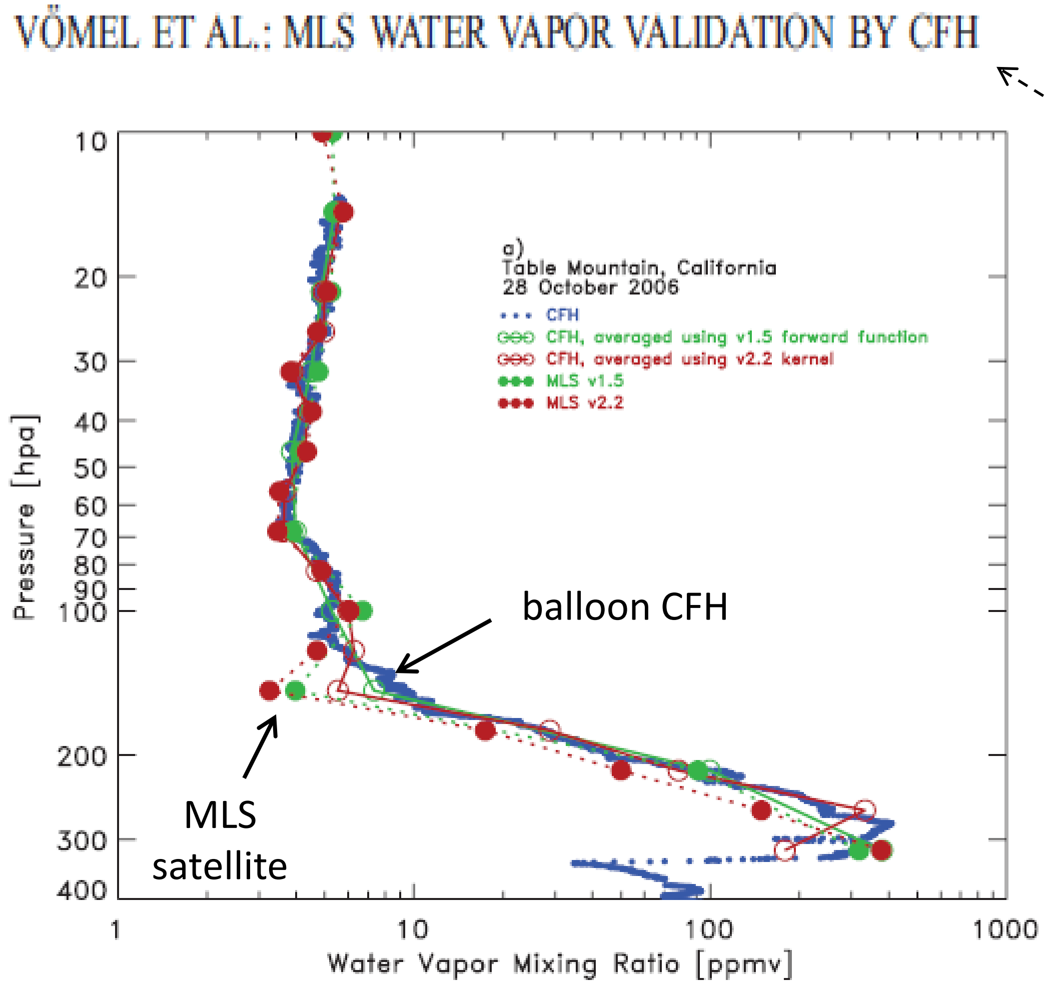
Stratospheric water vapor

- Measurements of stratospheric H_2O
- Global variability and seasonal cycle
- Simulations of H_2O: trajectory models and global models
- Long-term variability, trends and links to tropical tropopause temperatures
- Summer monsoons

Measurements of stratosphere water vapor

JGR, 2009



cryogenic
frostpoint
hygrometer

JGR, 2011

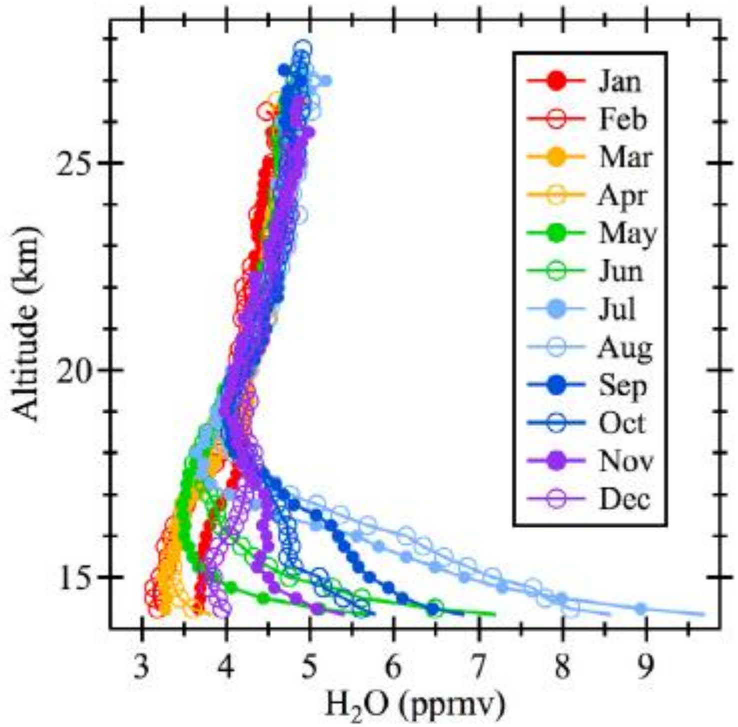
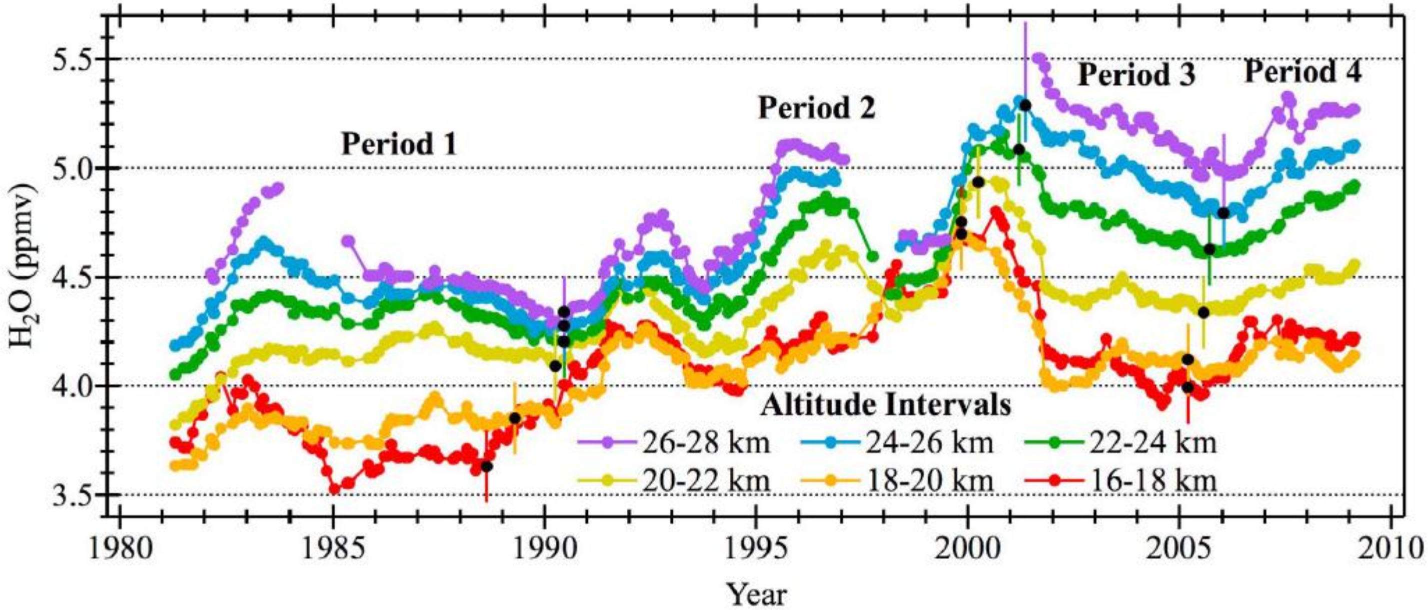


Figure 3. Monthly averaged vertical profiles of stratospheric water vapor over Boulder, Colorado. Each average profile is based on 22–37 individual soundings in the specified month during 1980–2010. The seasonal cycle is evident for altitudes <19 km.

balloon frostpoint hygrometer measurements at Boulder (40° N)

(~ 1 per month)
1980 - present

Famous long record from Boulder



Oltmans and Hoffman 1995; Oltmans et al, 2000; Hurst et al 2011

Increase in lower-stratospheric water vapour at a mid-latitude Northern Hemisphere site from 1981 to 1994

S. J. Oltmans & D. J. Hofmann

Nature 1995

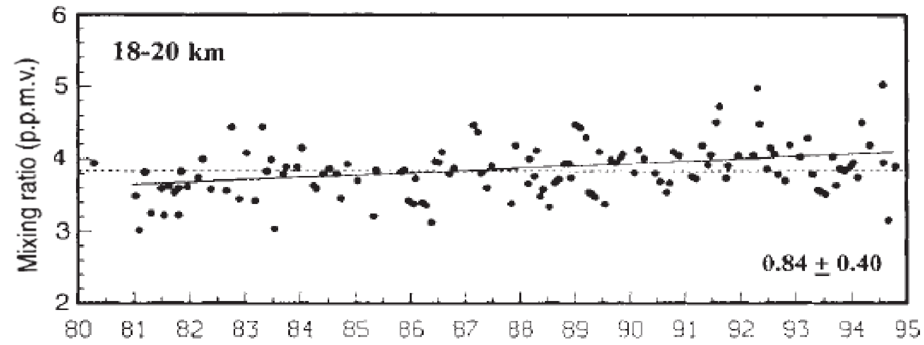
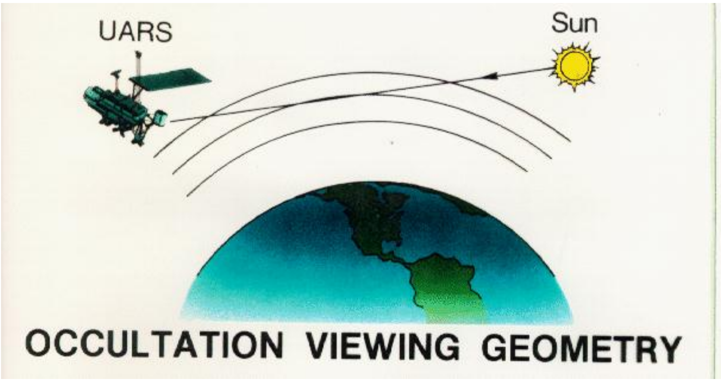


TABLE 1 Observations of water vapour mixing ratios

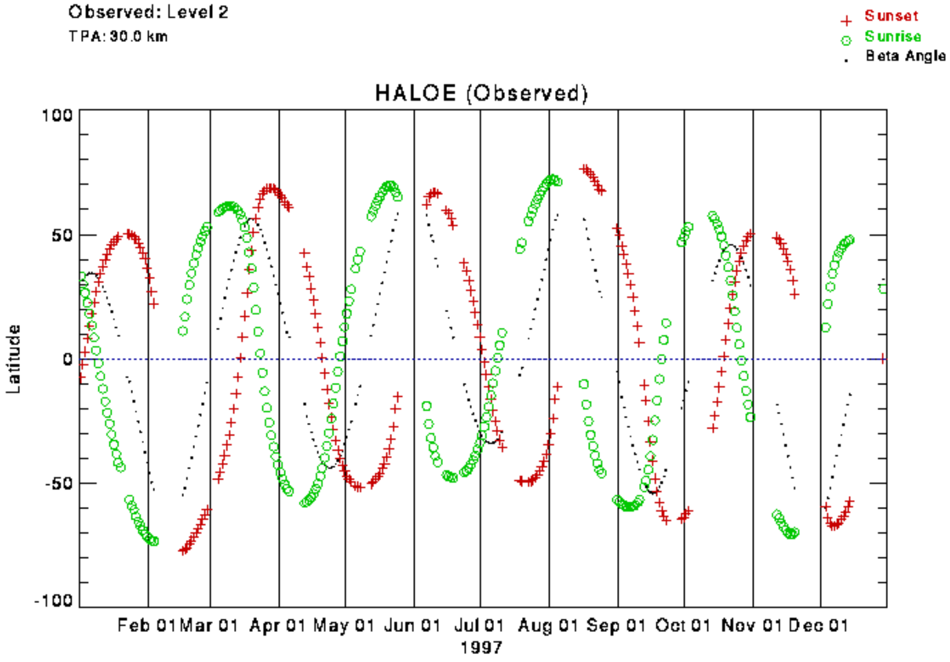
Height (km)	Mean (p.p.m.v.)	Standard deviation (p.p.m.v.)	Number of observations	Trend (% yr^{-1})	95% confidence interval (% yr^{-1})
10–12	59.2	36.46	125	1.03	2.72
12–14	11.88	5.94	125	0.49	2.21
14–16	4.66	0.98	125	0.54	0.93
16–18	3.87	0.48	125	0.73*	0.55
18–20	3.85	0.35	124	0.84*	0.40
20–22	4.07	0.29	119	0.54*	0.32
22–24	4.21	0.29	114	0.38*	0.31
24–26	4.29	0.30	97	0.34	0.34

significant trends
nearly + 1 % / year

HALOE solar occultation Measurements



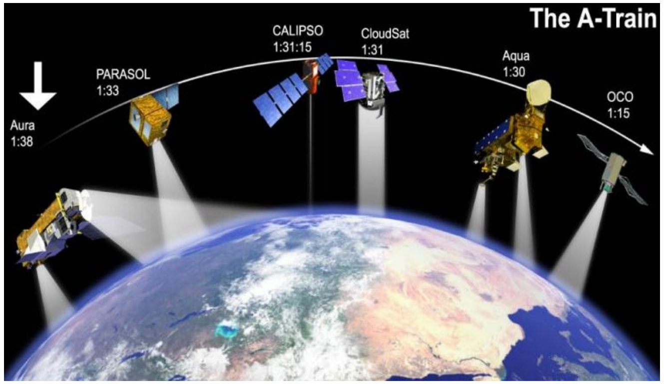
- Good vertical resolution ~2 km
- Limited space-time sampling
- Observations 1992-2005



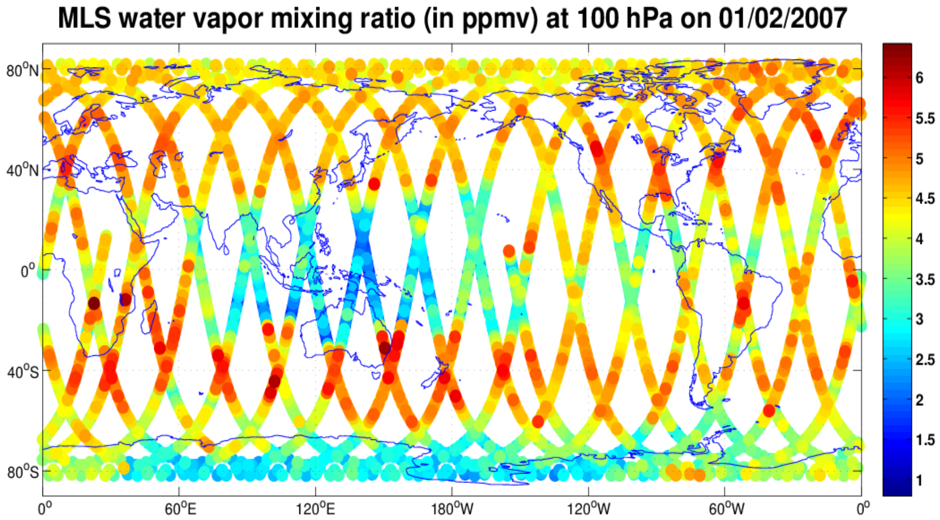
Latitude Progression

HALOE sampling for one year

Aura Microwave Limb Sounder (MLS)



- Vertical resolution ~3 km
- Daily global sampling
- Observations 2004-present



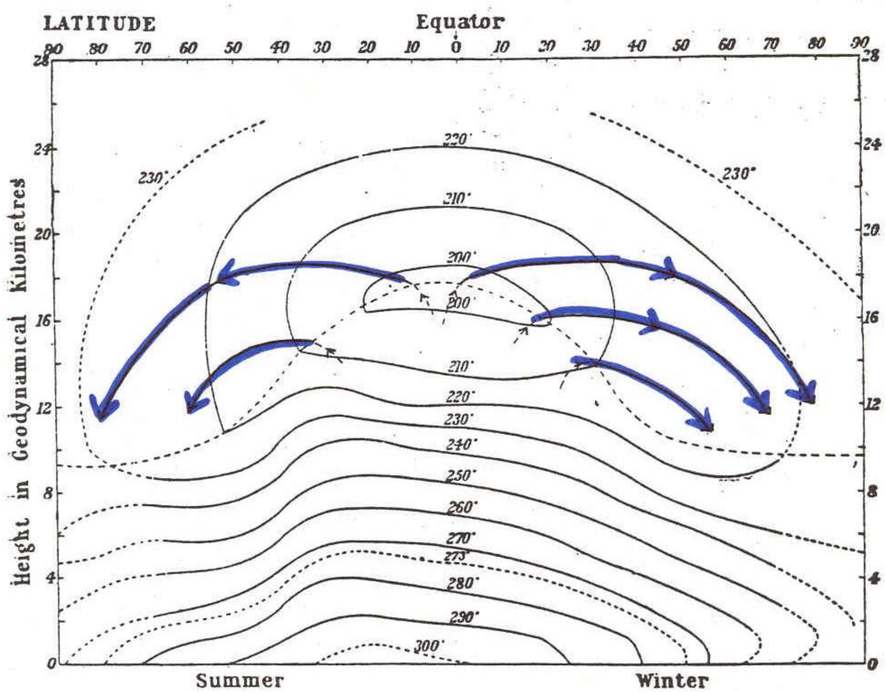
MLS daily orbital data

EVIDENCE FOR A WORLD CIRCULATION PROVIDED BY MEASUREMENTS OF HELIUM AND WATER VAPOUR DISTRIBUTION IN THE STRATOSPHERE

QJRMS, 1949

By A. W. BREWER, M.Sc., A.Inst.P.

