Updates and New Developments of WRF "Obs-nudging" FDDA and Operational Applications

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Acknowledgements: RTFDDA development team, users, and our collaborators including ATEC, DTRA, AirDat, Gov. of Israel, Xcel Energy and other agencies.

(11th WRF Users Workshop, 22 - 24 June 2010, Boulder, CO)

Outline

NCAR

1. Obs-nudging Updates in WRF v3.2
2. WRF RTFDDA, Ensemble RTFDDA and Real-time Operational Applications
3. Roadmap Advancing Obs-nudging
4. Continue Incremental Enhancements
5. Toward Nex-Gen Advanced Capability

1. Obs-nudging Updates in WRF v3.2

- NCAR RAL leads the “obs-nudging” in WRF-ARW, sponsored by the US Army.
- In the last 2.5 years, DTRA sponsored NCAR and Penn State to validate and enhance “analysis nudging” (PSU) and “obs-nudging” FDDA in WRF.
- Paper 2.3 (Tue. Morning) has covered the new upgrades of both nudging schemes in WRF v3.2.
- This talk will focus on “obs-nudging”-based RTFDDA applications and the new developments.

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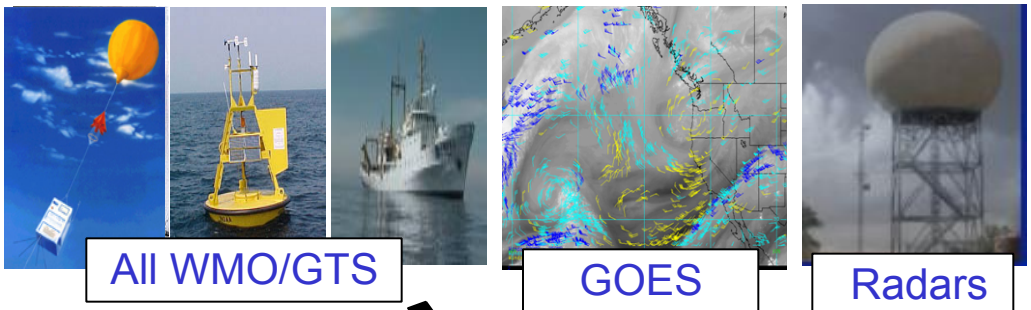
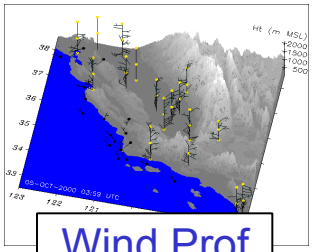
RTFDDA: Cycling 4DDA and Forecasting



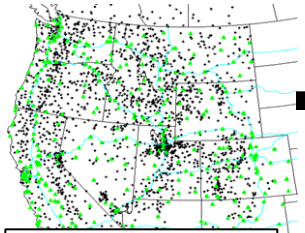
All WMO/GTS

GOES

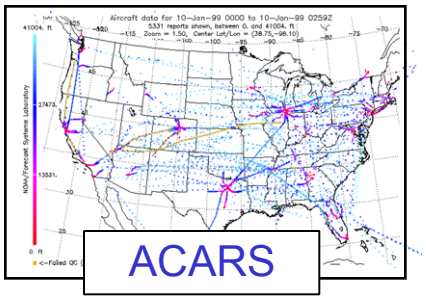
Radars



Wind Prof

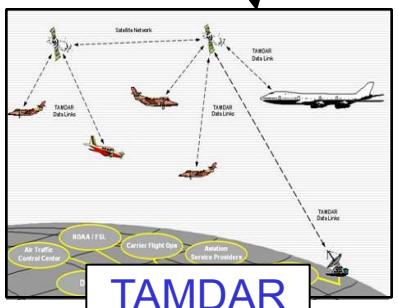


MESONETs



ACARS

Etc.



TAMDAR

RTFDDA

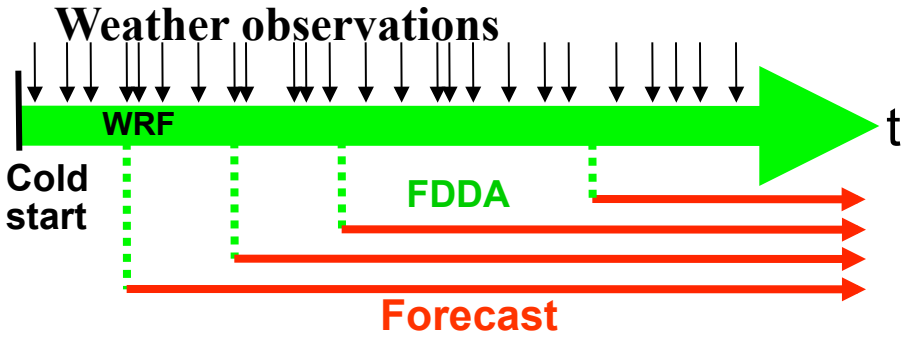
Regional-scale model, based on **WRF**

Obs-nudging FDDA:

