

Evolution of cloud properties and radiative fluxes observed from space

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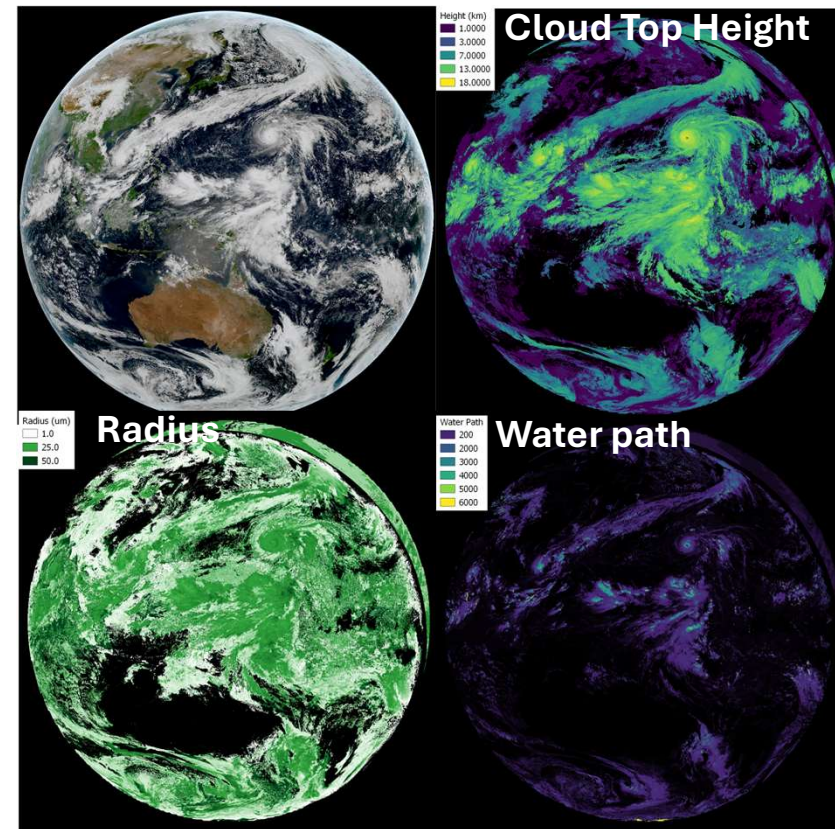
ORAC: Optimal Retrieval of Aerosol and Cloud algorithm

ORAC is an optimal estimation (OE) scheme for retrieving aerosol and cloud properties from VIS-IR satellite imagers.

- It has been applied to the (A)ATSR, SLSTR, SEVIRI, AHI, FCI, MODIS, VIIRS & AVHRR sensor families
- All state parameters retrieved simultaneously using all measurements and a priori constraints, weighted by their uncertainty.
- Full uncertainty propagation pixel by pixel
- Solution found through iteration to minimize cost function (a posteriori Quality Control)

Open source code (Fortran & Python) :
<https://github.com/ORAC-CC/orac/wiki>

SLSTR ORAC projects:
Cloud CCI, NCEO (NERC), EOCIS (NERC), C3S



ORAC Himawari dataset (2015 – 2022)

ORAC scheme: Cloud

ORAC Retrieved **Cloud properties**:

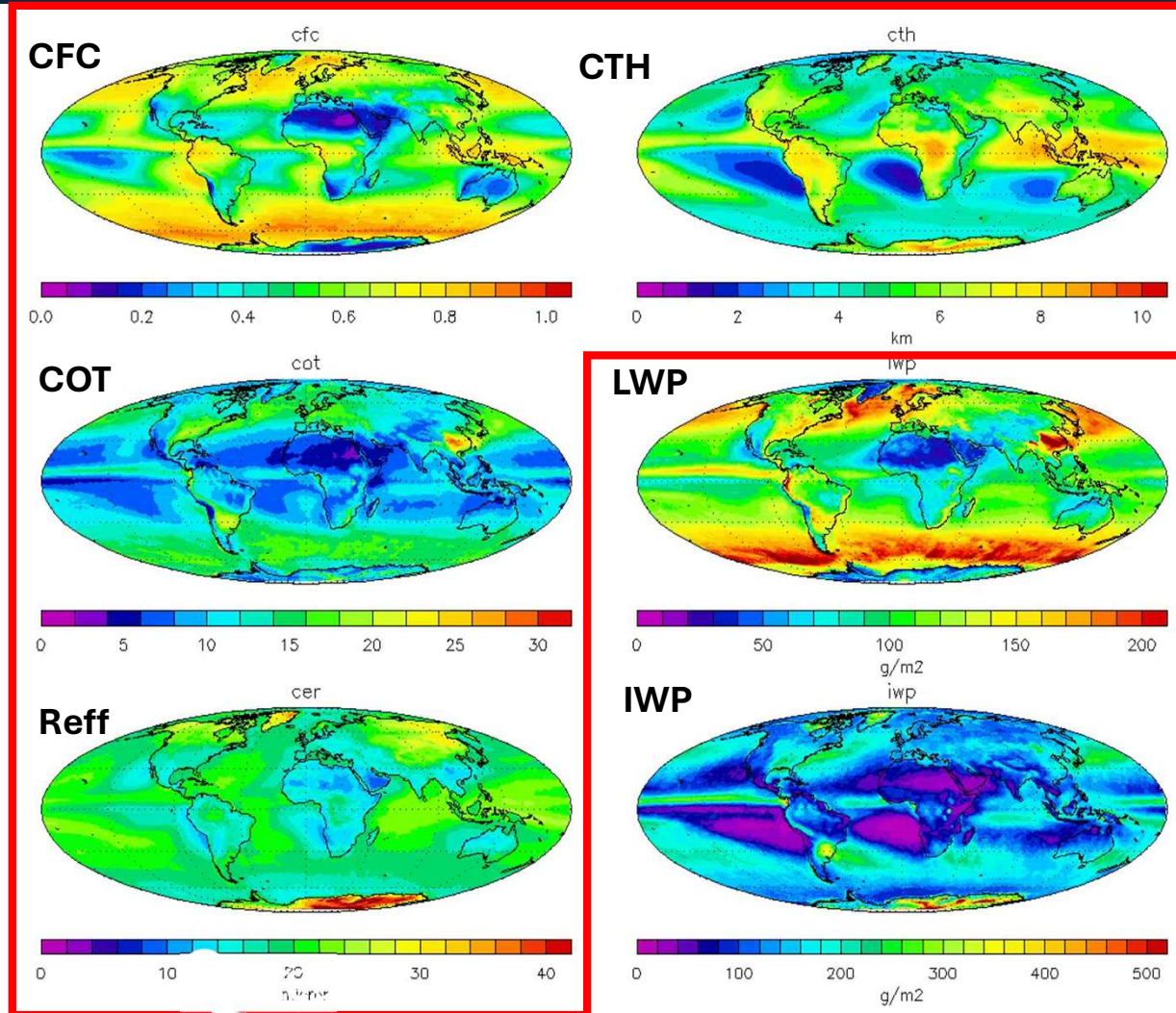
- Cloud Top height / temperature / pressure
- Cloud phase (liquid / ice)
- Optical thickness
- Effective radius

=> Liquid water path
Ice water path

+ **Radiative fluxes**: Longwave and shortwave
(top and bottom of atmosphere)

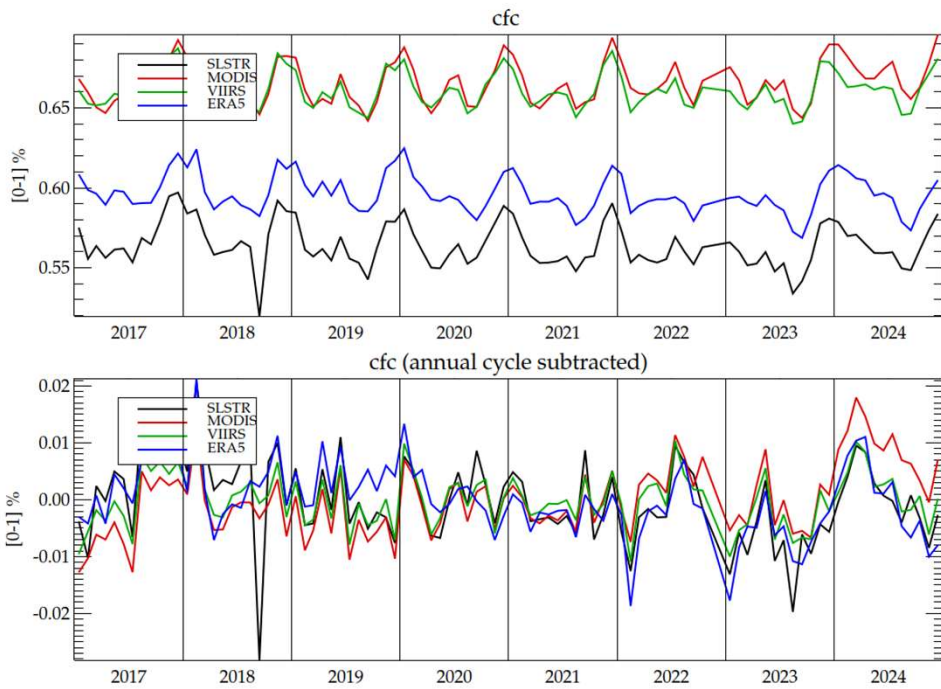
derived using the cloud (and aerosol) properties
+ ERA5 profile and broadband radiative transfer
(BugsRad)

