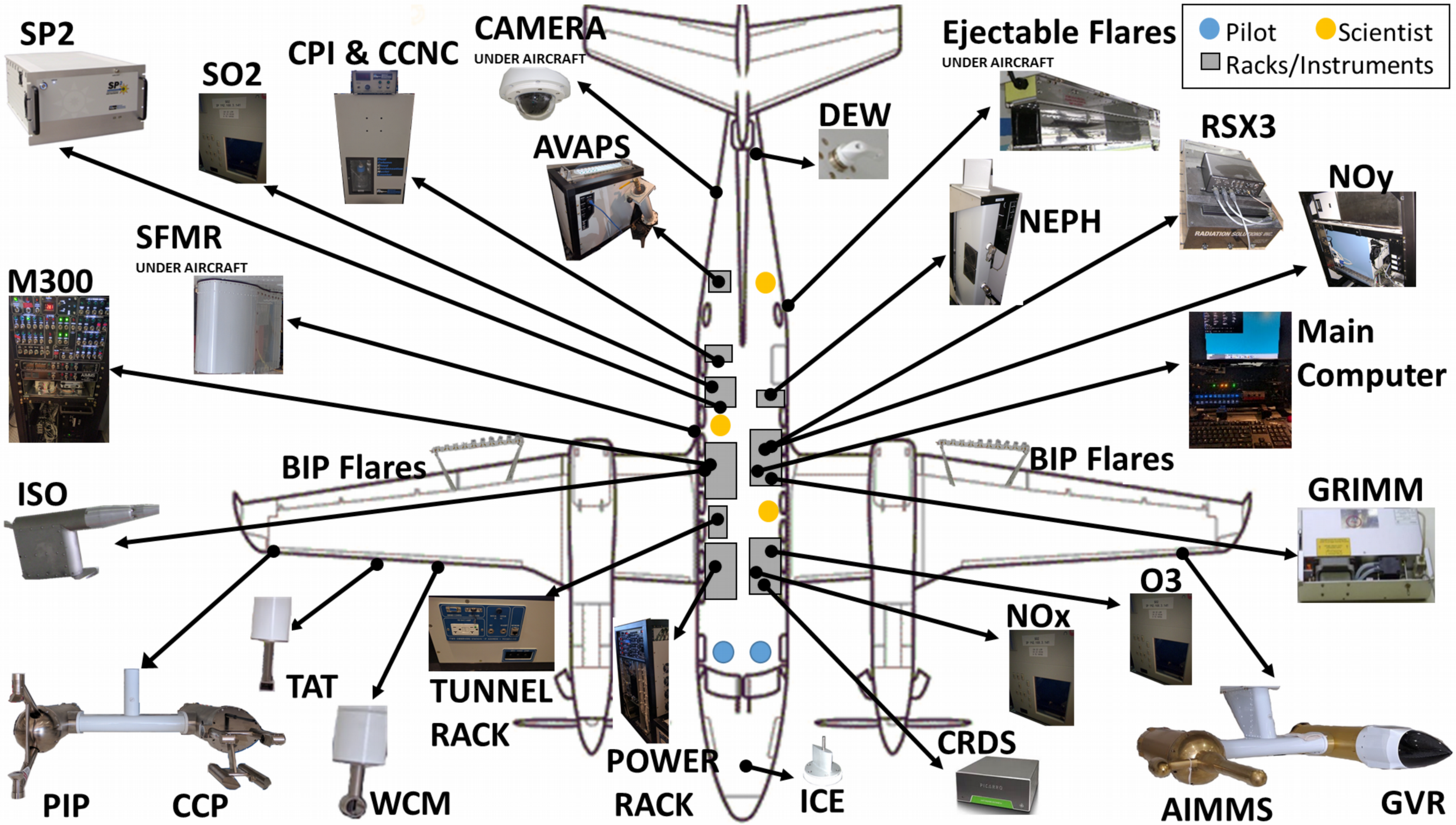
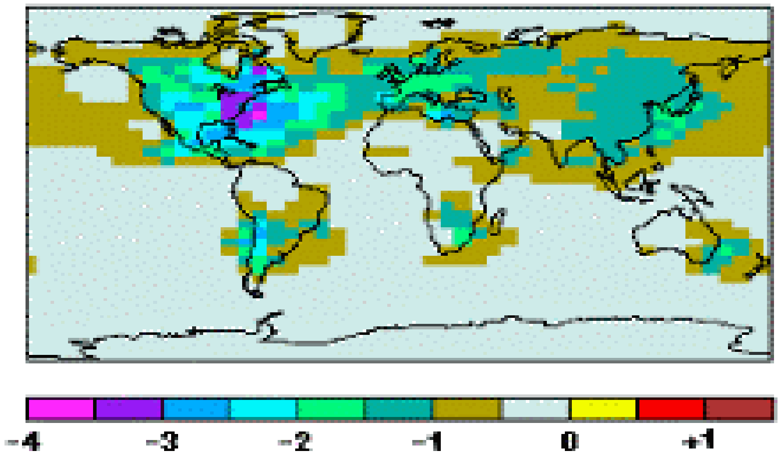
Aerosols: Flights, Theory, and Data



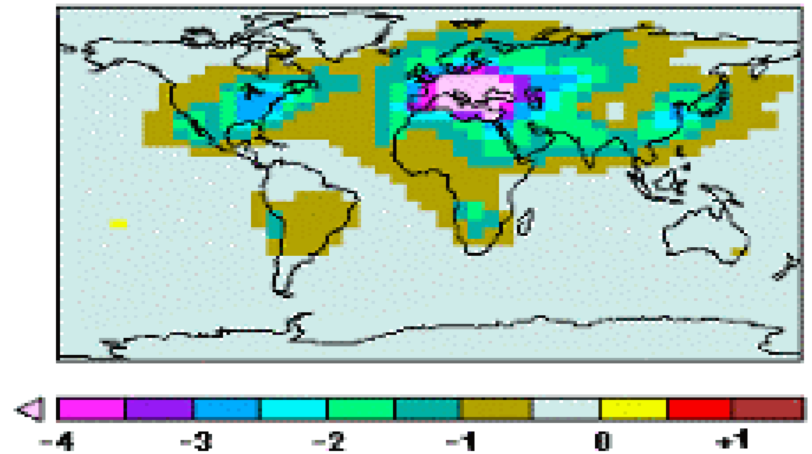
Dr. David Delene
University of North Dakota

Aerosol Importance

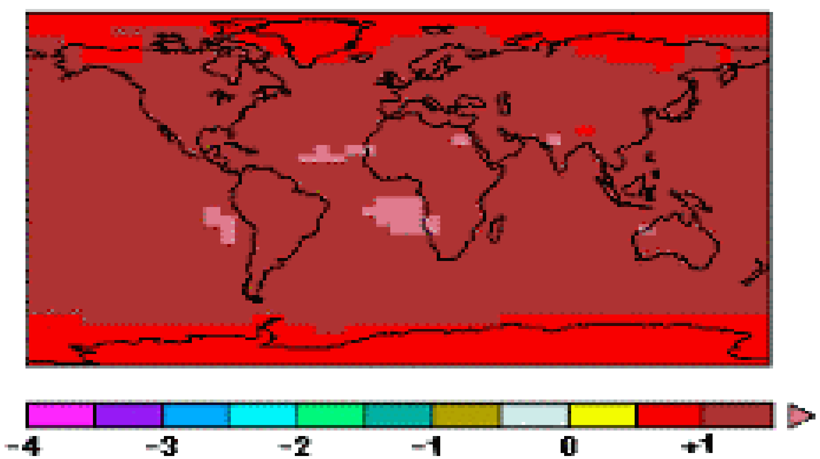
Indirect Forcing



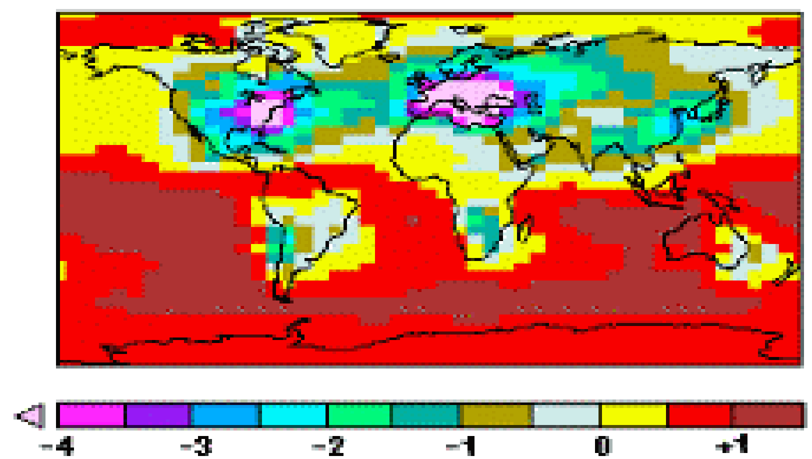
Direct Forcing



Carbon Dioxide Forcing



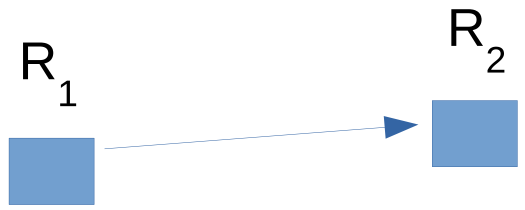
Total Forcing



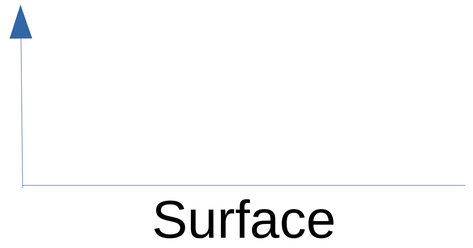
Climate forcing predicted from the Lawrence Livermore National Laboratory Global Aerosol Model [Catherine C. Chuang and Joyce E. Penner].

