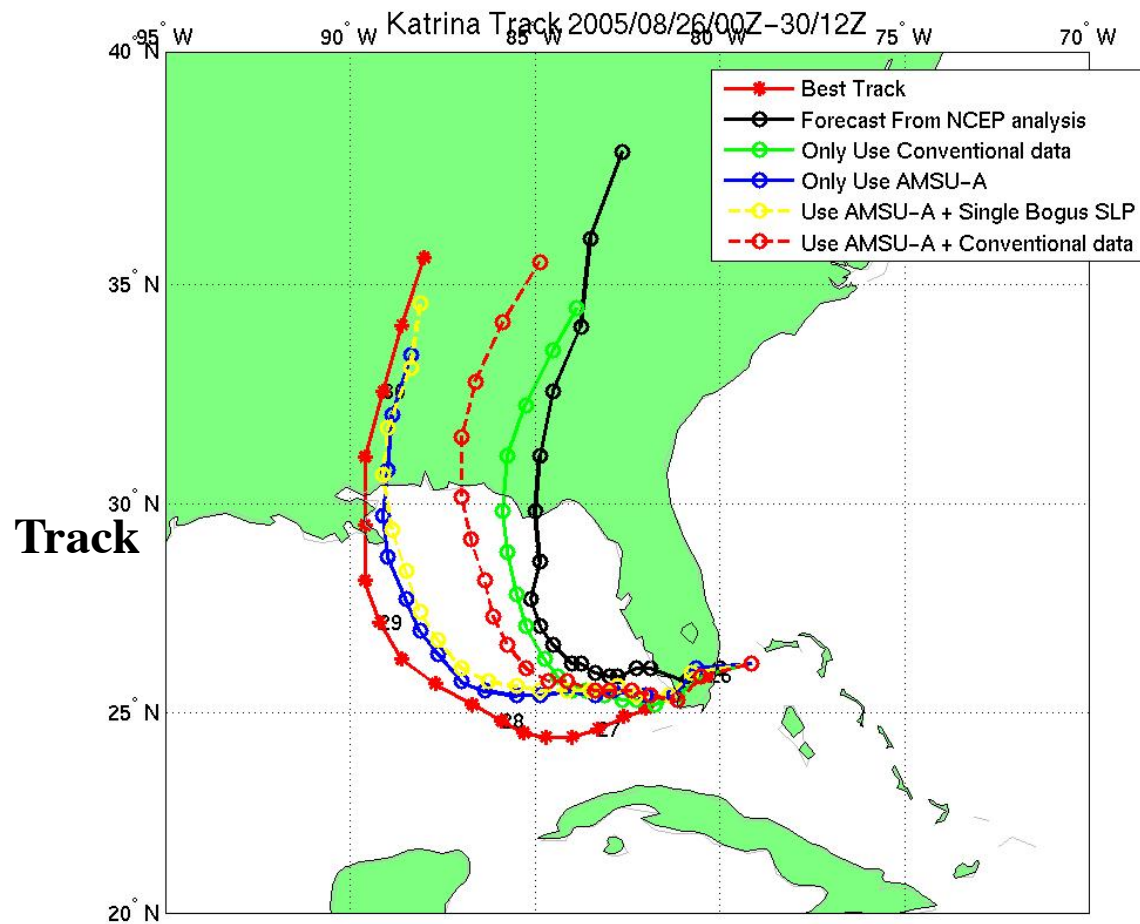
Why data assimilation?

- Initial conditions
- Calibration and validation
- Observing system design, monitoring and assessment
- Reanalysis
- Better understanding:
 - Data assimilation methods
 - Model errors
 - Data errors
 - Physical process interactions
 - ...



