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POST-PROCESSING AND VERIFICATION OF ANALYSES AND FORECASTS OF OPERATIONNAL WRF-RTFDDA SYSTEM FOR WIND POWER APPLICATIONS

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Motivations



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- ❖ Needs of high-resolution wind speed analysis and forecasts for wind energy production and management
- ❖ Since last year, RTFDDA implemented for Xcel energy, to support wind power forecasting
- ❖ Needs high precision hub-height wind speed (4-15 m/s)
- ❖ Previous studies show WRF overestimating the 10-m wind speed

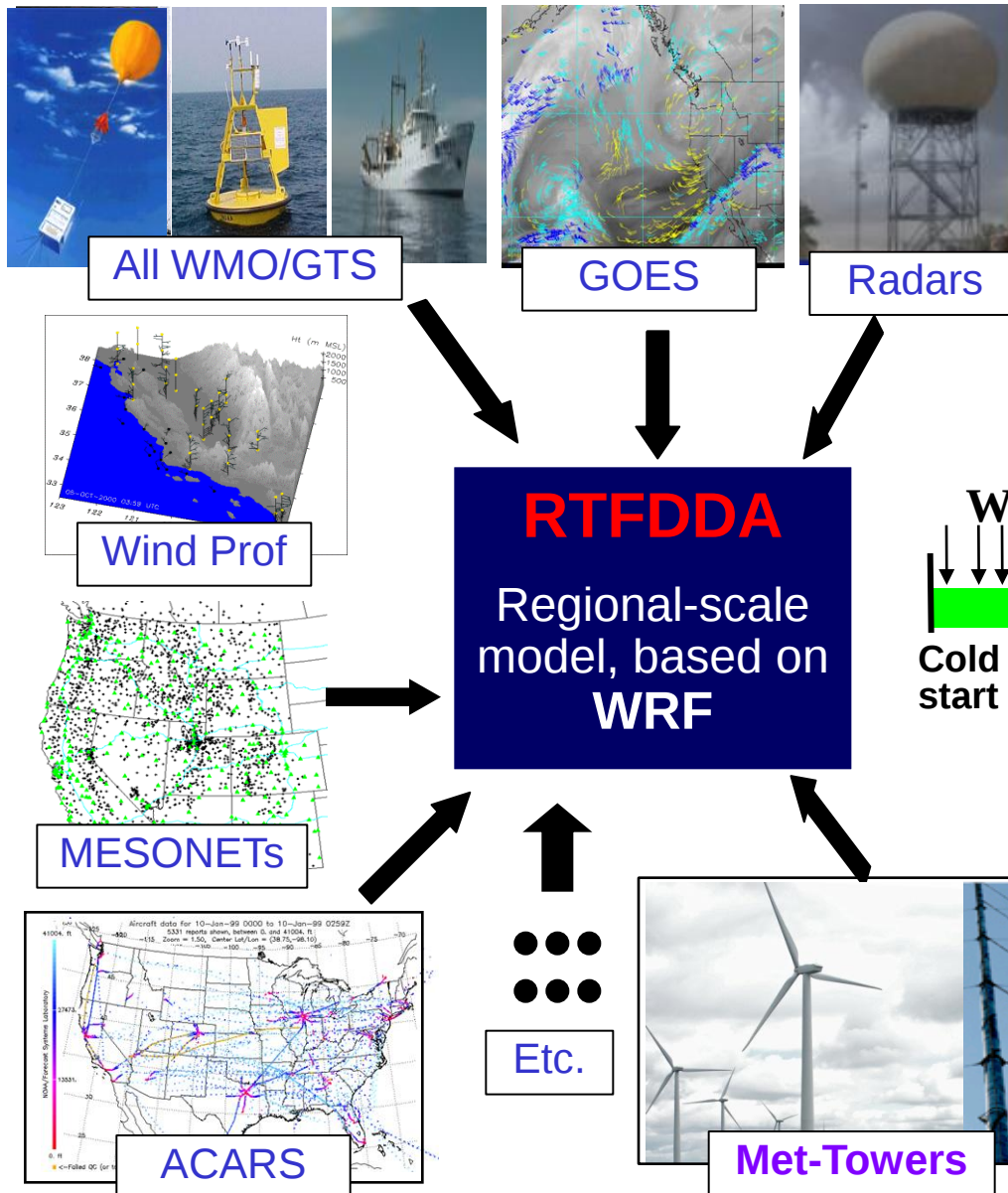
Outline

- 1) WRF-RTFDDA Modeling System
 - 2) Verification of SPD at wind farms
 - 3) Statistical bias corrections schemes
- Ensemble-RTFDDA will not be covered.



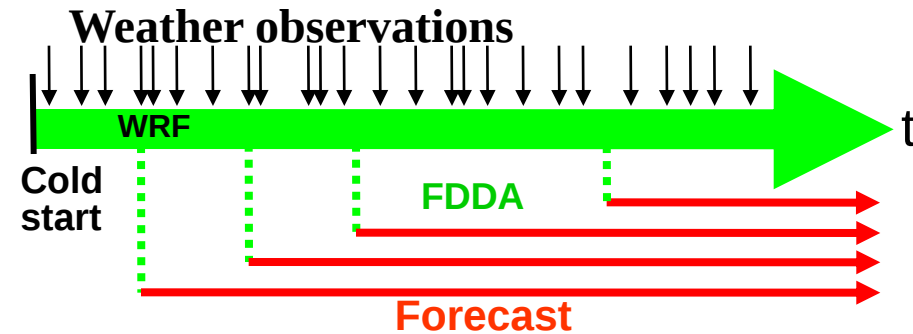
RTFDFA - 4D Continuous DA and Forecasting

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8 cycles a day

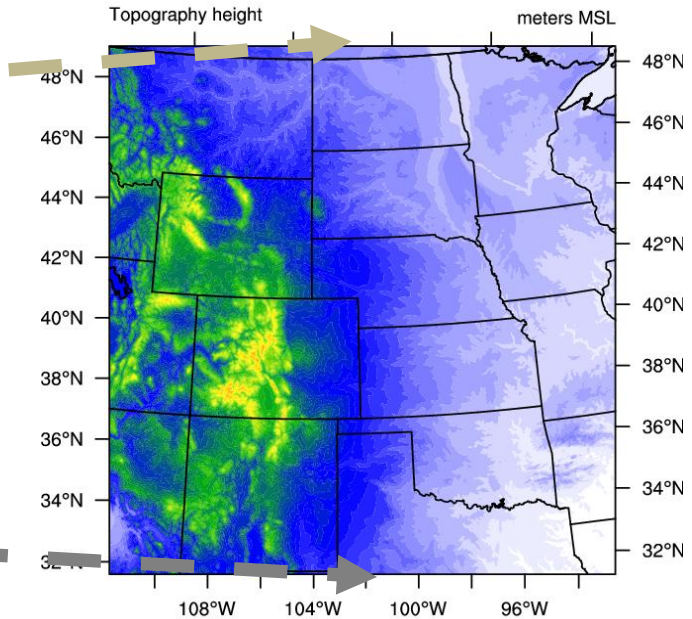
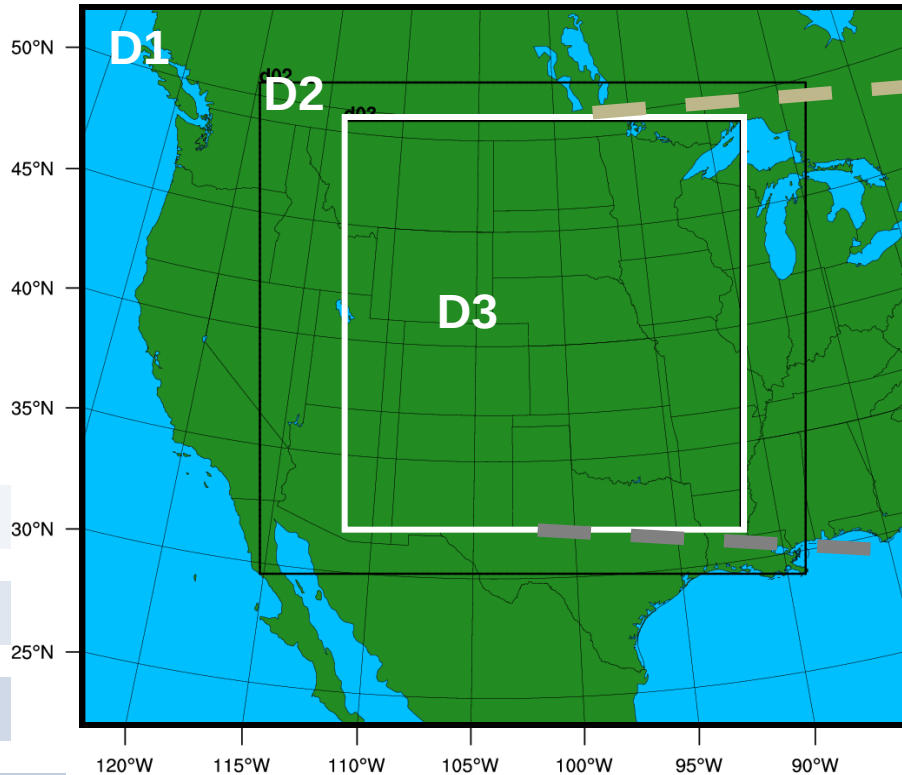
- 3-hour FDDA analysis
- 24 hour forecast (D3)
- 72 hour forecast (D1/2)



