Long-term Measurements of Aerosol Radiative Properties at the Surface and Aloft

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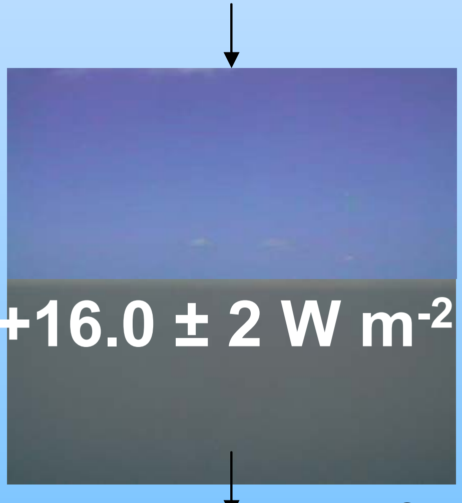
http://www.cmdl.noaa.gov/aero/

Clear-sky Aerosol Radiative Forcing over North Indian Ocean

-7.0 ± 1 W m^{-2} — **energy loss at top of atmosphere due to backscattering of sunlight to space**



$+16.0 \pm 2$ W m^{-2} — **heating of atmosphere due to aerosol absorption of sunlight**

-23 ± 2 W m^{-2} — **cooling of surface due to aerosol absorption and backscattering**

Source: Ramanathan,… Ogren,… et al., J. Geophys. Res., 2001
average for Jan - March, 1999; 0 - 20°N; $\tau_a = 0.3$

NOAA Aerosol Monitoring Program

- **What is the climate forcing by anthropogenic aerosols?**
  - What are the means, variabilities, and trends of the climate-forcing properties of different types of aerosols?
  - What are the factors that control these properties?

Objective

- **Obtain measurements of aerosol properties that will allow evaluation of the anthropogenic climate forcing by aerosols, when combined with chemical transport models, radiative transfer models, and global satellite observations.**

Strategy for Evaluating Aerosol Forcing

- **Systematic integration of global satellite observations and global chemical transport models will provide an internally-consistent diagnosis of the aerosol forcing of climate, with a predictive capability.**
- **In-situ observations, like those from NOAA monitoring stations, provide the glue that holds the satellites and models together.**
- **The in-situ data ensure that the integrated satellite+model results agree for the right reasons.**

NOAA/CMDL Aerosol Network

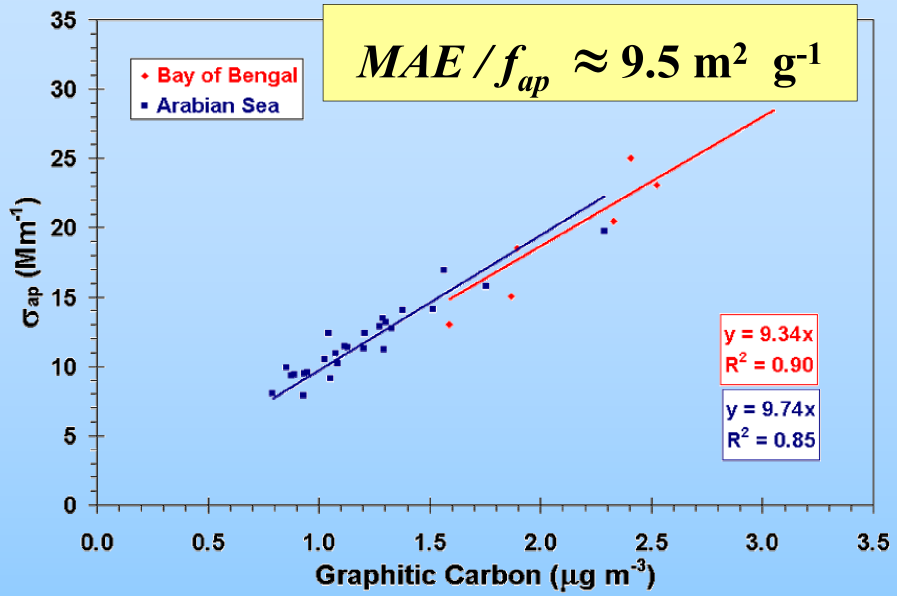
Legend
- regional
- baseline
- movable
- former sites

What Do We Measure?

- **Primary quantities measured**
  - light scattering coefficient (σ_{sp})
  - light absorption coefficient (σ_{ap})
    aerosol cross-sectional area for absorption per unit volume of air ($m^2\ m^{-3}$, $10^{-6}\ m^{-1} = 1\ Mm^{-1}$)
  - particle number concentration
  - chemical composition (mass, major ions)
- **Derived properties**
  - single-scattering albedo (scattering vs. absorption)
  - hygroscopic growth factor (RH-dependence)
  - submicron scattering fraction (size dependence)
  - hemispheric backscatter fraction (angular dep.)
  - Ångström exponent (wavelength dependence)
  - radiative forcing efficiency

Black Carbon and Light Absorption

- **Optical methods for determining BC really measure σ_{ap} (PSAP, aethalometer, MAAP, integrating sphere, photoacoustic, …)**
- **BC = σ_{ap} *x* f_{ap} / *MAE***
  - f_{ap} = fraction of light absorption due to BC
  - *MAE* = mass absorption efficiency of BC (m^2 g^{-1})
- **Climate forcing calculations require σ_{ap}**



- **Empirical relationships, like the one show above for the Indian Ocean, are required to determine BC from σ_{ap} (WMO/GAW report #153)**

Aerosol Radiative Forcing and SSA

- **Single-scattering albedo is the fraction of aerosol light extinction caused by scattering, SSA = $\sigma_{sp} / (\sigma_{sp} + \sigma_{ap})$**
- **The sign of the aerosol forcing at the top of the atmosphere (TOA) depends on surface albedo, aerosol backscatter fraction, and SSA.**
- **Absorbing aerosols generally cause negative TOA forcing over dark surfaces (oceans) and positive TOA forcing over bright surfaces (clouds, snow, ice)**