Aerosol Variability

- **Regional Variability**

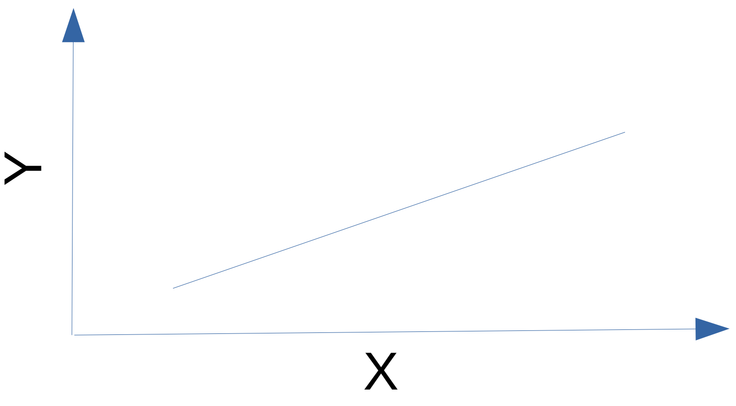


- **Vertical Variability**

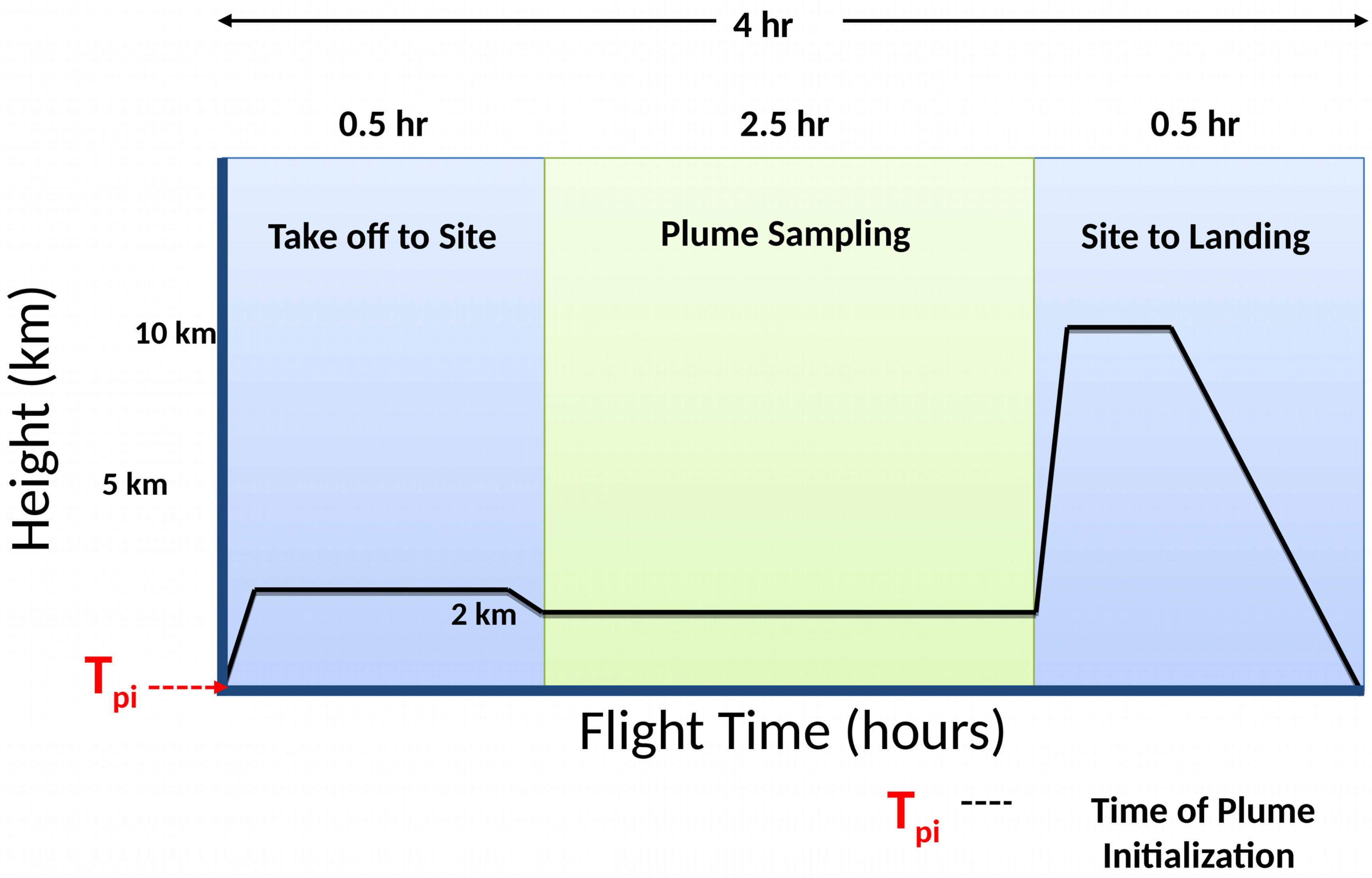


- **Temporal Variability**

- **Systematic Relationships**

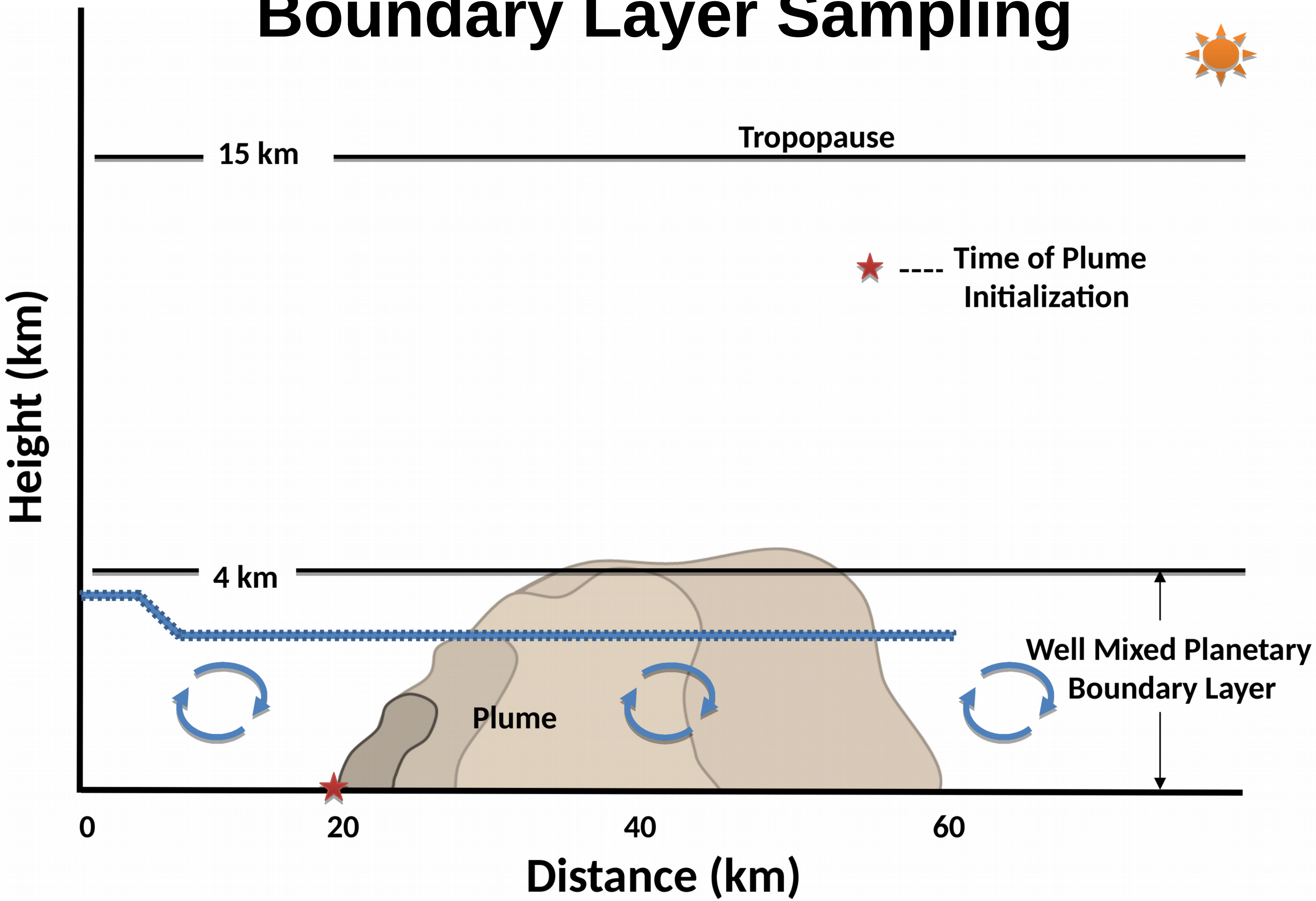


Flight Planning: Aerosol Missions



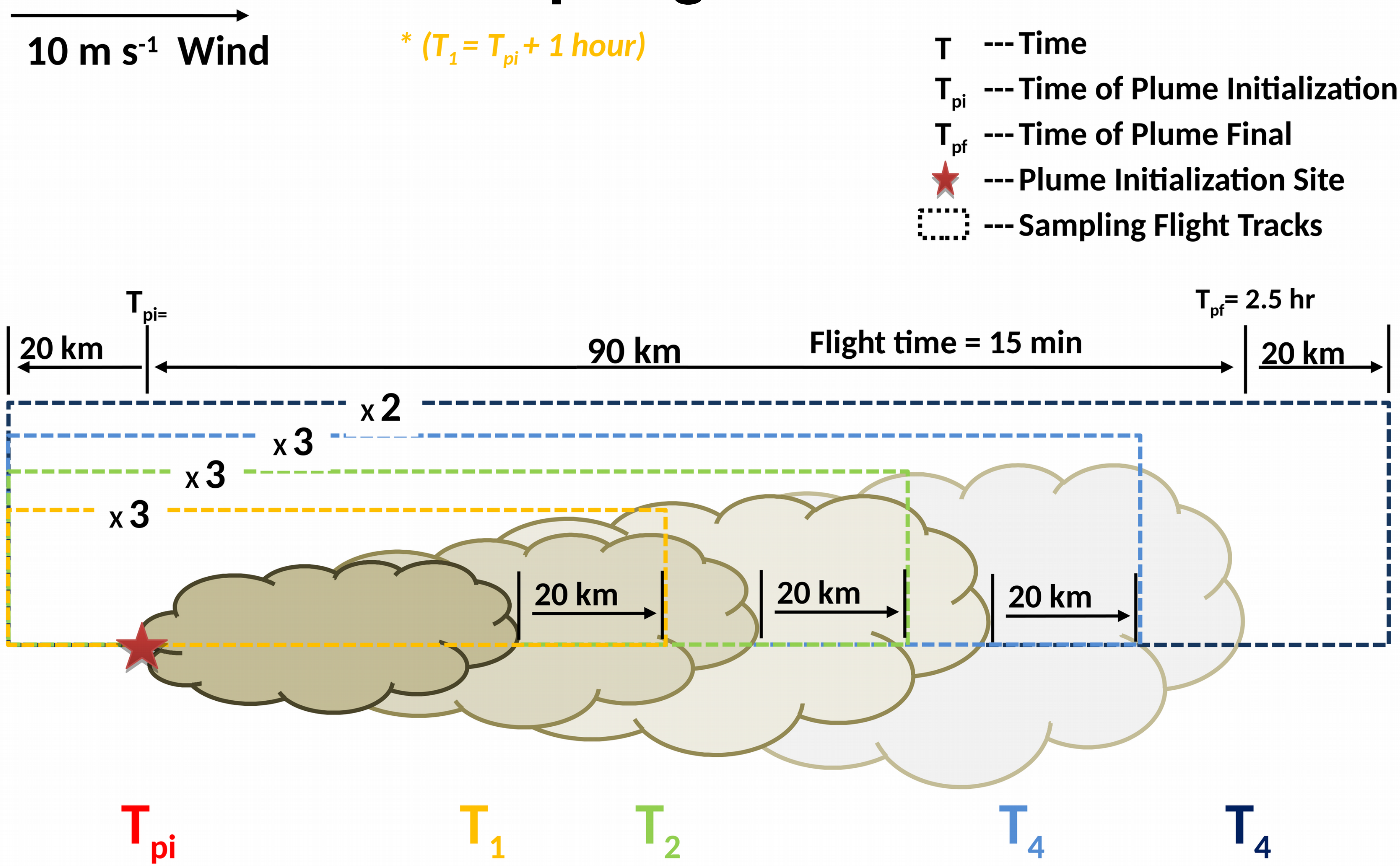
- Stay low after take off for good CCN counter measurements, but can return high.

Boundary Layer Sampling



- Sampling a large plume from a city or forest fire.

Plume Sampling: Horizontal View



- Develop operations plan with clear objectives and methods for data sampling to obtain required measurements.

Definition of Aerosols

- Suspended Solid or Liquid Matter
- Small Settling Velocity

- Aerosols have residence times of days, to weeks.
- Atmospheric Aerosols are sometimes referred to as “particles”.

