Atmospheric Vapor Pressure Trend Biases in the Southwestern United States

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Introduction

The vapor pressure deficit (VPD), defined as the difference between saturation vapor pressure (SVP) and actual vapor pressure (VP), is closely related to wildfire occurrence and spread in the Southwest United States (SWUS). Despite its importance, previous studies have identified notable discrepancies between observations and model simulations. This study aims to investigate the long term SWUS VP trends using both the observational data and model simulations to pinpoint the source of the VP trend biases in the climate models.

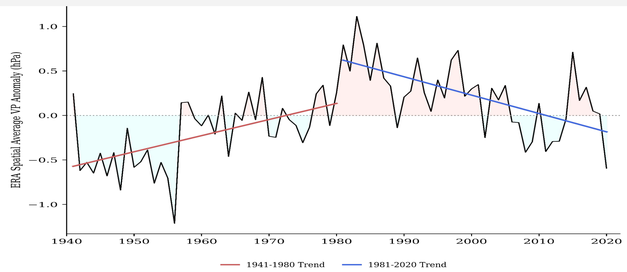


Figure 1. Observed vapor pressure annual times series in the SWUS has distinct shift from positive trend to negative trend around 1980. Positive 1941-1980 trend shown in red, negative 1981-2020 trend shown in blue.

Data

Observations: Monthly ERA5 reanalysis

Model: SPEAR-MED (atmosphere/land resolution of approximately 50 km; Delworth et al. 2020, JAMES)

Simulations: Historical large ensembles with 30 members; SPEAR pre-industrial control simulation (piControl; 3000 years), SPEAR prescribed sea surface temperature (prescribedSST)

(SPEAR: Seamless System for Prediction and EArth System Research)

Identifying the VP trend Biases

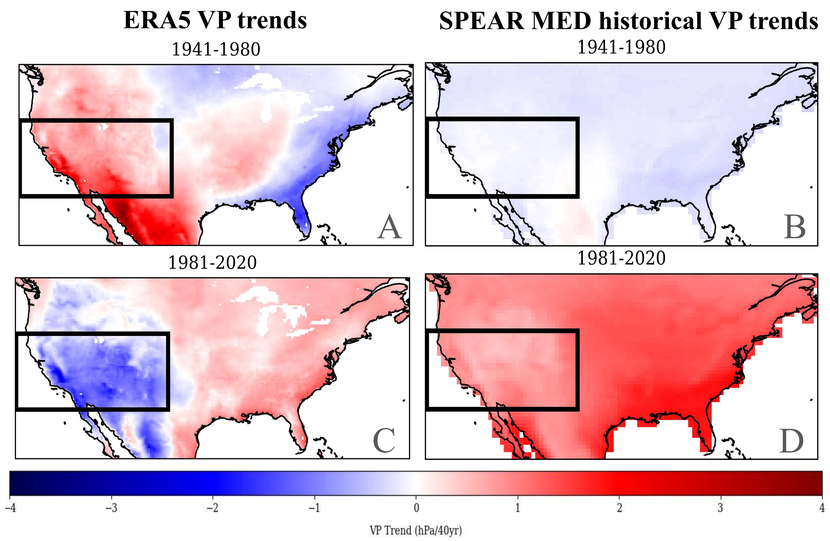


Figure 2. SPEAR MED historical simulation does not capture the SWUS VP trend from 1941-1980 or 1981-2020. VP spatial trend shown in hPa/40 year. A) VP trend from 1941-1980 ERA5 Reanalysis. B) VP trend from 1941-1980 SPEAR MED Historical Simulation. C) VP trend from 1981-2020 ERA5 Reanalysis. D) VP trend from 1981-2020 SPEAR MED Historical Simulation.

