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….
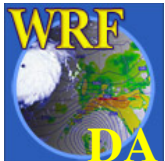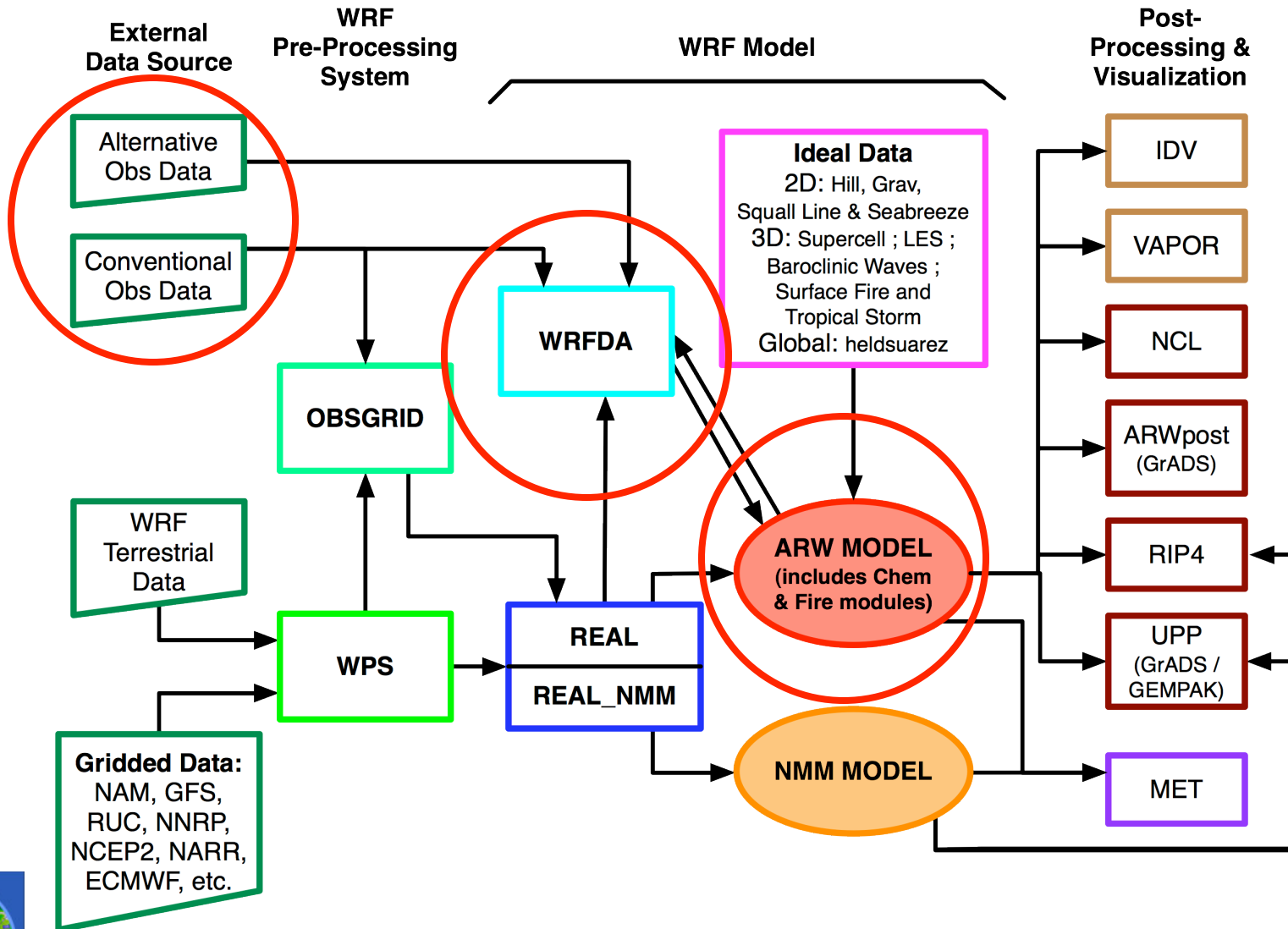
Acknowledge:

NCAR/MMM/DAS

NCAR, AFWA, USWRP, NSF-OPP, KMA, CWB, CAA, NASA, EUMETSAT, BMB, AirDat
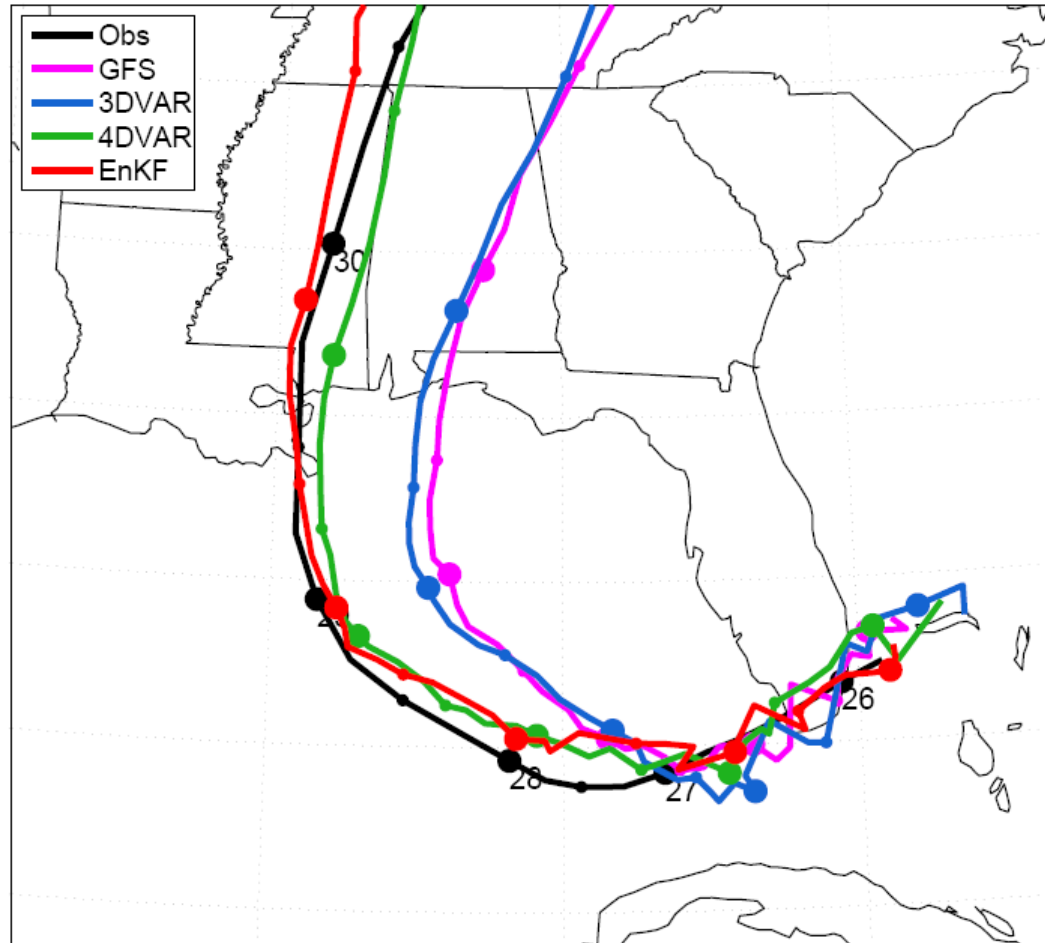
WRFDA in WRF Modeling System

Why data assimilation?

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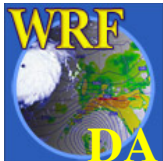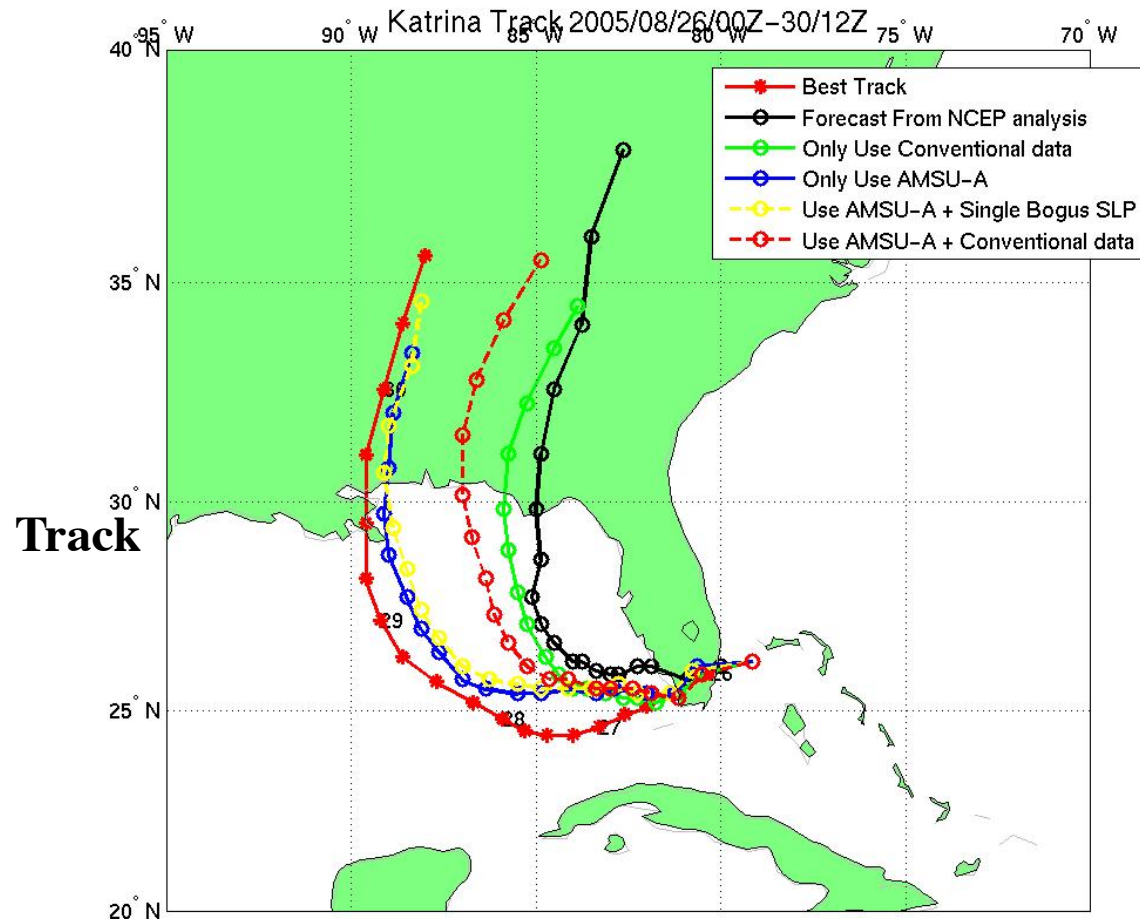 - Data errors
  - Physical process interactions
  - …

