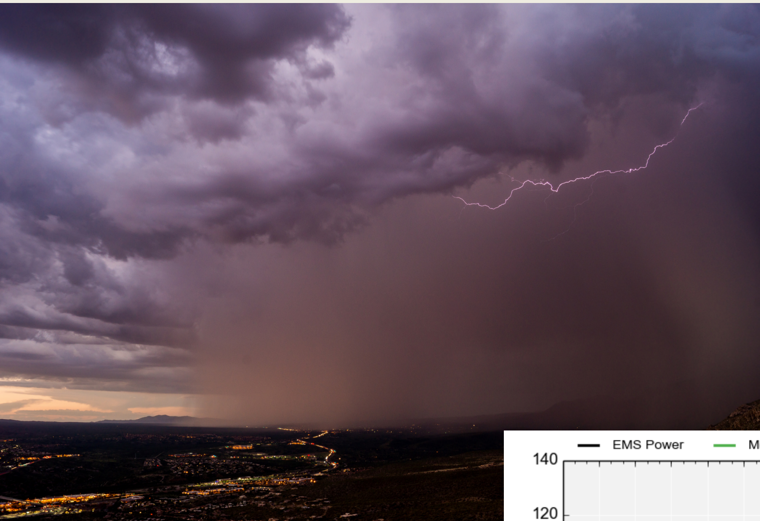
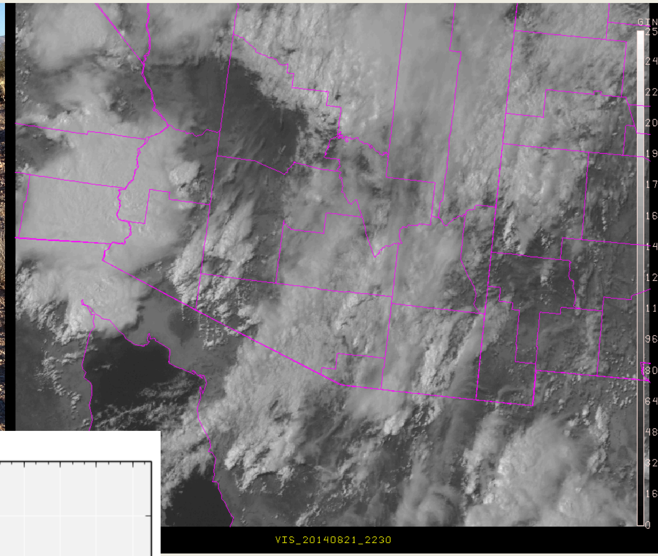
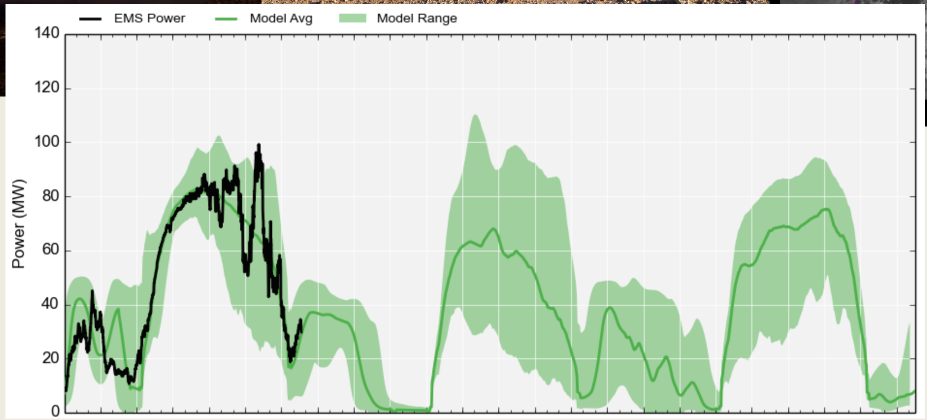
U. Arizona Renewable Power Forecasting



Charles Miles, Creative Commons





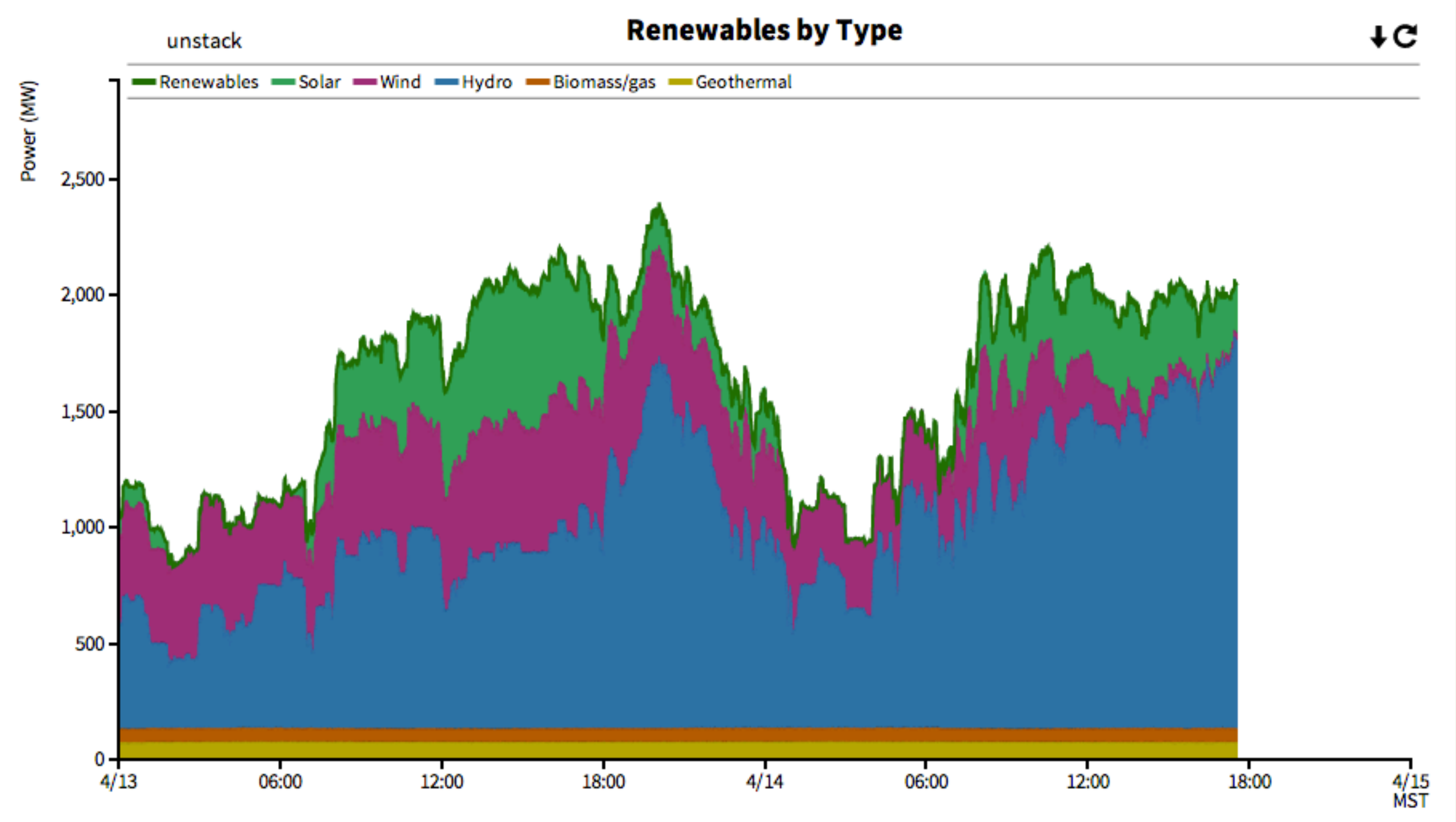
Will Holmgren
DOE EERE Postdoctoral Fellow
UA Department of Atmospheric Sciences

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

ARIZONA

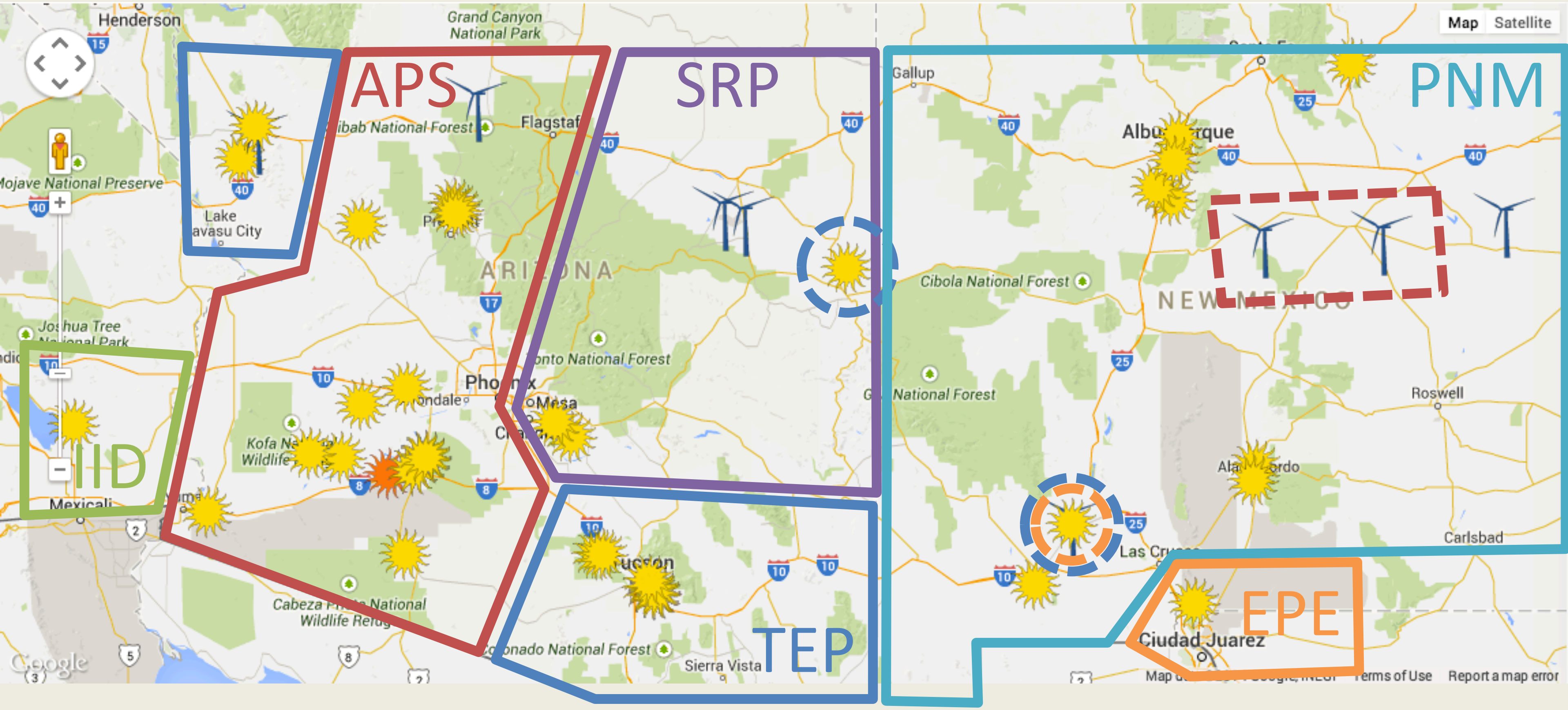
But first,

The status and future of renewables in the Southwest



SVERI

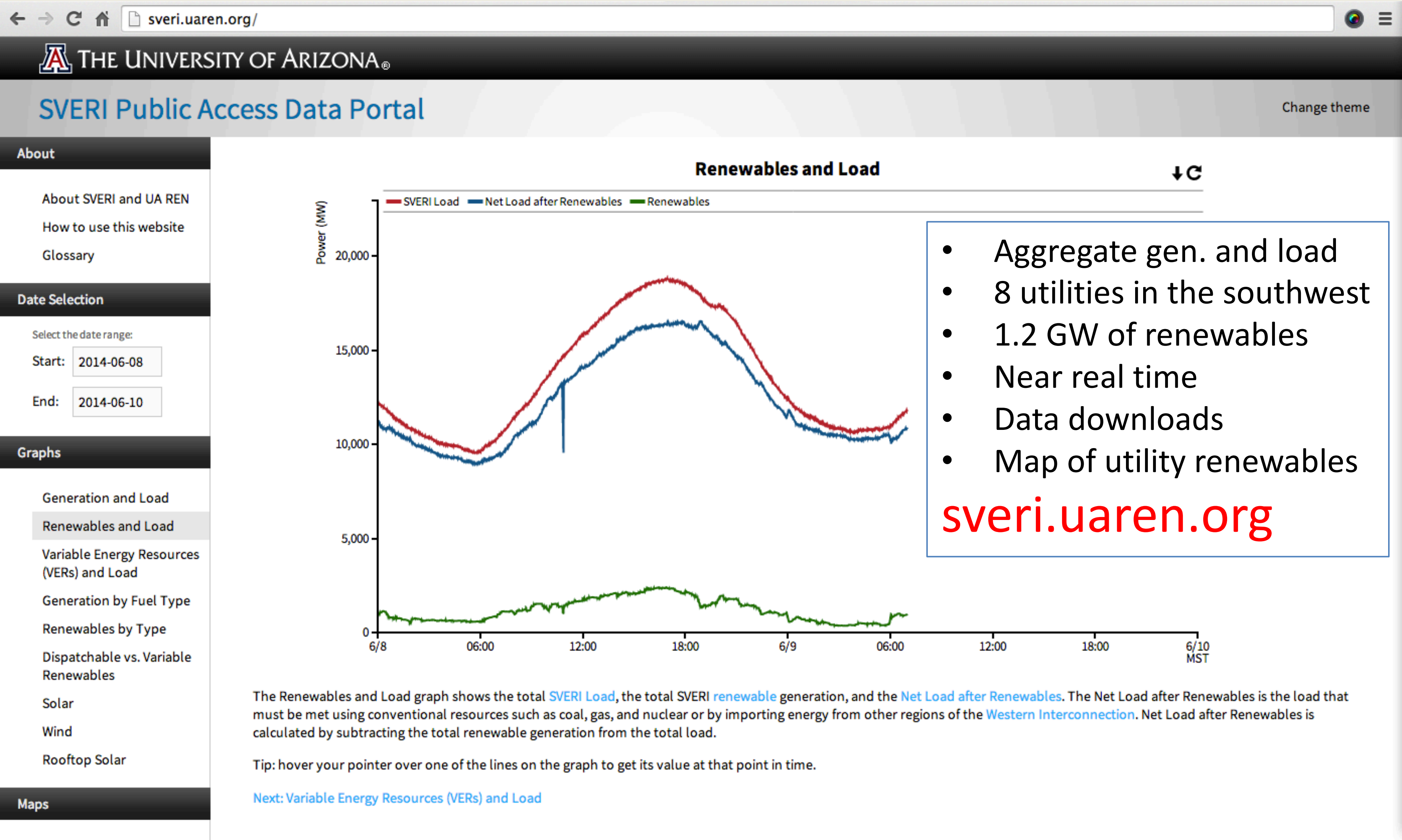
Southwest Variable Energy Resource Initiative



from sveri.uaren.org

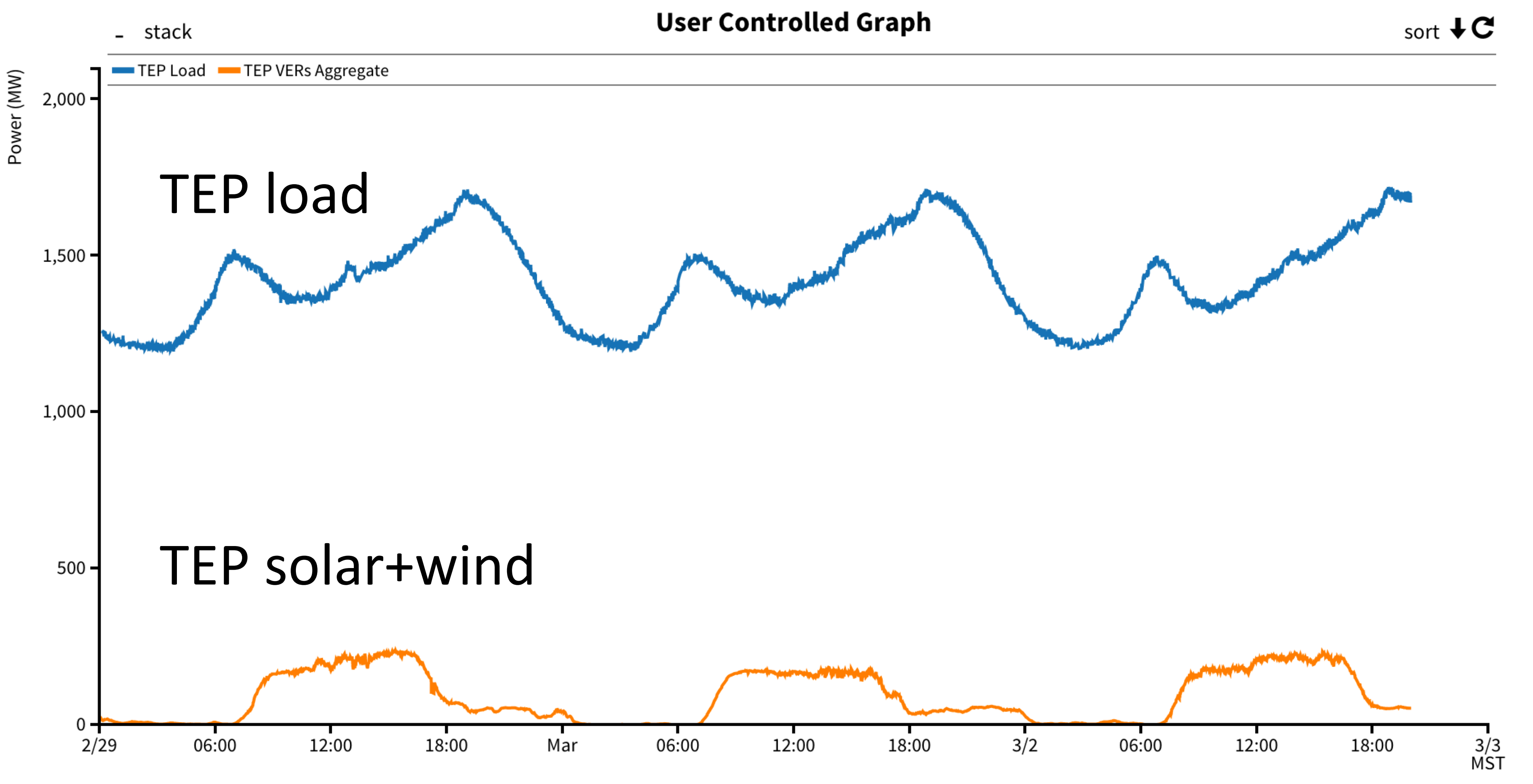
sveri.uaren.org

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

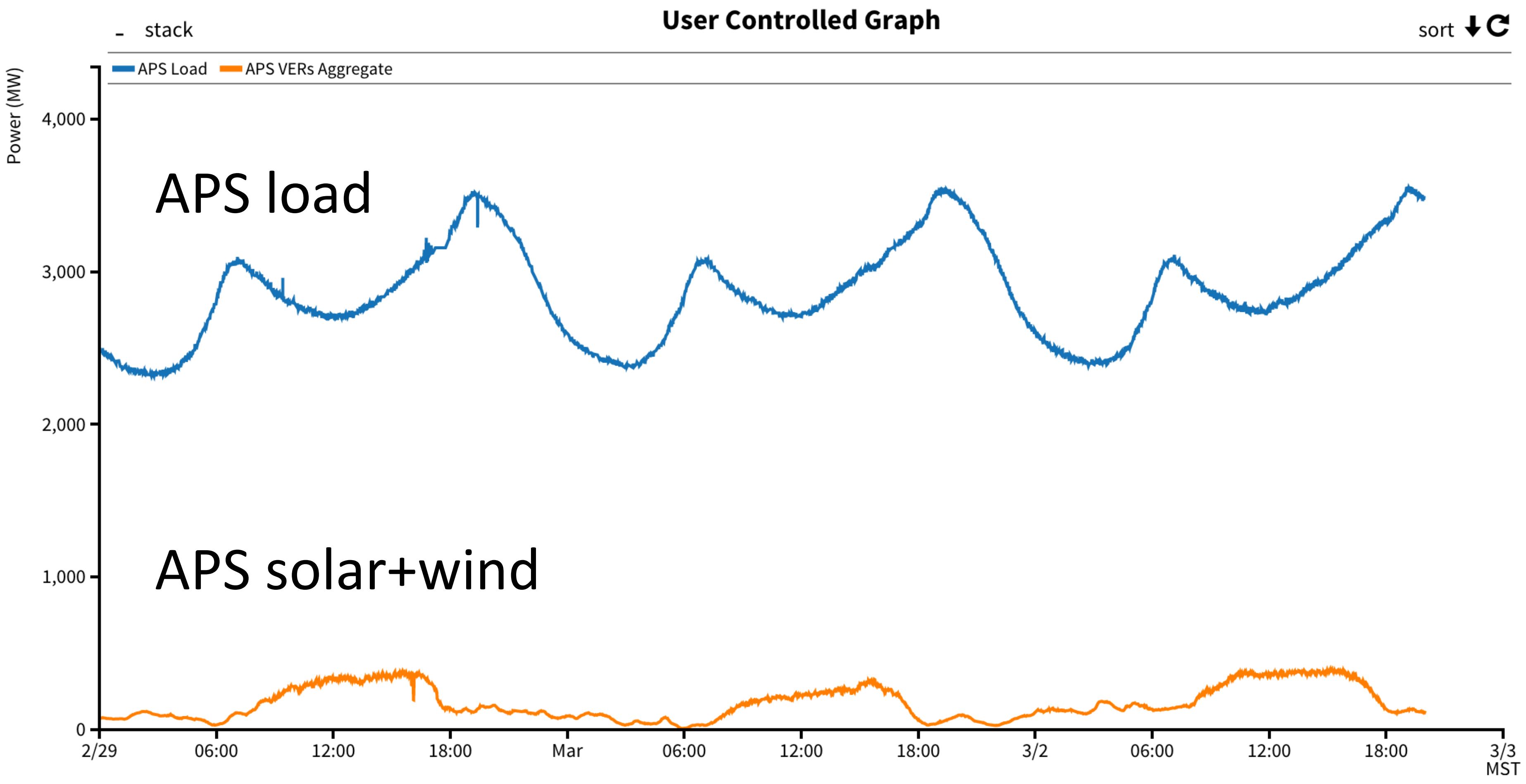


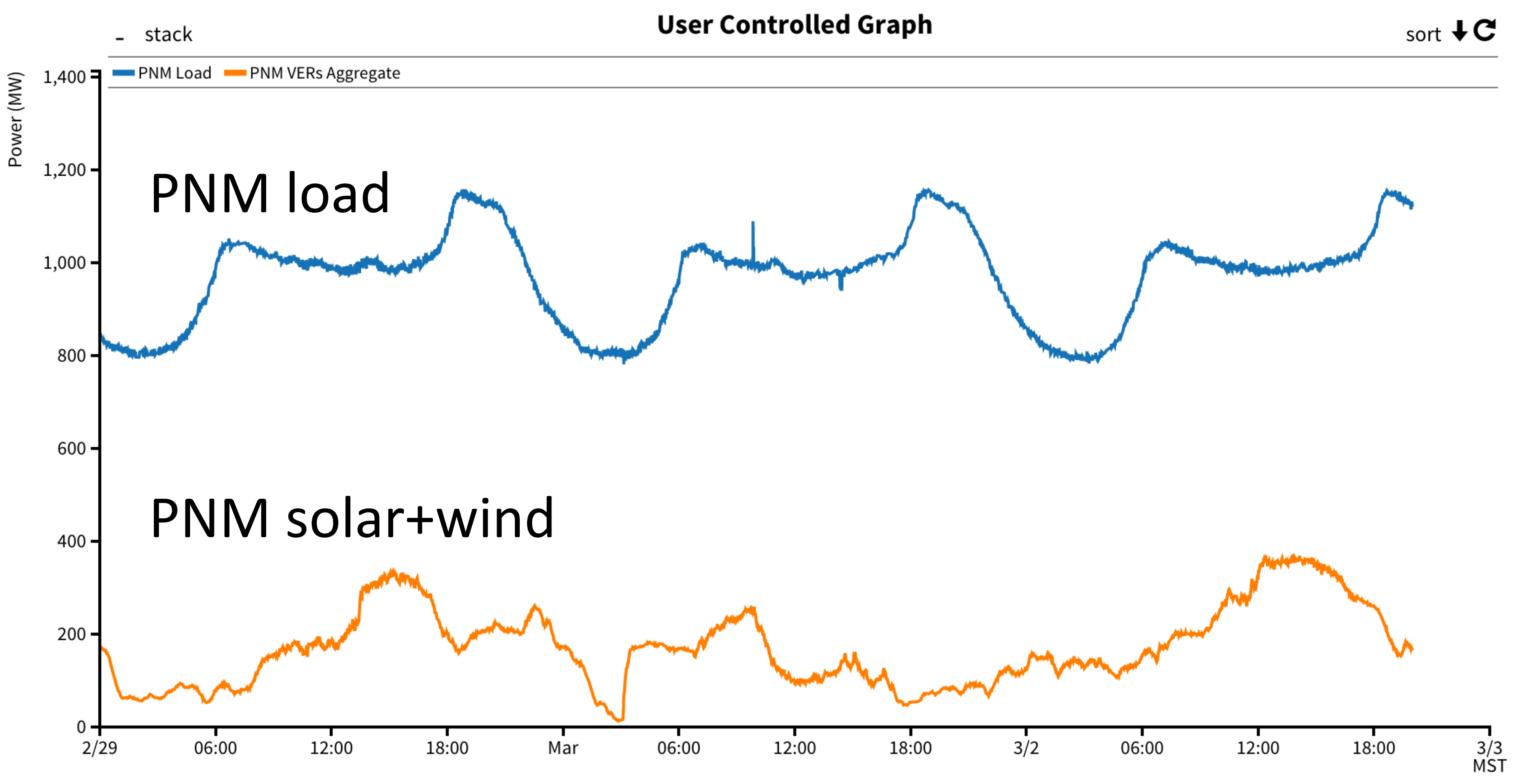
- Aggregate gen. and load
- 8 utilities in the southwest
- 1.2 GW of renewables
- Near real time
- Data downloads
- Map of utility renewables

sveri.uaren.org



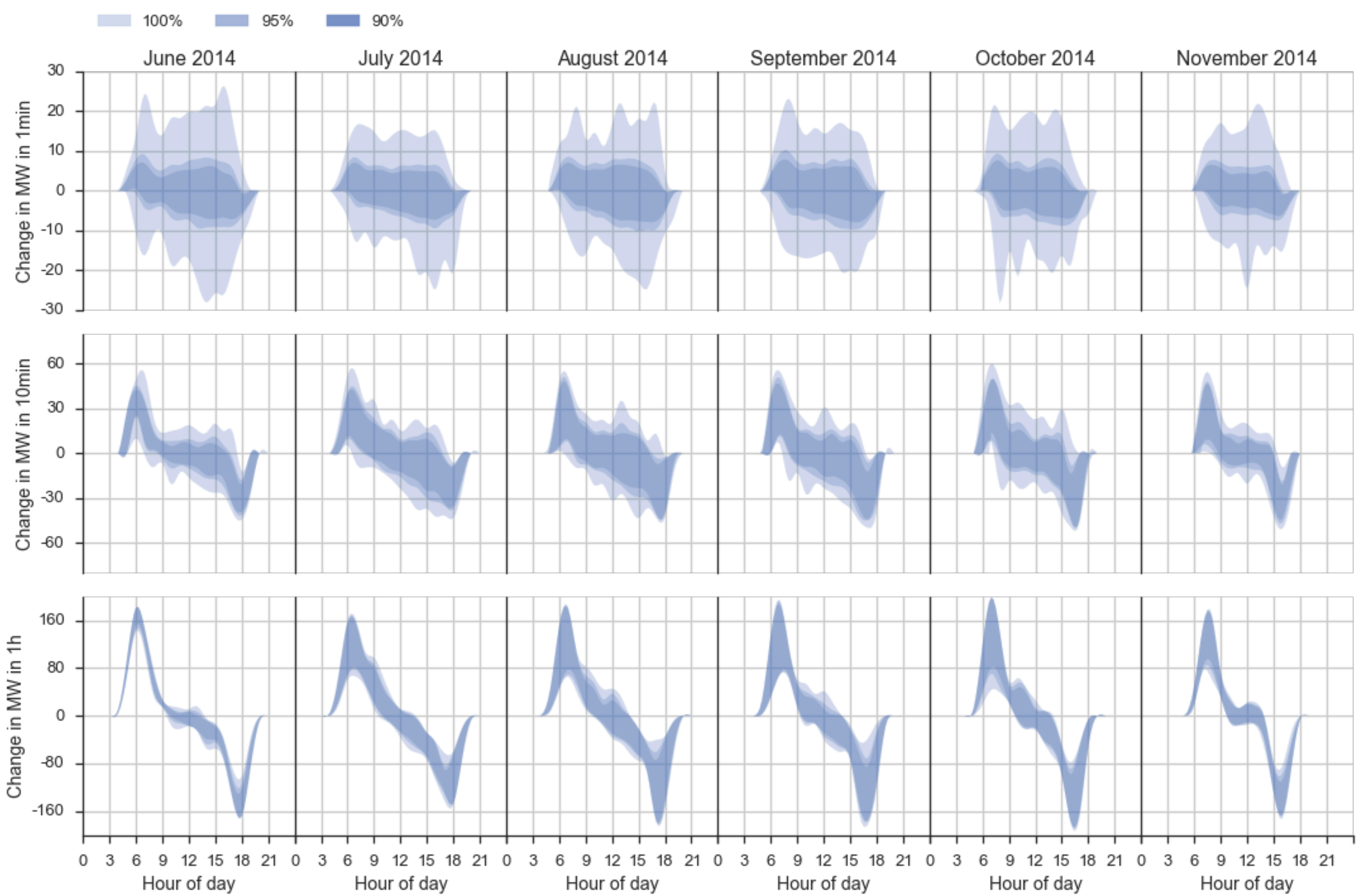
User Controlled Graph
- stack
sort
TEP Load
TEP VERs Aggregate
Power (MW)
2,000
1,500
1,000
500
0
TEP load
TEP solar+wind
2/29
06:00
12:00
18:00
Mar
06:00
12:00
18:00
3/2
06:00
12:00
18:00
3/3
MST


User Controlled Graph
stack
sort
APS Load
APS VERs Aggregate
Power (MW)
4,000
3,000
2,000
1,000
0
APS load
APS solar+wind
2/29
06:00
12:00
18:00
Mar
06:00
12:00
18:00
3/2
06:00
12:00
18:00
3/3
MST

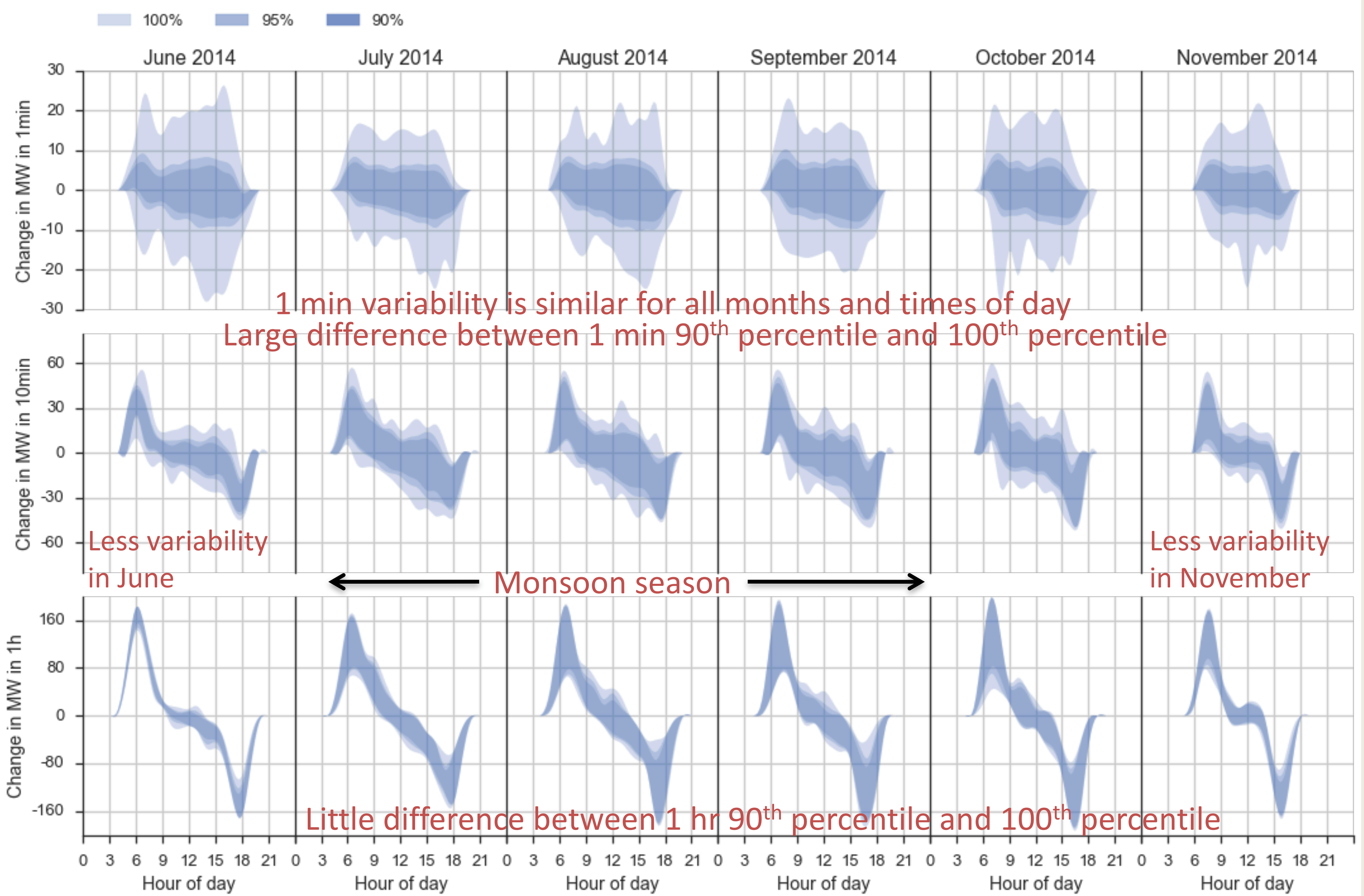


User Controlled Graph
stack
sort
PNM Load
PNM VERs Aggregate
Power (MW)
1,400
1,200
1,000
800
600
400
200
0
PNM load
PNM solar+wind
2/29
06:00
12:00
18:00
Mar
06:00
12:00
18:00
3/2
06:00
12:00
18:00
3/3
MST

