Short-Term PV Power Forecasts Based on a Real-Time Irradiance Monitoring Network

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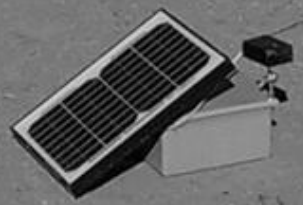

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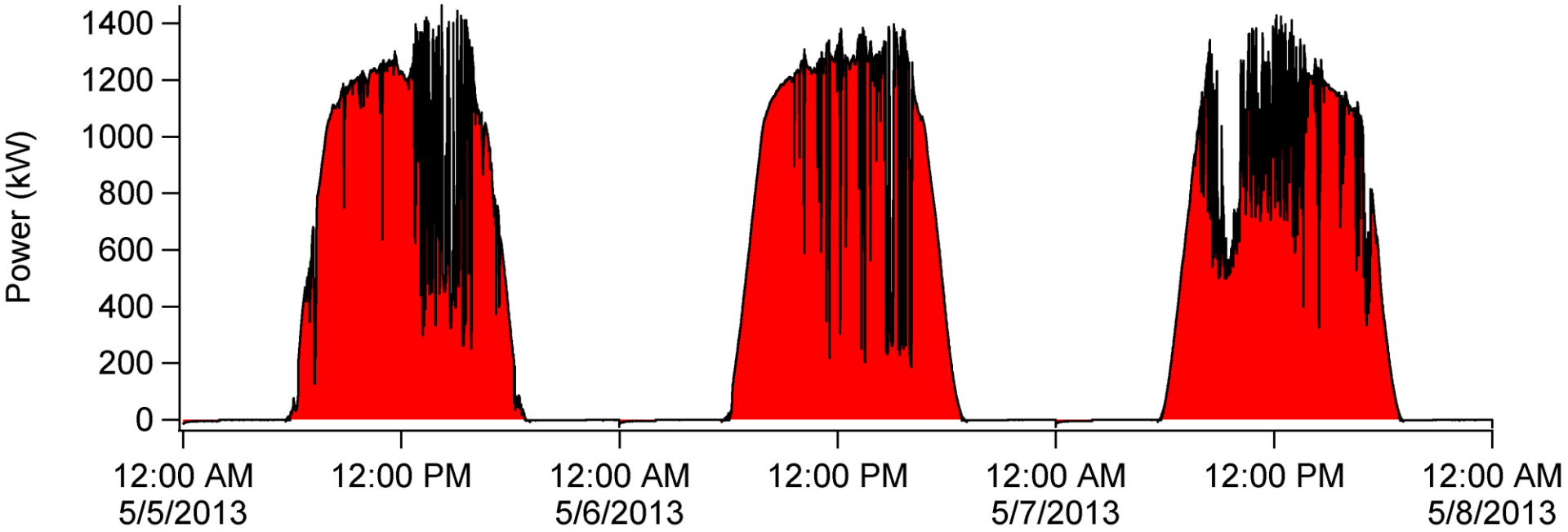
Alex Cronin, Assoc. Prof., Physics

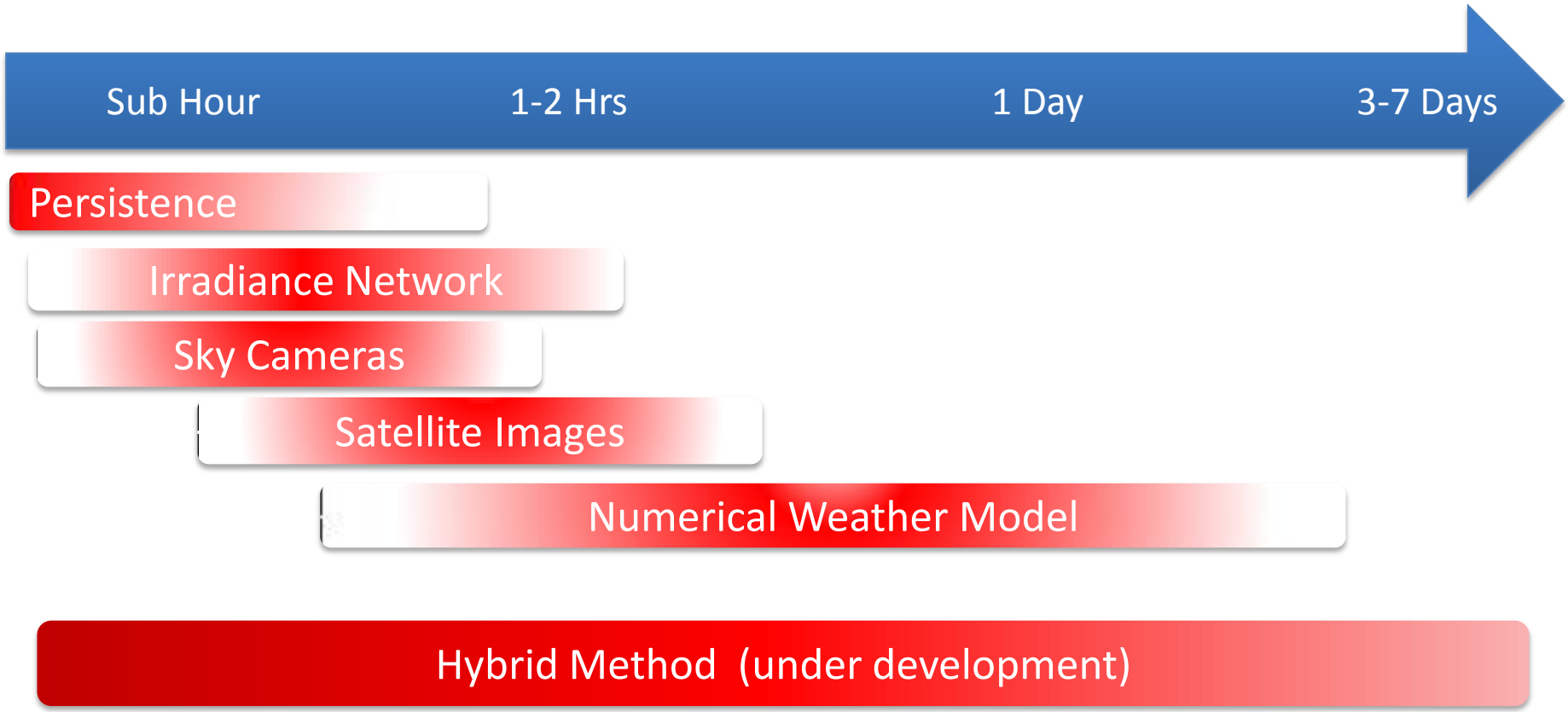
Eric Betterton, Dept. Head, Atmo. Sci.
Mike Leuthold, Meteorologist, Atmo. Sci.
Chang Ki Kim, Post doc, Atmo. Sci.