Katrina track forecasts   (Zhang, Zhang, Huang, Zhang)
- Impact of DA methods

Katrina track forecasts (Zhiquan Liu)
- Impact of data

Katrina Track 2005/08/26/00Z–30/12Z

Track

Legend:
- Best Track
- Forecast From NCEP analysis
- Only Use Conventional data
- Only Use AMSU-A
- Use AMSU-A + Single Bogus SLP
- Use AMSU-A + Conventional data

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.
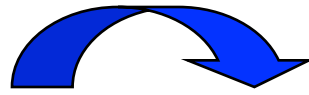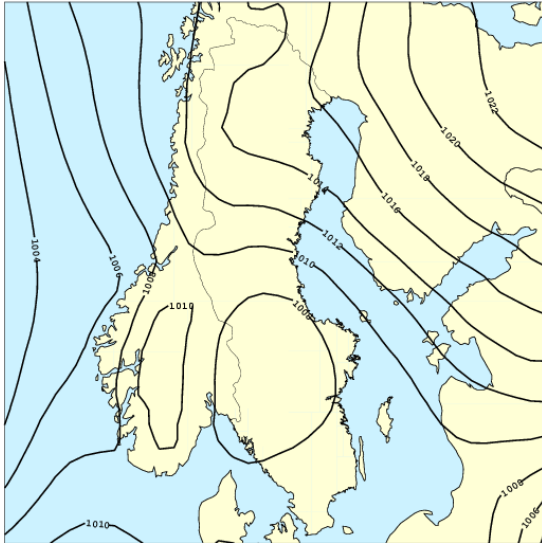
Vilhelm Bjerknes (1862–1951)

- 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"
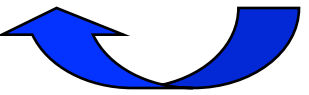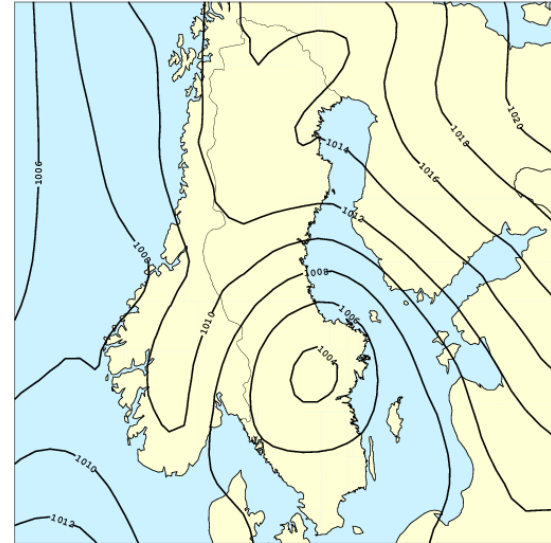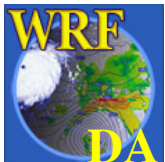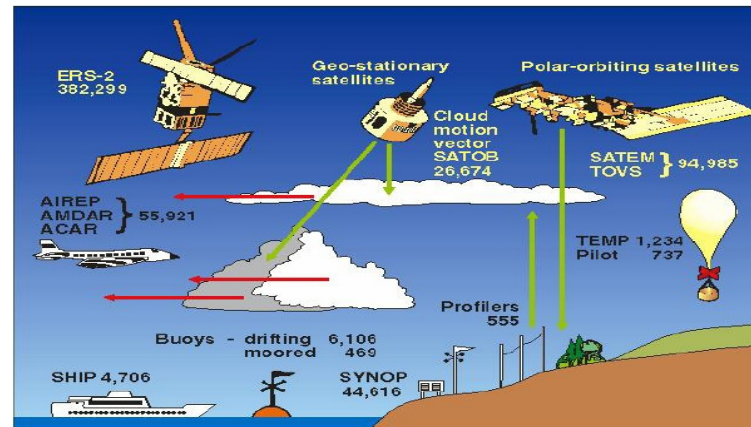
(Peter Lynch)

