On the relationship between cloud vertical structure and the large-scale tropical circulation: observational analysis and evaluation of climate models

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1. Introduction

➢ Clouds control both the distribution and intensity of diabatic heating sources in the atmosphere (e.g., convection, radiation).

➢ In turn, these heating sources strongly interact with atmospheric dynamics and determine the spatial structures and temporal variability of the large-scale atmospheric circulation simulated by climate models.

➢ Characterization and understanding of relationships between cloud properties, tropospheric radiative heating and local/large-scale atmospheric circulations and climate variability should provide guidance for future GCMs improvements.

Objectives: elaborate a framework to diagnose GCM biases in their representation of tropospheric radiative heating and its relationship with cloud properties and local dynamics.

2. Datasets

"**Observations**": monthly averages, on a 2.5°x2.5° horizontal grid

- **ERA-Interim** (1989-2010): vertical pressure velocity ω(p)
- **GPCP** Precipitation version 2.1 (1979-2009) .
- SRB release 3.0 (1983-2007): clear- and total-sky radiative flux
  - Observed **TOA** SW and LW fluxes;
  - Parameterized **Surface** SW and LW fluxes

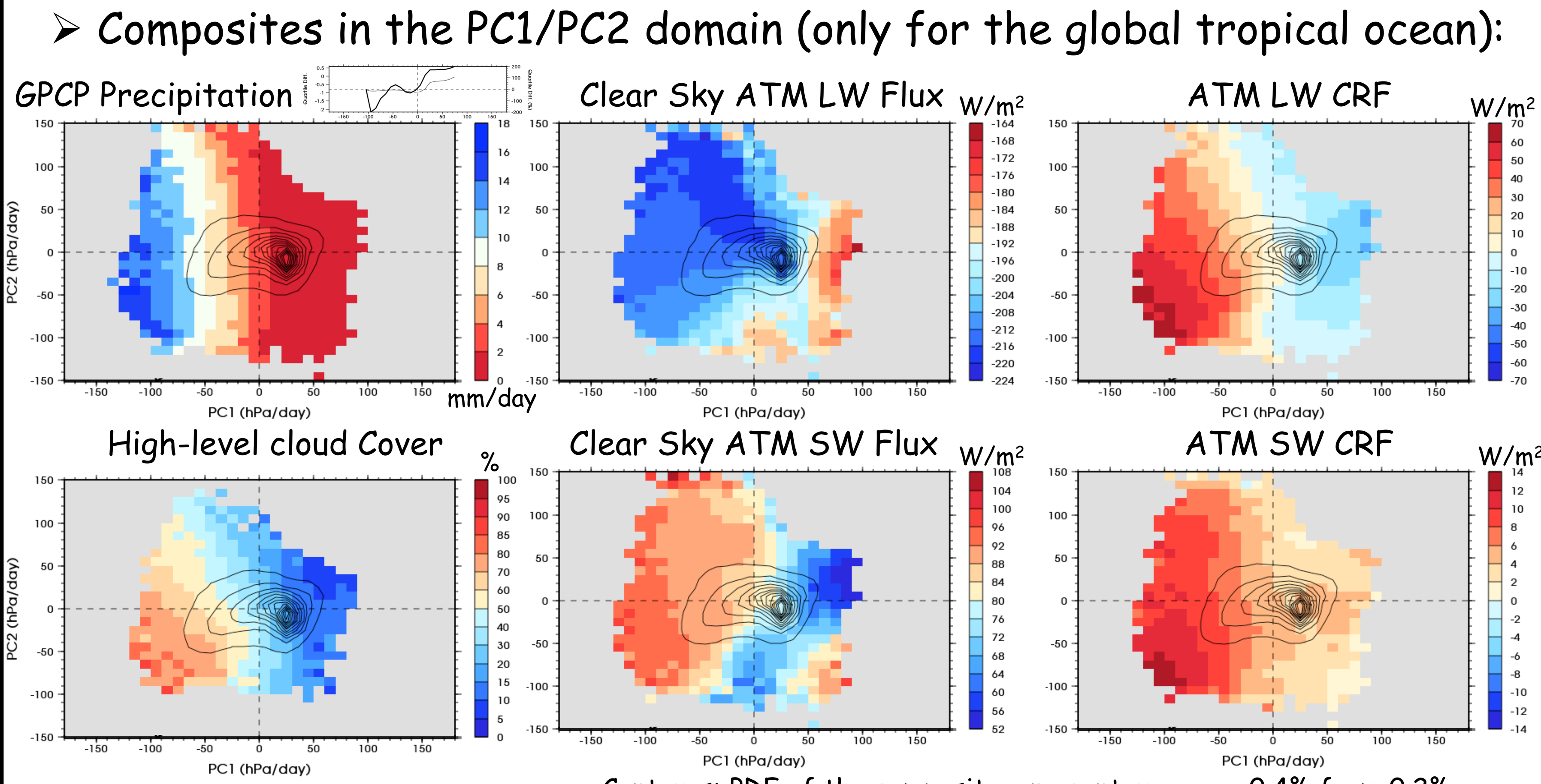
  } **Atmospheric** (ATM) radiative flux divergence
- **CALIPSO-GOCCP** Dataset (2006-2010 - Chepfer et al. 2010)
  - Low-, mid- and high-level and total cloud cover, as well as vertical profiles of cloud cover

