Cloud-type Mean Cloud Properties of the Tropical Lands and Ocean and the "Chimney" Zones from 19-Year High-Resolution CERES Satellite Data

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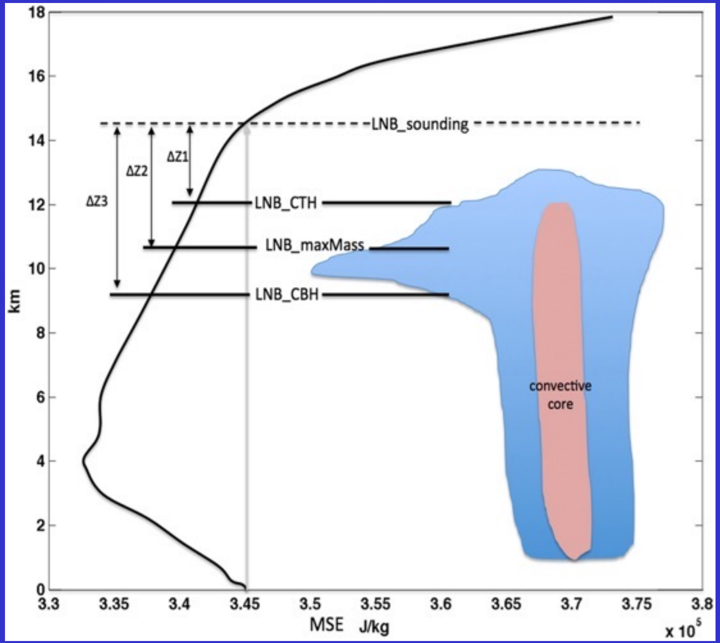
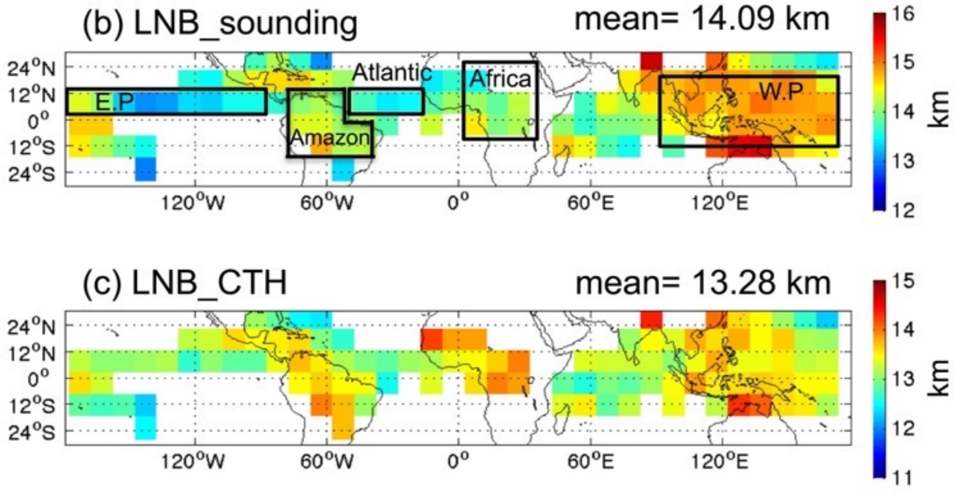
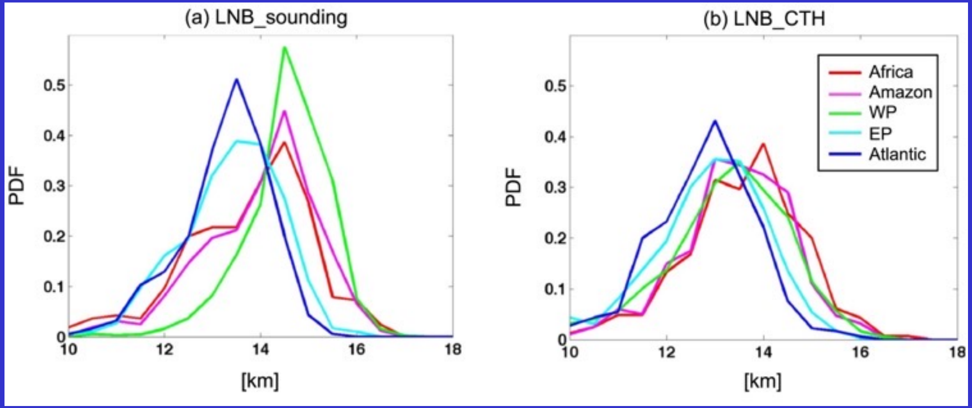
Where are the Tropical "Chimney" Zones? (Takahashi *et al.* 2017)







Tropical "Chimney" zones:

1. Lands: Equatorial Africa and Amazonia
2. Ocean: Eastern Pacific, Equatorial Atlantic, and Tropical Western Pacific

Motivations, Objective and Data Set

Motivations:

1) Convection tends to be more intense over land than over ocean;
2) Land convection generally contains wider cores that are protected from entrainment than their oceanic counterparts;
3) How do these differences in convective intensity and entrainment impact the rest of cloud types and associated cloud radiative effects (CREs)?

Objective:

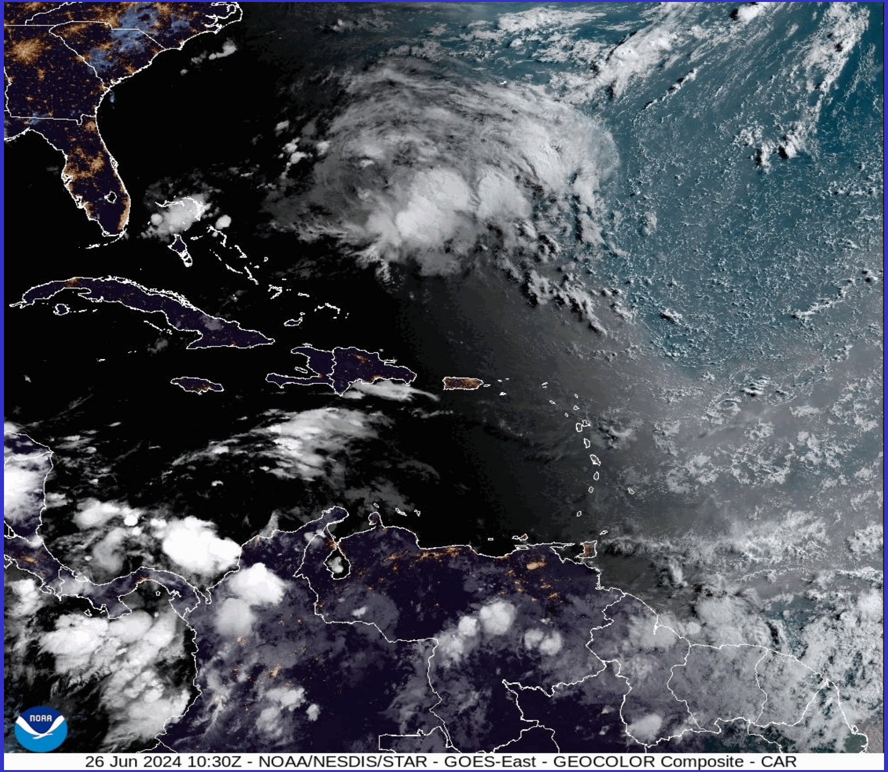
To characterize the differences and similarities in the cloud-type mean cloud properties and CREs and their annual variations between tropical oceanic and continental convection

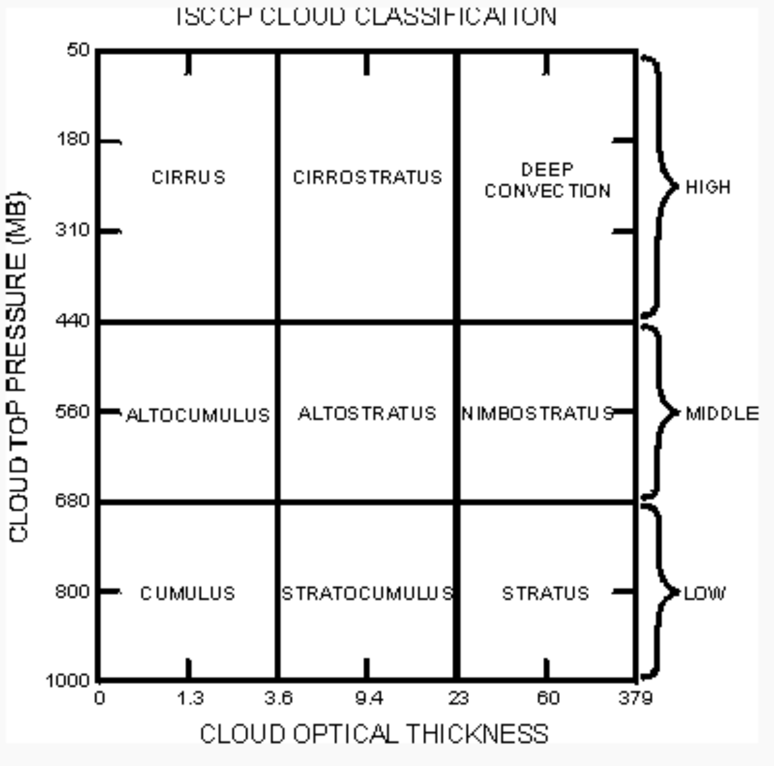
Data set:

19-yrs high-resolution (2x2 km^2) CERES FBCT (flux by cloud type; Sun *et al.*, 2022) data, similar to the ISCCP data but adding cloud-type mean cloud properties, radiative fluxes and CREs.

Sun, M., *et al.*, (2022). Clouds and the Earth's Radiant Energy System (CERES) FluxByCldTyp Edition 4 data product. *J. Atmos. Oceanic Tech.*, 39, 303–318.

The ISCCP Cloud Classification (Rossow & Schiffer 1999)

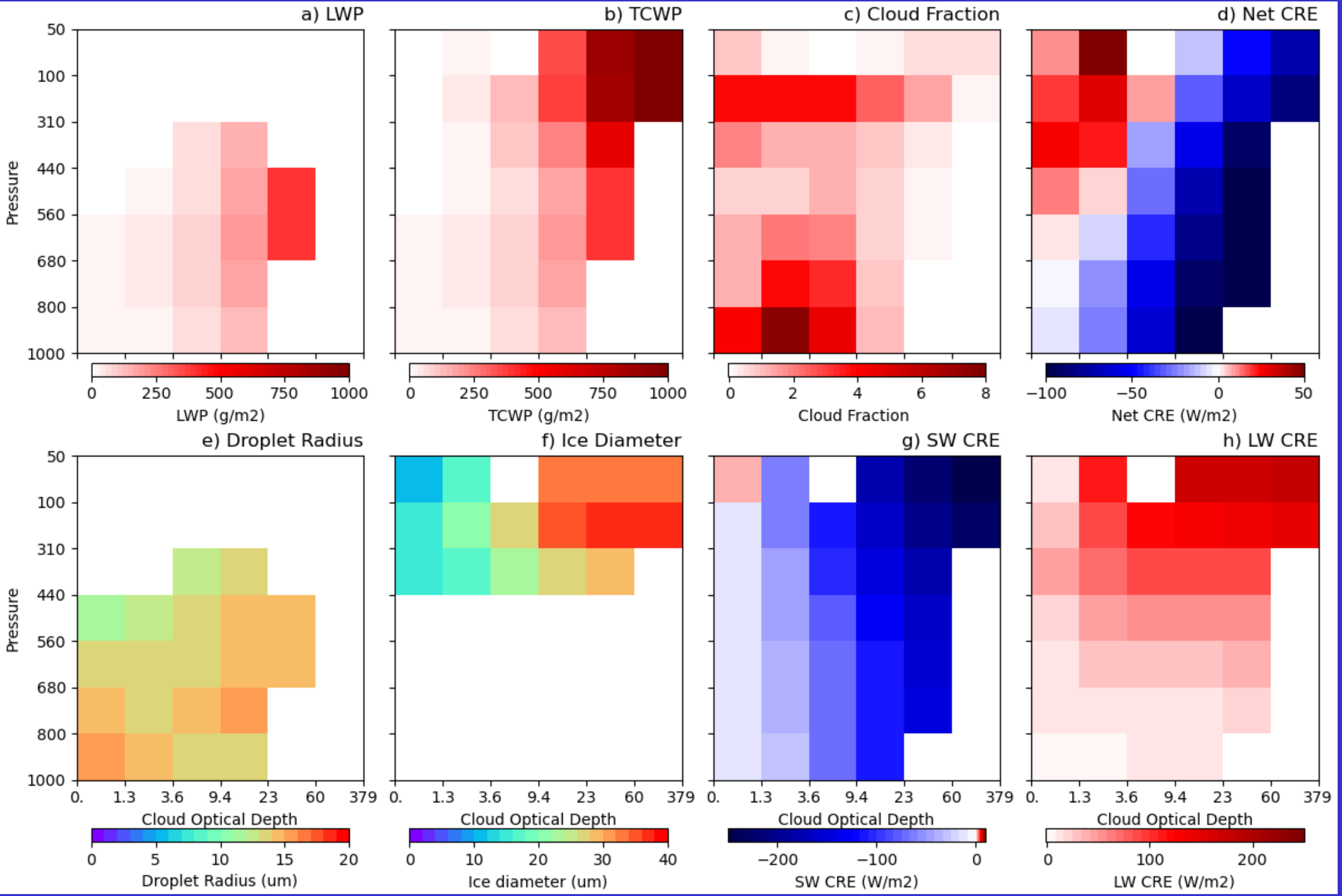




Rossow, W. B., & Schiffer, R. A. (1999). Advances in understanding clouds from ISCCP. *Bulletin of American Meteorological Society,* 80(11), 2261–2287.

