



# Introduction to WRFDA

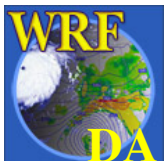
Tom Auligné and Hans Huang

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

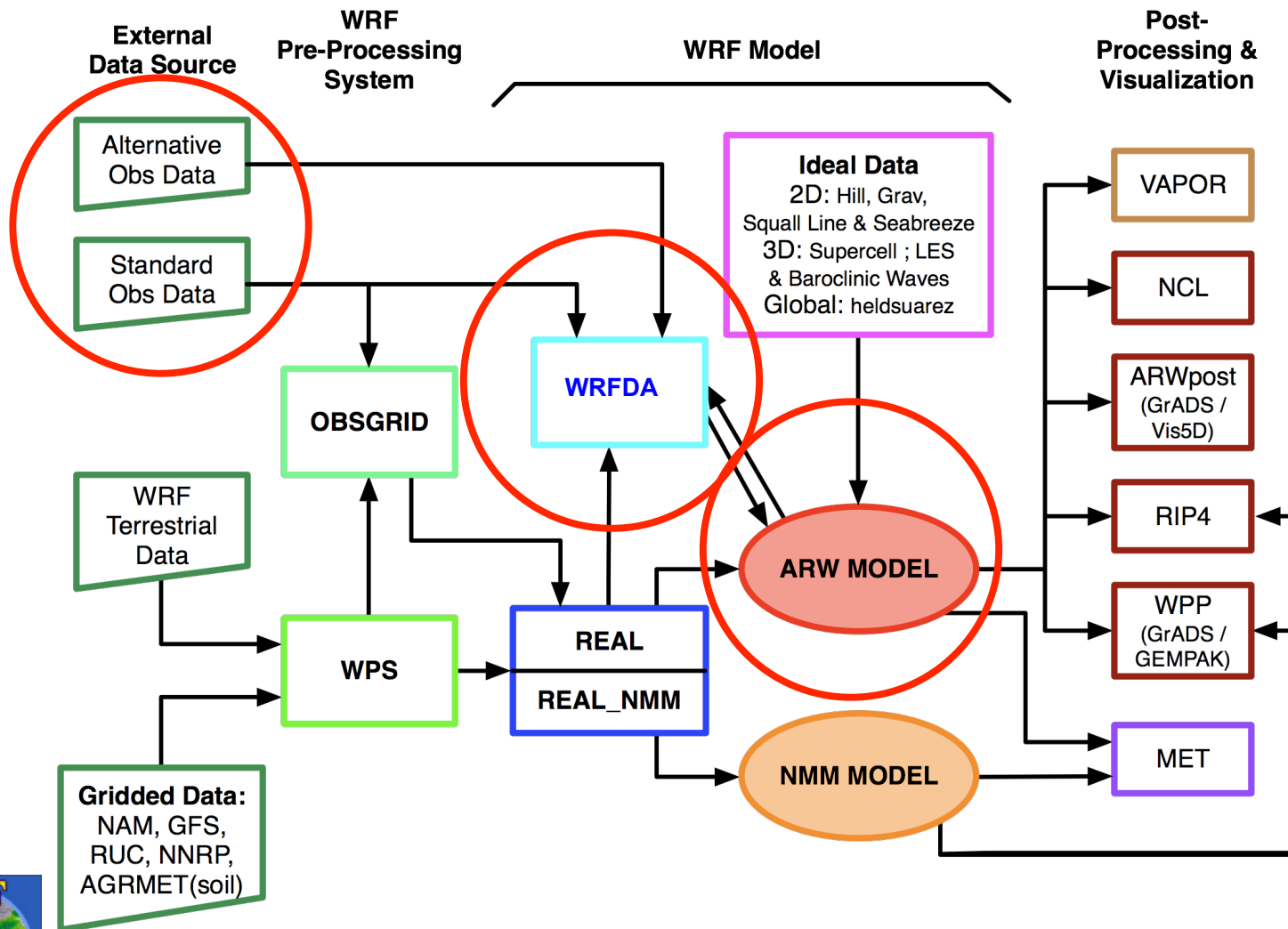
*National Center for Atmospheric Research  
(NCAR is sponsored by the National Science Foundation)*