Average of SLSTR A+B
Level-3C V5.0



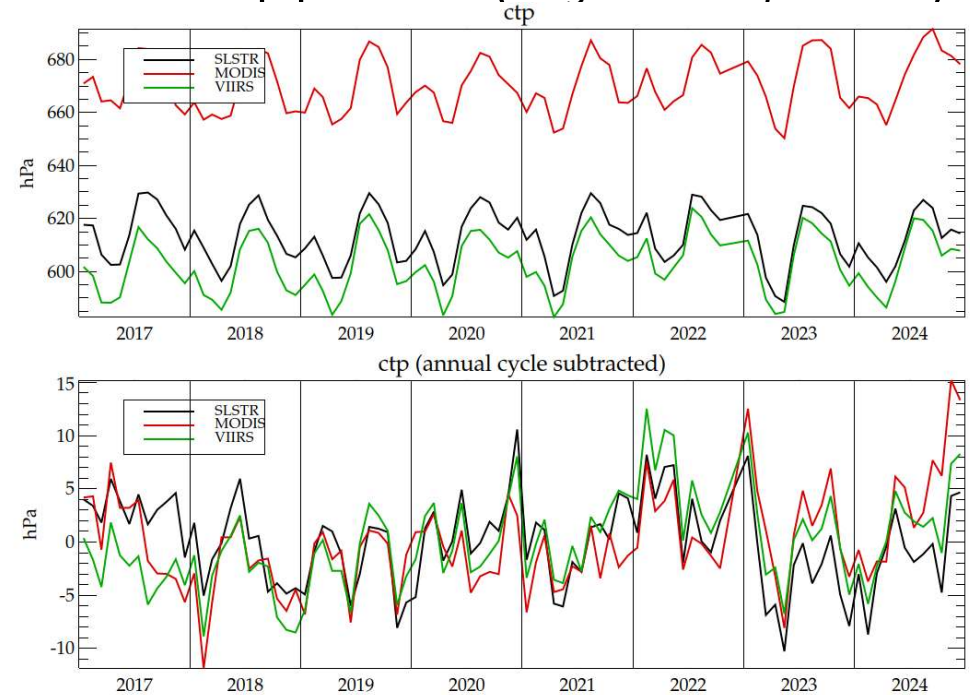
SLSTR (A+B) cloud properties

Cloud fractional cover



SLSTR shows a low cloud fraction compared to most comparable datasets, but a **high correlation**.
September 2018 is anomalous.

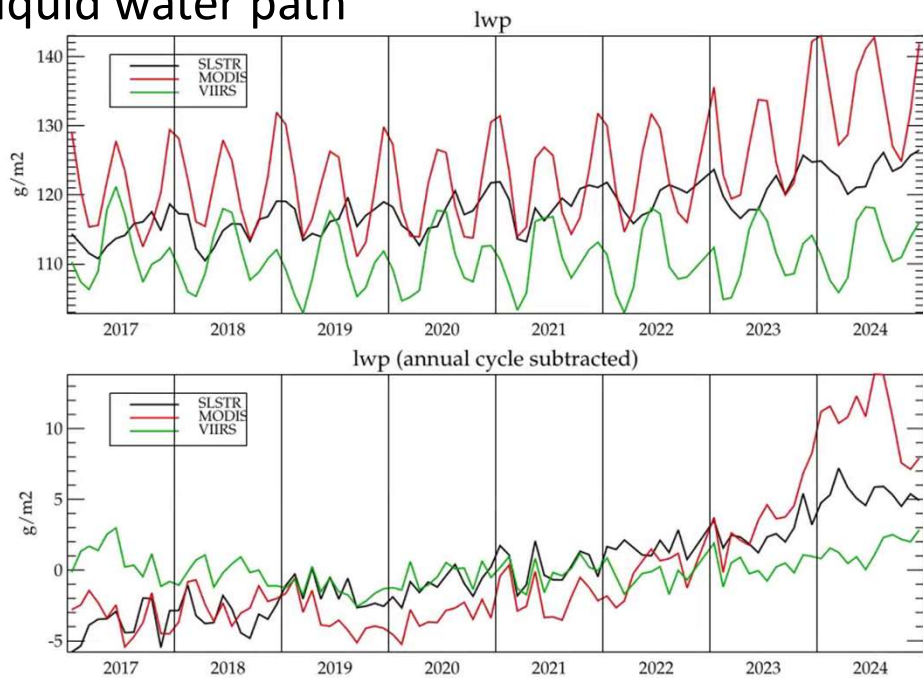
Cloud-top pressure (*height or temperature*)



SLSTR agrees well with VIIRS. On average shows *higher* clouds than MODIS!
Again, **correlation** between the datasets is strong.

SLSTR (A+B) cloud properties

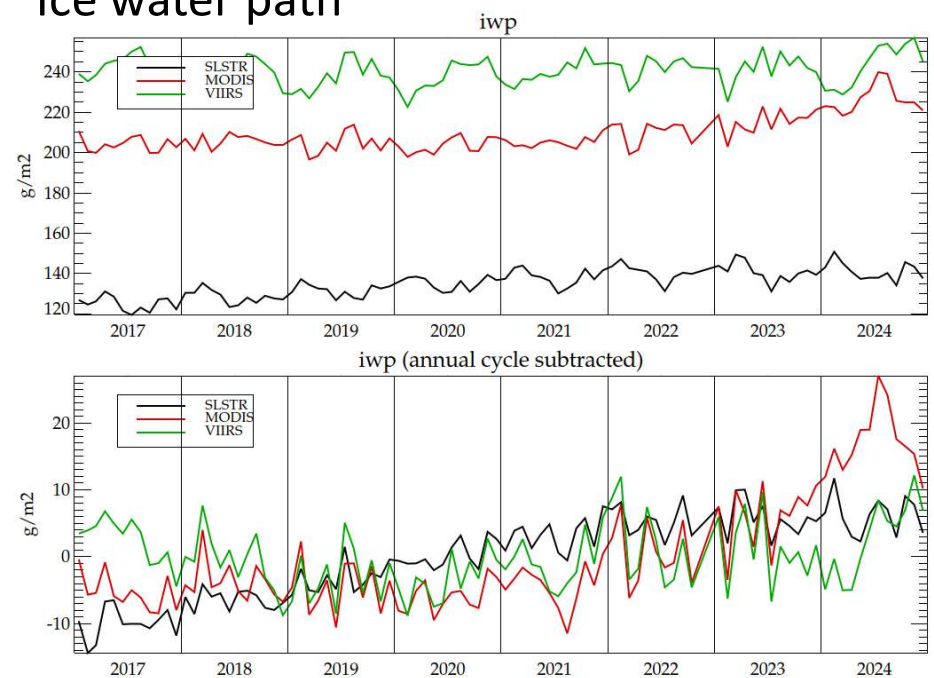
Liquid water path



Quite a large spread in annual cycle.

- Driven by differences at high latitudes?
- positive trend from about 2020? but there are inconsistencies at the start and end of the time-series.

