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Impacts of the antartic ozone hole influence events over southern Brazil in October 2015

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Abstract: The impact of the Antarctic Ozone Hole Influence over Southern Brazil in October 2015 was analyzed using daily mean data of the Total Column Ozone (TCO), Ultraviolet Index (UVI) and Radiative Cloud Fraction (RCF) from the Ozone Monitoring Instrument satellite instrument. Vertical profiles and fields of ozone content and Potential Vorticity available from the European Centre for Medium-Range Weather Forecast reanalysis, air masses backward trajectories from the HYbrid Single-Particle Lagrangian Integrated Trajectory model and channel 3 water vapor images from the Geostationary Operational Environmental Satellite GOES-13 were also analyzed. The five identified events showed an -7.4±2.3% average TCO reduction, leading to an +16.6±54.6% UVI increase even with a predominance of partly cloudy days. Other impacts were observed in the ozone profiles, where the most significant anomalies occurred from 650 K reaching 1.2 ppmv at the 850 K level. In the ozone fields at 700 K, the presence of a polar origin tongue was observed causing negatives anomalies between -0.2 and 0.4 ppmv in a transient system format forced with eastward-traveling Rossby waves passing through the Southern of Brazil and Uruguay.

Key words: Antarctic Ozone Hole, Southern Brazil, potential vorticity, UV index.

INTRODUCTION

Located approximately between 15 km and 35 km altitude (London 1985), is in the “ozone layer” that photochemical and dynamic processes occur, protecting the Earth and make life possible as it is today (Salby 1996). In the mid-1980s, a massive ozone depletion was discovered during the southern spring over the Antarctic region (Farman et al. 1985), which became known as the “Antarctic Ozone Hole” (Solomon 1999).

The, solar ultraviolet radiation (UVR), corresponds in the electromagnetic spectrum wavelengths from 100 to 400 nm is divided into three groups: UVC (100-280 nm), UVB (280-315 nm) and UVA (315-400 nm) (Liou. 2002; ICNIRP, 2004), being the first completely absorbed in the in the stratospheric ozone layer (Dessler 2000). The UVA type contributes to the synthesis of vitamins (McKenzie et al. 2009), but in excess it can be highly harmful (Oliveira 2014), as well as the type B (UVB), harmful to single-celled organisms and superficial cells of plants and animals, also being partly filtered in the stratosphere (Corrêa 2015). Thus, the UVR is now seen as a public health issue, where different nations carry out actions aimed at reeducating habits of exposure of populations to the sun (WMO 2002).

The ultraviolet index (UVI) has become a measure for determining the intensity of UVR, first used in Canada in 1992, then adopted as a standard indicator of UVR levels by the World Meteorological Organization (WMO) and the World Health Organization (WHO) in 1994. The total amount of ozone in the atmosphere, cloud cover, snow reflectance, local pollution, and sunrise are the conditions that affect UVI according to a study by Fioletov (2010). Research published by Kirchhoff et al. (2000), Rodriguez (2017) and Sánchez-Pérez et al. (2019) also highlight the importance of this index in cases of sunburn, photodermatoses and even skin cancer, making it possible to determine the sun exposure for each type of skin without suffering strong damage, which can in the long term bring greater effects.

Studies by Kirchhoff et al. (1996) identified from atmospheric balloons (ozone sondes) and surface instruments, such as the Brewer spectrophotometer, that ozone-poor air masses can by ejected from the Antarctic Ozone Hole region (Farman et al. 1985, Solomon 1999, Hassler et al. 2011) and reach mid-latitude regions such as Southern Brazil, in a phenomenon known as the "Antarctic Ozone Hole Secondary Effect" (Pinheiro et al. 2011). This type of phenomenon occurs due to the end of the polar winter, when the increase in temperature causes stratospheric warming and destabilizes the polar vortex, causing an increase in the activity of planetary waves and a break in the Rossby wave (Ndarana et al. 2012), and with that, ejections of these ozone-poor air masses out of the polar vortex, in the form of towards the equator filaments (Schoeberl 1988).

Several studies on a regional scale have begun to observe the occurrence of the Antarctic Ozone Hole Influence events over Southern Brazil, motivated by studies on the air masses isentropic transport in the lower stratosphere and your ability to determine the ozone content in different regions of the planet (Portafaix et al. 2003, Semane et al. 2006, Gettelman et al. 2011). Between 2008 and 2012, was identified fourteen this type events, with an average reduction of 9.3 ±2.9% in the TCO (Pinheiro et al. 2011, 2012, Peres et al. 2016). In addition, this events type is one of the explanations for the amphibian species decline over the Southern Brazil (Schuch et al. 2015) and Steffenel et al. (2016) detected these events using Pervasive Computing in order to carry out alerts about the ozone reductions that cause increases in UV radiation.

Dias Nunes et al. (2020), analyzed the impact of ozone content on UVR variability in South America between 2005 and 2014. This analysis proved that only low ozone levels are not determinant for high UVR values. This inverse correlation being seasonally dependent and more intense between July and October over large areas of South America. Cloud cover stands out among the factors that also influence in UVR quantities over South America. This helping to explain the differences between observations obtained by satellite equipment and reconstructed by models using measurements from ground equipment over Chile (Damiani et al. 2014) and the observed UVR attenuation on stations in Peru compared to those compared to numerical simulations carried out for clear sky conditions (Yamamoto et al. 2018).

Peres et al. (2017) analyzed the climate variability in total column ozone (TCO) measurements obtained by Brewer Spectrometer, and Total Ozone Mapping Spectrometer (TOMS) and Ozone Monitoring Instrument (OMI) satellite instruments between 1992 and 2014 over southern Brazil. Seasonal variability presents a minimum in April and a maximum in September and the Quasi-Biennial Oscillation (QBO) is the main mode of interannual variability. This work served as a climatological basis for works such as Bresciani et al. (2018), that using a multi-instrumental and air parcel trajectories from

HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) model analysis to observe a large area of critical ozone depletion over Rio Grande do Sul and Uruguay in mid-October 2016. Bittencourt et al. (2018) also used this climatological basis and model trajectories analysis to identified that this event was the most intense recorded in the last 20 years and carried out an analysis of the tropospheric and stratospheric dynamics around your occurrence period.

The long-term monitoring of this phenomenon type conducted by Peres et al. (2019) covered the period between 1979 and 2013 and identified the occurrence of 62 events with -9.35 ± 2.93 % of average reduction in ozone content. Such events were caused by anomalies in the potential vorticity, wind and temperature fields at isentropic levels of the stratosphere, where the observed wave displacement observed in Potential Vorticity (PV) fields, is within of cyclonic circulation area and with predominantly southern winds. The motivation for the present work is that, for the year 2015, events of Influence of the Antarctic Ozone Hole over Southern of Brazil have not yet been identified. The year 2015 have a gap in the identification of this events. Thus, the present work aims to identify and characterize the Influence of the Antarctic Ozone Hole over Southern of Brazil events that occurred in October 2015 and thus collaborate to analyze the impacts in terms of the ozone depletion in multilevels and the ultraviolet index.