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

where x = T, U, V, Q, P1, P2 …

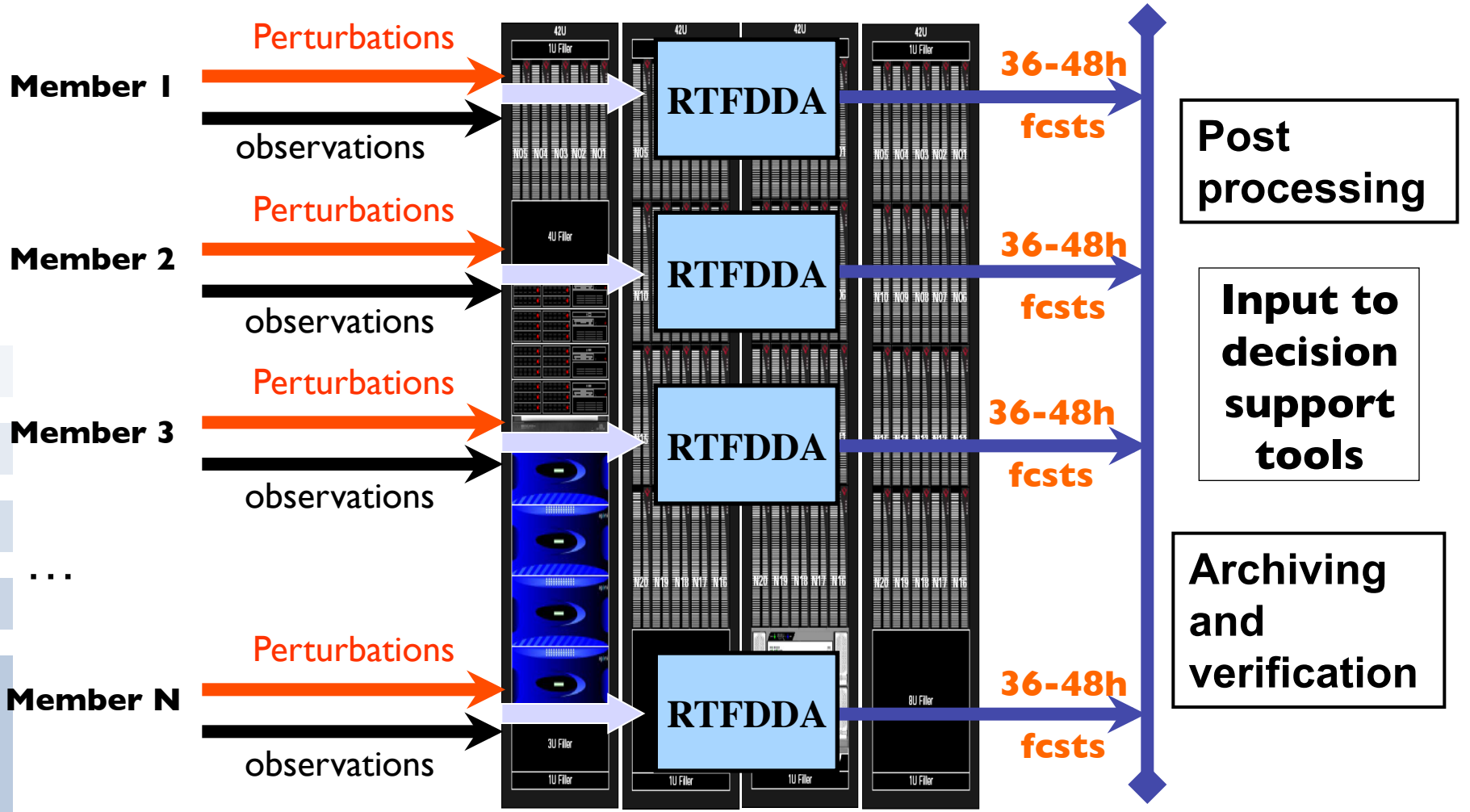
W is weight function



Obs-nudging Properties:

- ✓ *4DDA: $W = W_t \times W_h \times W_v \times W_{qc}$*
- ✓ *Tolerance to suboptimal B, R*
- ✓ *DA by state synchronization*
- ✓ *Extendable with new DA techs*

Ensemble-RTFDDA



N forecasting nodes **x spare nodes** M pre/post- proc nodes

Example: 30 Member Xcel E-RTFDDA

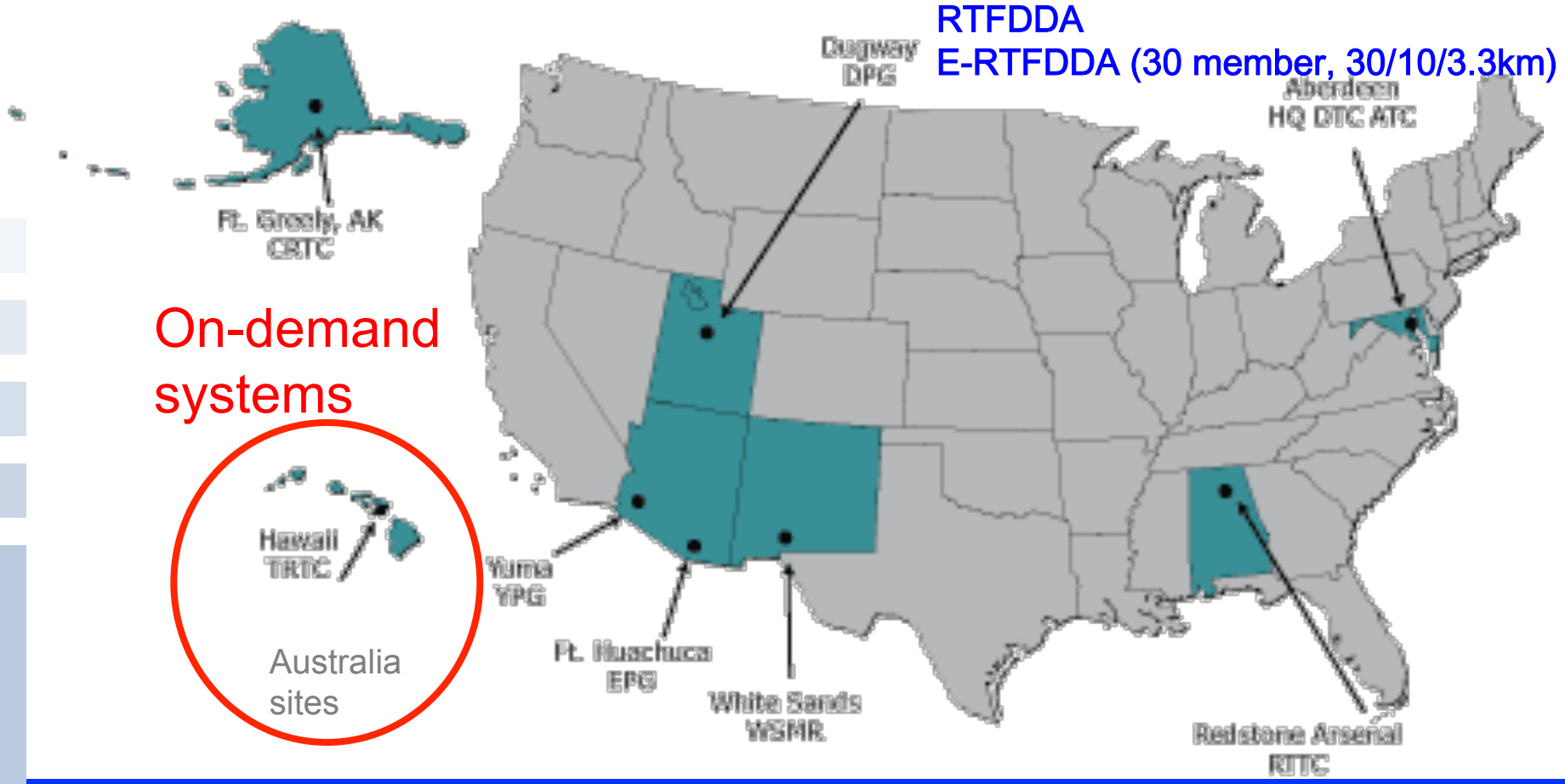
30 members, 30/10 km Doms, 6h cycles, 72h fcsts

E#	LBC	WRF Members (15)
1	NAM	Control: WRF baseline physics
2	GFS	Control: WRF baseline physics
3	NAM	RUC PBL + Thompson MP
4	NAM	MYJ PBL
5	NAM	QNSE PBL
6	NAM	WMS6 microphysics
7	NAM	Goddard Radiation
8	GFS	BouLac PBL
9	GFS	MYNN2.5 PBL
10	GFS	Betts-Millar CUP
11	GFS	Slope effect radiation
12	GFS	BMJ cumulus
13	GFS	CAM radiation
14	NAM	Morrison MP
15	GFS	Thompson MP

E#	LBC	MM5 Members (15)
16	NAM	Control: MM5 baseline physics
17	GFS	Control: MM5 baseline physics
18	NAM	Simple cloud-effect radiation
19	NAM	ETA TKE PBL
20	NAM	Kain-Fritsch cumulus
21	NAM	Goddard microphysics
22	GFS	Betts-Miller cumulus
23	GFS	Reisner 3-ice microphysics
24	GFS	CCM2 radiation
25	GFS	GFS LBC Phase-uncertainty 1
26	GFS	Symmetric perturb to Member 25
27	NAM	NAM LBC Phase-uncertainty 1
28	NAM	Symmetric perturb. to Member 27
29	GFS	Surface/sounding perturbation
30	GFS	Symmetric perturb. to Member 29

