Radiative Influences of Natural Variability in Tropical Lower Stratospheric Water Vapor and Ozone

Daniel M. Gilford (dgilford@mit.edu) and Susan Solomon

Department of Earth, Atmospheric, and Planetary Sciences, MIT

Motivation

How do tropical lower stratospheric H_2O/O_3 seasonal cycles and QBO structures radiatively impact temperatures in the upper troposphere and lower stratosphere (UTLS)?

Wave-driving and temperatures vary seasonally and with QBO → Associated vertical structure in H_2O and O_3 anomalies → Radiative impact on UTLS temperatures

Why is this important?

- Increase understanding of UTLS radiative controls
- Predictability and model representations of variability
- Upper tropospheric stability (convection and hurricanes)
- Stratospheric H_2O important for surface climate and very sensitive to temperatures
- Further applications exploring UTLS trends

Methods

Data

Aura Microwave Limb Sounder (**MLS**), version 3.3 [Livesey et al. 2011]

- H_2O, O_3, and Temperature measurements, over 20S – 20N.
- 5° x 5°, 316–0.02 hPa, 39 vertical levels

QBO Index: Normalized 50hPa Singapore Winds [Free University of Berlin 2015]

Model

Parallel Offline Radiative Transfer (**PORT**) model [Conley et al. 2013]

- 10° x 15°, 992–3.5 hPa, 26 Hybrid vertical levels
- Seasonally Evolving Fixed Dynamical Heating (SEFDH) assumption, Q → Heating Rates, T → Temperature, c → Constituents, t → Time:

$$\frac{dT_{adj}}{dt} = Q(T,c) - Q(T_p, c_p)$$

- $T_{adj} = T - T_p$ → Radiative Temperature Adjustment from Perturbation (p)
- One-year simulations with 4 month spin-up time (16 months total)

Determine H_2O and O_3 perturbations → Apply perturbations to PORT background → Run PORT with SEFDH → Analyze resulting Temperature Adjustments

Runs

For the Seasonal Cycle and QBO, we perform the following calculations to test the importance of anomaly vertical structures:

- **Full runs** – Perturbations applied everywhere above tropopause
- **Cutoff runs** – Perturbations applied *at and below* the cutoff pressure level and above the tropopause

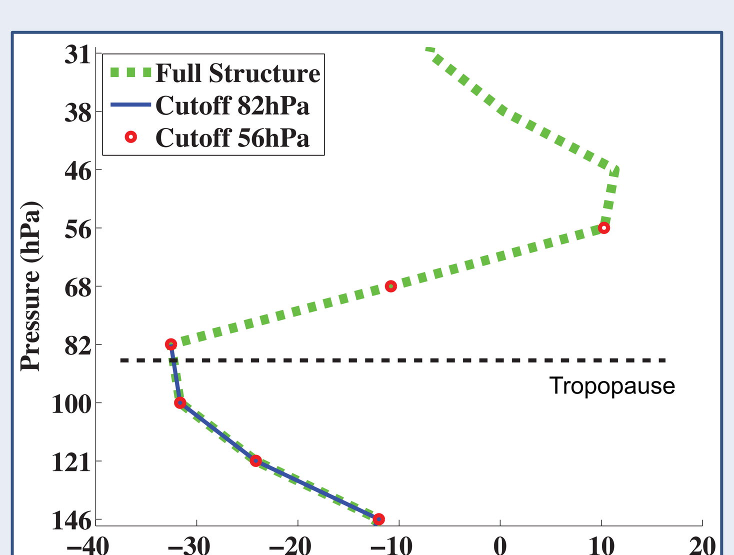

Fig. 1: Example H_2O profile to illustrate run methodology

Seasonal Cycle Results

MLS Observed Seasonal Cycles:

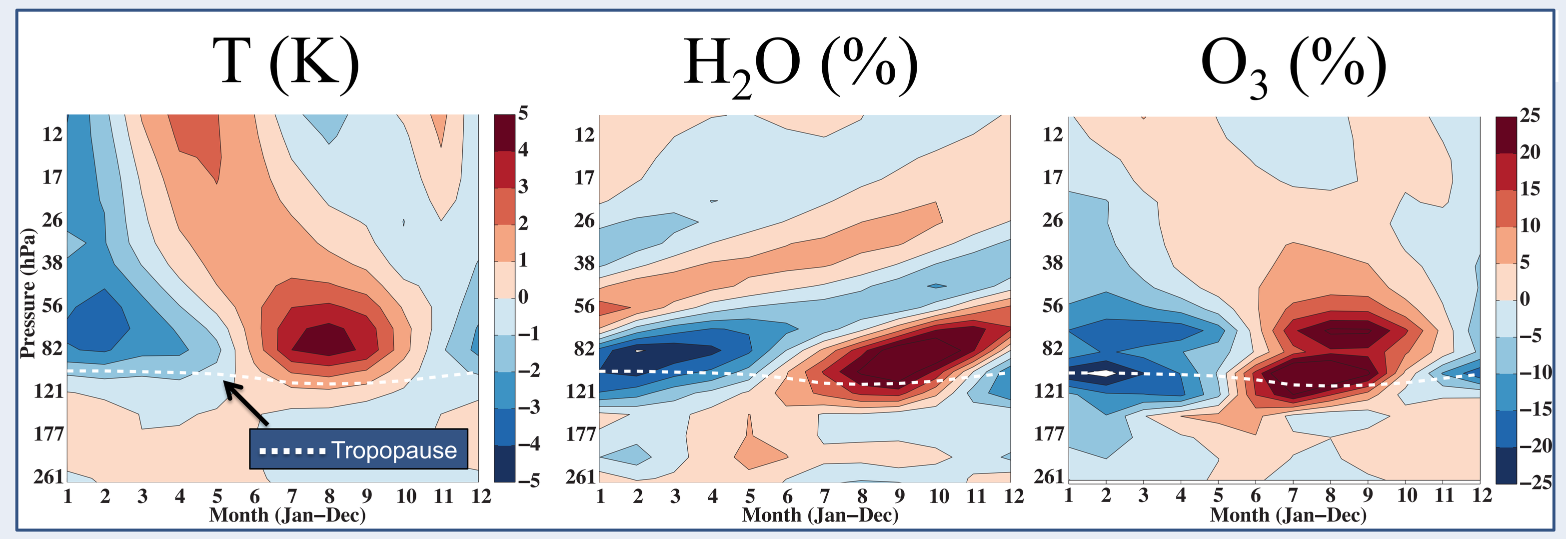

Fig. 2: Mean tropical seasonal cycles of Temperature, H_2O and O_3 vs. pressure level

How do the anomalies at higher levels affect temperatures below?

Temperature Adjustments (T_{adj}):

