WRFDA: the 2010 Update and Recent Development

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Acknowledge:

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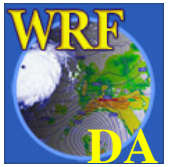
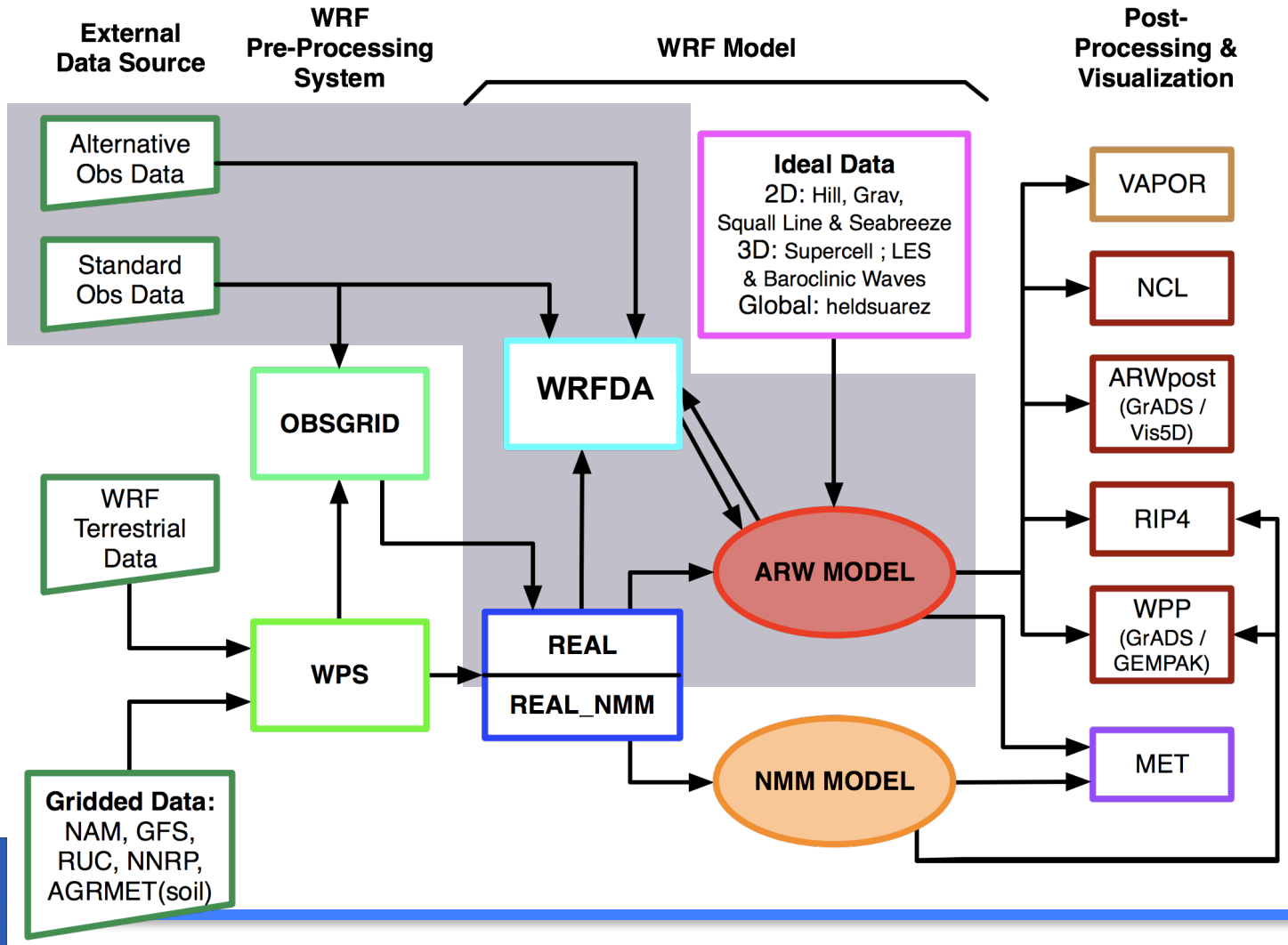
Outline

1. WRFDA 2010 overview
2. WRFDA 2010 update
   - 4D-Var optimization
   - Forecast sensitivity to observations
3. Recent developments
   - CV6 – Multivariate humidity analysis
   - Hybrid 4D-Var/EnKF

