Developing an AVHRR-based CDR of TOA radiative fluxes within the CMSAF Project

Akkermans, T., Clerbaux, N., Baudrez, E., Velazquez, A., Moreels, J., Moutier, W., Ipe, A.

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Overview

1. Introduction: CM-SAF, CLARA, radiative flux products
2. Developing the CDR: details of algorithm
3. Results and validation with CERES datasets
4. Conclusions and outlook
1. Introduction

What is CM SAF?

- Project generating and delivering Climate Data Records from weather satellites (part of EUM ground segment)
- Products target the energy and water cycles: radiation, IWV, clouds, precip, turb. fluxes,..
- Polar and geo satellites (regional+global products)

TOA radiation products in CMSAF:

- Until now, all based on geostationary satellites (Meteosat) with GERB instrument, in combination with imager SEVIRI/MVIRI
- Currently released datasets:
  - MVIRI/SEVIRI data record (Urbain et al., 2017); 1982-2015, GERB used “offline”, Resolution 0.05°x0.05°
  - GERB/SEVIRI data record (Clerbaux et al., 2017); 2004-2015, Drift corrected, All-sky and clear-sky fluxes, Resolution 0.1°x0.1°
What is CLARA? “CM SAF cLoud, Albedo and RAdition dataset from AVHRR data” (=Similar to Patmos-X)

- Polar orbiting satellites NOAA and MetOp
- FCDR from NOAA (Heidinger et al., 2010)
- Currently released versions:

Some of the modifications in upcoming version CLARA-A3:

- Inclusion of AVHRR-1 sensor (TIROS-N, NOAA-6, -8, -10): extension of time range to 1978-2019 i.e. 42yr
- Updated FCDR, from Fiduceo project (http://www.fiduceo.eu)
- Updated cloud treatment algorithms (NWCSAF/PPS v.2018; Karlsson et al.)
- Addition of new product “TOA radiative fluxes” -> this presentation
2. Development of algorithm

**PART 1**
- **Land use map**
  1. USGS
  2. IGBP
- **AVHRR NB reflectances**
- **Cloud mask**
  1. Binary (0 or 100)
  2. Probabilistic

**ADM’s**
- **NB-to-BB**
  - BB reflectance
  - BB radiance
- **BB flux**
- **BB albedo**

**PART 2**
- **Spatial aggreg. regridding 0.25°**
  1. Simple/fast: reproject pixel centre
  2. Complex: reproject pixel area

**PART 3**
- **Diurnal cycle modeling**
  - Per pixel: match observed albedo with modelled diurnal cycle (5'bins) + interpolate

**PART 4**
- **Daily mean**
- **Monthly mean**
2. Development of algorithm

Narrowband-to-broadband (NB-to-BB) conversion:

*Newly derived regressions AVHRR-CERES*

\[ \alpha_{SW} = b_0 + b_1 \cdot \alpha_{0.6} + b_2 \cdot \alpha_{0.8} + b_3 \cdot \ln \left( \frac{1}{\mu_0} \right) \]

**PART 1**

- Land use map
  1. USGS
  2. IGBP
- AVHRR NB reflectance
  \( \alpha_{erg} \)
  \( \alpha_{SW} \)
- Cloud mask
  1. Binary (0 or 100)
  2. Probabilistic

**NB-to-BB**

- BB reflectance
- BB radiance

**ADM’s**

- BB flux
- BB albedo

**PART 2**

- Spatial aggreg. regridding 0.25°

  1. Simple/fast: reproject pixel centre
  2. Complex: reproject pixel area

**PART 3**

- Diurnal cycle modeling
  - Per pixel: match observed albedo with modelled diurnal cycle (5' bins) + interpolate

**PART 4**

- Daily mean
- Monthly mean

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2. Development of algorithm

Narrowband-to-broadband (NB-to-BB) conversion:

- Newly derived regressions are needed!

