Introduction to WRFDA

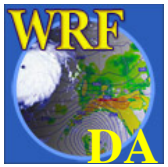
Hans Huang

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

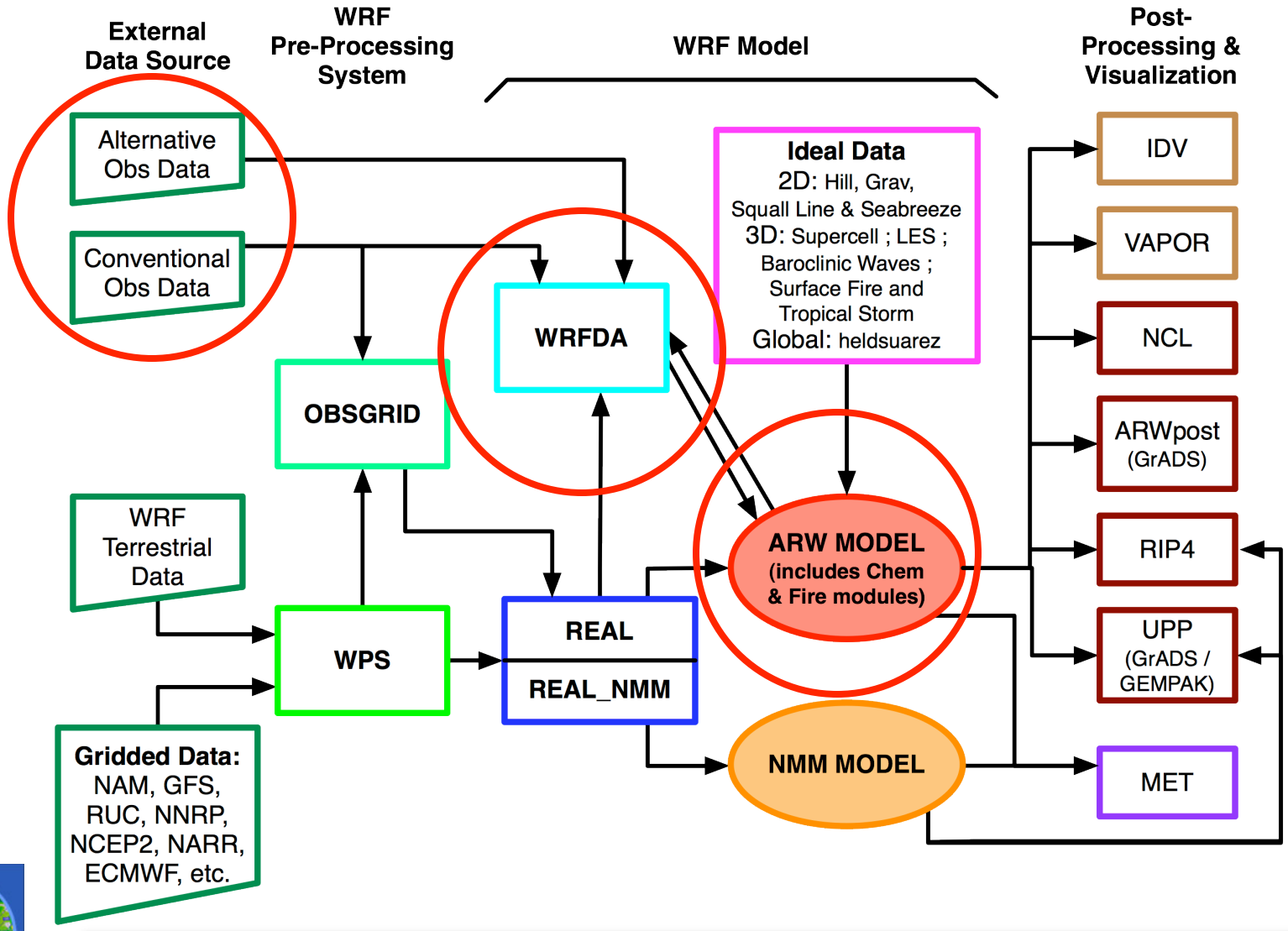
Acknowledge:

NCAR/MMM/DAS

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

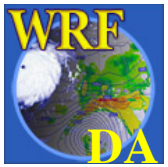


WRFDA in WRF Modeling System



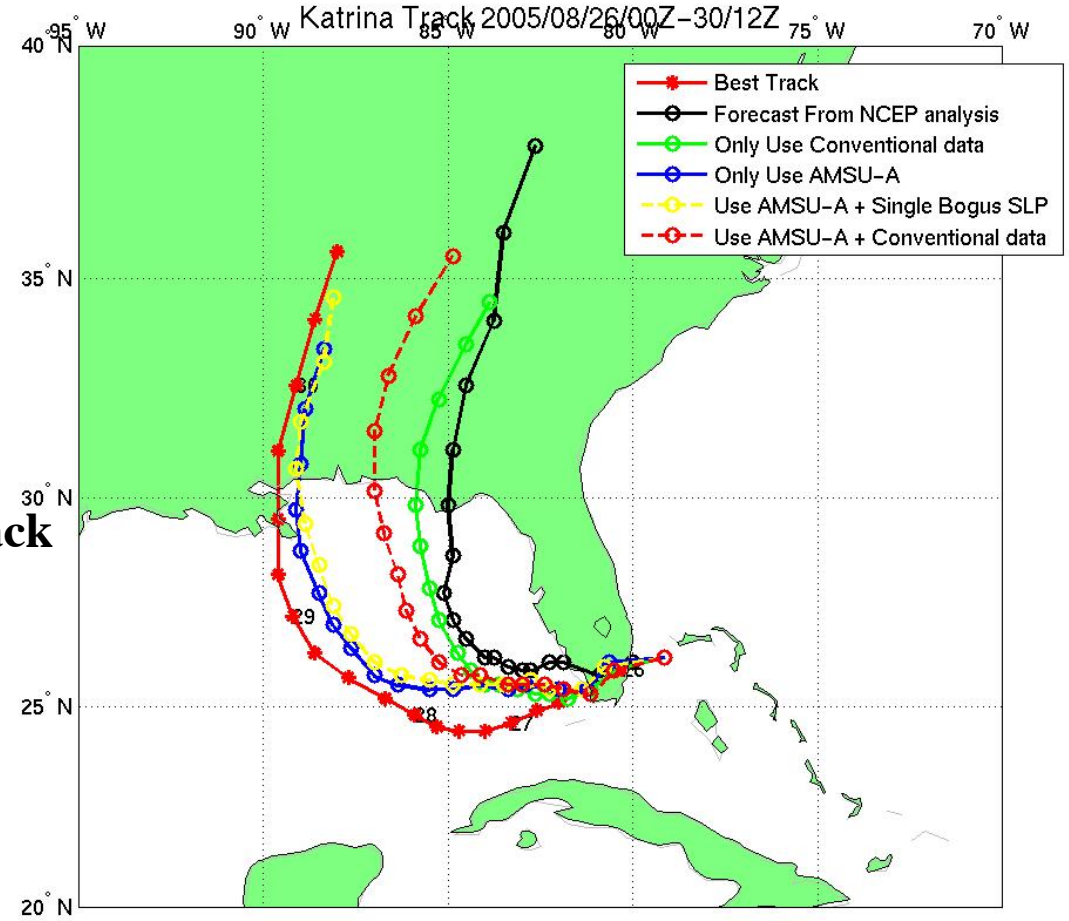
Why data assimilation?

- 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)