initial state

forecast

Model

Analysis

observations
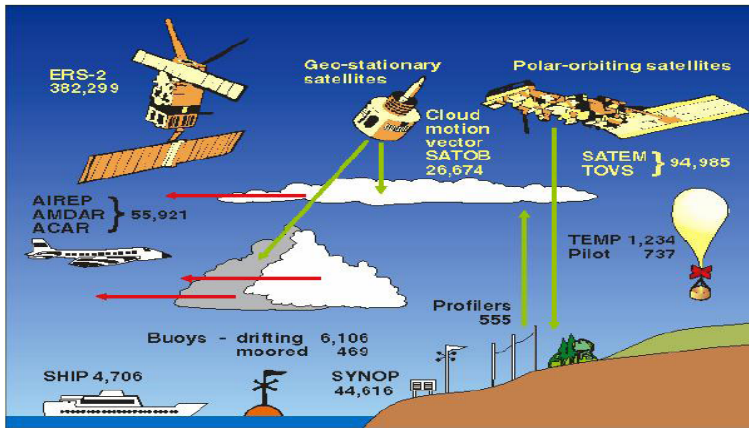
Observations
y^o, $\sim 10^5$-10^6

Model state
x, $\sim 10^7$
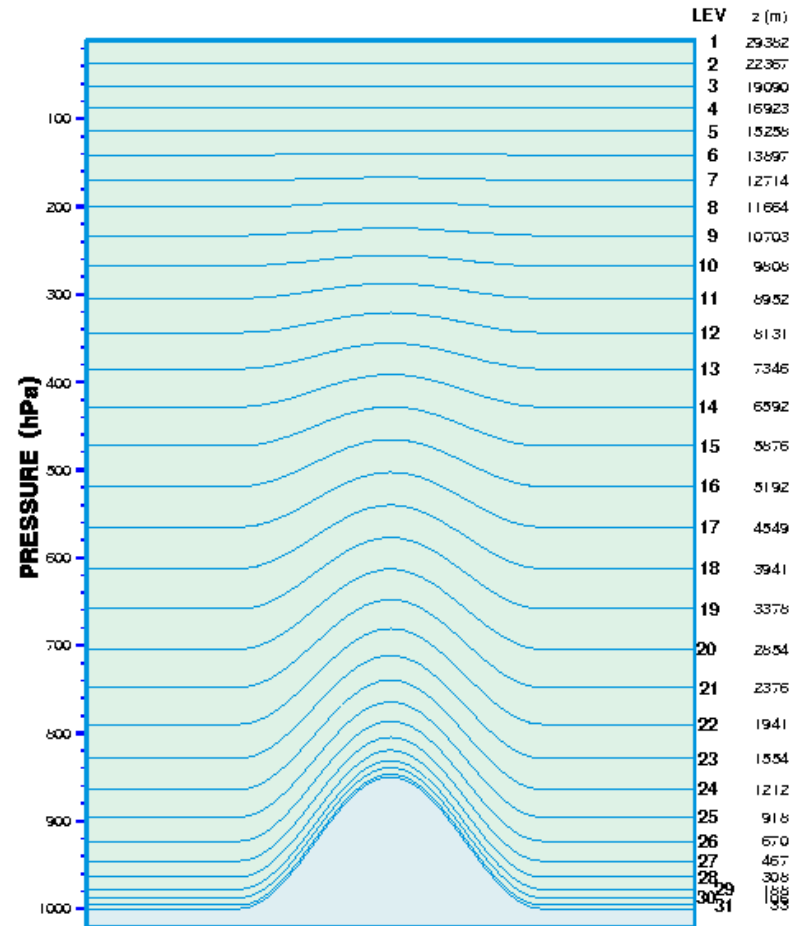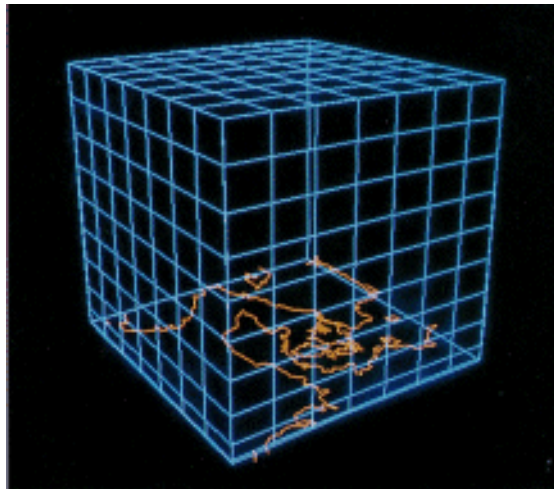
Vertical resolution of the DMI-HIRLAM system
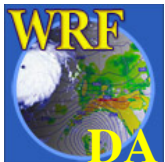
Assimilation methods

