Depletion of the ozone column over the Andes Mountains of South America(*)

L. Da Silva(**)

Departamento de Física, Universidad Técnica Federico Santa María
Casilla 110V, Valparaiso, Chile

(ricevuto il 12 Giugno 2000; revisionato il 14 Marzo 2001; approvato il 21 Agosto 2001)

Summary. — Data on the ozone column has been published by NASA since 1978. They show a clear decrease every summer in the ozone column over the Andes Mountains, extending from Ecuador southward to approximately 33° latitude in Chile. In order to determine the characteristics of this decrease, cross-sections of the column were taken at different latitudes using satellite data. The resulting graphs clearly confirm a significant decline in the concentration of the ozone column in the form of a depleted strip, flanked by asymmetric areas of higher ozone concentration. To find the cause of this seasonal ozone decrease, wind field velocities in the region and their vorticities were analysed at different heights. This revealed evidence that the ozone layer is being compressed by winds coming from above and winds moving upward from the troposphere, causing a redistribution in ozone density.

PACS 92.70.-j – Global change.
PACS 92.60.Vb – Solar radiation.
PACS 93.30.Jg – Information related to geographical regions: South America.

1. – Introduction

Since 1978, data publicly available from NASA show that during the summer of each year a decrease in the total ozone column appears in the form of a strip over the Andes Mountains, extending from Ecuador to approximately 33°S latitude in Chile. At these latitudes, ozone concentration averages on the order of 270 DU, but when the aforementioned depletion occurs this figure can fall as low as 230 DU. The process by which the depletion occurs indicates that the strip may begin in Ecuador and stretch southward down the Pacific coast, passing along western Peru and reaching as far as 33°S in Chile.

(*) An earlier version of this work was accepted for presentation at the Quadrennial Ozone Symposium held on 3-8 July, 2000, at Sapporo, Japan, and later published in the Symposium Supplement.
(**) E-mail: ldasilva@fis.utfsm.cl

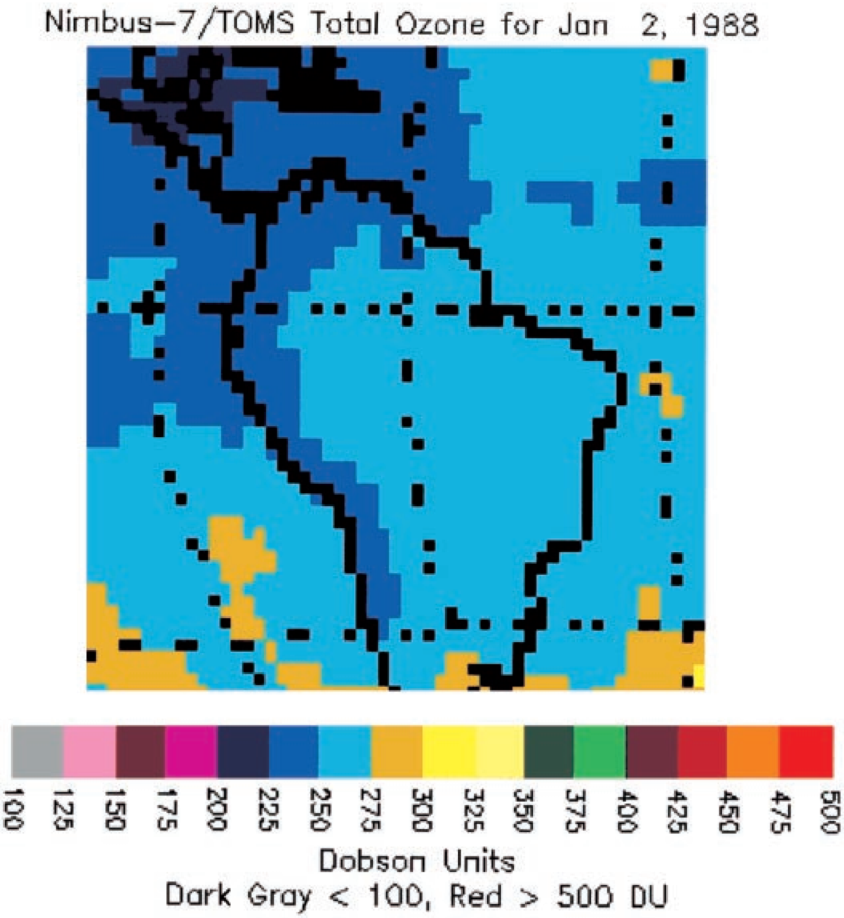

Fig. 1. – Map of the distribution of stratospheric ozone, showing the depletion of the ozone column over the Andes Mountains, January 2, 1988.