The Problem:



MW-scale solar power is variable

Forecasting Technologies and Time Scales



Outline

- Our Irradiance Network
- Network-Based Forecasts
  - Methods
  - Example Forecasts
  - Error Statistics
- Conclusions

Real-Time Irradiance Monitors

Sensor	Logger	Communication
• Pyranometer	• Microcontroller	• Ethernet
• Photodiode	• Raspberry Pi	• Xbee radio
• Rooftop PV data	• PV System Monitor	• Cellular Data
• Utility PV data	• TEP SCADA	• SFTP from EMS

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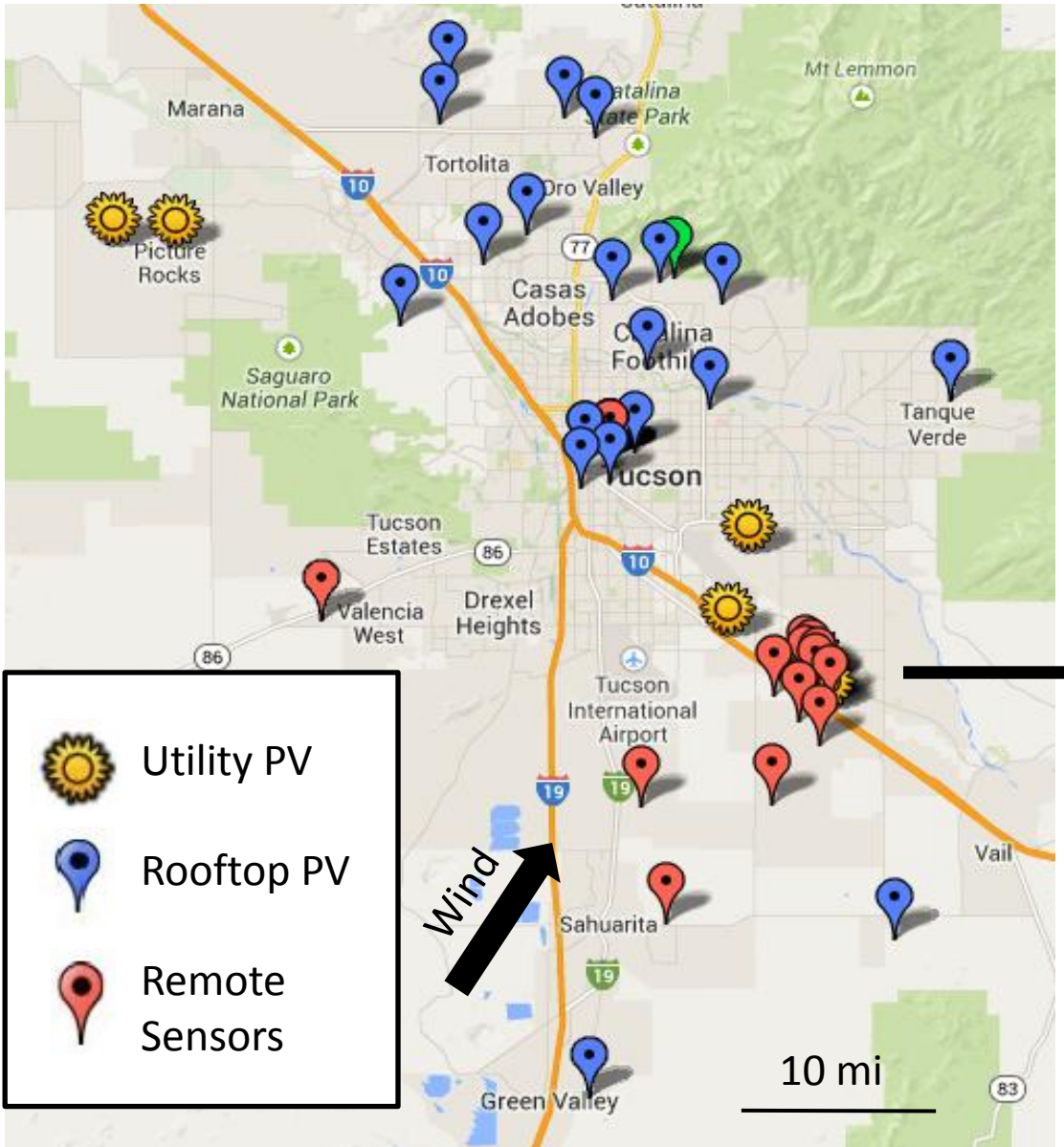
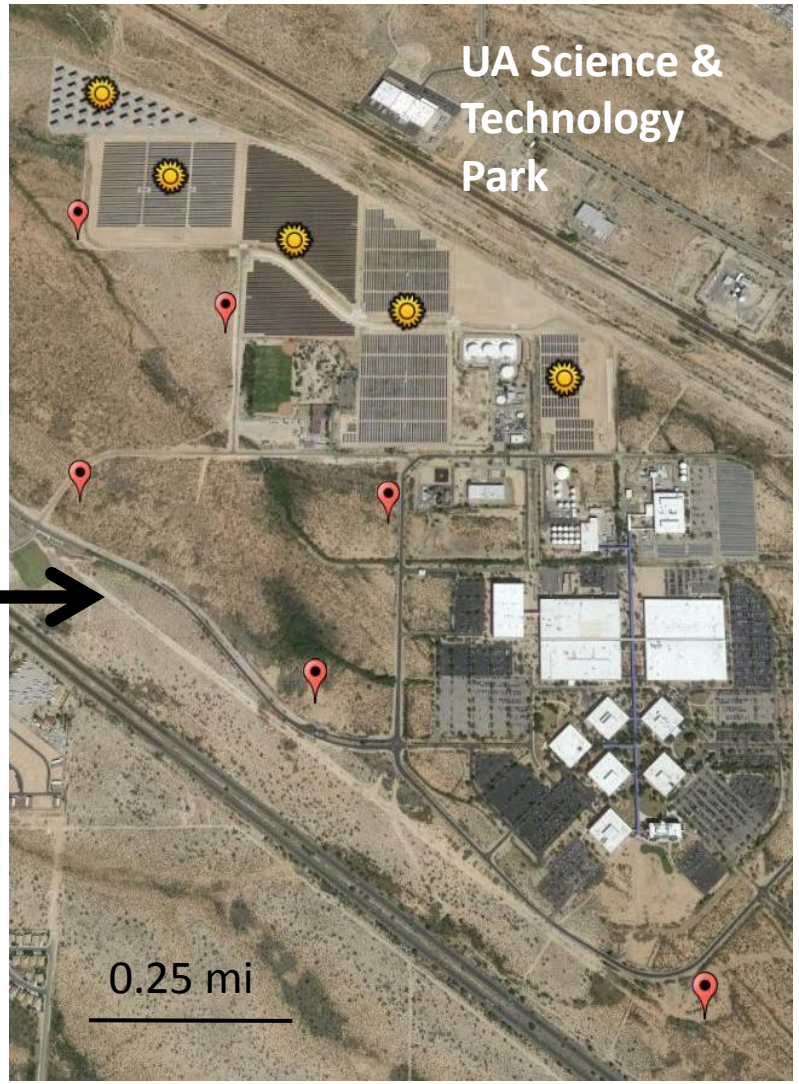
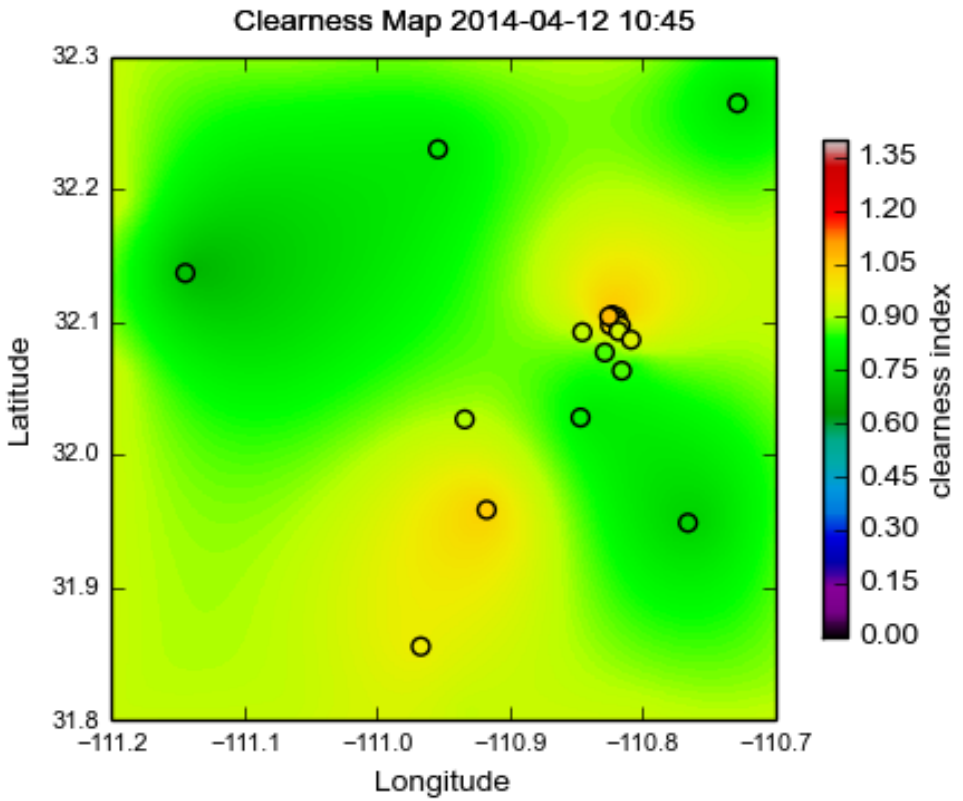
Map of Sensors