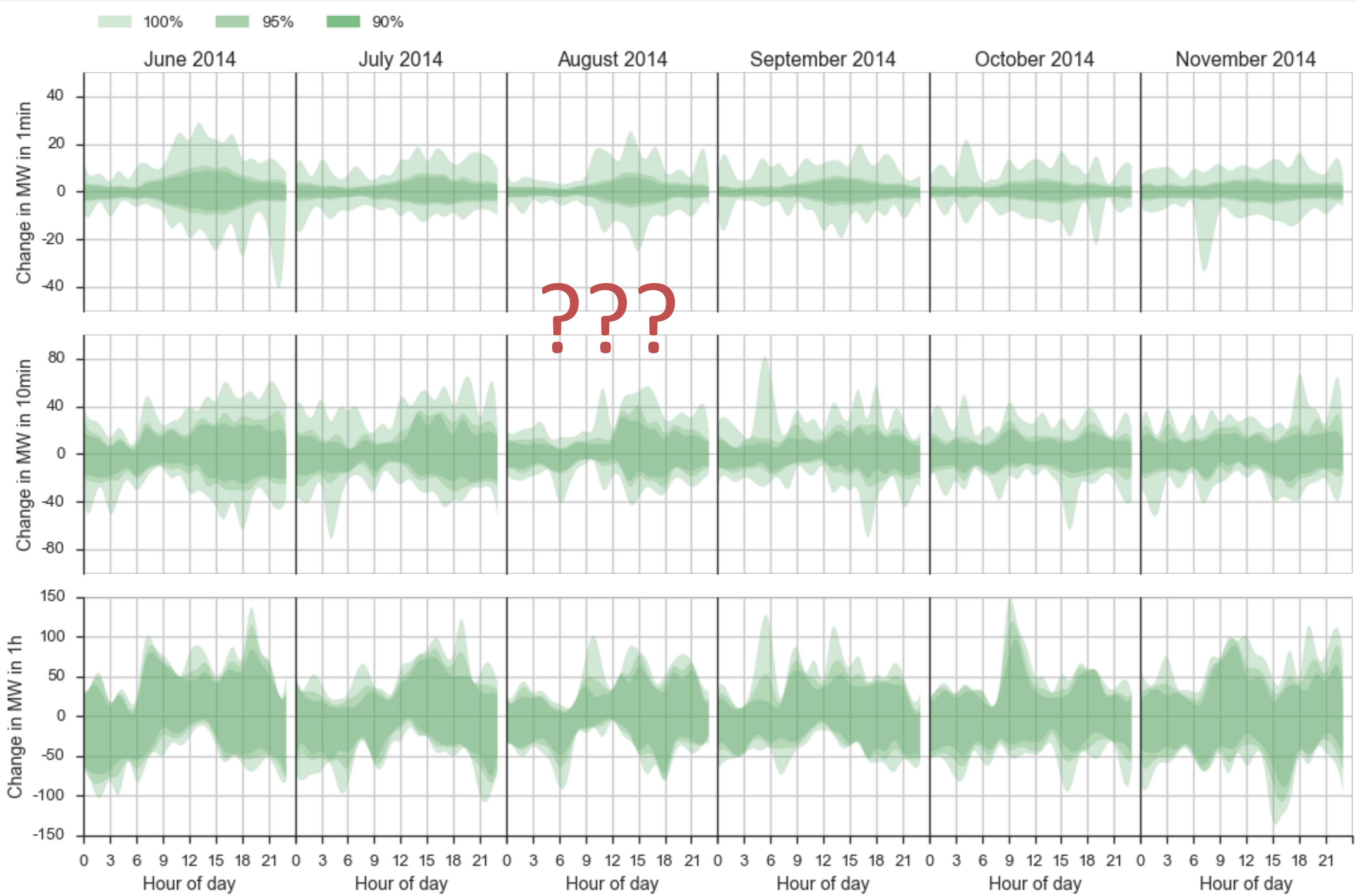
SVERI solar variability



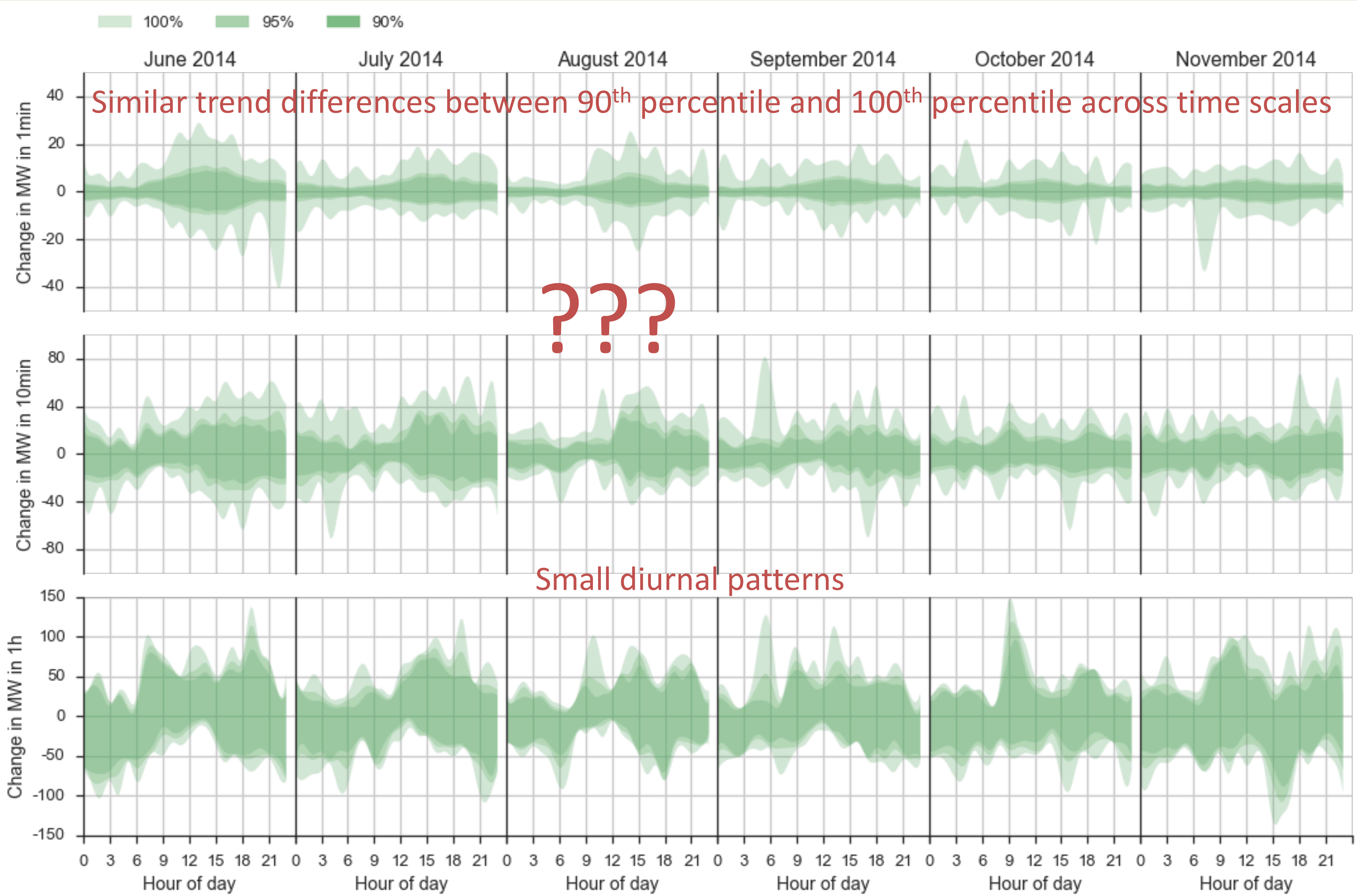
SVERI solar variability

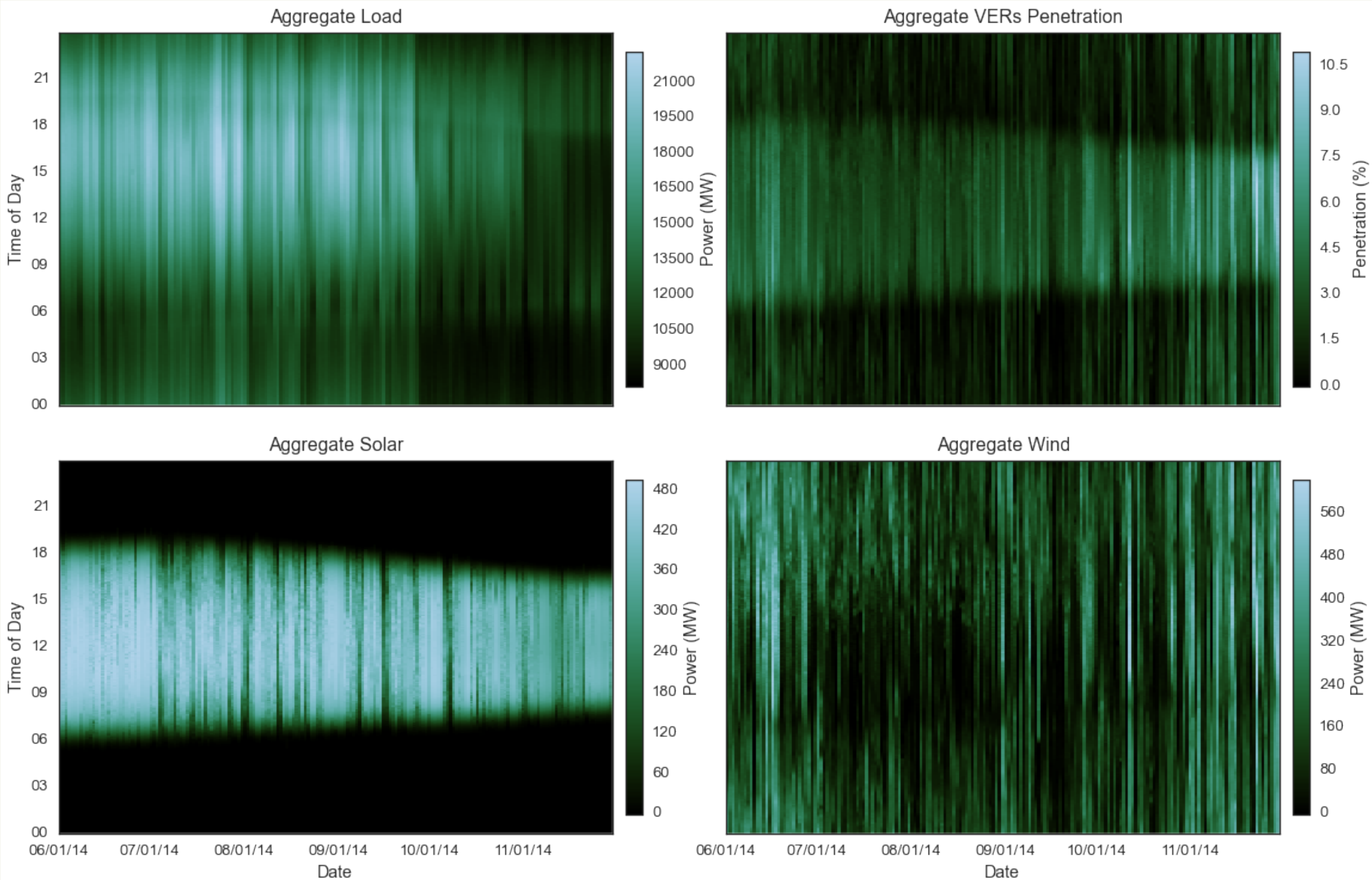


SVERI wind variability



SVERI wind variability





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

VERs penetration

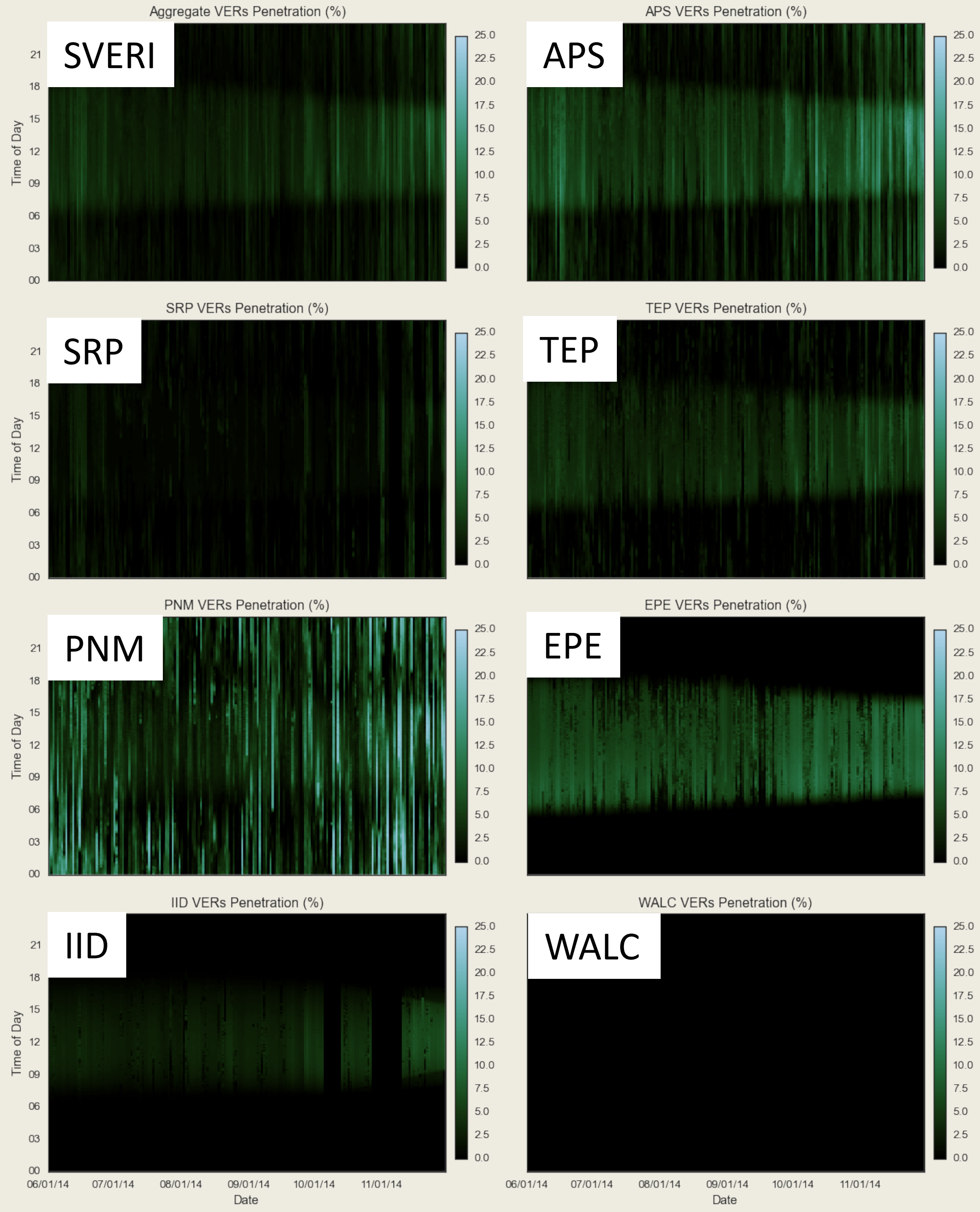
Penetration = renewables gen. / load

Black = 0%
White = 25%

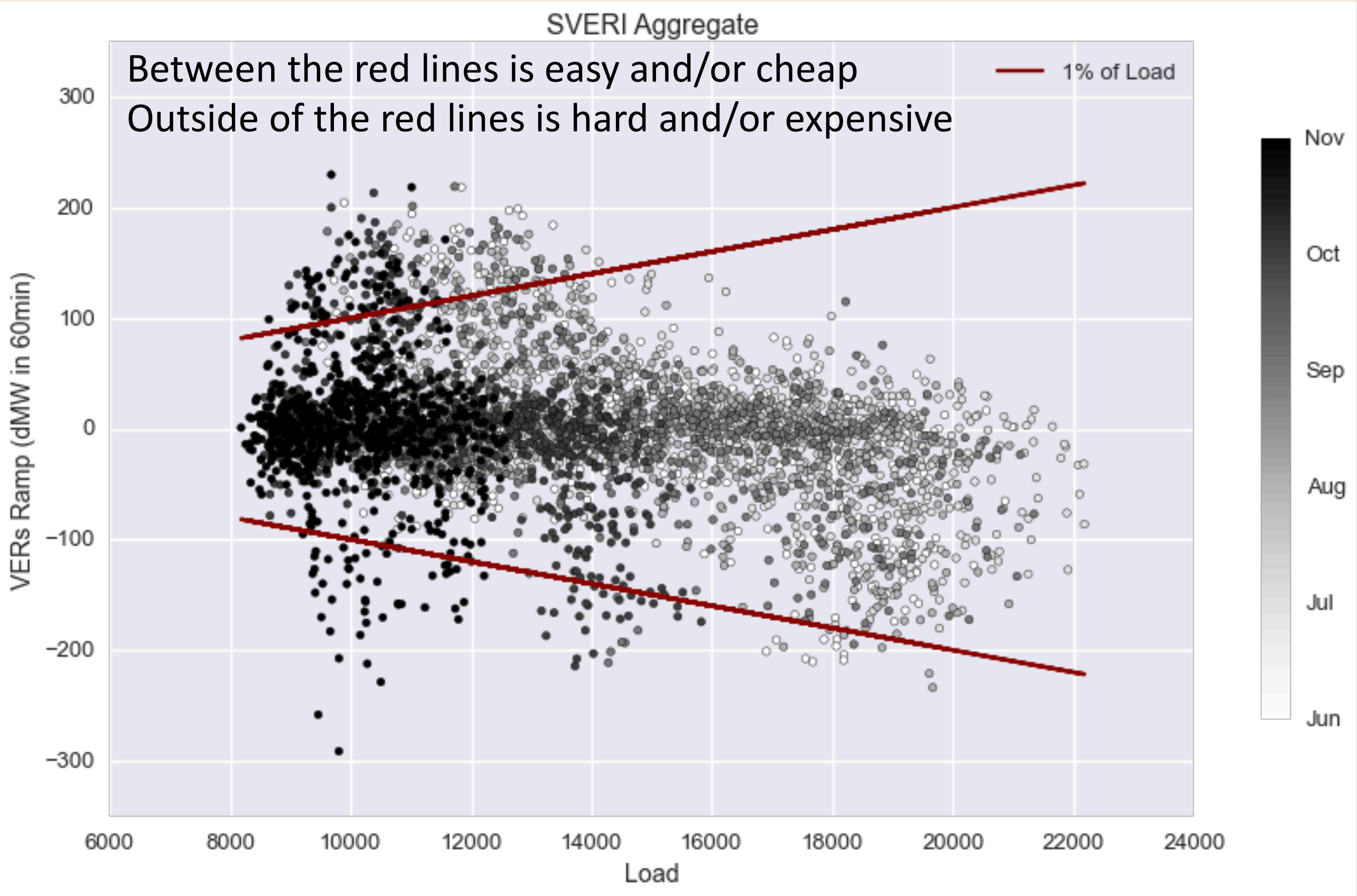
APS occasionally has high penetration

PNM penetration is huge

EPE solar penetration is consistently large



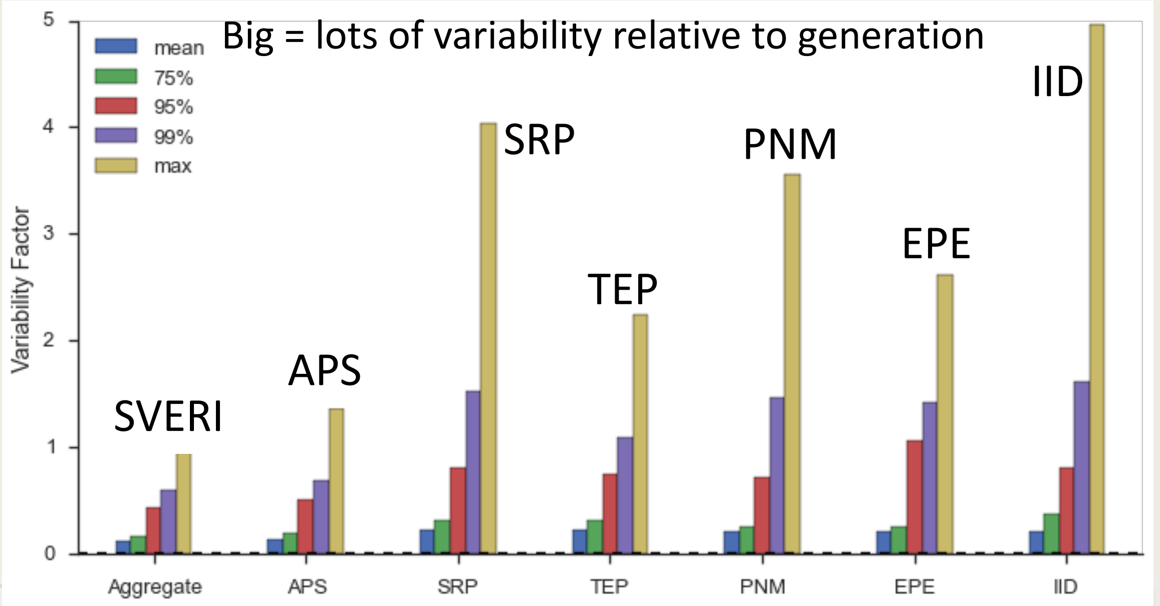
Renewables Ramps vs. Load



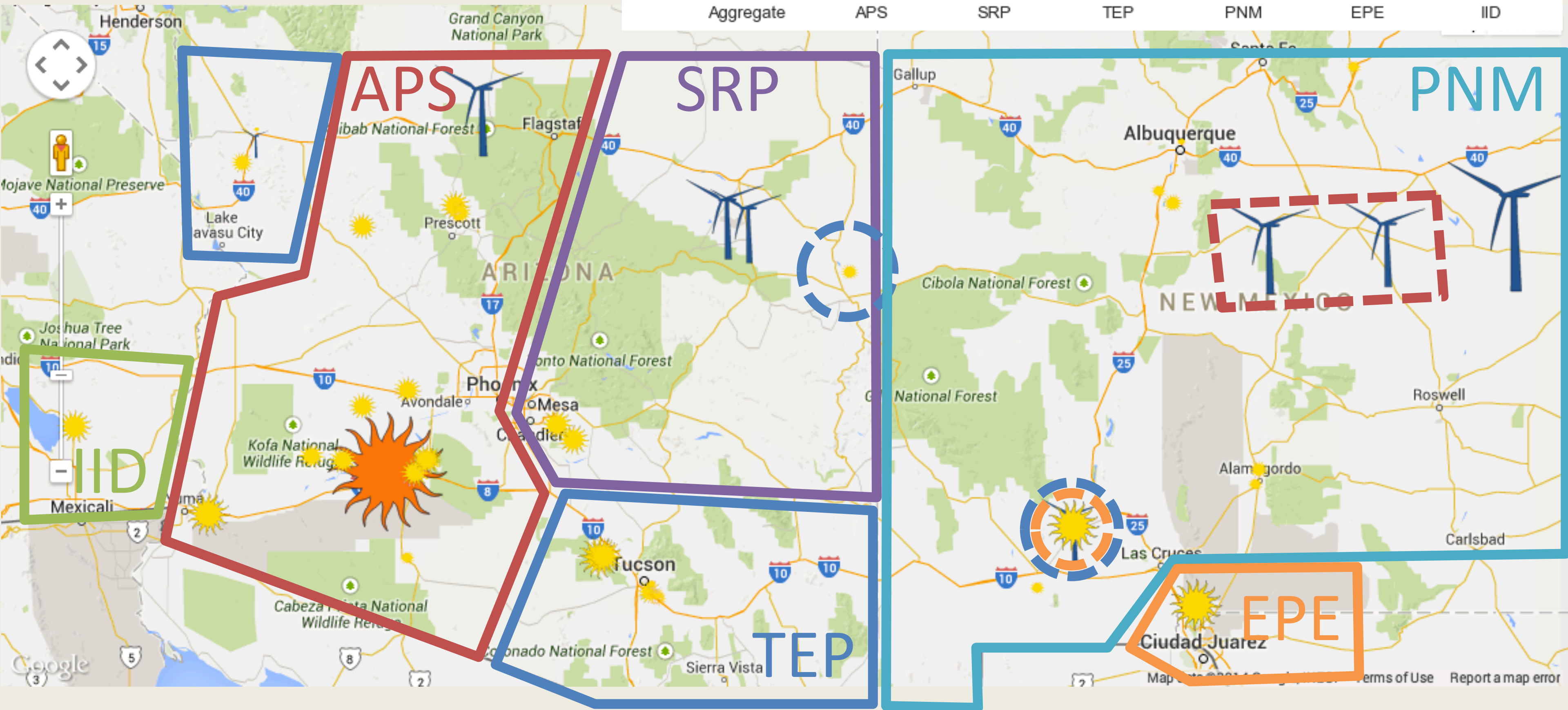
Change in renewable gen. in 1 hour (MW)

Load (MW)

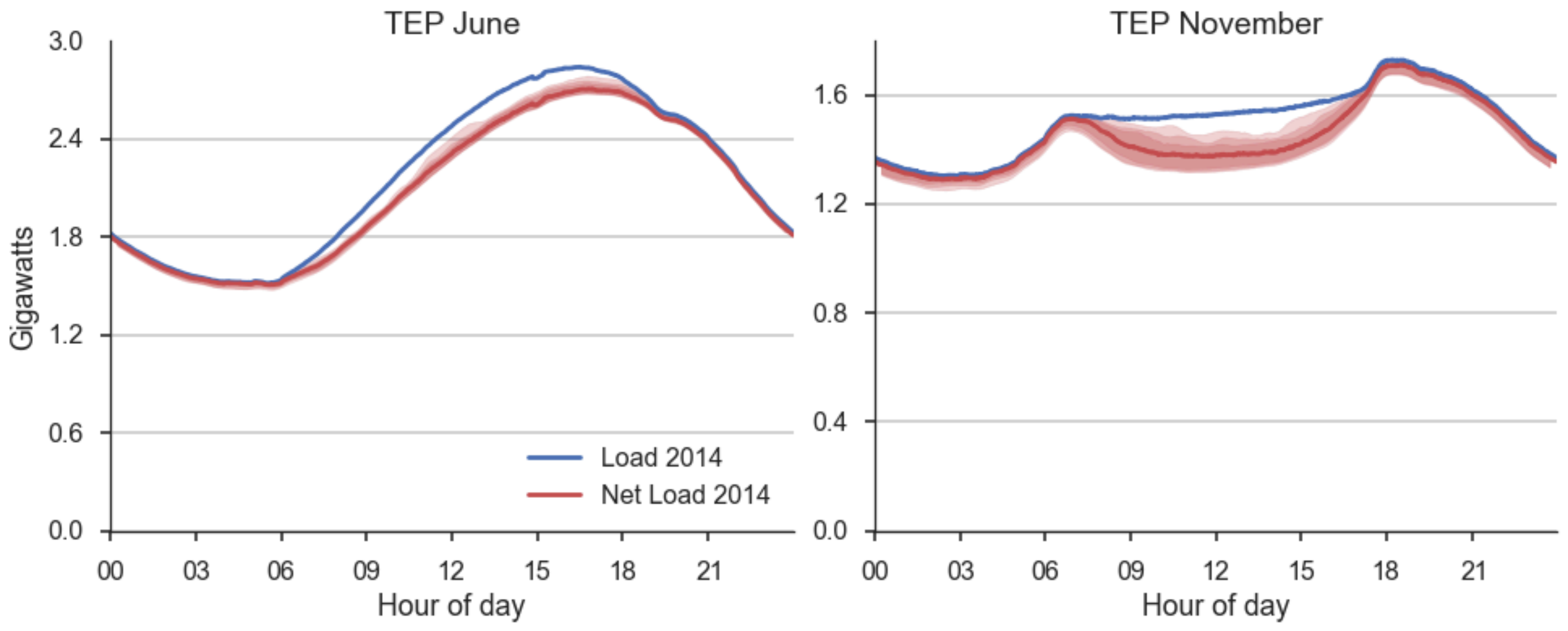
Geographic diversity is beneficial



Icon area proportional to max power



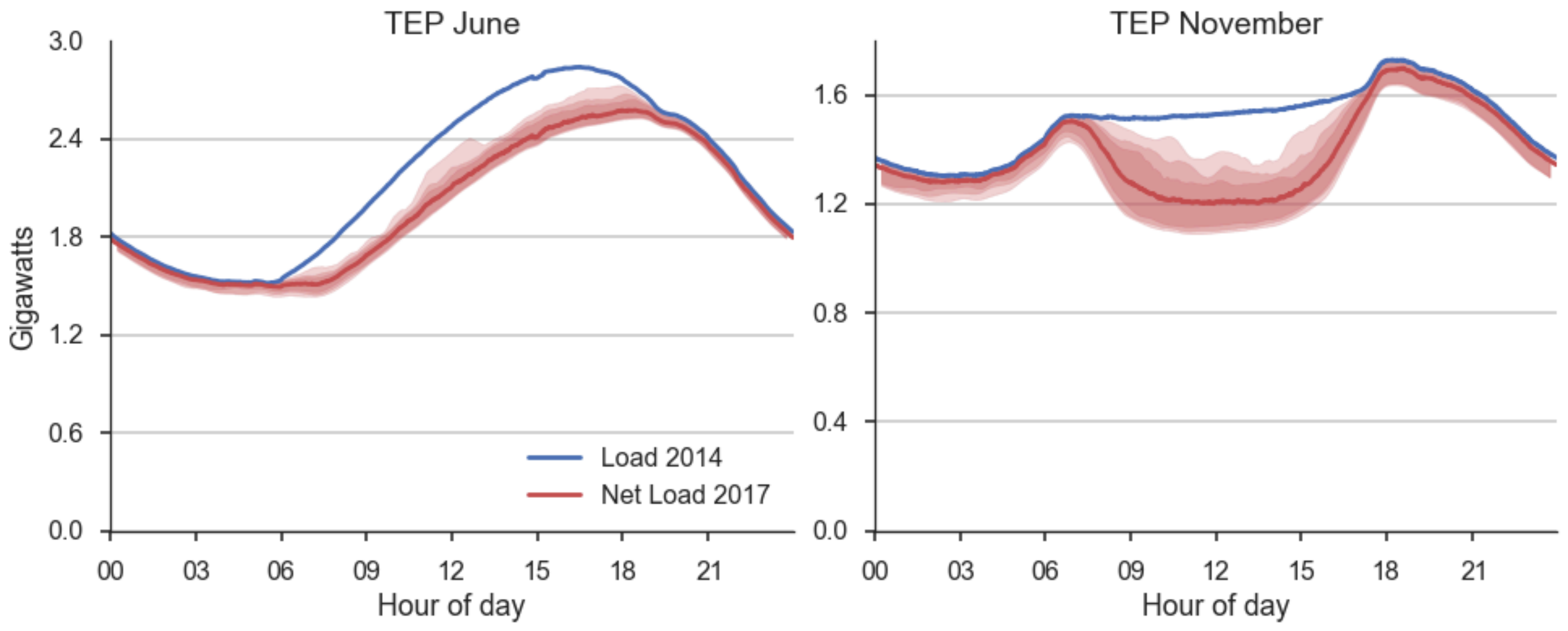
TEP 2014 Net Load Range



Light shading: all possibilities
Medium shading: 95%
Dark shading: 90%

Similar plots available for all SVERI utilities

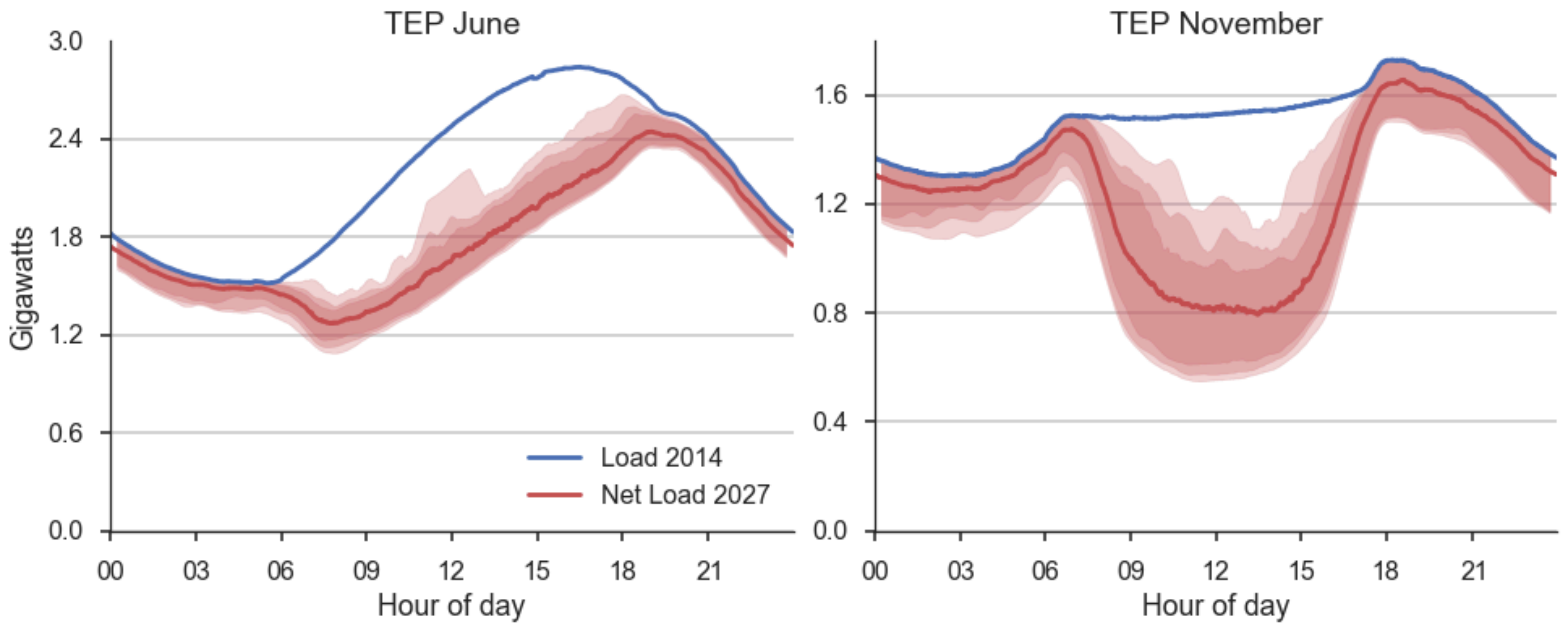
TEP 2017 Net Load Range



Light shading: all possibilities
Medium shading: 95%
Dark shading: 90%

Similar plots available for all SVERI utilities

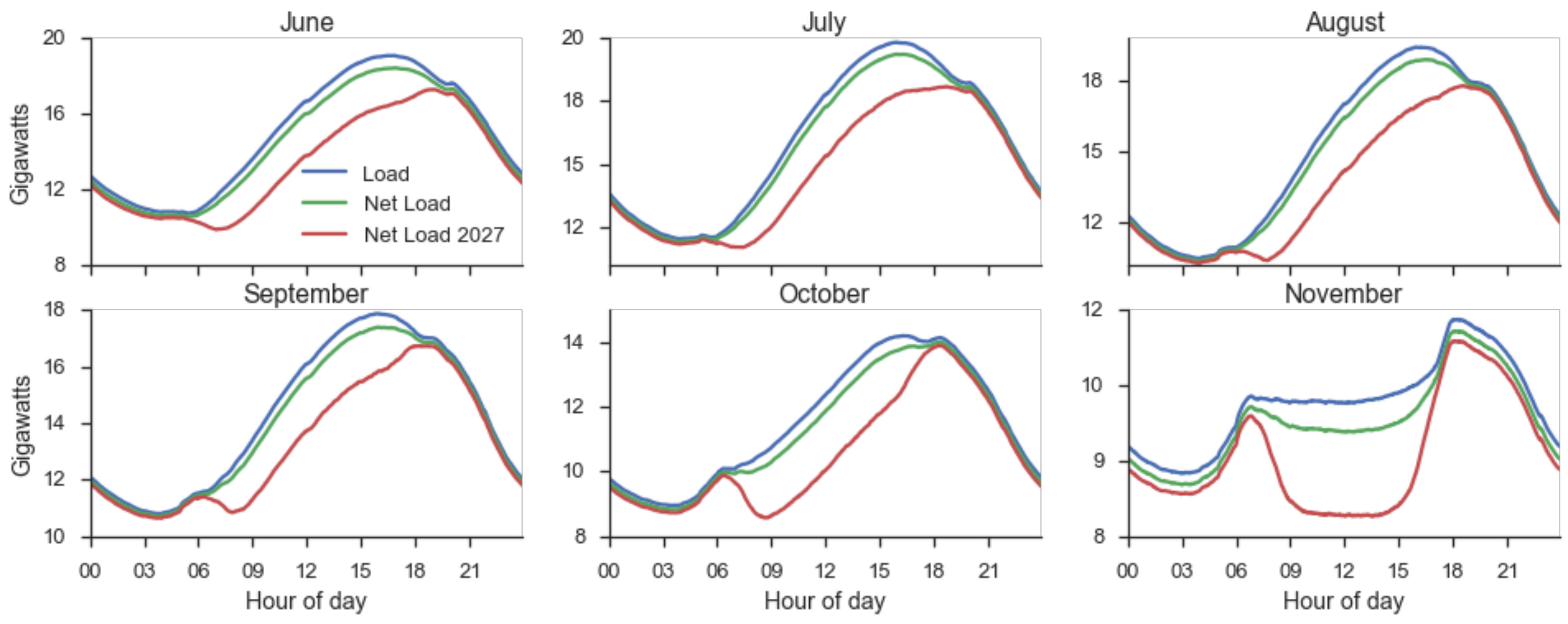
TEP 2027 Net Load Range



Light shading: all possibilities
Medium shading: 95%
Dark shading: 90%

Similar plots available for all SVERI utilities

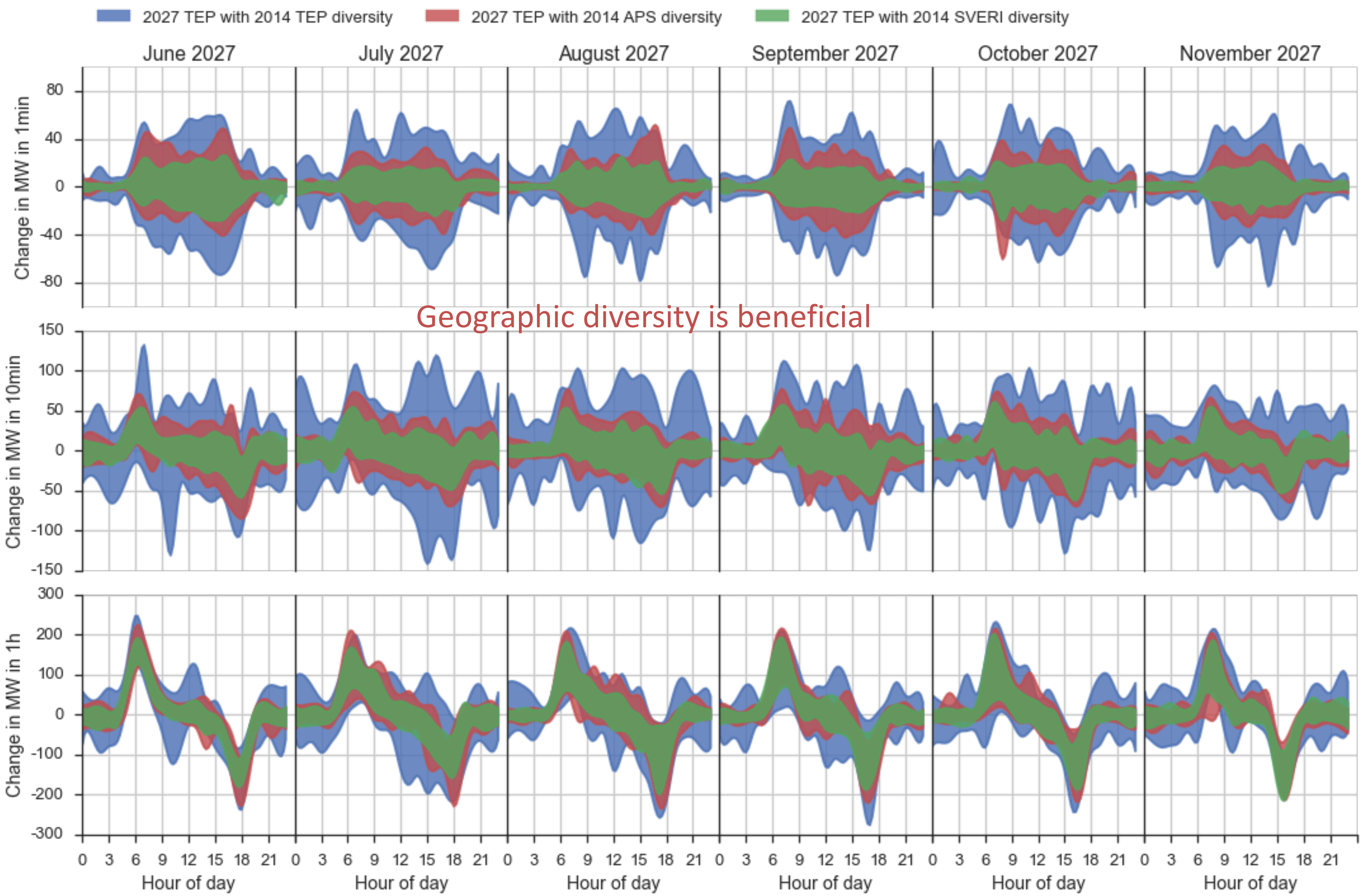
SVERI Net Load



Note the changing y axis range

The “duck curve”