In other cases, an ozone decrease originates in the area of southern Peru and northern Chile, extending both northward and southward from that region. The minimum points of these decreases in ozone concentration mainly occur over the Andes [1]. The decreases may last for a month or more, and are particularly pronounced both in duration and in intensity in the southern Peru-northern Chile region, bringing about an increment in ultraviolet radiation (UV) at these latitudes. Some authors consider that the decreases are due to the effect of the mountains. At high altitudes the thickness of the atmosphere diminishes, and so, therefore, does the thickness of the ozone layer [2]. The purpose of the present paper is to describe the characteristics of this strip of depletion in the total ozone column and provide an explanation of the phenomenon based on considerations related to the atmospheric dynamics of the affected area. It was already suggested that such dynamics may be the cause of ozone depletion over the Andes highlands [3, 4]. The results presented here tend to strongly bear out our hypothesis.

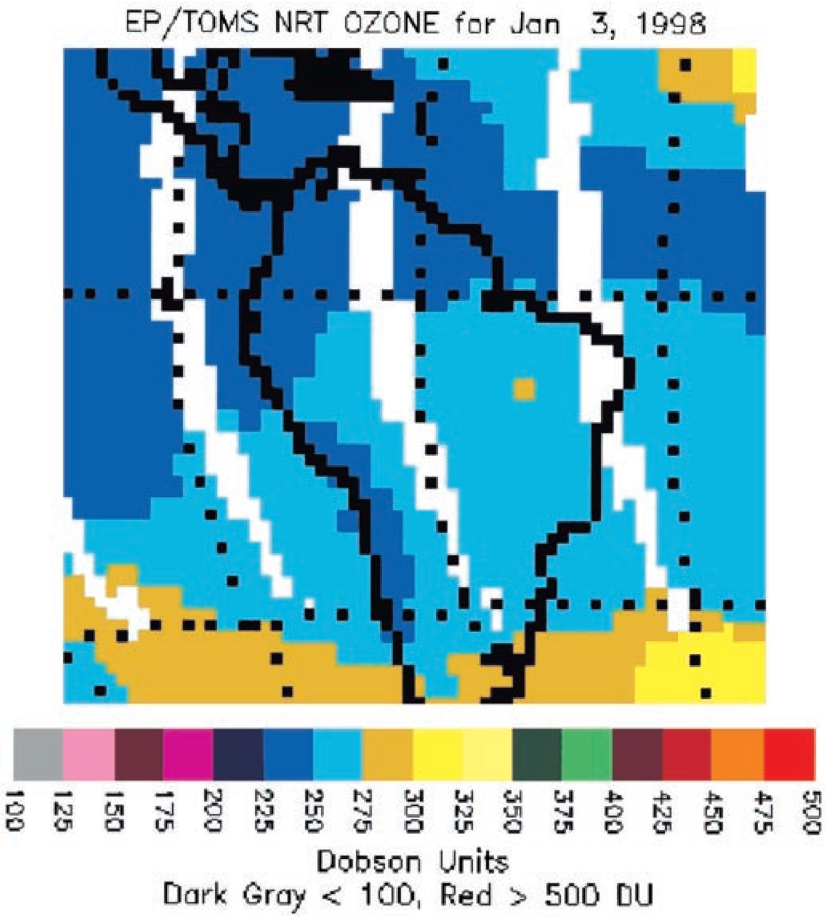

Fig. 2. – Map of the distribution of stratospheric ozone, showing the depletion of the ozone column over the Andes Mountains, January 3, 1998.

