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Relationship between Surface and Tropospheric Water Vapor Variation on Interannual Timescale: A Revisit

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01 Introduction

Motivations

- Water vapor: the most important greenhouse gas and a key "fuel" for the atmospheric circulations.

However, the understanding about its **distribution and variation** is **limited**.

Questions

- What is the **relationship** between the variations of water vapor in the **free troposphere** with those **at the surface**?
- How well does the state-of-the-art **models simulate** this relationship? If not, **why**?

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01 Introduction

Questions

- What is the **relationship** between the variations of water vapor in the **free troposphere** with those **at the surface**?
- How well does the state-of-the-art **models simulate** this relationship? If not, **why**?

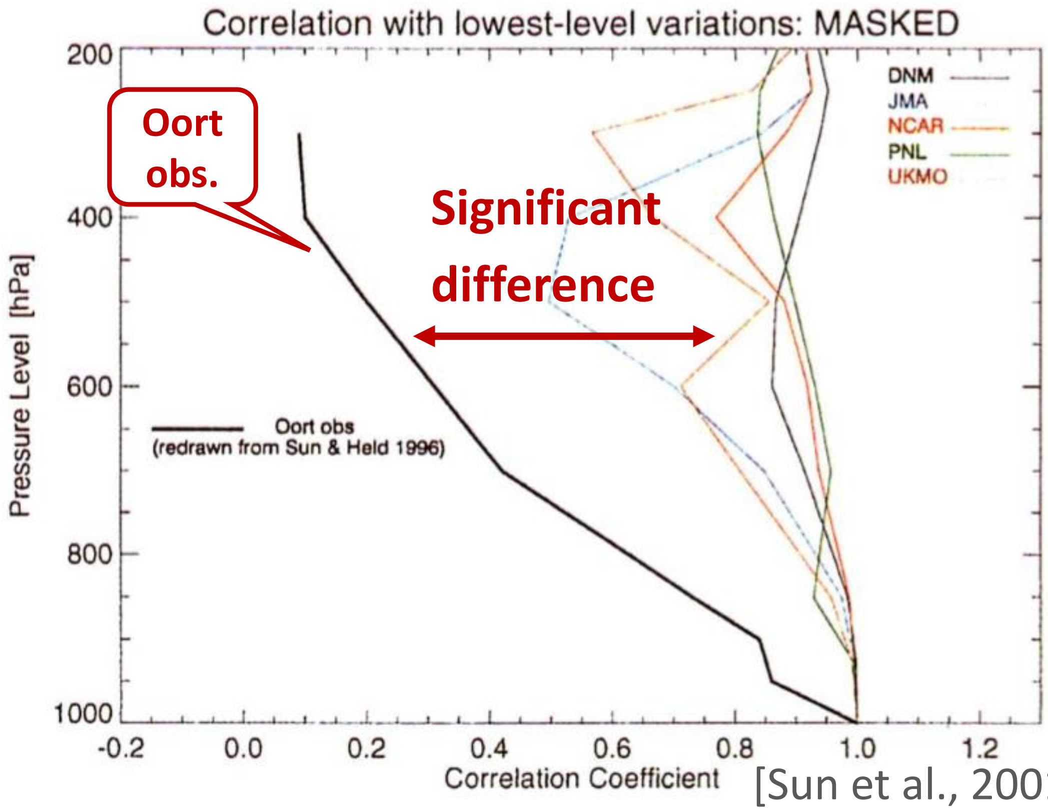
Previous Studies

- **Sun and Oort (1995):** radiosonde data (Oort, 1983)

  Positive correlations at all levels.

- **Sun and Held (1996), Sun et al (2001):** GFDL, AMIP1, AMIP2 models

  Models **overestimate** the correlations.