- 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 (EnKF)
  - 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)
- **Supported by NCAR/ESSL/MMM/DAS**
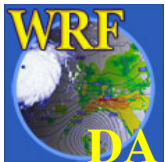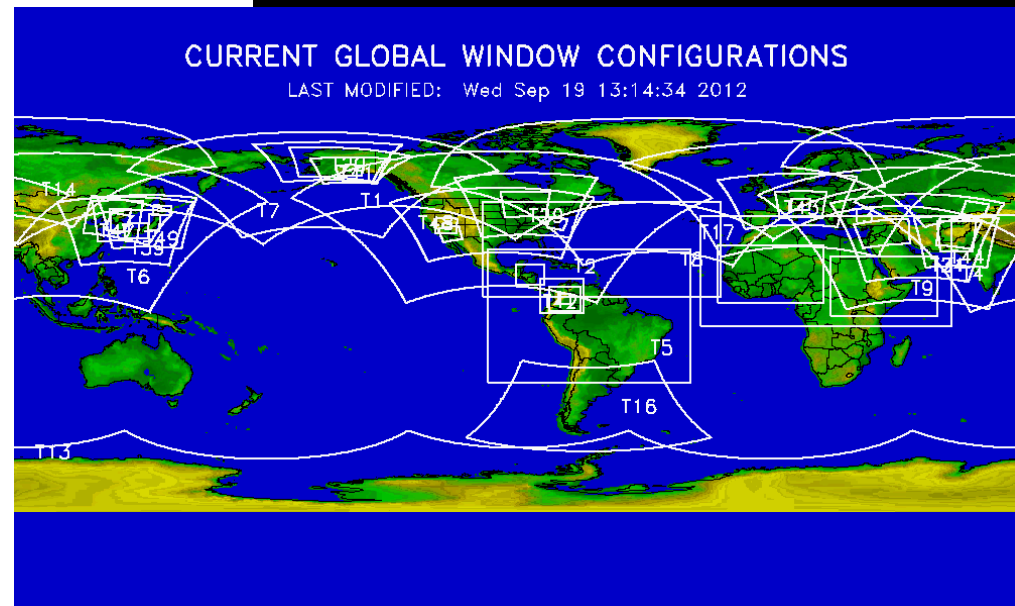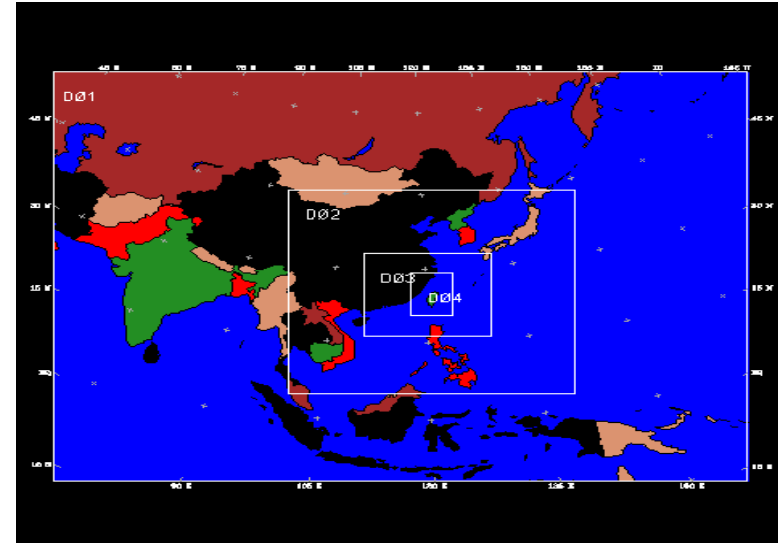
WRFDA 3/4D-Var

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

$$\mathbf{x}^a \rightarrow \mathbf{x}^f \rightarrow \boxed{\text{3/4D-Var}} \rightarrow \delta\mathbf{x}^a_{Var} \rightarrow \mathbf{x}^a$$