Xcel WRF-RTFDDA Model Domains



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D1: 30 km 128x114

D2: 10 km 253x232

D3: 3.3 km 541x571

37 vertical levels with 12 levels in the lowest 1-km

Model physics:

- Lin et al. microphysics
- YSU for PBL
- Monin-Oboukov for surface layer
- Kain-Fritsch CUP (Domain 1 / 2)
- Noah Land Surface Model

Surface Bias Characteristics

- WRF-RTFDDA against MADIS surface stations
 - >4500 stations over Dom 3
 - From May 2 2009 up to now

Wind Speed Average bias:

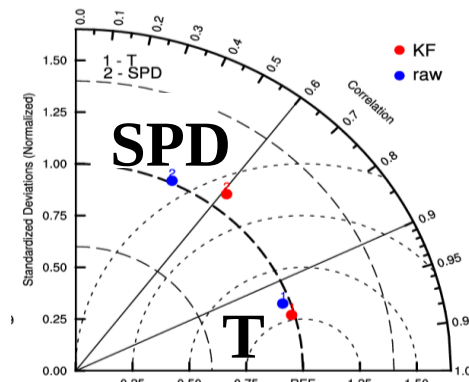
- 0.67m/s 2.14 m/s

Temperature Average bias:

- -0.24°C 2.48°C

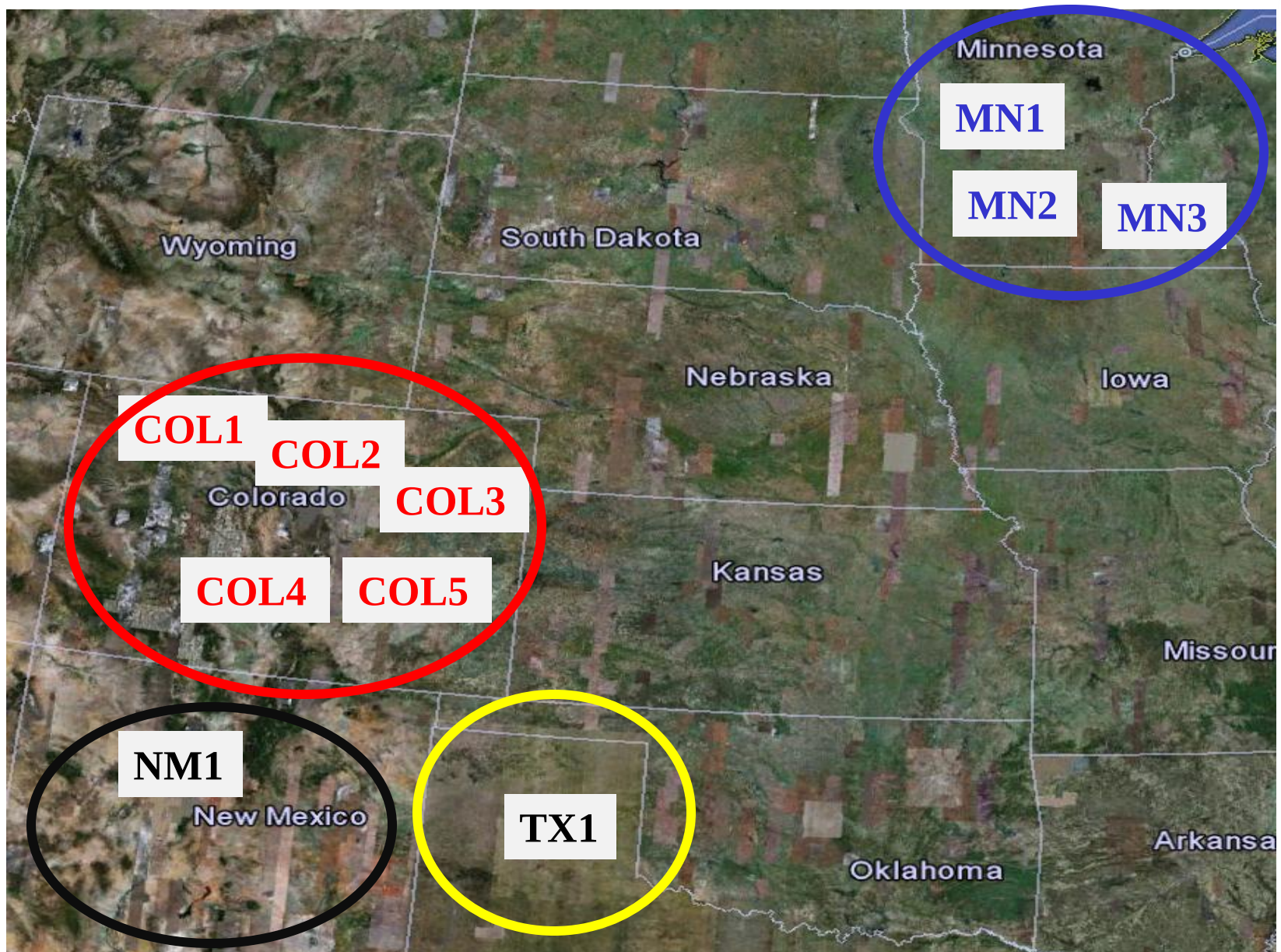
- Errors highly depend on diurnal cycles, geographic locations, forecasts ranges, weather regimes and season.