[Sun et al., 2001]

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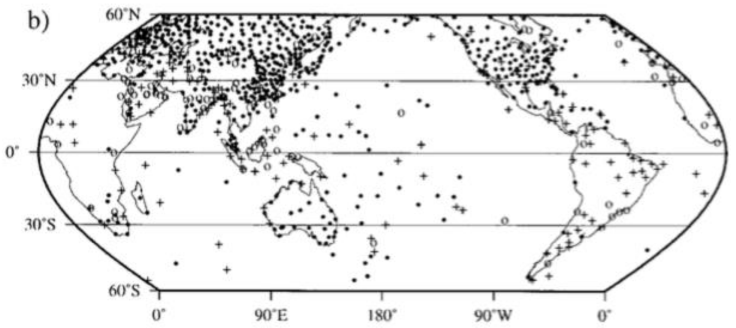
01 Introduction

Previous Studies

Tropospheric water vapor change is found to be **over-coupled** to the changes at the surface in models than in observations.

However…

- Station coverage limitation in radiosonde data (Oort, 1983)



Valid radiosonde stations in Oort (1983) at 700hPa.
[Bauer et al., 2002]

- Old models and short time coverage(~10 yrs)

In this study

Reexamine vertical correlations of water vapor change with

- ✓ **State-of-the-art** community models--- four leading CMIP5 models
- ✓ **Updated** NCEP and ERA-Interim reanalysis data (full coverage in the Tropics)
- ✓ **Longer** period (20 yrs)

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02 Data and Method

Data

- **4 CMIP5 models**
  CCSM4, HadGEM2-A, GFDL-CM3, MPI-ESM-MR
- **2 reanalysis data:** ERA-Interim & NCEP
- **Period:**
  1986-2005, 20 years monthly data
- **Variables:**
  specific humidity (q) at 10 levels from 1000 hPa to 200 hPa
  (NCEP 8 levels from 1000 hPa to 300 hPa)

Method

- **Interannual variability**

$$\boldsymbol{q} = \boldsymbol{q_a} + \boldsymbol{q_s} + \boldsymbol{q_l}$$

q_a: interannual variability
q_l: long − term trend
q_s: seasonal cycle

Tropical/zonal mean q_a→ correlate q_a at each level with surface q_a→r< $q_{a,surface}$, $q_{a,lev}$ >

- **Regime sorting method**

Divide zonal mean $q_{surface}$ into I regimes with 1.0 intervals. Within regime i, we could get N samples to obtain

- **averaged precipitation** $\overline{Prc_i} = \frac{\sum_{n=1}^{N} prc(n)}{N}$
- **correlation** r< $q_{a,surface}(i)$, $q_{a,lev}(i)$ >

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03 Results: Vertical structure of water vapor variations

Reanalysis data: right rotated V shape---
"Hot Tower"

