Recent Developments of WRF Obs-nudging and Relaxation Ensemble Kalman Filter FDDA

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A Note for Mesoscale DA

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- ✧ Mesoscale weather: rich flow features, fast-evolving and difficult to define proper Background Error covariance;
- ✧ Surface data are important. Complex terrain and PBL turbulences make surface data assimilation challenging;
- ✧ Radar data assimilation is important;
- ✧ Physical process (sources/sinks) are large terms, often interacting strongly with data ingested into WRF;
- ✧ Thus, four-dimensional data assimilation (FDDA) schemes that permit interaction between a full-physics model and observations data are advantageous.

FDDA: 4D continuous DA

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- ✧ 4DVAR, EN-4DVAR
- ✧ Obs-nudging
- ✧ REKF (Relaxation Ensemble KF)
- ✧ Pseudo-Continuous-FDDA:

  Grid-nudging,

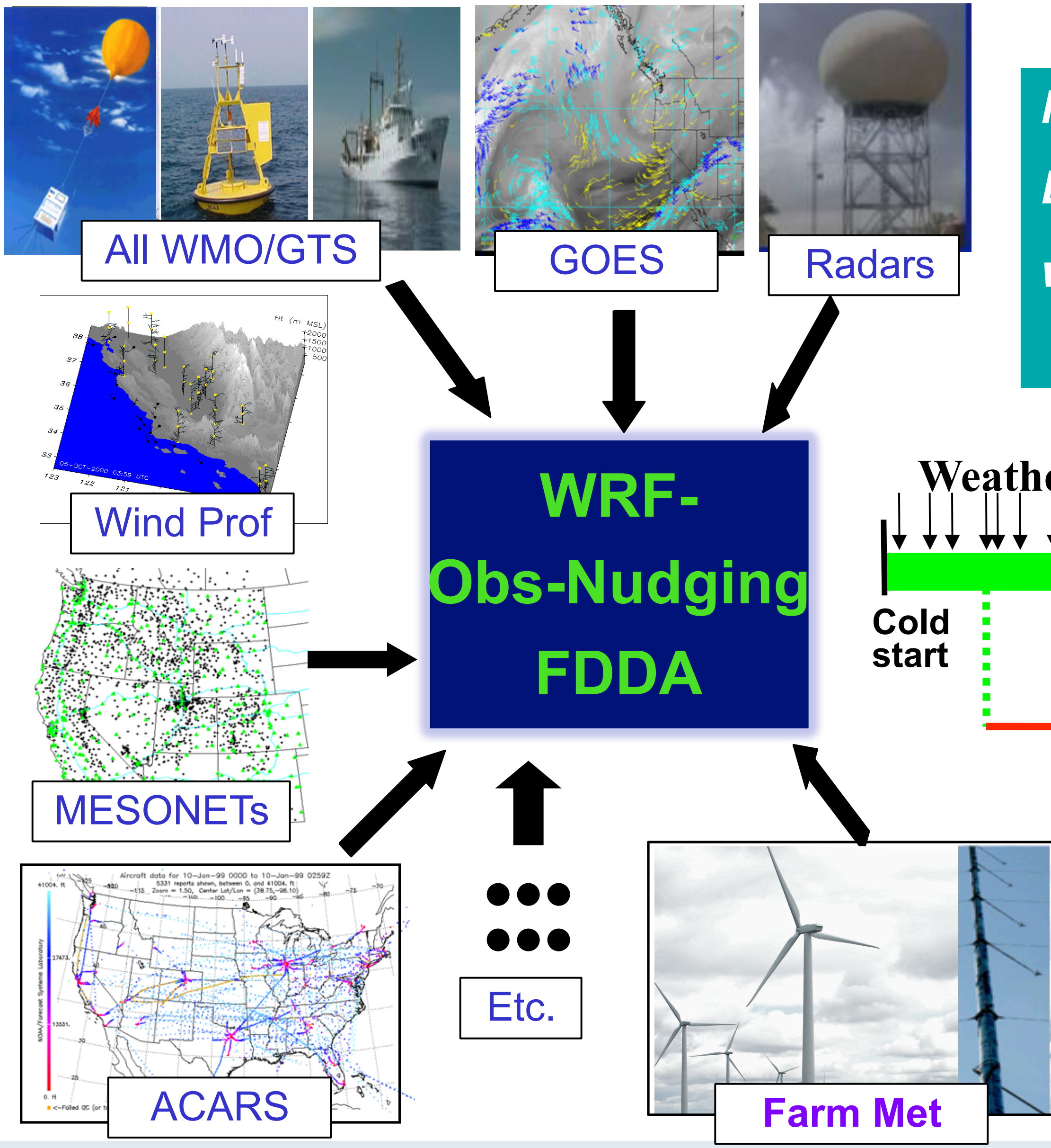
  4D-LETKF,

  High-frequency EnKF,

  …

REKF: an advanced obs-nudging FDDA scheme using the EnKF technology.

