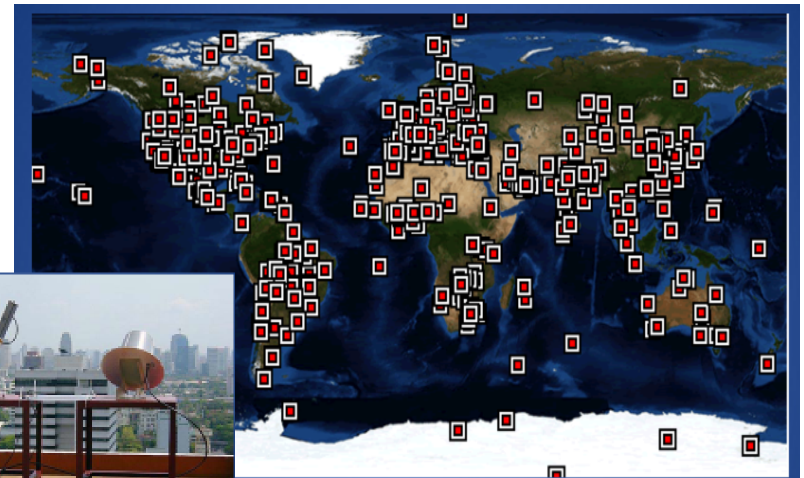
Column Retrievals of Aerosol Absorption

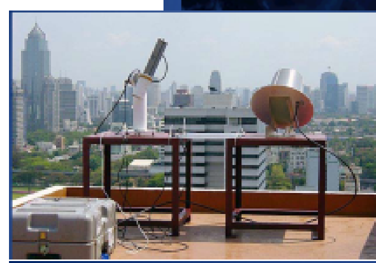
We currently lack accurate satellite measurements of aerosol absorption

- OMI retrievals of AAOD have not been sufficiently accurate for evaluating model AAOD retrievals
  - Requires aerosol type selection, albedo, aerosol height
  - Sensitive to sub-pixel cloud contamination, non-spherical aerosols
  - Reduced sensitivity near the surface
- MISR
  - Produces classes of absorbing aerosol, rather than quantitative values
  - Requires minimum AOT >0.15

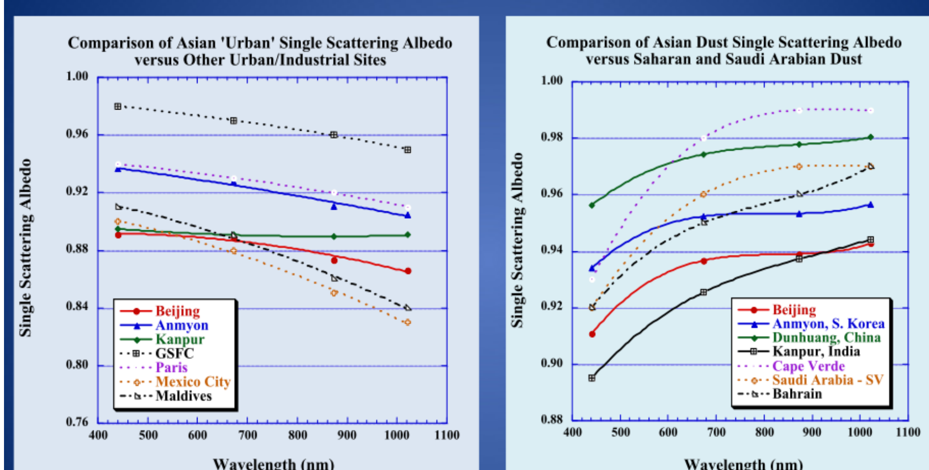
AERONET Sun Photometer Column Retrievals

- Standardized instruments, calibration, processing
- Near real time processing
- ~ 250 operational sites around the world (includes ARM sites)
- Results used extensively for satellite retrieval development and validation and model assessments
- Absorption AOD and SSA retrievals based on sun and almucantar sky radiance measurements and Dubovik et al. (2000, 2006) retrievals
- Level 1.5 SSA is qualitative only
- Level 2.0 SSA requires
  - Solar zenith angle > 50 deg (early morning or late afternoon)
  - Cloud-free skies
  - AOD (λ=440 nm) > 0.4
- Uncertainty (SSA ~ 0.03, AAOD ~ 0.01)
- **Sparse validation – more required!**





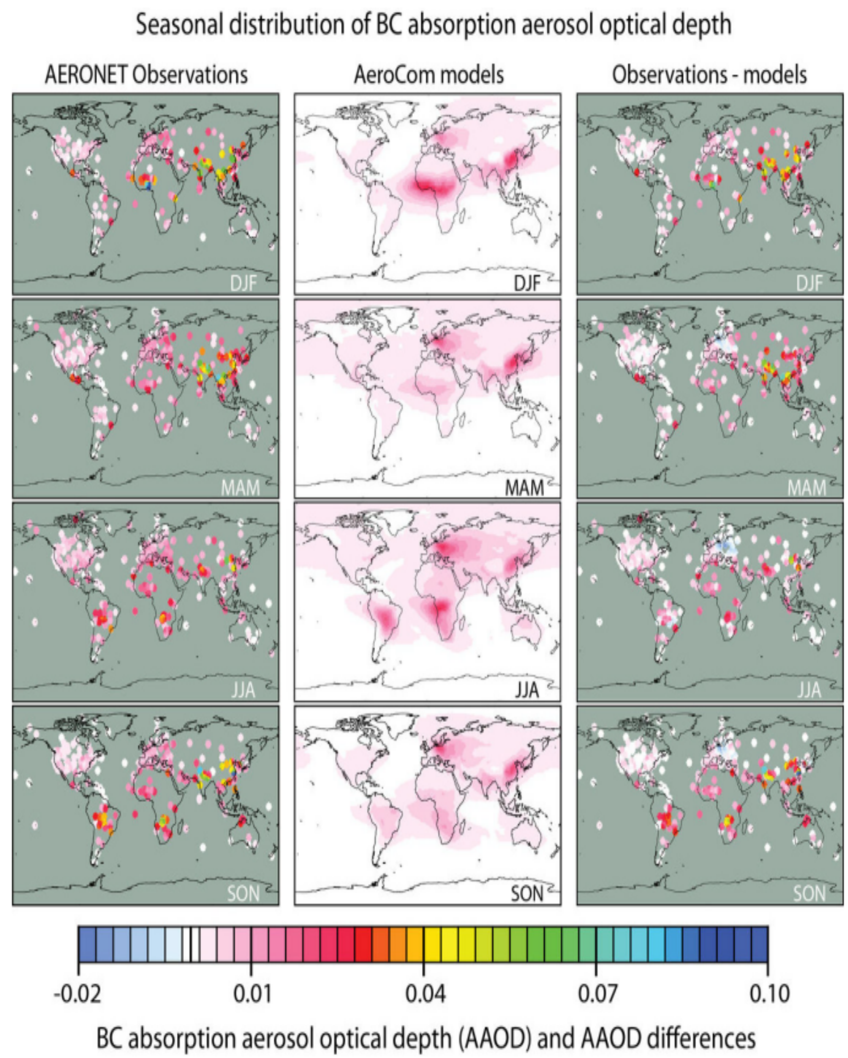
Climatological range of aerosol absorption (SSA) as determined from AERONET Almucantar Retrievals



(Eck et al., 2005, JGR)

AERONET AAOD important for constraining global aerosol models, but has limitations…

