Influence of the stratospheric shrinkage on the detected CCMI simulation trends

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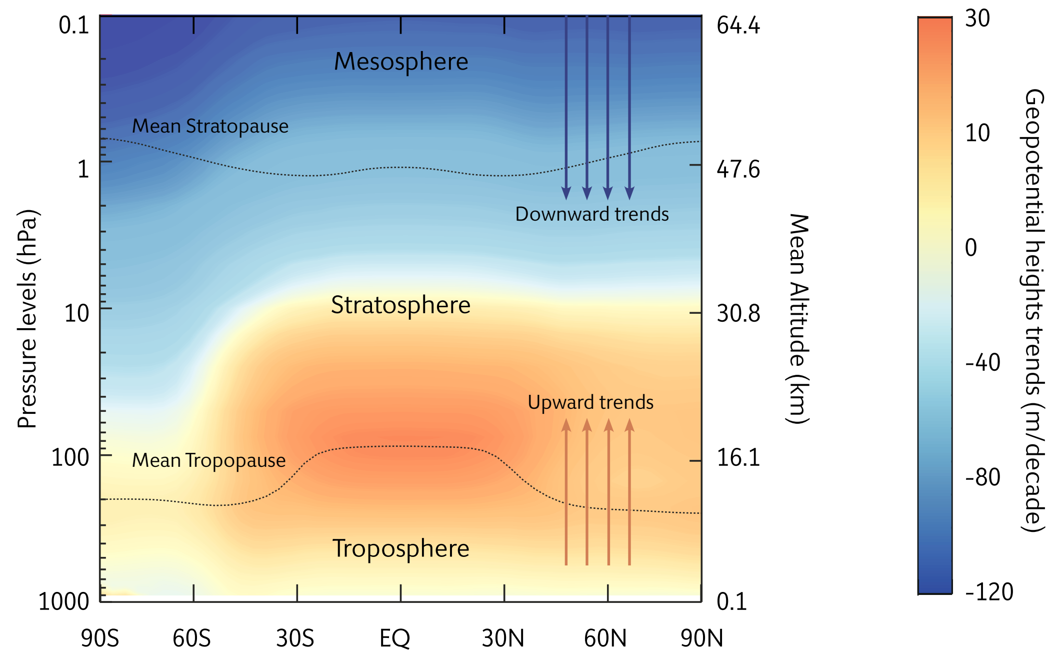
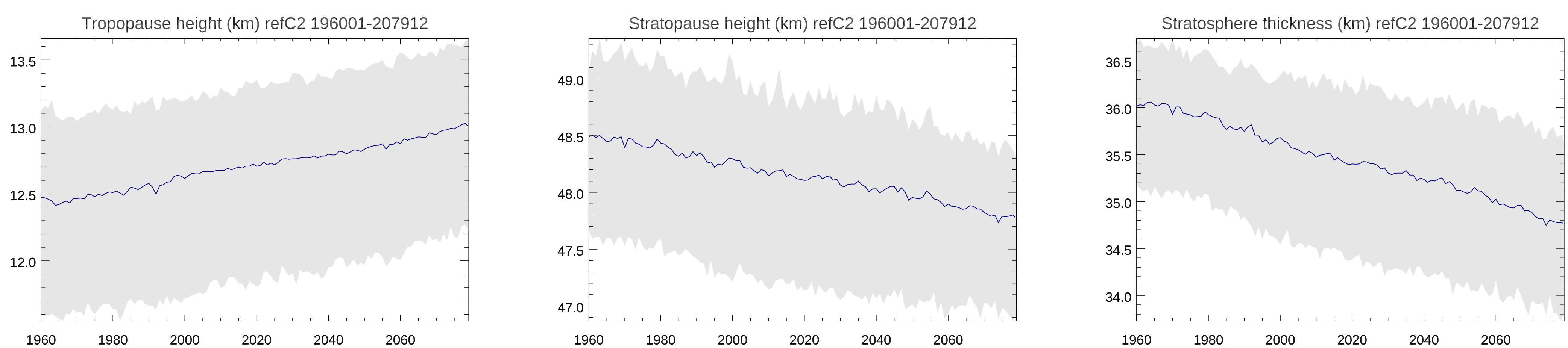
Introduction: There is a well-established observational evidence that the tropopause is shifting upward. Warming of the troposphere is directly connected with a positive trend of geopotential of pressure levels in the troposphere, which reaches its maximum around the tropopause. In the stratosphere, the geopotential height trends are affected by the stratospheric cooling resulting in a gradual reduction of the upward shift and even its reversal in the upper stratosphere. That leads to a decreasing trend of the stratospheric thickness and the stratospheric shrinkage. In GCMs, shrinkage is one of the strongest and most robust fingerprints of the changing climate. In this study, we investigate the question whether the shrinkage presents additional dynamical feedback influencing other detected trends in the middle atmosphere. Analyzing set of CCMI models, we compute inter-model correlations of shrinkage with trends of various variables to separate the possible shrinkage effect.



