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Stratosphere-troposphere exchanges: case studies recorded at Mt. Cimone during VOTALP project

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Abstract. In order to point out and study transports of ozone rich air masses in the lower troposphere from the stratosphere/upper troposphere, continuous measurements of several parameters have been undertaken at Mt. Cimone during the European Community VOTALP project (Vertical Ozone Transport in the Alps). Several high values of surface ozone concentration due to vertical stratospheric-tropospheric exchanges have been recorded in the four mountain peak stations involved in this project (Jungfraujoch, Sonnblick, Zugspitze and Mt. Cimone) in 1996-1997. This paper presents and analyses data concerning the Mt. Cimone ground-based station, which is the highest peak of the Italian Northern Apennines and the most representative WMO-GAW site in Italy. Episodes of vertical exchange in the lower stratosphere, as tropopause folding, or in the upper troposphere, as down draft transport, have been registered at Mt. Cimone since March 1996 and subsequently studied. In fact, the comparison between the behaviours of different background trace gases at a mountain baseline station, the weather situations and the backward trajectory analyses can bring to light these events and be very useful for a better knowledge of transport phenomena. Correlation between high level of ozone concentration, chemical and meteorological parameters and three-dimensional backward trajectories relative to two particular events are herein presented.

1 Introduction

A contribution to stratospheric-tropospheric exchanges and related ozone downward transport studies (Beekmann et al., 1994; Davies et al., 1994; Elbern et al., 1997, Reiter 1983, 1990) can be supplied by the VOTALP project in which one of the four work packages concerns the study of these phenomena, and in particular, the effects that stratospheric intrusions may produce on the Alpine ozone concentrations. These investigations involve four high mountain peak stations which provide continuos measurements of ozone and other related atmospheric compounds. Mt. Cimone (2165 m a.s.l.) is one of these stations, the only one south of the Alps and close to an area particularly favourable to intense cyclogenesis (the Gulf of Genova). The measurements carried-out at this station, allow the continuous monitoring for the first time of stratospheric intrusion episodes in a mountain representative site, as the high northern Apennines. A preliminary evaluation of the Mt. Cimone measurements connected to stratosphere-troposphere exchange studies performed during the VOTALP project and two representative episodes of stratospheric intrusions are presented in this paper.

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2 Data selection and analysis

The MTC surface ozone concentration presents usually a minimum in winter, a principal maximum in summer and a secondary one in spring while a typical reverse diurnal variation is present during the warm season. The ozone hourly mean value statistical analysis conducted on the 1996 data shows that 2% of them exceeded 80 ppbv while 65% were included in the range of 40-60 ppbv. We can quantify in 26 the episodes connected to stratospheric intrusions recorded at Mt. Cimone (2165 m a.s.l.) during the 1996-1997 period. This value agrees with that observed by Reiter (1990), 1-2 days per month, and Elbern et al. (1997), 195 over a 10 year period, at the Zugspitze summit (2962 m a.s.l.) in the northern Alps. These Mt. Cimone episodes - besides by meteorological analysis - have been identified by an evident increase in the ozone concentration, a lowering in relative humidity, high origin levels of the air masses traced by backward trajectories and high Be-7 concentrations. Unfortunately, only 45 Be-7 measure-

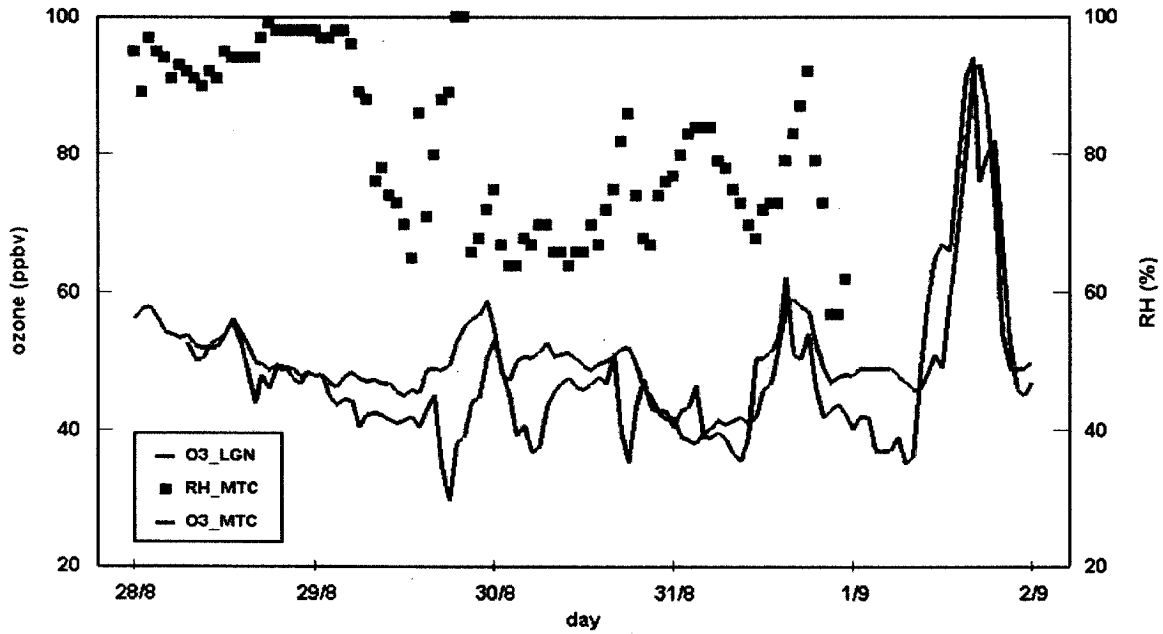

Fig. 1. Ozone concentrations (continue) and relative humidity values (symbol) at Mt. Cimone, with ozone concentration at Lago della Ninfa (dotted) during the August 29-30 episode.

ments were available at the site in 1996-1997: of these, 13 values exceeded 8 mBq/m^3 (max. 23.6 mBq/m^{3}on July 8, 1997). This is the value suggested as threshold above which the Be-7 can be considered of stratospheric origin.

The analysis of the ozone data recorded when the Be-7 concentrations were more than 8 mBq/m3, showed a mean ozone concentration of 64 ppbv against a yearly mean of 54 ppbv in 1996 and 60 ppbv against 55 ppbv in 1997. This confirms that elevated concentrations of Be-7, characteristic of air masses coming from the upper troposphere-lower stratosphere, are always associated to ozone concentrations that are definitely higher than their mean value.

These events recorded at Mt. Cimone, have shown themselves as deep intrusions or as intrusions of a more moderate strength, sometimes more difficult to reveal. In fact, in the latter case, an elevated mountain station can be reached by air masses of stratospheric origin after their chemical-physical composition could have been modified by dilution, dispersion or removal processes when they passed through the troposphere. In these cases the ozone concentration might have suffered significant variations and to identify if this ozone is characteristic (totally or in part) of high altitudes, we have tried to correlate the Mt. Cimone ozone concentration together with boundary layer tracers, as CO, and Rn-222 or Pb-210 (Bonasoni et al., 1997). Moreover, measurements of cosmogenic Be-7 ($t_{0.5}$=53.3 d), P-32 ($t_{0.5}$=14.2 d) and their activity ratio will allow to obtain reliable indication of whether the stratospheric air mass was recent or not. Similarly the ratio Be-7/Pb-210 should supply information about the presence of boundary layer air in the considered air mass.

In this paper we present two episodes recorded at Mt. Cimone: in the former the measurement of the chemical compounds allowed to clearly identify the stratospheric intrusion event, while the latter, although of moderate strength, was identified at two different altitudes and followed by a photochemical ozone horizontal transport.

3 Case studies

3.1 May 30-31, 1996.

This episode has been thoroughly studied in the VOTALP project. The air masses which reached Mt. Cimone on May 30 and 31 passed over the Balkan tropopause folding area, as confirmed by the backward trajectories analysis calculated with FLEXTRA model (Stohl et al., 1995). The levels of Be-7 concentration recorded on May 29-30 (17.6 mBq/m^3) and May 31-June 1 (15.5 mBq/m^3) together with those of Pb-210 (0.38, 0.68 mBq/m^3) and high values of Be-7/Pb-210 ratio (38.5 and 18.8 respectively) unambiguously showed the characteristics of the stratospheric air mass. In the