42 cloud types are based upon joint cloud top pressure (p_c; 7 bins) and cloud optical depth (τ; 6 bins) distributions

Tropical Mean Cloud Properties and Cloud Radiative Effects (CREs)

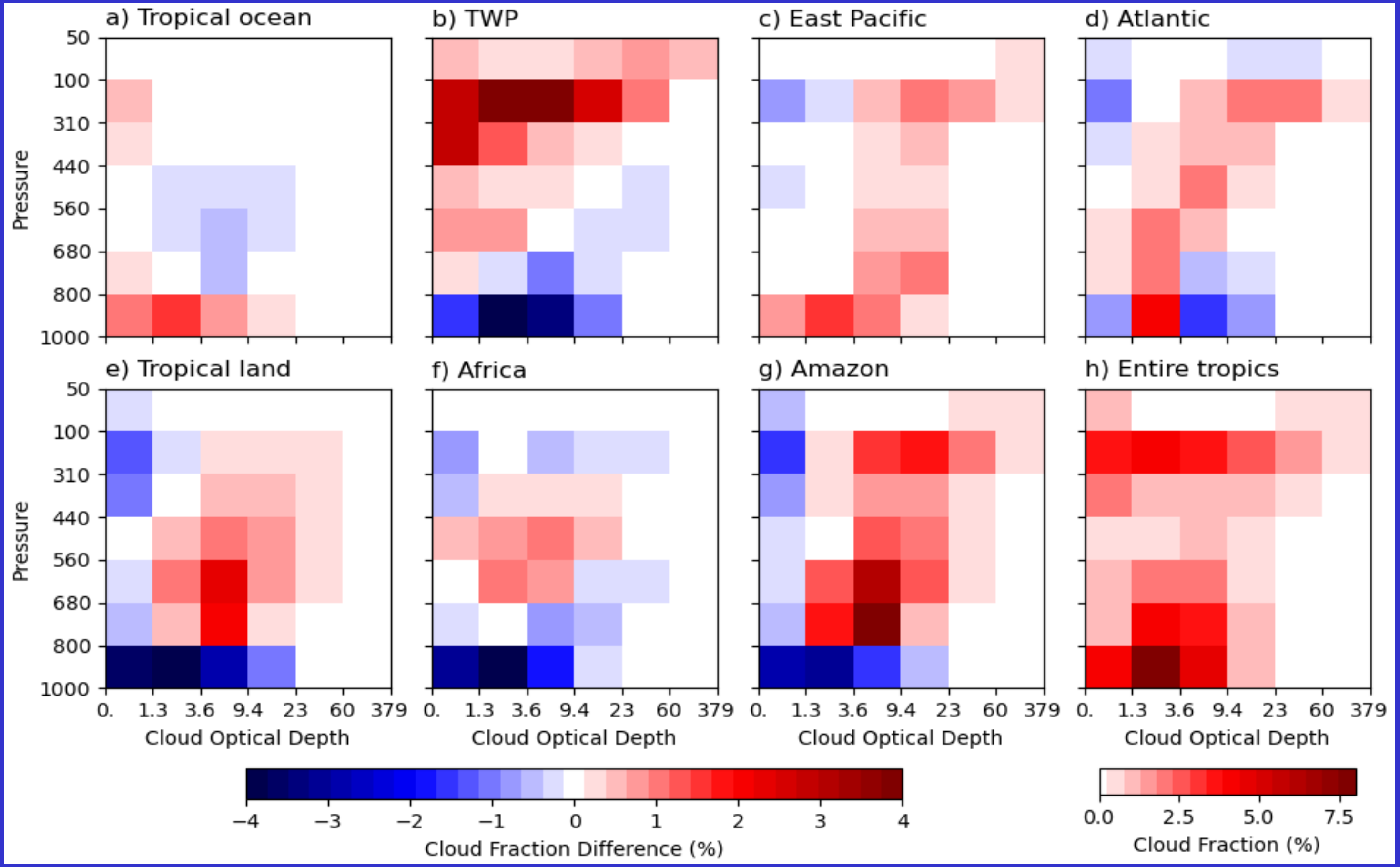


Cloud-type mean CRE:

CRE = F_{clear} - F_{cloudy}

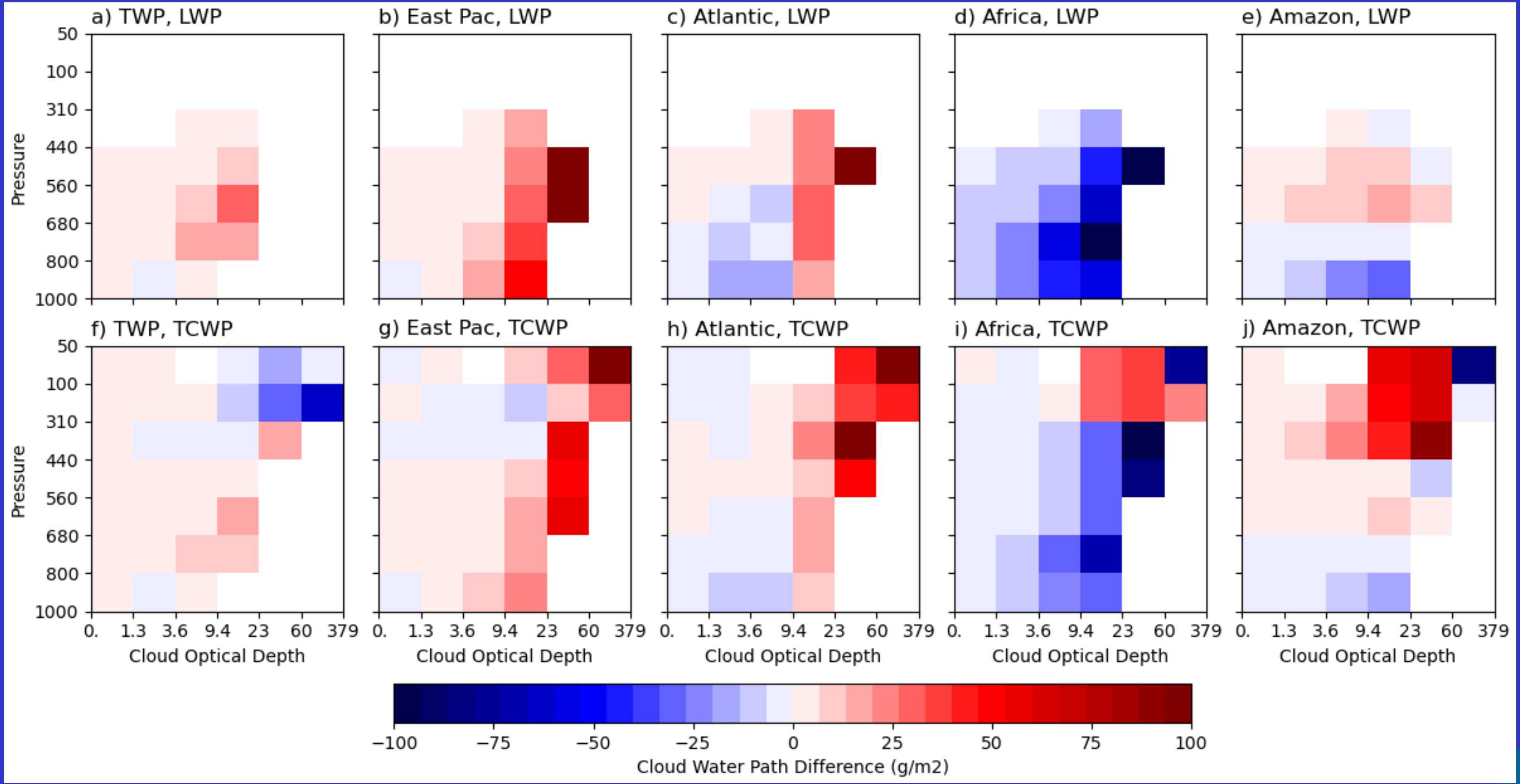
1) Maximum cloud fractions in the lower and upper troposphere;
2) Strong dependence on cloud optical depth for cloud properties except for droplet radius;
3) SW, LW and net cloud radiative effects also depend strongly on cloud top pressure;
4) Cloud types with lower tops and higher optical depths tend to have net cooling effects.

Comparison of cloud fraction differences from the tropical mean among the five regions, plus all tropical ocean and tropical land regions



1) The five "chimney" regions (b, c, d, f, g) are cloudier than the entire tropical mean (h) except for the lowest cloud types in four of them
2) Tropical Western Pacific (TWP) has the highest fractions of anvil cloud types; while Africa has the lowest
3) Amazon has the smallest fraction of optically thin cloud types
4) Land regions (e) have more optically moderate, middle-level cloud types, compared to oceanic regions (a, b)

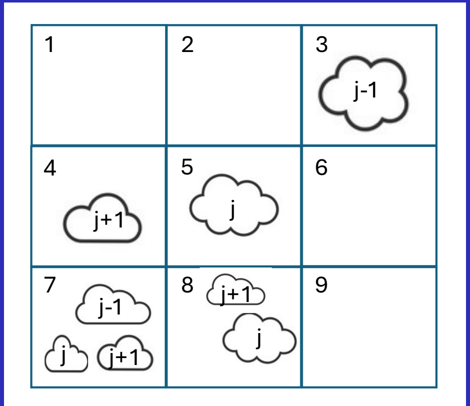
Comparison of liquid water path (LWP, *top row*) and total cloud (liquid + ice) water path (TCWP, *bottom row*) among the five regions



1. Deep convective cloud types have higher ice water paths (IWPs) than the tropical mean, except for TWP
2. Liquid water paths (LWPs) are lower over land regions than oceanic regions, particularly, in Africa

CREs (W m^{-2}) with/without the influence of immediate environments (CRE = Sum of cloud-type mean CREs multiplied by cloud fractions)

Two methods to calculate cloud-type mean CREs; they differ in how regional-mean clear-sky fluxes are calculated (Xu *et al.*, 2024).

