Spatiotemporal Analysis of China’s Precipitable Water Vapor under a Changing Climate

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Introduction

Atmospheric water vapor plays an important role in climate change and various weather processes. According to the Clausius-Clapeyron equation, a 1 K increase in air temperature will increase the atmosphere’s water-holding capacity by approximately 7%, assuming constant relative humidity. Strong positive feedback associated with increased water vapor significantly affects the Earth’s climate. Changes in water vapor are important indicators for temperature variations within the climate system and hydrological processes like precipitation. In this work, we focus on the spatiotemporal patterns of long-term Precipitable Water Vapor (PWV) trends and the relationships between PWV trends and key meteorological variables to better understand the driving mechanisms of water vapor changes in different climate regions of China.

Study area and Datasets

- **China** can be divided into five major climate types: Tropical Monsoon (TM), Subtropical Monsoon (SM), Midlatitude Monsoon (MM), Humid Continental (HC), and PLateau climate (PL) (see Fig. 1).
- **GPS data** collected during the period 2000-2020 by 25 stations (see Fig. 1) are reprocessed.
- **ERA5 model data** during the period 2000-2020.
- **MODIS NIR PWV** data from the MOD08_D3 products during the period 2000-2020.

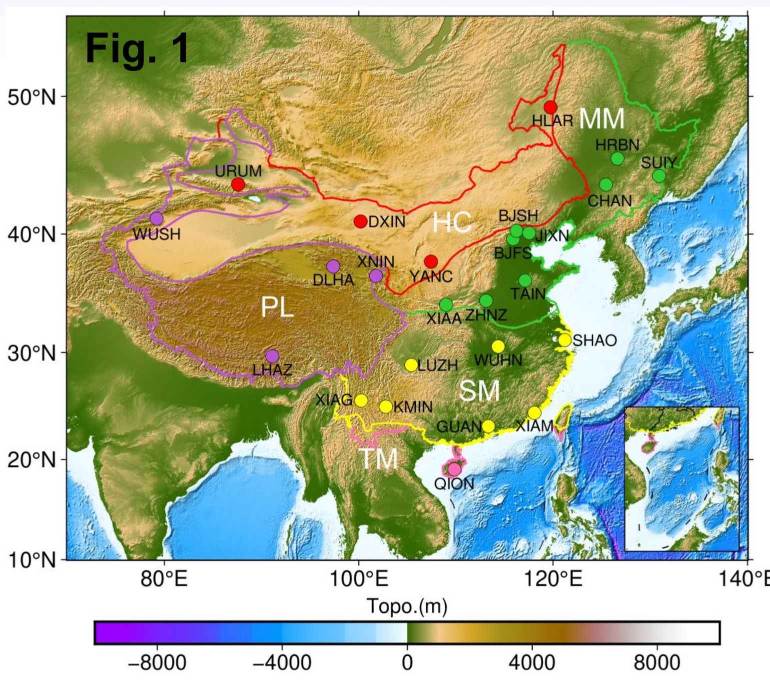
Fig. 1

Datasets Assessment

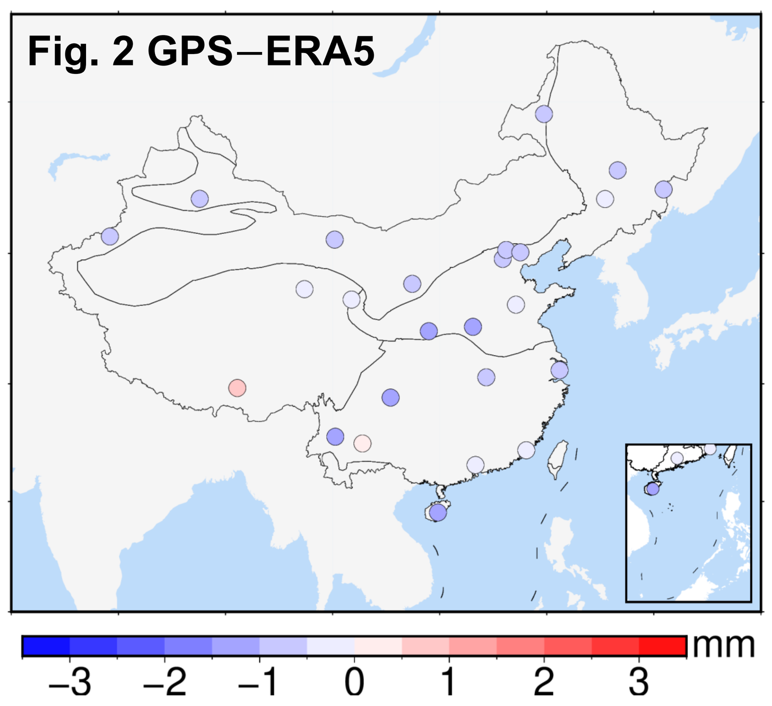
Fig. 2 GPS−ERA5

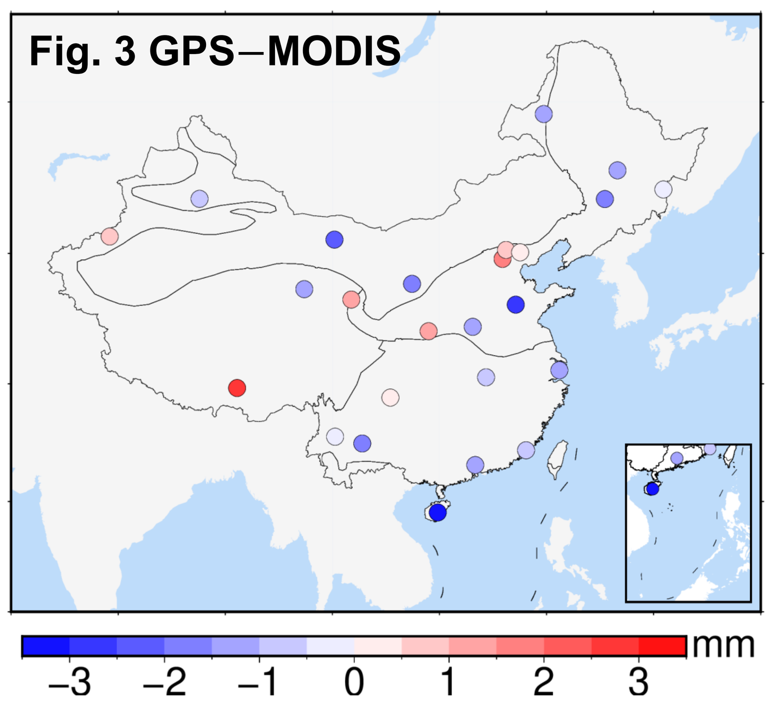
Fig. 3 GPS−MODIS

- The PWV differences between GPS and ERA5, and GPS and MODIS are presented in Fig. 2 and Fig. 3, respectively.
- ✓ **Both ERA5 and MODIS are slightly wetter than GPS PWV, and ERA5 PWV agrees better with GPS PWV than MODIS PWV does.**

