Supplement of

Evolution of the eastward shift in the quasi-stationary minimum of the Antarctic total ozone column

A. Grytsai et al.

Correspondence to: G. P. Milinevsky (genmilinevsky@gmail.com)

Supplement 1. Calculations of the long-term tendencies for timeseries presented in Fig. 2. Polynomial approximation was calculated with a least-squares method by a following scheme (see, e.g. Krishnan, V.: Probability and random processes, John Wiley & Sons, Inc., Hoboken, New Jersey, 420 p., 2006). We consider n pairs of values (x_i, y_i). In our calculations x_i and y_i are time and the phase of the TOC distribution (e.g. in the quasi-stationary minimum at 65°S), respectively. The purpose is to find a polynomial fit of degree k to minimize

$$f(x_i, y_i) = \sum_{i=1}^{n} (P_k(x_i) - y_i)^2$$

where

$$P_k(x_i) = \sum_{m=0}^{k} a_m x_i^m$$

is a polynomial of k-th power with unknown coefficients a_j. The minimization condition for the function f is written as

$$\frac{\partial f}{\partial a_j} = 0,$$

which includes a system from $k + 1$ equations for different j. In solving the system we obtain each coefficient as the ratio of the two determinants:

$$a_m = \frac{\begin{vmatrix} n & \sum_{i=1}^{n} x_i & \dots & \sum_{i=1}^{n} x_i^{m-1} & \sum_{i=1}^{n} y_i & \dots & \sum_{i=1}^{n} x_i^k \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ \sum_{i=1}^{n} x_i^k & \sum_{i=1}^{n} x_i^{k+1} & \dots & \sum_{i=1}^{n} x_i^{k+m-1} & \sum_{i=1}^{n} x_i^k y_i & \dots & \sum_{i=1}^{n} x_i^{2k} \end{vmatrix}}{\begin{vmatrix} n & \sum_{i=1}^{n} x_i & \dots & \sum_{i=1}^{n} x_i^{m-1} & \sum_{i=1}^{n} x_i^m & \dots & \sum_{i=1}^{n} x_i^k \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ \sum_{i=1}^{n} x_i^k & \sum_{i=1}^{n} x_i^{k+1} & \dots & \sum_{i=1}^{n} x_i^{k+m-1} & \sum_{i=1}^{n} x_i^{k+m} & \dots & \sum_{i=1}^{n} x_i^{2k} \end{vmatrix}}$$

Supplement 2. Polynomial fits for the timeseries of the QSW minimum longitude at 65°S in comparison with Fig. 2b (k = 3).