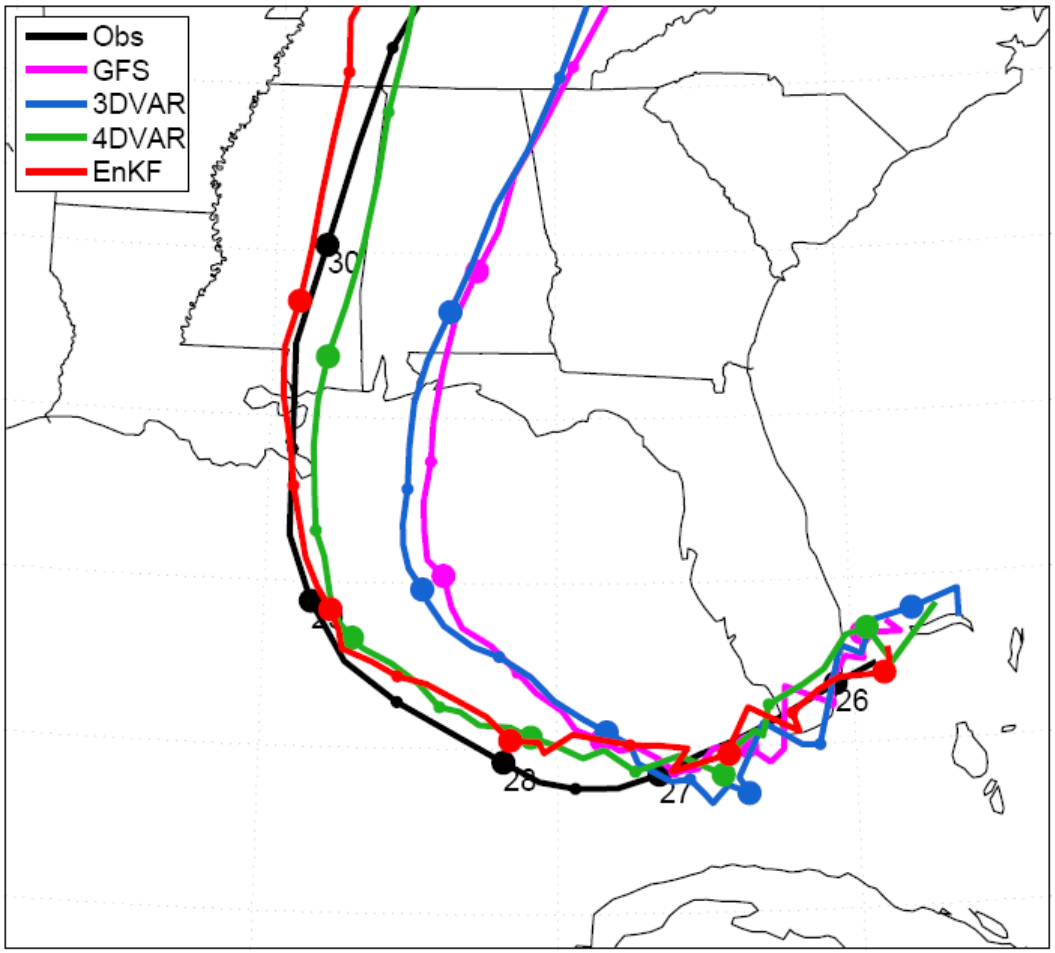
- Impact of data



Track

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

- Impact of DA methods



Modern weather forecast (Bjerknes,1904)

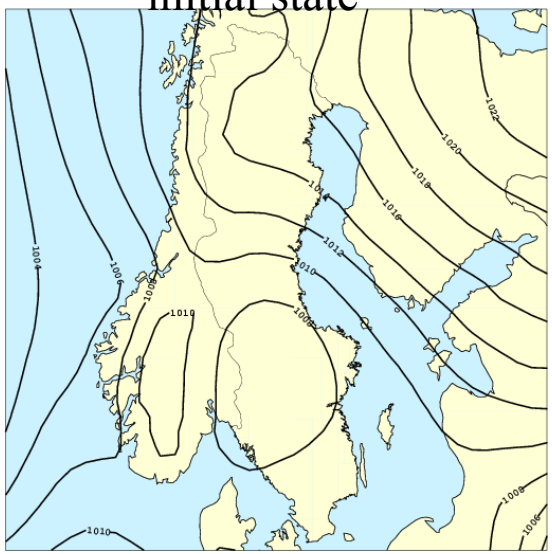
- A sufficiently accurate knowledge of the state of the atmosphere at the initial time
- A sufficiently accurate knowledge of the laws according to which one state of the atmosphere develops from another.

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)

