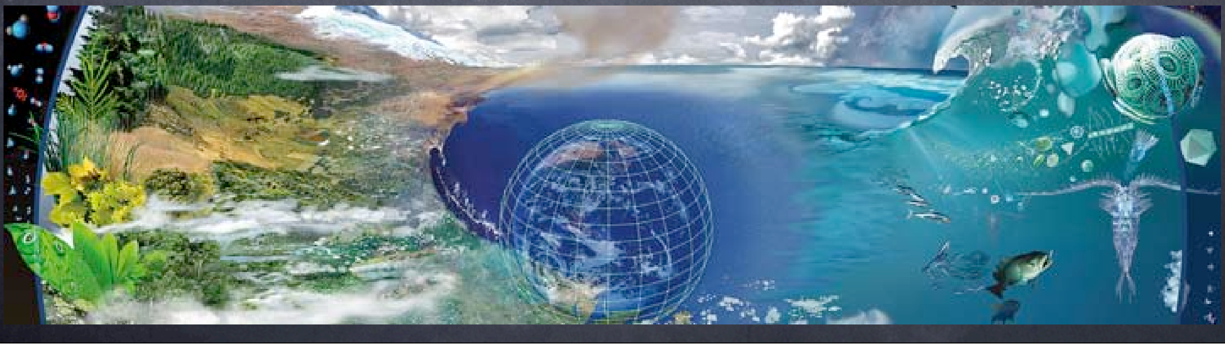
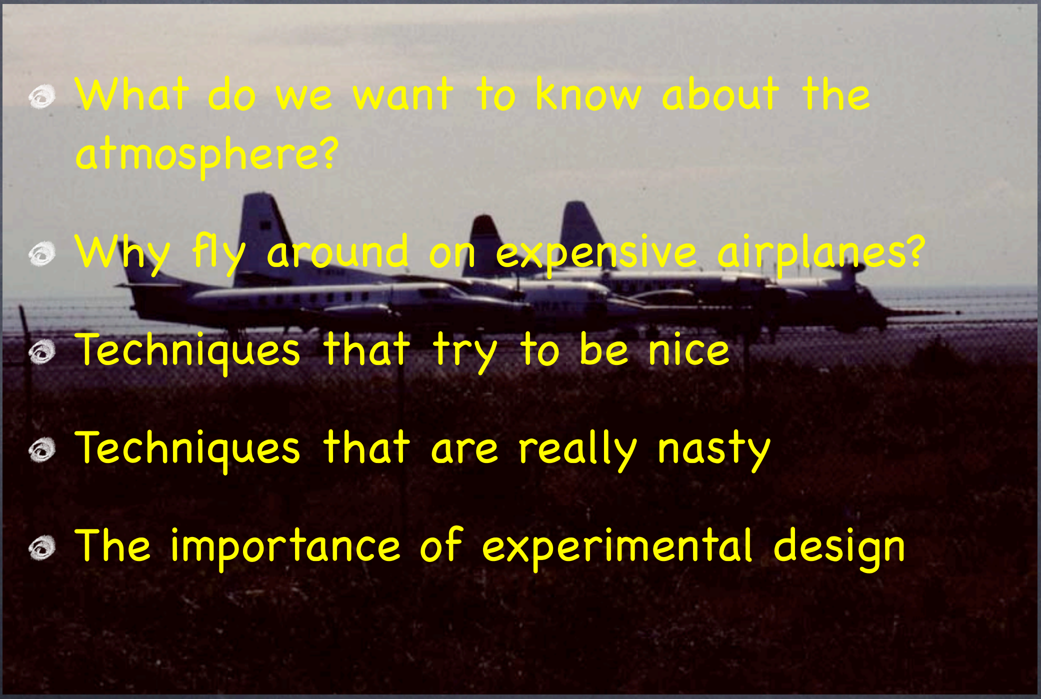
# Airborne measurements in atmospheric science

Kevin Noone
Executive Director, IGBP

GLOBAL
IGBP
CHANGE



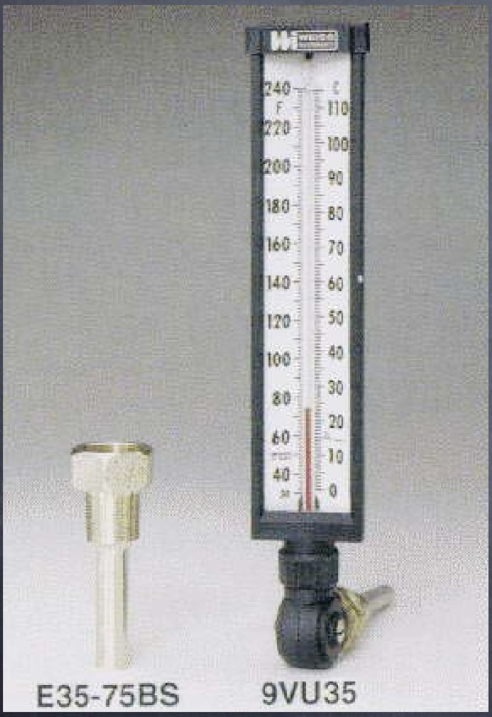
# Outline



- What do we want to know about the atmosphere?
- Why fly around on expensive airplanes?
- Techniques that try to be nice
- Techniques that are really nasty
- The importance of experimental design

# What do we want to know about the atmosphere?

# Measuring Temperature



# Measuring Temperature

- **Static Air Temperature (SAT or Ts):** This is the physical temperature of the air which the aircraft is flying through. It is also know as the outside air temperature (OAT); it is the temperature that we need to determine.

- **Total Air Temperature (TAT or Tt):** This is the temperature that would be measured by a probe if all of the kinetic energy of the air resulting from the aircraft's motion was absorbed. Because this is impossible, it can never be measured!

- **Recovery Temperature (Tr):** This is the temperature that the total air temperature is approximated by because of the incomplete recovery of the kinetic energy of the air by the temperature probe.

- **Measured Temperature (Tm):** As the name implies, this is the temperature that is actually measured by the aircraft's temperature probe. It differs from the recovery temperature, Tr, because of parasitic heating or cooling of the temperature sensor.

http://mtp.jpl.nasa.gov/notes/sat/sat.html

# Measuring Temperature

$$\frac{T_r}{T_s} = 1 + r\frac{(\gamma - 1)}{2}M^2$$

$$r = 1 - \eta\left[1 + \frac{2}{(\gamma - 1)M^2}\right]$$

$$\gamma = \frac{C_p}{C_v}$$

$$\eta = \frac{T_t - T_r}{T_t}$$

http://mtp.jpl.nasa.gov/notes/sat/sat.html

# Conclusion

You never get to directly measure the quantity in which you are interested

# Types of measurements

| Measurement type | Nice | Nasty |
|---|---|---|
| State variables | IR | T probe |
| Radiation | MARSS | |
| Microphysics | FSSP, SID | Nevzarov |
| Chemistry | Spectrometry | Mohnen sampler |
| Turbulence | Sonic | Mechanical |

# Lessons from Cloud Base

Time constants, concentrations, optics and such stuff

# “Nice” Measurements

Measurement techniques that don’t disturb the sample **all** too much: optical probes

# "Nasty" Measurements

Measurement techniques that **really** disturb the sample: impactors, inlets, filters

# Cloudwater Chemistry

What do we want to know about cloudwater chemistry?

# Mohnen Slotted Rod Sampler

- Cloud/precip. droplets impact on slotted rods
- Water runs down rods into common collector (flask) inside the aircraft
- Water sample capped and saved for analysis in lab

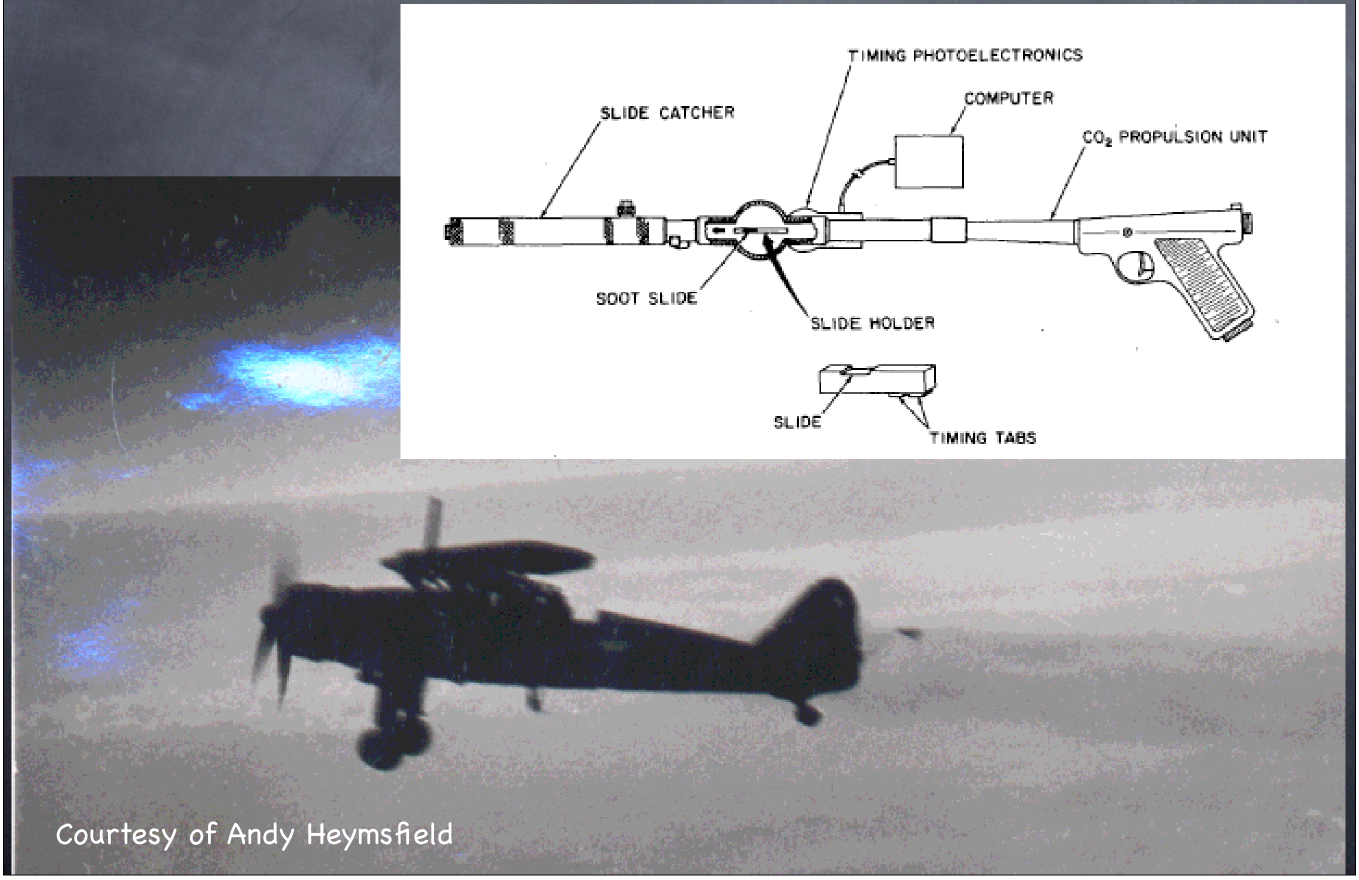
# Cloudwater Chemistry

Discussion: what do we need to know, and what improvements can be made on our measurements?

# Cloud Microphysics

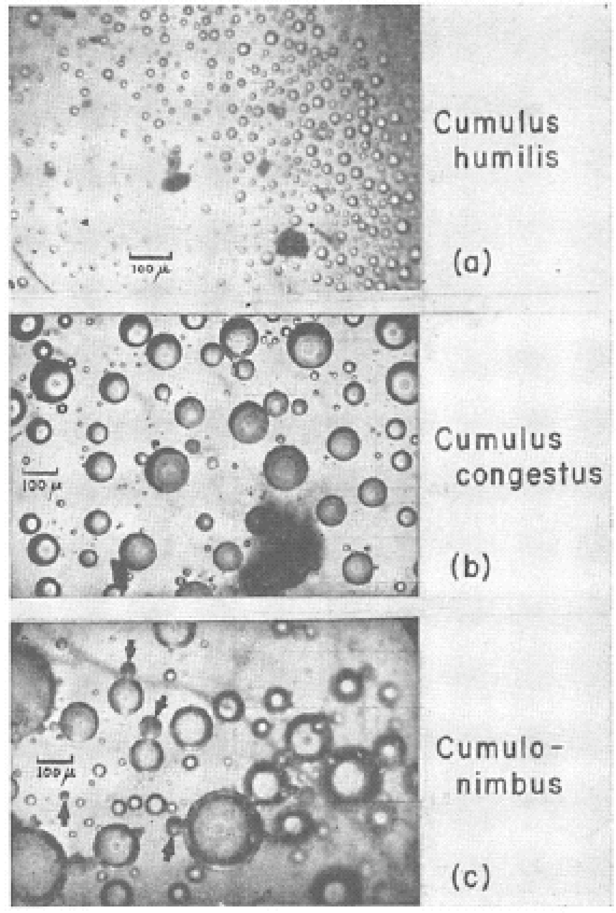
What microphysical properties do we need to know about clouds?