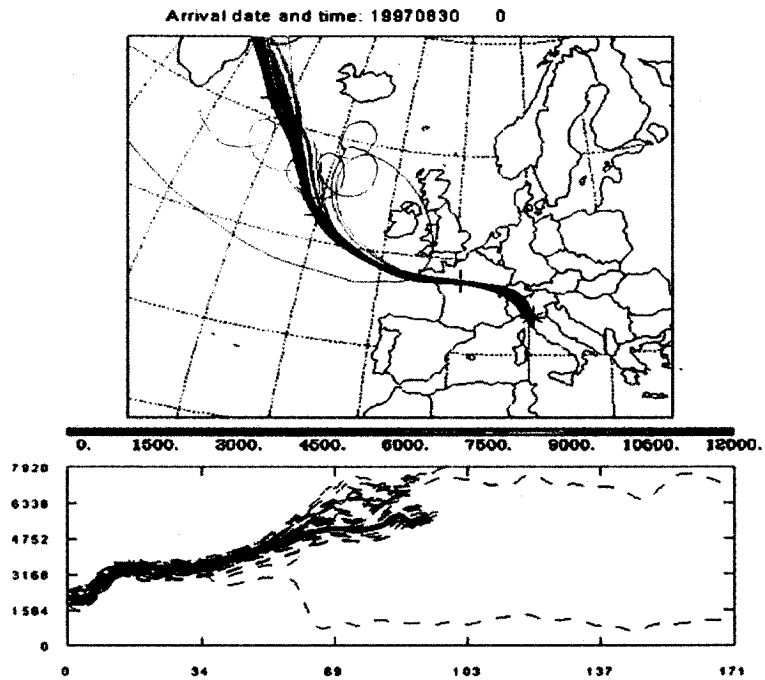

Fig. 2. Backward trajectory ensemble arriving at Mt. Cimone on August 30, 1997, 0 UTC. Hours before the arrival at MTC are reported on the x-axis; altitudes (m) on the y-axis.

evening of May 30, Mt. Cimone was reached by very dry air masses for a period of more than 12 hours characterised by an ozone concentration which doubled up to 100 ppbv in the morning of May 31. Here we highlight the fact that during this period the relative humidity was around 0% and very low values of Rn-222 and an almost constant concentration of CO (195 ppb) were recorded. This last value suggests that, even if the air undoubtedly was of stratospheric origin (see RH, Be-7 and Pb-210 values on May 29-30), it passed and mixed in the lower troposphere (see CO, Pb-210 on May 31 and June 1) and was transported downward under a subsidence regime. This is confirmed by the strong positive correlation between ozone and pressure and between ozone and temperature at Mt. Cimone during the last days of May (.84, .81, respectively) in comparison with the other days of the month (.42, .42).

3.2 August 29, 1997.

This is an interesting episode, because. even if the intrusion results in a relatively moderate effect at our ground monitoring station, the origin of upper air mass is confirmed not only by the measurements performed at Mt. Cimone, but also by three-dimensional backward trajectories and water vapour satellite maps. Moreover, this intrusion was also revealed at Lago della Ninfa - another lower station.

The meteorological analysis shows an upper trough at 300 hPa (August 29, 12 UTC) located over the central-eastern Alps while the surface situation was characterised by the transit of a low pressure system. A sharp ozone increase from 45 ppbv up to 60 ppbv and a simultaneous decrease of relative humidity (Fig. 1), together with a low level of Rn-222, were registered at Mt. Cimone during the night between August 29 and 30. The origin of the air mass is traced by the three dimensional backward trajectories ensemble calculated for 00 hours of August 30 and shown in Fig.2. On this occasion the intrusion reached lower levels than MTC: in fact, a similar increase of ozone was recorded at Lago della Ninfa (Fig. 1), situated beside Mt. Cimone, in N-NE direction about 1550 m a.s.l.. At the end of August and beginning of September high concentrations of photochemical ozone produced and accumulated in the Po valley were transported and recorded (100 ppbv) first at Lago della Ninfa and after a short time at Mt. Cimone. The characteristics of these two different transport phenomena have been evidenced by the fact that during the vertical transport episode, the maximum of ozone concentration reached first Mt. Cimone (2165 m) and afterwards Lago della Ninfa (1550 m). The higher concentration value was reached at the highest station while, during the horizontal episode, almost the same ozone concen-

tration was recorded at two different time periods - first at Lago della Ninfa and later at Mt. Cimone. In this occasion the contribution of photochemical ozone transport to the background ozone concentrations at a mountain site was clearly predominant compared to the upper stratospheric ozone transport.

4 Conclusion

Although stratosphere-troposphere exchange phenomena associated to transports of ozone rich air masses down to ground have been studied by several authors (Beekmann et al., 1994; Davies et al., 1994; Elbern et al., 1997, Reiter 1983, 1990; Singh et al., 1978), an accurate characterisation of these phenomena as stratospheric intrusion episodes has always been fairly difficult. This is mainly due to the fact that stratospheric intrusions normally occur both on a limited spatial extension and a short time scale resolution (Elbern et al., 1997); furthermore, they can rarely reach low altitudes (Reiter, 1990) and owing to the exiguous number of measurement stations operating at high altitudes, the identification of stratospheric intrusions is often rather problematic.

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