CMIP3/CMIP5 Models: monthly averages, interpolated on the same grid

- CMIP3: 20c3m experiment (1971-2000), 10 models.
- CMIP5: historical experiment (1976-2005), 5 models + AMIP experiment for 2 models.

4. Observational Analysis

➢ Composites in the PC1/PC2 domain (only for the global tropical ocean):



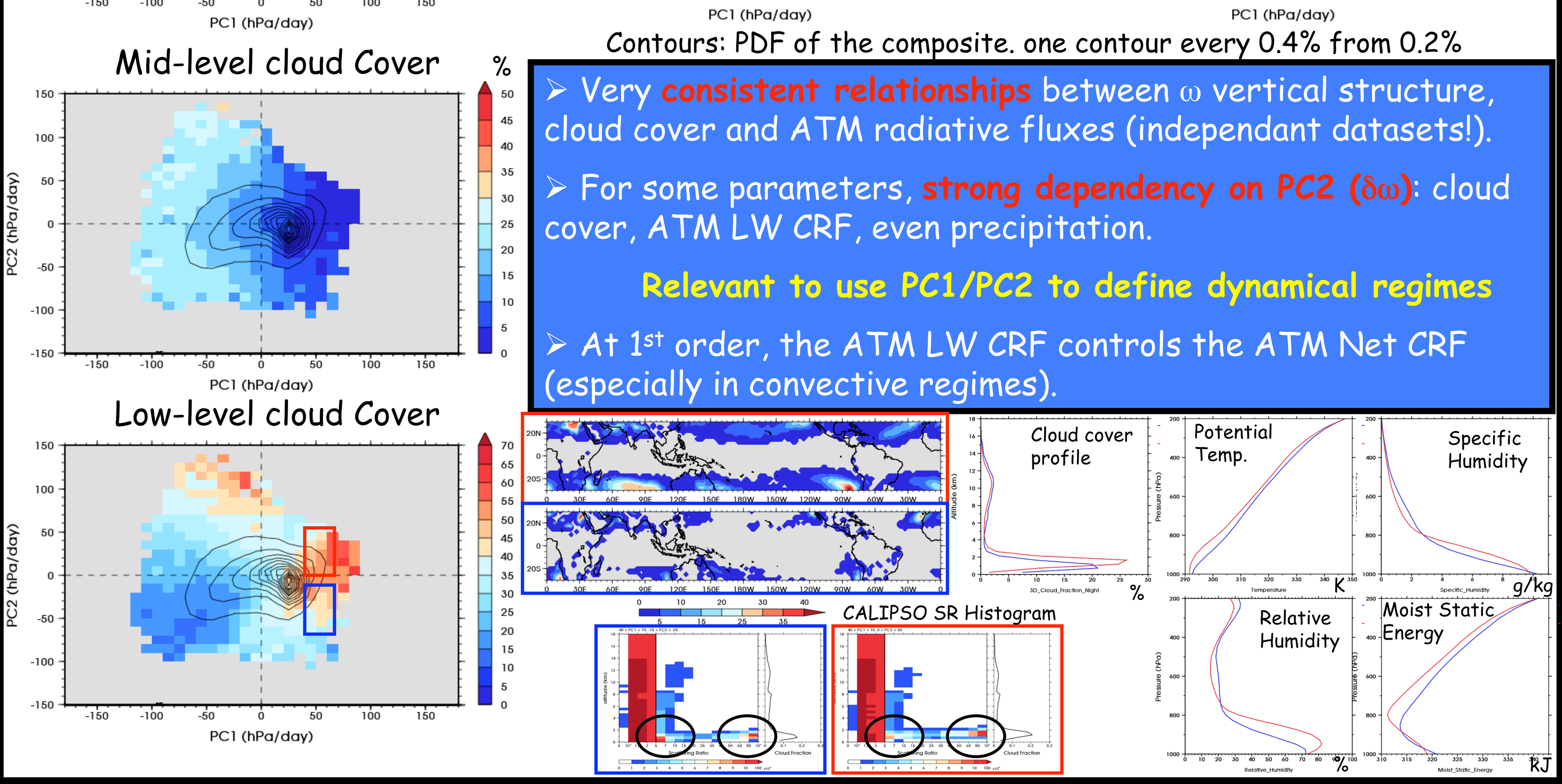
Contours: PDF of the composite, one contour every 0.4% from 0.2%

