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Discussions

Interactive comment on “Impact of convectively lofted ice on the seasonal cycle of tropical lower stratospheric water vapor” *by* Xun Wang et al.

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This manuscript describes a modeling study of the impacts of deep convection on lower stratospheric water vapor and its seasonal cycle. Simple trajectory calculations are combined with the anvil ice water content (IWC) from the Goddard Earth Observing System Chemistry Climate Model (GEOSCCM). The calculated impact of convectively-generated ice on stratospheric humidity is far larger than those from recent studies using observed convective cloud-top heights (*Schoeberl et al.*, 2018; *Ueyama et al.*, 2018). In some places, the manuscript seems to indicate that the purpose of the paper is to diagnose what is happening in the GEOSCCM model. However, in the abstract and several places in the main text, the authors seem to be arguing that the modeling framework here is useful for understanding what is happening in the real atmosphere.

This distinction should be made clear such that readers are not given a misleading impression. The applicability of the modeling approach to physical processes in the real atmosphere depends on whether the GEOSCCM anvil ice product accurately represents the distribution of convectively-generated ice with respect to the tropopause. As described in detail below, I am not convinced that the realism of the GEOSCCM anvil ice water content distribution is adequately confirmed by the comparisons with measurements presented in the manuscript. Further, the conclusions presented here contradict various other lines of evidence suggesting that direct ice injection by deep convection has a relatively small impact on stratospheric humidity; acknowledgment and discussion of these discrepancies is generally lacking in the manuscript.

Figures 3 and 4 present comparisons of the anvil IWC from GEOSCCM and the total cloud IWC from CALIOP measurements. The height distributions shown in Figure 3 show a reasonable agreement. However, as noted in passing by the authors, the CALIOP cloud products include convectively-generated clouds as well as clouds formed in situ in the upper troposphere. The CloudSat cloud classification product (specifically deep convection) would be more appropriate for this comparison. Previous analyses of satellite measurements have shown that the occurrence of deep convection cloud tops drops off rapidly above about 15 km in the tropics (*Liu and Zipser*, 2005; *Massie et al.*, 2010; *Ueyama et al.*, 2018), and most clouds occurring in the tropical tropopause region are formed in situ. As a result, the CALIOP IWC (including all clouds) should be much higher than the GEOSCCM anvil IWC in the uppermost tropical troposphere; however, the comparison shown in Figure 2 for the tropical tropopause region indicates larger IWC in GEOSCCM than in the CALIOP data. This comparison suggests the GEOSCCM model had too much ice near (or above) the tropopause, which is presumably why the model predicts such a large impact of the convective ice on stratospheric humidity.

Figure 4 shows geographic distributions of the CALIOP and GEOSCCM IWC integrated between 177 and 68 hPa. This layer average is dominated by ice at the lowest model level included (177 hPa), and it is therefore not useful for assessing the realism of the GEOSCCM anvil IWC in the vicinity of the tropical tropopause. Comparisons of the CALIOP and GEOSCCM IWC at 100 and 82 hPa would be more useful for this purpose, but again the CALIOP cloud product near the tropical tropopause is likely dominated by clouds formed in situ.

Various lines of evidence indicate that direct injection of ice into the lower stratosphere by deep convection has a relatively weak impact on stratospheric humidity. Numerous studies over the past 20 years have documented the strong correlation between tropical cold-point tropopause temperature and the lower stratospheric humidity (e.g. *Randel et al.*, 2004; *Fujiwara et al.*, 2010; *Liang et al.*, 2011; *Fueglistaler et al.*, 2013). This strong coupling would break down if direct convective injection significantly contributed to the stratospheric water vapor budget. Further, as shown by *Dessler et al.* (2007) and others, a significant contribution from sublimation of convectively-lofted ice to the lower stratospheric humidity would result in higher water isotope (HDO) enrichment than indicated by satellite and in situ observations. The current version of the manuscript does not include discussion of either of these issues.

Direct calculations conducted by a co-author on this paper indicate a far smaller impact of convective hydration on lower stratospheric humidity (*Schoeberl et al.*, 2018). The *Schoeberl et al.* (2018) study used an observation-based convective cloud-top product along with a forward-trajectory approach similar to the approach used in the current paper. With the observation-based convective cloud product, *Schoeberl et al.* (2018) concluded that convective hydration produces a less than 2% increase in stratospheric humidity. The current study using GEOSCCM anvil ice gives a gives a convective impact nearly two orders of magnitude higher (1.9 ppmv enhancement in the northern subtropical lower stratosphere). The authors should acknowledge this glaring discrepancy clearly and discuss the reasons for the difference.

The authors conclude that most of the convective moistening in their simulations comes from the Asian monsoon region. However, analyses of convective moistening using

aircraft and satellite (MLS) measurements suggest that this process primarily occurs over the north American monsoon region where the tropopause is relatively low and deep convection extends well into the lower stratosphere (*Schwartz et al.*, 2013; *Smith et al.*, 2017). Furthermore, as noted above, significant sublimation of convectively-lofted ice in the lower stratosphere would cause a large enhancement in the HDO/H_2O ratio. HDO observations from the Atmospheric Chemistry Experiment (ACE) satellite show that the HDO/H_2O ratio is significantly enhanced in the lowermost stratosphere over the north American monsoon region, but there is no indication of enhancement over the Asian monsoon region (*Randel et al.*, 2012). The observed HDO/H_2O isotope regional distribution is inconsistent with the conclusion of this paper that convective hydration primarily occurs over the Asian monsoon.