- Application of a Kalman Filter bias correction improves the forecasts



Xcel Wind Farms

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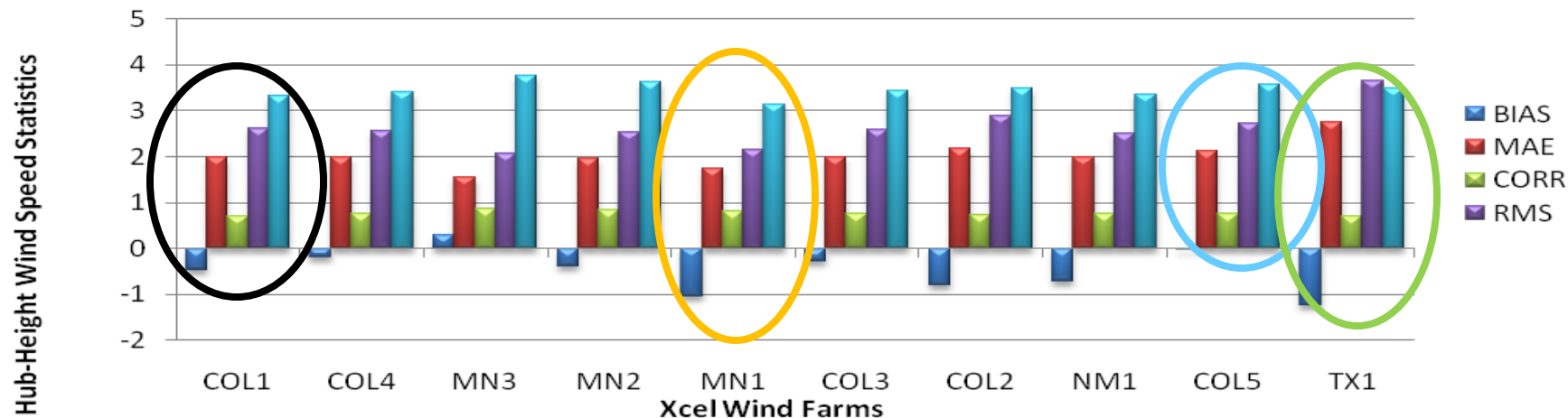


Xcel Wind Farms Statistics



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Hub-Height Wind Speed Statistics



Under-estimation of wind-speed
0.2 m/s $\rightarrow$ -1.3 m/s ($\neq$ surface stations)

Model results differ, but overall good correlation

TX1, MN1: underestimate higher winds

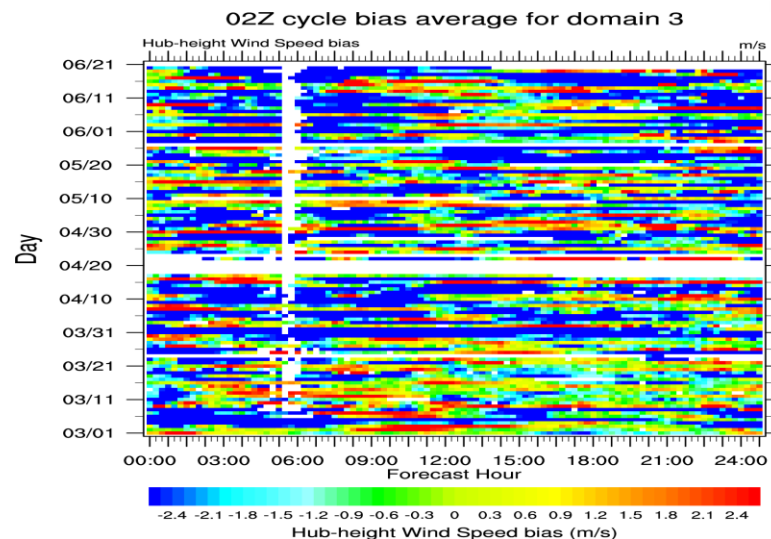
TX1 Hub Height Wind Speed Stat



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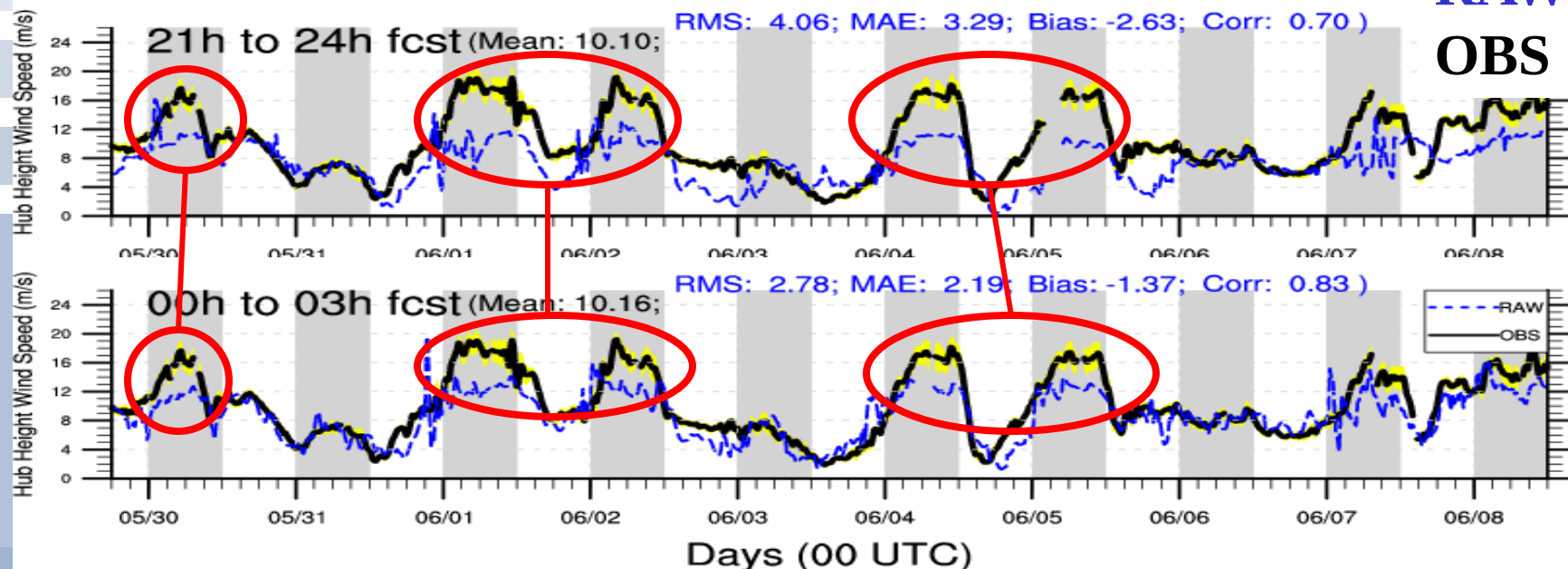
Wind Speed (obs avg 8.9 m/s):

- Bias: -1.23 m/s
- RMS: 3.66 m/s
- MAE: 2.75 m/s
- Corr: 0.7



Hub Height Wind Speed (m/s) (Average)