# Cloud Gun



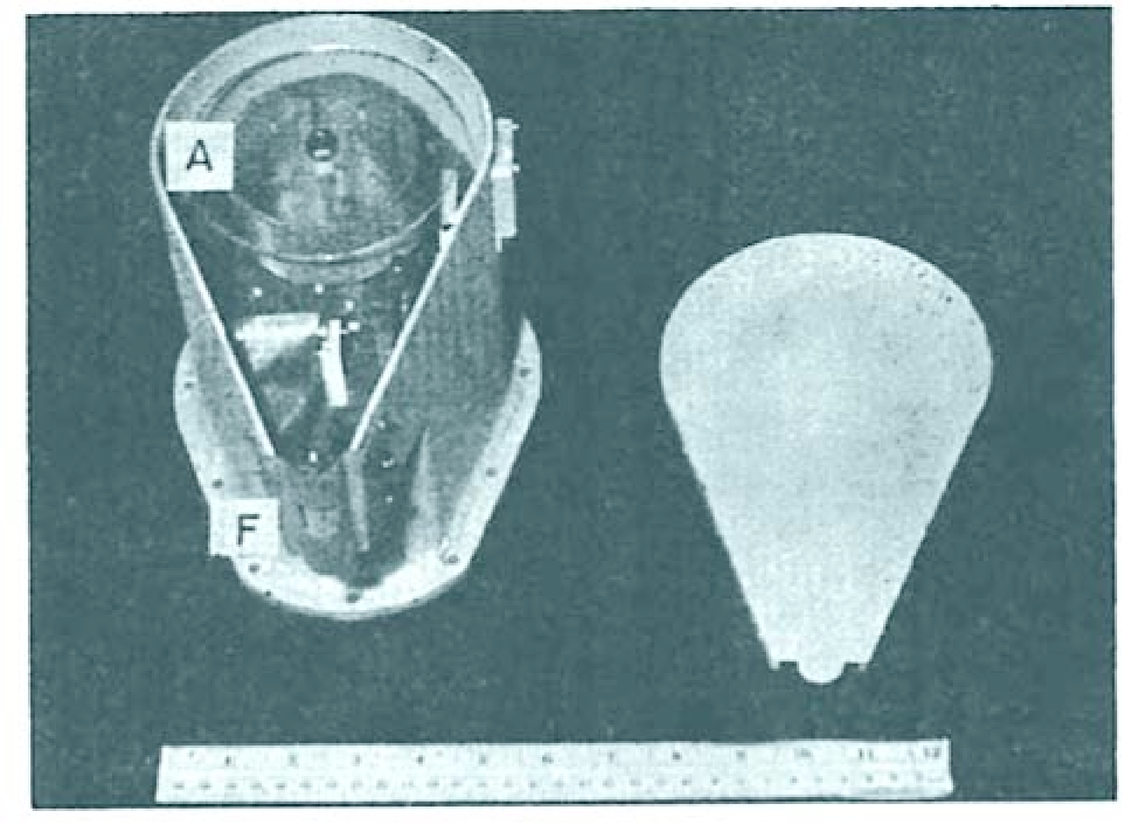
Courtesy of Andy Heymsfield

# Cloud Gun



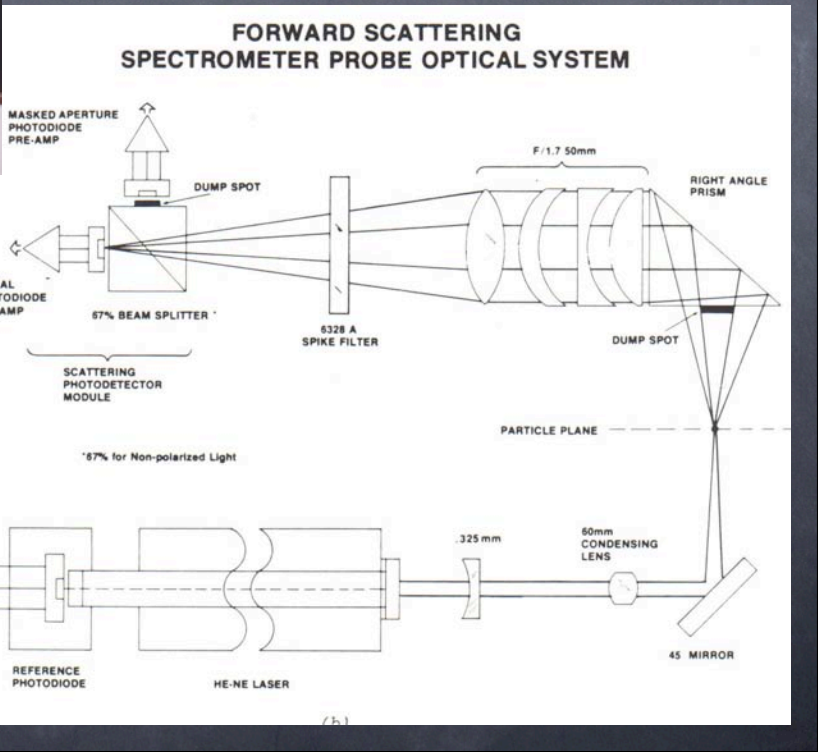
Courtesy of Andy Heymsfield

# Replicators



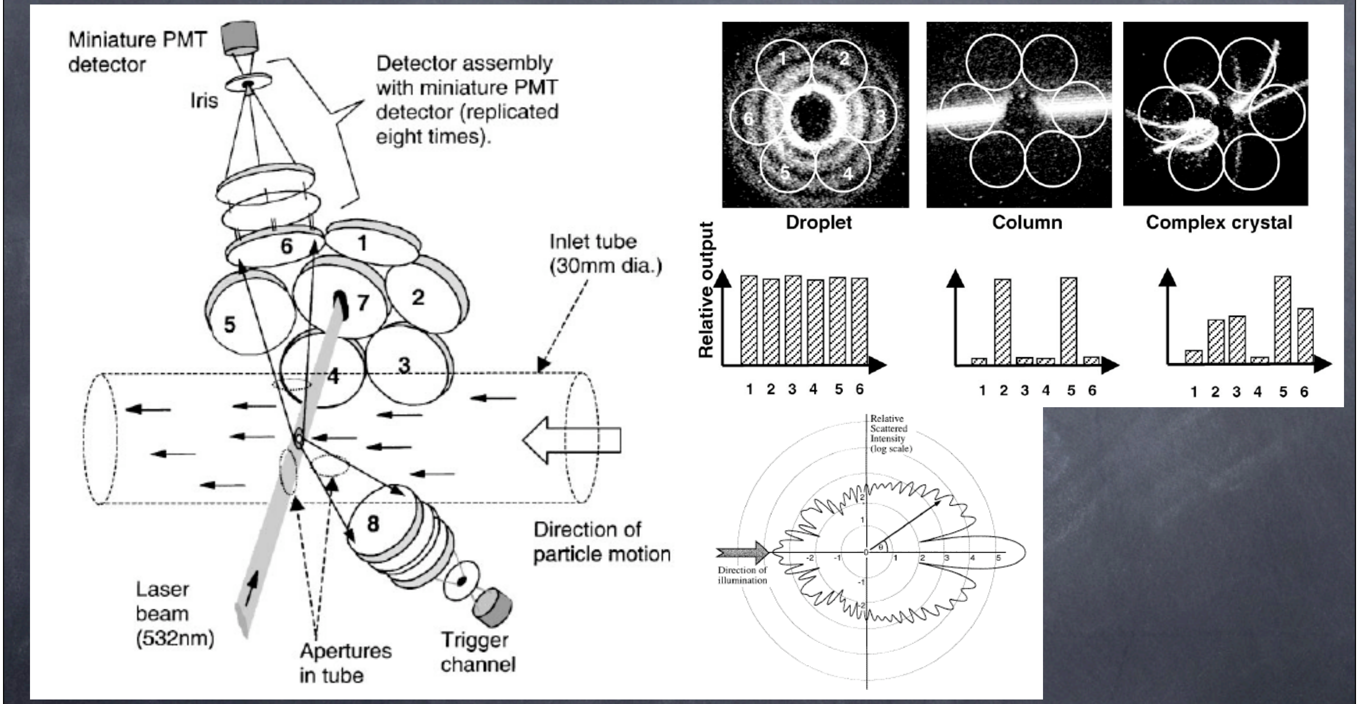
Courtesy of Andy Heymsfield

# Forward Scattering Spectrometer Probe (FSSP)



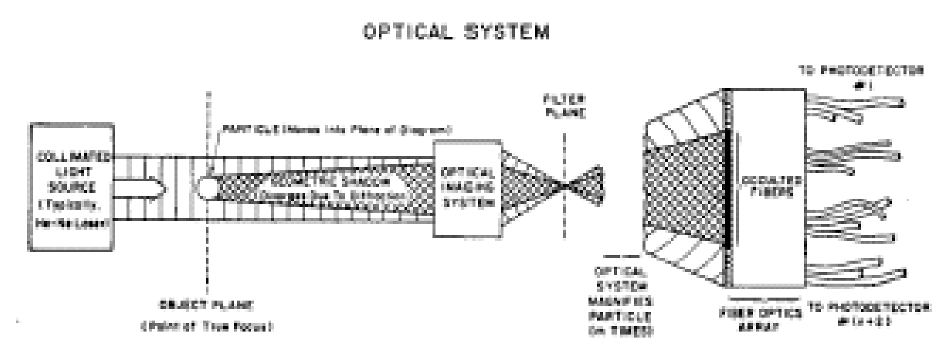
# Small Ice Detector (SID)

# Small Ice Detector (SID)

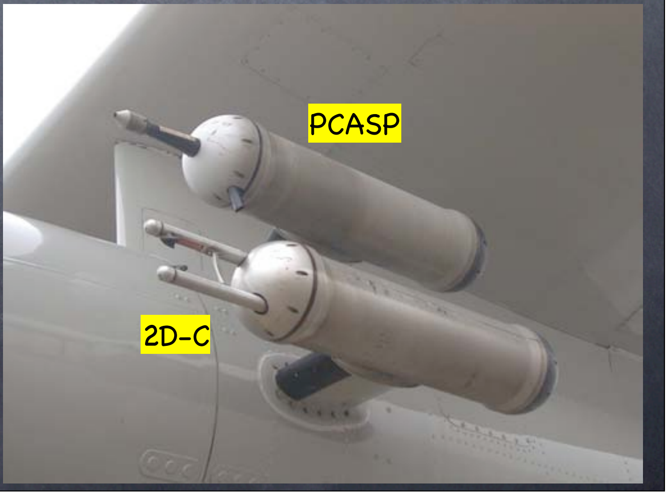


Hirst, et al.,
Atmospheric Environment 35 (2001) 33-47

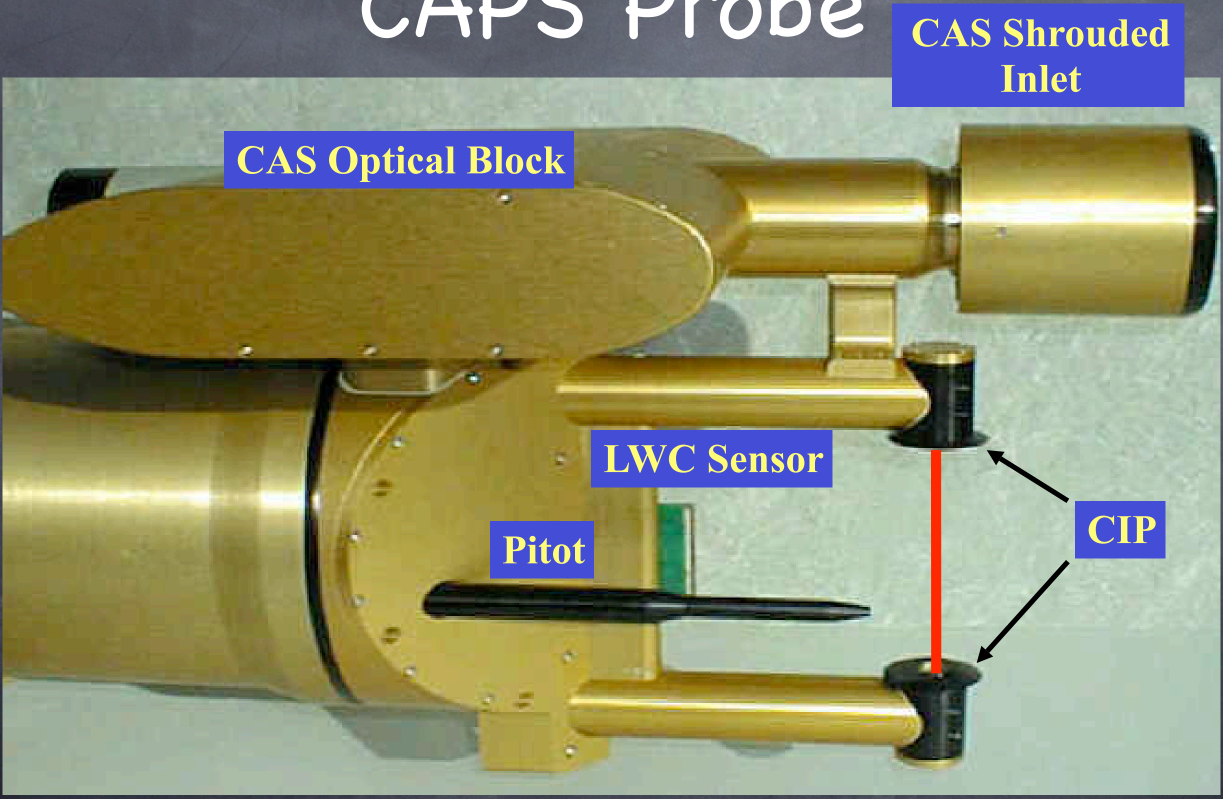
# 2-D Probes


OPTICAL SYSTEM
COLLIMATED LIGHT SOURCE (Typically, He-Ne Laser)
PARTICLE (Moves into Plane of Diagram)
GEOMETRIC SHADOW (Diverges Due To Diffraction)
OPTICAL IMAGING SYSTEM
FILTER PLANE
OBJECT PLANE (Point of True Focus)
OPTICAL SYSTEM MAGNIFIES PARTICLE (m TIMES)
OCCULTED FIBERS
TO PHOTODETECTOR #1
FIBER OPTICS ARRAY
TO PHOTODETECTOR #(n+2)