The stratosphere is extremely dry because air is dehydrated passing the cold tropical tropopause



Isotherms over the Globe

FIG. 5. A supply of dry air is maintained by a slow mean circulation from the equatorial tropopause.

Workshop on Brewer-Dobson circulation, Oxford University, December 1999

EVIDENCE FOR A WORLD CIRCULATION PROVIDED BY MEASUREMENTS OF HELIUM AND WATER VAPOUR DISTRIBUTION IN THE STRATOSPHERE

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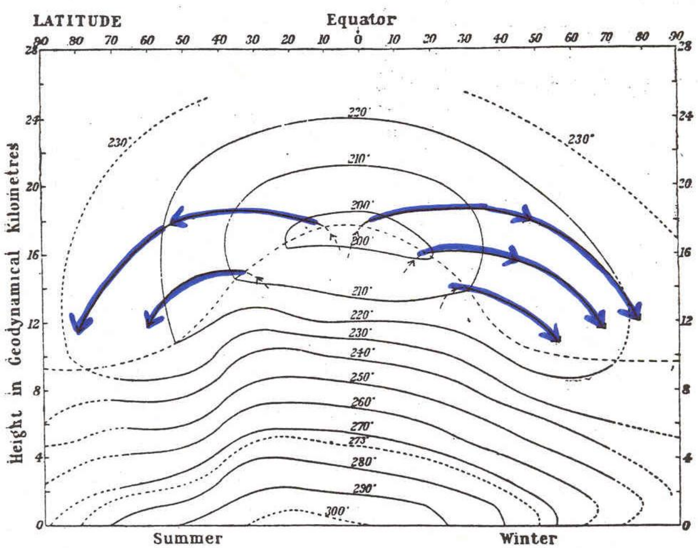
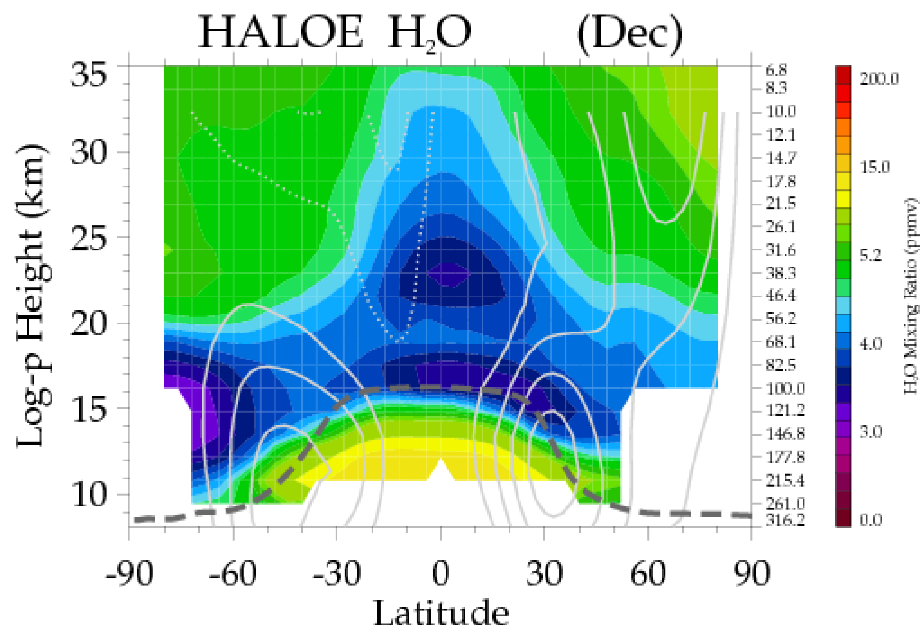


Isotherms over the Globe

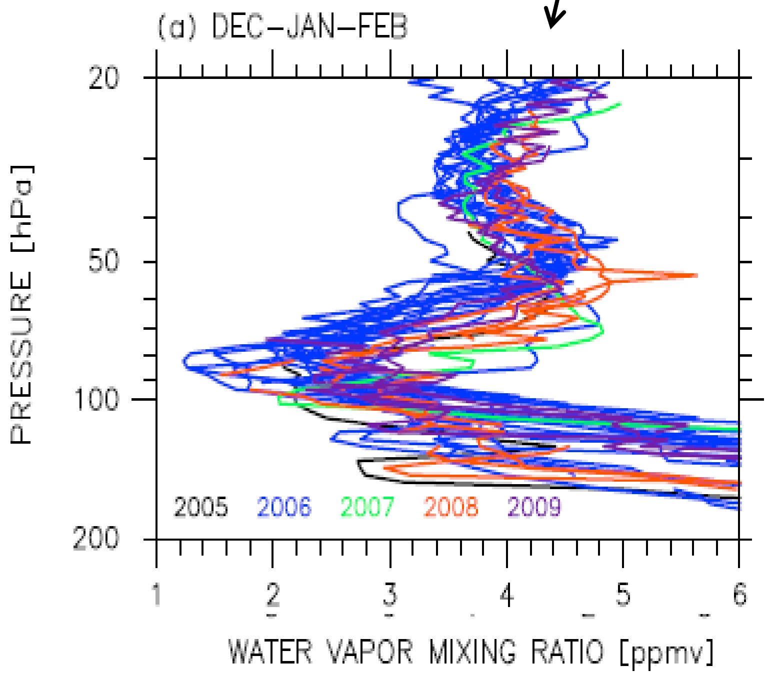
FIG. 5. A supply of dry air is maintained by a slow mean circulation from the equatorial tropopause.

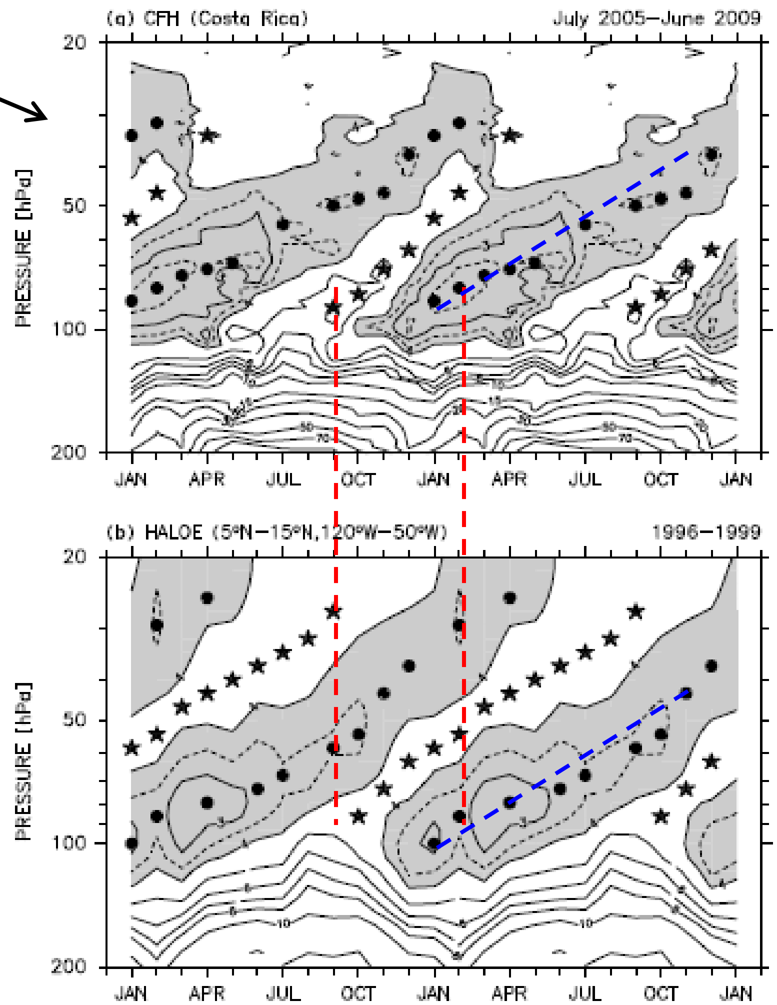
HALOE global climatology



JGR 2010

Tropical balloon measurements

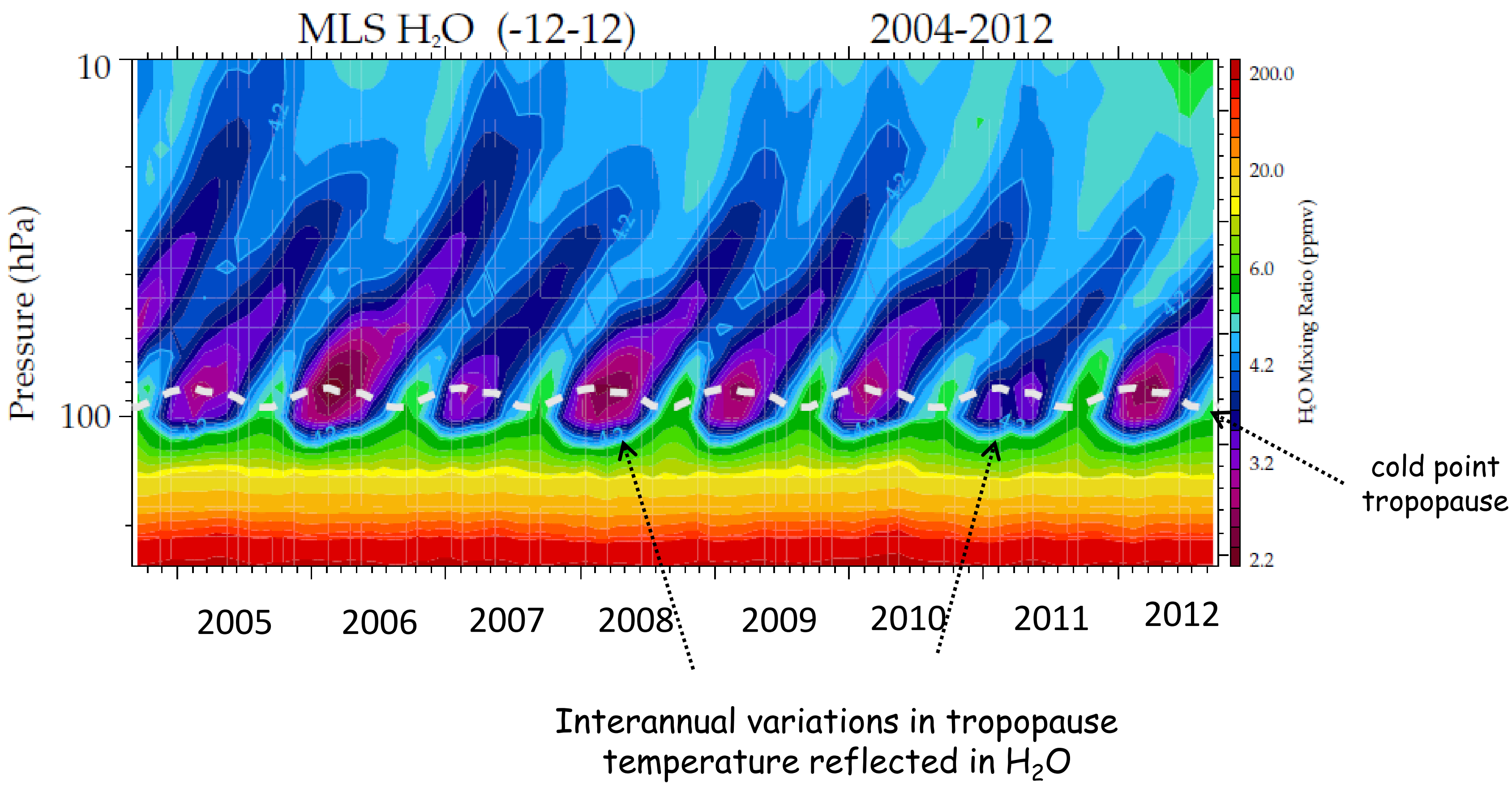




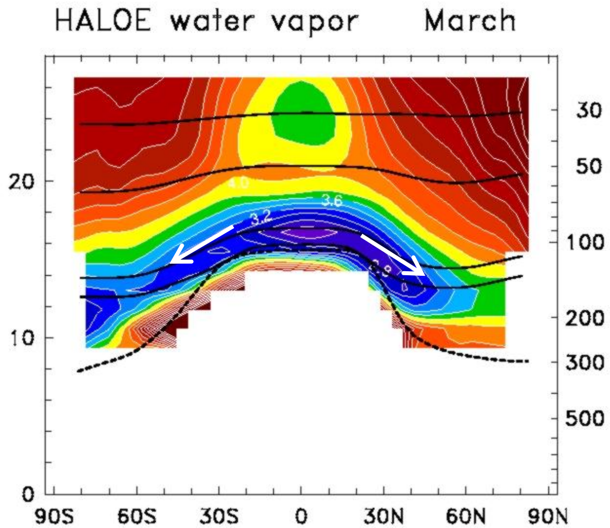
balloons

HALOE satellite data

Tropical tape recorder observed by MLS 2004-2012

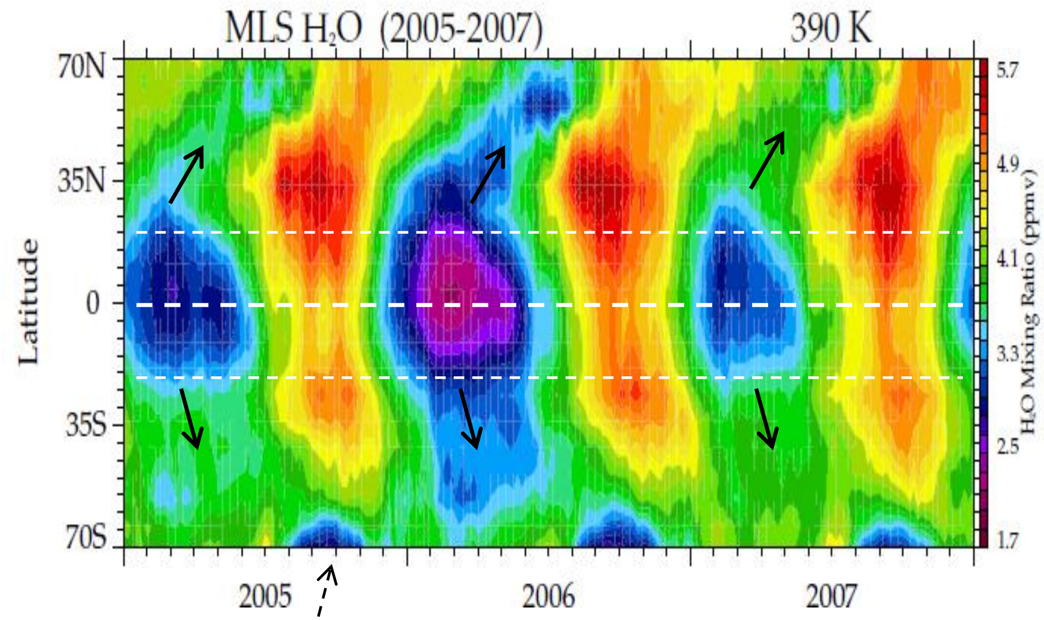


Lower stratosphere horizontal tape recorder 390 K



quasi-horizontal transport
in lower stratosphere, approximately
following 400 K isentrope

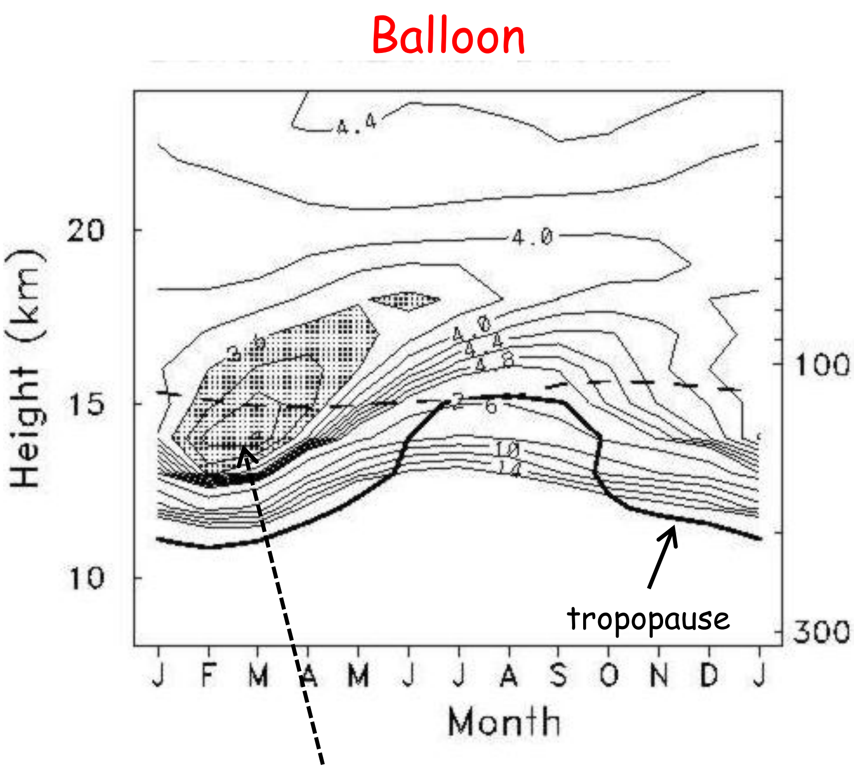
3 years from MLS observations

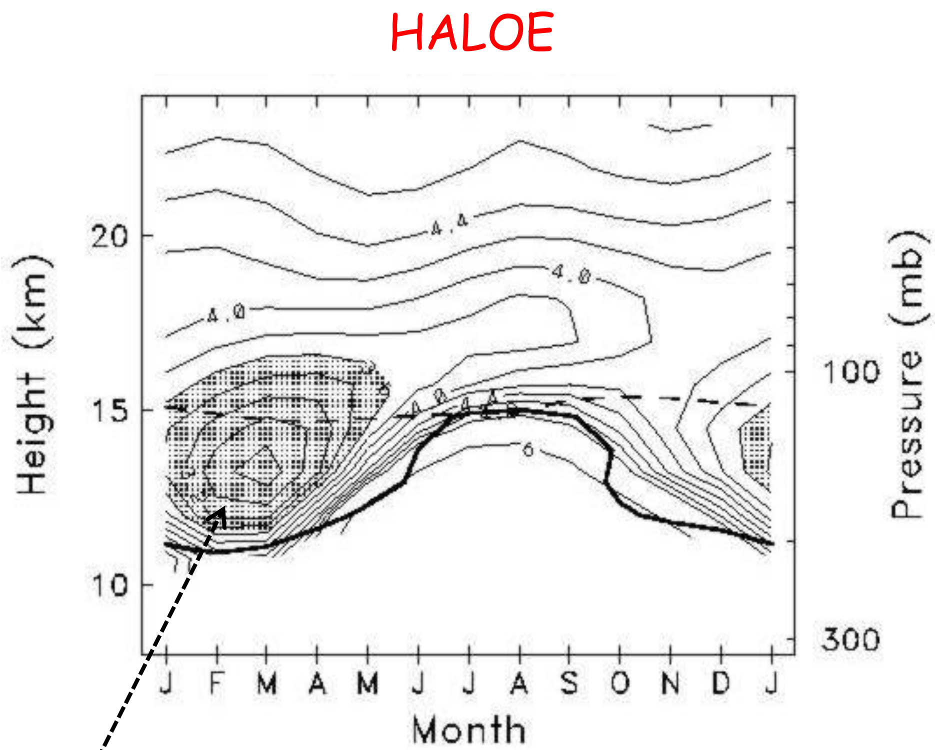


dehydration in
Antarctic polar vortex

Tropical dehydration
zone is ~20 N-S

Climatology at Boulder (40° N)

