The EUMETSAT's Climate Monitoring Satellite Application Facility (CM SAF):

TOA Radiation "GERB" Datasets

Nicolas Clerbaux, Stijn Nevens, Ilse Decoster (RMIB)

with contributions from the CM SAF International Board and RMIB GERB team

http://www.cmsaf.eu

Today speaker…

CM SAF International Board visiting KNMI/Cabauw, NL.

Content

- The GCOS Essential Climate Variables and CM SAF overview
- TOA radiation science and current challenges
- The GERB instruments and data processing
- The CM SAF TOA radiation "GERB" datasets, illustration and validation results
- Discuss some applications
- Related activities during CDOP-2 (2012-2017)
- Summary

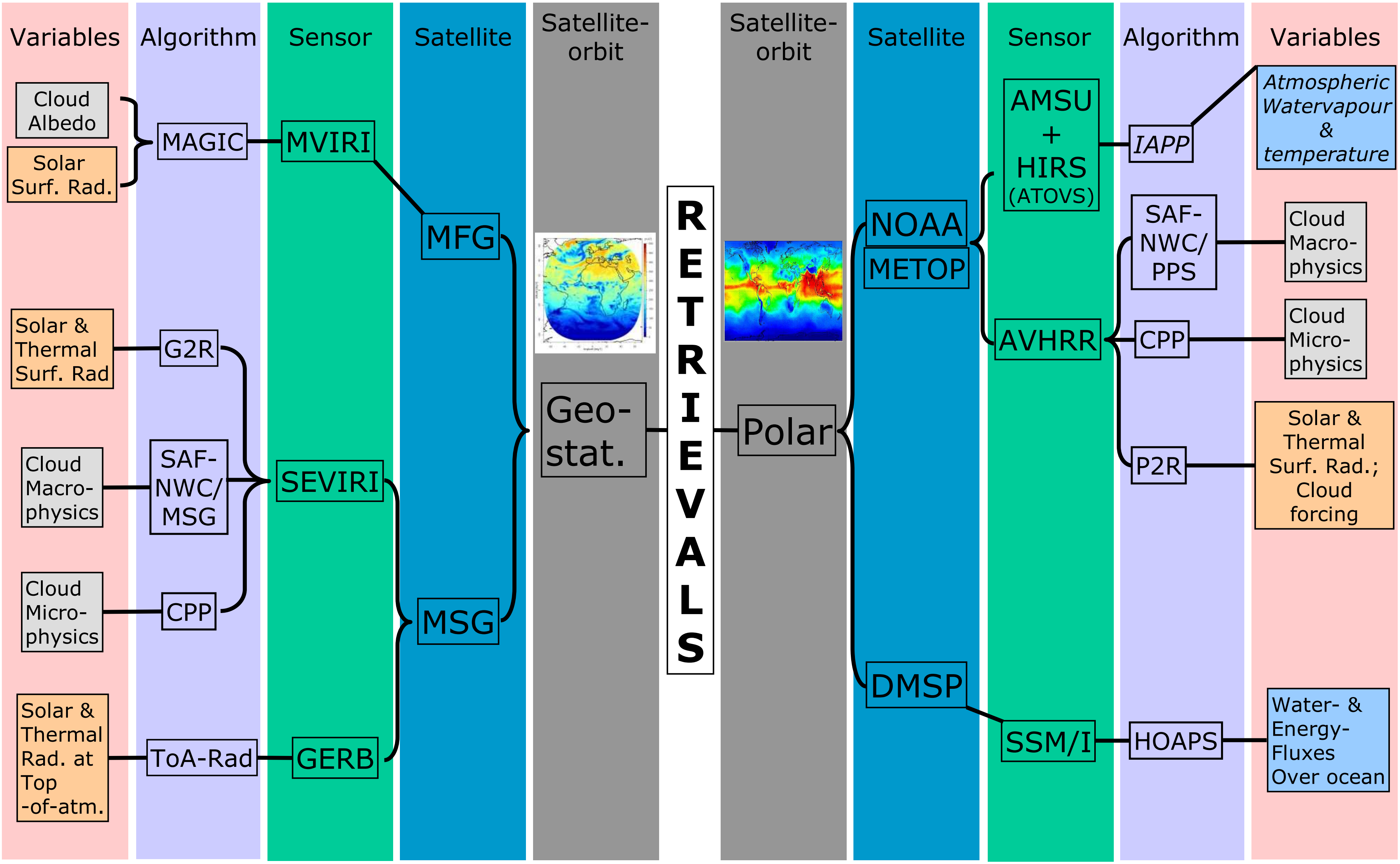
GCOS Essential Climate Variables (ECVs)

The 50 GCOS Essential Climate Variables (ECVs) (2010) are required to support the work of the UNFCCC and the IPCC. All ECVs are technically and economically feasible for systematic observation. It is these variables for which international exchange is required for both current and historical observations. Additional variables required for research purposes are not included in this table. It is emphasized that the ordering within the table is simply for convenience and is not an indicator of relative priority. **Bold : ECVs largely dependent upon satellite observations.** **Red : ECVs targeted by CM SAF.**

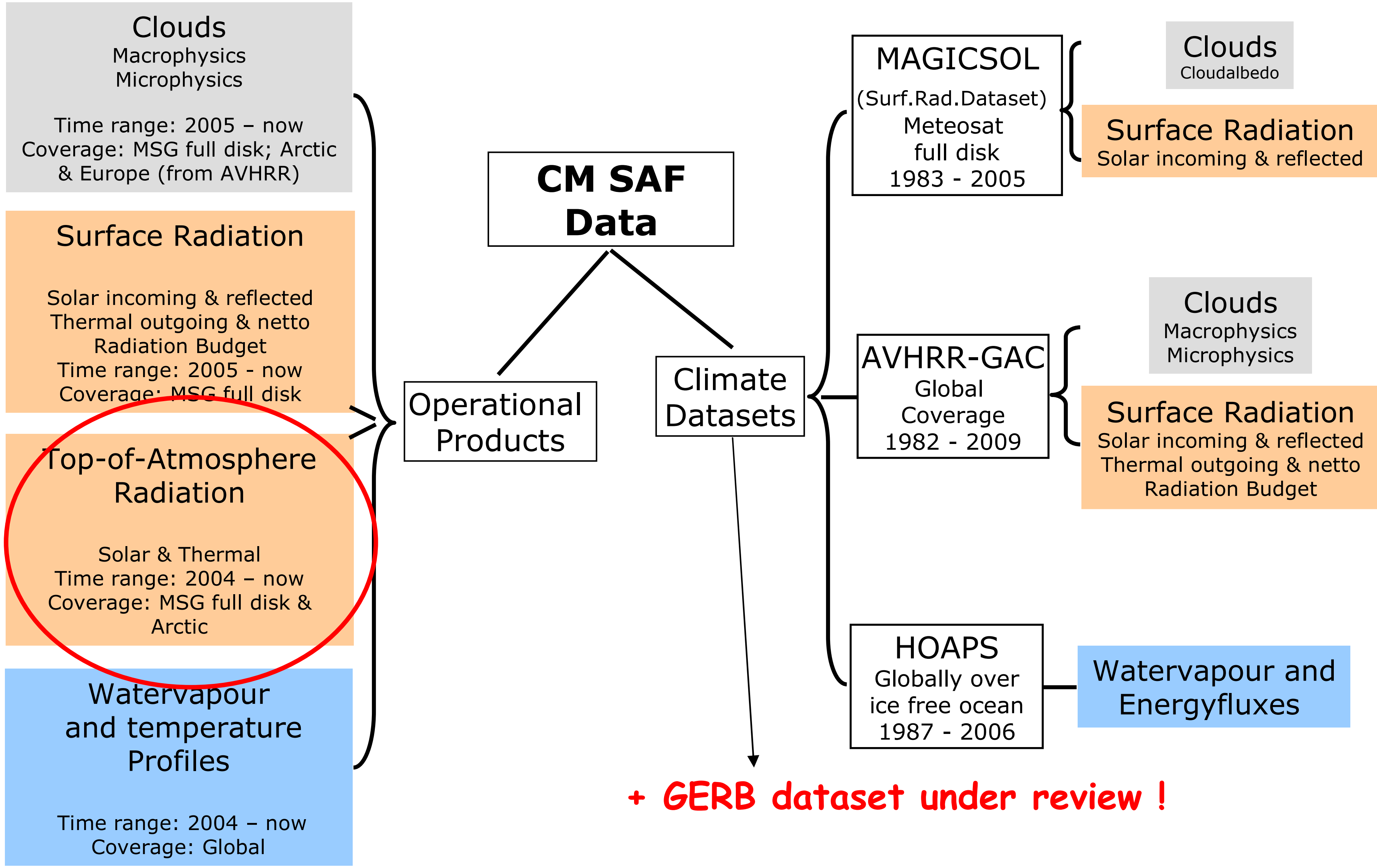
Domain	GCOS Essential Climate Variables
Atmospheric (over land, sea and ice)	Surface:[1] Air temperature, **Wind speed and direction**, Water vapour, Pressure, **Precipitation**, **Surface radiation budget**. Upper-air:[2] **Temperature**, **Wind speed and direction**, **Water vapour**, **Cloud properties**, **Earth radiation budget (including solar irradiance)**. Composition: **Carbon dioxide**, **Methane**, and other long-lived greenhouse gases[3], **Ozone** and **Aerosol**, supported by their precursors[4].
Oceanic	Surface:[5] **Sea-surface temperature**, **Sea-surface salinity**, **Sea level**, **Sea state**, **Sea ice**, Surface current, **Ocean colour**, Carbon dioxide partial pressure, Ocean acidity, Phytoplankton. Sub-surface: Temperature, Salinity, Current, Nutrients, Carbon dioxide partial pressure, Ocean acidity, Oxygen, Tracers.
Terrestrial	River discharge, Water use, Groundwater, **Lakes**, **Snow cover**, **Glaciers and ice caps**, Ice sheets, Permafrost, **Albedo**, **Land cover (including vegetation type)**, **Fraction of absorbed photosynthetically active radiation (FAPAR)**, **Leaf area index (LAI)**, **Above-ground biomass**, Soil carbon, **Fire disturbance**, **Soil moisture**.

[1] Including measurements at standardized, but globally varying heights in close proximity to the surface. [2] Up to the stratopause. [3] Including nitrous oxide (N_2O), chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6), and perfluorocarbons (PFCs). [4] In particular nitrogen dioxide (NO_2), sulphur dioxide (SO_2), formaldehyde (HCHO) and carbon monoxide (CO).[5] Including measurements within the surface mixed layer, usually within the upper 15m.

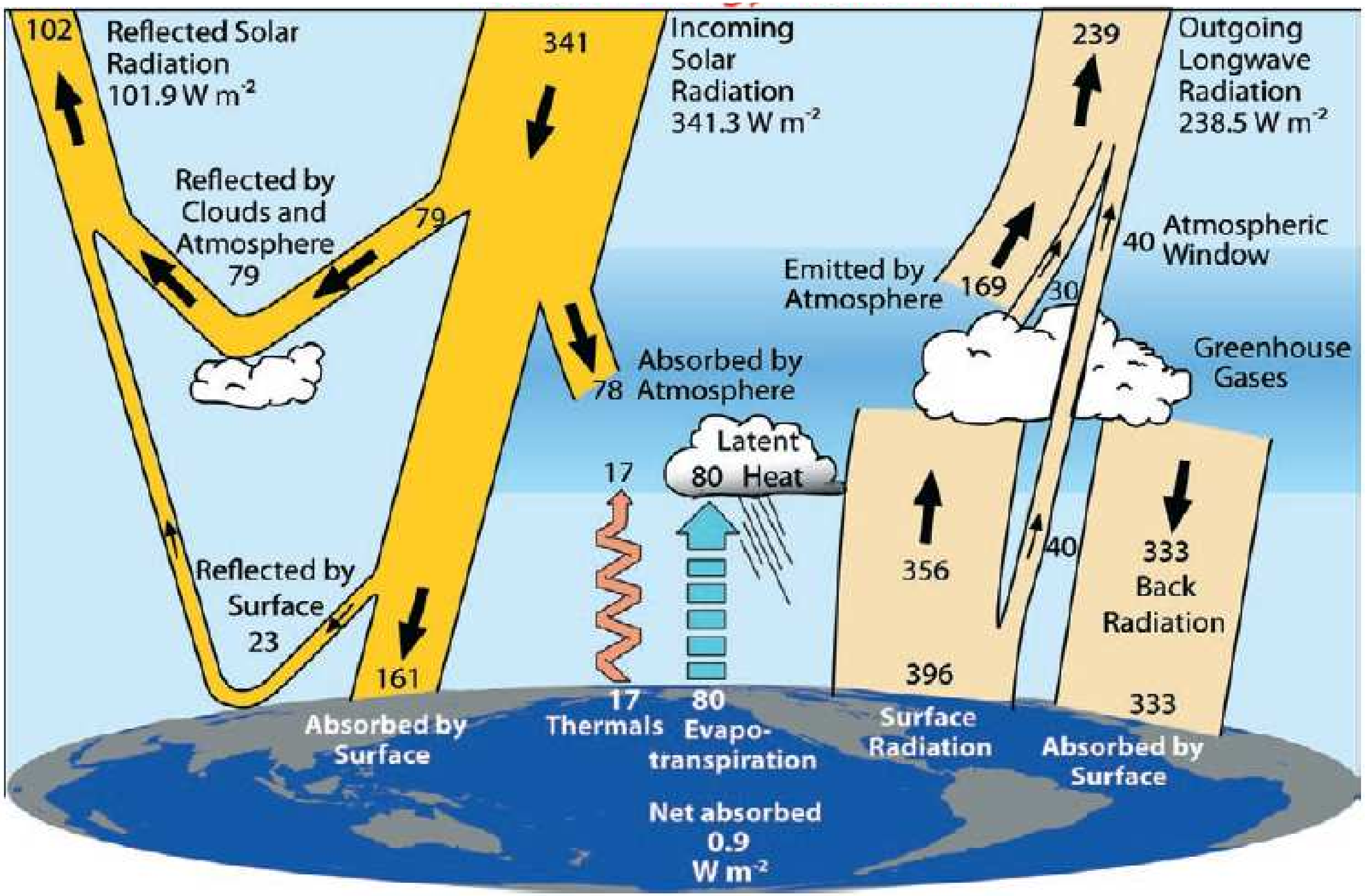
CM SAF Retrieval Overview



Available operational Products and Datasets



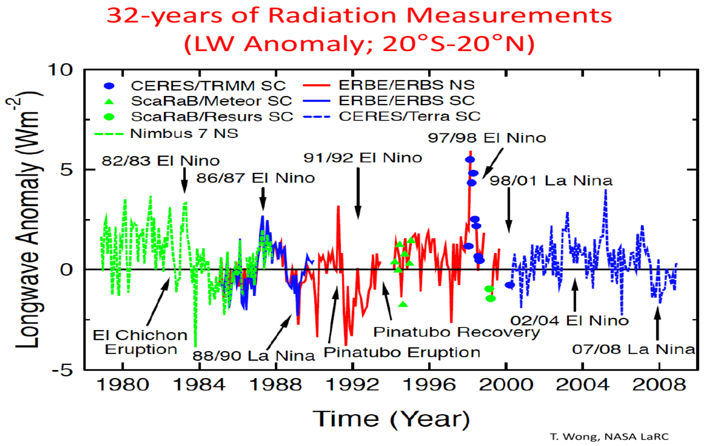
Energy and Water cycle



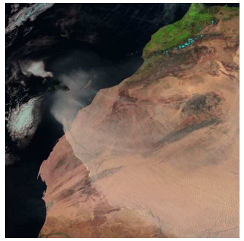
Trenberth at al., BAMS, 2009

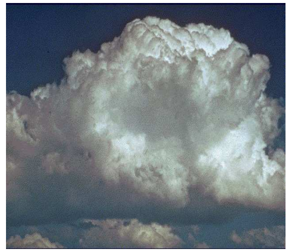
Why do we measure ERB?

