

## Abstract

Changes in cloud properties play an important role in the Earth's radiative budget, and cloud responses to climate change can either cool or warm the planet. Cloud feedbacks and cloud-aerosol interactions remain major sources of uncertainty in assessments of radiative impacts. To support studies of cloud behaviour and the Earth's energy balance it is important to have records of cloud and aerosol characteristics, together with consistent estimates of radiative fluxes. The Optimal Retrieval of Aerosol and Cloud (ORAC) algorithm is applied to multiple satellite instruments to generate self-consistent, long-term datasets of cloud and aerosol properties and associated radiative fluxes. ORAC has been implemented and validated within the EOCIS, UK NCEO and ESA Climate Change Initiative (CCI) programmes, and has recently been applied to observations from the Sea and Land Surface Temperature Radiometer (SLSTR) for the period 2017–present, as well as to data from geostationary satellite instruments. The resulting SLSTR dataset is being made available through the Copernicus Climate Change Service (C3S) and is updated every six months. Radiative fluxes at both the top of the atmosphere and the surface are computed for all-sky and clear-sky scenarios, allowing quantification of cloud and aerosol radiative effects. Monthly averaged (Level-3) cloud property products are further stratified into low-, mid-, and high-level cloud categories according to retrieved cloud-top height, supporting vertically resolved investigations. This study presents a comparison between ORAC cloud and radiative flux products and a range of independent satellite and reanalysis datasets (VIIRS, MODIS, AVHRR, CERES, HIRS, ERA5), with particular emphasis on interannual variability and recent anomalies in shortwave and longwave fluxes, low-cloud cover, and cloud radiative effects.

## 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.

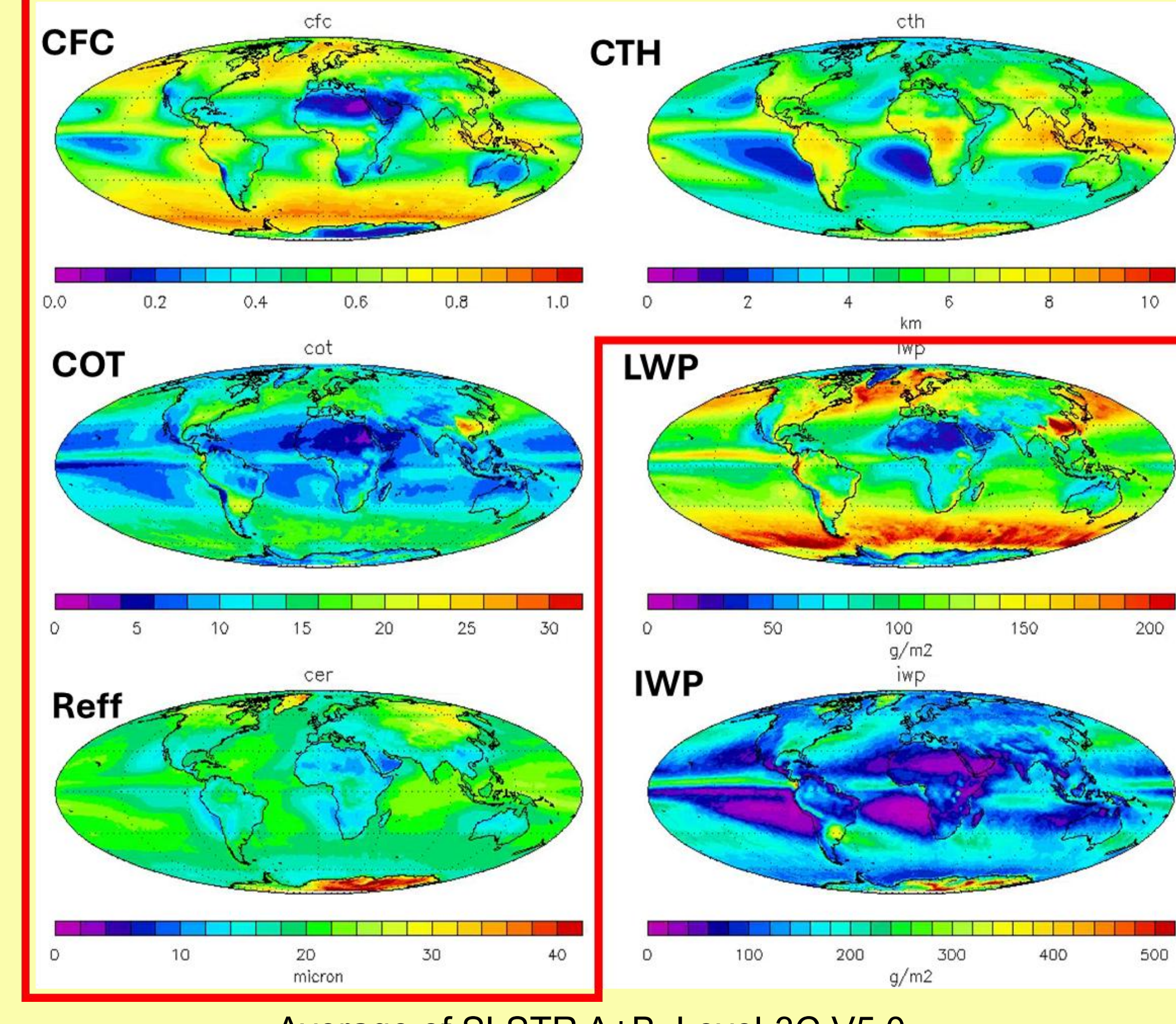
- It has been applied to the (A)ATSR, SLSTR, SEVIRI (NRT Vis tool), AHI, FCI, MODIS, VIIRS & AVHRR sensor families
- All state parameters retrieved simultaneously using all measurements and a priori constraints, weighted by their uncertainty.
- Full uncertainty propagation pixel by pixel
- Solution found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