$$\mathbf{y}^o$$

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

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

Var and ETKF
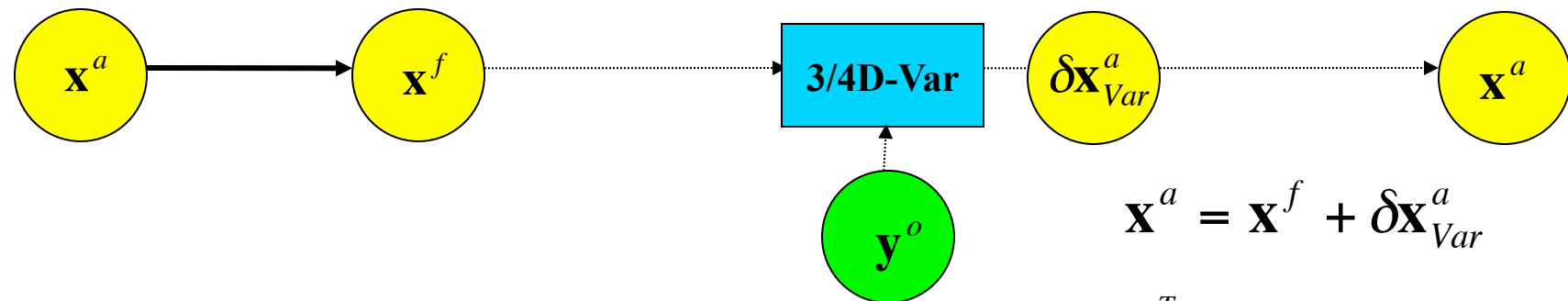
$$\mathbf{x}_n^a = \overline{\mathbf{x}^f} + \delta\overline{\mathbf{x}_{Var}^a} + \delta\mathbf{x}_{ETKFn}^a$$
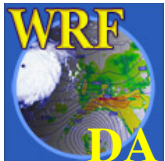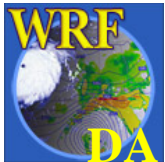