



## **Fleets of enduring drones to probe atmospheric phenomena with clouds**

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A full spatio-temporal four-dimensional characterization of the microphysics and dynamics of cloud formation including the onset of precipitation has never been reached. Such a characterization would yield a better understanding of clouds, e.g. to assess the dominant mixing mechanism and the main source of cloudy updraft dilution.

It is the sampling strategy that matters: fully characterizing the evolution over time of the various parameters (P, T, 3D wind, liquid water content, aerosols...) within a cloud volume requires dense spatial sampling for durations of the order of one hour. A fleet of autonomous lightweight UAVs that coordinate themselves in real-time as an intelligent network can fulfill this purpose.

The SkyScanner project targets the development of a fleet of autonomous UAVs to adaptively sample cumuli, so as to provide relevant data to address long standing questions in atmospheric science. It mixes basic researches and experimental developments, and gathers scientists in UAV conception, in optimal flight control, in intelligent cooperative behaviors, and of course atmospheric scientists. Two directions of researches are explored: optimal UAV conception and control, and optimal control of a fleet of UAVs.

The design of UAVs for atmospheric science involves the satisfaction of trade-offs between payload, endurance, ease of deployment... A rational conception scheme that integrates the constraints to optimize a series of criteria, in particular energy consumption, would yield the definition of efficient UAVs. This requires a fine modeling of each involved sub-system and phenomenon, from the motor/propeller efficiency to the aerodynamics at small scale, including the flight control algorithms. The definition of mission profiles is also essential, considering the aerodynamics of clouds, to allow energy harvesting schemes that exploit thermals or gusts. The conception also integrates specific sensors, in particular wind sensor, for which classic technologies are challenged at the low speeds of lightweight UAVs.

The overall control of the fleet so as to gather series of synchronized data in the cloud volume is a poorly informed and highly constrained adaptive sampling problem, in which the UAV motions must be defined to maximize the amount of gathered information and the mission duration. The overall approach casts the problem in a hierarchy of two modeling and decision stages. A macroscopic parametrized model of the cloud is built from the gathered data and exploited at the higher level by an operator, who sets information gathering goals. A subset of the UAV fleet is allocated to each goal, considering the current fleet state. These high level goals are handled by the lower level, which autonomously optimizes the selected UAVs trajectories using an on-line updated dense model of the variables of interest. Building the models involves Gaussian processes techniques (kriging) to fuse the gathered data with a generic cumulus conceptual model, the latter being defined from thorough statistics on realistic MesoNH cloud simulations. The model is exploited by a planner to generate trajectories that minimize the uncertainty in the map, while steering the vehicles within the air flows to save energy.