# Longitudinal and latitudinal variations of the total ozone over the Central Andes

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**Summary.** — From the Total Ozone Mapping Spectrometer (TOMS) data released by NASA, some analyses had been done in order to point out anomalies in the time and space distributions of the total ozone. Also some explanations for them have been tried. Here we focus on the longitudinal and altitudinal anomalies in a region characterised by strong variations in orography, as are the Andes at low and mid latitude. As a result of the analysis, we conclude that there is a depletion of the total ozone over the Altiplano and discuss some possible explanations of the phenomenon.

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## 1. – Introduction

Several analyses of the data from the Total Ozone Mapping Spectrometer (TOMS) instrument on board the NASA's Nimbus satellites, have been devoted to study latitudinal variations of the total ozone; few to the longitudinal ones, due to the alternance of ocean and land, and even fewer to the altitudinal variations, due to orography.

Inspecting the TOMS data, people find out the NASA commentary that the reduced values of the total ozone over the largest chain mountains (Himalayas, Andes) are trivial, due to the reduced atmosphere.

In order to go deeper on this subject, we analysed the TOMS data from 1979 to 1992, scanning longitudinally along arcs covering different orographic regions, at low and mid South latitudes (see the map, fig. 1). A good feature of those latitudes is the

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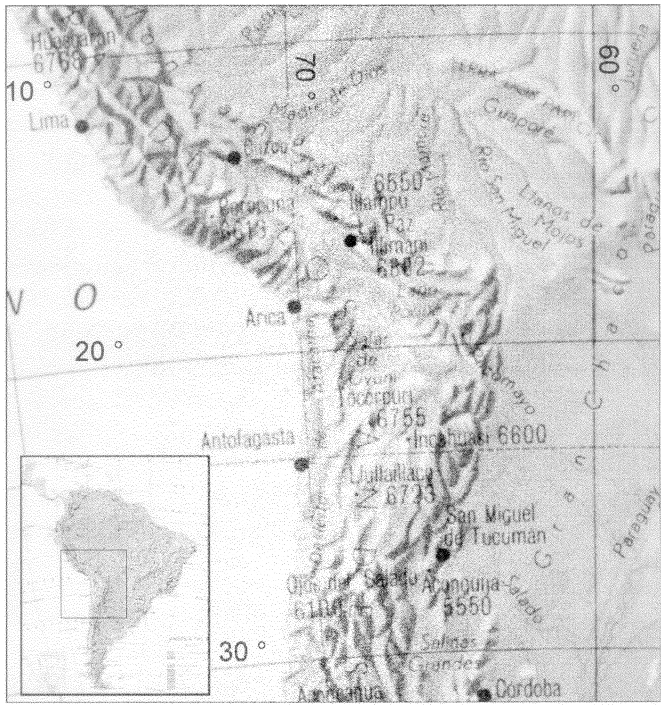


Fig. 1. – Map of the region under analysis.

relative stability of the ozone layer above them and their independence from the Antartic hole phenomenon.

Aiming to confirm the existence of that effect, quantify it and discuss some possible explanations, we rose the next questions: Is there any longitudinal and altitudinal variation of the total ozone? If so, how to characterise them? If so, what explanations can be given?

## 2. – Time variations of the total ozone at low latitude

We started checking the claimed stability of the ozone layer at low latitude in order to discard other disturbing effects.

In fig. 2 the small yearly variability (less than 6% between maximum and minimum) of the total ozone over La Paz (lat. 16.5 °S) is shown, as monthly mean values for November. Similar results may be obtained for others months. Also can be seen no influence of the Antartic ozone hole and a trend that roughly follows the eleven-year solar cycle can be seen.

In fig. 3, we show a similar result when we consider the yearly mean values, at the same location. Notice the very small variation of the values (less than 3% from the average). In addition, our ground station (Brewer # 110) has been measuring very similar values along the last years, confirming the stability of the ozone layer at that latitude.

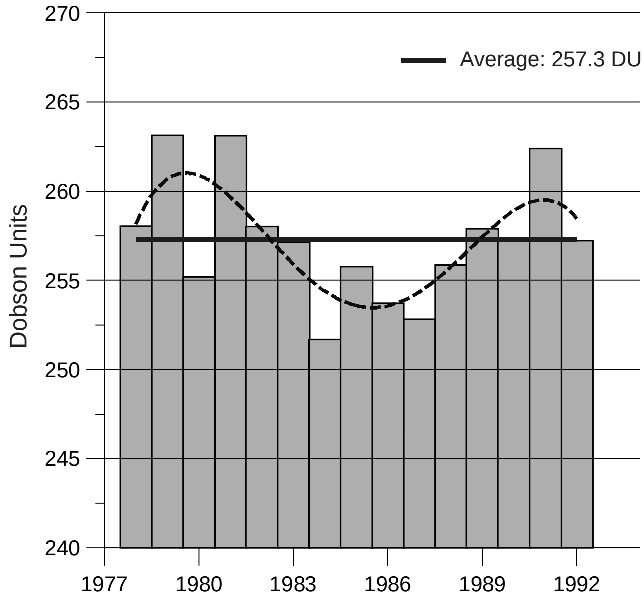


Fig. 2. – Total ozone trend at La Paz (16.5 °S, 68.1 °W) for November (TOMS-NASA data). The curve is a polynomial fit of the trend.

