Improving the Accuracy of Particle Mass Concentration Prediction

Lessons learned from the Eyjafjallajokull crisis and other cases

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EUFAR Coordinator

Köln, 8-9 September 2010

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Overview of the Operator's Activities

To provide a forum for aircraft operators to share experience in flying in the ash plume and with scientists to share expertise on ash particle measurements.

Number of operators Participating	**12**
Number of research flights (15/4-20/5)	**70**
Total distance flown	**>100000 km**
Hours flown	**~250**
Coordination e-mails	**~500**
Flight/data coordination teleconferences	**7**

Overview of the Operator's Activities

- DLR Falcon 20 (DE) – 17 flights

- Metair Dimona (CH) – 9 flights

- FAAM BAe146 (UK) – 11 flights

- NLR Citation (NL) – 7 flights

Overview of the Operator’s Activities

- NERC Dornier228 (UK) – 6 flights

- SAFIRE Falcon 20 – 5 flights

- SAFIRE ATR42 – 5 flights

- INTA Casa212 (ES) – 4 flights

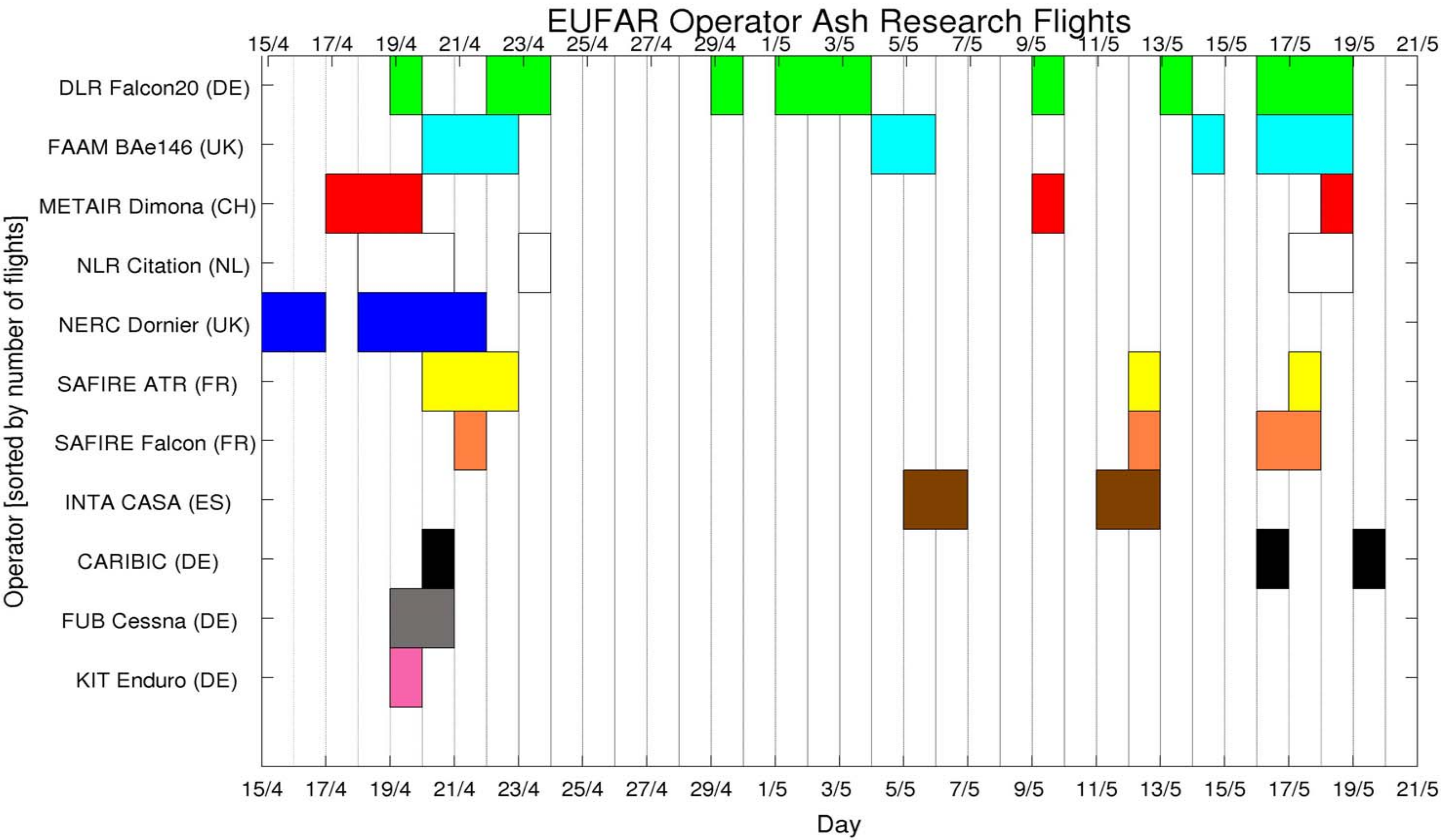
Overview of the Operator's Activities

- CARIBIC Container (DE) – 3 flights

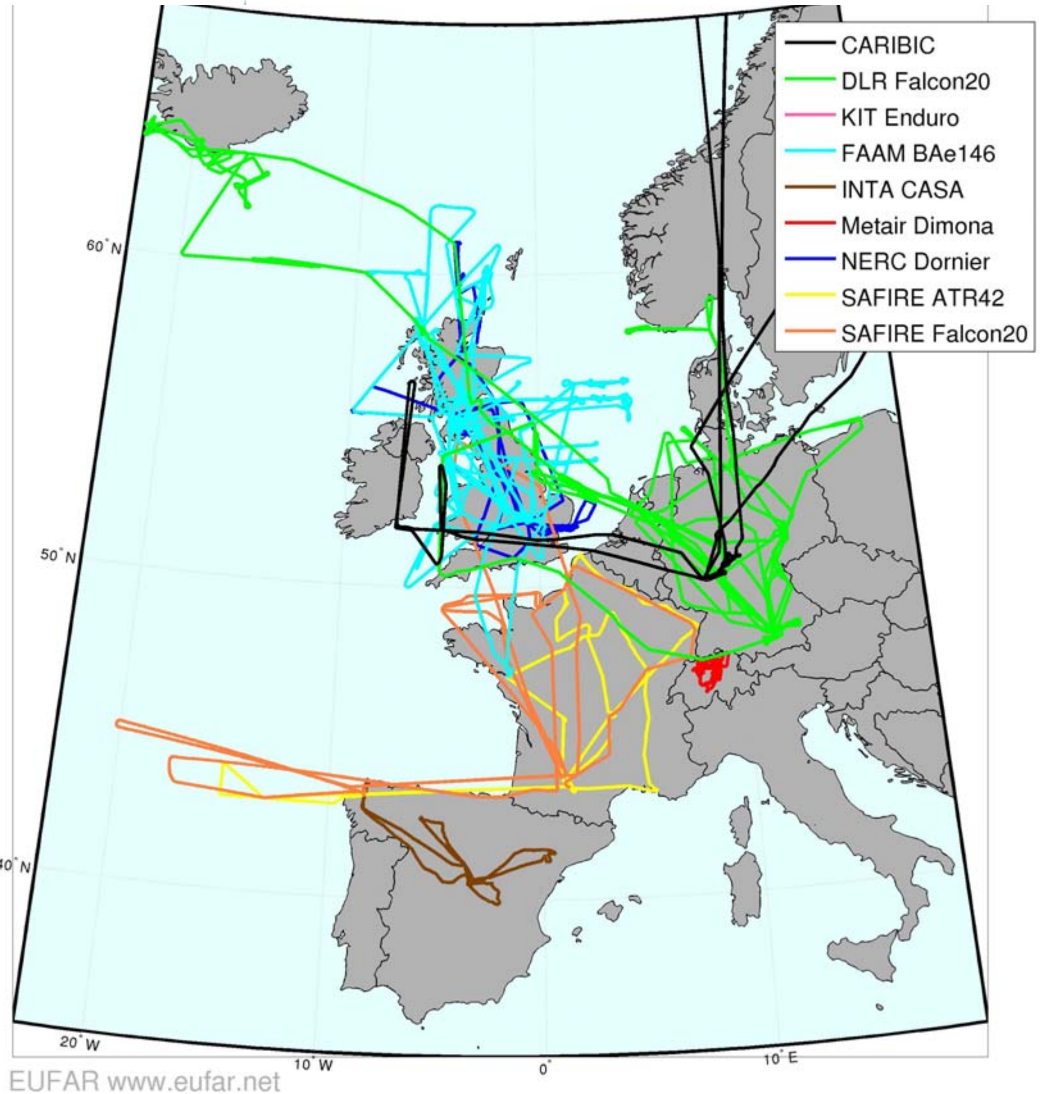
- FUB Cessna (DE) – 2 flights

- KIT Enduro (DE) – 1 flight

Overview of the Operator's Activities



Overview of the Operator's Activities



➢ Research aircraft are national infrastructures that have mainly been used over their own territory

➢ By chance they were all available and rapidly instrumented for aerosol measurements

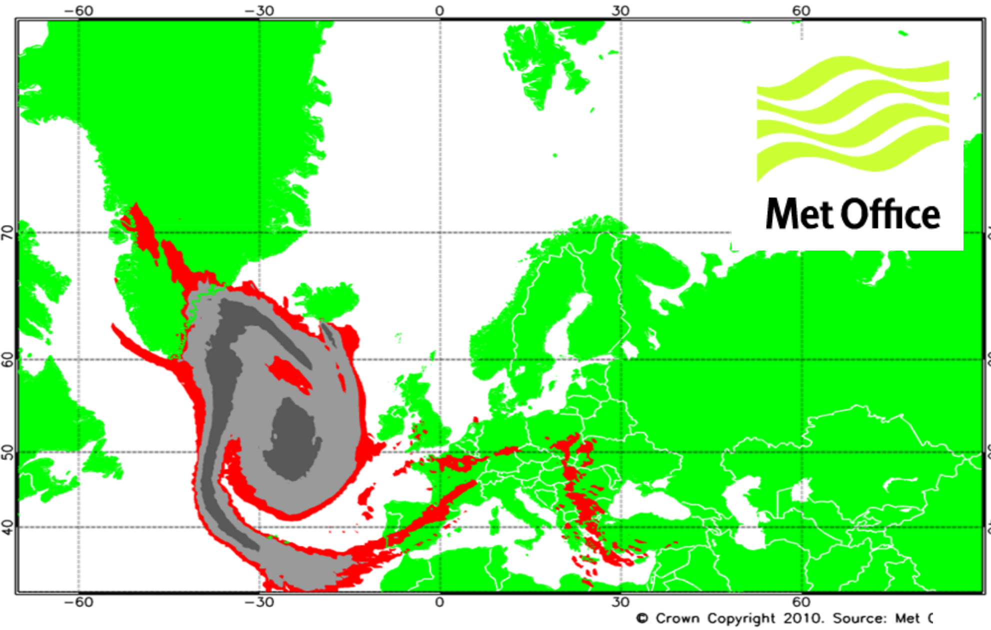
➢ The management of the next crisis cannot rely on chance

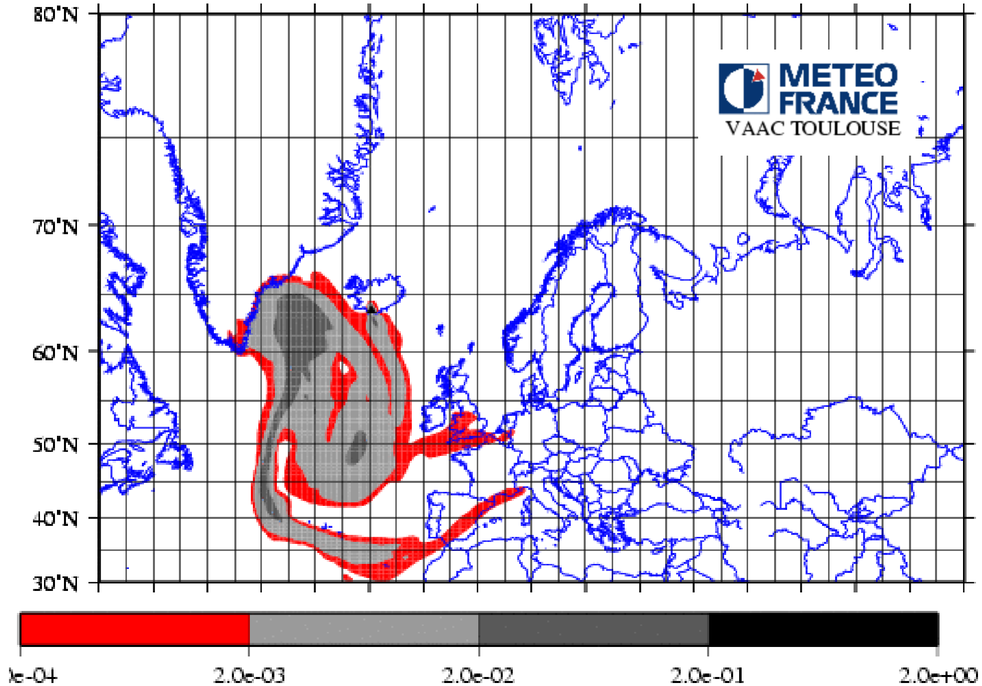
➢ Schemes must be developed for trans-national use of the research aircraft

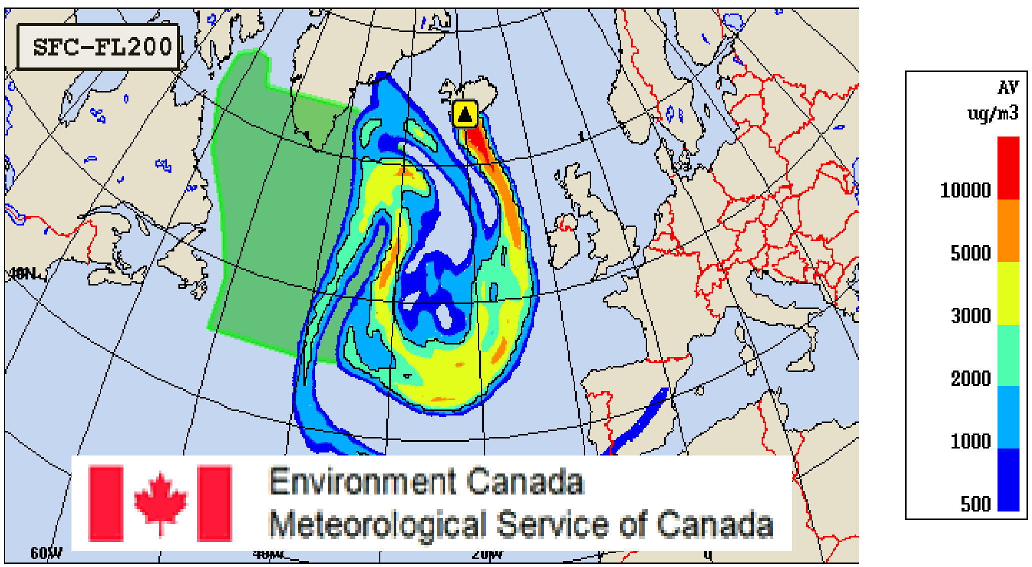
Prediction of Particle Mass Concentration