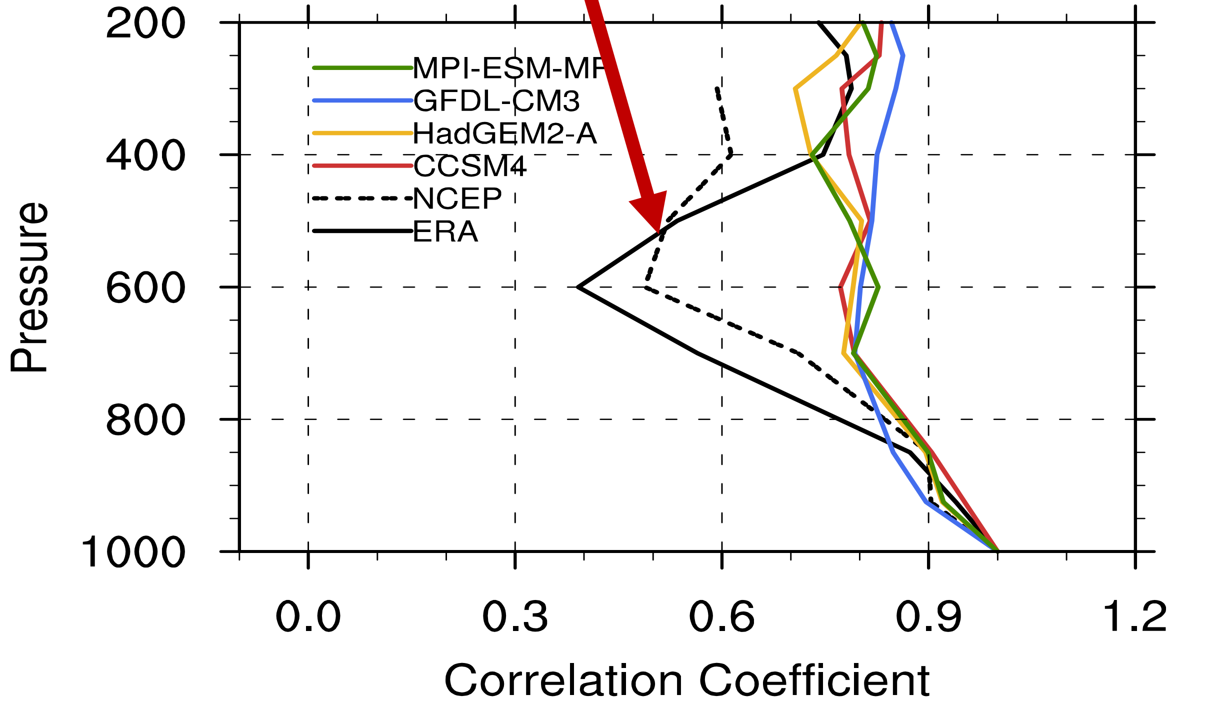

Figure 1. Vertical structure of correlation between interannual variations of specific humidity and surface specific humidity

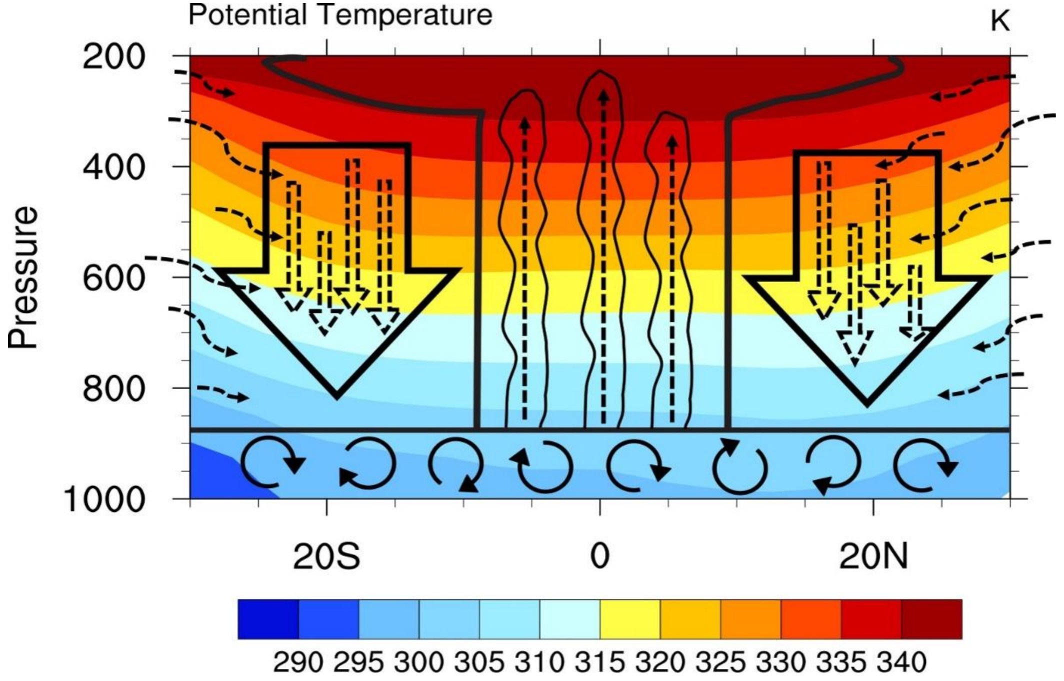

Figure 2. The illustration of "Hot Tower" hypothesis in the Tropics. Dashed curve line indicate the isentropic mixing outside the Tropics. In the Tropics, convections and large-scale upward motion compose the ensemble hot tower in the atmosphere. It transports energy to upper troposphere and spread at the top of the tower. Outside the hot tower, collective downward branches are shown to balance the tropical energy. It composes of large-scale downward motions and descending between convections. Isentropic layers are overlaid in the background with potential temperature.