**Acknowledge:**

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

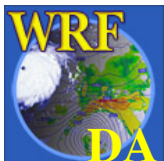


# WRFDA in WRF Modeling System



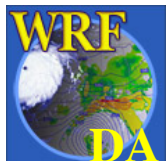
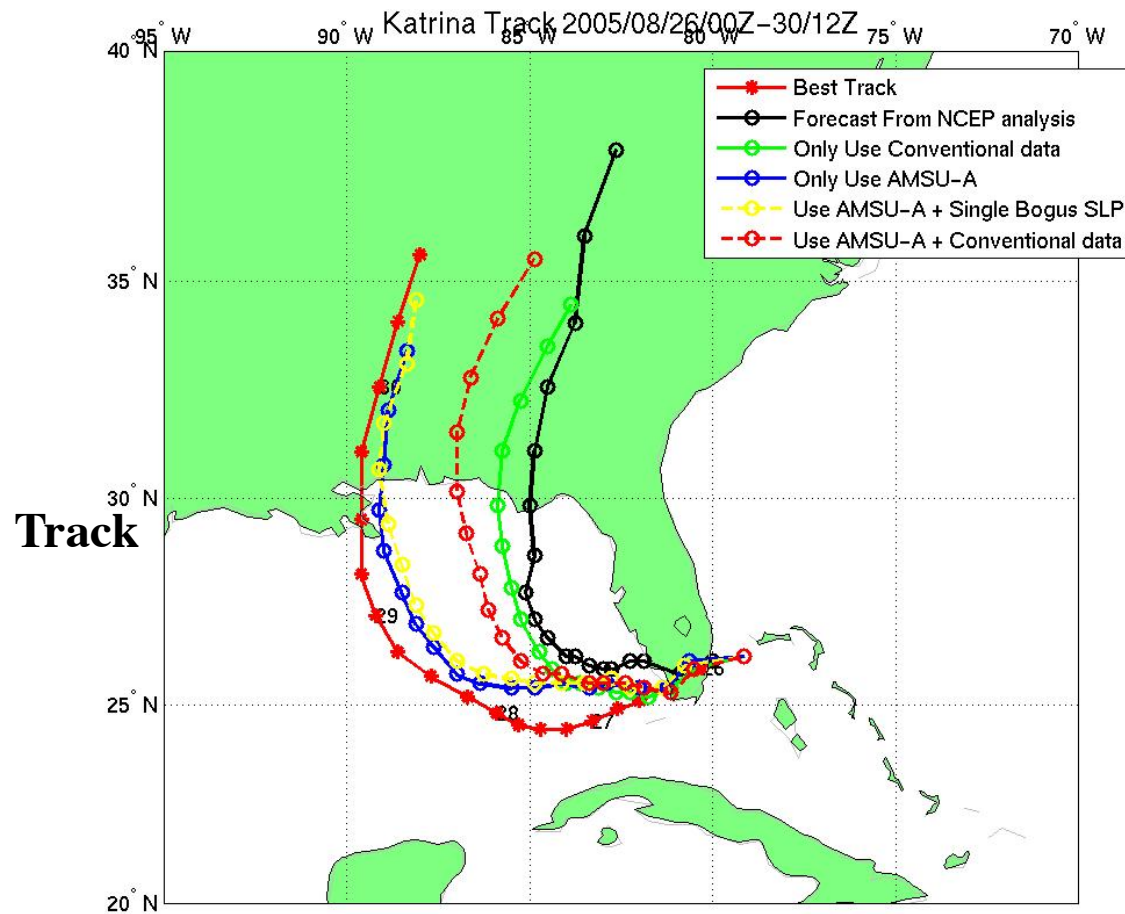
# Why data assimilation?

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



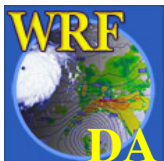
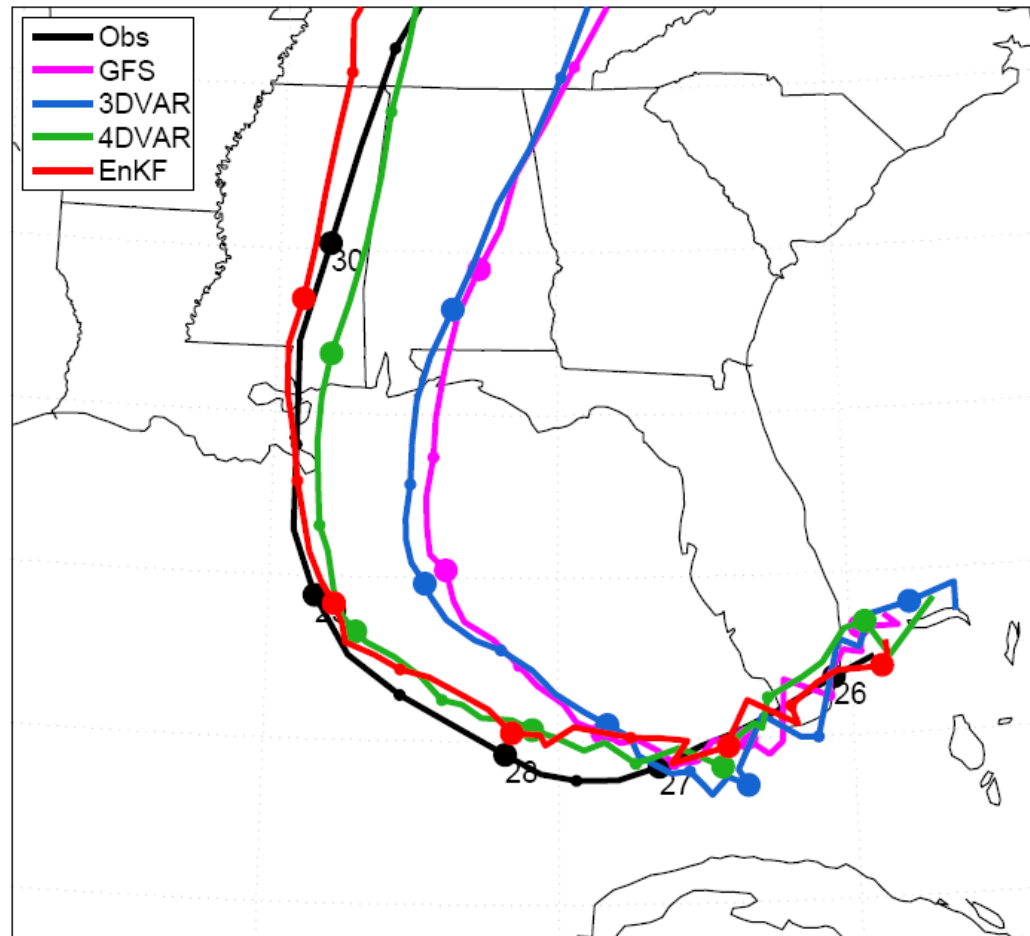
# Katrina track forecasts (Zhiquan Liu)

