Relationship between Water Vapor and Cold Point Tropopause during Boreal Summer

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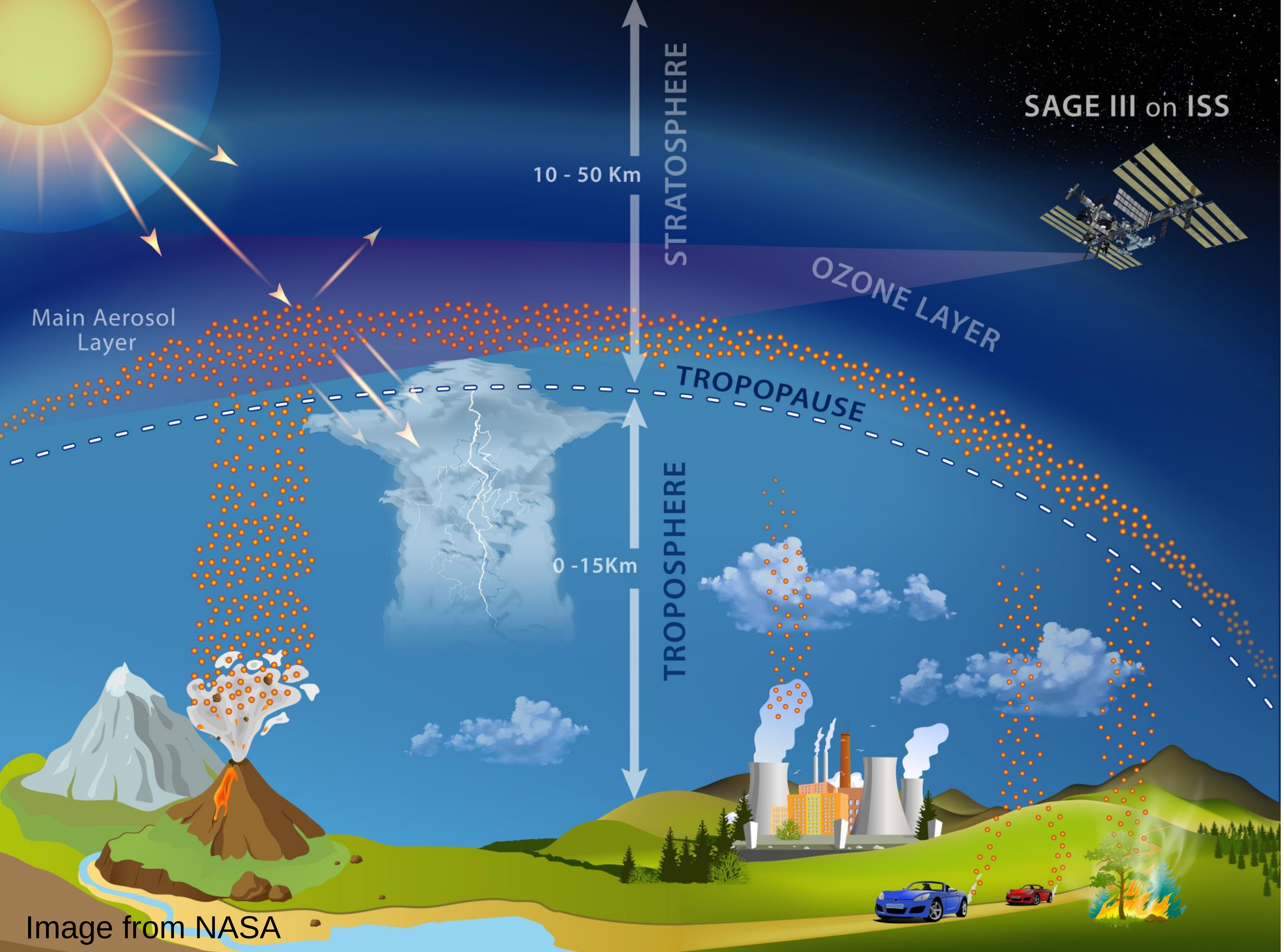
What I am going to talk about today.

1. Water vapor over Asian *vs.* N. American monsoon regions

2. Cold point tropopause (CPT) in the UTLS region

3. COSMIC-2 temperatures and atmospheric waves

4. Plans – In situ measurements and a global chemistry climate model (WACCM)

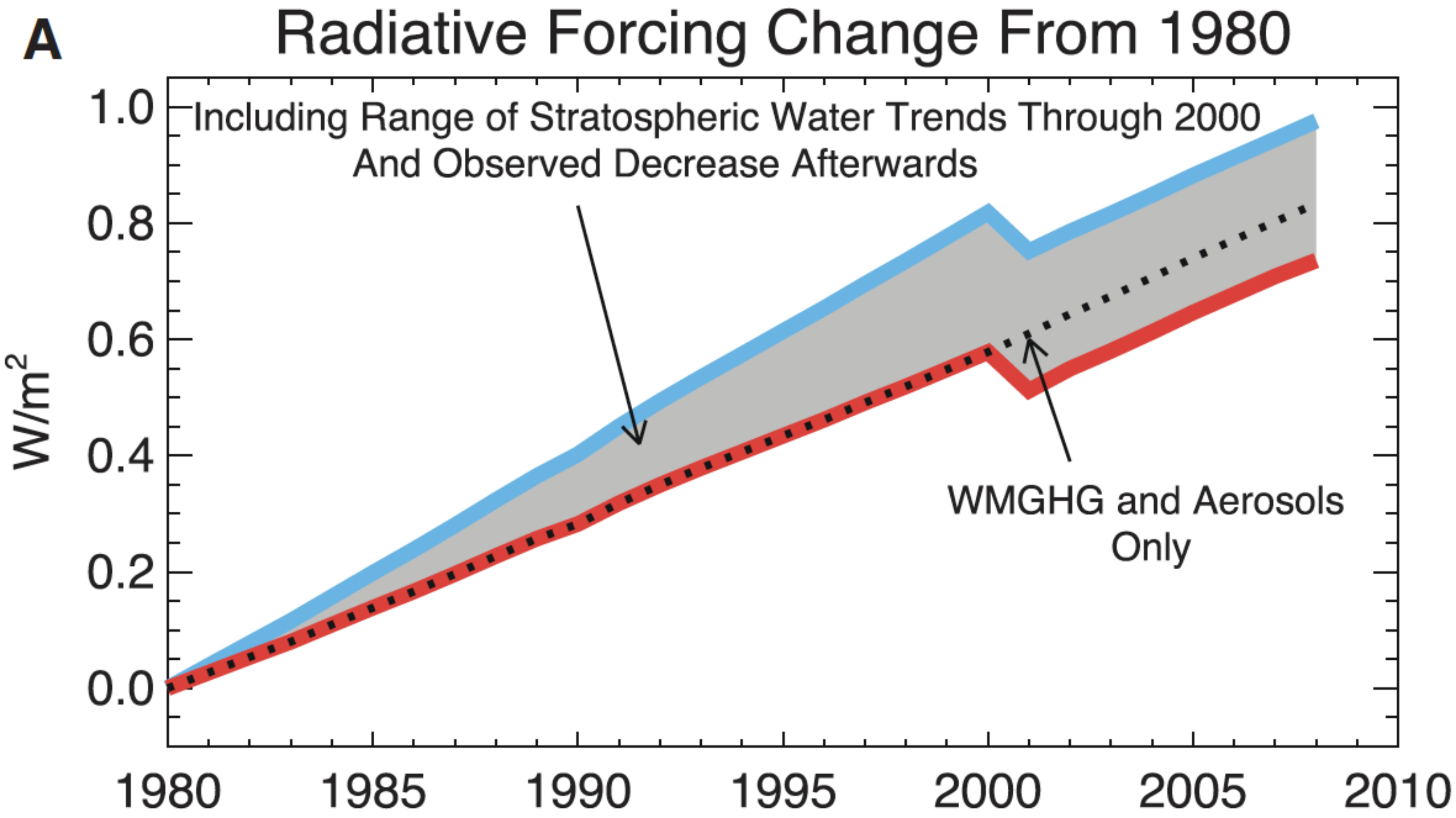


STRATOSPHERE

TROPOPAUSE (8-16 KM)

TROPOSPHERE

Stratospheric H_2O is an important driver of decadal global surface climate change.

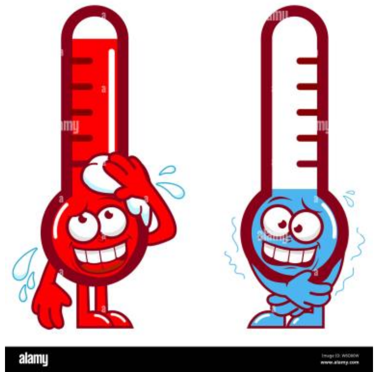


with H_2O

without H_2O

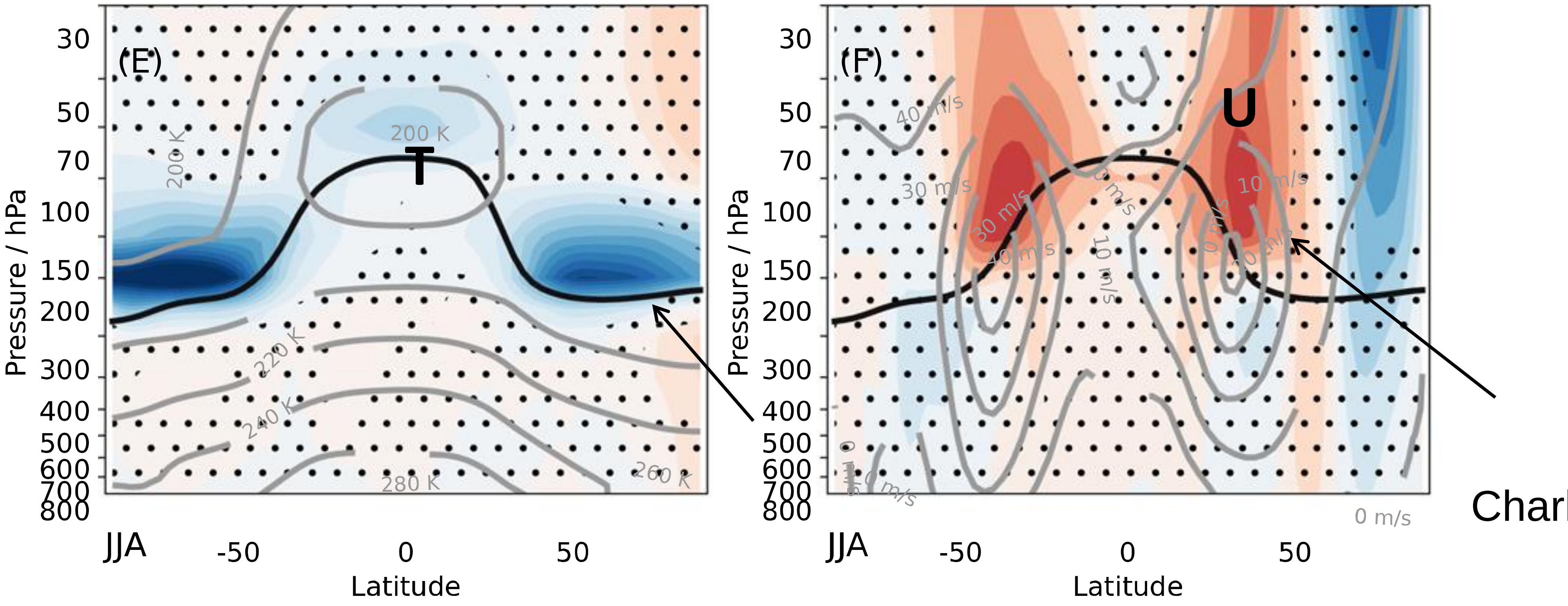
Solomon et al. [2010]

Fig. 3. Impact of changes in stratospheric water vapor on surface climate. (**A**) Time series of the changes in radiative forcing since 1980 due to well-mixed greenhouse gases (WMGHG), aerosols, and stratospheric water vapor.



Increase in stratospheric H_2O will accelerate the warming of surface temperature.

Lower stratospheric water vapor impacts atmospheric circulation.

