Supplemental material to
Extreme events in total ozone over Arosa: Part 1
Application of extreme value theory
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1. Discussion of the drawbacks of threshold estimation based on detrended datasets or various sub-periods

1.1 Trend components derived for the Arosa total ozone time series by STL decomposition with various time windows for trend extraction

As stated in section 2.4 the Arosa total ozone time series was not detrended before the threshold selection process. In the following section of the supplementary material the reasons are outlined in detail.

Detrending of a time series leads conditionally to a subjective a priori decision on the type of trend applied. Figure S1 shows various trend components for the Arosa total ozone time series after applying the Seasonal Decomposition based on LOESS (STL) (e.g. Cleveland et al., 1990) with different time windows (see caption of Fig. S1) for the trend estimator. From Fig. S1a-f it is obvious how strong a trend estimator is influenced by the time window chosen. Large time windows, as chosen in Figs. S1a-c, lead to almost linear trend estimates while shorter time windows, as chosen in Figs. S1d-f, lead to a highly variable structure of the trend component with time. Detrending of the Arosa total ozone time series with the trend components shown in Fig. S1 would lead to a highly diverse remainder simply depending on the time window chosen for the trend component. Therefore, we decided using two clearly different regimes for threshold estimation, namely an anthropogenically and volcanically unperturbed (1927-59) and an anthropogenically and volcanically perturbed time period (1960-2008) instead of a threshold estimation based on a detrended time series, which would lead to subjective results as outlined above.

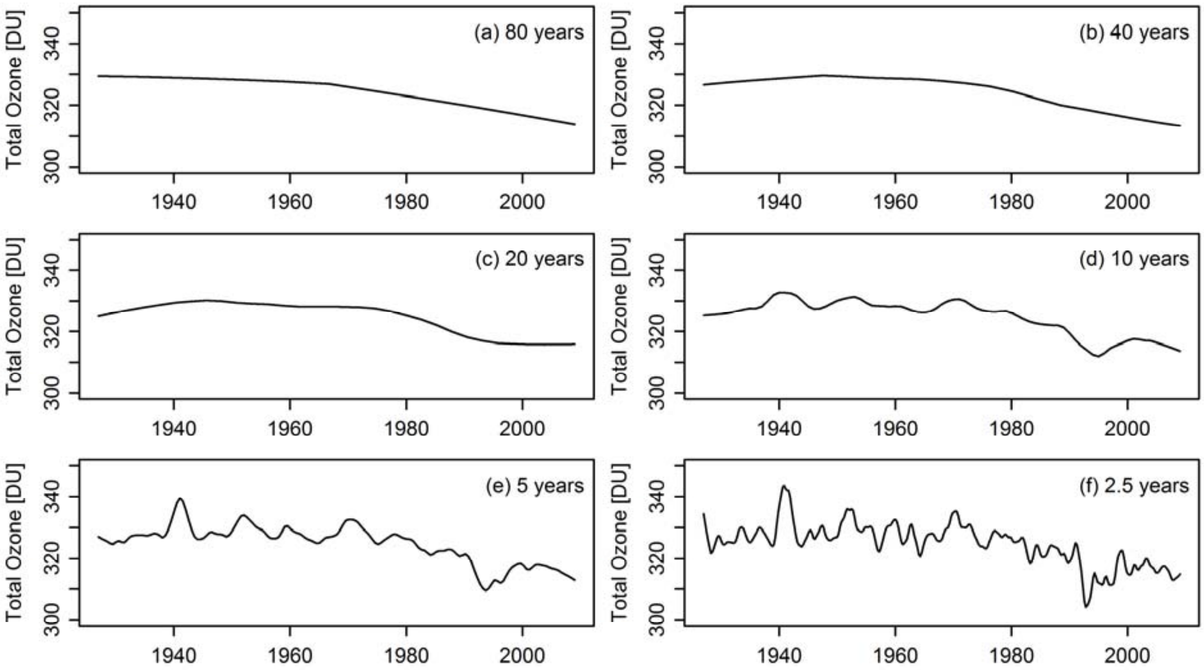

Fig. S1: Trend component of the Arosa total ozone time series (1927-2008) based on the Seasonal Trend decomposition procedure based on LOESS (STL) with time window (span in lags of the LOESS window for trend extraction) of (a) 80 years, (b) 40 years, (c) 20 years, (d) 10 years, (e) 5 years, and (f) 2.5 years.

1.2 Threshold estimation on various time windows

One might argue that threshold estimation should be based on various shorter time periods as a lot of inter-annual to decadal variability is visible in the Arosa total ozone time series (compare Fig. 1 in the main paper). We decided not to use different sub periods, first for statistical reasons as a sufficient amount of data is necessary for the threshold selection process, and second this would lead to a subjective a priori decision on time series properties (similar as detrending of the time series, described in Sect. 1.1 of the supplement).

However, for discussion on the stability of threshold estimates, thresholds for low and high total ozone have been estimated also for four 20 year periods (1930-49, 1970-89 and 1980-99, 1989-2008) and an extended “unperturbed” period (1927-69). The results for the threshold estimates for these 5 time periods and the applied thresholds (based on estimation on the time periods 1927-59 and 1960-2008) are shown in Fig. S2. From Fig. S2 it is obvious that differences among the thresholds are quite small and so threshold selection is not highly sensitive on the time period chosen.