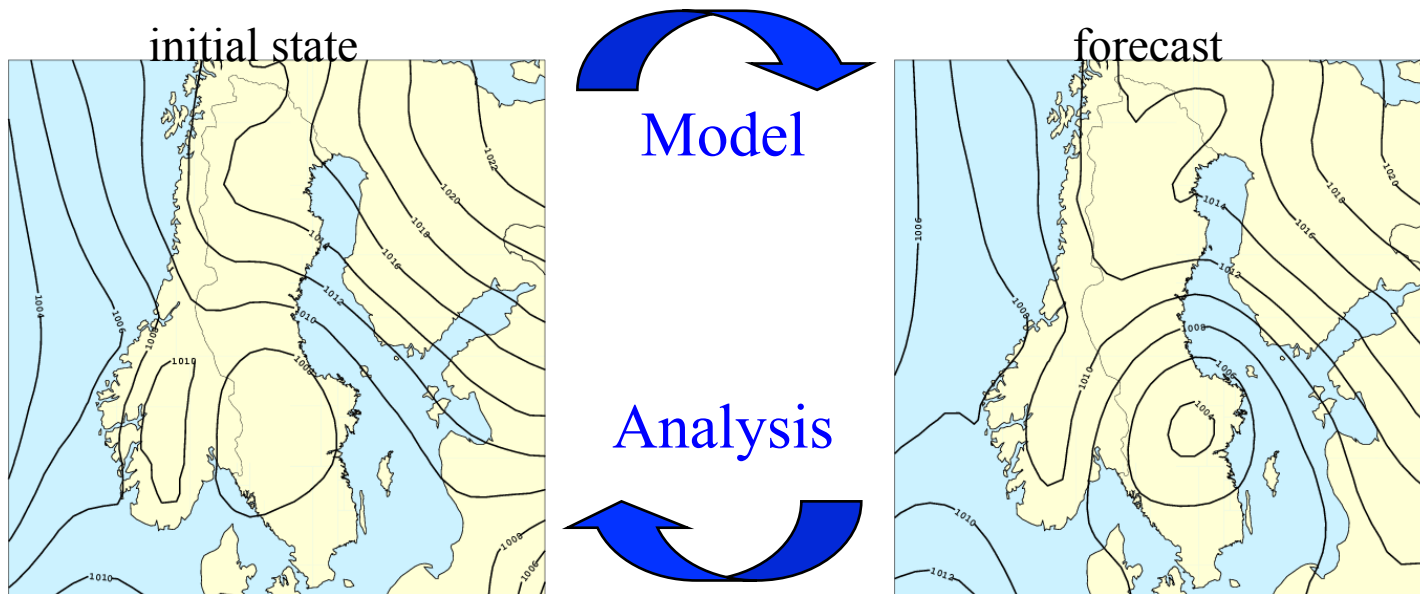
## - Impact of data



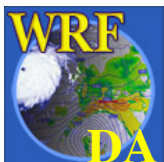
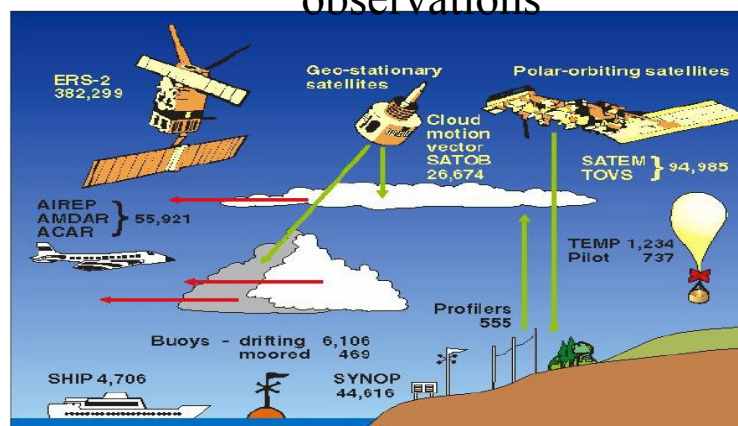
# Katrina track forecasts (Zhang, Zhang, Huang, Zhang)

