Tropical water vapor and large-scale circulation from CMIP6 GCMs and ESA CCI+ "Water Vapor" climate data records

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Jia He[1], Helene Brogniez[1], Laurence Picon[2]

[1] LATMOS/IPSL, UVSQ Université Paris-Saclay, CNRS, Guyancourt, France [2] LMD/IPSL, Sorbonne Université, Paris, France

Abstract: The atmospheric water cycle is strongly associated with global climate variations, especially in the tropical region (30°S - 30°N). However, the representation of the relation from models and observation results remains unknown. Here the water vapor observed during 2003 ~ 2014 over the tropical region is analysed concerning large-scale circulation for 7 global climate models (CMIP6 framework), ERA5 reanalysis data, and the new global water vapor climate data records (CDR) generated within the ESA Water Vapor CCI+ project (ESA TCWV-COMBI). As the ESA TCWV-COMBI observes water vapor over the land area under clear-sky conditions and all-weather conditions without heavy precipitation in the ocean areas, the evaluation is conducted with land-sea separation. The observational diagnostic relies on the decomposition of the tropical atmosphere into large-scale dynamical regimes using the 500 hPa atmospheric vertical velocity ω500 (in hPa/day) as a proxy. The datasets are sorted according to dynamical regimes (intervals of 10 hPa/day) to analyze the evolution of the regimes in terms of frequency of occurrence and is linked to water vapor variation. Although the inter-model spread lies within the interannual spread of the ESA CCI+_WV data, there are noticeable differences between the models and observations that are linked to large-scale dynamics.

Introduction

Water vapor is one of the most important greenhouse gases in the atmosphere and it plays an critical role in the hydrological cycle and climate system. It is a radiatively important atmospheric constituent that influences atmospheric energy exchange through interactions with solar and thermal radiations (Raval and Ramanathan, 1989) with strong positive feedbacks (Sherwood et al., 2010). Because of its important role in weather, climate and environment, the Global Climate Observing System (GCOS) declared the atmospheric water vapor as one of the Essential Climate Variables (ECVs) (GCOS, 2016). Unfortunately, the required accuracy at all spatial and temporal scales is difficult to achieve. The water vapor data generated from ESA Climate Change Initiative (CCI+) project merged observations from multiple sensors to get homogeneous measurement in space and time on the global scale (https://climate.esa.int/en/projects/water-vapour). To unravel the dynamic and thermodynamic components of water vapor variations, we attempt to make more explicit the link between total column water vapor and the large-scale atmospheric circulation (**ω**500).