Obs-Nudging FDDA

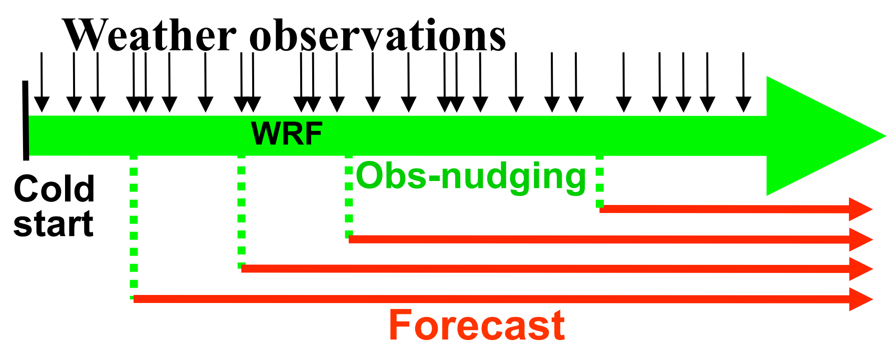


Modified WRF:

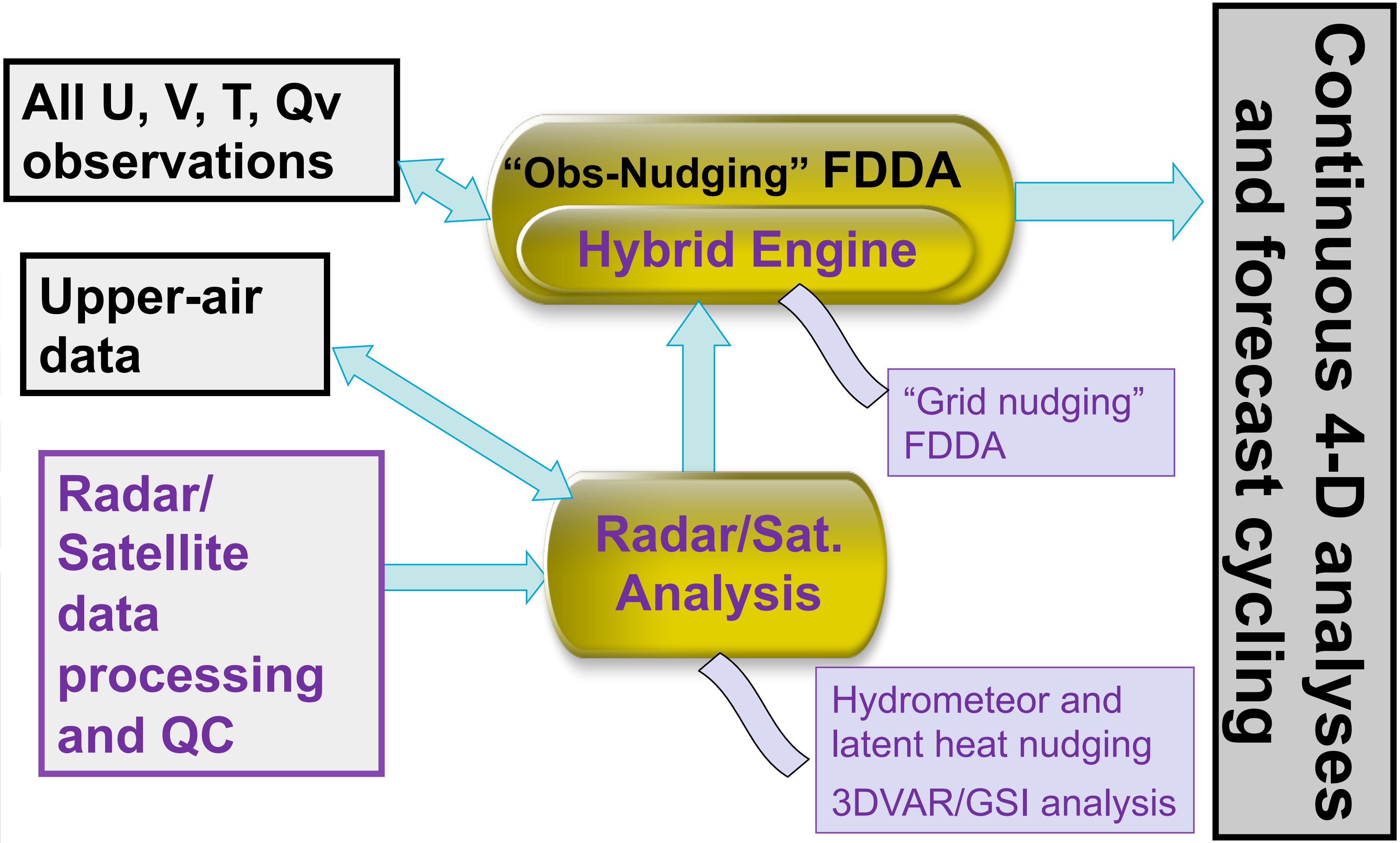
$Dx/Dt = \ldots + GW\,(x_{obs} - x_{model})$

where $x = T, U, V, Q, P1, P2 \ldots$

W is weight function



Obs-Nudging+3DVAR/GSI hybrid DA



Obs-Nudging and REKF

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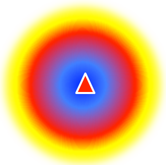
Obs-nudging

$$\frac{\partial X}{\partial t} = F(X,x,y,\sigma,t) + G_x \frac{\sum_{i=1}^{N} W_{h,i}^2 W_{\sigma,i}^2 W_{t,i}^2 \cdot W_{qc,i}^2 \cdot (x_i^{obs} - HX)}{\sum_{i=1}^{N} W_{h,i}^2 W_{\sigma,i}^2 W_{t,i}^2 \cdot W_{qc,i}^2}$$