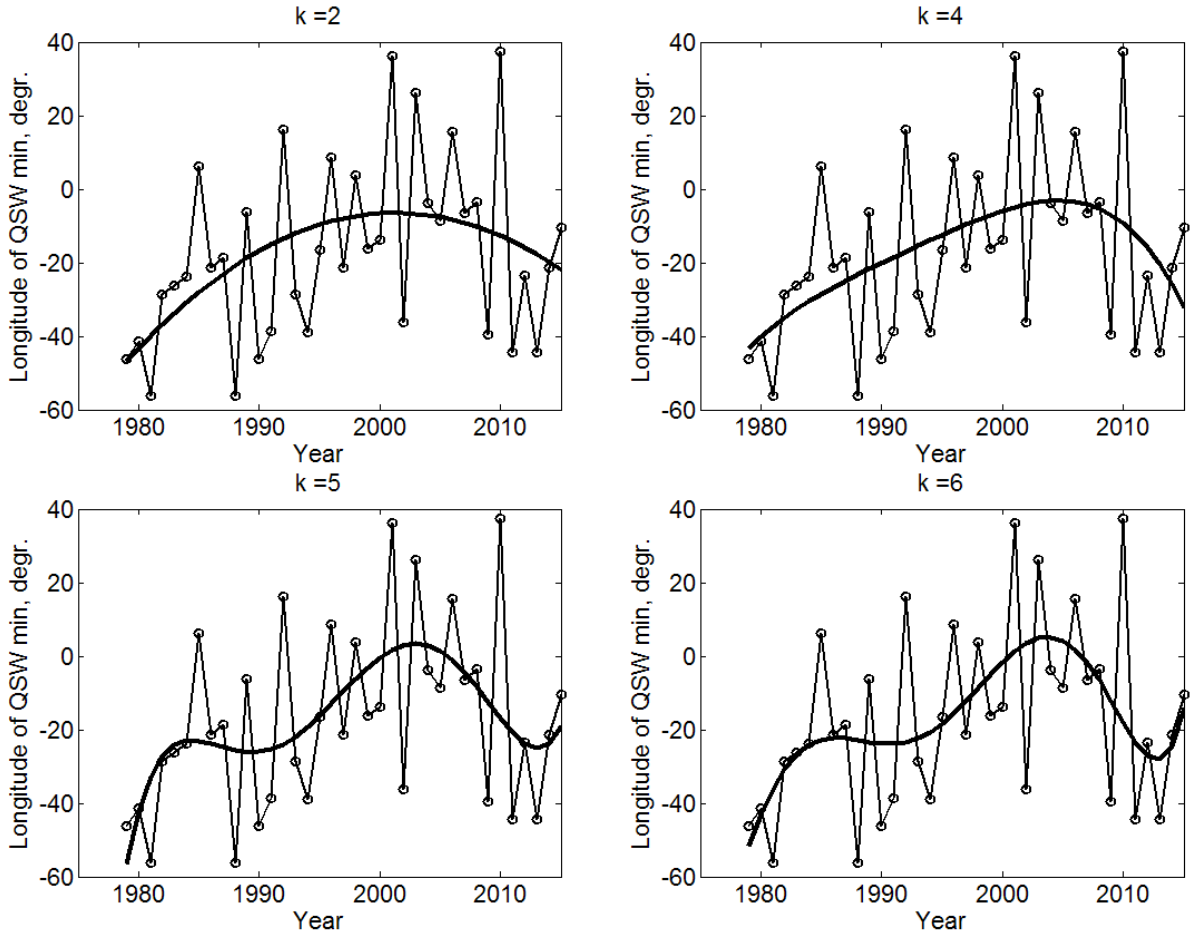

Figure S1: Longitude of the QSW minimum at 65°S averaged for September–November. Thin lines are timeseries of 1979–2015 and thick lines are polynomial fits of degree k = 2, 4–6 .

Supplement 3. Images in Figs. S2–S6 based on data by the NOAA/ESRL Physical Sciences Division, Boulder Colorado from their Web site at http://www.esrl.noaa.gov/psd/.

