The Counterflow Virtual Impactor (CVI)

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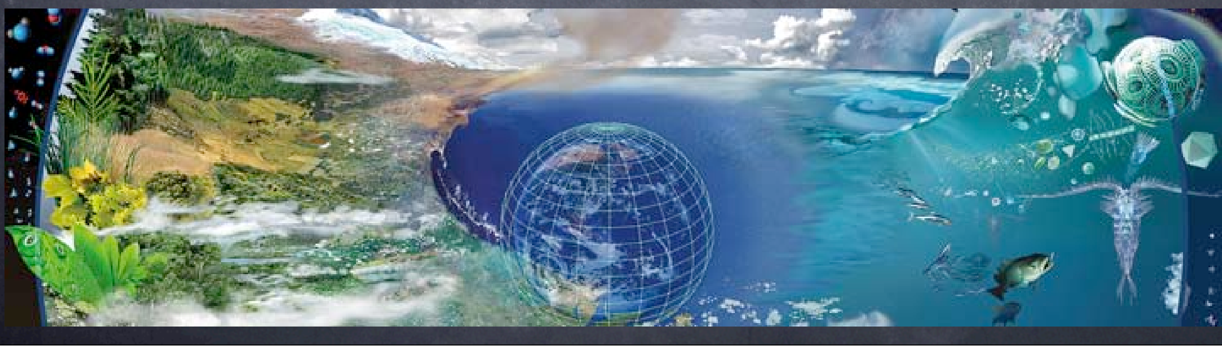
Executive Director, IGBP



Outline

- What questions stimulated the development of the CVI?
- Basic principles
- Example results
- Ground-based examples
- Airborne examples

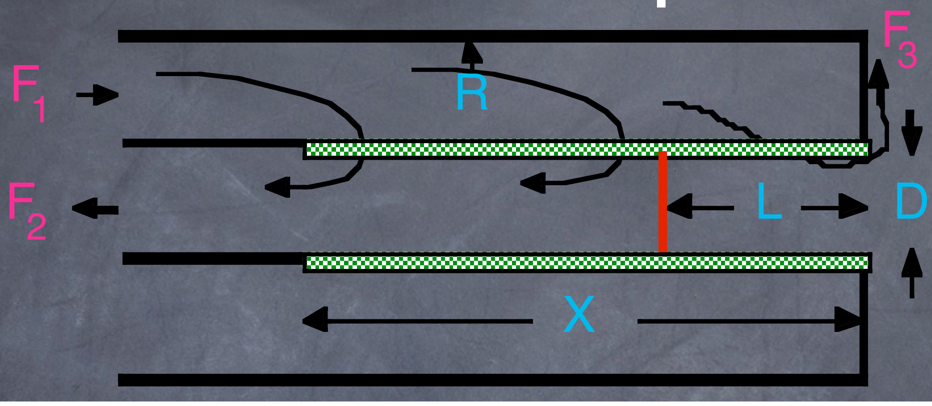
The big question: Which particles form droplets and ice crystals, and which do not?

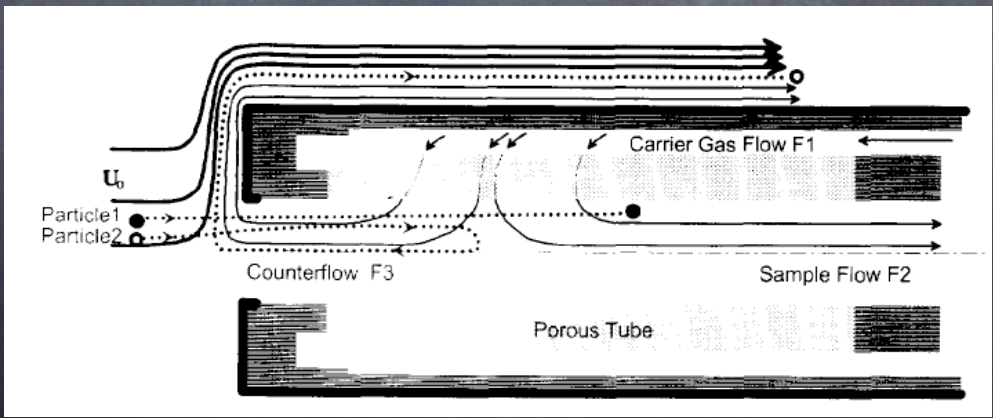
A Very Useful Number

$$Stk = \frac{\tau V}{L} = \frac{\rho_p d_p^2 V}{18 \mu L}$$

Small Stokes numbers: particles behave like gases
Large Stokes numbers: particles behave like rocks

