CMSAF AVHRR-based CDR of TOA radiative fluxes (CLARA-A3): preliminary results and validation

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1. Introduction

**What is CLARA?** “CM SAF cLoud, Albedo and RAdiation dataset from AVHRR data” (≈similar to Patmos-X):
- Polar orbiting: NOAA and MetOp
- FCDR from NOAA (Heidinger, 2010)
- L3 products on 0.25° x 0.25°
- Currently released versions:

**Some of the modifications in the upcoming version CLARA-A3:**
- Inclusion of the AVHRR-1 sensor (TIROS-N, NOAA-6,-8,-10): extension of time range to 1979-2020, which is 42 years
- Updated FCDR: new calibration for visible channels (latest PATMOS-x coefficients)
- Updated cloud treatment algorithms (NWC SAF / PPS v.2018; Karlsson et al.)
- Addition of new product “TOA radiative fluxes” → this presentation
2. Methods

Level-2 processing: instantaneous observations

Level-3 processing: daily mean

Level-3b processing
2. Methods

Level-2 processing: instantaneous observations

- AVHRR ch4: 11µm
- AVHRR ch5: 12µm

"all-in-one" conversion from narrowband directional brightness temp. to broadband hemispherical flux, based on database with co-angular AVHRR-CERES obs.

- OLR [W/m²]

Aggregation from orbit to regular CMSAF grid (0.25°x0.25°)

remapped OLR (0.25°)

Level-3 processing: daily mean

- ERA5 diurnal cycle OLR

ERAS diurnal cycle scaled to Level-2 observations, then interpolate:

Daily mean OLR

Level-3b processing

- Monthly mean OLR

Monthly mean RSF

Method: Young et al. ('98): match scene-dependent average diurnal cycle to observations, then interpolate

Convert albedo to flux based on database with co-angular AVHRR-CERES obs.

NB-to-BB regressions based on database with co-angular AVHRR-CERES obs.

ADM's from CERES Ed2B: TRMM, +TERRA for snow/ice

Albedo [%] (hemispherical)

Aggregation from orbit to regular CMSAF grid (0.25°x0.25°)

remapped Albedo (0.25°)
2. Methods

2.1 Level-2 processing: instantaneous observations

- **AVHRR ch4:** 11µ
- **AVHRR ch5:** 12µ
- **AVHRR ch1:** 0.6µ
- **AVHRR ch2:** 0.9µ

**NB-to-BB regressions** based on database with co-angular AVHRR-CERES observations.

**Albedo (%)**

Aggregation from orbit to regular CMSAF grid (0.25°x0.25°)

**Daily mean OLR**

**Monthly mean RSF [W/m²]**

**For OLR:**
- Interpolate between diurnal cycles
- Convert albedo to flux
- Brightness temp. to broadband hemispherical flux
- Sunrise, Noon, Sunset

**For RSF:**
- ERA5 diurnal cycle
- Scale to Level-2 observations, then interpolate
- Angular AVHRR-CERES observations
- Convert albedo to flux
- Brightness temp. to broadband hemispherical flux

**Part 4:**

**Mean OLR**

**Level-3b processing**

- **Bulk OLR**
- **Albedo (0.25°)**
- **OLR (0.25°)**
- **Remapped Albedo (0.25°)**

**All-in-one** conversion from narrowband directional observations to broadband hemispherical observations.
2. Methods

Level-2 processing: instantaneous observations

- AVHRR ch4: 11µ
- AVHRR ch5: 12µ

"all-in-one" conversion from narrowband directional brightness temp. to broadband hemispherical flux, based on database with co-angular AVHRR-CERES obs.

Level-3 processing:

- ERAS diurnal cycle OLR

ERAS diurnal cycle scaled to Level-2 observations, then interpolate:

- Daily mean OLR

Level-3b processing:

- Monthly mean OLR

Method: Young et al. ('98): match scene-dependent average diurnal cycle to observations, then interpolate

Convert albedo to flux

Daily mean RSF [W/m²]

Monthly mean RSF

NB-to-BB regressions based on database with co-angular AVHRR-CERES obs.