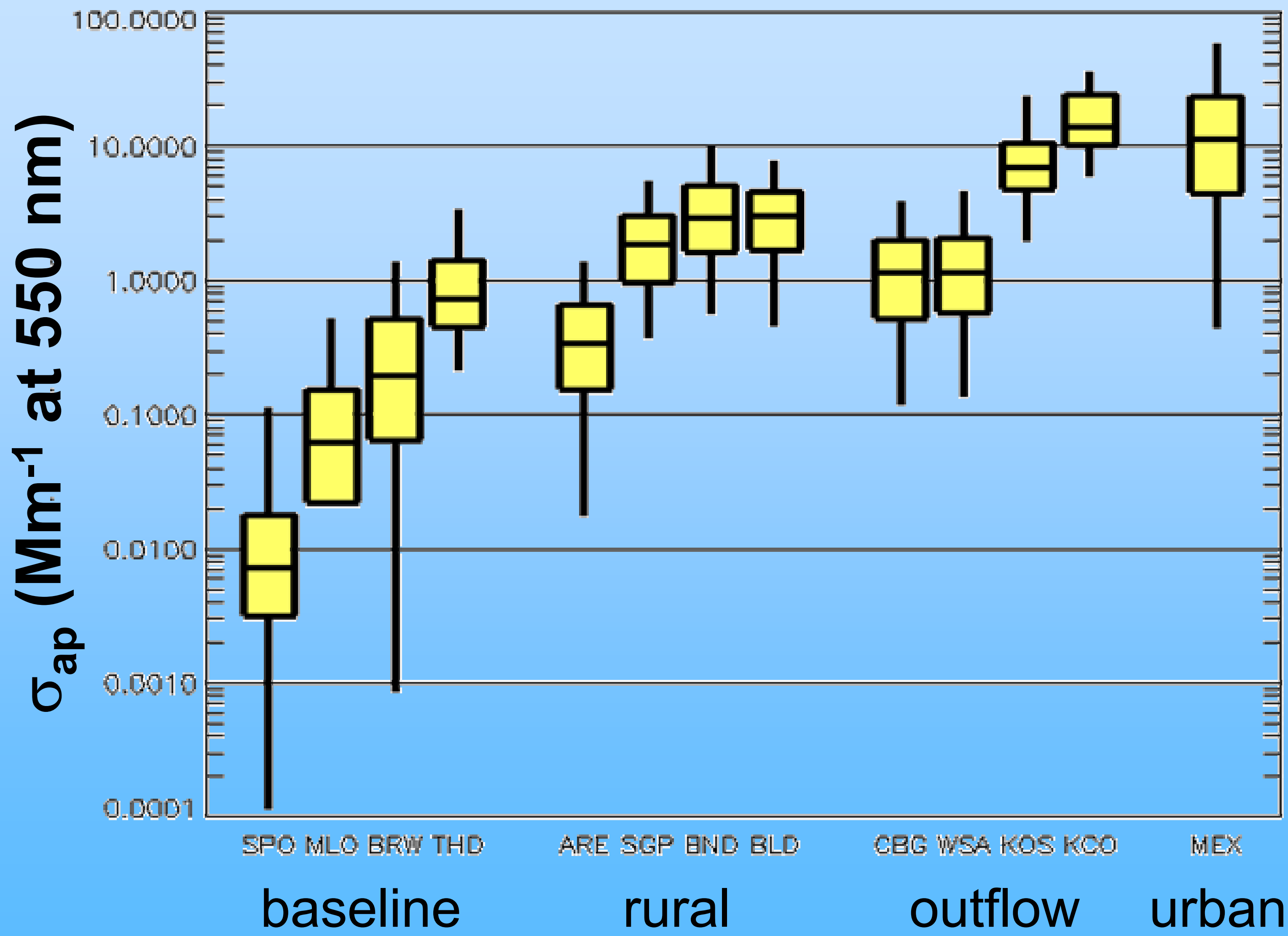
Parameters controlling aerosol forcing

$$\Delta F \approx -DS_0 T_{at}^2 (1 - A_c)(1 - R_s)^2 \varpi_0 \bar{\beta} \delta \left[1 - \frac{2R_s}{(1 - R_s)^2} \left(\frac{1 - \varpi_0}{\varpi_0 \bar{\beta}} \right) \right]$$

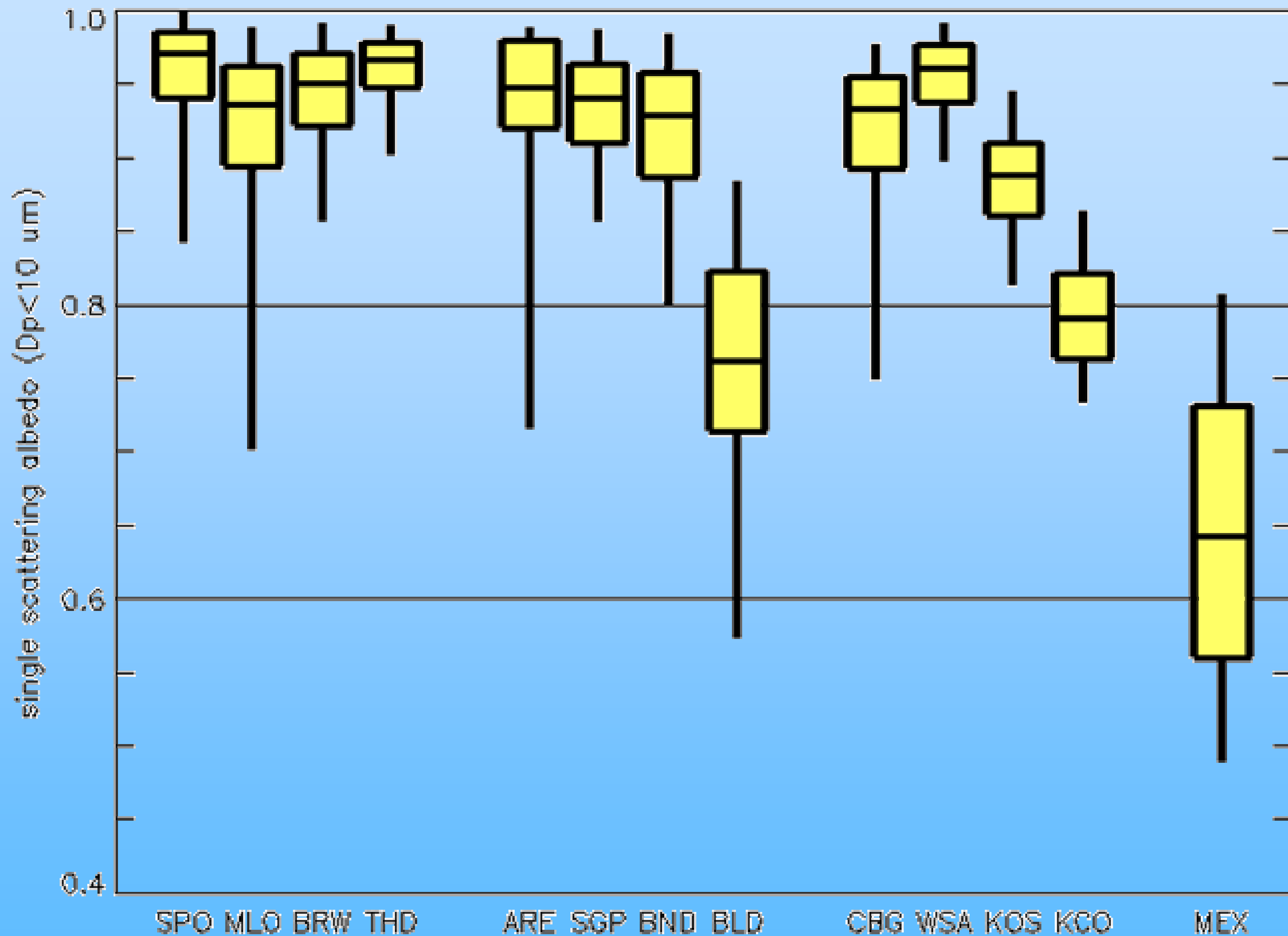
D	daylight fraction	ΔF	average aerosol forcing at top of atmosphere (TOA)
S_0	solar constant	δ	aerosol optical depth
T_{at}	atmospheric transmission	ϖ_0	aerosol single-scattering albedo
A_c	cloud fraction	$\bar{\beta}$	average aerosol up-scatter fraction
R_s	surface albedo		