2D-P


PCASP
2D-C

# CAPS Probe

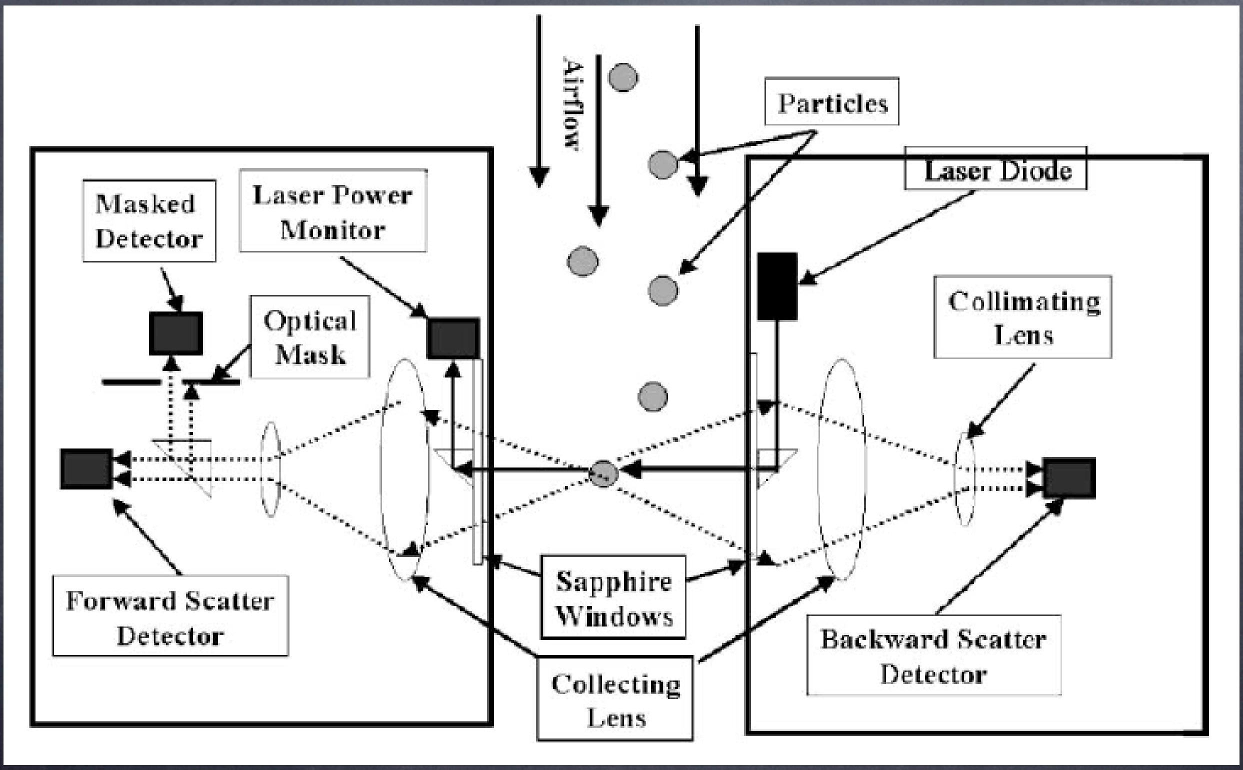


Droplet Measurement Technologies
5710 Flatiron Parkway Suite B
Boulder, CO 80301

# CAPS Probe

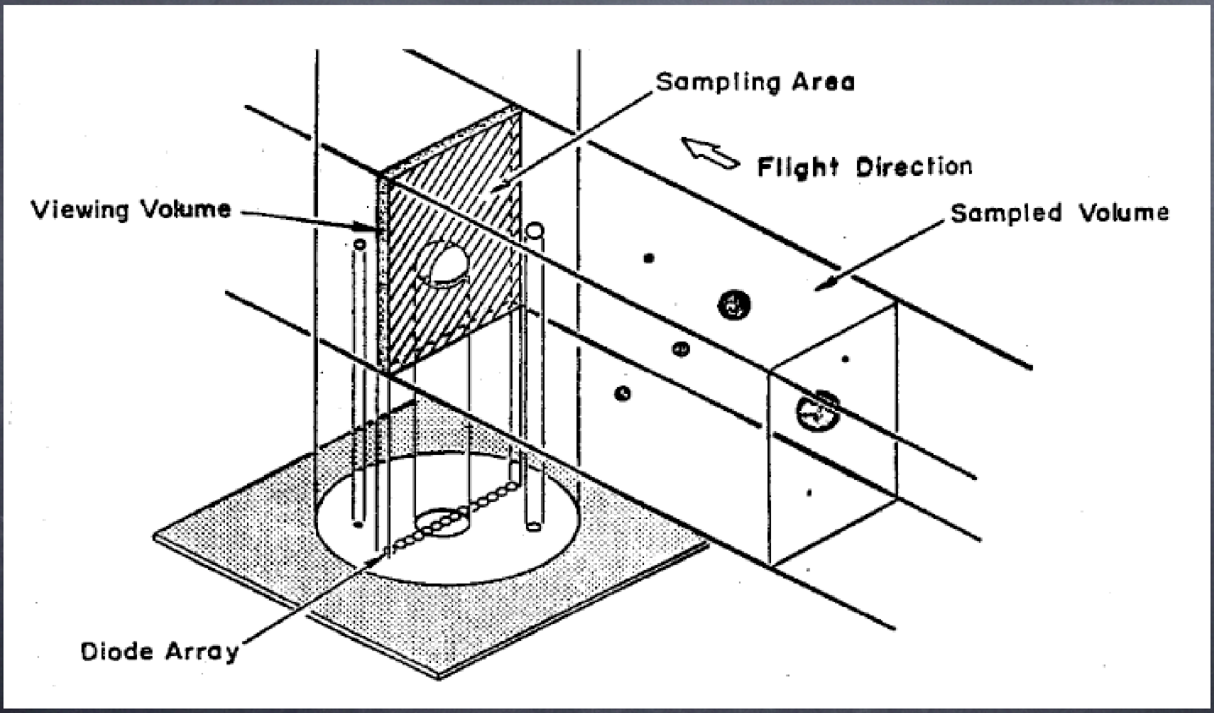
- Multiple Instruments in one flight canister, covering a sizing range from 0.5µm to 1550µm, plus Hot-Wire LWC sensing, Temperature and RH
- Cloud and Aerosol Spectrometer (CAS) section uses forward-scatter and back-scatter techniques to measure particles from 0.5 µm to 50µm
- Cloud Imaging Probe (CIP) section uses a fast 64-element photodiode array to generate 2-Dimensional Images of particles from 25-1550µm, as well as sizing in 1-Dimensional Histogram form, and includes housekeeping data
- Liquid Water Content: Hot-Wire sensor measures up to 3g/m$^3$
- Airspeed and Altitude measurements from the heated Pitot tube
- Temperature sensor measures ambient air, +/- 1C
- Relative Humidity measurement via the Honeywell Humicap

# CAPS Probe



D. Baumgardner et al., Atmospheric Research 59- 60 (2001) 251-264

# CAPS Probe



D. Baumgardner et al., Atmospheric Research 59– 60 (2001) 251–264

# Particle Volume Monitor

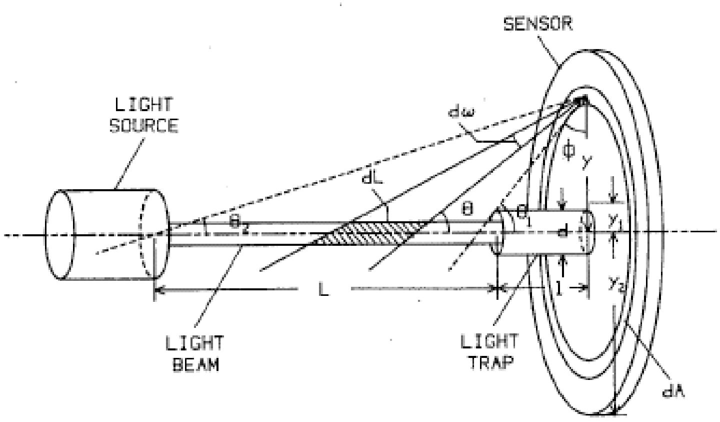


FIG. 1. Schematic diagram of instrument for measurement of liquid water content of fogs, clouds and hazes.

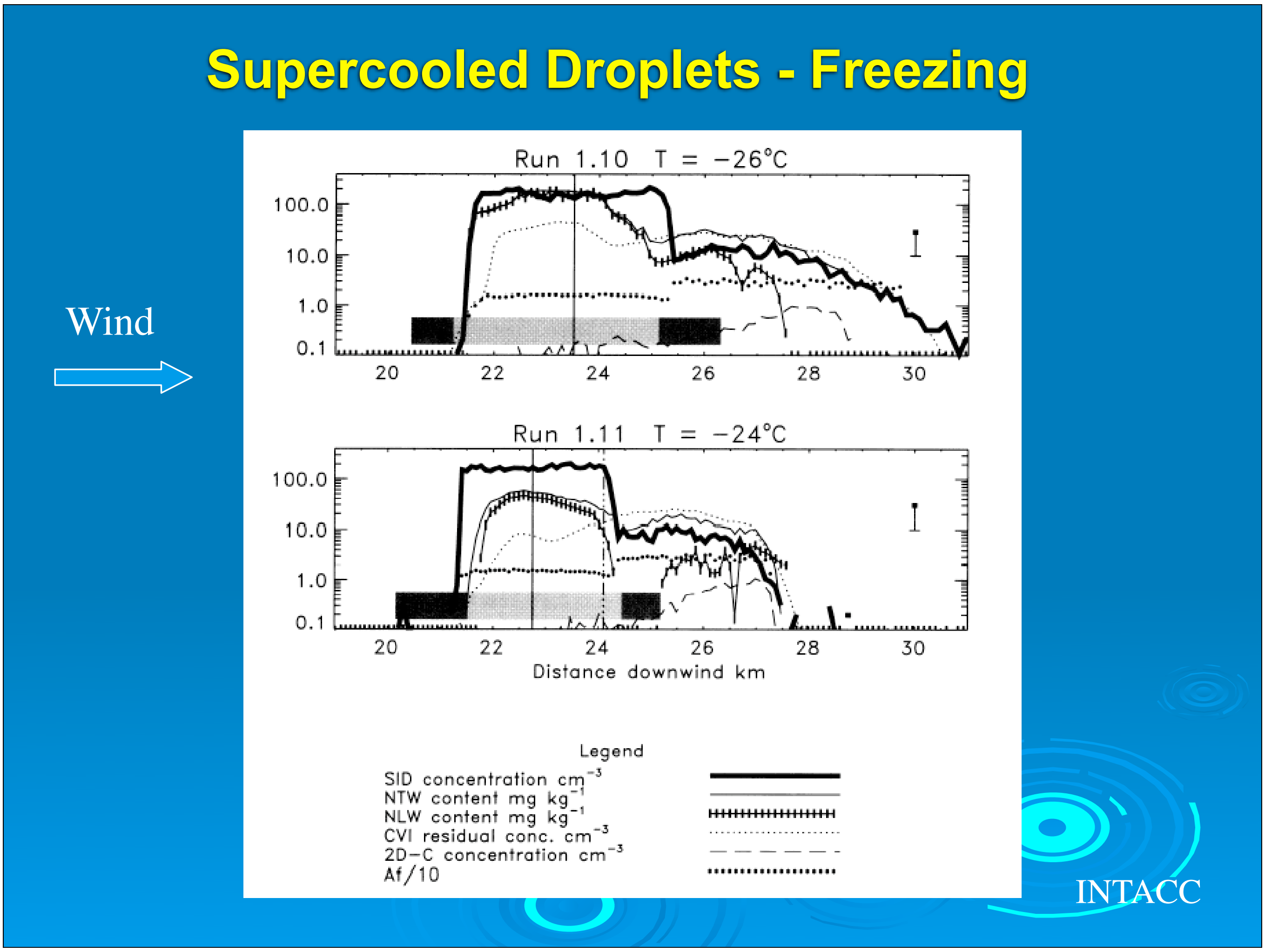
# MRF Total Water Probe

# Supercooled Orographic Clouds

Wind

Photo: Paul Field, MRF

INTACC



# Supercooled Droplets - Freezing

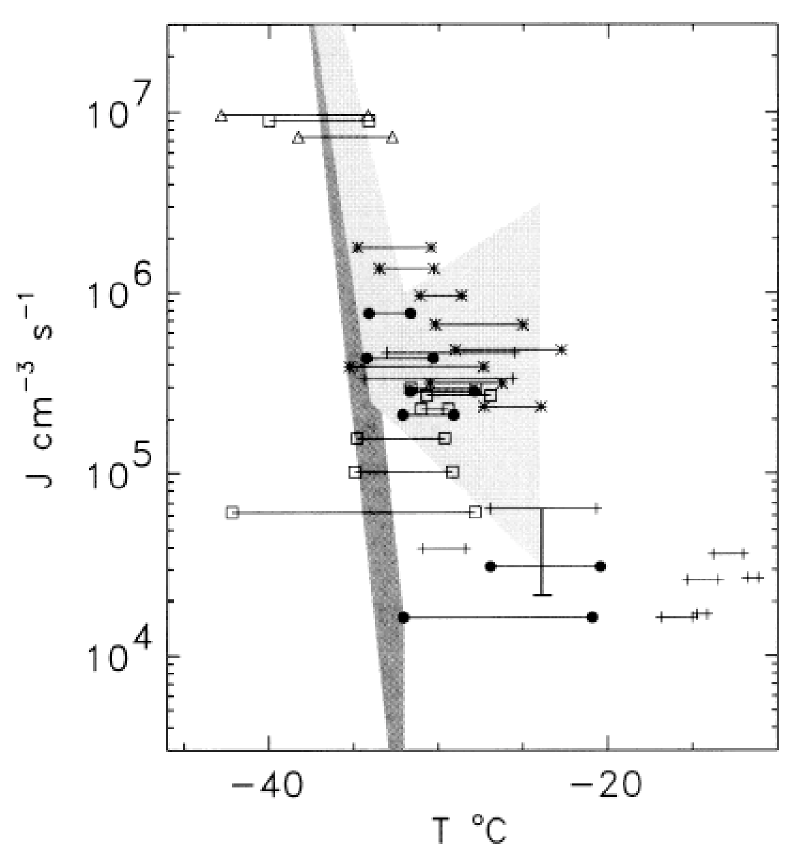
Wind

INTACC

From

Field, P.R., R.J. Cotton, K.J. Noone, P. Glantz, P.H. Kaye, E. Hirst, R.S. Greenway, C. Jost, R. Gabriel, T. Reiner, M.O. Andreae, C.P.R. Saunders, A. Archer, T.W. Choularton, M. Smith, B. Brooks, C. Hoell, B. Bandy, D.W. Johnson, and A.J. Heymsfield, Ice nucleation in orographic wave clouds: Measurements made during INTACC, Quart. J. Roy. Meteor. Soc., 127 (July), 1493-1512, 2001.

