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Atmospheric Chemistry and Physics Discussions

Interactive comment on "The millennium water vapour drop in chemistry-climate model simulations" *by* S. Brinkop et al.

Anonymous Referee #3

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"The millennium water vapour drop in chemistry-climate model simulations " by Brinkop et al

Recommendation: major revisions

This paper explores the ability of models to capture the post-2000 drop in stratospheric water vapor, and the factors that led to the drop. The authors find that a specified dynamics version of the model can capture the drop, while a free-running model with observed SSTs and a QBO nudged to observations grossly underestimates it but can capture some elements of it. They then argue that El Nino/La Nina and the QBO were crucial forcing mechanisms for the drop.

I found this work to be somewhat unconvincing. If SSTs were so important, then both the free-running model and the specified dynamics version should show the millennium drop. While the lower stratospheric QBO is weaker in the free-running version as compared to the specific dynamics version, and thus the model is under-representing this pathway, it is difficult to draw conclusions as to the importance of the QBO unless additional simulations are performed in which the QBO does propagate far enough downward. Finally, the weak drop in the free-running simulation doesn't last as long as the drop in the specified dynamics simulation, and part of why the millennium drop was so interesting is its >5 year duration.

General Comments on Content:

A. Fundamentally, it is unclear to me how the QBO and ENSO could even potentially be the answer to the millennium drop, as both of them have a characteristic timescale (2.5 years and $\sim$5 years respectively for a full period) that is shorter than the duration of the drop (>5 years). Any given ENSO event lasts one or two years at most, and stratospheric memory for a quantity like water vapor is on the order of months, so it isn't clear how ENSO could even mechanistically lead to a long-lived drop. Stated another way, any drop that lasts longer than 5 years must be driven by a process that can persist in a given phase for 5 years. It is worth noting that there is not a single long-lived (>5 year) drop in either RC1 or RC2 in figure 4. IN addition, the composite analysis in section 5 also suggests that the events are of relatively short duration (at most two years). (That being said, the millennium drop in figure 4 in RC1 does seem to last for 4 years, so there is some hope. There are modes of SST variability that last longer than ENSO.)

B. My intuition based on previous work is that ENSO and the QBO are important for changes in stratospheric water vapor, and probably contributed a big chunk of the drop for least a couple of years. In terms of ENSO, two publications not cited should be discussed in the manuscript:

Garfinkel, C. I., M. M. Hurwitz, L. D. Oman, D. W. Waugh (2013), Contrasting Effects of Central Pacific and Eastern Pacific El Nino on Stratospheric Water Vapor, GRL, 40, 4115–4120, doi: 10.1002/grl.50677

Garfinkel, C.I., D. W. Waugh, L.D. Oman, L. Wang, and M.M. Hurwitz, (2013). Temperature trends in the tropical upper troposphere and lower stratosphere: connections with sea surface temperatures and implications for water vapor and ozone, Journal of Geophysical Research: Atmospheres, 118(17), 9658-9672, doi: 10.1002/jgrd.50772

The first paper demonstrated that La Nina leads to moistening of the stratosphere, while the impacts of El Nino were dependent on the specific nature of the El Nino event (some lead to dehydration, others to little effect in the annual mean). This paper is entirely consistent with the authors' arguments, as they find that large drops follow La Nina events when the stratosphere is moistened. Note that this is somewhat in contrast with the analysis of Dessler, A.E., M.R. Schoeberl, T. Wang, S.M. Davis, K.H. Rosenlof, and J.-P. Vernier, Variations of stratospheric water vapor over the past three decades, J. Geophys. Res., 119, doi:10.1002/2014JD021712, 2014

who find that warmer mid-tropospheric temperatures lead to more stratospheric water vapor. This point should be discussed in more detail in the revised manuscript, specifically near line 24920:15-20.

The second paper shows that SSTs have led to a dehydration trend over the historical record, and more relevantly, to a period of enhanced dehydration in the early 2000s (that is weaker than suggested from satellite/balloon products). This second paper is also consistent with the present analysis. However, both of these papers as well as the authors' RC1 simulations indicate that SSTs are not the full answer to the millennium drop.

In terms of the QBO, the authors claim that the QBO is crucial, but don't provide the analysis to convincingly demonstrate this. The present experiment will (by design unfortunately) miss some of the influence of the QBO. Figure 14 strongly indicates that

the QBO in the lowermost stratosphere is mis-represented and much too weak in the RC1 experiment, while the QBO at these levels is likely crucial in order to capture the effect of the QBO on water vapor. I strongly suggest that the authors perform a modified RC1 experiment in which the QBO nudging is strong enough so that lower stratospheric winds mimic those observed. It would be very interesting to compare such a revised RC1 experiment to the present one to see whether the QBO does, in fact help with explaining the magnitude of the drop.

C. I found the manuscript somewhat tedious to read, somewhat repetitive, and difficult to follow. I have several suggestions for how to improve the text below, but I suggest that the authors carefully edit the paper before submitting their revised version.

D. On a relatively minor note, the bottom row of figure 3 doesn't appear to be consistent with figure 1. Figure 1 suggests that the RC1SD integration is quite good at capturing the length of the drop, but the bottom row of figure 3 gives a gloomier picture.

Minor comments: 24911:2 the first sentence of the manuscript is very unclear

24913:5 section 5 is about ENSO and the QBO (i.e. contributors to the drop). Section 6 is a discussion.

24914:21 "in water vapour we supplement the EMAC simulations with a combination of satellite observations . . ."

24915:26 to my eye, both temperature and water vapor are captured quite well. Can this be quantified via a correlation analysis?

24916:24 Figure 3 is introduced quite abruptly. How was this figure constructed? I think reference to the appendix is necessary (assuming I understood the appendix).

24917:25 this discrepancy between water vapor and temperature is very confusing. Section 5 "attributes" this to the QBO (as far as I can tell), but it is hard to believe the analysis in section 5 considering the poor quality of the QBO in the lowermost stratosphere.

Figure 6: I suggest removing the RC2 curve. It doesn't contribute in any way to the authors' points.

24924:18 "we experience" is the wrong word

24925:28-24926:25 This is somewhat long-winded and tedious. The authors' point is that the model is missing processes that are potentially important. This could be stated more concisely.

Section A4: I assume this is for figure 3. This should be stated explicitly

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