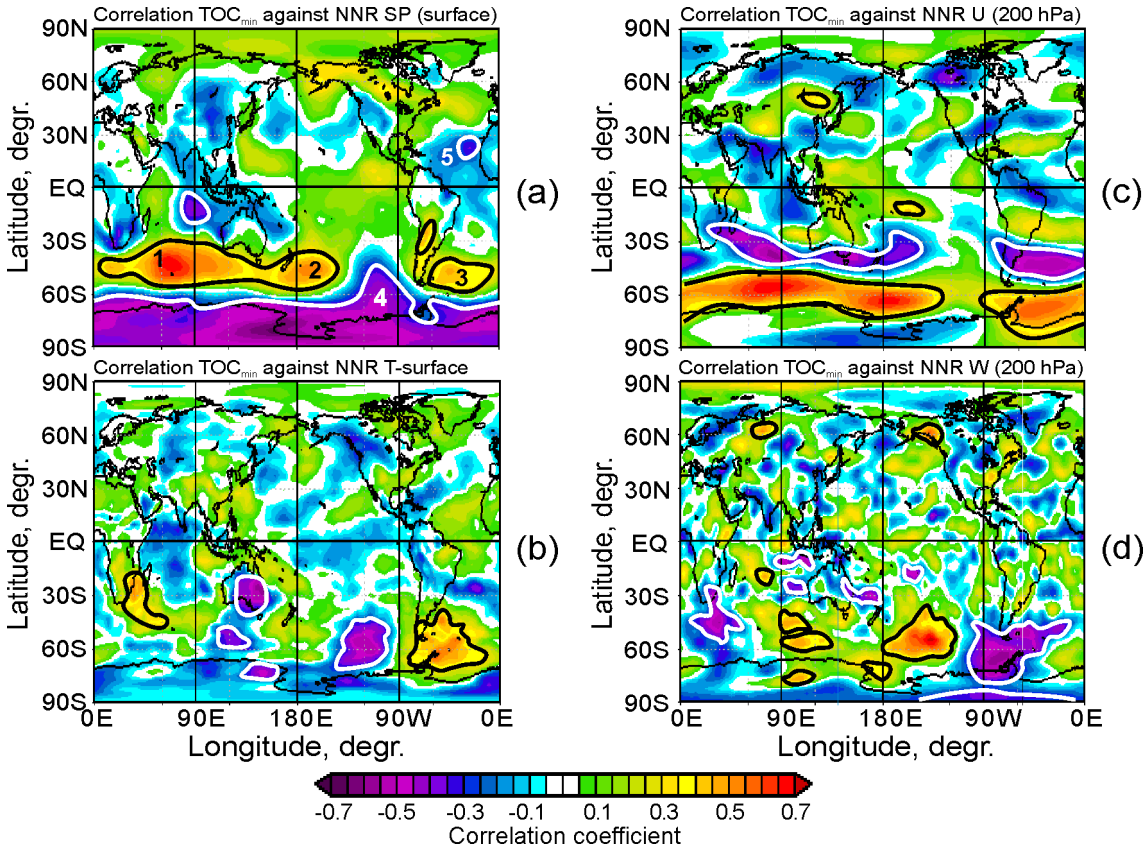

Figure S2: Correlations between the TOC QSW minimum longitude against NCEP–NCAR reanalysis climatological anomalies of (a) surface pressure (SP), (b) surface temperature, (c) 200-hPa zonal wind speed (U200) and (d) 200-hPa vertical pressure wind speed (W200) for SON 1979–2014. Black (white) contours show positive (negative) correlations significant at the 95% confidence limit. To compare with Fig. 6 based on the the ERA-Interim data.

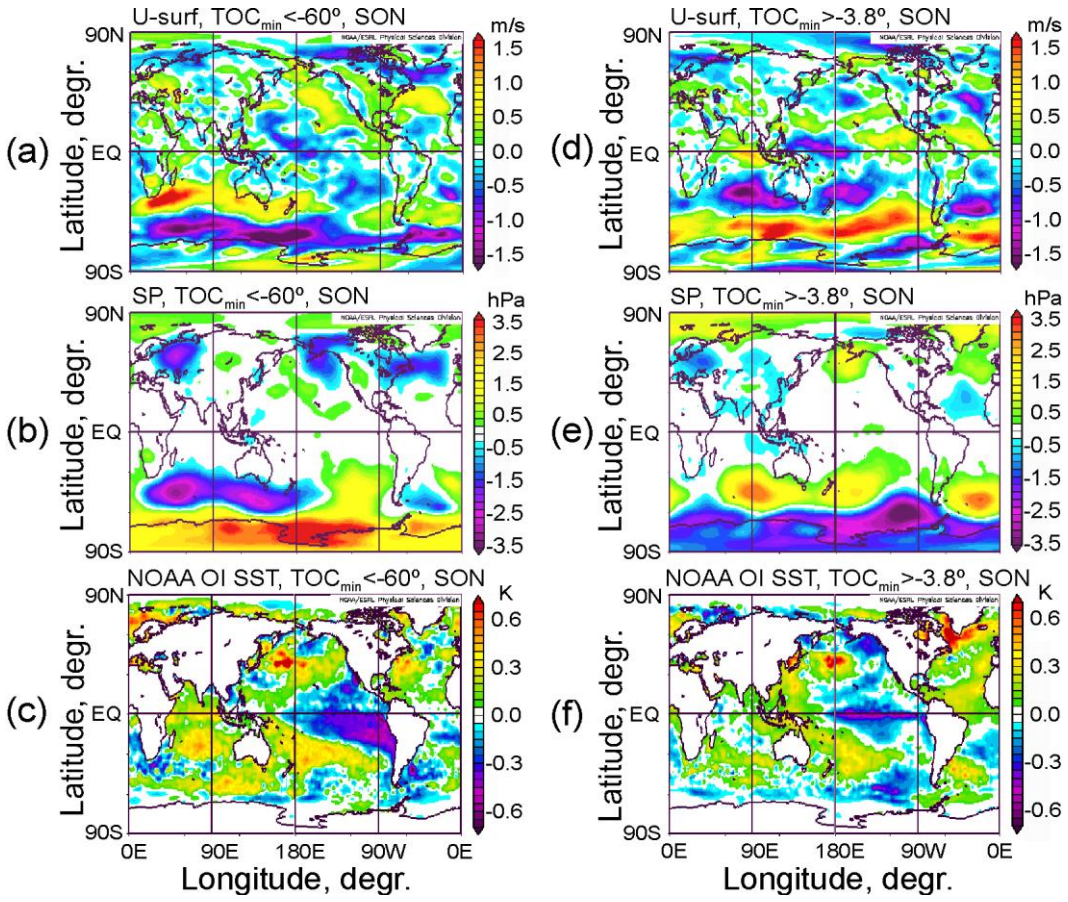

Figure S3: As in Fig. 7, but for the NCEP–NCAR reanalysis.