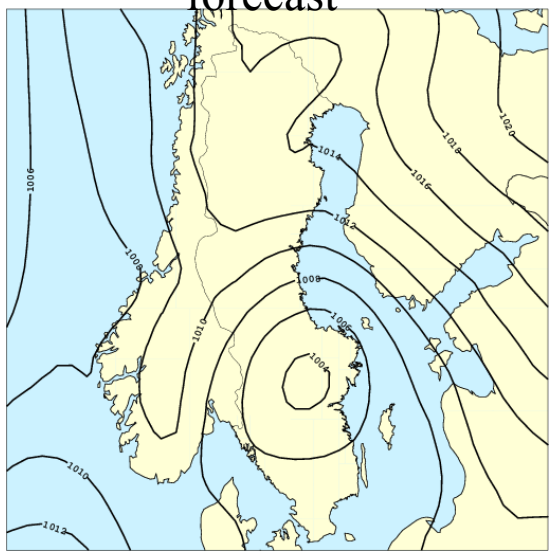
initial state



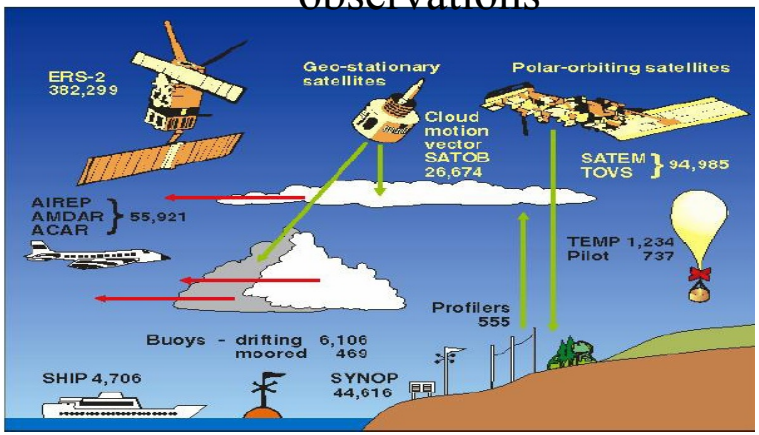
Model

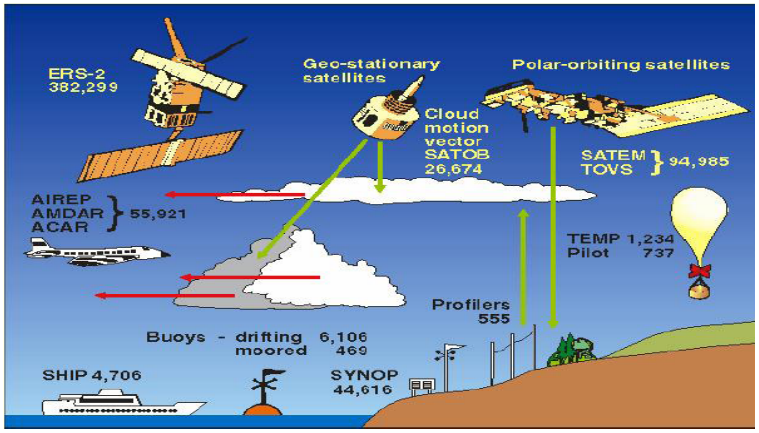
Analysis

forecast



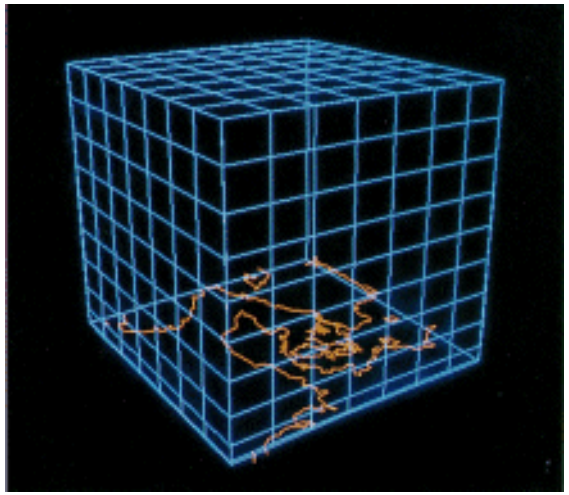
observations

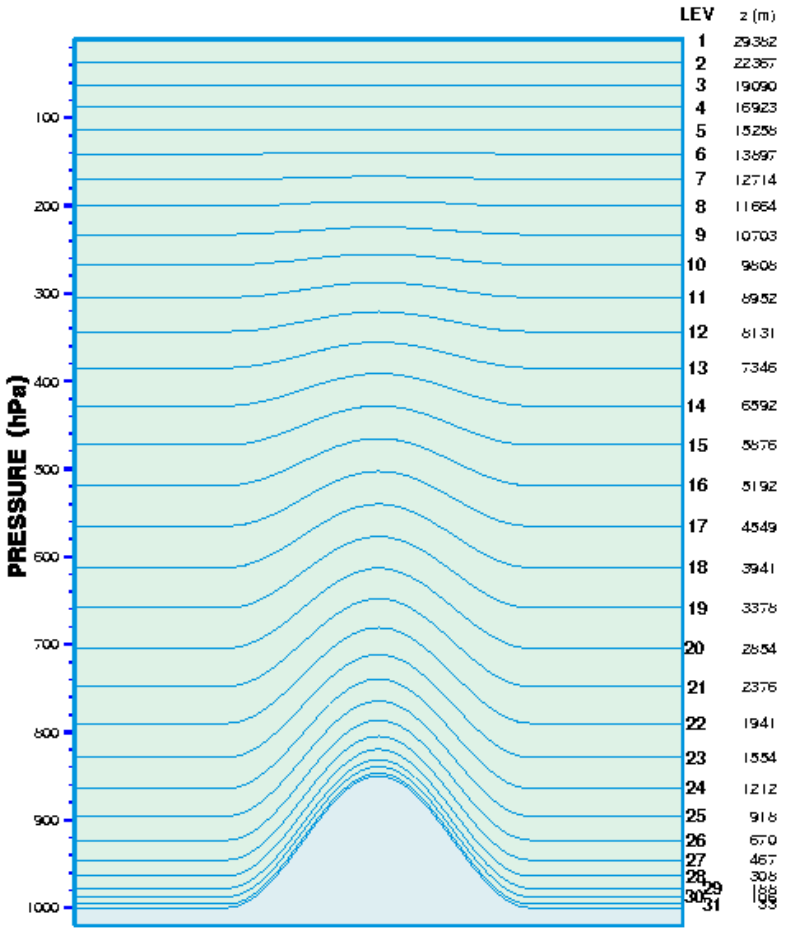




Observations
y^o, ~10^5-10^6

Model state
x, ~10^7

