**9TH MEETING OF OZONE RESEARCH MANAGERS OF THE PARTIES TO THE VIENNA CONVENTION FOR DE PROTECTION OF THE OZONE LAYER.**
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# NATIONAL REPORT - BRAZIL


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# THE BRAZILIAN NETWORK FOR OZONE AND UV RADIATION

## 1. OBSERVATIONAL ACTIVITIES

The ozone layer observations by National Institute for Space Research (INPE) are made using a network of ground based spectrophotometers Dobson and Brewer types. We currently operate two Dobson at Natal and Cachoeira Paulista, and six Brewer in the sites: Natal, Cuiabá, Cachoeira Paulista, Santa Maria, La Paz (Bolivia) and Brazilian Antarctic Station Comte. Ferraz (table 1). In addition, ozone concentrations are also measured by the ECC sounding technique on balloons by participation in the SHADOZ Project (The Southern Hemisphere Additional Ozonesonde Network - http://croc.gsfc.nasa.gov/shadoz). A long term measurement program at Brazil has been operational since 1974. Special field campaigns have also been made at other sites, especially in Antarctica, Punta Arenas (Chile) and Rio Gallegos (Argentina). Biomass burning effects are observed by satellite and airplane for INPE. More recently, instruments to measure the UV-B radiation have been added to the network.

***Table1 – INPE's NETWORK* SPECTROPHOTOMETERS DOBSON AND BREWER**

| SITE | LAT.<br>(SOUTH) | LONG.<br>(WEST) | DOBSON<br>NUMBER | BREWER<br>NUMBER | PERIOD<br>and<br>TYPE |
|---|---|---|---|---|---|
| NATAL<br>BRAZIL | 5.84° | 35.21° | 093<br>since 1978 | 110<br>073 | 1994-1996<br>MARK IV<br>1996 - today<br>MARK IV |
| CUIABÁ<br>BRAZIL | 15.3° | 56.1° | - | 056<br>081 | 1991-1997<br>MARK II<br>2002-today<br>MARK IV |
| LA PAZ,<br>BOLÍVIA | 16.54° | 68.06° | - | 110 | 1996-2004<br>MARK IV |
| CACHOEIRA PAULISTA<br>BRAZIL | 22,68° | 45,00° | 114<br>since 1976 | 124 | 1997<br>MARK IV |
| SAO JOSE DOS CAMPOS<br>BRAZIL | 23,2° | 45,86° | - | 056 | 2000 - 2006<br>MARK II |
| SANTA MARIA<br>BRAZIL | 29,26° | 53,48° | - | 081<br>056<br>167 | 1992-1998<br>MARKIV<br>2000-2002<br>MARK II<br>2003 - today<br>Mark III |
| RIO GALLEGOS<br>ARGENTINA | | | | 124 | 2010 - 2012 |
| PUNTA ARENAS<br>CHILE | 53,20° | 70,90° | - | 068 | 1992-2000<br>MARKIV |
| BRAZILIAN<br>ANTARCTIC<br>STATION | 62.1° | 58.4° | - | 068 | SPRING<br>2002 - 2010 |


***Figure 1. Map of INPE's NETWORK Spectrophotometers Dobson and Brewer.***

### 1.1 Calibration activities

Five Brewer spectrophotometers were calibrated by International Ozone Services Inc. (IOS) in 2004, 2007 and 2009.

INPE participated in international calibration in 1994, in Spain, where the Natal Dobson (093) was shipped with our expert. In 1997, the expert Bob Evans, from NOAA, checked the Natal Dobson, on a visit to Natal, but did no adjustments in the instrument. Buenos Aires WMO Intercomparison was made in 2001, 2003, 2006 and 2010 with the participation of our two Dobson instruments.

Three GUV was calibrated in 2001, in São José dos Campos, Brazil, using standard instrument of Biospherical Instruments Inc. The GUV 9285 is operating in Natal, the GUV 9255, in Cachoeira Paulista and the GUV 9285, in Brazilian Antarctic Station. Nowadays, only one GUV is operational in São José dos Campos.

## 2. RESULTS FROM OBSERVATIONS AND ANALYSIS

### 2.1 Ozone Total Column Observations

#### *2.1.1 Dobson spectrophotometers*

Ground based ozone total column has been measured continuously at low latitude sites, using Dobson spectrophotometer at Natal (6º S, 35º W) and Cachoeira Paulista (23º S, 38º W). The ozone data from 1974 to 2012 for the two Dobson spectrophotometers are presented in the figure 2.

The ozone total column varies between 240 and 290 DU and shows large year variability. In the period from 1974 to 2000, the average is 266.5 DU with standard deviation about 10.5 at Natal and 269.3 DU with 12.9 of standard deviation at Cachoeira Paulista. In the period from 2000 to 2012, the average is 264.6 DU with standard deviation about 12.0 at Natal and average 265.3 DU with 14.0 of standard deviation at Cachoeira Paulista.

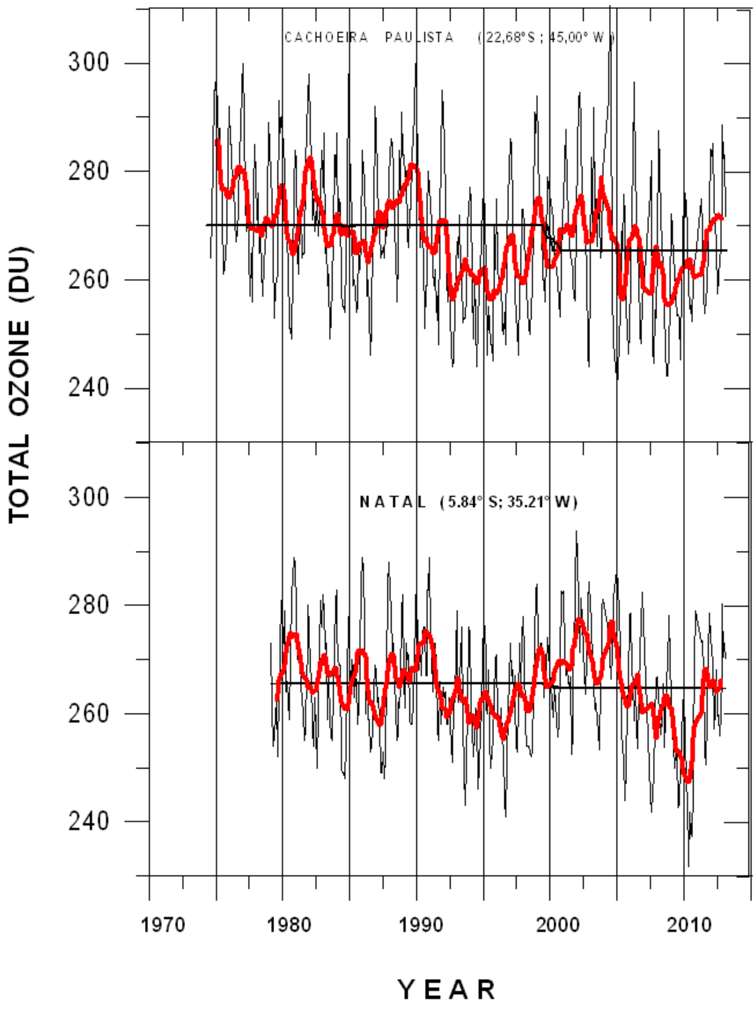


***Figure 2.*** *The figure shows 38 years data set of Dobson, obtained at Cachoeira Paulista and Natal, Brazil. The data are presented as monthly average (black line) and running mean of the 11 days (red line).*

### 2.1.2 *Brewer spectrophotometers*

From data collected by ground and satellite installed equipments: instruments Brewer Spectrophotometer, TOMS (Total Ozone Mapping Spectrometer) and OMI (Ozone Monitoring Instrument), comparisons were made (TOMS-BREWER and OMI-BREWER) between these data. With the good correlation between these instruments, a single data series was created, in which were made and analyzed monthly averages between the periods from 1979 to 2011, showing the behavior of the ozone total column over the South of Brazil, Southern Space Observatory (Observatório Espacial do Sul - OES/CRS/CCR/INPE-MCTI, 29,42°S; 53,87°W), in São Martinho da Serra city (Crespo, N.M. et all, 2012), shown in figure 3**.**

