Precipitable Water Vapor Trends by Layer Over Florida

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Introduction:

Precipitable Water Vapor (PWV) is the total amount of water vapor contained in a vertical column of the atmosphere. The PWV is an indicator of how much water is available for precipitation (Trenberth et al. 2005). Scientists have increasingly studied this parameter to provide insight on extreme precipitation events, atmospheric rivers, tropical cyclones, and climate feedbacks as PWV is a clear thermodynamic fingerprint of a warming climate (IPCC AR6 2021). This study explores PWV trends by layer over the Florida Peninsula over 83 years.

Data & Methods:

The ERA5 Reanalysis monthly averaged (all pressure levels) data used in this study were obtained from the European Center for Medium-Range Weather Forecasts (ECMWF). The footprint was 24°N to 31°N and from -87°W to -79°W (Figure 1). Temperature, specific humidity, and pressure were retrieved and used to analyze the column (precipitable) water vapor content. Decadal PWV trends from 1940-2023 were investigated from 1000hPa to 300hPa for summer months (JJA). PWV is defined as

$$\mathrm{PWV} = \frac{1}{g}\int_{p_{\text{top layer}}}^{p_{\text{bottom layer}}} q(p)\,dp$$

$$\mathrm{PWV} \approx \frac{1}{g}\sum_{i} q_i \times \Delta p_i$$

PWV: Precipitable Water Vapor (kg/m^2)

g: Gravitational Acceleration (m/s^2)

p: Pressure (Pa)

$q(p)$: Specific Humidity (kg/kg)

Results

- The PWV anomalies are largest at mid altitude (Figure 1) and the maxima have shifted southeast toward South Florida.

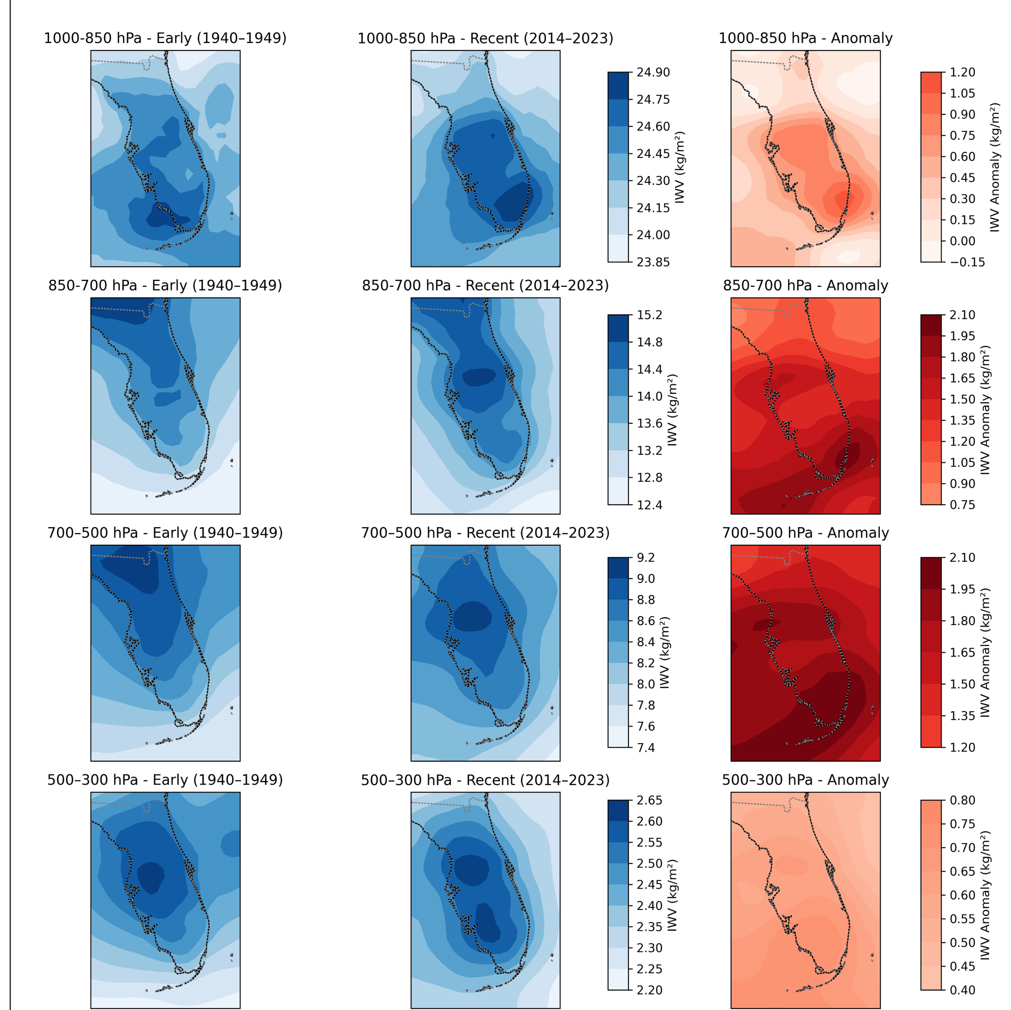

Figure 1. JJA layer (rows) contribution with respect to the total precipitable water vapor (kg m^{-2}). Columns (left-to-right) 1940-1949, 2014-2023, and the associated anomalies.