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03 Results: Vertical structure of water vapor variations

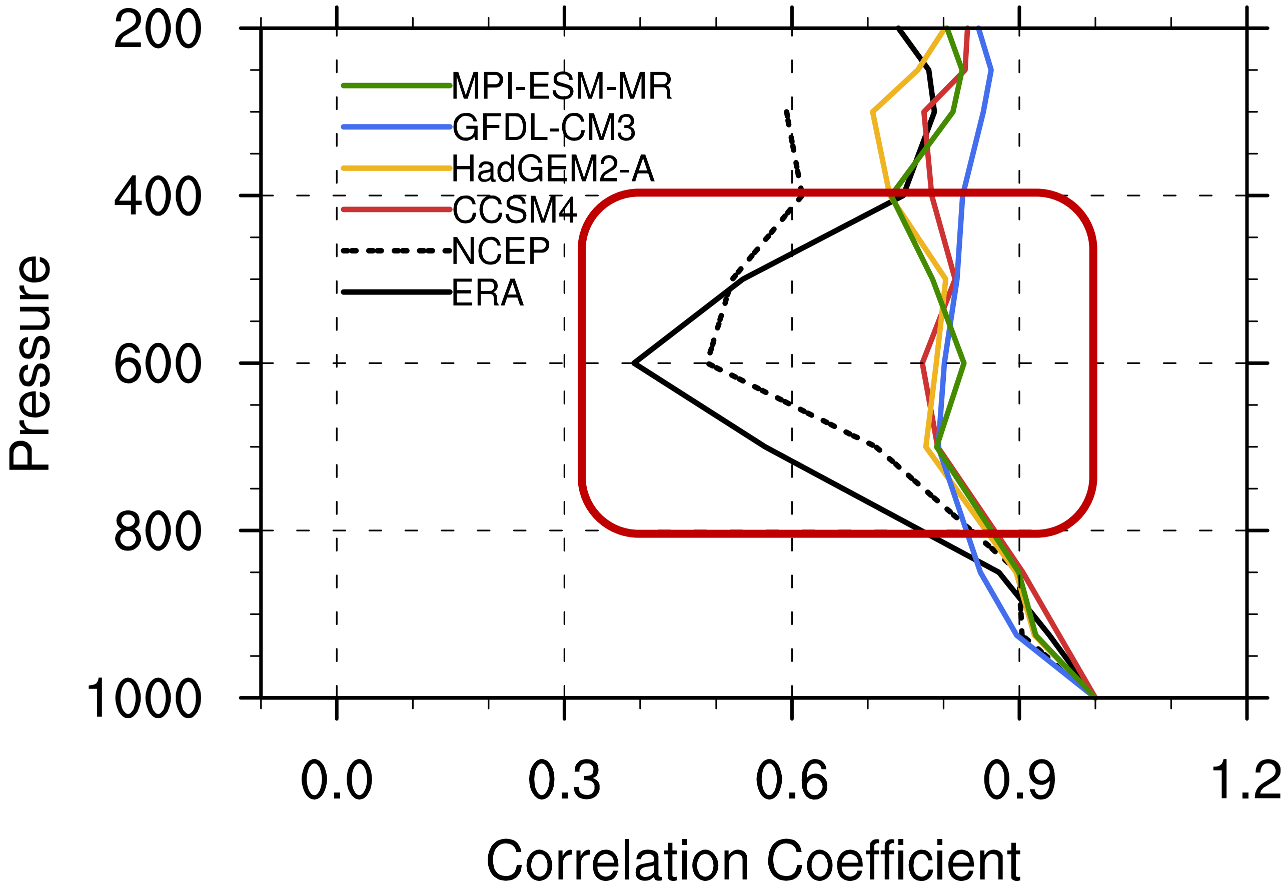

Figure 1. Vertical structure of correlation between interannual variations of specific humidity and surface specific humidity.

- Reanalysis data: right rotated V shape--- **"Hot Tower"**
- Model still **overestimate** the correlations

Large biases are in **middle troposphere** (800 hPa – 400 hPa), especially at 600 hPa.

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03 Results: Vertical structure of water vapor variations

r$< q_{a,surface}, q_{a,lev} >$

- **Deep tropics**
  - High correlation in upper and lower troposphere
- **Subtropics**
  - Correlation decrease with increasing height.

Overestimations in models happen in all latitude and is most obvious in the **middle levels**.
Vertical mixing in models are **overly simulated**.