2027 TEP Variability Scenarios



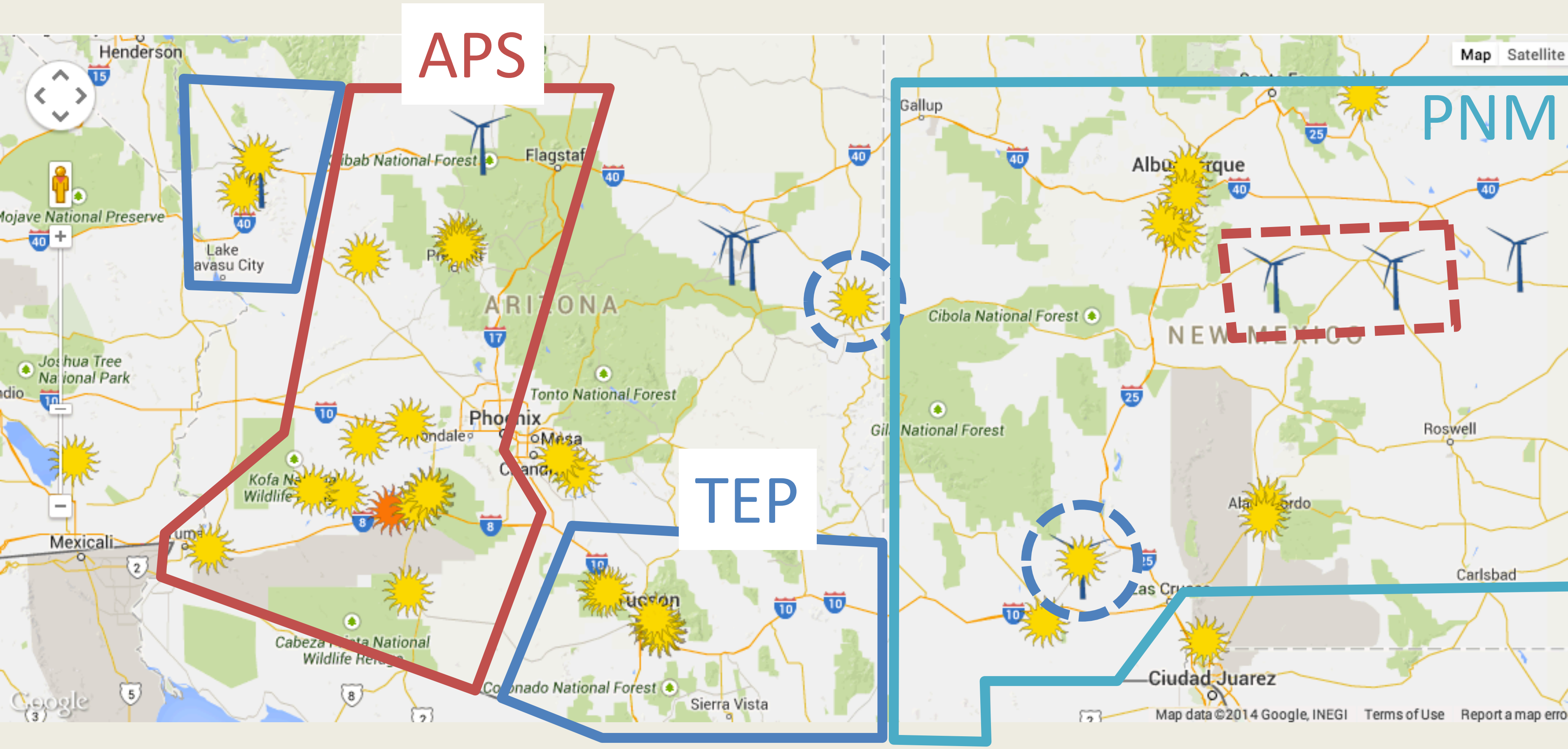
(Part of) The Solution: UA renewable power forecasts

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

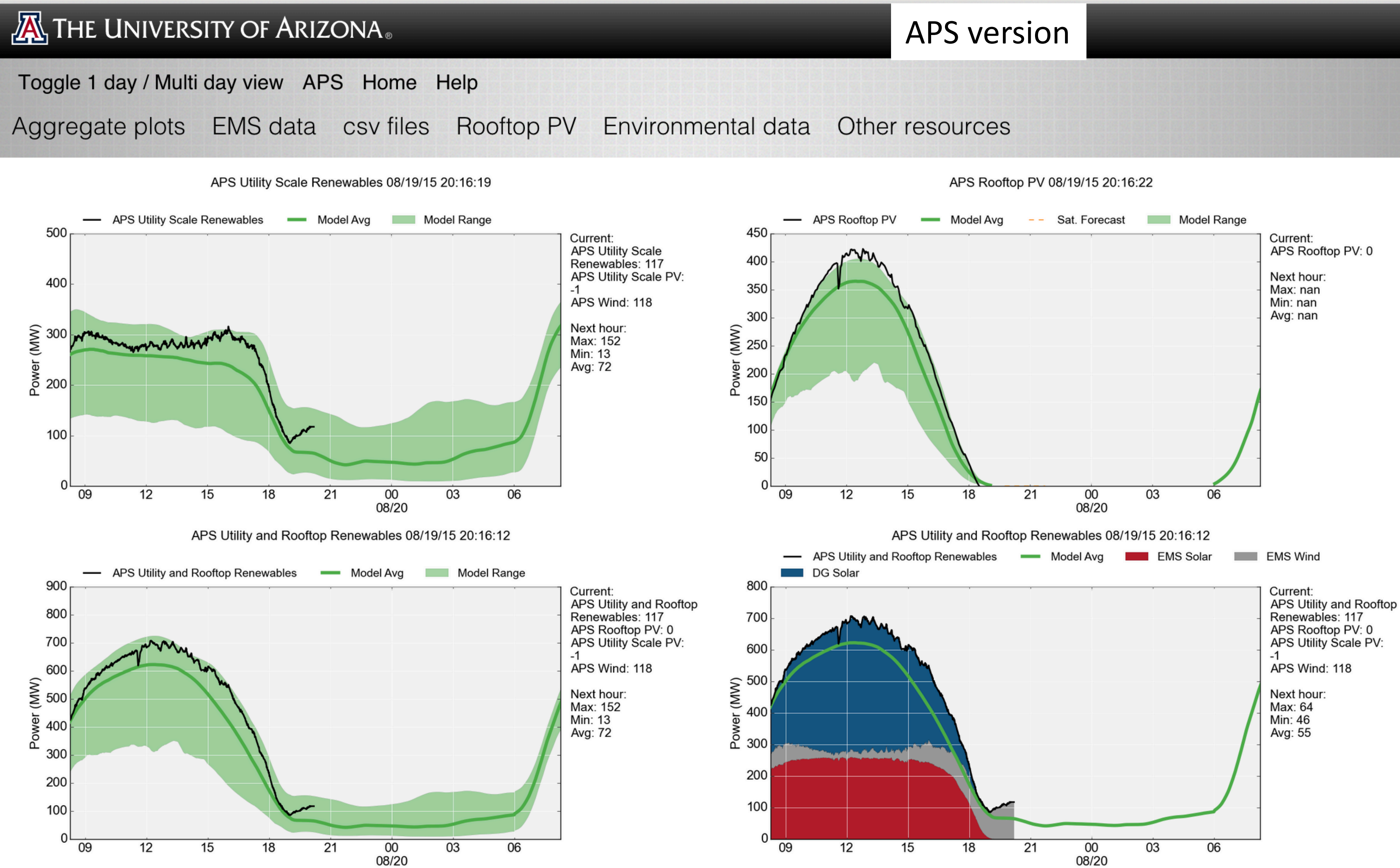
UA is providing TEP and APS with forecasts as we speak

Renewable Power Forecast Clients: TEP, APS, PNM



from sveri.uaren.org

UA Forecasting Website for TEP, APS, PNM



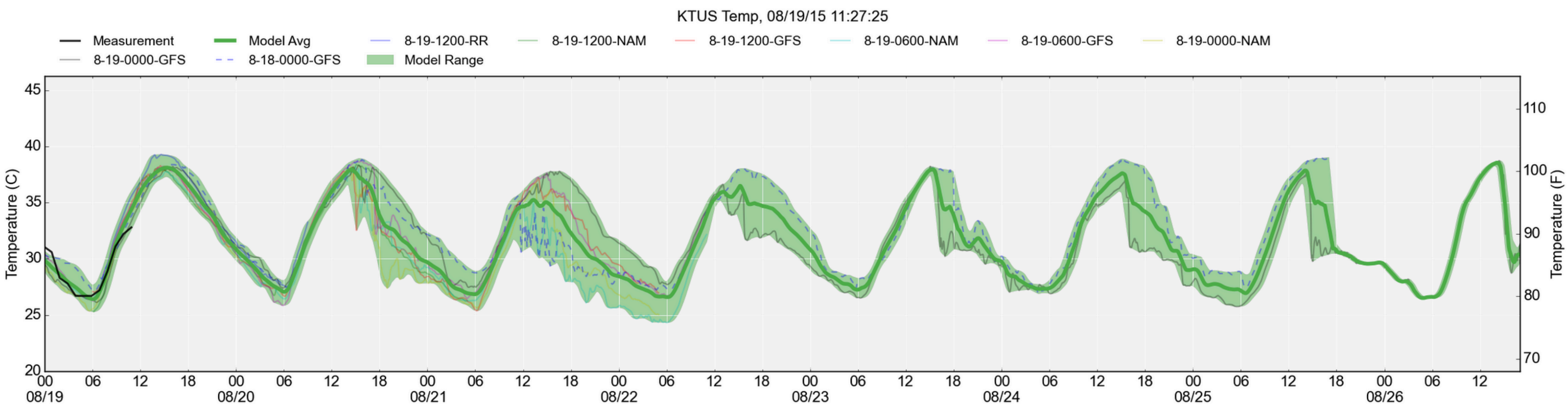
UA Forecasting Website for Public

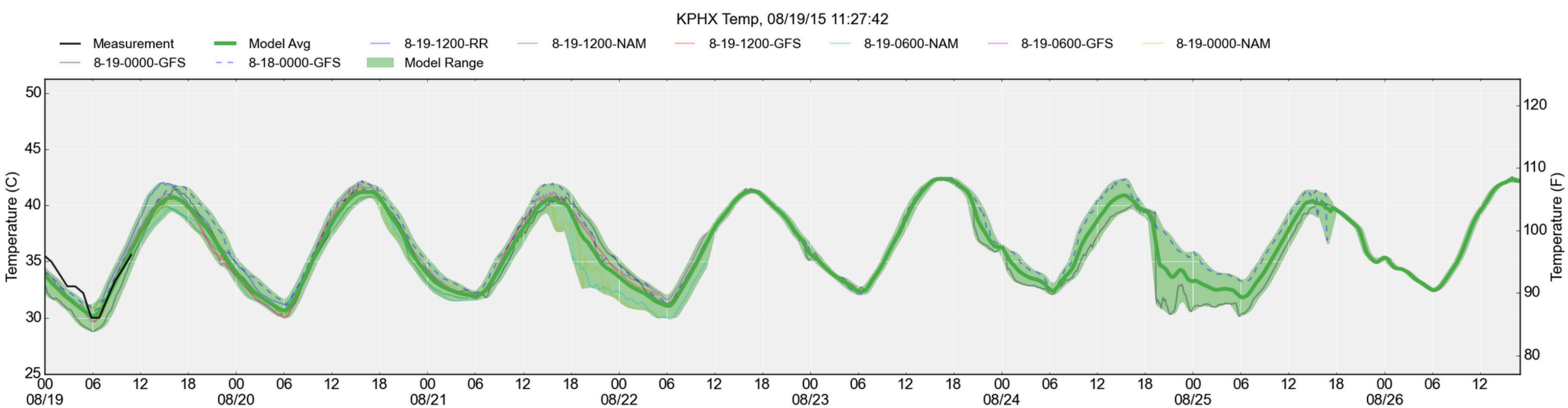
THE UNIVERSITY OF ARIZONA

forecasting.uaren.org/public

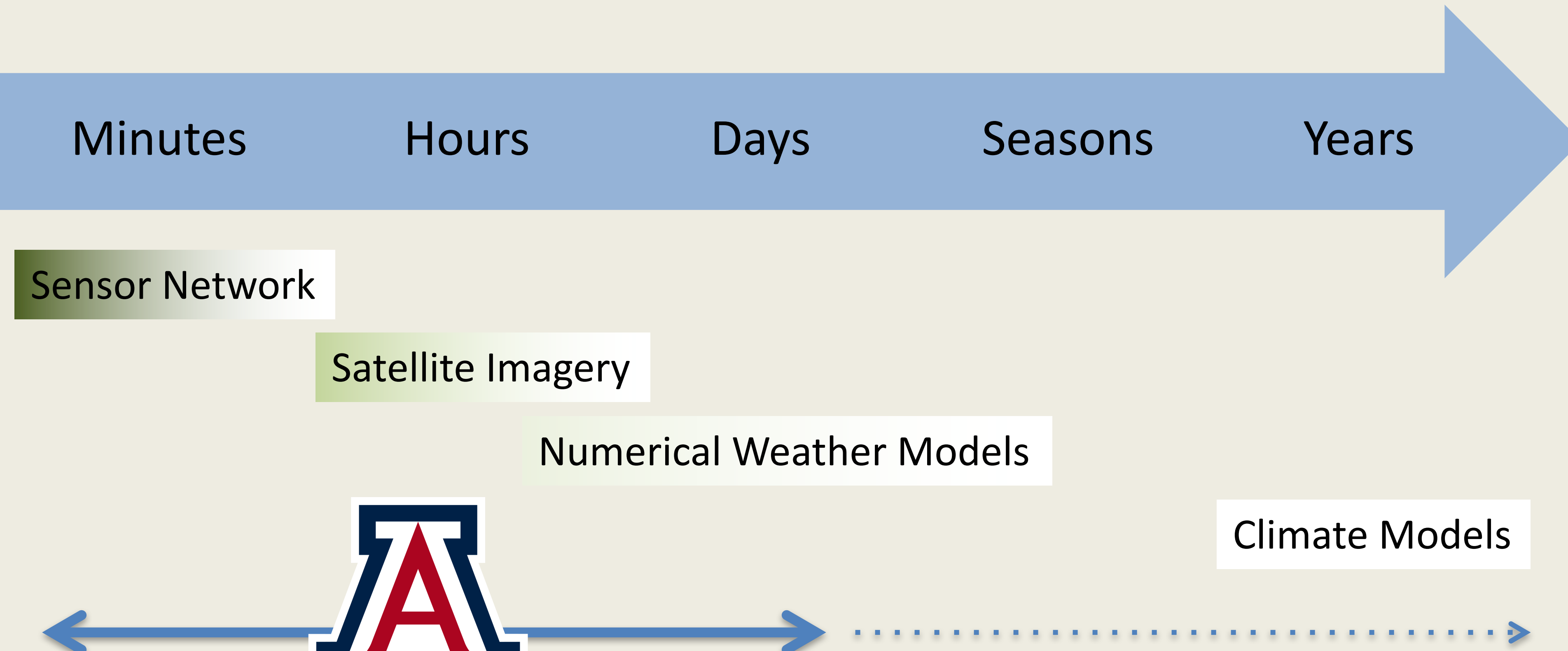
Toggle 1 day / Multi day view   Public   Home

Irradiance sensors   Environmental data   Other resources

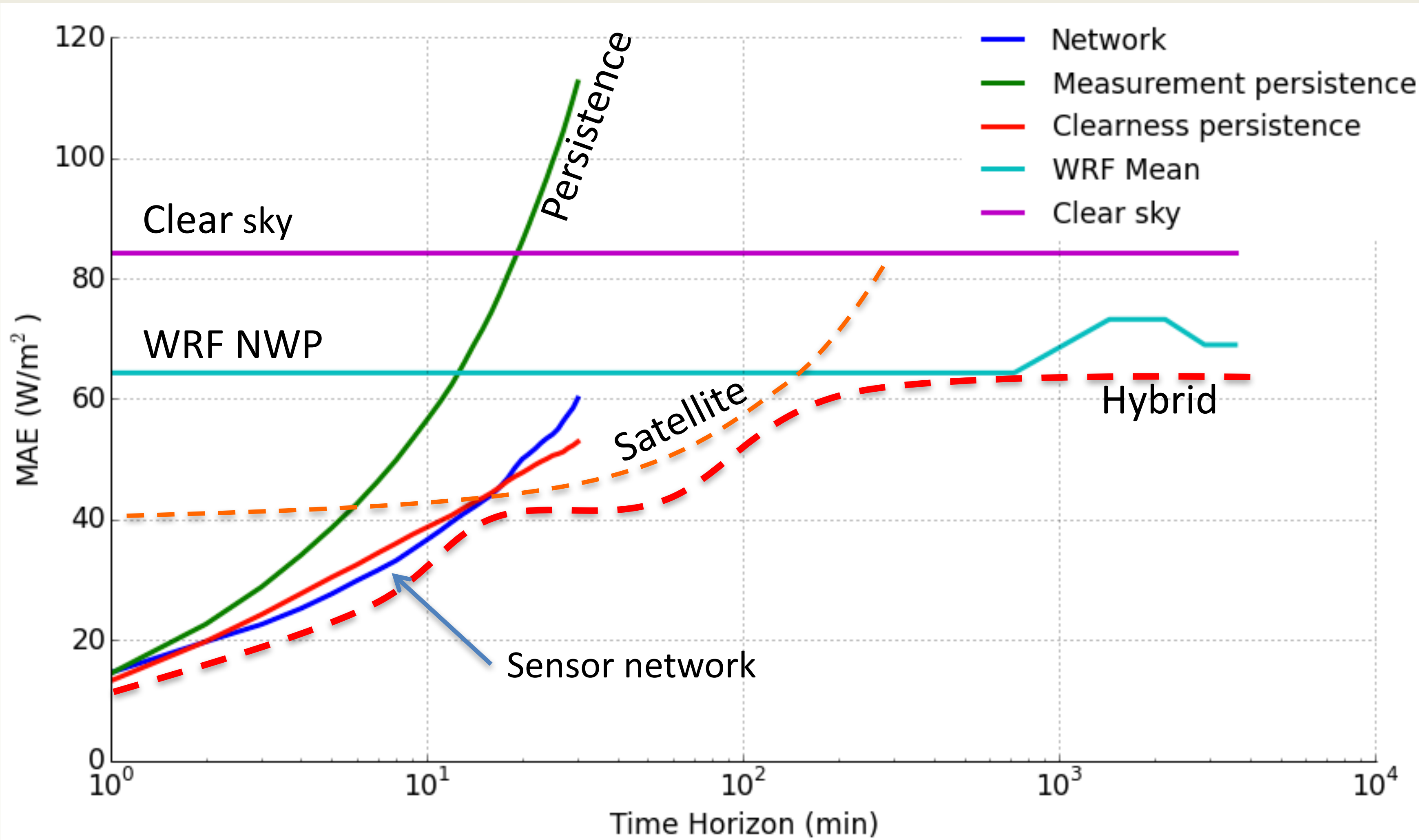




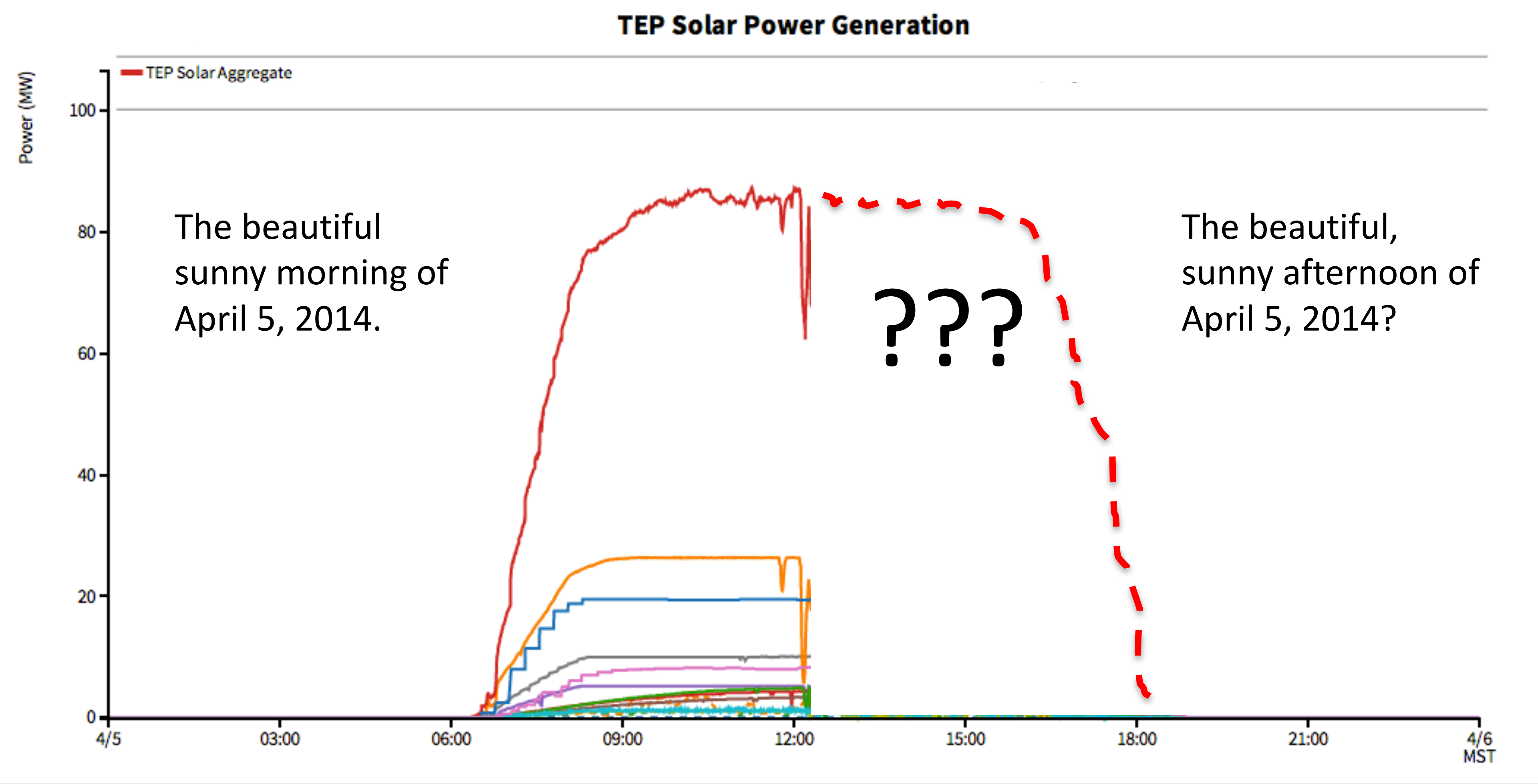
Different forecasting methods work better at different time scales



UA forecasting summary



TEP's Solar Power Variability



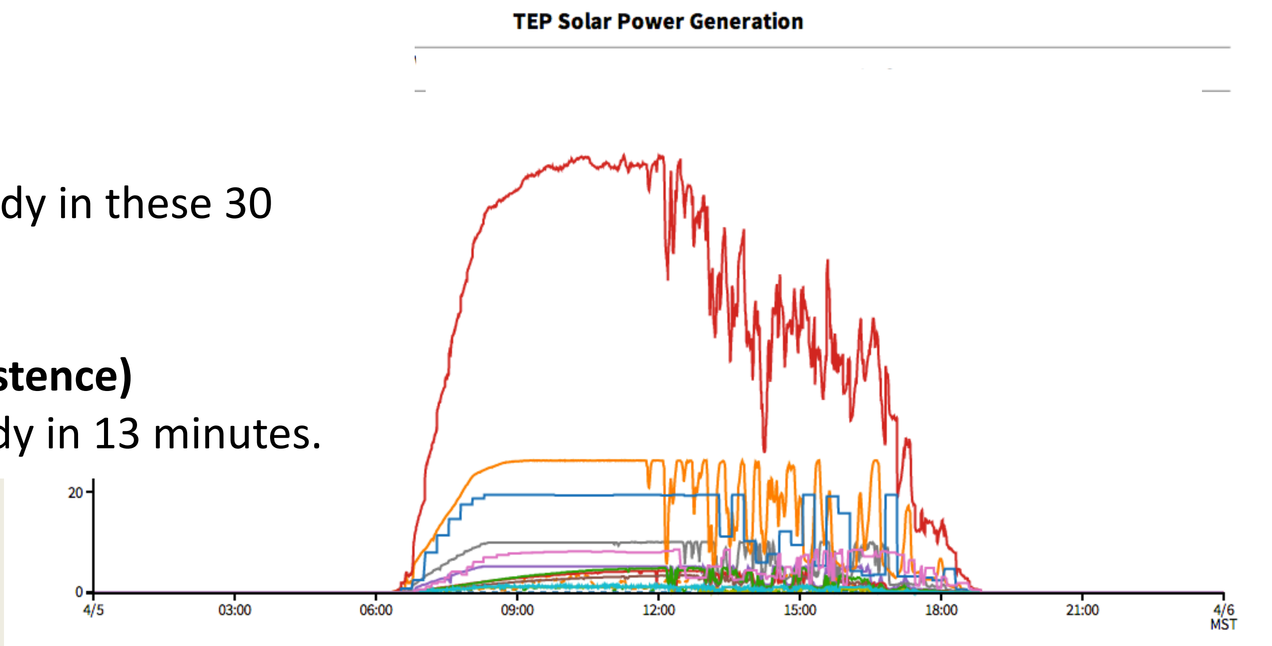
TEP's Solar Power Variability

Days ahead (NWP)
It's going to be sunny in the morning and cloudy in the afternoon.

Day ahead (NWP)
It's going to be this cloudy in these hours with that much variability.

Hours ahead (Satellite)
It's going to be roughly this cloudy in these 30 minute chunks.

Minutes ahead (network, persistence)
It's going to be exactly this cloudy in 13 minutes.



Numerical Weather Prediction at UA

Christopher Marks, Creative Commons

- UA WRF Model highlights
  - 5.4 km outer domain, 1.8 km inner domain
  - Initialized on the 0Z, 6Z, and 12Z GFS and NAM
  - Many days include 13Z RAP initialization (esp. in summer)
- 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

WRF configuration details:

- RRTMG
- Morrison 2 mom. or SBUYLIN
- Bougeault-Lacarre or ACM2
- Noah LSM

Weather Research and Forecasting (WRF) community model developed at NCAR, NCEP, ESRL, universities, and more

Raw UA WRF forecasts available at atmo.arizona.edu

The University of Arizona

www.atmo.arizona.edu/in...

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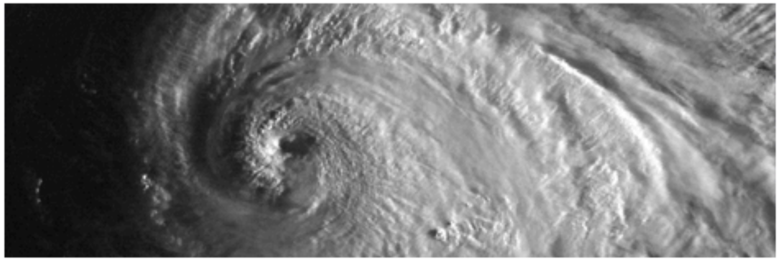

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Arizona Regional WRF Model Data

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					

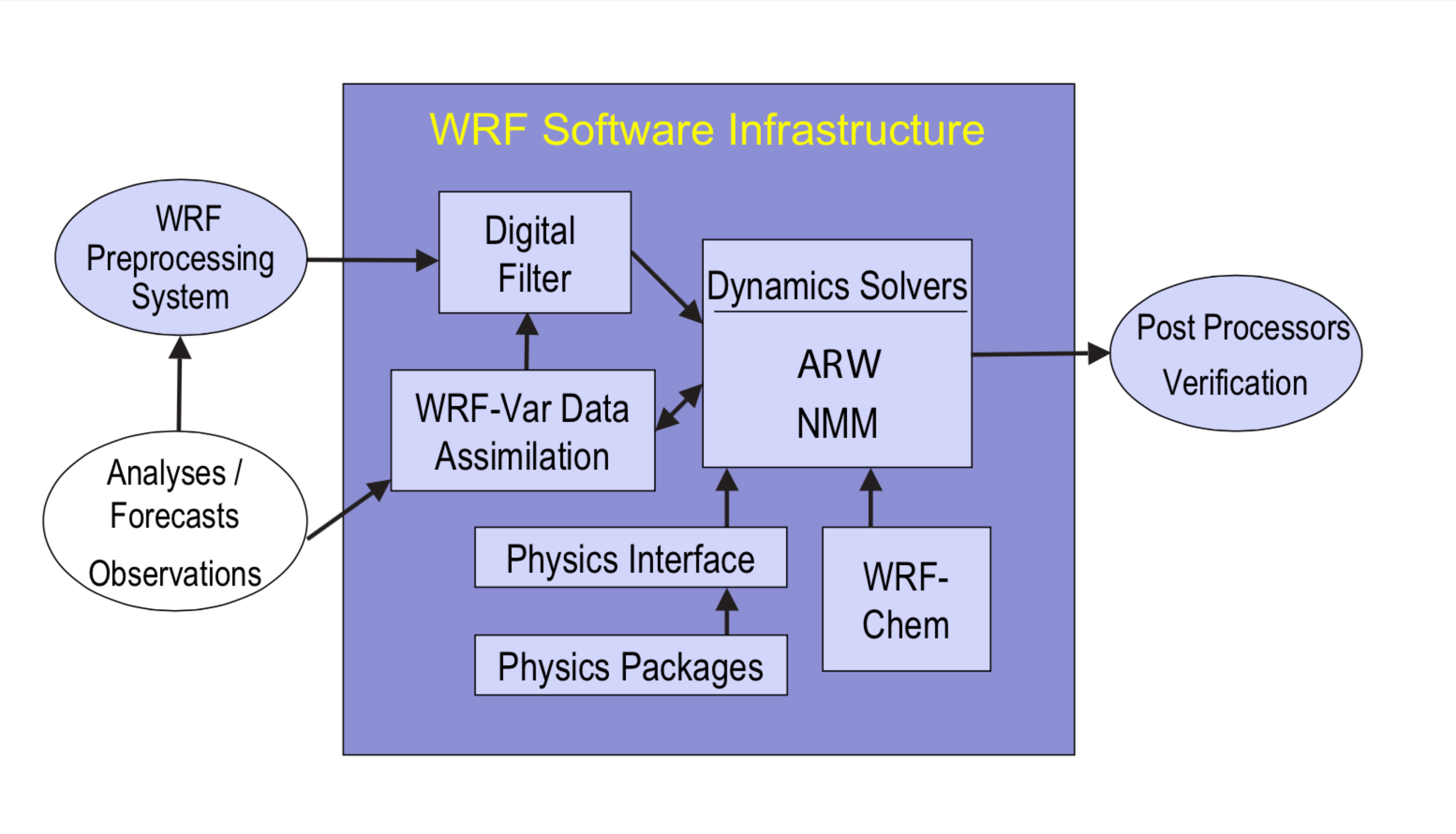
- Current Weather

- 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

A small selection of WRF details



Skamarock et. al. “A description of the Advanced Research WRF Version 3” (2008)

A small selection of WRF details

2.2 Flux-Form Euler Equations

Using the variables defined above, the flux-form Euler equations can be writt

$$\partial_t U + (\nabla \cdot \mathbf{V}u) - \partial_x(p\phi_\eta) + \partial_\eta(p\phi_x) = F_U$$
$$\partial_t V + (\nabla \cdot \mathbf{V}v) - \partial_y(p\phi_\eta) + \partial_\eta(p\phi_y) = F_V$$
$$\partial_t W + (\nabla \cdot \mathbf{V}w) - g(\partial_\eta p - \mu) = F_W$$
$$\partial_t \Theta + (\nabla \cdot \mathbf{V}\theta) = F_\Theta$$
$$\partial_t \mu + (\nabla \cdot \mathbf{V}) = 0$$
$$\partial_t \phi + \mu^{-1}[(\mathbf{V} \cdot \nabla\phi) - gW] = 0$$

along with the diagnostic relation for the inverse density

$$\partial_\eta \phi = -\alpha\mu,$$

and the equation of state

$$p = p_0(R_d\theta/p_0\alpha)^\gamma.$$

In (2.3) – (2.10), the subscripts x, y and η denote differentiation,

$$\nabla \cdot \mathbf{V}a = \partial_x(Ua) + \partial_y(Va) + \partial_\eta(\Omega a),$$

and

$$\mathbf{V} \cdot \nabla a = U\partial_x a + V\partial_y a + \Omega\partial_\eta a,$$

where a represents a generic variable. $\gamma = c_p/c_v = 1.4$ is the ratio of the heat air, R_d is the gas constant for dry air, and p_0 is a reference pressure (typically right-hand-side (RHS) terms F_U, F_V, F_W, and F_Θ represent forcing terms a physics, turbulent mixing, spherical projections, and the earth's rotation.