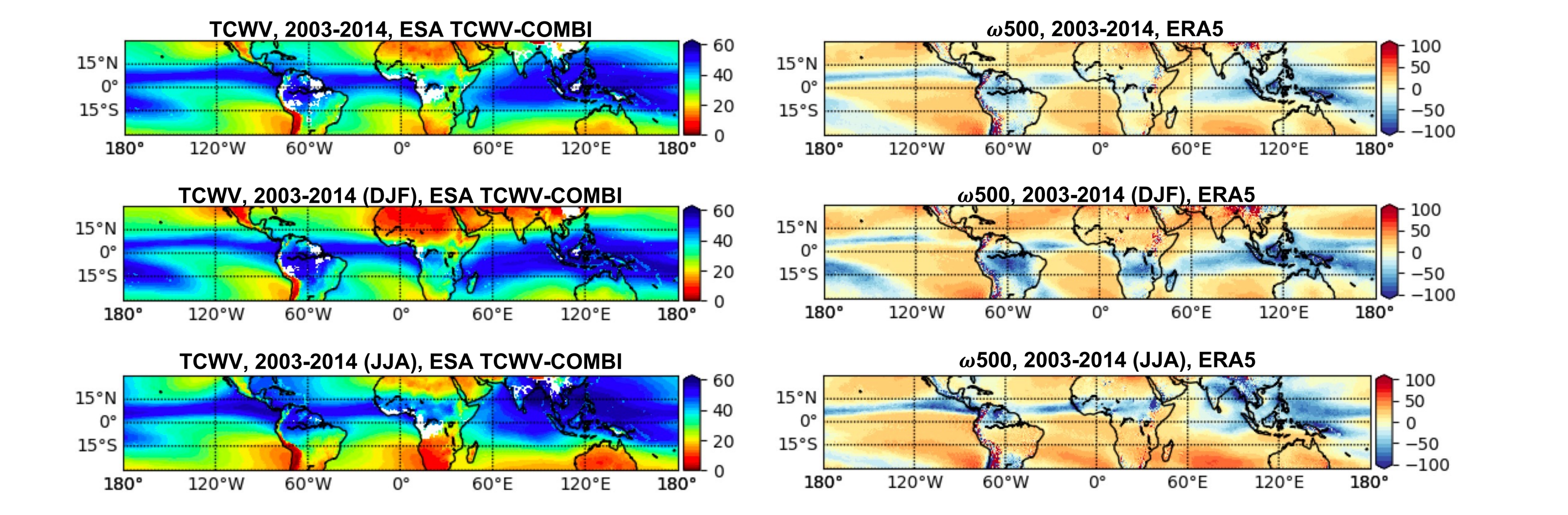
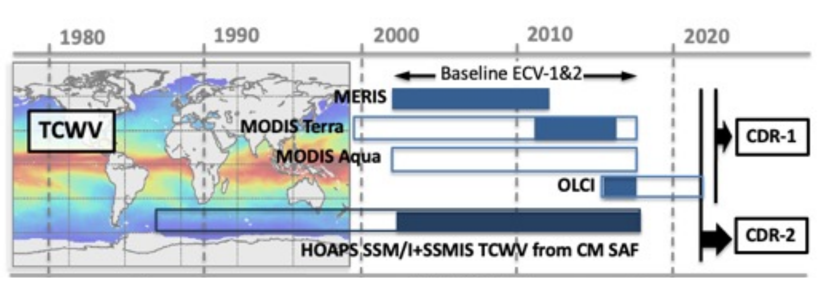


Fig. 1. Maps of the ESA TCWV-COMBI (in kg/m^2) during 2003 - 2014 for the tropical region (30°S - 30°N) for the whole period, Winter (December, January and February - DJF), and Summer (June, July, and August - JJA) and the corresponding maps of ERA5 ω500 (in hPa/day).

Data and Methods

ESA Climate Change Initiative (CCI):

- NIR observations over land (MERIS, MODIS/Terra, OLCI)
- Microwave over ocean (SSM/I and SSMIS)
- 0.5 degree spatial resolution
- 2003-07 ~ 2017-12
- clear-sky only over land
- all-weather (without heavy precipitation) over ocean



https://climate.esa.int/en/projects/water-vapour/about/

CMIP6 Models:

- 7 models from 5 Institution via the ESFG node of IPSL;
- Amip simulations
- Mostly from 1979-01 ~ 2014-12
- cloud cover < 50% at all vertical levels over land
- precipitation < 0.001 kg/m^2/s over ocean

ERA5:

- 0.25 degree spatial resolution
- 1979-01 ~ current
- total cloud cover < 90% & total cloud liquid water < 0.005 kg/m^2 over land (Sohn et al., 2008)
- Total precipitation < 0.001 m/h over ocean

This research is based on the fact that the water vapor distribution is strongly controlled by the large-scale vertical motion of the atmosphere. The mid-tropospheric atmospheric vertical velocity at 500 hPa (noted ω500 in hPa/day) is employed as the proxy for the vertical motions in the tropics (Bony et al., 2004). Firstly, the ω500 of individual data records are decomposed into 10 hPa/day intervals in the range of -120 to 120 hPa/day. The TCWV of each dataset is then sorted into the vertical velocity bins by the corresponding value of ω500. Please be noted that since no atmospheric circulation data from the ESA TCWV-COMBI record, so the ω500 from ERA5 is also employed as the reference for this dataset.

Results

Most of the ω500 reside in around 10 – 20 hPa/day over both tropical-land and tropical-ocean areas, which characterizes the dominance of the large-scale Hadley subsidence in subtropical free troposphere and explained the clear-sky radiative cooling of the tropics as discussed in Bony et al. (see Fig. 2a and Fig. 2b).

