Anonymous Referee #2

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This paper focuses on a problem of interest to the scientific community: understanding the trends in the temperatures around the tropopause. Nevertheless, this paper falls far short of what is necessary for publications.

The basic approach of this paper is to take observations over a 10-year period and compare those to a climate model simulation in order to determine the factors that control the trend. There are major problems, however, with this approach that lead me to conclude that the results of this paper are simply not reliable.

1. Model does not reproduce the trend: it is not stated as explicitly as it should be, but in Sections 4 and 5 it is revealed that the model produces a TTL trend that is much smaller than the 10 years of observations. In fact, in the final summary, more than half of the observed trend is attributed to errors in the model's vertical resolution. Given such a large difference between the model and the observations, how can you trust that the model tells us anything about the observed trend?

Response:

We agree with the reviewer that the simulated TTL variability trend is smaller than in observations and that it is highly sensitive to the period used for the analysis (see also our comment in reply to reviewer 1 and the two additional supplementary material). The smaller modeled TTL variability does not indicate a failure of the model. We show that with finer vertical resolution, the model captures the observed TTL variability better (Wang et al., 2013). However, the simulations using a fully interactive chemistry and ocean module are so demanding in computer time and real time resources, that it was impossible to complete all simulations with the high vertical resolution version of the model. The idea of this paper is instead to use the low vertical resolution simulations, which are standard in most CCMs and GCMs, and estimate the general contributions of different natural and anthropogenic variability factors, such as solar GHGs and aerosol, to the TTL variability.

For this estimate we use a fully coupled atmosphere-ocean model which represents better the processes needed to study TTL variability. It is well known that using SSTs as lower boundary conditions only without interactive feedback between the ocean and the atmosphere may have problems in reproducing a "correct" atmospheric variability. Here we investigate the influences of different factors on TTL temperatures in a fully-coupled way, and at the same time highlight the importance of finer model vertical resolution while using SSTs as a climate forcing.

Changes in manuscript:

We have extended our analysis method and hope that we explain better now what our main findings are.

It is an interesting conclusion that vertical resolution has such an important effect, but it calls into question all of the other conclusions about attribution of the observed trend. One could write an entire paper about the effect of vertical resolution, but the paper would be quite different from this paper (it would, for example, not contain Section 3).

Thank you very much for this suggestion. As a next step, we are indeed planning to investigate the effects of finer vertical resolution in more detail.

2. 10-year trends are unreliable: Anyone who has done any kind of atmospheric data analysis knows that looking at a 10-year trend is fraught with danger. In particular, a few outlier months can really torque the trend, so the model must simulate the yearto- year variability really well. The big worry here is that there is short-term variability in the atmosphere that is not accurately captured by the model. The model does use observed SST, but I don't see any reason to expect that this therefore includes all the short-term variability.

Thank you very much for your comments. We agree that a 10-year dataset is relatively short to investigate robust trends. We have added supplementary figures as well as a discussion about uncertainties of the observed trends and the sensitivity to the time period employed.

Since the observed dataset is so short, we used CESM-WACCM to perform longer simulations (145 years each) and calculate more statistically reliable signals from these longer model records. We use composite analysis to avoid the problem of different interanual variability in the coupled model runs and observations. For our WACCM atmosphere-only simulations, especially for the W_Aerosol run, we have observed SSTs, almost real GHGs and ODSs, observed solar irradiance, nudged QBO based on observed winds and observed stratospheric aerosols to capture the recent variability. And we also did 3 ensembles for the WACCM atmosphere-only simulations except for the W_Aerosol run to reduce the uncertainties by short simulations.

As an example, it is well-known that Brewer-Dobson variability has a big impact on TTL temperatures. Is the model getting the right BD circulation variability, with the right phase? Lack of correctly simulating this variability could be one of the reasons that the model does not reproduce the observed TTL trends. Note that using a much longer time series would avoid these problems.

We agree, the B-D circulation is important for TTL temperatures. However, as mentioned in the introduction, the strengthening or weakening of the B-D circulation is still an open question. One of our conclusions is that the finer vertical resolution may be important for representing the variability in the B-D circulation, which is consistent with previous work (Bunzel and Schmidt (2013)).

3. no autocorrelation in error estimates: Based on the discussion of error bars, it does not appear that the authors have taken autocorrelation of the time series into account in calculating error bars on the trend. All of the time series considered here are autocorrelated – meaning that a month is more likely to be high if the previous month was high – and this means that there are fewer independent samples in the time series than there are months. As a result, I suspect that the error bars will be larger than those presented here, which will reduce the statistical significance of the paper's conclusions. If the authors choose to revise this paper, they must recalculate the error bars to incorporate autocorrelation.

