DESIGN AND USE OF AN IRRADIANCE MONITORING NETWORK FOR SHORT-TERM IRRADIANCE FORECASTING

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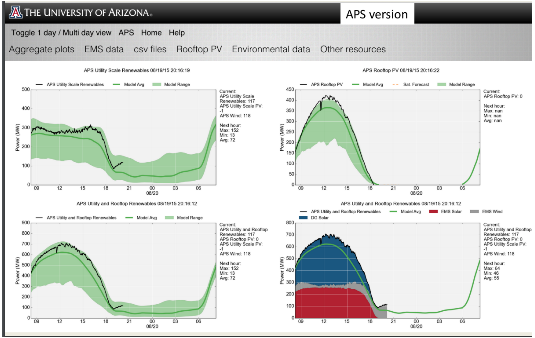
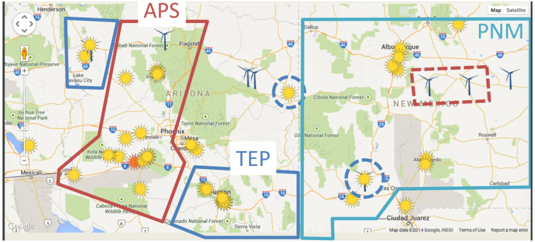
Introduction

- Operational solar power forecasts are provided to TEP, APS, and PNM for solar PV generation totaling over 500 MW.
- Forecasts save the utilities money and encourage them to install solar to replace coal and other fossil fuel plants.
- Broad area irradiance nowcasts derived from satellite images are also useful to utilties that lack real-time monitoring of rooftop PV systems.

Operational Forecasting





Theoretical Errors

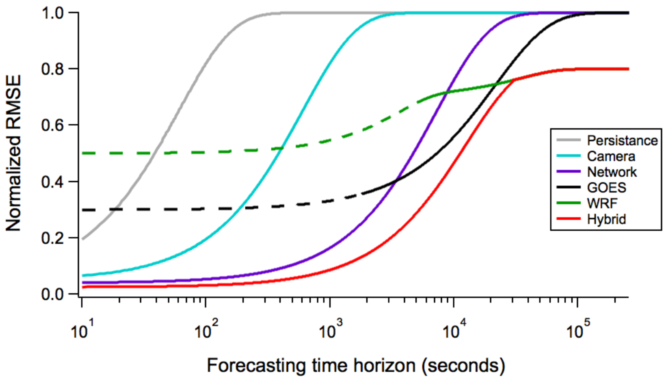


Figure: Theoretical forecast errors circa 2013.

Actual Errors

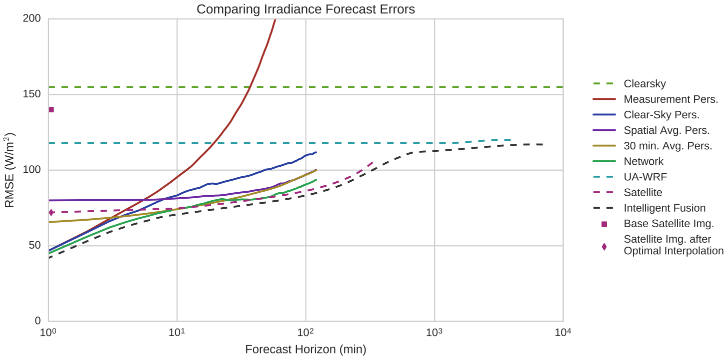
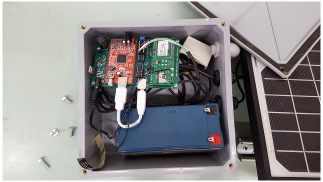
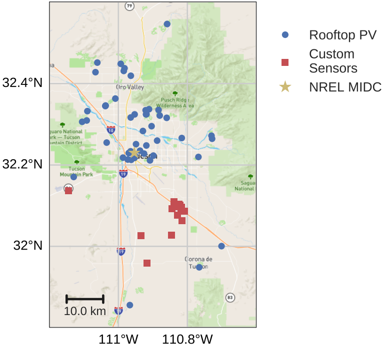


Figure: Actual forecast errors as a result of my research. Solid lines and points are those studied in this dissertation. Dashed are preliminary or theoretical estimates.