WRF



Cressman weight Function

$$W_{h,i} = \frac{R^2 - d_i^2}{R^2 + d_i^2}$$

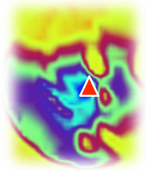
Nudging coefficient

Ensemble Kalman Gain (EnKF; e.g. DART)

$$W_{h,i} = K_e = P^f H^T (HP^f H^T + R)^{-1}$$

REKF

$$\frac{\partial X}{\partial t} = F(X,x,y,\sigma,t) + G_x \frac{\sum_{i=1}^{N} W_{h,i} W_{\sigma,i}^2 W_{t,i}^2 W_{qc,i}^2 \cdot (y_i^{obs} - HX)}{\sum_{i=1}^{N} W_{\sigma,i}^2 W_{t,i}^2 W_{qc,i}^2}$$



REKF: Leverage obs-nudging with ensemble Kalman gains.

Characteristics of REKF

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✧ **Flow-dependent obs-nudging weight function**

✧ **Assimilate non-prognostic variables**

✧ **Dynamical and physical initialization**

✧ **Good tolerance of nudging coefficients (G)**

✧ **Readily adopting EnKF achievements, e.g.**

- (adaptive) localization
- ensemble and climatological hybrid BE (EnVar…)

✧ **Hybrid with GSI, DART, latent heat nudging RDA**

WRF FDDA Data Structure Change

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Old WRF obs-nudging data structure:

VAROB (n, time, lat, long, U, V, T, Q)

New WRF REKF data structure:

VAROB (n, time, lat, long, U)
VAROB (n+1, time, lat, long, V)
VAROB (n+2, time, lat, long, T)
VAROB (n+3, time, lat, long, Q)
VAROB (n+4, time, lat, long, Vr)

Remove missing data; readily add new data type; and significantly reduce the memory of REKF.

Validation experiments

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✧ **Code validation with “OSSE”:**
- Compare with Obs-nudging, WRF-VAR, DART, GSI

✧ **Kalman gain approximation in WRF:**
- Spatial interpolation
- Temporal interpolation

✧ **Dealing with model errors and rank deficiency**
- Localization
- Spurious noises
- Ensemble and climatological hybrid BE

✧ **Assimilation of radar radial velocities**
- Covariance: COV(U, Vr), COV(V, Vr)

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  - Temporal interpolation
- **Dealing with model errors and rank deficiency**
  - Localization
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"Perfect-Model-Perfect-Obs" Exps

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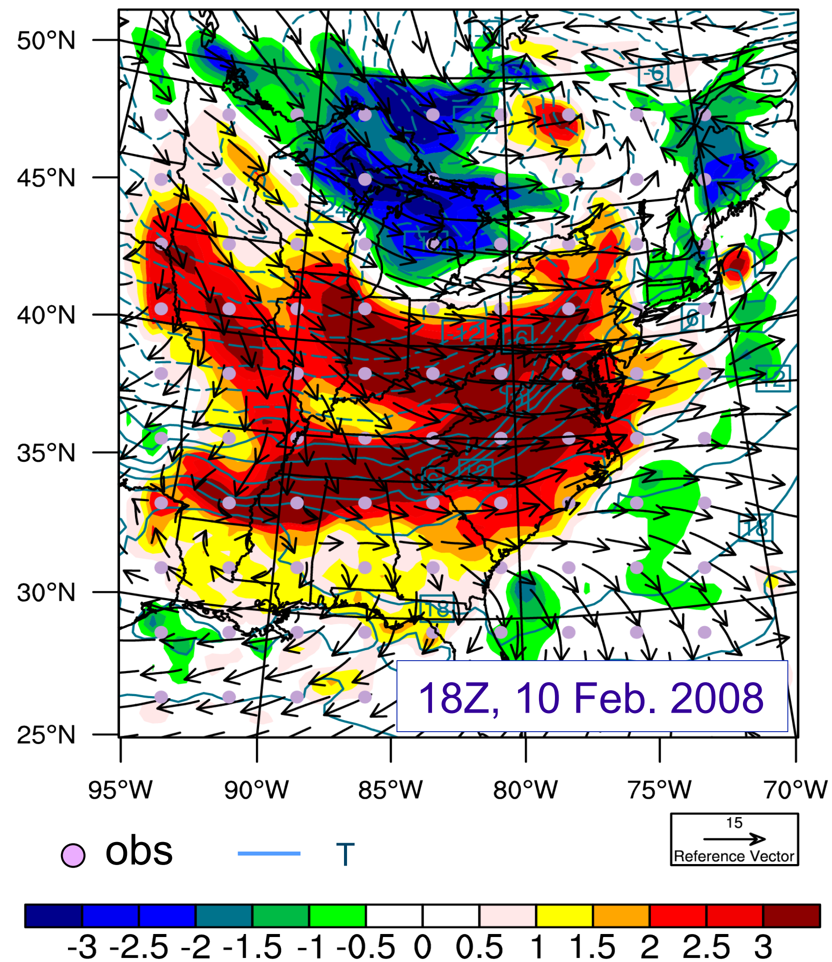
EXPs	Description
TRUTH: Natural un (WRFv3.6)	Nature run from unperturbed initial conditions (Ics) OBS: simulated soundings from the TRUTH
CTRL	Forecast from perturbed ICs.
3DVAR	CTRL ICs + WRF 3DVAR
4DVAR	CTRL ICs + WRF 4DVAR
DART	CTRL ICs + DART EAKF
GSI	CTRL ICs + GSI 3DVAR
Obs-Nud	CTRL ICs + WRF Obs-Nudging
REKF	CTRL ICs + WRF 4D-REKF



T (contour) and wind of the nature run, and T errors of the CTRL I.Cs.

