Drones et instrumentation miniaturisée

Session ‘Vecteurs et instrumentation embarquée’

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AEI, 17 October 2017, IFREMER, Brest

Motivation for using UAS

- **In-situ observations are needed**
  - **to extend ground-based measurements**
  - **processes in the lower 5 km of the atmosphere**
  - **in remote or inaccessible locations**
- **Long-term sampling / monitoring (seasonal cycles)**
- **Track complete life cycle of event (process studies)**
- **Formation flying (multi-dimensional observations)**
  - **Simultaneous, mission-specific sampling**
  - **high-resolution spatial / temporal measurements**

UAS Projects at CNRM

1. VOLTIGE (**V**ecteurs d'**O**bservation de **L**a **T**roposphère pour l'**I**nvestigation et la **G**estion de l'**E**nvironnement), ANR, 2013 – 2015 • Feasibility of using multi-drone observations to study fog events

2. BACCHUS (**I**mpact of **B**iogenic versus **A**nthropogenic emissions on **C**louds and **C**limate: towards a **H**olistic **U**nderStanding), EU FP7, 2013 – 2018 • Reducing the uncertainty of aerosol-cloud interactions in climate change assessments

3. SkyScanner, RTRA-STAE, 2014 – 2017 • Develop at strategy for deploying a fleet of UAVs to study the evolution and entrainment mixing of clouds

4. STRAP (**S**ynergie **T**ransdisciplinaire pour **R**épondre aux **A**léas liés aux **P**anaches volcaniques), ANR, 2014 – 2017 • Study the composition and evolution of aerosols and gases of volcanic plumes

5. BACC+ (**BA**sse **C**ouche **C**ampagne pour les études à fines échelles), Météo-France, 2015 – 2018 • Pilote phase project to study the development of the boundary layer and fog; toward an operational program.

6. MIRIAD (**M**esures sc**I**entifiques de flux de su**R**face en m**I**lieu m**A**ritime embarqué sur **D**rone), FEDER Région Midi-Pyrenées, 2015-2018 • Marine aerosol and energy fluxes from the surface to top of boundary layer

7. NEPHELAE (**N**etwork for studying **E**ntrainment and micro**PH**ysics of couds using **A**daptive **E**xploration), ANR, 2018-2021 • Adaptive sampling using a fleet of UAVs to study the evolution of cloud life cycles.

UAV Fleet at CNRM

Operated by CNRM / ENM

Ultralight UAV
(< 1 kg / payload ~ 300 g)

Electric motor
Endurance: 30 mn / 25 km
Altitude max: 1 km
Airspeed: 40 – 54 km/h



VOLTIGE
BACC+
Skyscanner

METEO FRANCE
STAE TOULOUSE
ANR

http://paparazzi.enac.fr

Lightweight UAV
(< 2.5 & 5 kg / payload ~ 0.8 to 1.5 kg)

Electric motor
Endurance: 1.5 h / 75 km
Altitude max: 4 km
Airspeed: 50 - 90 km/h


BACCHUS
STRAP

ANR

Operated by Boréal SAS (previously AJS)

Mid-size UAV
(< 25 kg / payload ~ 5 kg)

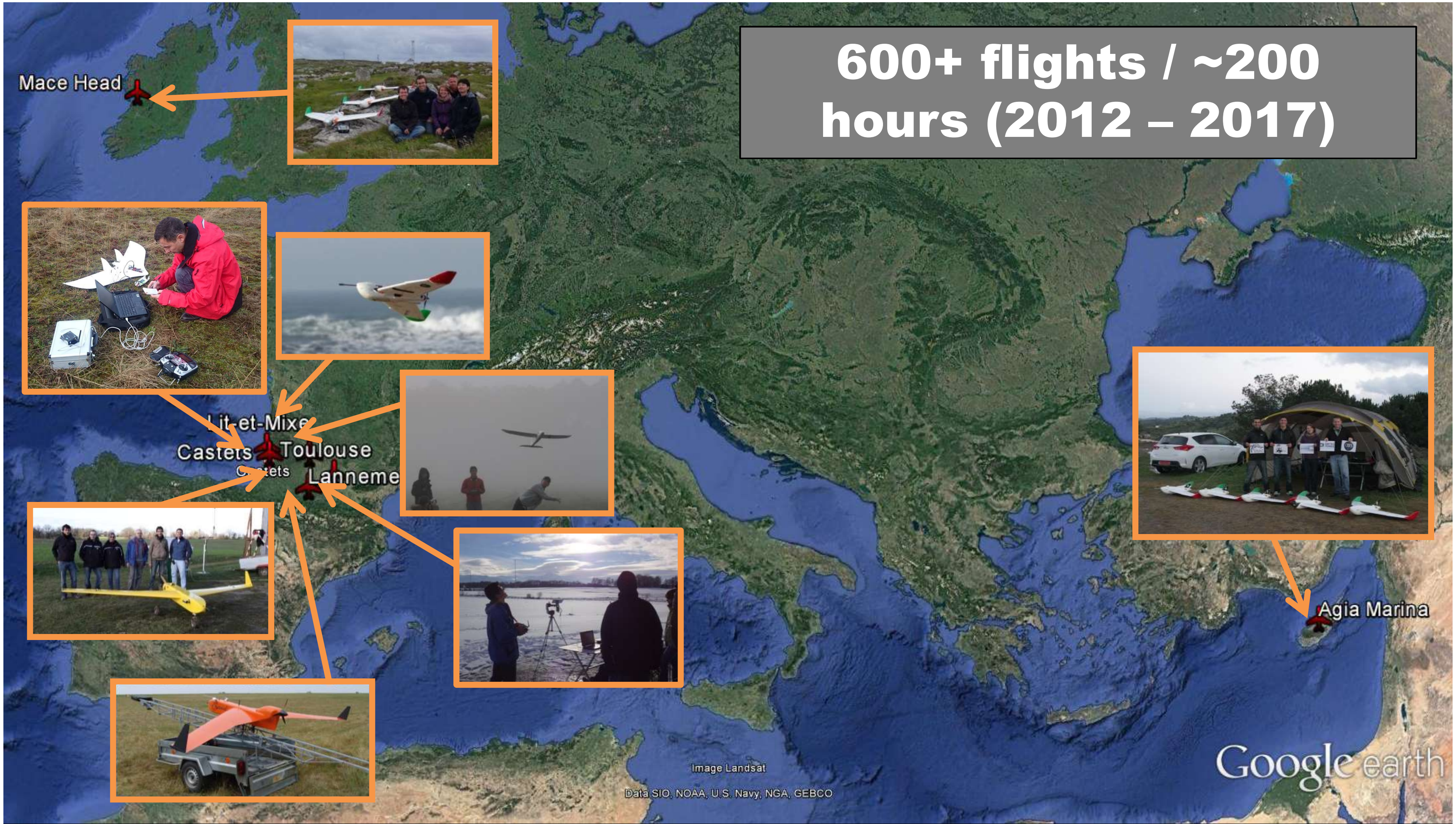
Gas engine
Endurance: 10 h /1000 km
Altitude max: 5 km
Airspeed: 60-130 km/h

MIRIAD

OCCITANIE LA RÉGION Pyrénées Méditerranée
UNION EUROPÉENNE

Increase size, complexity, risk, cost

Summary of UAS Flights at CNRM



- 10 different types of platforms (all fixed-wing)
- Weather conditions: winds up to 17 m/s, snow, ice, rain, fog; up to 3350 m.agl

UAV payloads

charge sensor

Backscatter cloud sensor

5-hole probe

aerosol inlet

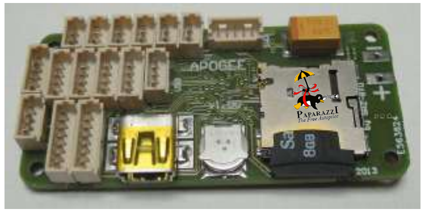
temperature, moisture, pressure, airspeed

↑ & ↓ visible SW flux

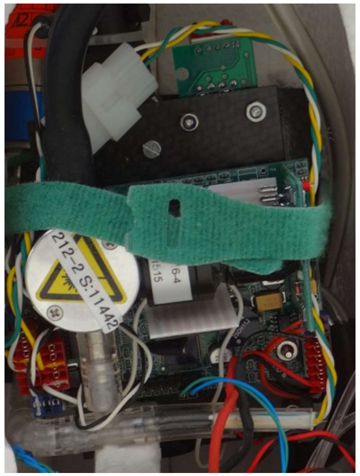
Video camera

aethelometer

data acquisition

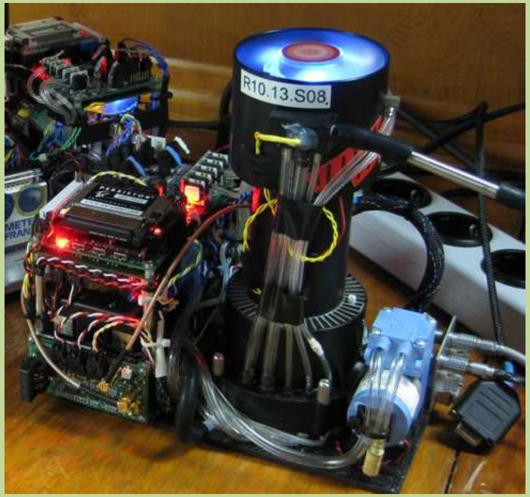


PPZ autopilot



optical particle counter

At research station



mCCN counter

UAS Payloads at CNRM

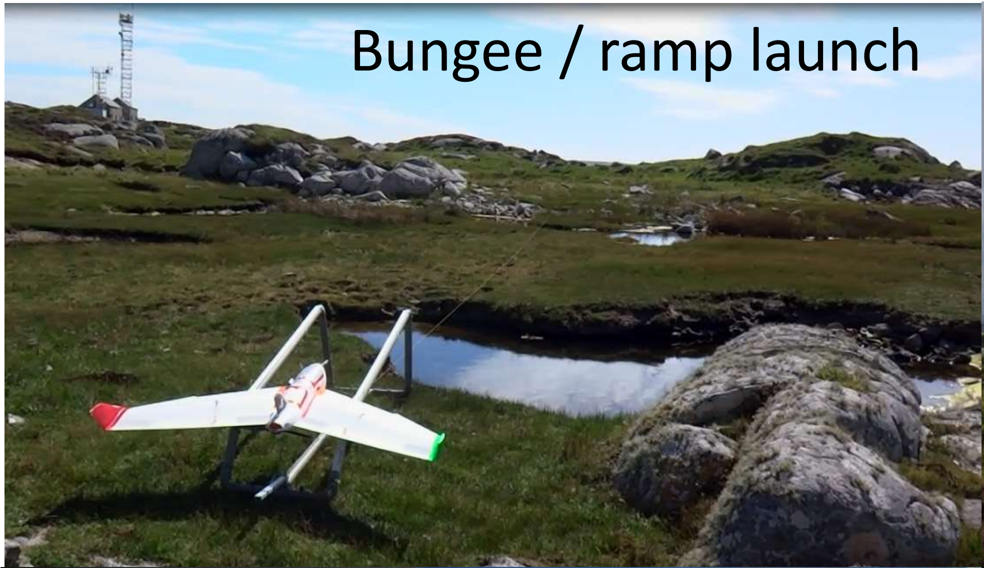
Atmospheric dynamics	**3D winds and solar fluxes**
5-hole probe	$w \rightarrow$ supersturation $\rightarrow$ $n_{D\_f(CCN,SS)}$
Pyranometer (up & down)	$\sigma_e \rightarrow n_D \times r^2$; $F_\uparrow / F_\downarrow \rightarrow$ Albedo

Aerosol / charge	**Aerosol physical properties**
Optical Particle Counter	Number concentration ($D_p > 0.3\ \mu m$)
Charge Sensor	Atmospheric charge
Aerosol Inlet	Size distribution ($0.3 < D_p < 3\ \mu m$)