Image by Fred Remer, Saturday August 29, 2015 at 8000 ft over Devils Lake

Atmospheric Aerosol Size Range

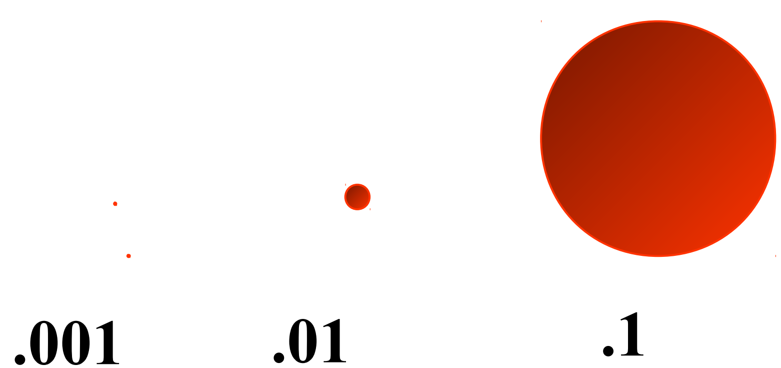
10^{-9}m to 10^{-5} m

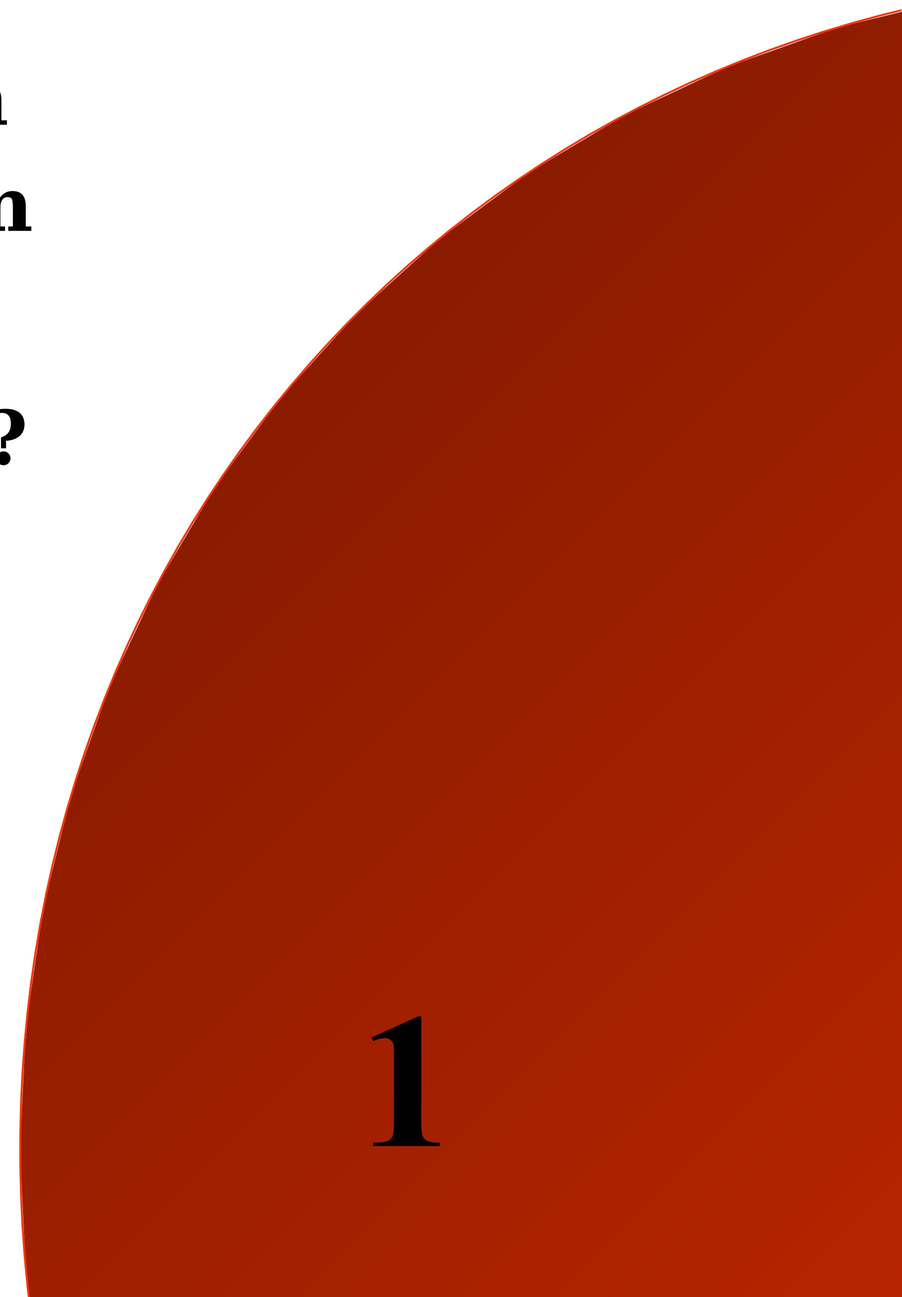
.001 µm to 10 µm

1 nm to 10,000 nm

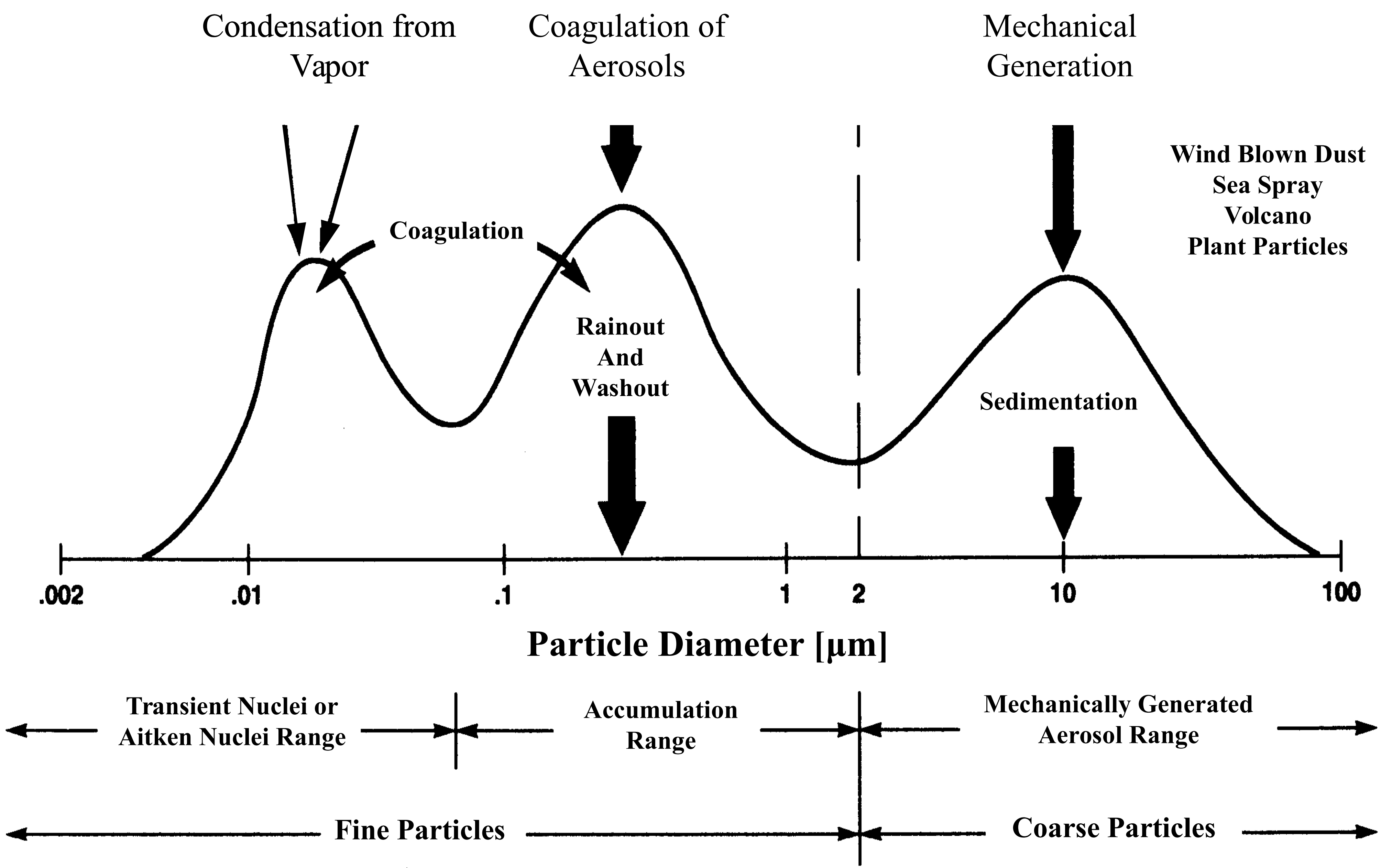
Wavelength of Visible Light?

Size of a human hair?