All Exps: 6h DA + 24h fcsts

Test different DA schemes in the same framework (OSSE)

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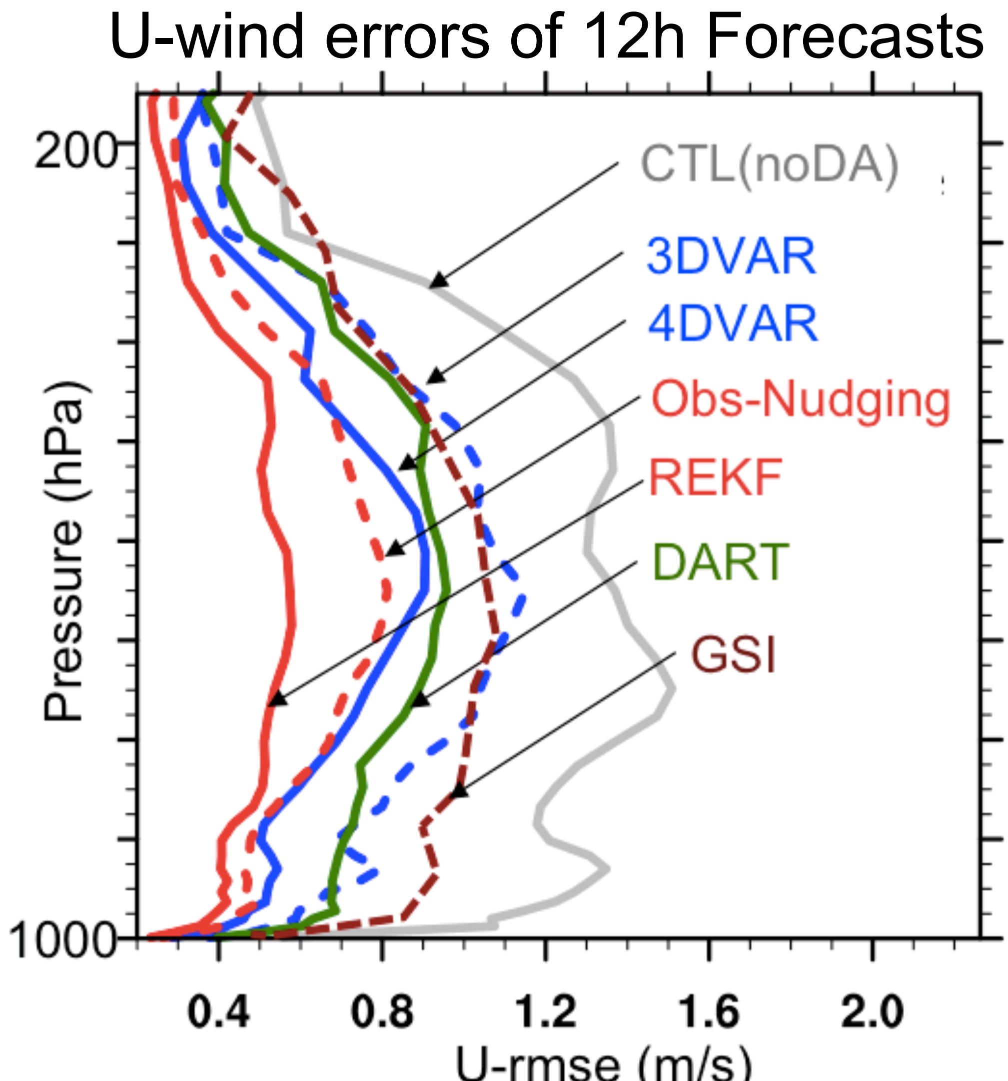

6h DA before the fcsts

3DVAR: hourly
GSI: hourly
DART: hourly
4DVAR: 2 3h-windows
Obs-Nud: continuously
REKF: continuously