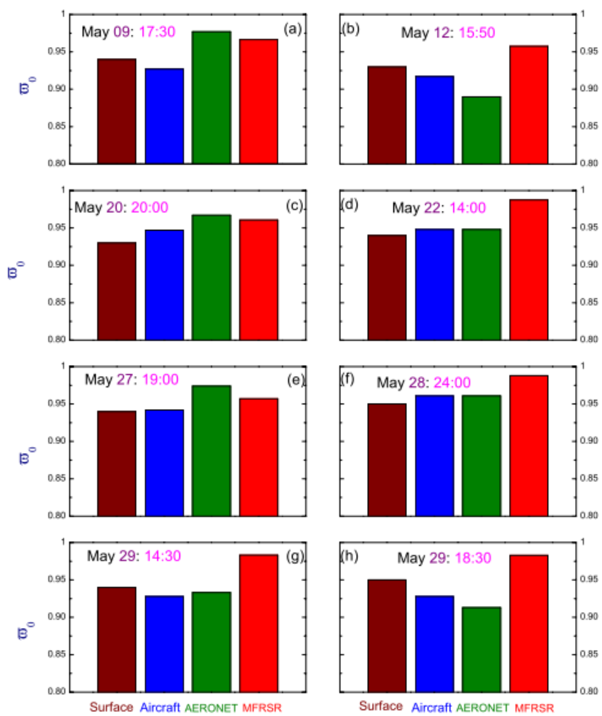
- AAOD derived from AERONET is sensitive assumptions related to
  - Sampling bias – AERONET AAOD most accurate when AOD > 0.33 at 550 nm, excluding data at low AOT introduces bias
  - Retrieving BC AAOD requires separating contributions from BC, dust, OC
- Uncertainties associated with separating BC and dust responsible for half of BC forcing uncertainty (Bond et al., 2013)



(Bond et al, 2013)

MFRSR Column Retrievals

- Size distribution retrieved based on measurements of direct irradiance at 5 wavelengths
- Optical properties derived based on retrieved size distribution, measured direct and diffuse irradiances, assumed real refractive index, and assumed surface spectral albedo
- Retrievals are sensitive to surface albedo – less so below 500 nm
- Diffuse to direct ratio used to derive SSA
- Cloud screening is important
- MFRSR-CIP Evaluation Product available for SGP during 2011 (Kassianov)
- Uncertainty (SSA ~ 0.03-0.04)
- **Sparse validation – more required!**



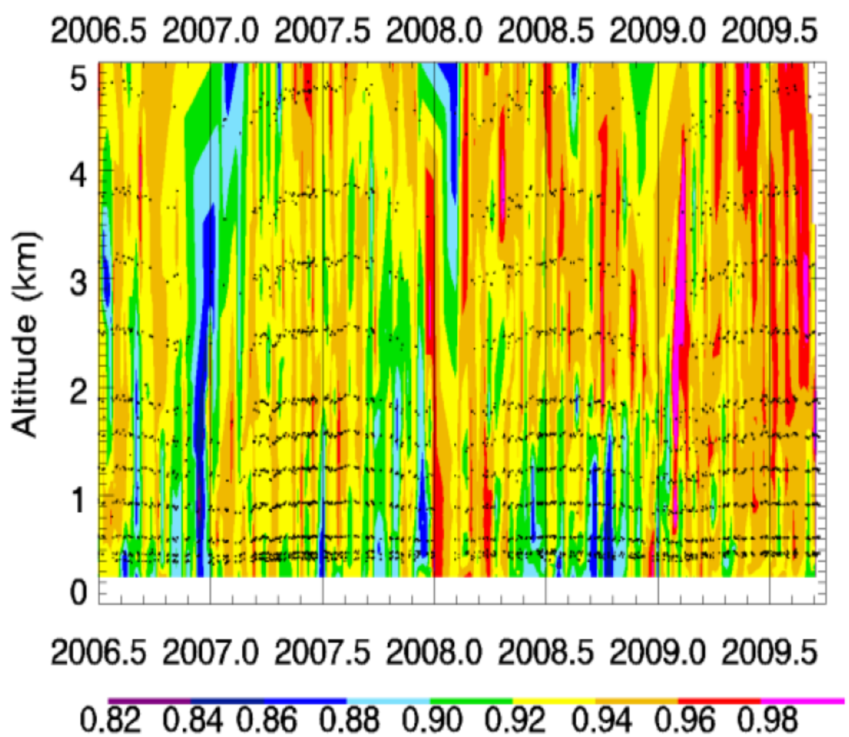
In situ surface
In situ aircraft
AERONET
MFRSR

(Kassianov et al., 2007, ACP)

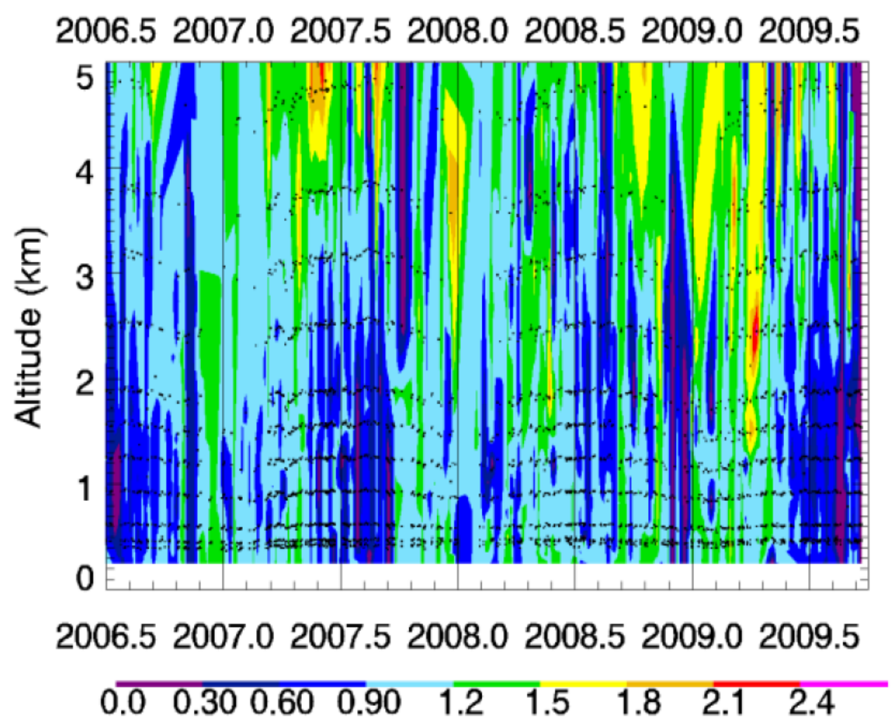
Vertical Variability of Aerosol Absorption

Vertical Variability of Aerosol Single Scattering Albedo derived from airborne in situ data

- **Airborne in situ PSAP measurements of aerosol absorption over Bondville, IL during 2006-2009**
- **Measurements show vertical variability of aerosol absorption and Absorption Ångström exponent**



(g) Single-scattering albedo



(k) Absorption Ångström exponent

Sheridan et al., (ACPD 2012)

AEROCOM models representations of BC and absorption differ from measurements & retrievals

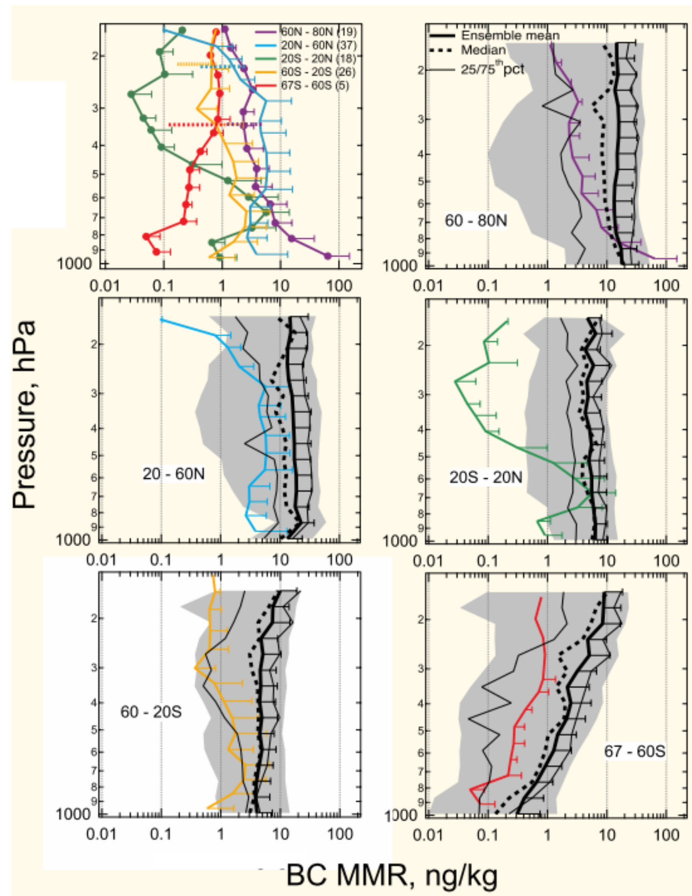
Koch et al. (2009) (ACP)