Schematic illustration of the stratospheric shrinkage, trends of geopotential heights of pressure levels based on CCMI refC2 CMAM data.



Time series of the tropopause height, stratopause height and the thickness of the stratosphere. Based on the refC2 CCMI data.

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Dataset & Method: The stratospheric shrinkage is analysed using the REF-C2 scenario (Eyring et al., 2013) climate projection from models participating in the Chemistry Climate Model Initiative (CCMI; Morgenstern et al., 2017). We have analyzed 15 models that are listed in the table below. The tropopause height claculation was based on the WMO lapse rate definition. The stratopause height was calculated as the level of maximum temperature between 40-65 km (corresponding to the level of maximum radiation absorption). The trends of analyzed variables were computed for global stratospheric means based on the evolution on the pressure levels or geopotential heights. Trends of all variables have been estimated by the Theil-Sen estimator and their significance have been computed using the Mann-Kendall test.

We have analyzed trends of the following variables: temperature (ta), potential temperature (tp), density (dens), B/V frequency (n22), volume mixing ratio of O3 (vmro3), tendency of eastward wind due to Eliassen Palm flux divergence (acceldivf), tendency of eastward wind due to gravity wave drag (accelgw), tendency of eastward wind due to nonorographic gravity wave drag (accelnogw), tendency of eastward wind due to orographic gravity wave drag (accelogw), northward Eliassen Palm flux in air (fy), upward Eliassen Palm flux in air (fz). The trends of the analyzed variables are calculated based on evolution on constant geopotential or pressure levels.

Model	**Reference**	**Resolution**	**Model top**
ACCESS CCM	Morgenstern et al. (2009, 2013)	3.75º × 2.5º	84 km
NIWA-UKCA	Stone et al. (2016)	3.75º × 2.5º	84 km
CCSRNIES MIROC3.2	Imai et al. (2013); Akiyoshi et al. (2016)	T42	1 Pa
CHASER - MIROC-ESM	Sudo et al. (2002); Sudo and Akimoto (2007), Watanabe et al. (2011), Sekiya and Sudo (2012, 2014)	T42	56 km
CMAM	Jonsson et al. (2004); Scinocca et al. (2008)	T47	0.0575 Pa
CNRM-CM	Voldoire et al. (2012); Michou et al. (2011)	T63	0 Pa
EMAC	Jöckel et al. (2010, 2016)	T42	0 Pa
GEOSCCM	Molod et al. (2012, 2015), Oman et al. (2011, 2013)	~ 2º × 2º	1 Pa
HadGEM3-ES	Walters et al. (2014); Madec (2008)	1.875º × 1.25º	85 km
MRI-ESM1r1	Yukimoto et al. (2012, 2011), Deushi and Shibata (2011)	TL159	0 Pa
SOCOL	Revell et al. (2015), Stenke et al. (2013)	T42	500 Pa
ULAQ-CCM	Pitari et al. (2014)	CP126	4 Pa
UMSLIMCAT	Tian and Chipperfield (2005)	L64	0.77 Pa
UMUKCA-UCAM	Morgenstern et al. (2009), Bednarz et al. (2016)	3.75º × 2.5º	84 km

List of the CCMI models used for the analysis of the net stratospheric shrinkage.
Full information about the references can be found in Morgenstern et al., 2017.

