A Hybrid Data Assimilation System (WRF-VAR and Ensemble Transform Kalman Filter) Based Retrospective Tests

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10th Annual WRF User's Workshop
23-27 June 2009, Boulder, Colorado

An outline of my hybrid story

- ***Why*** do we need a hybrid data assimilation system?
- ***What*** are the basic ingredients of a hybrid system?
- ***How*** have we implemented the hybrid system at the Data Assimilation Testbed Center (DATC)?
- ***What*** we have found: Highlights of preliminary results
- Summary and conclusions
- Future work

Why do we need a hybrid system?

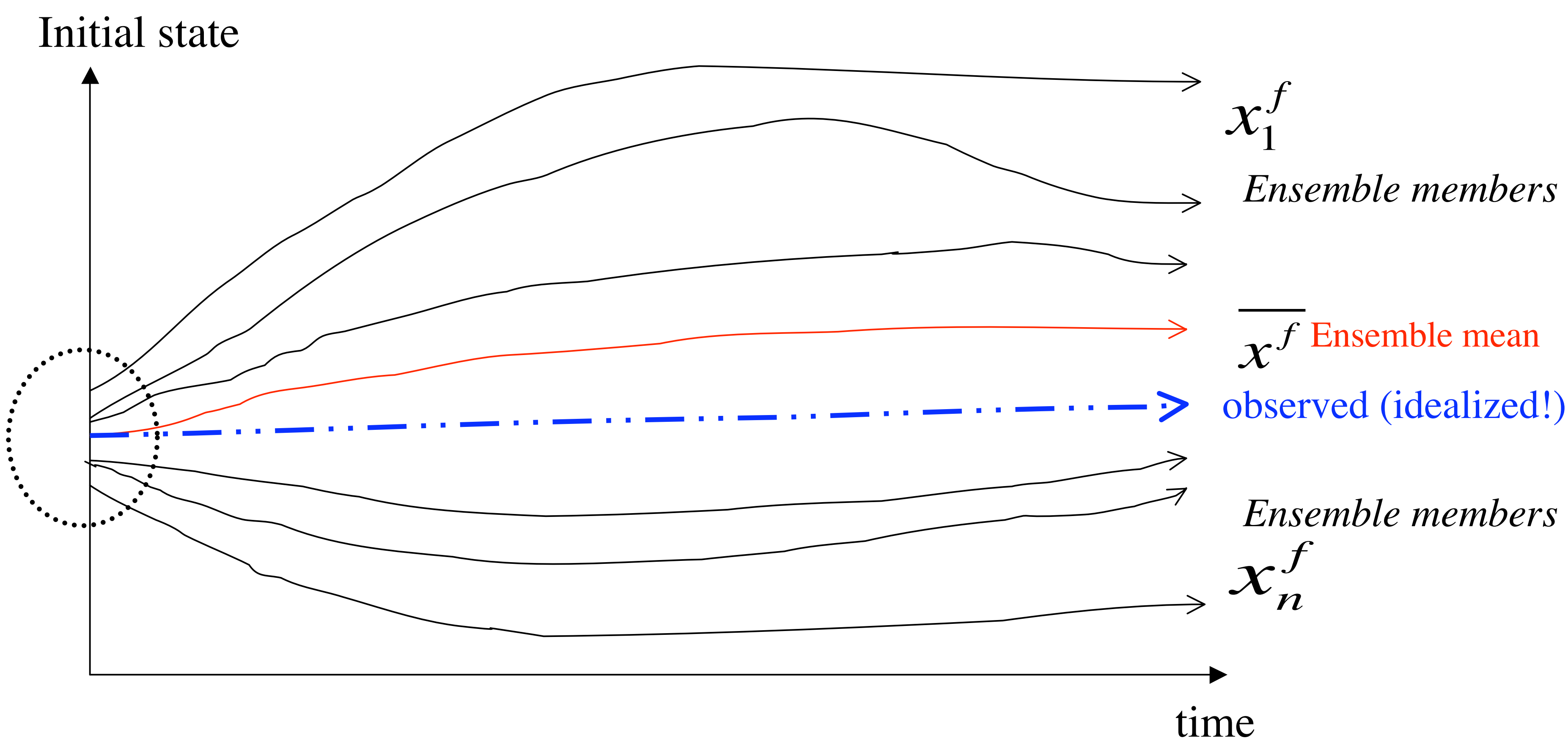
- The WRF 3D-VAR system uses only *climatological* (static) background error covariances.
- *Flow-dependent* covariance through ensemble is needed.
- Hybrid combines *climatological* and *flow-dependent* background error covariances.
- It can be adapted to an existing 3D-VAR system.
- Hybrid can be robust for small size ensembles.