2.3 Inclusion of Moisture

In formulating the moist Euler equations, we retain the coupling of dry air ma variables, and we retain the conservation equation for dry air (2.7), as oppo variables to the full (moist) air mass and hence introducing source terms in th equation (2.7). Additionally, we define the coordinate with respect to the d on these principles, the vertical coordinate can be written as

$$\eta = (p_{dh} - p_{dht})/\mu_d$$

where μ_d represents the mass of the dry air in the column and p_{dh} and hydrostatic pressure of the dry atmosphere and the hydrostatic pressure at atmosphere. The coupled variables are defined as

$$\mathbf{V} = \mu_d\mathbf{v}, \quad \Omega = \mu_d\dot{\eta}, \quad \Theta = \mu_d\theta.$$

With these definitions, the moist Euler equations can be written as

$$\partial_t U + (\nabla \cdot \mathbf{V}u) + \mu_d\alpha\partial_x p + (\alpha/\alpha_d)\partial_\eta p\partial_x\phi = F_U$$
$$\partial_t V + (\nabla \cdot \mathbf{V}v) + \mu_d\alpha\partial_y p + (\alpha/\alpha_d)\partial_\eta p\partial_y\phi = F_V$$
$$\partial_t W + (\nabla \cdot \mathbf{V}w) - g[(\alpha/\alpha_d)\partial_\eta p - \mu_d] = F_W$$
$$\partial_t \Theta + (\nabla \cdot \mathbf{V}\theta) = F_\Theta$$
$$\partial_t \mu_d + (\nabla \cdot \mathbf{V}) = 0$$
$$\partial_t \phi + \mu_d^{-1}[(\mathbf{V} \cdot \nabla\phi) - gW] = 0$$
$$\partial_t Q_m + (\nabla \cdot \mathbf{V}q_m) = F_{Q_m}$$

with the diagnostic equation for dry inverse density

$$\partial_\eta \phi = -\alpha_d\mu_d$$

s dry air)

Skamarock et. al. "A description of the Advanced Research WRF Version 3" (2008)

A small selection of WRF details

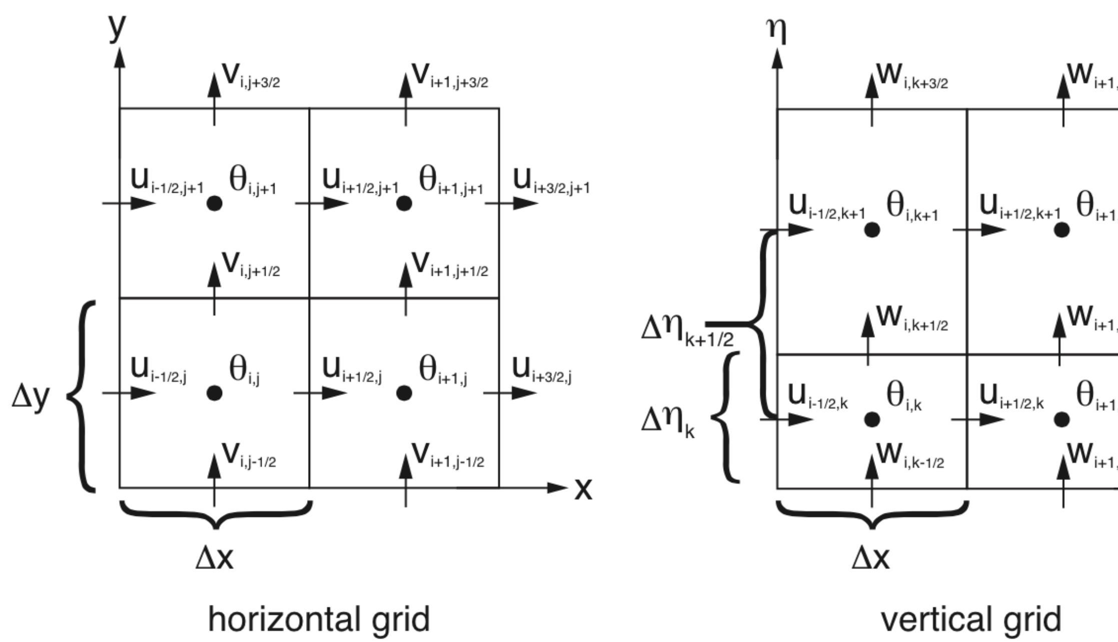
Runge-Kutta Time Integration Scheme

3 scheme, described in Wicker and Skamarock (2002), integrates a set of ordinary ial equations using a predictor-corrector formulation. Defining the prognostic variables RW solver as $\Phi = (U, V, W, \Theta, \phi', \mu', Q_m)$ and the model equations as $\Phi_t = R(\Phi)$, the egration takes the form of 3 steps to advance a solution $\Phi(t)$ to $\Phi(t + \Delta t)$:

$$\Phi^* = \Phi^t + \frac{\Delta t}{3} R(\Phi^t) \quad (3.1)$$

$$\Phi^{**} = \Phi^t + \frac{\Delta t}{2}$$

$$\Phi^{t+\Delta t} = \Phi^t + \Delta$$



Skamarock et. al. "A description of the Advanced Research WRF Version 3" (2008)

1.2 Major Features of the ARW System, Version 3

ARW Solver

- *Equations:* Fully compressible, Euler nonhydrostatic with a run-time hydrostatic option available. Conservative for scalar variables.
- *Prognostic Variables:* Velocity components u and v in Cartesian coordinate, vertical velocity w, perturbation potential temperature, perturbation geopotential, and perturbation surface pressure of dry air. Optionally, turbulent kinetic energy and any number of scalars such as water vapor mixing ratio, rain/snow mixing ratio, cloud water/ice mixing ratio, and chemical species and tracers.
- vertical grid stretching

ıge-Kutta scheme with
ne step capability.
tal and vertical.
ılation in both coordi-
ing, vertically implicit

l three-dimensional for
able (real-data cases).
d options available.
h damping, or implicit
top boundary along a

Model Physics

- *Microphysics:* Schemes ranging from simplified physics suitable for idealized studies to sophisticated mixed-phase physics suitable for process studies and NWP.
- *Cumulus parameterizations:* Adjustment and mass-flux schemes for mesoscale modeling.
- *Surface physics:* Multi-layer land surface models ranging from a simple thermal model to full vegetation and soil moisture models, including snow cover and sea ice.
- *Planetary boundary layer physics:* Turbulent kinetic energy prediction or non-local K schemes.
- *Atmospheric radiation physics:* Longwave and shortwave schemes with multiple spectral bands and a simple shortwave scheme suitable for climate and weather applications. Cloud effects and surface fluxes are included.

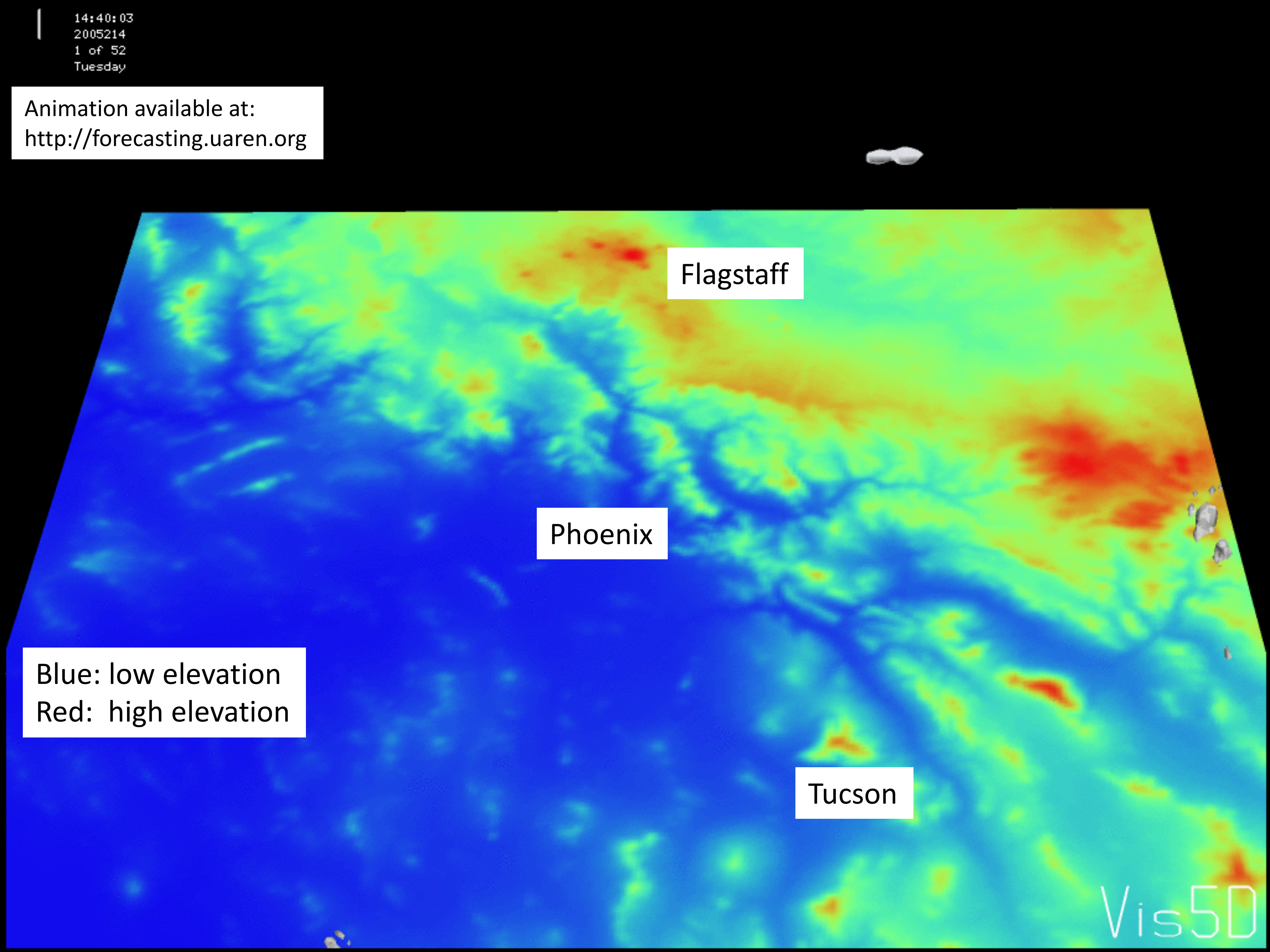
- *Earth's Rotation:* Full Coriolis terms included.
- *Mapping to Sphere:* Four map projections are supported for real-data simulation: polar stereographic, Lambert conformal, Mercator, and latitude-longitude (allowing rotated pole).

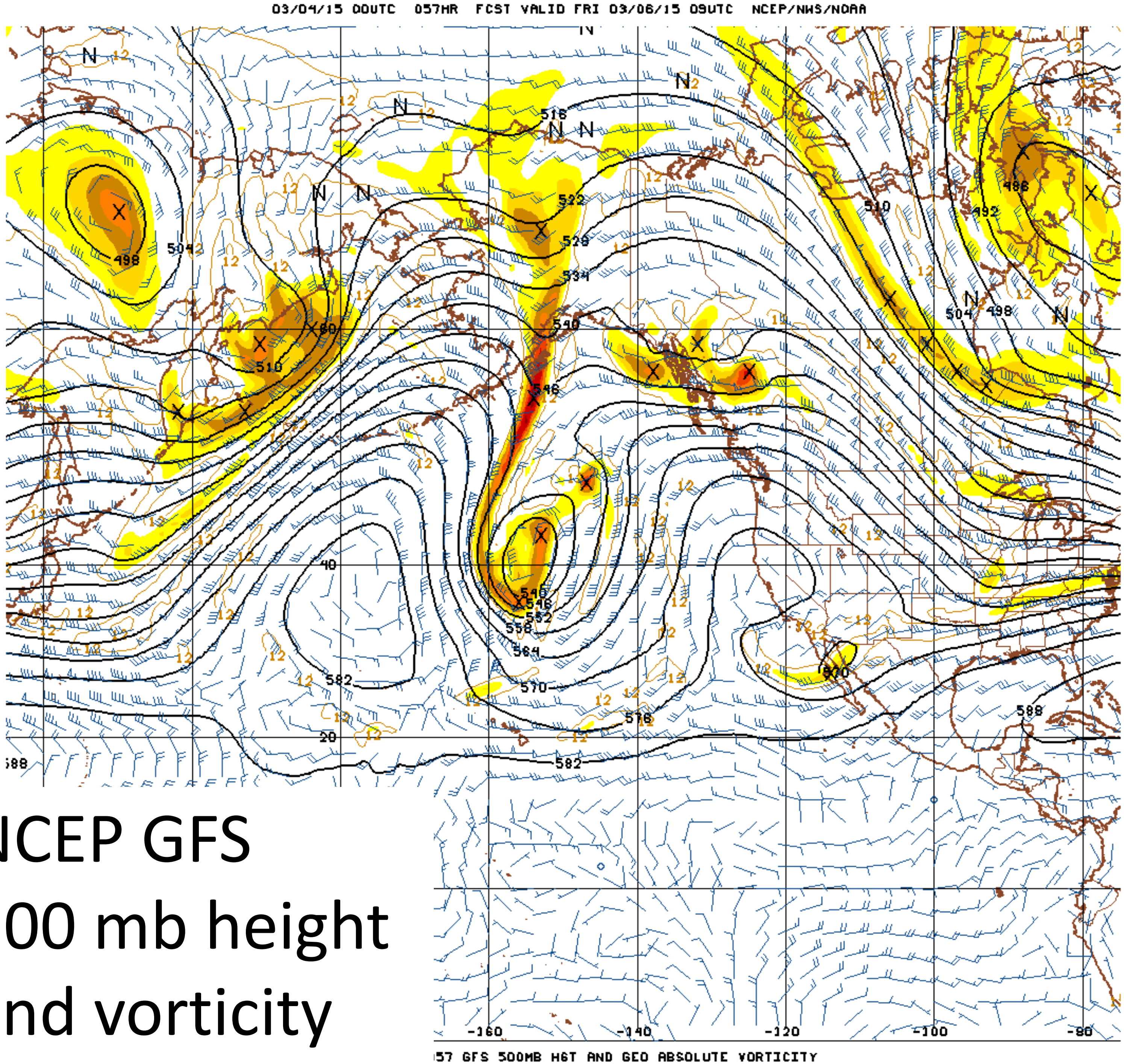
and

-west

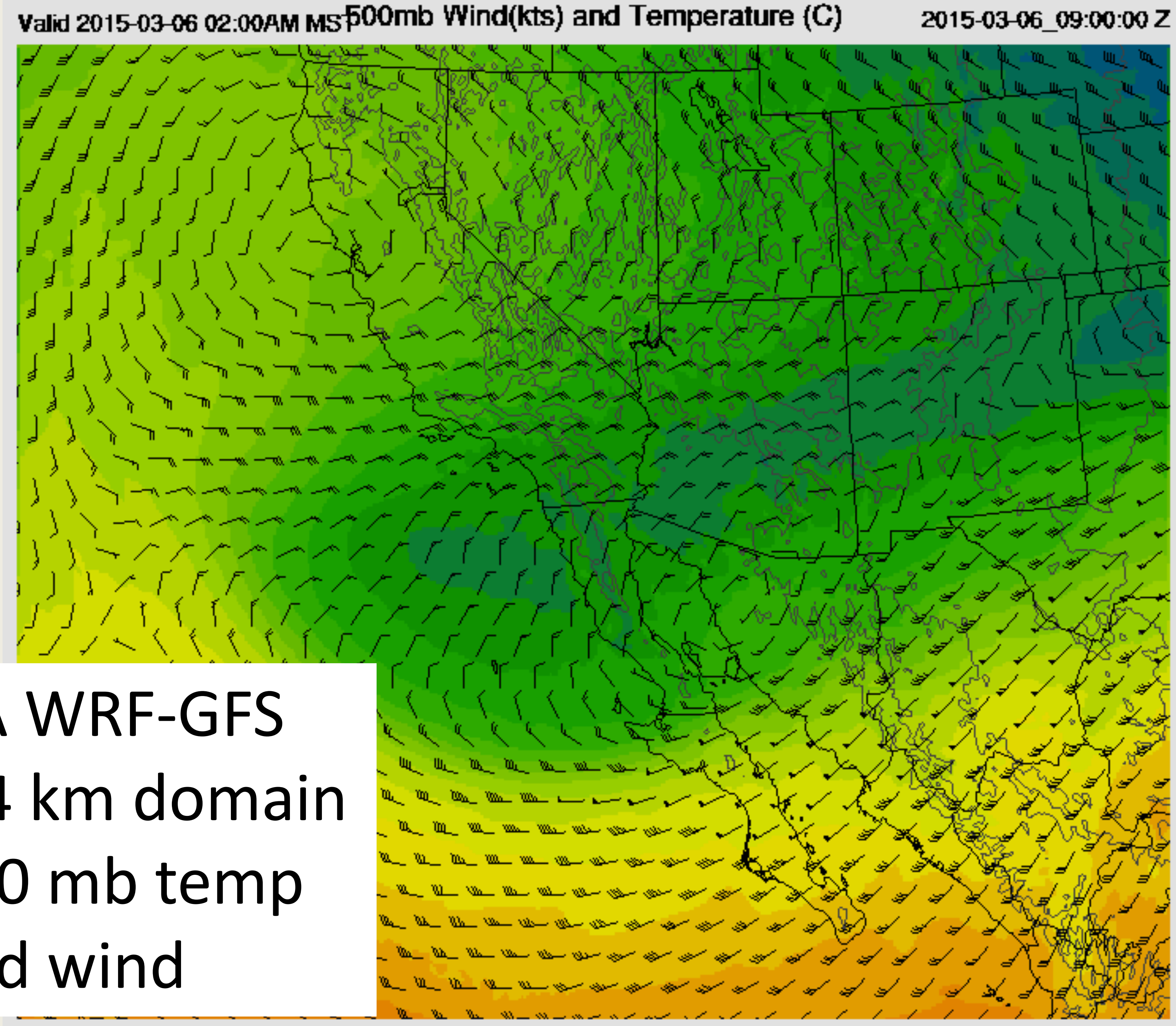
conditions.

A complicated model with a lot of options. With effort and expertise, you can tune it to perform better in your environment. We've tuned it to perform better in Arizona.

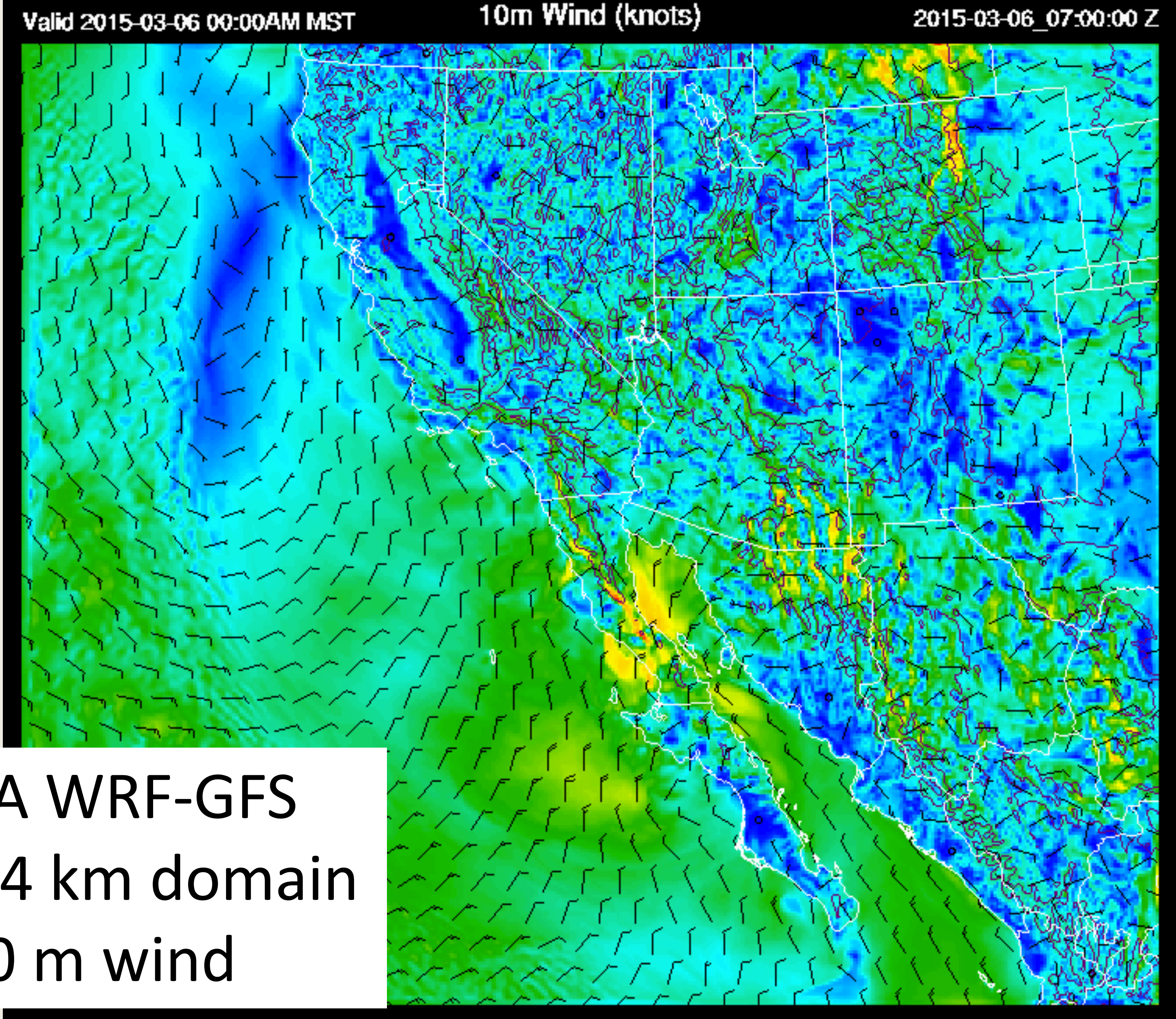

14:40:03
2005214
1 of 52
Tuesday
Animation available at:
http://forecasting.uaren.org
Flagstaff
Phoenix
Tucson
Blue: low elevation
Red: high elevation
Vis5D



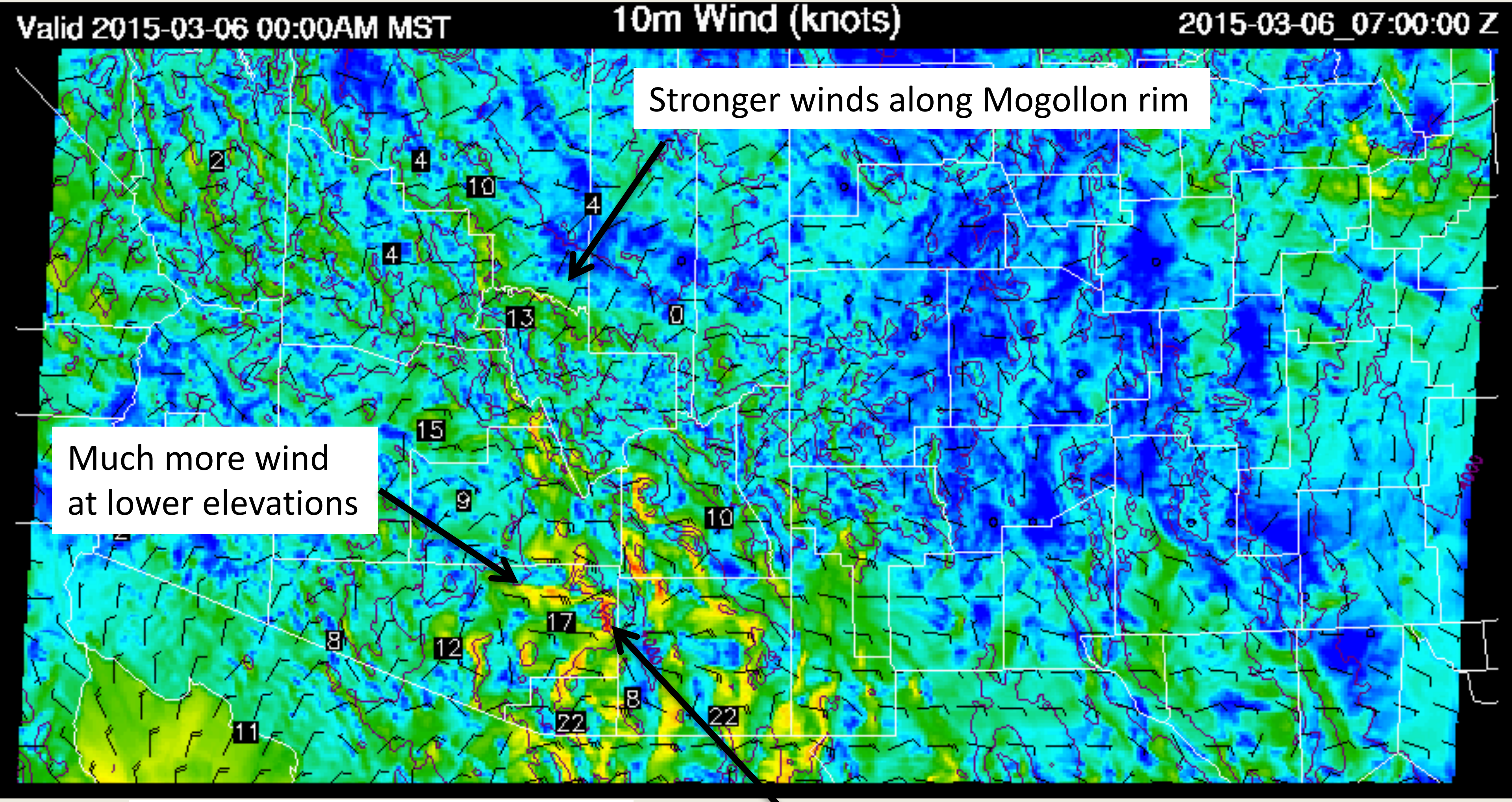
NCEP GFS 500 mb height and vorticity



UA WRF-GFS
5.4 km domain
500 mb temp
and wind



UA WRF-GFS
5.4 km domain
10 m wind

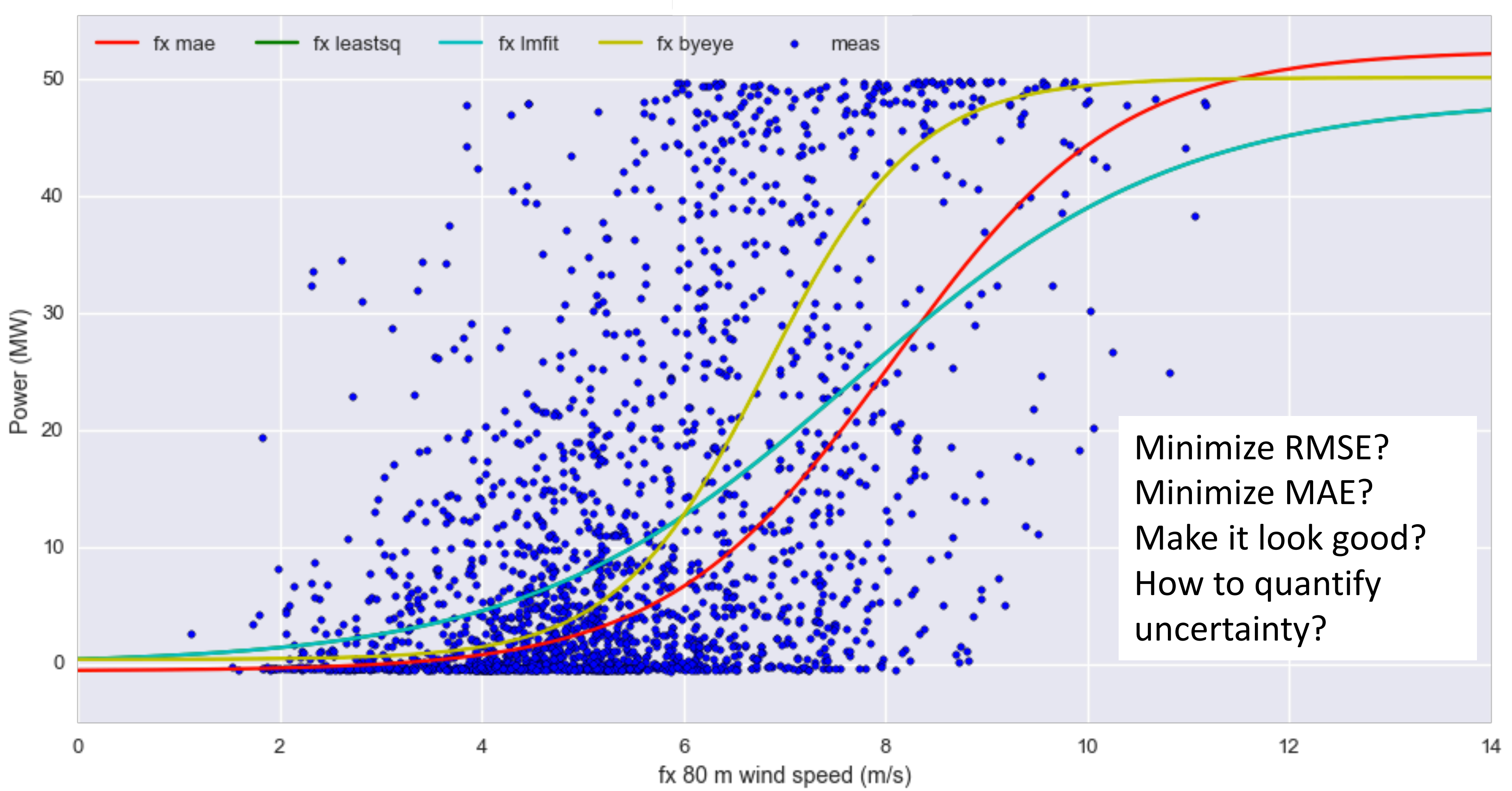


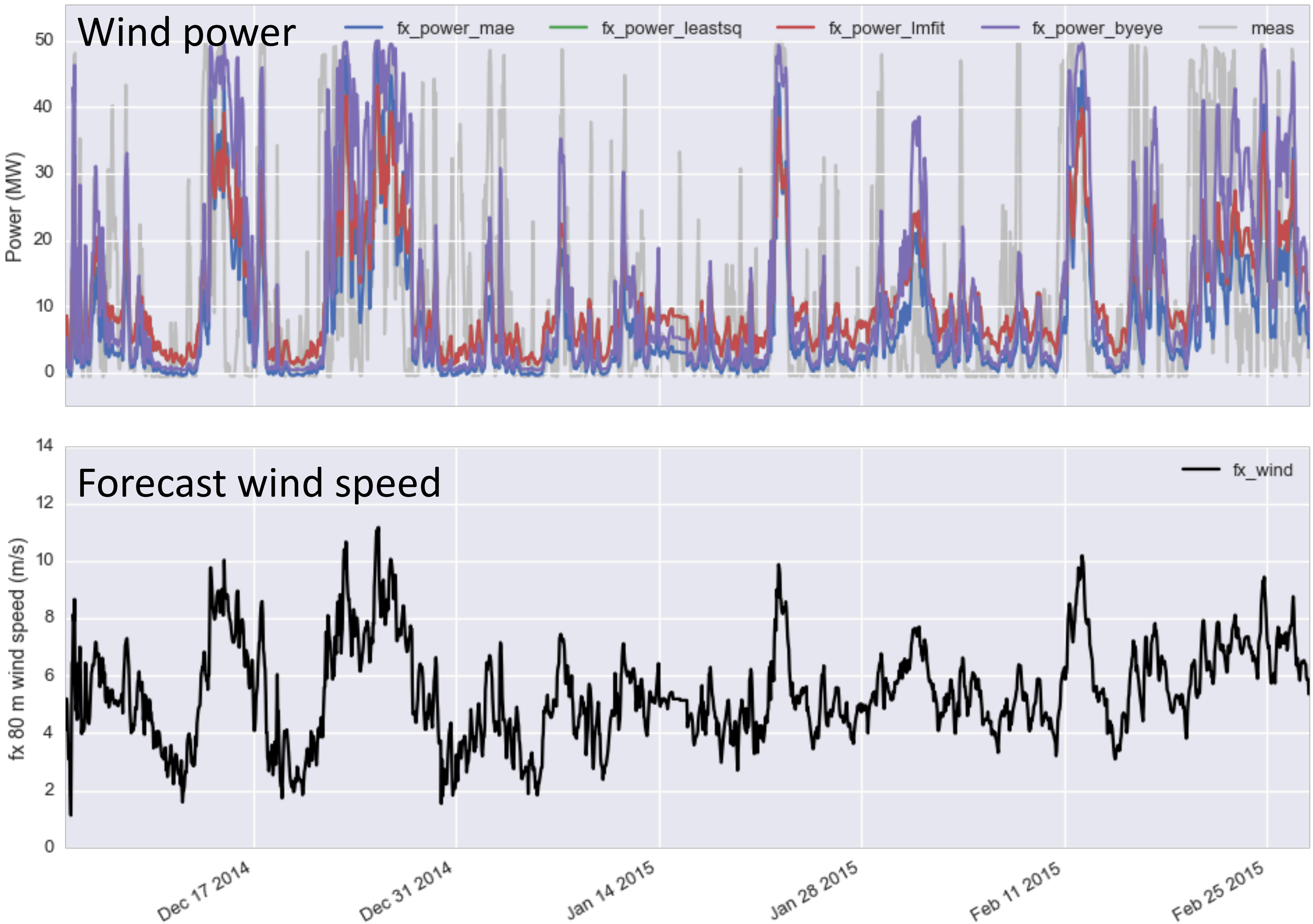
UA WRF-GFS 1.8 km domain 10 m wind

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

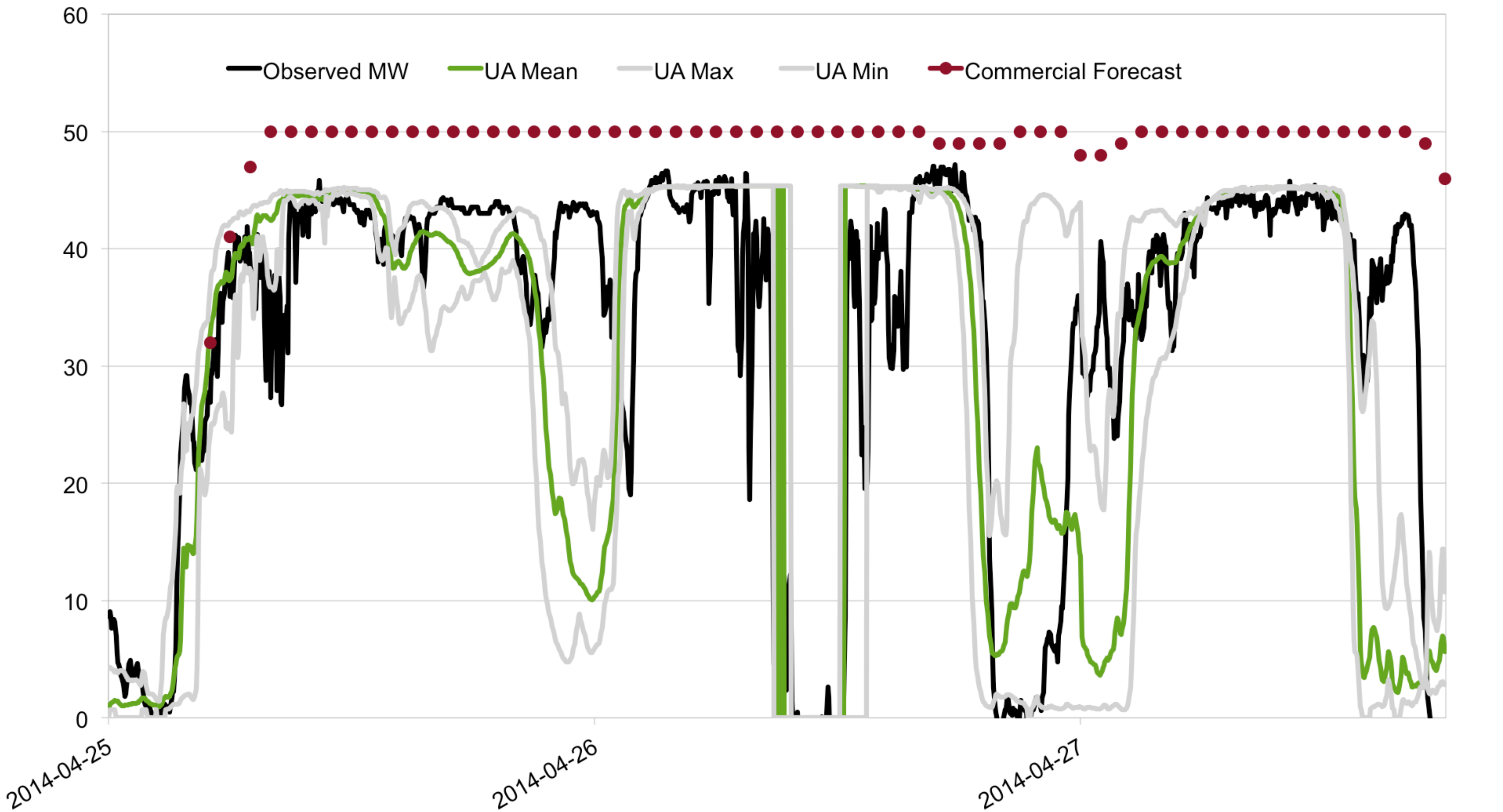
UA-WRF Wind Power Curve

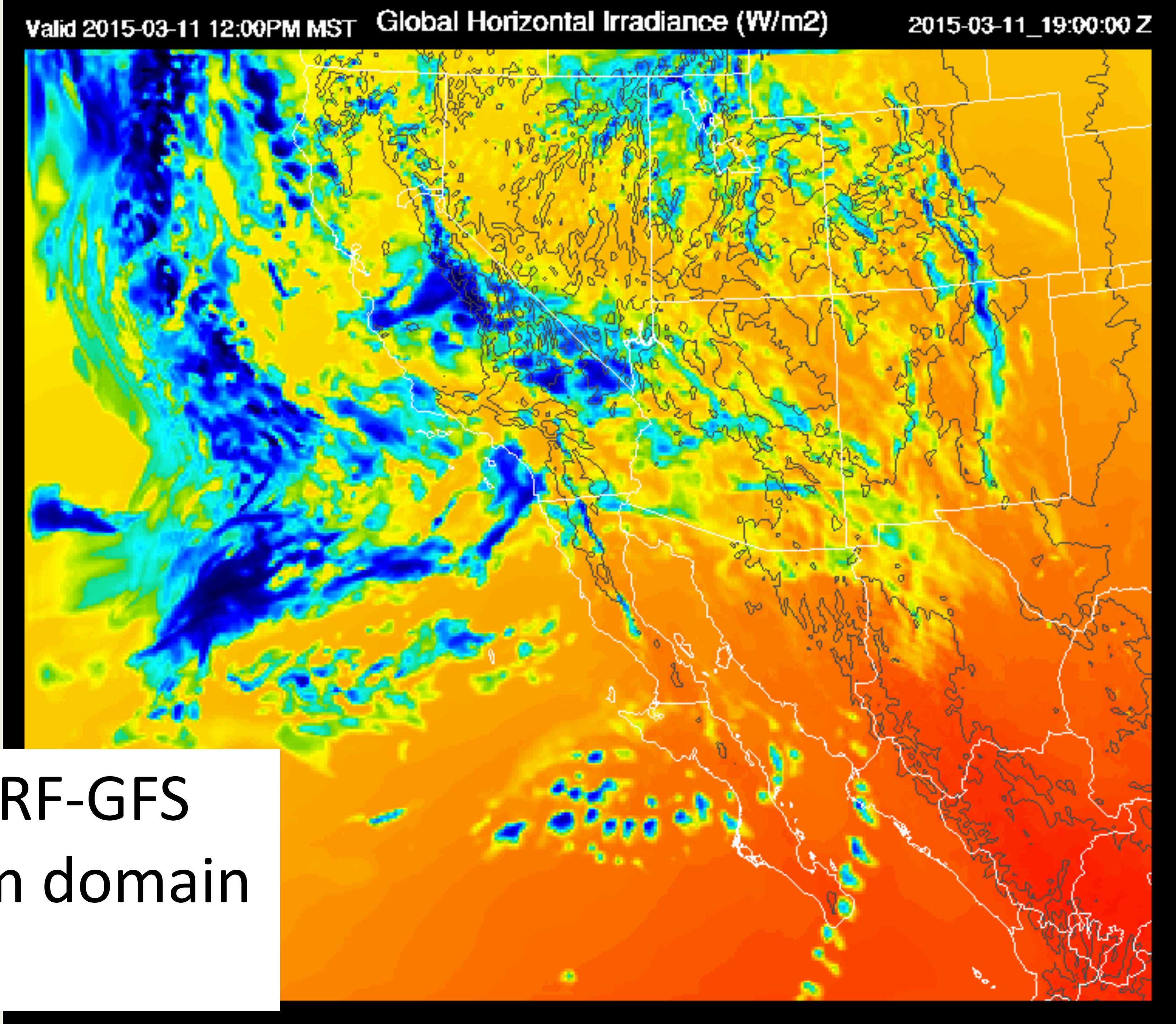
Hourly average wind power vs. hourly average forecast wind speed



