Development of the NCAR 4D-REKF System and Comparison with RTFDDA, DART-EaKF and WRFVAR

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Outlines

1. Review of NCAR RTFDDA and E-RTFDDA
2. Description of the NCAR 4D-REKF
3. Comparison experiments of DA schemes with "perfect model and perfect obs"
4. Summary

Many Applications Critically Rely on Meso-/Micro-scale Weather Processes

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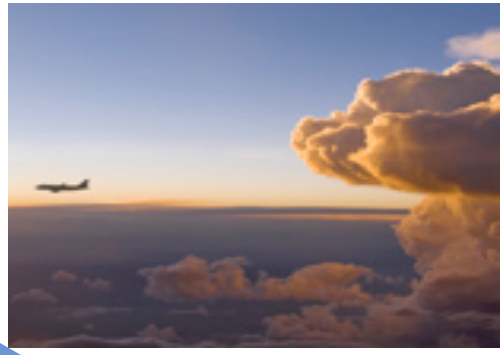

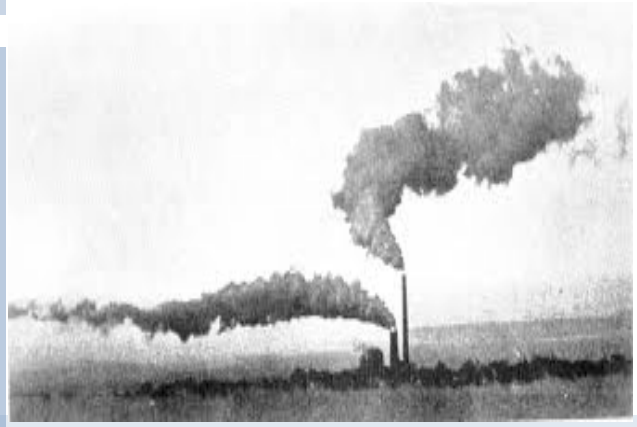

Meso-/micro-scale DA and NWP

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- Complex mesoscale processes
  - Impact of fine-res terrain, land use and land cover, soil
  - Multi-scale interactions (~1000 - 1 km)
  - With rich features and fast evolving

  (Spatiotemporal flow-dependent error co-variance is, if not critical, highly valuable.)
- Dynamic and diabatic “spin-ups”

  (Requires strong model constraints, i.e., 4DDA)
- Efficient and effective assimilation of the obs

Data Assimilation Technologies and Meso-/micro-scale Applications

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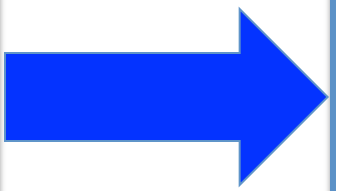
The world of data assimilation

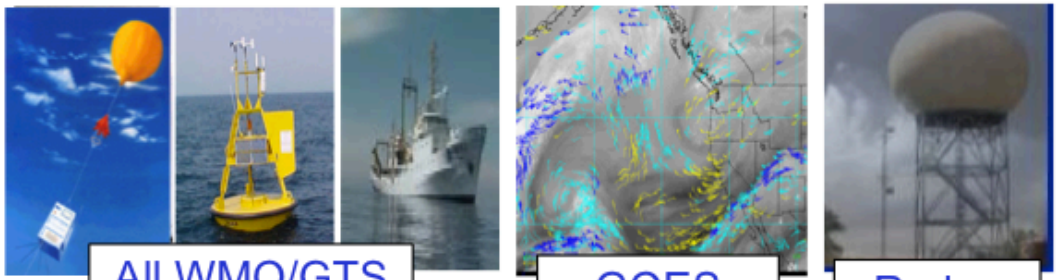
- **OA,** OI, SI
- **3DVAR**, **4DVAR**
- **FDDA** (Nudging)
- **DART** (EnKF, EaKF, Kernel Filter…)
- ETKF, **LETKF**, Smoother
- **Latent Heat Nudging**
- **Hybrid** "A", "B" …



User and application -oriented system

- Works for me!
  - → My region(s)
  - → My time scales
  - → My data
  - → My applications
- Advanced
- Uncertainties

The NCAR WRF Real-Time FDDA



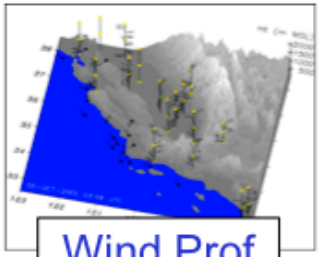
All WMO/GTS | GOES | Radars

Modified WRF/MM5:

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

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

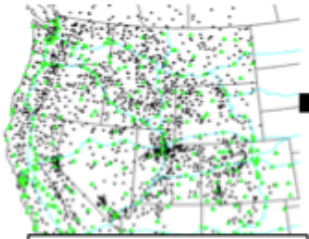
W is weight function



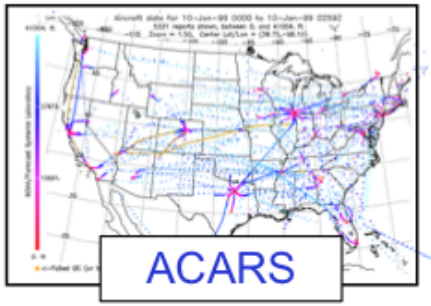
Wind Prof

RTFDDA

Regional-scale model, based on **WRF / MM5**



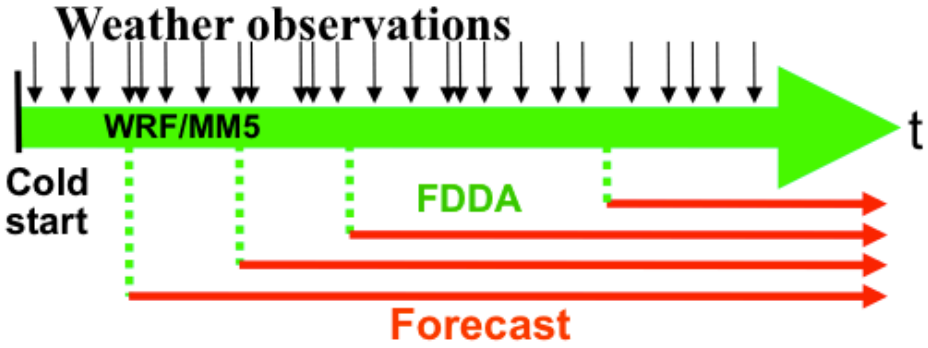
MESONETs



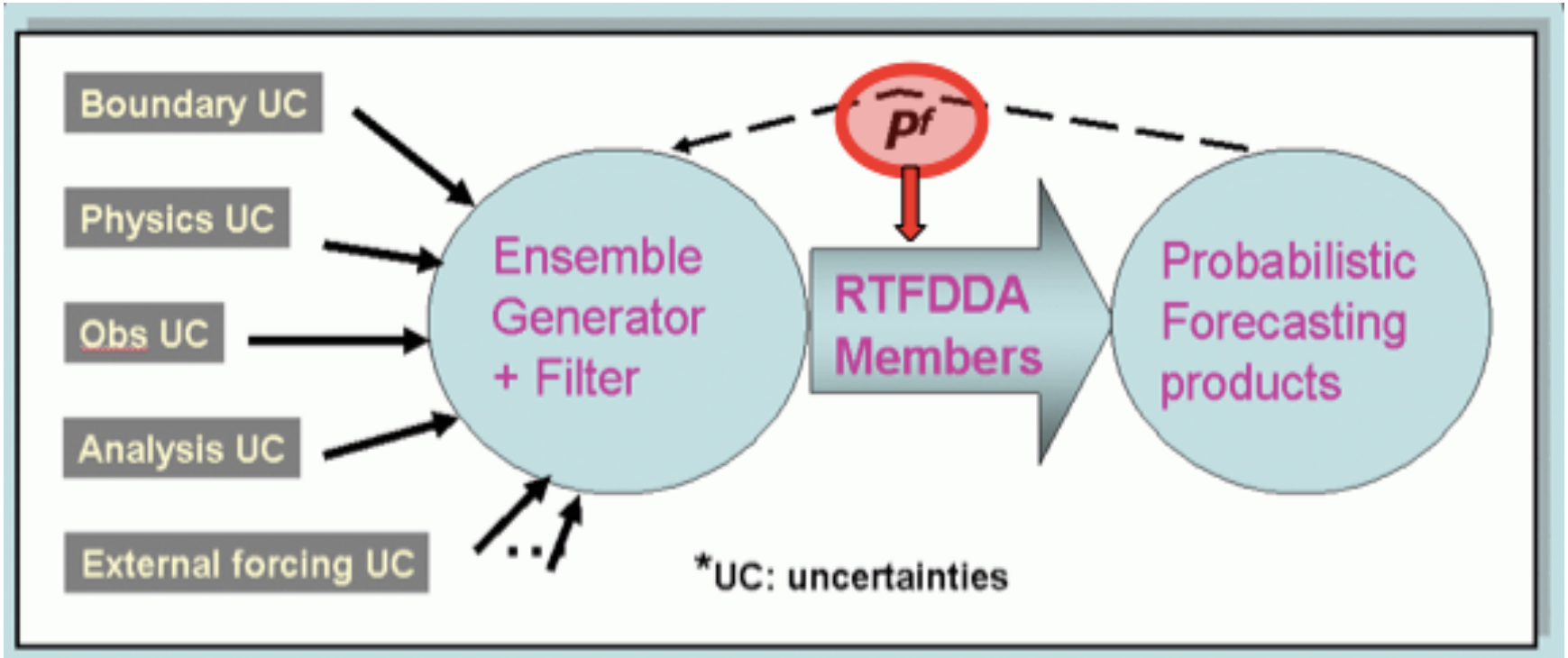
ACARS

Etc.

Farm Mets



Ensemble-RTFDDA



Multi-models: WRF-ARW, MM5, WRF-NMM
Multi-physics: PBL, LSM, MP, CUP, SW/LWRA …
Multi-ICBCs: GFS, NAM, GEM, GSM
Multi-DAs: FDDA, DART-EAKF, GSI, WRF3DVAR
Other perturbations: SKEB, obs, land properties …