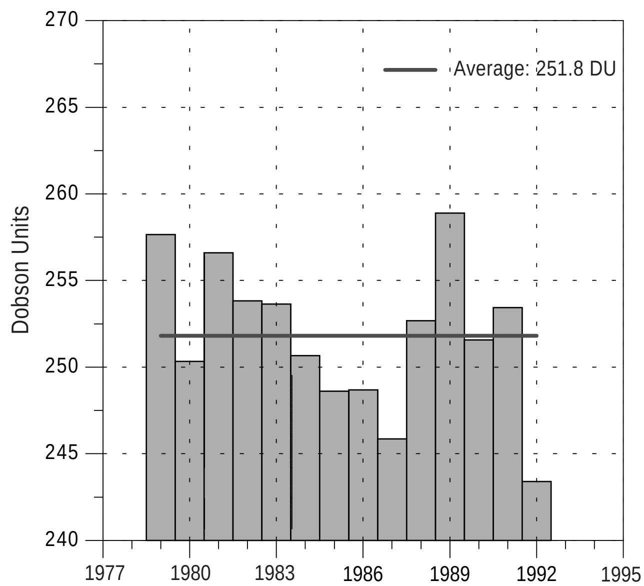


Fig. 3. – Yearly ozone column average at La Paz.

Even more, the seasonal variation (fig. 4) reflects the general trend, with the maximum total ozone in (austral) spring and the minimum at the end of autumn.

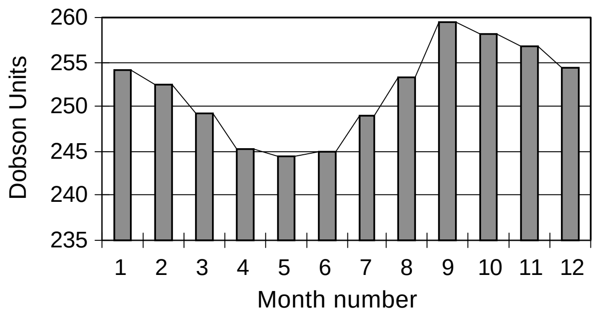


Fig. 4. – Monthly ozone column average (1979-1992) at La Paz.

## 3. – Spatial variations of the total ozone at low and mid latitudes

As mentioned above, we chose a region from the west coast of South America, because it spans, with few satellite observation points, a wide orographic range: Ocean, West Andean Cordillera, Altiplano (high plateau), East Cordillera, Valleys and Plains. We selected three parallels: 16.5 °S, 17.5 °S and 32.5 °S, in correspondence to an Altiplano of medium extension (200 km), of larger extension (400 km) and of negligible extension (see map).

Avoiding positioning errors, we picked up exactly the same observation points taken by the TOMS, which are separated by approximately 100 km from each other. We began at a point in the ocean, as the reference for each latitude, and we followed the parallel arc eastward until we reached the plains.

Figures 5 and 6 show the 14 years average ozone content (1979-1992) from TOMS data, at the mentioned parallels, for different longitudinal points. The trend, already shown (Cuevas, 1996), of a decrement in the total ozone at the cross from the ocean to the continental land is evident, followed by a larger ozone loss over the high plateau. Then the total ozone recovers, as we move over the valleys and toward the plains. Notice that at 32.5 °S (fig. 6), where there is not a plateau, the transitions are steeper.

We can see that the absolute difference, in Dobson units (DU), reaches,

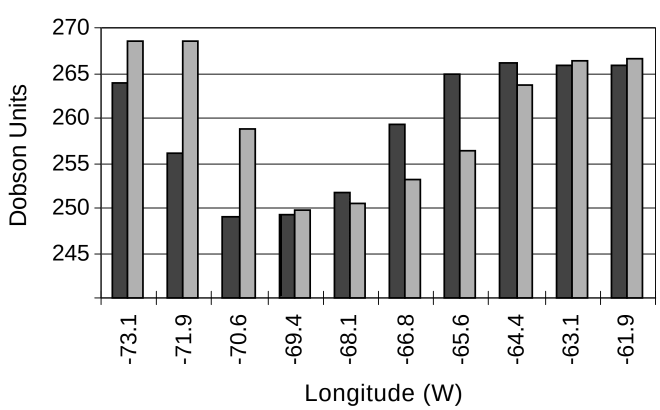


Fig. 5. – Longitudinal total ozone profile at 16.5 °S and 17.5 °S.

