Study of a Mesoscale Convective System Using a Raman Lidar in the Frame of the Convective and Orographically-Induced Precipitation Study

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ABSTRACT.

On 20 July 2007, a vorticity maximum at the east side of a jet initiated over middle - eastern France triggered cyclogenesis and a Mesoscale System (MCS) passed over the *Convective and Orographically-induced Precipitation Study* (COPS) region. The University of BASILicata Raman lidar system (*BASIL)* was deployed in Rhine valley at Achern, (Supersite R, Lat: 48.64°N, Long: 8.06^{0}E, Elev.: 140 m) in the frame of the *COPS*. *BASIL* was operated continuously during this day, providing measurements of aerosols, temperature and water vapour. The approaching thunderstorm modified the pre-storm environment and determined a lowering of the anvil clouds, which is visible in the lidar data, to changing the state of the layer. In particular, a mid-level outflow region was present, with hydrometeor-debris leaving the main thunderstorm core and being recycled back into it (mostly in the form of virga). The MCS modified the pre-storm environment at 1.6-2.5 km directly (outflow) and at lower levels through precipitation (in the form of virga). Wave structures were also evident in the particle backscatter data, a result of the shear produced by the outflow and inflow winds. There was also increase in moisture ahead of the cold front and decrease as the cold front passed by, explained as a combination of the "moisture pooling" before the front and subsequent cold air displacement. This MCS generation and cold front passage was associated with a temperature decrease of about 4.5 K. Data collected on this day demonstrate the utility of Raman lidar systems as *BASIL* in visualizing multi-scale interactions that occurred during the *MCS* and its effects in terms of modification of the pre-storm environment.

1. INTRODUCTION

Convective and Orographically-induced Precipitation Study (COPS) was an international field campaign which took place in South-Western Germany and Eastern France [1] over a period of three months from June to August 2007. The main objective of *COPS* was to identify the physical and chemical processes responsible for the deficiencies in Quantitative Precipitation Forecast (QPF). On 20 July 2007 a vorticity maximum at the east side of a jet initiated over middle eastern France, triggered cyclogenesis and a Mesoscale System propagated north-eastwards. The MCS reached the *COPS* area at 8:45 UTC and ahead of the weak cold front, in which the MCS was imbedded; outflow boundaries produced a squall line with severe thunderstorm activity. The Raman lidar system *BASIL* visualized the interaction of the MCS with the prevailing pre-storm environment and its modification. Additionally during the passage of the squall line, deep convection was triggered in the *COPS* region modifying the structure of the squall line and of related precipitation pattern.
A brief description of the BASIL system and data on this day is given in section 2, followed by results in section 3 and discussion in section 4.

2. BASIL SYSTEM

The Raman Lidar system *BASIL*, deployed in Achern, Rhine valley (Supersite R, Lat: 48.64 ° N, Long: 8.06 ^{0} E, Elev.: 140 m), operated from 25 May to 30 August 2007, collecting more than 500 hours of measurements, distributed over 58 measurement days. The major feature of *BASIL* is represented by its capability to perform high resolution and accurate measurements of atmospheric temperature and water vapour, both in daytime and night-time, based on the application of the rotational and vibrational Raman lidar techniques in the UV. Besides temperature and water vapour, *BASIL* is capable to provide measurements of particle backscatter at 355, 532 and 1064 nm, particle extinction coefficient at 355 and 532 nm and particle depolarization at 355 and 532 nm. The experimental set-up of *BASIL* was described in various papers [2,3,4]. *BASIL* includes a Nd:YAG laser emitting pulses at 355 and 532 nm and Newtonian telescope as a receiver. *BASIL* was operated continuously during 20 July 2007 from 04:33 to 19:22 UTC. *BASIL* has a superb capability to visualise the fine-scale structure of the atmosphere. *BASIL* has the capability to penetrate thin clouds and provide valuable information on aerosol physical properties and atmospheric thermodynamic quantities. In what follows we focus on the variability, evolution and modification of the aerosol and water vapor fields as derived from *BASIL* during a frontal passage.

