Characterization of aerosols using airborne lidar and MODIS

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MODIS Atmospheres Meeting, January 5, 2006

Outline

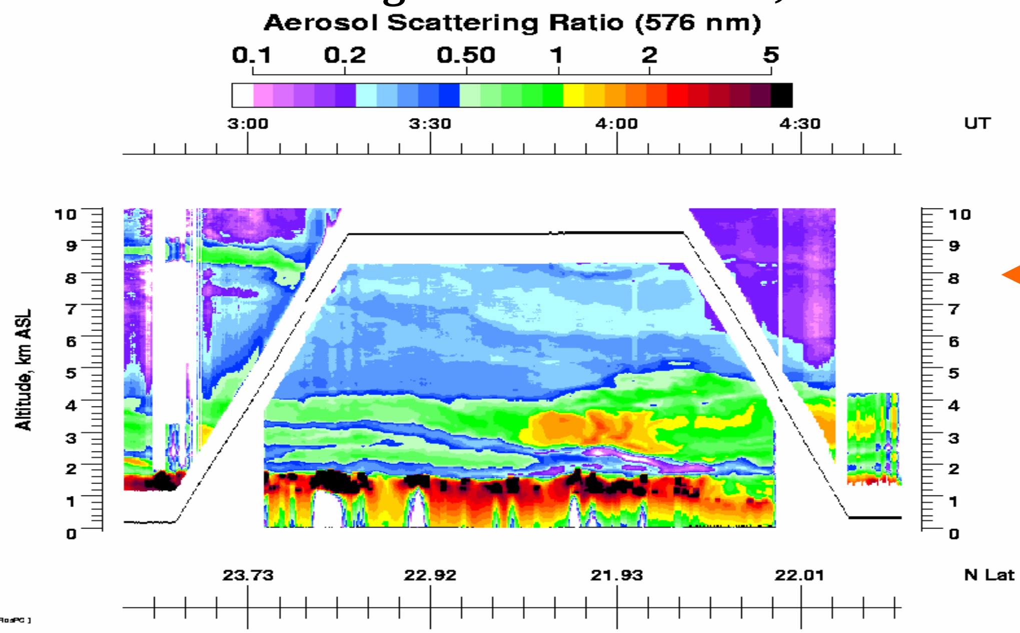
- Objectives
- Airborne Lidar Aerosol Measurements
- Lidar + MODIS retrievals
- GOCART model evaluation
- Summary and Future

Objectives

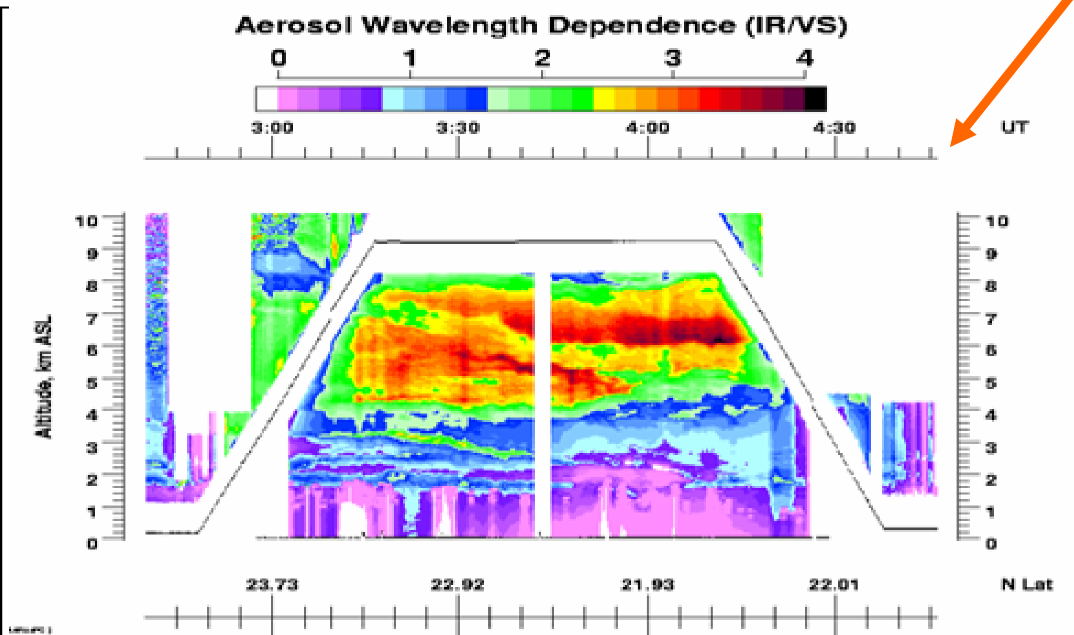
- Retrieve aerosol extinction and optical thickness profiles from lidar data
- Use combination of airborne lidar and MODIS to provide information regarding the vertical distribution of aerosol properties (size, fine mode fraction)
- Identify aerosol types vs. altitude
- Evaluate ability of GOCART model to simulate aerosol extinction profiles and aerosol type

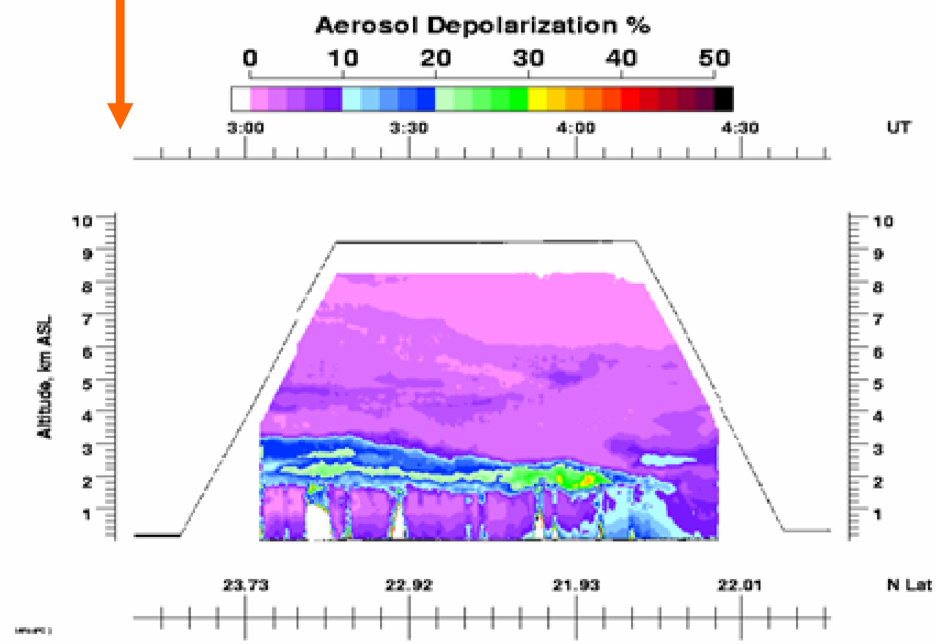
NASA Langley Airborne UV DIAL Measurements

TRACE-P Flight 14 March 23-24, 2001



- Simultaneous Nadir and Zenith Ozone & Aerosol Profiling
- Deployed on NASA DC-8 for TRACE-P (2001), INTEX NA (2004)
- Aerosol extensive parameters (300, 576, 1064 nm)
  - aerosol scattering ratio
  - backscatter
  - extinction
- Aerosol intensive parameters
  - backscatter wavelength dependence
  - depolarization





Aerosol Profile Retrievals

• Problem - Backscatter lidar equation (1 equation with 2 unknowns)

Measured Signal

Range from Instrument

Calibration Constant

Molecular Backscatter Coefficient

Molecular Extinction Coefficient

← **Known**

Determined from measured signals and meteorological data

$$P(r) = \frac{C}{r^2}\left[\beta_m(r) + \beta_p(r)\right]\exp\left\{-2\int_0^r \left[\sigma_m(r') + \sigma_p(r')\right]dr'\right\}$$

Particulate Backscatter Coefficient

Particulate Extinction Coefficient

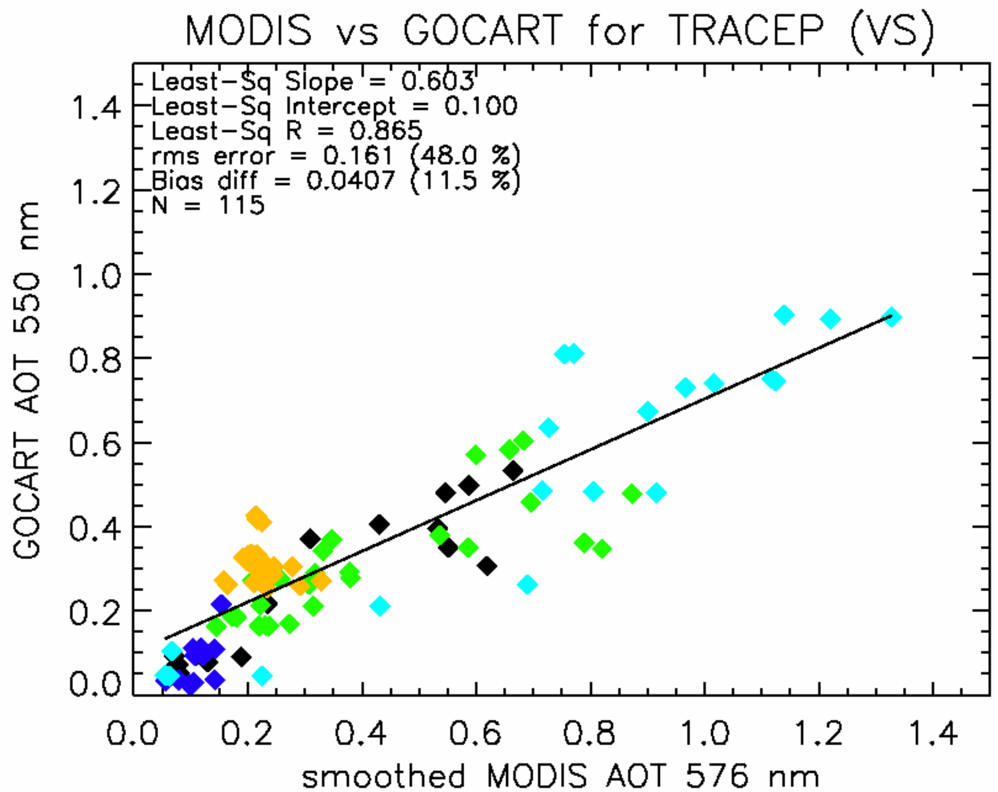
← **Retrieved Parameters**

"Lidar Ratio" = $\frac{\sigma_p(r)}{\beta_p(r)} = S_p$ ← Assumption of value for extinction-to-backscatter (S_p) ratio required for backscatter lidar retrieval

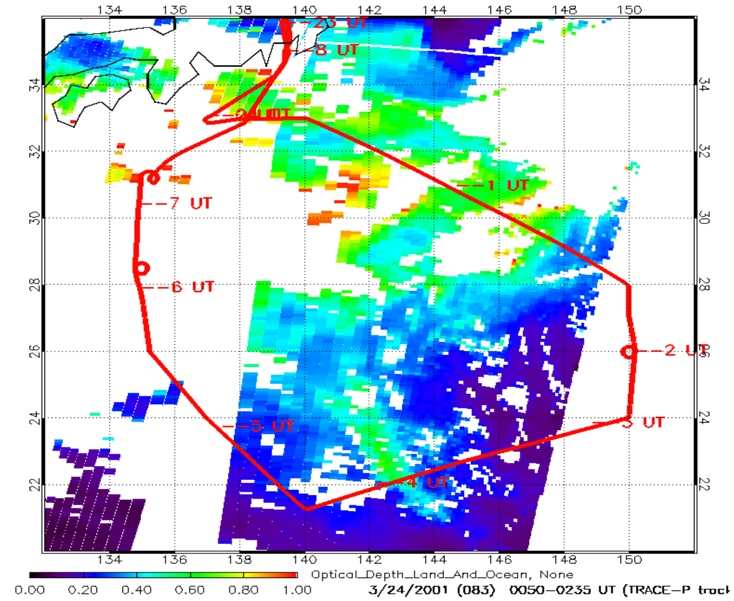
• Solution – we use aerosol optical thickness (e.g. total aerosol transmission) derived from MODIS and/or model (e.g. GOCART) to constrain solution and derive average lidar ratio

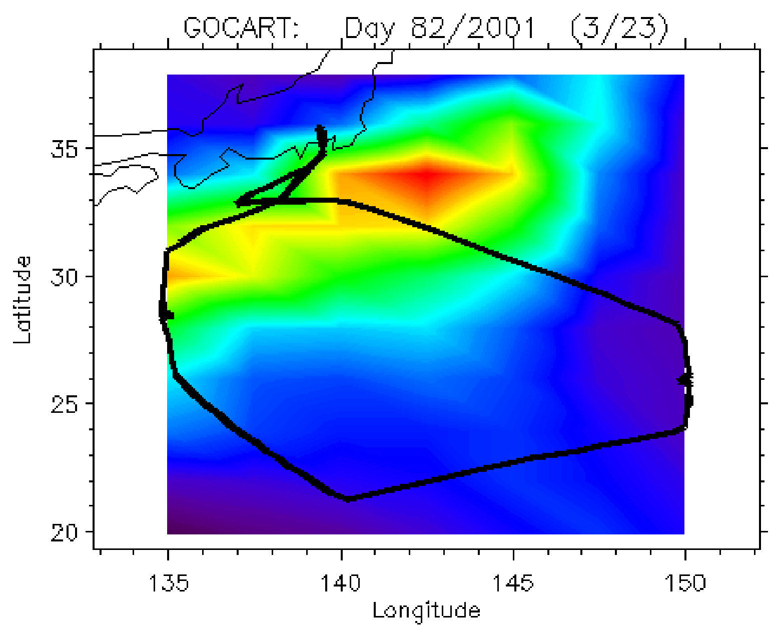
MODIS and GOCART AOT – TRACE-P

- Since DC-8 flights occurred over areas not measured by MODIS, we require other ways to estimate AOT over flight tracks
- For TRACE-P, we used GOCART simulations of AOT that have been adjusted according to least-squares fit between GOCART and MODIS AOT

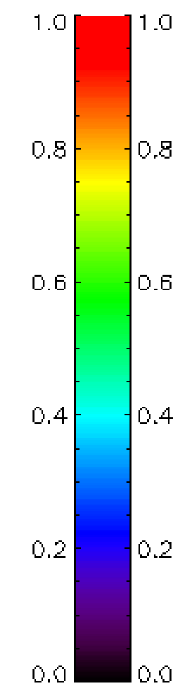


TRACE-P Flt 14 – 03/23-24/2001





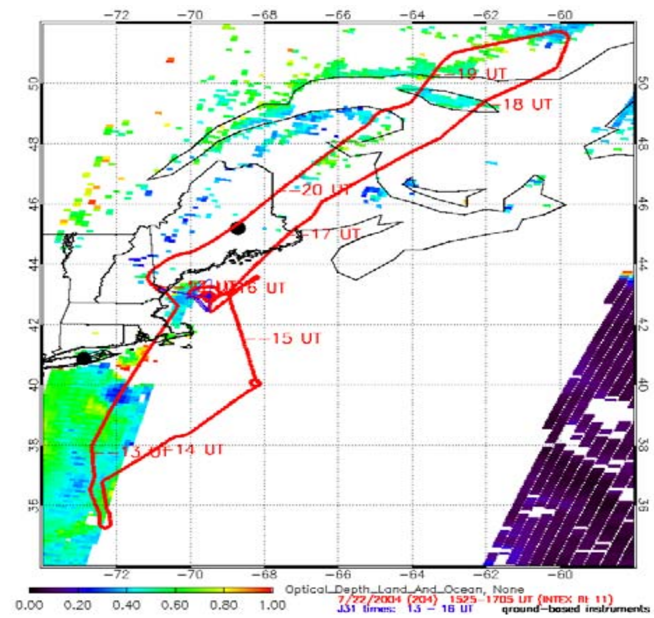
AOT (550 nm)