1. Climate monitoring
   - Long term climate variations and trends
   - El Nino/La Nina
   - Effect of natural events (volcanic eruptions, …)
   - Land cover change, snow and sea ice
   - …

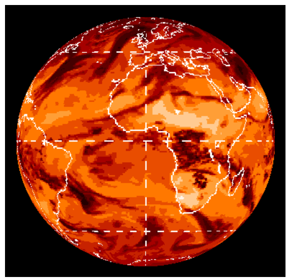


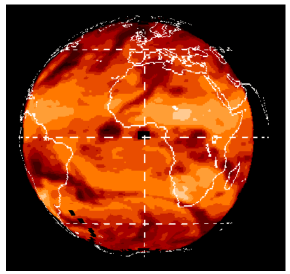
2. Processes study
   - Cloud and aerosol forcing
   - …





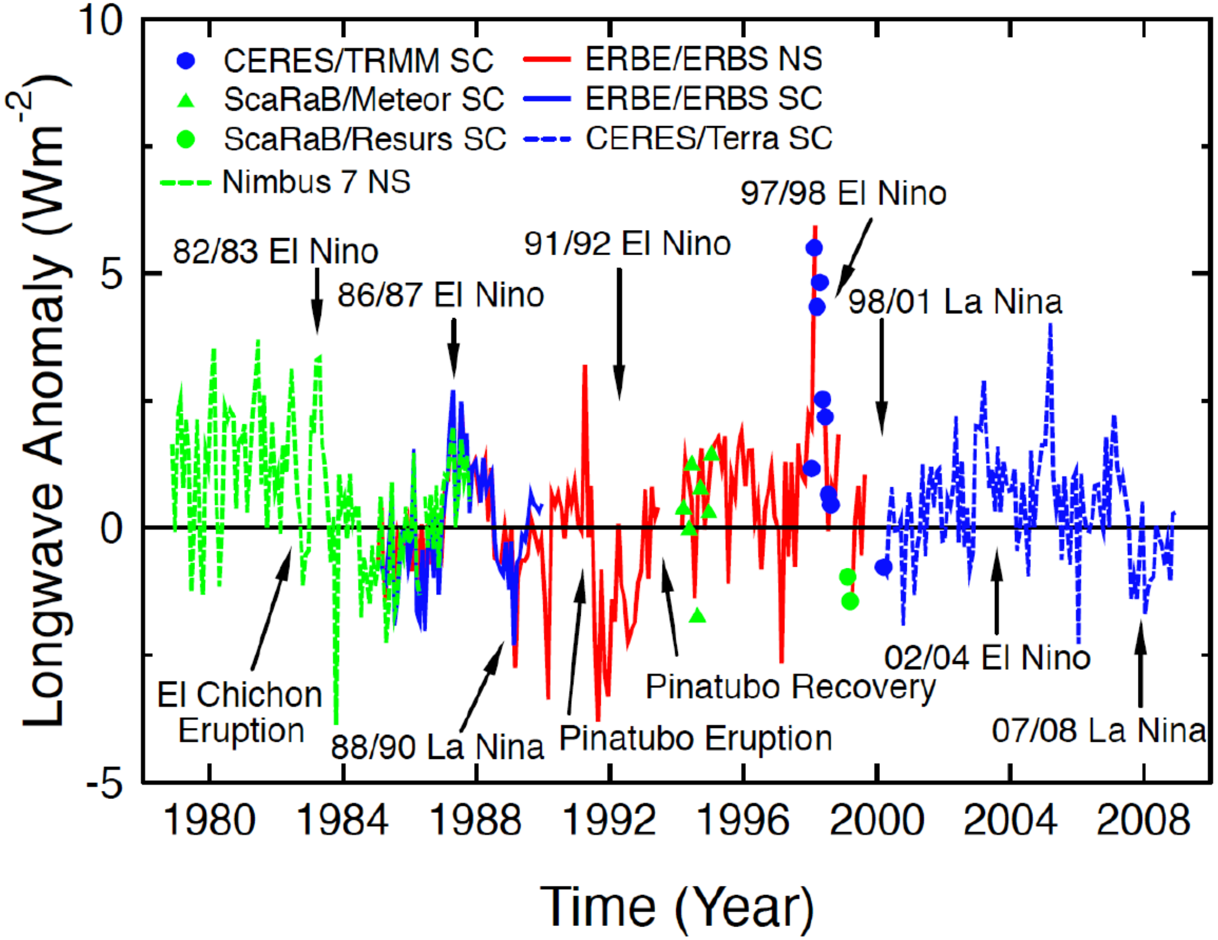
3. Climate modelling
   - Radiation in climate model
   - …





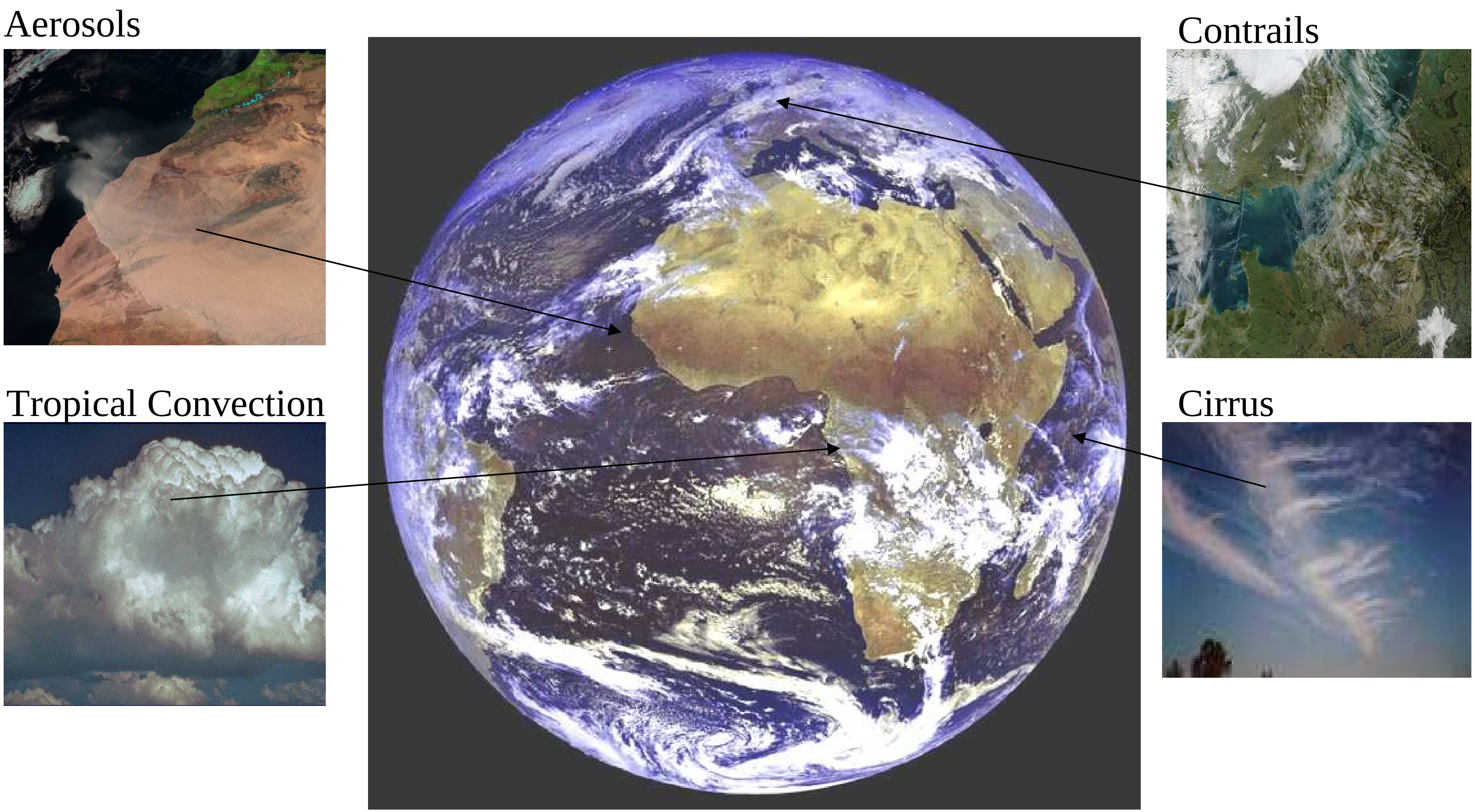
Climate monitoring

32-years of Radiation Measurements
(LW Anomaly; 20°S-20°N)



T. Wong, NASA LaRC

Processes Study



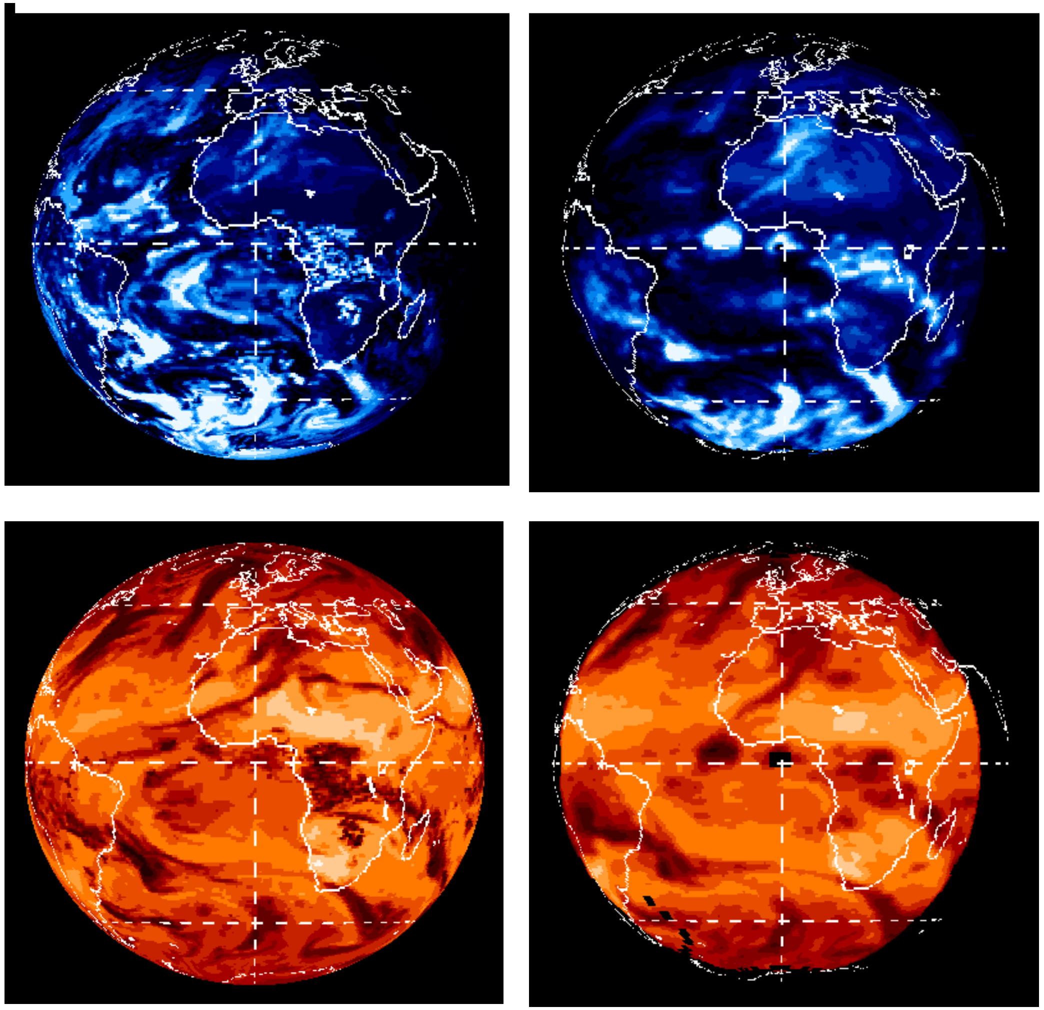
Also: desertification, African monsoon, marine stratocumulus, vulcaneos, biomass burning, …

Climate models evalution/improvement

UK-MO Unified Model GERB

Solar Flux

Thermal Flux



(Courtesy UK Met Office)

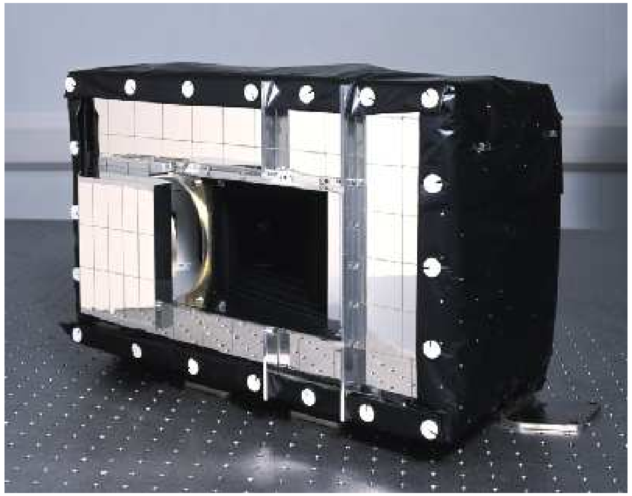
How do we measure the ERB?

