Performance Plus
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Meteorological modeling: Short-term forecasting and nowcasting of solar irradiance

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Motivation
Outline

- Introduction: forecasting and time horizons
- Sky imagery, hardware and application
- Cloud shadow mapping
- Cloud motion vectors
- Irradiance forecasting and evaluation
Irradiance Forecasting and PV Prediction

- Forecast horizon
- Minutes
- Hours
- Days

- Sky images
- Satellite data
- ECMWF forecast
- DWD forecast

- Irradiance measurement
- PV power measurement

- Site-specific irradiance prediction
- Power prediction
- PV simulation
- Up-scaling

- Representative PV system sites
- PV system description
- Regional PV power prediction

- Module type
- Nominal power

- Tilt and orientation
Very short-term forecasting

Applications for shortest solar forecasting:
- Offgrid PV-Diesel-plants, optimizing standby of the Diesel generator
- Self-consumption, intelligent household electrics
- Battery management
Sky imagery – cloud remote sensing

Sky imager

- Monitoring, archiving
- Calculation of cloud cover, cloud type, direct sun
- Cloud motion vectors
- Retrieve irradiance forecast
- Advantage: Reproducebility of the data
Cloud decision process

- Analyse each single pixel: Red-Blue-Ratio to separate Cloud and blue sky
- Clear sky library for corrections
- Apply global threshold
- Calculate cloudy and blue pixels
Shadow mapping

From binary cloud cover to surface shadow maps:

1. Consider orientation of imager
2. Lens function -> undistorted 2D clouds
3. Estimation of cloud height or ceilometer measurement (single layer assumption)
4. Geometric calculation of position of clouds (zenith and azimuth angle)
Surface Irradiance Estimation

- Interpolating image pixels to regular grid
- Smoothing values with Gaussian filter (3x3 cells)
Surface Irradiance Estimation

- Interpolating image pixels to regular grid
- Smoothing values with Gaussian filter (3x3 cells)
- Analyse past clear sky indices (1 hour) to find typical values for shadow / no shadow

\[
\text{ClearSkyIndex} = \frac{\text{GHI}_{\text{meas}}}{\text{GHI}_{\text{clearsky}}}
\]
1. Corner Detection (Shi-Tomasi-Algorithm): Find good points to track (mask horizon and sun region)

2. Optical flow (Lucas-Kanade-Algorithm): Find the points in the subsequent image

3. Quality check of vectors

4. Averaging to global vector
Experimental validation, HD(CP)$^2$ campaign

100 pyranometer stations, high temporal and spatial resolution:
- Investigation of cloud-radiative-effects (shadowing, enhancements)
- Validation of 4D MC radiative transfer models
- Validation of satellite products
- Analysis of cloud shadows for PV-power modelling
Experimental validation, HD(CP)$^2$ campaign

100 autonomous stations:
10 Hz sampling
- Solar irradiance
- Temperature
- Rel. humidity
- GPS: time, lat., lon.

Photodiode-Pyranometer EKO ML20 VM
- Spectral range: 300-1100nm
Experimental validation, HD(CP)$^2$ campaign

- 100 pyranometers in Jülich Apr. - July 2013
- 8 x 10 km$^2$
- Irradiance: 1sec resolution
- Sky imager, resolution 15sec
- Ceilometer for cloud height detection
Experimental validation, HD(CP)$^2$ campaign

Experimental validation, HD(CP)$^2$ campaign

2013-05-24 12:06:00 UTC

Raw Image (masked and rotated)

Cloud Decision Map

Cloud Base Height: 2230.0m

Station 45

Irradiance [W/m$^2$]

0 200 400 600 800 1000 1200 1400

Forecast Horizon [s]

Analyses
Forecast
Measurement
Clear Sky
Forecast evaluation

Performance of sky imager forecast is estimated as forecast skill:

\[ FS = 1 - \left( \frac{relRMSE_{Forecast}}{relRMSE_{Persistance}} \right) \]

- \( FS > 0 \): Forecast better than Persistence
- \( FS < 0 \): Forecast worse than Persistence

FS increases with forecast lead time

On most days forecast performance is worse than persistence
Forecast evaluation

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Example:
24th May 2013
FS > 0 after 6 min
Forecast evaluation

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Example:
24th May 2013
FS > 0 after 6 min
Forecast evaluation
→ What do we learn?

• Sky imager analysis can improve irradiance forecasts on small temporal and spatial scales

• Improvements exist for broken cloud scenarios, not for clear sky and overcast

• Sky imager based forecast quality depend on:
  – Wind speed
  – Cloud height, cloud development, vertical extension
  – Solar elevation
  – Imager position / geometric projection
Thank you for Your attention!