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

### ORAC Retrieved Cloud properties:

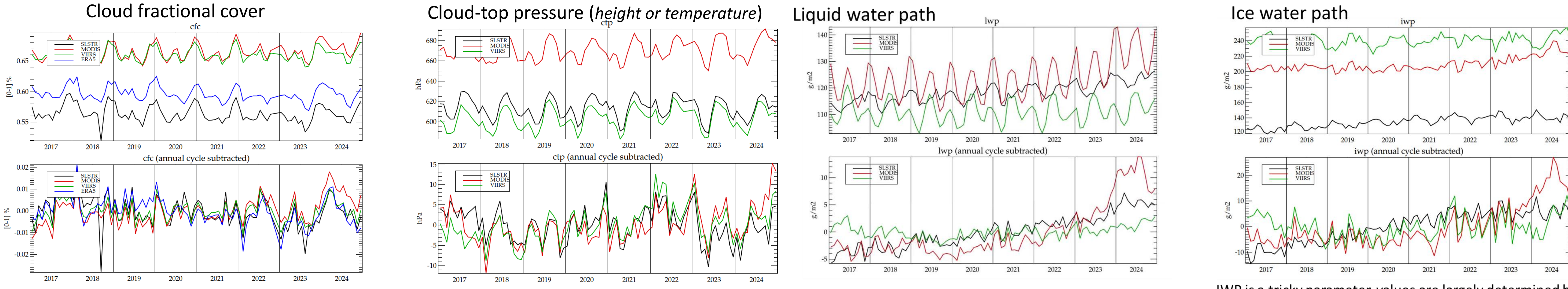
- Cloud Top height / temperature / pressure
- Cloud phase (liquid / ice)
- Optical thickness
- Effective radius
  - => Liquid water path
  - Ice water path

+ 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-ORAC (A+B) cloud properties – global average time series



