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Decreased stratospheric ozone levels contribute towards increased ultraviolet (UV) radiation at the Earth's surface with potential negative impacts on public health. This study sought to determine whether or not the break-up of the polar vortex has an effect on stratospheric ozone levels and the resulting UV-B radiation at Cape Point. Using a dynamical model, it was shown that the polar vortex has a limited effect on ozone levels at Cape Point in September and that tropical air-masses had a larger impact on ozone levels during summer months. Decreased levels of stratospheric ozone resulted in increased UV radiation at the surface.

Keywords: stratospheric-ozone, clear-sky, UV radiation

Introduction

Ozone gas occurs naturally throughout the atmosphere with approximately 90% of all ozone found in the stratosphere. Ozone in the stratosphere absorbs ultraviolet (UV) radiation with a wavelength of 280 – 310 nm (UV-B) (Hegglin et al., 2014). Ozone levels in the atmosphere vary due to natural and anthropogenic factors. Ozone Depleting Substance (ODS's) have caused a decrease in ozone levels around the world (Hegglin et al., 2014). This has resulted in increased levels of UV-B radiation at the surface of the Earth (Herman et al., 1996).

The Antarctic ozone hole forms during the Southern Hemisphere winter due to the unique conditions in the Antarctic atmosphere. The Antarctic ozone hole has a direct impact on ozone levels in the Southern hemisphere (Ajtic´ et al., 2004; de Laat et al., 2010) and atmospheric phenomena such as the Southern Annular Mode (SAM) (Bandoro et al., 2014). Decreases in atmospheric ozone due to the Antarctic ozone hole have led to increased levels of UV-B radiation in Australia, New Zealand and Chile (McKenzie et al., 1999; Gies et al., 2013; Abarca and Casiccia, 2002).

The occurrence of a low-ozone event over Irene, South Africa can be attributed to the transport of both tropical and polar air-masses (Semane et al., 2006). Over South Africa, the Total Ozone Column (TOC) is affected by the seasonal variability of synoptic scale weather systems (Barsby and Diab, 1995).

This paper presents a portion of the analyses and results from a larger study. Presented here, are the outcomes based on the following objectives:1) to identify specific low Stratospheric Column Ozone (SCO) and TOC events over Cape Point during spring and summer seasons; 2) to determine the origin of ozone-poor air-masses during low-ozone events using a dynamical transport model; 3) to determine the subsequent effect of low-ozone events on surface UV-B radiation.

Data and Methods

Daily satellite TOC and SCO data in Dobson Units (DU) for 2007-2016 were obtained for the following grid-area (West: 16.5 °E, South: 36.35 °S, East: 20.6 °E, North: 31.98 °S) over the Cape Peninsula in the Western Cape, South Africa. The Cape Peninsula is affected by a south-easterly wind which transport maritime air from the South Atlantic Ocean (Kruger, et al., 2010). TOC data from the Ozone Monitoring Instrument (OMI) a 0.25° spatial resolution (Levelt, et al., 2006). SCO data from the Microwave Limb Sounder (MLS) provided SCO levels up to the thermal tropopause (Livesey et al., 2017). Both the OMI and MLS are on National Aeronautics and Space Administration (NASA's) Aura satellite (NASA Goddard Space Flight Center, 2006).

The origin of ozone-poor air was determined using the Mesoscale Isentropic Transport Model of Stratospheric Ozone by Advection and Chemistry (Modèle Isentropique du transport Méso-échelle de l'ozone stratosphérique par advection avec CHIMIE or MIMOSA-CHIM). The dynamical component of the model is forced by meteorological variables from the European Centre for Medium-Range Weather Forecasts (ECMWF) daily analyses. The model has a 1° x 1° resolution and isentropic levels from 350 – 950 K (Hauchecorne et al., 2002).

