Simulations of Stratospheric Dehydration

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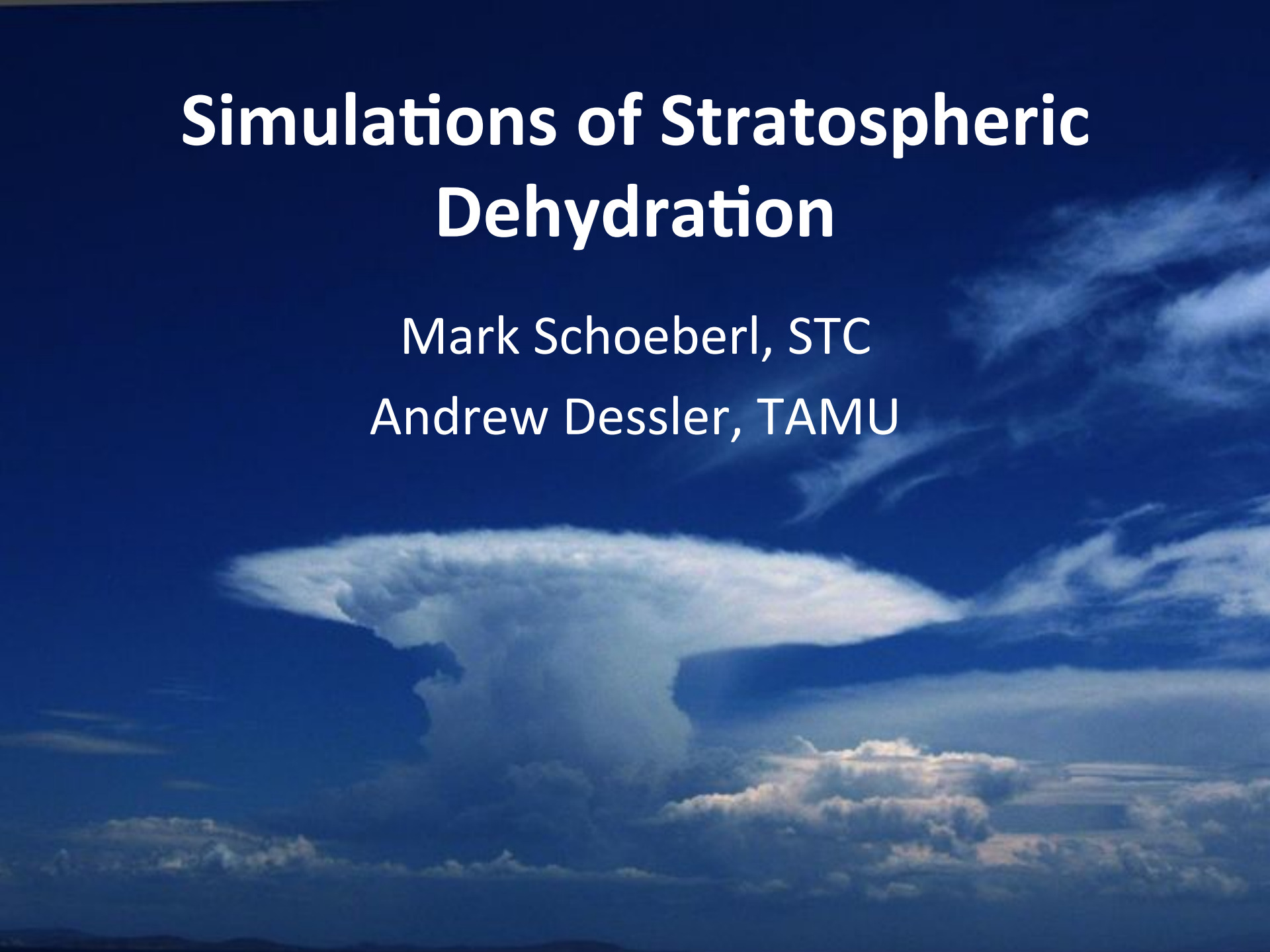


Scientific Goals of Simulation

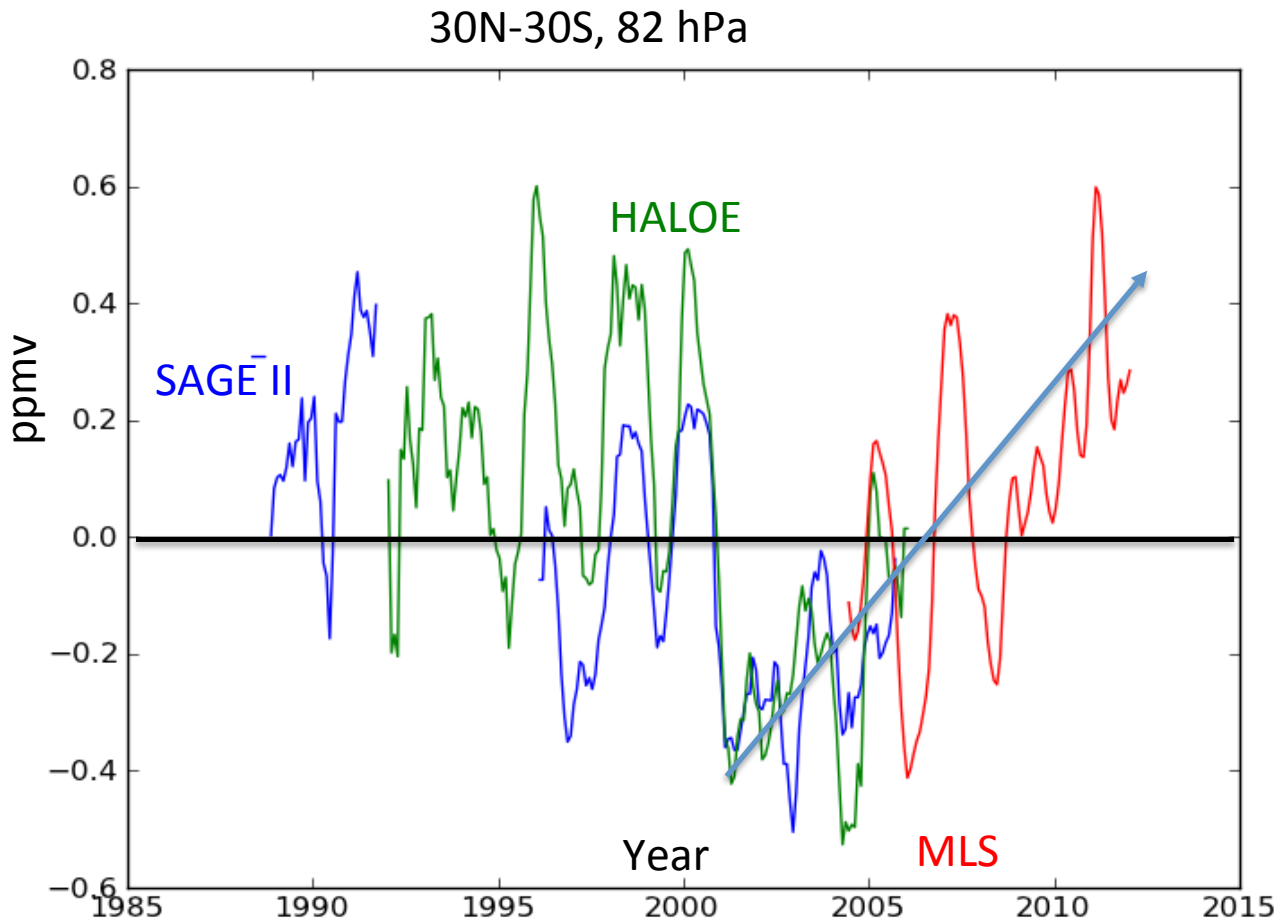
- What controls the stratospheric water vapor – what seems to be important and what is unimportant – in the model world?
- Where is dehydration taking place in the stratosphere <u>according to the assimilation models</u>?
- How do models differ their determination of stratospheric water vapor?
- How does our model compare with satellite observations?

Water Trends

Anomalies for the SAGE, HALOE, and MLS data sets are computed separately and then adjusted so the anomalies are equal on average during overlap periods.

2005: HALOE and MLS

2000-2005: HALOE and SAGE



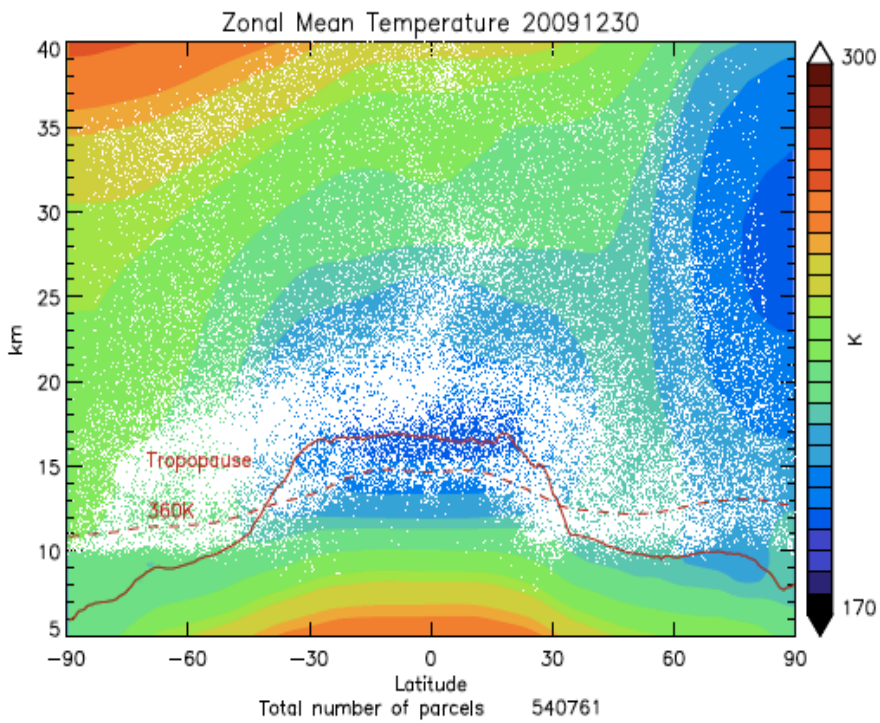
- Satellites roughly agree
- Trends are confusing
- Based on recent trends H2O will be ~8 ppmv by 2050 and we will all die.

