PhD Thesis at Laboratoire de Météorologie Dynamique, Ecole Polytechnique, Palaiseau (Paris), France.

Title.
Development of conceptual models describing dynamic, thermodynamic, radiative and microphysical processes, and their interactions, driving the life cycle of continental radiative fogs and fog-stratus transitions.

Context.
Fogs are studied because of the proven and direct impact of reduced visibility on major activities of our societies, such as transport and surveillance [Gultepe et al. , 2007]. The intensification of maritime, air and land transport is accompanied by the need to provide enhanced precision in space and time of fog appearance, development, intensity and dissipation. However, the complexity, diversity and fine scales of the processes involved [Dupont et al. , 2012] make the prediction of fog episodes by conventional meteorological numerical weather prediction models, rather uncertain. A better understanding of the dynamics , radiative and microphysical processes governing the life cycle of fog is then necessary to refine these estimates [Haeffelin et al , 2013. ; Elias et al., 2014] . Recent studies [Dupont et al. , 2014] and projects [DGA RAPID Previboss , T. Elias] showed interest but also limitations of the exclusive use of surface measurements, that must obviously be complemented and reinforced by measurements from active and passive remote sensing.

Since 2006, the French scientific community has established a fog research program (ParisFog ; http://parisfog.sirta.fr ; Haeffelin et al 2010.) to better understand dynamic, radiative , microphysical and chemical processes, and their interactions. This program is based on measurement campaigns carried out each winter on SIRTA atmospheric observatory (http://sirta.ipsl.fr/) . Using different tracers and different means of remote sensing, measurements made SIRTA allow to finely characterize the properties of atmospheric particles which have a strong impact on the life cycle of fog and low cloud layers. For the ParisFog measurement campaign October 2012 - March 2013 , ten French and European laboratories teamed up to develop comprehensive observations of vertical profiles of aerosols and droplets in fog conditions by in-situ measurement devices (at ground and balloon profiles) and remote sensing (lidar and radar) .

Scientific objectives.
The thesis aims to advance our understanding of the dynamic , thermodynamic , radiative and microphysical processes that drive the life cycle of fog events. Recent articles (Dupont et al , 2012; Haeffelin et al , 2013; Stolaki et al., 2014) point to the particular importance of vertical distributions of particles (aerosols and fog droplets) and dynamic and thermodynamic parameters on the processes involved in the formation and fog dissipation : (i) interactions between the size distribution of particles and the internal dynamics of the cloud layer controlling the transitions between stratus and fog (subsidence or elevation) ; (ii) the vertical distribution of aerosols growth and the appearance of the liquid phase or at the surface (radiation fog) or a few hundred meters (stratus) , and their impact on the radiative exchanges that drive the development (or not) of the fog. The thesis should allow to achieve more precise conceptual models describing the processes involved in continental radiative fog and transitions between fog and stratus.

Detailed research program.

The first part of the thesis will focus on inversions of active and passive remote sensing measurements to derive the properties of aerosols and water droplets, and the dynamic and thermodynamic conditions encountered. In a second step , analysis (case studies and statistics) will focus on quantification and prioritization of the various processes (intervals of critical values) . In a third step , the work will lead to the development of conceptual models describing the formation , development and dissipation of fog . The thesis work will be guided by the following scientific questions:

1. To what extent the study of the spatial and temporal variability of Lidar backscatter signals may allow us to better understand the hydration and activation processes of aerosols favorable to the formation of radiation fog?

2 . To what extent the study of spatial and temporal variability of the reflectivity and Doppler radar velocity can help us identify conditions and thresholds favorable to the vertical development of the fog or the rapid dissipation of fog?

3 . To what extent the spatial and temporal variability of stability and turbulence at low level provided by microwave radiometer and Doppler lidar can help discriminate conditions favorable or unfavorable to the formation of fog ?

Year 1. Inversion of radar, lidar and radiometer signals to derive geophysical properties of the atmosphere (clear air, cloudy air),

- Apply variational algorithms (RaDon, SYRSOC) on Doppler radar measurements at 94 GHz to retrieve dynamic and microphysical properties of cloud layers
- Apply inversion algorithms on Lidar and radiometer measurements to retrieve the microphysical and thermodynamic properties of the layers without hydrometeors
- Validate retrievals with in-situ observations from surface and tether balloon profiles
- Write a scientific paper on remote sensing observation of key parameters and processes controlling the fog

Year 2. Process studies to better understand the phase transitions in the life cycle of fog

- Quantify the variability of key geophysical parameters by statistical analysis of retrieved products
- Determine the intervals of critical values (that variables from remote sensing must take) favorable or not favorable to the formation, vertical development and dissipation of fog
- Prioritize and analyze the interactions between key processes controlling the life cycle of fog

Year 3. Development of conceptual models on the formation , development and dissipation of fog

- Develop conceptual models on the formation , development and dissipation of fog
- Quantify the critical values of some key parameters in the conceptual models to use these patterns to anticipate and predict the evolution of fog.