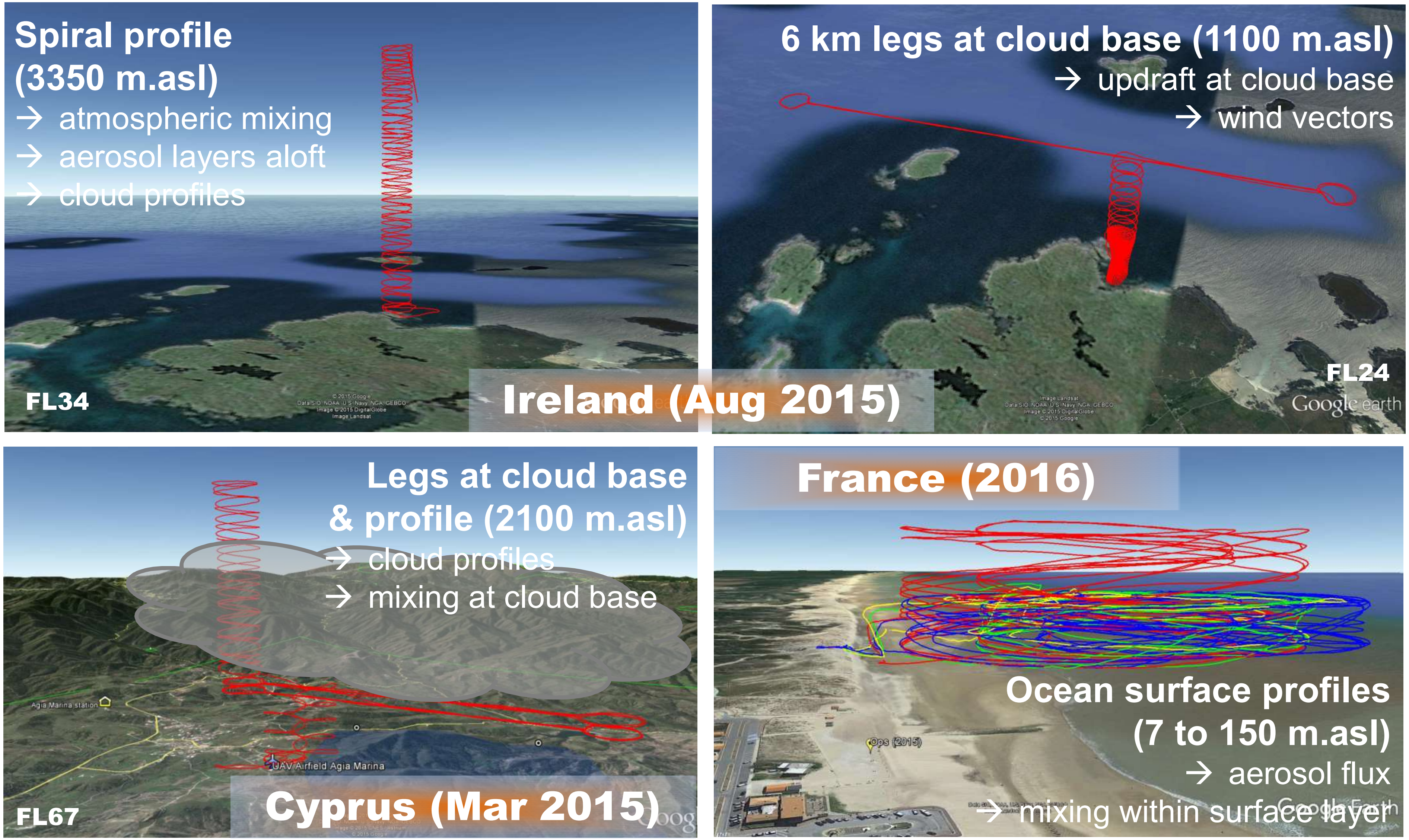
Absorbing Aerosol	**Aerosol optical properties**
Aethelometer	Aerosol absorption (g m^{-3} BC)
Pyranometer (up & down)	$\Delta F_{aerosol} \rightarrow W\ m^{-2}$
Aerosol Inlet	$\sigma_e \rightarrow n_D \times r^2$; $F_\uparrow / F_\downarrow \rightarrow$ Albedo

Cloud / charge	**Cloud microphysical properties**
Cloud sensor (2-l / polarization)	$\sigma_e \rightarrow n_D \times r^2$; R_{eff}
Charge sensor	Atmospheric charge

UAS Operations (Mace Head)



UAS Research Flights



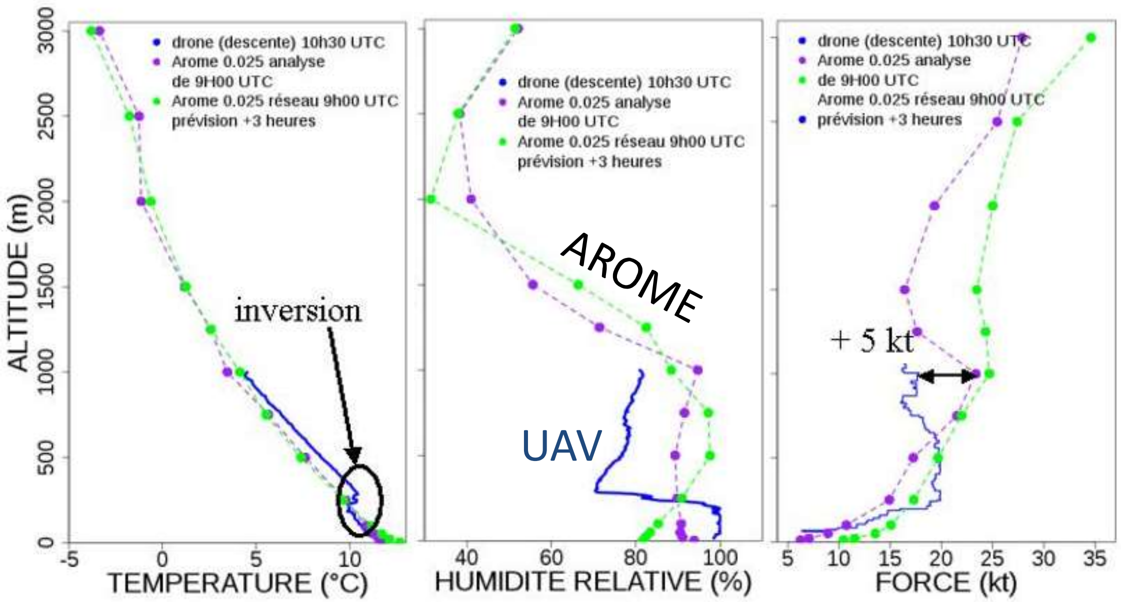
→ Research flights probe atmosphere from surface to 5 km, in-clouds, BVLOS ←

Each component must work …

… to get to the science.

VOLTIGE

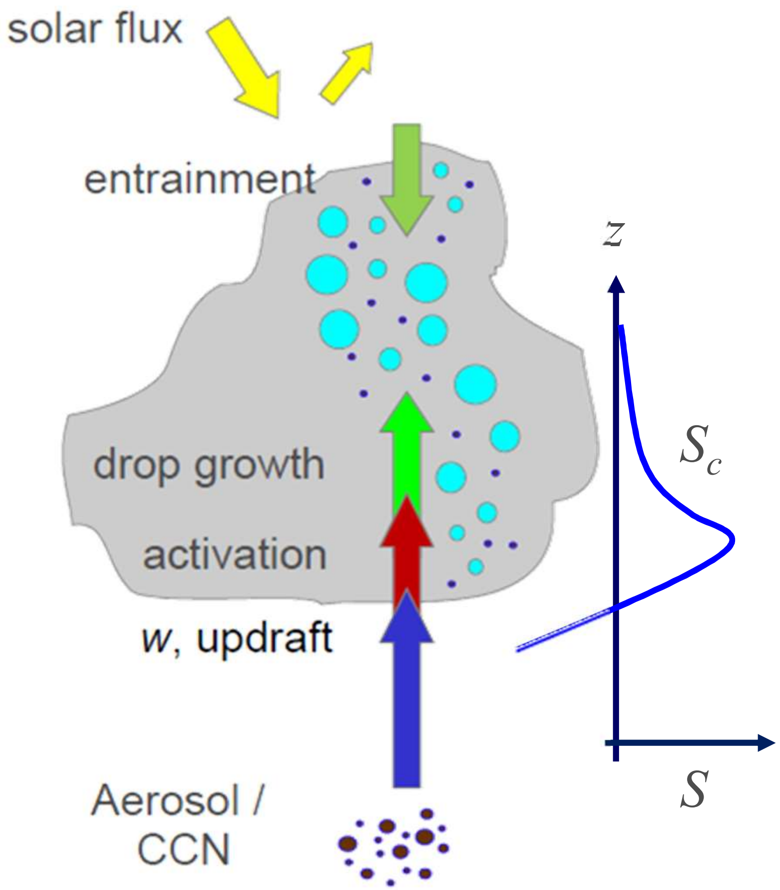
Vecteurs d'Observation de La Troposphère pour l'Investigation et la Gestion de l'Environnement

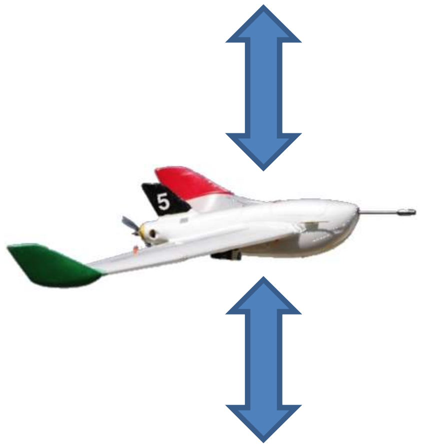


Roberts et al., Météo et Climat, 2015.

- Deploying UAS to study the atmosphere (focus on fog)
- Temperature profiles in Les Landes generally well characterized by AROME 2.5km operational model
- In-situ profile profiles show strong inversion not captured in model.

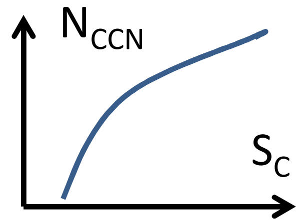
Linking ground-based & satellite obs.





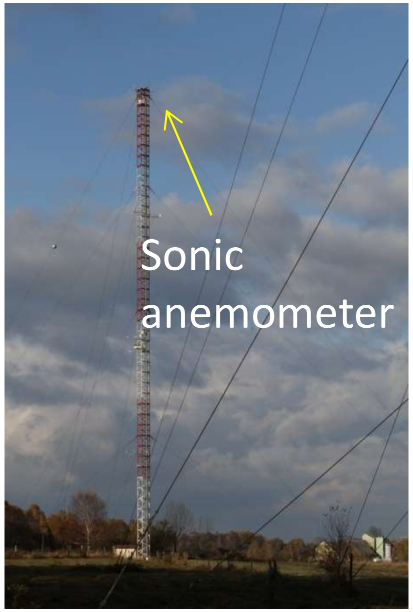
'top-down' closure
→ compare R_{eff} derived from satellite

'bottom-up' closure
→ use w and CCN spectra to find cloud droplet number

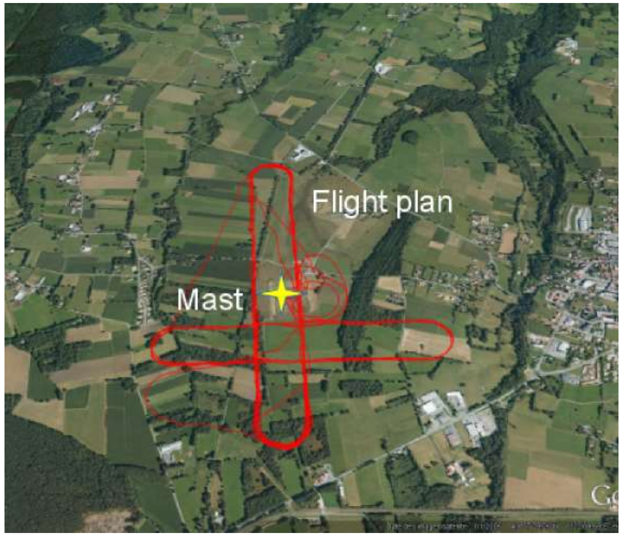


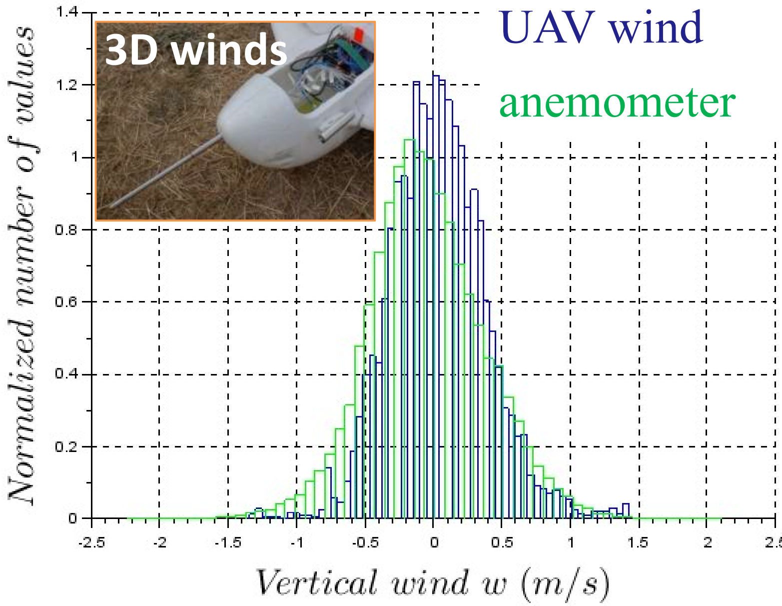
Related publications: doi:10.1002/2015JD024595; doi.org/10.5194/amt-2017-233; doi: 10.1175/BAMS-D-15-00317; doi: 10.1038/nature22806