Operational RTFDDA Systems

8 systems for seven Army test ranges



DPG E-RTFDDA: https://dpg-ingest.dpg.army.mil/images/ens/

Operational RTFDDA System

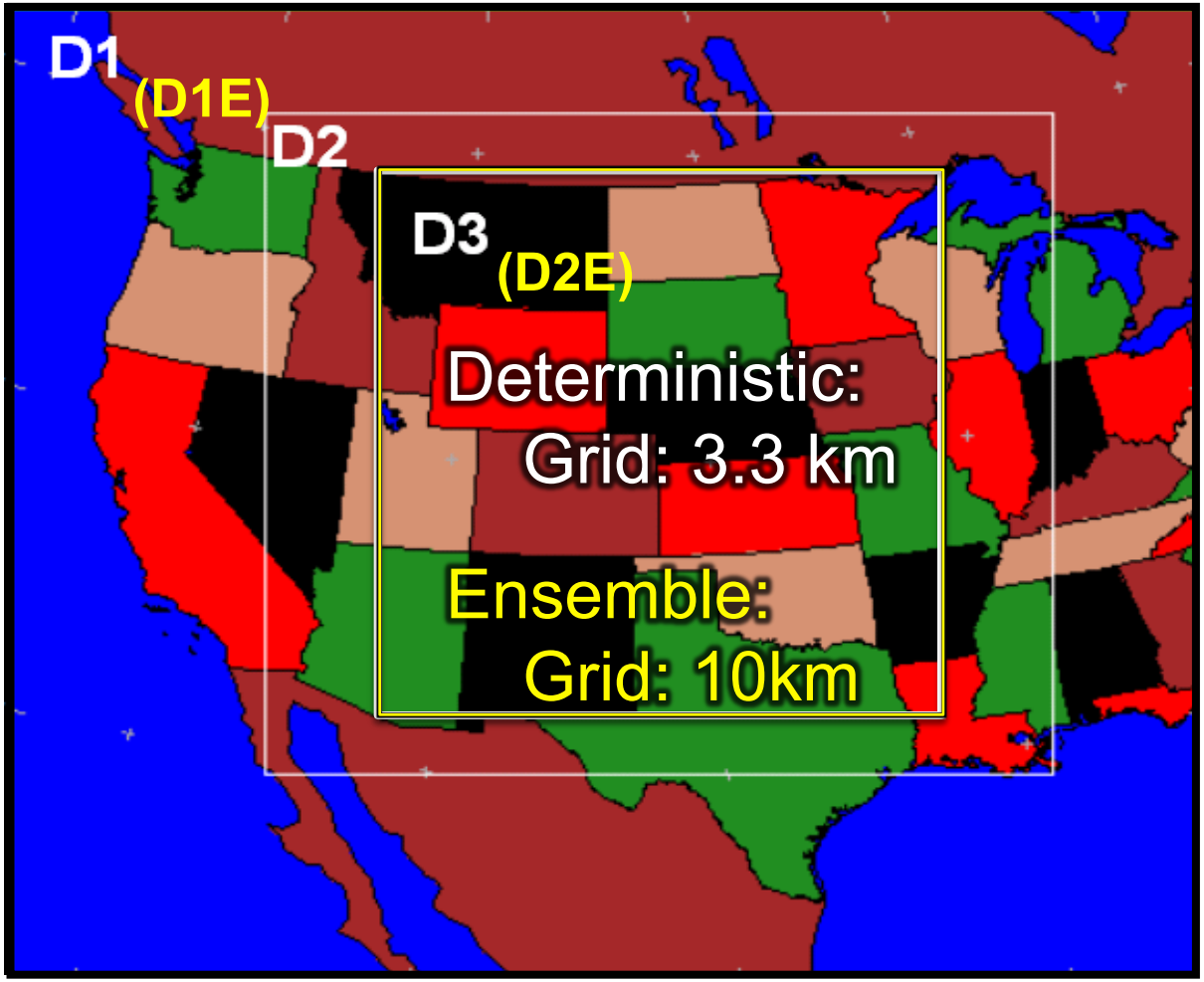
Wind energy forecasting for Xcel Energy

RTFDDA Deterministic Prediction:

- 3h update cycles
- 24-72h forecasts
- 15min to 1h outputs

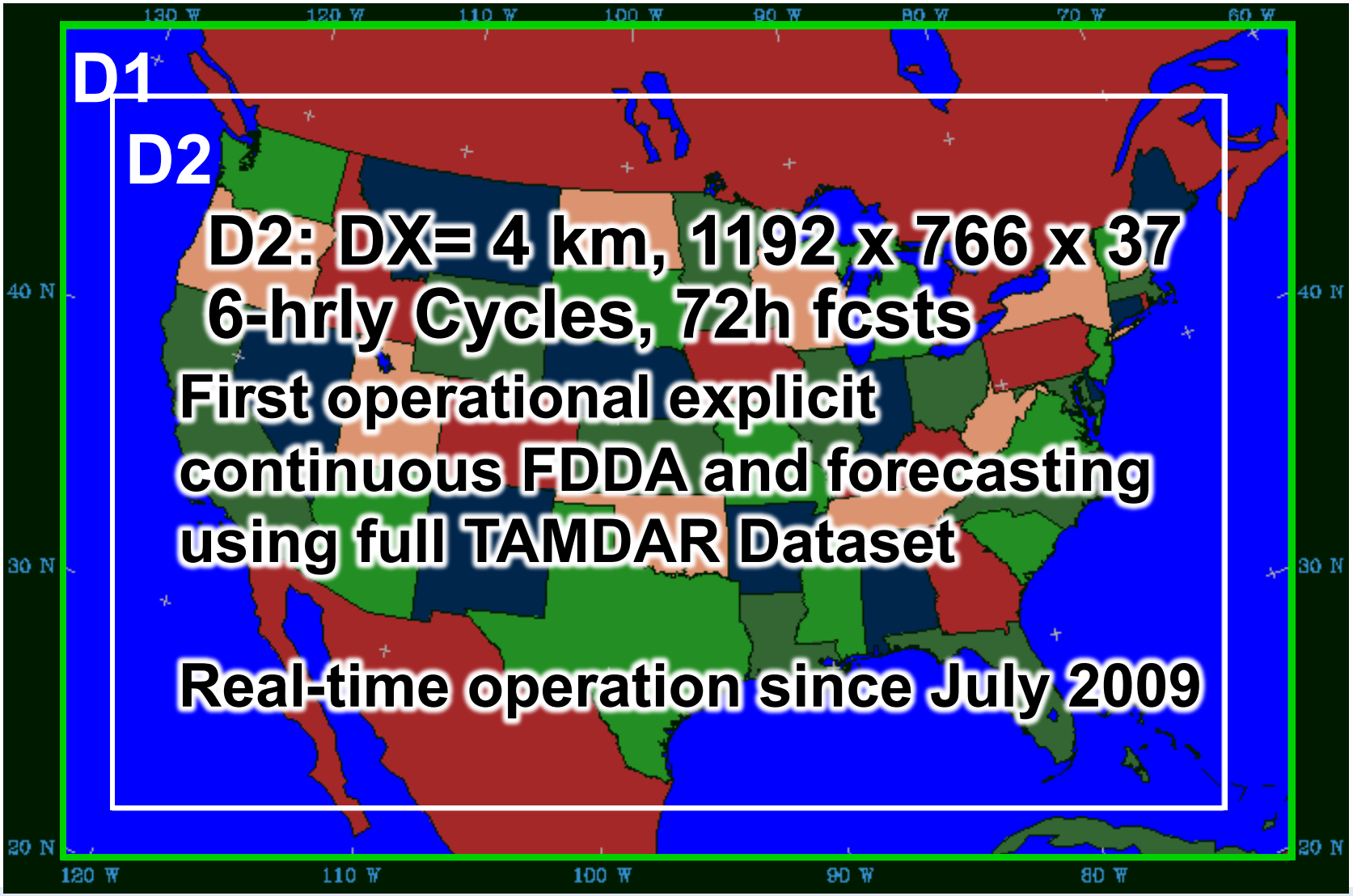
30 member E-RTFDDA Probabilistic Prediction:

- 6h update cycles
- 72h forecasts
- 1h outputs



Operational RTFDDA Systems

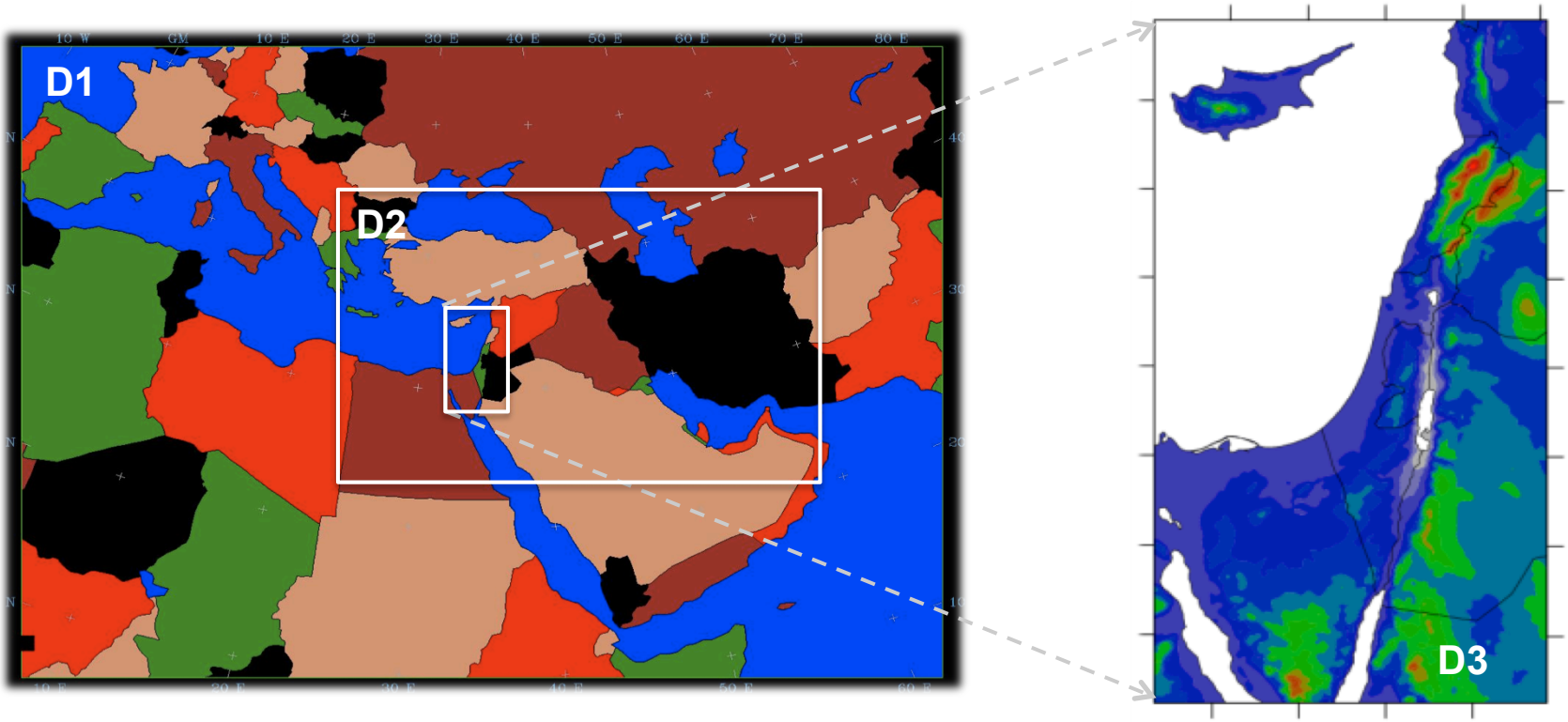
AirDat 12/4km CONUS RTFDDA System



Real-time Operational RTFDDA Systems

30/10/4km RTFDDA for Government of Israel

Real-time semi-operational since June 2009



Real-time Operational RTFDDA Systems

More Operational RTFDDA systems

- "Pentagon shield" – Homeland Security
- New York – Support T&D forecast
- Saudi Arabia Weather Modification
- Wyoming Weather Modification
- DOT Mixon-Hill Road Weather Forecasting