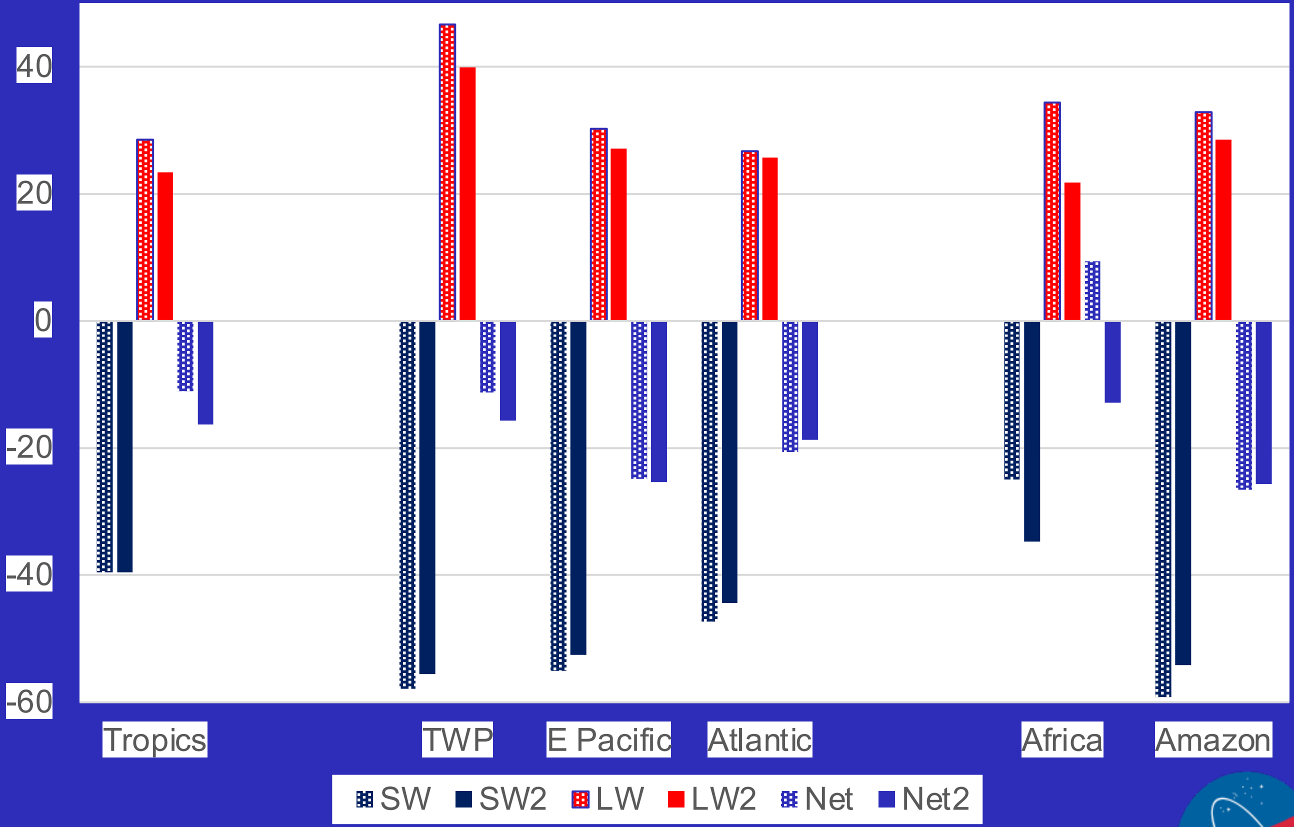


Cloud type J-1: Grids 3, 7

Cloud type J: Grids 5, 7, 8

Cloud type J+1: Grids 4, 7, 8

Grids 1, 2, 6 & 9 do not contribute to regional-mean clear sky radiative fluxes



1. The new method slightly reduces SW cooling and LW warming, except for Africa
2. Net CRE becomes cooling in Africa, due to increased SW and reduced LW CREs

Comparison of annual cycles of cloud type-mean CREs

1. Are the annual/semi-annual variations of CREs related to those of cloud fraction and/or total cloud (liquid + ice) water path (TCWP)?
2. If they are due to variations of cloud fraction alone, amplitudes of the CRE variations should be reduced for a single subtype.

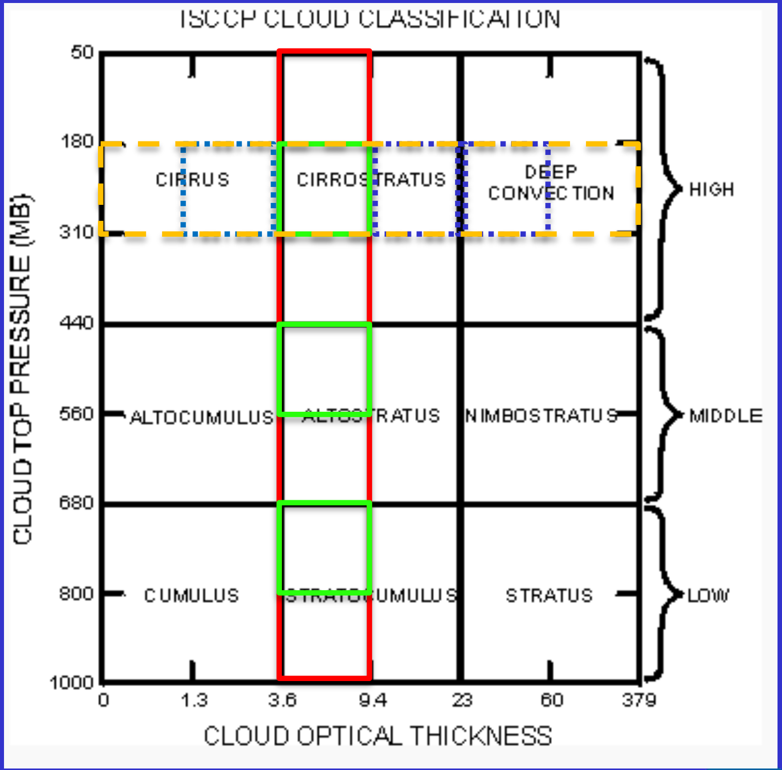
Results to be shown below for TWP and Africa regions:

a) Total (42), low (12), middle (12), high (18 subtypes)

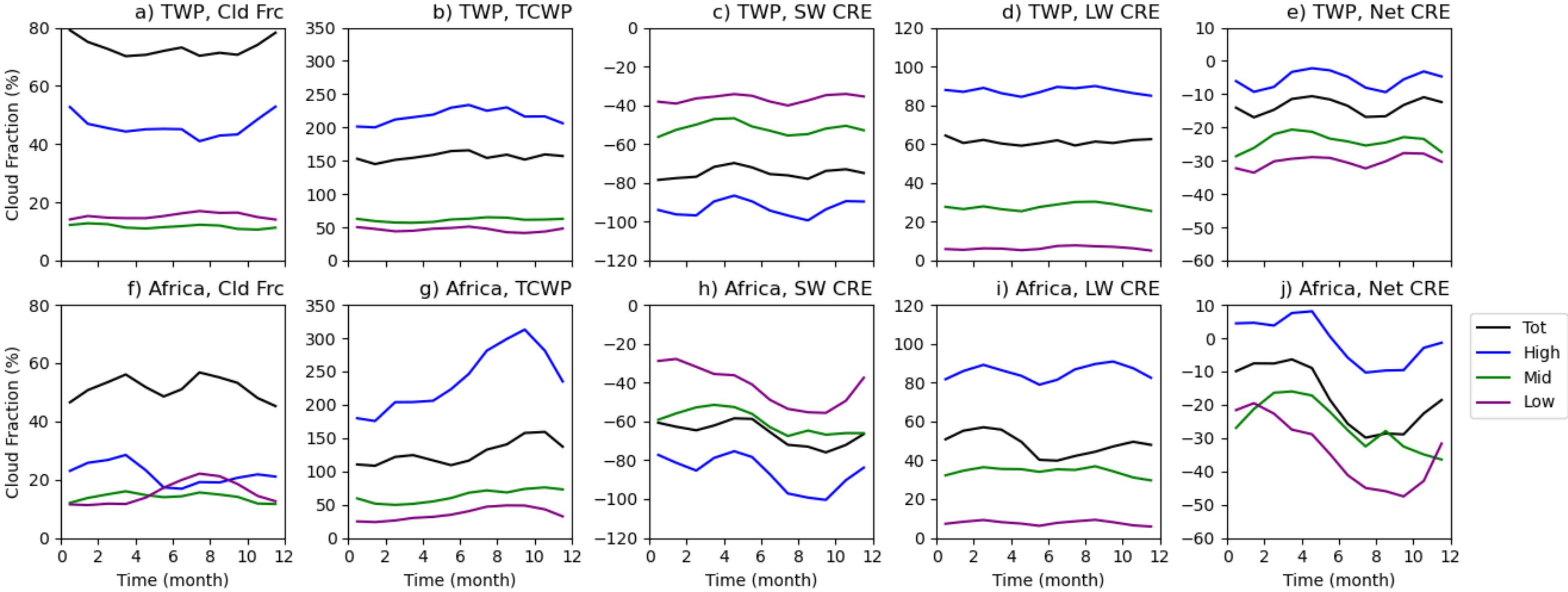
b) A single column ($3.6 < \tau \lesssim 9.4$), Cl3 (7 subtypes), Cl3-L, Cl3-M and Cl3-H single subtypes

c) Cirrus, cirrostratus, deep convection (6 subtypes each) and shallow cumulus (4 subtypes)

d) A single row ($180 < p_c \lesssim 310$ hPa), Rw6 (6 subtypes), Rw6-Ci, Rw6-Cs and Rw6-DC subtypes

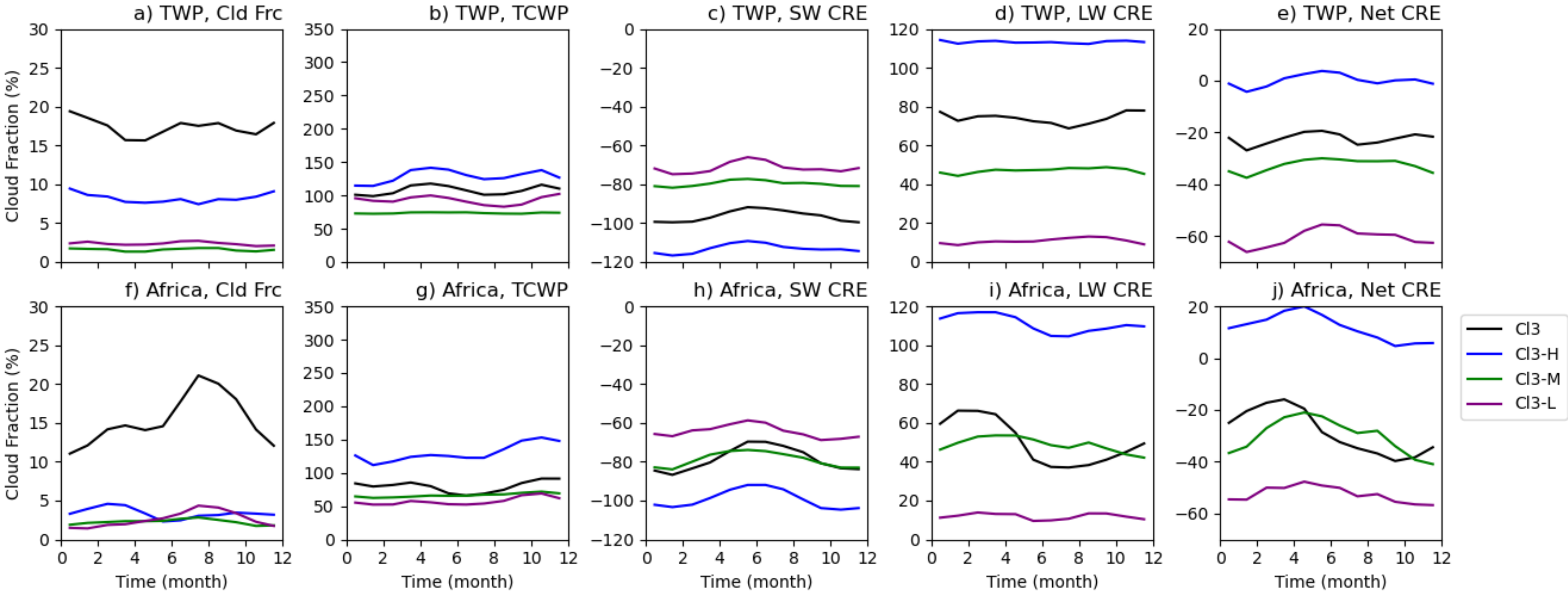


Annual variation of cloud fraction & TCWP/(cld frac) and SW/LW/net CREs Total (all), low-, mid- and high-level clouds for TWP and Africa