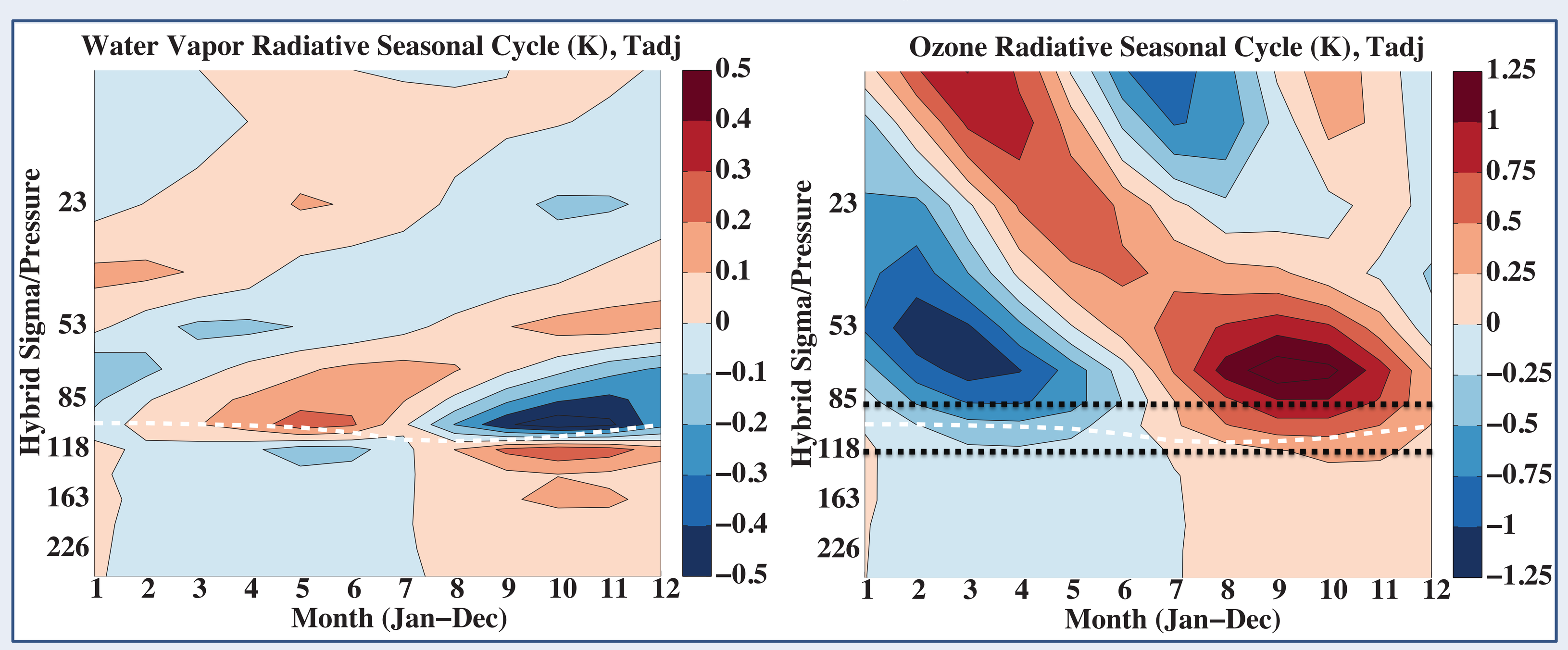

Fig. 3: Mean tropical seasonal cycles of Tadj for H_2O and O_3 vs. pressure level. Black dashed curves are the levels analyzed below.

Seasonal Temperature Range (K)	H_2O Full Structure	O_3 Full Structure	H_2O Cutoff ~85hPa	O_3 Cutoff ~85hPa	H_2O Cutoff ~53hPa	O_3 Cutoff ~53hPa
85 hPa	*0.50**	*1.77*	*0.41**	*0.94*	*0.48**	*1.48*
118 hPa	*0.44*	*0.51*	*0.48*	*0.15*	*0.44*	*0.36*

Table 1: Seasonal cycle temperature ranges for radiative Tadj. (*) indicates cycle offsets sign of the observed temperature cycle

- UTLS T_{adj} lag H_2O / O_3 anomalies by 2-3 months
- Lower stratosphere: H_2O T_{adj} offset seasonal cycle; O_3 T_{adj} amplify the cycle
- Upper troposphere: H_2O and O_3 T_{adj} constructively amplify/positively shift the seasonal cycle
- H_2O T_{adj} ~insensitive to cutoff altitude. Nearly all radiative influences due to local lower stratospheric anomalies
- Lower stratosphere O_3 T_{adj} strongly depends on nonlocal radiative influences. ~46% of 85hPa T_{adj} and ~66% of 118hPa T_{adj} due to O_3 anomalies above 85hPa

