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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Long term changes in the upper stratospheric ozone at Syowa, Antarctica" *by* K. Miyagawa et al.

K. Miyagawa et al.

koji.miyagawa@gmail.com

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Reply to Short Comments:

We would like to thank your comments in order to improve the manuscript. We marked the original and the author's comments by SC: and AC:.

SC: In Fig. 8, you showed the negative correlation between ozone and temperature (November) in the high stratosphere (2-5 hpa). As you may know, however, Solomon et al. (2005) shows the 'positive' correlation between ozone and temperature. The difference is that Solomon et al. (2005) showed results for October and 70 hpa height at maximum. I don't think this time and height difference make the opposite results. Solomon et al. (2005) explained the positive correlation based on the extent of wave

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activity according to the temperature (so in terms of low-frequent dynamic variability) and mentioned that the data at Syowa does not seem to be influenced by these lowfrequent pattern. So now I guess your negative correlation implies the strong relation of polar stratospheric cloud. Is it right? (I cannot reach to your conclusion for this correlation between ozone and temperature). If right, then you need to discuss the influence of stratospheric wave activity to the ozone variability carefully.

AC: The short comment suggests that ozone at 70 hPa and at 4 hPa is driven by the same processes. This is not correct, ozone variability at 4 hPa is driven mostly by chemistry, while dynamics plays role through the change of the temperature in the vortex. The temperature decline of the upper stratosphere leads to the increase in ozone (O3), via a Chapman mechanism and the ClOx cycle first described by Molina and Rowland (1974). We would suggest to read more information in Aeronomy of the middle stratosphere by Brusseur and Solomon (1984). Molina, M. J., and Rowland, F. S.: Stratospheric sink for chlorofluoromethanes: Chlorine atom catalyzed destruction of ozone, Nature, June 28, pp. 810-12, 1974. G. Brasseur and S. Soloman: Aeronomy of the middle atmosphere (441 pp). D. Reidel, Dordrecht, 1984.

SC: Including the introduction, you suggested many factors influencing the variability of stratospheric ozone such as ODS(or EESC), SAM, ENSO, QBO, solar cycle, wave propagation, etc. Then which one explains the stratospheric ozone variability best? In other words, I don't reach which is the main factor we need to consider for the analysis of ozone variability. If you want to mention the impacts by all these factors, I think there is another better way to show the evaluation or comparison of all these factors.

AC: Thank you very much for this comment. We performed more analysis and now statistical model has been changed to use only proxies that improve the fit. See the new version of Table 2. We have also added discussion to the text to explain how the proxies were chosen. We find the contribution of Heat Flux to ozone variability comparable to the EqLat850K in the springtime season and only in the lower and middle stratosphere, According to our analysis of ozone variability in the summer season, we find that Solar, QBO, AOD and EqLat explain 2-35 % of the variability, whereas EqLat at 520 K is preferred to fit time series in layers 1 and 2+3, whereas for layers 5, 6, 7 and 8, EqLat at 850 K is a better proxy. It is also interesting to note that ozone variability in layer 2+3 and 4 during summer time is defined by Solar, AOD, QBO, EqLat 850 K and SAM proxies. Layer 7 and 8 appears to have additional improvement in the explained variances when Heat Flux proxy is used. On the other hand the improvement is similar when SAM is used in place of Heat Flux. The best fit with the statistical model was obtained by applying time-lag for SOR, QBO, and AOD proxies (See new Table 2b, 2c).

SC: It seems better to comment the meaning of layer number in the section 2 (ozone data sets) or the caption of first figure. I'm confused whether larger number layer means high altitude or not and there is no specific information of layer height (only commented layer 8+ is higher than 4 hap), making difficult to read Table 2 and 4.

AC: We added the caption of atmospheric pressure to Table 2. The value indicates the atmospheric pressure at the bottom of Umkehr layer.

Layer number 1 2+3 4 5 6 7 8 8+9+10

Pressure [hPa] 1000 250 62.5 31.2 15.6 7.8 3.9 3.9

Interactive comment on Atmos. Chem. Phys. Discuss., 13, 379, 2013.

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Table 2.