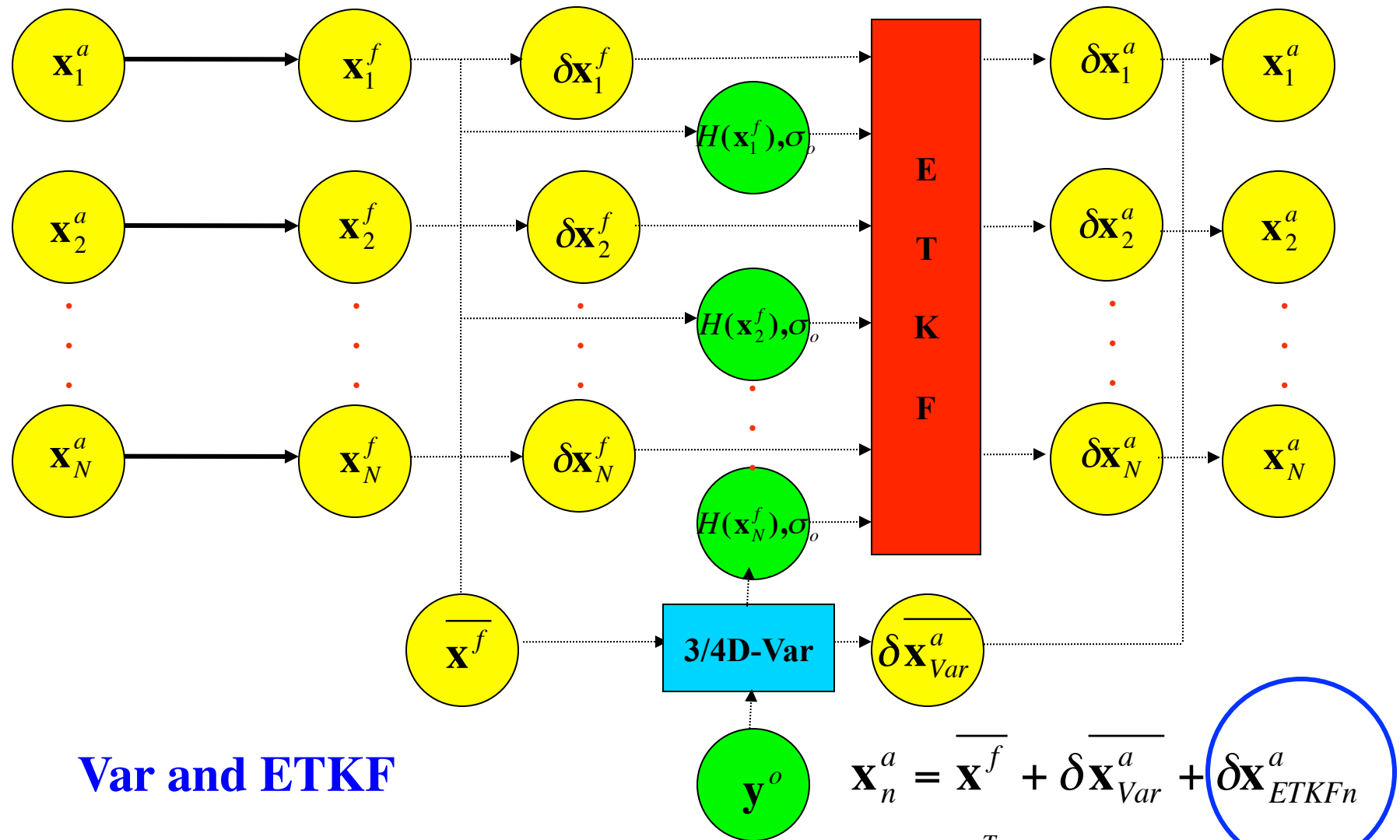
$$J = \frac{1}{2}\delta\mathbf{x}_0^T \mathbf{B}_o^{-1}\delta\mathbf{x}_0 + \frac{1}{2}\sum_{i=0}^{n}\left[\mathbf{H}_i\delta\mathbf{x}(t_i) - \mathbf{d}_i\right]^T \mathbf{R}_i^{-1}\left[\mathbf{H}_i\delta\mathbf{x}(t_i) - \mathbf{d}_i\right]$$
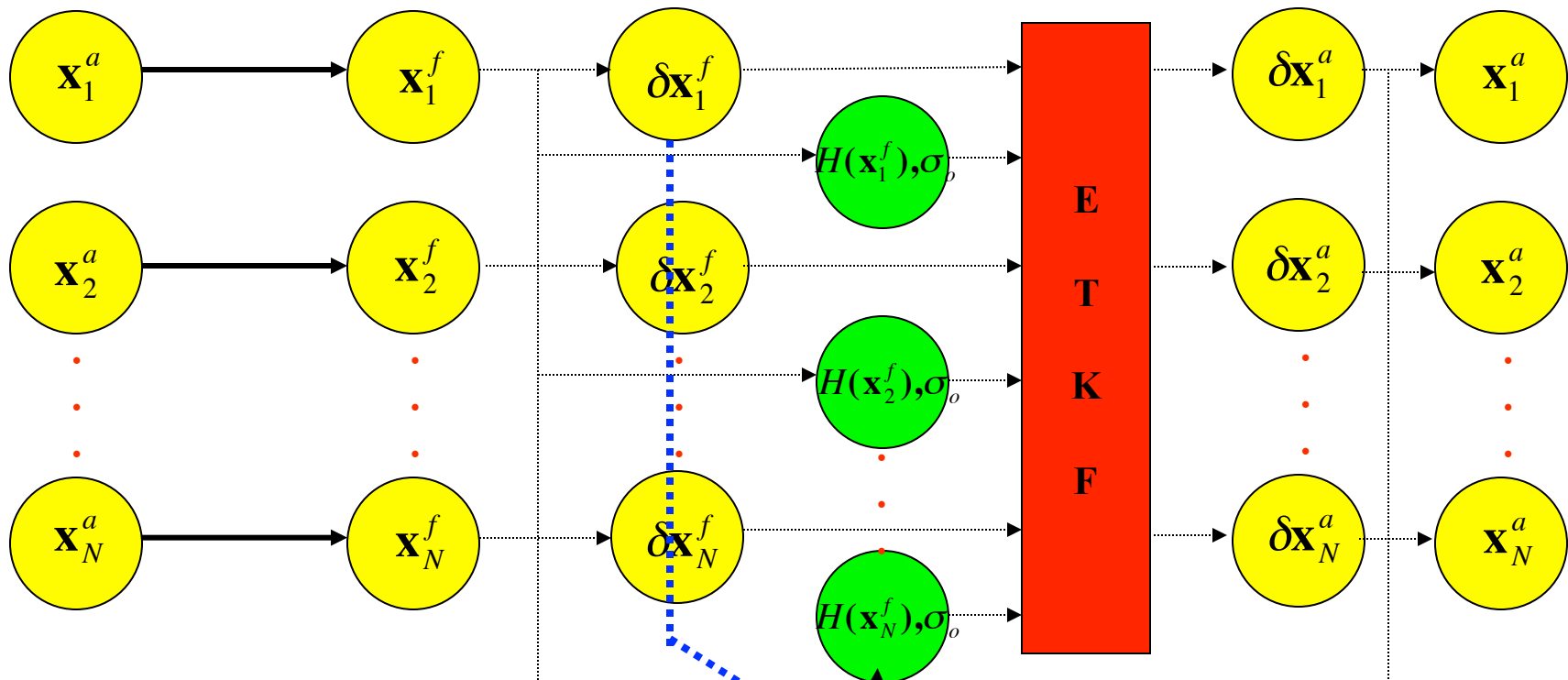
Hybrid Var+ETKF