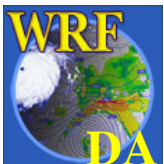
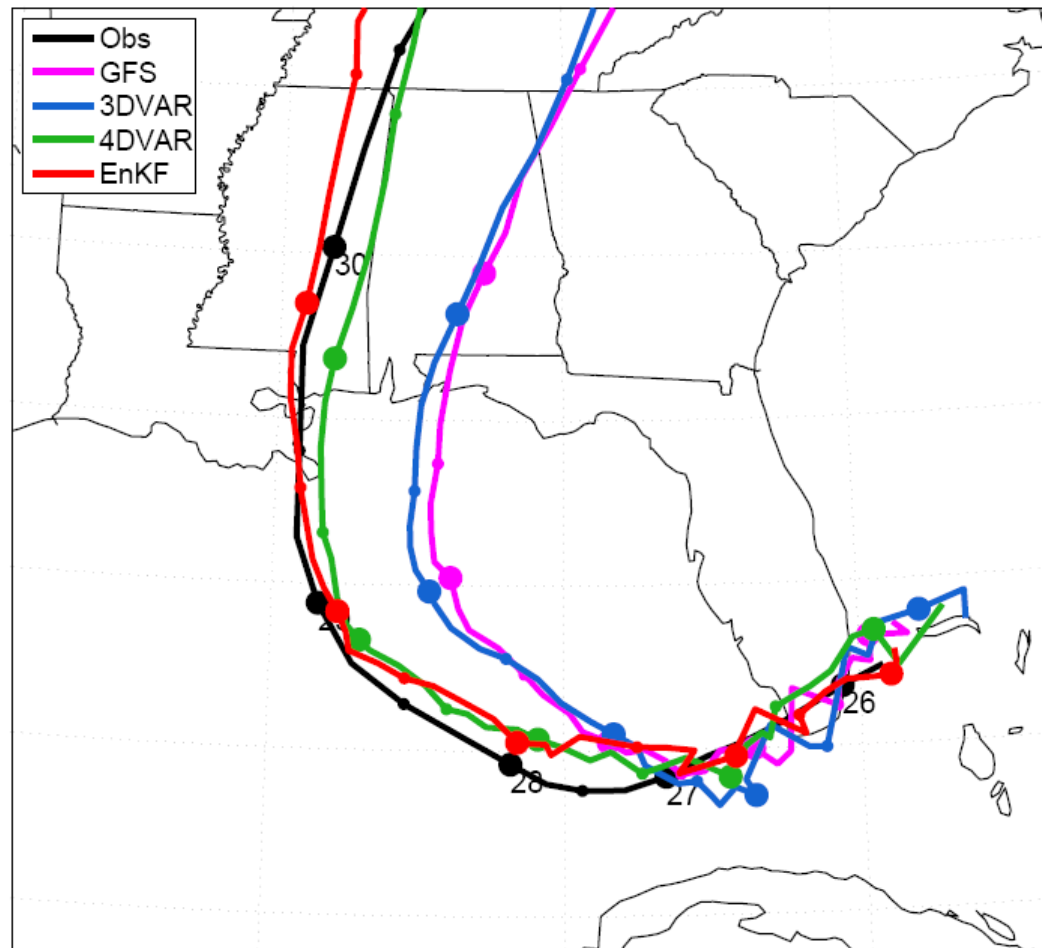
Katrina track forecasts (Zhiquan Liu)

- Impact of data



Katrina track forecasts (Zhang, Zhang, Huang, Zhang)

- Impact of DA methods



Modern weather forecast (Bjerknes, 1904)

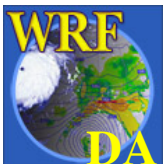
- A sufficiently accurate knowledge of the state of the atmosphere at the initial time
- A sufficiently accurate knowledge of the laws according to which one state of the atmosphere develops from another.