2. – Analysis of the data

Information on the decreases in the total ozone column over the Andes region of South America has been available since 1978, the year NASA began publishing data on the subject, and the decreases have been detected principally during the summer season in the southern hemisphere. There exist some cases of decreases in the same region at other times of the year, but only in sporadic fashion. In fig. 1, the depletion is shown for January 2, 1988. The phenomenon can be seen to extend from Ecuador to 30°S latitude. Figure 2 shows the depletion on January 3, 1998, one of various examples of the situation 10 years later in which it may be observed that the ozone decrease now stretches further south.

In order to determine the characteristics of this decrease in the total ozone column, cross-sections of the column were taken using data from NASA's EARTH PROBE/TOMS satellite ([5], 1978–93) for various latitudes in the region at which major urban centres are located: Guayaquil (lat. 2.5°S), Lima (lat. 13.5°S), Arica (lat. 19.5°S), Antofagasta

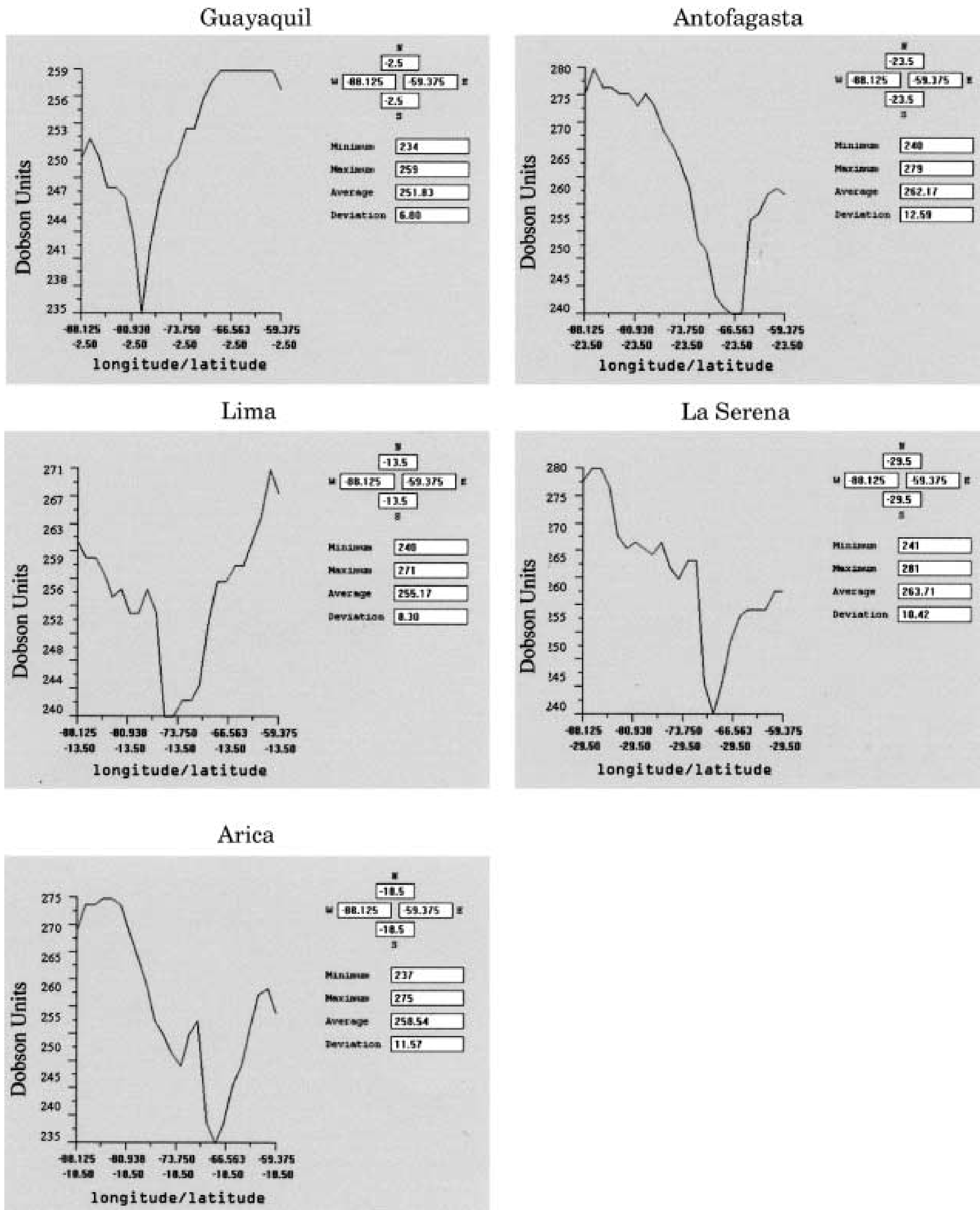

Fig. 3. – Latitudinal cross-sections of the total ozone column over the cities of Guayaquil, Lima, Arica, Antofagasta and La Serena, showing decrease in ozone.