# Ice Formation - Freezing Rates



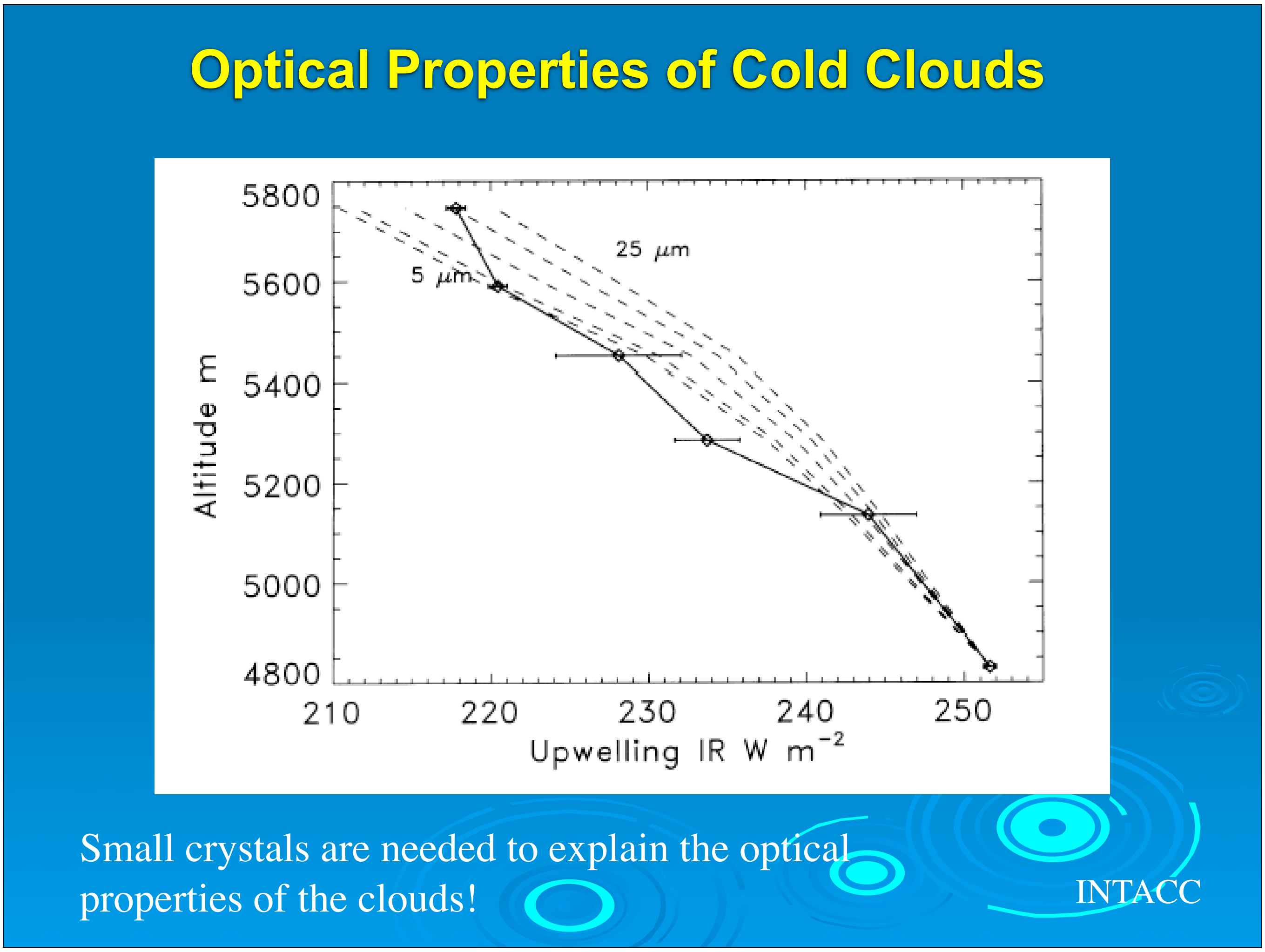
Dark shading:
homogeneous freezing

Light shading:
heterogeneous freezing

INTACC

From

Field, P.R., R.J. Cotton, K.J. Noone, P. Glantz, P.H. Kaye, E. Hirst, R.S. Greenway, C. Jost, R. Gabriel, T. Reiner, M.O. Andreae, C.P.R. Saunders, A. Archer, T.W. Choularton, M. Smith, B. Brooks, C. Hoell, B. Bandy, D.W. Johnson, and A.J. Heymsfield, Ice nucleation in orographic wave clouds: Measurements made during INTACC, Quart. J. Roy. Meteor. Soc., 127 (July), 1493-1512, 2001.



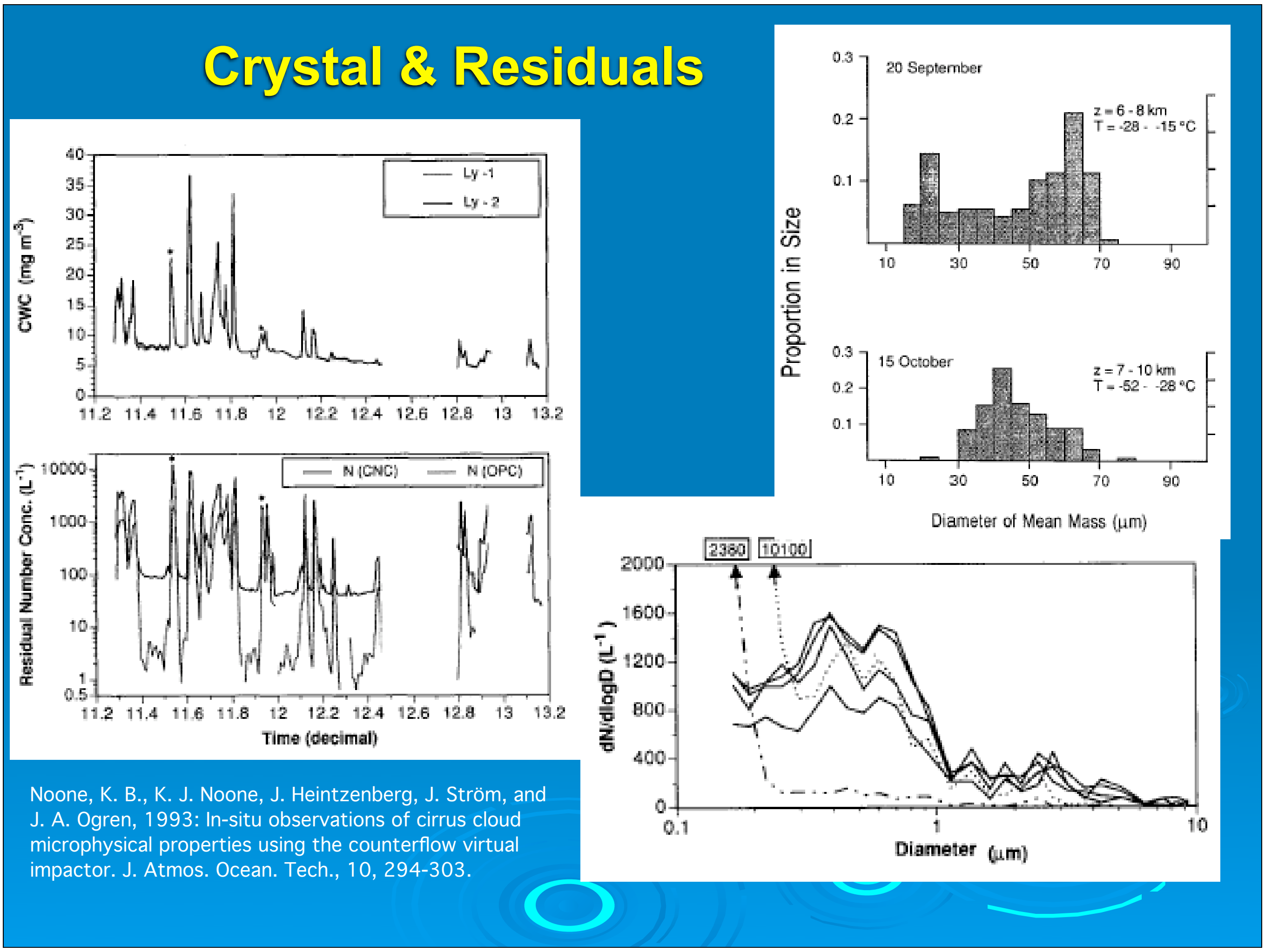
# Optical Properties of Cold Clouds

Small crystals are needed to explain the optical properties of the clouds!

INTACC

From

Field, P.R., R.J. Cotton, K.J. Noone, P. Glantz, P.H. Kaye, E. Hirst, R.S. Greenway, C. Jost, R. Gabriel, T. Reiner, M.O. Andreae, C.P.R. Saunders, A. Archer, T.W. Choularton, M. Smith, B. Brooks, C. Hoell, B. Bandy, D.W. Johnson, and A.J. Heymsfield, Ice nucleation in orographic wave clouds: Measurements made during INTACC, Quart. J. Roy. Meteor. Soc., 127 (July), 1493-1512, 2001.

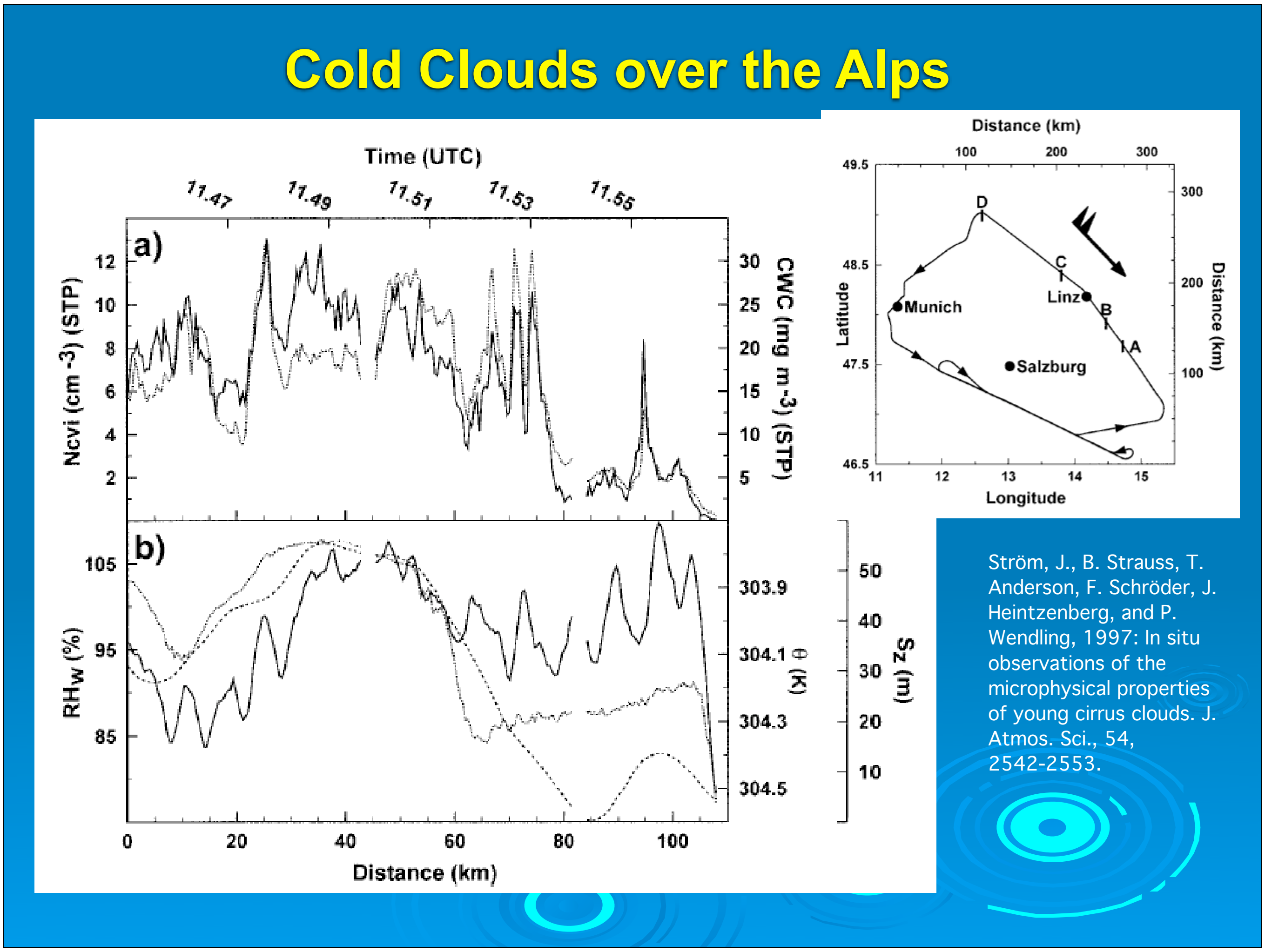


# Crystal & Residuals

Noone, K. B., K. J. Noone, J. Heintzenberg, J. Ström, and J. A. Ogren, 1993: In-situ observations of cirrus cloud microphysical properties using the counterflow virtual impactor. J. Atmos. Ocean. Tech., 10, 294-303.