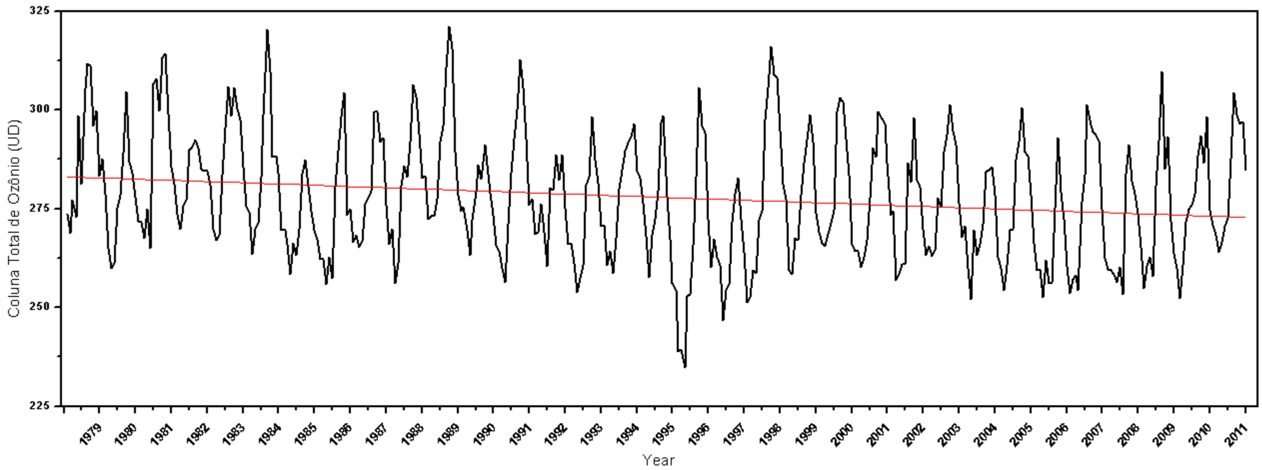


**Figure 3.** *The figure shows a new 38 years data set of the Brewer, TOMS and OMI, for Southern Space Observatory (Observatório Espacial do Sul), São Martinho da Serra, RS, Brazil (29,42°S; 53,87°W).*

**Table 2.** *Values obtained from the comparison between the instruments TOMS-Brewer and OMI-BREWER: number of points used (N), correlation coefficient (R ²), MBE* **(***Mean Bias Error) and MABE* (*Mean Absolute Bias Error)***.**

| | **TOMS - BREWER** | **OMI - BREWER** |
|---|---|---|
| **N** | 2164 | 1184 |
| **$R^2$** | 0,88 | 0,94 |
| **MBE (%)** | 0,23±3,55 | -0,85±2,38 |
| **MABE (%)** | 2,67±2,35 | 1,85±1,72 |

For other latitudes, ozone data were not validated because the Brewers need calibration. A reanalysis of the data will be presented in

### 2.1.3 Ozonesondes

From 1978 to 2002, weekly ozonesondes were launched in Natal, Rio Grande do Norte, Brazil and, after 2002, in Maxaranguape, a city near Natal. Specials campaigns were made in Punta Arenas, Chile (1995, 1997, 2001 and 2005), in La Paz, Bolivia (2000) and Brazilian Antarctic Station (1992, 1999, 2003 and 2004).

### 2.1.4 Ozone Climatology

We present a regional and seasonal climatology, at Natal, of SHADOZ ozone profiles in the troposphere and tropical tropopause layer (TTL) based on measurements taken during the first five years of Aura, 2005–2009, results published in ***Thompson, A. M., et al. (2012), Southern Hemisphere Additional Ozonesondes (SHADOZ) ozone climatology (2005–2009): Tropospheric and tropical tropopause layer (TTL) profiles with comparisons to OMI-based ozone products, J. Geophys. Res., 117, D23301, doi:10.1029/2011JD016911.***

Thompson, A. M. et all (2012) present "a regional and seasonal climatology of SHADOZ ozone profiles in the troposphere and tropical tropopause layer (TTL) based on measurements taken during the first five years of Aura, 2005–2009. In all, 15 stations operated during that period. A west-to-east progression of decreasing convective influence and increasing pollution leads to distinct tropospheric ozone profiles in three regions:
(1) western Pacific/eastern Indian Ocean; (2) equatorial Americas (San Cristóbal, Alajuela, Paramaribo); (3) Atlantic and Africa. Comparisons in total ozone column from soundings, Ozone Monitoring Instrument (OMI, on Aura, 2004-) satellite and ground-based instrumentation are presented. Most stations show better agreement with OMI than they did for EP/TOMS comparisons (1998–2004; Earth-Probe/Total Ozone Mapping Spectrometer), partly due to a revised above-burst ozone climatology. Possible station biases in the stratospheric segment of the ozone measurement noted in the first 7 years of SHADOZ ozone profiles are re-examined. High stratospheric bias observed during the TOMS period appears to persist at one station. Comparisons of SHADOZ tropospheric ozone and the daily Trajectory-enhanced Tropospheric Ozone Residual (TTOR) product (based on OMI/MLS) show that the satellite-derived column amount averages 25% low. Correlations between TTOR and the SHADOZ sondes are quite good (typical $r^2$ = 0.5–0.8), however, which may account for why some published residual-based OMI products capture tropospheric interannual variability fairly realistically. On the other hand, no clear explanations emerge for why TTOR-sonde discrepancies vary over a wide range at most SHADOZ sites."