4D-REKF: An Advanced FDDA

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Obs-nudging FDDA

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

WRF

Cressman Weight

$$W_{xy} = \frac{R^2 - d^2}{R^2 + d^2}$$

Nudging coefficient

Ensemble Kalman Gain

$$W_{xy,j} = K_e = P^f H^T (H P^f H^T + O)^{-1}$$

4D-REKF FDDA

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

4D-REKF: 4-D Relaxation Ensemble Kalman Filter

4D-REKF Data Flow Diagram

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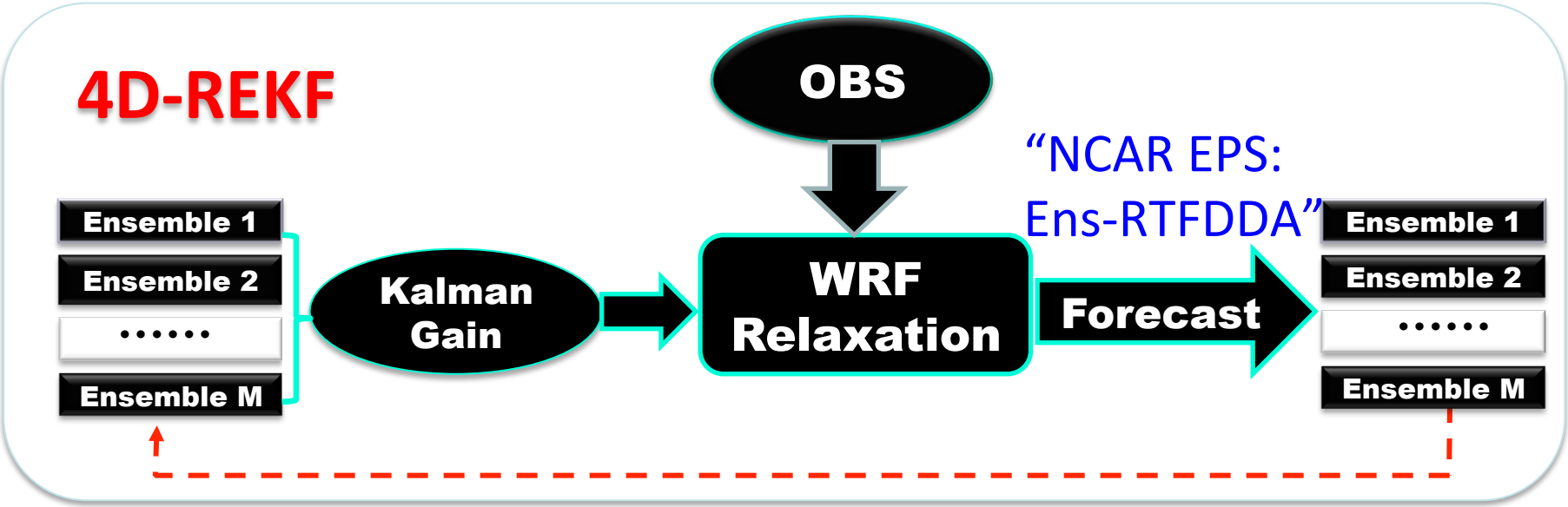

- **Note:**

✓ The filter needs to be built in the NWP (WRF) model code;

✓ Needs deal with spatiotemporal interpolation of Kalman gains;

✓ Needs run along with a "good" ensemble system

Better EPS → Better 4D-REKF, Better 4D-REKF → Better EPS

4D-REKF vs. other 3DDA and 4DDA

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3DDA		4DDA
OA: Simple empirical isotropic (distance) function	Nudging → WRF or MM5	RTFDDA
3DVAR: Historical daily(24h-12h forecast) isotropic weight function	Constraint → WRF	4DVar
ENKF: Ensemble flow-dependent anisotropic weight function	Nudging → WRF	4D-REKF

4D-REKF: 4-Dimensional Relaxation Ensemble Kalman Filter

"Perfect-Model-Perfect-Obs" EXPs

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A Cold Air Damming event in NE US	
Model	WRF and WRFDA V3.4.0
Initial Time	18Z 10 Feb 2008
Grid Number	82x92x37
Grid Size	32.4 km
Microphysics	Lin et al.
Land-Surface	Unified Noah
Longwave Rad	RRTM
Shortwave Rad	Goddard
PBL	YSU
CU Physics	Kain-Fritcsh

"P-M-P-O" Experiment Design

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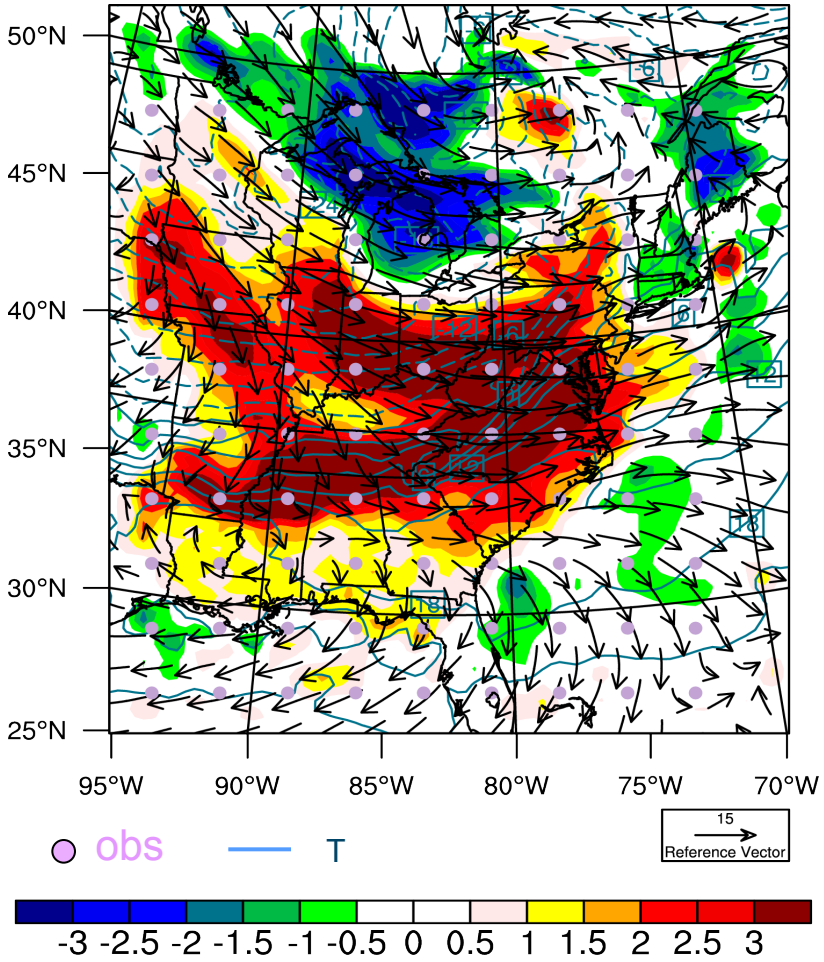
Exp	Description
TRUTH: Natural run	Nature run of unperturbed initial cond. at 18Z 10 Feb. OBS: Soundings from the Truth, hourly from 18Z 10 to 00Z 11, every 8th grid points (~260km), error-free
CTRL	Forecast from a perturbed ICs. at 18Z 10 Feb.
3DVAR	CTRL ICs + WRF 3DVAR
4DVAR	CTRL ICs + WRF 4DVAR
DART	Perturbed CTRL ICs + DART
RTFDDA	CTRL ICs + WRF RTFDDA
4D-REKF	CTRL ICs + WRF 4D-REKF