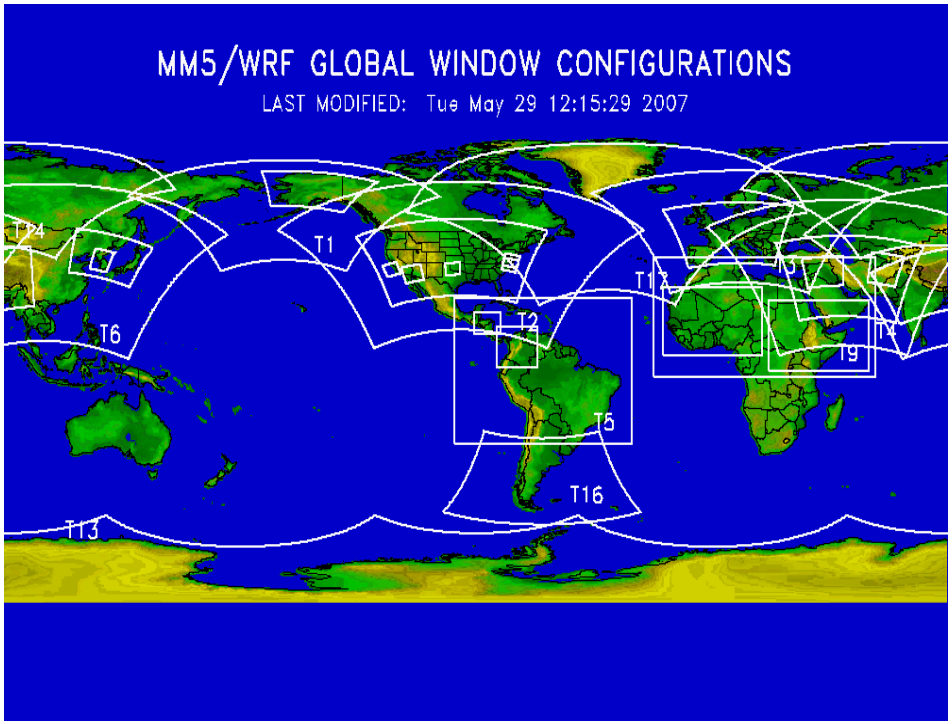


WRFDA in the WRF Modeling System

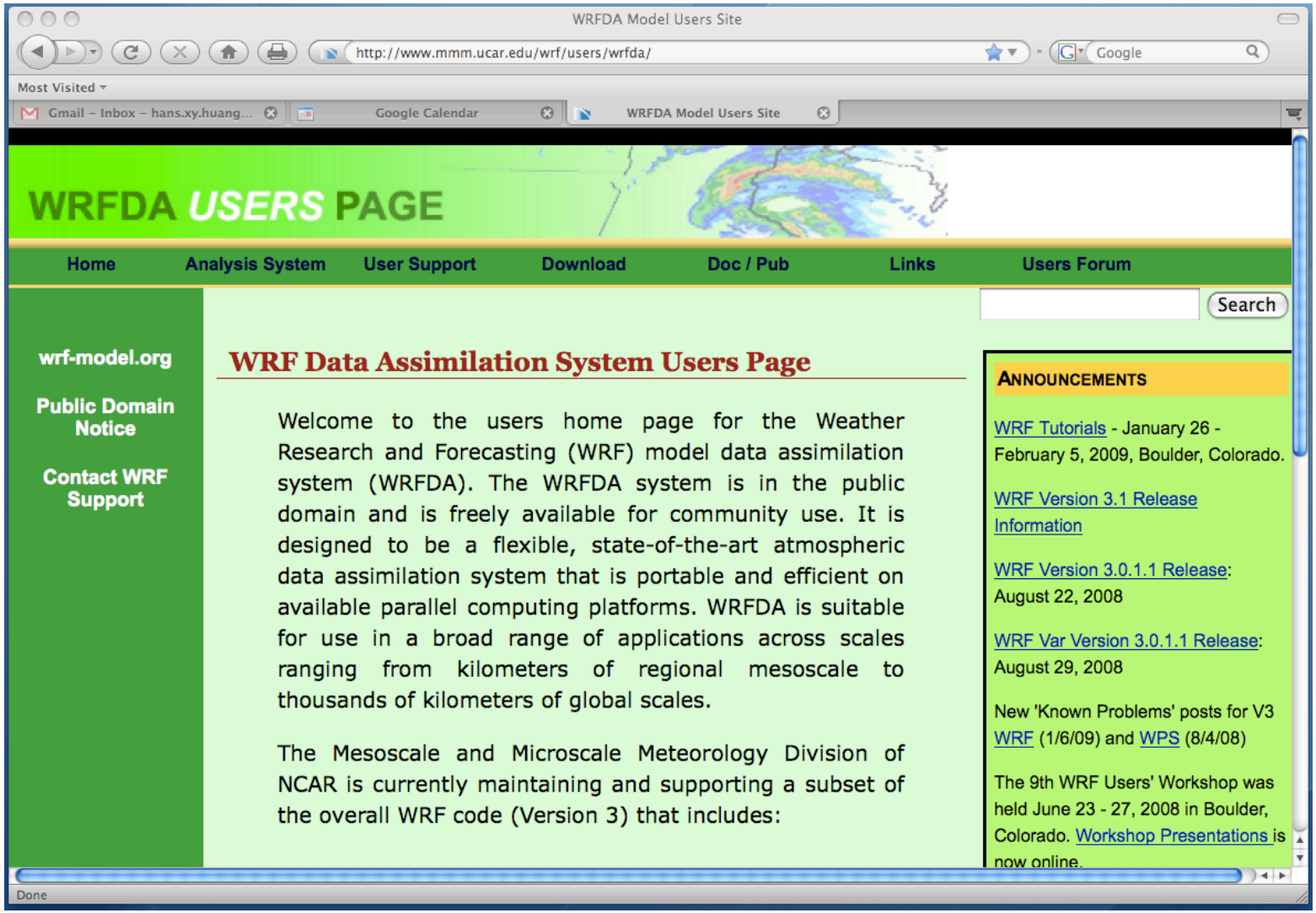


WRFDA

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

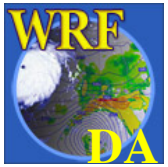


www.mmm.ucar.edu/wrf/users/wrfda



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.

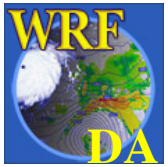


Tutorials at NCAR

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)

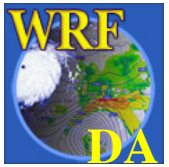


WRFDA 3.2
(April 2010)

- Bug fixes.
- Optimization of TL, AD and 4D-Var.
- Forecast Sensitivity to Observations.

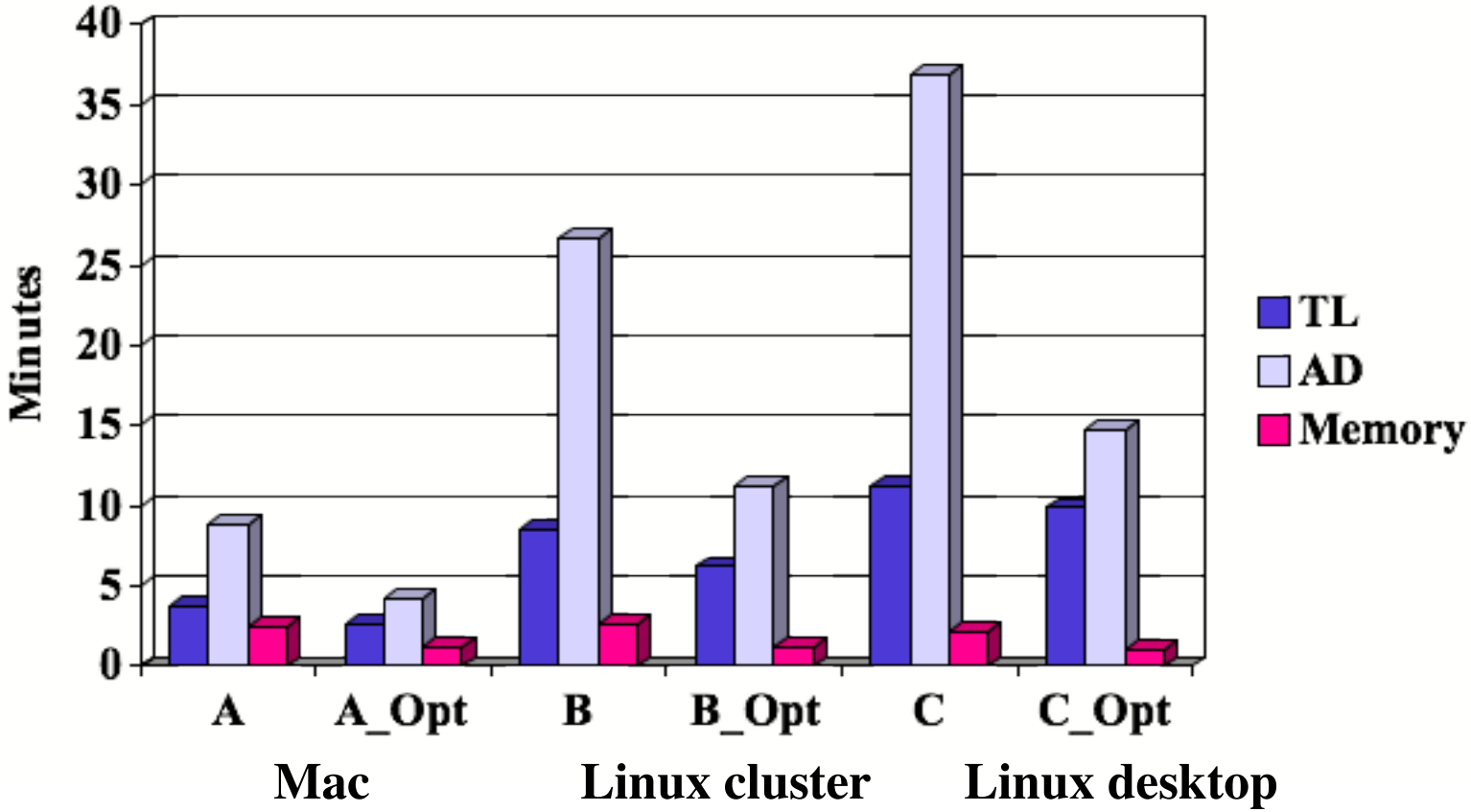
  (the Lanczos minimization algorithm; the adjoint of analysis; etc.)
- Further development of hybrid code.