Hourly solar UV-B radiation from the South African Weather Service (SAWS) Cape Point (34.35°S, 18.5°E) weather station given in Minimal Erythemal Dose (MED) units was converted to Standard Erythemal Dose (SED) using Eq. (1). The UV-B radiation was recorded with a Solar Light 501 UV-B Biometer. The biometer has an analog voltage output which is proportional to the amount of radiation received (Solarlight, 2014).

$$SED = MED \times 2.1 \quad (1)$$

where: MED is 210 $J.m^{-2}$ and SED is 100 $J.m^{-2}$

Low-ozone events were only identified on clear-sky days during the spring and summer seasons. Clear-sky days were determined using the method defined by du Preez and Wright (2018). Low-ozone days were determined as days when TOC or SCO levels were one and a half standard deviations (1.5 STD) below the climatological mean

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(Schuch, et al., 2015). The TOC and SCO climatological means as referred to in du Preez and Wright, 2018, were used to determine the low-ozone events.

The MIMOSA-CHIM model was initialised 14-days before each low-ozone event to account for model spin-up and Potential Vorticity (PV) maps were analysed at isentropic levels that correspond to 18 km, 20 km and 24 km above ground level. The lower part of the ozone layer is covered by these heights (Sivakumar and Ogunniyi, 2017). PV can be used to trace ozone-poor air when diabatic and frictional terms are small and PV is conserved on isentropic levels over short time periods (Holton and Hakim, 2013).

The UV-B radiation levels at solar noon on low-ozone days were compared to the UV-B climatology for Cape Point as described by du Preez and Wright, 2018.

Results and Discussion

The summer seasons of 2009/2010 and 2015/2016 are classified as El Niño seasons during which period higher TOC levels are expected over the midlatitude region (Kalicharran et al., 1993). From the identified low-ozone events (Table 1), only one event occurred during an El Niño season.

Table 1. Low-ozone events on clear-sky days at Cape Point during spring and summer months.

Date	*Decrease TOC (%)*	*Decrease SCO (%)*	*Increase SED (%)*
30 Jan 2009	6.1*	10.1*	29.9
6 Feb 2009	5.0*	4.5*	35.0
15 Feb 2009	4.7*	1.9	33.4
28 Feb 2011	4.3*	4.1*	6.4
16 Jan 2012	0.6	5.1*	20.9
8 Feb 2012	3.8*	2.2	29.8
13 Nov 2012	13.3*	13.3	43.8
14 Nov 2012	11.7*	11.1	39.8
6 Sep 2013	12.7*	11.6*	22.5
9 Nov 2013	4.6	13.3*	21.4
1 Sep 2014	9.5*	18.0*	-1.7
2 Sep 2014	14.9*	15.3*	-2.1
9 Sep 2014	6.4*	14.9*	-4.8
11 Jan 2016	-0.3	5.1*	-8.0

*Note: * -Indicates if TOC or SCO was low during event.*

Stratospheric ozone reductions are dominant when TOC and SCO decreases are similar. Tropospheric ozone reductions are dominant when the TOC percentage decrease is high and the SCO percentage decrease low. 1 September 2014 had the largest SCO reduction (18% decrease) (Table 2) with low-ozone events in September mainly due to SCO reductions. Low-ozone events in February months were characterised by dominant decreases in tropospheric ozone.

The low-zone events that occurred during November months resulted in the largest increases in SED levels (~35%) this resulted from a dominant reduction in stratospheric ozone. In a previous study decreases in SCO over southern Australia have resulted in increases in UV-B radiation of 40% (Gies et al., 2013).

The origin of ozone-poor air-masses over Cape Point during low-ozone events was determined using MIMIOSA-CHIM. A low-ozone event during September is used to demonstrate the limited effect of the Antarctic polar vortex on SCO over Cape Point. The low-zone event of 2 September 2014 (Fig. 1) shows the general pattern for September months.