Source: Haywood and Shine (1995)

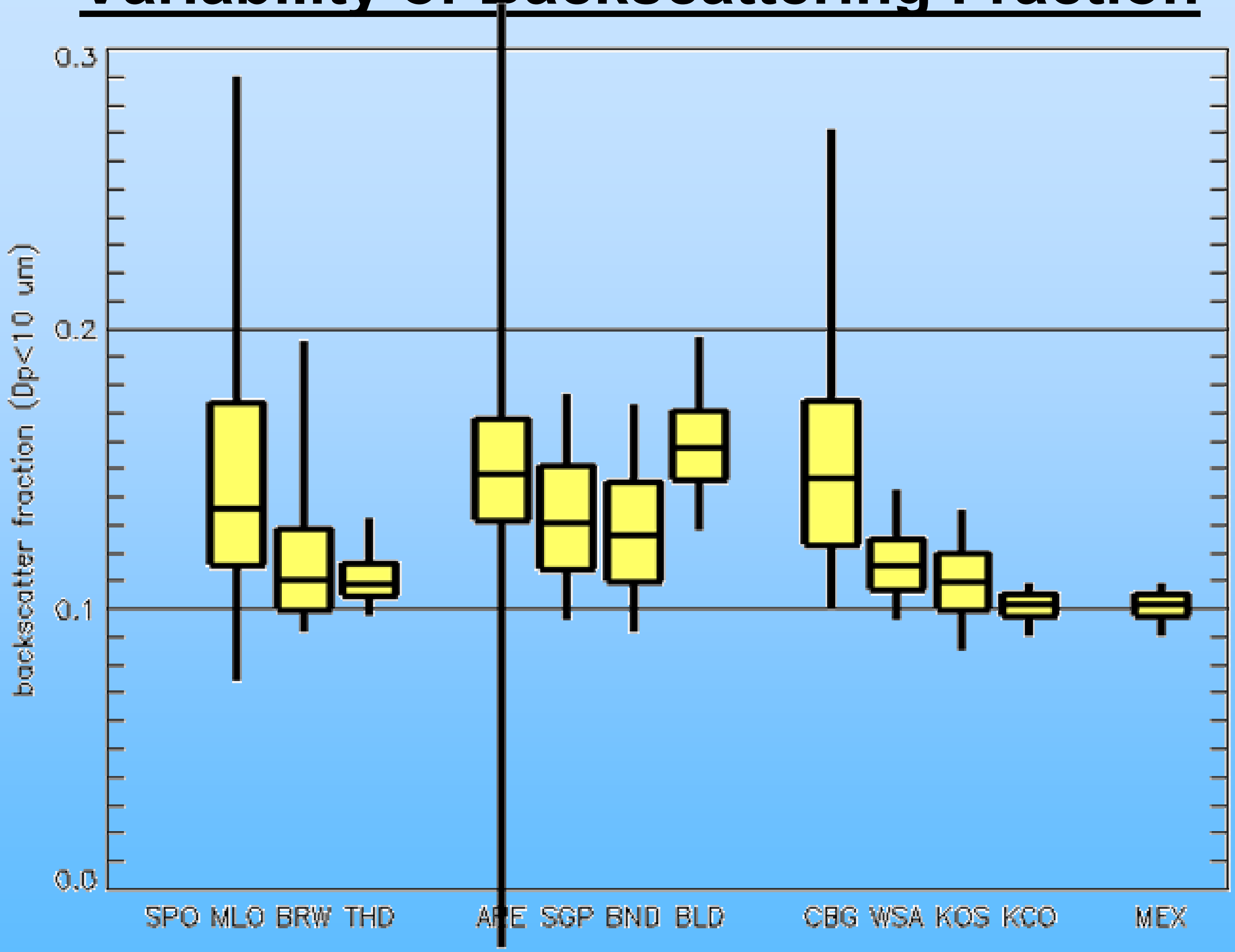
Variability of Light Absorption Coefficient