  (vertical localization; 3D alpha control variable; etc.)
- Using PrepBufr format in 4D-Var.



4D-Var optimization (Cheng)

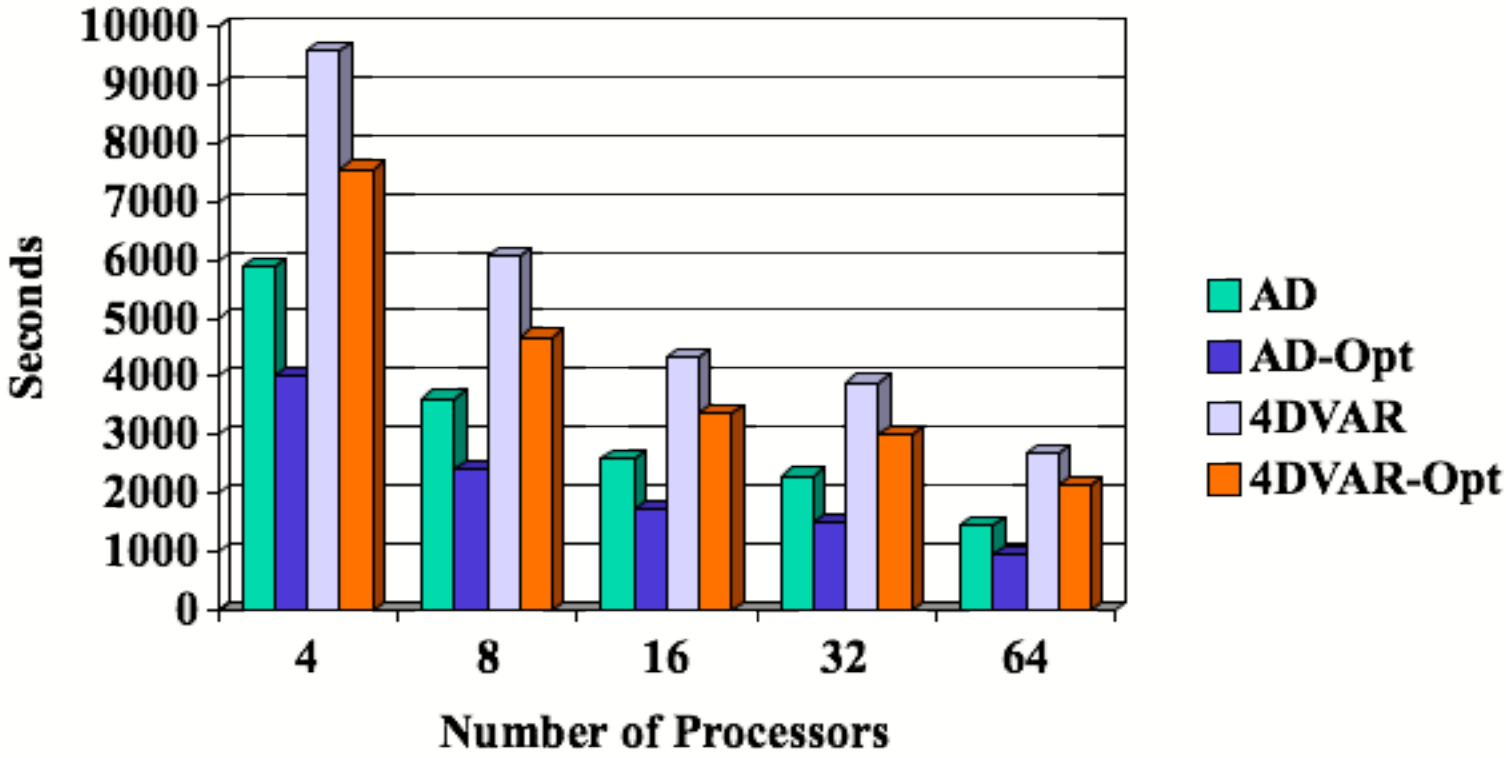
Single processor



Grid: 140x97x57

4D-Var optimization (Cheng)

