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

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What is CLARA? “CM SAF cLoud, Albedo and RAdiation 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: new calibration for visible channels (latest PATMOS-x coefficients)
- Updated cloud treatment algorithms (NWCSAF/PPS v.2018; Karlsson et al.) SMHI
- Addition of new product “TOA radiative fluxes” -> this presentation
1. Outgoing Longwave Radiation

Level-2 processing: instantaneous observations

- CM-11342 Outgoing Longwave Radiation (OLR)
- CM-11312 Reflected Solar Flux (RSF)

Level-3 processing: daily mean

- Outgoing Longwave Radiation (OLR)
- Reflected Solar Flux (RSF)

Level-3b processing

OLR

RSF
1. Outgoing Longwave Radiation

**Level-2 processing: instantaneous observations**

- CM-11342
  - Outgoing Longwave Radiation (OLR)
- CM-11312
  - Reflected Solar Flux (RSF)

**Level-3 processing: daily mean**

- Outgoing Longwave Radiation (OLR)
- Reflected Solar Flux (RSF)

**Level-3b processing**

- OLR
- RSF
1. Outgoing Longwave Radiation

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 coangular AVHRR-CERES obs.

OLR [W/m²]

Aggregation from orbit to regular CMSAF grid (0.25° x 0.25°)

remapped OLR (0.25°)

Level-3 processing: daily mean

ER5 diurnal cycle OLR

ERA5 diurnal cycle OLR scaled to Level-2 observations, then interpolate:

Daily mean

Level-3b processing

Monthly mean

Reflected Solar Flux (RSF)
1. Outgoing Longwave Radiation

Level-2 processing: instantaneous observations

- AVHRR ch4: 11µ
- AVHRR ch5: 12µ

OLR [W/m²]

Aggregation from orbit to regular CMSAF grid (0.25° x 0.25°)

remapped OLR (0.25°)

For each 10°x10° gridbox: fit monthly regression to predict CERES OLR; predictors: AVHRR T_b (ch4,ch5*), T_sur, VZA, column IWV

Level-3 processing

ERAS diurnal cycle OLR

 ERA5 diurnal cycle scaled to Level-2 observations, then interpolate:

Daily mean

Monthly mean

Level-3b processing
1. Outgoing Longwave Radiation

**Part 1**

**Outgoing Longwave Radiation (OLR)**

- 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 obs.

**OLR (W/m²)**

Aggregation from orbit to regular CMSAF grid (0.25° x 0.25°)

**Remapped OLR (0.25°)**

**Part 2**

**Outgoing Longwave Radiation (OLR)**

**OLR (W/m²)**

**Part 3**

**ERA5 diurnal cycle OLR**

ERA5 diurnal cycle scaled to Level-2 observations, then interpolate:

**Daily mean**

**Level-3 processing: daily mean**

**ERA5**

**Reflected Solar Flux (RSF)**

**Level-3b processing**

**RSF**

**Monthly mean**

**CM-11312**

Reflected Solar Flux (RSF)

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

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 obs.

OLR [W/m²]

Part 2
- Aggregation from orbit to regular CMSAF grid (0.25° x 0.25°)

remapped OLR (0.25°)

Part 3
- ERA5 diurnal cycle OLR

ER5 diurnal cycle scaled to Level-2 observations, then interpolate:

Daily mean

P4
- Monthly mean

CM-11312
Reflected Solar Flux (RSF)

Reflected Solar Flux (RSF)

NOAA17

NOAA15

NOAA16

Time (0-24h UTC)

ERA5 diurnal cycle AVHRR L2 observations

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

OLR [W/m²]

NOAA17

NOAA15

NOAA16

Time (0-24h UTC)

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NOAA16

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OLR [W/m²]

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NOAA15

NOAA16

Time (0-24h UTC)

ERA5 diurnal cycle AVHRR L2 observations

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

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 coangular AVHRR-CERES obs.

- OLR [W/m²]

Aggregation from orbit to regular CMSAF grid (0.25° x 0.25°)

remapped OLR (0.25°)

Level-3 processing:

- ERA5 diurnal cycle OLR

ERA5 diurnal cycle scaled to Level-2 observations, then interpolate:

Daily mean

P4 OLR Monthly mean

CM-11312
Reflected Solar Flux (RSF)

NOAA17
NOAA16
NOAA15

Scale cycle to obs.

ERA5 diurnal cycle

AVHRR L2 observations

Time (0-24h UTC)
1. Outgoing Longwave Radiation

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 obs.

