SkyScanner

"Deploying fleets of enduring drones to probe atmospheric phenomena"

Kicked off on June the 16th, 2014

Project supported by the STAE foundation, 2014 / 2016

STAE TOULOUSE

RTRA STAE
Sciences et Technologies pour l'Aéronautique et l'Espace

Scope of the project

- Overall target: follow the evolution of a cloud with multiple drones to study entrainment and the onset of precipitation
  - Characterize state of boundary layer below and surrounding a cloud
    - atmospheric stability
    - lifting condensation level
    - cloud updraft
  - Follow 4D evolution of the cloud
    - entrainment at edge
    - liquid water
    - cloud microphysical properties

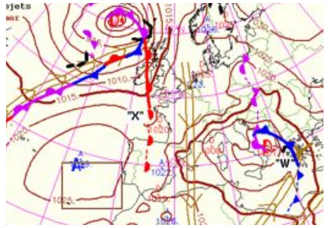
➡ Impacts the drone conception and the fleet control

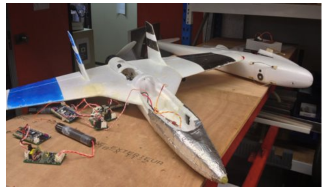
Involved Partners

CNRM

“Centre National de Recherches Météorologiques”

Experts in atmospheric sciences, fly drones

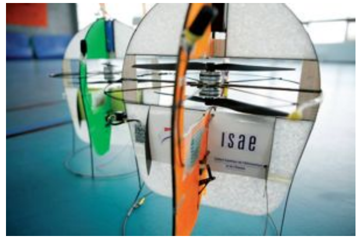




ISAE

“Institut Supérieur de l’Aéronautique et de l’Espace”

Experts in fluid dynamics, flight mechanics & drones



ONERA

“The french aerospace lab”

Experts in flight control

ENAC

“École Nationale de l’Aviation Civile”

Experts in drones (cf Paparazzi autopilot)