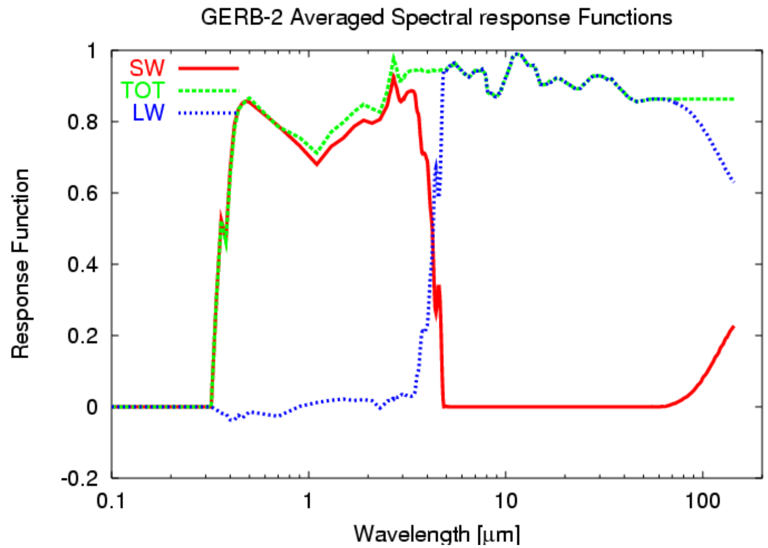
- From … satellites
- Broadband radiometer -> total channel
- Need of a SW channel, why? How?
- Scanner/non-scanner instruments

- Limitations of the NB-to-BB

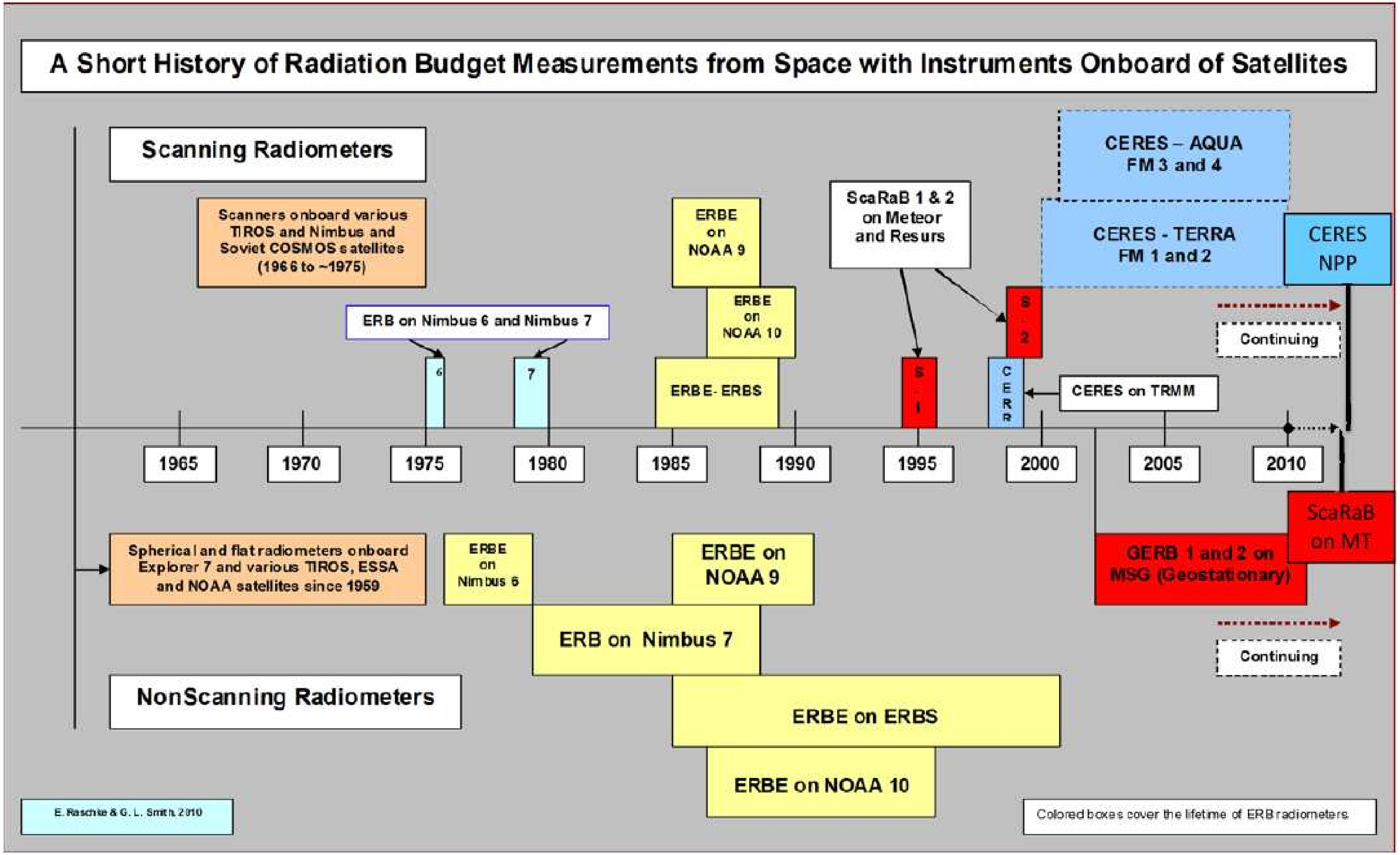
- Geo versus polar orbits

GERB instrument (on MSG)



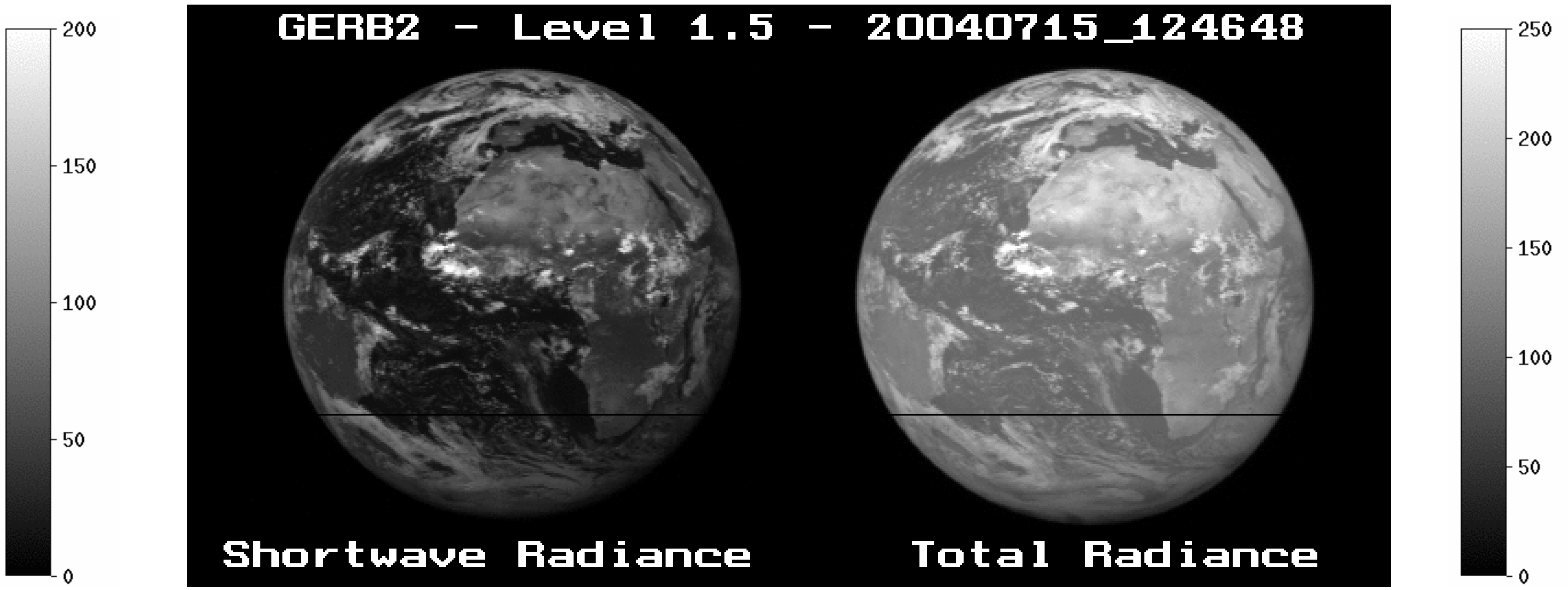


TOA radiation missions



The GERB instruments

- First BB instrument on geo orbit
- On the 4 MSG satellites (Meteosat-8, -9, 10 and -11)
- Repeat cycle : 5’ (!)



W/m²/sr W/m²/sr

GERB Data processing

Level 1 -> 1.5 (GERB team @ RAL & ICL)
- Calibration
- Geolocation

Level 1.5 -> level 2 (GERB team @RMIB)
- Unfiltering
- Angular modelling
- Spatial modelling (including resolution enhancement)
- Temporal modelling

Level 2 -> level 3 (CM SAF)
- Monthly averaging
- Gap filling

Illustration GERB level 2

- Each 15’
- Instantaneous TOA fluxes
- 3 formats : ARG, BARG, HR

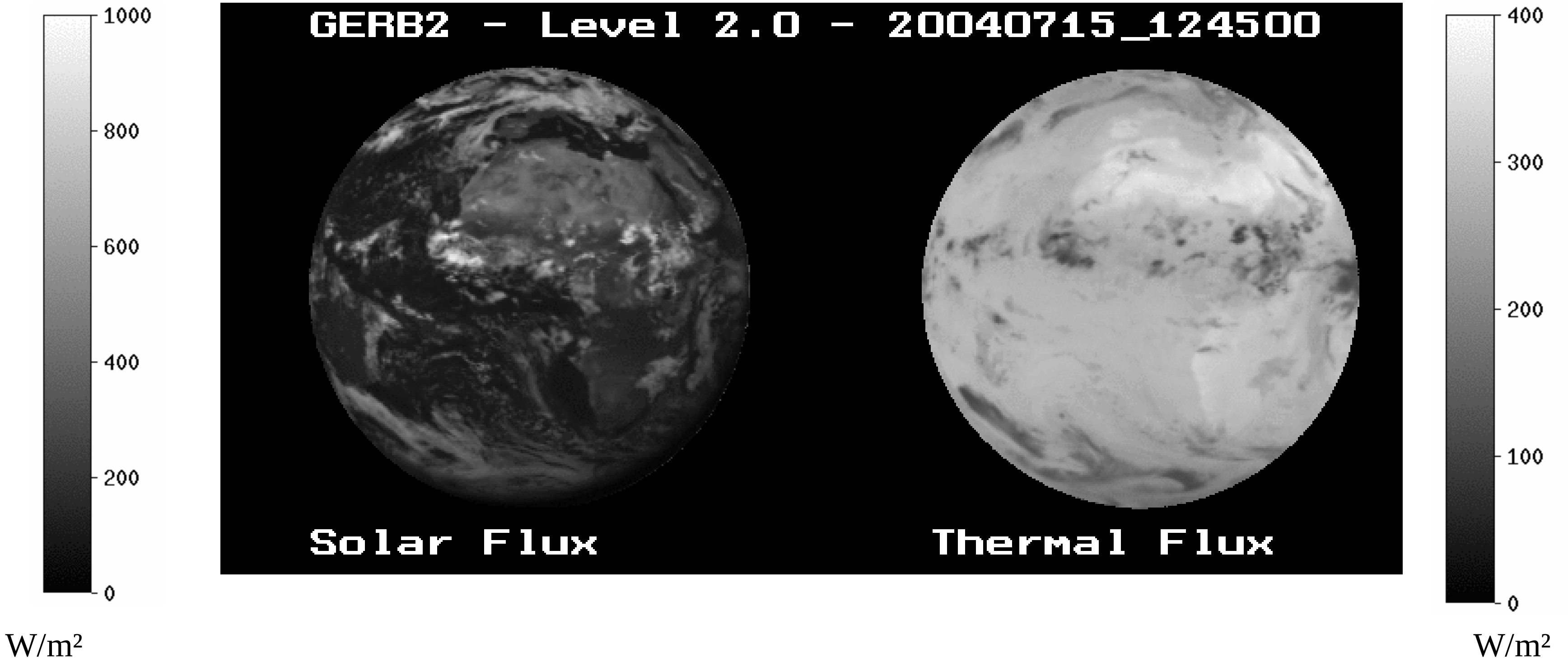
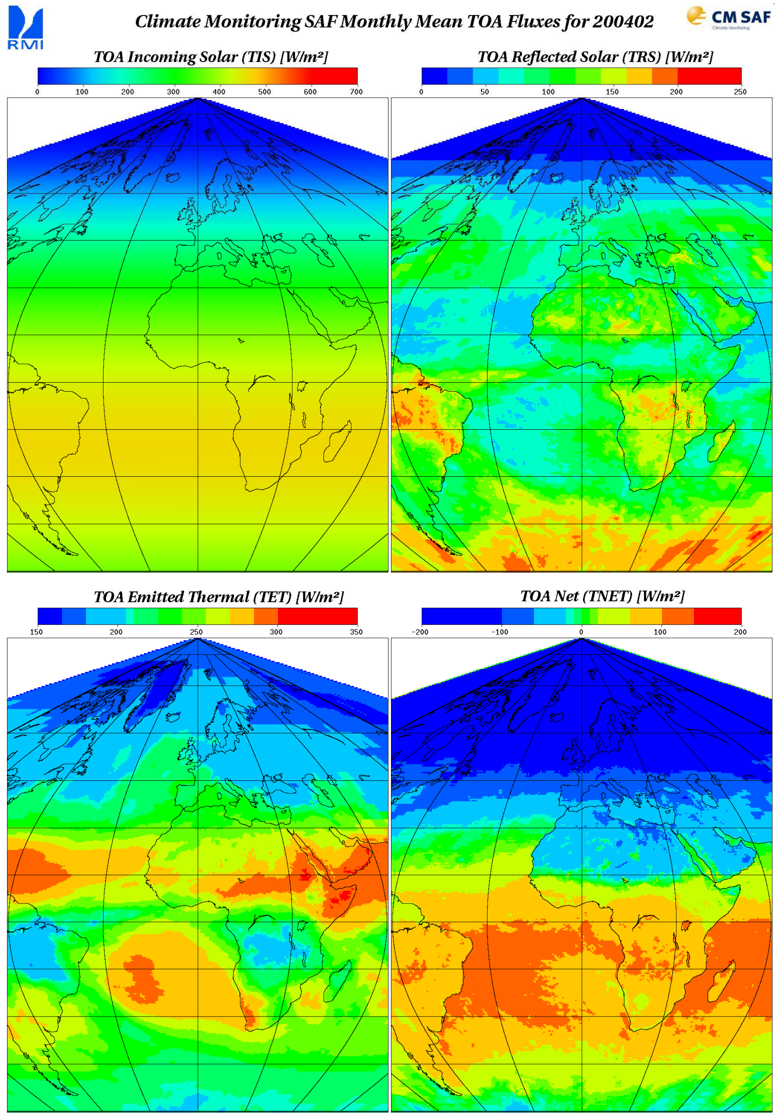