- Meteorological dispersion models have reached a high level of accuracy

Prediction of Particle Mass Concentration







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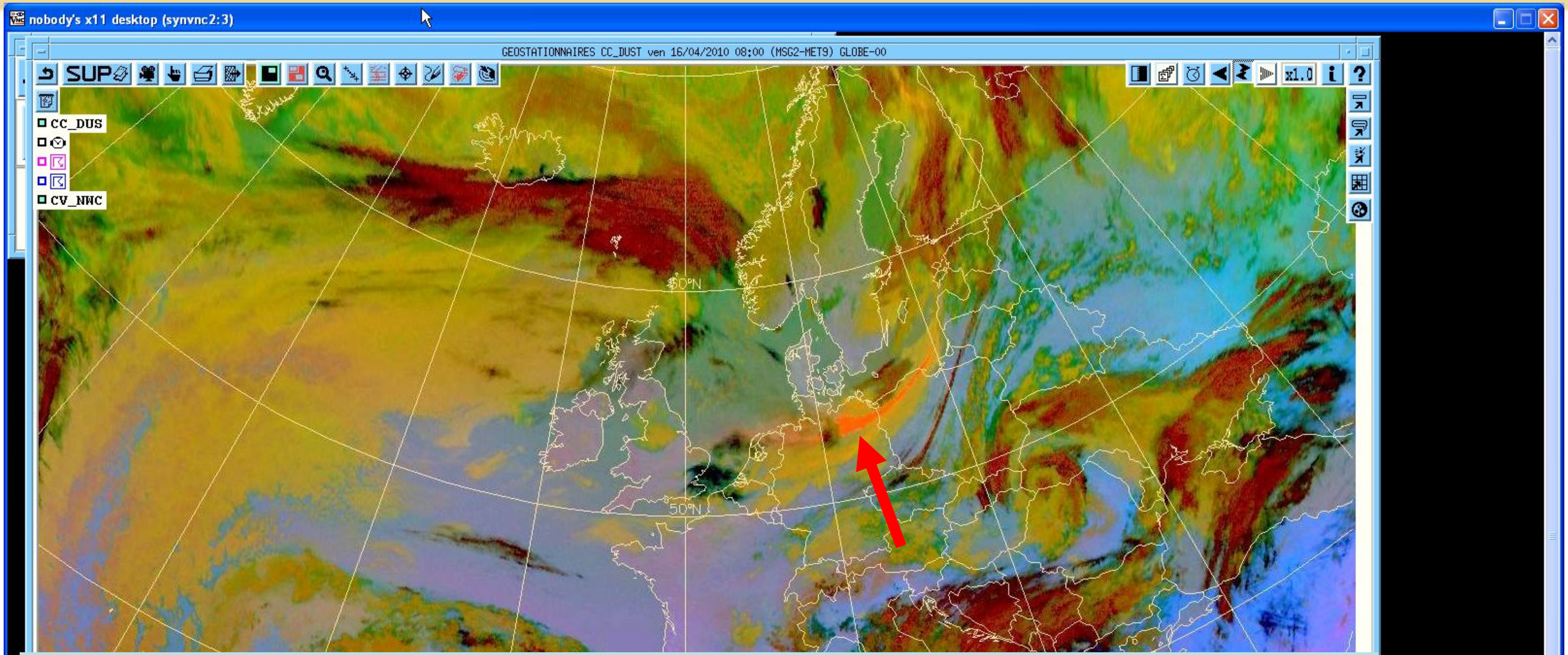
Prediction of Particle Mass Concentration

- Meteorological dispersion models have reached a high level of accuracy
- Data assimilation is a key ingredient of the accuracy

Available Observations: Satellites



(Meteosat 16 April 2010, 0h UTC)

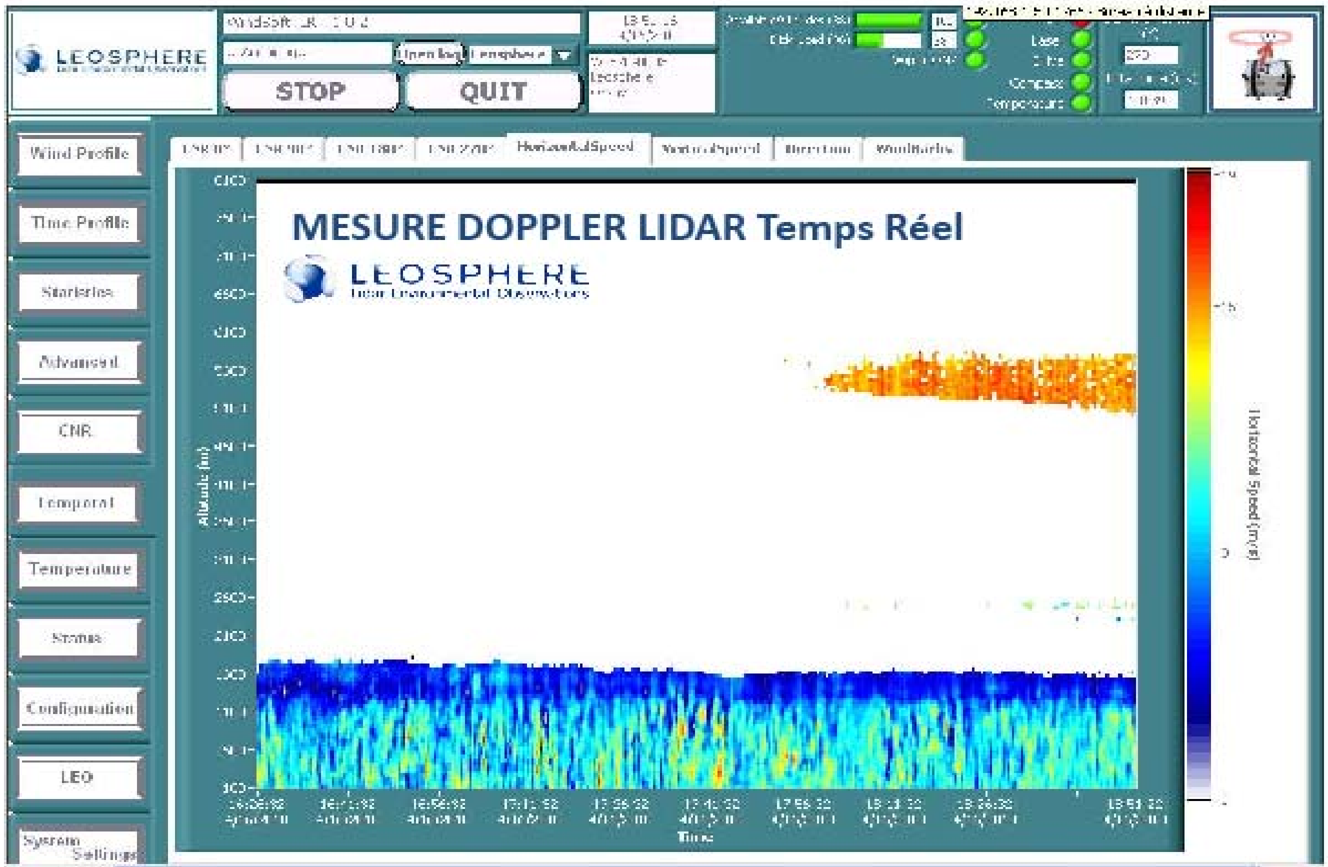
Satellite passive remote sensing images are essential for 2-D characterization of the plume geographical extent, with additional quantitative information about column integrated properties (optical thickness) and size range (effective radius)