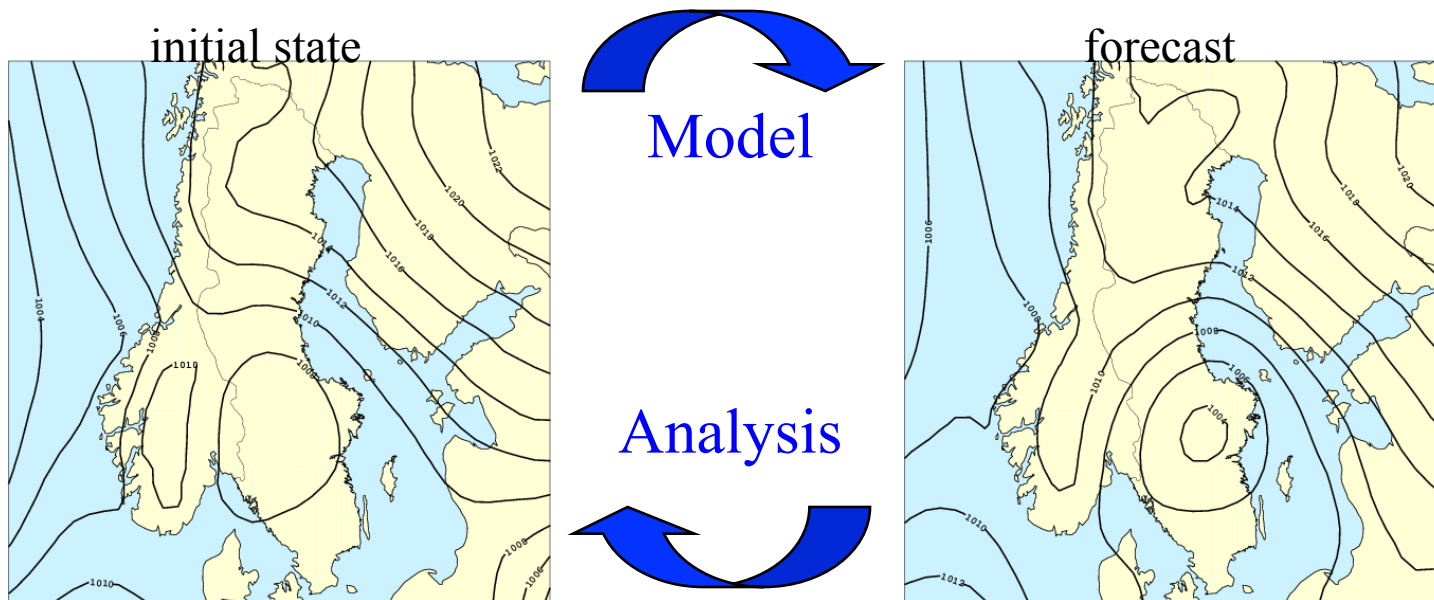


Vilhelm Bjerknes (1862–1951)

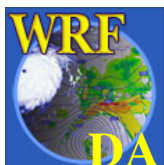
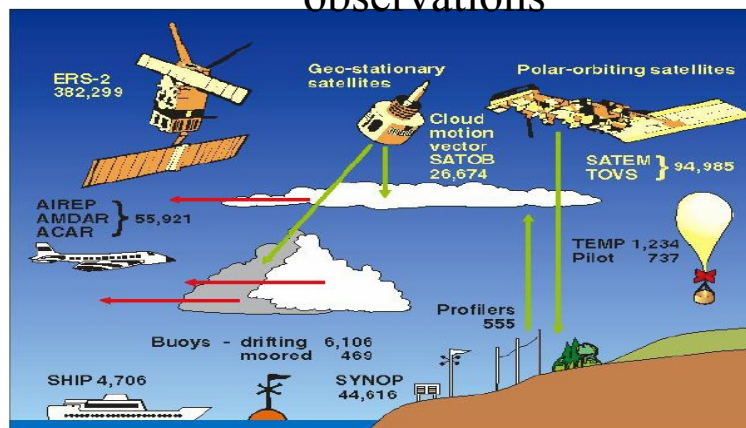
- **Analysis:** using observations and other information, we can specify the atmospheric state at a given initial time: “Today’s Weather”
- **Forecast:** using the equations, we can calculate how this state will change over time: “Tomorrow’s Weather”

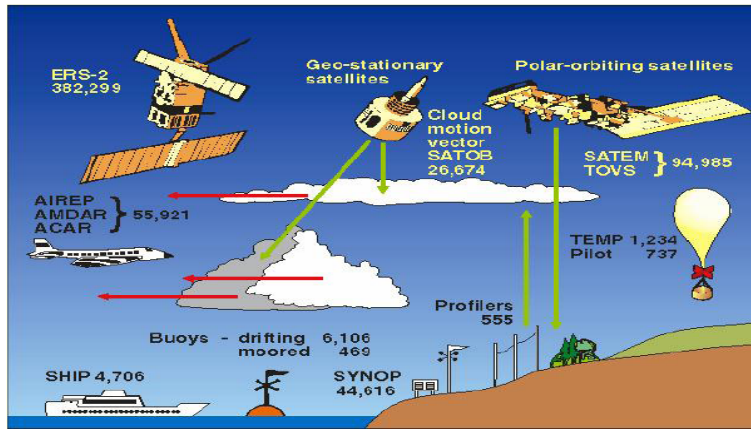
(Peter Lynch)