Potential source of VP trend biases

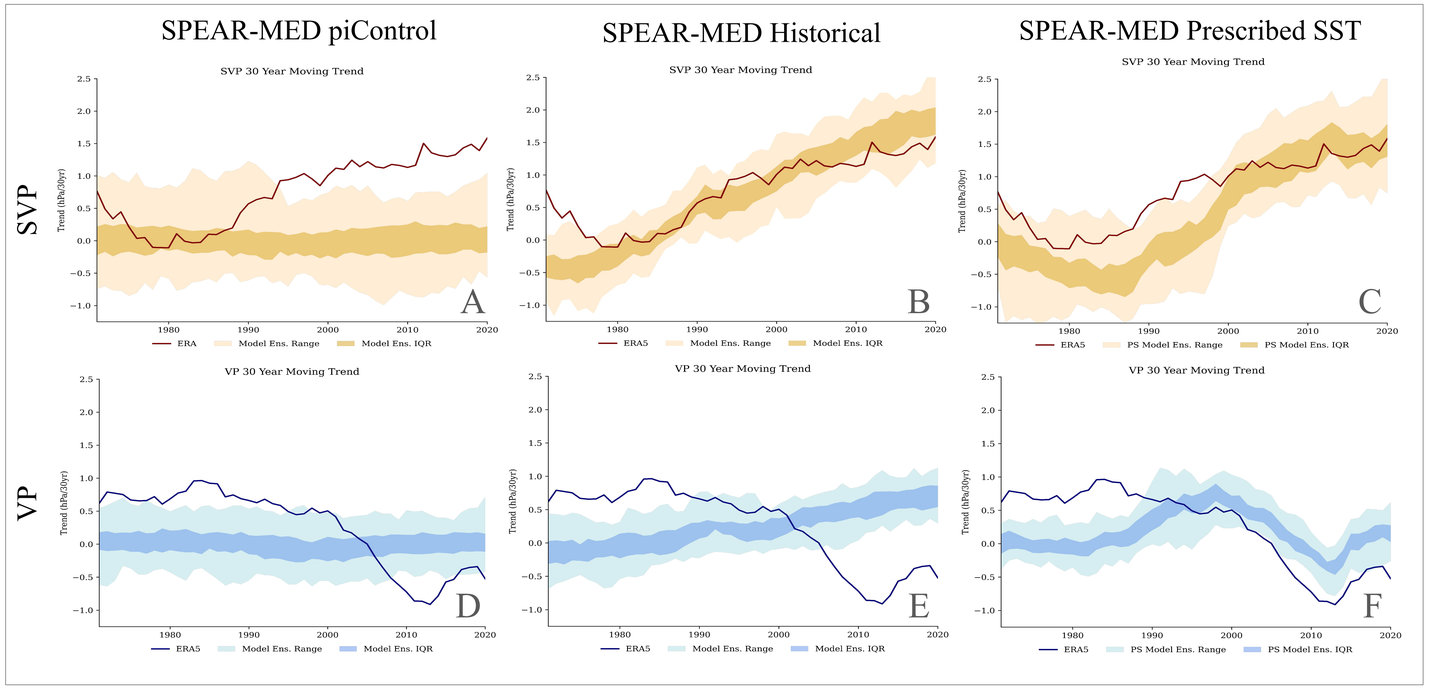


Figure 3. SPEAR piControl and historical simulations fail to capture the 30 year moving trends for SWUS saturated vapor pressure (SVP) and vapor pressure (VP). Full ensemble range depicted in light shading, ensemble interquartile range depicted in darker shading. Solid line shows ERA 30-year moving trend. Panels A (SVP) and D (VP) use SPEAR MED piControl simulation with emissions fixed at 1850 levels. Panels B (SVP) and E (VP) use SPEAR medium resolution historical runs with all radiative forcings. Panels C (SVP) and F (VP) use SPEAR MED with prescribed sea surface temperatures.

There is no obvious pattern in simulated SVP and VP trends when external forcing is fixed in the piControl simulations.

Historical simulations can reasonably represent the positive trend in observed SVP, but not VP. SVP trends may be attributed to external forcing using model simulations.

Prescribed SST simulations reflect the patterns of ERA SVP and VP trends. This indicates the VP trend biases are closely linked to SST biases.

Conclusion

Observed VP transitions from an increasing trend to a decreasing trend in the late 1970s - a pattern not reflected in SPEAR historical simulations, where VP increases over the historical period consistent with Clausius-Clapeyron scaling. The prescribed SST simulations are much closer to simulating the observed VP pattern, suggesting that VP trend biases in the models are closely linked to SST biases. This further justifies a deeper delve into the influence of internal variability and SST bias as a contributor to both the observed VP trends and SWUS VP model bias. Preliminary composite maps indicate an overall relationship between El Nino (La Nina) and periods of negative (positive) VPD anomaly. Future work will explore model representation of Eastern Tropical Pacific SST and humidity to identify the underlying physical mechanism contributing to the VP and SST biases.

Future Work

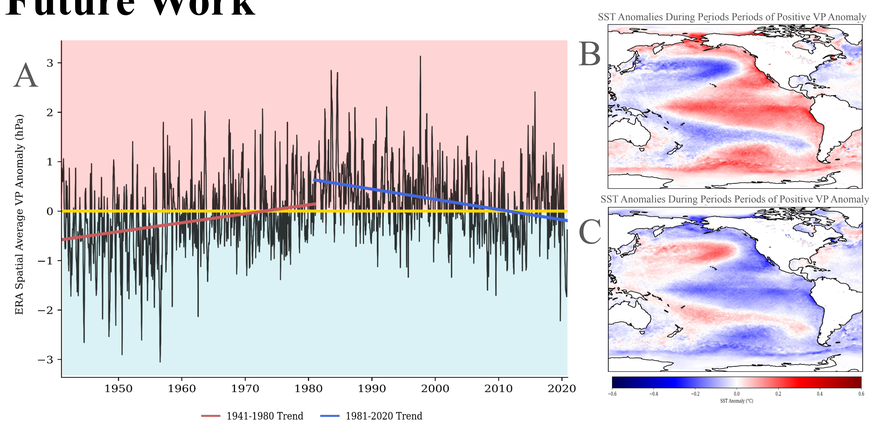


Figure 4. Sea surface temperature (SST) composite maps indicate potential linkage with climate indices. A) Monthly ERA SWUS VP time series. B) SST anomaly during periods of positive SWUS VP anomaly from 1940-2020. C) SST anomaly during periods of negative SWUS VP anomaly from 1940-2020.

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