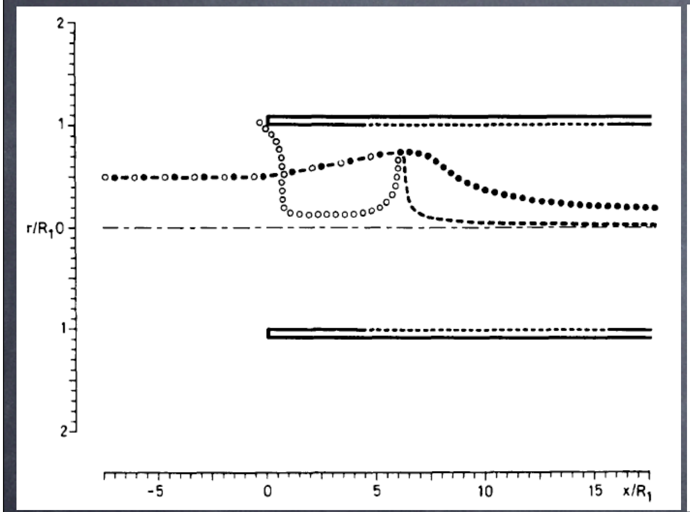
Basic Principles

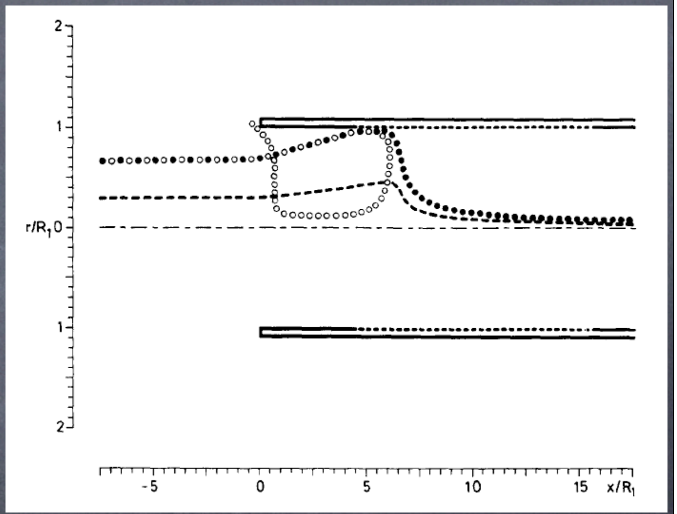




Lin & Heintzenberg, J. Aerosol Sci. 26, 903-914, 1995

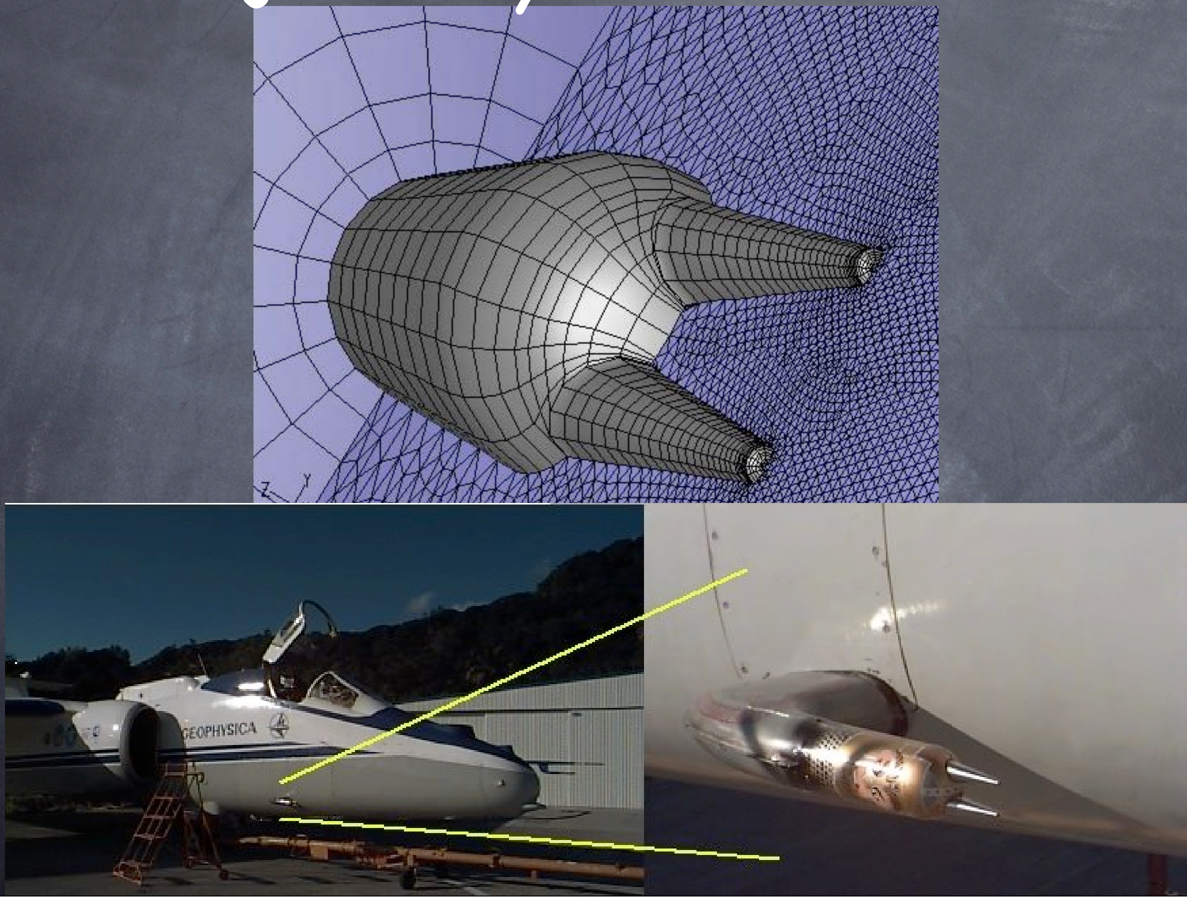
Basic Principles



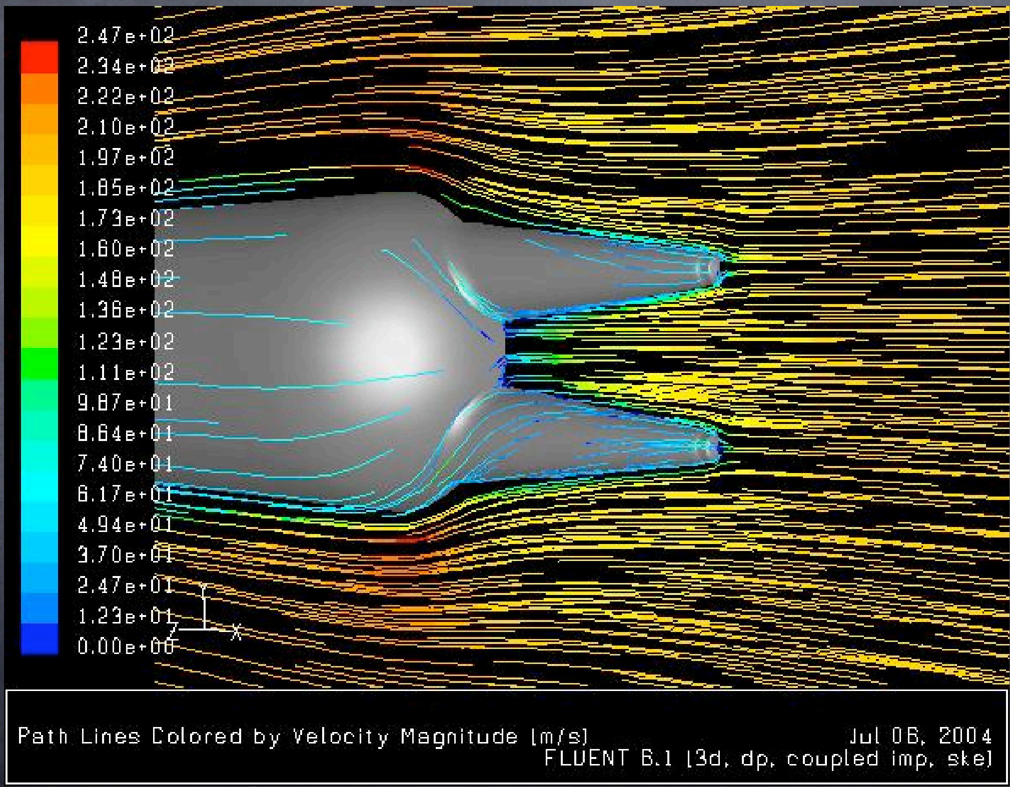


Lin & Heintzenberg, J. Aerosol Sci. 26, 903-914, 1995

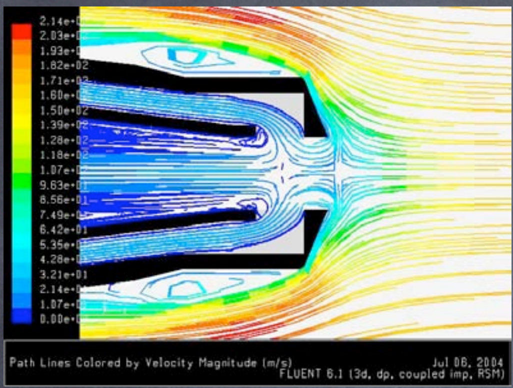
Trajectory calculations



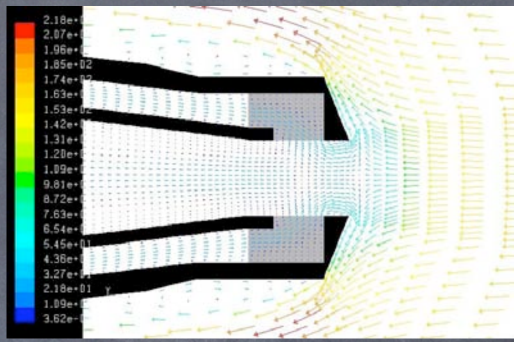
Exterior flow

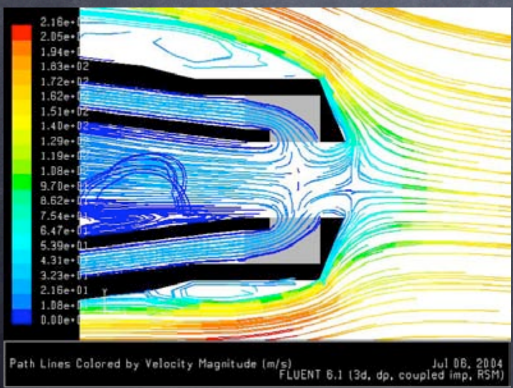


Interior flow

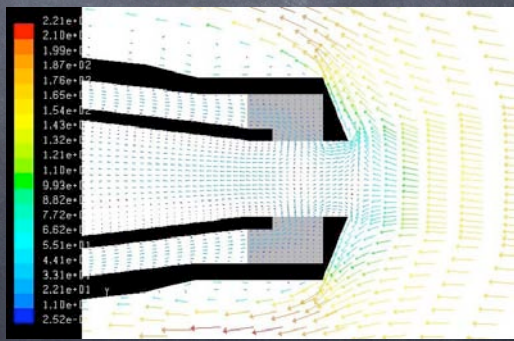


0°

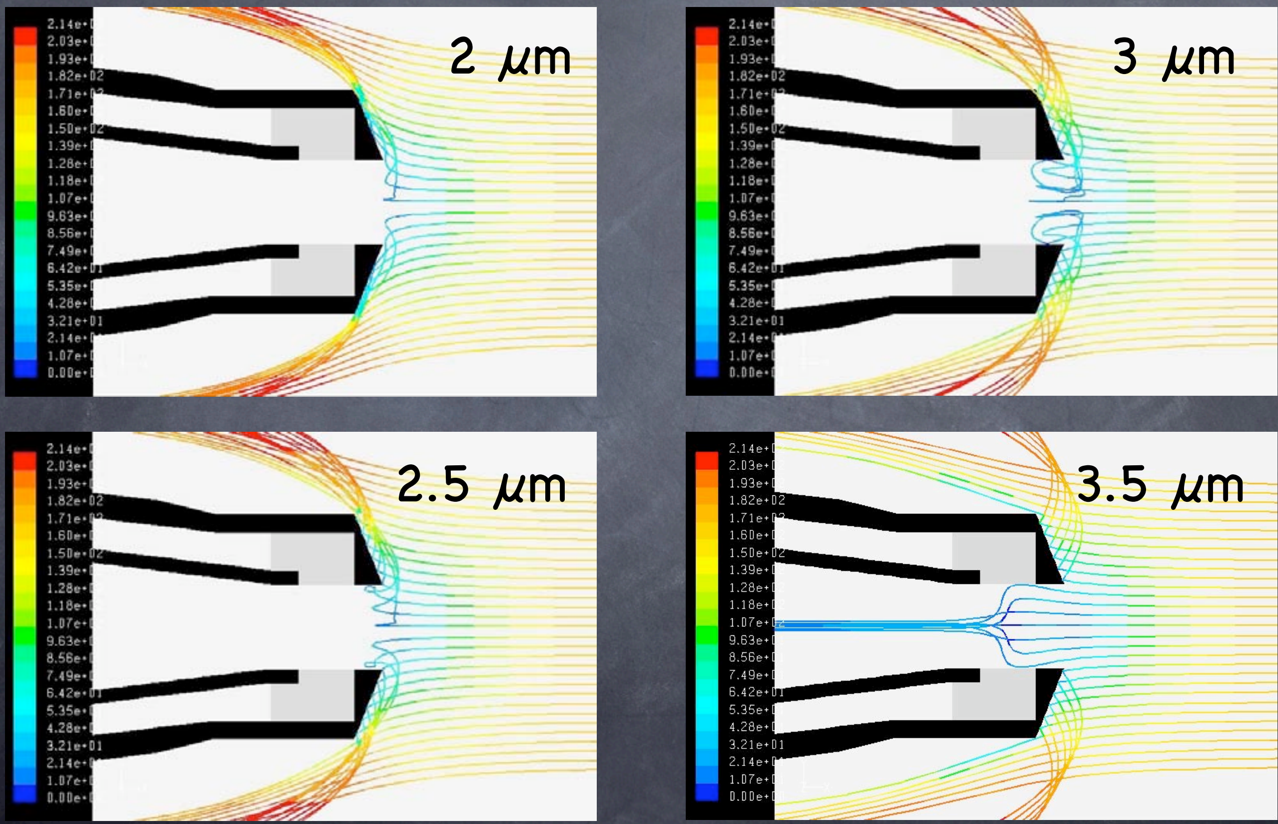