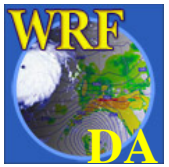




Vertical resolution of the DMI-HIRLAM system

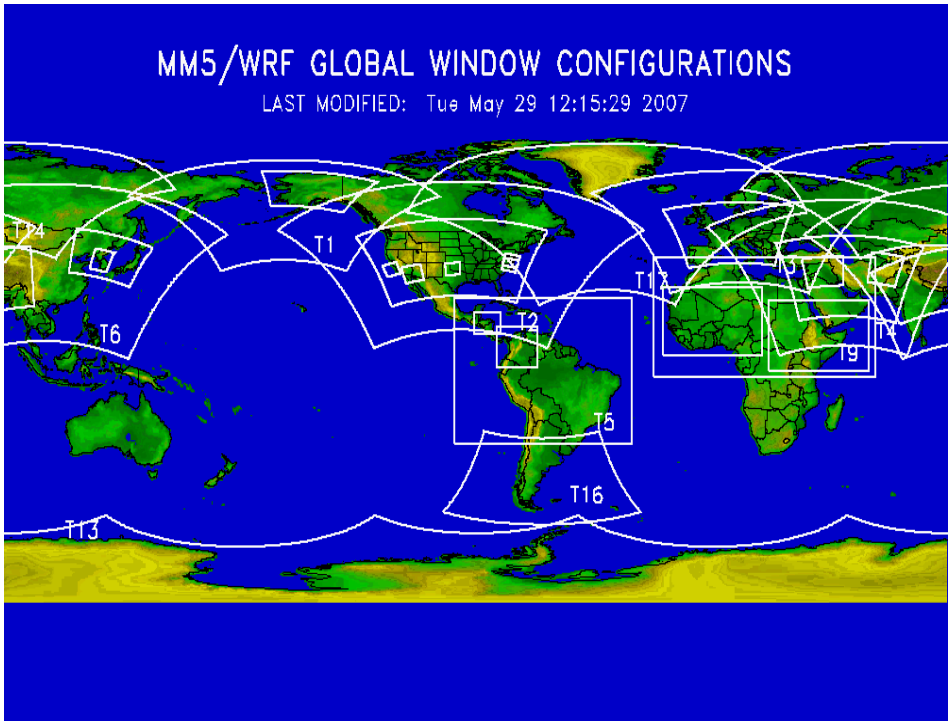
Assimilation methods

- 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



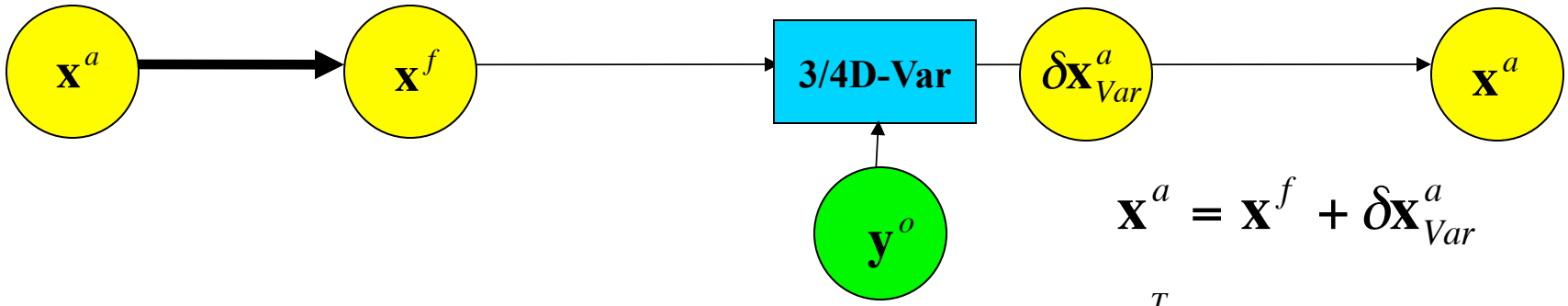
WRFDA

- **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)



