1. INTRODUCTION

One of the consequences of climate change is an alteration in precipitation regimes, hence making it necessary to study the mechanisms that may cause these alterations. Aerosol concentration is among the main factors triggering rain because aerosols function as condensation nuclei (CCN) inside clouds. On the other hand, in aerosol-precipitation interaction the elimination of aerosols through precipitation must also be taken into account. Thus, variations in aerosol concentration may be seen as one of the causes of precipitation or as one of its consequences. This balance has prompted the present study, which is an attempt to relate the air masses causing precipitation in León to aerosol size distribution and aerosol concentration. Changes in aerosol size distributions during rain events will also be studied because aerosol size distribution influences the dynamics of aerosol population (Vakeva et al., 2001), their production and removal processes, size transformation, lifetime, optical properties and radiative effects (Huebert et al., 1996). The size distribution of atmospheric aerosols strongly depends on the sources and sinks as well as on the meteorological processes prevailing during their lifetime (Suzuki and Tsunogai, 1988; Ito, 1993).

Authors such as Slinn (1971) or Dana and Hales (1976) established theoretically the linear relationships between the scavenging coefficient and rain intensity for different aerosol types and this can also be used to describe the time variation of mass/number concentration of pollutants in the atmosphere in other areas. Other authors such as Mircea et al. (2000), Dana (1971) and Dana (1972) obtained experimental data showing that below-cloud scavenging is much more efficient for the polydisperse aerosol than might be expected for particles with a specified mean size.

2. STUDY ZONE

The measurements were performed in León, Spain, a city in the northwest of the Iberian Peninsula (42º 36’ N, 05º 35’ W and 838 m above sea level) shown in Fig.1. Because of the lack of large emitting industries, the main source of particulate emissions is considered to be vehicular traffic. León has a population of about 135,000 inhabitants.

3. MATERIALS AND METHODS

Continuous particle number/size distributions were measured using a passive cavity aerosol spectrometer probe:

Fig. 1. Geographic location of the city of León, Spain.
PCASP-X. This instrument measures aerosol size distribution from diameters ranging between 0.1 and 10µm in 31 channels on the basis of the light-scattering properties of the particles at a wavelength of 633 nm between angles of 35º and 135º. The probe was calibrated by the manufacturer using polystyrene latex particles of a known size. The refractive index of latex beads (1.59 - 0i) is different from that of atmospheric particles, resulting in an aerosol size distribution that is "latex equivalent". Here, we are presenting PCASP size distributions corrected for an average refractive index of 1.56-0.087i typical of urban aerosols (Lide, 1993). During each study day, two sets of measurements were taken every hour. Each set lasted 15 minutes and the data registered were saved every minute.

The precipitation was collected by a rain gauge in a Davis weather station. The data were registered every 15 minutes and the minimum volume was 0.25 liters per square meter. The weather station and the aerosol probe were installed in the same site to the southwest of the city of León, Spain.

Back trajectories for three different altitudes (500, 1,500 and 3,000 m) were calculated with the HYSPLIT model in order to interpret the different source regions of the air masses reaching the study zone. Back trajectories for the 5 previous days are considered up until the time the rain event began. This study will be complemented by a description of these air masses.

The surface-level synoptic maps that have been used were those published in the official bulletins issued by the Spanish National Institute for Meteorology.

In order to identify the type of weather associated to a particular synoptic situation a Circulation Weather Type classification (CWTs) was carried out based on Jenkinson and Collison (1977) and Jones et al. (1993). These procedures were developed to define objectively Lamb Weather Types (LWTs) (Lamb, 1972) for the British Isles. The daily circulation affecting the Iberian Peninsula is described using a set of Indices associated to the direction and vorticity of the geostrophic flow. The Indices used were the following: southerly flow (SF), westerly flow (WF), total flow (F), southerly shear vorticity (ZS), westerly shear vorticity (ZW) and total shear vorticity (Z). These Indices were computed using sea level pressure (SLP) values obtained for the 16 grid points, distributed around the Iberian Peninsula. This method allows for a maximum of 26 different CWTs. Like Trigo and Câmara (2000) in their study for Portugal, this study did not use an unclassified class, but rather opted for disseminating the fairly few cases (<2%) with possible unclassified situations among the retained classes.

The study period comprises the 59 days of the months of February and March 2005. For each day the aerosol size distributions are analyzed, as well as the Count Mean Diameter (CMD) and the Geometric Deviation.

In addition, the distributions corresponding to the five most intense precipitation events in these two months are studied in depth. In these five cases the Circulation Weather Type and the corresponding air masses are also described.

4. RESULTS AND DISCUSSION

4.1 Meteorological study

A total of 59 days were analyzed and the meteorological study of the two months is shown in Table 1. The average temperatures (3.8ºC in February and 8.1º C in March) were typical of winter months and the humidity was about 60%. The rainiest month was March with 31.9 mm of precipitation: it rained on 8 days. In contrast, in February rain was registered only on 3 days and the total precipitation registered was 15.9 mm.
Table 1. Meteorological study of the months of February and March with data on maximum, minimum and average temperatures, relative humidity, and total precipitation registered and wind intensity.

<table>
<thead>
<tr>
<th></th>
<th>February</th>
<th>March</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tmin(ºC)</td>
<td>-5.6</td>
<td>-8.5</td>
</tr>
<tr>
<td>Tmax(ºC)</td>
<td>17.9</td>
<td>21.9</td>
</tr>
<tr>
<td>Tav(ºC)</td>
<td>3.8</td>
<td>8.1</td>
</tr>
<tr>
<td>Relative Humidity (%)</td>
<td>60.2</td>
<td>56.1</td>
</tr>
<tr>
<td>Total Precipitation (mm)</td>
<td>15.9</td>
<td>31.9</td>
</tr>
<tr>
<td>Wind (m/s)</td>
<td>1.0</td>
<td>1.7</td>
</tr>
</tbody>
</table>

The 5 most intense rain events in those two months were studied (Table 2) by analyzing several meteorological parameters such as the duration of the event, the total precipitation registered and the rain intensity. The relative humidity is remarkably high on these days, between 80% and 90%, and the wind intensity can be classified according to the Beaufort scale as between calm and moderate breeze for the most intense event with 5.9 m/s. The precipitation registered varied between 2.5 mm and 14.7 mm.