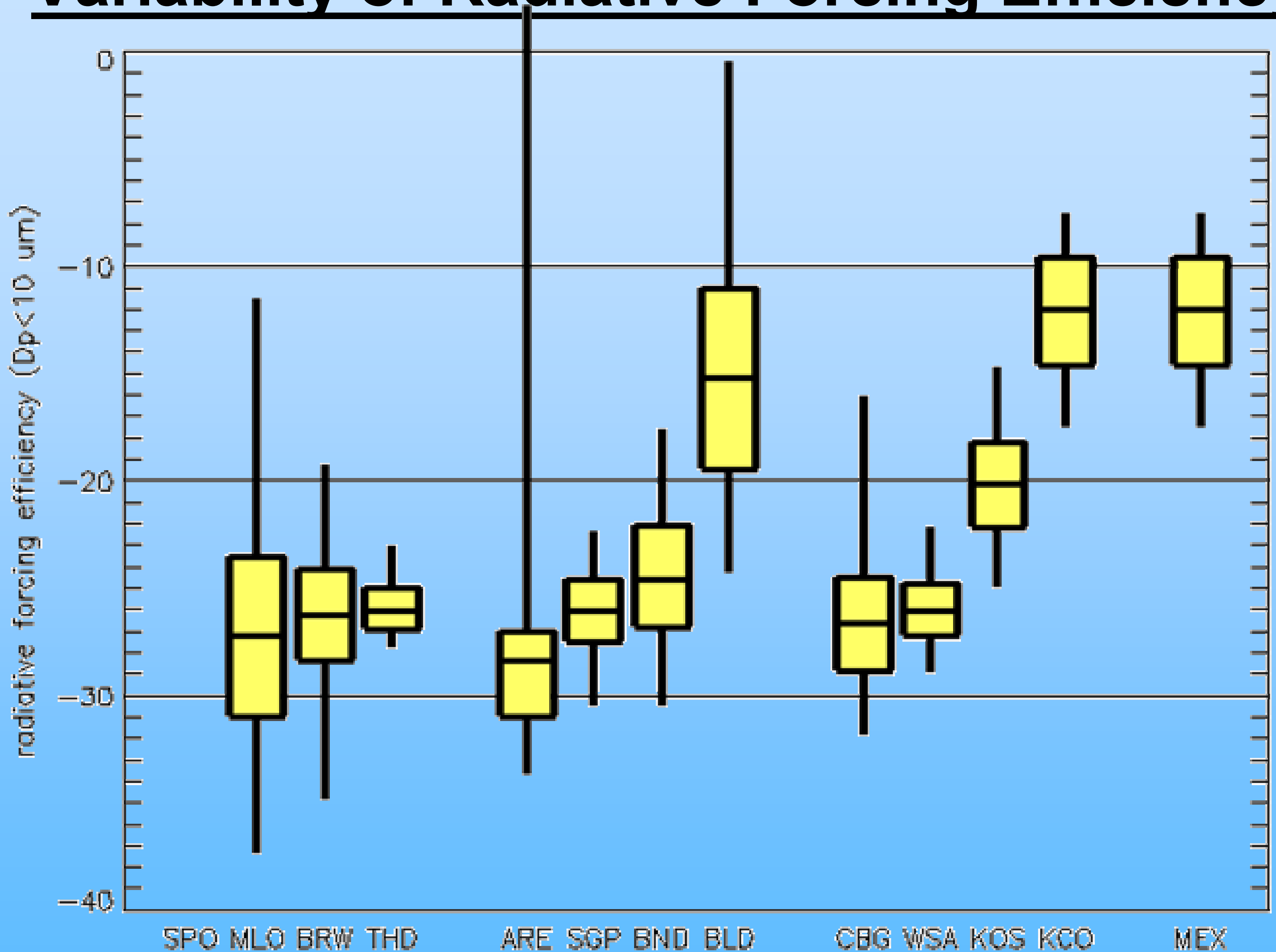
Variability of Single-scattering Albedo



Variability of Backscattering Fraction

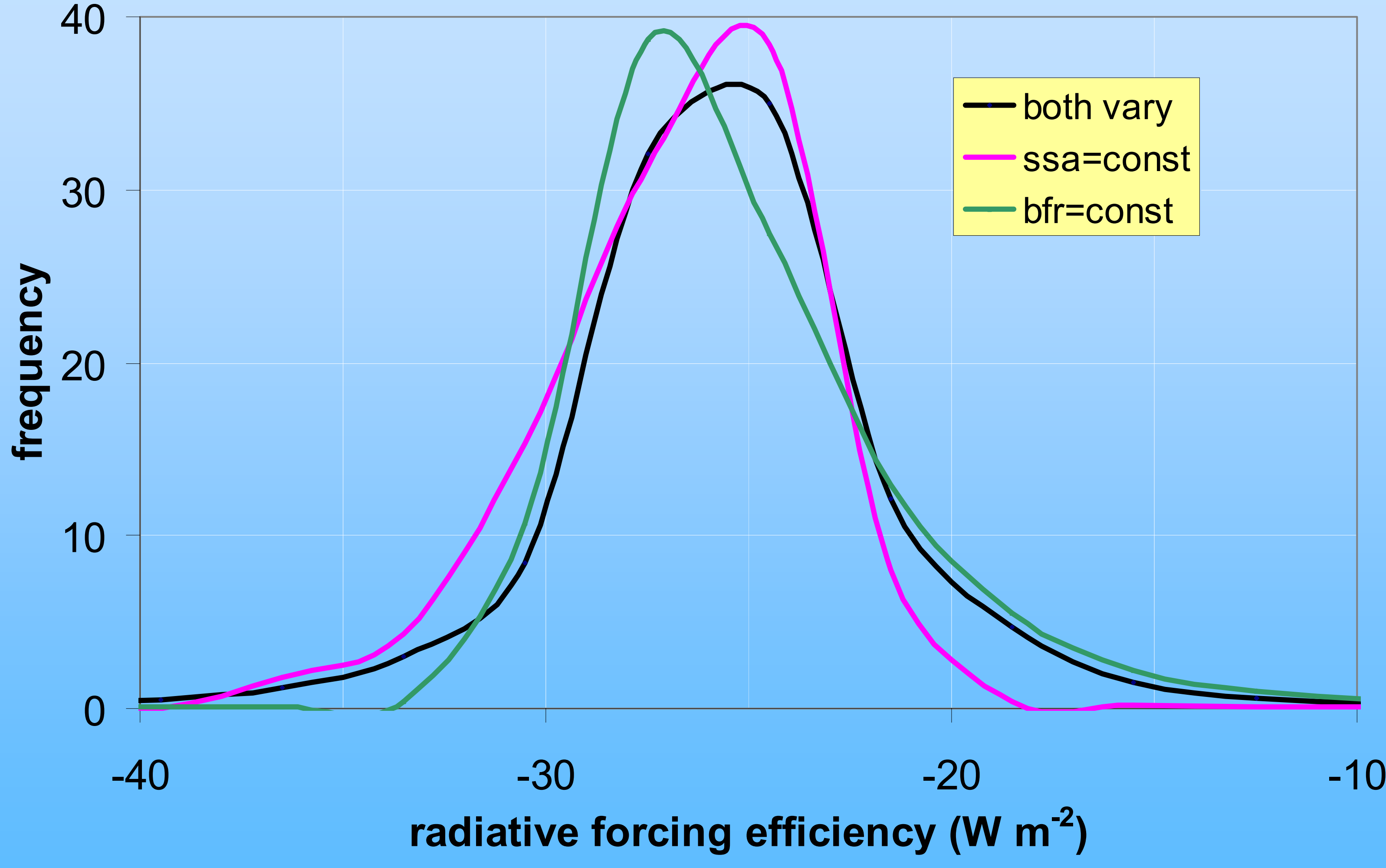


Variability of Radiative Forcing Efficiency

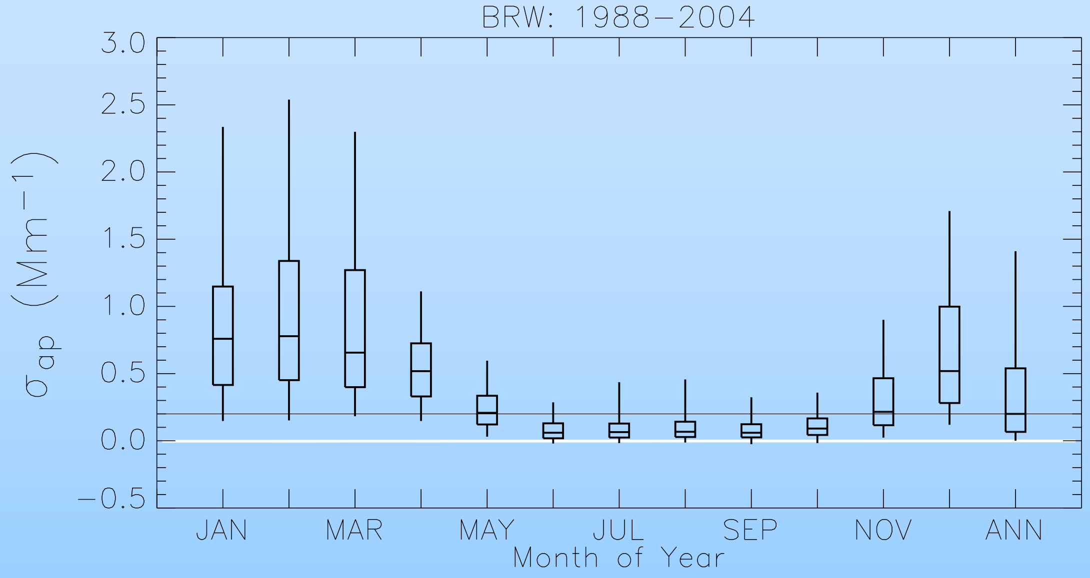


RFE = ΔF / δ (W m^{-2} per unit AOD). Upscatter fraction is estimated using measured backscatter fraction.