Our Model of Stratospheric H_2O

- We use diabatic Lagrangian simulation of stratospheric water vapor using long forward parcel integrations – basically forward domain fill
- Regular grid of parcels are initiated at 360K hPa, 2° spacing ±40° lat.
- New grid is initiated each day
- Parcels falling below ~10 km (250 hPa) are removed
- Parcels reaching the top (~0.2 hPa, 60 km) are removed

- MERRA, ERAi or NCEP CSFR meteorological data.

- Integration for 10 years takes about 3 days for ~ 1e6 parcels



Schoeberl and Dessler, ACP , 2011

Water vapor

- Parcels are initiated with 50 ppmv H_2O.
- At each trajectory time step, parcels are dehydrated to frost point value when water vapor exceeds some relative humidity (RH) threshold (e.g. RH > 104%).
- Convective injection of water vapor tied to and MLS ice observations and OLR [Dessler et al., 2007] .
- Gravity wave temperature perturbations based on Jensen and Pfister [2004].
- Methane photolysis is included (increases water vapor), methane initialized at 1.75 ppmv, rates from Jackman 2D model.
- Last (final) and current saturation locations are book-kept

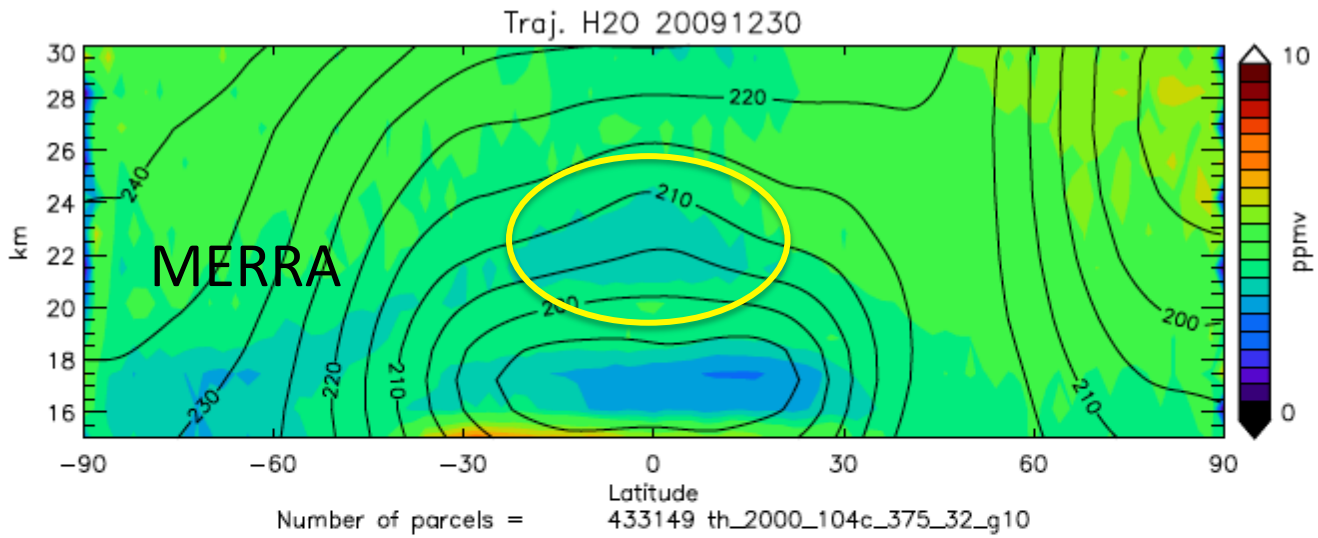
Tuning Stratospheric Water Vapor: Three Knobs

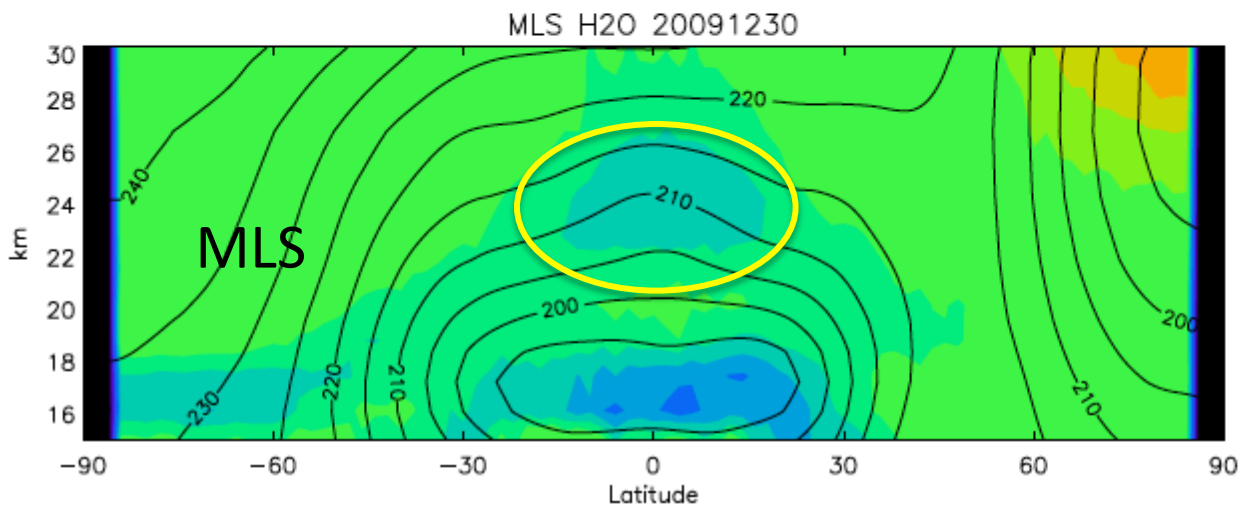
- **Observations show that cloud formation in the TTL often occurs in super-saturated environment – we can change the dehydration trigger to account for supersaturation**
- **Convective injection produces an overall increase in stratospheric water vapor by saturating sub-saturated layers**
- **Gravity wave temperature perturbations cause a decrease in water vapor**

Sensitivity Tests Summary

- Convection adds ~0.5 ppmv (once a day) to global mean lower stratospheric water vapor
- Gravity waves subtract ~0.2-0.3 ppmv
- 100% -> 104% RH saturation adds 0.2 ppmv
- Convection and super saturation are not linearly additive…
- Increasing the time resolution decreases water vapor somewhat – replicates gravity wave dehydration
- ERAi and MERRA at full time resolution at 104% RH with C + G are dry biased relative to MLS obs.
- CFSR is wet biased – tropopause too warm

Comparison with MLS



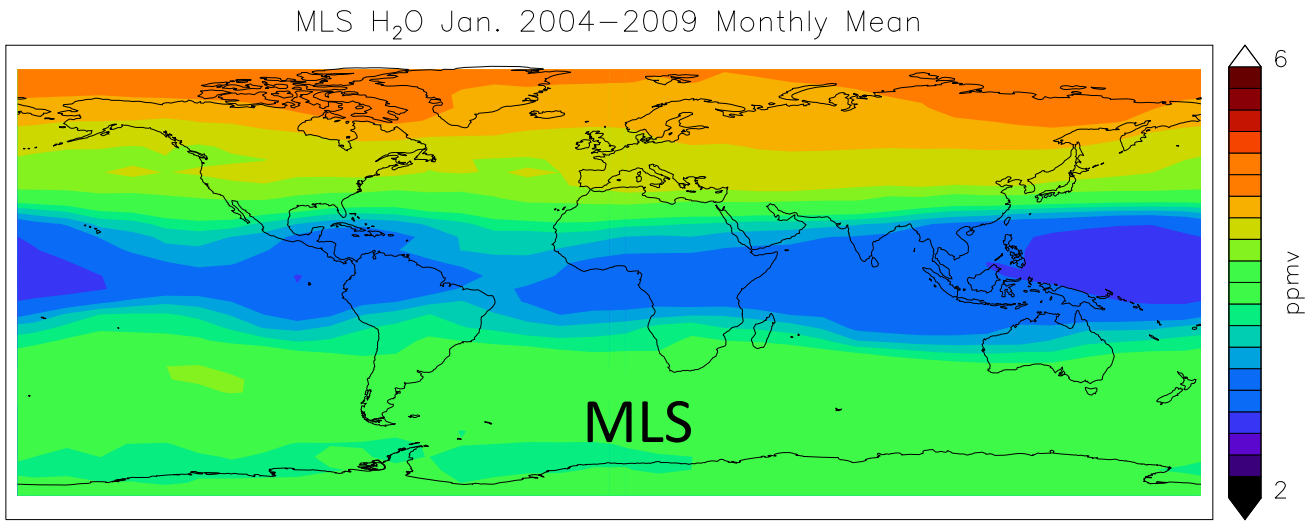


Zonal mean water vapor field for 12/30/2009 compared with MLS. Deh. at 104% RH + Conv. +GW

MLS tape recorder minimum is moving upward faster than MERRA. Implies model heating rates are too weak.

MERRA

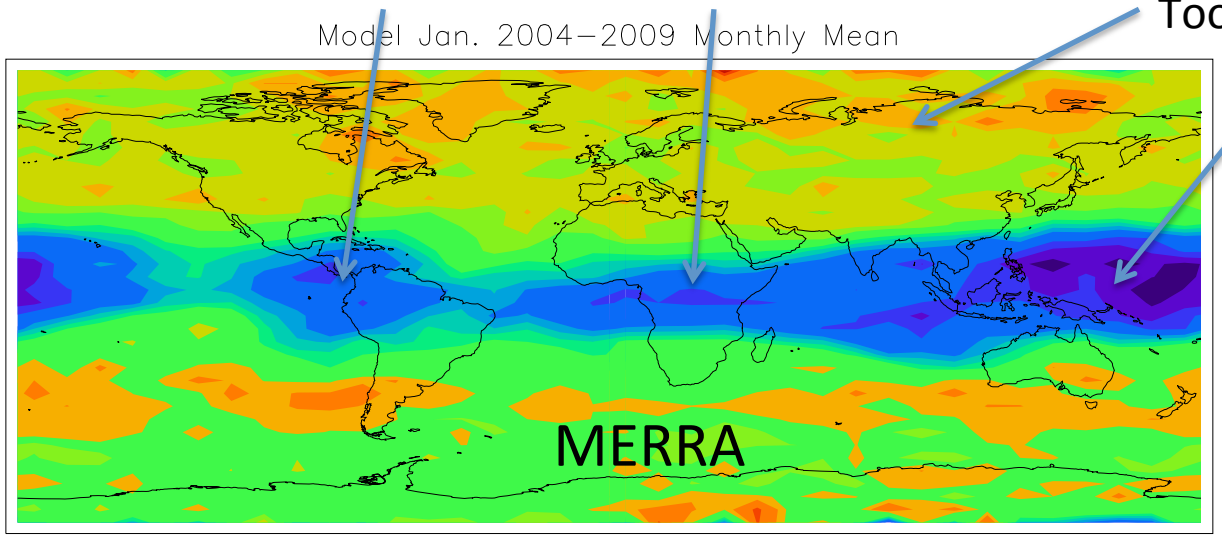
Comparison with MLS



5 year average Jan. water vapor at 85 hPa.