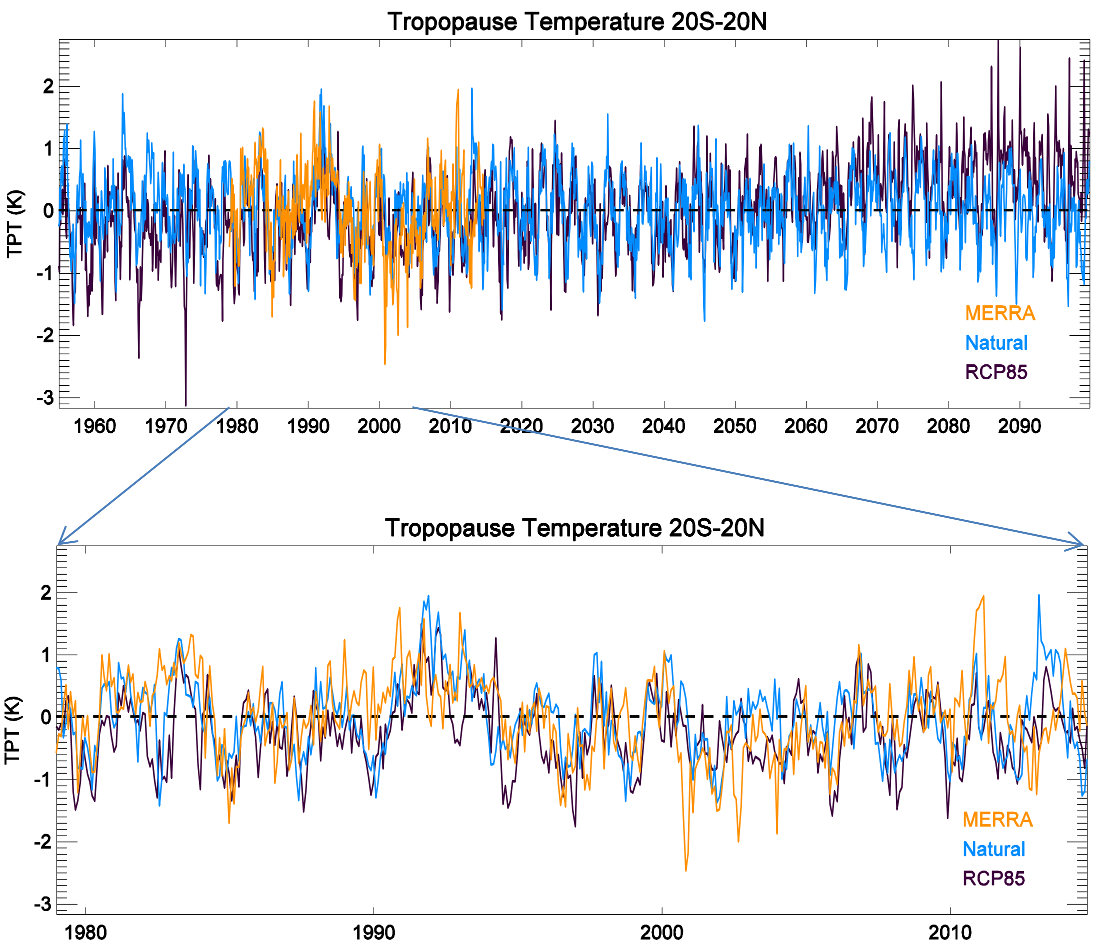
Thank you very much for raising the autocorrelation issues (also requested from reviewer 1). We have reconsidered our method how to get to statistically significant tests with autocorrelation considerations. See details of the methods and results in the revised manuscript.

4. paper's conclusions make no sense: Finally, the conclusions of the paper make no sense. It is well known, for example, that tropopause-level temperatures increase over the 21st century in climate models. It seems virtually certain that this is due to some combination of increasing surface temperature and increasing greenhouse gas concentrations (after all, what else could it be?). However, this paper concludes the opposite: that warming SST and increasing greenhouse gases COOLS the TTL. Given that this goes against every other analysis of models that I've seen, I strongly suspect that problems in the methodology (discussed above) are the cause of this highly curious conclusion. If the author's revise this paper, they have to more directly explain these results.

We apologize to have contributed to confusion on this point. We couldn't find any references indicating a well known long-term increase of tropopause temperatures over the 21st century. Neither of the CCMVal and CMIP5 models can reproduce the cooling in tropical tropopause temperatures during some decades shown in observational and reanalysis data. The model predictions of the long-term trend are also highly uncertain and have large spreads (CCMVal report chapter 7, Kim et al., 2013 JGR).

The temperature structure and variability around the tropical tropopause, i.e. in the tropical tropopause layer (TTL), is very complex, and can be influenced by a number of different factors.

This includes natural and anthropogenic factors as discussed in this paper but also other factors such as lower stratospheric ozone and water vapor. The dynamics and thermal characteristics of the TTL are important in determining stratospheric composition, affecting radiative and dynamical properties at both stratospheric and tropospheric levels. In particular, the coldest level in the TTL, the cold-point tropopause (CPT), is known to play a crucial role in stratosphere-troposphere exchange (Holton et al ., 1995). The CPT temperature largely determines the concentration of water vapor in the lower stratosphere, which serves as a key radiative constituent for surface climate (e.g., Solomon et al ., 2010).



The Figure above shows the time series of tropical tropopause temperature anomalies from the past to the future in MERRA reanalysis data and our Natural and RCP85 runs. Obviously, the tropical tropopause temperature has large interanual fluctuations in both MERRA data and the two CESM runs. The CESM model simulates similar interanual (bottom), decadel to multidecadal (top) variability in the tropical tropopause temperature compared to MERRA data over the time period 1979 through 2014. Even with a very strong GHG scenario RCP8.5 (black line), the tropical tropopause temperature only shows a slight increase after 2050. Understanding the contributing factors to this decadal tropical tropopause temperature variability is the goal of our paper. We come to the conclusion that this decadal variability seems to be related to internal climate variability.

We have added this Figure to the revised manuscript.

I wish I could be more encouraging, but in the end I am not convinced that the results of this paper are correct. There are too many methodological errors and logical flaws in it for the results to be considered reliable.

We hope to have addressed all the concerns of you with our detailed reply and the additional analysis and changes to the text.

References

Bunzel, F. and Schmidt, H.: The Brewer–Dobson circulation in a changing climate: impact of the model configuration, J. Atmos. Sci., 70, 1437–1455, doi:10.1175/JAS-D-12-0215.1, 2013.

Kim, J., K. M. Grise, and S.-W. Son (2013), Thermal characteristics of the cold-point tropopause region in CMIP5 models, J. Geophys. Res. Atmos., 118, 8827–8841, doi:10.1002/jgrd.50649.