MATERIALS AND METHODS

In this work, Total Column Ozone (TCO), Ultraviolet index (UVI) and Radiative Cloud Fraction (RCF) daily data were obtained from the Ozone Monitoring Instrument (OMI) sensor, that was launched in July 2004 aboard NASA (National Aeronautics and Space Administration) AURA satellite to continued the TOMS (Total Ozone Mapping Spectrometer) instrument recordings that ended yours activities in 2005. The OMI instrument employs hyperspectral imaging in a scanning mode to observe backscattered solar radiation in the electromagnetic spectrum ranges between 0.270nm to 0.314nm and 0.306nm to 0.380nm. The hyperspectral capabilities improve the accuracy of TCO measures and allow radiometric self-calibration of precise and long term wavelengths (Levelt et al. 2006).

The daily TCO, UVI and RCF data acquisition was performed for the central region of the state of Rio Grande do Sul, on a 1° x 1° latitude / longitude grid, comprising the surroundings of the Santa Maria city (29.72°S; 53.72°O), as shown in Figure 1. The satellite passage is close to local midday and corresponding to days with all sky conditions, so not only clear sky days. Both the daily TCO (OMTO3d v003 product), UVI (OMUVBd v003 product) and RCF(OMTO3d v003 product) data are available on the NASA Giovanni platform (Acker & Leptoukh 2007), which is an online environment for visualization and preliminary analysis of geophysical parameters and data download (https://giovanni.gsfc.nasa.gov/giovanni/).

The identification of the Antarctic Ozone Hole Influence events over Southern Brazil start in select days in which the value of TCO was below the value of the mean minus 1.5 of its respective standard deviation in the month of October 2015, following the criterion detailed by Peres et al. (2019). For this, the climatology of the TCO between 1992 and 2014 calculated by Peres et al. (2017) was used, being 290.2 DU (Dobson Unit) the october climatological value, 8.8 DU its respective standard deviation and 277.0 DU the threshold value of climatological mean minus 1.5 of the standard deviation. In addition, the evolution of UVI and RFC daily data were also

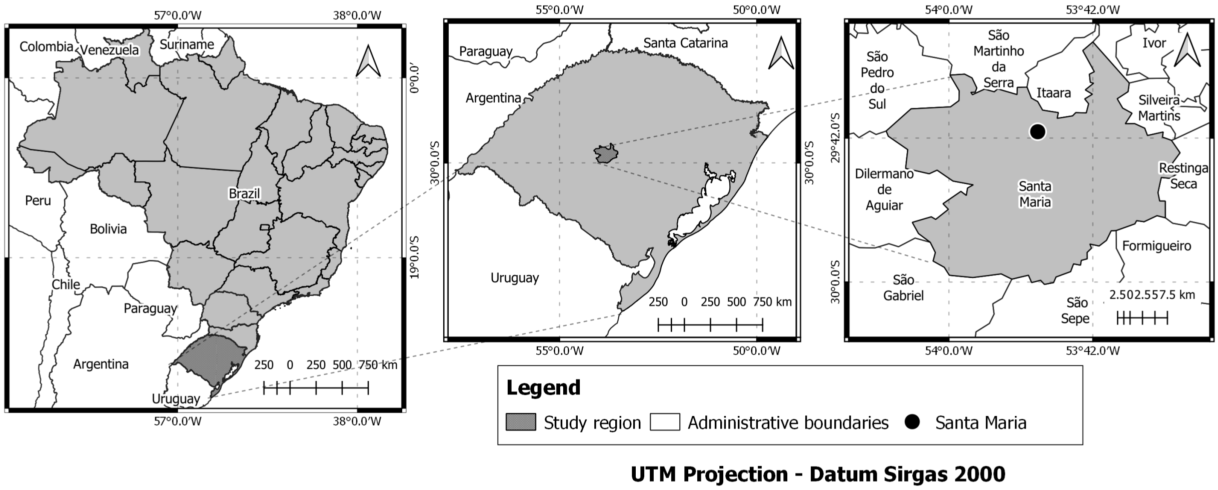

Figure 1. **Santa Maria city location, in the central area of Rio Grande do Sul State, Brazil.**

analyzed in order to verify our impact during the mentioned TCO reductions.

For the selected TCO reduction days, an stratospheric dynamics analysis was performed from meteorological fields of Potential Vorticity (PV), wind magnitude (u and v) and Ozone mass mixing ratio, obtained for 15 potential temperature levels between 265 and 850 Kelvin, as similary used by Dos Reis et al. (2021) in identifying the Antarctic Ozone Hole Influence events over Southern Brazil. The ERA-Interim Pressure and Isentropic (Theta) Levels in Relation to a Standard Atmosphere can be verified in https://rda.ucar.edu/datasets/ds627.1/docs/Pressure_and_isentropic_levels/, as a function of the potential temperature equation, showing that the maximum in the ozone layer occurs at 25Km or 25.492 hPa or 634.5K. These meteorological fields are provided by ERA - Interim reanalysis from European Centre for Medium-Range Weather Forecast (ECMWF), detailed in Dee et al. (2011), for a 1.0°x1.0° latitude / longitude resolution grid.

This stratospheric dynamics analysis starts with the observation of the ozone vertical profiles, comparing the 1986 to 2015 October average ozone profile with the daily average ozone profiles and respective anomaly calculations (1986 to 2015 October average ozone profile minus daily average ozone profile), in order to verify the height at this ozone reductions occur. At the height of observed ozone reduction, PV fields from the previous days for the day in question were analyzed in order to determine the origin of the stratospheric air masses that caused such reductions, similar to that performed by Bittencourt et al. (2018, 2019), in accordance with described in Semane et al. (2006), where a stratospheric air mass has a polar origin when a reduction in PV values is verified.

Complementing this analysis, the ozone mass mixing ratio fields from ERA - Interim reanalysis and air masses back trajectories obtained by the HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) model (Rolph et al. 2017) were also analyzed in order to confirm the air masses polar origin that caused the observed ozone reductions, thus determining the occurrence of the Antarctic Ozone Hole Influence events over Southern Brazil, according to Bresciani et al. (2018).

In order to verify the presence and type of cloudiness and your impact on the observed UVI value, channel 3 water vapor images from the Geostationary Operational Environmental Satellite GOES-13, obtained from the Satellites and Environmental Systems Division of the Center for Weather Forecasting and Climate Studies (CPTEC / INPE 2021) were also analyzed.

