The AVIRAD aerosol sampling system: design and validation

Paola Formenti, Noël Grand and Michel Maillé
Laboratoire Interuniversitaire des Système Atmosphériques (LISA), Univ. Paris12&7/CNRS, Créteil, France

Rémi Caillou and Philippe Nacass
SAFIRE, Météo-France/CNRS/CNES, Toulouse, France

Christophe Berthod, Stéphane Letourneur and Rodrigue Loisil
DT-INSU, CNRS, Meudon, France

formenti@lisa.univ-paris12.fr
http://www.dt.insu.cnrs.fr/avirad/avirad.php

Scientific motivation

- ▷ Study of the emissions and properties of mineral dust due to convective systems
- ▷ Validation study of the LISA Dust Production Model (DPM, Marticorena and Bergametti, 1995; Alfaro and Gomes, 2001)
- ▷ AMMA project, three stations along 13°N since 2005 (“Sahelian Dust transect”), IOP field campaign over Niger in summer 2006

AMMA web site:
www.amma-international.org;

see also
Redelsperger et al., BAMS, Dec. 2006

Requirements

- ▷ **Dust is emitted then uplifted in the free troposphere (at least up to 6 km)**
  - ▷ coupling ground-based and aircraft sampling (F/ATR-42)

- ▷ **Studying dust emissions and properties**
  - ▷ measure simultaneously and under controlled conditions the number and mass concentrations and composition as a function of size as well as the optical properties
  - ▷ all instruments are connected to one inlet to reduce ambiguities due to different passing efficiency

- ▷ **The size distribution ranges from fractions to tenths of microns**
  - ▷ isokinetic sampling
  - ▷ avoid particle losses, connections should be short and as straight as possible

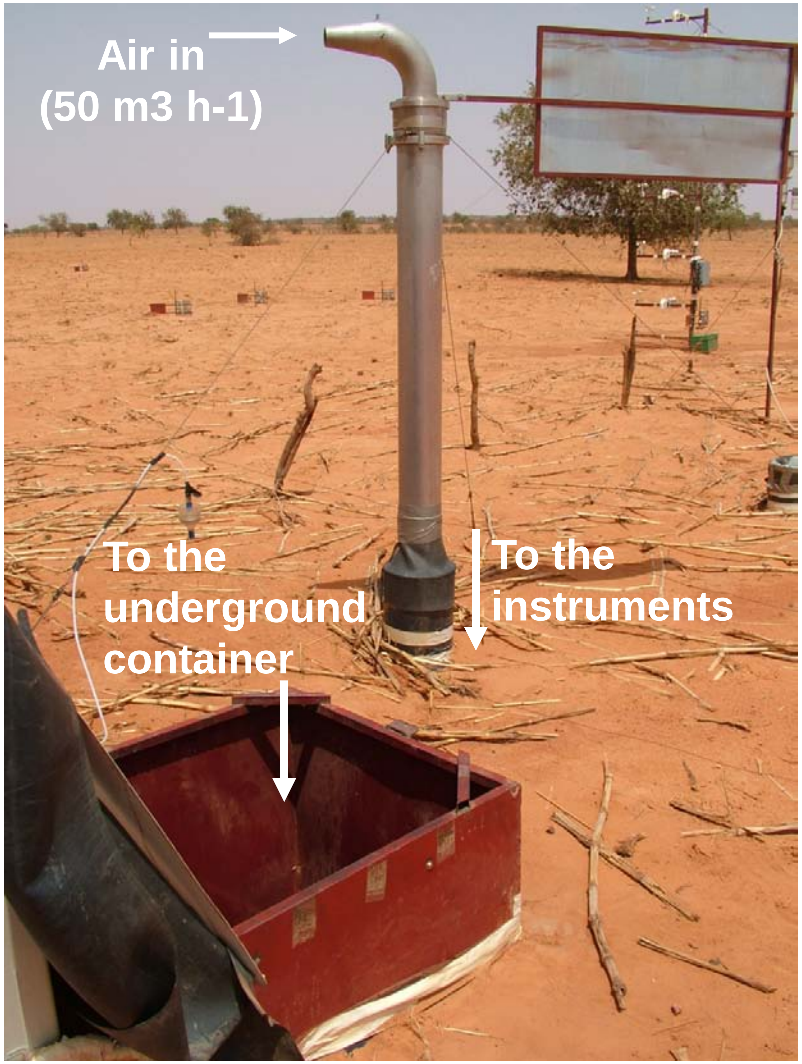
Measurements and instrumentation

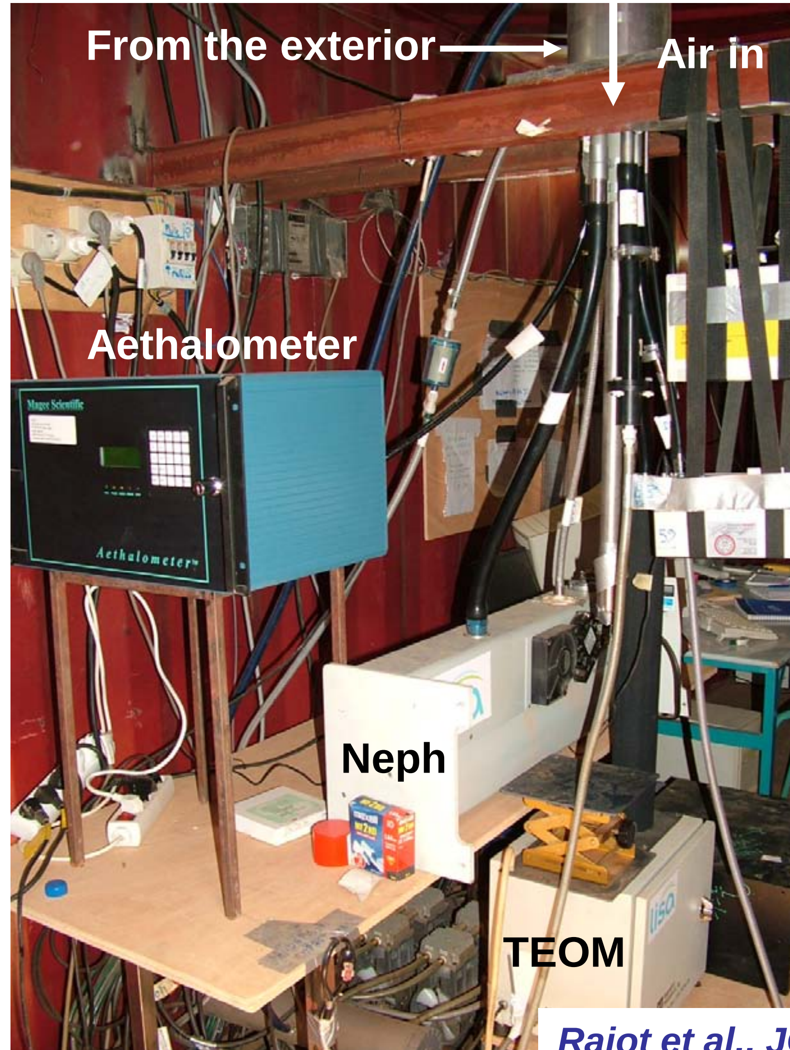
Aerosol property	Instruments	Flow rate (L min^{-1})	Inlet internal diameter (mm)
Bulk aerosol concentration and mineralogy	Sampling on bulk filters (X 2)	16	6.25 (1/4")
Size-segregated aerosol concentration and mineralogy	Sampling on 4-stage DEKATI impactors (x 2)	10	18
Number size distribution (0.3-20 µm diameter)	GRIMM particle counter	1.2	3
Aerosol scattering coefficient	Spectral nephelometer (TSI)	30	25 (1")
Aerosol absorption coefficient	Spectral aethalometer (Magee)	20	6.25 (1/4")

▷ Instruments with different flow rates and inlet diameters

▷ Simultaneous online measurements and filter sampling, necessity of isolating the different sampling lines

Ground-based station (Banizoumbou, Niger)

