Global validation of satellite-based and reanalysis surface solar radiation data sets

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Motivation of this study

- Consistent evaluation of available global climate data records of surface irradiance
- Identify regions of consistency and of inconsistency between the different data records
- Focus on the absolute accuracy and decadal trends
Data: 3 reference data sets, 6 gridded data sets

- **Reference Data**
  - BSRN, GEBA / WRDC, Buoy networks: TAO / TRITON, PIRATA, RAMA

- **Satellite Data**
  - CERES EBAF ed 4.0 (1°x1°; 2000-2018)
  - CM SAF CLARA-A2.1 (0.25°x0.25°; 1982-2017)
  - ESA Cloud_cci AVHRR-PMv3 (0.5°x0.5°; 1982-2018)
  - GEWEX SRB v3 (1°x1°; 1983-2007)

- **Reanalysis Data**
  - ECMWF ERA-5 (0.25°x0.25°; 1983-2018)
  - NASA MERRA-2 (0.5°x0.625°; 1980-2018)
Methods

- Evaluate monthly mean surface irradiance for a total of about 400 reference stations on land and ocean
- Estimate various statistical quantities, e.g., bias, abs. bias, anomaly correlation, trends, ...
- Provide information for the full period (for each gridded data set) and for a common time period (2000 to 2017) to allow comparison between data sets
- Calculate the ‘ensemble’ climatology and trend including spread between the gridded data sets
### Results: Global values

<table>
<thead>
<tr>
<th>Data</th>
<th>Full time periods</th>
<th></th>
<th></th>
<th>Correlation</th>
<th>Common period (2000-2017)</th>
<th></th>
<th></th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>#</td>
<td>Bias</td>
<td>MAB</td>
<td>RMSE</td>
<td>#</td>
<td>Bias</td>
<td>MAB</td>
<td>RMSE</td>
</tr>
<tr>
<td>CERES</td>
<td>~69k</td>
<td>2.33</td>
<td>9.14</td>
<td>14.0</td>
<td>~63k</td>
<td>2.30</td>
<td>9.15</td>
<td>14.0</td>
</tr>
<tr>
<td>CLARA</td>
<td>~119k</td>
<td>1.76</td>
<td>10.85</td>
<td>15.2</td>
<td>~63k</td>
<td>2.15</td>
<td>10.28</td>
<td>15.4</td>
</tr>
<tr>
<td>ESA CCI</td>
<td>~119k</td>
<td>5.46</td>
<td>11.66</td>
<td>16.5</td>
<td>~63k</td>
<td>4.76</td>
<td>10.93</td>
<td>15.8</td>
</tr>
<tr>
<td>GEWEX</td>
<td>~75k</td>
<td>3.81</td>
<td>13.13</td>
<td>18.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ERA-5</td>
<td>~117k</td>
<td>7.29</td>
<td>12.55</td>
<td>16.1</td>
<td>~63k</td>
<td>6.38</td>
<td>11.89</td>
<td>15.7</td>
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<tr>
<td>MERRA-2</td>
<td>~123k</td>
<td>19.6</td>
<td>23.61</td>
<td>22.8</td>
<td>~63k</td>
<td>17.3</td>
<td>22.02</td>
<td>22.2</td>
</tr>
</tbody>
</table>

# = number of months; MAB = mean absolute bias [W/m²]; bias, rmse in W/m²; cor = anomaly correlation

- Satellite data compare better to reference data than reanalysis data records
- CERES and CLARA-A2.1 data records have comparable quality
- Quality of MERRA-2 data set significantly reduced compared to other data sets
Regional Results: bias, common period, satellite data sets

- Comparable spatial distribution*
- Low bias in Europe, North America*
- Overestimation of surface irradiance in China / India*

*Please zoom-in for the details
Regional Results: bias, common period, reanalysis data sets

→ ERA-5
   → moderate bias in Europe, North America*
   → overestimation of surface irradiance in China / India*