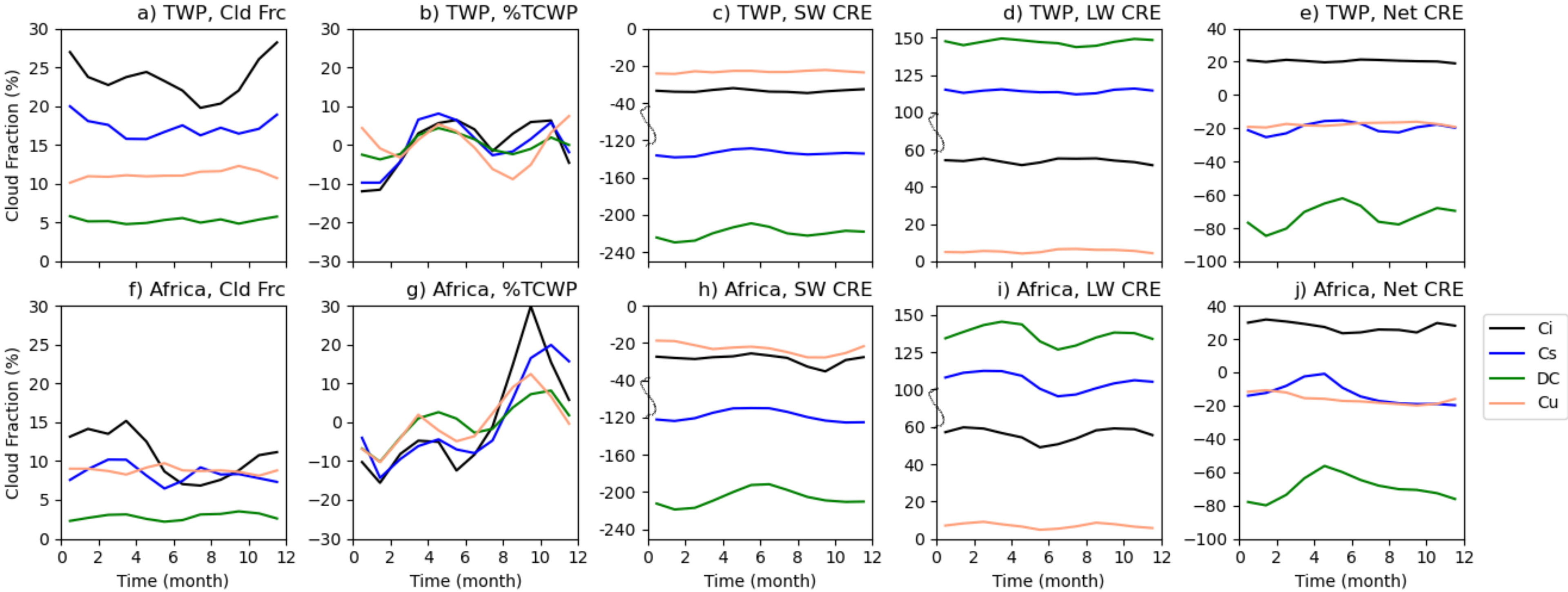
1. Are the annual/semi-annual variations of CREs related to those of cloud fraction and/or TCWP?
2. Over TWP, semi-annual variations of net/SW CREs cannot be explained by either cloud fraction or TCWP alone.
3. Over Africa, LW CREs are related to cloud fraction, but SW/net CREs are explained by TCWP.

Annual variation of cloud fraction & TCWP/(cld frc) and SW/LW/net CREs
3.6 < $\tau \leq$ 9.4, single low, mid and high subtypes for TWP and Africa



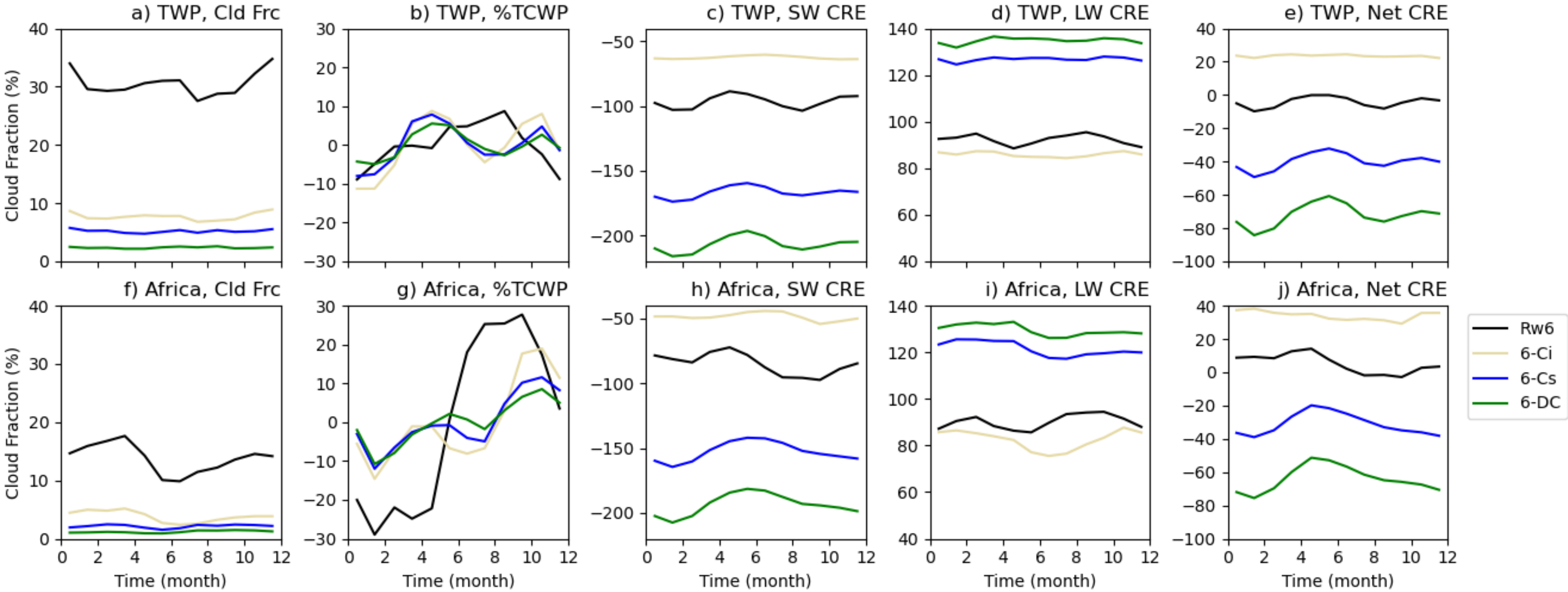
1. The amplitudes of the variations are slightly reduced for subtypes, but annual variations remain in LW/SW CREs
2. The semi-annual variations in net CREs are still pronounced over TWP, related possibly to TCWP variations

Annual variation of cloud fraction & %TCWP/(cld frc) and SW/LW/net CREs Cirrus, cirrostratus, deep convection and shallow cumulus for TWP & Africa



1. Semi-annual variations are most pronounced for DC (all CREs over TWP; LW CRE over Africa)
2. The amplitudes of SW CRE variations are much larger than those of LW CRE variations;
3. Net CRE variations follow those of SW CREs; TCWP deviations have strong semi-annual variations.

Annual variation of cloud fraction & %TCWP/(cld frc) and SW/LW/net CREs High cloud subtypes (Rw6, Ci, Cs and DC) for TWP & Africa



1. The amplitudes of the variations are not reduced for subtypes, compared to previous results (Ci, Cs and DC types)
2. Semi-annual variations of SW and net CREs are closely related to TCWPs for TWP
3. %TCWP = 100 x (difference from the annual mean) / (the annual mean)

Summary

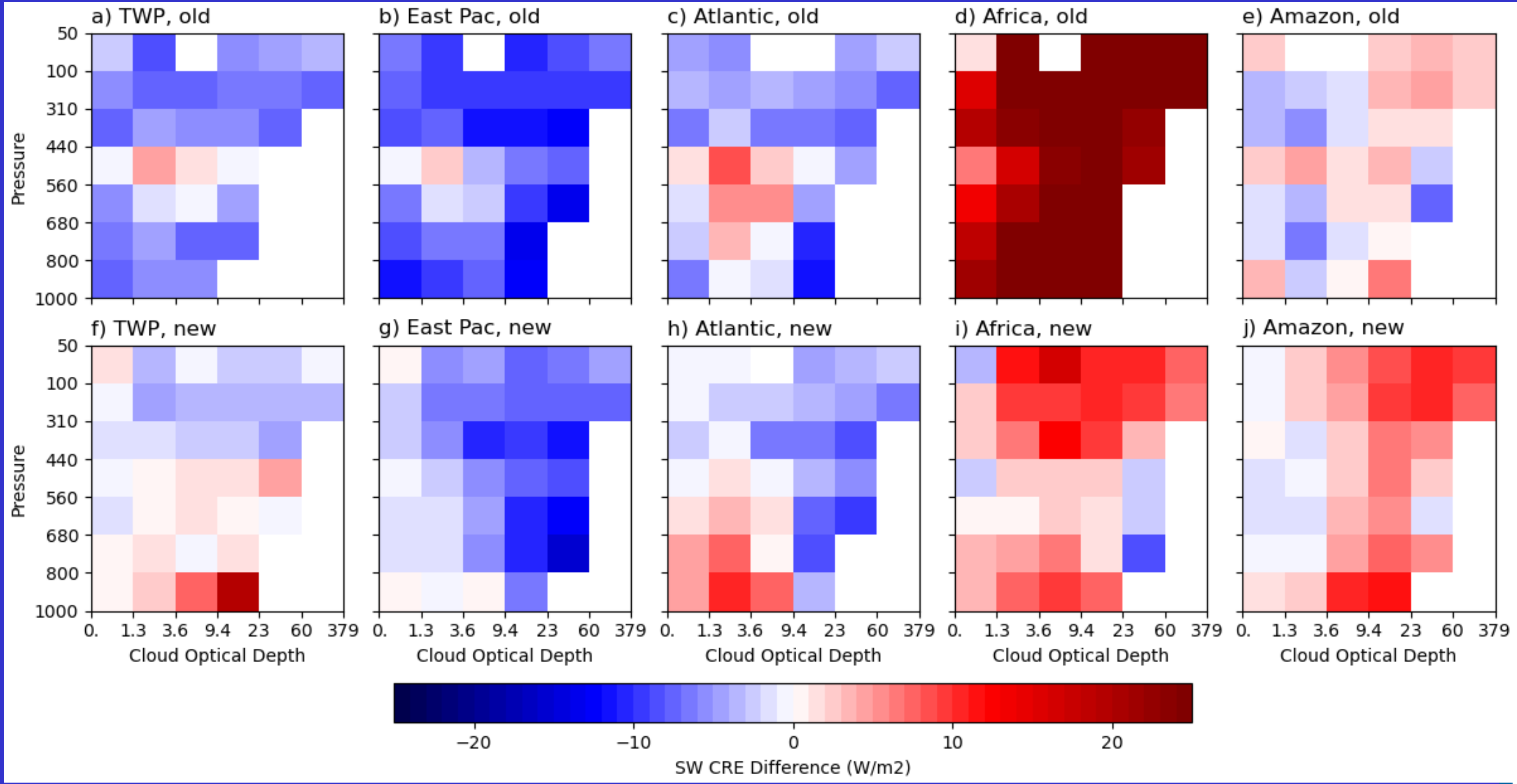
- For the 19-yr mean of the entire tropics,
  - abundance of low-level (& $\tau \leq 9.4$) cloud types and upper-tropospheric anvils ($p_c \leq 310$ hPa),
  - cloud microphysical properties strongly depend cloud optical depth (τ) except for liquid droplet radius,
  - SW, LW and net cloud radiative effects (CREs) also strongly depend on cloud top pressure (p_c).
- Land-ocean contrasts in cloud properties and CREs:
  - All five regions are considerably cloudier than the entire tropical mean except for the lowest (p_c > 800 hPa) cloud types over Africa, Amazon, TWP and Atlantic regions.
  - TWP has the highest fractions of anvil clouds, but the lowest ice water paths (IWPs).
  - Africa has the lowest fractions of high clouds ($p_c \leq 310$ hPa) and the lowest liquid water paths (LWPs).
  - Land regions have considerably more mid-level clouds ($1.3 < \tau \leq 60$) but fewer low-level clouds, compared to oceanic regions.
  - Clouds have net cooling effects over all regions (-13 to -26 W m^{-2}) with the influence of immediate environments considered (Africa has net warming using the conventional method).