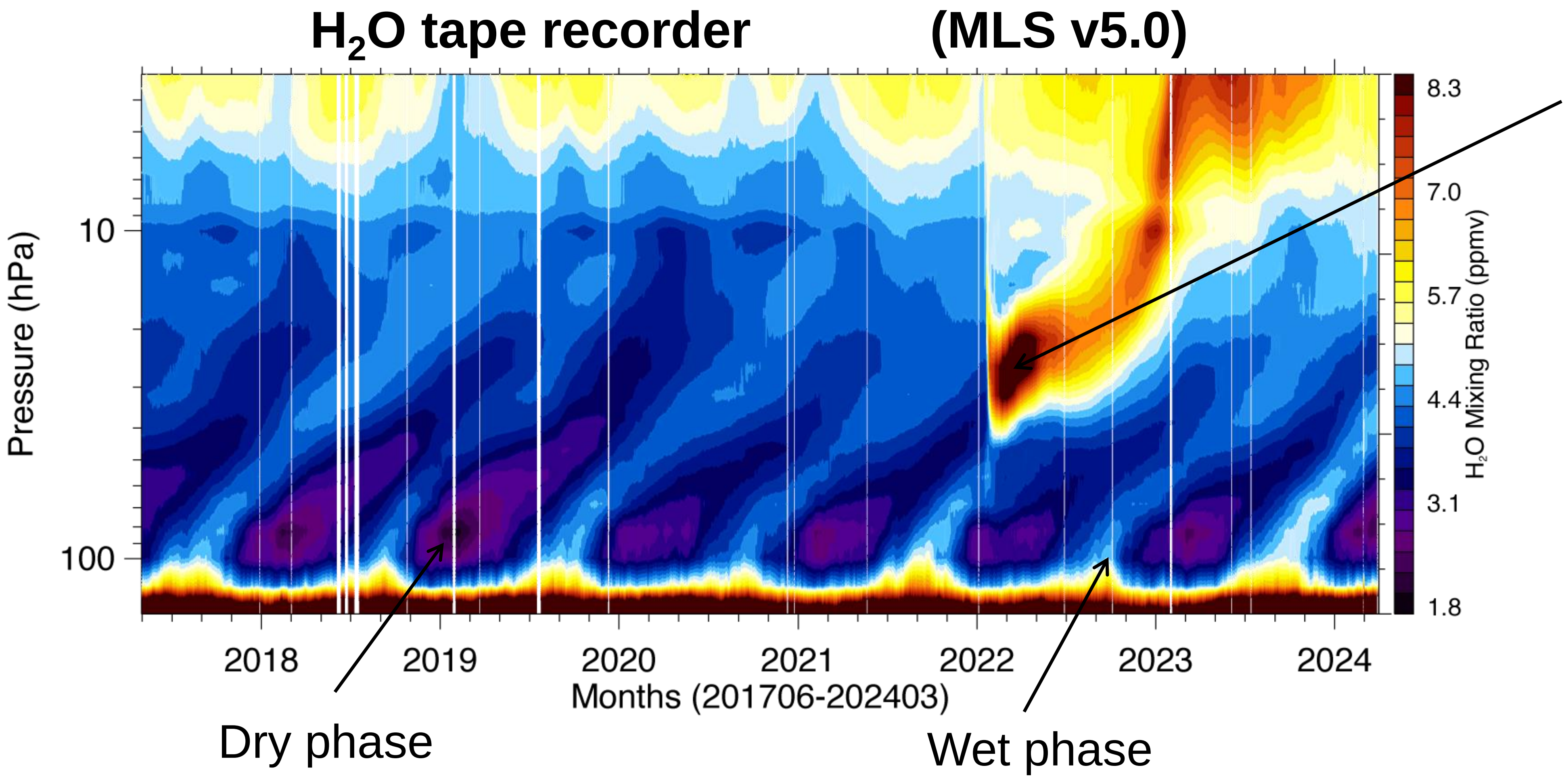


Charlesworth et al. (2023)

Fig. 2 Atmospheric circulation effects and dynamical mechanism induced by lowermost stratospheric water vapor changes. (E) Temperature, (F) Zonal wind (JJA).

Upward and poleward shift of subtropical jets
Strengthening of the stratospheric circulation

The seasonal variation in H_2O entering the stratosphere follows the CPT temperature, setting the "base" for the tropical tape recorder during the dry phase.



During the wet phase of the tropical tape recorder, enhanced H_2O over the NH summer monsoons makes its way into the lower stratosphere.

H_2O in the Stratosphere – Boreal Summer (JJA)

Enhancements in HDO/H_2O (*i.e.*, δD) over N. America are closely tied to deep convection

δD depleted over Asia

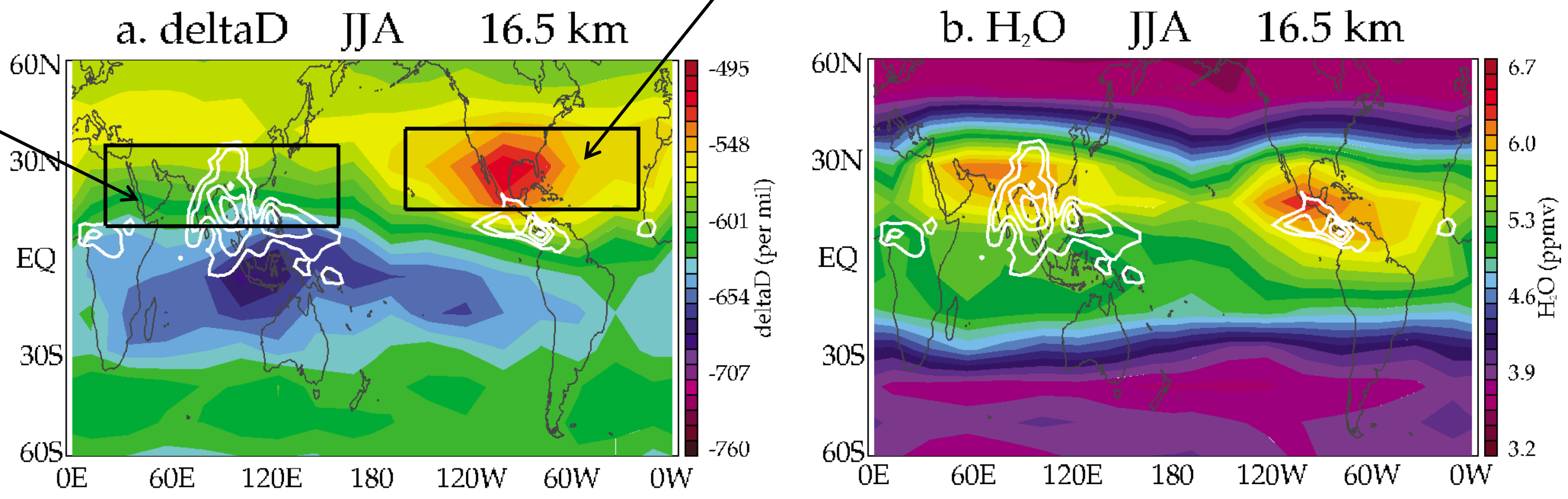


Figure 12. Cross sections of (a) dD and (b) H_2O at 16.5 km during JJA. The dD field has been corrected for methane effects, although this effect is small and only influences the highest latitudes. White contours denote strongest climatological tropical convection, and the black boxes denote the averaging regions for Figures 13 and 14. Note the isotopic enrichment correlated with high water vapor over the North American (NA) monsoon but the lack of a similar signal over the SE Asian monsoon region.

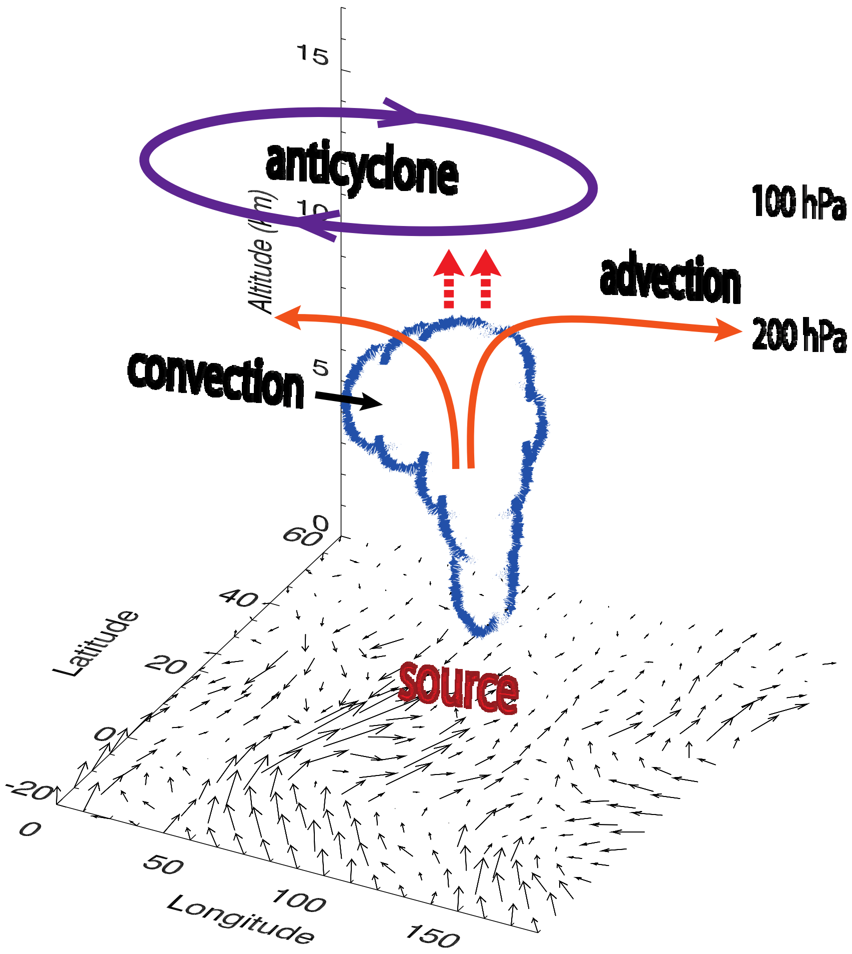
Randel et al. (2012)

$$\delta D(‰) = \left\{\left[(HDO/H_2O)/(HDO/H_2O)_{SMOW}\right] - 1\right\} \times 1000,$$

Transport -> H_2O

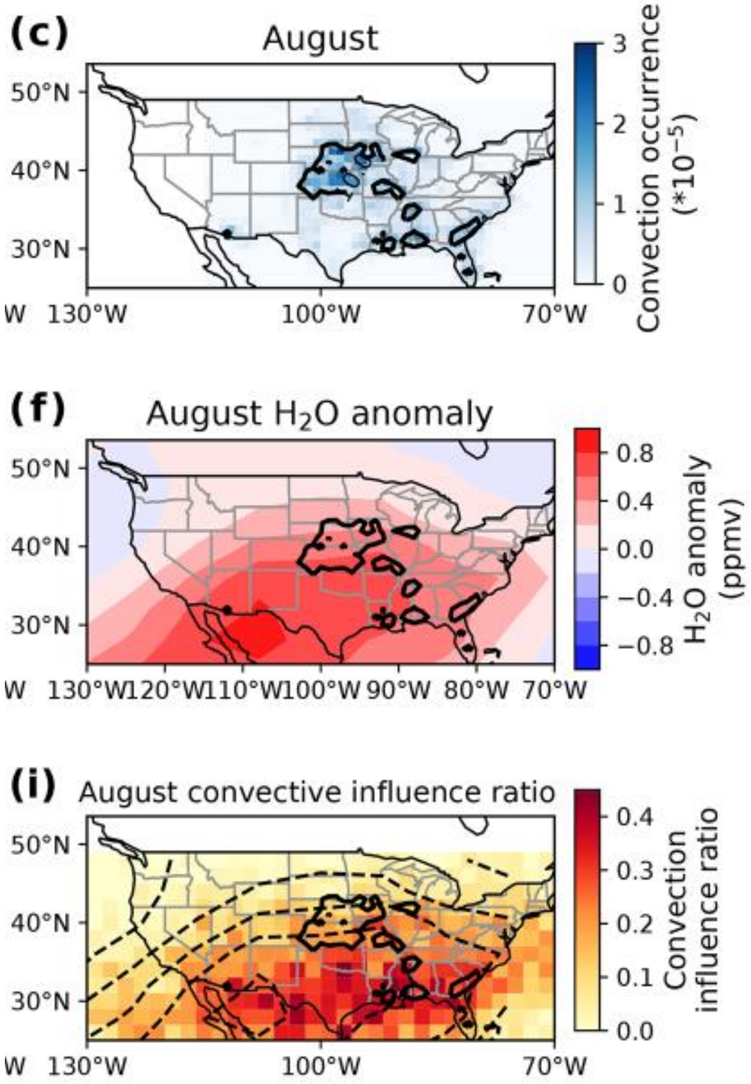
Convection -> H_2O

Asian Monsoon



Park et al. [2009]
Ploeger et al. [2013]

North American Monsoon



convection

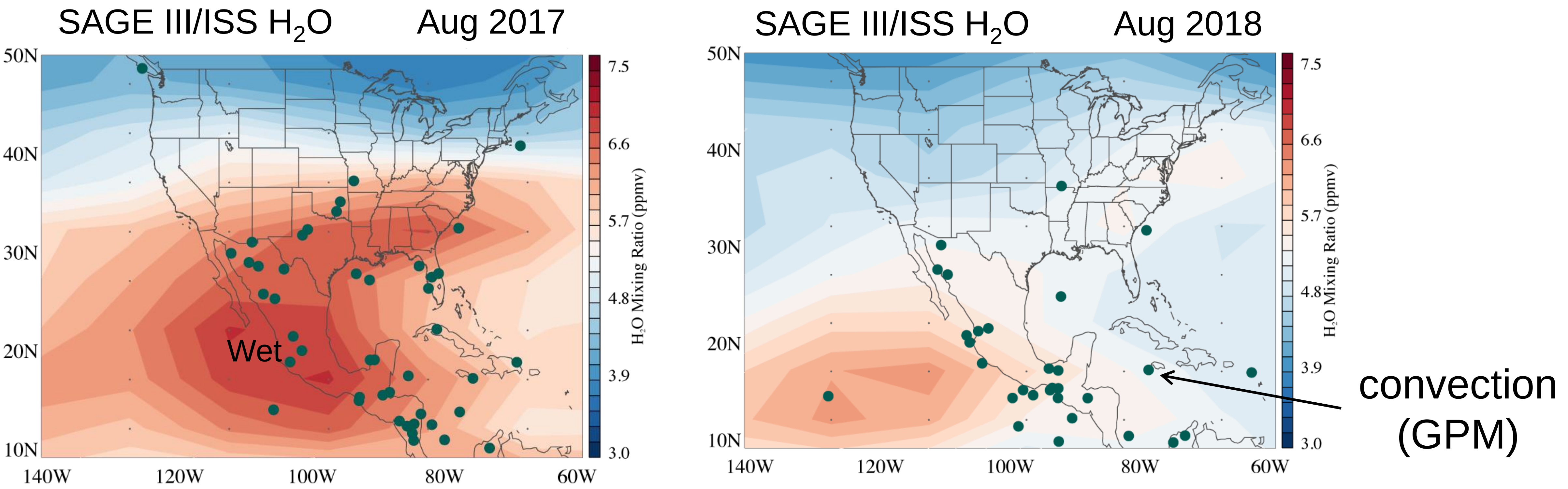
H_2O

convective influence

Yu et al. [2020]