“Climate analog ensemble” K-gains

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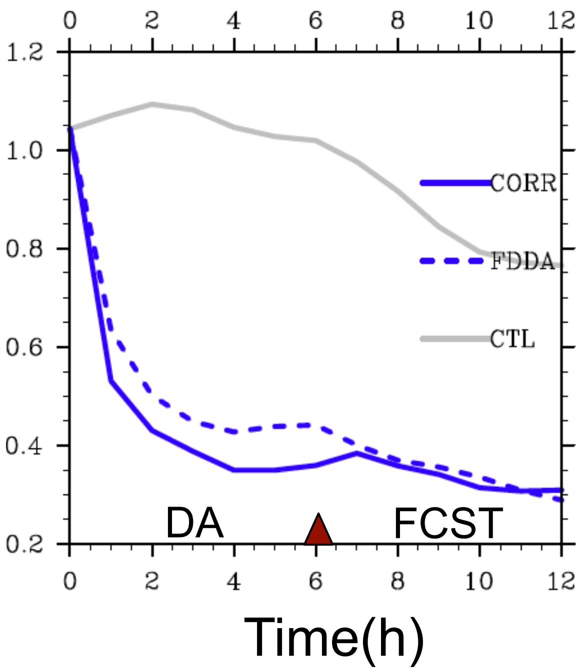
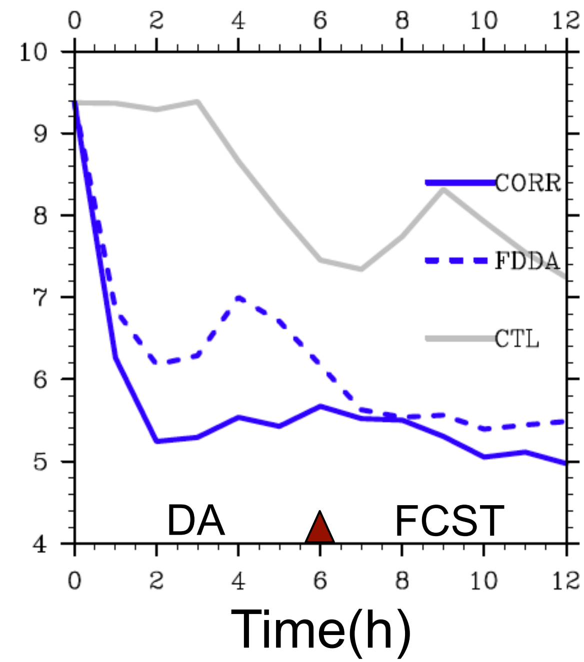
$$\frac{dx}{dt} = \ldots + G\boxed{Ke}WtWq(y^o - Hx^b)$$

CTL: *Ke*=0
FDDA: *Ke*=Cressman
CORR: *Ke*=20 clim-analogs

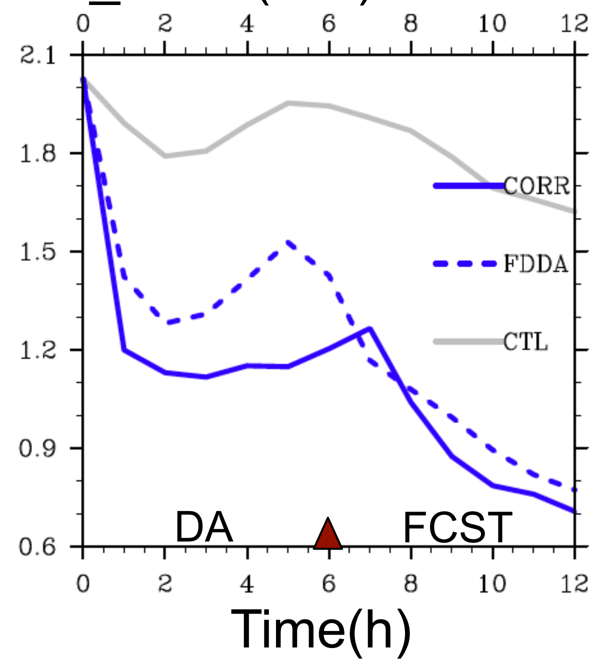
T_rmse (C)



RH_rmse (%)



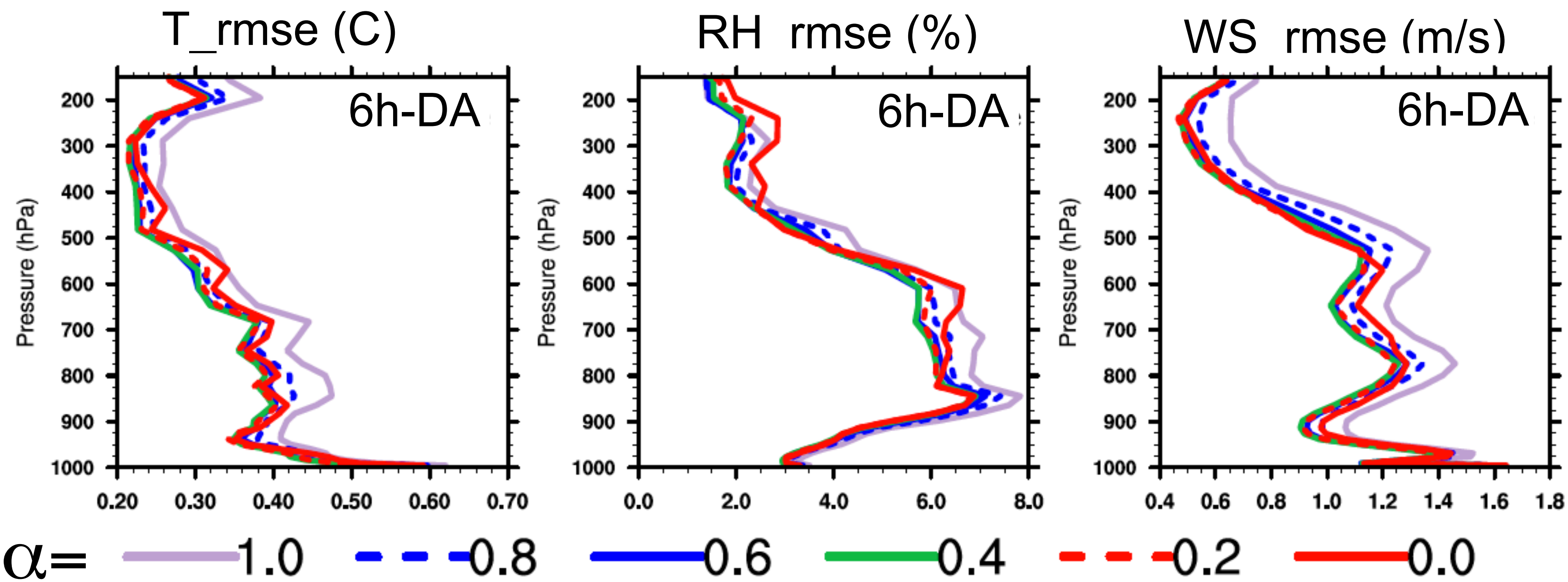
WS_rmse (m/s)