Finally, the impact of the October 2015 occurrence events was quantified in relation to the 1986 to 2015 October period behavior average. For this, the average ozone profile for this period (1986 to 2015) was compared with the average ozone profile of the days considered to be events in October 2015 and the difference between them was calculated, presenting the preferred levels of ozone reduction. In these levels, the ozone average fields of the period 1986 to 2015, average ozone field of the events and the anomaly (Wilks 2011) between these were analyzed.

RESULTS AND DISCUSSION

The daily TCO, UVI and RCF data for October 2015 are presented in the Figure 2. In function your 114° viewing angle range of the telescope, that corresponds to a 2600 km wide swath on the Earth's surface (Levelt et al. 2018), OMI measurements can present systematic observed gaps as observad in Figure 2. The OMI satellite daily TCO values (blue) and the -1, 5σ (277 DU) threshold value (black starred line) for October 2015 are presented in the Figure 2a. From thirty-one days, sixteen (51.6%), were observed below the -1.5σ threshold, being considered of TCO reduction, which were verified by the ozone profiles and atmospheric dynamics analysis in order to search of the Antarctic Ozone Hole Influence events over southern Brazil. The search for days in which the TCO was below the -1.5σ threshold resulted in the identification of two Antarctic Ozone Hole Influence events over southern Brazil in 2012 by Peres et al. (2016), 62 events in the 1979 to 2013 period by Peres et al. (2019) including the major event in October 20, 2016, by Bittencourt et al. (2018), which caused 23% TCO reduction.

In the Figure 2b, the daily UVI values (blue) and the 7.6 UVI October 2015 average value (black starred line) are presented. It is observed

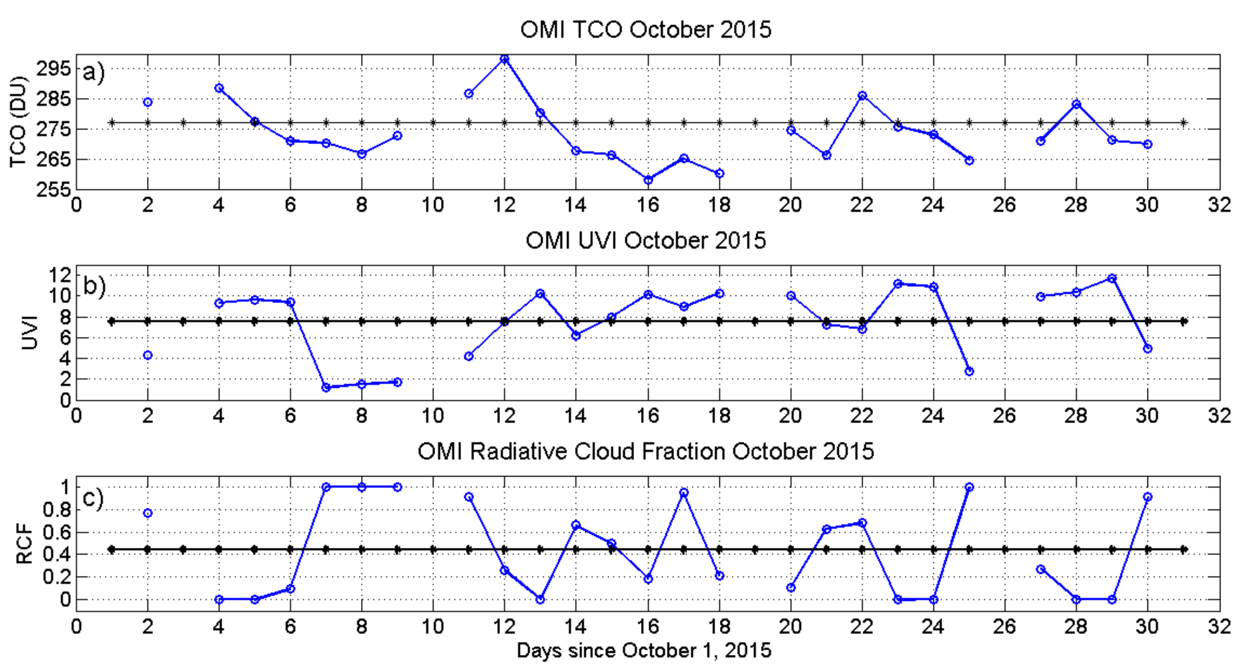

Figure 2. (a): Daily TCO values (blue) and the -1.5σ threshold value(black starred line). (b) Daily UVI values (bleu) and UVI October 2015 average (starred black line). (c) Daily RCF values (bleu) and RCF October 2015 average (starred black line).

that 45.2 % of the days were above the referred monthly average.Analyzes over Southern Brazil detected that 1% ozone variations can cause 0.94% to 1.36% UV variations Guarnieri et al. (2004), being this type of correlation already well established as mentioned by Calbó et al. (2005). The Figure 2c present the dayly RCF values (blue) and the 0.44 RCF October 2015 average value (black starred line), on what 38.7 % of the days were above this monthly average. Since clouds can exert great influence on UV radiation, how to reduce its transmittance by 81% in high clouds conditions over Argentina (Cede et al. 2002), analyzing your occurrence as a function of ozone depletion events and UV variations becomes important.

The October 29, 2015, stands out in this analysis for having 271.1 DU TCO value, representing a 7.1% ozone reduction in relation to the 290.2 DU October climatological value (Peres et al. 2017), the highest UVI value (11.8) for October 2015, representing +53.9 UVI increase and resent clear sky (0 RCF) condition. The sum of these factors makes this event the best example to demonstrate the methodology used to identify the influence of the Antarctic Ozone Hole over Southern Brazil in october 2015.

The vertical ozone profile for the present day (red line), obtained from the ECMWF ERA - Interim reanalysis, was compared whit 1986 to 2015 october average ozone profile (black line) in order to verify what level occour the major ozone reduction (Figure 3a), by calculating the anomaly between them (Figure 3b) .