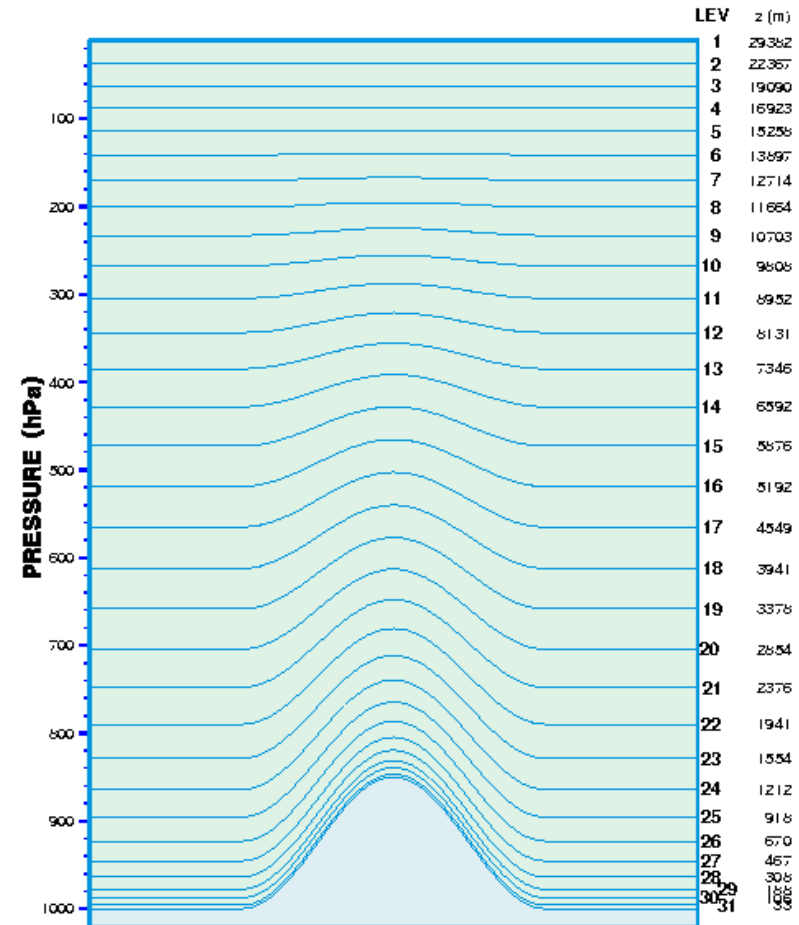
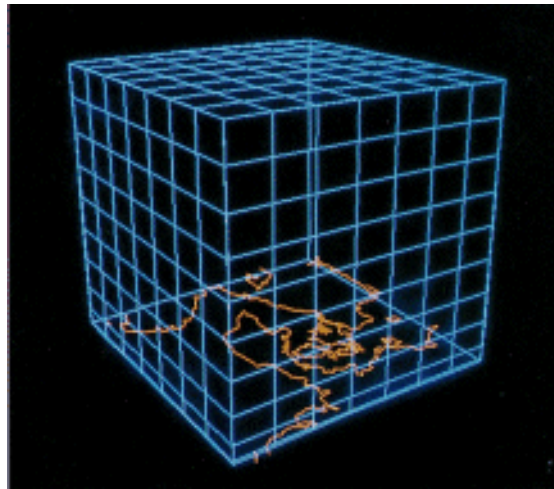
observations