(lat. 23.5°S) and La Serena (lat. 29.5°S). In fig. 3, the cross-sections are shown for January 2, 1988. They clearly reveal the existence of a strip of significant depletion in the total ozone column, flanked on either side by areas of higher ozone density. These lateral high-density areas are not symmetric along the length of the depleted strip, being

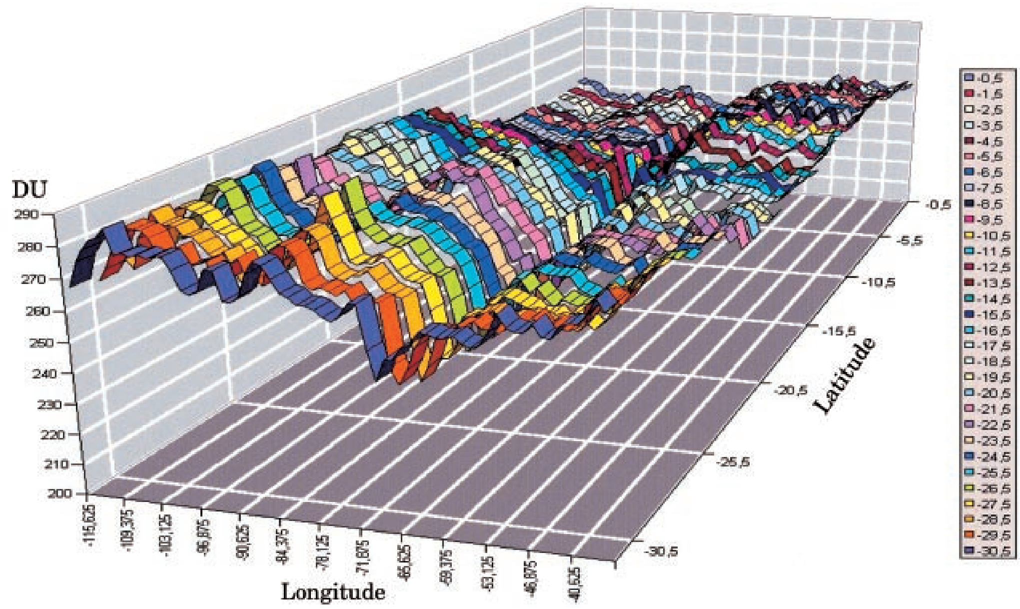

Fig. 4. – Latitudinal cross-sections taken at intervals of one degree, showing the decrease in ozone, in the form of a trough, flanked by asymmetrically distributed areas of higher ozone density.

higher on the Andes side in the more northern parts of the area analysed, and higher on the Pacific side in the southern parts. The minimum points of the depleted zone are located over the Andes range. To analyse the depletion and the same region in more detail a latitudinal sweep was carried out, with cross-sections taken at intervals of one degree between the latitudes 0.5°S and 30.5°S and longitudes 40.625°S and 115.625°S. The results are shown in fig. 4, and indicate that the depleted area in the total ozone column takes the shape of a trough or furrow. The ozone decrease is sharp, displaying an approximate depth of between 20 and 40 UD with respect to the immediately surrounding maxima. The diagram also confirms that the areas flanking the trough are asymmetrical in relation to it. The ozone concentration on the Pacific side is low in the northern region and increases as one moves southward, while on the Andes side the situation is just the reverse. The transition point in this asymmetry occurs at about 15°S. It is important to note that in this part of the Andes there exists a double chain of mountains of comparable altitude that begins at 13°S and that may be responsible for this asymmetry. In fig. 5, a physical map of South America shows the total ozone column minima obtained in this analysis. The maximum depth of this depletion, with respect to the average values was 21.4 DU, and the minimum was 8.3 DU.