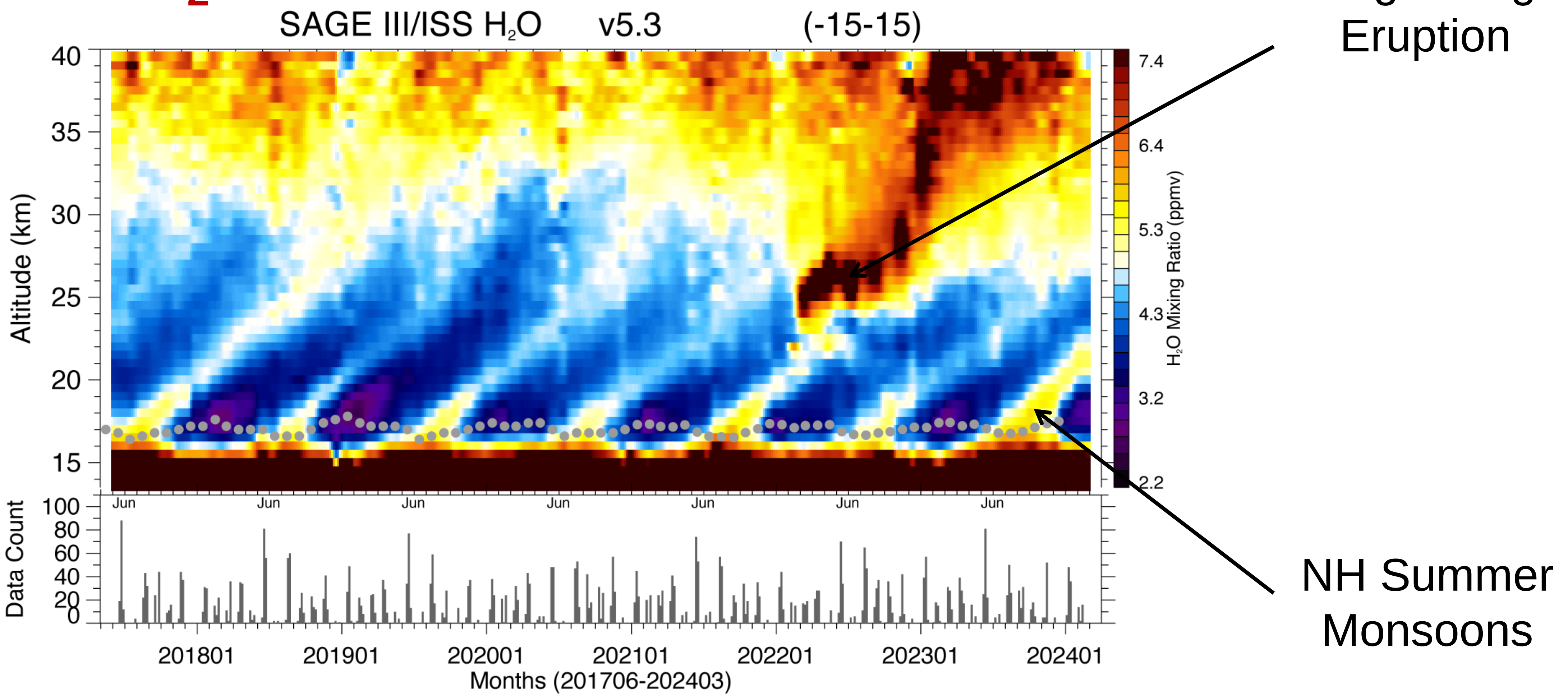
Convective influence in H_2O?

N. American Monsoon



Convective influence on lower stratospheric water vapor is unclear.

SAGE III/ISS H_2O



[SAGE III/ISS]

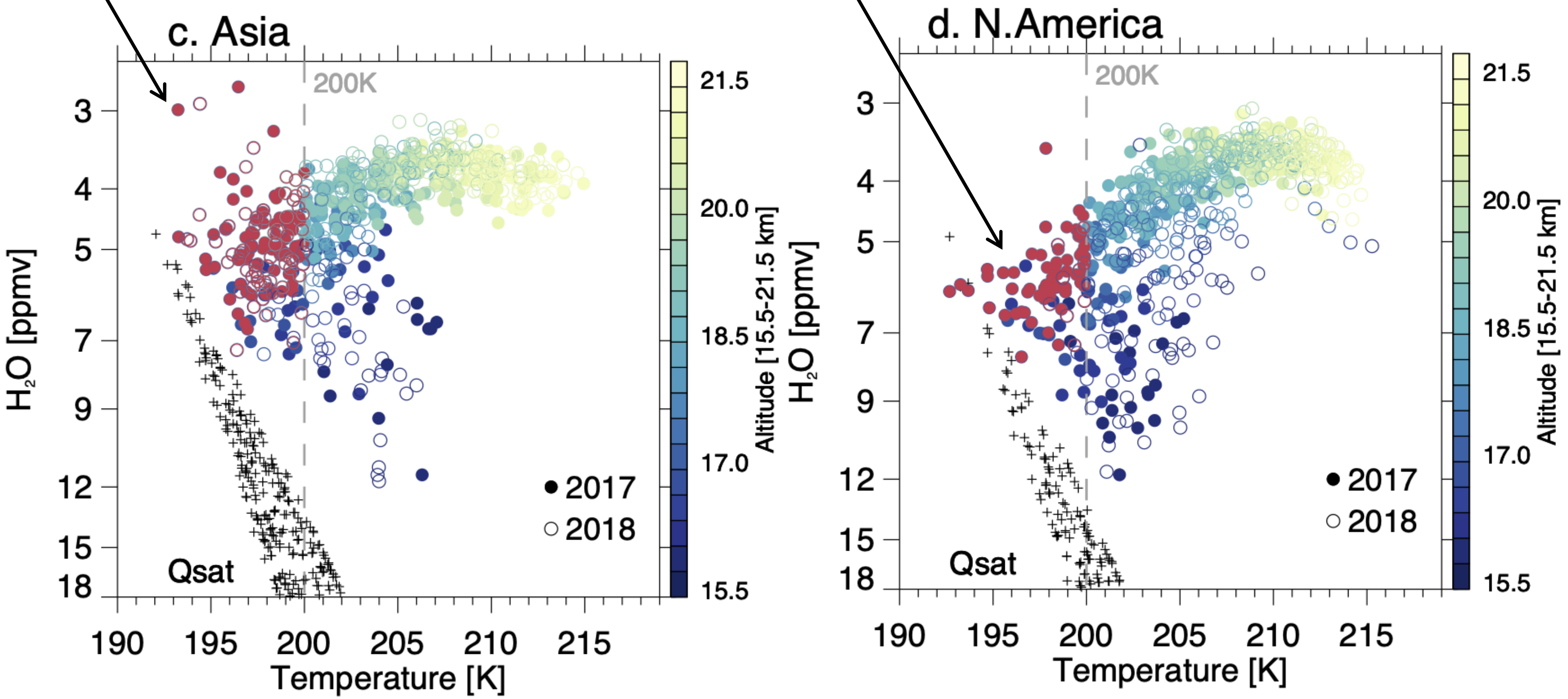
The Stratospheric Aerosol and Gas Experiment III on the International Space Station (SAGE III/ISS) was launched in **February 2017**. The SAGE III/ISS instrument provides measurements of aerosol extinction, NO_2, O_3, and H_2O between 70°S-70°N latitude using the techniques of solar occultation.

Asian *vs.* N. American monsoon regions (2017 *vs.* 2018)

Drier and colder

Wetter and warmer

Large year-to-year variability over N. America in August.

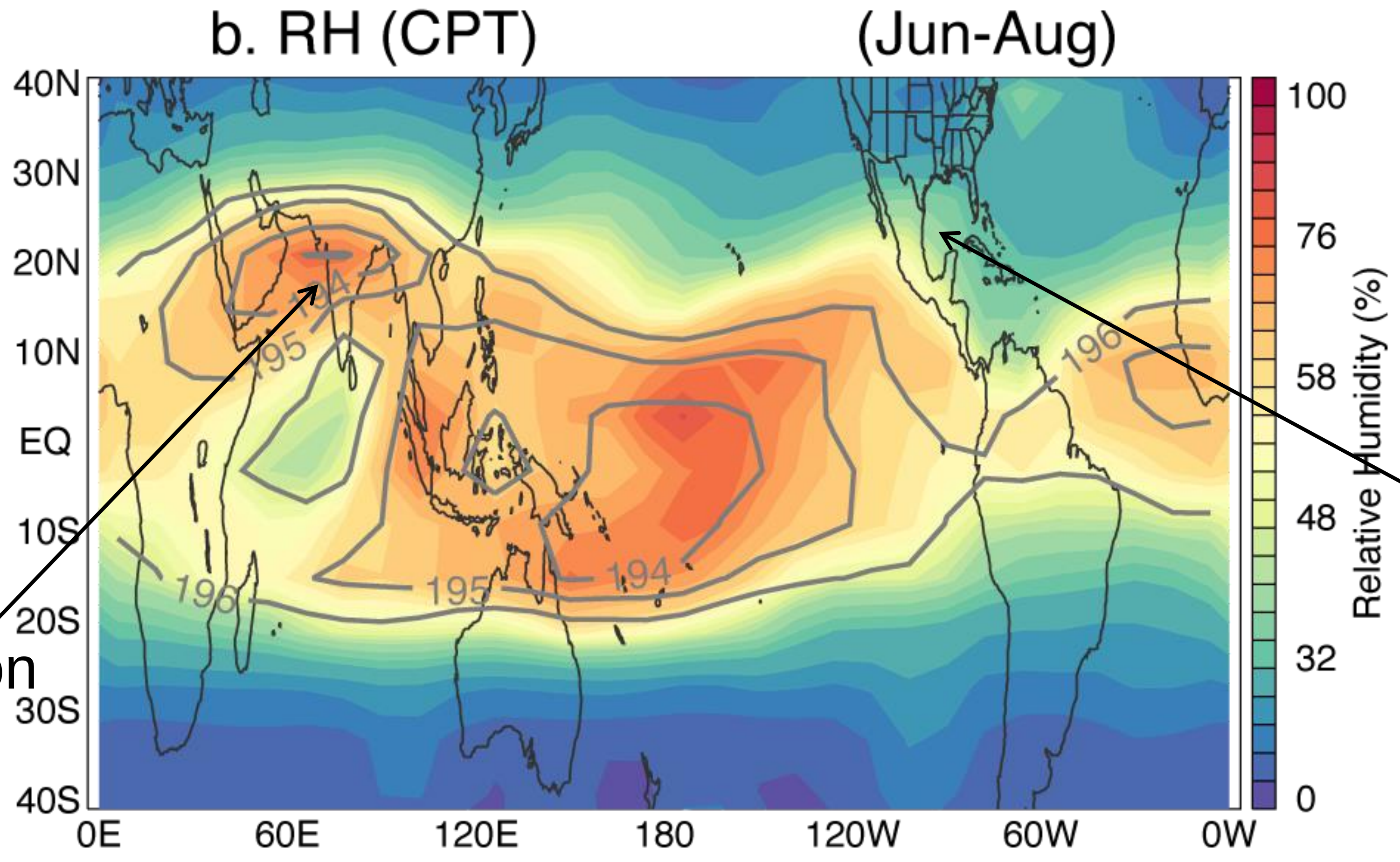


Park et al. [2021]

2017>2018

H_2O - CPT

The enhanced H_2O over the Asian monsoon region is collocated with colder CPT temperature. In comparison, tropopause over the North American monsoon is warmer.



