Comparison of the Positive and Negative Phases of the Southern Annular Mode (SAM) - *from the Polar Vortex Perspective*

Kelebogile Mathole[1], Pam Harvey[3], Koketso Molepo[2], Annette Nyaga[4], Ridick Ronald Takong[2]

South African Weather Service [1], University of Cape Town [2], University of the Witwatersrand; [4]Kenya Meteorological Office

INTRODUCTION

The presence of the large-scale pattern of variability in the extra-tropical stratosphere and troposphere resembles what is known to be the Southern Annular Mode (SAM, Thomson and Wallace, 2000). This is one of the dominant modes of variability in the southern hemisphere (IPCC, 2017). The Australian Government Bureau of Meteorology describes this mode to be associated with the movement of the westerlies which encircles the Antarctic region and therefore dominates middle to higher latitudes. The mode has provided evidence that the stratosphere can influence the troposphere on both shorter (Baldwin and Dunkerton, 1999) and longer time scales (Thompson and Solomon, 2002; Gillet and Thompson 2003). On timescales of a few weeks to months, anomalous stratospheric circulation during winter has been shown to modify tropospheric circulation patterns, which in turn affect the strength of the middle-latitude storm tracks and their location (Baldwin and Dunkerton, 2001).

Suggestions as to how this dynamical mechanism this downward influence occurs have been raised by several studies (e.g. Polvani and Kushner, 2002; Song and Robinson, 2004; Perlwitz and Harnik, 2004; Kushner and Polvani, 2006), mainly with wave propagation stated to be the fundamental mechanism (Perlwitz and Harnik, 2004). Even though Plumb and Semeniuk (2003) describe the cause of this downward influence, studies using comprehensive idealized models have tried to establish the dynamical insights of this coupling (e.g. Polvani and Kushner, 2002; Kushner and Polvani, 2004; Kushner and Polvani, 2006). The notion is that during periods of downward influence, an anomalous zonal wind circulation pattern perturbed by either planetary waves or external factors tend to appear first in the stratosphere and then propagate down into the troposphere.

Unlike in the troposphere, the SAM index in the stratosphere is a measure for the polar vortex strength (Waugh and Polvani, 2010). The study here uses the SAM index to assess the stratospheric polar vortex strength and the role it could have played during the early days of a strong winter storm (June 2017) over South Africa. During this period, the south western parts (esp. Western Cape) of the country were overwhelmed by an anomalous weather event which resulted in massive storms accompanied by gale force winds, reaching up to 120 km/h (See Fig. 1)

Fig.1: Impacts of the massive storm that took place during the first week of June 2017 in Cape Town, South Africa. Pictures adapted from https://www.westerncape.gov.za/news/situation-report-severe-weather-event-6-%E2%80%93-8-june-2017

DATA AND METHODS

We use the vertical cross sections maps of the geopotential height anomalies provided by the National Oceanic and Atmospheric Administration (NOAA) – Climate Prediction Centre (CPC) and the associated index to assess polar vortex strength. Possible dynamical coupling is also assessed using these cross sections. To demonstrate the possible wave-mean flow interactions, Eliassen-Palm (EP) flux cross section maps are used. These EP flux maps are also provided by the NOAA Earth System Research Laboratory. For this particular demonstration, we focus on the period preceding the event.

RESULTS

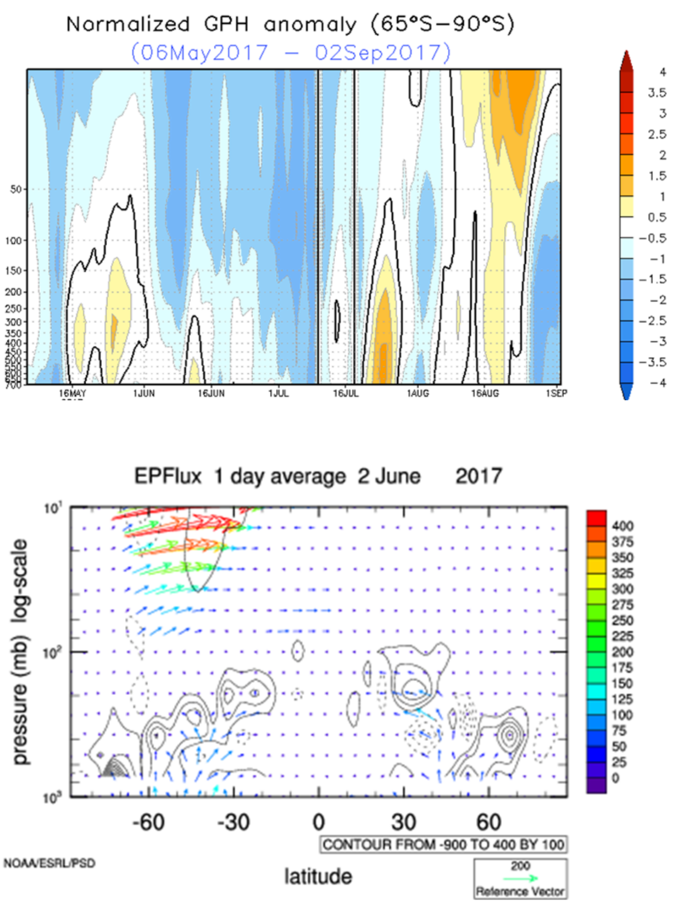

FIG. 2: (top) Time-height vertical cross-sections of geopotential height anomalies averaged at 14 pressure levels over 65-90°S. Blue (red) colours indicate strong (weak) polar vortex in the stratosphere. (bottom) Latitude-height Eliassen – Palm Flux cross section indicating both vectors and divergence contours. Negative (positive) contours indicated by dotted (solid) lines. Figures adapted from:

http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/hgt.aao.cdas.gif

https://www.esrl.noaa.gov/psd/data/epflux/

The vertical cross section of geopotential height anomalies as used here to measure the polar vortex strength in the stratosphere indicates the typical introduction of a winter circulation during austral autumn (Fig. 2, top). This is also confirmation that the stratospheric circulation is starting to change to westerly flow due to hemispheric temperature changes as required by the thermal wind relation (Holton, 2004). However, as much as this circulation gets maintained throughout the winter-spring period, there can be periods when the flow gets weaker (stronger) hence the variability in the stratosphere. This is indicated by the light blue (dark blue) colour (Fig. 2, top) in the stratosphere. While this is the case, it can be seen that the stratospheric flow during the period of May and early June was weakened to some extent. The basic explanation for this weakened flow is confirmed by wave activity which is evident in the lower stratosphere in the EP flux map (Fig. 2, bottom). By referring to the basic interpretation of the EP Flux, it can be seen that not only was there anomalous net propagation of planetary waves (indicated by vectors), but there also a dipole pattern appears, as indicated by the EP flux contours. The negative contour which is indicative of EP flux convergence occurs on the poleward side and therefore we can expect a deceleration of the zonal wind (Painemal, 2007). This further results in interactions of eddies with the mean flow.

A surface response also appears, as indicated by the positive anomalies of geopotential height during this period. This is indicative of the negative SAM and therefore associated with the equatorward shift of storm tracks. At face value, this could also be an indication that the stratosphere was coupled to the troposphere in some way.

CONCLUSIONS AND FUTURE WORK

A simple analysis using different phases of the SAM to diagnose the polar vortex and its possible impact on the surface climate has been conducted. It has been shown that the stratospheric circulation was weakened during the late autumn to early winter. This is the period prior to the anomalous weather event that occurred over the western cape of South Africa. The observed extra-tropical response at the surface could be a hint for an increased chance of frontal activity as the storm track shifts toward the equator. Notwithstanding, research that has been conducted locally has indicated that there is a negative association of SAM and rainfall over South Africa (esp. over the South Western Cape), even on inter-annual timescales (e.g. Reason and Rouault, 2005; Gillet *et al* 2006, Beraki and Landman, 2013).

In general, what this means is that during positive SAM there are fewer storms and cold fronts that reach the south western areas of South Africa, thus winter and spring seasons experience drier conditions (Reason and Rouault, 2005). However, the opposite occurs during the negative phase of SAM. During this phase, the subtropical jet and the westerlies move toward the equator. Stronger depressions occur more frequently and closer to south western South Africa. Frontal systems thus track further north, reaching south western South Africa, bringing rainfall, resulting in wetter conditions.

It is acknowledged that more in-depth and thorough analyses/research is still required to quantitatively confirm the real cause of the June2017 South Western Cape event. Efforts are currently underway to establish such connections.

REFERENCES

Baldwin, M. P. and Dunkerton, T. J. 1999 Propagation of the Arctic Oscillation from the Stratosphere to the Troposphere *J. Geophys. Res.*, **104,** 30937–30946.

Baldwin, M. P., and Dunkerton, T. J, 2001. Stratospheric Harbingers of Anomalous Weather Regimes. Science, Volume 294, pp. 581-584.

Beraki, A. F., and Landman, W, 2013. The role of Southern Annular Mode in a dynamical coupled model, SASAS Conference proceedings, Kwa-Zulu Natal.

Gillet, N.P., and Thompson, D.W.J, 2003. Simulation of recent Southern Hemisphere climate change. Science, Volume 302, p. 273–275.

Haynes, P, 2005. STRATOSPHERIC DYNAMICS. Annu. Rev. Fluid Mech, Volume 37, p. 263.

Holton, J. R, 2004. An introduction to dynamic meteorology. Burlington, MA: Elsevier Academic Press.

Perlwitz, J., and Harnik, N, 2004. Downward Coupling between the Stratosphere and Troposphere: The Relative Roles of Wave and Zonal Mean Processes. J. Clim, Volume 17, pp. 4902-4909.

Polvani, L.M., and Kushner, P.J, 2002: Tropospheric response to stratospheric perturbations in a relatively simple general circulation model. *Geophys. Res. Lett.*, **29**, 14284–14287.

Plumb, R. A., and Semeniuk, K, 2003. Downward migration of extratropical zonal wind anomalies. J. Geophys. Res, Volume 108, pp. doi:10.1029/2002JD002773, D7

Reason, C. J. C. and Rouault. M, 2005. Links between the Antarctic Oscillation and winter rainfall over western South Africa. Geophys. Res. Lett, Volume 32, p. doi:10.1029/2005GL022419.

Song, Y., and Robinson, W. A, 2004. Dynamical Mechanisms for Stratospheric Influences on the Troposphere. J. Atmos. Sci, Volume 61, pp. 1711-1725

Thompson, D. W. J., and Wallace, J. M, 2000. Annular Modes in the Extratropical Circulation. Part I: Month-to-Month Variability. J. Clim, Volume 13, pp. 1000-1016.

Thompson, D., and Solomon, S., 2002: Interpretation of recent Southern Hemisphere climate change, Science, **296,** 895–899.

Waugh, D. W., and Polvani, L. M, 2010. Stratospheric Polar Vortices. Geophys. Mon. Ser, p. doi10.1029/2009GM000887.