Returning to the purpose of the manuscript, it is worth noting again that the results of the paper depend critically on the geographic distribution and height distribution of the GEOSCCM anvil ice water content product. Convective cloud in the global model is produced by a convective parameterization with poorly constrained tuning parameters, and the IWC in the model also depends on the assumed detrained ice crystal size and corresponding fall speed, which are poorly constrained by observations. As described above, the comparisons with CALIOP total cloud products are not appropriate for this purpose, and even these apples-to-oranges comparisons indicate the model has more ice mass near (or above) the tropopause than indicated by the measurements. The current version of the manuscript gives the misleading impression that the modeling approach used provides a quantitatively useful assessment of the impact of convectively-lofted ice on stratospheric humidity in the real atmosphere.

The analysis presented here might be useful as a diagnostic for understanding the control of stratospheric humidity in the GEOSCCM model. However, my understanding is that the GEOSCCM model fields used here come from a version of the model that is several years old. Newer versions of the GEOSCCM model have made substantial changes to the treatments of deep convection and stratiform ice. Recent versions of the model anvil ice product may well have less ice mass near or above the tropopause than the version used here, in which case the analysis presented here may be of little interest to the GEOSCCM developers and users.

Additional technical comments

The FDF model parcels are launched at 370 K potential temperature. Particularly during Boreal summertime, the tropical cold point tropopause is often below 370 K; therefore, some of the parcels are not experiencing the true Lagrangian dry point. This error will affect both the seasonal cycle and the impact of convective hydration. The authors should re-run the simulations with parcels launched at a lower altitude (perhaps 360 K) to ensure proper representation of the tropopause cold-trap dehydration.

The manuscript states that ice forms at 80% relative humidity with respect to ice. This assumption makes some physical sense in the framework of a global Eulerian model where the cloud only occupies a fraction of the grid box. In the Lagrangian parcel model framework, this assumption is obviously unrealistic and should give a stratospheric humidity 20% too low in the absence of convective ice input. This assumption also exaggerates the impact of convective ice sublimation. Again, the 80% RH threshold could only be reasonable if the sole purpose of the paper was diagnosing processes in the GEOSCCM model.

References

Dessler, A. E., T. F. Hanisco, and S. Füglistaler (2007), Effects of convective ice lofting on H_2O and HDO in the tropical tropopause layer, *J. Geophys. Res.*, *112*, doi:10.1029/2007JD008,609.

Fueglistaler, S., Y. S. Liu, T. J. Flannaghan, P. H. Haynes, D. P. Dee, W. J. Read, E. E. Remsberg, L. W. Thomason, D. F. Hurst, J. R. Lanzante, and P. F. Bernath (2013), The relation between atmospheric humidity and temperature trends for stratospheric water, *J. Geophys. Res.*, *118*, doi:10.1002/jgrd.50,157.

Fujiwara, M., H. Vömel, F. Hasebe, M. Shiotani, S.-Y. Ogino, S. Iwasaki, N. Nishi, T. Shibata, K. Shimizu, E. Nishimoto, J. M. V. Canossa, H. B. Selkirk, and S. J. Oltmans (2010), Seasonal to decadal variations of water vapor in the tropical lower stratosphere observed with balloon-borne cryogenic frost point hygrometers, *J. Geophys. Res.*, *115*, doi:10.1029/2010JD014,179.

Liang, C. K., A. Eldering, A. Gettelman, B. Tian, S. Wong, E. J. Fetzer, and K. N. Liou (2011), Record of tropical interannual variability of temperature and water vapor from a combined AIRS-MLS data set, *J. Geophys. Res.*, *116*, doi:10.1029/2010JD014,841.

Liu, C., and E. J. Zipser (2005), Global distribution of convection penetrating the tropical tropopause, *J. Geophys. Res.*, *110*, doi:10.1029/2005JD006,063.

Massie, S., J. Gille, C. Craig, R. Khosravi, J. Barnett, W. Read, and D. Winker (2010), HIRDLS and CALIPSO observations of tropical cirrus, *J. Geophys. Res.*, *115*, doi:10.1029/2009JD012,100.

Randel, W. J., F. Wu, S. J. Oltmans, K. Rosenlof, and G. E. Nedoluha (2004), Interannual changes of stratospheric water vapor and correlations with tropical tropopause temperatures, *J. Atmos. Sci.*, *99*, in press.

Randel, W. J., E. Moyer, M. Park, E. J. Jensen, P. Bernath, K. A. Walker, and C. Boone (2012), Global variations of HDO and HDO/H_2O ratios in the upper troposphere and lower stratosphere derived from ace-fts satellite measurements, *J. Geophys. Res.*, *117*, doi:10.1029/2011JD016,632.

Schoeberl, M. R., E. J. Jensen, L. Pfister, R. Ueyama, M. Avery, and A. E. Dessler (2018), Convective hydration of the upper troposphere and lower stratosphere, *J. Geophys. Res.*, *123*, doi:10.1029/2018JD0282,865.

Schwartz, M. J., W. G. Read, M. L. Santee, N. J. Livesey, L. Froidevaux, A. Lambert, and G. L. Manney (2013), Convectively injected water vapor in the north American summer lowermost stratosphere, *Geophys. Res. Lett.*, *40*, doi:10.1002/grl.50,421.

Smith, J. B., D. M. Wilmouth, K. M. Bedka, K. P. Bowman, C. R. Homeyer, J. A. Dykema, M. R. Sargent, C. E. Clapp, S. S. Leroy, D. S. Sayres, J. M. Dean-Day, T. P. Bui, and J. G. Anderson (2017), A case study of convectively sourced water vapor observed in the overworld stratosphere over the united states, *J. Geophys. Res.*, *122*, doi:10.1002/2017JD026,831.

Ueyama, R., E. J. Jensen, and L. Pfister (2018), Convective influence on the humidity and clouds in the tropical tropopause layer during boreal summer, *J. Geophys. Res.*, *123*, doi:10.1029/2018JD028,674.

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