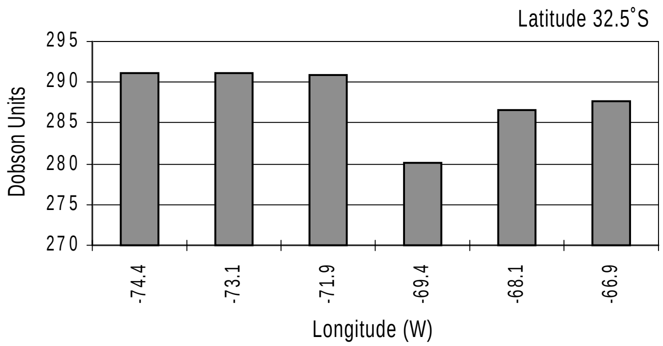


Fig. 6. – Longitudinal total ozone profile at 32.5 °S.

respectively, 15 and 19 DU, at 16.5 °S and 17.5 °S, between the ocean and the Altiplano, while at 32.5 °S the difference is lower, just 11 DU. If we consider values relative to the ocean, the result is clearer: a 7% decreasing over the Altiplano (at 17.5 °S) and just 4% over the narrow mountains at 32.5 °S, with peaks 6 to 7 km high.

## 4. – Some explanations for the altitude effect

With the evidence gathered on the depletion of the total ozone over the Altiplano, we can consider some hypotheses.

4˙1. *Tropospheric ozone depletion, due to the reduction of the atmosphere.* – As a matter of fact, the high-altitude lands occupy a spatial region of the atmosphere, making it thinner, as seen by satellite as well as by ground instruments.

Nevertheless, such hypotheses cannot explain the difference in total ozone between the ocean and the coast, nor the ocean and the tropical plains (Cuevas, 1996). In addition, despite that we do not get updated measures of the tropospheric ozone profile over La Paz, we do have data from campaigns carried out in the sixties (Schulszewski, 1964). If we consider that the local atmosphere has not changed during the last 30 years, we conclude that the ozone profile over La Paz is similar in trend and in values to the sea level profiles at the same latitude. As an example, the tropopause height is, in both cases, around 16 km (Salby, 1996).

From ozonesonde data at Natal (6 °S, 35 °W), (Kirchhoff, 1991), we conclude that, from sea level, a 17 DU accumulated ozone is measured up to 10 km height, while up to 4 km height the accumulated content is between 6 and 10 DU, in dependence on the season of the year. Anyway, the latter is around 50% of the total loss, not enough to explain the ozone loss measured by the TOMS (see fig. 7, where more recent data from ozonesonde at Natal are plotted). Therefore this hypothesis, even being quite important, is not the unique feature accounting for the ozone loss.

4˙2. *Albedo effect.* – The albedo of the high mountains and the Altiplano is higher than the sea surface: this could "deceive" the satellite instruments. Nevertheless, the Amazonian forests have an albedo lower than the sea surface, which should be reflected in a major increase of total ozone difference between ocean and tropical plains, but the general analysis (Cuevas, 1996) and data in fig. 6 do not display such effect.

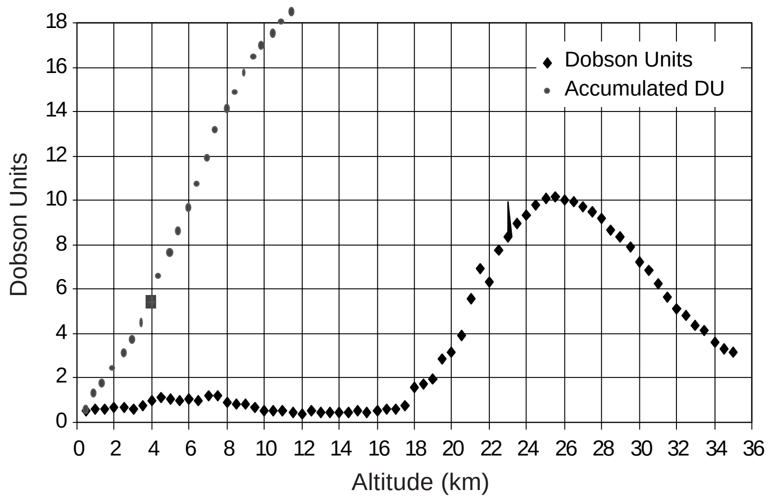


Fig. 7. – Tropospheric ozone values at Natal (6 °S, 35 °W) for April 2nd, 1997.