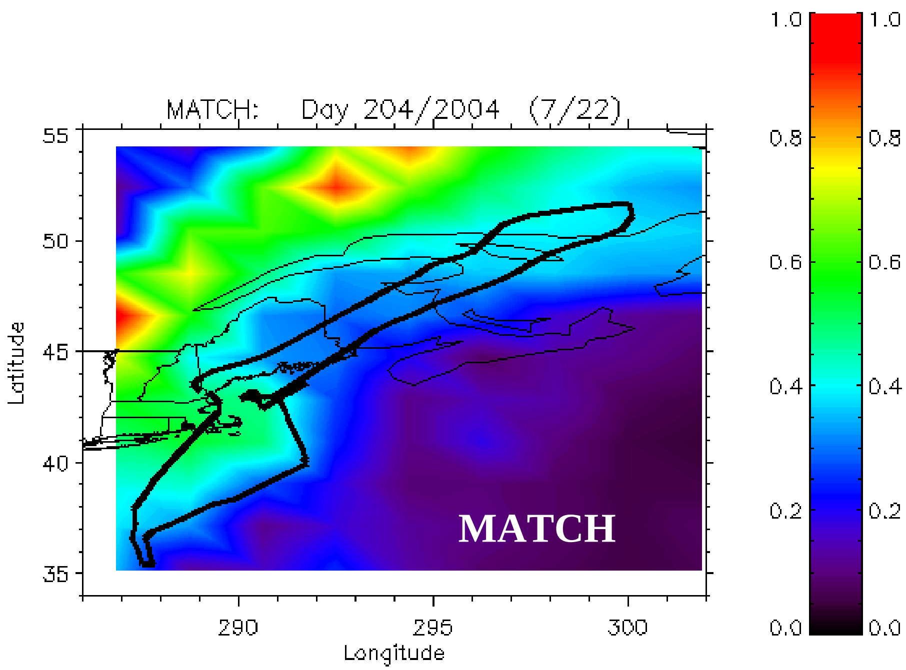
MODIS and MATCH AOT – INTEX NA

- Since DC-8 flights occurred over areas not measured by MODIS, we require other ways to estimate AOT over flight tracks
- For INTEX-NA, we have initially used MATCH simulations of AOT provided by NCAR for CERES
- MATCH assimilates MODIS AOT

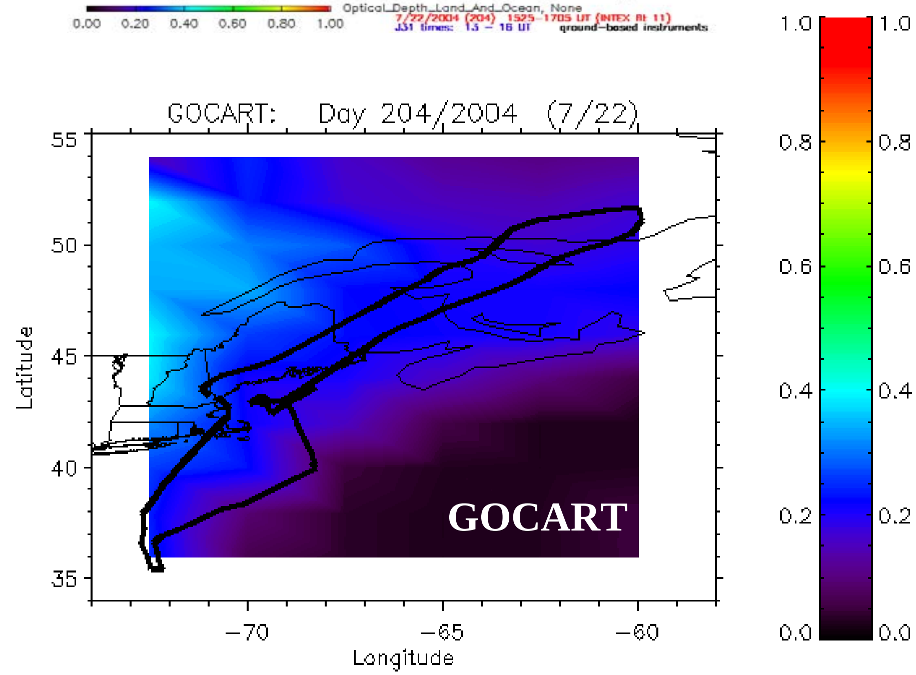
INTEX-NA Flt 11 – 07/22/2004



AOT
(550 nm)

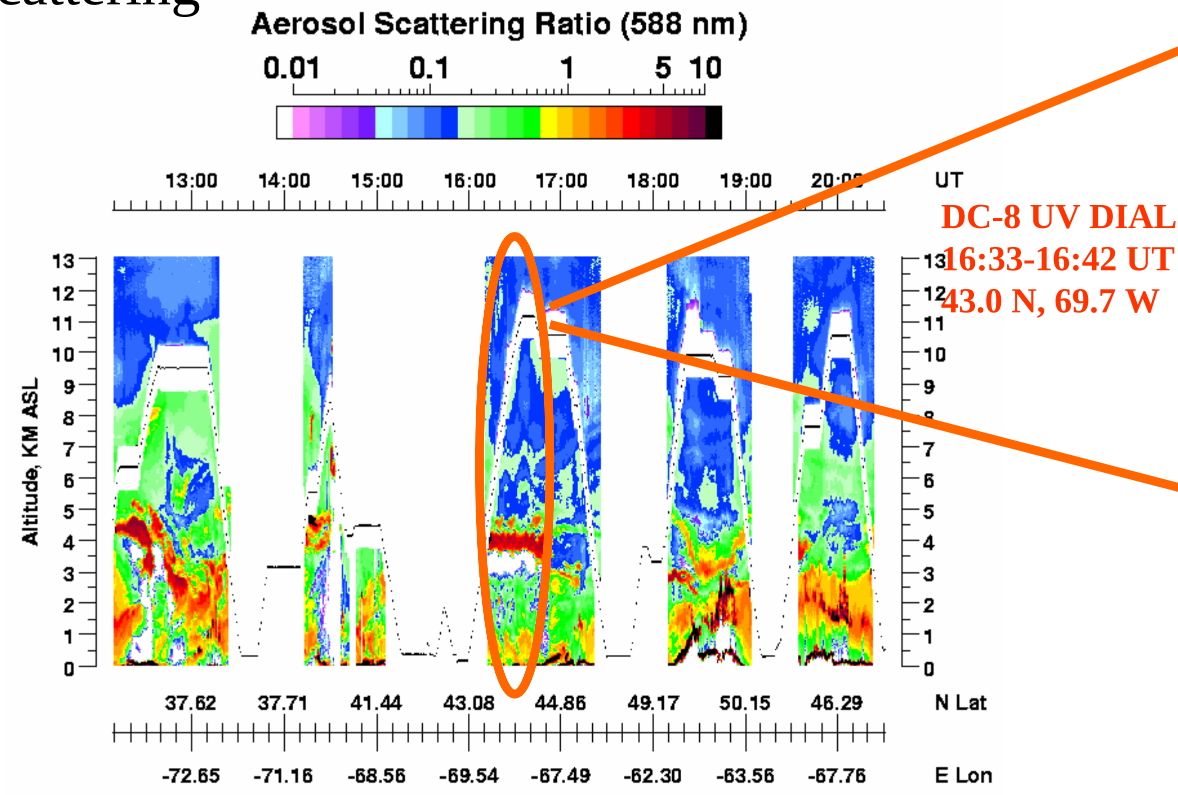


AOT
(550 nm)

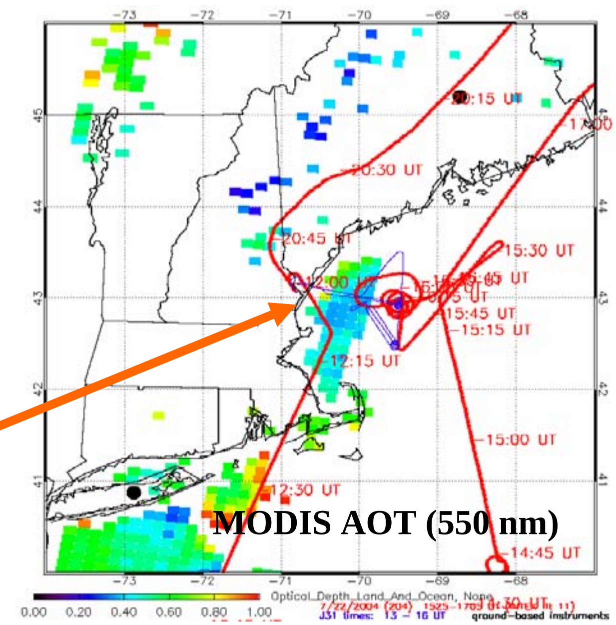


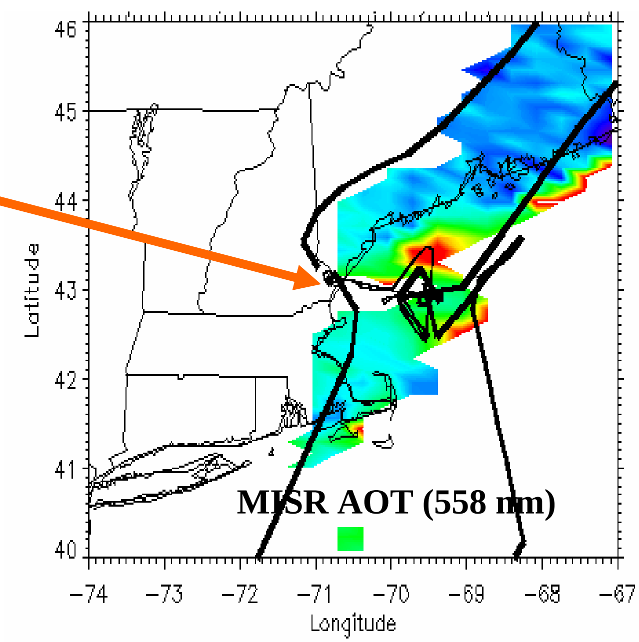
Aerosol Profile Retrieval – July 22, 2004

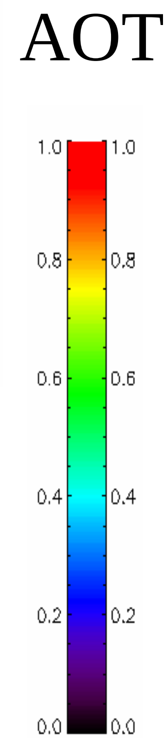
- MODIS and MISR Aerosol Optical Thickness (AOT)
- Terra Overpass at 15:30 UT on July 22, 2004 – DC-8 Flight 11
- Aerosol scattering ratio - (aerosol/molecular) scattering



UV DIAL ASR (uncorrected)

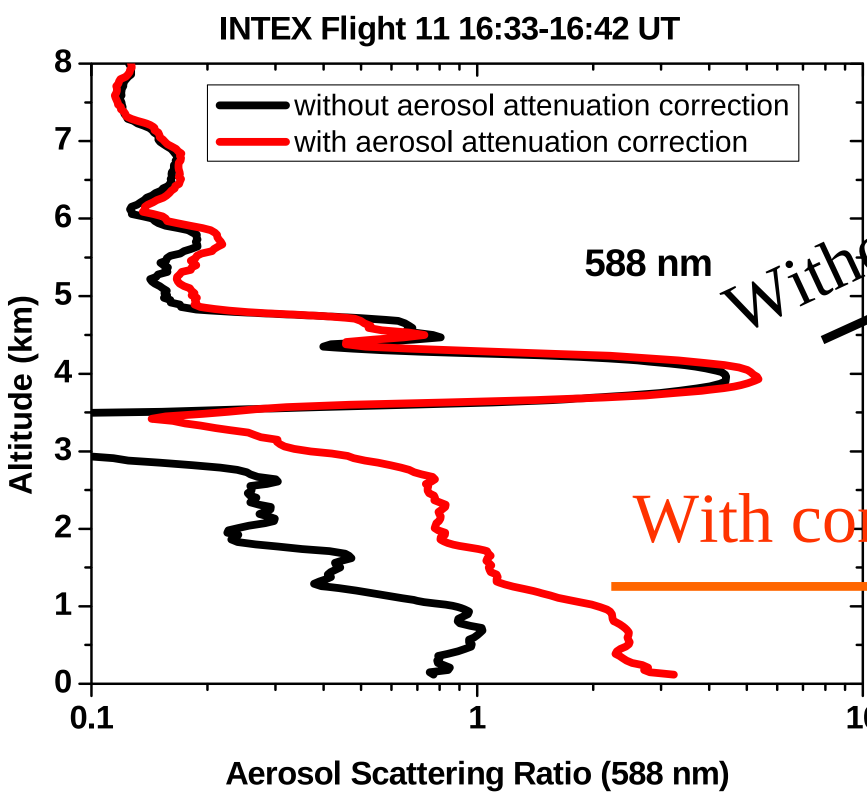




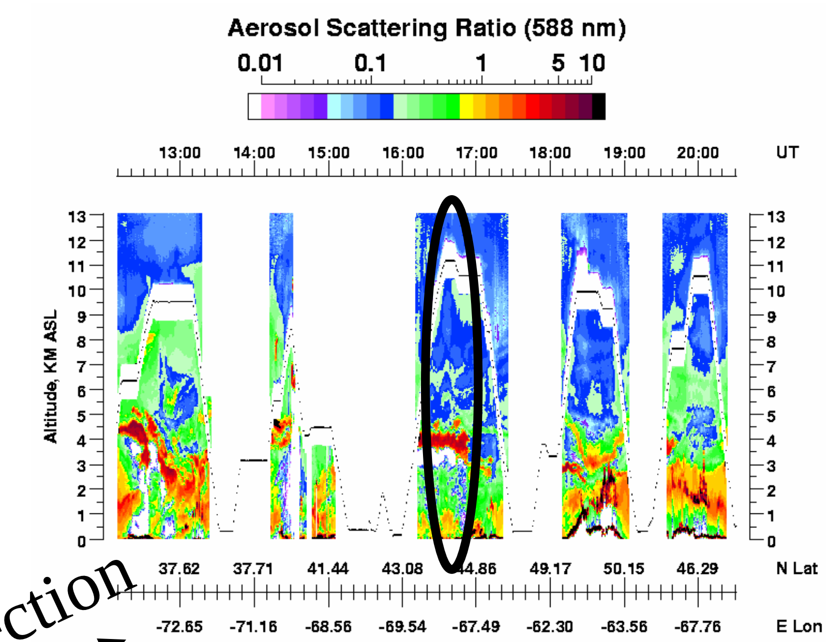


Aerosol Scattering Ratio – July 22, 2004

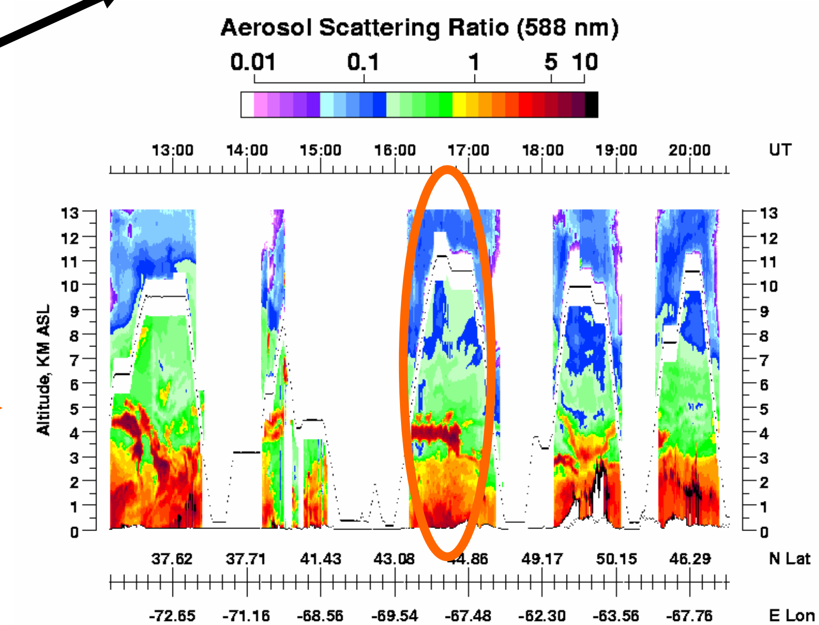
- Attenuation correction applied using MODIS AOT constraint
- Correction at low altitudes ~ 200-300% at 588 nm, 20-40% at 1064 nm



