Fog Deposition Measurement using Eddy Covariance Method, FDMECM

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Introduction and motivation

Fog is a meteorological phenomenon and a product of the interplay of many physical processes. Although fog frequently occurs under calm atmospheric conditions, turbulence is one of the key processes determining the fog life cycle. Turbulent exchange of a fog layer with other layers of the atmosphere or with the surface leads to exchange of sensible heat and water vapor. However, our understanding of turbulent processes in fog is more than incomplete. Accordingly, this project is designed to employ an eddy covariance technique, which is a direct method to measure air parcel exchange, to investigate turbulent processes in different fog types occurring at the Site Instrumental de Recherche par Télédétection Atmosphérique (SIRTA). This technique is special by its kind and employed for the first time under radiation and stratus lowering fog types.

Scientific objectives

The scientific objectives of this project are:

- To quantify and characterize turbulent flux of fog droplets/liquid water by using the eddy covariance (EC) technique. Size resolved fluxes of fog droplets are measured. This is the first time that this technique is applied in radiation fog and stratus fog events.
- To investigate the influence of fog on energy fluxes and the interaction between liquid water and water vapor fluxes near the surface during various types of fog events. Opposite fluxes of liquid water and water vapor are expected, it is however unclear if these occur and what their role in the energy balance near the surface is.
- To collect fog water at least on an event basis employing an active fog collector, analyze the chemical composition (major ions, heavy metals and organic compounds) of fog water, in order to understand the role of air pollution on the size distribution of fog droplets.
- To compare EC results and ground based remote sensing techniques (i.e Lidar and Sodar) to characterize physical fog phenomena in order to understand the interaction between fog forming and fog dissipation processes, fog layer thickness, and near-surface liquid water and water vapor fluxes. Generally, these ground based remote sensing techniques are used to understand key physical processes driving fog life cycle. The opportunity of integrating the eddy covariance technique with ground based remote sensing techniques produce intensive data of high temporal resolution.
- To provide detailed high resolution data for evaluation of fog forming and fog forecast models.

Reason for choosing this station

SIRTA is one of the French main atmospheric observatory stations, which is found near to Paris, equipped with ground level *in situ* measurement instruments, atmospheric remote sensing instruments and 30 meter masts with meteorological instruments. The fog research program entitled PARISFOG was established in 2006 (Haeffelin et al., 2005) by relying intensive field campaign measurements from October to March at the SIRTA station. Moreover, the field campaigns involve many institutes, laboratories, universities and private companies focusing on fog research with different instrumentations.
Hence, the station is special in terms of combining different atmospheric measuring instruments, having well established a research program that relies on atmospheric measurements carried out in the station, and providing space and logistics for additional research institutes in order to create conducive environment for collaborative work beyond exchanging of idea and data sharing.

Method and experimental set-up

Eddy covariance is the main technique employed in this study to directly measure turbulent fluxes in a fog. This technique is a key atmospheric measurement method to measure and calculate vertical turbulent fluxes within atmospheric boundary layers. Accordingly, two flux measurement setups having the following instrument were deployed during the winter season (November –March) of 2012/2013 at the SIRTA site at a height of 2.5 m above ground (figure 1a). The instruments are: FM-100 high-resolution droplet spectrometer, fast response CO_2/ H_2O Infrared gas analyzer (Licor-7500 & Licor-7200) and two 3D ultrasonic anemometers (Gill R3-50). Additionally an active fog collector was used to collect fog water for chemical analysis (figure 1b). The FM-100 high-resolution droplet spectrometer was used to measure the number-size distribution of fog droplets at high time resolution (10 Hz) for up to 40 channels ranging from 2 µm to 50 µm droplet diameter. The fast response CO_2 / H_2O gas analyzer was used to measure the respective concentrations at 10 Hz frequency. The 3D ultrasonic anemometer was used to measure three dimensional wind components and sonic temperature at 10 Hz throughout the measuring periods. Turbulent fluxes of sensible heat, water vapor, CO_2, and liquid water can be calculated by the covariance of the vertical wind speed and the respective high frequency data. The active fog collector was used for this measurement is built of 'PEEK' and Teflon and therefore well suited for organic analysis as well as for ions and heavy metals. The use of a strong fan enables a rich harvest of fog water even when fog is not very thick.