PAPARAZZI
The Free Autopilot

LAAS

Laboratory for Analysis and Architecture of Systems

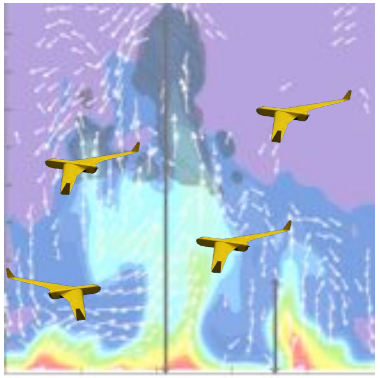
Roboticists

Scope of the project

- 3 research axes:
  - Refine aerologic models of clouds

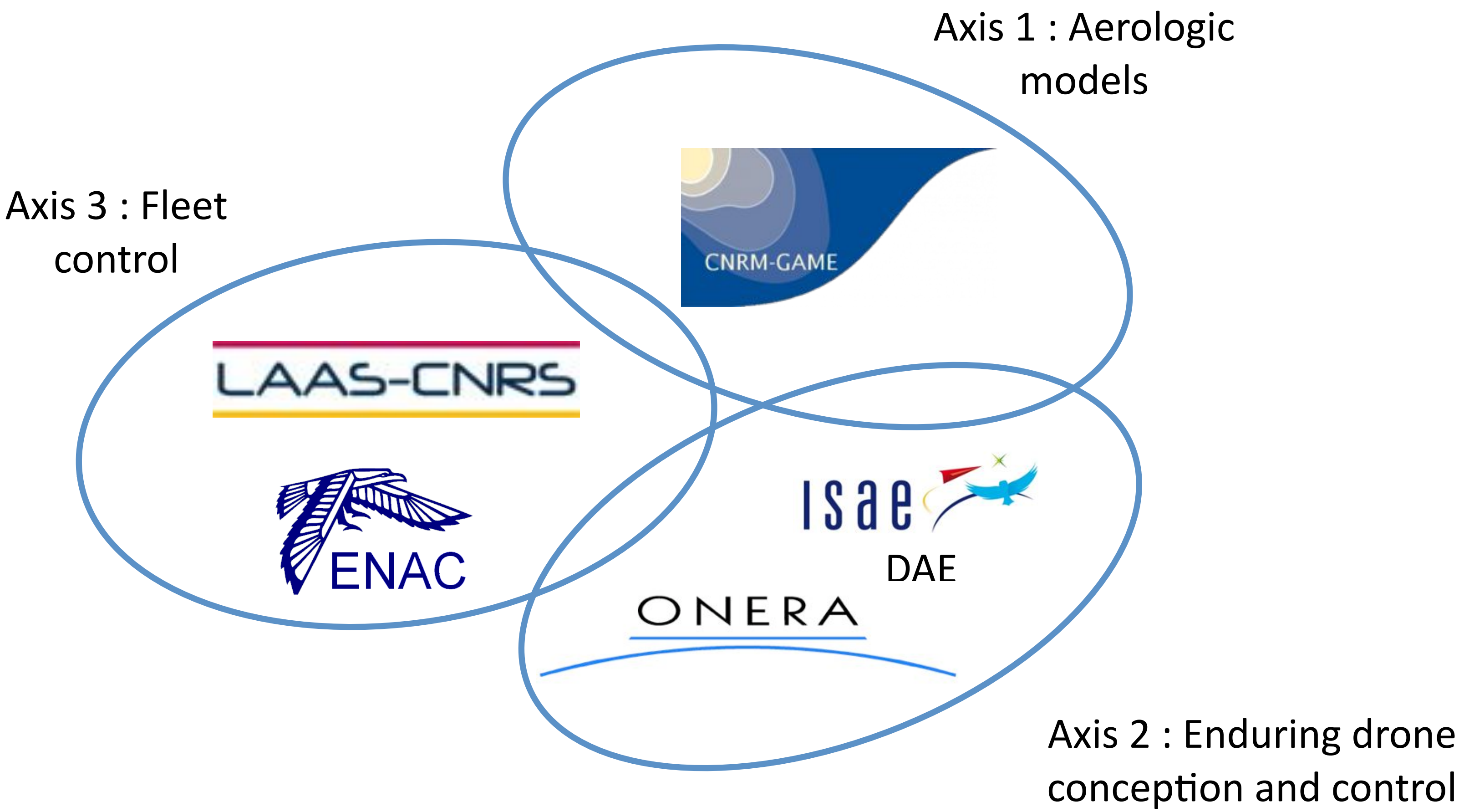
  - Conceive enduring micro-drones

  - Fleet control



Plus: experimental developments and validations

The partners



- Funding amounts to five 18 months postDocs / research engineers

Beyond SkyScanner

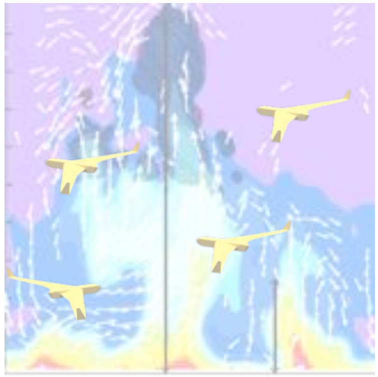
- Numerous other dynamic atmospheric phenomena to analyze
- Very similar problems in ocean sciences (*e.g.* mapping flows, plumes…)
- Numerous researches related to the conception and control of (micro)-drones (*e.g.* 24/7 flight, innovative platforms and actuators…)
- Numerous researches in fleets of aerial / ground / marine autonomous robots
- …

Outline

- 3 research axes:
  - Refine aerologic models of clouds
    - The scientific challenge
    - On the interest of drones

  - Conceive enduring micro-drones

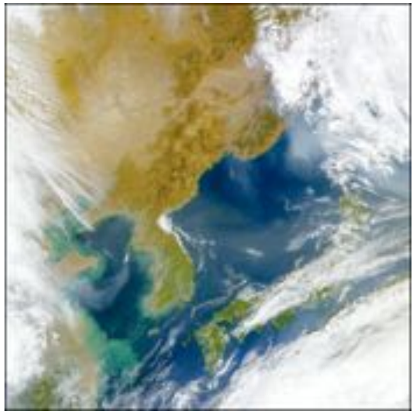
  - Fleet control



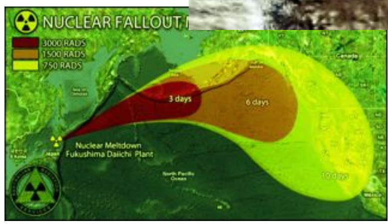
Plus: experimental developments and validations

Airborne measurements

- Different sources and transport (i.e., volcanic eruptions, biomass burning, industrial pollution, dust)
- Aerosol-cloud interactions
- In-situ validation of numerical models, satellite data







Important to characterize atmospheric structure and spatial/temporal variability

Cloud microphysics

- Entrainment is the mixing of saturated and unsaturated air into a cloud.

- Entrainment coefficient among most sensitive variables causing uncertainty in climate models.

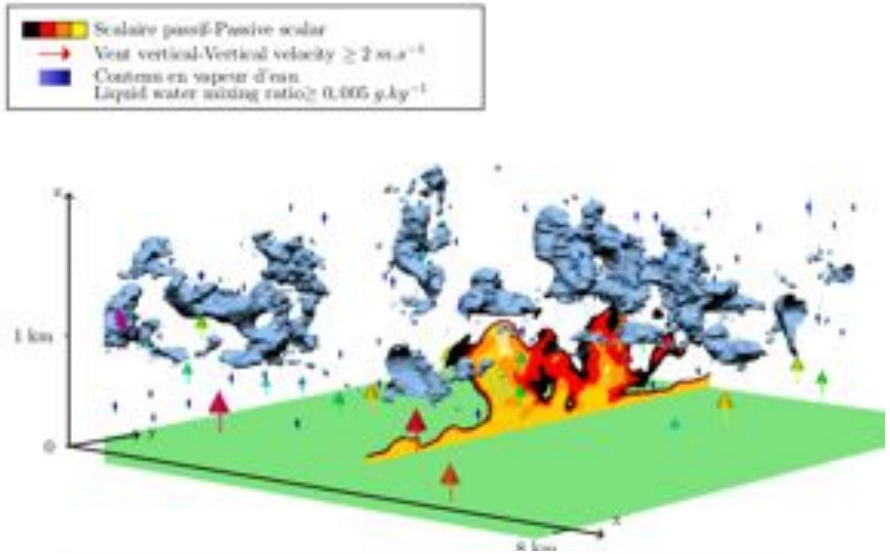
- **Homogeneous mixing:** $\tau_{evaporation} > \tau_{mixing}$
  → evaporation of all cloud drops, but no change in droplet number
  → narrow cloud droplet spectrum

- **Inhomogeneous mixing:** $\tau_{evaporation} < \tau_{mixing}$
  → evaporation of cloud drops within entrained area reduces the total droplet number
  → no change in cloud droplet spectrum

Large Eddy simulations (LES)