- AEROCOM model intercomparisons with surface, column, and profile measurements of BC and/or absorption
- Most models biased high compared to surface measurements
- Most models biased low compared to column AAOD or BC burden
- Models overestimate BC at high altitudes
- Additional measurements requested :
  - Additional aircraft measurements over Eurasia, oceans, biomass regions
  - Long term surface measurements co-located with AERONET stations in remote and biomass regions

Average model biases	N Am	Eur	Asia	S Am	Afr	Rest
Surface concentration	1.6	2.6	0.50	NA	NA	1.4
BC burden	0.42	0.58	0.64	0.42	0.64	0.40
AERONET AAOD	0.86	0.81	0.67	0.68	0.53	0.55
OMI AAOD	0.52	1.6	0.71	0.35	0.47	0.26

Schwarz et al. (2010) (GRL)

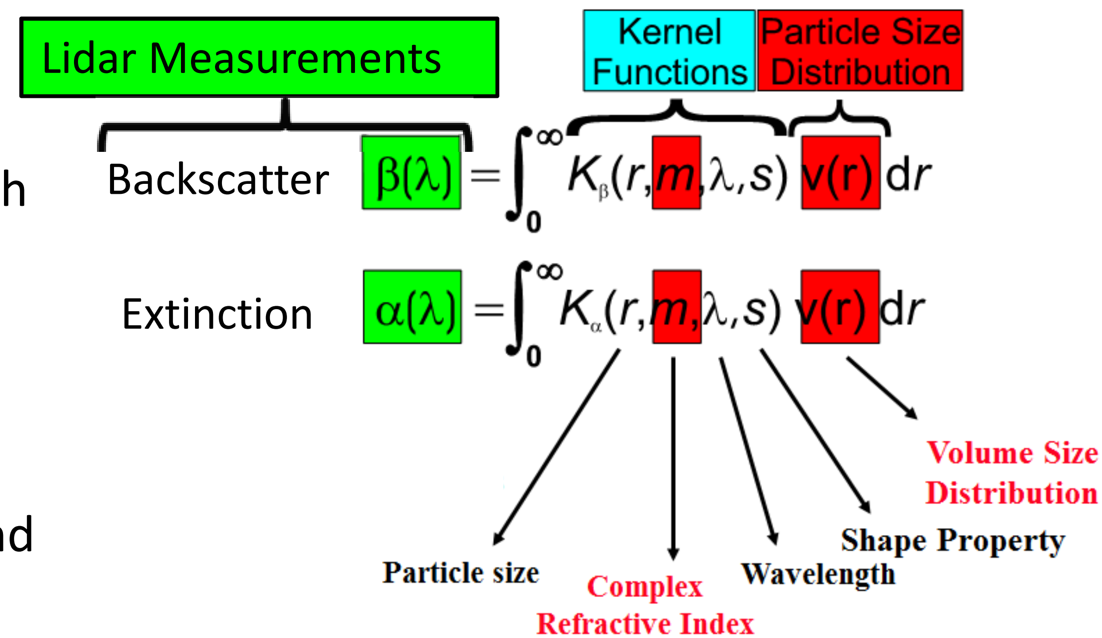
- Airborne SP2 BC profiles compared to AEROCOM profiles
- Models overestimate BC profiles



Lidar Retrievals of Aerosol Absorption

Aerosol Retrievals Based on Lidar Measurements

- Initial methodology is to combine lidar profile measurements of aerosol backscatter and extinction with Sun photometer (or MFRSR) measurements of AOT
- Data Inversion with regularization
  - Particle effective radius and complex refractive index derived with inversion algorithm (Müller et al. 1999, Veselovskii et al., 2002, etc.)
  - Derived microphysical parameters + Mie code provide SSA



$$\beta(\lambda) = \int_0^\infty K_\beta(r, m, \lambda, s)\, v(r)\, dr$$

$$\alpha(\lambda) = \int_0^\infty K_\alpha(r, m, \lambda, s)\, v(r)\, dr$$

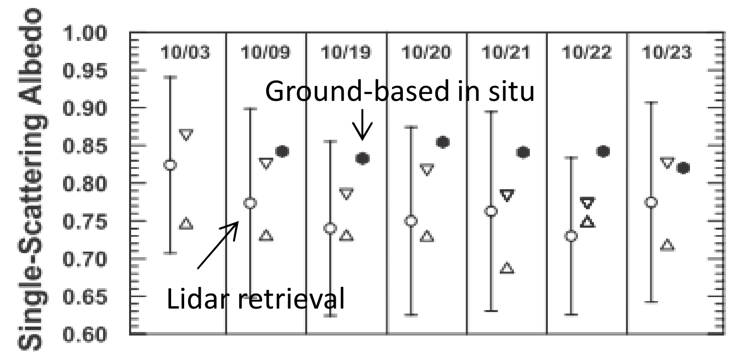
- Inversion procedure is repeated for grid of complex refractive indices
- Average solutions that produce errors within error bound (derived and input optical parameters)

Derived parameters and uncertainties depend on the number of input parameters and uncertainties

Active+Passive Retrievals (Lidar+Sun Photometer)

Case 1: Lidar (1 β + 1 α) + Sun Photometer

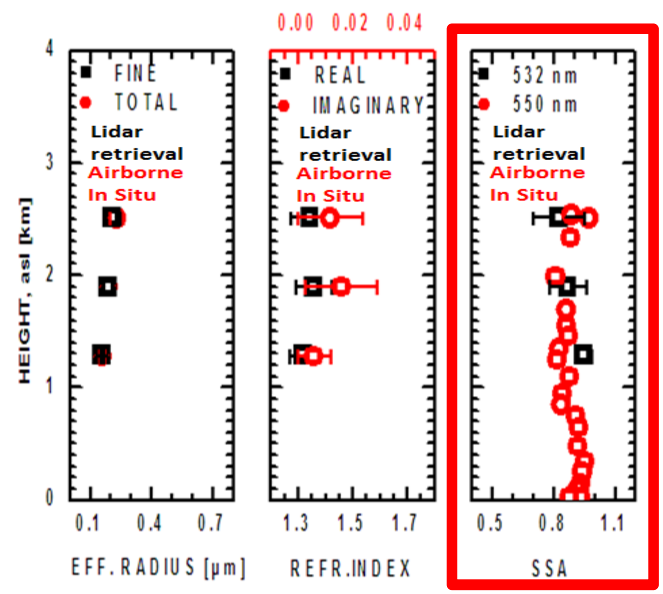
- **Limited to single aerosol layer with spherical, fine mode aerosols**
- Does not require sky radiance measurements and so may be applicable in partly cloudy situations
- Somewhat large (+/- 0.1) uncertainty in SSA
- Examples from Müller et al. (2006), Tesche et al. (2008) (532 nm)
- Could be possible via ground-based lidars at ARM site(s)
  - Raman lidar (355 nm)
  - HSRL (532 nm)



Tesche et al., (2008)

Case 2: Lidar (2 β + 1 α) + Sun Photometer

- **Layer-Resolved Aerosol Parameters**
- Limited to spherical, fine mode aerosols
- Does not require sky radiance measurements and so may be applicable in partly cloudy situations
- Reduced (+/- 0.05-0.1) uncertainty in SSA
- Example from Balis et al. (2010) (β (355,532), α(355))
- Could be possible via ground-based lidars at ARM site(s)
  - Raman lidar (β (355), α(355))
  - MPL β (523)
  - HSRL (β (532), α(532))