Summary (cont.)

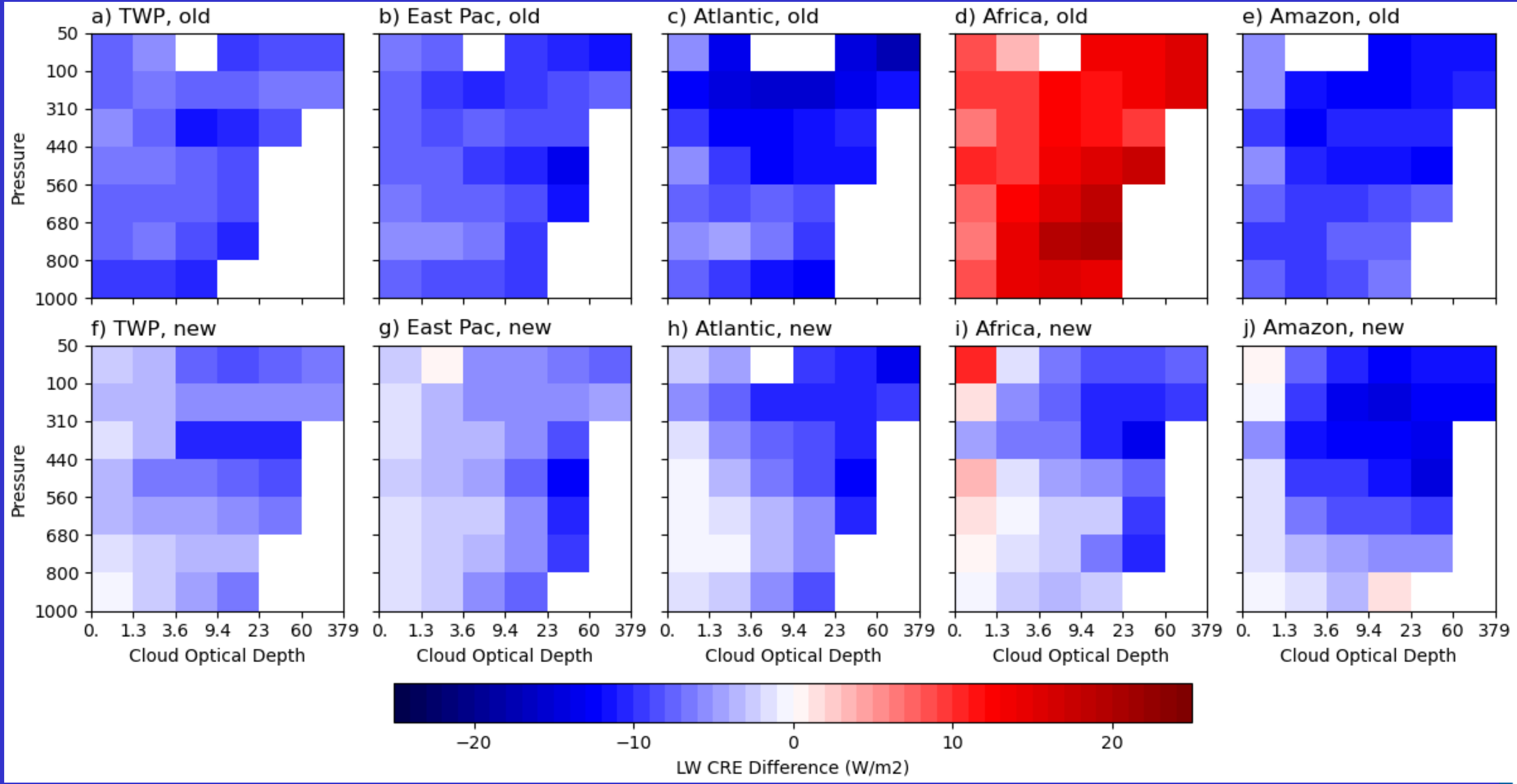
- Annual variations in CREs:
  1) The variations of SW, LW, and net CREs for low-, mid- and high-level and all clouds are not small at all and there are semi-annual variations in all regions.
  2) These CRE variation signals are greatly reduced for individual cloud types (Ci, Cs, DC and Cu) and subtypes (Cl3-L, Cl3-M, Cl3-H) except for high cloud (Rw6, Rw6-Ci, Rw6-Cs and Rw6-DC).
  3) The variations of CREs cannot be totally explained by those of TCWP per unit cloud fraction, and thus, suggesting that the partitioning of sub types may play an important role.
  4) The semi-annual variations of net CREs for deep convection are most significant among all cloud types over ocean, but the annual variations dominate over Africa.

Backup slides

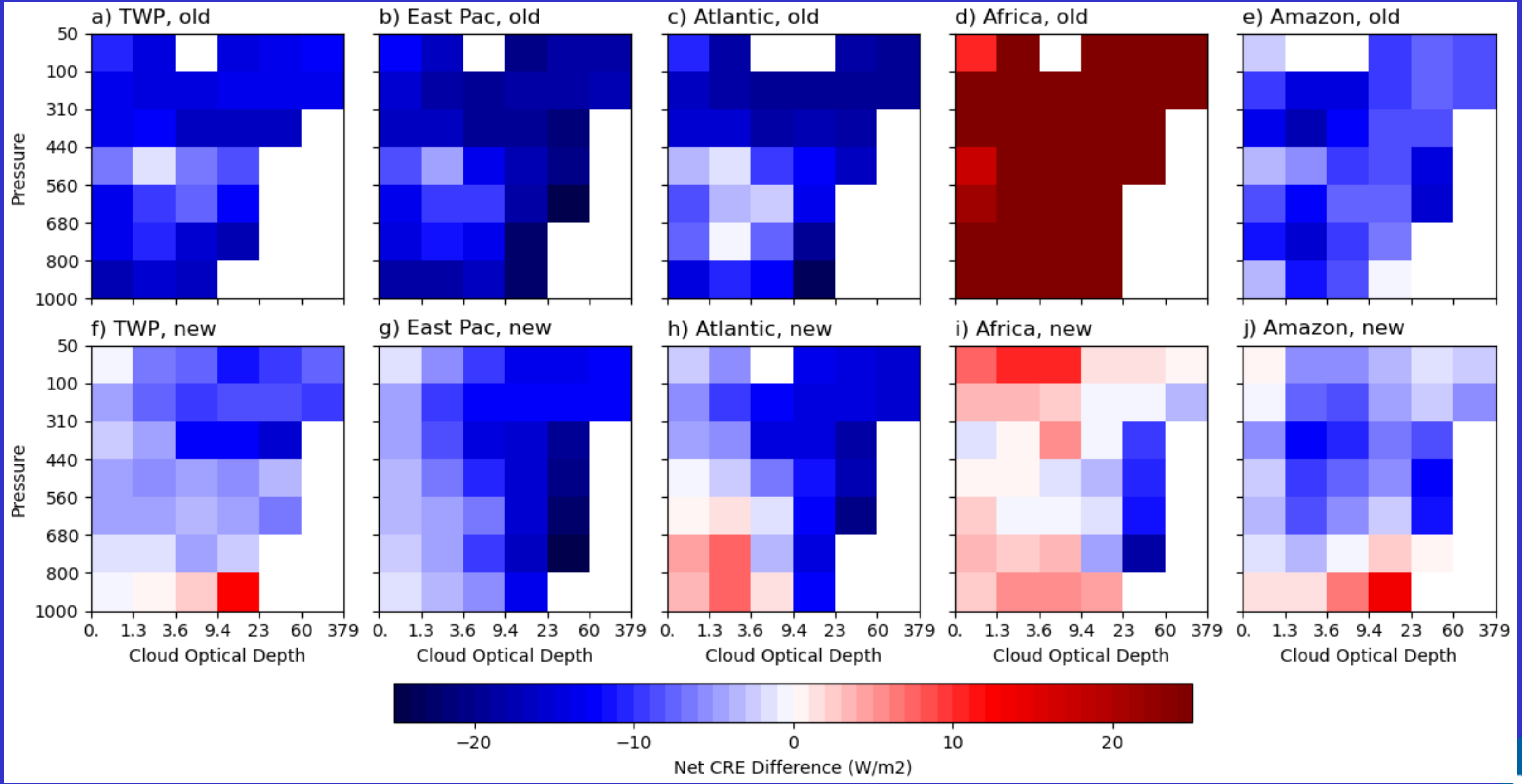
Comparison of the two methods for differences from the tropical mean: Shortwave CRE



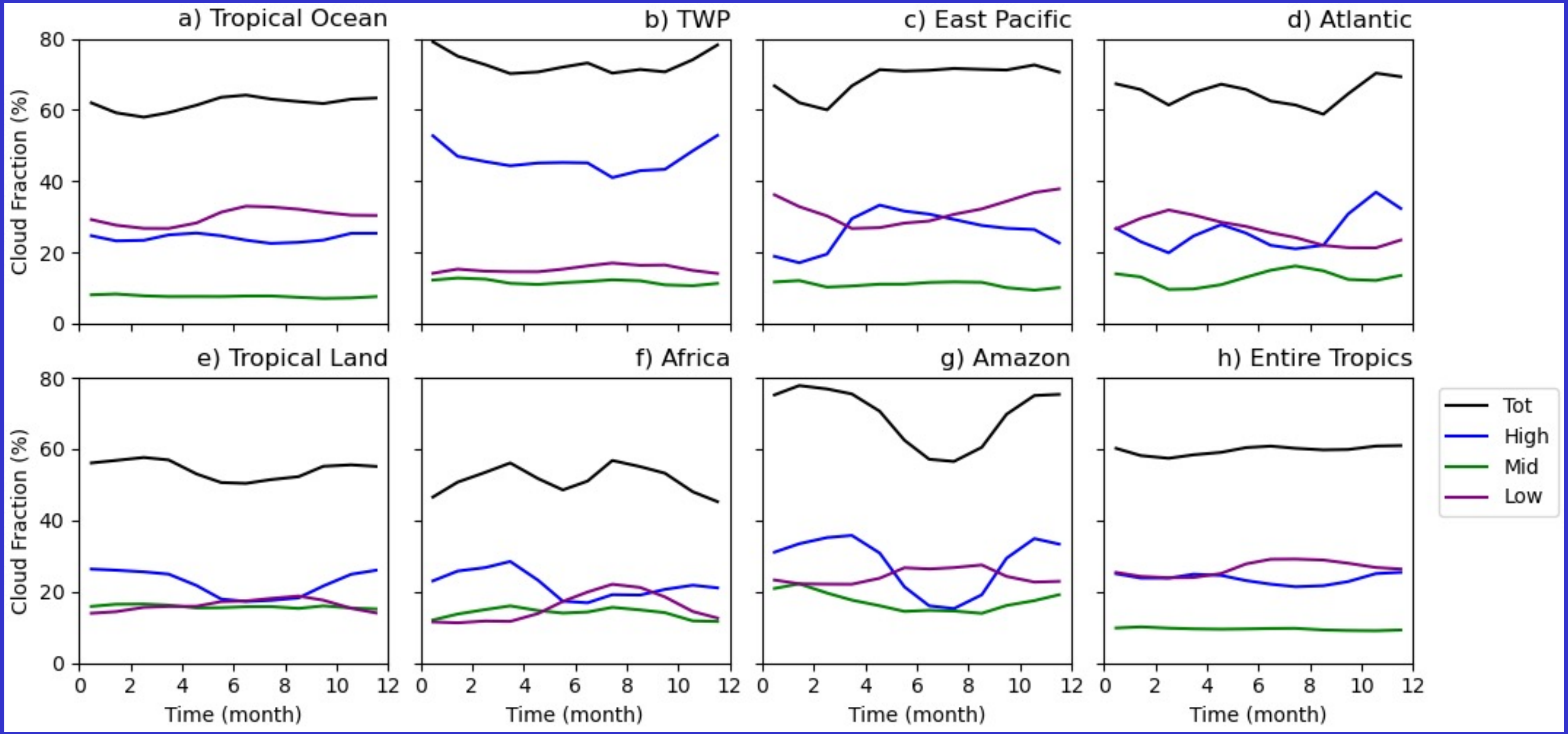
Comparison of the two methods for differences from the tropical mean: Longwave CRE