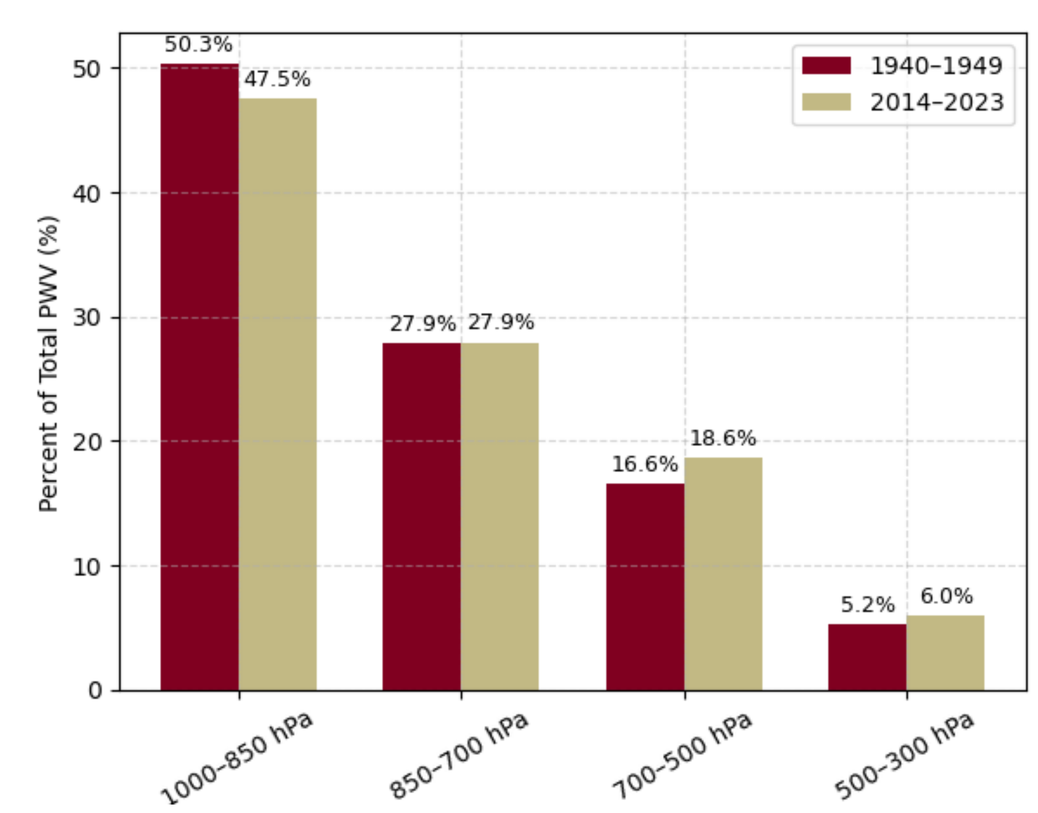

Figure 2. JJA percent contribution by layer as a function of the of the total precipitable water vapor (kg m^{-2}) for 1940-1949 (maroon) and 2014-2023 (tan).