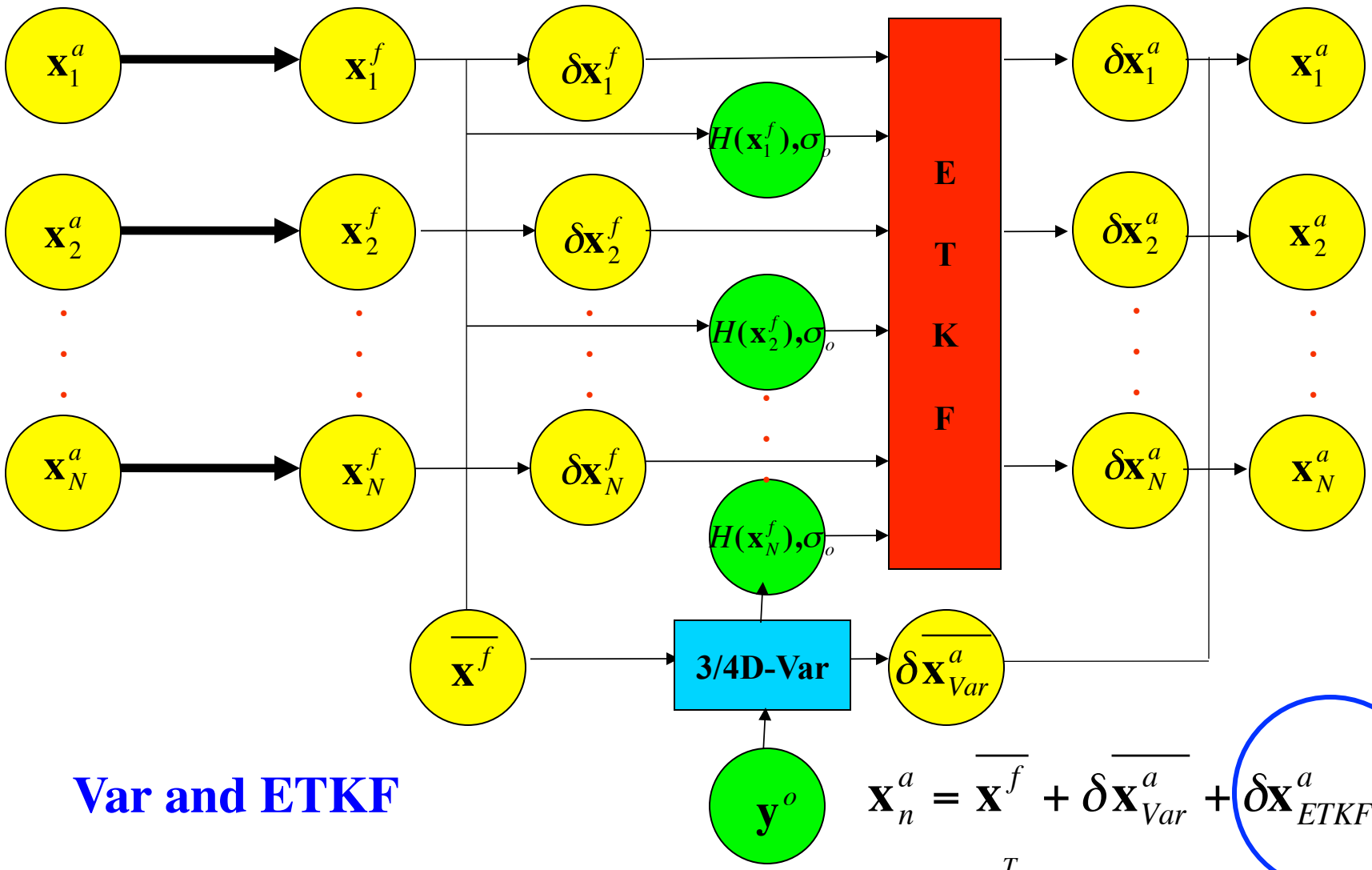
WRFDA
3/4D-Var

3D-Var: Barker et al. 2004
4D-Var: Huang et al. 2009



$$\mathbf{x}^a = \mathbf{x}^f + \delta\mathbf{x}^a_{Var}$$

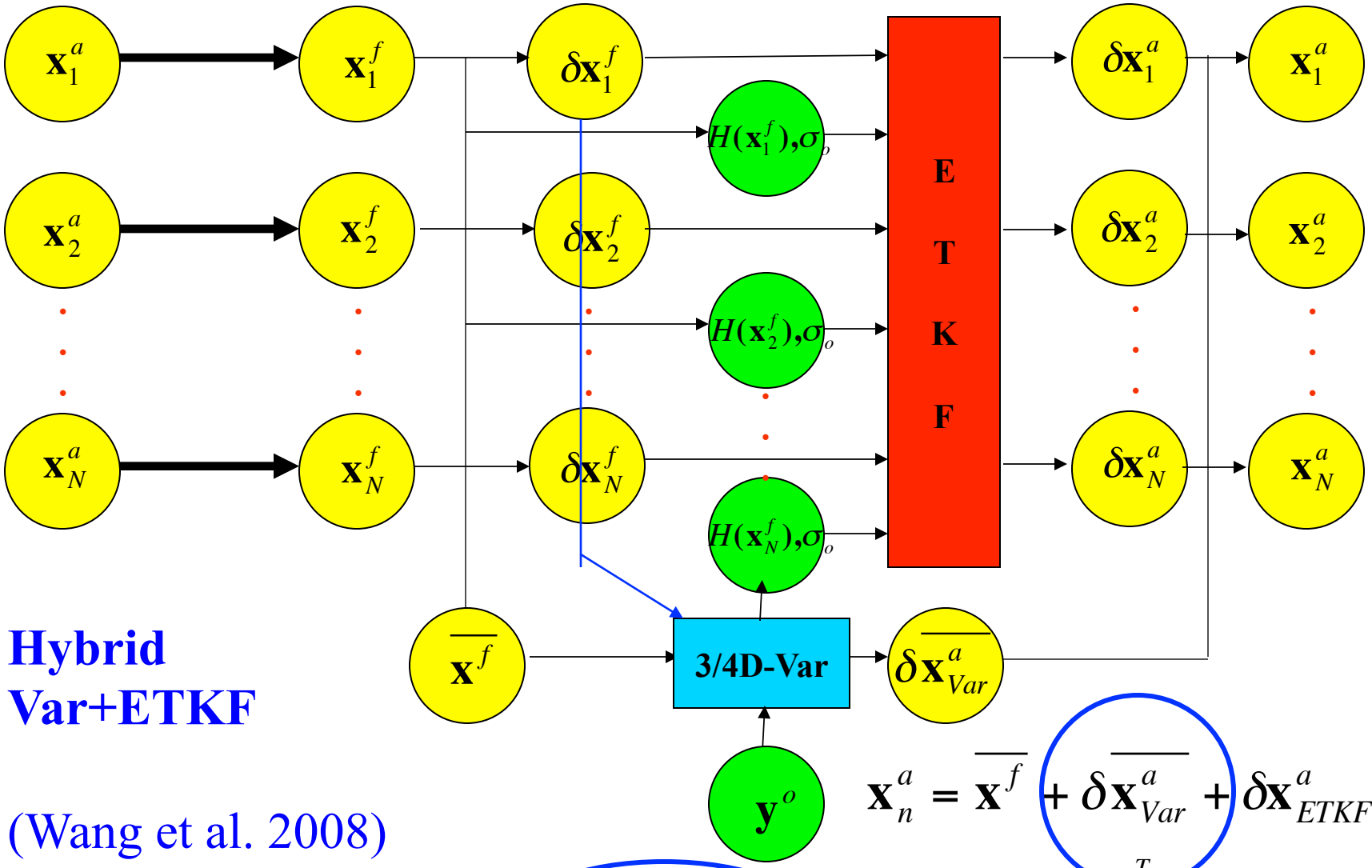
$$J = \frac{1}{2}\delta\mathbf{x}_0{}^T\mathbf{B}_o^{-1}\delta\mathbf{x}_0 + \frac{1}{2}\sum_{i=0}^{n}\left[\mathbf{H}_i\delta\mathbf{x}(t_i) - \mathbf{d}_i\right]^T\mathbf{R}_i^{-1}\left[\mathbf{H}_i\delta\mathbf{x}(t_i) - \mathbf{d}_i\right]$$