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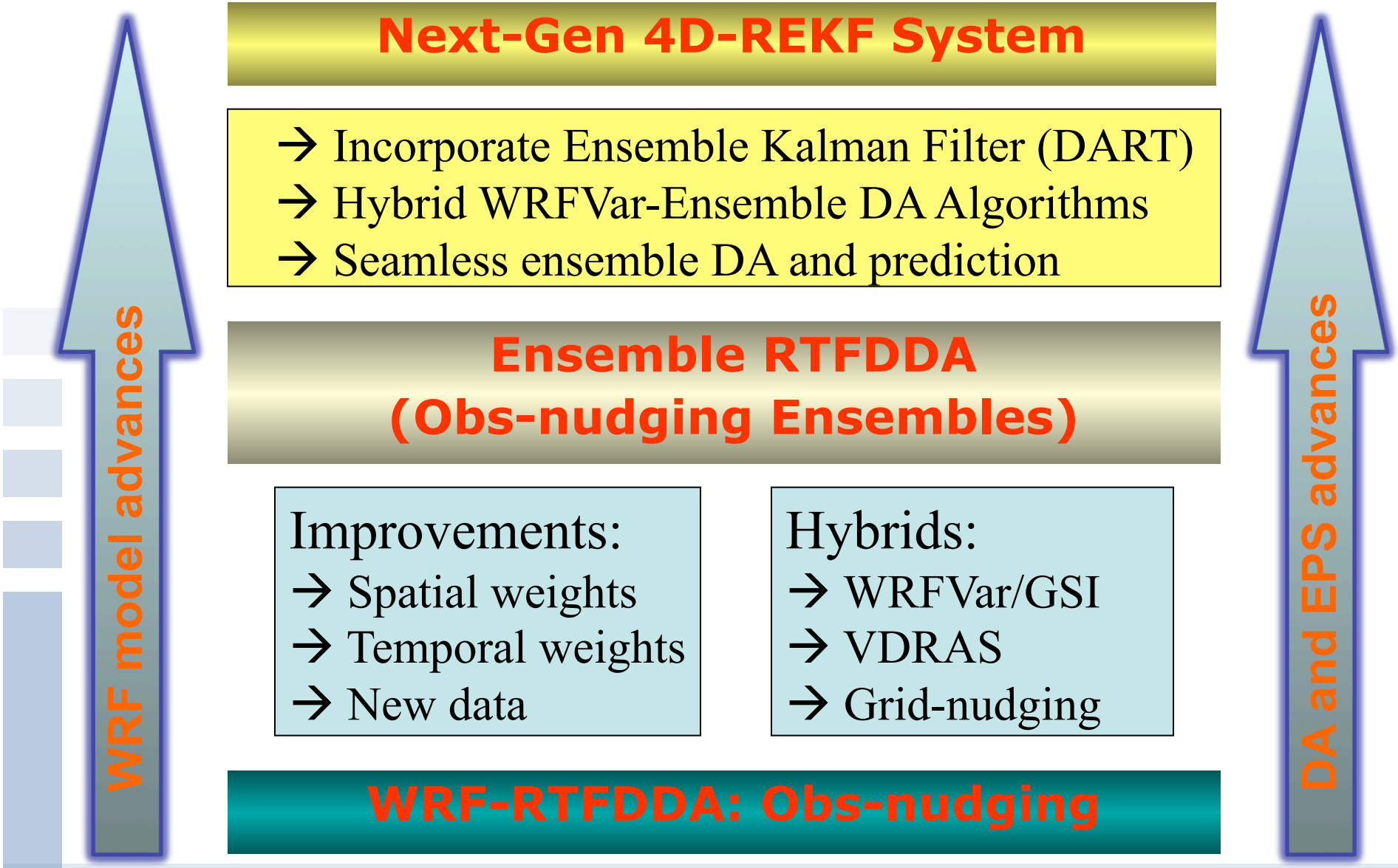
Roadmap Toward Advanced RTFDDA



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New "Obs-nudging" Capability Planned for WRF V3.3

- "Properly" assimilate observations with an existence of displacement of model terrain and observation station elevation

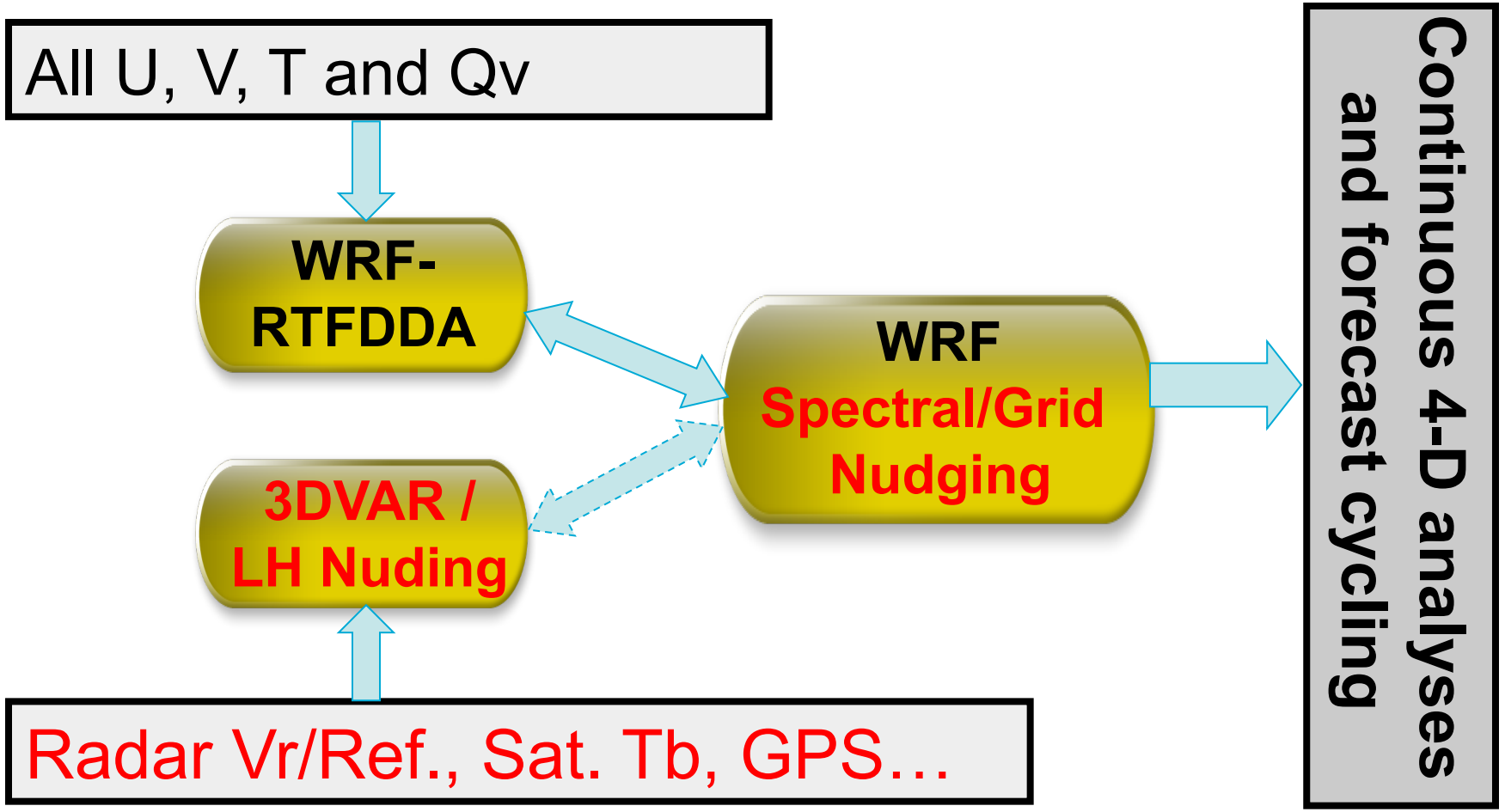
  (*A fundamental issue?!*)

- New obs, new assimilation approaches

  (e.g. Wind farm data: Speed only?)

