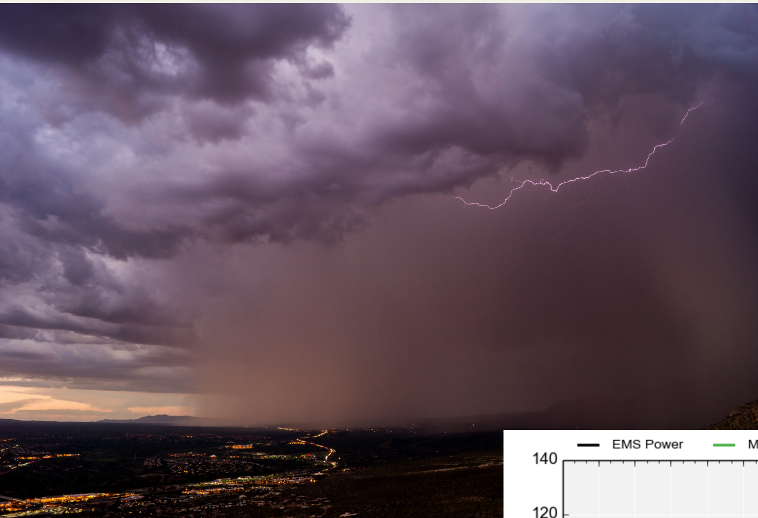
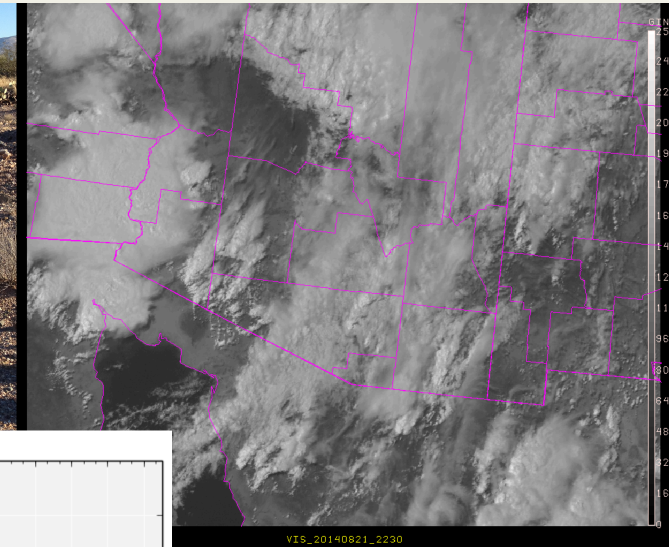
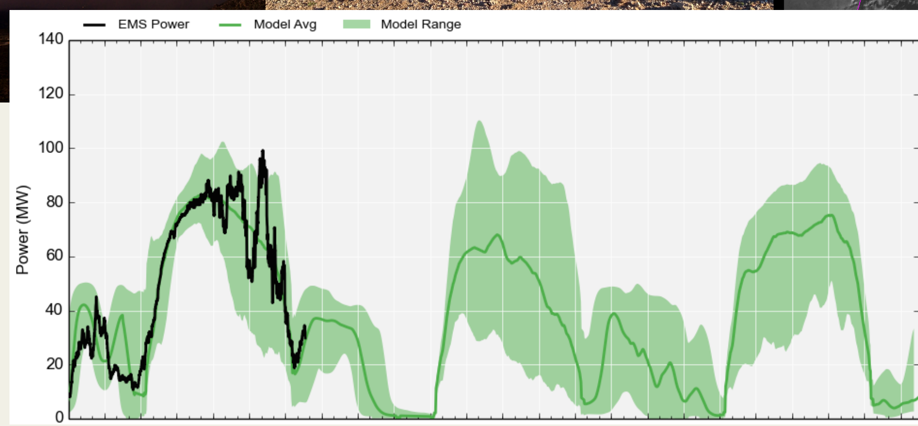
U. Arizona Renewable Power Forecasting



Charles Miles, Creative Commons





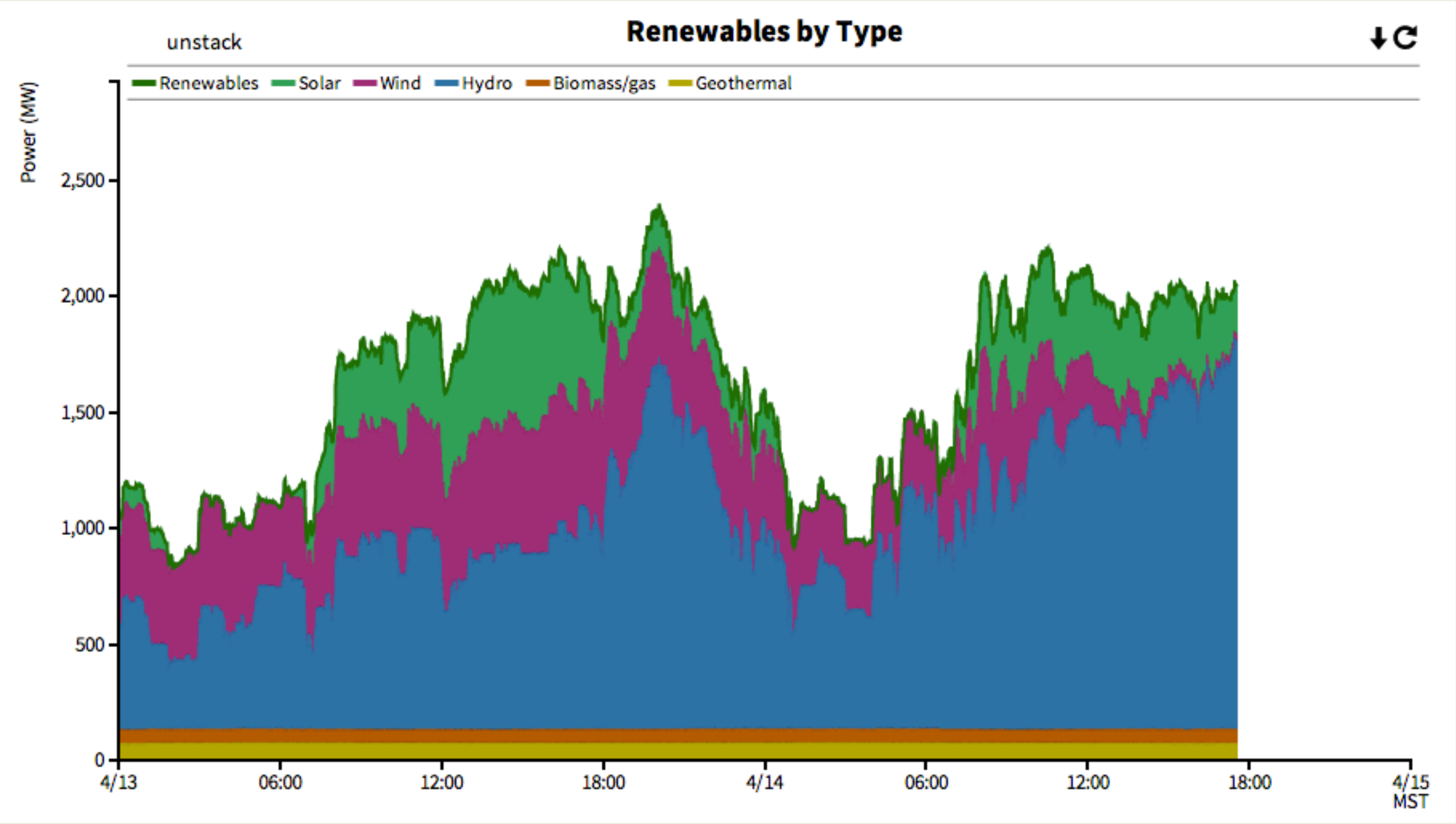
Will Holmgren
DOE EERE Postdoctoral Fellow
UA Department of Atmospheric Sciences

Antonio Lorenzo, Grad Student, Opt. Sci.
Mike Leuthold, Meteorologist, Atmo. Sci.
Chang Ki Kim, Post doc, Atmo. Sci.
Rey Granillo, Developer, UA-REN
Alex Cronin, Associate Professor, Physics
Eric Betterton, Dept. Head, Atmo. Sci.
Ardeth Barnhart, Director, UA-REN

ARIZONA

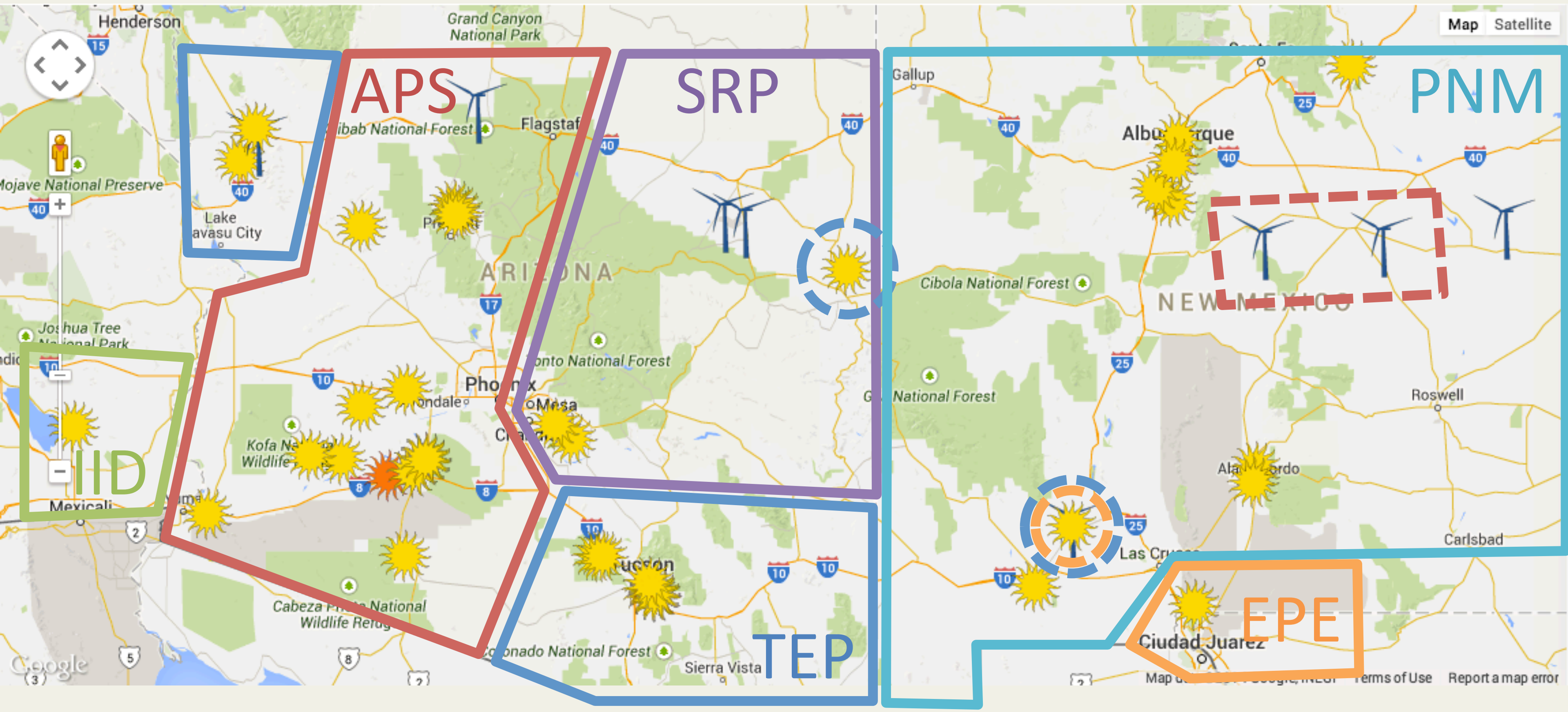
But first,

The status and future of renewables in the Southwest



SVERI

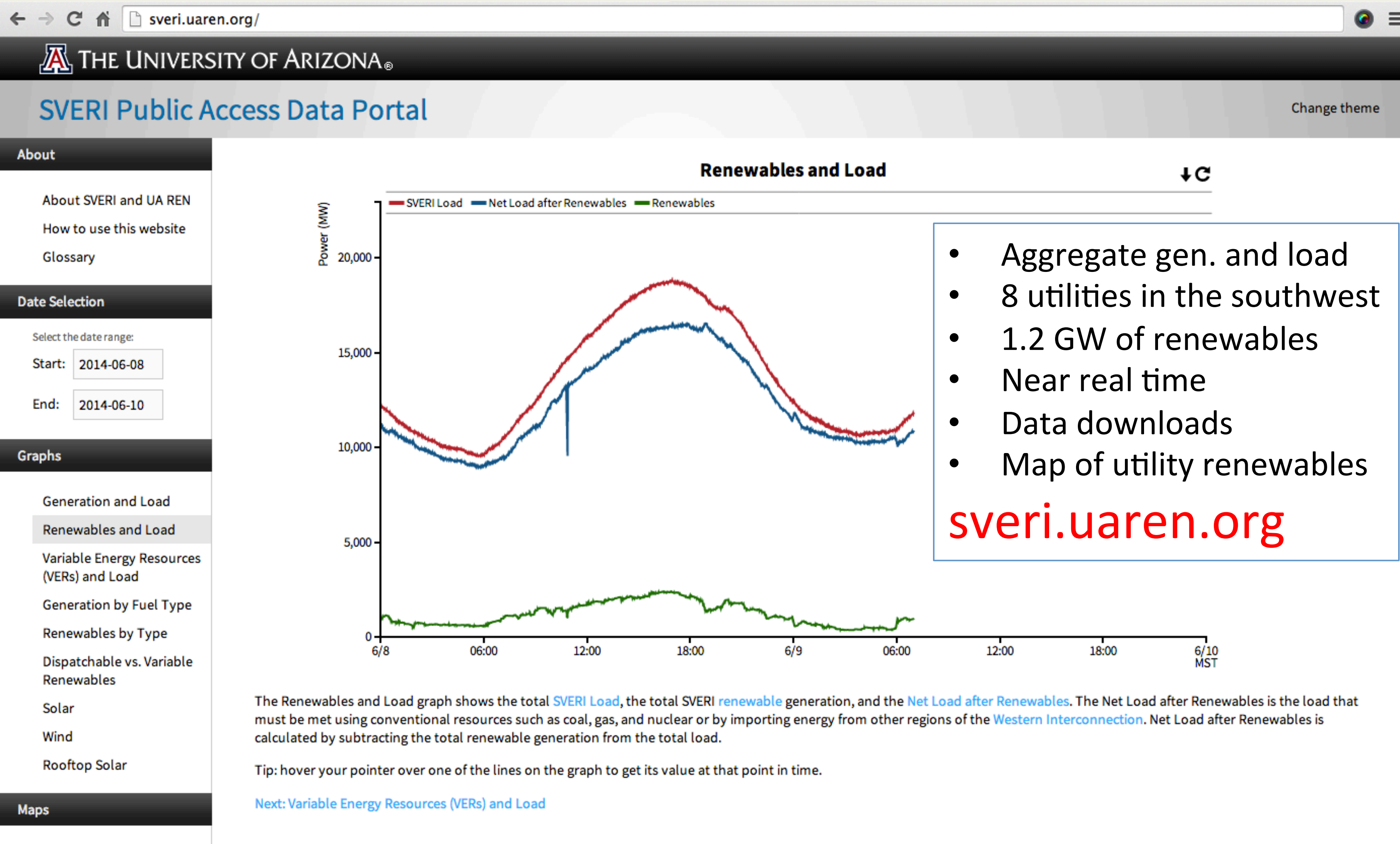
Southwest Variable Energy Resource Initiative



from sveri.uaren.org

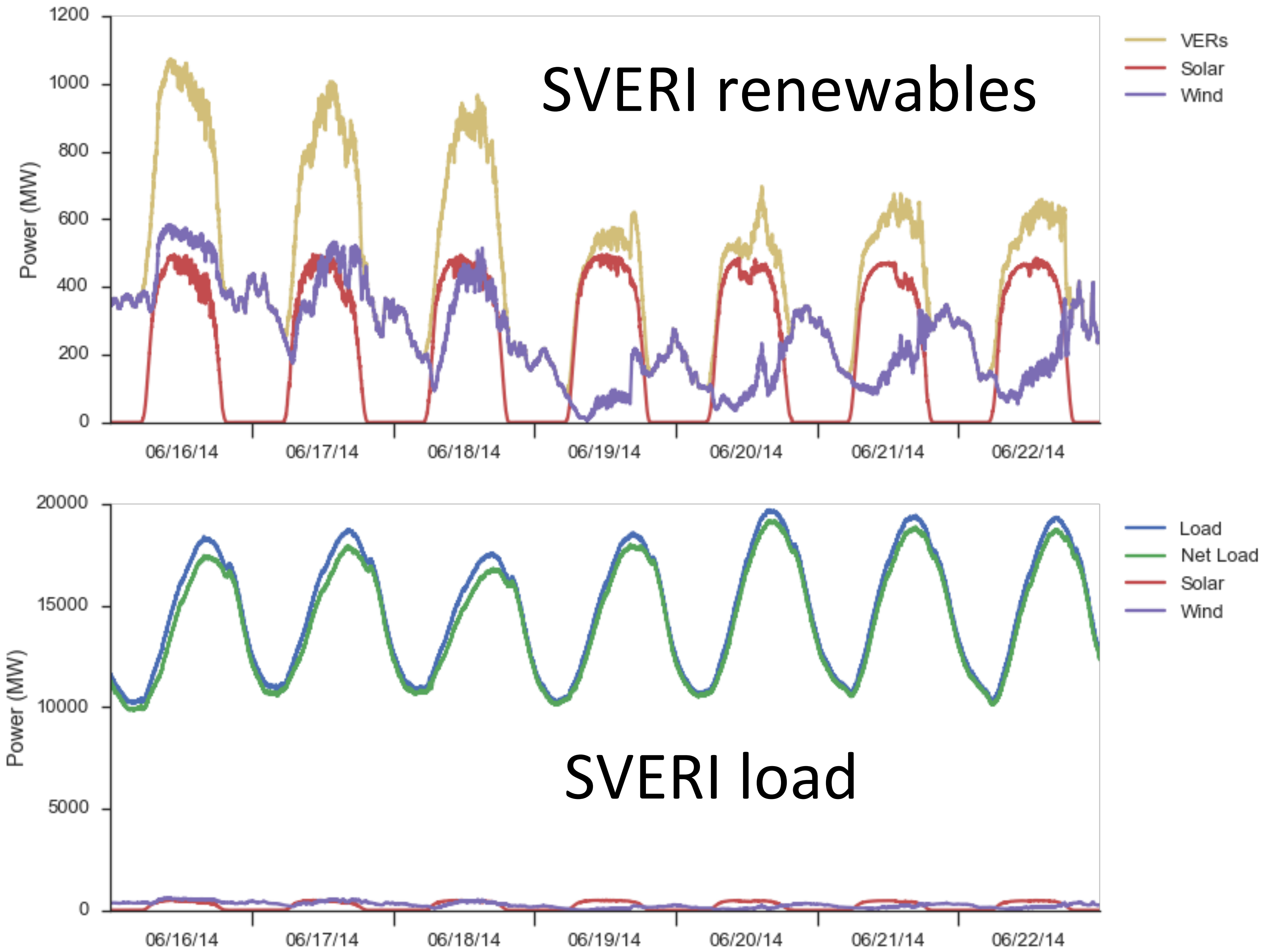
sveri.uaren.org

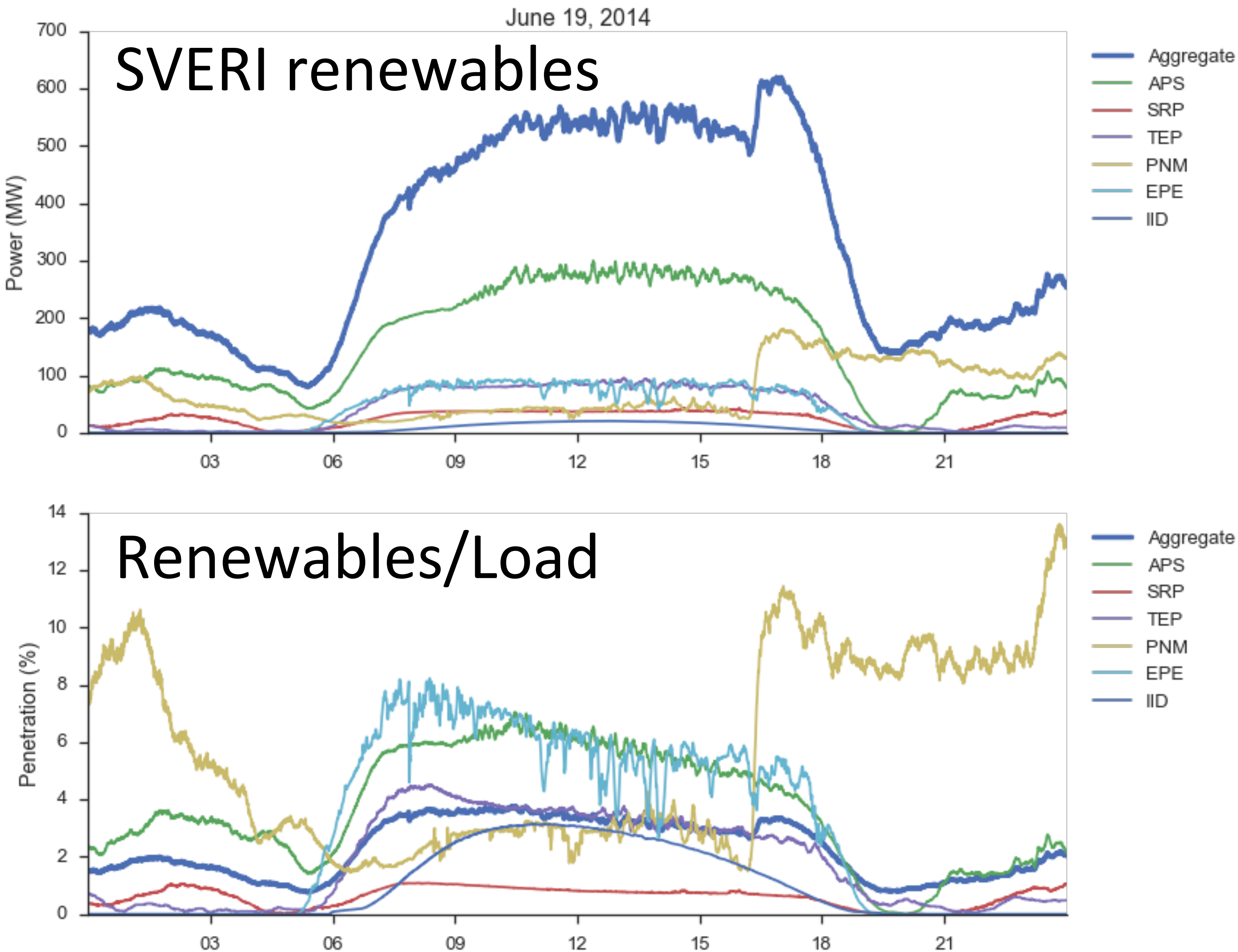
Southwest Variable Energy Resource Initiative • University of Arizona Renewable Energy Network • org



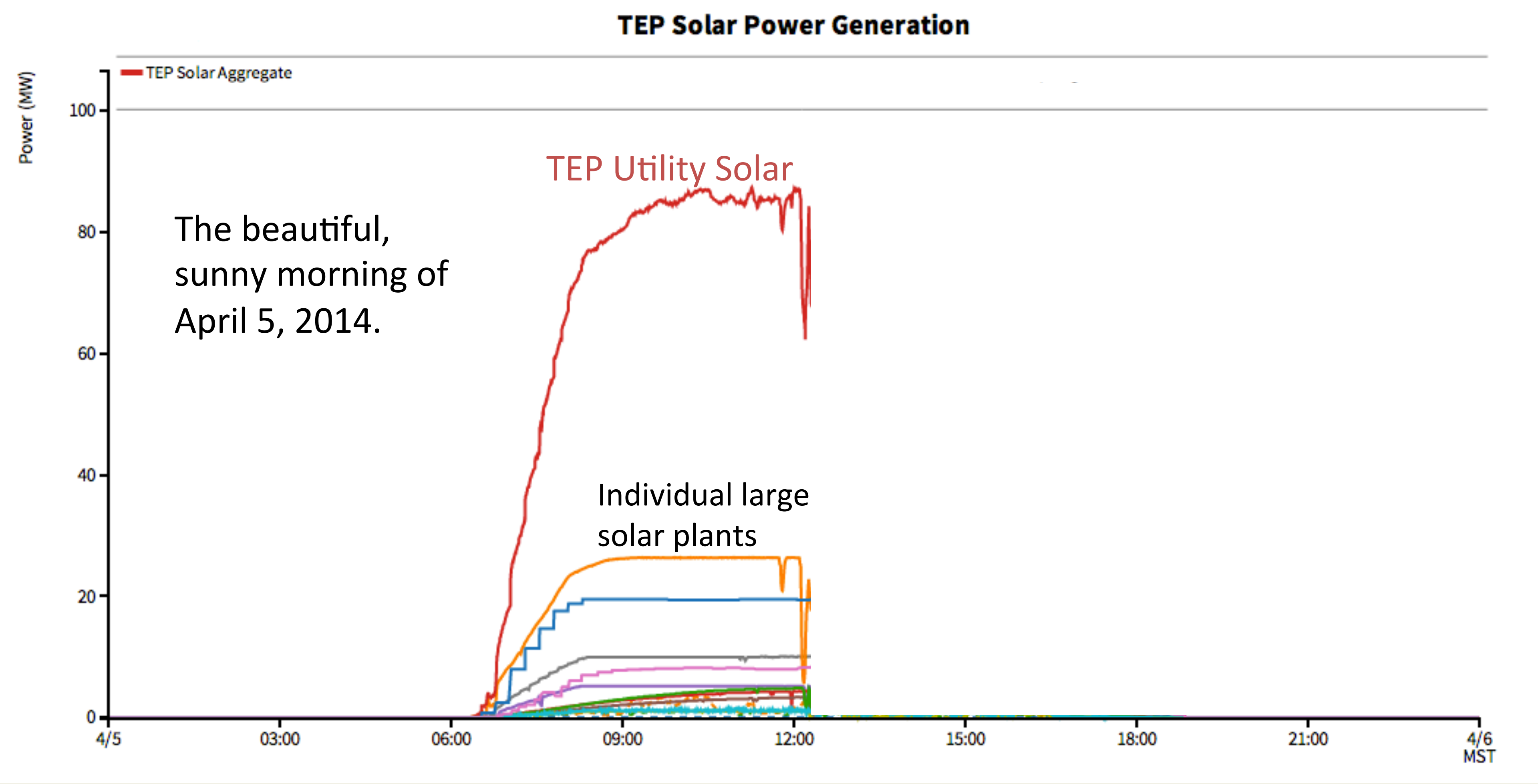
- Aggregate gen. and load
- 8 utilities in the southwest
- 1.2 GW of renewables
- Near real time
- Data downloads
- Map of utility renewables

sveri.uaren.org

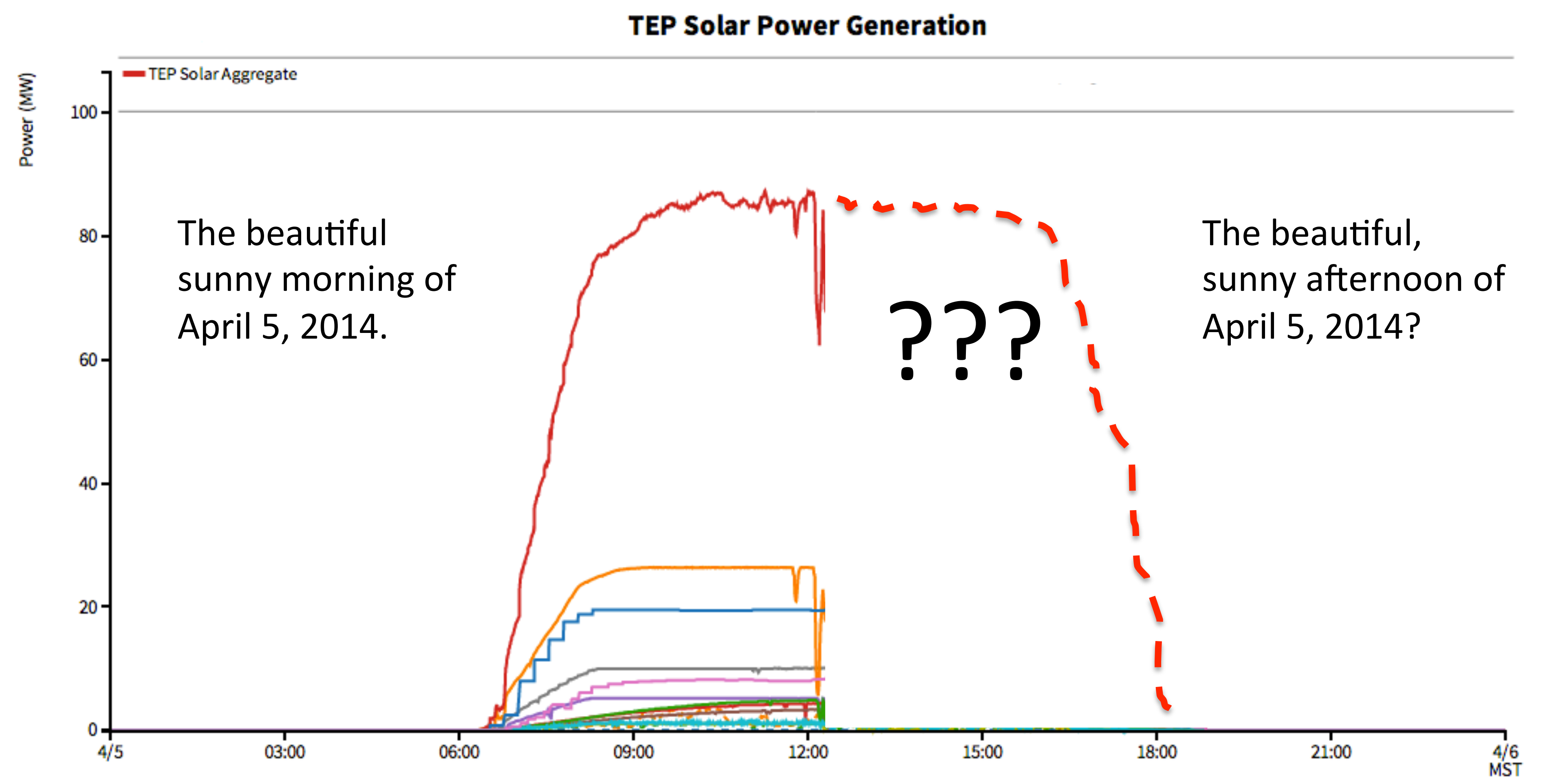

SVERI renewables
1200
1000
800
600
400
200
0
Power (MW)
VERs
Solar
Wind
06/16/14
06/17/14
06/18/14
06/19/14
06/20/14
06/21/14
06/22/14
SVERI load
20000
15000
10000
5000
0
Power (MW)
Load
Net Load
Solar
Wind
06/16/14
06/17/14
06/18/14
06/19/14
06/20/14
06/21/14
06/22/14