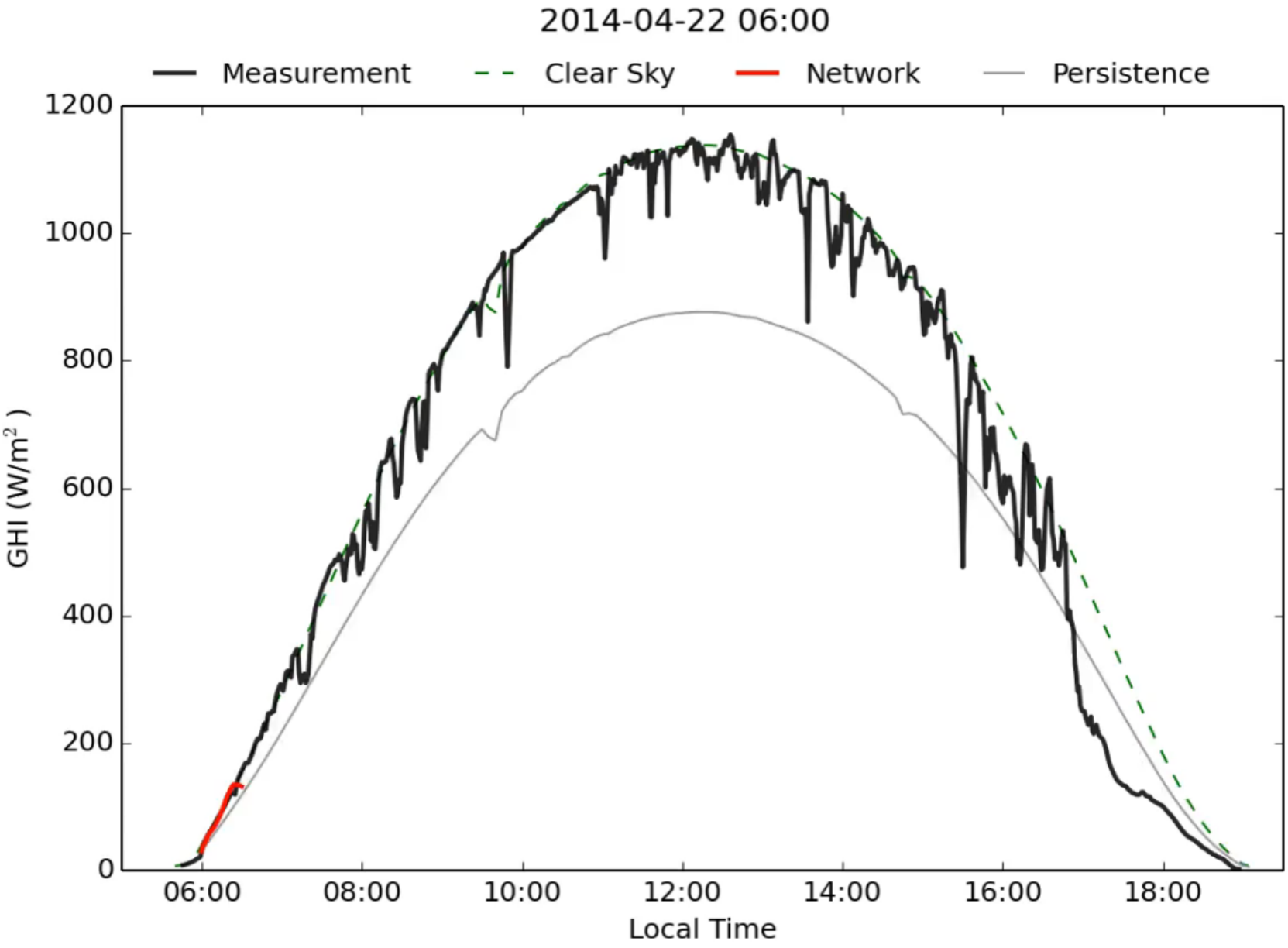
Network Forecasting Method

$$K(x, y, t) = \frac{i_{meas}(t)}{i_{clear}(t)}$$

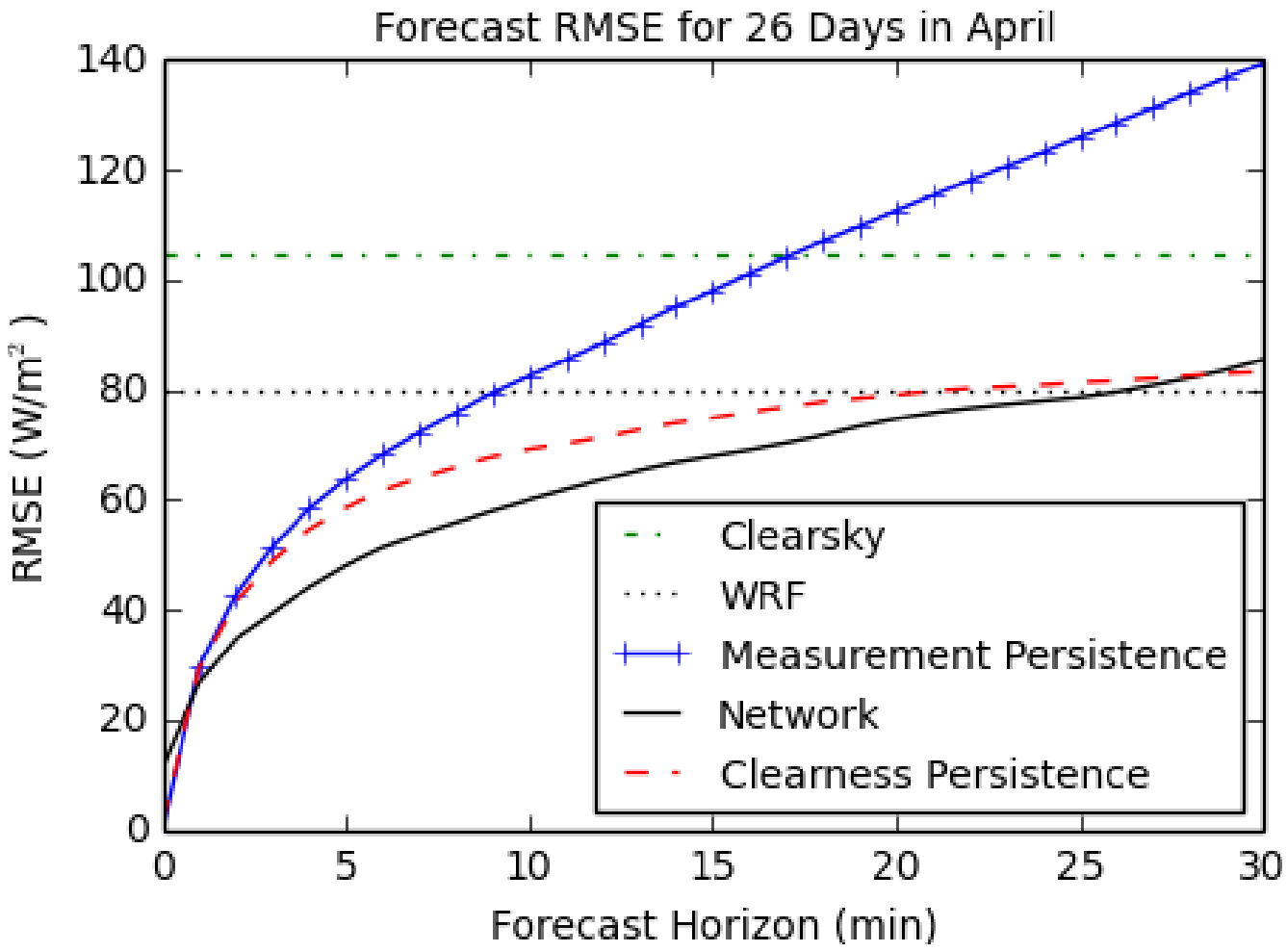


- Pull latest irradiance data from database (1 minute max latency)
- Calculate current clearness using data-driven clear sky expectation
- Make interpolated clearness map
- Use cloud motion vectors from our numerical weather model to propagate map and make forecasts

