Short-term solar forecasting with statistical models and combination of models

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Forecasting methods

- **CM-SI**: Cloud-motion based on sky-imagers
- **CM-Sat**: Cloud-motion based on satellite images
- **NWP**: Numerical Weather Prediction model

Use of statistical models for intra-day solar forecasting

Focus on intra-day solar forecasting i.e. predictions of the solar irradiance from 1h up to 6 hours in the future

Forecast horizon

1h - 6h
Outline of the presentation

Past ground measurements of GHI

GHI: Global Horizontal Irradiance

Forecasting model

GHI forecasts
Outline of the presentation

Past ground measurements of GHI

Forecasting model

GHI forecasts

Forecasting Error
Outline of the presentation

Past ground measurements of GHI

Forecasting model

GHI forecasts

Ground observations vs. Forecast

Forecasting Error

Ground vs. Ground+NWP

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Outline of the presentation

Past ground measurements of GHI

Forecasting model

GHI forecasts

Forecasting Error

Ground

Ground+NWP

Ground+NWP+Satellite

Forecast Horizon (hour)

1 2 3 4 5 6

10 15 20 25 30 35 40 45 50

Satellite data

NWP
Sites for intra-day solar forecasting

2 stations from the SURFRAD network: Desert Rock and Fort Peck

Sites for intra-day solar forecasting

3 insular sites: La Réunion island (2) and Gran Canaria island
Data processing

Forecasting models are fitted to the clear sky index time series

Clear sky model

Clear sky index: \[ k^* = \frac{GHI}{GHI_{\text{clear}}} \]

Heure

Rayonnement global (W/m²)

GHI

0 10 20 30 40 50 60 70
0 500 1000

0 10 20 30 40 50 60 70
0 0.5 1

Clear sky

Cloudy

Overcast

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Sky conditions analysis

Solar variability

- Saint-Pierre: intermediate
- Le Tampon: low
- Desert Rock: high
- Fort Peck: intermediate

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Benchmarking of the forecasting models

2 references models: Persistence and climatological mean

1 time series model model (ARMA model) with recursive estimation of the parameters

1 machine learning technique (Artificial Neural Network)

Evaluation of the forecasting performance:

\[ RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (GHI_{\text{forecast}.i} - GHI_{\text{measured}.i})^2} \]

Forecast skill parameter: \[ s(\%) = \left(1 - \frac{RMSE_{\text{method}}}{RMSE_{\text{pers}}}\right) \times 100 \]
Results - Reference models

Saint-Pierre

Le Tampon

Desert Rock

Fort Peck

<table>
<thead>
<tr>
<th>Forecast Horizon (hour)</th>
<th>Relative RMSE (%)</th>
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<tbody>
<tr>
<td>1</td>
<td>15</td>
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<td>2</td>
<td>20</td>
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<td>3</td>
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<td>5</td>
<td>35</td>
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<td>6</td>
<td>40</td>
</tr>
</tbody>
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Climatology: \( \bar{k}^*(t + h) = \text{mean}(k^*) \)

Persistence: \( \bar{k}^*(t + h) = k^*(t) \)
Results - Reference models

\[ \overline{k}(t + h) = \text{mean} (k^*) \]
\[ \overline{k}(t + h) = k^*(t) \]
Forecasting methodology with time series model

Past ground measurement values of $k^*$

Forecast $k^*$ for time horizon $h$

$k^*(t) ightarrow k^*(t-1) ightarrow k^*(t-2)$

Forecasting model

$k^*(t+h), h=1,2,3...,6$

Ground observation

Forecast

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Results – Use of ground data only

Saint-Pierre

Le Tampon

Desert Rock

Fort Peck

\[ k^*(t) \]
\[ k^*(t - 1) \]
\[ k^*(t - 2) \]

\[ k^*(t + h) \]

Forecasting model: Arma.RIs or Neural Network

Climatology - - - ARMA.RIs
Persistence - - - ANN
Use of exogenous inputs provided by NWP models

GHI and TCC forecasts provided by the European Centre for Medium Range Weather Forecasts (ECMWF)

- IFS model
- Generated at 12h00 UTC (16h00 in Reunion)
- Available at 18h55 UTC (22h55 in Reunion)
- Spatial resolution: 0.125° x 0.125° (≈ 14 x 14 km near Reunion)
- Temporal resolution: 1 hour
Results – Combination of Ground and ECMWF data

Climatology

ARMA.RIs

Persistence

ANN

Ground+NWP

k^∗(t)
k^∗(t-1)
k^∗(t-2)
k^∗ECMW(t+h)
TCC^∗ECMW(t+h)

Neural Network
Results – Combination of Ground and ECMWF data

Higher values of s-skill scores are obtained with the combination of on-site measured irradiance and NWP model output.
Exogenous inputs provided by Satellite data

Satellite-derived GHI for Gran Canaria obtained from HelioClim solar radiation databases

- Spatial resolution: 3 km x 3km
- Temporal resolution: 15 mins

Fig. 1. Geographic distribution of satellite-derived data obtained from HC3v5 for Gran Canaria Islands. Courtesy of MINES ParisTech/ARMINES.
Selection of Satellite pixels

Selection of satellite pixels by calculating the cross-correlation between ground clear sky index and satellite clear sky indices:

\[ C_{k^*}(i,j)_h = \text{corr} \left( k_{\text{ground}}^*(t), k_{\text{satellite}}^*(t - h) \right) \quad \text{for} \quad h = 0, 1, 2 \& 3 \]

Fig. 8. Intercorrelation annual map for clear sky index between ground measurement and each satellite pixel around the measurements at station C1 – Las Palmas for time lag \( h = 0, 1, 2 \) and \( 3 \) h.
Overall, the forecast skill of the combination GROUND+ECMWF+SAT is better than the forecast skill of the two other models GROUND+ECMWF and GROUND+SAT.
Conclusions and further investigations

✓ Use of exogenous inputs (such as those provided by NWP models or Satellite data) improve the accuracy of the intra-day solar forecasts.

Further investigations:

◆ Use of other input parameters e.g. wind fields, humidity, cloud height provided by a NWP model

◆ Implementation of ECMWF forecasts in an ARMAX Recursive Least Square model
Further readings: Use of exogenous inputs in forecasting models:


