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EPISODES OF VERTICAL AND HORIZONTAL OZONE TRANSPORT MONITORED AT ITALY'S MT. CIMONE OBSERVATORY

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ABSTRACT

Variatons in the concentration of surface ozone measured at a pollution-free mountain site from March 1991 to March 1992 are reported and discussed. Two of the ozone-transport episodes are presented in this case study: a stratospheric intrusion recorded in November 1991 and a horizontal transport in August 1991.

1. INTRODUCTION

A great deal of attention has been focused in recent years on the tropospheric ozone concentration, which has doubled in the northern hemisphere over the last century (Bojkov, 1986). A high surface concentration is not only harmful to human health and toxic to vegetation but contributes, along with other trace gases such as CO_2, CH_4, and CFCs, to produce the greenhouse effect - a fact that has important climatic implications. The present study, which is based on measurements of mid-latitude ozone taken at a mountain site in the northern hemisphere far from sources of anthropogenic pollution, provides a brief overview of the seasonal variations in surface-ozone concentration and focuses on two transport episodes. The first deals with a case of vertical transport of stratospheric origin and the second with a horizontal transport of man-made, photochemical ozone that occurred over the Po valley.

2. SITE AND INSTRUMENTATION

The Mt. Cimone Meteorological Observatory (44°12' N, 10° 42' E, 2,165 m asl) is situated atop the highest peak in Italy's north-central Apennines and divides the Po valley from the Tyrrhenian Sea's Gulf of La Spezia (Fig.1). It is accessible by vehicle only via a private road that begins at 1,500 m asl (timberline is at 1,600 m asl) and ends at the entrance to a cable-railway within the mountain itself that covers the final 300 m. The closest inhabited areas are small villages situated 15 km from and about 1,200 m below the Observatory; the large towns are situated in the lowlands about 70 km away. In comparison to the other weather stations in Itlay, Mt. Cimone features the highest recorded wind values (yearly average wind speed about 16 knots). It is thus a privileged vantage point for measuring meteorological parameters and monitoring atmospheric trace compounds (Cundari et al., 1986).

Apart from collecting the usual meteorological data, it has been used since 1979 to measure atmospheric CO_2 in baseline conditions and, since March 1991, for continuous monitoring of surface ozone concentration via a UV Dasibi 1108 photometer. The teflon sampling line runs to the heated air intake 7 m above the ground. The VDC signal is processed by PC via an A/D card converter. An original software package continuously logs concentrations on the hard disk and transforms the data in one-minute averages so as to generate therecorded ten-minute and hourly averages .

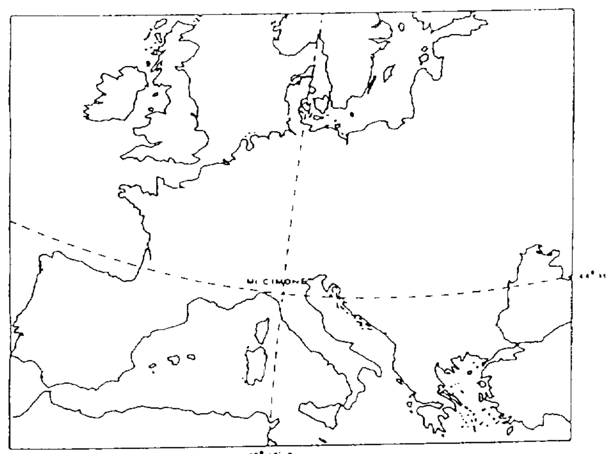

Fig. 1 Measurement site .

3. TRANSPORT PHENOMENA

The reported surface-ozone time series is for continuous measurements taken from March 1991 to March 1992. The monthly averages of O_3 concentrations (fig. 2) clearly evince the yearly variation, which is marked by a main peak in August, a secondary one in May and a minimum in December. The spring peak can likely be attributed to a stratospheric air intrusion, a frequently occurring phenomenon at mid-latitudes at this time (Bojkov, 1985), whereas the summer peak is the result of transport phenomena associated with photochemical production (Austin et al., 1991; Bonasoni et al., 1991) of anthropic emissions in Po valley.
The hourly seasonal averages of the ozone concentrations were also plotted (fig. 3): the readings for late spring and summer show the typical night-maximum and day-minimum pattern. This daily swing in ozone concentration is likely due both to diurnal updrafts, which peak at noon and lift ozone-poor air from the valley woodlands, a trend similar to that recorded at Mauna Loa and at a mountain station in Japan (Oltmans, 1981; Tsuruta et al., 1989), and to the nocturnal

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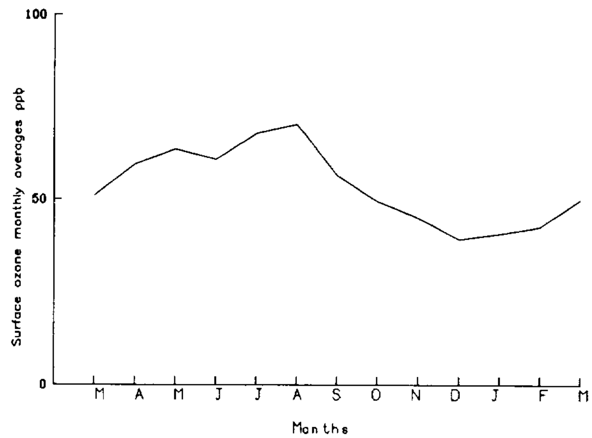

Fig. 2. Yearly trend of surface ozone from March 1991 to March 1992.

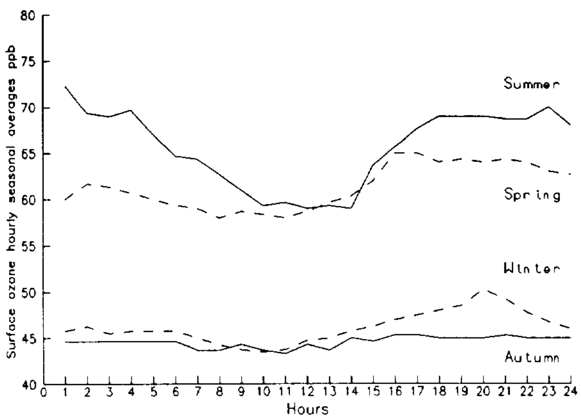

Fig. 3. Hourly seasonal average.

downdrafts, which are marked by prevailing free tropospheric air and background ozone concentrations. The air samples from Mt. Cimone are thus a mixture of free tropospheric air and air masses from the underlying local valleys, although in high pressure conditions persistent inversions confine surface air below the observatory in late autumn, winter and early spring. Daily variability is lower than 5 ppb over the given time span when the mountain's slopes are covered with snow as ozone destruction is held to be slight in snowy conditions (Hakola et al., 1991). By contrast, the daily swing in late spring, summer and early autumn peaks at 20 ppb. A similar, seasonally oriented daily swing is also found upon analysis of the twelve-year data for CO_2 concentration values registered at Mt. Cimone, a pattern resulting from the effect on mid-day values of vegetative uptake from the surrounding valleys (Cundari et al., 1986).

An examination of the hourly average surface-ozone values shows two types of event: rapid consistent increases in concentration (two-four orders of magnitude) as compared to the seasonal average associated with stratospheric intrusions linked to upper tropospheric lows, and concentration increases more limited in extent yet of greater duration that are linked to horizontal transport phenomena occurring mainly in summer in conjunction with high pressure and temperature. An intrusion of stratospheric air is usually associated with a surface cold front stemming from a cyclonic vortex. The air from such an intrusion is marked by high values of both potential vorticity and ozone and low values of water vapour with respect to upper tropospheric air (Danielsen et al., 1968; 1987; Buzzi et al., 1984; Hoskins et al., 1985; Appenzeller et al., 1992).

Several of these stratospheric intrusions were registered over the survey year but did not occur in any one particular season. One such episode of a rapid increase of ozone concentration is here examined by correlating it to the overall meteorological situation in Europe at the time of the event, to the potential vorticity (PV) map of 350° K isentropic surface, to an image of radiance measurement in the water vapour band, and to local wind speed and direction.

This first event covered the period from 24 to 26 November 1991, which was characterized by the presence in the Mediterranean Basin of a cut-off low moving slowly northeastward that retained its intensity throughout the monitored period. The meteorological picture on 24 November 1991 at 300 hPa (fig.4) shows the cut-off low in southern Europe: the ozone values registered at Mt. Cimone on this date rose abruptly to a peak of 120 ppb on 25 November. Figure 5 shows the hourly average surface ozone, along with synoptic measurements of wind speed and prevaling direction, as measured at Mt. Cimone.

An analysis of these data indicates the drop in ozone concentration and the sudden shift of the prevailing wind direction associated with high speed values. The PV map for 24 November shows a zone of high PV, about 700 1E-8 K m^2 Kg^{-1} s^{-1} (fig. 6), extending eastward of the low (Knudsen, 1992): this value is typical for air stemming from the lower stratosphere (Keyser et al., 1986). On the same date the dry stratospheric air slanted several kilometers into the troposphere: this is shown in fig. 7 by the water vapour image (5.7-7.1 μm band, supplied by METEOSAT 4) where a dark dry band with a vortex-like structure appears as an effect of the altered radiance properties of part of the low. The contemporary events recorded over the same period clearly indicate the occurrence of a stratospheric air intrusion.

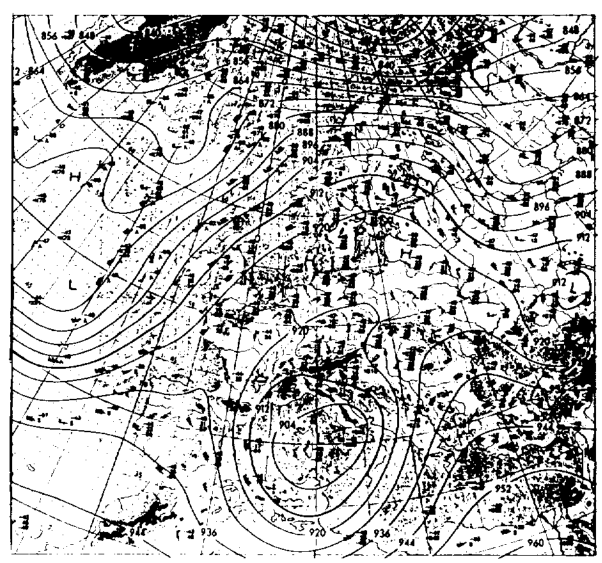

Fig. 4. Meteorological chart on 24 November at isobar 300 hPa, Deutscher Wetterdienst.

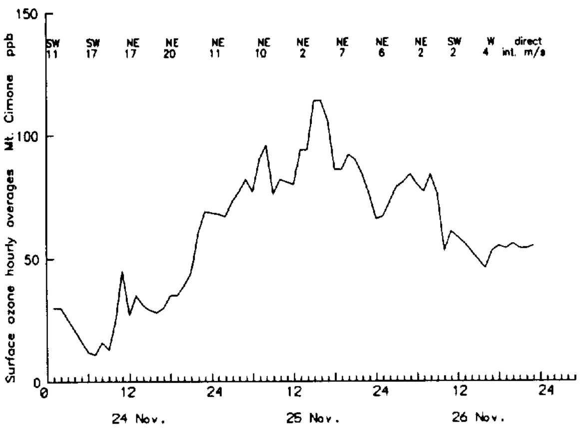

Fig. 5. Ozone concentration recorded on 24-26 November 1991 and synoptic measurements of wind direction and speed recorded at Mt. Cimone observatory.

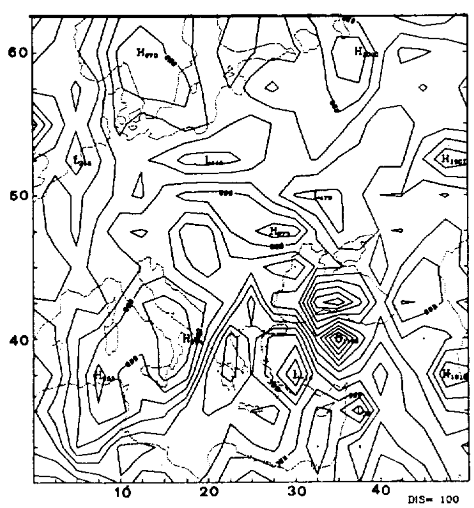

Fig. 6. Potential vorticity distribution on the 350 °K isentropic surface in central and eastern Europe (as 100 contour spacing; 1 E-8 K m^2 Kg^{-1} s^{-1} measurement unit) on 24 November 1991.

Fig. 7. Map of radiance in the water vapor band (5.7-7.1 μm) coded in grey-scale for Europe at 12:00 GMT on 24 November 1991.