Additional dry zones

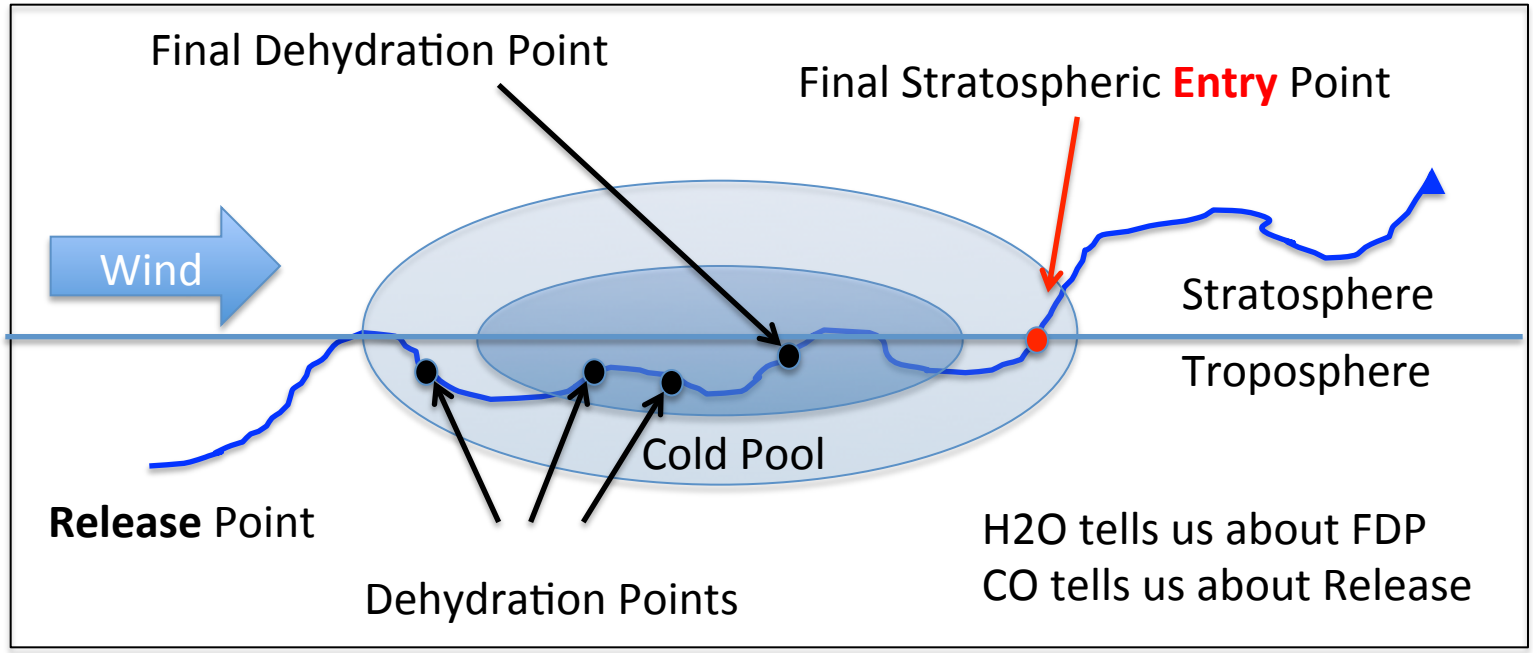
Too little water



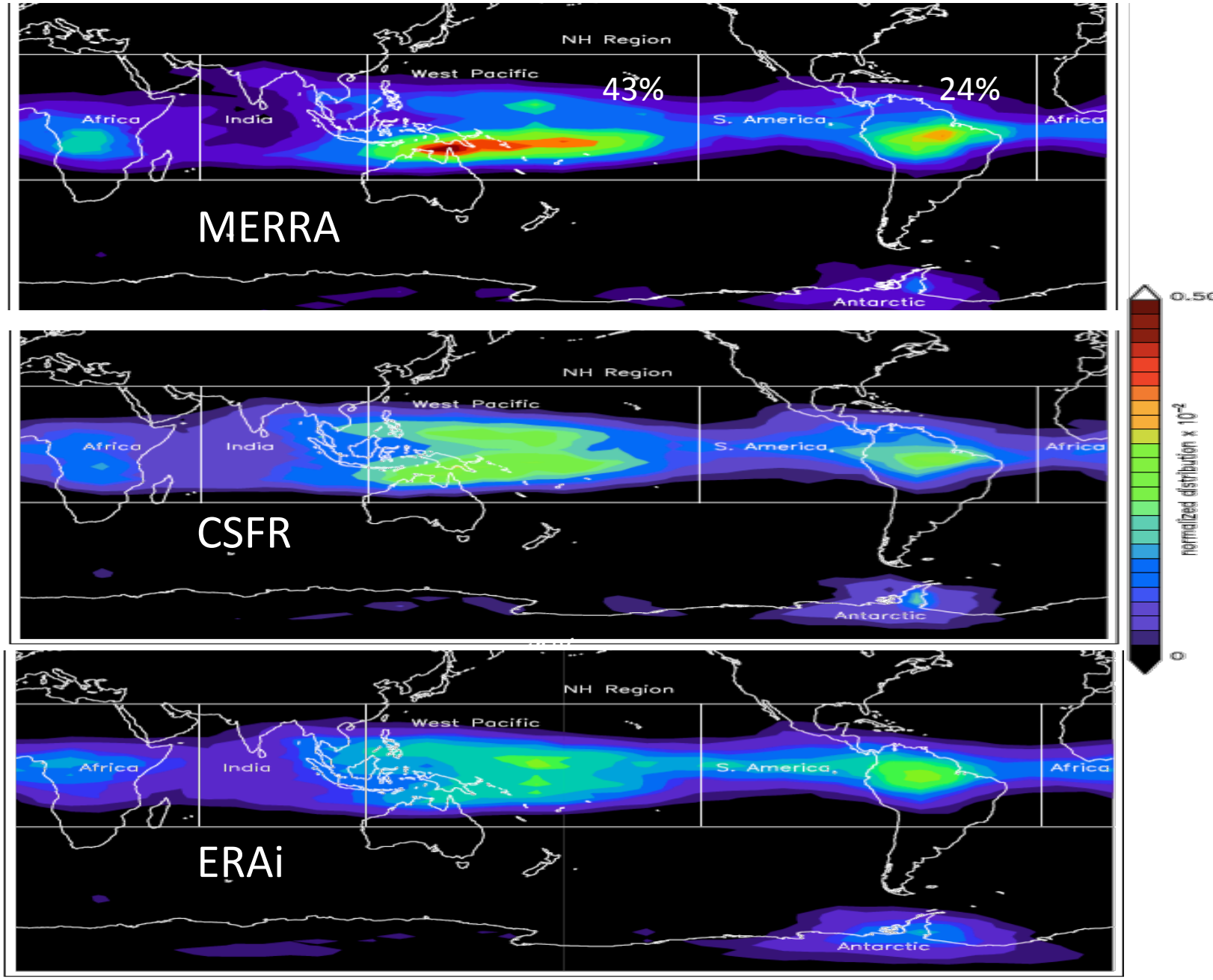
MERRA

Final Dehydration Point

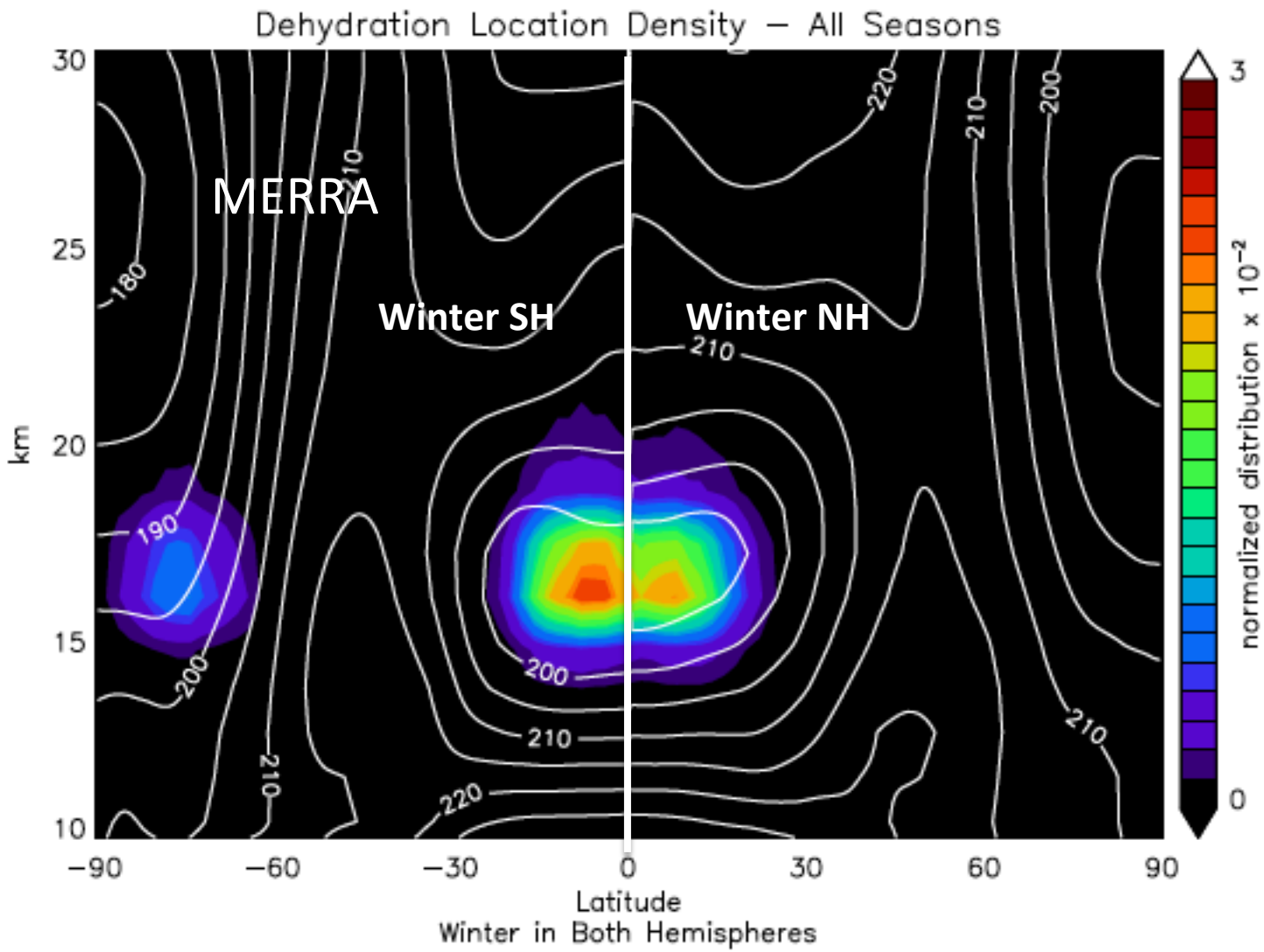
This is the point on the path where stratospheric water vapor is fixed. It is distinct from Entry and Release points. Liu et al. calls this the Lagrangian Dry Point (LDP) – there is no difference between the two.