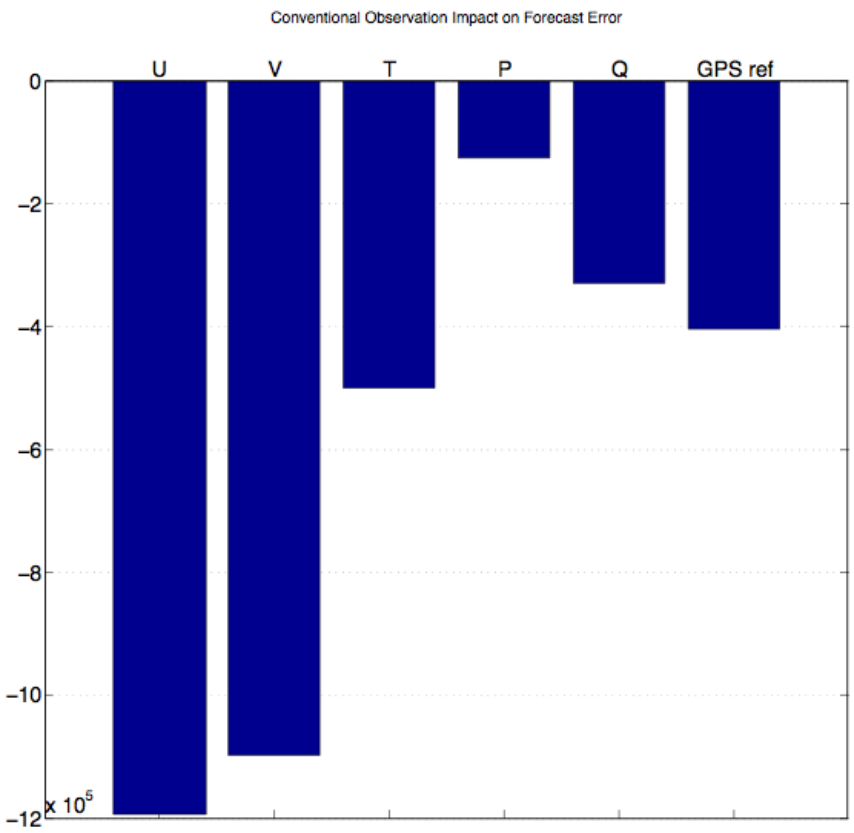
Multiple processors

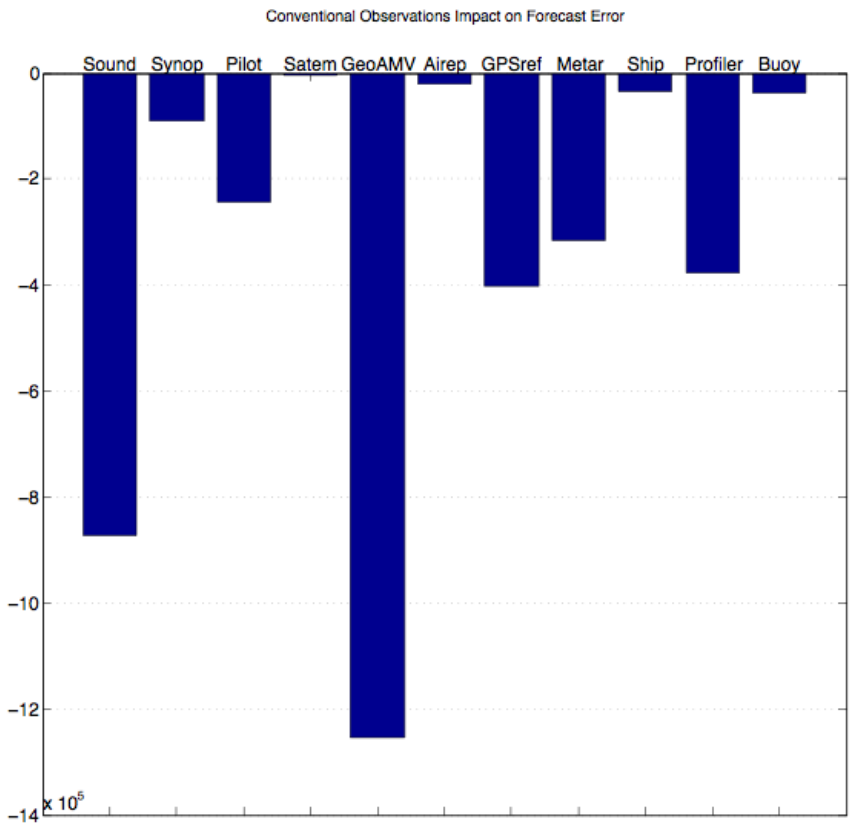


NCAR bluefire **Grid: 140x97x57**

Forecast Sensitivity to Observations (Auligne)

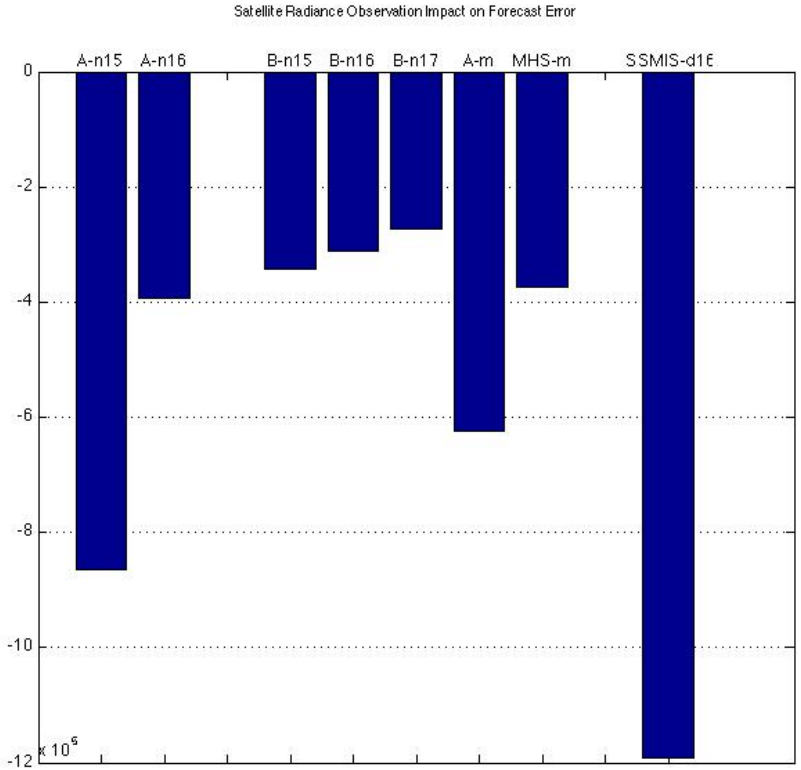
Conventional Data

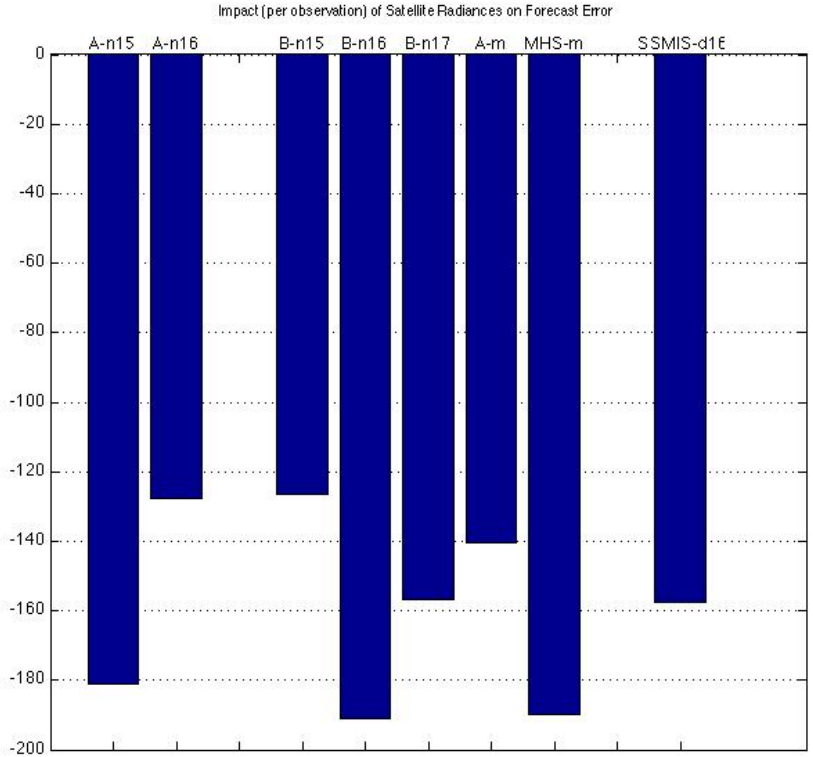




Forecast Sensitivity to Observations (Auligne)