RAW
OBS

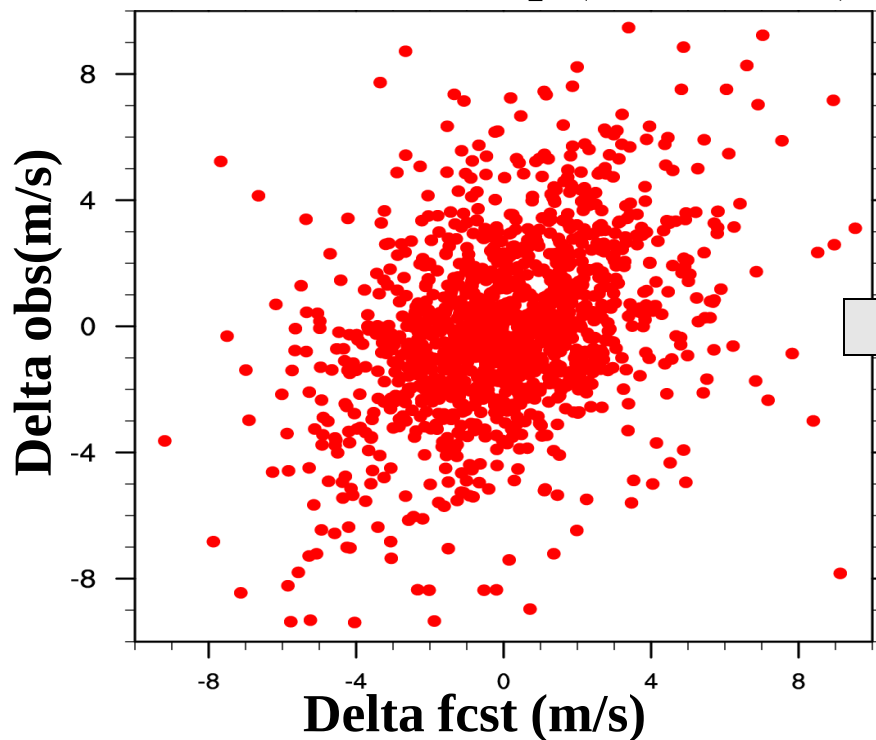


Forecast of ramp events: TX1

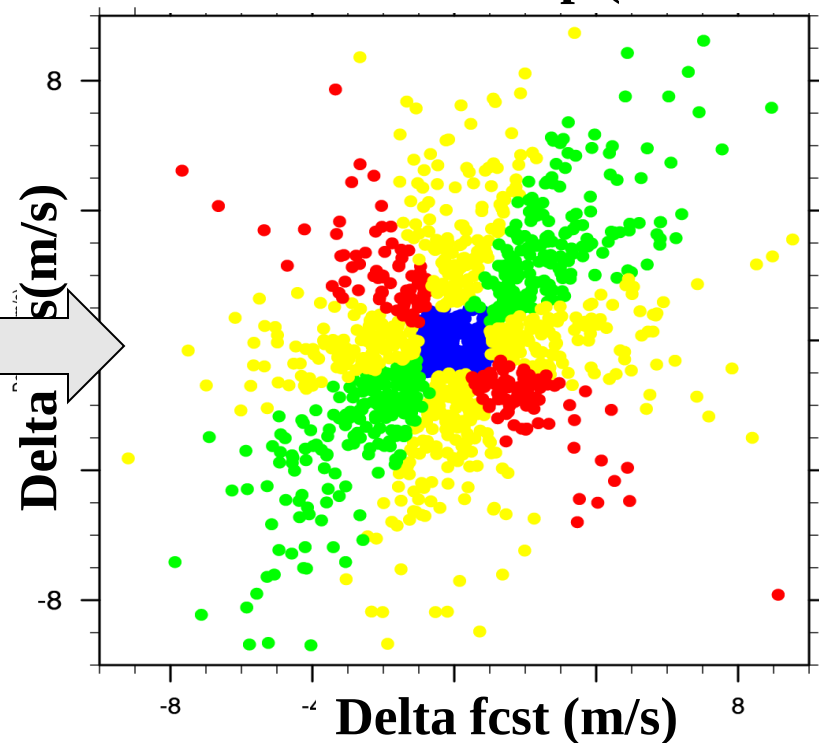


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3h Duration ramp (3h forecast)



3h Duration ramp (3h forecast)



Observation

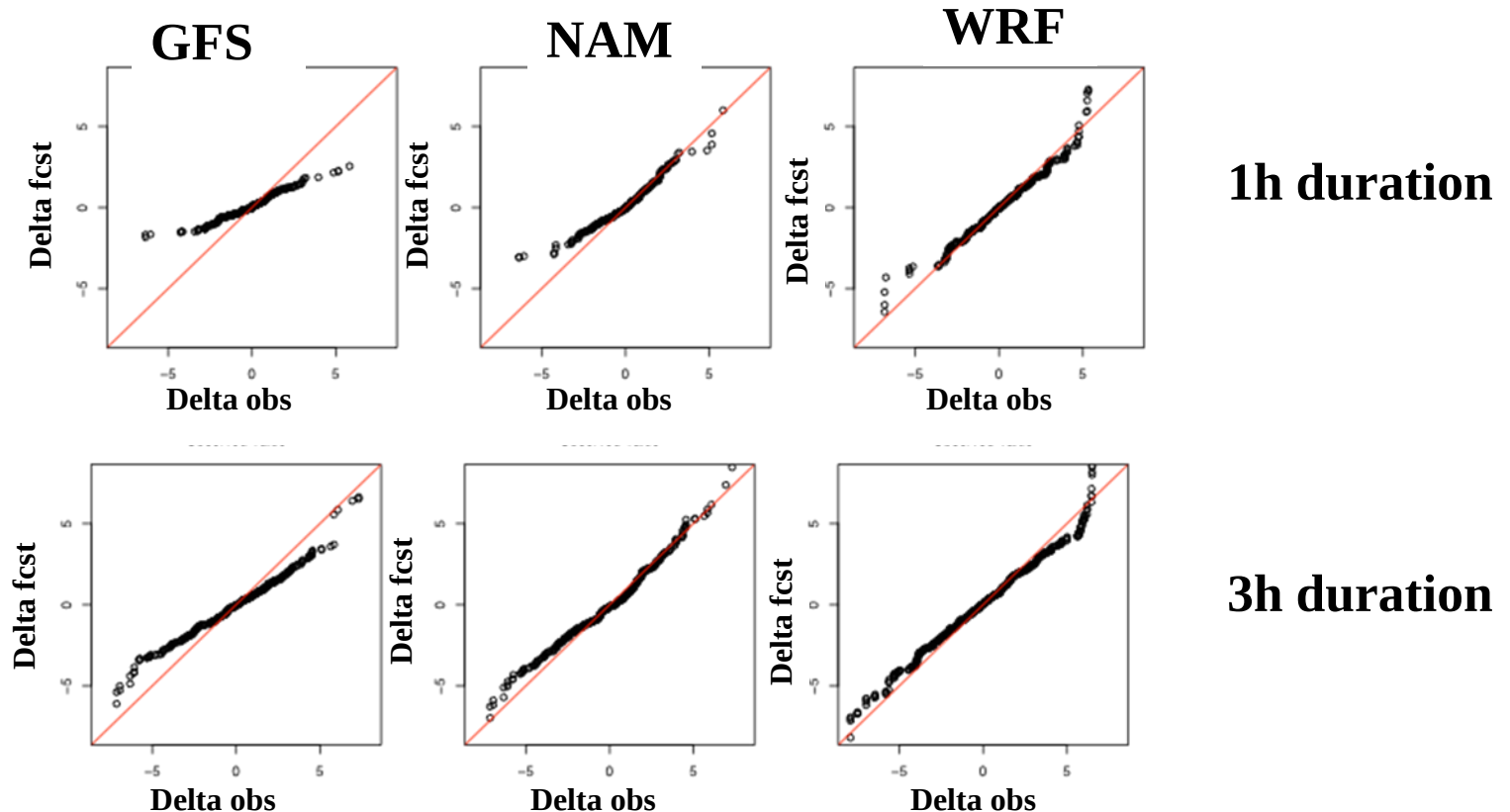
Forecast	Observation		
	Up	Neutral	Down
Up	16%	10%	5%
Neutral	12%	14%	11%
Down	6%	11%	15%

Percent Correct: 45%

(work by: Matt Pocernich)