→ MERRA
   → Significant overestimation in Europe, North America, China, India, Japan*
   → Underestimation in the Indian and Western Pacific Oceans*

*Please zoom-in for the details
Surface Radiation Ensemble Climatology I

- Estimate the surface radiation ensemble climatology (2000 to 2017) as the average of the mean surface irradiance from the three satellite data records and ERA-5 (i.e., neglecting MERRA due to degraded accuracy)

- Spatially averaged surface irradiance:
  188 W/m²
Surface Radiation Ensemble Climatology II

- Regions with largest (relative) range between data set:
  - Southern polar ocean
  - Himalaya
  - West Coast of South America

![Map showing climate data range and mean values between 2000-2017](image)
Evaluation by reference dataset

<table>
<thead>
<tr>
<th>Ref Data</th>
<th>CERES</th>
<th>CLARA</th>
<th>ESA_CCI</th>
<th>ERA-5</th>
<th>MERRA-2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>bias</td>
<td>MAB</td>
<td>cor</td>
<td>bias</td>
<td>MAB</td>
</tr>
<tr>
<td>BSRN</td>
<td>-0.6</td>
<td>8.4</td>
<td>0.90</td>
<td>-1.8</td>
<td>9.8</td>
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<tr>
<td>GEBAD/WRDC</td>
<td>2.6</td>
<td>9.3</td>
<td>0.85</td>
<td>2.3</td>
<td>10.4</td>
</tr>
<tr>
<td>Buoys</td>
<td>2.9</td>
<td>7.9</td>
<td>0.86</td>
<td>6.0</td>
<td>9.5</td>
</tr>
</tbody>
</table>

MAB = mean absolute bias [W/m²]; bias in W/m²; cor = anomaly correlation

- Comparable performance for all reference data sets
- No systematic uncertainty in any reference data set of monthly mean surface irradiance
- The correlation with BSRN data is highest for all gridded data sets
Validation: Stability / Trend

Times series of the mean bias [W/m2] vs. all stations

→ Constant bias required for high quality estimates of trends / changes

- Most station-based trends (2000 – 2017) are within ±3 W/m²/dec
- Correlation coefficients > ~0.7 for all data sets except MERRA-2
- Gridded data sets tends to underestimate the absolute value of the trend, ie., slopes are always well below 1.
Average trend based on gridded data sets

Mean trend [W/m²/decade], 2000-2017

- Substantial regional differences in the mean trend
- See the trends for the individual data sets in the Appendix

*Results from MERRA-2 not included in the average
Range of the trends based on gridded data sets*

Data sets agree on the trend in many regions

Regions with higher range include Indo-Pacific, Arctic, Western South America

*Results from MERRA-2 not included in the average
Summary

- Satellite-based data sets of surface irradiance outperform reanalysis data set
- ERA-5 performs significantly better than MERRA-2
- Measurements from buoy networks are a useful source of irradiance data
- Best estimate of Global Surface Irradiance: 188 W/m²
- Trends vary regionally
Appendix
CM SAF CLARA-A2

→ Variables
   → Cloud properties
   → Surface albedo
   → Surface Radiation

→ Resolution
   → Spatial: 0.25° × 0.25°
   → Temporal: daily-, pentad-, monthly mean

→ Coverage
   → Spatial: global
   → Temporal: 1982 to 2015
     (2016 to 2019 available upon request)

Available at www.cmsaf.eu


DOI:10.5676/EUM_SAF_CM/CLARA_AVHRR/V002
Regional Results: abs. bias, common period, satellite data sets

- CERES_EBAF_Ed4 abs. bias [W*m-2] vs. all stations
- CLARA-A2 abs. bias [W*m-2] vs. all stations
- ESACCI abs. bias [W*m-2] vs. all stations

⇒ Comparable spatial distribution*

*Please zoom-in for the details
Regional Results: abs. bias, common period, reanalysis data sets

*Please zoom-in for the details*
Trends (2000 – 2017), satellite and reanalysis data

- Many regions with consistent trends
- MERRA-2 has different pattern compared to the other data sets