Introduction to WRFDA

Hans Huang

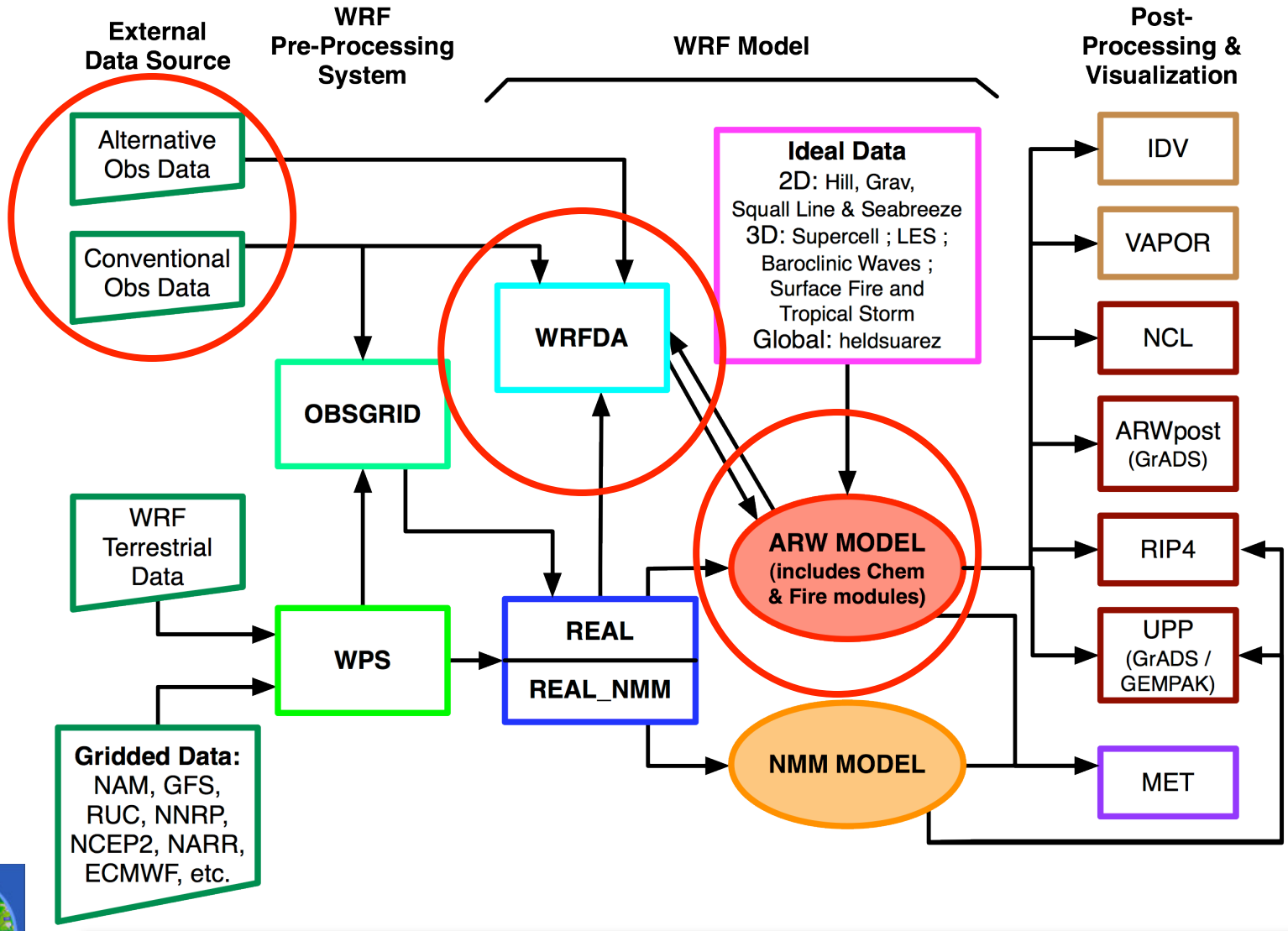
WRFDA is a Data Assimilation system built within the WRF software framework, used for application in both research and operational environments….

Acknowledge:

WRFDA team and many visitors,

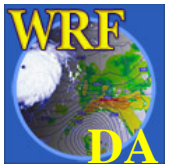
AFWA, NCAR, AirDat, NSF-AGS, USWRP, NSF-OPP, NASA, PSU,CWB, BMB, CAA, KMA, EUMETSAT, NUIST

WRFDA in WRF Modeling System



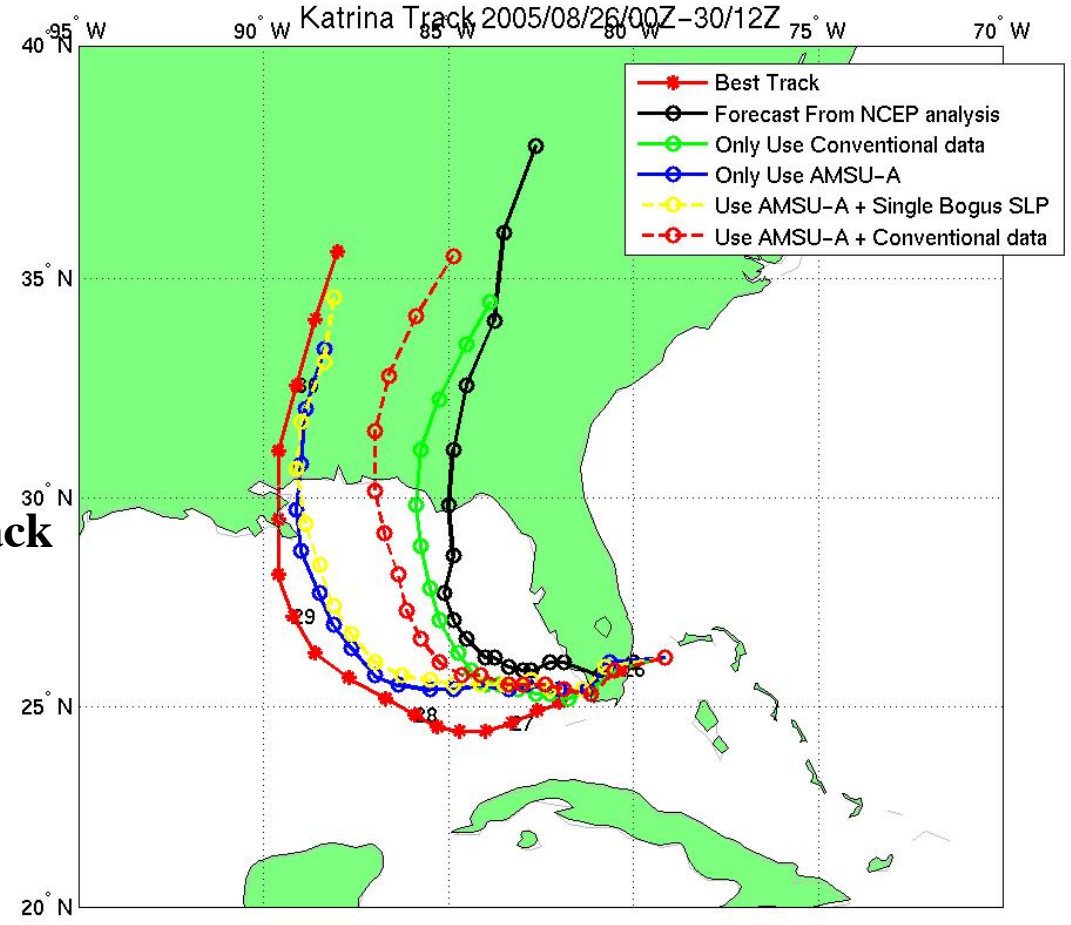
Why data assimilation?

- 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)

