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Presence of stratospheric humidity in the ozone column depletion on the west coast of South America

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Summary. — The ozone column depletion over the western coast of South America has been previously explained, based on the existence of winds in the area of the depletion, which cause compression and thinning of the ozone layer. However, the presence of humidity and methane transported by these winds to the stratosphere where the ozone depletion is present gives evidence that these compounds also participate in the depletion of the ozone layer. These two compounds, humidity and methane, are analysed during the ozone depletion of January, 1998. It is observed that when humidity presents fluctuations, ozone has fluctuations too. A maximum of humidity corresponds to a minimum of ozone, but there is a shift in altitude between them. This shift is observed in the stratosphere and upper troposphere and corresponds to approximately 500 m. It is important to point out that during this event El Niño was present and the sources of methane are the Amazon forest and the Pacific Ocean. The data for this study was obtained from NASA and HALOE.

PACS 92.70.-j – Global change.
PACS 92.60.Vb – Radiative processes, solar radiation.
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1. – Introduction

For decades, depletion of the total ozone column over the West Coast of South America has been detected. These reductions in total ozone can be observed, especially during the

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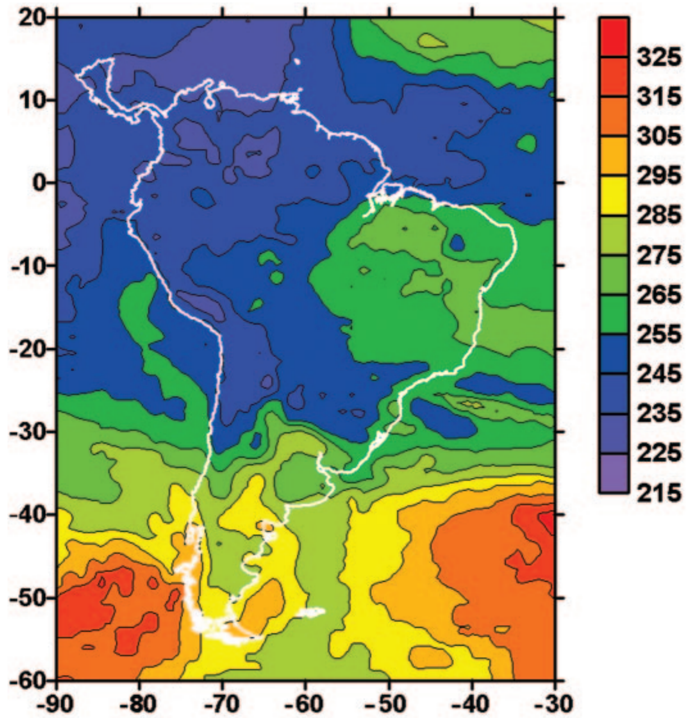

Fig. 1. – Map of the distribution of stratospheric ozone that shows the depletion of total ozone column on west side of South America, January 1st, 1998. EP/TOMS Total Ozone ($1.0° \times 1.25°$).

summer season of the Southern Hemisphere. The area of depletion extends from Ecuador in the north to latitude 30°S in Chile [1]. This depletion strip has its lowest total ozone over the Andes Mountains Range and the width of the depletion strip is from the Pacific Ocean in the west to the eastern edge of the mountain range. An analysis of the velocity of the winds in this area has shown that there is a vertical component to the wind velocity from below up to the ozone layer, compressing it, thereby generating this depletion [2,3]. However, it was recently determined that during the presence of this ozone depletion there was also a high content of humidity present in the same zone. This fact has caused to be considered that if this humidity succeeds in reaching stratospheric regions, it can cause ozone destruction, collaborating in this way in the decline of stratospheric ozone over the West Coast of South America. Observations of water vapour and ozone in the tropical upper troposphere over Juazeiro do Norte, Brazil (7.2°S, 39.3°W), show that when there is an increase of humidity there is a decrease of ozone [4]. In addition, it has been confirmed that for the last fifty years there has been an increase of stratospheric humidity, on the order of a 1%/y increase in stratospheric water vapour [5]. In this study, two compounds that contribute to the stratospheric ozone depletion are analysed. One, the presence of increased amounts of stratospheric humidity over the West Coast of South America and, two, the presence of stratospheric methane in this region. In particular, the depletion that was present in January 1998 will be analysed using the data provided by NASA and HALOE.