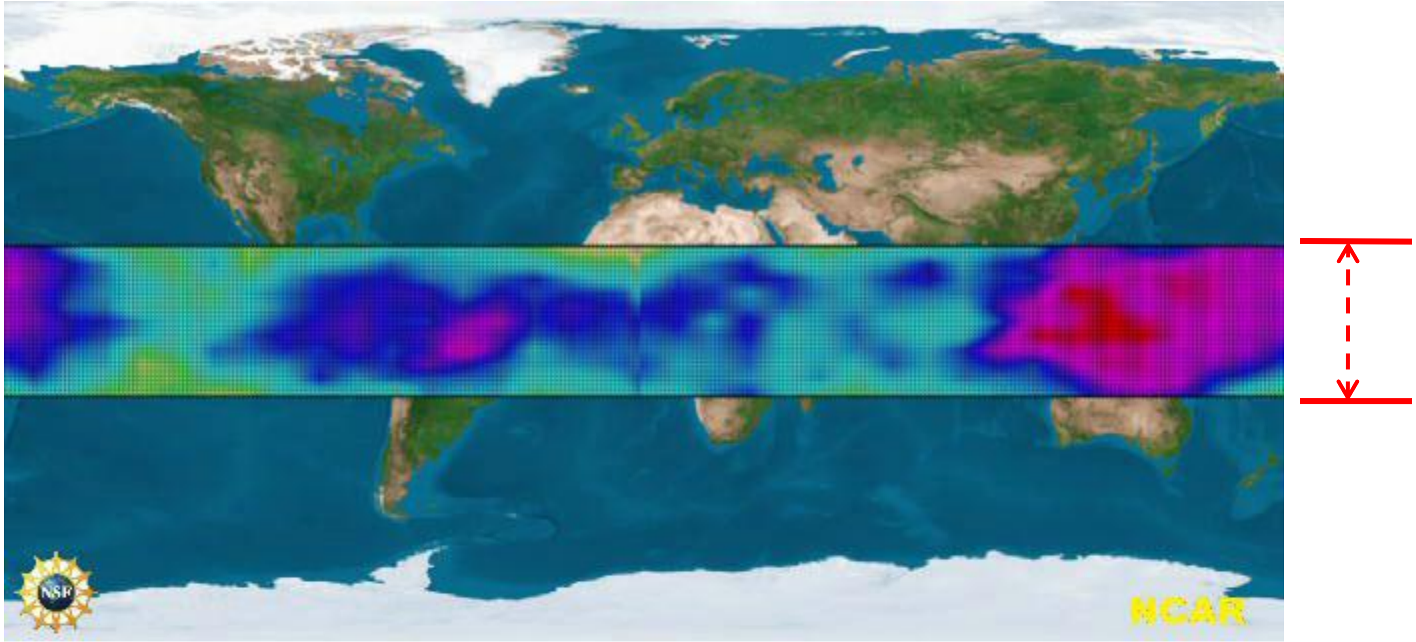




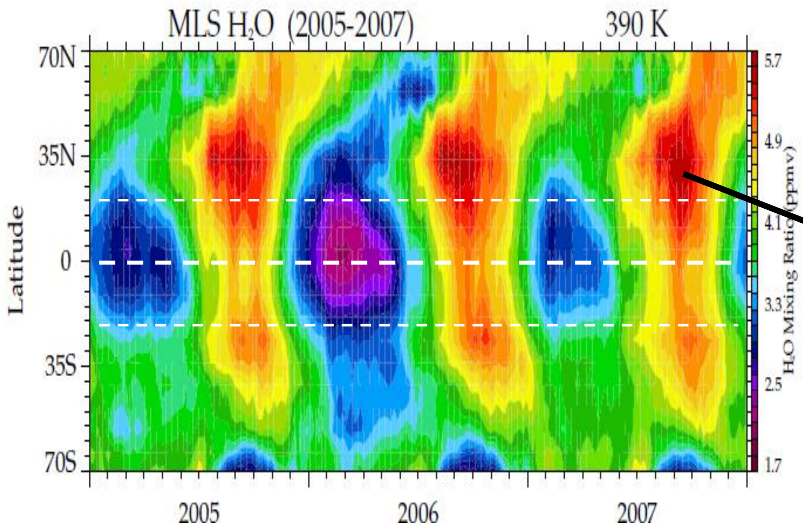
seasonal minimum due to transport from tropics

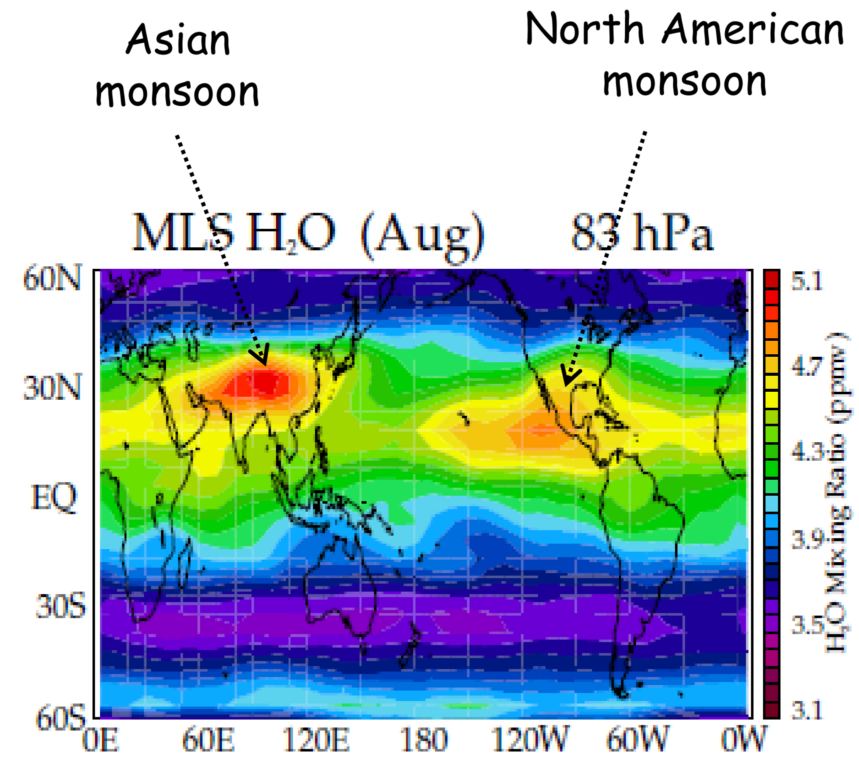
Trajectory simulation of transport on 400 K isentrope

calculations for June-August 2001



Summertime lower stratosphere maxima linked to monsoon circulations

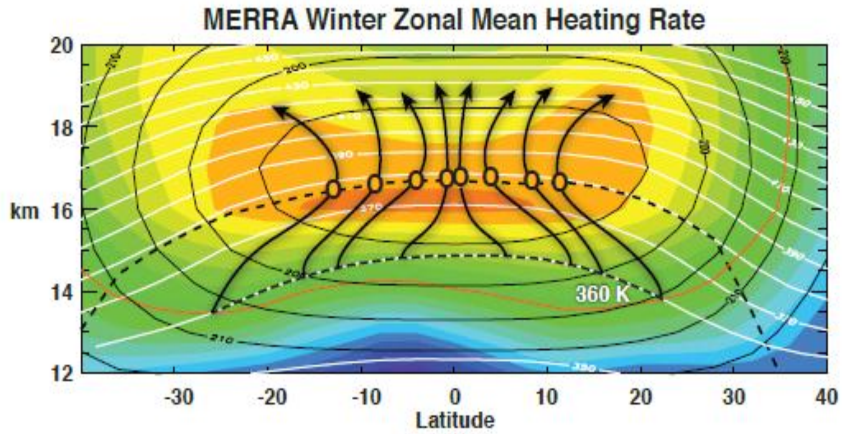




Trajectory simulations

* dehydration at Lagrangian cold point *

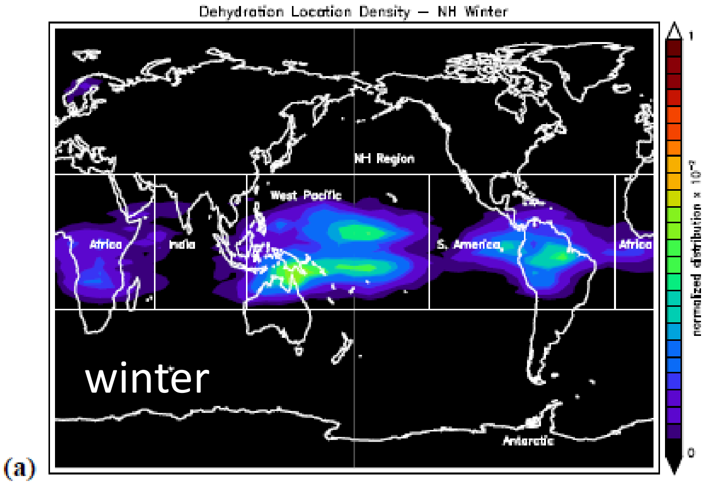
Schoeberl and Dessler 2011

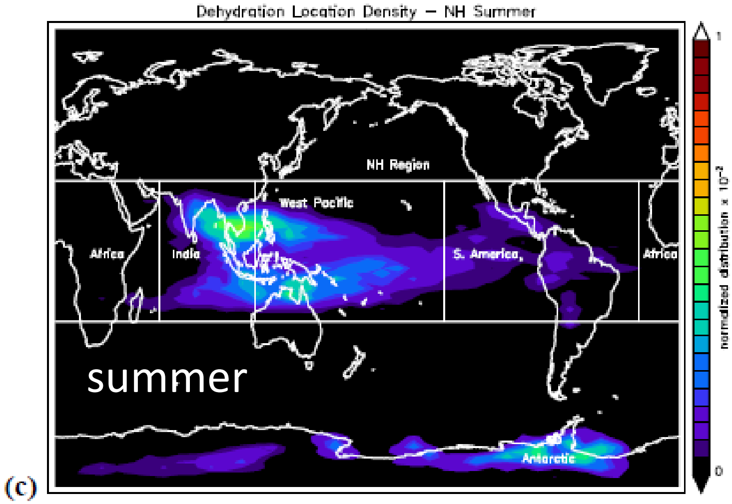


Note that results are sensitive
to many details of the calculations:
kinematic vs. diabatic trajectories,
temperature data, supersaturation,….

also Fueglistaler et al 2005 JGR
Liu, Fueglistaler, Haynes, JGR 2010
Wright et al 2011, others…

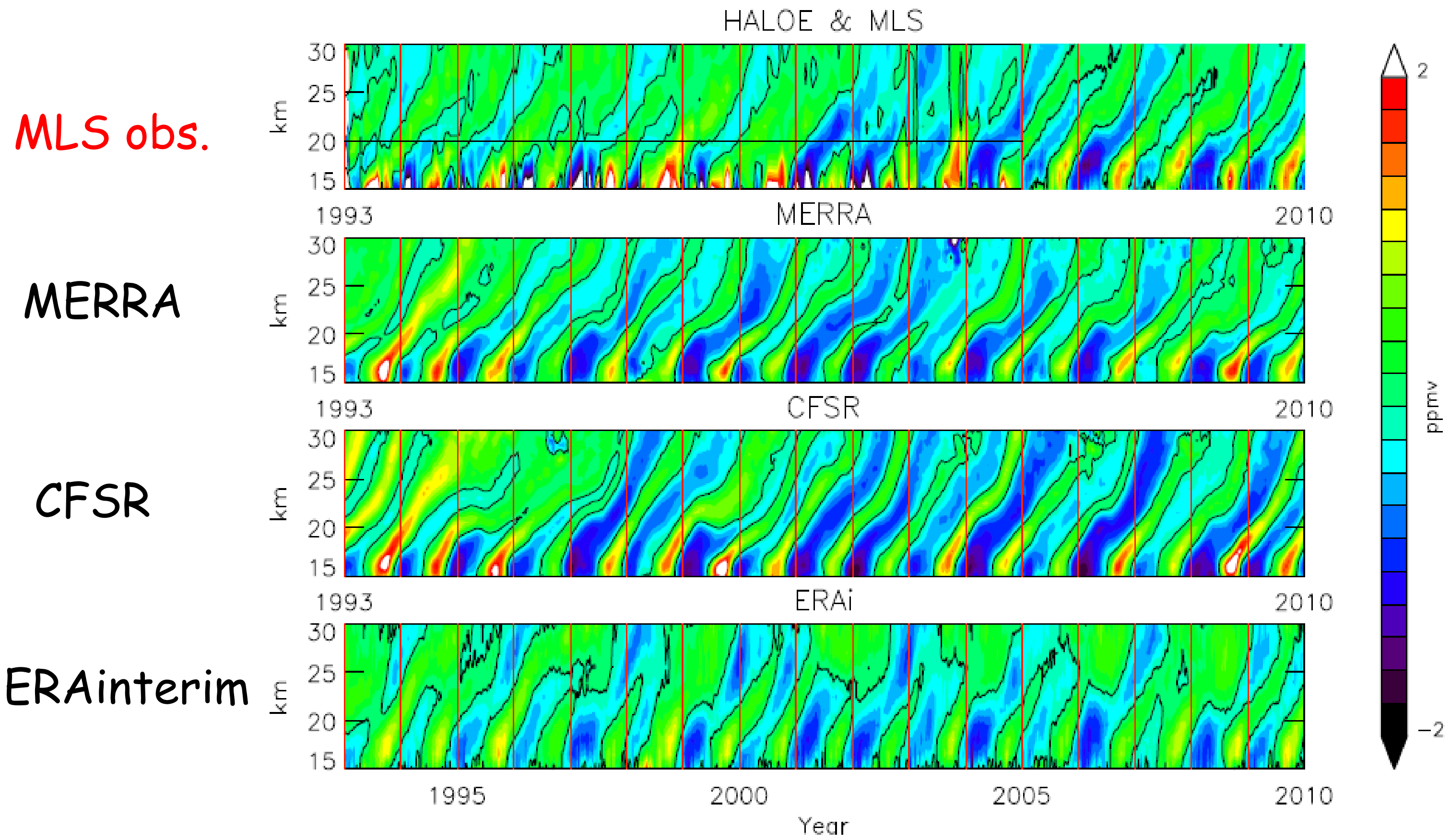
Final dehydration locations





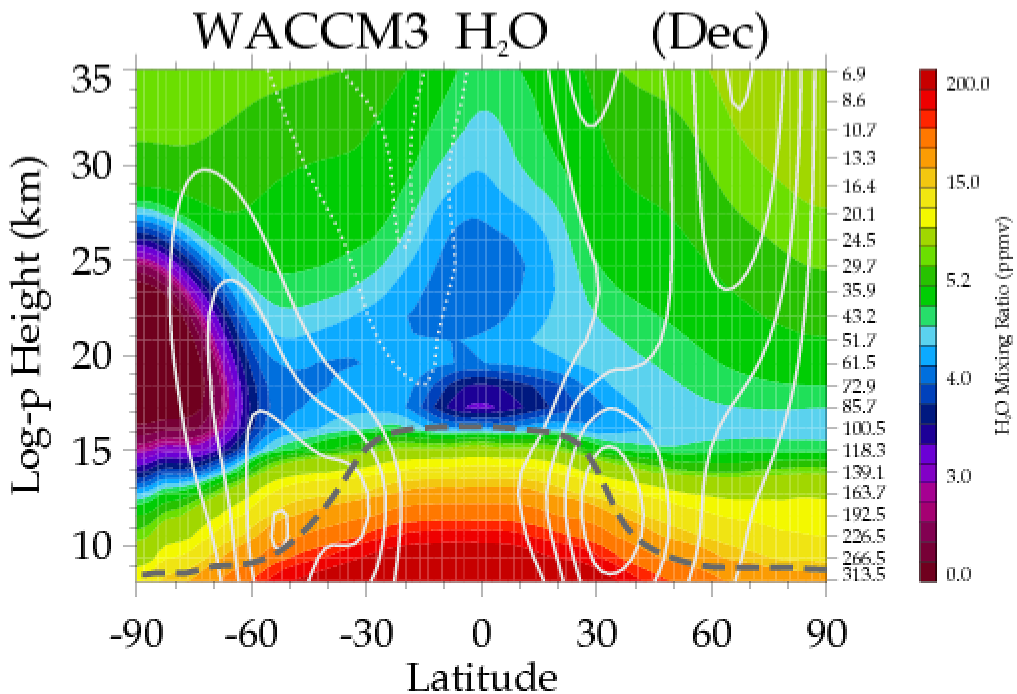
Trajectory calculations based on different reanalysis data sets

