Intra-hour solar power forecasts using a real-time irradiance monitoring network

Antonio T. Lorenzo, William F. Holmgren, Michael Leuthold, Chang Ki Kim, Alexander D. Cronin, Eric A. Betterton
Departments of Physics and Atmospheric Sciences, University of Arizona

Motivation

- Intra-hour solar power forecasts can help electric utilities schedule regulating reserves, optimize short-term energy trading, and manage grid-connected batteries for ramp-rate avoidance.
- However, some intra-hour forecasting methods develop errors during conversion from pixel brightness to irradiance. Some also require large sets of training data. Our network method overcomes these challenges with irradiance measurements and a physical model of cloud motion.
- Forecasts based on our network of irradiance sensors perform better than the benchmark persistence model for forecast horizons greater than 1 minute.

Irradiance network

- Solar powered irradiance sensors with cellular network backhaul were developed.
- The logging equipment is versatile and can be configured for a number of different weather sensors (ask if interested in the design).
- We collect one-second data from each irradiance sensor every minute to produce real-time forecasts for a utility (TEP), although the results presented here are a reanalysis of the data.
- Thirteen sensors were placed strategically around the Univ. of Arizona Science and Technology Park to forecast for roughly 20 MW of PV power plants.
- We also use 5 minute-averaged data from 50 rooftop PV systems in the Tucson area as "irradiance" sensors in our network.

