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EPJ Web of Conferences **119**, 15002 (2016) DOI: 10.1051/epjconf/201611915002
ILRC 27

LIDAR OBSERVATIONS OF LOW-LEVEL WIND REVERSALS OVER THE GULF OF LION AND CHARACTERIZATION OF THEIR IMPACT ON THE WATER VAPOUR VARIABILITY

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ABSTRACT

Water vapour measurements from a ground-based Raman lidar and an airborne differential absorption lidar, complemented by high resolution numerical simulations from two mesoscale models (Arome-WMED and MESO-NH), are considered to investigate transition events from Mistral/Tramontane to southerly marine flow taking place over the Gulf of Lion in Southern France in the time frame September-October 2012, during the Hydrological Cycle in the Mediterranean Experiment (HyMeX) Special Observation Period 1 (SOP1). Low-level wind reversals associated with these transitions are found to have a strong impact on water vapour transport, leading to a large variability of the water vapour vertical and horizontal distribution. The high spatial and temporal resolution of the lidar data allow to monitor the time evolution of the three-dimensional water vapour field during these transitions from predominantly northerly Mistral/Tramontane flow to a predominantly southerly flow, allowing to identify the quite sharp separation between these flows, which is also quite well captured by the mesoscale models.

1. INTRODUCTION

Mistral and Tramontane are two strong dry northerly winds which are often found to blow in the Mediterranean basin. They usually blow in winter or spring, though they occur in all seasons. Mistral and Tramontane sometimes last only one or two days, frequently lasts several days, and sometimes lasts more than a week. They bring cold and dry continental air over the sea and are frequently observed to extend few hundred kilometres off the coast (among others, [1] Jansa, 1987). In the Gulf of Lion, Southern France, the occurrence of Mistral and Tramontane at the coast are often observed to alternate with southerly marine flows. Marine flows advect moist air onshore, its inland penetration being strongly dependent on the large scale flow [2]. During *HyMeX-SOP1* (September-November 2012, Ducrocq *et al.*, 2014) several events when the southerly marine flow broke through and overcame the Mistral/Tramontane flow were observed. The complex interaction between the southerly marine flow and the Mistral/Tramontane events may lead to a rapid transition between the two wind regimes along the coastline [3]. This research effort is dedicated to the measurements performed by the ground-based University of BASILicata Raman Lidar system (*BASIL,*[4]) and the airborne differential absoption lidar (DIAL) system LEANDRE 2 [5], which are used to illustrate the high time and space variability of the water vapour field associated with the occurrence of transition events from Mistral/Tramontane to southerly marine flow in Southern France during *HyMeX-SOP 1*. Measurements from these two systems are also used to validate the numerical simulations from the mesoscale model MESO-NH and the mesoscale numerical weather prediction model AROME-WMED.

2. METHODOLOGY

BASIL is a ground-based Raman Lidar hosted in a transportable sea-tainer. 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 also capable of providing measurements of particle backscatter at 355, 532 and 1064 nm, particle extinction at 355 and 532 nm and particle depolarization at 355 and 532 nm [6].
In the frame of *HyMeX-SOP1*, *BASIL* was deployed in Candillargues and operated between 5 September and 5 November 2012, collecting more than 600 hours of measurements, distributed over 51 measurement days and 19 intensive observation periods (IOPs).

During *HyMeX-SOP1*, the CNRS DIAL-LEANDRE2 was located onboard the French ATR42, operated by SAFIRE. The system was operated in zenith and nadir-pointing mode with the primary mission of characterizing the water vapour and aerosol inflow feeding heavy precipitating systems. The system includes a tunable laser whose emission is tuned upon a water vapour absorption line selected from two rotation–vibration bands in the near infrared (727–770 nm). The system allows water vapour mixing ratio measurements to be performed with a precision ranging from less than 0.1 g kg^{-1} at 4.5 km above sea level to less than 0.4 g kg^{-1} near the surface for an along-beam resolution of 150 m and accumulation of 100 individual profiles, which, for an ART42 flying speed of 100 m/s, corresponds to an along-track resolution of nearly 1 km. During *HyMeX SOP1*, the CNRS DIAL performed over 60 flight hours: 8 of which supported by the *European Facility For Airborne Research* Project "*WaLiTemp"* and in coordination with the Raman lidar BASIL, and the reminder as part of the *HyMeX SOP1* endowment supported by the MISTRAL program.

Numerical simulations considered in this paper are performed with two non-hydrostatic models: Méso-NH and AROME-WMED. The Méso-NH has been jointly developed by the Laboratoire d'Aérologie and by CNRM-GAME. It makes use of two interactively nested model domains with a horizontal mesh size of 9 km and 3 km for the coarse and the fine domain, respectively. AROME-WMED is a convection-permitting model with a domain covering the entire western Mediterranean basin, with a forecast interval up to 48 h. In addition to the operational observations used in the 3-h data assimilation cycle, the model assimilates some of the observations made available in real-time during SOP1 (i.e. surface observations over Spain, radiosoundings from the research sites, radar data (Doppler winds and reflectivity) and satellite data).