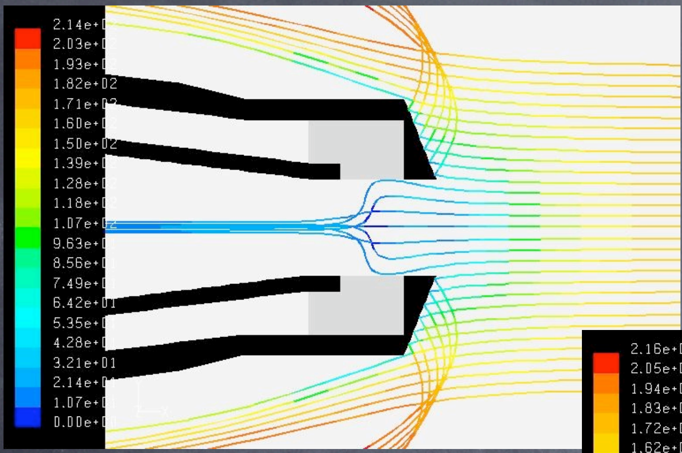
5°



Interior trajectories

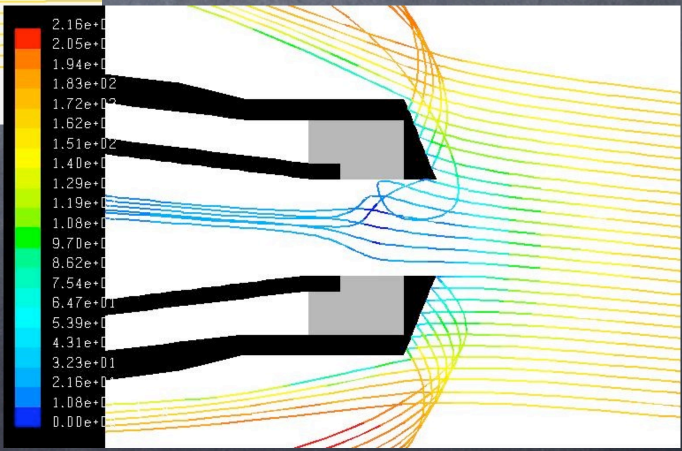


Interior trajectories

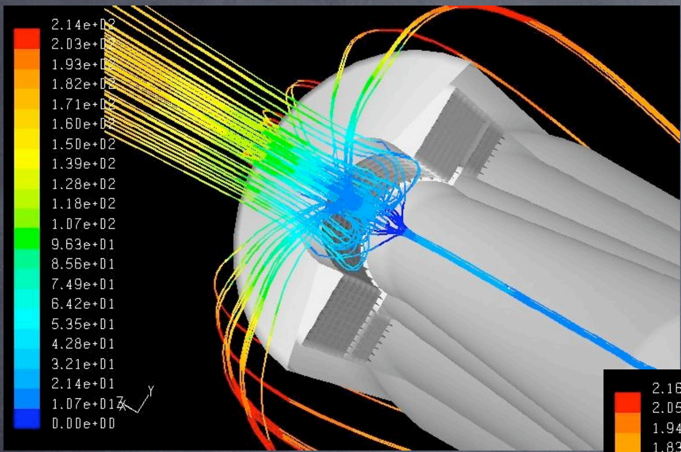


0° attack angle

5° attack angle

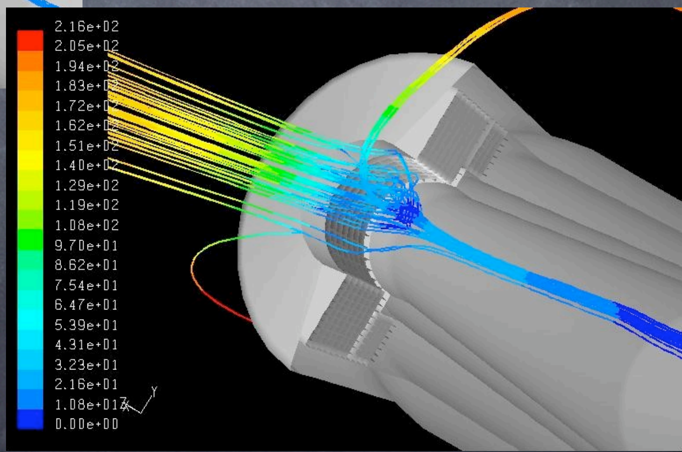


Trajectories

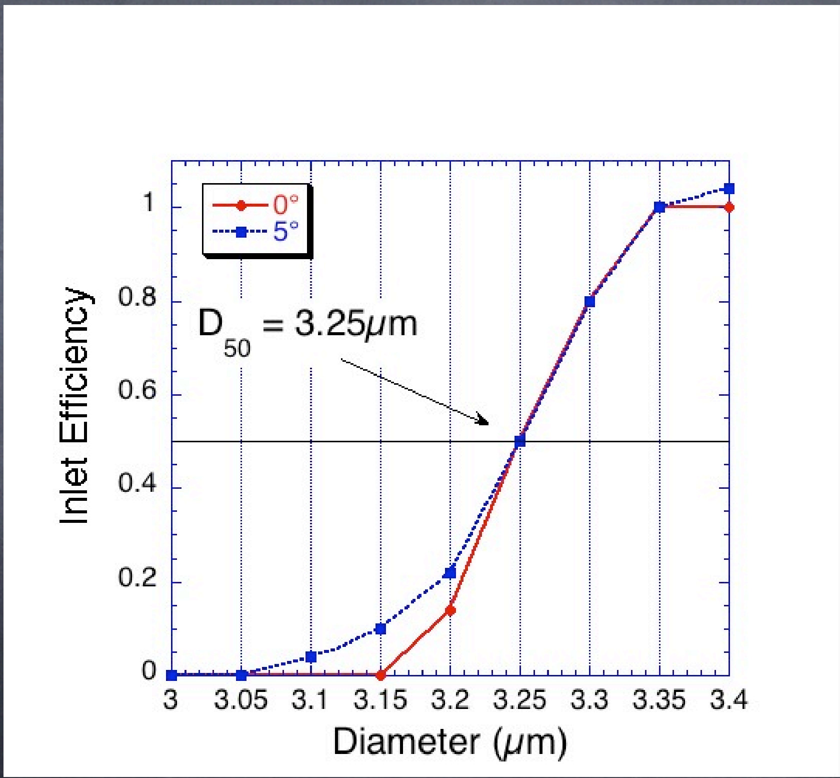


3.5μm, 5° attack angle

3.5μm, 0° attack angle

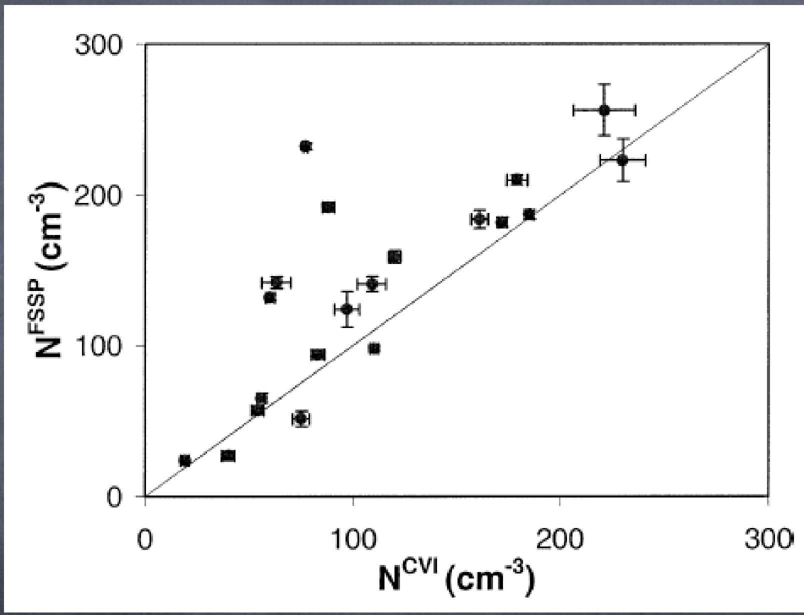


Sampling efficiency



CVI-FSSP Comparison

UK
C-130
+
UW
C-131



Glantz, P., K. J. Noone, and S. R. Osborne, 2003: J. Atmos. Ocean Technol., 20, 133-142.