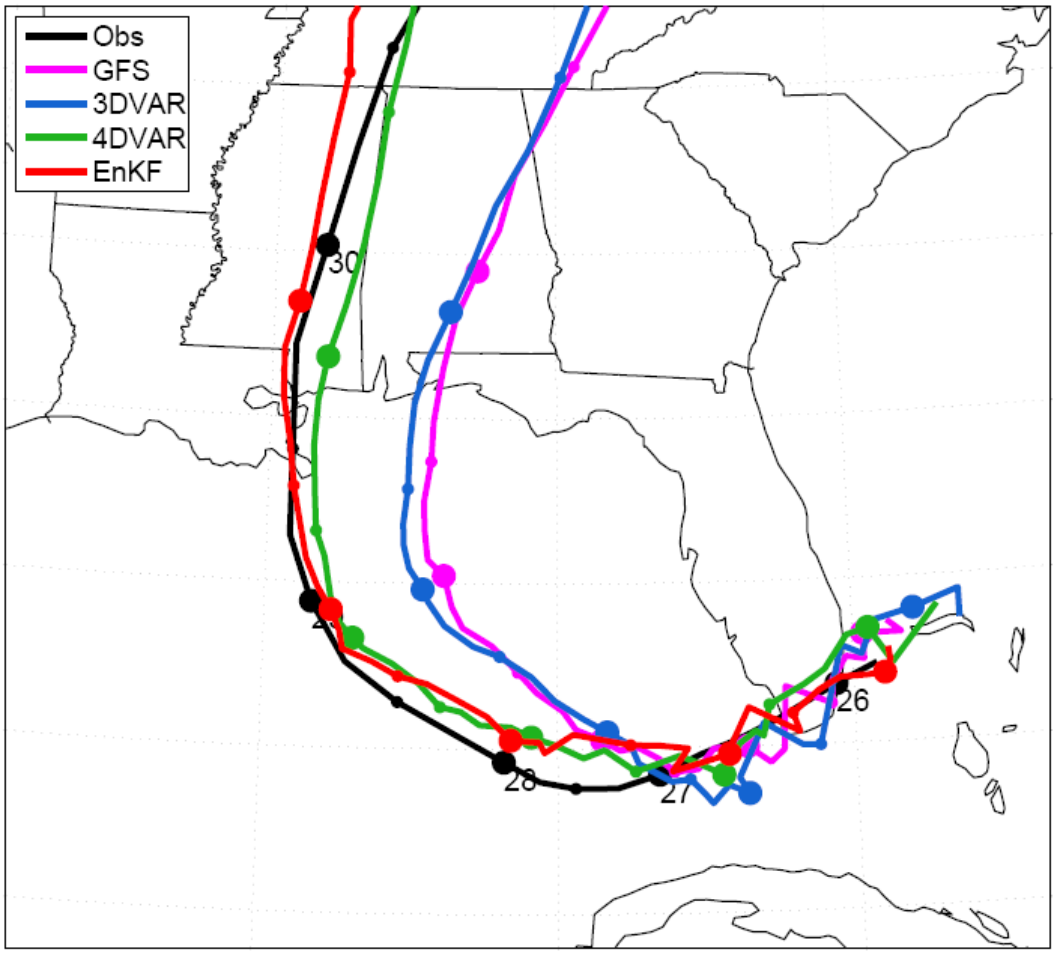
- Impact of data



Track

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

- Impact of DA methods



Modern weather forecast (Bjerknes,1904)

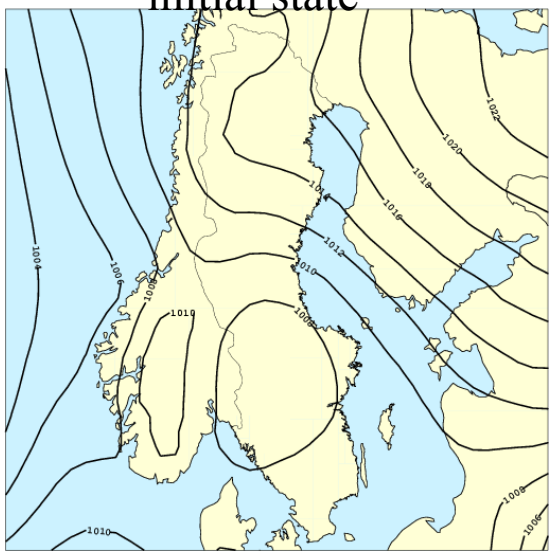
- A sufficiently accurate knowledge of the state of the atmosphere at the initial time
- A sufficiently accurate knowledge of the laws according to which one state of the atmosphere develops from another.

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)