WRF/NAM/GFS comparison

Q/Q plots for delta values

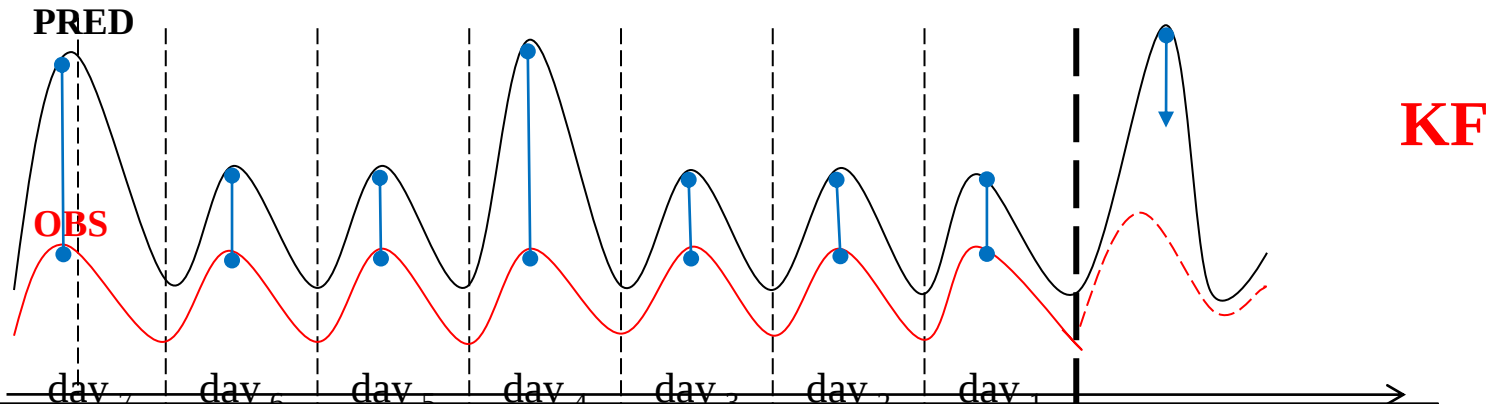


WRF → reproduces quite well the observed distribution

Statistical Bias Correction Schemes

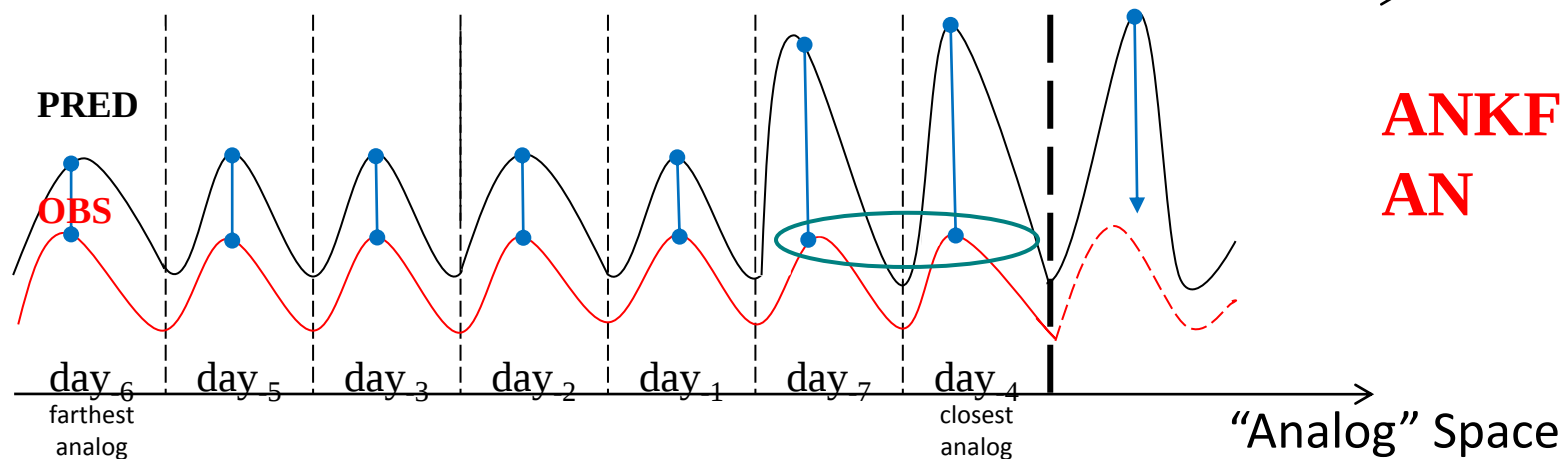


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NOTE

This procedure is applied independently at each observation location and for a given forecast time



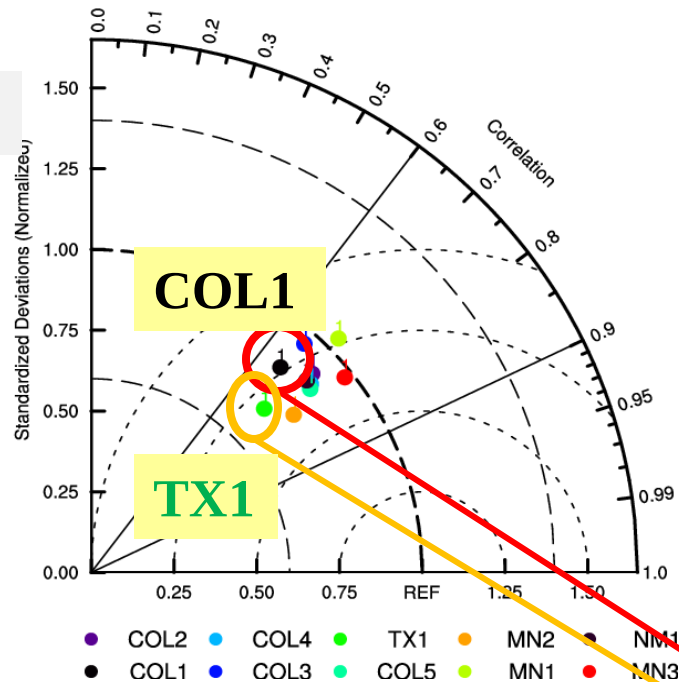
(work by: Luca Delle Monache)

Xcel Wind Farms Bias Correction

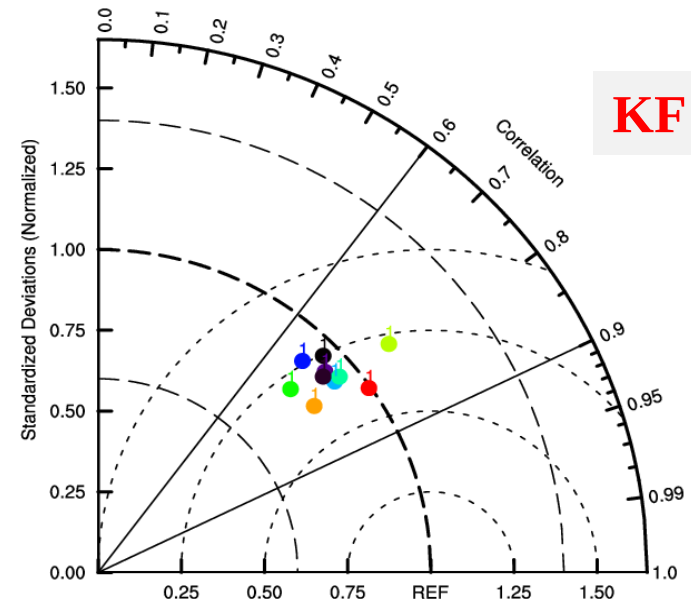


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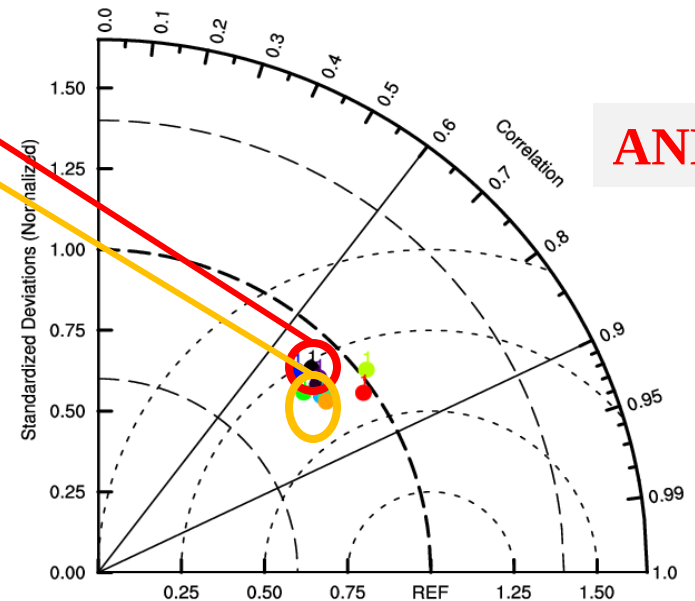
WRF