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

Data Assimilation Experiments

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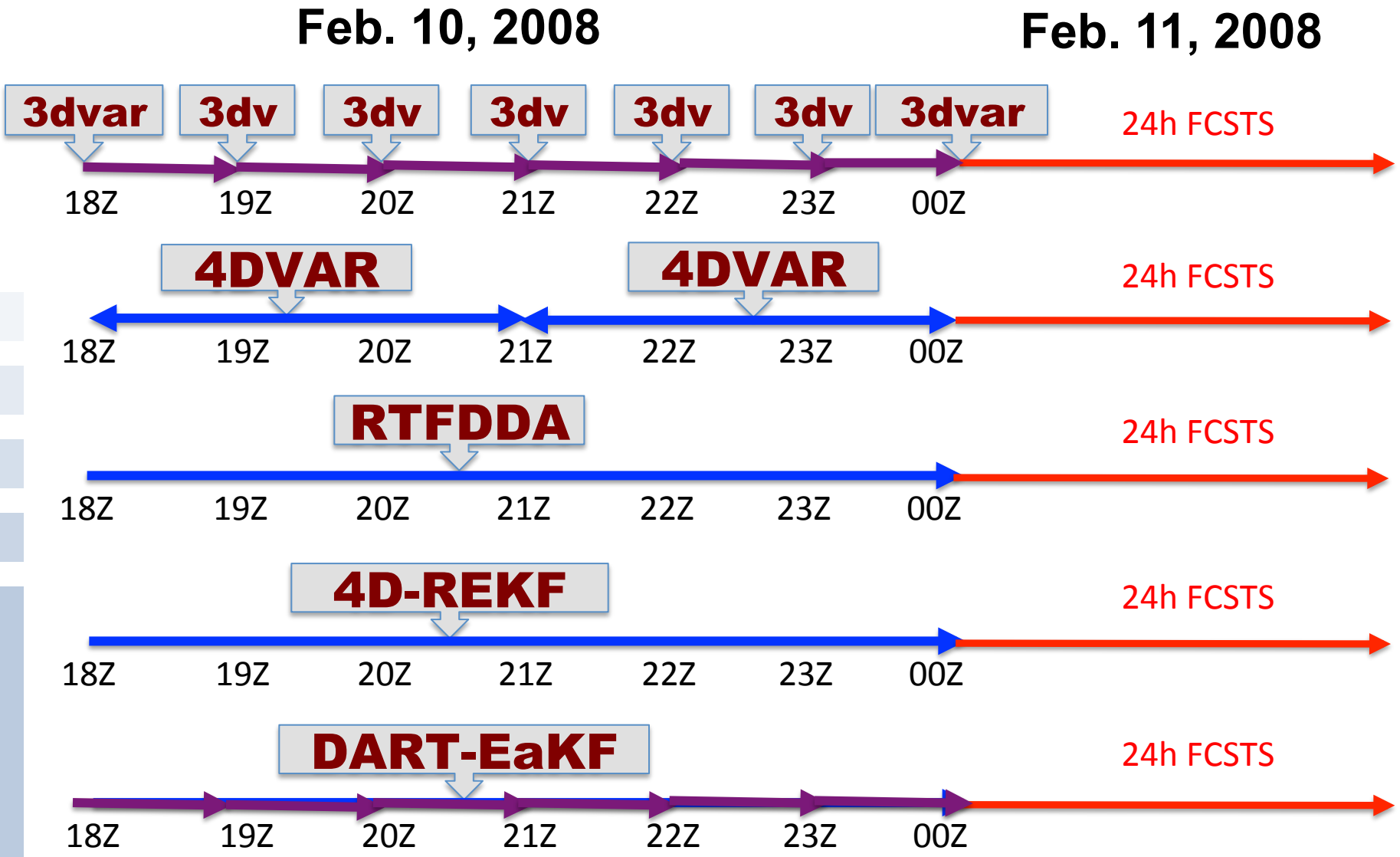
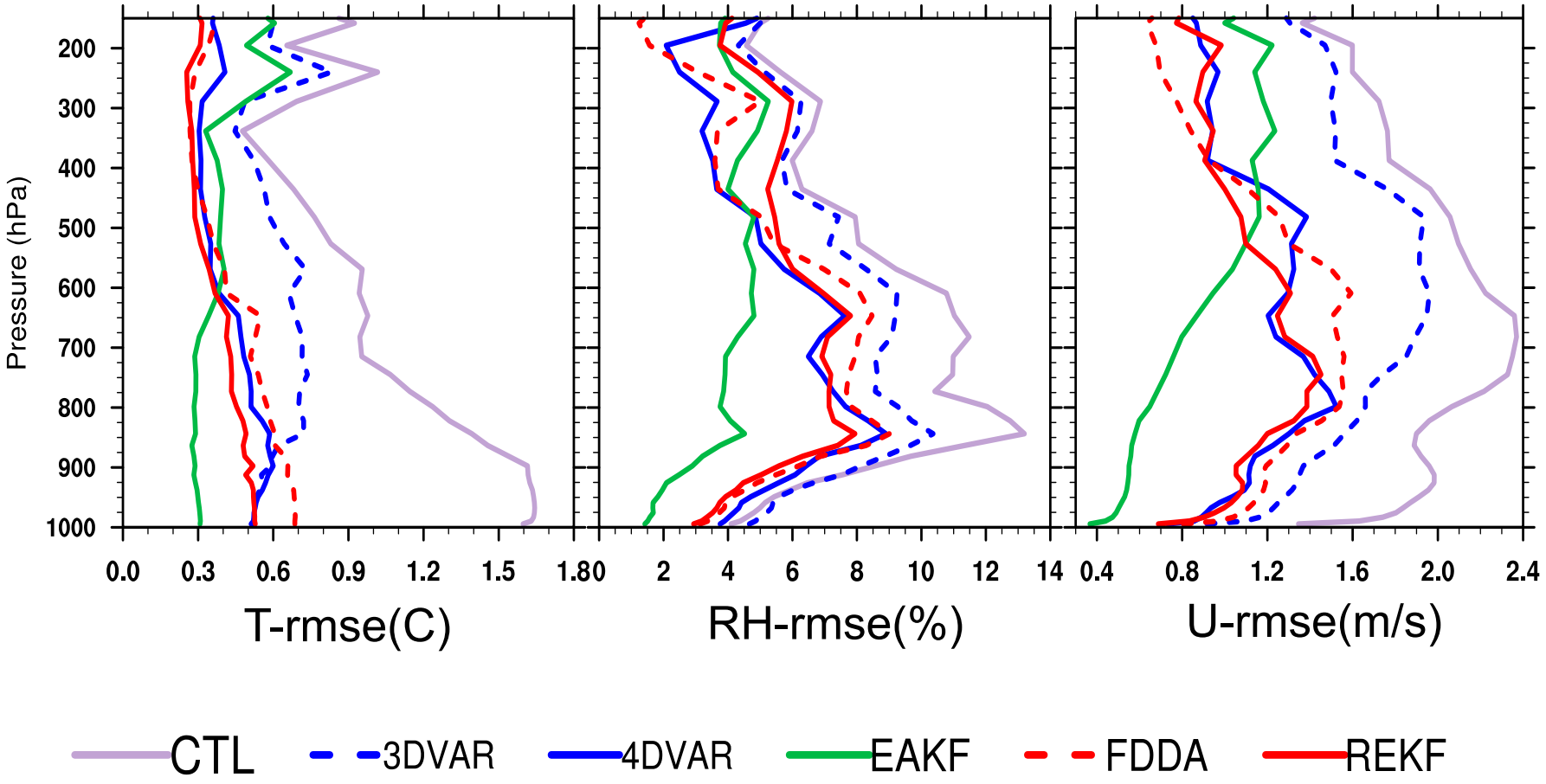
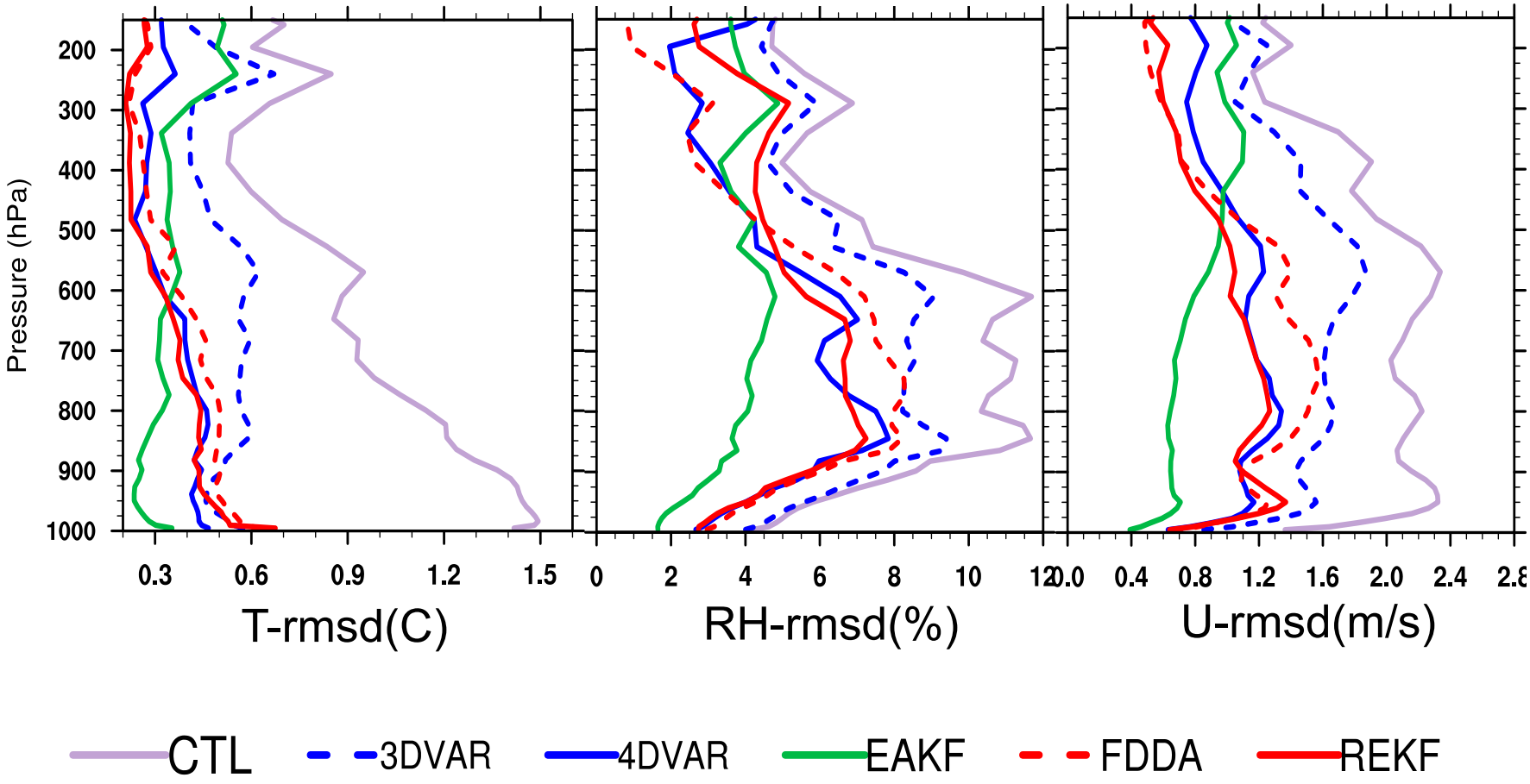


