Wind and Solar Forecasts: Lessons Learned and Sensor Needs

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Can wind energy and solar energy forecasts be improved?

Outline

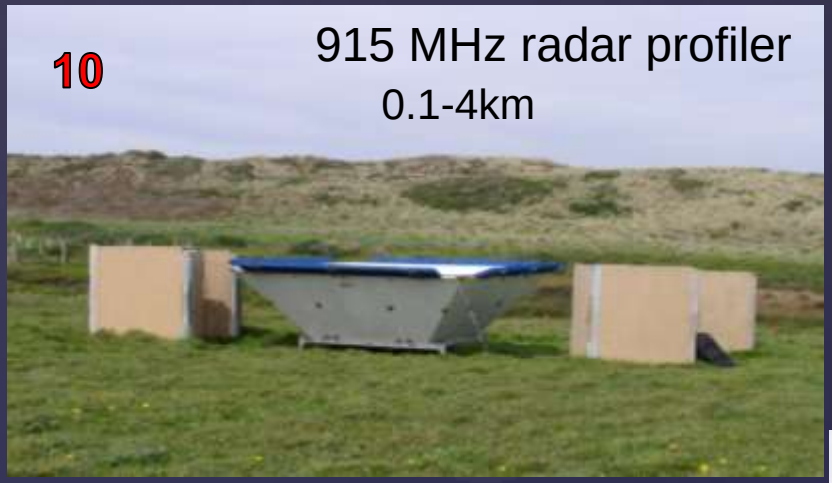
- Wind Forecast Improvement Project (WFIP)
- Wind energy forecasting results: WFIP
- Solar energy forecasting insights: WFIP
- Post-processing

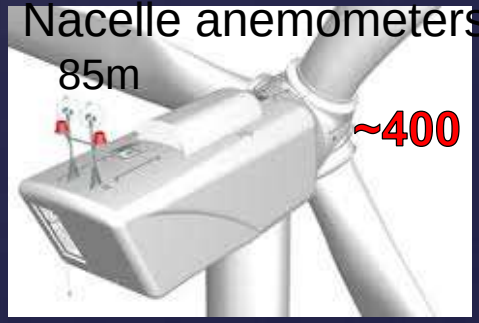
Wind Forecast Improvement Project

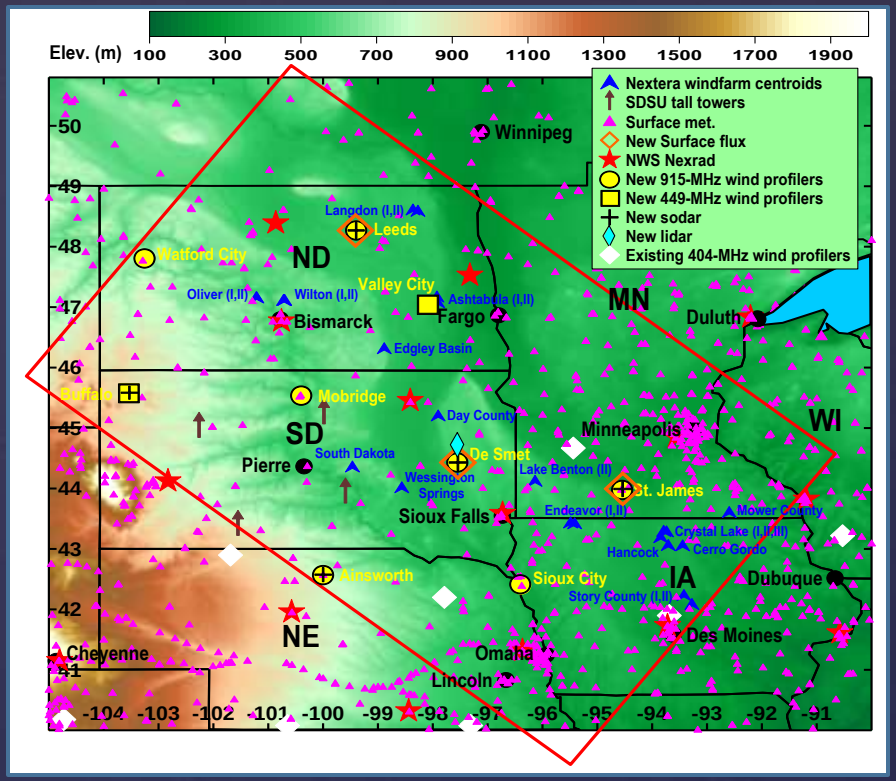
- Improve short-range forecasts (0-6 h) of wind speed, direction, and turbulence at wind turbine hub-height.
  - Deploy a regional network of upper-air remote sensing observations
  - Combine this network with industry provided tall-tower and wind turbine nacelle meteorological observations
  - Assimilate this data into NOAA's developmental Rapid Refresh (RR) and High Resolution Rapid Refresh (HRRR) NWP models
- Demonstrate that the improved forecasts can reduce the cost of wind energy

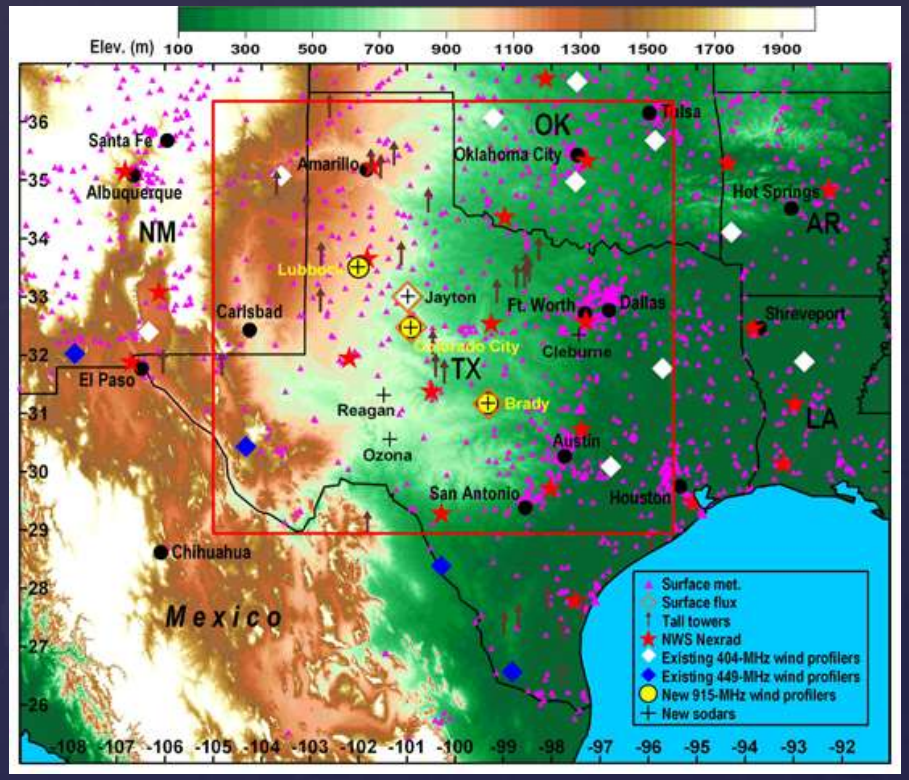
WFIP instrumentation is being deployed for an ~12 month period: August 2011 – September 2012

New Instrumentation









Northern Study Area

Southern Study Area

Hourly Updated NOAA NWP Models

RUC – older oper model - 13km

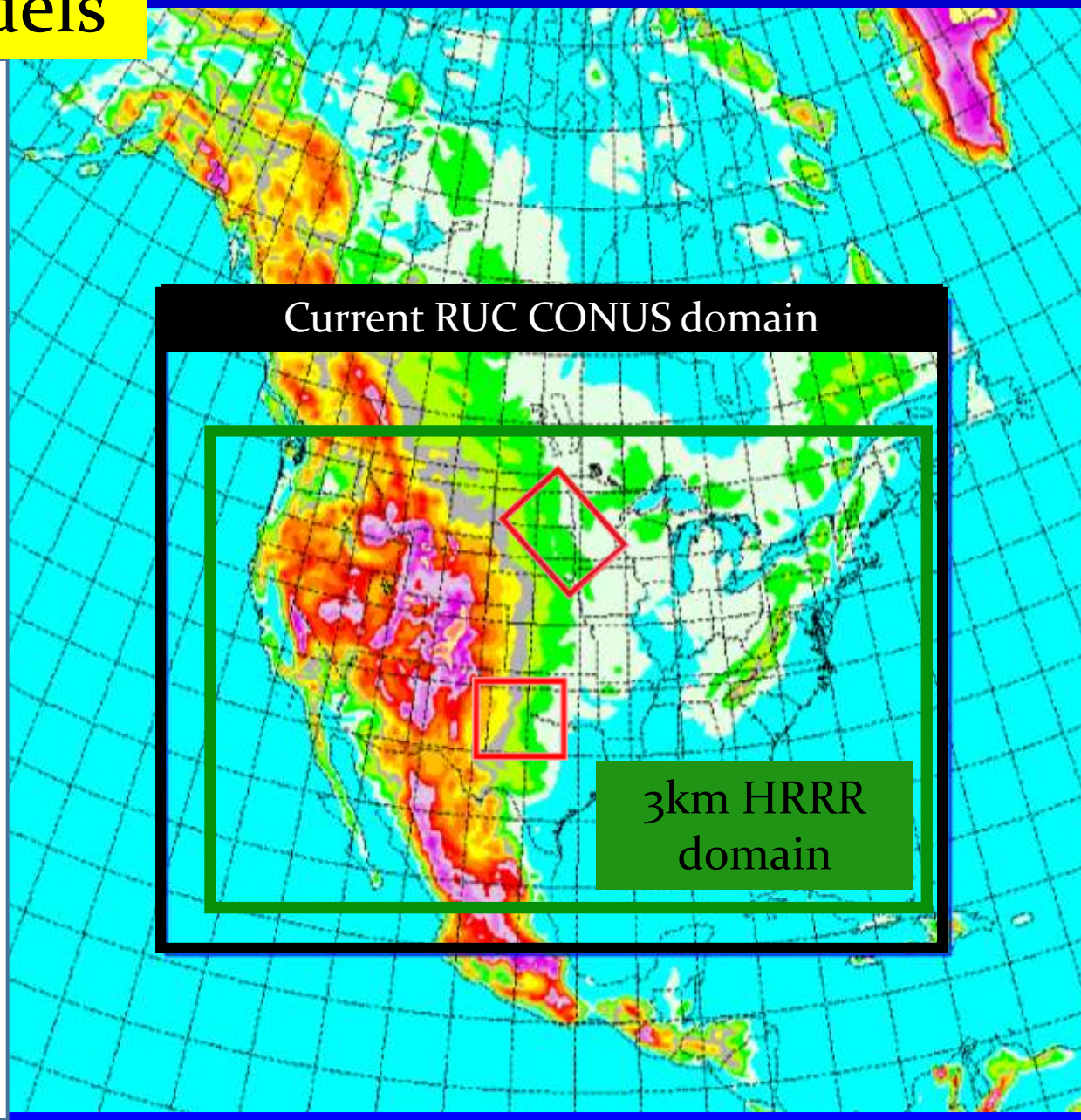
Rapid Refresh (RR)

– new oper model in March 2012
- WRF model, 3D var assimilation

HRRR - Hi-Res Rapid Refresh

-Experimental 3km
-15h fcst updated every hour
- Initialized from RUC/RR

HRRR 3D fields are available to the RE community through DOE WFIP funding



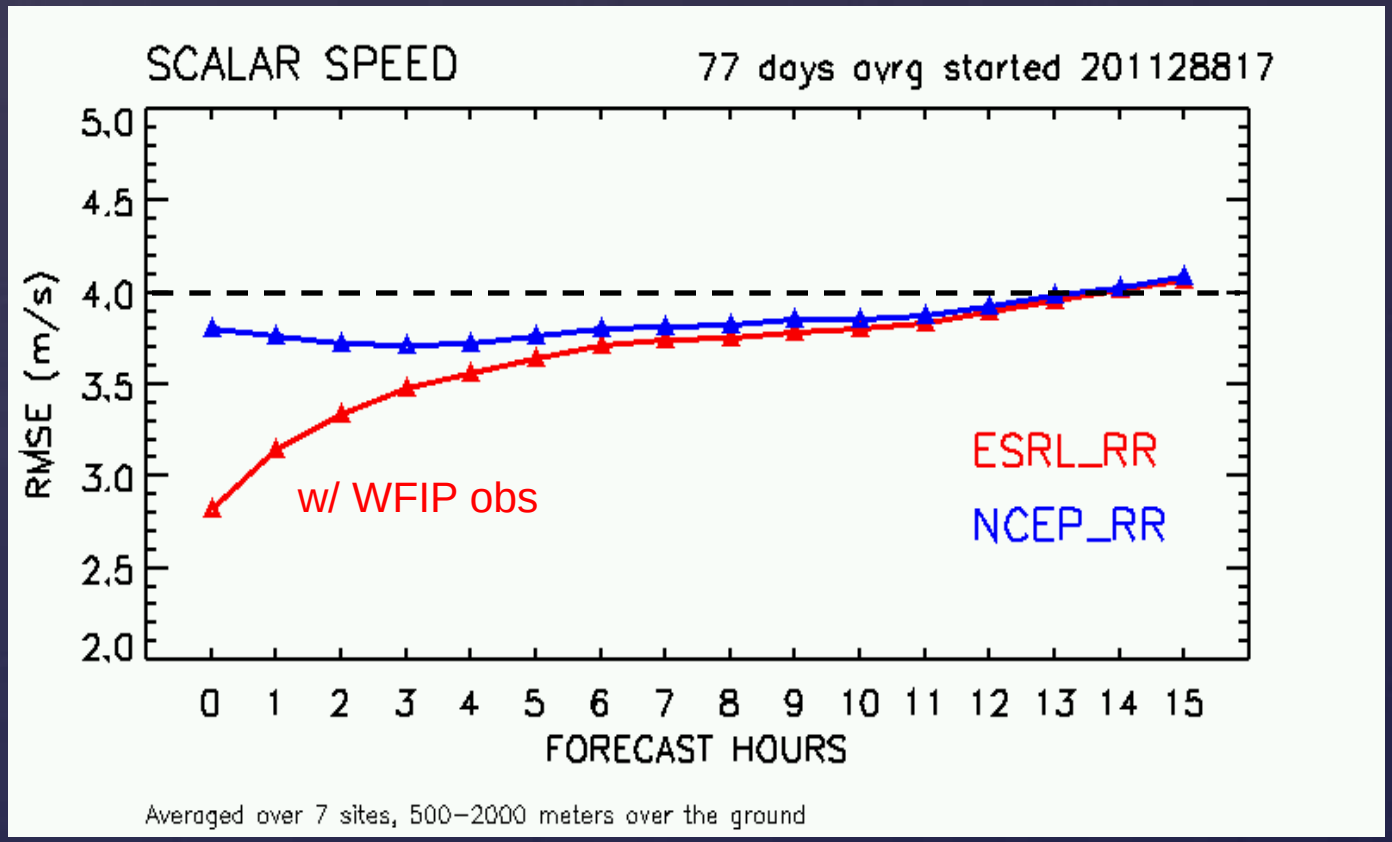
Preliminary model comparisons

OPERATIONAL	RESEARCH
	HRRR (w/ WFIP obs assimilation)
Rapid Refresh (RR)	RR (w/WFIP obs assimilation)
Rapid Update Cycle (RUC)	RUC (w/ WFIP obs assimilation)

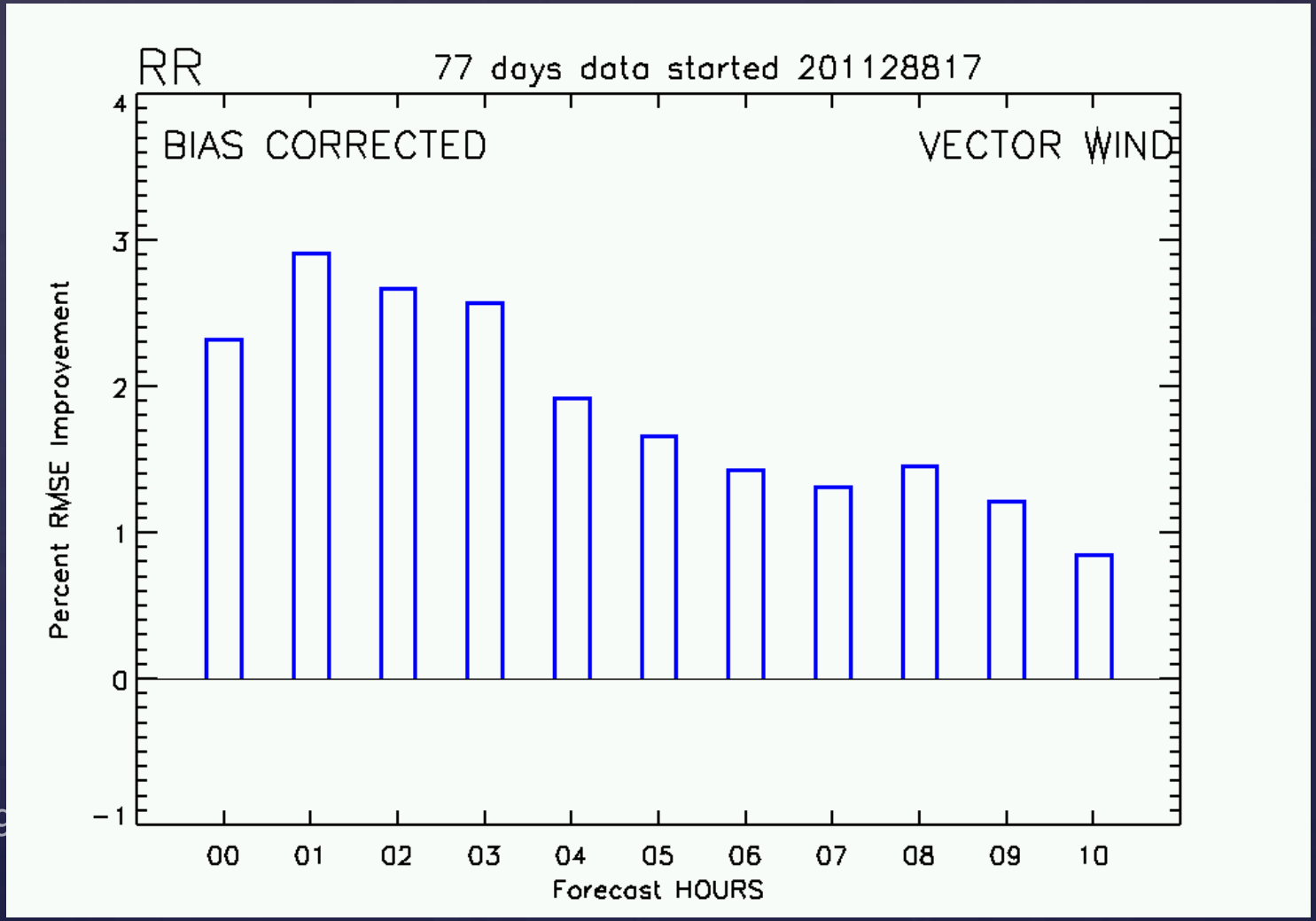
- Operational and research models of the same name are similar but not identical.
- 30 day data denial experiment will soon be begun using identical models, w/wo new data.