Ice water path



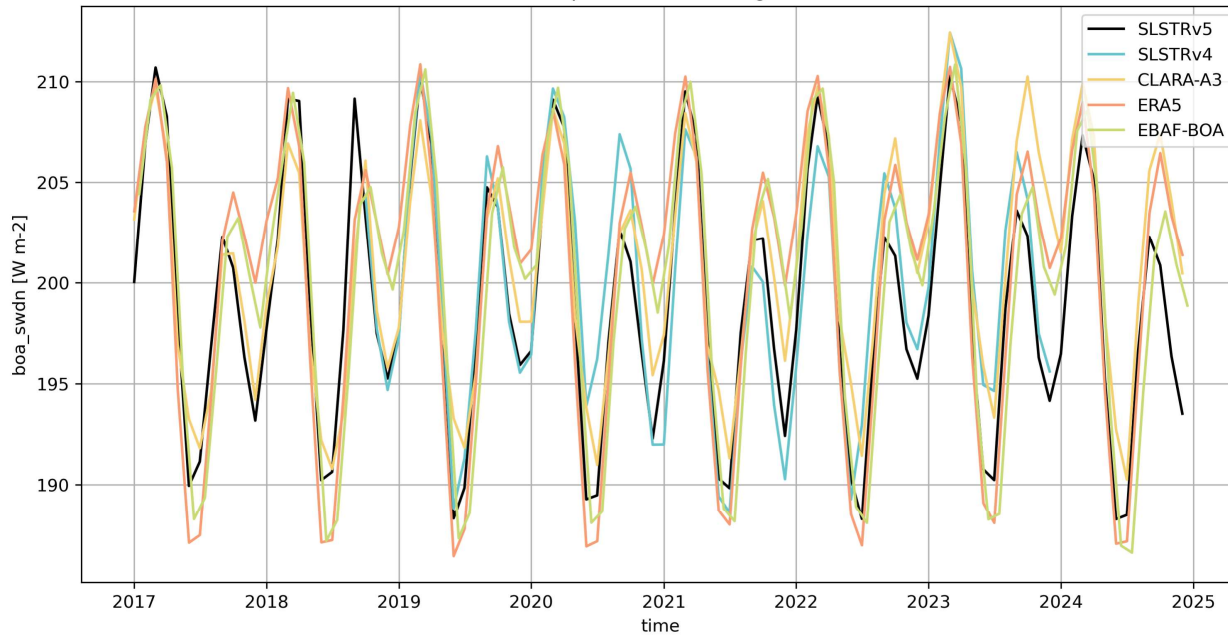
IWP is a tricky parameter, values are largely determined by:

- cloud-phase determination
- assumed ice-habit properties in each retrieval
- how ice/snow surfaces are handled
- any detection / parameterisation of multi-layer cloud.

Bottom of Atmosphere (BOA) fluxes - Surface Radiation Budget

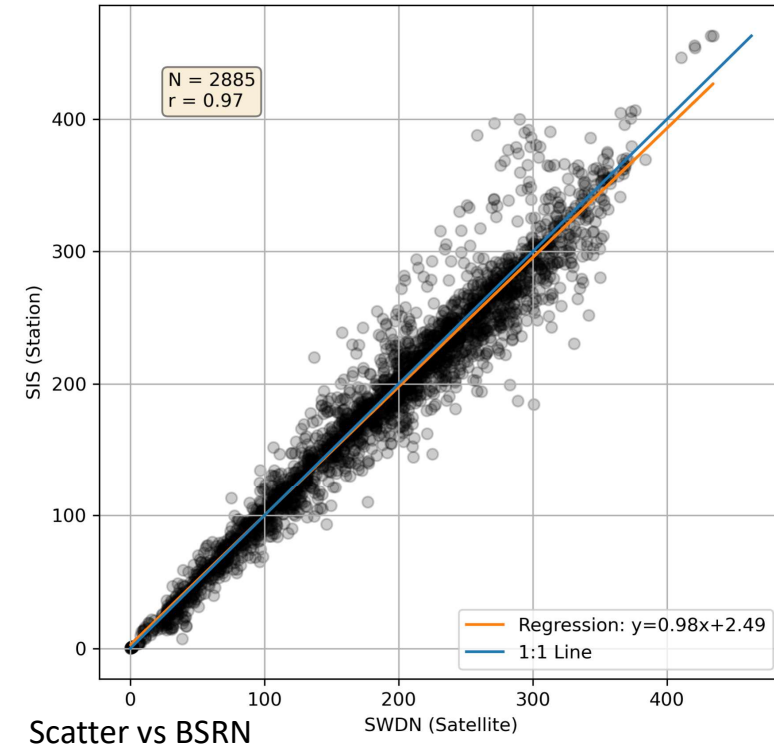
Shortwave down

bottom of atmosphere downwelling solar radiation



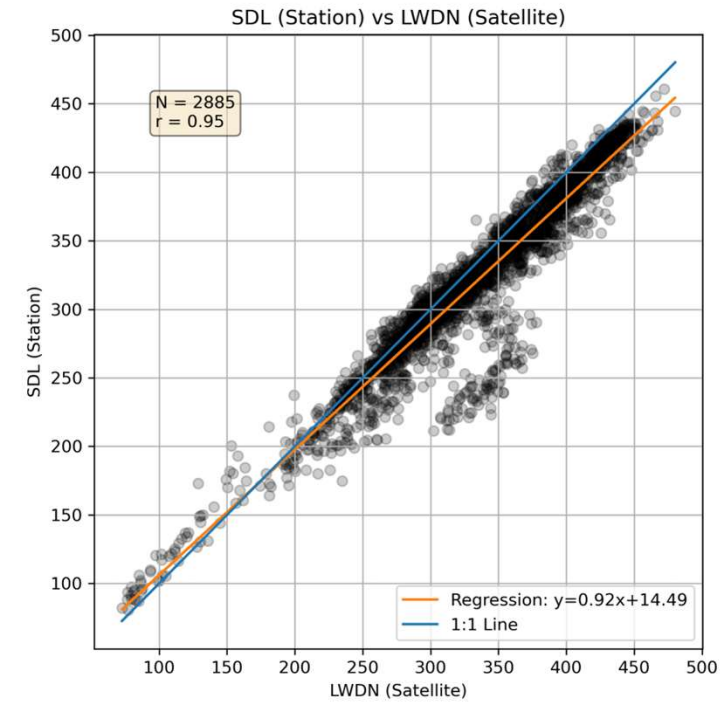
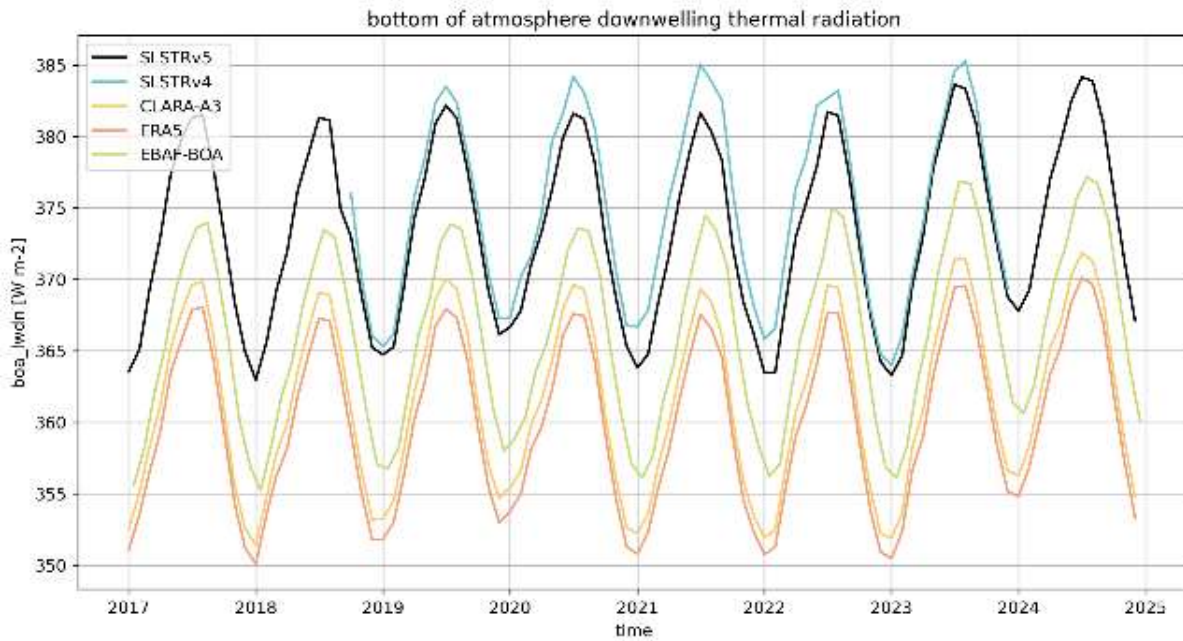
Overall very good agreement with both satellite and ground stations