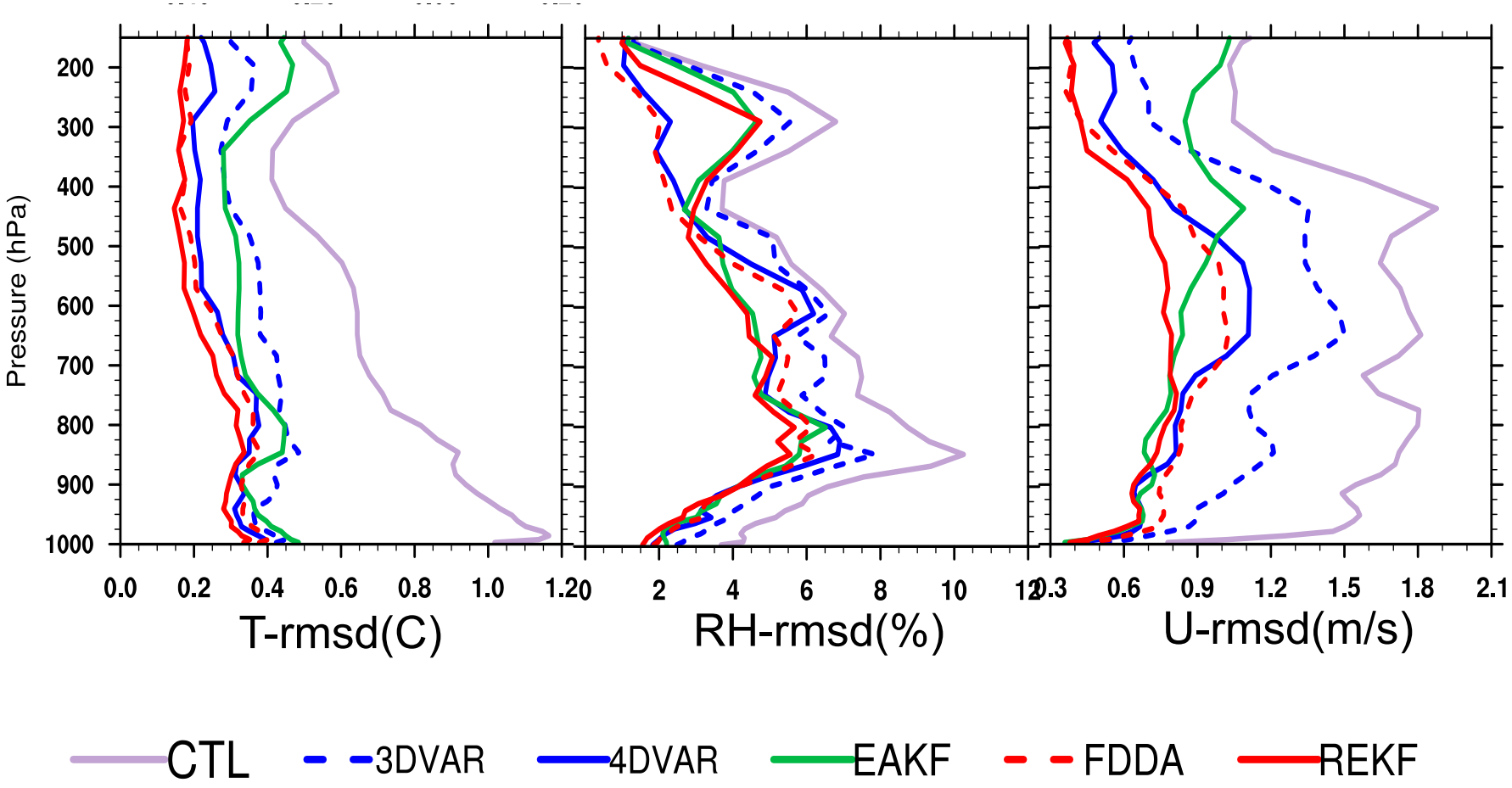
RMSD of 3h DA (-3h Forecasts; 21Z Feb. 10)