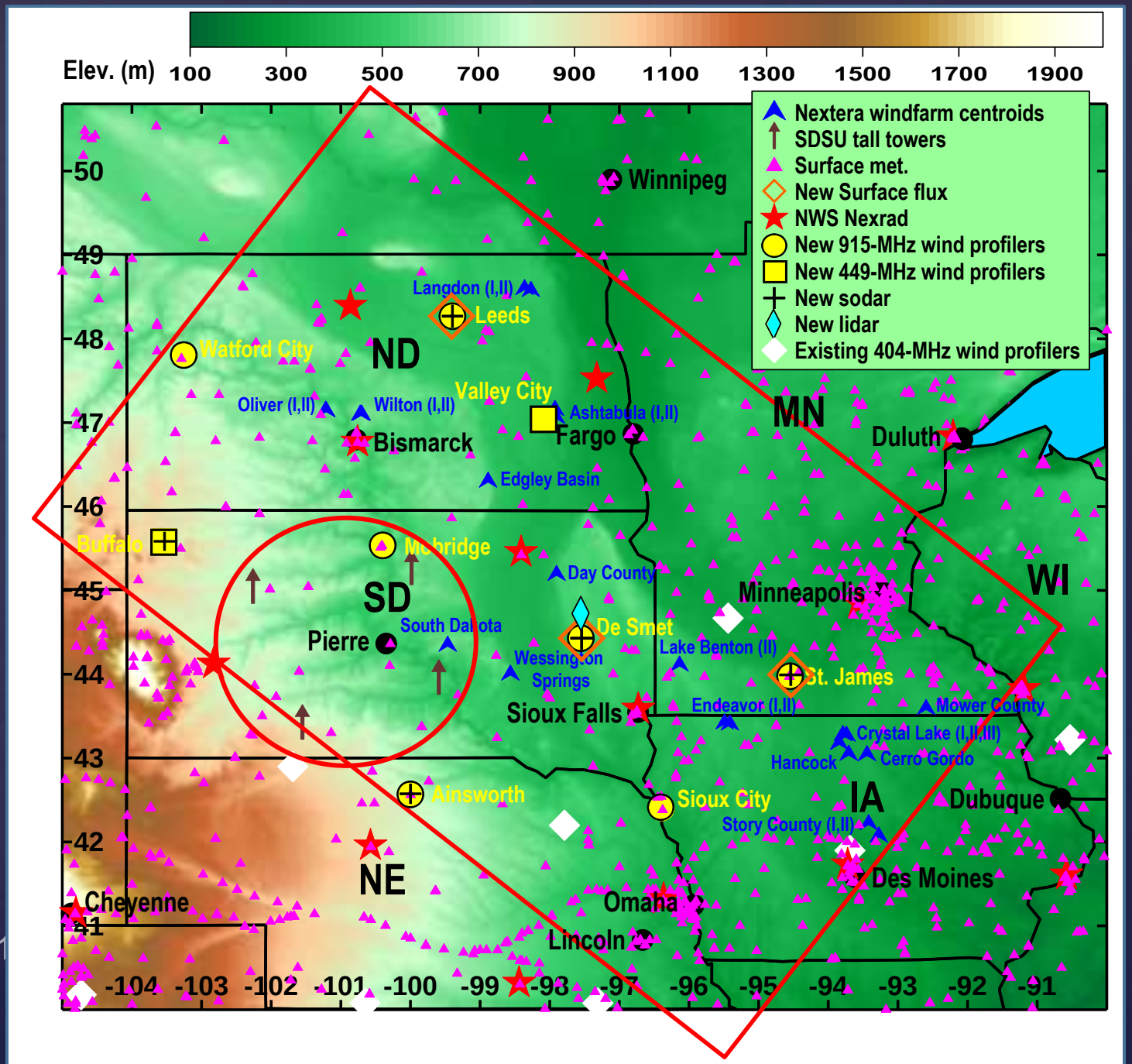
- *WFIP radar wind profiler data assimilated since August 27, 2011*
- *WFIP RASS and sodar data assimilated since Dec. 23, 2011*

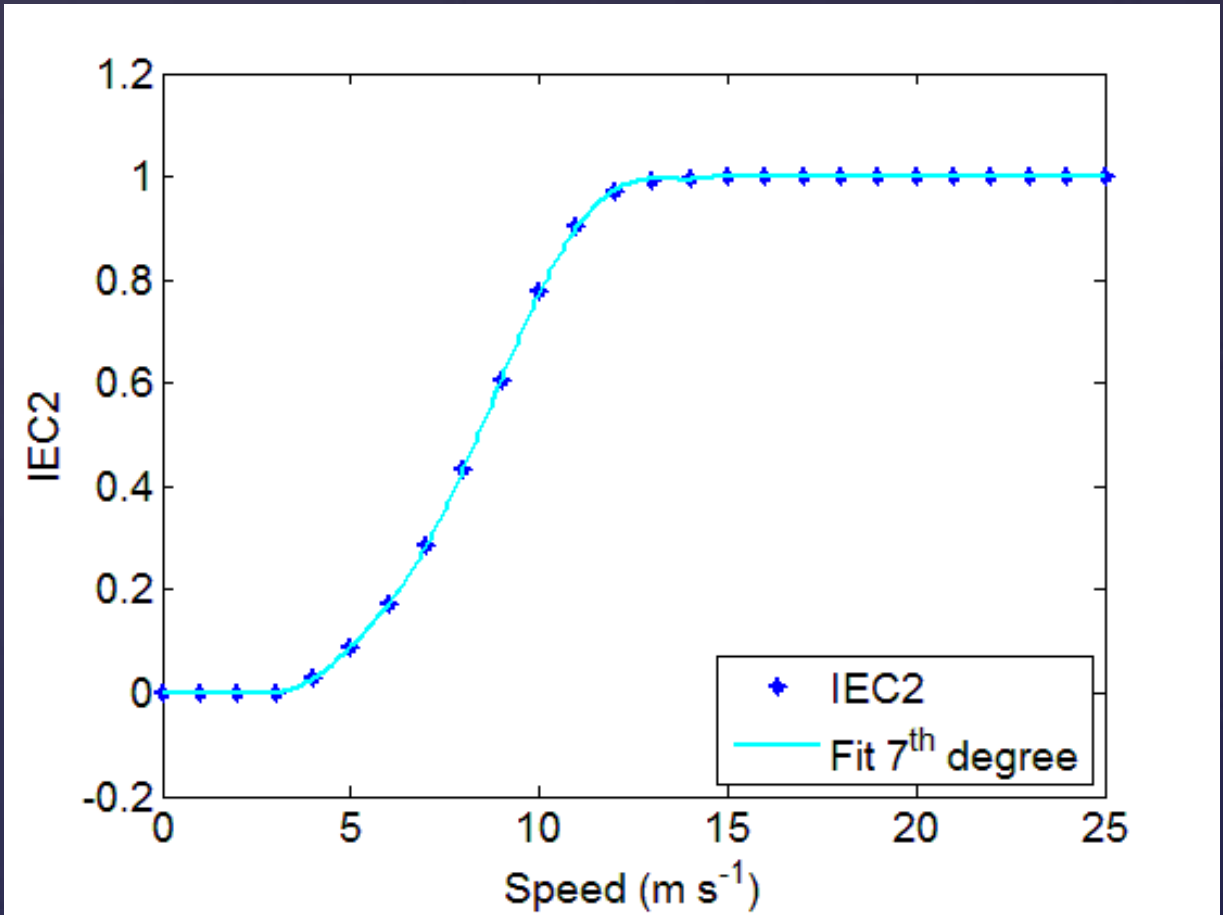
RR vertically averaged wind profiler RMSE

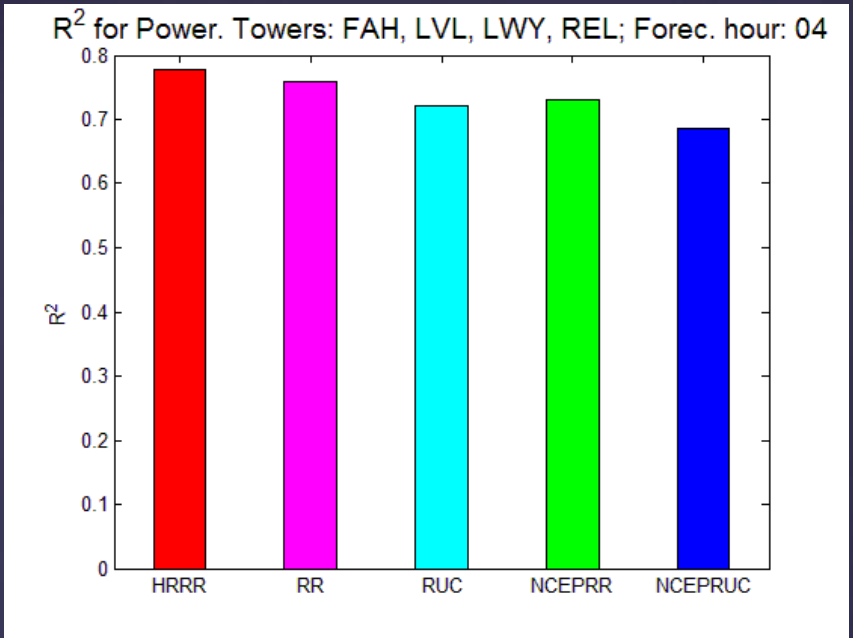


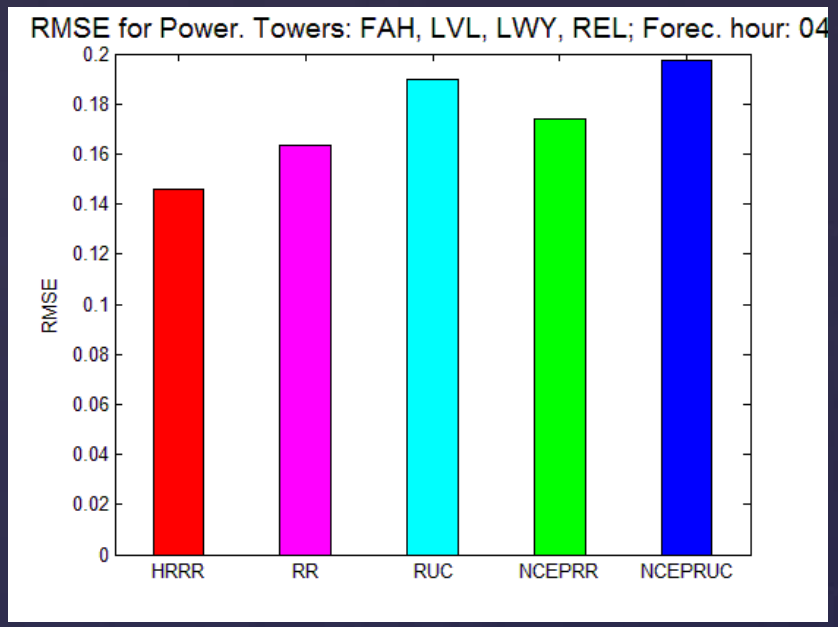
RR Percent RMSE Improvement – vector wind 38 tall towers, northern study area

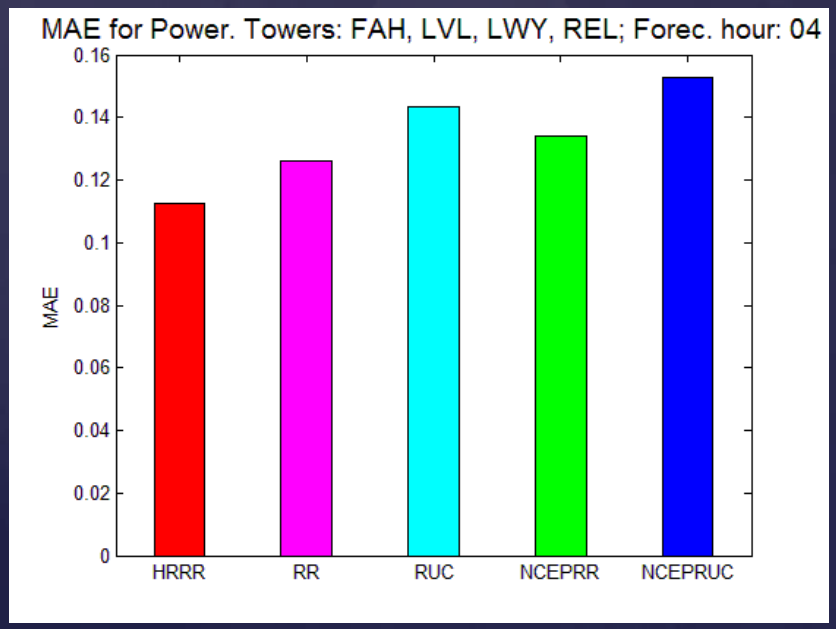


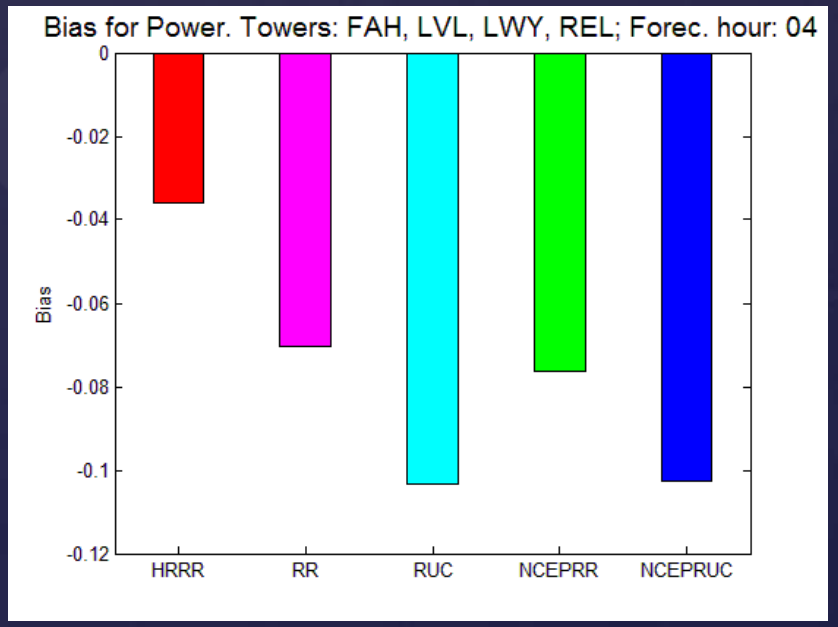

Elev. (m)
100
300
500
700
900
1100
1300
1500
1700
1900
Nextera windfarm centroids
SDSU tall towers
Surface met.
New Surface flux
NWS Nexrad
New 915-MHz wind profilers
New 449-MHz wind profilers
New sodar
New lidar
Existing 404-MHz wind profilers
Winnipeg
Langdon (I,II)
Leeds
Watford City
ND
Valley City
Oliver (I,II)
Wilton (I,II)
Ashtabula (I,II)
Fargo
MN
Duluth
Bismarck
Edgley Basin
Buffalo
Mcbridge
Day County
SD
Minneapolis
WI
Pierre
South Dakota
De Smet
Lake Benton (II)
Wessington Springs
St. James
Sioux Falls
Endeavor (I,II)
Mower County
Crystal Lake (I,II,III)
Hancock
Cerro Gordo
Ainsworth
Sioux City
IA
Dubuque
Story County (I,II)
NE
Des Moines
Cheyenne
Omaha
Lincoln
50
49
48
47
46
45
44
43
42
41
-104
-103
-102
-101
-100
-99
-98
-97
-96
-95
-94
-93
-92
-91


1.2
1
0.8
0.6
0.4
0.2
0
-0.2
IEC2
0
5
10
15
20
25
Speed (m s-1)
IEC2
Fit 7th degree