	LAYER							
Pressure [hPa]	1000	250	62.5	31.2	15.6	7.8	3.9	3.9
Spring (SON)	1	2+3	4	5	6	7	8	8+9+10
SEASONAL VARIANCE [DU^2]	1.08	117.3	103.0	33.5	7.51	1.54	0.21	0.36
1.1)SOR+QBO+AOD [%]	-49	-48	-41	-29	-25	-34	-28	-28
2.1)SOR+QBO+AOD+EqL520K [*a] [%]	-58	-58	-51	-35	-25	-27	-13	-10
2.2)**SOR+QBO+AOD+EqL850K** [%]	-61	-71	-71	-57	-44	**-60**	**-60**	**-58**
2.3)SOR+QBO+AOD+EqL1300K [%]	-51	-49	-42	-37	-46	-55	-39	-36
2.4)SOR+QBO+AOD+ENSO [%]	-56	-55	-47	-34	-25	-34	-28	-25
2.5)SOR+QBO+AOD+SAM [%]	-56	-61	-63	-60	-49	-43	-35	-33
2.6)SOR+QBO+AOD+HF10 [%]	-52	-54	-50	-43	-34	-38	-28	-28
3.1)SOR+QBO+AOD+EqL850K+ENSO [%]	-56	-67	-69	-62	-50	-44	-42	-41
3.2)SOR+QBO+AOD+EqL850K+SAM [%]	-56	-68	-74	-70	-56	-45	-42	-41
3.3)**SOR+QBO+AOD+EqL850K+HF10** [%]	-61	**-74**	**-80**	**-79**	**-64**	-52	-39	-39
3.4)SOR+QBO+AOD+EqL520K+SAM [%]	-58	-63	-62	-56	-44	-35	-21	-19
3.5)SOR+QBO+AOD+EqL1300K+SAM [%]	-57	-62	-62	-59	-54	-43	-28	-28
3.6)**SOR+QBO+AOD+EqL520K+HF10** [%]	**-73**	-71	-64	-49	-34	-32	-13	-13
4.1)SOR+QBO+AOD+EqL850K+ENSO+HF10 [%]	-56	-68	-73	-69	-57	-47	-42	-41
4.2)SOR+QBO+AOD+EqL850K+ENSO+SAM [%]	-56	-69	-75	-71	-56	-45	-42	-41
Summer (JFM)								
1.0)SEASONAL VARIANCE [DU^2]	0.32	15.1	9.1	13.2	2.99	0.50	0.10	0.18
1.1)SOR+QBO+AOD [%]	**-20**	-2	-25	-33	-35	-19	-12	-9
2.1)SOR+QBO+AOD+EqL520K [%]	-20	-15	-39	-35	-35	-19	-18	-13
2.2)**SOR+QBO+AOD+EqL850K** [%]	-17	-14	-41	**-42**	**-50**	**-36**	**-23**	**-22**
2.3)SOR+QBO+AOD+EqL1300K [%]	**-20**	-16	-39	-35	-42	-33	-18	-18
2.4)SOR+QBO+AOD+ENSO [%]	**-20**	-16	-41	-39	-37	-19	-18	-18
2.5)**SOR+QBO+AOD+SAM** [%]	-20	-22	**-59**	-37	-35	-19	-18	-18
2.6)SOR+QBO+AOD+HF10 [%]	-17	-13	-40	-32	-30	-19	-12	-13
3.1)SOR+QBO+AOD+EqL850K+ENSO [%]	**-23**	-21	-43	-42	-49	-36	-23	-22
3.2)**SOR+QBO+AOD+EqL850K+SAM** [%]	**-23**	**-24**	-57	-40	-48	-36	-23	-22
3.3)**SOR+QBO+AOD+EqL850K+HF10** [%]	-23	-18	-44	-37	-45	**-40**	**-29**	-22
3.4)SOR+QBO+AOD+EqL520K+SAM [%]	-20	-22	-56	-36	-35	-19	-18	-18
3.5)SOR+QBO+AOD+EqL1300K+SAM [%]	-20	-21	-57	-37	-44	-38	-23	-22

[*a] $\%_{2.1} = (VAL_{2.1} - VAL_{1.0})/VAL_{1.0} * 100$

a) Summary of the explained variance for the statistical models fit separated into spring and summer season. Results are provided for Umkehr layers (columns) and for different statistical models that include several proxies (rows of the table). The first row of spring and summer season section of the Table 2 represents the RMSD of the residuals between monthly averaged ozone time series and a statistical model that includes seasonal and EESC Polar 2 curve parameters (de-seasonalized and detrended time series). This result is considered as a benchmark and is set at 100 %. Other rows show percent reduction of the variance in the residuals for several statistical models that includes additional proxies relative to the first row. For example, the second row shows change in the variance of the residual for the model fit that included seasonal, EESC, SOR, QBO and AOD proxies as compared to the residual of the model that had only seasonal component and EESC proxy. Note, that negative values indicate improvement of the fit and the reduction in the unexplained variance (-10 means that the original ozone variability was reduced by 10 %).
The boldface numbers in the table shows the best fit of the model for the layer in each section of the table. The yellow marker shows the best final result of the model fit for each layer and in each season separately. A positive value (gray color) shows the increase in the ozone variation caused by the use of specific proxies. It means that the use of that proxy resulted in the poor fit. And not further reduction in variance was achieved. EqL850K proxy represents the one-month averages of the MERRA Equivalent Latitude values at 850 K level that is also temporally matched with Umkehr ozone measurement (within 24 hours). The best fit of data with a statistical model is indicated by the bold faced text. Results of the Table 2 provide information that allows to choose a set of proxies that reduces ozone variability in the most effective way. The first row features atmospheric pressure at the bottom of the Umkehr layer. The green color marks the best fit of the model with proxies identified in the left hand column.

Fig. 1. Table 2

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