Rotational Raman Lidar measurements for the characterization of a dry stratospheric intrusion event

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ABSTRACT

A UV Raman lidar system (*BASIL*) is operational at DIFA-Univ. of Basilicata (Potenza-Italy). The system was recently involved in *LAUNCH 2005* – the International Lindenberg campaign for assessment of humidity and cloud profiling systems and its impact on high-resolution modelling - held from 12 September to 31 October 2005. During this period *BASIL* collected approx. 250 hours of measurements distributed over 13 Intensive Observation Periods (IOPs) and 25 days. One specific IOP was continuously run between 1-3 October 2005, covering a dry stratospheric intrusion episode associated with a tropopause folding event and the subsequent onset of perturbed weather conditions that leaded to the development of clouds and precipitations. The use of water vapour to trace stratospheric air intrusion allows to clearly identify a dry structure (approx. 1 km thick) originated in the stratosphere and descending in the free troposphere down to ~ 3 km. A similar feature is present in the temperature field, with lower temperature values observed within the dry air tongue. Relative humidity measurements reveal values as small as 0.5-1 % within the intruded air. The stratospheric origin of the observed dry layer has been verified by the application of a Lagrangian trajectory model. The subsidence of the intruding heavy dry air is most probably responsible for the gravity wave activity observed beneath the dry layer.
Lidar measurements have been compared with forecasts from a MM5 mesoscale model. Comparisons in term of water vapour reveal the capability of the model to forecast the deep penetration in the troposphere of the dry intruded layer.

1. INTRODUCTION

Tropopause folds are the dominant and most efficient mechanism of stratosphere-troposphere exchange (STE) in the middle latitudes. Tropopause folds are events in which the boundary between the stratosphere and the troposphere folds into the troposphere, frequently leading to dynamical instability, enhanced turbulence [1] and chemical mixing between the two levels. Tropopause folds lead to the intrusion into the troposphere of stratospheric air that sinks into the baroclinic zone beneath the upper tropospheric jet stream. Folds usually take place on the western flank of cutoff low systems. Clean, dry stratospheric air, rich in ozone and potential vorticity, is transported downward to tropospheric levels. Intruding stratospheric air forms filamentary features in ozone and water vapour profiles [2]. These filaments can subside deep into the troposphere, triggering severe weather events and high wind speeds at the surface [3]. Finally, these features are destroyed by turbulence [1], which can be generated by convection, breaking gravity waves, wind shear and radiation. Little is known about the timescales of dry stratospheric air mixing with surrounding tropospheric air. Raman lidars including temperature measurement capability are very suitable tools to resolve the spatial an temporal scales of these atmospheric features and to provide information about their evolution.

2. LIDAR DATA & MESOSCALE MODELLING

Lidar measurements discussed in this paper were performed in Potenza (40°38'45"N, 15°48'32" - Southern Italy) by the DIFA-Univ. of BASILicata Raman lidar system (*BASIL)*. The major feature of *BASIL* is its capability to perform high-resolution and accurate measurements of atmospheric temperature, both in daytime and night-time, based on the application of the rotational Raman lidar technique in the UV [4]. Besides temperature, *BASIL* is capable to provide measurements of particle backscatter at 355 and 532 nm, particle extinction at 355 nm, particle depolarization at 355 and water vapour mixing ratio both in daytime and night-time. Relative humidity measurements are obtained from simultaneous water vapour and temperature measurements. These parameters represents a suitable ensemble of measurements for the study of meteorological processes.
The Penn State University/National Center for Atmospheric Research (PSU/NCAR) MM5 mesoscale model is running operational at CETEMPS – University of Aquila [5]. This is a limited-area, non-hydrostatic, terrain-following sigma-coordinate model designed to simulate or predict mesoscale and regional-scale atmospheric circulation. The configuration used for the present experiment considers 3 two-way-nested domains (27 km the mother, 9 km and 3 km the nested) and 29 vertical sigma levels.

ECMWF data analyses are used for the initial and boundary conditions; the model simulation starts at 1800 UT on October 1, and lasts for 48 hours. Runs from this model are considered for comparison with lidar measurements and results are discussed in the next session. The assessment of the impact of lidar data assimilation on model output is on the way based on the use of data from single and multiple lidar stations.