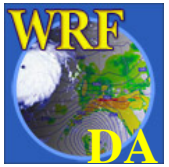
Satellite radiances





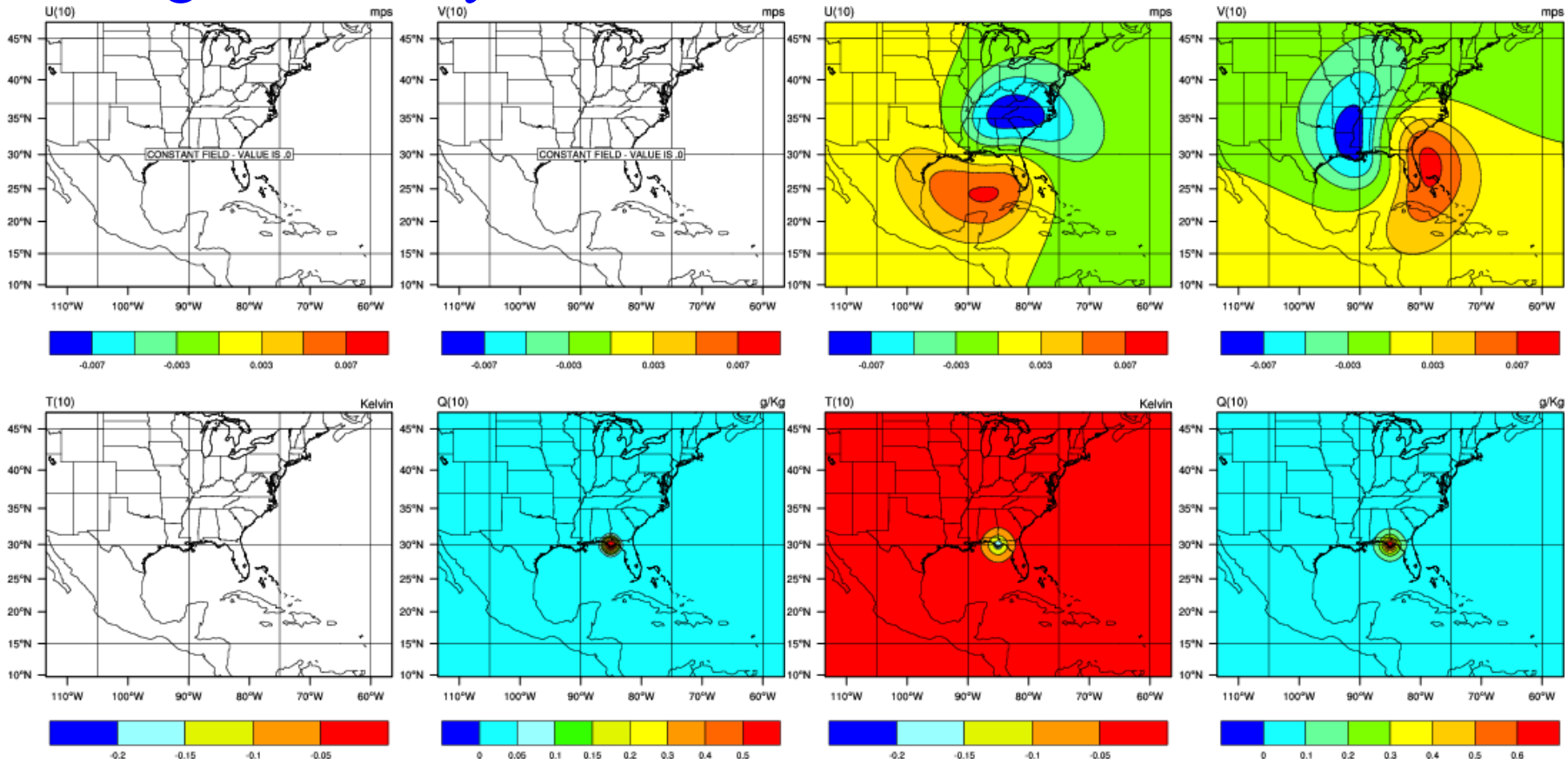
WRFDA 3.2.1
(July-August 2010)

- Bug fixes.
- Enhanced support for radiance assimilation on platforms with Intel and GFORTRAN compilers.
- CRTM interface upgrade to version 2.0.2.
- RTTOV interface upgrade to version 9.3.
- Lateral boundary control in 4D-Var.
- CV6 – Multivariate analysis for humidity.
- A prototype single executable 4D-Var.



CV6 – Multivariate humidity analysis (Rizvi, Krysta and Huang)

Single humidity observation test



Old BE

New BE

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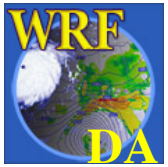
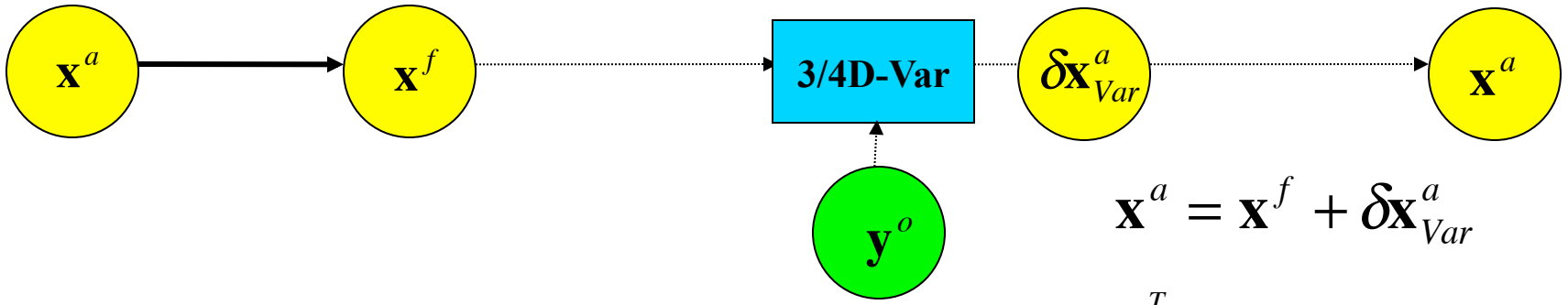