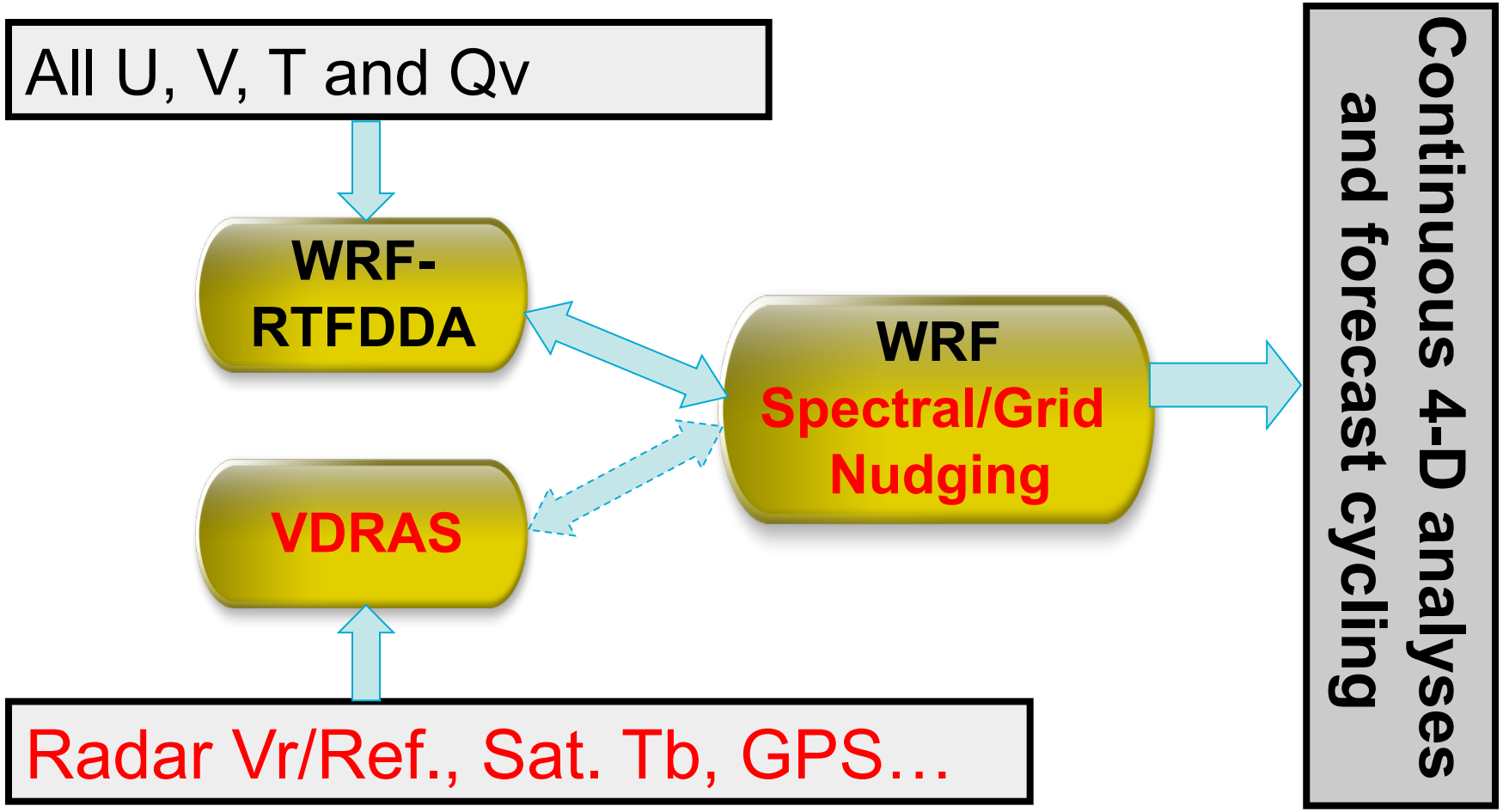
- Platform-dependent temporal/spatial/bogus weighting function

Bring Non-conventional Obs into RTFDDA with RTFDDA-WRFVar Hybrid DA



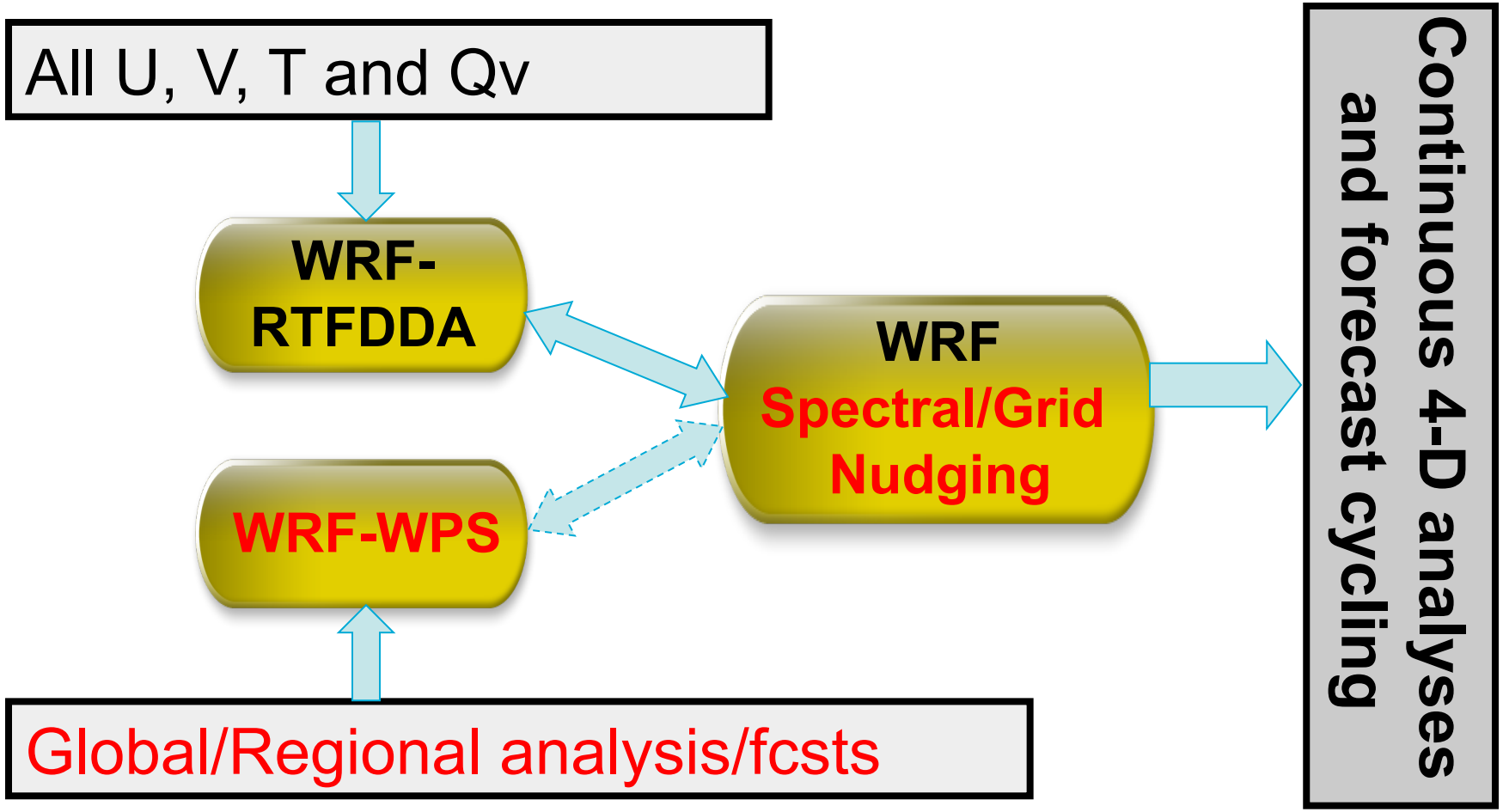
Incorporate 3DVAR capability to assimilate indirect measurements of radars, satellite, etc

Bring Non-conventional Obs into RTFDDA with RTFDDA-VDRAS Hybrid DA



Incorporating RAL nowcasting technologies to enhance RTFDDA nowcasting capabilities