5-hole probe comparison with sonic anemometer

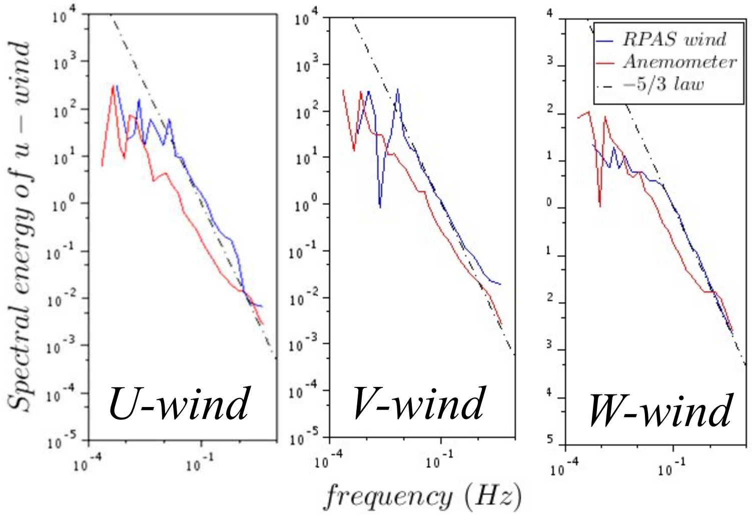


Lannemezan, France

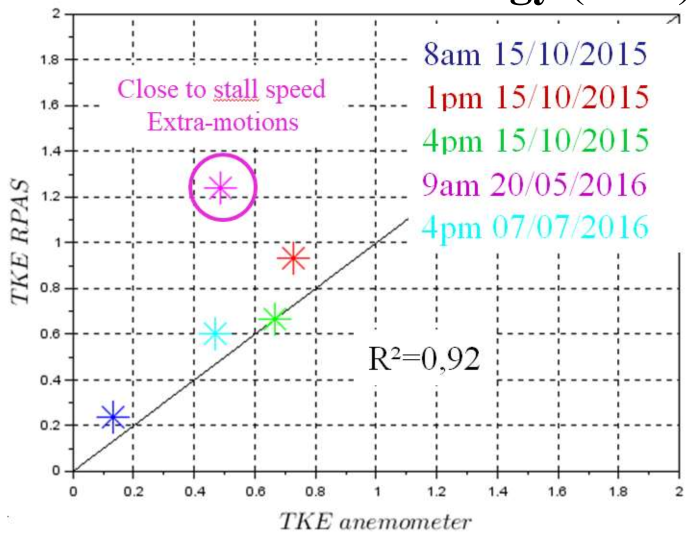




Power spectral density



Turbulent Kinetic Energy (TKE)



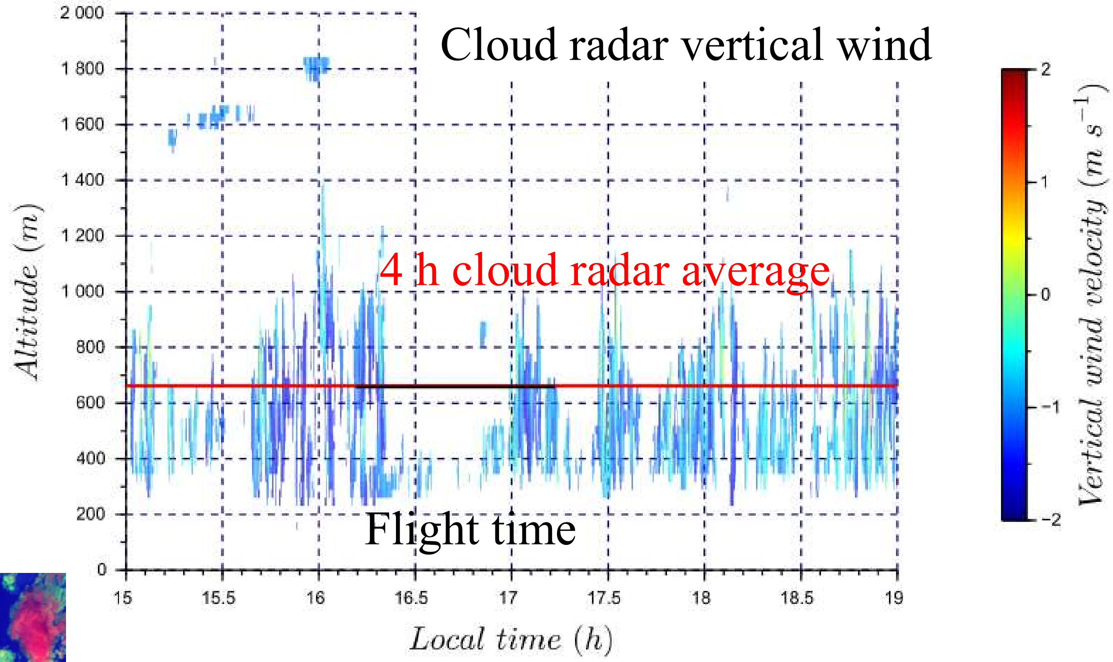
R. Calmer et al., *AMTD*, : doi.org/10.5194/amt-2017-233

Mace Head case study

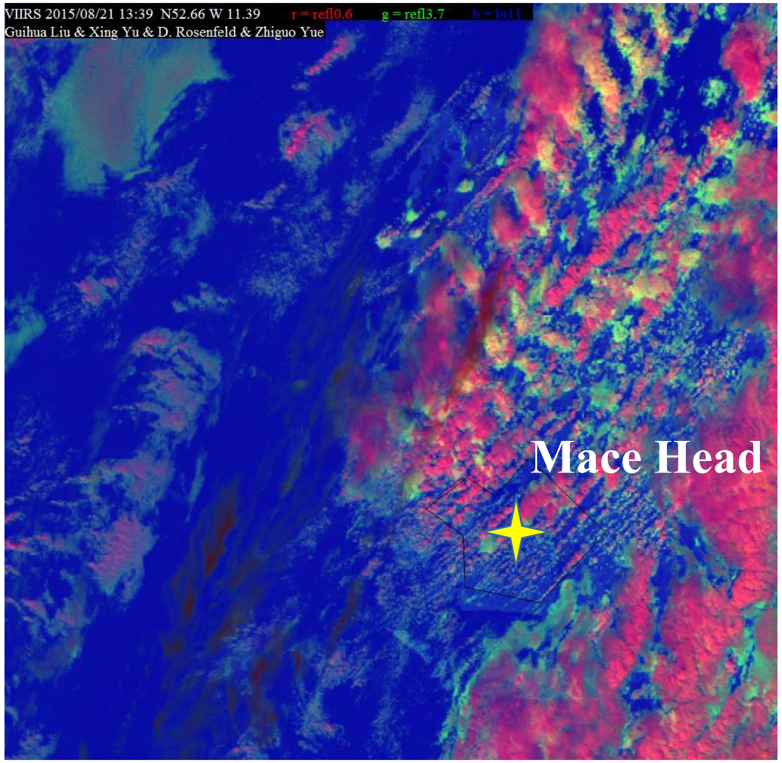
08/21/2015 Flight 38

UAV within clouds
(660 m asl)

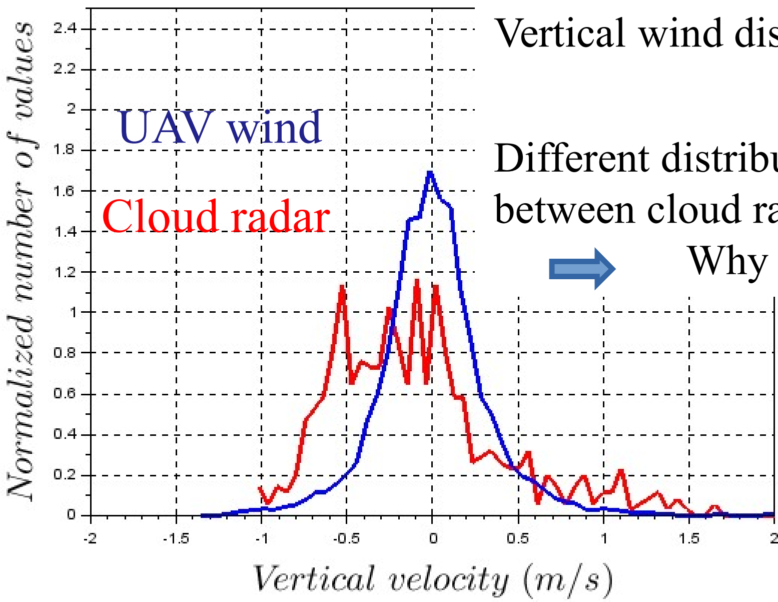
Different clouds above land and ocean



Satellite NPP Suomi



Vertical wind distributions



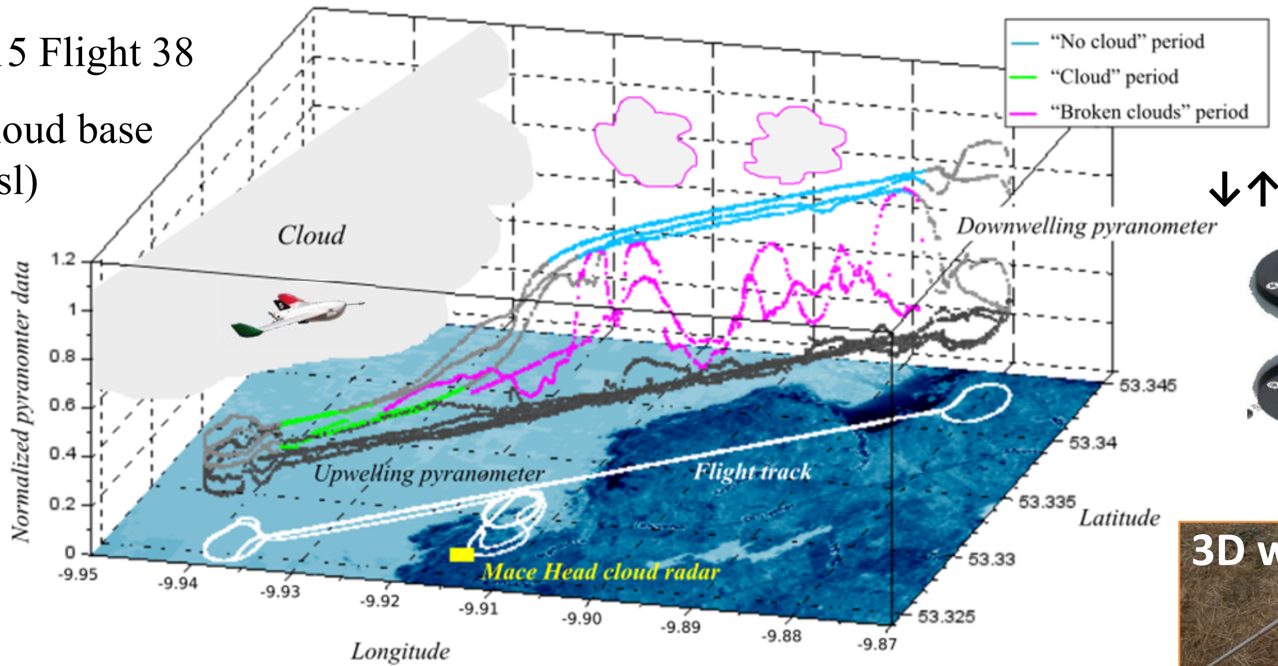
Different distributions between cloud radar and UAV → Why ?

R. Calmer et al., *AMTD*, : doi.org/10.5194/amt-2017-233

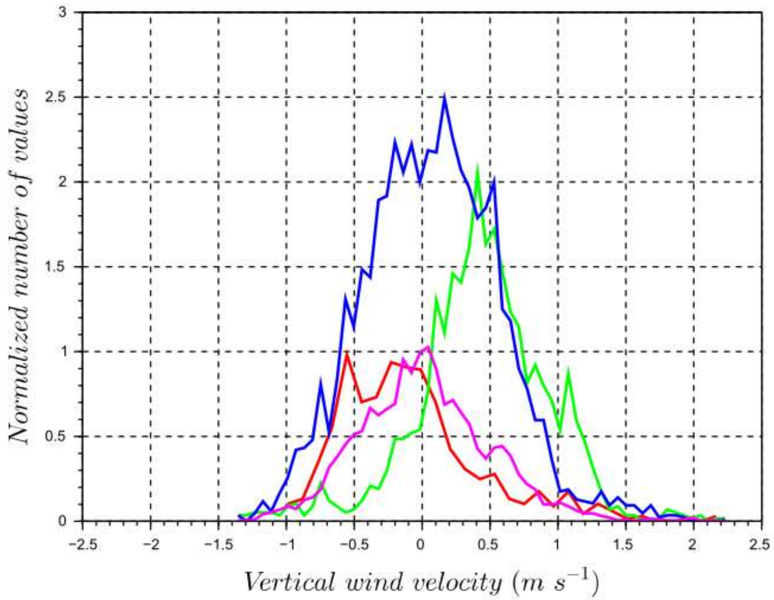
Mace Head case study

08/21/2015 Flight 38

UAV at cloud base
(660 m asl)