What are the basic ingredients of a hybrid system?

1. Ensemble forecasts: WRF-ensemble forecasts
2. A mechanism to update ensemble perturbations: Ensemble Transform Kalman Filter (ETKF)
3. A data assimilation system: WRF 3D-VAR

It sounds simple…. :-)

Ensembles to address uncertainties in the initial state



Ensemble Basics

Assume the following ensemble forecasts:

$$X^f = (x_1^f, x_2^f, x_3^f, \ldots\ldots x_N^f)$$

Ensemble mean: $\overline{x}^f = \frac{1}{N}\sum_{i=1}^{N} x_n^f$

Ensemble perturbations: $\delta x_n^f = x_n^f - \overline{x^f}$

Ensemble perturbations in vector form:

$$\delta X^f = (\delta x_1^f, \delta x_2^f, \delta x_3^f, \ldots\ldots, \delta x_N^f) \quad n = 1, N$$

How to update ensemble perturbations?

ETKF technique updates ensemble perturbations by rescaling innovations with a transformation matrix (*Wang and Bishop 2003*).

$$x^a = x^f T$$

T*ransformation matrix*
(solved by Kalman Filter Theory)

An adaptive scalar inflation factor has been introduced to inflate at time ***i*** by matching spread to innovation vectors, $\prod$:

$$x_i = x_i^f T_i \prod_i$$

Inflation factor
(For the derivation of $\prod$ *see Wang and Bishop 2003.)*

The hybrid DA formulation….

Ensemble covariance is implemented into the 3D-VAR cost function via ***extended control variables***:

$$J(x_1^{'},\alpha) = \beta_1 \frac{1}{2} x_1^{'T} B^{-1} x_1^{'} + \beta_2 \frac{1}{2} \alpha^T C^{-1} \alpha + \frac{1}{2}(y^{o'} - Hx^{'})^T R^{-1} (y^{o'} - Hx^{'})$$

$$x^{'} = x_1^{'} + \sum_{k=1}^{K} (\alpha_k \circ x_k^e)$$

(Wang et. al. 2008)

