A comparison of radiative heating rate profiles derived from EarthCARE and CALIPSO/CloudSat

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EarthCARE 2026 Science and Validation workshop
8-12 June 2026, Oxford, UK

Motivation of this study

- Although EarthCARE and CALIPSO/CloudSat instruments and orbits are different, we still hope to analyze cloud and aerosol changes synergistically.
- Toward achieving this goal, the first step is to compare cloud and radiative heating rates derived from EarthCARE and CALIPSO/CloudSat.
- Comparisons also provide evaluation of EarthCARE and CALIPSO/CloudSat derived cloud and heating rate profiles.

Orbits and instruments

	EarthCARE	CALIPSO/CloudSat
Orbit	14:00 MLST$\pm$ 5min at the equator (descending)	13:30 local time at the equator (ascending)
Altitude	~ 393 km	~705 km
LIDAR wavelength	ATLID (355 nm)	CALIOP (532 nm and 1064 nm)
LIDAR vertical sampling	103 m (20.2 km), 500 m (20.2 - 40 km)	30 m
LIDAR Along track sampling interval	285 m	335 m
CPR center frequency	94.05 GHz	94 GHz
CPR Height range	Up to 20 km	Up to 30 km
CPR vertical resolution	500 m (100 m sampling)	500 m (240 m sampling)
CPR Horizontal resolution	750 m	1.4 km
CPR Minimum sensitivity	-35 dB	-28 dBZ

EarthCARE versus CCCM Products

- **EarthCARE ESA Products**
  - ✓ Cloud mask and optical properties from the ACM_COM_2B product, which include COMPOSITE (Cole et al. 2023) and CAPTIVATE (Mason et al. 2023) retrievals.
  - ✓ Fluxes and heating rate profiles from the ACM_RT_2B (Cole et al. 2023) product, which were produced based on the CAPTIVATE (Mason et al. 2023) cloud retrievals.
  - ✓ "BC" version is used (for one-month data for December 2025).

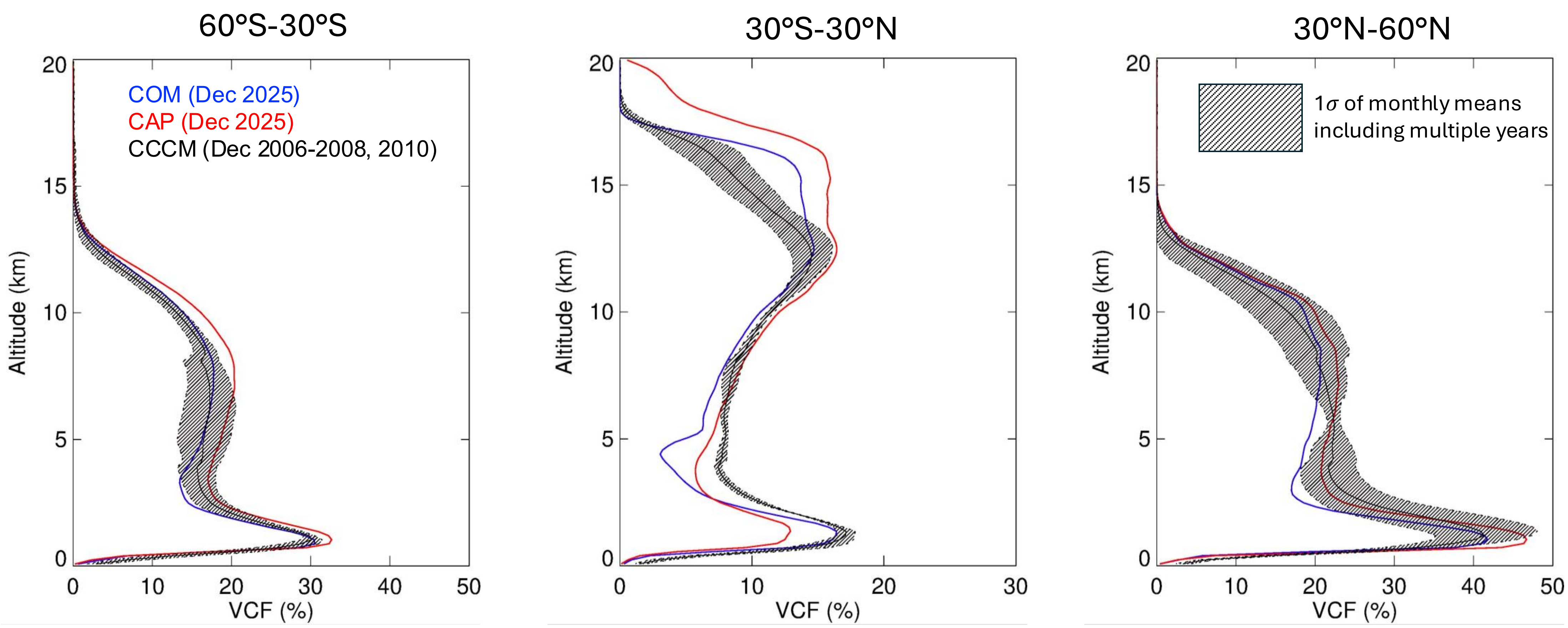
- **CERES-CALIPSO-CloudSat-MODIS (CCCM) Product from A-train mission**
  - ✓ Cloud properties are based on merging process of CALIPSO, CloudSat, and MODIS properties and saved for every CERES footprints. When merging cloud properties, if available, active-sensor-measured (CALIPSO and/or CloudSat) cloud properties are used, otherwise passive-sensor derived (MODIS) cloud properties are used.
  - ✓ Cloud boundaries are derived from active sensors only (CALIPSO and CloudSat).
  - ✓ Total column optical properties are constrained by the passive sensor measurements.
  - ✓ Release D (RelD) version is used (2006-2010).