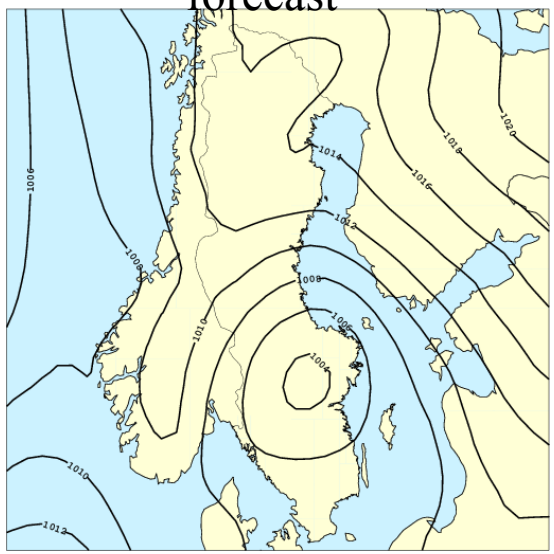
initial state



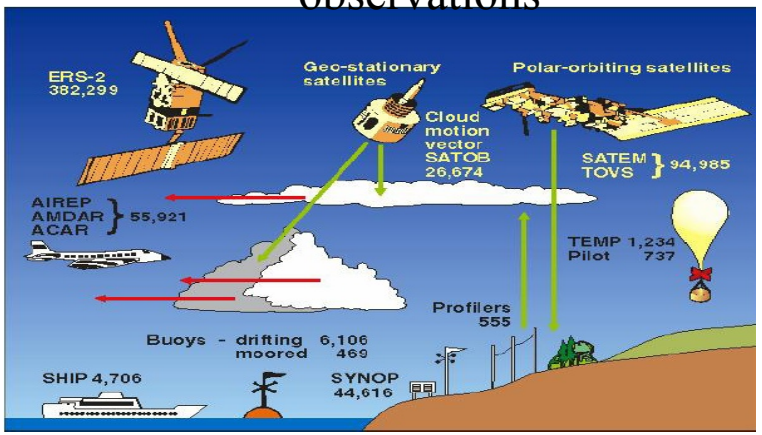
Model

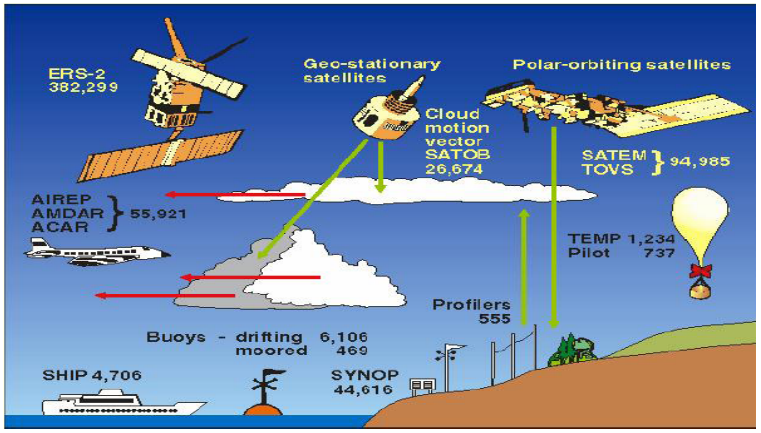
Analysis

forecast



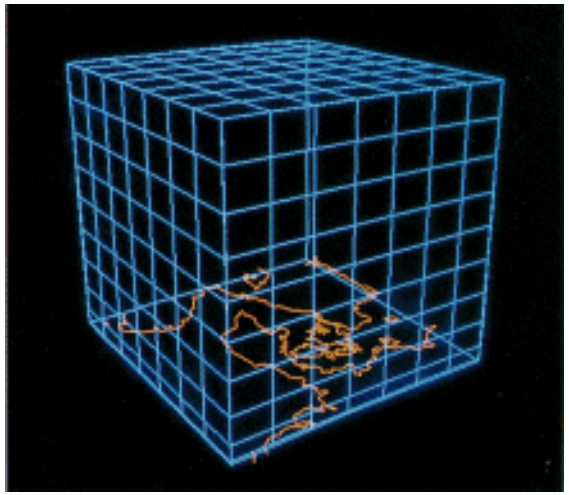
observations

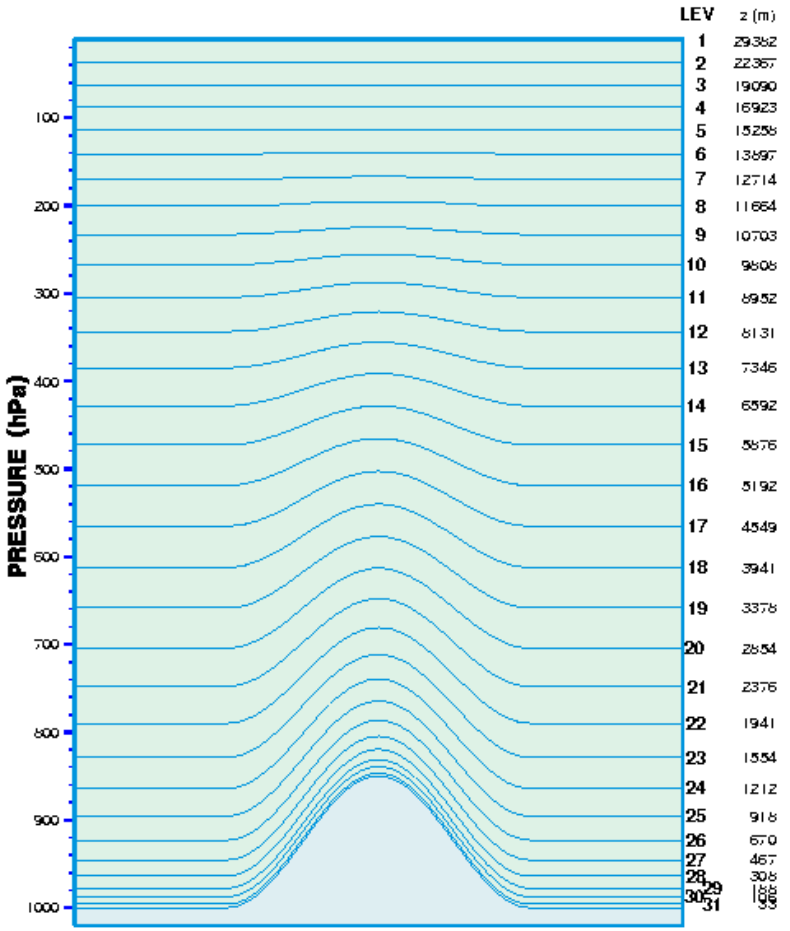




Observations
y^o, ~10^5-10^6

Model state
x, ~10^7

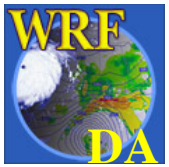




Vertical resolution of the DMI-HIRLAM system

Assimilation methods

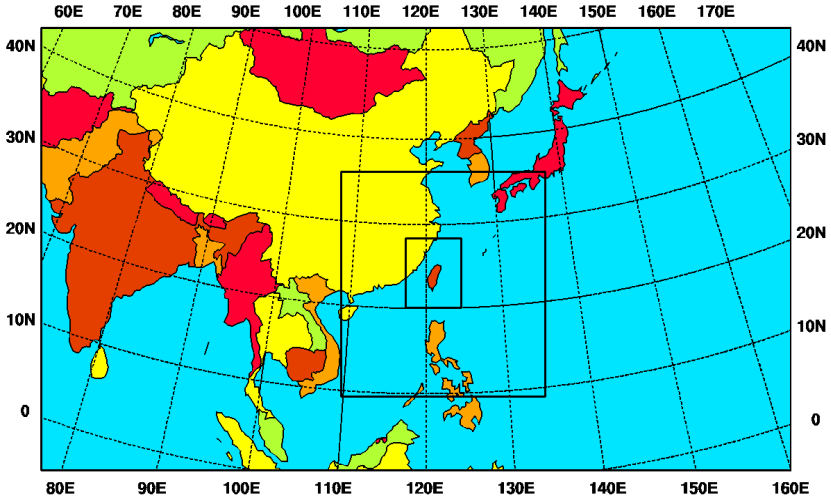
- Empirical methods
  - Successive Correction Method (SCM)
  - Nudging