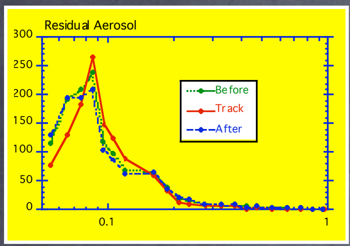
Example measurements

Direct	Indirect
CWC N_{res} SD_{res} $\sigma_{s,res}$ $\sigma_{a,res}$ Resid. Chem.	M_{res} Mass conc. in droplets Mass avg. D_d Particle size determining N_d Conc., comp. vs size

Airborne examples

INTACC
INCA

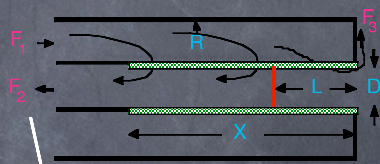
Snoopy ACE-2, INTACC Payload



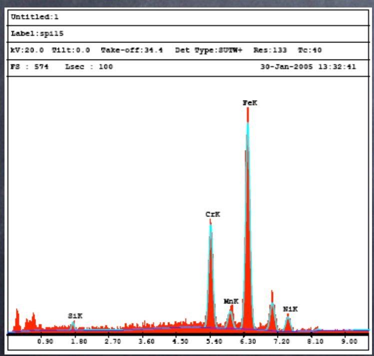
PCASP

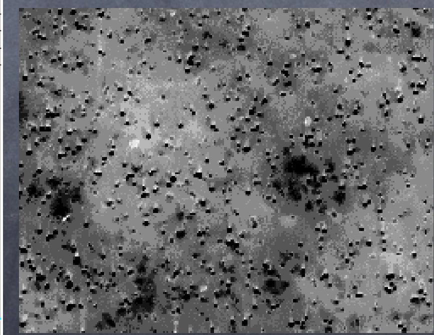
Condensation Particle Counter (CPC)

Cloud Droplet Residual Particles



Condensed water content (CWC) with Lyman-alpha hygrometer





Filter/SPA

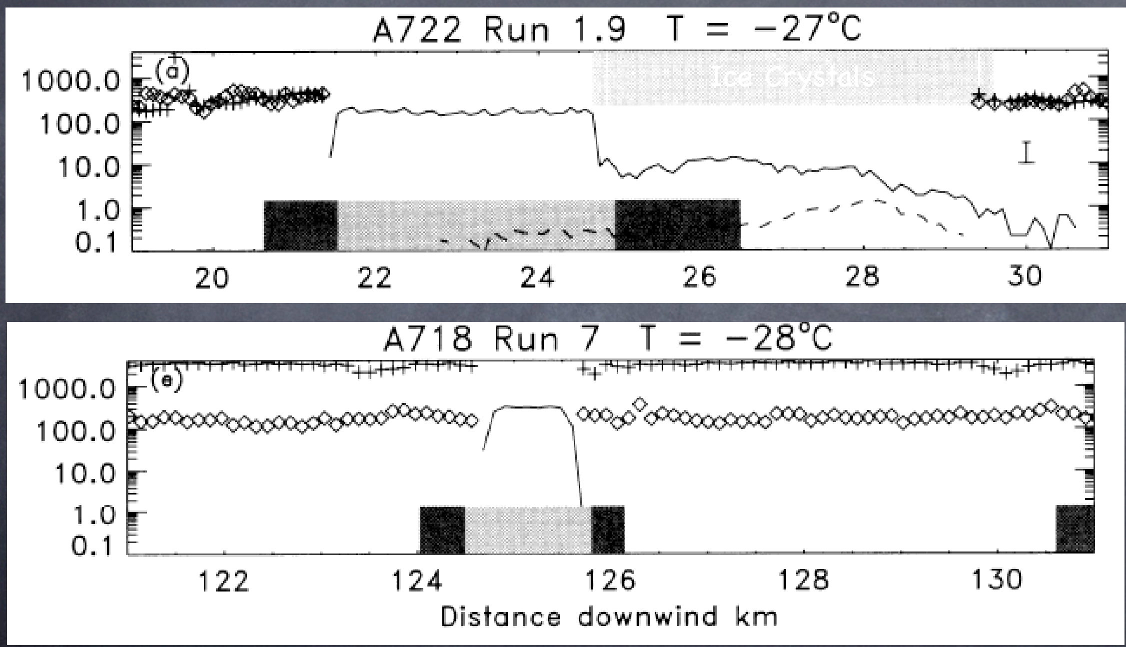
INTACC chemical analysis

- Ice crystal residuals collected on Nuclepore polycarbonate membrane were analyzed with SEM-EDAX (*Energy dispersive x-ray analysis*)
- Only elements with atomic number $Z \geq 11$ (Na) were considered in this study
- Only particles ≥ 100 nm were analyzed
- Groups identification: Hierarchical cluster analysis was applied to the X-ray intensities

Orographic supercooled clouds

- Low N scavenging fractions (≤10%)
- N dominated by submicrometer aerosol

Chemical influences on freezing

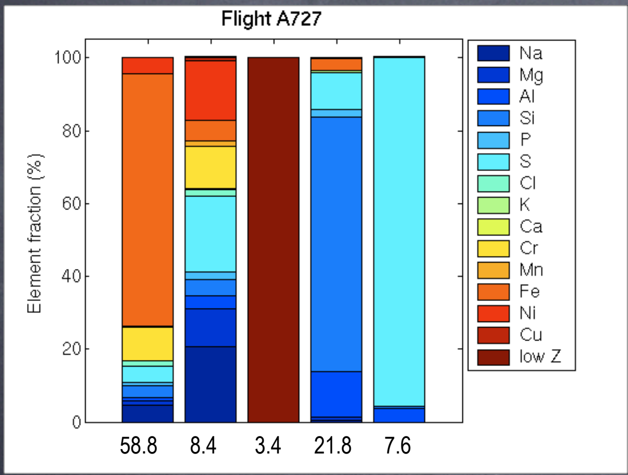


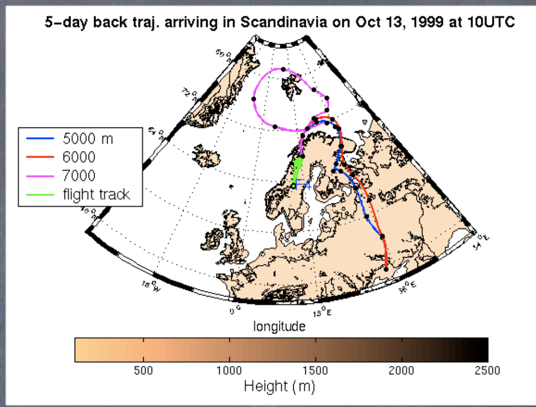
Continental

Marine

Field, et al., Q. J. R. Meteorol. Soc., **127**, 1493-1512, 2001

Continental case

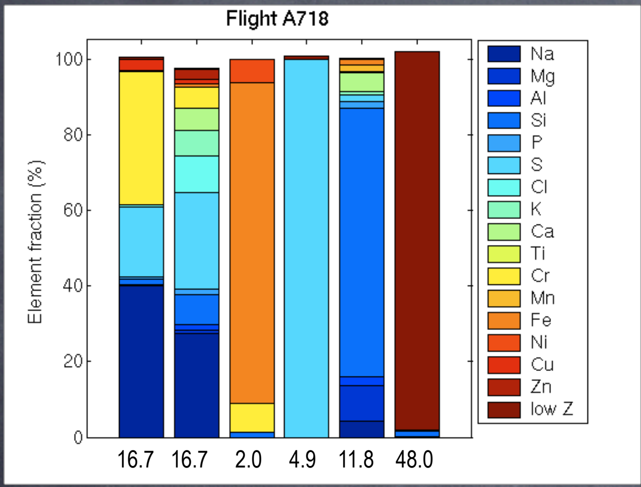


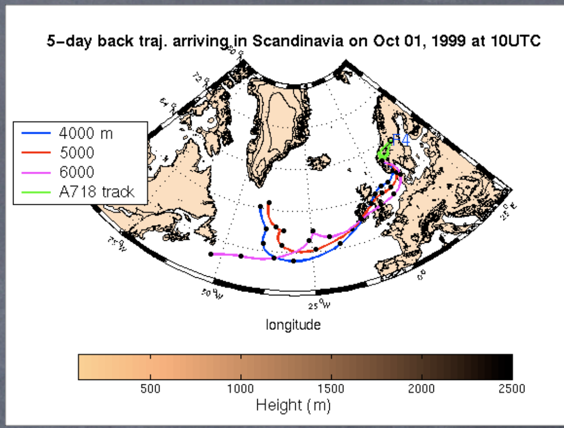


Targino, et al., Atmos. Phys. Chem. 6, 1977-1990, 2006

Cr-Fe:	58.8%
Al-Silicates:	21.8
Mixed mineral:	8.4
S + organics:	7.6
Organics:	3.4