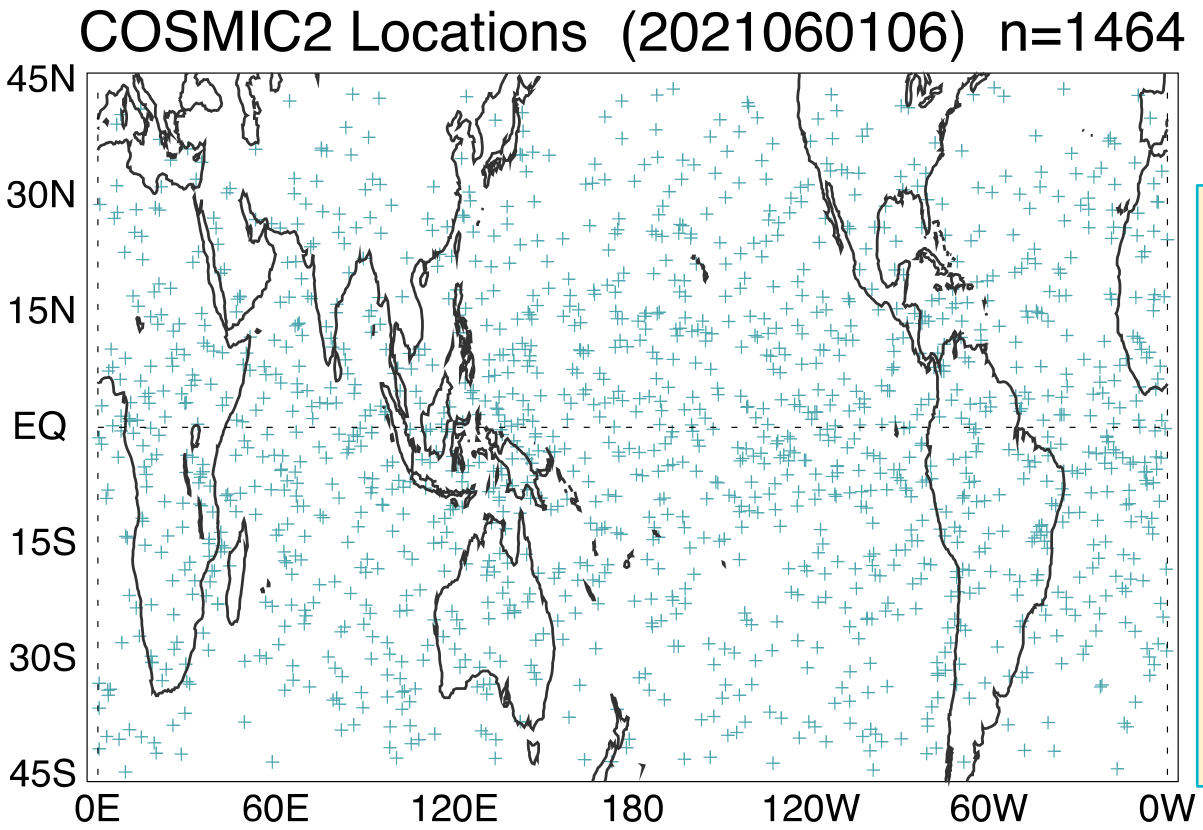
Asian monsoon (colder)

N. Am. monsoon (warmer)

Park et al. [2021]

COSMIC-2 Temperature

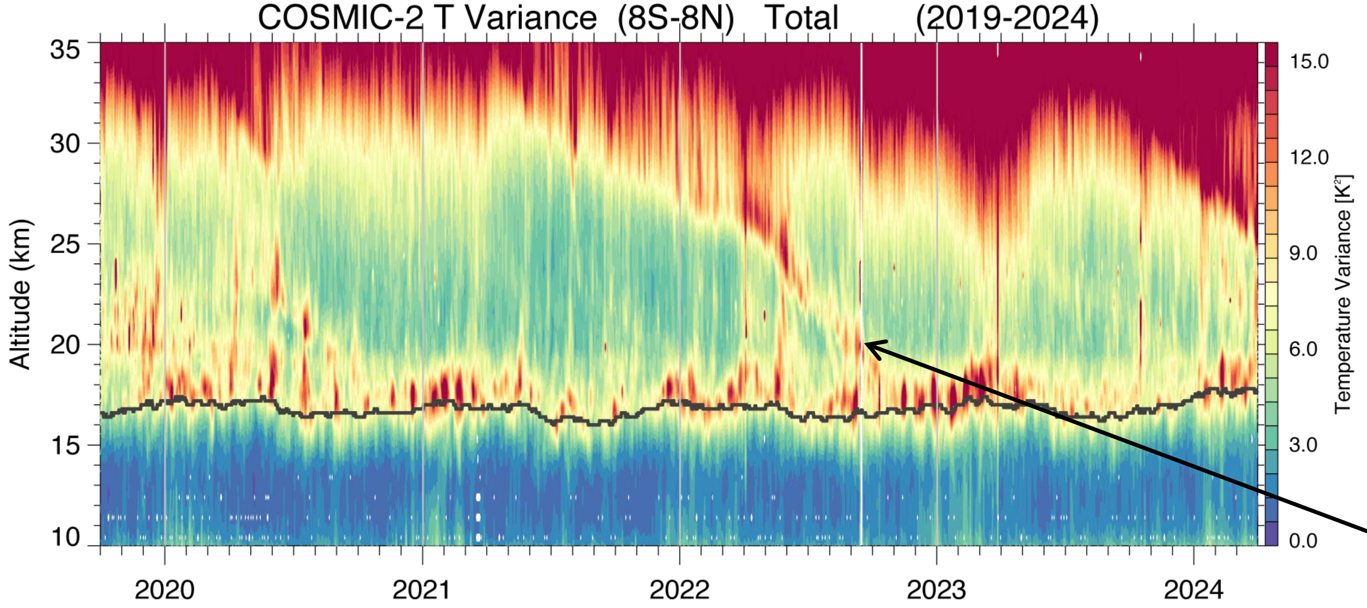
The Constellation Observing System for Meteorology, Ionosphere and Climate-2 is an equatorial constellation of radio occultation satellites that was launched on **25 June 2019.**



Global coverage - every 6 hours (~5000 profiles/day)

COSMIC-2 provides key observations for characterizing **equatorial waves**. An important aspect of equatorial waves is their relatively narrow vertical scales (typical vertical wavelengths of ~4–8 km).

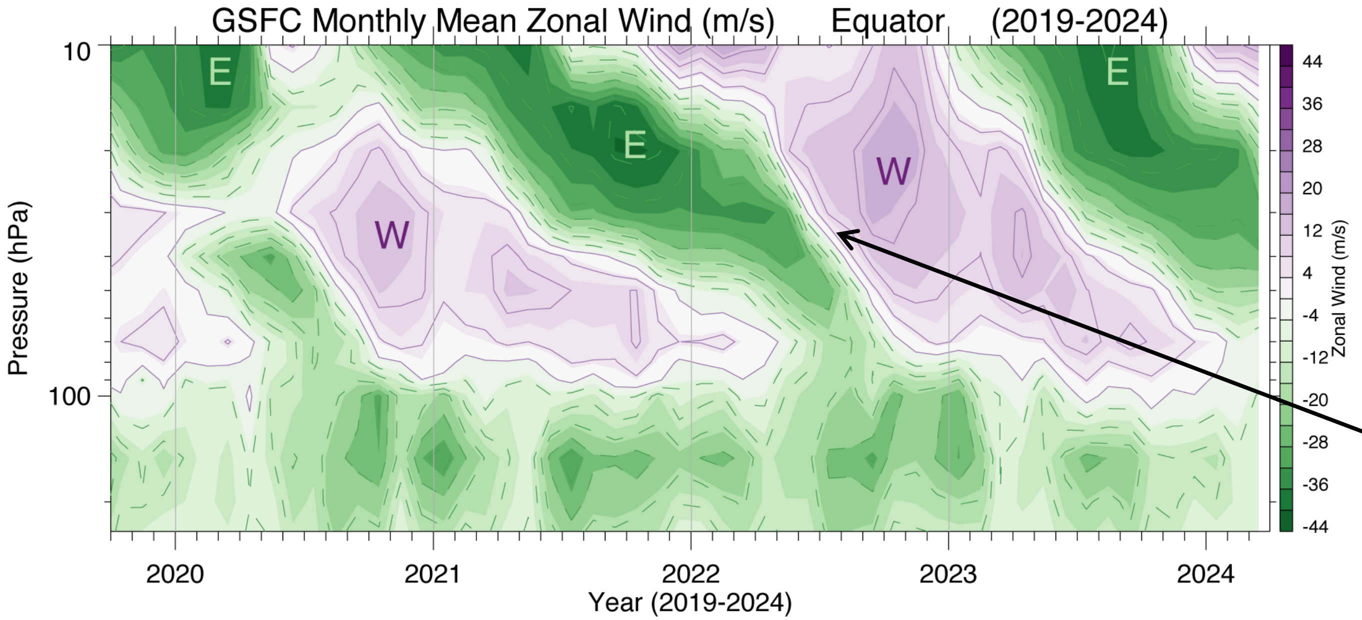
COSMIC-2 T Total Variance



high vertical resolution - fine structure of the **Kelvin Waves**

Max. Variance

Zonal mean zonal wind (Equator)



QBO Westerly Shear

The quasi-biennial oscillation (**QBO**) dominates the variability of the equatorial stratosphere (~16–50 km) and is seen as downward propagating easterly and westerly wind regimes, with a variable period averaging ~ 28 months [Baldwin et al., 2001].

H_2O *vs*. Temp Variance (waves)   Asia *vs*. N. America

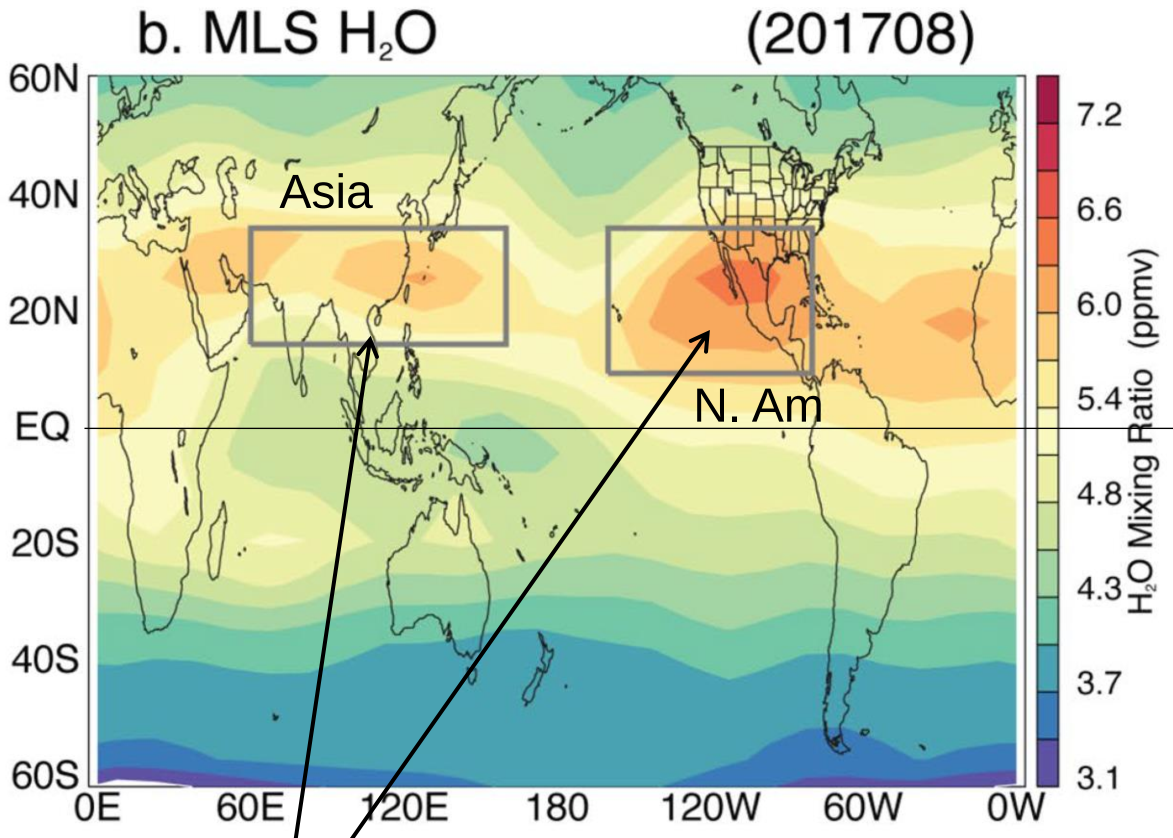
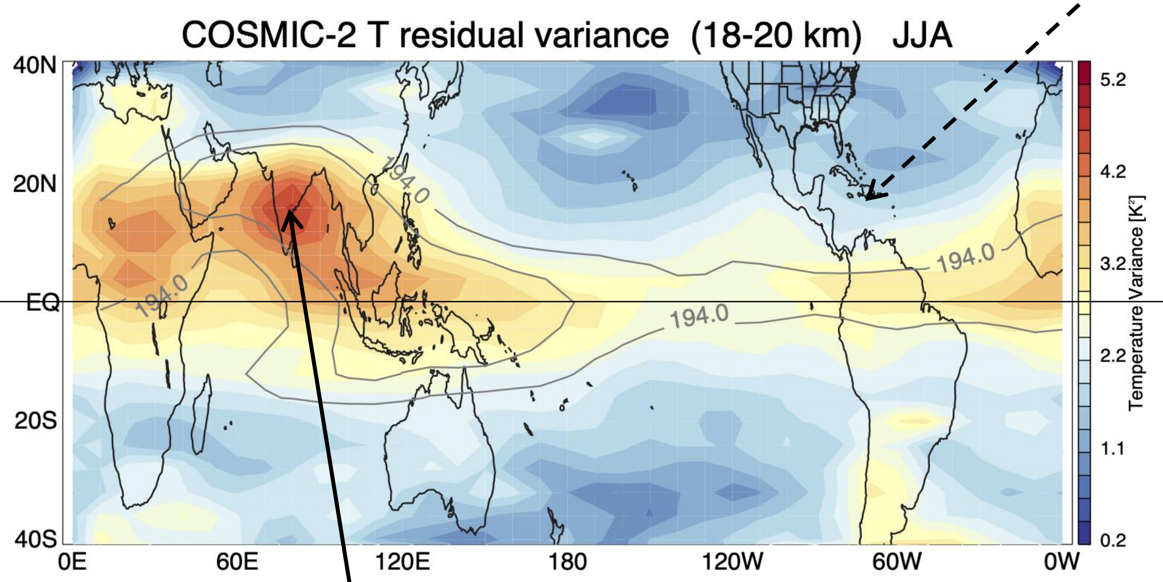


