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ANALYSIS OF THE MICROPHYSICAL STRUCTURES OF FOG DURING THE PARISFOG PROJECT

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1. INTRODUCTION

The occurrence and development of fogs result from the nonlinear interaction of competing radiative, thermodynamic, microphysical and dynamical processes and the forecasting of their life cycle still remains a challenging issue.

To better understand relationships between such processes field campaigns are carried out at the SIRTA observatory in the Paris suburb area (France). During these experiments state of art measurements of particle size distribution were performed in addition to a suite of active and passive remote sensing instruments and in situ sensors deployed to monitor the vertical thermodynamic structure of the surface layer and the dynamic conditions.

A strength of the instrumental set up deployed for the PreViBOSS project (2010-2013) is the in situ measurement of fog particles at ambient humidity. These data are investigated here to document the fog microphysical properties and to study the evolution of these properties along the fog life cycle.

2. DATA ANALYSIS

The FM-100 Fog-Monitor from DMT is a single particle counter that provides the size distribution of droplet from ~2 to 50 μ m in diameter. A PVM-100 from Gerber Scientific Inc. provides the liquid water content (LWC) and the particle surface area (PSA) over the same size range. Finally a Palas-2000 from Welas measures the size distribution of particles from 0.4 to 40 μ m in diameter. These instruments were installed side by side on a scaffolding at 2.5 m AGL and operated on 24/7 during wintertime from Oct 1st to March 31st.

Eighty-two fog events occurred during winters 2010 and 2011. However due to laser failures only 21 events were sampled by the FM-100, half of them during Nov 2011. Acording to the Tardif and Rasmussen (2007) classification, most of them are radiation fogs (60%) and stratus-lowering fogs (20%).

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Fig. 1: Frequency distribution for the 21 fog events of (a) effective diameter (D_{eff}), (b) total droplet number concentration (N) and LWC. Median values (diamond) and percentiles 5,10,25,75,90 and 95 % (ticks on the error bar) are also indicated.

Note however that over all the fog events the proportion of each of these fog type is about 40% as already reported in Haeffelin et al. (2010) for a previous experiment.

For each fog case the 1 Hz size distribution measured by the FM-100 is cumulated every minute to derive the effective diameter (D_{eff}), total droplet number concentration (N) and LWC values. The frequency distributions computed by using samples with N > 5 cm⁻³ of all the cases, are shown in Fig. 1 for each microphysical parameter: 9757 samples have been used that represents about 163 hours of fog.

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Fig. 2: Statistics of the microphysical parameters of the 21 fog cases represented by the median (diamond) and percentiles 10,25,75 and 90 % of the frequency distribution (ticks on the error bar) of, from top to bottom: D_{eff} , N and LWC, as function of the number of the one minute samples. The scale on the top indicates the corresponding cumulated duration in hours.

The distributions of LWC and N are similar to those reported in Gultepe et al (2009) (their Fig. 17) but for the ocean fog cases (FRAM-L). The shape of the LWC distribution exhibits an exponential decrease but the median value (0.038 g m⁻³) is slightly larger. The frequency of N is roughly constant from 50 to 150 cm⁻³. But the proportion of low values is larger, with 25% of the values $< 30 \text{ cm}^{-3}$, and then the median is 75.5 cm⁻³ that is in between the values reported in Gultepe et al (2009) for the land (\sim 50 cm⁻³) and for the ocean (~90 cm⁻³) fog cases. In contrast the D_{eff} distribution exhibits a different shape with a pronounced mode around the median value (13.5 µm) and a second mode around 6 µm.

The comparison of the distributions for each fog event reveals that there is a significant variability among the cases. This is illustrated in Fig 2 where the statistics are reported as function of the sample number. This latter is used here as a proxy of the fog duration but note that the real duration of the event could be longer when the fog is intermittent. Most of the events have duration between 1h30 and 10h. Only one case lasted about 24h but during Nov 2011 some consecutive events are separated by just a few hours.

Median values of LWC range from 0.012 to 0.089 g m⁻³, except one case that reaches 0.168 g m⁻³, but most of them (15 over 21) are < 0.05 g m⁻³. Concentration values encompass also an order of magnitude from 17 to 170 cm⁻³. This variability is reflected on the droplet size with D_{eff} values that range from 6.9 to 22.3 µm.

The shape of these distributions is also highly variable. For D_{eff} for example, it can be very narrow with mean and $25^{th}-75^{th}$ percentile interval of 10.8 ± 1.31 µm, or in contrast very broad as 14.1 ± 12.56 µm with a bimodal shape.

The time evolution of the microphysical parameters follow very different behaviours depending on the events. But at this stage no systematic trend along the fog life cycle was pointed out.