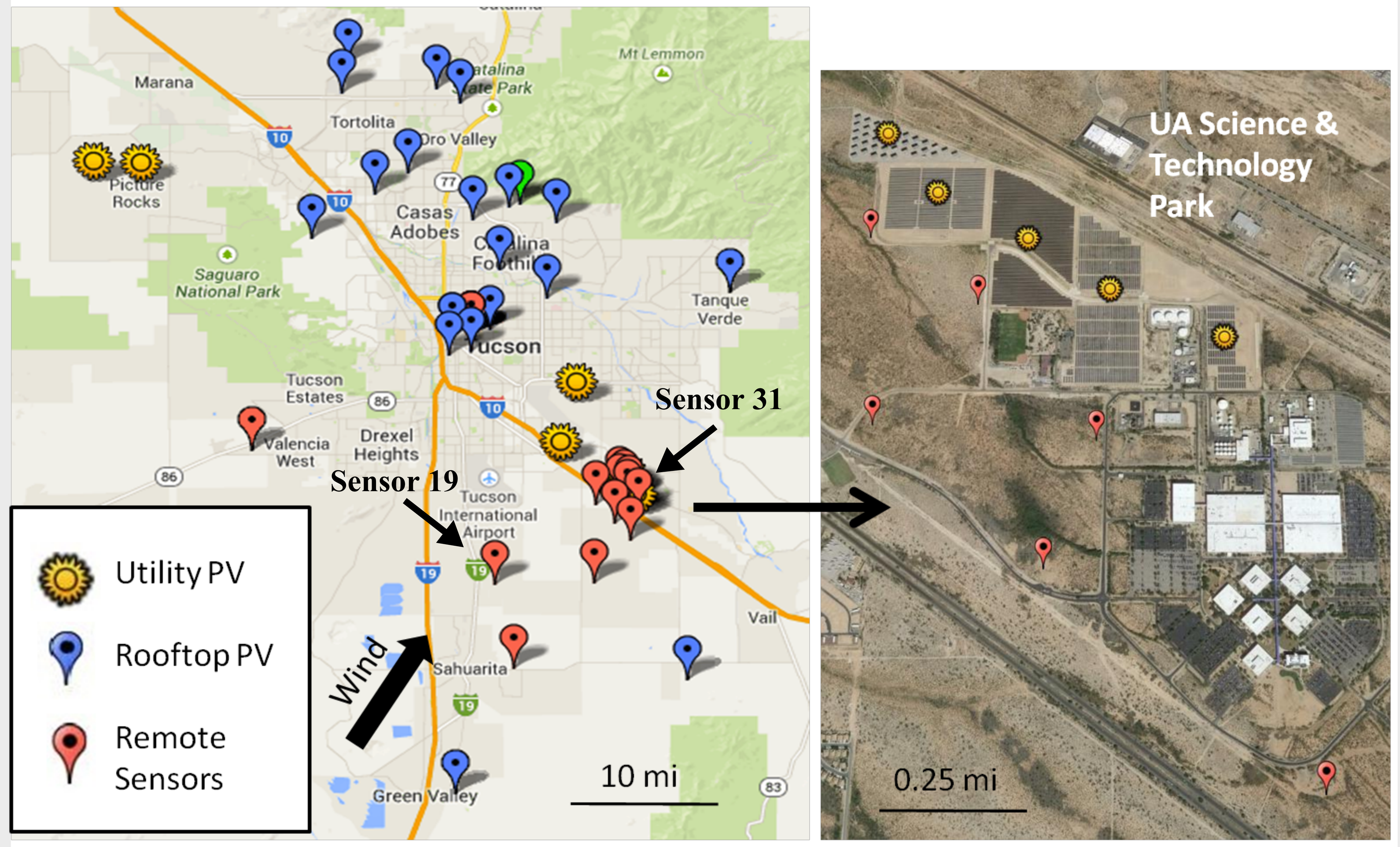


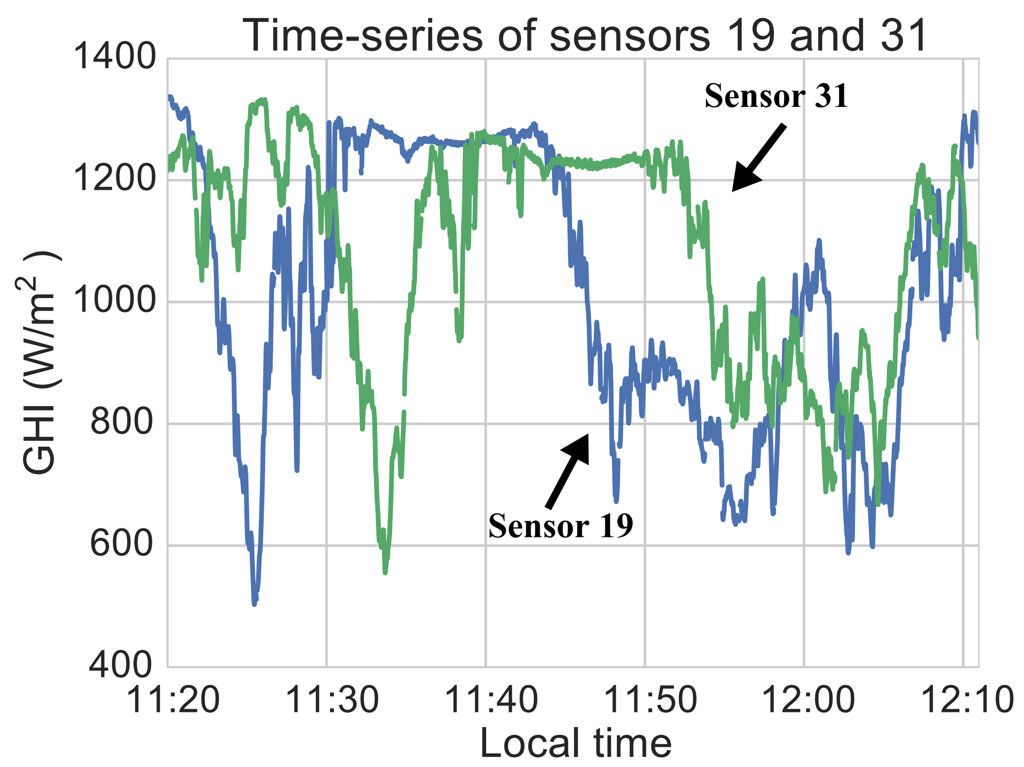
Figure 1. Map of irradiance sensors, rooftop PV systems, and utility scale PV systems in Tucson, AZ.