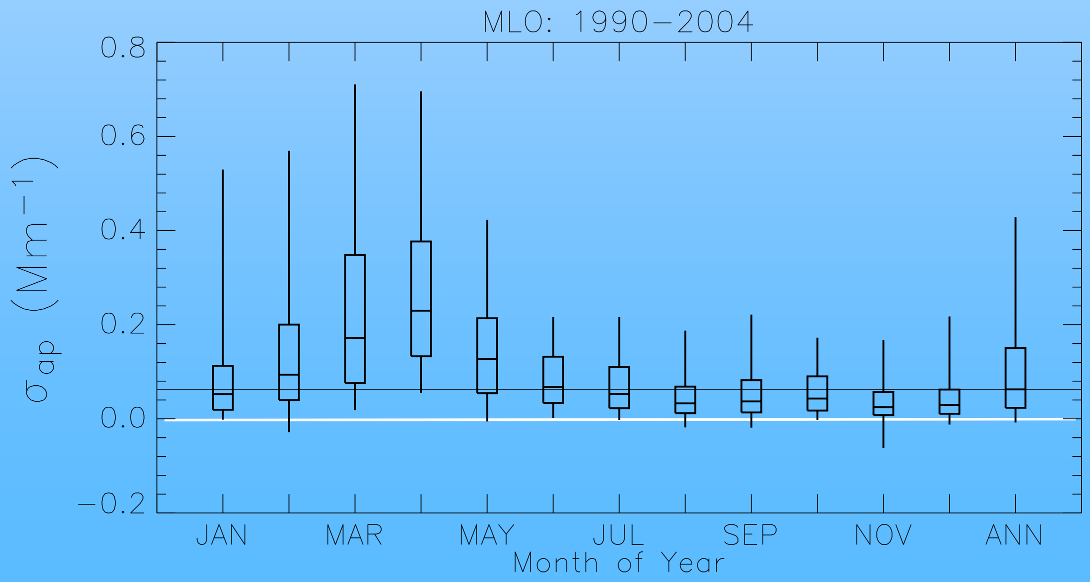
Single-scattering Albedo and Backscatter Fraction are Both Important to Variability of RFE



Seasonal Cycles of σ_{ap} at BRW and MLO



Pollution aerosols from Eurasia reach Barrow frequently during the winter (Arctic Haze)



Pollution and dust aerosols from Asia reach Mauna Loa frequently during the spring months.

NOAA/CMDL In-situ Aerosol Profiling

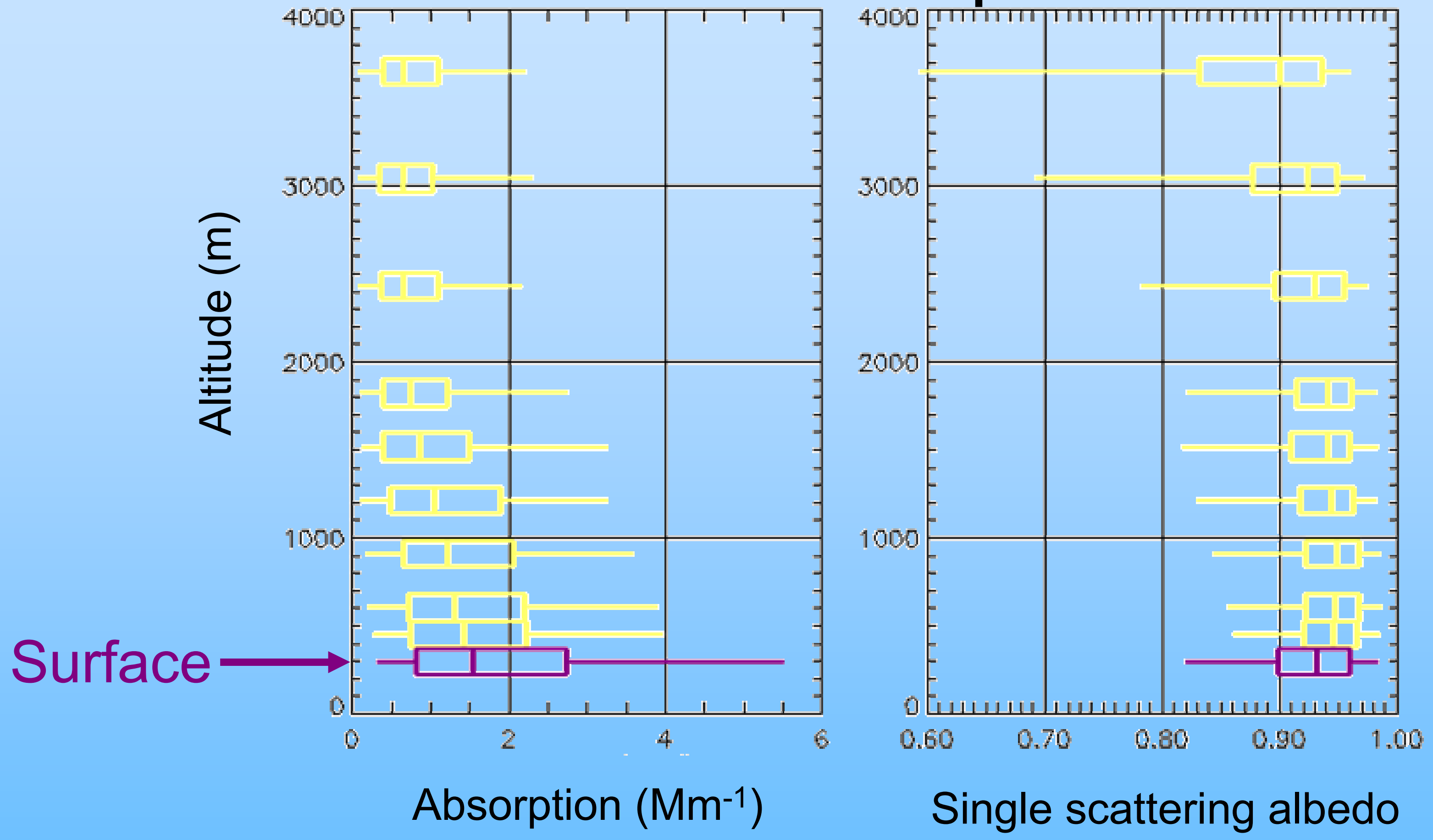
- **Information on aerosol properties aloft is scarce, satellites and surface stations give limited data.**
- **Light airplanes can be used to monitor vertical profiles of key aerosol properties at modest cost.**
- **Objectives:**
  - obtain aerosol climatology aloft
  - determine relevance of surface climatology
- **Summary: Cessna 172 (4-seat), profiles to 3.7 km asl, aerosol light scattering and absorption, automated operation.**