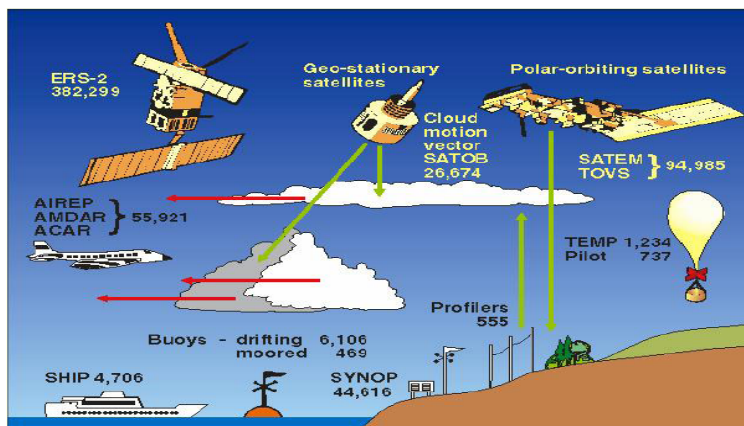
## - Impact of DA methods





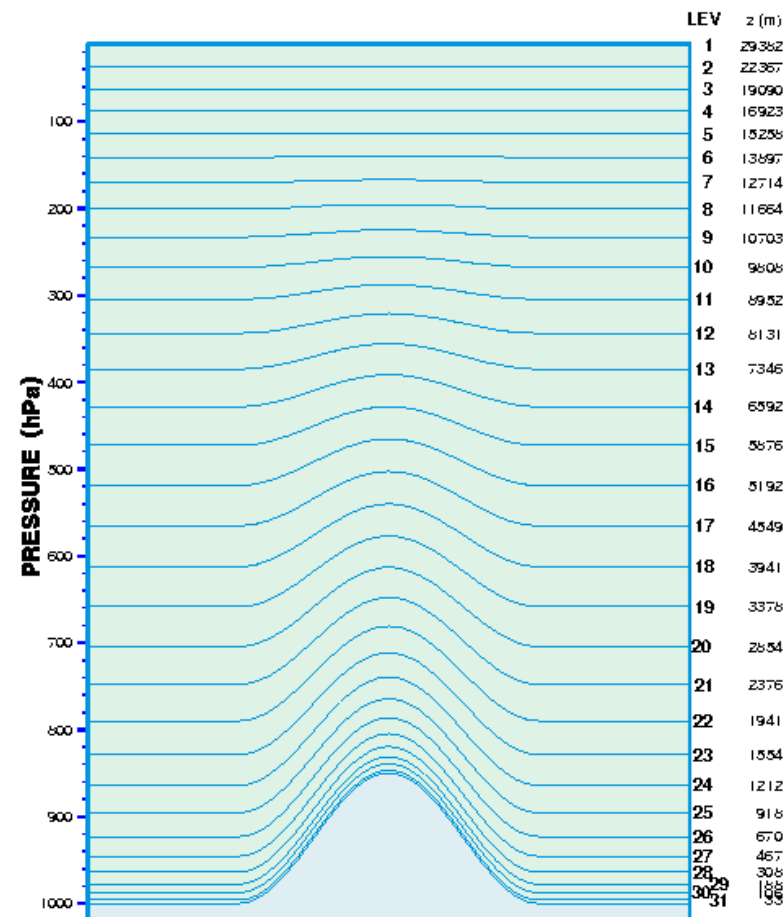
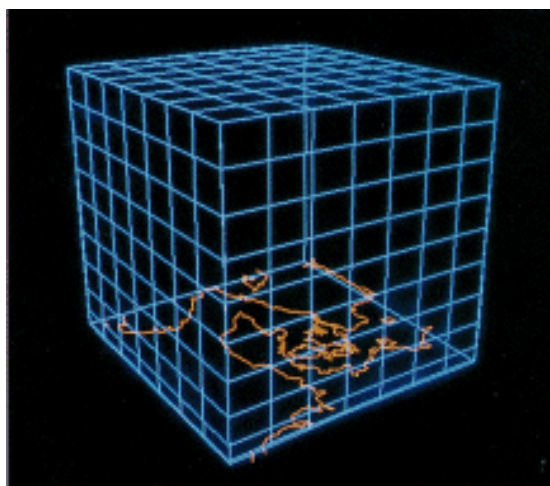
### observations