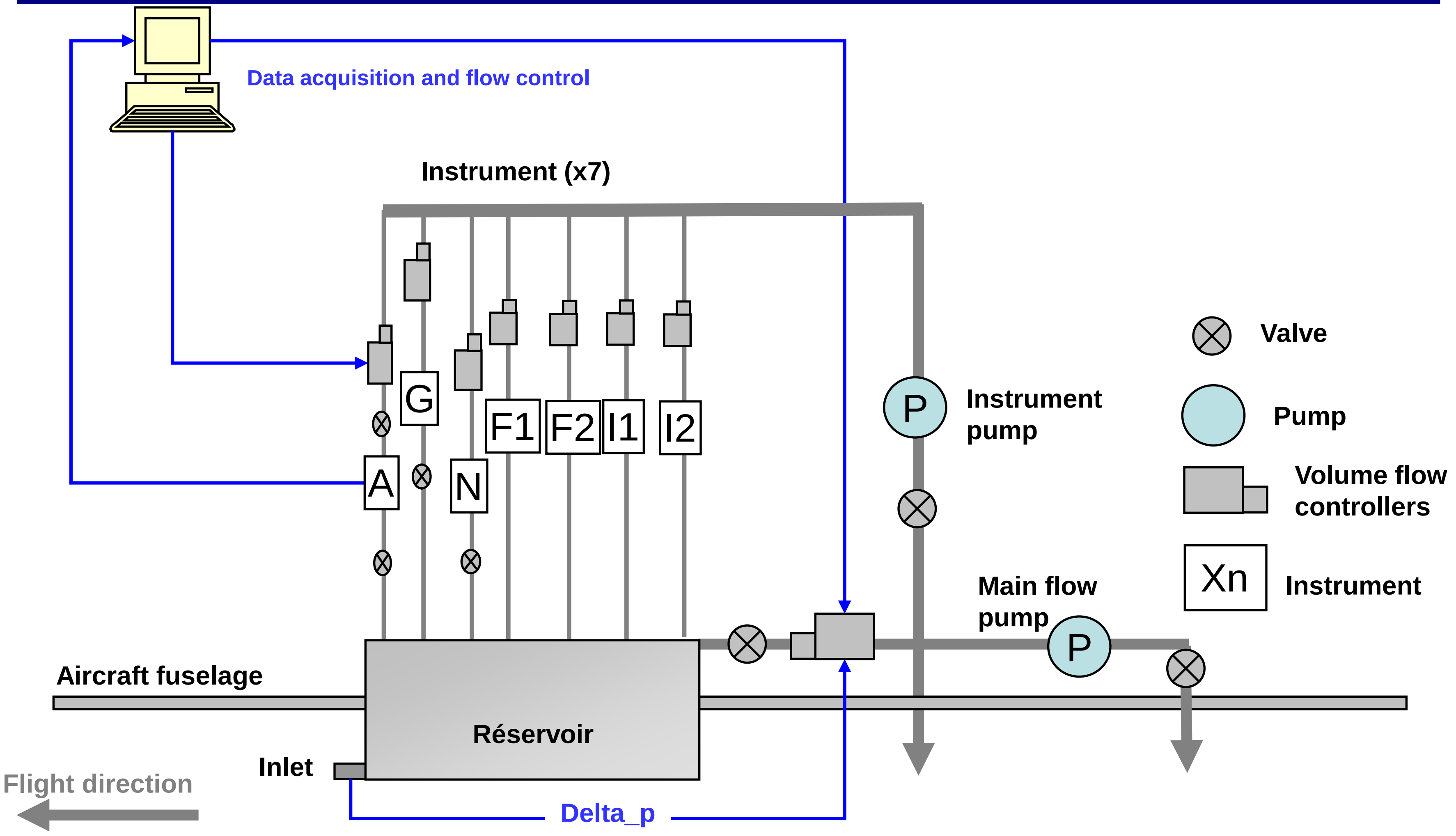




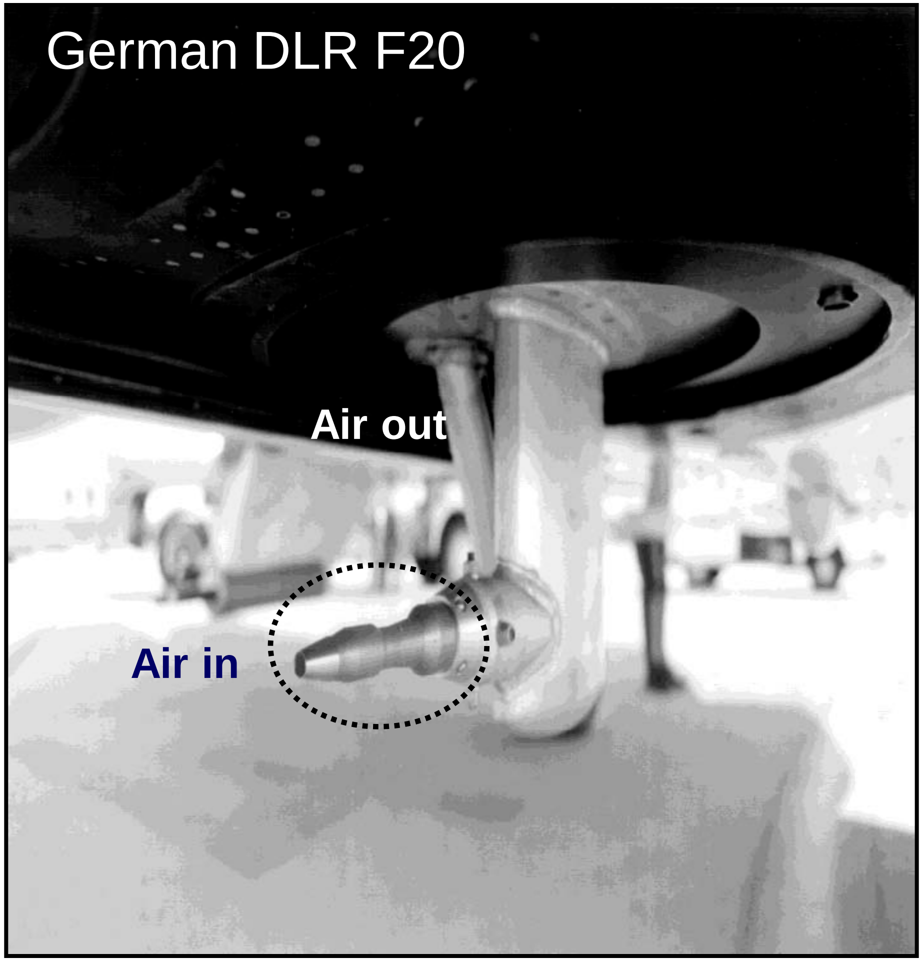
GRIMM OPC

Rajot et al., JGR, 2008

AVIRAD, working scheme



Choice of the aerosol inlet



Inlet AVIRAD/LSCE

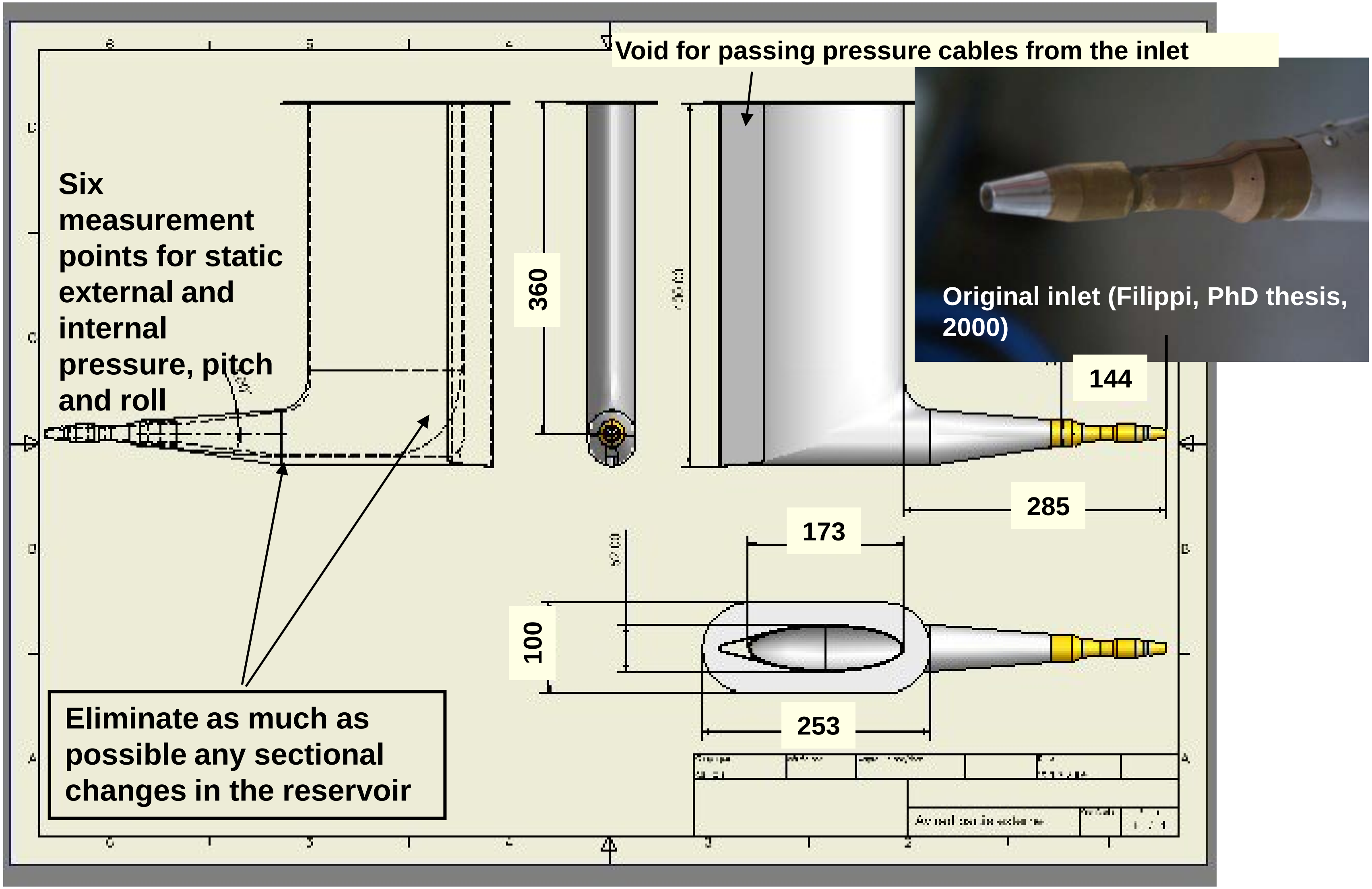
1. The inlet was tested and validated by numerical simulations (D. Filippi, PhD thesis, 2000)

2. Already certified and flown on the DLR-F20 (research speed ~200 m s^{-1})

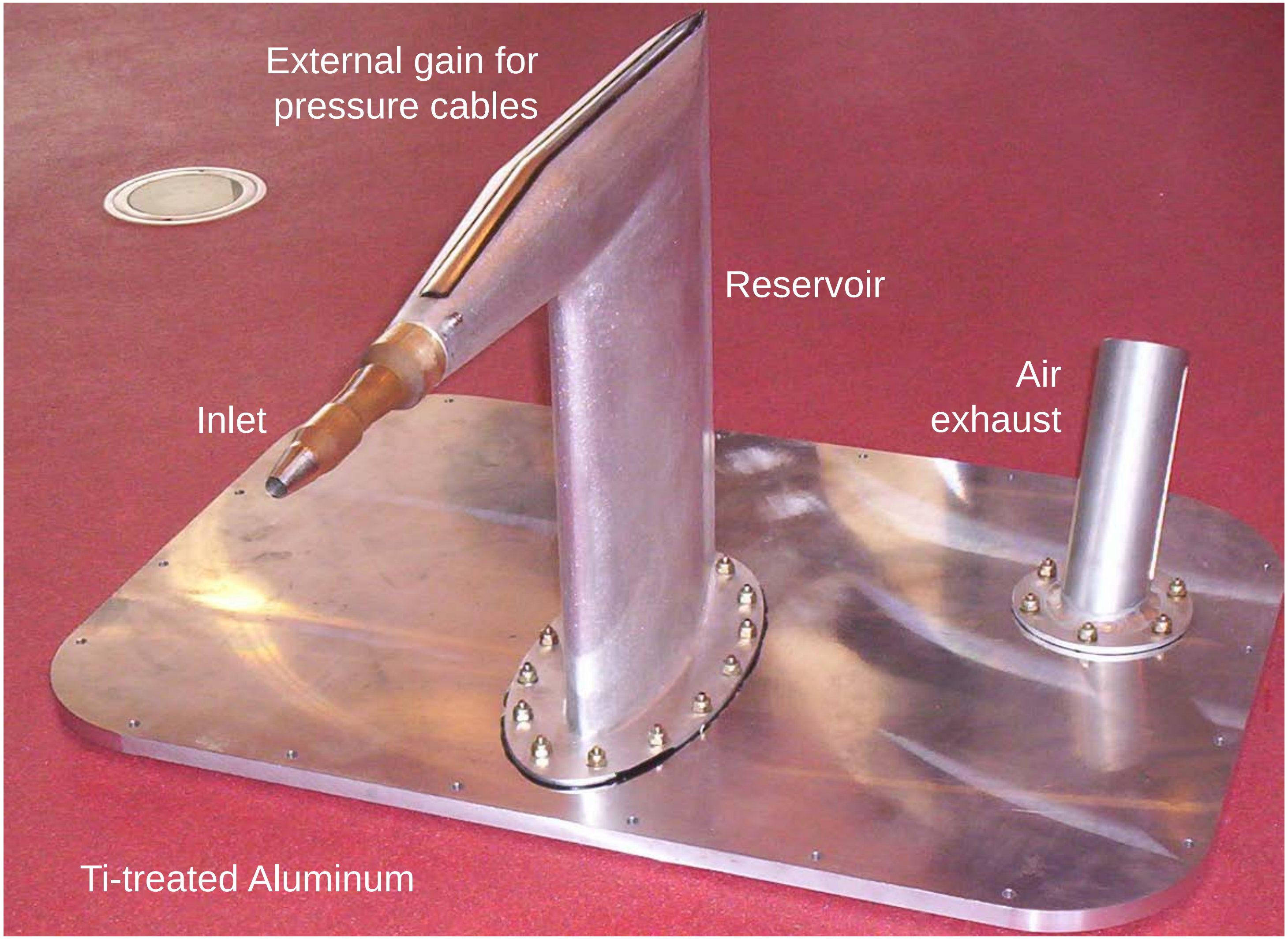
3. Entrance section diameter 8. 72 mm. At the ATR-42 research speed (93 m s^{-1}) the flow rate is high (21.5 m^3 h^{-1}), allowing multiple-sampling

4. "The AVIRAD inlet seems well adapted for studying large aerosols" (Chazette et al., 2002), recommendations for improvements

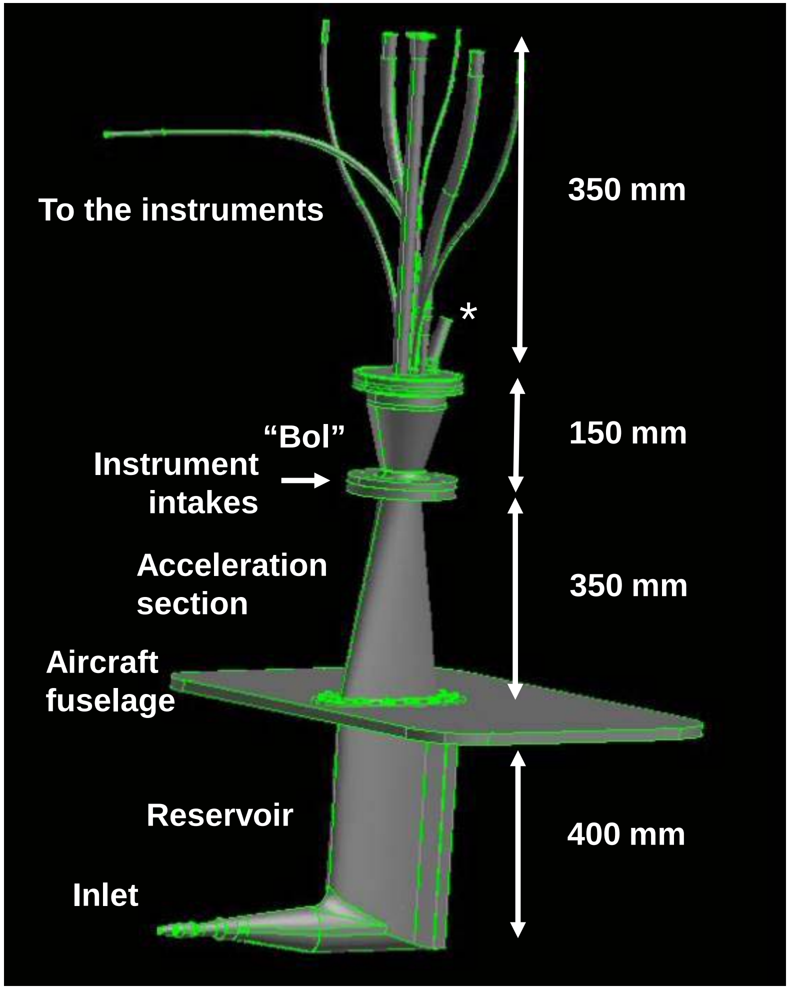
Inlet and reservoir (1)



Inlet and reservoir (2)



Sampling system structure (1)



About 1/3 of the flow (~ 8 $m^3 h^{-1}$) to the instruments

*** To the main volume flow controller and air exhaust (2/3 of total flow)**

"Bol" = sampling chamber
Air speed at the entrance of the instruments 2.83 $m\ s^{-1}$ (corresponding to the GRIMM OPC working air speed)