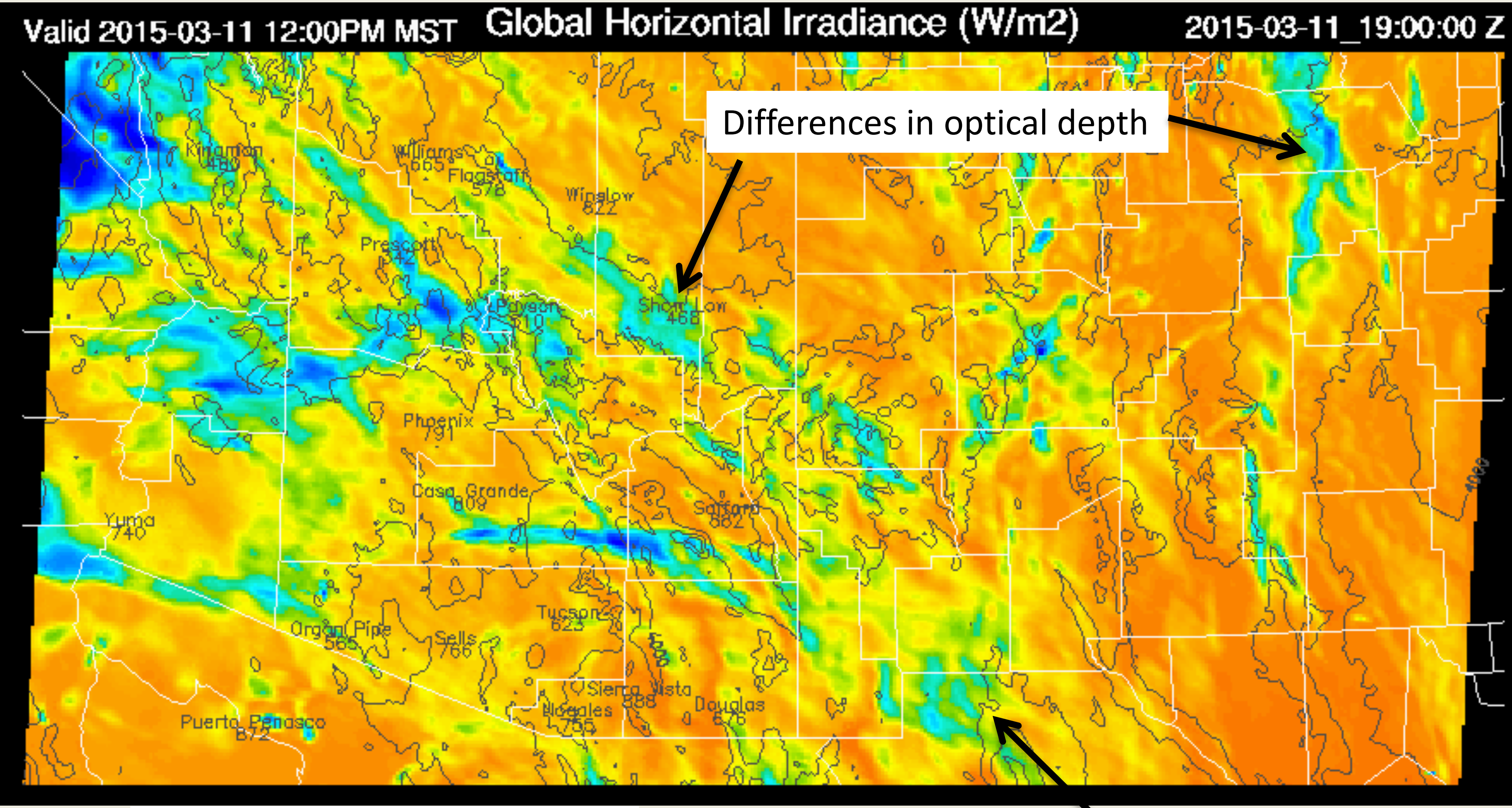

Wind power
fx_power_mae
fx_power_leastsq
fx_power_lmfit
fx_power_byeye
meas
Power (MW)
0
10
20
30
40
50
Forecast wind speed
fx_wind
fx 80 m wind speed (m/s)
0
2
4
6
8
10
12
14
Dec 17 2014
Dec 31 2014
Jan 14 2015
Jan 28 2015
Feb 11 2015
Feb 25 2015

Wind forecasting: UA vs. TEP vendor





UA WRF-GFS
5.4 km domain
GHI



Finer structure

UA WRF-GFS 1.8 km domain GHI

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

PVLIB Python

Tool for modeling solar power systems in a Matlab-like environment

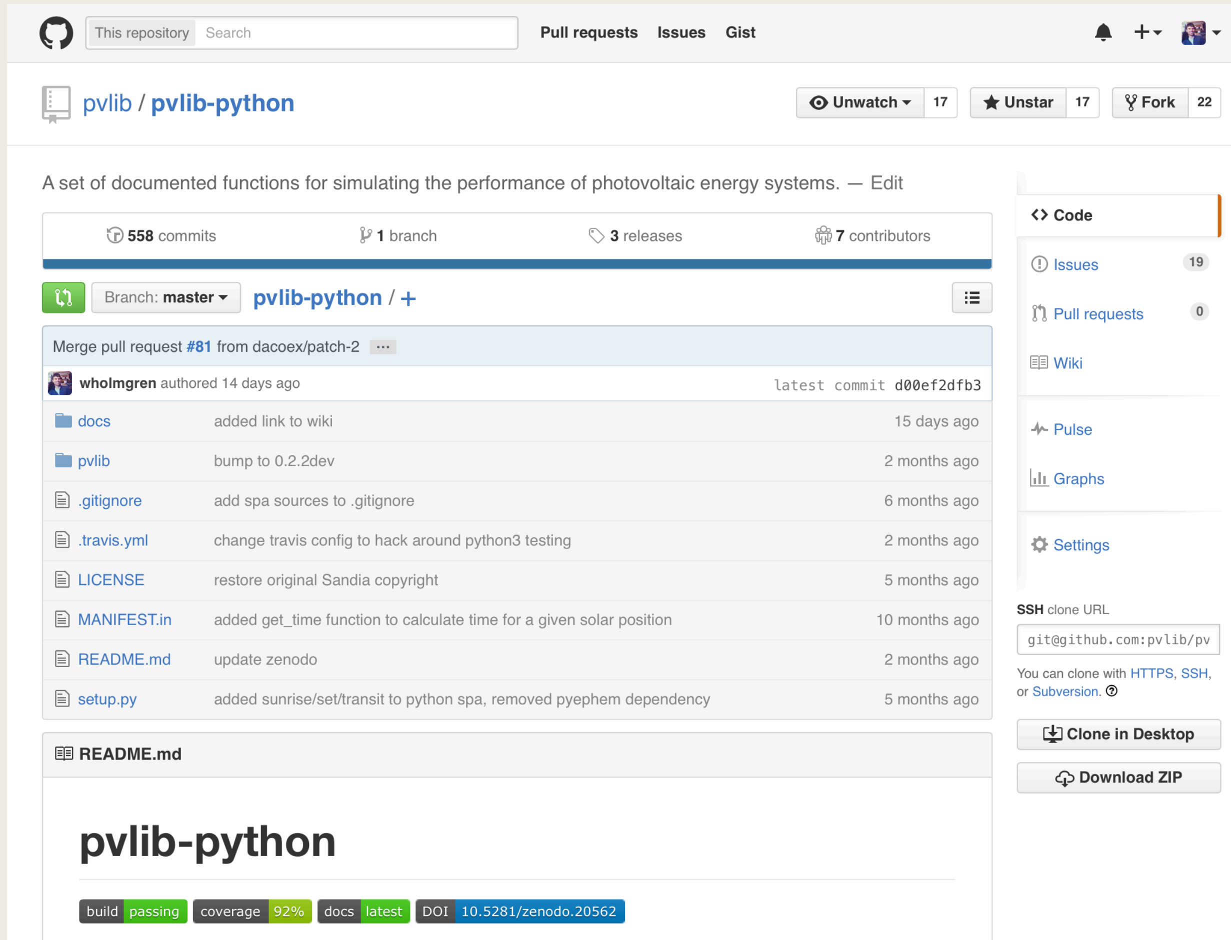
Open source

Descendant of Sandia's PVLIB MATLAB

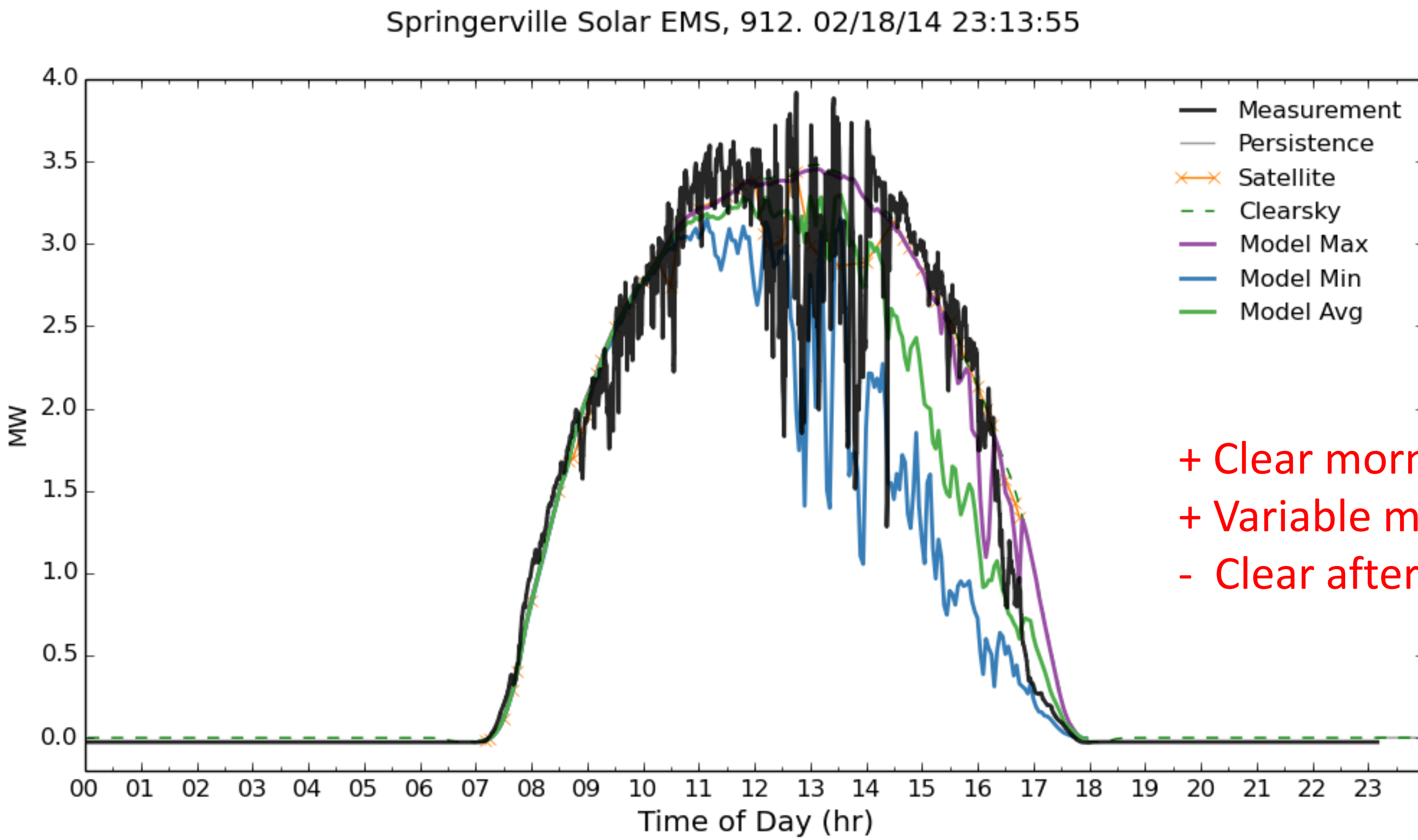
Basis for some of the UA modeling

Solar power forecast module

github.com/pvlib

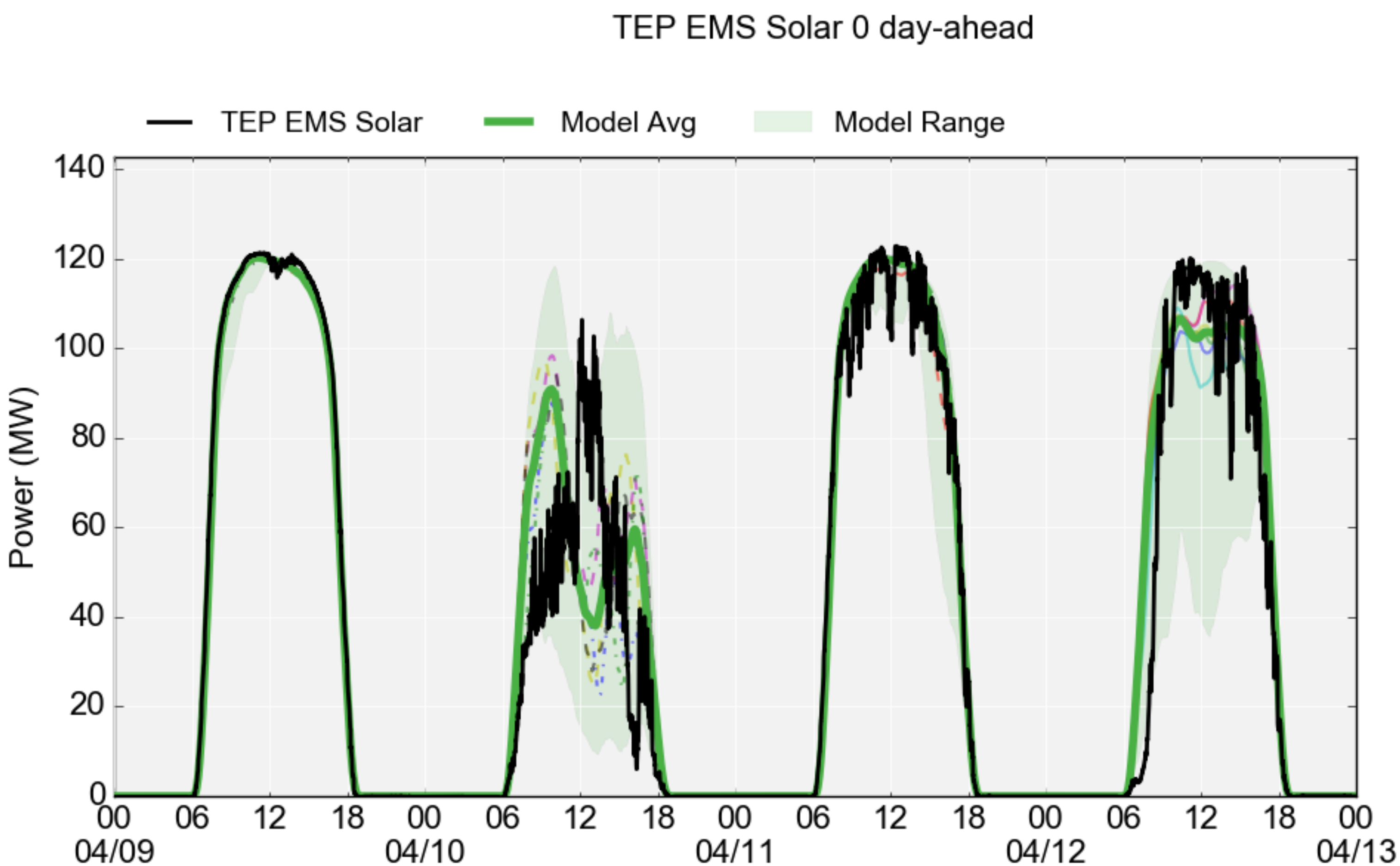


UA-WRF Solar Power Forecast

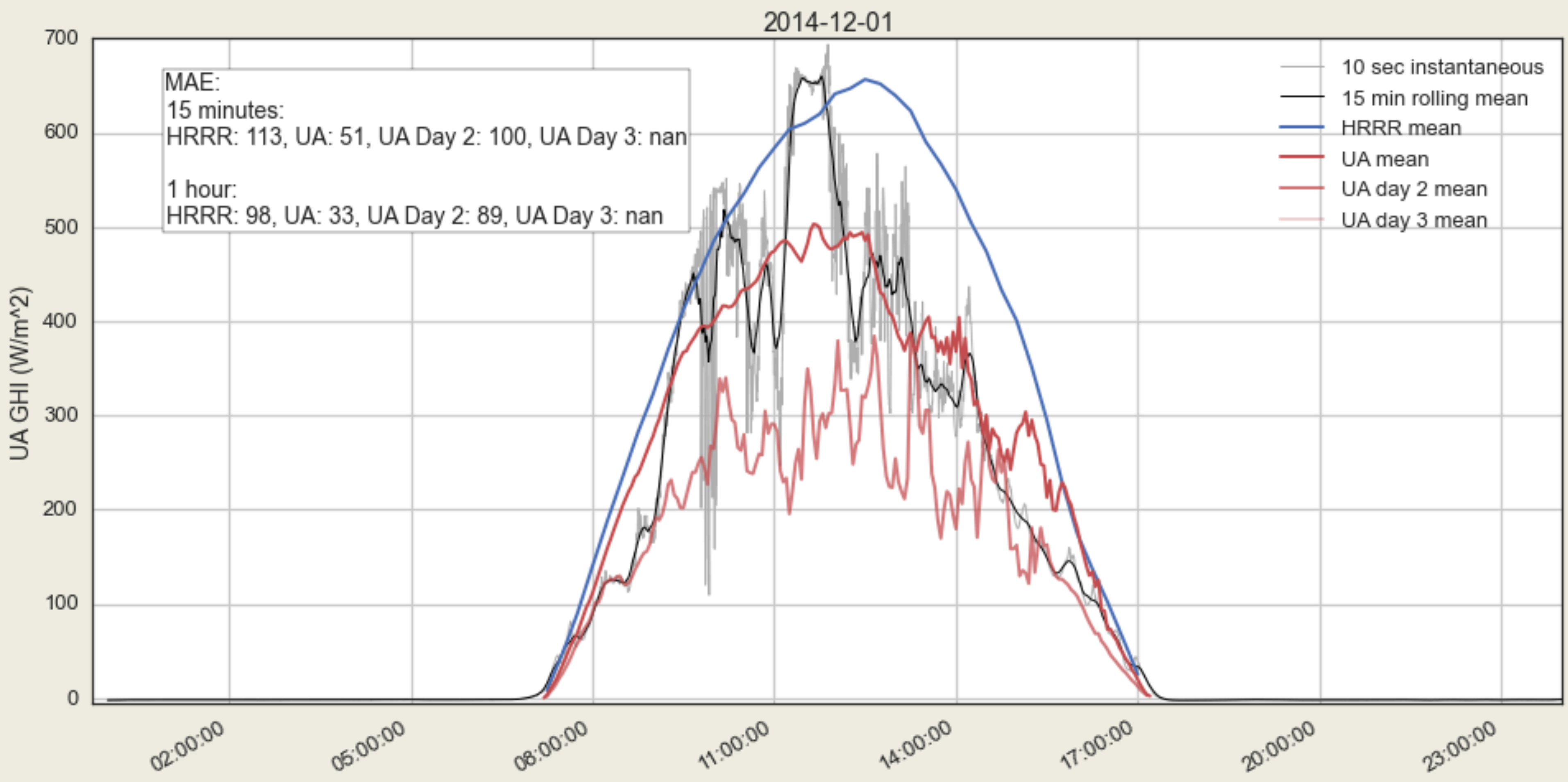


+ Clear morning
+ Variable mid-day
- Clear afternoon

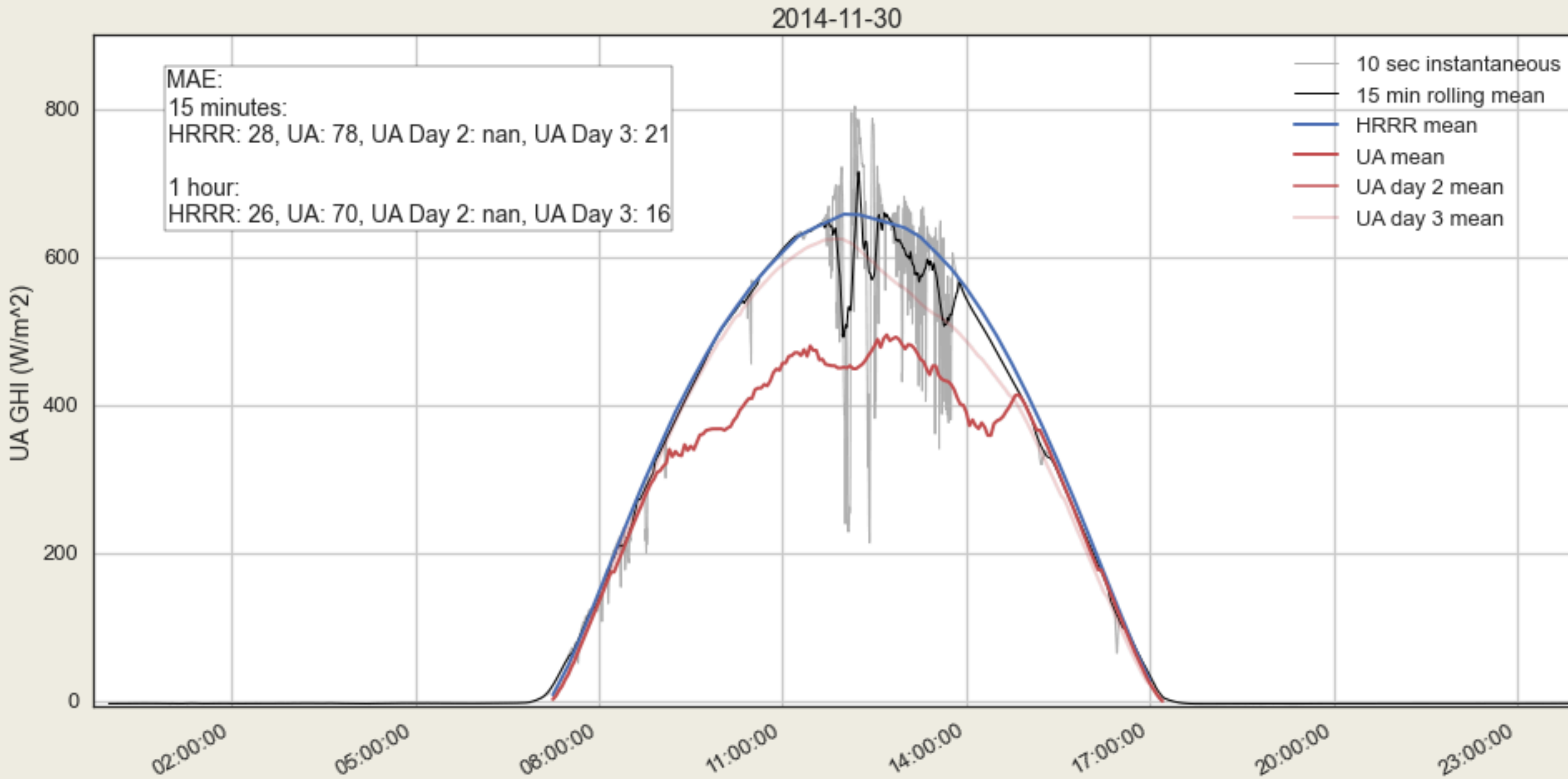
UA-WRF Solar Power Forecast



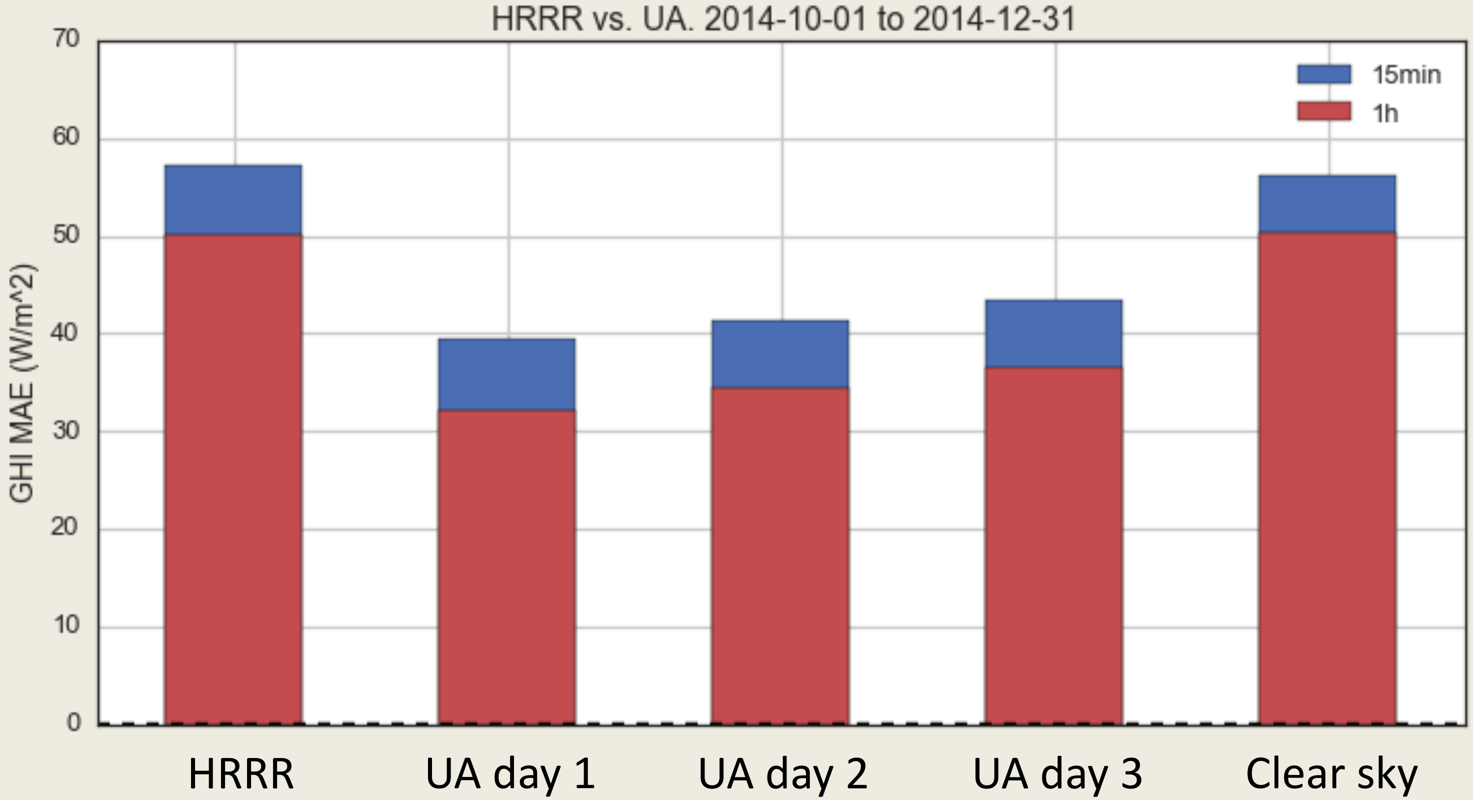
UA-WRF vs. NCEP HRRR Tucson GHI



UA-WRF vs. NCEP HRRR Tucson GHI



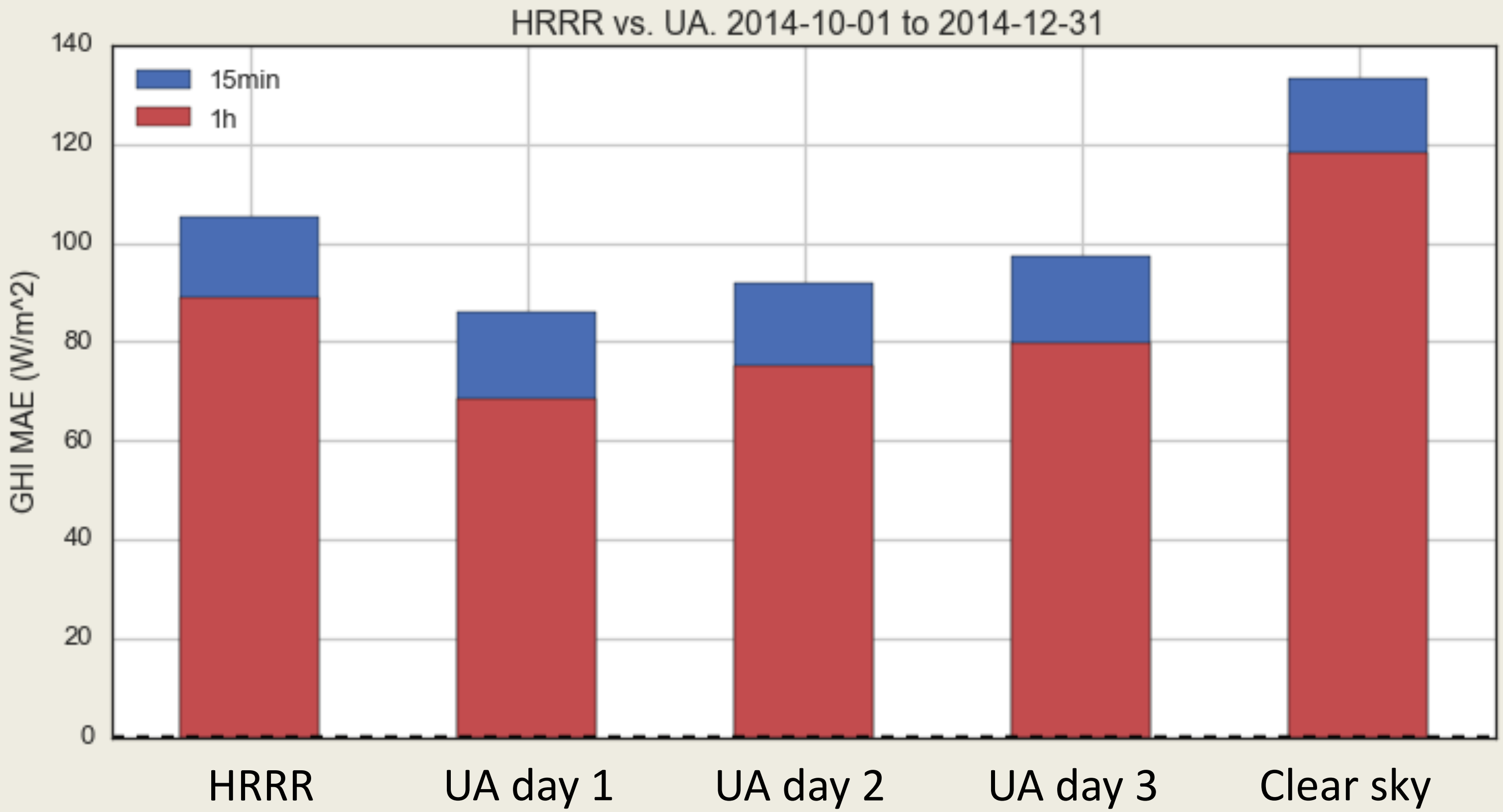
UA-WRF vs. NCEP HRRR Tucson GHI



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

WRF Microphysics

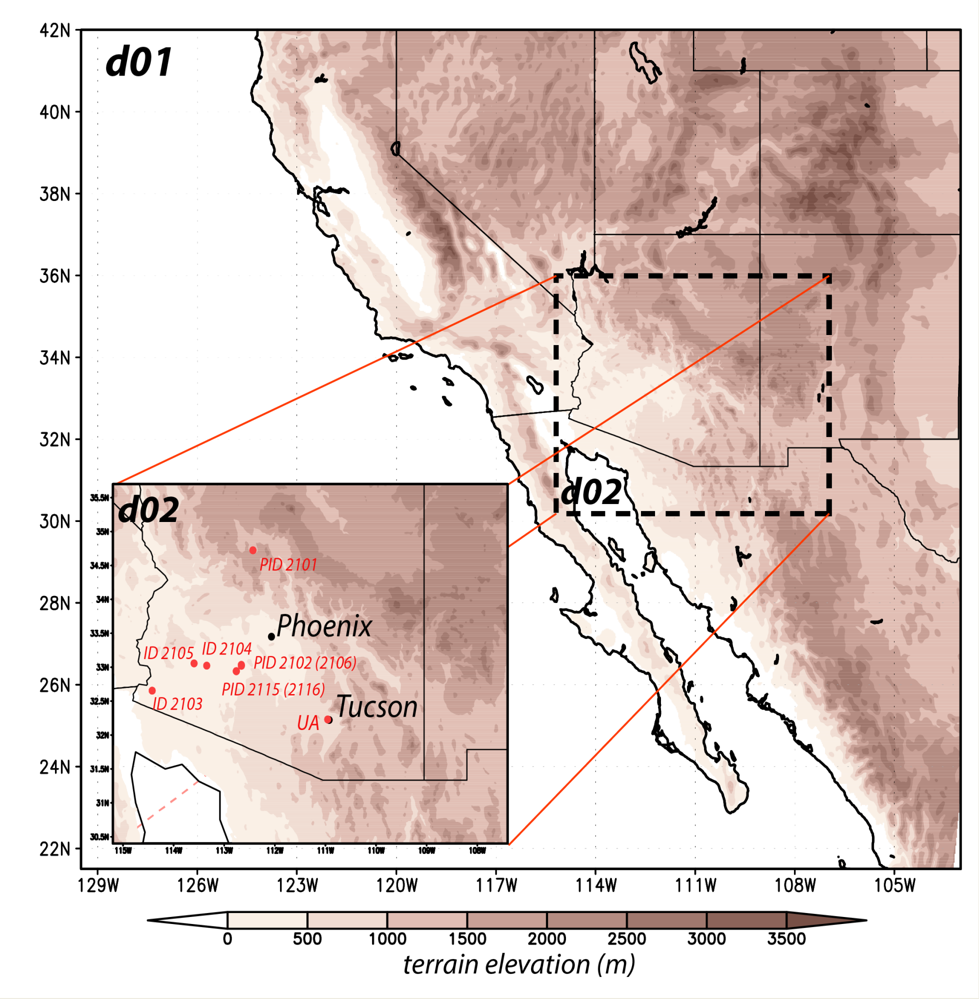
The model **microphysics scheme** governs how water changes from gas to liquid and different solids, so it is essential to cloud and irradiance forecasts.

Most microphysics research focuses on the impacts for e.g. severe storm or snow forecasts, not much concern for irradiance. Best parameterization may also depend on regional climate.