The same analysis has been performed on other summertime depletions, as well as on those that occurred in other years, and the results obtained confirm the findings just described.

To check the satellite data on the ozone column, they were compared to data from the ultraviolet B radiation station at the Cerro Tololo Astronomical Observatory, situated 2220 m above sea level at latitude 30°10′S and longitude 70°48′W. At this station, which belongs to the Dirección Meteorológica de Chile, measurement of irradiance is carried out

Fig. 5. – Phisycal map of South America showing the minima of ozone column in the depletion (red points).

by means of a Yankee Environmental Systems ultraviolet pyranometer, model UVB-1, which measures the band between 280 nm and 320 nm. Figure 6 illustrates the agreement between the two types of data: ozone column and maximum intensity of UVB radiation. Note in particular the period between February 25, 1998 and March 3 of that same year, when similar conditions of depletion being analysed here were present. It is clearly observable that an increase in the maximum intensity of UVB radiation coincided with a decrease in the total ozone column, as was expected. This indicates that the decreases in ozone are real phenomena, not simply spurious effects or an erroneous interpretation of the satellite data.

The occurrence of this seasonal decline in the ozone column was further confirmed by the Dobson spectraphotometer readings obtained at the Instituto Geofisico in Huancayo,

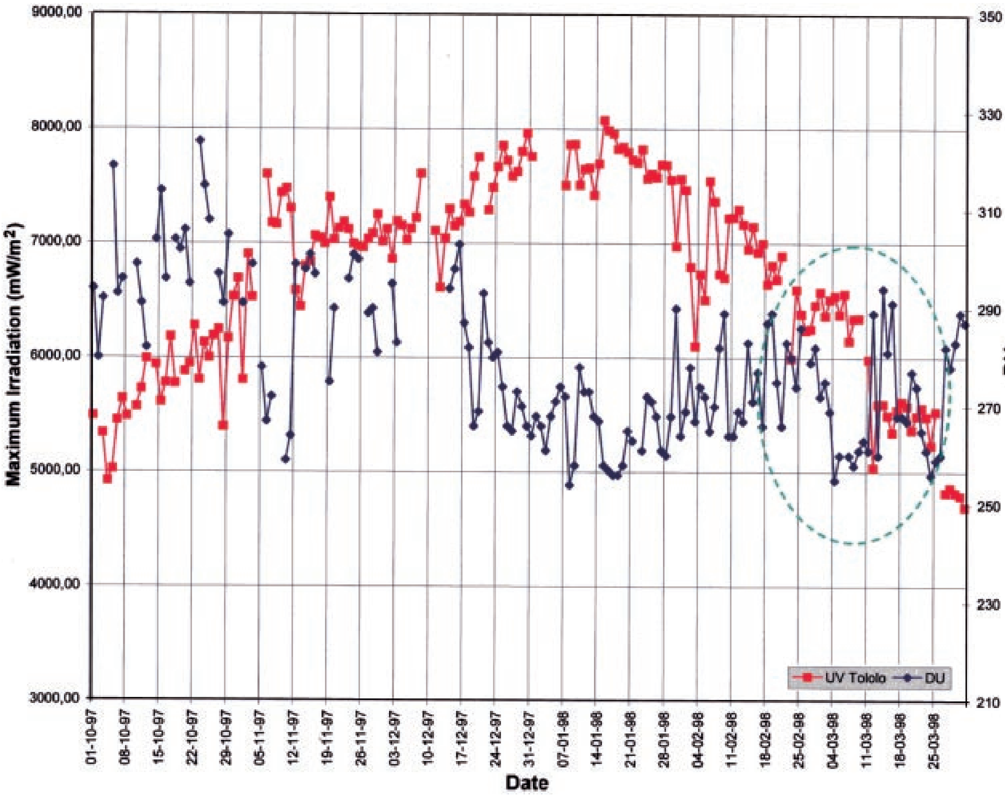

Fig. 6. – Relationship between total ozone column and UVB radiation at Cerro Tololo (30°10′S, 70°48′W). Note in particular the period between February 25, 1998 and March 3, 1998.