**Figure 4.** *Map of SHADOZ stations that operated during the early Aura era, July 2004–2010. Malindi (ceased in 2006) is not included here. See operating period and technical summary for individual stations in Table 3. Technical details of SHADOZ sondes used at each site during 1998–2004, within the Earth-Probe/TOMS period, are given in Thompson et al. [2003a, 2007]. Tahiti operated in 1998–1999.*

**Table 3.** *SHADOZ Station Locations Used in This Study, With Years of Record and Sample Number (SN) Analyzed for 2005 – 2009.*

| Site Longitude | Latitude, SHADOZ Data | Years of | SN, 2005–2009 |
|---|---|---|---|
| Cotonoua | 07N, 15E | 2005–2007 | 100 |
| Irenea | 25S, 28E | 1999–2007 | 64 |
| Nairobi | 01S, 35E | 1999–2010 | 189 |
| La Réunion | 21S, 55E | 1998–2010 | 158 |
| Hanoi | 21N, 106E | 2005–2009 | 106 |
| Kuala Lumpur | 2.7N,102E | 1998–2010 | 114 |
| Watukosek | 7.5S,112.6E | 1998–2010 | 65 |
| Fijia | 18S, 178E | 1998–2008 | 44 |
| Hilo | 19N, 157W | 1998–2010 | 217 |
| Am. Samoa | 14S, 171W | 1998–2010 | 157 |
| Paramaribo | 05N, 55W | 1999–2009 | 140 |
| Alajuela/Heredia | 10N, 84W | 2006–2010 | 192 |
| San Cristóbala | 01S, 90W | 1999–2008 | 103 |
| Natal (Brazil) | 06S, 35W | 1998–2010 | 173 |
| Ascension Is. | 08S, 15W | 1998–2010 | 207 |

Gaps are significant at Fiji, Irene, San Cristóbal (launches interrupted in 2008, resumed in 2011). Cotonoua operated from Dec. 2004 through Jan. 2007.

**Table 4.** *Profile Characteristics of Ozone for Tropical SHADOZ Stations (Within ± 18 Degrees)*

| Site Minimum Altitude (km) | Ozone Mixing Ratio (5 km - 12 km) | FT Mean O3 Mixing Ratio (14 km–18.5 km) | TTL Mean O3 ( km), LRT ( km) | Ozonopause (This Study) | Ozonopause (km) [Sivakumar et al., 2011]b | Mean GWI, Altitude of GW Max.c |
|---|---|---|---|---|---|---|
| **Eastern Indian/Western Pacific Oceans** | | | | | | |
| Kuala Lumpur | 13 | 35.8 | 120 | 16.6, 16.9 | – | 19.4, 17.0 |
| Watukosek | 14 | 30.8 | 95.6 | 17.0, 16.9 | 6.6 ± 1.3 | 18.5, 18.1 |
| Fiji | 13 | 40.1 | 140 | 16.6, 16.9 | 16.2 ± 1.2d | 12.6, 18.1 |
| Am. Samoa | 12 | 35.7 | 135 | 16.5, 17.1 | 16.4 ± 0.95 | 16.1, 18.1 |
| **Equatorial Americas** | | | | | | |
| San Cristóbal | 11 | 48.1 | 135 | 16.5, 16.9 | 16.6±1.1 | 12.6, 18.1 |
| Alajuela/ Heredia | 11 | 48 | 137 | 16.3, 17.1 | – | – |
| Paramaribo | 11 | 59 | 123 | 15.6, 17.0 | – | 7.85, 18.1 |
| **Atlantic Ocean and Africa** | | | | | | |
| Natal | 11 | 58.6 | 140 | 16.2, 17.0 | 15.9± 1.6 | 10.9, 18.2 |
| Ascension | 11 | 63.9 | 134 | 16.2, 17.1 | 15.5 ±_ 1.9 | 8.35, 18.0 |
| Cotonou | 11 | 72.5 | 155 | 15.5, 16.9 | – | – |
| Nairobi | 11 | 55.3 | 134 | 16.4, 17.0 | 16.3 ± 1.6 | 16.6, 18.0 |

a Altitude corresponding to 100 ppbv ozonopause as in Figures 5; data from 2005–2009.
b From ozonopause definition of Sivakumar et al. [2011] based on 1998–2008 data. Mean difference between their ozonopause and LRT averages 0.25 km, with five of 7 tropical sites having ozonopause higher than LRT.
c GWI = Gravity Wave Index, based on 1998–2007 soundings [Thompson et al., 2011a].
d Sivakumar et al. [2011] categorizes Fiji as a Sub-tropical site.