C: correlation matrix for ensemble covariance localization

$x_1^{'}$ 3D-VAR increment

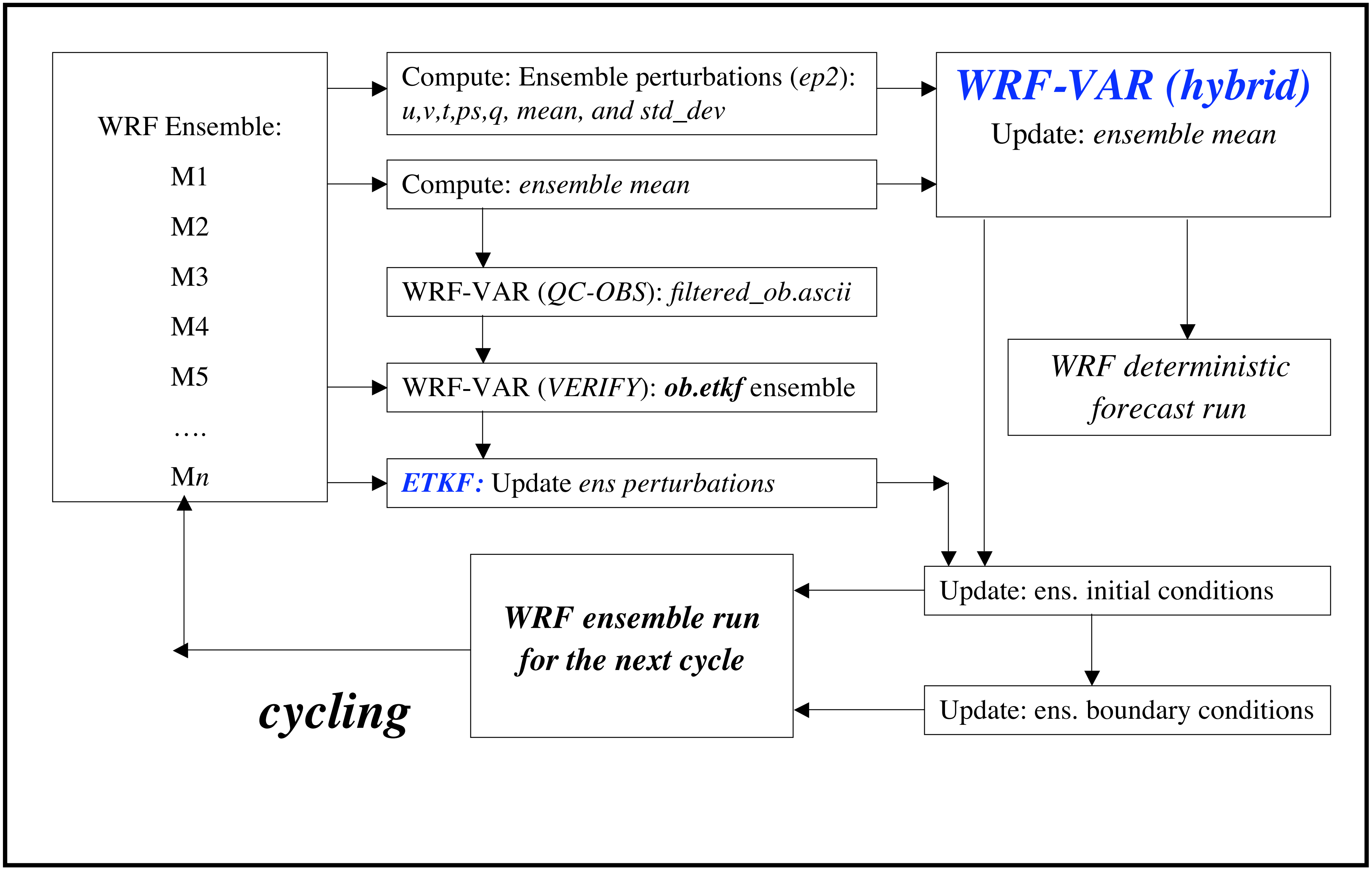
$x^{'}$ Total increment including hybrid

α Extended control variable

β_1 Weighting coefficient for static 3D-VAR covariance

β_2 Weighting coefficient for ensemble covariance

How have we implemented hybrid (3DVAR -ETKF) system at the (DATC)?



A few notes on hybrid settings

- alpha_corr_scale=1500km (Default)
- je_factor (β_1)=2.0
- jb_factor (β_2)=je_factor/(je_factor -1)=2.0
- alphacv_method=2 (ensemble perturbations on model space)
- ensdim_alpha=10 (ensemble size)

N.B. Conservation of total variance requires: $\frac{1}{\beta_1} + \frac{1}{\beta_2} = 1$

Retrospective Test Runs

- Base runs: WPS, REAL and WRF
- Generate background error covariance for 3D-VAR
- Three hourly full cycling with conventional observations:
    - Hybrid (3D-VAR and ETKF)
    - Only standard 3D-VAR