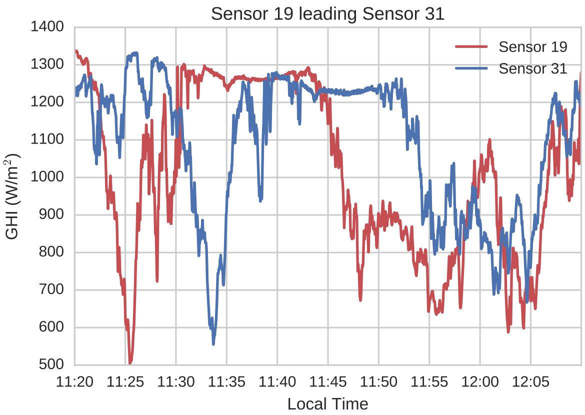
Outline

Irradiance Network





Irradiance Network Forecasts



Irradiance Network Forecasts

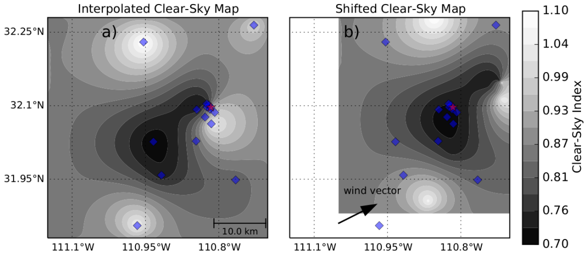


Figure 2: An example interpolated map of clear-sky index on 5/19/14 near noon is shown in a). Using the estimated cloud motion vectors this map is shifted according to desired forecast horizon as shown in b). Then, samples from this shifted map are taken to as the forecasted clear-sky index for a particular location. The white space at bottom and left of b) is filled in with the average clear-sky index of all sensors at the time the forecast is generated. The red star indicates the sensor that was used to evaluate forecasts.

Forecast Error Metrics

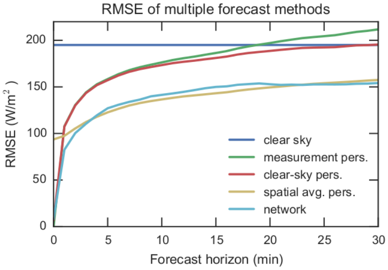


Figure 10: RMSE of many types of forecasts averaged over 46 cloudy days. Clear sky refers to a forecast where one assumes the sky is always clear ($k_n^*(t) = 1$).

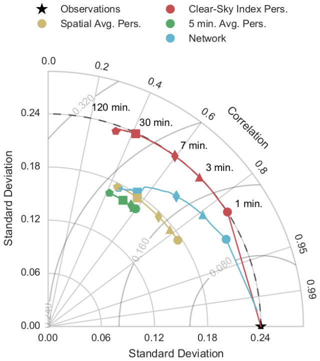


Figure 13: Taylor diagram for clear-sky index persistence (red), spatially-averaged persistence (yellow), 5-min time-averaged persistence (green), and network (light blue) forecasts for 1 min (circle), 3 min (triangle), 7 min (diamond), 30 min (square), and 120 min (pentagon) forecast horizons. The black dashed line indicates the standard deviation of the data. Solid contours around the observations point are lines of constant CRMSE. Forecasts for clear-sky index were used so all quantities are dimensionless. At the 120 min forecast horizon, the spatially-averaged persistence and network points overlap. Network forecasts start with a standard deviation near that of the measurements, but this decreases at longer time horizons as the network forecast begins to resemble spatially-averaged persistence.

Optimal Interpolation

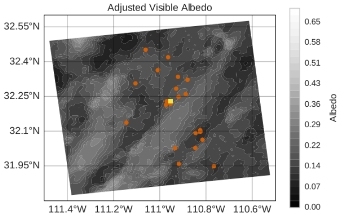


Figure 1: Visible albedo image derived from the visible channel of the GOES-W satellite. Lighter colors indicate cloudier areas. The orange dots represent the locations of the sensors used in this study which includes both irradiance sensors and rooftop PV systems as described in Section 2.2. The yellow square in the center indicates the location of a calibrated GHI sensor on the University of Arizona campus. The image covers an area of roughly 75 × 80 km over Tucson, AZ.

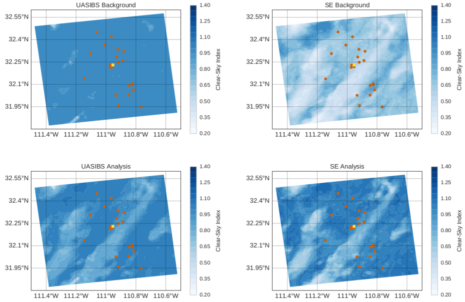


Figure 2: Example background (top row) and analysis (bottom row) clear-sky index images using the UASIBS (left column) and SE (right column) satellite image to ground irradiance models applied to the visible satellite image shown in Fig. 1. Note that in this case, UASIBS failed to produce many clouds. OI adds clouds to the analysis and also makes the darker, clear areas even more clear. In this case, the SE model overproduces clouds. OI reduces the cloud amount while keeping clouds in suitable locations.