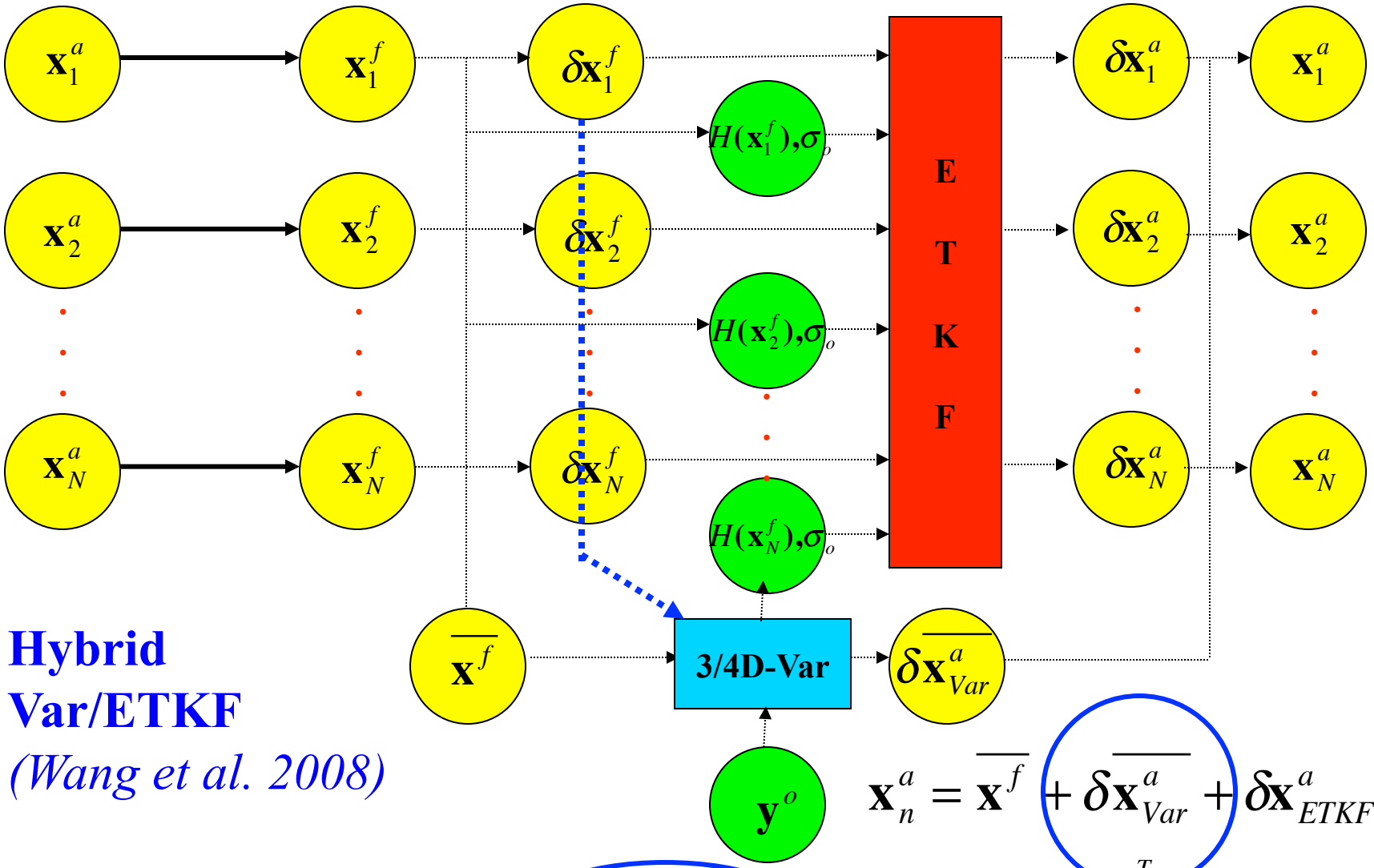
WRFDA
3/4D-Var

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



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

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



Hybrid Var/ETKF

(Wang et al. 2008)

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

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

Weakness and strength of DA methods

Zhang, M. (PSU), Zhang, F. (PSU), Huang, X.-Y. (NCAR), Zhang, X. (NCAR)

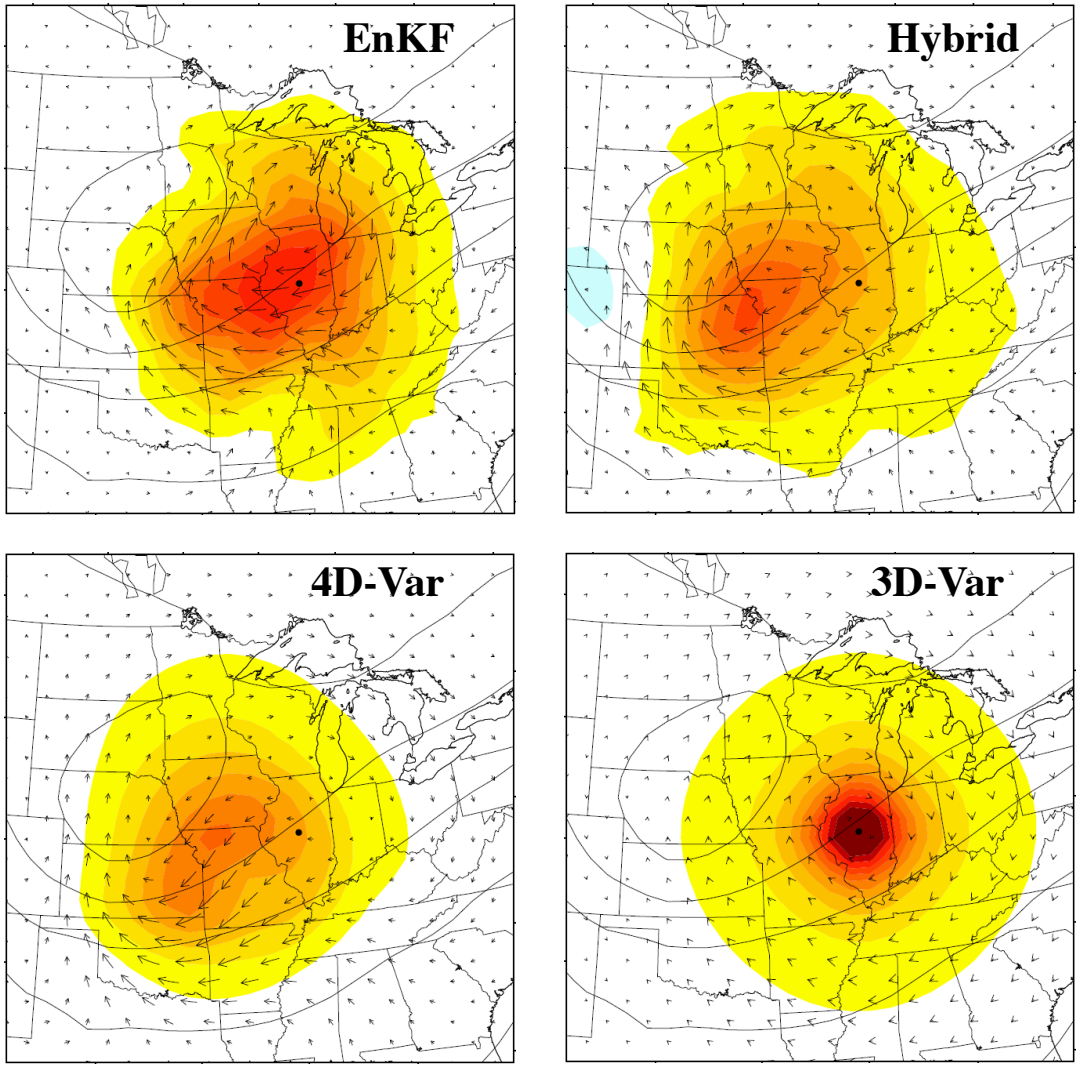
- **3D-Var:** Low cost
  Lack of flow-dependent

- **4D-Var:** Trajectory fitting for asynchronous observations
  Model as a (strong/week) constraint
  Implicit flow-dependent estimation
  Poor background error covariance at t=0
  Difficulties in TL and AD
  High cost

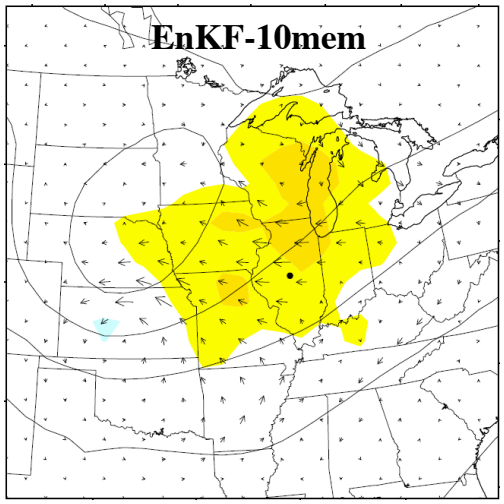
- **EnKF:** Flow-dependent B [Ensemble forecasts]
  Easy coding and maintenance
  Sensitive to the quality of ensembles
  Sampling errors
  Non-linear operators

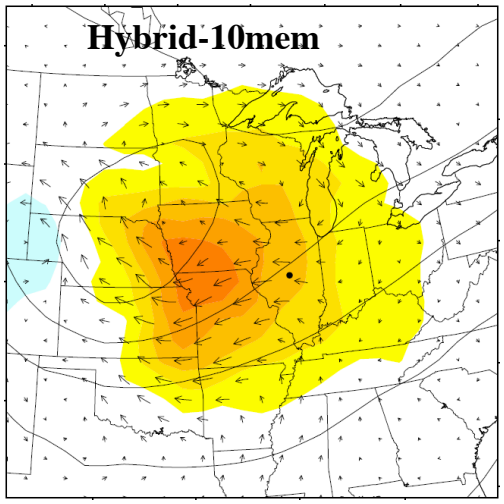
- **Hybrid:** Get the best from both EnKF and 4D-Var