  - Physical Initialisation (PI), Latent Heat Nudging (LHN)
- Statistical methods
  - Optimal Interpolation (OI)
  - 3-Dimensional VARiational data assimilation (3DVAR)
  - 4-Dimensional VARiational data assimilation (4DVAR)
- Advanced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



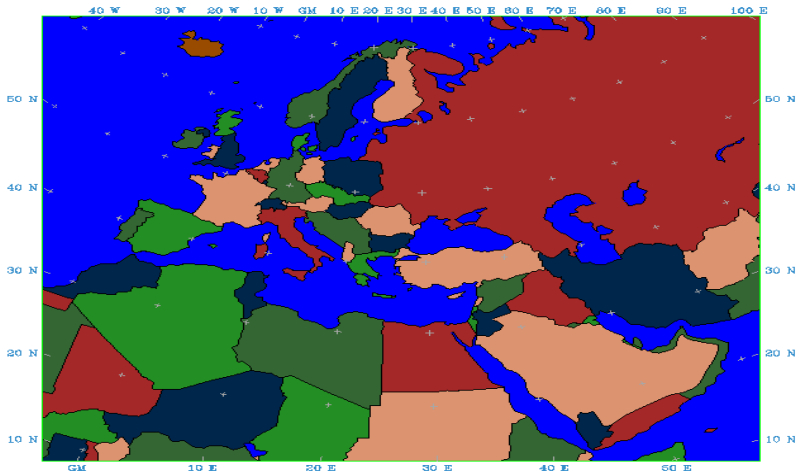
WRFDA is a Data Assimilation system built within the WRF software framework, …

- **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)
- **Support:**
  - NCAR/ESSL/MMM/DAS
- **Observations:** Conv.+Sat.+Radar(+bogus)