Requirements:
- Simultaneous
- Coangular

\[ \alpha_{SW} = \frac{1}{\mu_0} \]

\[ \alpha_{BB} = b_0 + b_1 \cdot \alpha_{SW} + b_3 \cdot l \]

PART 1

<table>
<thead>
<tr>
<th>Land use map</th>
<th>NB-to-BB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. USGS</td>
<td>BB reflectance</td>
</tr>
<tr>
<td>2. IGBP</td>
<td>BB radiance</td>
</tr>
</tbody>
</table>

Cloud mask
- 1. Binary (0 or 100)
- 2. Probabilistic

PART 2

Spatial aggreg. regridding 0.25°
- 1. Simple/fast: reproject pixel centre
- 2. Complex: reproject pixel area

PART 3

Diurnal cycle modeling
- Per pixel: match observed albedo with modeled diurnal cycle (5' bins) + interpolate

PART 4

Daily mean
- Monthly mean

- Large database of collocated NB and BB observations is needed!
2. Development of algorithm

- CERES -> AQUA orbit: stationary, 700km, period 99’
- AVHRR -> NOAA19 orbit: orbital drift, 850km, period 102’ (slower)

Coangular observations occur with similar viewing geometry, so mainly with coinciding orbital plane (=similar local solar time); hence, focus on these months to gather data:

![Graph showing local time and orbit comparison](image)
Within coinciding orbital plane:

- CERES -> AQUA orbit: 700km, period 99’ (faster)
- AVHRR -> NOAA19 orbit: 850km, period 102’ (slower)

At least once every 48 hours, the faster AQUA catches up with the slower NOAA19: near this point, collocated observations from both satellites have:

- Minimal time lag ~*simultaneous* observation
- Similar viewing geometry ~*coangular* observation
2. Development of algorithm

- Temporal (<450s) and angular (<4.5°) constraints are used in matching algorithm.
- CERES pixel dimensions (size, shape) increase with viewing zenith angle due to an increasingly spread-out projected area (which is even more magnified by the earth's curvature)
- AVHRR pixels inside CERES footprint are identified, aggregated, and compared with CERES
- Calibration on subset of 80% observations, validation on remaining 20%
Equation: \[ \alpha_{SW} = b_0 + b_1 \cdot \alpha_{0.6} + b_2 \cdot \alpha_{0.8} + b_3 \cdot \ln \left( \frac{1}{\mu_0} \right) \]

CERES BB reflectance  AVHRR channels 1 and 2  cosine of solar zenith angle
Equation:

\[ \alpha_{SW} = b_0 + b_1 \cdot \alpha_{0.6} + b_2 \cdot \alpha_{0.8} + b_3 \cdot \ln \left( \frac{1}{\mu_0} \right) \]

CERES BB reflectance = AVHRR channels 1 and 2

cosine of solar zenith angle

2. Development of algorithm

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2. Development of algorithm

Equation:

\[ \alpha_{SW} = b_0 + b_1 \cdot \alpha_{0.6} + b_2 \cdot \alpha_{0.8} + b_3 \cdot \ln \left( \frac{1}{\mu_0} \right) \]

CERES BB reflectance  AVHRR channels 1 and 2  cosine of solar zenith angle
2. Development of algorithm

Equation:

\[ \alpha_{SW} = b_0 + b_1 \cdot \alpha_{0.6} + b_2 \cdot \alpha_{0.8} + b_3 \cdot \ln \left( \frac{1}{\mu_0} \right) \]

CERES BB reflectance  AVHRR channels 1 and 2  cosine of solar zenith angle

Table 3. Resulting coefficients (from regression on calibration subset; 80% of sample) for clear, overcast, and allsky conditions; period: 1/7/2011-30/6/2012 (NOAA-19).