Sample Inlet


Port view of rack

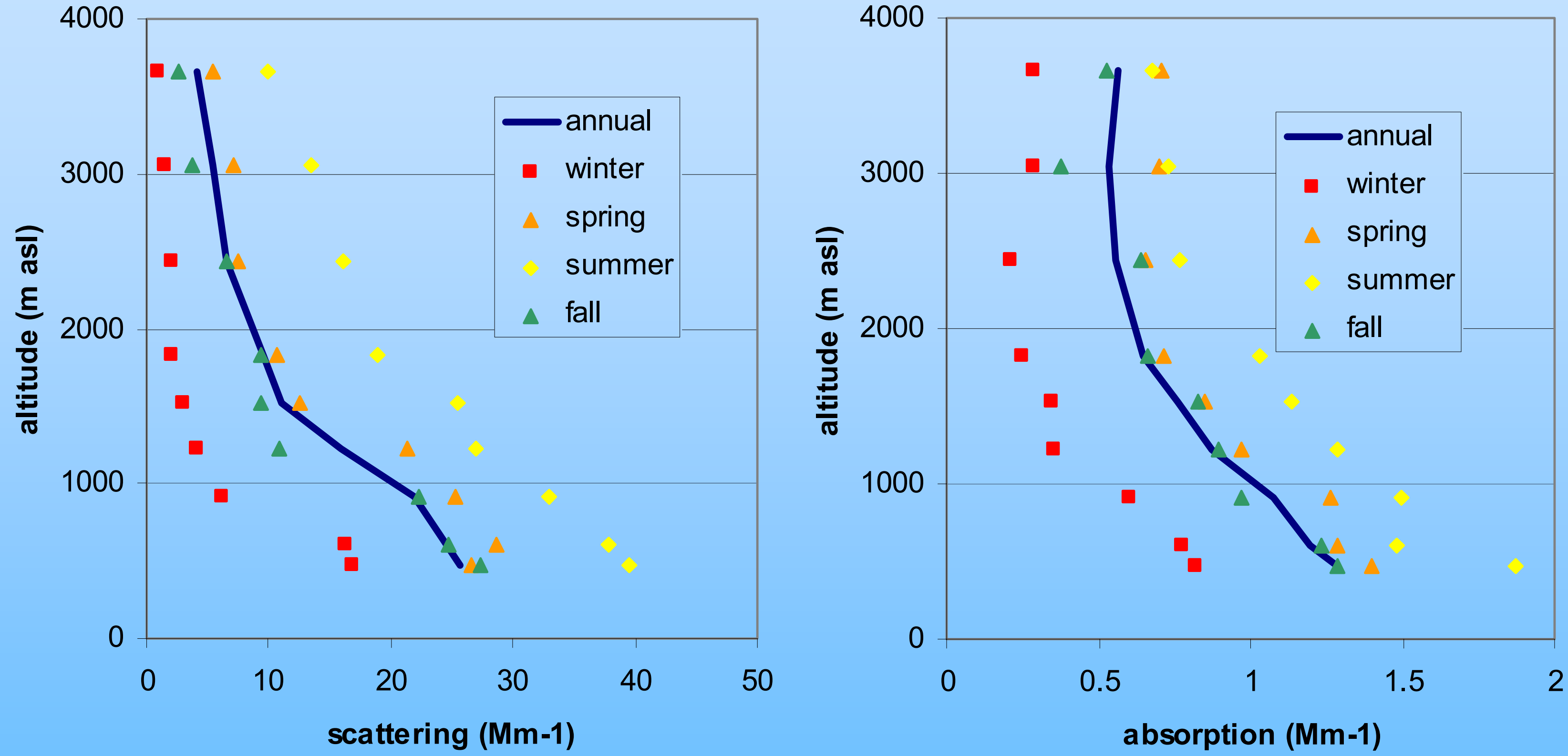
- DOE/ARM funding for Oklahoma project, >500 flights since 3/2000
- NOAA funding starting 2003 to begin sampling over another site with an enhanced payload. Start flying mid 2005.

Vertical Profiles of σ_{ap} and ω at SGP



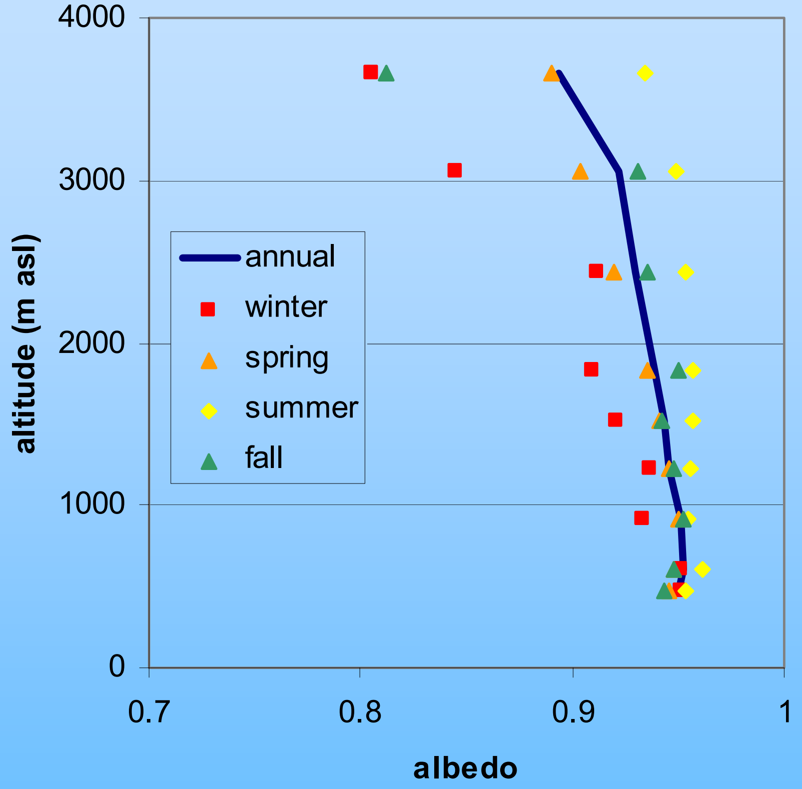
Values are adjusted to STP and at RH < 40%, for λ = 0.55 μm and Dp < 1 μm, from 490 flights (3/2000 - 10/2004). All 9 levels were sampled on 442 flights.

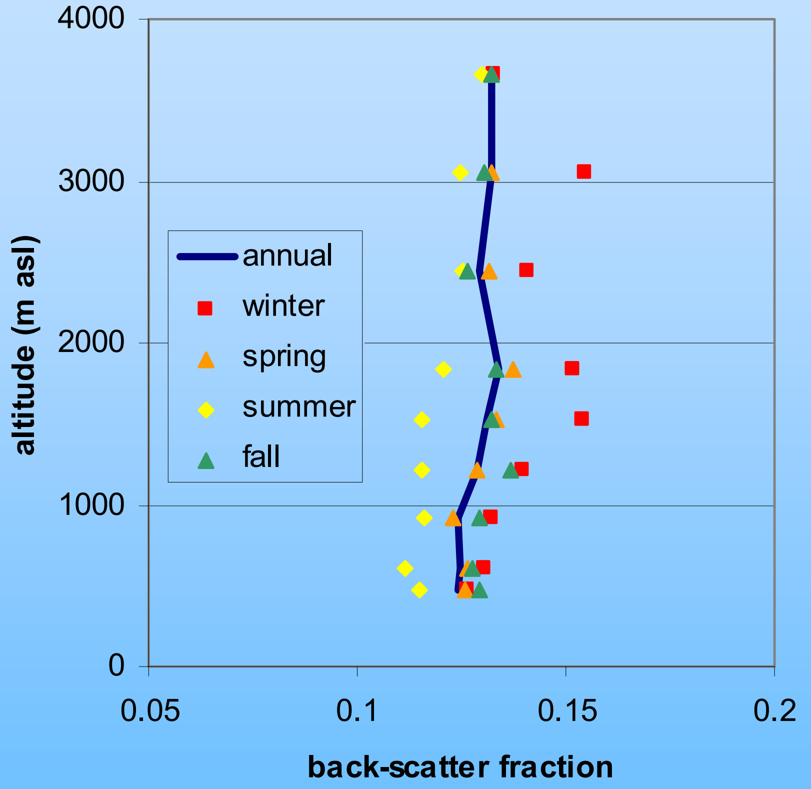
Seasonal Variation of Average Aerosol Profiles over Oklahoma: Aerosol Amount



Notes: Results are for 324 profiles from March, 2000 – March, 2003 over the DOE/ARM site. Aerosol radiative properties reported at 550 nm wavelength, RH<40%, and particle diameter below 1 μm.