Comparison of the two methods for differences from the tropical mean: Net CRE

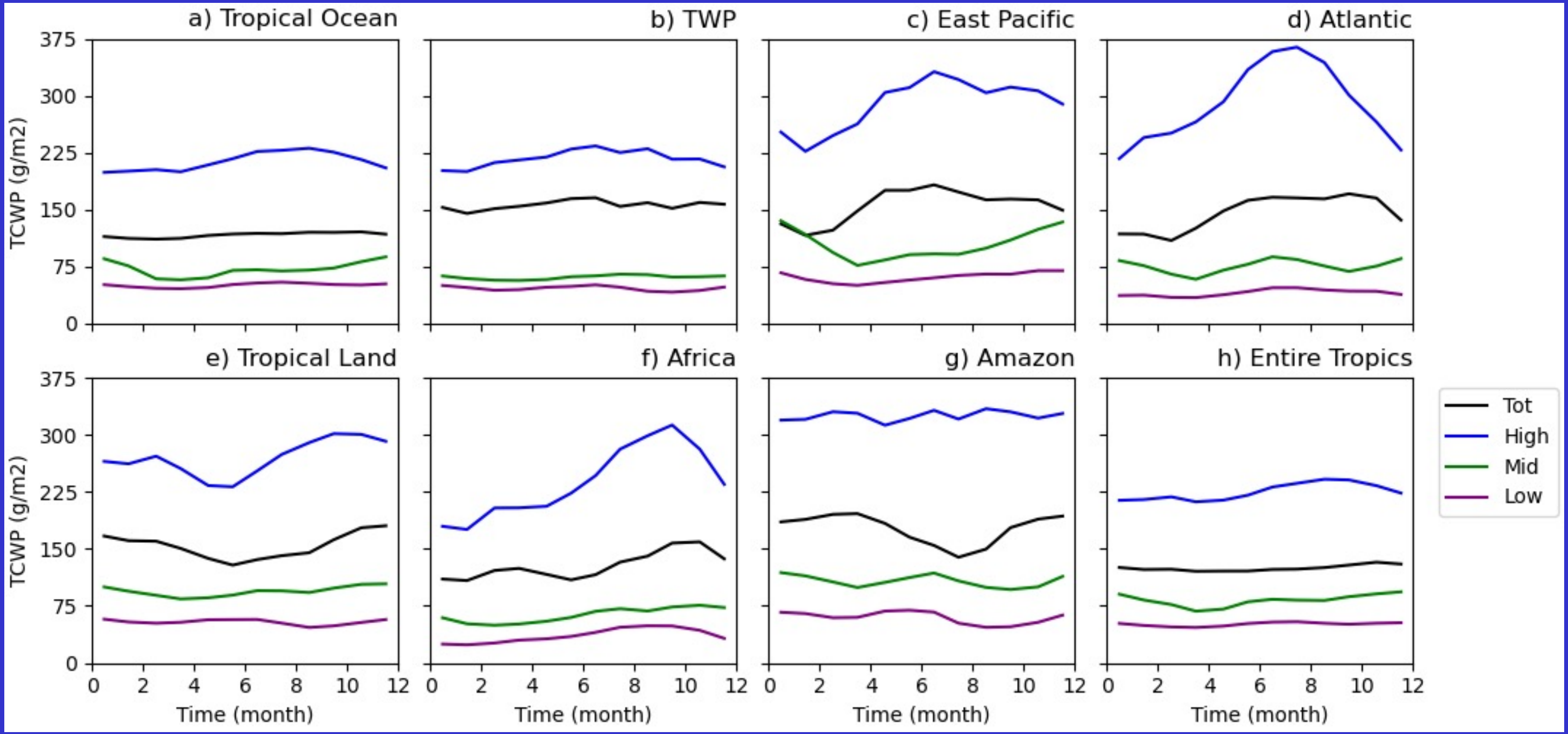


Annual variation of total, low-, mid- and high-level cloud fractions among the eight regions



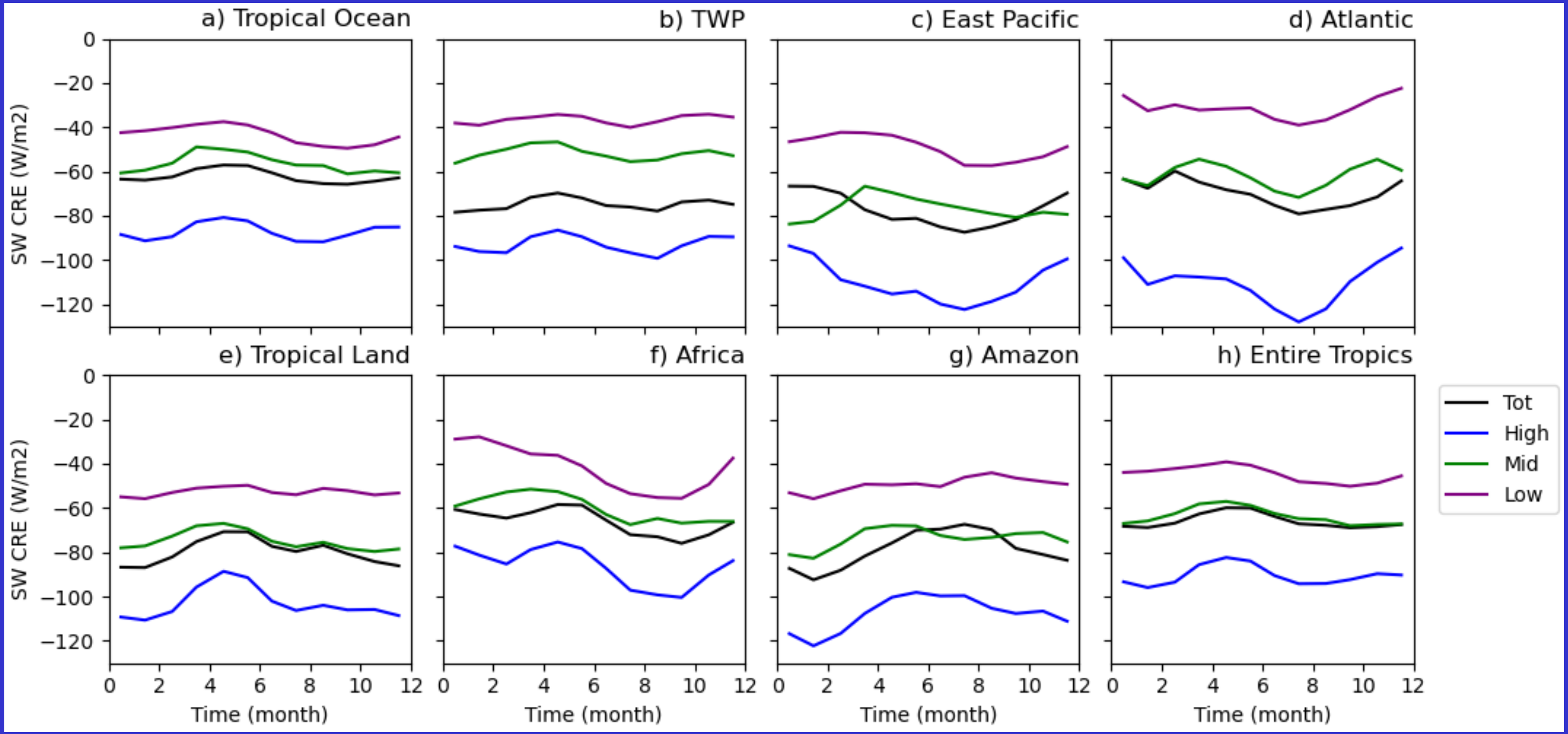
1. Weak annual variation for the entire tropics, with opposite phases between low- and high-level clouds
2. Tropical land: dominated by high-level clouds; Tropical ocean: phase shifts between low- and high-level clouds
3. Chimney zones: much larger amplitudes of variation in high- than in low-level clouds; various amounts of phase shifts

Annual variation of total (liquid and ice) cloud water paths (TCWP)



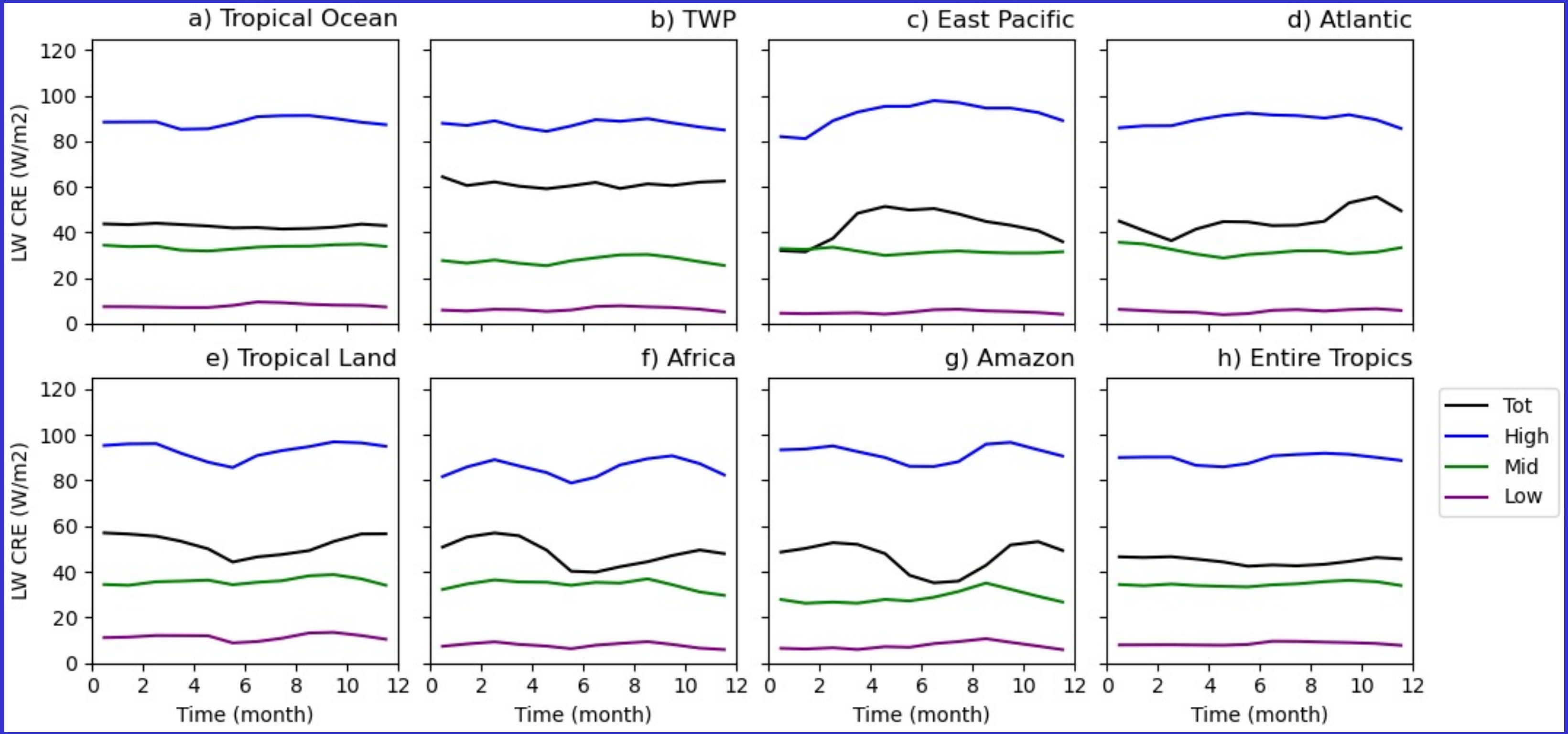
1. TCWP per unit cloud fraction has significant annual variations for all cloud types, particularly high and all clouds
2. Large amplitudes for high-cloud TCWP in Africa, East Pacific and Atlantic, but weak over TWP and Amazon
3. TCWP for all clouds (Tot) is influenced by annual variations of cloud fractions, particularly those of high-level clouds