SIS (Station) vs SWDN (Satellite)



Bottom of Atmosphere (BOA) fluxes - Surface Radiation Budget

Longwave down



There is some spread in the various datasets,
but the time-series are very consistent

Scatter vs BSRN

Top of Atmosphere (TOA) fluxes - Earth Radiation Budget

Shortwave Up

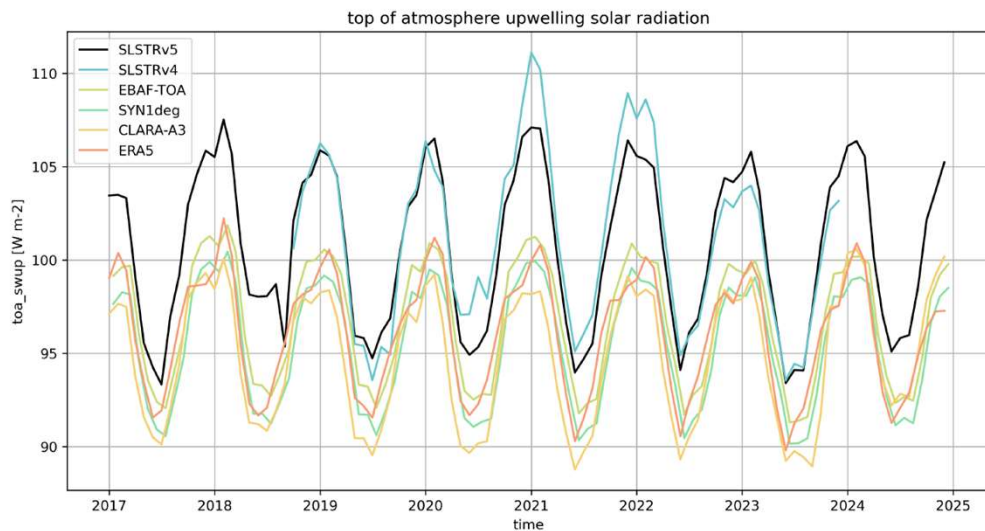


Figure 2-4: Climatology of collocated and latitude-weighted global monthly means (60°S-60°N) of Top of Atmosphere Upwelling Solar Radiation for SLSTR and reference datasets.

Longwave Up

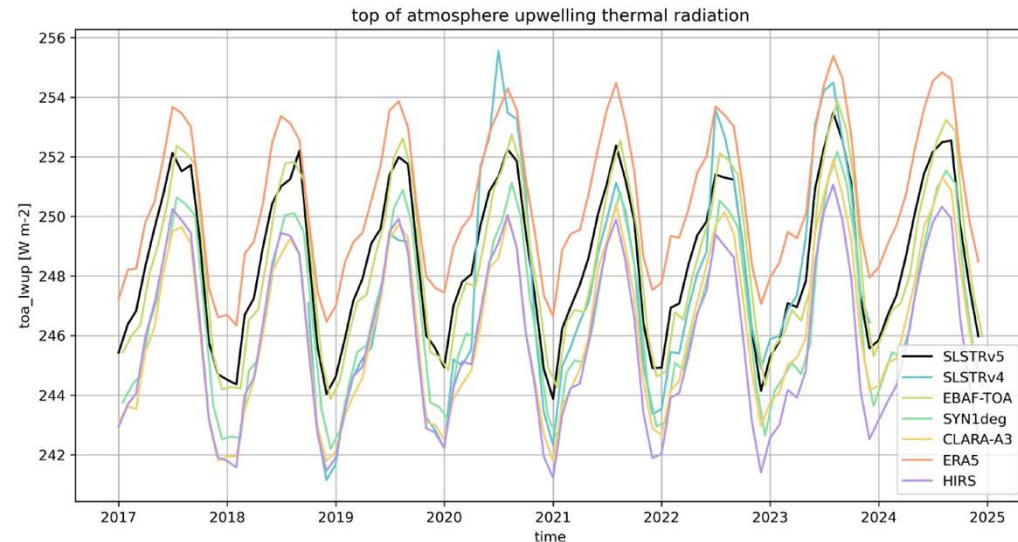
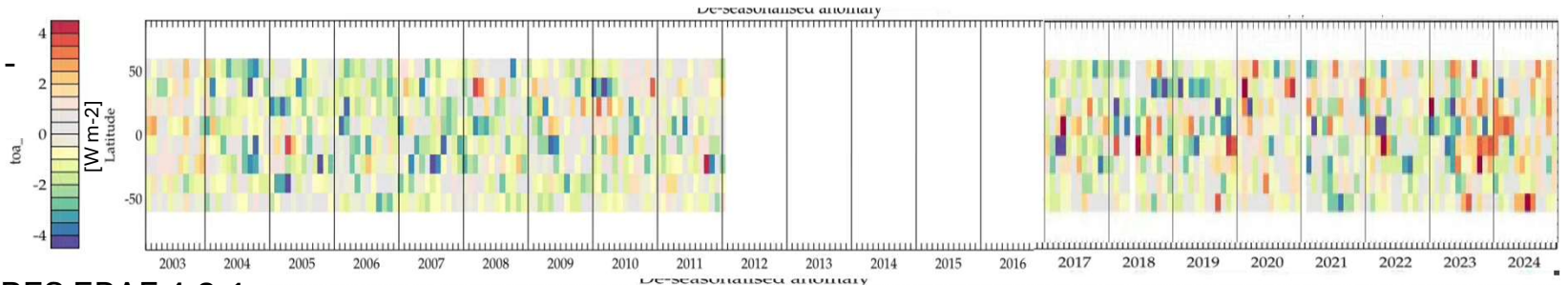


Figure 2-1: Climatology of collocated and latitude-weighted global monthly means (60°S-60°N) of Top of Atmosphere Upwelling Thermal Radiation for SLSTR and reference datasets.

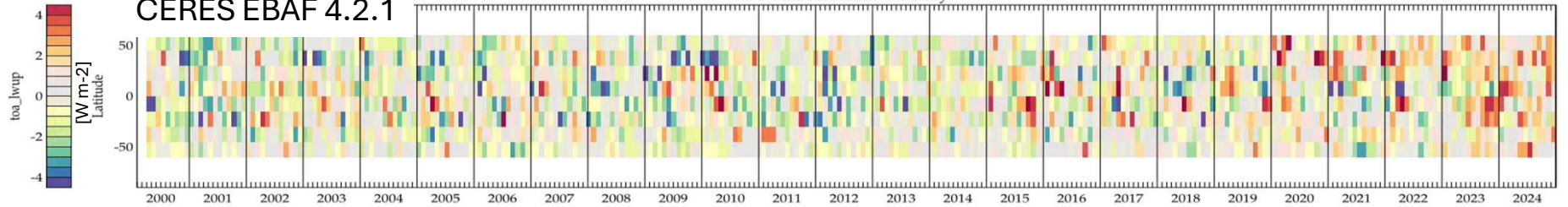
- TOA: some bias in the shortwave, very good agreement in the longwave