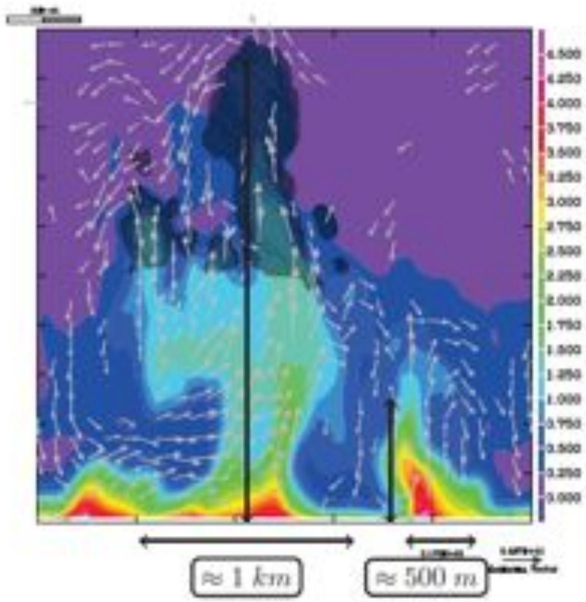
• Use of Meso-NH model

• Existing set of dry and cloudy convective boundary layer case studies

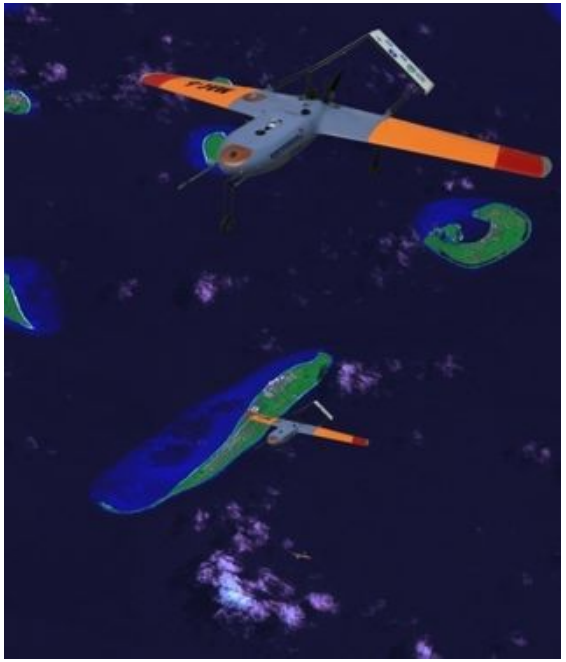


• Select cases and perform higher resolution simulations (10m) with release of UAS to

1. provide measured parameters
2. determine the flight strategy

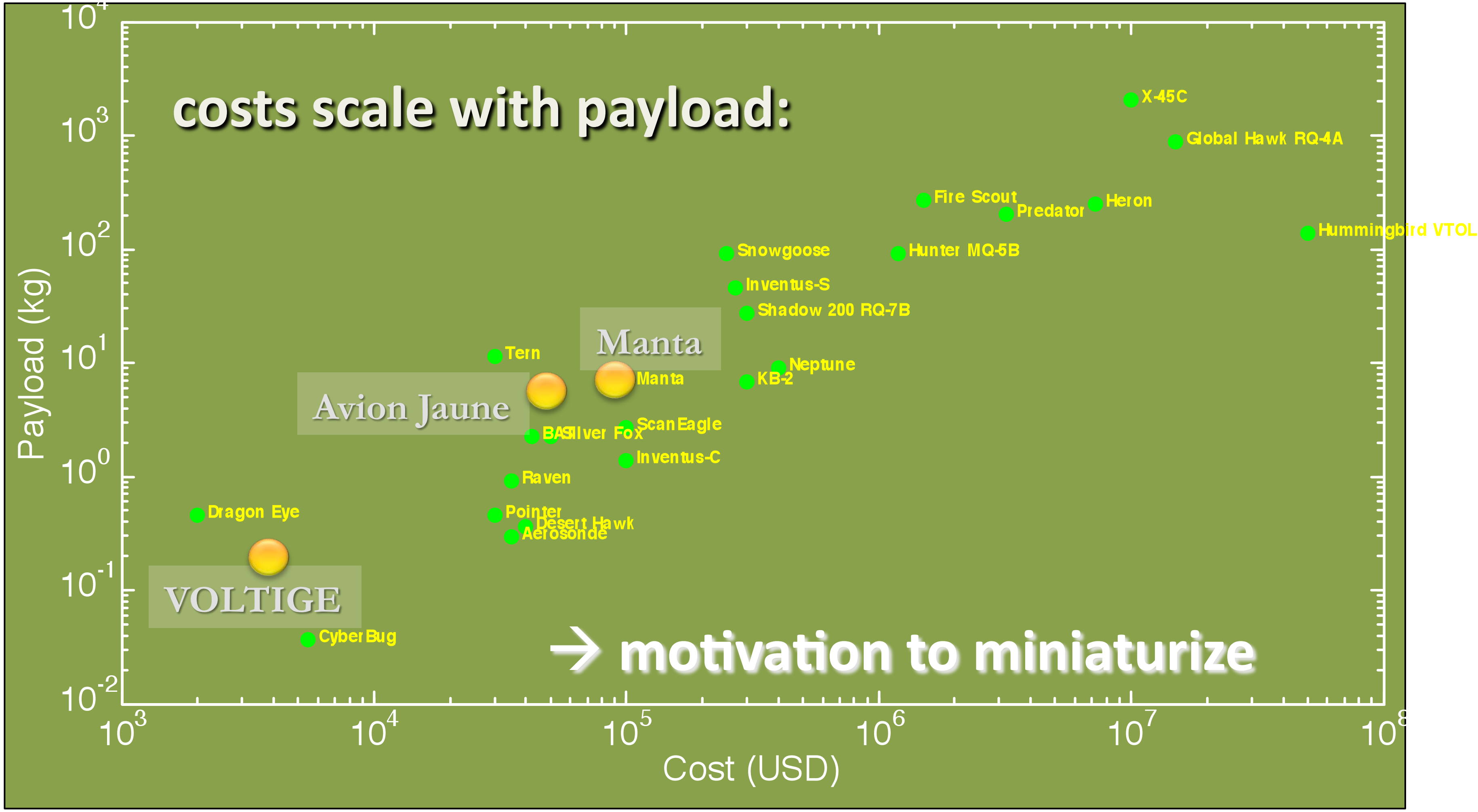


Simultaneous observations with UAS



- aerosol-cloud interactions & cloud microphysics
- atmospheric heating of aerosol layers

UAS Cost Comparison



Requirements and constrains on drones

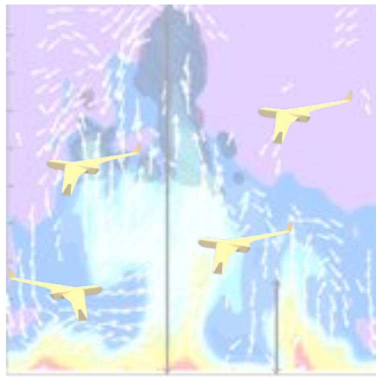
- 4D sampling : 10m resolution within ~ a km^3, the longer the better (1/2 hour minimum)
- Dynamic and local phenomena (need for maneuverability)
- Dedicated instruments: PTU, 3D winds, droplets counter, radiation, aerosols…

➡ Need to optimize the drones conception, control and coordination

Which is the best platform?