ADM’s from CERES Ed2B: TRMM, +TERRA for snow/ice

Aggregation from orbit to regular CMSAF grid (0.25°x0.25°)

Albedo [%] (hemispherical)

Remapped OLR (0.25°)

Remapped Albedo (0.25°)

Monthly mean OLR

Daily mean OLR

ERAS diurnal cycle OLR

Interpolate between diurnal cycles

ALB %

NOAA over/under:

NOAA19 contrast:

Sunrise                 Noon               Sunset

Interpolation between scaled diurnal cycles

Time (0-24h UTC)
2. Methods

Level-2 processing: instantaneous observations

Part 1

AVHRR ch4: 11µ
AVHRR ch5: 12µ

"all-in-one" conversion from narrowband directional brightness temp. to broadband hemispherical flux, based on database with coangular AVHRR-CERES observations

OLR [W/m²]

Aggregation from orbit to regular CMSAF grid (0.25°x0.25°)

remapped OLR (0.25°)

Part 2

Level-3 processing

ERAS diurnal cycle scaled to Level-2 observations, then interpolate:

Daily mean OLR

Part 3

OLR

Interpolation between scaled diurnal cycles

Time (0-24h UTC)

OLR [W/m²]

Level-3b processing

Monthly mean OLR

Monthly mean RSF

Part 4

Monthly mean OLR

OLR (0.25°) remapped

Albedo (0.25°) scaled to Level-2 observations, then interpolate:

ERAS diurnal cycle

First, the narrowband reflectances are converted to broadband reflectance using empirical regressions with the Clouds and the Earth’s Radiant Energy System (CERES) observations. Second, the anisotropy is corrected by applying Angular Distribution Models (ADMs), which convert directional reflectance into a hemispherical albedo. Third, the instantaneous albedos are temporally interpolated by a flexible diurnal cycle model, capable of ingesting any number of observations at any time of day, making it suitable for any orbital overlap conditions, providing near-surface and surface energetics are accumulated appropriately.

References:

Young et al. (‘98): match scene-dependent average diurnal cycle to observations, then interpolate

Convert albedo to flux based on database with coangular AVHRR-CERES brightness temp. to broadband hemispherical flux,

Ed2B: TRMM, +TERRA for snow/ice

ALL-in-one” conversion from narrowband directional brightness temp. to broadband hemispherical flux, based on database with coangular AVHRR-CERES observations

NB-to-BB regressions based on database with coangular AVHRR-CERES observations

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3. Results

- Example: daily mean RSF (15/6/2008)
3. Results

- Example: daily mean RSF (15/6/2008)
3. Results

CLARA-A3 TOA SW radiation (200803)
Mean = 95.73 W/m²

CLARA-A3 TOA SW radiation (200806)
Mean = 93.50 W/m²

CLARA-A3 TOA SW radiation (200809)
Mean = 93.13 W/m²

CLARA-A3 TOA SW radiation (200812)
Mean = 104.40 W/m²

March

June

September

December
Global monthly statistics CLARA-A3, ERA-5, CERES, ISCCP and CLOUD-CCI (RSF)
3. Results

March

June

September

December
Global monthly statistics CLARA-A3, ERA-5, CERES, HIRS, ISCCP and CLOUD-CCI (OLR)

Year
2008
2009

W/m²
230
235
240
245

CLARA-A3
ERA-5
CERES-SYMN-Ed4.1
CERES-EBAF-Ed4.1
HIRS
ISCCP-FH
CLOUD-CCI
4. Validation

- **Longwave: Outgoing Longwave Radiation:**
  - **Bias:**
    - Daily mean OLR
    - Monthly mean OLR
  - **RMSE (bias corrected):**
    - Daily mean OLR
    - Monthly mean OLR

- **Shortwave: Reflected Solar Flux:**
  - **Bias:**
    - Daily mean RSF
    - Monthly mean RSF
  - **RMSE (bias corrected):**
    - Daily mean RSF
    - Monthly mean RSF
  - **MAB (daily and hourly)**
4. Validation

**Daily mean OLR:** 365 bias maps/year, each with global bias and RMSE:

- Bias of CLARA-A3 TOA OLR radiation w.r.t. CERES-SYND-Ed4.1 (20080612) ME=-0.81 W/m²; MAE=3.41 W/m²
- Bias of CLARA-A3 TOA OLR radiation w.r.t. CERES-SYND-Ed4.1 (20080613) ME=-0.77 W/m²; MAE=3.34 W/m²
- Bias of CLARA-A3 TOA OLR radiation w.r.t. CERES-SYND-Ed4.1 (20080614) ME=-0.70 W/m²; MAE=3.27 W/m²
- Bias of CLARA-A3 TOA OLR radiation w.r.t. CERES-SYND-Ed4.1 (20080615) ME=-0.72 W/m²; MAE=3.32 W/m²

RMSE-bc=4.34 W/m²
RMSE=4.40 W/m²
MAE=3.32 W/m²
ME=-0.72 W/m²
4. Validation

- **Monthly mean OLR:** 12 bias maps/year, each with global bias and RMSE:

  - Bias of CLARA-A3 TOA OLR radiation w.r.t. CERES-SYNM-Ed4.1 (200803)  
    - ME=-0.60 W/m²; MAE=1.27 W/m²
  
  - Bias of CLARA-A3 TOA OLR radiation w.r.t. CERES-SYNM-Ed4.1 (200804)  
    - ME=-0.38 W/m²; MAE=1.25 W/m²
  
  - Bias of CLARA-A3 TOA OLR radiation w.r.t. CERES-SYNM-Ed4.1 (200805)  
    - ME=-0.28 W/m²; MAE=1.21 W/m²
  
  - Bias of CLARA-A3 TOA OLR radiation w.r.t. CERES-SYNM-Ed4.1 (200806)  
    - ME=-0.54 W/m²; MAE=1.26 W/m²
4. Validation

- Actual temporal coverage of CLARA-A3 (currently being generated...):
4. Validation

- **Global mean bias** of Daily Mean OLR:
• **Global mean bias** of Daily Mean OLR:

![Graph showing global daily bias of CLARA-A3 w.r.t. ERA-5, CERES, and HIRS (OLR)]
4. Validation

- **Global mean bias** of Monthly Mean OLR:

![Graph showing global monthly bias of CLARA-A3 w.r.t. ERA-5, CERES, ISCCP, CLOUD-CI, and HIRS (OLR)]
4. Validation

- **ERA5 annual mean OLR:**

![Graph showing annual mean OLR for mtnwrf from 1979 to 2020. The graph shows fluctuations in mtnwrf values with a range from -243.19 to -241.73. The data points are marked with red squares and a red line connects them. The x-axis represents time from 1979 to 2020, and the y-axis represents mtnwrf values. The minimum value is at 1995, and the maximum value is at 2015.]
• **Global mean bias** of Monthly Mean OLR:
4. Validation

• **Global mean bias** of Monthly Mean OLR:

![Graph showing global monthly bias of CLARA-A3 w.r.t. ERA-5, CERES, ISCCP, CLOUD-CI, and HIRS (OLR)]
4. Validation

- **Global RMSE (bias-corrected) of Daily Mean OLR:**

![Graph showing Global daily bc-RMSE between CLARA-A3, CERES, and HIRS (OLR)](image)
4. Validation

- **Global RMSE (bias-corrected) of Monthly Mean OLR:**

  Global monthly bc-RMSE between CLARA-A3 and ERA-5, CERES, ISCCP, CLOUD-CI, and HIRS (OLR)
4. Validation

- **Global RMSE (bias-corrected) of Monthly Mean OLR**:

  [Graph showing global monthly bc-RMSE between CLARA-A3 and ERA-5, CERES, ISCCP, CLOUD-CCI, and HIRS (OLR).]
4. Validation

**Longwave: Outgoing Longwave Radiation:**
- **Bias:**
  - Daily mean OLR
  - Monthly mean OLR
- **RMSE (bias corrected):**
  - Daily mean OLR
  - Monthly mean OLR

**Shortwave: Reflected Solar Flux:**
- **Bias:**
  - Daily mean RSF
  - Monthly mean RSF
- **RMSE (bias corrected):**
  - Daily mean RSF
  - Monthly mean RSF
- **MAB (daily and hourly)**
4. Validation

• **Daily mean RSF**: 365 bias maps/year, each with global bias and RMSE:

  - **Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYND-Ed4.1 (20080612)**
    - $\text{ME} = -0.28 \text{ W/m}^2$; $\text{MAE} = 4.55 \text{ W/m}^2$

  - **Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYND-Ed4.1 (20080613)**
    - $\text{ME} = -0.40 \text{ W/m}^2$; $\text{MAE} = 4.43 \text{ W/m}^2$

  - **Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYND-Ed4.1 (20080614)**
    - $\text{ME} = -0.29 \text{ W/m}^2$; $\text{MAE} = 4.47 \text{ W/m}^2$

  - **Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYND-Ed4.1 (20080615)**
    - $\text{ME} = -0.33 \text{ W/m}^2$; $\text{MAE} = 4.48 \text{ W/m}^2$

  - RMSE$_{bc} = 6.58 \text{ W/m}^2$
  - RMSE = 6.58 W/m$^2$
  - MAE = 4.48 W/m$^2$
  - ME = -0.33 W/m$^2$
4. Validation

- Monthly mean RSF: 12 bias maps/year, each with global bias and RMSE:
4. Validation

- **Global mean bias** of Daily Mean RSF:
4. Validation

- **Global mean bias** of Monthly Mean RSF:

![Graph showing global monthly bias of CLARA-A3 w.r.t. ERA-5, CERES, ISCCP, and CLOUD-CCI (RSF).](image_url)

- Graph shows W/m^2 on the y-axis and Year on the x-axis, ranging from 1979 to 2021.