Fig. 7 Park et al. [2021]

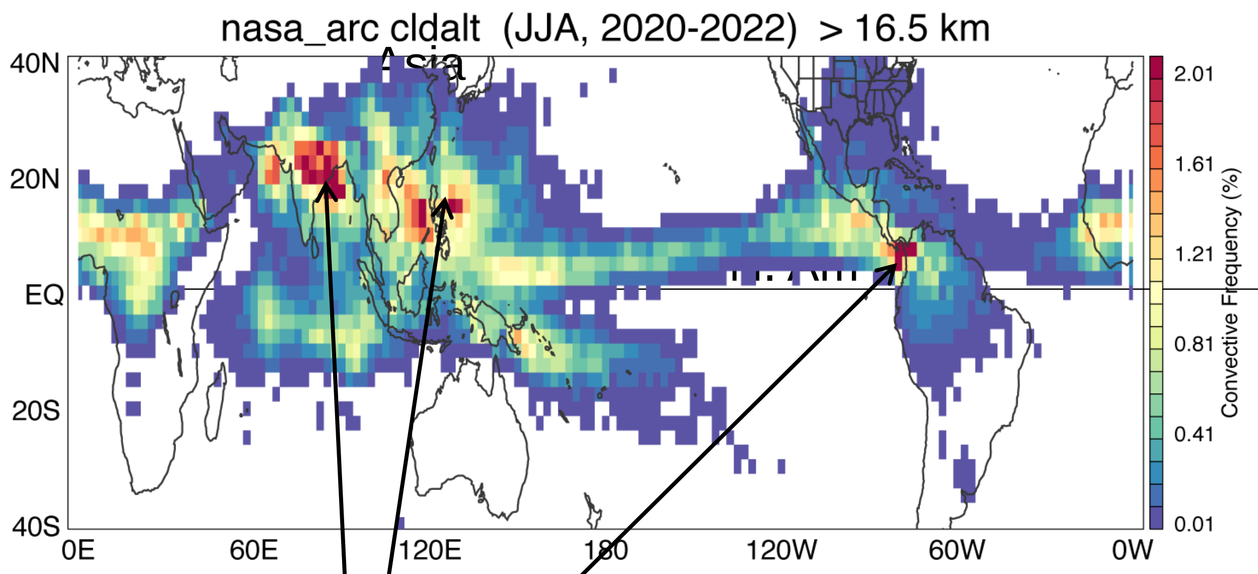


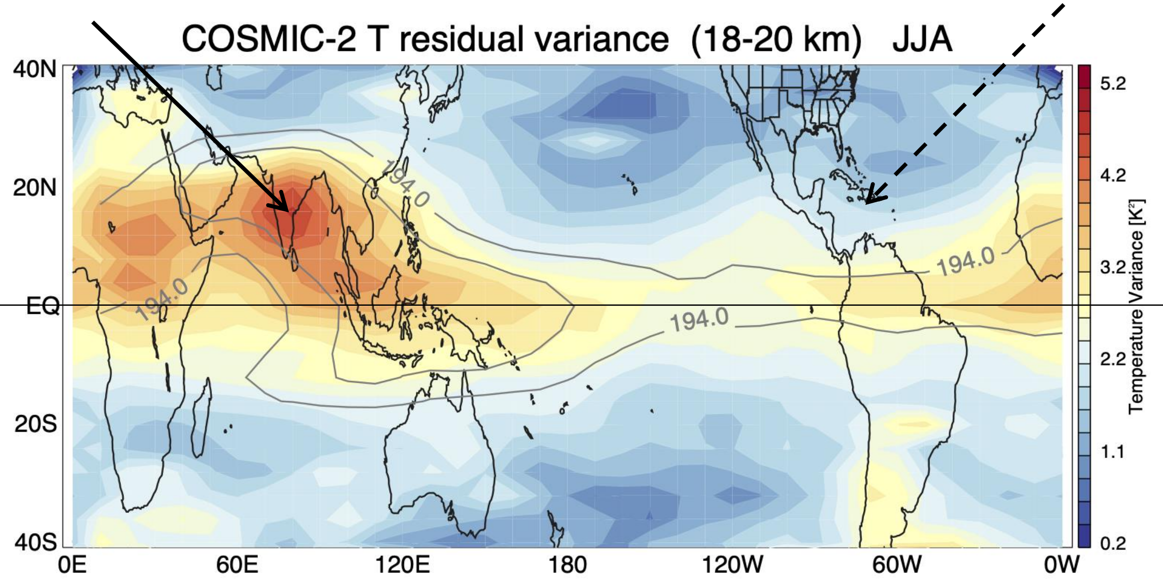
High water vapor

Asian monsoon
(wave activities)

Convection *vs*. Temp Variance (waves) Asia *vs*. N. America

Asian monsoon
(wave activities)



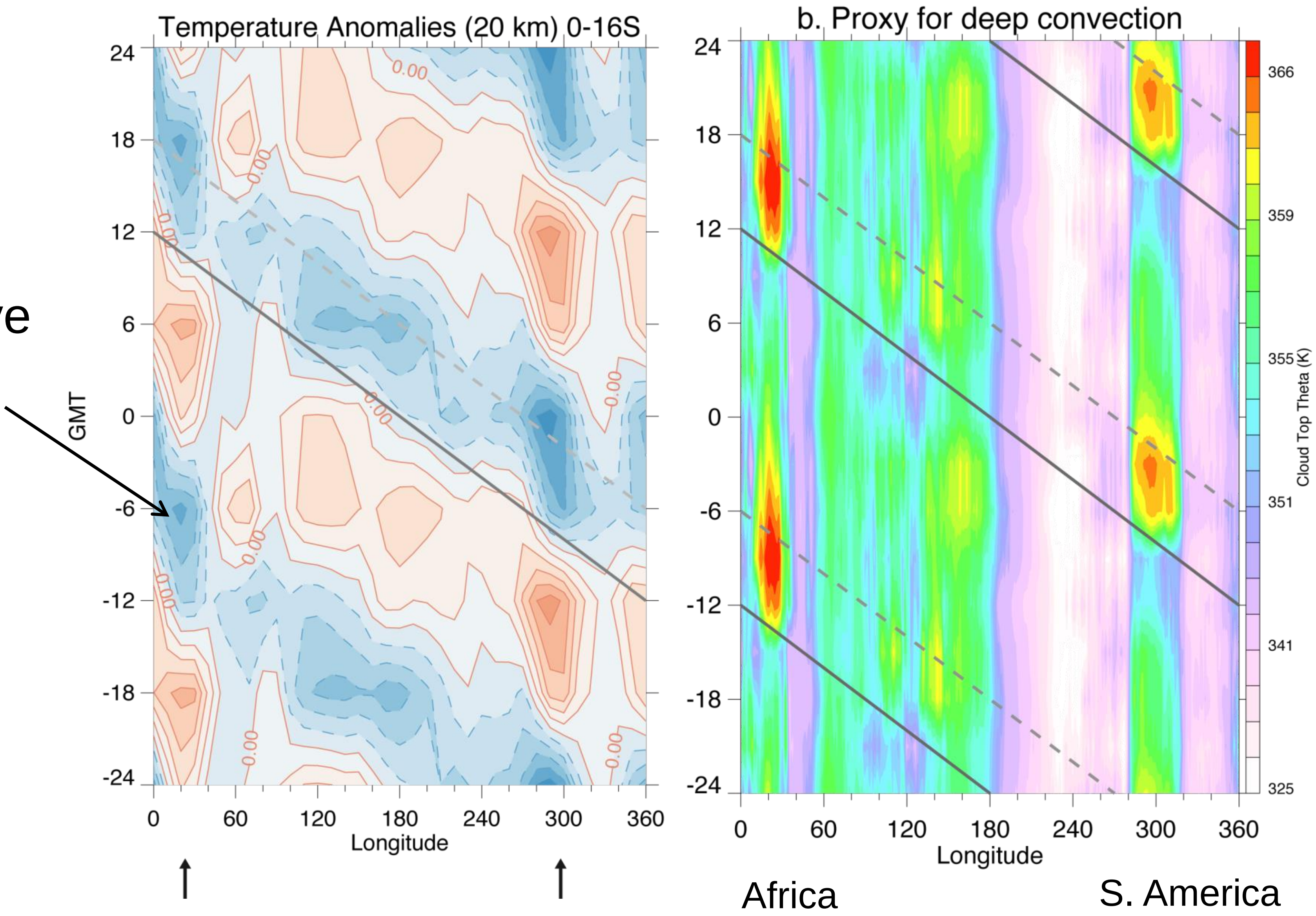


Convection

Large wave activities over Asian monsoon region where CPT is colder (not N. American monsoon region)

Deep convection modifies the temperature (diurnal cycle).

Westward propagating planetary wave pattern in temperature



Diurnal cycle in convection

Localized lower stratospheric cooling associated with tropical deep convection over continental regions [Randel et al. 2021].

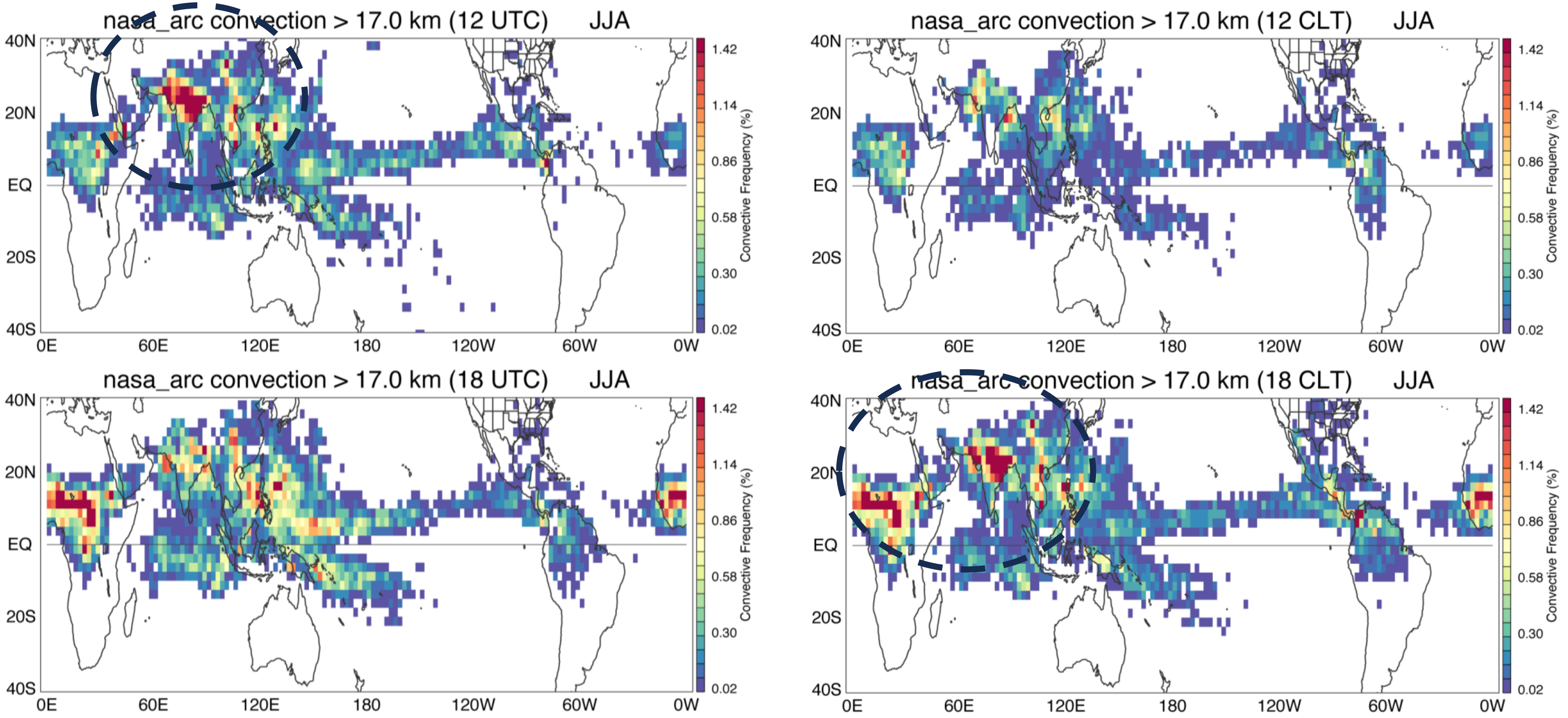
Diurnal cycle in convection better represented in current local time.