New UA study:

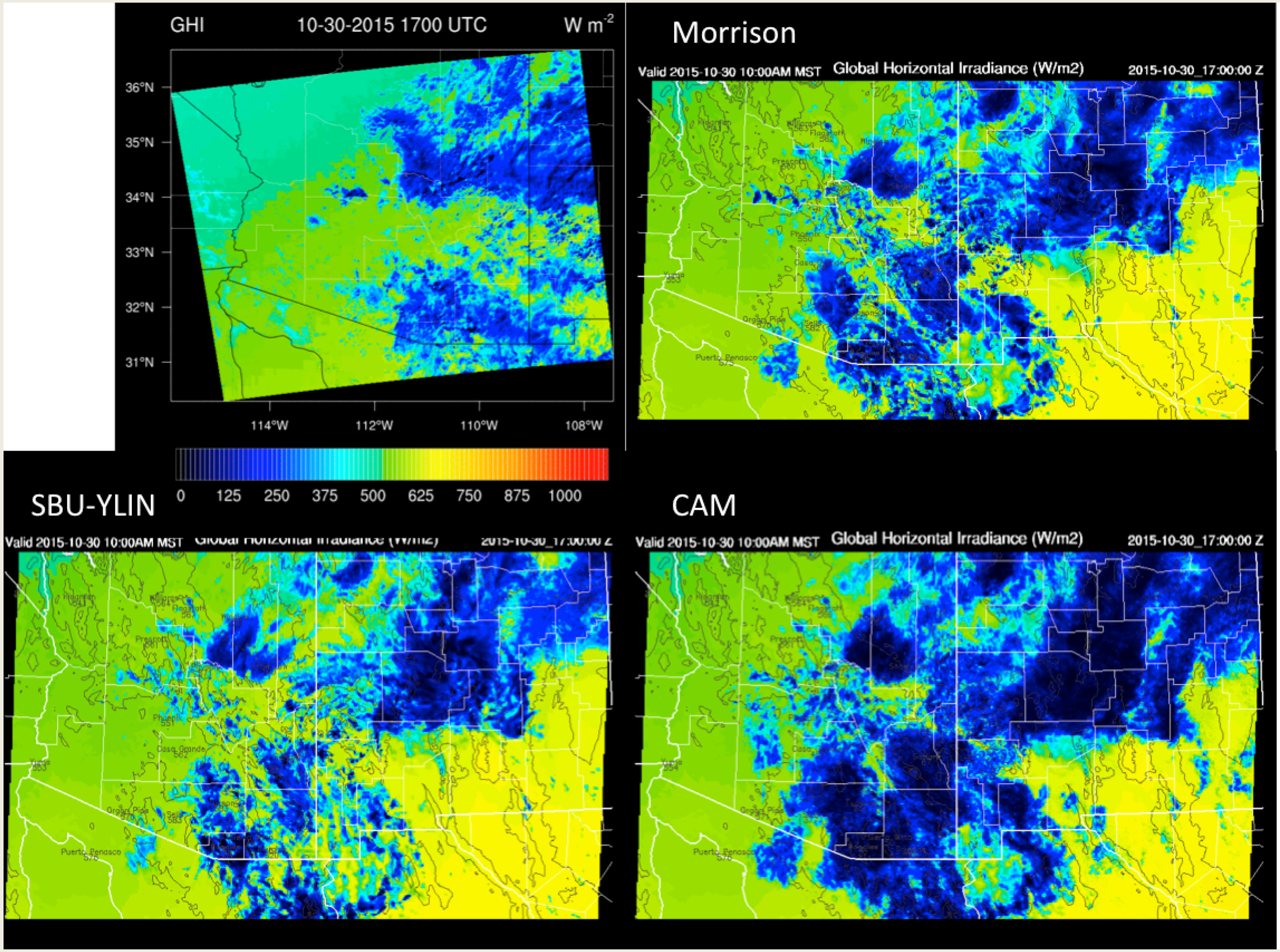
Reevaluate the microphysics parameterizations for solar irradiance forecasting in AZ.

Use UA and APS AZ Sun irradiance sensors.



WRF Microphysics

None of the models look exactly like reality, but the range in models can be useful.



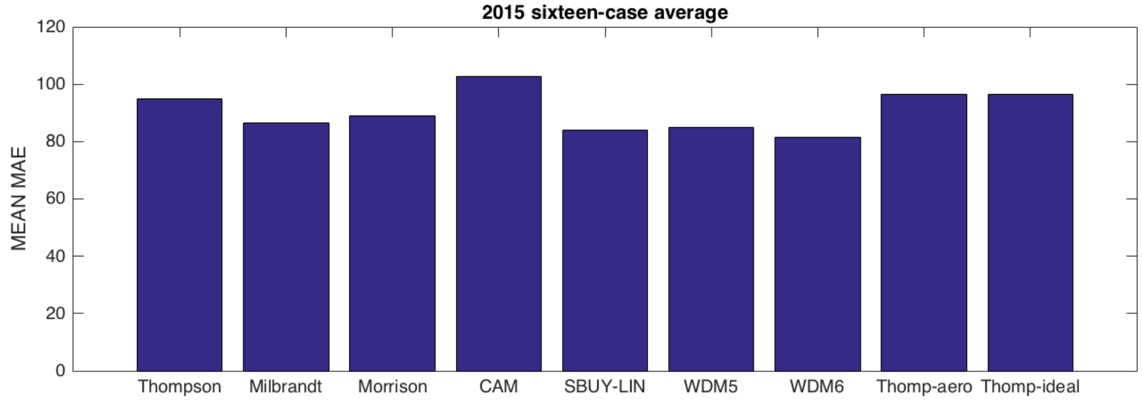
WRF Microphysics

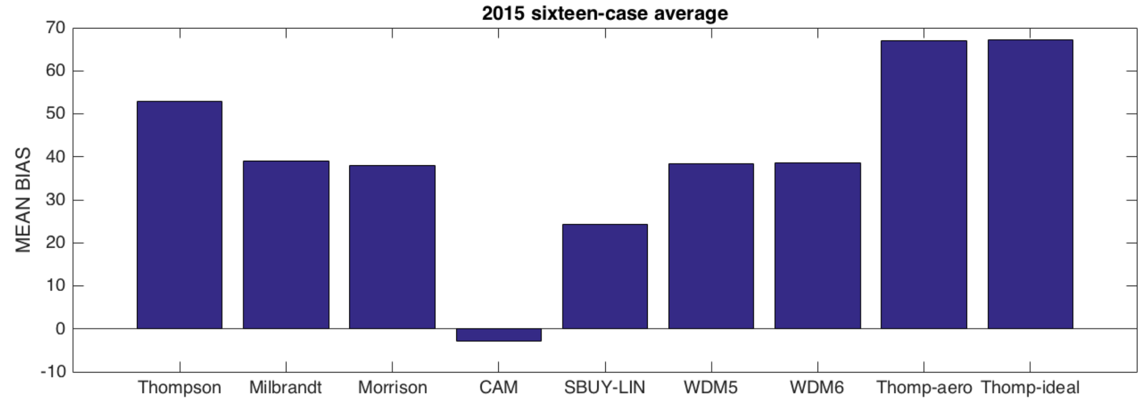
Conclusions:

Not much difference between existing schemes.

Clouds are hard.

The new “WRF-Solar” microphysics scheme is worse than most (in AZ)!





Forecast Email Discussions

[atmo-uwrf] Utility Discussion 20150812 — Inbox

Mike Leuthold August 12, 2015 at 9:21 AM

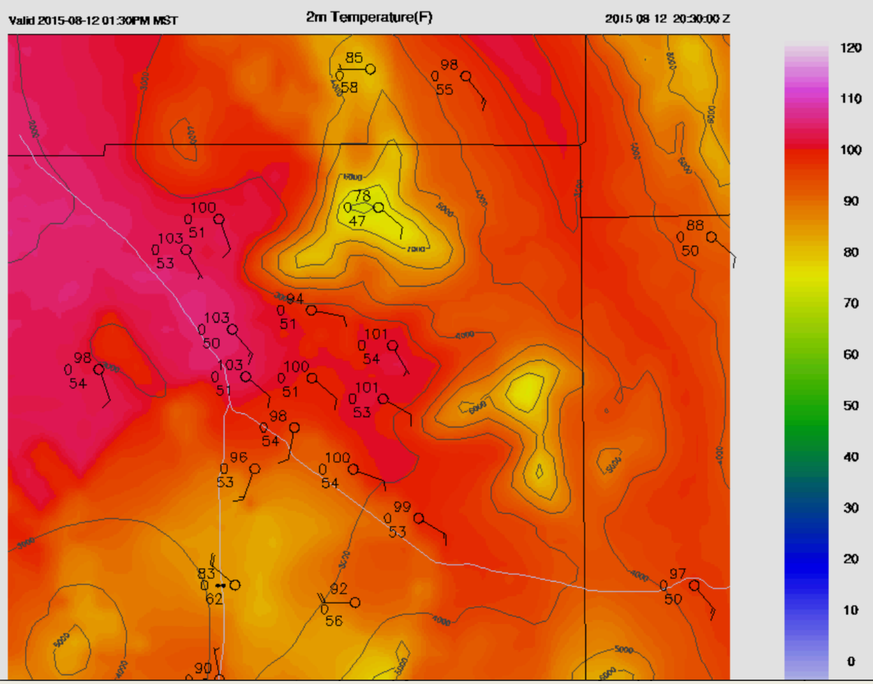
To: uwrf@atmo.arizona.edu

Reply-To: Mike Leuthold

[atmo-uwrf] Utility Discussion 20150812

I made a terrible forecast by not calling for late afternoon/evening redevelopment. Most of the models were correct and I went against them and paid the price and I apologize for the mistake. My excuse is that I did not follow my typical morning routine of checking the weather details because of the ongoing storms. You can see the detailed postmortem in the WRF discussion.

As I was concerned about yesterday, the model runs were too aggressive with moving in the dry air from the east. Also, it's mostly clear so there is good heating so I now expect more activity than was previously forecast. However, the dividing line is very close to both Tucson and Phoenix so it's a tough call. My guess is storms forming during the afternoon, 2-3pm, just south through west of the Tucson area and mostly staying out of the valley proper.



[atmo-wrf] Arizona Regional WRF Discussion 20150812 — Inbox

Mike Leuthold August 12, 2015 at 9:04 AM

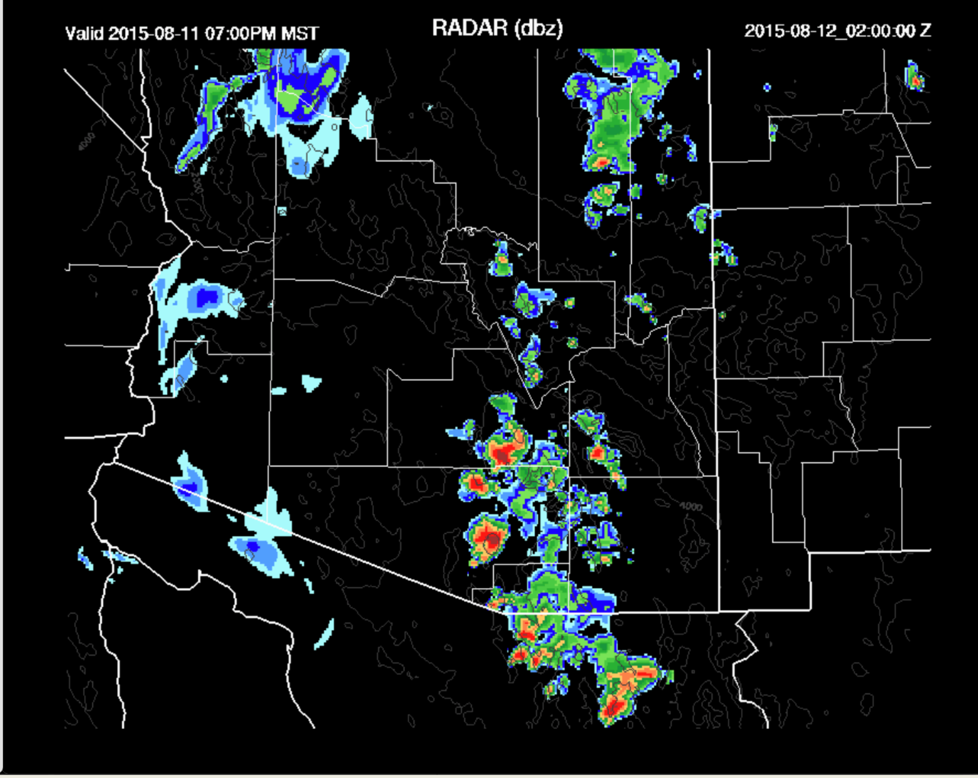
To: wrf@atmo.arizona.edu

Reply-To: Mike Leuthold

[atmo-wrf] Arizona Regional WRF Discussion 20150812

Previous Day

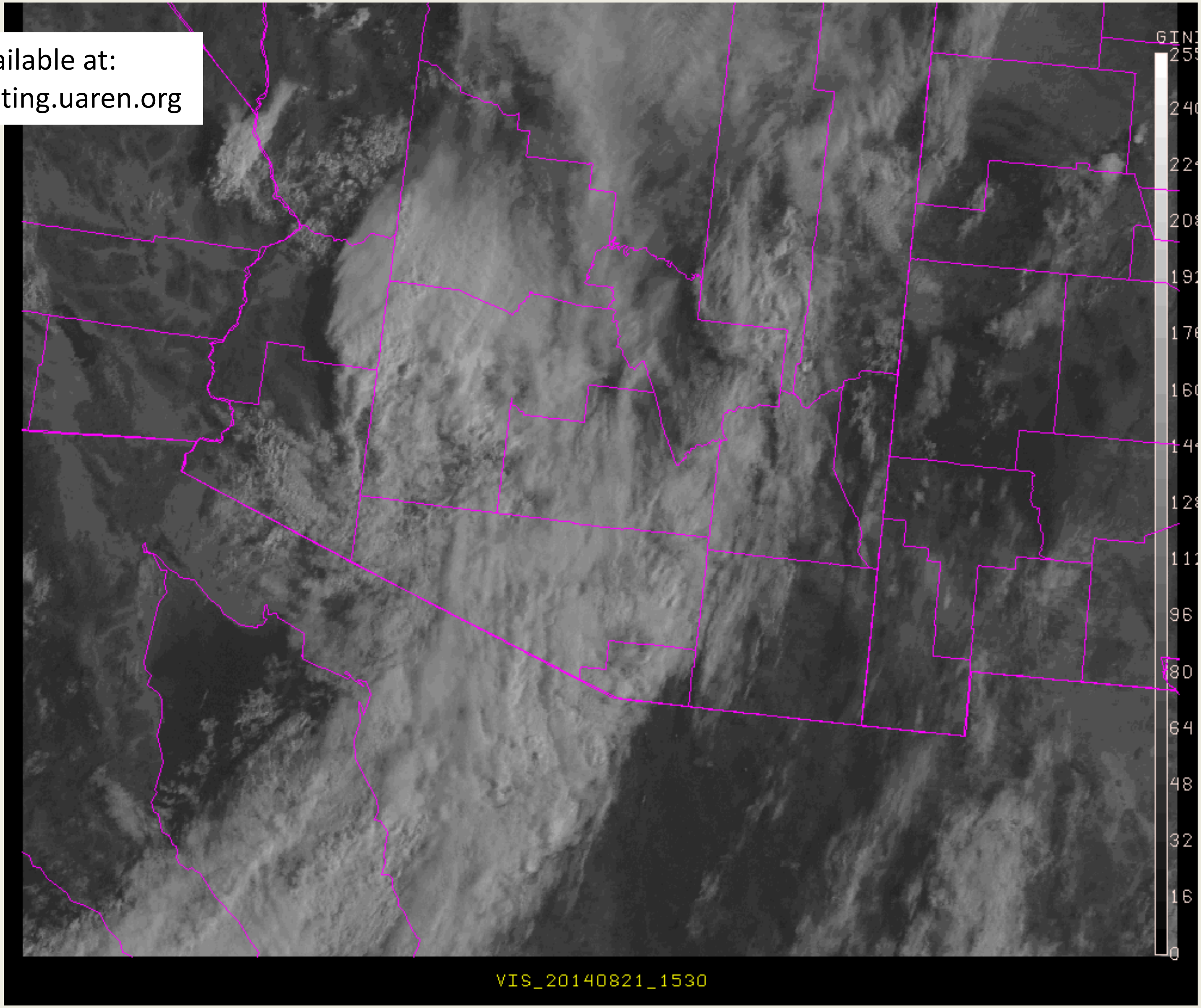
Not a good day for the human (me) but an excellent day for the model. I really didn't think the atmosphere would recover enough in the lower deserts between Tucson and Phoenix for a second round during the evening. That was not the case as 0z MLCAPE at Tucson was 1500 J/Kg with great mid level steering of 30 knots between 700 and 500mb. Another excuse is that I was preoccupied with the morning activity and skipped my usual process thus missing the obvious inverted trough which moved into the southern part of the state during the afternoon which helped organize the storms. The 15Z WRFRR which I typically run later in the morning was especially good as it developed strong storms around Tucson from 5-7pm and moved them rapidly to the northwest into Pinal and Maricopa counties. The 12Z WRFRR was similar. The 12Z WRFGFS also had a lot of activity around the Tucson area up towards Phoenix during the evening.



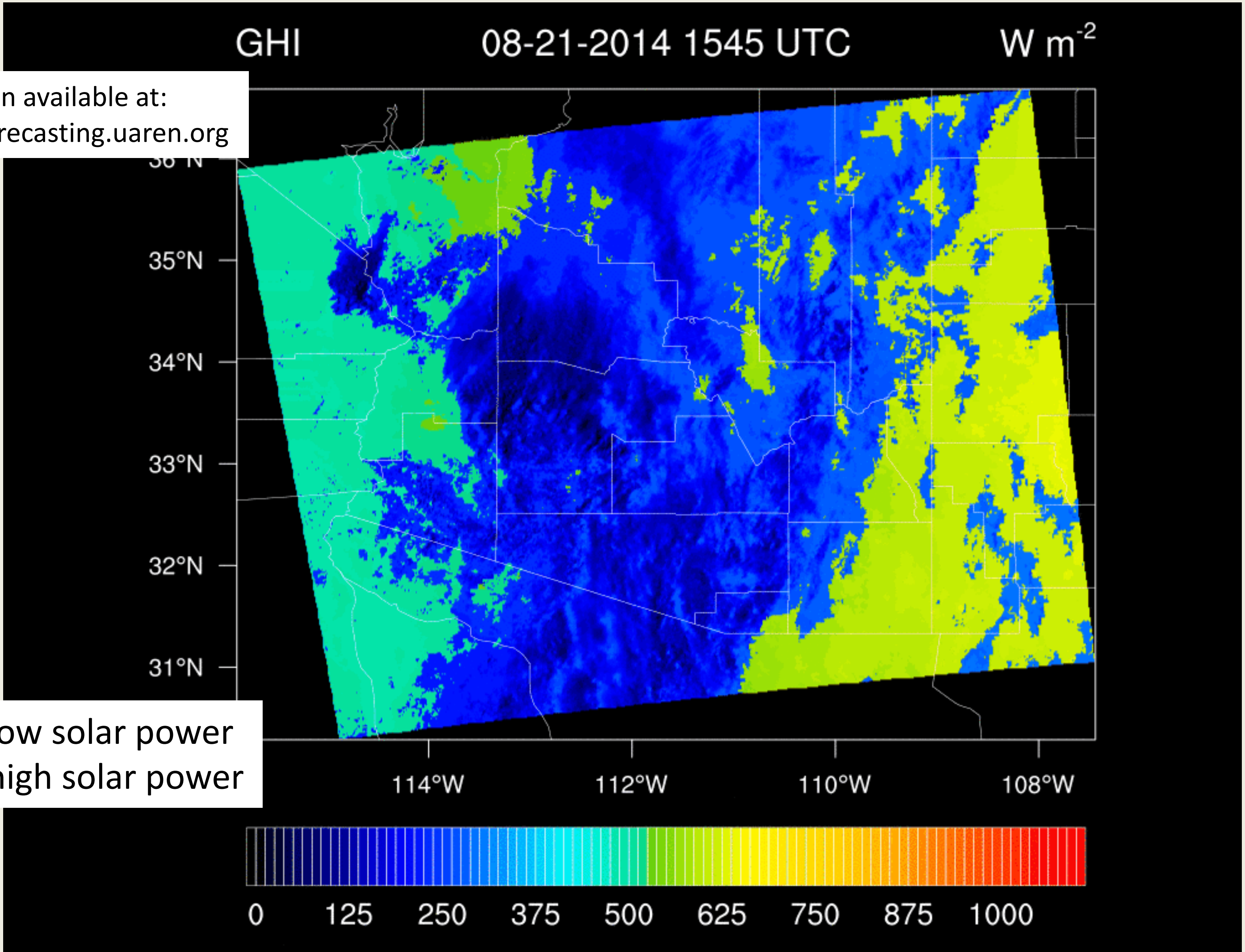
Satellite Imagery

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

GOES
1 km visible



Satellite Derived Solar Irradiance

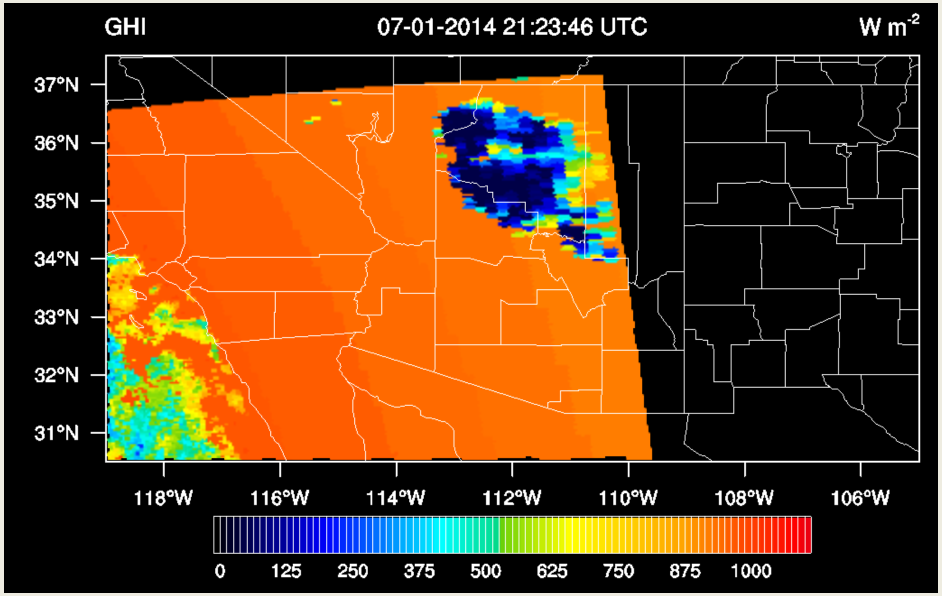


Animation available at:
http://forecasting.uaren.org

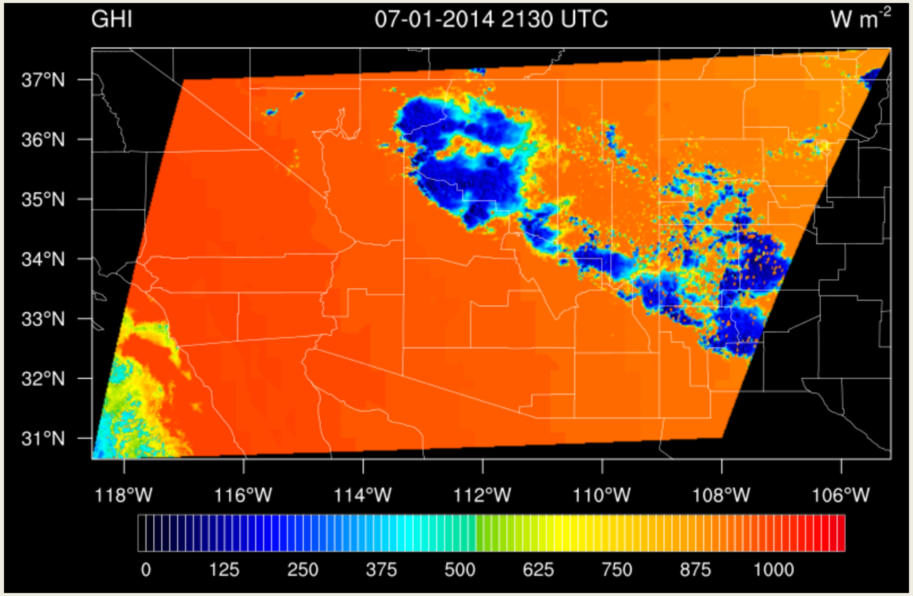
Blue: low solar power
Red: high solar power

Satellite Derived Solar Irradiance

MODIS onboard Aqua

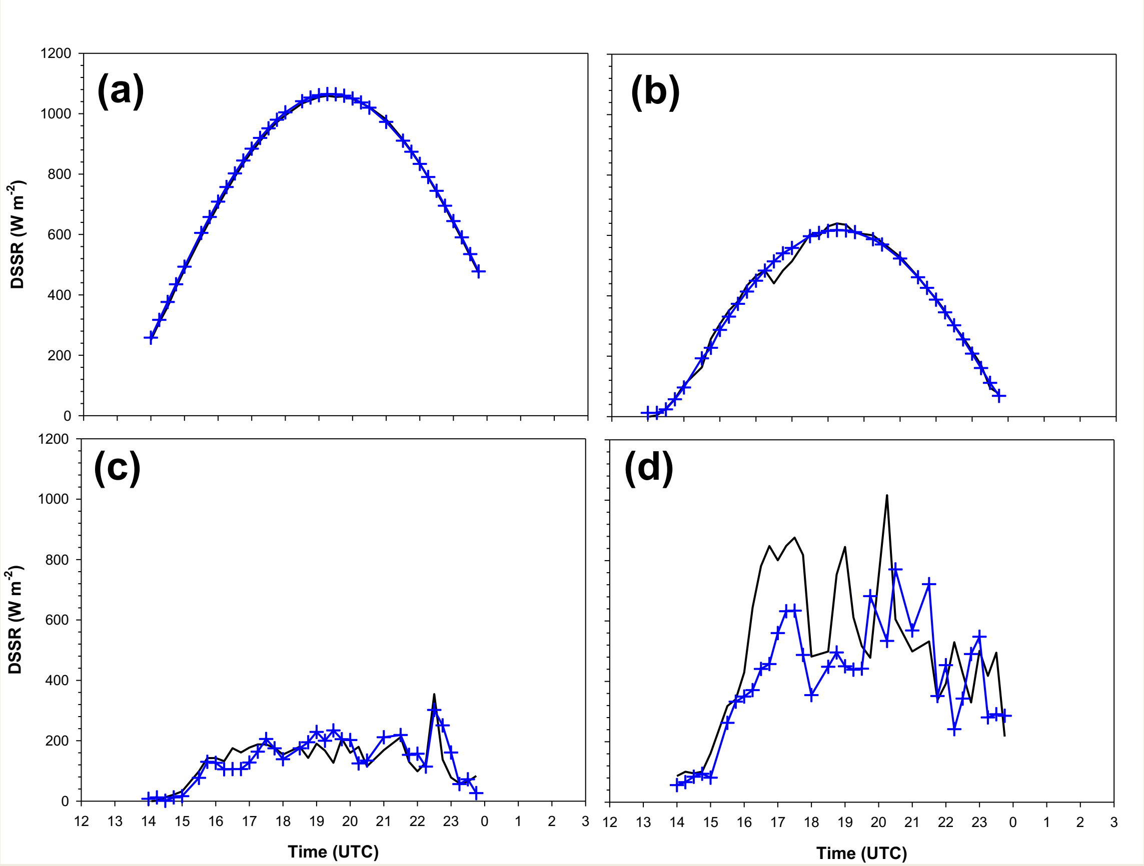


UASIBS



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

Satellite Derived Solar Irradiance

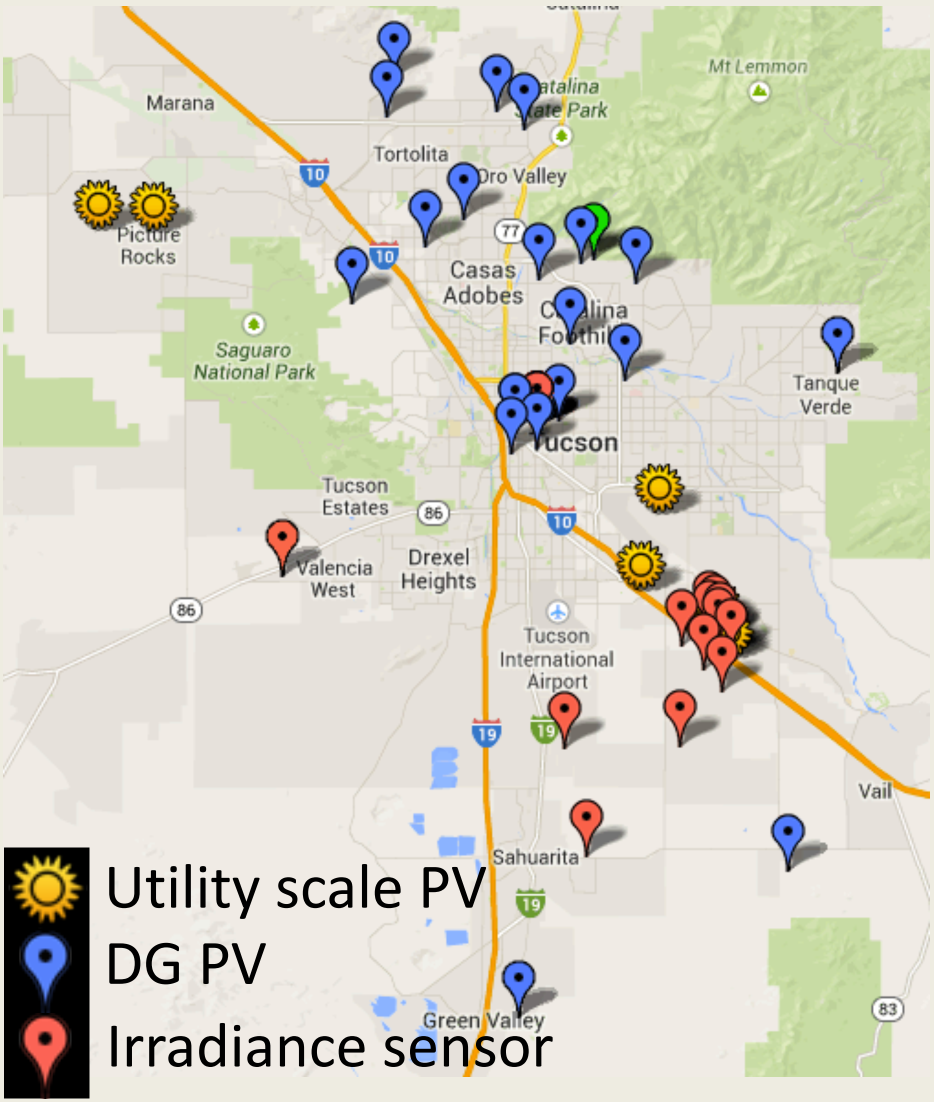


Clear sky conditions

Cloudy sky conditions

- Forecasts made by advecting clouds using wind speeds from WRF model (easy, ok accuracy)
- Image to image changes can also been used (hard to do well, potentially more accurate)

Sensor network forecast



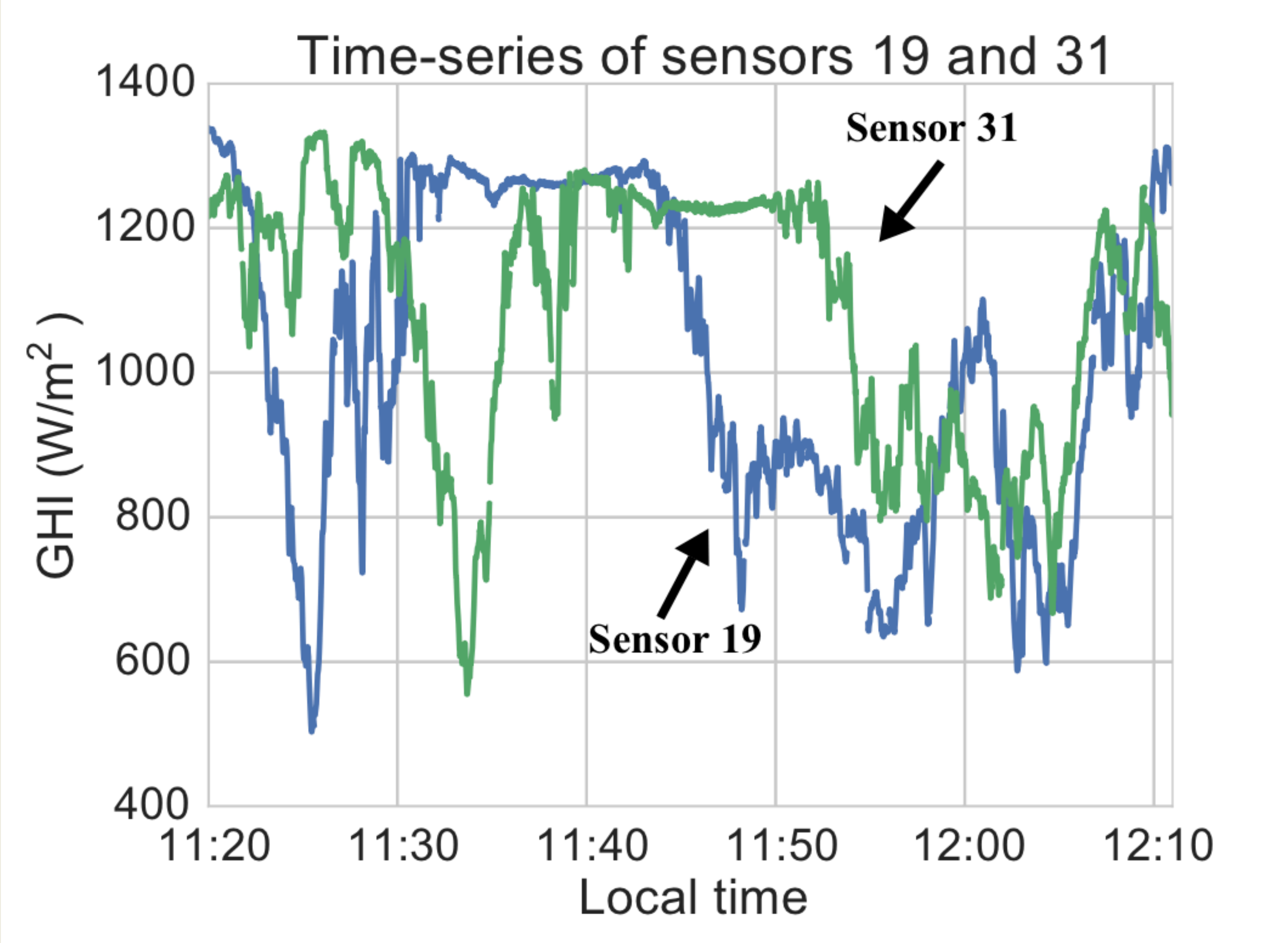
Partnered with local PV installer Technicians for Sustainability to obtain access to real-time (5 min latency) data feeds from residential PV systems.