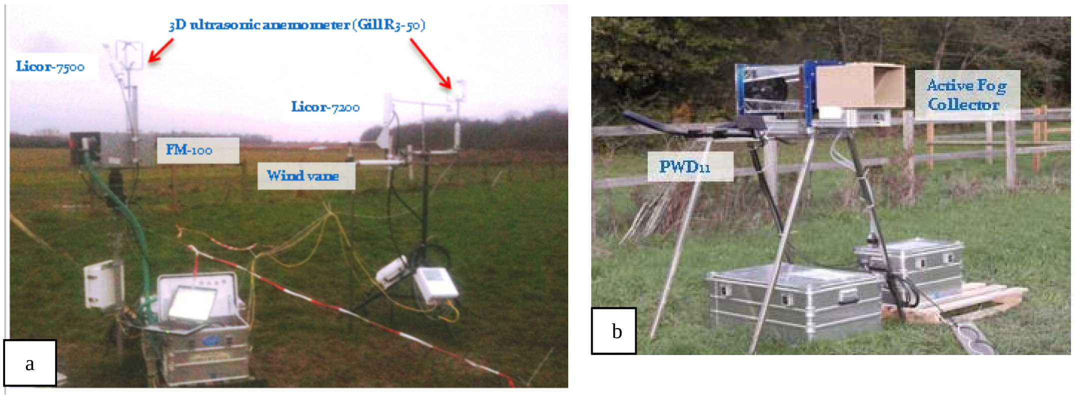

Figure 1. The two eddy covariance measurement setups (left) and the active fog collector (right) at the SIRTA site

Preliminary results and conclusions

Each fog event occurring during the field campaign exhibited distinct characteristics in terms of fog droplet size distribution, liquid water content, and the temporal evolution of these parameters. Computed average fog water flux distributions of radiation and stratus lowering fog types, respectively, exhibited different patterns (figure 2a). The droplet diameter ranges from 23 to 27 µm predominately contributed to fog water flux under radiation fog, whereas under stratus lowering fog, a wider range of droplet diameters (10 to 30 µm) contributed to the liquid water flux. During stratus lowering fog, the magnitude of the fog water flux is much larger as compared to radiation fog. The magnitude of fog droplet number fluxes was also significantly different between the two fog types (figure 2b); however, the droplet sizes contributing most to the number fluxes were similar (figure 2b). In both fog types, droplets with diameter above 7 µm did almost not influences the overall droplet number flux

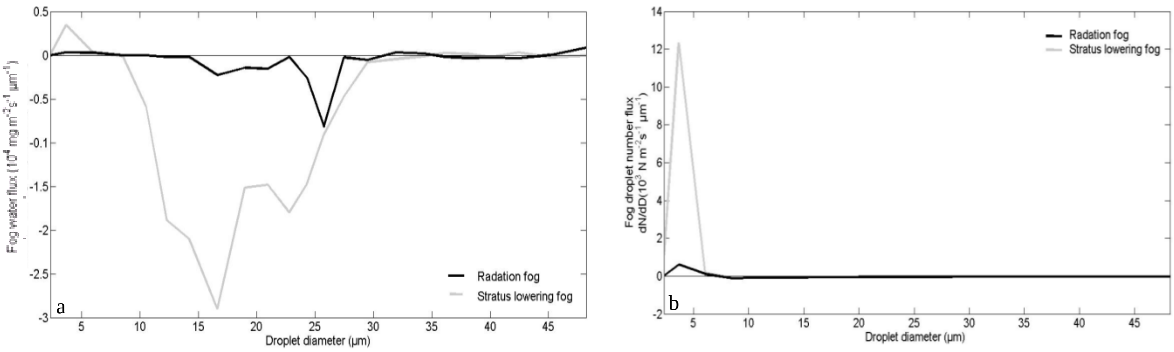

Figure2. Average fog water fluxes and fog droplet number fluxes in a radiation and stratus lowering fogs

Depending on the actual conditions, the major fog forming process (condensation) and fog dissipation may occur above or below the height of the measurement set-up. Moreover, both the liquid water droplets and the water vapor are subject to turbulent transport. Downward (negative) liquid water fluxes were mostly observed in stratus lowering fog, whereas rather complicated patterns emerged in radiation fog events. The directions of fluxes were determined by the dynamic position of the mean condensation process with respect to the measurement height of the eddy covariance setup during the course an event. Opposite direction fluxes with different magnitude were also observed between the fog liquid water and water vapor fluxes in both fog types, however, switching of direction was only observed in radiation fog (c.f., figure 3).

Regarding fog chemistry, 144 samples from 19 fog events were collected and analysis has been undertaking for about 25 inorganic constituents in fog water. Based on the analysis, which has been completed so far, the pH of collected fog-water samples ranged between 4.1 and 6.3. However, the intra-event variability of pH value was almost as large as the inter-event variability. In general, the ammonium concentrations were large, leading to substantial neutralization of nitric and sulfuric acids.