Location of FDH Points all seasons

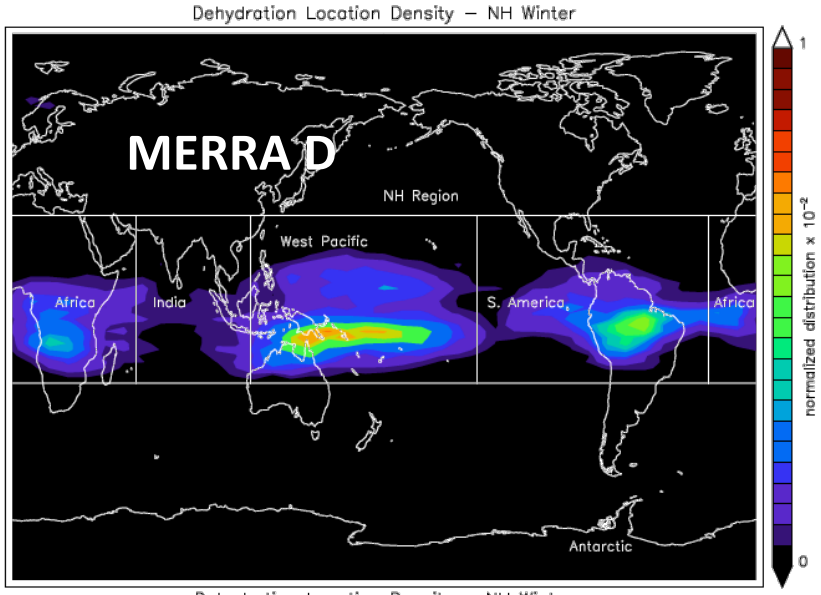


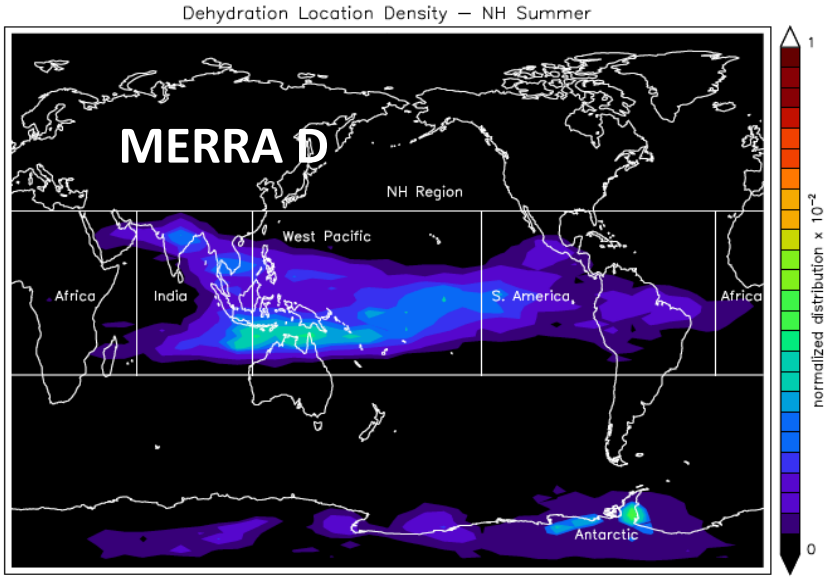
Location of FDH Points

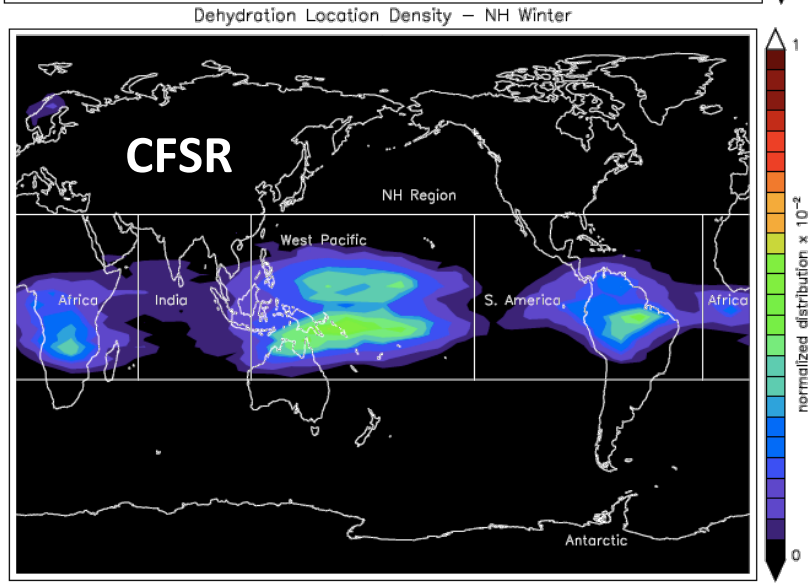


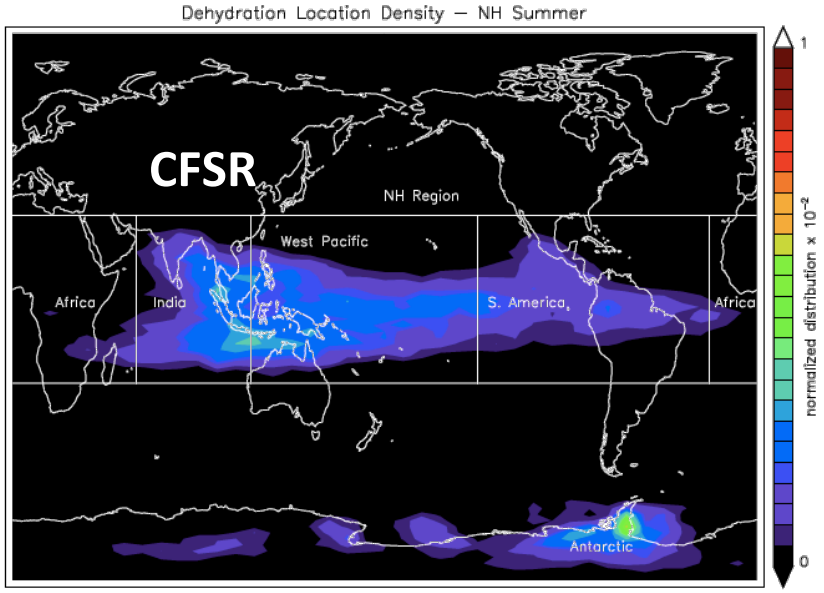
Winter – Dehydration zones are split across the equator. SA contributes