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

Model state  
 $x, \sim 10^7$

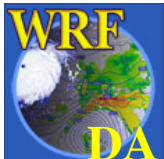


Vertical resolution of the DMI-HIRLAM system



# Assimilation methods

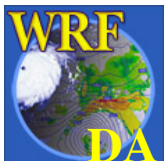
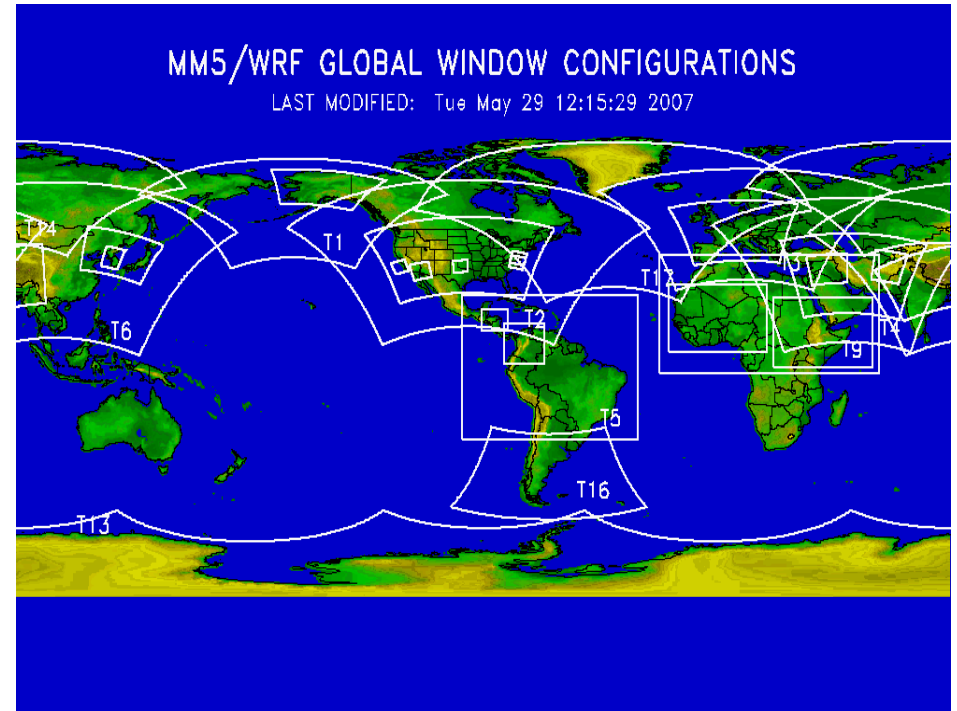
- Empirical methods
  - Successive Correction Method (SCM)
  - Nudging
  - Physical Initialisation (PI), Latent Heat Nudging (LHN)
- Statistical methods
  - Optimal Interpolation (OI)
  - 3-Dimensional Variational data assimilation (3DVar)
  - 4-Dimensional Variational data assimilation (4DVar)
- Advanced methods
  - Extended Kalman Filter (EKF)
  - Ensemble Kalman Filter (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)
- **Support:**
  - NCAR/NESL/MMM/DAS (Data Assimilation Section, also supporting [WRF/DART](#))
  - NCAR/RAL/JNT/DAT (Data Assimilation Team, also supporting [GSI](#))

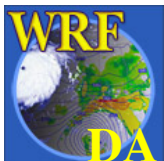
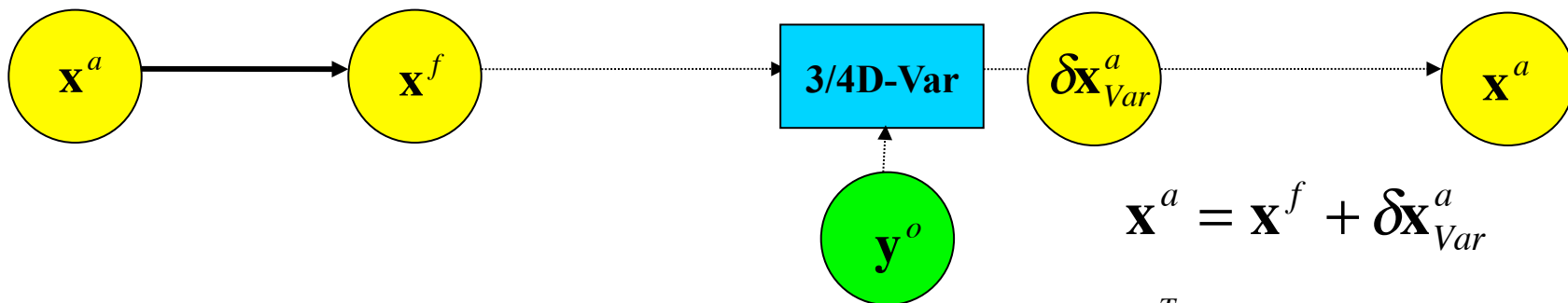