Observations
 $y^0, \sim 10^5 - 10^6$

Model state
 $x, \sim 10^7$

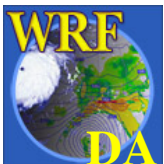


Vertical resolution of the DMI-HIRLAM system



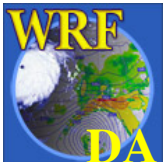
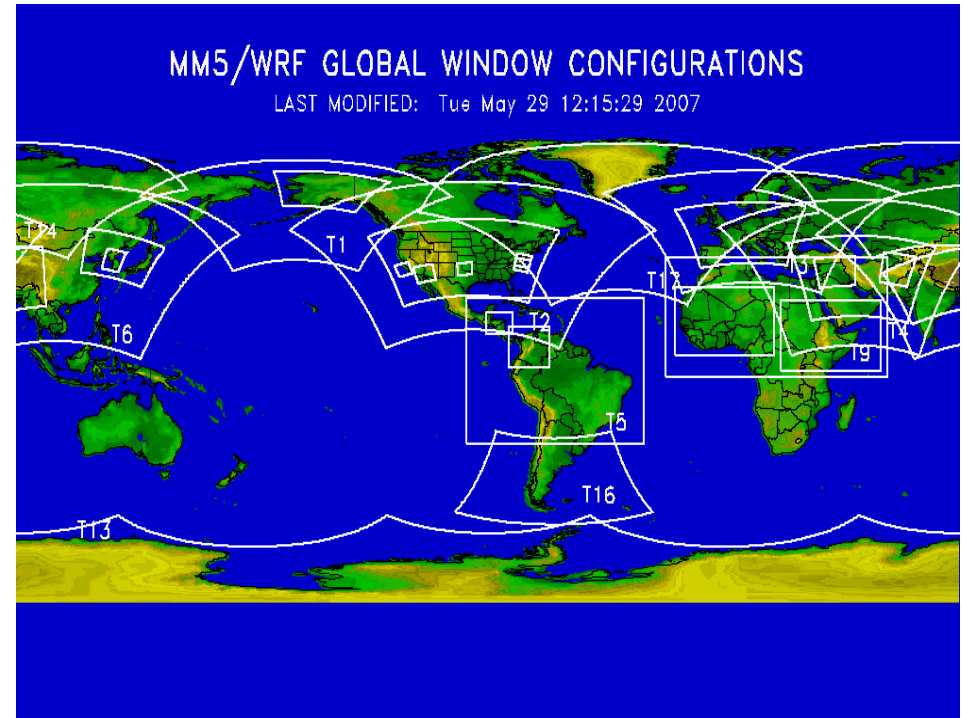
Assimilation methods

- 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

- **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](#).
- **Model:** WRF (ARW, NMM, Global)
- **Observations:** Conv. + Sat. + Radar (+Bogus)
- **Support:**
 - NCAR/NESL/MMM/DAS (Data Assimilation Section, also supporting [WRF/DART](#))
 - NCAR/RAL/JNT/DAT (Data Assimilation Team, also supporting [GSI](#))

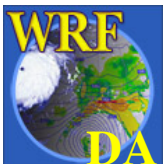
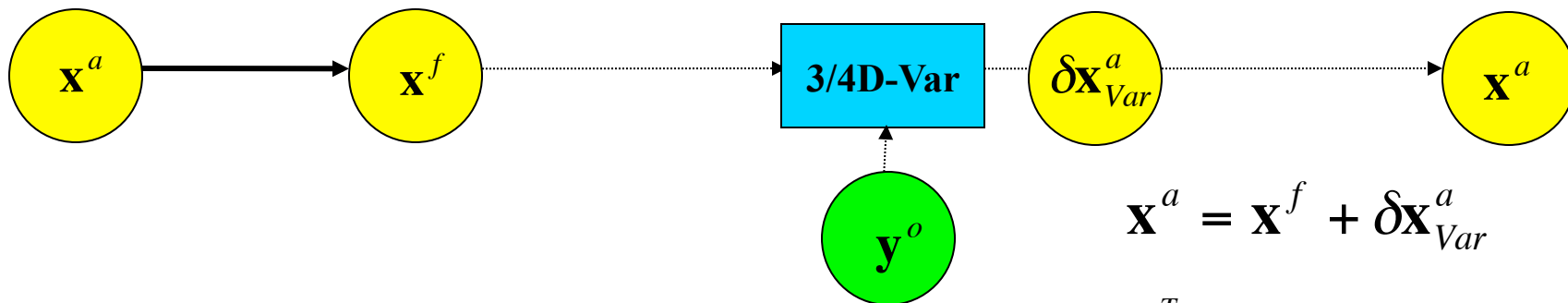