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

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

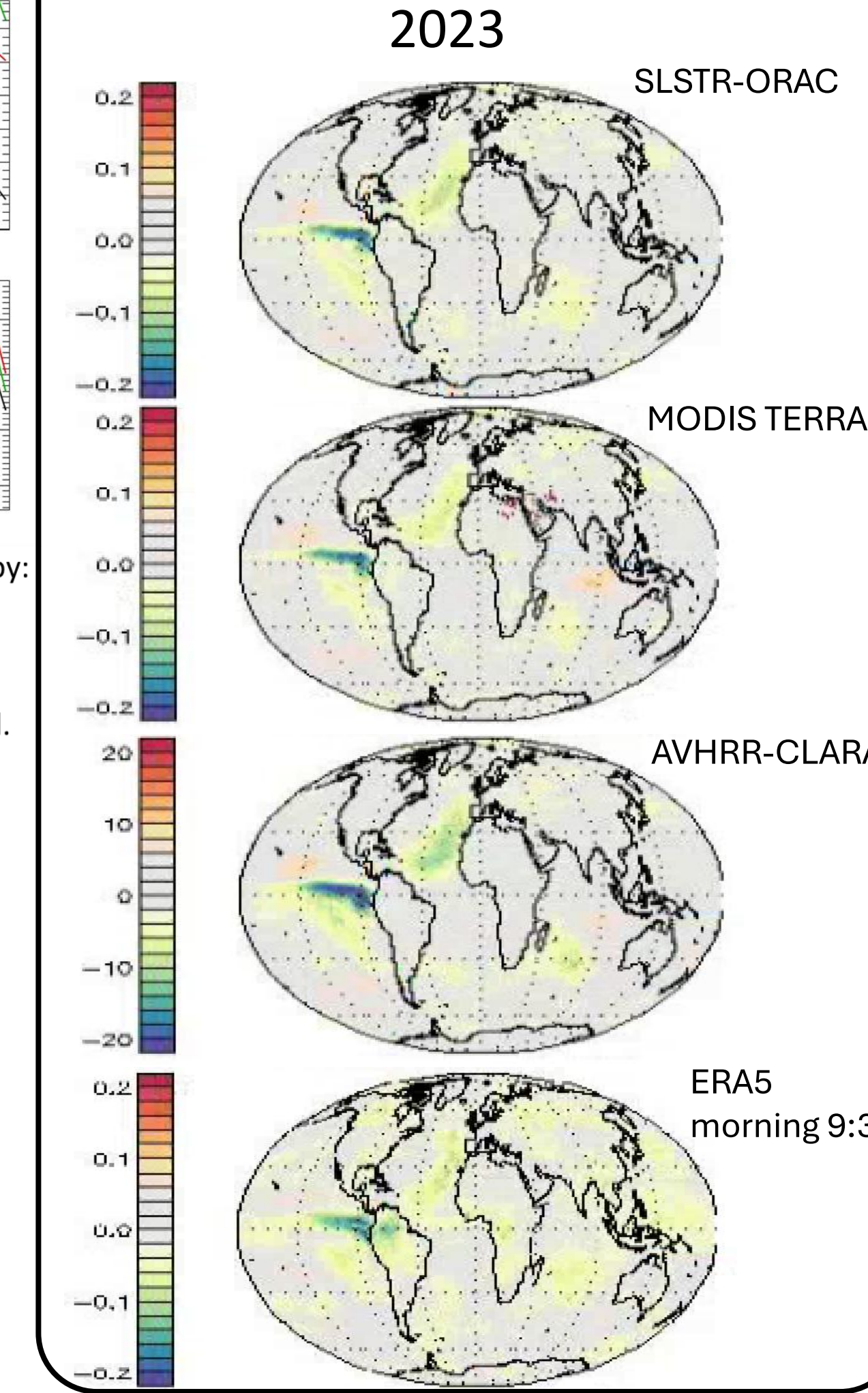
Quite a large spread in annual cycle.
 