From

Noone, K.B., K.J. Noone, J. Heintzenberg, J. Ström, and J.A. Ogren, In-situ observations of cirrus cloud microphysical properties using the counterflow virtual impactor, J. Atmos. Ocean. Tech., 10, 294-303, 1993.

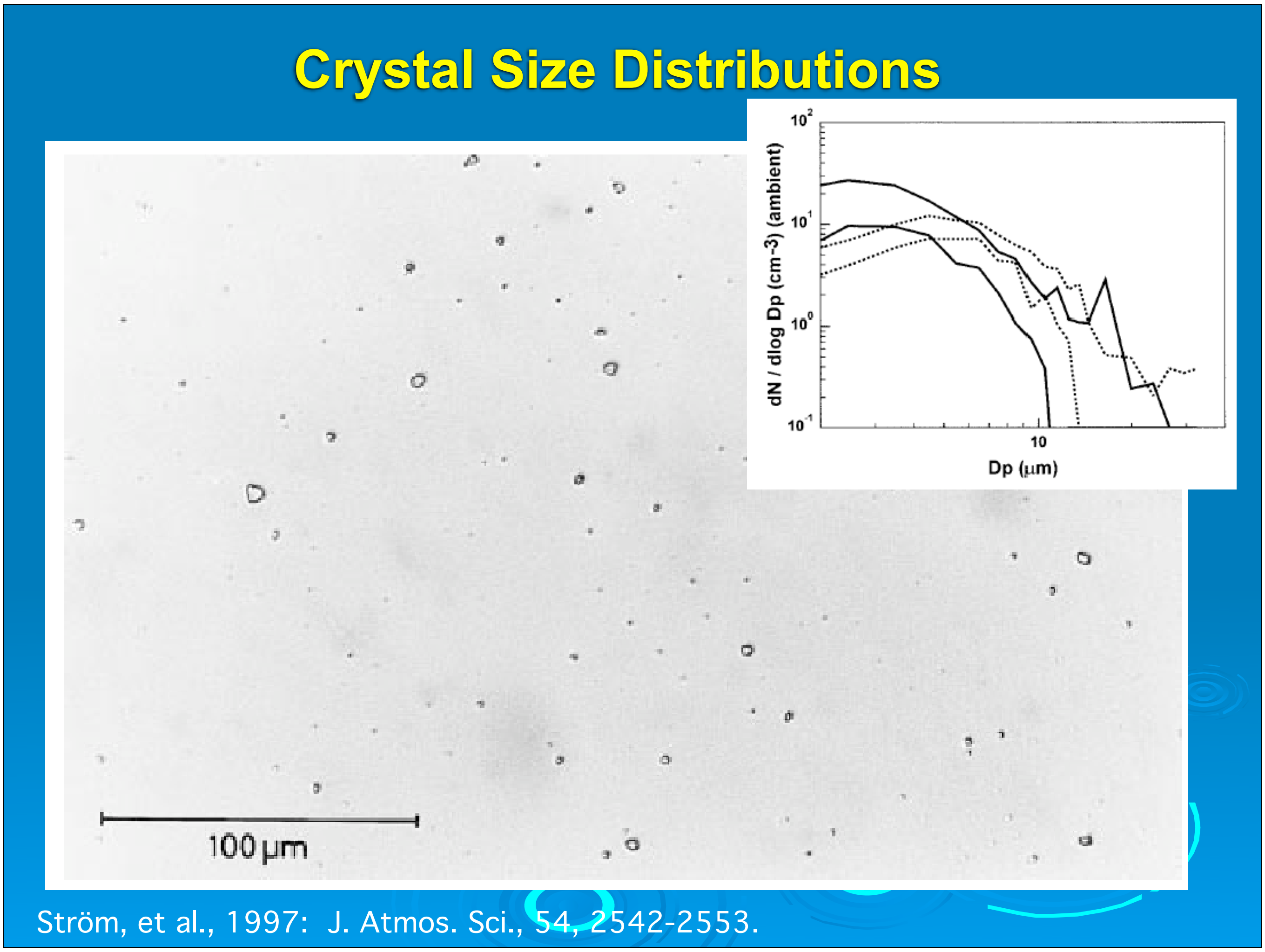


# Cold Clouds over the Alps

Ström, J., B. Strauss, T. Anderson, F. Schröder, J. Heintzenberg, and P. Wendling, 1997: In situ observations of the microphysical properties of young cirrus clouds. J. Atmos. Sci., 54, 2542-2553.

From

Ström, J., B. Strauss, T. Anderson, F. Schröder, J. Heintzenberg, and P. Wendling, In situ observations of the microphysical properties of young cirrus clouds, J. Atmos. Sci., 54, 2542-2553, 1997.

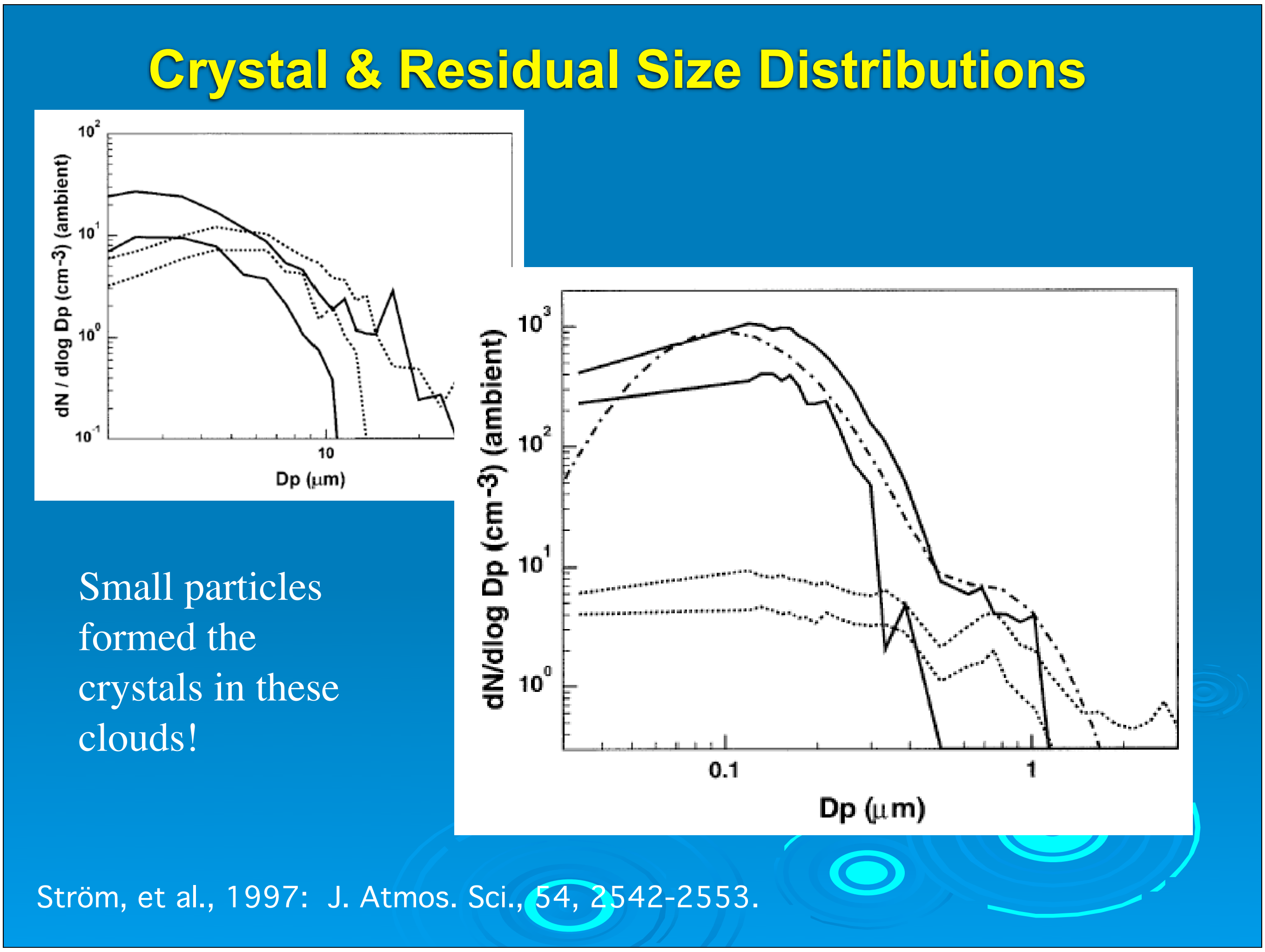


## Crystal Size Distributions

Ström, et al., 1997: J. Atmos. Sci., 54, 2542-2553.

From

Ström, J., B. Strauss, T. Anderson, F. Schröder, J. Heintzenberg, and P. Wendling, In situ observations of the microphysical properties of young cirrus clouds, J. Atmos. Sci., 54, 2542-2553, 1997.



# Crystal & Residual Size Distributions

Small particles formed the crystals in these clouds!

Ström, et al., 1997: J. Atmos. Sci., 54, 2542-2553.

From

Ström, J., B. Strauss, T. Anderson, F. Schröder, J. Heintzenberg, and P. Wendling, In situ observations of the microphysical properties of young cirrus clouds, J. Atmos. Sci., 54, 2542-2553, 1997.

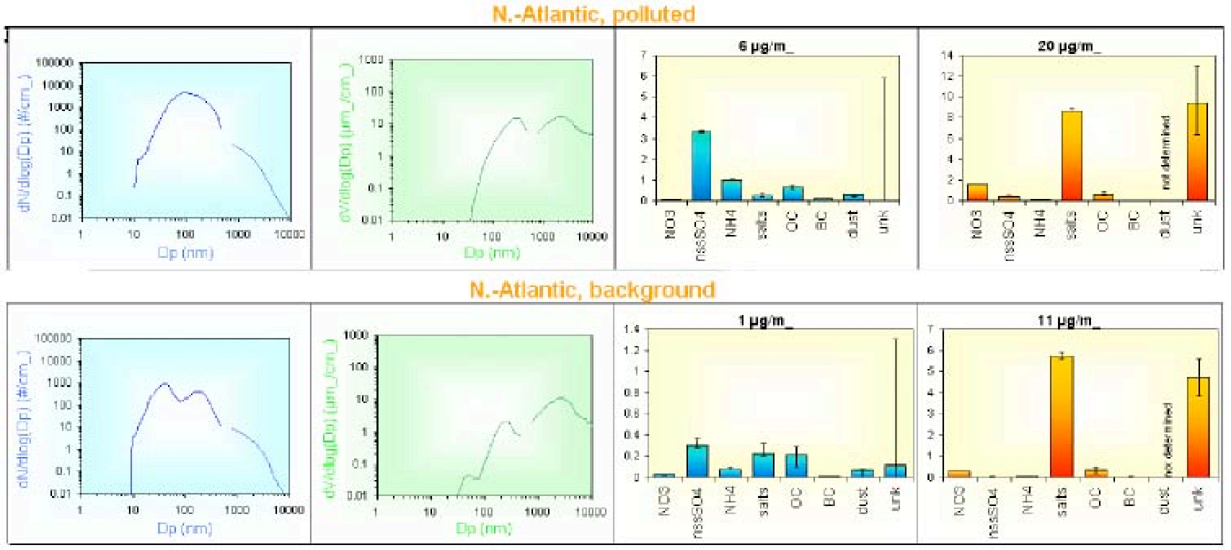
# Cloud Microphysics

Discussion: Are we still “searching under the streetlight”? If so, what new things do we need to know?

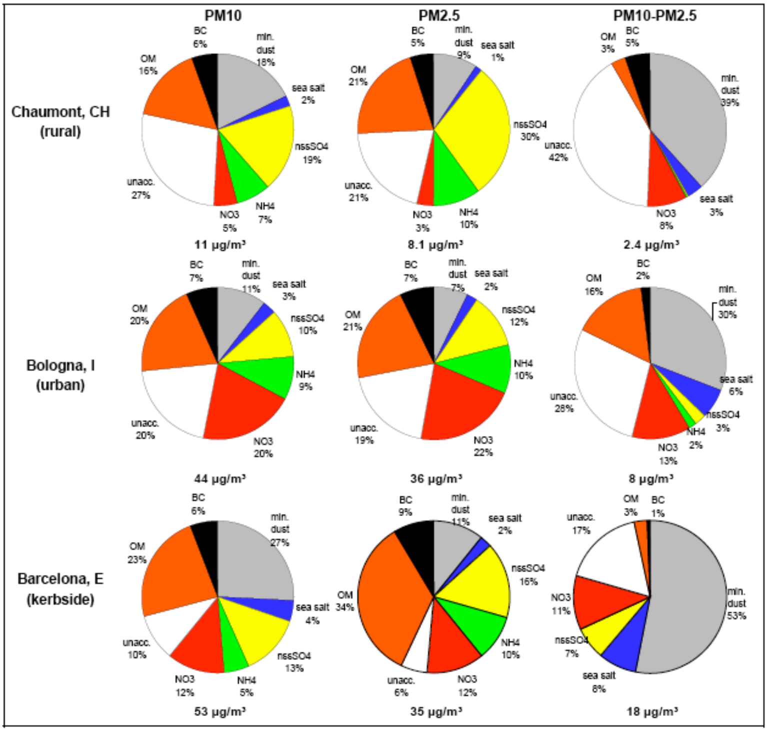
# Aerosol Properties

What do we want to know about aerosol chemistry, microphysics and optics?