Outline

- 3 research axes:
  - Refine aerologic models of clouds
  - Conceive enduring micro-drones
    - Conception issues
    - Flight control, energy management
    - Instrumentation
  - Fleet control



Plus: experimental developments and validations

From user needs to specifications

Optimize numerous trade-offs, considering:

1. Payload requirements (temporal and spatial resolution)
2. Mission profiles (duration, characteristic velocities, …)
3. Weight / energy management
4. Realistic manufacturing constraints

Main trade-off for SkyScanner: endurance vs. maneuverability

ISAE SUPAERO ENAC THALES

→ Calls for system modeling / validation and optimization strategies

Energy management

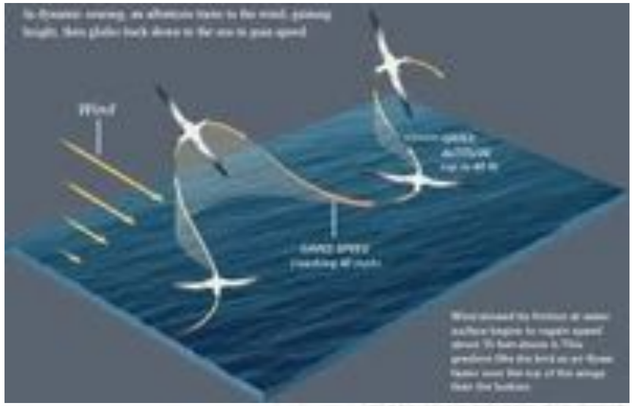
- Exploiting thermals

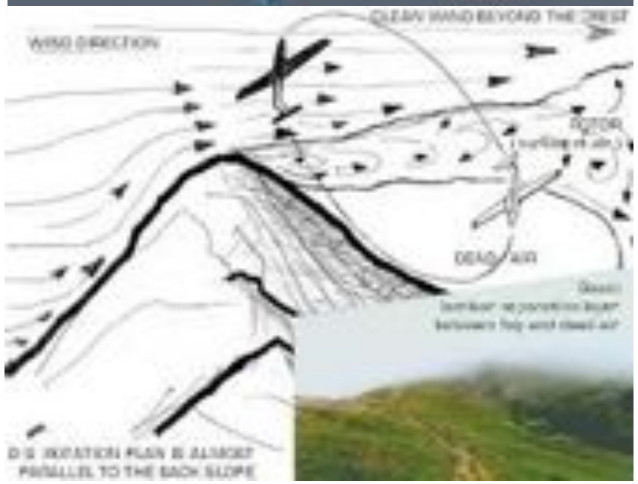
Thermal detection, optimizing the trajectory w.r.t. altitude gain and atmospheric measures

➡ Use of LES flow fields to specify flight strategies and deduce all-round designs

- Harvesting gusts / shears

"Dynamic soaring"





(on-going thesis @ ISAE / UWE)

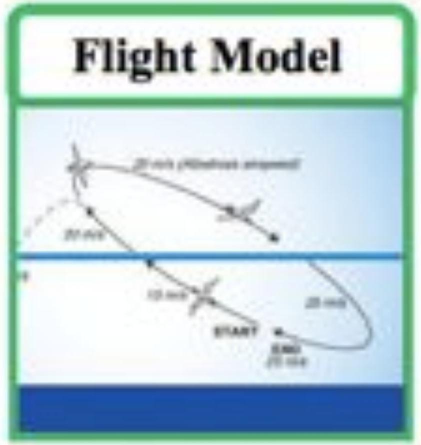
(Parenthesis: dynamic soaring)

(Parenthesis: dynamic soaring)

- On-going thesis @ ISAE / UWE (V. Bonnin)

Which vehicle would be suitable for DS flight?

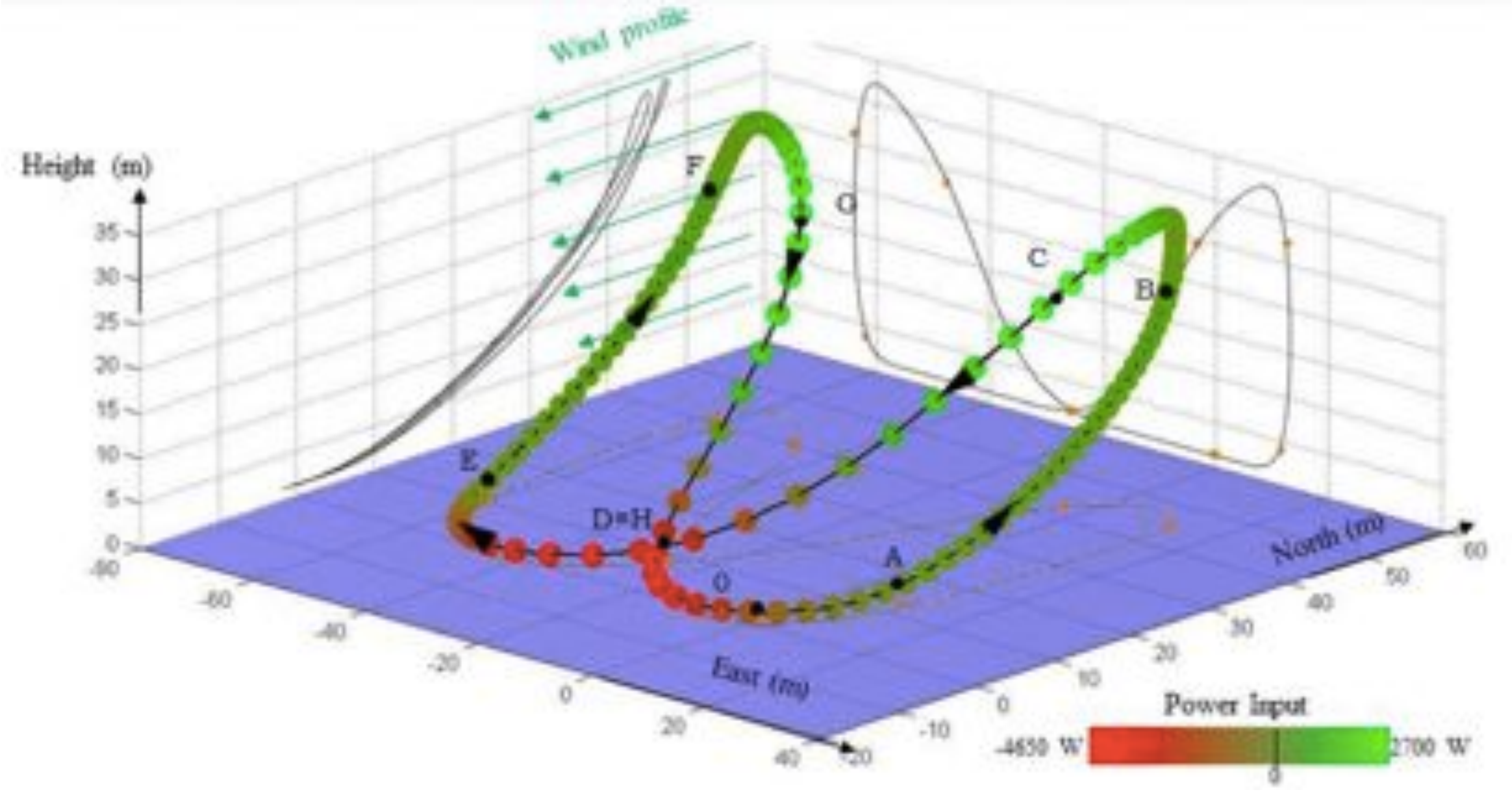
What are the environment condition required for DS?