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

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

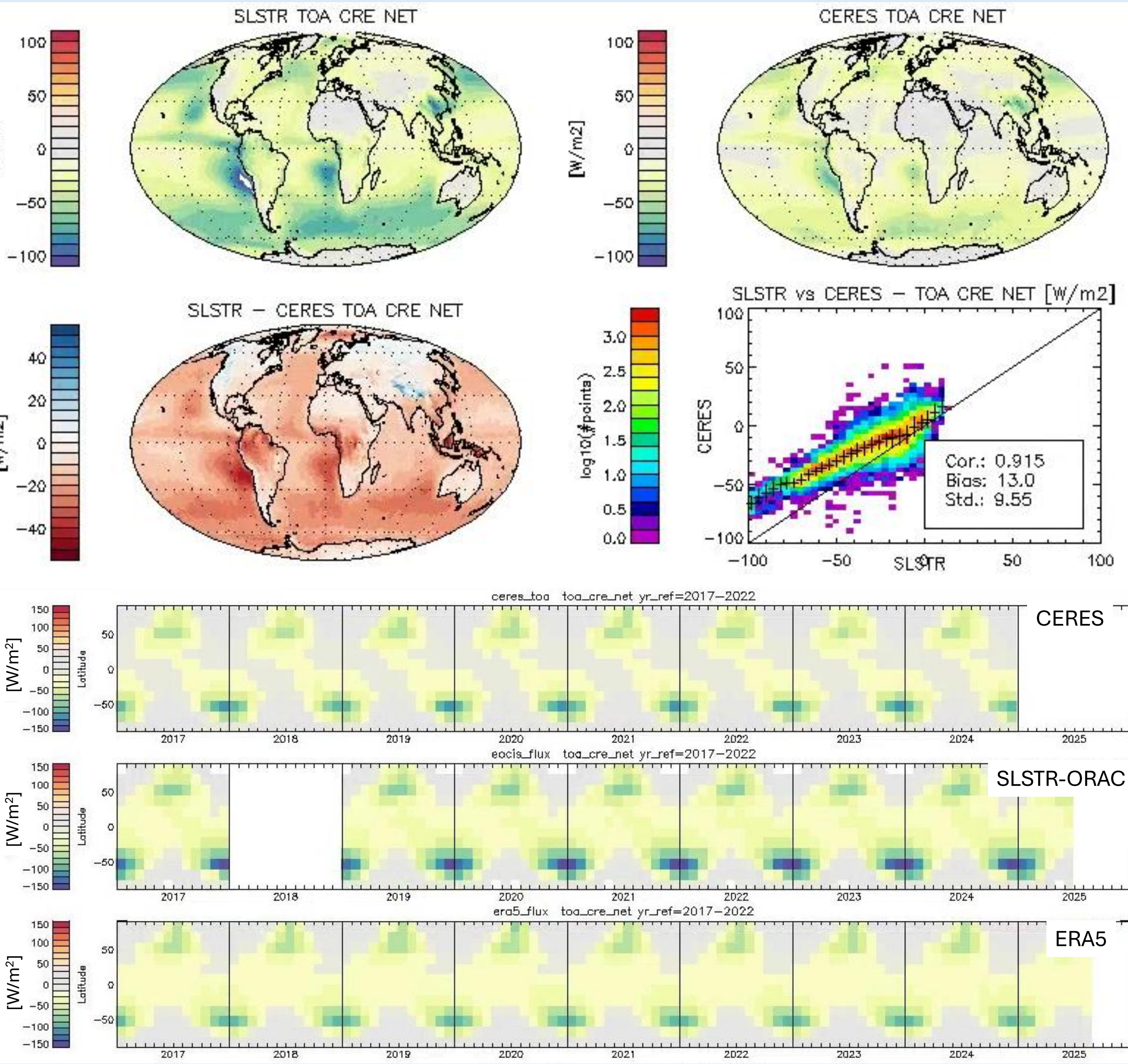
- cloud-phase determination
- assumed ice-habit properties in each retrieval
- how ice/snow surfaces are handled
- any detection / parameterisation of multi-layer cloud.

## Low cloud fraction annual anomaly



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

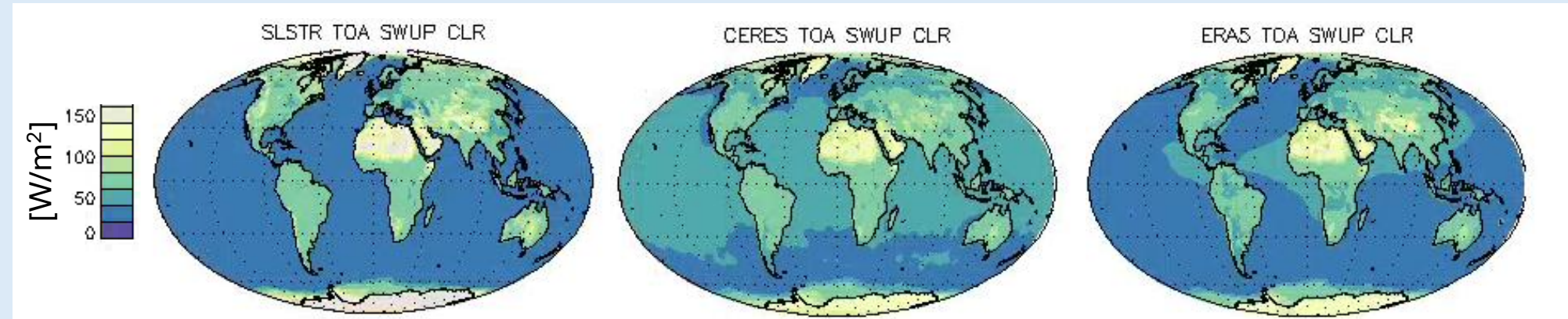
## Top Of Atmosphere (TOA) Cloud Radiative Effect (CRE) – NET