➢ Very **consistent relationships** between ω vertical structure, cloud cover and ATM radiative fluxes (independant datasets!).

➢ For some parameters, **strong dependency on PC2 (δω)**: cloud cover, ATM LW CRF, even precipitation.

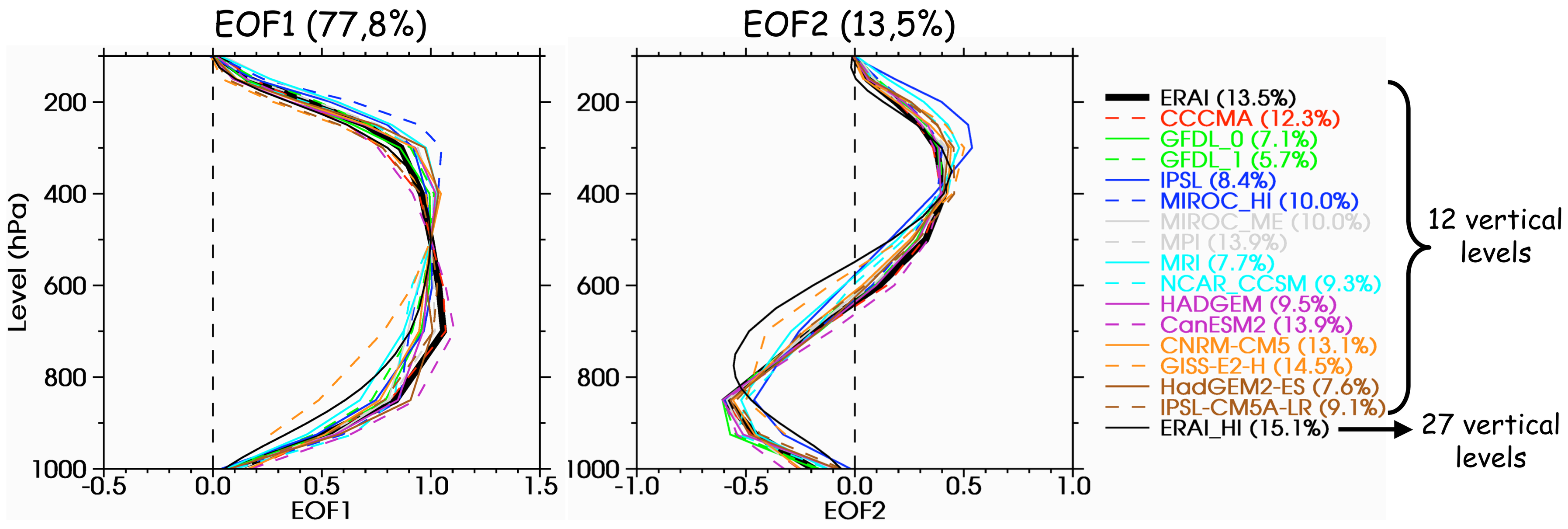
Relevant to use PC1/PC2 to define dynamical regimes