Example Network Forecasts



Error Statistics

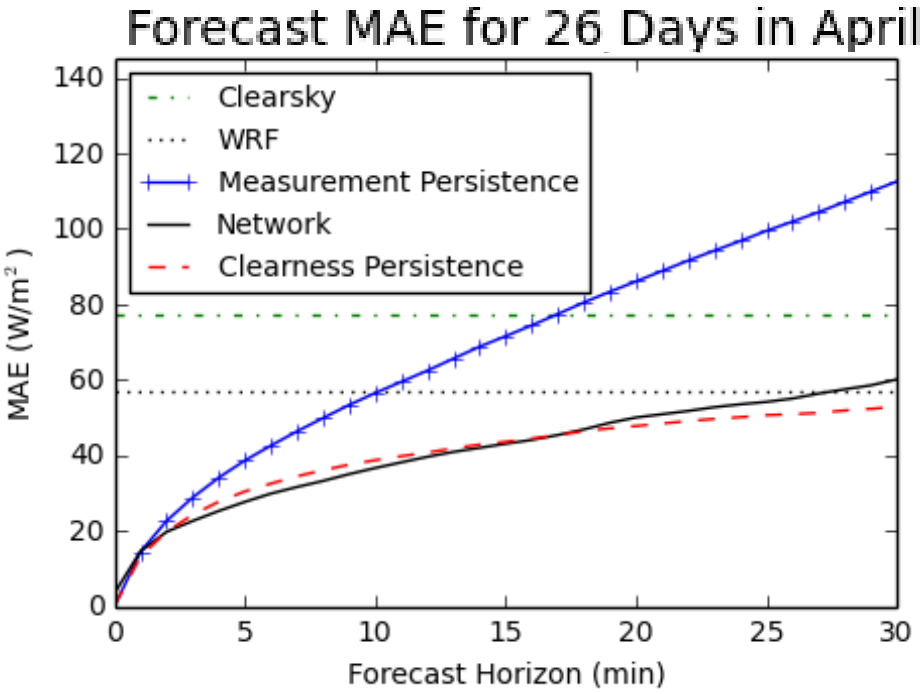


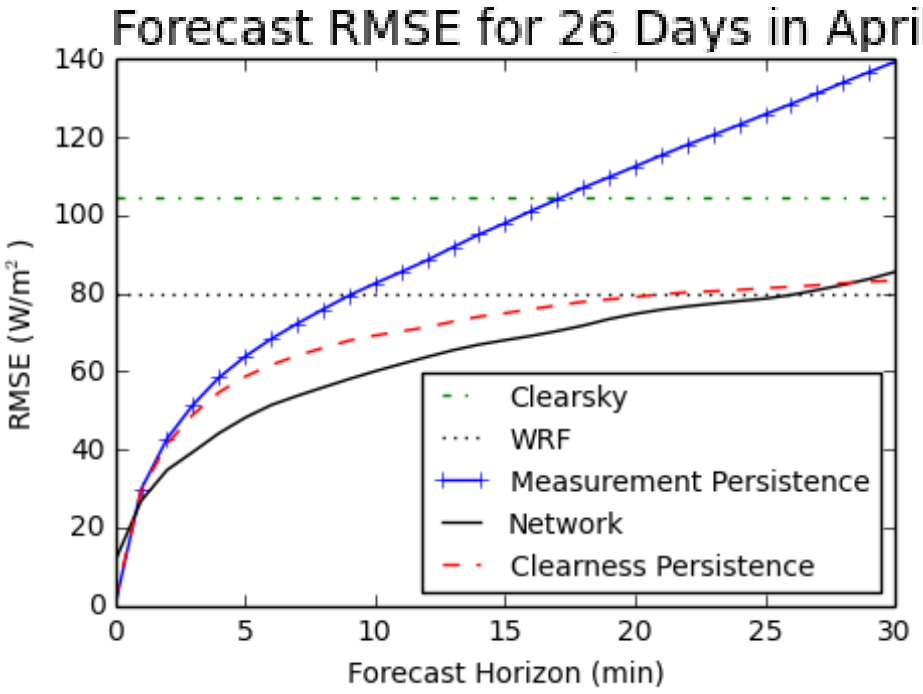
Error Statistics

Forecast Horizon	Clearness Persistence		Network Forecast	
	MAE (W/m^2)	RMSE (W/m^2)	MAE (W/m^2)	RMSE (W/m^2)
0 min	0.166	1.23	3.26	11.3
5 min	30.4	58.6	**27.6**	**48.1**
10 min	38.7	69.1	**36.6**	**60.0**
15 min	43.6	74.8	**43.0**	**67.9**
20 min	47.7	79.0	50.0	**74.7**
25 min	50.6	81.3	54.1	**78.6**
30 min	52.9	83.2	60.1	85.4

- Only daylight hours considered
- 26 days in April analyzed
- Forecasts made each minute out to 30 minutes
- 12 clear days, 2 overcast, 12 variable
- Stats calculated for each day and then averaged for the 26 days