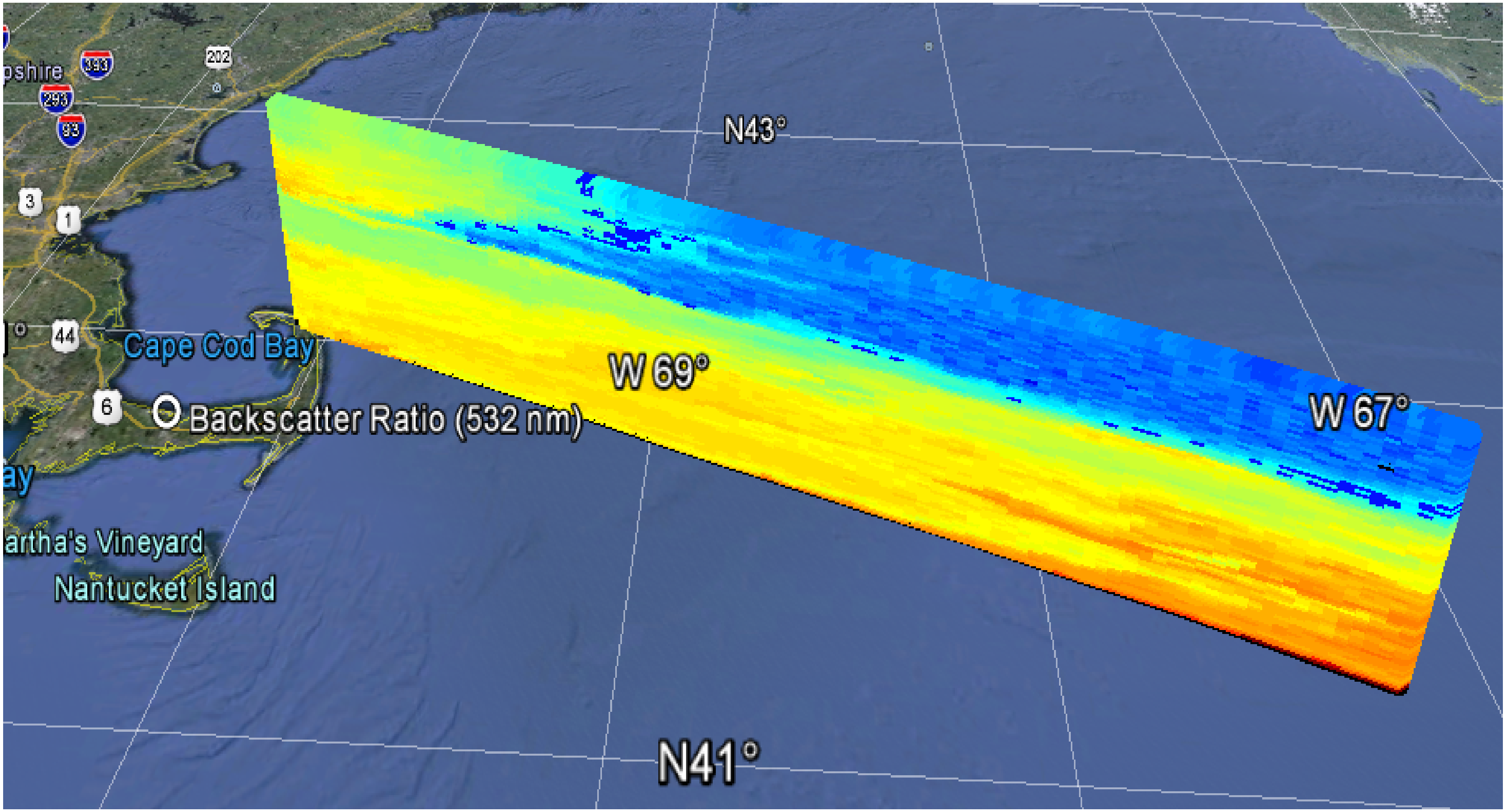
Specific retrieval methodology would have to be developed for and tailored to ARM instruments

Balis et al., (2010) (JGR)

Multiwavelength ("3+2") Lidar Retrievals

- Retrievals of layer-resolved, aerosol microphysical/macrophysical parameters demonstrated extensively with ground-based Raman lidar (Müller et al., 1999, 2000, 2001, 2004; Veselovskii et al.,2002,2004)
  - Effective and mean particle radius (errors < 30-50%)
  - Concentration (volume, surface) (errors < 50%)
  - Complex index of refraction
    - real (±0.05 to 0.1)
    - imaginary (order of magnitude if < 0.01; <50% if > 0.01)
  - **Single scatter albedo (±0.05; error increases for $r_{eff} > 0.3\ \mu m$)**
- Microphysical retrieval issues
  - Assumes wavelength independent and size independent refractive index
  - Assumes spherical particles; upgrade to spheroids is planned
  - Retrieval is restricted to particle radii > 50 nm
  - Until recently was not operational and usually required extensive computation time and expert operator
- **Automated algorithm recently developed by Drs. Müller and Chemyakin for application to large datasets**
  - Software completely automated
  - Processing of vertical profiles and large data sets is possible
  - Absorption coefficients can be retrieved
- Ground-based implementation at ARM sites would require additional lidars
- **Sparse validation – more required!**

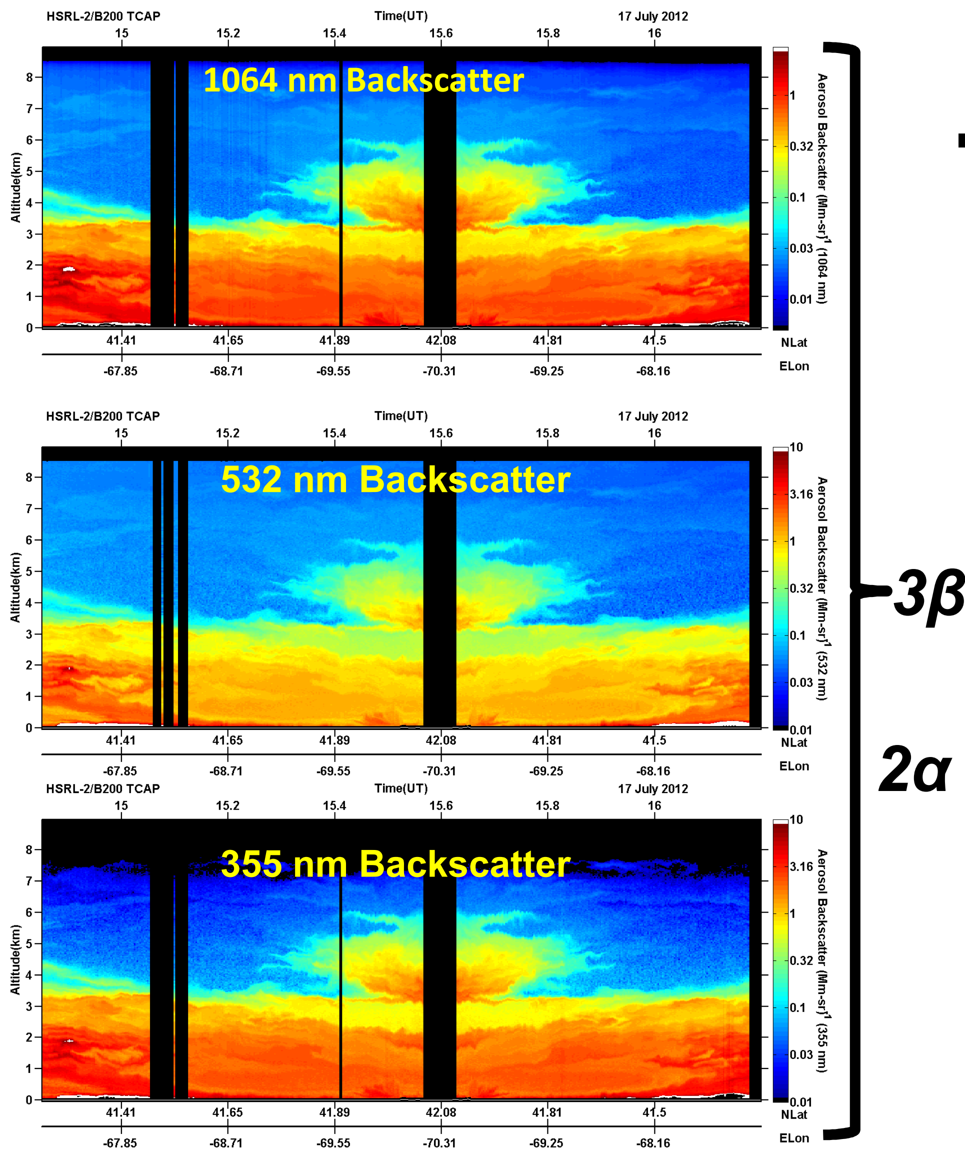
532-nm Aerosol Scattering Ratio from 17 July 2012