June 19, 2014
SVERI renewables
Power (MW)
700
600
500
400
300
200
100
0
03
06
09
12
15
18
21
Aggregate
APS
SRP
TEP
PNM
EPE
IID
Renewables/Load
Penetration (%)
14
12
10
8
6
4
2
0
03
06
09
12
15
18
21
Aggregate
APS
SRP
TEP
PNM
EPE
IID

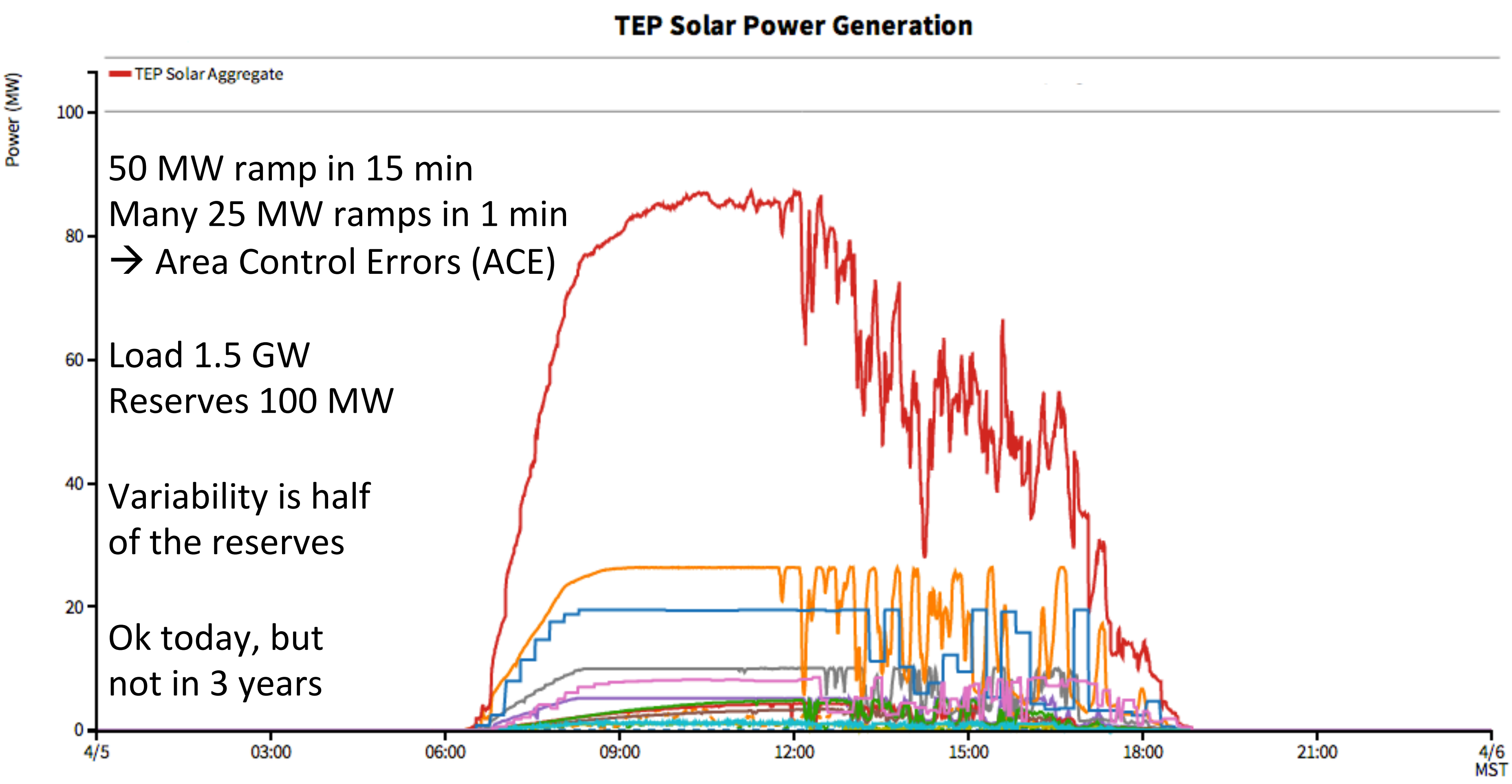
TEP's Solar Power Variability



TEP's Solar Power Variability

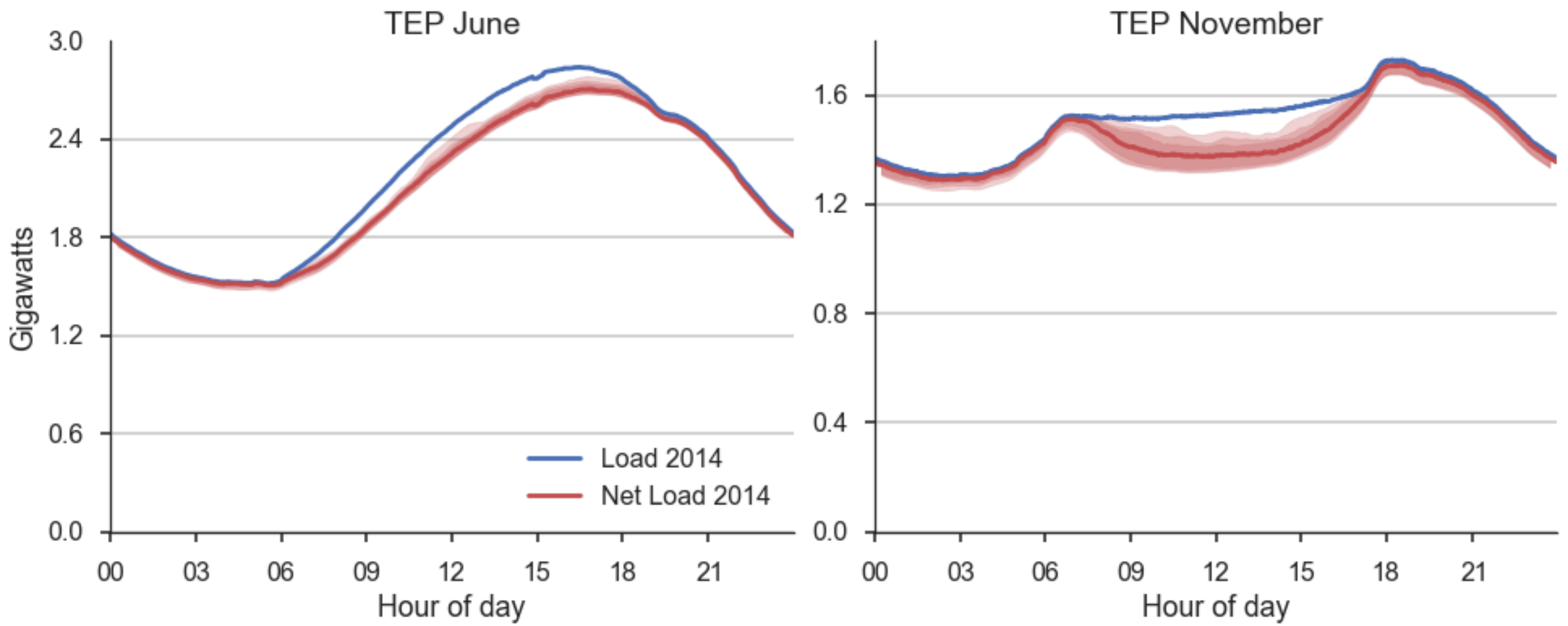


TEP's Solar Power Variability



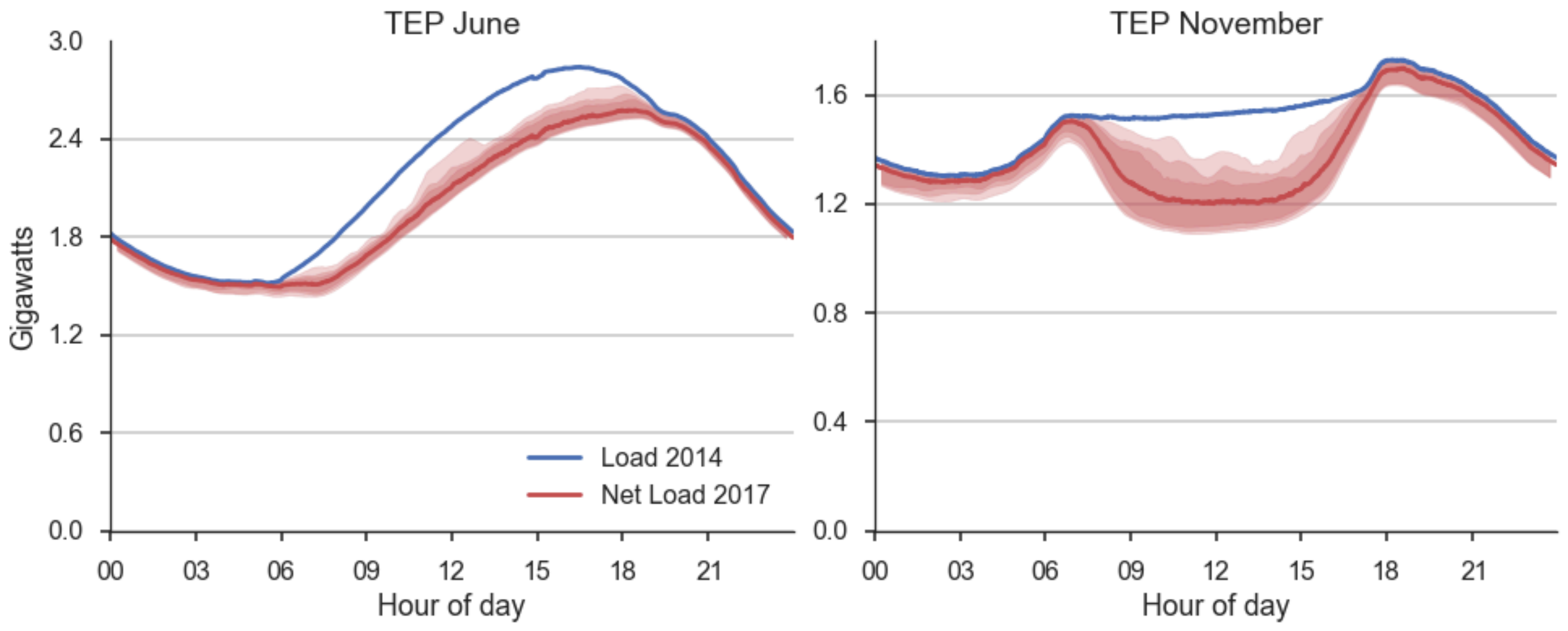
April 5, 2014.

TEP 2014 Net Load Range



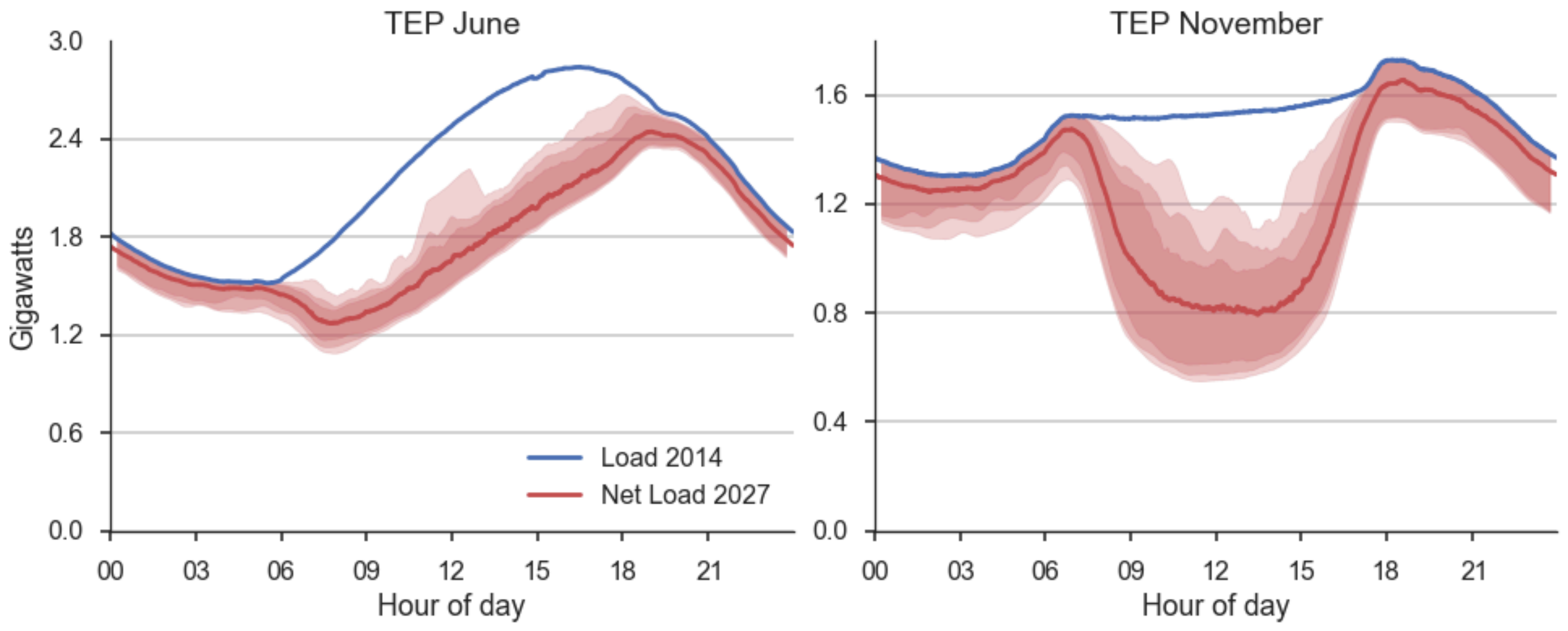
Similar plots available for all SVERI utilities

TEP 2017 Net Load Range



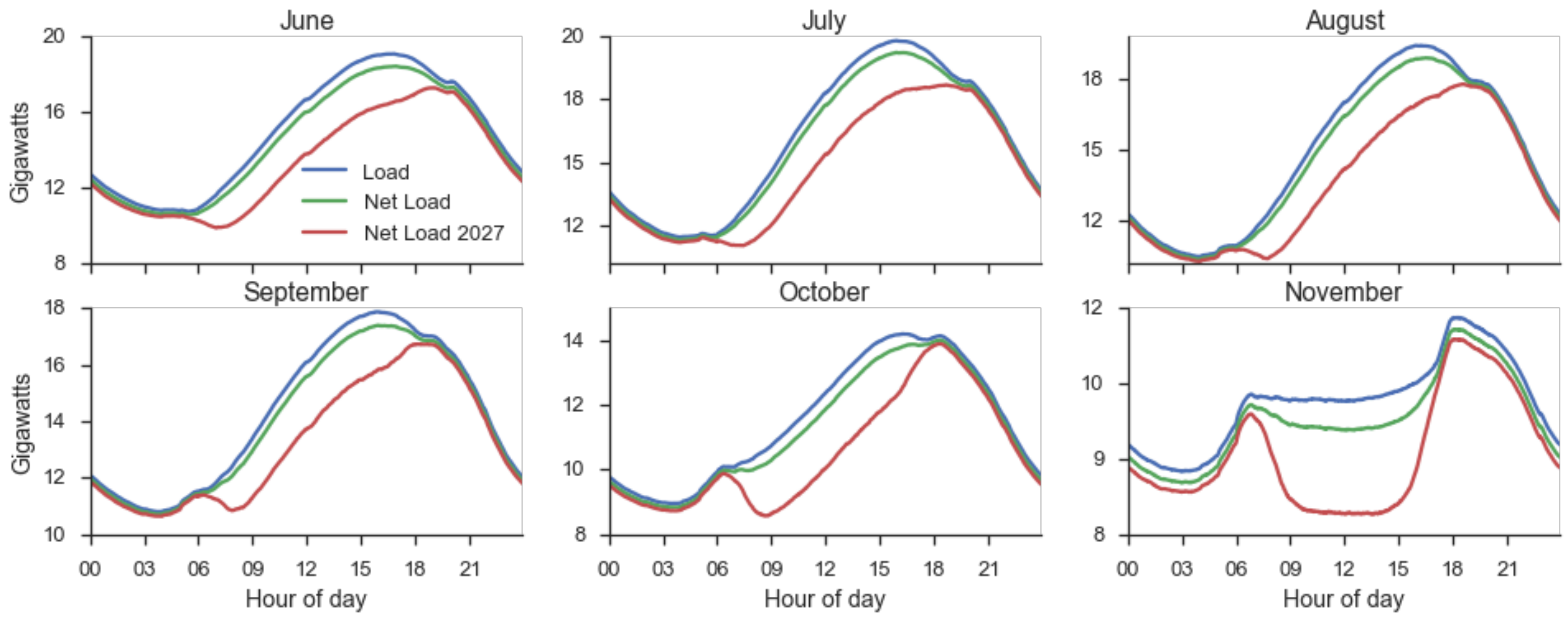
Similar plots available for all SVERI utilities

TEP 2027 Net Load Range



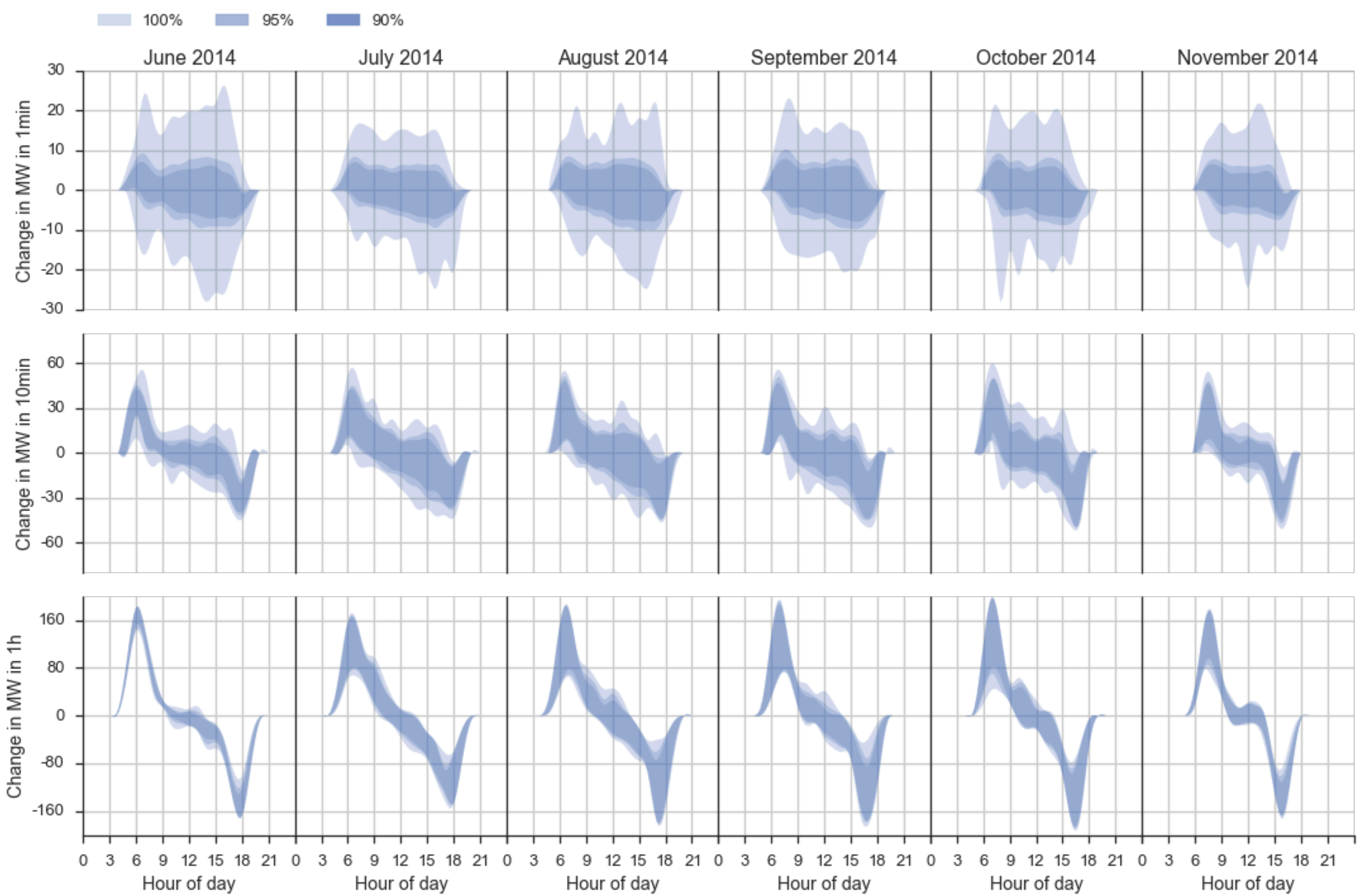
Similar plots available for all SVERI utilities