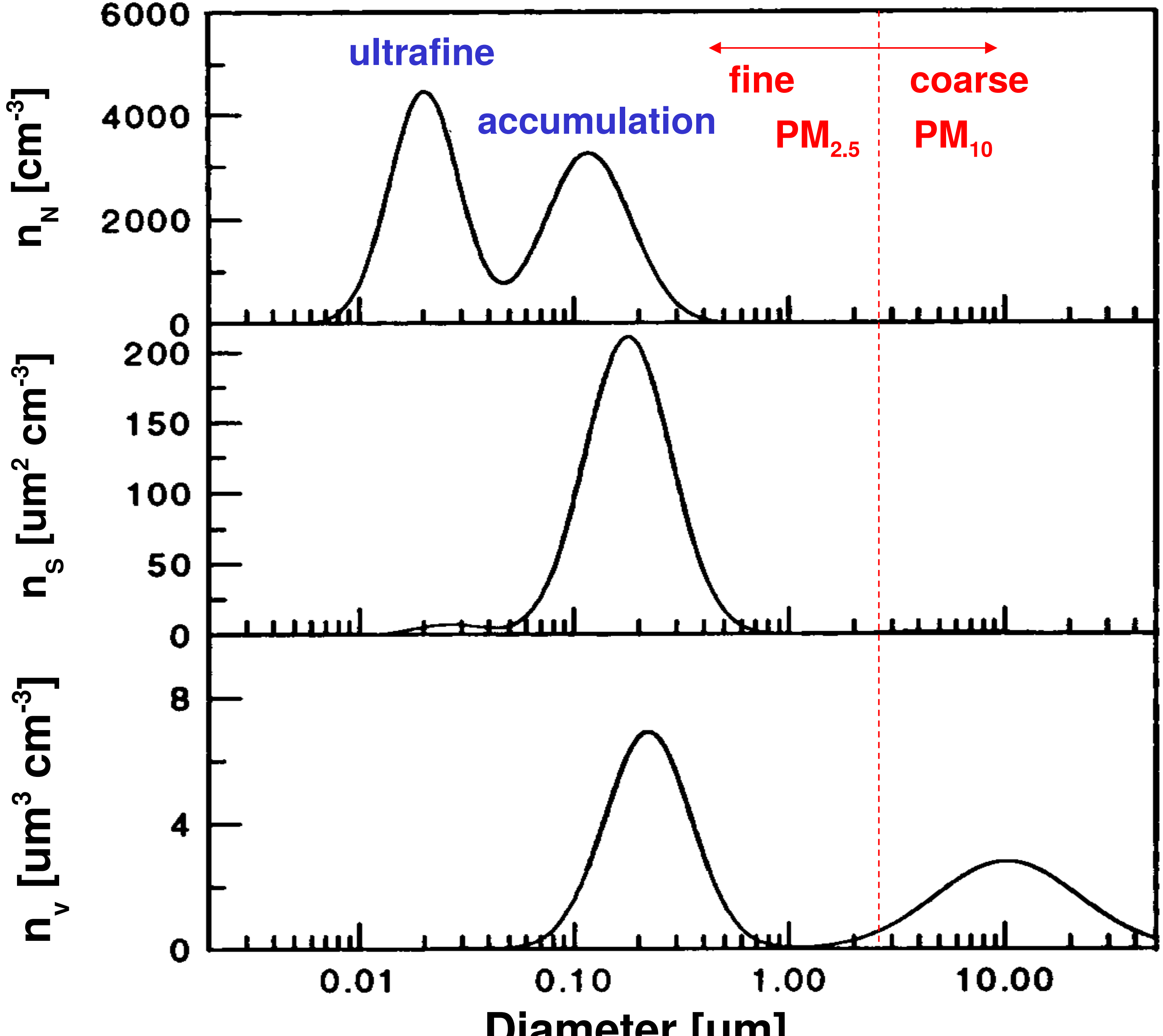


Aerosol Modes



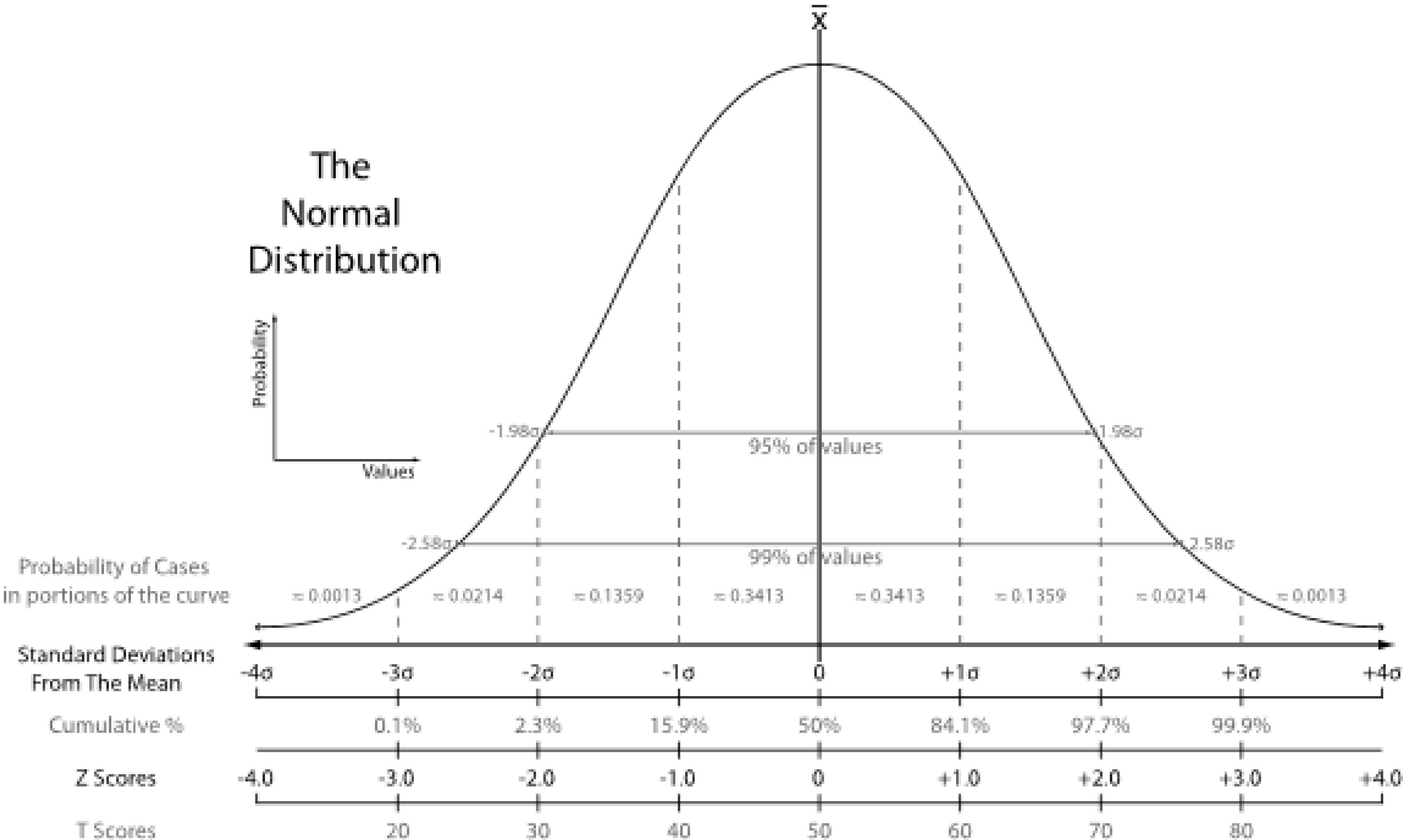
Adapted from Singh: Figure 5.4

Aerosol Size Distribution



Courtesy of Daniel J. Jacob

Normal Distribution



Lognormal Distribution

- **Normal distribution has the characteristic bell shape, with maximum at the average ($\bar{u}$)**

- **Log-normal distribution is a distribution whose logarithm (natural log of u) is normally distributed. Appears as a normal distribution when x-axis is plotted on log scale.**

- **The log -normal distribution is a maximum entropy probability distribution.**
  - **Many physical systems tend to move towards maximal entropy configurations over time.**

Instrumentation Based Aerosol Definitions

Ultrafine Aerosols (UF)

- **Aerosols larger than 3 nm diameter.**

Condensation Nuclei (CN)

- **Aerosols larger than 10 nm diameter.**

Optical Aerosols ($D_{0.3}$)

- **Aerosols larger than 0.3 µm diameter.**

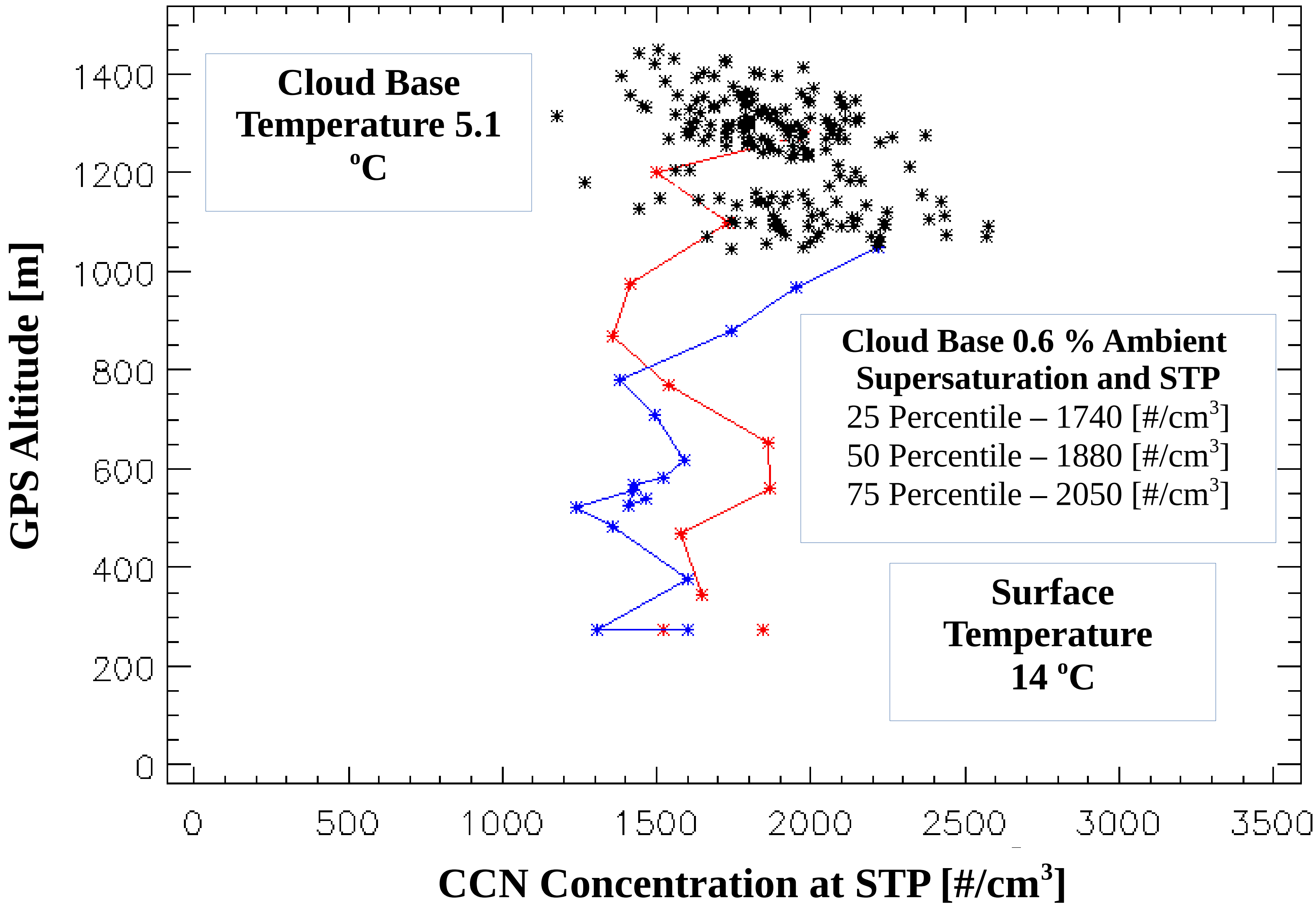
Cloud Condensation Nuclei (CCN)

- **Nuclei on which cloud droplets form.**

Ice Nuclei (IN)

- **Nuclei on which ice crystals form.**

July 8, 2012

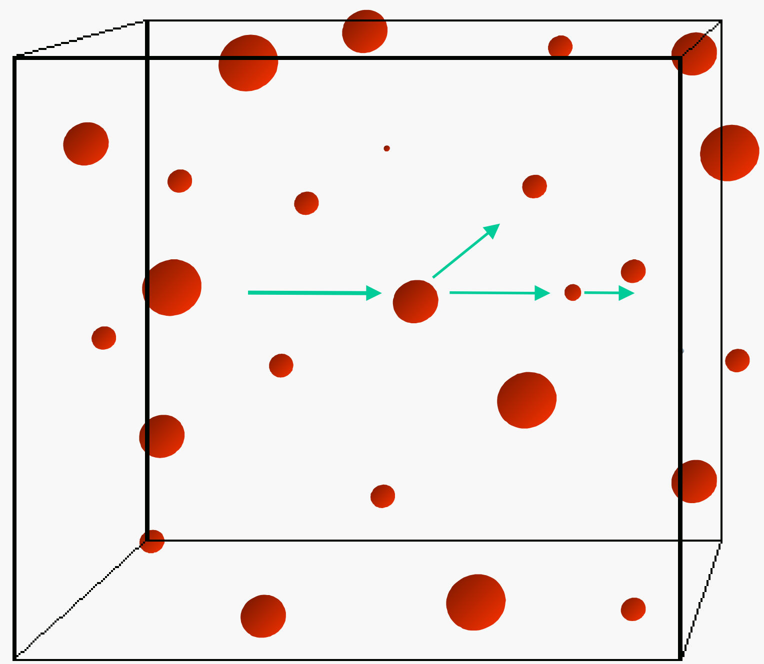


University of Wyoming cloud condensation nuclei (CCN) counter measurements (0.6 % ambient supersaturation) adjusted to standard pressure and temperature (STP) on aircraft ascent (red, 17:40:00-17:45:00 UTC), during cloud base sampling (black stars, 18:04:00-19:36:10) and during descent (blue, 19:36:20-19:56:40).

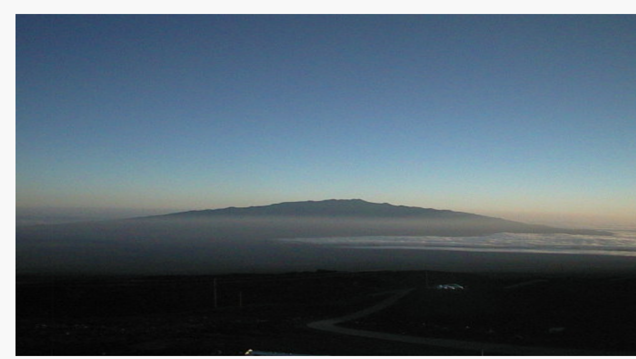
Light Scattering and Absorption by Aerosols

Volume of Air

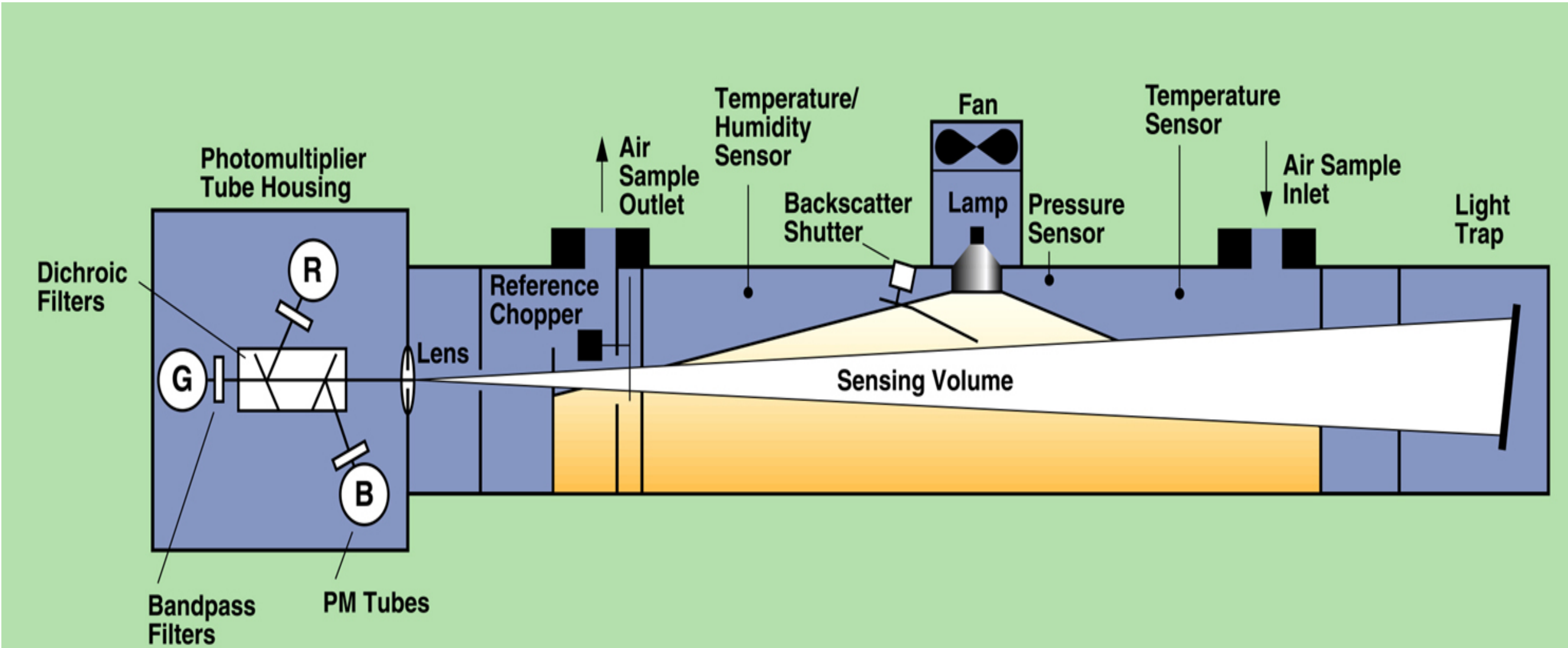
In Coming Light



Out Going Light



Integrating Nephelometer



TSI 3563 Nephelometer schematic courtesy of TSI Incorporated

Beer-Lambert Law

$$I / I_o = e^{(- \tilde{A}\, x)}$$

I_o = intensity of light source

I = intensity of light after passing through atmospheric path

x = thickness of medium through which light passes

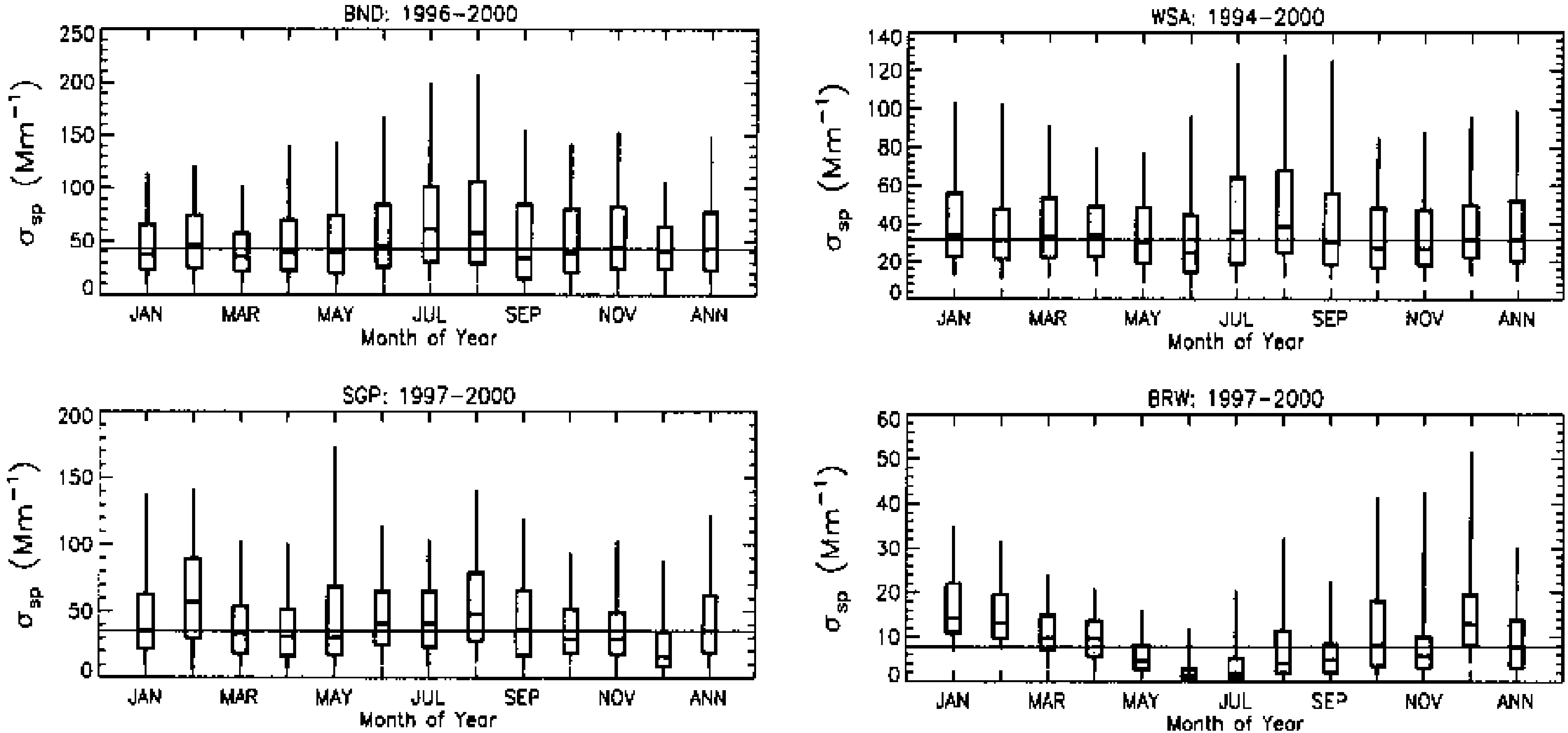
Ã = total **extinction coefficient** (scattering + absorption)

τ = Ã x = Optical Thickness

- What is optical depth?