Without correction

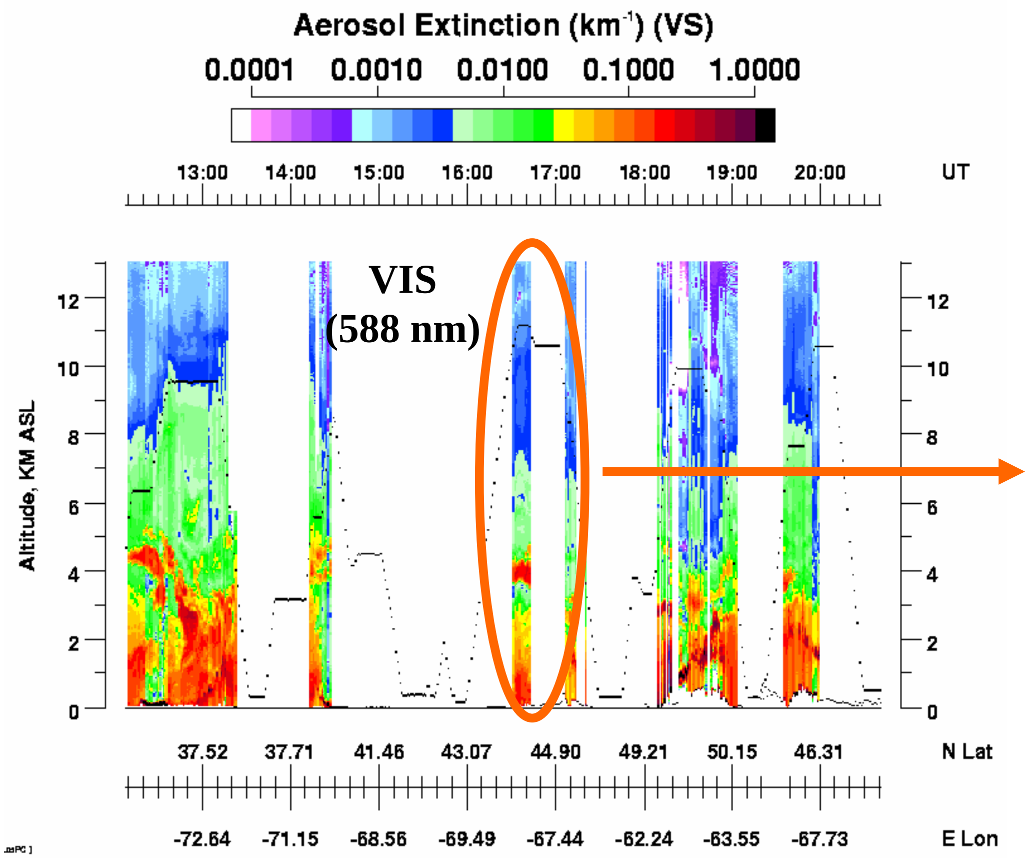


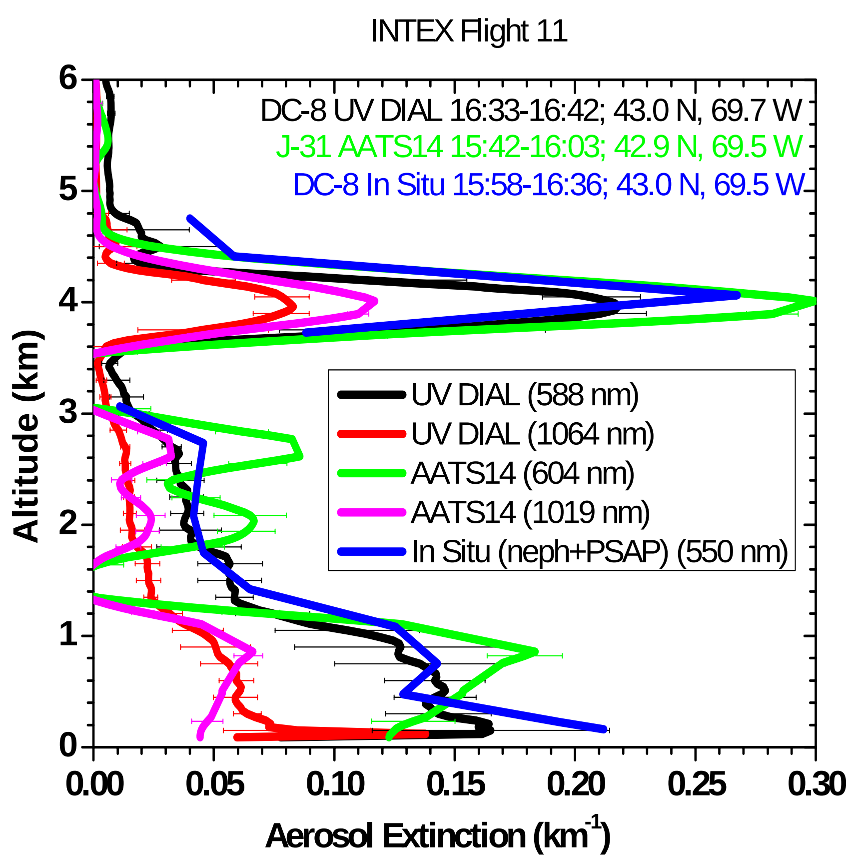
With correction



Preliminary Aerosol Extinction Comparison – July 22, 2004

- UV DIAL
- NASA Ames Airborne Sun Photometer (AATS14) on J-31 aircraft
- Scattering (nephelometer) + Absorption (PSAP) in situ on DC-8





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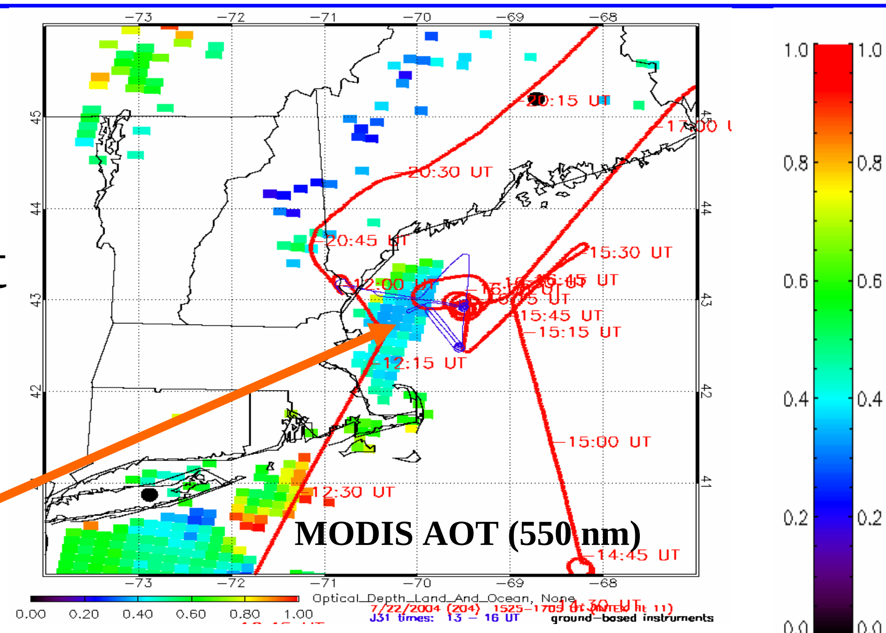
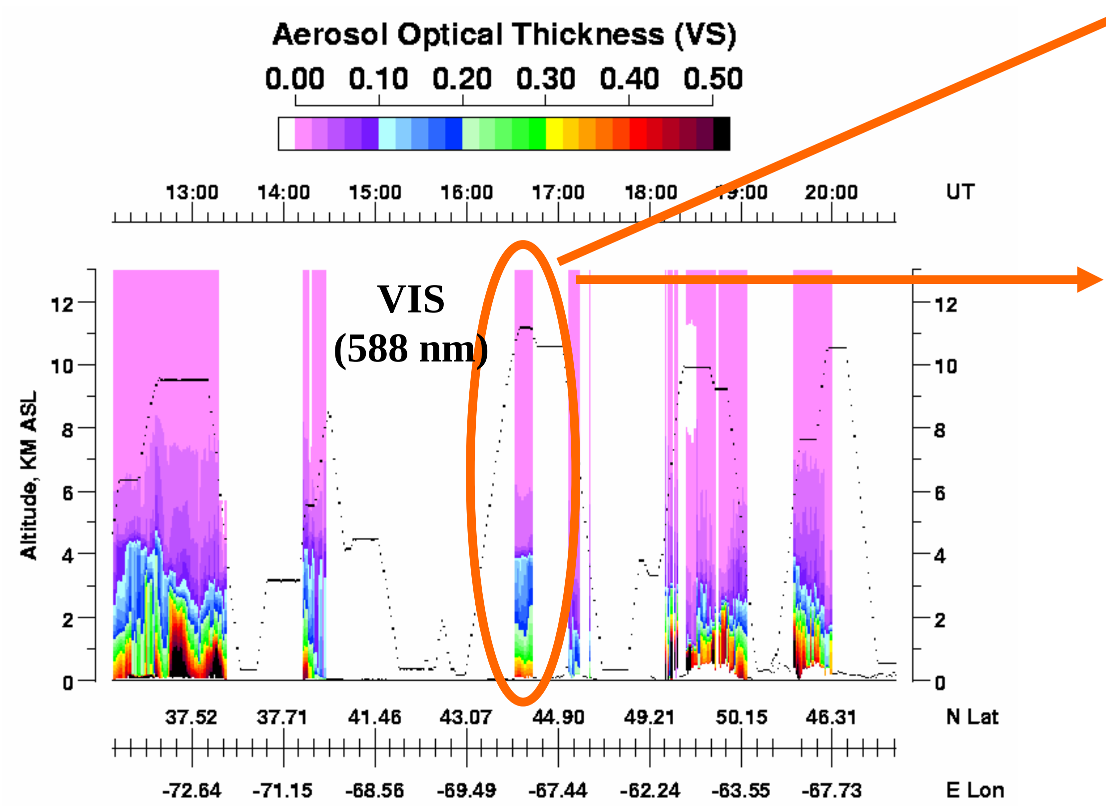
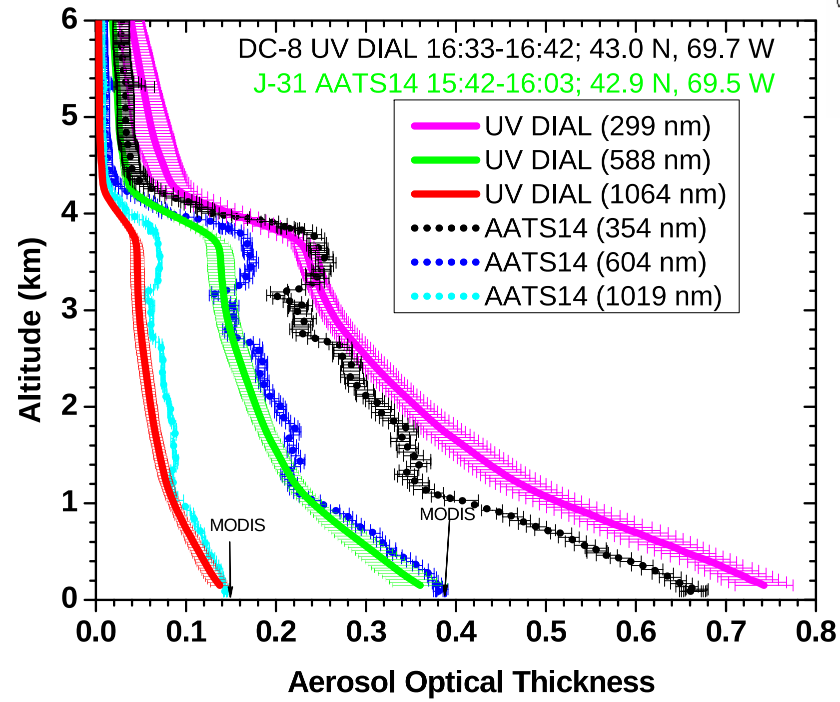




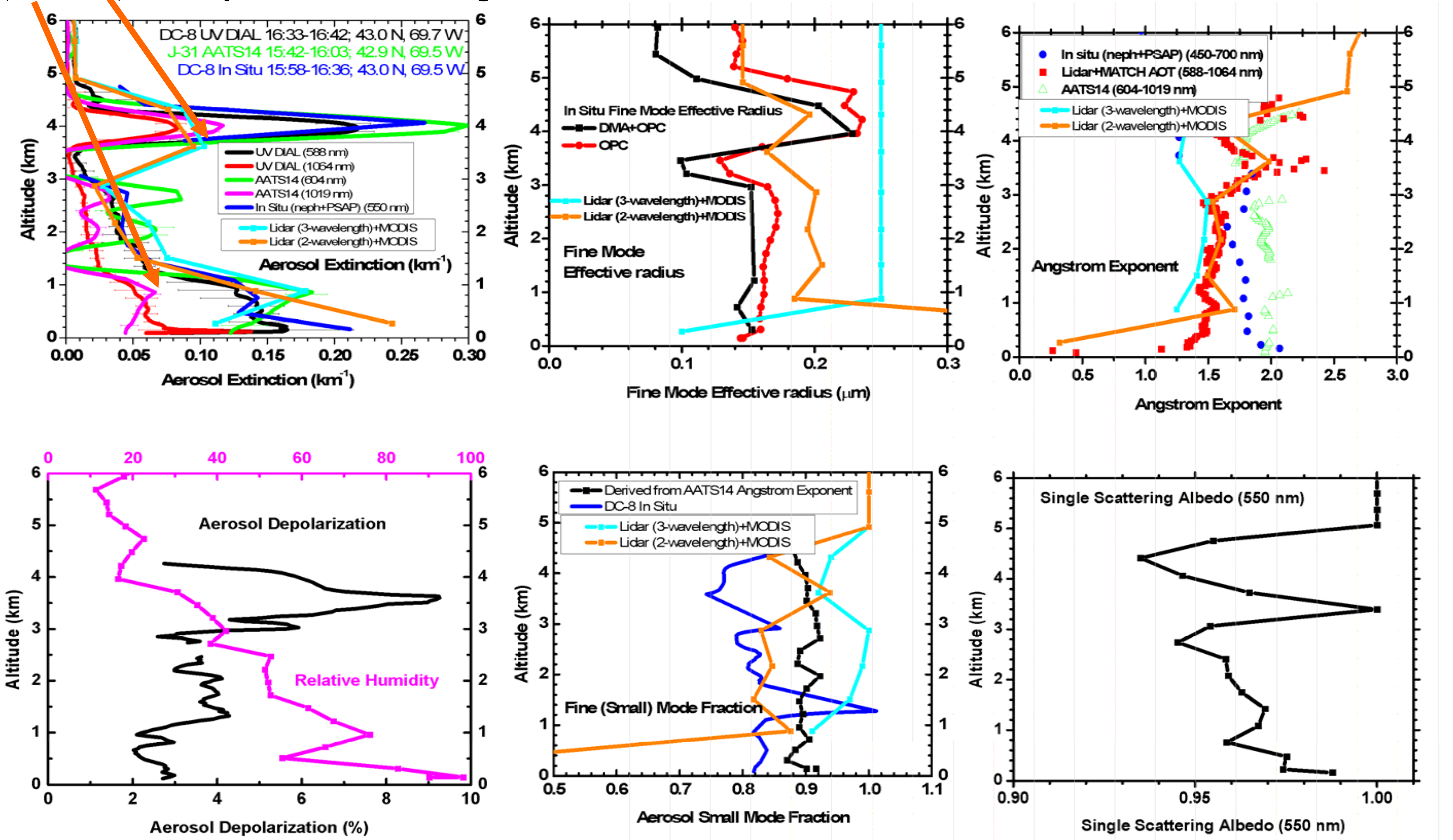


MODIS+lidar Aerosol Retrieval

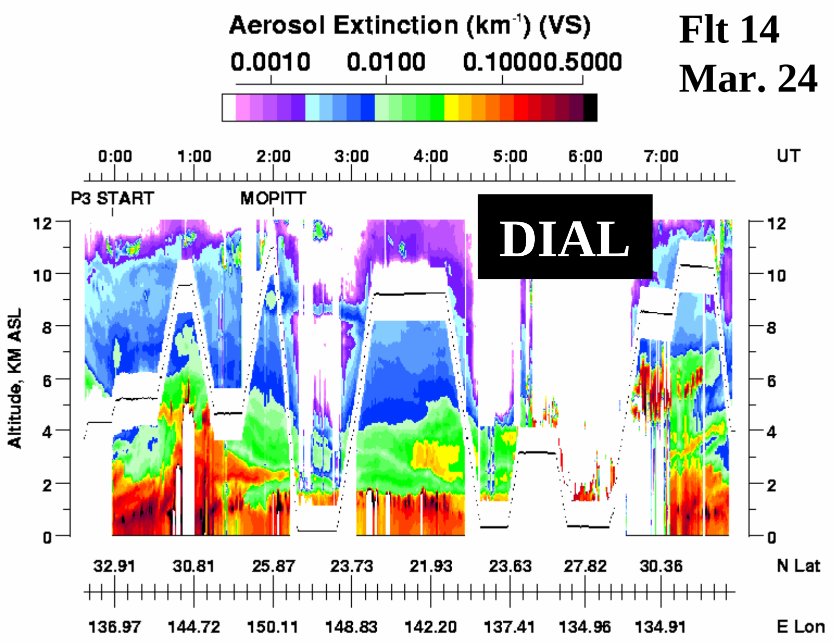
- Retrieval algorithms – (2 Wavelength)
  - (Kaufman et al., IEEE, 2003; GRL, 2003; Léon et al., JGR, 2003)
  - Aerosol size distribution – bimodal lognormal
  - MODIS aerosol models – 20 combinations of 4 fine, 5 coarse particles
  - Size of each mode is assumed to be altitude independent
  - Relative weight of each mode is determined as a function of altitude from lidar backscatter color ratio
  - Retrievals are constrained to fit MODIS measurements
    - Spectral reflectance
    - Column AOT and r_{eff}
- Modifications – (3 Wavelength)
  - UV wavelength (300 nm) – more information on fine particle size
  - Depolarization – adjust the backscatter phase function for nonsphericity