TOA LW UP – Longwave Radiative Fluxes – De-seasonalized Anomaly

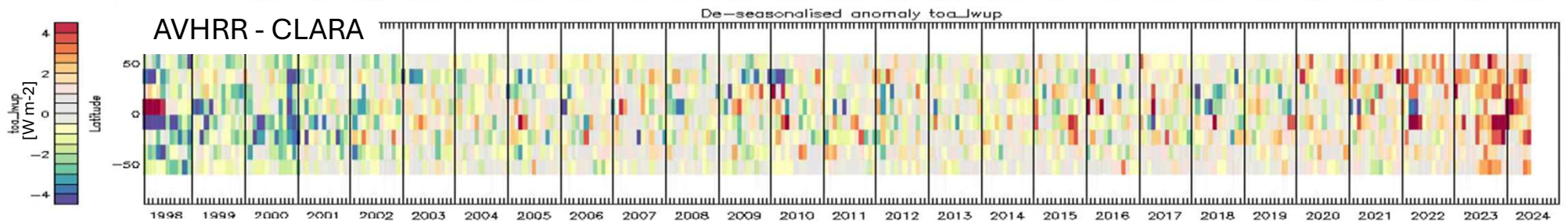
(A)ATSR-SLSTR -
ORAC



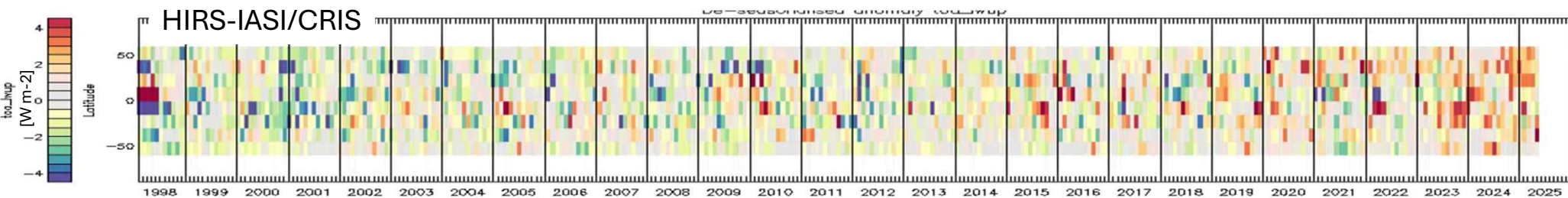
CERES EBAF 4.2.1



AVHRR - CLARA

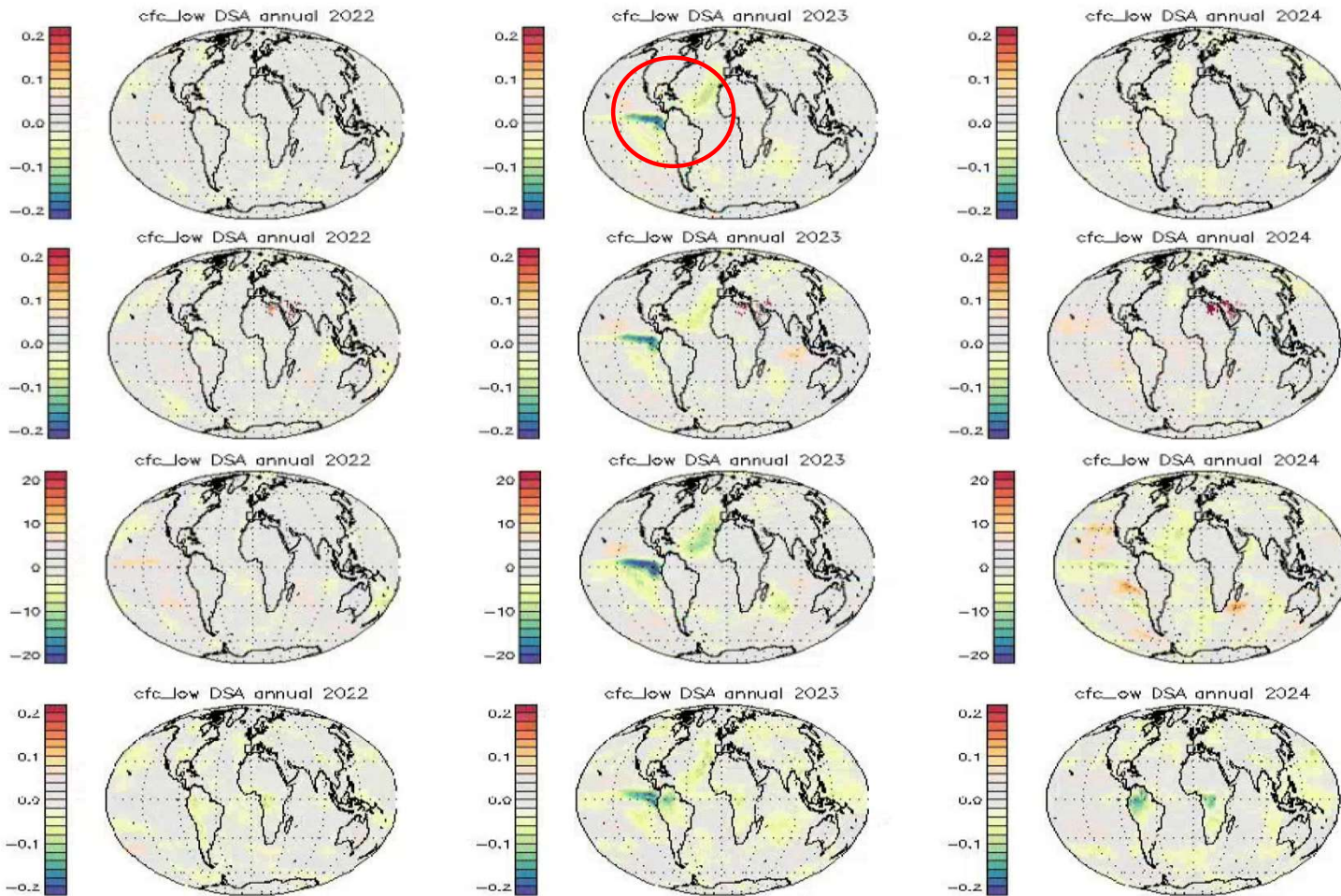


HIRS-IASI/CRIS



Low cloud fraction Annual anomaly

CFC_low



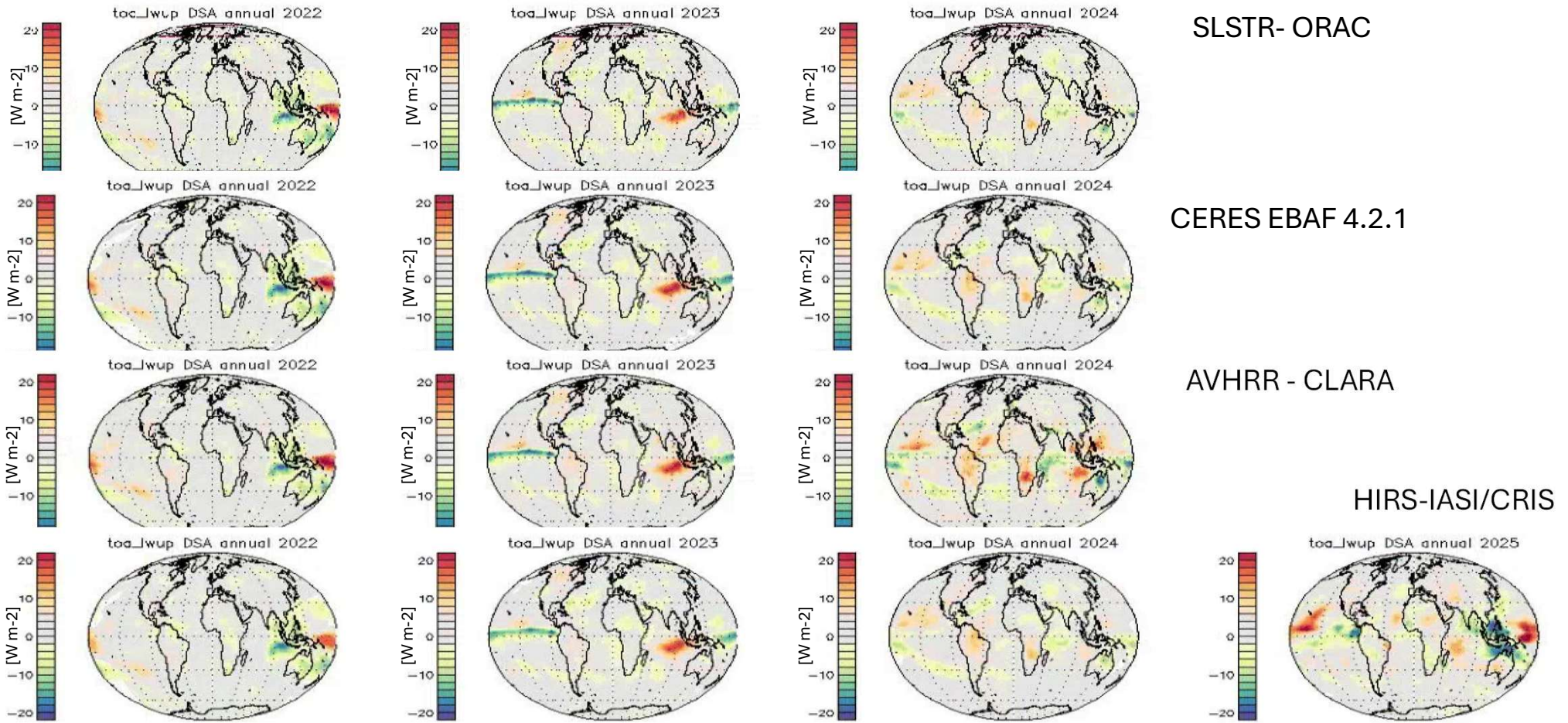
ORAC-SLSTR(A+B)