WRFDA

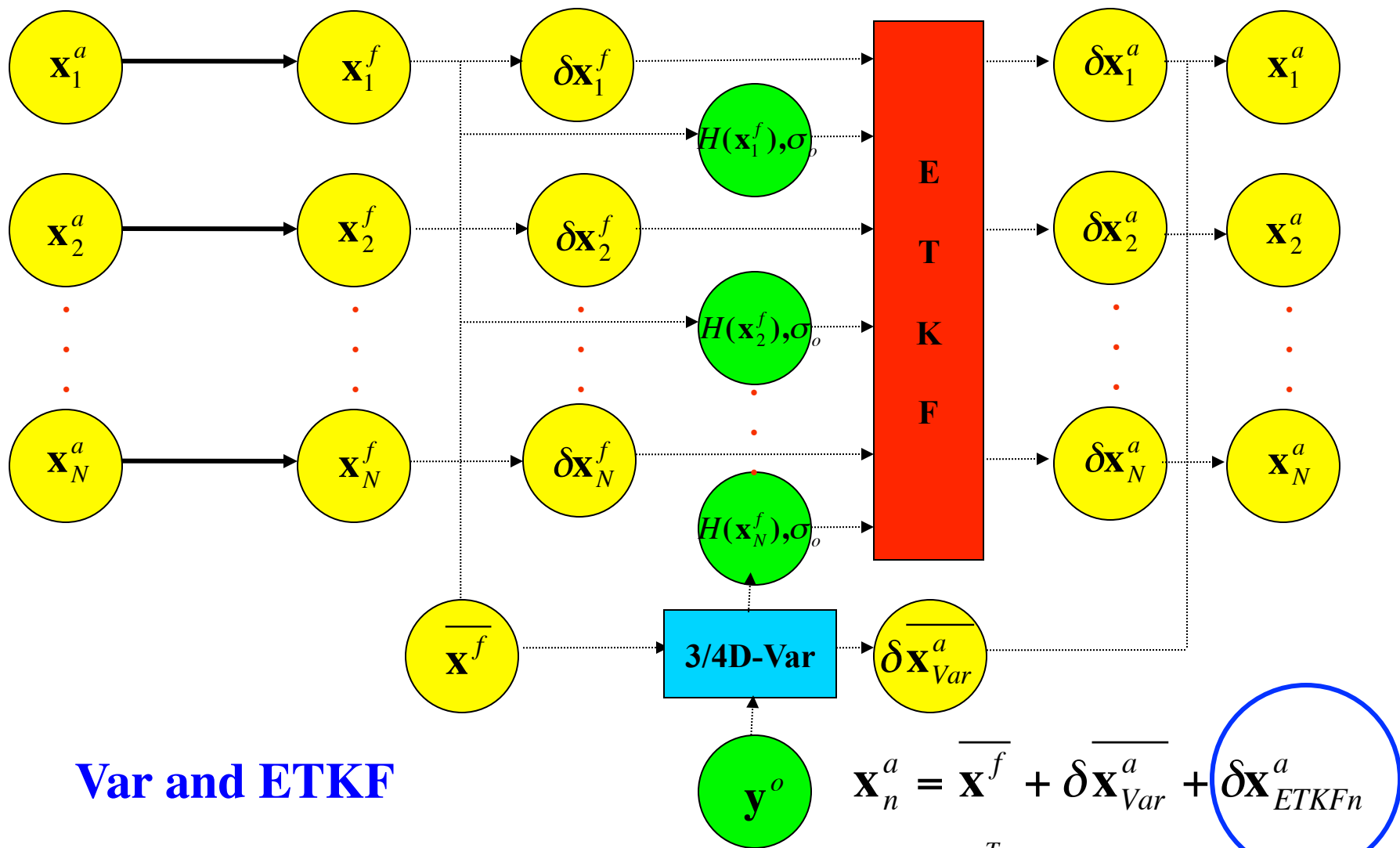
3/4D-Var

3D-Var: Barker et al. 2004

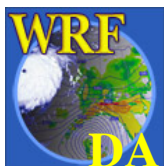
4D-Var: Huang et al. 2009

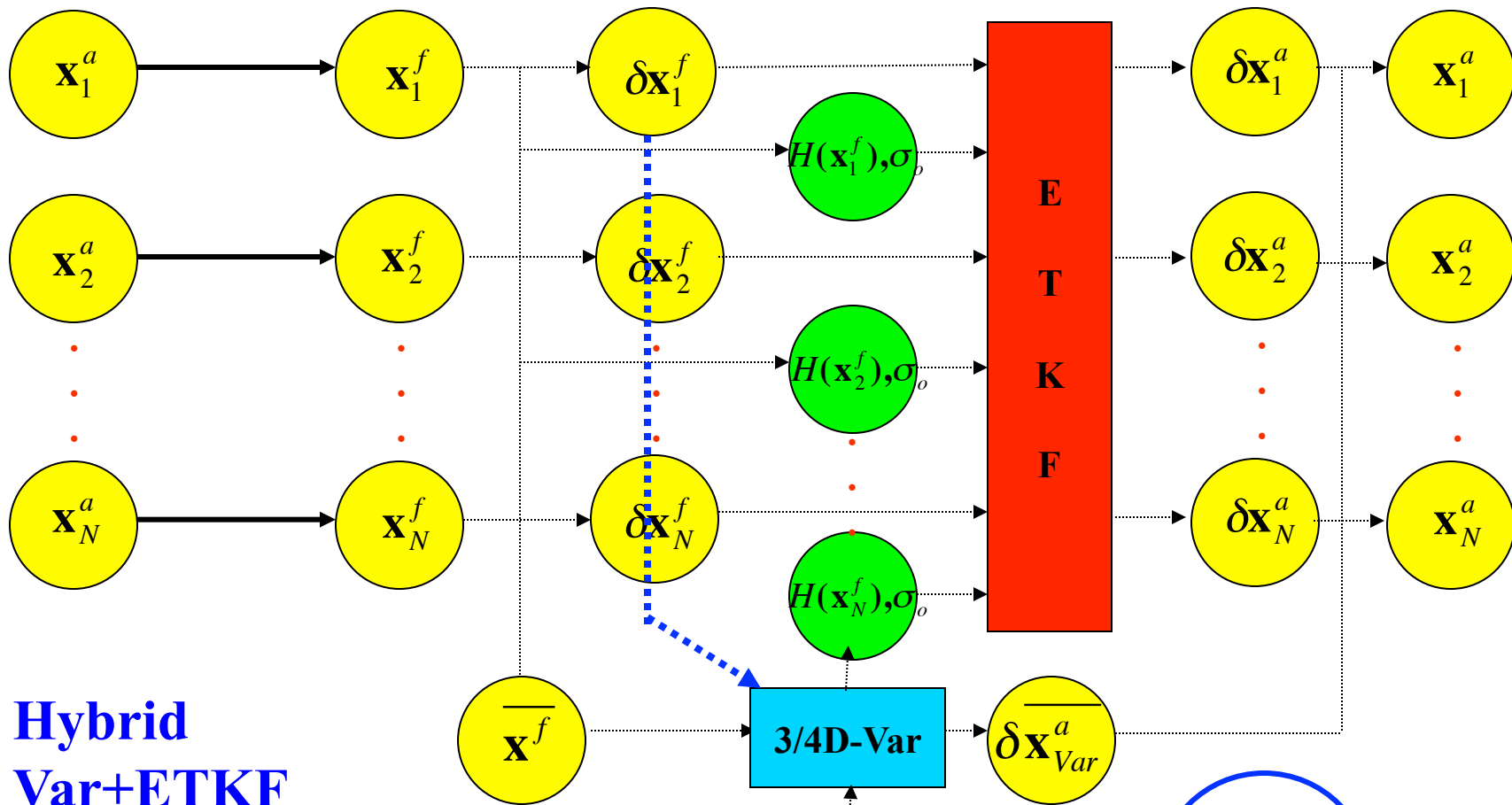


$$J = \frac{1}{2} \delta \mathbf{x}_0^T \mathbf{B}_o^{-1} \delta \mathbf{x}_0 + \frac{1}{2} \sum_{i=0}^n \left[\mathbf{H}_i \delta \mathbf{x}(t_i) - \mathbf{d}_i \right]^T \mathbf{R}_i^{-1} \left[\mathbf{H}_i \delta \mathbf{x}(t_i) - \mathbf{d}_i \right]$$

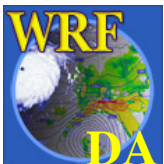


$$J = \frac{1}{2} \delta \mathbf{x}_0^T \mathbf{B}_o^{-1} \delta \mathbf{x}_0 + \frac{1}{2} \sum_{i=0}^n \left[\mathbf{H}_i \delta \mathbf{x}(t_i) - \mathbf{d}_i \right]^T \mathbf{R}_i^{-1} \left[\mathbf{H}_i \delta \mathbf{x}(t_i) - \mathbf{d}_i \right]$$





(Wang et al. 2008)



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

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