3. RESULTS

Although stratosphere-troposphere exchange processes associated with mid-latitude tropopause folding episodes have been widely studied over the last four decades using both observational case studies and numerical models, in literature there is a limited number of case studies characterising the evolution of deep intrusion events based on both measurements and modelling. In the present paper we illustrate the measurements carried out by a rotational Raman lidar system to characterize a stratospheric air intrusion event on its way down to the lower troposphere. Water vapour lidar measurements during stratospheric intrusions and tropopause fold events have been reported among others by D'Aulerio et al. [6]. The present paper represent to our knowledge the first reported measurements of these phenomena based on the application of a lidar system with both water vapour and temperature measurement capability.
Fig. 1 illustrates the time evolution of specific humidity q over a period of approx. 32 hours from 18:05 UT on 1 October 2005 to 02:15 UT on 3 October 2005. Measurements were stopped shortly afterwards because of the onset of thick clouds and precipitation. The figure covers both the night-to-day and the day-to-night transition, with the daytime portion clearly distinguishable at the center of the measurement record with noisy data above approx. 4 km. Fig. 1 is plotted as a succession of 10 min averaged consecutive profiles. In order to reduce signal statistical fluctuations, vertical smoothing is applied to the data to achieve an overall vertical resolution of 75 m up to 5 km and of 150 m above. Two distinct dry laminae are observed between 18:05 UT on 1 October 2005 and ~ 06:30 UT on 2 October 2005: an upper lamina with a vertical extent of 1-1.5 km showing a descending trend from an initial altitude of 6-7 km down to approx. 3 km and a lower lamina with an almost stable altitude of 2-2.5 km and a vertical extent of 0.5-1 km. The upper lamina is found to descent with an apparent fall speed of 220-250 m/h. The upper lamina has been identified to be associated with the intrusion of dry stratospheric air, as revealed by the back-trajectory analysis illustrated in fig. 6. The two laminae appear to merge into a single layer after 06:30 UT and vanish around 14:30 UT on 2 October 2005. Fig. 1 reveals large humidity gradients in the vicinity of the intrusion, with very dry air within the intrusion (q less than 0.5 g/kg) and very moist air ahead of the intrusion (q in excess of 2 g/kg). Values of q within the intrusion are consistent with air originating in the lowermost stratosphere, while increased values ahead of the intrusion are consistent with deep convection which rapidly transports moist air from the lower into the upper troposphere.

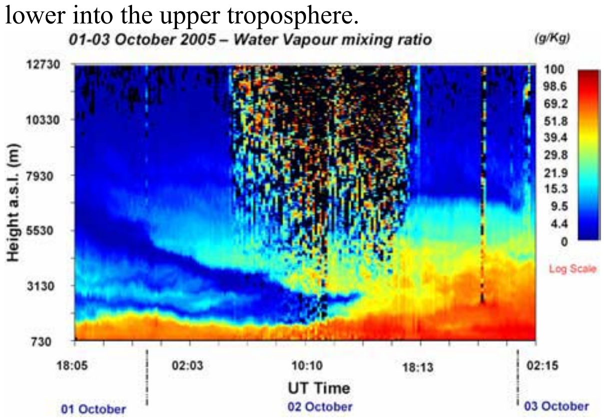

Fig. 1: Time evolution of specific humidity from 18:05 UT on 1 October 2005 to 02:15 UT on 3 October 2005.

Fig. 2 illustrates a sub-portion of fig. 1, specifically focusing on the night-time part of the dry intrusion event. This sub-section extends for period of approx. 14.5 hours from 18:05 UT on 1 October 2005 to 08:25 UT on 2 October 2005. Data in this figure are characterized by a higher vertical and temporal resolution (60 m and 1 min, respectively) in order to highlight the fine structures in the water vapour field. This figure reveals a strong wave activity in the low troposphere, most probably activated by the subsiding heavy dry air intruded from the stratosphere. The propagation of gravity waves is clearly highlighted by the wavy structure of the humidity filaments observed between 3 and 4 km. The presence of intense wave activity is confirmed by both MM5 vertical wind velocity w and water vapour mixing ratio q. Fig. 3 represents w (black solid positive and dashed negative lines) and q (grey lines) at 21:00 UT on 1 October 2005 covering a 190 km transect along the 40°38'N parallel. Potenza is located approximately at the middle of the transect. The figure reveals the alternation of cells with positive and negative values of w in the 750-900hPa region in the proximity of Potenza, which confirms the presence of an intense wave activity at these levels. Moreover, q is clearly modulated by the wave activity up to 700hPa, whereas the intrusion of dry air is shown by the compressed structure on the western side, expanding eastward where moist air is present. This produces an upward (from east to west) tilting of the curves.