12UTC

12CLT

18UTC

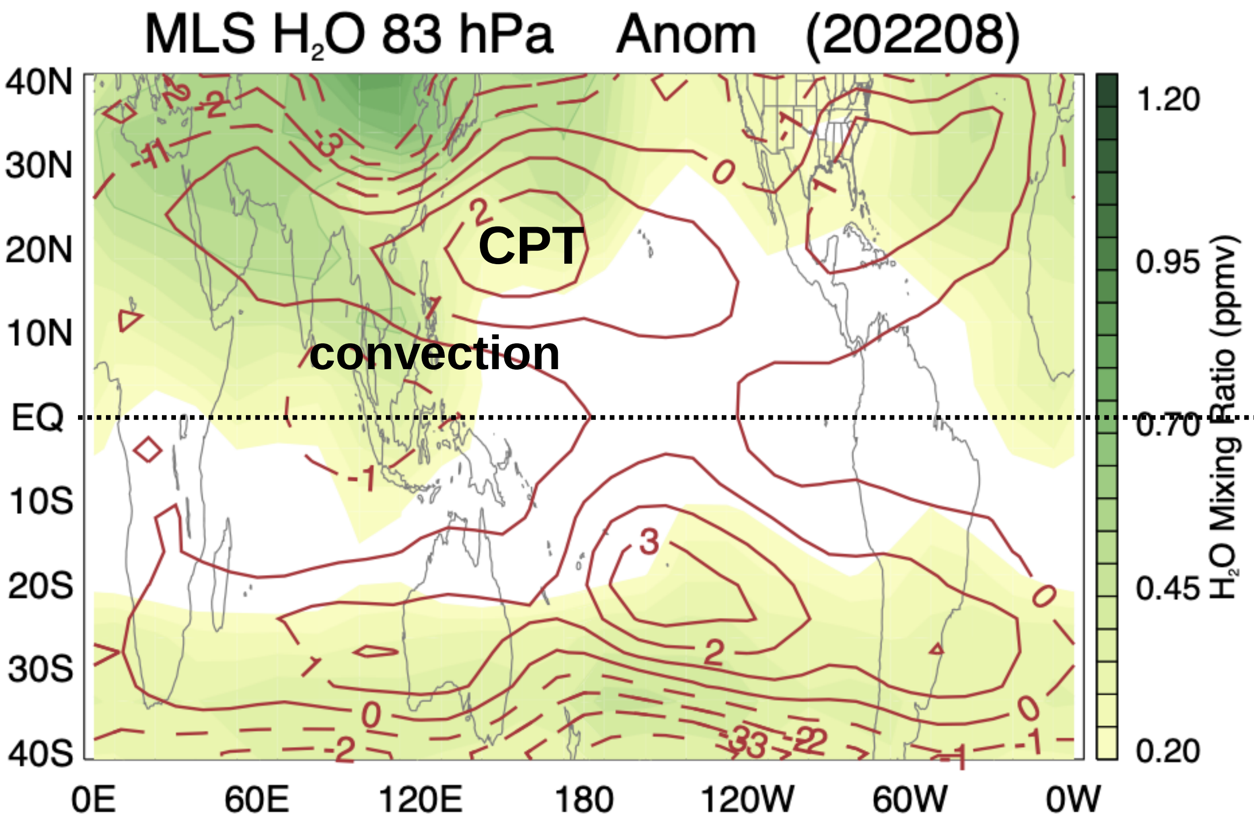
18CLT



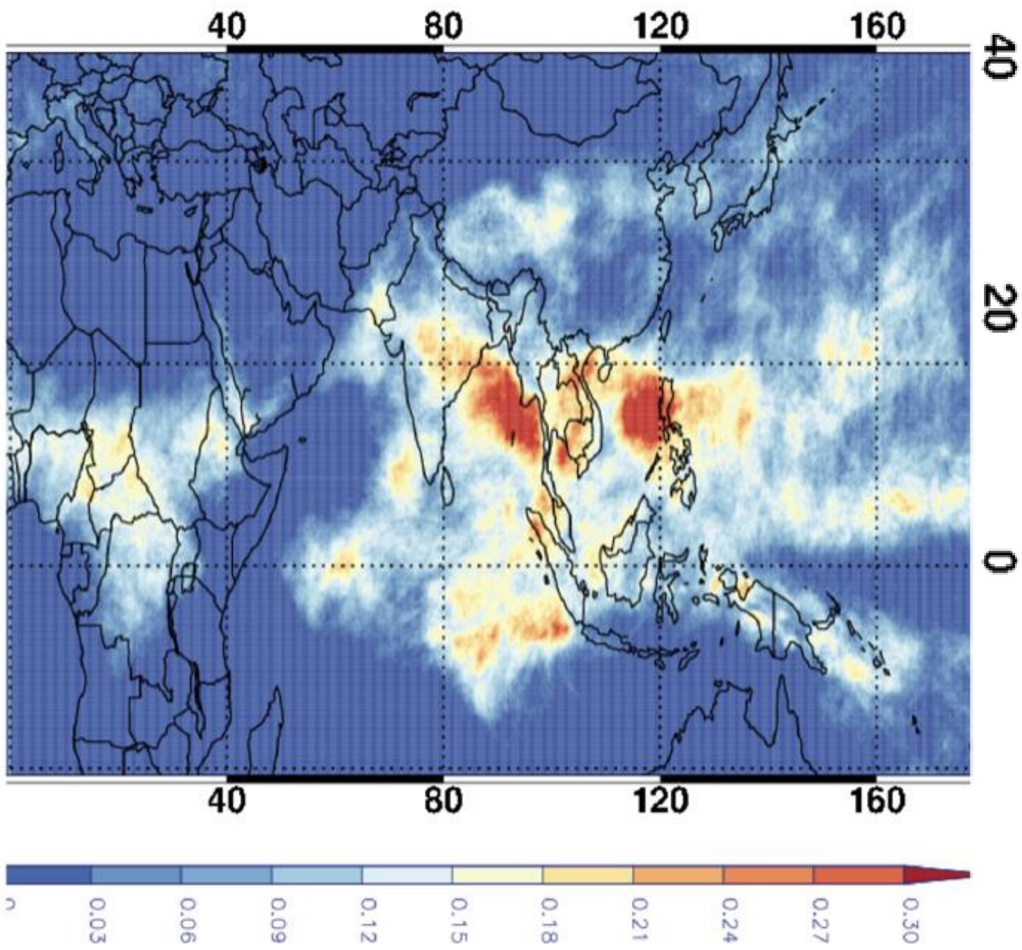
Convection
(UTC)

Convection
(Current Local Time)

Convective influence on CPT
(August 2022, ACCLIP)



August 2022

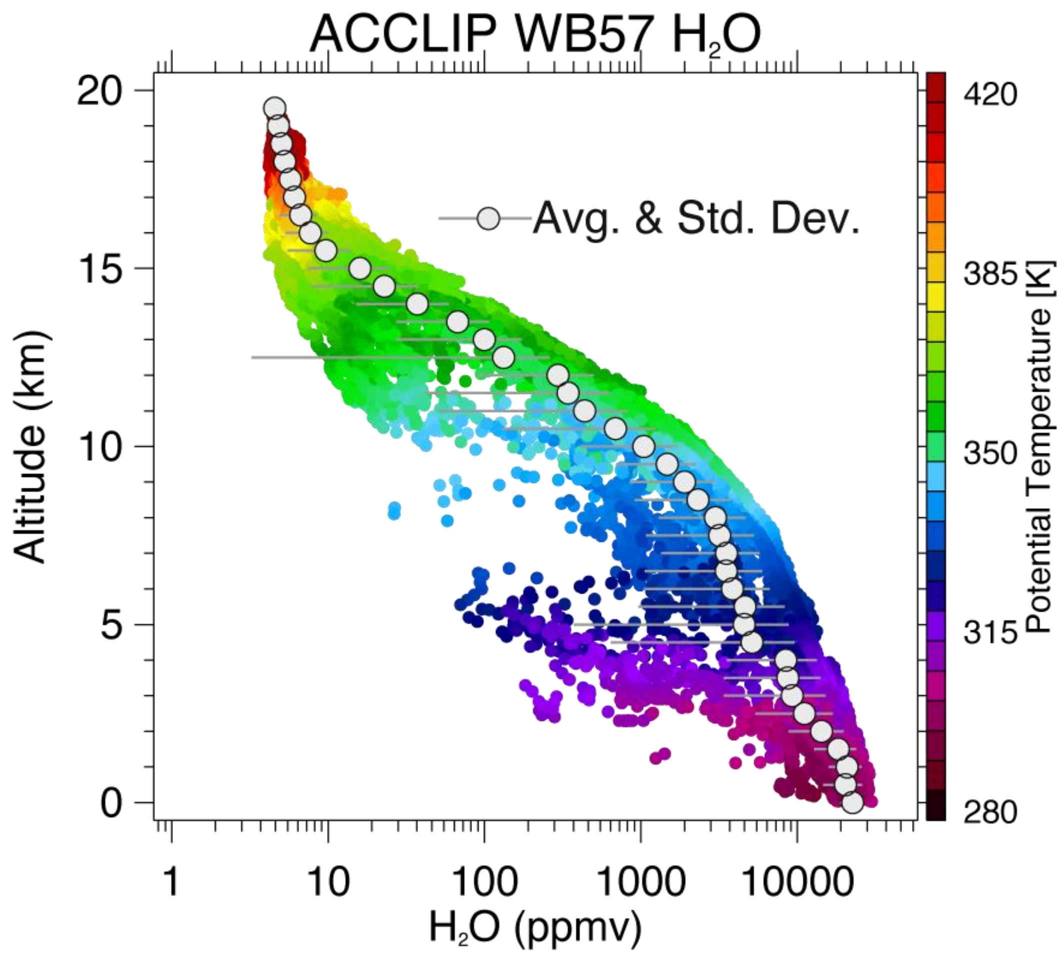


GPM MERG IR Brightness T < 235K
[Figure from Rei Ueyama]

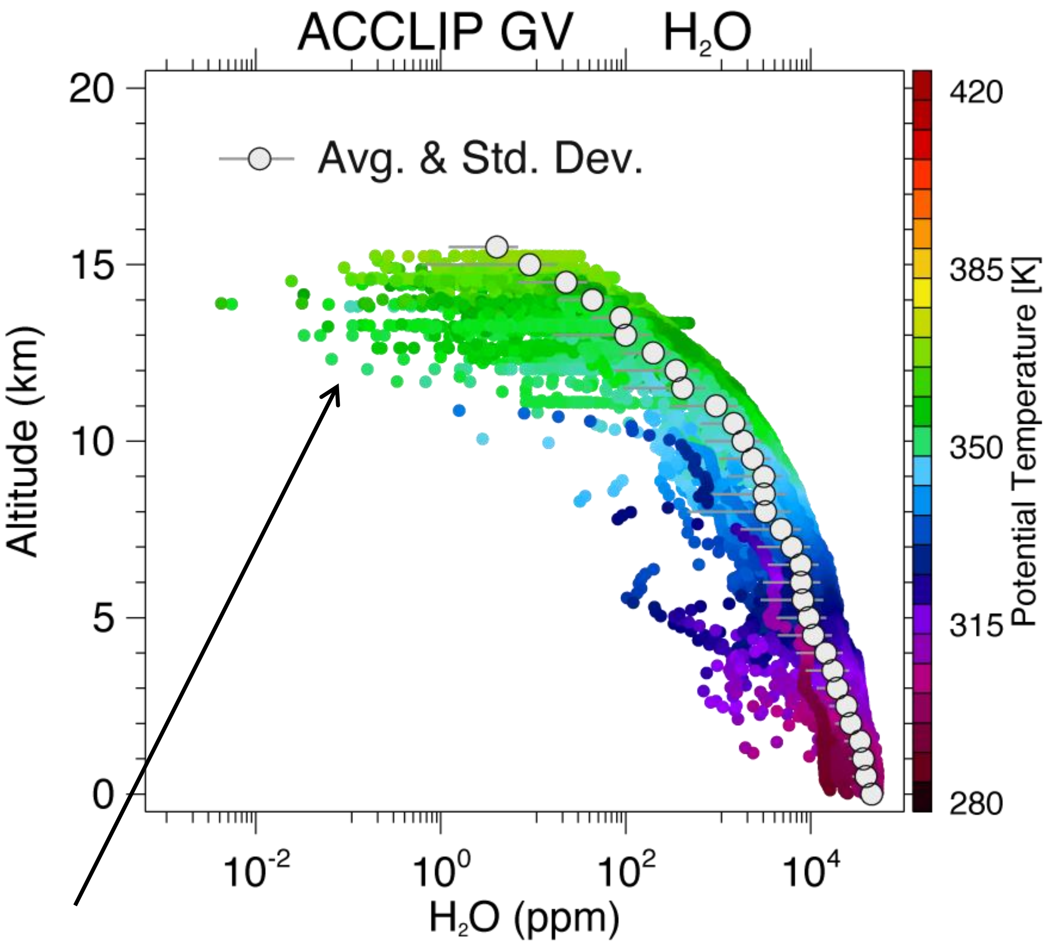
Convection was more frequent over Bay of Bengal and west of the Philippines in August 2022 compared to climatology (2006-2022).