Experiment Set-up

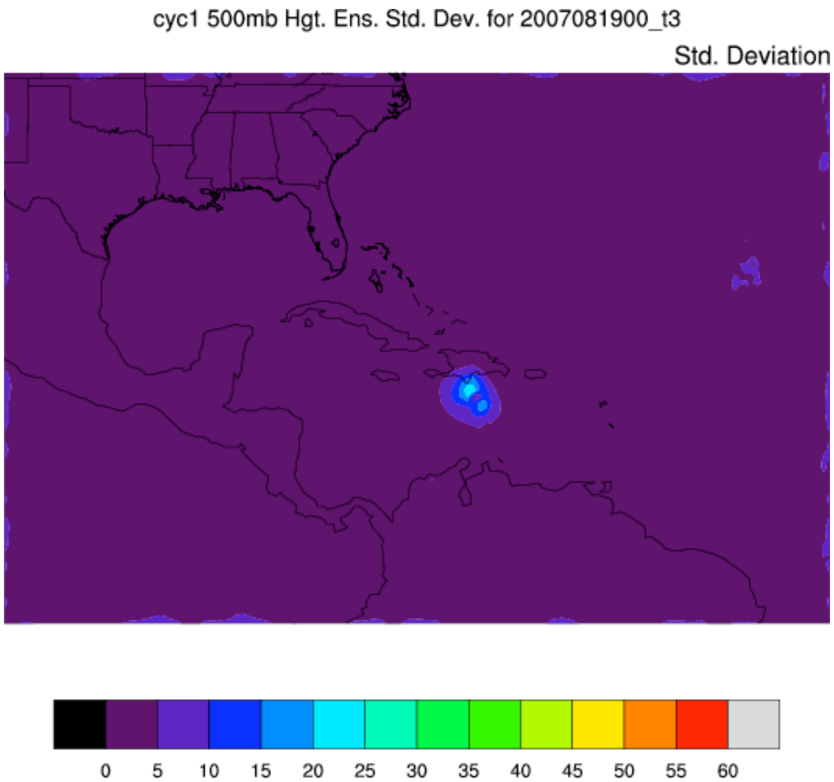
- Ensemble size: 10
- Test Period: 15th August - 15th September 2007
- Cycle frequency: 3 hours
- Observations: GTS conventional observations
- Deterministic ICs/BCs: Down-scaled GFS forecasts
- Ensemble ICs/BCs: Produced by adding spatially correlated Gaussian noise to GFS forecasts (*Torn et al. 2006*). (WRF-VAR and some additional tools.)
- Horizontal resolution: 45km
- Number of vertical levels: 57
- Model top: 50 hPa

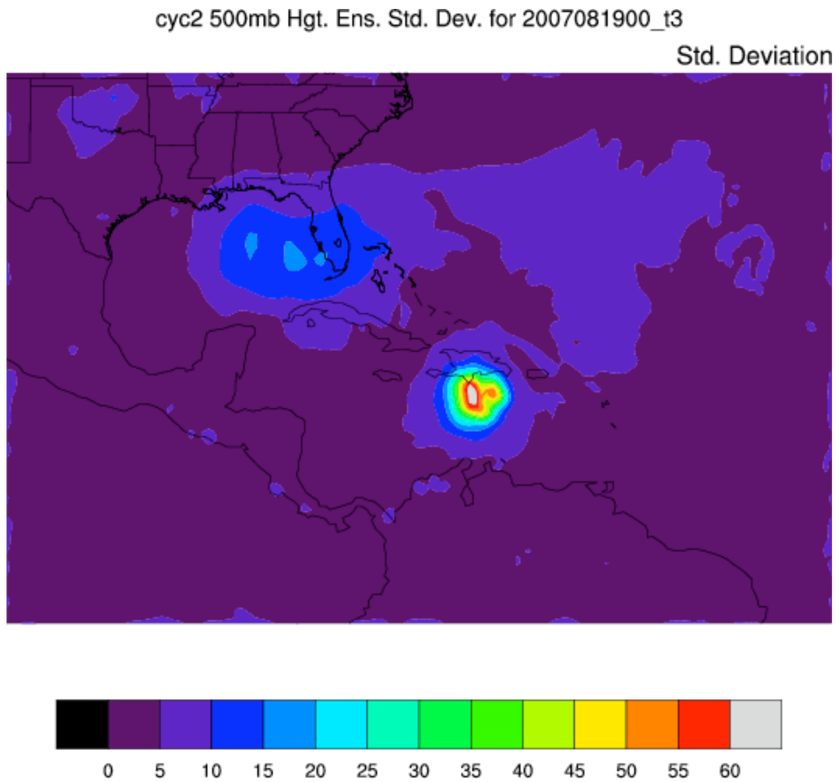
For details see: Demirtas et al. 2009

What we have found: Highlights of preliminary results

Ensemble Spread: 500 hPa height (m) std. dev.