SVERI Net Load

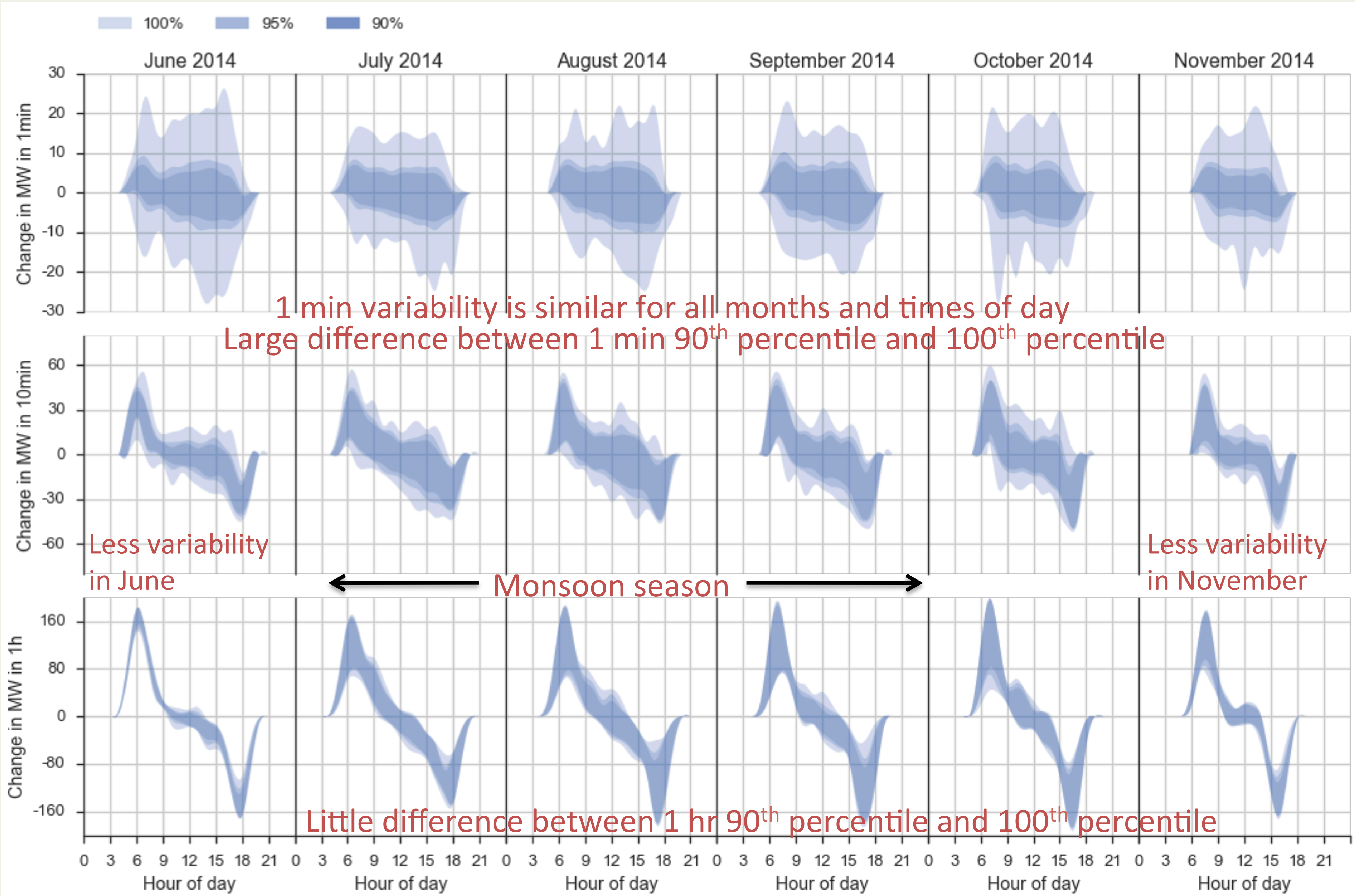


Note the changing y axis scales

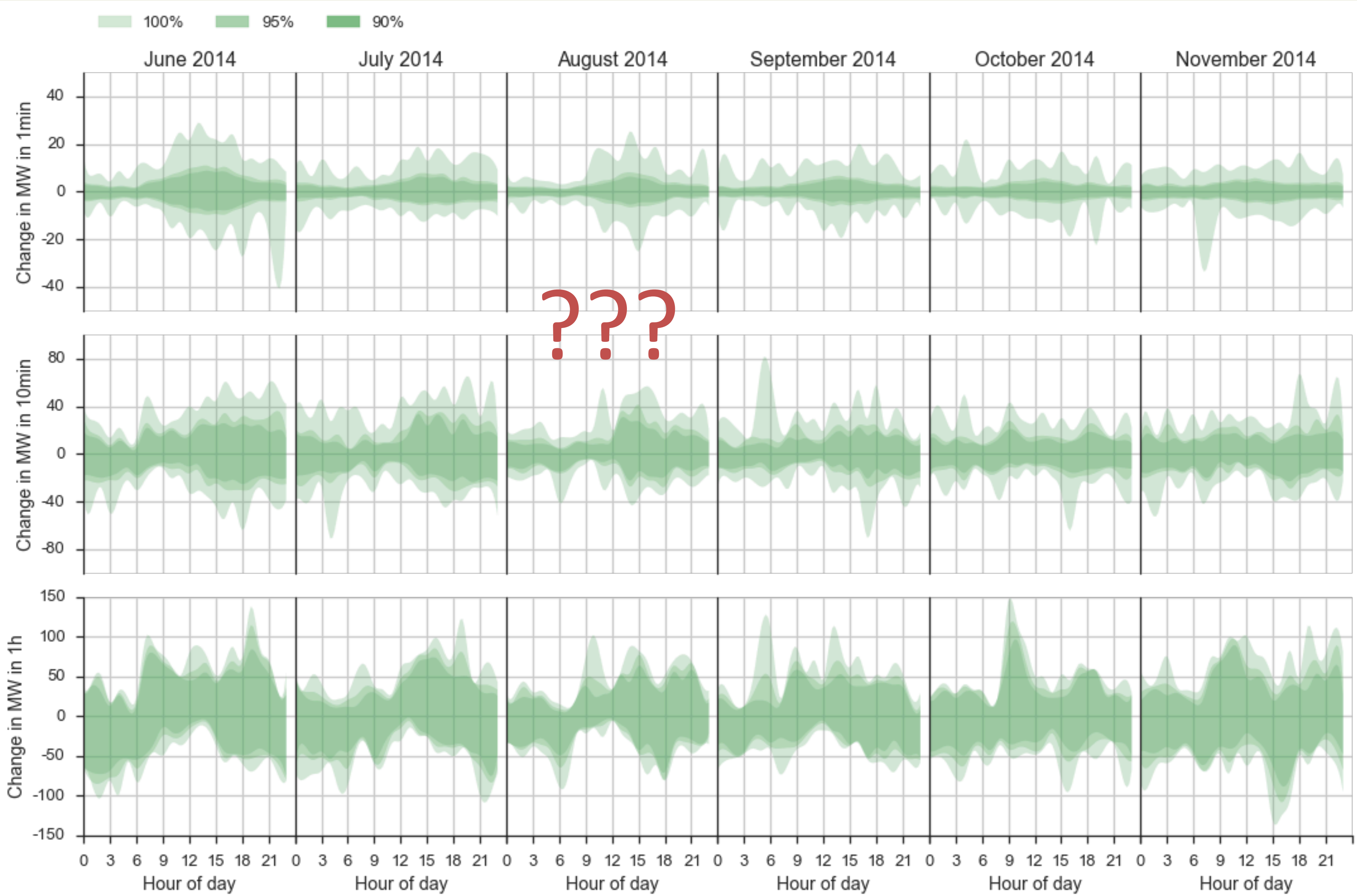
SVERI solar variability



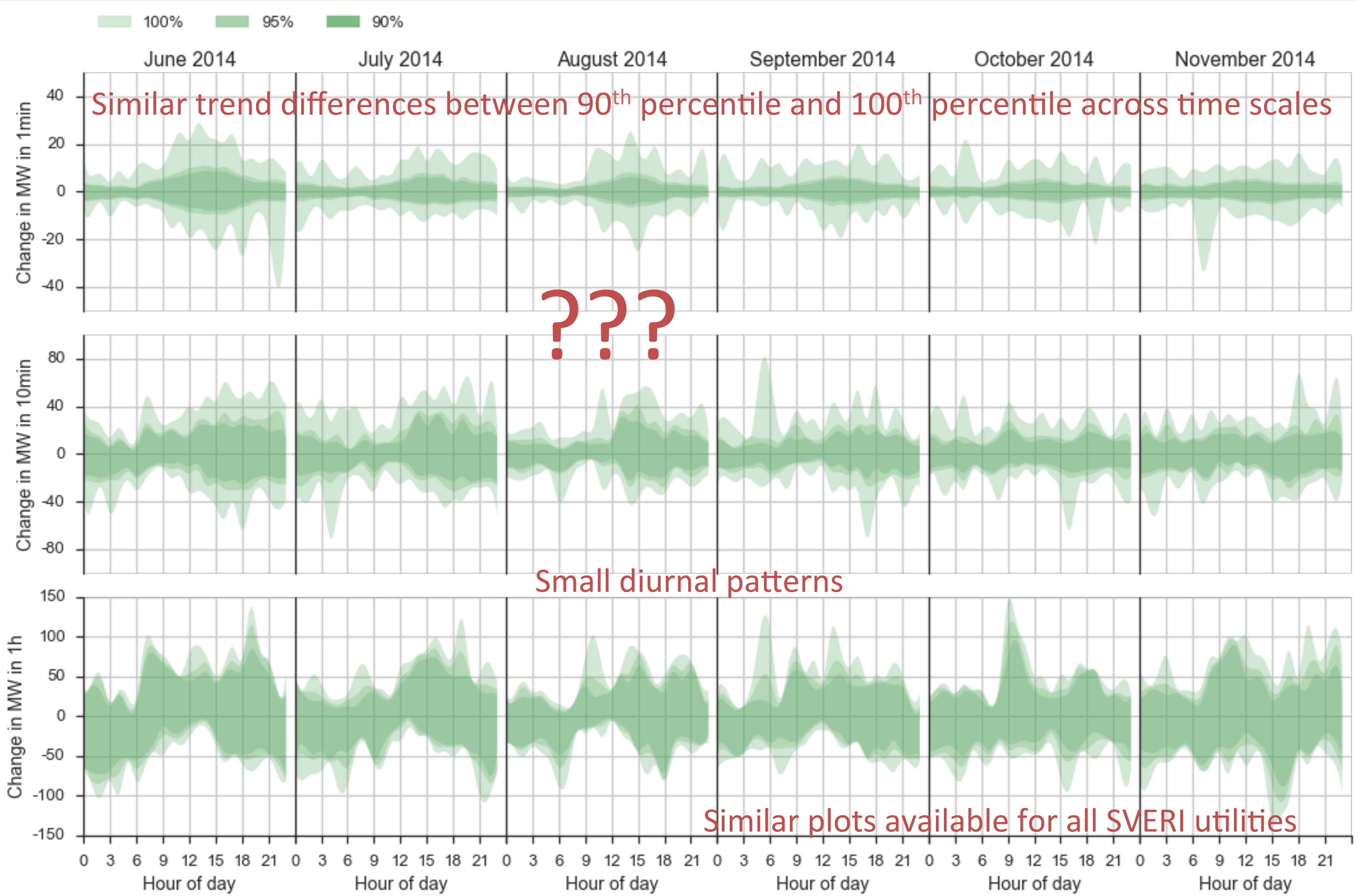
SVERI solar variability

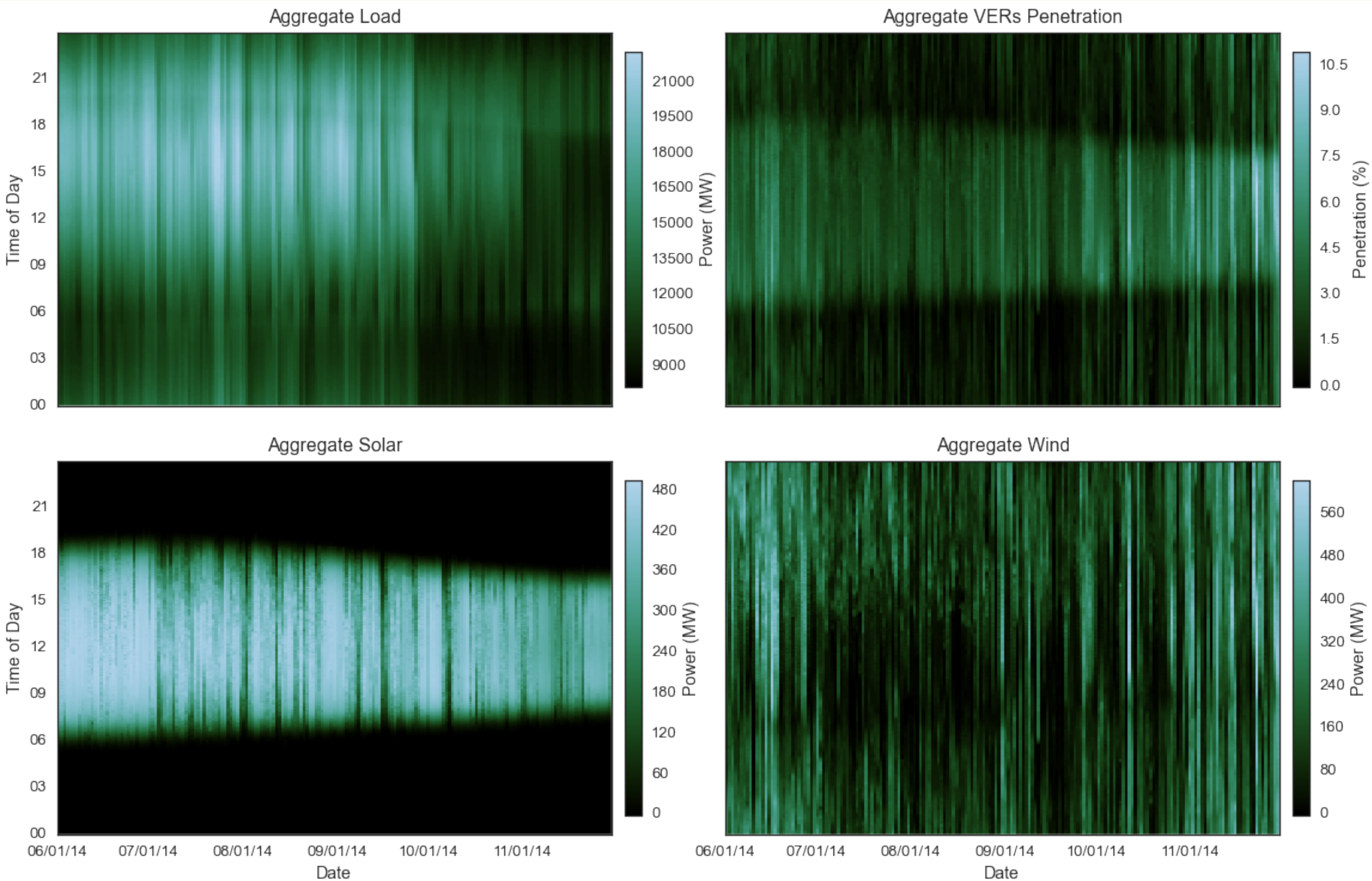


SVERI wind variability



SVERI wind variability





Aggregate Load
Aggregate VERs Penetration
Aggregate Solar
Aggregate Wind
Time of Day
Date
Power (MW)
Penetration (%)
00
03
06
09
12
15
18
21
06/01/14
07/01/14
08/01/14
09/01/14
10/01/14
11/01/14
9000
10500
12000
13500
15000
16500
18000
19500
21000
0.0
1.5
3.0
4.5
6.0
7.5
9.0
10.5
0
60
120
180
240
300
360
420
480
0
80
160
240
320
400
480
560

VERs penetration

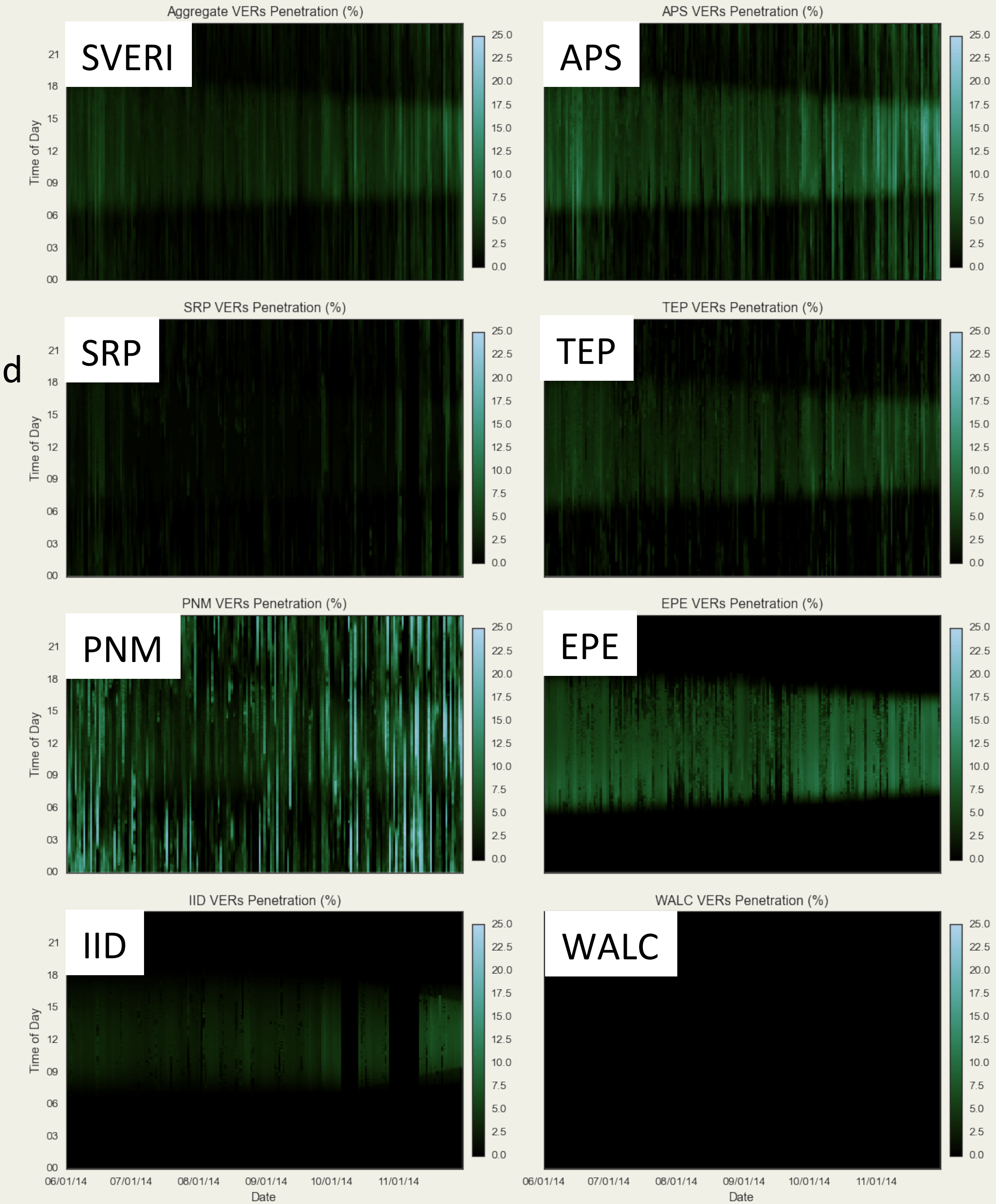
Penetration = renewables gen. / load

Black = 0%
White = 25%

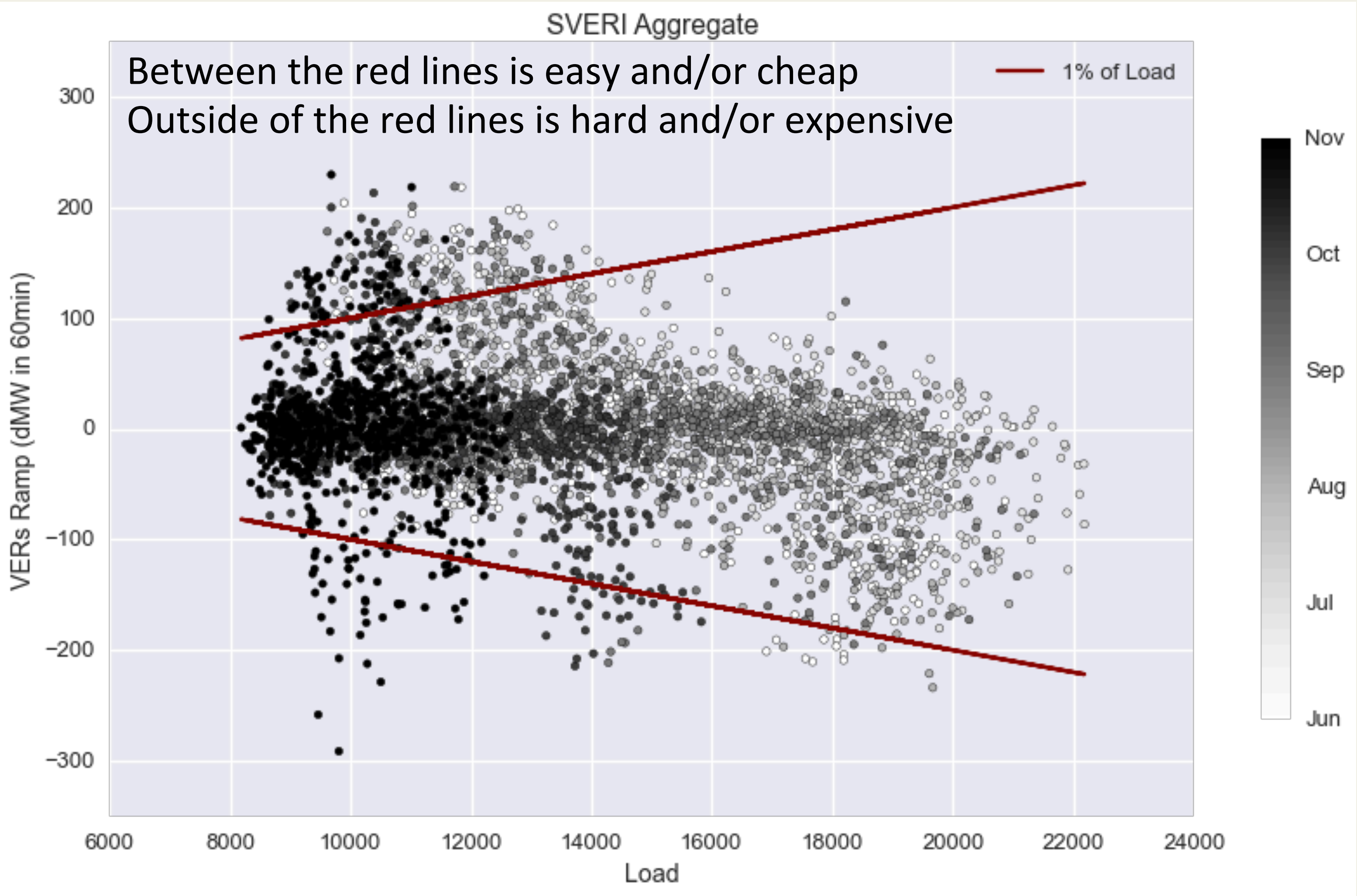
APS occasionally has high penetration

PNM penetration is huge

EPE solar penetration is consistently large



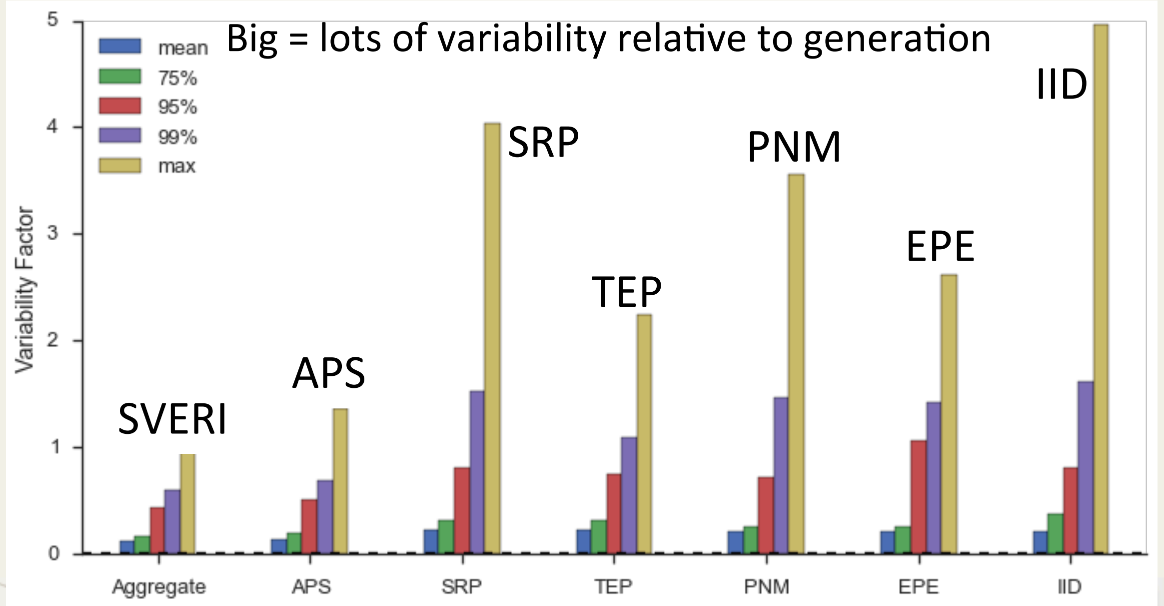
Renewables Ramps vs. Load



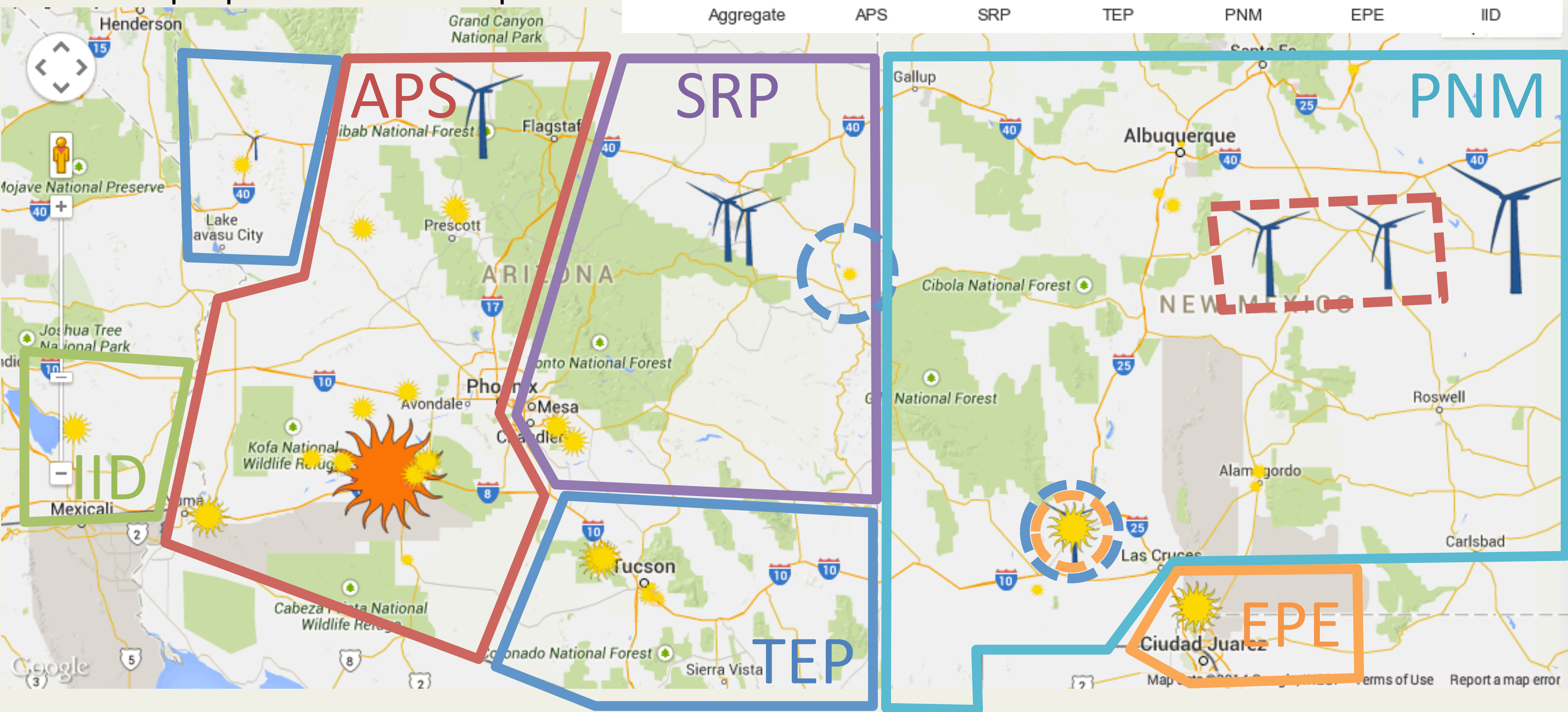
Change in renewable gen. in 1 hour (MW)

Load (MW)

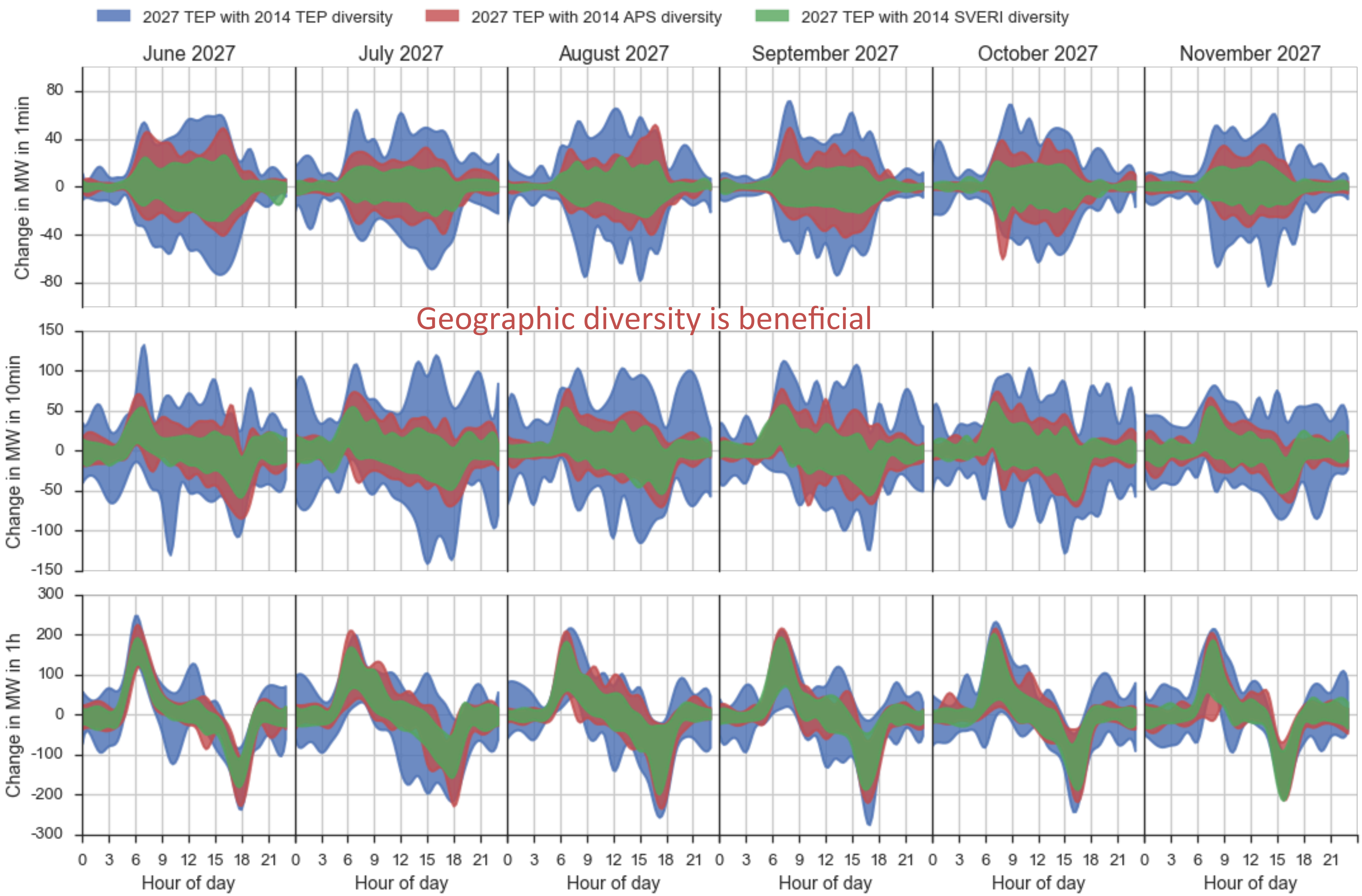
Geographic diversity is beneficial



Icon area proportional to max power



2027 TEP Variability Scenarios



(Part of) The Solution:
UA renewable power forecasts

How can forecasts help utilities keep energy costs low and maintain grid reliability?