Available Observations: Ground Lidar Network

Observations LIDAR
Verticale ORSAY (91)
16/04/2010 – 18h51

Panache arrivé à 17h45
Altitude moyenne 5600m
Epaisseur d'environ 800m

Vitesse de déplacement : 15m/s
Origine : 72° (E-NE)



50 to 100 k€

Courtesy Leosphere

Contact Leosphere :
Alexandre Sauvage 06 75 48 31 70 – www.leosphere.com

Confidentiel – Leosphere / Données non contractuelles

Lidar are essential for high resolution vertical 1D sampling of the particle layers on a few fixed geographical locations

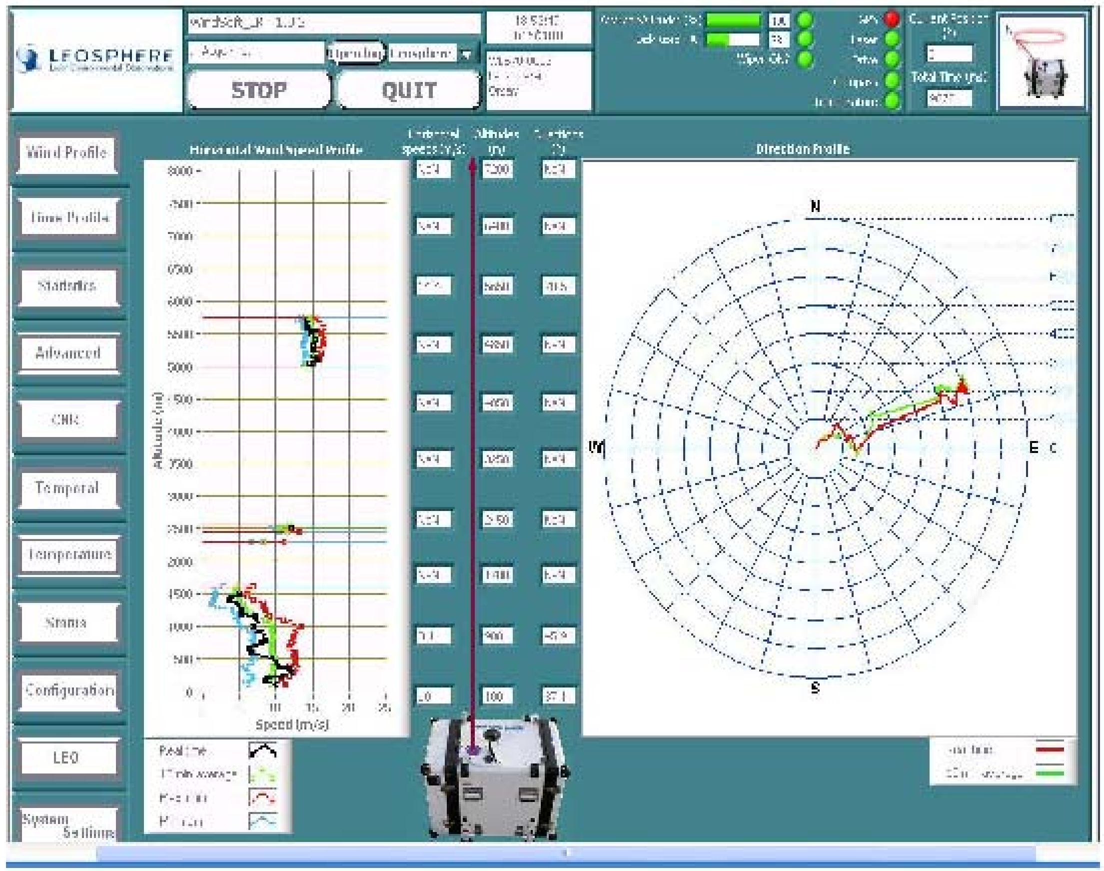
FRANCE
mps d'avance

Available Observations: Ground Lidar Network

Observations LIDAR
Verticale ORSAY (91)
16/04/2010 – 19h00

Panache arrivé à 17h45
Altitude moyenne 5600m
Epaisseur d'environ 800m

Vitesse de déplacement : 15m/s
Origine : 72° (E-NE)



300 to 400 k€

Courtesy Leosphere

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……and transport (with Doppler lidar)

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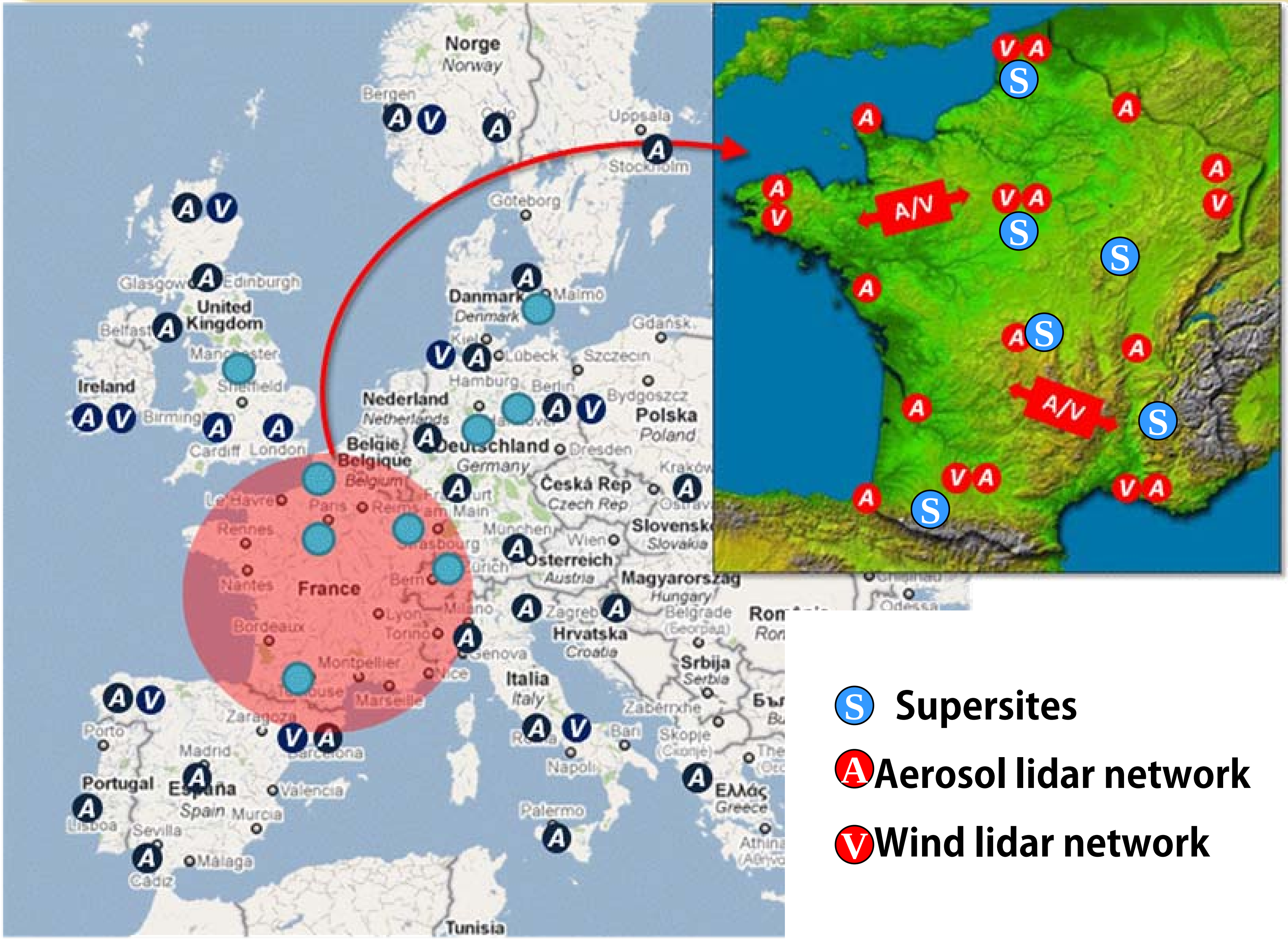
Develop National Lidar Networks



S Supersites

A Aerosol lidar network

V Wind lidar network

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Prediction of Particle Mass Concentration

- Meteorological dispersion models have reached a high level of accuracy

- Data assimilation is a key ingredient of the accuracy

- Available (optical) observations for assimilation are satellites and ground network lidar.
  Both observation systems require accurate assessment of the particle optical indices (scattering & absorption), of the particle size distribution and particle density for sedimentation and retrieval of mass flux from optical extinction.