Annual variation of SW cloud radiative effects



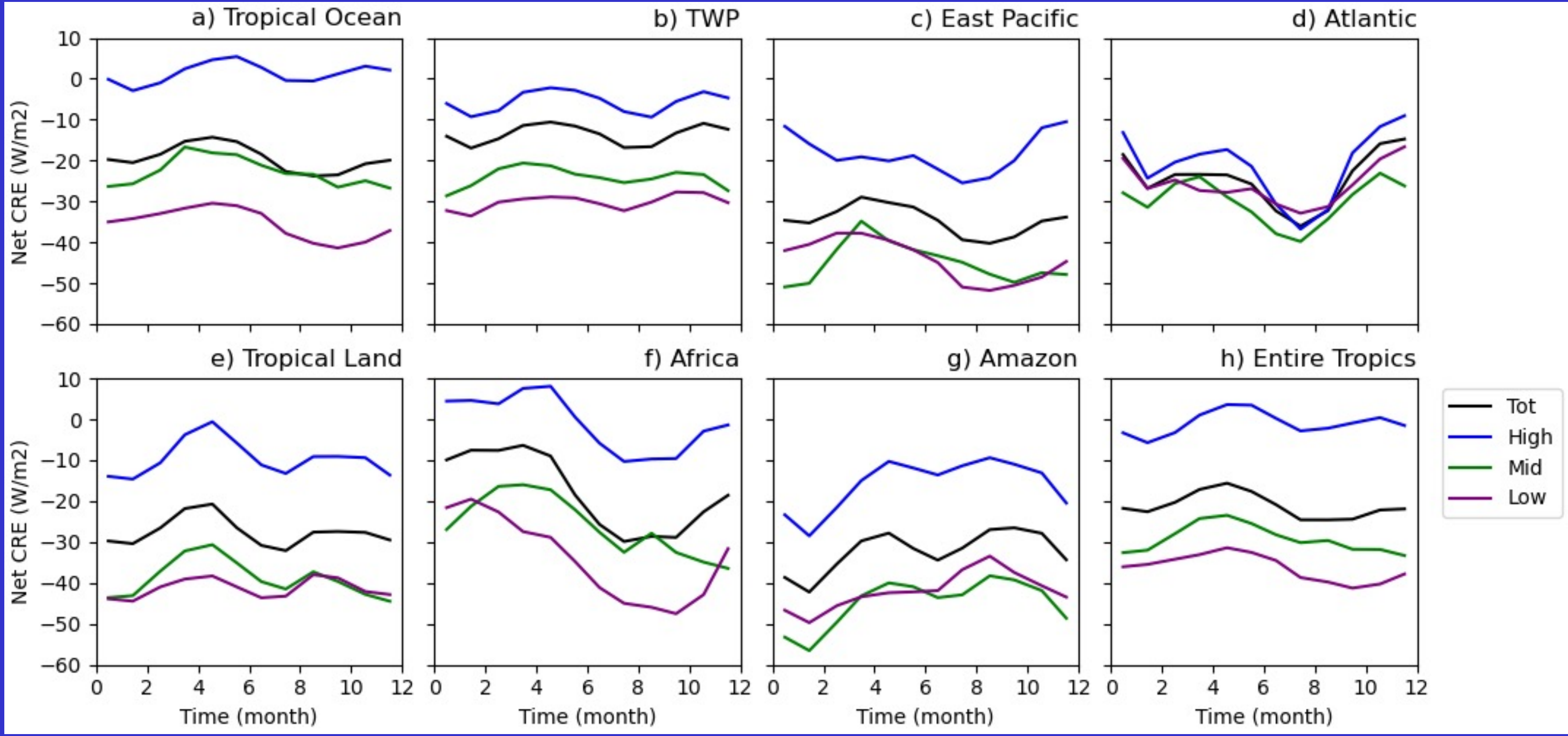
1. SW CREs have significant annual and semi-annual (e.g., TWP and Atlantic) variations
2. Strongest cooling for high clouds over East Pacific, Atlantic and Amazon, but weakest over Africa
3. Strongest for high clouds and weakest for low clouds over Atlantic are the reason for similar net CREs

Annual variation of LW cloud radiative effects



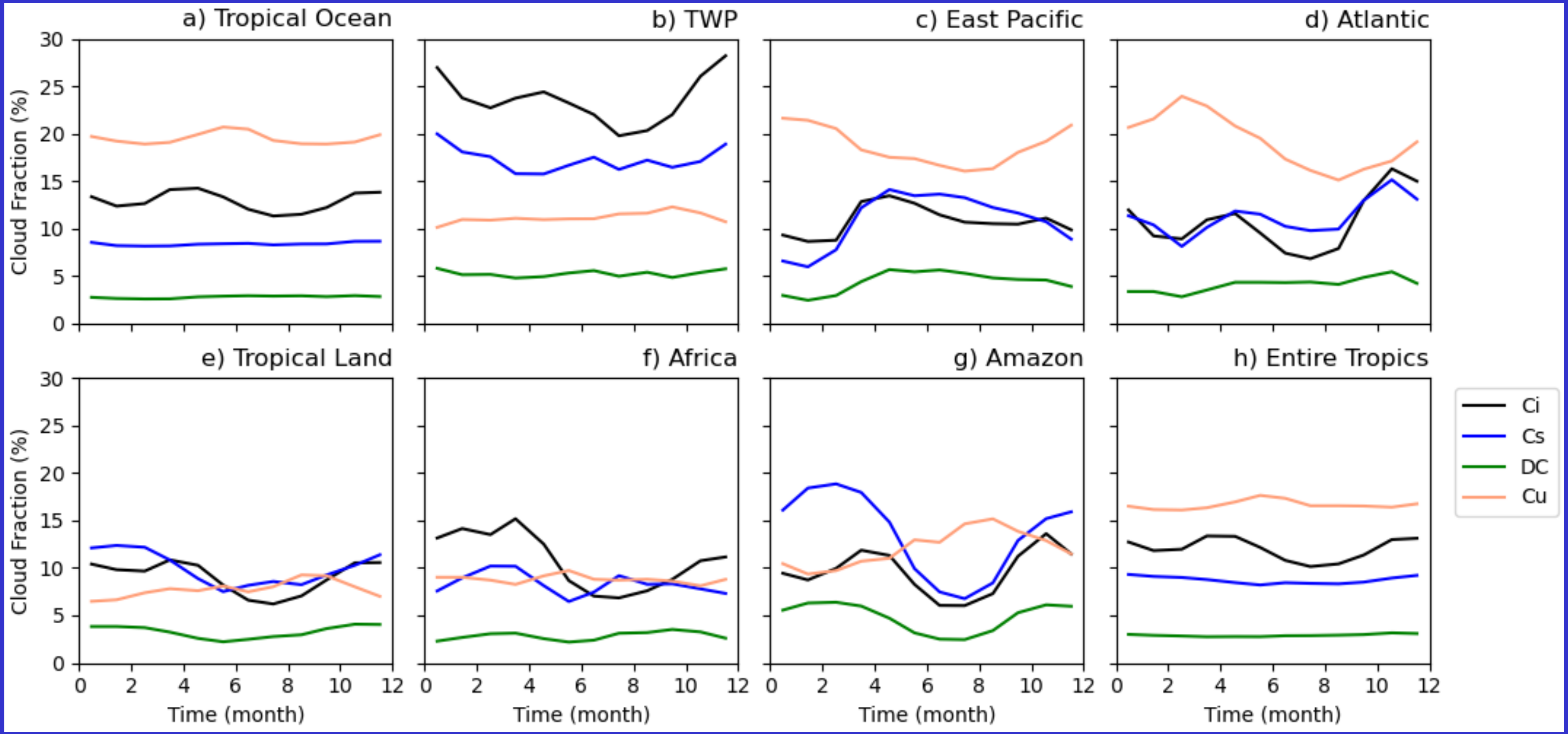
1. Relatively small annual variations for low- and mid-level clouds, compared to high-level and all clouds
2. Unlike SW CRE, semi-annual variations are more pronounced over lands than over ocean for high-level and all clouds

Annual variation of net cloud radiative effects



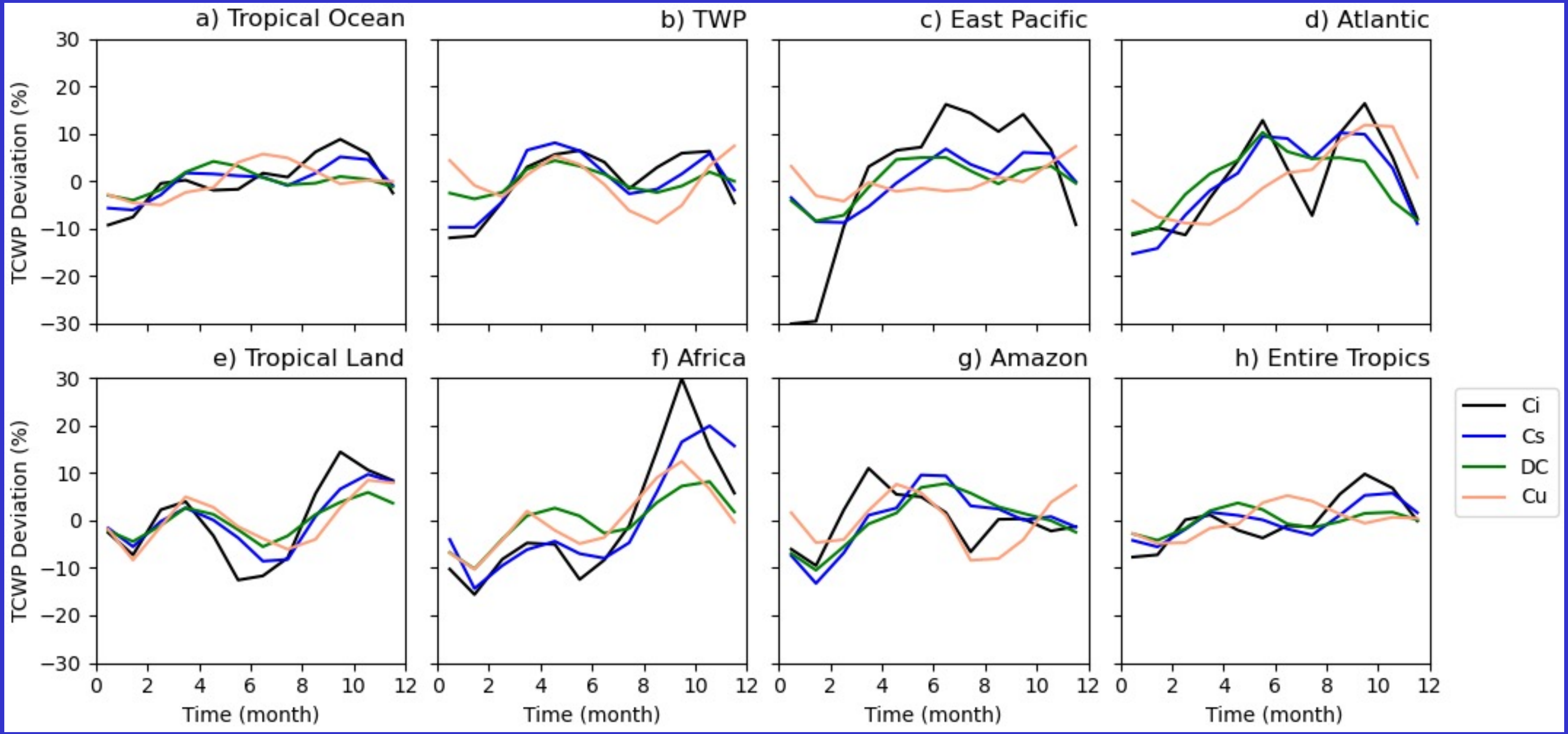
1. For net CREs, semi-annual variations appear over all regions and all cloud types
2. Net CRE differences among the cloud types are less than 20 W m^{-2} over Atlantic
3. Net CREs are ~ 0 ($\pm$8 W m^{-2}) for high clouds over tropical ocean and entire tropics, and a few months over Africa

Annual variation of cirrus, cirrostratus, deep convection and shallow cumulus fractions among the eight regions