Clean marine case

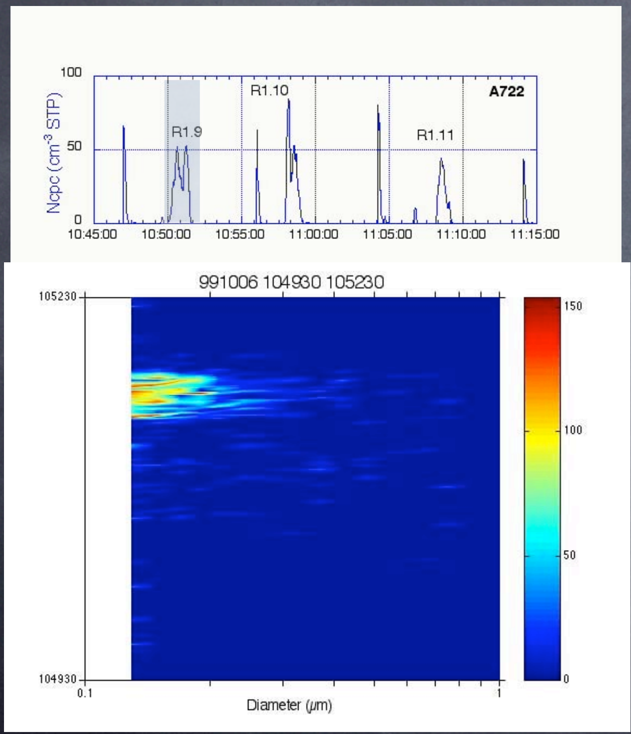




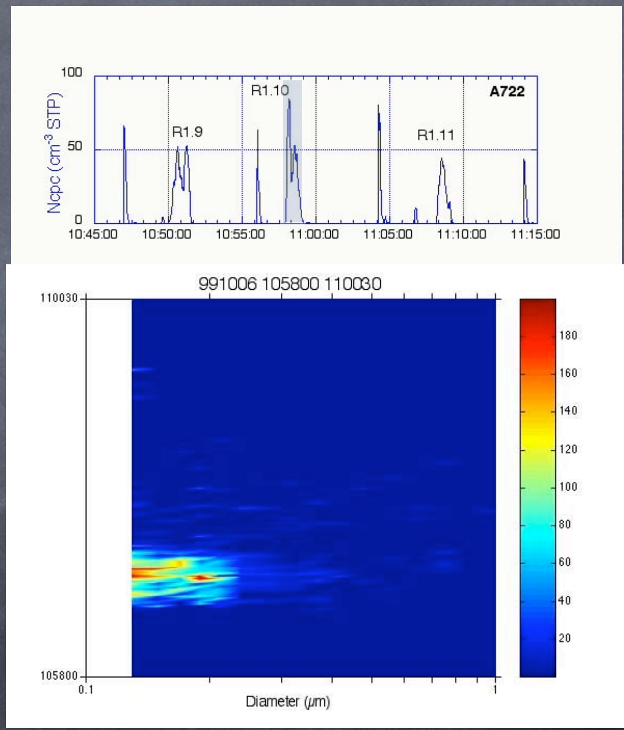
Organics:	48.0%
Aged sea salt:	16.7
Aged Cr-Na:	16.7
Silicates:	11.8
S + organics:	4.9
Fe-rich:	2.0

Targino, et al., Atmos. Phys. Chem. 6, 1977-1990, 2006

Dilute droplets froze first



ice ⇉ liquid Alt = 5760m T = -27°C

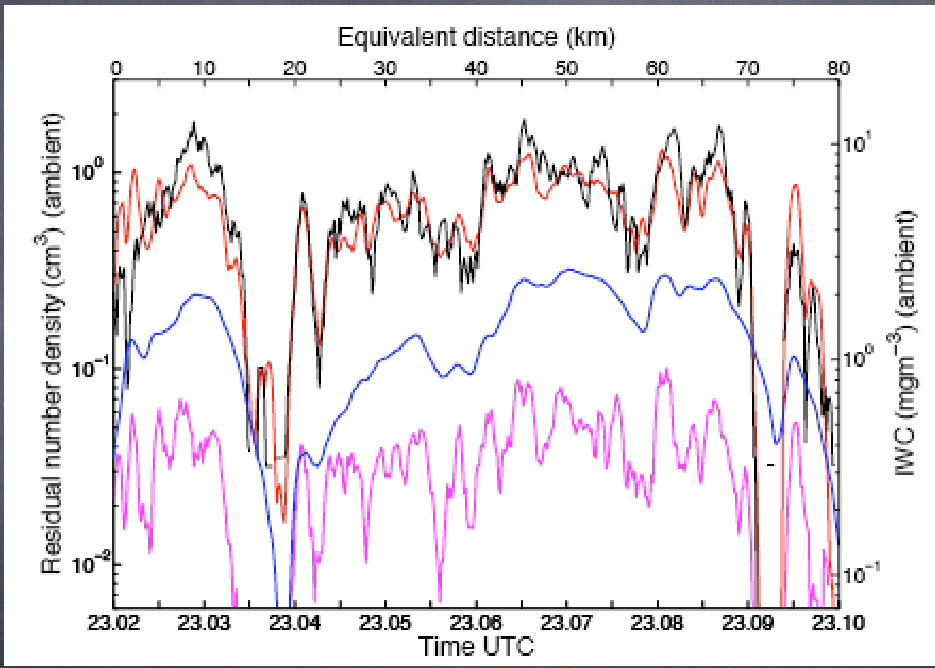


liquid ⇉ ice Alt = 5590m T = -27°C

INTACC conclusions

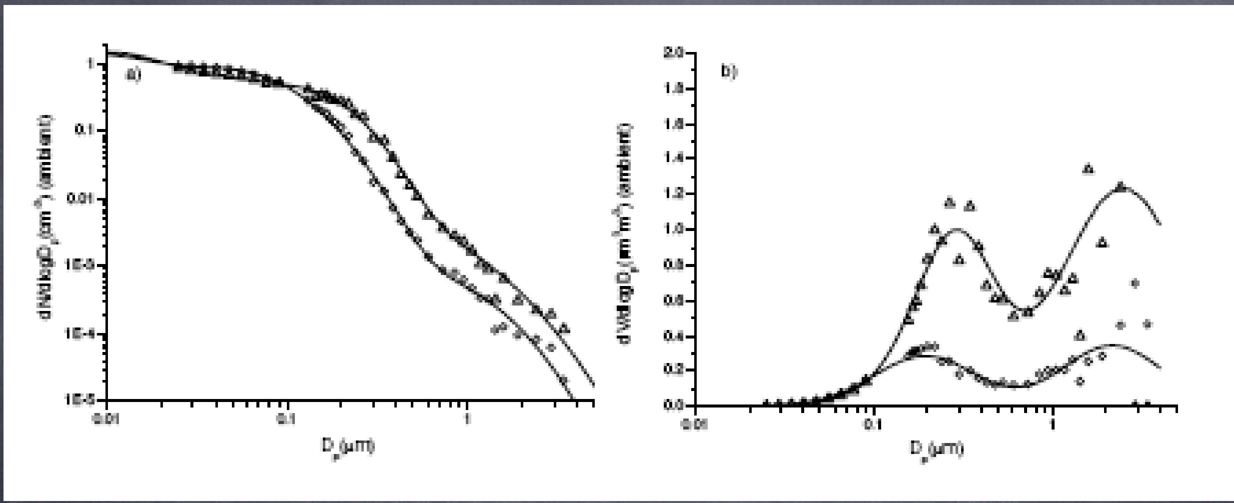
- Freezing occurred very rapidly in the downdraft part of the cloud
- Freezing was inhibited when organic aerosols were present in large concentrations
- More dilute droplets (those that formed on smaller particles) appeared to freeze first