3. RESULTS

Figure 1illustrates the time evolution of the wind direction and speed and relative humidity for the period from 00:00 UT on 19 September 2012 to 00:00 UT on 21 September 2012 from a meteorological surface station located in Candillargues. Gradients of surface wind direction and speed and relative humidity are considered to identify the transitions from Mistral/Tramontane to predominantly southerly marine flow and vice versa.

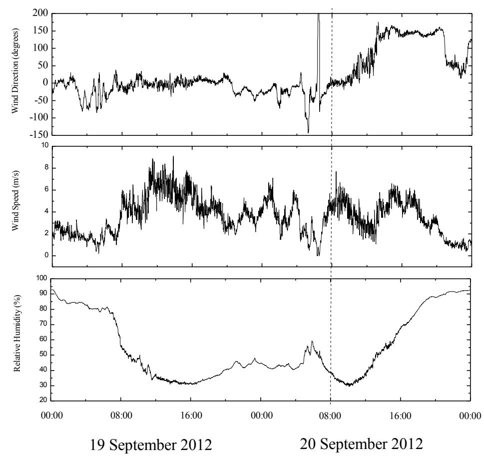

Figure 1: Time evolution of the wind direction and speed and relative humidity for the period 19-21 September 2012 as measured by the surface meteorological station located in Candillargues. The vertical dashed line identifies the time when the chance in wind direction and speed takes place.

The observed variability of surface wind direction and speed and relative humidity which is depicted in figure 1 clearly identifies the southerly marine flow onset from a previous weak

Mistral/Tramontane event around 08:00 UT on 20 September 2012, with wind direction progressively changing from about 0 to about 150 degrees (from Northerly to South-easterly), wind speed progressively decreasing from approx. 6 to 2 m/s and relative humidity increasing from 30 to 90 %.

Figure 2a illustrates the time evolution of the water vapour mixing ratio as measured by BASIL over a time period of approx. 24 h from 16:49 UT on 19 September 2012 to 16:33 UT on 20 September 2012. This figure reveals the arrival of the moist air in Candillargues associated with the south-easterly marine flow starting from approx. 08:00 UT. A strong gradient in the water vapour field is visible starting from 09:30 UT. Before the arrival of the humid layer, during the Mistral/Tramontane flow, the mixing ratio values in the boundary layer are not exceeding 5-6 g/kg. The humid layer associated with the marine flow is found to extend up to the boundary layer top, with mixing ratio values as large as 15 g/kg. Above the boundary layer top the water vapour mixing ratio variability is very limited, with mixing ratio values not exceeding 3 g/kg, both before and after the arrival of the flow, mainly because the wind reversal is taking place only in the lower levels (primarily in the boundary layer) and it is not extending throughout the free troposphere. The humid layer is first revealed in the upper portion of the boundary layer and then it is found to progressively fill the boundary layer extending down to the surface. In the presence of the south-easterly flow the earlier arrival of the humid layer in the upper portion of the boundary layer and its progressive later arrival at lower levels is caused by the presence of higher horizontal wind speed values (7-8 m/s) in the upper portion of the boundary layer with respect to those found (2-5 m/s) in the lower portion, as can be easily revealed in figure 2c from the measurements performed by the UHF wind profiler located in Candillargues.

Figure 2b illustrates the time evolution of the range corrected signal at 532 nm, RCS_{532}, as measured by BASIL over a time period of 18 h from 00:00 UT to 18:00 UT on 20 September 2012. As the range corrected signal is expressed in arbitrary units no colour legend was introduced for this panel. The figure reveals a sensitive change in particle backscatter, which is caused by the arrival of an aerosol-loaded air mass associated with the south-easterly marine flow shortly after the low-level wind reversal. This change in particle backscatter is superimposed to the particle backscatter variability associated with the development of the boundary layer, which starts building up around the same time when the wind reversal takes place. The warmer and more humid air advected by the marine flow is characterized by a larger aerosol loading, predominantly of maritime origin, which is replacing the colder and drier air advected by the Mistral/Tramontane flow, predominantly loaded with continental aerosol. RCS_{532} is found to increase by approx. 50 % after the marine flow onset.