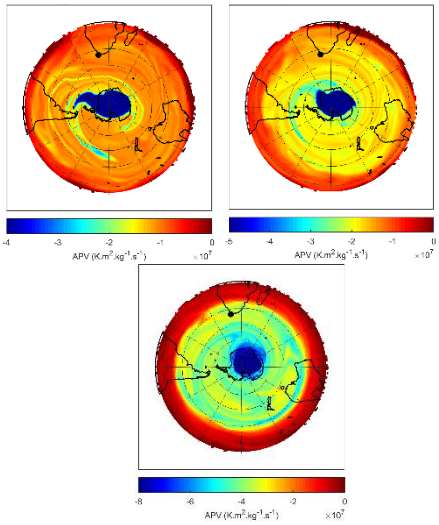

Figure 1. PV maps from MIMOSA-CHIM at 435 K (top left), 485 K (top right) and 600 K (bottom) on 2 September 2014. the

September 2014.

Considering the origin of air-masses during other low-ozone events it was found that Cape Point was affected by air-masses from tropical and polar regions through the distortion of the polar vortex. The effect of tropical air-masses on atmospheric ozone over South Africa has been demonstrated with the isentropic transport across the subtropical barrier (Semane et al., 2006).

Conclusions

This study investigated if the 15 largest low-ozone events (2007-2016) over Cape Point were as a resulted of the break-up of the Antarctic ozone hole during spring and summer.

SCO levels during September were slightly influenced by the Antarctic polar vortex. During September months, air-masses did not move between latitude regions (tropical, midlatitude and polar).Increased UV radiation due to low-ozone resulted in an average increase ~14% over September months.

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References

Abarca, J. F. and Casiccia, C. C. (2002). Skin Cancer and ultraviolet-B radiation under the Antarctic ozone hole: southern Chile, 1987-2000. *Photodermatol Photoimmunology Photomed. 18:* 294-302.

Ajtic´, J.V., Connor, B. J., Lawrence, B. N., Bodeker, G. E., Hoppel, K. W., Rosenfield, J. E. and Heuff, D. N. (2004). Dilution of the Antarctic ozone hole into the southern midlatitudes. *Journal of Geophysical Research. 109:* 1-9. doi:10.1029/2003JD004500.

Bandoro, J., Solomon, S., Donohoe, A., Thompson, D. W. and Santer, B. D. (2014). Influences of the Antarctic Ozone Hole on Southern Hemispheric Summer Climate Change. *Journal of Climate.27*: 6245-6264. doi: 10.1175/JCLI-D-13-00698.1.

Barsby, J. and Diab, R. D. (1995). Total ozone and synoptic weather relationships over southern Africa and surrounding oceans. *Journal of Geophysical Research. 100*: 3023-3032. doi:10.1029/94JD01987.

de Laat, A., van der A, R. J., Allaart, M. F., van Weele, M., Benitez, G. C., Casiccia, C., Paes Leme, N.M., Quel, E., Salvador, J. and Wolfram, E. (2010). Extreme sunbathing: Three weeks of small total O3 columns and high UV radiation over the southern tip of South America during the 2009 Antarctica O3 hole season. *Geophysical Research Letters. 37*: doi:10.1029/2010GL043699.

du Preez, D.J. and Wright, C.Y.(2018). Spring-time ozone and solar ultraviolet radiation variations over the Western Cape, South Africa. *Masters dissertation, University of Pretoria.*

Gies, P., Klekociuk, A., Tully, M., Henderson, S., Javorniczky, J., King, K., Lemus-Deschamps, L. and Makin, J. (2013). Low ozone over southern Australia in August 2011 and its imapct on solar ultraviolet radiation levels. *Photochemistry and Photobiology. 89*: 984-994. doi:10.1111/php.12076.

Hauchecorne, A., Godin, S., Marchand, M., Hesse, B. and Souprayen, C. (2002). Quantification of the transport of chemical constituents from the polar vortex to midlatitudes in the lower stratosphere using the high-resolution advection model MIMOSA and effective diffusivity. *Journal of Geophysical Research. 107*: doi:10.1029/2001JD000491.