Peru, situated 3314 m above sea level at latitude 12°02′S and longitude 75°19′W. On the days during which the decline in ozone occurred over the Andes, a decrease of 15 DU was detected relative to the averages calculated for daily ozone data collected over a period of 29 years.

The depletion in the total ozone column is an anomaly whose existence is undoubtedly due, in part, to the presence of the Andes mountain range, whose peaks reach an elevation approximately 6000 m above sea level. Furthermore, at certain times of the year eastern winds arrive from the Brazilian plains, and on coming into contact with the natural barrier formed by the Andes, strong disturbances are produced which may also affect the ozone distribution. Because of this, it was decided to analyse the winds' velocity fields at various elevations in an area bounded by Ecuador to the north, latitude 33°S to the south, longitude 50°W to the east and longitude 90°W to the west.

The direction and magnitude of the wind velocities were analysed in the horizontal plane in the area of the ozone depletion. The data on horizontal velocity were constructed on the basis of data from the NCEP/NCAR Reanalysis CD [6]. Figure 7 shows a map of wind velocity fields in the above-mentioned area for January 2, 1988 at various elevations: 200 hPa, 100 hPa, 50 hPa and 20 hPa. At 200 hPa the horizontal components of the wind velocities constitute a counterclockwise vorticity centred over southern Peru (15°S by 57°W). At 100 hPa the configuration still holds, with an area of low horizontal velocity