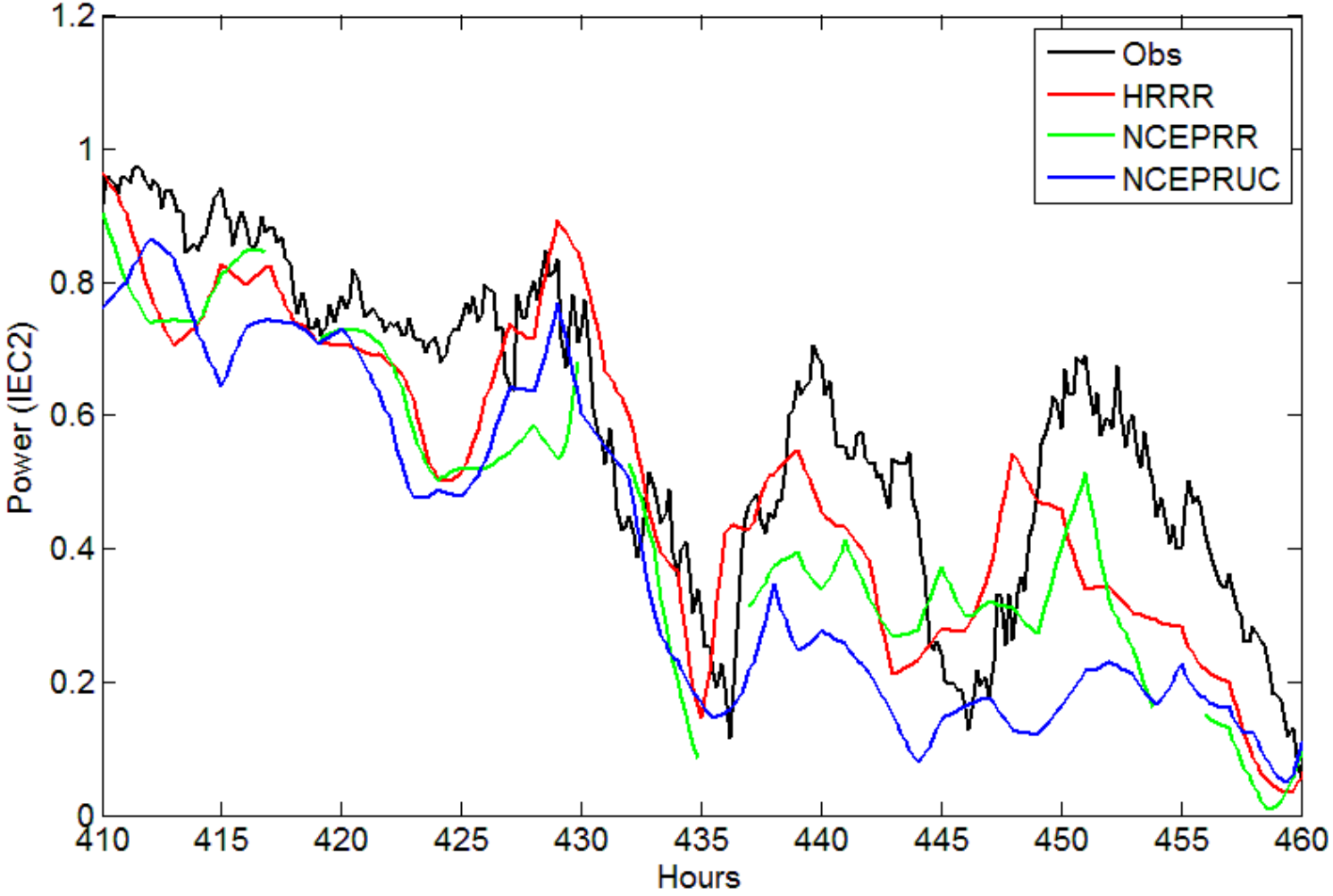


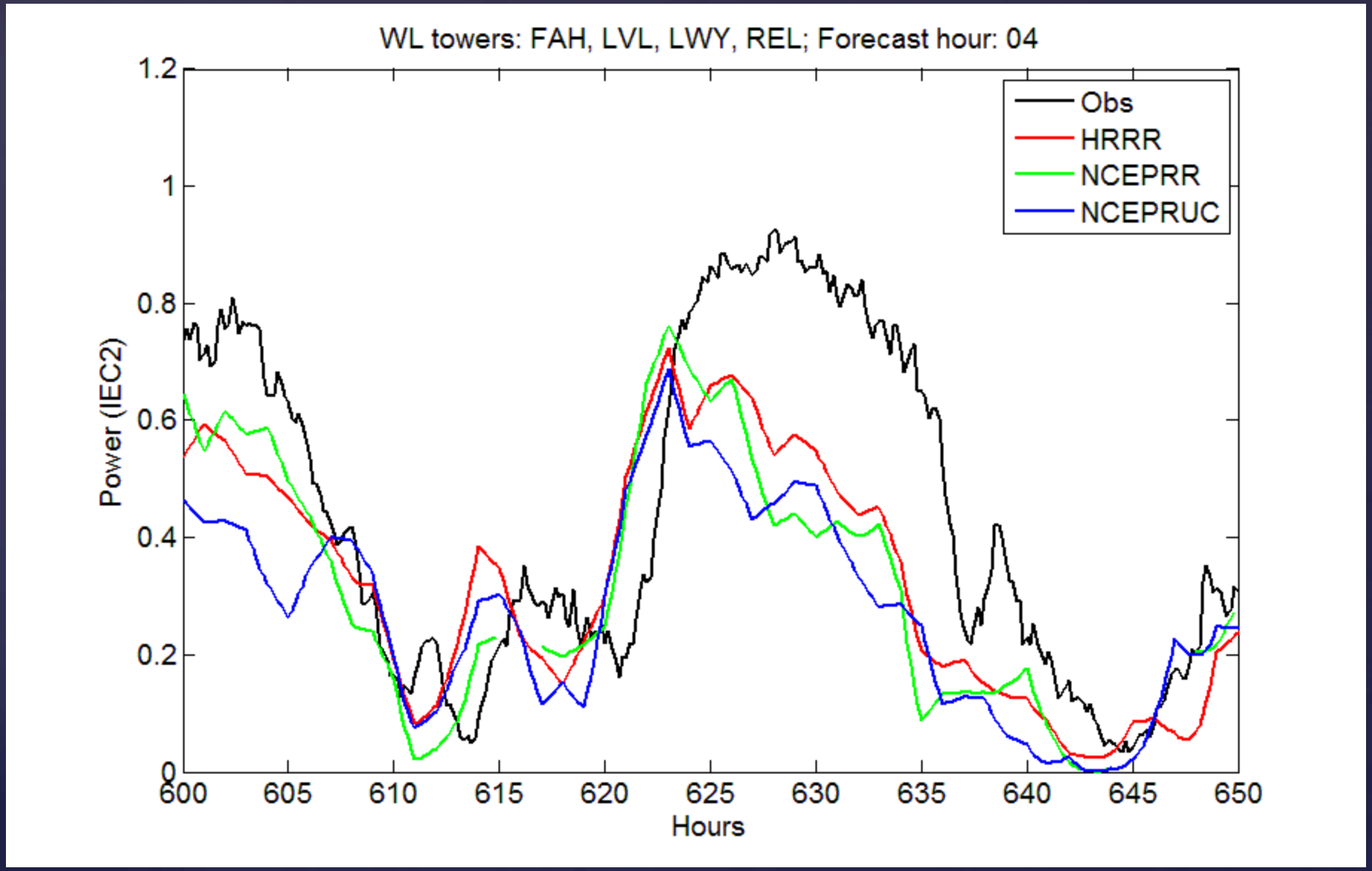


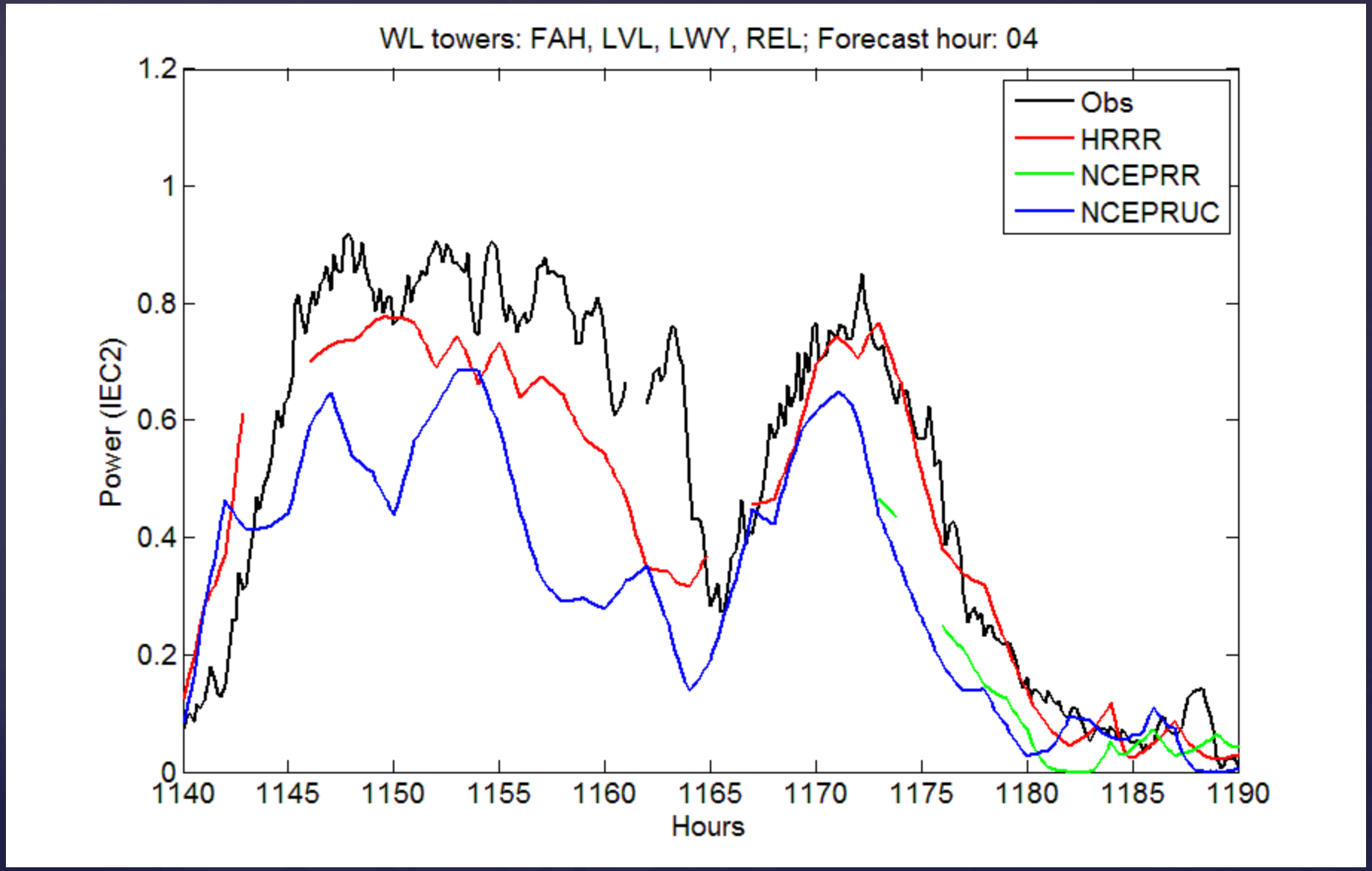


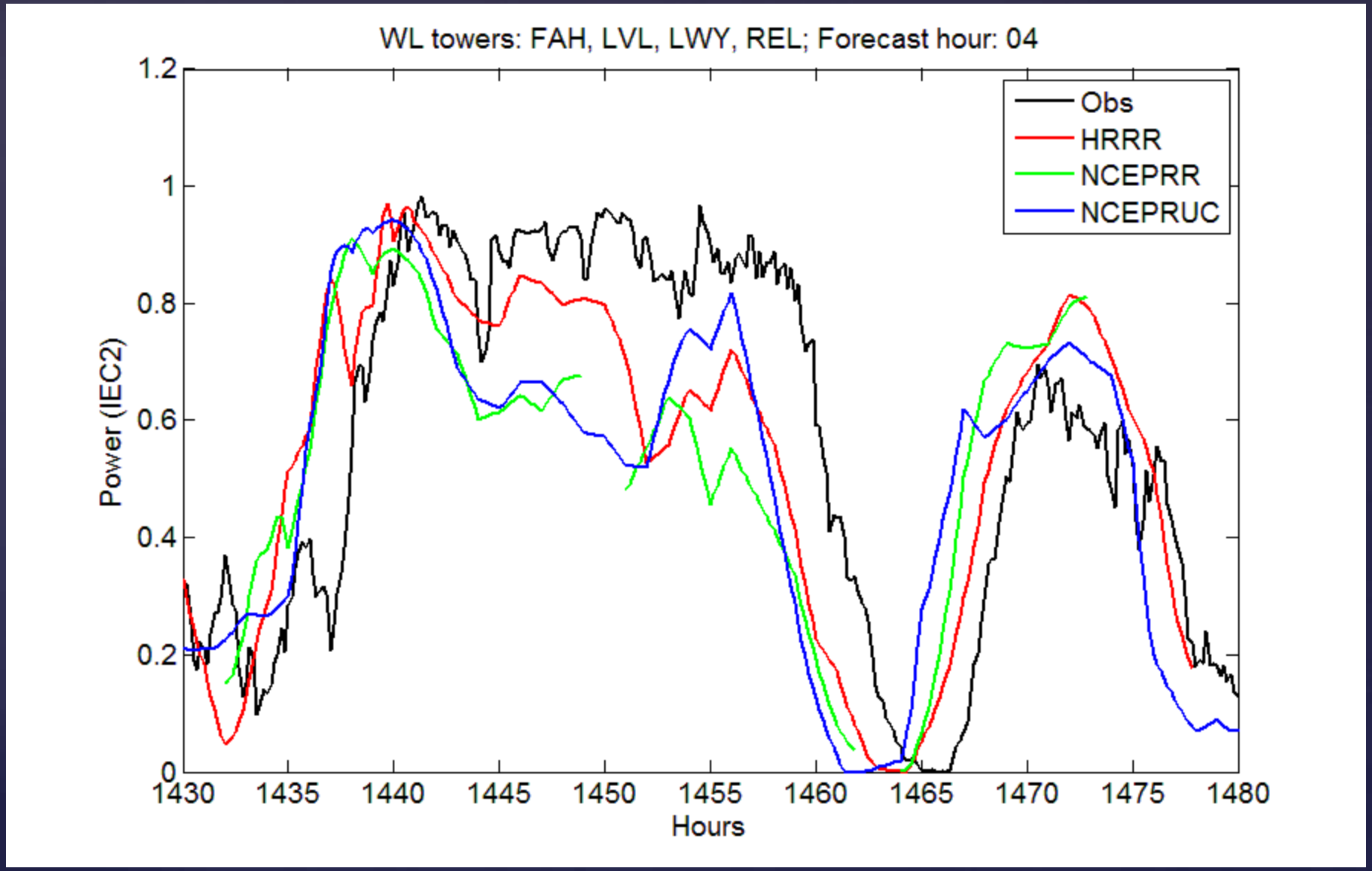


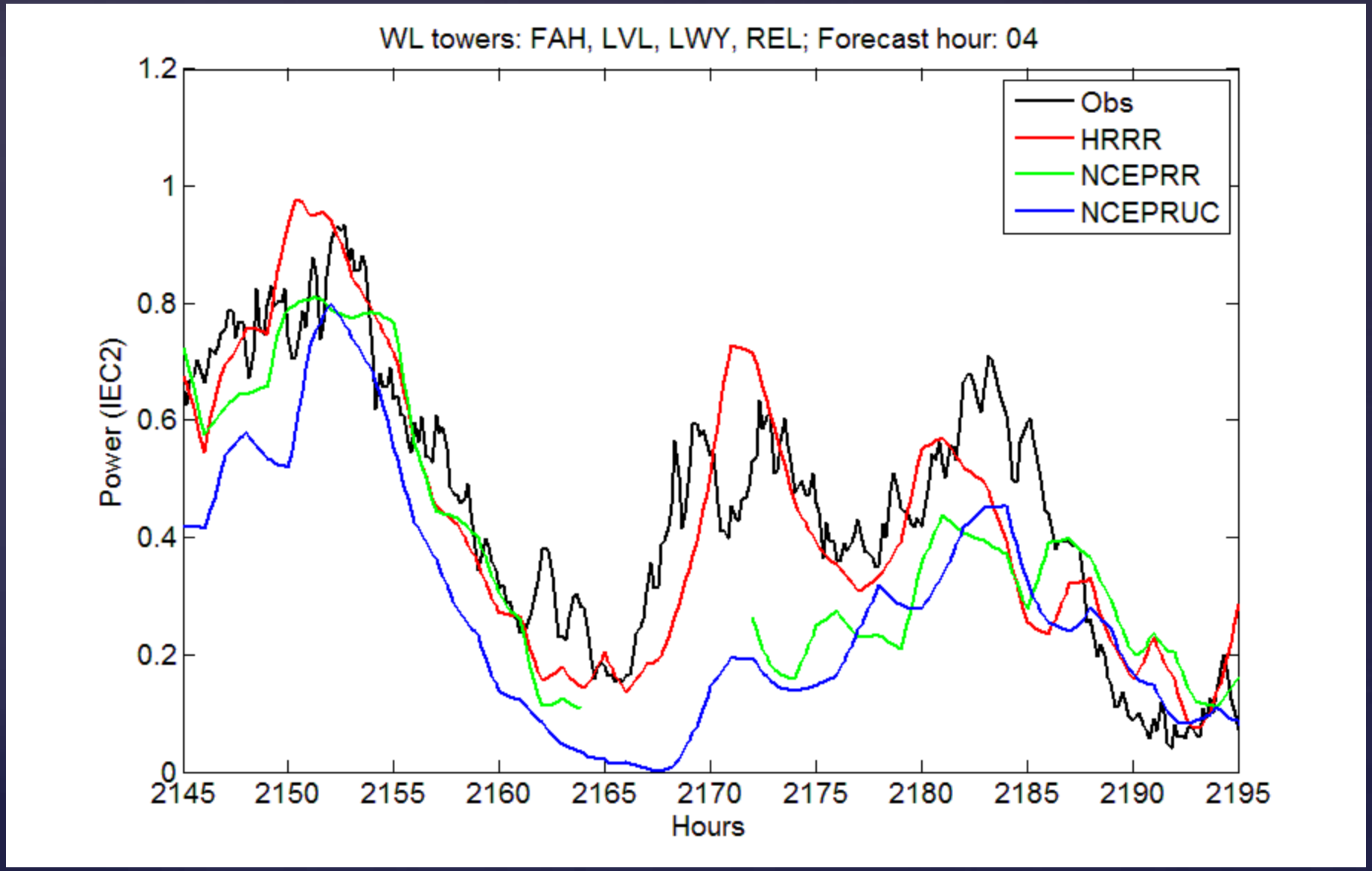
Statistics for 100 days (August 31 – Dec 08, 2012)