INCA



Seifert, et al., Atmos. Chem. Phys. 2002

INCA



Triangles - SH; Circles - NH

Seifert, et al., Atmos. Chem. Phys. 2002

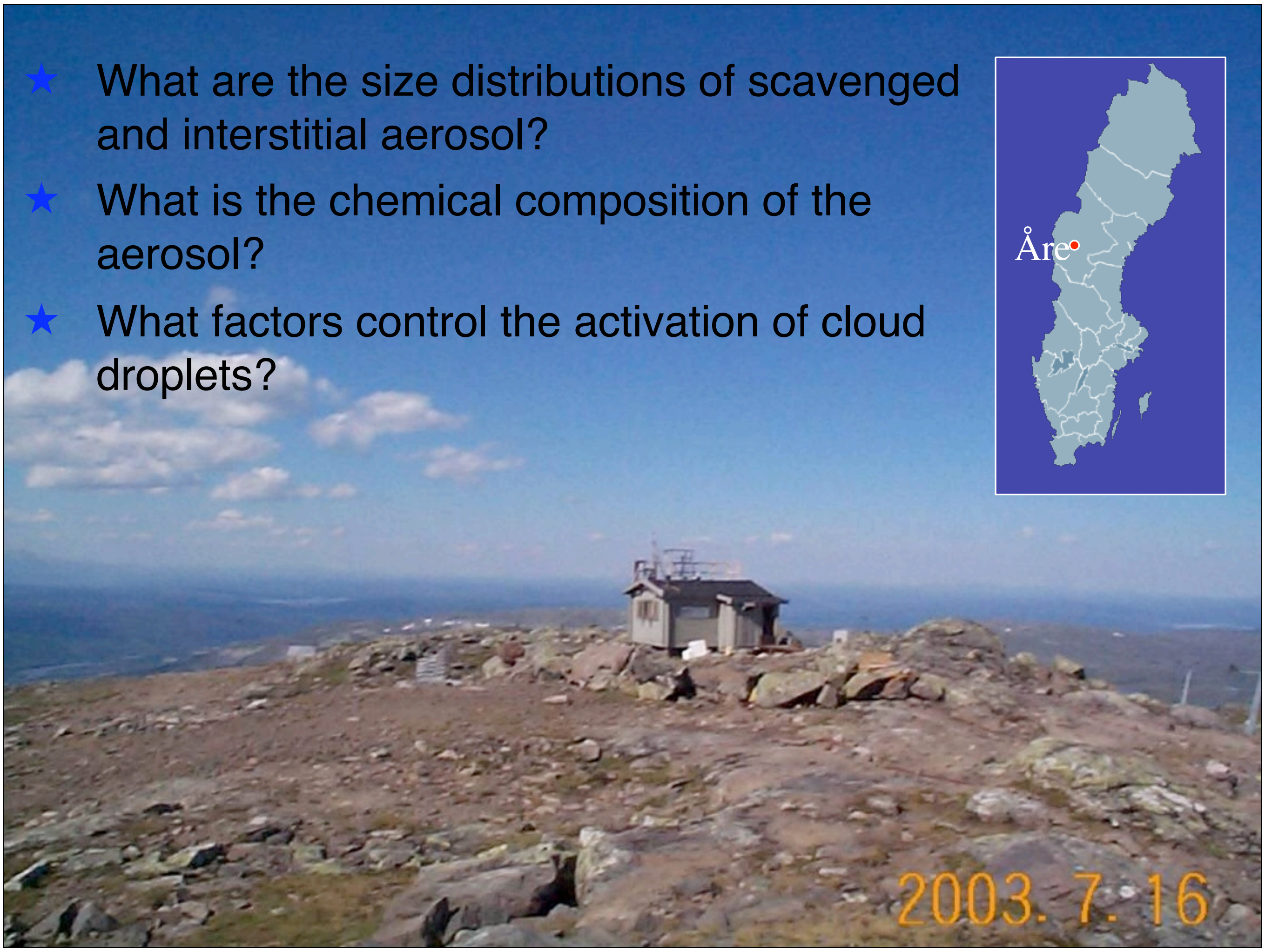
INCA Conclusions

- SH residuals are larger, and more aerosol volume is incorporated into the crystals than in the NH
- Residual number dominated by particles < 0.1μm, volume by particles > 0.1μm. Sub-0.1μm particles will control initial crystal concentrations
- The shape of the RSD is insensitive to T variations
- As crystal number increases, the residual volume mean diameter increases (large particles become more important)
- Scavenging ratios of 1% or less, and does not vary much with particle size; no strong preference for nucleation to occur on large particles
- Excellent agreement between CVI and FSSP-300

Seifert, et al., Atmos. Chem. Phys. 2002

Ground-based example

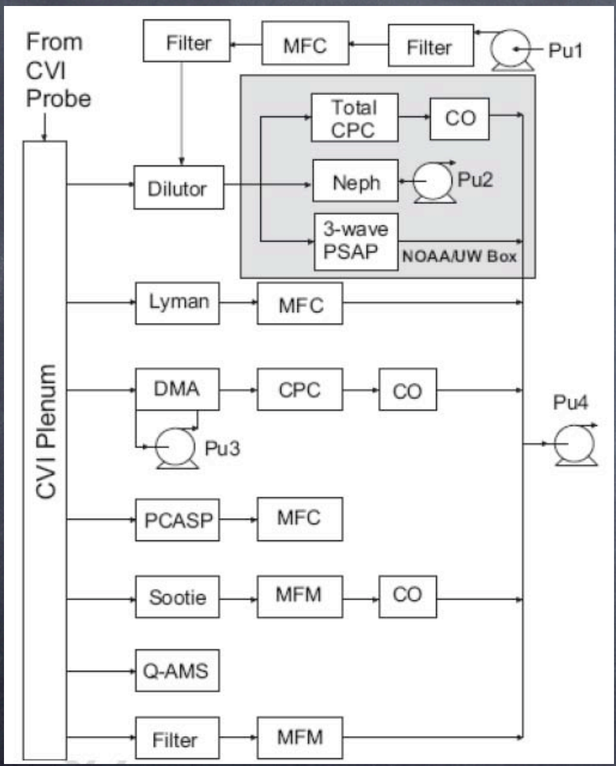
SOACED

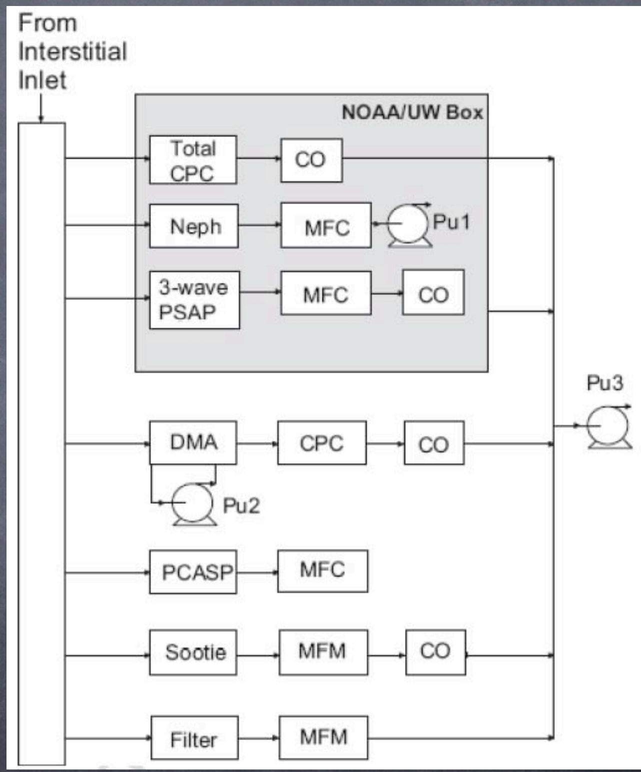

★ What are the size distributions of scavenged and interstitial aerosol?
★ What is the chemical composition of the aerosol?
★ What factors control the activation of cloud droplets?
Åre
2003. 7. 16

Hypotheses & questions

Accumulation-mode particles control the number of cloud droplets	What are the size distributions of the scavenged and interstitial aerosol?
Organic compounds are a substantial fraction of the aerosol that forms cloud droplets	What is the chemical composition of the aerosol?
Organic compounds enhance ice formation in supercooled clouds	What are the chemical and physical properties of the ice residuals?