In situ measurements - ACCLIP Campaign (2022)

NASA WB57



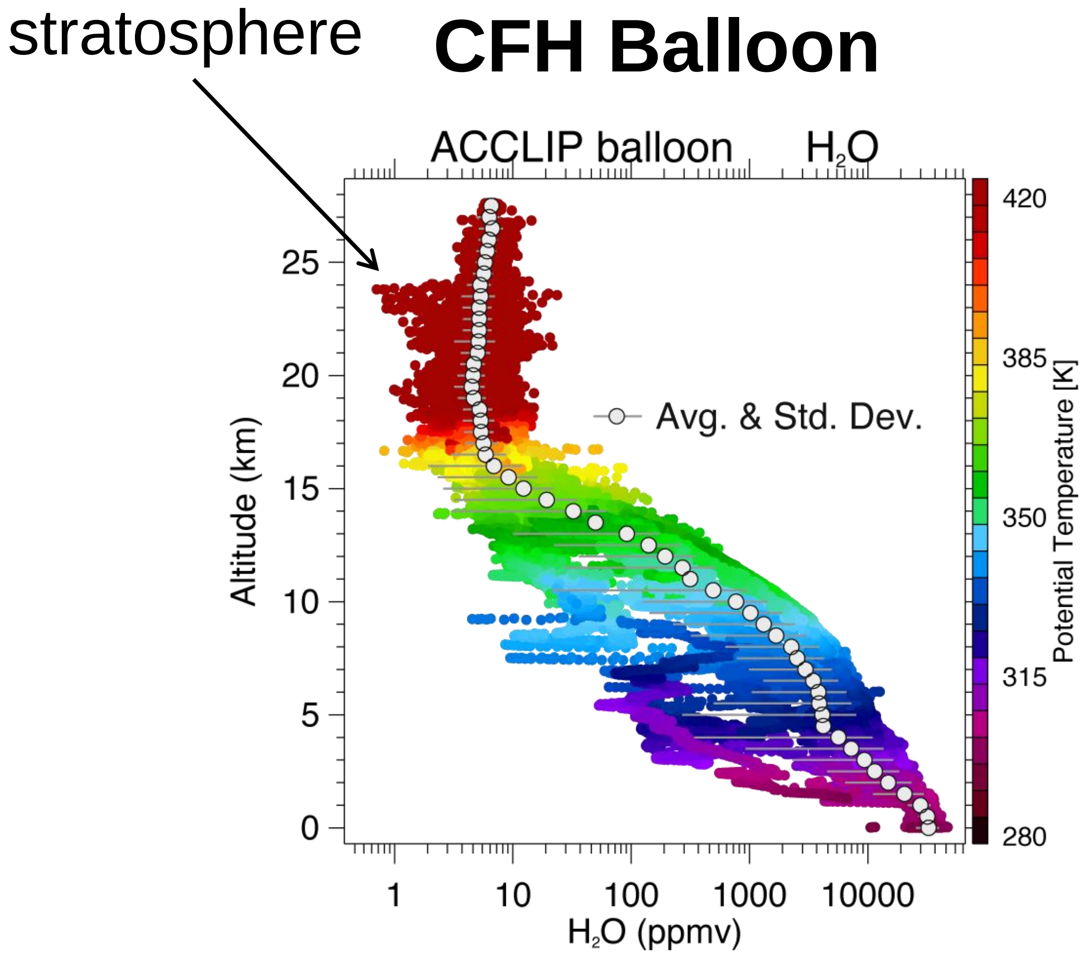
NSF GV



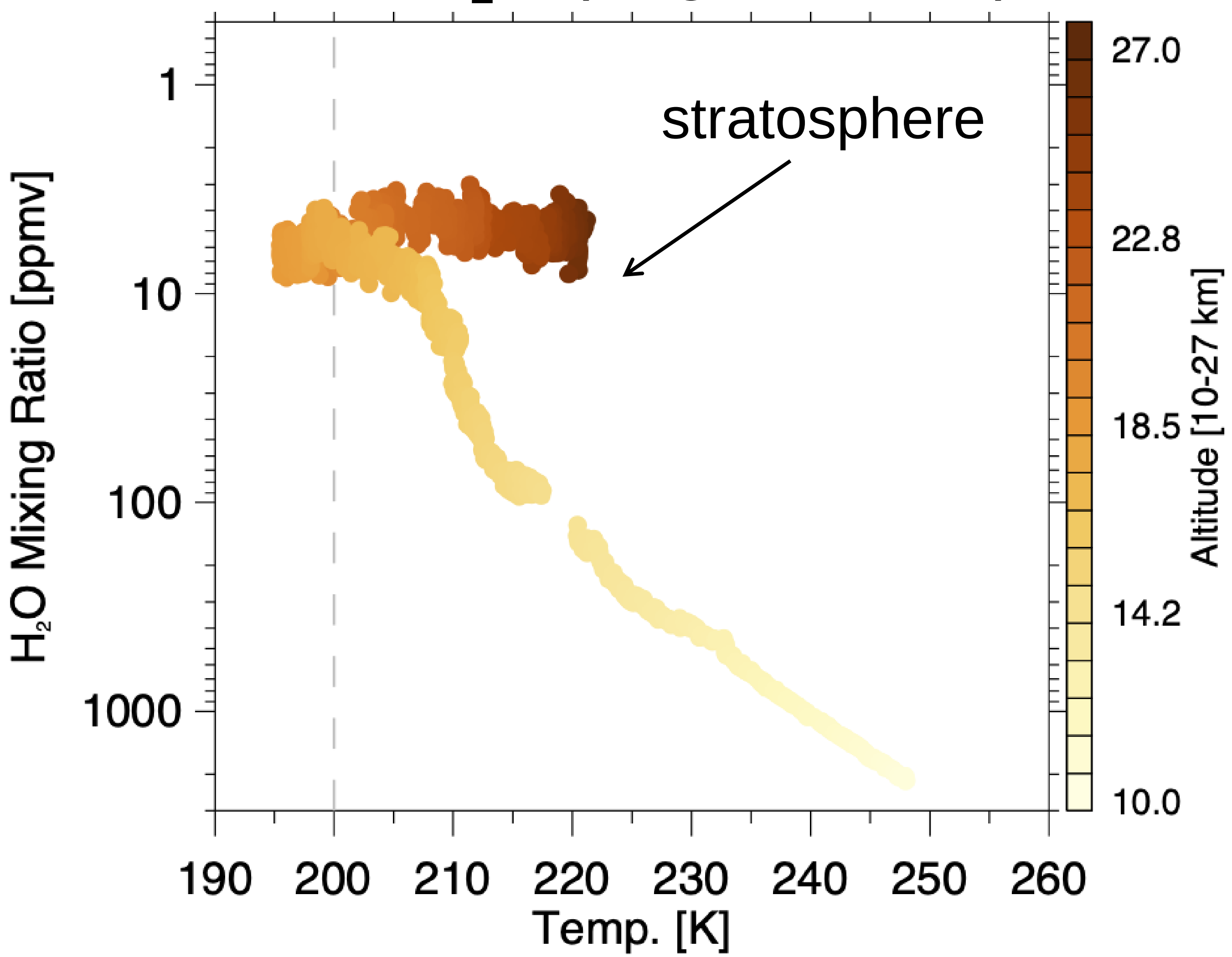
Low H_2O measured during ACCLIP

Balloon measurements - ACCLIP Campaign (2022)

CFH Balloon



T. *vs*. H_2O (Aug 19, 2022)



Further investigate Temperature & H_2O relationships over Asia.

Global chemistry climate model (WACCM) simulations

The Whole Atmosphere Community Climate Model (**WACCM**) is a comprehensive numerical model, spanning the range of altitude from the Earth's surface to the thermosphere (140 km).

WACCM-X

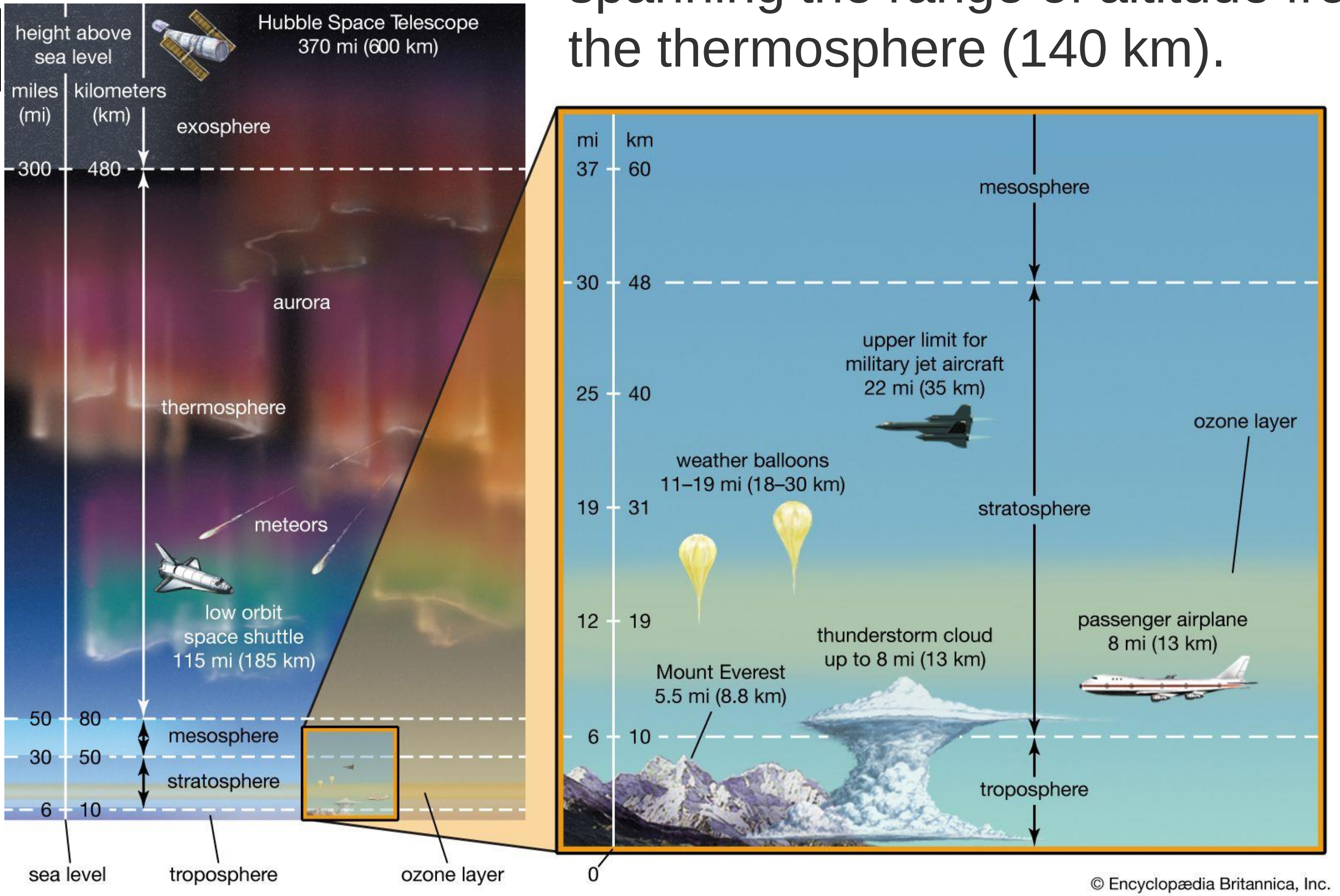
600 km

WACCM

140 km

CAM

45 km



https://cdn.britannica.com/42/90442-050-6CB42E65/layers-atmosphere-Earth-phenomena-heights.jpg

