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Atmospheric Chemistry and Physics Discussions

Interactive comment on "The Tropical Tropopause Layer 1960–2100" *by* A. Gettelman et al.

A. Gettelman et al.

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Reply to Reviewer #1 We have tried to correct the “oversights’ identified in the manuscript Specifically we have addressed the reviewers major concerns:

1.) CCM Models are of high enough vertical resolution: We have now provided information on the vertical resolution of the models in addition to the horizontal resolution in Table 2. We have also explicitly shown the analysis levels in Figure 3 and noted them in the text. We have also added more text throughout which references the results of Gettelman and Birner 2007, that clearly show (a) at least two of these models (WACCM and CMAM) compare vary well to observations and (b) that vertical resolution does not affect the quality of the simulation. 2.) We have added trends for the TTL derived from a radiosonde archive (provided by W. J. Randel, and referenced in the text). This allows us not to rely on the Reanalyses for interpretation of the trends in figures 4,5,6 and table 3.

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Discussion Paper

We address the specific comments below (>> indicates replies):

- A motivation is missing why is it meaningful to do this tropopause study see your questions and answers in the conclusions.

>>Motivation from the conclusions has been added

- There are many repetitions of words within the introduction, please avoid this and re-write your intro: region (Page 1368), TTL 13x on Page 1369 within one sentence up to 3 times

>>We eliminated about half of the appearances of ‘TTL’

- Add volcanoes as a natural variability for the TTL.

>>Done

- Page 1369 lines 7-10 add missing references here: e.g. Gettelmann et al. 2001, Fueglistaler and Haynes 2005; Krüger et al 2008.

>>We have added the references to the papers (Kruger et al we were not able to find, so the Gettelman and Fueglistaler references were added)

- "Several studies..." line 17-4(1370). The sentences are only lined up, please re-write and add more relevant references e.g. add Lagrangian TTL studies (complex 3D structure of the TTL) > Bonnazola and Haynes 2004, Fueglistaler et al 2004 and related work.

>>Actually, the Fueglistaler and Haynes is the most relevant here. We have added some additional clarification for the references as suggested.

Page 1370: - "multi-model ensemble run" > "multi model ensemble" no run

>>Done

- Line 23: 1980-2100 or 1979-2100??? In table 3 it says 1979-2001, etc. Be precise with the years. This is used differently throughout the whole ms!

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>> This has been corrected throughout the whole manuscript. Trends are performed on 1979-2001 for REF1 and 1980-2050 for REF2.

2. Methodology Page 1372: - LZH was already written out, repetition

>>Corrected

- Add a cartoon picture to clarify your 5 acronyms from table 1. Otherwise very unclear what you mean here.

>>We now reference pictures and schematics already published, rather than duplicating them. The levels are shown in Gettelman and Birner 2007, and a schematic is shown in Gettelman and Forster 2002

- 2 C or 2K !

>>Corrected

- "1960 or 1980 to the present" what should be present here? See the details from table 3: 1960-2001 or 1979-2005, 1979-2001 1960-2004; present means here 2001, 2005 and 2004? A lot mixed up details here!

>>As noted, we have been more consistent with use of dates throughout.

- Transient run : what means transient here? Incl. SSTs, volcanoes, QBO and solar cycle? This is very important detail for the trends and variability you are referring later on!

>> We have been more specific with the forcing here. The long term trends we are looking at are not strongly affected by solar cycles or volanoes.

Page 1373: - 1980?

>>Corrected. As noted we are using 1979-2001 for quantitative purposes for REF1

- NCEP and ERA40 data vertical resolution? Did you use the 23 standard pressure levels or the 60 model levels from ERA40?

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>>23 levels. Noted in the text

Page 1374: - line 2: reanalyses use Pl.

>>Corrected

- Analysis 2.3 : Add all the details of the vertical resolutions here a) the hybrid model levels, b) the standard model output used for this study!

>> Standard output levels used are noted, original model resolutions are noted in the table

- Son et al 2008 seems to be very important for this paper here, but it is not available for the readership. Please add a web link to it or cut the reference out of the whole ms.

>>The reference should have appeared as a footnote. We also expect that Son et al 2008 will be ‘in press’ soon.

Page 1375: - Line 1: abbreviations w/o the Figure location > (CPTT) instead of (CPTT-top) see the other examples as well.

>>Done

- "on model levels" see my comment before.