Bring Non-conventional Obs into RTFDDA by Incorporating Other Analyses



Relax toward any other good global or regional analysis that makes use of more data than RTFDDA

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5.1 "Seamless" EDA and EPS system

5.2 4D-REKF: a seamless obs-nudging - EnKF hybrid

5.1 “Seamless” EDA and EPS

The NCAR Ensemble Real-Time Four-Dimensional Data Assimilation (E-RTFDDA) and forecasting system

+

The NCAR Data Assimilation Research Testbed (DART) EnKF tools

=

E-RTFDDA-EnKF

(A “seamless” EnKF DA and EPS system)

Ensemble DA versus Prediction

- **Even though not well recognized by many, EDA and EPS development diverge. Typically,**
  - An ensemble for EDA is not well formulated for probabilistic prediction
  - An ensemble for EPS does not contain ensemble DA components
  - "Best-analysis" of Kalman Filter is not used
- **Recent studies show benefit of integrating physics perturbations for EnKF**

Theoretically, both EDA and EPS are built on the same foundation: both rely on an ensemble (forecast) that can properly estimate PDF

Modeling Experiments

4 EXPs (5 day long)

Ensemble size: 30

Forecast model: WRF-ARW

B.C.s: GFS and NAM

Observations assimilated:

Radiosondes, ACARS, Satellite cloud drifting winds, Wind profilers, various SFC data including mesonets

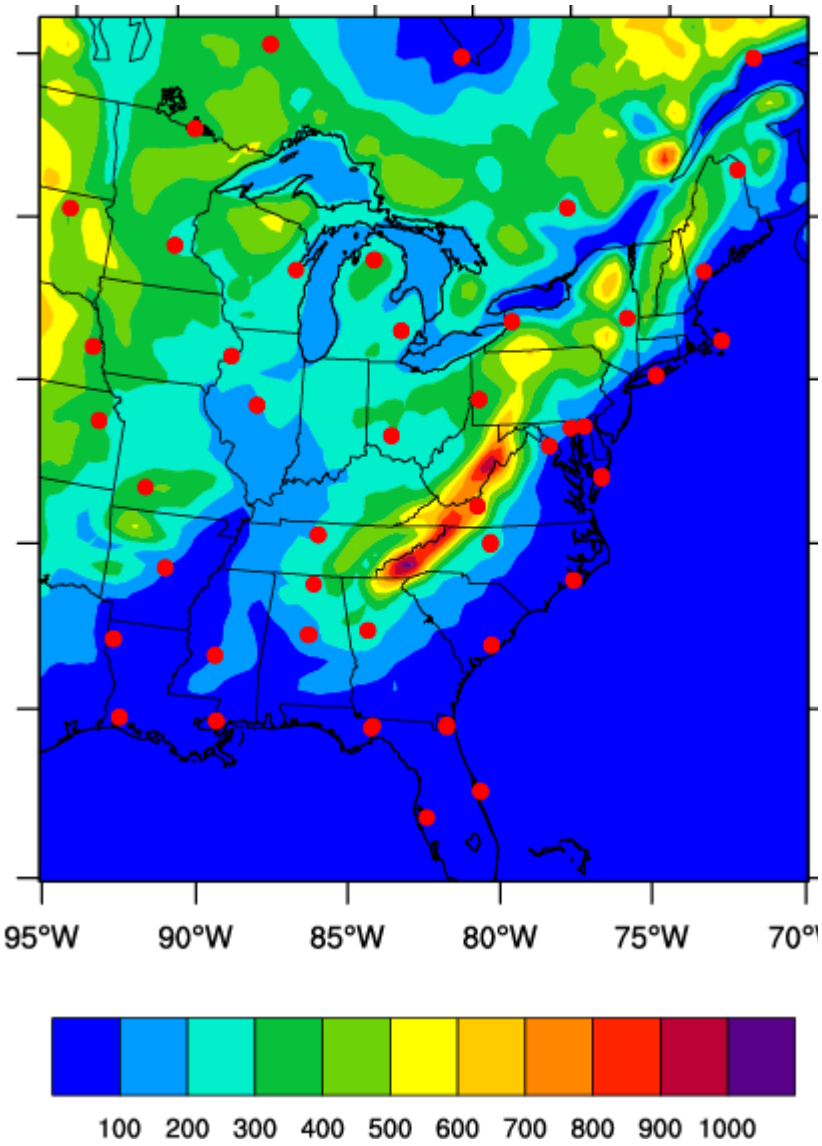
(U,V, T only; not q)

EaKF Filter:

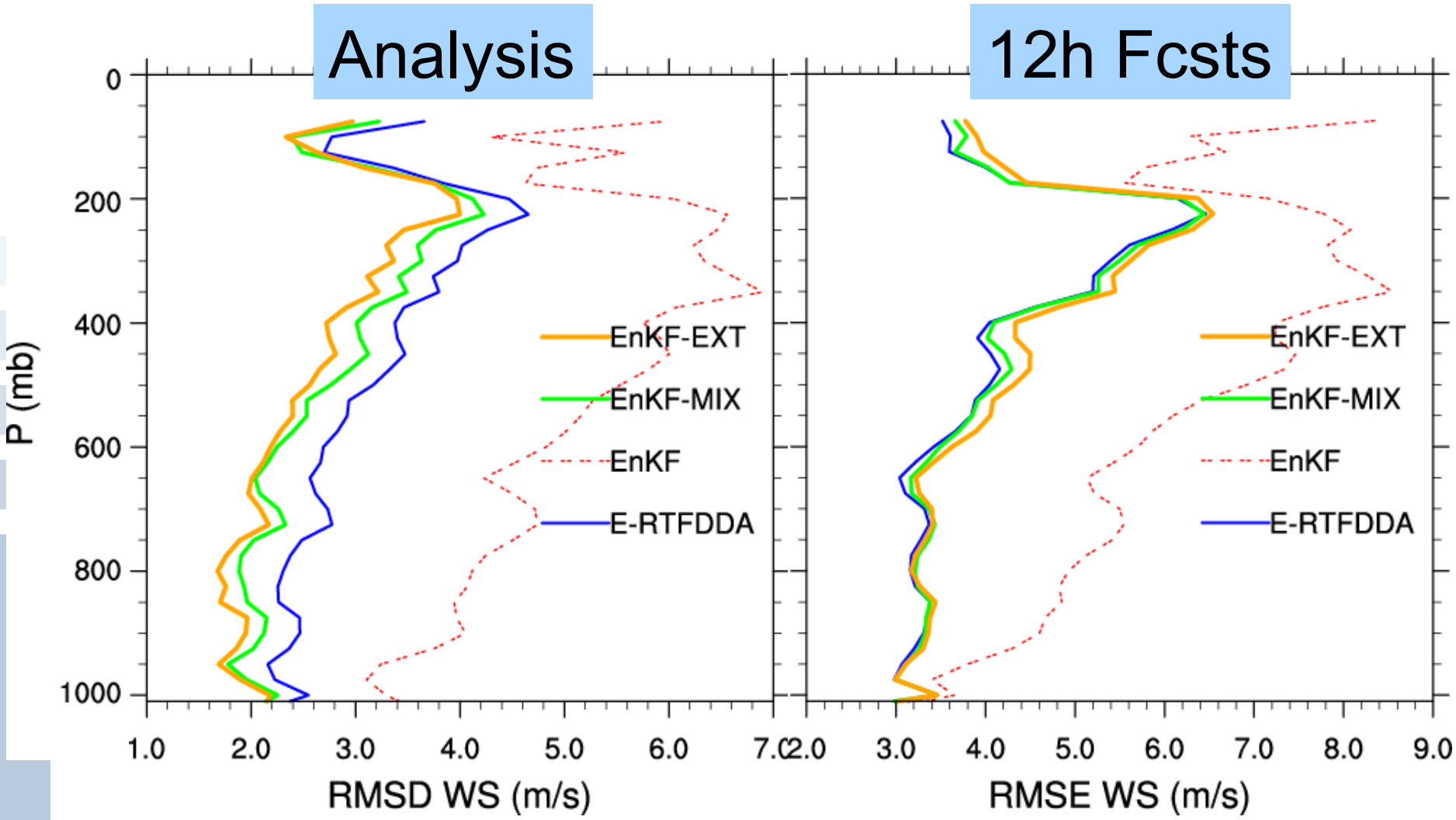
Assimilation period: 1 hr

Fixed inflation: 1.02

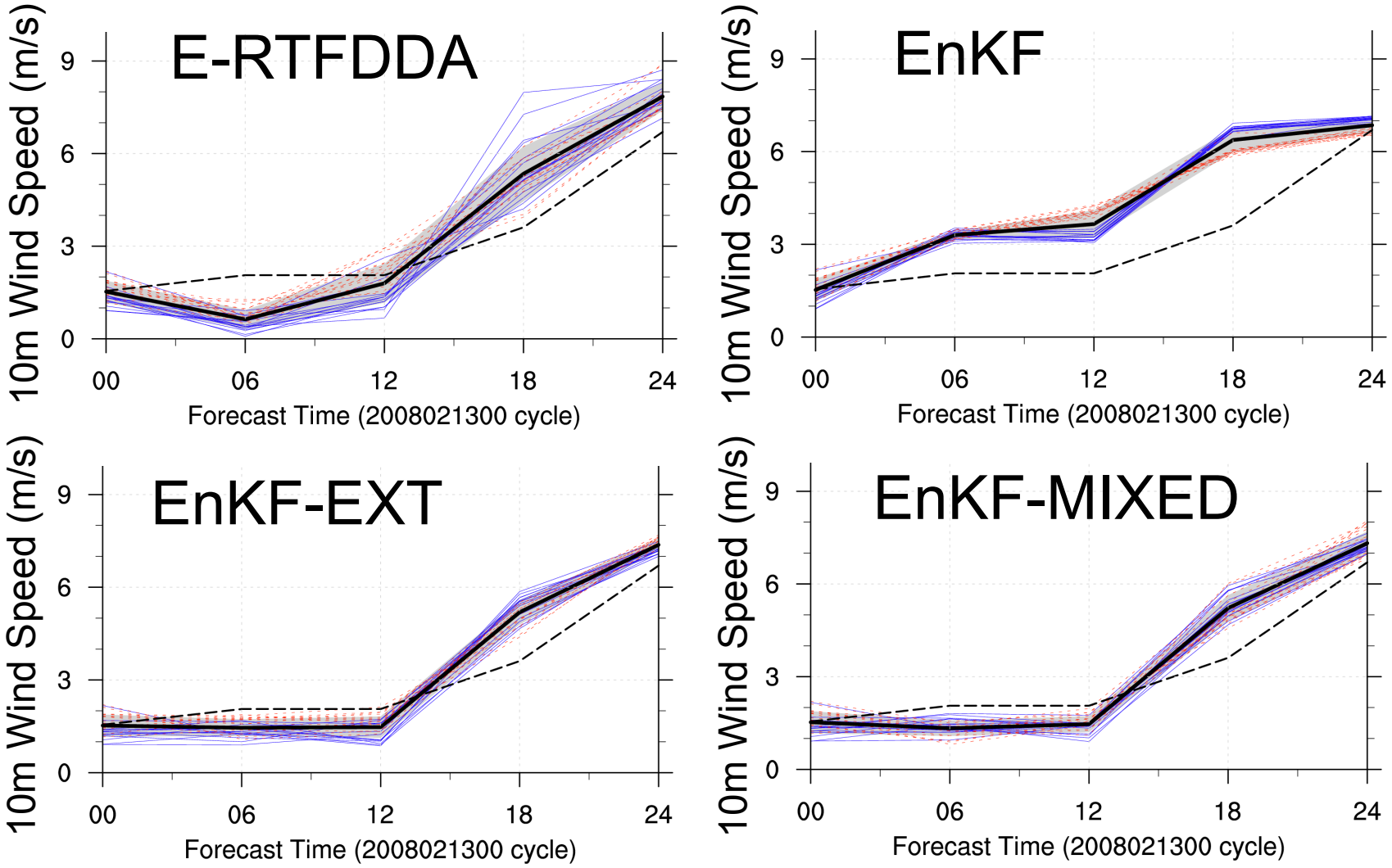
Cutoff: 0.05 radius (~320 km)



Results: Comparison with 45 radiosondes
Wind speed errors averaged for 4-day cycles



Comparison of Wind Speed at IAD



5.2 4D-REKF: Four Dimensional Relaxation Ensemble Kalman Filter

- Combine E-RTFDDA obs-nudging and EnKF
  - E-RTFDDA → Error Covariance → Kalman Gain
  - Kalman Gain → Obs-nudging → (E-)RTFDDA
  - It brings EDA Kalman Gain into WRF equations, not I.Cs.

- 4D-REKF inherits advantages of EnKF and FDDA
  - A complete Seamless EDA + EPS technology
  - A 4DDA algorithm producing "spun-up" I.C.s for NWP
  - Indirect observations can be assimilated
  - Capable of incorporating new EDA/EPS advances

Theory of 4D-REKF

Obs-nudging:

$Dx/Dt = ... + G\,W\,(y^o - Hx^f)$

$W = W_q\,W_{time}\,W_{horizontal}\,W_{vertical}$

EnKF:

$$x^a = x^f + Ke(y^o - Hx^f)$$

$$Ke = P_e^f H^T (H P_e^f H^T + R)^{-1}$$

$$P^a = (I - KH) P_e^f$$

Obs-nudging → EnKF:

$X^a = X^f + DtGW\,(y^o - Hx^f)$ ← one Dt nudging

where $X^f = X_{t-1} + Dt\,(...)$

EnKF: $DtGW = K_e$ ← EnKF

4D-REKF: $DtGW = G\,W_q W_{time}\,K_e$ ← Nudging-EnKF

$$Dx/Dt = ... + GW_q W_{time} K_e\,(y^o - Hx_{model})$$

Summary

NCAR

- New features of “Obs-nudging” has been added to WRF v3.2
- At present ~20 WRF “Obs-nudging” based RTFDDA and E-RTFDDA systems are running for mesoscale applications.
- On-going developments of WRF “obs-nudging” include incremental refinements and building “seamless” EDA/EPS ensemble capability and nex-gen 4D-REKF.

Thank you!