# Aerosol Chemistry



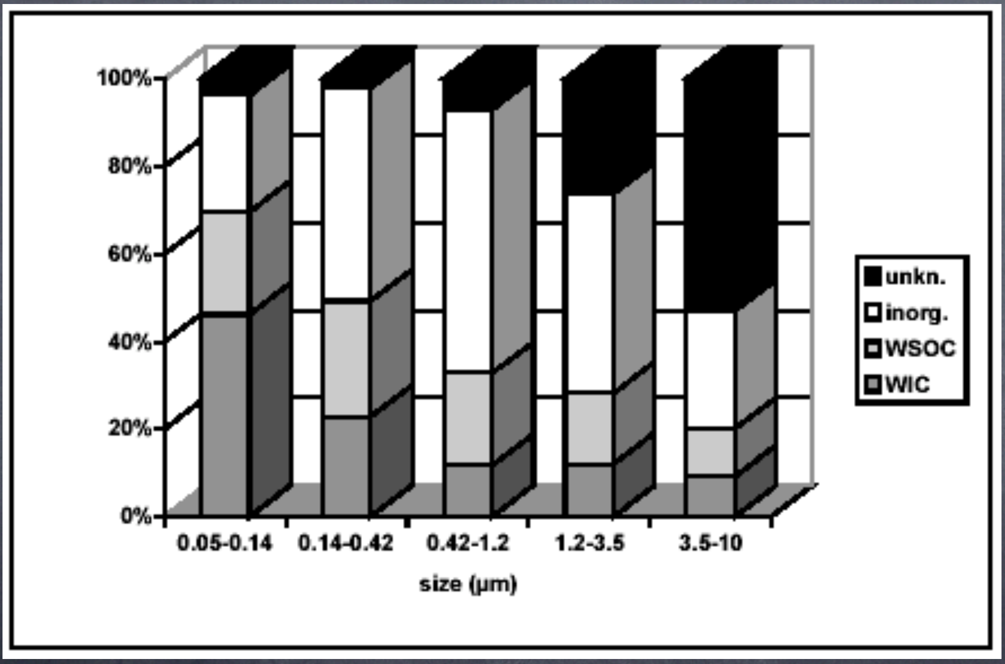
# Aerosol Chemistry



Putaud, et al. (2002) http://ies.jrc.cec.eu.int/Download/cc

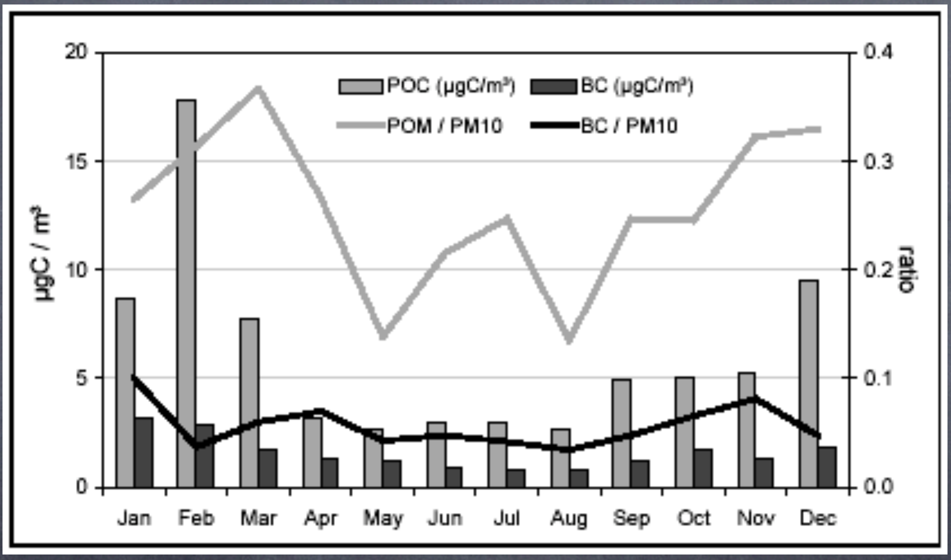
From Noone, et al., Tropospheric Aerosols and Clouds, in Towards Cleaner Air for Europe - Science, Tools and Applications, edited by P.M. Midgley, P.J.H. Builtjes, R.M. Harrison, and K. Tørseth, pp. 157-194, Margraf Publishers, Weikersheim, 2003.

# Organic Aerosols



Data from the Po Valley, Italy
From Noone, et al., Tropospheric Aerosols and Clouds, in Towards Cleaner Air for Europe - Science, Tools and Applications, edited by P.M. Midgley, P.J.H. Builtjes, R.M. Harrison, and K. Tørseth, pp. 157-194, Margraf Publishers, Weikersheim, 2003.

# Black & Organic Carbon



Data from Ispra, Italy (2000). From Noone, et al., Tropospheric Aerosols and Clouds, in Towards Cleaner Air for Europe - Science, Tools and Applications, edited by P.M. Midgley, P.J.H. Builtjes, R.M. Harrison, and K. Tørseth, pp. 157-194, Margraf Publishers, Weikersheim, 2003.

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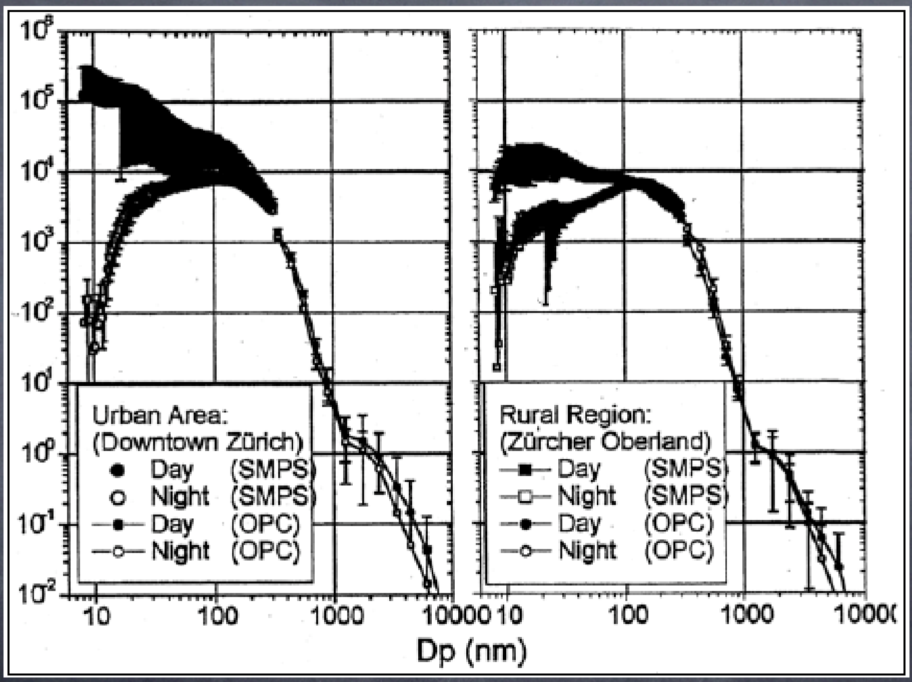


Data from Bukowiecki et al., 2002. From Noone, et al., Tropospheric Aerosols and Clouds, in Towards Cleaner Air for Europe - Science, Tools and Applications, edited by P.M. Midgley, P.J.H. Builtjes, R.M. Harrison, and K. Tørseth, pp. 157-194, Margraf Publishers, Weikersheim, 2003.

# Aerosol Sampling Challenges

- Many chemical species (e.g., ionic, elemental, organic)
- Wide range of sizes - nanometers to hundreds of micrometers
- Aerosols are a matrix quantity rather than a scalar one
- Very different conditions inside and outside the aircraft

# Aerosol Inlets

Getting stuff from **outside** the aircraft to **inside** where you can do something with it

# Inlet Issues

- VERY different conditions outside aircraft, in inlet system, and inside aircraft
- Calibrating inlets and characterizing losses
- Gases, particles, droplets and crystals: what to do with them all?
- Inlet placement: we all want good seats on the plane

# Stokes Number

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

Small Stokes numbers: particles behave like gases

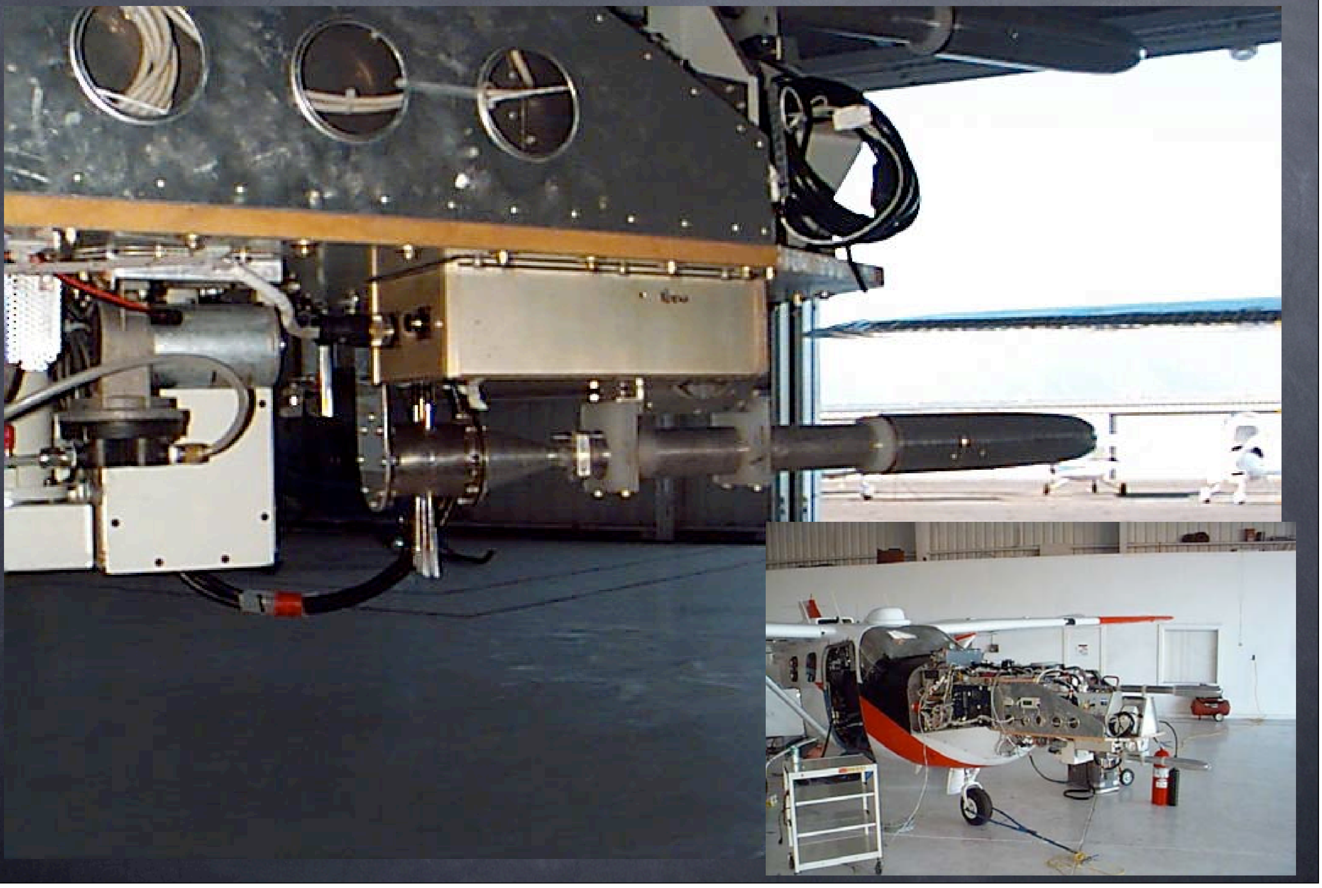
Large Stokes numbers: particles behave like rocks

# Inlets - Citation

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

Photo: Johan Ström

# Isokinetic Inlet



# Snoopy Inlets

What's on the other side?