↓↑ SW flux



Cloud

No cloud

Broken clouds

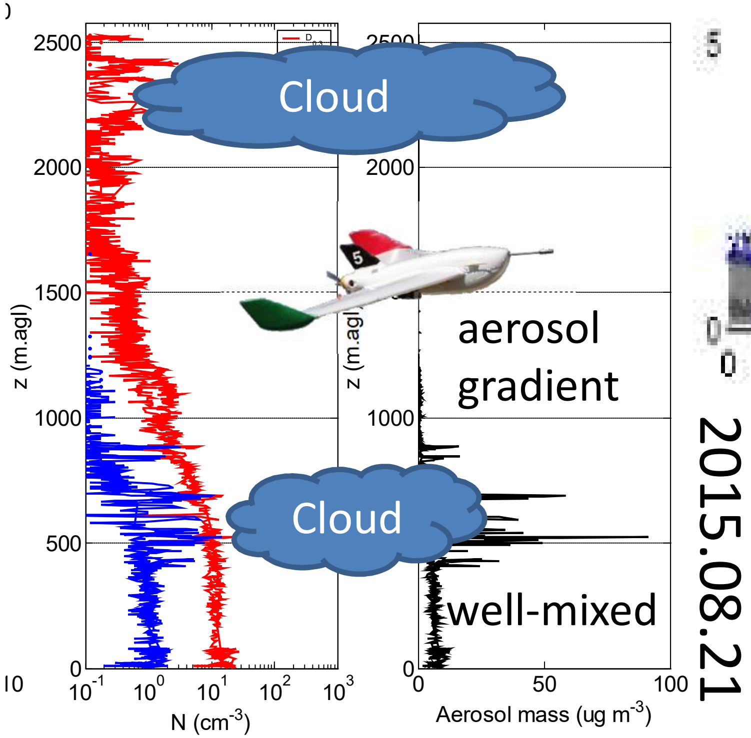
Cloud radar

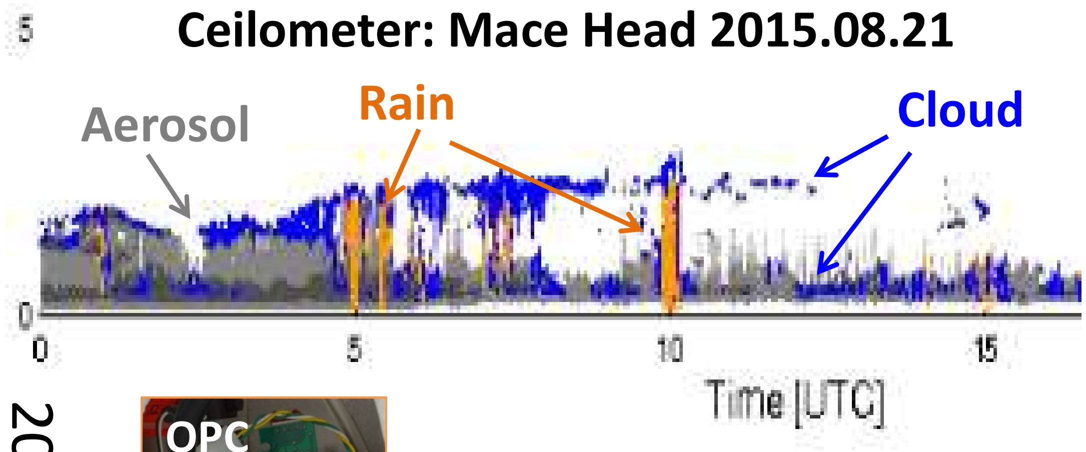
- Updrafts change in/out of clouds and with atmospheric conditions

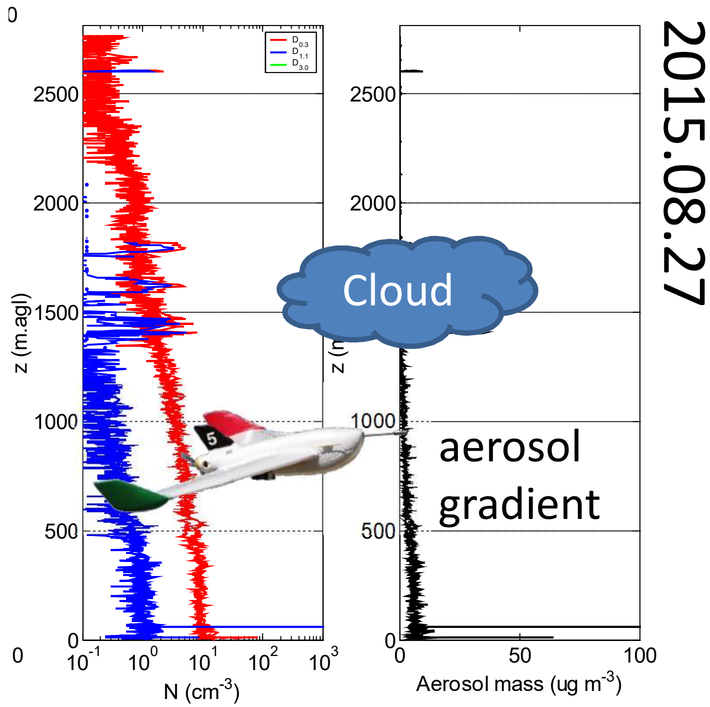
- UAV and cloud radar similar for broken clouds (conditions over land)

R. Calmer et al., *AMTD*, : doi.org/10.5194/amt-2017-233

Mixing of aerosol in MBL

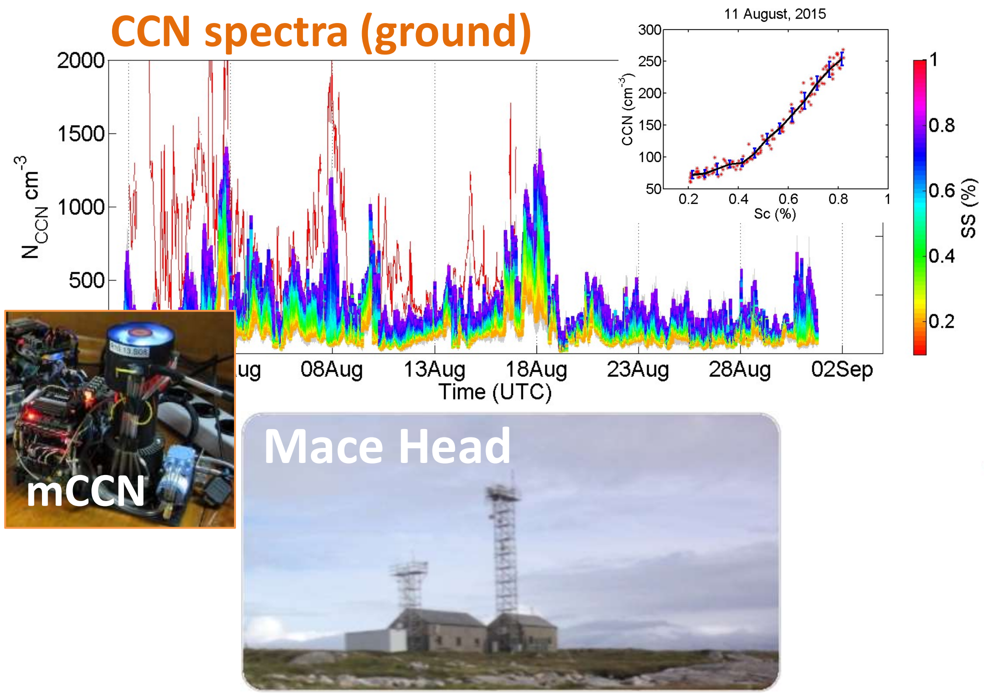




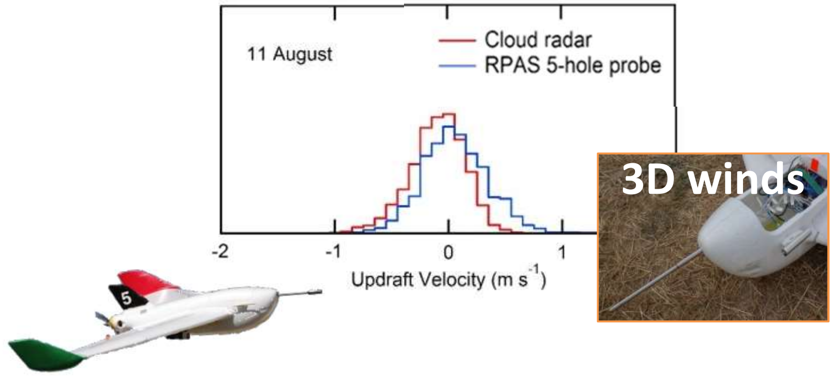


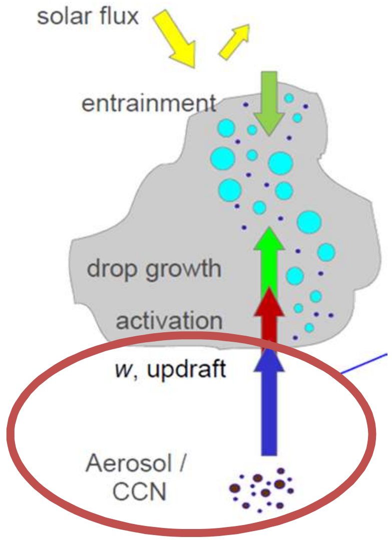
- Cloud layers often at ~ 400 and above 2000 m at Mace Head
- Aerosol not always well mixed in lower MBL; rarely mixed to upper level clouds at 2000 m

Cloud base updrafts / CCN spectra



Vertical velocity distributions (UAV and cloud radar)

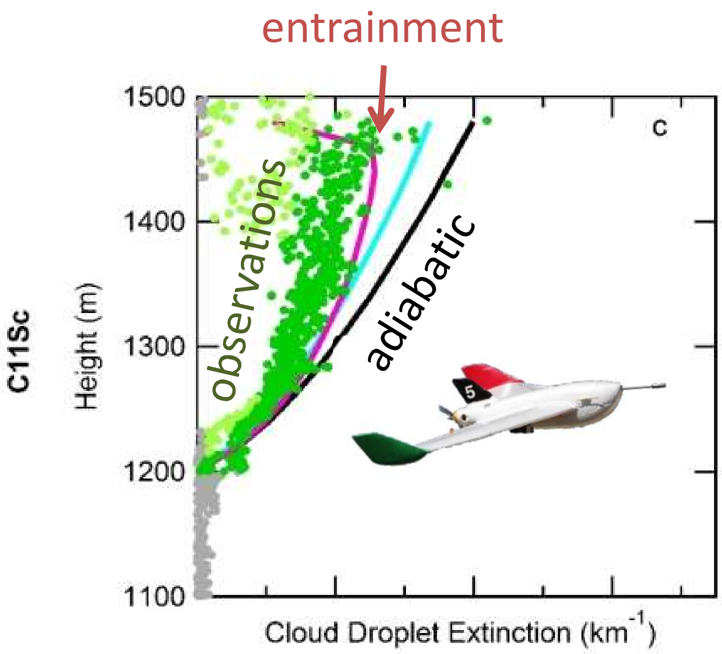




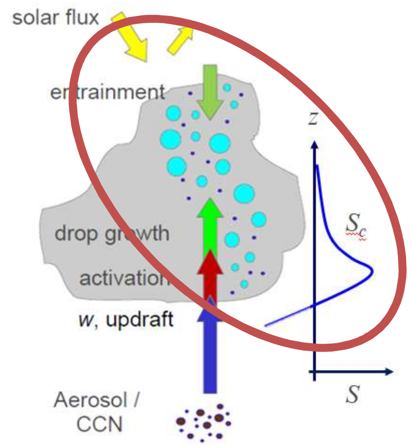
Combine vertical velocity distributions (UAV) and cloud active aerosol (CCN; ground) to derive cloud properties with an air-parcel model (Russell et al., 1998).