Schoeberl et al 2012   ACP

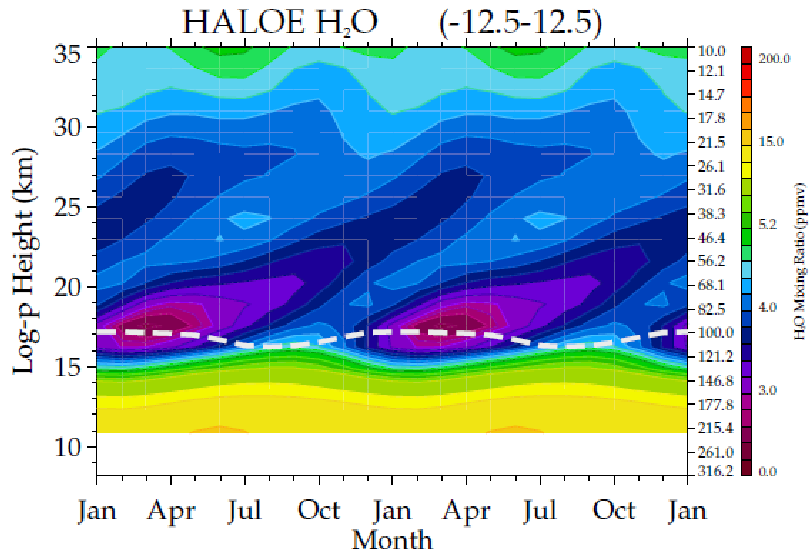


Details are sensitive to the meteorological data

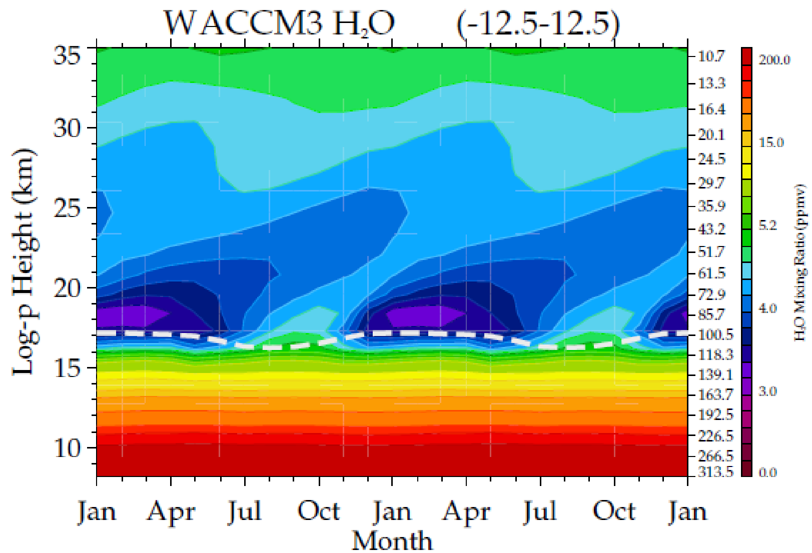
Chemistry-climate model simulations from WACCM



'tape recorder'
HALOE vs. WACCM



HALOE



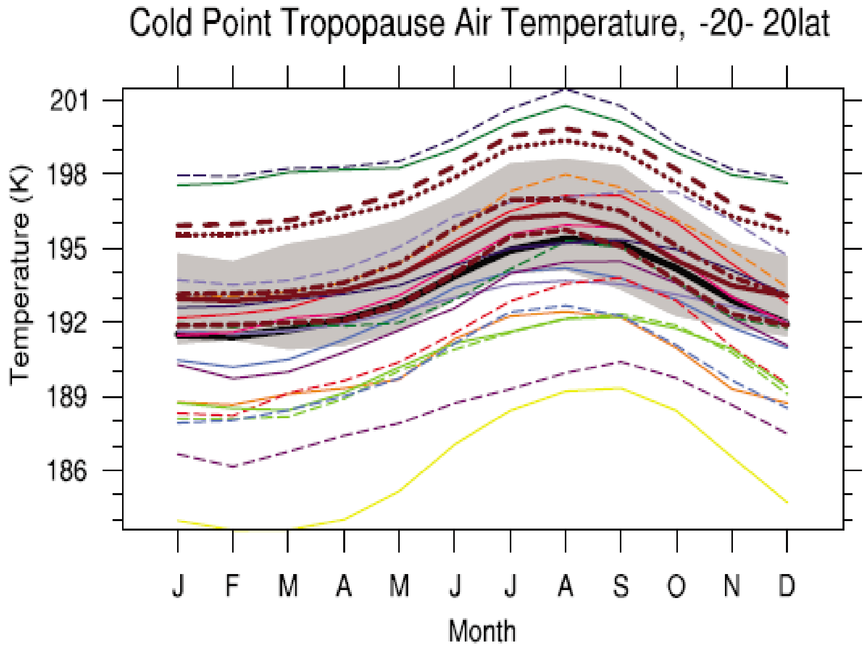
WACCM

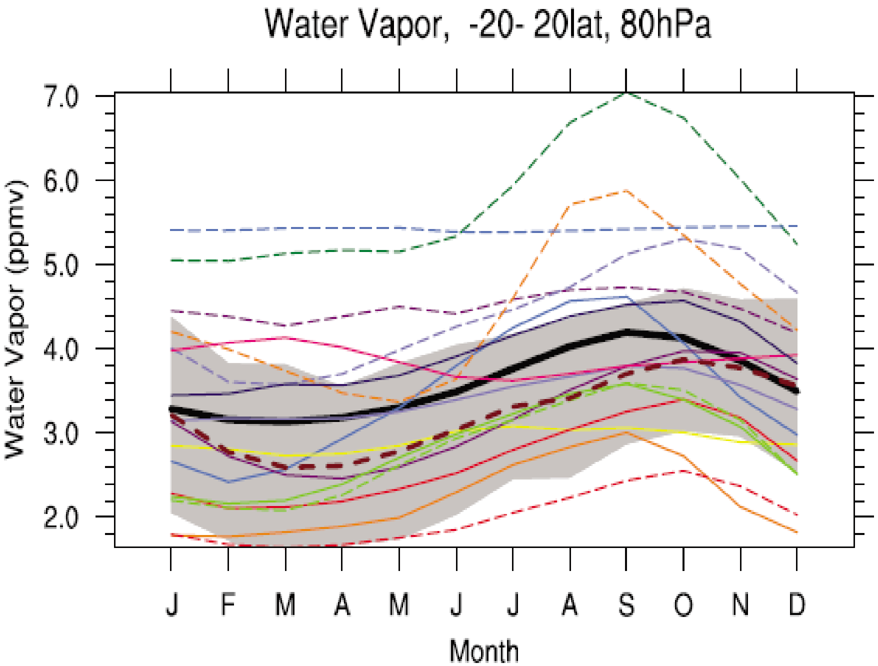
models have varying biases in tropopause temps and stratospheric H_2O

Tropical cold point temperatures and H_2O from chemistry-climate models

Gettelman etal 2010

(from CCMval assessment)

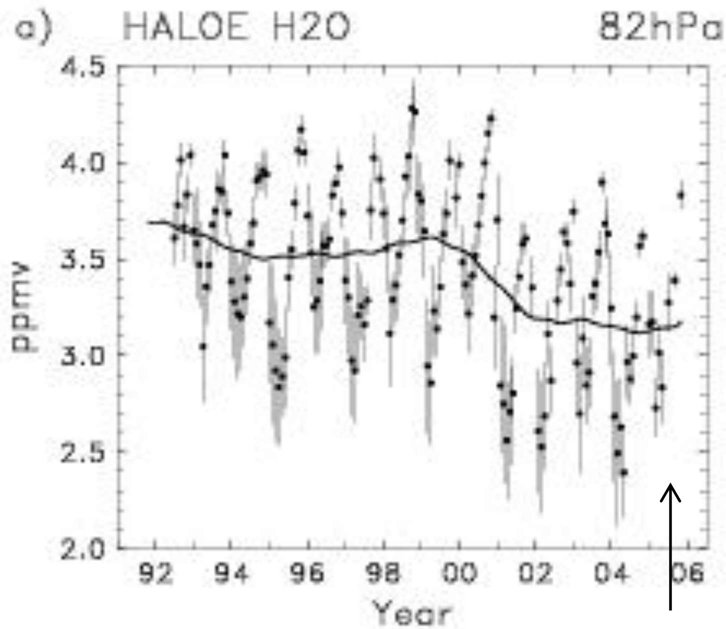




also a large range of future trends predicted from models

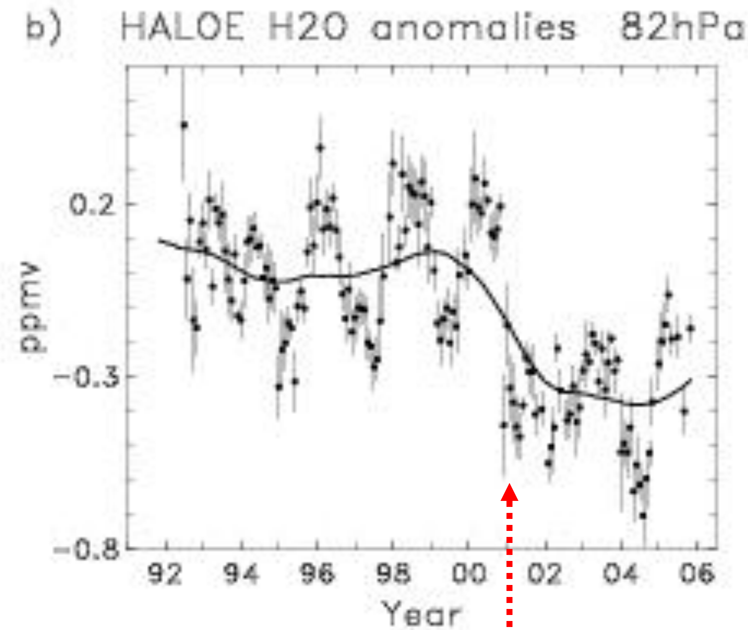
<u>Interannual changes in stratospheric water vapor</u>

HALOE global mean, 82 hPa



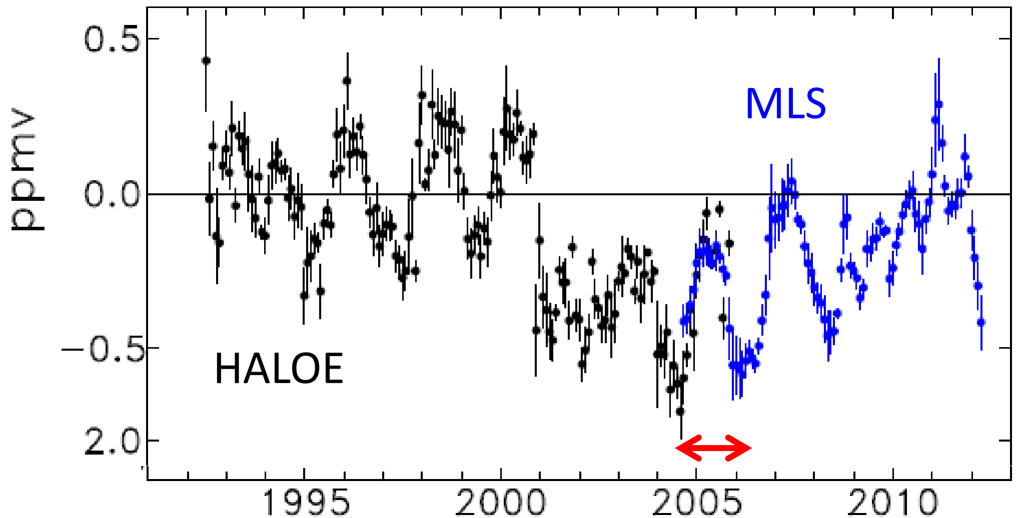
HALOE ends
In 2005

<u>deseasonalized</u>



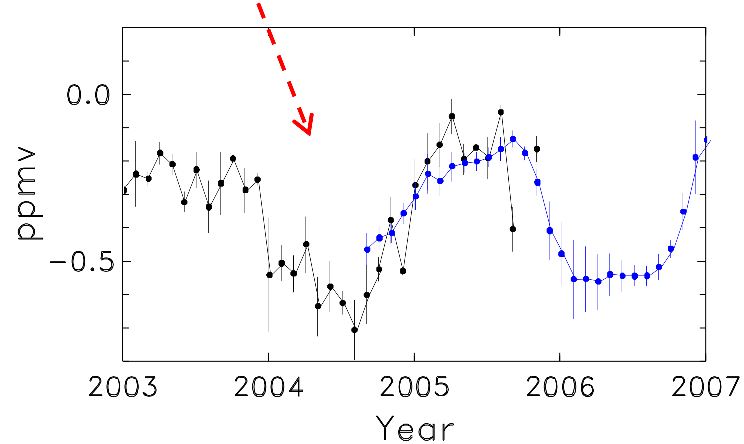
decrease after 2001

Extending the satellite record: HALOE + Aura MLS data

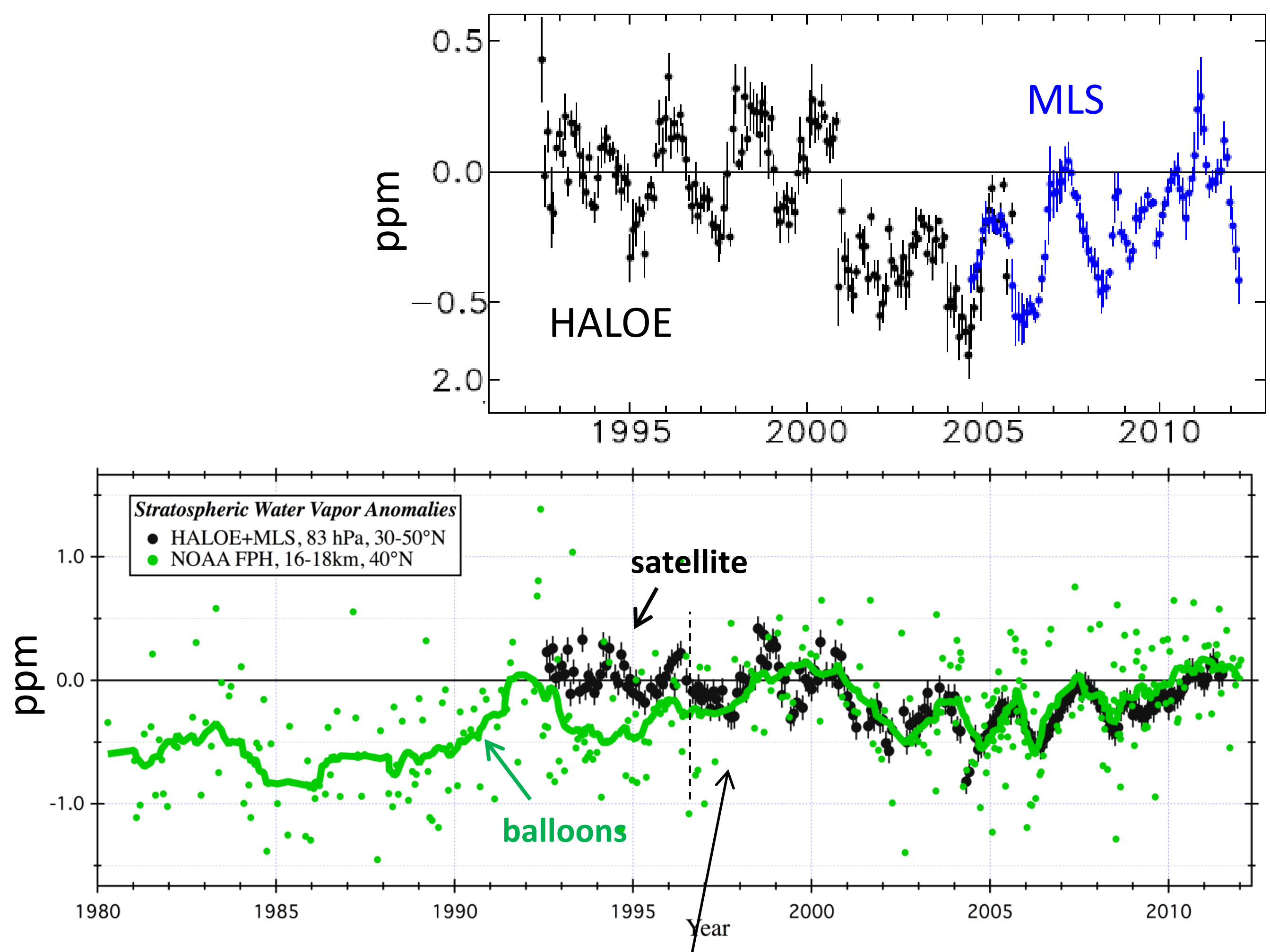


Variability tied to the QBO. What else?

overlap during 2004-2005



Comparisons with the Boulder balloon record



near-global

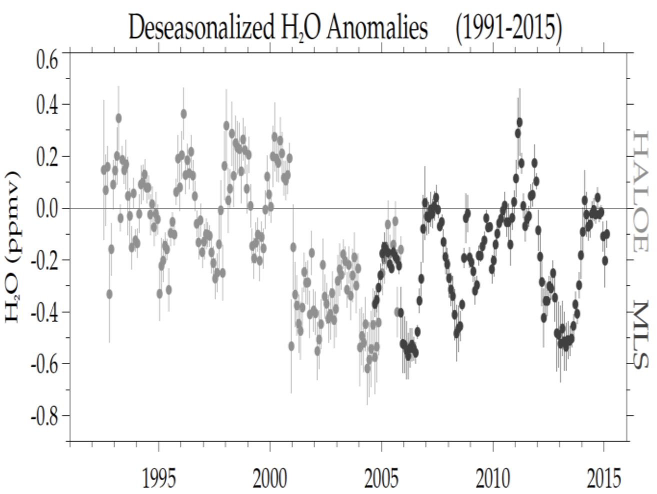
measurements
near Boulder (40º N)