<table>
<thead>
<tr>
<th>Surface type</th>
<th>Clear-sky</th>
<th></th>
<th>Overcast</th>
<th></th>
<th>Overcast</th>
<th></th>
<th>All-sky</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( b_0 )</td>
<td>( b_1 )</td>
<td>( b_2 )</td>
<td>( b_3 )</td>
<td>( b_0 )</td>
<td>( b_1 )</td>
<td>( b_2 )</td>
<td>( b_3 )</td>
</tr>
<tr>
<td>Ocean</td>
<td>1.806</td>
<td>1.265</td>
<td>-0.724</td>
<td>-0.365</td>
<td>4.819</td>
<td>0.293</td>
<td>0.449</td>
<td>0.261</td>
</tr>
<tr>
<td>Forests</td>
<td>0.213</td>
<td>0.644</td>
<td>0.400</td>
<td>0.778</td>
<td>3.439</td>
<td>0.322</td>
<td>0.433</td>
<td>1.029</td>
</tr>
<tr>
<td>Savannas</td>
<td>1.087</td>
<td>0.430</td>
<td>0.427</td>
<td>2.055</td>
<td>3.607</td>
<td>0.404</td>
<td>0.344</td>
<td>3.525</td>
</tr>
<tr>
<td>Grass/crop</td>
<td>1.770</td>
<td>0.450</td>
<td>0.372</td>
<td>1.306</td>
<td>3.885</td>
<td>0.376</td>
<td>0.373</td>
<td>1.410</td>
</tr>
<tr>
<td>Dark deserts</td>
<td>2.280</td>
<td>0.312</td>
<td>0.424</td>
<td>1.352</td>
<td>2.642</td>
<td>0.168</td>
<td>0.596</td>
<td>1.634</td>
</tr>
<tr>
<td>Bright deserts</td>
<td>3.295</td>
<td>0.369</td>
<td>0.327</td>
<td>1.702</td>
<td>0.719</td>
<td>0.439</td>
<td>0.338</td>
<td>3.589</td>
</tr>
<tr>
<td>Perm. snow/ice</td>
<td>5.949</td>
<td>0.171</td>
<td>0.523</td>
<td>-0.675</td>
<td>18.891</td>
<td>0.100</td>
<td>0.494</td>
<td>-2.018</td>
</tr>
<tr>
<td>Fresh snow</td>
<td>2.375</td>
<td>0.246</td>
<td>0.464</td>
<td>1.164</td>
<td>2.751</td>
<td>0.239</td>
<td>0.529</td>
<td>0.794</td>
</tr>
<tr>
<td>Sea ice 100%</td>
<td>-1.359</td>
<td>0.190</td>
<td>0.591</td>
<td>0.383</td>
<td>-0.352</td>
<td>0.284</td>
<td>0.525</td>
<td>1.685</td>
</tr>
<tr>
<td>Sea ice 95-99%</td>
<td>2.385</td>
<td>0.157</td>
<td>0.579</td>
<td>-0.203</td>
<td>8.370</td>
<td>0.138</td>
<td>0.578</td>
<td>-0.425</td>
</tr>
<tr>
<td>Sea ice 90-95%</td>
<td>7.368</td>
<td>0.198</td>
<td>0.464</td>
<td>-0.152</td>
<td>9.583</td>
<td>0.142</td>
<td>0.556</td>
<td>-0.599</td>
</tr>
<tr>
<td>Sea ice 80-90%</td>
<td>-1.496</td>
<td>0.408</td>
<td>0.367</td>
<td>1.547</td>
<td>9.191</td>
<td>0.165</td>
<td>0.534</td>
<td>-0.359</td>
</tr>
<tr>
<td>Sea ice 60-80%</td>
<td>2.496</td>
<td>0.492</td>
<td>0.192</td>
<td>0.523</td>
<td>5.833</td>
<td>0.248</td>
<td>0.492</td>
<td>0.247</td>
</tr>
<tr>
<td>Sea ice 10-60%</td>
<td>4.000</td>
<td>0.468</td>
<td>0.144</td>
<td>-0.020</td>
<td>5.075</td>
<td>0.212</td>
<td>0.540</td>
<td>-0.023</td>
</tr>
<tr>
<td>Sea ice 0-10%</td>
<td>1.237</td>
<td>1.392</td>
<td>-0.662</td>
<td>-0.820</td>
<td>5.076</td>
<td>0.219</td>
<td>0.534</td>
<td>-0.156</td>
</tr>
</tbody>
</table>