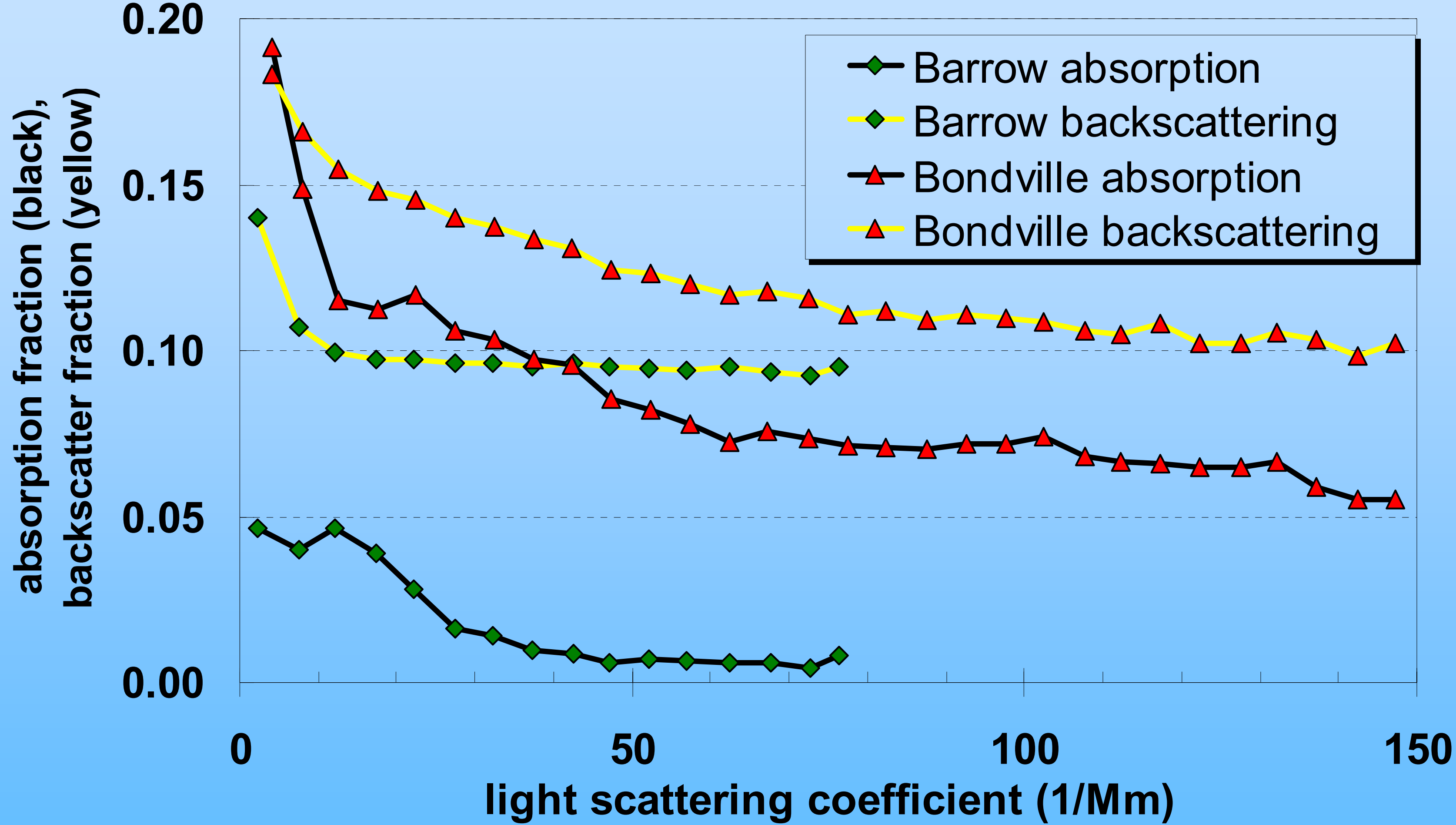
Seasonal Variation of Average Aerosol Profiles over Oklahoma: Aerosol Character





Notes: Results are for 324 profiles from March, 2000 – March, 2003 over the DOE/ARM site. Aerosol radiative properties reported at 550 nm wavelength, RH<40%, and particle diameter below 1 μm.

Fractional backscattering and absorption decrease as pollution increases



Absorption fraction is the contribution of light absorption to total light extinction.
Backscatter fraction is the contribution of backwards scattering to total light scattering
Results for D<10 μm, RH<40%, λ=550 nm for Bondville, IL and Barrow, AK

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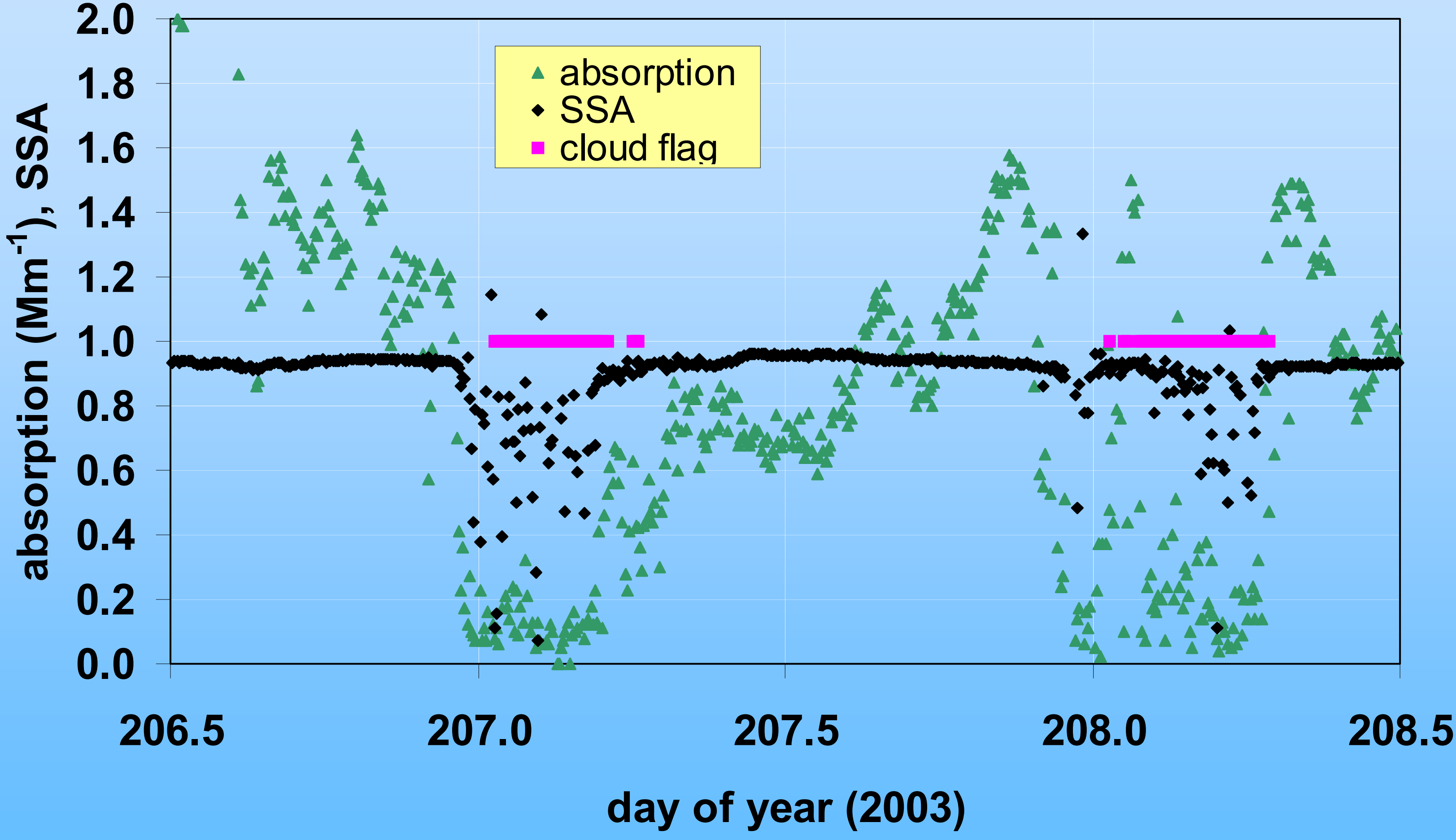
Effects of Cloud Scavenging on Aerosol Radiative Properties