- Both EarthCARE and A-train missions include active (Lidar & radar) and passive (imager) instruments, enabling to obtain more accurate cloud properties compared to those from a single sensor.

- Since there is no overlap between the A-train and EarthCARE missions, direct comparison for the consistent period is impossible. Instead, a consistent month of a year (December in this presentation) is used for comparing different years. Also, interannual variability is examined using the multiple years of the CCCM product. For the CCCM product, December months of 2006, 2007, 2008, and 2010 years are analyzed. Dec 2009 is excluded since CloudSat was not operating in that month.

Ocean Day

Cloud Fraction Profiles from EarthCARE and CCCM Products

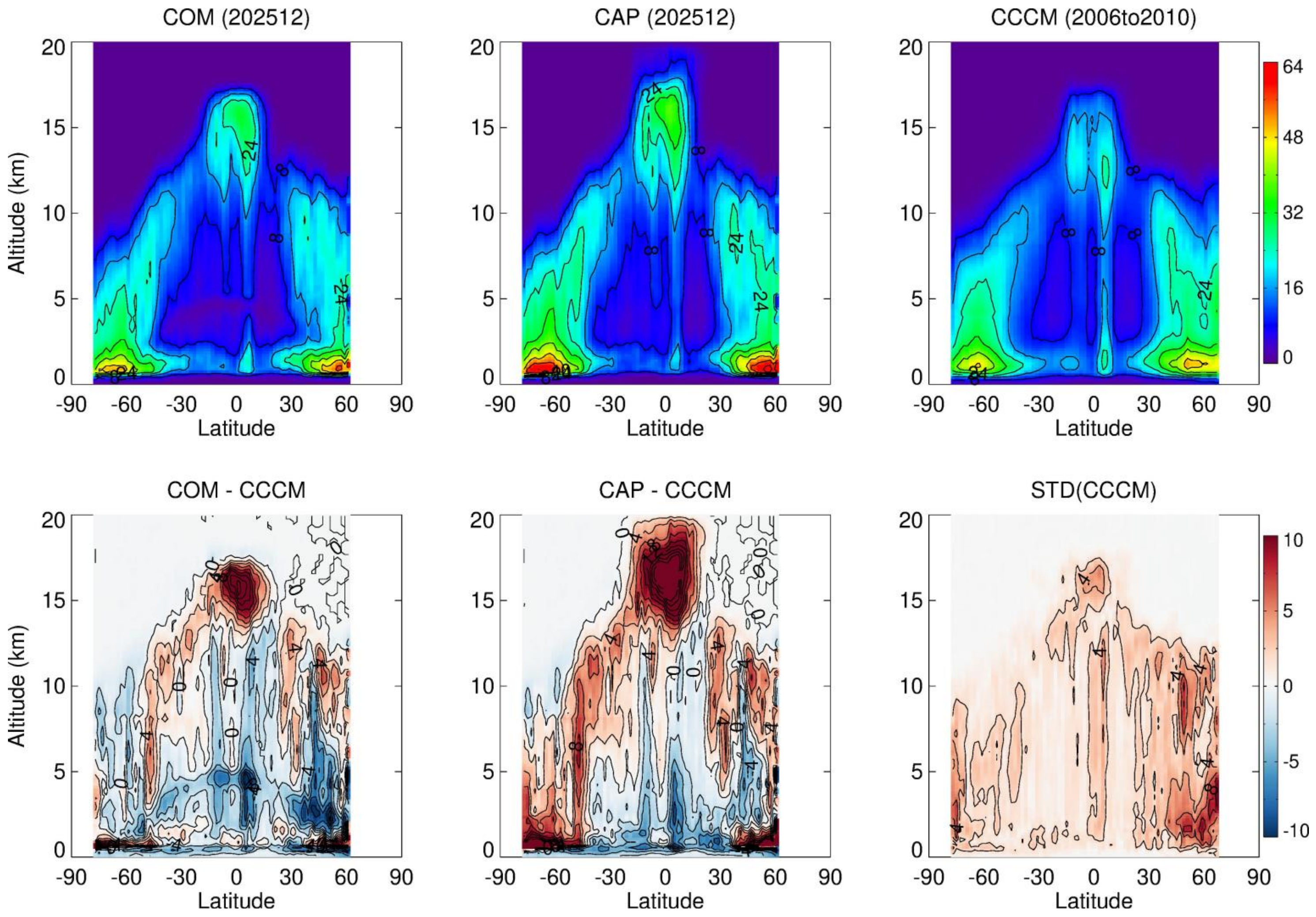