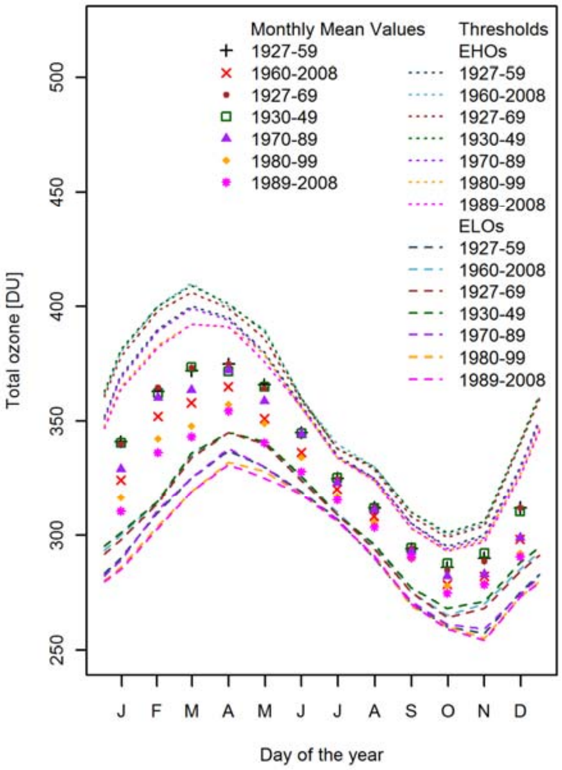

Fig. S2: Threshold for extreme high (EHOs) and low (ELOs) total ozone and monthly means of total ozone over Arosa for the time periods 1927-59, 1960-2008, 1927-69, 1930-49, 1970-89, 1980-99 and 1989-2008. Note: Thresholds estimated on the time periods 1927-59 and 1960-2008 (see also Fig. 8 in the main paper) are used for determination of ELOs and EHOs.

However, threshold estimates for February, March and May, based on the time periods 1980-1999 and 1989-2008 differ slightly from those for other time windows. This is expected as both 20 year time periods are strongly influenced by the volcanic eruption of Mt. Pinatubo. Note that a similar deviation does not occur for thresholds estimated on the time period 1970-89 (influenced by the eruption of El Chichón), indicating the major influence of the Mt. Pinatubo eruption on column ozone, visible also in annual mean values. However, the effect of this deviation in threshold estimates is rather small as it affects only late winter and early spring.

To analyze the influence of this threshold deviation Fig.S3 and Fig.S4 provide a comparison of the frequency of days with extreme low and high total ozone, computed from the thresholds used in the main paper plus those estimated based on the 1980-1999 and 1989-2008 time windows (see also Interactive Discussion in ACPD). Figure S3a shows results for spring and Fig. S3b for winter in 1980-1999. Analogously, Fig. S4a shows results for spring, Fig. S4b for winter in 1989-2008. It is obvious that the overall pattern in ELOs and EHOs is not changed for spring season (Figs.S3a and S4a). The use of a different threshold does not affect the shape of the distribution and only slightly the total frequency, increasing the frequency of EHOs on average by 3% and decreasing the frequency of ELOs by 5%. For the winter season (Figs. S3b and S4b) a similar result is found. However, one should note that the pattern in the frequency of ELOs is different between 1985 and 1988 (see Fig. S3) and 1989-2000 (see Fig. S4). The difference in the threshold values applied leads during winter season on average to a slight increase in the frequency of EHOs (about 3%) and a slight decrease in the frequency of ELOs (about 5%). From both figures it is obvious that fingerprint identification of dynamical and chemical phenomena, as described in the main paper, is not affected by the application of a slightly different threshold value.

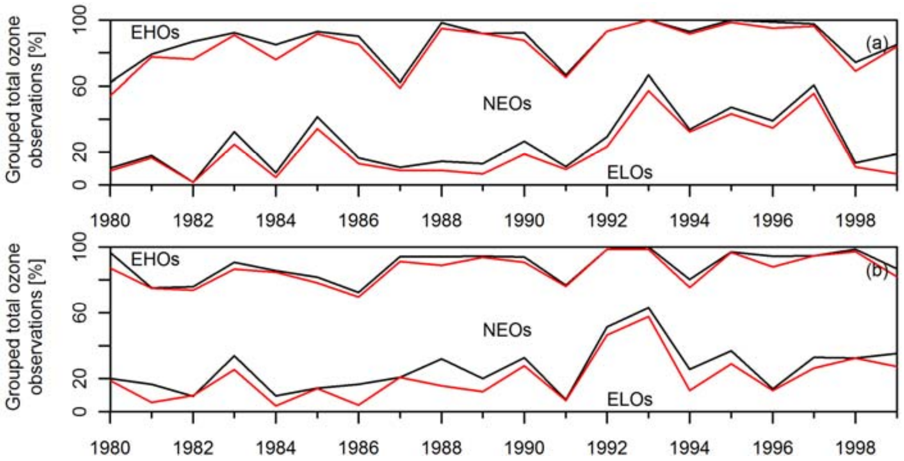

Fig. S3: Evolution of fractions of extreme low (ELOs) and high (EHOs) total ozone and not extreme days (NEOs) for (a) spring (MAM) and (b) winter (DJF) in 1980-99 based on different thresholds applied. Solid black lines represent the result based on thresholds estimated on the time period 1960-2008 (used in the analysis of Rieder et al. (2010a,b)), solid red lines represent the results based on thresholds estimated on the time period 1980-99.

