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Variability of Water Vapor in the Lowermost Stratosphere

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Abstract

Water vapor (WV) is a key trace gas that amplifies warming through positive climate feedbacks. Even small changes in WV in the upper troposphere and lower stratosphere can significantly impact radiation. However, climate models vary widely (0.1- 0.3 W $m^{-2}K^{-1}$) in simulating stratospheric water vapor (SWV) feedback, especially in the lowermost stratosphere (LMS), which accounts for two-thirds of the total SWV feedback. This study examines WV variability in the LMS and stratosphere-troposphere exchange (STE) using CCMI simulations and COSMIC Radio Occultation data (2007–2010), employing the dynamic upper isentrope method to enhance understanding of WV changes in the LMS.

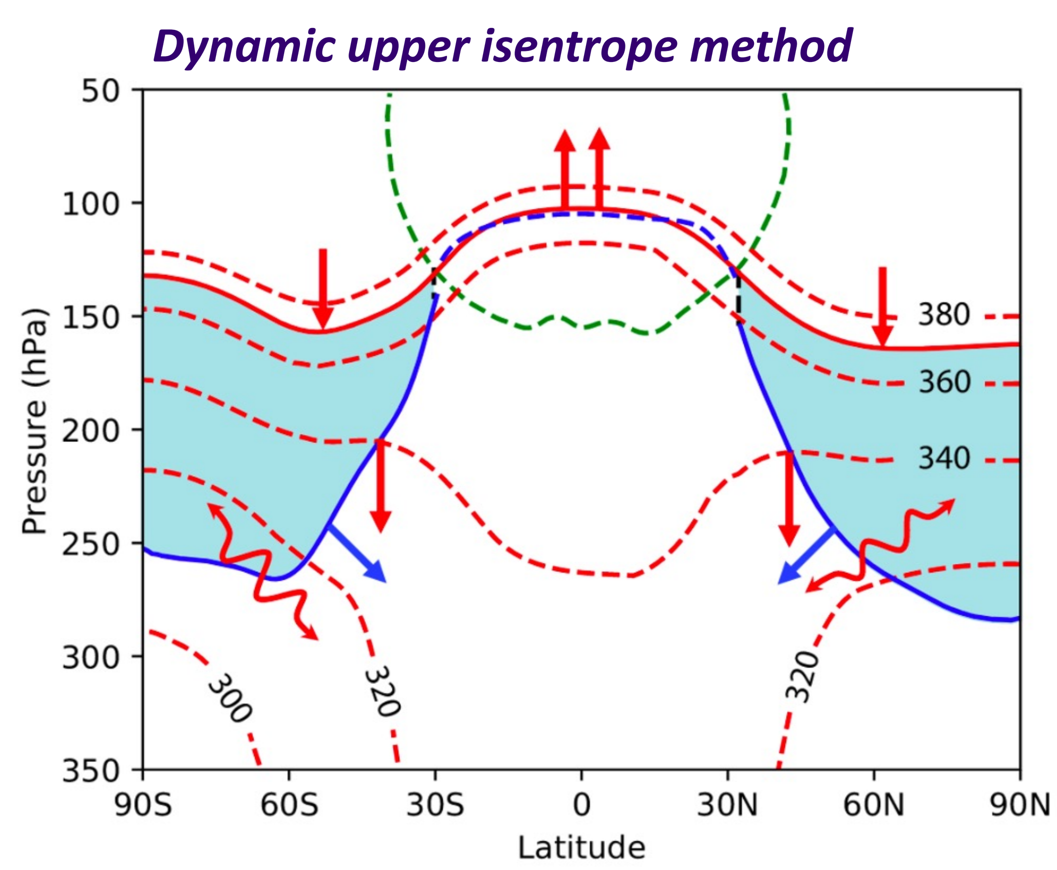
Introduction

Water vapor plays a crucial role in the climate system, influencing radiation, cloud formation, atmospheric chemistry, and dynamics. While WV concentrations in the stratosphere are low, even small changes in the upper troposphere and lower stratosphere can have significant radiative impacts.

Future increases in stratospheric water vapor risk amplifying climate change. We are motivated to research on the water vapor in the lowermost stratosphere because contributes to the majority (two-thirds) of the total SWV climate feedback (Dessler et al., 2013). However, the simulated stratospheric water vapor feedback shows a substantial spread between different models (Banerjee et al., 2019).