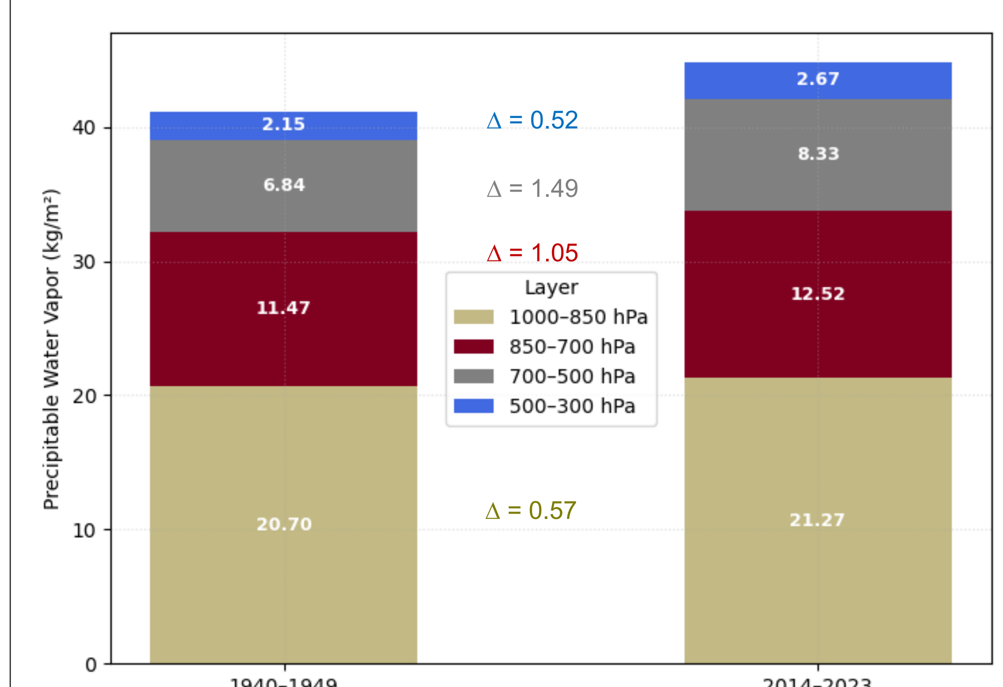

Figure 3. JJA layer contribution of precipitable water vapor (kg m^{-2}) for 1940-1949 (left) and 2014-2023 (right).

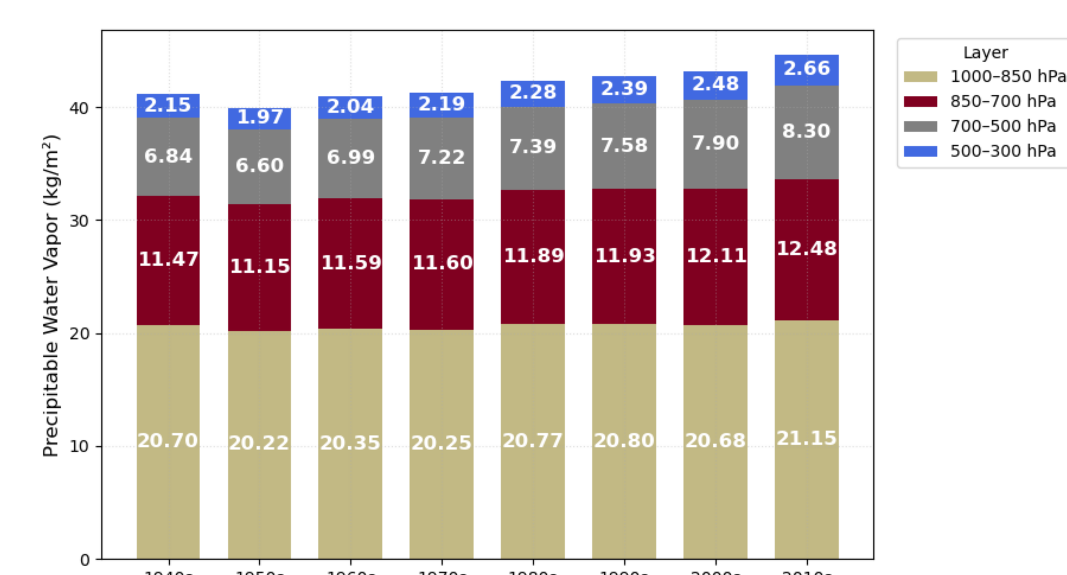

Figure 4. JJA layer contribution of precipitable water vapor (kg m^{-2}) by decade (1940-2020).