K. Sanchez et al., *ACP*, : doi:10.1002/2015JD024595

Comparing models and observations of cloud properties

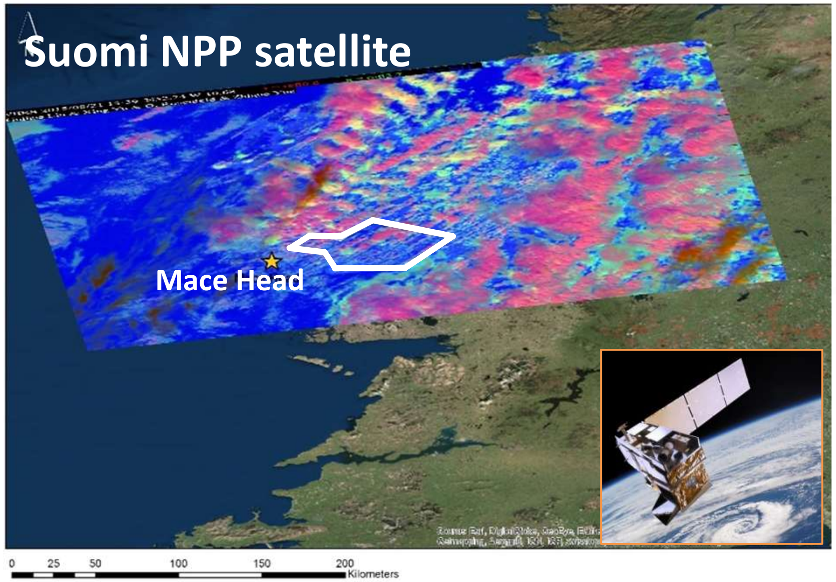


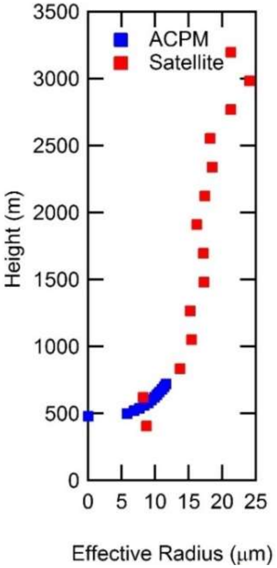
- In-situ measurement of cloud extinction by UAV
- Difference between modelled and observed cloud properties often related to entrainment or decoupling in the atmosphere.
- Simulations overestimate cloud radiative fluxes (up to ~90 W m^{-2} in our cases in Ireland)

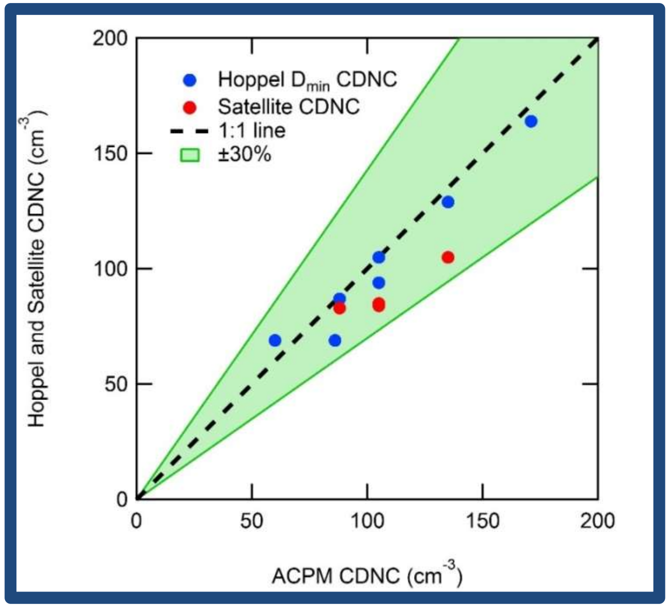


K. Sanchez et al., *ACP,* : doi:10.1002/2015JD024595

Satellite – in-situ comparison of cloud properties



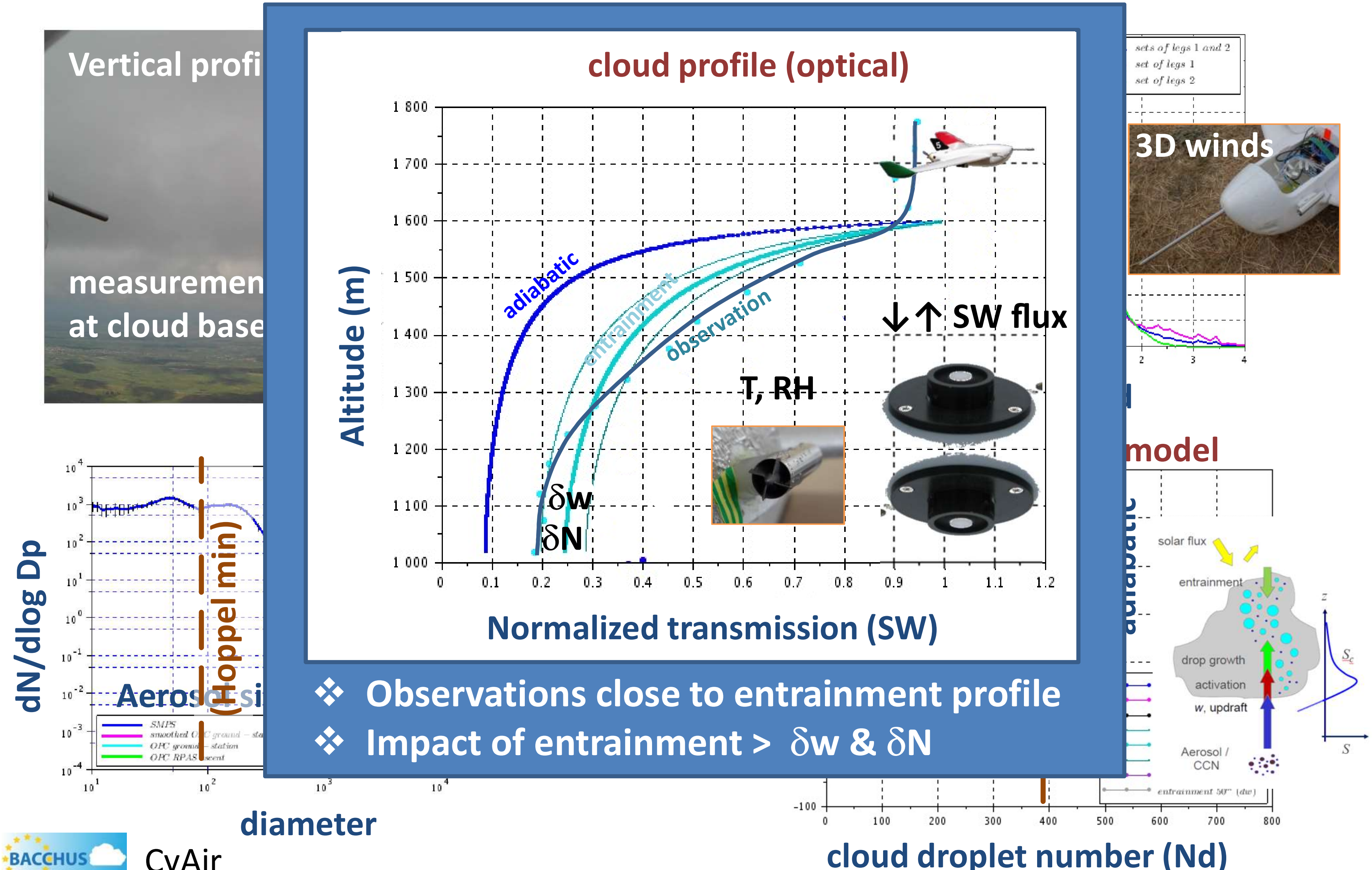




- Effective radius profiles show relatively good agreement between satellite and simulation
- Cloud droplet concentrations derived from Hoppel-minimum diameter and NPP satellite within 30% of model

K. Sanchez et al., *ACP,* : doi:10.1002/2015JD024595

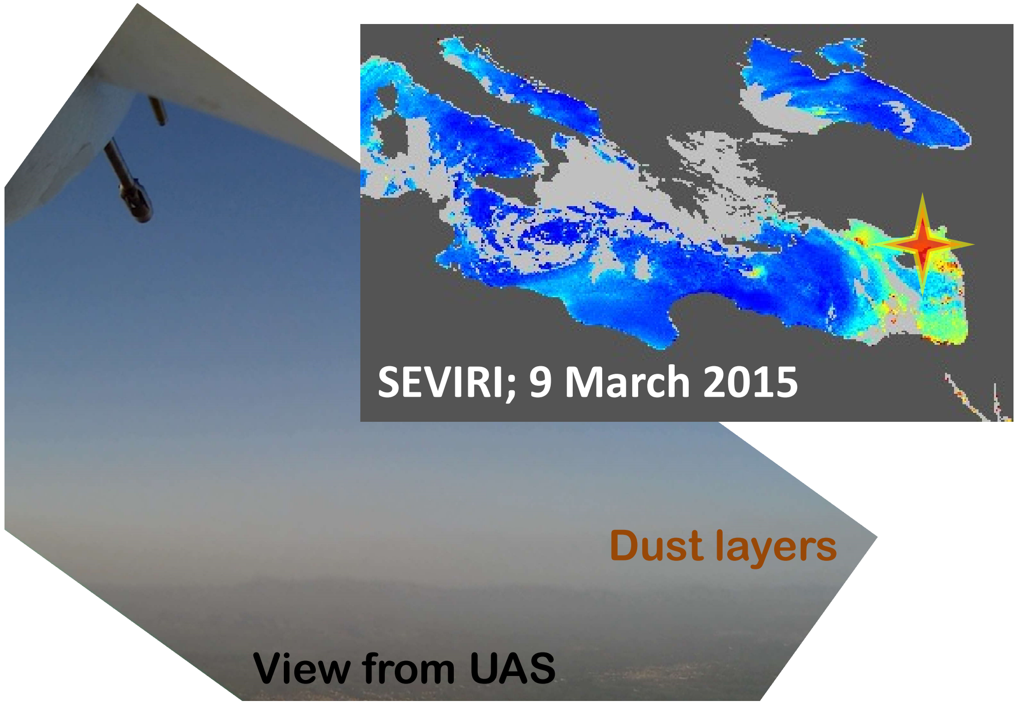
Aerosol-cloud closure (Cyprus)

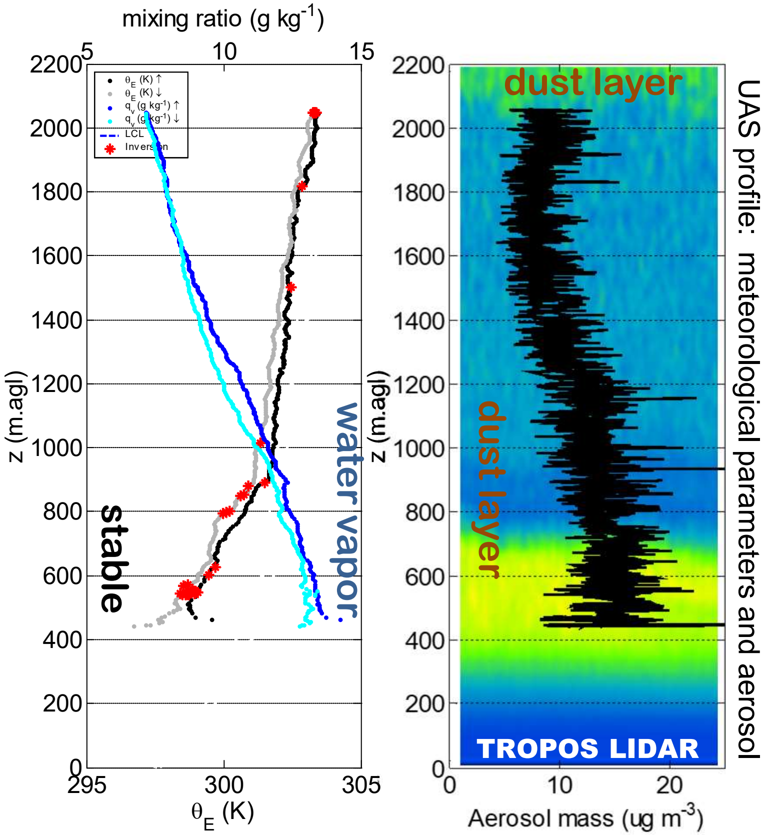


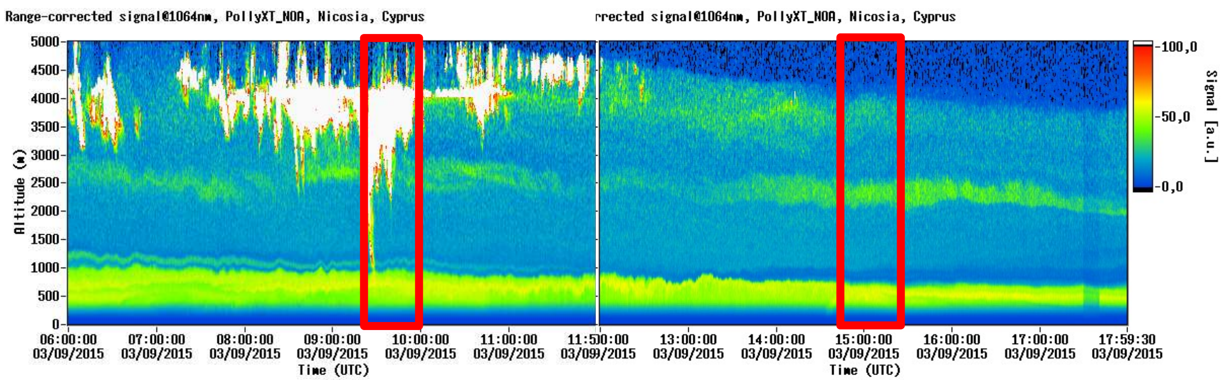
- ❖ Observations close to entrainment profile
- ❖ Impact of entrainment > δw & δN