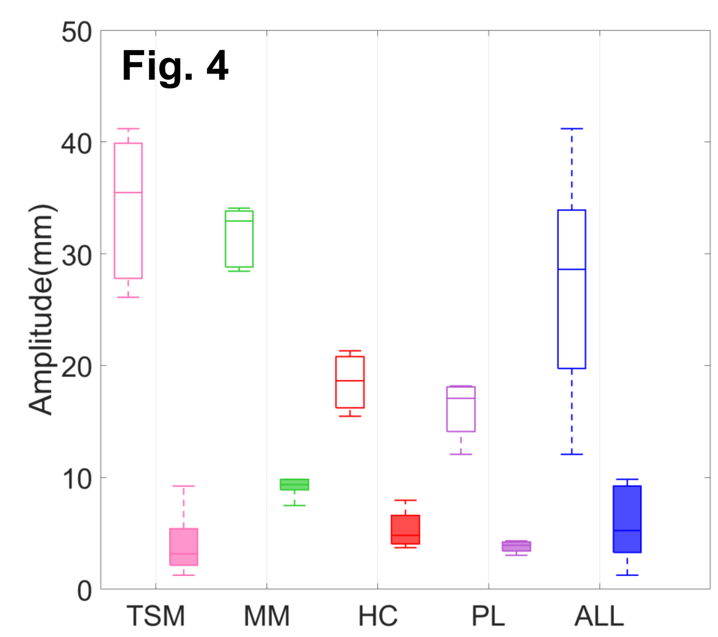
Fig. 4

- Fig. 4 shows the statistics of the GPS PWV annual and semi-annual amplitudes for the various climate regions.
- ✓ **The PWV annual amplitude is larger in the eastern coastal monsoon area. The semi-annual amplitude is largest in the midlatitude monsoon region.**

Homogenization

- Change points detection Software: GNSSseg and Hector.
- Reference Data: ERA5 and MODIS PWV data.
- Change points detection: For each PWV difference time series (GPS-ERA5 and GPS-MODIS), we obtained five different change point detection results (4 GNSSseg solutions + 1 Hector software solution), and we accepted a change point in the GPS time series only if it appears within six months in at least (1) three out of the five detection results or (2) 1 out of the five detections but supported by the logfile.
- Change points correction: the mean shift from the de-seasonalized GPS time series were used.
- ✓ **25 change points are identified, among which 20 are supported by station log file records.**

Spatiotemporal Variability of PWV

(1) Linear PWV Trends Analysis

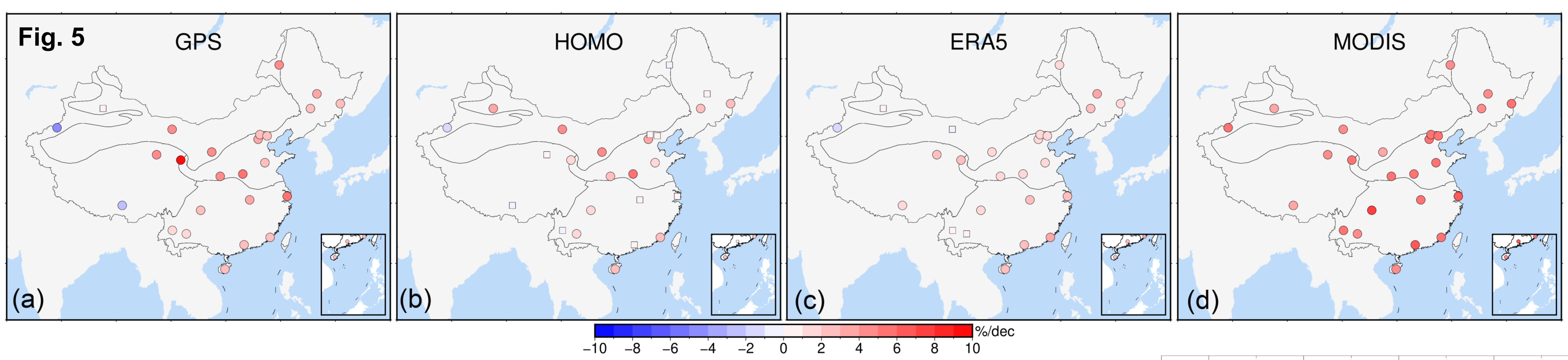
Fig. 5 (a) GPS (b) HOMO (c) ERA5 (d) MODIS

- Fig. 5 is showing the relative PWV trends estimated from original GPS, homogenized GPS (HOMO), ERA5 and MODIS, respectively.
- ✓ The corresponding average PWV trends are 0.61, 0.35, 0.40, and 1.14 mm per decade.
- ✓ In general, **PWV trends are significantly positive.**
- ✓ **All four datasets exhibit a west-to-east gradient in increasing PWV trends across China.**