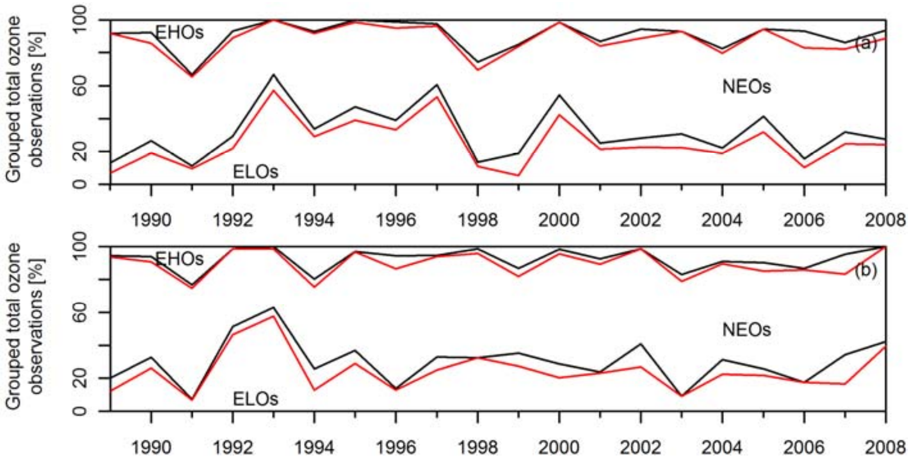

Fig. S4: Evolution of fractions of extreme low (ELOs) and high (EHOs) total ozone and not extreme days (NEOs) for (a) spring (MAM) and (b) winter (DJF) in 1989-2008 based on different thresholds applied. Solid black lines represent the result based on thresholds estimated on the time period 1960-2008 (used in the analysis of Rieder et al. (2010a,b)), solid red lines represent the results based on thresholds estimated on the time period 1989-2008.

Figure S5 shows the ratios between the differences in thresholds for extremes and mean values derived for the periods 1980-1999 minus 1960-2008 and 1989-2008 minus 1960-2008. With a few exceptions (particularly concerning the October values) it is obvious that the difference among mean values is significantly larger than those between threshold values (on average by about a factor of 2).

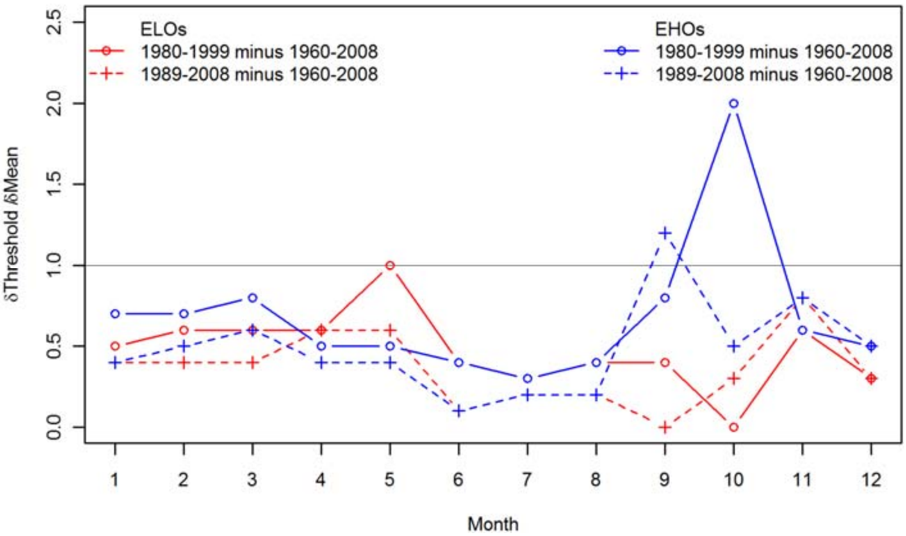

Fig. S5: Ratio of differences (δ) in threshold values for extremes for different time periods over their difference in mean values. The latter is typically larger by a factor of ~2, irrespective of the time periods chosen (long-dashed: 1980-1999 minus 1960-2008; short-dashed: 1989-2008 minus 1960-2008) or the type of extremes (red: ELO; blue: EHOs).

Based on the results presented above, we decided to use clearly defined time periods for threshold estimation and fingerprint analysis instead of partly subjective sub-sets or detrended data. Therefore, threshold estimates have been performed as outlined in Sect. 3.4. of the main paper based on a clearly anthropogenically and volcanically unperturbed period (1927-59) and a clearly anthropogenically and volcanically perturbed period (1960-2008).