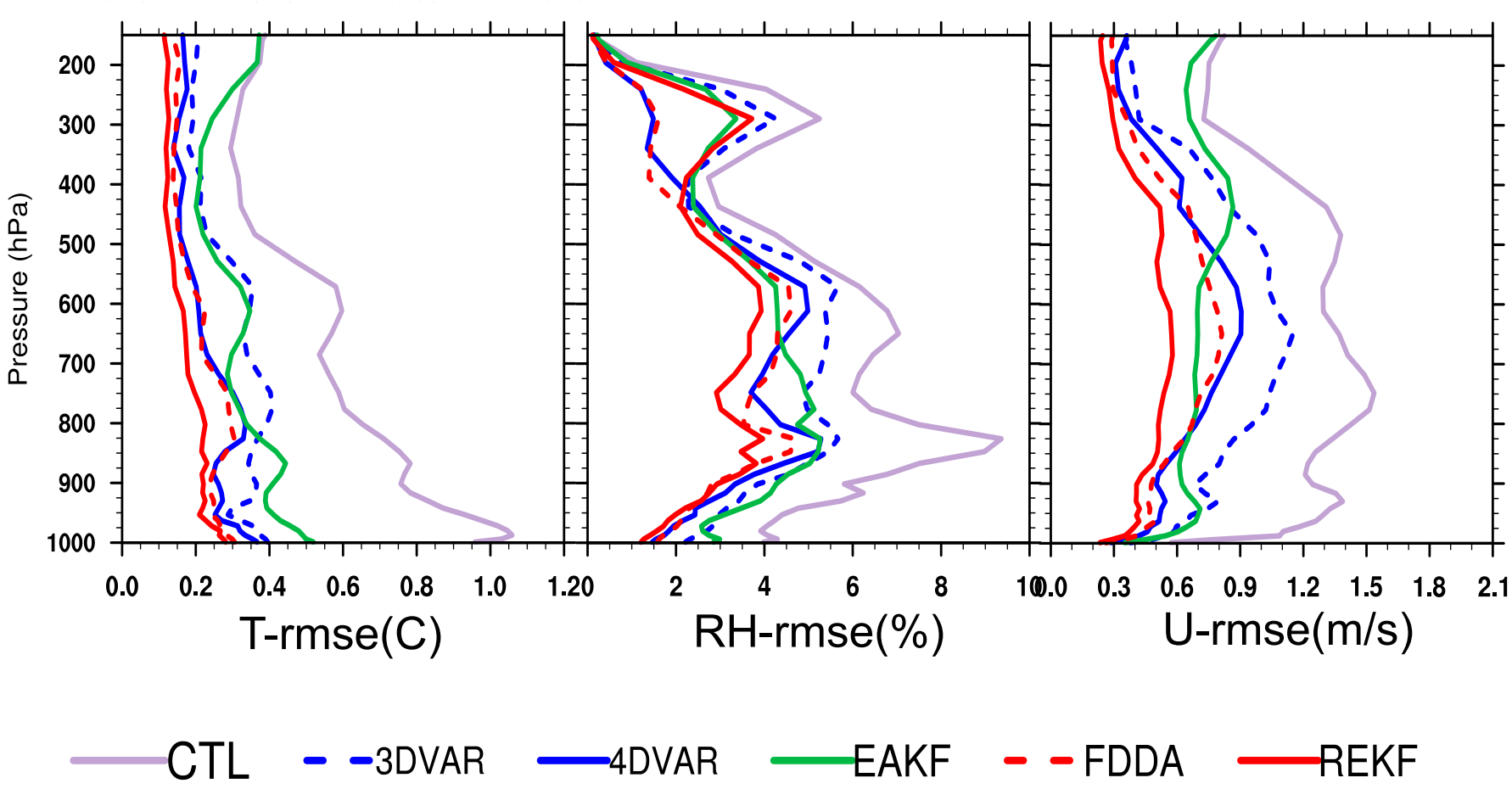
RMSD of 6h DA (0h Forecasts; 00Z Feb. 11)