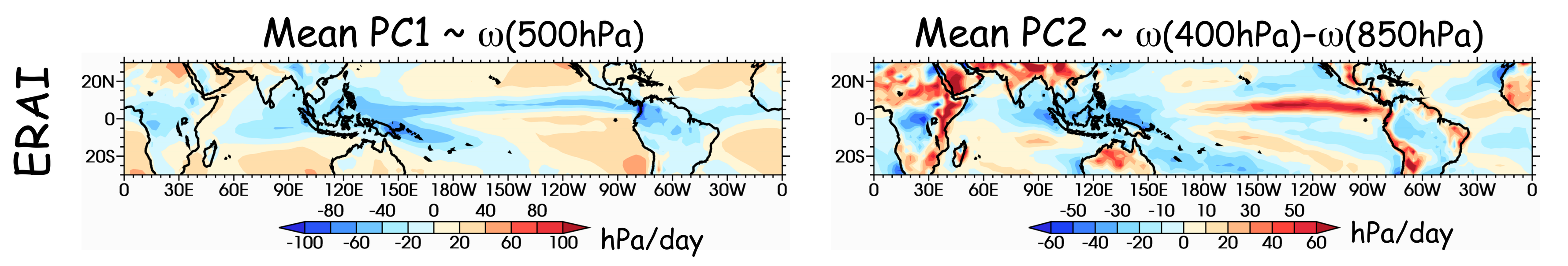
➢ At 1st order, the ATM LW CRF controls the ATM Net CRF (especially in convective regimes).



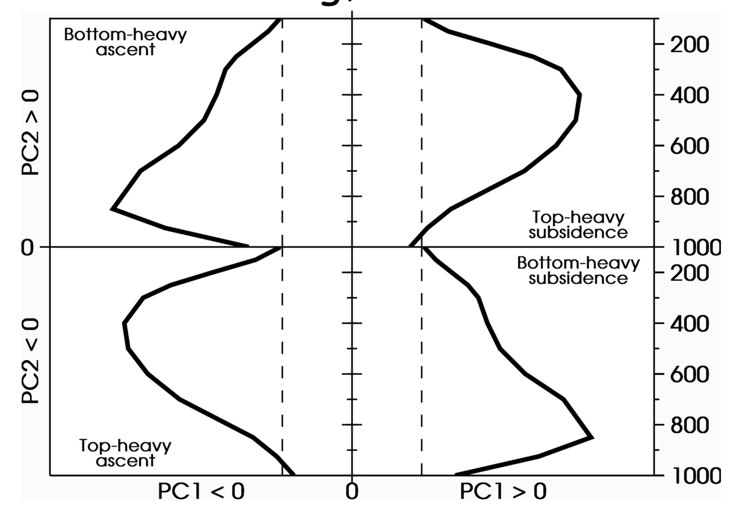
3. Decomposition of Vertical Velocity

➢ Principal Component Analysis (PCA) of monthly ω(p) over the global tropics (30°S-30°N, 180°W-180°E), as in Yuan and Hartmann (2008).





➢ Composites in the PC1/PC2 domain of various variables, to relate the ω vertical structure to convection, radiative heating, clouds…



➢ ω monthly vertical structure is very well represented by its projection on the above EOF1/EOF2 (more than 90% of explained variance).

➢ The vertical position of EOF2 min/max clearly depends on the vertical resolution, especially in the low levels.