WL towers: FAH, LVL, LWY, REL; Forecast hour: 04
Obs
HRRR
NCEPRR
NCEPRUC
Power (IEC2)
Hours
0
0.2
0.4
0.6
0.8
1
1.2
410
415
420
425
430
435
440
445
450
455
460

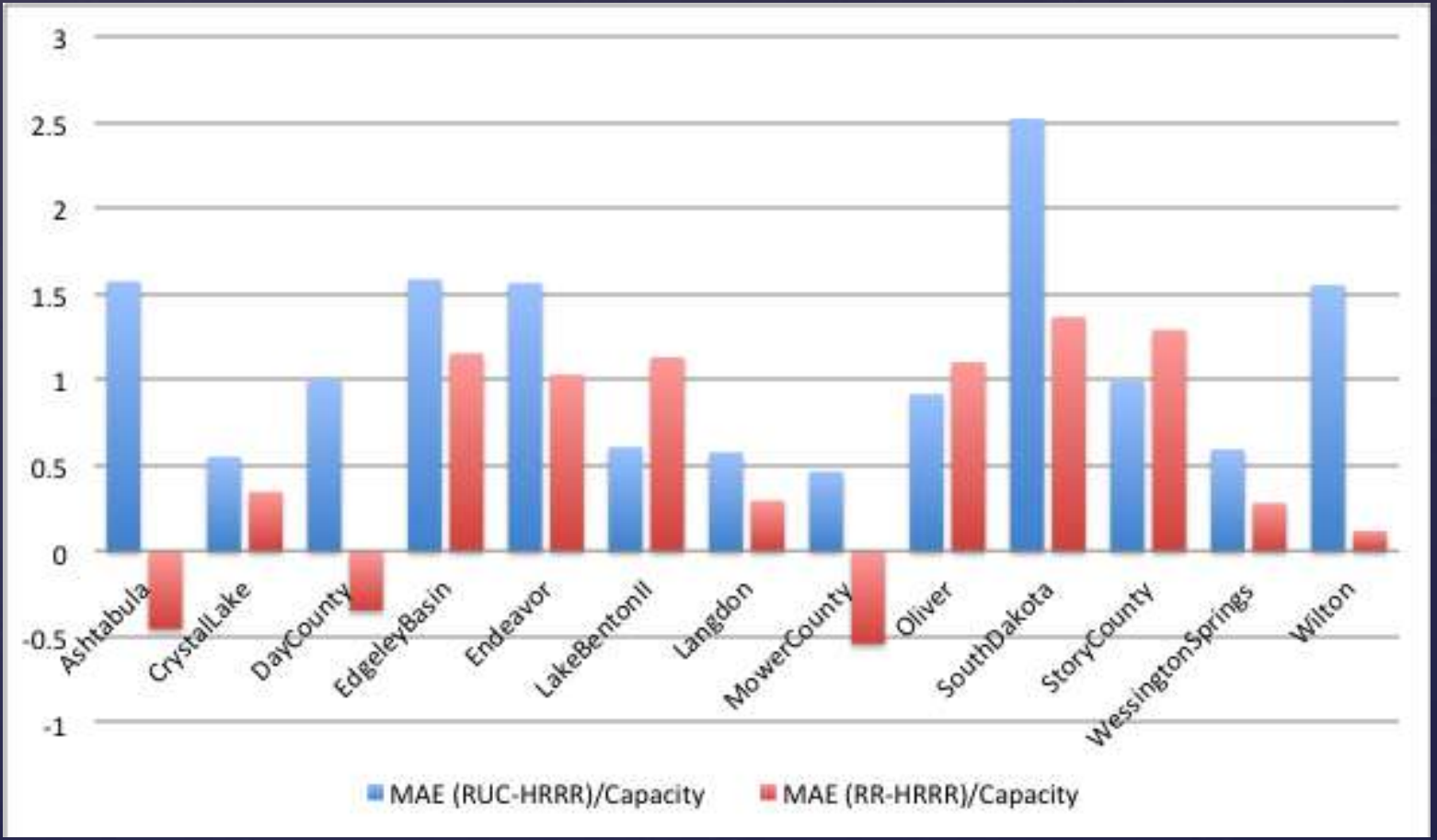

WL towers: FAH, LVL, LWY, REL; Forecast hour: 04
Obs
HRRR
NCEPRR
NCEPRUC
Power (IEC2)
Hours
0
0.2
0.4
0.6
0.8
1
1.2
600
605
610
615
620
625
630
635
640
645
650

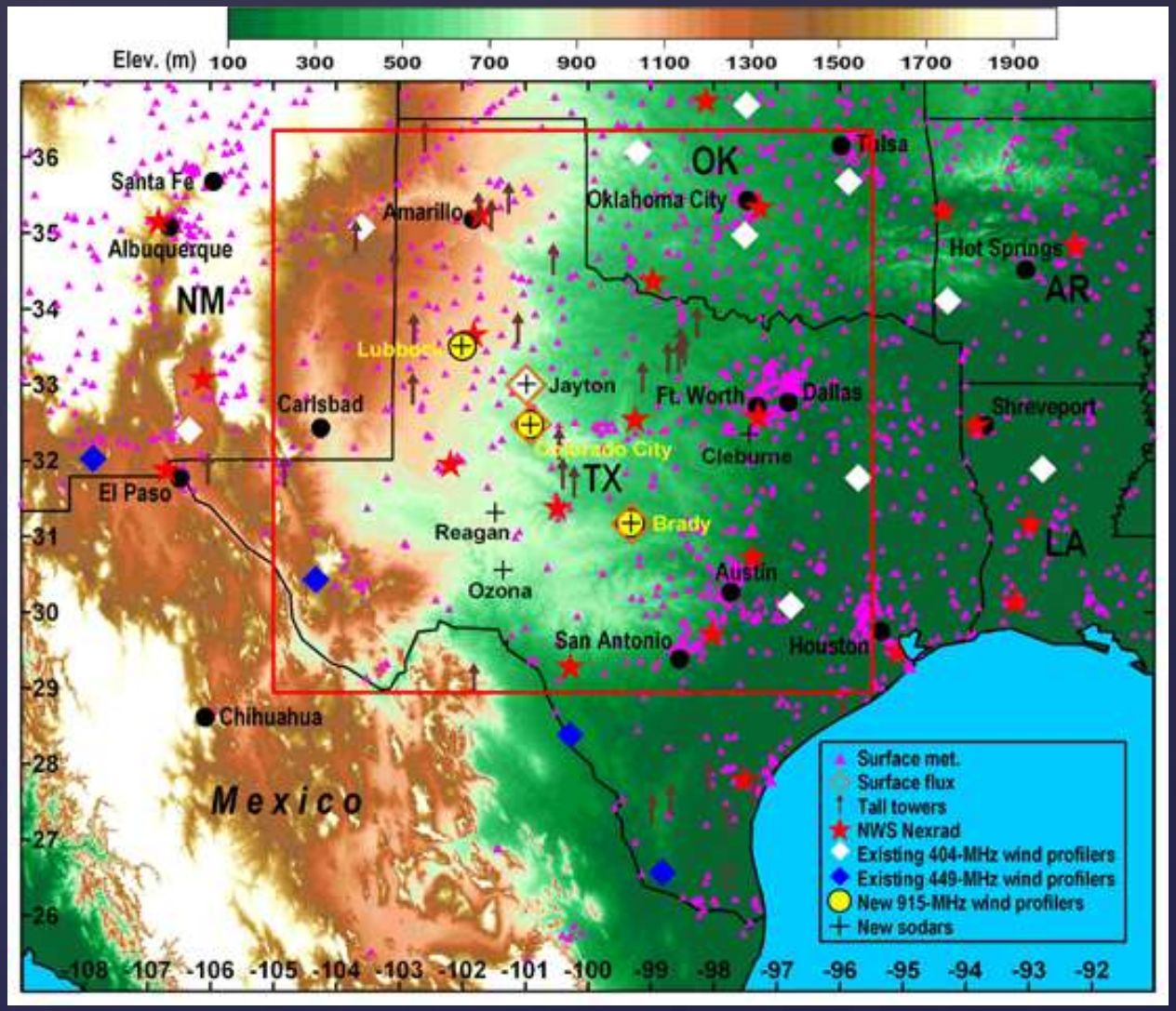

WL towers: FAH, LVL, LWY, REL; Forecast hour: 04
Obs
HRRR
NCEPRR
NCEPRUC
Power (IEC2)
Hours
0
0.2
0.4
0.6
0.8
1
1.2
1140
1145
1150
1155
1160
1165
1170
1175
1180
1185
1190

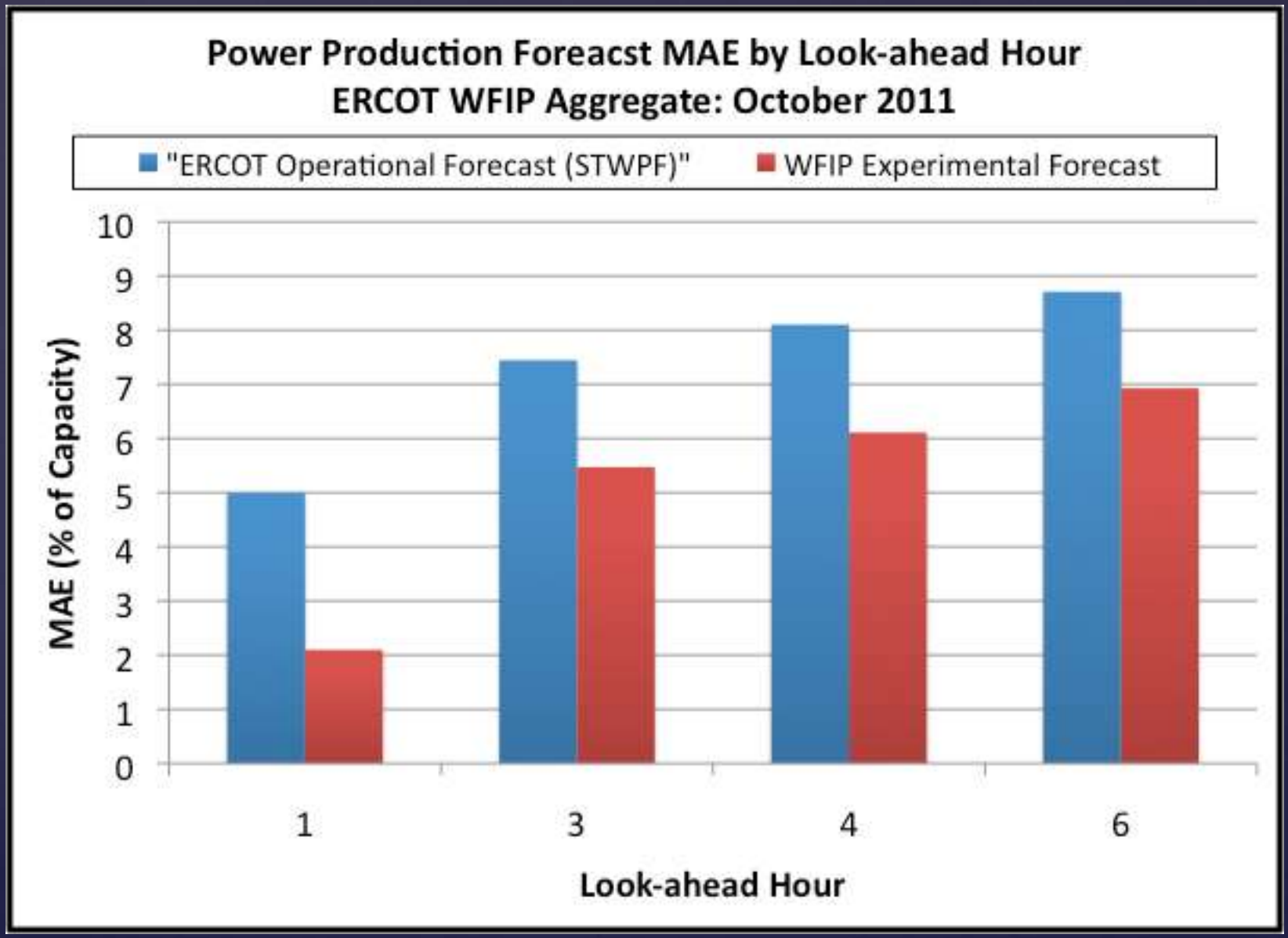

WL towers: FAH, LVL, LWY, REL; Forecast hour: 04
Obs
HRRR
NCEPRR
NCEPRUC
Power (IEC2)
Hours
0
0.2
0.4
0.6
0.8
1
1.2
1430
1435
1440
1445
1450
1455
1460
1465
1470
1475
1480


WL towers: FAH, LVL, LWY, REL; Forecast hour: 04
Obs
HRRR
NCEPRR
NCEPRUC
Power (IEC2)
Hours
0
0.2
0.4
0.6
0.8
1
1.2
2145
2150
2155
2160
2165
2170
2175
2180
2185
2190
2195

Raw 6 hour Forecasts




Elev. (m) 100 300 500 700 900 1100 1300 1500 1700 1900
Santa Fe
Albuquerque
NM
Amarillo
OK
Oklahoma City
Tulsa
Hot Springs
AR
Lubbock
Jayton
Ft. Worth
Dallas
Shreveport
Carlsbad
Cleburne
Colorado City
TX
El Paso
Reagan
Brady
LA
Ozona
Austin
San Antonio
Houston
Chihuahua
Mexico
Surface met.
Surface flux
Tall towers
NWS Nexrad
Existing 404-MHz wind profilers
Existing 449-MHz wind profilers
New 915-MHz wind profilers
New sodars
36
35
34
33
32
31
30
29
28
27
26
-108 -107 -106 -105 -104 -103 -102 -101 -100 -99 -98 -97 -96 -95 -94 -93 -92


Power Production Foreacst MAE by Look-ahead Hour
ERCOT WFIP Aggregate: October 2011
"ERCOT Operational Forecast (STWPF)"
WFIP Experimental Forecast
MAE (% of Capacity)
10
9
8
7
6
5
4
3
2
1
0
1
3
4
6
Look-ahead Hour

Preliminary Results—Southern Region

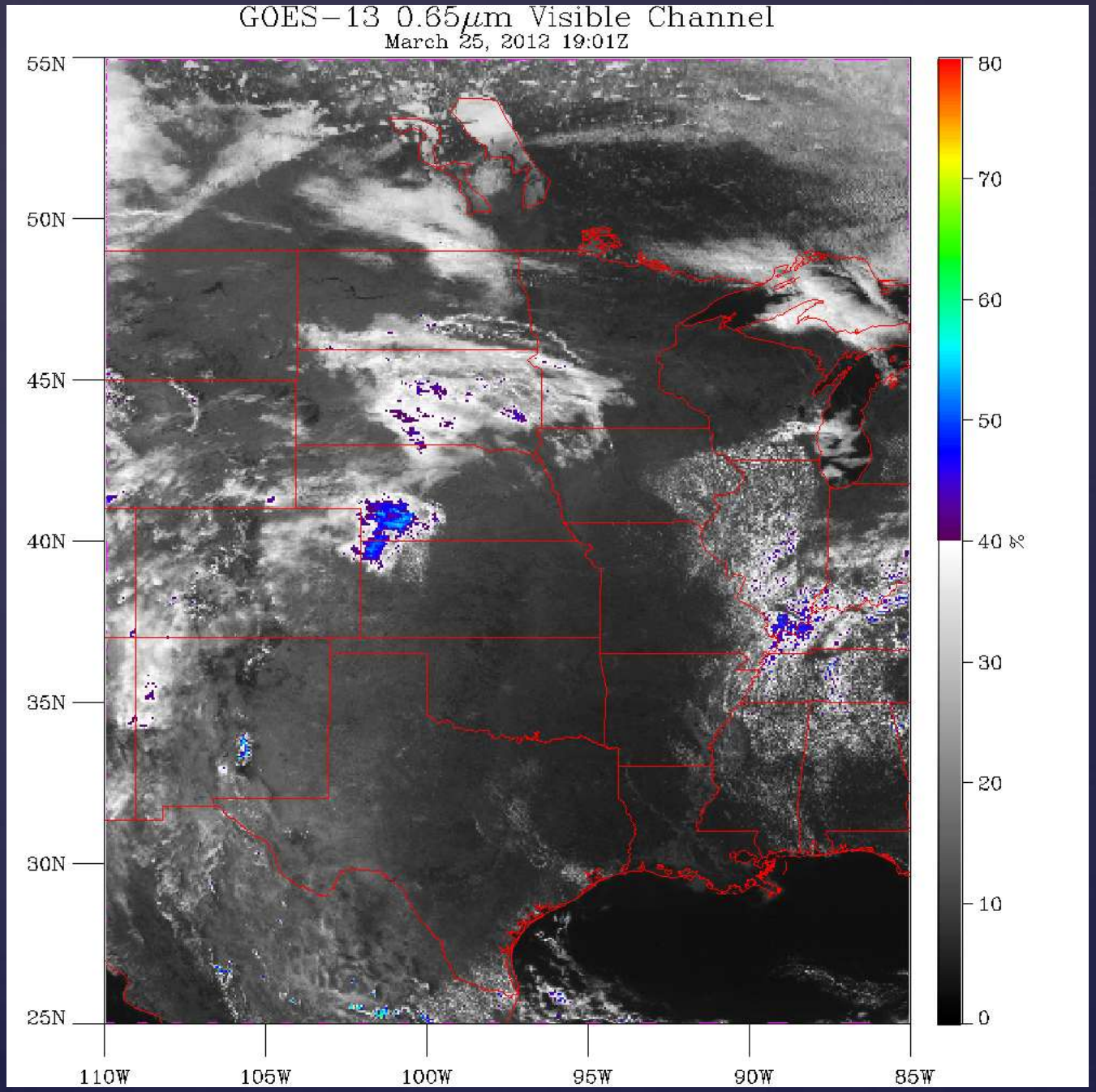
- Analyses performed for "shoulder" month – October 2011 when load is low and wind speeds are higher
- Operational Cost Savings are dependent on natural gas prices – average actual price of 3.44 $/MMBtu used for October in Texas
- Preliminary results show both environmental and cost benefits as a result of improved forecasts