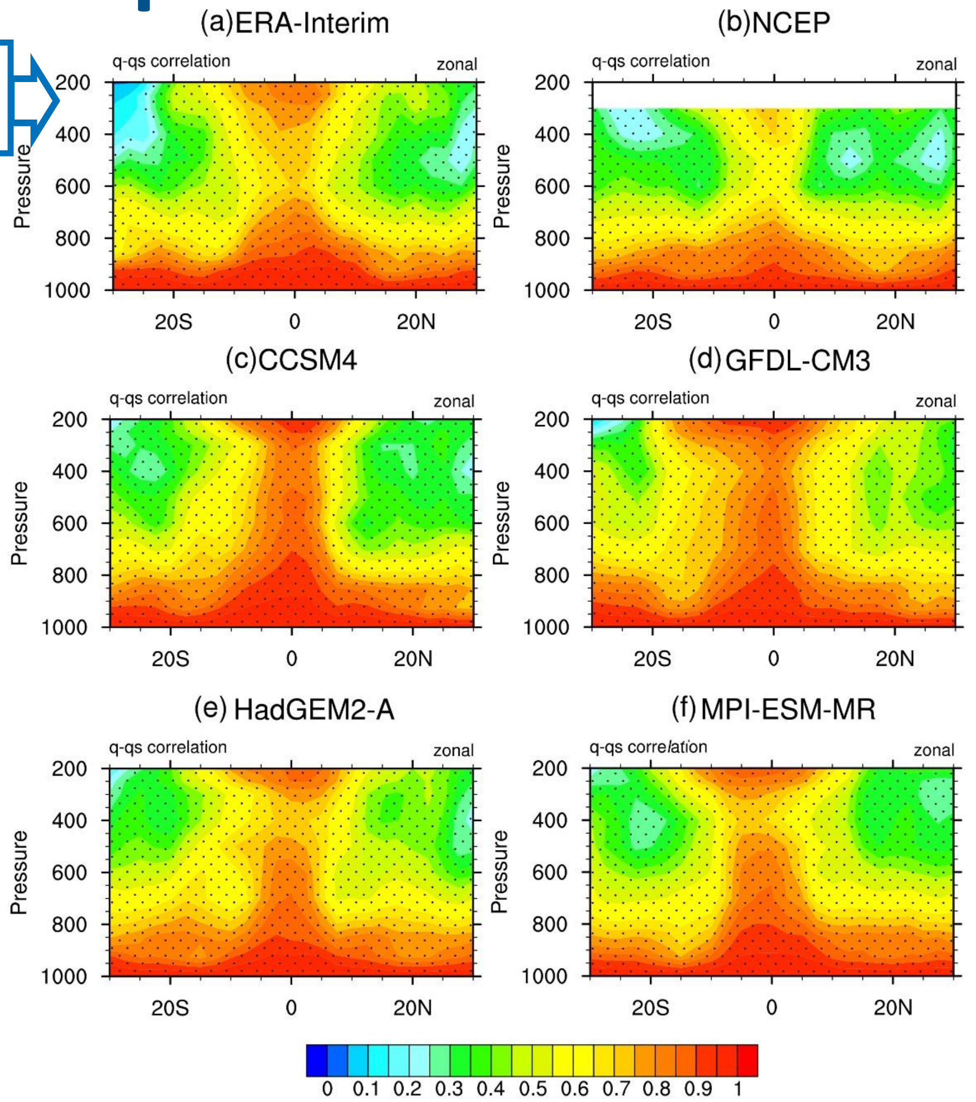

Figure 3. Cross section of the correlations of the zonal mean specific humidity variations with those at the surface on interannual timescale, correlations with a statistical significance level greater than 99% are stippled.

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03 Results: Causes for this over-coupling

r<Conv. Pre., $q_{a,lev}$>

- **Vertical mixing←→convections**
- Assuming the TRMM is the truth, models clearly overestimate the correlations between q and convective precipitation in the subtropics, the northern hemisphere in particular. Overestimation is mainly from middle levels.

