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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Antarctic stratospheric warming since 1979" *by* Y. Hu and Q. Fu

Anonymous Referee #1

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The paper analyses trends in Antarctic stratospheric temperature over the period 1979 to 2006 for austral winter and spring. Trends are calculated in satellite data (microwave sounding unit, MSU), NCEP/NCAR reanalysis and in idealized model experiments using the GISS-modelE. A special focus lies on the regional manifestation of the trend patterns over the high-latitude Southern Hemisphere, which shows a high spatial and temporal variability. It is interesting that in September and October over parts of the Southern high latitudes positive trends are observed which are of similar or even bigger magnitudes than the well-documented stratospheric cooling. The second part deals with the causes behind this phenomena. The authors connect the increase in temperatures with enhanced wave-driving analysed by the Eliassen-Palm flux divergence. Moreover, they find a high correlation between the vertical Eddy heat flux and October temperatures, averaged over the area where the biggest positive trend occurs. The study is finalized by investigating the relationship between increasing stratospheric

temperatures and sea surface temperatures which could be the cause for enhanced wave-driving and explain the pathway from the surface to the polar stratosphere.

In general, I think the paper raised an important topic which is of great interest to both the journal and the scientific community. To my knowledge, most studies so far addressed Antarctic stratospheric temperature trends in zonally and/or seasonally averaged fields. In this sense, the paper, by looking at the spatial pattern in each individual month and giving reasons for the patterns, contributes to a better understanding of the stratospheric climate variability over the Southern high latitudes. This is important to the scientific community where in recent times much effort has been undertaken to understand the connection between the stratosphere and surface climate anomalies over the Southern Hemisphere. However, I think the paper at the current stage (although well-structured and logically sequenced) is rather short of evidence and could greatly benefit from adding important details (see comments below). I therefore recommend to substantially revise the paper.

=== General comments ===

1. In the title the word "Antarctic" is appearing which is misleading. As shown in the first five figures, the maximum warming trend is not over Antarctica but rather situated over the Southern Ocean. This must be changed in the title. Since the warming is not inside the polar vortex, the argument in the Discussion and Conclusions section and the Abstract about the impact on ozone recovery must also be rewritten, as it is unlikely that temperatures at this location affects the area covered with temperatures below 198 K (the temperature below which PSC I type clouds are formed).

2. More than 50% of the figures (fig. 1 to 5) detail the warming pattern over the polar stratosphere, which are plotted all in the same style (yet for different datasets, time, and height). To me, this seems not appropriate given that only a small portion of the results section in the text is describing these plots. This also reflects that some of the first five figures do not add much of required information I agree that it is important to look at

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the trends without the extreme event of 2002. However, in my opinion this could be exclusively mentioned in the text and figure 2 and figure 4 could therefore be omitted. Also, figure 3 could be integrated into figure 5 which shows the altitude dependence.

I would leave figure 1 as is (MSU temperature trends), but make an enhanced figure 2, which deals with trends within NCEP/NCAR reanalysis. Besides temperature I think it is important to further show geopotential height (GPH) trends (The authors mention at several times the interaction with the polar vortex.). So reanalysis trends in figure 2 could be presented as a matrix: with columns for temperature and GPH trends during September and October, and rows for different altitude levels from 20 hPa to 100 hPa.

3. Currently, trends are presented as absolute values over the specific time periods, which however have not the same number of years in the different plots (e.g. figure 1, 2, 9). Trends should have the same units to make them comparable. I would suggest either K/year or K/decade.

I found it rather strange to plot t-test values of 1.7 and 2.5 as an illustration of the significance. This is clearly not the state-of-the-art method. I suggest that you overplot the 95% significance-level (p-value).

Trends are calculated linearly, hence neglecting other possible driving factors, such as solar variability, stratospheric aerosols, El Niño/Southern Oscillation variability, and quasi-biennial oscillation. It is well possible that the observed trends can to some degree explained by these forcings. To account for that a multiple linear regression model should be applied, as done in most of previous studies about stratospheric temperature trends.

4. By reading the paper it was not obvious to me what was already done in the field before. I think you should better separate between introduction where you present the work that has been done by others and your contribution.

5. Figure 6: Can you change the y-axis to pressure-scale to make it comparable to

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previous plots? Also, the EP flux diagnostics should be shown much further upward than 30 km as the upper stratospheric levels contribute to the polar vortex disturbance as well.

I am not completely convinced that the shown EP flux convergence is really enhancing the residual meridional circulation (RMC). I would add a plot of the streamfunction to this figure. The time-series on the right is interesting. However, it should be shown not only for the area of maximum warming but to the whole temperature field as presented in the first figures.