Error Statistics

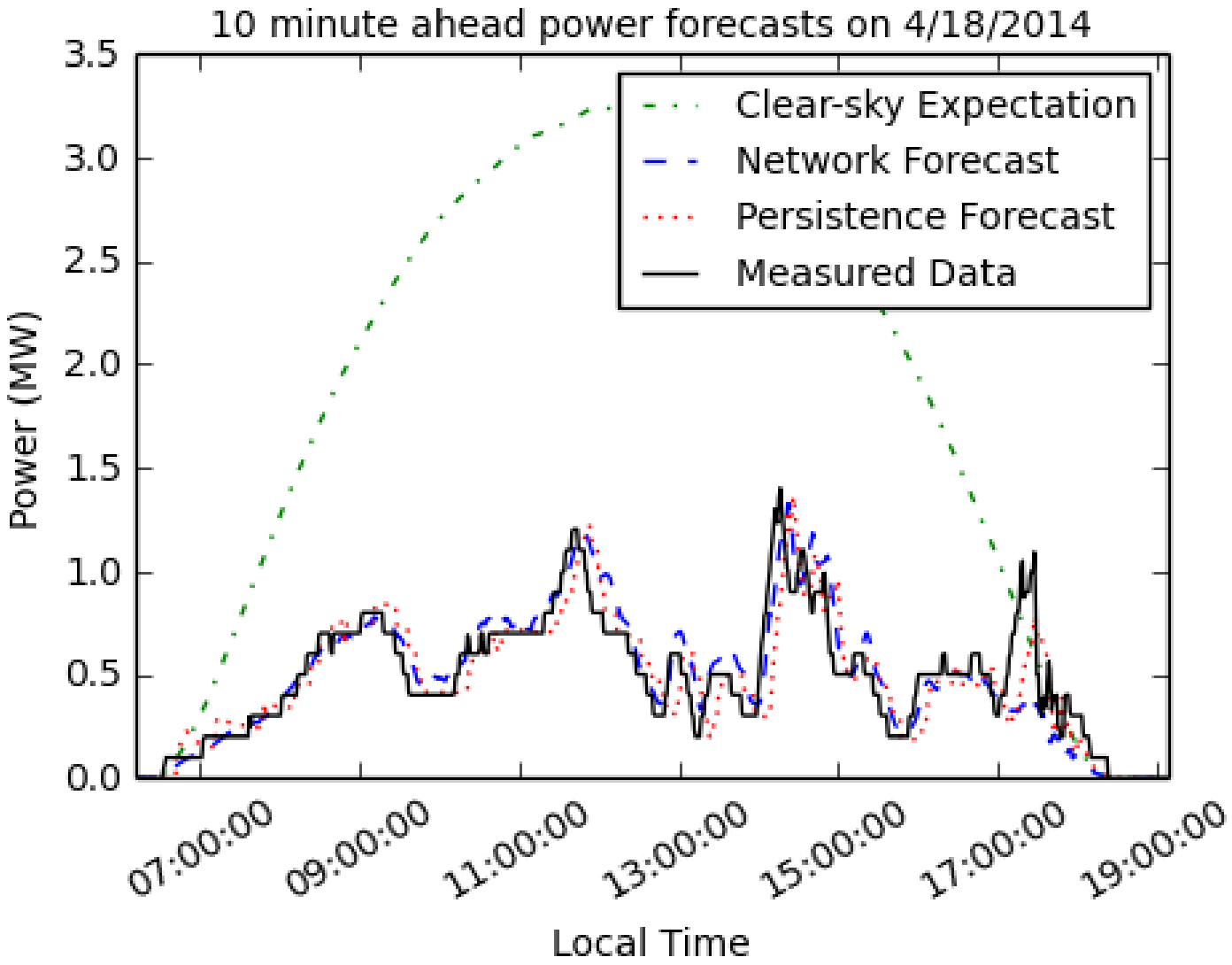




Improvements to come

- Larger network → more advanced notice
- More accurate cloud motion vectors from ground sensor correlation, upper-air soundings, WRF forecasts, ANNs, or some combination
- Incorporate satellite imagery to fill in gaps
- Improve interpolation routine and investigate other methods incl. correlation analysis