OLR [W/m²]

Aggregation from orbit to regular CMSAF grid (0.25° x 0.25°)
remapped OLR (0.25°)

Part 2

Outgoing Longwave Radiation (OLR)

Part 3

Level-3 processing:
daily mean

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

Daily mean

Scaled diurnal cycles that match observations

ERS-2 diurnal cycle OLR

Monthly mean

Reflected Solar Flux (RSF)

CM-11312

Reflected Solar Flux (RSF)

CM-11312

Reflected Solar Flux (RSF)
1. Outgoing Longwave Radiation

**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 coangular AVHRR-CERES obs.

**OLR [W/m²]**

Aggregation from orbit to regular CMSAF grid (0.25° x 0.25°)

**remapped OLR (0.25°)**

**Level-3 processing**

**ER5 diurnal cycle OLR**

 ERA5 diurnal cycle scaled to Level-2 observations, then interpolate:

**Daily mean**

**Monthly mean**

**Interpolation between scaled diurnal cycles**

Time (0-24h UTC)

**CM-11312**  
Reflected Solar Flux (RSF)

**CM**-11312

Reflected Solar Flux (RSF)

CM

CM

CM

CM

CM

CM
Example 1: OLR in clearsky desert scene: impact of including ERA5 diurnal cycle:
1. Outgoing Longwave Radiation

Example 1: OLR in clear sky desert scene: impact of ERA5.

Single satellite (NOAA15) with simple linear interpolation:

Date: 20120613; Location: 21.875°N, 52.625°E; Daily mean: 325.4 W/m²
Developing an AVHRR-based CDR of TOA radiative fluxes within the CMSAF Project

Tom Akkermans

1. Outgoing Longwave Radiation

Example 1: OLR in clearsky desert scene: impact of ERA5.

Single satellite (N15) interpolated with ERA5 diurnal cycle:

Date: 20120613; Location: 21.875°N, 52.625°E; Daily mean: 330.4 W/m²

Corresponding diurnal cycle:

- Local solar noon
- Observations

UTC time (hours)

OLR [W/m²]

0 4 8 12 16 20 24
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Tom Akkermans

April 2012

CLARA-A3 monthly mean OLR (W/m²)

June 2012
• Validation of result: calculate bias with CERES-EBAF (Ed4.1)
• First, re-grid CMSAF monthly mean to CERES nested grid:
Developing an AVHRR-based CDR of TOA radiative fluxes within the CMSAF Project

**Tom Akkermans**

April 2012

Bias OLR w.r.t. CERES-EBAF (W/m²)

Mean bias = -2.6 W/m²
Bias-corrected RMSE = 1.7 W/m²

June 2012

Mean bias = -2.8 W/m²
Bias-corrected RMSE = 1.7 W/m²
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Tom Akkermans

April 2012

June 2012

Relative Bias OLR w.r.t. CERES-EBAF (%)
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Tom Akkermans

April 2012

Relative Bias OLR w.r.t. CERES-EBAF (%)

June 2012

Mostly below +/- 2%
1. Outgoing Longwave Radiation

**Level-2 processing: instantaneous observations**

<table>
<thead>
<tr>
<th>Part 1</th>
<th>AVHRR ch4: 11µ</th>
<th>AVHRR ch5: 12µ</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>“all-in-one” conversion from narrowband directional brightness temp. to broadband hemispherical flux, based on database with coangular AVHRR-CERES obs.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>OLR [W/m²]</td>
<td></td>
</tr>
</tbody>
</table>

**Aggregation from orbit to regular CMSAF grid (0.25° x 0.25°)**

**Remapped OLR (0.25°)**

**Level-3 processing: daily mean**

<table>
<thead>
<tr>
<th>Part 3</th>
<th>ERA5 diurnal cycle OLR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ERA5 diurnal cycle scaled to Level-2 observations, then interpolate:</td>
</tr>
</tbody>
</table>

**Daily mean**

**Level-3b processing**

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

2. Reflected Solar Flux (RSF)

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 coangular AVHRR-CERES obs.