- Write a scientific paper presenting each conceptual model
- Thesis writing

Expected results.

- Quantification of the variability of the key parameters controlling the continental fogs.
- Description of added benefit of remote sensing instruments (radar, lidar, radiometer) for fog phase identification and support for fog prediction
- Identification of conditions favorable for different phases of the life cycle of fog (formation, development, dissipation)
- Development of conceptual models describing these phases for continental radiative fog and stratus fog transitions .

Tools necessary for the study.

- The existing homogeneous , validated and comprehensive fog database based on 4 campaigns ParisFog (6 months each, 2006 and 2010-2013) : in- situ ground measurements, tethered balloon measurements and remote sensing lidar, radar and radiometer.
- Inversion algorithms for lidar , radar, and microwave radiometer measurements

PhD thesis:

- PhD thesis proposed and directed by Martial Haeffelin (IPSL / CNRS) . Co-supervision by Jean- Charles Dupont (IPSL / UVSQ)
- Funding : DGA/Ecole Polytechnique Fellowship, jointly funded with MODEM
- Graduate School of Ecole Polytechnique (Palaiseau, France)
- Thesis to start October 2015.

Application:

Deadline:

- Early application: from today until 20 March 2015
- Latest application: 15 April 2015

PhD Scholarship sponsored by French Ministry of Defense. Scholarship is open to European citizens (including from Switzerland).

Application documents: send to martial.haeffelin@ipsl.polytechnique.fr

- detailed CV
- motivation letter (motivation to pursue PhD, motivation for the proposed research topic). Include a description of your current situation
- letters of reference from a prior advisor, tutor or employer
- information regarding your scores in graduate-level scientific classes

Recent Team bibliography on the topic.

Dupont J.-C., M. Haeffelin' A. Protat, D. Bouniol, N. Boyouk, Y. Morille (2012). Stratus fog formation and dissipation. A 6-day case study. Boundary-Layer Meteorol 143: 207–225.

Elias, T., M. Haeffelin, P. Drobinski, L. Gomes, J. Rangognio, T. Bergot, P. Chazette, J.-C. Raut, M. Colomb (2009). Particulate contribution to extinction of visible radiation: pollution, haze, and fog. Atmospheric Research 92, 443–454.

Haeffelin, M., T. Bergot, T. Elias, R. Tardif, D. Carrer, P. Chazette, M. Colomb, P. Drobinski, E. Dupont, J-C. Dupont, L. Gomes, L. Musson-Genon, C. Pietras, A. Plana-Fattori, A. Protat, J. Rangognio, J-C. Raut, S. Rémy, D. Richard, J. Sciare, X. Zhang (2010). PARISFOG: Shedding New Light on Fog Physical Processes. Bull. Amer. Meteor. Soc., 91, 767-783.

Haeffelin, M., F. Angelini, Y. Morille, G. Martucci, S. Frey, G.-P. Gobbi, S. Lolli, C. D. O'Dowd, L. Sauvage, I. Xueref-Rémy, B. Wastine, D. Feist (2011). Evaluation of mixing height retrievals from automatic profiling lidars and ceilometers in view of future integrated networks in Europe. Boundary Layer Meteorology, 143:49–75.

Haeffelin, M., J-C. Dupont, N. Boyouk, D. Baumgardner, L. Gomes, G. Roberts (2013). A comparative study of radiation fog and quasi-fog formation processes during the Paris Fog field experiment 2007. Pure and Applied Geophysics, v. 170, pp. 2283-2303

Pal, S., M. Haeffelin, and E. Batchvarova (2013). Exploring a geophysical process-based attribution technique for the determination of the atmospheric boundary layer depth using aerosol lidar and near-surface meteorological measurements. *Journal of Geophysical Research: Atmospheres*, *118*(16), 9277-9295.

Stolaki, S., Haeffelin, M., Lac, C., Dupont, J. C., Elias, T., & Masson, V. (2014). Influence of aerosols on the life cycle of a radiation fog event. A numerical and observational study. *Atmospheric Research*. In press.