OI Corrections

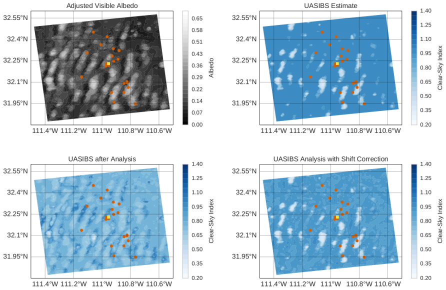
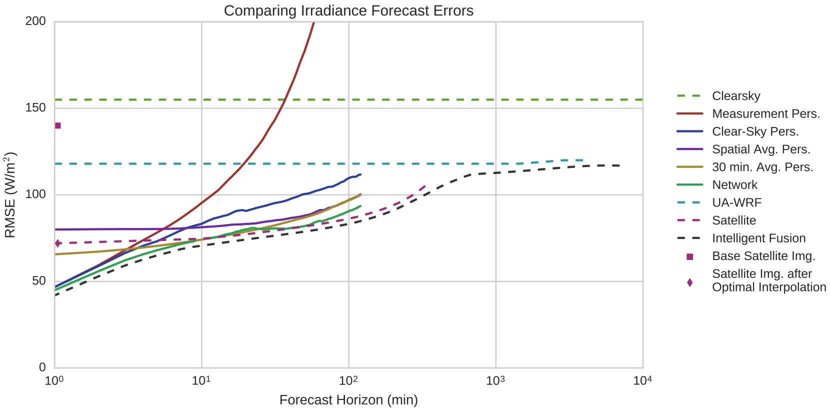


Figure 3: An example of a time when errors in geolocation of the satellite image result in an analysis that is inconsistent with the actual satellite image. The background estimate in this case (upper right) agrees well with the visible satellite image (upper left). However, after performing OI, the analysis (lower left) has clouds in areas that should be clear according to the visible image and sometimes makes areas that should have clouds clear. After shifting the background image slightly, OI produces an analysis (lower right) that is consistent with the visible image.

Conclusion


Comparing Irradiance Forecast Errors
200
150
100
50
0
RMSE (W/m^2)
10^0
10^1
10^2
10^3
10^4
Forecast Horizon (min)
Clearsky
Measurement Pers.
Clear-Sky Pers.
Spatial Avg. Pers.
30 min. Avg. Pers.
Network
UA-WRF
Satellite
Intelligent Fusion
Base Satellite Img.
Satellite Img. after Optimal Interpolation

Publications

- A. T. Lorenzo, W. F. Holmgren, M. Leuthold, C. K. Kim, A. D. Cronin, and E. a. Betterton, "Short-term PV power forecasts based on a real-time irradiance monitoring network," in 2014 IEEE 40th Photovoltaic Specialist Conference (PVSC), 2014, pp. 0075-0079.
- A. T. Lorenzo, W. F. Holmgren, and A. D. Cronin, "Irradiance forecasts based on an irradiance monitoring network, cloud motion, and spatial averaging," Sol. Energy, vol. 122, pp. 1158-1169, 2015.
- A. T. Lorenzo, M. Morzfeld, W. F. Holmgren, and A. D. Cronin, "Optimal Interpolation of Satellite Derived Irradiance and Ground Data," in 2016 IEEE 43th Photovoltaic Specialist Conference (PVSC), 2016.
- A. T. Lorenzo, M. Morzfeld, W. F. Holmgren, and A. D. Cronin, "Optimal interpolation of satellite and ground data for irradiance nowcasting at city scales," Sol. Energy, vol. 144, pp. 466-474, 2017.

Presentations & Posters

Presentations

- PVSC 2014, "Short-term PV power forecasts based on a real-time irradiance monitoring network"
- AZSEC 2015, "Operational Wind and Solar Power Forecasting in the Southwest"
- PVSC 2016, "Optimal Interpolation of Satellite Derived Irradiance and Ground Data"

Posters

- AMS 2015, "Intra-hour solar power forecasts using a real-time irradiance monitoring network"
- AGU 2016, "Fusing Satellite-Derived Irradiance and Point Measurements through Optimal Interpolation"
- AMS 2017, "nabu: A distributed, parallel, data processing platform"

Classes

- OPTI 501 Electromagnetic Waves
- OPTI 502 Optical Design and Instrumentation
- OPTI 506 Radiometry, Sources & Detectors
- OPTI 507 Solid State Optics
- OPTI 508 Probability & Statistical Optics
- OPTI 510R Photonics
- OPTI 511L Laser & Solid State Lab
- OPTI 512L Mathematical Optics Lab
- OPTI 514A Photovoltaic Solar Energy Systems
- OPTI 544 Foundations of Quantum Optics
- OPTI 546 Physical Optics
- OPTI 570A Quantum Mechanics
- OPTI 637 Principles of Image Science
- ATMO 536A Fundamentals of Atmospheric Sciences
- ATMO 545 Intro to Data Assimilation
- ATMO 558 Mesoscale Meteorological Modeling
- MATH 599 Independent Study
- OPTI 589 Optics Outreach
- LIBR 696A Info Research Strategies