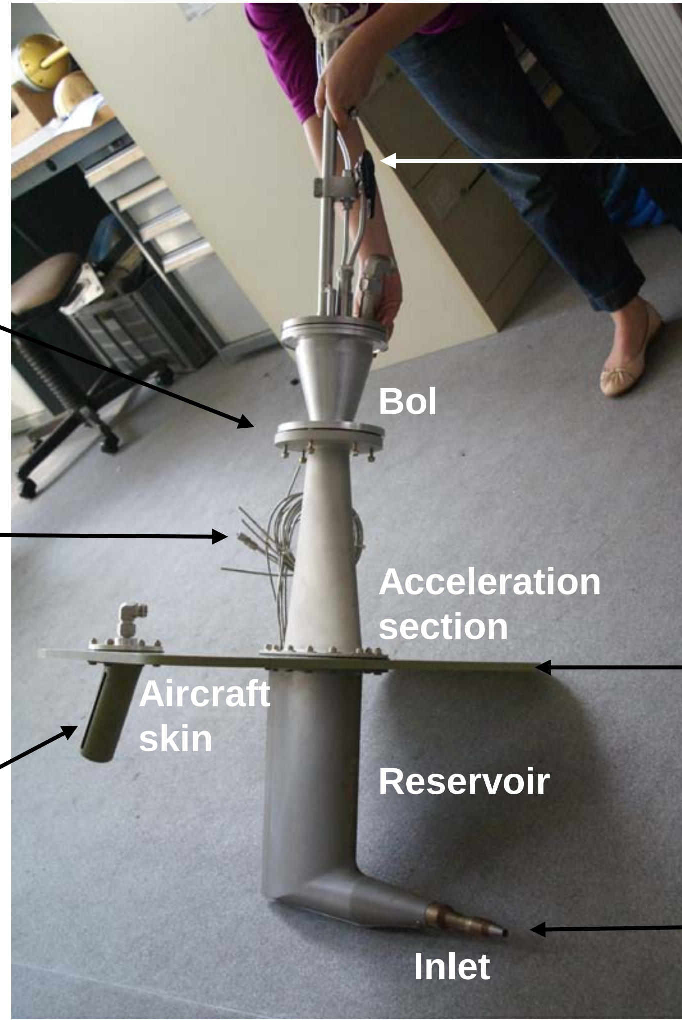
Air speed at the reservoir exit 0.87 $m\ s^{-1}$

Air speed at the inlet 93 $m\ s^{-1}$ (21.5 $m^3 h^{-1}$)

Sampling system structure (2)

"Bol" = sampling chamber
Air speed at the entrance of the instruments 2.83 m s^{-1}

About 1/3 of the flow (~8 m^3 h^{-1}) go to the instruments, the rest to the air exhaust



Weight ~ 20 kg

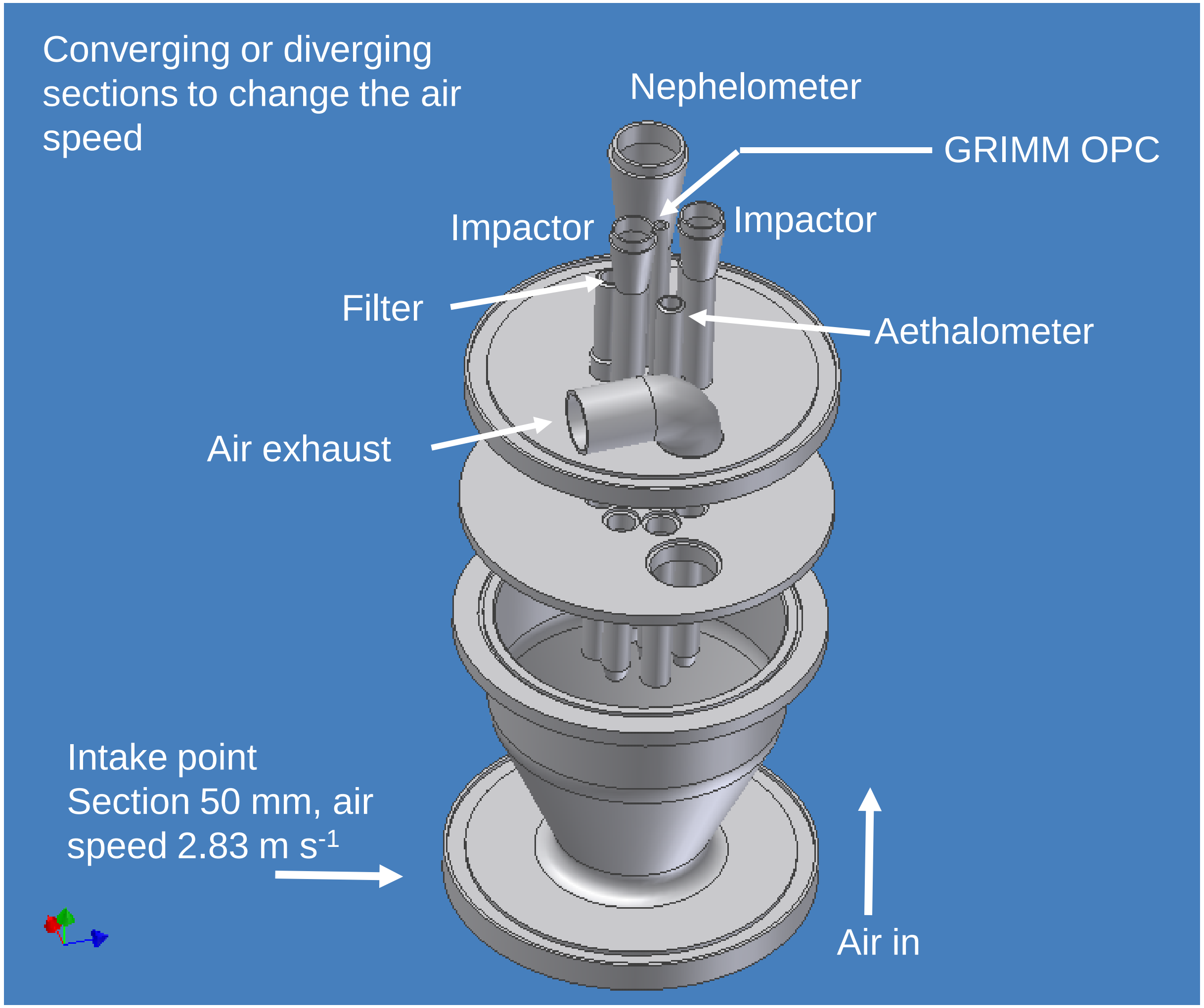
To the pressure sensors

Air speed at the reservoir 0.87 m s^{-1}

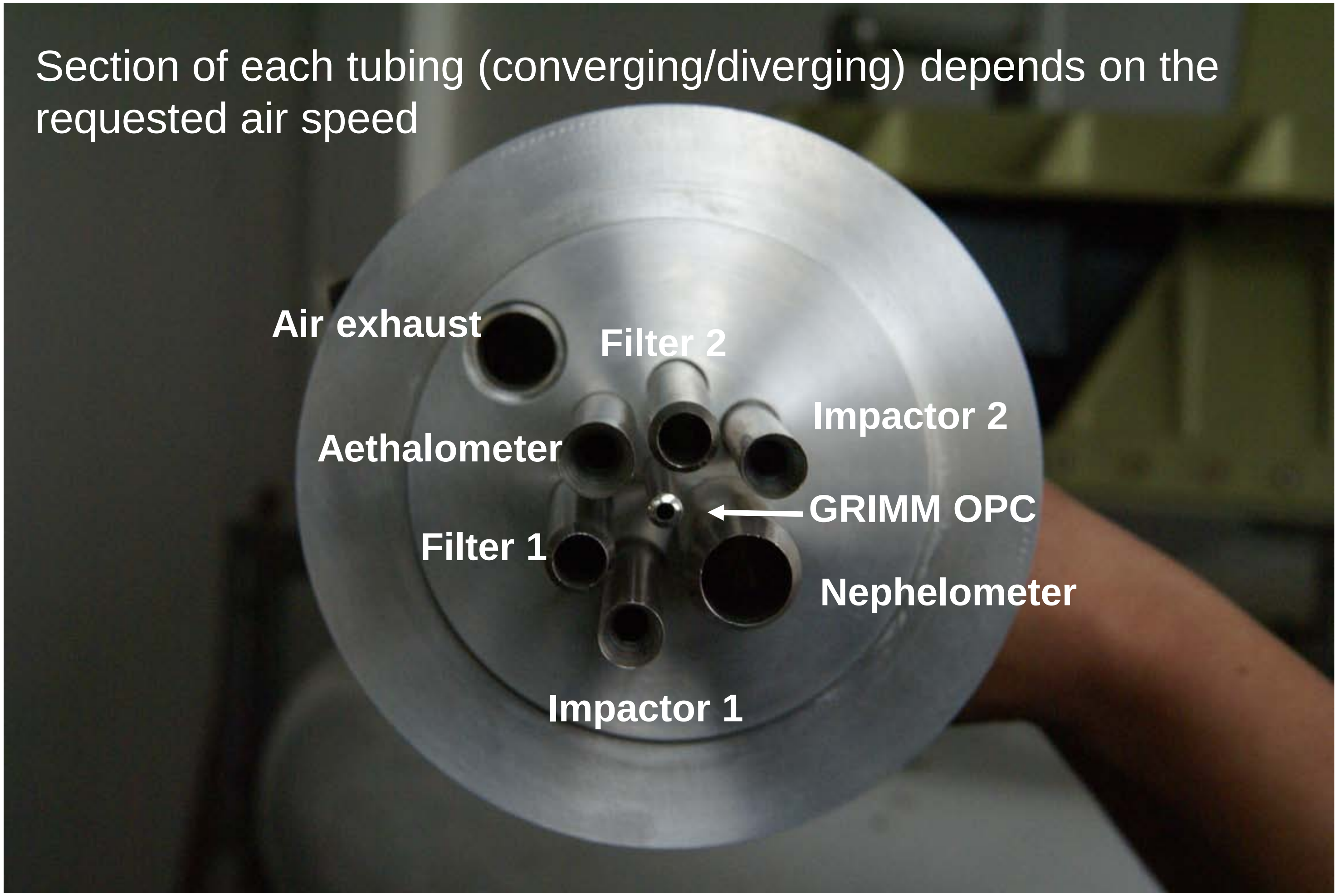
Air exhaust
(~ 13 m^3 h^{-1}, 2/3 of the flow)

Air speed at the inlet 93 m s^{-1}
(21.5 m^3 h^{-1})

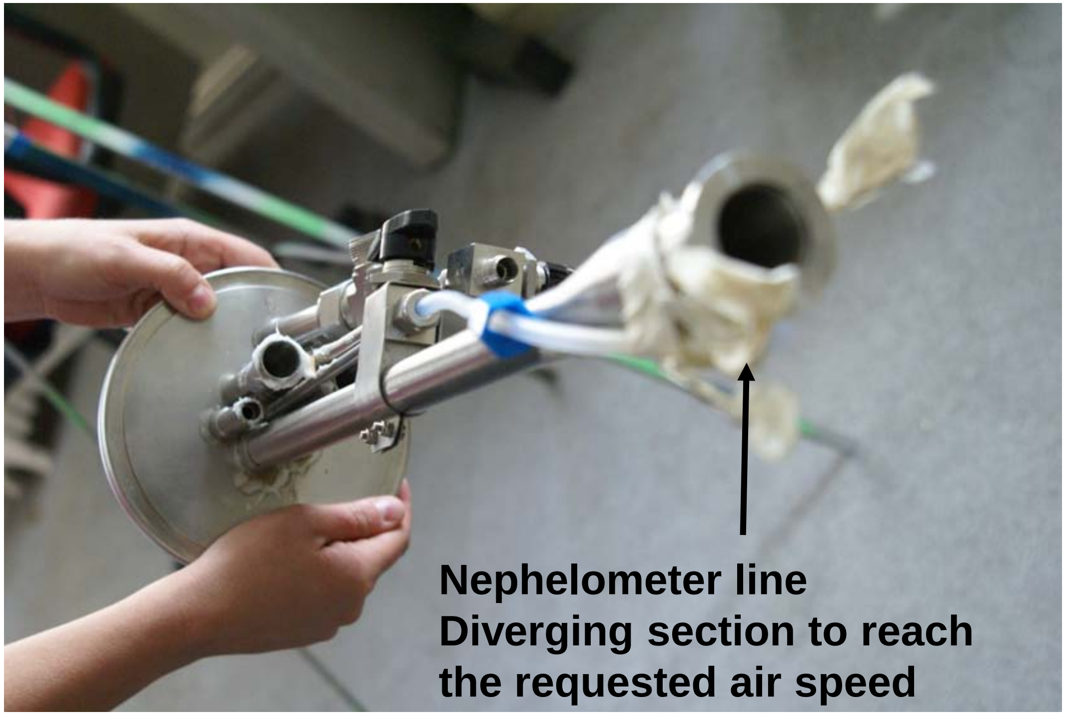
Sampling intakes (1)



Sampling intakes (2)