Hegglin, M. L., Fahey, D. W., McFarland, M. and Montzka, S. A. (2014). Twenty Questions and Answers About the Ozone Layer: 2014 update. In *Scientific Assessment of Ozone Depletion* (p. 84). Geneva: World Meteoroligcal Organisation.

Herman, J. R., Bhartia, P. K., Ziemke, J., Ahmad, Z. and Larko, D. (1996). UV-B increases (1979-1992) from decreases in total ozone. *Geophysical Research Letter., 23:* 2117-2120. doi:10.1029/96GL01958

Holton, J. R. and Hakim, G. J. (2013). Circulation, Vorticity and potential vorticity. In *An Introduction to dynamic meteorology* (Fifth ed., p. 121). Oxford: Academic Press.

Kalicharran, S., Diab, R. D. and Sokolic, F. (1993). Trends in total ozone over southern African stations between 1979 and 1991. *Geophysical Research letters. 20*: 2877-2880. doi:10.1029/93GL03427.

Kruger, A.C., Goliger, A.M., Retief, J.V., and Sekele, S. (2010). Strong wind climatic zones in South Africa.*Wind and Structures 13.*pp37-55.

Levelt, P. F., van den Oord, G. H., Dobber, M. R., Mälkki, A., Visser, H., de Vries, J., Stammes, P., Lundell, J.O.V. and Saari, H. (2006). The Ozone Monitoring Instrument. *Transcations on Geoscience and remote sensing. 44*: doi:10.1109/TGRS.2006.872333.

Livesey, N. J., Read, W. G., Wagner, P. A., Froidevaux, L., Lambert, A., Manney, G. L., Valle, L.F.M., Pumphrey, H.C., Santee, M.L., Schwartz, M.J., Wang, S., Fuller, R.A., Jarnot, R.F.,knosp, B.W. and Martinez, E. (2017). *The earth observing system (EOS) Aura microwave limb sounder (MLS) Version 4.2xlevel 2 data quality and description document.* Retrieved April 25, 2017, from https://mls.jpl.nasa.gov/data/v4-2_data_quality_document.pdf

McKenzie, R., Connor, B. and Bodeker, G. (1999). Increased Summer time UV radiation in New Zealand in response to ozone loss. *Science. 285:* 1709-1711.

NASA Goddard Space Flight Center. (2006). *Earth Science Reference Handbook : A guide to NASA's Earth science program and Earth observing satellite missions* (Annual ed.). Washington, D.C.: National Aeronautics and Space Administration.

Schuch, A. P., dos Santos, M. B., Lipinski, V. M., Vaz Peres, L., dos Santos, C. P., Cechin, S. Z., Schuch, N.j., Pinheiro, D.K. and da Silva Loreto, E. L. (2015). Identification of influential events concerning the Antarctic ozone hole over southern Brazil and the biological effects induced by UVB and UVA radiation in an endemic treefrog species. *Ecotoxicology and Environmental Safety. 118*: 190-198.http://dx.doi.org/10.1016/j.ecoenv.2015.04.029.

Semane, N., Bencherif, H., Morel, B., Hauchecorne, A. and Diab, R. D. (2006). An unusual stratospheric ozone decrease in the southern hemisphere subtropics linked to isentropic air-mass transport as observed over Irene(25.5°S, 28.1°E) in mid-May 2002. *Atmos. Chem. Phys. 6*: 1927-1936.

Sivakumar, V. and Ogunniyi, J. (2017). Ozone climatology and variablity over Irene, South Africa detrermined by ground based and satellite observations. Part 1: Vertical variations in the troposphere and stratopshere. *Atmosfera*. *30:* 337-353.

Solarlight. (2014). *Solar Light.* Retrieved January 23, 2017, from http://solarlight.com/wp-content/uploads/2015/01/Meters_Model-501-.pdf