Median values of N are reported in Fig. 3-a as function of LWC for each cases. Various values of N are observed for a given LWC illustrating the diversity of the dataset. While liquid water production is mainly controlled by radiative cooling, the number of fog droplets depends on the aerosol properties (size distribution and chemical properties). Once droplets have been formed during the activation they compete for the available water : the less numerous they are, the larger the size they can reach by water vapour diffusion growth. Fig 3-b shows indeed that median values of D_{eff} decrease as the concentration values increase, reflecting the expected inverse relationship between the size and the number of droplets, but only for $\mathsf{D}_{\mathsf{eff}}$ > ~12 μ m. For cases with lower D_{eff} values however the concentration remains surprising low with values less than ~100 cm⁻³. Fig 3-c reveals that LWC values of such samples are also rather low. Lack of available water could obviously limit the droplet growth. But since LWC depends on the cube of the droplet size, this factor alone could hardly explain the observed discrepancy.

Comparison with measurements from the PVM reveal however noticeable differences. This is illustrated on Fig 4 that shows scatterplots of LWC and $\mathsf{D}_{\mathsf{eff}}$ for three fog events. PSA comparisons are not shown here but they follow the same trend as LWC. Fig 4-a indicates a good agreement between both instruments. In contrast Fig 4-b-c reveal large discrepancies with LWC values from the FM-100 much lower and larger than the PVM ones for cases on 17/11/10 and 20/11/11, respectively. A bias on D_{eff} appears on Fig 4-b. The disagreement for low values of D_{eff} is more pronounced on Fig 4-c where median values are 8.05 and 12.56 µm, for FM-100 and PVM data, respectively. All the cases that exhibits too low values of D_{eff} on Fig. 3-b show similar comparisons. It is then likely that the FM-100 underestimates the smallest values of D_{eff} in such cases.

Examples of particle size distributions are displayed on Fig. 5. They reveal that the Palas underestimates the concentration of the large particles that confirms the assumption of Elias et al. (2009). In contrast the FM-100 underestimates the droplet counts in the first two size classes. Otherwise Fig 5 attests a nice overlap of both spectra.

These size distributions were sampled at different stages of the fog event on 19/11/10. At 03:00:00 UTC a few hours before the onset of fog, the spectrum is mainly composed of submicronic deliquesced aerosols. Between 05:00:00 and 05:30:00 the visibility at 3 m AGL slightly decreases from ~2 to 1.3 km. Spectra show a huge increase of the concentration of particles around 1 μ m and a mode of droplets > 10 μ m diameter has also appeared. After 05:30:00, as the visibility drops down below 300 m, both probes indicates a third mode around 5 μ m and a large increase of the concentration of



Fig. 3: Scatterplots of the median values of each cases. a) N vs. LWC, b) D_{eff} vs. N and c) D_{eff} vs LWC. Error bars correspond to the 25th-75th percentile intervals.

the largest droplets. Finally during the mature stage where the visibility remains below than 160 m, concentration of the mode of the smallest particle has decreased while both the others have increased by a factor of ten. Such a bimodal size distributions with most of the mass concentrated in the large drop mode are typical of fog (Wendish et al 1998, Gultepe et al 2009).



Fig. 4: PVM vs FM-100 measurements of LWC (left) and D_{eff} (right) for three fog events. One to one (dashed) and linear regression (continuous) lines are overlaid on the one minute samples. On the Deff panel median values (diamond) and 25^{th} -75th percentile intervals are also shown

4. SUMMARY

Microphysical measurements collected during 21 wintertime fog events have been examined to document their properties. Statistics of the droplet number concentration, LWC and effective diameter derived from the FM-100 particle size distribution show a large variability of their characteristic values among the different cases, as well as various evolutions of these properties during the fog life cycle.

Comparisons between FM-100 and PVM measurements however reveal noticeable differences depending on the events, with estimations of LWC that range in a factor of two. A bias appears on D_{eff} comparisons under some circumstances which leads to a substantial underestimation of the FM-100 compared to the PVM when droplets are small. Reasons for this bias is not clear yet and further investigations are needed to validate the dataset. However the agreement is excellent for some cases.



Fig. 5: Particle size distributions as measured with the Palas (dashed) and with the FM-100 (continuous) during the fog event on 19/11/2010. Each spectra is an average over 20 minutes starting at time as indicated on the legend.

Finally, analysis of size distributions shows that the FM-100 underestimates the droplets number in the two first size bins and confirms that the Palas underestimates the concentration of the larger droplets. Otherwise the overlap is very nice and the evolution of both spectra during the fog life cycle are consistent suggesting that this instrumental set up is well suited to study the impact of aerosols on the fog life cycle.

5. ACKNOWLEGMENTS

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