4·3. *Forest burning effect.* – Tropospheric ozone, a by-product of the seasonal forest burning, could increase the total ozone, as measured by TOMS, over the polluted regions, as the Amazon basin and, in a lesser amount, over the valleys and the Altiplano, due to wind regime, disturbing, in this way, the yearly averages.

This effect should be present only seasonally (from August to November) and must be located at low latitude. However, there is not significant variation of the total ozone during the mentioned months. In effect, figs. 8 and 9 show opposite seasonal trend at 16.5 °S: in the dry season the total ozone difference between ocean and Altiplano is increasing. However, the ozone column over the plain is higher than over the ocean during the dry season, possibly due to the burning. This is also shown in fig. 5, from the same latitude, in agreement with other measurements (Crutzen, 1990; Kirchhoff, 1992).

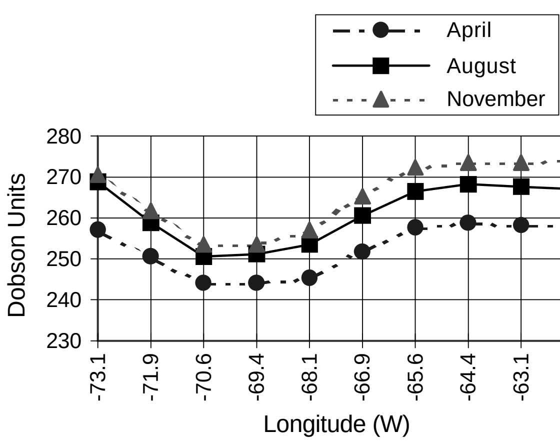


Fig. 8. – Total ozone seasonal change at 16.5 °S.

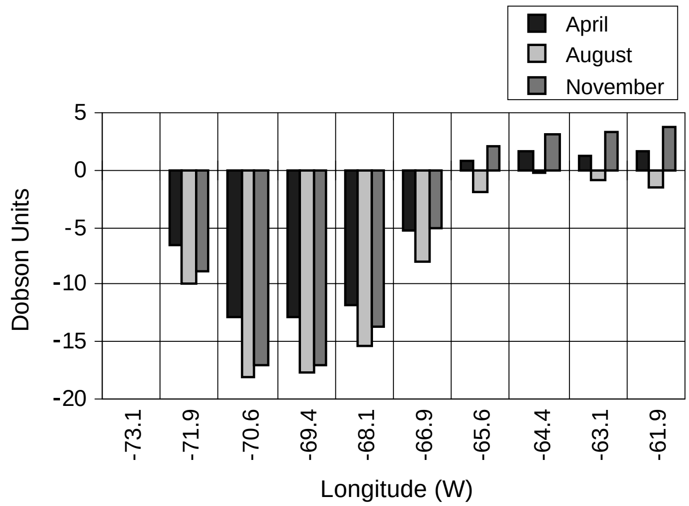


Fig. 9. – Total ozone variation relative to the ozone column over the ocean.

4·4. *Atmospheric dynamics.* – As the considered explanations cannot give us a complete picture of the ozone loss over the Altiplano, we take the dynamical hypothesis which is twofold: the tropopause altitude change over the continental land and the gravity wave effect from the mountain chains.

Actually, there is a correlation between the tropopause altitude and the mountains height, as seen by the satellite (Cuevas, 1996). This implies a reduction of the total ozone under those conditions. However, we cannot confirm this, due the few ozone profile data over our location.

The second branch (Thomas, 1984), is based on the existence of stationary gravity waves in correspondence of mountain chains. A similar work, (Kazimirovsky, 1997), shows a puzzling result of an opposite behaviour between the Andes and the Himalayas: according to this analysis, in the Himalayas plains the total ozone is less than over the mountains chain.

An explanation could be in the different orientation of the two chains, related to the wind direction: while the Andes are from North to South, forming a barrier for the tradewinds, the Himalayas is oriented from East to West, acting in a different way for the production of gravity waves, which, apparently, are responsible for the stratospheric ozone variations (Thomas, 1984; Schoeberl, 1985).

In addition, in the case of the Andes, the influence produced by the double chain, with a high plateau in between, is evident as can be seen (figs. 5 and 8) for low and mid latitudes.

## 5. – Conclusions

Our analysis confirms the existence of a depletion of the total ozone over the high lands, comparing with the ocean, at the same latitude. For the case of the Andes, this cannot be explained only by the atmospheric reduction, or by the albedo changes, or by anthropogenic causes. We think that the explanation comes from the atmospheric dynamics of the stratosphere-troposphere border, as a consequence of the height and size of the mountain chains.

In order to continue the research, and test the hypothesis, we consider it necessary to perform ozonesonde campaigns over the Altiplano in a near future.

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