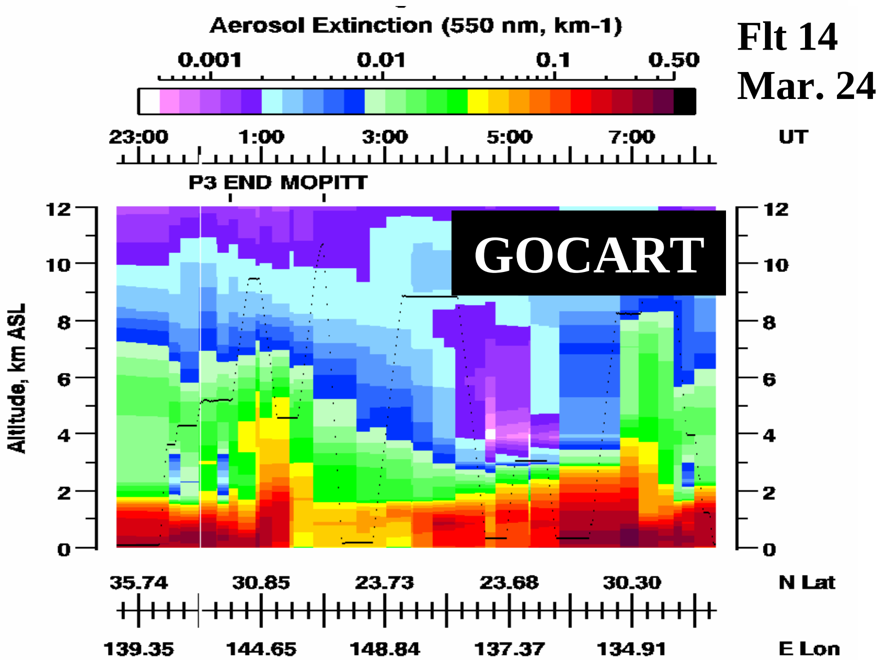
Preliminary Aerosol Profile Properties – Retrieval Results - July 22, 2004

- (biomass) High HCN, ethyne, CO, O3, H2O, airmass from Canada, mixed with pollution (NO2 spike)
- (pollution) High SO2, CO, O3, low H2O, fresh urban and industrial. trajectories from great lakes, and East Coast (near end) but very similar chemical signature

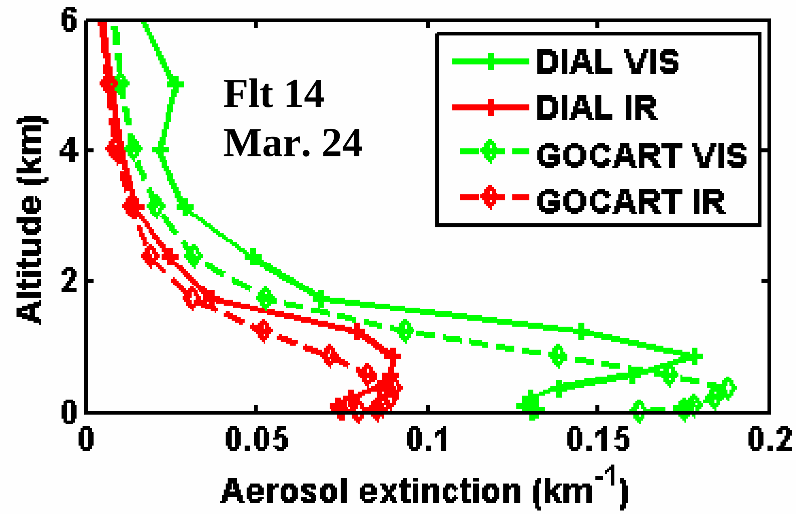


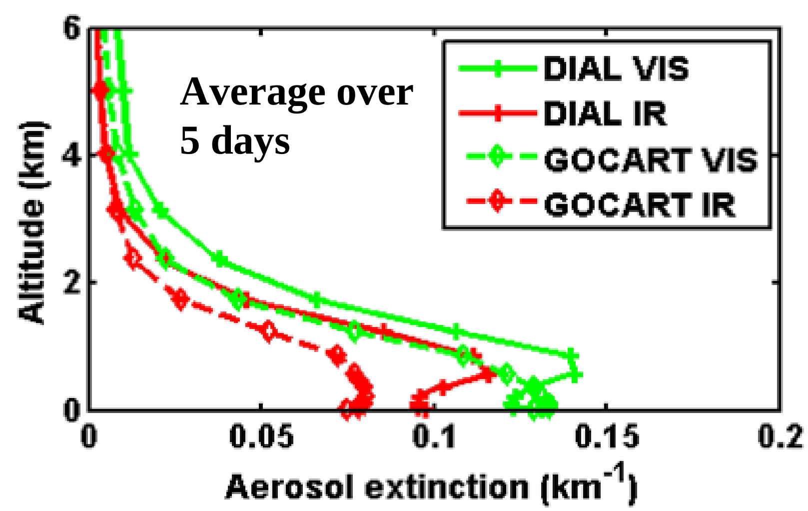
Comparison of Vertical Profiles – DIAL and GOCART (TRACE-P)



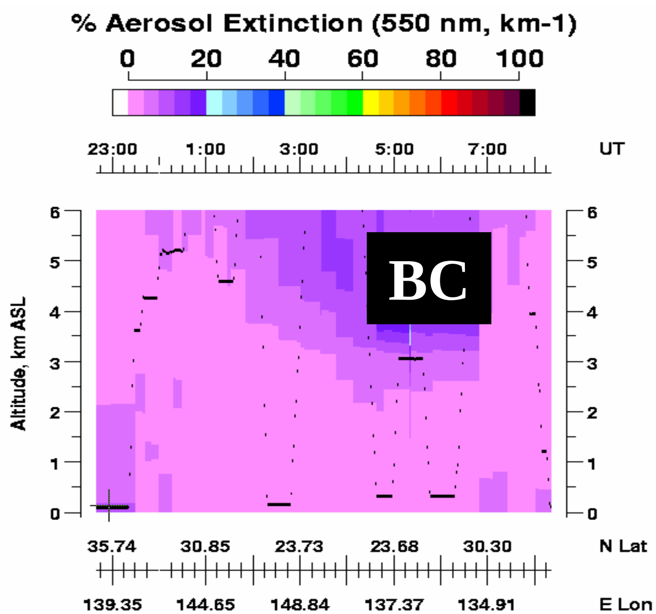


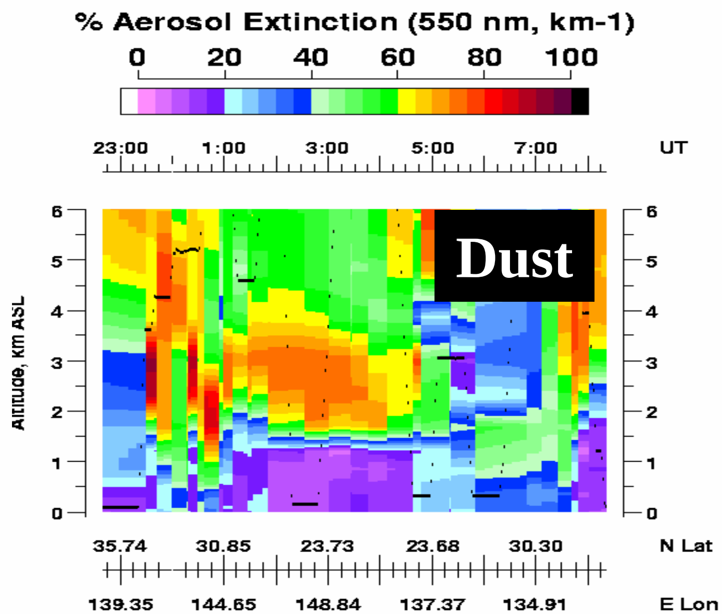
- DIAL, GOCART close near surface
- GOCART has lower amounts aloft





Vertical Profile of Aerosol Composition – GOCART

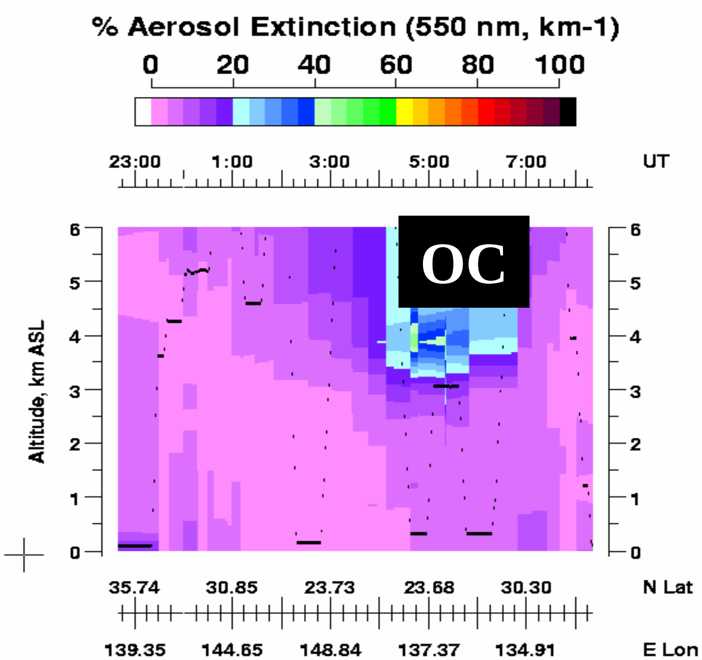


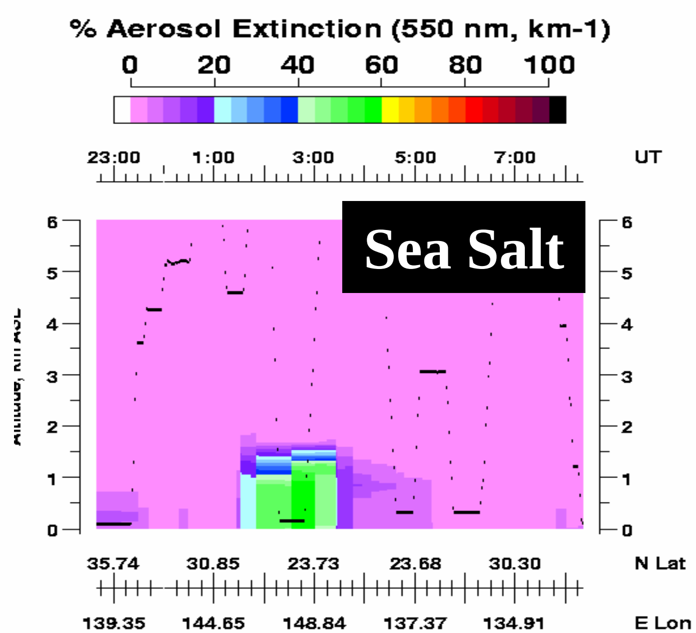


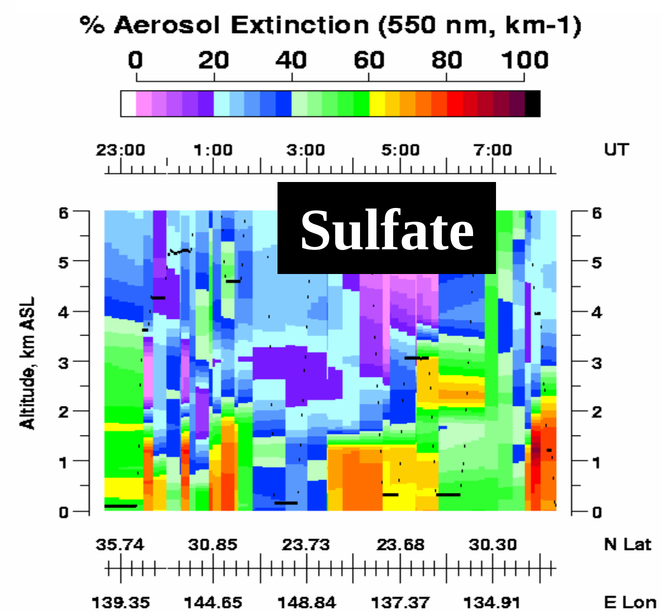
TRACE-P March 24, 2001

When examining impact on aerosol extinction, AOT (550 nm); according to GOCART

- **Sulfate, Dust, Sea salt dominate near surface**
- **Dust dominates aloft**

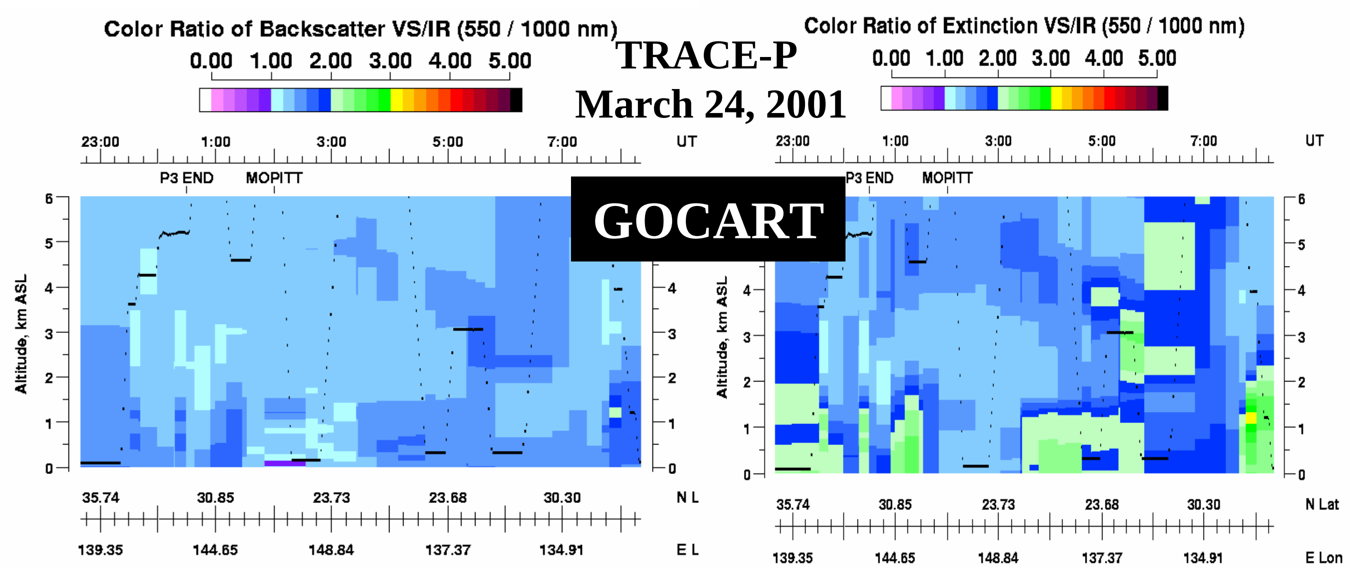






Comparison of Vertical Profiles – DIAL and GOCART- TRACE-P

Can we use DIAL measurements of aerosol intensive parameters (backscatter and extinction color ratios, depolarization) to help identify aerosol type?