- Volumetric cloud fraction (VCF) (%) profile is computed for the reference vertical layers, defined from 0 to 20 km, with a 0.16 km interval. Cloud top and base boundaries at a pixel scale are used to compute VCF profiles. Then profiles are gridded monthly, and these are further averaged for the range of latitudes indicated above the plots.
- CAP cloud fraction (red lines) is generally larger than COM cloud fractions (blue lines).
- CCCM cloud fraction (black lines) is smaller than CAP or COM cloud fractions especially for the high-level clouds.

Cloud Fraction Profiles from the EarthCARE and CCCM Products

Day, Ocean

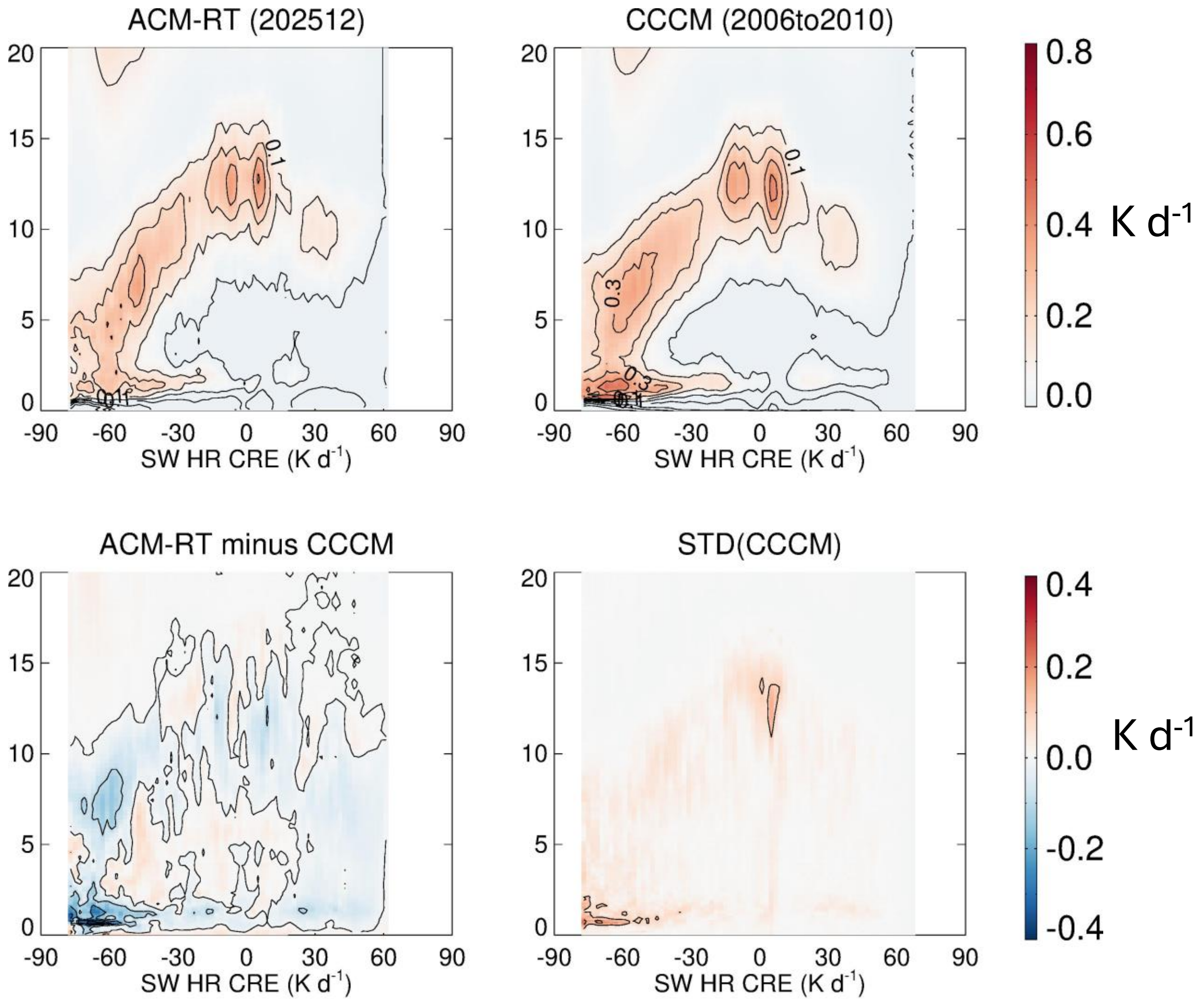
EarthCARE (Dec 2025) vs CCCM (Dec 2006, 2007, 2008, and 2010)



- Cloud fractions from the COMPOSITE and CAPTIVATE algorithms are larger than the CCCM cloud fraction for high-level clouds. Differences due to EarthCARE and CCCM algorithm differences seem to be larger than the inter-annual variability derived with the CCCM product (i.e., STD(CCCM)).