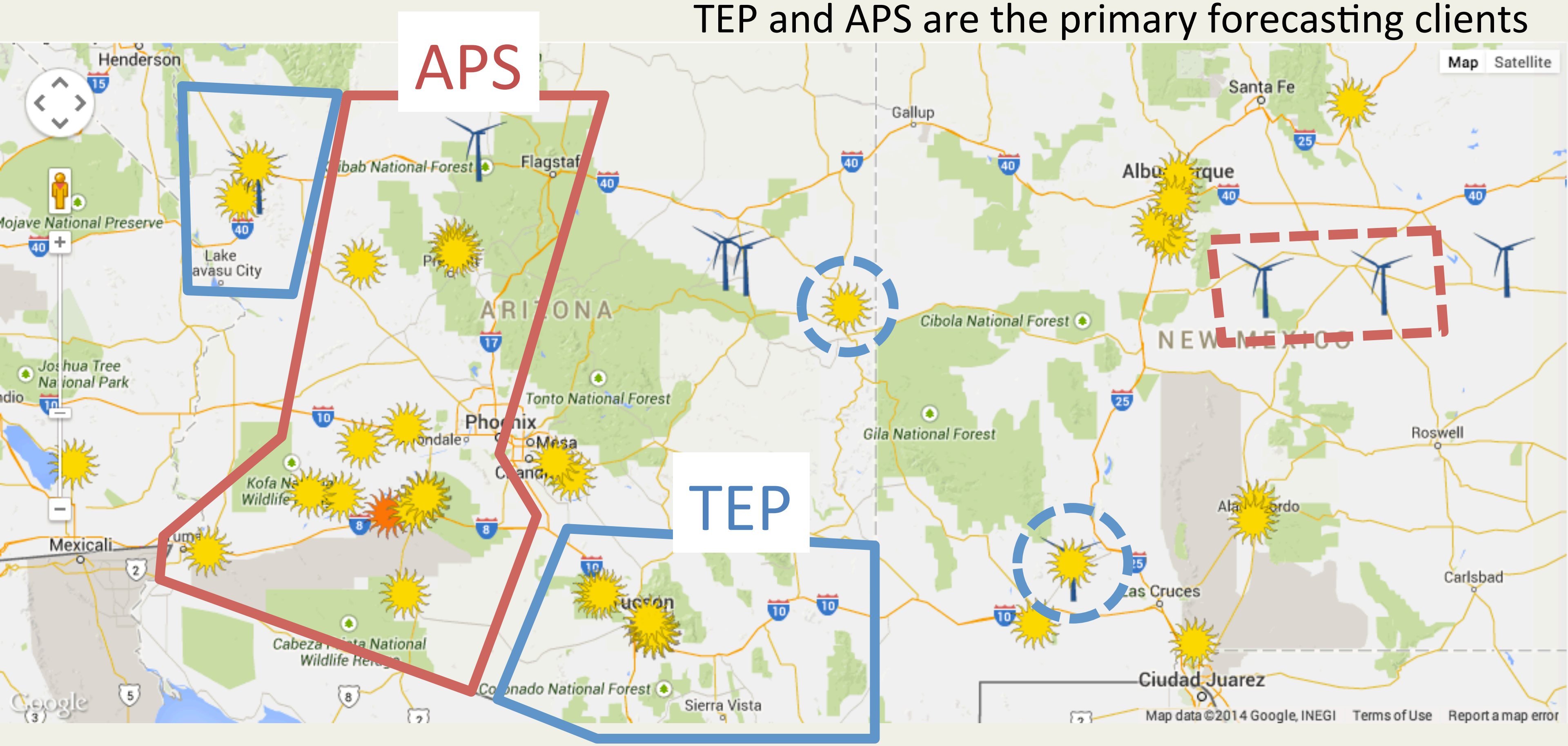
- Improve energy market trading strategies
- Schedule more efficient generators (e.g. combined cycle vs. combustion turbine)
- Reduce costs associated with generator starts
- Defer maintenance associated with excessive generator set point seeking
- Optimize the use of battery storage

UA is providing TEP and APS with forecasts as we speak

SVERI

Southwest Variable Energy Resource Initiative

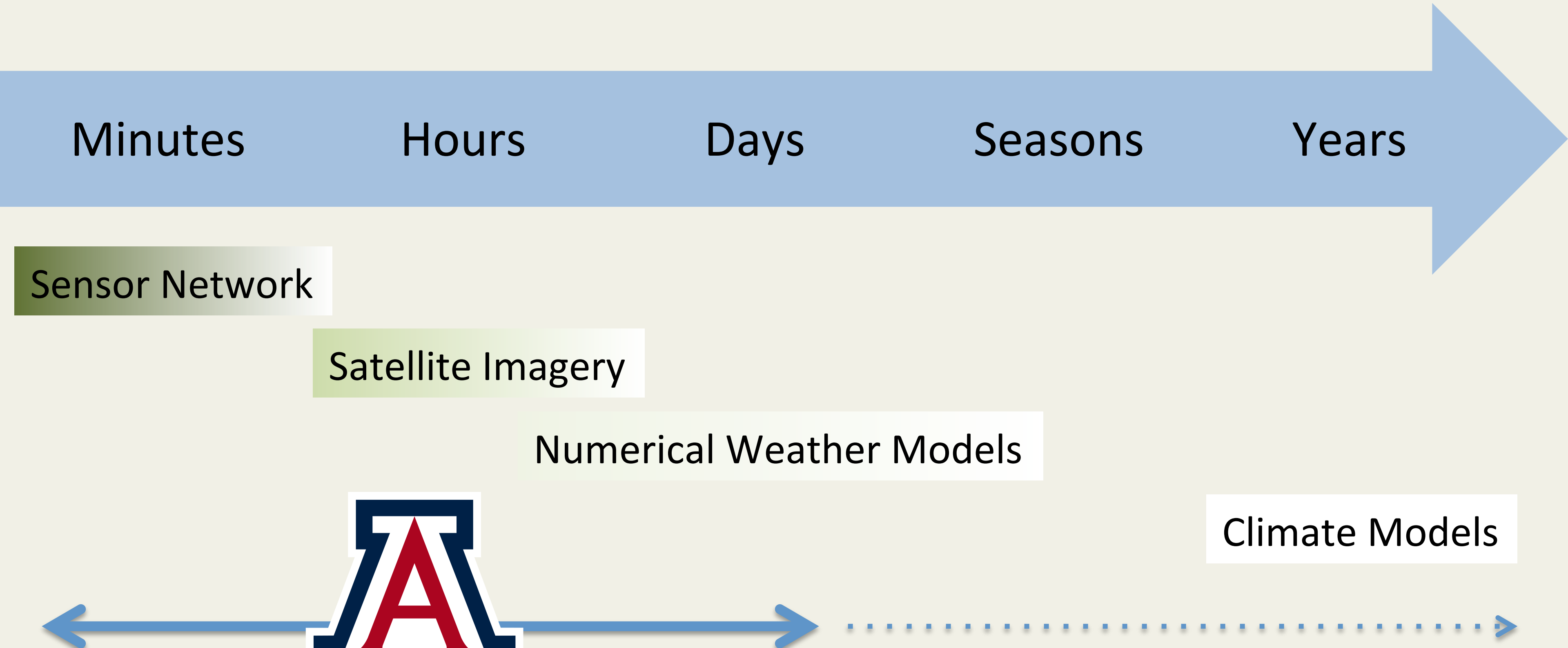
TEP and APS are the primary forecasting clients



from sveri.uaren.org

UA Forecasting Website for TEP + APS

Different forecasting methods work better at different time scales



ARIZONA

Numerical Weather Prediction at UA

Christopher Marks, Creative Commons

- Model highlights
  - 5.4 km outer domain, 1.8 km inner domain
  - Initialized on the 6Z and 12Z GFS and NAM
  - Many days include 12Z RAP initialization (esp. in summer)

WRF configuration details:
- RRTMG
- Morrison 2 mom. or SBUYLIN
- Bougeault-Lacarre or ACM2
- Noah LSM

- Local challenges include:
  - Mountains + moisture + heating = monsoon storms
  - Unreliable initialization data from Mexico
  - Extreme planetary boundary layer heights
  - Rapidly changing land/surface characteristics

- 1.8 km resolution, 3 minute outputs of:
  - GHI, DNI, 10 m wind, 80 m wind, temp

UA WRF forecasts available at atmo.arizona.edu

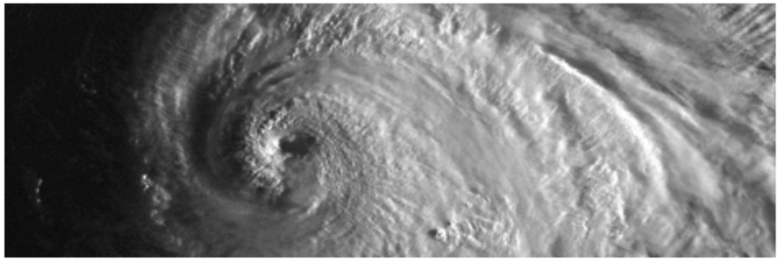
Contact me for access to raw data

The University of Arizona

www.atmo.arizona.edu/in

THE UNIVERSITY OF ARIZONA®

ADMIN WEBMAIL SEMINA



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UASCIENCE

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Arizona Regional WRF Model Data

Model Derived Forecasts

SE AZ Forecast Phx Area Forecast AM Optical Depth

Model Discussion

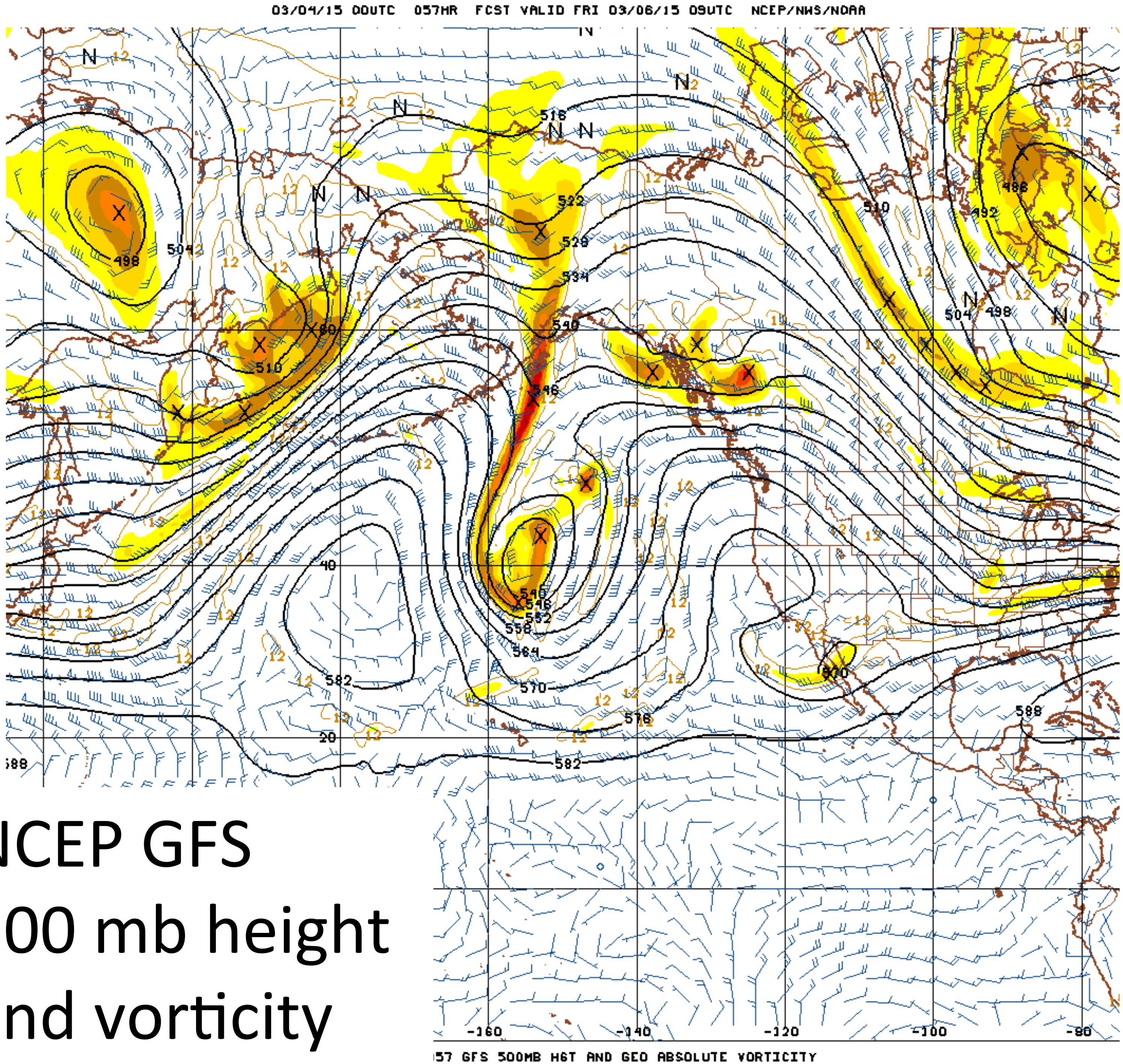
During the monsoon season and for significant weather events, a model discussion may be available.

Current Discussion Previous Discussion

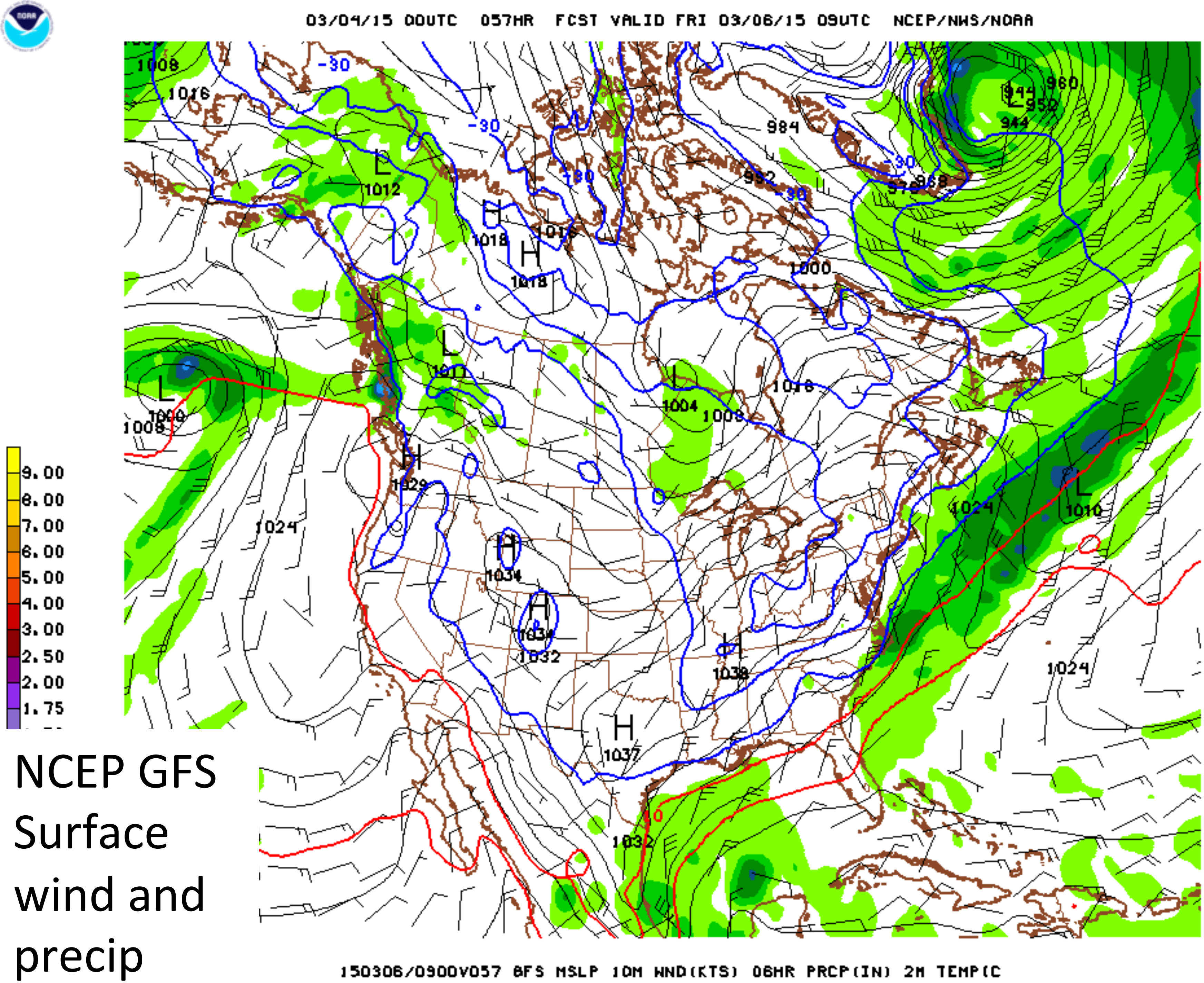
Model Products

	06z AZ WRF-GFS	06z AZ WRF-NAM	12z AZ WRF-NAM	12z AZ WRF-GFS	12z AZ WRF-RUC
Domain-Level Products					
Composite RADAR	1.8km|5.4km	1.8km|5.4km	1.8km|5.4km	1.8km|5.4km	1.8km|5.4km
Precipitation	1.8km|5.4km	1.8km|5.4km	1.8km|5.4km	1.8km|5.4km	1.8km|5.4km
Accumulated Precipitation	1.8km|5.4km 1.8kmz|5.4kmz	1.8km|5.4km 1.8kmz|5.4kmz	1.8km|5.4km 1.8kmz|5.4kmz	1.8km|5.4km 1.8kmz|5.4kmz	1.8km|5.4km 1.8kmz|5.4kmz
Accumulated Snow	1.8km|5.4km	1.8km|5.4km	1.8km|5.4km	1.8km|5.4km	1.8km|5.4km
Snow Cover	1.8km|5.4km	1.8km|5.4km	1.8km|5.4km	1.8km|5.4km	1.8km|5.4km
2m Temp	1.8km|5.4km 1.8kmz|5.4kmz	1.8km|5.4km 1.8kmz|5.4kmz	1.8km|5.4km 1.8kmz|5.4kmz	1.8km|5.4km 1.8kmz|5.4kmz	1.8km|5.4km 1.8kmz|5.4kmz
10m Wind	1.8km|5.4km 1.8kmz|5.4kmz	1.8km|5.4km 1.8kmz|5.4kmz	1.8km|5.4km 1.8kmz|5.4kmz	1.8km|5.4km 1.8kmz|5.4kmz	1.8km|5.4km 1.8kmz|5.4kmz
Precipitable					

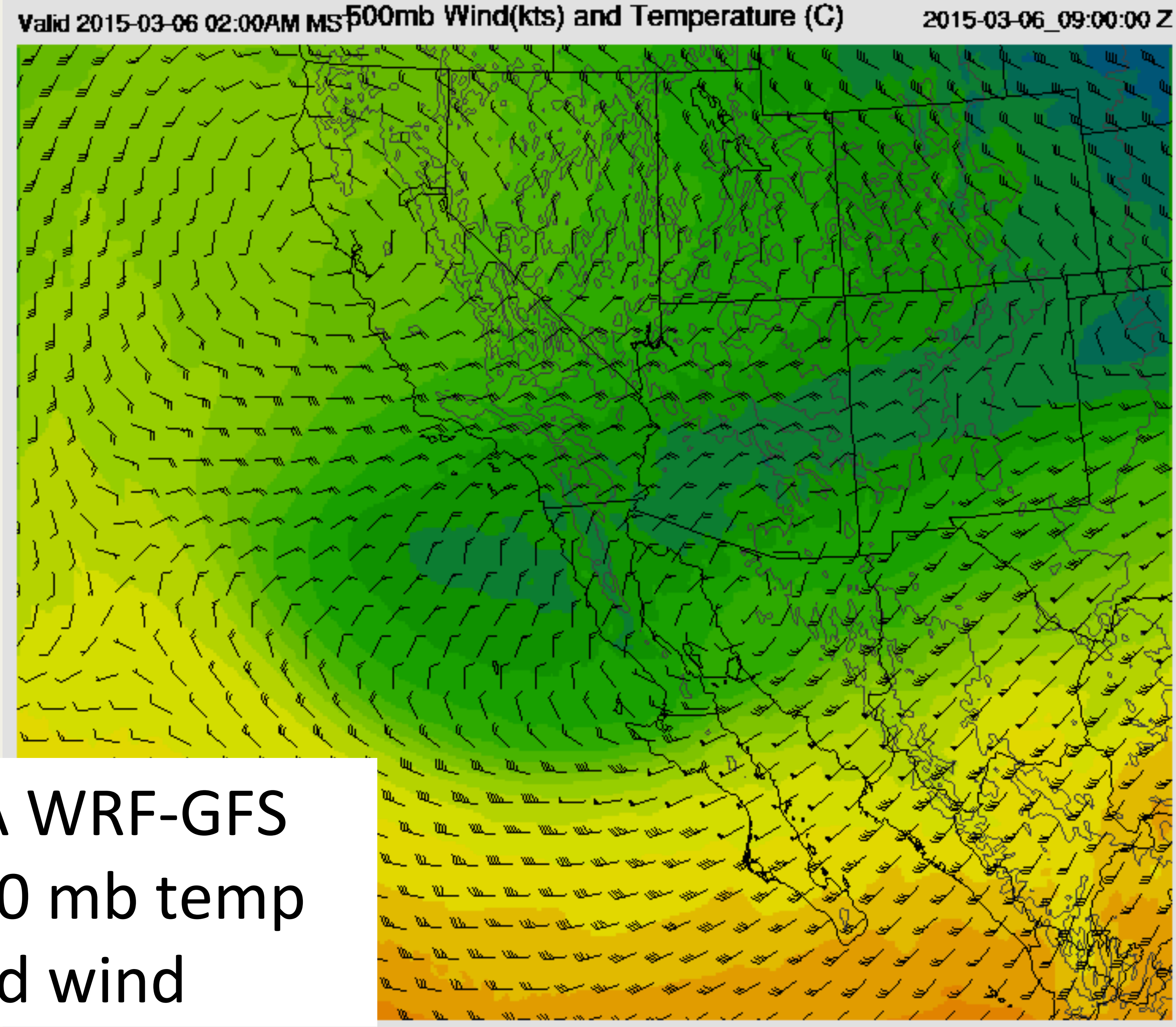
- Current Weather
- Campus Weather Conditions
- Campus Weather Plots (English Units)
- Daily, Weekly & Monthly Plots
- Solar Observatory Data (opens new tab or window)
- Satellite Imagery
- RADAR
- Lightning Plots (arizona.edu only)
- Maps and Plots
- Arizona Regional WRF Model Data
- Idaho Regional WRF Model Data
- GPS Precipitable Water
- Cloud movies
  - Full Day Cloud Camera Movie
  - Last 90 mins. Movie
  - Yesterday's Movie
  - "Best Of" ATMO Cloud Movies