Domain area of CWB WRF



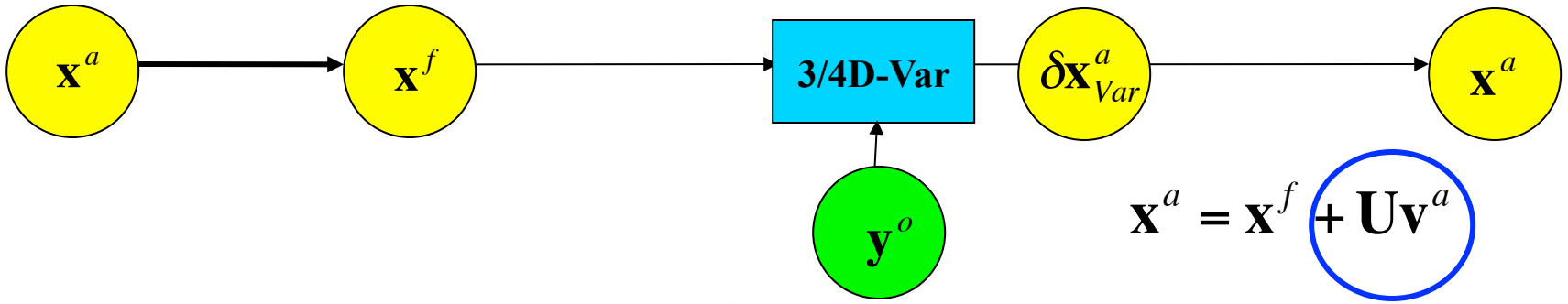
Panasonic European WRF



WRFDA
3/4D-Var

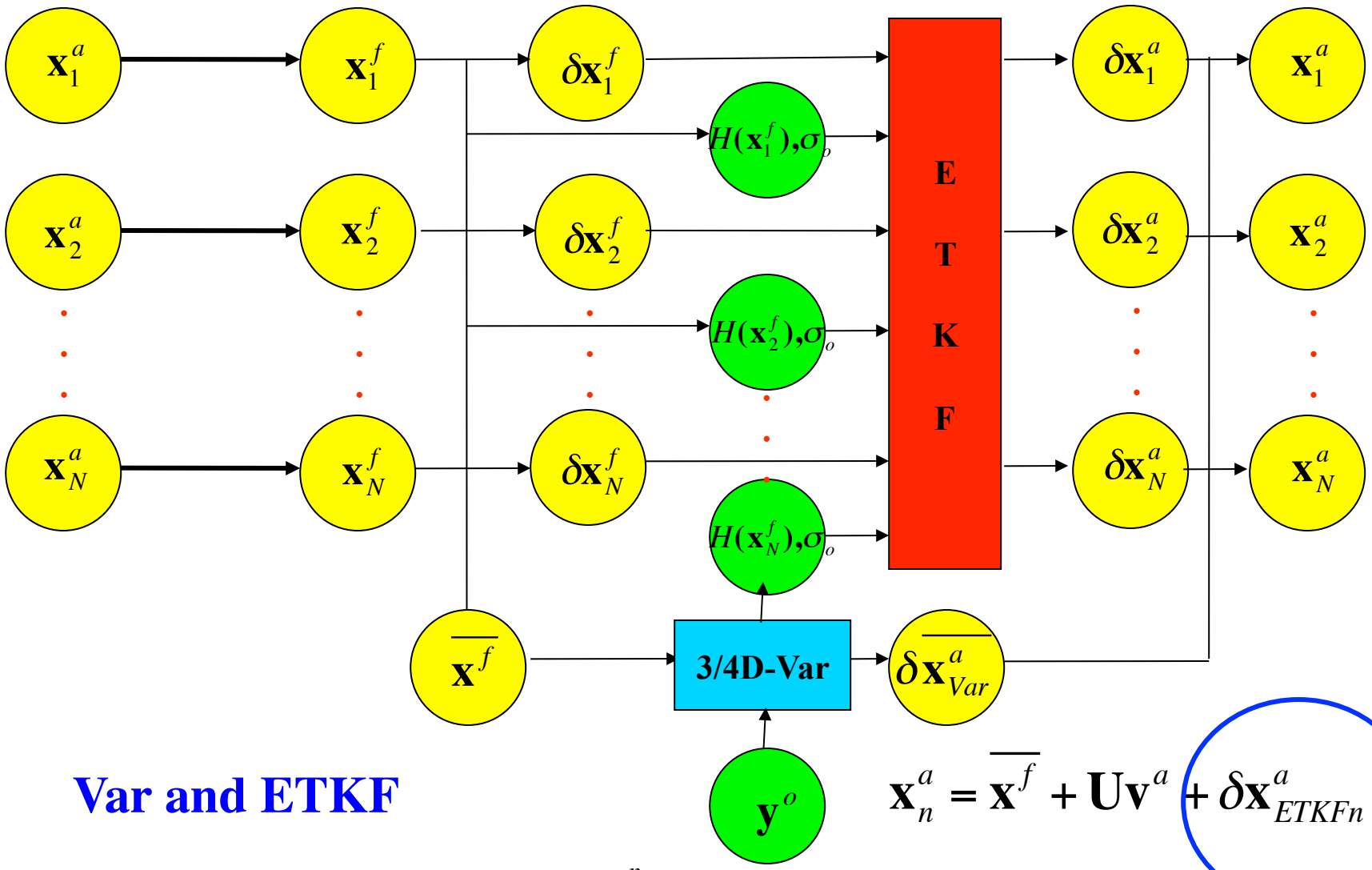
$$\delta \mathbf{x}^a_{Var} = \mathbf{U}\mathbf{v}^a$$

