The Use of Analog Ensembles to Improve Short-Term Solar Irradiance Forecasting

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Background

- AWS Truepower developed the Solar and Wind Integrated Forecast Tool (SWIFT) (Zack et al., 1:30 PM).
- As part of SWIFT, a Pyramidal Image Matcher (PIM) cloud advection algorithm has been employed as a short term solar irradiance forecast tool.
- Analog Ensemble (AE) has been successfully applied to day-ahead NWP output by Delle Monache, et al. (2013).

Question

- Can AE improve upon the PIM irradiance forecast?
Analog Ensemble Method

1) Compute one or more normalized case-matching variables for the current case and each case in the training sample.

2) Case-matching score: distance between current case and a training sample case in case-matching variable space.

3) Choose the N cases with the lowest case matching scores.
Analog Ensemble Details

- All case-matching variables are normalized.
- Ensemble is calculated independently at each forecast interval with some blending to prevent abrupt transitions.
- Case matching variables are chosen by trial and error using local forecasting knowledge.
Analog Ensemble Forecast Process

Visible Satellite Image

Irradiance software

Gridded Observed Clear Sky Factor

Image Matcher

Analog Ensemble

Ensemble of observed Analogs to current Forecast Situation at Each forecast Site

Case Matching Score Components for each Forecast site

Regime_finder

Gridded Cloud Displacement Vectors and Predicted Clear Sky Factor

Forecast site locations

Case Matching Score Definitions

Definitions
Pyramidal Image Matcher Attributes

- Multi-scale approach enables the PIM to capture the motion and development/dissipation of clouds at all important scales of motion.
- Estimates coarse cloud motion vector field a larger scales using visible satellite images averaged to coarse resolution.
- Refines cloud motion vector field at successively finer scales until the full resolution image is reached.
- Estimates future images by propagating current image forward in time using the motion vector field.

Pyramidal Image Matcher Method

Step 1: Compute 8-km averaged images.

Step 2: Compute Motion Vectors at 8 km resolution.

Step 3: Use motion vectors to estimate 1400 HST 1 km from 1330 image.

Step 4: Average estimated 1 km image to 4 km.

Step 5: Estimate correction to motion vectors using 1330 HST observed 4 km and estimated 1400 HST observed 4 km images.

Step 6: Repeat steps 2-4 at 2 km and 1 km scales.
Pyramidal Image Matcher Configuration

• Motion vector field is derived from the most recent 2 observed images at 16 km resolution, then refined at 8, 4 and 2 km.

• Prediction is done using clear sky factor or CSF.
  – CSF = transmissivity / clear sky transmissivity
  – CSF is derived from visible brightness using the techniques of Perez, et. at. (2002)
  – A bias correction is applied to CSF. Correction varies by solar zenith angle, cloud amount and time (before noon, after noon).

• A 7 hour forecast is produced at 15-minute intervals.


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Experiment Details

- Two forecast periods: January 2013, August 2013.
- The period from 7 hours before to 2 weeks after each forecast time is excluded from its training sample.

Forecast locations:
- Sample of electric substations with substantial rooftop PV.
- Surface irradiance observations.

Verification Variables:
- Satellite-estimated irradiance.
- Observed irradiance.
- Both converted to CSF.
Choice of Case Matching Variables

- Mean over a 10 km box centered on the forecast site.
  - CSF (CSF MEAN).
  - Cloud Displacement vector amplitude (DISPAMP).
  - Cloud displacement vector direction (DISPDIR).
  - Standard deviation of CSF (20 km box) (CSF STDEV).
- Mean cloud X and Y displacement over a larger area 50-100 km upstream in the prevailing east-northeasterly flow (DISPXY).
- Time of day
  - As a case matching variable (TMATCH).
  - As a regime variable (limit ensemble members to those within a certain time window) (TWIN).
Choice of Case Matching Variables
Baseline Forecasts

Mean MAE of ensemble 50% POE over all sites, times vs. satellite estimated CSF.
Choice of Case Matching Variables

Single Variables

Mean MAE of ensemble 50% POE over all sites, times vs. satellite estimated CSF.
Choice of Case Matching Variables

3 Variables - Time is Case Matching Variable

Mean MAE of ensemble 50% POE over all sites, times vs. satellite estimated CSF.
Choice of Case Matching Variables
3 Variables - Time is Regime Variable

Mean MAE of ensemble 50% POE over all sites, times vs. satellite estimated CSF.
Mean MAE of ensemble 50% POE over all sites, times vs. 7 surface observations.
Choice of Case Matching Variables

Single Variables

Mean MAE of ensemble 50% POE over all sites, times vs. 7 surface observations
Choice of Case Matching Variables
3 Variables - Time is Case Matching Variable

Mean MAE of ensemble 50% POE over all sites, times vs. 7 surface observations.
Choice of Case Matching Variables
3 Variables - Time is Regime Variable

Mean MAE of ensemble 50% POE over all sites, times vs. 7 surface observations
Performance By Island
Skill Score vs. Persistence.

JAN

AUG

Skill is higher in August, especially for Maui
Performance by Time of Day
Skill Score vs. Persistence at Different forecast Look ahead times for 7 surface observations

JAN
Skillful Jan 10:00 forecast

AUG
Persistence forecast for 17:00 is poor

Forecast Issue Hour (HST)
Main Points

• An analog ensemble technique was applied as a bias correction tool for a pyramidal image matcher based solar irradiance forecast.
• Verification Results over 2 months showed significant reduction of error over the raw PIM and persistence forecasts.
• Error reduction was more significant at some times of day.

Future Work

• Improve forecast skill at around solar noon.
• Add frequent update NWP-derived variables to the case-matching variables.
• Test the analog ensemble’s utility as a probabilistic forecast tool.
• Apply the technique to other locations.
Questions?