Developing an AVHRR-based CDR of TOA radiative fluxes within the CMSAF Project: Outgoing Longwave Radiation

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- See previous presentation of Tom Akkermans

- Already many OLR products from AVHRR and HIRS covering the same time period (1979 onward).

- **Interests of this new OLR product:**
  - New development using state of the art OLR (e.g. from CERES)
  - Targeting 0.25° spatial resolution
  - Synergy and consistency with the other CM SAF CLARA products (cloud products, surface radiation, RSF, ...)
  - Intercomparison with other OLR products (AVHRR, HIRS, CERES, GERB, ScaRaB ...) and reanalysis
  - Triple collocation CERES – GERB – AVHRR
  - Possibility to merge with HIRS OLR products

- **Some specific questions:**
  - Can we work with only channel 4 (AVHRR/1 instrument without channel 5)?
  - What is the effect of the number of satellites?
  - What is the effect of orbital drift?
Content of the talk

- Instantaneous OLR estimation
  - Method
  - Results

- Daily and Monthly mean
  - Method
  - Results
  - Evaluation with CERES

- Feedback loop results

- Summary and next steps
Developing an AVHRR-based CDR of TOA radiative fluxes within the CMSAF Project: OLR

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Method:

- Regressions between AVHRR brightness temperatures $T_4$ (10.8µm) and $T_5$ (12µm) and CERES OLR:

$$\text{OLR} = c_0 + c_1 \cdot T_4 + c_2 \cdot (T_5 - T_4) + c_3 \cdot (T_4 - T_{surf}) + c_4 \cdot T_4^2 + c_5 \cdot T_4 \cdot (T_5 - T_4) + c_6 \cdot TCWV$$

  $OLR$ from CERES SSF Edition 4a
  $T_4$ and $T_5$ aggregated in the CERES PSF (~20km).

- Ancillary interpolated from ERA5 reanalysis
  
  $T_{surf}$ : surface skin temperature
  $TCWV$ : Total Column Water Vapor

- Huge database of colocated coangular CERES-AVHRR observations (157 millions pairs)

- Regression coefficients $(c_0, c_1, ..., c_6)$ from least square fit after sorting the data in:
  - monthly bins (Jan, Feb, ..., Dec)
  - $10^\circ \times 10^\circ$ latitude – longitude boxes
  - $5^\circ$ VZA bins

- AVHRR/1 instrument without channel 5 :

$$\text{OLR} = c_0 + c_1 \cdot T_4 + c_2 \cdot (T_5 - T_{surf}) + c_3 \cdot T_4^2 + c_4 \cdot TCWV$$

Results: RMS error of the regression in CERES PSF

RMS error (Wm$^{-2}$) in CERES PSF (including collocation error) : (top) for the two channels regression and (bottom) when Channel 5 is not available
Instantaneous OLR : evaluation

Results : regional bias

Systematic error (bias, W/m²) of OLR regression : (top) for the two channels regression (bottom) when Channel 5 is not available.

Results : VZA dependency of RMS

~50° : good angle for OLR estimation
Method:

- Spatial aggregation of instantaneous OLR to 0.25°x0.25°
- Ocean and cloudy pixels: simple linear temporal interpolation between instantaneous OLR
- Clear land pixels: use of the shape of the ERA5 OLR diurnal variation rescaled to observations
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Daily/Monthly mean : evaluation

Difference between the June 2012 monthly mean OLR calculated by using the individual satellites and the reference monthly mean.

Reference monthly mean maps computed using 8 observations/day (from Metop-A, NOAA-15, NOAA-18, NOAA-19).

Metop-A
~09:30 LT
~21:30 LT

NOAA-15
~05:00 LT
~17:00 LT

NOAA-18
~15:00 LT
~03:00 LT

NOAA-19
~13:45 LT
~01:45 LT

Equator crossing time (local hour)

Year

June 2012
Monthly mean OLR difference NOAA-19 – NOAA-15 (worst case)

Difference between the monthly mean OLR calculated by only using NOAA-19 and by only using NOAA-15, for April (a,b) and June (c,d) 2012, with (a,c) linear temporal interpolation and (b,d) ERA5 diurnal cycle modeling for clear land pixels.
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Overall comparison with CERES

Monthly mean using 4 satellites (METOP-A, NOAA-15, NOAA-17, NOAA-19) - RMSE-bc of ~ 1.7 W/m²

Monthly mean using 2 satellites (METOP-A + NOAA-19) - RMSE-bc of ~ 2.2 W/m²
Monthly mean using 1 satellites:

- Metop-A: 2.6 W/m² ~09:30 LT ~21:30LT
- NOAA-15: 2.5 W/m² ~05:00 LT ~17:00 LT
- NOAA-18: 2.4 W/m² ~15:00 LT ~03:00 LT
- NOAA-19: 2.6 W/m² ~13:45 LT ~01:45 LT