BACCHUS CyAir

Dust Transport Over Cyprus

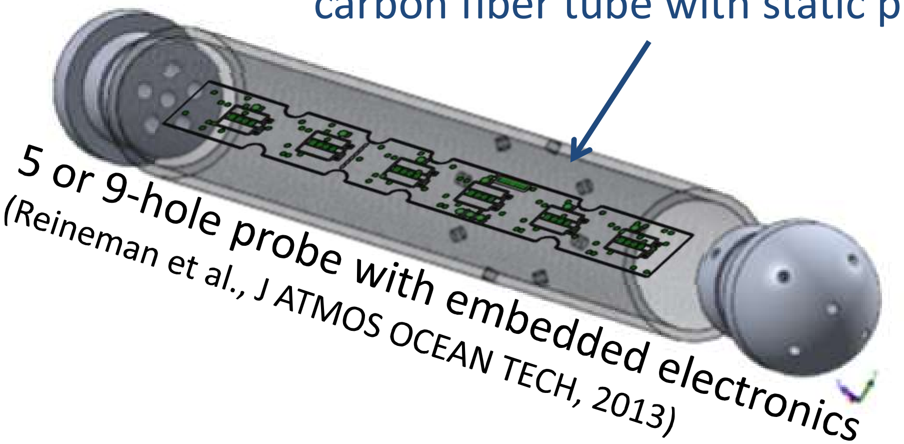


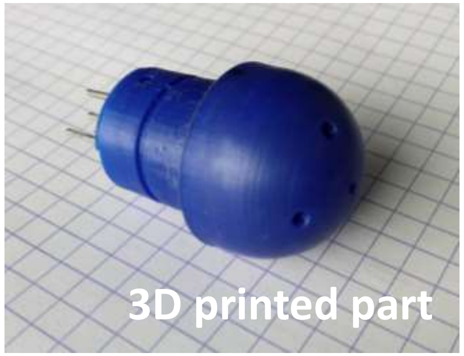


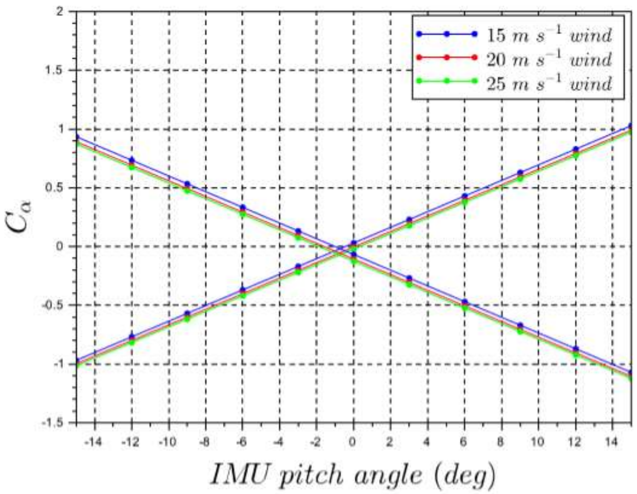


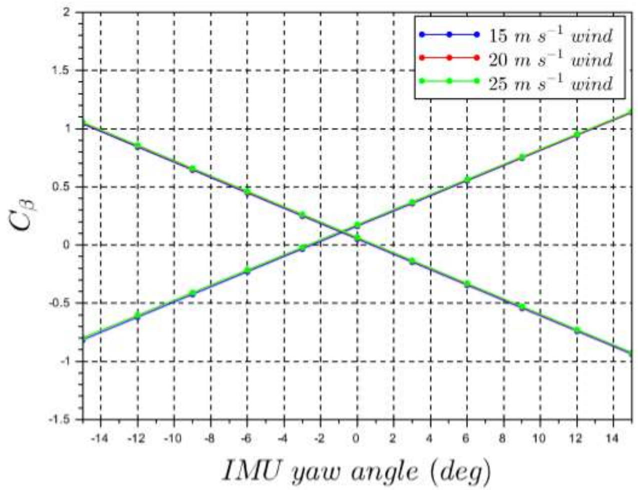
Multiple layers of dust transport from Arabian Peninsula and Sahara Desert

turbulence probe (new design)









Stage: Axel Roy

Calibration shows higher sensitivity compared to Aeroprobe

MIRIAD: système de **M**esures sc**I**entifiques de flux de su**R**face en m**I**lieu m**A**ritime embarqué sur **D**rone

1. Identifier les sources et les puits des aérosols marins
2. Caractériser la structure verticale de l'atmosphère et d'évaluer le mélange vertical des aérosols dans la couche limite marine.
3. Vols rasants très proche à la surface (< 10 m; couplage d'un radar altimétrique avec l'autopilote)

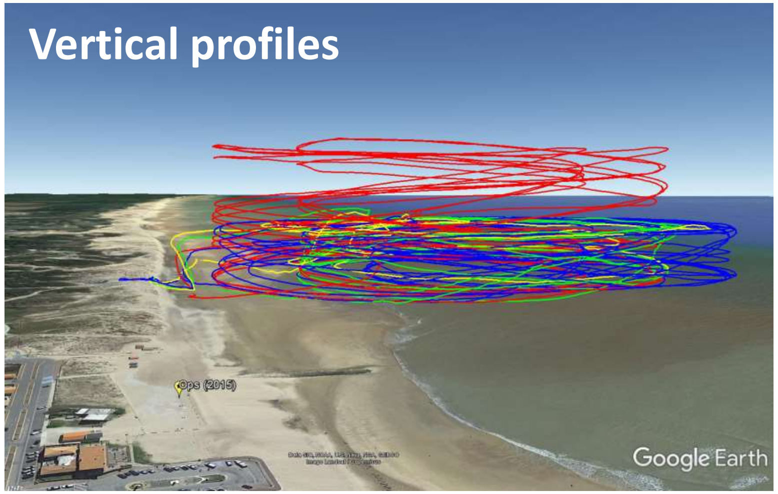
Greg Roberts (CNRM/GMEI/MNPCA), **Fredéric Burnet** (CNRM/GMEI/MNPCA), **Sébastien Barrau** (CNRM/GMEI), **Patrice Medina** (LA), **Pierre Durand** (LA), **Michel Gavart** (Boréal)

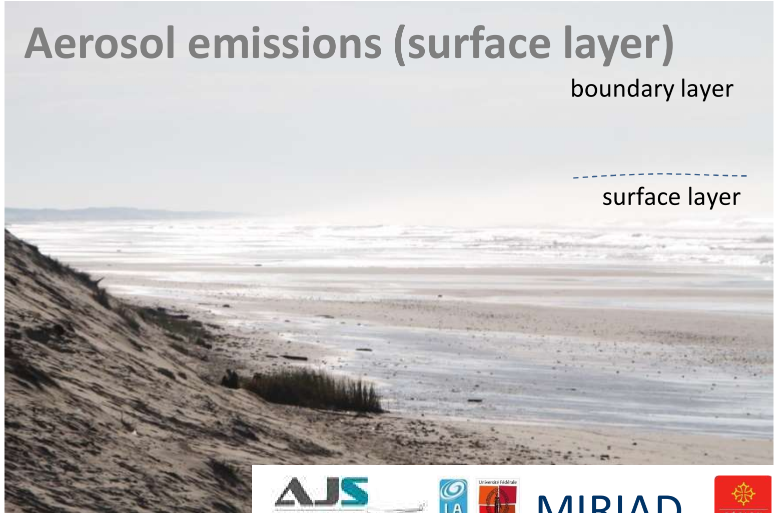
MIRIAD

FEDER Région Midi-Pyrenées 2015-2018

Primary marine aerosol in surf zone

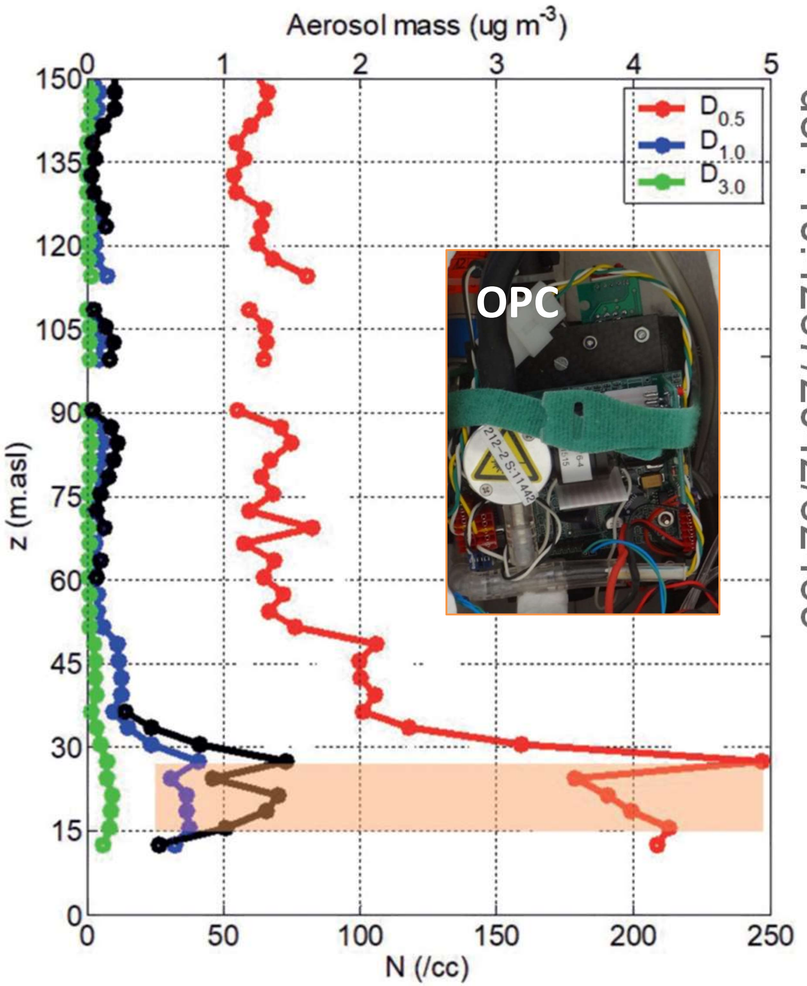
- Transects across surf zone (Montalivet)
- Spiral vertical profiles from ~ 7 to 150 m.asl
- Aerosol size distribution (0.5 < Dp < 10 um; RH < 40%), PTU





MIRIAD

Sea salt emissions (surf zone)



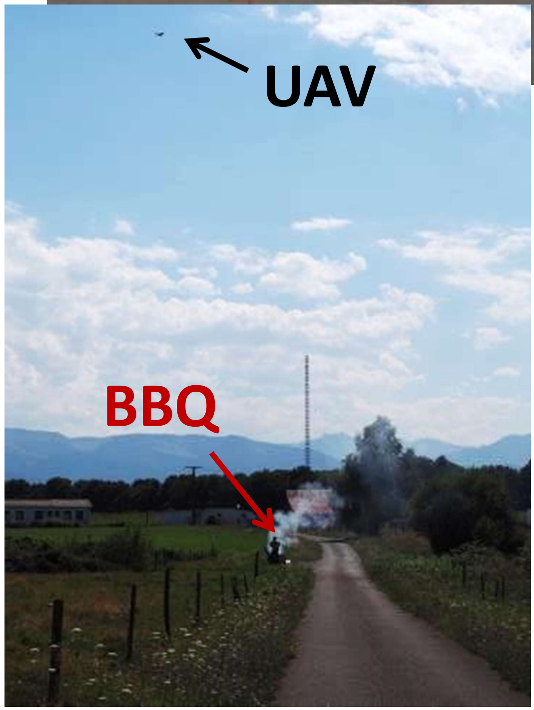
Roberts et al., La Météorologie,
doi : 10.4267/2042/62453

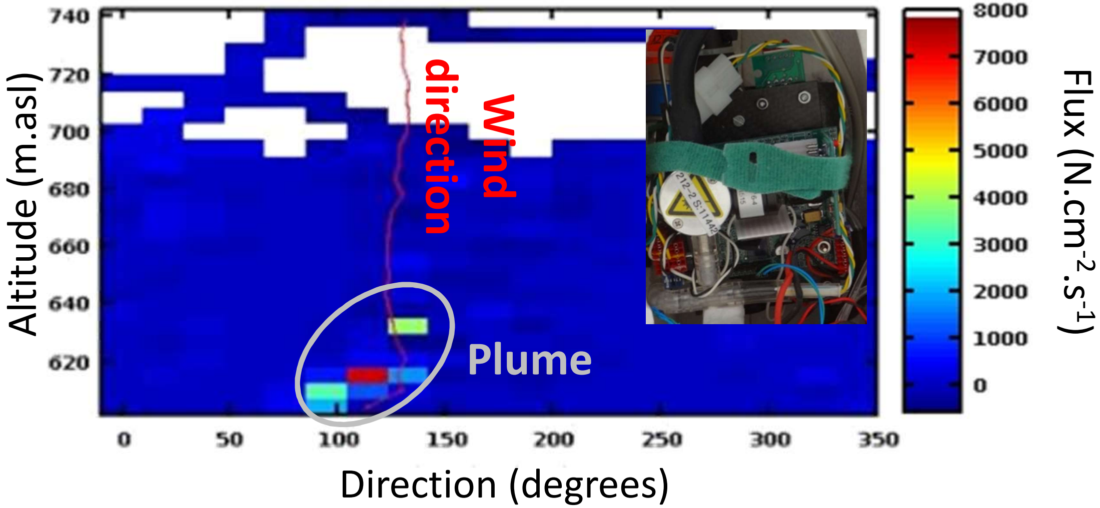
- Steep gradient in aerosol concentration < 30 m.asl
- Number concentrations (Dp > 0.5 um; red): ~ 200 / cc in surface layer; ~ 60 /cc in boundary layer
- Aerosol mass (black): ~ 1.5 ug / m^3 surface layer; < 0.2 ug / m^3 in boundary layer

Flux estimate: F = D (dC / dz)
:: ρ ~ 2 g/cm^3; D ~ 10^{-2} m^2 / s

→ F ~ 1 ng / m^2.s (PMA surf zone)
(note: not all mass measured
– see next slide)