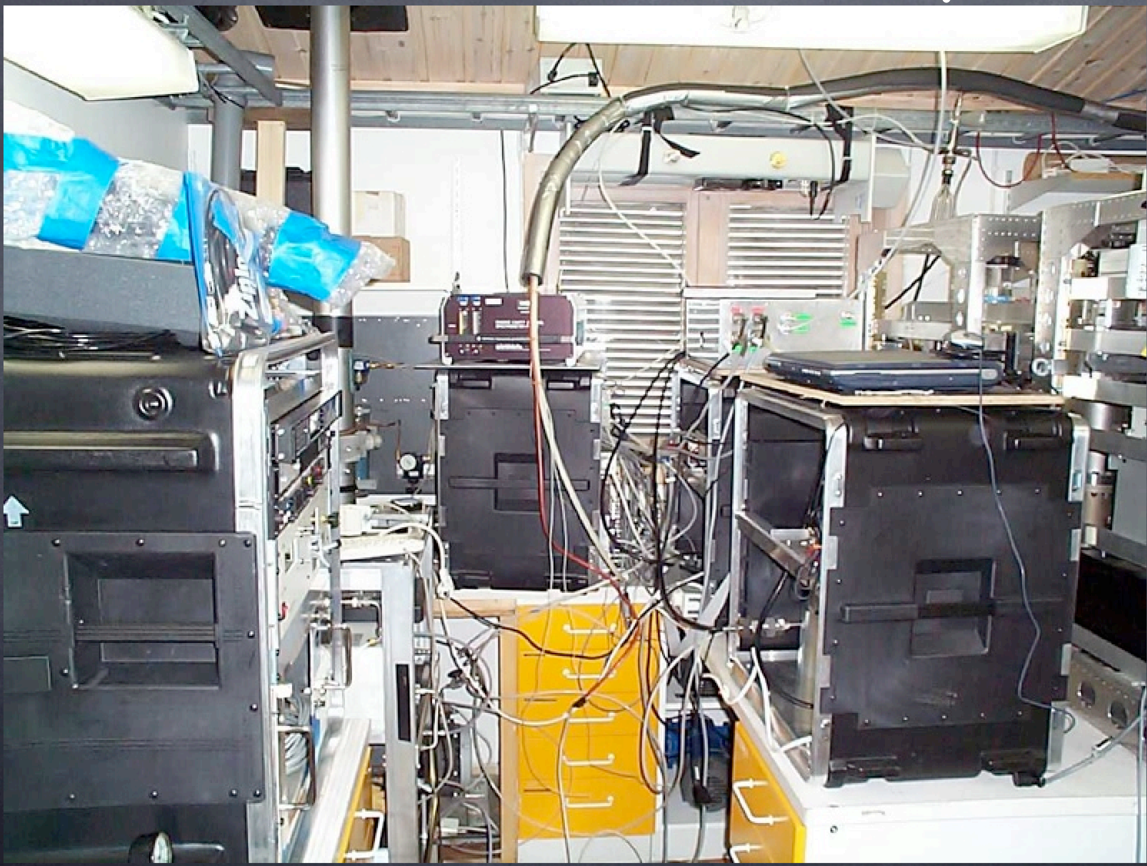
SOACED Instrumentation





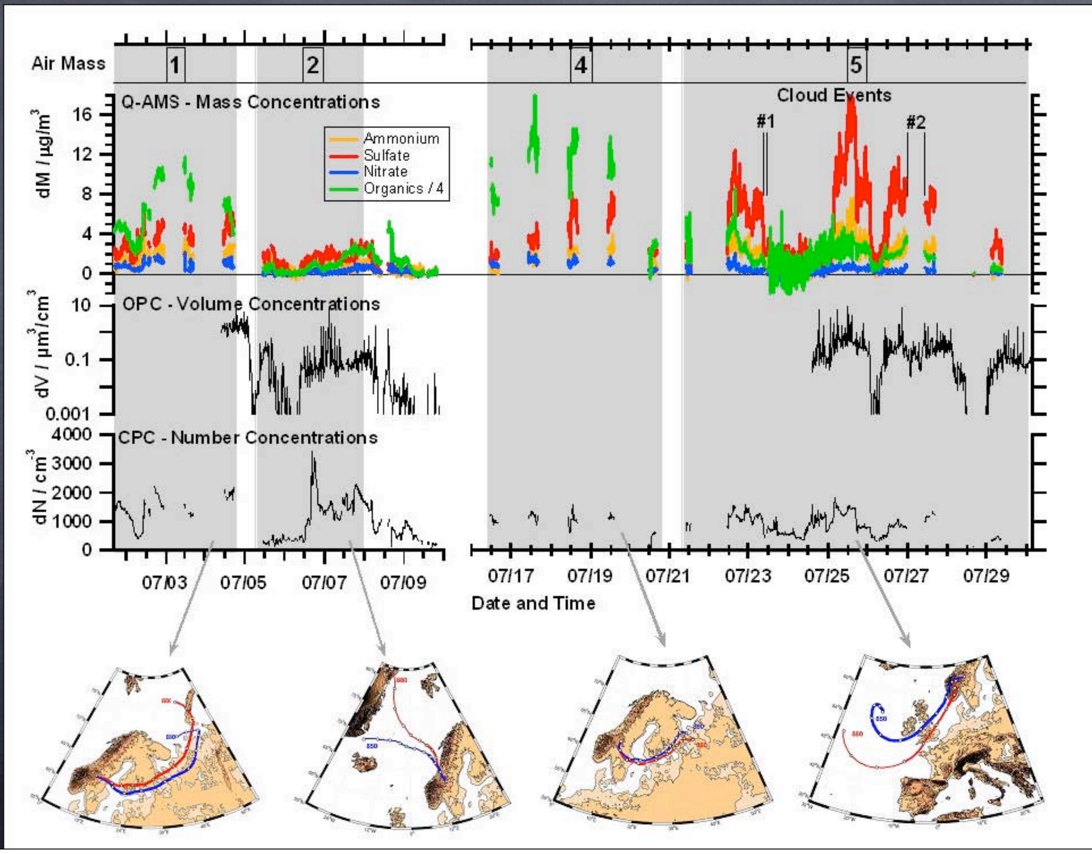
Targino, et al., Atmos. Res. 86, 225-240, 2007

Ground-based example

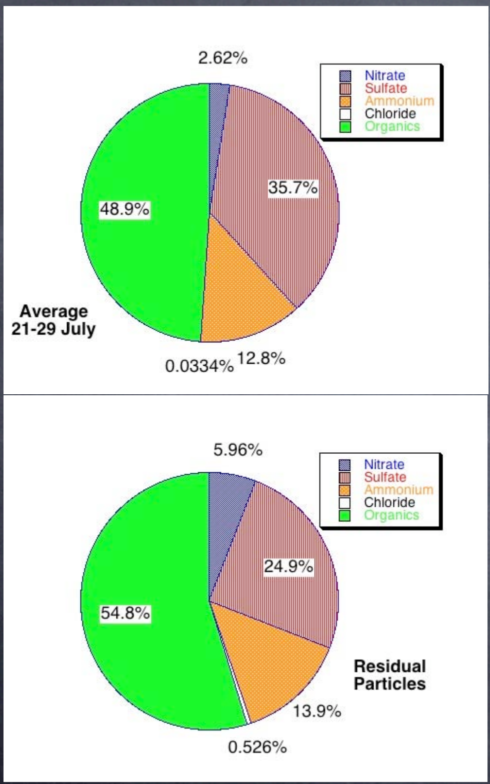


Overall chemical composition

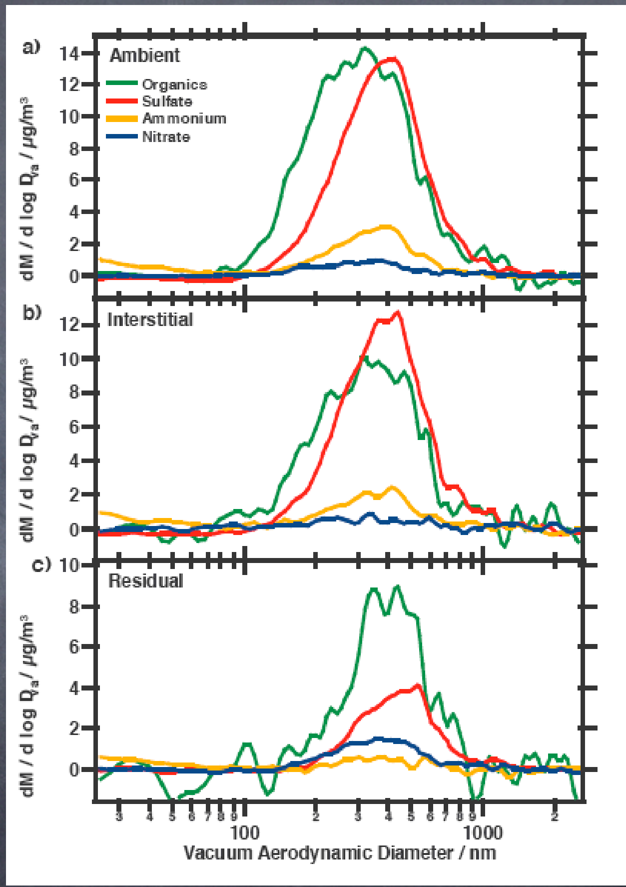
Drewnick et al., J. Atm. Chem., 56, 1-20, 2007