Was observed in the Figure 3a, that on average, the highest values begin to occur from the 450 K potential temperature level, when they begin to exceed 2 ppmv, reaching their maximum at 850 K when it reaches nearly 9 ppmv. These values are in agreement with the mean values observed for 30°S latitude by Davis et al. (2017), using SPARC (Stratosphere-troposphere

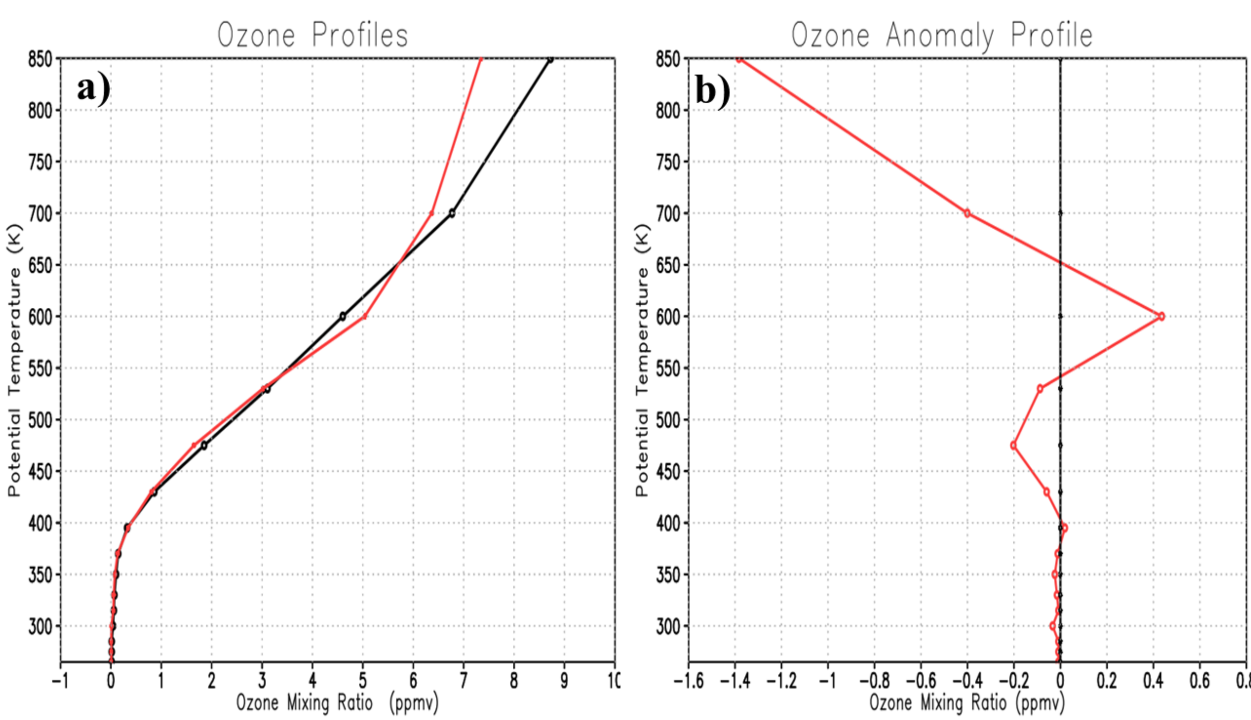

Figure 3. (a) 1986 to 2015 october average ozone profile (black line) and October 29, 2015 ozone profile (red line). (b) October 29, 2015 ozone anomaly profile (red line) relative to zero (black line). Both obtained from the ECMWF ERA-INTERIM Reanalysis in ppmv.

Processes and their Role in Climate) Reanalysis data sets. From 650 K potential temperature level to up, ozone reductions were identified, region where the October 29, 2015 ozone profile (red line) has values below of the 1986 to 2015 october average ozone profile (black line). In order to quantify this reduction, the anomaly between them was calculated (Figure 3b) and no significant anomalies are observed from initial to around 400 K potential temperature levels. Between 400 and 500 K levels, ~0.2 ppmv negative anomalies are observed and more than 0.4 ppmv positive anomaly is observed in 600 K level.

These levels are in contrast with the levels above 600 K, where intense ozone reductions are evident, with a maximum negative anomaly close to 1.4 ppmv at 850 K level are observed. From the 700K potential temperature level, approximately 24 km and the average ozone layer level at mid-latitudes (Solomon 1999), the potential vorticity maps were analyzed in order to performe the dynamics analysis and verify the origin of the air masse that caused this ozone reduction (Figure 4). The 700K potential temperature level is often used in studies about ozone isentropic transporte by atmospheric dynamics as performed by Portafaix et al. (2003) and Semane et al. (2006) in the stratospheric South Hemisphere.

With the beginning of SH winter, increase the stratospheric circumpolar winds speed, delineating the barrier between polar and mid-latitude air called “Polar Vortex”(Mizuta & Yoden 2001) with your edge positioned around 60°S (Joseph & Legras 2002). The area of the Antarctic Ozone Hole is characterized by the polar vortex edge positioning (Shepherd 2007), which is determined by the high potential vorticity gradient region (Nash et al. 1996, Serra & Haller 2017). Air masses advection processes, induced by planetary Rossby waves (McIntyre & Palmer 1984), can result in polar filaments, which detach from the edge of the polar vortex

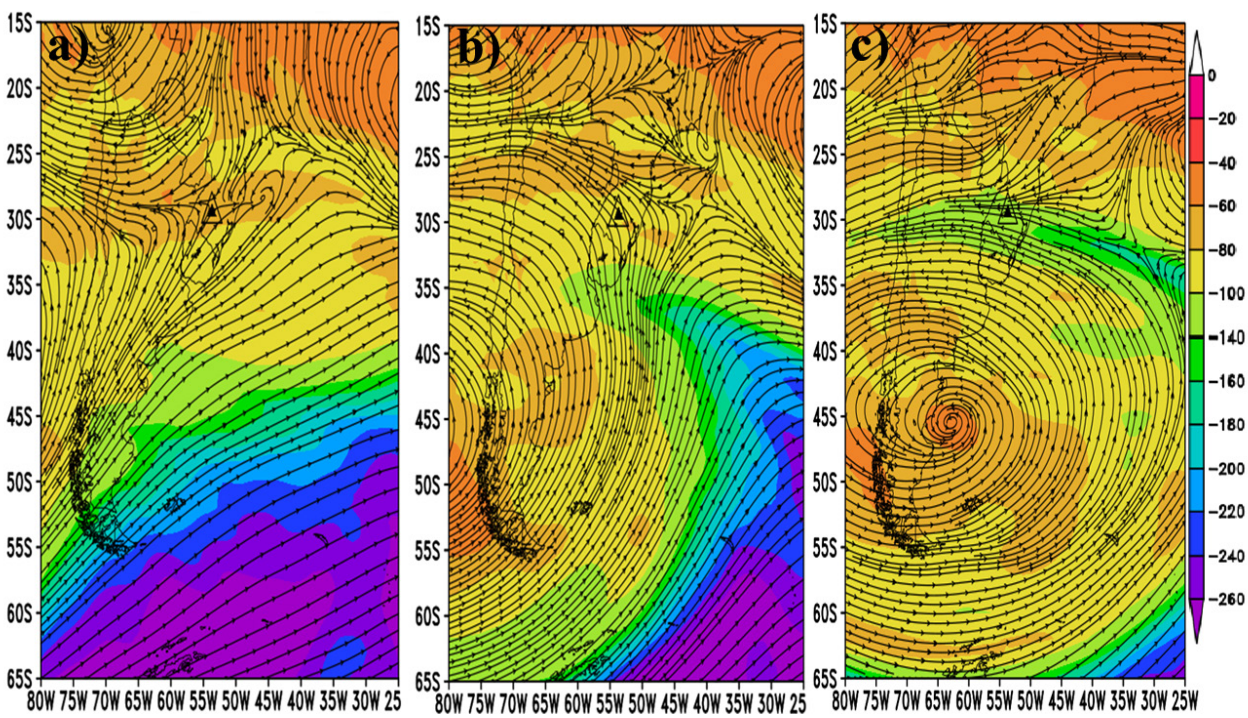

Figure 4. Potential Vorticity and wind fields in 700 K isentropic potential temperature level signaling the air masses stratosphereric dynamics from October 27 (a), 28 (b) and 29 (c), 2015 at 12 UTC.

and reach mid-latitudes and reduce the ozone content over these regions (Schoeberl et al. 1995).