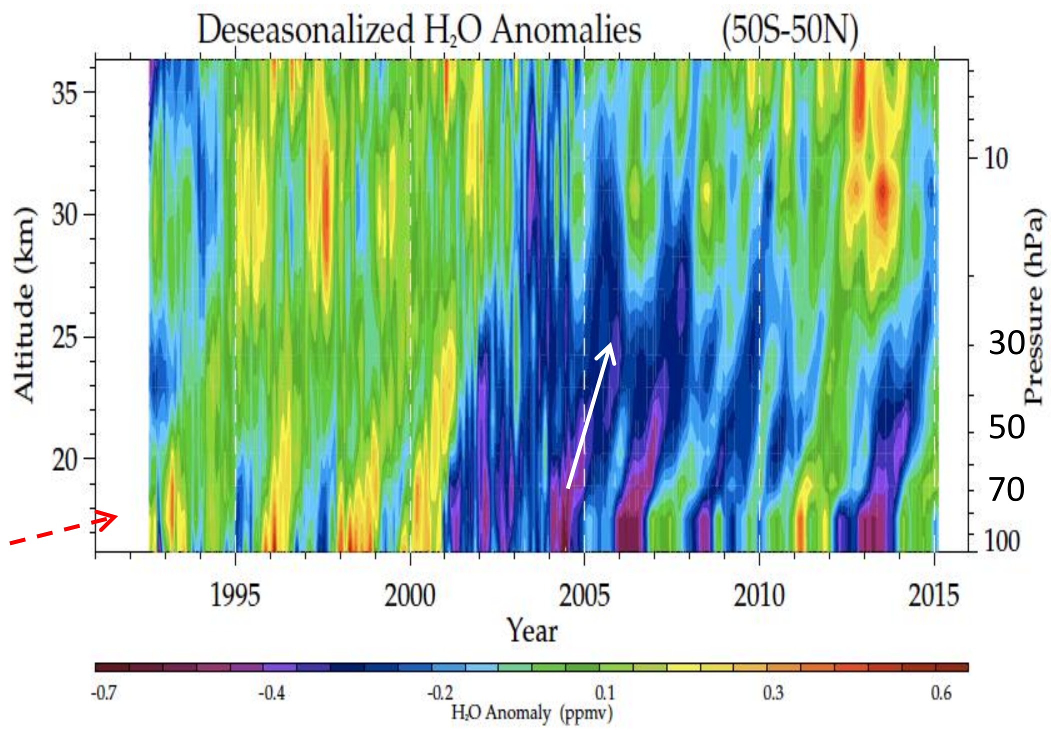
excellent agreement
after ~ 1996

IPCC AR5 2014

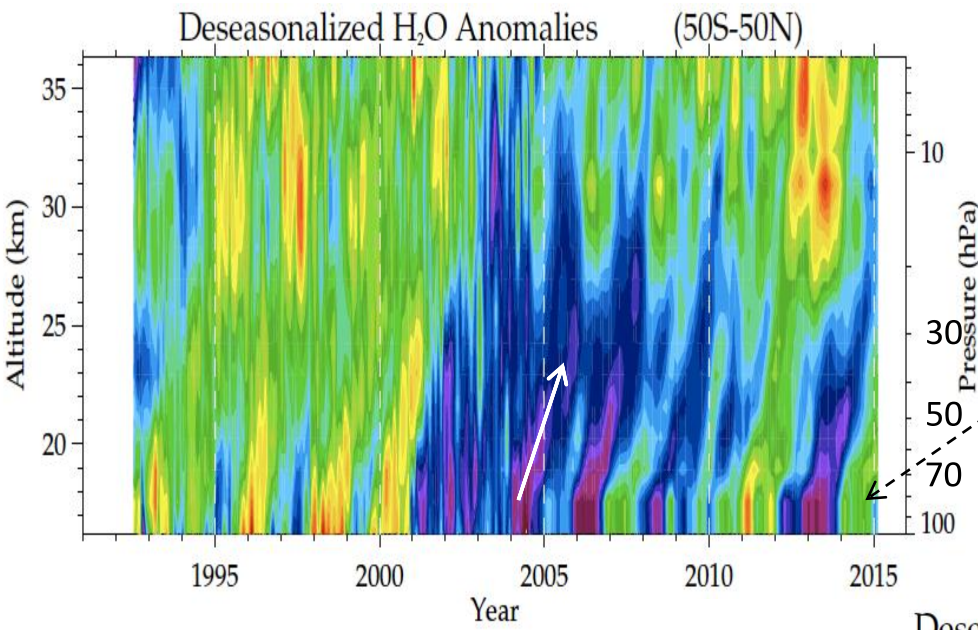
H_2O anomalies originate near the tropical tropopause, and propagate coherently with time

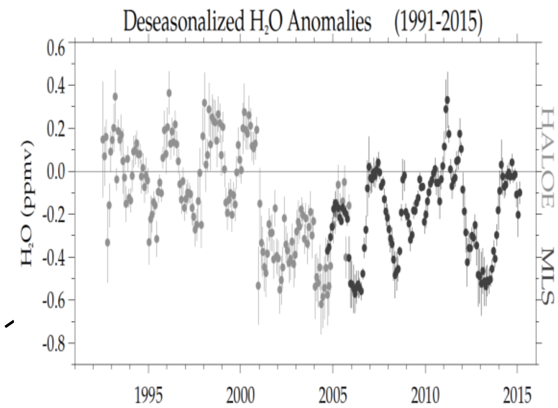
vertical propagation



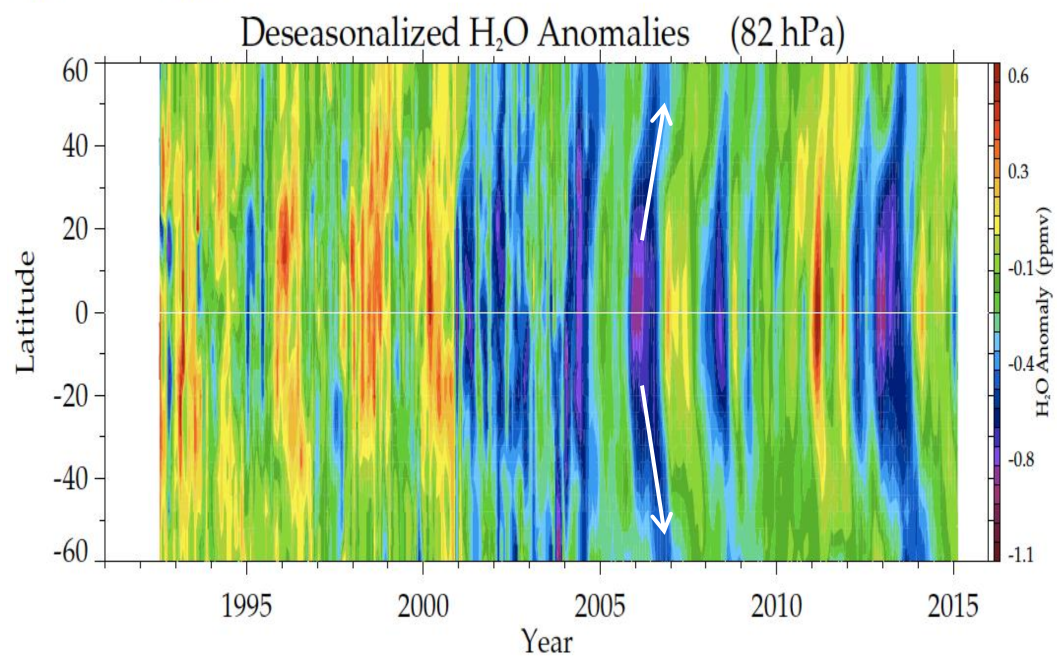


vertical propagation



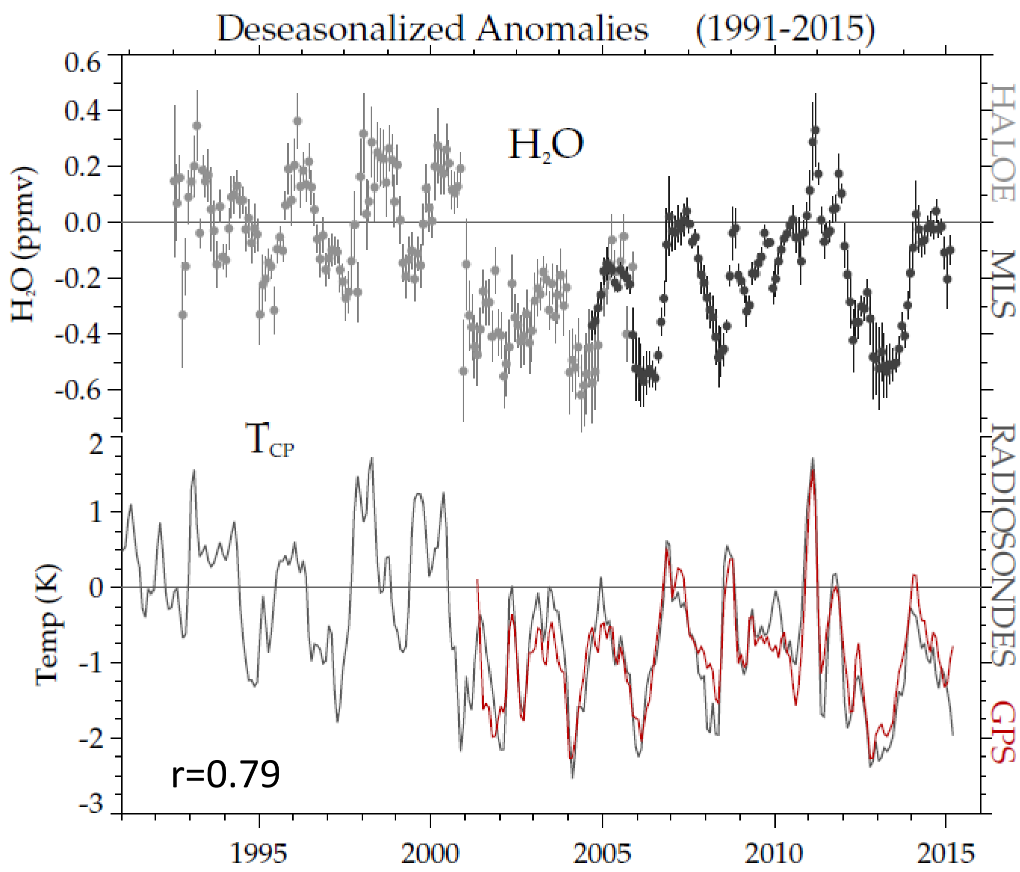


latitudinal propagation from tropics



Correlated variations in stratospheric H_2O and cold point temperatures

most recent plot, updated through early 2015

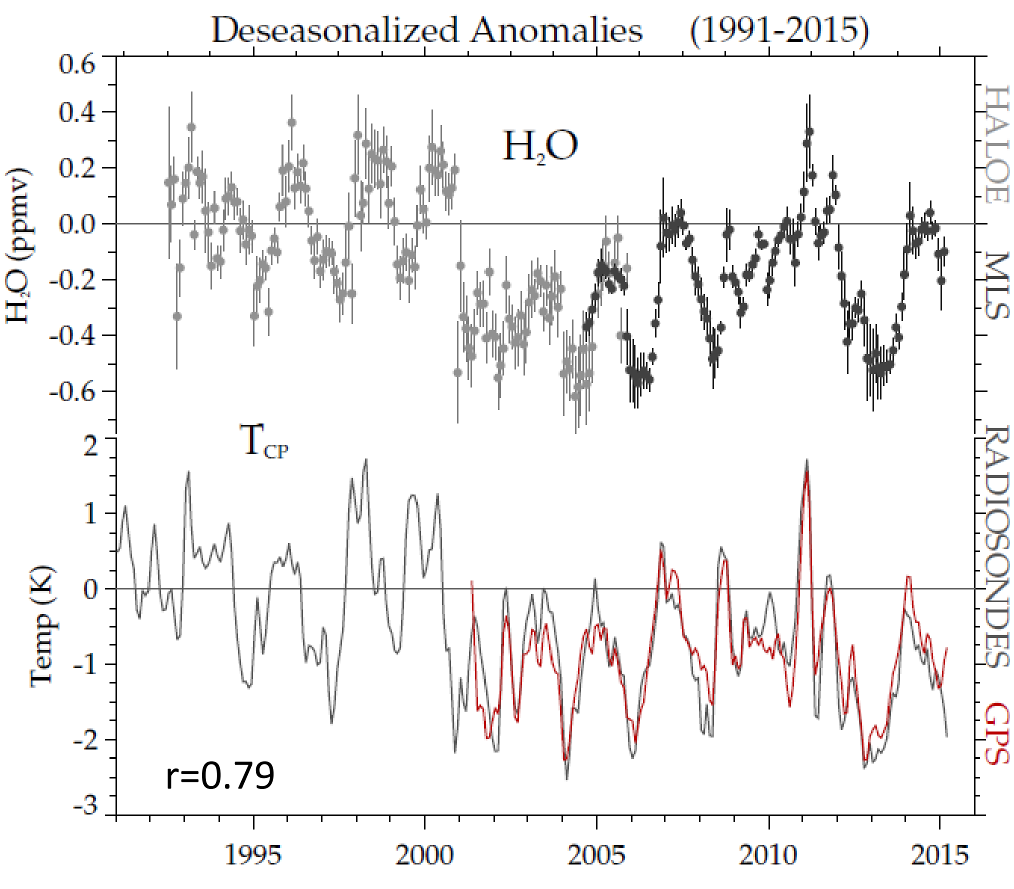


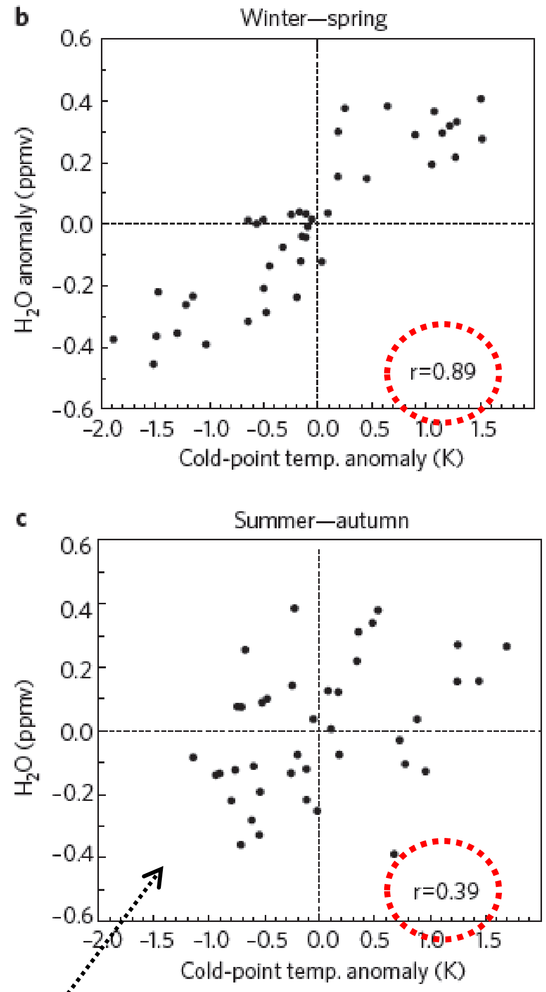
near-global mean (60° N-S)
water vapor at 82 hPa
from combined HALOE-MLS data

near-equatorial
cold-point tropical
tropopause temperatures

black: radiosondes
red: GPS (after 2001)

Correlated variations in stratospheric H_2O and tropical cold point temperatures

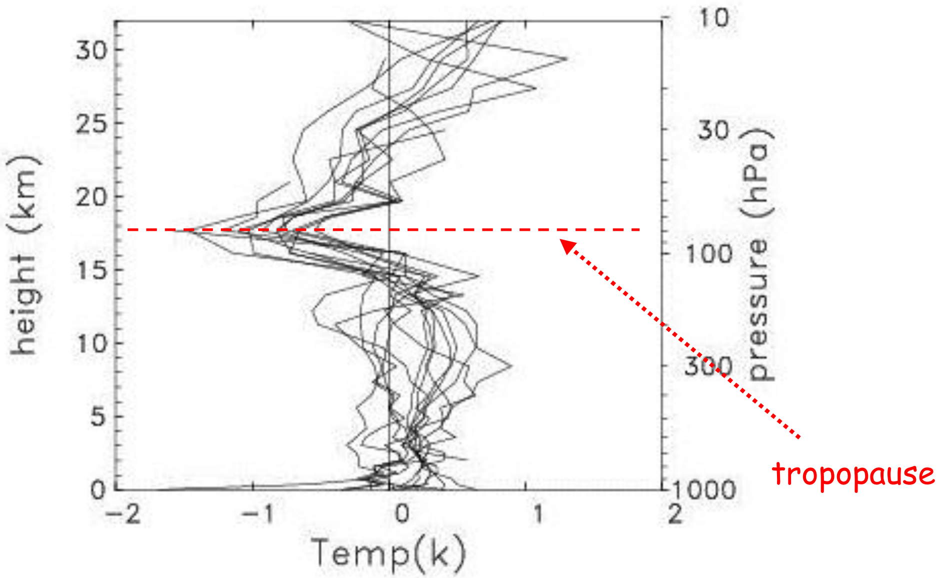




weaker correlations during summer

what else is controlling H_2O during summer?

tropical temperature anomalies
associated with 2000 H_2O decrease
(from radiosondes)



similar changes in ozone profiles suggest a response to increases tropical upwelling

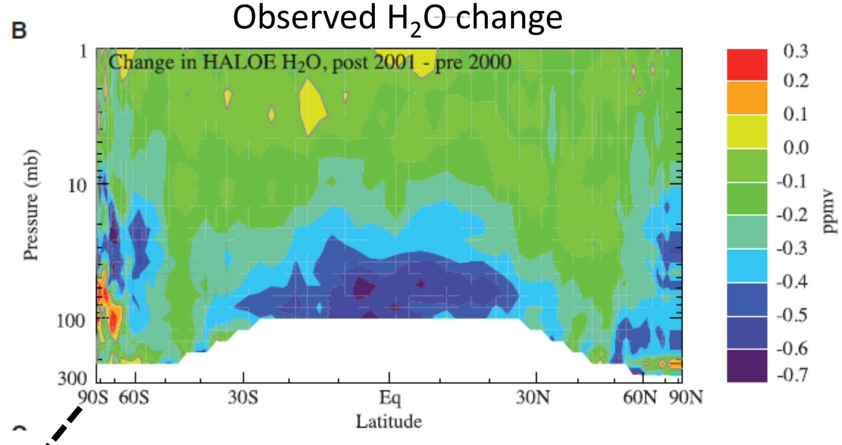
still a topic of active research

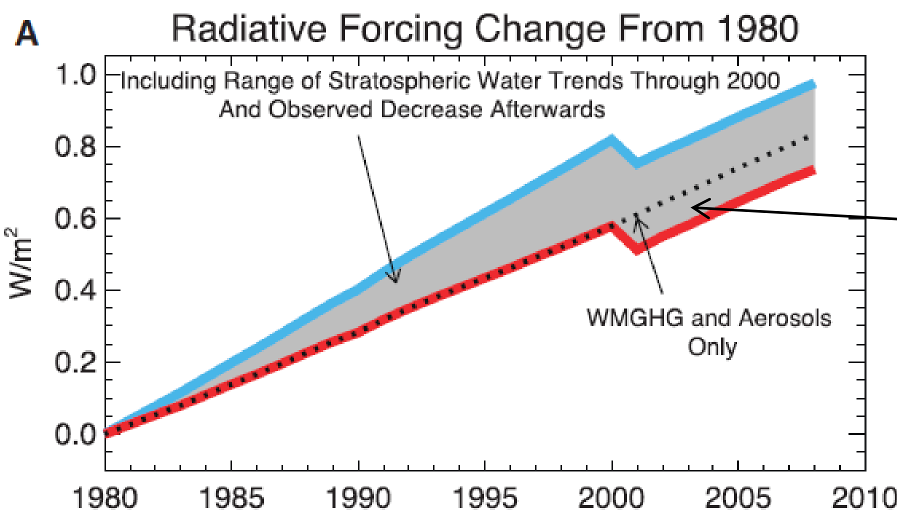
Science 2010

Contributions of Stratospheric Water Vapor to Decadal Changes in the Rate of Global Warming