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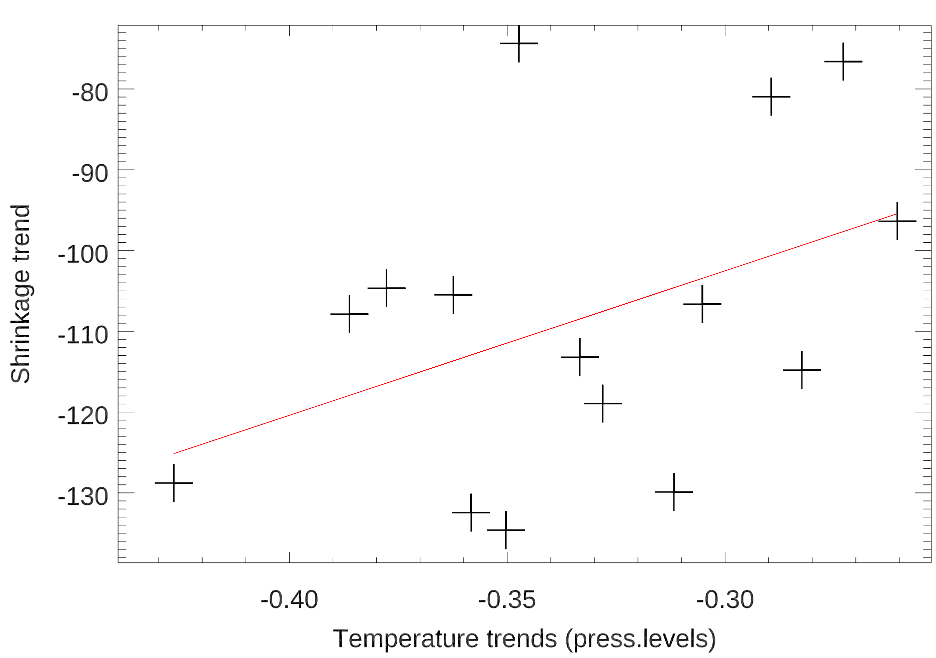
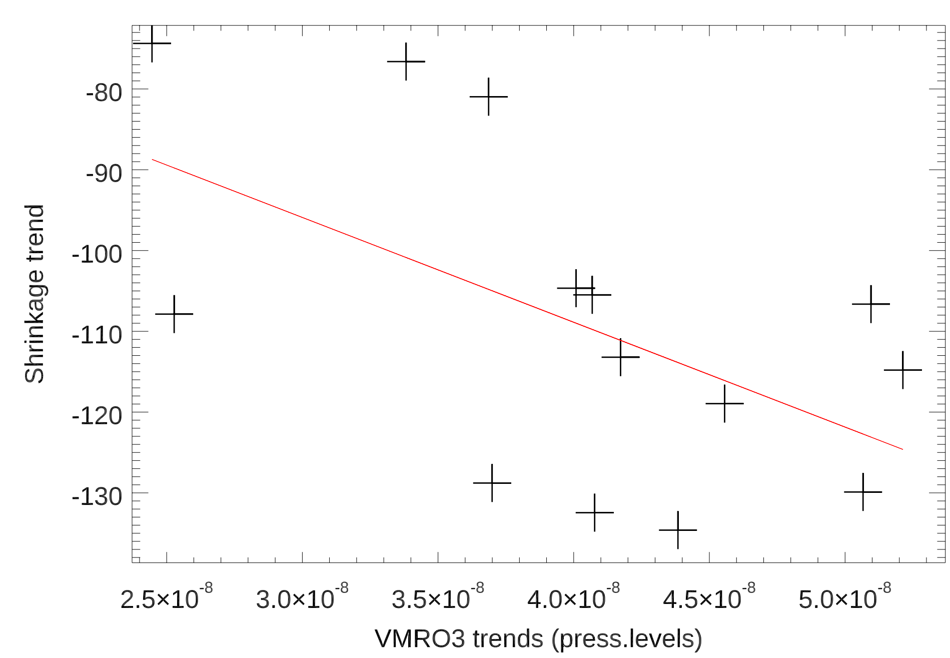
Results and discussion: The analysis illustrates relation between the trends of the stratospheric thickness and the trends of selected variables. We have also studied relation of the temperature trends to the trends of the analyzed variables. Particular values in the following figures represent specific CCMI models and their trend of the studied variable and the stratosperic thickness (or temperature).