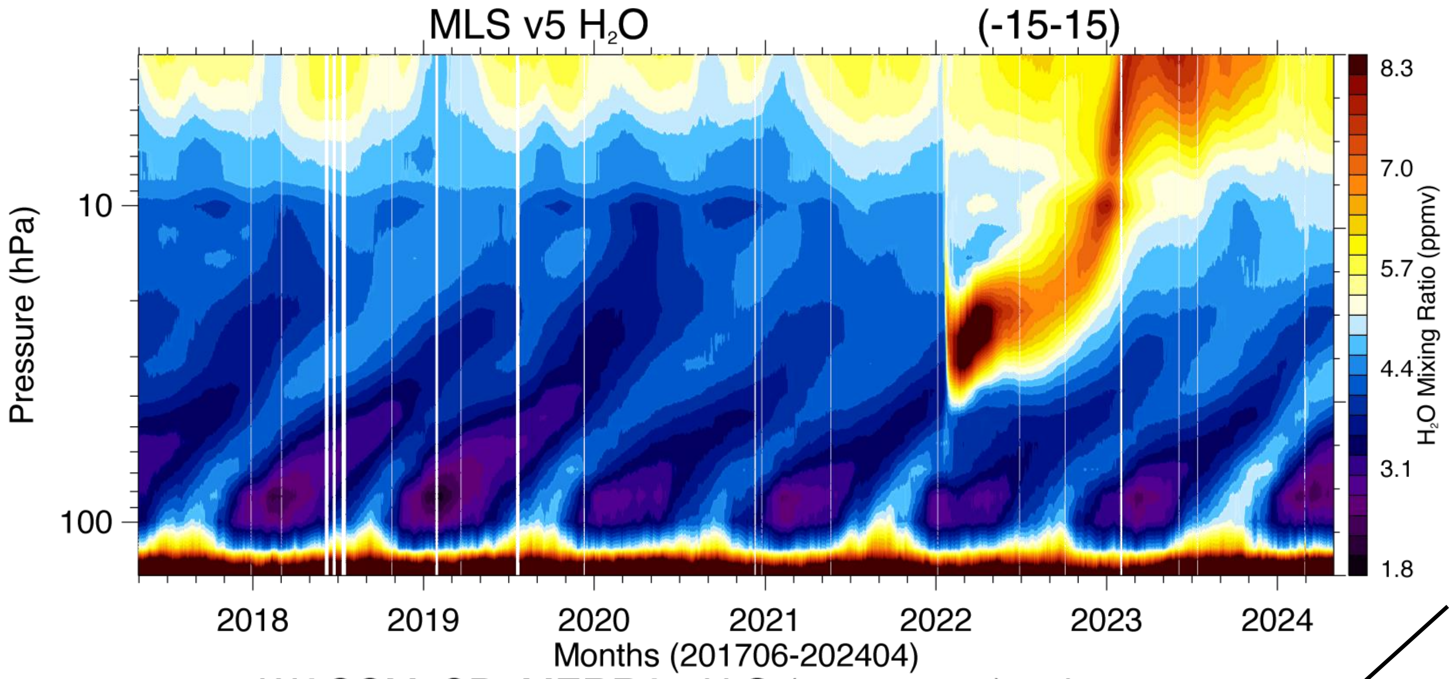
Learn more about **WACCM**

NSF NCAR CESM website

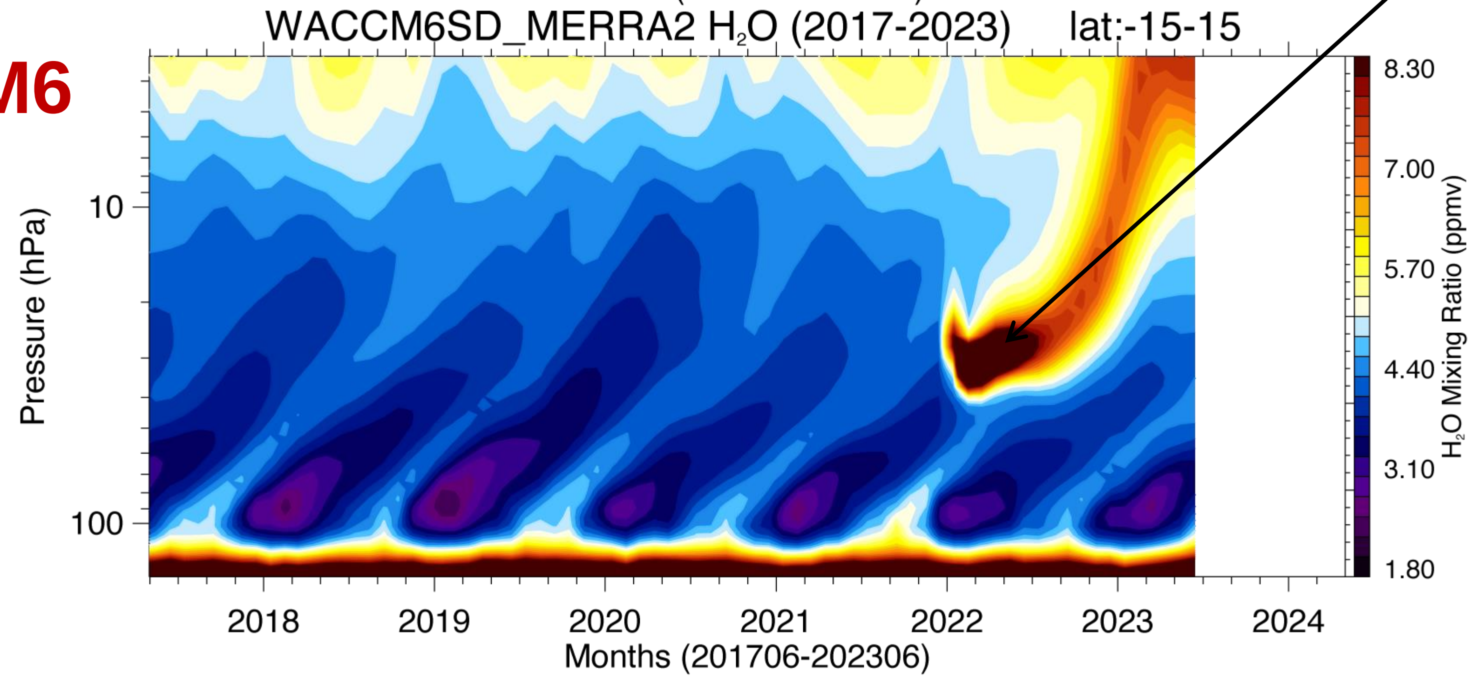
https://www.cesm.ucar.edu

H_2O Tape Recorder

MLS



WACCM6

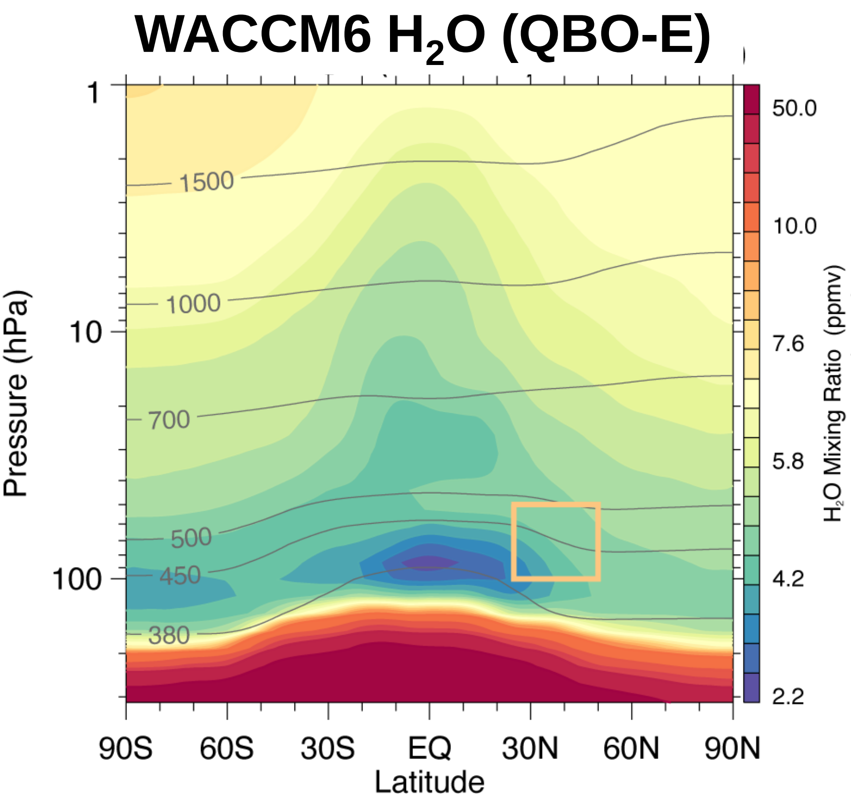


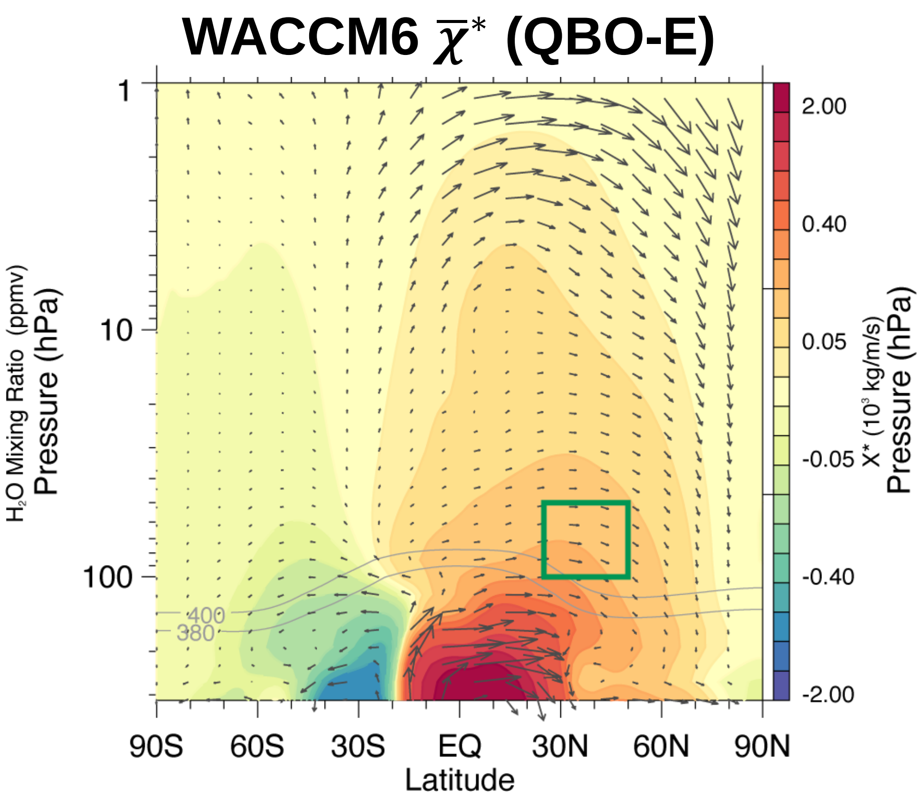
Hunga Tonga (Jan 2022)

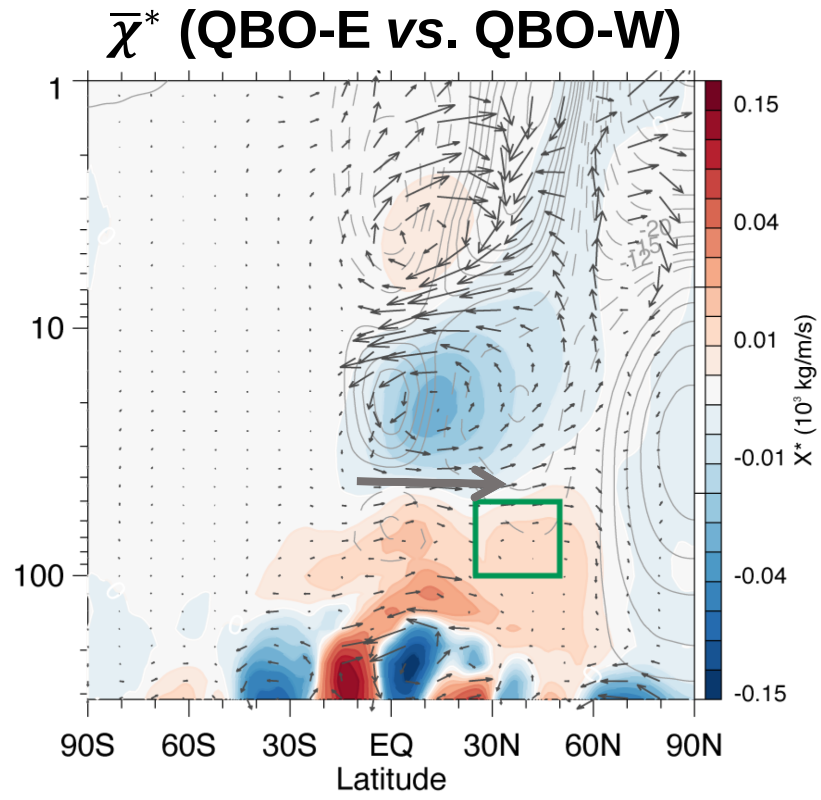
WACCM SD is able to simulate the Hunga Tonga Eruption (Jan 2022).

WACCM SD simulations (Jun Zhang)

Changes in H_2O and circulation in WACCM (*e.g.*, QBO)







Transformed Eulerian Mean (**TEM**) Mass stream function ($\bar{\chi}^*$)
Positive: clockwise
Negative: counter-clockwise

Stronger transport from the tropics to midlatitude during QBO-E.

Summary & Plans

1. During the NH summer, stratospheric **H_2O** is enhanced over Asian and North American monsoon regions in the **UTLS**. However, the correlations between **H_2O**, **CPT** and **convection** are unclear.

2. Large-scale transport plays a role in controlling lower stratospheric **H_2O** in boreal summer. Convection might control water vapor indirectly by modifying atmospheric waves thorough affecting local temperatures.

3. Higher **H_2O** and relatively warmer **CPT** were observed over the Western Pacific during the ACCLIP campaign in August 2022. Further work is needed to examine the correlations between **H_2O** and **CPT**.

4. Along with observational datasets, a global chemistry climate model (**WACCM**) will provide quantitative information on the changes in large-scale circulation in the **UTLS** region.