RMSE-bc:

- Metop-A: 2.6 W/m²
- NOAA-15: 2.5 W/m²
- NOAA-18: 2.4 W/m²
- NOAA-19: 2.6 W/m²
Regression for AVHRR/2 and AVHRR/3 (Ch4 + ch5)
RMSE-bc ~ 1.7 W/m²

Regression for AVHRR/1 (Ch4 only)
RMSE-bc ~ 1.9 W/m²

Overall comparison with CERES

Bias of CLARA-A3 TOA OLR radiation w.r.t. CERES-SYN deg (201204)

Bias of CLARA-A3 TOA OLR radiation w.r.t. CERES-SYN deg (201206)
First month: January 1979

TIROS-N (AVHRR/1) only
~ 03:00 LT and 15:00 LT

RMSE-bc wrt HIRS OLR
daily mean: ~ 7 W/m²
monthly mean: 4.01 W/m²
Second month: April 1981

NOAA-6 (AVHRR/1): ~07:30 LT and ~19:30 LT

RMSE-bc wrt HIRS OLR
  daily mean: ~ 7 W/m²
  monthly mean: 5.66 W/m²

Daily mean ok

Monthly mean evaluation affected by HIRS data gap (AVHRR ok)
Third month: Jan 1983

NOAA-6 (AVHRR/1): ~07:30 LT
NOAA-7 (AVHRR/2): ~15:00 LT

RMSE-bc wrt HIRS OLR
  daily mean: ~7 W/m²
  monthly mean: 3.19 W/m²

Daily mean ok
Monthly mean ok
April 2002 – Monthly mean

NOAA-15 (AVHRR/3): ~07:00 LT
NOAA-16 (AVHRR/3): ~14:00 LT

RMSE-bc
  wrt HIRS OLR : 1.88 W/m²
  wrt SYN : 1.77 W/m²
April 2002 – Daily mean

NOAA-15 (AVHRR/3): ~07:00 LT
NOAA-16 (AVHRR/3): ~14:00 LT

RMSE-bc
  wrt HIRS OLR : 5.5 W/m²
  wrt SYN : 5.6 W/m²
Evaluation on feedback loop

Monthly mean

Global monthly statistics CLARA-A3 w.r.t. ERA-5, CERES, and HIRS (OLR)

- RMSE-bc
- Bias

Year


W/m²
Evaluation on feedback loop

Daily mean

Global daily statistics CLARA-A3 w.r.t. ERA-5, CERES, and HIRS (OLR)

Year

W/m²


Bias

RMSE-bc
Triple collocation

- Triple collocation of $1^\circ \times 1^\circ$ monthly means OLR from
  - CERES EBAF (Ed4.1)
  - CM SAF GERB/SEVIRI (ed2.0)
  - CM SAF CLARA (A3)

- Assumption: the uncertainties (retrieval errors) of the 3 products are not correlated.

- In average uncertainty (at 1-sigma) of
  
  CERES EBAF : $0.87 \pm 0.22$ W/m$^2$
  CLARA A3 : $1.73 \pm 0.23$ W/m$^2$
  GERB ed02 : $1.32 \pm 0.63$ W/m$^2$

- Using CERES EBAF as the "truth" (no error) uncertainties (at 1-sigma):
  
  CLARA : $1.96$ W/m$^2$
  GERB : $1.62$ W/m$^2$

<table>
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<th>Month</th>
<th>1-sigma uncertainties (W/m$^2$)</th>
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<tr>
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Average: $0.874 \pm 0.229$
Std.Dev.: $1.731 \pm 0.232$
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- Regression between CERES OLR and AVHRR ch-4 and -5 BTs
- Instantaneous OLR RMS error ~ 5W/m² (~ 6W/m² for AVHRR/1)
- Diurnal cycle modelling using ERA5 (for clear land warming)
- Feedback loop gives encouraging results:
  - RMS error ~ 4W/m² → 2W/m² for monthly mean
  - RMS error ~ 10 W/m² → 4.5W/m² for daily mean
- Next steps: full CDR processing, comprehensive validation, CDR release expected Q4 2021, development and inclusion of AVHRR-like from VIIRS (S-NPP, NOAA-20).

Thanks for your attention!

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2. 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°)

**Broadband reflectance**

**Albedo [%]** (hemispherical)

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

remapped Albedo (0.25°)

**Level-3 processing: daily mean**

- **ERA5 diurnal cycle OLR**

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

**Daily mean**

**Interpolation between diurnal cycles**

Convert albedo to flux

Daily mean RSF [W/m²]

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

**Level-3b processing**

- **Monthly mean RSF**