3. RESULTS

Figure 1 shows the range-corrected elastic lidar signals at 1064 nm during the entire observation period from 09:30 to 19:22 UTC. Low level clouds and/or fog were present in the valley until 09:30 UTC followed by development of convective clouds during the afternoon and several precipitation

© Proceedings of the 8th International Symposium on Tropospheric Profiling, ISBN 978-90-6960-233-2
Delft, The Netherlands, October 2009. Editors, A. Apituley, H.W.J. Russchenberg, W.A.A. Monna

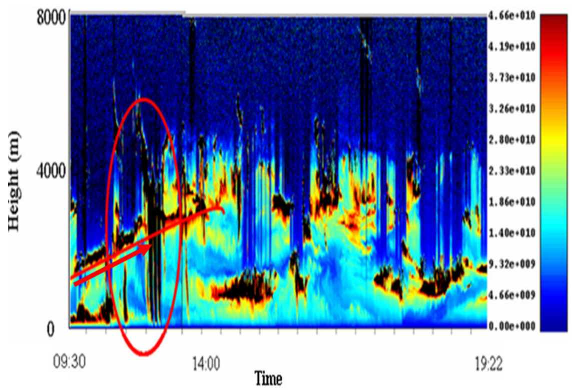

FIGURE 1. *Range-corrected signals at 1064 nm wavelength throughout the measurement period on 20 July 2007.*

intervals throughout the day. The lidar revealed the interaction of the MCS with the prevailing pre-storm environment and details of its modification. A signature of the thunderstorm approaching is present in the 1064 nm range corrected lidar signals in figure 1, visible in the lowering of the anvil clouds up high around 5 km (circled in figure).

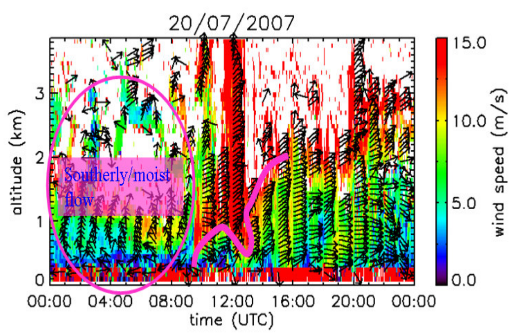

FIGURE 2. *Wind speed and direction from the co-located wind profiler.*

Low level winds below about 1km were towards the centre of the thunderstorm within the cold air mass at an altitude range of 0.5 to 2.5 km during the time period 10 to 12 UTC. Wind direction prior to 09:00 UTC was southerly; changing to westerly between 10 to 12 UTC, below about 1 km. This is the signature of the cold frontal passage. The maximum wind speed observed was around 15 m/s at 11:15 UTC. The time period considered in this paper is from 10:46 UTC to 11:37 UTC, which is a period prior to the arrival of the thunderstorm and it is characterized by westerly winds.

Figure 3, shows the mesoscale view (10:46 to 11:37 UTC): in the left panel is the range corrected signals at 1064 nm while the right panel shows the water vapor mixing ratio with the lowest possible resolution (20 seconds) available. An interesting observation is the cloud deck at 2 km, which represents a mid-level outflow from the thunderstorm/MCS. The wind flow at higher levels was opposite to that at low levels as seen in figure 2. The effect of wind flow is to moisten that level and generate precipitation (mostly virga). The result, as can be seen in the lidar data, is a conveyor belt of recycling hydrometeors, where the thunderstorm mid-level outflow *"spits"* out hydrometeor-debris and these are recycled back into the thunderstorm through modified moisture influx and/or virga structure.

In the water vapor mixing ratio we observe a moist layer below about 1 km and a drier layer about 2 km. This means that the MCS was modifying the environment at 1.6-2.5 km directly (outflow) and at the lower levels through the virga/precipitation. In addition, the MCS can only survive by pulling in moisture from a large area (~100km radius or more) around it (below about 1km), which is somewhat modified by the virga [5], as seen in the figure 3. The black patch in the water vapour mixing ratio map represents a time interval with no data. At this time the site was reached by winds with a speed of 15 m/s; these are associated with the core of the jet/nose in the cold front. The water vapour profiles prior to the data-gap were characterized by values up to 14 g/kg which are observed up to 2.5 km. As a result of the intense shear region, the depth of the moist layer decreases and much lower mixing ratio values are observed in the altitude region of 1 – 3 km. This reduction of the depth of the moist layer is to be attributed to the fact that the moisture is swept into the approaching MCS, this being a mechanism playing an important role in the formation of precipitation and latent heat balance of the system.