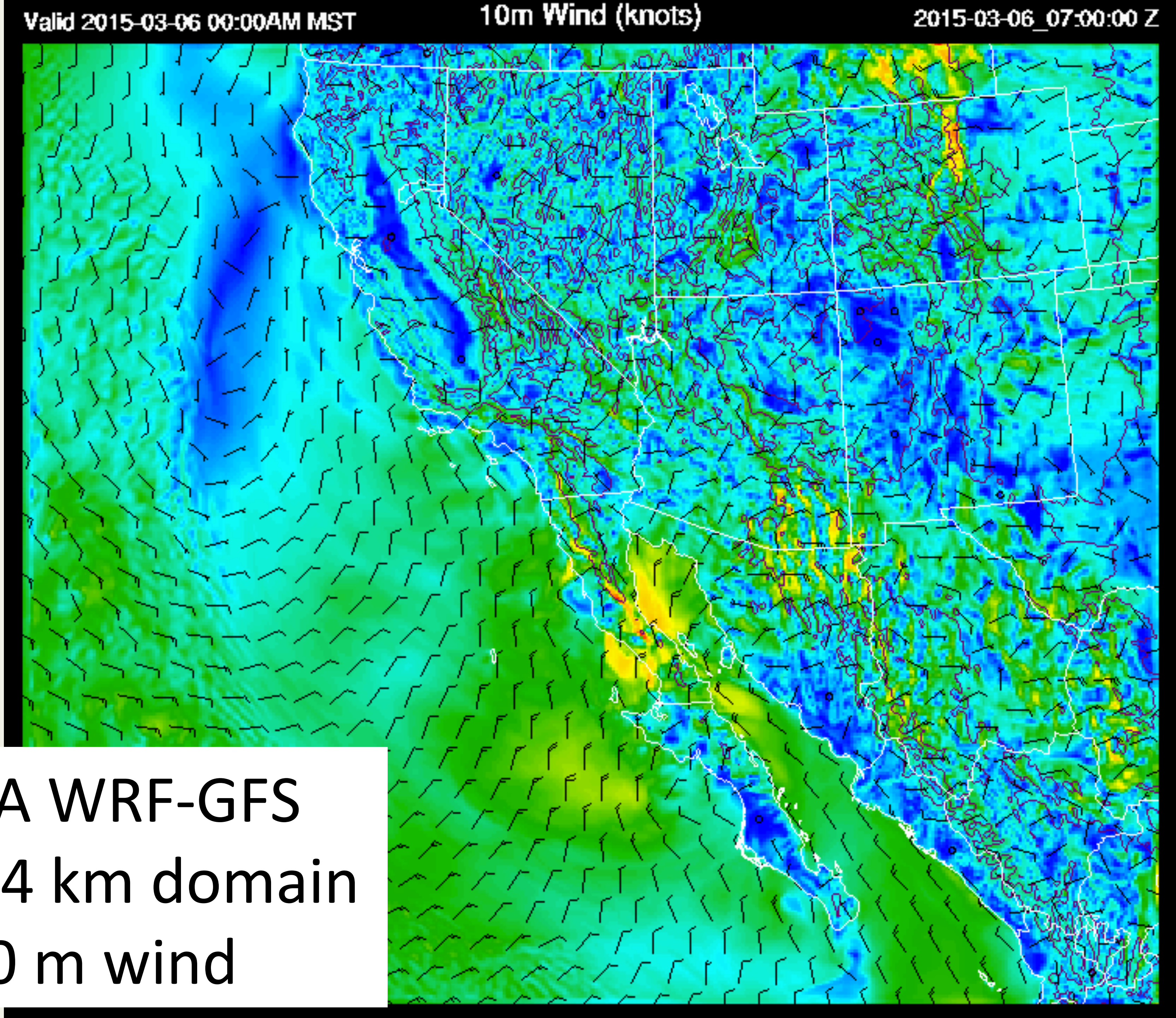
NCEP GFS
500 mb height
and vorticity



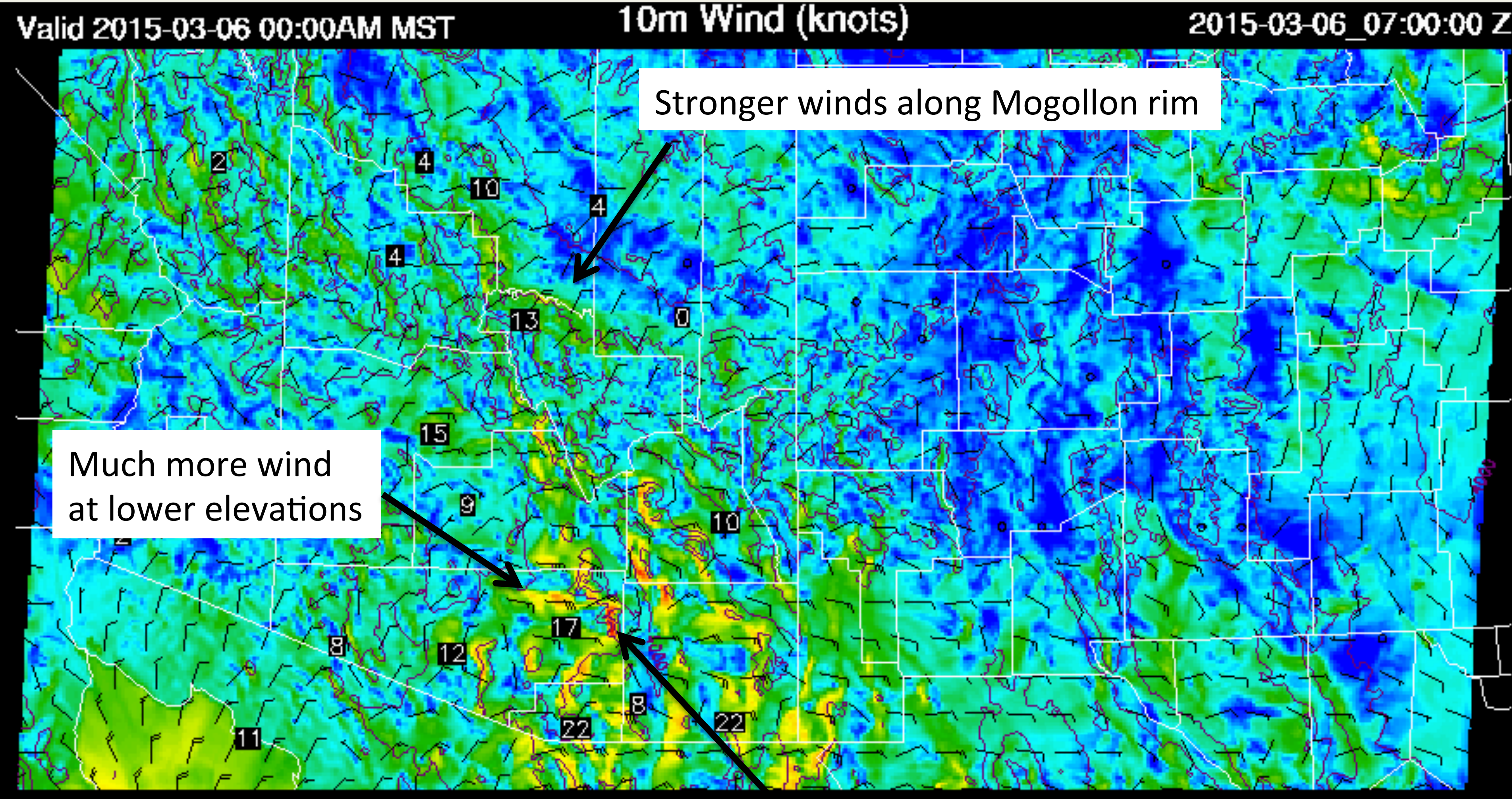
NCEP GFS Surface wind and precip



UA WRF-GFS
500 mb temp
and wind



UA WRF-GFS
5.4 km domain
10 m wind

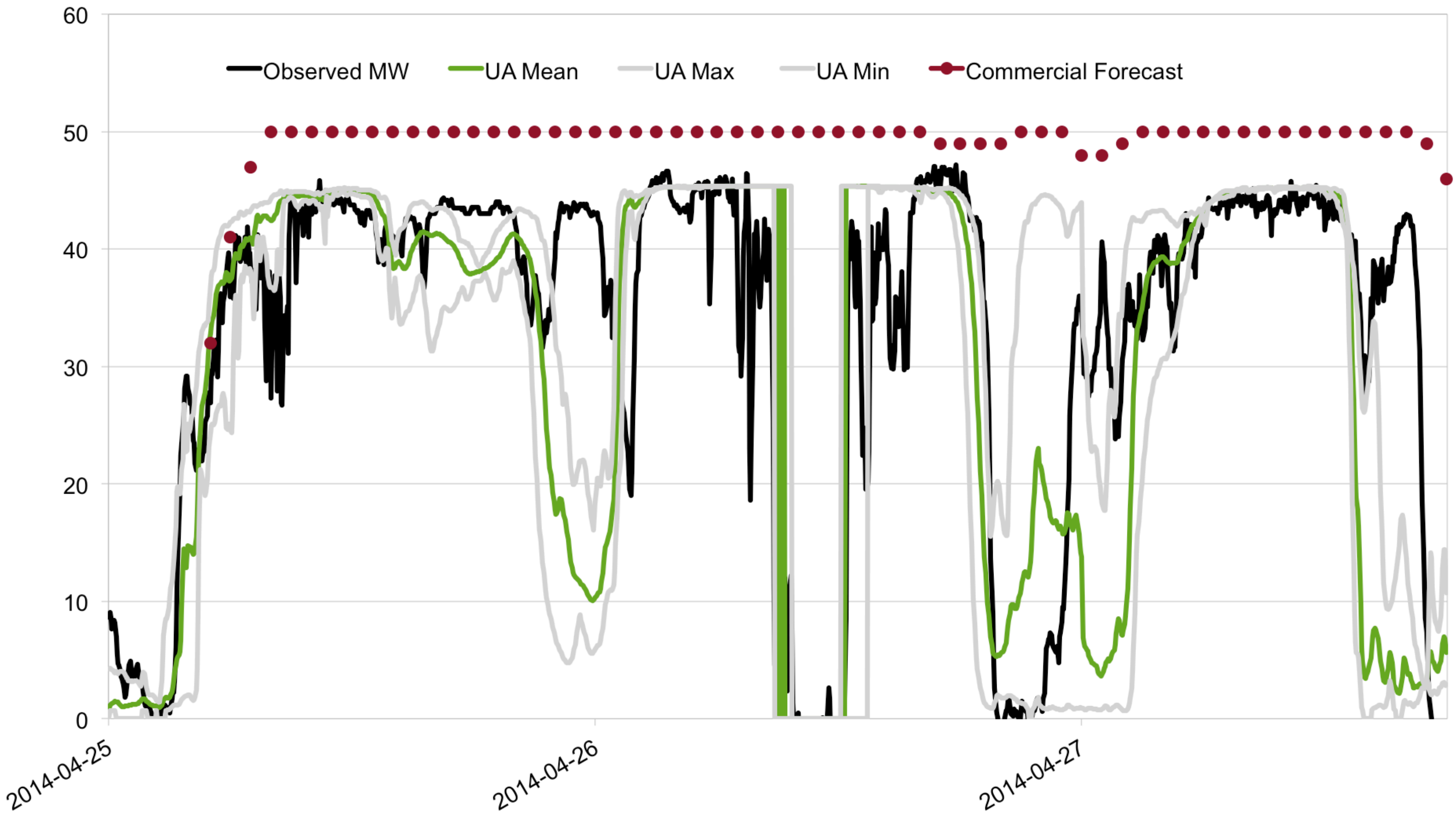


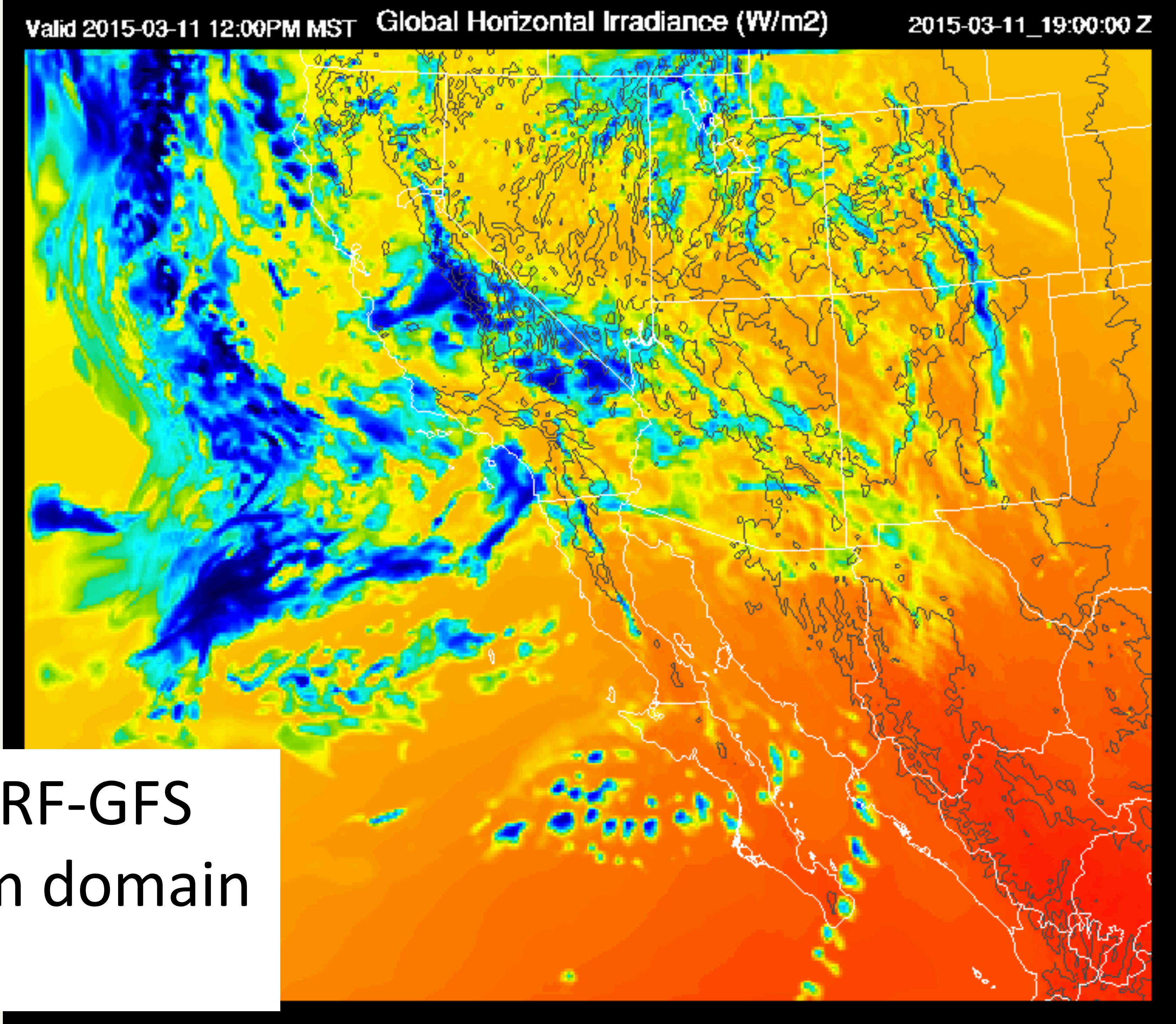
UA WRF-GFS
1.8 km domain
10 m wind

Stronger mountain winds

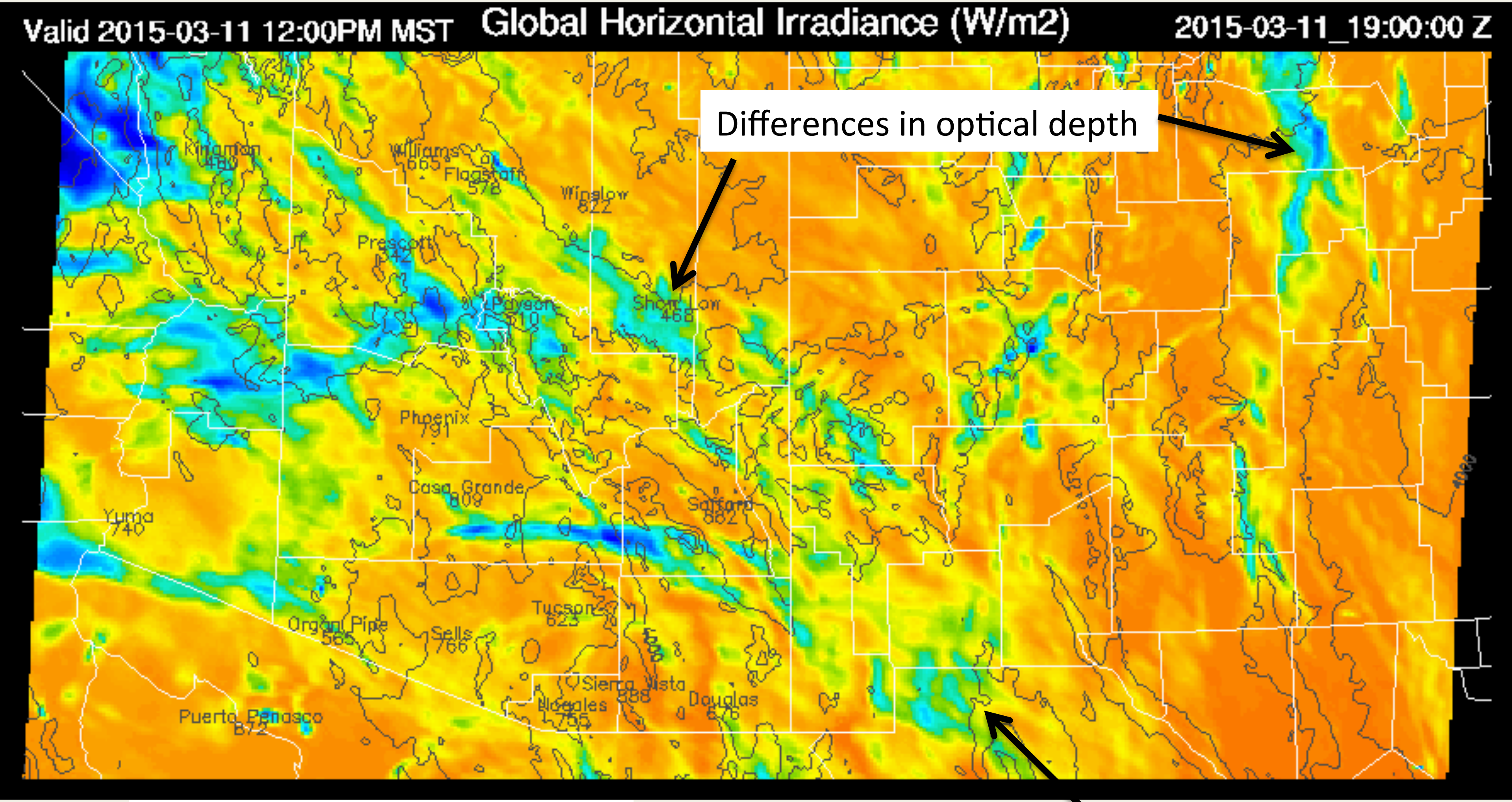
Difference between 5.4 km and 1.8 km domains increases as weather becomes more severe

Wind forecasting: UA vs. TEP vendor



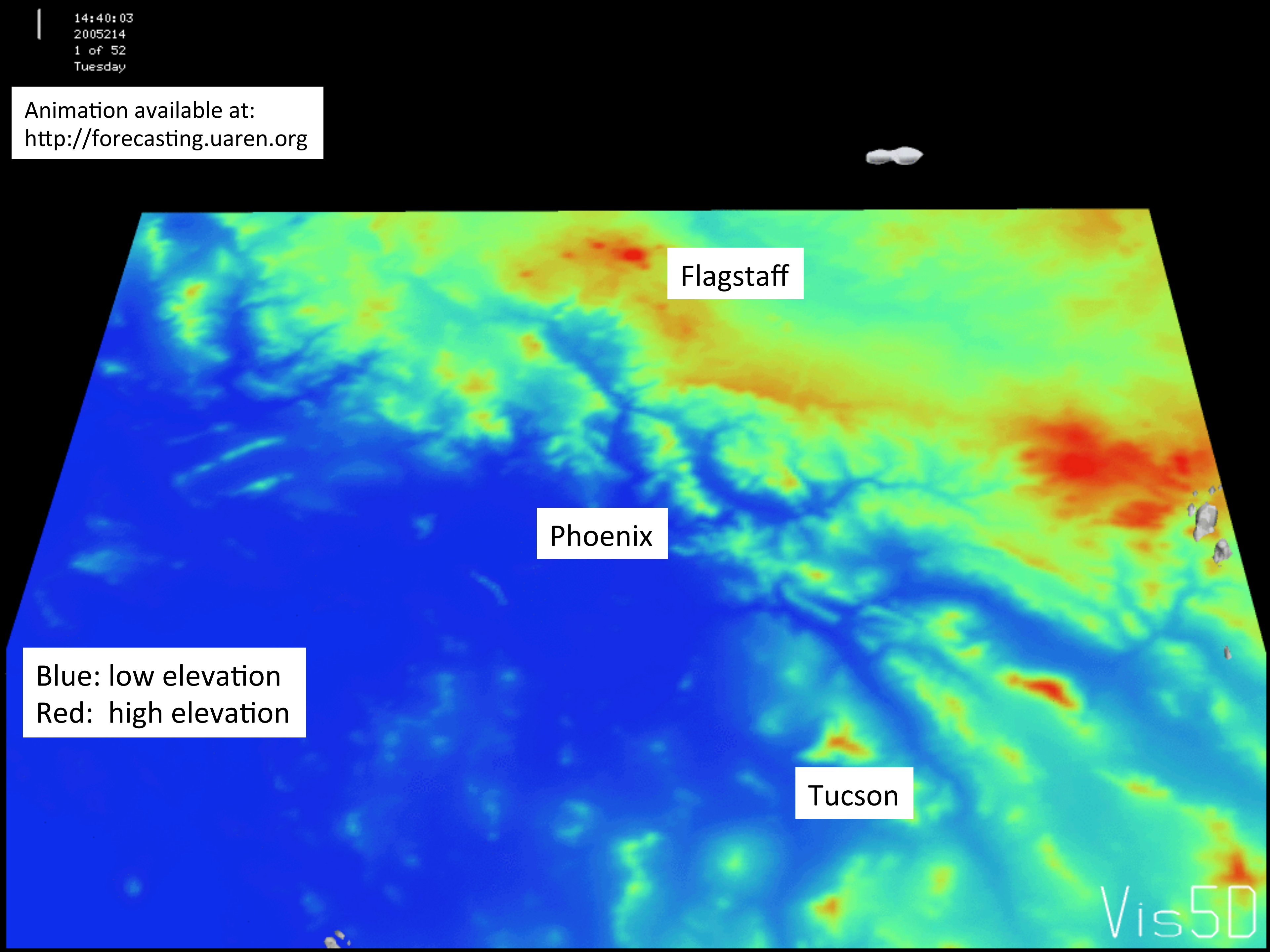


UA WRF-GFS
5.4 km domain
GHI

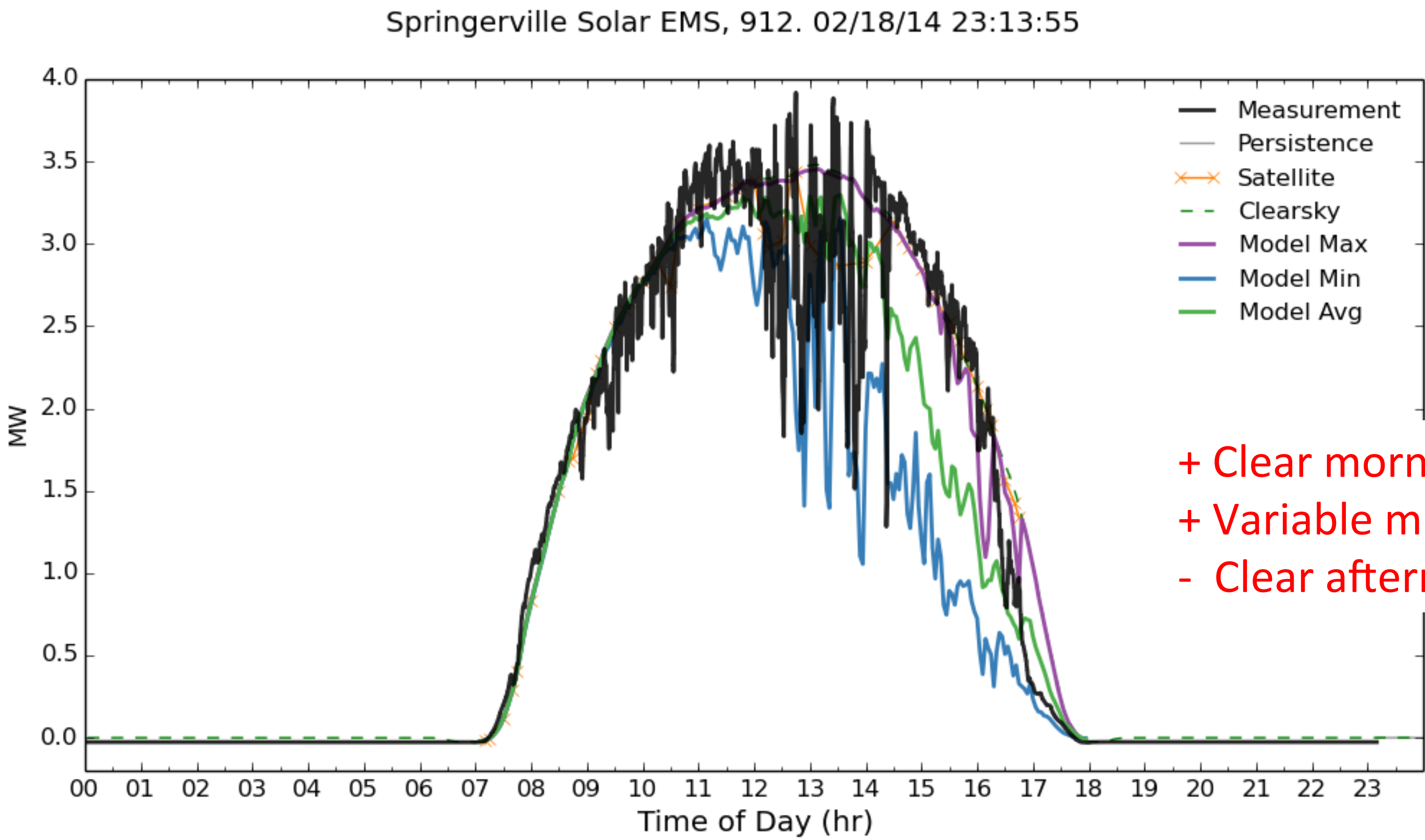


UA WRF-GFS 1.8 km domain GHI

Difference between 5.4 km and 1.8 km domains increases as weather becomes more severe

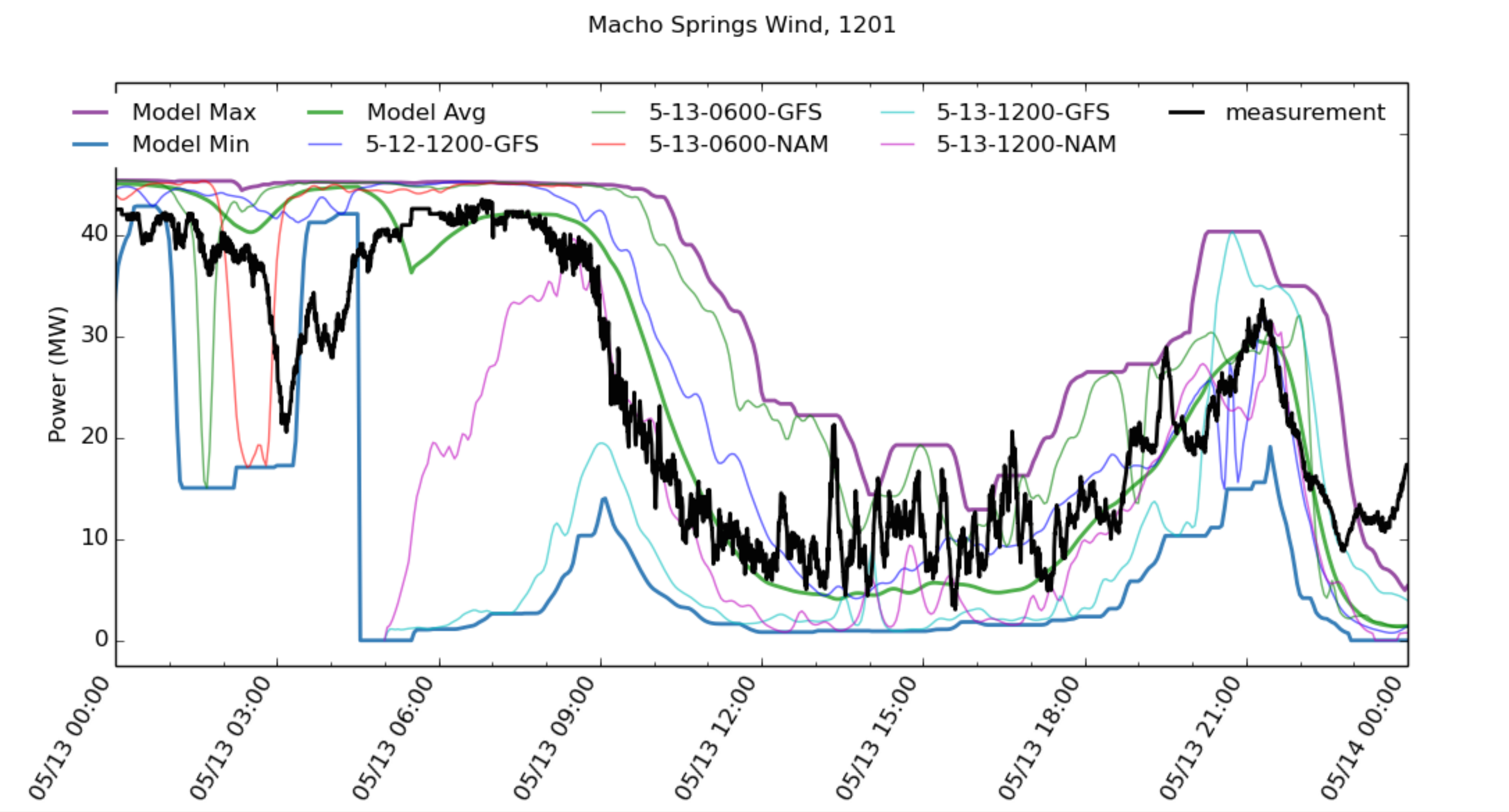

14:40:03
2005214
1 of 52
Tuesday
Animation available at:
http://forecasting.uaren.org
Flagstaff
Phoenix
Tucson
Blue: low elevation
Red: high elevation
Vis5D

UA-WRF Solar Power Forecast



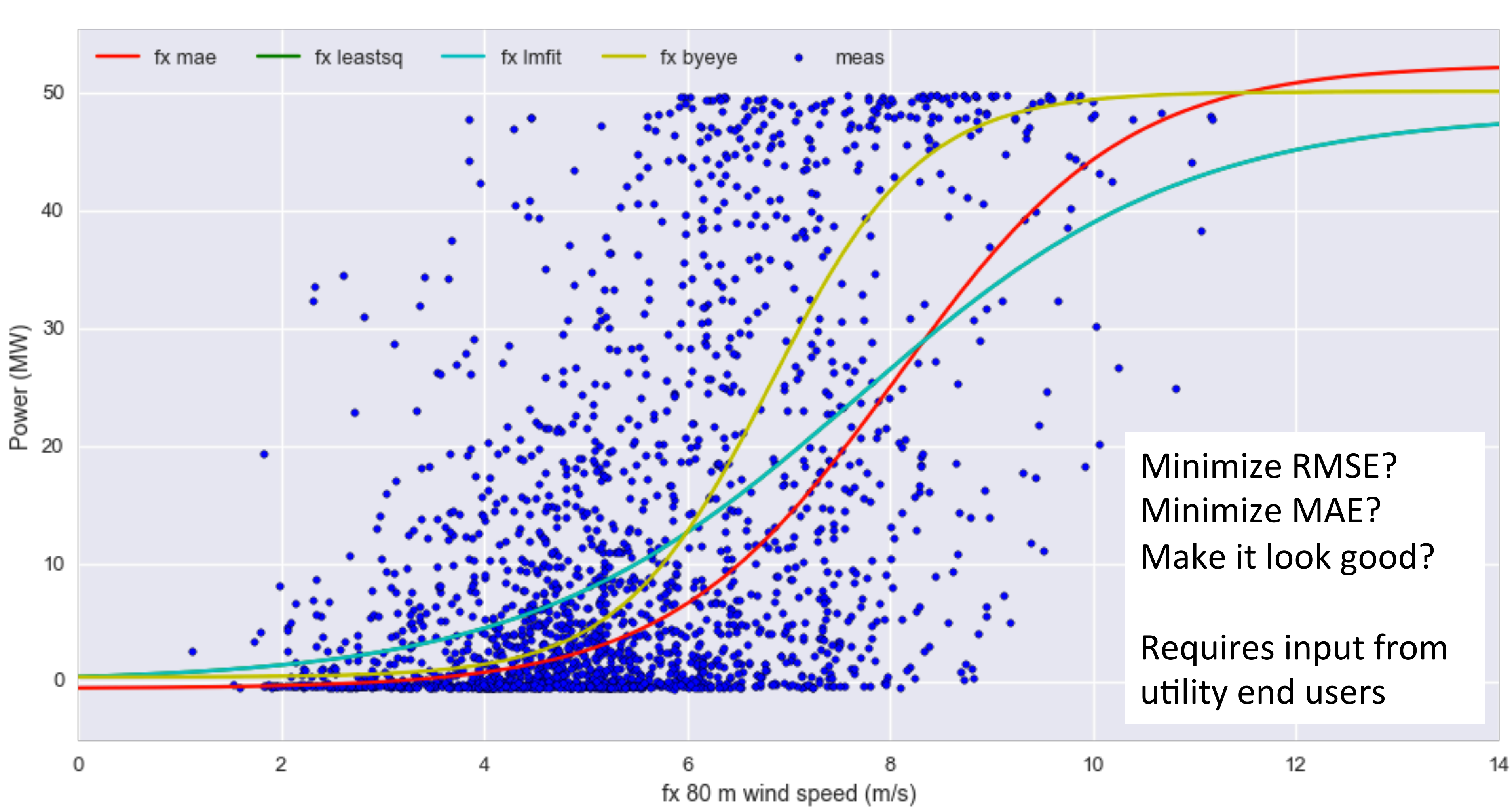
+ Clear morning
+ Variable mid-day
- Clear afternoon