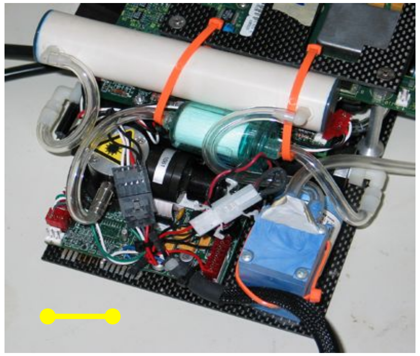
What trajectories would optimize energy-extraction?

(Parenthesis: dynamic soaring)

- On-going thesis @ ISAE / UWE (V. Bonnin)



Dedicated instrumentation


Particle size & number (580 g)

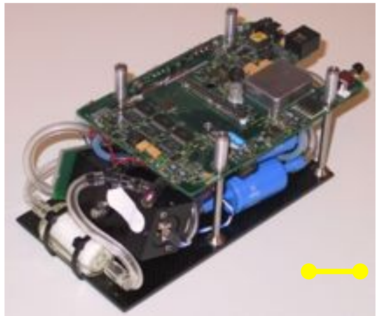

Aerosol sampling (150 g)


Cloud droplets (1.4 kg)


Electrical field (<30 g)

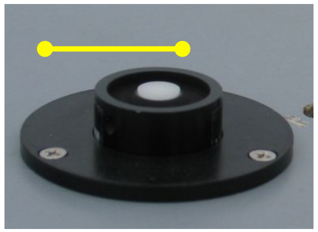

Smoke aerosol (280 g)


CCN aerosol (1.9 kg)


Total particle number (870 g)


Radiometers (<2 g)


Broadband flux (190 g)


Sun energy: visible (45 g)

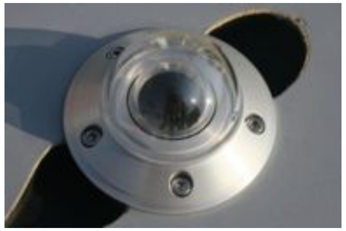

Ozone (600 g)


Turbulence (100 g)

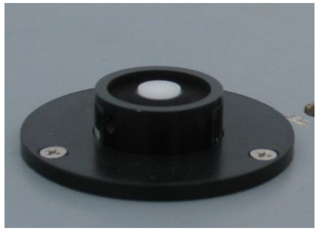

Temperature / humidity / airspeed (<20 g)

Optimize the instrumentation

Turbulences
(3D pitot tube, 190 g)



Broadband flux (190 g)



Sun energy
(visible, 45 g)

PTU

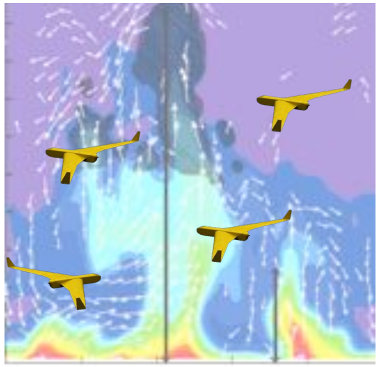
- Fulfill both scientific and guidance tasks:
  - Scientific targets: PTU, 3D winds, droplets counter, radiation, aerosols…
  - Flight control: reactivity to environment (lift detection, gusts) and optimization of flight path (scientific target and energy management)
- Stringent compactness and weight constraints (overall mass < 2.0 kg)

Outline

- 3 research axes:
  - Refine aerologic models of clouds

  - Conceive enduring micro-drones

  - Fleet control
    - Problem statement
    - Foreseen solutions



Plus: experimental developments and validations

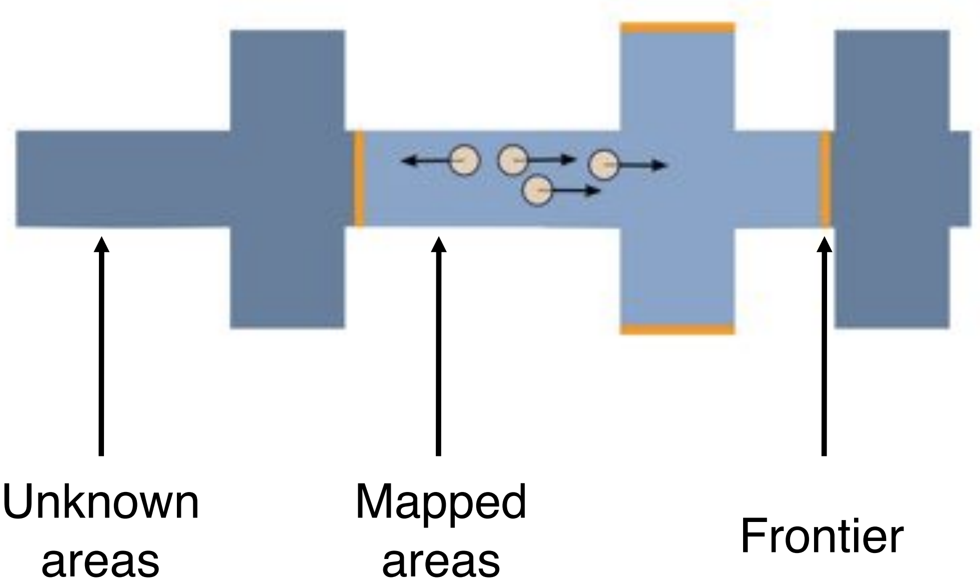
Fleet control

- An adaptive sampling problem
  - Servo on the gathered information to gain more information
  - Optimize the drones trajectories (trade-off: explore vs. sustain)