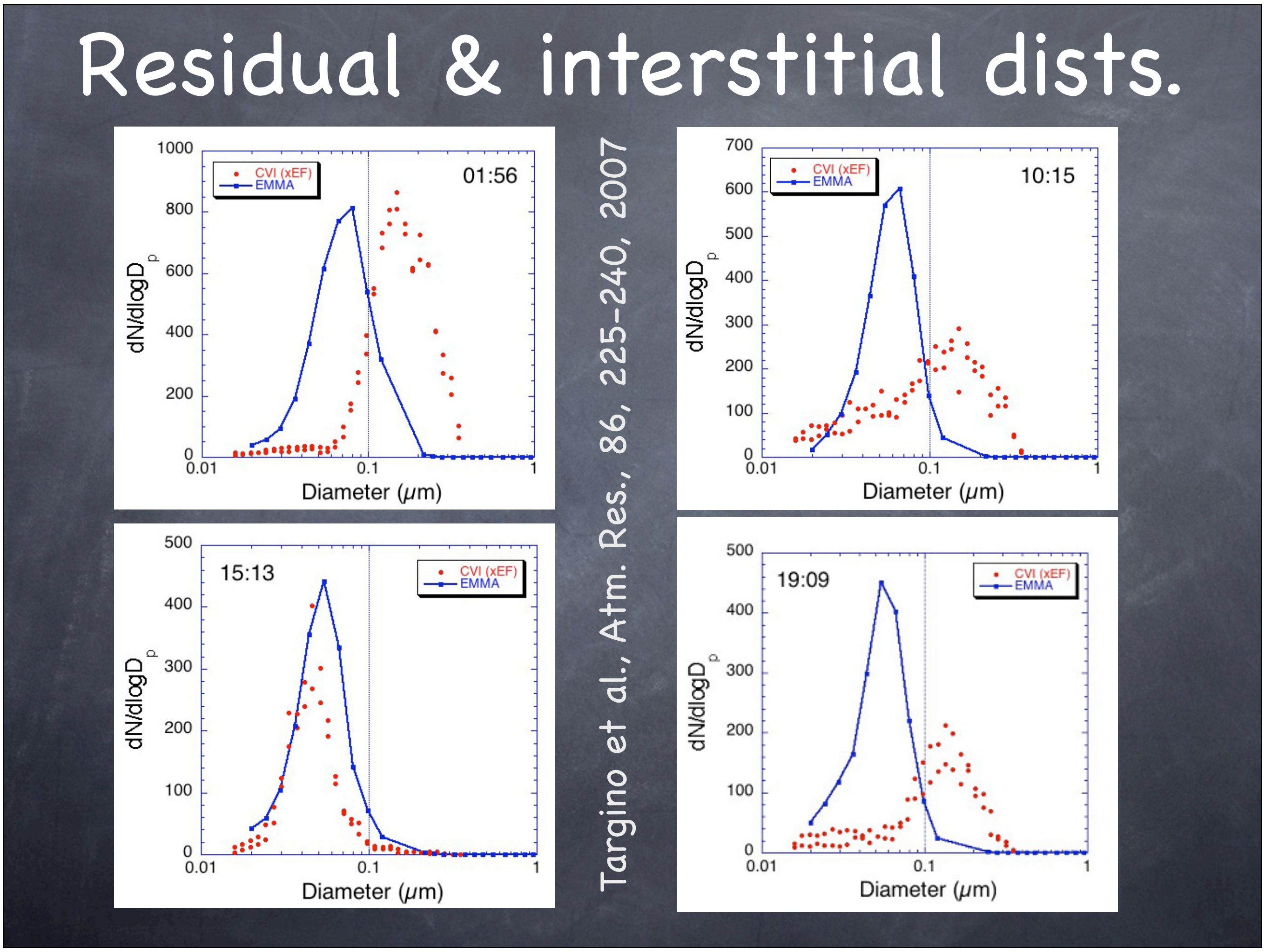


AMS Data



Drewnick et al., J. Atm. Chem.,56, 1-20, 2007




Residual & interstitial dists.
CVI (xEF)
EMMA
01:56
10:15
15:13
19:09
dN/dlogD
p
Diameter (μm)
0.01
0.1
1
0
100
200
300
400
500
600
700
800
1000
Targino et al., Atm. Res., 86, 225-240, 2007

SOACED conclusions

- Accumulation-mode particles don't always control droplet number
- Organic aerosols were a substantial fraction of the aerosol that formed cloud droplets

Acknowledgments

SOACED: Admir Targino, Dave Covert, Lynn Russell, John Ogren, Stephan Borrmann, Frank Drewnick

INTACC: Paul Glantz, Admir Targino, Paul Field, and the MRF scientists, technicians and crew

CVI Remarks

- Aerodynamically separates and samples cloud droplets and ice crystals; excludes small aerosol particles - excellent for looking at aerosol-cloud interactions
- A multitude of measurement techniques can be used with the CVI (even gases like H_2O_2)
- The combination of an interstitial sampling system and a CVI can produce real-time chemical and microphysical information about which particles do and do not form cloud droplets and crystals
- Possible artifacts due to droplet/crystal shattering and perhaps etching of the interior surfaces of the probe

What experiments would you like to do using a CVI?

A menagerie of flying machines

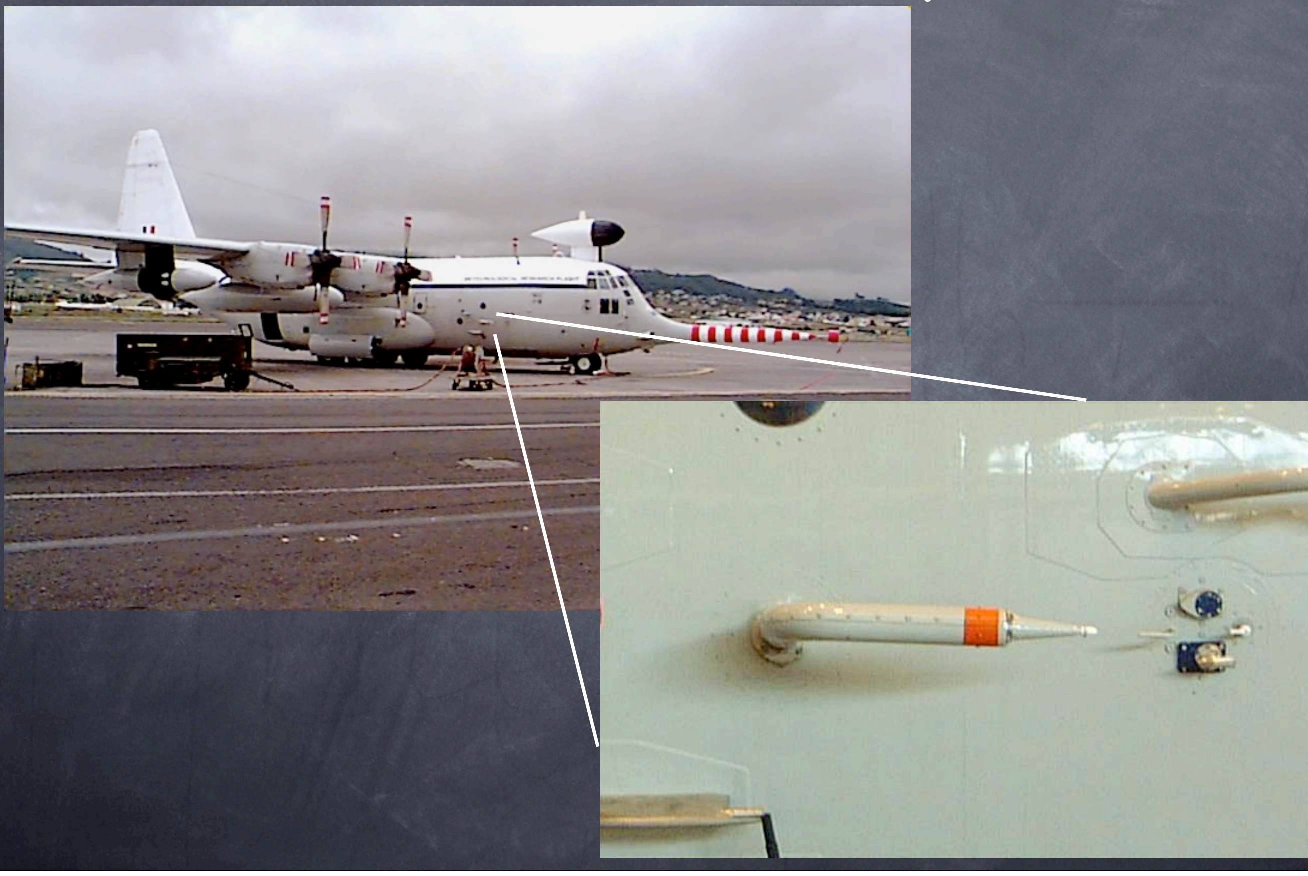
Some of the aircraft that have carried a CVI

UW C-131

The wonderful things you can do with duct tape

DLR Falcon 20

UK C-130 (Snoopy)



NASA DC-8

Probe: Cynthia Twohy, OSU/NCAR

AES Convair 580

Battelle G-1

Photos: John Ogren, NOAA

Cessna ??

Photo: Stephan Mertes, IfT

M55 Geophysika

Inlets - Citation

- Inlets take up the emergency exit hatch (!)
- Complicated airflow
- CVI

Photo: Johan Ström


Thanks for your attention!