We aim to enhance our understanding of WV changes in the lowermost stratosphere from the perspective of radiative flux by employing the dynamic upper isentrope method. Through this research, we will examine the radiation flux at the upper boundary and the tropopause, aiming to understand how radiative flux influences the changes in WV concentrations and their trends.

Method & Data



$$F_{\text{upper}}^{H_2O} = \iint Q\, \sigma_{H_2O} q_{H_2O}\, dA$$

Diabatic heating rate : $Q = R\frac{\theta}{T}$

Isentropic density : $\sigma = \frac{1}{g}\frac{\partial p}{\partial \theta}$

$$F_{\text{trop}}^{H_2O} = F_{\text{upper}}^{H_2O} + \frac{dM_{H_2O}}{dt}$$

WV mass in LMS :

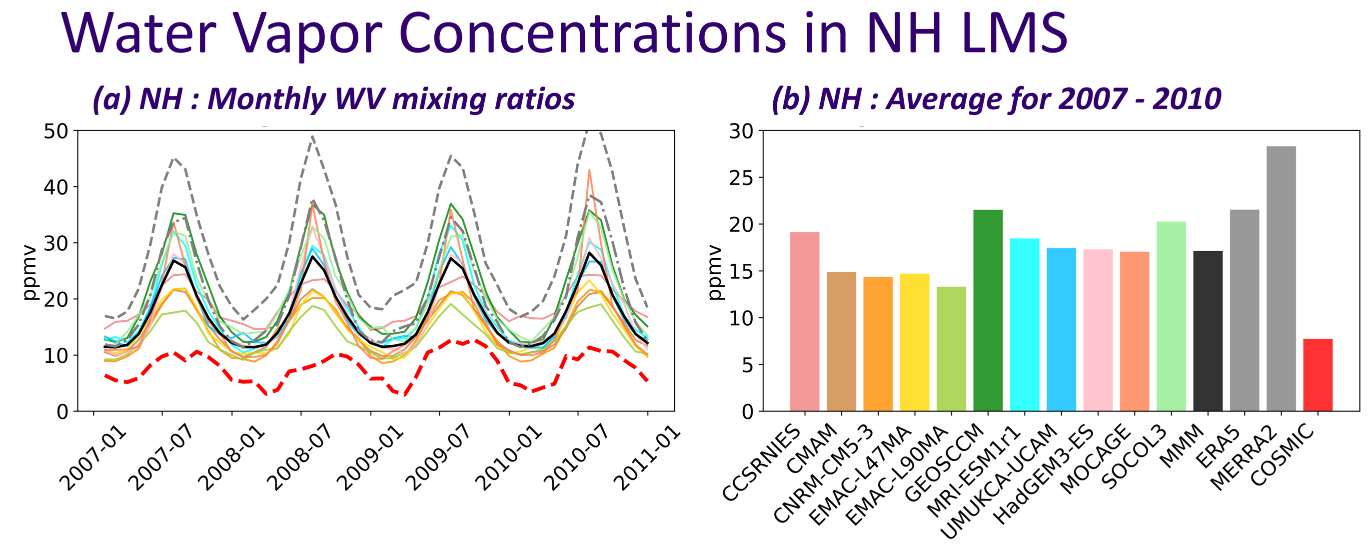
$$M_{H_2O} = \iiint_{P_i}^{P_t} \frac{q_{H_2O}(p)}{g}\, dp\, dA$$

COSMIC Radio Occultation data (2007–2010)
Chemistry Climate Model Initiative (CCMI)

Figure Caption: The light blue area represents the lowermost stratosphere (LMS). The blue solid line indicates the WMO (World Meteorological Organization) tropopause, the red solid line indicates the upper boundary, the red dashed line represents the isentropic surface, and the green dashed line indicates the zero diabatic heating rate. The red unidirectional arrow denotes diabatic flux, the bidirectional red arrows indicate adiabatic flux, and the blue arrows represent STE flux. θ is the potential temperature, T is the temperature, p is pressure, g is the gravitational acceleration constant, and A is the area at the fitted isentropic surface in the NH extratropics, SH extratropics, and tropics.