Illustration level 3 : TOA radiation Environment Data Record

- TIS : TOA Incoming Solar
- TRS : TOA Reflected Solar
- TET : TOA Emitted Thermal

- Monthly mean
- Daily mean
- Monthly mean diurnal cycle

- Not homogeneous time series



Example for October 2004

CM SAF Datasets

Products	Data Record length	Available	Coverage
Cloud Properties (fraction, type, height, optical depth, effective radius) surface radiation fluxes surface albedo water vapour aerosol optical depth	2004 – 2010	09.2012	**Regional (Meteosat Coverage)**
TOA GERB dataset	**2004 - 2011**	**2012**	
Surface radiation products (SIS, SAL, SDL)	**1983 – 2010**	**03.2011**	
Free tropospheric humidity (Partner: LMD) (Cloud mask also included)	1983 – 2010	02.2012	
Cloud properties / Surface radiation products	**1982 – 2011**	**12.2011**	**Global**
HOAPS (Latent heat flux, Precipitation, etc.) (MPI/Uni-HH, NOAA-STAR)	**1987 – 2008**	**03.2011**	
SSM/I FCDR	1987 – 2008	03.2012	
Layered precipitable water vapour, relative humidity, temperature in 5 layers (HLW)	1998 – 2010	02.2012	
Specific humidity and temperature at 6 pressure levels (HSH)	1998 – 2010	02.2012	
Total Precipitable Water (HTW)	1998 – 2010	02.2012	

TOA « GERB » dataset

- GCOS requirements :
  - 5 W/m² outgoing solar/thermal
  - 100 km / 3-hourly
  - Stability 0.2 W/m²/decade
- Input data
  - GERB,
  - GERB-like (SEVIRI)
  - CERES
- Processing
  - Homogenization
  - Correction of the GERB-like
  - Hourly averaging
  - Daily/Monthly averaging
  - Projection on SEA grid
  - Creation HDF files
- Output : MM, DM, MD in HDF5 (NetCDF upon req.)
- Validation
- Documentation: ATBD, PUM, Val. Rep., DGCDD
- Still under Review…