Fig. 4 illustrates the time evolution of atmospheric temperature over the same 14.5 hour period of fig. 2. Vertical and temporal resolution of temperature data are 300 m and 10 min, respectively. Temperature data faithfully reproduce the tongue-shaped feature present in the humidity field, with colder temperatures observed within the dry air tongue. Fig. 5 illustrates the relative humidity field as obtained from the simultaneous lidar measurements of specific humidity and atmospheric temperature. Relative humidity values as small as 0.5-1 % are measured within the stratospheric intruded air, while the lower dry lamina at 2-2.5 km is characterized by relative humidity values of 5-10 %.

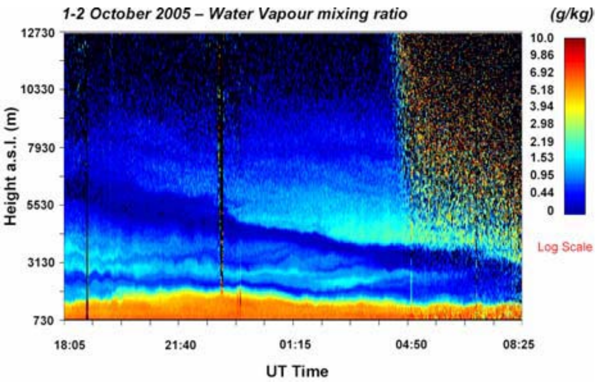

Fig. 2: Time evolution of specific humidity from 18:05 UT on 1 October 2005 to 08:25 UT on 2 October 2005.

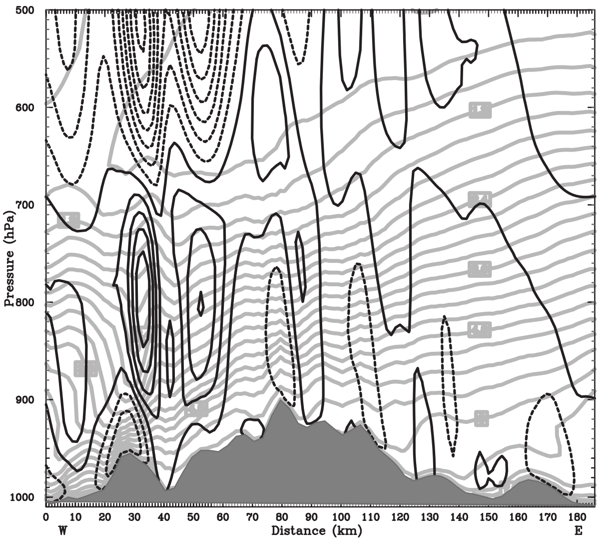

Fig. 3: MM5 forecast for vertical wind velocity (c.i.= 20cm/s) and water vapour mixing ratio (c.i.=0.3 g/kg) at 21:00 UT on 1 October 2005 covering a 190 km transect along the 40°38'N parallel.

The use of a Lagrangian trajectory model allowed to identify the origin of the observed dry layer. The trajectory analysis was performed through the application of NOAA-ARL HYSPLIT transport and dispersion model [7]. The model was applied using meteorological data from global reanalysis. Fig. 6 illustrates the backward trajectories ending at 18:00 UT on 1 October 2005, this being the time when the lidar measurements were started and the elevated dry layer was first observed at an altitude of 6-7 km. The three considered trajectories are those ending at altitudes of 6, 6.5 and 7 km. These trajectories, extending back 36 h, clearly reveal that the air mass in the altitude range 6-7 km descend from an height ranging between 8 and 10 km in the UTLS region above Scandinavia (panel a and b in fig. 6).

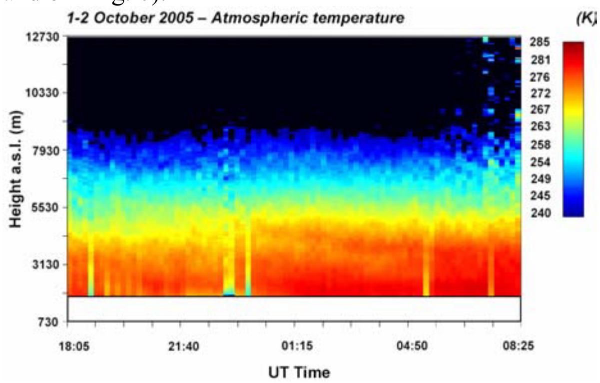

Fig. 4: Time evolution of atmospheric temperature (same time-frame as fig. 2).