The most interesting results are connected to the relation of the temperature trends to the trends of stratospheric thickness. As expected, those indicate that the more pronounced shrinkage is connected to more intensive cooling of the stratosphere (bigger negative trends of temperature). However, the correlation is 0.42 suggesting that the shrinkage of the stratosphere is significantly connected also to other processes than the temperature cooling. In that context, there are quite interesting results regarding the trends of vmro3. The correlation of the vmro3 trends and the stratospheric shrinkage is about -0.55. That is still not a high correlation but the correlation of the vrmo3 trends and temperature trends is very low (-0.38, not shown) indicating that besides the cooling, the vmro3 trends might provide the other forcing mechanism behind the stratospheric shrinkage.

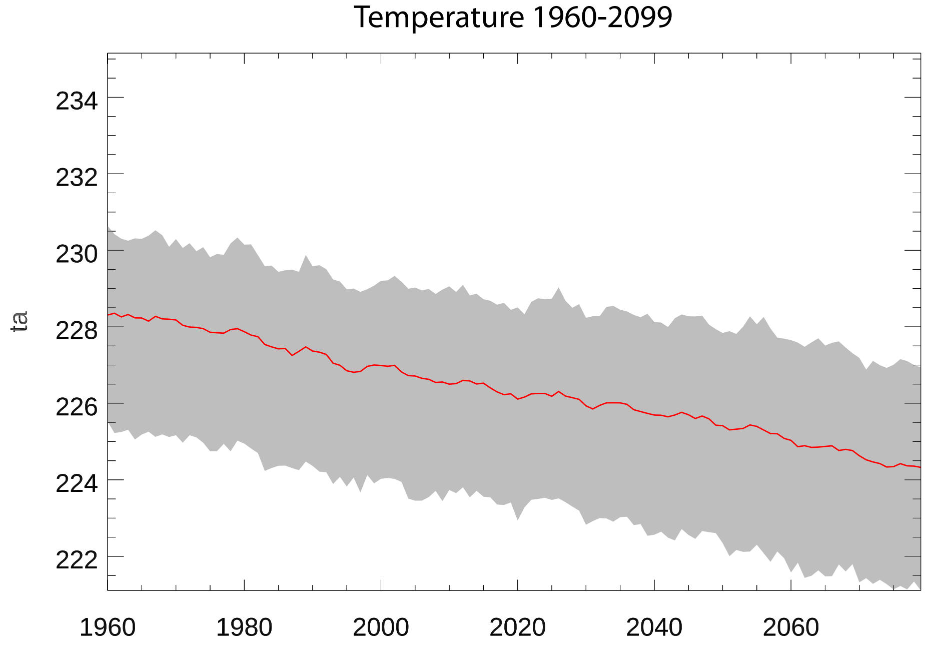
Temperature trends vs Stratospheric thickness trends
(corr. 0.42)