>> As noted, model levels are explicitly called out.

- Concerning the multi-model ensemble trend: is it clever to calculate a multi-model ensemble trend if the spread of the models is so large? If you still want to do this you need to give the numbers of the trend uncertainties/spread as well! (see table 3).

>> The spread of the models is large, but for these diagnostics the spread of trends is not that large. The trend uncertainties are indicated in table 3: an asterix indicates that the trend is significantly different from zero at the 2 sigma (95%) level, and no asterix indicates it is not significant.

3. Multi-model climatology Page 1376: - 8-10: repetition of the figure caption text in the

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ms text as well, cut this out.

>> Text has been modified

- "the lowest CPTT occurs from Jan-March": Really in March? Please cite papers for this as evidence! -Line 18-20: mention cold bias problem of GCMs in the tropics (Pawson et al, 2000 BAMS).#

>> This has been clarified (December—March). Regarding a ‘cold bias’: actually there is not a cold bias to these runs when compared to what we now think are the best available observations (GPS radio occulation). The results of the Pawson study do not include this data, and the tropopause is too warm there. This is discussed and shown by Gettelman and Birner 2007, and now mentioned in the text

- 23-24: Figure 5b: order of figures in the text does not correspond to the order of the figures itself!

>> Unavoidable in this case. It is only a minor reference to a later figure, and to maintain the flow of the paper, the reference has been kept.

- "Variations are due to model level resolution and vertical interpolation to standard pressure levels" which are?

>> The vertical levels have been explicitly stated in the text now. This statement is vague and misleading and has been eliminated.

- "indicate about 1-2 K temperature differences" Between what?

>>Calculations with 2D data and full 3D data: clarified.

- "It also makes it difficult to know how much the CPTT is affected..." very vague!

>>Clarified and changed to be more explicit

Page: 1377: -"which maybe a bias in the analysis or due to coarse vertical resolution..." only two papers are cited here, but there are many more papers directly addressing re-

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analysis problems in the TTL! Cite more papers and give more examples this is really not reflecting the research going on.

>> We prefer to to be too exhaustive here. And just focus on the tropopause, so these are the most relevant papers. We are now not focusing on the reanalyzes, and are using radiosonde data to explore trends. We have added a reference ‘among others’ to indicate we are not trying to cite everything.

- "The cold point is ALWAYS... the same level": this is not true for reality and maybe only valid for this CCM study which seems to be biased by the standard model output used.

>>Yes, that is why we do not use the pressure of the cold point as a diagnostic. We have tried to clarify the interpolation issue here and below. The cold point is not interpolated.

- "92-102 hPa": How can you extract different pressure levels for the LRTP if you are using standard model output???

>>The LRTP is interpolated between pressure levels based on the lapse rate. This is a standard practice. We have clarified this in the text and Table 1.

- Line 21-26: How meaningful is such an intercomparison/analysis, if you are restricted to only 2D output?

>>The discussion in the text shows that using 2D output does not substantially alter the results: either of basic position/temperature, or of trends. We do this by comparing to two models (WACCM and CMAM) for which we have access to 3D data.

4. Long term trends Page 1378: - Line 3: double correlation

>>Fixed

- Ref1: 1960-2005 table 3 say 1960-2004 ?

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>>Fixed, and harmonized throughout for REF1: trends are 1979-2001

- The whole paragraph from 15-25: So far no "real" TTL paper using assimilations is trying to argument that there are trends in ERA40 or in NCEP/REA so this paper should also avoid this (see general comment above)!

>>We have now done this, and not discussed the trends from the reanalyses as being accurate, and instend us a radiosonde archive.

Page 1379: - "are 50% larger": from table 3 I derive less?

>>We intended to mean ‘magnitude’: (larger negative). This has been clarified.

- "other work with models" which models/ observations?

>> We have clarified the specific models.

- "These changes represent": Not the changes but the CPT represents the top of the TTL, change words.

>>Done

- Use your abbreviation LRMP instead of LRM pressure.

>> Done

- "significant trends" where are the significances?

>> Vague and incorrect. Significance is noted in the table.

- Fig. 6: Add ULAQ shows a strong offset.

>> Done

- Trends in re-analysis: leave them out! Or use other independent reliable observational data sets!

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>>Done, we have added radiosonde observations and are not commenting on the analysis system trends, except to highlight uncertainities.

- LRM can vary with model formulation” But why? more details or leave this out!