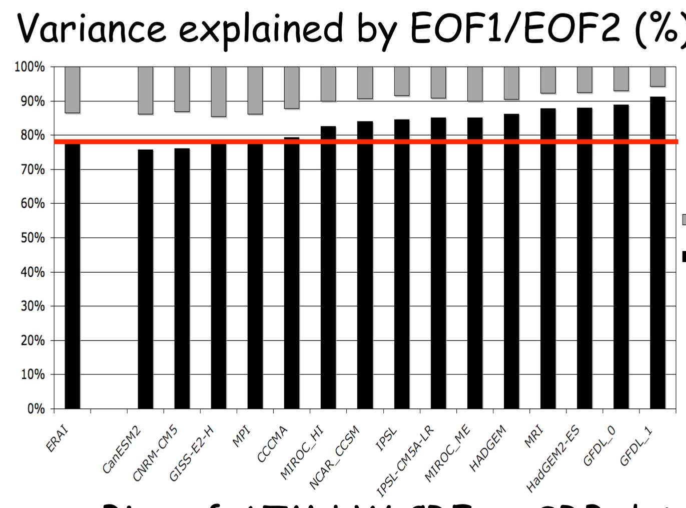
➢ Different structure of convective regimes between the western and eastern Pacific (top- vs. bottom-heavy)