Summer– Dehydration over east Asia and N. Australia and across Pacific

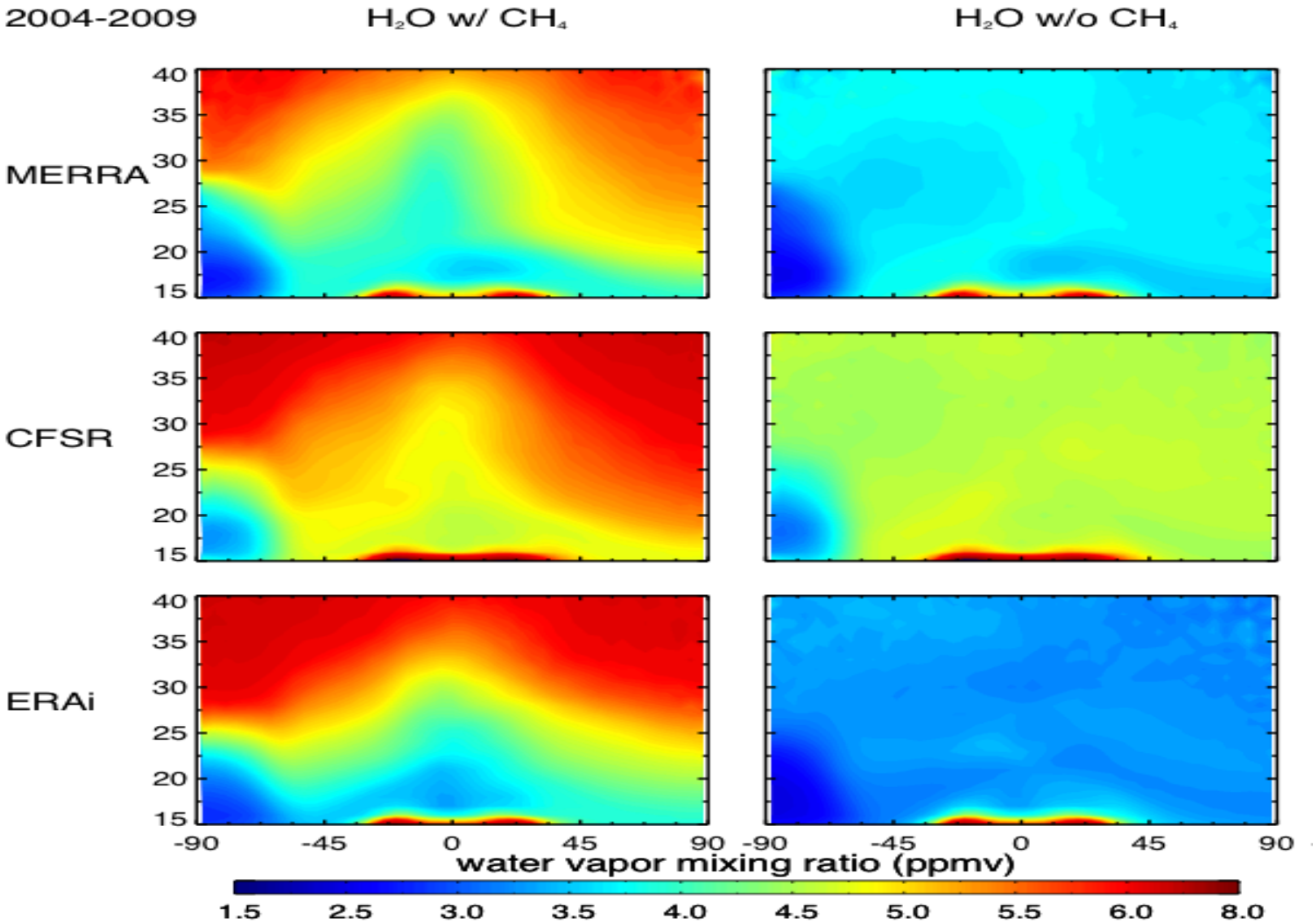








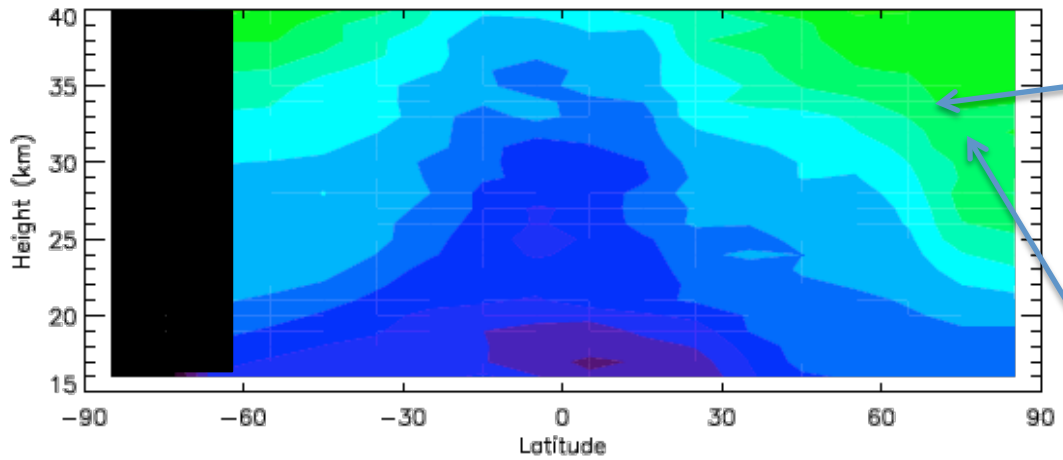
Role of Methane Photolysis



HDO – Convective Injection

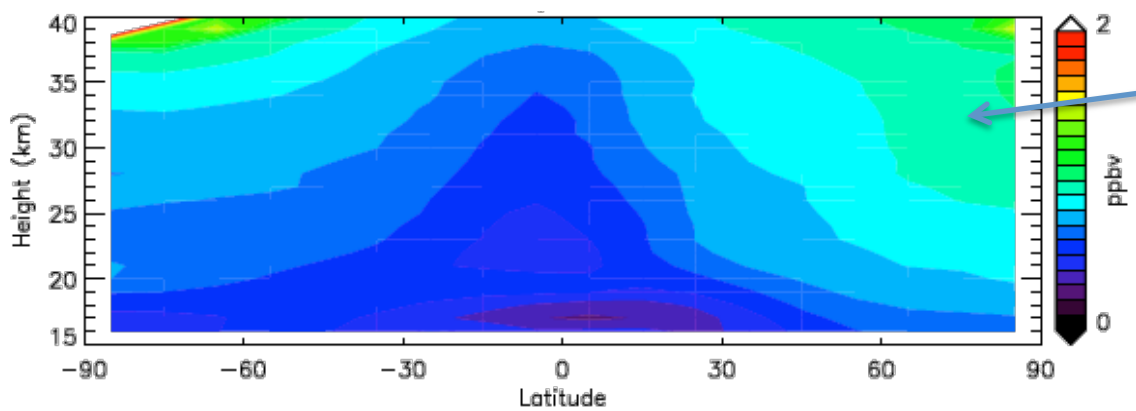
The model includes HDO injection though ice lofting and methane as source of HDO. DJF average of 4 years of data and MERRA model.

ACE DJF HDO



Increase due to photolysis of CH_3D

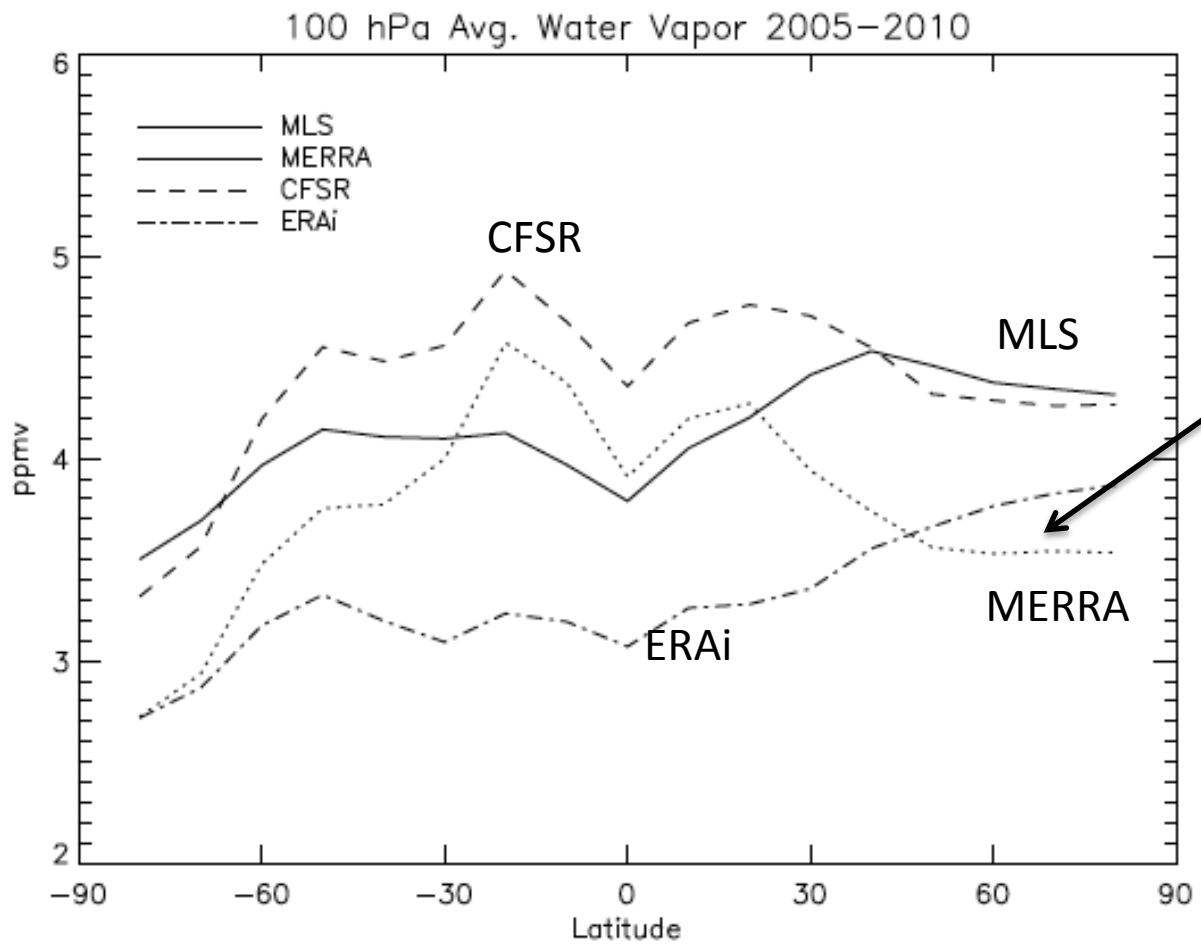
Trajectory model DJF HDO



Model does not photolyze enough methane due to lid so HDO not as high in model

see Randel et al. [2011]