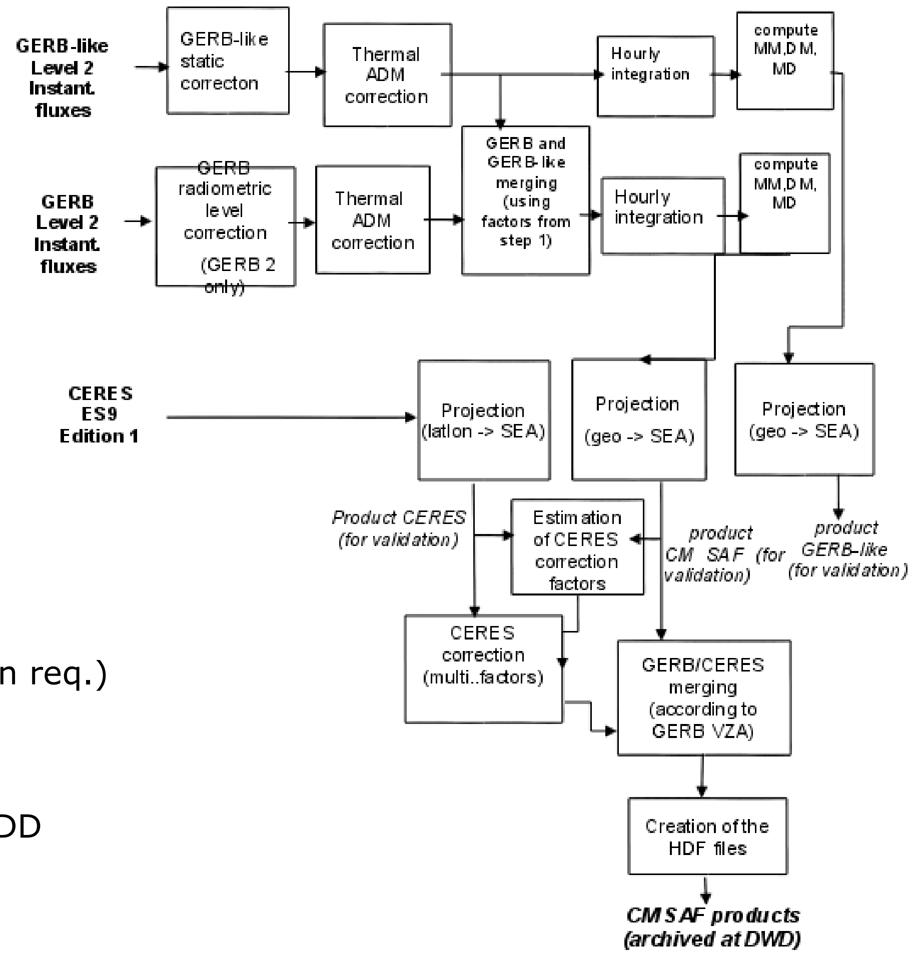


Illustration : TOA radiation monthly means

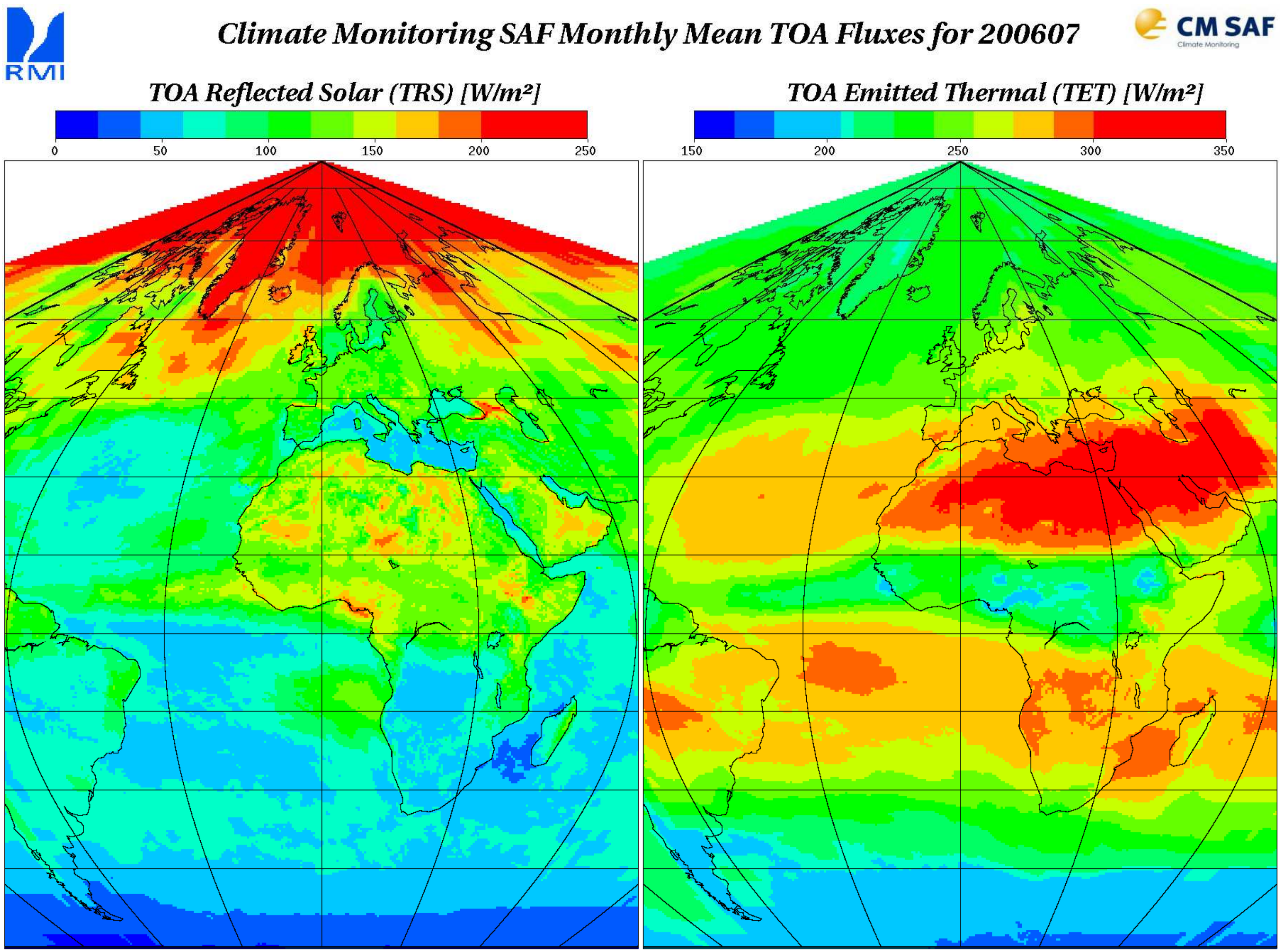


Illustration : TOA radiation daily means

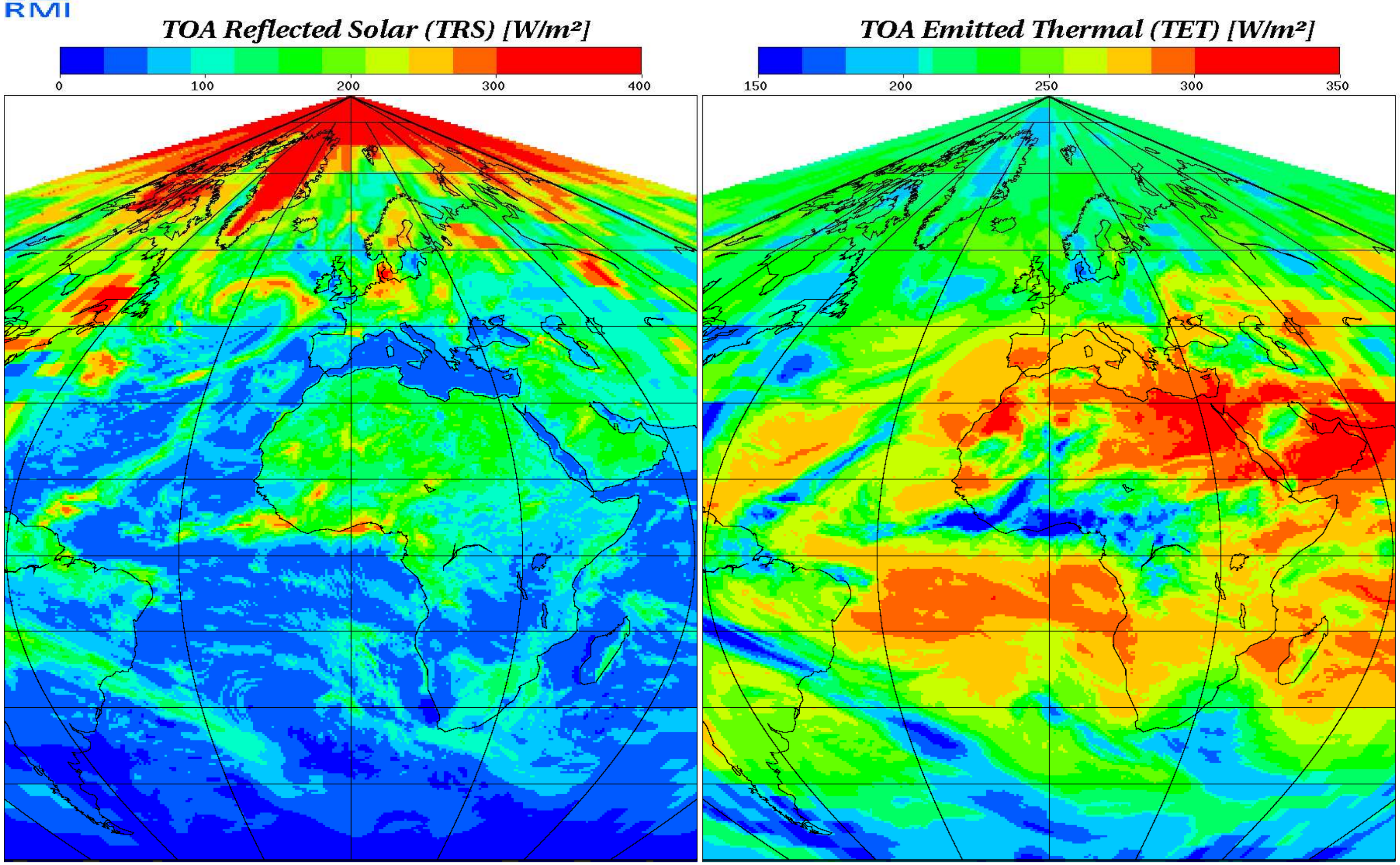
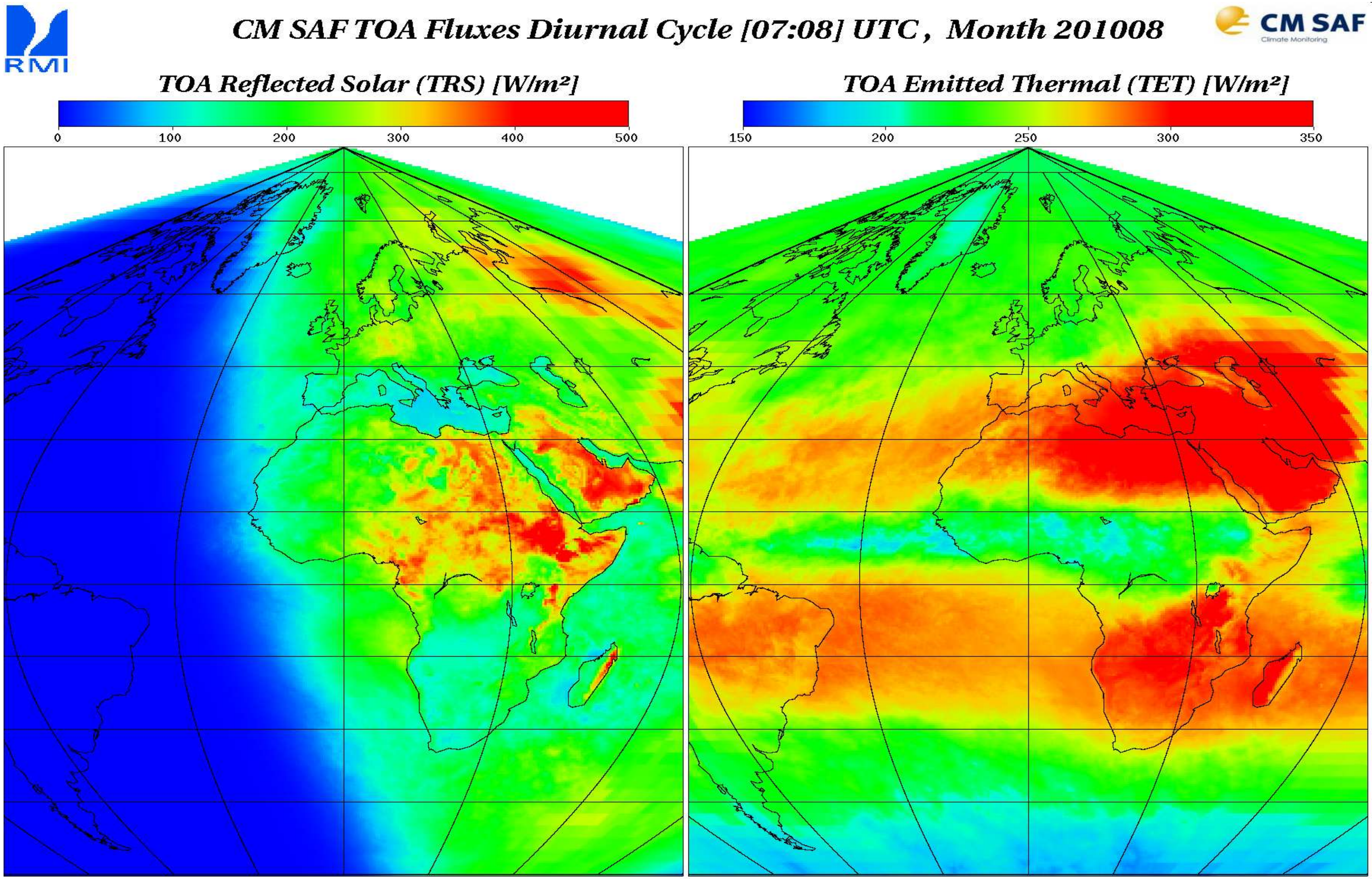
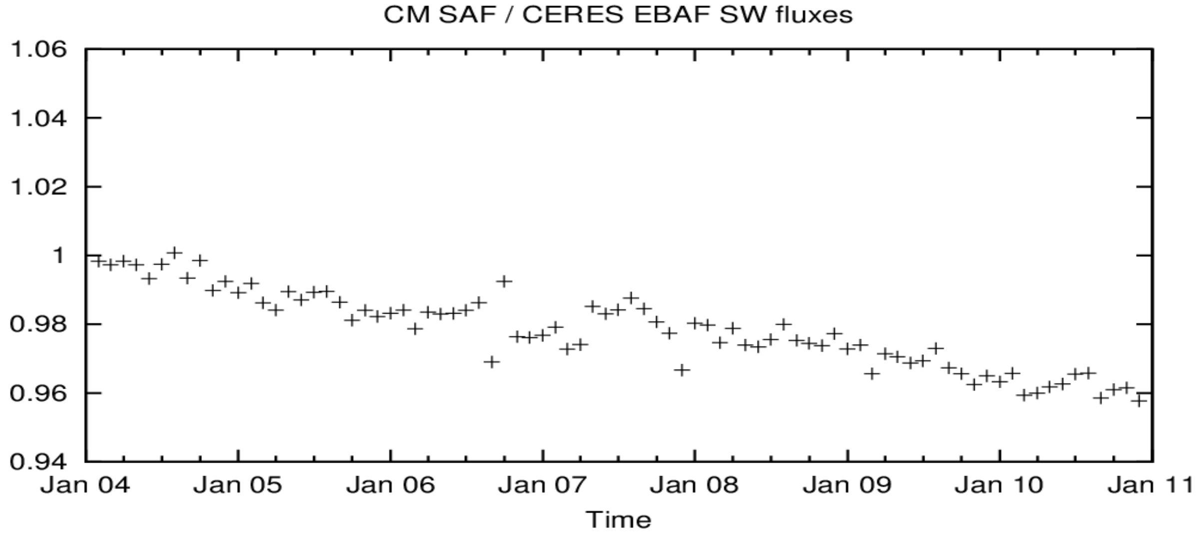