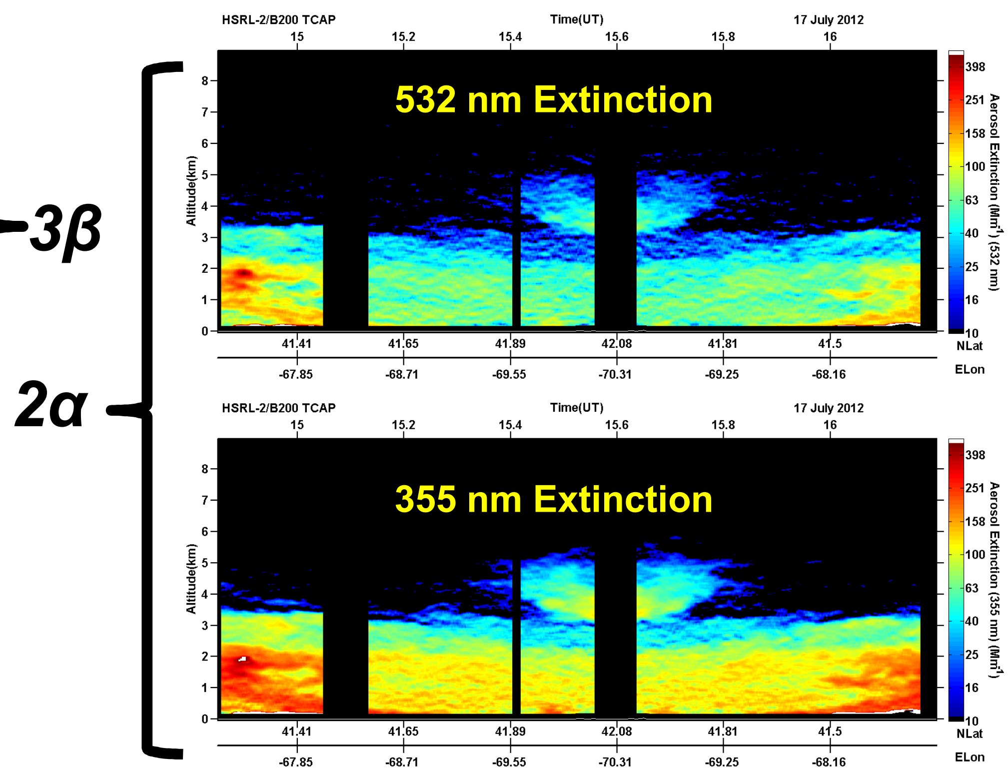
Airborne multi-wavelength "3β+2α" HSRL measurements from the TCAP field campaign

ASR Atmospheric System Research

07/17/2012 TCAP flight on B200 aircraft



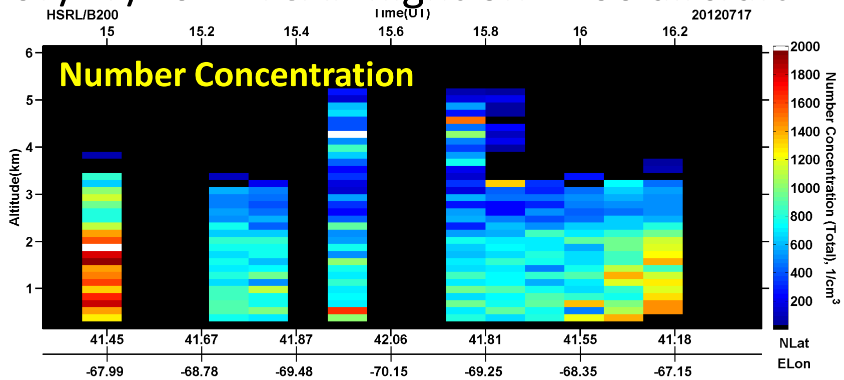
- High Spectral Resolution Lidar (HSRL) provides independent retrievals of aerosol extinction and backscatter
- HSRL-2 Capabilities
  - Backscatter at 355, 532, and 1064 nm
  - Extinction at 355 and 532 nm (HSRL)
  - Depolarization at 355, 532, 1064 nm



HSRL-2 "3β+2α" Microphysical Retrieval

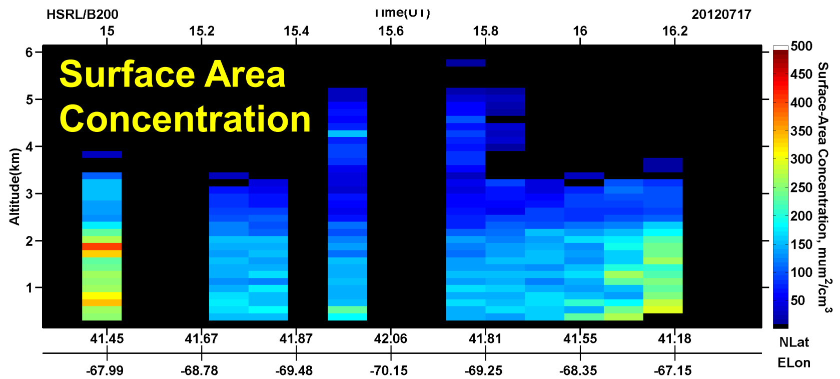
ASR Atmospheric System Research

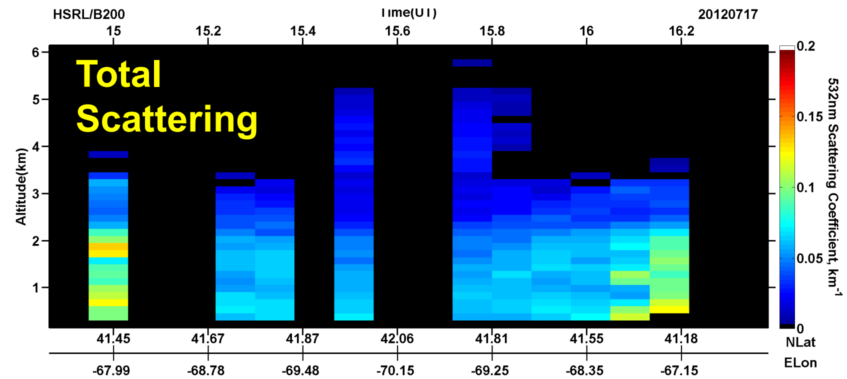
07/17/2012 TCAP flight on B200 aircraft

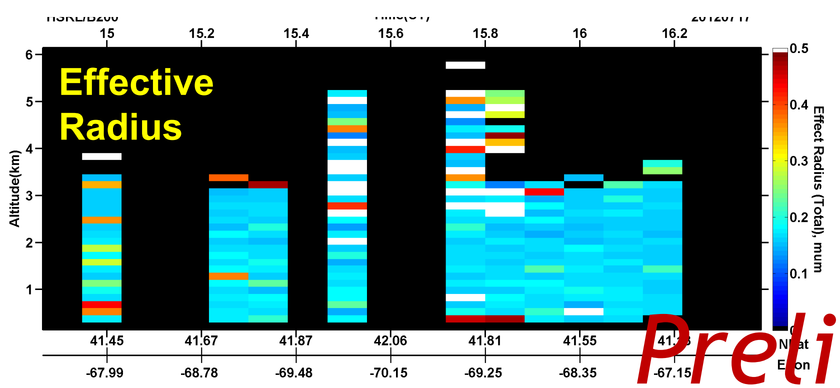


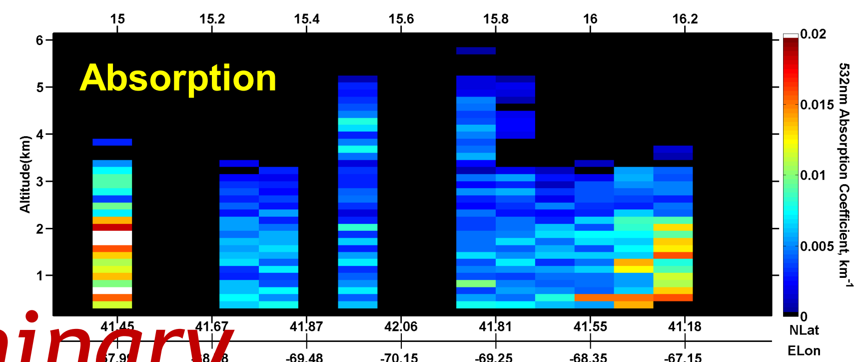
- Inversion with Regularization (Muller et al. 1999, Veselovskii et al 2002)
- Produces horizontally and vertically resolved curtains of microphysics including:

  Effective radius – Complex index of refraction – Scattering coefficient – Absorption coefficient – Single scatter albedo – Number, Surface and Volume Concentration









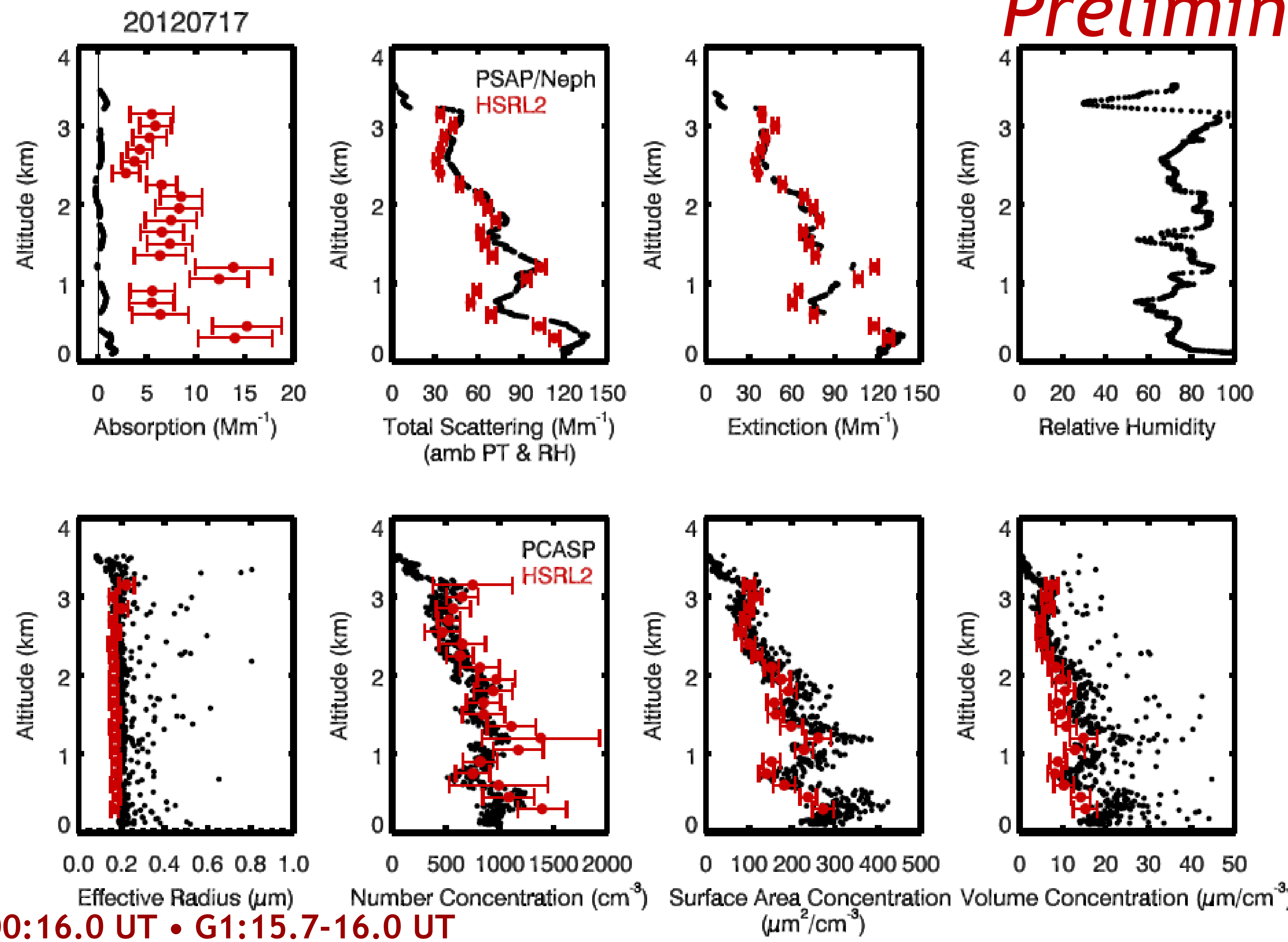
Preliminary

Extra Slides

HSRL-2 Microphysics Comparison with G1 In Situ

17 July

Preliminary

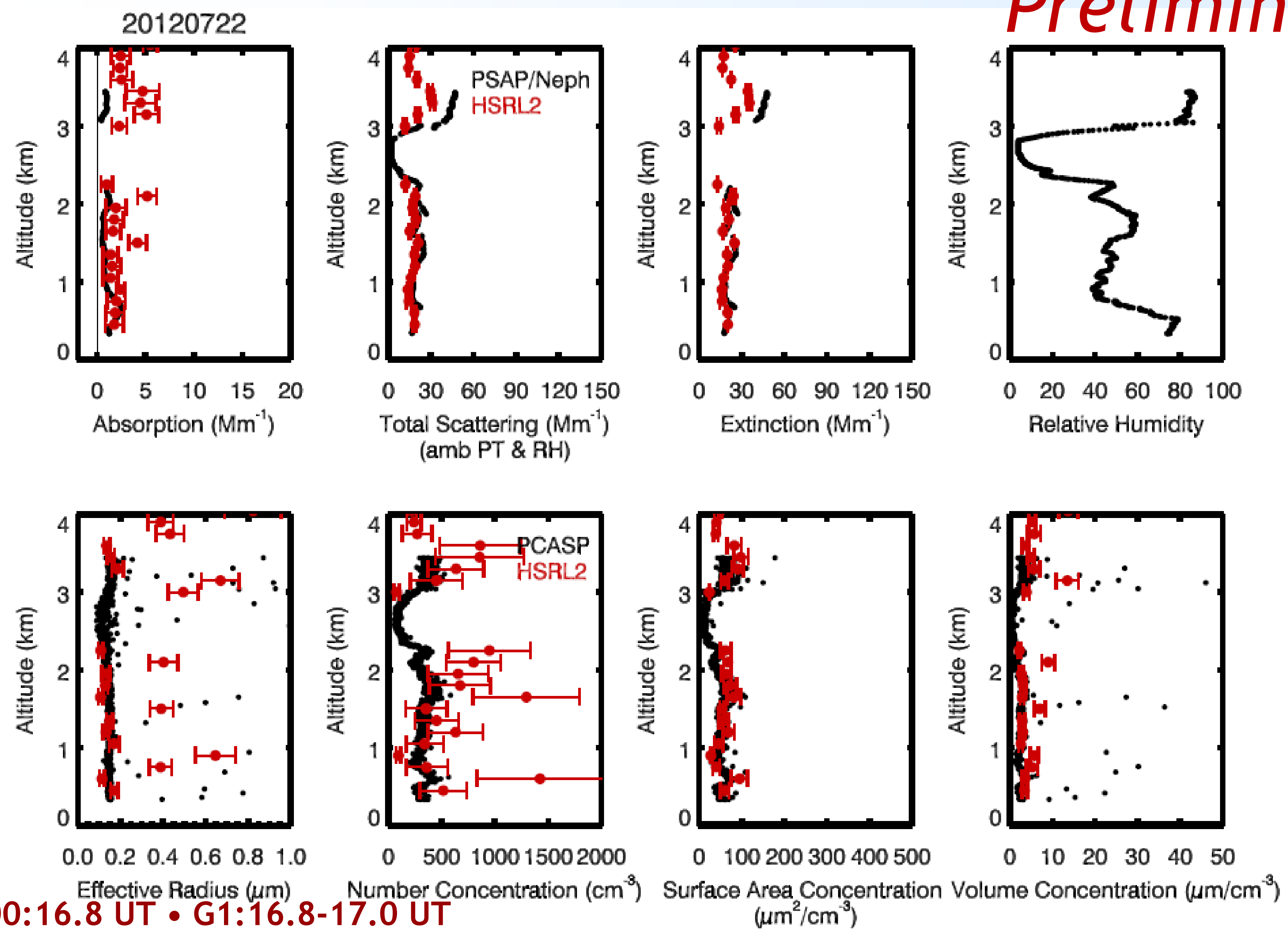


B200:16.0 UT • G1:15.7-16.0 UT

HSRL-2 Microphysics
Comparison with G1 In Situ

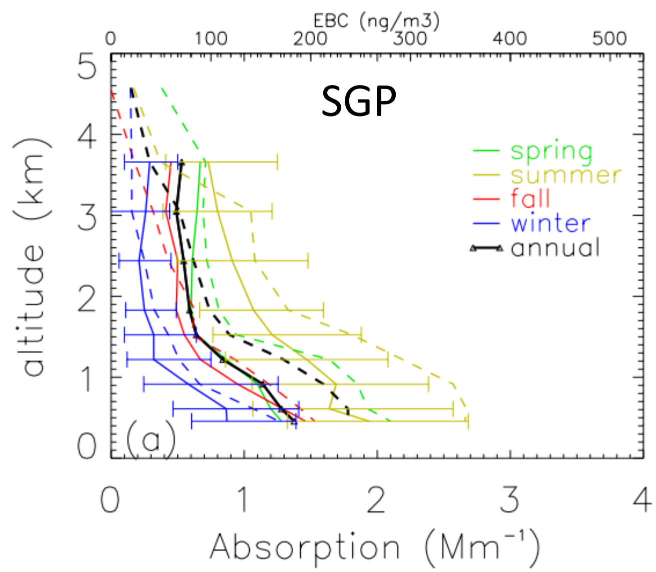
22 July

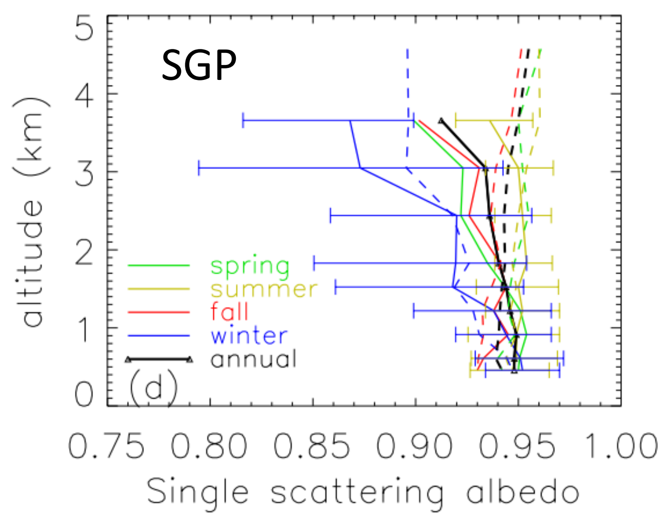
Preliminary



B200:16.8 UT • G1:16.8-17.0 UT