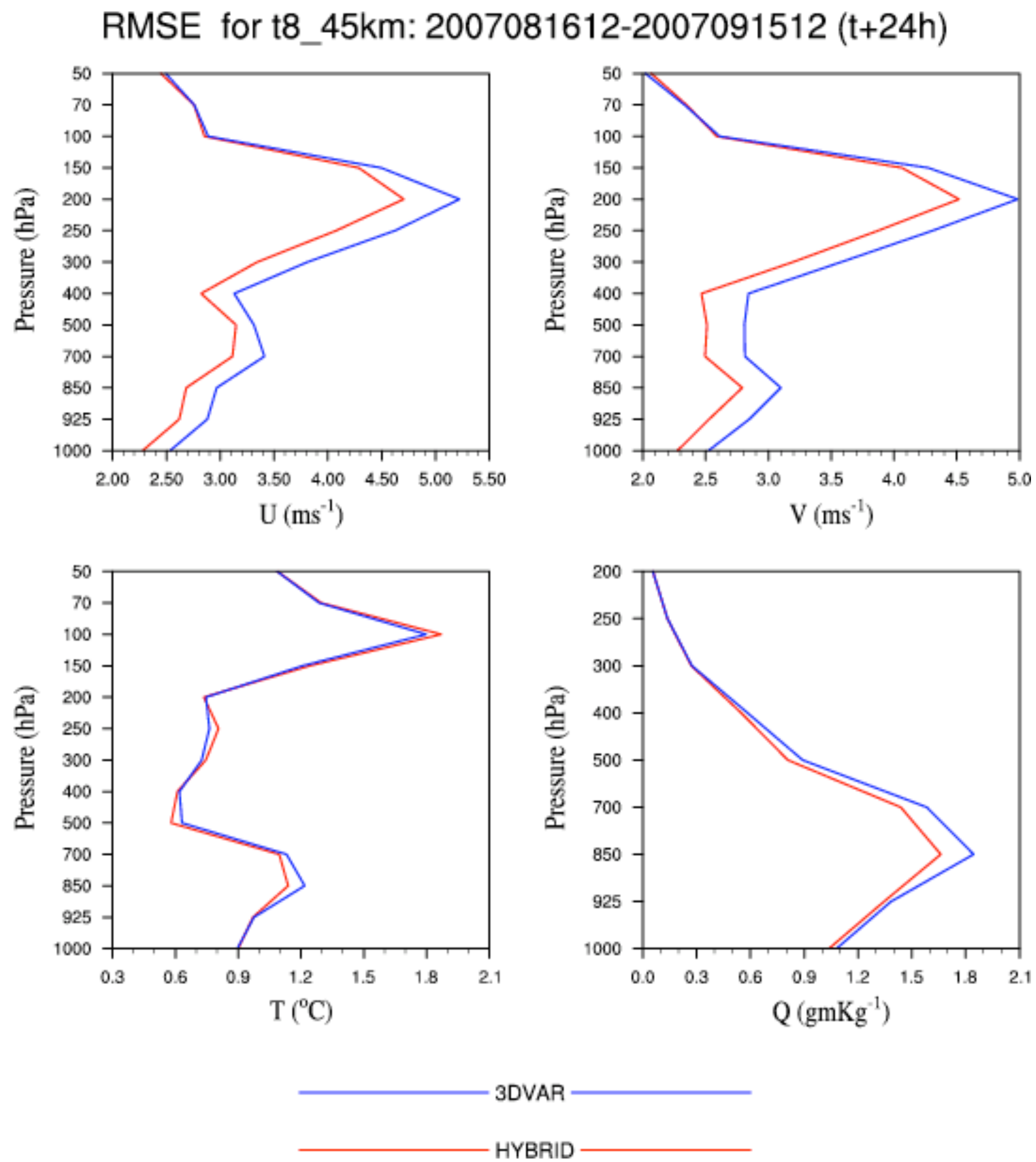
WRF t+3 valid at 2007081900





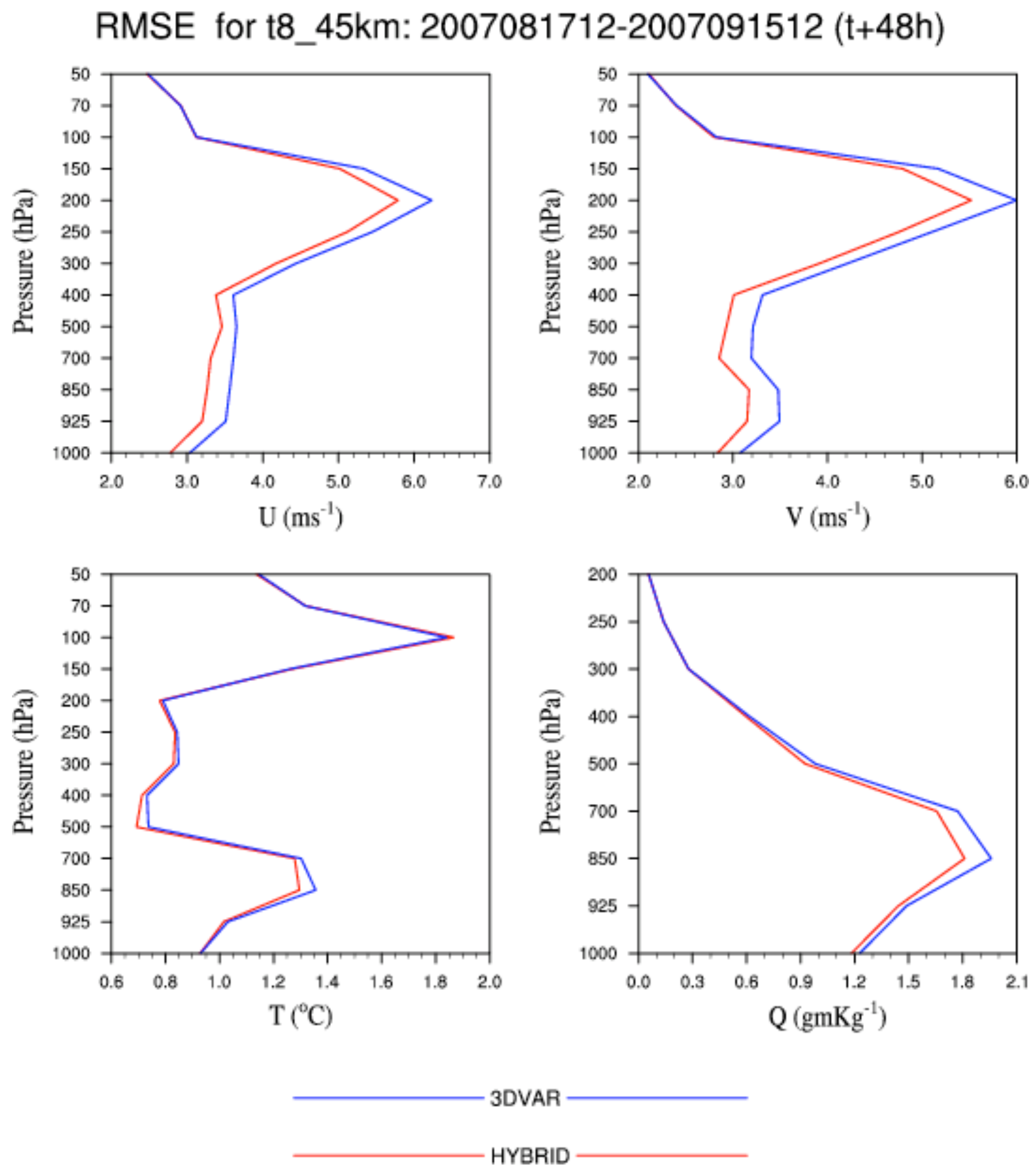
ETKF: Adaptive modest inflation factors used

ETKF: Adaptive high inflation factors used



ECMWF analysis data (T106) used.

Hybrid gives better RMSE scores for wind compared to 3D-VAR.