MODIS terra 6.1

AVHRR-clara

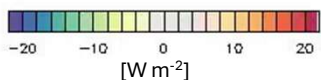
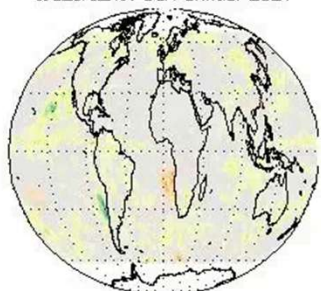
ERA5 morning 9:30

TOA LW UP – Longwave Radiative Fluxes – Annual Anomaly

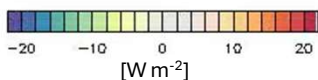
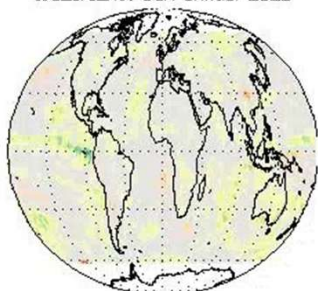


Top Of Atmosphere (TOA) Cloud Radiative Effect (CRE) – NET Annual anomaly

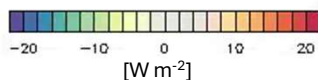
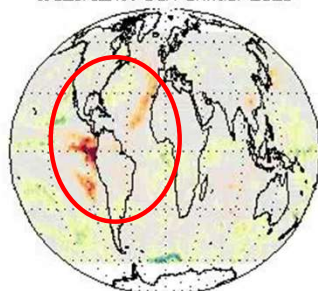
toa_cre_net DSA annual 2021



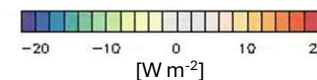
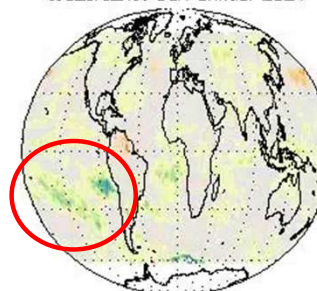
toa_cre_net DSA annual 2022



toa_cre_net DSA annual 2023

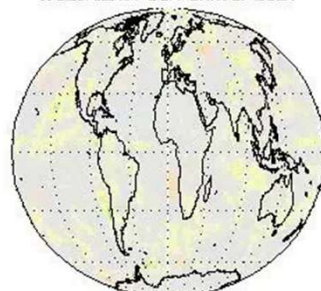


toa_cre_net DSA annual 2024

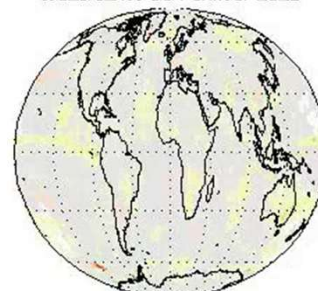


SLSTR - ORAC

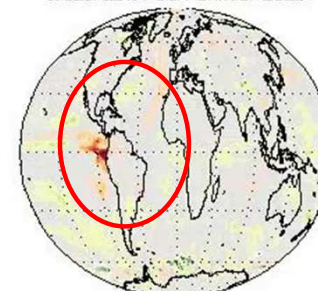
toa_cre_net DSA annual 2021



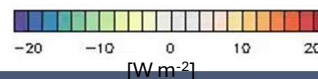
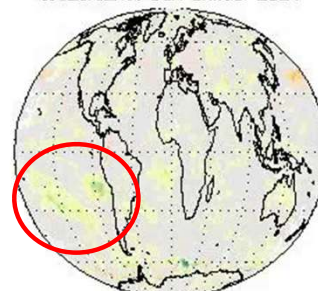
toa_cre_net DSA annual 2022



toa_cre_net DSA annual 2023



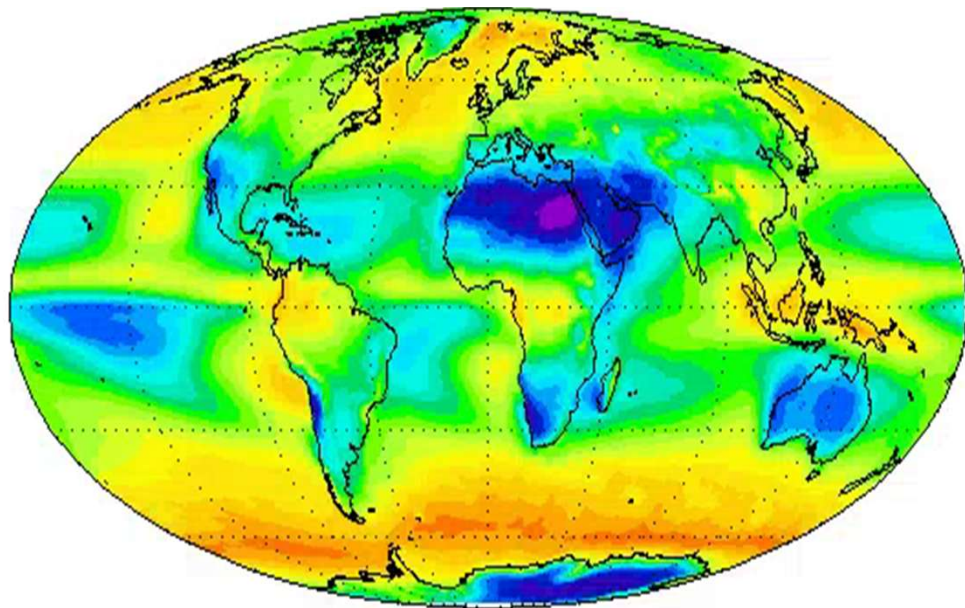
toa_cre_net DSA annual 2024



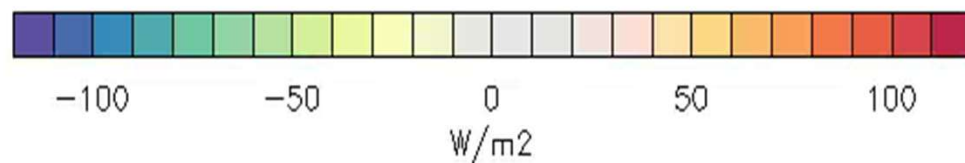
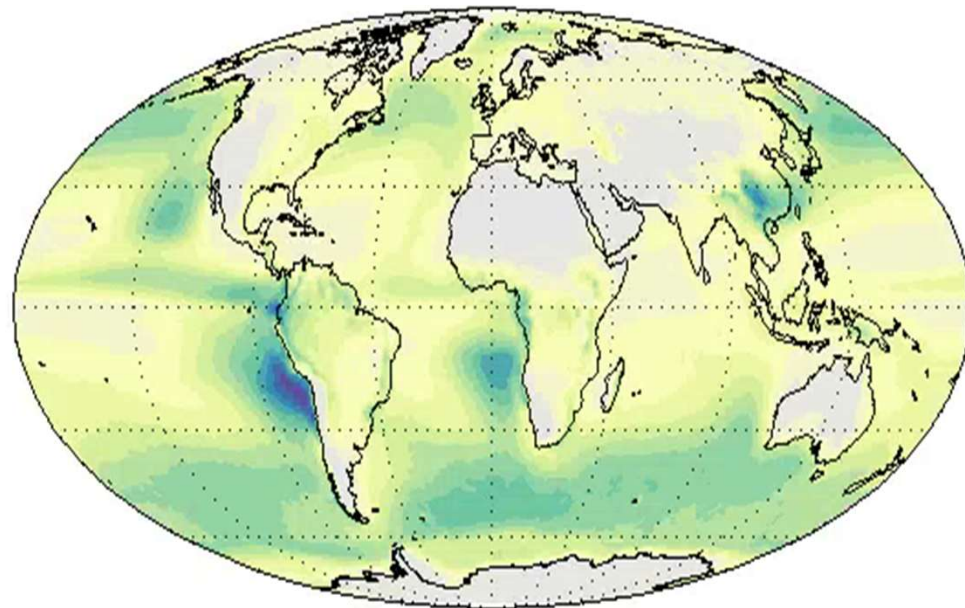
CERES EBAF