KF



ANKF



On average, ANKF performs the best

Improved performance for farms with larger errors (TX1)

TX1: ANKF Results



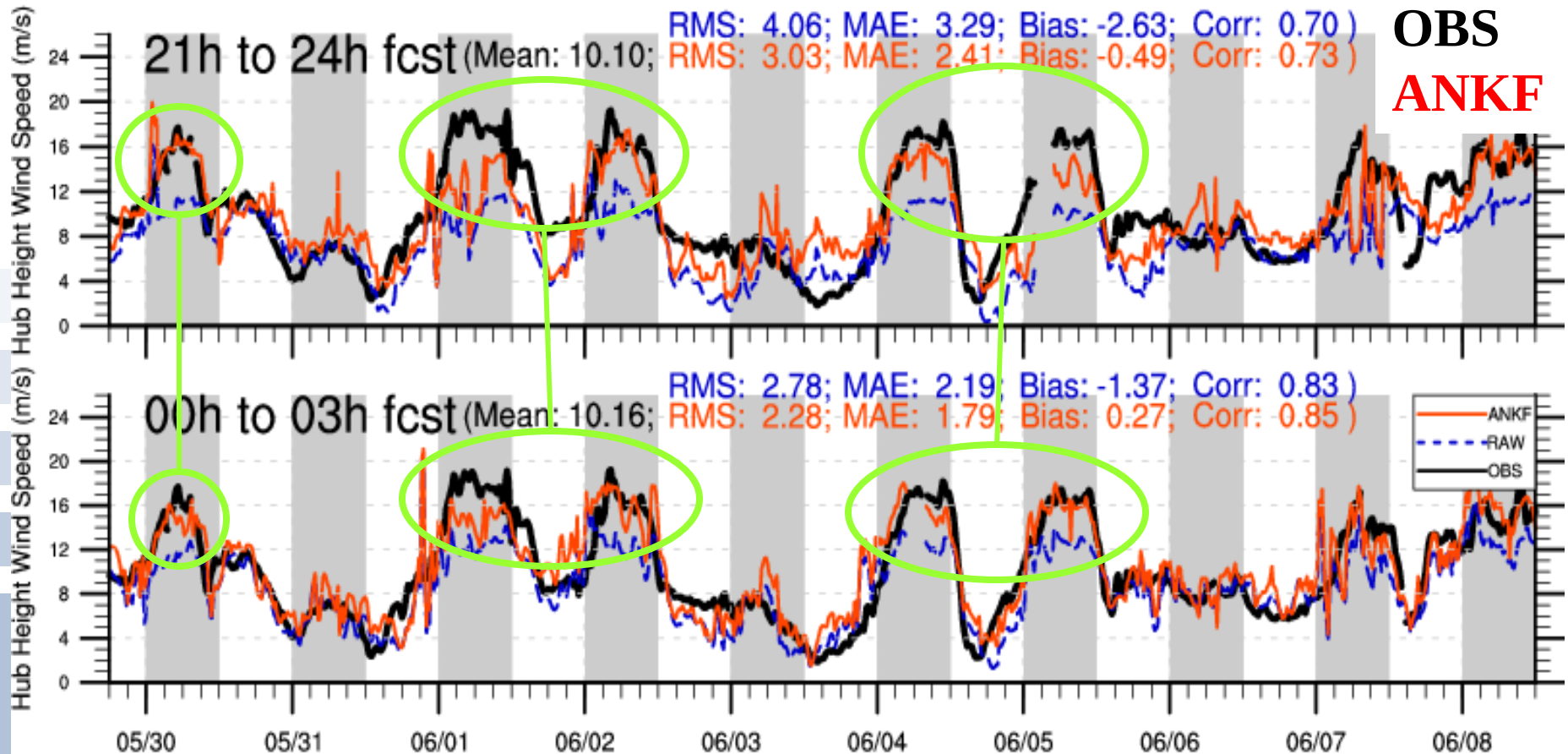
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Hub Height Wind Speed (m/s) (Average)

RAW

OBS

ANKF



For TX1, ANKF improves statistics for all forecast hours and is better for ramp detection.

Wavelet filtering



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Time Series

Raw Pred

OBS

Corrected Pred

Sum

Smoothest
Component

15 min.

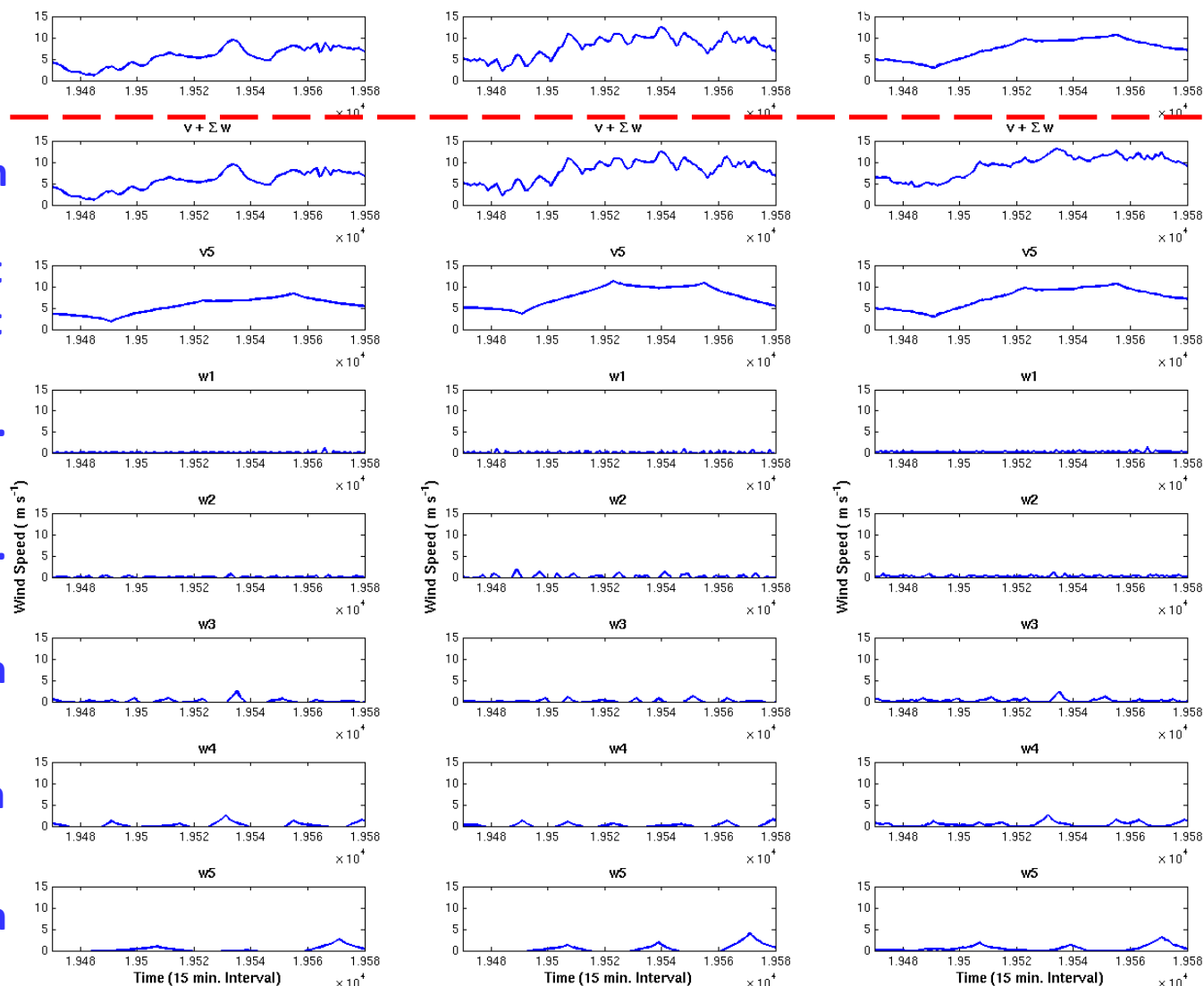
30 min.