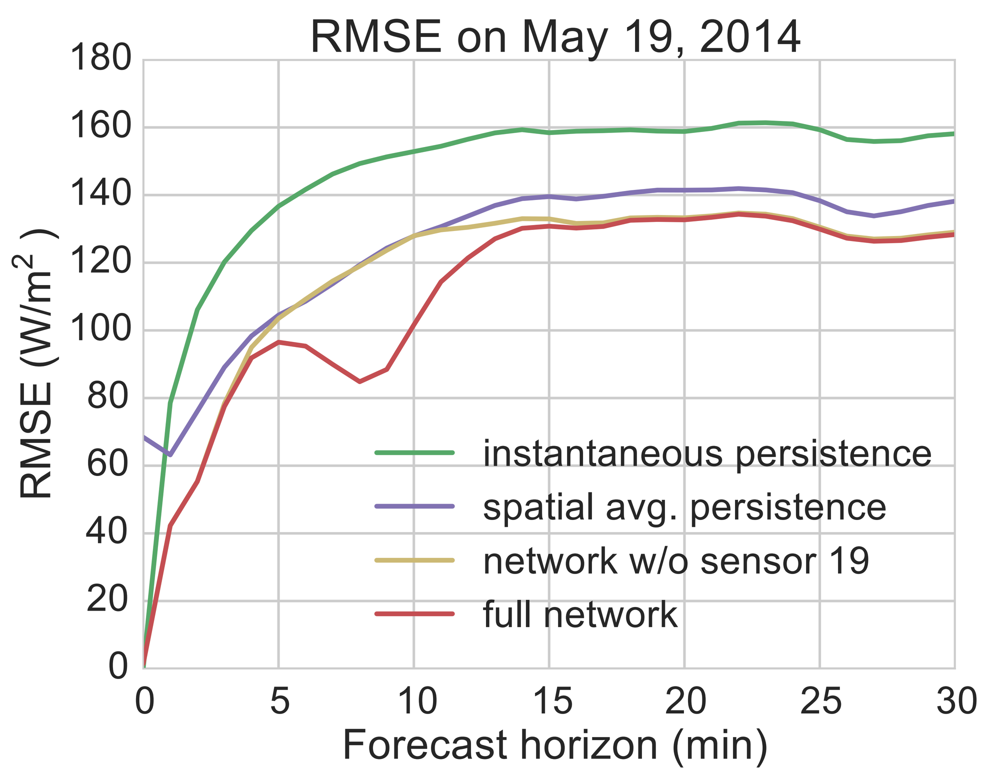
Methods

1. Irradiance data are gathered from a database and normalized by clear-sky profiles to produce clear-sky indices for each sensor.
2. An interpolated map of clear-sky index (cloud opacity) is produced for the Tucson area.
3. Cloud velocity is estimated by analyzing WRF forecast output or radiosonde data.
4. The clear-sky index map is shifted based on forecast time horizon and estimated cloud velocity.
5. The clear-sky index at a location of interest on the shifted map is multiplied by an appropriate clear-sky profile to produce an irradiance or solar power forecast.