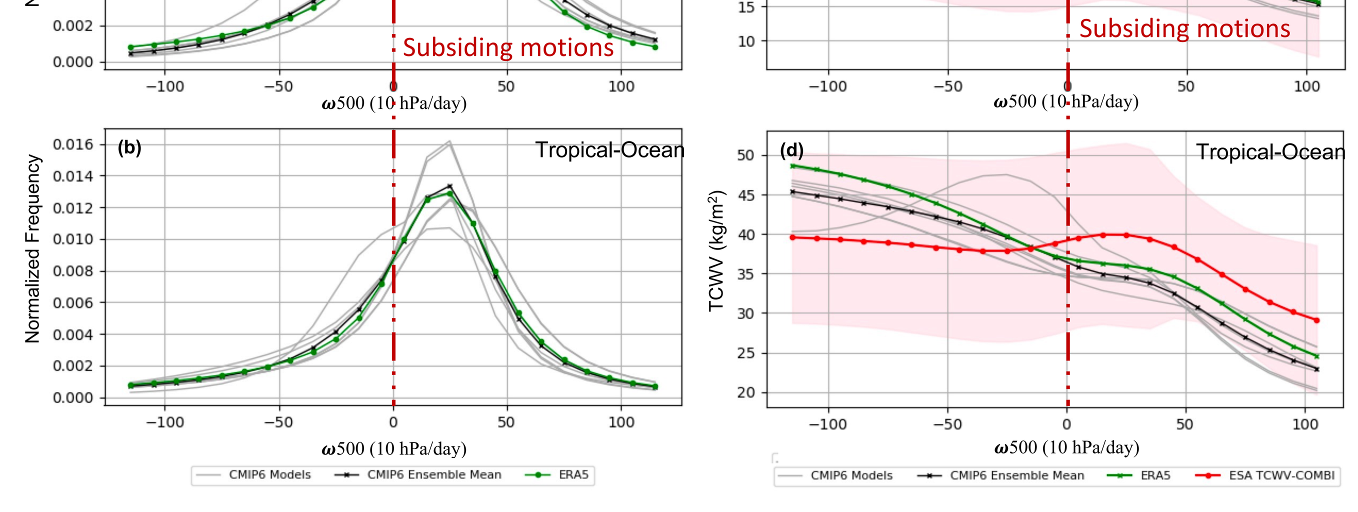


Fig. 2. (Left) Normalized PDFs of ω500 (in hPa/day) over land (a) and ocean (b) for CMIP6 models (grey lines), their ensemble mean (black line), as well as ERA5 (green line); (Right) Mean TCWV from the CMIP6 models (grey lines), their ensemble mean (black line), ERA5 (green line), and ESA TCWV-COMBI (red line) in different circulation regimes of ω500 over land (c) and ocean (d) areas. The shaded area in pink represents the σ of each bin in TCWV-COMBI data.

There are differences among the ESA TCWV-COMBI data, CMIP6 models and the ERA5 data in the amplitude of the signal and the gradient of moisture between the ascending and descending regions (see Fig. 2c and Fig. 2d). While the large-scale atmospheric dynamics are consistent among the datasets, the discrepancies in the TCWV reveal difficulties in the moistening processes of the tropical atmosphere: lateral mixing outflows from clouds, too high/too low precipitation efficiencies of the convective schemes.