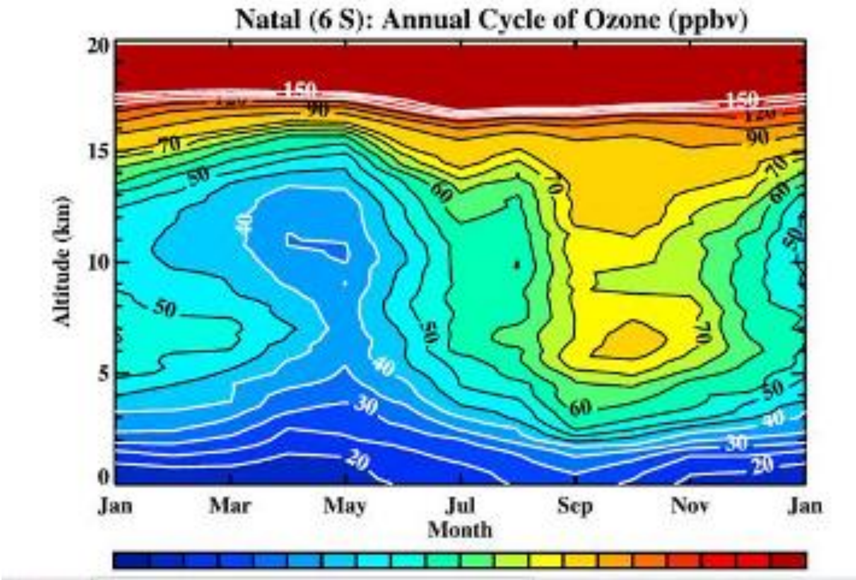


**Figure 5** . *Displays annual cycles of ozone in the troposphere, TTL (Tropical Tropopause Layer) and LS for the Natal SHADOZ stations, based on contouring mean monthly-averaged ozone profiles for the years 2005–2009.* ***Thompson, A. M. et al. (2012).***

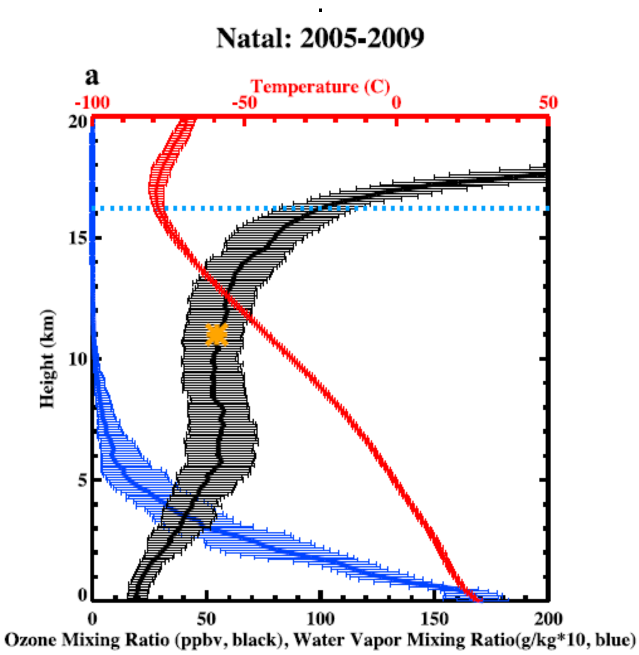


**Figure 6.** *Average ozone, temperature, water vapor profiles over Natal SHADOZ station. The minimum corresponds to the 25th percentile for each parameter; the maximum corresponds to the 75th percentile. The asterisk locates local minimum O3 mixing ratio in the UT and TTL, from which location of most prevalent convective outflow inferred. Horizontal dashed line indicates ozonopause (Table 4).*