1 h

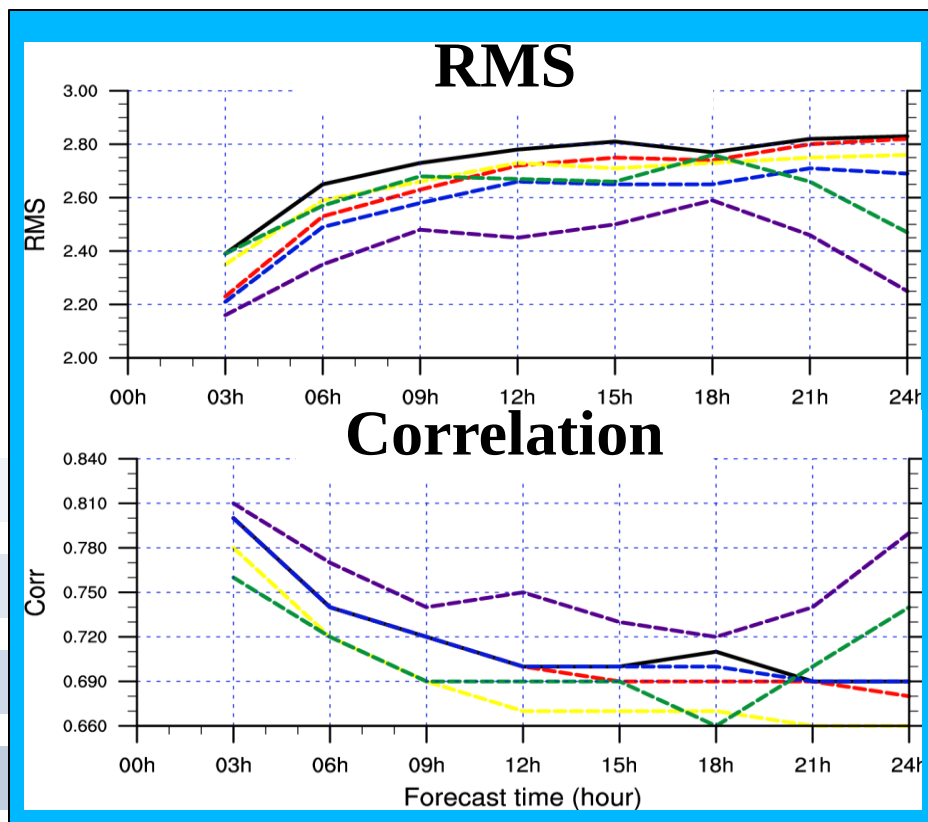
2 h

4 h

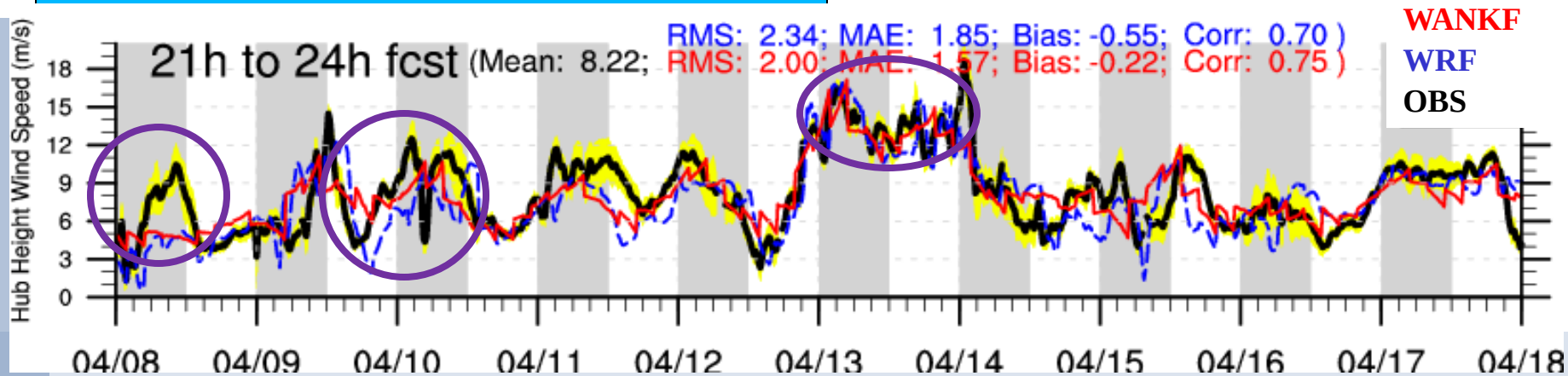
Wavelet Components



Wavelet filtering: Stat Results at COL1



➔ WANKF lowest RMS and highest correlation for all forecast hours.



Summary



- ❖ WRF-based RTFDDA system has been developed for Xcel Energy for Wind Power forecasting since May, 2009. This study investigates the wind forecast bias characteristics at Wind Farms and post-processing approaches. It is found that:
 1. Underpredict hub-height wind speed (down to -1.2 m/s) at 10 farms, in contrast to the surface wind speed overprediction;
 2. Underestimation of strong wind events (low-level jet);
 3. Tools are developed for wind ramp prediction/verification;
 4. Applying a statistical bias correction (KF/ANKF) improves the forecasts at some farms. ANKF appears to perform the best;
 5. Wavelet scale decomposition was applied to support scale-dependent bias correction with KF and ANKF, and improved wind prediction with noisy data;
 6. Ensemble-RTFDDA outputs have been processed : the results will be showed in the future;
 7. Next, improve statistical bias correction, use a calibrated ensemble, higher resolution domain for E-RTFDDA...