Ensemble-Cressman Hybrid

$$\frac{dx}{dt} = \ldots + G\boxed{K_h}WtWq(y^o - Hx^b)$$

ObsNud: $K_h = K_c$ Cressman
REKF: $K_h = K_e$ Ensemble
Hybrid: $K_h = \alpha K_c + (1 - \alpha)K_e$



ObsNud → REKF

Ensemble-Cressman Hybrid

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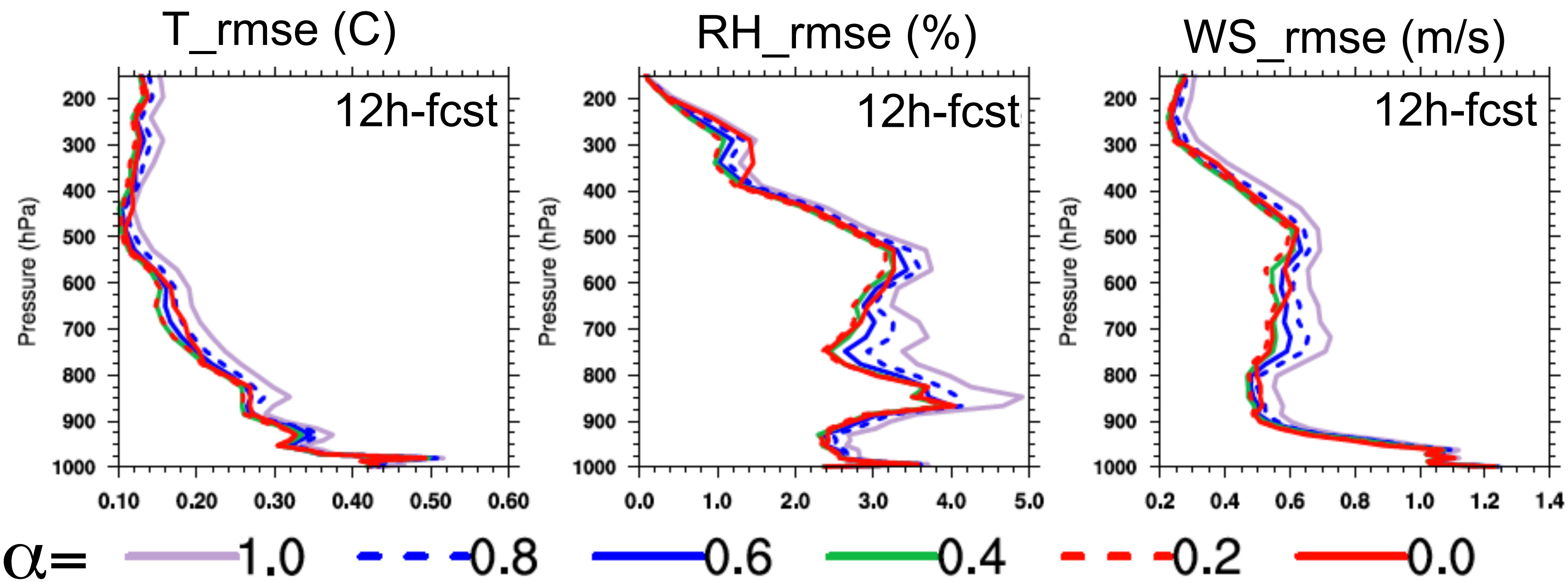

ObsNud → REKF

Assimilating Radar Radial Wind (Vr)