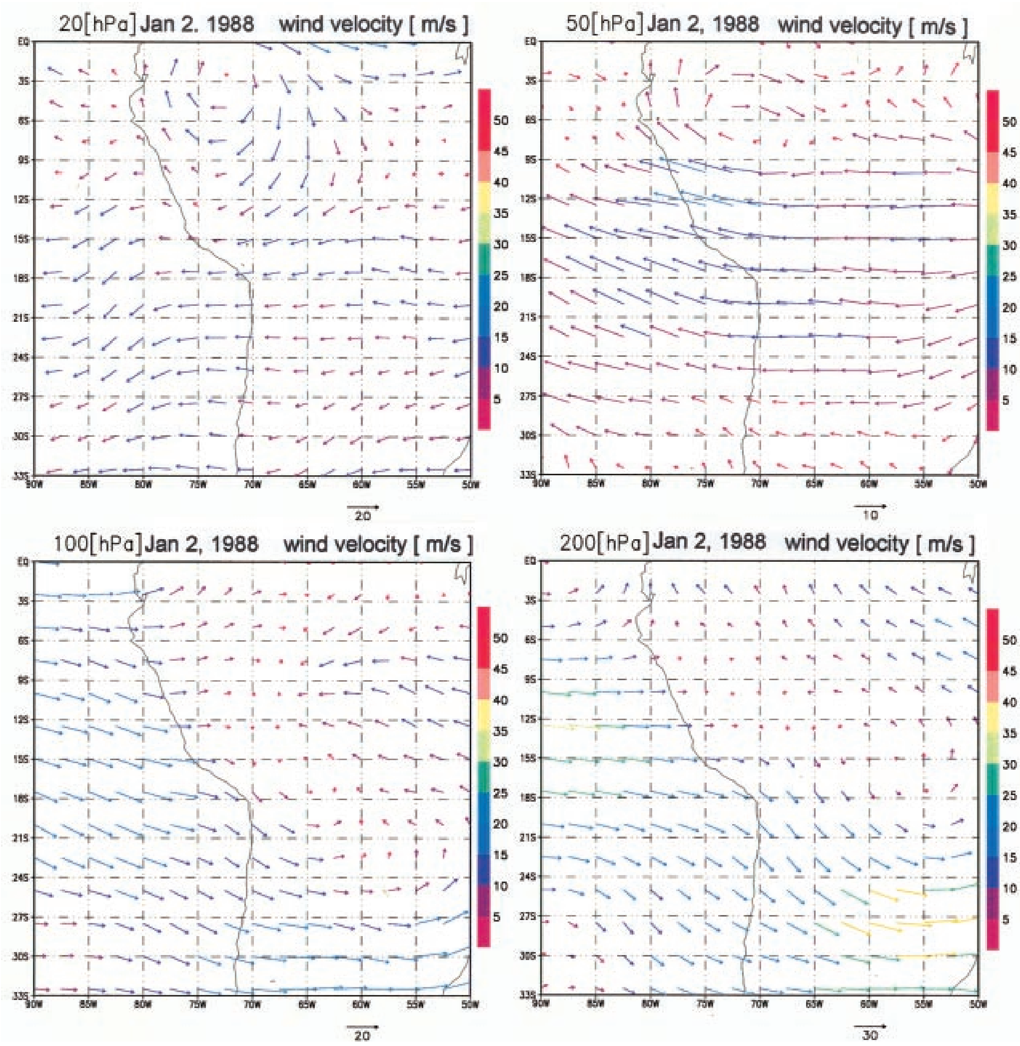

Fig. 7. – Map of wind velocity fields at various heights, showing vorticities of these winds on January 2, 1988.

observed over the Andes. At 50 hPa a long stretch of winds moving towards the west are observed as well as some vorticity in the northern zone, but the latter is now in a clockwise direction. This situation is maintained at 20 hPa. To determine precisely whether the winds produced by these vorticities are moving upwards or downwards, graphs of the vorticities were constructed for the various heights, and are displayed here in fig. 8. The arrows show the direction of the vorticities, and the scale of colours indicate their magnitude. At 20 hPa in the northern zone, the graphs reveal the existence of winds with velocities whose vertical components move downwards over a wide area in which ozone depletion is present. At 50 hPa the centre of vorticity has moved southward, while remaining over the slopes of the Andes. At 100 hPa, on the other hand, the vorticity changes direction, indicating that the winds have velocities whose vertical component

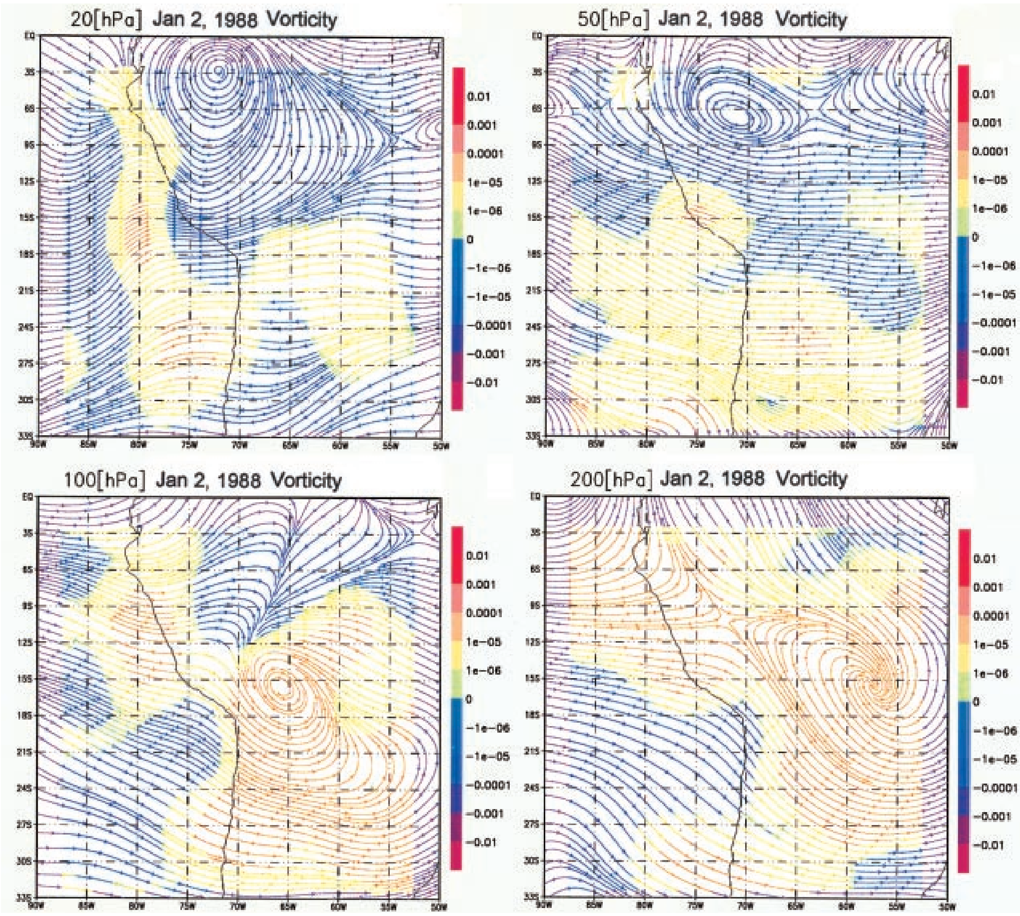

Fig. 8. – Map of vorticities at various heights, showing changes in the direction of vorticity as a function of the height, January 2, 1988.

