The influence of Ozone Hole interannual variability on Southern Hemisphere Climate

Marisol Osman[1], Leandro B. Diaz[1], Stefaan Conradie[2] and Sabina Abba Omar[2]

1. Centro de Investigaciones del Mar y la Atmósfera/UBA-CONICET, DCAO/FCEN, UMI IFAECI/CNRS, Buenos Aires, Argentina
2. Climate System Analysis Group, Department of Environmental and Geographical Science, University of Cape Town, South Africa

Background

The depletion of stratospheric ozone over the Antarctic was first reported in the 1980s. Severe ozone depletion, leading to very low stratospheric ozone concentrations particularly in Austral spring (peaking in October), has come to be referred to as the “ozone hole”. Although the rate of depletion increased at the beginning of the 1980s, ozone concentrations over the Antarctic have stabilised since the late 1990s, after the implementation of the Montreal Convention in 1987 (Hegglin et al. 2015).

The Antarctic ozone hole has been shown to contribute to observed changes in Southern Hemisphere (SH) climate anomalies during summer (e.g. Son et al. 2009; Bandoro et al. 2014). While many studies have assessed the impacts of Antarctic ozone trends in the SH climate (e.g. Thompson et al. 2011), the influence of its interannual variability has been less studied. Therefore, here we consider interannual variability of Ozone concentrations in the Antarctic and its impacts on SH climate anomalies in the subsequent spring and summer.

Methods

To characterise Antarctic ozone concentrations, we consider three annual time series, obtained from NASA Ozone Watch[1] or computed from data obtained from the KNMI Climate Explorer[2]: Antarctic ozone daily minimum concentration (in Dobson Units, DU), monthly mean ozone concentration in November (in DU) and maximum daily ozone hole area, defined as the surface area (in km^2) south of 40°S with ozone concentrations below 220 DU. To assess the influence of strong non-linear trend that all these series have in the 1980s, we considered both the complete time series since the start of the satellite era (1979) and a reduced series over the period between 1990 and the present. Detrended data show slightly stronger relationships and are consequently displayed in the figures below. To quantify

[1] https://ozonewatch.gsfc.nasa.gov/
[2] http://climexp.knmi.nl/

circulation anomalies in the SH, we used geopotential heights at different levels and 2 metre temperature from ERA-interim Reanalysis (Dee et al. 2011).

Results

Figure 1 shows the correlation between ozone concentration in November and geopotential heights at 30 hPa (in the stratosphere), 200 hPa (in the upper troposphere) and 500 hPa (in the middle troposphere) for the months between October and January. We found that this ozone metric presented a stronger correlation with climate anomalies than the others consider in this study (not shown). The relationship is characterised by positive correlations at the pole, which are most pronounced in spring in the stratosphere, peaking later in December in the upper troposphere. Also, negative correlations are seen at midlatitudes in the stratosphere during October and November while in the troposphere it manifests as a wave-3 pattern at midlatitudes, together with a weak wave-1 pattern at polar latitudes that persist from October until December. In January, significant correlations are seen only at the Pole in the stratosphere and upper troposphere.