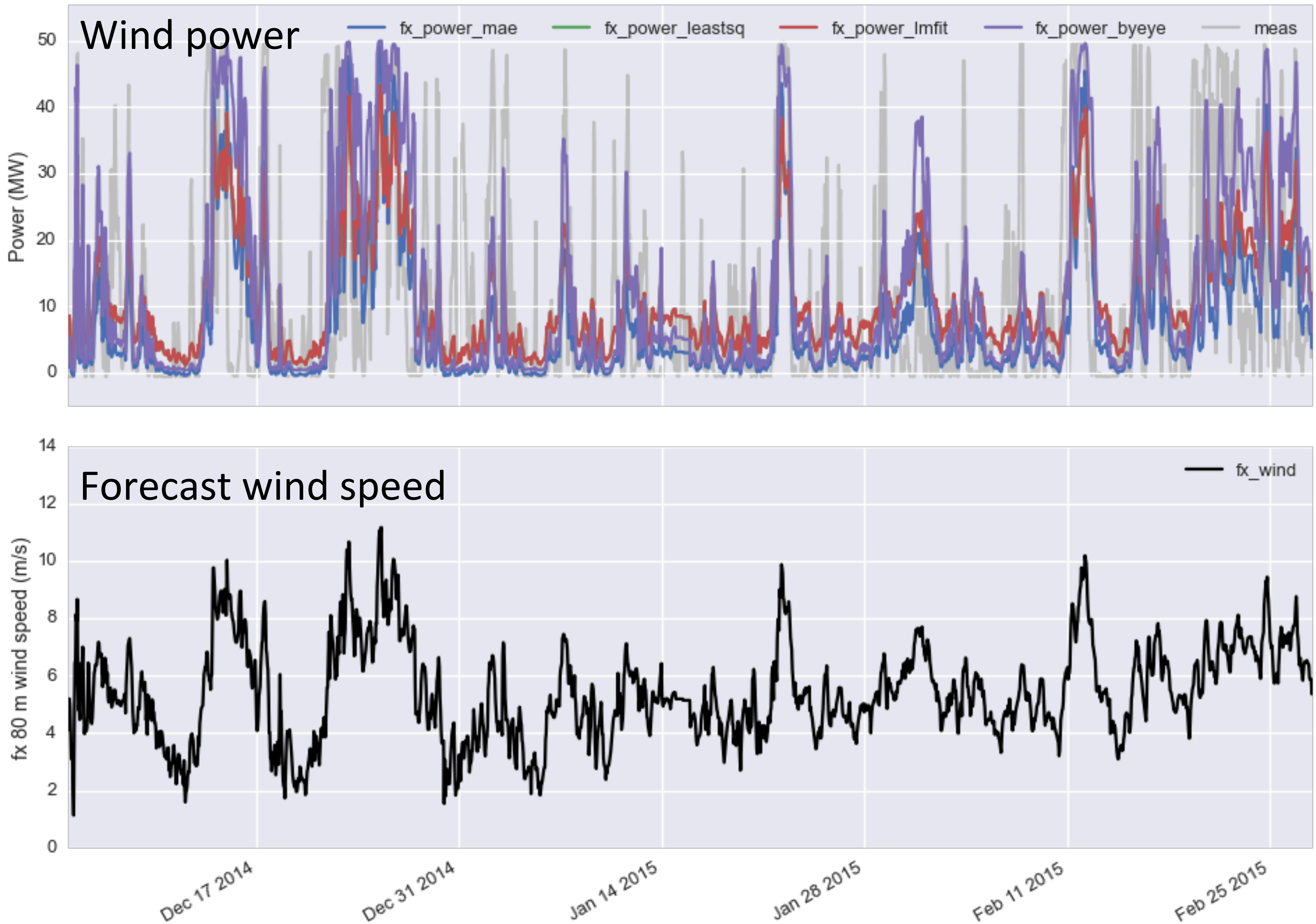
UA-WRF Wind Power Forecast



UA-WRF Wind Power Curve

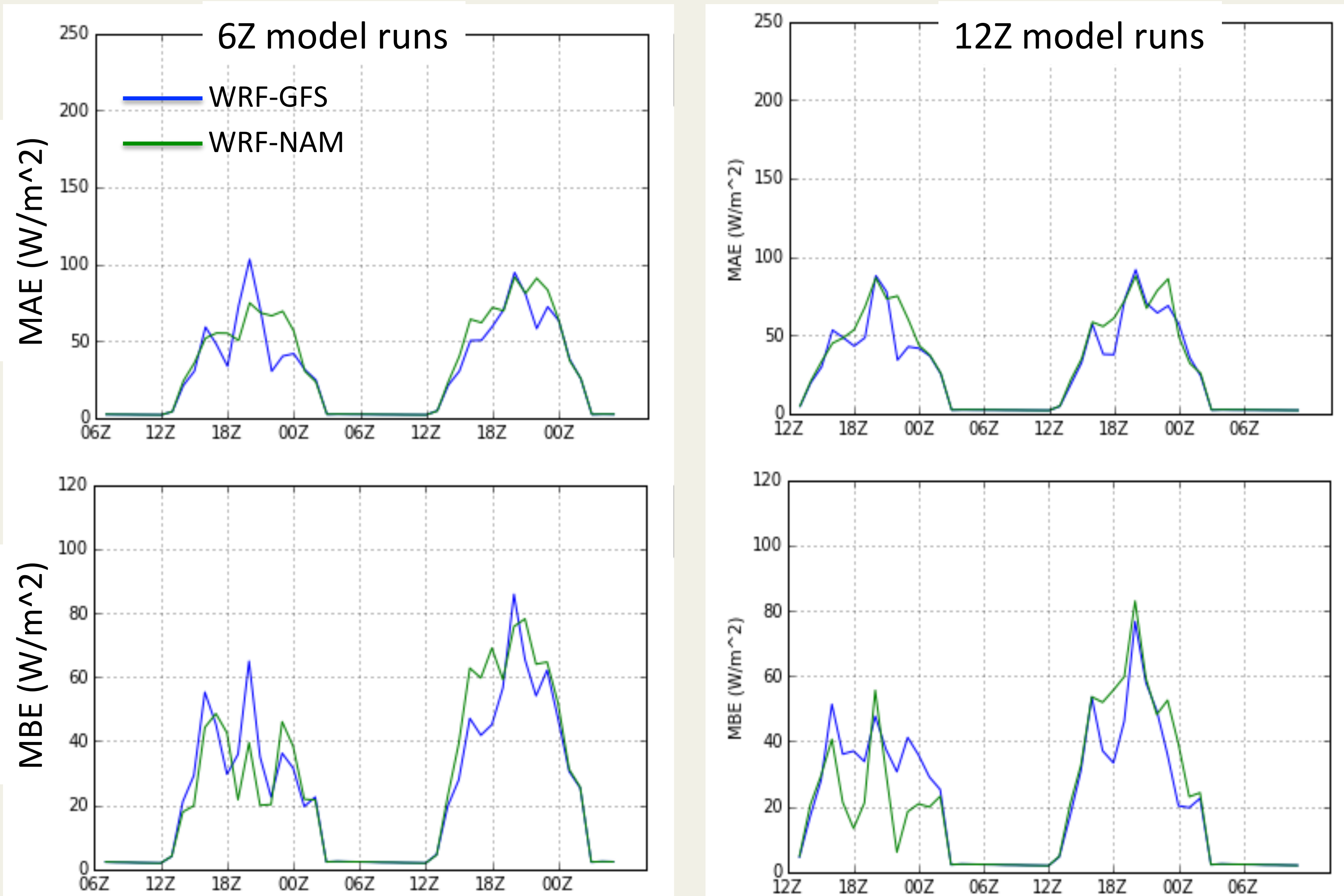
Hourly average wind power vs. hourly average forecast wind speed



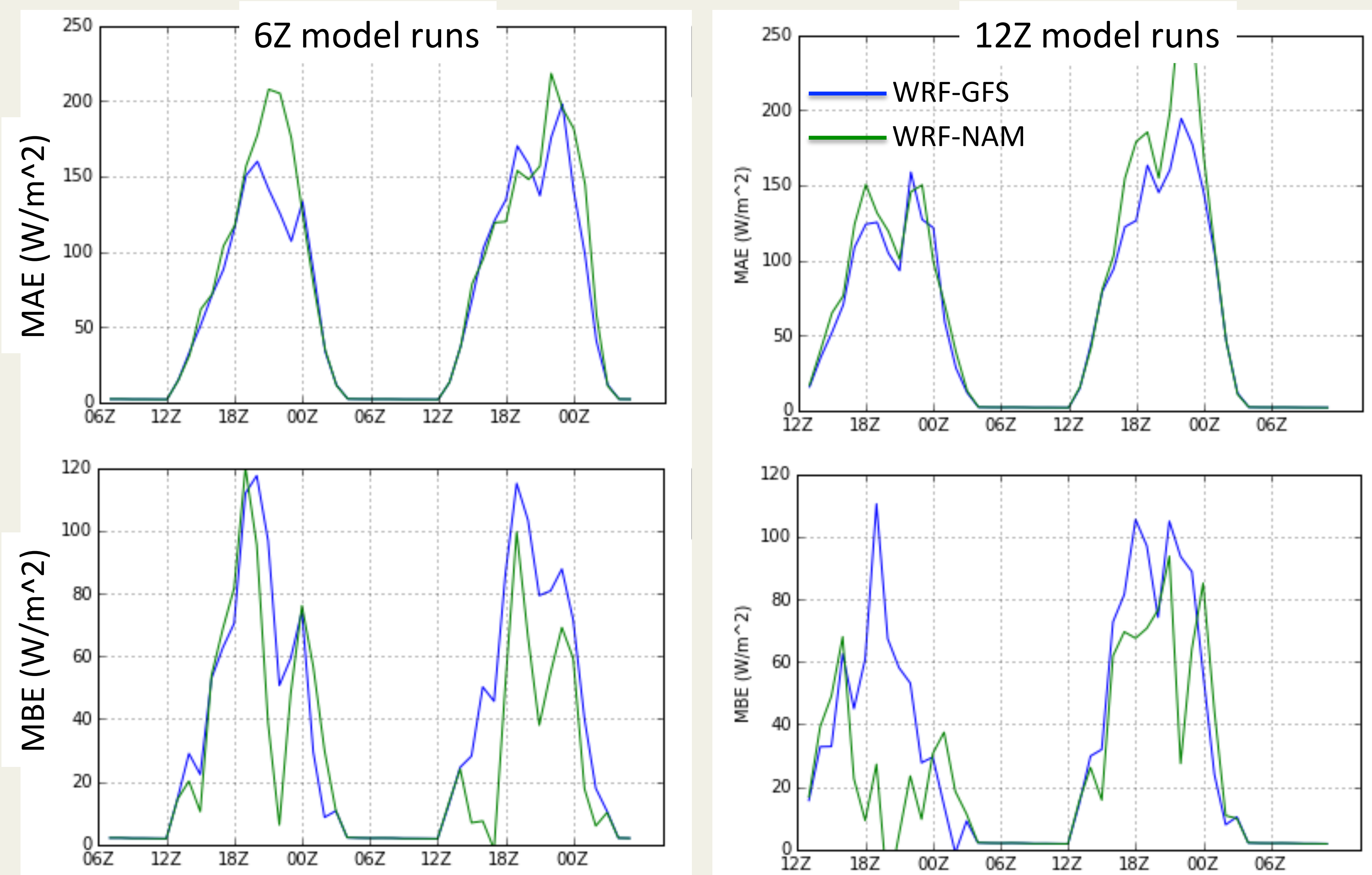


Wind power
fx_power_mae
fx_power_leastsq
fx_power_lmfit
fx_power_byeye
meas
Power (MW)
0
10
20
30
40
50
Forecast wind speed
fx_wind
fx 80 m wind speed (m/s)
0
2
4
6
8
10
12
14
Dec 17 2014
Dec 31 2014
Jan 14 2015
Jan 28 2015
Feb 11 2015
Feb 25 2015