Flux Measurements Using UAS



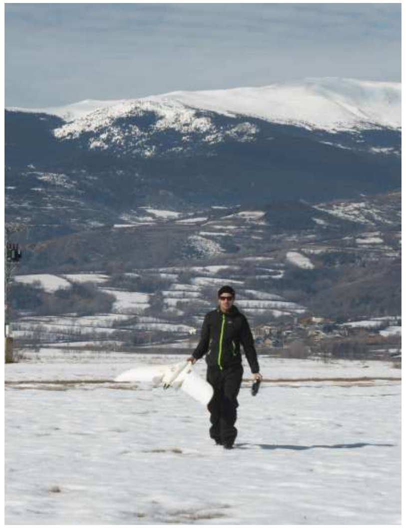


Flux (N.m^{-2}.s^{-1}) = Speed (m/s) * Concentration(N/m^3)

Wind (GPS) **Particle Counter (OPC)**

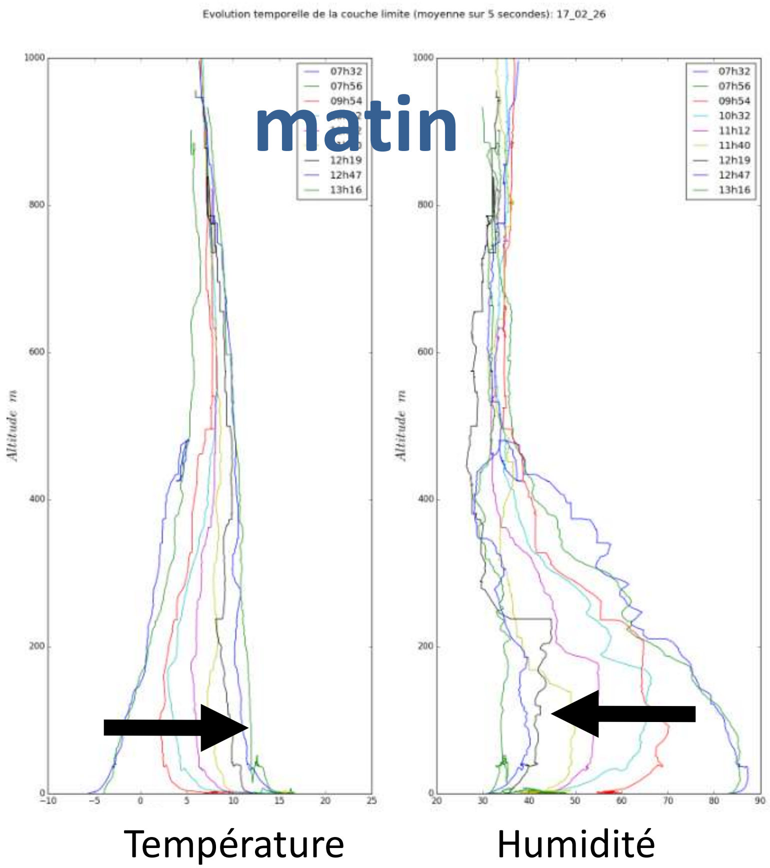
- Cylindrical flight around source (1 hour up to 150 m.agl; vertical res. ~5 m; horizontal res. ~15 m)
- Measured aerosol concentration and wind vector;
- Subtract background to calculate particle flux

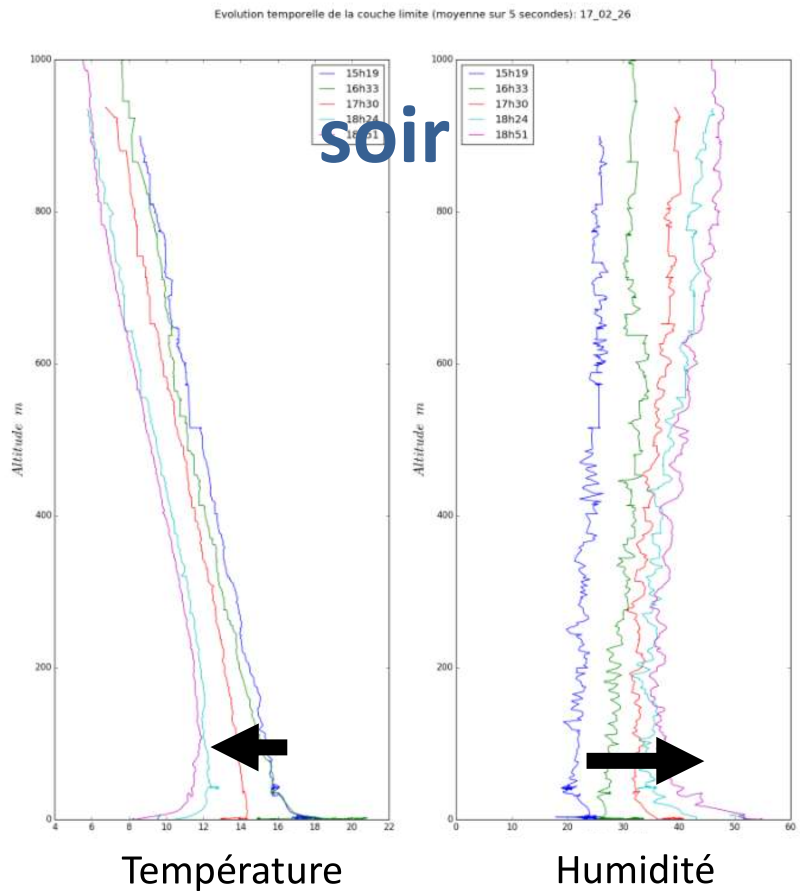
STRAP : Stage – Antoine Hubans



Campagne à Cerdagne :

- vols jusqu'à 1000m/sol (tous les 20 min)
- étudier l'évolution de la couche limite



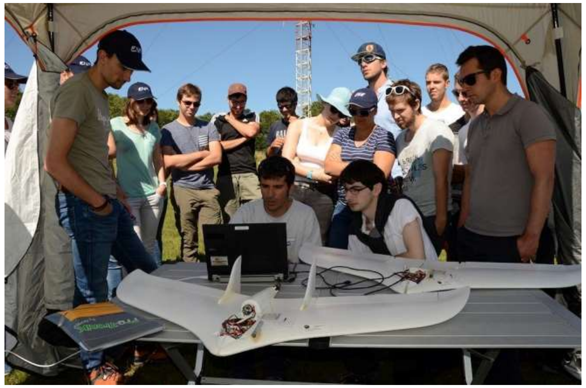


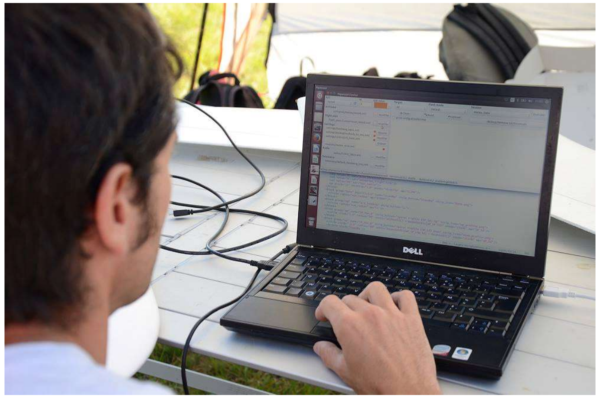
Project BACC+

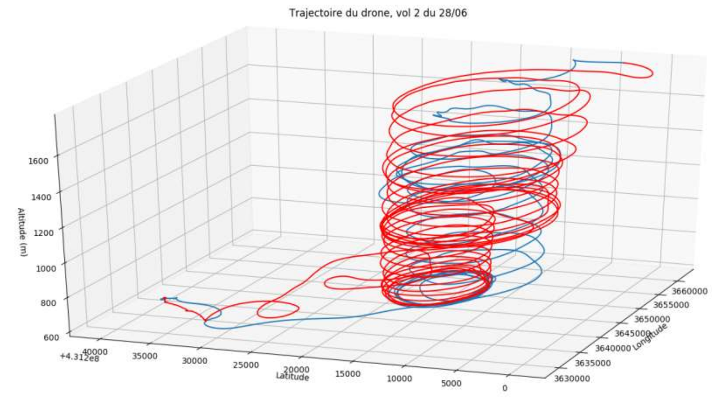
TP ENM : vols et traitement de données

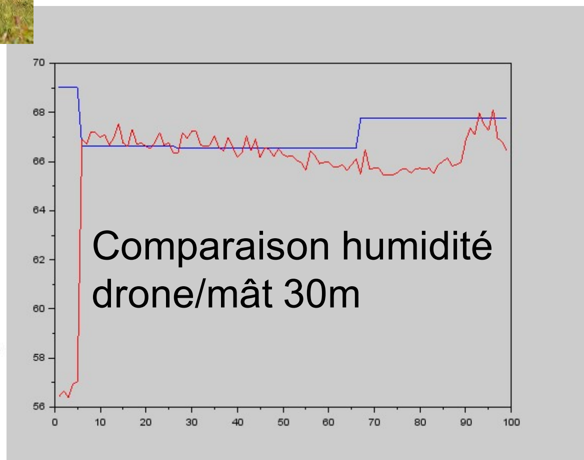
P2OA CRA, Lannemezan

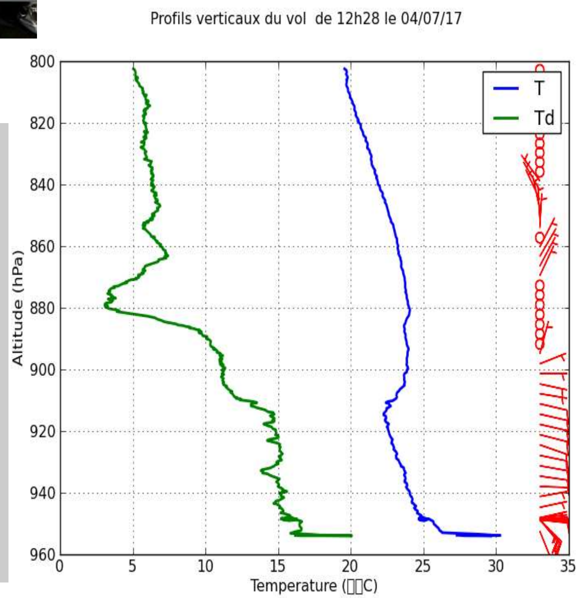
G. Cayez, F. Lohou (ENM et Université de Tarbes)







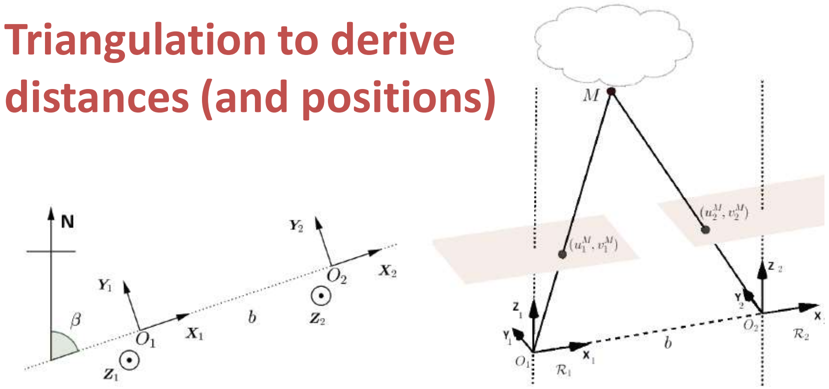


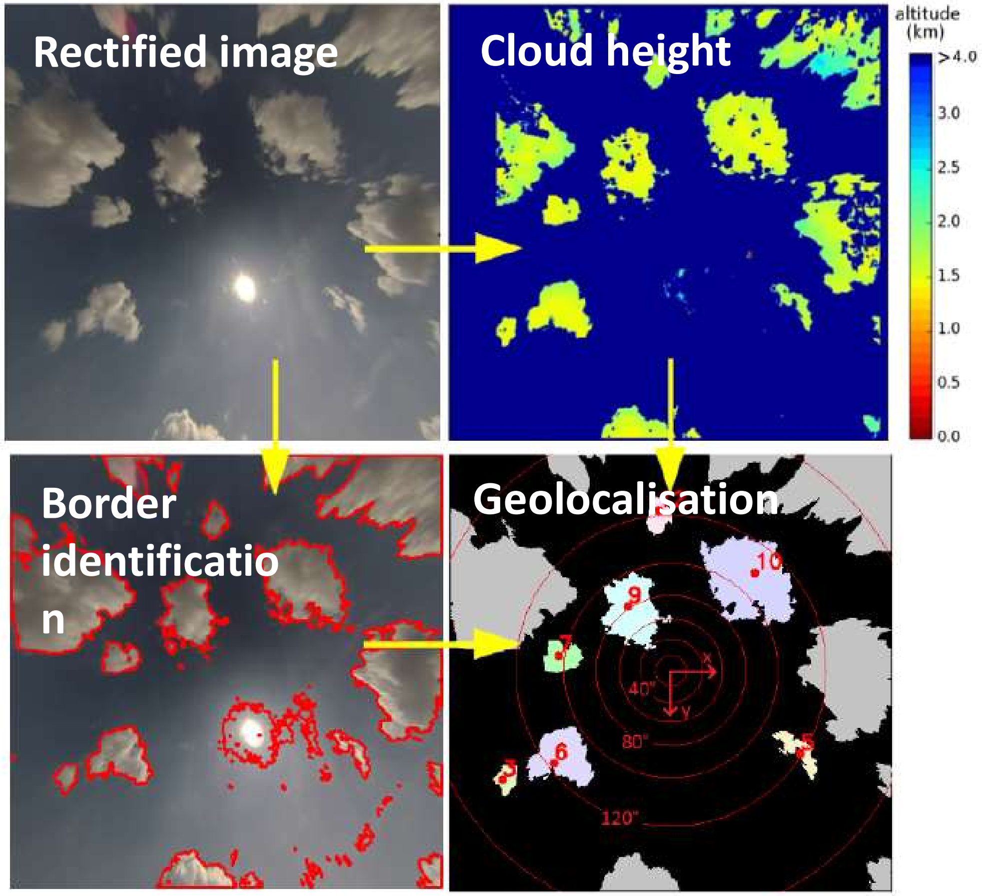


All-sky photogrammetry techniques to georeference a cloud field

P. Crispel, G. Roberts, (*AMTD,* doi.org/10.5194/amt-2017-203)

Triangulation to derive distances (and positions)