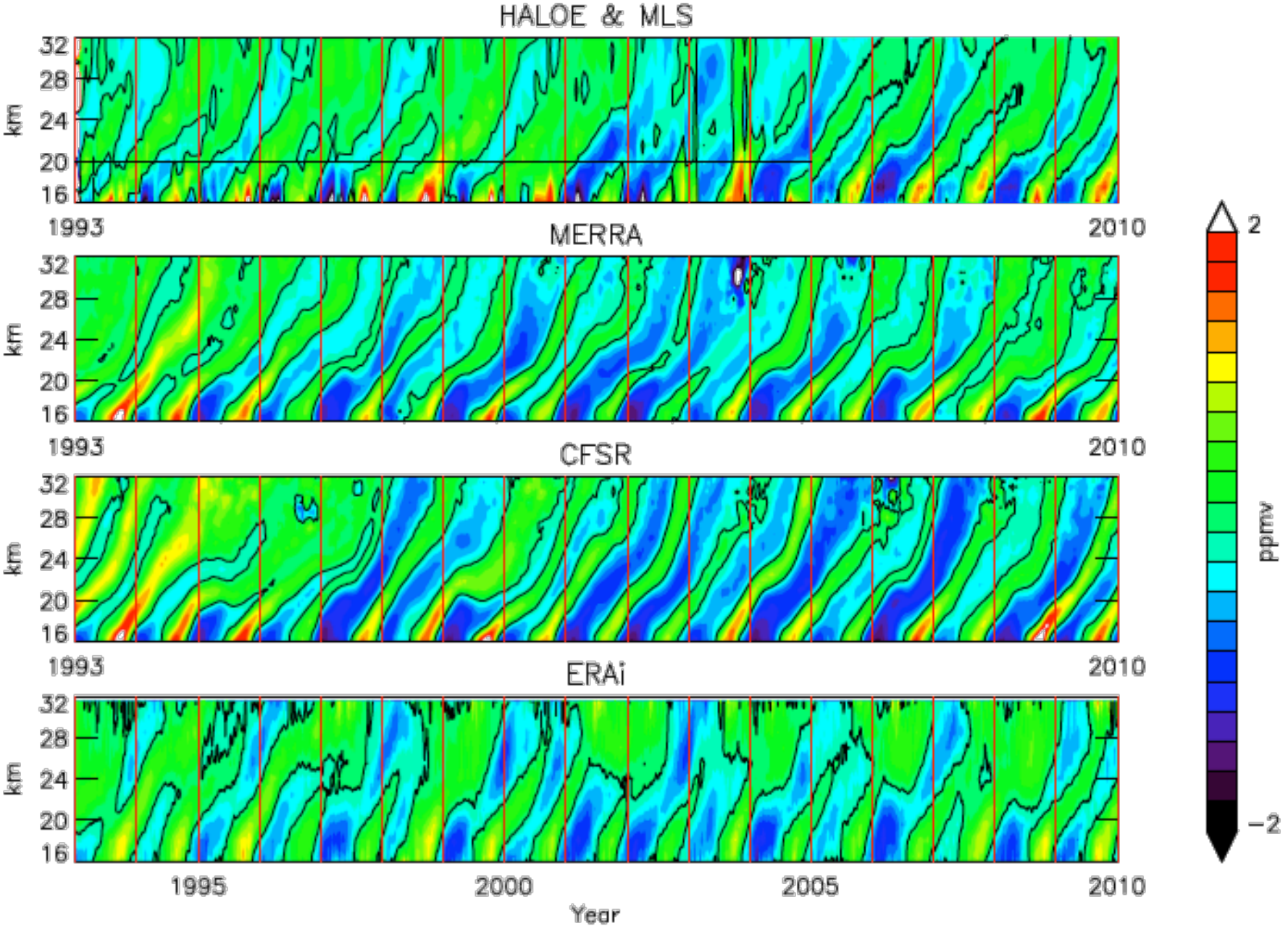
Zonal Mean H_2O at 100 hPa



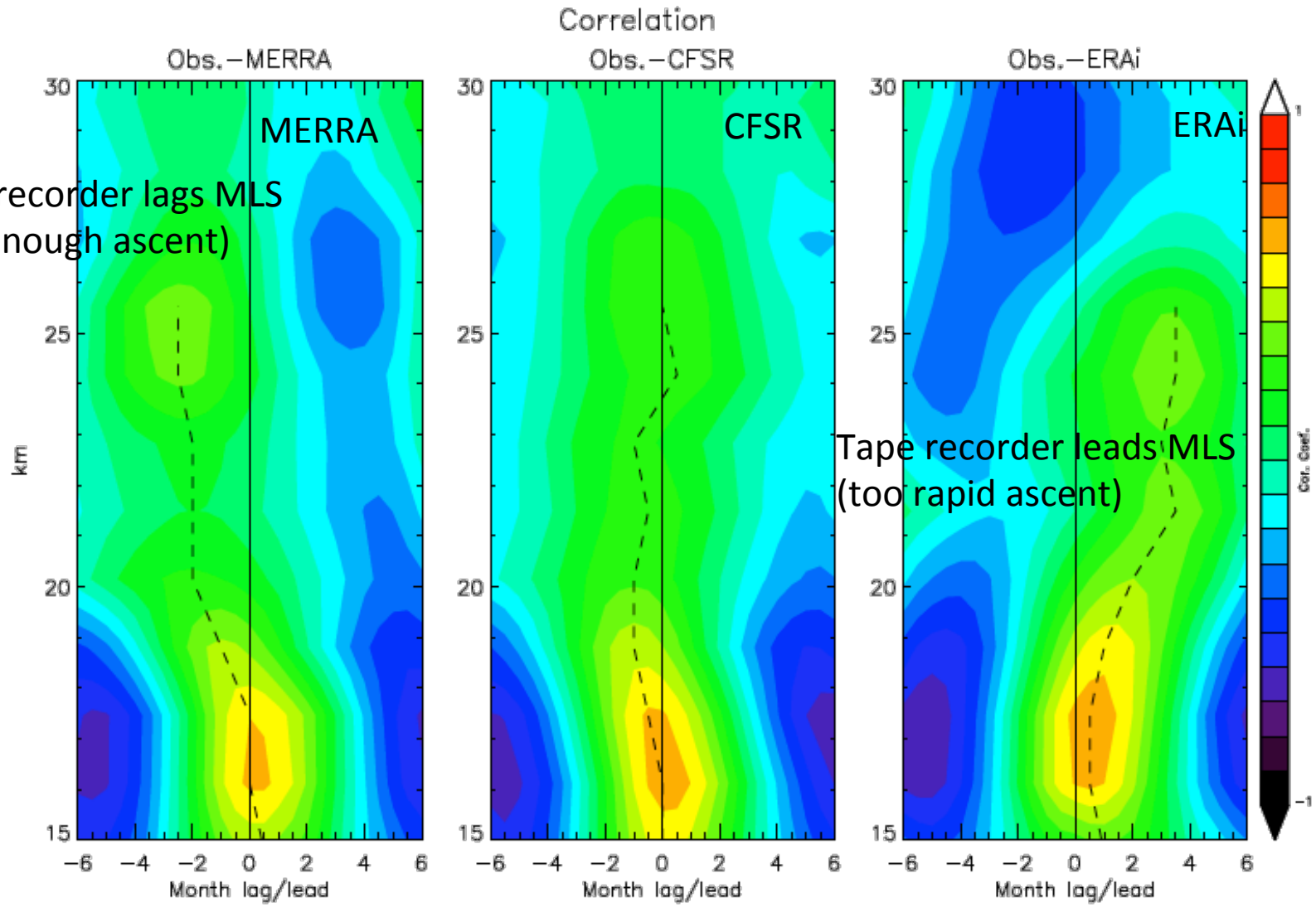
Not enough methane enhanced water descending for MERRA

Long Term Integration

Tropical Tape Recorder



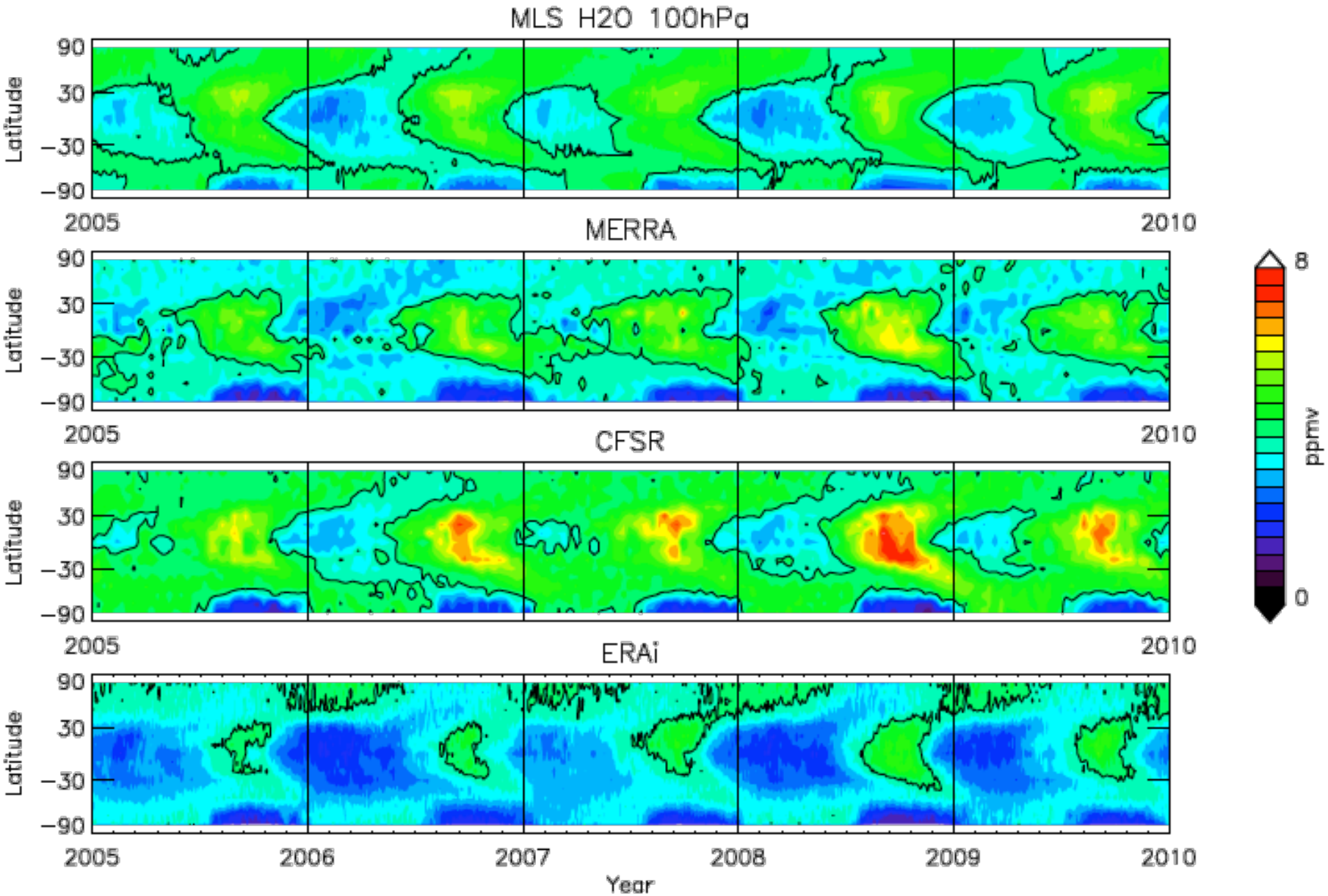
Correlation with MLS vs Altitude



Tape recorder lags MLS
(not enough ascent)

Tape recorder leads MLS
(too rapid ascent)