Mid latitude cloud tend to have 'cooling' effect in 'summer' months. There are area where cloud always have cooling effect. ORAC L3 radiative fluxes daily cycle is represented with a multiplicative factor

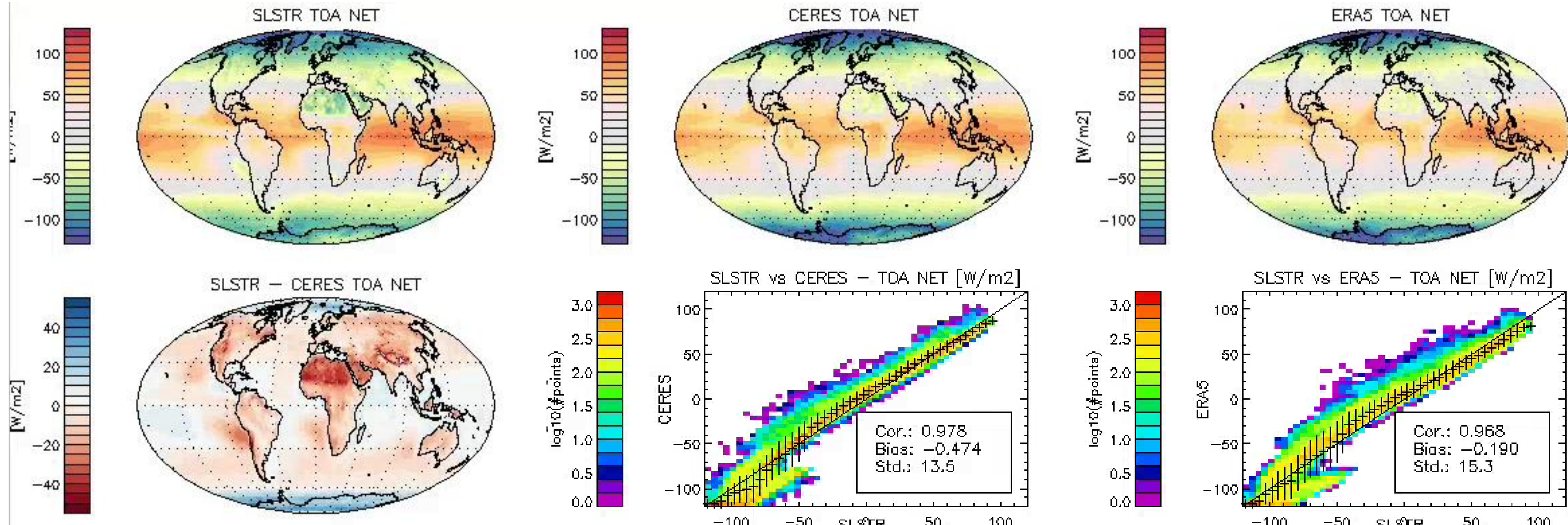
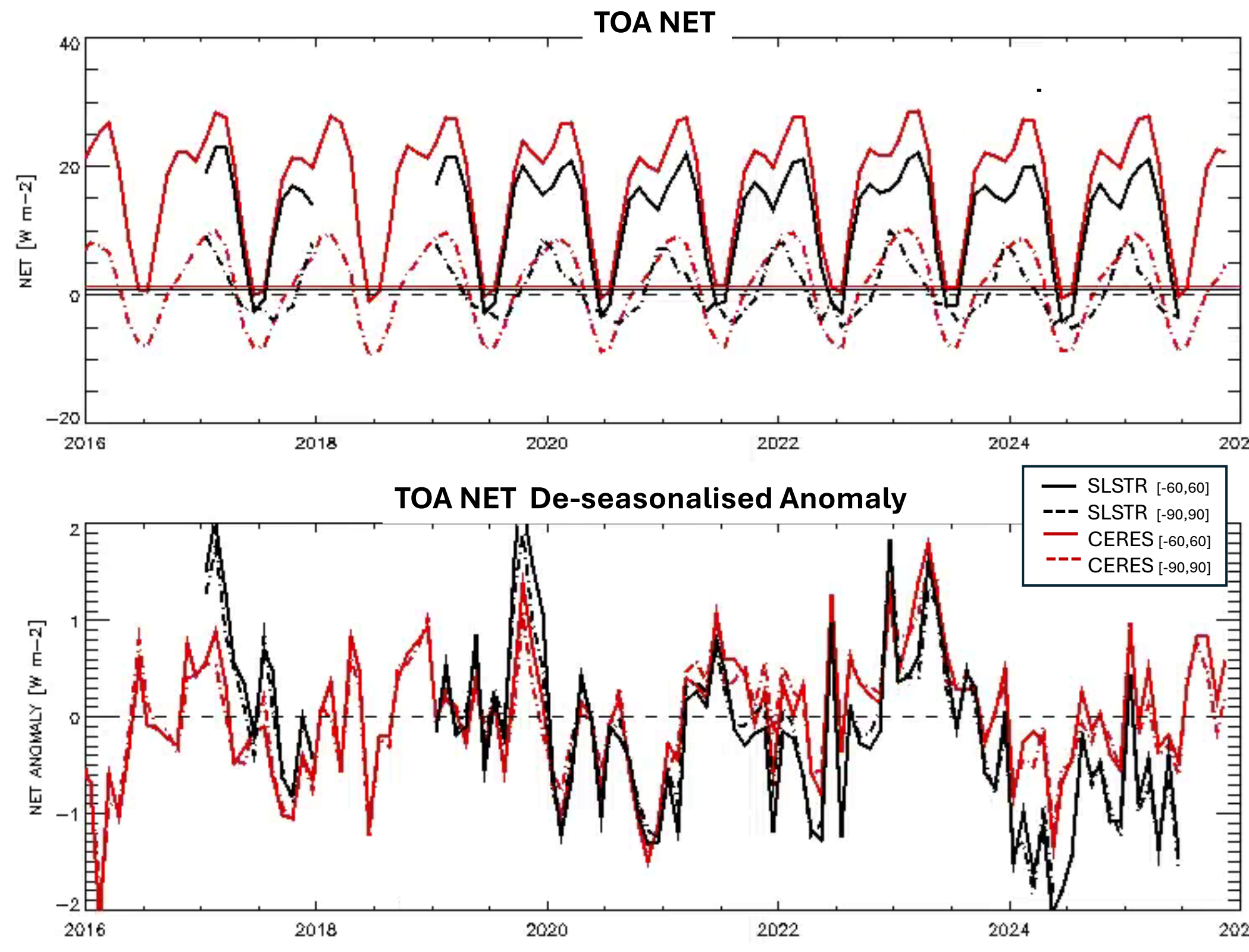
TOA SWUP CLR (Clear sky) show differences between ORAC, CERES and ERA5

- Can this be due to daily cycle?
- Radiative transfer intercomparison?



**Acknowledgements**  
This work was funded by the National Centre for Earth Observation (NCEO) at RAL Space. SLSTR-ORAC v5.0 will be available at Copernicus climate data store. All satellite datasets are publicly available.

## TOA NET Radiative fluxes (= Solar - SWUP - LWUP)



## Summary

- Biases between different satellite datasets, but monthly de-seasonalized anomalies are consistent with each other and show high correlation.
- ORAC scheme estimates surface and TOA radiative fluxes for polar orbiting and geostationary satellites. See Robbins's poster on FCI-ORAC!
- Surface fluxes: very good agreement in the shortwave, some bias in the longwave, compare well with ground stations. (See C3S report)
- TOA fluxes: some bias in the shortwave, very good agreement in the longwave.
- All-sky fluxes have been validated in different projects; we need comparison of clear sky fluxes and radiative transfer.
- First look at CRE, good correlation (anomaly) but ~13 [W/m<sup>2</sup>] bias, consistent with West Pacific study using Himawari [Gopalakrishnan et al paper in prep.]
- EarthCARE to validate/compare cloud properties and fluxes, but we will have coincidences only at high latitude.