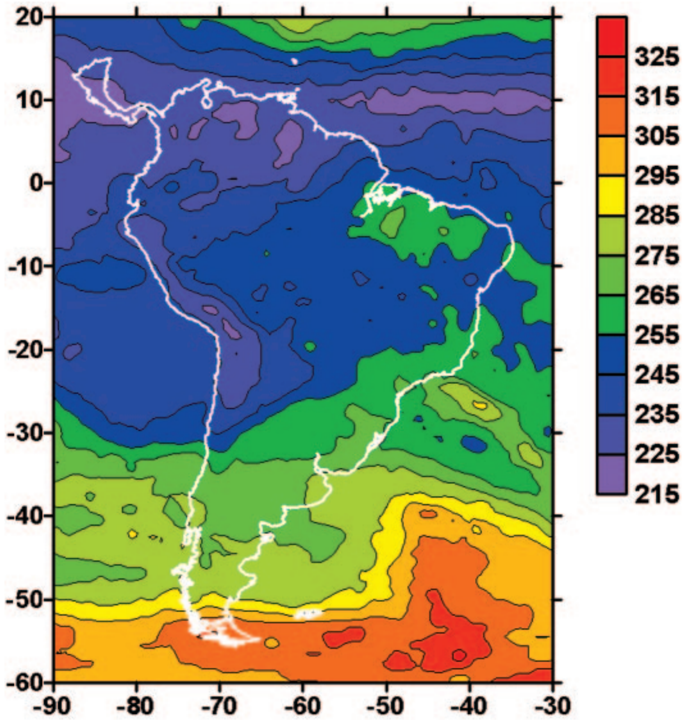

Fig. 2. – Map of the distribution of stratospheric ozone that shows the depletion of total ozone column on west side of South America, January 8th, 1998. EP/TOMS Total Ozone (1.0°×1.25°).

2. – Data analysis

During the summer of 1997/1998 in the Southern Hemisphere, a depletion of the ozone column was present over the West Coast of South America. This event started

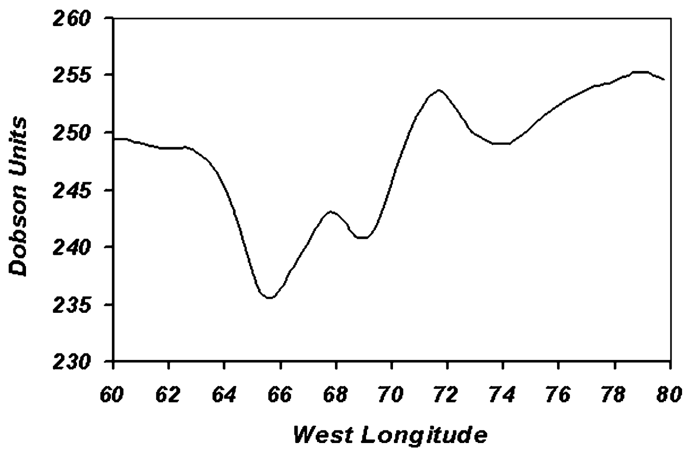

Fig. 3. – Latitudinal cross-section of the total ozone column at 20° S, January 8th, 1998.

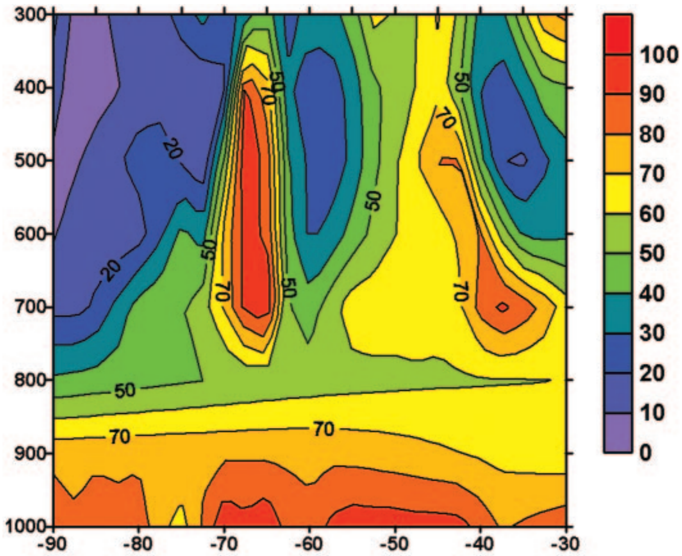

Fig. 4. – Latitudinal cross-sections of humidity at 20° S, January 8th, 1998.

on November 6th, 1997 and ended on March 11th, 1998. There were other events that followed which extended further into 1998. Figures 1 and 2 show two situations of the first depletion event. Figure 1 shows the depletion on January 1st, 1998 and fig. 2 shows the depletion on January 8th, 1998. These figures show how this depletion extends along the coast of South America, reaching as far as latitude 30°S. Figure 1 also shows that this depletion is confined between the Pacific coast and mountainous chain of The Andes; in contrast, fig. 2 shows a wider strip of ozone depletion as it extends out over the Pacific Ocean. Shown in fig. 3 is a latitudinal cut of the ozone layer in the area of Arica (20°S) between the longitudes 80°W and 60°W. This graph shows the minimum thickness of the layer whose value is 229 DU which is located over the mountain range. Towards the edges of this depletion, a rise in value of the ozone column, such as has been detected in other studies. This analysis has been conducted at different latitudes and on different dates of this event, maintaining the characteristics already indicated.