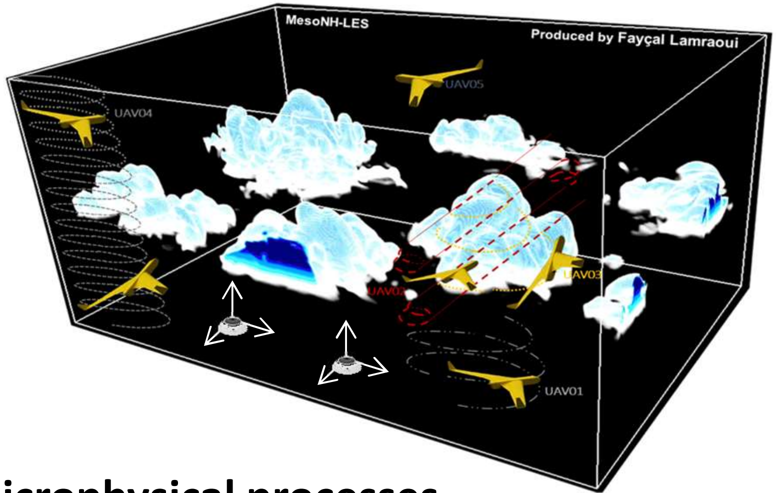


NEPHELAE

NEPHELAE: Network for studying Entrainment and microPHysics of cLouds using Adaptive Exploration

ANR 2017

01/2018 – 06/2021



Atmospheric science driven with focus on cloud microphysical processes

- Identify dominant entrainment mechanism and timescale of cloud development and onset of precipitation
- Assess impact of aerosol on entrainment and precipitation as well as feedback mechanisms

NEPHELAE aims to develop a UAS fleet with decentralized cooperative sampling

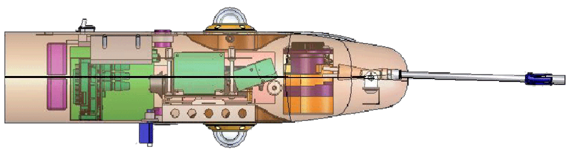
- inter-UAV communication
- Adaptively plan and control fleet to maximize utility of gathered data

ISARRA 2018
9 – 12 July
Boulder, CO, USA

International Society for Atmospheric Research using Remotely piloted Aircraft

Take Aways

- Modular UAV payloads for science missions to study aerosol, clouds, atmospheric state
- Aerosol-cloud studies using UAVs to measure aerosols, 3D winds and cloud microphysical properties → quantify effect of entrainment on cloud optical properties
- Sea salt fluxes estimated from near-suface UAV flights.
- High resolution (temporal and spatial) vertical profiles to study evolution of boundary layer
- Next steps: Sea salt fluxes, volcano emissions, UAV fleet to study evolution of clouds



acknowledgements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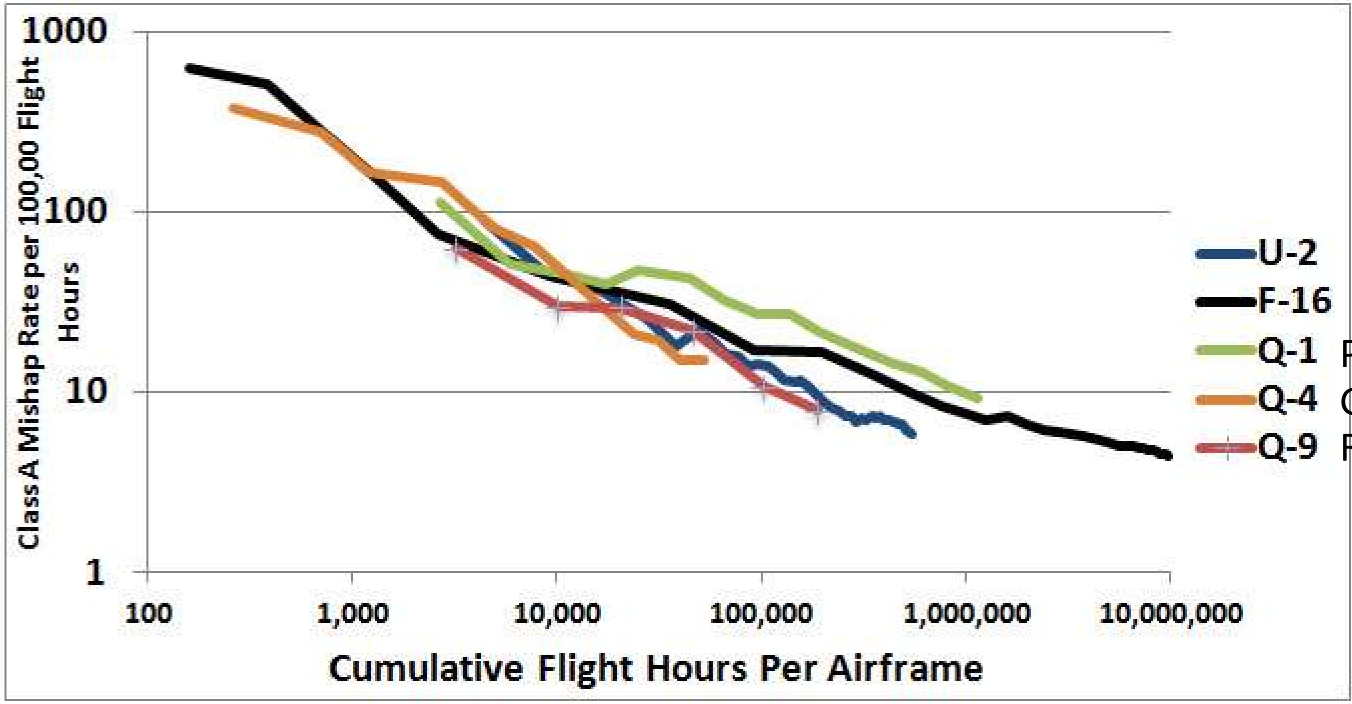
ENAC
BACCHUS
THE CYPRUS INSTITUTE
with special thanks to the Cyprus Institute for their logistical support.

UAS Accidents

Class A mishaps (fatal or destruction of aircraft)

UAS Accident Causes (2001 – 2006)

- Stress
- ıvironment
- ot followed
- nication



http://www.auvsi.org/SafetyStatisticsofFlyingUASforUSAF

- Reducing accidents a result of experience and continuous improvements
- Predator first mass-use UAS; higher accident rate (dangerous situations)
- Global Hawk and Reaper are on par with manned airframes (U-2 and F-16)

→ UAS attain accident rates similar to manned airframes without risk to crew

Risk Assessment

In aviation, not possible to eliminate all risks (ICAO Safety Course)

Severity						
Catastrophic	5	5 Review	10	15 Unacceptable	20 Unacceptable	25 Unacceptable
Hazardous	4	4 Accepta	8 Review	12 Unacceptable	16 Unacceptable	20 Unacceptable
Major	3	3 Accepta	6 Review	9 Review	12 Unacceptable	15 Unacceptable
Minor	2	2 Acceptable	Acceptable	6 Review	8 Review	10 Unacceptable
Negligible	1	1 Acceptable	2 Acceptable	3 Acceptable	4 Acceptable	5 Review
		Extremely improbable	Improbable	Remote	Occasional	Frequent
		1	2	3	4	5

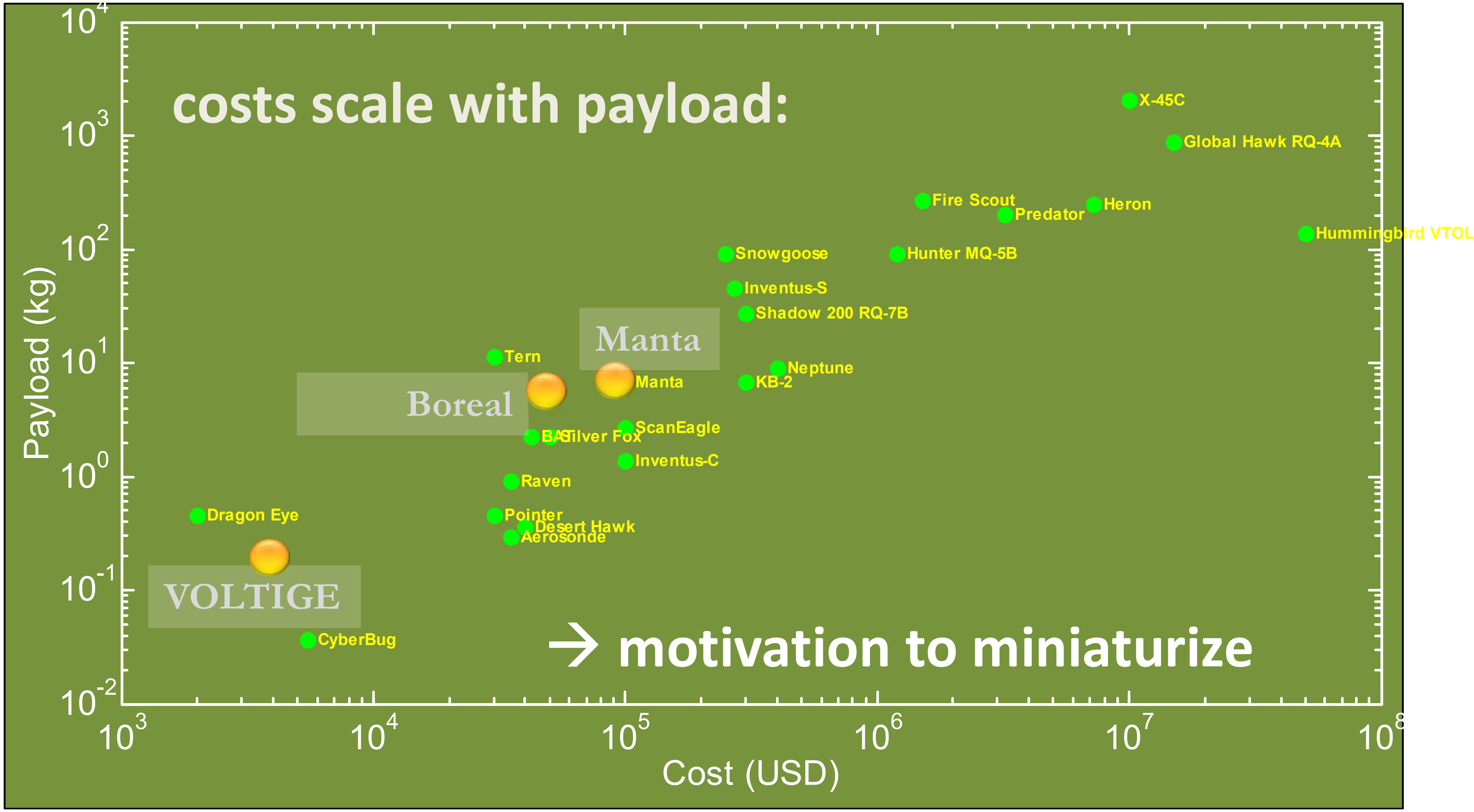
Probability

Example:

- Assess risk during RPAS flights (straight and level) over a road at Lannemezan; Severity of Consequence → Major to Hazardous
- Probability of RPAS impact on road (infrequent traffic) → ~ 10^{-5} (Improbable);
  (7 m road / 1600 m leg) x (27 legs / flight) x (2 failures / 500 flights) x (1 vehicle / 30 s)

+ Adapt check lists and flight procedures to mitigate risk to acceptable level

UAS Cost Comparison



Future for UAS in atmospheric science

- Increased reliability (all weather / take-off & landing)
- Ability to launch from remote platforms (ships or buoys)
- Coordinated flying with multiple platforms (decentralized architecture)
- High altitudes (most platforms limited to < 5 km)
- Long duration, long distance (> 8 hours; 1000+ km)
- Payload engineering & miniaturizing instruments
- Integration of UAS into civilian airspace