Illustration : TOA radiation monthly mean diurnal cycle

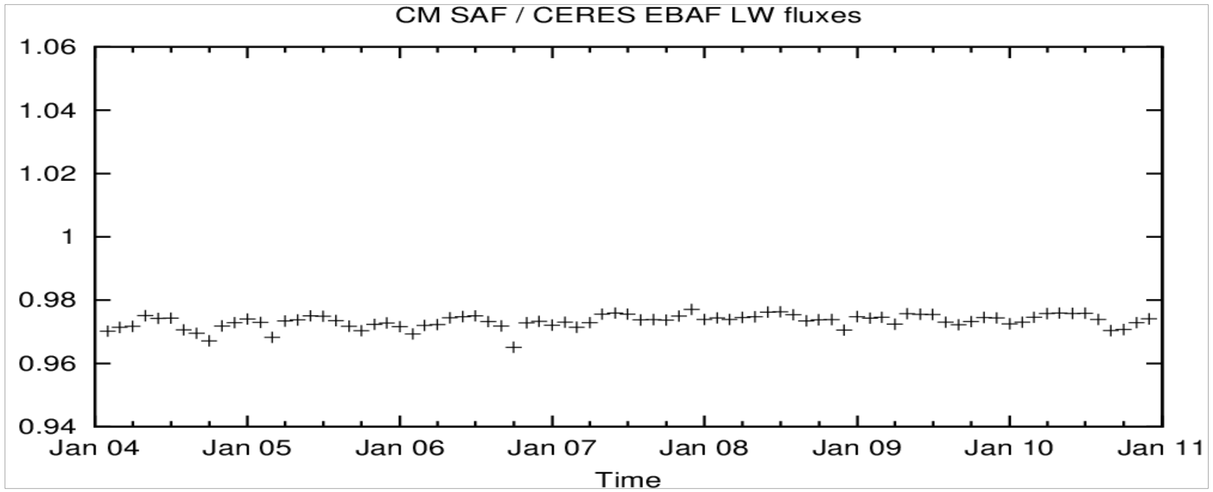


Validation: stability of the MM products

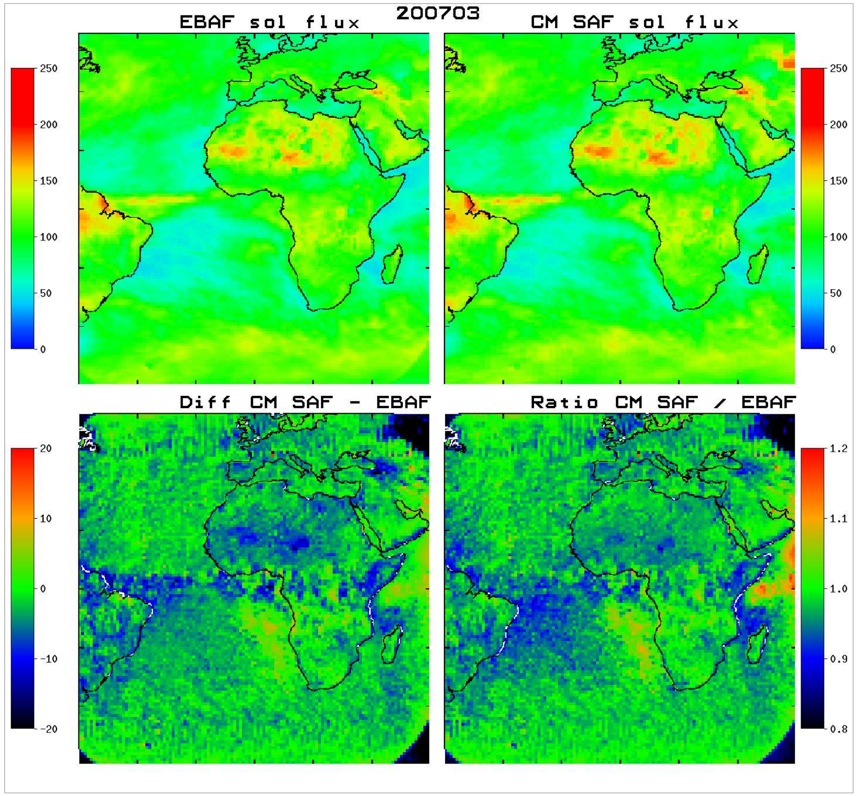
TRS stability

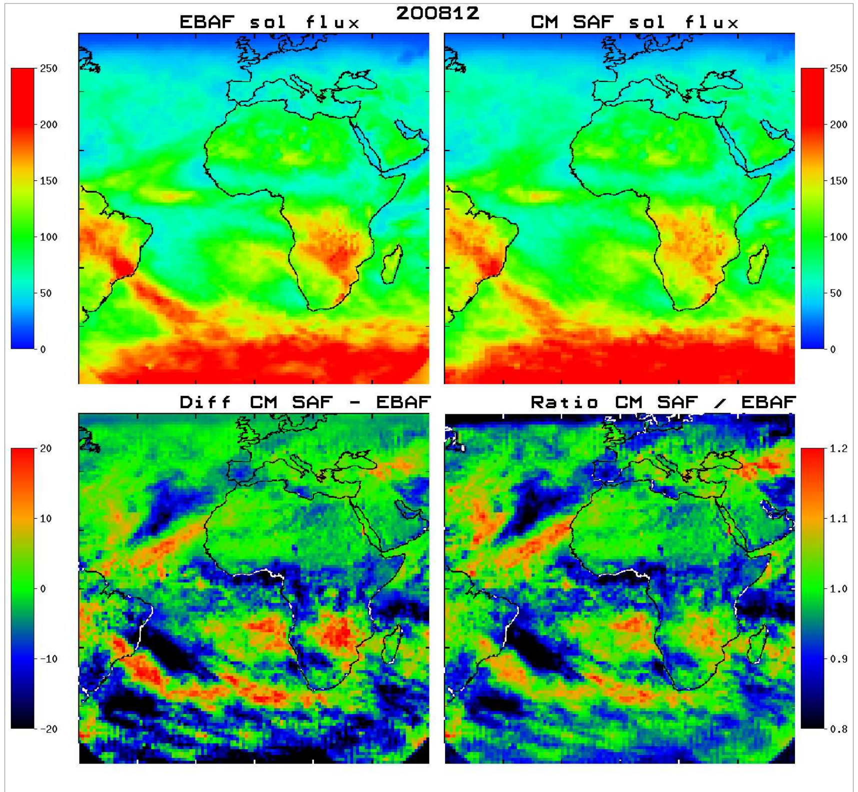


TET stability

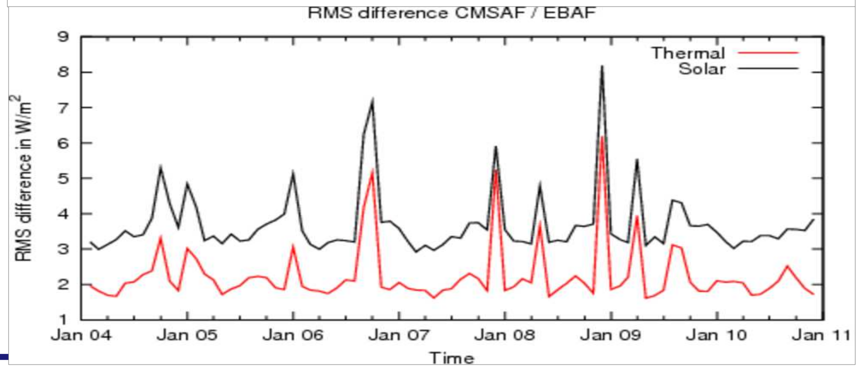


TRS MM validation : intercomparison with CERES

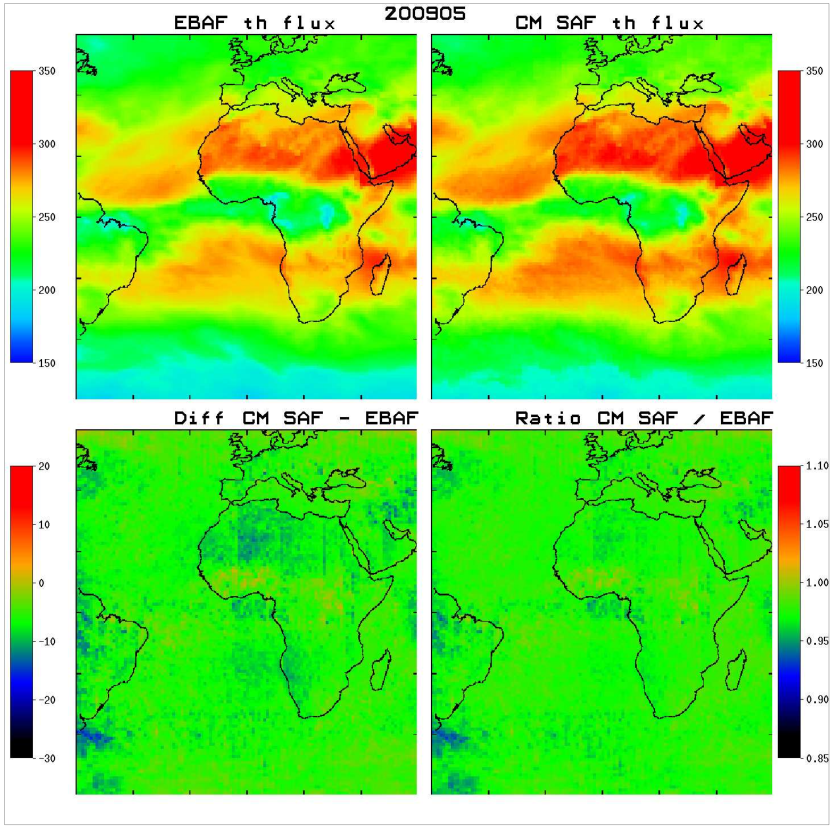


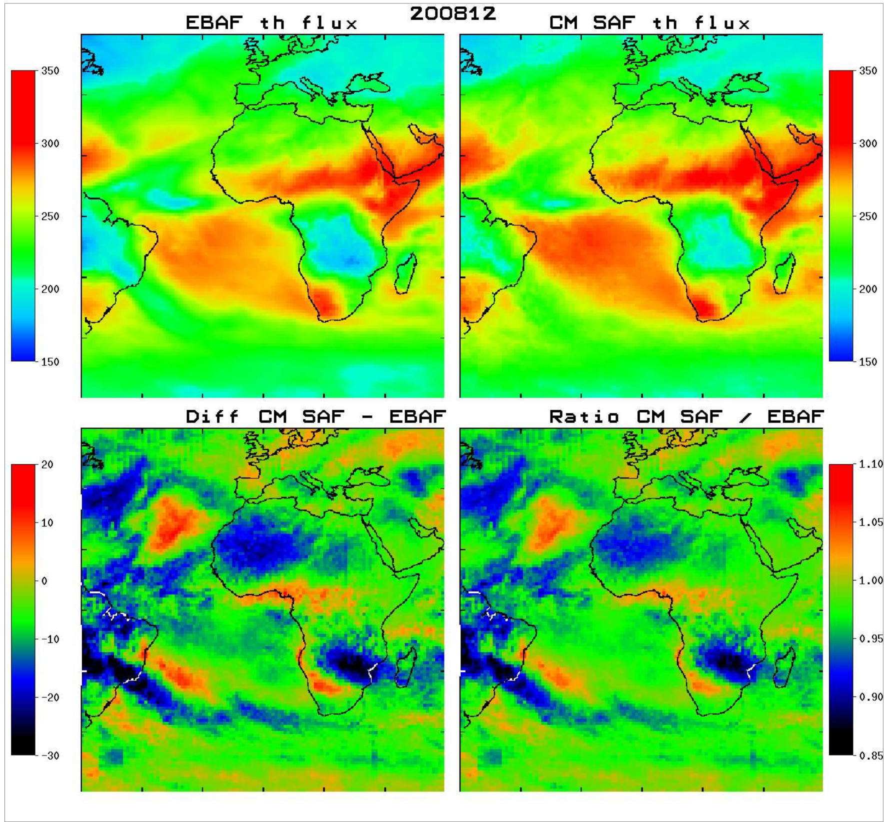


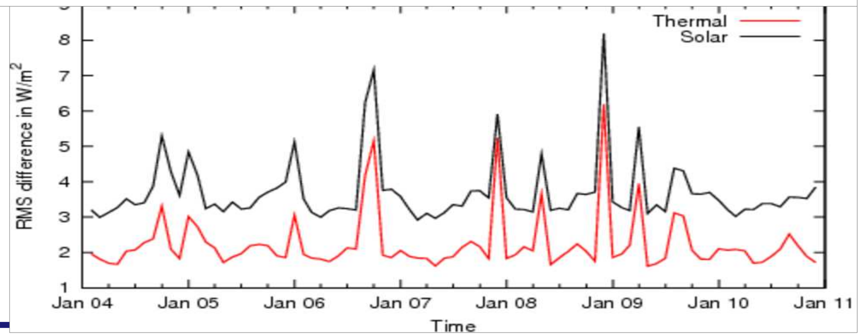
RMS difference
with CERES EBAF ~
3 W/m²



TET MM validation : intercomparison with CERES



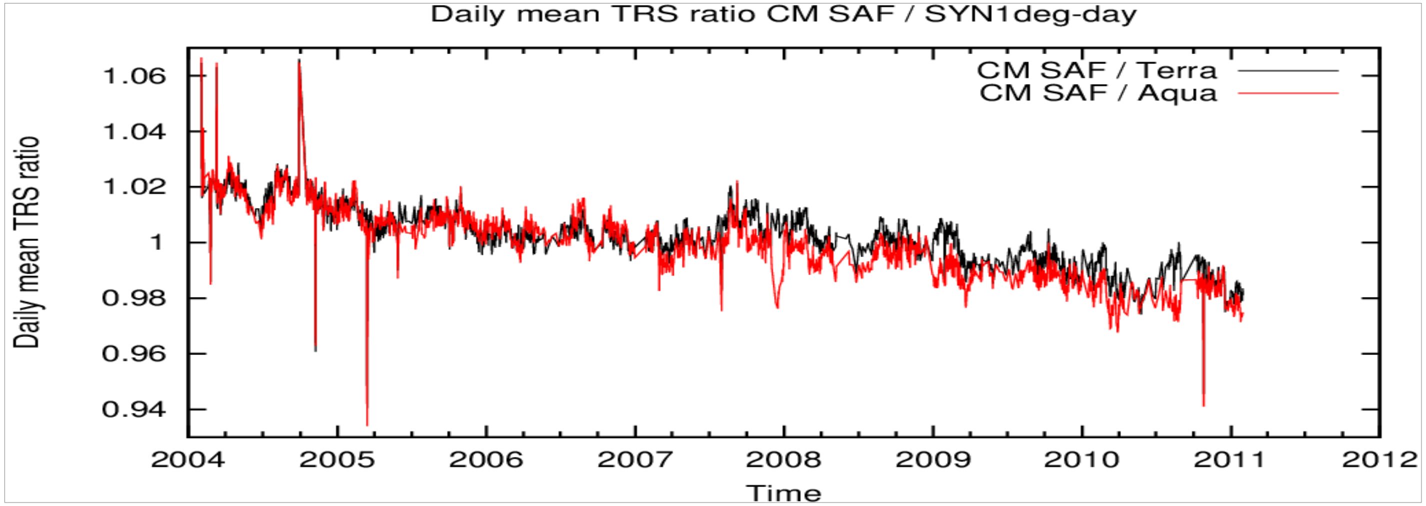




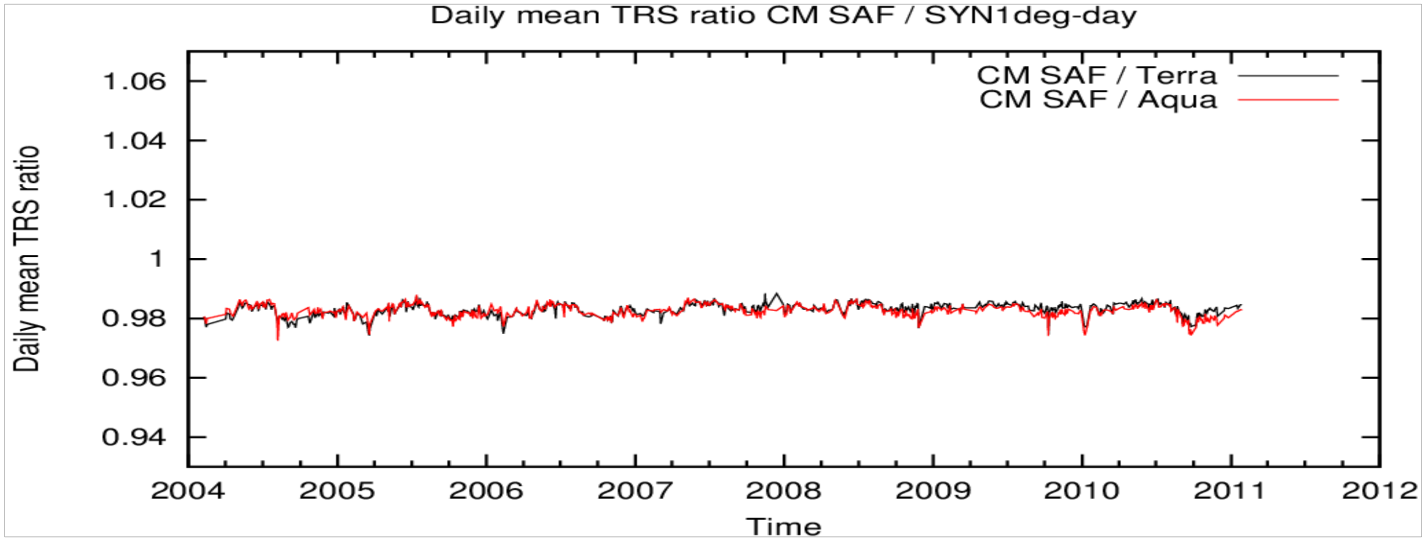
RMS difference with CERES EBAF ~ 2 W/m^2