Results

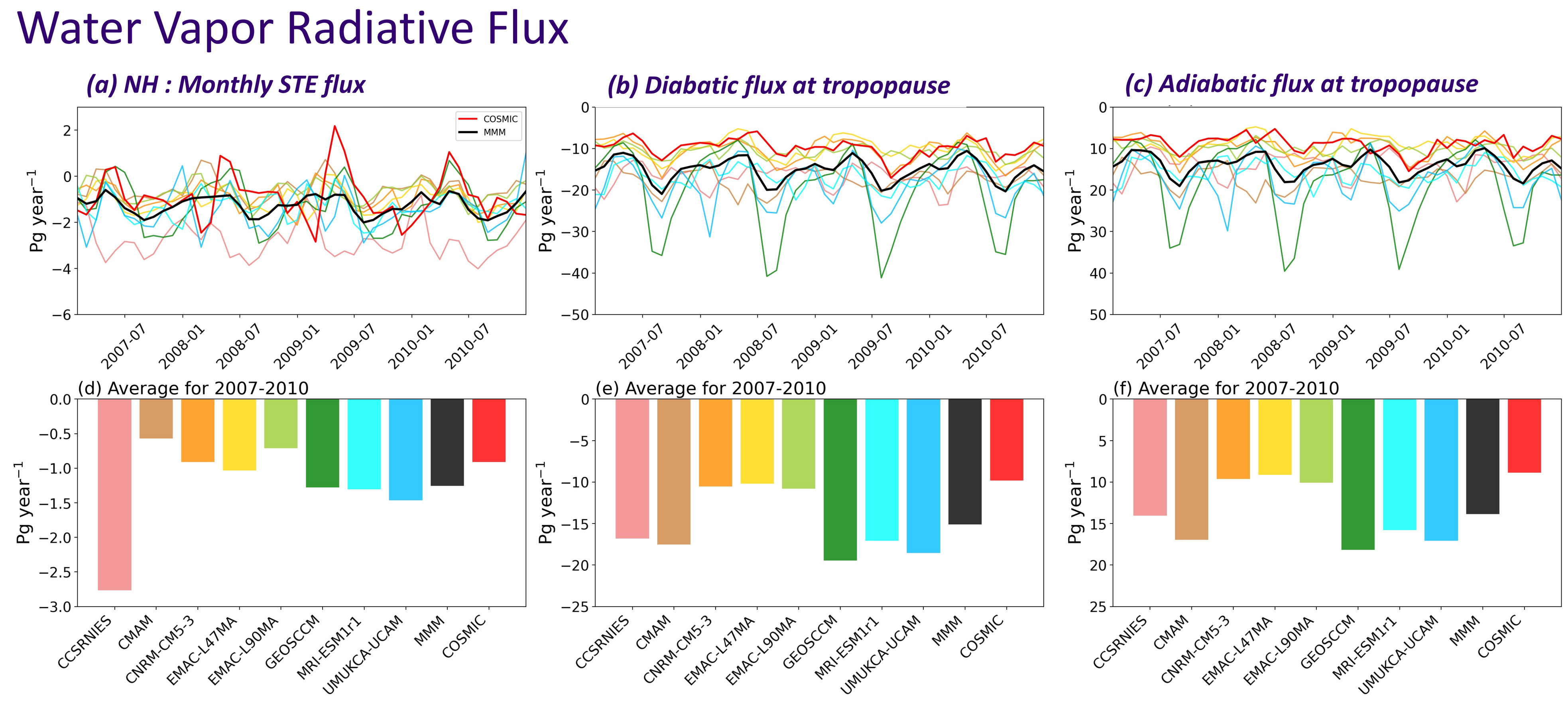
Water Vapor Concentrations in NH LMS



WV mixing ratios in Northern LMS :

> WV concentrations peak during August and September
> Since COSMIC data is only available for 2007-2010, long-term trends in water vapor cannot be observed. However, model predictions show a systematic overestimation bias.
> The results of the models indeed show a large spread considering small changes can significantly impact radiation.