Moisture change at middle levels in models are greatly influenced by **convections.**

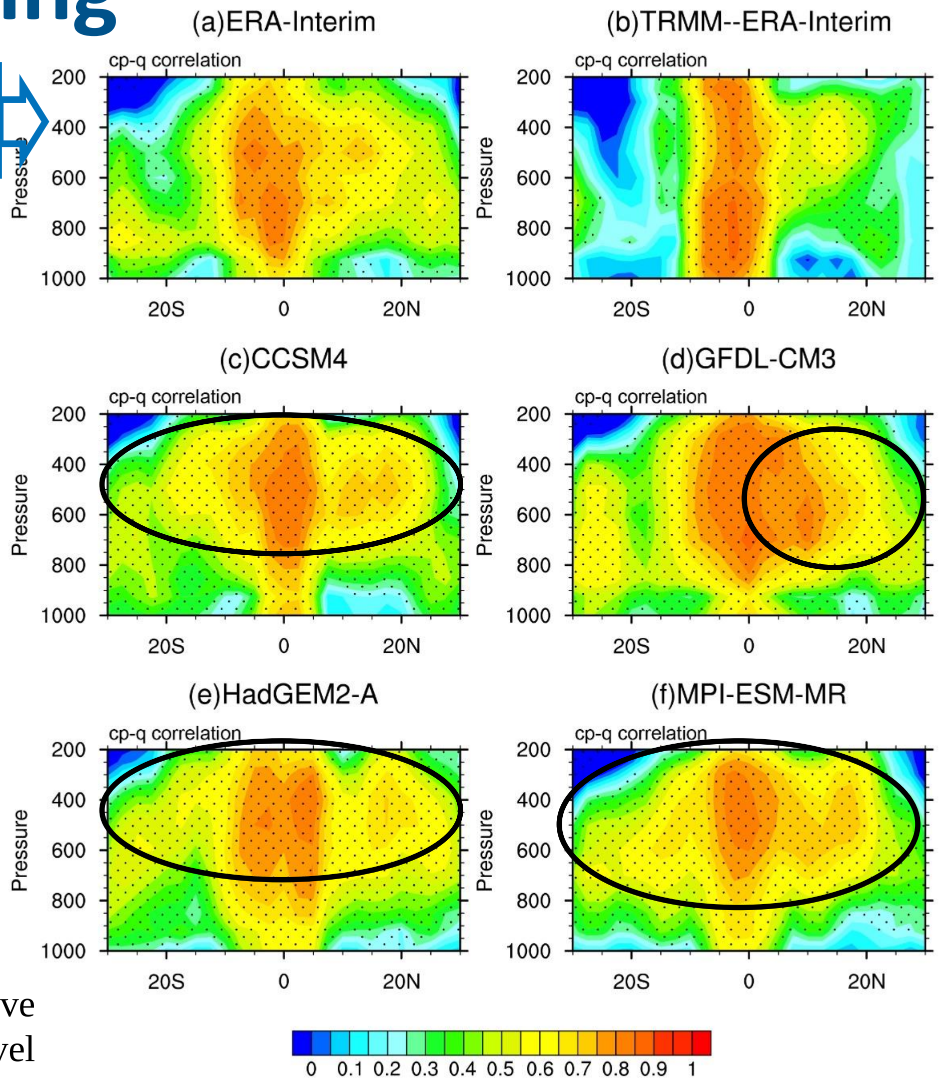

Figure 4. Cross section of the correlations of the zonal mean specific humidity and convective precipitation at each level on interannual timescale, correlations with a statistical significance level greater than 99% are stippled.

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03 Results: Causes for this over-coupling

Moisture change at middle levels in models are greatly influenced by **convections.**

Too frequent convections are found in all precipitation intensity regimes in models, especially in **strong convections.**

Water vapor variations in the middle levels are overly coupled with surface moisture change.