Var and ETKF

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

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



Hybrid Var+ETKF

(Wang et al. 2008)

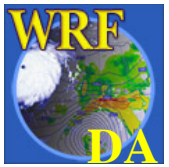
$$\mathbf{x}_n^a = \overline{\mathbf{x}^f} + \delta\overline{\mathbf{x}^a_{Var}} + \delta\mathbf{x}^a_{ETKFn}$$

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

WRFDA Observations

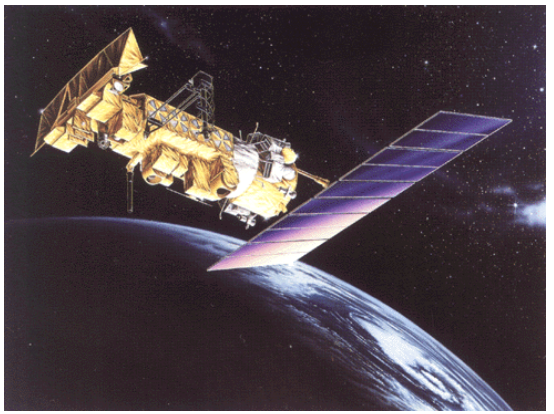
- **In-Situ:**
  - Surface (SYNOP, METAR, SHIP, BUOY).
  - Upper air (TEMP, PIBAL, AIREP, ACARS, TAMDAR).
- **Remotely sensed retrievals:**
  - Atmospheric Motion Vectors (geo/polar).
  - SATEM thickness.
  - Ground-based GPS Total Precipitable Water/Zenith Total Delay.
  - SSM/I oceanic surface wind speed and TPW.
  - Scatterometer oceanic surface winds.
  - Wind Profiler.
  - Radar radial velocities and reflectivities.
  - Satellite temperature/humidity/thickness profiles.
  - GPS refractivity (e.g. COSMIC).
  - Stage IV precipitation/rain rate data (4D-Var)
- **Radiative Transfer (RTTOV or CRTM):**
  - HIRS NOAA-16, NOAA-17, NOAA-18, NOAA-19, METOP-2
  - AMSU-A NOAA-15, NOAA-16, NOAA-18, NOAA-19, EOS-Aqua, METOP-2
  - AMSU-B NOAA-15, NOAA-16, NOAA-17
  - MHS NOAA-18, NOAA-19, METOP-2
  - AIRS EOS-Aqua
  - SSMIS DMSP-16, DMSP-17, DMSP-18

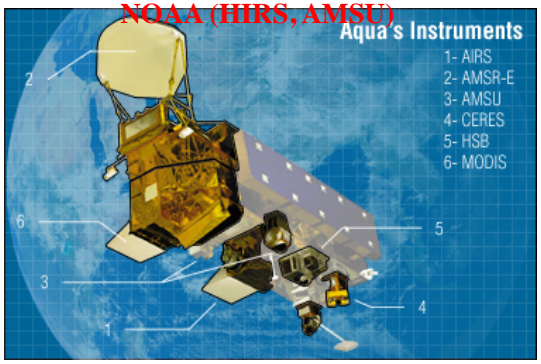
- **Bogus:**
  - TC bogus.
  - Global bogus.

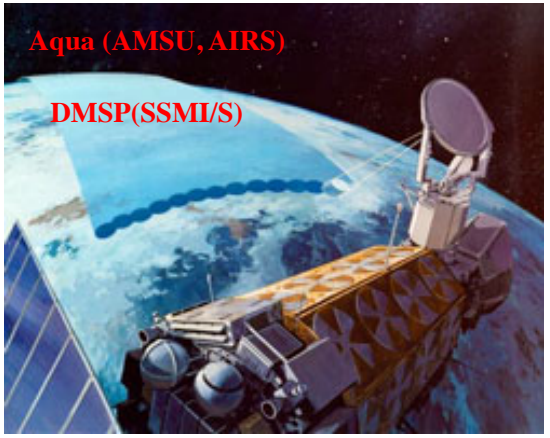


WRFDA
Radiance Assimilation
Liu and Auligne, NCAR

- BUFR 1b radiance ingest.
- **RTM interface:**
  RTTOV (v10.1) 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







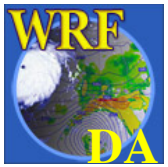
WRFDA tutorials

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.

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.

WRFDA online tutorial and user guide

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



Recent Tutorials 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: 22-24 July 2013

Google WRFDA:

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