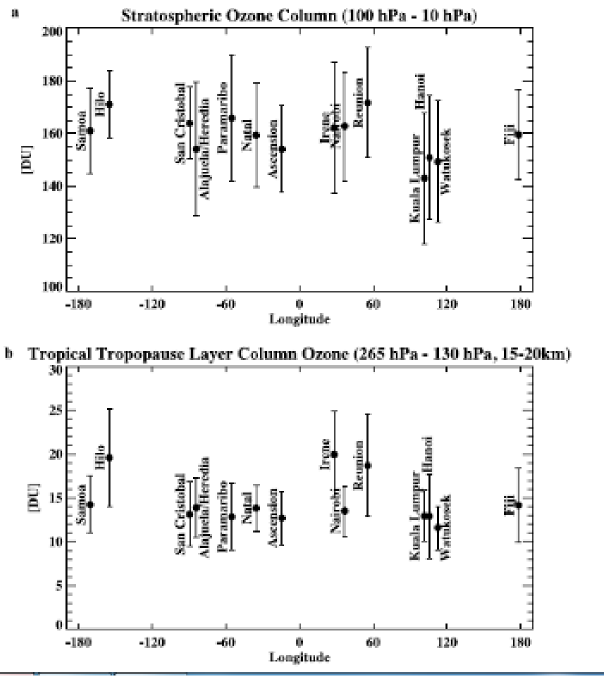


**Figure 7.** *(a) Zonal view of stratospheric column O3, in Dobson Units (DU,±1ϭ) determined from integrated stratospheric O3 of 2005–2009 soundings. (Cotonou not shown due to small number of samples to 10 hPa). Bars indicate 1± 1ϭ standard deviation. For two subtropical stations, Hilo and Réunion, a column >170 DU may result from intrusion of mid-latitude air parcels. Lack of distinct zonal variation signifies the absence of a wave-one in the stratosphere [cf. Thompson et al., 2007, Figure 6]. (b) Zonal view of integrated column O3 between 115 and 42 hPa (15–20 km).*

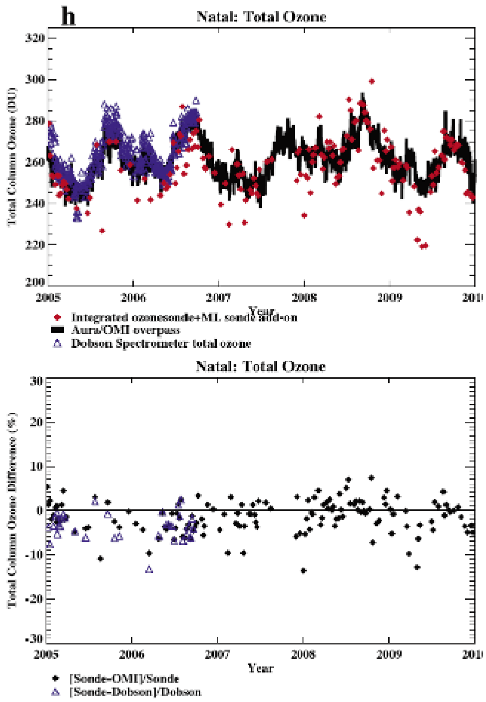


**Figure 8.** *Time-series of OMI overpass ozone total column (solid line) with integrated total ozone (red) from all soundings in 2005–2009 that reached 20 hPa. Above burst addition to total ozone is from the most recent SBUV/SAGE/MLS climatology [McPeters and Labow, 2012]. The latter is similar to McPeters et al. [2007] but differs 5–10 DU typically from the SBUV add-on used in earlier EP/TOMS comparisons [McPeters et al., 1997; Thompson et al., 2003a, 2007]. Where available, total O3 from co-located Dobson, Brewer or SAOZ instruments (blue triangle) is given. The lower panel includes sonde-OMI difference and the ground-based-sonde.*

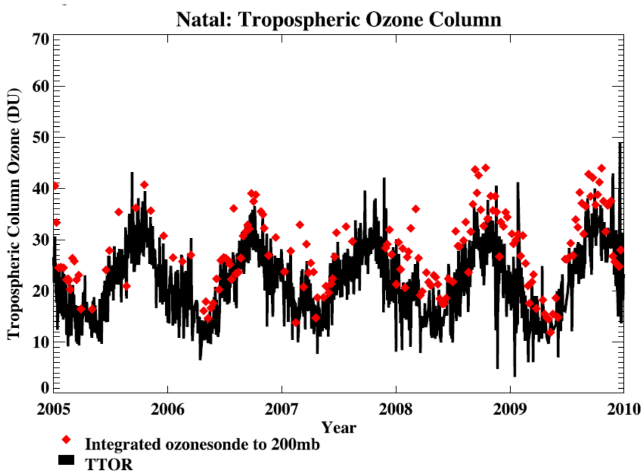


**Figure 9.** *TTOR (trajectory-enhanced tropospheric ozone residual) - sonde offsets for ozone integrated from the surface to 200 hPa AT Natal*