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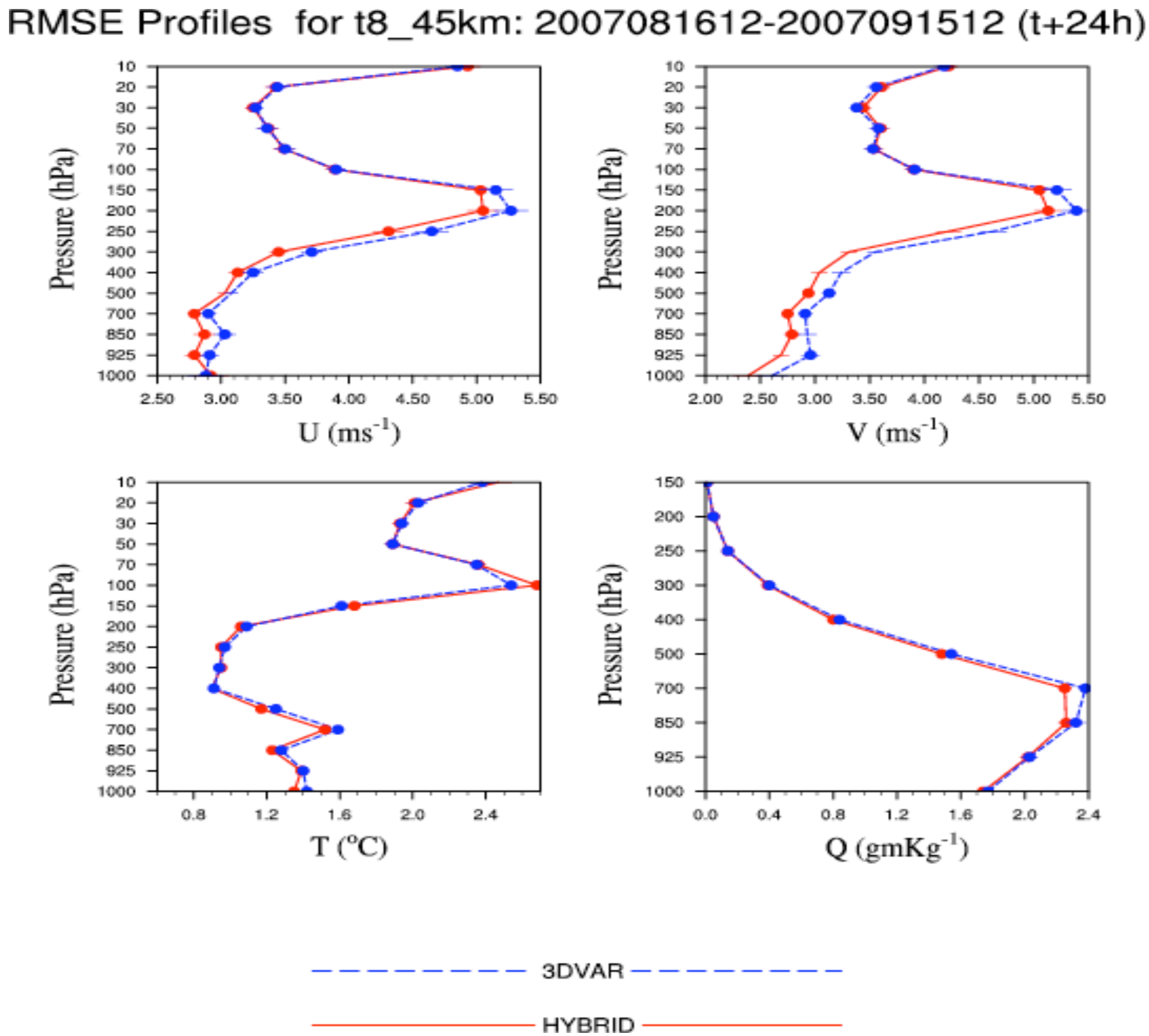

Real obs.