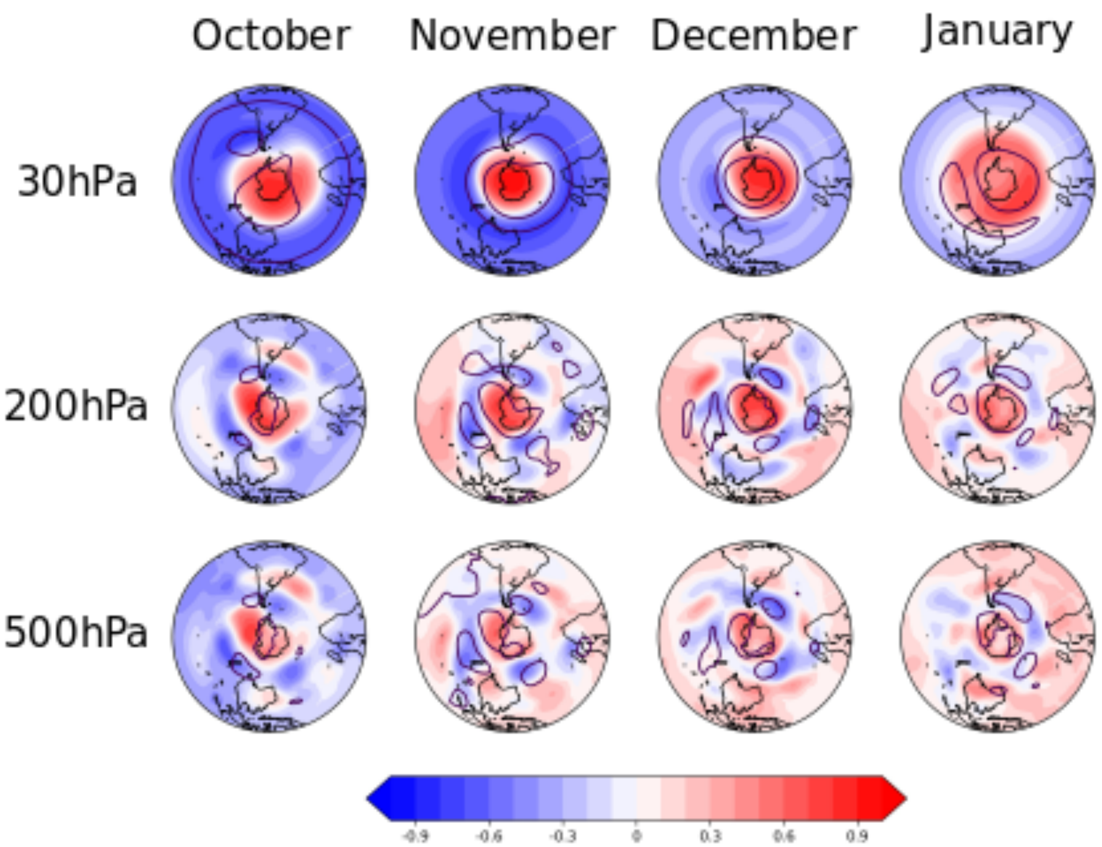

Fig1: Correlations between ozone concentration in November over the Southern Hemisphere polar cap (65-90°S) and Geopotential Heights at 3 0hPa (first row), 200 hPa (second row) and 500 hPa (third row) in October (first column), November (second column), December (third column) and January (fourth column). The thick black line delineates correlations significant at the 95% level.

Figure 1 indicates a relationship between ozone depletion and atmospheric variability that appears reminiscent of the Southern Annular Mode (SAM), the primary mode of SH circulation variability of the SH. Positive trends in SAM, representing poleward migration of the SH westerly wind belt and extratropical storm tracks, has previously been attributed at least in part to ozone depletion (Arblaster and Meehl, 2006; Thompson et al., 2011). To test the hypothesis that variability of ozone is also influential for interannual SAM variability, we compute the correlation between DJF geopotential height anomalies at 500 hPa and November ozone concentration over the SH Polar Cap (65ºS-90ºS) and compare it to the SAM, calculated as the leading empirical orthogonal function of SH extratropical geopotential height at the same level. We used November ozone concentration as it was the only Spring month that showed significant correlation with the DJF geopotential height anomalies. This coincides with the fact that the increase in lower stratospheric radiation, due to ozone, is highest in November (Bandoro et al. 2014). We confirm that the response obtained resembles the SAM structure (see Figure 2). Also, we found that this link is relatively insensitive to the period of record chosen for the analysis (not shown).

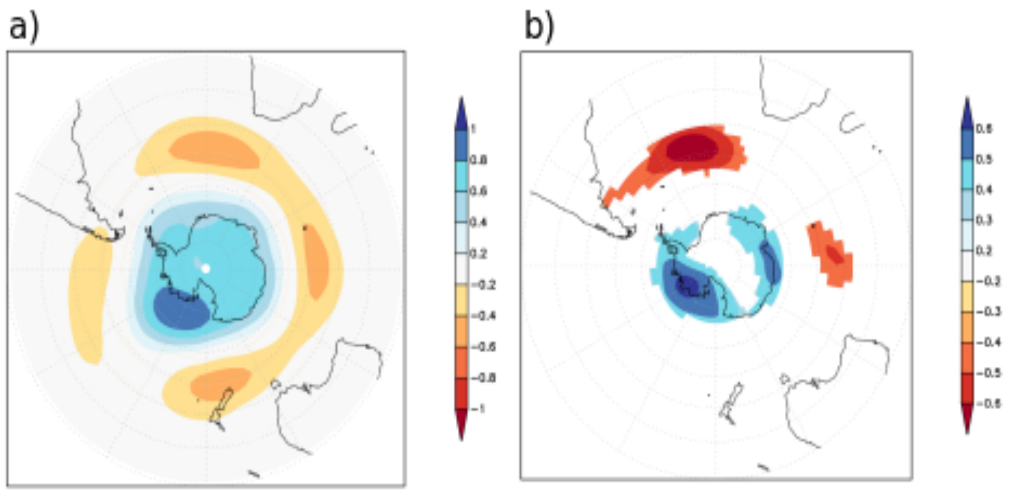

Fig2: Correlations between December-January-February (DJF) Geopotential heights at 500 hPa and a) the Southern Annular Mode (SAM), b) ozone concentration in November over the Southern Hemisphere polar cap. Only correlations significant at the 95% level are shown.

Conclusion

Among the Antarctic ozone metrics considered here, November mean Antarctic total column ozone exhibits the strongest correlation with SH circulation variables. Furthermore, we found a significant relationship between Antarctic ozone interannual variability and subsequent spring/summer variability in the SH stratosphere and troposphere. The signal appears firstly in the stratosphere as a well defined zonal annular mode (closely related to SAM) and then becomes evident in the troposphere, maximizing in December/January. These results suggest that knowledge of Antarctic spring ozone variability could improve predictions of summer climate in the SH (as suggested by Bandoro et al. 2014), although the physical mechanisms driving the correlations found here need to be further explored.

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