#### *2.1.5 Influence of Antarctic Ozone Hole over South of Brazil*

The Antarctic Ozone Hole is a cyclical phenomenon which occurs over the Antarctic region from August to December each year. The polar vortex turns it into a restricted characteristic dynamics for this region. However, from time to time, some air masses with low ozone concentration could escape and reach regions of lower latitudes. Pinheiro et al. (2011 and 2012) and Peres (2013) analyzed the influence of the Antarctic Ozone Hole over the South of Brazil in the years from 2008 to 2011, and from 1979 to 2011, respectively. To verify these events, ozone total column from Brewer Spectrophotometers MKIV #081 (from 1992 to 2000), MKII #056 (from 2000 to 2002) and MKIII #167 (from 2002 to nowadays) installed at Southern Space Observatory (29.42°S, 53.87°W), in São Martinho da Serra, South of Brazil, and TOMS and OMI Spectrometer overpass data for the same coordinates were used. In addition to ozone data, potential vorticity maps using GrADS (Grid Analysis and Display System) generated with the NCEP reanalysis data and air mass backward trajectories, using the HYSPLIT model of NOAA, were analyzed. Ozone total column for the days with low ozone were compared with monthly climatological average from 1979 to 2011. Considering only the days with ozone lower than climatological means minus 1.5 standard deviation, increased absolute potential vorticity and backward trajectories indicating the origin of polar air masses, 66 events were observed in the period analyzed, with an average decreased about $8.66 \pm 3.13$ % when compared with climatological means.

**Table 5.** *Distribution of the events of influence of the Antarctic Ozone Hole over South of Brazil, occurred from 1979 to 2011, during August, September, October and November, at Southern Space Observatory (29.42°S; 53.87°W; 488,7m). (Results from Peres, 2013)*

| Month | Number of Events | Percentage of Events (%) |
|---|---|---|
| **August** | 9 | 13.6 |
| **September** | 20 | 30.3 |
| **October** | 30 | 45.5 |
| **November** | 7 | 10.6 |

In Figure 10 is shown an event example (Peres et all., 2012) of the influence of Antarctic Ozone Hole over South of Brazil occurred at October 13$^{th}$ and 14$^{th}$, 2012, with total ozone column about 252.6 DU, a reduction of 13.7 % in comparison with October climatological mean 292.7 ± 9.85 DU. The stratosphere dynamic is shown by potential vorticity maps at isentropic level of 620 K potential temperature, Figure 11, (a) for October 13th, 2012 and (b) for October 14th, 2012. From 13th to 14th, it can be seen an increase at absolute potential vorticity over South of Brazil. The backward trajectory by NOAA HYSPLIT Model for October 14th, 2012, Figure 11 (c), showed the polar origin of the ozone poor air mass over South of Brazil. Finally, in Figure 11(d), OMI image for October 13th, 2012, is shown.

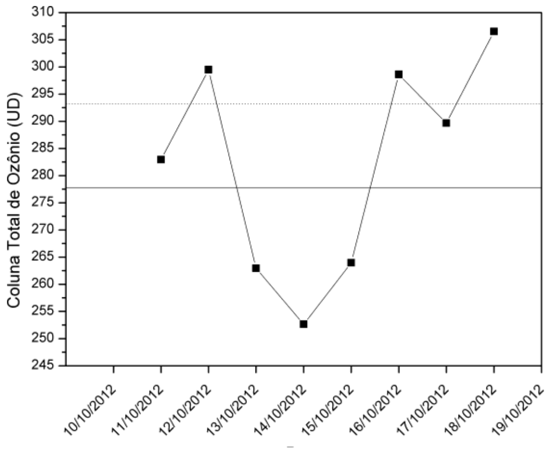


**Figure 10.** *Ozone total column (DU) from October, 11th to 18th, 2012, at Southern Space Observatory, South of Brazil. The lines represent climatological mean and its value minus 1.5 the standard deviation for October.*