Tom A
14/27
2. Development of algorithm

Root-Mean-Square residual (RMSr):

$$\sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n} [(\hat{\alpha}_{SW,i} - \alpha_{SW,i})^2]}$$

relative Root-Mean-Square residual (rRMSr):

$$\sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n} [(\hat{\alpha}_{SW,i} - \alpha_{SW,i})^2]} \cdot \frac{1}{\frac{1}{n} \cdot \sum_{i=1}^{n} \alpha_{SW,i}}$$

relative Mean Bias (rMB):

$$\frac{1}{n} \cdot \sum_{i=1}^{n} (\hat{\alpha}_{SW,i} - \alpha_{SW,i}) \cdot \frac{1}{\frac{1}{n} \cdot \sum_{i=1}^{n} \alpha_{SW,i}}$$

Table 4. Overview of linear regression performance statistics (on validation subset; 20% of the observations) for clear, overcast, and allsky conditions; period: 1/7/2011-30/6/2012 (NOAA-19).

<table>
<thead>
<tr>
<th>Surface type</th>
<th>Clear-sky</th>
<th>Overcast</th>
<th>All-sky</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>rMB</td>
<td>rRMSr</td>
<td>rMB</td>
</tr>
<tr>
<td>Ocean</td>
<td>-0.04%</td>
<td>4.82%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Forests</td>
<td>-0.04%</td>
<td>3.12%</td>
<td>0.06%</td>
</tr>
<tr>
<td>Savannas</td>
<td>0.07%</td>
<td>3.03%</td>
<td>-0.41%</td>
</tr>
<tr>
<td>Grass/crop</td>
<td>0.01%</td>
<td>3.58%</td>
<td>0.06%</td>
</tr>
<tr>
<td>Dark deserts</td>
<td>0.01%</td>
<td>3.48%</td>
<td>-0.14%</td>
</tr>
<tr>
<td>Bright deserts</td>
<td>0.00%</td>
<td>2.61%</td>
<td>-0.12%</td>
</tr>
<tr>
<td>Perm. snow/ice</td>
<td>0.00%</td>
<td>0.86%</td>
<td>-0.01%</td>
</tr>
<tr>
<td>Fresh snow</td>
<td>-0.05%</td>
<td>2.82%</td>
<td>-0.03%</td>
</tr>
<tr>
<td>Sea ice 100%</td>
<td>0.03%</td>
<td>1.55%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Sea ice 95-99%</td>
<td>0.01%</td>
<td>1.51%</td>
<td>0.02%</td>
</tr>
<tr>
<td>Sea ice 90-95%</td>
<td>0.00%</td>
<td>1.83%</td>
<td>0.07%</td>
</tr>
<tr>
<td>Sea ice 80-90%</td>
<td>0.00%</td>
<td>1.55%</td>
<td>0.01%</td>
</tr>
<tr>
<td>Sea ice 60-80%</td>
<td>-0.14%</td>
<td>2.84%</td>
<td>0.01%</td>
</tr>
<tr>
<td>Sea ice 10-60%</td>
<td>0.14%</td>
<td>9.53%</td>
<td>-0.01%</td>
</tr>
<tr>
<td>Sea ice 0-10%</td>
<td>-0.20%</td>
<td>4.41%</td>
<td>0.09%</td>
</tr>
</tbody>
</table>

rMB: relative mean bias (%); rRMSr: relative root-mean-square residual (%)
3. Results/validation

**PART 1**
- Land use map
  1. USGS
  2. IGBP
- AVHRR NB reflectances
- Cloud mask
  1. Binary (0 or 100)
  2. Probabilistic

**NB-to-BB**
- BB reflectance
- BB radiance

**ADM’s**
- BB flux
- BB albedo

**PART 2**
- Spatial aggreg. regridding 0.25°

**PART 3**
- Diurnal cycle modeling
  - Per pixel: match observed albedo with modelled diurnal cycle (5' bins) + interpolate

**PART 4**
- Monthly mean

4 monthly means: Mar, Jun, Sep, Dec
3. Results/validation

CLARA-A3 TOA SW radiation (201203)

March

Mean = 96.01 W/m²

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3. Results/validation

CLARA-A3 TOA SW radiation (201206)

June

Mean = 92.08 W/m²

Map: Mollweide projection, 26x26km (GCS-World)
3. Results/validation

CLARA-A3 TOA SW radiation (201209)

September

Mean=91.06 W/m²

Map: Mollweide projection, 26x26km (GCS-WGS84)
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3. Results/validation