So, in order to diagnose the stratosphereric dynamics that caused these observed ozone reduction, the 700K PV maps from October 27 to 29, 2015 where analised in Figure 4. In October 27, 2015 (a), was observed a zonal behavior of PV, with values between -60 and -80 PVU over the central region of the Rio Grande do Sul state (marked with a triangle). The polar origin air masses advection starts to be observed over the Uruguay in October 28, 2015 (b), with lower PV values is inside an elongated system as a cyclonic circulation tongue. Southern Brazil begins suffer advection from prevailing southerly winds, reducing their PV values to -80 to -100 PVU.

On October 29, 2015 (c), arrive the polar origin air mass over Southern Brazil on the rear of the cyclonic circulation system, carried by an amplification of anticyclonic circulation system. Thus, the stratospheric fields indicated a PV decrease that reach values between -100 to -120 PVU in the 700 K level of potential temperature, evidencing the polar origin of the air mass in a manner analogous to that verified by Leblanc et al. (2004), that identified large transient displacements of stratospheric air masses causing ozone variability through advection analysis in potential vorticity fields at isentropic levels, accompanied by Rossby wave breaking events.

High degree of correlation between PV and ozone that can be observed from 340 to above 700 K isentropic level, responsible for negative/positive ozone deviations coincident with transport from regions with climatologically low/high ozone values (Koch et al. 2002). Similar behavior of a transient system, whit alternation of wind dynamic system from a cyclonic circulation to an anticyclonic circulation system, preferentially coming from the south, transported polar origem lower PV and ozone values over Southern Brazil over the 700 K isentropic level as observed in the Figures 4 and 5.

Similar to the PV field in Figure 4, the 700K ozone field and the NOAA's HYSPLIT model backward trajectory at the 20, 24 and 26 km heights in the Figure 5, presents an air masses polar origin advection process that reduced the ozone content over southern Brazil. In October 27, 2015 (a) and (d), a zonal behavior of air masses over Southern Brazil is observed, with 7 to 6.65 ppmv ozone values. A polar tongue air mass is observed in the 700K ozone field over de Uruguay in October 28, 2015 (b), which begins to impact the ozone content over the Santa Maria region, reducing it to between 6.65 and 6.3 ppmv. However for that day, the HYSPLIT backward trajectory (e) still not point to the air mass passing inside the polar circle.

The southern air mass advection process continues and in October 29, 2015 (c) the polar tongue reaching Southern Brazil. This causes the ozone depletion to 6.3 and 5.95 ppmv and is evidenced that the air mass pass over the polar circle in the HYSPLIT backward trajectory (f), configuring the occurrence of Influence of the Antarctic Ozone Hole over Southern Brazil in this date, similarly to observed by Bresciani et al. (2018) and Bittencourt et al. (2018) for other events of this type. These strengthening of ridge-related to negative PV and ozone anomalies in stratospheric levels is associated with Rossby wave breaking events, here diabatic heating reduces the static stability near the tropopause and contributes to this process (Zhang & Wang 2018).

The present ozone reductions observed in the Antarctic Ozone Hole Influence event over Southern Brazil on October 29, 2015 also presented an 11.7 UVI value, representing a

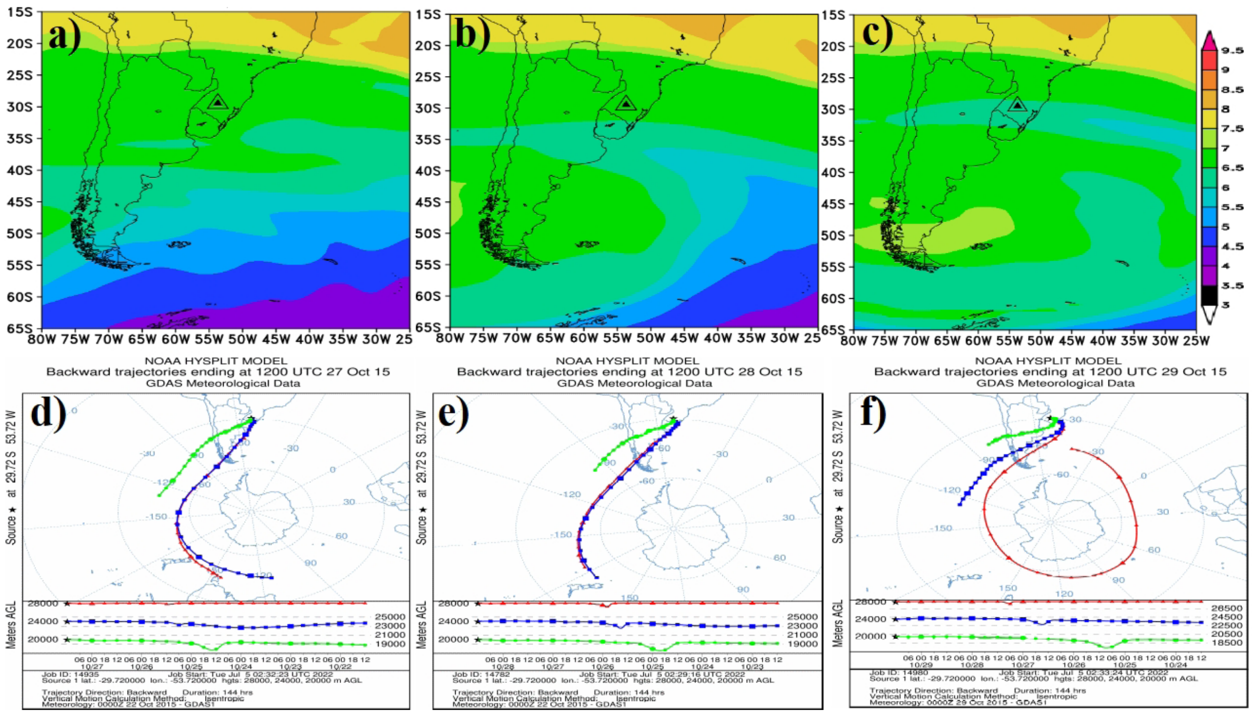

Figure 5. Era Interin 700 K daily ozone average fields (in ppmv) and NOAA's HYSPLIT model air masses backward trajectory for October 27 (a and d), 28 (b and e) and 29 (c and f) at 12 UTC.