- During the recent crisis, the main source of uncertainty (a factor 100 to 1000) was the input to the dispersion models : particle mass flux and size distribution : (sedimentation scales with r^5 for small particles <40 µm and r^4 for big ones)

- Chances to improve mass flux estimates at the source in the medium term are small

Error Propagation & Accuracy

- Without additional observation and data assimilation, the uncertainty in particle mass concentration is directly proportional to the initialisation input (a factor 1000 for the Eyjafjallajokull case).

- Without data assimilation, the dispersion model adds a factor of 2 every 24 h, due to errors in divergence and vertical mixing. Much more by sedimentation if particles are large and the size distribution is unknown.

- Observations at the source reduce the initialisation error

- Continuous monitoring along the plume trajectory reduces the model dispersion error and compensates initialisation errors.

- Remote sensing accuracy on mass concentration is limited by uncertainties on optical indices and particle density, typically a factor of 10 to 100. This can be improved using Raman and multi-wavelength lidar.

- In Situ Errors are mainly due to counting statistics, typically a factor of 2 to 10, but can be improved using specific instruments, down to 50%.

Prediction of Particle Mass Concentration

In situ characterization of ash particles is the first priority for improving VAAC forecast, and progress from detection to prediction of mass concentration.

Such observations are required both at the source for model initialisation and away from the source for assimilation and model nudging.

In Situ Measurements of Particle Properties

- Research aircraft and crew can hardly fly in volcanic ash (no fly zone)
- Radiosounding (balloon or drop sondes) offer limited payload for instrumentation and very short sampling of an atmospheric layer (vertical sampling)
- Some aircraft (test aircraft and crew) might be authorized to fly, but they are not equipped with state-of-the-art particle measurement systems.

$\Rightarrow$

EUFAR Aerosol Pods or UAS
are two promising options

EUFAR Airborne Aerosol Reference Pod

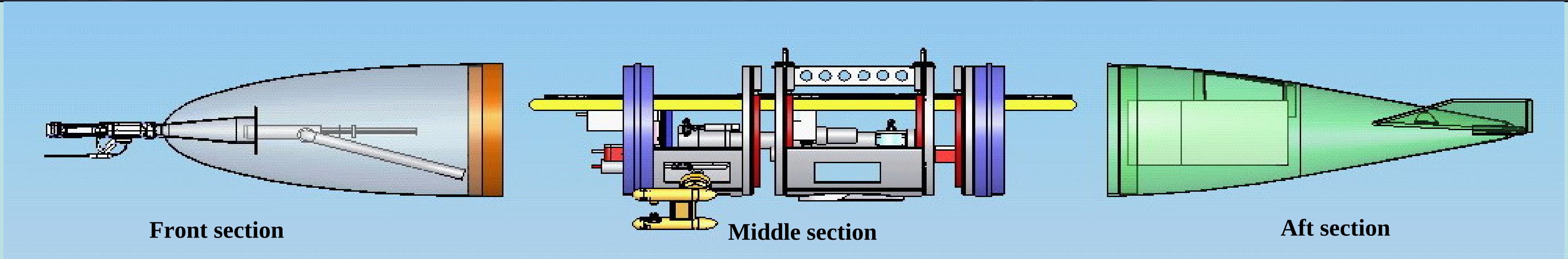
The AARP project was conducted by 7 research institutions representing 5 countries:

Leader : University of Manchester (UK) : Coordination; aerosol optical properties

- Météo-France, CNRM (FR) : Inlet system
- Enviscope GmbH (DE) : Integration and test flights
- Stockholm University (SE) : Advisor
- Max-Planck-Institute for Chemistry (DE) : Aerosol counters
- National University of Ireland, Galway (IE) : Acquisition system
- Leibniz-Institut for Tropospheric Research (DE): Particle flow simulations

To design and construct an Aerosol Reference Pod that can be flown on several aircraft and will serve as a true basis for inter-calibration of airborne aerosol instrumentation, as well as being a stand-alone aerosol payload.

EUFAR Airborne Aerosol Reference Pod



Inlet components:

Isokinetic Inlet
- High speed inlet incl. Pitot
- Low speed inlet incl. Pitot
- Pressure sensors
- Heaters control unit

Diffusor and Flow Splitter
- Diffusor
- Restrictor Disc
- Provision to achieve isokinetic conditions at entrance of sampling tubes
- Sampling lines
- Excess air tubes

Peripherie:

Excess Air:
- Volume Flow Sensing Element
- Control Valve (Isokineticity Inlet)
- Excess Air Bracket
- Venturi ??

Several temperature sensors

Externally mounted instruments:

-**CDP** sensor unit
(electronic box inside pod)
-**ASPEN** Probe
(electronics integrated in pylon)

Internally mounted instruments:

- **MARIE**
  2 x CPC
  separate electronic unit
- **SMPS**
  various components
- **OPC**
  (1 unit)
- **Data Acquisition Unit**
  (PC104)
- **Static Temperature Sensor**

Peripherie:

- Power distribution
- Vacuum Pump
- Front Connector Bracket to a/c

Basic Infrastructure:

-Power Converters
- DC/DC
- DC/AC
- AC/DC
- EMV Filter

-Rear Connector Bracket to aircraft

Pod 1: Microphysics

Location of instruments

EUFAR Airborne Aerosol Reference Pod

Pod 2: Optical Properties

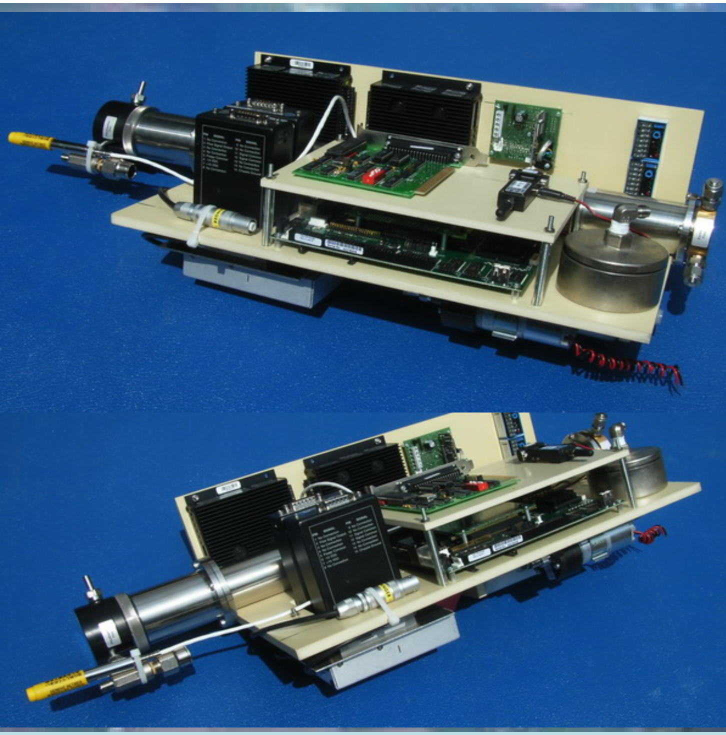
MAAP

NEPHELOMETER

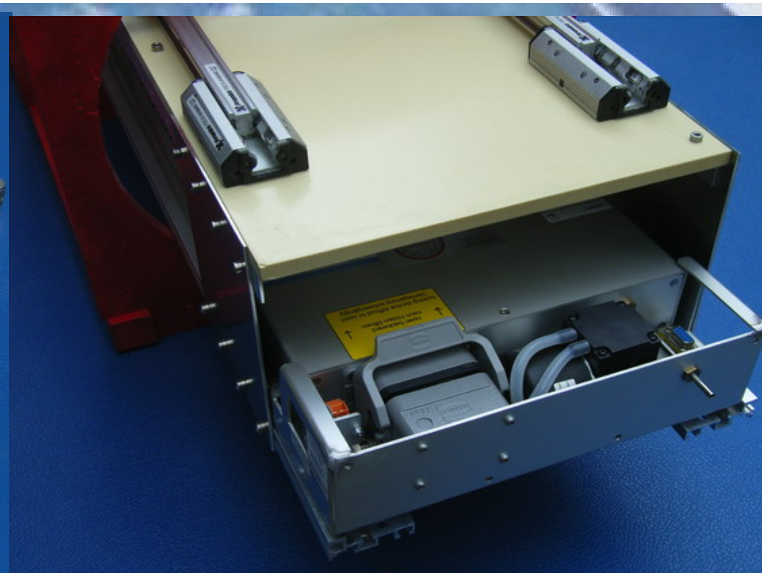
OPC

EUFAR Airborne Aerosol Reference Pod

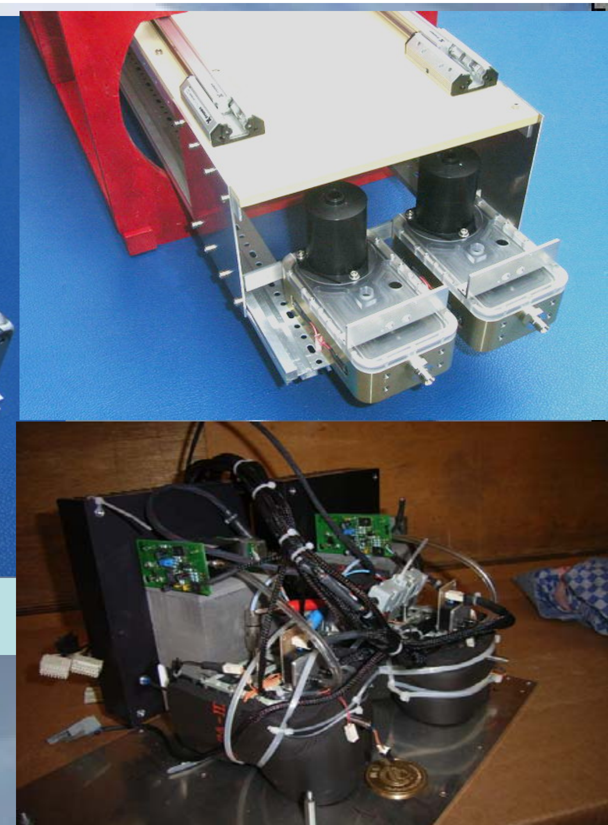
EUFAR Airborne Aerosol Reference Pod