100 hPa (16 km) Time Series



Summary

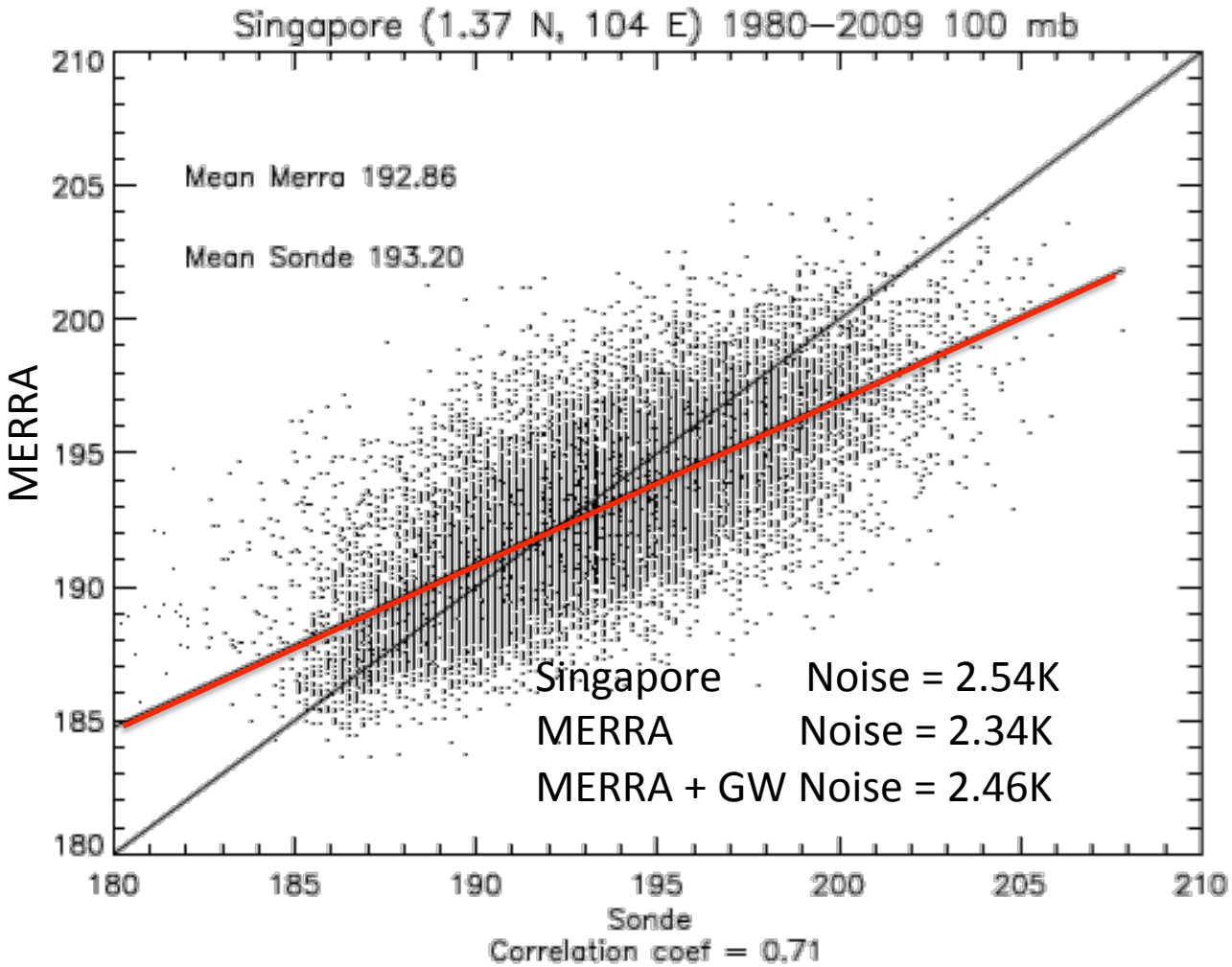
- Results from domain filling forward-trajectory technique compare favorably with MLS water observations (and HALOE)
- Three knobs in this model
  - Supersaturation – increases H_2O
  - Convective injection – increases H_2O especially in NH summer, needed for HDO
  - Gravity waves – decreases H_2O
- Assessment of FDPs provides some surprising results
  - More that 20% of winter final dehydration events are occurring over South America (~50% over TWP and East Asia). Warmer tropopause there.
  - MERRA, ERAi and CSFR broadly agree, but MERRA shows more dehydration in tropical SH during winter than ERAi and CSFR – probably an error in MERRA.
  - Parcels older than 2 months show little evidence of FDH over Tibet
- Stratospheric tropical assent rates differ MERRA slowest, ERAi highest.
- Extra-tropical dynamics more complex – pipe leakage vs. methane photolysis

What can ATTREX help with?

- How should we best parameterize super saturation? Is it globally the same? Will one number do?
- How can we improve convective moistening?
- How important (and what is the magnitude) of gravity wave fluctuations?
- Is dehydration really prevalent in other regions (e.g. Northern Australia, South America) as the models indicate?

Backup

Gravity Waves



MERRA shows excellent agreement with mean Singapore sonde temperatures – but shows less variability.

"Noise" = stdev ($T - T_s$)
Ts= 30 day smoothed data

Gravity waves are making up for this by increasing the "Noise"

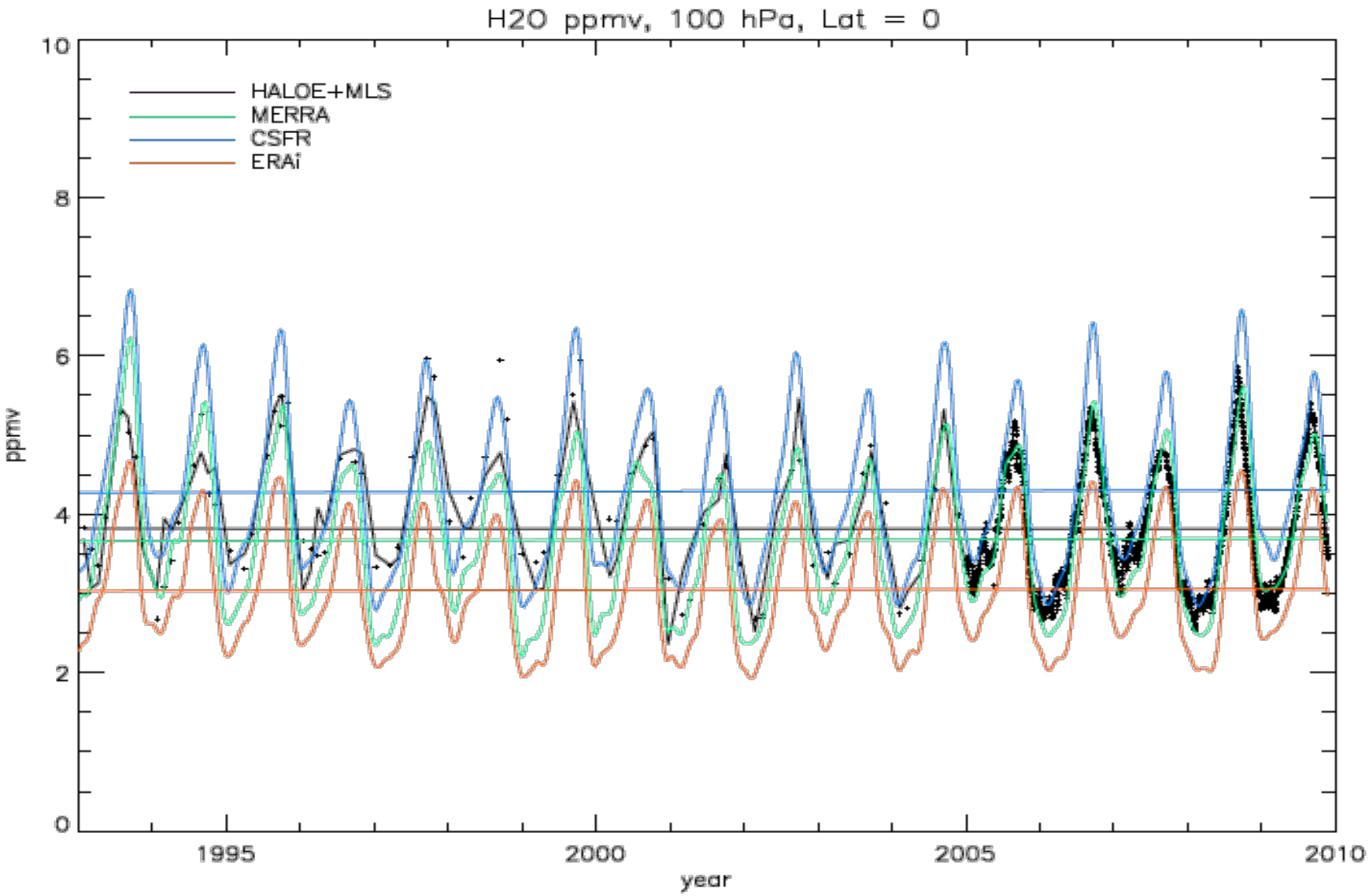
Some Experiments

Experiment (MERRA Daily unless specified)	H_2O (global mean 18-28 km)	Comment
MLS Observed	4.53±0.3 ppmv	Perfect in every way
100% saturation	4.0 ppmv	Too dry
104% saturation	4.25 ppmv	Still too dry – adds 0.25 ppmv
104% + Convection	4.7 ppmv	Now too wet - adds 0.45 ppmv
100% + Convection +1xG waves	4.48 ppmv	Closer - GWs subtract 0.17 ppmv
104% + Convection+ 1xG waves	4.53 ppmv	Nailed it.
CSFR 104% + Convection + 1xG	4.89 ppmv	Too wet, tropopause is too warm.
ERAi 6 hr 104% + Convection + 1xG	4.13 ppmv	Too Dry
MERRA 3hr, 104% + 1xG	3.73 ppmv	Way too dry
ERAi 6 hr, 104% + 1xG	3.35 ppmv	“”