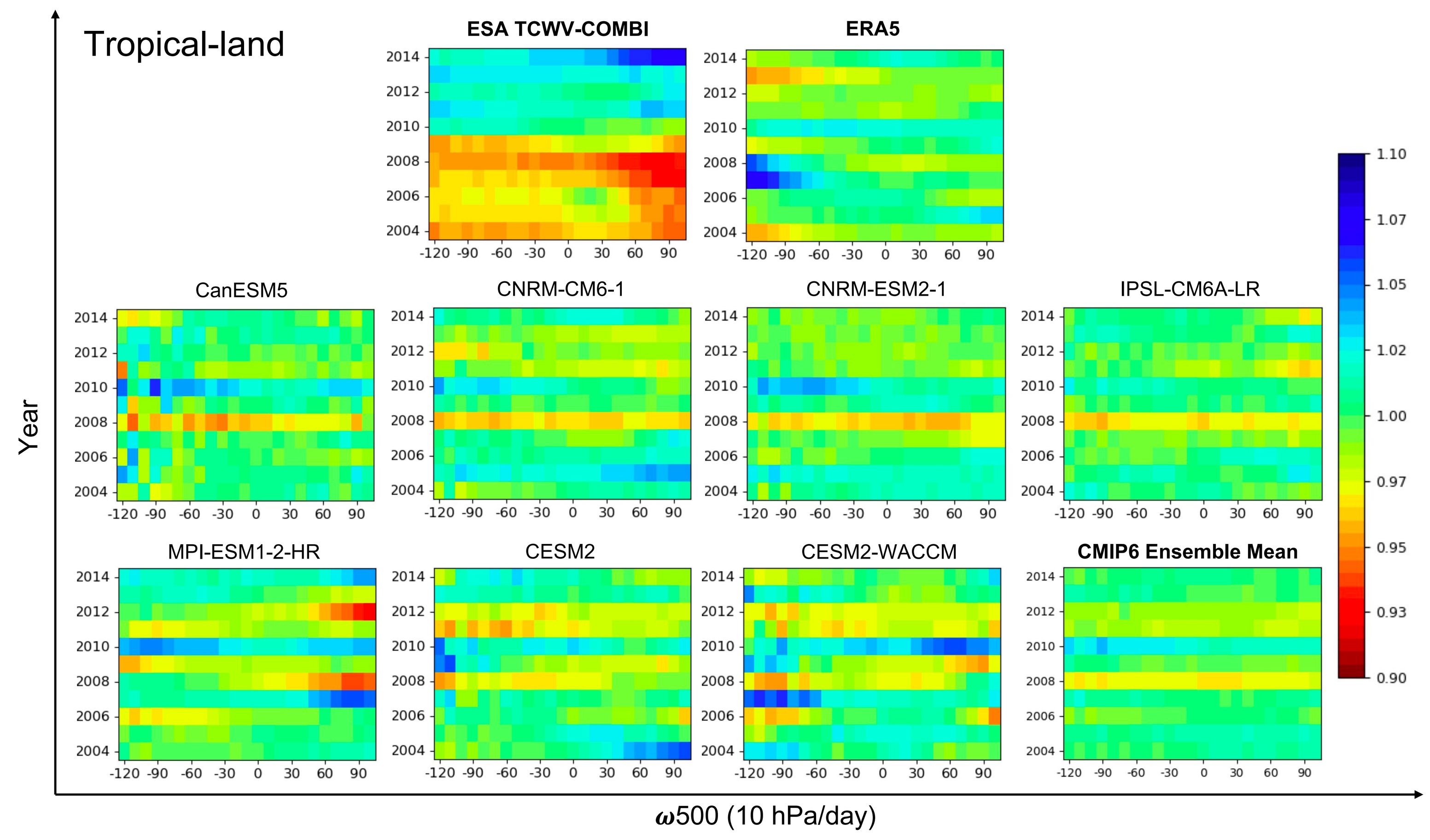


Fig. 3. Normalized TCWV with respect to the 2004-2014 mean over tropical land areas at each dynamical intervals (ω500) in 10 hPa/day computed from each data record.