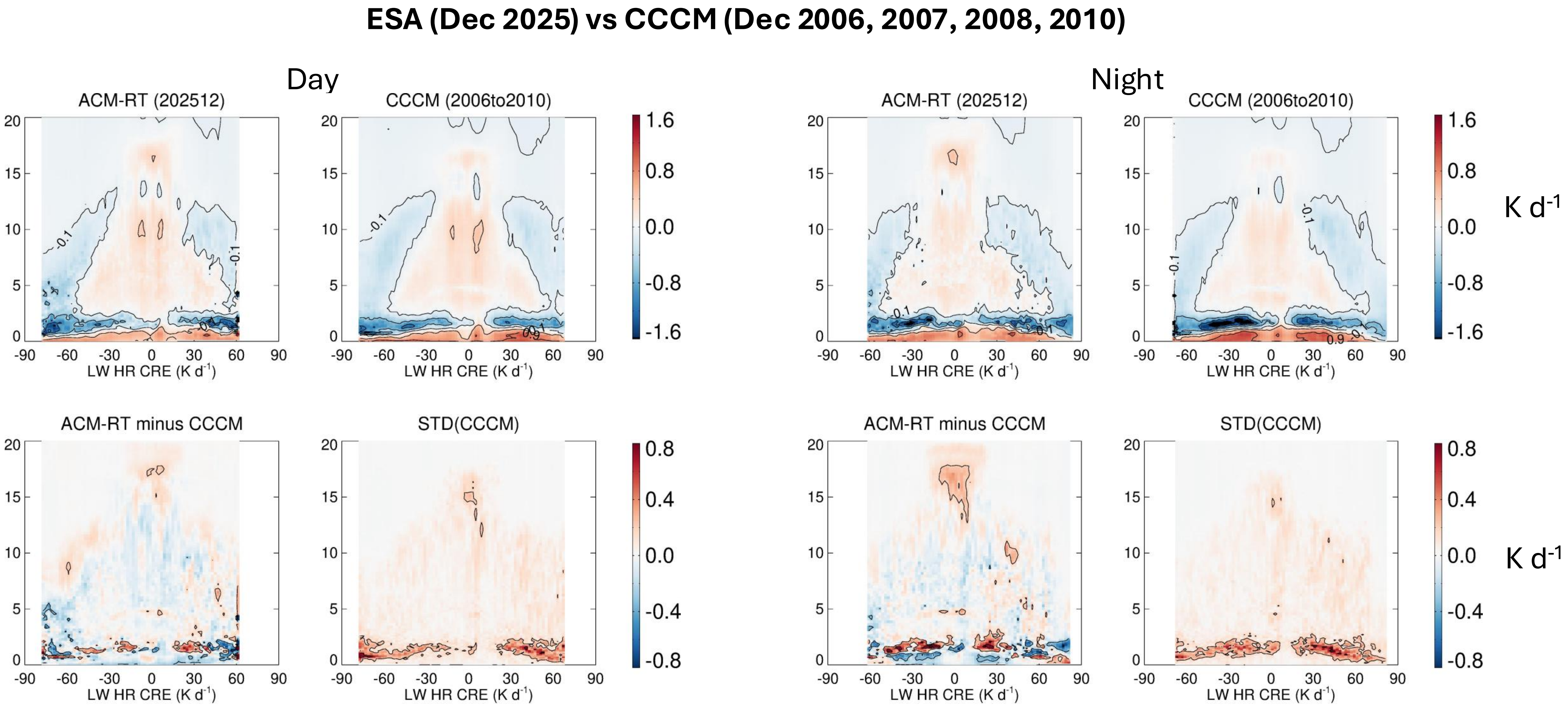
Cloud Radiative Effect (CRE) of the SW Heating Rates over Ocean

ESA (Dec 2025) vs CCCM (Dec 2006, 2007, 2008, 2010)



- CCCM SW CRE is slightly larger than that from the EarthCARE product.
- The interannual variability of the SW CRE seems to be small, according to the CCCM product.
- Note that the cloud occurrence in the EarthCARE product is higher than that in the CCCM product primarily for the high-level clouds. However, the impact of the cloud occurrence difference is small in the SW HR comparison results, probably because the differences are caused by optically thin clouds.
- The CCCM SW CRE is larger than EarthCARE CRE.
- Note that SW CRE is scaled by the solar insolation for the 2007-2017 means.