6. Figure 8: To me figure 8b does not add much information. It is somehow obvious that two variables with significant trends in the same direction have high correlation coefficients and vice versa. Instead it could be interesting to see how previous months of SSTs correlate with the warming pattern in the Southern high latitudes (lagged correlation).

7. Figure 9: The authors mention in the paper that the variability of the warming pattern shows a high spatial and temporal variability. In this sense, I think it is rather inappropriate to show the ensemble mean of a model simulation. The inter-ensemble variability must be considered here.

8. I have not understood why the model simulations are only presented with respect to temperature trends. It is important to extend this section by showing the same diagnostics as above (RMC, EPflux divergence, correlation temperature and SST) and add a detailed section about the performance against reanalysis data.

=== Minor comments ===

*** P1704 ***

L18: change "the severe ozone depletion" to "severe ozone depletion"

L24: add "Langematz et al., JGR, 2003" behind "Shindell and Schmidt, 2004"

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*** P1705 ***

L4-7: It is strange that in the introduction already parts of the results are presented. From a reader's point of view at that stage it is not clear whether this is a result of the paper or stems from another study. I would take these statements out.

L9: Please make sure that the reference given (Andrews et al. 1987) is the appropriate at this place. I actually doubt that they were the first to discover this issue.

L12: please explain the mechanism for the connection between stratospheric warming and wave activity.

L12ff: please explain what else (apart from greenhouse gases and ozone depletion) could contribute to stratospheric warming trends in general.

L16: add reference to 2002 event

L16: delete ";"

L21: add "the" before "SH stratosphere"

L24: change "and" to "as well as"

L24: change "GCM" to "model setup"

*** P1706 ***

L4: "anomalies" from what?

L8: change "one" to "dataset"

L10: Reference to NCEP/NCAR reanalysis: add "Kistler et al., 2001" behind "(Kalnay et al., 1996)"

L10: give a reference for the calculation of EP fluxes

L11: change "Student" to "Student's"

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L13: change "confidence" to "significance"

L15ff: can you briefly say for what the model has been used in the past. What are its strength and where does it show weaknesses? How and where was it validated?

L18: change "high" to "height"

L18: add "the" before "stratosphere"

L21: what was done with other forcings? E.g. Solar variability, tropospheric aerosols, stratospheric aerosols, QBO?

L21: how were the initial conditions been derived?

L18: add "up" before "to 0.02 hPa"

L26: change "less significant" to "not significant"

*** P1707 ***

L3: change "less significant" to "not significant"

L5: change "spatially" to "spatial"

L8-9: from where do you know that "the spatial pattern in October resembles minor sudden warmings in the Arctic stratosphere?" Give reference.

L8ff: Maybe state that in October and September cooling trends and warming trends are of similar magnitude.

L17: please clarify what you mean with "ending year". Note that testing if a robust trend is occurring one would need to apply more sophisticated methods (e.g. jackknife method), which however is beyond the scope at this place here.

*** P1708 ***

L1-7: this should be added to the introduction section

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L11: change "with" by "to"

L18: add point after cooling; Begin new sentence with "Ozone depletion during.."

*** P1709 ***

L6: add "to" after "contribute"

L12-13: from a reader's point of view: can you explain how you separate between travelling and quasi-stationary waves? This could also be added to the methods section

*** P1710 ***

L4: change "showed" to "shown"

L20-22: no evidence or reference is given for the proposed shifting of warming pattern to the East

L24: add ", as for instance shown in modeling (Fischer et al., GRL 2008) and observational (Fusco and Salby, Journal of Climate, 1999) studies." after "..from low to high latitudes"

L25: change "blocks" to "block"

L25: replace "into the polar vortex" by "across the polar vortex edge"

*** P1713 ***

L20: change "is due to SST warming" to "is connected to SST warming" (there is no evidence. What would be needed to prove it, are idealized model experiments where the ocean's surface temperature would be fixed at a climatological state). Maybe the authors should mention this point in the discussion section (as an outlook maybe).

Fig.1

add "(in a layer between about 20 and 120 hPa, see text)" behind "observations"

Fig. 7

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the caption uses the words "transient" and "stationary" whereas the text mentions the words "travelling" and "quasi-stationary". Can you clarify this?

can you also add the unit of the y-axis?

Fig. 8

"confidence level" change to "significance level"

Interactive comment on Atmos. Chem. Phys. Discuss., 9, 1703, 2009.