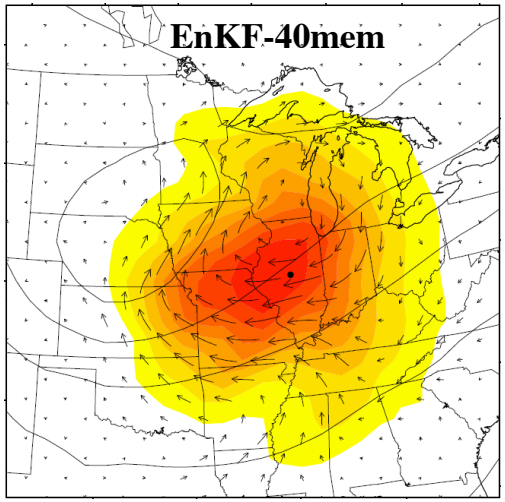
Temperature (shaded) and horizontal wind (vector) increments

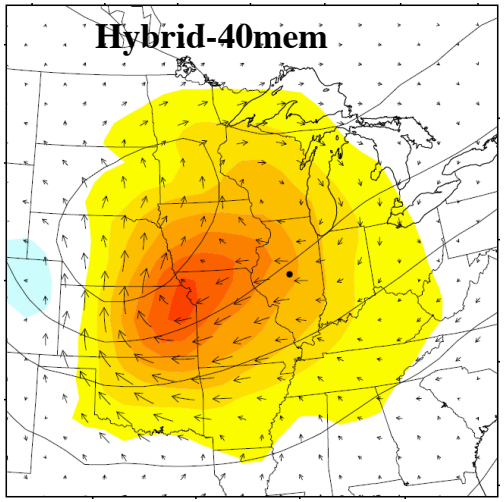


Compare EnKF and Hybrid with small ensemble size (10 members)