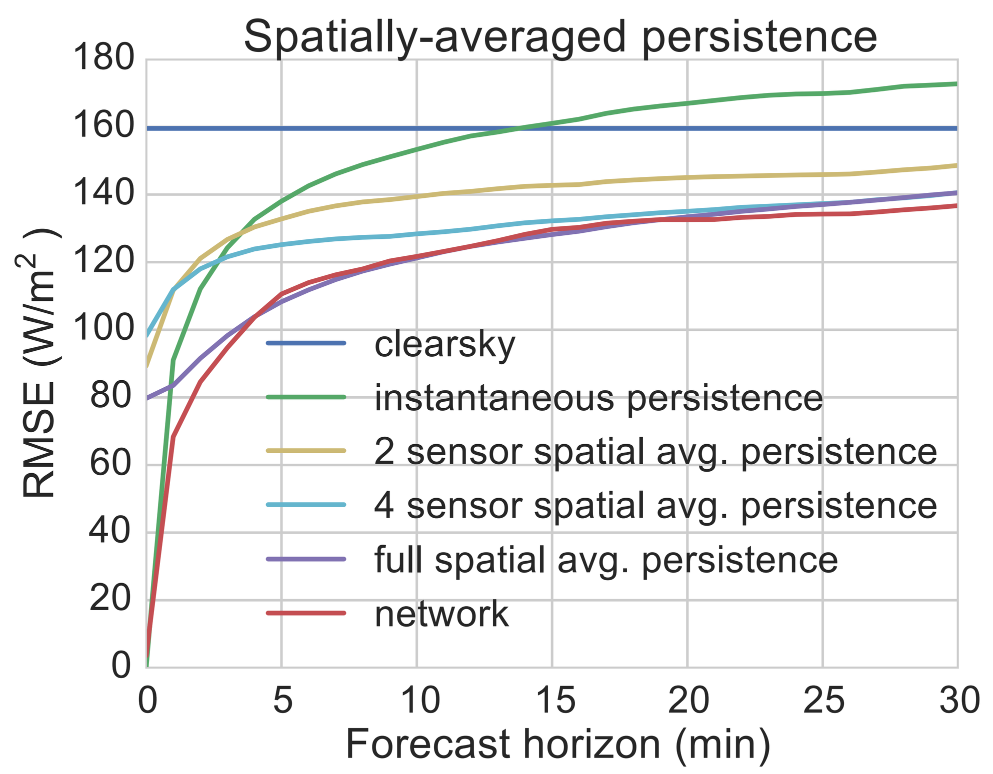
Results

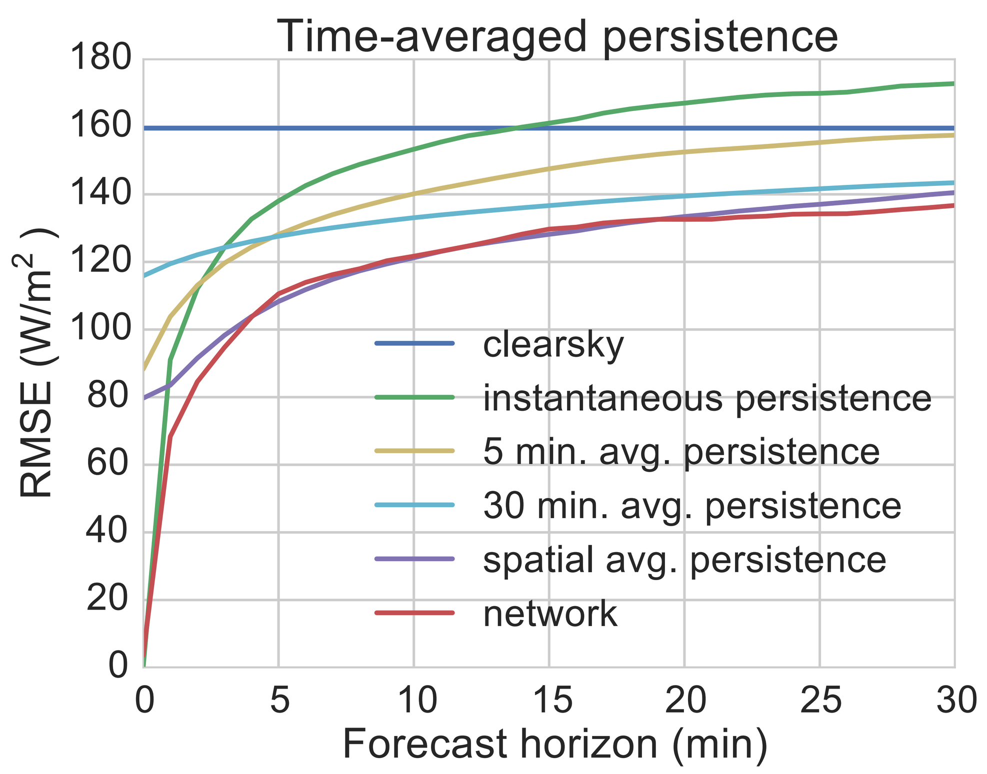
The network forecasts are based on the idea that time-series of two sensors that are spatially separated lag/lead each other when the cloud velocity vector is properly oriented.





Data from three months (April, May, June) on cloudy days ignoring nighttime values were analyzed. The errors were averaged for each day and then for the three months. Below, network forecasts are compared to an always clear forecast, a clear-sky index persistence forecast, spatially averaged persistence forecasts made possible by the sensor network, and time-averaged clear-sky index persistence forecasts.