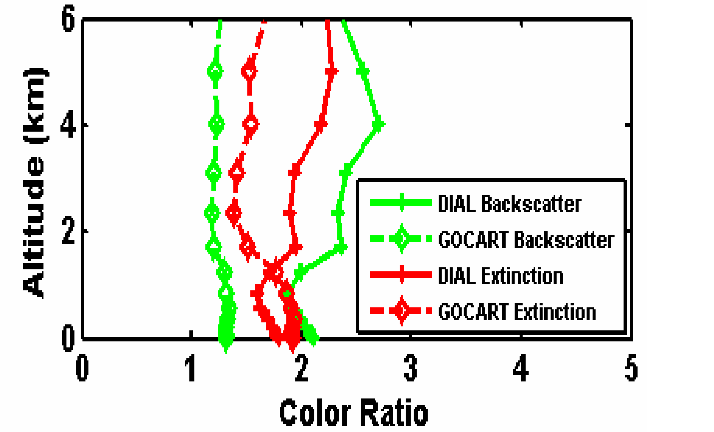


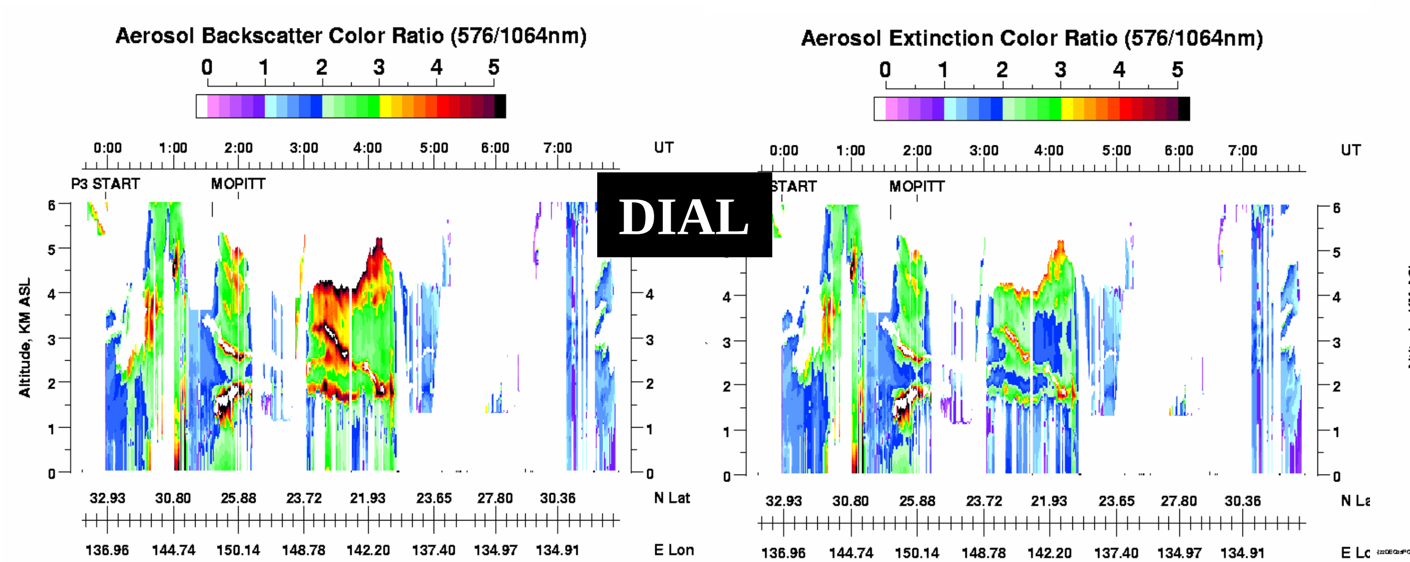
Backscatter Color Ratio

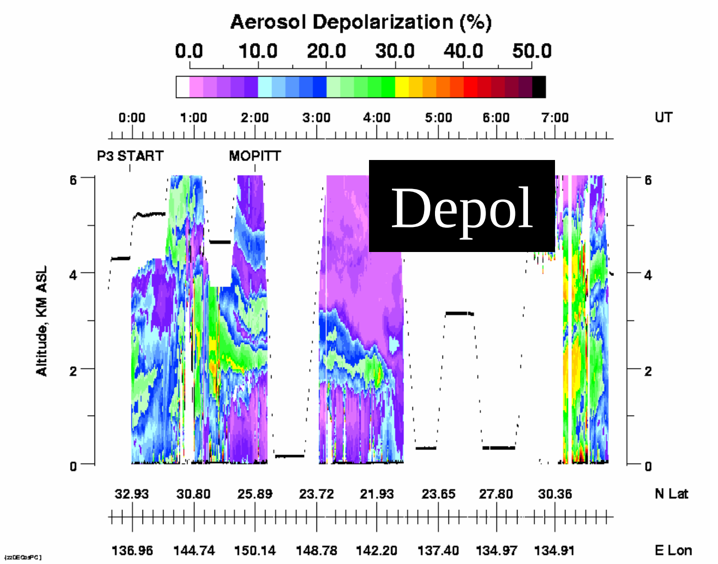
Extinction Color Ratio

Color ratios

- General agreement near surface
- DIAL shows more vertical variability

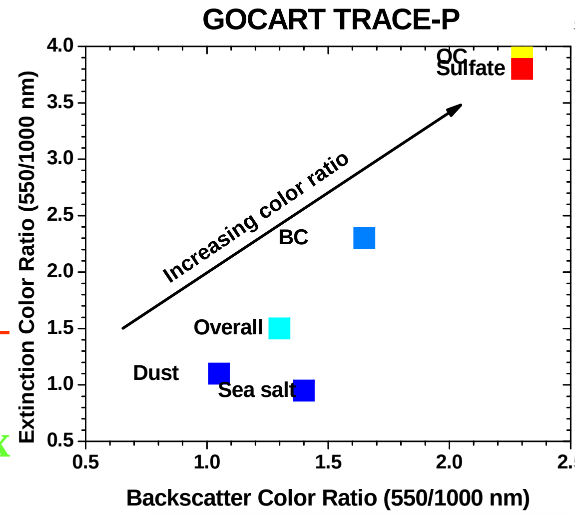


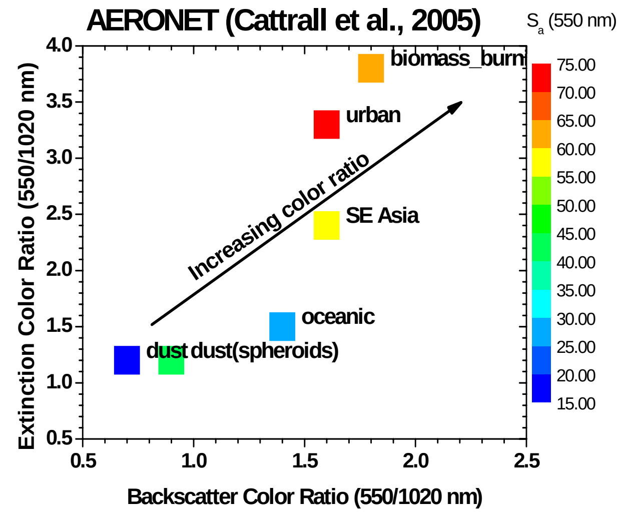




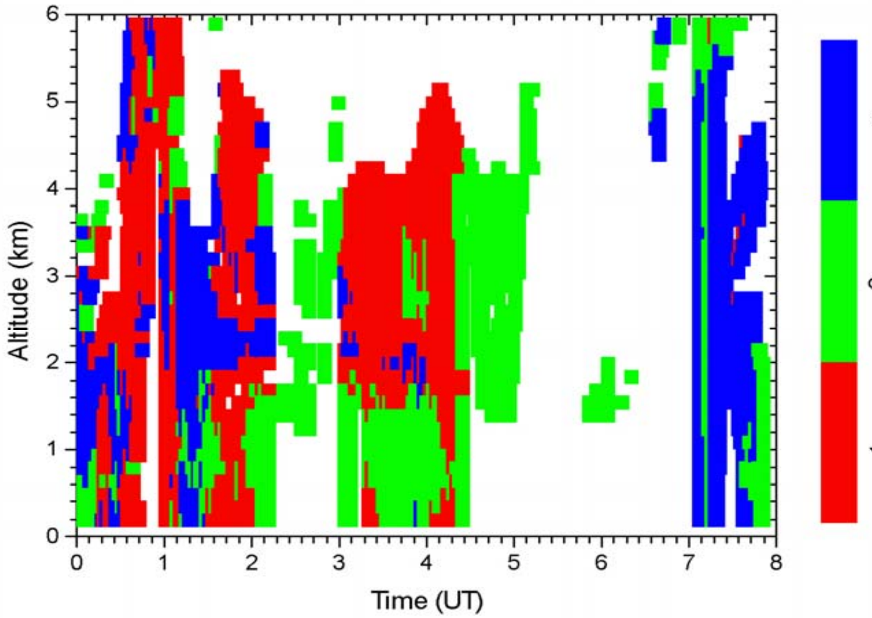
Aerosol Classification Using DIAL Measurements

- Aerosol types were grouped using intensive parameters derived from DIAL
  - Extinction color ratio
  - Backscatter color ratio
  - Depolarization
- Three main clusters were identified
  - Cluster 1 – high ratio, elevated depol – mix of dust, urban (sulfate)
  - Cluster 2 – mid ratios, low depol – mix of urban and oceanic (sea salt)
  - Cluster 3 – low ratios, high depol - dust