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



$$\mathbf{x}^a = \mathbf{x}^f + \mathbf{U}\mathbf{v}^a$$

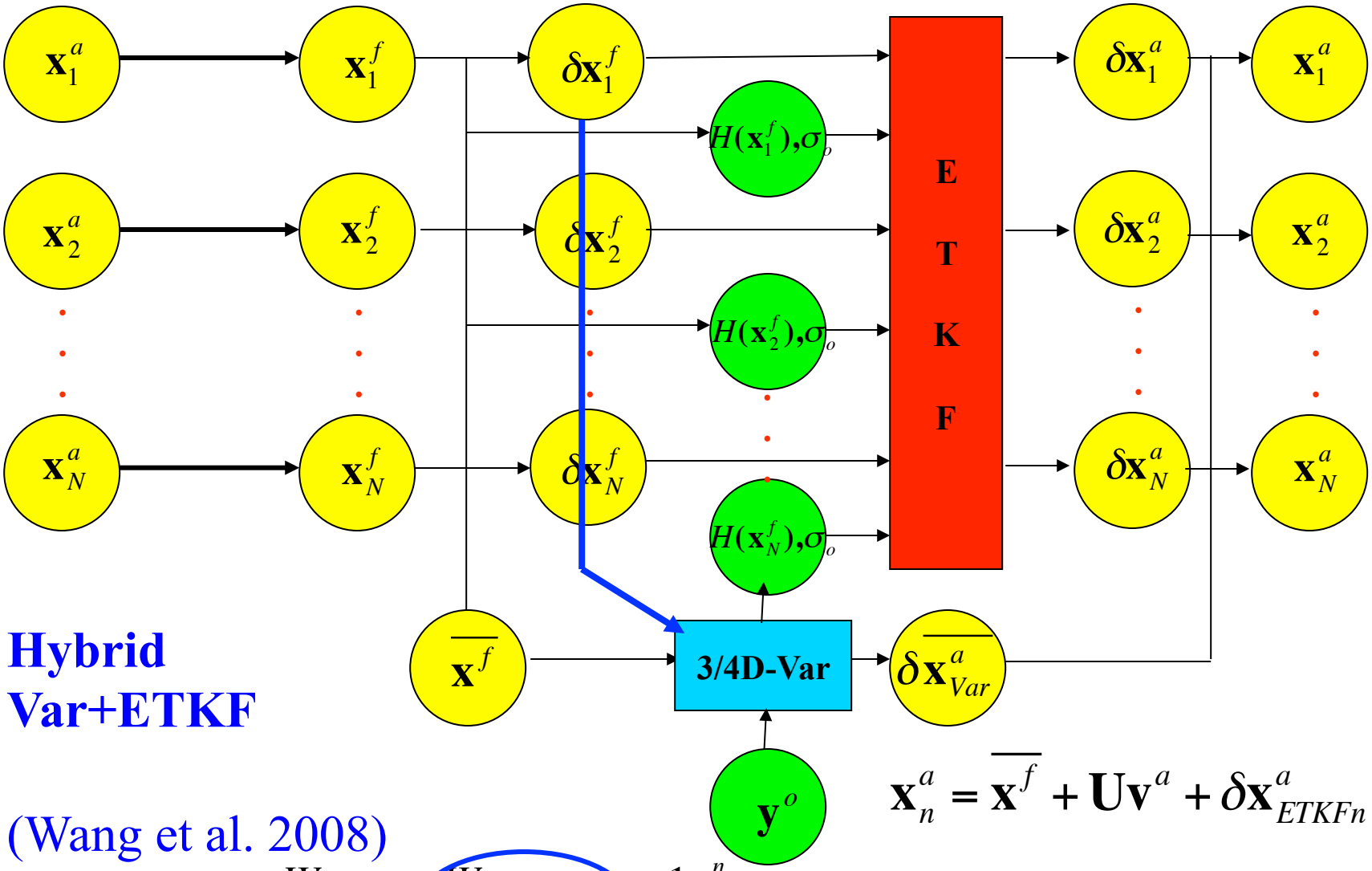
$$J = \frac{1}{2}\mathbf{v}^T\mathbf{v} + \frac{1}{2}\sum_{i=0}^{n} \left[\mathbf{d}_i - \mathbf{H}_i\mathbf{M}_i\mathbf{U}\mathbf{v}\right]^T \mathbf{R}_i^{-1}\left[\mathbf{d}_i - \mathbf{H}_i\mathbf{M}_i\mathbf{U}\mathbf{v}\right]$$