CRE on the LW Heating Rates over Ocean



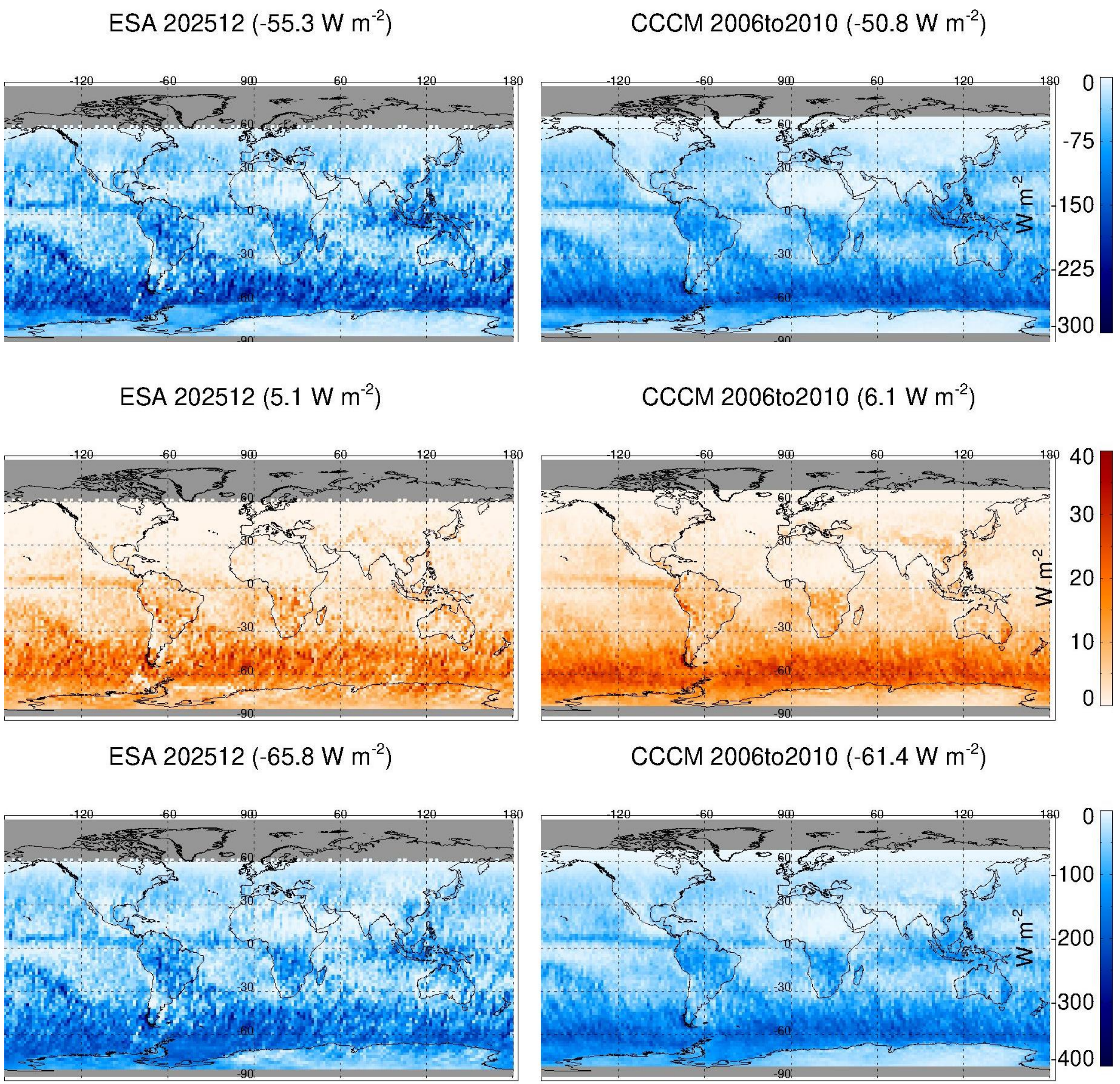
- LW CRE from the EarthCARE and CCCM products are consistent.
- Interannual variability of the CRE is significant for the low-level clouds, according to the CCCM product.

CRE on the SW Net Fluxes at TOA, Atmosphere, and Surface over Ocean

TOA Net
(+: Downward)

Atmosphere
(+: Absorb)

SFC Dn
(+: Downward)