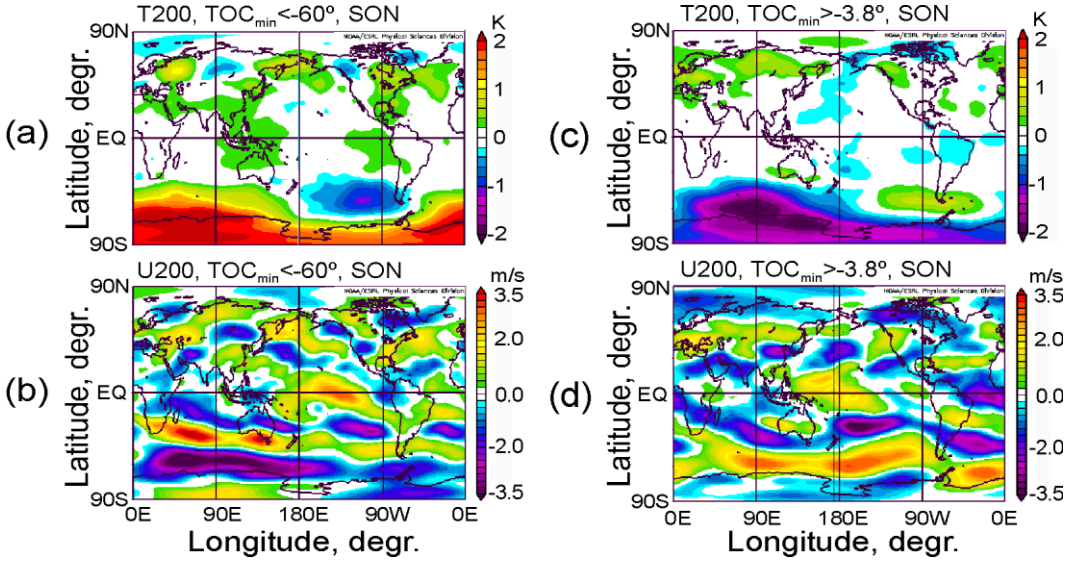

Figure S4: As in Fig. 9a, 9b, 9e and 9f, but for the NCEP–NCAR reanalysis.

Figs S5 and S6 show correlations between the QSWmin longitude and NCEP–NCAR air temperature to compare with those from the ERA-Interim data presented in Fig. 10 and Fig. 11, respectively.

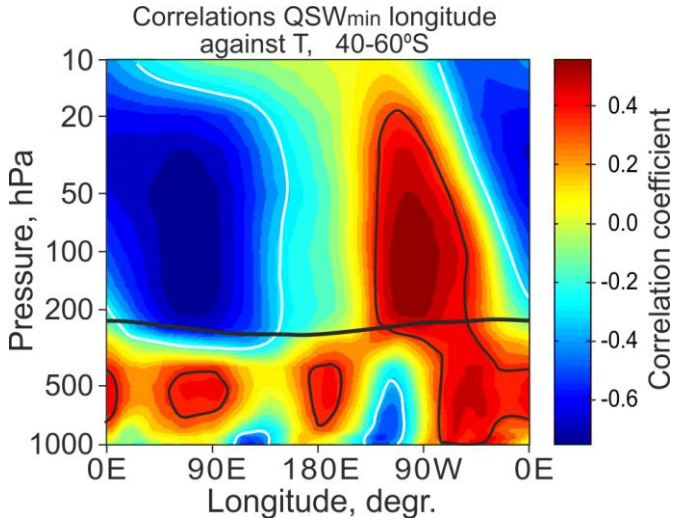

Figure S5: Longitude–height cross-section of the correlation between the QSW_{min} longitude at 65°S and air temperature averaged over the zone 40–60°S for SON 1979–2014. Thick black curve marks climatological thermal tropopause from the NCEP–NCAR reanalysis. Black (white) contours show positive (negative) correlations significant at the 95% confidence limit.