**OLR (W/m²)**

Outgoing Longwave Radiation (OLR)

Aggregation from orbit to regular CMSAF grid (0.25° x 0.25°)

remapped OLR (0.25°)

Level-3 processing: daily mean

- ERA5 diurnal cycle OLR

ERA5 diurnal cycle scaled to Level-2 observations, then interpolate:

**Daily mean**

Reflected Solar Flux (RSF)

Level-3b processing

**Monthly mean**
2. Reflected Solar Flux (RSF)

**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.

- **OLR [W/m²]**

Aggregation from orbit to regular CMSAF grid (0.25° x 0.25°)

**Part1**

- **Outgoing Longwave Radiation (OLR)**
- **remapped OLR (0.25°)**

**Part2**

- **Broadband reflectance**
- **ADM's from CERES [Loeb et al.]**

**Reflected Solar Flux (RSF)**

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

**Part3**

**Level-3 processing: daily mean**

- **ERA5 diurnal cycle OLR**
- **Interpolate between diurnal cycles**

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

**Convert albedo to flux**

- **Daily mean RSF [W/m²]**

**Part4**

**Monthly mean**

**Level-3b processing**

**Monthly mean RSF**

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

2. Reflected Solar Flux (RSF)

**Level-2 processing: instantaneous observations**

- **Part 1**: Outgoing Longwave Radiation (OLR)
  - 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.
  - OLR [W/m²]
  - Aggregation from orbit to regular CMSAF grid (0.25° x 0.25°)
  - remapped OLR (0.25°)

- **Part 2**: Reflected Solar Flux (RSF)
  - AVHRR ch1: 0.6µ
  - AVHRR ch2: 0.9µ
  - NB-to-BB regressions based on database with co-angular AVHRR-CERES obs.
  - Broadband reflectance
  - ADM's from CERES [Loeb et al.]
  - Albedo [%] (hemispherical)

- **Part 3**: ERA5 diurnal cycle OLR
  - ERA5 diurnal cycle scaled to Level-2 observations, then interpolate:
  - Daily mean
  - Monthly mean

**Level-2 observations with scene type**

- NOAA17 overcast
- NOAA16 clearsky

**Time** (1 day, only during daylight)
2. Reflected Solar Flux (RSF)

Level-2 processing: instantaneous observations

Part 1
- AVHRR ch4: 11 µ
- AVHRR ch5: 12 µ

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

OLR [W/m²]

Aggregation from orbit to regular CMSAF grid (0.25° x 0.25°)

remapped OLR (0.25°)

Part 2

Outgoing Longwave Radiation (OLR)

Broadband reflectance

ADM’s from CERES [Loeb et al.]

Part 3

Level-2 processing: daily mean observations

ERAS diurnal cycle OLR

ERA5 diurnal cycle scaled to Level-2 observations, then interpolate:

Daily mean

P4

Monthly mean

Average diurnal cycle: overcast scene

ALB %

NOAA17 overcast

Time (1 day, only during daylight)
2. Reflected Solar Flux (RSF)

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 coangular AVHRR-CERES obs.

OLR \([W/m^2]\)

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

remapped OLR (0.25°)

Part 1: Outgoing Longwave Radiation (OLR)

Part 2: Reflected Solar Flux (RSF)

- AVHRR ch1: 0.6µ
- AVHRR ch2: 0.9µ

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

Broadband reflectance

ADM’s from CERES [Loeb et al.]

Albedo [%] (hemispherical)

Part 3: Level 3 Processing

ERAS diurnal cycle OLR

ERA5 diurnal cycle scaled to Level-2 observations, then interpolate:

Daily mean

Monthly mean

Scale diurnal cycle: match observation

NOAA17 overcast

Time (1 day, only during daylight)

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

NB - TO BB regressions based on database with co-ANGLAR AVHRR-CERES obs.

Brightness temp. to broadband hemispherical flux, (1 day, only during daylight)
2. Reflected Solar Flux (RSF)

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 coangular AVHRR-CERES obs.

- **OLR [W/m²]**

Aggregation from orbit to regular CMSAF grid (0.25° x 0.25°)

- **remapped OLR (0.25°)**

**Broadband reflectance**

- **ADM's from CERES [Loeb et al.]**

- **Albedo [%] (hemispherical)**

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

**Average diurnal cycle: clear sky scene**

- **NOAA17 overcast**
- **NOAA16 clear sky**

Time (1 day, only during daylight)

**Part1**

- Outgoing Longwave Radiation (OLR)

**Part2**

- **Level-2 processing:** daily mean

**Part3**

- ERA5 diurnal cycle OLR

**P4**

- Monthly mean
2. Reflected Solar Flux (RSF)

Level-2 processing: instantaneous observations

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

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

- Outgoing Longwave Radiation (OLR)
  - OLR [W/m²]
  - Aggregation from orbit to regular CMSAF grid (0.25°x0.25°)
  - remapped OLR (0.25°)

Part 1

- ERA5 diurnal cycle OLR
- ERA5 diurnal cycle scaled to Level-2 observations, then interpolate:

Part 2

- Level-3 processing:
  - Daily mean
  - Monthly mean

Part 3

- Albedo [%] (hemispherical)
- Broadband reflectance
- Albedo [%] (hemispherical)

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

ADM’s from CERES [Loeb et al.]