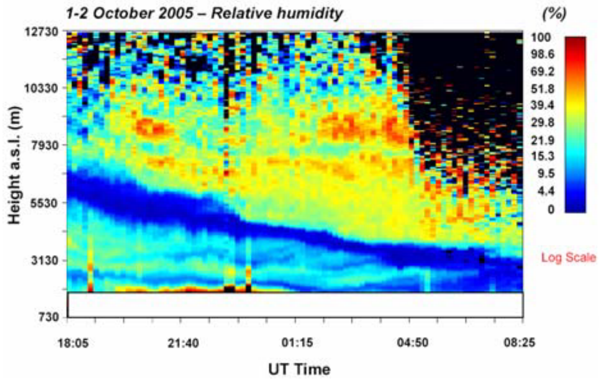

Fig. 5: Time evolution of relative humidity (same time-frame as fig. 2).

Forward trajectories starting at 18:00 UT on 1 October 2005 from the same altitude levels are found to descend down to 5-6 km in the following 12 h (panel c in fig. 6). The trajectory analysis was also verified at a later moment: the intruded air is at an altitude of 4.5-5.5 km around 00:00 UT on 2 October 2005 (see fig. 1 and 2). Backward trajectories show that the air mass ending at 4.5-5.5 km at 00:00 UT on 2 October 2005 descend (36 earlier) from an altitude of 6-8 km again above Scandinavia (panel d in fig. 6). Forward trajectories starting at 00:00 UT on 2 October 2005 from an altitude of 4.5-5.5 km are found to descend down to 3.5-4.5 km in the following 12 h (panel e in fig. 6). Trajectory analysis (plot not shown here) also reveal that the lower dry layer at 2-2.5 km includes air masses that have stationed at almost the same height in the previous 36 h and didn't intrude from higher levels.

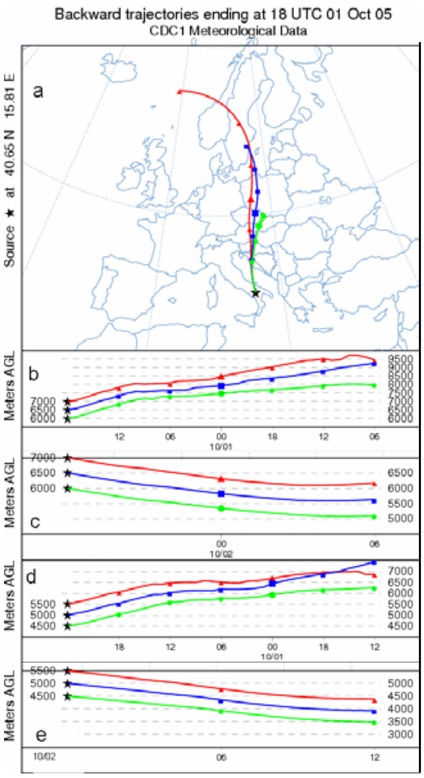

Fig. 6: Trajectory analysis. Panel a: geographical path of back-trajectories ending of 6-7 km on 1 October 2005 (18:00 UT); panel b: time-height cross-section of back-trajectories ending at 6-7 km on 1 October 2005 (18:00 UT); panel c: time-height cross-section of forward trajectories starting at 6-7 km on 1 October 2005 (18:00 UT); panel d: time-height cross-section of back-trajectories ending of 4.5-5.5 km on 2 October 2005 (00:00 UT); panel c: time-height cross-section of forward trajectories starting at 4.5-5.5 km on 2 October 2005 (00:00 UT).

The MM5 specific humidity time series is illustrated in fig. 7. The model predicts a dry subsiding layer, reaching the lower levels approximately at 09:00 UT on October 2. These results compare well with the q time series as measured by *BASIL* (figs. 1 and 2) and reveal a good capability of the model to forecast the behaviour of the dry stratospheric intruding layer. More results from the comparison of lidar and model data will be discussed at the conference.

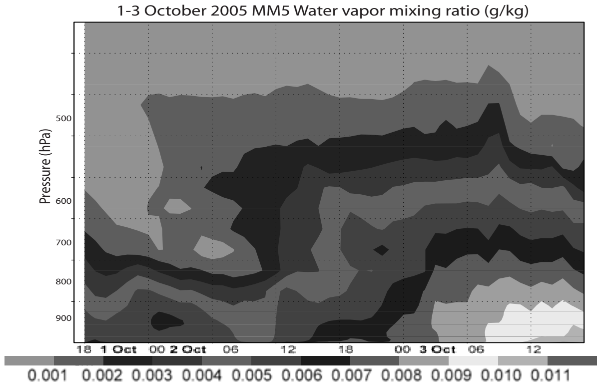

Fig. 7: MM5 forecast for specific humidity from 18:00 UT on 1 October 2005 to 18:00 UT on 3 October 2005.

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