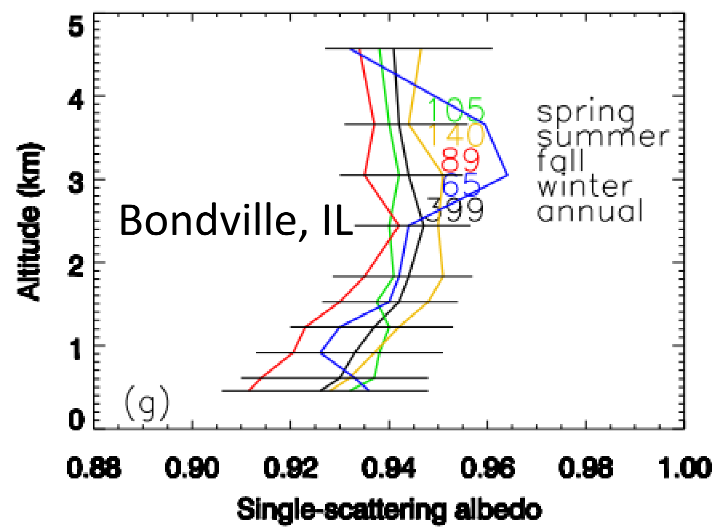
Vertical Variability of Aerosol Single Scattering Albedo derived from airborne in situ data





Andrews et al. (2011) (ACP)

- **Airborne in situ PSAP measurements of aerosol absorption over ARM SGP CRF during 2000-2007 and Bondville, IL (2006-2009)**
- **Measurements show different systematic behavior of SSA with height**



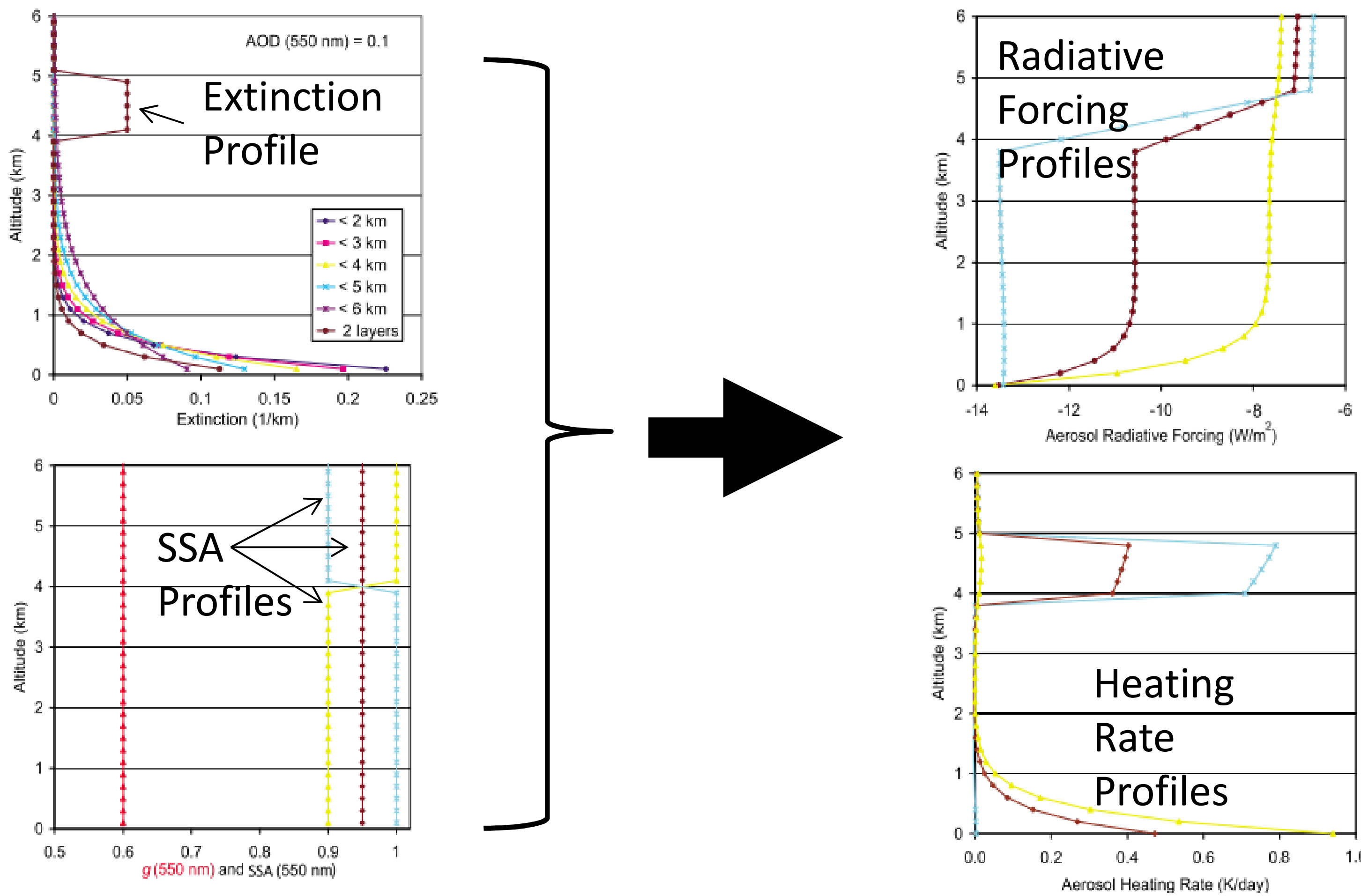
Sheridan et al., (ACPD 2012)

Vertical Variability of Aerosol Absorption Impacts Solar Radiative Forcing and Heating Rate Profiles