Scale diurnal cycle: match observation

- NOA17 overcast
- NOA16 clearsky

Time (1 day, only during daylight)

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

Interpolate between diurnal cycles.
2. Reflected Solar Flux (RSF)

Level-2 processing: instantaneous observations

- AVHRR ch4: 11 μm
- AVHRR ch5: 12 μm

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

- OLR [W/m²]

Aggregation from orbit to regular CMSAF grid (0.25° x 0.25°)

- Level-2 processing: daily mean

ERAS diurnal cycle OLR

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

- Monthly mean

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

- Broadband reflectance

ADMs from CERES [Loeb et al.]

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

ALB %

Interpolate between diurnal cycles

Time (1 day, only during daylight)

NOAA17 overcast

NOAA16 clearsky
2. Reflected Solar Flux (RSF)

Example 2: coastal cloud passage near Algiers
Example 2: coastal cloud passage near Algiers
2. Reflected Solar Flux (RSF)

Example 3: cloud formation on Zagros mountain range
**Example 3:** cloud formation on Zagros mountain range; Landuse is mixture of bright vegetation and desert.

Date: 20120613; Location: 29.625°N, 52.125°E

**2. Reflected Solar Flux (RSF)**

- **Diurnal cycle (colors):**
  - Grey: theoretical, per landuse
  - Green: theoretical, all landuse
  - Blue: modified to observations
  - Red: interpolated

- **Local solar noon**
  - **Observations**

**Corresponding diurnal cycle:**
- 1
- 2
- 3
- 4
2. Reflected Solar Flux (RSF)

Sunglint algorithm

- **Sunglint angle < 15°**
  - "strong sunglint"
  - **sun glint flag = 1**

- **15° < sunglint angle < 25°**
  - "mild sunglint"
  - PPS: CMAPROB <50%
  - PPS: CMAPROB >50%

- **PPS: CMAPROB 50%-90%**
  - FALSE CLOUD DETECTION

- **PPS: CMAPROB <40%**
  - Set pixel to NO DATA

- **Clearskey sunglint**
  - Use fixed sea albedo

- **Overcast**
  - Use observed cloud albedo
April 2012

CLARA-A3 monthly mean RSF (W/m²)

June 2012
Developing an AVHRR-based CDR of TOA radiative fluxes within the CMSAF Project

Tom Akkermans

April 2012

Bias RSF w.r.t. CERES-EBAF (W/m²)

Mean bias = -1.5 W/m²
Bias-corrected RMSE = 3.0 W/m²

June 2012

Mean bias = -1.6 W/m²
Bias-corrected RMSE = 3.5 W/m²
Developing an AVHRR-based CDR of TOA radiative fluxes within the CMSAF Project

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Bi April 2012 – June 2012

Relative Bias RSF w.r.t. CERES-EBAF (%)
Developing an AVHRR-based CDR of TOA radiative fluxes within the CMSAF Project

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April 2012

June 2012

Relative Bias RSF w.r.t. CERES-EBAF (%)

Mostly below +/- 5%
2. Reflected Solar Flux (RSF)

Twilight conditions when SZA is between 84°-100°

![Graph showing reflected solar flux with SZA conditions]

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

Date: 20120902; Location: 30°N, -105°E
Twilight: plot SSF Aqua/Terra CERES SW TOA flux (W/m²) as function of SZA (limited at 86.5°)
2. Reflected Solar Flux (RSF)

Twilight: derive linear regression on known data (84° < SZA < 86.5°) and extrapolate regression line.
2. Reflected Solar Flux (RSF)

Impact of using new CERES ADMs (Ed.4): example for overcast sea-ice:

Bias of CLARA-A3 TOA RSF w.r.t. CERES EBAF (201206)

New Ed4 ADMs (Su et al, 2015)  Old Ed2.8 ADMs (Loeb et al, 2005)

2-6 W/m² less bias
Thanks for your attention!
2. Improvements/additions

- **All** satellites (N15-18-19/MetA):

  Date: 20120613; Location: 21.875°N, 52.625°E; Daily mean: 329.2 W/m²