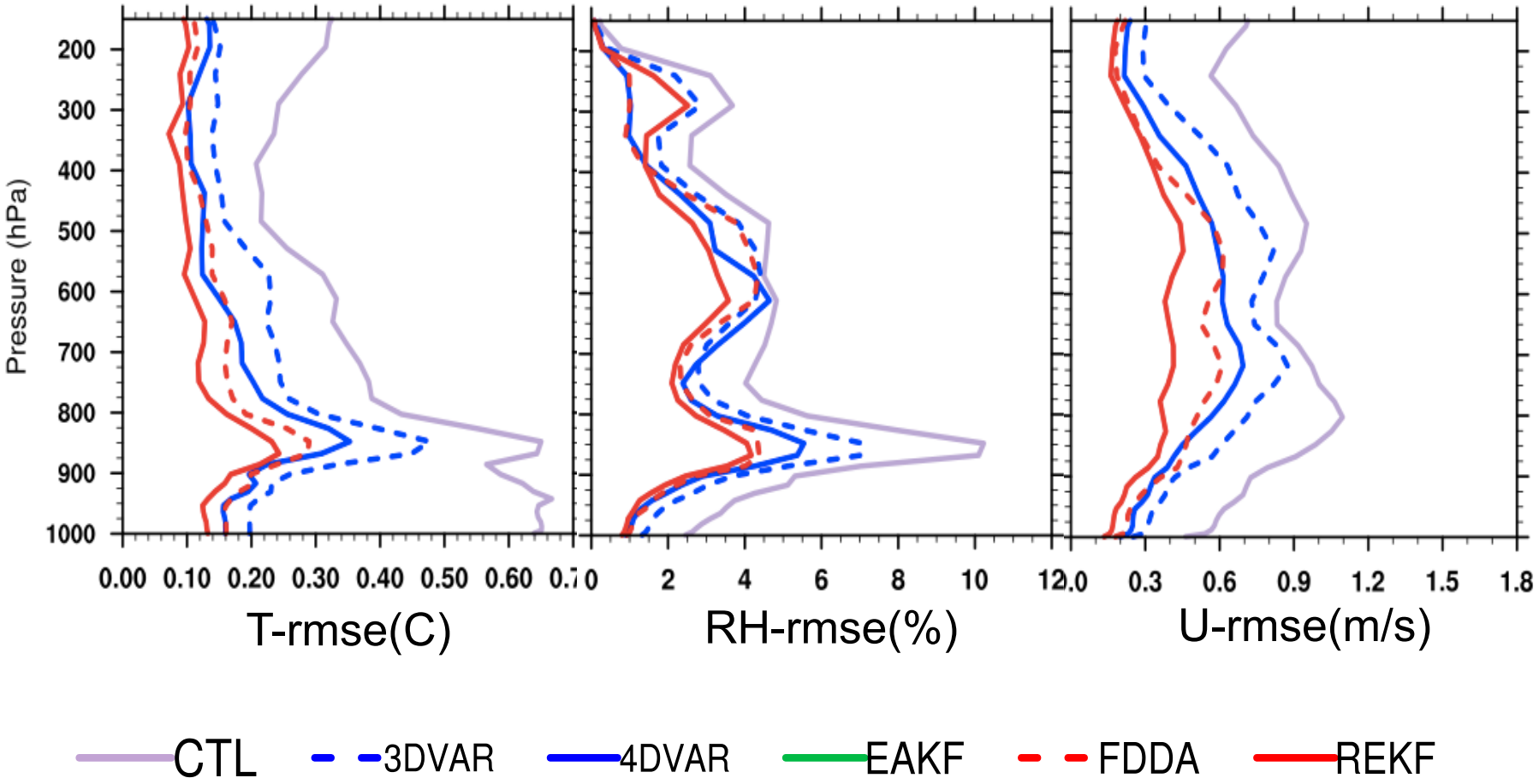
RMSE of 6h Forecasts (06Z Feb. 11)



RMSE of 12h Forecasts (12Z Feb. 11)