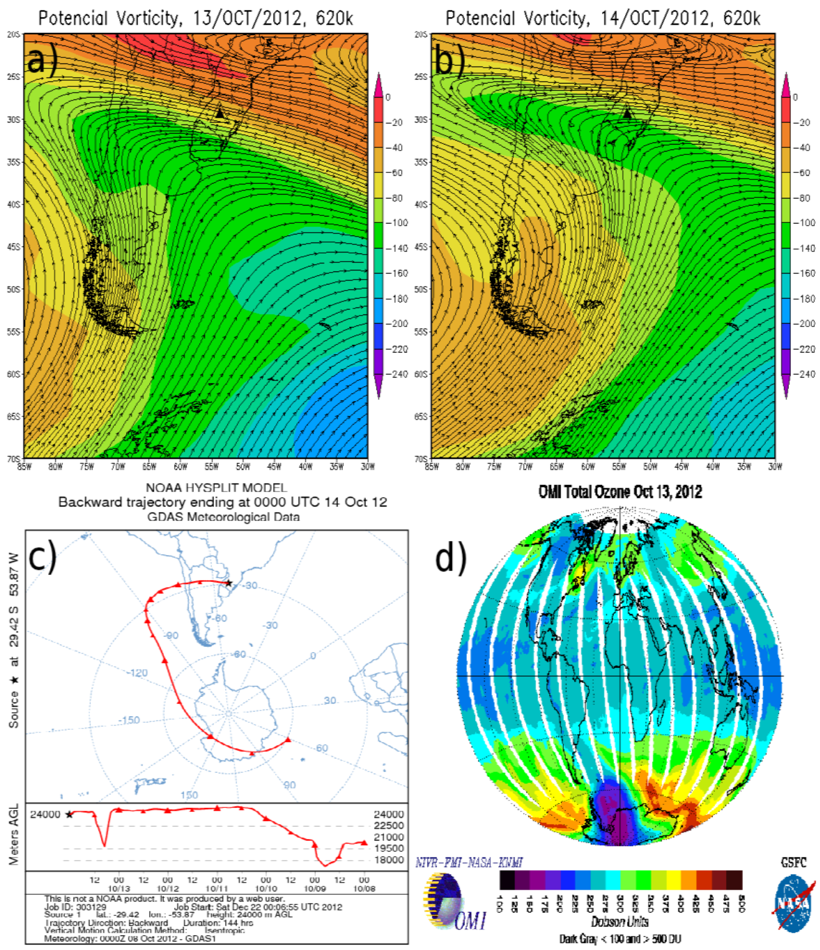


**Figure 11.** *Potential Vorticity and wind for October (a) 13th and (b) 14th, 2012, (c) backward trajectory by HYSPLIT model at 620K for October 14th, 2012, and (d) OMI satellite image for October 13th, 2012. (Peres et all., 2012)*

### *2.1.6 Ozone and UV Forecast*

The forecast of Ozone Layer Concentration and UV radiation can be obtained from INPE/CPTEC site (http://satelite.cptec.inpe.br/uv), which used satellite data NOAA 16, sensor SBUV/2.


**Figure 12**. *Example of Ozone forecast by INPE/CPTEC for 04/14/2014.*

## 4. DISSEMINATION OF RESULTS

### 4.1 Data Reporting

The Brewer data have been submitted to WOUDC since 2004 and Dobson data since 1978.

### 4.2 Information to the public

The Ozone e UV forecasts are in web sites: **www.crn2.inpe.br/lavat** and **http://satelite.cptec.inpe.br/uv.**

### 4.3 Relevant scientific papers


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## 5. PROJECTS AND COLLABORATION

The Project in the Brazilian Antarctic Program: **INCT- Antarctic Environmental Research,** Project Antarctic Atmosphere and Environmental Impacts in South America, operated through the knowledge and monitoring of Antarctic atmosphere and its environmental impacts on South America.

Objectives of the Area***:***

1. To monitor and evaluate:
• The regions of movement of Antarctic Cold Fronts as far as South America, especially Brazil;
• The greenhouse effect perceived in Antarctica;
• The chemical changes of the atmosphere and their influence on the climate, involving: the interaction Sun - Earth, the temperature of the mesosphere and the hole in the ozone layer;

2. To offer supporting information to numerical models of climate and weather forecasting.

Collaboration with the Centro de Investigaciones en Láseres y Aplicaciones, CEILAP-UNIDEF (MINDEF-CONICET),
Collaboration with the San Andres University, La Paz, Bolivia
Collaboration with the Magallanes University, Punta Arenas, Chile
Collaboration with the Magallanes University, Punta Arenas, Chile
Collaboration with the Takushok University, Tokyo-Japan
Collaboration with the Federal University of Santa Maria, Santa Maria, Brazil.

**FUTURE PLANS**
The current monitoring networks are to be maintained operational. However, there is no special plan or project for building new capacities to conduct ozone or UV radiation. Some projects, such

as projects focusing on climate change, may include instruments installation and research related to ozone and UV.

## 7. NEEDS AND RECOMMENDATIONS

It is very important the support for the annual calibrations and maintenance of the Brewer. The last calibration of the Brazilian Brewers was in 2009. All instruments needed calibrations as soon as possible. Financial support for trips techniques and participation in Ozone and UV Meetings, Congresses and Symposium are also needed.