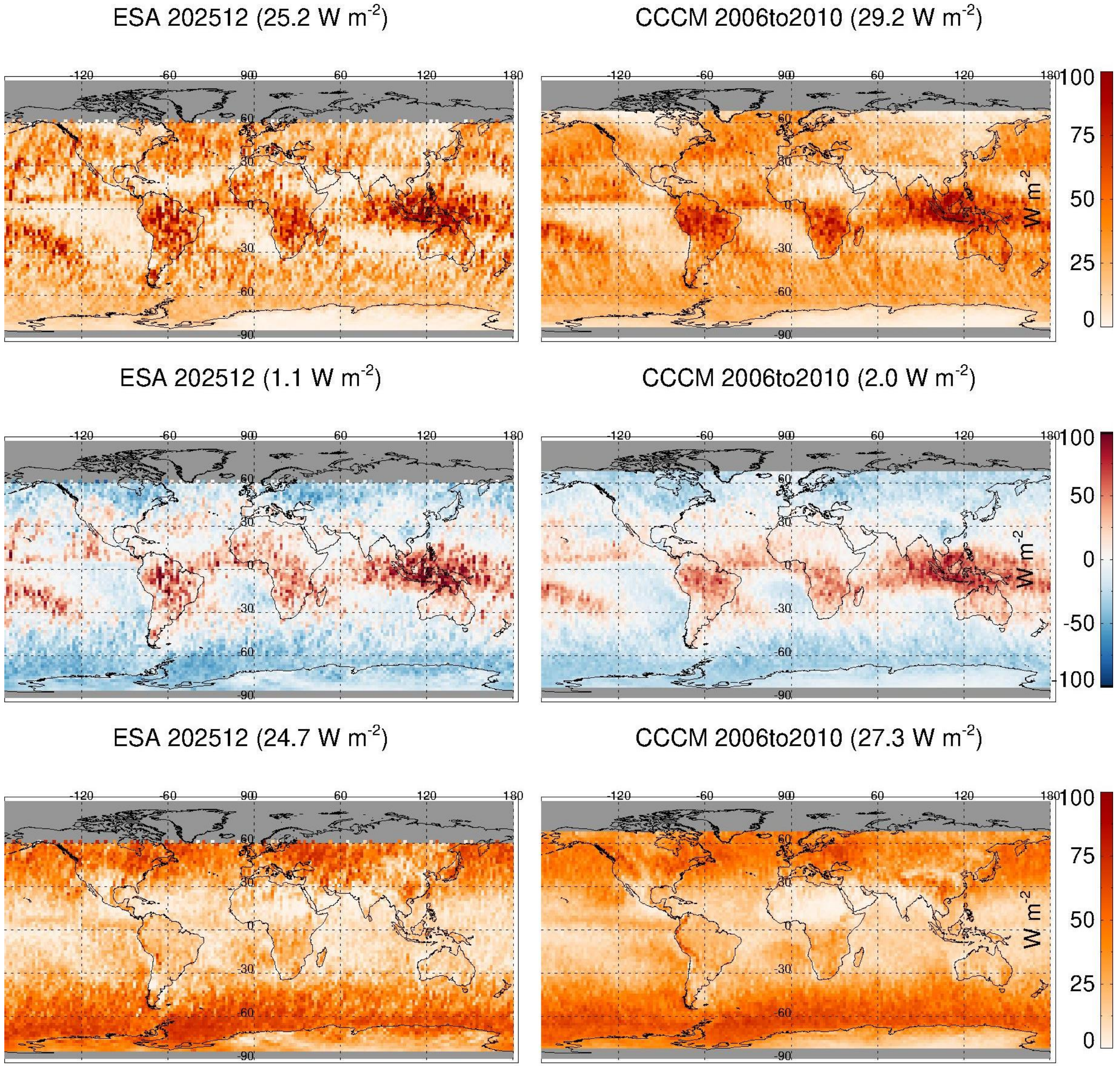
- For the atmosphere-absorbed SW fluxes, CRE from EarthCARE is smaller than that from the CCCM product, consistent with the CRE on SW HR comparison.
- For the TOA and surface net fluxes, EarthCARE CRE is larger than CCCM CRE (larger negative).
- Note that SW CRE is scaled by the solar insolation for the 2007-2017 means.
- Spatial patterns resemble each other despite different time periods.

CRE on the Daytime LW Net Fluxes at TOA, Atmosphere, and Surface over Ocean

TOA Net
(+: Downward)

Atmosphere
(+: Absorb)

SFC Dn
(+: Downward)



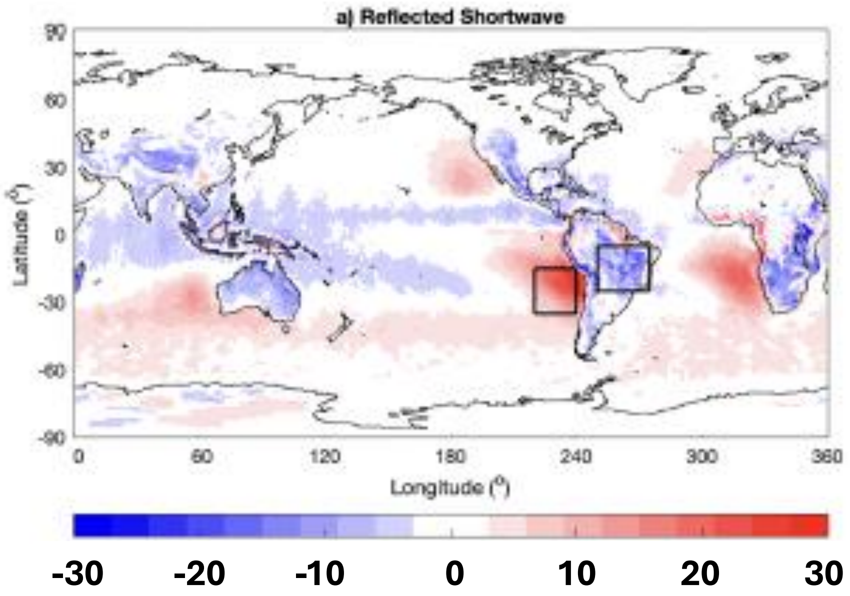
- LW CRE from CCCM is larger than EarthCARE CRE, at TOA, atmosphere, and surface.