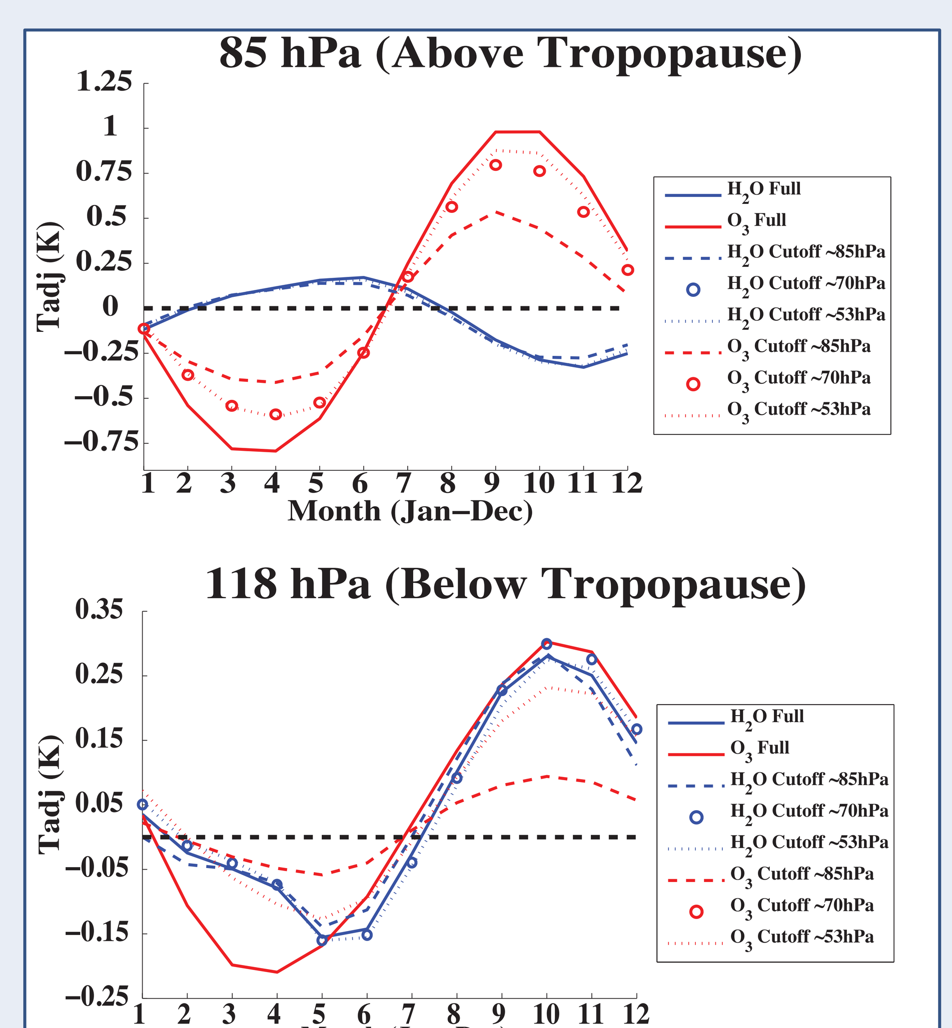

Fig. 4: Seasonal cycles of H_2O and O_3 Tadj on 85, 118hPa hybrid surfaces

QBO Results

Lag Correlations (β) between H_2O / O_3 and QBO:

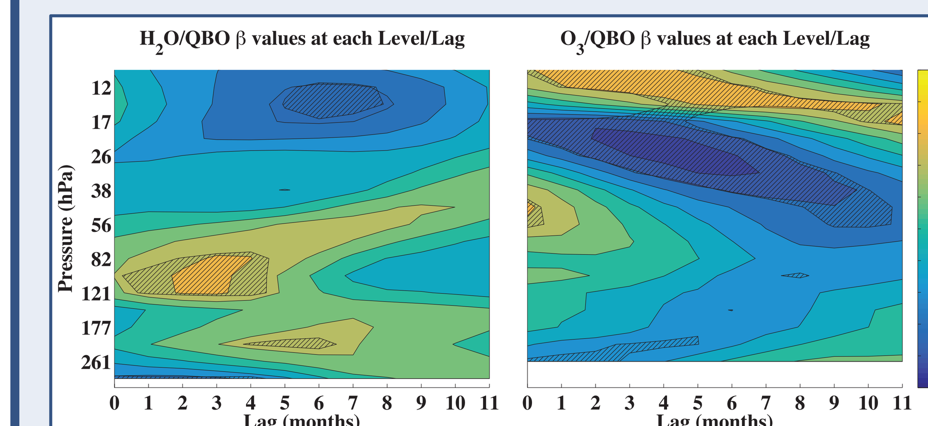

Fig. 5: Pearson Correlation coefficients, hatching indicates >90% confidence

- A "tape recorder" signal is apparent in H_2O lag correlations; significant in lower stratosphere
- O_3 lag correlations follow QBO signal; significant at higher altitudes

QBO-Regressed Anomalies at Optimal Lag:

- Structures are consistent with correlations; a "low" QBO period (▬ ▬ ▬) is selected for radiative runs