53.9% increase in relation to 7.6 UVI October 2015 average value. This IUV value is considered very high according to the criteria of the World Health Organization (WHO 2002), which recommends extra protection to the population, such as avoiding being outdoors during the midday, seeking shade and essential use of long sleeve shirt, sunscreen and cap. This high observed UVI value was favored due to clear sky condition in this day, verified by 0 RCF value and in the channel 3 water vapor images from the Geostationary Operational Environmental Satellite GOES-13 (Figure 6), in both hours of high brightness of the day as 12 UTC (a), 15 UTC, (b) and 18 UTC (c), not attenuating the present radiation that reached the surface in the central region of the Rio Grande do Sul state.

Analyzing this sequence of satellite images in Figure 6, it is possible to observe that the synoptic characteristics in October 29, 2015 points to a stable post-frontal air mass acting over southern Brazil, without significant cloudiness. This is related to the presence of subsidence region of the polar jet and the post-frontal high pressure system, which advects cold air, that discouraging the cloudiness formation over this region. This postfrontal synoptic condition pattern has already been observed by Peres et al. 2011 and 2014 in other events of Influence of the Antarctic Ozone Hole over Southern Brazil in 2008 and 2012 respectively.

Table I shows all five events of Influence of the Antarctic Ozone Hole over Southern Brazil in October 2015. On average, this events presented 258.7±6.6 DU TCO values, 7.4±2.3% ozone rediction in relation to October climatological value, 8.8±4.1 UVI value that representing 16.6% UVI increases in relation to 2015 October average and 0.25±0.42 RCF value, representing that on average the events occur on partially cloudy days.

The cloudiness analysis in each event is presented and observed that clear sky days (0 RCF) predominates in both events with the

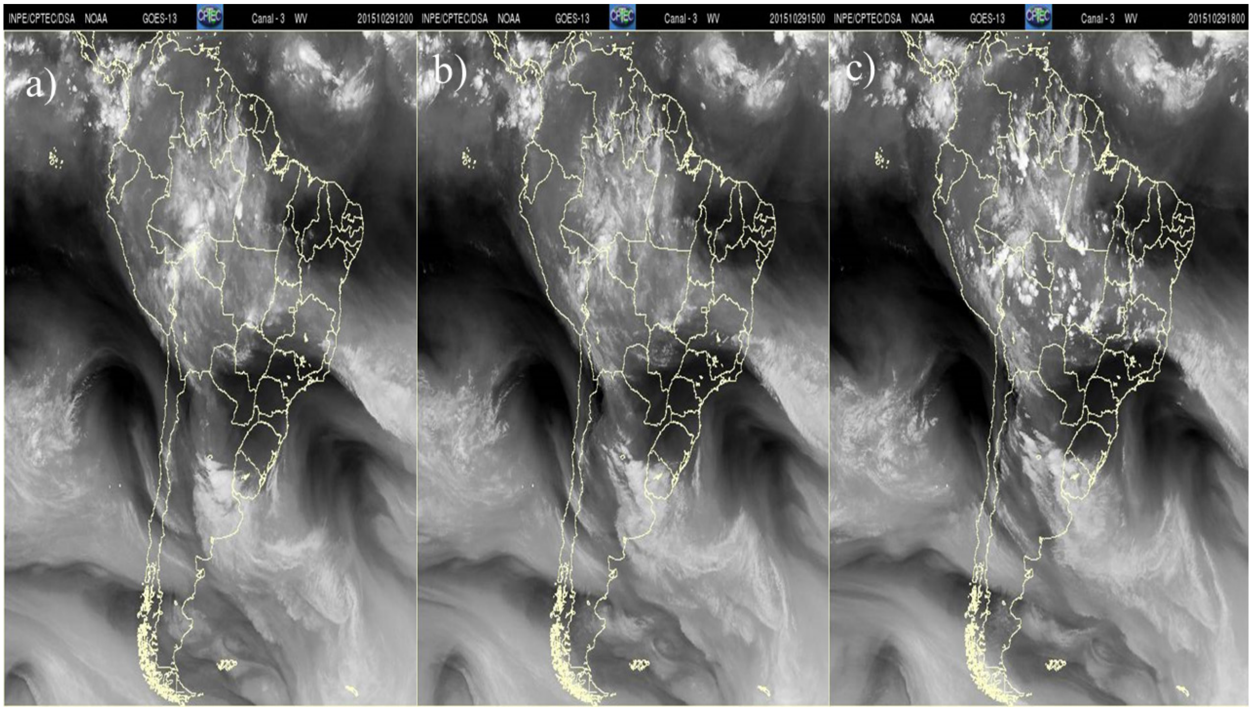

Figure 6. Channel 3 Water vapor images from the Geostationary Operational Environmental Satellite GOES-13 of the Environmental Satellites and Systems Division of the Center for Weather Forecasting and Climate Studies for 12 UTC (a), 15 UTC, (b) and 18 UTC (c) on October 29, 2015.

highest UVI value in October 29 (11.7 UVI and +53.9% UVI variation) and 24 (10.9 UVI and +43.4% UVI variation) 2015, despite ozone reductions in relation to october climatology are not as deep, -6.54% and 5.89% respectively. Partly Cloudy events as in October 16 and 20, 2015 showed the same 10.1 UVI values despite of different ozone reductions (-11.1% and -5.37%) and cloud cover (0.18 and 0.11 RCF). October 8, 2015, showed Cloudy sky condition (1 RCF), resulting in low UVI value (1.53) despite relatively deep ozone depletion (-8.1%).

In 37 events of Influence of the Antarctic Ozone Hole over Southern Brazil investigated by Bittencourt et al. (2019), the atmospheric behavior was predominant with 70% of cases occurring after the passage of frontal systems and 92 % occurred in the presence of the subtropical and/or polar jet stream over the region of study. However, even if the passage of ozone-poor air masses can cause increase in UV radiation to in relation to expected for a specific time of year, factors such as aerosols and clouds can cause decrease these levels (Palancar & Toselli 2004, Utrillas et al. 2018), corroborating with the results found in this analysis.

