Intra-hour forecasting with a total sky imager at the UC San Diego solar energy testbed

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May 18, 2011
Ground-Image Based Forecasting

- High time resolution coverage
  - Limited by computing power
- Granular spatial resolution
  - Multi-megapixel cameras
- Reasonable coverage
  - ~15 km² - cloud field dependent
- Short time-horizon
  - 10 to 20 minutes
## Resource Assessment Scales

<table>
<thead>
<tr>
<th></th>
<th>NWP (HRRR)</th>
<th>Satellite (GOES)</th>
<th>Sky Imager</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spatial Resolution</strong></td>
<td>3 km horizontal</td>
<td>1 km² at nadir</td>
<td>100 m² ground projected</td>
</tr>
<tr>
<td><strong>Spatial Coverage</strong></td>
<td>Continental</td>
<td>Continental</td>
<td>15 km²</td>
</tr>
<tr>
<td><strong>Temporal</strong></td>
<td>Hourly</td>
<td>15+ minutes (routine operations)</td>
<td>30 seconds (or faster)</td>
</tr>
</tbody>
</table>
UCSD Operational Forecasting

Monitoring Node

Image Acquisition

Calibrations

Cloud Decision

Cloud Motion

Ancillary Info

Forecast

Database

Legend

- External data
- Matlab code
- Non-Matlab software
- Internet

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Web Service
Cloud Decision

• Ratio of red content to blue content
  – Small values indicate clear sky
  – Values near unity indicate cloud
Cloud Mapping

- Cloud projection
  - Plane formed by cloud base
  - Ceilometer used for height
Cloud Shadow

- Shadow is projected to ground from binary cloudmap using solar angles
  - binary: clear or cloudy
- Sky condition mapped to ground (“shadowmap”)
  - 10 × 10 m grid cells
  - Topography included (SRTM1)

Topography not shown in shadowmap illustration
Sensor Network Layout

Sky Imager
Weather Monitoring Station
Photovoltaic Array
Sky Imager Coverage
TIOG
HUBB
RIMC
MOCC
BMSB
EBU2
Sky Imager

2 km
**Irradiance Parameterization**

- Global Horizontal Irradiance (GHI) [W/m²] parameterized as:

  \[ GHI = kt \cdot GHI_{csk}, \quad kt = \begin{cases} 0.4 & \text{cloudy} \\ 1.0 & \text{clear} \end{cases} \]
Capturing ramps
Cloud Motion

- Cross correlate image subsection within prescribed neighborhood

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

\[ t = t_o \]
Sky Condition Forecasting

- Binary cloudmap → binary comparison metric
  - Condition is **clear** or **cloudy**
- Sky imager derived condition determined from projected cloud shadows
- For pyranometer measurements:
  \[
  \text{clear} \equiv k_t > 0.7 \\
  \text{cloudy} \equiv k_t \leq 0.7, \quad k_t = \frac{GHI}{GHI_{csk}}
  \]
- Four possible outcomes:

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<tr>
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<th>Sky Imager Forecast</th>
<th>match</th>
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<tr>
<td>Clear</td>
<td>clr_m clr_f</td>
<td>clr_m cld_f</td>
</tr>
<tr>
<td>Cloudy</td>
<td>cld_m clr_f</td>
<td>cld_m cld_f</td>
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5-min Forecast Results

a) All 4 days†
b) October 4, 2009
c) March 10, 2010

Sky Imager Forecast

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†includes September 15, 2009 and March 04, 2010
Thank you for your time

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