SMPS

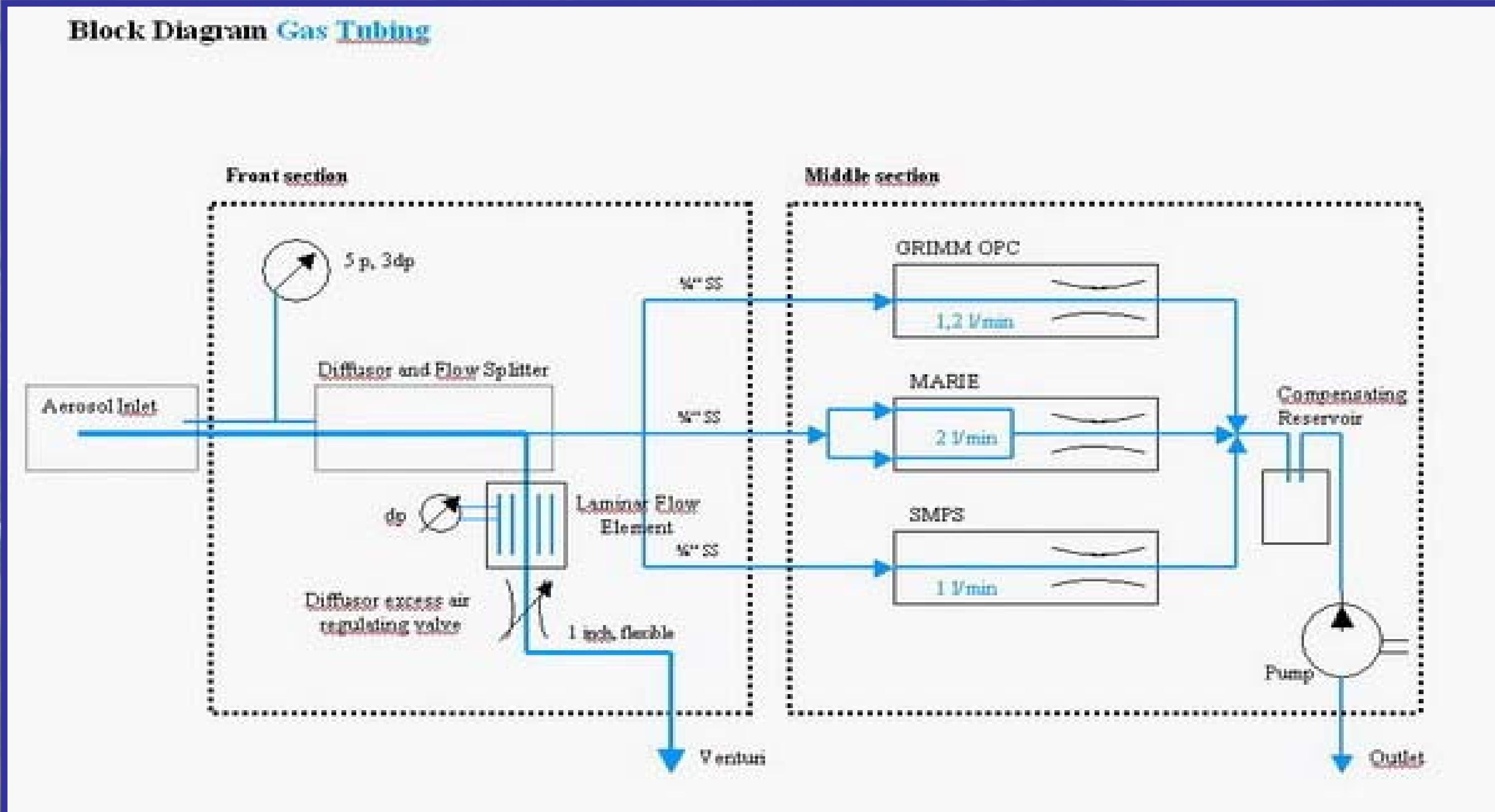


OPC

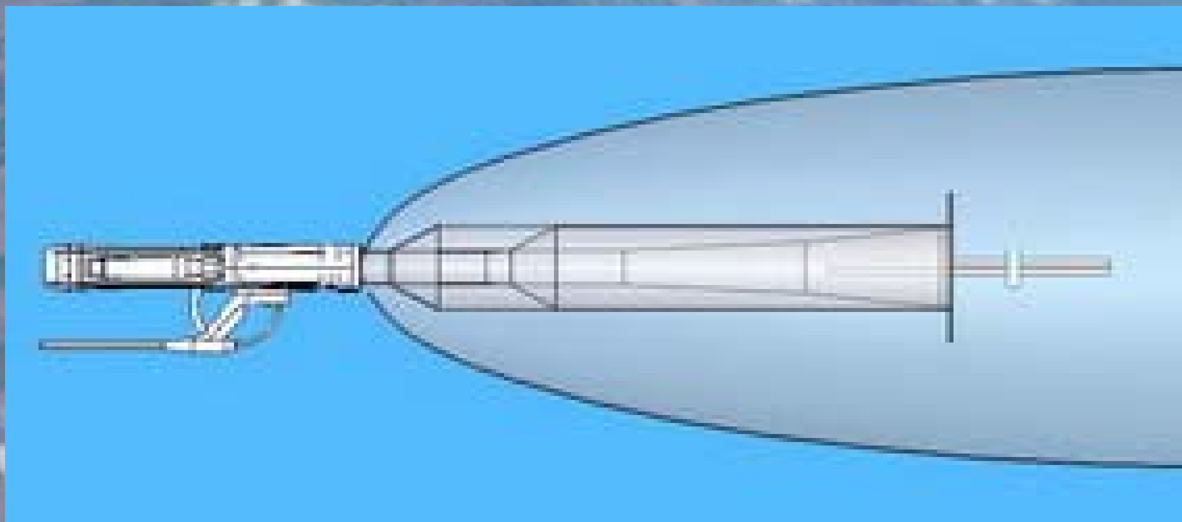


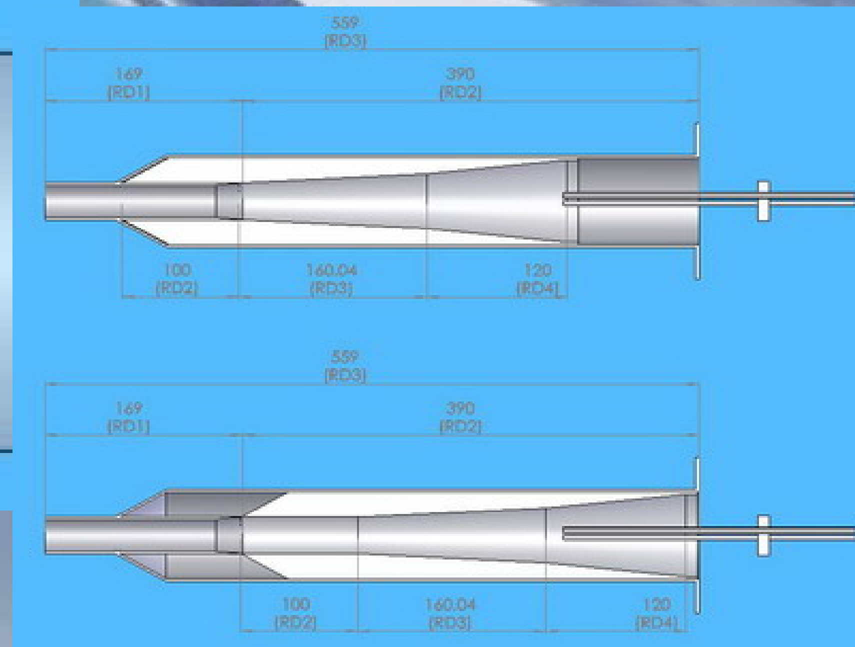
MARIE

EUFAR Airborne Aerosol Reference Pod



EUFAR Airborne Aerosol Reference Pod

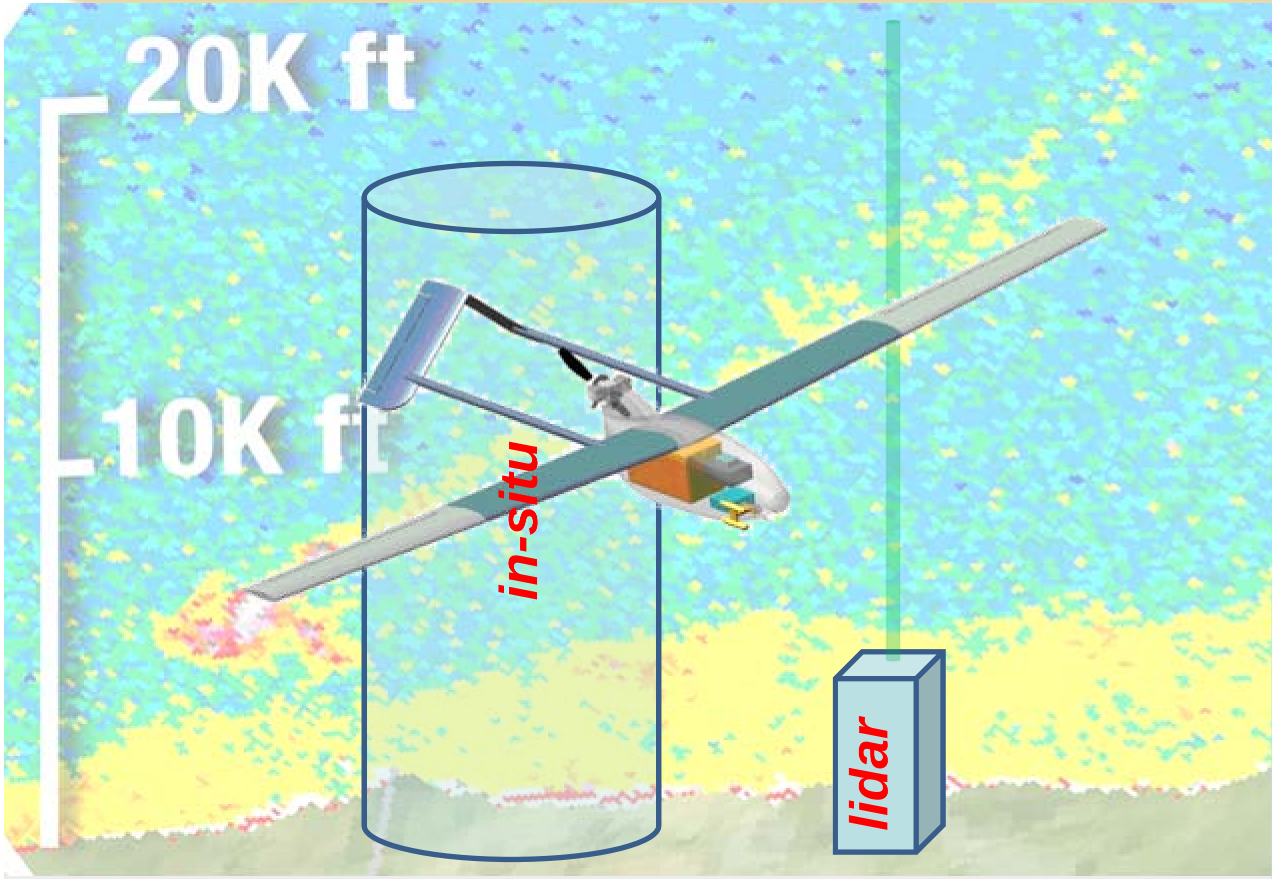


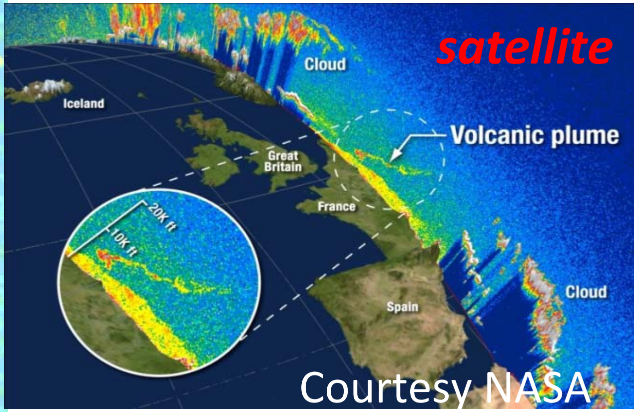


Removable lips on the diffuser and on the shroud to adapt the inlet to slow (100 m/s) and fast (200 m/s) flying aircraft