- Inputs
  - Models of the drones
  - Model of the cloud (initiated by LES, continuously updated on-flight)

Analogy with multi-robot exploration

- A well studied problem

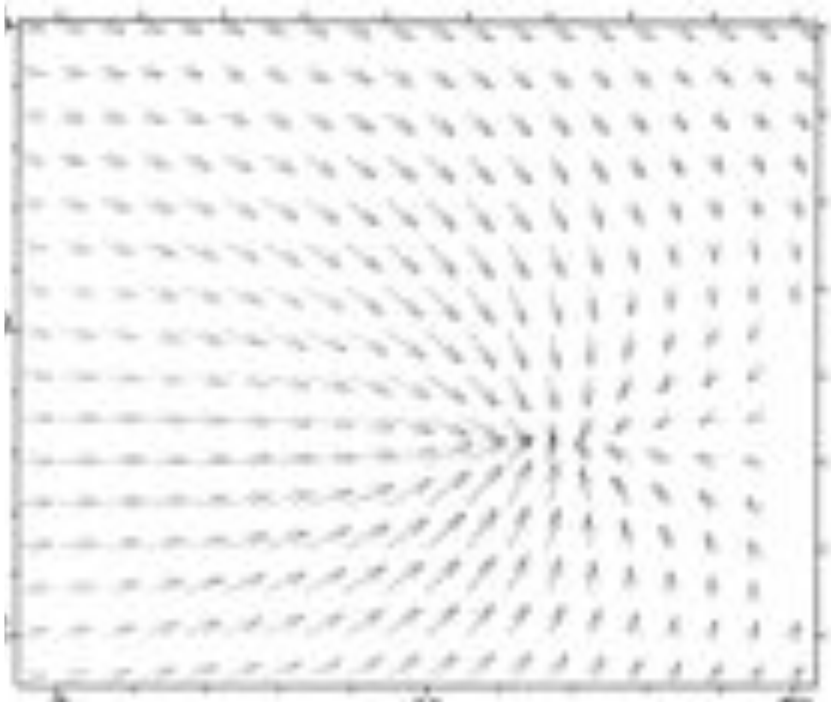


Frontier-based exploration:

- Who goes where?
- How?

Limits of the analogy…

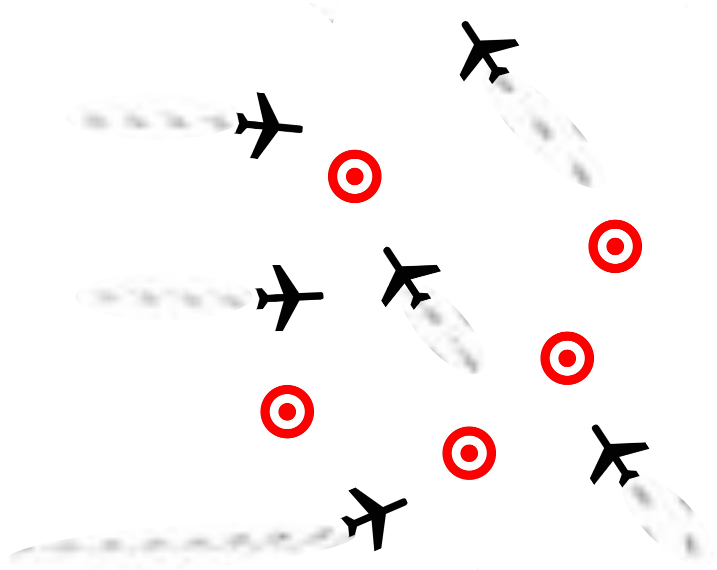
- A *dynamic* phenomenon…
- … observed *locally*



“Air truth”

Limits of the analogy…

- A *dynamic* phenomenon…
- … observed *locally*



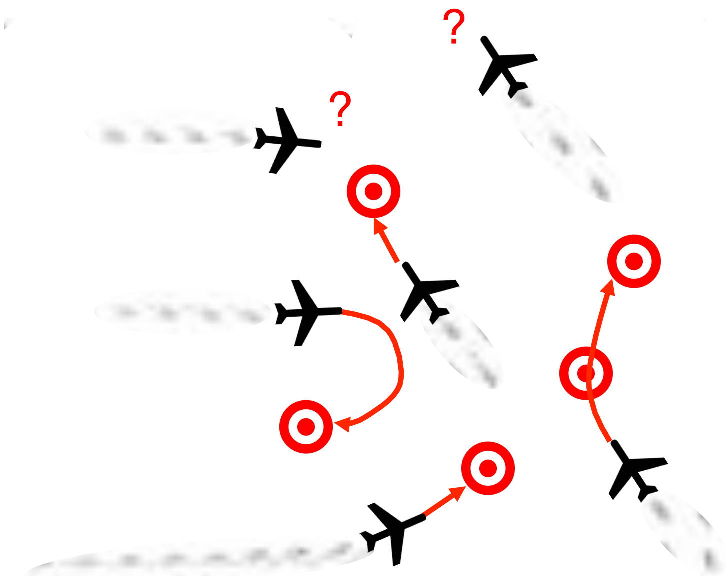
Known information at time *t*

1. Where to gather new information?

2. Who is flying where?

Limits of the analogy…

- A *dynamic* phenomenon…
- … observed *locally*



Known information at time *t*

1. Where to gather new information?

2. Who is flying where? And how?

➡ Numerous issues to tackle

- Predefined patterns vs. pure adaptive solutions?
- Distributed vs. centralized solutions?
- Planning vs. optimizing?
- Waypoint nav. vs. trajectory following?
- Heterogeneous fleet?