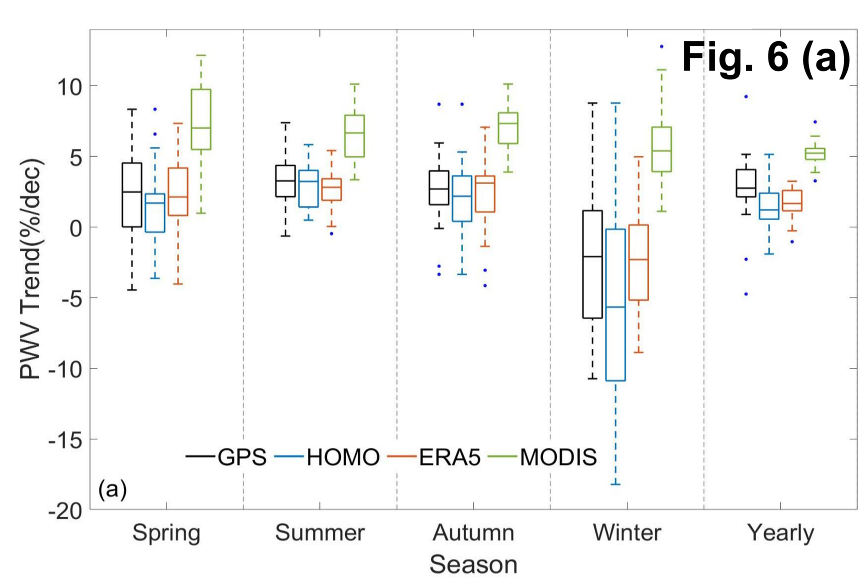
Fig. 6 (a)

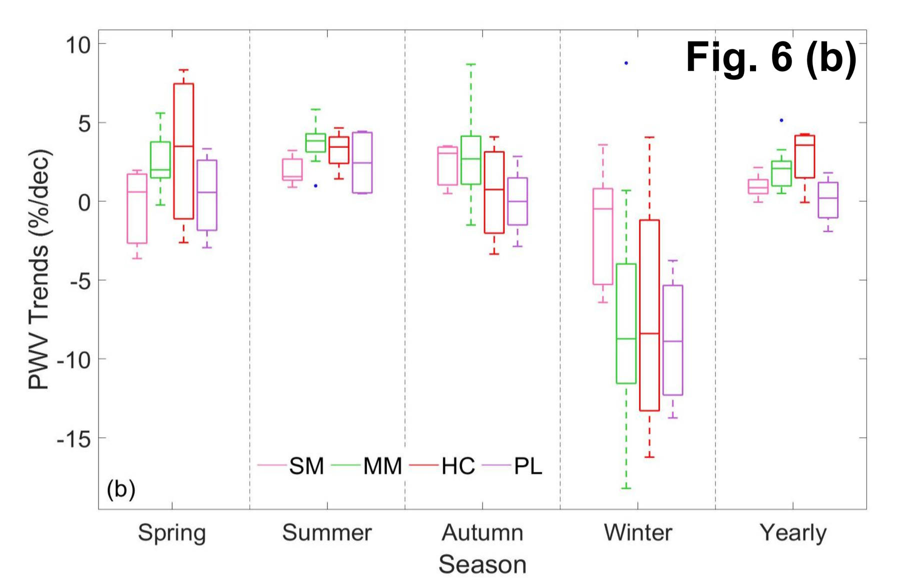
Fig. 6 (b)

- Boxplot of relative PWV trends per season. (a) For the four datasets and (b) for the different climate regions taking HOMO-GPS dataset as an example are presented in Fig. 6.
- ✓ **In summer, a wetting is observed in central and eastern China. In contrast, a strong drying signal is detected in winter over central and northern China.**