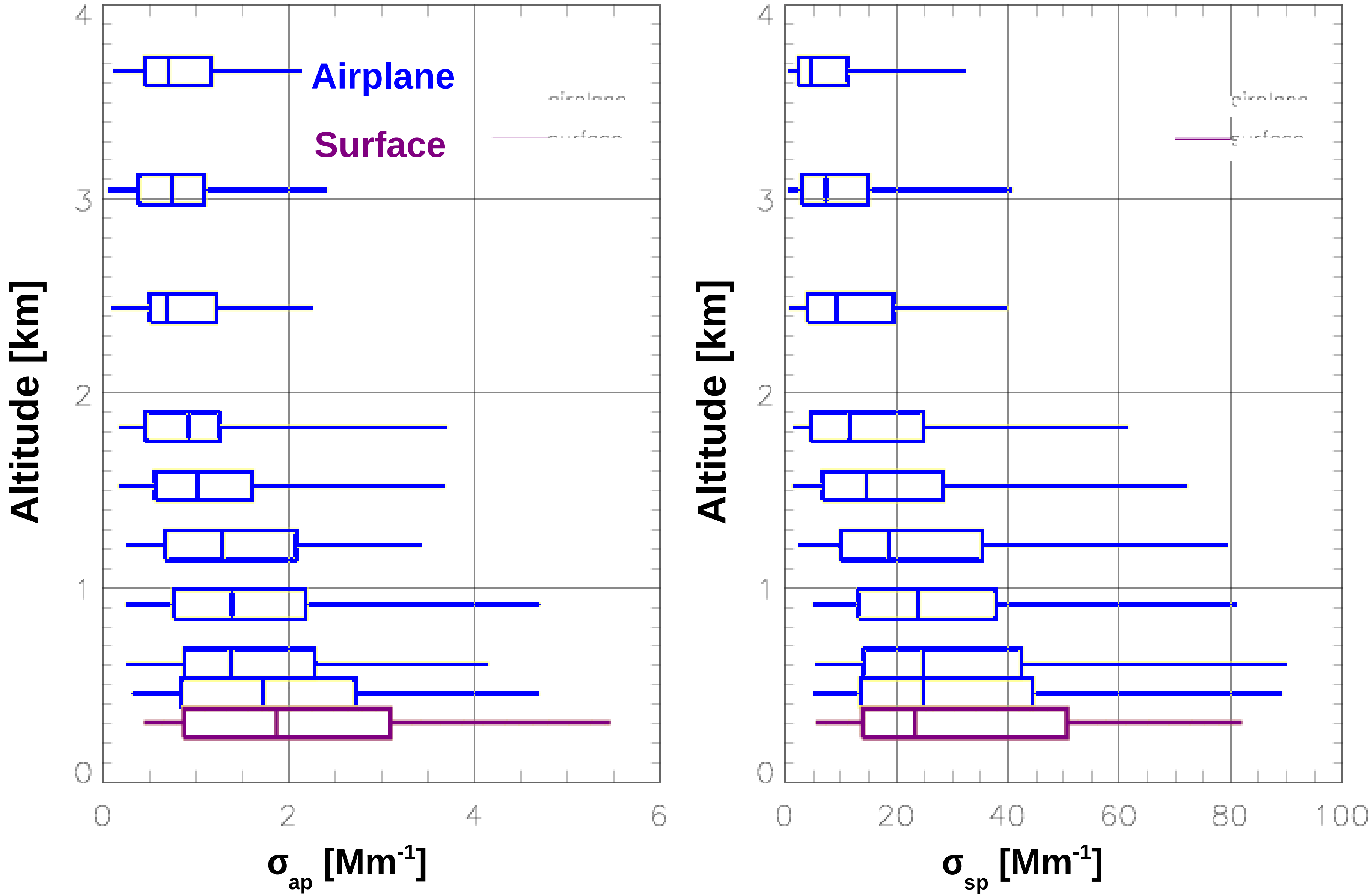
NOAA Aerosol Network

Seasonal and Regional Variability: Aerosol Scattering Coefficient



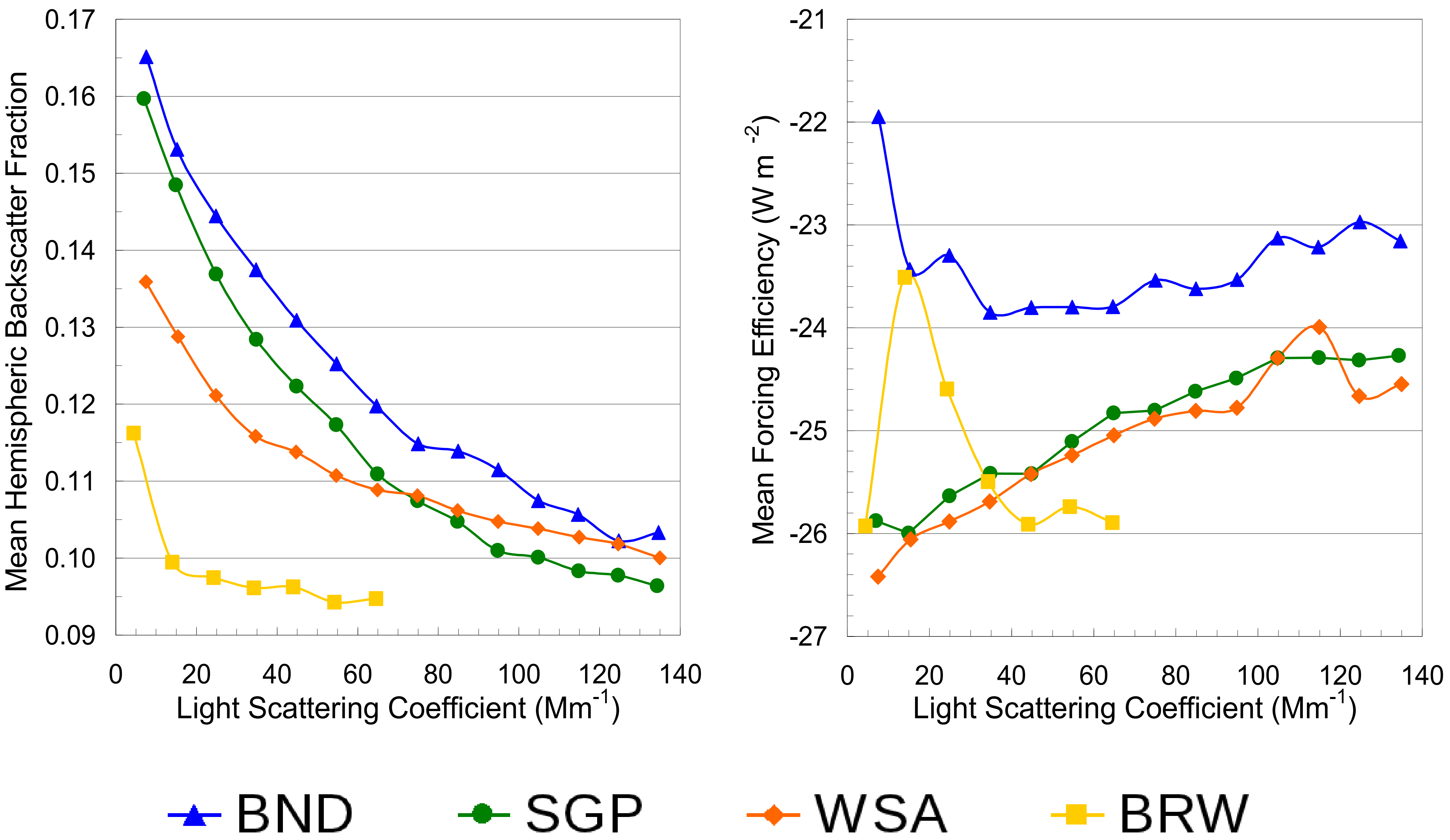
λ = 550 nm, D < 10 μm, RH < 40%

Vertical Variability



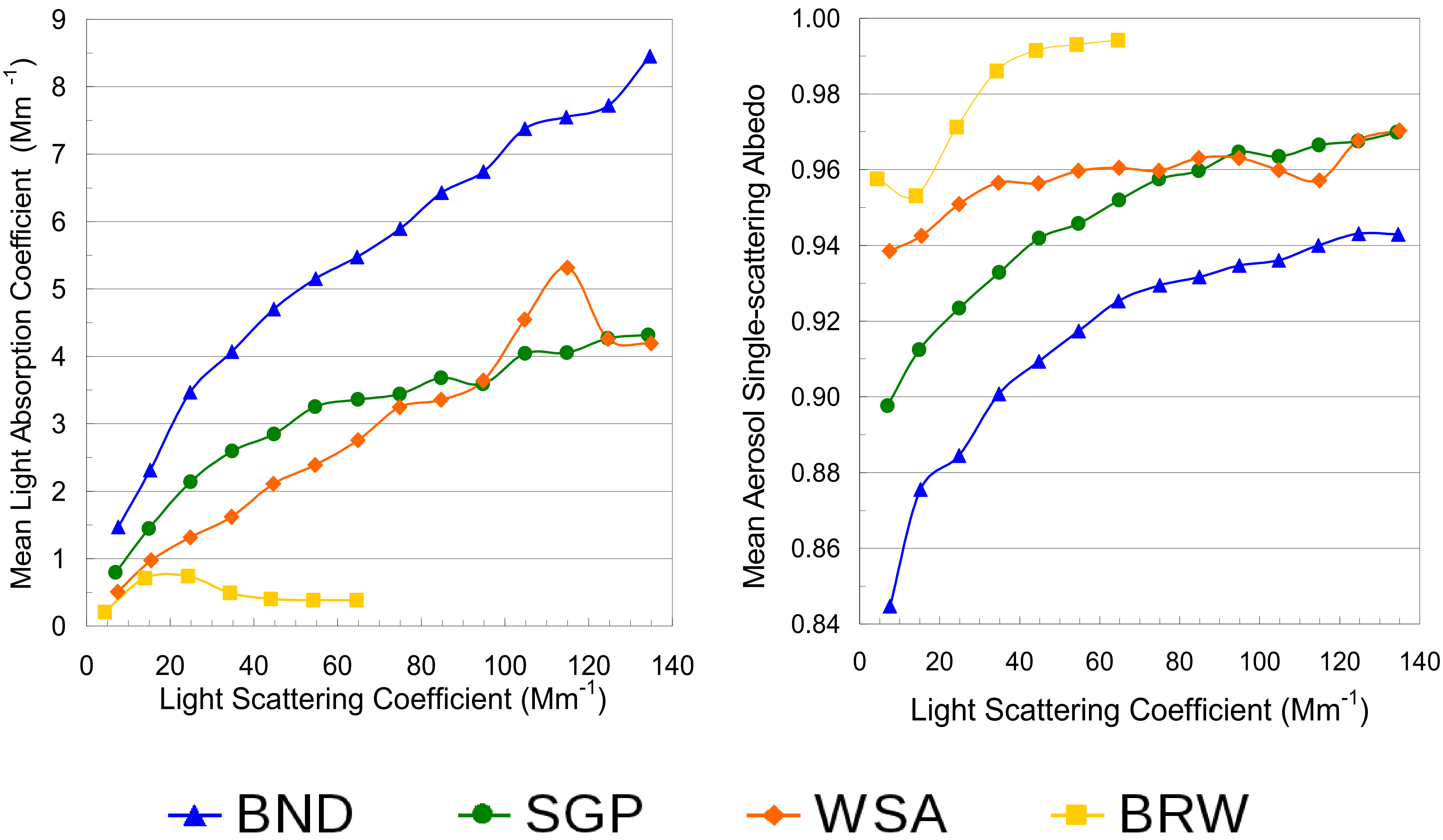
104 flights at SGP (March 25 – December 31, 2000)
Values are adjusted to STP, λ = 550 nm, D < 1 μm, RH < 40%

Systematic Relationships



λ=550 nm, D<10 μm, RH < 40%

Systematic Relationships



λ=550 nm, D<10 μm, RH < 40%

TSI Nephelometer (Neph)

Operating Principles – Total and Backscatter Light Scattering

Primary Measurements – Scattering Coefficient

Quality Control – Leak Check, Calibration with Zero Air and CO_2

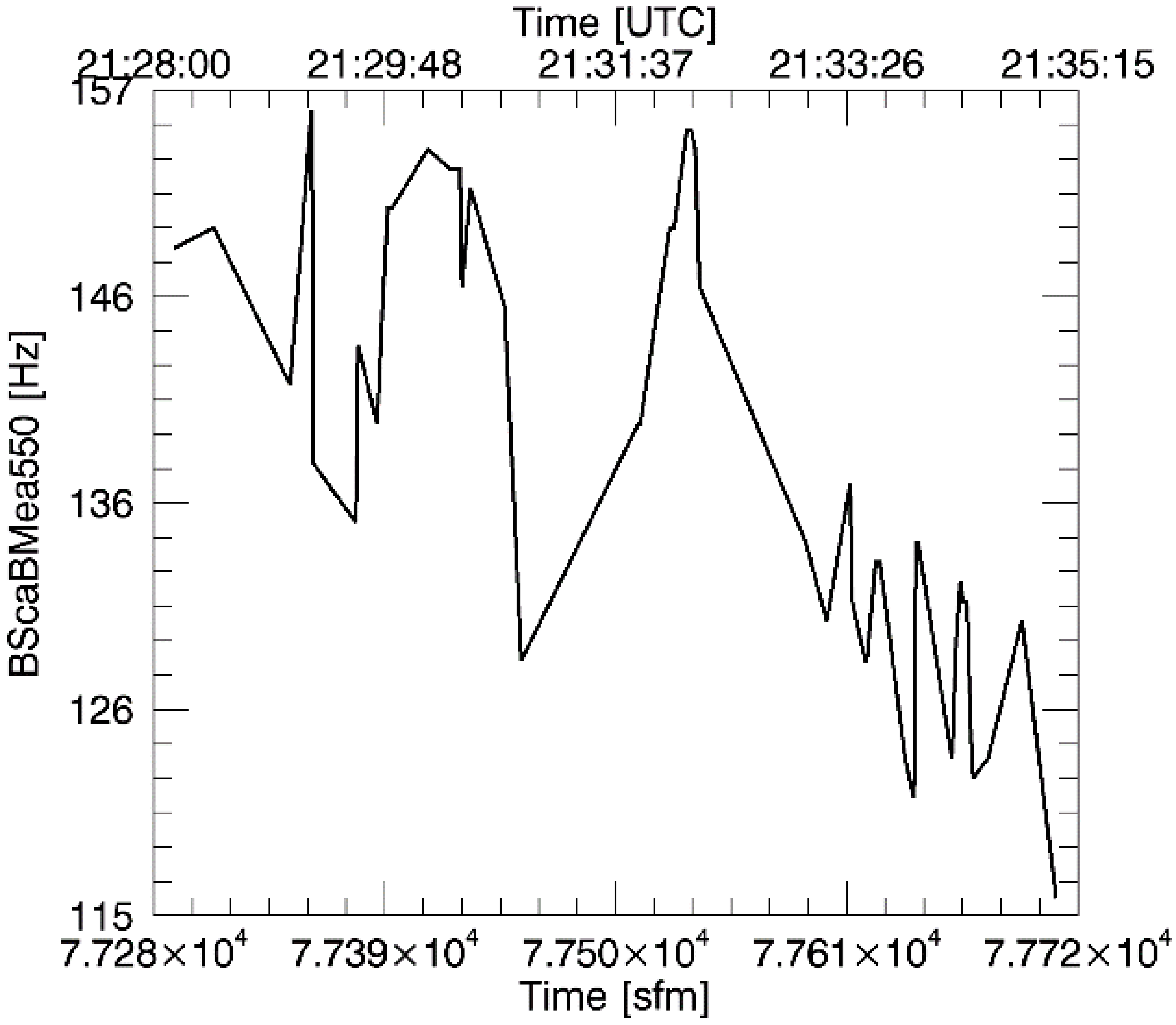
Flight Profile Consideration

Sufficiently long flight legs for Data Analysis

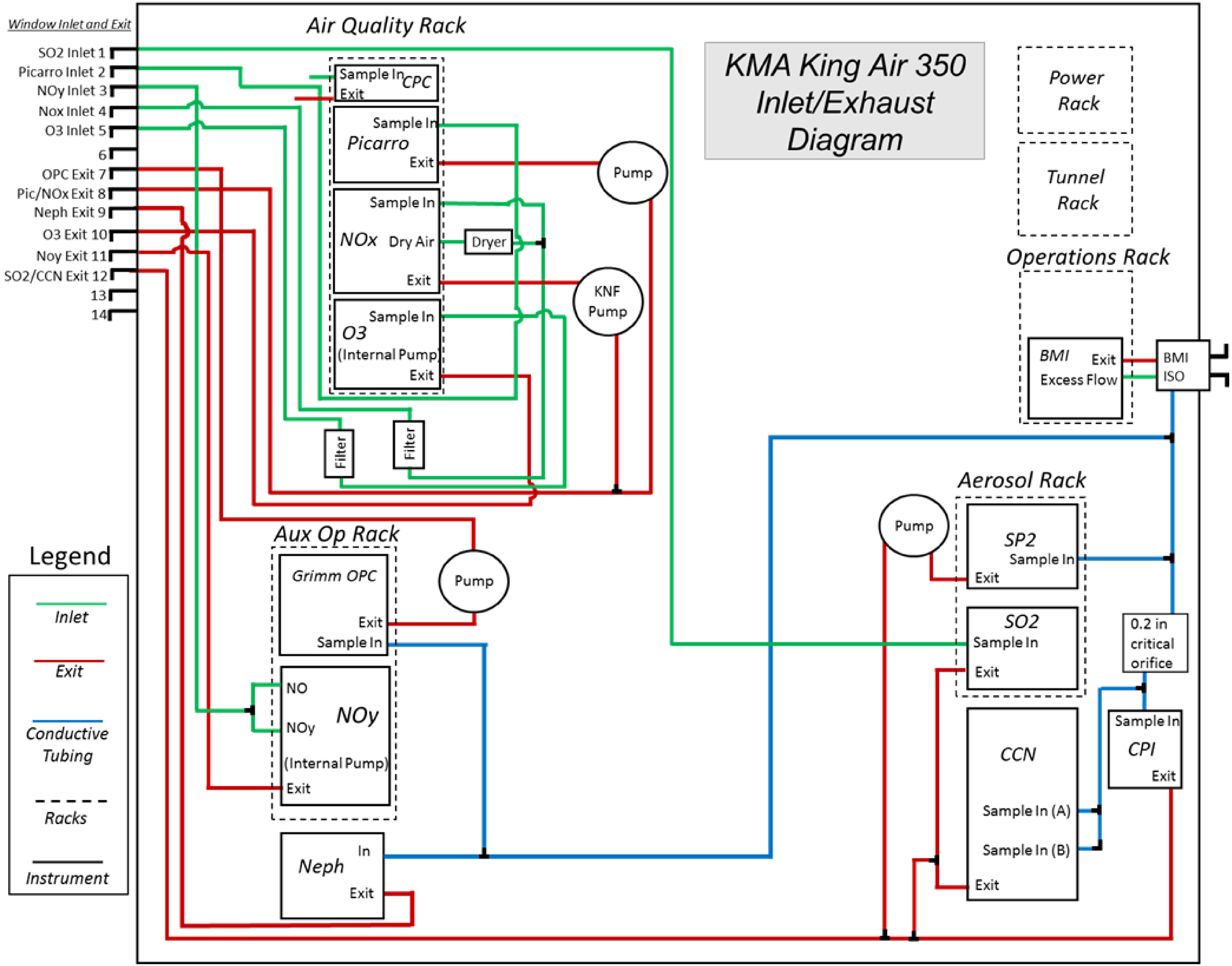
Data Acquisition – 1 s Serial Data

Special Notes – 30 l/min Flow

TSI Nephelometer (Neph) Flight Data



Time series plot of the 550 nm wavelength backscattering component for the Nephelometer taken during the 13 March 2017 flight near Fargo, North Dakota.