# Snoopy Front Cabin

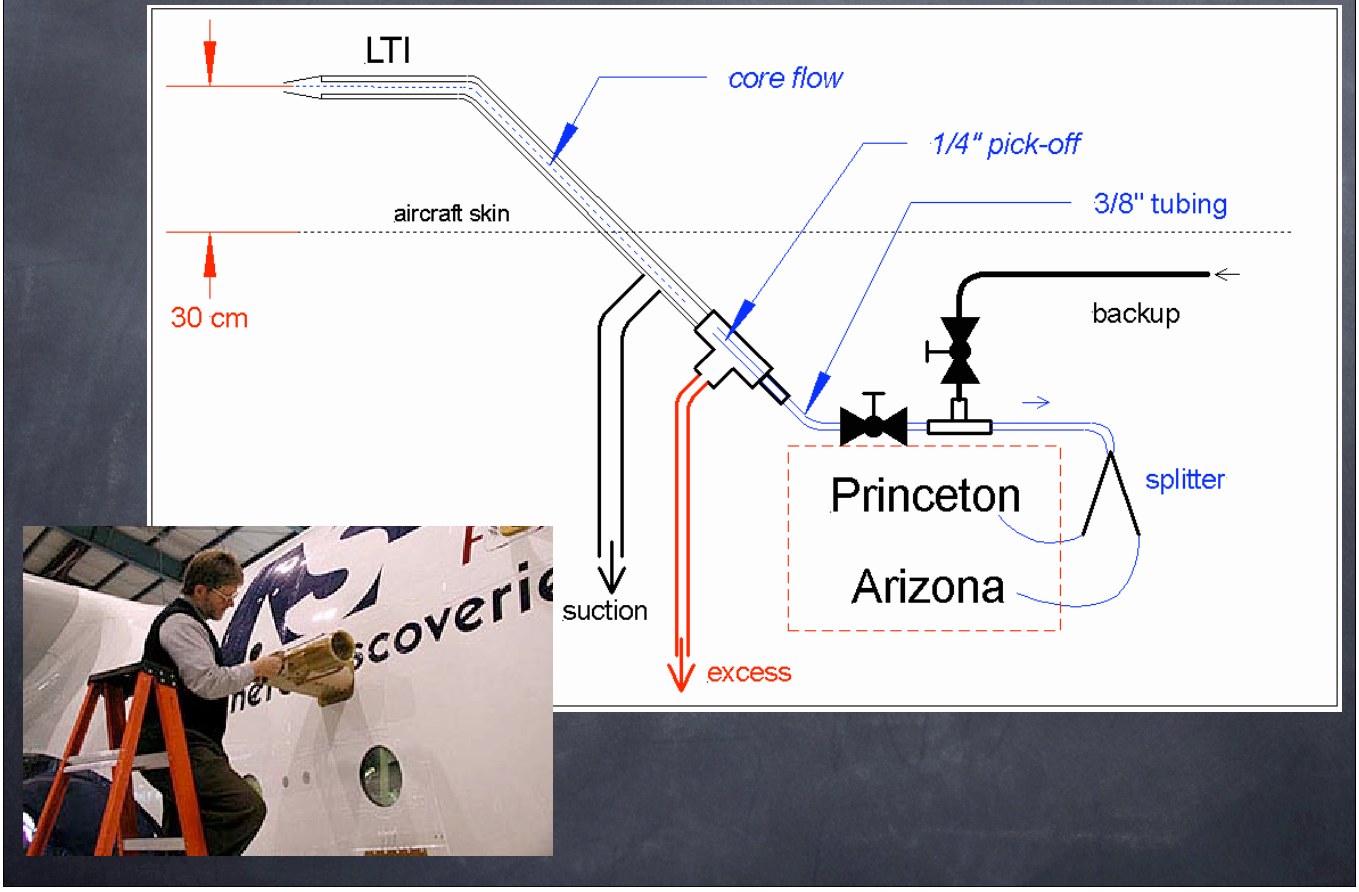
VACC CVI CCN

# Snoopy Front Cabin

VACC

# MRF FSSPs & PVM

# Low Turbulence Inlet



# Low Turbulence Inlet

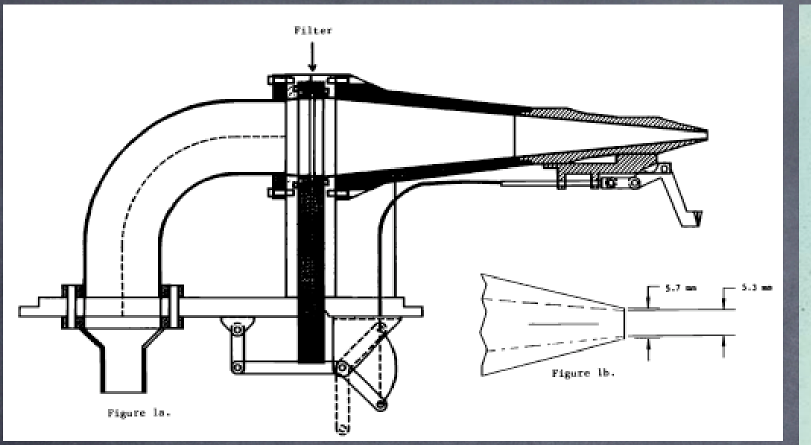
# Aerosol Inlets

Discussion: What can we do to make aerosol inlets more intercomparable?

# Aerosol Chemistry

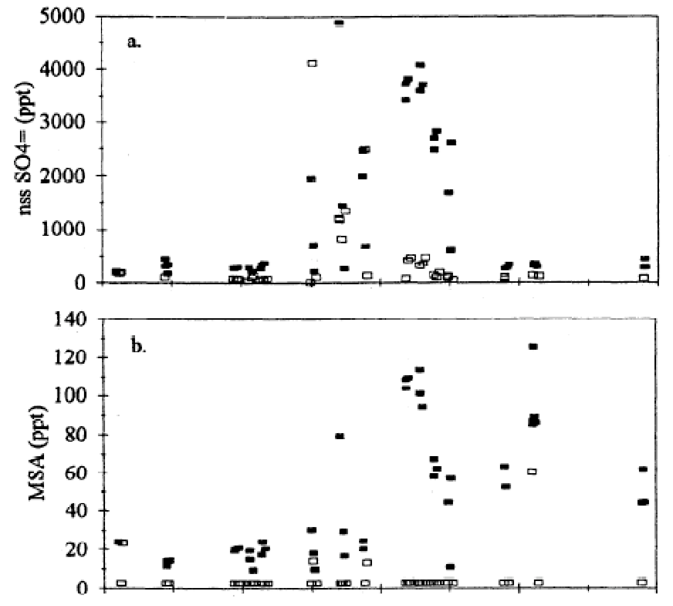
Filter-based measurements, wet chemistry, single particle analysis, mass spectrometry

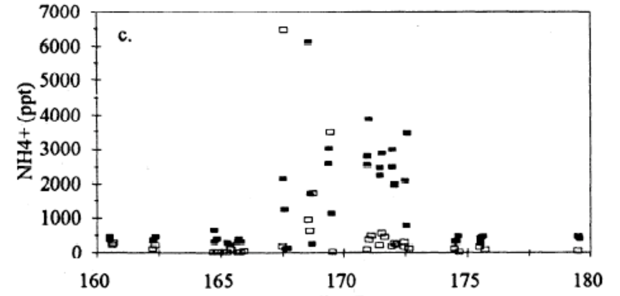
# Airborne Filter Samplers



Heubert, et al., JGR 95 (D10), 1990

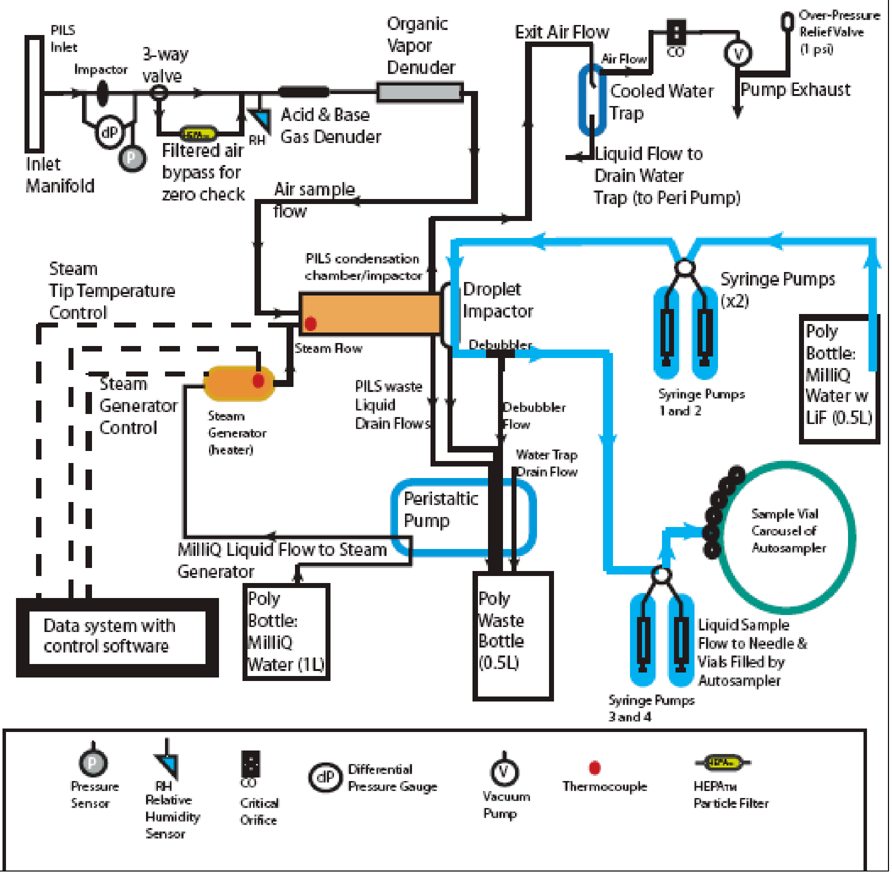
# Airborne Filter Samplers





Heubert, et al., JGR 101 (D2), 4413-4423, 1996

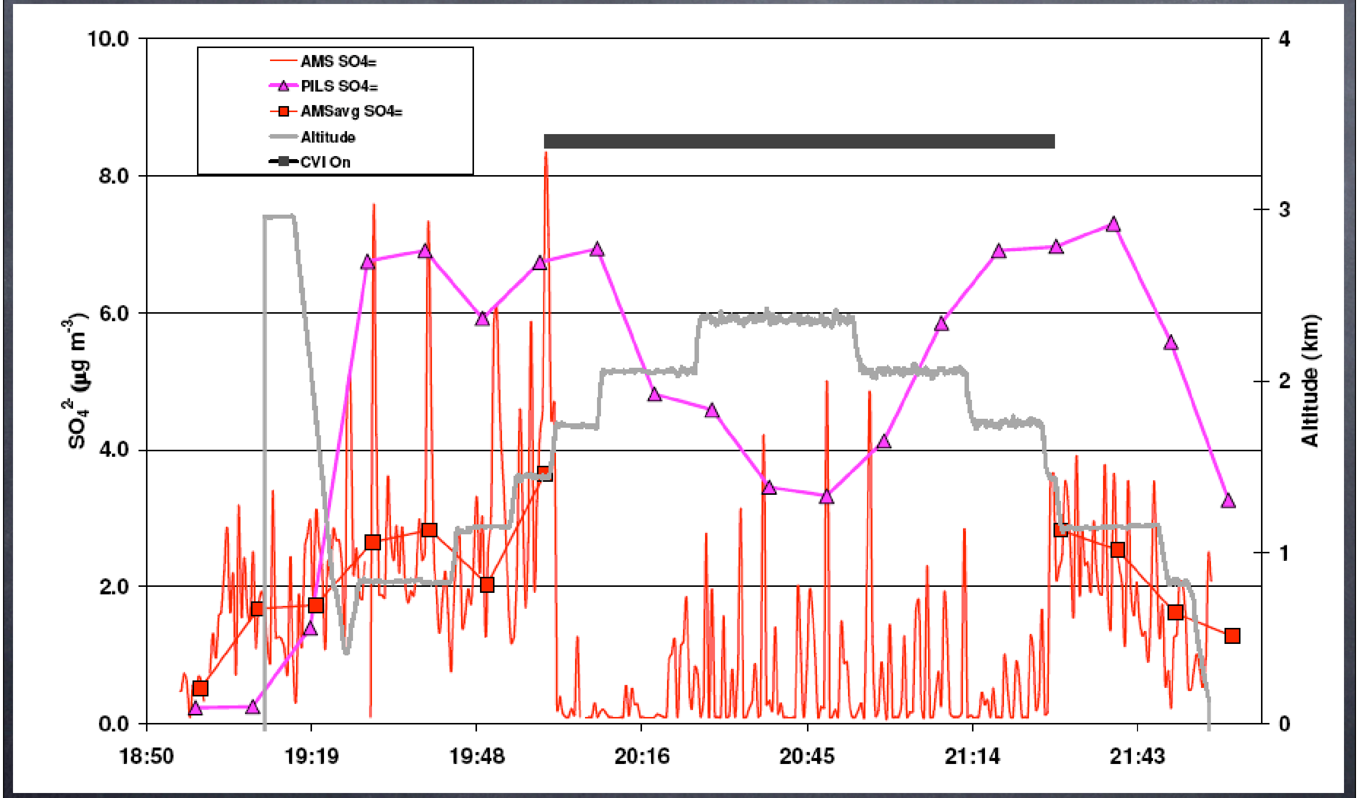
# Particle Into Liquid Sampler (PILS)



**Brechtel Manufacturing, Inc.**
1789 Addison Way, Hayward, CA 94544
Phone: (510) 732-9723
Fax: (510) 732-9153
www.brechtel.com
bmi_info@brechtel.com

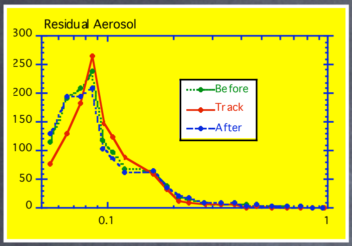
# Convair 580 - ICARTT

# Particle Into Liquid Sampler (PILS)



Hayden, et al., JGR, in press

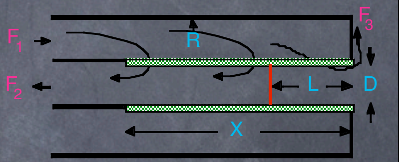
# Counterflow Virtual Impactor

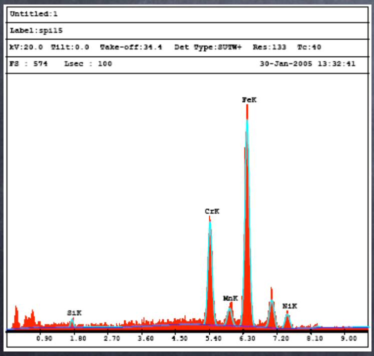


PCASP

Condensation Particle
Counter (CPC)