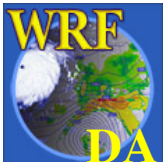
WRFDA Observations

- **In-Situ:**
 - Surface (SYNOP, METAR, SHIP, BUOY).
 - Upper air (TEMP, PIBAL, AIREP, ACARS, TAMDAR).
- **Remotely sensed retrievals:**
 - Atmospheric Motion Vectors (geo/polar).
 - SATEM thickness.
 - Ground-based GPS Total Precipitable Water/Zenith Total Delay.
 - SSM/I oceanic surface wind speed and TPW.
 - Scatterometer oceanic surface winds.
 - Wind Profiler.
 - **Radar radial velocities and reflectivities.**
 - Satellite temperature/humidity/thickness profiles.
 - GPS refractivity (e.g. COSMIC).
- **Radiative Transfer (RTTOV or CRTM):**
 - HIRS from NOAA-16, NOAA-17, NOAA-18, [NOAA-19](#), METOP-2
 - AMSU-A from NOAA-15, NOAA-16, NOAA-18, [NOAA-19](#), EOS-Aqua, METOP-2
 - AMSU-B from NOAA-15, NOAA-16, NOAA-17
 - MHS from NOAA-18, [NOAA-19](#), METOP-2
 - AIRS from EOS-Aqua
 - SSMIS from DMSP-16

•Bogus:

–TC bogus.