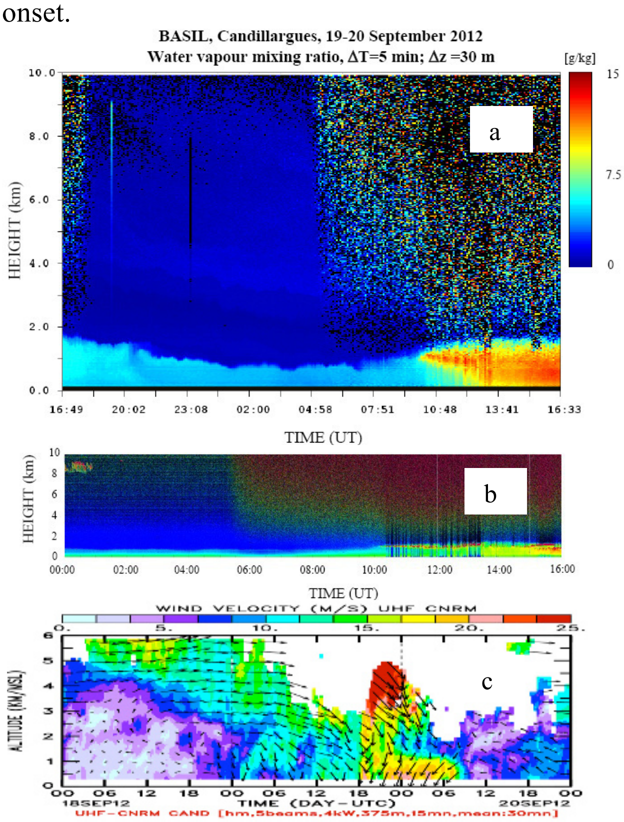

Figure 2: a) Water vapour mixing ratio as measured by BASIL over a the time period from 16:49 UT on 19 September 2012 to 16:33 UT on 20 September 2012. b) RCS_{532} as measured by BASIL over the time period from 00:00 UT to 16:00 UT on 20 September 2012. c) Wind speed and directions on 18-19-20 September 2012 as measured by the UHF wind profiler located in Candillargues.

Figure 3 illustrates the time evolution of the water vapour mixing ratio as simulated by the mesoscale models MESO-NH (lower panel) and AROME WMED (upper panel) over the time period of approx. 24 h from 17:00 UT on 19 September 2012 to 17:00 UT on 20 September 2012. MESO-NH and AROME-WMED outputs are provided with a time step of 1 h. Model analysis from both MESO-NH and AROME-WMED properly simulate the time-height structure of the humidity field observed by BASIL, reproducing the arrival of the humid air in the boundary layer with similar mixing ratio values (8-12 g/kg) for AROME-WMED and slightly lower values (in the range 6-8 g/kg) for MESO-NH. The depth of the moist layer also seems to be slightly different for the two models, with AROME-WMED being in better agreement with BASIL (moist layer extending for both up to approx. 1500 m) than the one from MESO-NH (moist layer extending up to approx. 1300 m).

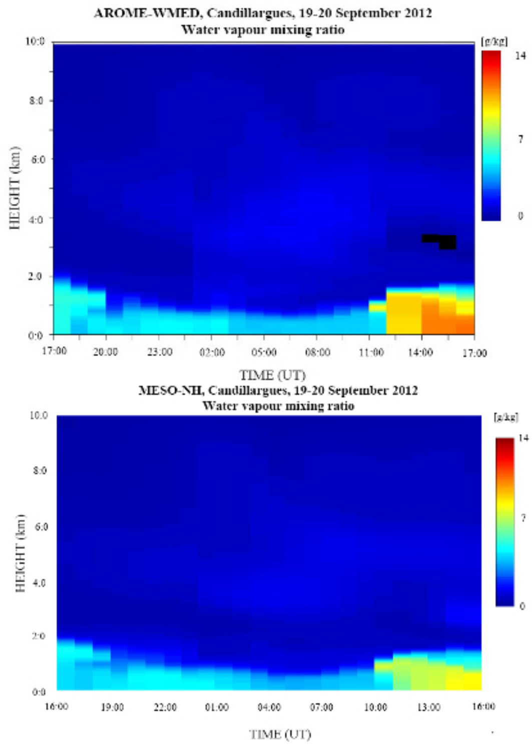

Figure 3: Time evolution of the water vapour mixing ratio as simulated by the mesoscale models AROME WMED (upper panel) and MESO-NH (lower panel) over the 24 h time period from 16:00 UT (17:00 UT for AROME WMED) on 19 September 2012 to 16:00 UT (17:00 UT for AROME WMED) on 20 September 2012.

However, both models well capture the elevated humid layer present in the free troposphere which is visible in BASIL data, this layer having a vertical extent of approx. 2 km, with a base at 4 km around 16:00 UT and progressively descending down to 3 km around 06:00 UT. The bias and RMS deviation between BASIL and the two mesoscale models have been computed and will be discussed at the Conference. Unfortunately, the CNRS DIAL-LEANDRE2 was not flying during this period. More cases describing low-level wind reversals associated with transition events from Mistral/Tramontane to southerly marine flow taking place in Southern France, complemented by the availability of simultaneous measurements by CNRS DIAL-LEANDRE2, will be discussed at the Conference.

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