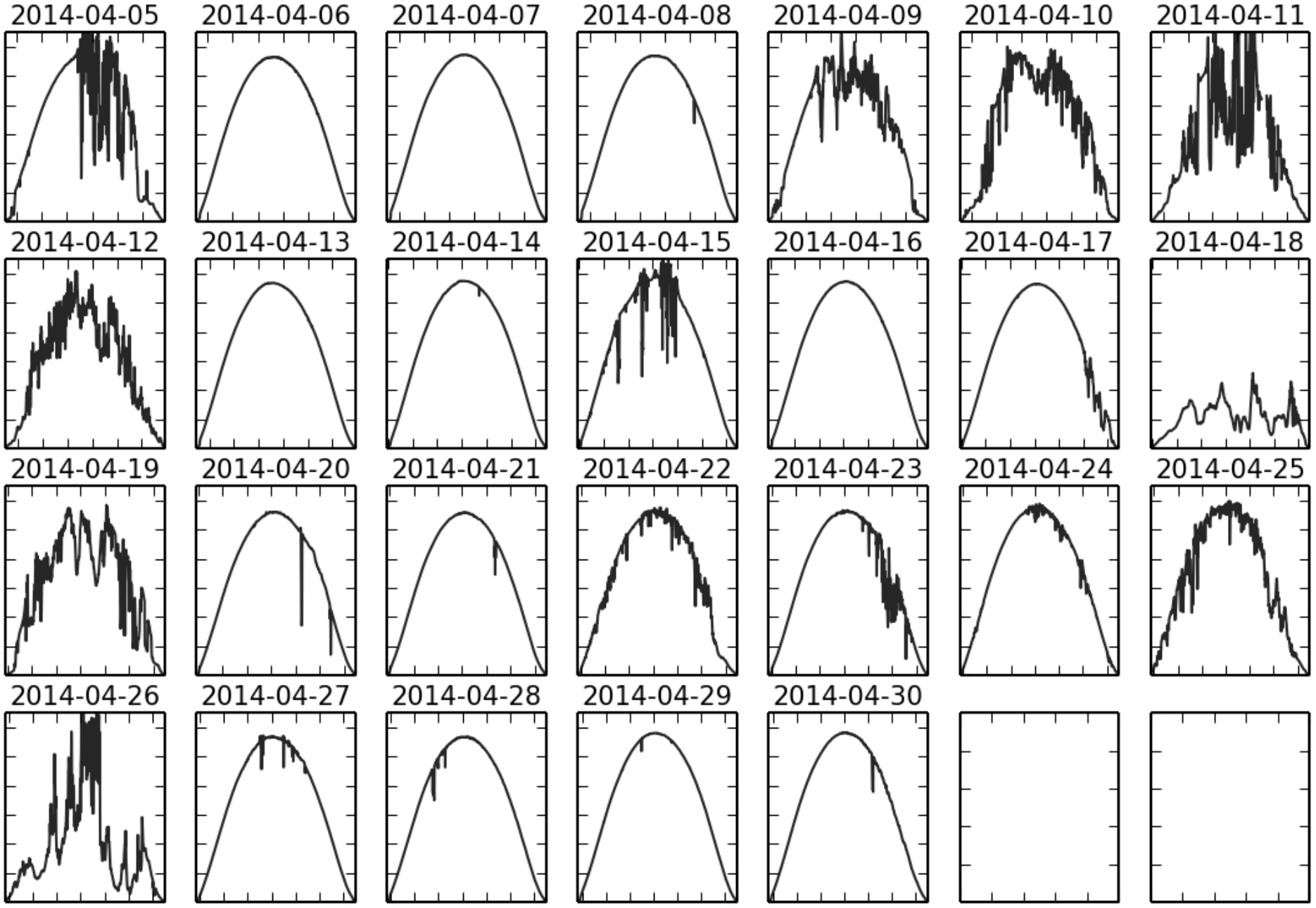
Power Forecast



Conclusions

- We have a network of irradiance sensors throughout Tucson that we use to make forecasts
- An evaluation of 26 days of network forecasts in April shows our forecasts beat persistence for:
  - 1 to 28 minute forecast horizons measured by RMSE
  - 2 to 17 minute forecast horizons measured by MAE
- Many improvements to be made for better sub-hourly forecasts