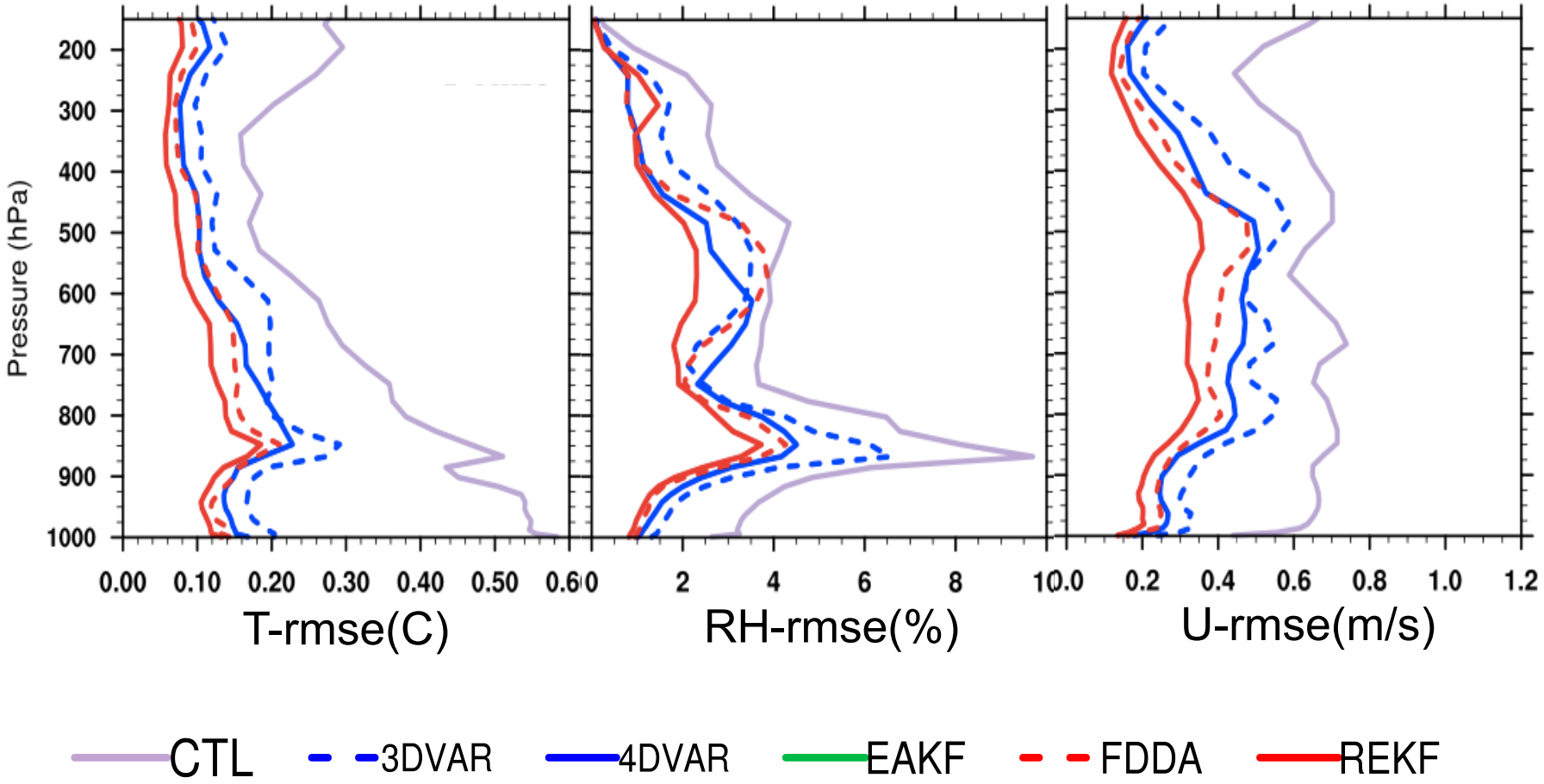


RMSE of 18h Forecasts (18Z Feb. 11)



*EAKF has trouble beyond 12h forecast; debugging

RMSE of 24h Forecasts (00Z Feb. 12)



*EAKF has trouble beyond 12h forecast; debugging

Summary

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- The NCAR 4D-REKF combines and leverages the EnKF into the NCAR E-RTFDDA system (based on WRF-ARW);
- 4D-REKF is the next-generation data assimilation for the NCAR/ RAL mesoscale applications, replacing (E-)RTFDDA. It performs both EDA and EPS in a unified system framework;
- R&D of 4D-REKF is on-going, for bug fixes, completeness, and the advanced capabilities;
- 4D-REKF was tested with a "Perfect Obs and Perfect Model" framework, and compared with RTFDDA, WRF3DVar, WRF4DVar and DART-EnKF. The results show interesting differences among the WRF data assimilation family, and expose obvious advantages of the new 4D-REKF scheme.

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Thank you!

Questions?

Variational DA

1. Generating background error matrix: use 31 ensemble members at 18Z 10 Feb, 2008.
2. Preparing observations using OBSPROC for both 3DVAR and 4DVAR.
3. 3DVAR is done every hour starting from 18Z 10 to 00Z 11, in between an hour fcst is done, and the output is used as background for next assimilation. The main parameters in the namelist.input are
   cv_options = 5, (using self generated Be)
   var_scaling = 1.00, (scaling factor to the covariance in Be, tried from 0.1 to 5.)
   len_scaling = 1.00, (lenth scaling is for generating the modes of BE, tried from 0.1 to 2)
   rf_passes = 6,
   check_max_iv = false, (don't check the obs data)
   num_max = 80 (maximum of minimization iteration)
   eps = 0.005 (stop when the gradient ratio of cost function reach it)
4. 4DVAR is done in 2 cycles, each cycle the assimilation window is 3 hour. The first cycle starts from 18Z to 21Z of 10th Feb 2008, and the second cycle from 21Z 10th to 00Z 11th . The main parameters applied in 4DVAR are as follows
   var4d_lbc = true (update the lbc)
   var_scaling = 5.00, (scaling factor to the covariance in Be, tried from 0.1 to 5.)
   len_scaling = 1.00, (lenth scaling is for generating the modes of BE, tried from
   check_max_iv = false (reject the obs if OMB/obs_error)> max_error
   max_ext_iters=2, max_num = 40, eps = 0.005

DART setting

- Assimilation period 1hr
- EaKF filter
- Fixed inflation: 2.5 (tried with 1.02, 2, 3 and adaptive inflation)
- Cut off: 0.05 radius (~320km)
- 30 members