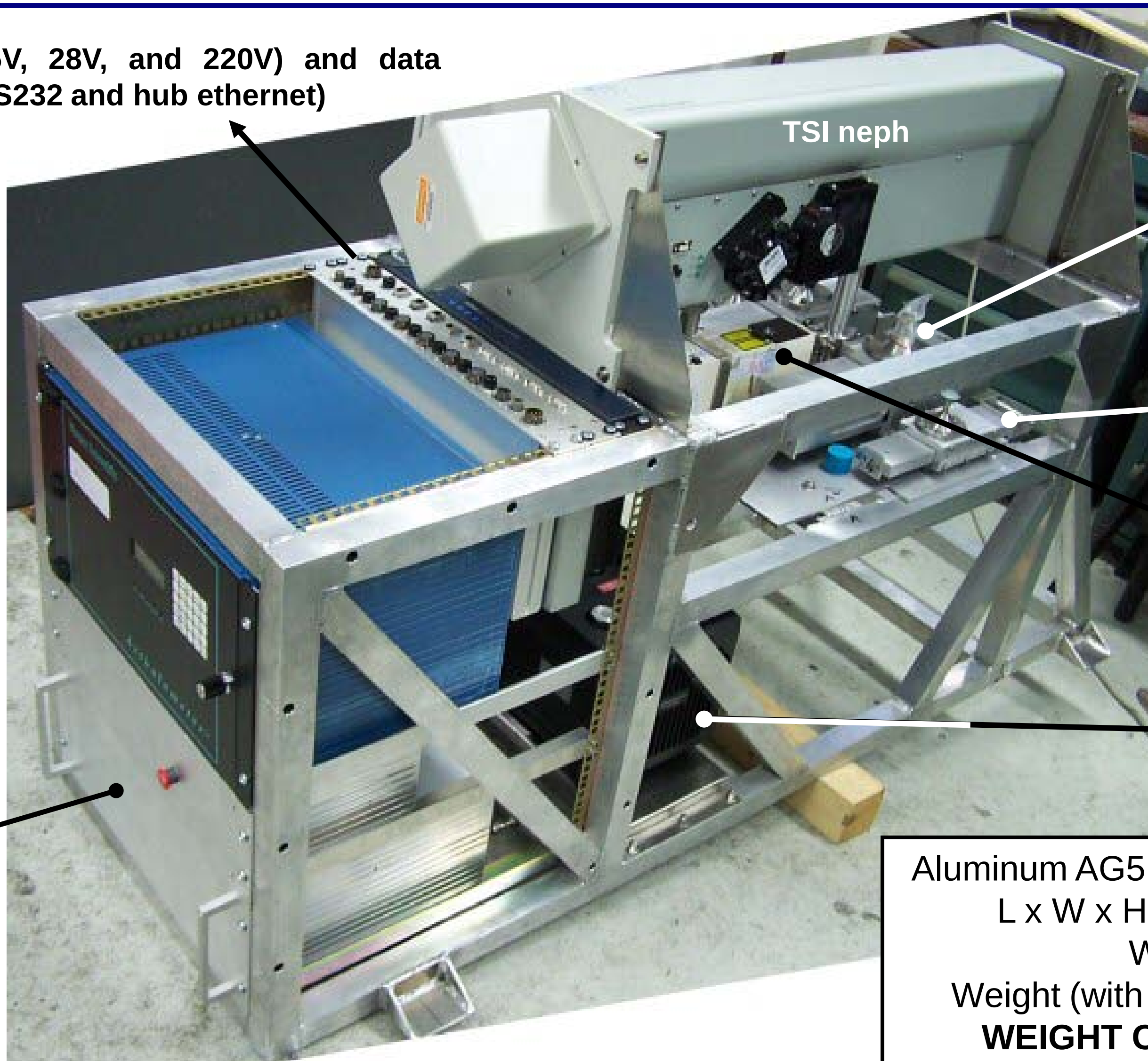


Sampling lines



Instrumented rack (1)

Power supply (15V, 28V, and 220V) and data acquisition (hub RS232 and hub ethernet)



Impactors

Filters

Aethalometer

GRIMM OPC

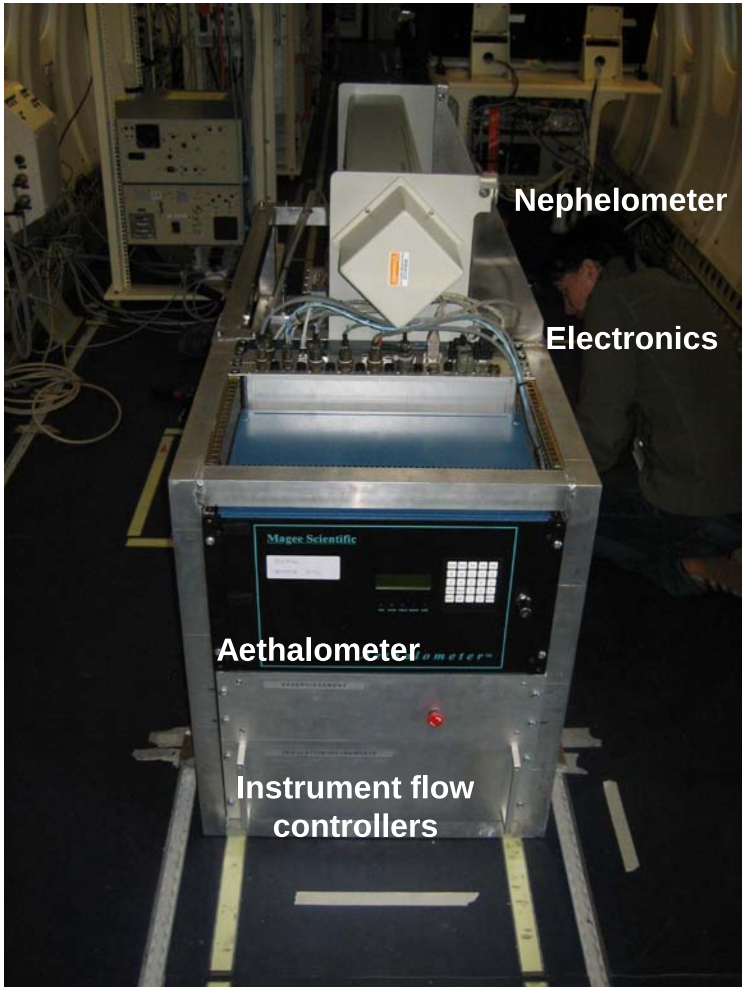
Instrument pump (Riestchle VLT15)

Instrument flow controllers

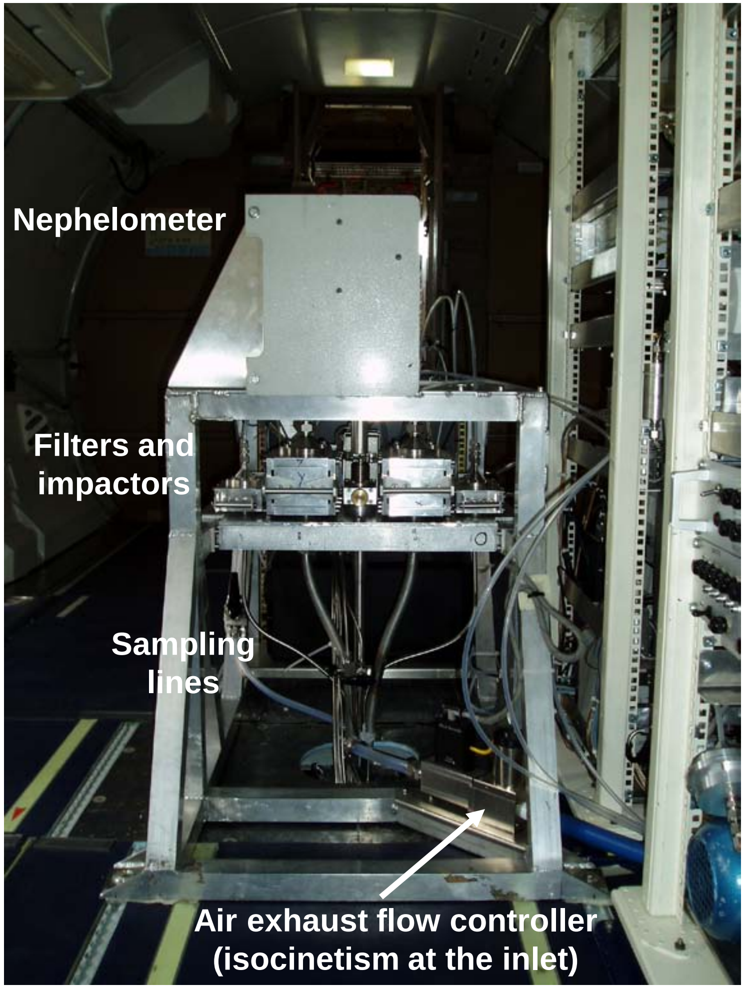
Aluminum AG5 (5083), 2 mm depth
L x W x H 1745×570×680 mm
Weight (empty) 17 kg
Weight (with instruments) 162 kg
WEIGHT CAN BE REDUCED!

Instrumented rack (2)