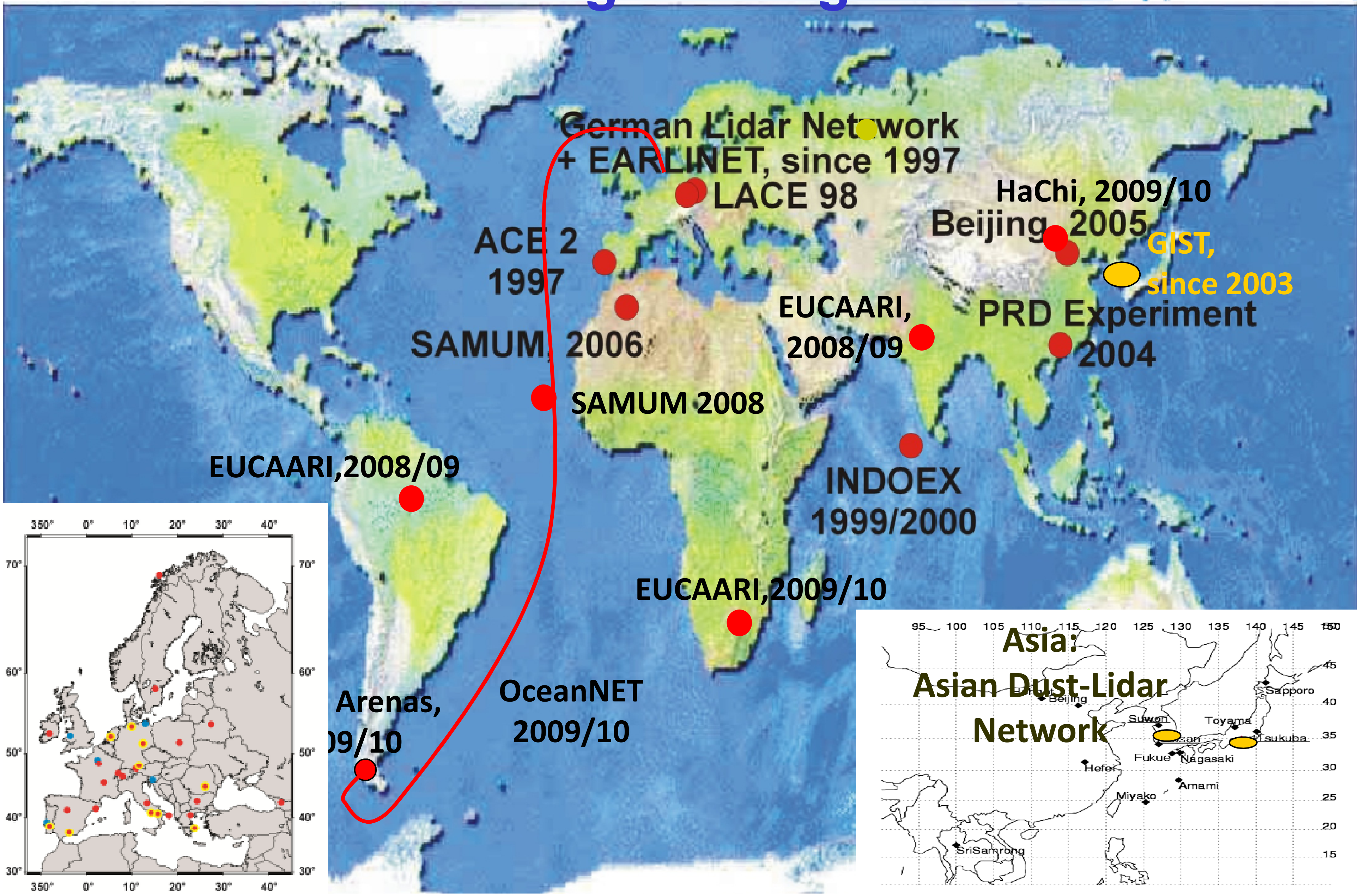
ASR Atmospheric System Research

Guan et al. (2010) (JGR)

- Identical extinction profiles with different absorption profiles drastically influence the radiative forcing and heating rate profiles

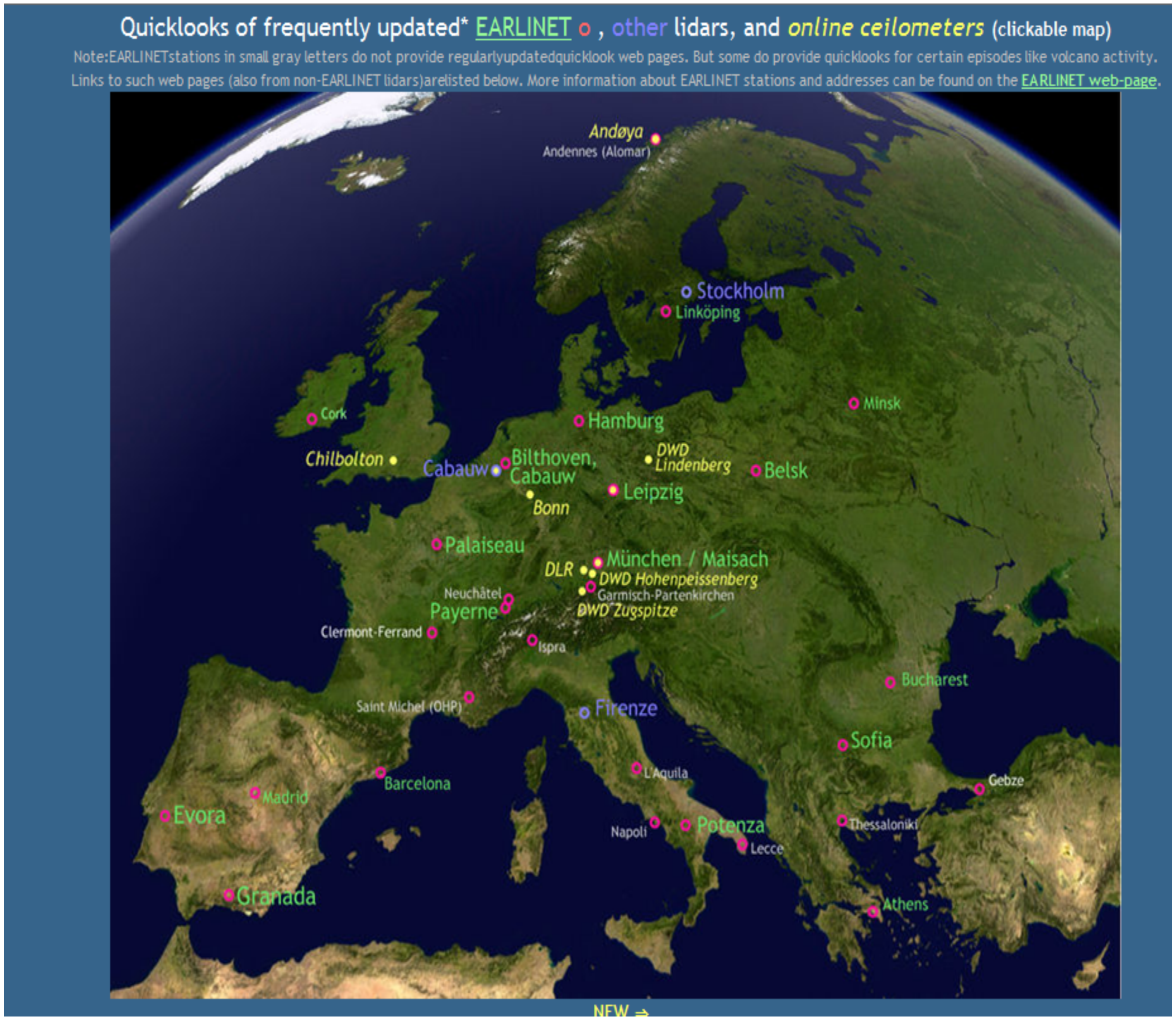


Multiwavelength Raman Lidars in Other Places: data inversion- setting the stage for ACE



EARLINET

- EARLINET Stations
- Several lidar stations have “3+2” capability
- Automated centralized software being developed and implemented for retrievals of aerosol extinction and backscattering
- Advanced “3+2” aerosol retrievals are also being developed



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Preliminary results from automated, unsupervised retrieval algorithm using NASA LaRC airborne HSRL-2 3β +2α data collected during the DOE TCAP mission