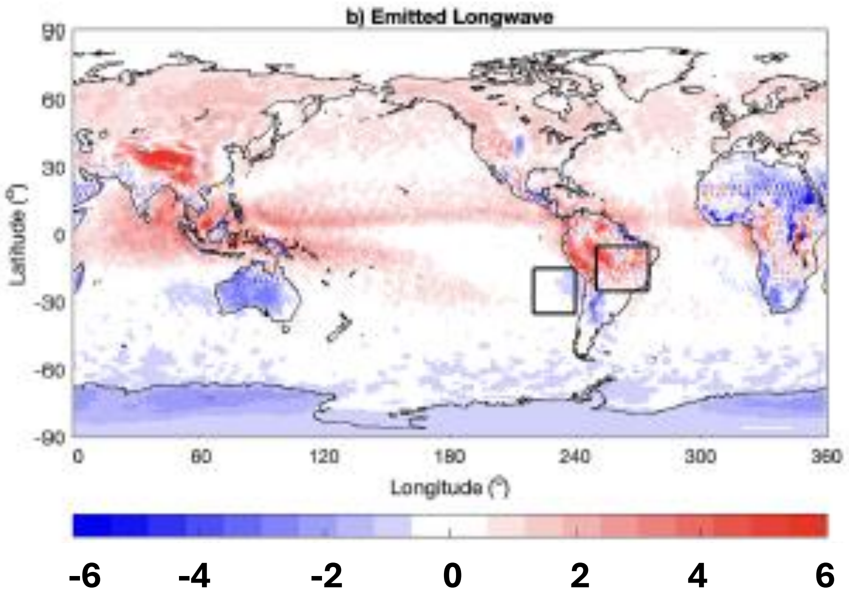
Summary

- Cloud occurrences from EarthCARE (both from COMPOSITE and CAPTIVATE algorithms) are larger than those from the CCCM product for high-level clouds.
- Despite the cloud fraction difference for the high-level clouds, the cloud radiative effect (CRE) from the two products are generally well agreed, while rather larger cloud absorption is noted from the CCCM algorithm. The Larger cloud particle size explains the larger SW cloud absorption in the CCCM algorithm.
- While the CRE on the atmosphere-absorbed fluxes is larger in the CCCM product, the CRE on the SW TOA and surface fluxes are larger in the EarthCARE product.
- LW CRE from the CCCM product is larger than the EarthCARE Product, at TOA and surface.
- Compared to the CCCM product, cloud optical depth is larger and effective radius is smaller in the EarthCARE product.