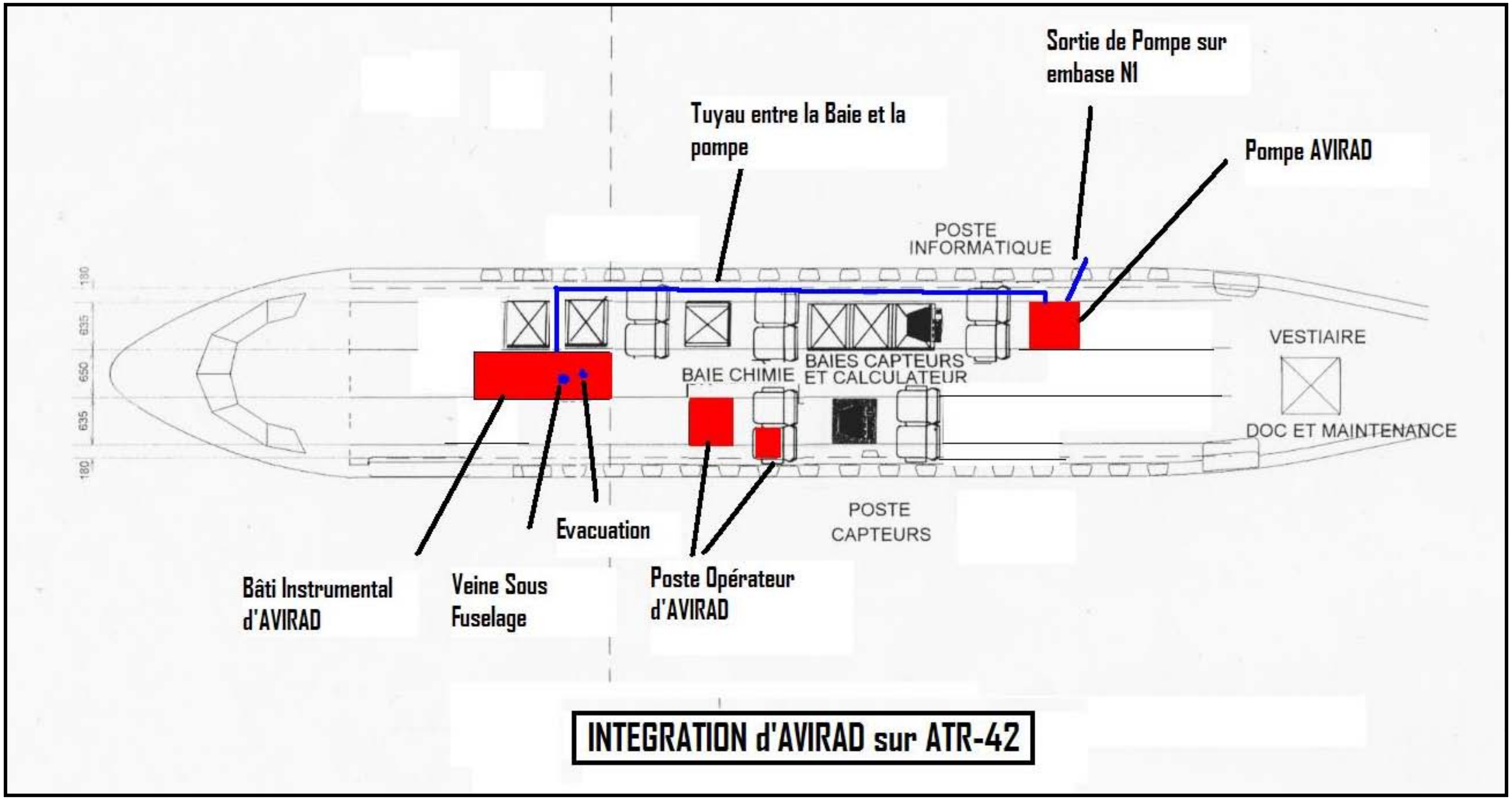
View from the front of the cabin



View from the rear of the cabin



Integration onboard the F/ATR-42



SAFIRE web site www.safire.fr; EUFAR web site www.eufar.net

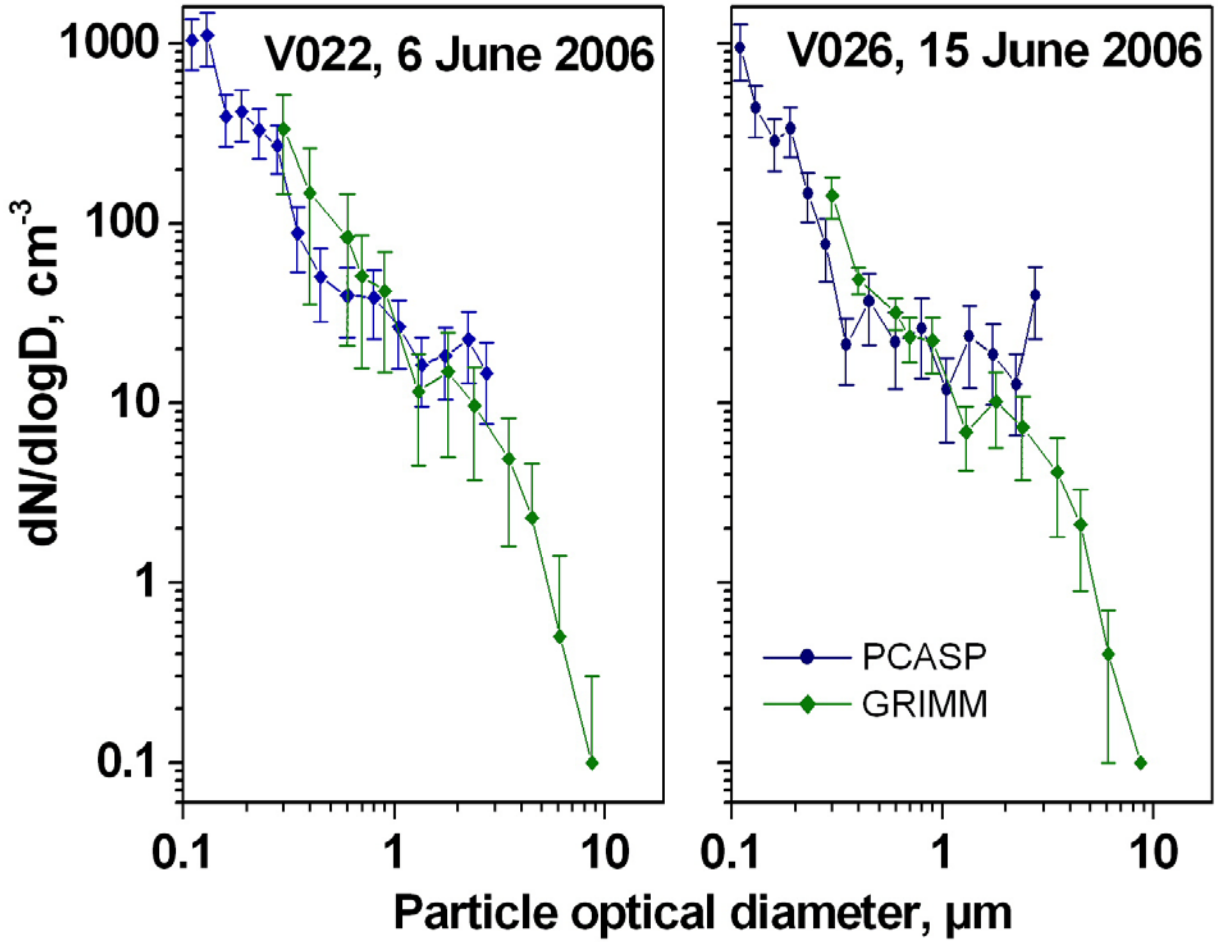
The inlet is located below the aircraft

Validation studies: field measurements

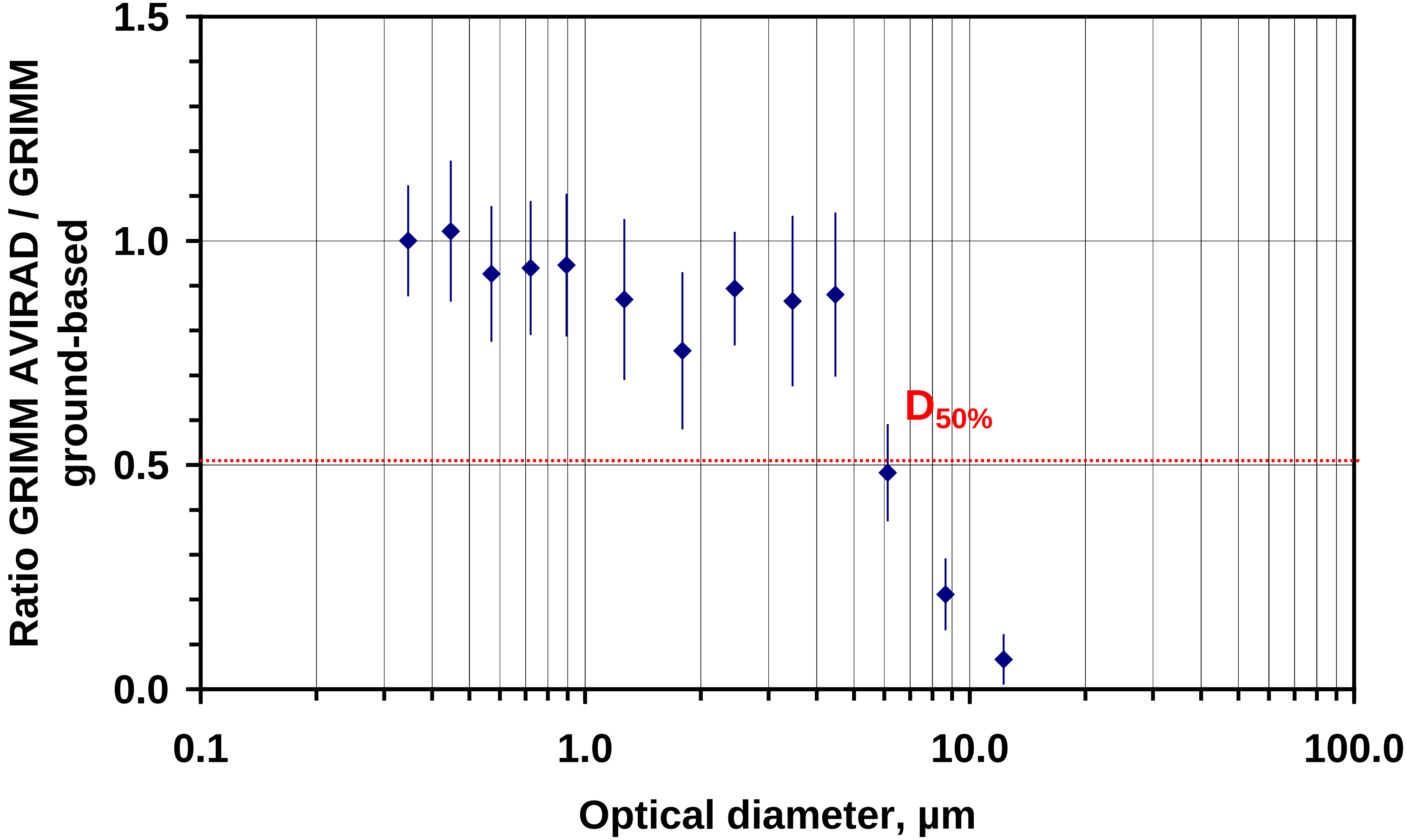
Heterogeneous distribution (horizontally and vertically)

- ▷ 20 flights in June-July 2006
  - ▷ Compare airborne measurements (GRIMM OPC vs. PCASP, 9 flights)
  - ▷ Compare ground-based and airborne measurements (number size distribution and elemental composition, 1 flight only)

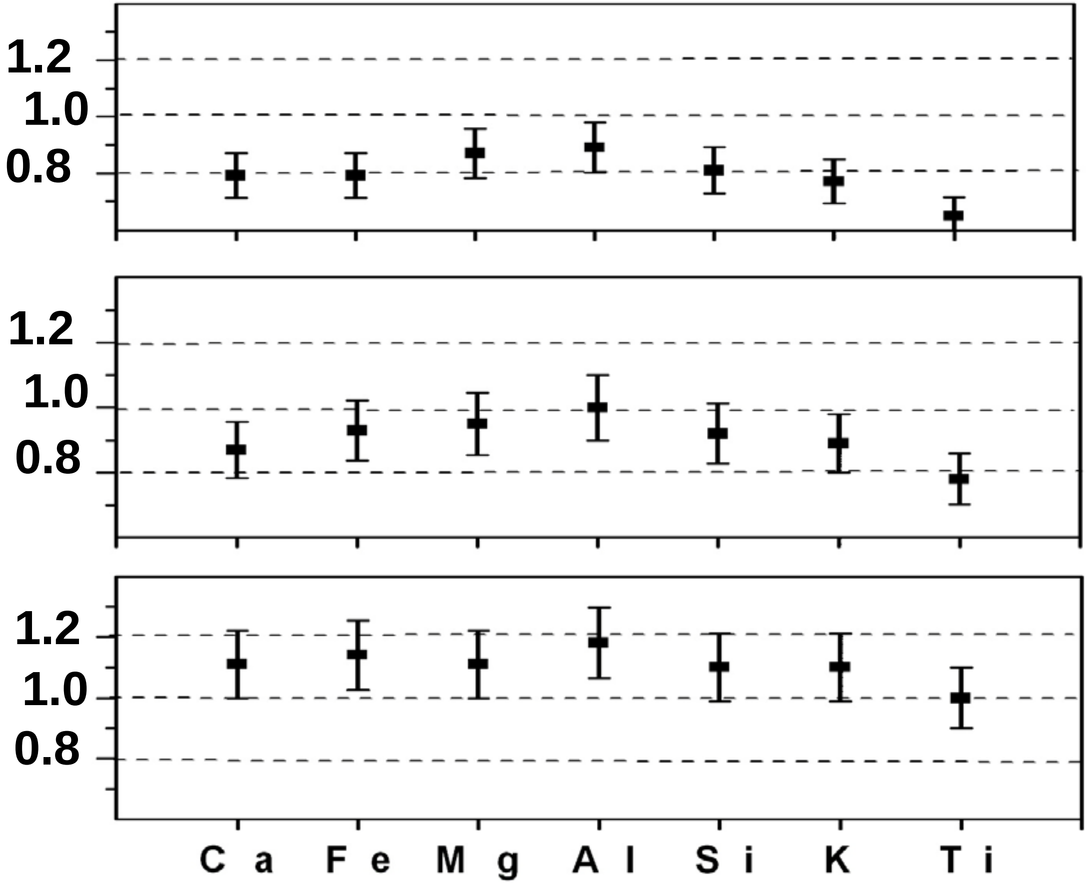
Comparison airborne measurements: GRIMM OPC vs. PCASP



Comparison ground-based vs airborne: GRIMM OPC number size distributions



Comparison elemental concentrations (bulk filter sampling + XRF analysis)