A wave train travelling horizontally is also observed in the range corrected signals shown in figure 3. An interesting feature in the lidar data is represented by the wave like structure observed in the data just prior to the arrival of the thunderstorm in the altitude region 1-2.5 km. This is primarily due to the shear between the inflow and outflow regions. Thus, two primary processes stand out: the elevated outflow region above the BL (2-3.5km) and the presence of the associated shear. Shear and mid-tropospheric moistening are important processes to consider in convection: shear can inhibit convection, but also aid it if waves break and create self sustaining turbulence at the right level. With larger wind shear, new cells are more likely to form from thunderstorm outflow [6].The moistening of the mid-levels allows for a rising moist air parcel to travel higher in altitude without being depleted by drier air aloft [7].

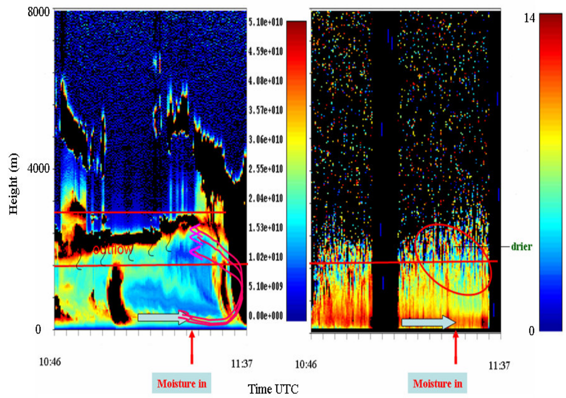

FIGURE 3. *Range corrected signals at 1064 nm and water vapour mixing ratio for the Mesoscale view in time frame 10:46-11:37 UTC on 20 July 2007.*

The development of clouds in the afternoon, which is observed in figure 1, is probably due to the post frontal cold/ dry air masses. The aerosol load also shows a decrease after the frontal passage as compared to the pre-frontal conditions. The water vapor variability observed by *BASIL* before and after the thunderstorm event reveals an increase in moisture content ahead of the cold front, oscillating along the frontal surface and a decrease after the frontal passage.

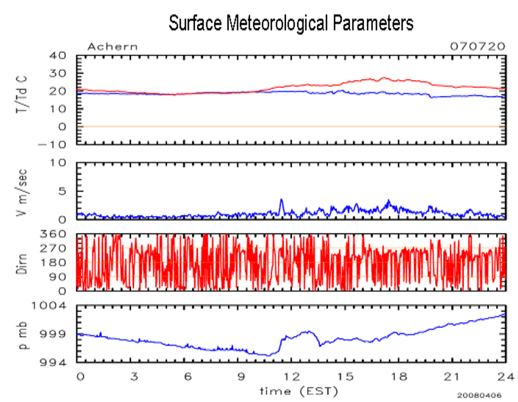

FIGURE 4. *Surface- meteorological parameters over the experimental site*. (panel 1 surface air temperature and dew point temperature, panel 2 surface wind speed, panel 3 wind direction and panel 4 pressure).

Advanced RS92 radiosondes were launched at 09:08, 11:00, 14:03 and 16:53 UTC. The 09:08 UTC radiosonde reveal the presence of two distinct humidity layers: a moist layer below about 1 km and upper dry layer around 2 km. The temperature profiles at 09:08 UTC shows high values; however, as the frontal system passed over the site, the temperature decreased by almost 4-5 K as a result of the intrusion of cold air. It is to be pointed out that the fine scale features observed by the Raman lidar cannot be deduced from the radiosondes, which are launched every 3 hours. Figure 4 shows the surface meteorological parameters measured at supersite R. Atmospheric pressure is found to decrease continuously ahead of the cold front and then it undergoes a sudden increase after the frontal system has passed by. Surface and dew point temperatures have very similar values in the morning hours, which testify saturation conditions and led to the development of fog in the valley. The time interval 10:30-11:30 corresponds to the pre-frontal conditions; afterwards drier conditions are present as testified by the lower values of the dew point temperature. Surface wind data shown here are not reliable because of the presence of obstacles which obstructed the surface wind flow.

4. DISCUSSION

Results shown in this abstract demonstrate the excellent capability of Raman lidars in detail visualizing the time evolution of the vertical structure of the atmosphere, both in pre and post-frontal. Fine-scale structures at different altitudes were detected, thus allowing to explain some of the dynamic processes involved. We observed a decrease in moisture and aerosol content after the frontal passage. The temperature decreased by almost 4 K after the front passage as a result of cold air intrusion. The two primary processes which stand out are the elevated outflow region above the boundary layer and the presence of the associated shear, which helped in sustaining the process.

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