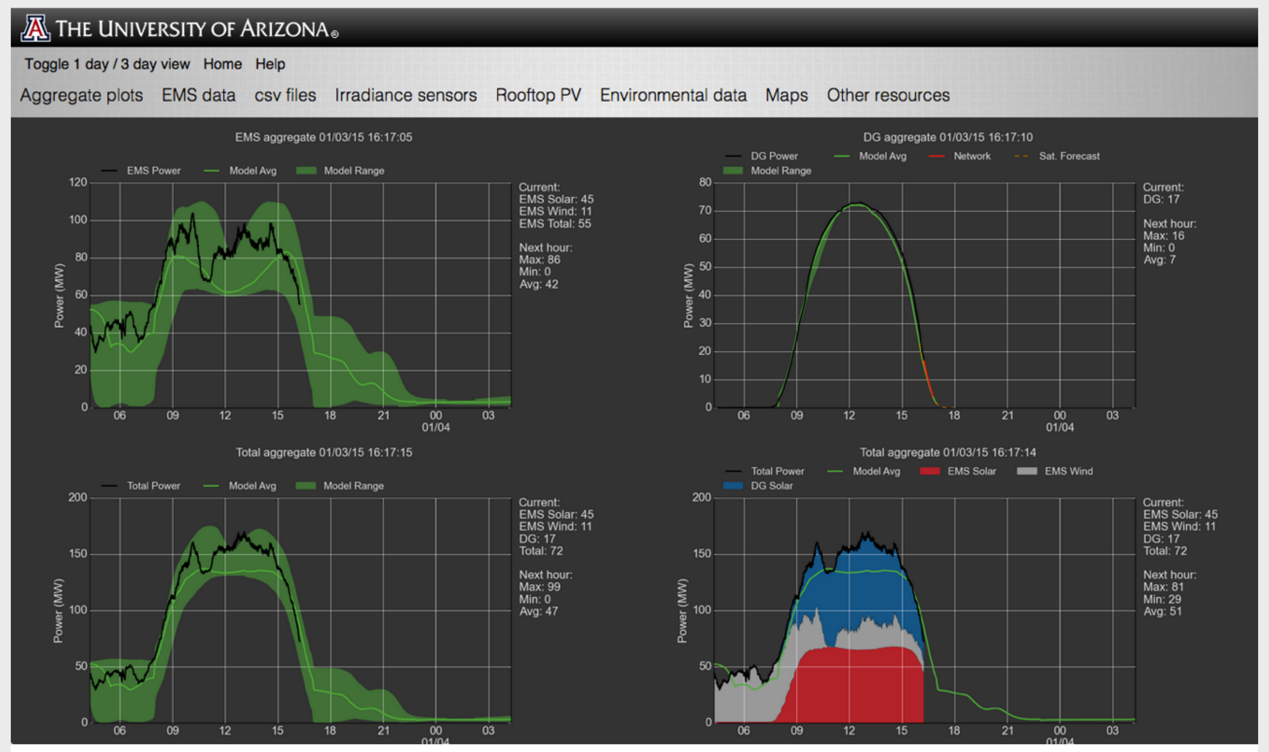


Figure 2. A screen-capture of the live website provided to our utility partners.

Conclusions

- Our irradiance network forecasts outperform, on average, the persistence model for the three months of study.
- Network forecasts outperform the persistence model for 45 of the 46 cloudy days studied.
- Most of this improvement is likely from a spatial averaging effect.
- Spatially averaged persistence with even a handful of sensors shows improvement over simple persistence.
- Cloud-motion on most days is too complicated and/or our network is not dense enough for the best possible forecasts.
- Future work will explore an optimal density of sensors through simulation and integration of our intra-hour forecasts with satellite and WRF forecasts.
- We recommend that utilities add irradiance sensors to existing and planned weather stations for resource assessment and forecasting.

Acknowledgements

The authors thank Tucson Electric Power, Arizona Public Service, and the UA Renewable Energy Network for supporting this and other forecasting work.

THE UNIVERSITY OF ARIZONA

95th American Meteorological Society Annual Meeting
Sixth Conference on Weather, Climate, and the New Energy Economy

atlorenzo@email.arizona.edu
forecasting.uaren.org