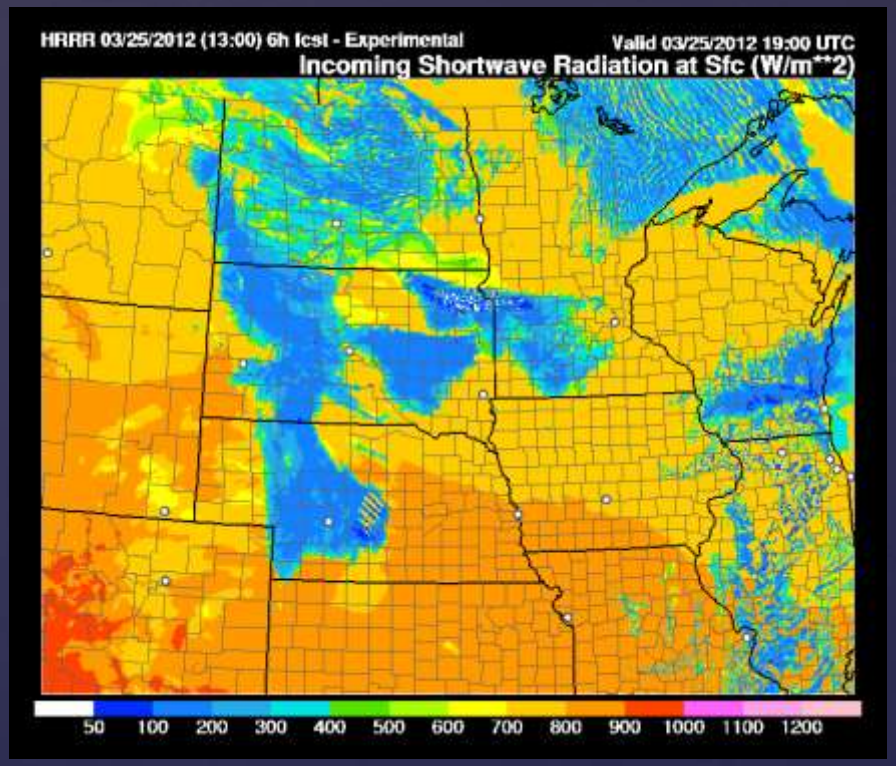
Parameter	Benefit (Savings)
Production Cost ($)	(1,086,000)
Cost to Serve Load ($)	(5,752,123)
Conventional Units - Number of Starts	(49)
Emissions (NOx Tons)	(4)
Reduction in Wind Generation Curtailment (GWh)	(22)
~ Energy Imbalance Costs paid by Wind Generators ($)	(1,500,000)

Case	Percent Error (% of total Wind Capacity)		MW Error (Based on 8,132 MW of installed wind capacity)	
	Mean Average Error (%)	Standard Deviation (%)	Mean Average Error (MW)	Standard Deviation (MW)
Old 6 hour Forecast	8.5%	7.0%	694	570
New 6 hour Forecast	6.8%	6.3%	554	513
Improvement	-1.7%	-0.7%	(140)	(57)
Old 4 hour Forecast	7.9%	6.4%	645	524
New 4 hour Forecast	6.0%	5.5%	489	448
Improvement	-1.9%	-0.9%	(155)	(76)
Old 2 hour Forecast	6.3%	5.4%	515	435
New 2 hour Forecast	4.2%	3.7%	345	298
Improvement	-2.1%	-1.7%	(170)	(137)

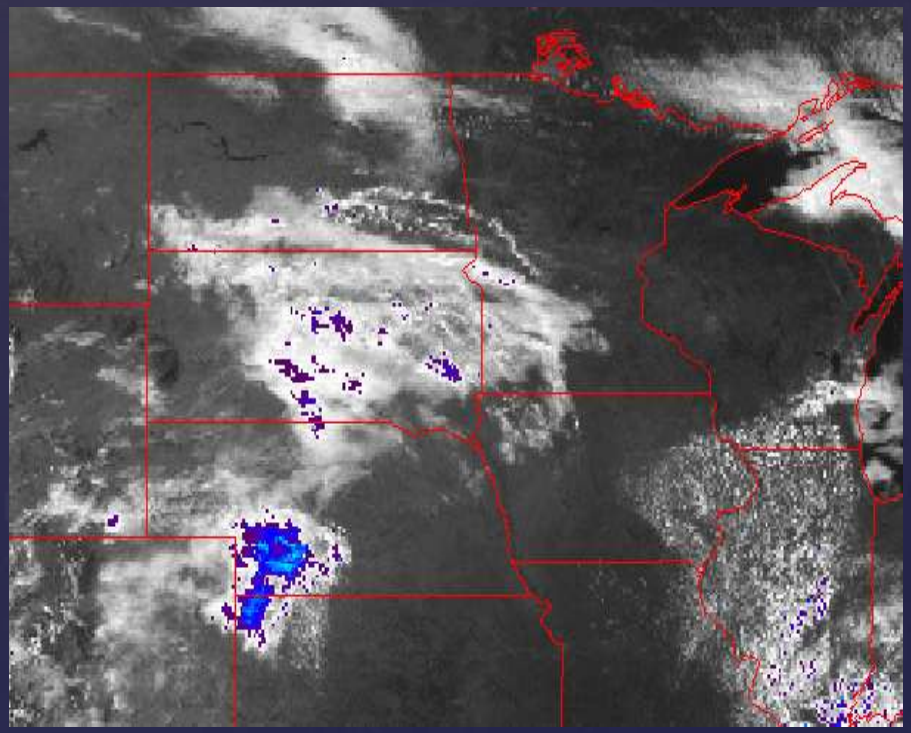
Solar Forecasting

- Insights from WFIP
  - WFIP focused on wind, but also designed to provide useful solar data
- HRRR model is advanced in its assimilation of cloud-related observations: WSR 88D and satellite data, plus aircraft data
- Case study from 25 March 2012, partly cloudy in upper midwest


GOES−13 0.65μm Visible Channel
March 25, 2012 19:01Z
55N
50N
45N
40N
35N
30N
25N
110W
105W
100W
95W
90W
85W
80
70
60
50
40
30
20
10
0
%

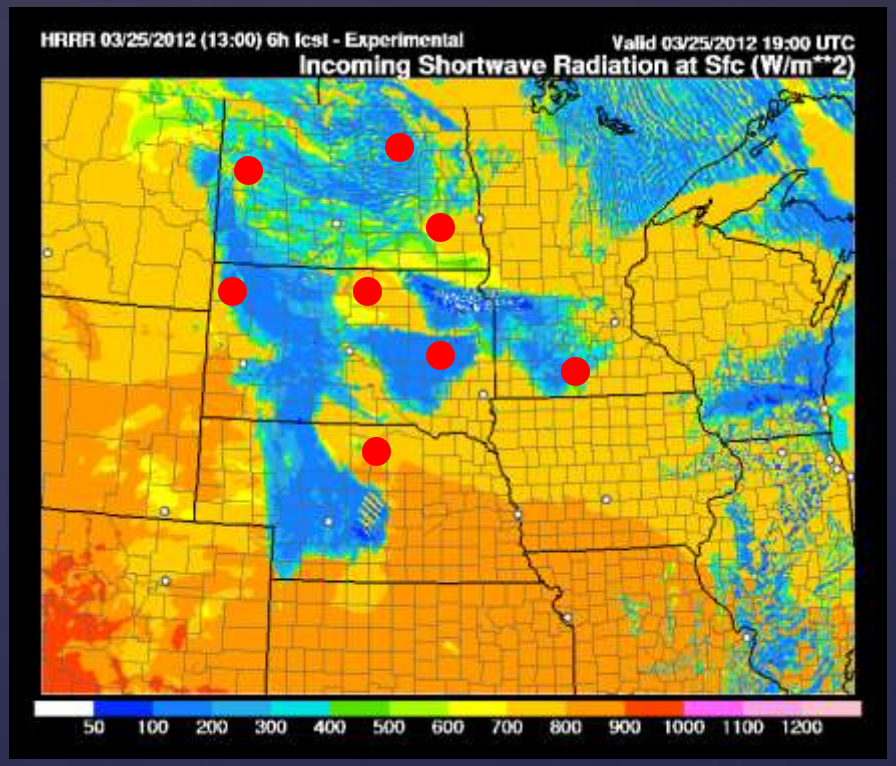


HRRR 6 h Solar Radiation forecast valid 19 UTC 25 March 2012

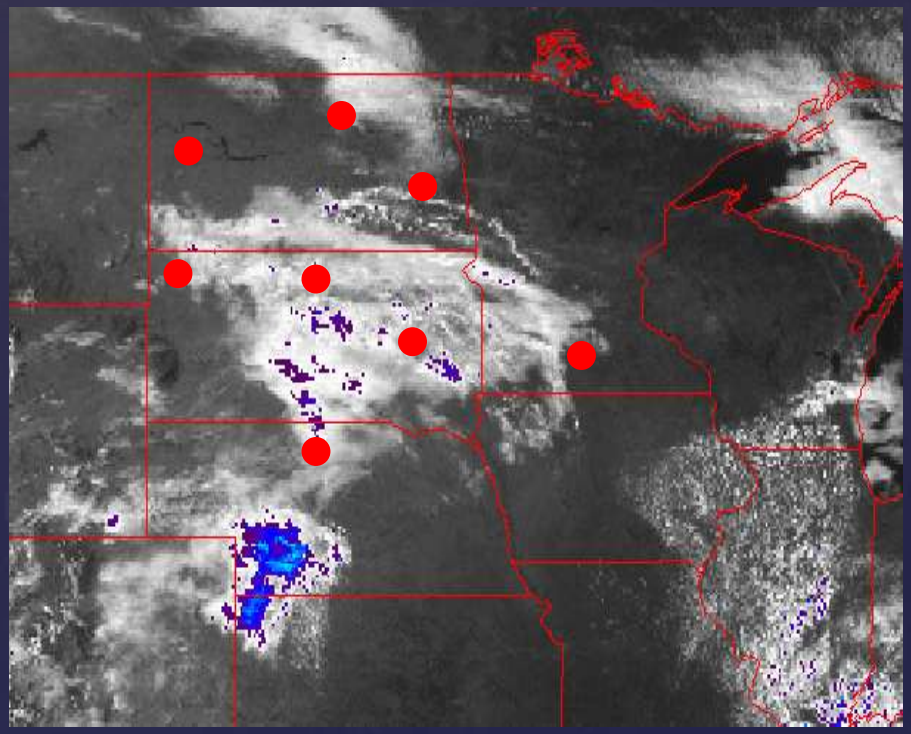


GOES Visible 19 UTC 25 March 2012

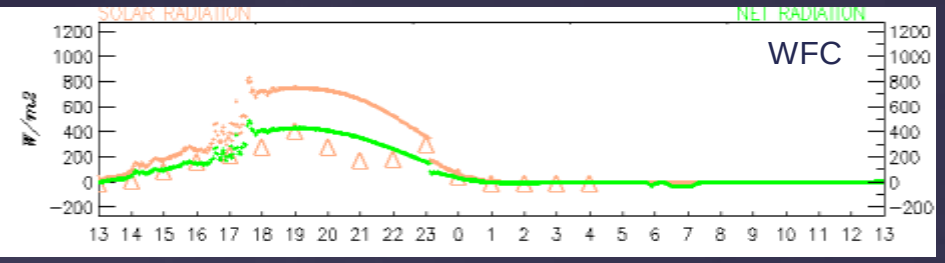
Solar radiation measurements taken at wind profiler sites

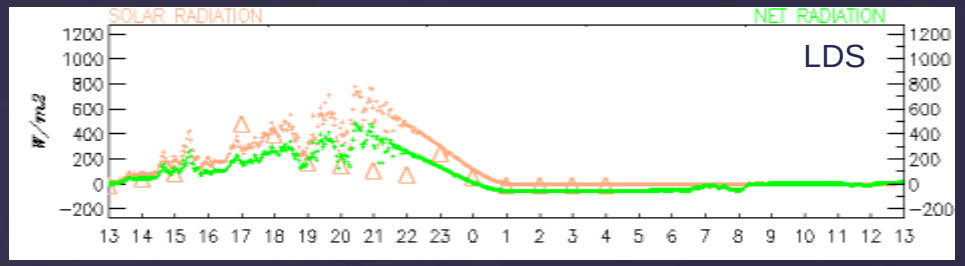


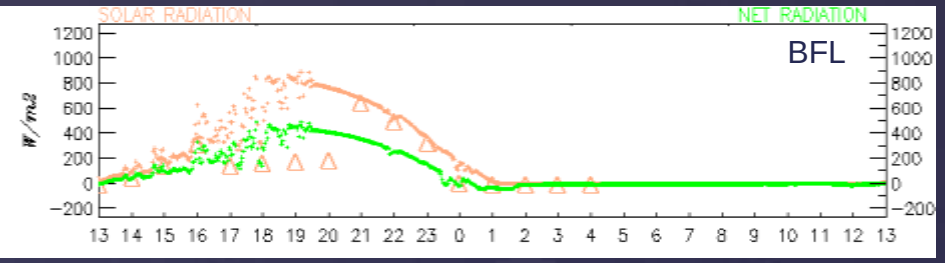
HRRR 6 h Solar Radiation forecast valid 19 UTC 25 March 2012