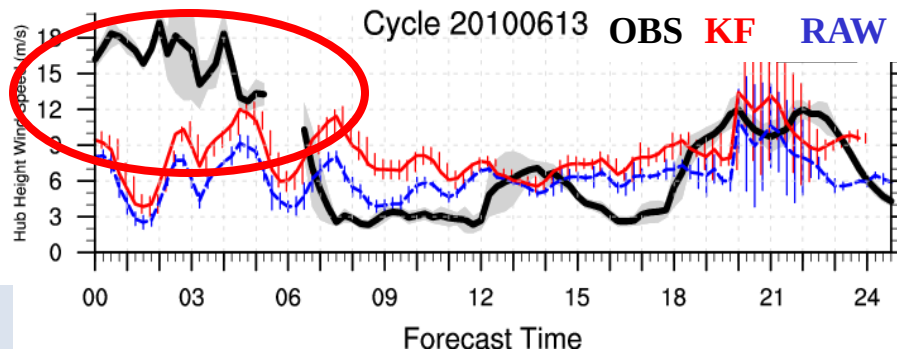
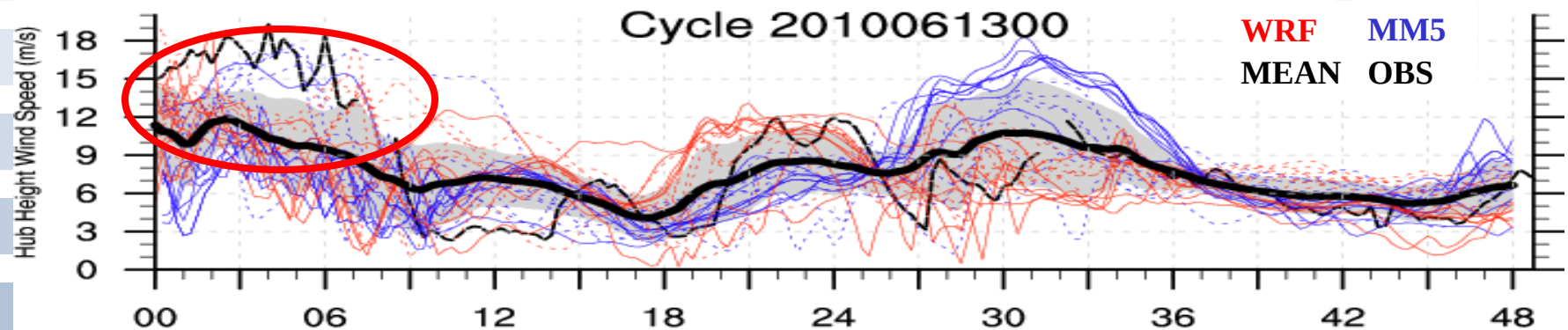
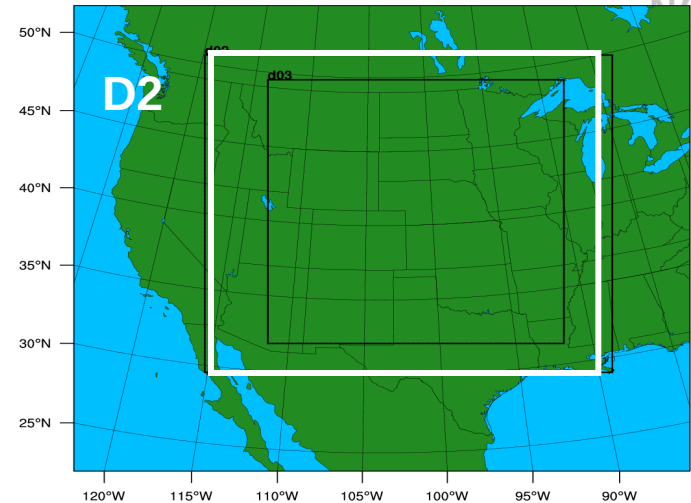


Thank you...

QUESTIONS?

Ensemble-RTFDDA

- D1: 30 km / D2: 10 km
- 30 members (15 MM5/15 WRF) (NAM/GFS, multi-physics)
- 6-hour cycles / 48h forecast (→ 72h forecast soon)



- **Ens mean: overall good results**
- **Observation within ensemble spread**

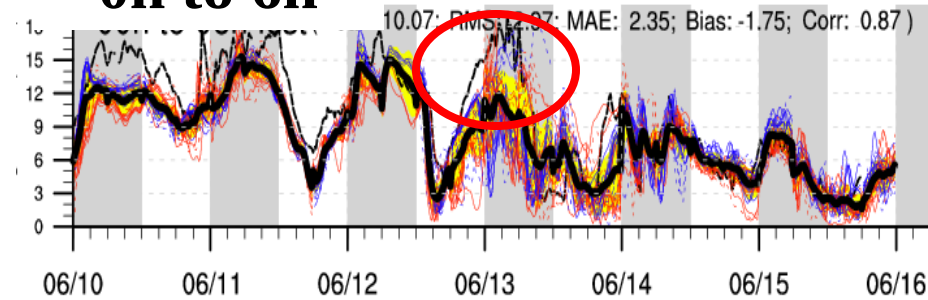
E-RTFDDA: results for WLDR



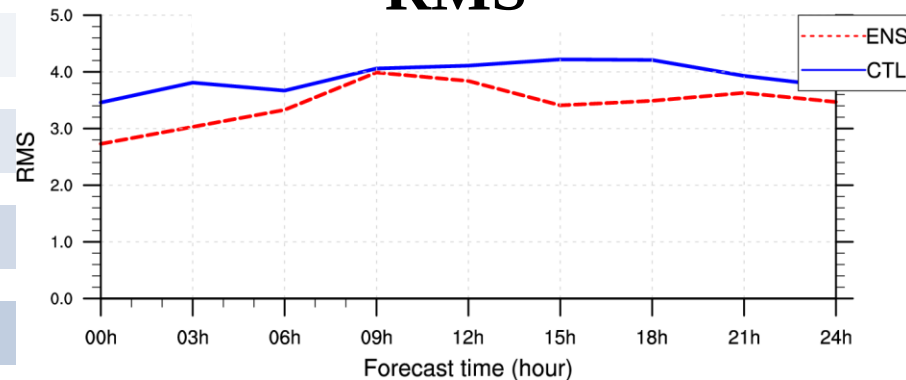
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Ensemble

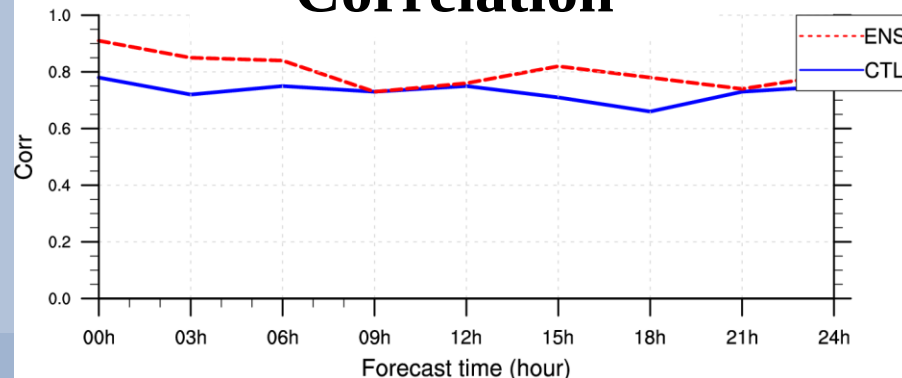
0h to 6h



RMS

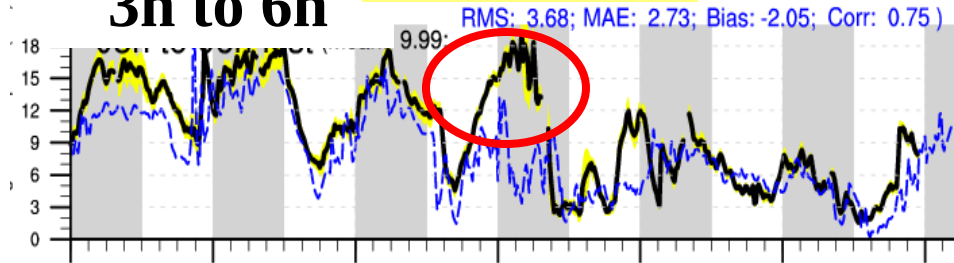


Correlation

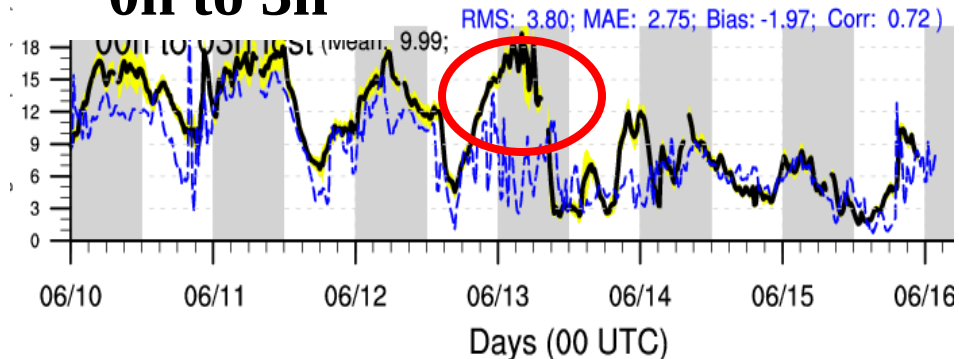


RTFDDA

3h to 6h



0h to 3h



- Ensemble mean: lower RMS/MAE, greater correlation
- Better Spread