The EUFAR AARP is presently maintained and operated by Uni Manchester. It is available for research at a very low cost <1000 € /FH

UAS in Geoscience

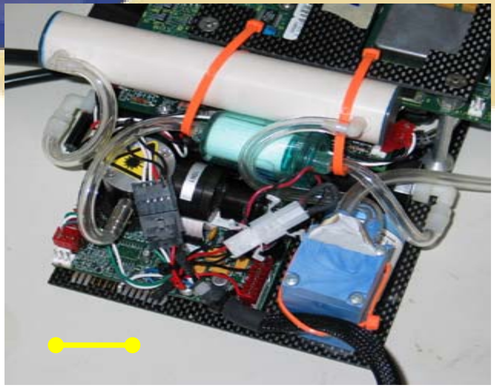




Size Distribution, Density
Refractive Indices (scattering & absorption)

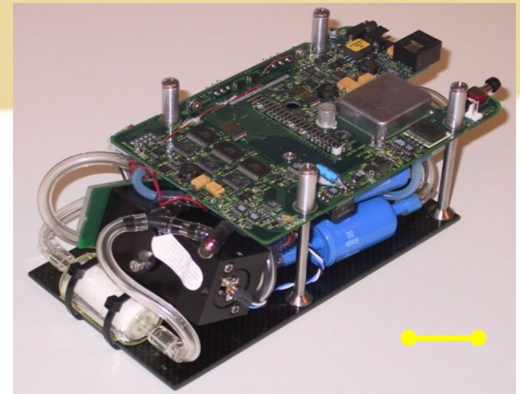
Targeted measurements from the start of an eruption, in relatively high density ash (no fly zone), then at variable distance from the source

UAS Instrumentation

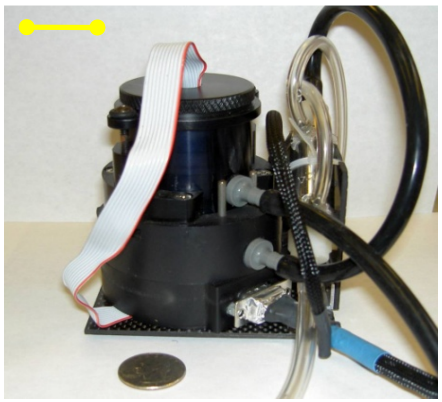


Particle size & number (580 g)

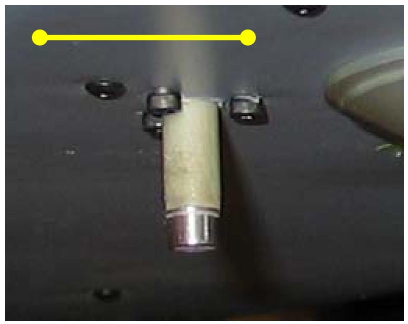
[=] 2.5 cm



Total particle number (870 g)



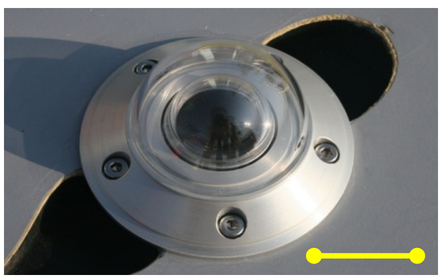
Smoke aerosol (820 g)



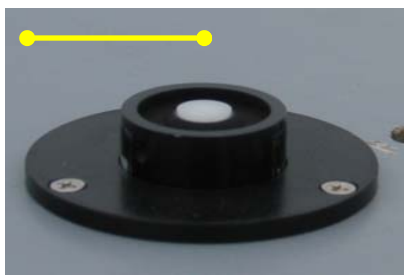
Temperature & relative humidity (50 g)

Unbiased aerosol sampling (150 g)

Cloud droplet size & number (1.4 kg)



Sun energy: broadband (190 g)



Sun energy: visible (45 g)

Cloud-forming aerosol (1.9 kg)

Ozone (600 g)

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UAS Experience in Geoscience

Unmanned Aerial Systems

Maldives AUAV Campaign

18 missions & 23 hrs of synchronized observations

COST ES-0802: French representative

2 Aug. 2007

Corrigan et al., *ACP*, 2008.
Ramana et al., *QJRMS*, 2007.
Ramanathan et al., *Nature*, 2007.
Roberts et al., *PNAS*, 2008.

Economic Model

	Aircraft <5.7 T	UAS Med. Range	Balloon Drop Sonde
Payload	800 kg	5 kg	0.5 kg
Endurance	5 h	8 h	min
Manoeuvrability	++	++	0
Infrastructures	Airport	ramp+nest	10 m^2
Ceiling	15 km	4 - 15 km	15 km
Procurement (platform + instruments)	5 M€	0.5 - 1.5 M€	500 €
Personnel	Crew (2) Tech (3)	Tech. (3)	Tech (1)
Unit Cost per flight hour Fixed (200 FH/year) Variable No depreciation	8000 € 2000 €	1500 € 100 €	500 € 3000 € (10 min sample)
Unit Cost per h x kg payload	12 €	200 €	7000 €

Conclusions

Research Aircraft can contribute to the monitoring of ash plumes (or any other environmental accident), but this is not their main mission.

Schemes must be developed to facilitate a trans-national use of the research aircraft.

Model predictions can be significantly improved if the lidar observation networks are extended (and harmonized).

The main step to improve particle mass flux prediction is the in situ sampling of the plume.

Two systems only can do it. Test (military) aircraft and UAS.

State-of-the-art measuring systems can be made available to test aircraft, such as the EUFAR Airborne Aerosol Reference Pod

Medium range UAS exist (Scan-Eagle-US, Manta-US, FulmaR-ES) and miniaturized instruments have already been developed for aerosol sampling

FULMAR UAS (SPAIN)

AEROVISIÓN

International Conference on Airborne Research for the Environment

*I*nternational *C*onference on *A*irborne *R*esearch for the *E*nvironment

ICARE 2010

Toulouse, October 25-31st 2010

Scientific Conference

Forward-look on user requirements and operators development strategy
Implementation of open access, Expert meetings

Aircraft Exhibition

More than 10 participating research aircraft
80 stands for research funding institutions, operators, experts and SMEs involved in airborne instrumentation

Inter-calibration Experiment

Training Course on QA/QC

Special session on Research Aircraft Contributions to Civil Contingencies

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International Conference on Airborne Research for the Environment

	Meteo-France Conference Centre									Toulouse-Blagnac Airport				
	MON 25		TUE 26		WED 27		THU 28		FRI 29		SAT 30		SUN 31	
	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
Open Access														
Forward Look														
ISPRS Meeting														
Training Course on data Processing and QC/QA														

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