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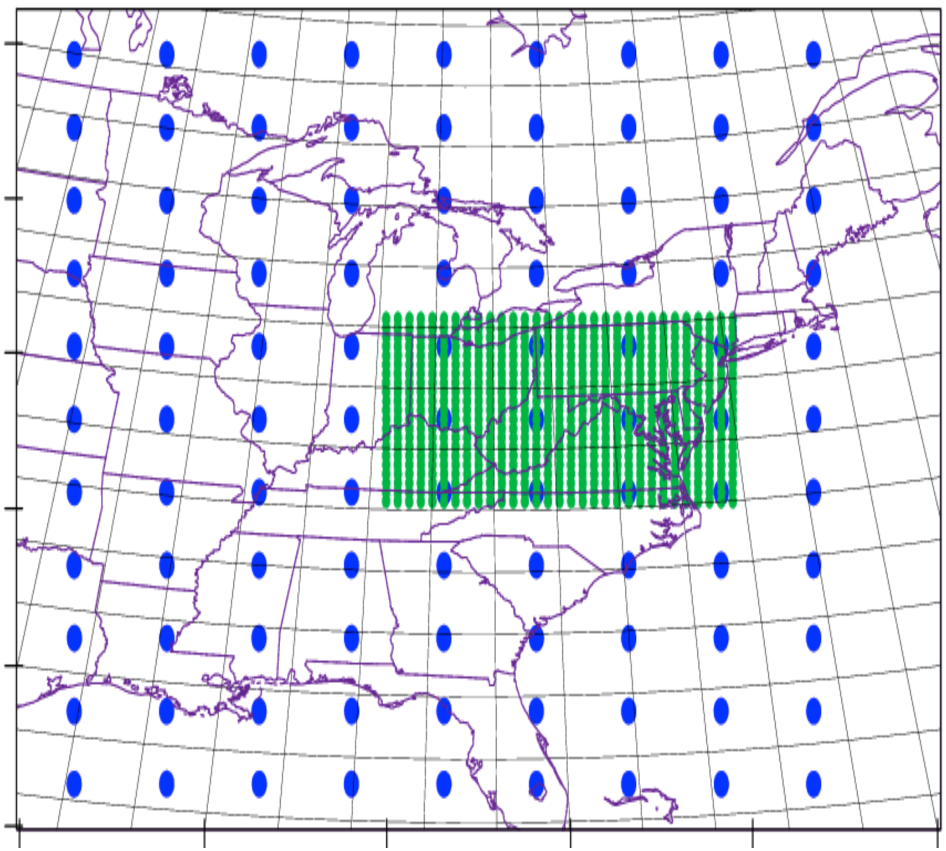

Soundings hourly

Radar (Vr) Every 15 min

Four Exps:

NODA: No DA
CRES: UVTQ
REKF: UVTQ
REKFVr: UVTQVr

Case: 10 Feb. 2008

Assimilating Radar Radial Wind (Vr)

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NODA: No DA

ONUD: Obs-nudging using soundings at 18Z and 19Z

REKF: REKF using soundings at 18Z and 19Z

REKFVr: REKF using soundings at 18Z and 19Z and
Vr at 18:15Z, 18:30Z, and 18:45Z.

Parameters used for soundings

$$R_{xy} = 200km \quad R_t = 48\min \quad coef = 6.0E-4$$

Parameters used for Radar

$$R_{xy} = 35km \quad R_t = 15\min \quad coef = 6.0E-4$$

Exps of assimilate radar wind (Vr)

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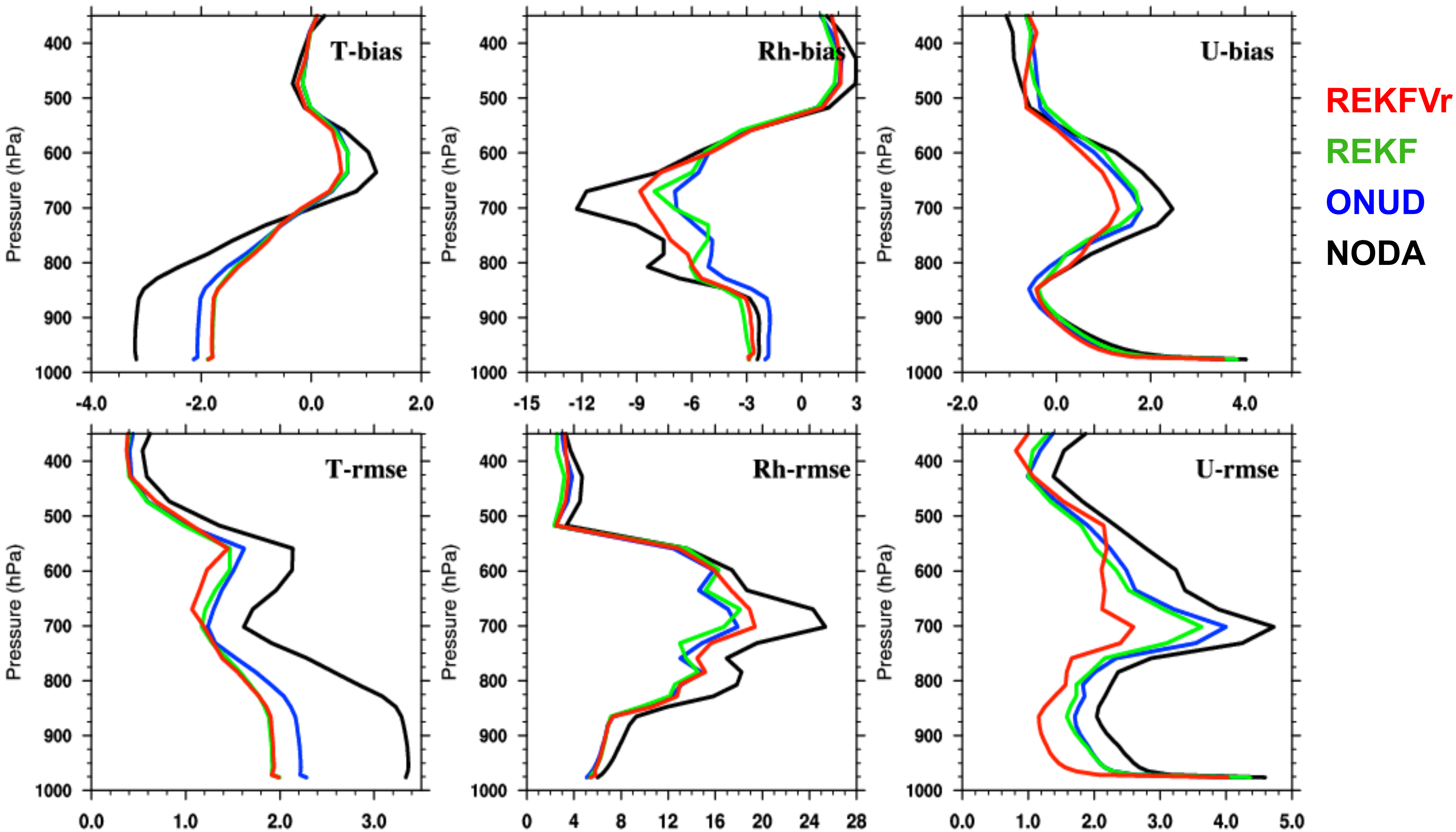
After 1h DA (18 -19Z)