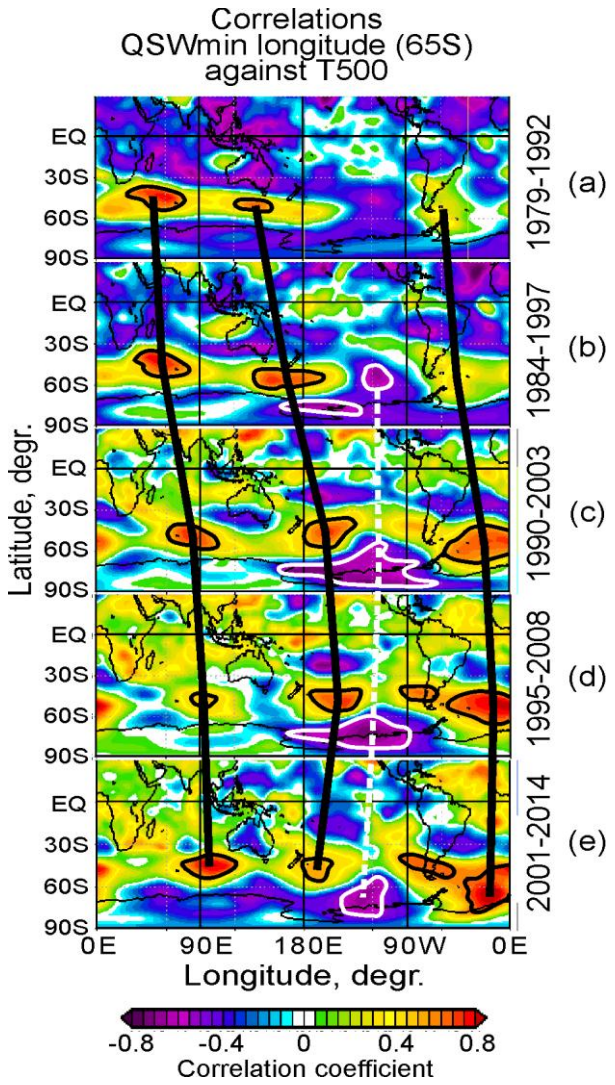

Figure S6: Correlation between the QSW_{min} longitude at 65°S and air temperature at 500 hPa south of 30°N. Five sequential 14-year intervals with 5–6 year step are presented. Black (white) contours show positive (negative) correlations significant at the 95% confidence limit. Thick solid black (dashed white) lines mark mean longitudinal positions of the positive (negative) correlation peaks in the QSW3 structure.

Fig. S7 shows the meridional cross-section of the linear correlation between temperature and QSW_{min} longitude from the ACCESS-CCM REF-C2 and REF-C1 simulations.

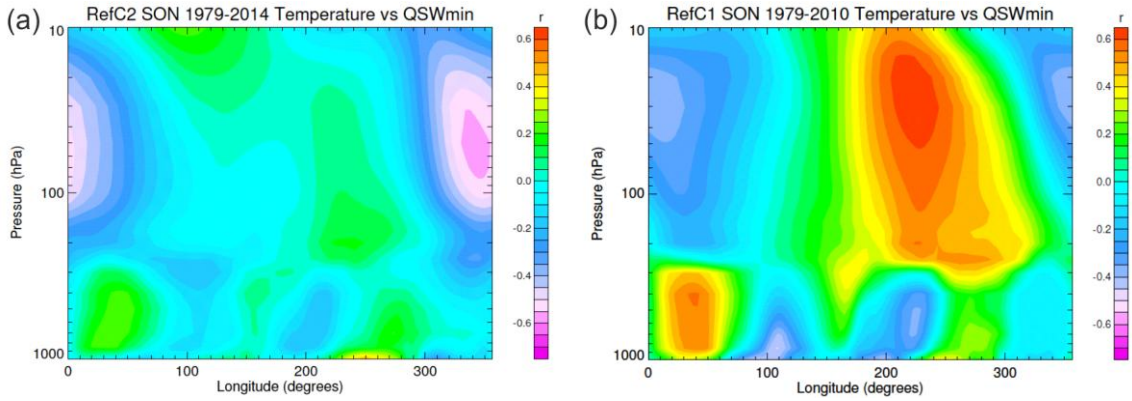

Figure S7: Similar to Fig. 10, but showing the longitude–height cross-section of the correlation between the QSW_{min} longitude at 65°S and air temperature averaged over the zone 40–60°S for (a) the REF-C2 simulation over 1979–2014 and (b) the REF-C1 simulation over 1979–2010.