(Wang et al. 2008)

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

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

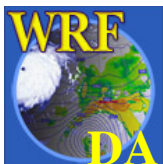**WRFDA Observations**

- **In-Situ:**
  - Surface (SYNOP, METAR, SHIP, BUOY)
  - Upper air (TEMP, PIBAL, AIREP, ACARS, TAMDAR)

- **Remotely sensed retrievals:**
  - Atmospheric Motion Vectors (geo/polar)
  - GPS refractivity (e.g. COSMIC)
  - Ground-based GPS Total Precipitable Water (PW)/Zenith Total Delay (ZTD)
  - SATEM thickness
  - Scatterometer oceanic surface winds
  - SSM/I oceanic surface wind speed and TPW
  - Radar radial velocities and reflectivities
  - Satellite temperature/humidity/thickness profiles
  - Stage IV precipitation/rain rate data (4D-Var)
  - Wind profiler wind profiles

- **Satellite radiances (using RTTOV or CRTM):**
  - 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
  - AMSU-B   NOAA-15, NOAA-16, NOAA-17
  - MHS   NOAA-18, NOAA-19, METOP-A
  - AIRS   EOS-Aqua
  - SSMIS   DMSP-16, DMSP-17, DMSP-18
  - IASI   METOP-A
  - ATMS   Suomi-NPP
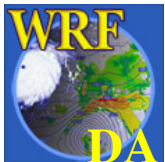 - MWTS   FY-3
  - MWHS   FY-3

•Bogus:
  – TC bogus
  – Global bogus

New, v3.5

WRFDA
Radiance Assimilation
Liu, Auligne and Lin 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

NOAA (HIRS, AMSU)

Aqua's Instruments
1- AIRS
2- AMSR-E
3- AMSU
4- CERES
5- HSB
6- MODIS

Aqua (AMSU, AIRS)

DMSP(SSMI/S)
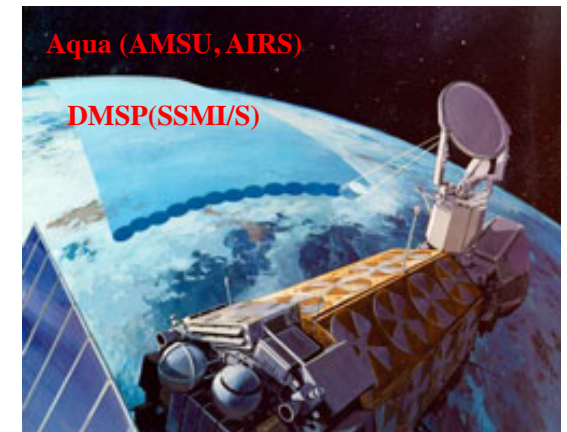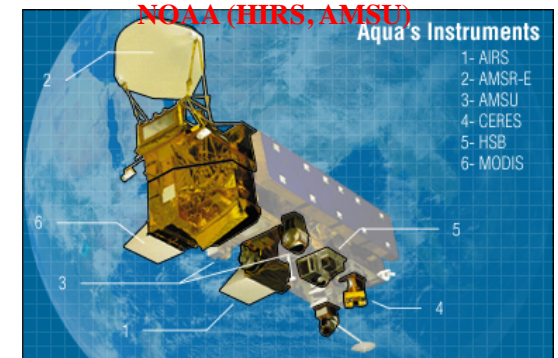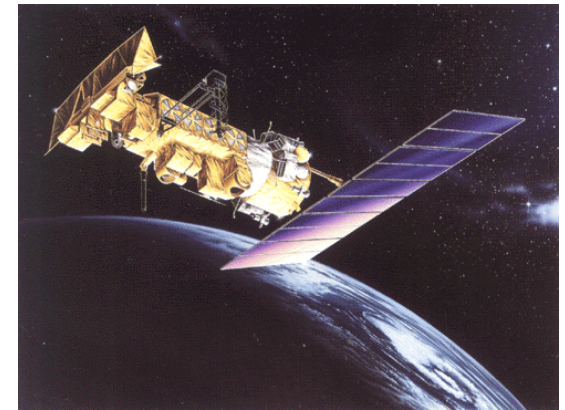
WRFDA tutorials

21-22 July 2008. NCAR.   18 April 2009. South Korea.
02-04 Feb 2009. NCAR.   15-31 Oct 2009. Nanjing, China.
20-22 July 2009. NCAR.   10 April 2010. Seoul, South Korea.
03-05 Aug 2010. NCAR.   16 April 2011. Busan, South Korea.
20-21 July 2011. NCAR.   10-20 Oct 2011. Bangkok, Thailand.
23-25 July 2012. NCAR.   21 April 2012. Seoul, South Korea.

The next: 24-26 July 2013

WRFDA online tutorial and user guide
http://www.mmm.ucar.edu/wrf/users/wrfda

WRFDA 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: 24-26 July 2013

www.mmm.ucar.edu/wrf/users/wrfda
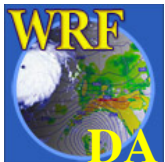
WRFDA **USERS** PAGE

| Home | Analysis System | User Support | Download | Doc / Pub | Links | Internal | Users Forum |

WRFDA Home

WRFDA News

Public Domain Notice

Contact WRF Support

Search [ ] Search

Click here for help with the transition to the Yellowstone Supercomputer
(updated February 26, 2013)

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) Division 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

LATEST WRFDA RELEASE

WRFDA Version 3.5
(Released April 18, 2013)

UPCOMING EVENTS

June 24–28, 2013

14th Annual WRF Users' Workshop, NCAR Center Green Campus, Boulder, CO, USA. Registration is now open.

July 24–26, 2013

2013 WRFDA New User Tutorial, NCAR Foothills Laboratory, Boulder, CO, USA. Registration is now open.

WHAT'S NEW

May 2, 2013

A patch is now available at the "Known Problems" page for a compilation bug affecting some old versions of certain compilers.