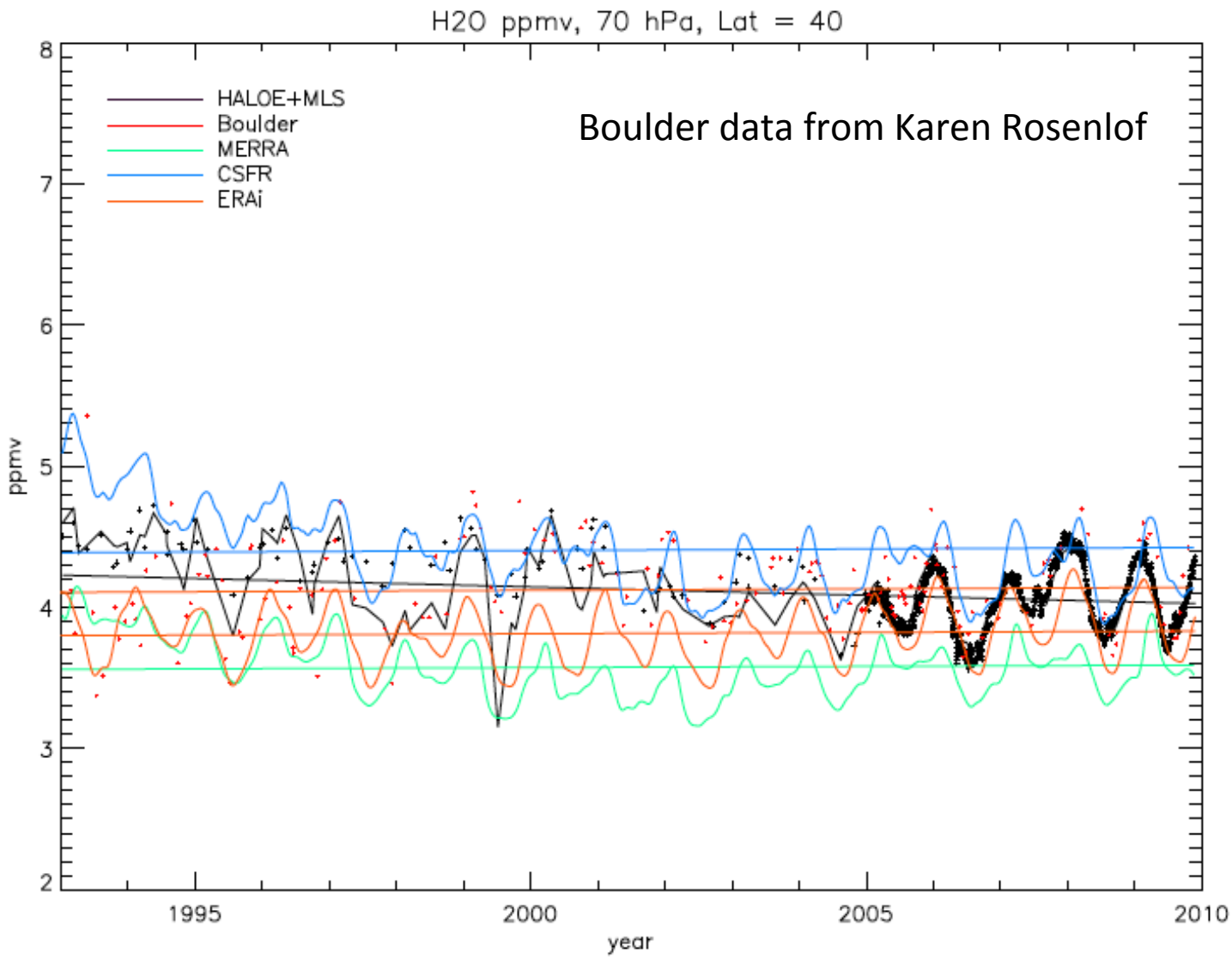
Experiments

MODEL	100%	104%	104%+C	104% +G	104%+C+G
MERRA D	4	4.25	4.7	(~4.0)	4.5
MERRA				3.7	
ERAi 8				3.3	4.1
CFSR 8					4.9
MLS	4.5	4.5	4.5	4.5	4.5

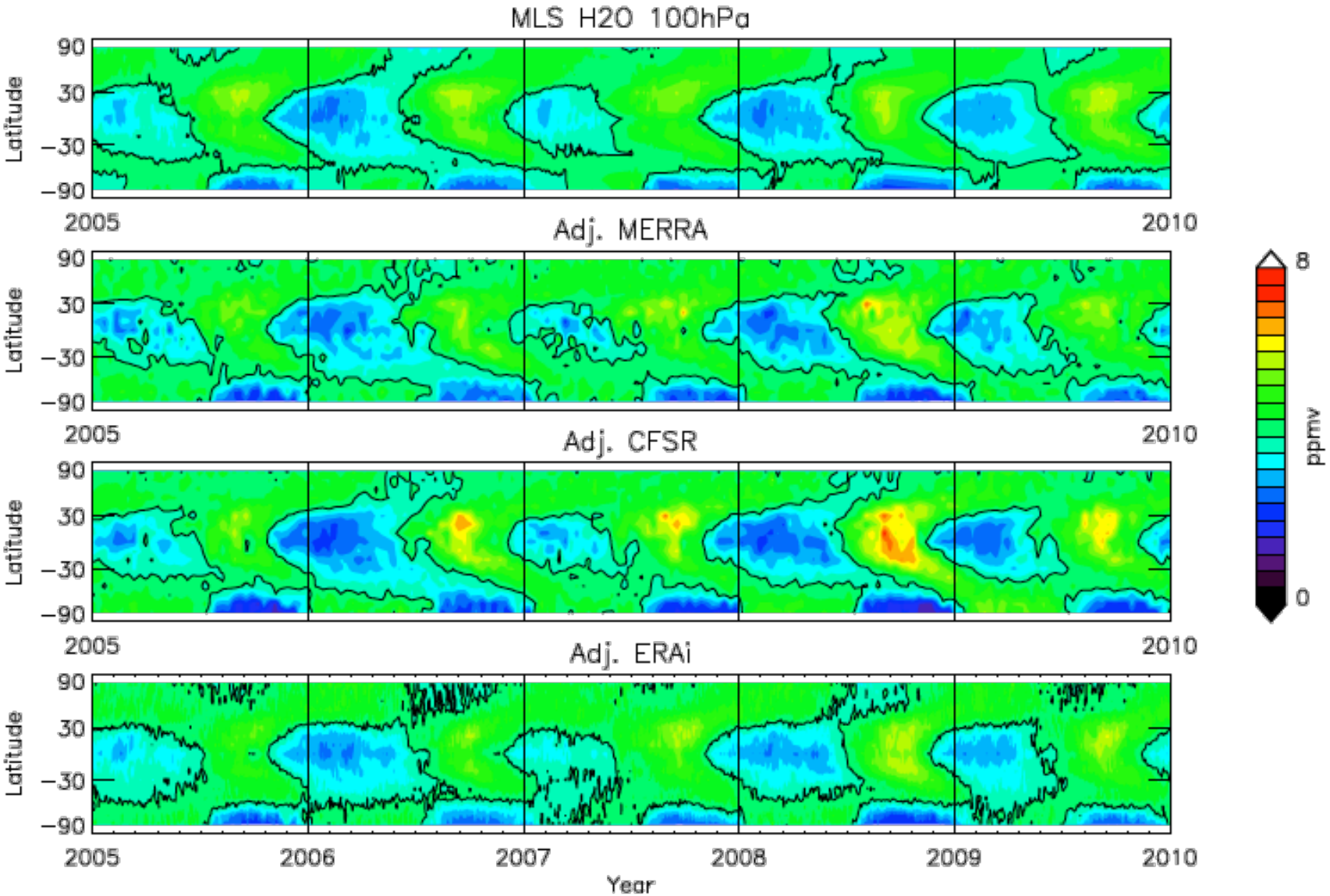
Trends at Eq.


H2O ppmv, 100 hPa, Lat = 0
HALOE+MLS
MERRA
CSFR
ERAi
ppmv
year
0
2
4
6
8
10
1995
2000
2005
2010

Trends at 40N

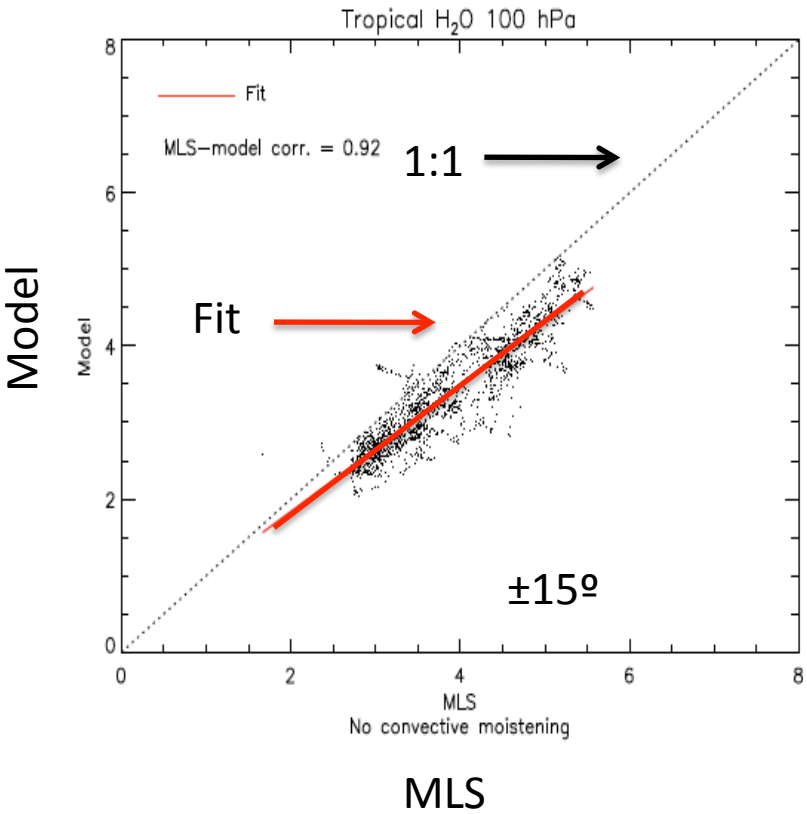


Normalized to MLS Zonal Mean

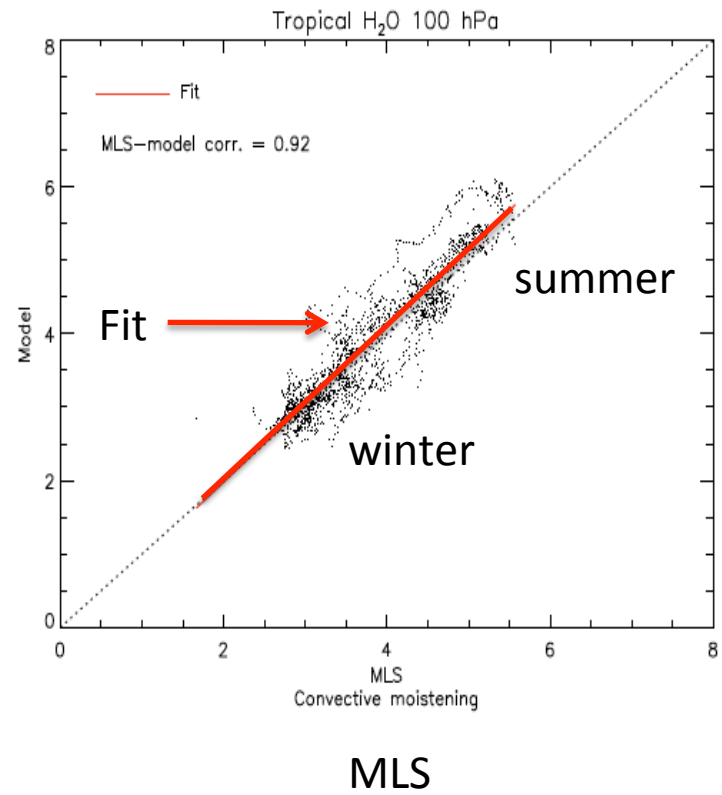


How does model compare to MLS Tropical H_2O?

No Convective Injection



Convective Injection



Model

MLS

MLS

Correlation = 0.92