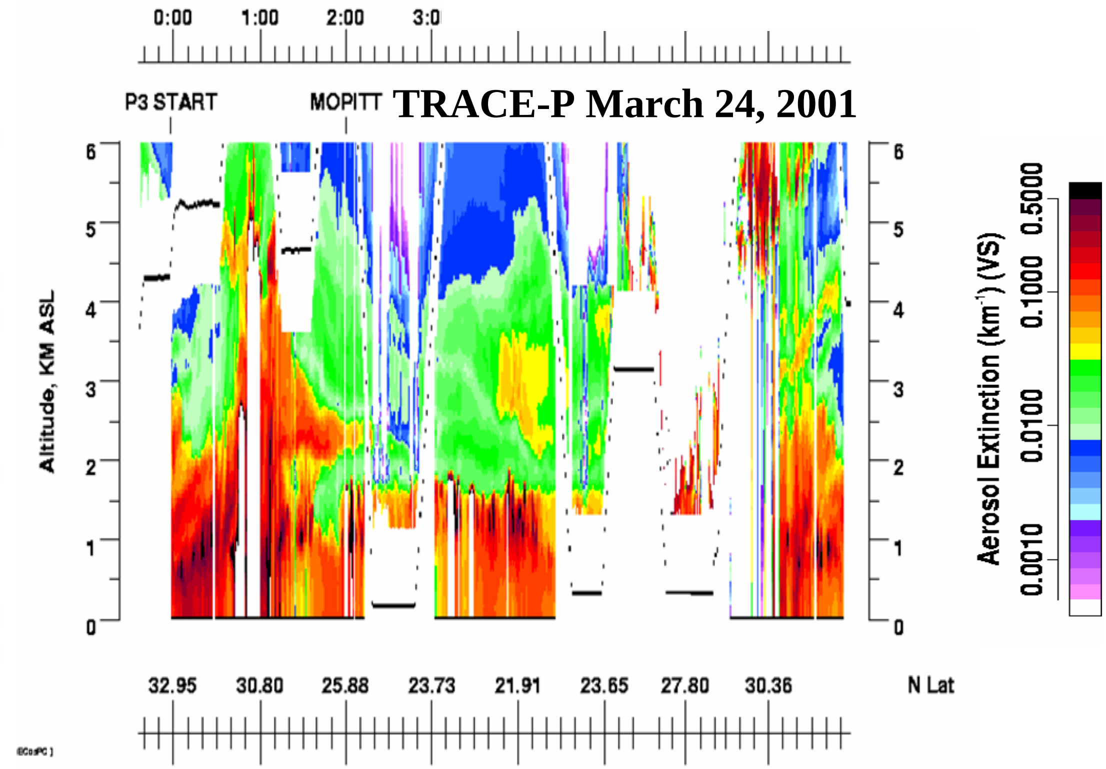




TRACE-P March 24, 2001



TRACE-P March 24, 2001



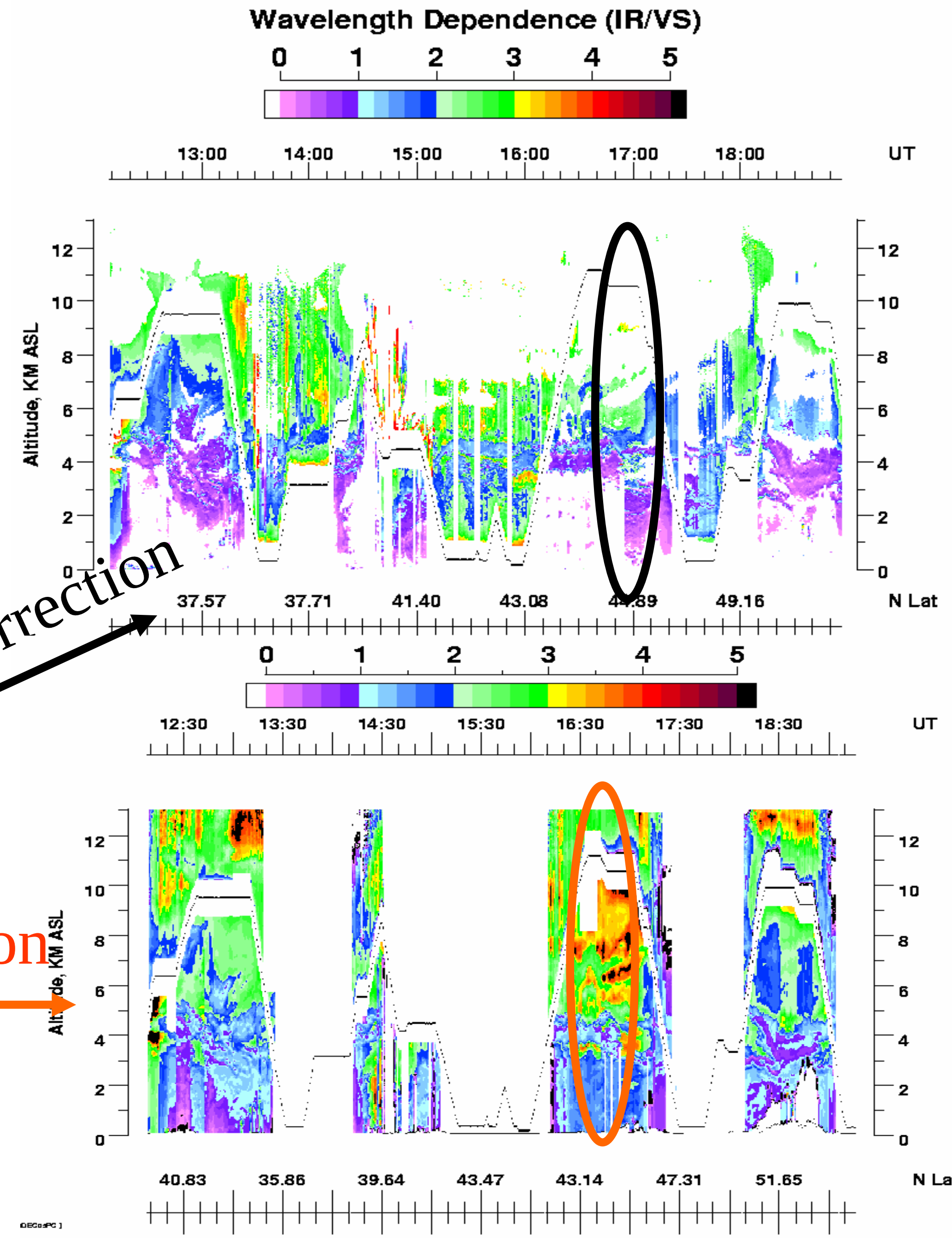
Summary

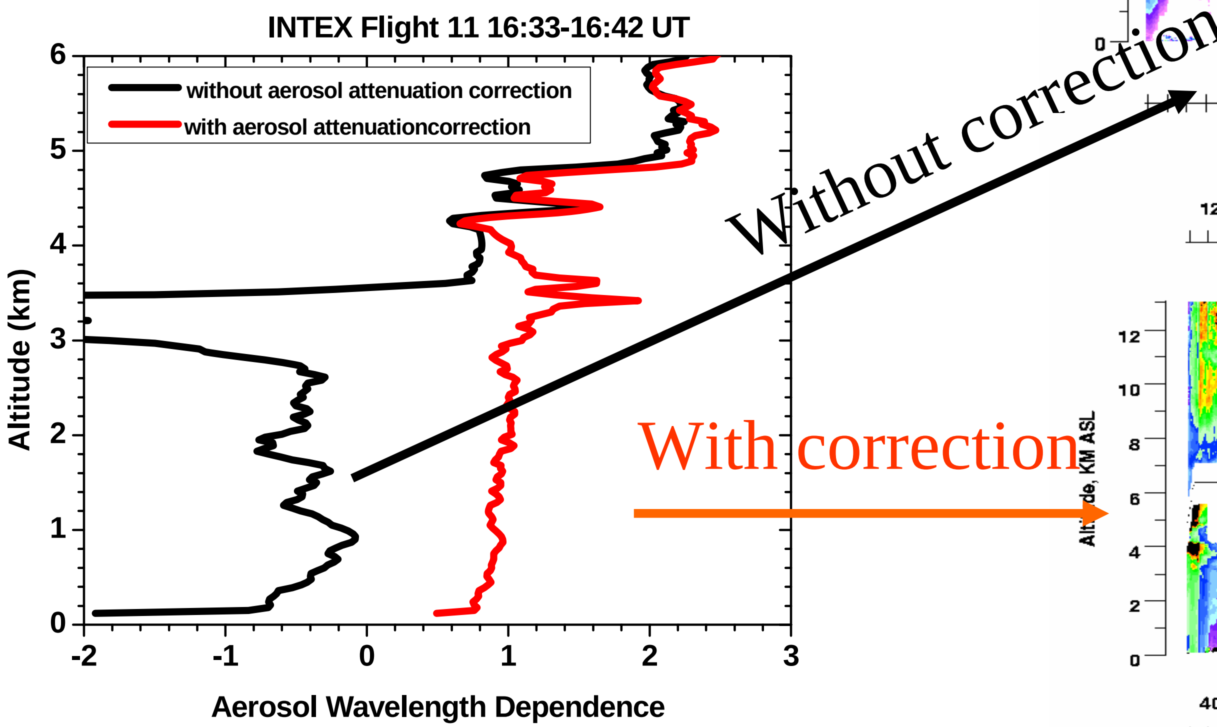
- MODIS data helped constrain airborne lidar retrievals of aerosol extinction profiles, and backscatter and extinction color ratios - TRACE-P (2001) and INTEX NA (2004)
- Combination of three-wavelength lidar/MODIS measurements over ocean used to retrieve profiles of fine mode fraction and effective radius
  - INTEX NA data used to evaluate results
  - General good agreement with extinction, fine mode fraction
- Evaluating GOCART simulations (TRACE-P)
  - Aerosol extinction - GOCART in generally good agreement with lidar near surface, somewhat lower amounts aloft
  - Backscatter and extinction color ratios – GOCART shows less vertical variability than derived from lidar
- On-going work (TRACE-P and INTEX NA, B)
  - Use cluster analysis techniques to identify and group aerosols
  - Derive aerosol types to help evaluate GOCART aerosol compositions
- Future
  - Use aerosol extinction, backscatter, depolarization measurements from LaRC airborne High Spectral Resolution Lidar (HSRL) – MILAGRO (Mexico City), TEXAQS/GoMACCS (Houston)
  - Proposed to use combination of CALIPSO/MODIS/PARASOL data

Backup Slides

Aerosol Wavelength Dependence – July 22, 2004

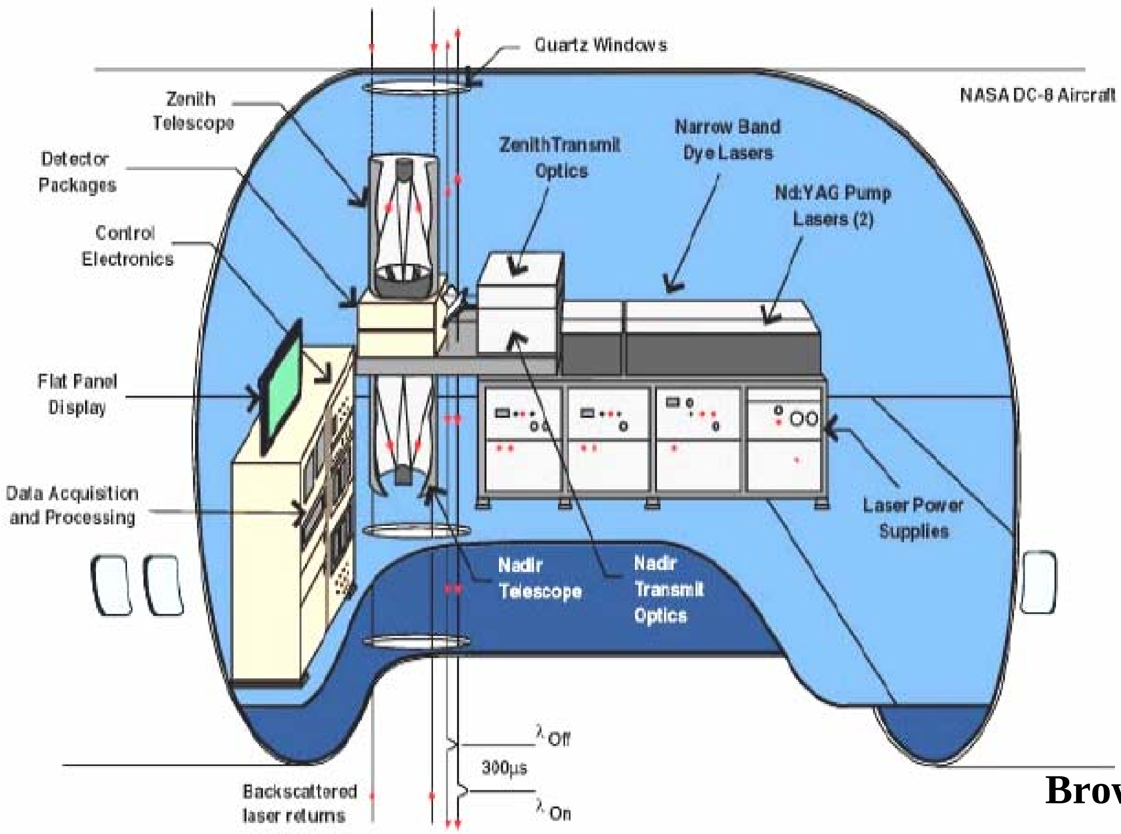
- Attenuation correction applied using MODIS AOT constraint
- Correction retrieves profiles under layers of large aerosol attenuation

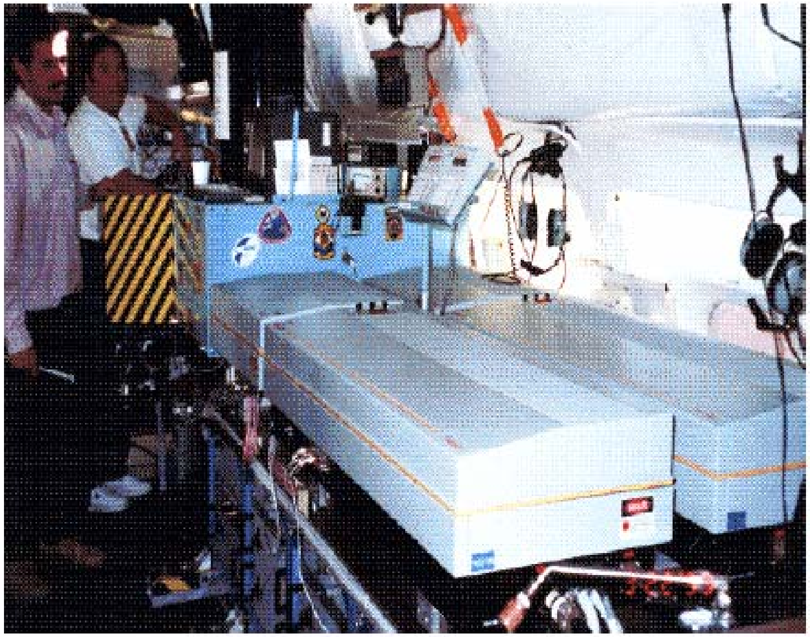




NASA Langley Airborne UV DIAL Measurements

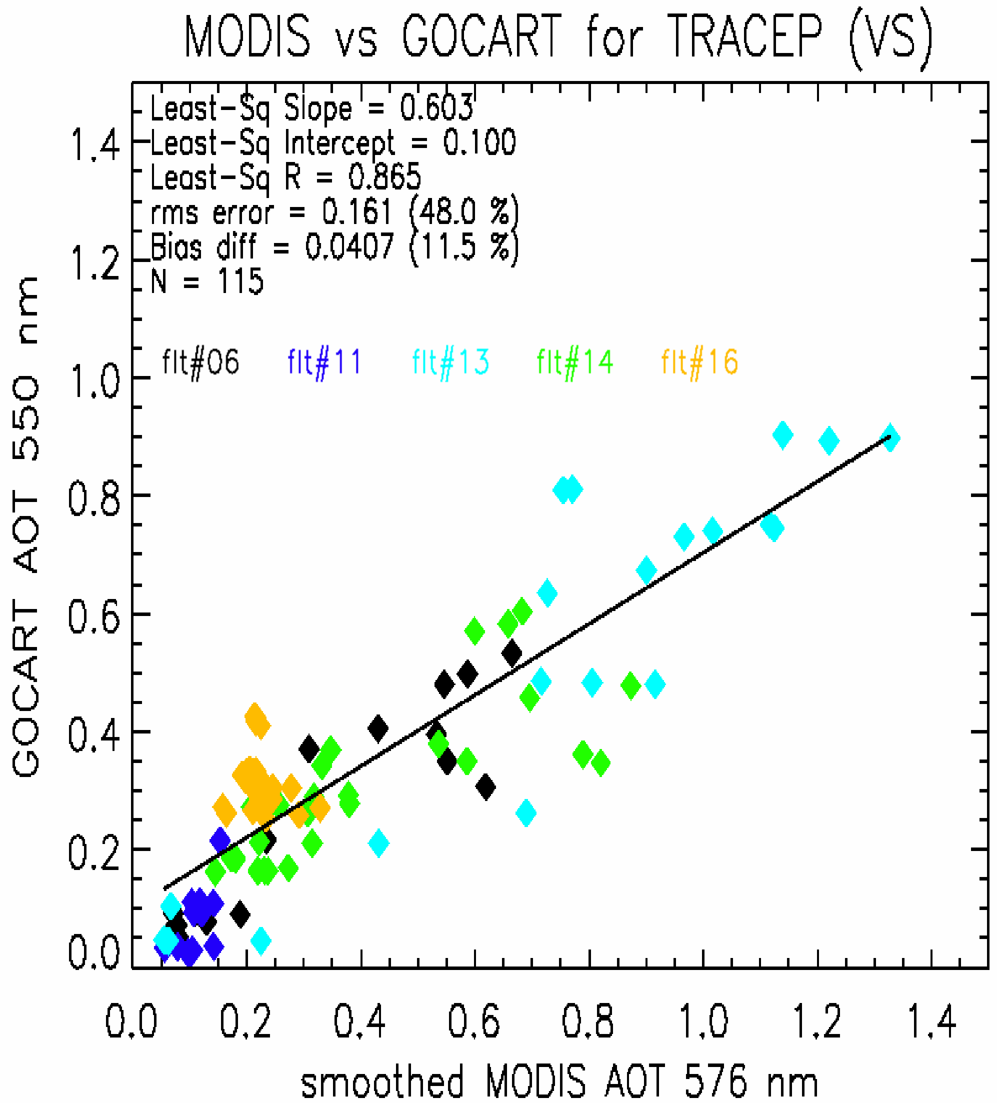
- Ozone Differential Absorption Lidar (DIAL) Profiles (λ_{on}=289 nm & λ_{off} =300 nm)
- Aerosol & Cloud Scattering Ratio Profiles (300, 576, & 1064 nm)
- Simultaneous Nadir and Zenith Ozone & Aerosol Profiling
- Nadir Aerosol Depolarization Profiles (576 nm)
- Deployed on NASA DC-8 for TRACE-P (2001), INTEX NA (2004)

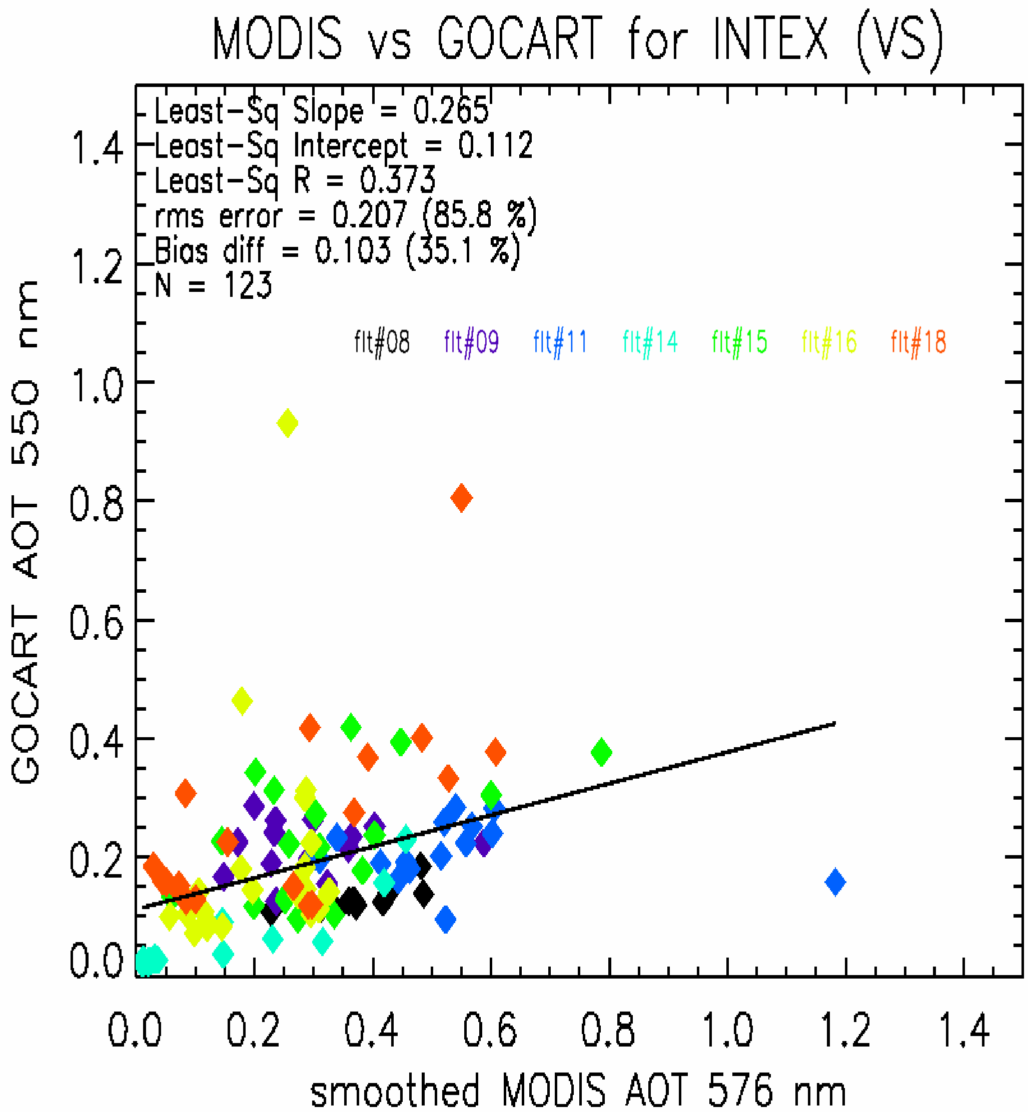




Browell et al., J. Geophys. Res, 108(D20), 8805, 2003.