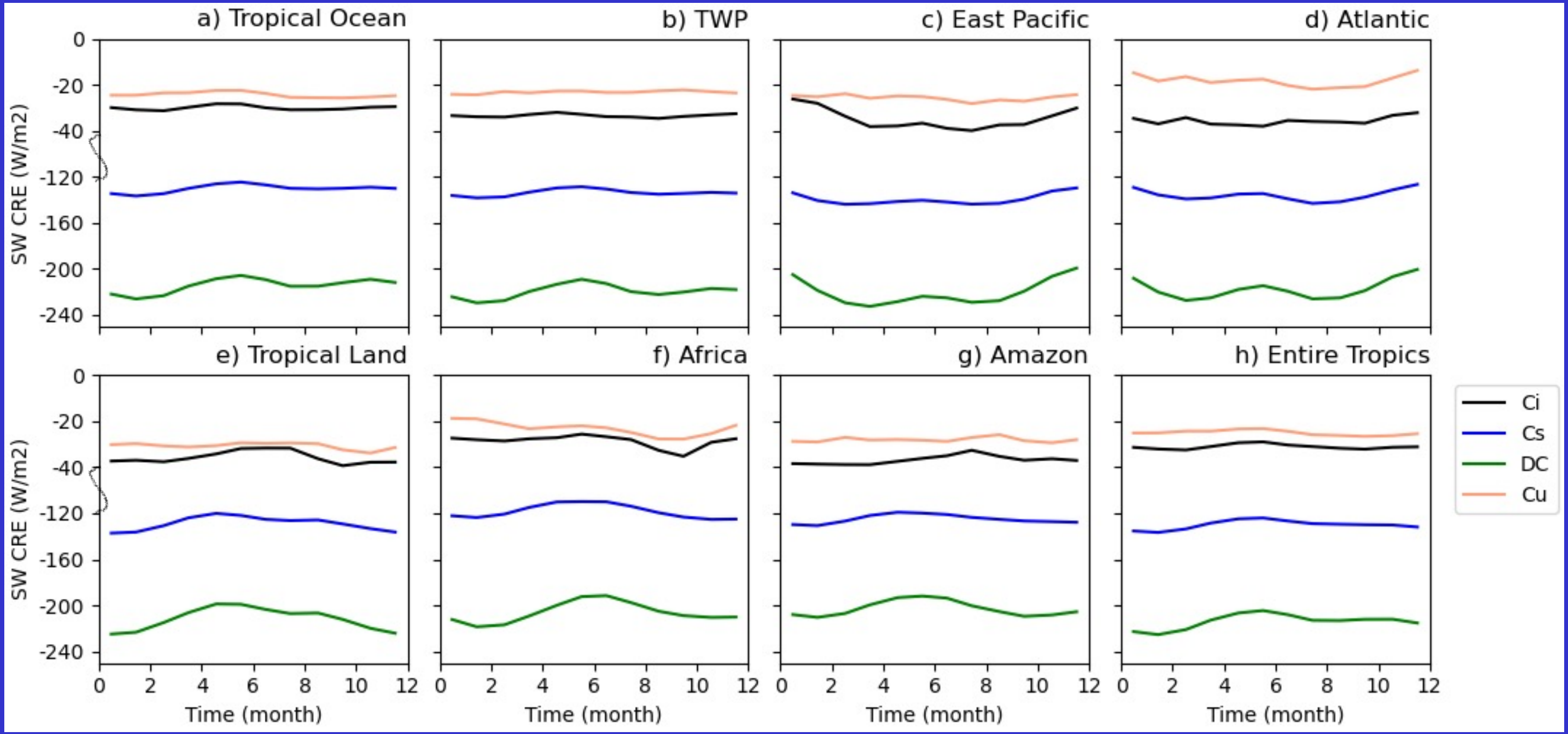
1. Deep convection over the chimney regions except for Africa is more abundant than the tropical mean/ocean/land.
2. Abundance of Ci and Cs over TWP, Cu over East Pacific, Atlantic and tropical ocean but less over lands
3. Semi-annual variations appear over every region for Ci and other types over Amazon (DC) and Atlantic (Cs)

Annual variation of total (liquid and ice) cloud water path (TCWP) per unit cloud fraction normalized by annual means



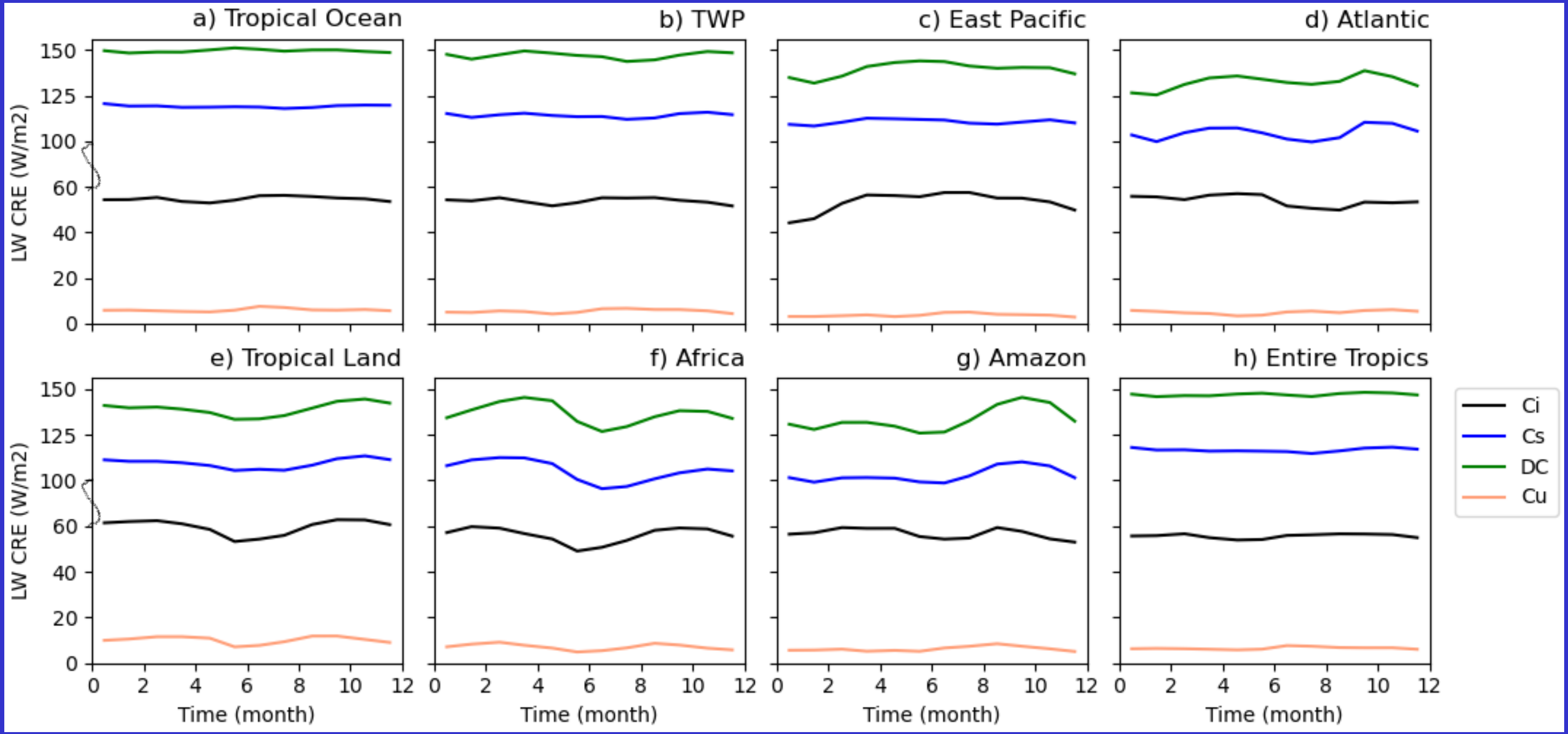
1. Semi-annual variations are very pronounced for all types and all regions with few exceptions
2. The amplitudes are ~10% of the annual means; but can be up to 30% (Ci over Africa and East Pacific)
3. Annual-mean TCWPs are 20-29 g m^{-2} for Cu and Ci, 206-252 g m^{-2} for Cs and 1078-1142 g m^{-2} for DC

Annual variation of SW cloud radiative effects



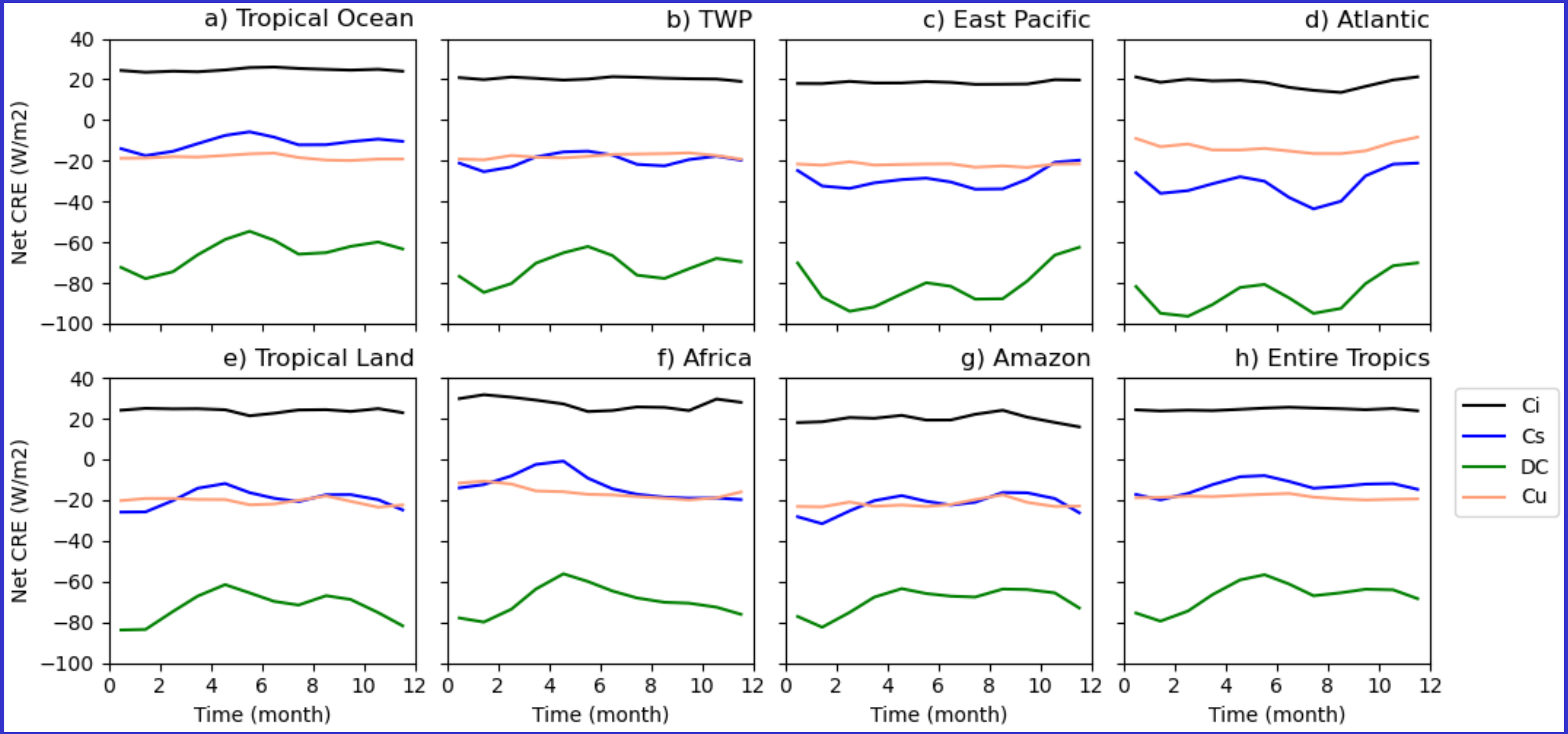
1. Annual/semi-annual variations for DC are very large (semi-annual over ocean, annual variations over lands)
2. Very small variations for Ci and Cu types

Annual variation of LW cloud radiative effects



1. Similar to SW CREs except that semi-annual variations are very pronounced for all cloud types over lands

Annual variation of net cloud radiative effects



1. Small variations for Ci and Cu, but large semi-annual (except for Africa) variations for Cs and DC
2. Ci is 20-25 W m^{-2} warming; Cu and Cs are ~-20 W m^{-2} cooling (larger for Cs over East Pacific and Atlantic)
3. Largest cooling for DC at -70 $\pm$ 10 W m^{-2}