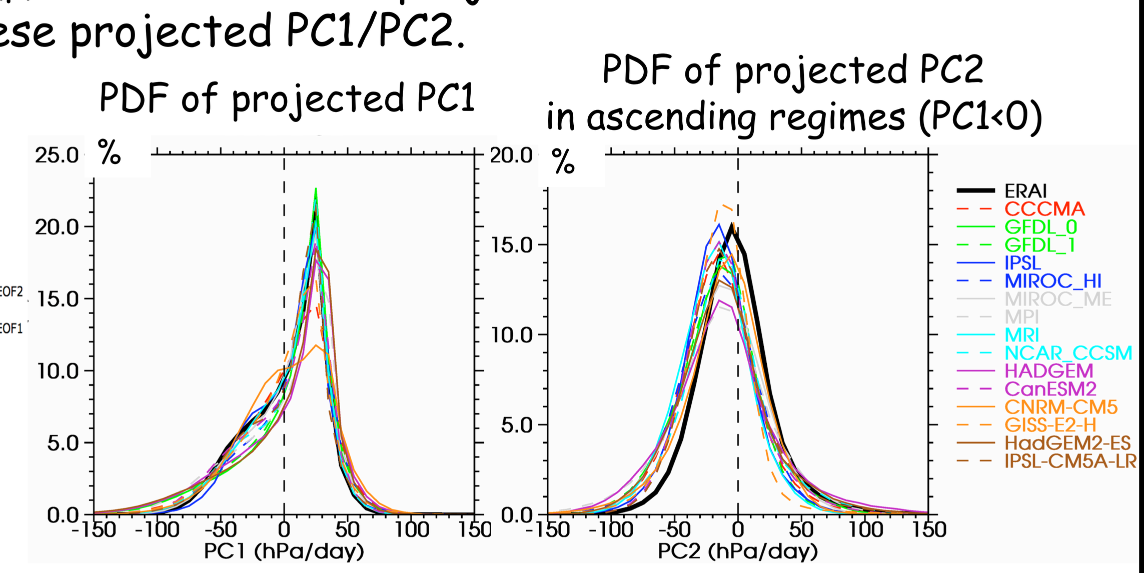
5. Application to CMIP3/CMIP5 models

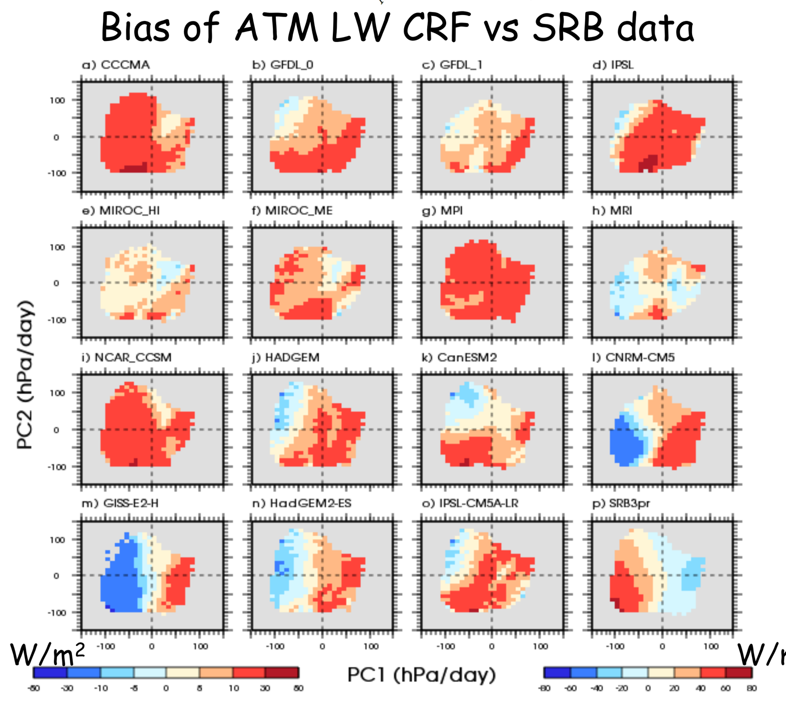
➢ PCA of ω(p) is performed for each model (see also section 3): EOF1 and EOF2 are very similar (models do capture the vertical structure of ω), but:

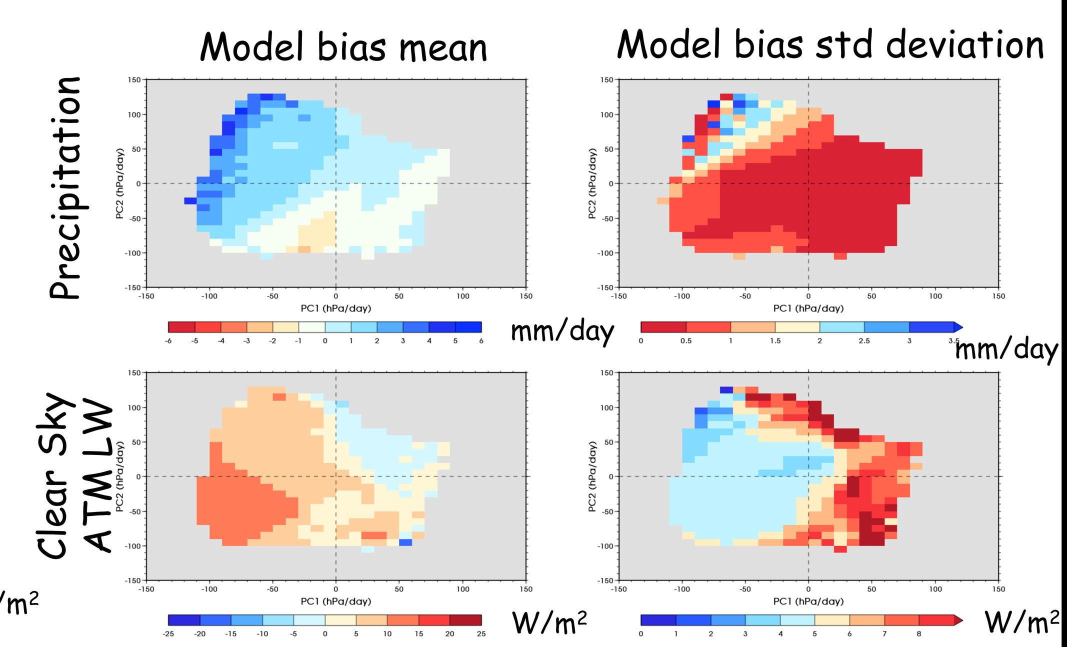
- about 2/3 of the models clearly overestimate the variance explained by EOF1 and underestimates that of EOF2, e.g. not enough variability in the ω vertical structure;
- some models represent a maximum of ω(p), which is two high (300 hPa vs 400 hPa).