The events studied on those days lasted between 2h 30m and 11h 30m. The maximum rain intensity was 2.4 mm/h and was registered on March 26.

4.2 Circulation Weather Type and Air masses

The Circulation Weather Type classification (CWTs) shows that during the months of February and March, (Figure 2), the CWTs were mainly of two types controlled by geostrophic vorticity: cyclonic (C) and anti-cyclonic (A), with 11 and 9 days, respectively. The next most frequent types were two purely directional types, southwesterly (SW) and westerly (W), followed by the NW, ASW and CSW types. In other words, westerly flows seem to have a strong influence on the Iberian Peninsula in the months of February and March.

Fig. 2. Circulation Weather Type classification in the months of February and March (59 days) on the days with precipitation events and surface-level synoptic map.
Back trajectories for three different altitudes (500, 1,500 and 3,000 m) were analyzed to determine the air masses present in the city of León during the days with rain events (Figure 3). On February 6 and 22 the air masses have been identified as of the maritime Polar (mP) type with low temperatures and a high relative humidity. On March 21 and 25 the air masses were of the maritime Tropical (mT) type and on March 26 of the mP type, with a considerable drop in the temperatures and a remarkable increase in the relative humidity.

4.3 Aerosol size distributions

Fig. 4 shows a comparative study of the average distributions of the days with rain events with reference to the month in which they occurred. The situation varies from one day to another.

In each event the evolution of the number of aerosols has been analyzed, as well as the Count Mean Diameter and its Geometric Deviation. This was done to detect the variations occurring and their development before the actual precipitation was registered, during the precipitation, and after the event, in intervals of 15 minutes (Fig 5, 6 and 7).

Fig. 5 shows the number of particles and the precipitation registered in each 15-minute interval. For each of these intervals the rain intensity was calculated to assess how the two parameters vary simultaneously. In the days analyzed it was found that during the rain event, if the rain intensity is over 2 mm/h, a drop in the number of aerosols is immediately detected due to the washout effect. However, if the rain intensity is about 0.4 mm/h or lower, the result is an increase in the number of aerosols measured. It may be the case that during weak rain events the probe does not discriminate adequately between aerosols and very small droplets or the extremely small droplets that remain in suspension in the atmosphere.
Fig. 4. Average aerosol size distributions in the day with the rain event and in the corresponding month.

Fig. 5. Time variation of the number of aerosols and the precipitation in the 5 days with intense rain events. Three stages are distinguished: before, during and after the rain event.
Because of this fact, the measurements carried out by an aerosol probe like the one employed for this study must be treated separately in the case of rain days and in the case of days with no rain. At least during the rain event, and even for several hours after it, there may be difficulties in the measurements that might make them less reliable.

The reason is that when assessing the size distributions before and after the rain event, there are cases where the total number of particle increases and other cases where it decreases. Count Mean Diameter was between 0.37-0.38 μm before precipitation and its Geometric Deviation was between 1.14-1.18 μm. It was found that after the rain event, if the intensity of the precipitation has been very low, it took several hours for the number of particles to regain values similar to or lower than the initial number registered before the rain event. The removal of the smallest droplets left in suspension is not immediate, but takes some time. However, when the precipitation intensity was over 2 mm/h, after the rain event the number of particles was smaller than before the event in a much shorter span of time.

This is related to the washout effect. If there is an intense washout, the number of particles decreases significantly, large and small particles alike. However, the average size of the particles after the precipitation and their geometric deviation is quite similar. This means that a short time after the precipitation the air mass recovers the same type of lognormal distribution it had before the rain event.

If no washout takes place, it is observed that immediately after the rain event the number of particles is higher, sometimes even considerably so, than before the rain event. In the event on February 22, before the rain there were 355 particles/cm³ and after there were 2,019 particles/cm³, and on February 6 there was an increase from...

Fig. 6. Time variation of the Count Mean Diameter and its Geometric Deviation in the in the 5 days with intense rain events. Three stages are distinguished: before, during and after the rain event.
1,297 to 2,117 particles/cm³, with average sizes and geometric deviations lower than the ones registered before the beginning of the rain event. In other words, the lognormal distributions varied greatly. Consequently, the number of small particles must not vary a lot, but the number of large particles must have decreased. In conclusion, the number of large particles decreases irrespective of the intensity of the precipitation, but the smaller particles are only washed out by the raindrops if the intensity of the precipitation is higher than 2 mm/h.

These preliminary results must still be confirmed in further studies.

5. CONCLUSIONS

When the precipitation intensity exceeds 2 mm/h the washout is obvious and quick, whereas in the case of weak precipitation of 0.4 mm/h or less, the number of particles increases. This may be due to the fact that the probe does not discriminate between aerosols and very small precipitating droplets or the smallest droplets that are left in suspension in the atmosphere.

The authors think that the measurements carried out using the aerosol probe employed in this study must be treated separately for the case of rain days and for the case of days with no rain. At least during the rain event, and even for several hours after it, there may be difficulties in the measurements that might make them less reliable.

When it rains the number of large particles decreases irrespective of the intensity of the precipitation, but the smaller particles are only washed out by the raindrops if the intensity of the precipitation exceeds 2 mm/h.

6. BIBLIOGRAPHY

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