Anonymous Referee #3

Received and published: 26 September 2014

Review of "Quantifying contributions to the recent temperature variability in the tropical tropopause layer" by Wang et al.

This paper investigates natural and anthropogenic contributions to the decadal variability of the tropical tropopause layer (TTL) temperature. Using a series of sensitivity experiments with NCAR's CESM model, the authors quantify the impacts of solar cycle, SST, QBO, stratospheric aerosol and greenhouse gas increase on the observed TTL warming in the 2001-2011 period. They find that the recent TTL warming is mainly caused by tropical SST decrease and QBO amplitude increase. This paper also highlights the importance of using high vertical resolution in order to correctly simulate TTL decadal variability.

Results presented in this paper are important to understand decadal variability in the TTL. I have some comments, especially on the design of model experiments, to improve the manuscript. I recommend publication after my comments are addressed.

Comments:

What is the benefit of using the fully-coupled CESM-WACCM instead of WACCM? It appears to me that the method used with the stand-alone WACCM runs (section 2.2) is more straightforward. All the runs listed in table 1 can be conducted with the standalone WACCM.

Response:

The atmosphere is the primary source of internal variability to the atmosphere-ocean system, especially in midlatitudes. The coupling between the atmosphere and the ocean can decrease the energy flux between the atmosphere and the ocean. Using SSTs as the lower boundary forcing for an atmospheric model may not generally lead to a correct simulation of low-frequency atmospheric thermal variance (Barsugli and Battisti, 1998 JAS; Wang et al., 2005 GRL).

Page 22122, How the nudged QBO is done in CESM? I know there are references, but it would be better to have a brief description in the text.

Response:

We appreciate the proposal to extend the QBO nudging procedure description in the paper.

Changes in manuscript:

We have adapted the text as:

The QBO is nudged by relaxing the modeled tropical winds to observations, which using a Gaussian weighting function decaying latitudinally from the equator with a half width of 10°. Full vertical relaxation extends from 86 to 64 hPa, which is half that strong in one model level below and above this range and zero for all other levels (see details in Matthes et al., 2010; Hansen et al., 2013).

Page 22125, last paragraph, Why don't just repeat the 2001-2011 solar cycle in the nature run? Then there would be more samples to compare with the SolarMean run.

It is true that by repeating only one solar cycle we could generate more samples and we agree with the reviewer that this would be a very valuable exercise. Unfortunately, the simulations with interactive chemistry and interactive ocean are computationally very expensive and we can only do a limited amount of experiments. The Natural run was designed to be a control experiment for other studies we are performing some of which are hindcasts of the recent past and require a realistic solar cycle forcing.

Page 22129, section 3.4, Why increased QBO leads to warming in the TTL? Maybe it is related to the weakening of upwelling in the TTL. If this is true, I suggest the authors compare differences in upwelling in the control and NOQBO runs.

Thank you for this comment. As indicated by Kawatani and Hamilton (2013), the QBO and tropical upwelling are closely related to each other. We have compared the tropical upwelling between the control and the NOQBO run, and the differences in tropical upwelling are highly correlated to the QBO time series in the control run. We also regressed temperature differences between these two runs onto both, the time series of the QBO in the control run, and the differences in tropical upwelling. The regressed temperature differences are very similar to each other. The results above indicate that the QBO has indeed an impact on the TTL temperatures very likely by modifying the tropical upwelling.

We have added a brief discussion in the revised manuscript.

Section 4, It's difficult to follow the discussions. Changes in the residual circulation shown in Figures 10c and 10d are complicated and not easy to explain. I suggest the authors using simple diagnostics, e.g., mean upwelling in the TTL and lower stratosphere, to illustrate differences in the BDC in the high and low resolutions runs.

We appologize for the inconvenience with this Figure. The other reviewers have also suggested to simplify the figures and to sharp the discussion.

We have combined Figures 9 and 10 and restructured the figure to be better readable.

Figure 10b shows a strong cooling trend in the Antarctic lower stratosphere in the high resolution run? What causes this cooling? Is it related to the Antarctic ozone hole? A more general question is how stratosphere ozone depletion might affect TTL temperature variability.

Thank you very much for this suggestion. We have checked the ozone differences in both runs W_L103 and W_L66, and the ozone shows indeed a strong decrease in the Antarctic . Ozone depletion therefore seems to play some role to the TTL temperature variability. Since we changed the Figure, the cooling is no longer in the figure and we therefore prefer to discuss only the effects in the tropics and subtropics. We agree that an extension of the analysis to higher latitudes would be interesting, but this is beyond the scope of the current paper.

Summary, I think it would be helpful to add a simple figure summarizing the contribution of different factors to the TTL decadal variability.

Thank you very much for this proposal.

We have added a table to summarize the contribution of the different factors in the revised manuscript.

References

Joseph J. Barsugli and David S. Battisti, 1998: The Basic Effects of Atmosphere–Ocean Thermal Coupling on Midlatitude Variability. J. Atmos. Sci., 55, 477–493.

Kawatani, Y. and Hamilton, K.: Weakened stratospheric quasibiennial oscillation driven by increased tropical mean upwelling, Nature, 497, 478–481, doi:10.1038/nature12140, 2013.

Wang, B., Q. Ding, X. Fu, I.-S. Kang, K. Jin, J. Shukla, and F. Doblas-Reyes (2005), Fundamental challenge in simulation and prediction of summer monsoon rainfall, Geophys. Res. Lett., 32, L15711, doi:10.1029/2005GL022734.