KMA King Air 350 Inlet/Exhaust Diagram
Window Inlet and Exit
SO2 Inlet 1
Picarro Inlet 2
NOy Inlet 3
Nox Inlet 4
O3 Inlet 5
6
OPC Exit 7
Pic/NOx Exit 8
Neph Exit 9
O3 Exit 10
Noy Exit 11
SO2/CCN Exit 12
13
14
Air Quality Rack
Sample In
CPC
Exit
Sample In
Picarro
Exit
Pump
Sample In
NOx
Dry Air
Dryer
Exit
KNF Pump
Sample In
O3
(Internal Pump)
Exit
Filter
Filter
Power Rack
Tunnel Rack
Operations Rack
BMI
Exit
Excess Flow
BMI ISO
Aerosol Rack
Pump
SP2
Sample In
Exit
SO2
Sample In
Exit
0.2 in critical orifice
CCN
Sample In (A)
Sample In (B)
Exit
Sample In
CPI
Exit
Aux Op Rack
Grimm OPC
Exit
Sample In
Pump
NO
NOy
NOy
(Internal Pump)
Exit
Neph
In
Exit
Legend
Inlet
Exit
Conductive Tubing
Racks
Instrument

Brechtel Isokinetic Inlet (ISO)

Operating Principles – Laminar Flow

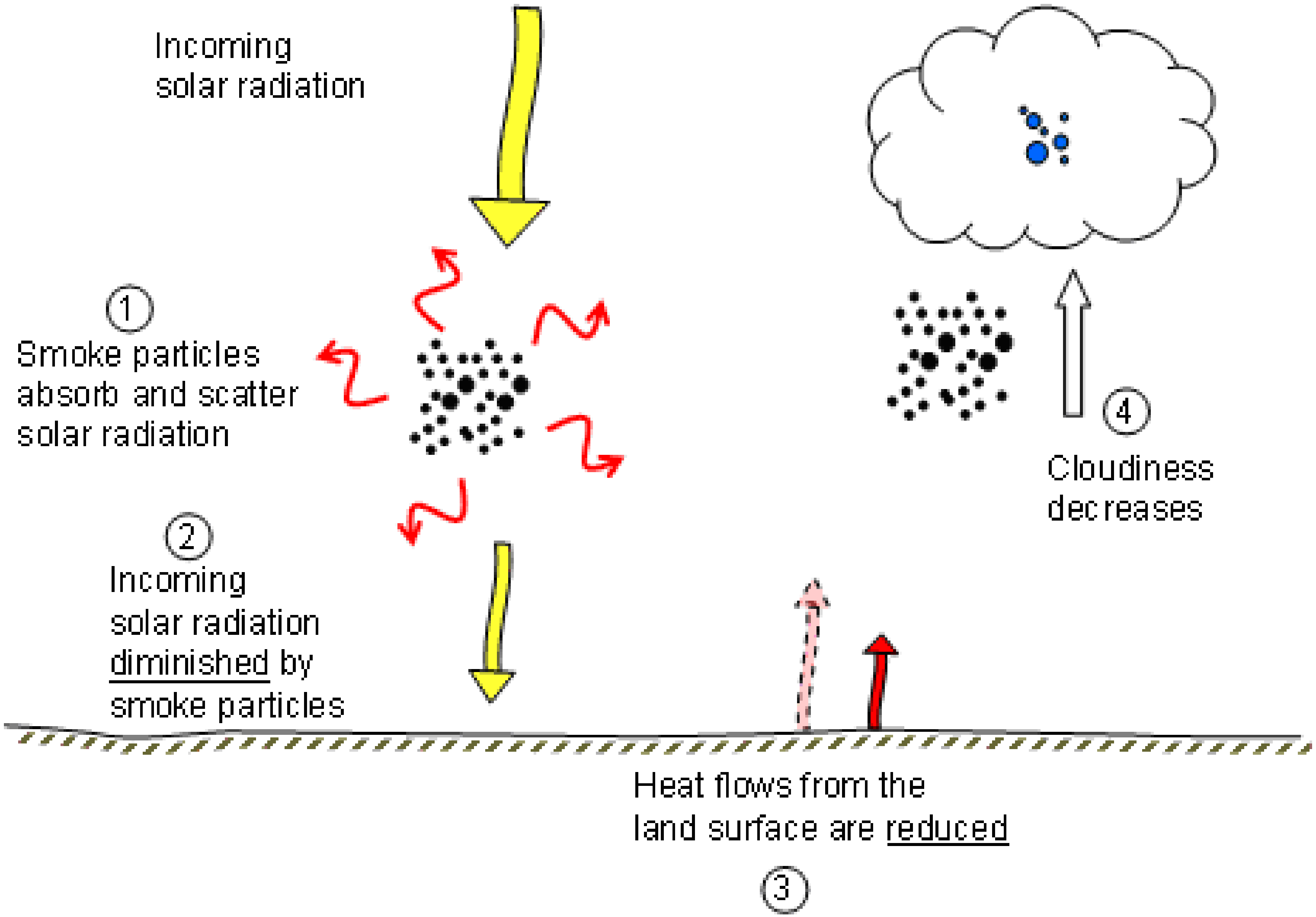
Primary Measurements – All aerosol < 3 um, Know Cut Size Characteristic

Quality Control – Leak Check, Calibration with Volumetric Flow Meter

Flight Profile Consideration – Air Speed Range to Maintain Laminar Flow

Data Acquisition – House Keeping Serial Data

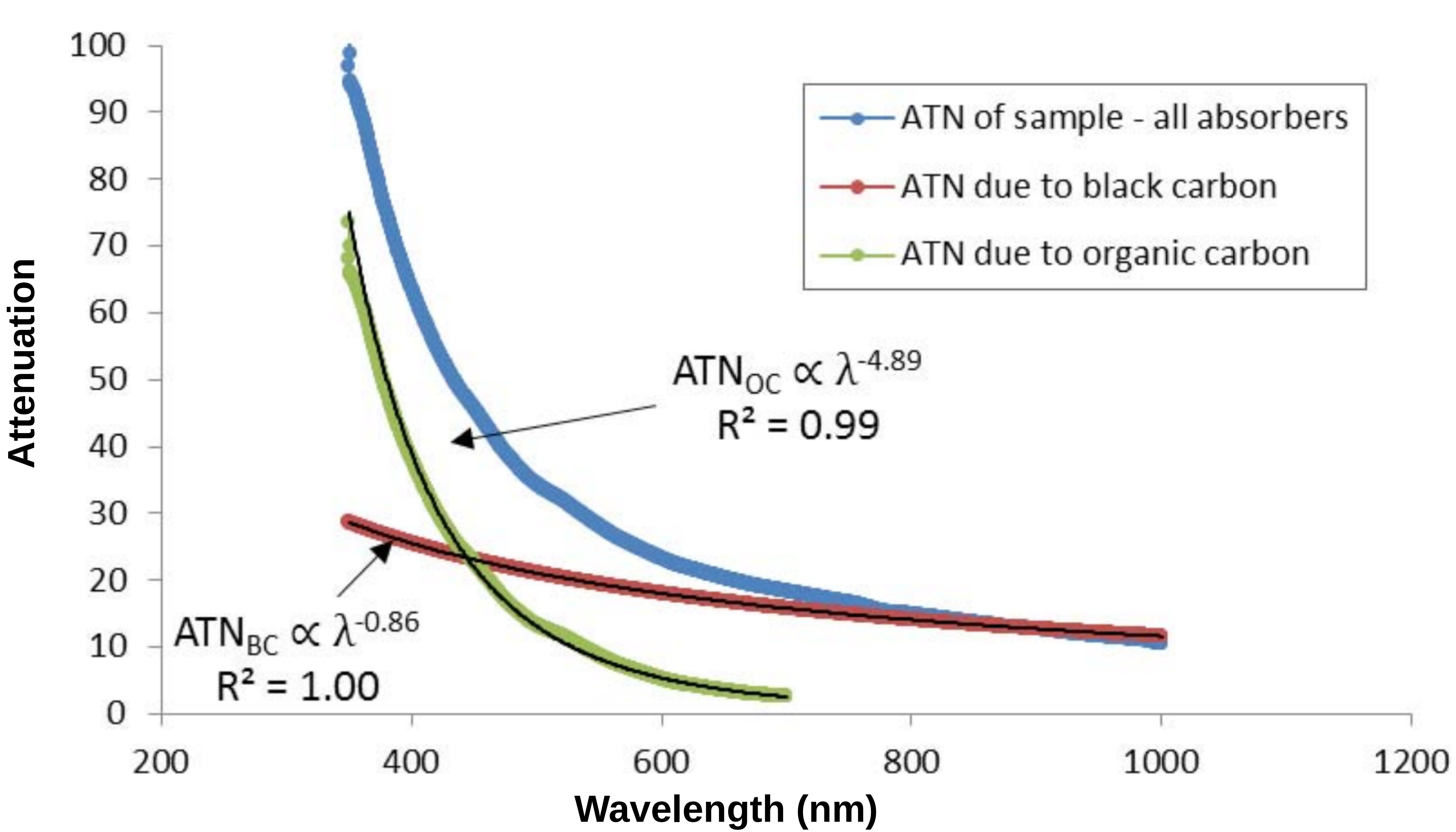
Partially Absorbing Aerosols



Schematic of the role of partially absorbing particles have on the surface radiation and cloud formation. Aerosols absorb and scatter radiation (1) and diminish the net radiation at the surface (2). The results is a reduction in surface latent and sensible heat flows from the surface (3), which reduces the strength of convection and cloud formation.