The effect of cloudiness on ultraviolet radiation has been subject of several studies and helps to explain the results found here. Mayer et al. (1998) found experimental and theoretical evidence explaining the UV radiation increase due to multiple scattering in clouds, showing that the paths of photons in clouds can be increased by a factor of 10 compared to the cloudless sky, this finding being of great importance in remote sensing applications that take advantage of the measurement of scattered radiation to infer the abundance of atmospheric trace gases. Cumulus clouds, common in frontal systems, can cause not only deep drops, but also remarkable increases in radiation levels, which constitute the so-called broken cloud

Table I. **Antarctic Ozone Hole Influence events over Southern Brazil in October 2015. Daily average TCO value, percentage of the TCO variation from the October climatological average, daily UVI value, the percentage of UVI variation from the October 2015 average, daily RCF value and cloudness.**

Events	TCO (UD)	Var TCO (%)	UVI	Var UVI (%)	RCF	Cloudness
08/10/2015	266.7	-8.1	1.53	-79.8	1	Cloudy sky
16/10/2015	258.1	-11.1	10.1	+32.9	0.18	Partly Cloudy
20/10/2015	274.6	-5.37	10.1	+32.9	0.11	Partly Cloud
24/10/2015	273.1	-5.89	10.9	+43.4	0	Clear sky
29/10/2015	271.2	-6.54	11.7	+53.9	0	Clear sky
Mean	258.7±6.6	-7.4±2.3	8.8±4.1	16.6±54.6	0.25±0.42	Partly Cloud

effect, in function that fragmented clouds are often brighter, leading to a radiation gain. (Nack & Green 1974).

Even in high places like Peru, where clear sky conditions register high UVI values, adverse weather conditions such as strong presence of clouds and precipitation, which block part of the solar radiation mainly in summer and autumn, with the highest UVI average only in winter where it presents less cloudiness (Yamamoto et al. 2018). Feister et al. (2015) point out that the scattering of solar radiation from clouds can affect the surface energy balance and obtain solar energy gains for power generation. In addition, in the ultraviolet region, cloudiness can cause an damage increased risk to living organisms, and the role of clouds is the main atmospheric agent that causes UVR variability (McKenzie et al. 2007). They are more transparent to UVR than to visible radiation (400 to 780 nm) meaning that their presence, even covering 100% of the sky, is not a guarantee of no harmless radiation levels (Seckmeyer et al. 1996).

Clouds generally reduce surface UV irradiances, although the magnitude of this effect is highly variable depending on cloud amount and coverage, cloud cell morphology, particle size distributions and phase (water droplets and ice crystals), and possible in-cloud absorbers (especially tropospheric ozone). It is useful to note that under some conditions, UV irradiances can be higher than for clear sky, as for example when both direct sunlight and light scattered by clouds reach the observer (Madronicha et al. 1998). Jesus (2015) found that UV radiation in the presence of clouds interacts as follows: When clouds are optically thin, it transforms direct irradiance into diffuse irradiance. When clouds are thicker, multiple scattering stands out, extinguishing surface irradiances and increasing upward radiances.

In order to quantify the impact of the Antarctic Ozone Hole influence on ozone profile over Southern Brazil in relation to isentropic levels during October 2015, the average ozone profile of the five events presented in Table I was calculated and analyzed in comparison to the 1986 to 2015 October average profile (Figure 7a) and the anomaly profile of the events was also calculated (Figure 7b).

In Figure 7a, is observed that the levels below 500 K can contain three times less ozone than the levels above 650 K and that in the October 2015 events average, negative anomalies in ozone content were observed between 400 and 550K, with maximum in 475K near -0.4 ppmv and above 650K with maximum in 850K near to -0.9 ppmv (Figure 7b). Below 400 K the ozone

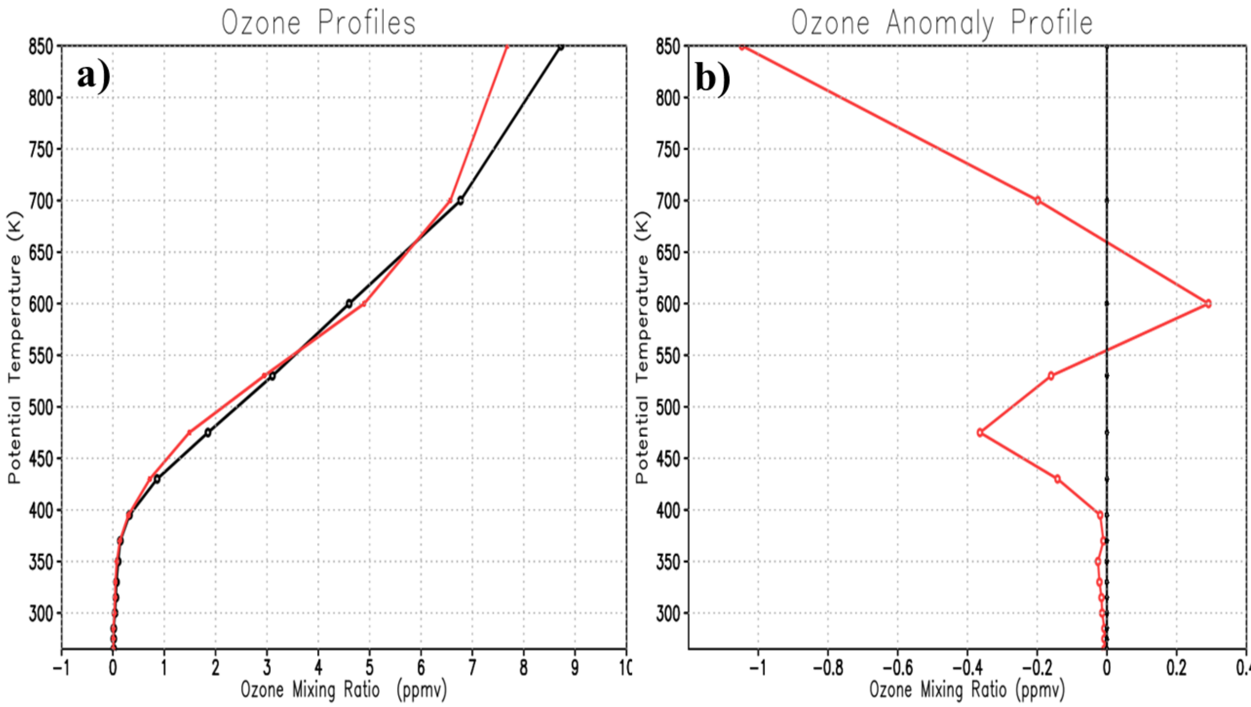

Figure 7. (a) 1986 – 2015 October average ozone profile (black line) and the October 2015 events average ozone profile (red line). (b) October 2015 average events ozone anomaly profile (red line) relative to zero (black line). Both obtained from the ECMWF ERA-INTERIM Reanalysis in ppmv.

reductions are close to 0 ppmv and between 550 K and 650 K positives anomalies are observed with maximum in 600K near to +0.4 ppmv. This magnitude of ozone anomaly in vertical profiles is consistent with variability and trend studies performed by Kiesewetter et al. (2010).