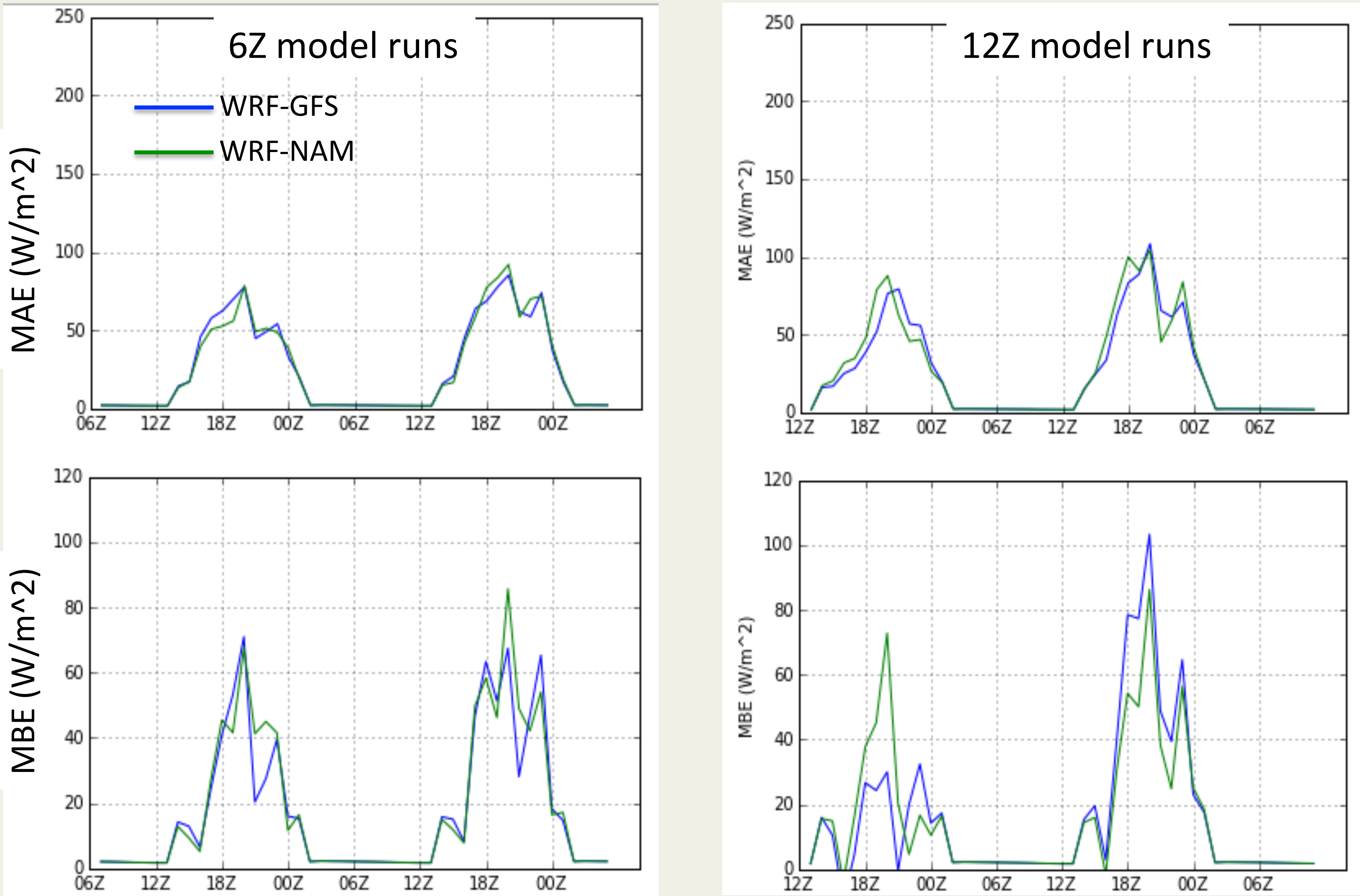
April 2014 UA-WRF GHI



July 2014 UA-WRF GHI



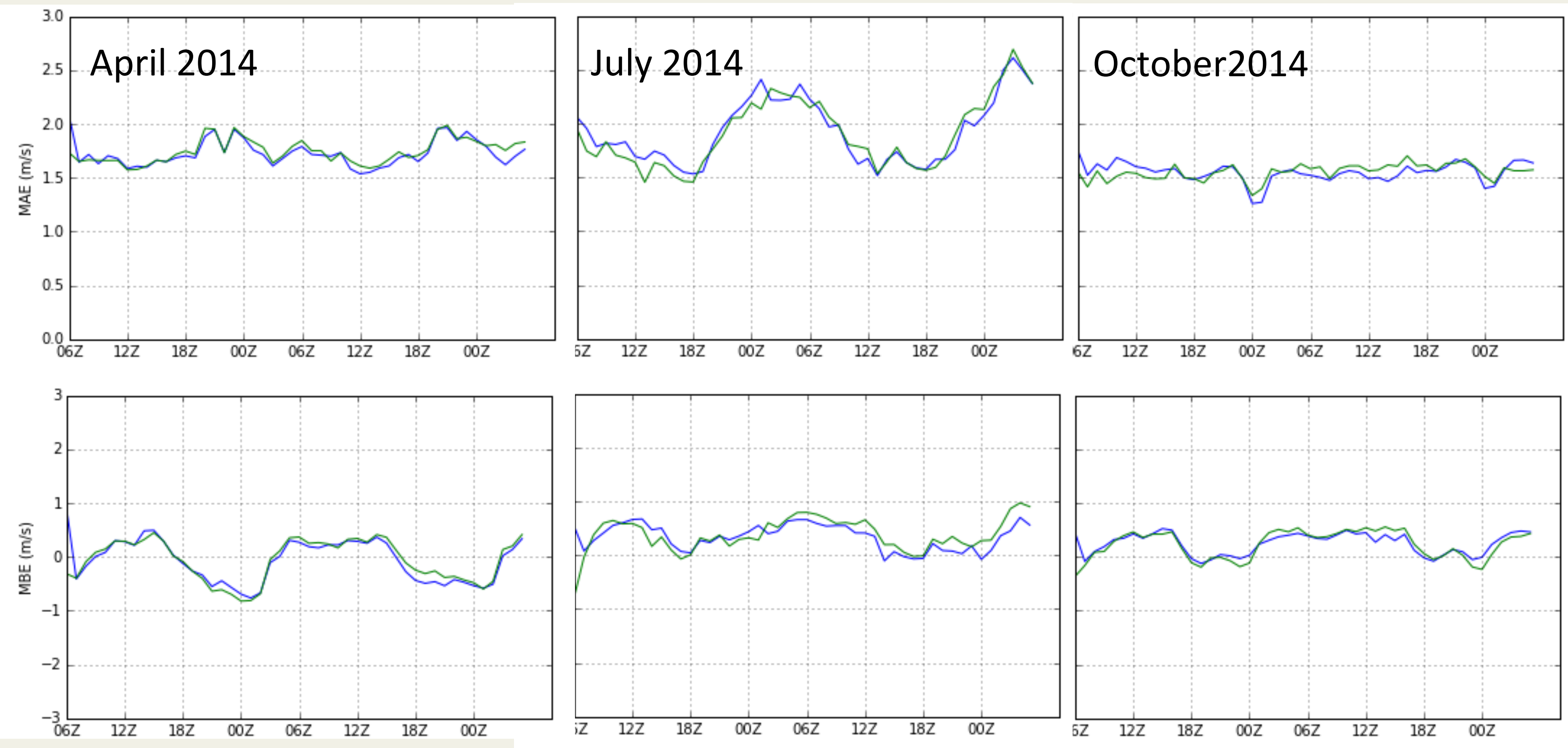
October 2014 UA-WRF GHI



Wind Errors 6Z UA-WRF

WRF-GFS

WRF-NAM

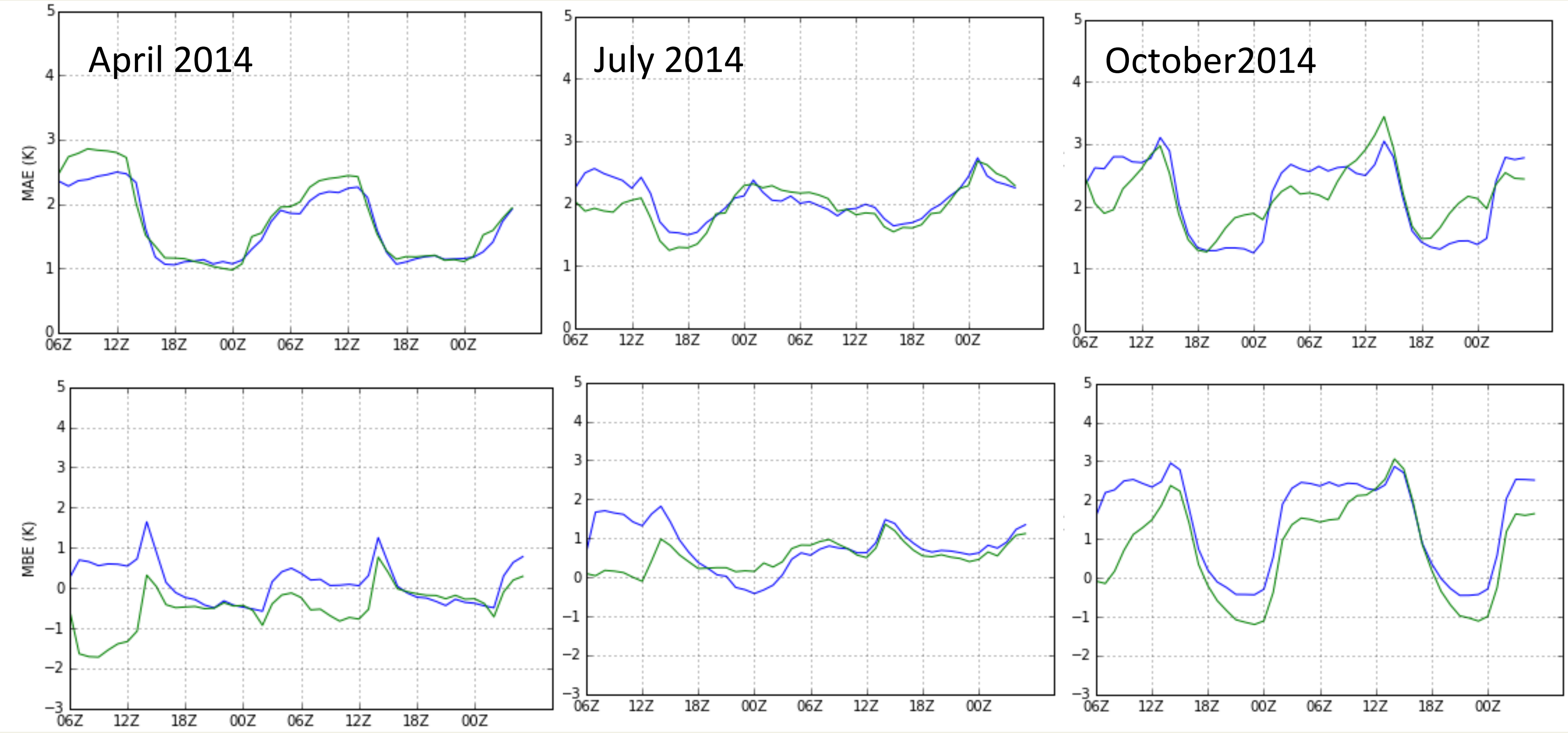


Average errors for all AZ METARs stations

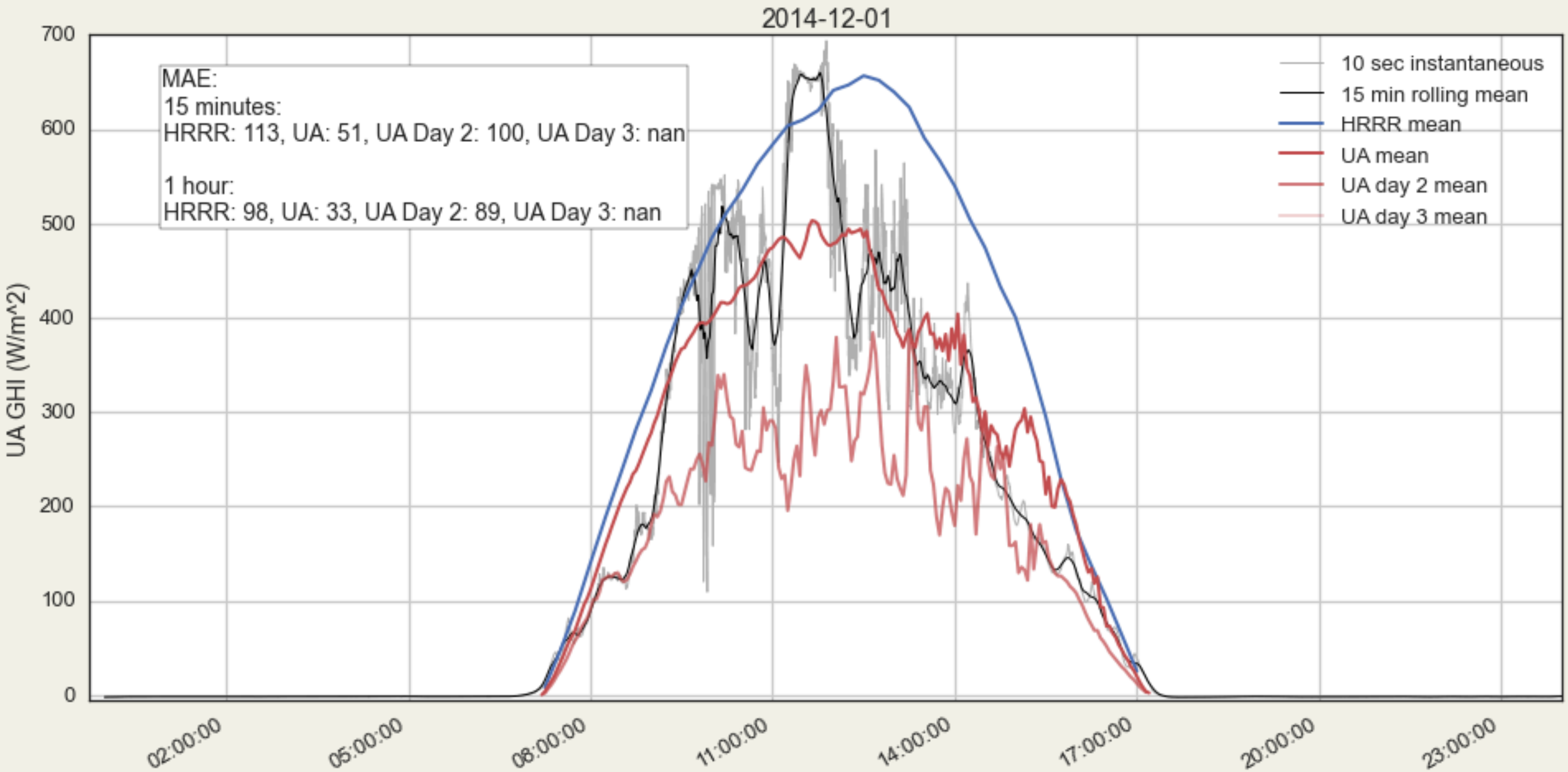
Temp Errors 6Z UA-WRF

WRF-GFS

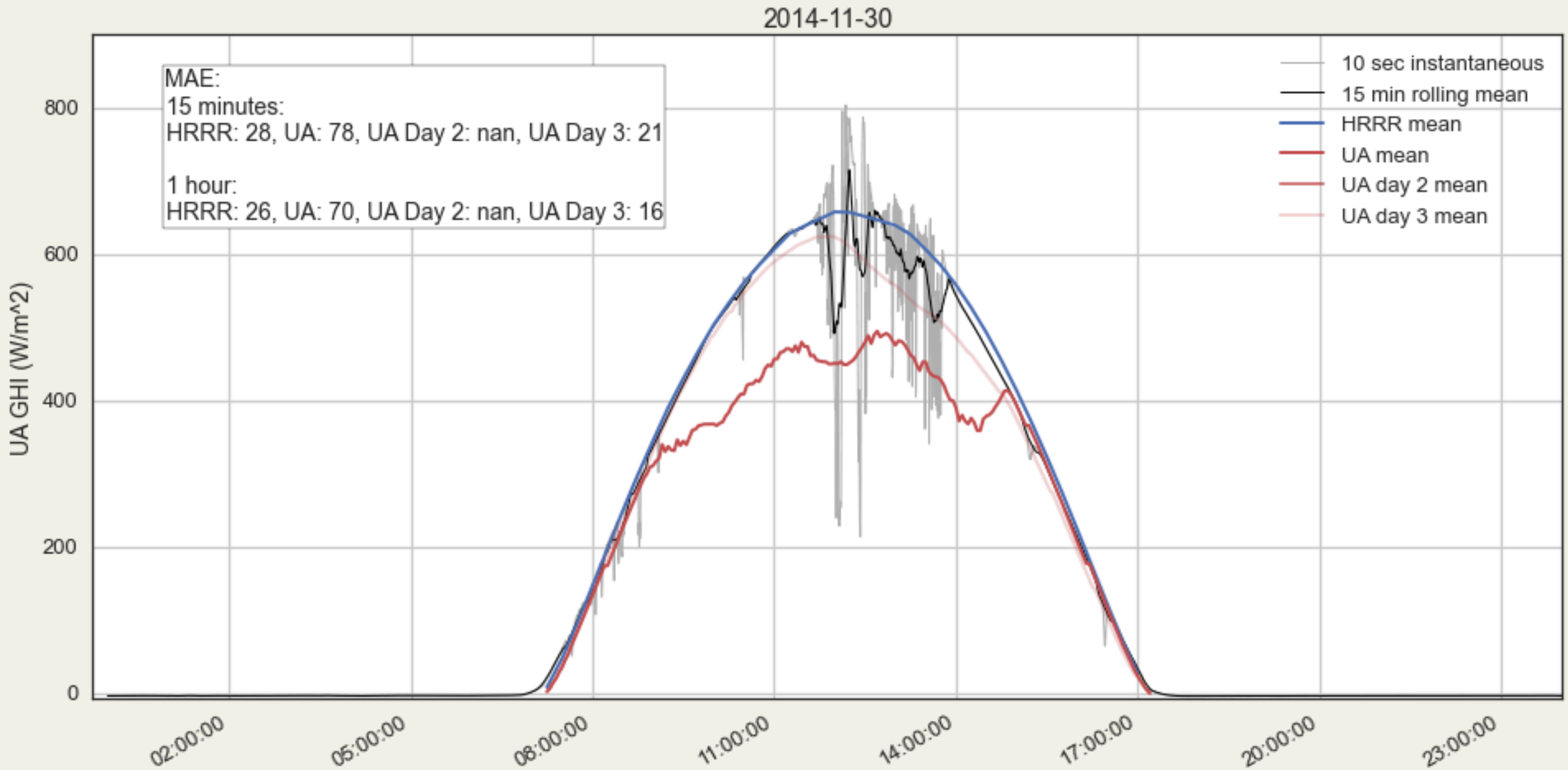
WRF-NAM



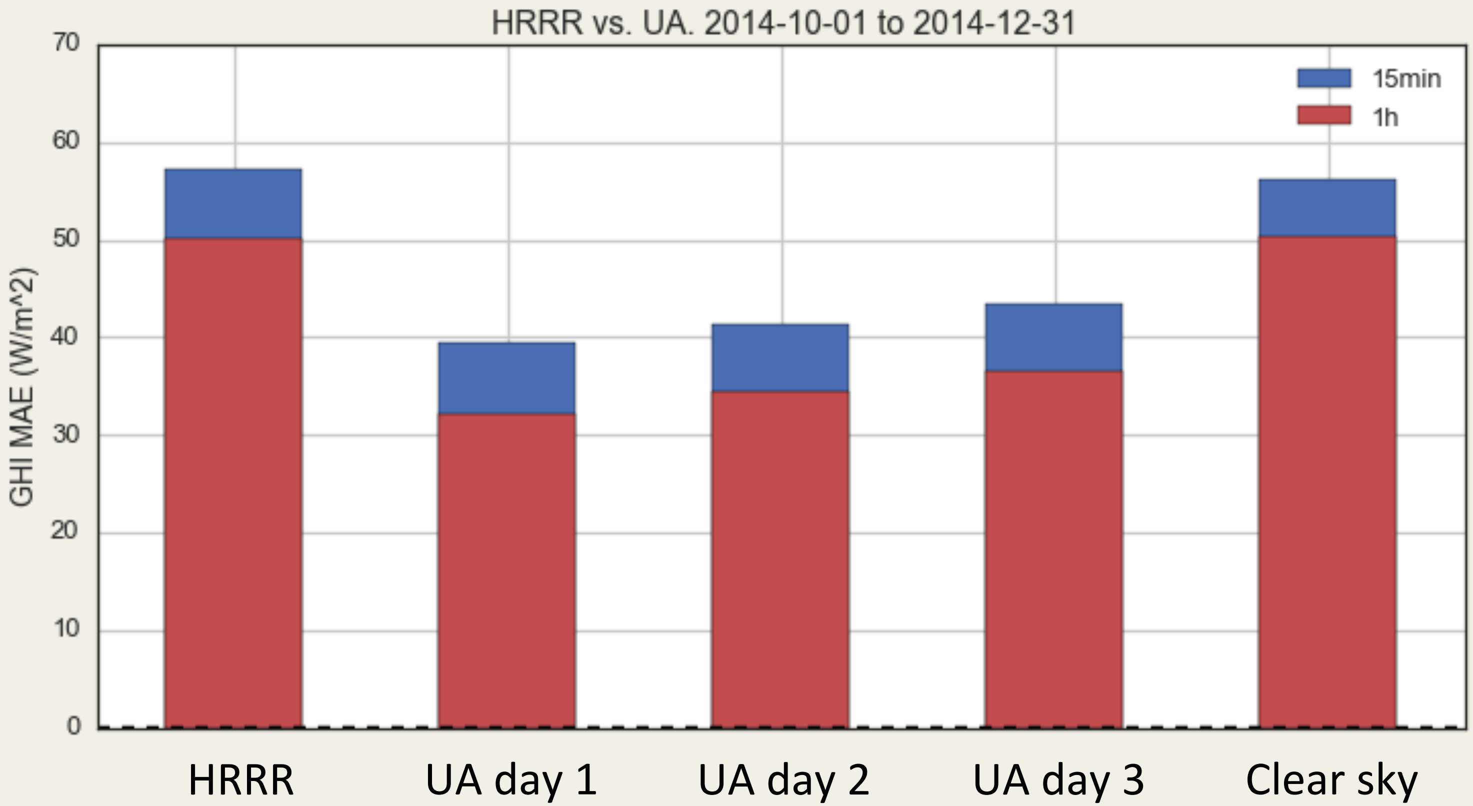
UA-WRF vs. NCEP HRRR Tucson GHI



UA-WRF vs. NCEP HRRR Tucson GHI



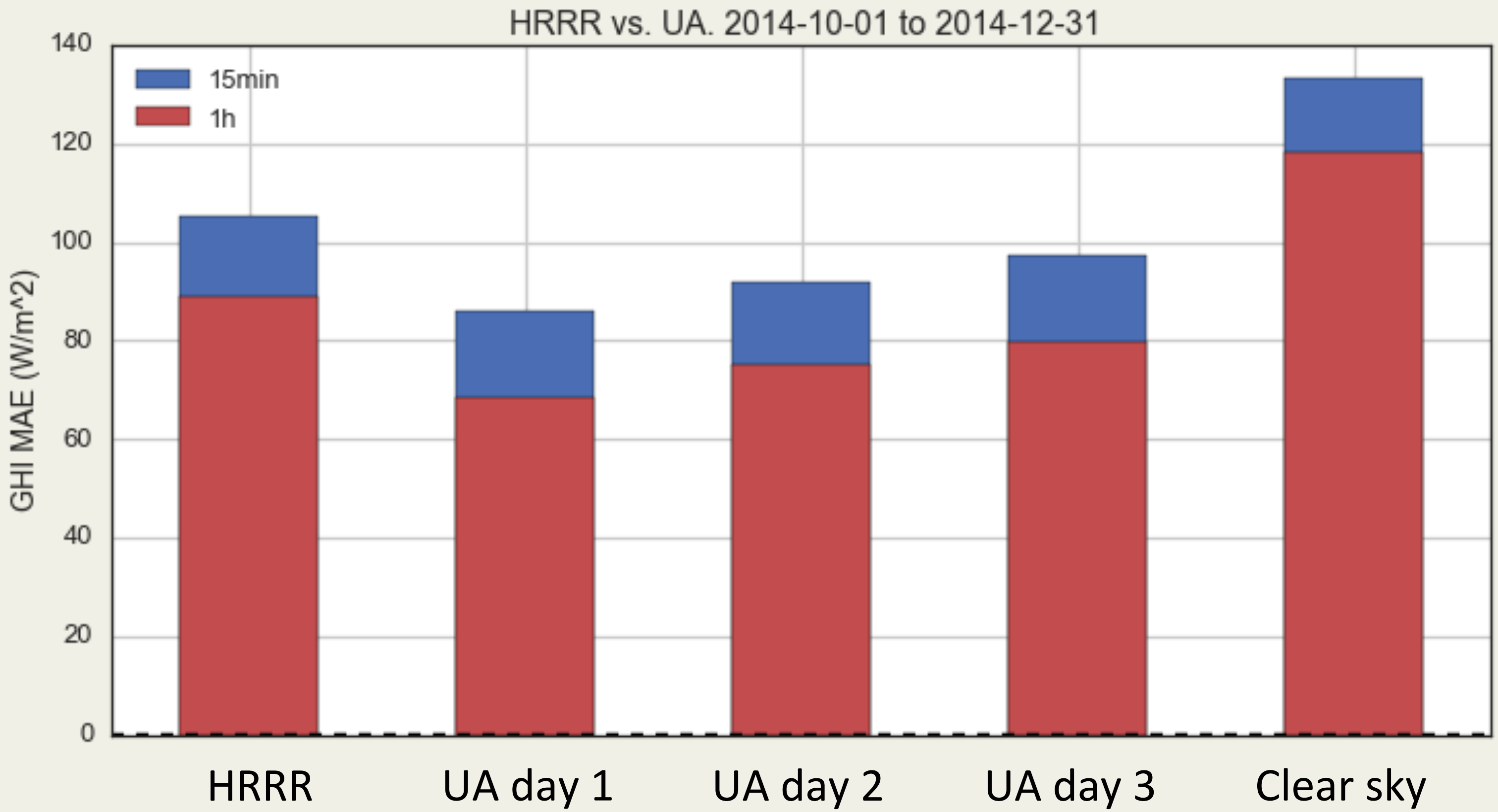
UA-WRF vs. NCEP HRRR Tucson GHI



Not a fair comparison because NCEP HRRR does not use the correct eqn. of time
So, we subtracted 15 minutes from HRRR time for approximate correction for these months
First HRRR point also discarded

Oct-Dec average of the daily average of 15 minute or 1 hour MAEs

UA-WRF vs. NCEP HRRR Tucson GHI

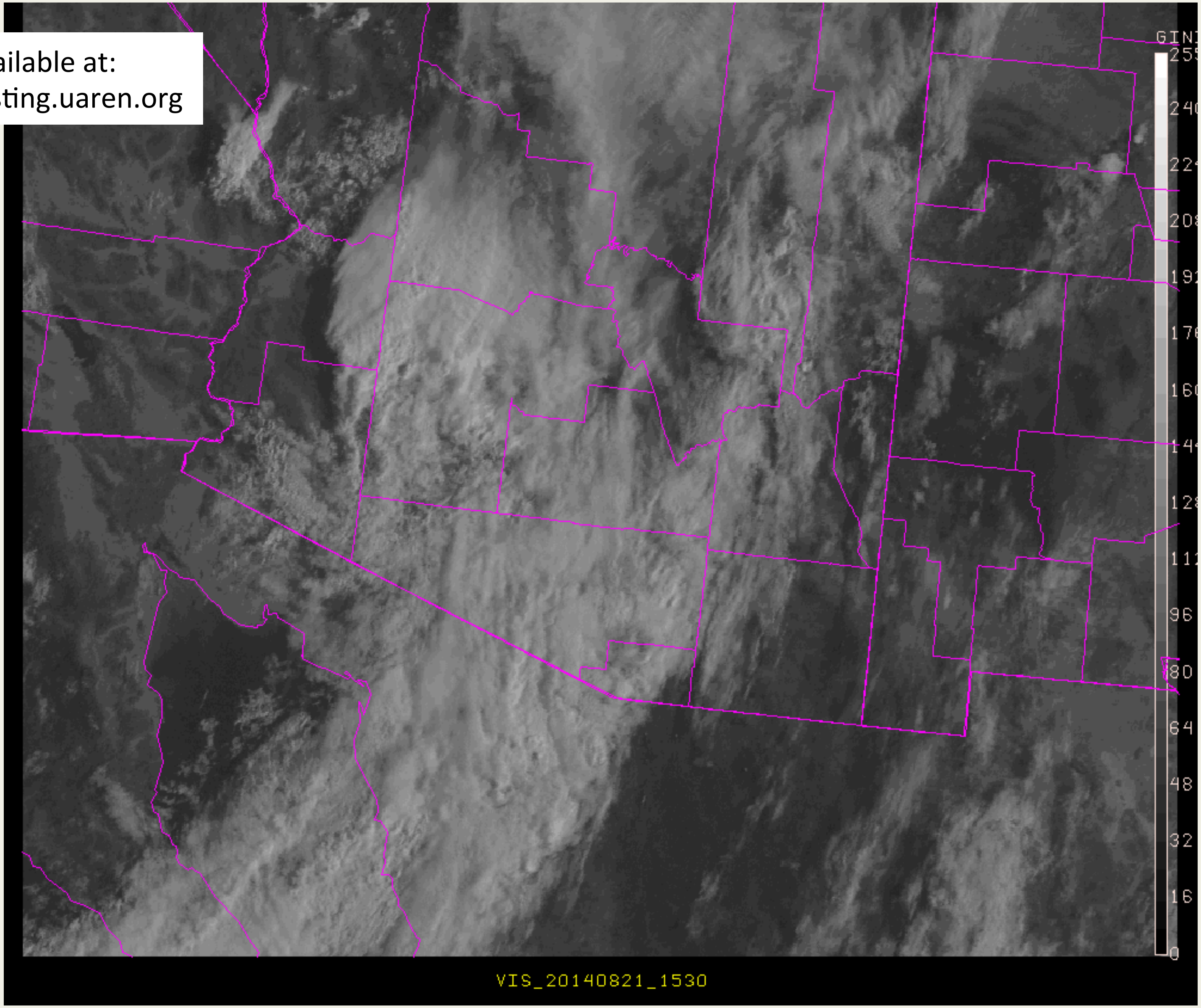


Limit analysis to large (MAE > 60) errors.
Eliminates clear days.
Helps HRRR, relatively, since it is much worse than UA on clear days.
UA day 3 still outperforming NCEP HRRR

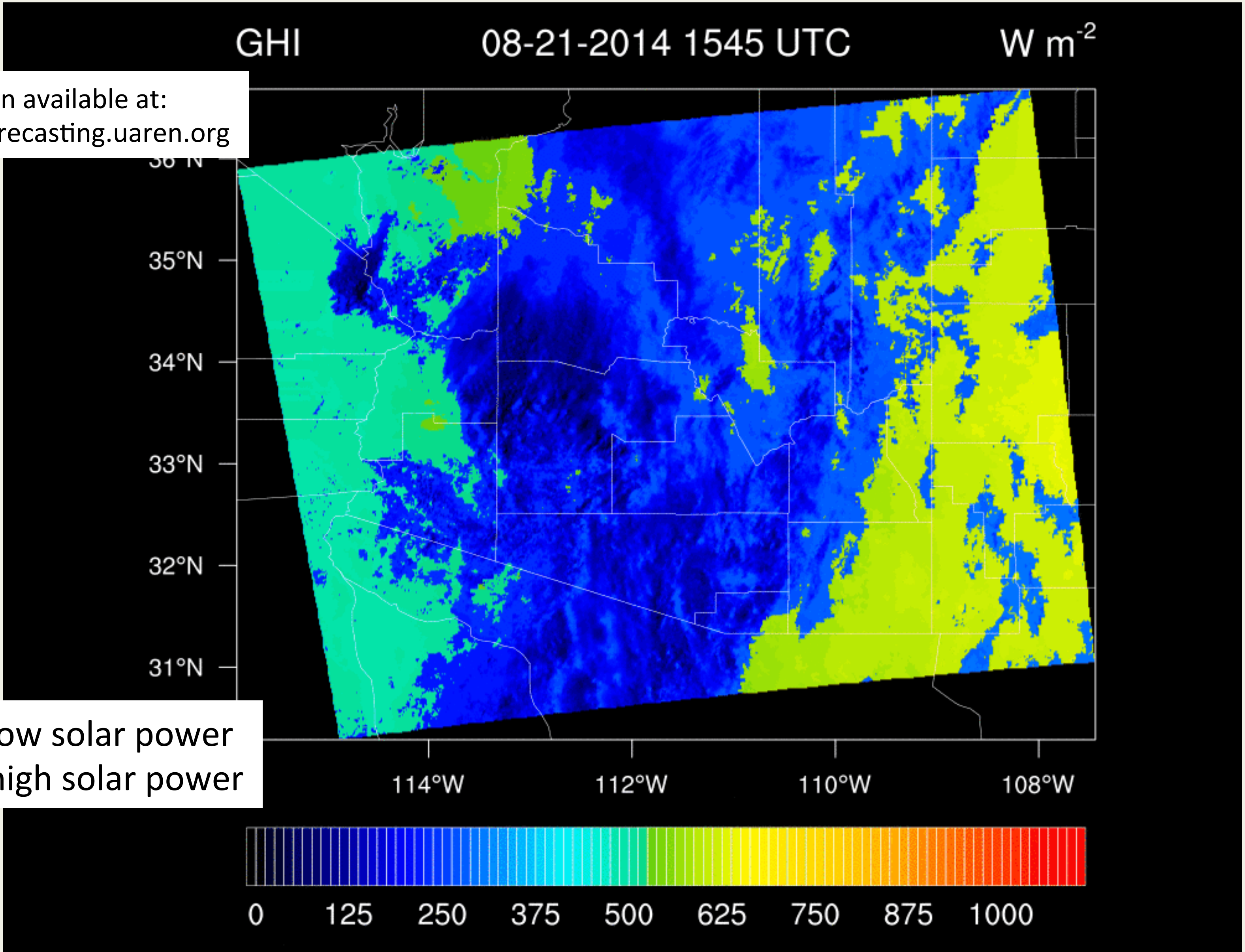
Satellite Imagery

Animation available at:
http://forecasting.uaren.org

GOES
1 km visible



Satellite Derived Solar Irradiance

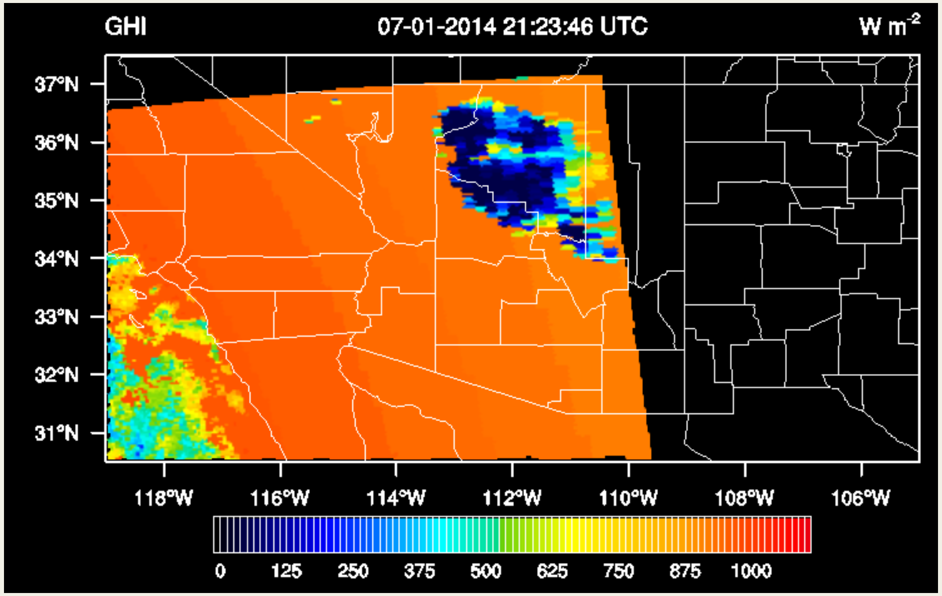


Animation available at:
http://forecasting.uaren.org

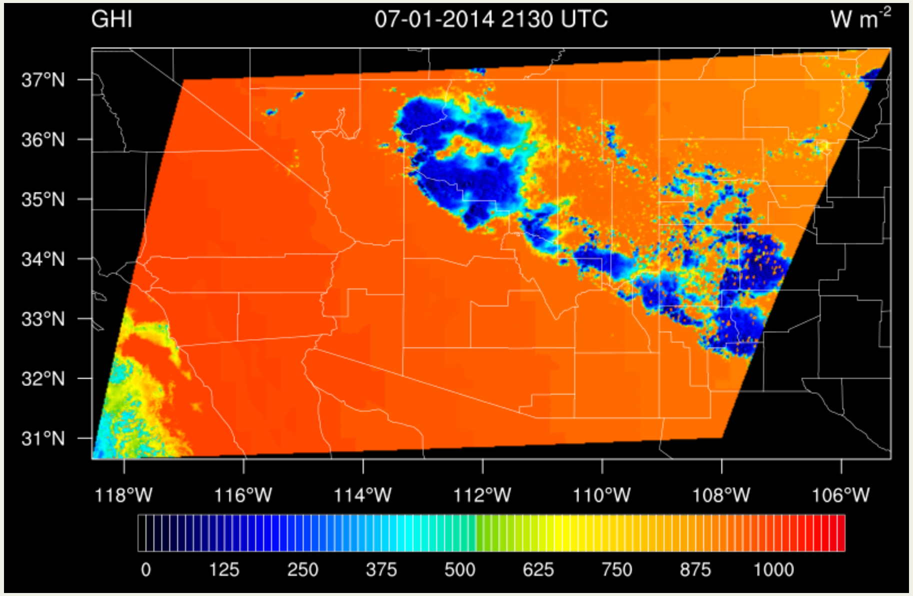
Blue: low solar power
Red: high solar power

Satellite Derived Solar Irradiance

MODIS onboard Aqua

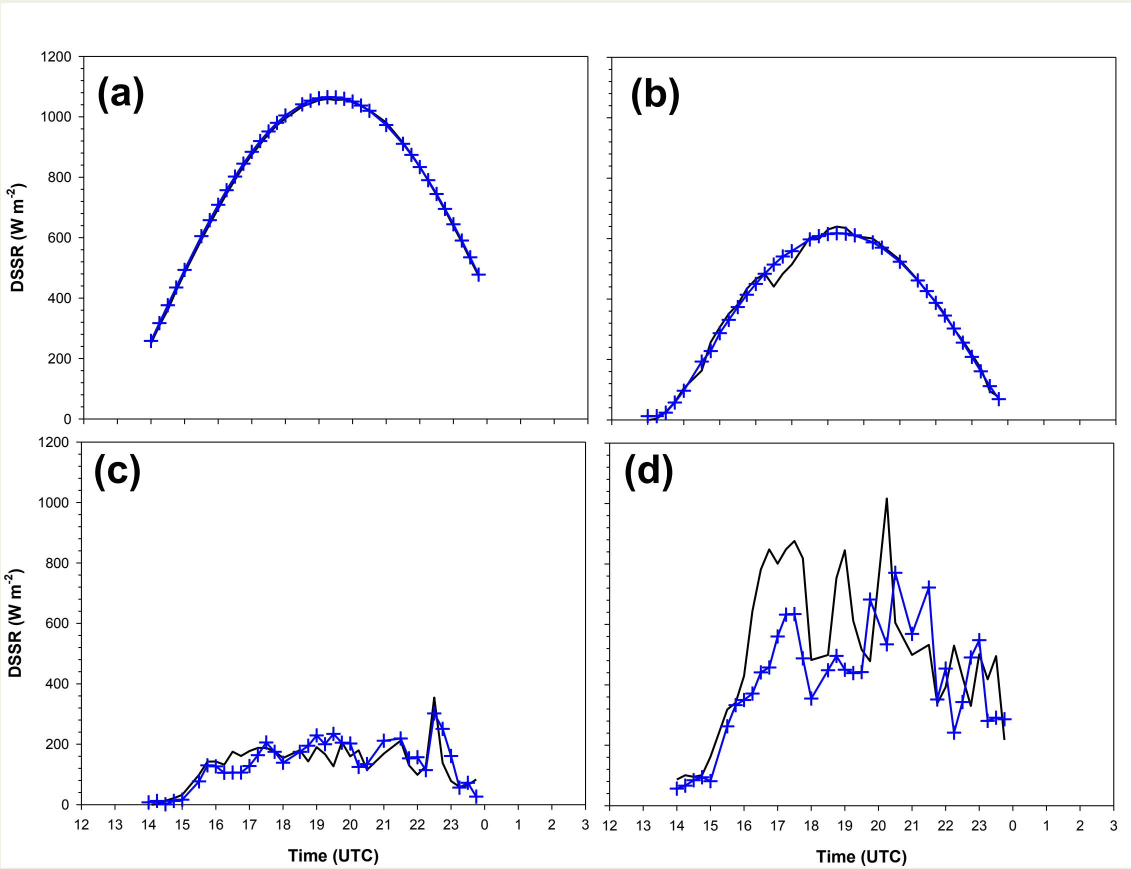


UASIBS



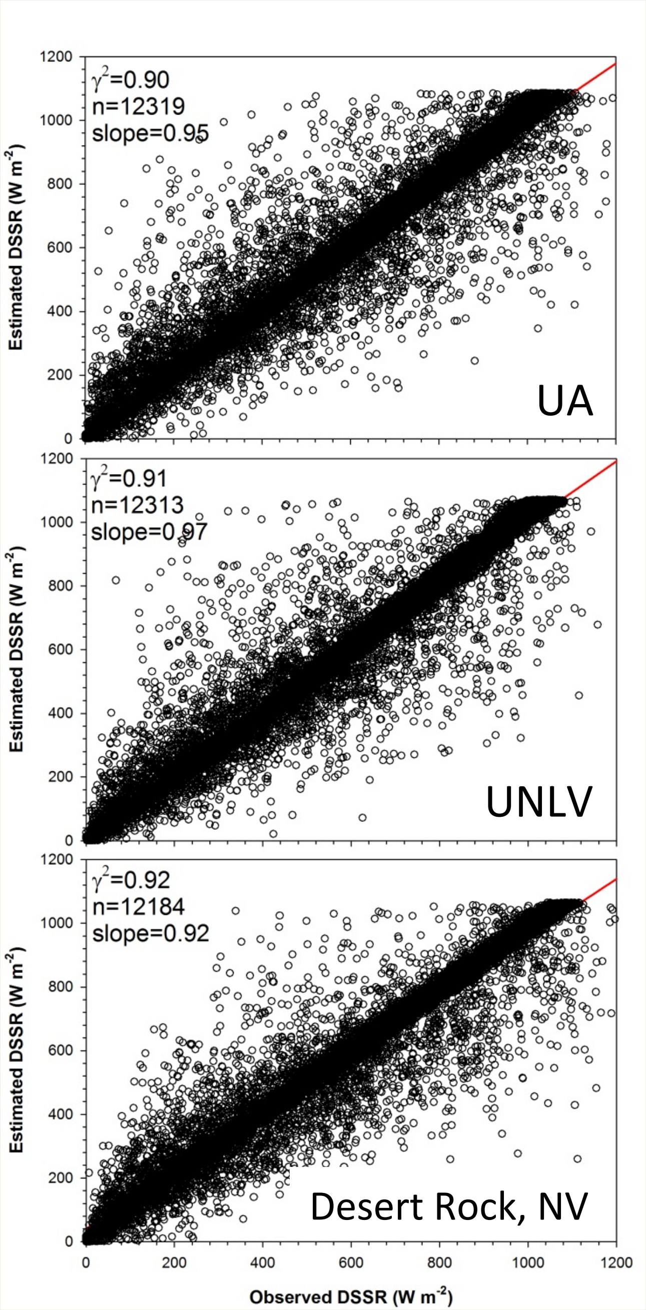
DSSR (GHI) is produced from Goddard Space Flight Center Radiative Transfer Model with MODIS L2 data.

Satellite Derived Solar Irradiance



Clear sky conditions

Cloudy sky conditions

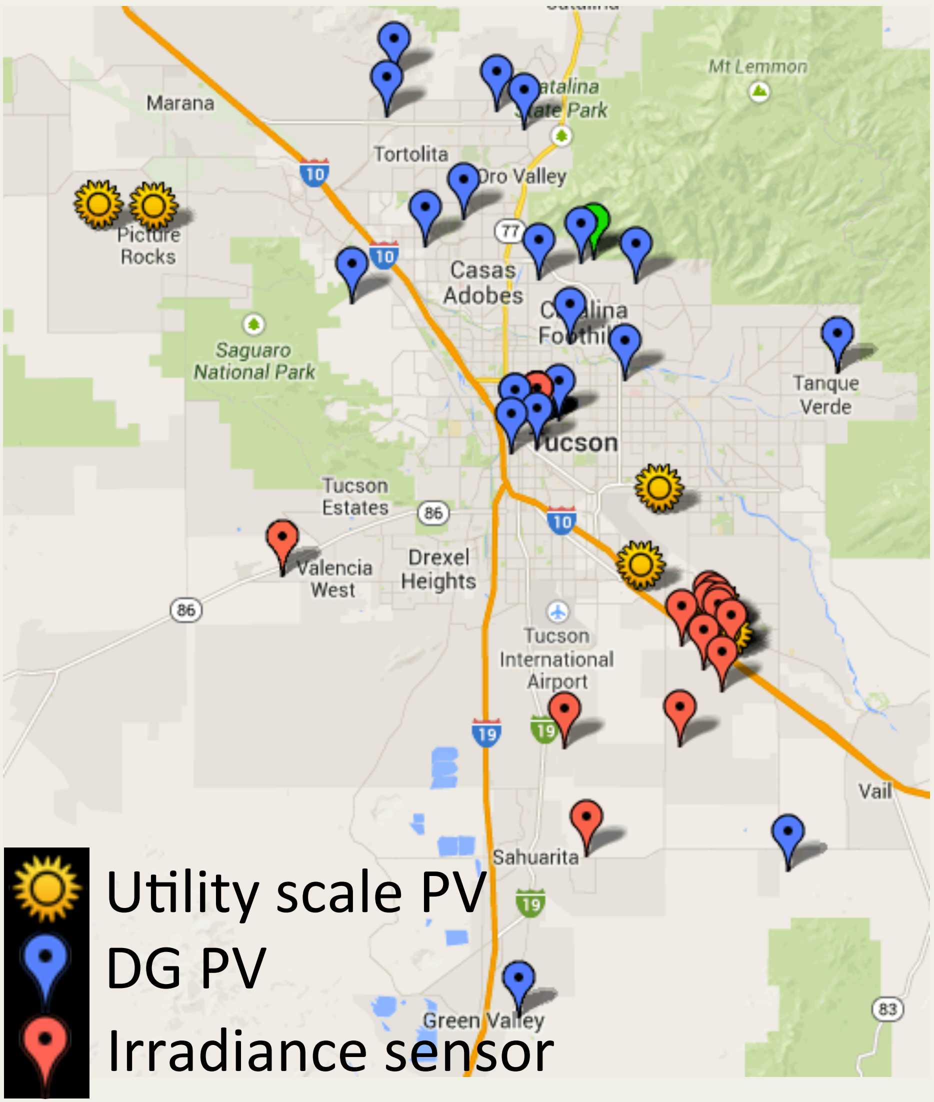


Satellite Derived Solar Irradiance

Instantaneous sat. estimated vs. observed irradiance at UA, UNLV, and Desert Rock, NV.

Cloudy and clear sky conditions

Sensor network forecast

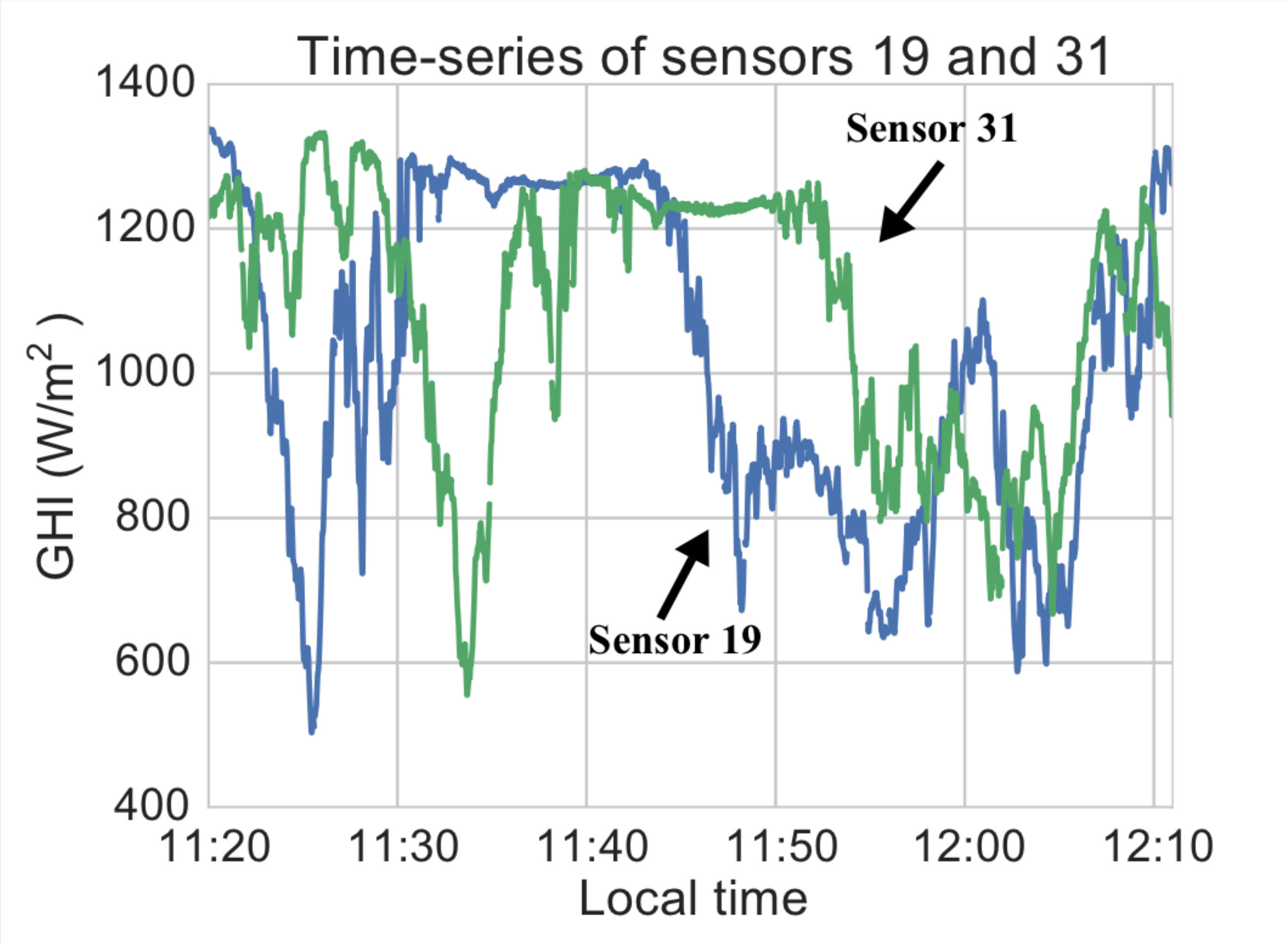


Partnered with local PV installer Technicians for Sustainability to obtain access to real-time (5 min latency) data feeds of residential PV systems.