Image from NOAA Earth System Research Laboratory site, http://www.esrl.noaa.gov/research/themes/aerosols/

Smoke Aerosol Absorption



Estimated contributions of black and organic carbon to the spectral attenuation of a residential wood smoke particulate matter sample. The exponents of the power law trend lines, 0.86 and 4.89, are the absorption Ångström exponents of the black and organic carbon, respectively, for this sample. ***Image from Kirchstetter and Thatcher, 2012.***

DMT Single Particle Soot Photometer (SP2)

Operating Principles – Incandescent Emission

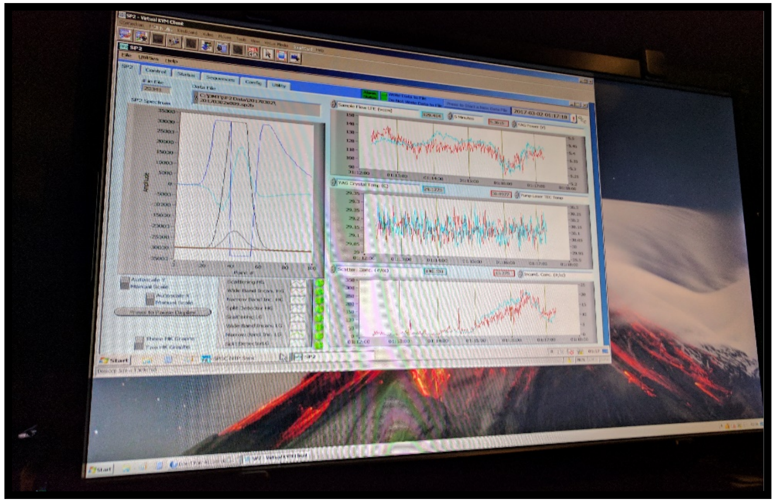
Primary Measurements – Single-particle Laser Incandescence, Single-particle Light Scattering (Black Carbon Mass Distribution, Particle Number Distribution)

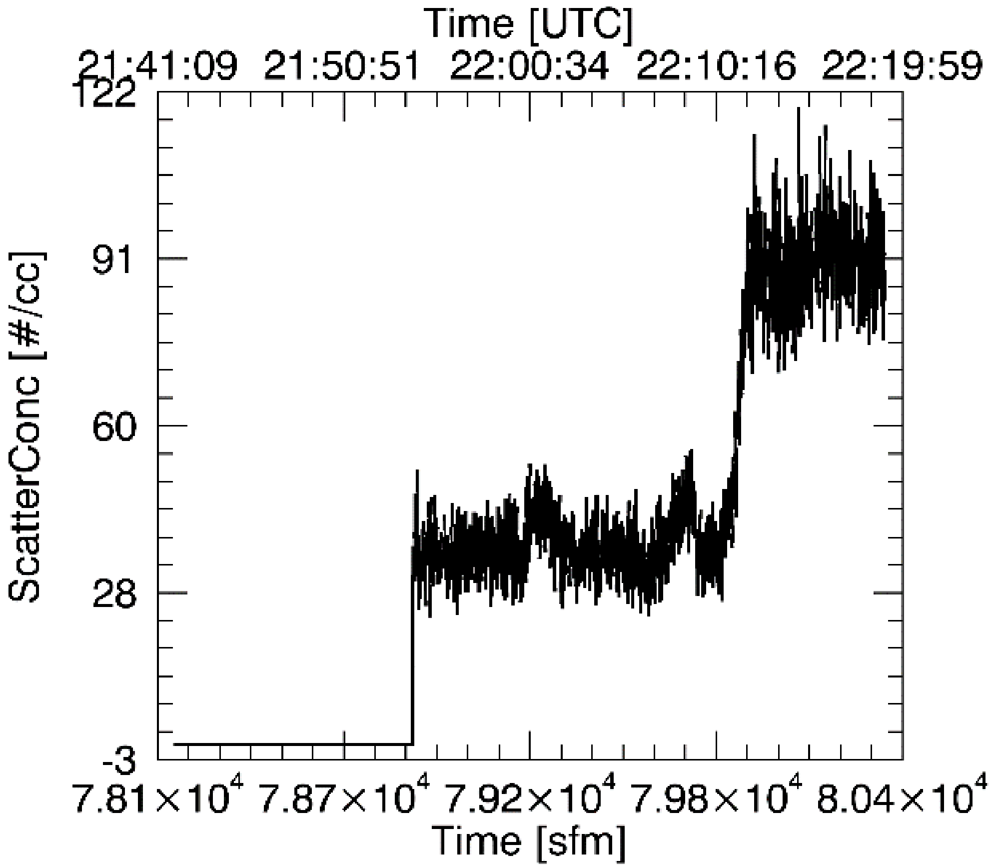
Quality Control – Leak Check (Zero Air), PSL Size Check to Monitor Laser Power

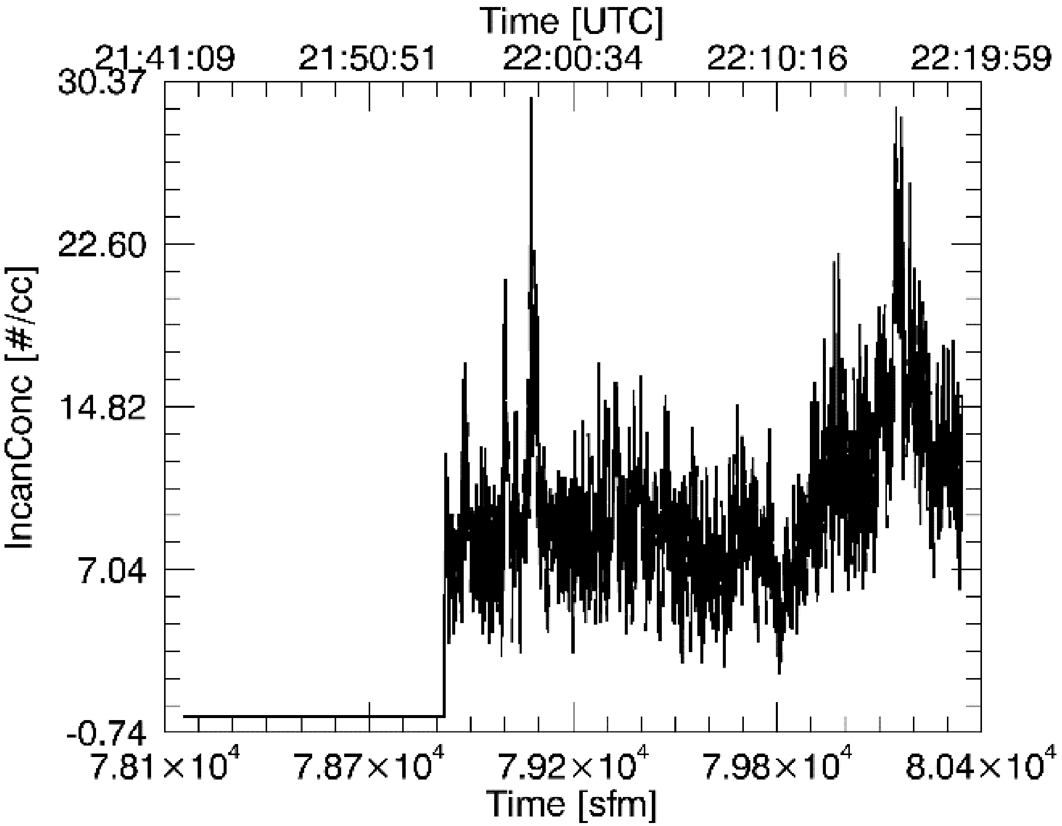
Flight Profile Consideration – Long Legs to Average

Data Acquisition – Serial Data

Single Particle Soot Photometer (Sp2)







Time series plot of Scattering Coefficient (left) and incandescent concentration (right) during the 13 March 2017 flight near Fargo, North Dakota.

Grimm Sky Optical Particle Counter (OPC)

Operating Principles - 90 Degree Light Scattering

Primary Measurements – Aerosols Size Spectrum from 0.25 µm to 32 µm in 31 Size Channels (Particular Matter less than 2.5 µm)

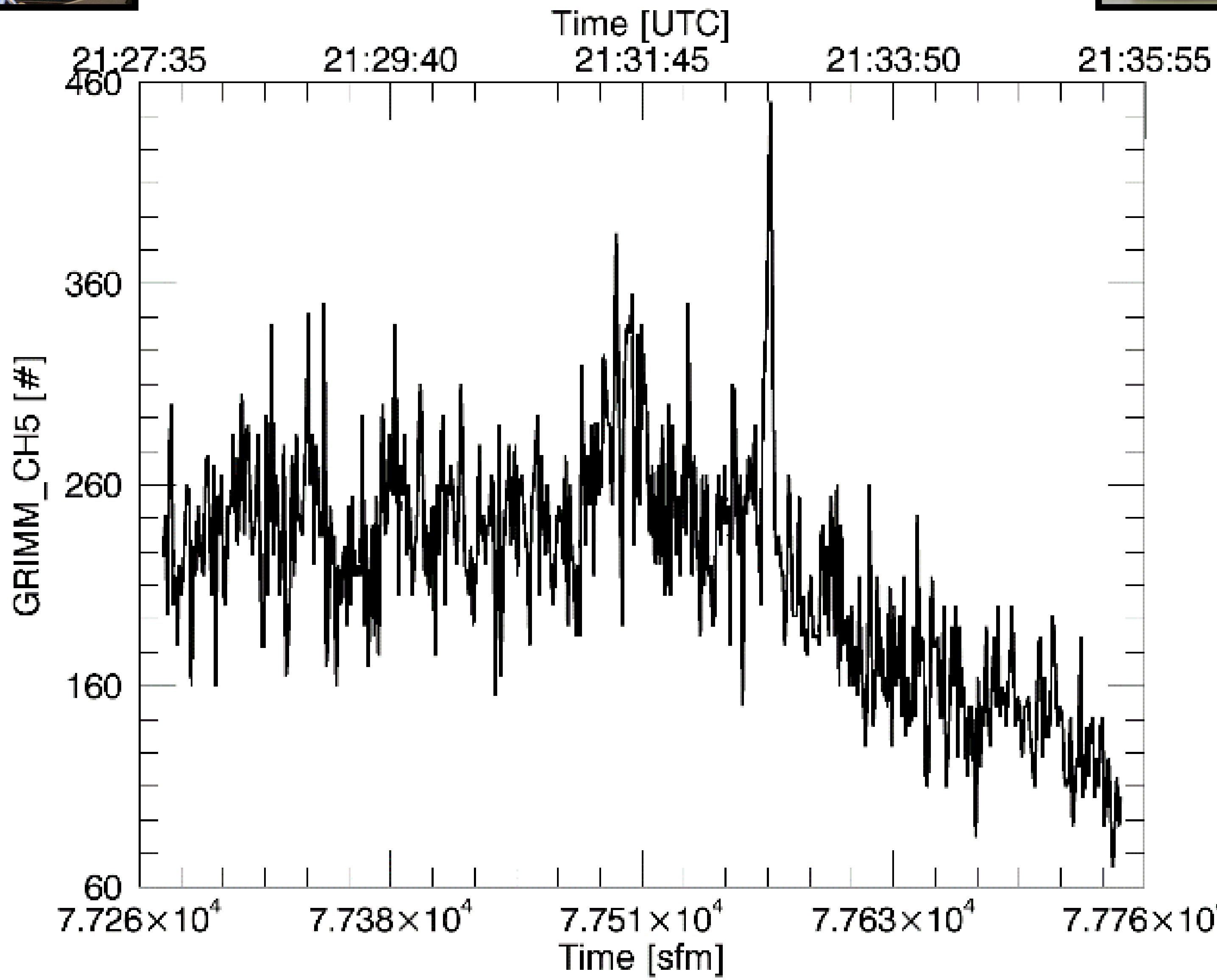
Quality Control – Leak Check, Calibration with Know Size Beads

Flight Profile Consideration – Power for 1.2 L/min Flow by External Pump, Critical Orifice

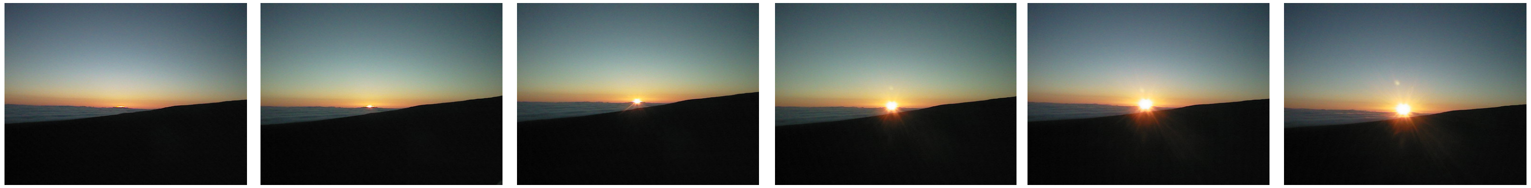
Data Acquisition – Fast 1 s Mode (Serial Data)

Special Notes – Requires a special initialization string to send serial data.

Grimm Sky Optical Particle Counter (OPC)



Time series plot of counts from channel 5 of the Grimm optical particle counter (OPC) during the beginning of the 13 March 2017 flight near Fargo, North Dakota.



For More Information See:

Delene, D. J., and J. A. Ogren, Variability of aerosol optical properties at four North American surface monitoring sites, Journal of Atmospheric Sciences, 59, 1135-1150, 2002.

http://aerosol.atmos.und.edu/

http://airborneresearch.atmos.und.edu/