Intra-hour Solar Forecasting

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Variability Reduction through Aggregation

Large ramps are detectable real-time by satellite and ground stations. Variability models primarily needed for large central power plants / microgrids.
PV Variability Model Based on Spatio-Temporal Correlations

Lave, Kleissl, American Solar Energy Society 2011 Conference
Total Sky Imager

Red Blue Ratio

UC San Diego Solar Energy Testbed
Cloud Types

Cirrus

Cumulus
Irradiance measurements on the same days
Offset to show different sites.
Black box corresponds to time period from sky imager.
Cloud Mapping

- Cloud projection
  - Plane formed by cloud base
  - Ceilometer used for height
Percentage co-occurrence of clear and cloudy conditions for measured/nowcast.

<table>
<thead>
<tr>
<th>Date</th>
<th>CLR/CLR</th>
<th>CLR/CLD</th>
<th>CLD/CLR</th>
<th>CLD/CLD</th>
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<td>20.6</td>
<td>8.1</td>
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<td>9.9</td>
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<td>18.3</td>
<td>7.8</td>
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<td>28.9</td>
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<td>56.1</td>
<td>17.3</td>
<td>6.7</td>
<td>19.9</td>
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</table>
Cloud Motion

• Cross correlate image subsection within prescribed neighborhood

\[ t = t_o - 30 \text{ sec.} \]
Cloud Motion Vectors

- Apply cross-correlation method to coordinate-transformed sky image.
- Retain only vectors for which high correlation is obtained.
- Assume homogeneous cloud velocity.

2009-10-04 16:26:30.000

U: -5.8532m/s V: 0.54762m/s
Advection of Frozen Clouds to Obtain Irradiance Forecast
1 to 5 minute forecast

Mean total matching error and total cap error for 30-sec to 5-min ahead forecast. Since errors during overcast and clear conditions are zero, the errors in the table are biased high.

<table>
<thead>
<tr>
<th>Date</th>
<th>30 sec</th>
<th>1 min</th>
<th>2 min</th>
<th>3 min</th>
<th>4 min</th>
<th>5 min</th>
<th>Time until advection out of scene [min]</th>
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<td>55.3</td>
<td>59.3</td>
<td>63.4</td>
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<tr>
<td>Mar 10, 2010</td>
<td>48.8</td>
<td>53.9</td>
<td>62.3</td>
<td>68.8</td>
<td>75.1</td>
<td>78.0</td>
<td>9 - 15</td>
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</table>

Error increases with forecast horizon, but 25% better than persistence after 5 minutes. After 10 to 25 minutes the scene is advected out of the field of view.
Solar forecasts to help optimize power systems
USCD uses numerical weather prediction (NWP) GHI forecasts to predict power output

**π server NWP Forecasts**
- Daily GHI and power forecasts for each campus PV array

**Sky Imagery Forecasts**
- Adding a sky imagery forecasts to be implemented at 10 minute forecast horizon

**Increased efficiency at UCSD**
- Forecasts are input into UCSD smartgrid power optimizer
Los Angeles Warehouse Roof Market

Los Angeles

Puente Hills

Anaheim

Ontario

Black and Veatch, 2010
Sempra Generation Copper Mountain
48 MW Thin Film PV Plant, Largest in the U.S.

PCS 33

1,800 m

PCS 41

TSI deployment site
Deployment

2 days
4 students
$31k in equipment
Success!
Conclusions

• NREL funded total sky imager forecasting at UC San Diego and CAISO Henderson, NV 48 MW PV plant; SCE and SDG&E territory

• Deterministic sky imager forecast valuable up to 5-15 minutes
  – For longer time scales use probabilistic sky cover fraction
  – Hardware limitations

• Integration of solar forecasting products will further reduce forecast error