Var and ETKF

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

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



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

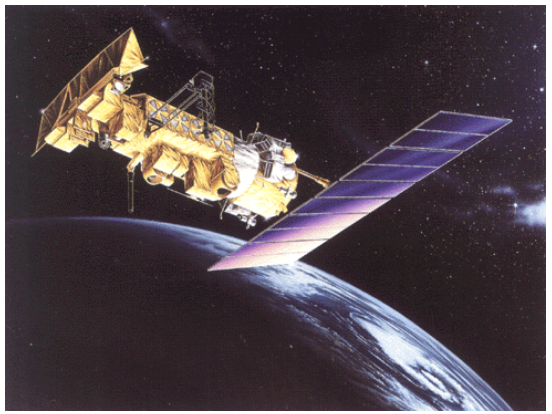
- **In-Situ:**
  - SYNOP
  - METAR
  - SHIP
  - BUOY
  - TEMP
  - PIBAL
  - AIREP, **AIREP humidity**
  - TAMDAR
- **Bogus:**
  - TC bogus
  - Global bogus

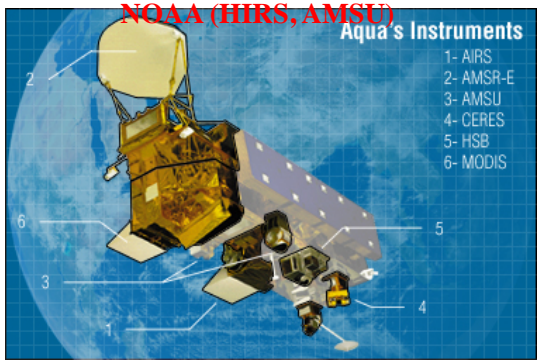
V3.6

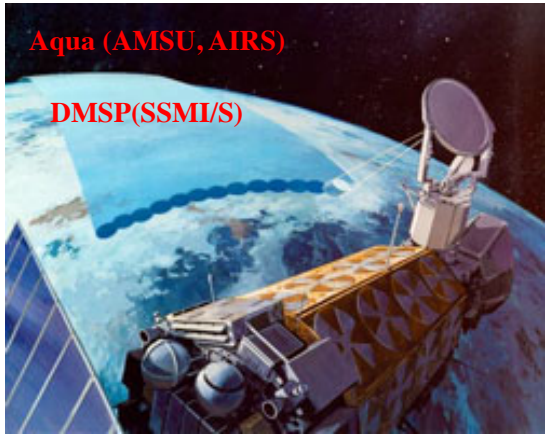
- **Remotely sensed retrievals:**
  - Atmospheric Motion Vectors (geo/polar)
  - SATEM thickness
  - Ground-based GPS TPW or ZTD
  - SSM/I oceanic surface wind speed and TPW
  - Scatterometer oceanic surface winds
  - Wind Profiler
  - Radar radial velocities and reflectivities
  - Satellite temperature/humidity/thickness profiles
  - GPS refractivity (e.g. COSMIC)
  - Stage IV precipitation/rain rate data (4D-Var)
- **Radiative Transfer (RTTOV_11.1 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** (**V3.6**)
  - AMSU-B — NOAA-15, NOAA-16, NOAA-17
  - MHS — NOAA-18, NOAA-19, METOP-A, **METOP-B** ← **V3.6**
  - AIRS — EOS-Aqua
  - SSMIS — DMSP-16, DMSP-17, DMSP-18
  - IASI — METOP-A, **METOP-B** ← **V3.6**
  - ATMS — Suomi-NPP
  - MWTS — FY-3
  - MWHS — FY-3
  - **SEVIRI** — **METEOSAT** ← **V3.6**

WRFDA
Radiance Assimilation
Liu and Auligne, NCAR

- BUFR 1b radiance ingest.
- **RTM interface (v3.5.1):**
  RTTOV (v11.1) 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







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.

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://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: 28-30 July 2014 (next week)

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