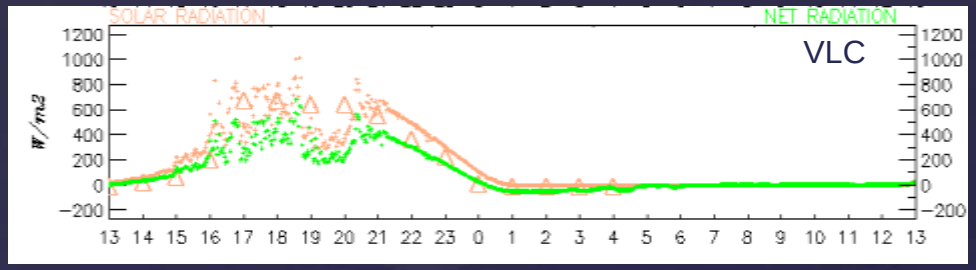


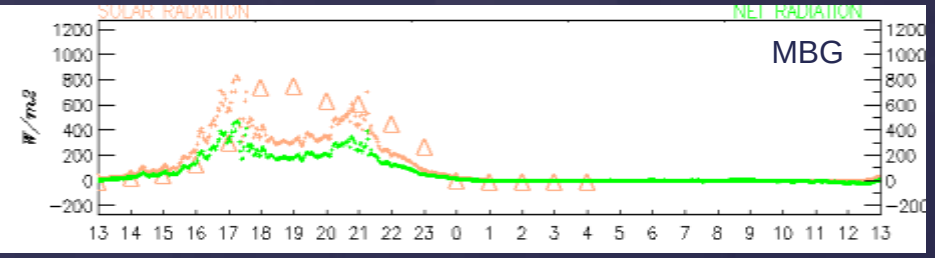
GOES Visible 19 UTC 25 March 2012

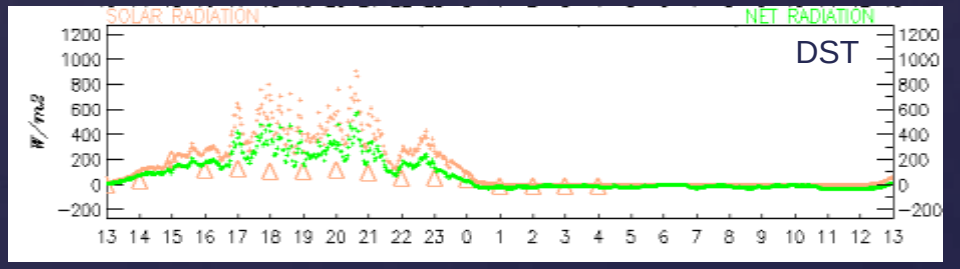


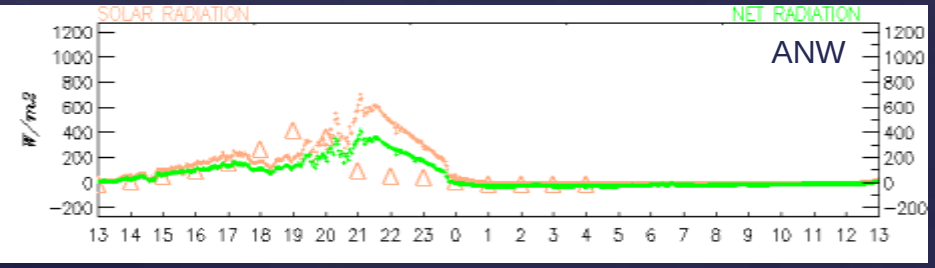


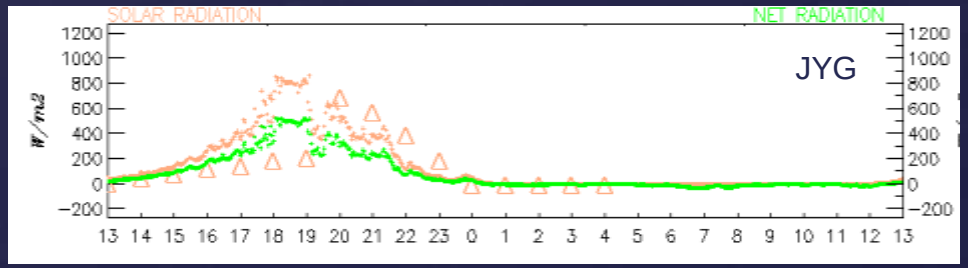




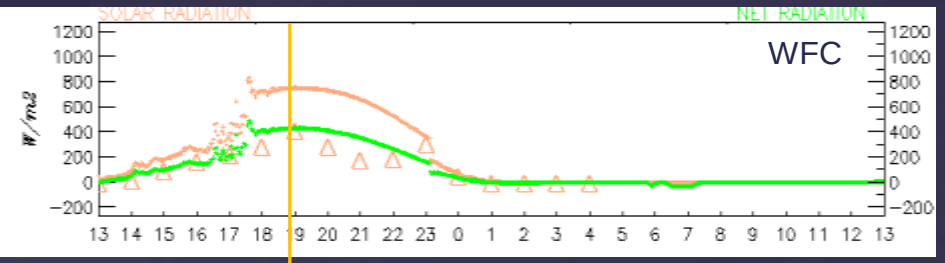


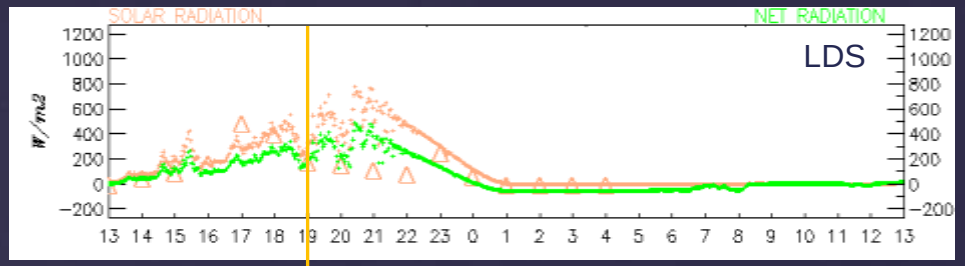


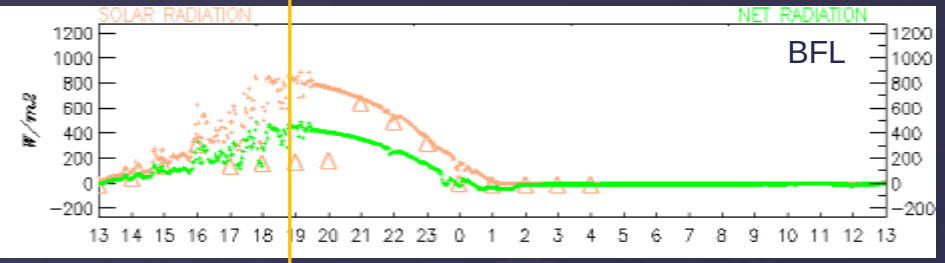


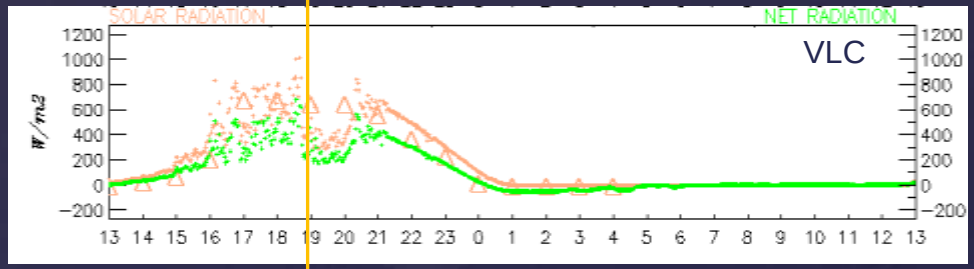


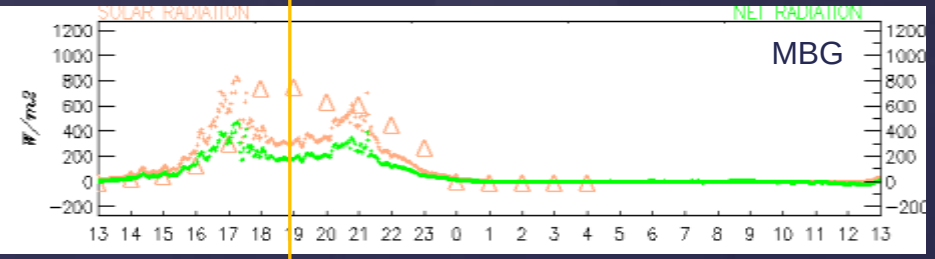
HRRR solar radiation forecasts initialized 13 UTC 25 March 2012

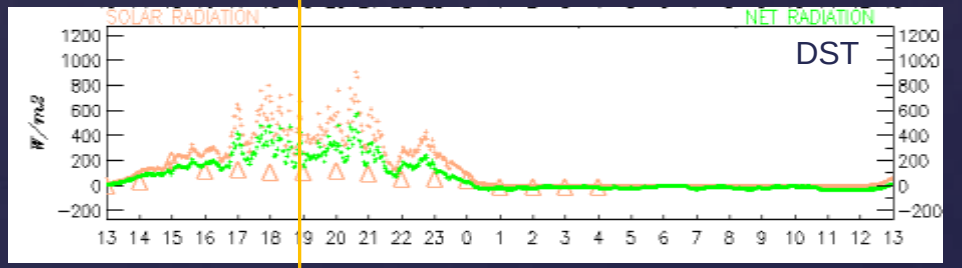


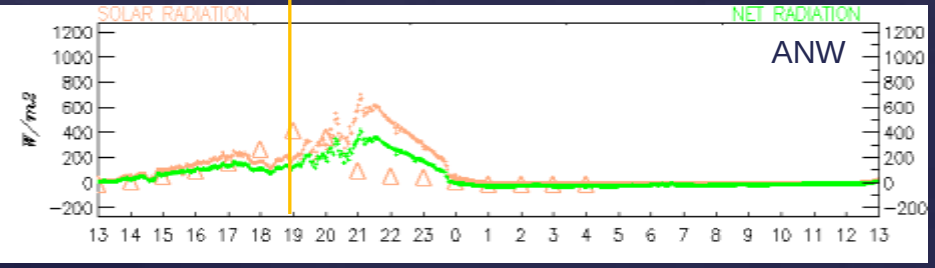


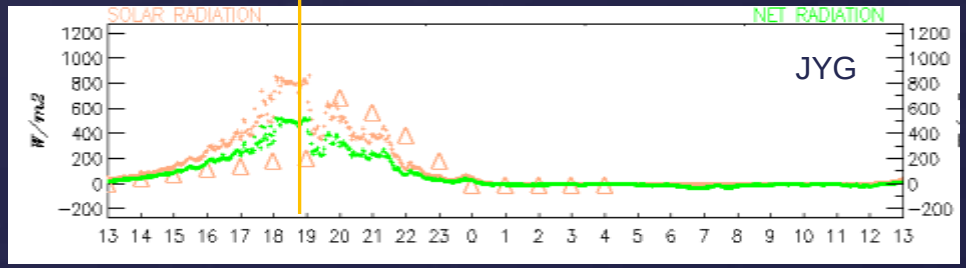




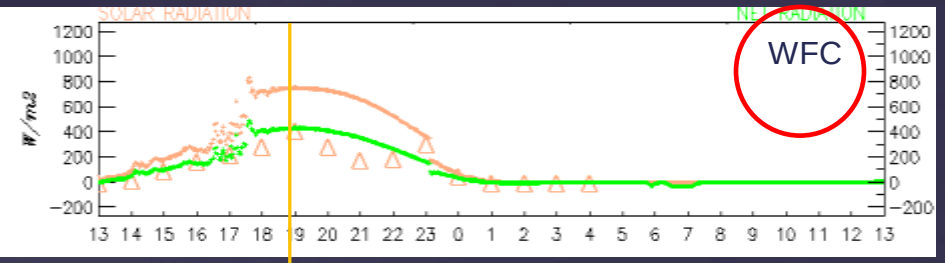


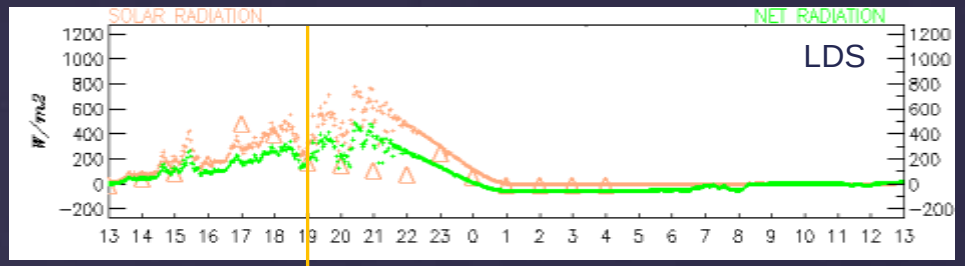


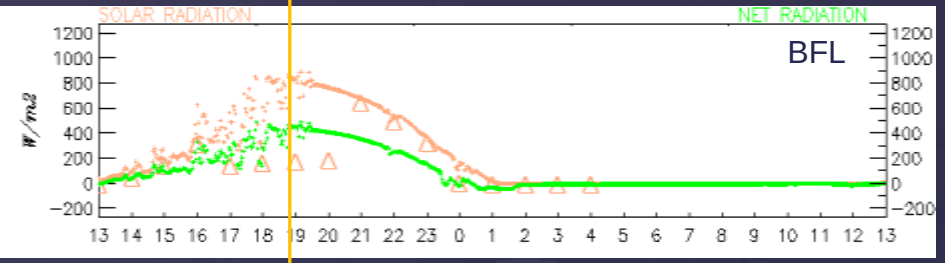


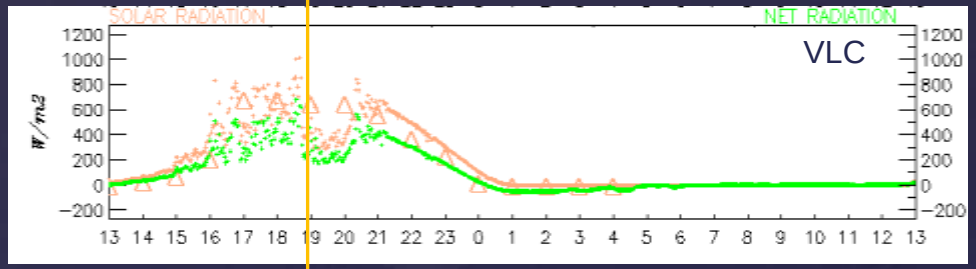


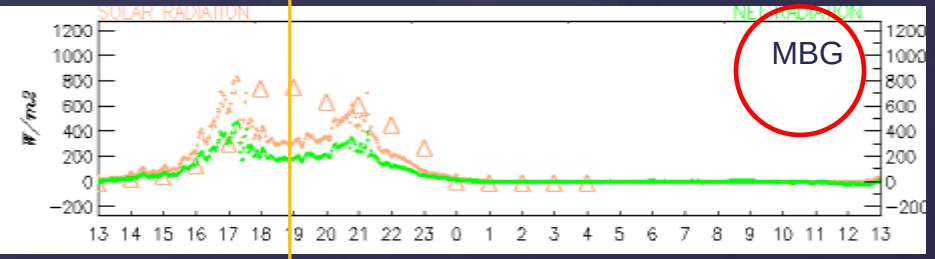
HRRR solar radiation forecasts initialized 13 UTC 25 March 2012