➢ For better intercomparison, ω(p) of each model is projected on ERAI EOF1/EOF2 and composites are done with these projected PC1/PC2.









➢ Overestimate of top- vs bottom-heavy ascent regime occurrence probability.

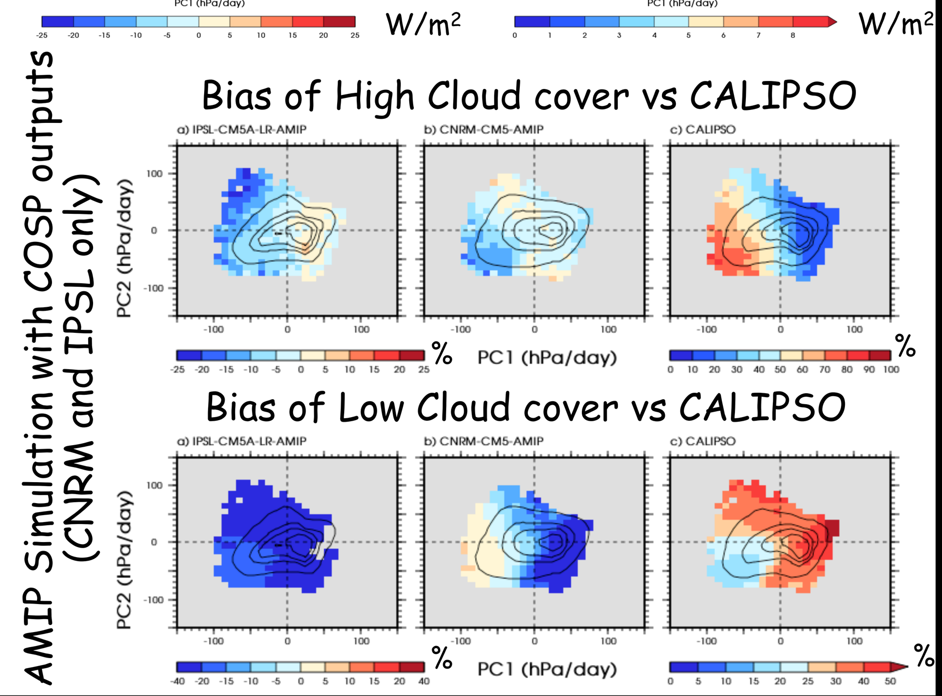
➢ Large spread in simulated ATM LW CRF.

➢ **Systematic biases**:

- overestimate of precipitation in bottom-heavy ascent regime and underestimate in "stratiform" regimes (PC1~0 and PC2<0).

  Organised convection? Precipitation efficiency? Precipitation evaporation?
- Positive bias in top-heavy ascent regime in LW clear-sky radiative fluxes.

➢ Using COSP outputs, links between CRF and cloud biases can be highlighted.



6. Conclusion and Perspectives

➢ **Conclusion**:

- The use of PC1/PC2 to define dynamical regimes is relevant to better document:

(i) relationships between local dynamics, atmospheric radiative heating and cloud properties;

(ii) some of (systematic) biases of climate models.

➢ **Future work**:

- Continue to use COSP outputs of CMIP5-EUCLISPE models to better relate the diagnosed biases in the atmopheric CRF to the cloud cover and properties
- Investigate how biases in atmospheric CRF can explain some other large-scale dynamic biases in climate models, e.g. Pacific Walker circulation, trade winds.

Chepfer, H., et al., 2010: The GCM-oriented CALIPSO Cloud Product (CALIPSO -GOCCP). *J. Geophys. Res.*, **115**, D00H16, doi: 1029/2009JD012251.

Yuan, J., and D. L. Hartmann, 2008: Spatial and temporal dependence of clouds and their radiative impacts on the large-scale velocity profile. *J. Geophys. Res.*, **113**, D19201, doi: 1029/2007JD009722.