CLARA-A3 TOA SW radiation (201212)

December

Mean=103.63 W/m²

Map: Mollweide projection, 26x26km (GCS:WGS84)
3. Results/validation

**PART 1**

- Land use map
  1. USGS
  2. IGBP
- AVHRR NB reflectances
- Cloud mask
  1. Binary (0 or 100)
  2. Probabilistic

**NB-to-BB**

- BB reflectance
- BB radiance

**ADM’s**

- BB flux
- BB albedo

**PART 2**

- Instantaneous *swath* grid
- Spatial aggreg. regidding 0.25°
  1. Simple/fast: reproject pixel centre
  2. Complex: reproject pixel area
- Instantaneous *regular* grid

**PART 3**

- Diurnal cycle modeling
  - Per pixel: match observed albedo with modelled diurnal cycle (5' bins) + interpolate
  - Daily mean

**PART 4**

- SYN1deg-Ed4A
  - Monthly mean
  - SYN1deg-Ed4A
  - bias

---

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3. Results/validation

Bias of CLARA-A3 TOA SW radiation w.r.t. CERES-SYN (201203) March

ME = -1.38 W/m²; MAE = 2.74 W/m²
3. Results/validation

Bias of CLARA-A3 TOA SW radiation w.r.t. CERES-SYN (201206) June

ME = -1.29 W/m²; MAE = 2.75 W/m²

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Developing an AVHRR-based CDR of TOA radiative fluxes within the CMSAF Project

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3. Results/validation

Bias of CLARA-A3 TOA SW radiation w.r.t. CERES-SYN (201209) September

ME=-1.47 W/m²; MAE=2.51 W/m²
3. Results/validation

Bias of CLARA-A3 TOA SW radiation w.r.t. CERES-SYN (201212)

December

ME=-1.89 W/m²; MAE=2.90 W/m²
3. Results/validation

ADM: Loeb et al. (CERES-TRMM/-TERRA)

2012-06
-1.29 W/m²

2012-09
-1.47 W/m²

2012-12
-1.89 W/m²

ADM: Suttles et al., 1988 (ERBE)

2012-06
-3.86 W/m²

2012-09
-4.29 W/m²

2012-12
-4.70 W/m²
3. Results/validation

**PART 1**
- Land use map
  1. USGS
  2. IGBP
- AVHRR NB reflectances
- Cloud mask
  1. Binary (classic)
  2. Probabilistic

**NB-to-BB**
- BB reflectance
- BB radiance

**ADM’s**
- BB flux
- BB albedo

1. Hucek & Jacobowitz, 1995 (ERBE)
2. Regression AVHRR-CERES (NOAA-Aqua) using SSF Aqua-FM3 Ed4A

**PART 2**
- Instantaneous swath grid

**Spatial aggreg. regridding 0.25°**
1. Simple/fast: reproject pixel centre
2. Complex: reproject pixel area

**PART 3**
- Diurnal cycle modeling
- Per pixel: match observed albedo with modelled diurnal cycle (5' bins) + interpolate

**PART 4**
- SYN1deg Ed4A
- Monthly mean

**Bias 12/2012:**

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Thanks for your attention!
Extra slides
Sample size of nb-to-bb matched observations (per scene type)
Table 1. Overview of surface types, corresponding IGBP categories, and number of matched shortwave NTB pairs for clear, overcast, and allsky conditions; period: 1/7/2011-30/6/2012 (NOAA-19).