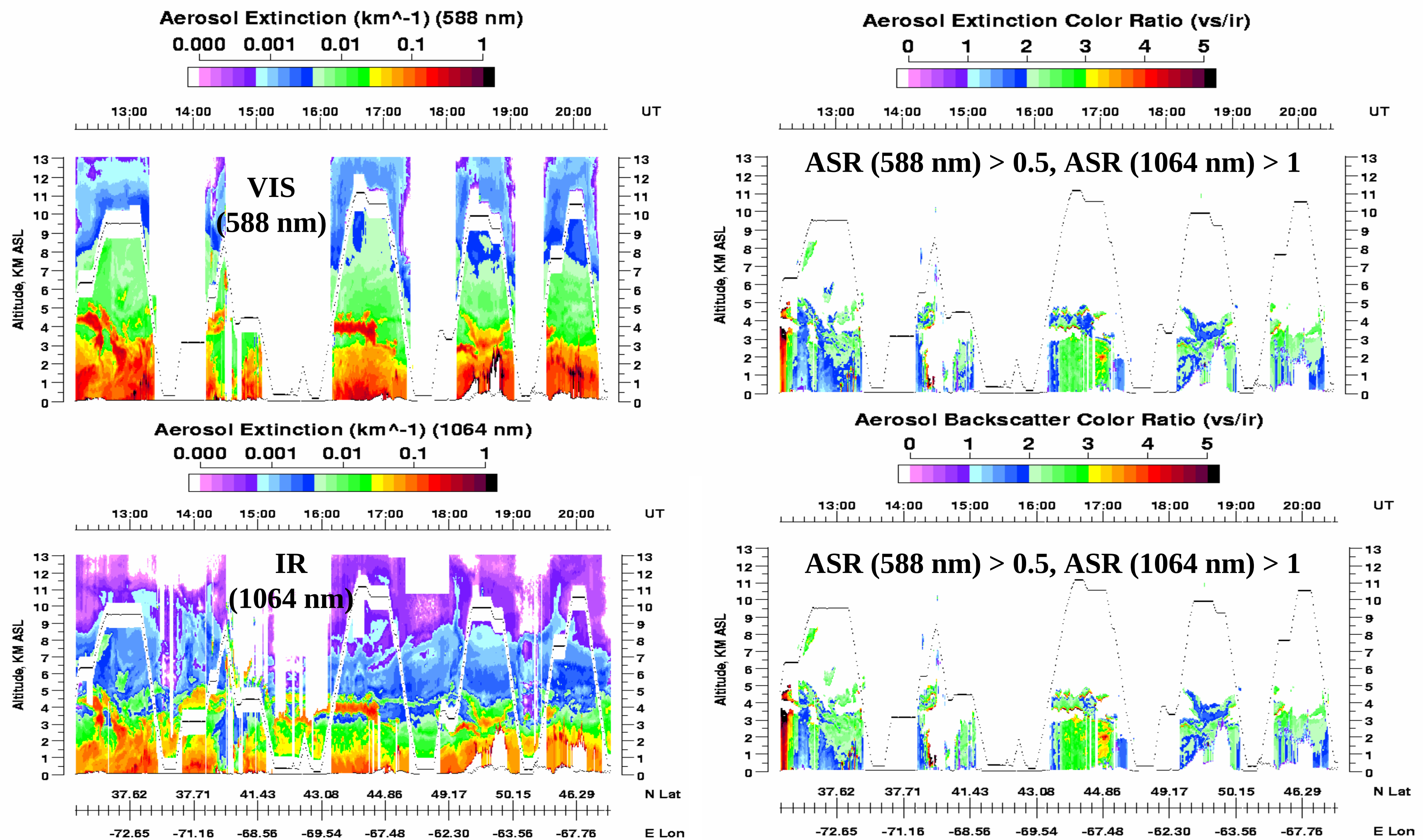
GOCART and MODIS AOT Comparisons





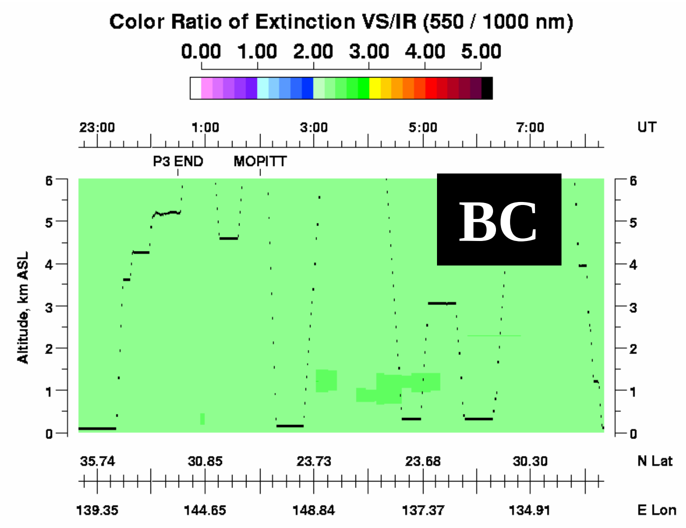
Aerosol Extinction and Color Ratio Profiles – July 22, 2004

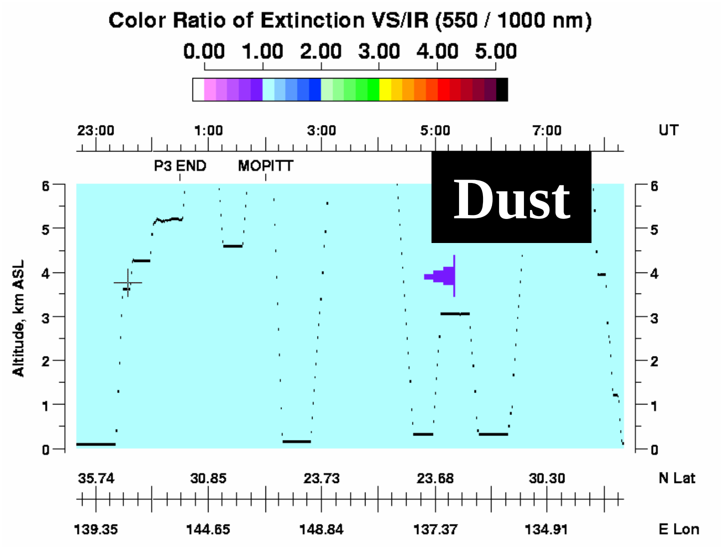
- Example retrievals constrained with MATCH AOT



Vertical Profile of Aerosol Extinction Color Ratio – GOCART

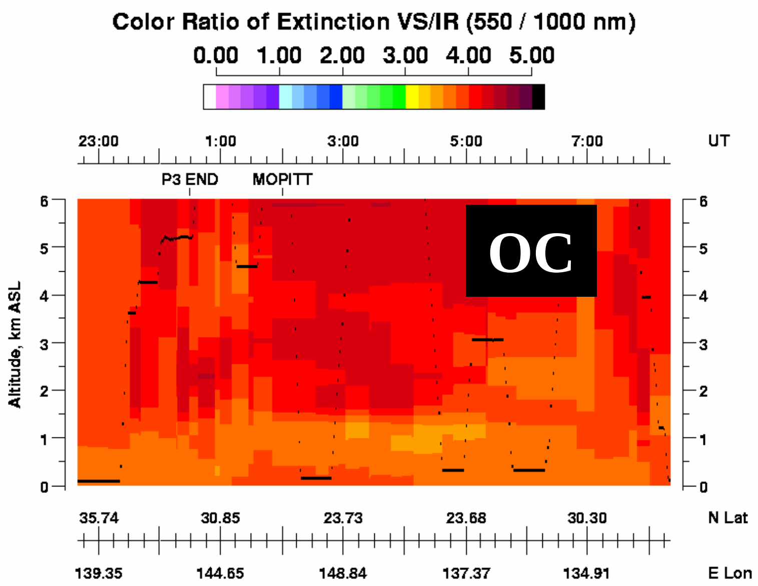
TRACE-P March 24, 2001

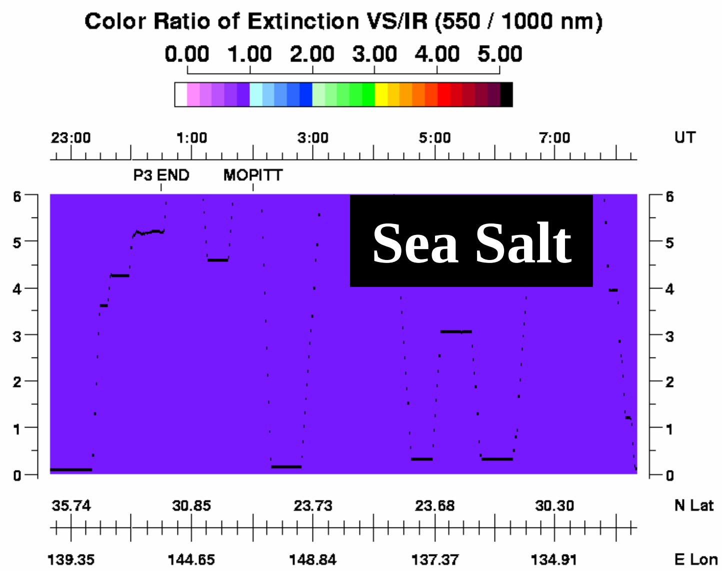


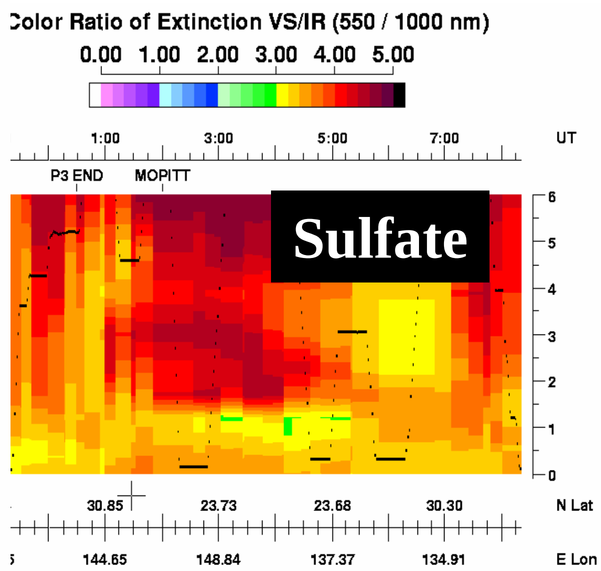


Extinction Color ratios

- BC – 2.2-2.4
- Dust – 1.1
- OC – 3.5-4.2
- Sea salt – 0.9-1.0
- Sulfate- 3.0-4.6

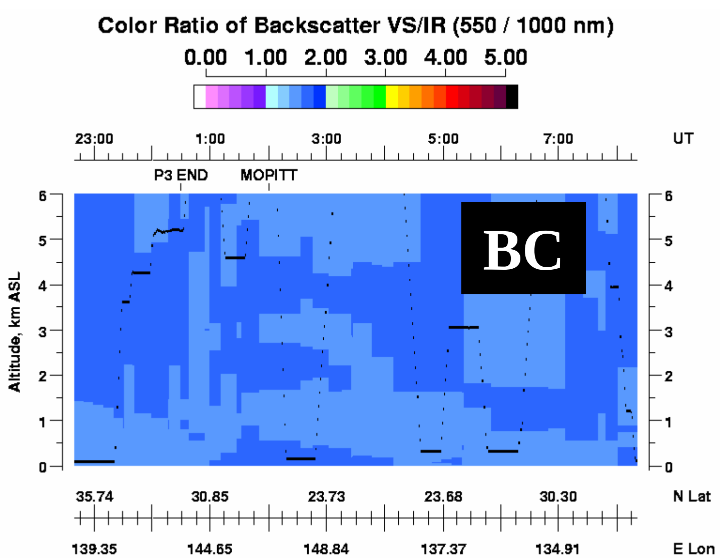


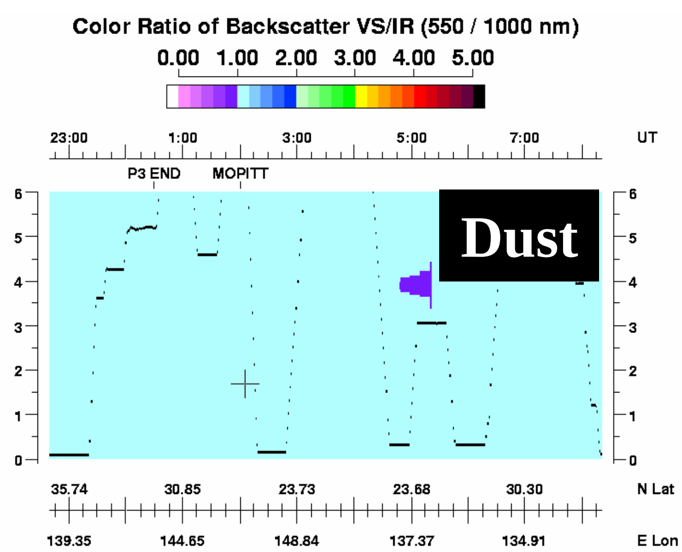




Vertical Profile of Aerosol Backscatter Color Ratio – GOCART

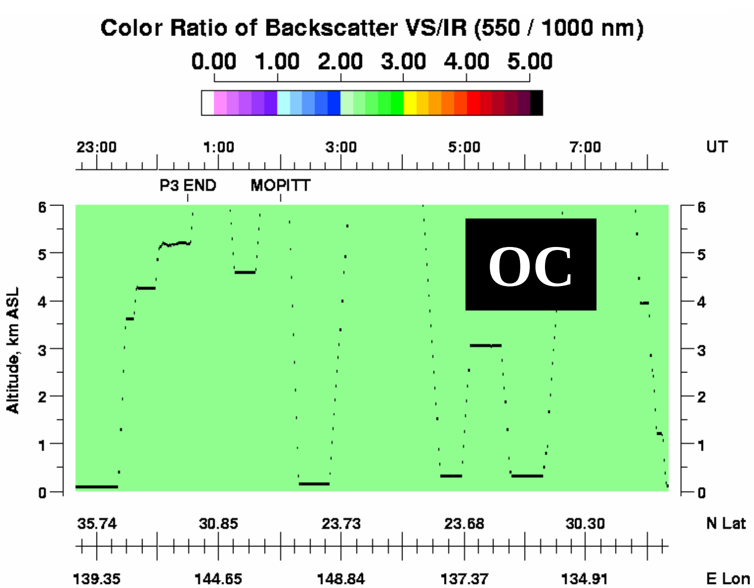
TRACE-P March 24, 2001

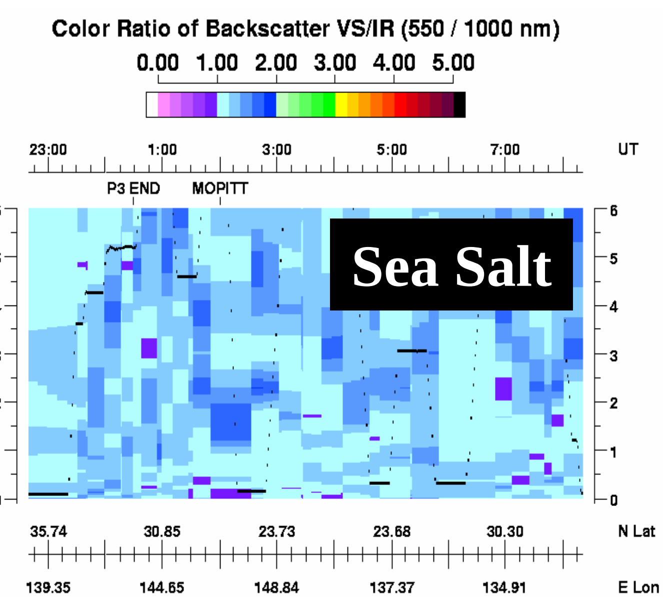


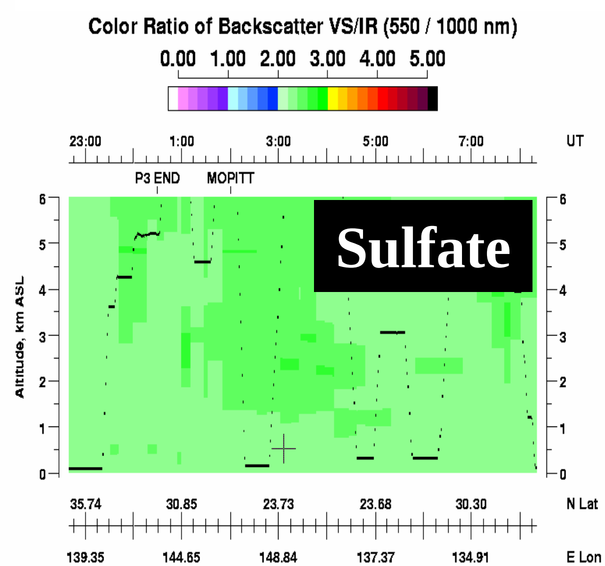


Backscatter Color ratios

- BC – 1.6-1.7
- Dust – 1.0-1.1
- OC – 2.3
- Sea salt – 1.1-1.7
- Sulfate- 2.2-2.4