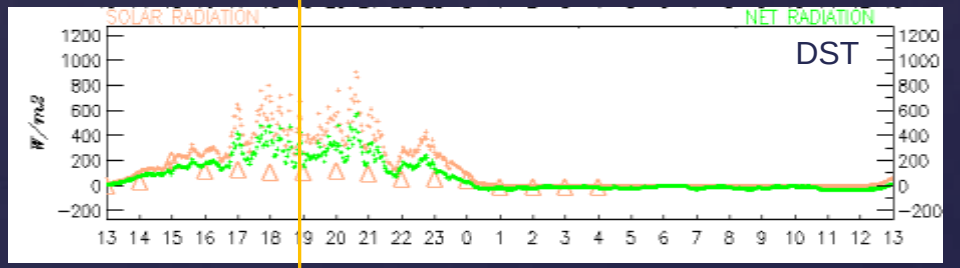


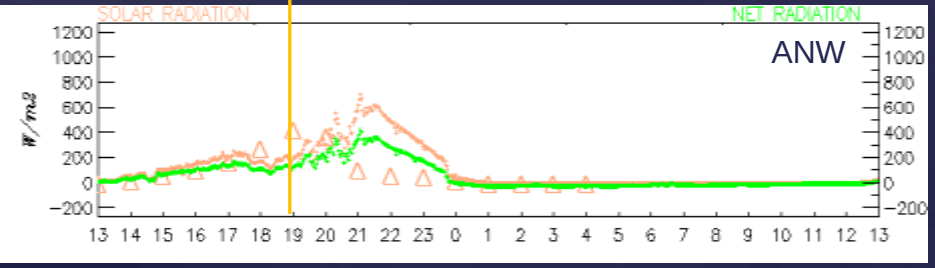


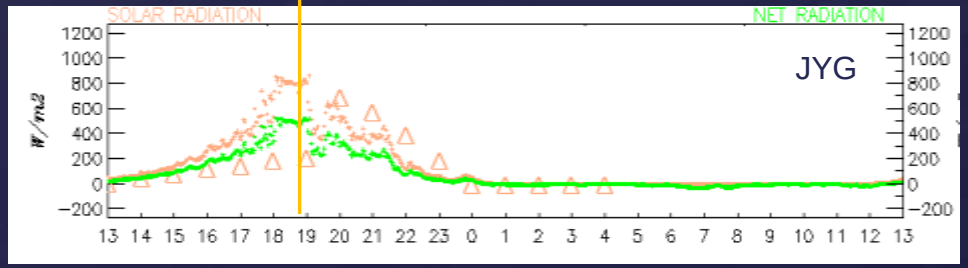




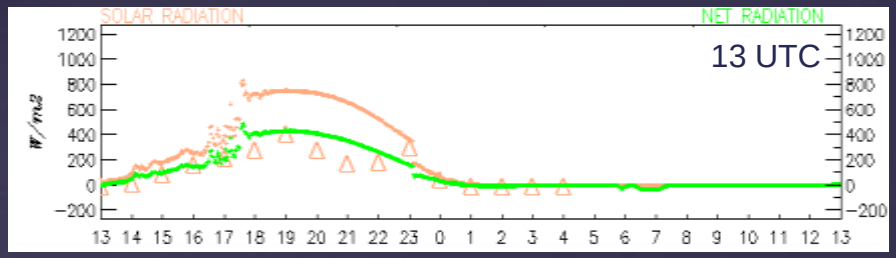


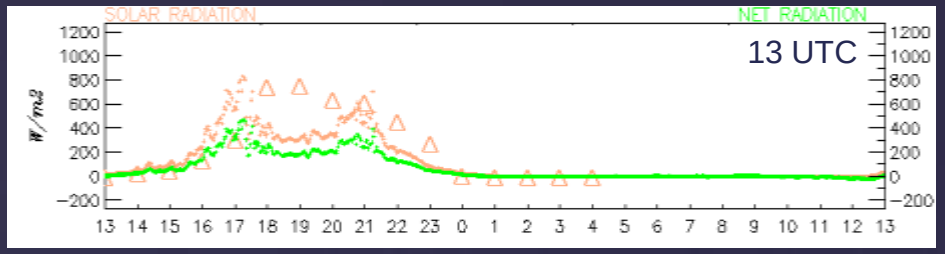


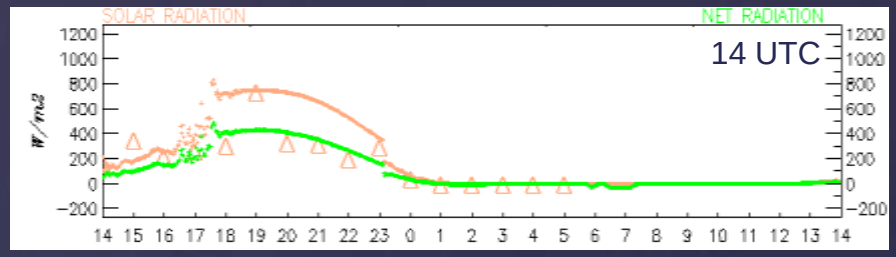


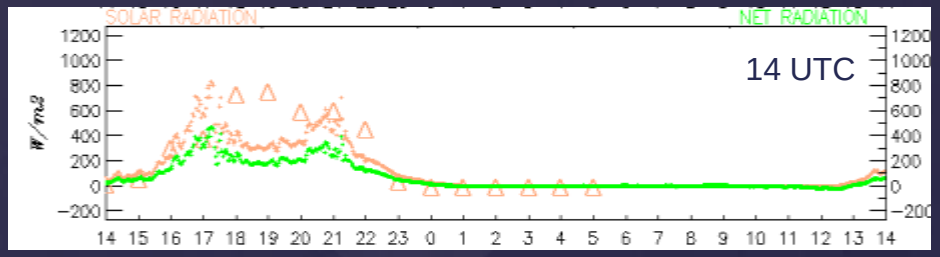


HRRR solar radiation forecasts initialized 13 UTC 25 March 2012


SOLAR RADIATION
NET RADIATION
13 UTC
W/m2


SOLAR RADIATION
NET RADIATION
13 UTC
W/m2


SOLAR RADIATION
NET RADIATION
14 UTC
W/m2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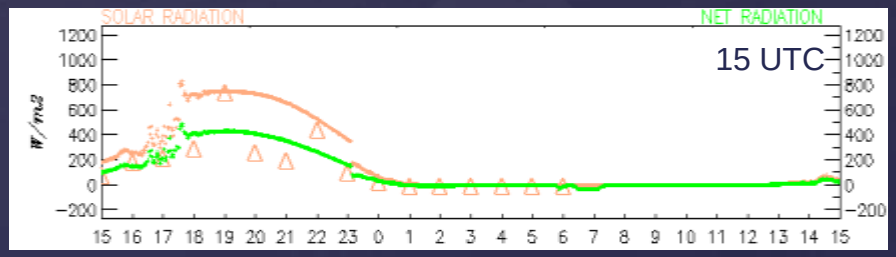
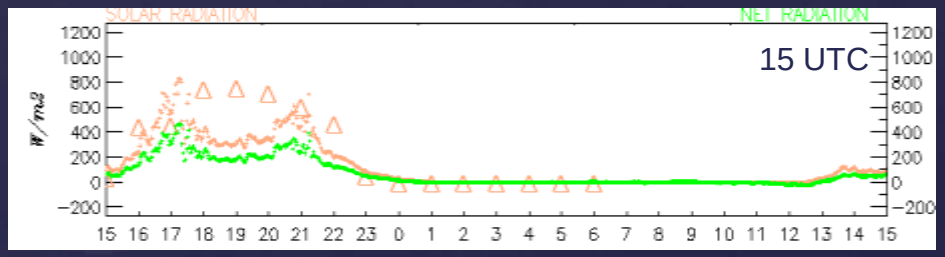
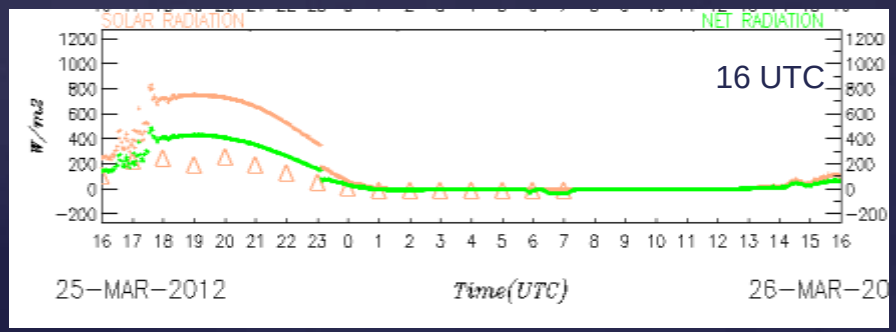
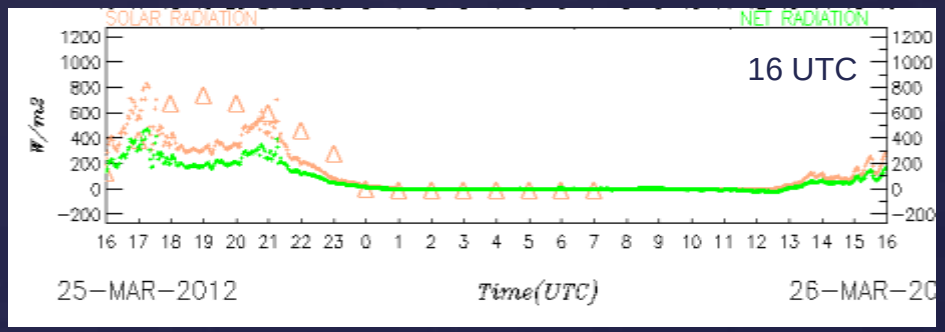
NET RADIATION
14 UTC
W/m2


SOLAR RADIATION
NET RADIATION
15 UTC
W/m2

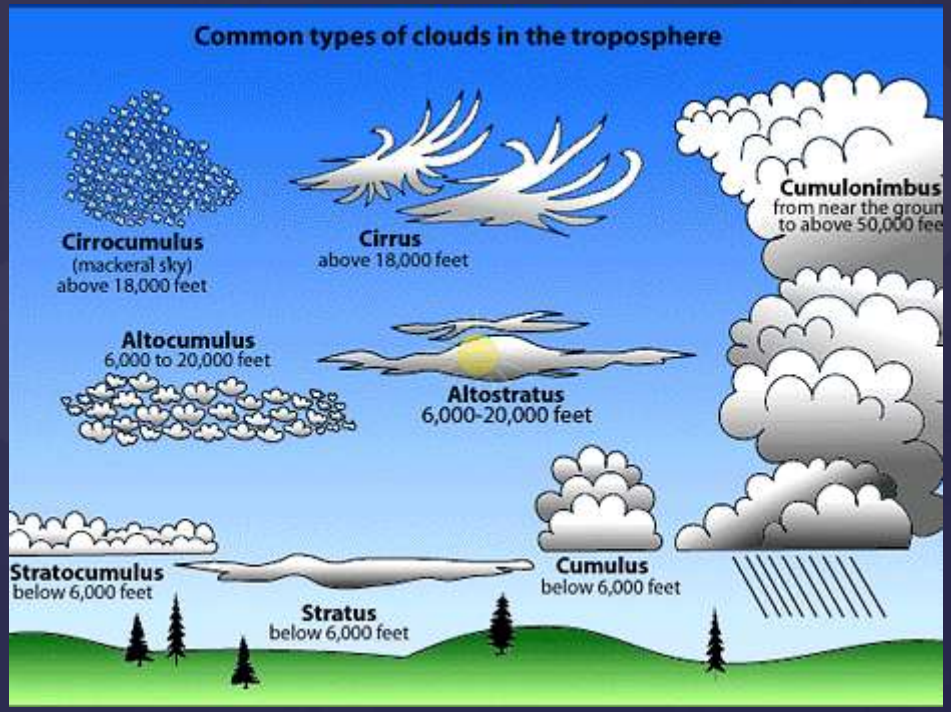

SOLAR RADIATION
NET RADIATION
15 UTC
W/m2


SOLAR RADIATION
NET RADIATION
16 UTC
W/m2
25-MAR-2012
Time(UTC)
26-MAR-20


SOLAR RADIATION
NET RADIATION
16 UTC
W/m2
25-MAR-2012
Time(UTC)
26-MAR-20

WFC

MBG


Common types of clouds in the troposphere
Cirrocumulus
(mackeral sky)
above 18,000 feet
Cirrus
above 18,000 feet
Cumulonimbus
from near the groun
to above 50,000 fee
Altocumulus
6,000 to 20,000 feet
Altostratus
6,000-20,000 feet
Stratocumulus
below 6,000 feet
Cumulus
below 6,000 feet
Stratus
below 6,000 feet

- What types of clouds exist at what heights?
- Can your model reproduce each of these types of clouds?
- How do the clouds interact with one another?
- To what degree are operational cloud forecasts limited by:
  - HPC?
  - Observations for initialization?
  - Physical understanding/parameterization?
- Would a focused research effort at solar forecasting produce improvements?

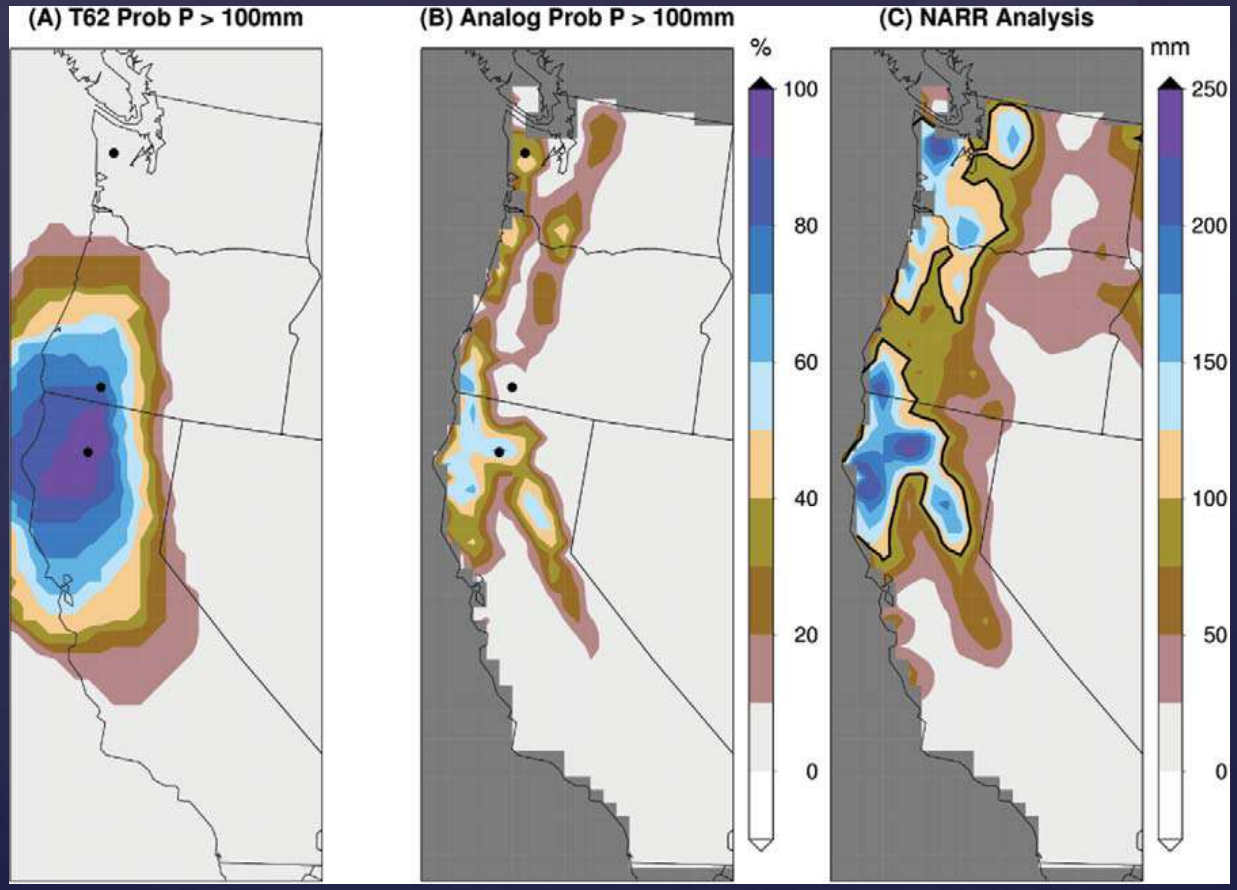
Post-processing

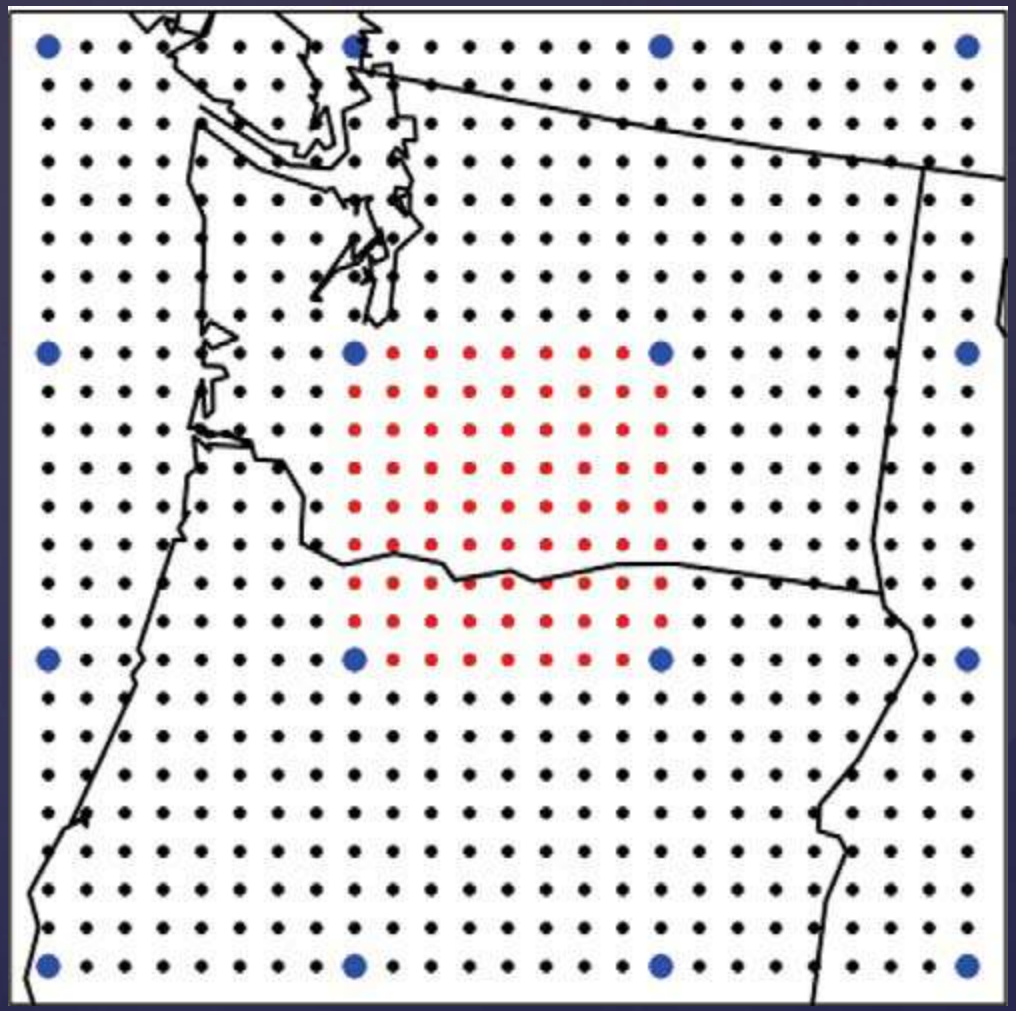
- Most NOAA/NWS NWP forecasts are bias-corrected (MOS)
- Private forecasting industry uses proprietary techniques
- "Reforecasting" is relatively recent development that has lead to large forecast skill improvements

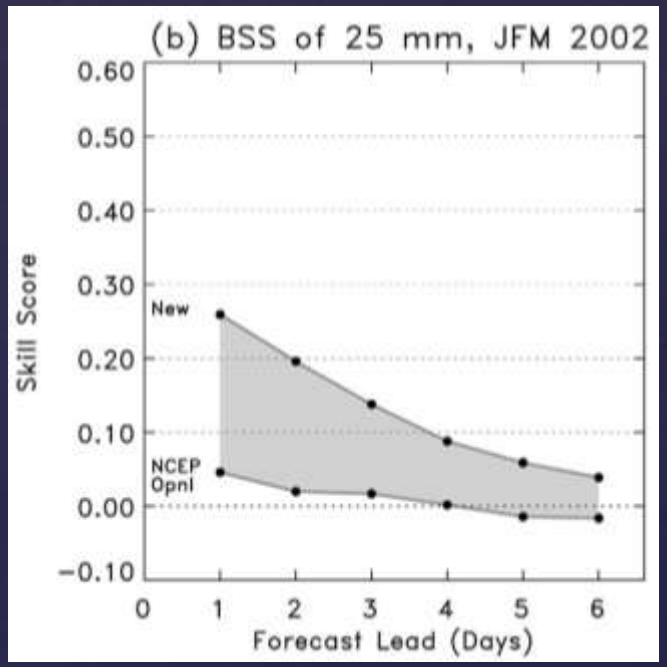
Reforecasting

Hamill and Whitaker (2004, 2005, 2008, 2011)

- Analogs – Select historical forecasts that are analogs the current forecast
- Observational data corresponding to each analog
- Ensemble formed from the analog observations







Ensemble of analog observations gives improved skill score

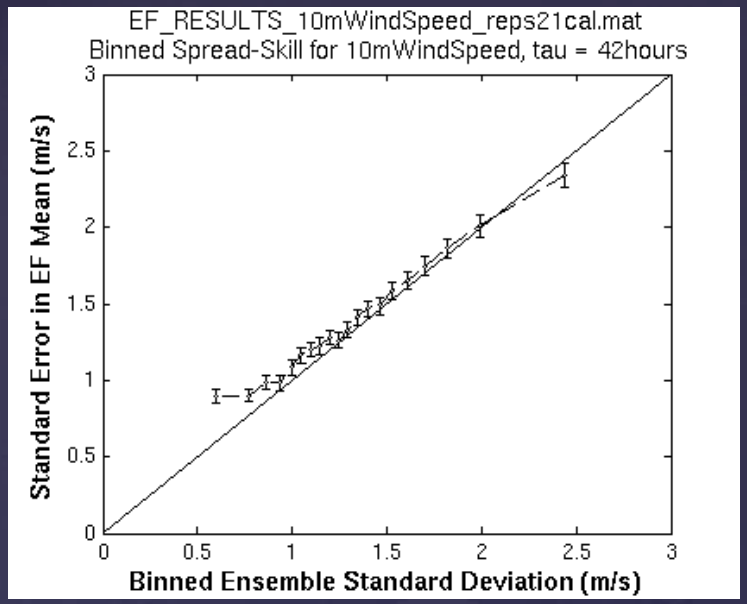
Analog selection is based on pattern recognition