<table>
<thead>
<tr>
<th>Surface type</th>
<th>IGBP category</th>
<th>Nr.(clear)</th>
<th>Nr.(overcast)</th>
<th>Nr.(all)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ocean</td>
<td>17</td>
<td>18091</td>
<td>146138</td>
<td>337625</td>
</tr>
<tr>
<td>Forests</td>
<td>1,2,3,4,5</td>
<td>2199</td>
<td>5235</td>
<td>20655</td>
</tr>
<tr>
<td>Savannas</td>
<td>8,9</td>
<td>4015</td>
<td>2643</td>
<td>15627</td>
</tr>
<tr>
<td>Grass/crop</td>
<td>6,10,11,12,13,14</td>
<td>5098</td>
<td>5888</td>
<td>27959</td>
</tr>
<tr>
<td>Dark deserts</td>
<td>7,18</td>
<td>13280</td>
<td>2960</td>
<td>32806</td>
</tr>
<tr>
<td>Bright deserts</td>
<td>16</td>
<td>40627</td>
<td>2538</td>
<td>74829</td>
</tr>
<tr>
<td>Perm. snow/ice</td>
<td>15</td>
<td>26285</td>
<td>15442</td>
<td>72252</td>
</tr>
<tr>
<td>Fresh snow</td>
<td>19</td>
<td>16883</td>
<td>28327</td>
<td>155349</td>
</tr>
<tr>
<td>Sea ice 100%</td>
<td></td>
<td>7490</td>
<td>10449</td>
<td>38176</td>
</tr>
<tr>
<td>Sea ice 95-99%</td>
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<td>4161</td>
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<tr>
<td>Sea ice 80-90%</td>
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<td>Sea ice 60-80%</td>
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<td>3624</td>
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<tr>
<td>Sea ice 10-60%</td>
<td></td>
<td>1798</td>
<td>150492</td>
<td>255814</td>
</tr>
<tr>
<td>Sea ice 0-10%</td>
<td></td>
<td>1534</td>
<td>23309</td>
<td>42766</td>
</tr>
</tbody>
</table>
What if we calculated biases with EBAF instead of SYN?
Developing an AVHRR-based CDR of TOA radiative fluxes within the CMSAF Project

Tom Akkermans

ADM: Loeb et al. (CERES-TRMM/-TERRA)

-1.29 W/m² 2012-06 -3.86 W/m²

-1.47 W/m² 2012-09 -4.29 W/m²

-1.89 W/m² 2012-12 -4.70 W/m²

ADM: Suttles et al., 1988 (ERBE)
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ADM: Loeb et al. (CERES-TRMM/-TERRA)

-2.89 W/m²

ADM: Sutties et al., 1988 (ERBE)

-5.56 W/m²

2012-06

-3.12 W/m²

2012-09

-5.94 W/m²

2012-12

-3.70 W/m²

-6.51 W/m²
What would cause the bias related to overcast seaice?
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Sea Ice Concentration, Dec 2012

Total Area = 7.4 million sq km
What if we applied original ADM’s for overcast seaice from Terra?

(instead of replacing them by weighted mean from ocean and permanent snow ADM’s)
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Weighted mean overcast ocean and perm. snow

Original Terra ADM's overcast sea ice (\(\tau<10\), \(\tau>10\))

Overcast sea ice ADM:

2012-06

2012-12
What if we calculate relative biases (instead of absolute)?
Rel bias of CLARA-A3 TOA SW radiation w.r.t. CERES-SYN (201206)

June

ME=93.36%; MAE=93.36%
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Rel bias of CLARA-A3 TOA SW radiation w.r.t. CERES-SYN (201212)

December

ME=105.51%; MAE=105.51%
Bias with CERES-SYN using ADM’s from Suttles et al., 1988 (instead of ADM’s from Loeb et al.)
3. Results/validation

Bias of CLARA-A3 TOA SW radiation w.r.t. CERES-SYN (201206) June

ME=-3.86 W/m²; MAE=4.61 W/m²
3. Results/validation

Bias of CLARA-A3 TOA SW radiation w.r.t. CERES-SYN (201209) September

Map: Mollweide projection, 111x111km (GCS W.)

ME=-4.29 W/m²; MAE=4.57 W/m²
3. Results/validation

Bias of CLARA-A3 TOA SW radiation w.r.t. CERES-SYN (201212) December

ME=-4.70 W/m²; MAE=5.11 W/m²
Diurnal cycle modeling
Diurnal cycle modeling:
- Based on Young et al., 1998
- cfr. CO-method in TISA (Doelling et al., 2013)
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Extra slides

Date: 20120902; Location: 30°N, −105°E

- SZA<84° daytime
- SZA>84° twilight
- SZA>100° nighttime

Convert daytime albedo to flux

UTC time (hours)

Flux (W/m²)