moves upwards. This continues to hold at 200 hPa, and in the latter case a vorticity in the whole of the ozone depletion zone is clearly noticeable.

A simultaneous follow-up of the ozone map, the horizontal direction of the winds, and vorticity—the latter two at different elevations—established that the ozone decrease is not present when these vorticities are weak or non-existent. This occurs on January 15, 1988, at the end of a period of ozone column depletion over the Andes Mountains. The results of this analysis have been confirmed by the study of depletions which have occurred in the summers of other years.

All the preceding analysis constitutes partial evidence suggesting that the ozone layer is being compressed by winds coming from a higher layer and winds moving upwards from the troposphere, producing a redistribution of the ozone's density.

3. – Conclusion and comments

This study provides evidence that the seasonal decreases in the total ozone column over the Andes mountains range of South America originate in the circulation of winds at various elevations in the affected region. This circulation generates one vorticity which pushes air upwards from below the ozone layer, and another vorticity which pushes air downward from above, thus compressing the layer and producing a redistribution in its density, which results in the observed ozone decrease over the region in question. The reason this occurs mainly in summer has to do with the wind patterns that create the vorticities which in turn account for the ozone decreases. It has been noted that the minimum ozone densities tend to occur to the east of the Andes peaks, leading some authors to claim these mountains as the cause of a thinner ozone layer. It is possible that they contribute to the depletion, but this does not explain the fact that the phenomenon occurs mainly in the southern hemisphere summer.

* * *

I would like to express my thanks to Dr. P. Crutzen, and Dr. F. Jaque, for having encouraged me to undertake this investigation, and to A. Torres, meteorologist, and D. Torres Araya, electronics engineer, both for their collaboration in preparing the vorticity maps and ozone column profiles and for their valuable comments which helped to improve this study. I am also grateful for the support of the Dirección General de Investigación y Postgrado of the Universidad Técnica Federico Santa María, and of the CYTED Project in Spain. Finally, I wish to thank the Dirección Meteorológica de Chile for its collaboration in supplying data from its network of UV radiation station.

REFERENCES

[1] Da Silva L. and Araya D., *The Ozone Layer Depletion on the West Border of South America*, in *Workshop: Understanding Stratospheric Ozone and UV-B Radiation*, Departamento de Ciencias de la Atmósfera, Universidad de Buenos Aires, Argentina, March 9-11, 1998.

[2] Cuevas E., Gil M., Rodríguez J. and Sancho J. M., *El Efecto GHOST (Global Hidden Ozone Structures from TOMS): Posibles Implicaciones Dinámicas*, in *IV Simposio Nacional de Predicción. Memorial "Alfonso Ascaso", Madrid, España, April 15-19, 1996.*

[3] Zaratti F., Andrade M., Forno R. and Palenque E. R., *Nuovo Cimento C*, **22** (1999) 145 and references cited therein.

[4] Da Silva L., *Depletion of the Ozone Column Over the West Coast of South America*, in *Proceedings of the Quadrennial Ozone Symposium, Sapporo 2000, Hokkaido University, Sapporo, Japan, 3-8 July 2000*, pp. 823-824.

[5] Nimbus-7 TOMS Data & Images. Data Record 11/01/1978 - 05/06/1993. Meteor-3 TOMS Data & Images. Data Record: 08/22/ 1991 - 11/24/1994. ADEOS TOMS Data & Images. Data Coverage: 09/11/1996 - 06/29/1997. Earth Probe TOMS Data & Images. Data Coverage: 07/25/1998 - Present.

[6] NCEP/NCAR Reanalysis, Global Atmospheric Analysis, various years. National Centers for Environmental Prediction, Washington DC and National Center for Atmospheric Research, Boulder, CO, USA.