>> The differences are largely due to convective parameterizations. We have noted this in the text

- At each ˆgridˆ point: add ˆˆ

>> Changed

Page 1380: - "in the subtropical stratocumulus regions" cut stratocumulus out or provide more evidence for this interpretation/statement.

>>Removed

- Ascent rates in MAECHAM are too high/low? Add this information.

>Low (leading to a build up of ozone)

Page 1381: - Line 1: "There is also a" Where?

>>Clarified

- "due to large inter-annual variability": But the models IAV is smaller than the obersved one? Contradiction in your arguments.

>>Edge discussion has been removed

- "Ab scenario" ? >> Done

Page 1382: - "Since trends are broadly linear...does not change..."; Not true, the circulations changed in the mid 1970s > step-wise change! No trend calculation should be carried out over this whole period.

>> The trends are now calculated for ref 1 for 1979-2001. For REF2 we show quantita-

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tive trends for 1980-2050. We note that the trends for the future (modified in the text to “‘Future’ trends”) are broadly linear: models which go to 2010 basically have similar trends from 1980-2050 and 1980-2100 (or 2050-2100).

- Line 8. which may be ˆrelatedˆ to: instead of ˆcoupledˆ

>>Done

- Figure 13: only show future trends from 2006-2050 from WACCAM!!! It should fit to the rest of the paper.

>> Done

Page 1383: - Fig 13a: This dumbbell pattern looks like the typical ENSO pattern in the TTL, add this info.

>>Discussed further

- Fig 13 a and d do not fit together, add this in the ms.

>>Actually they do (note the figure changes slightly with the different time period). This has been explained and clarified in the manuscript.

- "The multi-model ensemble indicates no significant trend..." Where are the significances given?

>>In the table. This is explained in the caption. It is also explained in the text when the table is introduced. We have added a sentence to better explain this.

5. Discussion Page 1384: -Line 12: The questions raised here should be clearly brought up in the introduction already as a motivation!

>>Done.

5.3: Page 1386: Fig. 16: Where is the NCEP dot? It is not in my figure 16! Add NCEP.
>>NCEP has a warm bias and is not shown, as we know it to be in error. This is noted more clearly in the text.

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Page1387: - lines 10-12, unclear sentence.

>> Modified

6. Conclusions: -"differences are related to the fundamental climatologies". Which are?

>> Reworded

- "warmer temperatures" should be higher temperatures

>>Done

- "Thus models are able to represent the TTL structure"; cut this sentence out.

>>Removed.

Figures/Tables: - table 3: time periods /years inconsistent

>>Fixed, as noted

- Table3: add the spread/uncertainties of the model trends "+/-..."

>>Already there (in the form of significance)

- All figures are far too small!

>> Text and axes made larger for all figures

- Figure 2: Ref1 years are in contradiction to table3.

>> Longer range shown, but trend lines are now consistent

- Figure 3: Add the used vertical levels in the figure, years.

>>Vertical levels used noted, years stated in caption

- Figure 4: Use reliable observational data set here as well e.g. based on radiosondes!

>>Done

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- Figure5: How can you derive variations of the LRTP when using vertical standard output?

>>LRTP is interpolated (see above)

- Figure 6: Cut Figure 6 out as it is not meaningful too large spread! See your own text.

>>Removed

- Figure 7: WACCM plots are shown from 1950-2005 why are you using an other period here? You should be self-consistent within your paper! Start with 1960! Add longitudes at the x-axis. Same style as in figure 13 hard to distinguish colours.

>>Done now 1960-2004

- Figure 8: Re-order plots first 8 b and then 8a.

>> Not changed. This ordering is to keep the upper level on top

- Figure 10: Why are you using different colours now? Add Ncep and EAR40 in red and stay with your old colours, be consistent within your ms.

>> Different models are shown, so the colors are different. The point is not the individual models, but the consensus (and outliers) and general scope. Since these runs have different forcings than the observations, we have not shown the reanalyses

- Figure 13: Calculate the trends for 2006-2050, why starting in 1975? This remains totally unclear! Contradiction between fig A and D.

>>Fixed. Panel a & d are better explained in the text.

- Figure 14: Add legend.

>> Eliminated

- Figure 15: Figure caption: Add "past and future scenarios"

>>Done

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- Figure 16: NCEP/HALOE dot is missing!

>>Yes, Noted above and in the text it is better explained

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