# WRFDA

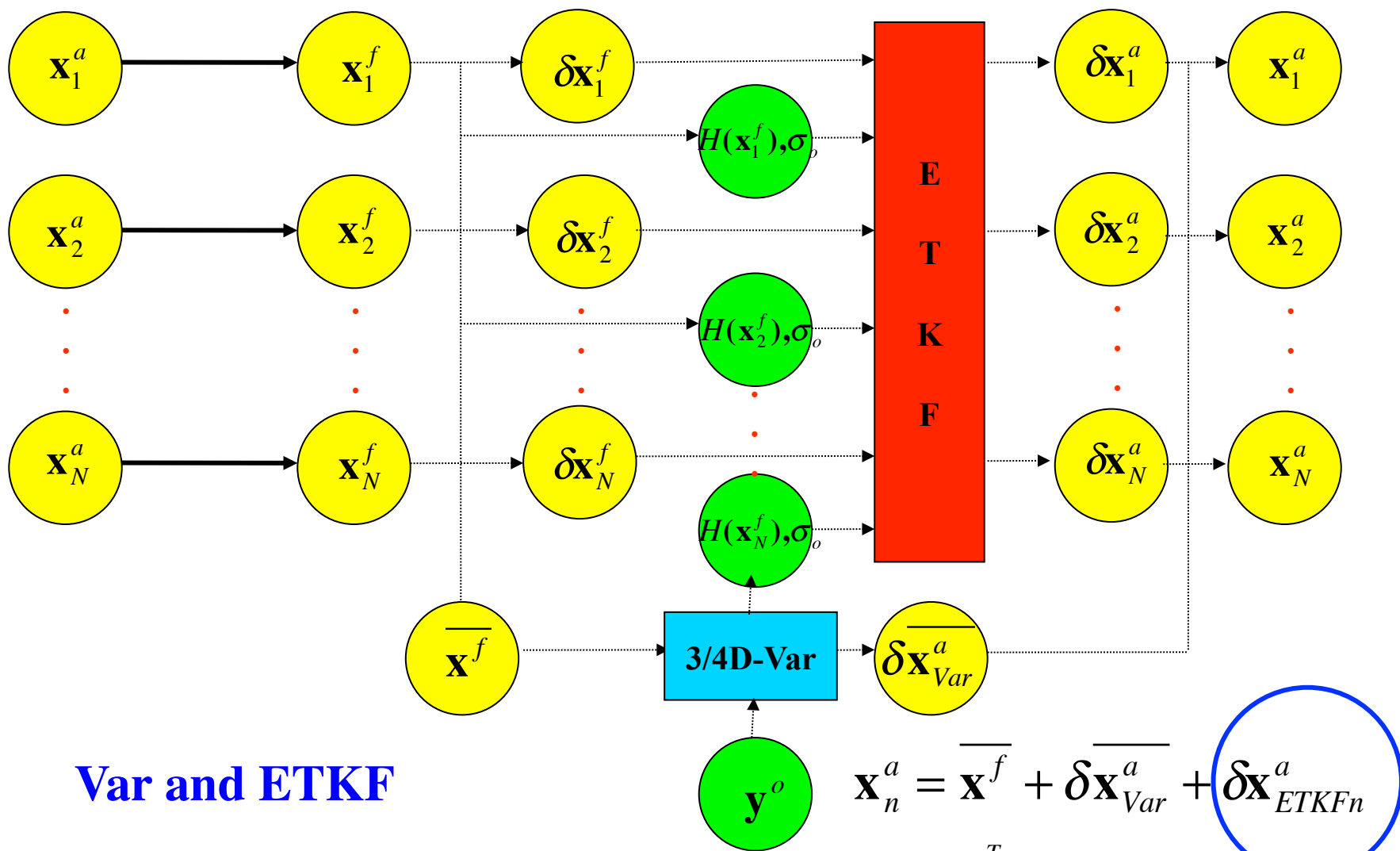
## 3/4D-Var

3D-Var: Barker et al. 2004

4D-Var: Huang et al. 2009

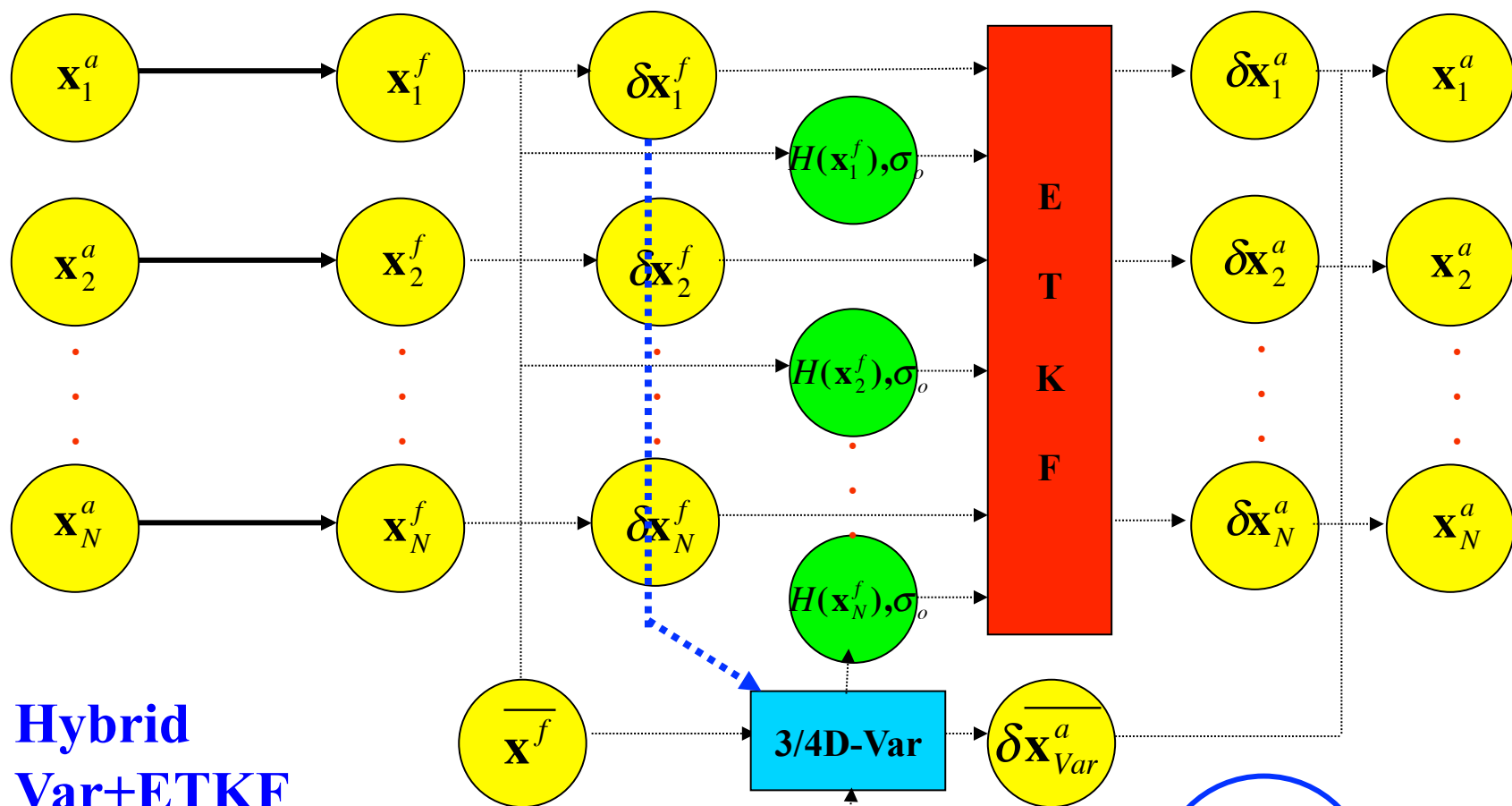


$$J = \frac{1}{2} \delta \mathbf{x}_0^T \mathbf{B}_o^{-1} \delta \mathbf{x}_0 + \frac{1}{2} \sum_{i=0}^n \left[ \mathbf{H}_i \delta \mathbf{x}(t_i) - \mathbf{d}_i \right]^T \mathbf{R}_i^{-1} \left[ \mathbf{H}_i \delta \mathbf{x}(t_i) - \mathbf{d}_i \right]$$



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





## Hybrid Var+ETKF

(Wang et al. 2008)



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

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

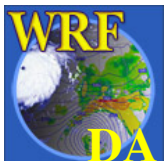
## WRFDA (v3.4) Observations

- **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 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, DMSP-17, DMSP-18

**•Bogus:**

– TC bogus.

– Global bogus.

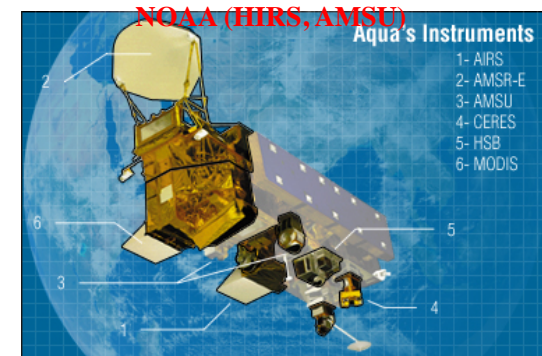
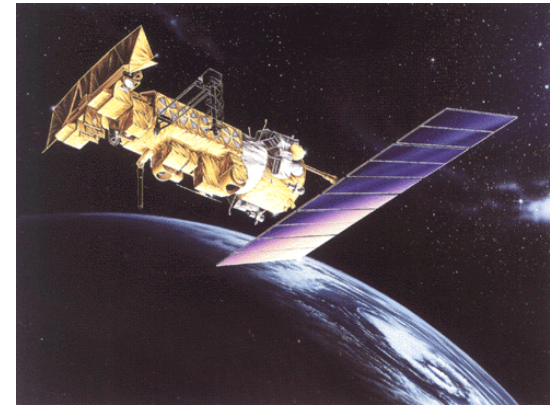
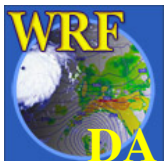


# WRFDA

## Radiance Assimilation

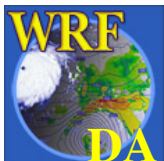
Liu and Auligné, NCAR

- 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



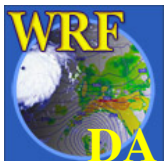
# New features, v3.4, April 2012

- WRFPLUS (WRF adjoint and tangent linear model) has been upgraded to V3.4 and it is consistent with the released WRF version 3.4;
- WRFDA was also upgraded to V3.4 and the 4D-Var system now supports compilation to run in parallel with distributed memory;
- **Precipitation data assimilation is now supported by the 4D-Var system;**
- Forecast Sensitivity to Observations (FSO) has been updated to work with WRFPLUS V3.4;
- Analysis control variables have been expanded to include four types of cloud hydrometeors: cloud liquid water, cloud ice, snow and rain.



# Ongoing work

1. 4D-Var optimization
2. Background error covariance improvement
3. Radiance data assimilation development
4. Direct assimilation of wind speed and wind direction observations
5. General WRFDA development





# WRFDA tutorials

21-22 July, 2008. NCAR.

2-4 Feb, 2009. NCAR.

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.

16 April. Busan, South Korea

20-22 July 2011. NCAR

10-20 October 2011. Bangkok, Thailand.