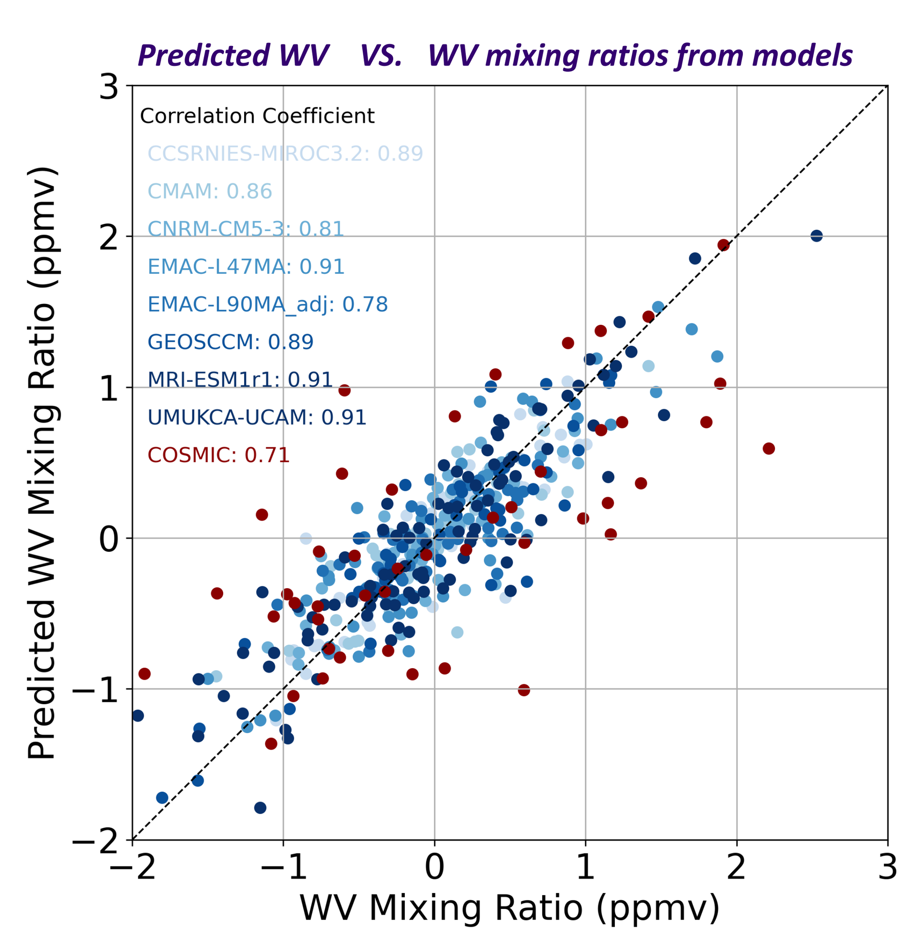
Water Vapor Radiative Flux



WV diabatic and adiabatic flux at tropopause in Northern LMS :

> Diabatic flux at tropopause is negative indicating the downwelling of the longitudinal circulation (BDC). The long term trends are negative from models which are consistent with the strengthening of the BDC.
> Adiabatic flux at tropopause is from troposphere to stratosphere by isentropic transport, a mechanism is unclear.
> The MMM results agree well with the COSMIC observational results.
> Both adiabatic and diabatic fluxes at the tropopause contribute to the variability of WV changes in the LMS. Additionally, the diabatic flux at the upper boundary is important (not shown).

Predictors of WV in NH LMS



WV mixing ratios VS. Predicted WV mixing ratios by the diabatic flux at tropopause and at upper boundary in Northern LMS :

> We found two predictors which work well on predicting the WV mixing ratios change. The predictors are the diabatic flux at tropopause and the diabatic flux at the upper isentrope.
> The correlation between predicted WV and the WV from models or COSMIC are from 0.71 to 0.91 which all pass the 95% significance test. The COSMIC result is consistent with results from models.

Reference

> Dessler A, Schoeberl M, Wang T, Davis S, Rosenlof K (2013) Stratospheric water vapor feedback. Proc Natl Acad Sci USA 110(45):18,087–18,091
> Banerjee, A., Chiodo, G., Previdi, M., Ponater, M., Conley, A. J., & Polvani, L. M. (2019). Stratospheric water vapor: an important climate feedback. Climate Dynamics, 53(6), 1697–1710.