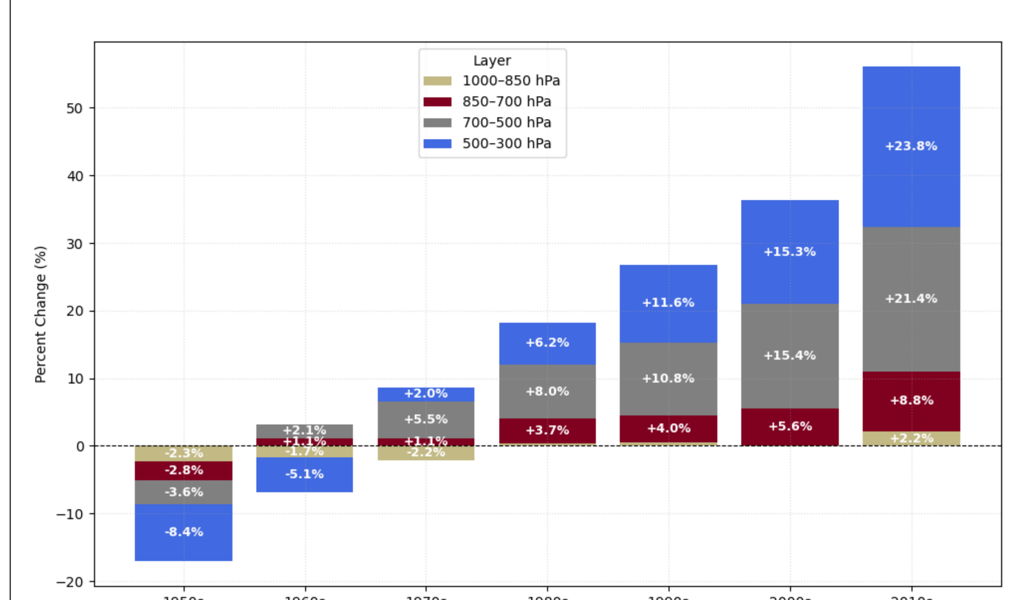

Figure 5. JJA decadal percent change (relative to the 1940s) in the precipitable water vapor as a function of layer.

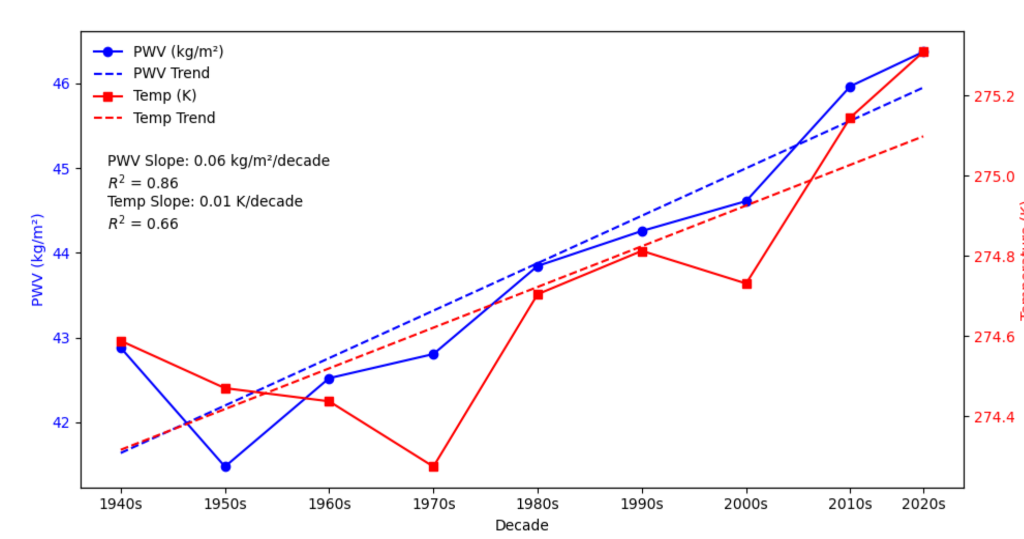

Figure 6. Decadal mean precipitable water vapor (kg m^{-2}) and temperature (K) (1000hPa – 300hPa) trends by decade (1940-2020).

- The relative contribution from 1000–850 hPa decreases slightly. While upper layers increases (Figure 2).
- Figure 3 indicates that the absolute moisture content in 850-700 and 700-500 layers increases more than the surface layer (1.05 and 1.49 versus 0.57 kg m^{-2}) while the change (increase) in the upper levels is comparable.
- PWV systematically increases in the middle and upper layers with each decade (Figure 4).
- With the exception of the 1950's, the PWV increases from the 1940s to 2010s. The largest relative increase occurs in the 500-300hPa layer (Figure 5).
- PWV and temperature shows a clear increasing trend (Figure 6) and the strongest relationship between the variables was found in the lower layer.

Conclusions:

Over the last 83 years, PWV had gradually increased throughout the troposphere However, the upper layers are moistening with the largest increases in the mid-tropospheric layers. Although the lower tropospheric PWV content has increased, it's percent contribution to the total PWV has declined. This suggests a shift in the vertical moisture structure, with more rapid moistening in the mid and upper troposphere. The observed increases in PWV and temperature is consistent with the Clausius-Clapeyron relationship which predicts that warmer air holds more moisture. It also aligns with the enhanced greenhouse effect aloft, where enhanced longwave radiative forcing from water vapor feedback leads to amplified warming via a positive feedback loop. (Held and Soden 2000). Moistening in the upper levels may suggest enhanced tropospheric stability by reducing the lapse rate. This might affect the timing, intensity and type of precipitation events, leading to more surface heat stress.

Future Work:

Investigate the relationship between increased PWV and changes in precipitation intensity and distribution, particularly during extreme rainfall events.

Acknowledgments:

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