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

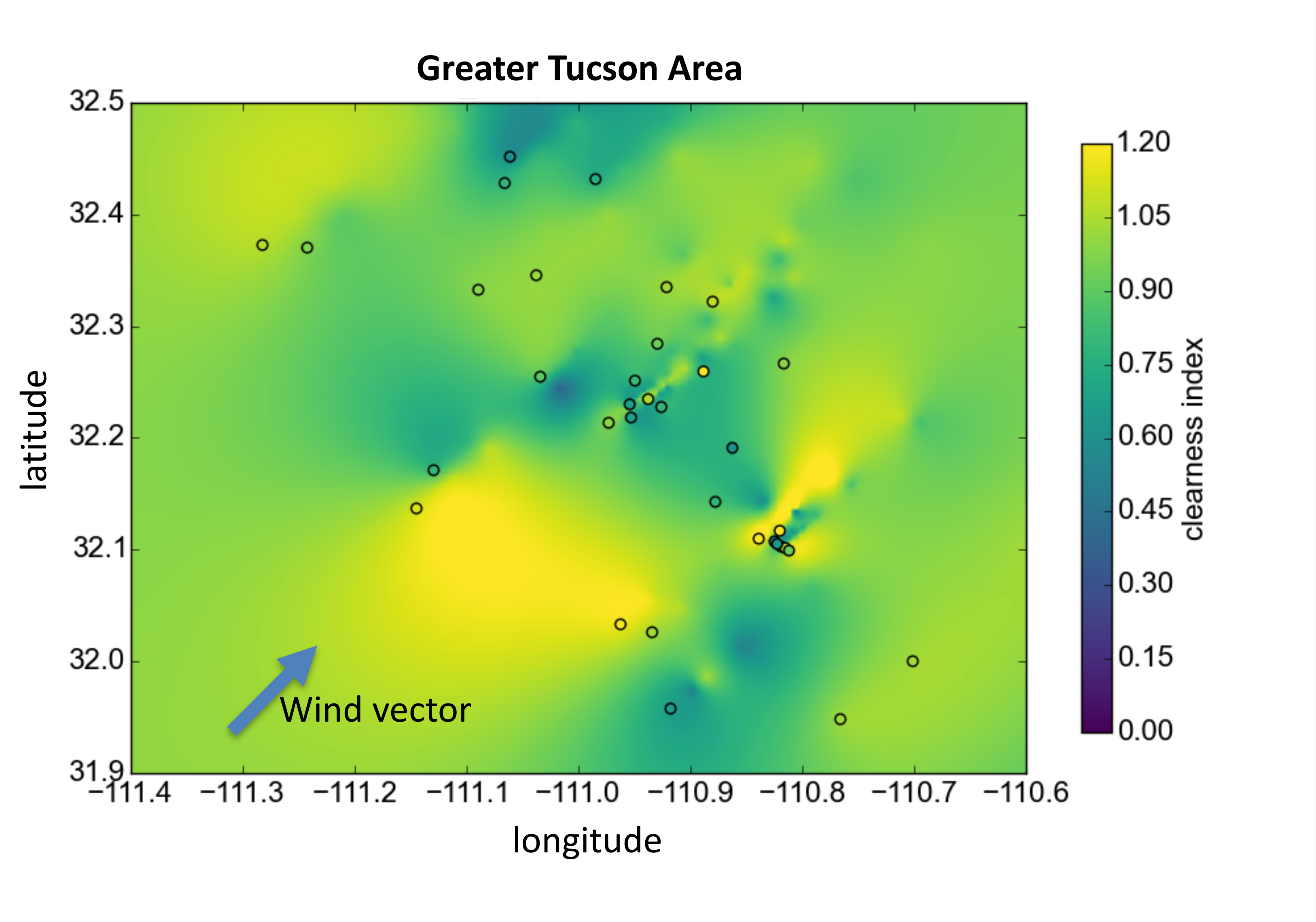
Next step: obtain real-time data from TEP and APS owned distributed generation.

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

Sensor network forecast

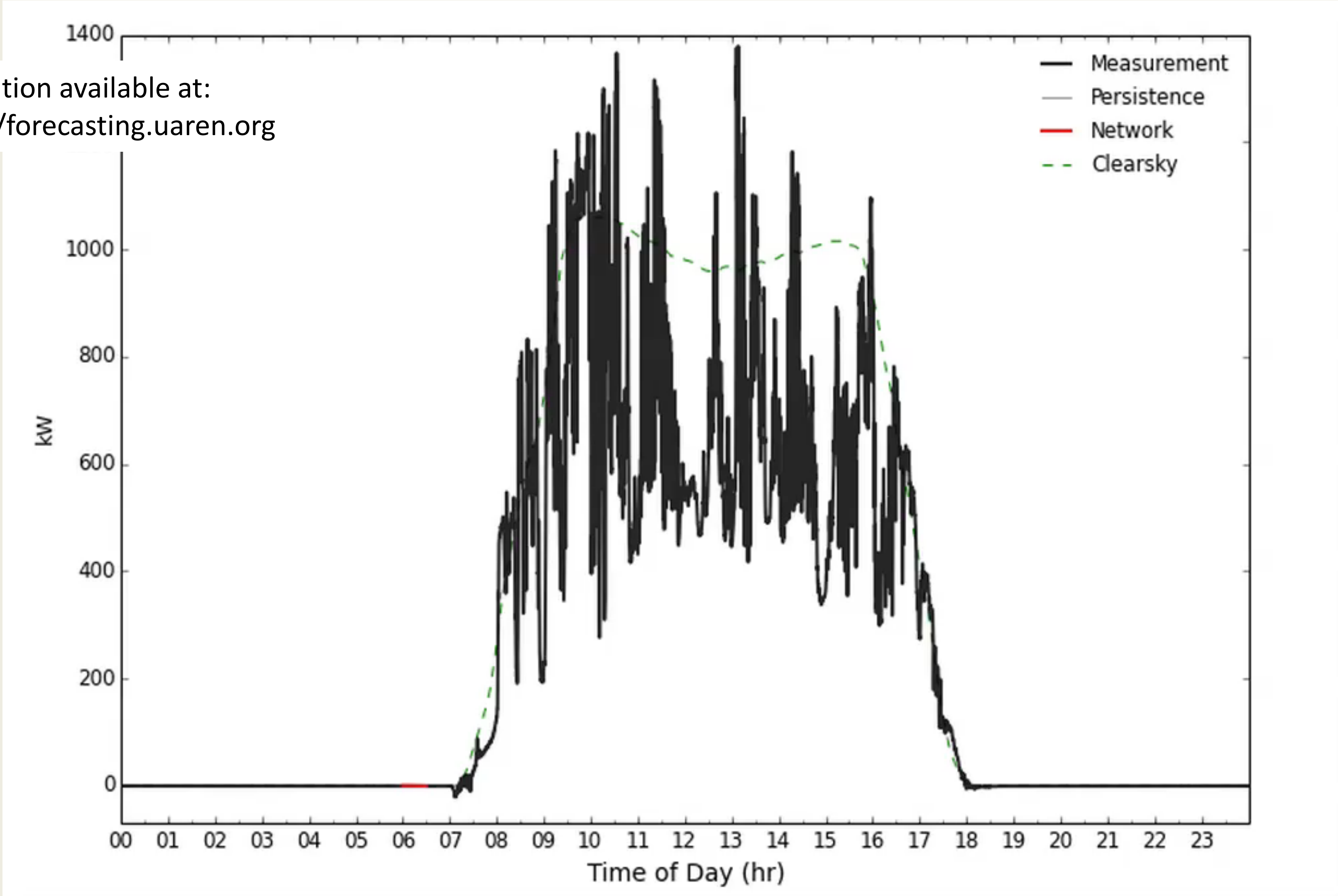


Sensor network interpolation

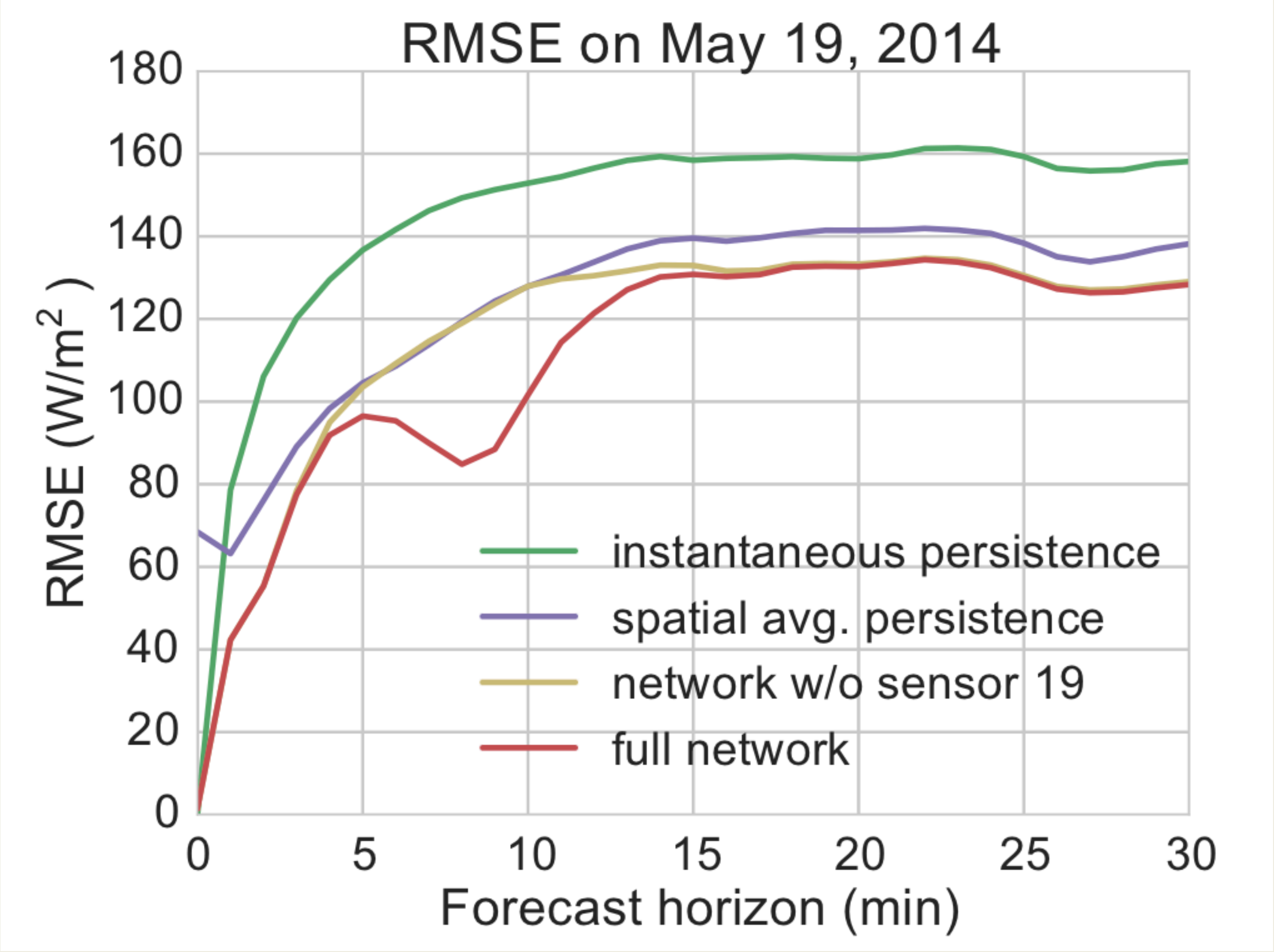


Sensor network forecast

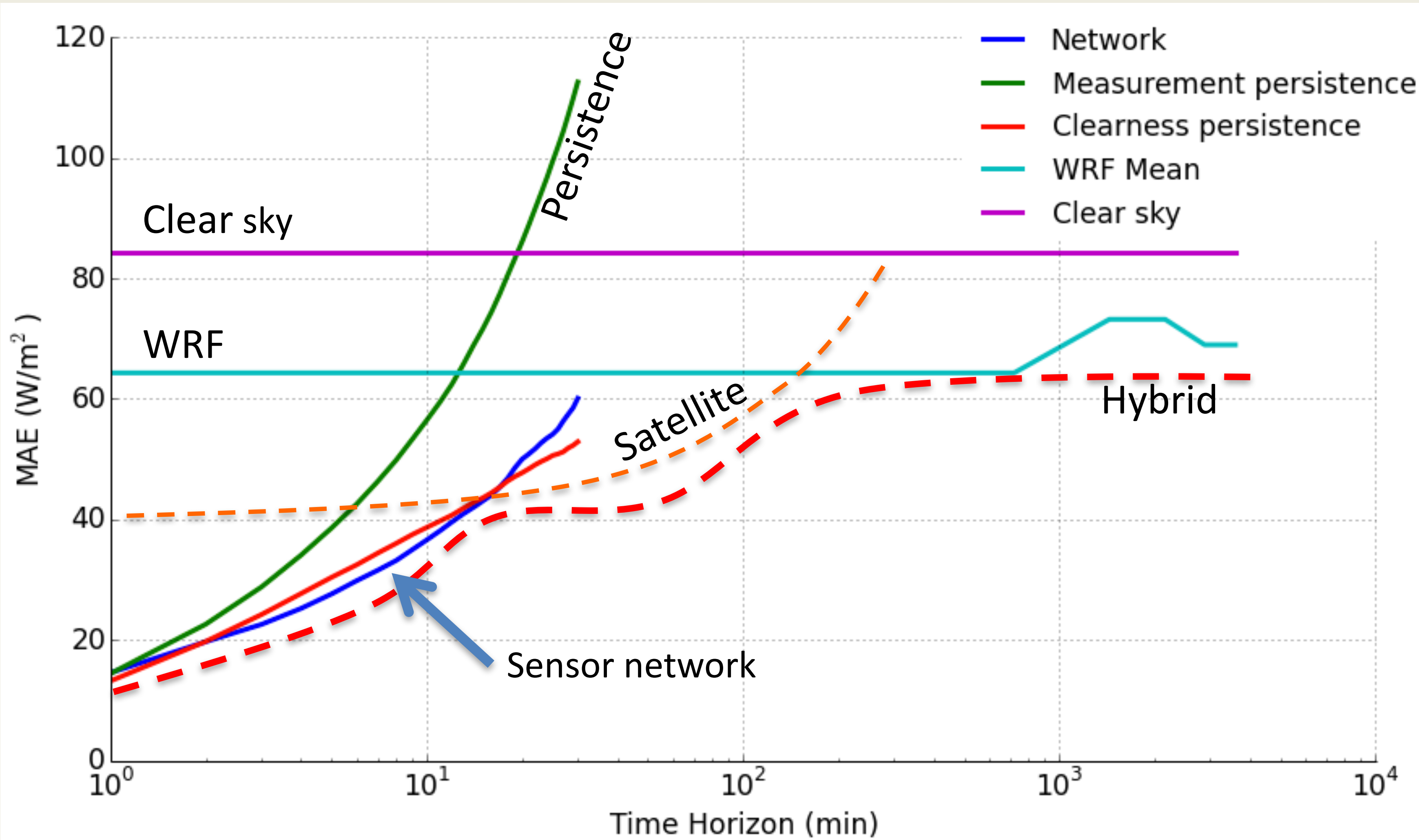
Animation available at:
http://forecasting.uaren.org



Sensor network error statistics



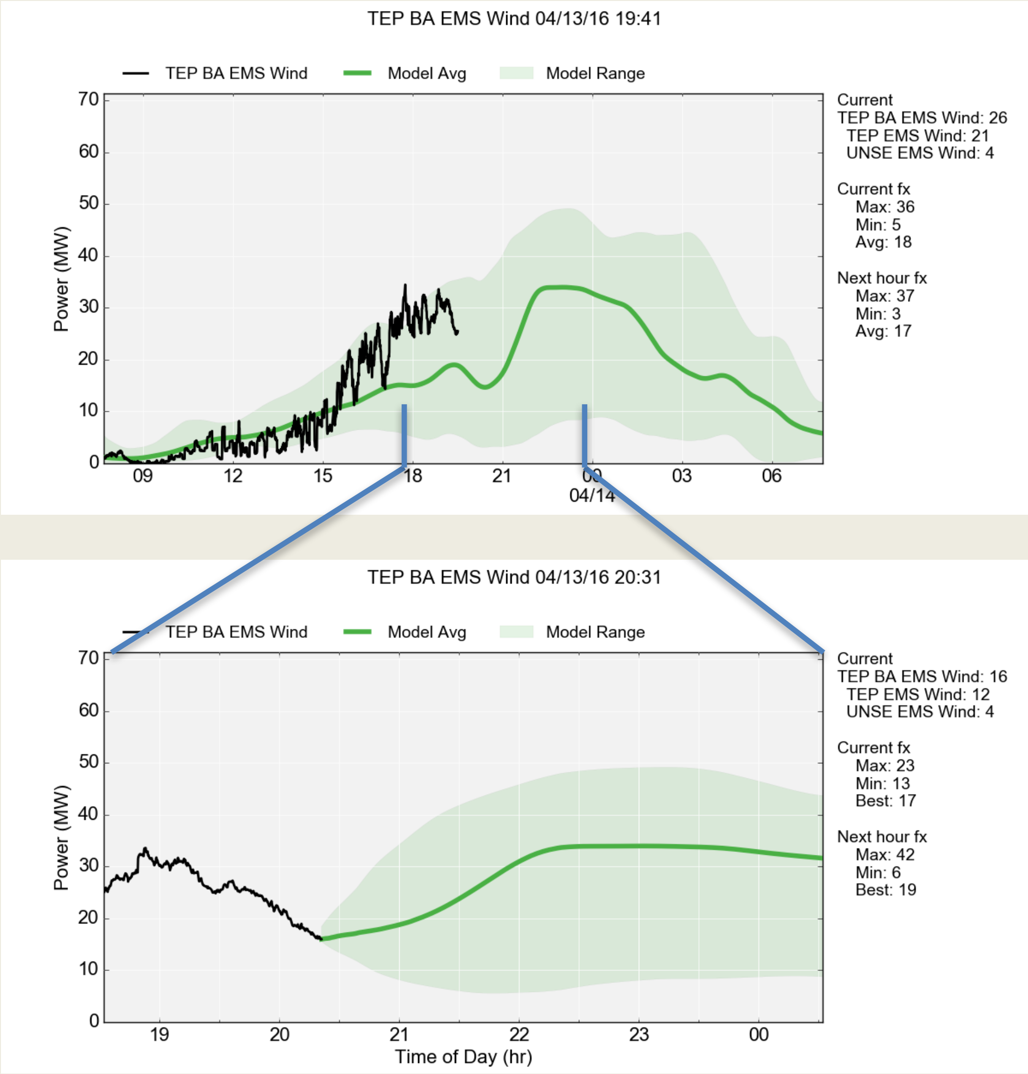
UA forecasting summary



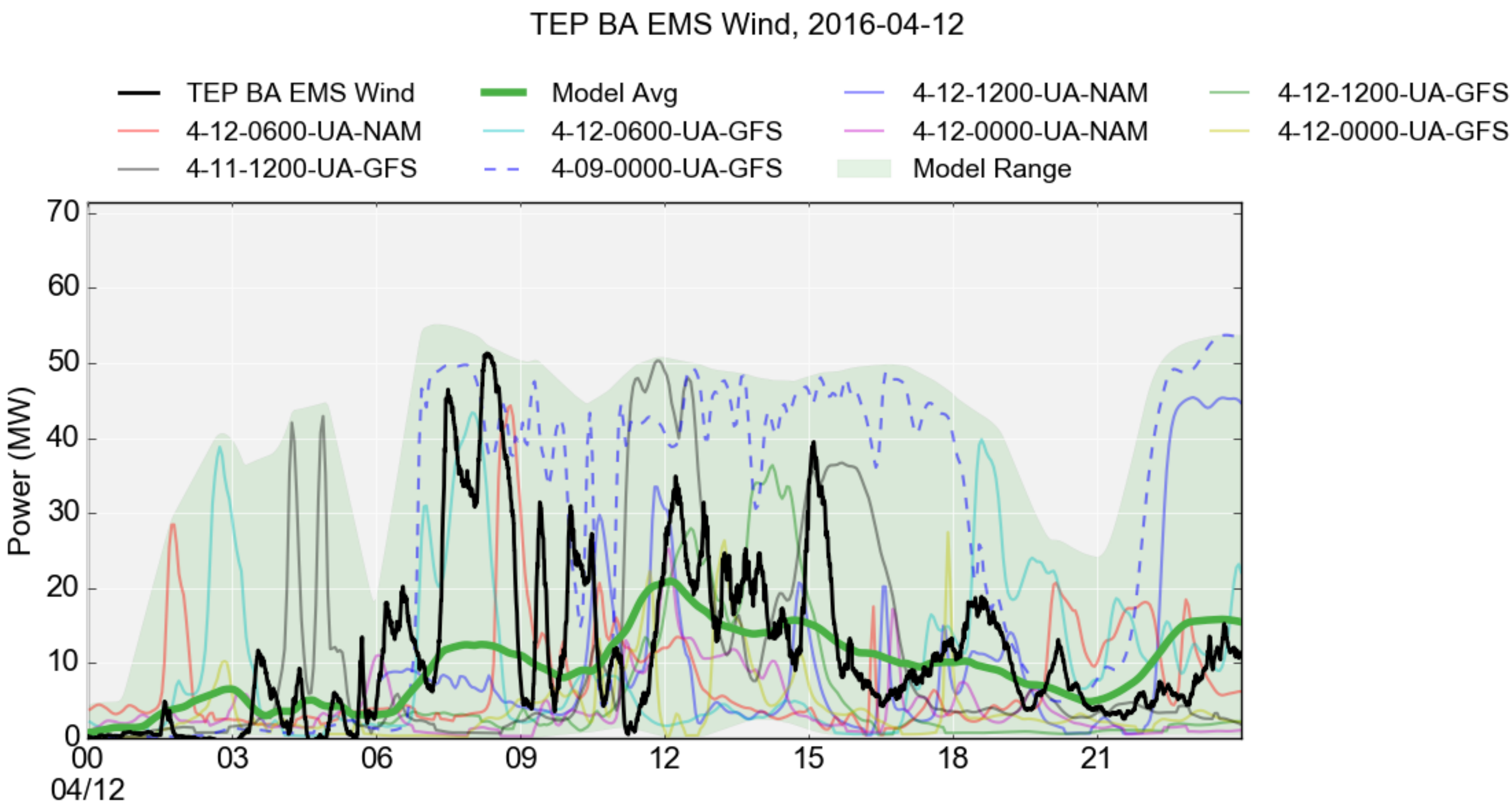
What about combining some or all of this data?

Short term forecast blending

Blending persistence and WRF forecast products into a single forecast

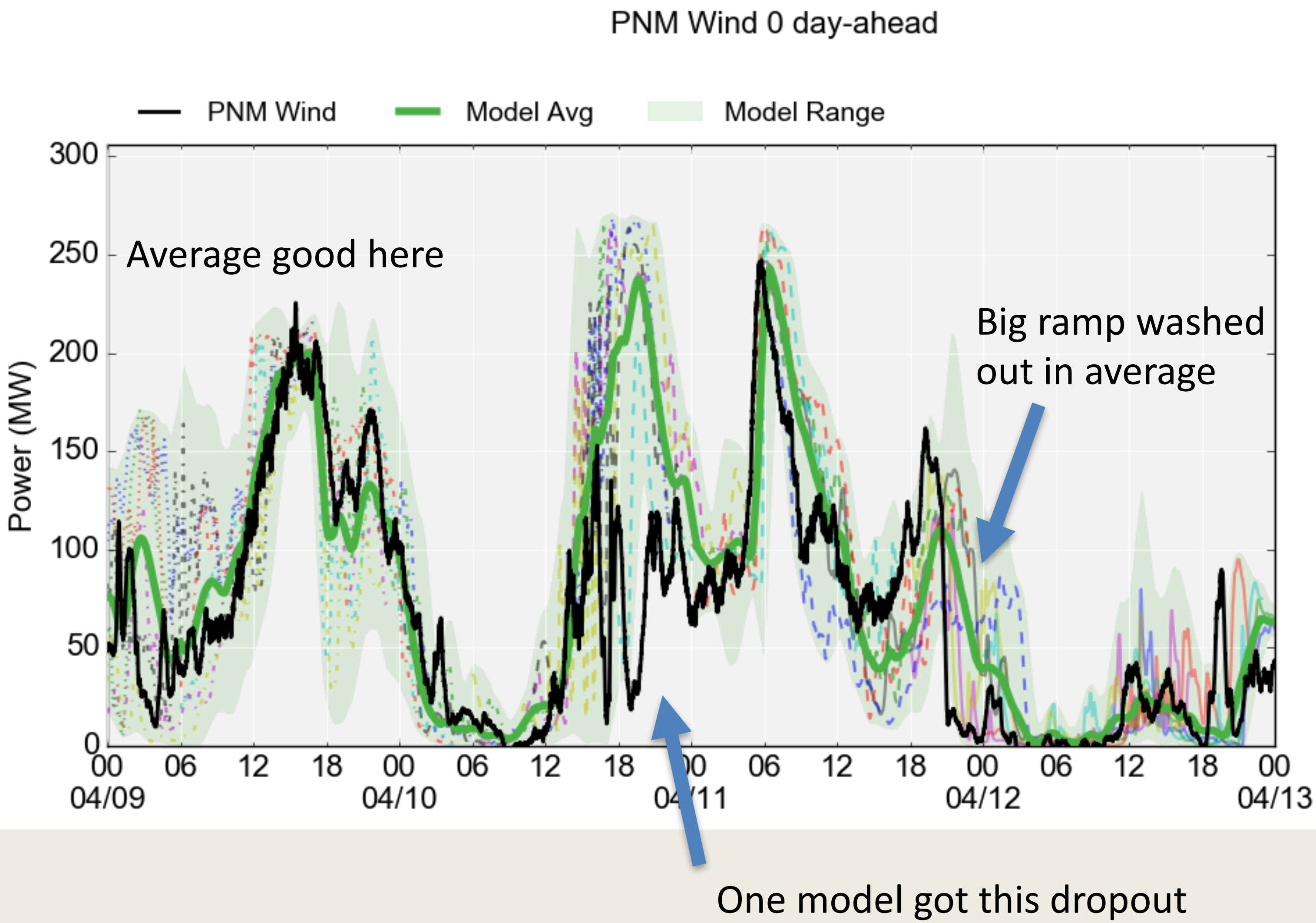


Model selection?



Average washes out variability

Model selection?



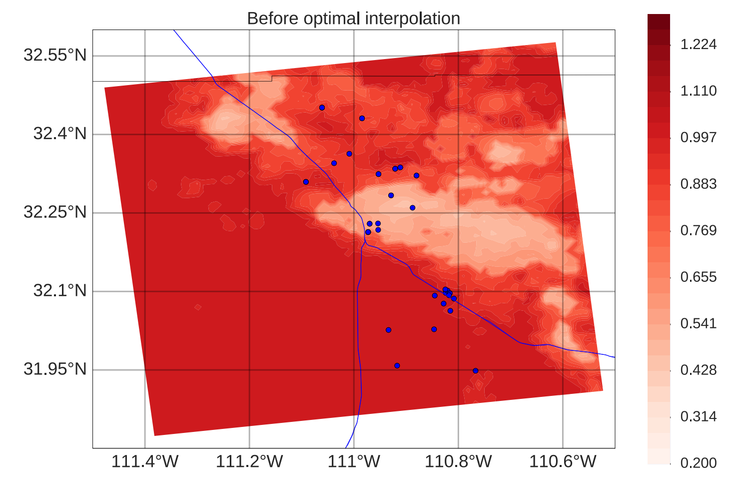
Ground irradiance data to improve satellite irradiance estimates

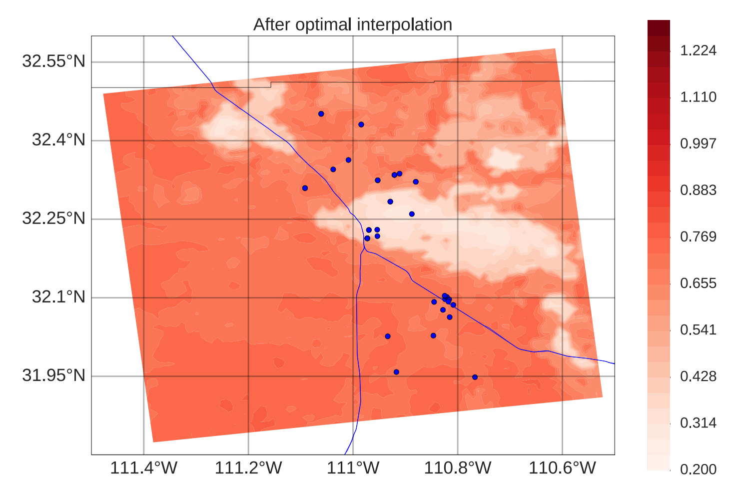
Satellite irradiance estimates rely on algorithms that convert the observation (light reflected by cloud tops) into transmitted irradiance.

Can we use real time ground data to improve the estimate?

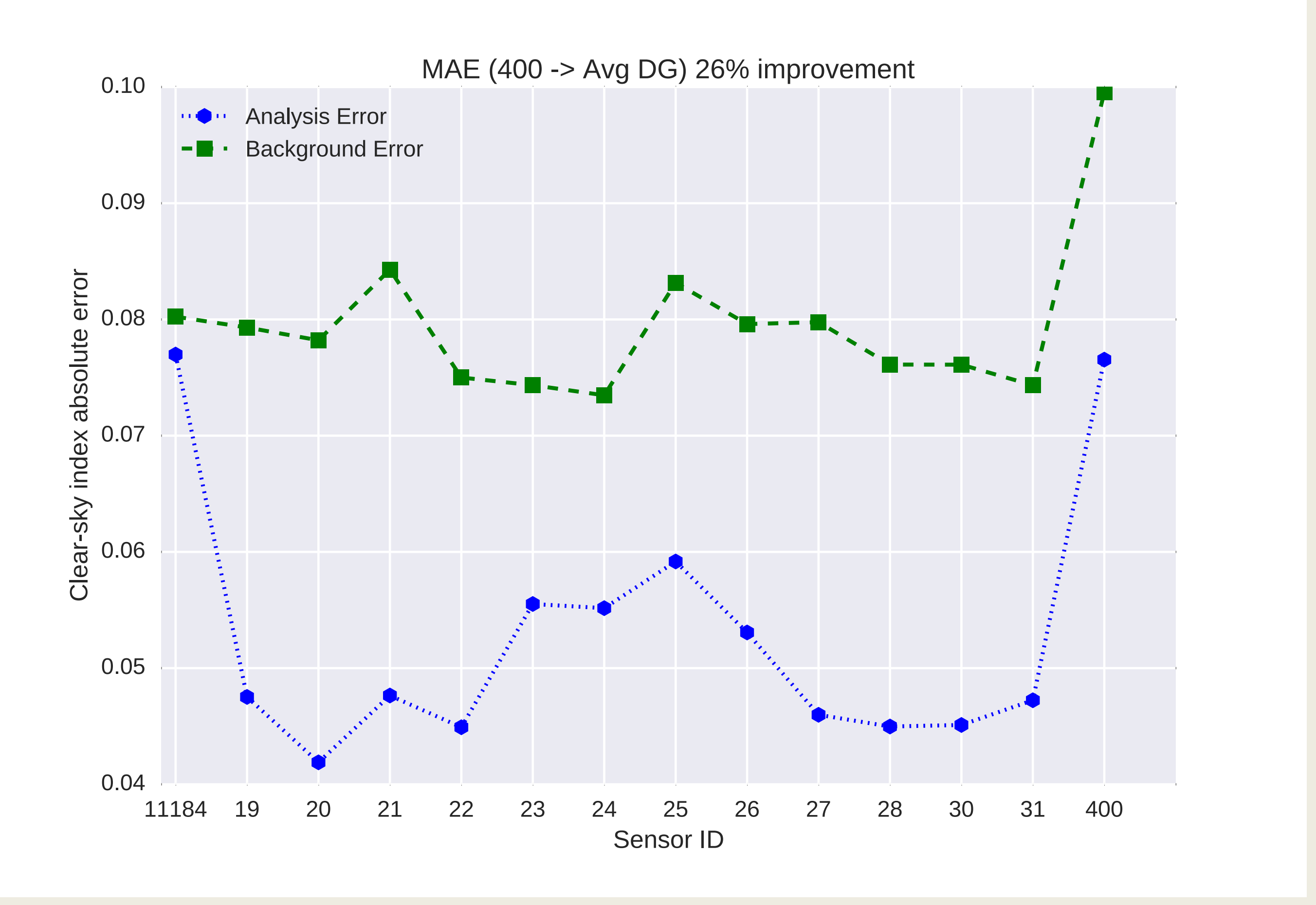
Yes, UA demonstrated that **optimal interpolation** can improve the accuracy.

Lorenzo, Holmgren, Morzfeld, Cronin, IEEE PVSC 2016 Proceedings





Ground irradiance data to improve satellite irradiance estimates



What about combining some or all of this data?

- Shove the data into WRF?
- Probably need a combination of complex and simple WRF configurations
- Create a separate blending platform?
- Throw it all into a black box machine learning algorithm and hope for the best?
- What is the effort to reward ratio for different approaches?

Thanks to our funding agencies

Major support from

DOE EERE
Postdoctoral
Fellowship

Additional support from

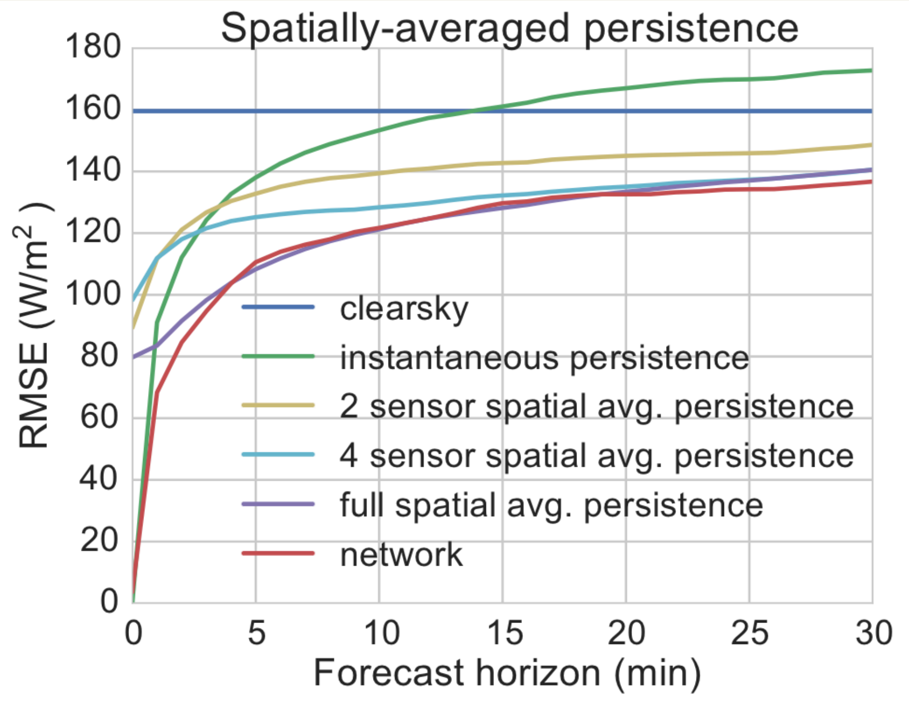
The SVERI utilities

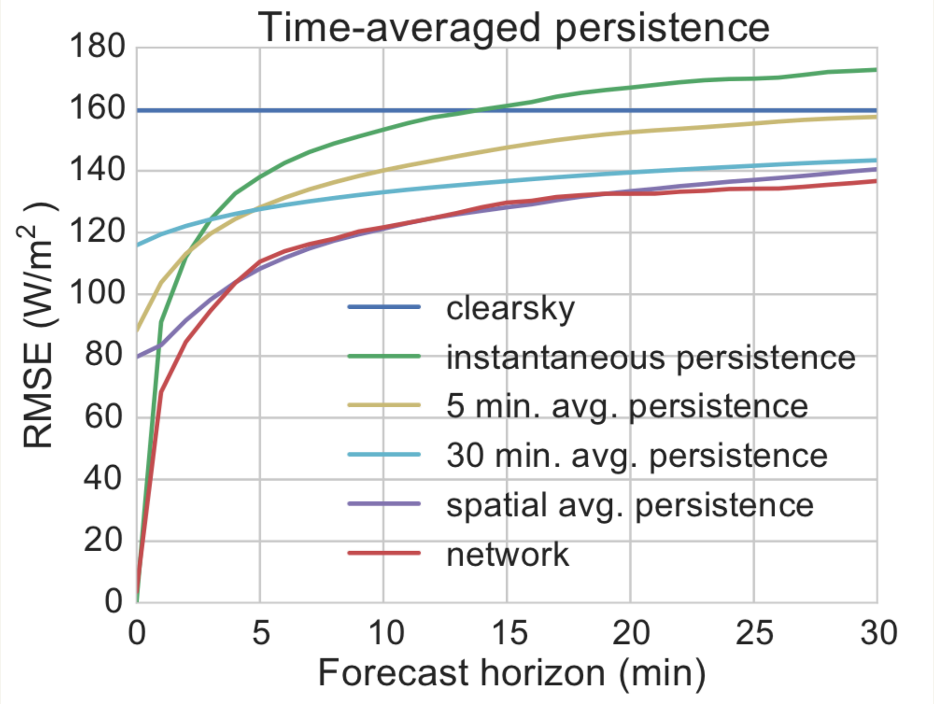
Arizona Department of
Environmental Quality

U of A

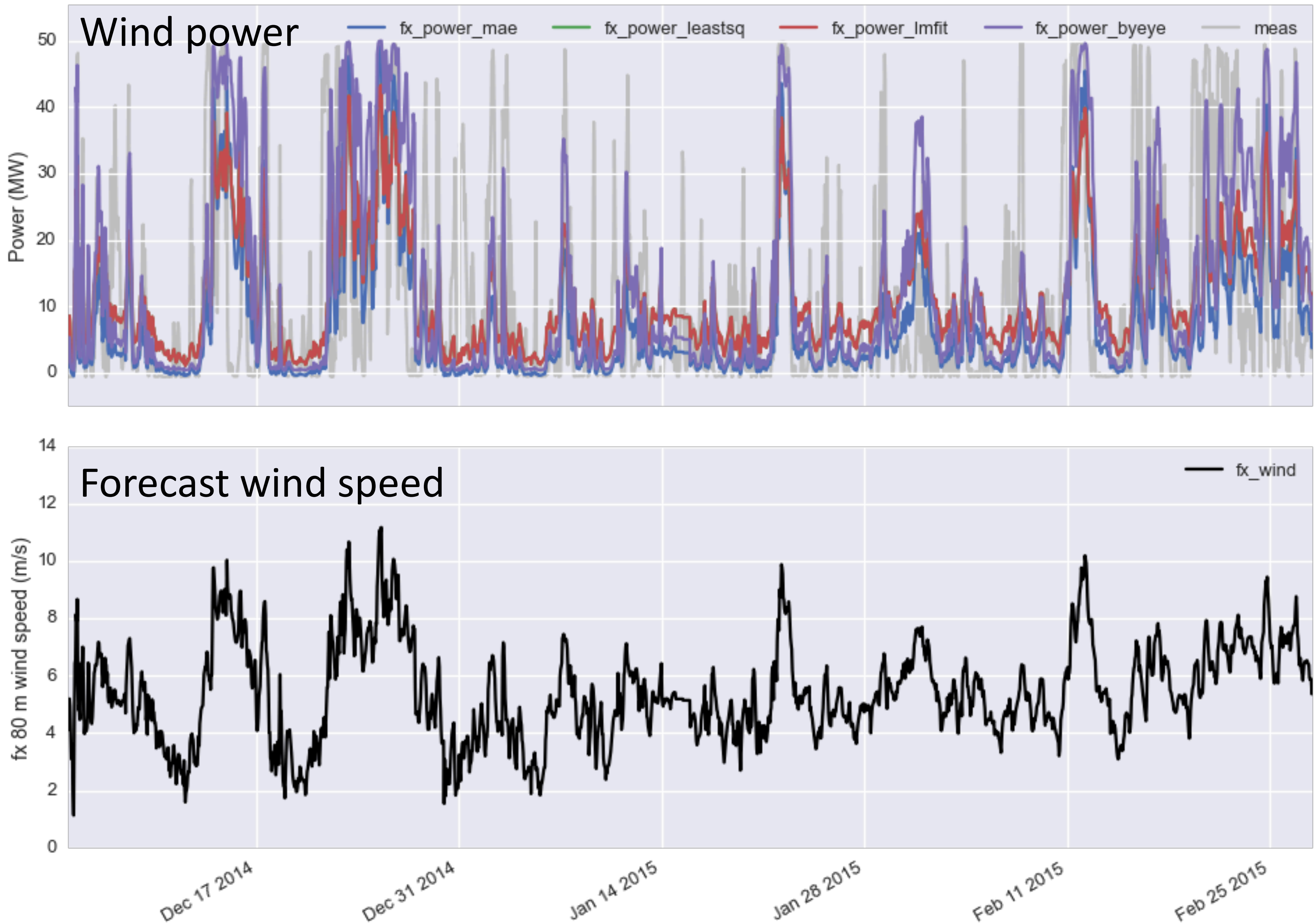
Sensor network error statistics

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?