Since 24 km height is closer to the mean ozone layer level at mid-latitudes, and shows significant negative ozone anomaly, the 700 K potential temperature level was selected to ozone anomalies verification in ozone concentration fields. The isentropic transport of polar origin air masses toward Southern Brazil can be quantified by analyzing the Figure 8, which presents the 1986 to 2015 October average ozone field (a), the October 2015 events average ozone field (b), and the October 2015 events anomalies (c), both for the 700 K isentropic level.

In the 1986 to 2015 October average ozone field (a), the presence of a zonal ozone gradient values is observed, with lower values positioned toward the pole and higher values toward the equator, with the central region of the state of Rio Grande do Sul having values between 6.65 and 7 ppmv. In the October 2015 events average ozone field, the propagation of a synoptic scale wave disturbance is observed, leading to northward the lines of lower values of this ozone gradient over the Atlantic Ocean, which resulted in the transport of a lower ozone values polar origin tongue toward the central region of Rio Grande do Sul state, which was left with values between 6.3 and 6.65 ppmv (b). This lower ozone values polar origin tongue, caused anomalies in relation to the 1986 – 2015 October average between -0.2 and -0.4 ppmv that extend from Pacific Ocean, passing through to Nort Chile and Argentina, Southern Brazil and Uruguay and go to the Southeast Atlantic Ocean.

This transient system format extending from the Pacific Ocean to the Atlantic Ocean, passing through Southern Brazil and Uruguay

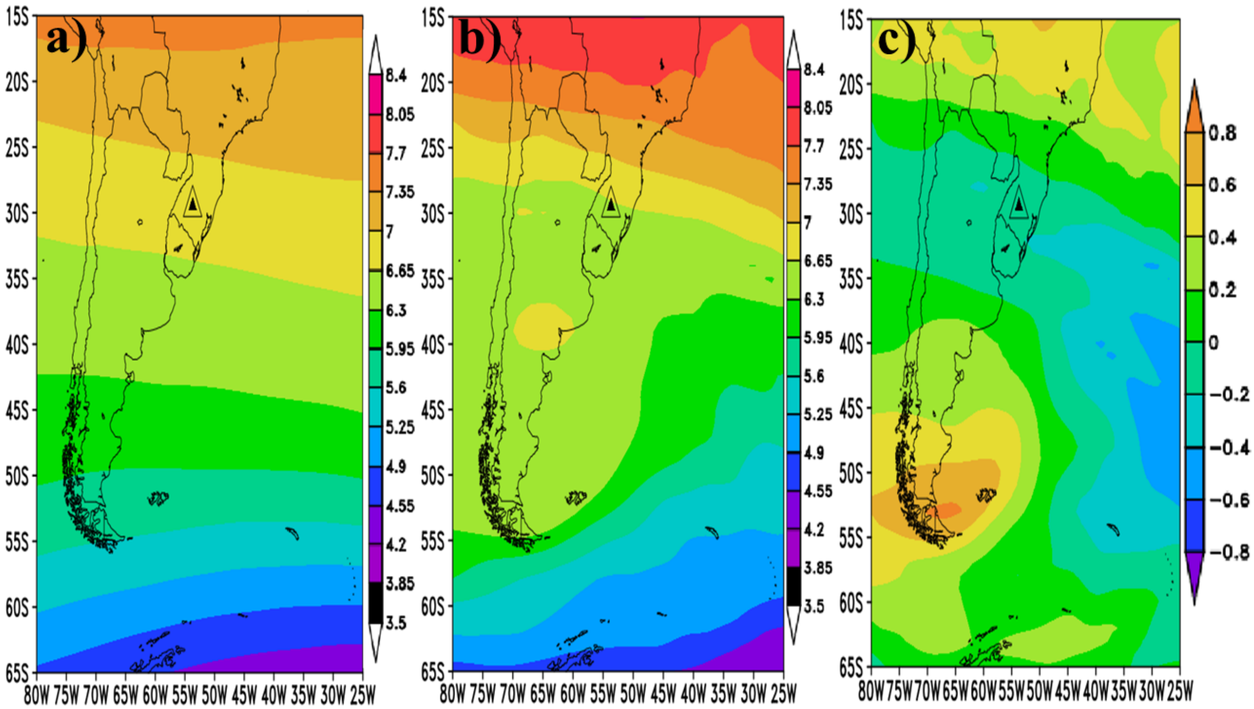

Figure 8. 1986 to 2015 October average ozone field (a), the October 2015 events average ozone field (b), and the October 2015 events anomalies (c). Both for the 700 K isentropic level.

from polar origen is similar to traveling disturbances forced with eastward-traveling Rossby waves identified by Guha et al. (2016). This transient sistens have a live period of 7–8 days and have been observed in the Southern Hemisphere during winter/springtime (Hio & Yoden 2004). This period of time is enough for the air masses to move from polar regions and reach medium latitudes as observed in the studies of ozone and PV similations on the HS carried out by Marchand et al. (2005) and Hauchecorne et al. (2002). Studies by Semane et al. (2006) also observed that isentropic transport of ozone in the stratosphere caused an unusual ozone reduction in the Southern Hemisphere subtropics, more precisely over Irene (25.5 °S, 28.1 °E) in mid-May 2002 and demonstrate the importance of the stratosphere dynamics impact studies during the Antarctic Ozone Hole Influence over Southern Brazil events occurrence for longer time periods.

CONCLUSIONS

The impact of the Influence of the Antarctic Ozone Hole over Southern Brazil events in October 2015 was analyzed in the present study. Was found that 51.6% of the days has ozone reduction below the -1.5σ limit and with UVI values above the October 2015 average, resulting in five events identified.

As an example of this type phenomenon identification, the event occurred in October 29, 2015 was presented. This event has a 6.54% TCO reduction and a 53.9% UVI increase with a clear sky day, intense reductions in ozone content above 600 K levels which reached close to 1.4 ppmv at the 850 K level, caused by an air mass polar origin tonge, surrounded by a cyclonic circulation with predominantly southerly winds. This type of analysis was effective to identifying five events in October 2015, with -7.4±2.3% TCO reduction which impacted an +16.6±54.6% UVI increase whit a predominance of partly cloudy days.

In addition, other impacts of these events were observed in ozone profiles that had negative anomalies at all levels, being more significant from 650 K where reached 1.4 ppmv at 850K. In 700K ozone fields, the isentropic transport pointed to the presence of lower ozone values polar origin tongue that caused anomalies between -0.2 and -0.4 ppmv extending from extend from Pacific Ocean, passing through to Nort Chile and Argentina, Southern Brazil and Uruguay and go to the Southeast Atlantic Ocean, with transient system format similar to traveling disturbances forced with eastward-traveling Rossby waves, demonstrating the importance of conducting this type of study for longer periods of time. With a better understanding of this phenomenon type and your future forecast, will be possible to inform the affected populations in advance, so that they can follow the recommendations established by the World Health Organization.

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