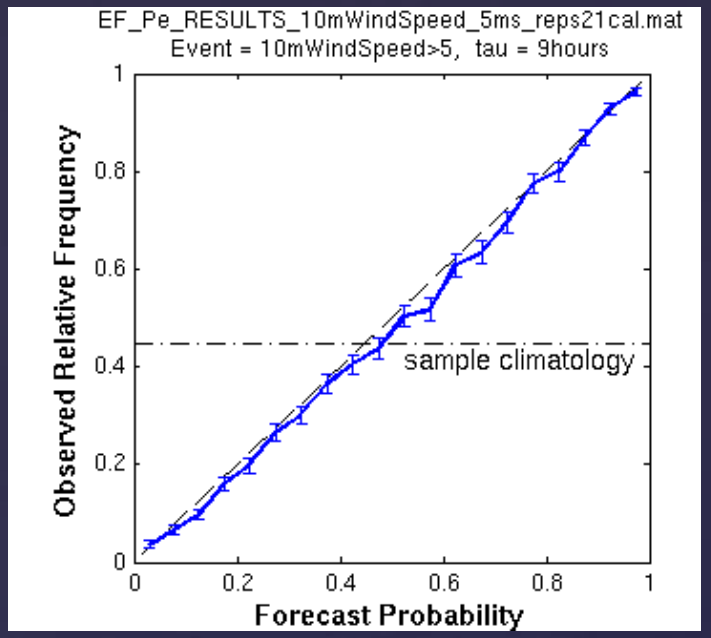
Analog Ensemble vs NWP Ensemble

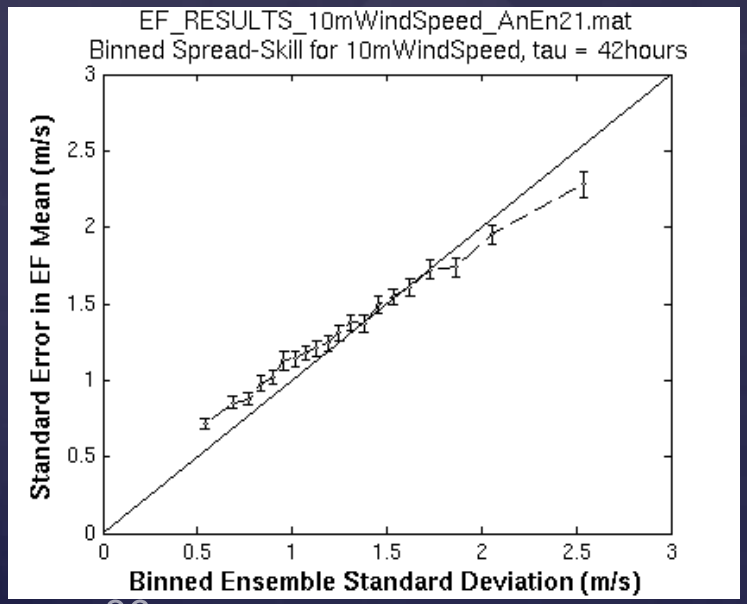
AnEn generated using Environment Canada GEM model (15 km)

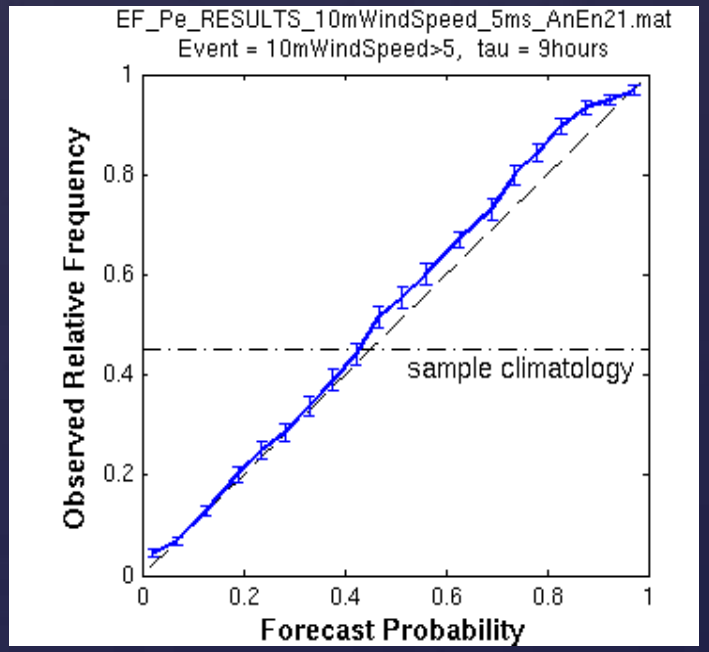
NWP Ensemble from Environment Canada
Regional Ensemble Prediction System (REPS) (33 km)

- 550 hourly METAR Surface Observations
- 1 May 2010 – 31 July 2011, for a total of 457 days
- 10-m wind speed









Spread---skill diagram,
10---m wind speed, 42---h fcst

Reliability diagram:
10-m wind speed > 5 m s-1, 9-h fcst

Closing Argument

Forecasts for wind (and hopefully solar) energy can be improved through:

- New observations (accuracy, quantity, depth of coverage, parameter)
- Data assimilation
- Physical processes/model resolution/ensembles
- Post-processing

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NORTH
Program Links
WFIP Home
South Region
Contact Us

Model Cycle
Select the model cycle initialization:
00 Z Aug 28

Sites
Select site type:
(•) Profiler
( ) Sodar
( ) Lidar
Select site location:
Ainsworth,NE
Select a date:

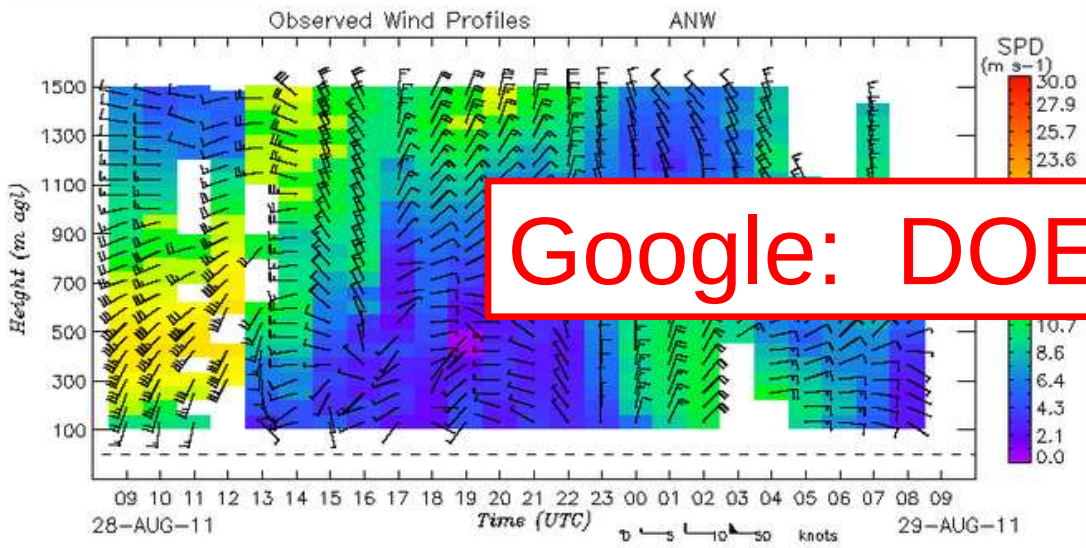
< August 2011 >						
Sun	Mon	Tue	Wed	Thu	Fri	Sat
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

Page Updated:
Sat, 15 Oct 2011
01:44:35 GMT

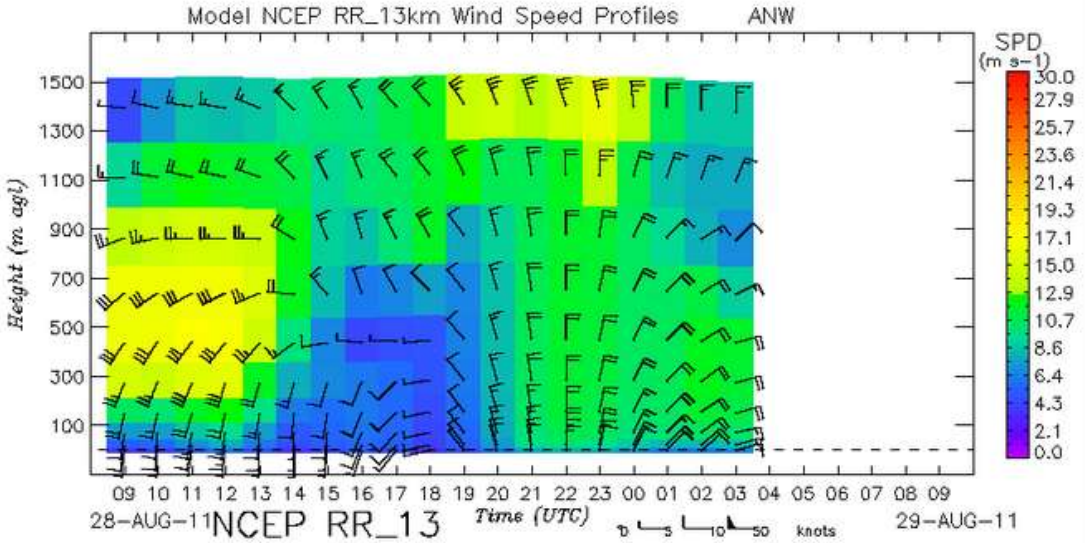
Contact
James Wilczak

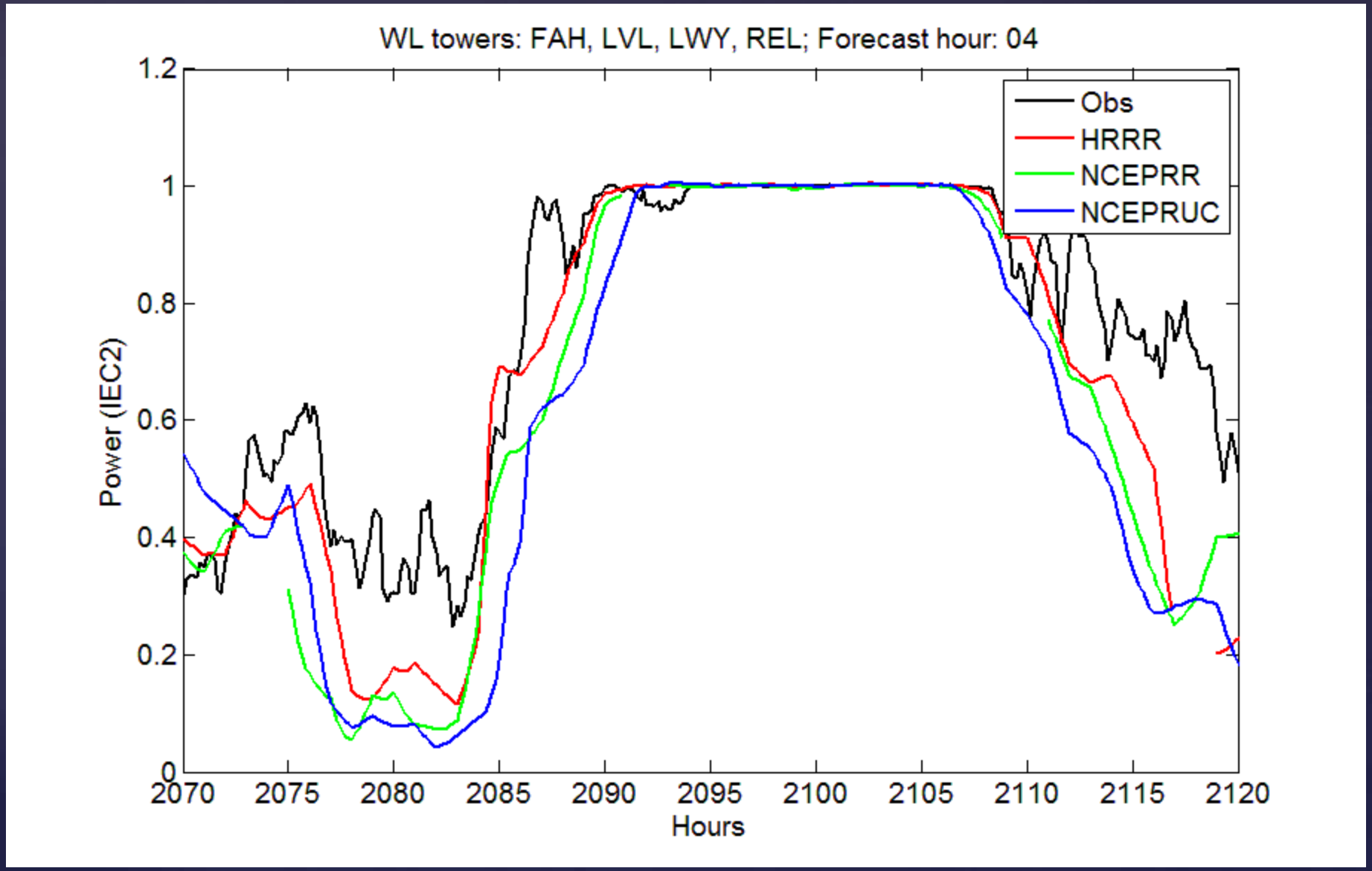
HRRR | RR | RUC | NCEP RR | NCEP RUC | NCEP NAM | NCEP GFS

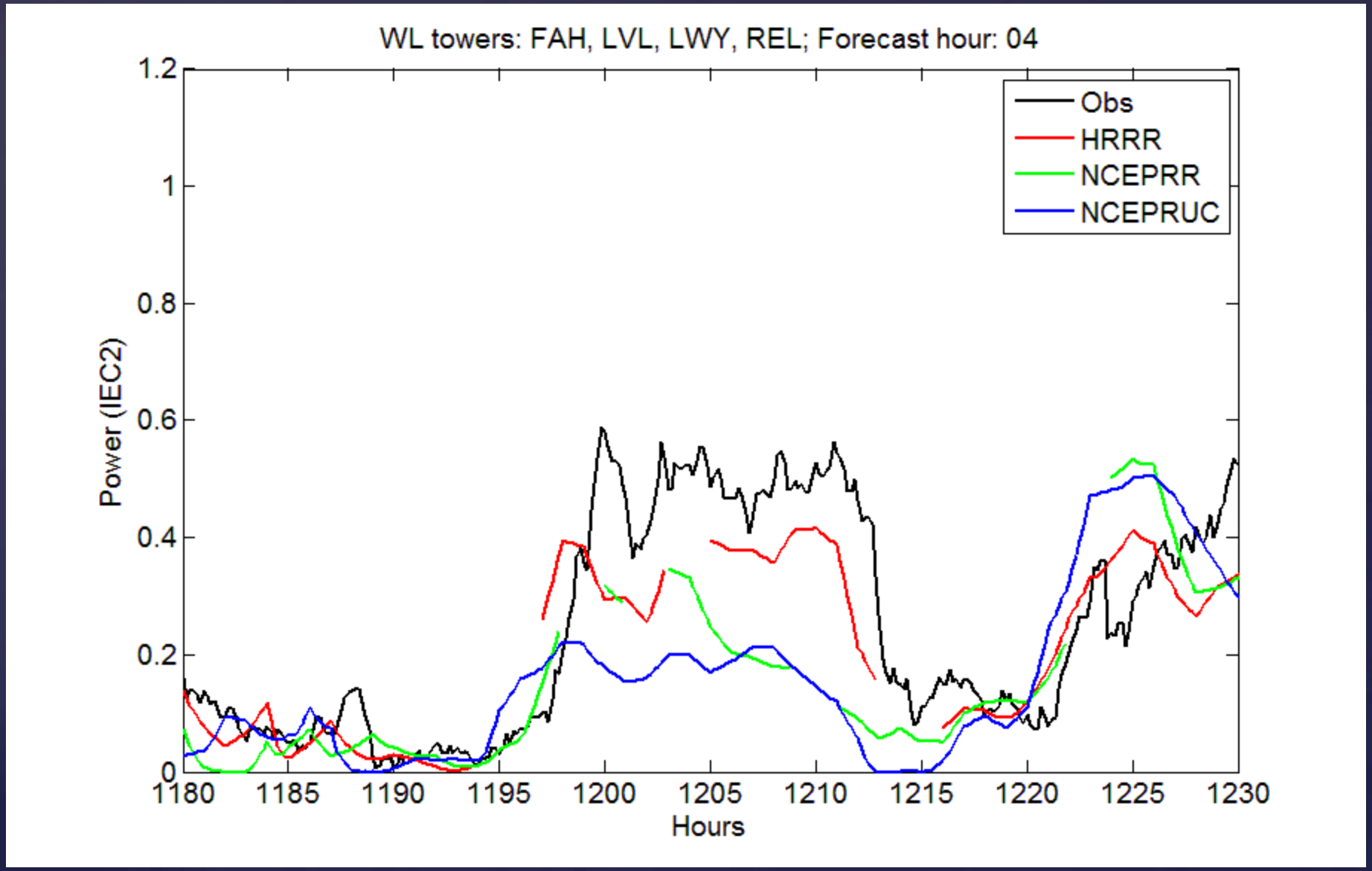
SNR/Winds | RASS/Winds | Surface | SPD LR | SPD HR



Google: DOE WFIP




WL towers: FAH, LVL, LWY, REL; Forecast hour: 04
Obs
HRRR
NCEPRR
NCEPRUC
Power (IEC2)
Hours
0
0.2
0.4
0.6
0.8
1
1.2
2070
2075
2080
2085
2090
2095
2100
2105
2110
2115
2120


WL towers: FAH, LVL, LWY, REL; Forecast hour: 04
Obs
HRRR
NCEPRR
NCEPRUC
Power (IEC2)
Hours
0
0.2
0.4
0.6
0.8
1
1.2
1180
1185
1190
1195
1200
1205
1210
1215
1220
1225
1230