U. Arizona Renewable Power Forecasting

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But first,

The status and future of renewables in the Southwest
SVERI
Southwest Variable Energy Resource Initiative
- 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

SVERI load
TEP’s Solar Power Variability

The beautiful, sunny morning of April 5, 2014.
The beautiful sunny morning of April 5, 2014.

???

The beautiful, sunny afternoon of April 5, 2014?
TEP’s Solar Power Variability

50 MW ramp in 15 min
Many 25 MW ramps in 1 min → Area Control Errors (ACE)

Load 1.5 GW
Reserves 100 MW

Variability is half of the reserves

Ok today, but not in 3 years

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

1 min variability is similar for all months and times of day.

Large difference between 1 min 90th percentile and 100th percentile.

Less variability in June.

Monsoon season.

Less variability in November.

Little difference between 1 hr 90th percentile and 100th percentile.
SVERI wind variability

Change in MW in 1 min

Change in MW in 10 min

Change in MW in 1 h

Hour of day
SVERI wind variability

Similar trend differences between 90th percentile and 100th percentile across time scales

Small diurnal patterns

Similar plots available for all SVERI utilities
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

Between the red lines is easy and/or cheap
Outside of the red lines is hard and/or expensive
Geographic diversity is beneficial.
Geographic diversity is beneficial.
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

(Part of) The Solution:

UA renewable power forecasts

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
UA Forecasting Website for TEP + APS
Different forecasting methods work better at different time scales

- **Minutes**
- **Hours**
- **Days**
- **Seasons**
- **Years**

- Sensor Network
- Satellite Imagery
- Numerical Weather Models
- Climate Models
Numerical Weather Prediction at UA

- 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)

- 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
## 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

<table>
<thead>
<tr>
<th></th>
<th>06z AZ WRF-GFS</th>
<th>06z AZ WRF-NAM</th>
<th>12z AZ WRF-NAM</th>
<th>12z AZ WRF-GFS</th>
<th>12z AZ WRF-RUC</th>
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<tbody>
<tr>
<td><strong>Domain-Level Products</strong></td>
<td></td>
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<tr>
<td>Composite RADAR</td>
<td>1.8km</td>
<td>5.4km</td>
<td>1.8km</td>
<td>5.4km</td>
<td>1.8km</td>
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<tr>
<td>Precipitation</td>
<td>1.8km</td>
<td>5.4km</td>
<td>1.8km</td>
<td>5.4km</td>
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<tr>
<td>Accumulated Precipitation</td>
<td>1.8km</td>
<td>5.4km</td>
<td>1.8km</td>
<td>5.4km</td>
<td>1.8km</td>
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<tr>
<td>Accumulated Snow</td>
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<td>5.4km</td>
<td>1.8km</td>
<td>5.4km</td>
<td>1.8km</td>
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<td>5.4km</td>
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<td>5.4km</td>
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<tr>
<td>2m Temp</td>
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<td>5.4km</td>
<td>1.8km</td>
<td>5.4km</td>
<td>1.8km</td>
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<td>10m Wind</td>
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<td>5.4km</td>
<td>1.8km</td>
<td>5.4km</td>
<td>1.8km</td>
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<tr>
<td>Precipitable Water</td>
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<td>5.4km</td>
<td>1.8km</td>
<td>5.4km</td>
<td>1.8km</td>
</tr>
</tbody>
</table>

Contact me for access to raw data at atmo.arizona.edu
NCEP GFS
500 mb height
and vorticity
NCEP GFS
Surface wind and precip
UA WRF-GFS
5.4 km domain
10 m wind
UA WRF-GFS
1.8 km domain
10 m wind

Stronger winds along Mogollon rim

Much more wind at lower elevations

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
Differences in optical depth

Finer structure

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

UA WRF-GFS
1.8 km domain
GHI
Animation available at: http://forecasting.uaren.org

Blue: low elevation
Red: high elevation
UA-WRF Solar Power Forecast

Springerville Solar EMS, 912. 02/18/14 23:13:55

+ 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

Minimize RMSE?
Minimize MAE?
Make it look good?

Requires input from utility end users
Wind power

Forecast wind speed
April 2014 UA-WRF GHI

6Z model runs

- WRF-GFS
- WRF-NAM

12Z model runs

MAE (W/m^2)

MBE (W/m^2)
July 2014 UA-WRF GHI

6Z model runs

12Z model runs

MAE (W/m^2)

MBE (W/m^2)
October 2014 UA-WRF GHI

6Z model runs

- WRF-GFS
- WRF-NAM

12Z model runs

MAE (W/m^2)

MBE (W/m^2)
Wind Errors 6Z UA-WRF

Average errors for all AZ METARs stations
UA-WRF vs. NCEP HRRR Tucson GHI

2014-12-01

MAE:
15 minutes:
HRRR: 113, UA: 51, UA Day 2: 100, UA Day 3: nan
1 hour:
HRRR: 98, UA: 33, UA Day 2: 89, UA Day 3: nan
UA-WRF vs. NCEP HRRR Tucson GHI

MAE:
15 minutes:
HRRR: 28, UA: 78, UA Day 2: nan, UA Day 3: 21

1 hour:
HRRR: 26, UA: 70, UA Day 2: nan, UA Day 3: 16
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.
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
Animation available at: http://forecasting.uaren.org
Satellite Derived Solar Irradiance

Blue: low solar power
Red: high solar power

Animation available at: htcp://forecasting.uareno.org
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

(a)  (b)

(c)  (d)

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

Cloudy and clear sky conditions
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

Time-series of sensors 19 and 31

GHI (W/m²)

Local time

11:20 11:30 11:40 11:50 12:00 12:10

Sensor 19

Sensor 31
Sensor network forecast

Animation available at: http://forecasting.uaren.org
Sensor network error statistics

RMSE on May 19, 2014

- **RMSE (W/m²)**
- **Forecast horizon (min)**

Legend:
- Green line: instantaneous persistence
- Purple line: spatial avg. persistence
- Yellow line: network w/o sensor 19
- Red line: full network
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?

- Spatially-averaged persistence
- Time-averaged persistence

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

- **Clear sky**
- **WRF**
- **Satellite**
- **Hybrid**
- **Sensor network**

The graph shows the Mean Absolute Error (MAE) in W/m² over time, with different lines representing different methods: Network, Measurement persistence, Clearness persistence, WRF Mean, and Clear sky.
Thanks to our funding agencies

Major support from

- TEP
- APS
- DOE EERE Postdoctoral Fellowship

Additional support from

- The SVERI utilities
- Arizona Department of Environmental Quality

U of A

Renewable Energy Network
SVERI Internal Secure Access Data Portal v0.3

- Generation and Load
  - Load
  - Net Load after VERS
  - Total Generation
  - Net Load after Renewables

- Generation by Utility
  - Aggregate
  - APS
  - SRP
  - WALC
  - PNM
  - TEP
  - EPE
  - IID

- Generation by Fuel Type
  - Total Generation
  - Gas
  - Renewables
  - Coal
  - Nuclear

- Renewables by Type
  - Renewables
  - Solar
  - Wind
  - Hydro
  - Biomass/gas
  - Geothermal

- Solar
  - Aggregate
  - APS
  - TEP
  - PNM
  - SRP
  - IID
  - EPE

- Wind
  - Aggregate
  - PNM
  - APS
  - SRP
  - TEP
Ramps vs. Load

![Graph showing the relationship between ramps and load](image)
5.4 vs. 1.8 km wind forecasts
5.4 vs. 1.8 km wind forecasts