Susan Solomon,[1] Karen H. Rosenlof,[1] Robert W. Portmann,[1] John S. Daniel,[1] Sean M. Davis,[1,2] Todd J. Sanford,[1,2] Gian-Kasper Plattner[3]

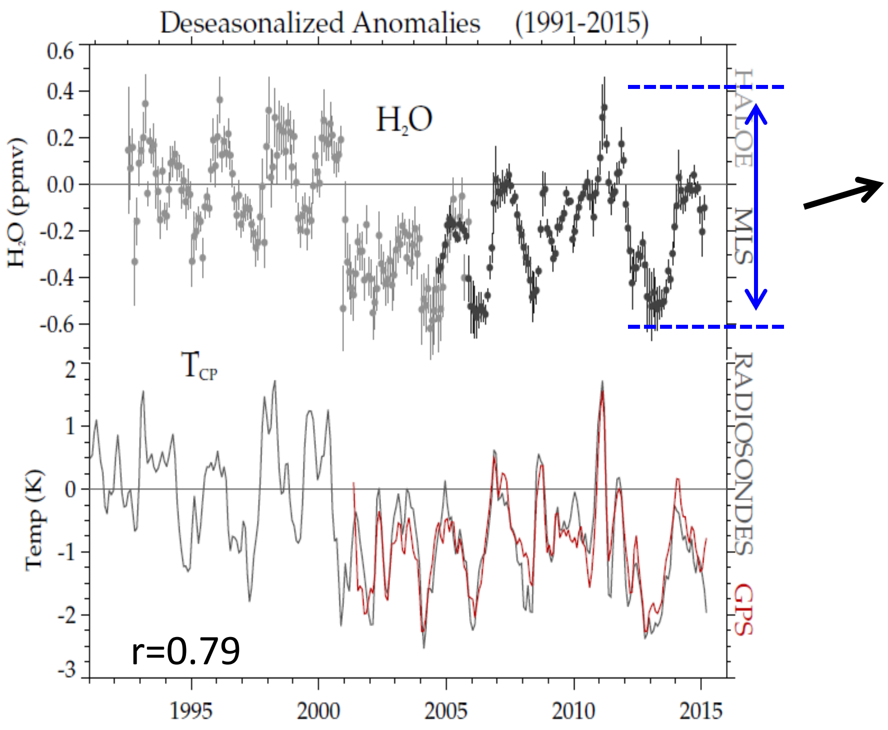
Observed H_2O change

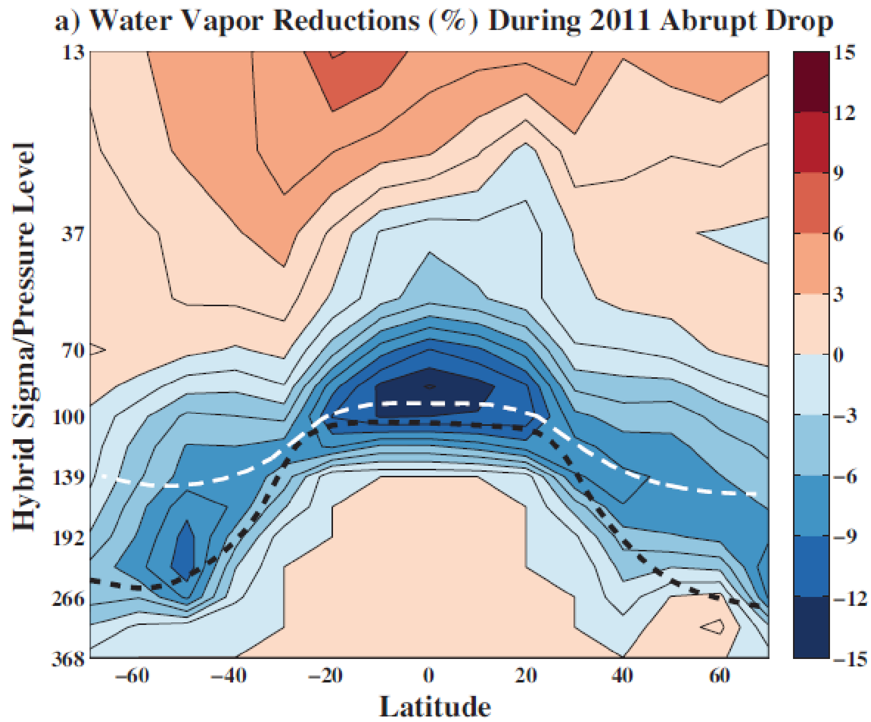




possible change linked
to stratospheric H_2O decrease

Water vapor changes during 2011-2013





from Dan Gilford

Key points:

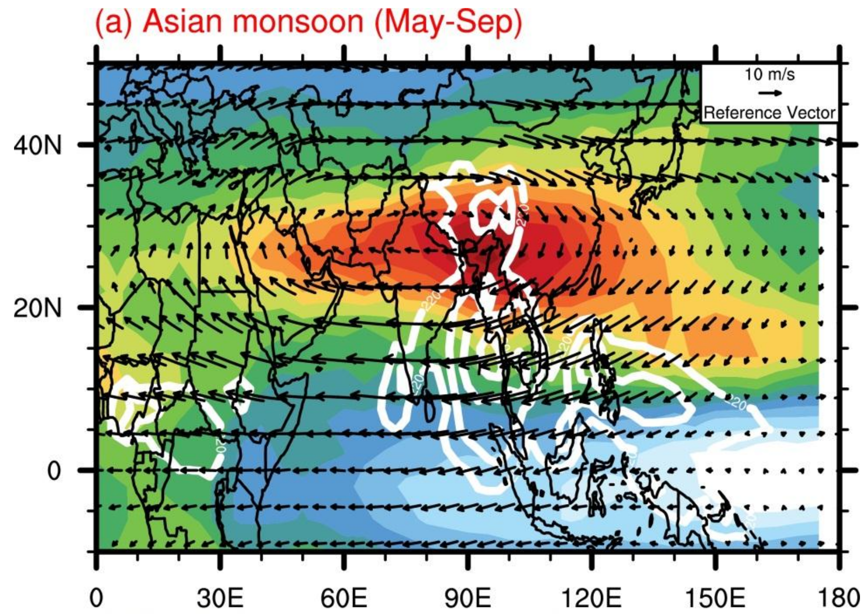
- Stratospheric H_2O seasonal cycle is well understood. Enhanced tropical dehydration during boreal winter (cold season). Tape recorder, rapid global transport in lower stratosphere, monsoons in UTLS during NH summer. Also Antarctic dehydration.

- Simulation of seasonal cycle in trajectory calculations and stratosphere-resolving climate models is reasonable. Interannual variability in climate models is different from observations.

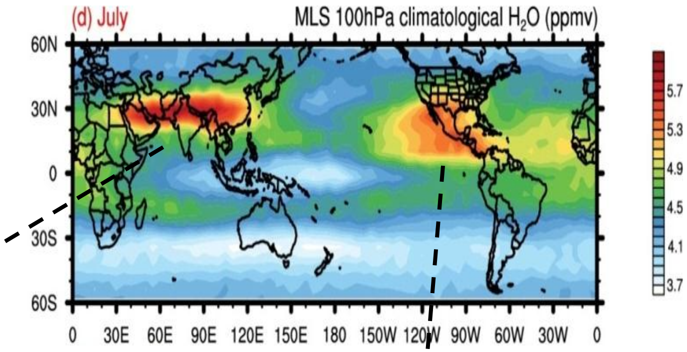
- Interannual changes for satellite record (1992-2015) in good (quantitative) agreement with tropical cold point. Cold point controls stratospheric water vapor; what controls the cold point?

- What processes control water vapor in summer monsoon regions?

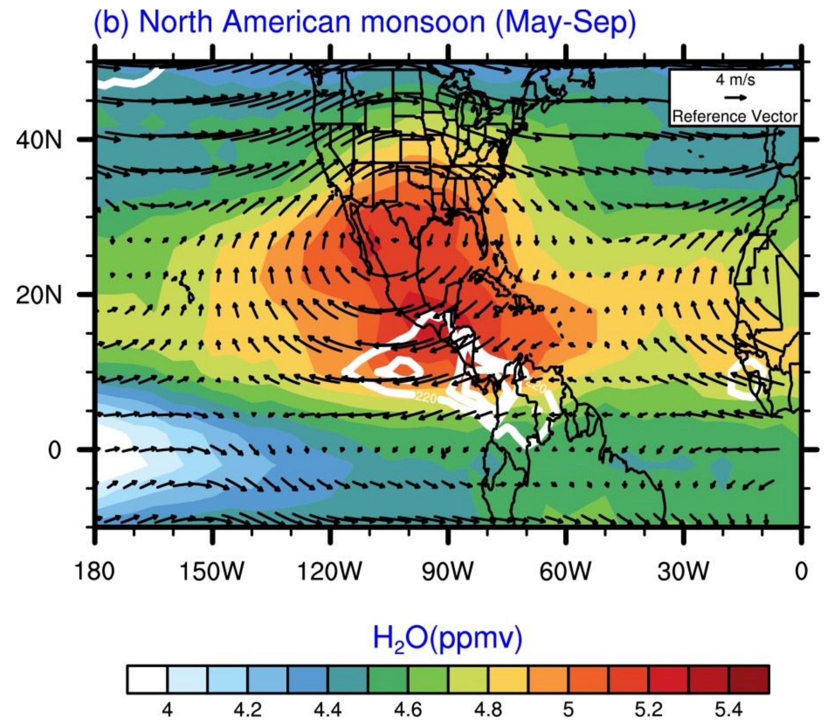
Summer monsoon circulations and H_2O



white contours = deep convection



monsoon anticyclones, stronger circulation over Asia



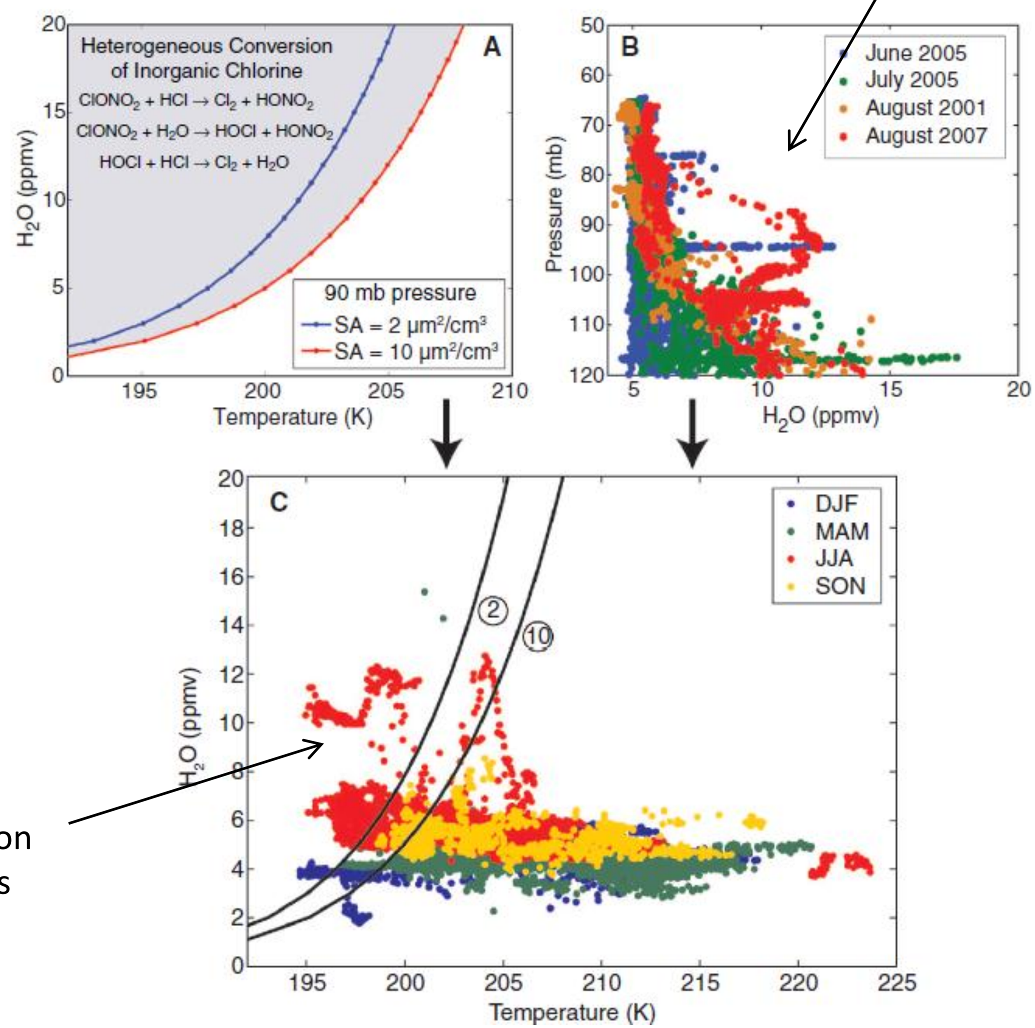
100 hPa H_2O aligned more with circulation than with deep convection

UV Dosage Levels in Summer: Increased Risk of Ozone Loss from Convectively Injected Water Vapor

Science 2009

James G. Anderson,* David M. Wilmouth, Jessica B. Smith, David S. Sayres

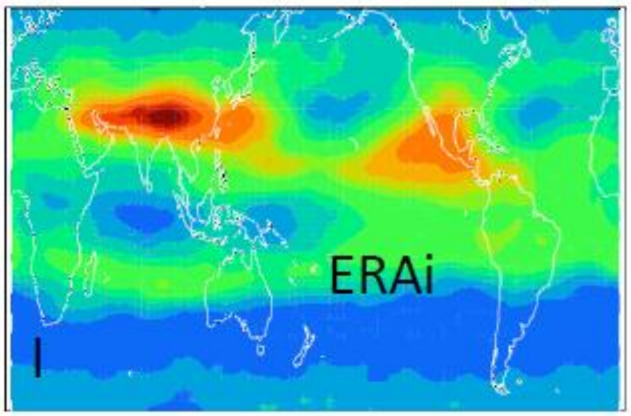
aircraft measurements; extreme values from overshooting convection



possibility of chlorine activation from cold temps and high H_2O

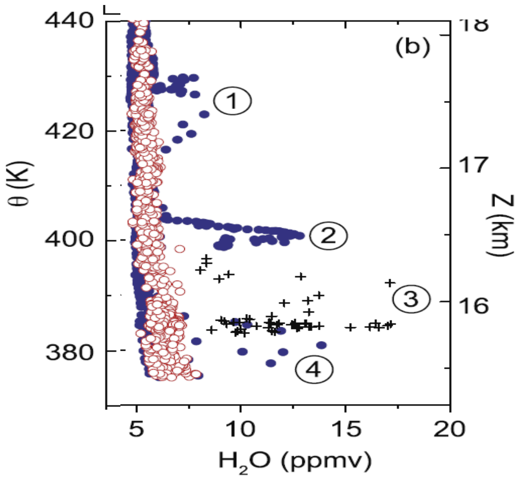
What processes maintain the monsoon H_2O maxima?

Large-scale circulation/temperatures



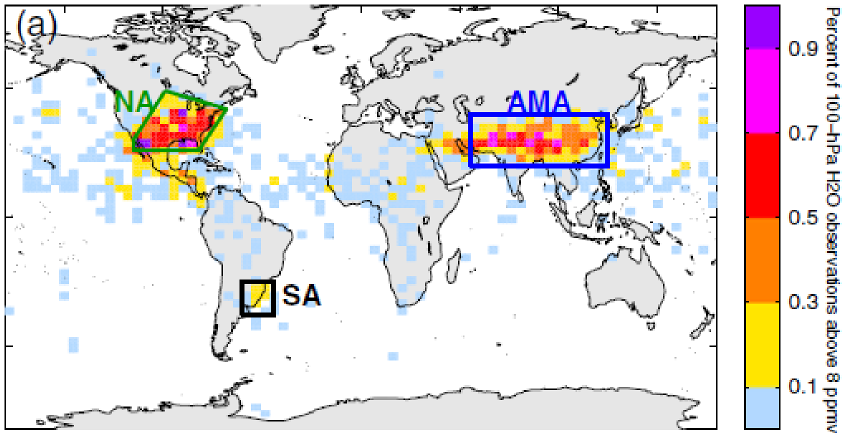
Domain filling trajectory calculations,
no explicit convection
Schoeberl et al, ACP 2013

Overshooting deep convection



aircraft
measurements,
Hanisco et al, GRL, 2007

MLS satellite
Schwartz et al, GRL, 2013



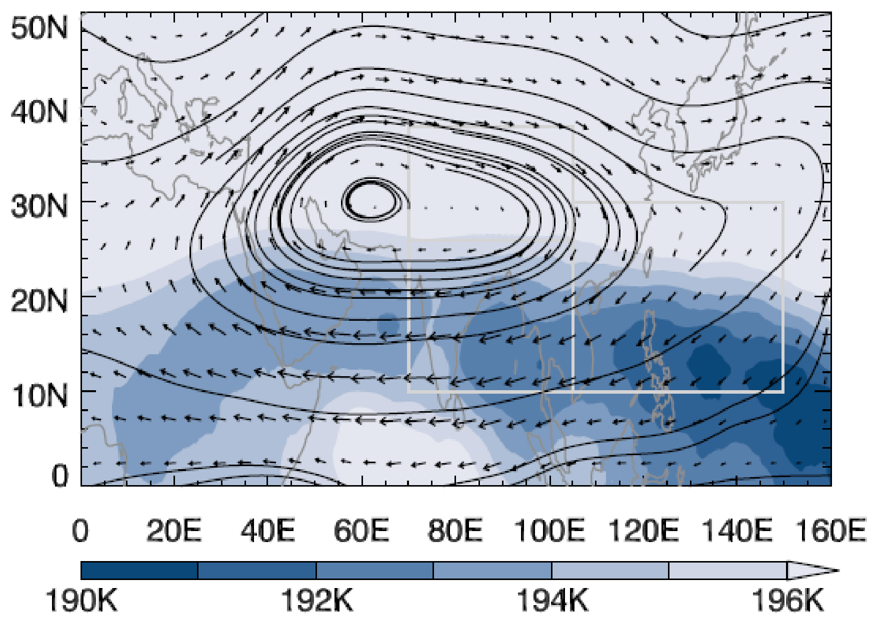
The influence of summertime convection over Southeast Asia on water vapor in the tropical stratosphere

J. S. Wright,[1] R. Fu,[2] S. Fueglistaler,[3] Y. S. Liu,[4] and Y. Zhang[5]

Received 1 December 2010; revised 3 March 2011; accepted 28 March 2011; published 17 June 2011.