Exps of Radar Wind (Vr) Assimilation

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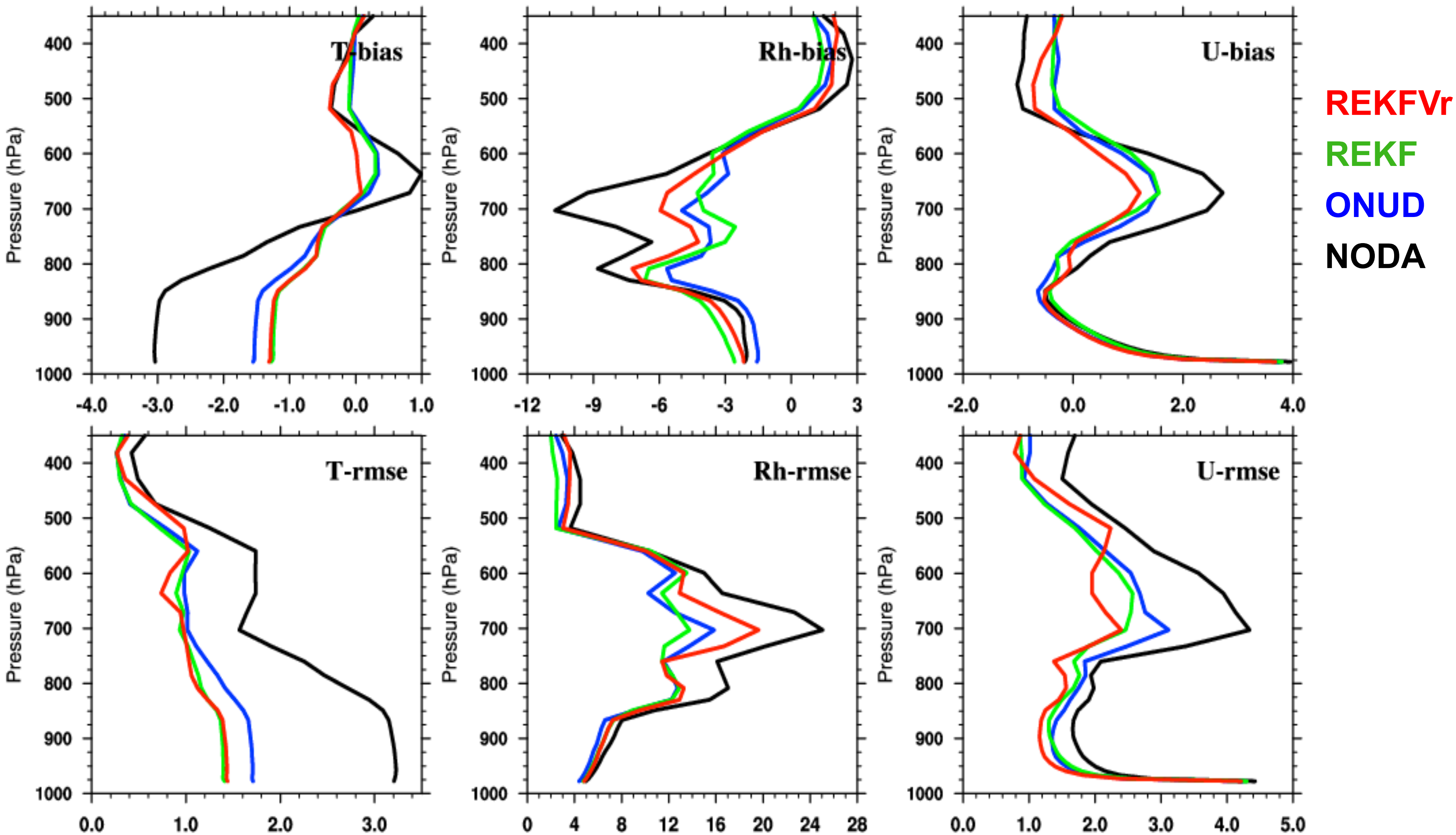
1h Fcst (20Z)



Summary

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- REKF advances WRF obs-nudging with ensemble-based flow-dependent weight function. It preserves the advantages of “obs-nudging” while taking in the EnKF capabilities.
- Validation of REKF with an OSSE data assimilation testbed shows very encouraging performances.
- REKF is capable of assimilating both standard observations (UVTQ) and remote sensing data (e.g. Vr).
- REKF has been employed in a real-time operational forecast system running at the Army Dugway Proving Ground with 32 ensemble members and 3km grid.

Thank you!