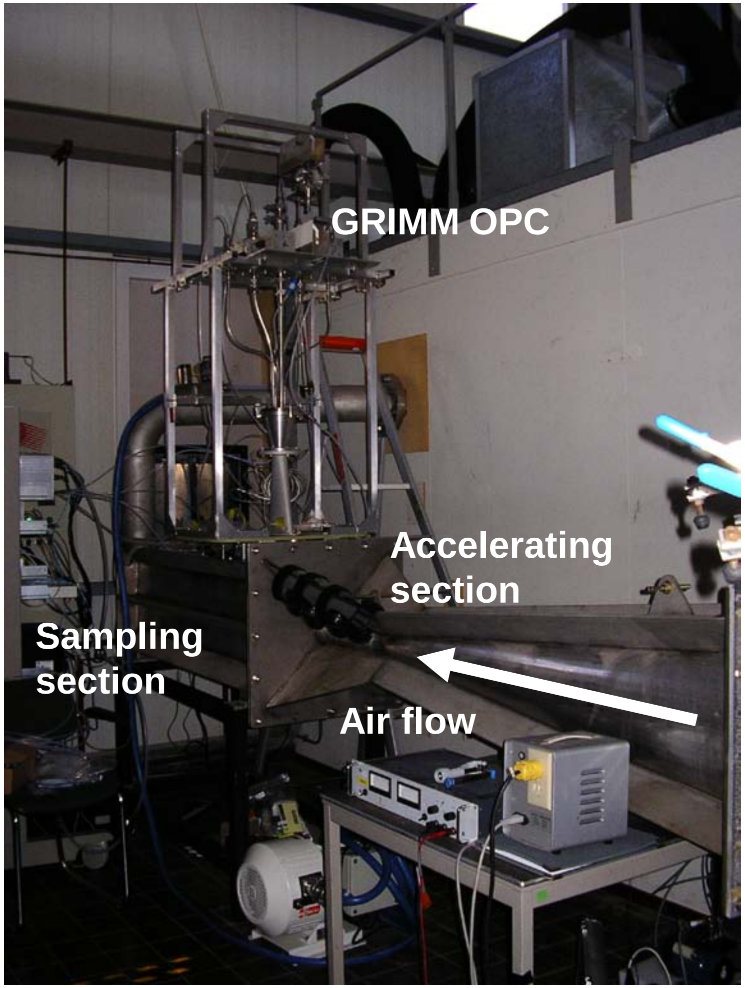


Ratio Aircraft/TSP high

Ratio Aircraft/TSP low

Ratio Aircraft/PM10

Wind-tunnel validation



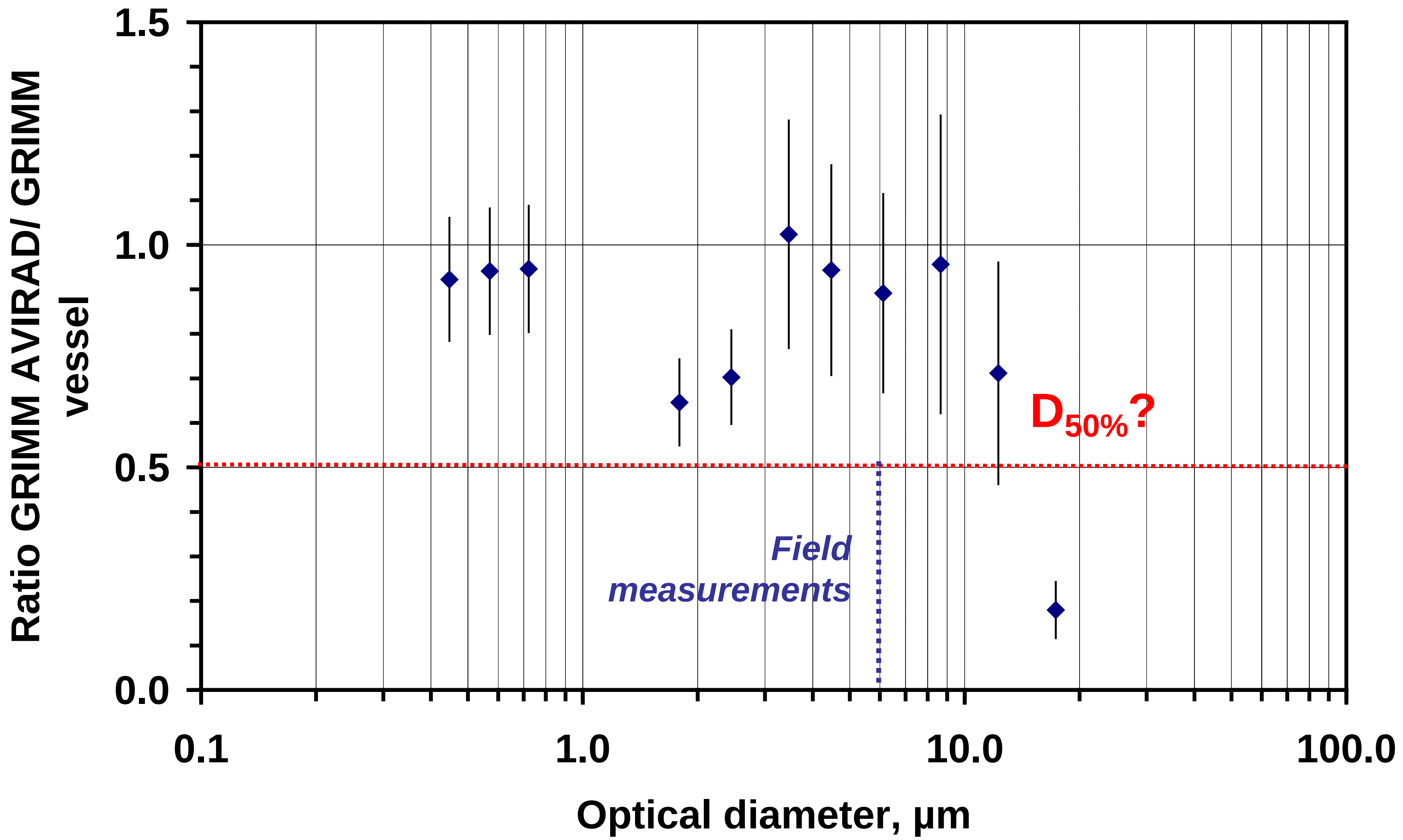
• June 2008, Energy Research Foundation (ECN), Petten, The Netherlands

• Air speed > 80 m s-1 (working 95 m s-1)

• Generation: PSL particles (Duke Scientific)
  • polydispersed (<35 µm)
  • mono-dispersed (0.6-11 µm diameter)

• Detection: various GRIMM OPCs behind the various sampling lines of AVIRAD and in the main flow (reference)

First data analysis (preliminary)

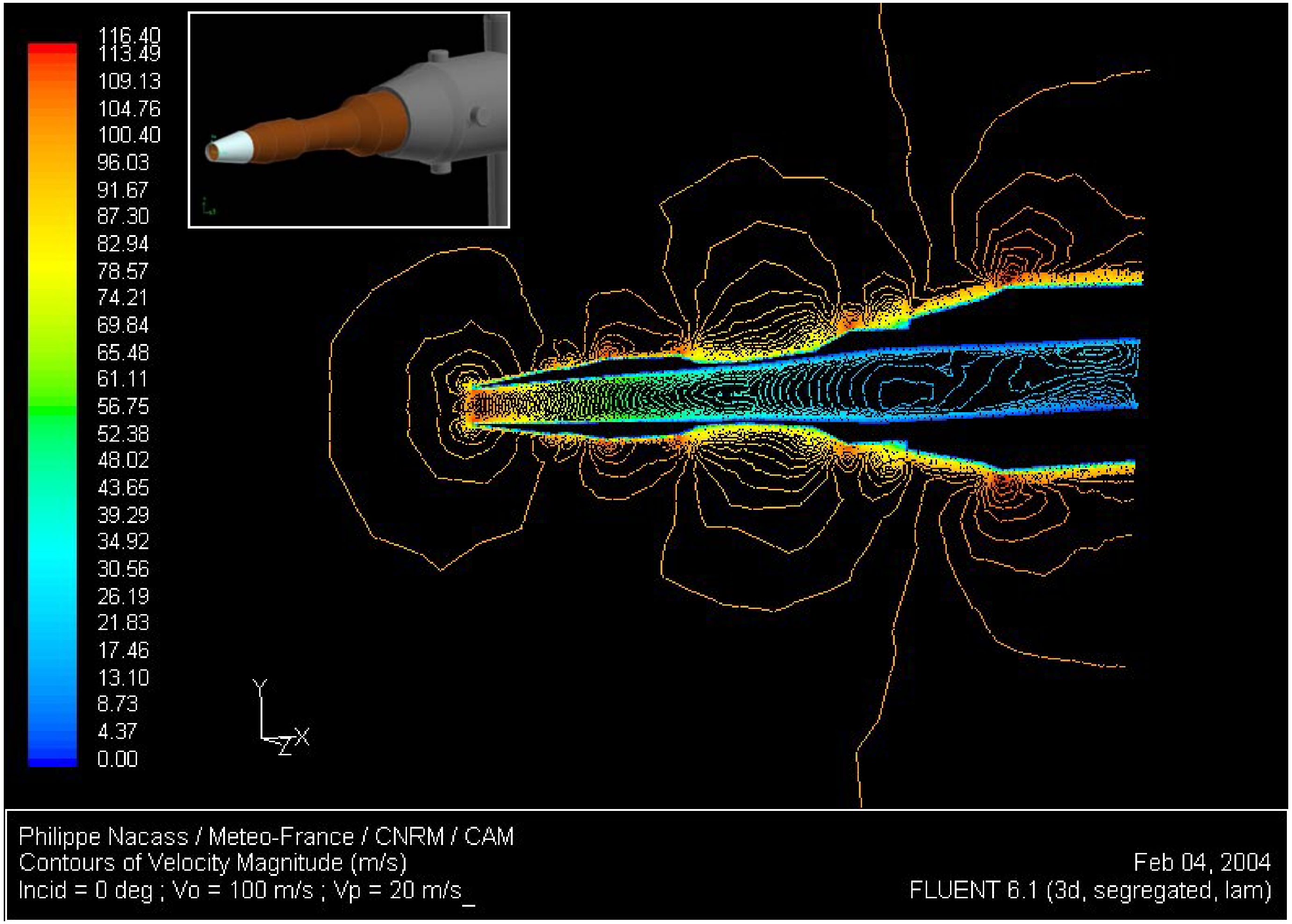


Summary of conclusions and future plans

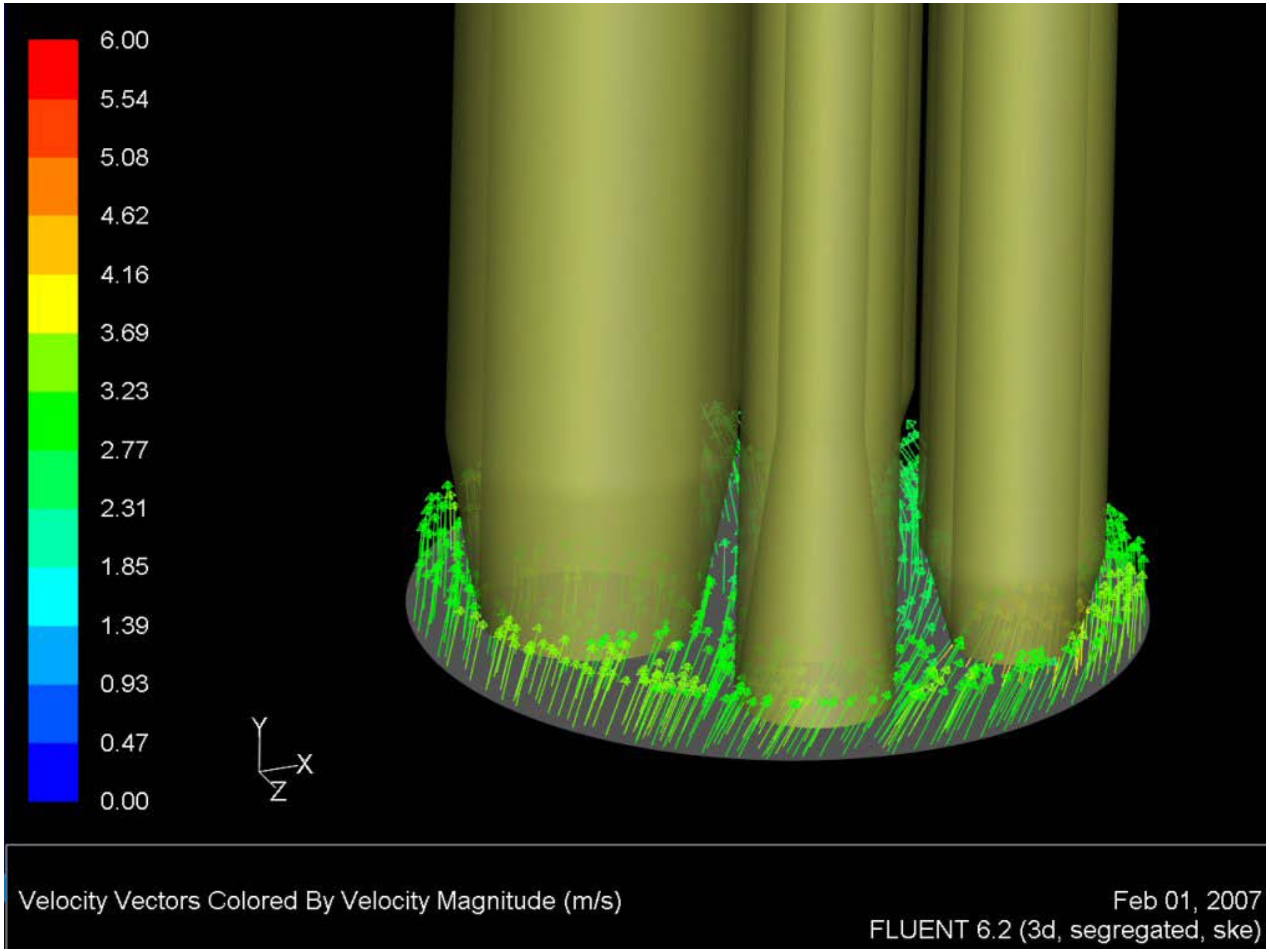
- ▷ First analysis of measurements by the AVIRAD aerosol sampling system seems encouraging, even for large particles
- ▷ "Cheap development" (110 k€ total cost including instruments, 45 k€ for inlet and rack), needs improvement
  - – Reduce the influence of the exhaust pump on the air flow
  - – Straighten some of the sampling lines
  - – Reduce the rack size and weight
  - – Add/change instrumentation? (there are ~16 $m^3\ h^{-1}$ still available)
- ▷ Future plans
  - – Continue data analysis (and hopefully publish the data!)
  - – Field campaign: the CHARMEX experiment in western Mediterranean (spring-summer 2011), study of the physical-chemical and optical properties of mixed mineral dust