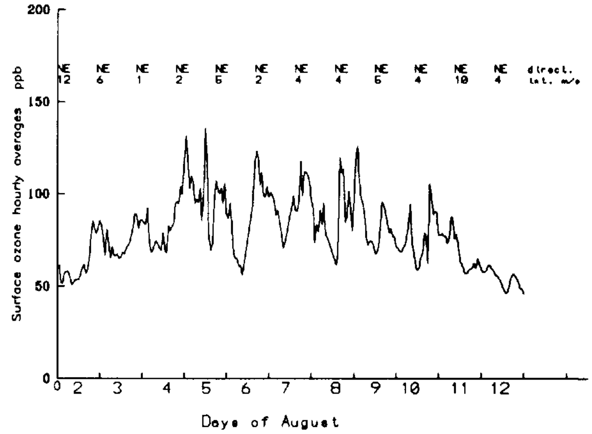

Fig. 8. Ozone trend, wind direction and speed recorded from 2-12 August 1991 at Mt. Cimone observatory.

Fig. 9. Meteorological surface chart on 6 August 1991, Deutscher Wetterdienst.

A marked increase in ozone (fig. 8) over the seasonal average (fig.3) was recorded at Mt. Cimone from 2-12 August 1991. Of the concomitant factors contributing to the interpretation of this episode, the stationary high pressure system extending in the surface chart (fig. 9) from southern to northeastern Europe, with a peak northeast of Italy, is the most essential. Accompanied by high values of solar radiation intensity, it produced high readings of ozone concentration over the Po valley (Giovanelli et al., 1985; Bonasoni et al., 1991; Georgiadis et al., 1992), a source of anthropogenic pollution in northern Italy. Fig. 10 shows that at the San Pietro Capofiume (45°N, 12°E, 10 m asl) station in the Po valley the ozone sounding for 5 August 1991 exhibits a distinct shift from the yearly average trend, the peak surge occurring at about 2 km in height - a level that coincides with the altitude of the Mt. Cimone site. This ozone-rich air was transported over the Mt. Cimone station by the weak north-east air circulation (fig. 8). At the same time, the daily swing of the ozone concentration registered at Mt. Cimone shows a nocturnal peak, which is probably due to the daily alternating of up- and downdrafts (*supra* and Oltmans, 1981).

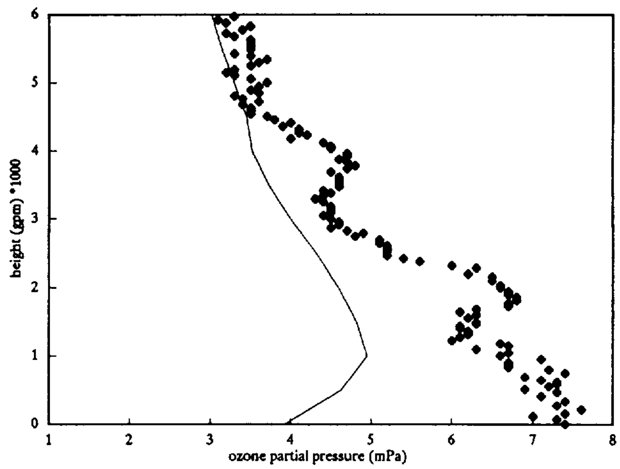

Fig. 10. Ozone concentration profile as measured at San Pietro Capofiume (45°N, 12°E), Po valley, Italy. Dots: 5 August 1991 ozonesounding. Solid line: yearly average over 1991-1992.

4. CONCLUSIONS

The extent to which the surface ozone concentrations recorded at Mt.Cimone are similar to other readings from mountainous, pollution-free stations (Oltmans, 1981; Tsuruta et al., 1989) is such that the former can be considered a baseline station for the monitoring of trace gases. The only exception would be the concentrations registered in summer that are affected by local diurnal mixing with ozone-poor low tropospheric air upwelling at noon (removal of these influences by excluding mid-day values so as to yield free tropospheric ozone concentrations will be undertaken).

Given its location in a cyclogenetic area like the Mediterranean Basin, Mt. Cimone can also be considered a suitable station for monitoring stratospheric air intrusion. This because episodes of high surface-ozone concentrations from stratospheric air intrusions are most likely to occur when cyclonic activity over southern Europe, i.e. autumn, winter and spring, is most likely to occur. By contrast, in summer, when extensive and persistent high-pressure systems are most frequent, it is horizontal transport phenomena that increase ozone concentrations.

5. ACKNOWLEDGEMENTS

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