In order to determine if there is humidity in the area of this ozone depletion, several latitudinal humidity graphs during this depletion event were analysed. In fig. 4, a latitudinal cut at 20°S shows the presence of relative humidity of 40% to 300 mb. In this graph, it can be observed that, between 60°W and 75°W, there is a high relative humidity value that reaches as high as 300 mb. This increase is presented as a "chimney" of humidity that coincides with the ozone depletion zone. This humidity chimney is generated by the presence of vertical winds that occur in the zone because of the presence of The Andes Mountain Range. In addition, the graph suggests that this humidity penetrates the stratosphere. To confirm this suggestion, the data provided by HALOE for January 8th, 1998 with 18.95°S / 70.7°W has been applied. In fig. 5 the humidity data provided by HALOE between 12.76 km and 84 km of altitude is shown. Also in fig. 5, ozone is present at different altitudes. It is observed that when humidity presents fluctuations, ozone has fluctuations too. The graph of fig. 6 that belongs to Juazeiro do Norte, Brazil (7.2°S, 39.3°W), shows similar characteristics with respect to humidity and

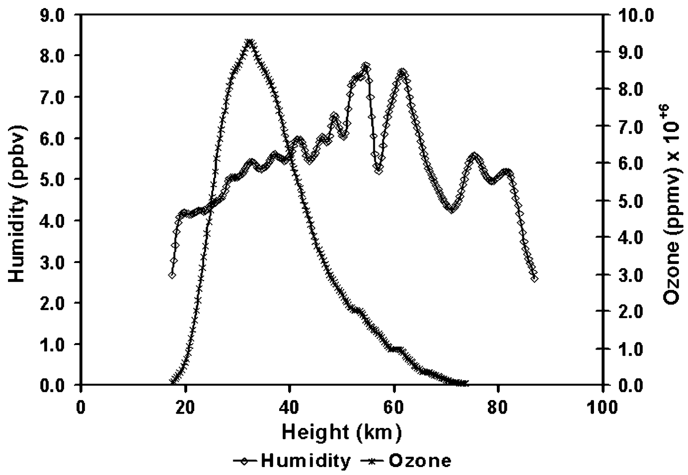

Fig. 5. – Satellite humidity and ozone measurements at 18.95°S/70.7° W between 12.76 km and 84 km (HALOE), January 8th, 1998.

ozone in the upper troposphere but in this case it is clear that when there is a maximum amount of humidity, there is a minimum amount of ozone and vice versa. To be more evident, the same behaviour in the data of ozone and humidity of HALOE given in the graph of fig. 5, a graph of the derivate of concentration of compounds with respect to vertical direction. The results are presented in fig. 7. Now, it is possible in this graph to see how variation of humidity corresponds to variation in ozone. The corresponding

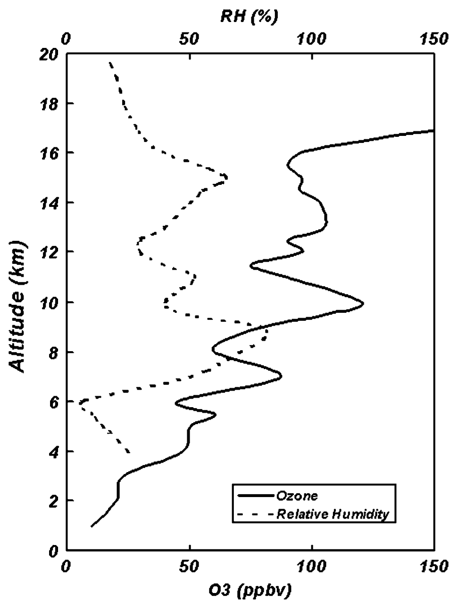

Fig. 6. – Humidity and ozone in the upper troposphere in Juazeiro do Norte, Brasil [4].