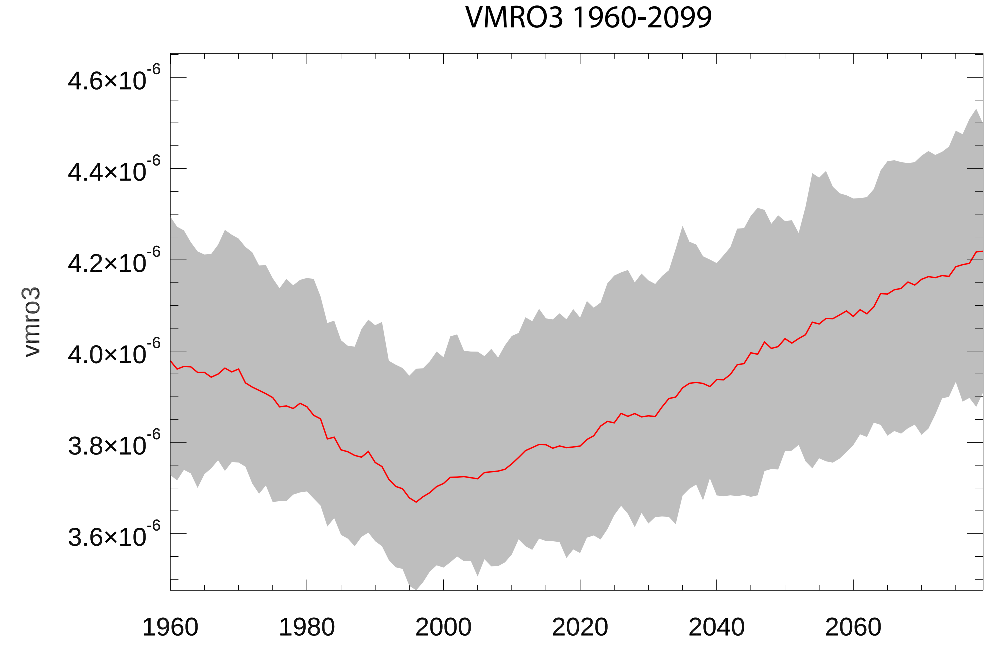
VMRO3 trend vs Stratospheric thickness trend
(corr. -0.55)