Top Of Atmosphere (TOA) Cloud Radiative Effect (CRE) – NET

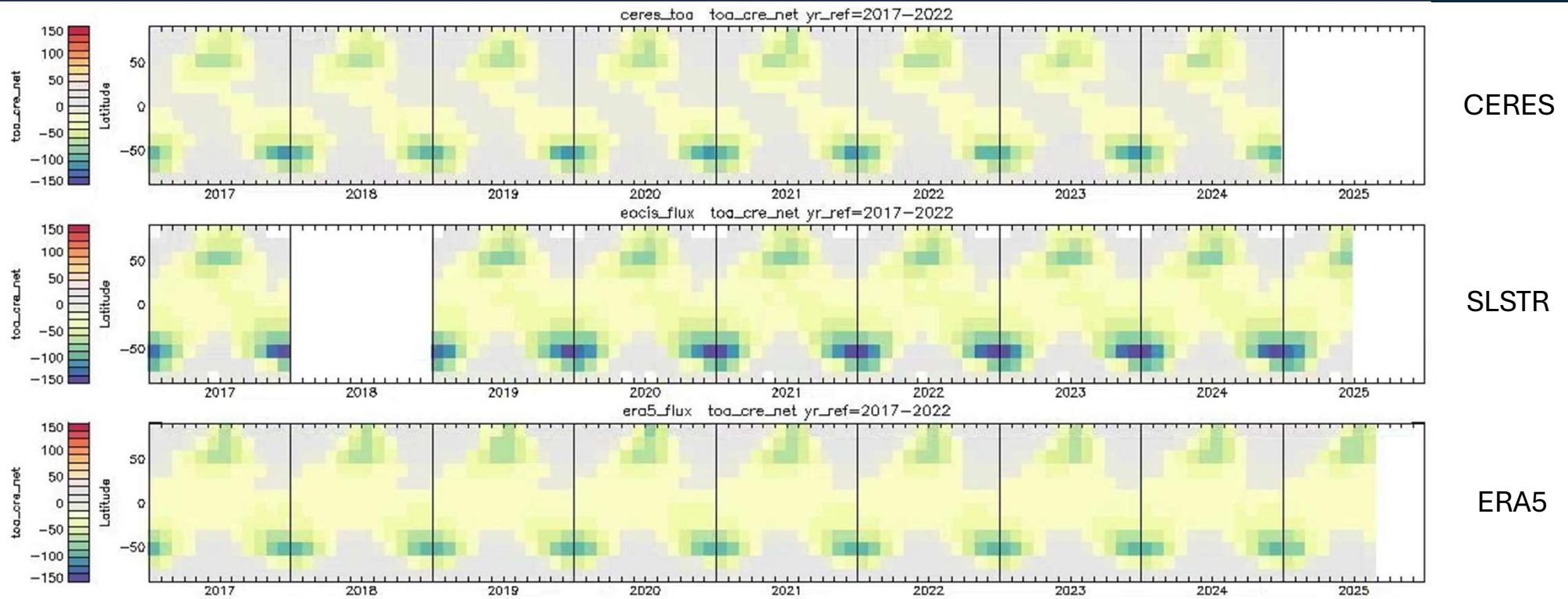
Cloud Fraction



TOA CRE NET



Top Of Atmosphere (TOA) Cloud Radiative Effect (CRE) – NET



Mid latitude cloud tend to have ‘cooling’ effect in ‘summer’ months

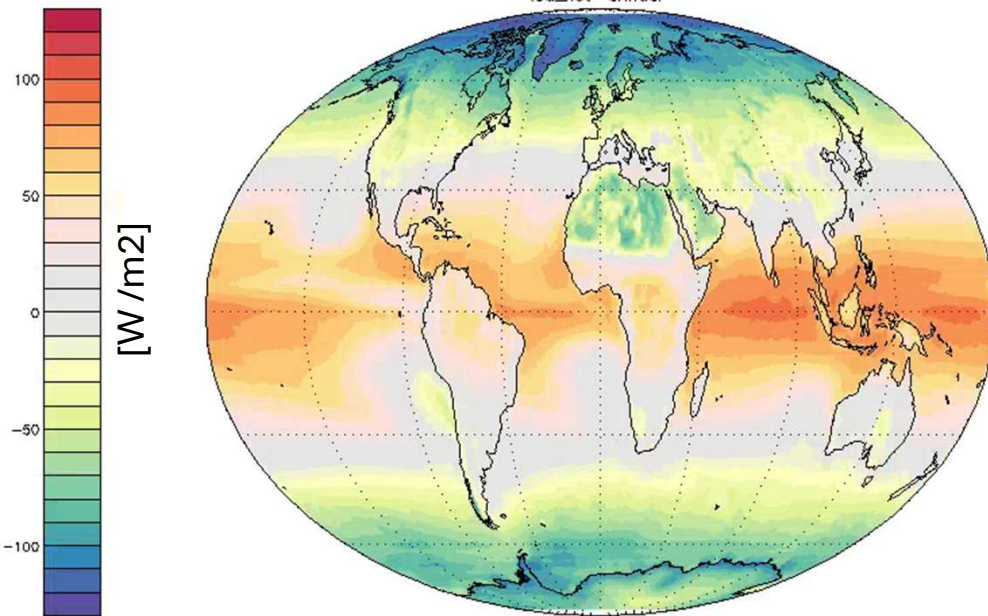
There are area where cloud always have cooling effect.

Warning:
ORAC L3 radiative fluxes daily cycle is represented with a multiplicative factor

TOA NET Radiative fluxes (Solar - SWUP - LWUP)