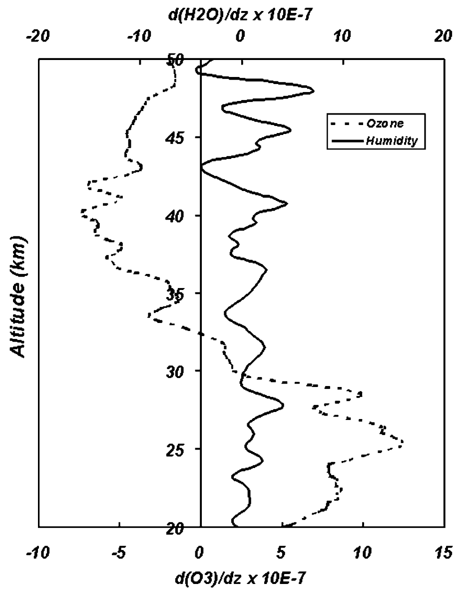

Fig. 7. – Derivate of concentrations of ozone and humidity with respect to altitude z for data of HALOE.

graphs are almost antisymmetric, except between 29 km and 37 km. An increment of humidity corresponds to an ozone depletion. Besides it is important to point out that the maximum of humidity is shifted in altitude with respect to the corresponding minimum of ozone. Maximum of humidity is always lower in altitude than the corresponding minimum of ozone. This shift is observed in the stratosphere and upper troposphere and it corresponds to approximately 500 m in the vertical direction.

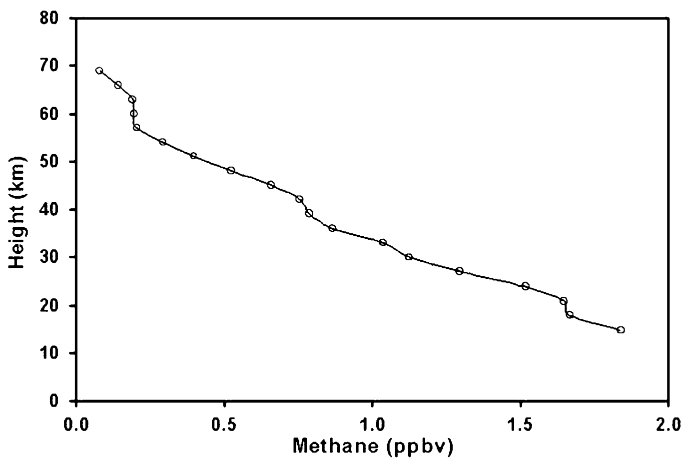

Fig. 8. – Satellite methane measurements at 18.95° S/70.7° W between 14.03 km and 80.40 km (HALOE), January 8th, 1998.

The action of humidity is through a previous reaction with atomic oxygen in an excited state which is produced through the decomposition of ozone by ultraviolet radiation. Humidity plus atomic oxygen generates OH and this, finally, interacts with ozone, destroying the ozone, as is indicated in the followings relations [6]:

$$\begin{array}{lll} O_3 + h\nu(\lambda \leq 320\ \text{nm}) & \rightarrow & O(^1D) + O_2 \\ O(^1D) + H_2 0 & \rightarrow & 2OH \\ OH + O_3 & \rightarrow & HO_2 + O_2 \\ HO_2 + O_3 & \rightarrow & OH + 2O_2 \end{array}$$

Analysing the presence of other components at a stratospheric level, methane is observed. In fig. 8, methane is shown in ppmv, present in the area of this analysis provided by HALOE. This graph shows CH_4 between 14.03 km and 80.40 km of altitude at latitude 18.95°S and longitude 70.7°W. It is confirmed that methane, through a reaction with the radical OH, generates humidity and this humidity contributes to the destruction of the ozone. In addition, it has been determined that for each molecule of methane that oxidises 1.6–2.0 molecules of water vapour are obtained [7,8]. The origin of the methane in the stratosphere can be natural as much as anthropogenic.

3. – Conclusion and comments

It has been previously shown that the depletion of the ozone column over the West Coast of South America is produced by the compression of the vertical winds that act upon the ozone layer. This analysis shows that there are other components that participate in the destruction of the ozone layer: stratospheric humidity and methane. The action of humidity upon ozone has been confirmed by measurements of ozone and humidity on site in other regions. With respect to methane, using measurements in the stratosphere, it has been determined that this contributes humidity after it oxidises and that one molecule of CH_4 produces 1.6 to 2.0 of H_2O [7]. It can be established, by hypothesis, that these components are transported to the stratosphere by the same winds that compress the ozone layer. The existence of this phenomenon is caused by the presence of The Andes Mountain Range, which serves as a barrier to the winds coming from the Pacific Ocean as well as the Amazon Basin. But it shows that the presence of humidity in the stratosphere affects the ozone: A humidity variation of 1% produces a change of 1.6 ppbv of ozone. In addition, there is a shift, in a vertical direction, between the maximum of humidity and the corresponding minimum of ozone and vice versa. In addition the topographic configuration and winds would give an explanation for high UV radiation in northern Chile and western Bolivia in this region. The sources of methane are the Amazon forest and the Pacific ocean. It is important to point out that this analysed depletion occurred when El Niño was present. It is not known to what extent El Niño contributes to the increase of humidity in the stratosphere in this region.

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