Temperature 1960-2099



VMRO3 1960-2099



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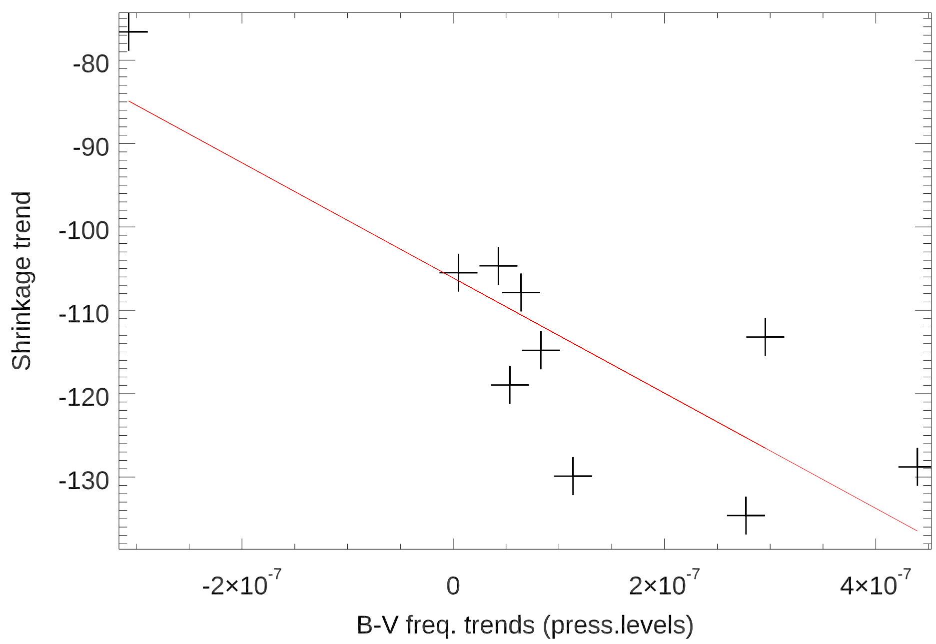
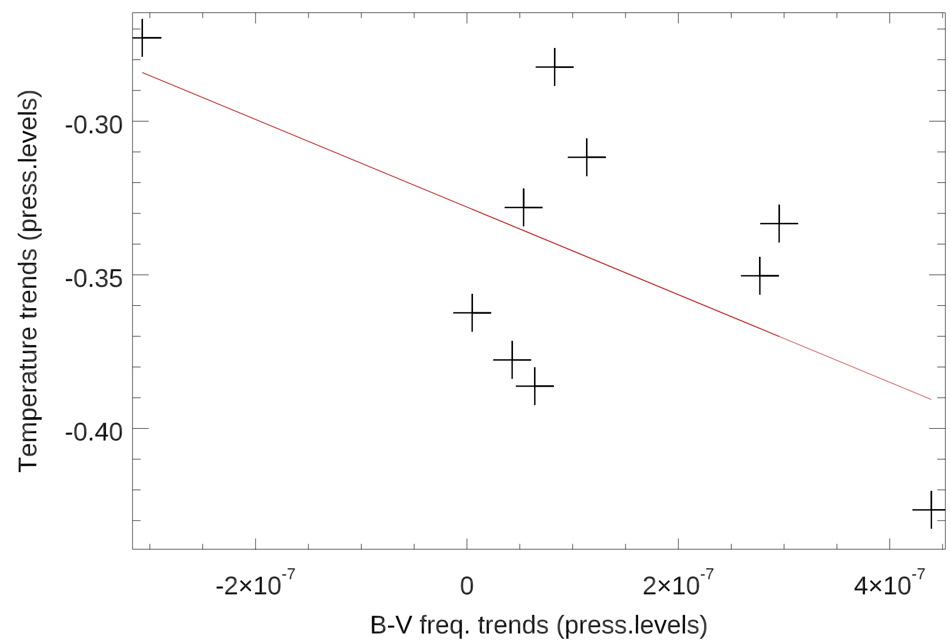
Results and discussion II: The results point also to a higher correlation of the shrinkage and BV frequency trends. There is an indication that the more pronounced shrinkage is connected to higher stability of the stratosphere (higher positive trends). The high correlation is found also for the BV frequency trends and the temperature trends..

BV frequency trends vs Stratospheric thickness trends
(corr. -0.83)