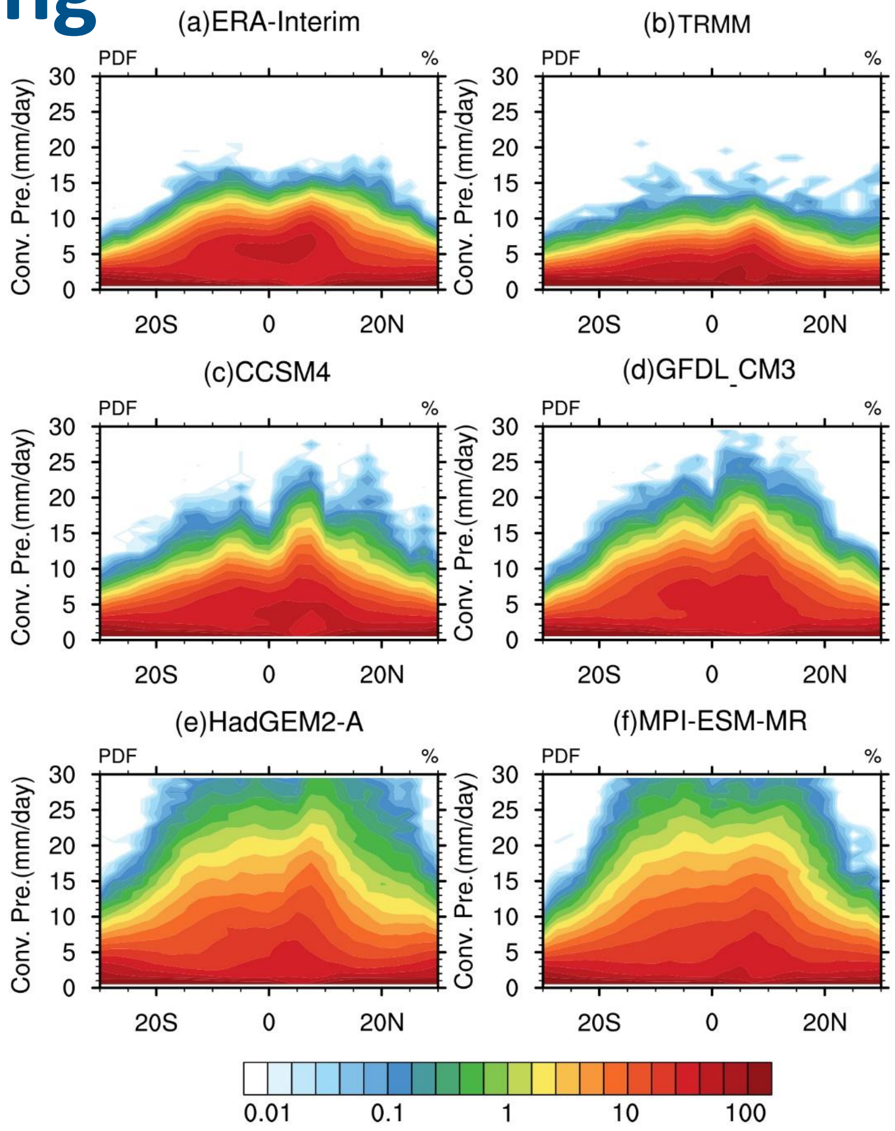

Figure 5. Probability Distribution Function of convective precipitation at each latitude

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03 Results: Causes for this over-coupling —regime sorting method