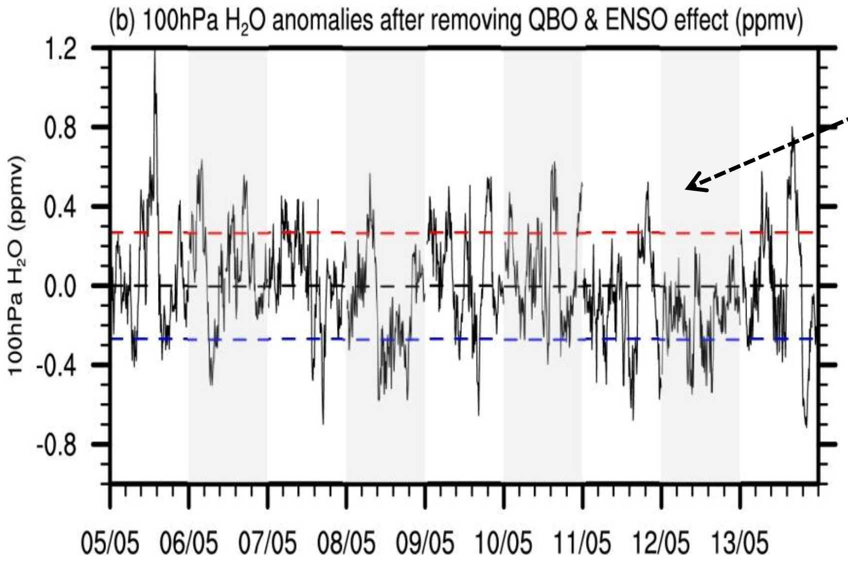
JGR 2011

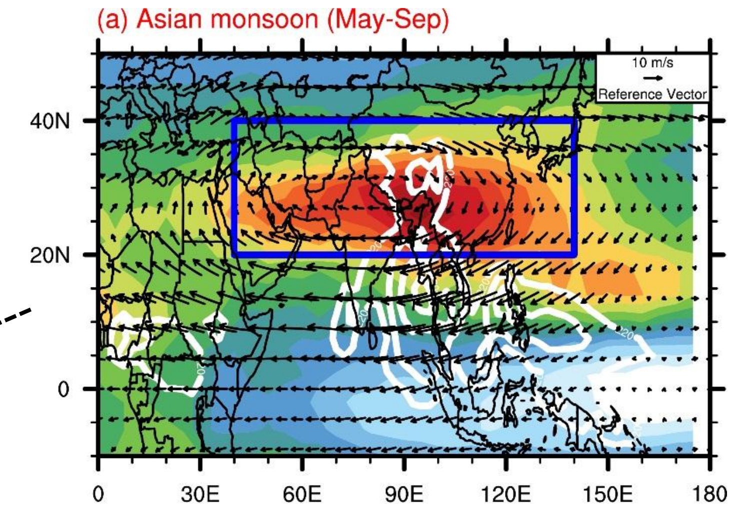
Lagrangian back trajectory model



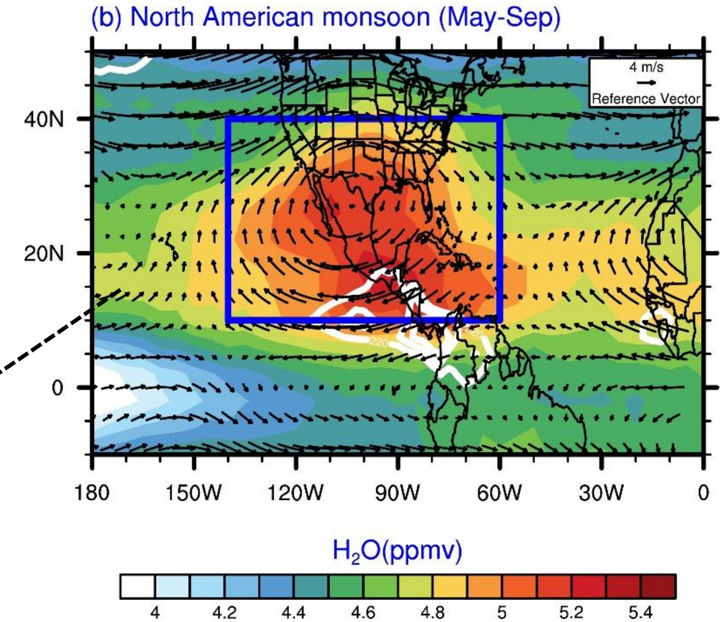
variability in Asian monsoon

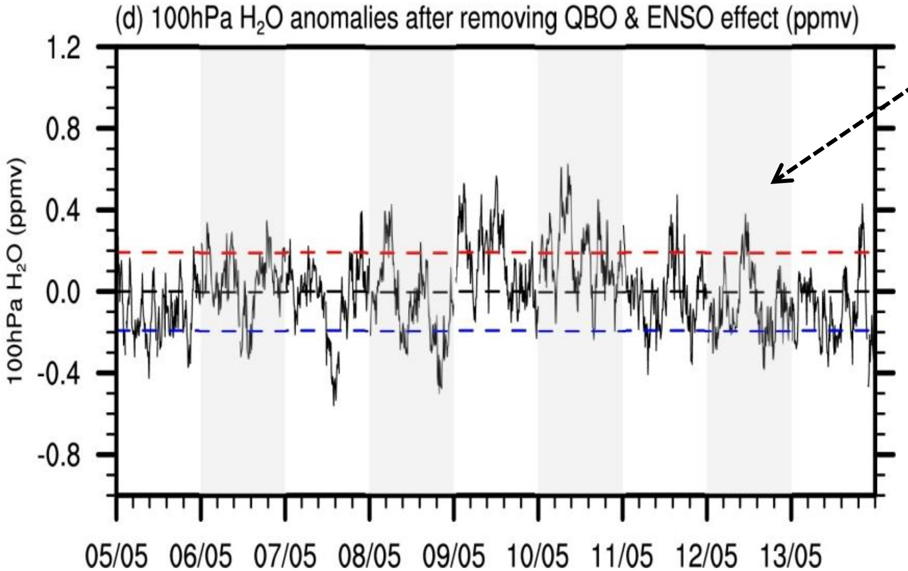
9 years of MLS observations



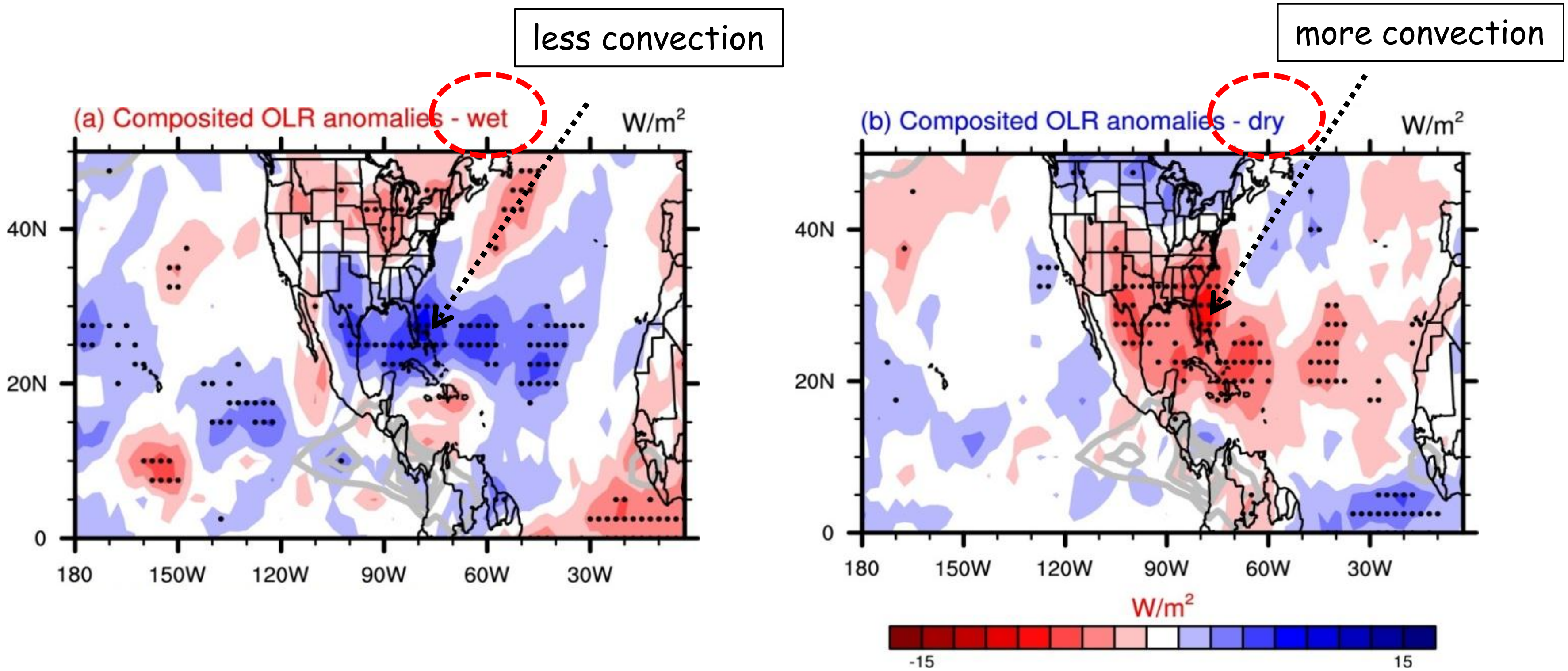


N American monsoon





Composites over N America wrt 100 hPa H_2O



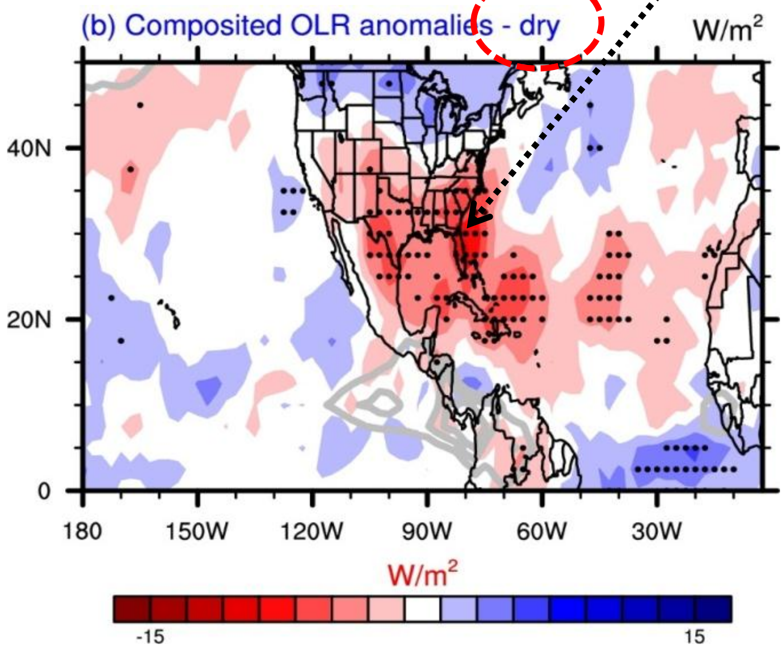
<u>Surprising result</u>: less (more) convection

↕

more (less) lower stratosphere H_2O

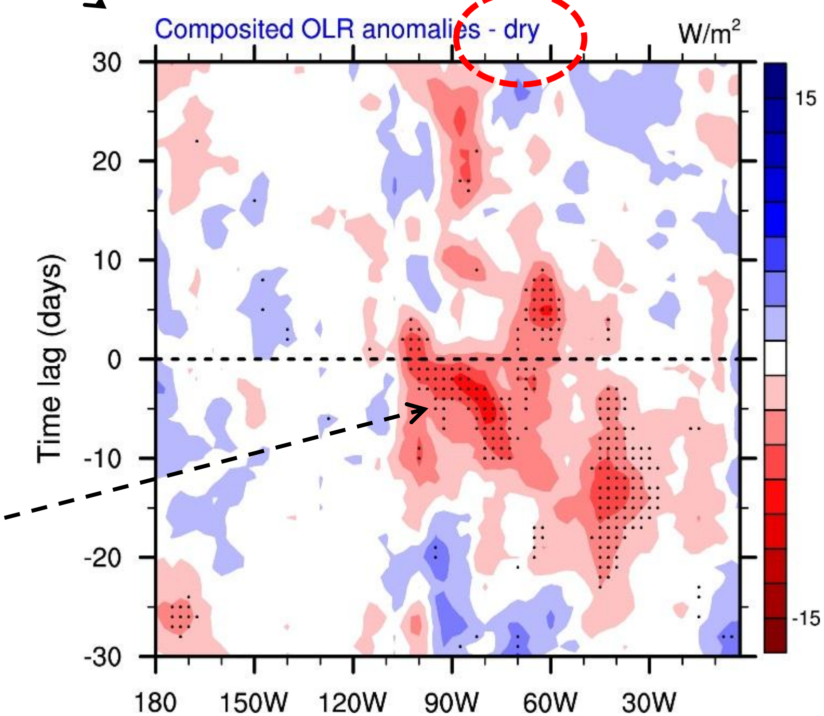
N. America

more convection



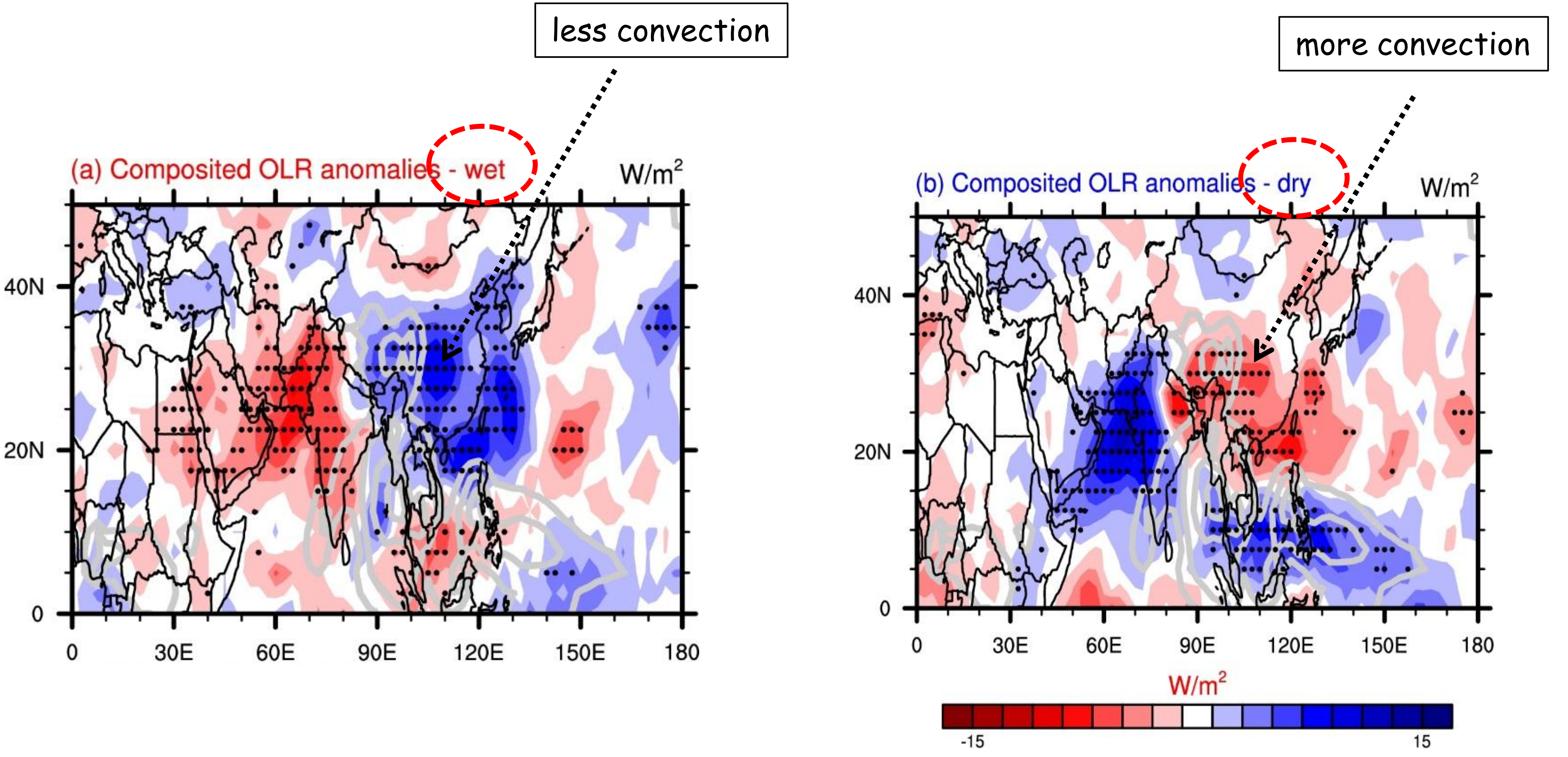
composites for dry stratosphere

time lag variation



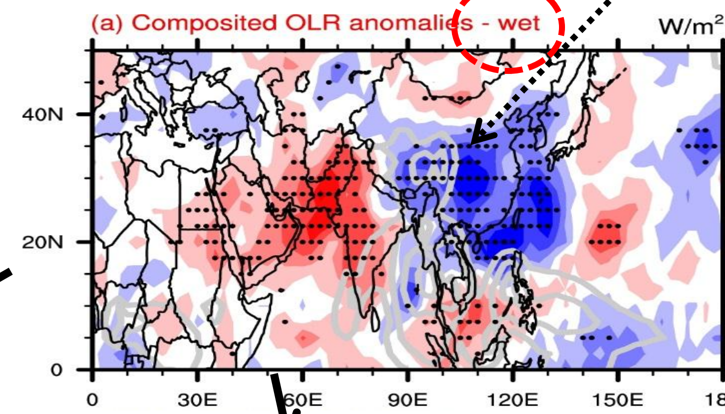
enhanced convection preceeds
dry stratosphere H_2O
by ~ 0-10 days