Validation of the daily mean (DM) products : stability

TRS stability

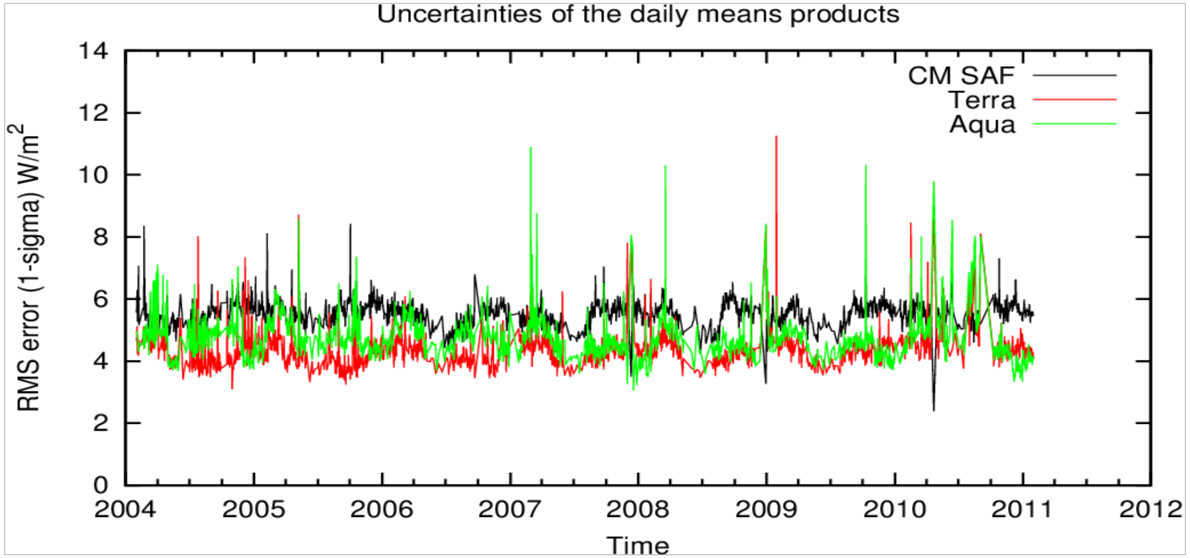


TET stability

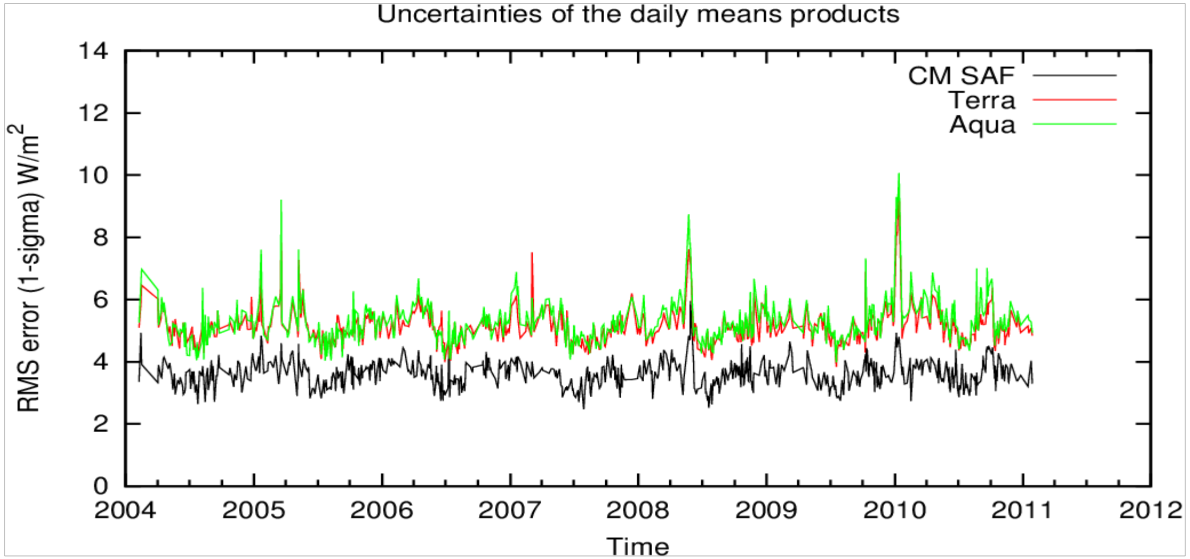


Validation of the daily mean products : accuracy

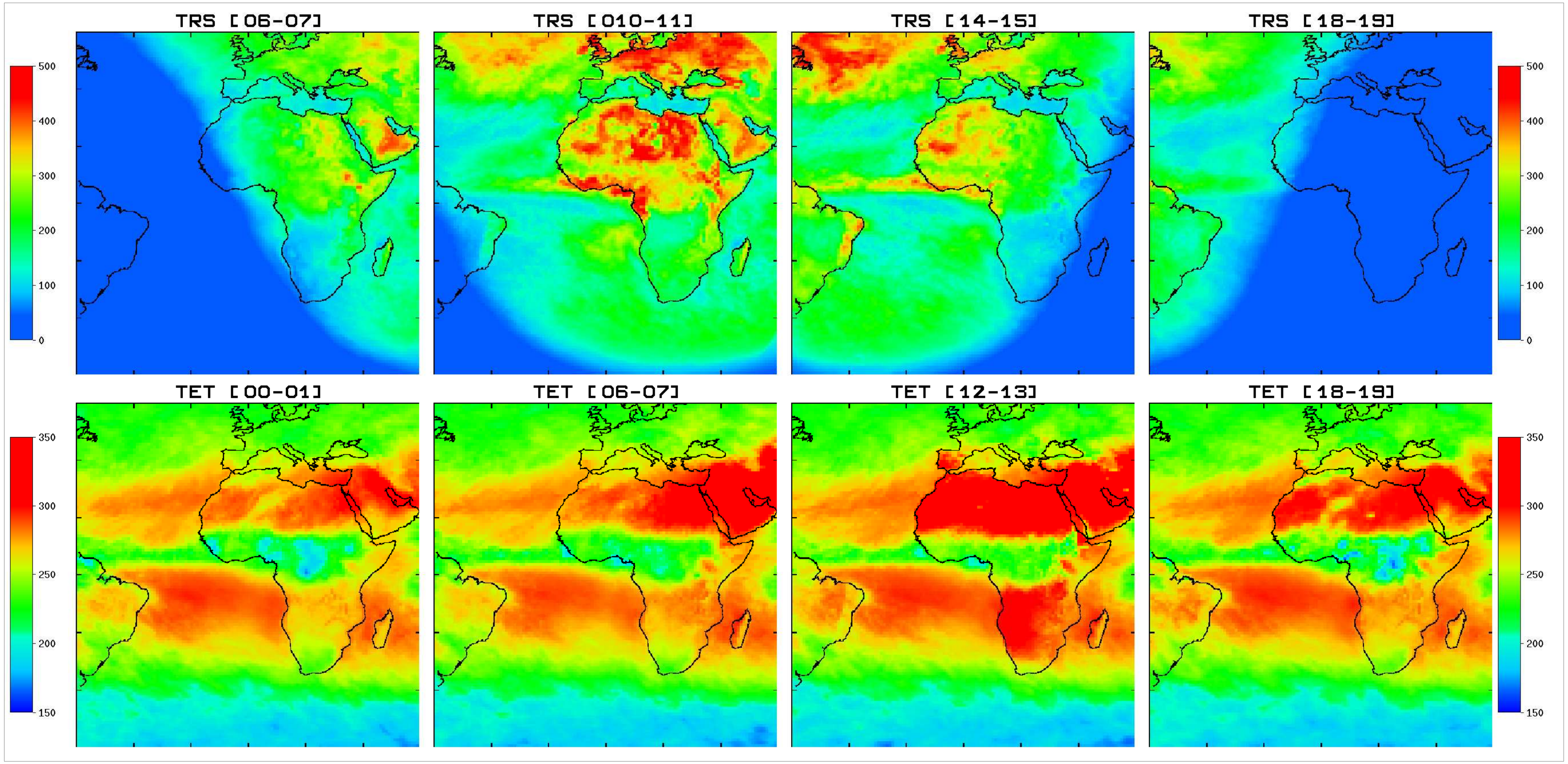
TRS daily mean accuracy ~ 5 W/m²
(~ 5%)



TET daily mean accuracy ~ 4 W/m²
(~ 2%)



Validation of the monthly mean diurnal cycle



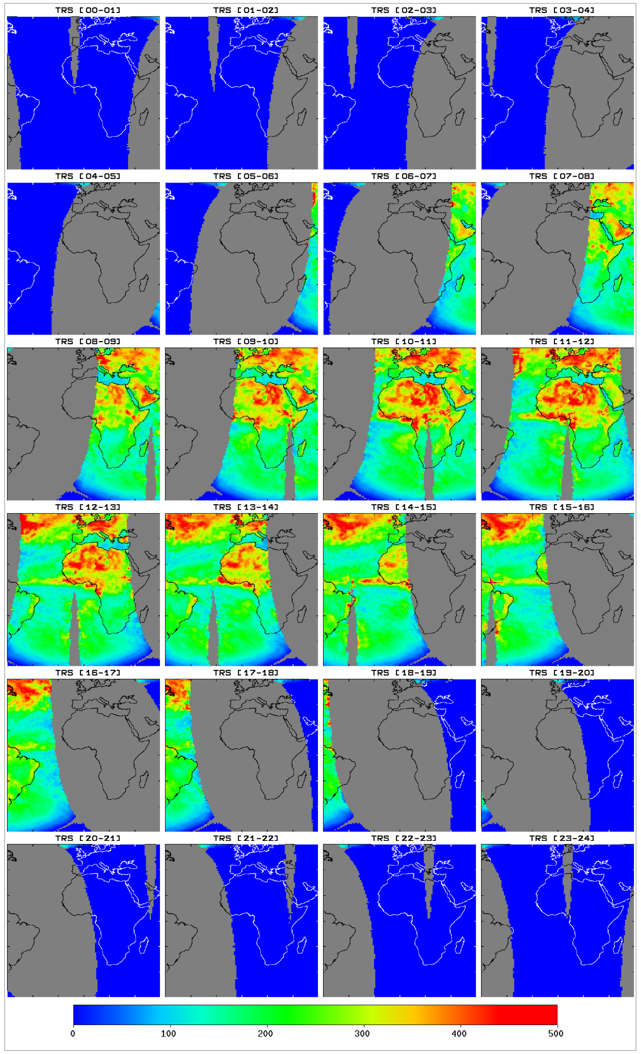
RMI

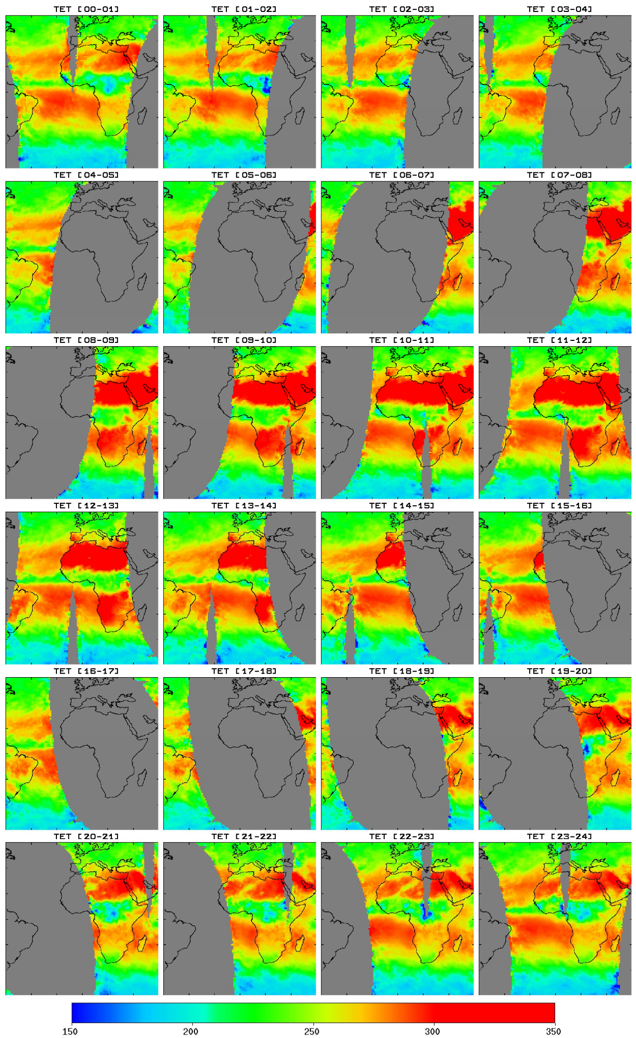
“Diurnal cycle” from CERES

The EUMETSAT Network of Satellite Application Facilities

CM SAF Climate Monitoring

TRS (left) and TET (right) diurnal cycle from 4 CERES instruments





Summary of the validation (1 σ uncertainty)

	TRS	TET
Monthly mean	4.0 W/m^2	3.4 W/m^2
Daily mean	6.2 W/m^2	4.6 W/m^2
MM diurnal cycle	14.5 W/m^2	4.3 W/m^2

Now let's discuss some applications

- Aerosol direct radiative effect
- Cooling effect of the Sahara region
- Climate monitoring with Earth Radiation Budget data : presentation of Steven tomorrow

Application 1: Direct aerosol forcing combining GERB and SEVIRI

Input:

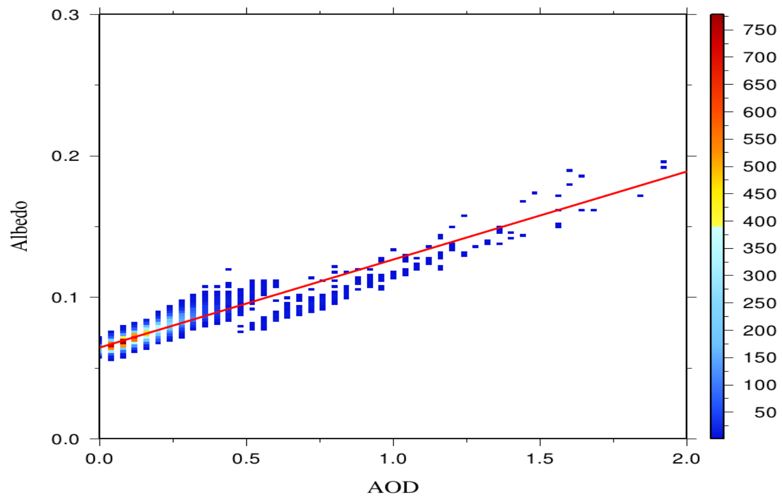
- SEVIRI AOD (CM-117 dataset!)
- GERB High Resolution TOA solar fluxes

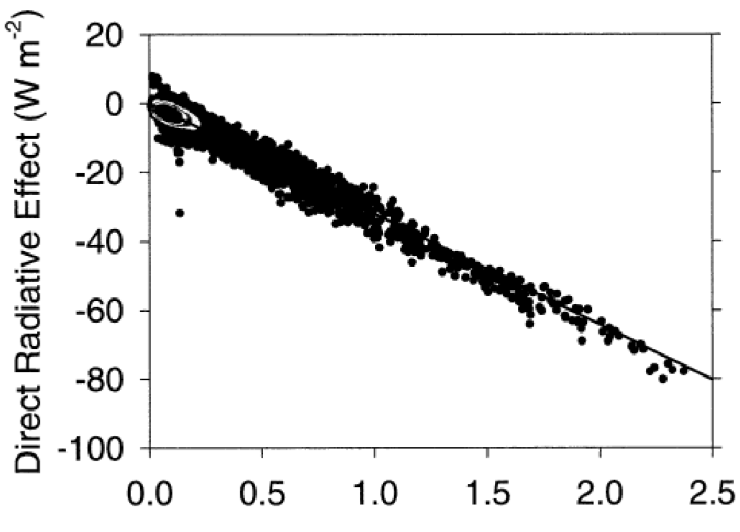
Method

- Scatterplot to determine « pristine » TOA albedo
- Aerosol sensitivity : Δalb / ΔAOD
- Compute instantaneous forcing
- Compute daily and monthly means

Results

- CM-118 dataset: Direct Aerosol Effect (DAE) under review (DRI-5).



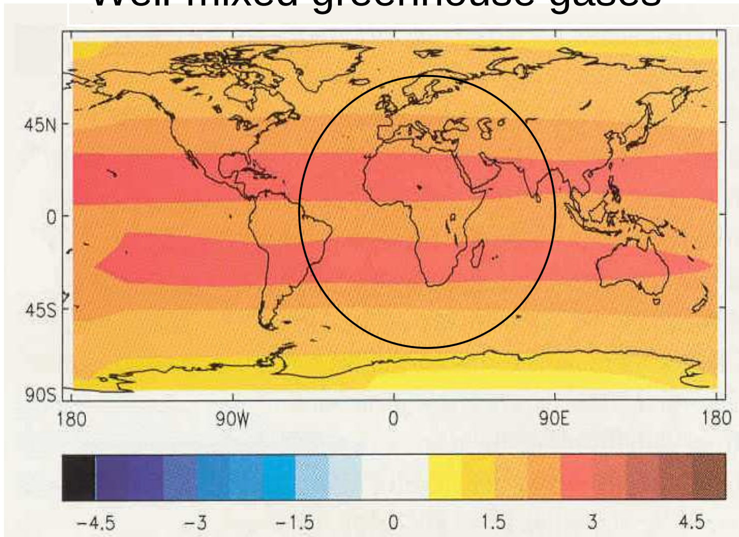


Loeb and Kato, 2002

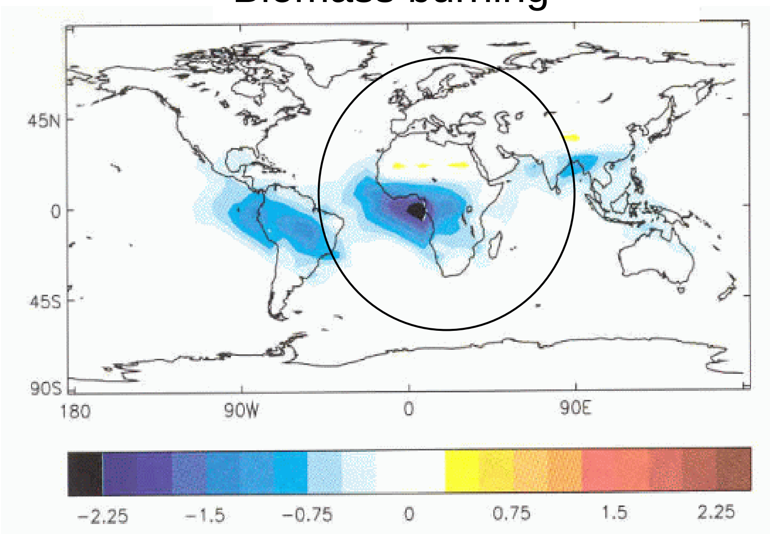
Radiative effect of aerosols: Interest of the Meteosat Field-of-View