Key: ERAS, SYN, EBAF, ISCCP, CLOUDCCI
4. Validation

- **Global mean bias** of Monthly Mean RSF:
4. Validation

- **Global RMSE (bias-corrected) of Daily Mean RSF:**

![Graph showing global daily bc-RMSE between CLARA-A3 and CERES (RSF)]
4. Validation

- **Global RMSE (bias-corrected) of Daily Mean RSF:**

  Global daily bc-RMSE between CLARA-A3 and CERES (RSF)

  - No mid-morning orbit
  - Orbital drift NOAA-19, i.e. no afternoon orbit
  - "golden period" 2006-2016
4. Validation

- **Global RMSE (bias-corrected) of Monthly Mean RSF:**

  "golden period" 2006-2016
4. Validation

- **Global RMSE (bias-corrected)** of Monthly Mean RSF:

```
Global monthly bc-RMSE between CLARA-A3 and ERA-5, CERES, ISCCP, and CLOUD-CCI (RSF)
```

![Graph showing global monthly bc-RMSE between CLARA-A3 and ERA-5, CERES, ISCCP, and CLOUD-CCI (RSF).](image)

- "golden period" 2006-2016
Until now: use of daily and monthly mean RSF. But what about intra-day compensating errors?

Do they exist? If yes, do they cause or dominate the validation timeseries that is based on daily mean RSF?

**Mean Absolute Bias (MAB)** for day $d$, calculated from daily and hourly RSF:

$$MAB_{d,\text{daily}} = |RSF_{\text{CLARA}, d} - RSF_{\text{CERES}, d}|$$

$$MAB_{d,\text{hourly}} = \frac{1}{24} \sum_{h=1}^{24} |RSF_{\text{CLARA}, d, h} - RSF_{\text{CERES}, d, h}|$$
4. Validation

- Mean Absolute Bias for each day $d$, from daily and hourly RSF:

$$MAB_{d,\text{hourly}} = \frac{1}{24} \sum_{h=1}^{24} |\text{RSF}_{\text{CLARA},d,h} - \text{RSF}_{\text{CERES},d,h}|$$

$$MAB_{d,\text{daily}} = |\text{RSF}_{\text{CLARA},d} - \text{RSF}_{\text{CERES},d}|$$
4. Validation

- Mean Absolute Bias for each day \(d\), from daily and hourly RSF:

\[
MAB_{d,\text{hourly}} = \frac{1}{24} \sum_{h=1}^{24} |RSF_{\text{CLARA},d,h} - RSF_{\text{CERES},d,h}|
\]

\[
MAB_{d,\text{daily}} = |RSF_{\text{CLARA},d} - RSF_{\text{CERES},d}|
\]

- Same patterns as seen for daily RMSE
- Almost constant difference of 4-5W/m² between \(MAB_{\text{hourly}}\) and \(MAB_{\text{daily}}\)
- Intra-day compensating errors do not cause or dominate validation time series based on daily mean biases
5. Future outlook

• Full data record of **CLARA-A3** is currently being generated. After validation, release is foreseen around mid-2022; an ICDR will also be developed.

• Update **CLARA-A3.5** will include VIIRS instrument (S-NPP and NOAA-20) without any code changes (i.e. to be used as extension to CLARA-A3).

• Potential code updates will be done as part of **CLARA-A4** (within CMSAF), or as stand-alone data record (within RMIB), including:
  - Use of new CERES ADM’s Ed4 (currently being implemented and tested at RMIB).
  - Use of new Narrowband-to-broadband regressions (based on reflectances with updated calibration coefficients, and updated scene types).
Thanks for your attention!
• Monthly Mean OLR for several data records:

Global monthly OLR (W/m²) from ERA-5, CERES, ISCCP, CLOUD-CCI, CLARA-A3, HIRS
6. Extra slides

- Monthly Mean RSF for several data records:

![Global monthly RSF (W/m²) from ERA-5, CERES, ISCCP, CLOUD-CCI and CLARA-A3](image)

- Year

- W/m²

- ERA-5
- CERES-SYNIM-Ed4.1
- CERES-EBAF-Ed4.1
- ISCCP-FH
- CLOUD-CCI
- CLARA-A3