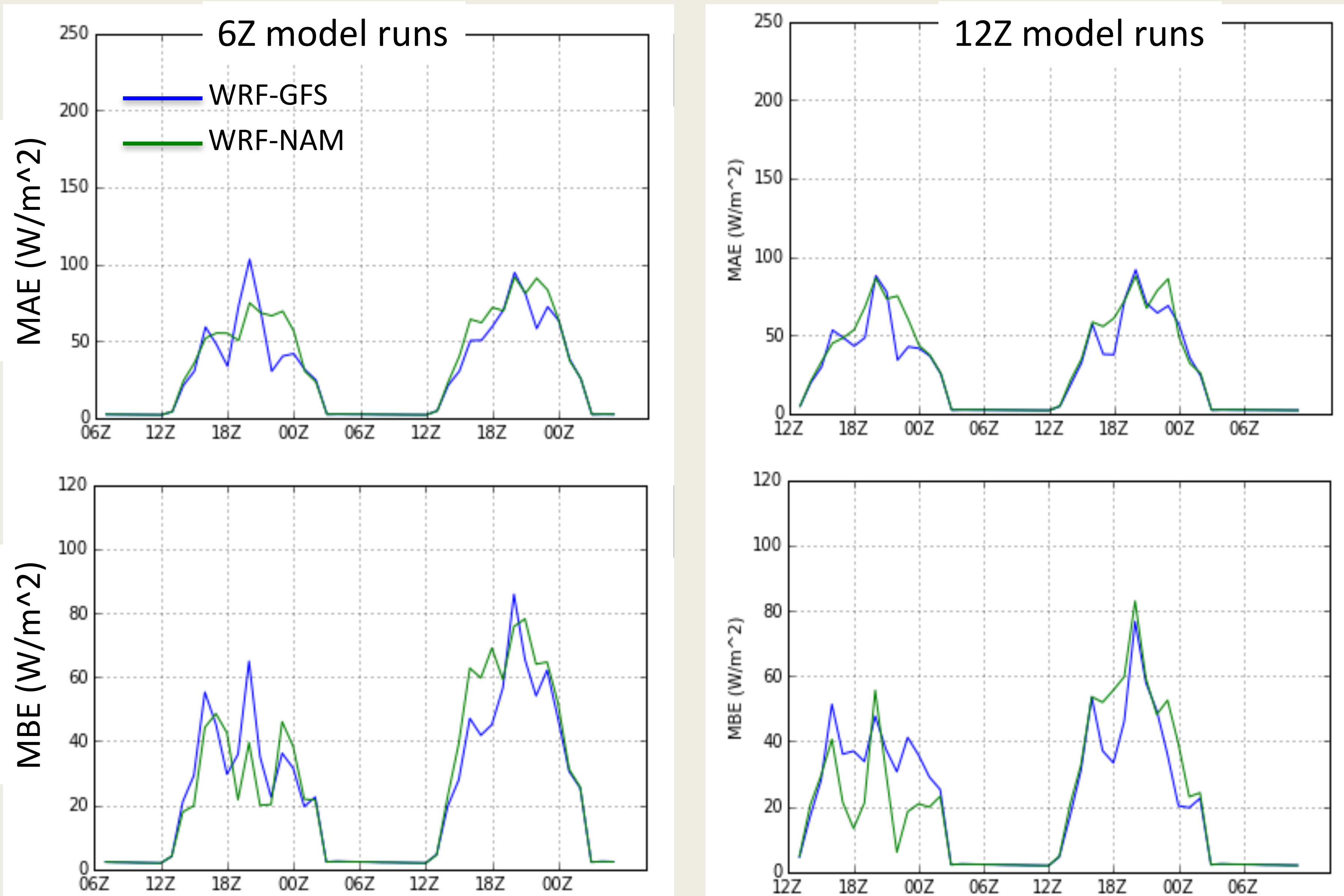




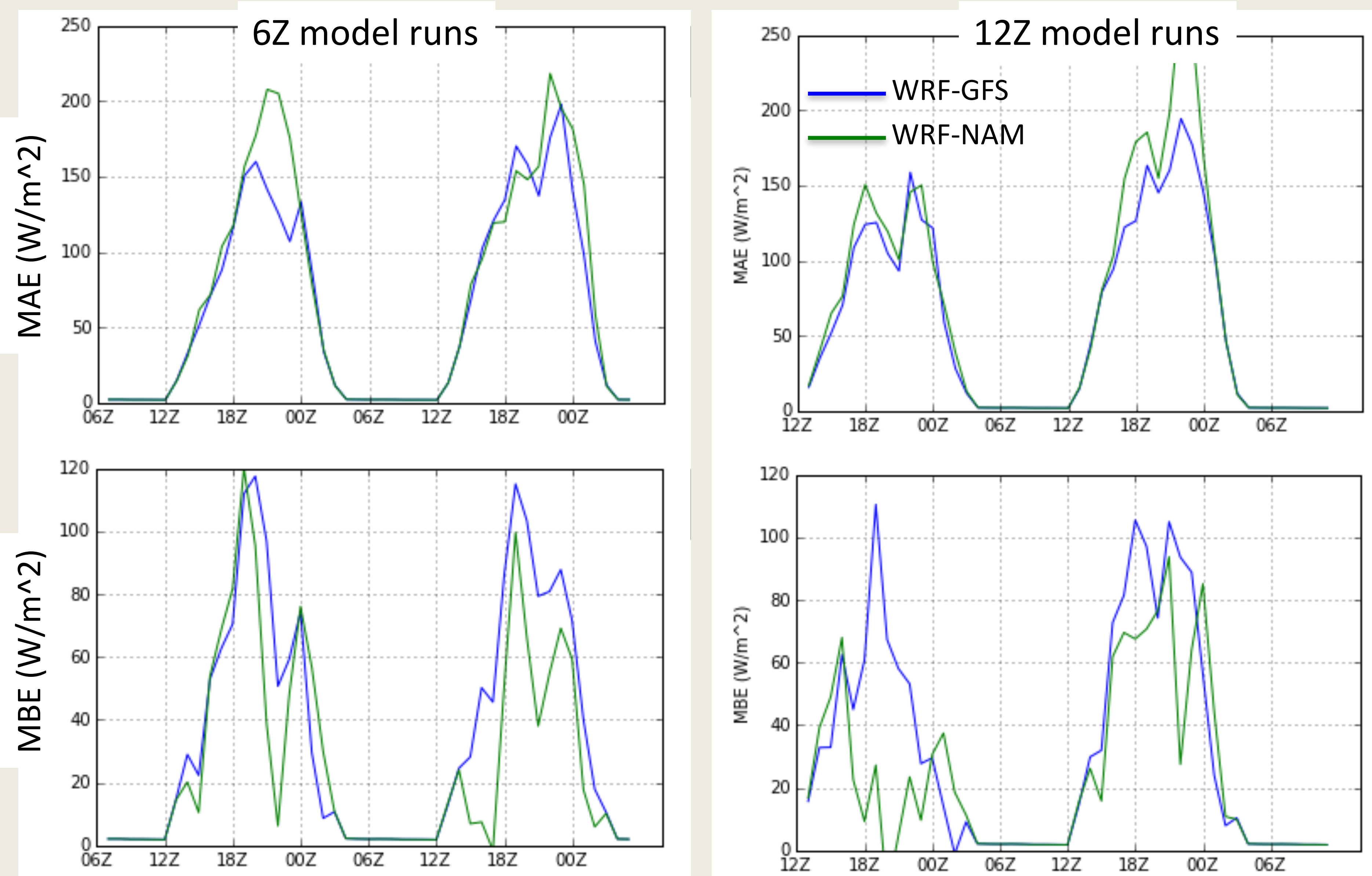
Depends on the day and the forecast horizon, but most of the improvement can usually be achieved by just averaging irradiance over space and/or time.


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

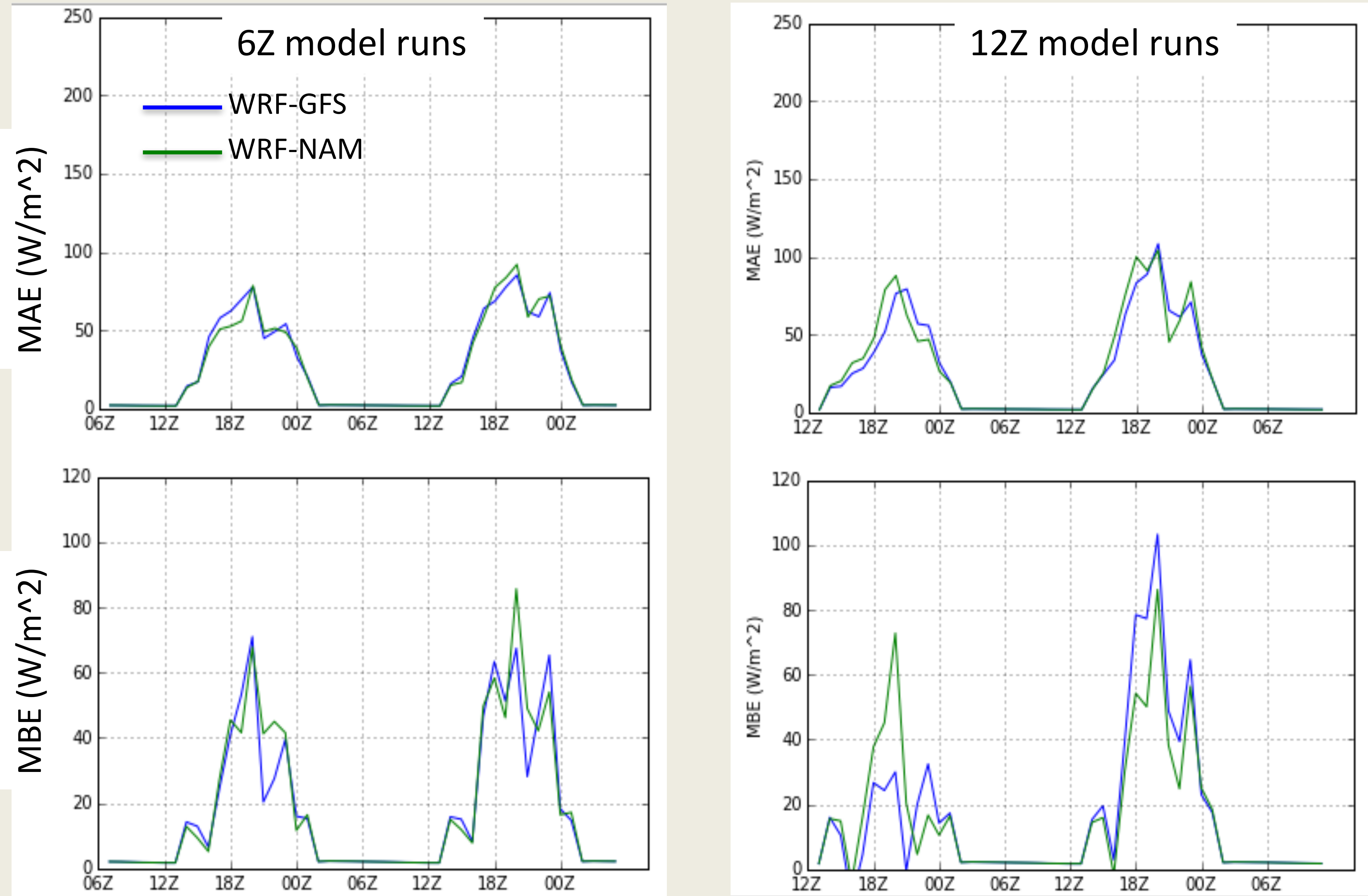
April 2014 UA-WRF GHI



July 2014 UA-WRF GHI

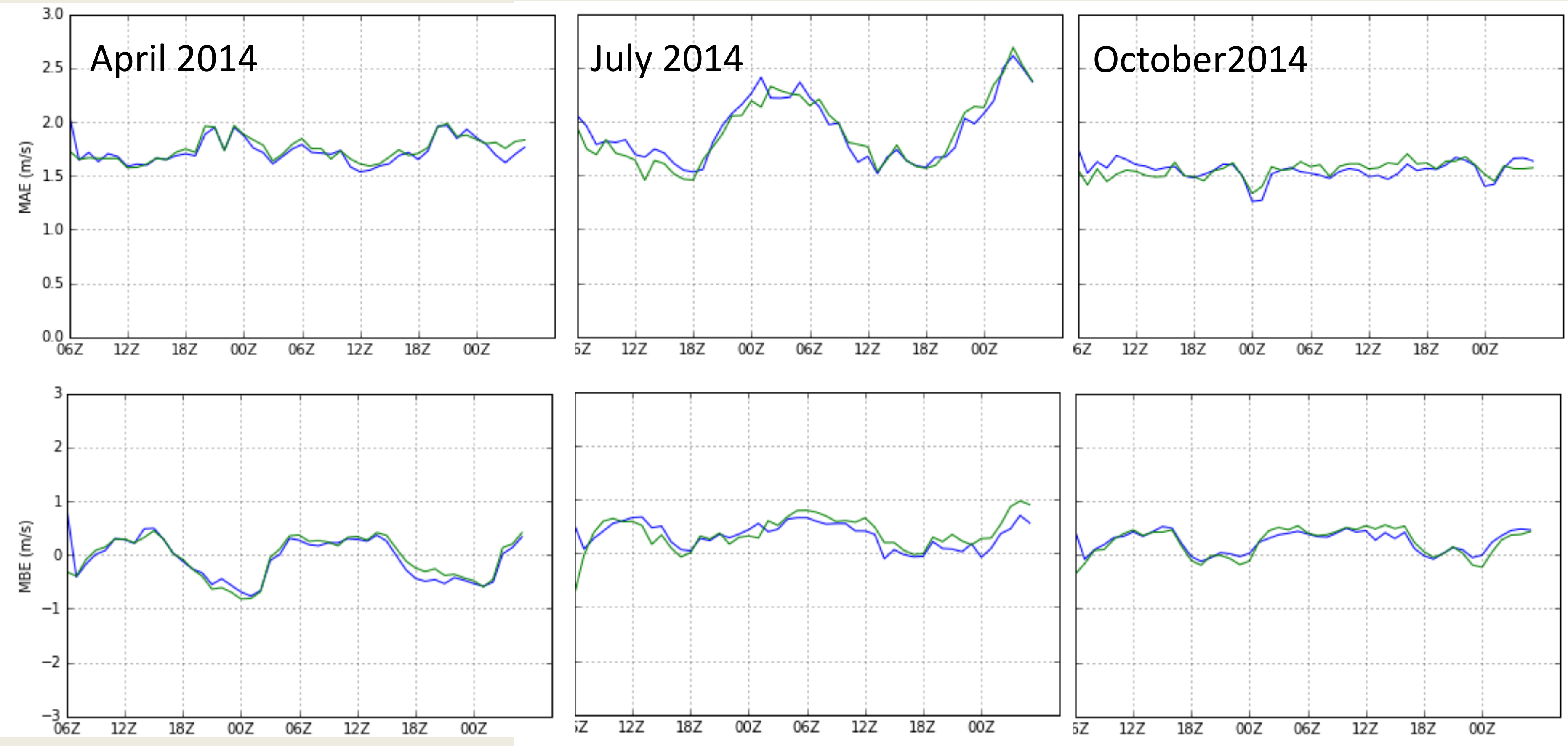


October 2014 UA-WRF GHI



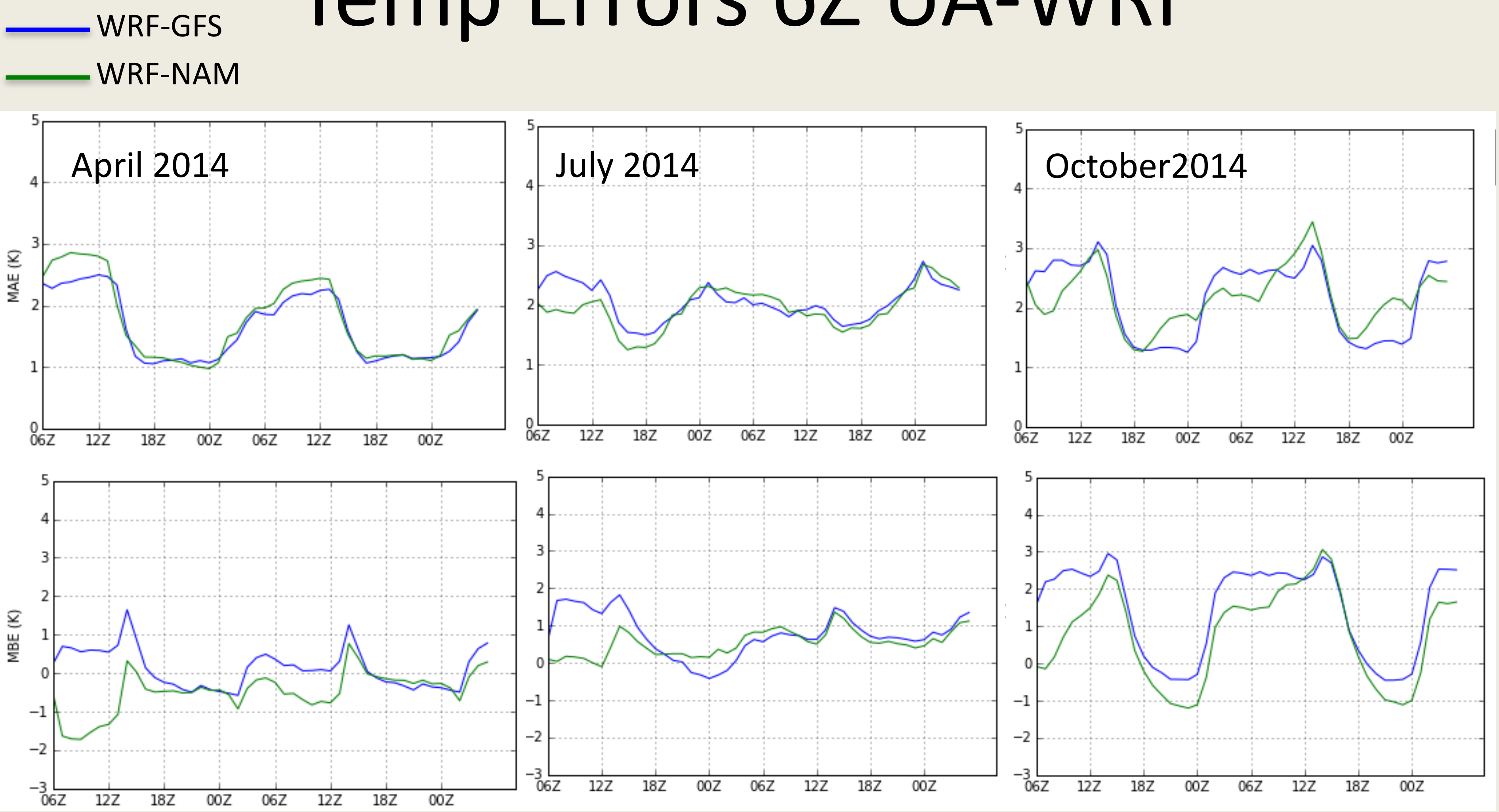
Wind Errors 6Z UA-WRF

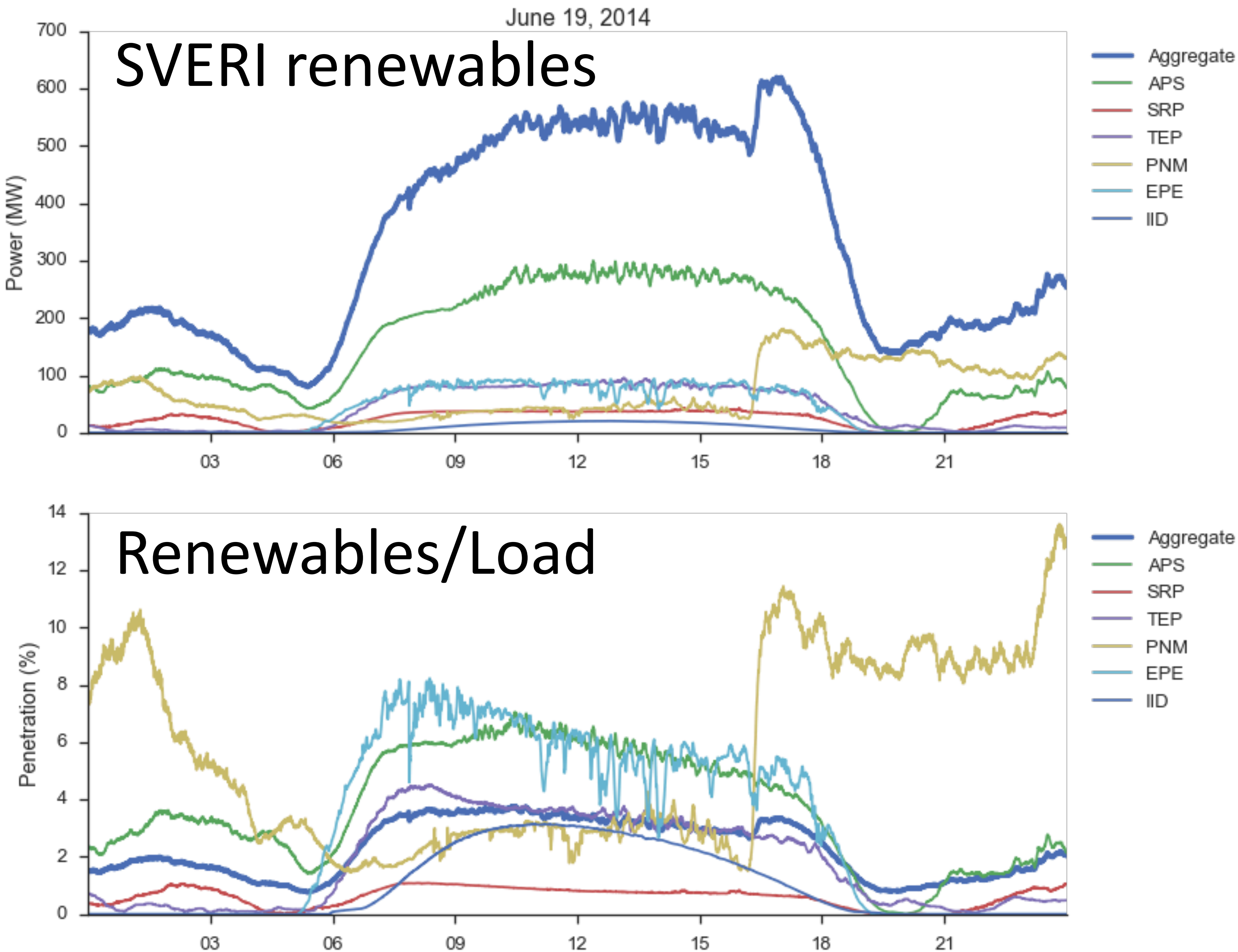
WRF-GFS
WRF-NAM



Average errors for all AZ METARs stations

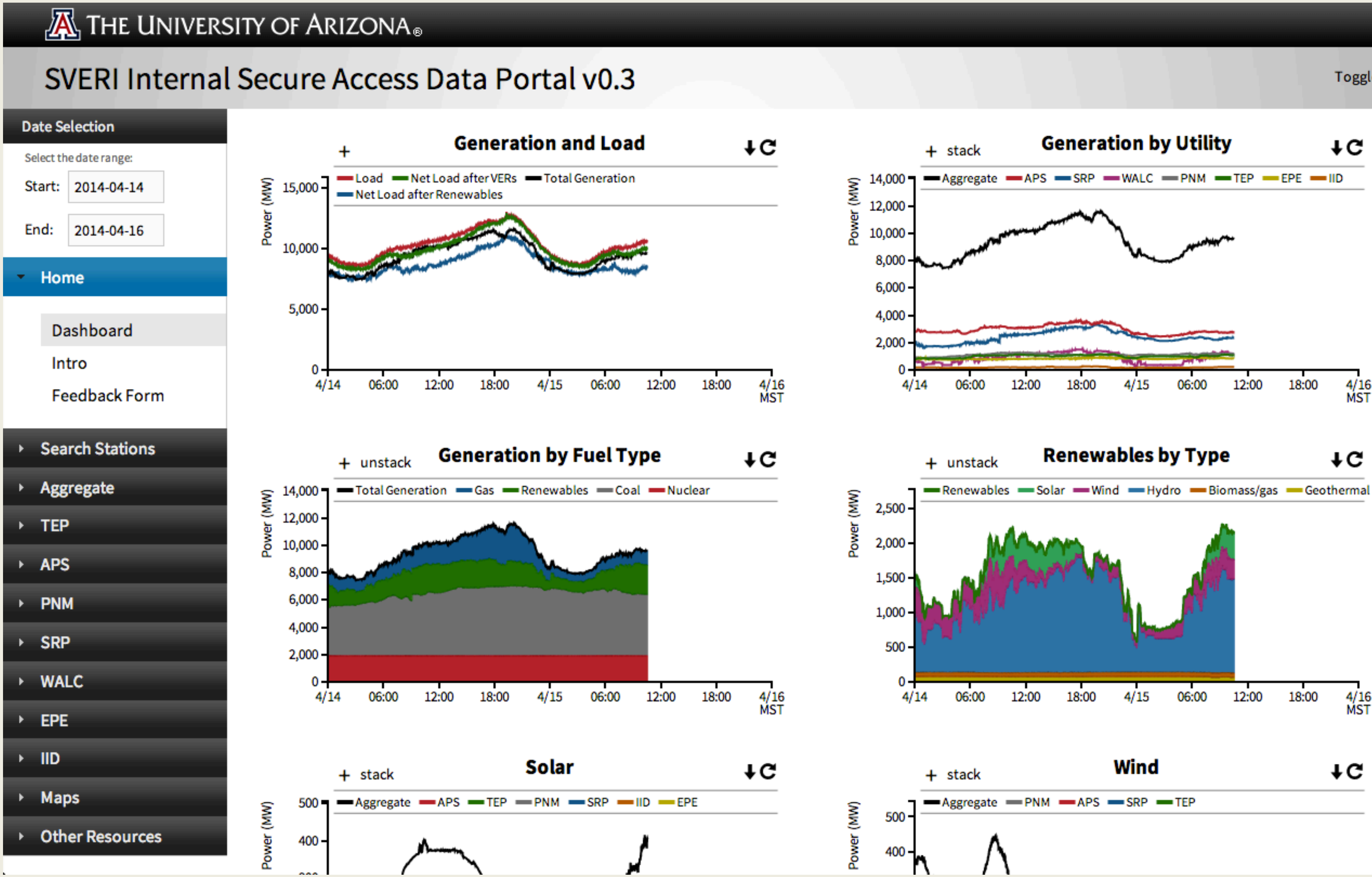
Temp Errors 6Z UA-WRF



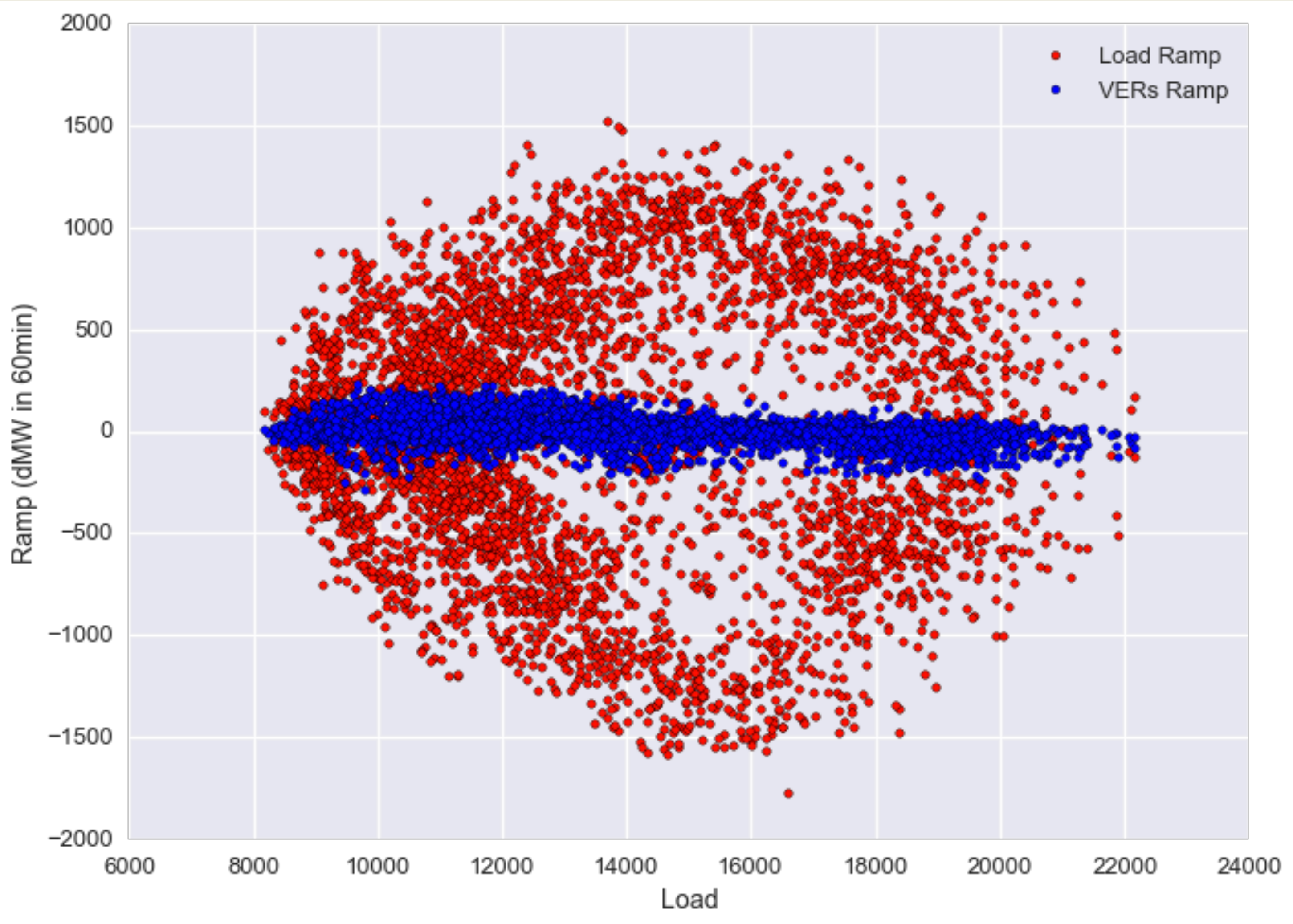


June 19, 2014
SVERI renewables
Power (MW)
700
600
500
400
300
200
100
0
03
06
09
12
15
18
21
Aggregate
APS
SRP
TEP
PNM
EPE
IID
Renewables/Load
Penetration (%)
14
12
10
8
6
4
2
0
03
06
09
12
15
18
21
Aggregate
APS
SRP
TEP
PNM
EPE
IID

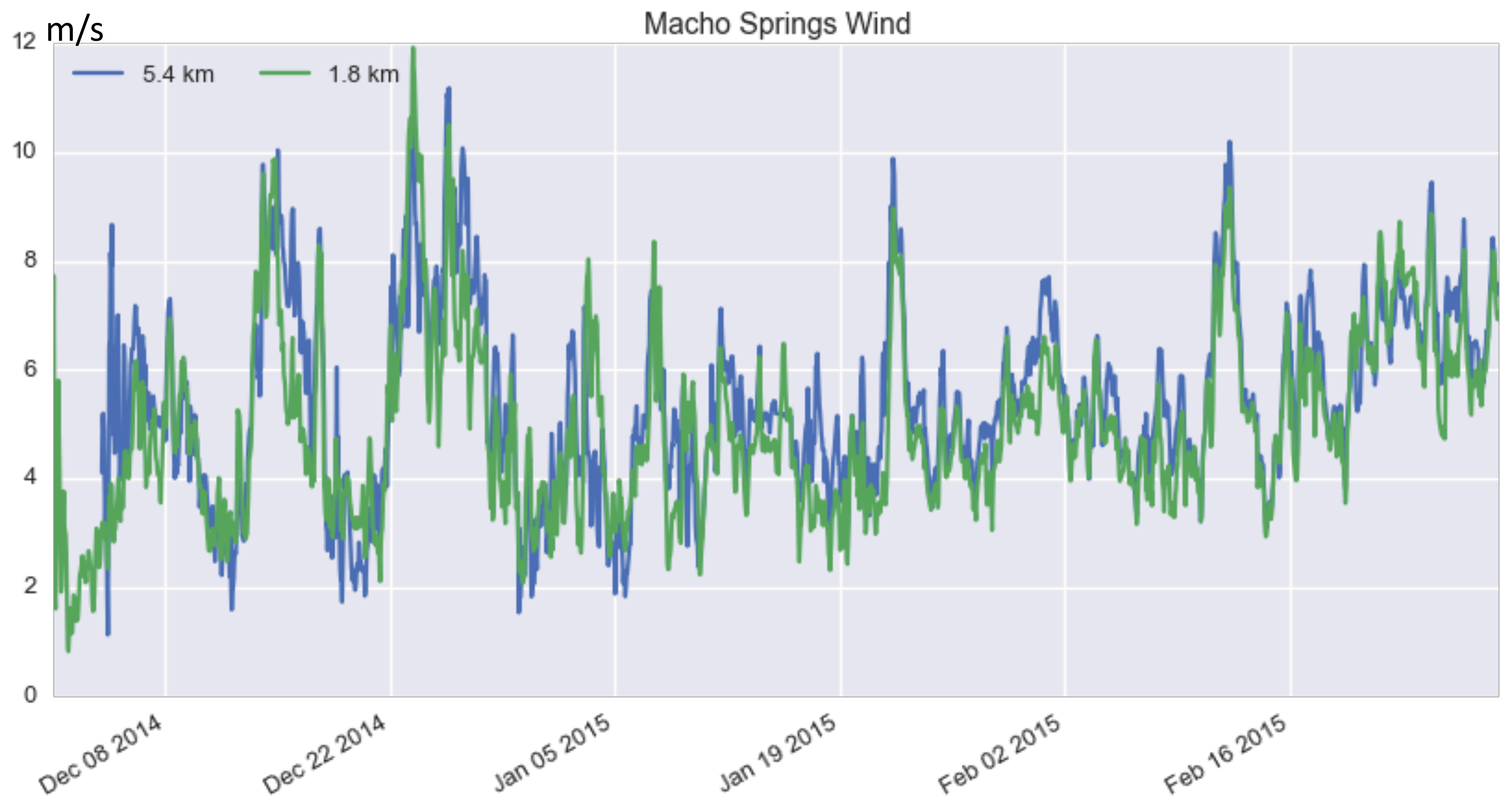
SVERI Internal Website



Ramps vs. Load



5.4 vs. 1.8 km wind forecasts



5.4 vs. 1.8 km wind forecasts