## WRFDA online tutorial and user guide

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

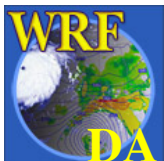


# WRFDA Tutorials at NCAR.

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

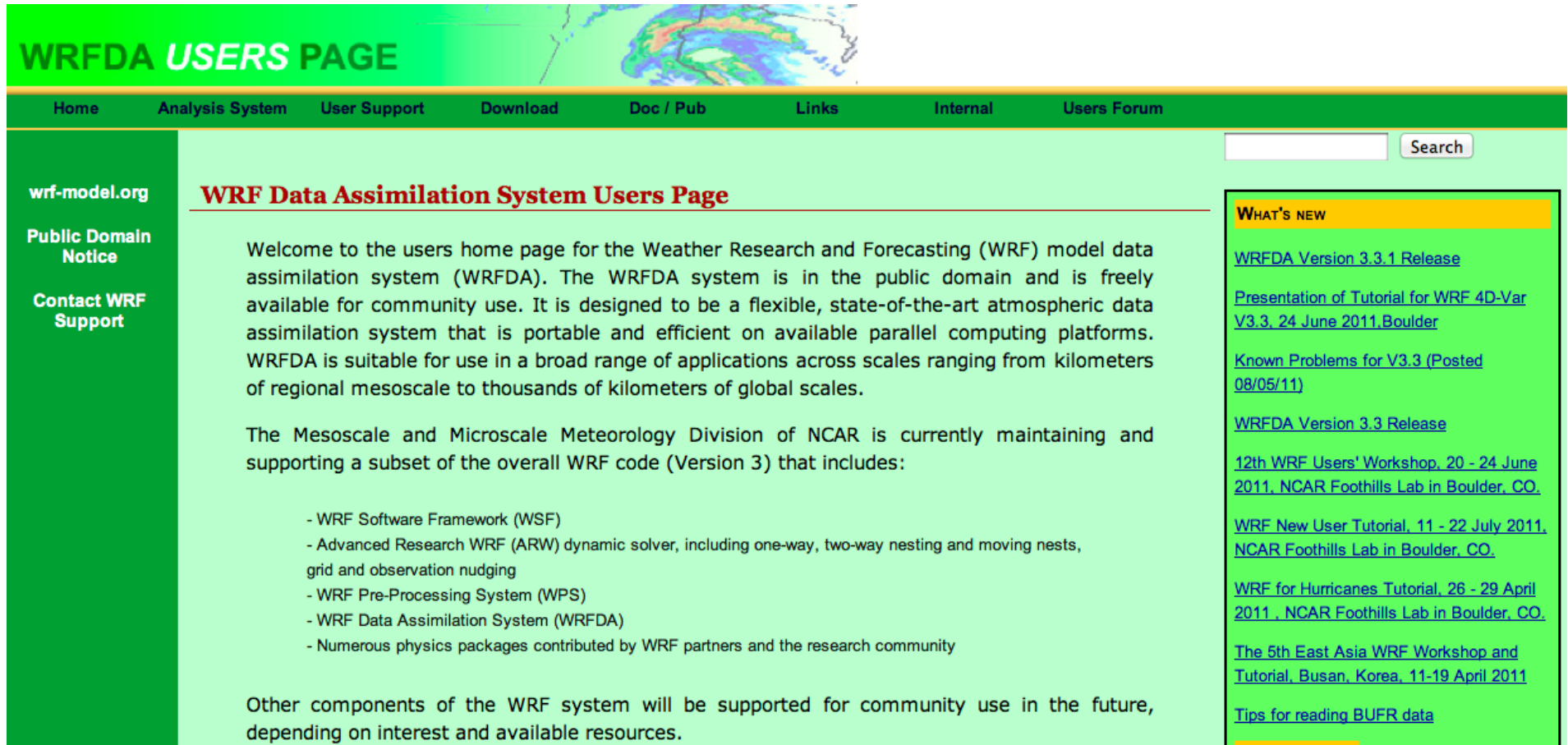
1. obsproc
2. wrfda (3D-Var)
3. Single-ob tests
4. Gen\_be
5. Radar
6. Radiance
7. 4D-Var
8. Hybrid
9. Advanced (optional)



**Next week...**

Google WRFDA:

[www.mmm.ucar.edu/wrf/users/wrfda](http://www.mmm.ucar.edu/wrf/users/wrfda)



The screenshot shows the WRFDA Users Page. At the top is a green banner with the text "WRFDA USERS PAGE" and a small map of the United States. Below the banner is a navigation bar with links: Home, Analysis System, User Support, Download, Doc / Pub, Links, Internal, and Users Forum. On the left side, there is a green sidebar with links: wrf-model.org, Public Domain Notice, and Contact WRF Support. The main content area has a title "WRF Data Assimilation System Users Page" and a welcome message. It lists the components of the WRF system supported for community use. On the right side, there is a "WHAT'S NEW" section with several links to recent releases and workshops.

**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 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)
- 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.

**WHAT'S NEW**

- [WRFDA Version 3.3.1 Release](#)
- [Presentation of Tutorial for WRF 4D-Var V3.3, 24 June 2011, Boulder](#)
- [Known Problems for V3.3 \(Posted 08/05/11\)](#)
- [WRFDA Version 3.3 Release](#)
- [12th WRF Users' Workshop, 20 - 24 June 2011, NCAR Foothills Lab in Boulder, CO.](#)
- [WRF New User Tutorial, 11 - 22 July 2011, NCAR Foothills Lab in Boulder, CO.](#)
- [WRF for Hurricanes Tutorial, 26 - 29 April 2011, NCAR Foothills Lab in Boulder, CO.](#)
- [The 5th East Asia WRF Workshop and Tutorial, Busan, Korea, 11-19 April 2011](#)
- [Tips for reading BUFR data](#)