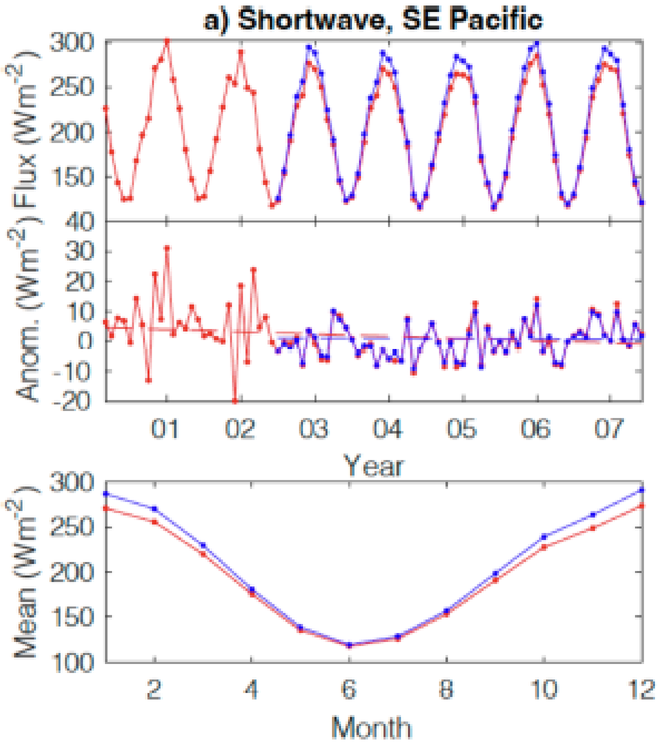
Back-ups

Cloud diurnal cycle: Terra - Aqua

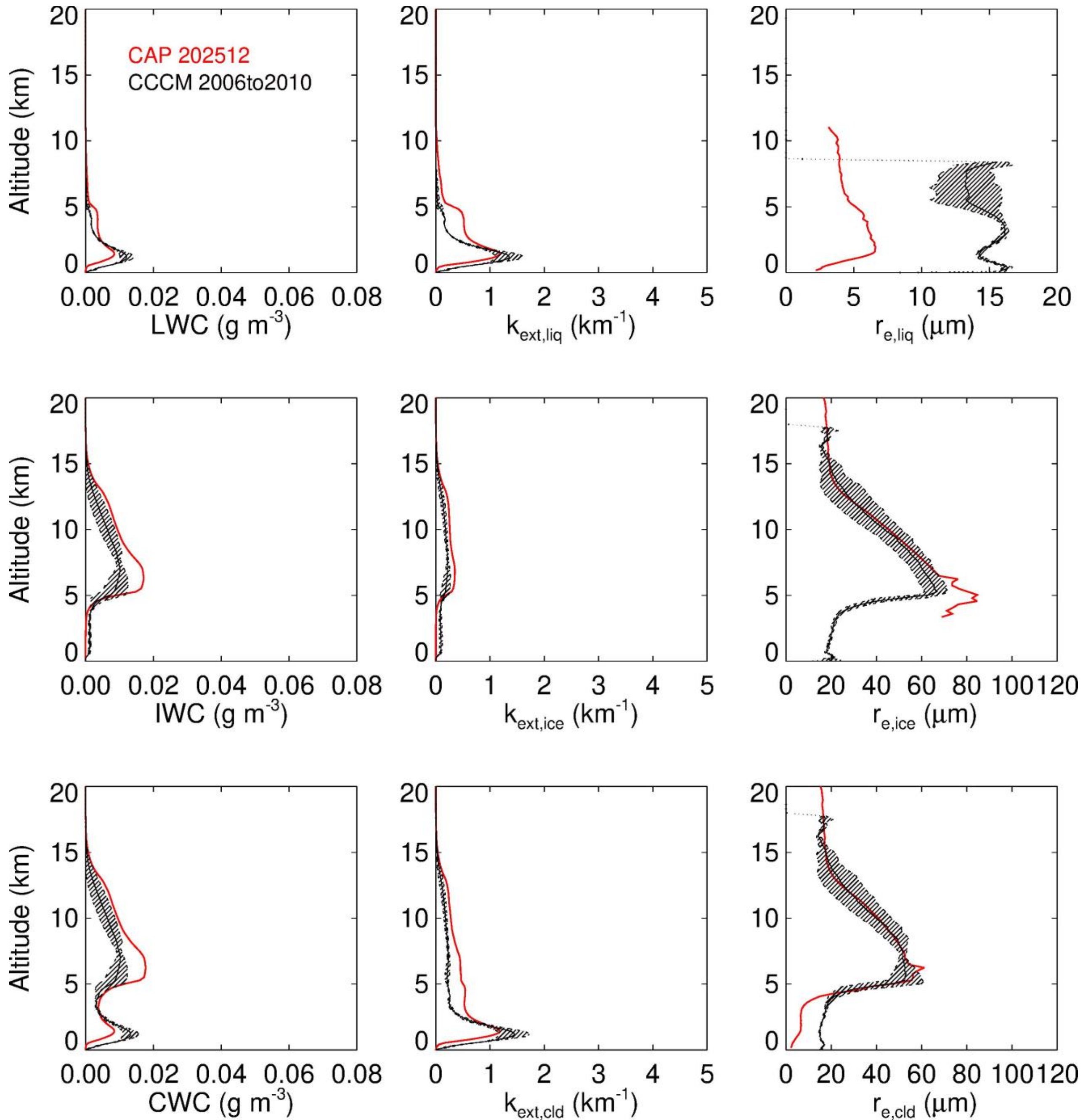




Downward shortwave irradiance at the surface



Cloud Property Profiles from EarthCARE and CCCM Products (30°S-30°N)



- For ice, extinction coefficient is computed from IWC and ice re as
  $k_{ext,ice} = 3/(2\rho_{ice})\ IWC / r_{e,ice}$
  where $\rho_{ice} = 0.917$ g cm^{-3}.

- For liquid, liquid extinction coefficient is computed as
  $k_{ext,liq} = 3/(2\rho_{liq})\ IWC / r_{e,liq}$
  where $\rho_{liq} = 1$ g cm^{-3}.

- For the ice and liquid combined extinction is computed as,
  $k_{ext} = k_{ext,ice} + k_{ext,liq}$
  CWC = IWC + LWC
  The equivalent cloud effective radius ($r_{e,eqv}$) is computed as
  $k_{ext} = 3/(2\rho_{liq})\ CWC / r_{e,equv}$
  Since the density of the liquid (ρ_{liq}) is used, there is uncertainty of 10% for the retrieved $r_{e,eqv}$.

- CWC and cloud extinction coefficient from the CAP product tend to be larger than the CCCM values. This is contributed from the differences in ice-phase clouds (i.e., IWC and ice extinction coefficient).
- Ice particle effective radius from the CAP and CCCM algorithms are consistent. In contrast, liquid particle size in the CAP algorithm is smaller than the CCCM particle size.