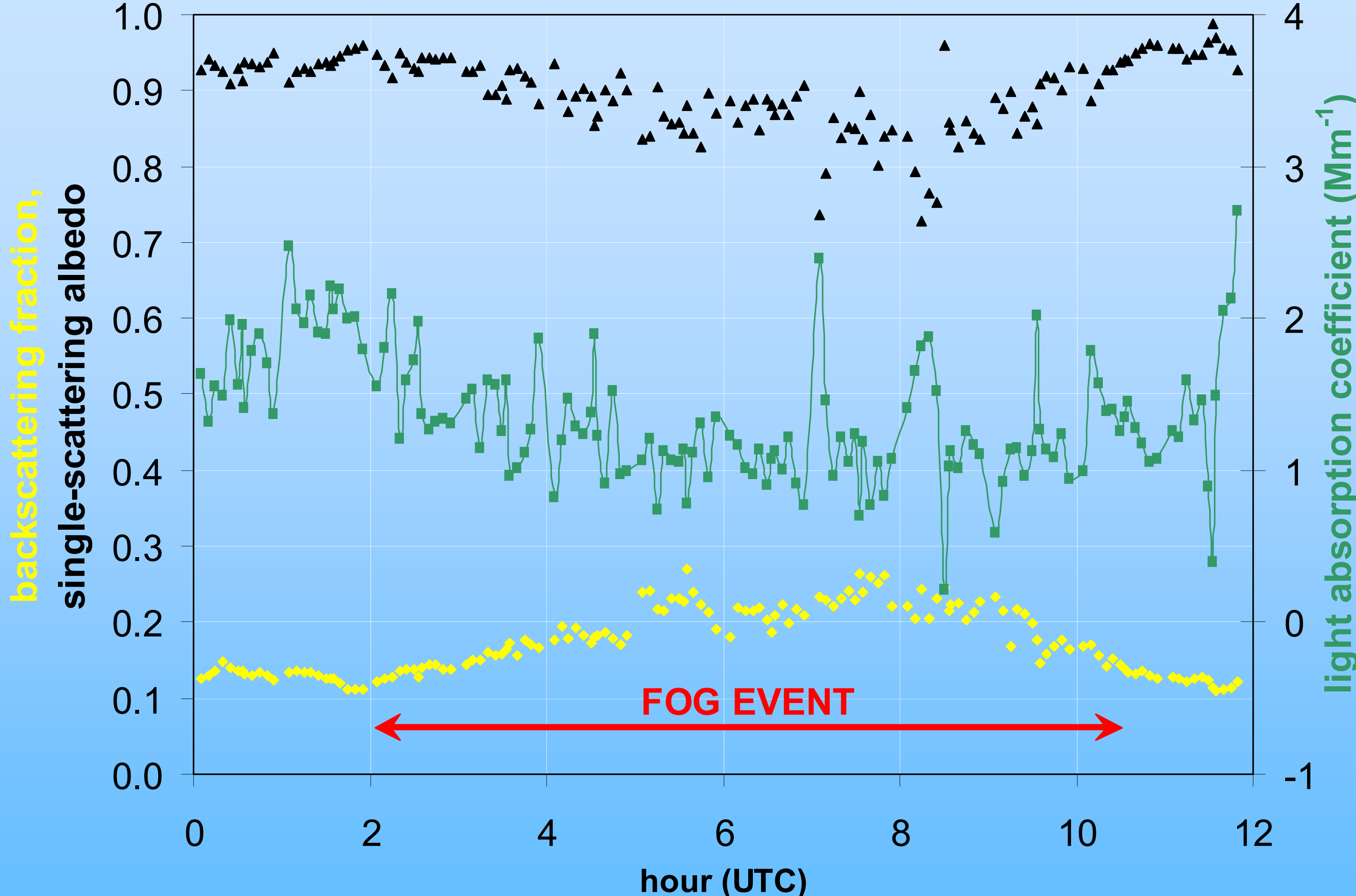
- **Aerosol light scattering is dominated by particles that are readily-scavenged by clouds, such as sulfates and water-soluble organics**
- **Aerosol light absorption is dominated by less readily-scavenged particles, such as graphitic carbon (soot)**
- **Cloud droplets are therefore enriched in light scattering particles relative to light absorbing particles**
- **When precipitation falls, it removes more of the light scattering particles than the light absorbing ones**
- **Cloud scavenging therefore systematically decreases aerosol single-scattering albedo**

Aerosol SSA during two cloud events



A clear decrease in single-scattering albedo is evident in clouds where the scavenging is not complete, as observed in these two events on Mt. Åreskutan, Sweden.

Effect of fog on aerosol radiative properties in Nova Scotia



Onset of fog causes strong decrease in light scattering (not shown), modest decrease in light absorption, increase in back-scatter fraction, and decrease in single scattering albedo.   Chebogue Point, July 4, 2004.

Evaluating Climate Forcing by BC Aerosols

- **Atmospheric cycle of black cargon**
  - sources, atmospheric processes, sinks, and mass concentrations
- **Aerosol radiative properties**
  - BC mass absorption efficiency
  - optical depth, single-scattering albedo, upscatter fraction
- **Observations of aerosol climate forcing properties reveal pronounced and systematic differences for different aerosol types and loadings.**
- **Variations in single-scattering albedo and backscatter fraction both contribute to variations in aerosol radiative forcing efficiency**

Acknowledgements

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