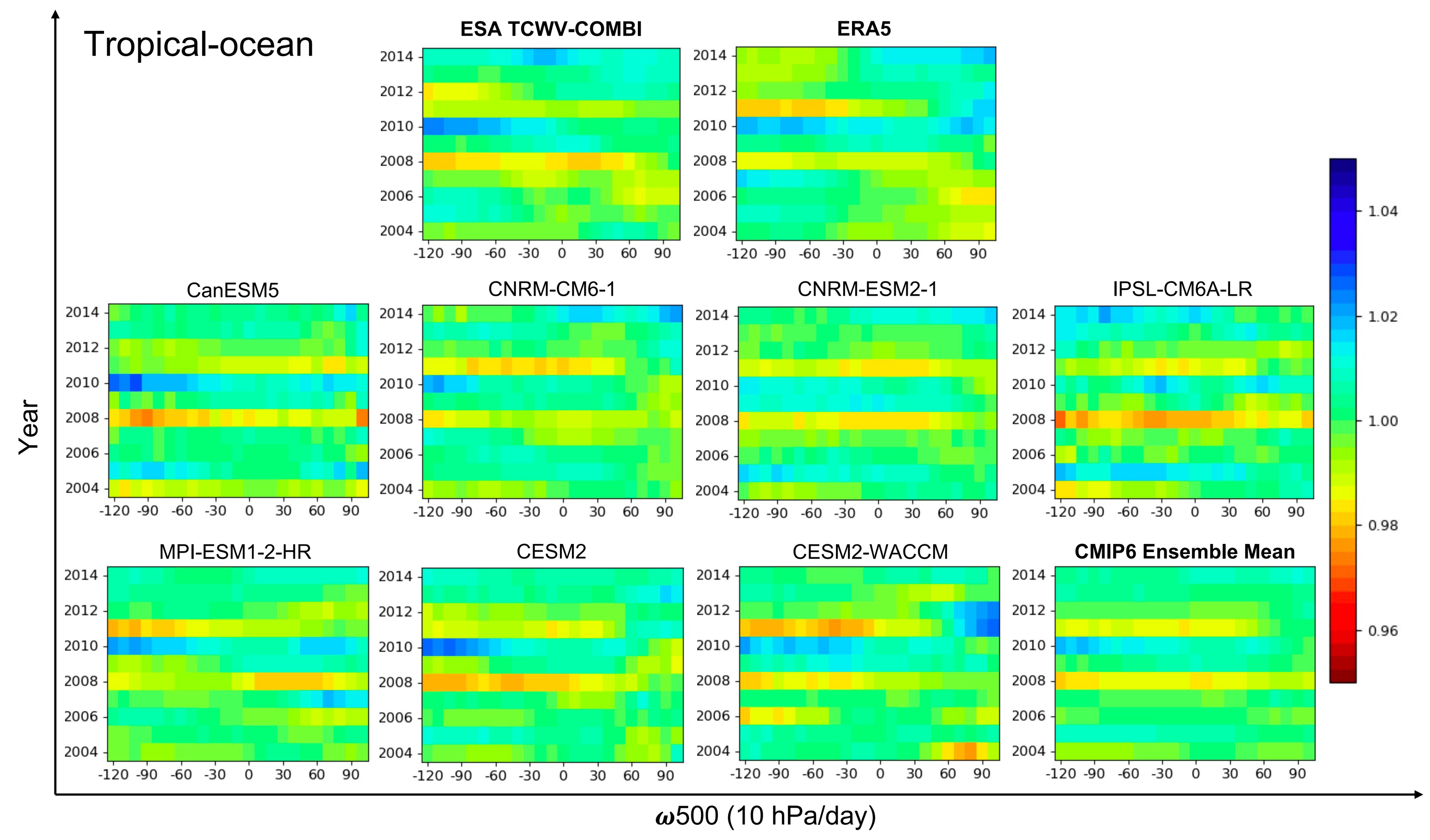


Fig. 4. Normalized TCWV with respect to the 2004-2014 mean over tropical ocean areas at each dynamical intervals (ω500) in 10 hPa/day computed from each data record.

This global assessment is further discussed by applying the TCWV-**ω**500 approach for every year of each data record to delineate the trends in TCWV. The mean value of tcwv concentration at **ω**500 dynamic regimes during the period of 2004 ~ 2014 are used as reference to normalize the variation of TCWV. As shown in Fig 3 and Fig 4, dry anomalies observed in all models and ESA TCWV-COMBI data in 2008, and moistening anomalies in 2010 over both land and ocean areas.

Conclusions

This study focused on water vapor variations over tropical-land and tropical-ocean areas (30°S - 30°N) at daily frequency during 2003 ~ 2014. The variability of TCWV are analysed according to the large-scale circulation using the atmospheric vertical velocity at 500 hPa (**ω**500) as a proxy for the tropospheric overturning circulation. Despite the differences among the datasets, the overall results agree well with each other:

- The large-scale downward motion is associated with a dry troposphere, while large-scale ascent is associated with a moist troposphere;
- Anomalies occurred in 2008 and 2010 for in data records, possibly characterized by ENSO events;

❖ The ESA TCWV-COMBI reveals a clear moistening tendency since 2011 over tropical-land area, this shall be partly explained by the inclusion of MODIS data.

❖ It is worth mentioning that although the screening thresholds are set to meet the criteria of the TCWV-COMBI product, the number of data retained for evaluation are not exactly the same for all models. This is particularly true over tropical land.

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