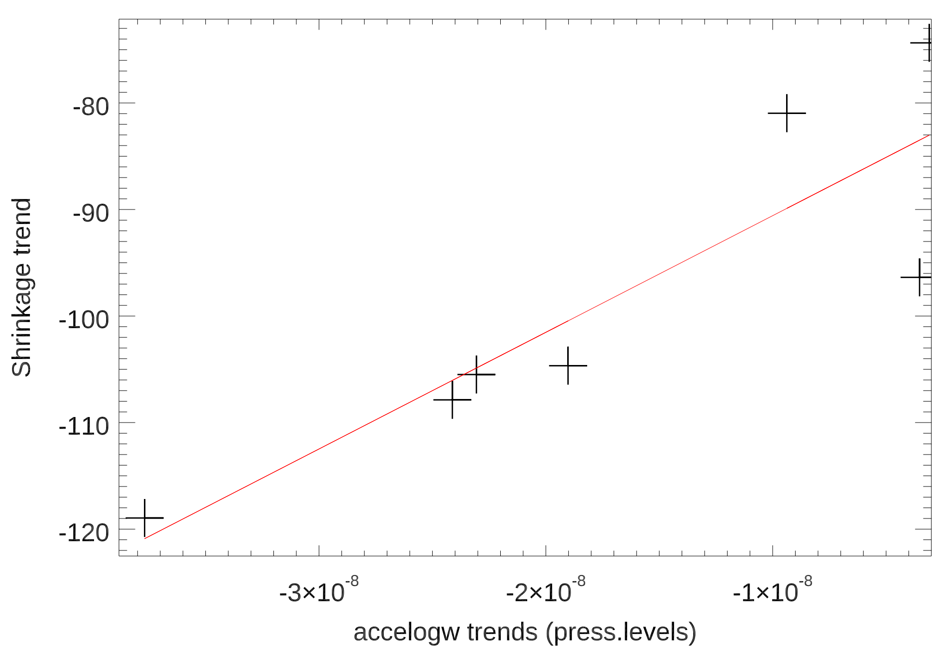


BV frequency trends vs Temperature trends
(corr. -0.60)

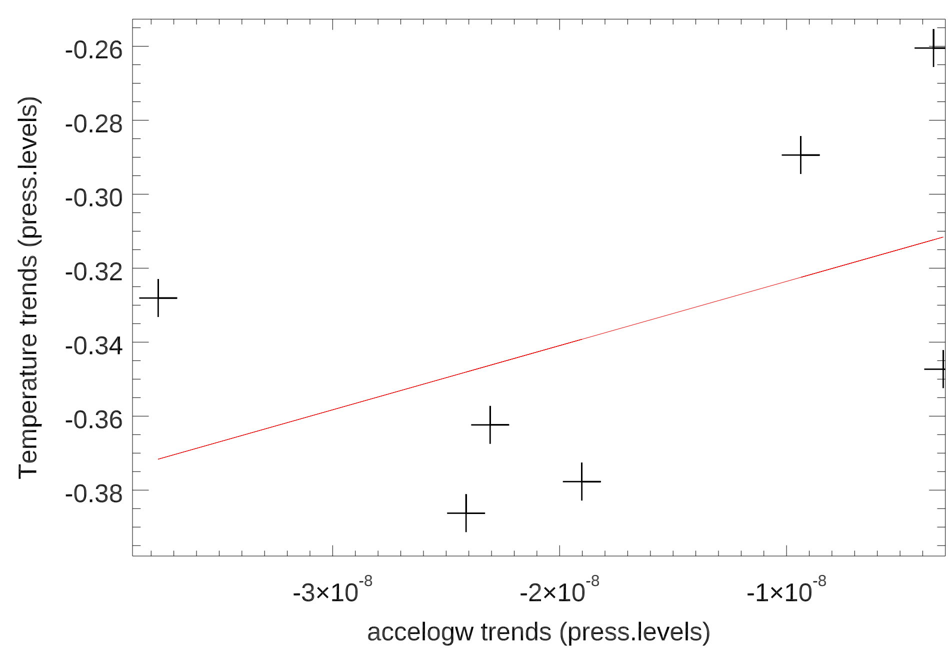


Considering the connection of the BV frequency to the (internal) gravity waves and their propagation, we have analyzed also several variables related to the wave activity. Among them, the most pronounced is the relation between the stratospheric shrinkage and the acceleration of the eastward wind due to orographic gravity wave drag (accelogw). There is indication that the bigger shrinkage is connected to higher OGW drag. Again, further analysis shows that there is high correlation of the accelogw trends and the temperature trends.