blue: "cooling effect"
red: "warming effect"
unit : W/m²

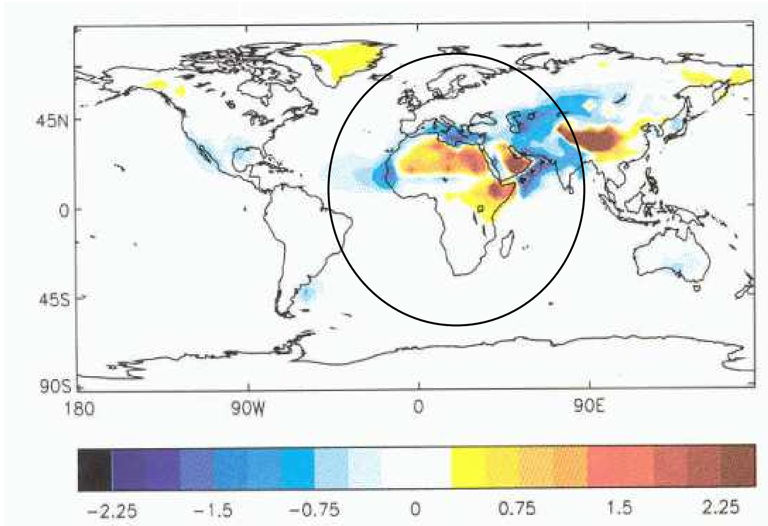
Well-mixed greenhouse gases



Biomass burning



Mineral dust

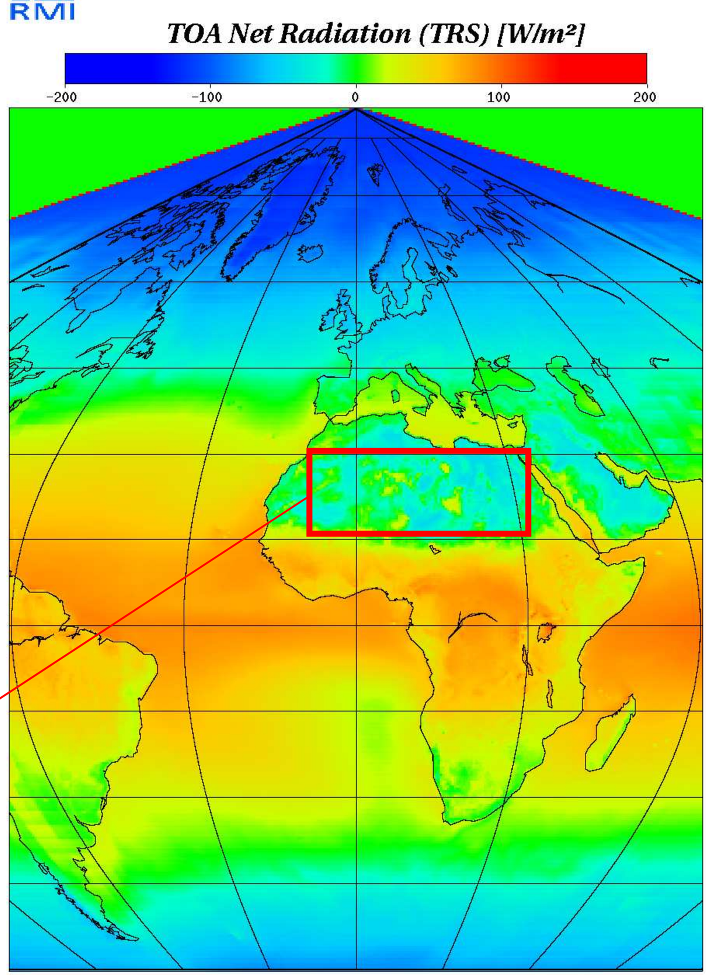


Application 2: cooling effect of saharan desert

The Sahara is a huge region (thousand of km) characterized by a negative net radiation budget of ~ -15 W/m^2 (more energy leaves the system than incoming -> "cooling effect") .

From where comes this energy?

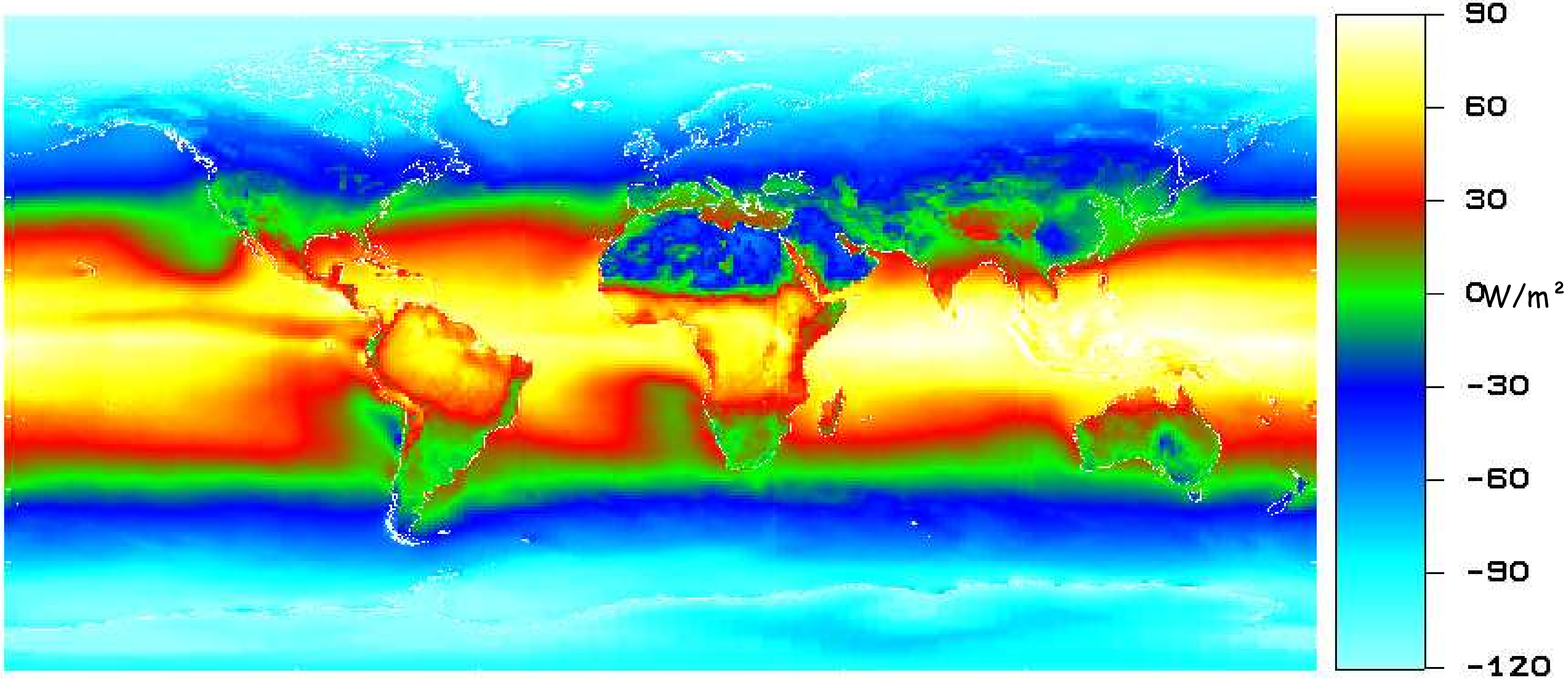
Average 15 W/m^2



7 years average net TOA radiation from CM SAF

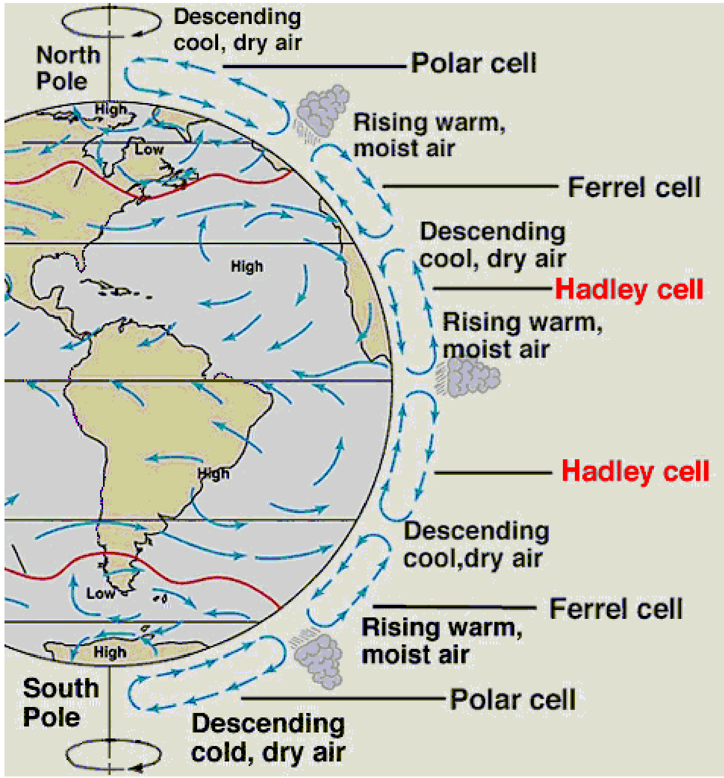
Application 2: cooling effect of saharan desert

Same with 10 years of CERES EBAF …

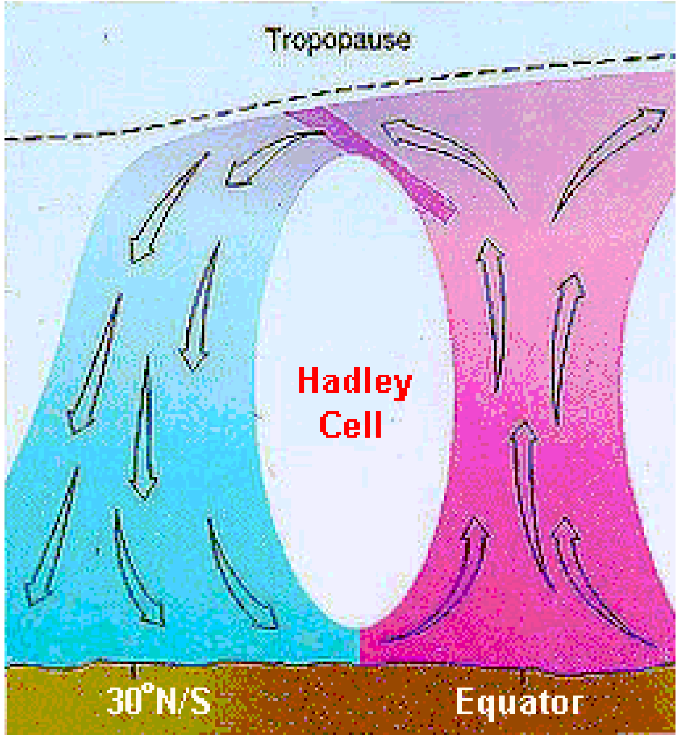


10 years average net radiation from CERES EBAF

Hadley Cell…



Descending
cool, dry air
North
Pole
Polar cell
High
Low
Rising warm,
moist air
Ferrel cell
Descending
cool, dry air
High
Hadley cell
Rising warm,
moist air
High
Hadley cell
Descending
cool,dry air
Low
Ferrel cell
Rising warm,
moist air
High
South
Pole
Polar cell
Descending
cold, dry air



Tropopause
Hadley
Cell
30°N/S
Equator

TOA Radiation in CDOP-2 (2012-2017)

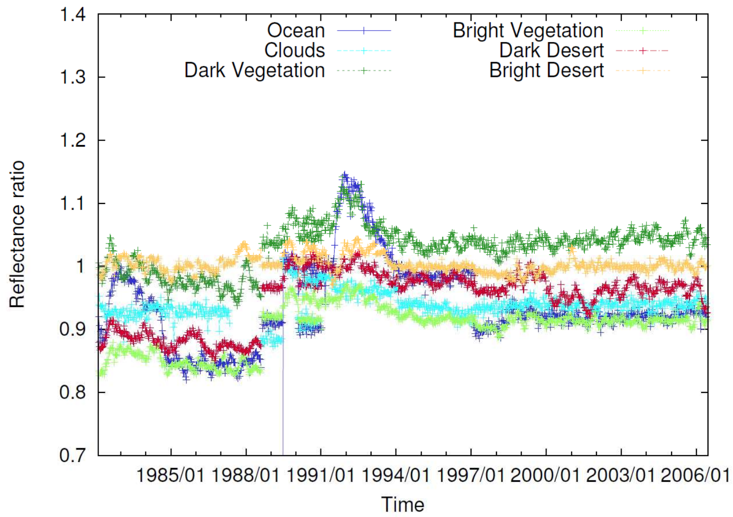
- Continue generation of the EDRs

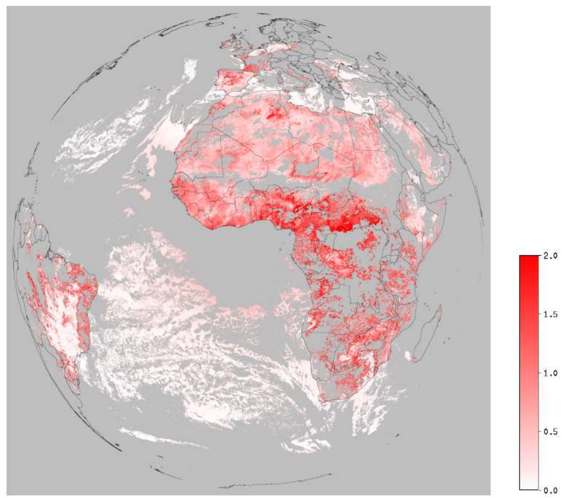
- New Editions of the current dataset with improved
    - input data (additional satellites, or reprocessed FCDR's)
    - algorithms

- New dataset : clear sky fluxes (synergy with the CM SAF cloud products)

- New dataset : MFG + MSG (1982-2014) development of an aging model of MVIRI VIS channel

- Aerosol properties over ocean and land





Summary

• TOA radiations are key elements of the energy and water cycles.

• CM SAF provides level 3 of TOA GERB radiation products as
  - monthly mean
  - daily mean
  - monthly mean diurnal cycle

•The diurnal cycle product is unique.

•The daily mean products present improvements wrt others daily mean products as for example CERES SYN1deg-day.

• The TOA radiation products have excellent synergy with other CM SAF datasets, in particular the surface radiation dataset, the cloud properties, the aerosols and the surface albedo.