(2) The relationship between PWV trends and meteorological variables

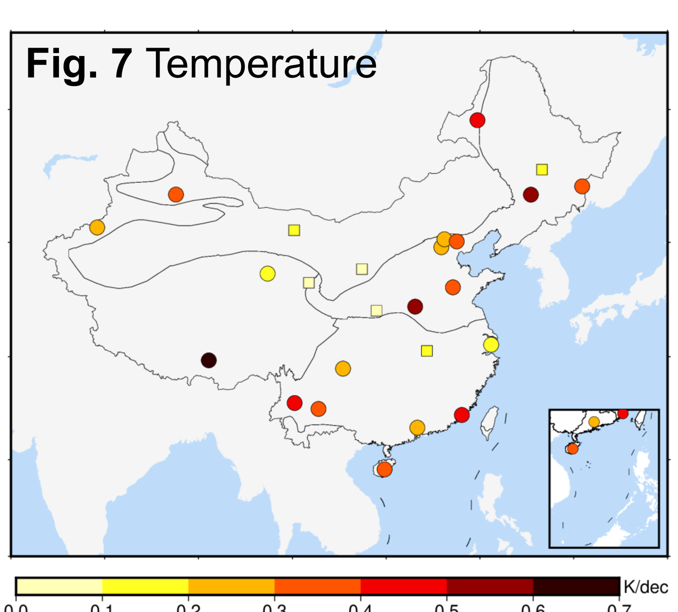
Fig. 7 Temperature

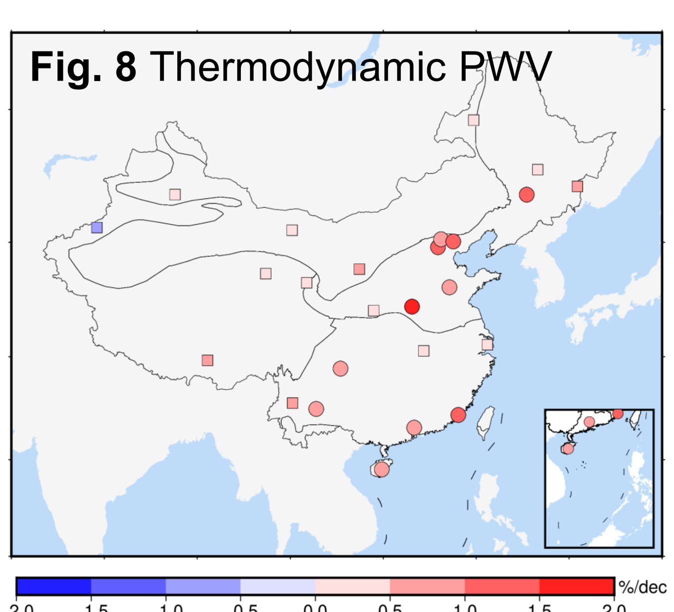
Fig. 8 Thermodynamic PWV

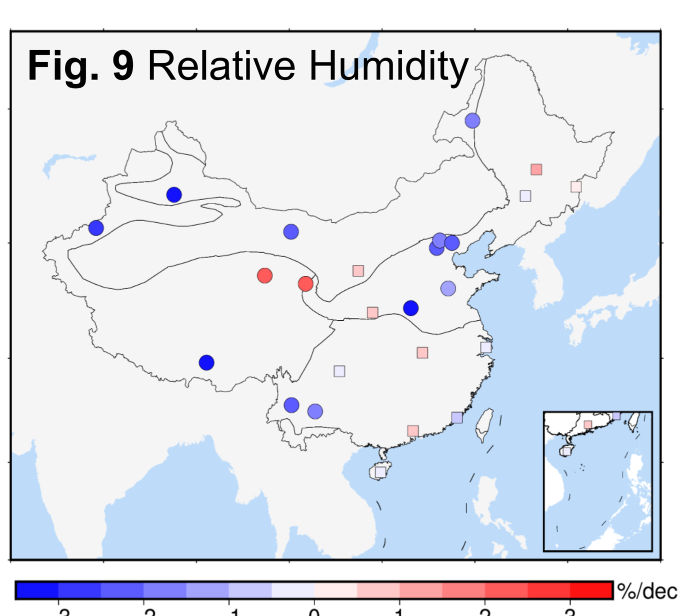
Fig. 9 Relative Humidity

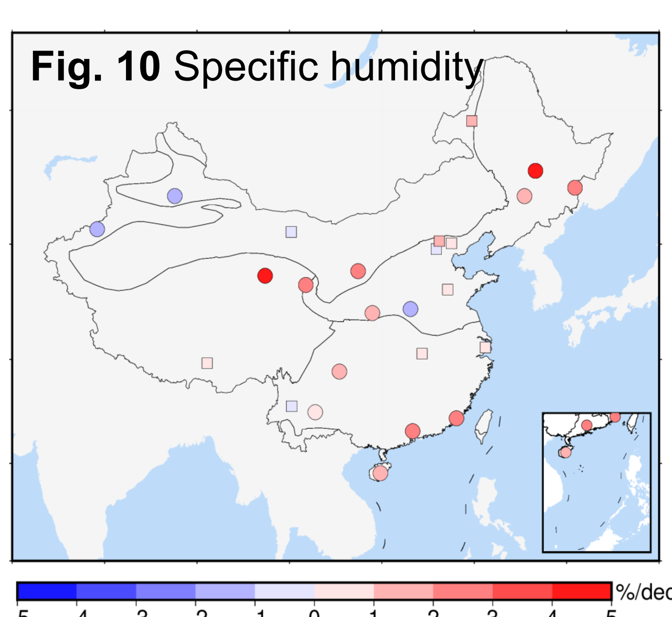
Fig. 10 Specific humidity

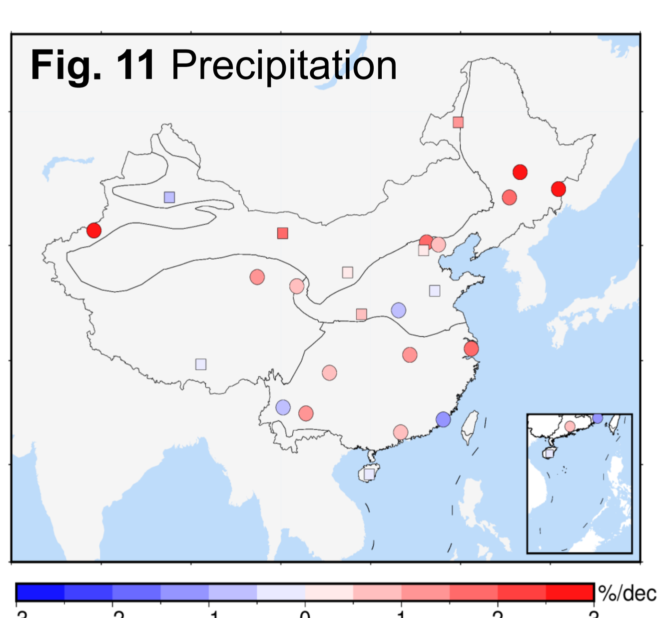
Fig. 11 Precipitation

- We modeled the theoretical changes in atmospheric water vapor (thermodynamic PWV) driven by surface temperature variations according to the Clausius-Clapeyron (C-C) equation (Vey et al., 2009, JGR).
- The trends for temperature (K/dec), and relative trends (%/dec) for thermodynamic PWV, relative humidity, specific humidity, and precipitation are presented in Fig. 7-Fig. 11.
- ✓ Temperature, theoretical “thermodynamic” PWV, specific humidity, and precipitation: **mainly positive trends**, except in northwestern China.
- ✓ Relative humidity: **slightly decreasing.**
- ✓ The PWV/specific humidity/precipitation-temperature relationships **more closely follow the scale of the C-C expectation in monsoon-dominated regions than in the plateau region.**

Conclusions

- The GPS, ERA5 and MODIS PWV datasets correlate well over China and the PWV differences between GPS and ERA5/MODIS mainly depend on topography and geographical location.
- We observed a good spatiotemporal consistency between the trends in the PWV, temperature, specific humidity, and precipitation time series, with their relationships largely governed by climate regions.

The manuscript has been submitted to the Journal of Climate. Further details will be provided in the manuscript.

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