Accelogw trends vs Stratospheric thickness trend
(corr. 0.88)



Accelogw trends vs Temperature trend
(corr. 0.47)



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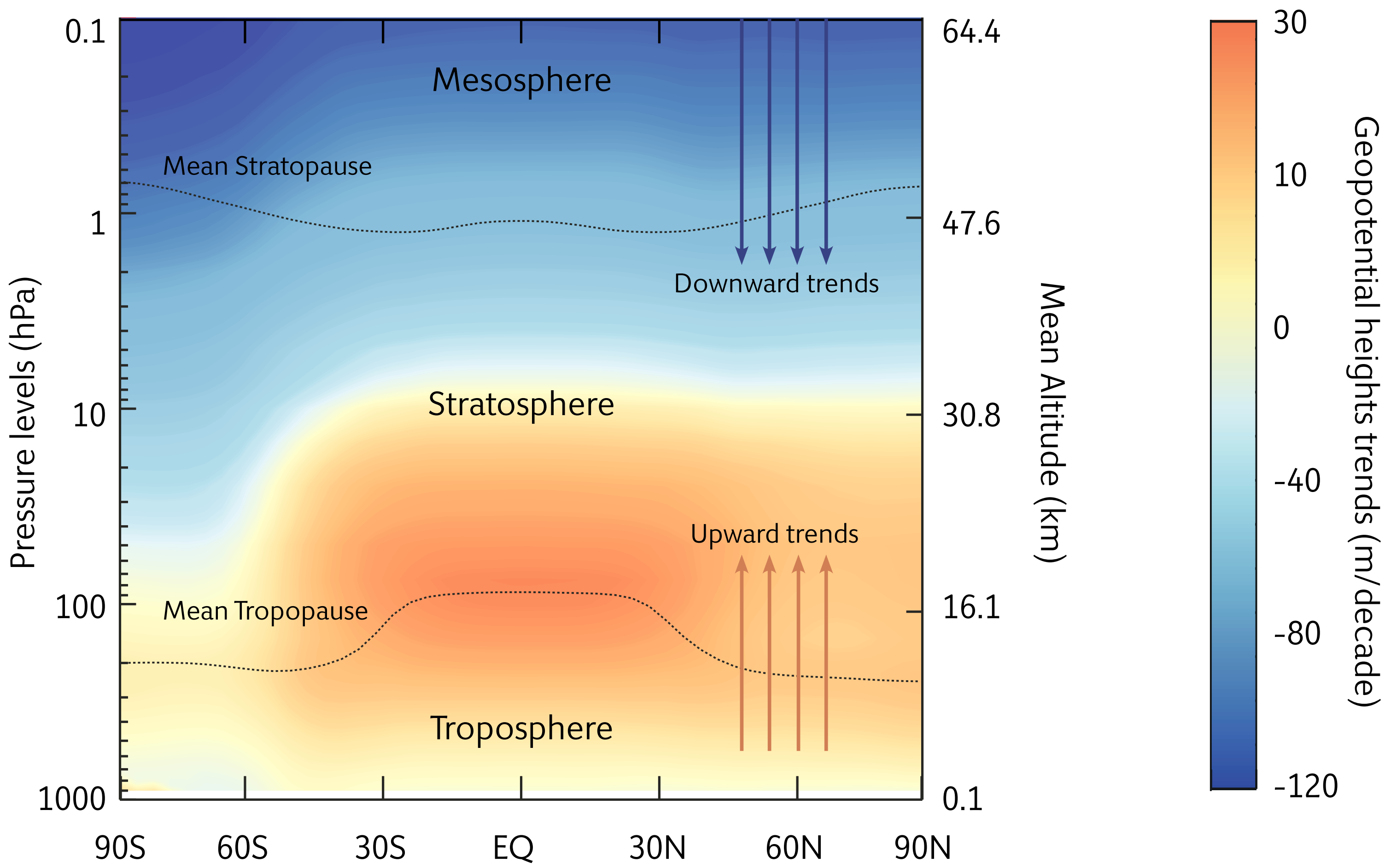
Summary

- The results suggest that the stratospheric shrinkage is connected also to other processes than the cooling
- There is an indication of an interesting role of the ozone
- High correlations are found for the BV frequency and orographic gravity waves drag



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