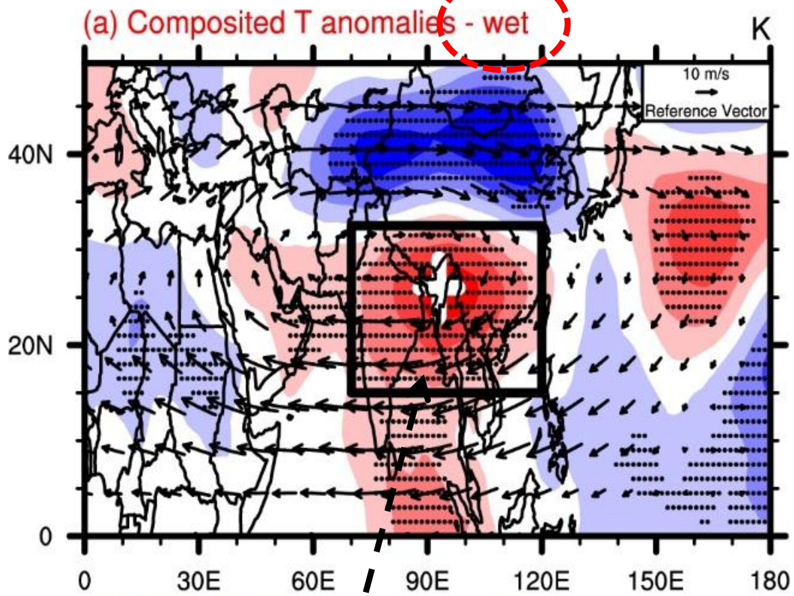
Composites over Asia wrt 100 hPa H_2O



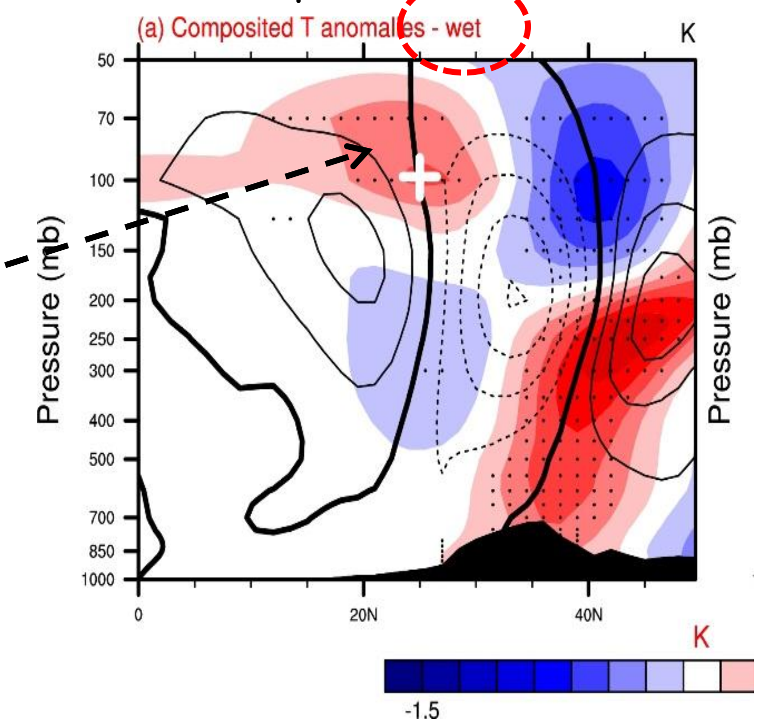
Asian monsoon:
links to temperatures at 100 hPa

less convection

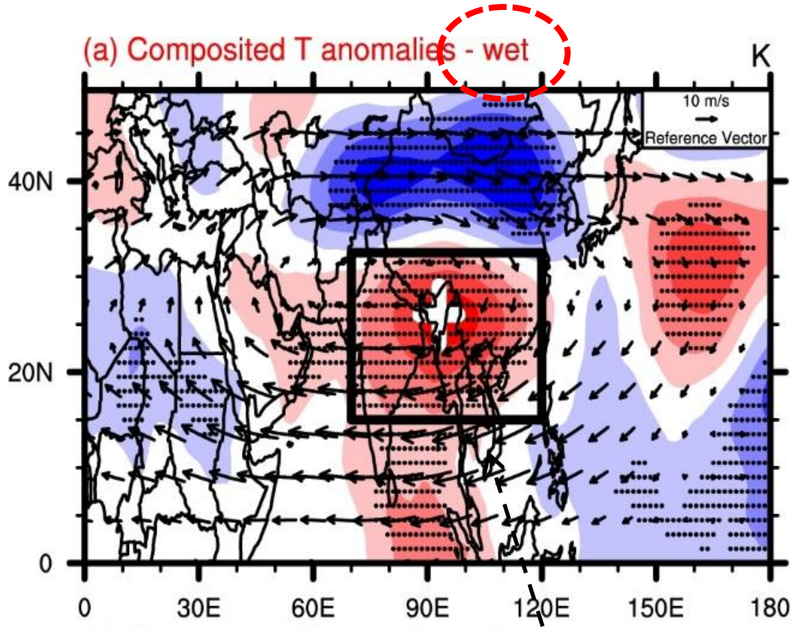




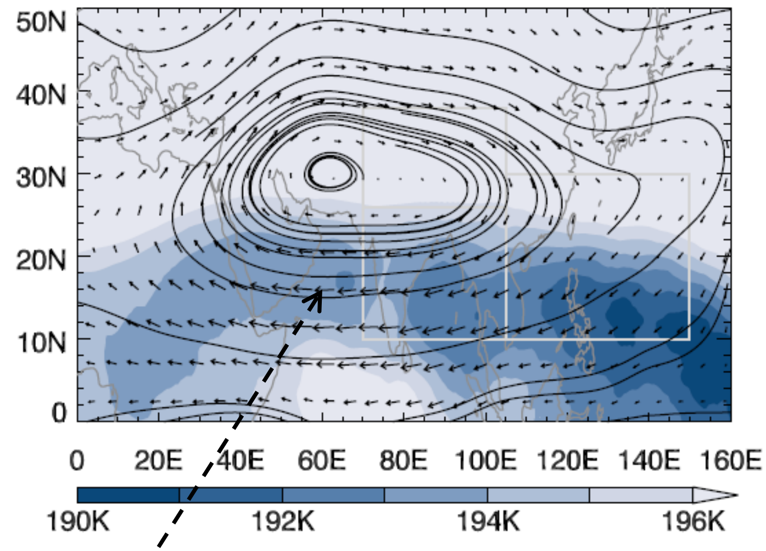
Temp anomalies near 90 E



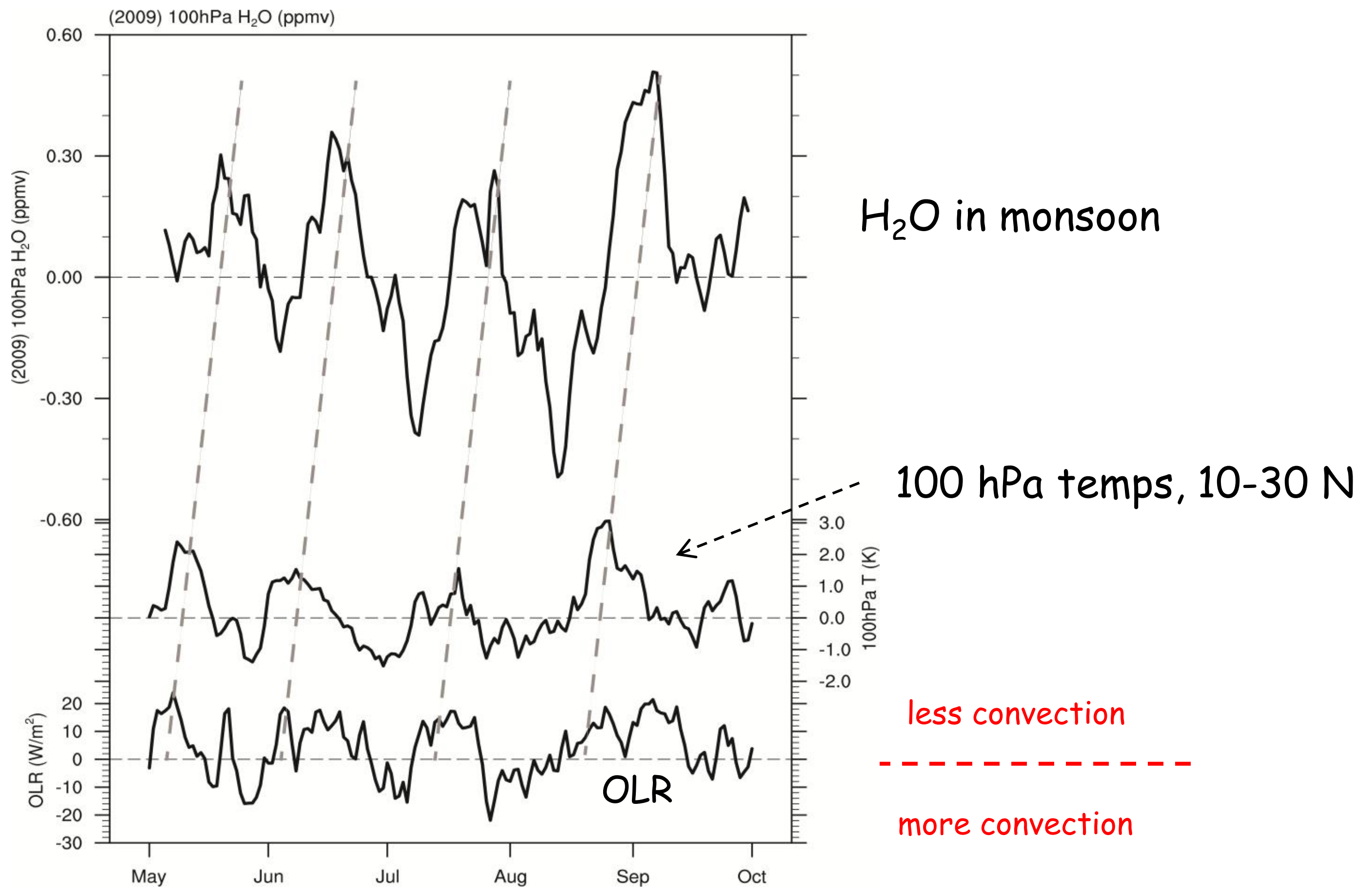
warm temps in low latitude stratosphere



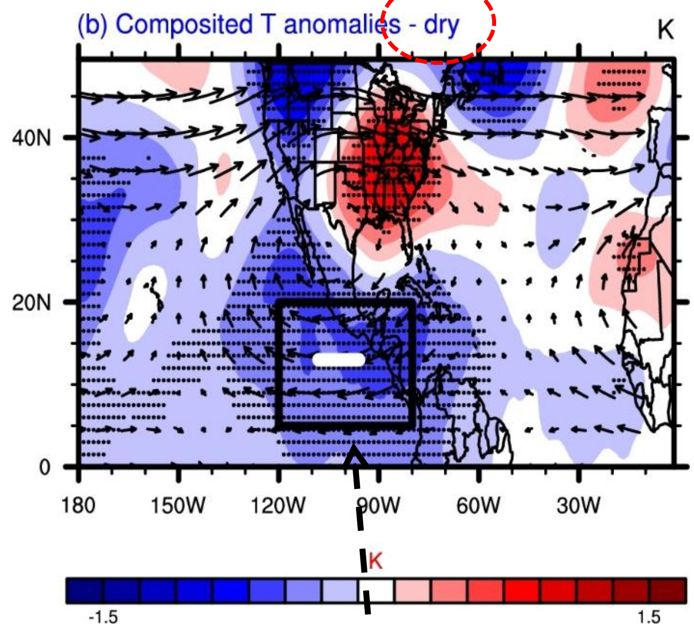
Wright et al, 2011

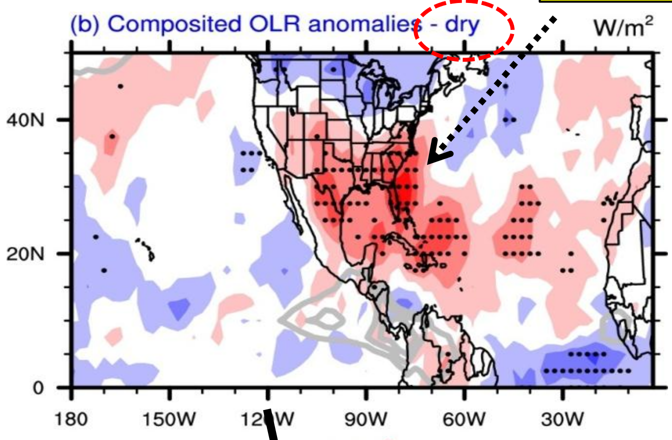


subtropics: most important region for dehydration time series over Asia during summer 2009

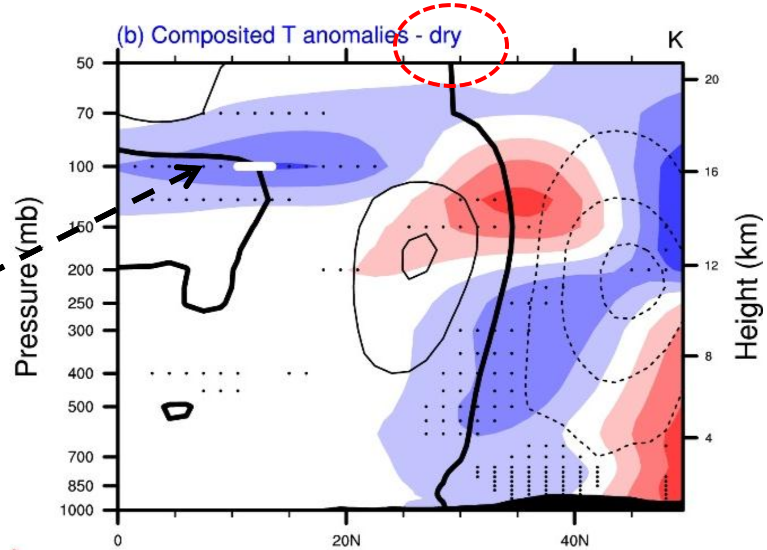


North American monsoon: links to temperatures at 100 hPa





Temp and zonal wind anomalies near 90 W



colder temps in low latitude stratosphere

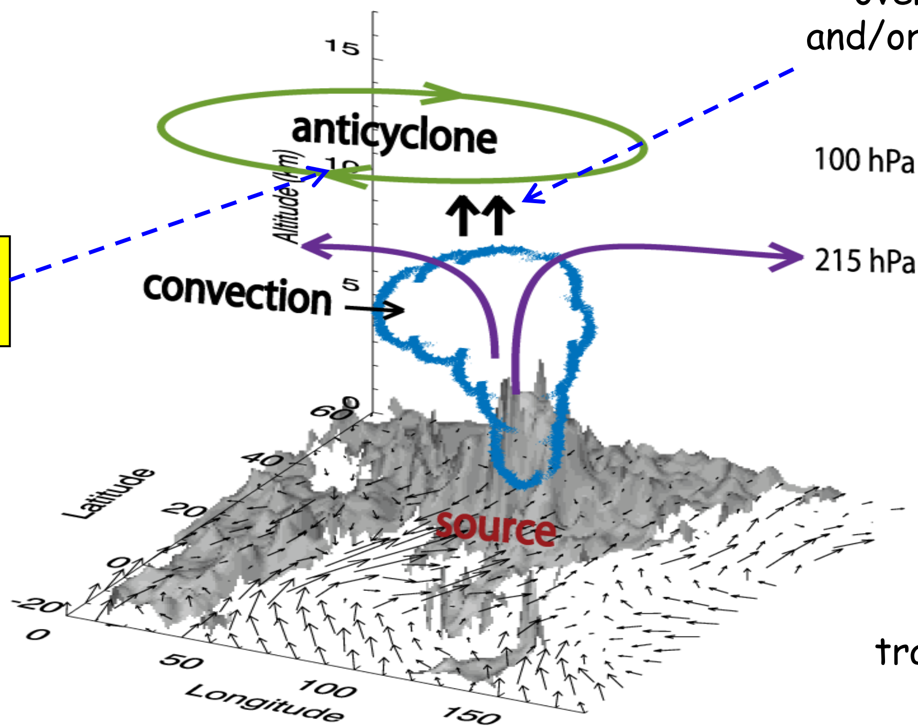
Similar physical process as in Asian monsoon

Key points:

- Surprising result: strong (weak) convection associated with ⟷ dry (wet) lower stratosphere
- Physical link: temperatures in the subtropical stratosphere
- Overshooting convection does not control monsoon H_2O

upward transport by
overshooting convection
and/or large-scale circulation

dehydration on
cold equatorward side



transport in Asian monsoon
Park et al, JGR, 2009


Thank you