Limits of the analogy…

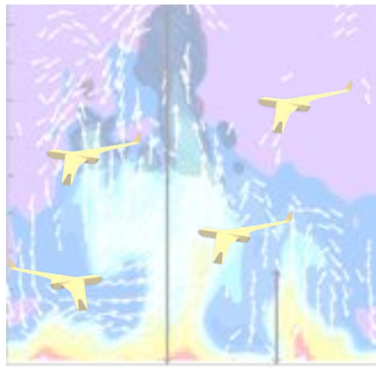
- Predefined patterns vs. pure adaptive solutions?
- Distributed vs. centralized solutions?
  - What information to exchange ?
- Planning vs. optimizing?
- Waypoint nav. vs. trajectory following?
- Heterogeneous fleet?

Outline

- 3 research axes:
  - Refine aerologic models of clouds

  - Conceive enduring micro-drones
    - Conception issues
    - Flight control

  - Fleet control



Plus: experimental developments and validations

Platforms

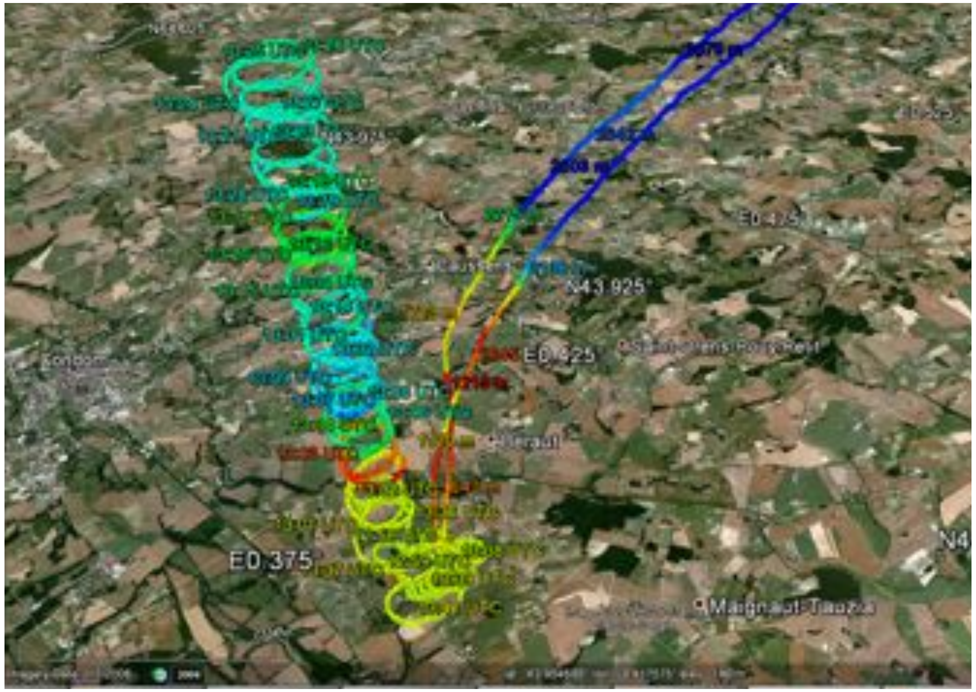
- Commercially available airplane models
- < 2.0 kg
- Controlled by Paparazzi autopilot

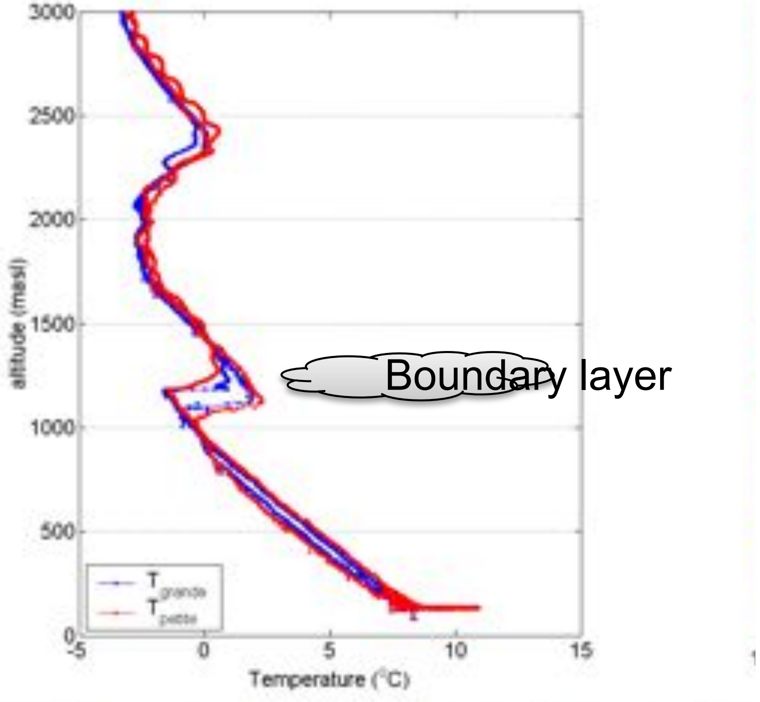
Recent experiments (CNRM & ENAC)

Typical flight patterns and data

Profile to 3000 m.asl (spiral w/ 700 m Ø)