Thank you!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2014-04-06
2014-04-07
2014-04-08
2014-04-09
2014-04-10
2014-04-11
2014-04-12
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2014-04-14
2014-04-15
2014-04-16
2014-04-17
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2014-04-19
2014-04-20
2014-04-21
2014-04-22
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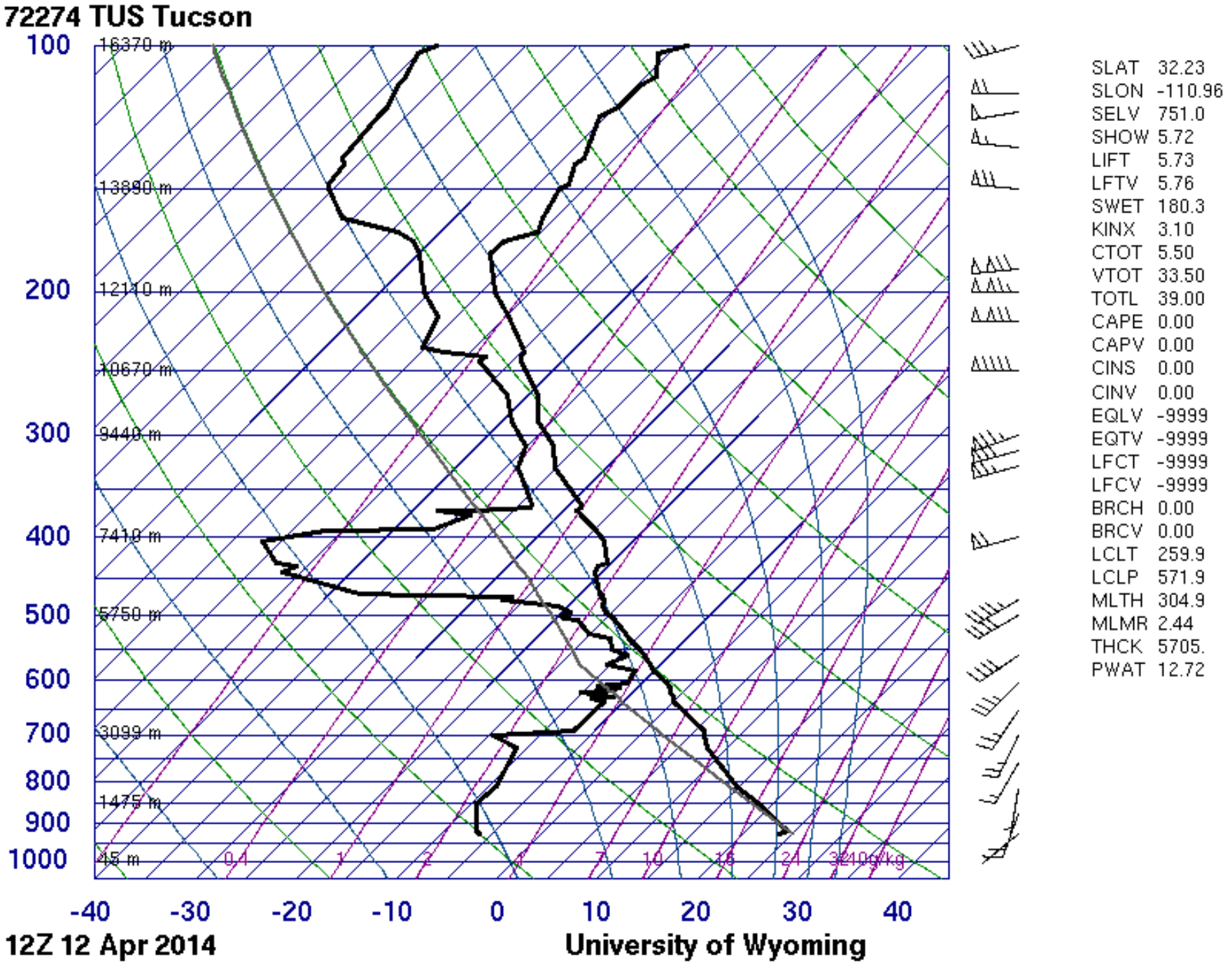
2014-04-29
2014-04-30


72274 TUS Tucson
100
200
300
400
500
600
700
800
900
1000
16370 m
13890 m
12110 m
10670 m
9440 m
7410 m
5750 m
3099 m
1475 m
45 m
0.1
1
2
4
7
10
16
24
32
40g/kg
-40
-30
-20
-10
0
10
20
30
40
12Z 12 Apr 2014
University of Wyoming
SLAT 32.23
SLON -110.96
SELV 751.0
SHOW 5.72
LIFT 5.73
LFTV 5.76
SWET 180.3
KINX 3.10
CTOT 5.50
VTOT 33.50
TOTL 39.00
CAPE 0.00
CAPV 0.00
CINS 0.00
CINV 0.00
EQLV -9999
EQTV -9999
LFCT -9999
LFCV -9999
BRCH 0.00
BRCV 0.00
LCLT 259.9
LCLP 571.9
MLTH 304.9
MLMR 2.44
THCK 5705.
PWAT 12.72