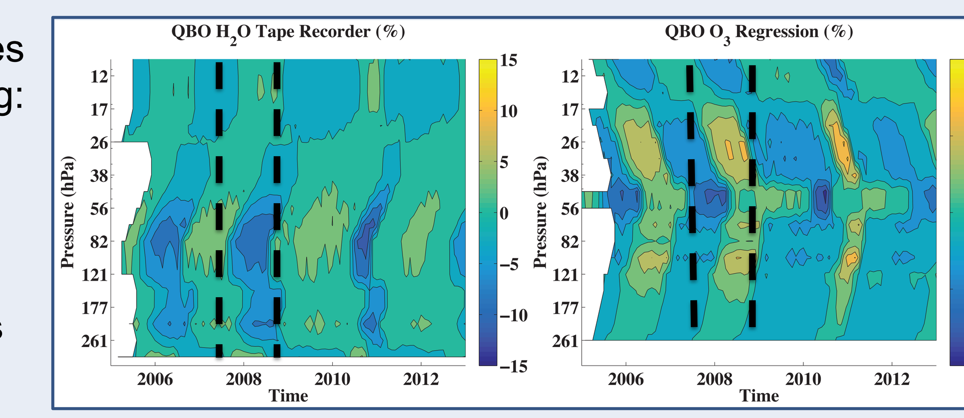

Fig. 6: Regression time series at each pressure level's optimal lag

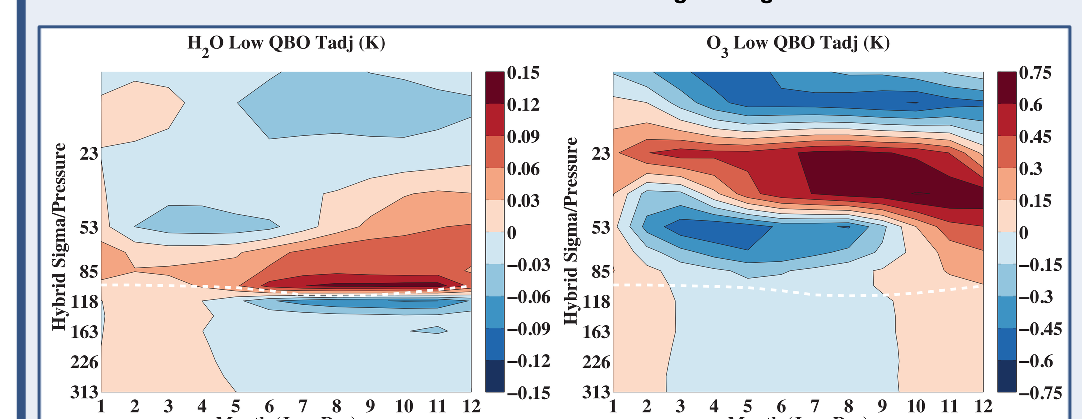

Fig. 7: Mean tropical QBO signals of Tadj for H_2O and O_3 vs. pressure level.

Associated T_{adj}:

- QBO-related T_{adj} much smaller than seasonal cycle, especially below tropopause
- O_3 impacts are strong locally—away from tropopause—inconsistent with weaker H_2O signal

Conclusions

1. Stratospheric seasonal cycles of H_2O and O_3 act to radiatively cool the upper troposphere in the boreal spring, and warm it in the boreal fall
2. Anomalies very close to the tropopause (~85hpa) dominate the H2O radiative signal, with little influence from the overlying structure
3. About half of the O_3 radiative influences in the UTLS result from anomalies above the lowermost stratosphere (p<85hPa)
4. QBO-related H_2O anomalies result in UTLS radiative influences smaller than those of the seasonal cycle; O_3 influences are larger, but primarily focused at higher altitudes

Selected References

- Mote, P. W., *and coauthors*, 1996. *J. Geophy. Res.*, **101**, 3989–4006.
- Conley, A. J., J.-F. Lamarque, F. Vitt, W. D. Collin, and J. Kiehl, 2013. *Geosci. Model Dev.*, **6**, 469–476.
- Folkins, I., P. Bernath, C. Boone, G. Lesins, N. Livesey, A. M. Thompson, K. Walker, and J. C. Witte, 2006. *Geophys. Res. Lett.*, **33**, doi:10.1029/2006GL026602.
- Free University of Berlin, 2015. [Available at: http://www.geo.fu-berlin.de/en/met/ag/strat/produkte/qbo/]
- Fueglistaler, S., P. H. Haynes, and P. M. Forster, 2011. *Atmos. Chem. Phys.*, **11**, 3701–3711, doi:10.5194/acp-11-3701-2011.
- Gilford, D. M., S. Solomon, and R. W. Portmann, in press. *J. Climate*, doi:10.1175/JCLI-D-15-0167.1.
- Livesey, N. J., and coauthors, 2011. Jet Propulsion Laboratory, Pasadena, California. [Available at: http://mls.jpl.nasa.gov/data/v3- 3_data_quality_ document.pdf]

Acknowledgements

This work was supported by NASA Headquarters under the NASA Earth and Space Science Fellowship Program - Grant NNX14AK83H. It was also supported by NSF Grant AGS-1342810 and 1461517.

January 2016