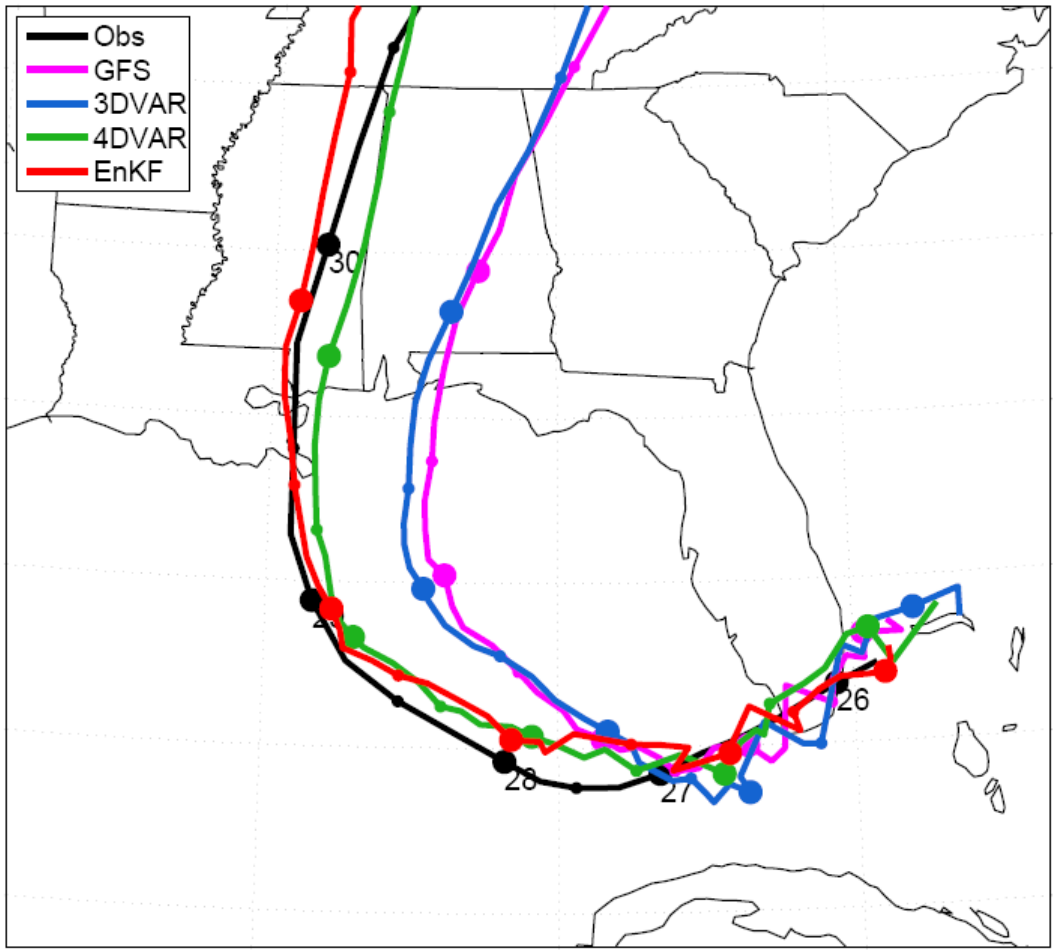


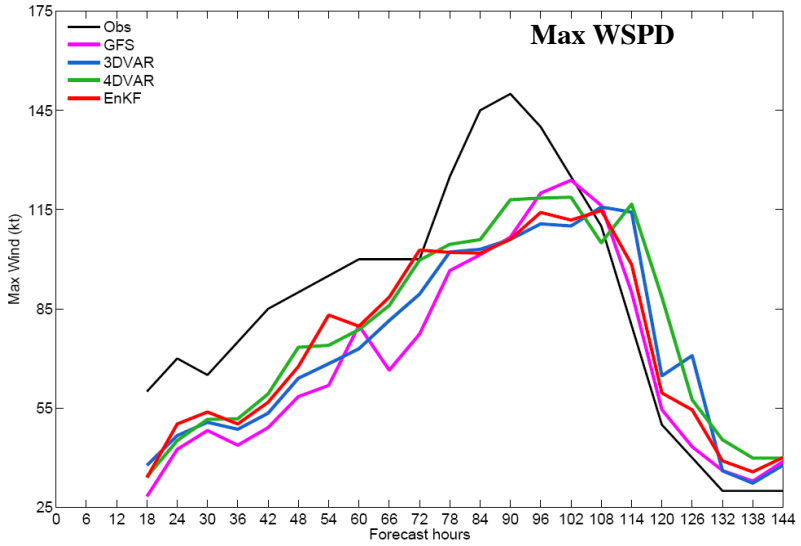


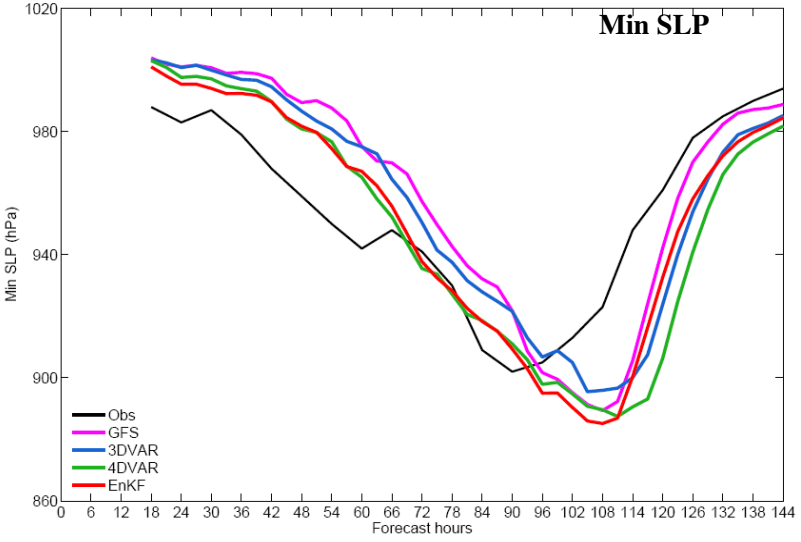




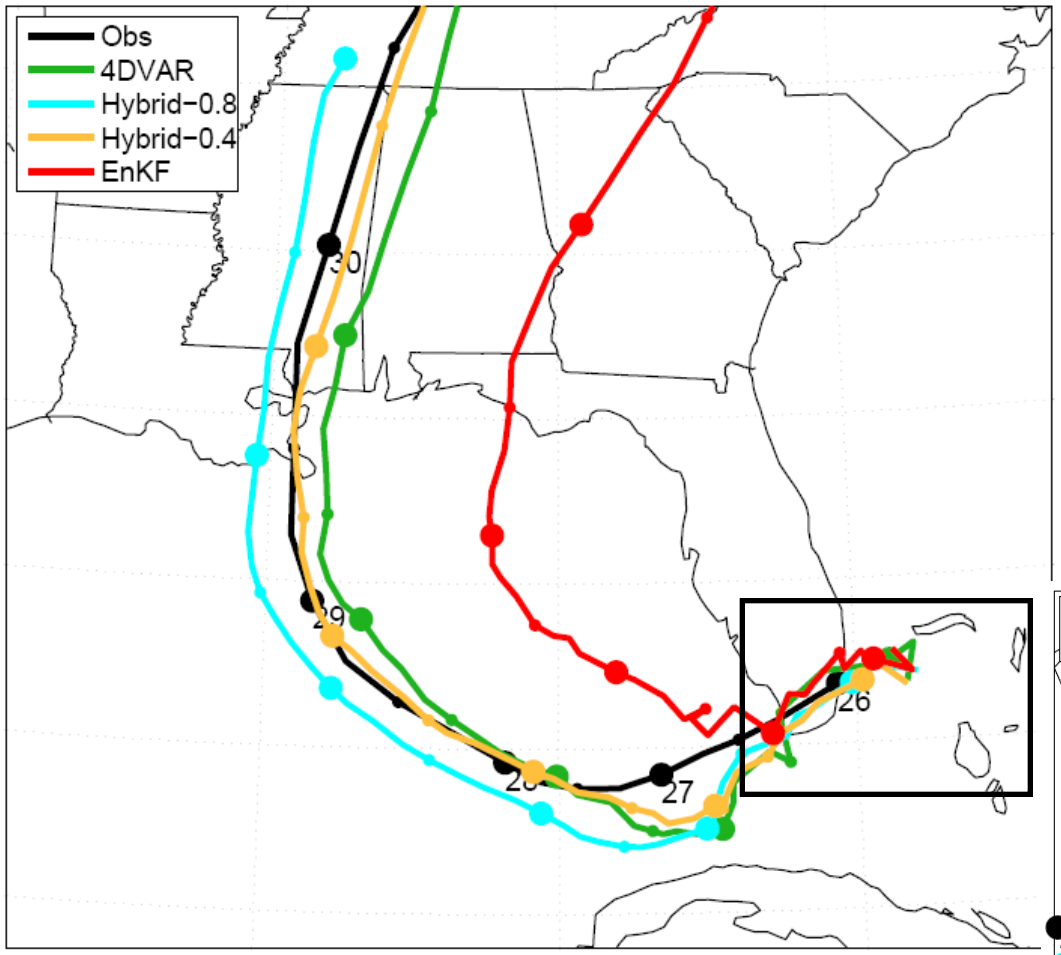
DA Performances on Track and Intensity forecasts

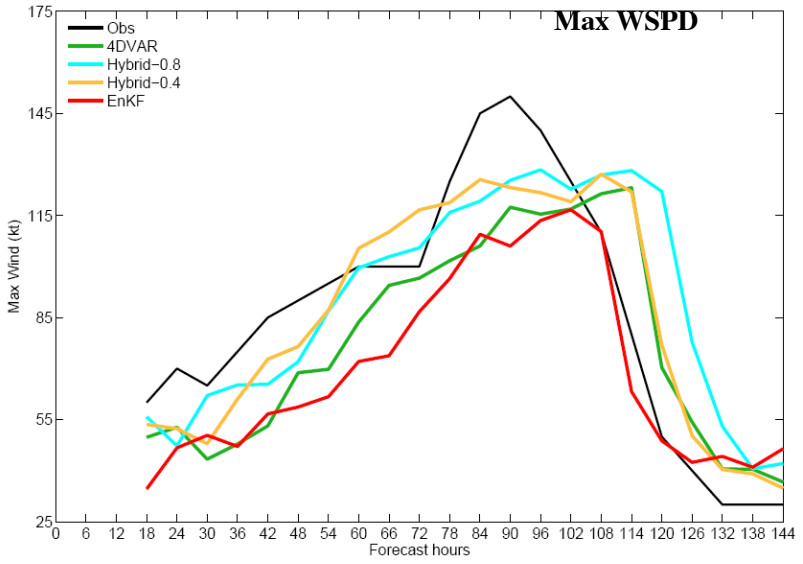


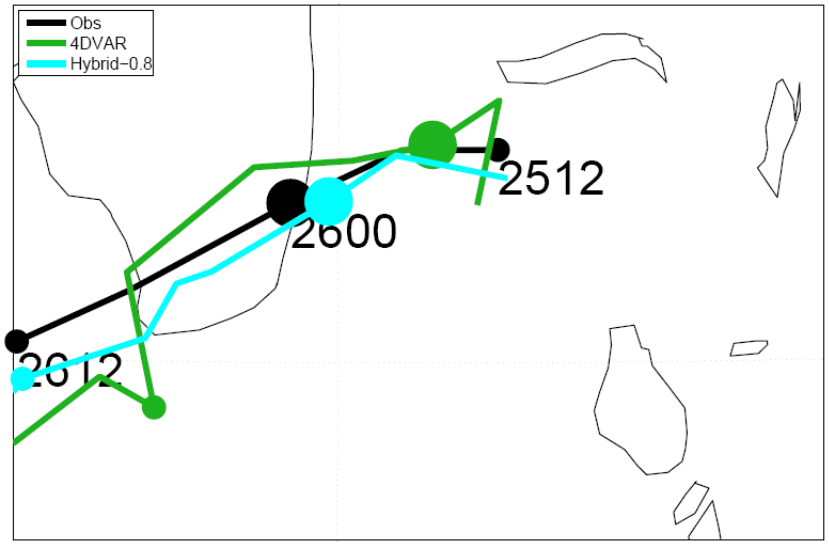




DA performances with "bad" first guess







Mean vertical profiles of U, V, T and Qv 12-h forecast RMSE
(06/01/2003 ~ 06/10/2003 with 12-h interval)