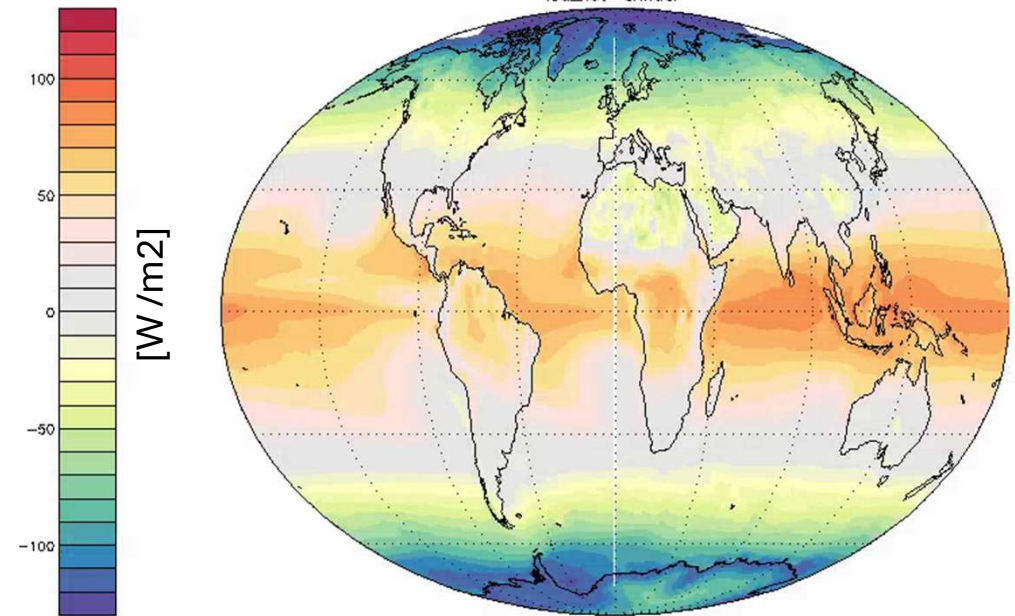
SLSTR ORAC

toa_net annual

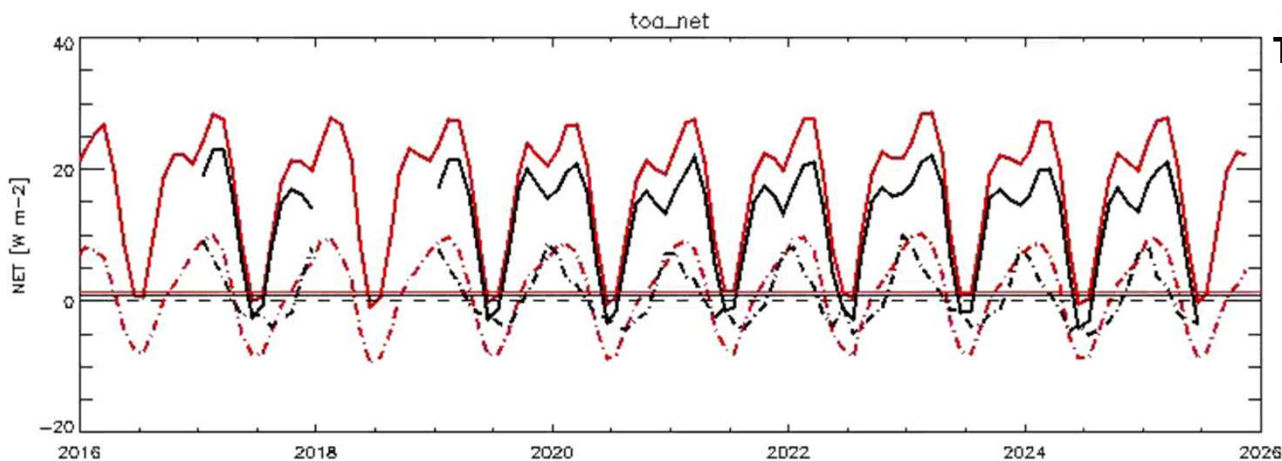


CERES-EBAF

toa_net annual

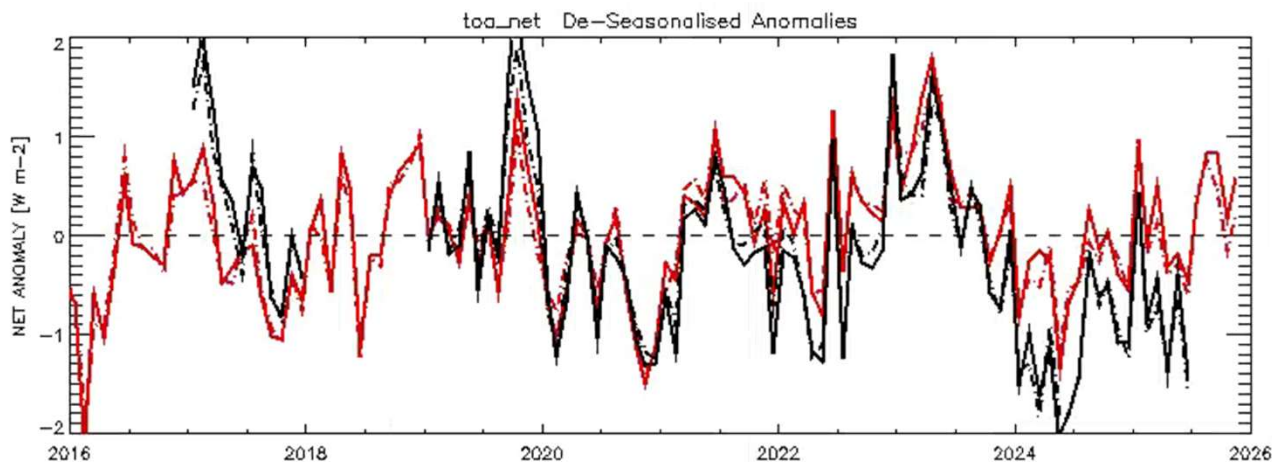


TOA NET Radiative fluxes (Solar - SWUP - LWUP)



TOA NET

- SLSTR [-60,60]
- - - SLSTR [-90,90]
- CERES [-60,60]
- - - CERES [-90,90]



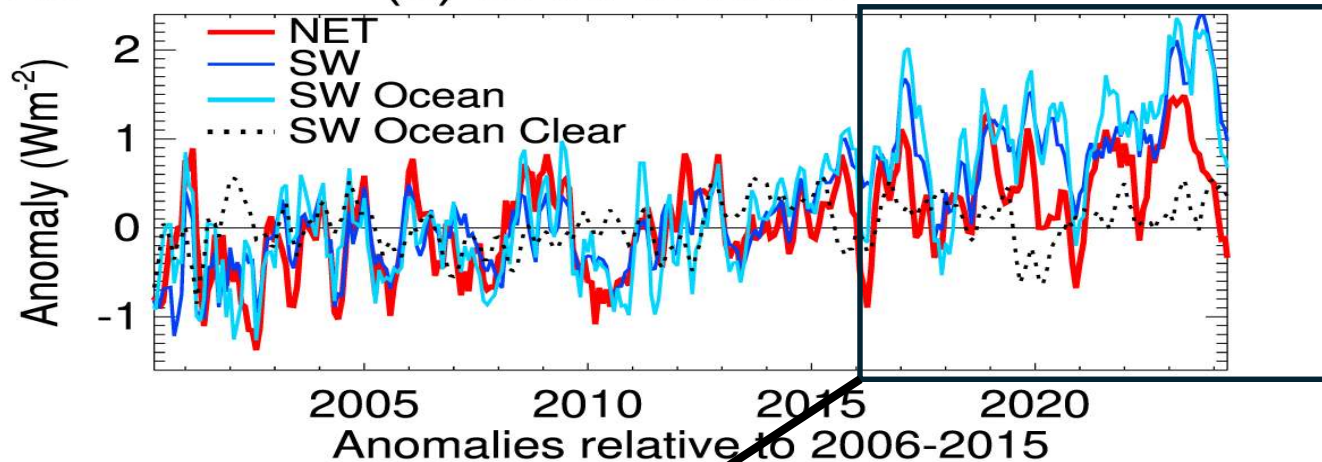
**Anomaly
TOA NET**

High latitudes are important. Tricky region, less information in the measurements, more dispersion between different satellite retrievals. Cloud CCI+ is focusing on improving performance at high latitudes

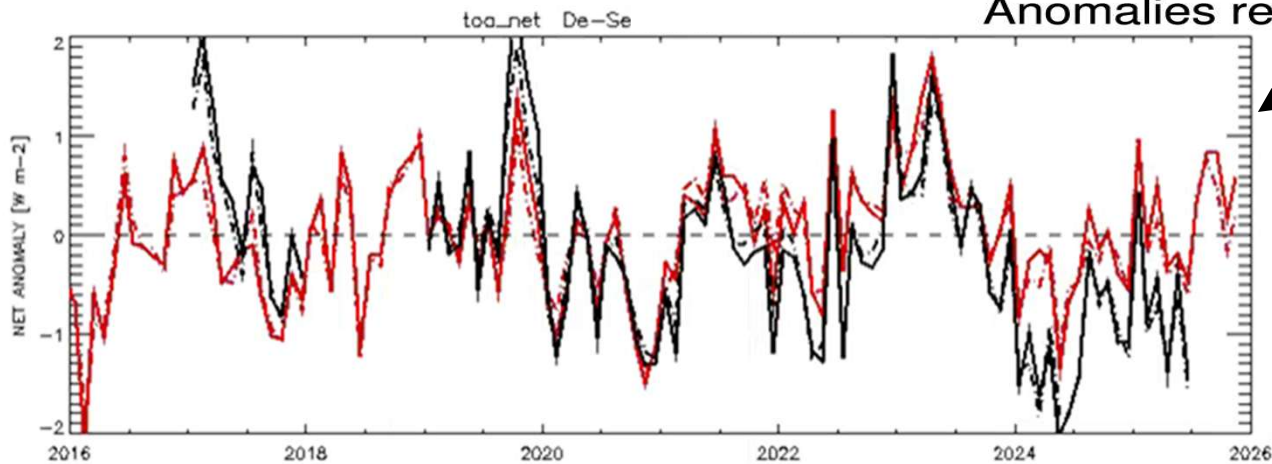
TOA NET Radiative fluxes (Solar - SWUP - LWUP)

1)-23

(b) CERES Anomalies



2)



[Allan & Merchant, Environ. Res. Lett. 2025]

Anomaly
TOA NET

Summary

Cloud properties dataset

- SLSTR does not have the spectral information provided by MODIS, VIIRS and new-generation meteorological sensors (FCI, AHI, AGI, MetImage, etc), but ORAC SLSTR performs well when compared to other products

Surface and TOA **radiative fluxes** datasets

- ORAC provides an independent estimate of radiative fluxes (it is not parameterised, trained or bias corrected against other datasets)
- **Surface:** very good agreement in the shortwave, some bias in the longwave, **compare well with ground stations**
- **TOA:** some **bias in the shortwave**, very **good agreement in the longwave**
- Where ORAC shows a bias, it is stable and predictable. *Correlation* with other datasets is very high.
- **TOA and surface radiative fluxes** estimates can be used to study
 - Cloud (and aerosol) radiative effects.
 - Cloud feedbacks
 - Energy balance/imbalance

THANK YOU!!!

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