Cloud Droplet
Residual Particles





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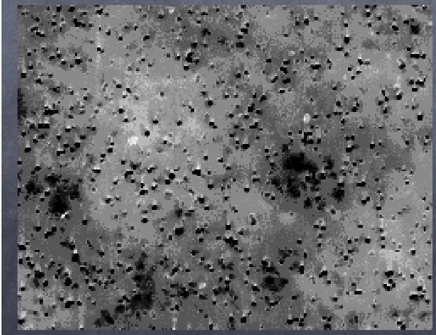
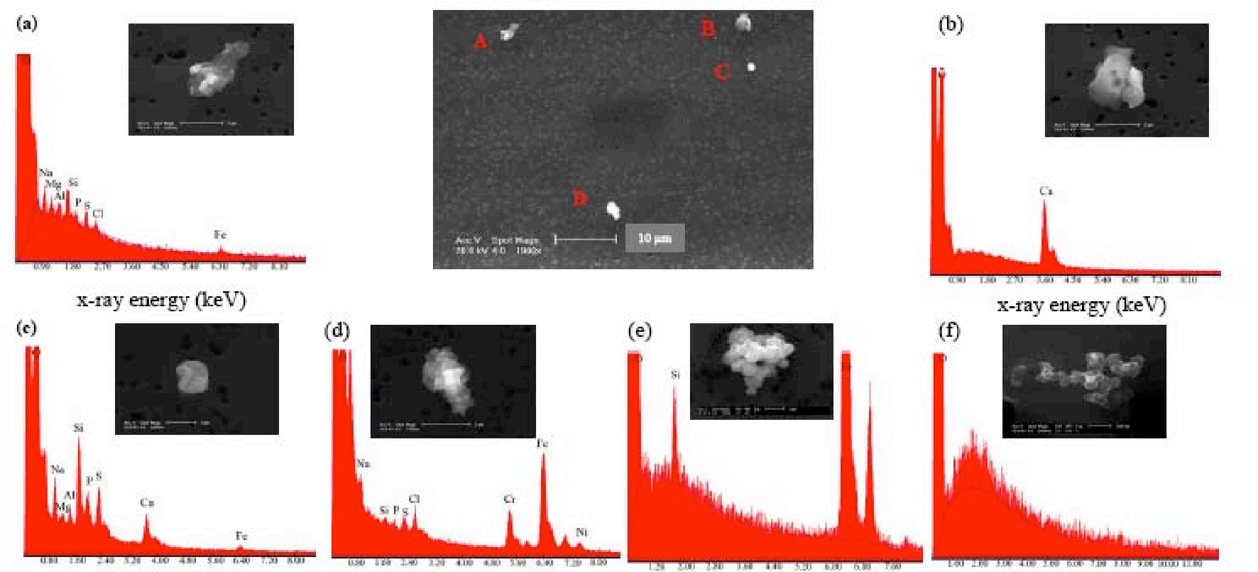
Untitled:1
Label:spi15
kV:20.0  Tilt:0.0  Take-off:34.4  Det Type:SUTW+  Res:133  Tc:40
FS : 574   Lsec : 100                      30-Jan-2005 13:32:41
```



Filter/SPA

# Single Particle Analysis



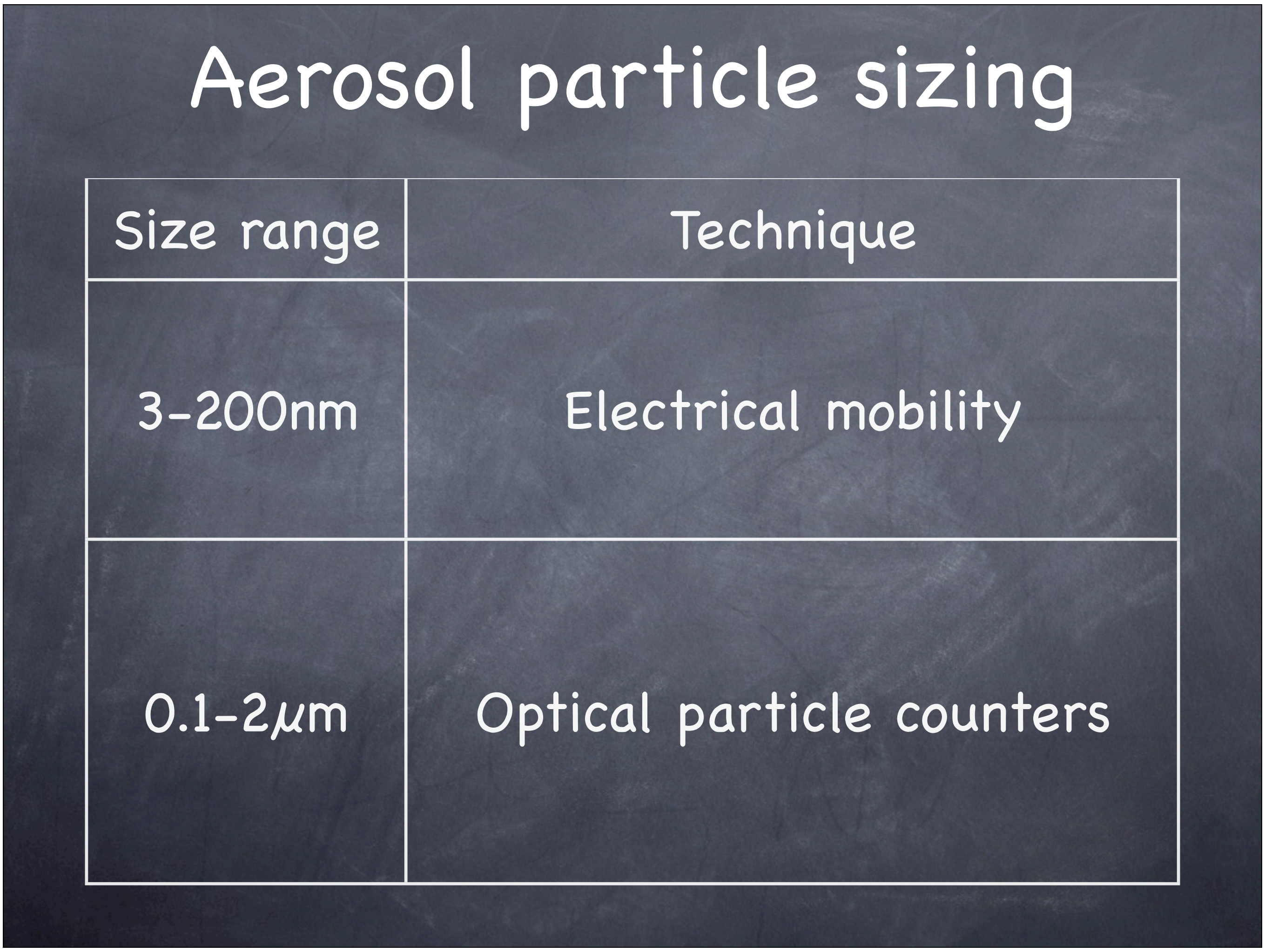
Targino et al., Atmos. Chem. Phys. 6 (2006) 1977-1990

# Aerosol Inlets

Discussion: What can we do to make aerosol inlets more intercomparable?

# Aerosol Microphysics

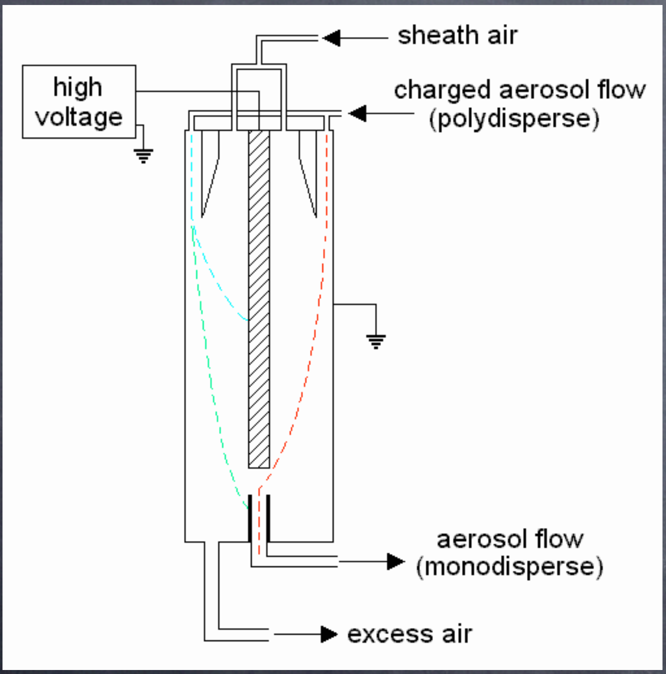
## Optical, electrical and other methods



# Aerosol particle sizing

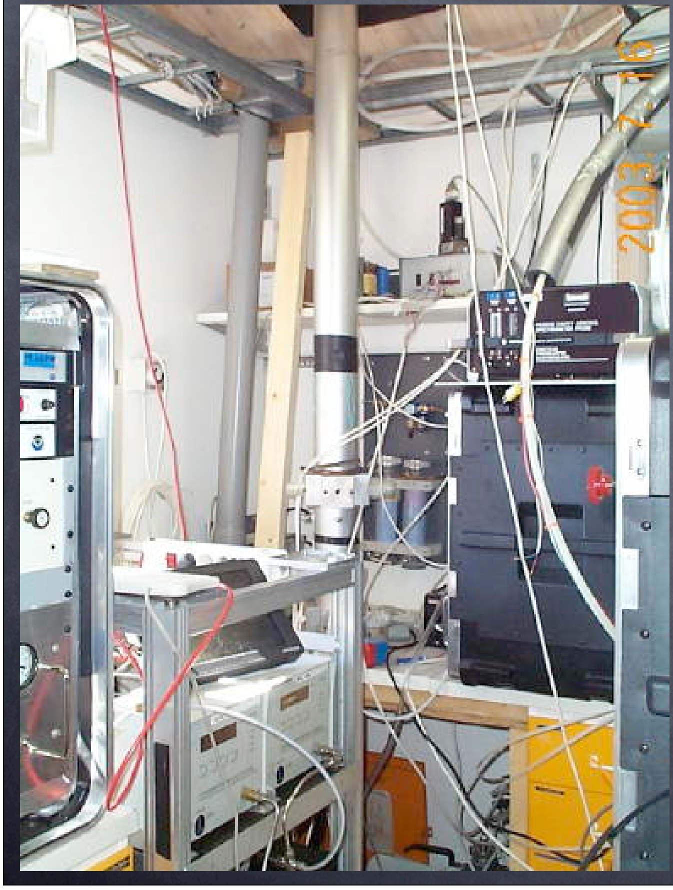
| Size range | Technique |
|---|---|
| 3-200nm | Electrical mobility |
| 0.1-2μm | Optical particle counters |

# Differential Mobility Analyzer



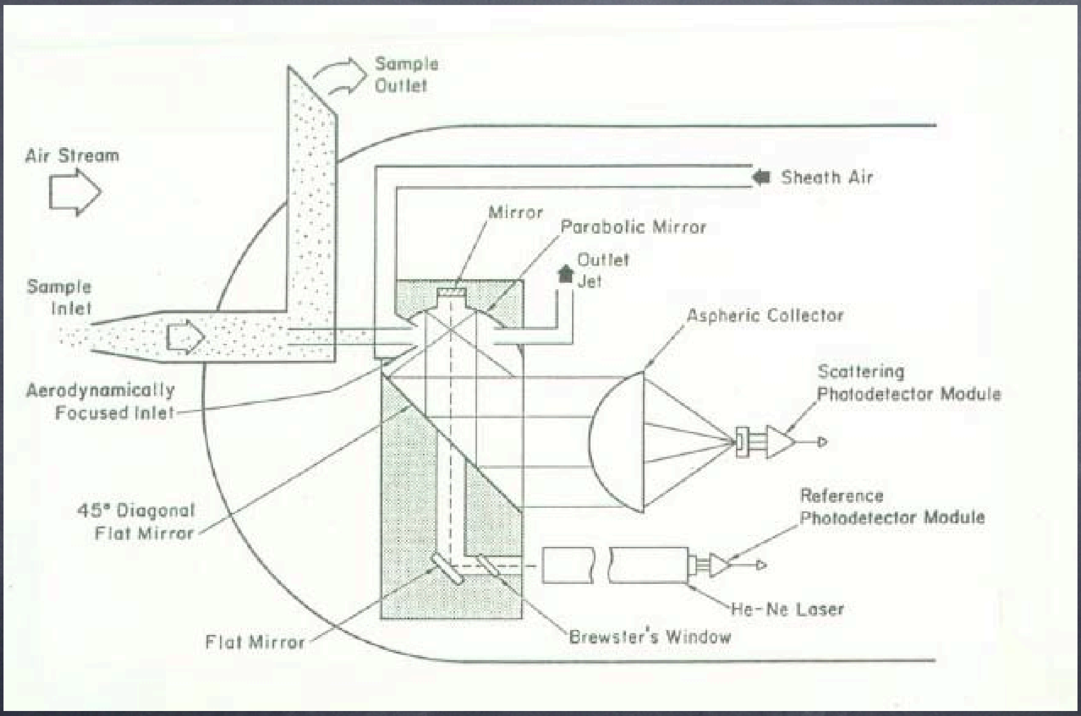
www.particleinstruments.com/ pics/ nanoranger.jpg

# Passive Cavity OPC



- Uses 632nm laser to illuminate particles
- sizes single particles between ca. 0.1 to 3$\mu$m
- sensitive to shape, refractive index

# Passive Cavity OPC



# Aerosol Microphysics

Discussion: What is the airborne particle sizing instrument dream team? What differences do you expect between land-based sampling and airborne sampling?