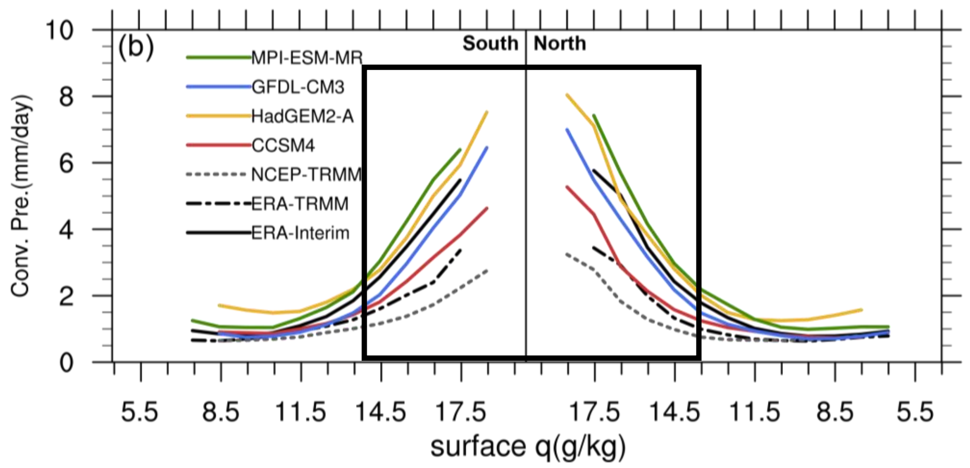
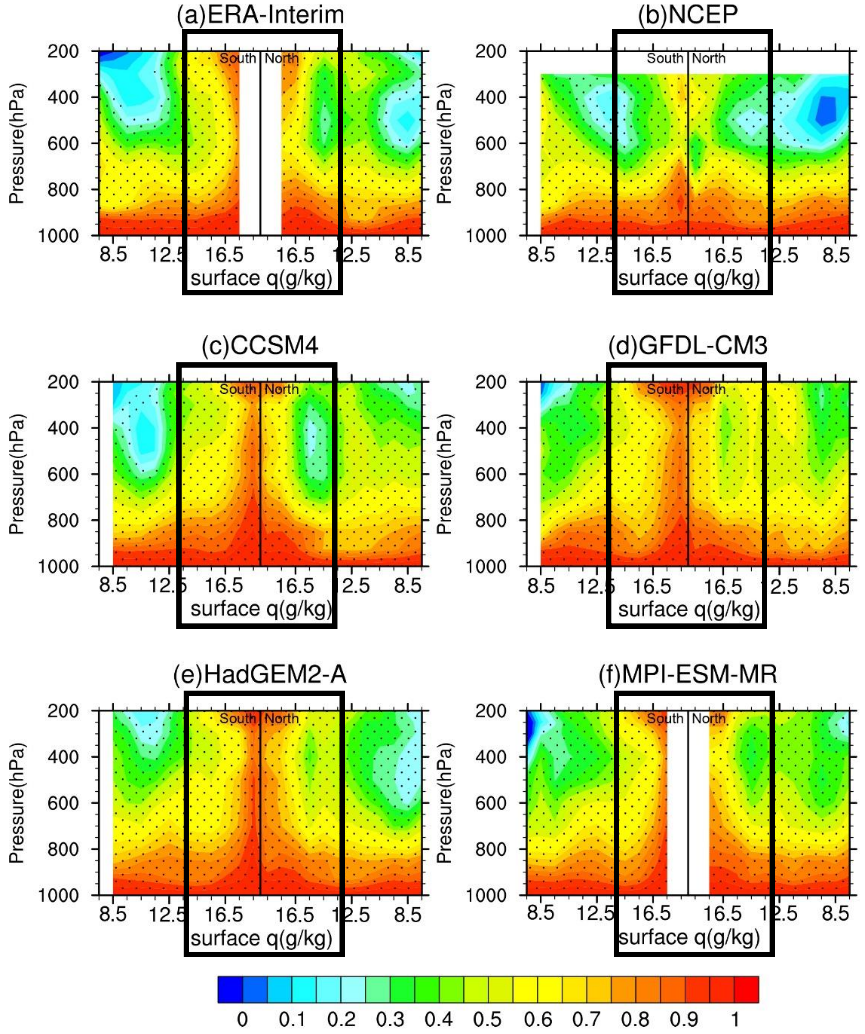


Figure 6. mean convective precipitation as a function of zonal mean surface water vapor for south and north hemisphere with 1.0 intervals

Figure 7. Correlation coefficient of interannual changes between tropospheric water vapor and surface moisture as a function of zonal mean surface water vapor, correlations with a statistical significance level greater than 99% are stippled.



- In moist regimes, overestimated conv. Pre. is most obvious. → over coupling of tropospheric water vapor change with surface moisture change.
- In dry regimes, slight overestimation in conv. Pre., slightly overestimated correlations may be come from the simulation error on the isentropic mixing outside the Tropics.

04 Conclusion and Discussion

Reexamine the relationship between tropospheric and surface water vapor variation on interannual time scale with **updated reanalysis** data, **longer** period and **new** models.

- It is found that four state-of-the-art models in CMIP5 still **overestimate** the q-qs correlations, especially in the **middle troposphere**.
- Model biases in water vapor correlation is related to convections. Biases are mainly attributed to **overestimated frequency of strong and moderate convections** in models.
- Results imply the important role of **correct parameterization of convection** in the simulation of the magnitude of water vapor feedback.