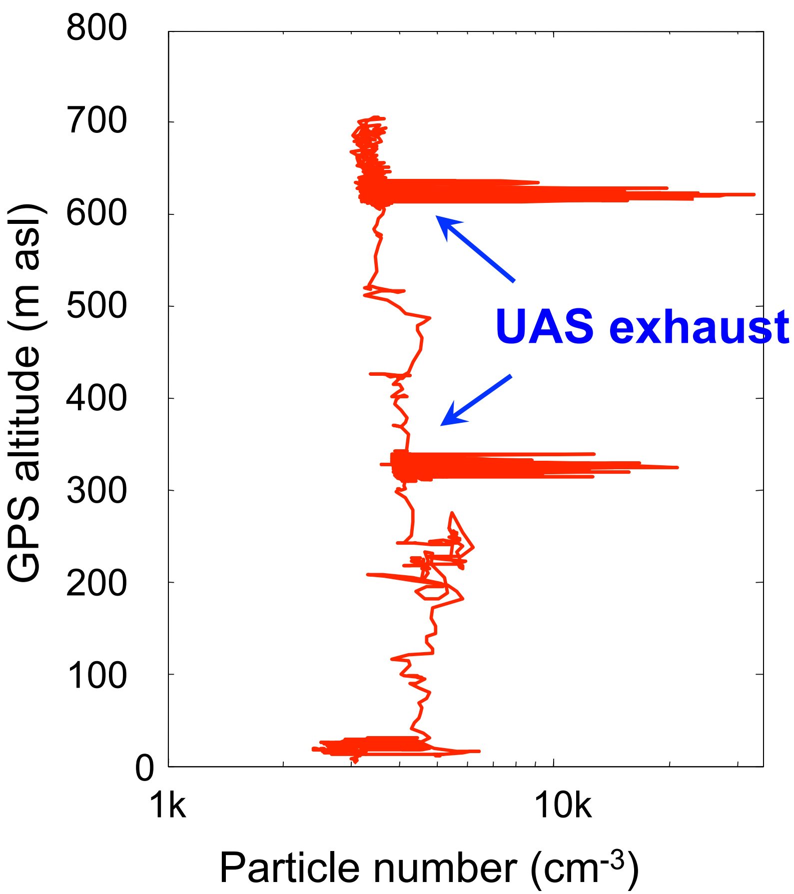
Ascent / descent ratio (100 / -230 m.min^{-1})

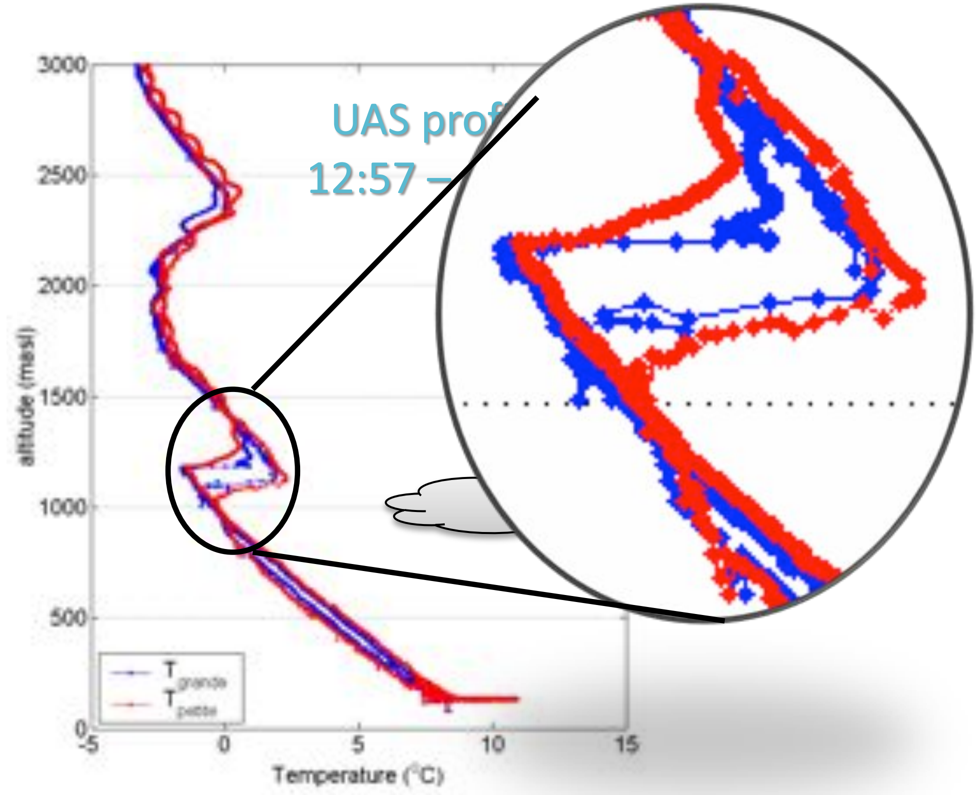




Recent experiments (CNRM & ENAC)

Qualifying the instruments



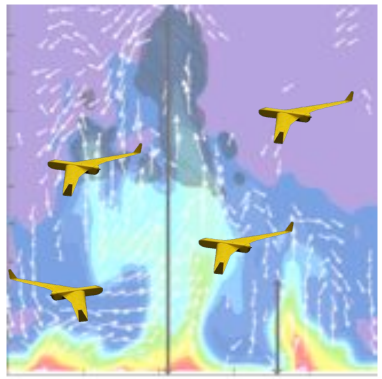


Long time lag of mini-temperature probes

Recent experiments (CNRM & ENAC)

Outline

- 3 research axes:
  - Refine aerologic models of clouds
  - Conceive enduring micro-drones
  - Fleet control



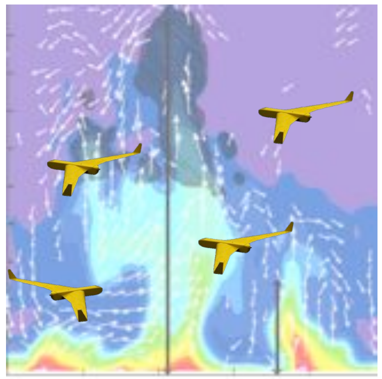
Plus: experimental developments and validations

Summary

- 3 research axes:
  - Refine aerologic models of clouds

  - Conceive enduring micro-drones

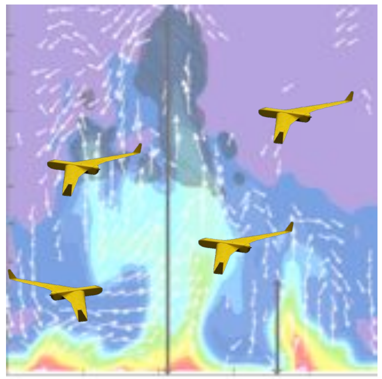
  - Fleet control



Plus: experimental developments and validations

Future work

- 3 research axes:
  - Refine aerologic models of clouds
  - Conceive enduring micro-drones
  - Fleet control



Plus: experimental developments and validations