–Global bogus.

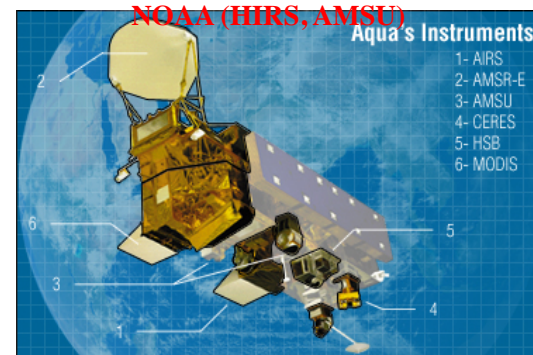
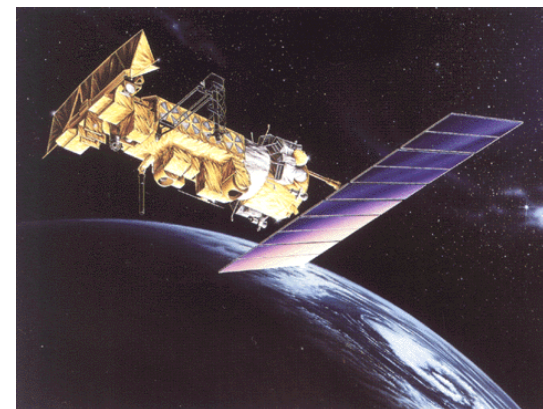


WRFDA

Radiance Assimilation

Liu and Auligne, NCAR

- BUFR 1b radiance ingest.
- **RTM interface:**
RTTOV (v9.3) or CRTM (v2.0.2)
- 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



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



WRFDA *USERS* PAGE

[Home](#) [Analysis System](#) [User Support](#) [Download](#) [Doc / Pub](#) [Links](#) [Internal](#) [Users Forum](#)

[wrf-model.org](#)
[Public Domain Notice](#)
[Contact WRF Support](#)

WRF Data Assimilation System Users Page

Welcome to the users home page for 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 of regional mesoscale to thousands of kilometers of global scales.

The Mesoscale and Microscale Meteorology Division of NCAR is currently maintaining and supporting a subset of

WHAT'S NEW

- [WRFDA Version 3.2.1 Release](#)
- [WRFDA Tutorial Schedule, Boulder, 3-5 August, 2010](#)
- [Tips for reading BUFR data](#)
- [WRFDA Version 3.2 Release](#)
- [The 4th East Asia WRF Workshop and Tutorial, 5-10 April, 2010](#)
- WRFDA Tutorial Feb.1-3. [Agenda](#)
- [WRFDA Version 3.1.1 Release](#)



WRFDA tutorials

21-22 July, 2008. NCAR.

2-4 Feb, 2009. NCAR.

17-24 Feb, 2009. Kunming, Yunnan, China.

18 April, 2009. South Korea.

20-22 July, 2009. NCAR.

15-31 Oct, 2009. Nanjing, China.

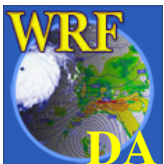
1-3 Feb, 2010. NCAR.

10 April, 2010. Seoul, South Korea.

3-5 August 2010. NCAR.

WRFDA online tutorial and user guide

<http://www.mmm.ucar.edu/wrf/users/wrfda>

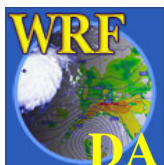


The recent WRFDA tutorial at NCAR

1. WRFDA Overview
2. Observation Pre-processing
3. WRFDA System
4. WRFDA Set-up, Run
5. WRFDA Background Error Estimations
6. Radar Data
7. Satellite Data
8. WRF 4D-Var
9. WRF Hybrid Data Assimilation System
10. WRFDA Tools and Verification
11. Observation Sensitivity

Practice

1. obsproc
2. wrfda (3D-Var)
3. Single-ob tests
4. Gen_be
5. Radar
6. Radiance
7. 4D-Var
8. Hybrid
9. Advanced (optional)



The next WRFDA tutorial at NCAR: July 18-20, 2011