These preliminary findings were communicated through presentation in the event of the 6th International Conference of Fog, Fog Collection and Dew, which was held in Yokohama, Japan in May 2013. Two presentations were delivered in the conference as oral and poster presentations that focused on fog turbulent flux and fog chemistry. The presentations are entitled ‘’Characterization of Fog Water Turbulent Flux in Radiation Fog and Stratus Lowering during PARISFOG’’ and ‘’Chemistry of fog water during the 2012 / 2013 PARISFOG campaign’’. Furthermore, a research paper is planned to be publish in a special edition of Atmospheric Research.

Outcome and future studies

The preliminary results show complex relationships between the turbulent fluxes of fog water, fog droplet number, latent heat, and sensible heat fluxes. Opposite direction fluxes were observed between fog water flux and water vapor flux in both fog types, however, switching of directions of fluxes within the course of single events was exhibited only in radiation fog types. The change of position (height above ground) of the mean condensation process with respect to the measurement height was the factor gearing the direction of fluxes. On the other hand, in stratus lowering fog types, downward (negative) liquid water fluxes were mostly observed.

Investigating the interaction between fog water fluxes with other energy balance components (sensible heat flux, short and long wave radiation fluxes) is under way. Eventually, we will develop a profound understanding of how the single energy balance components do exert influence on the dynamics of fog.

Concerning the chemical analysis of fog water samples, it is also under way. The identified chemical constitutes together with measured fog droplet size distribution and fog density will enable us to figure out how pollution of air influences on fog droplets size distribution and visibility.

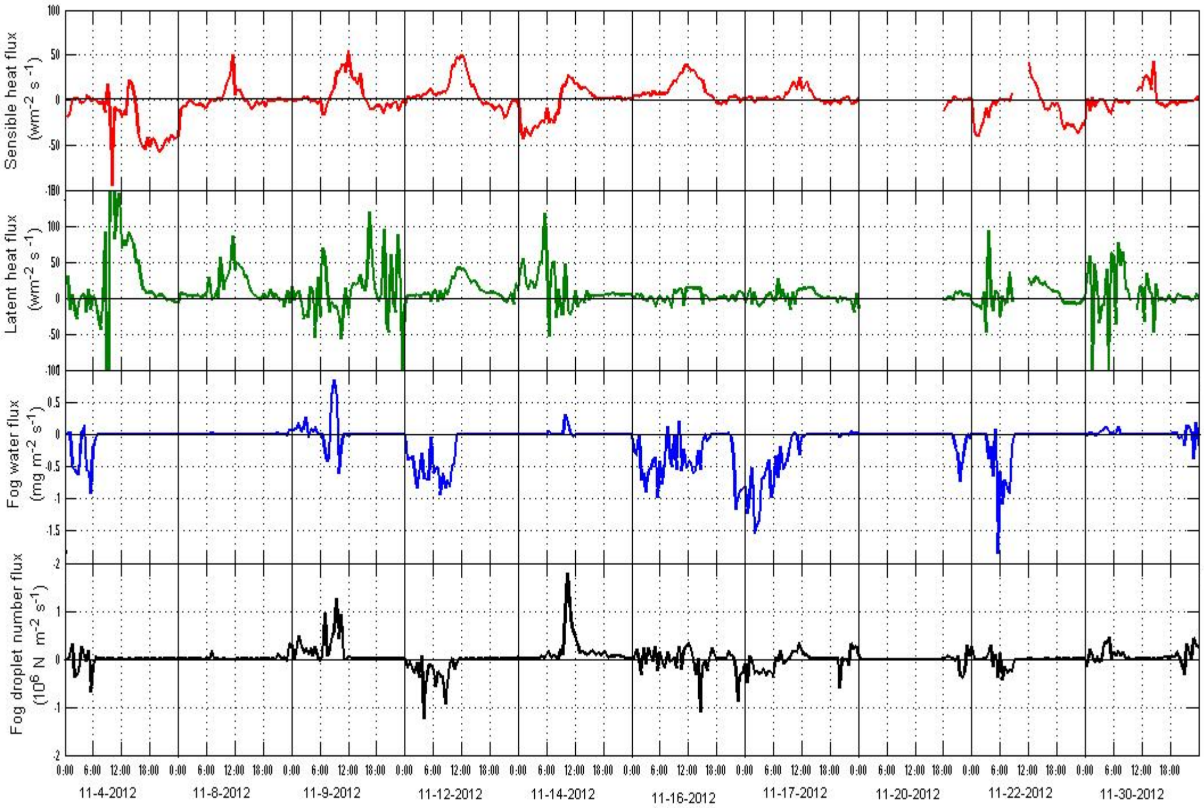

Figure 3. Sensible heat fluxes, latent heat fluxes, fog water fluxes and fog droplet number fluxes computed from 10 fog events occurred in the month of November, 2012.

References

Haeffelin, M. et al., SIRTA, a ground-based atmospheric observatory for cloud and aerosol research, Annales Geophysicae ***23****(2005), pp. 253-275.*