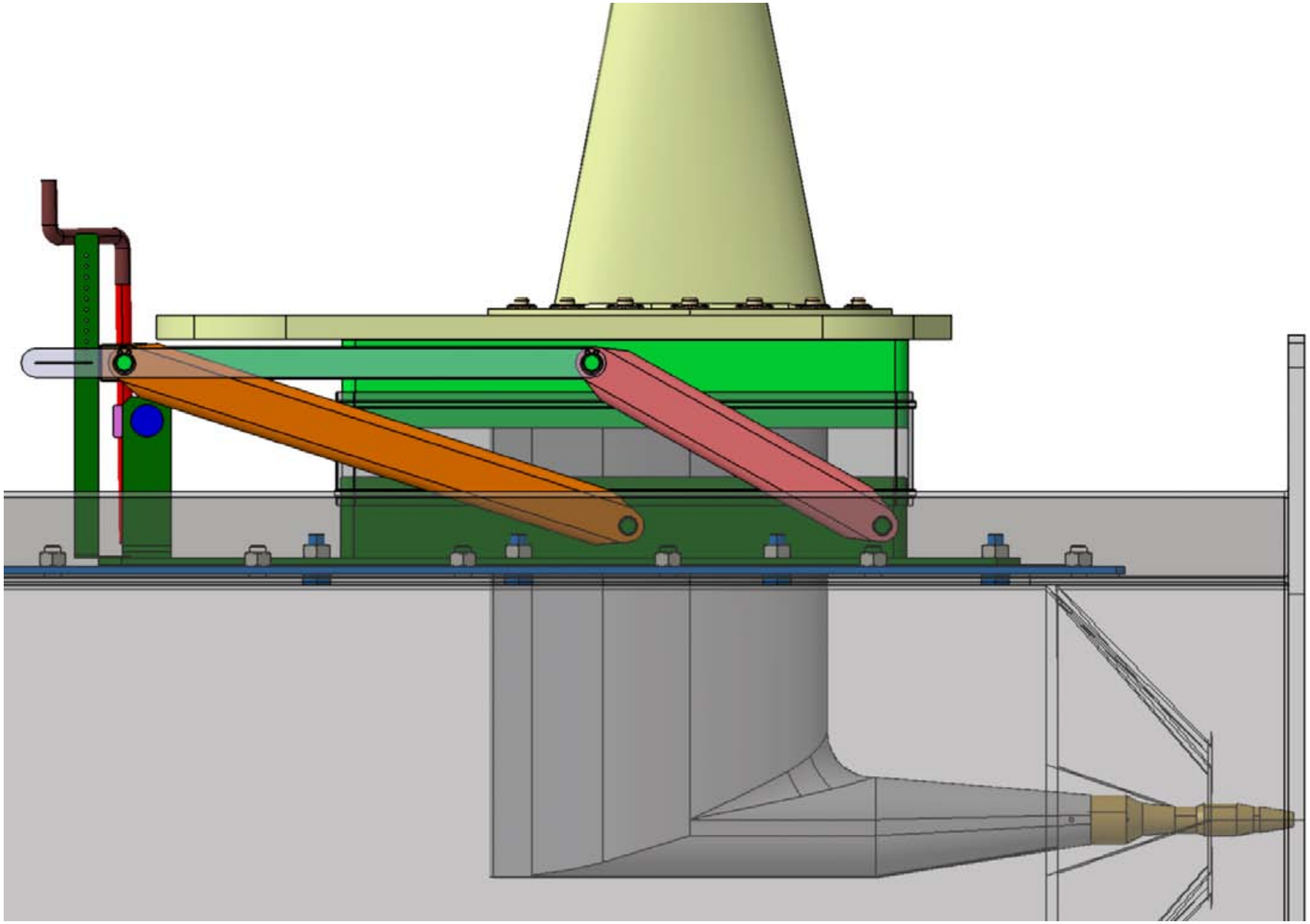
Thank to John Ogren, Greg McFarquhar and Beat Schmid for invitation and support!

Flow simulations (1)

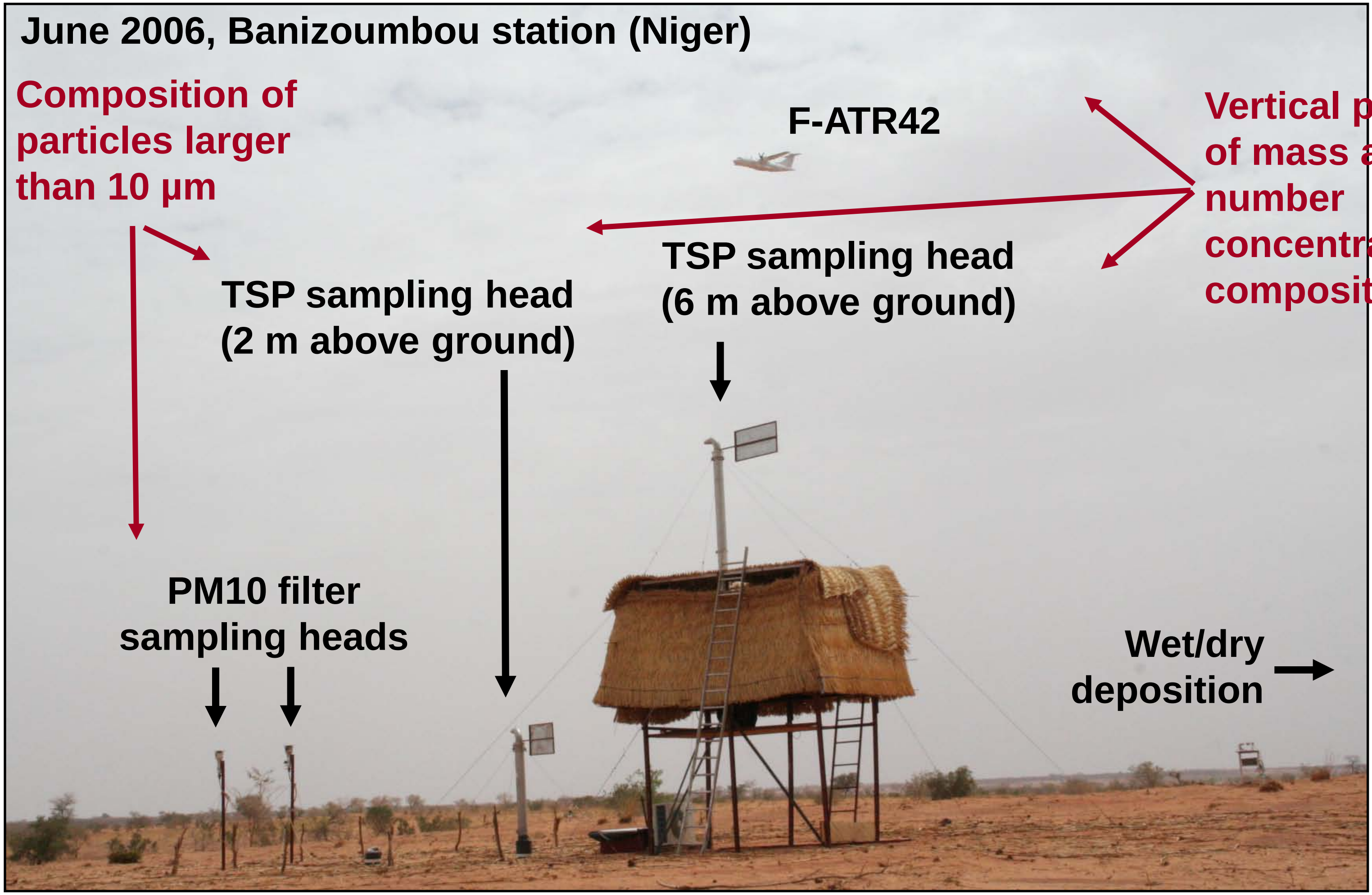


Flow simulations (2)