Homebuilt irradiance sensors will cell modems (see A. Lorenzo, AMS 2015).

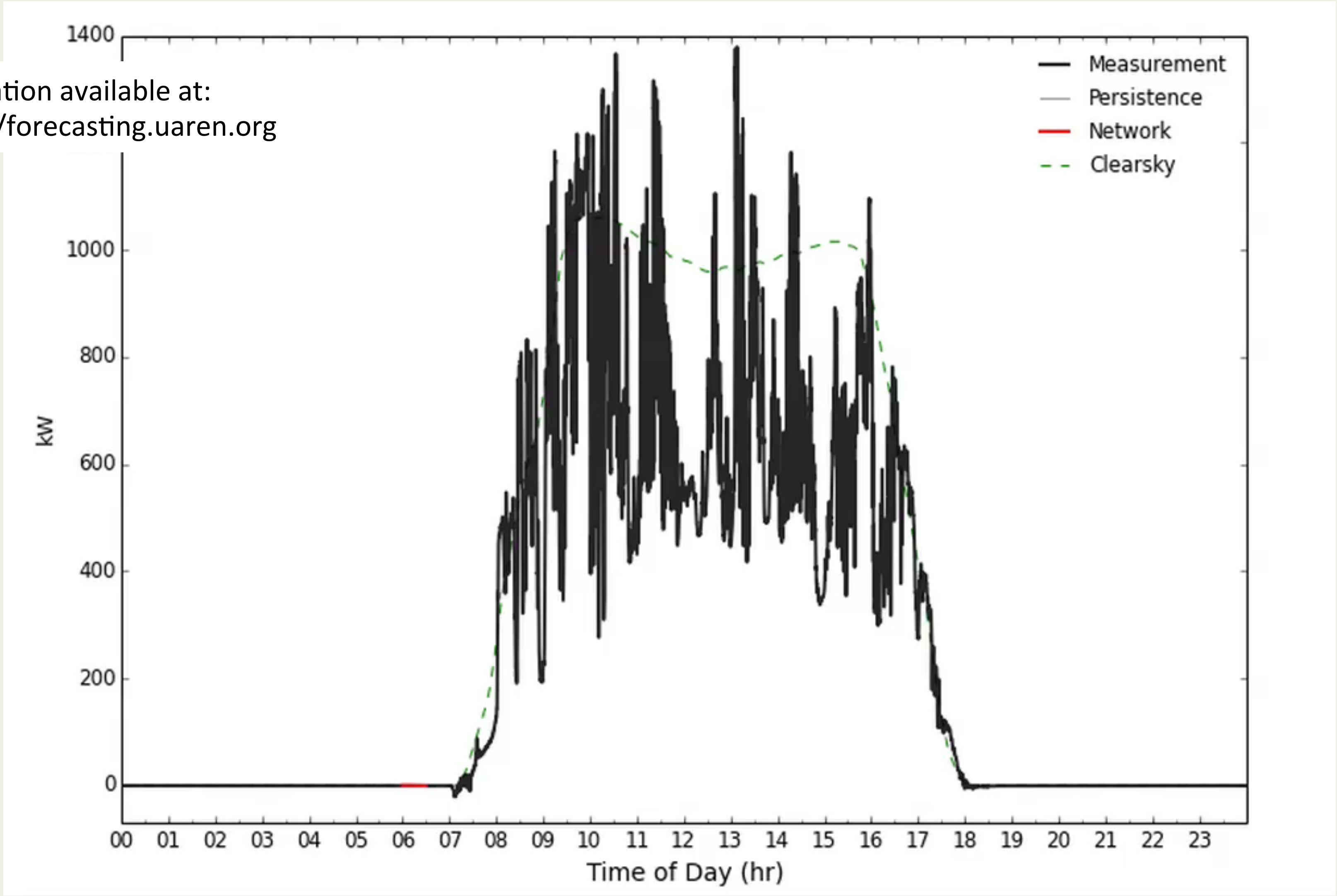
Network of rooftop solar data and irradiance sensors provides most accurate 30 minute forecasts.

Sensor network forecast

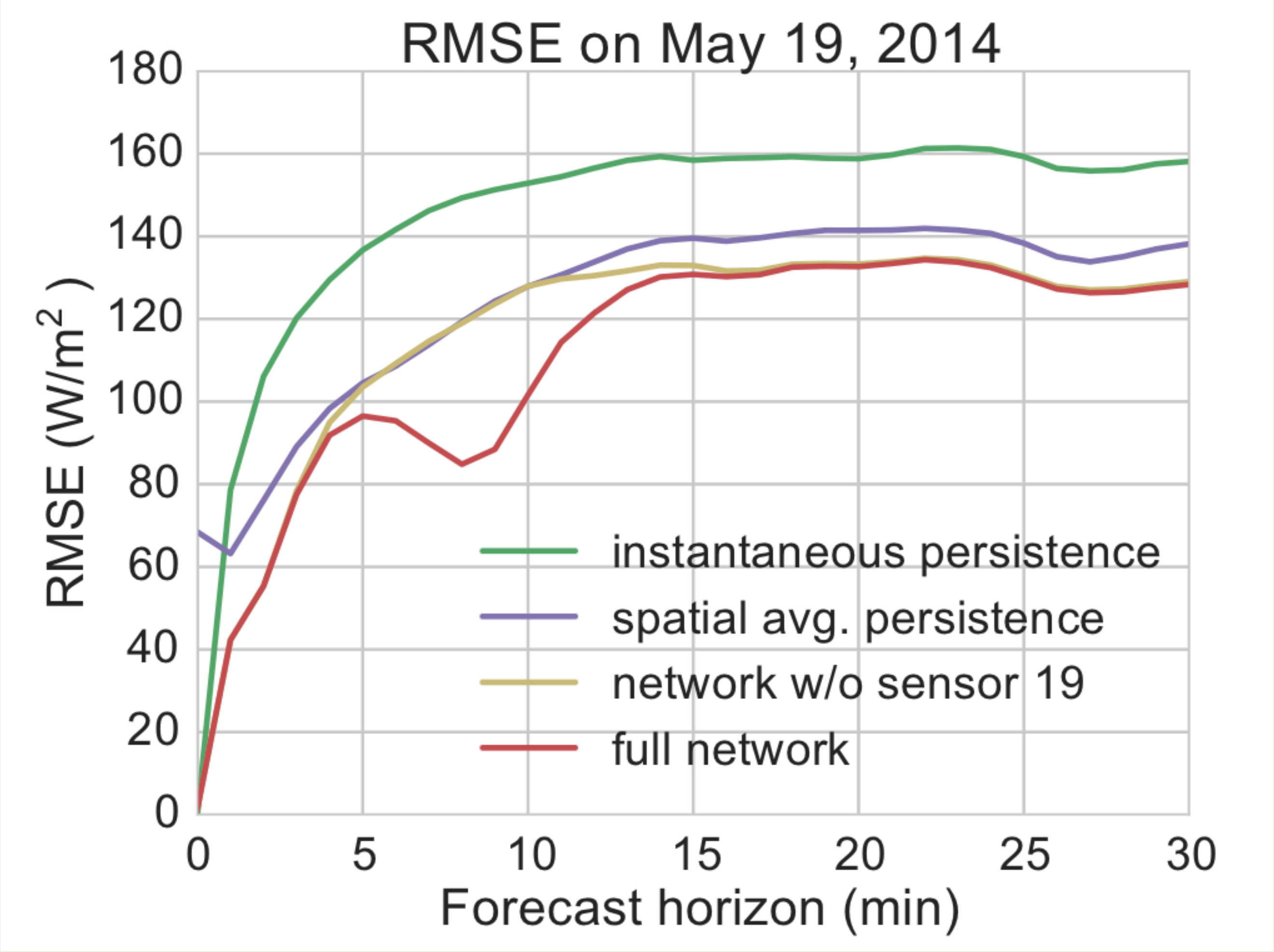


Sensor network forecast

Animation available at:
http://forecasting.uaren.org

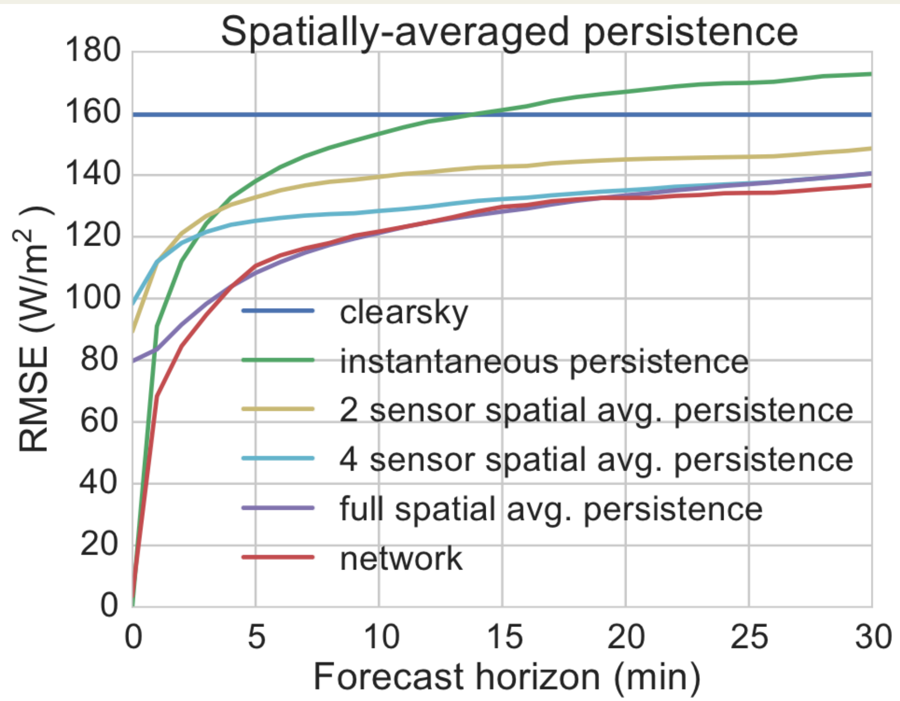


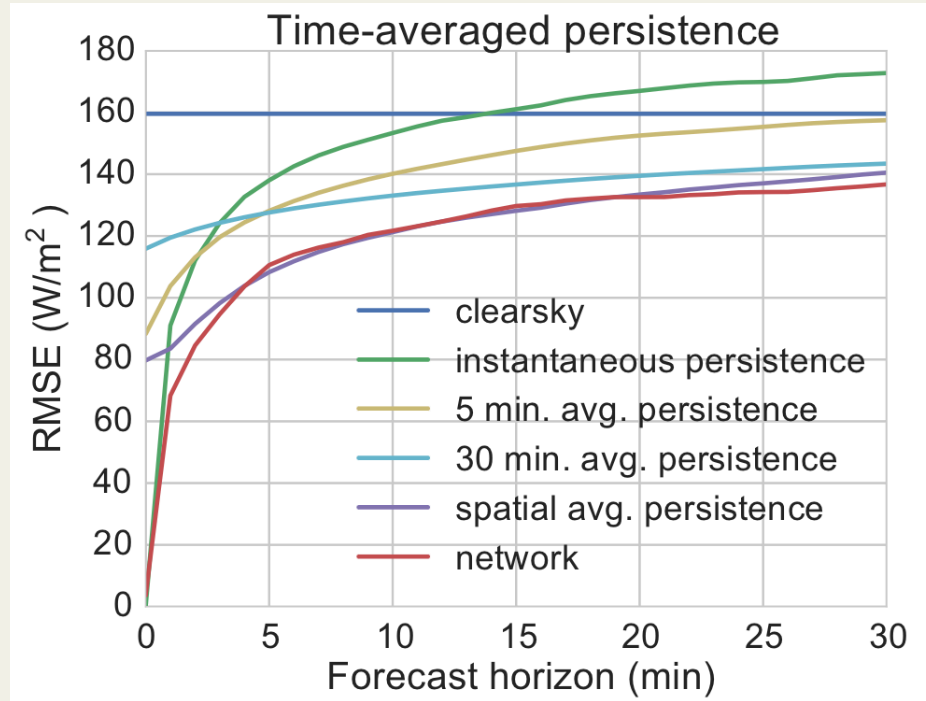
Sensor network error statistics



Sensor network error statistics

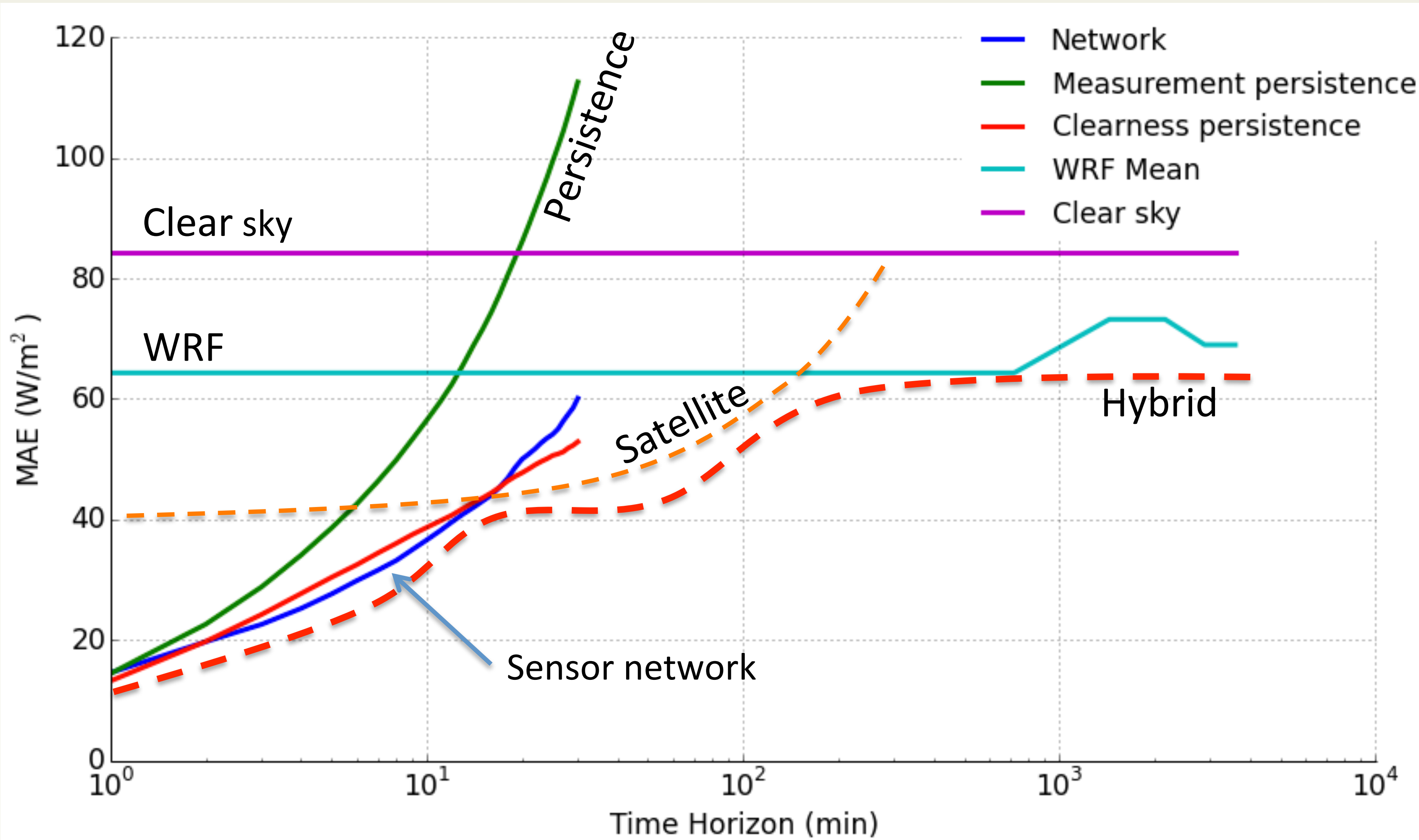
How much of the improvement over persistence is due to our fancy algorithm and how much is due to simple aspects such as averaging over space and/or time?





Depends on the day and the forecast horizon, but most of the improvement can usually be achieved by just averaging irradiance over space and/or time.

UA forecasting summary



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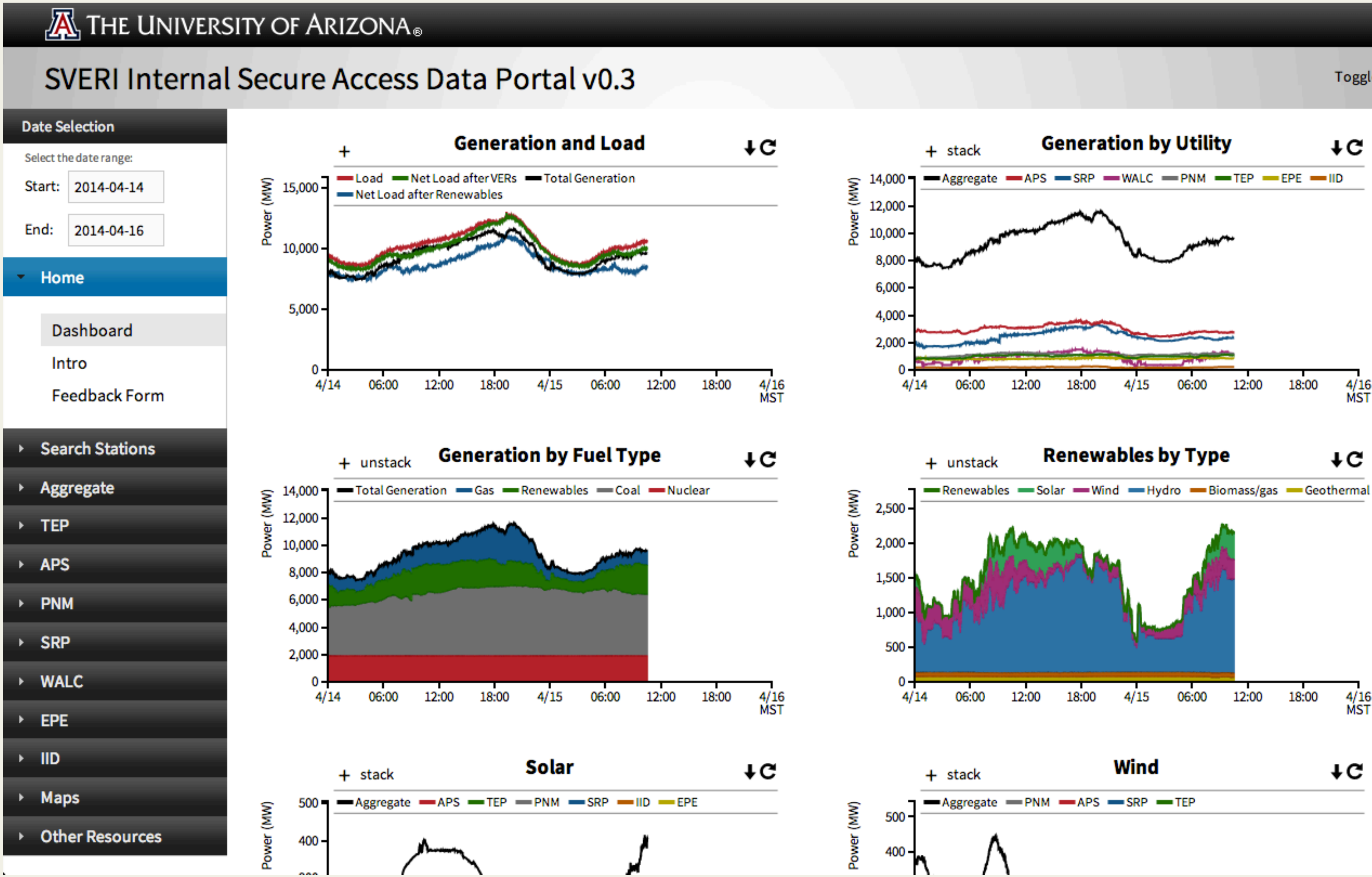
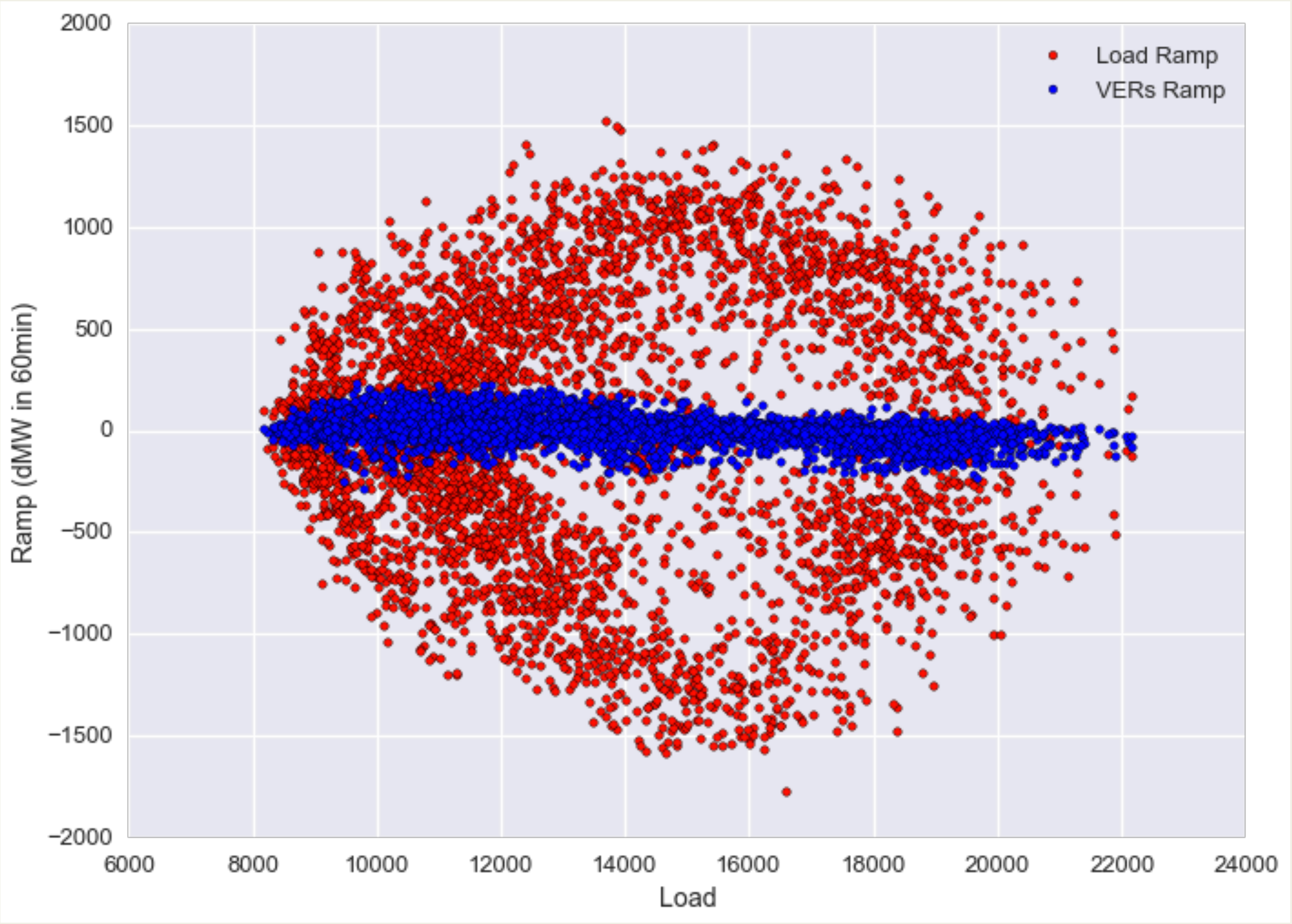
U of A

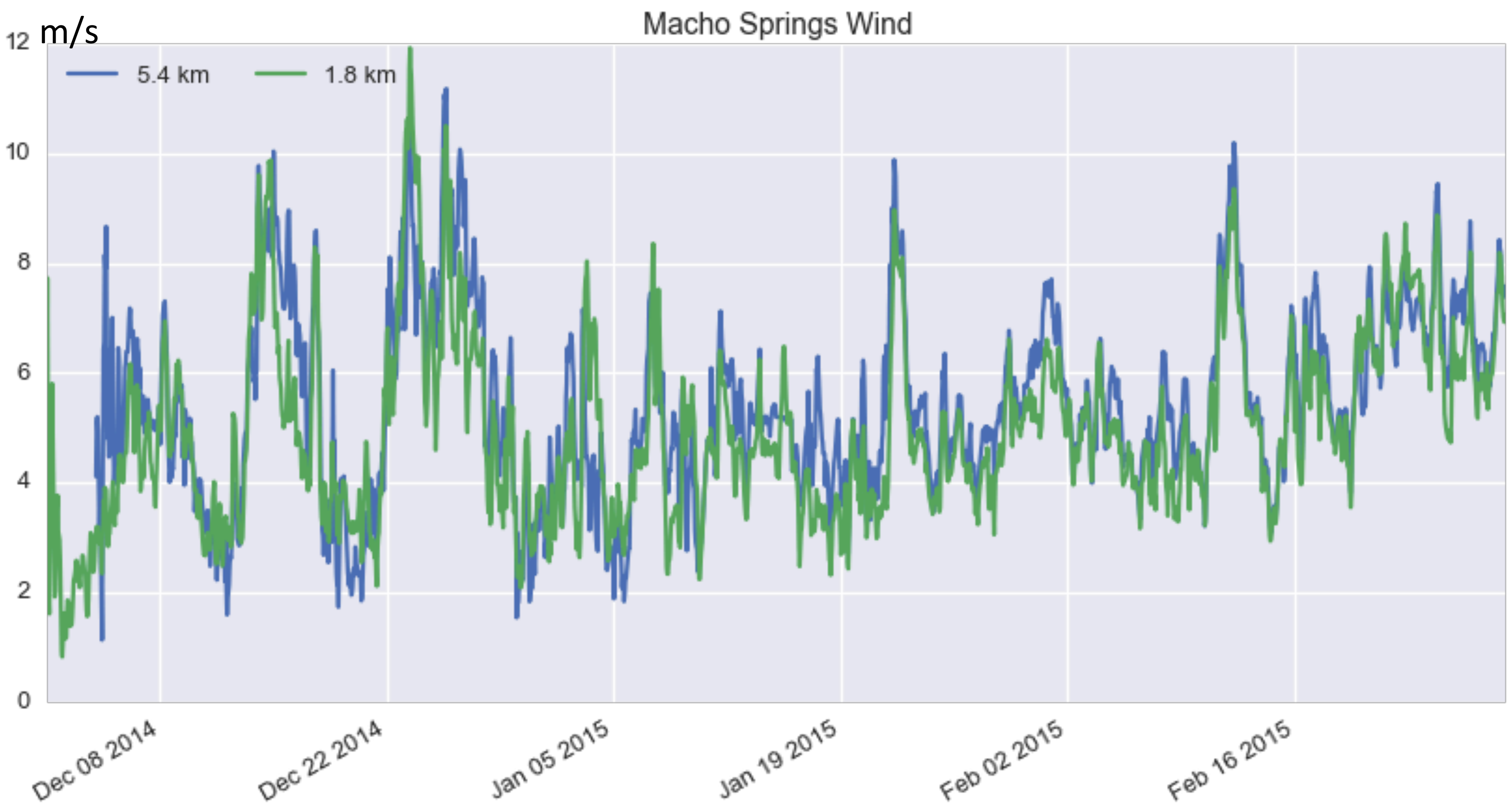
SVERI Internal Website



Ramps vs. Load



5.4 vs. 1.8 km wind forecasts



5.4 vs. 1.8 km wind forecasts