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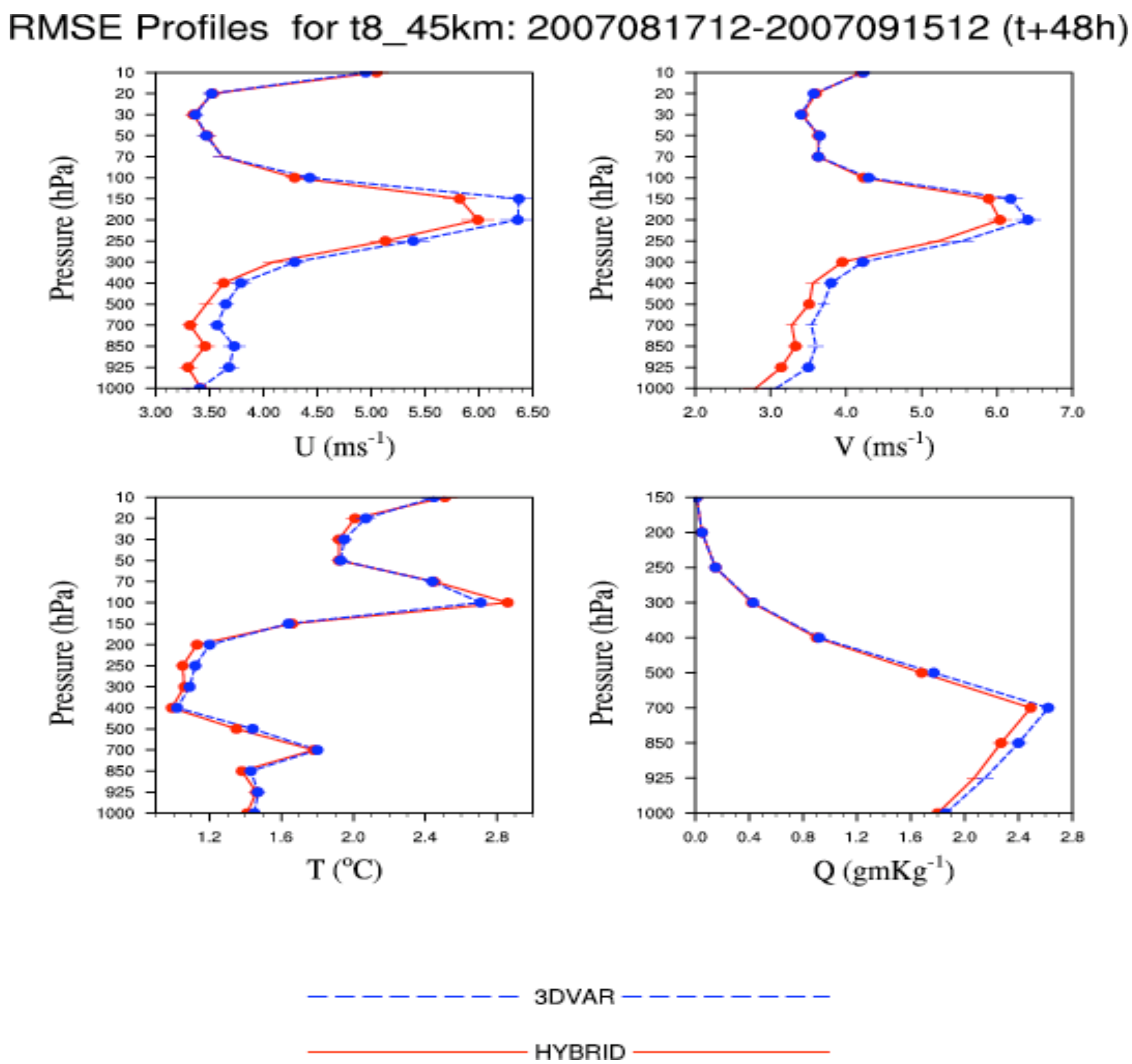

Real obs.

Hybrid gives better RMSE scores for wind compared to 3D-VAR.

Summary and Conclusions

- A WRF-VAR-ETKF based hybrid system has been constructed with some enhancements at the DATC.

- The hybrid system has been tested for the 30-day retrospective runs which coincided with the hurricane Dean’s active period. A few computational instabilities noted during WRF runs, otherwise it was stable.

- Ensemble spread is not *“the bee’s knees”*, but we noted better spread with high inflation factors.

- Verification (RMSE vertical profiles) results of hybrid test are encouraging particularly for the lower troposphere. They are better than those of standard 3D-VAR.

Future Work

- ETKF part: Update inflation generation mechanism in the light of recent applications.
- Hybrid part:
  - Vertical localization: It is currently being tested.
  - Additional isolated runs are needed to evaluate various tunable hybrid parameters:
    - impact of increased weighted contribution from ensembles
    - the impact of smaller/larger horizontal length scale for covariance localization
    - investigating the benefit of tuning background error covariance matrix with ensemble mean based forecasts
    - using higher horizontal resolution

Thanks for listening my hybrid saga… :-)

References

Demirtas, M., D., Barker, Y., Chen, J., Hacker, X-Y., Huang, C., Snyder, and X., Wang, 2009: A Hybrid Data Assimilation (WRF-VAR and Ensemble Transform Kalman Filter) System Based Retrospective Tests, 10th WRF User's Workshop, Boulder, CO, US, 23-27 June 2009.

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