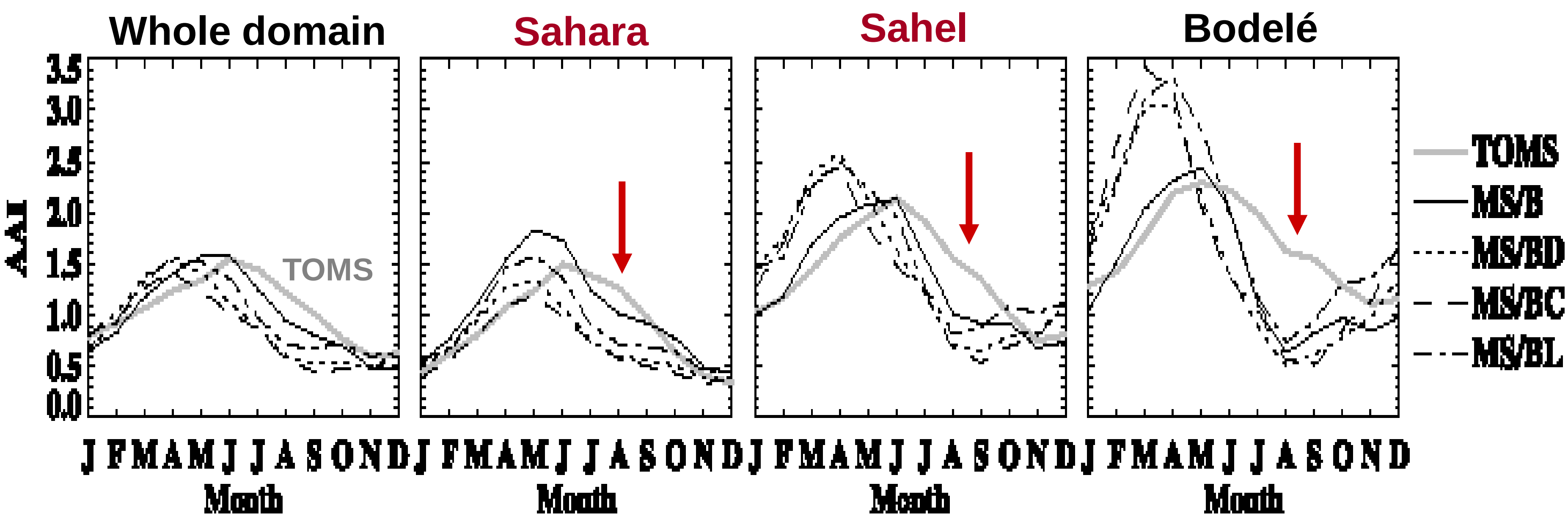




Observational strategy



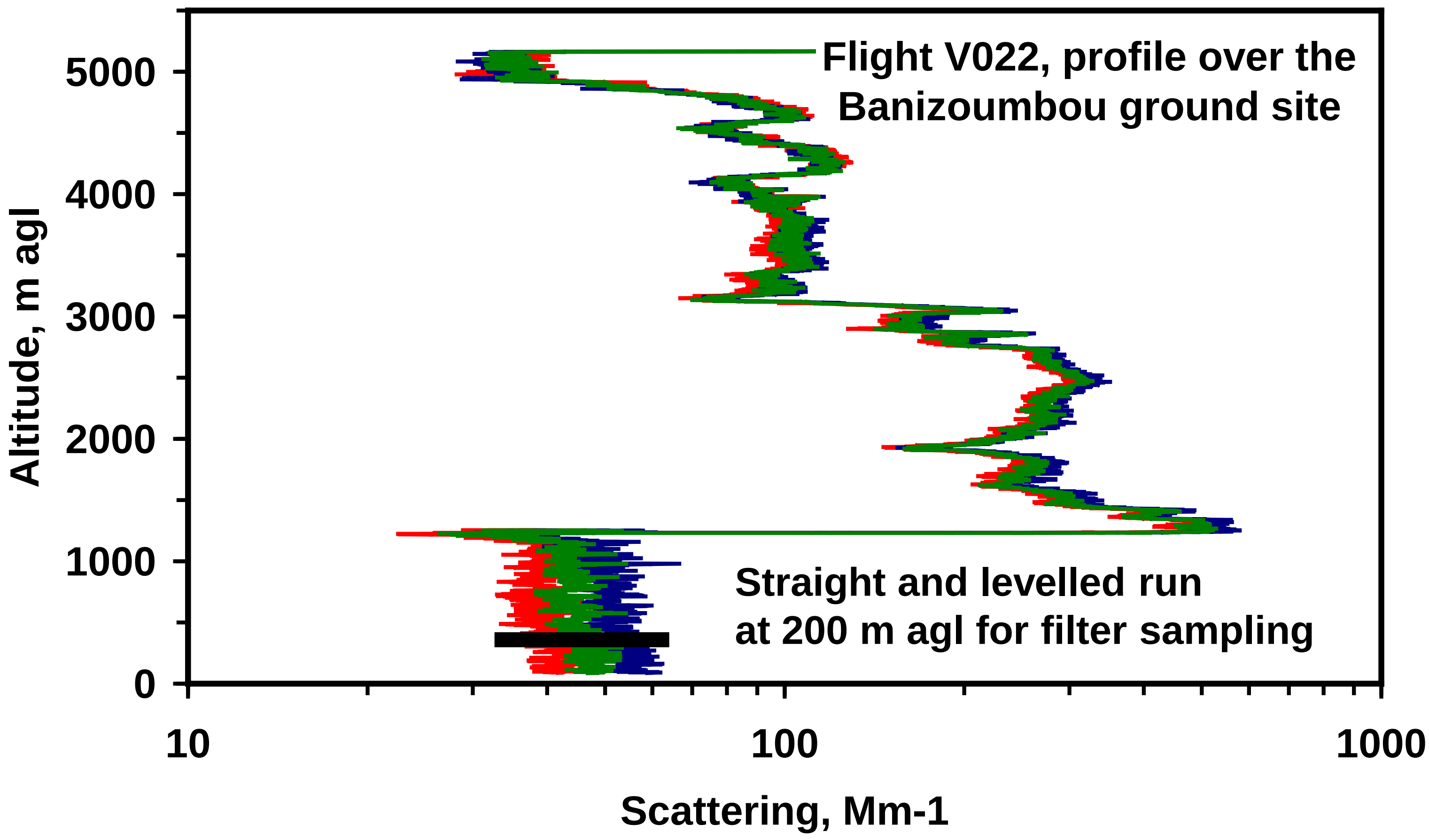
Uncertainties on African dust emissions



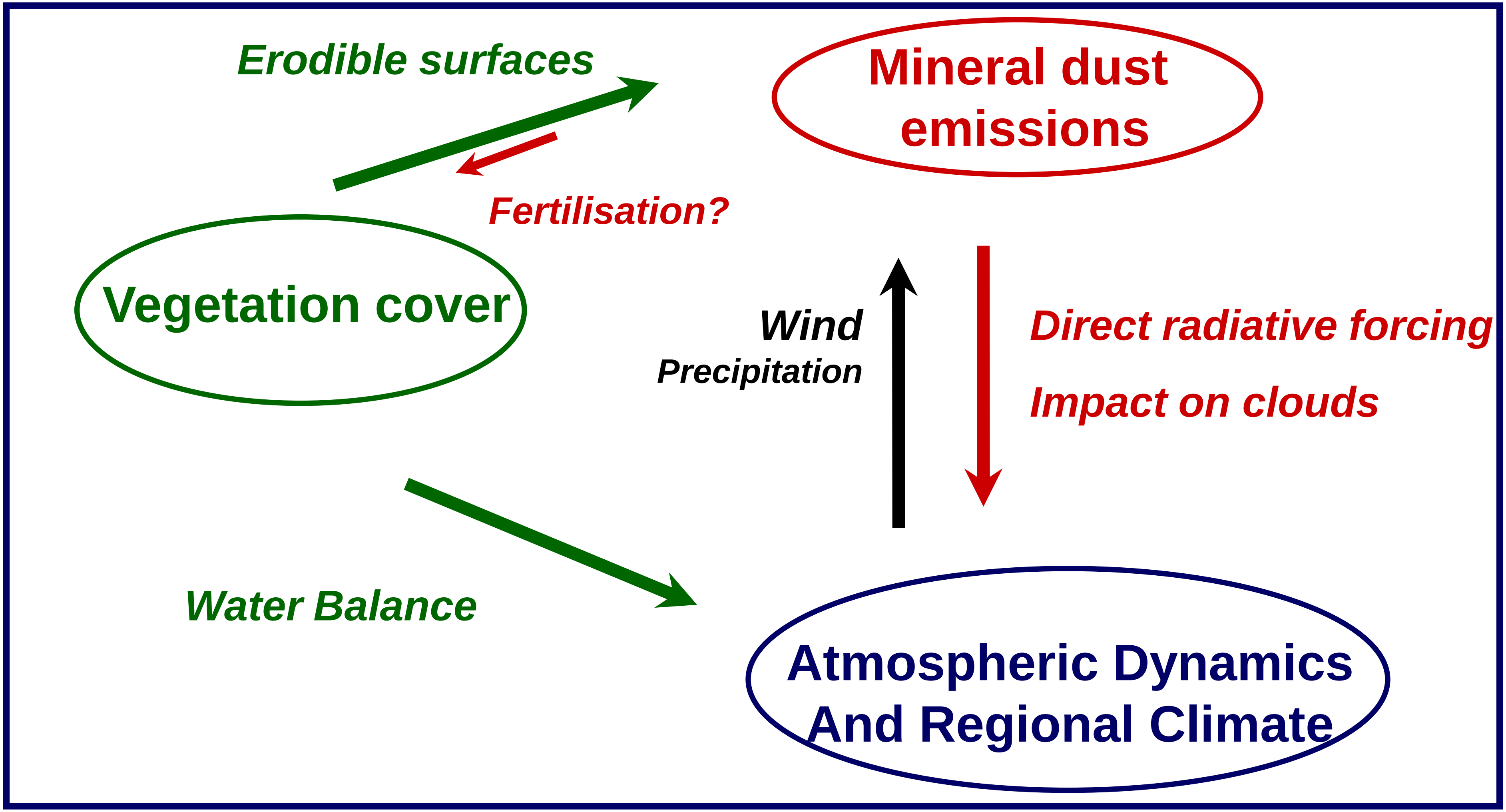
Yoshioka et al. 2005

- The seasonal cycle of mineral dust over western Africa is not correctly reproduced by global models
- The bias is attributed to the underestimation of mineral dust emitted by mesoscale convective systems

Comparison ground-based and airborne measurements: only one suitable flight



Climatic impact of mineral dust in Western Africa



Sahelian Dust Transect (SDT)

Mbour

LOP
AERONET

EOP
PM10 concentration
Vertical profile
Dry/wet deposition

UK BAe146
F / ATR42

Cinzana

LOP
AERONET

EOP
PM10 concentration
Vertical profile
Dry/wet deposition

Sahelian dust transect

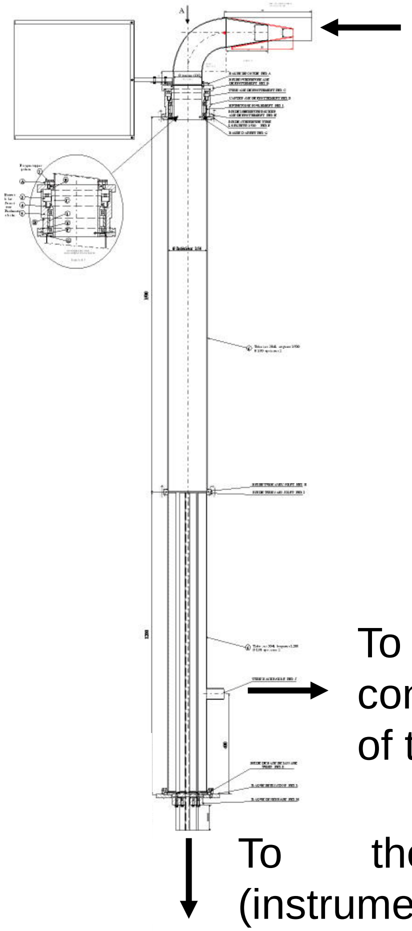
Banizoumbou

LOP
AERONET

EOP
PM10 concentration
Vertical profile
Dry/wet deposition

SOP0, 1, 2
Size distribution
Composition
Optical properties
Radiative fluxes
Particle fluxes
AMF (ARM)

Wind-oriented ground-based inlet



Air in (~50 m3 h-1)

To the main volume flow controller and pump (~ 2/3 of the flow)

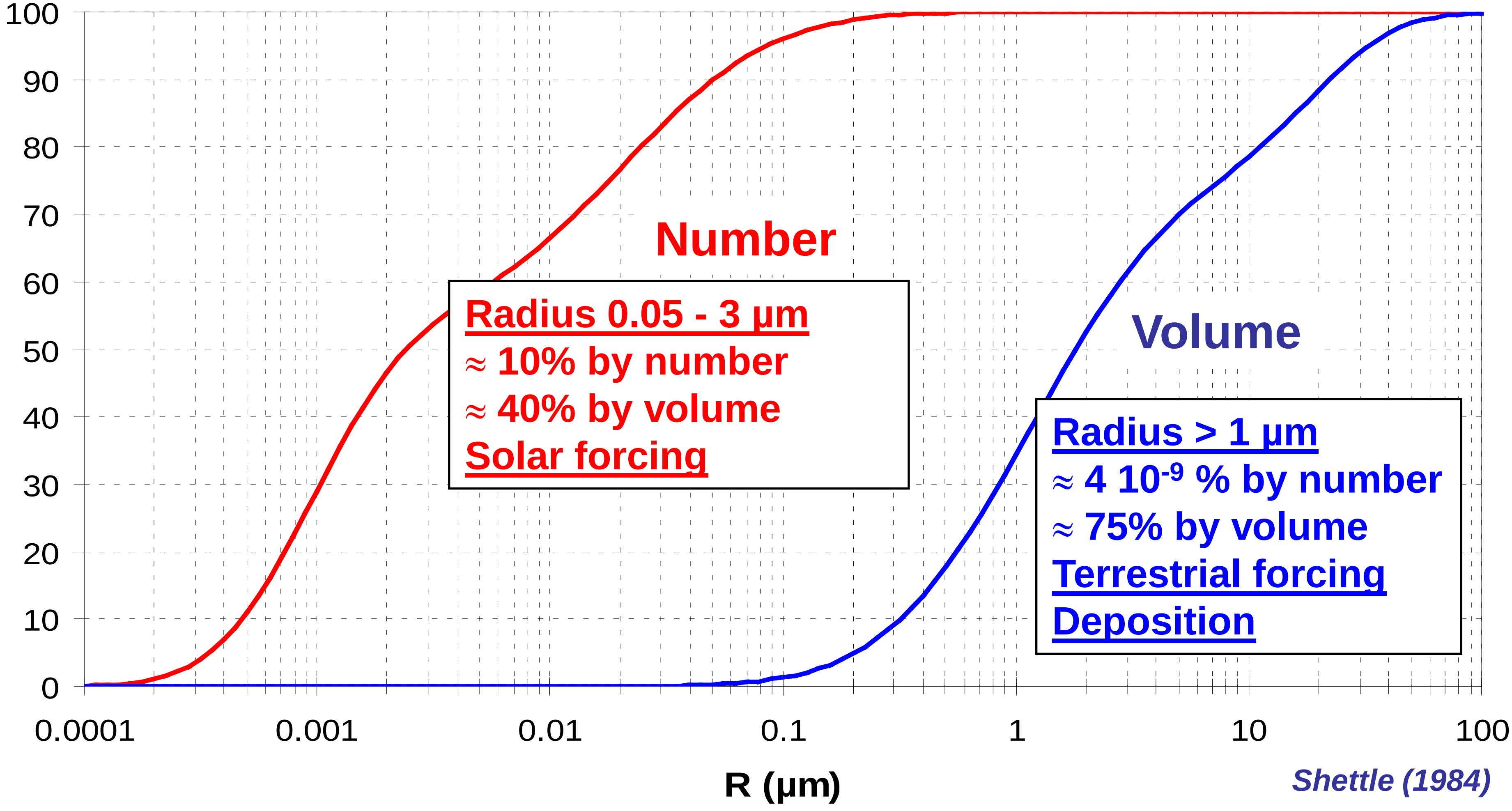
To the sampling lines (instruments + flow controllers + pump)

Rajot et al., JGR, 2008

Requirements (2)

- ▷ **Operate instruments with different flow rates and inlet diameters**
- ▷ **Simultaneous online measurements and filter sampling, necessity of isolating the different sampling lines**
- ▷ **Sampling system operated onboard the ATR-42, the tropospheric aircraft of the French fleet**
  - ▷ large aircraft, cohabitation with other instruments
  - ▷ not available at the time when the instrument was being developed
    → no clear specification for the assembly and certification of the rack
    → uncertainty on final costs
  - ▷ based in Toulouse (~1000 km from Paris)
    → all should fit in one rack so to reduce the integration time and costs
- ▷ **Could be run by one operator only**

Mineral dust size distribution (emission)



Shettle (1984)

Dust uplift by a convective system

Niamey (Niger)
30 May 2005

- ▷ How much dust is emitted (net balance)?
- ▷ Which are their properties?

Why mineral dust?

- ▷ **40% of the total aerosol mass at the global scale (IPCC, 2007)**
  - ▷ likely large but not well quantified fraction emitted from semi-arid areas which undergo rapid demographic growth and are sensitive to climatic feedbacks (western Africa)
- ▷ **20% optical depth at the global scale, 100% over source areas**
- ▷ **Multiple impacts, but large uncertainties due to poor knowledge of**
  - ▷ concentration fields (emission)
  - ▷ physico-chemical properties (composition, size and shape)
    - ▷ size distribution extends over various orders of magnitude (fractions to tenth of microns)
  - ▷ optical properties (scattering/absorption)