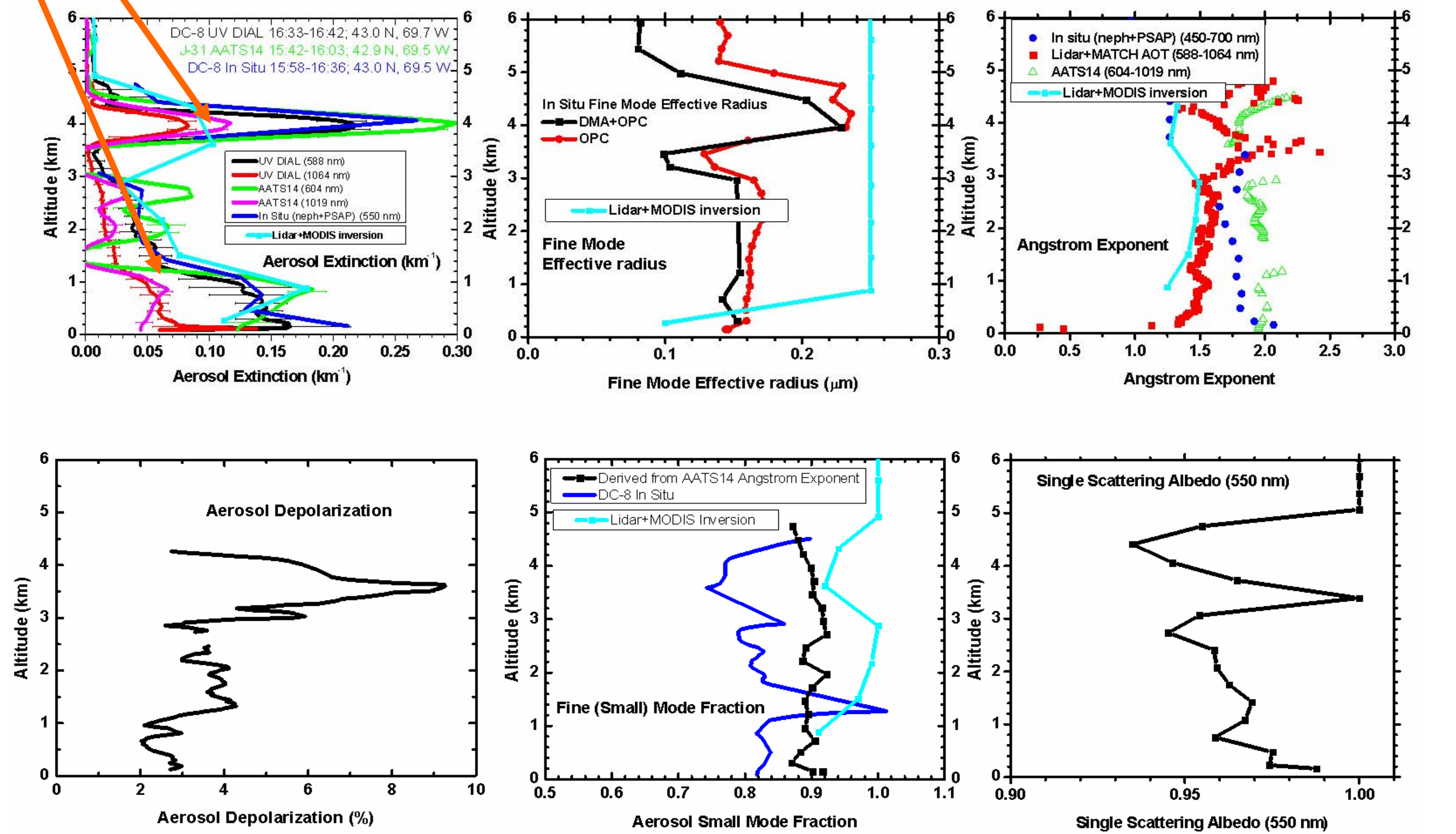




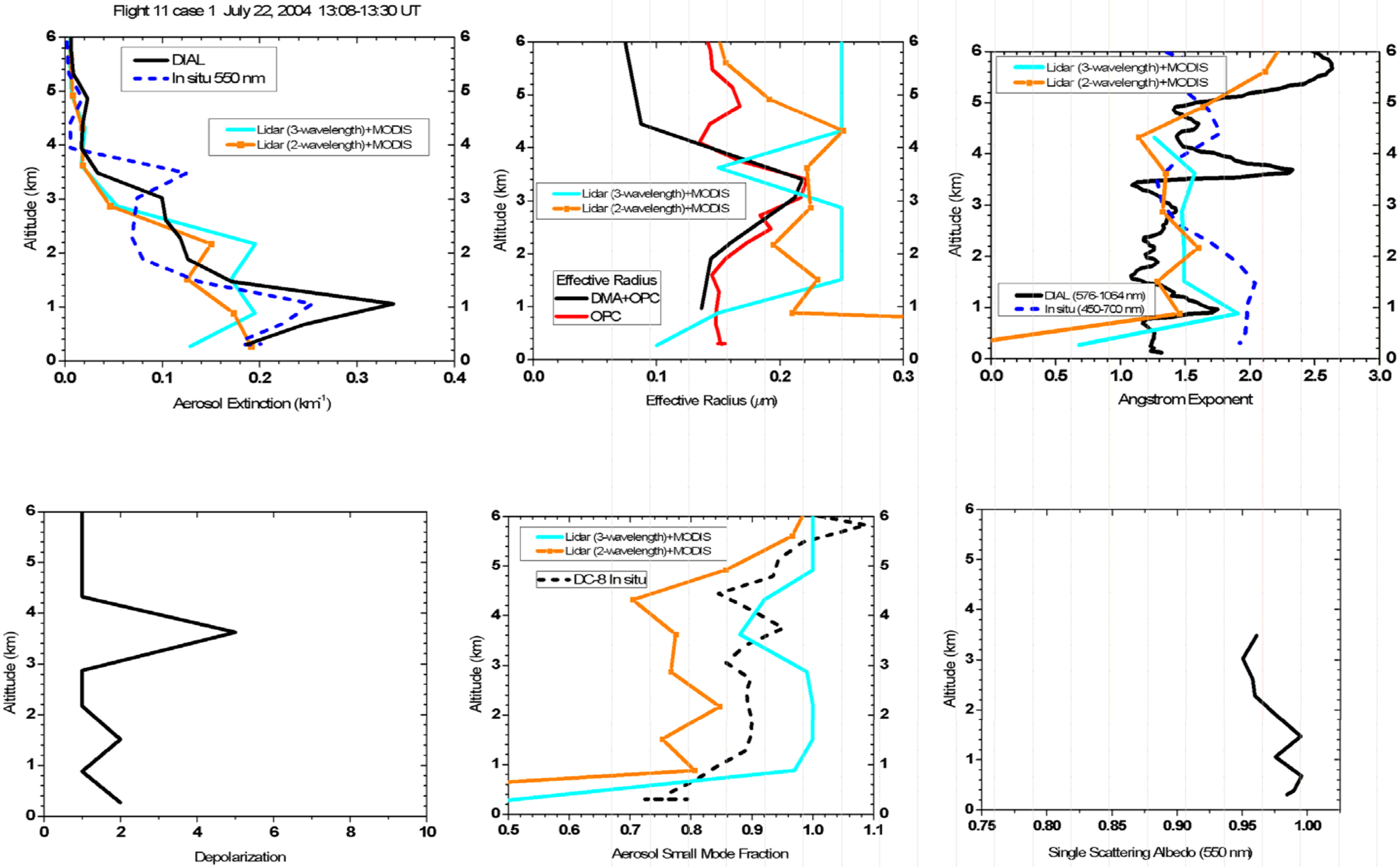


Preliminary Aerosol Profile Properties – Retrieval Results - July 22, 2004

- (biomass) High HCN, ethyne, CO, O3, H2O, airmass from Canada, mixed with pollution (NO2 spike)
- (pollution) High SO2, CO, O3, low H2O, fresh urban and industrial. trajectories from great lakes, and East Coast (near end) but very simimal chemical signature

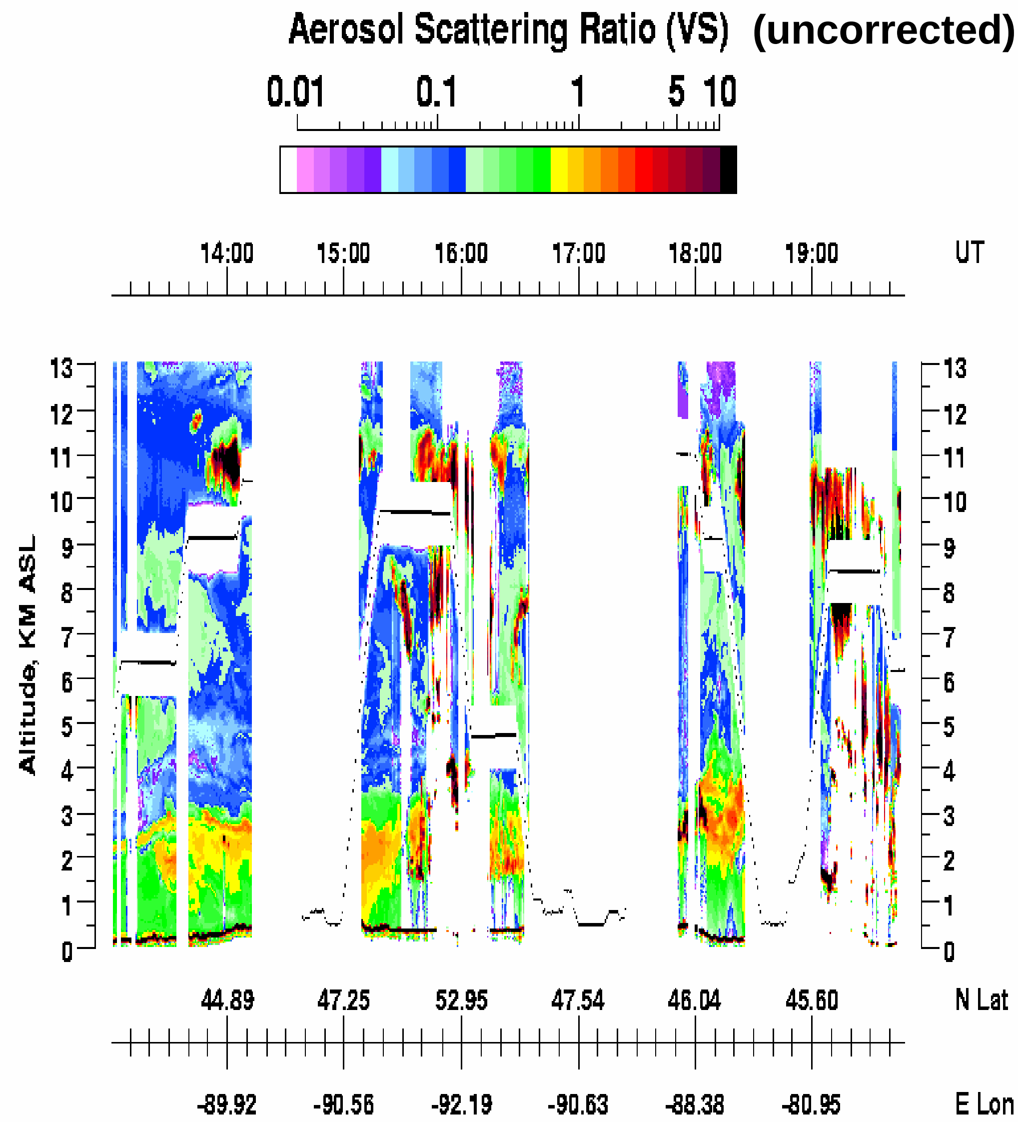


Flight 11, case 1, July 22, 2004 revised extinction, fine mode effective radius, JF

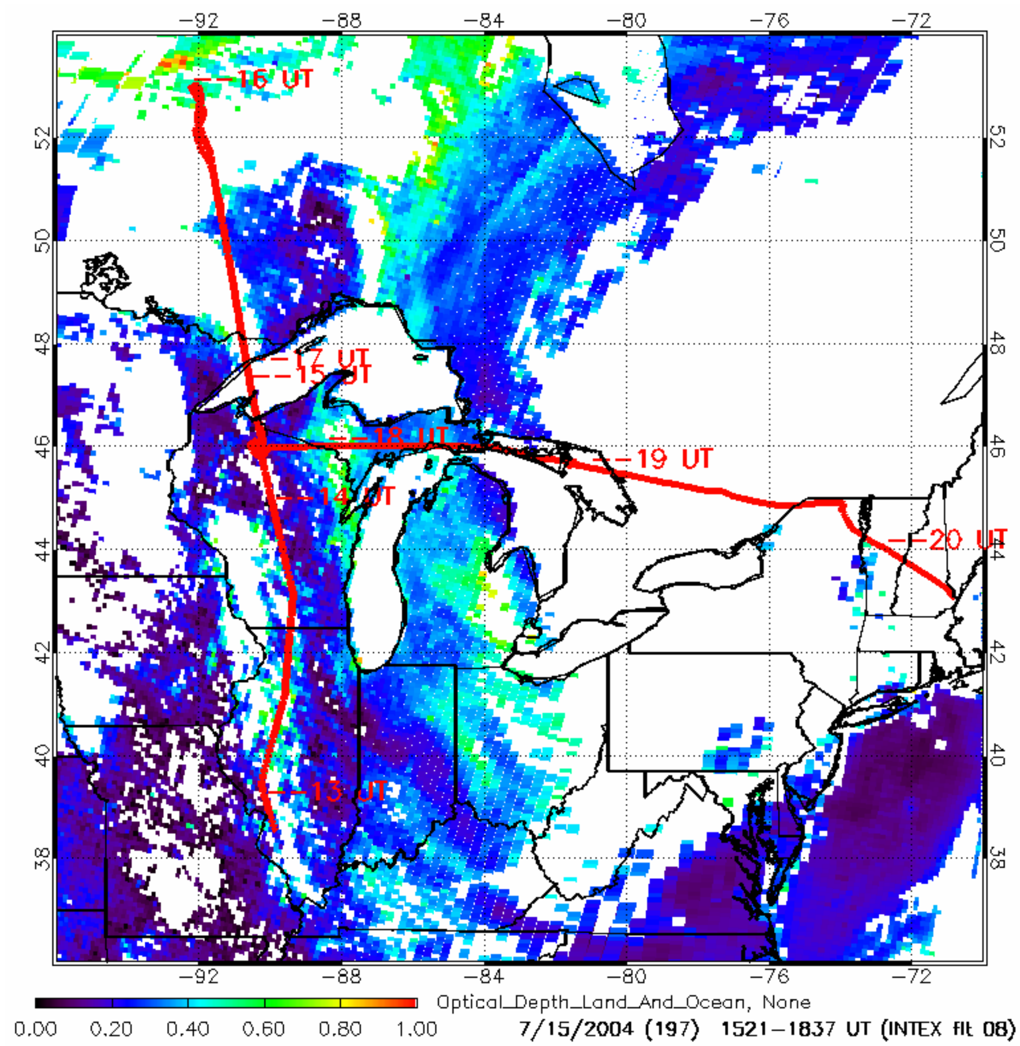


Aerosol Measurements – July 15, 2004

DC-8 Flight 8

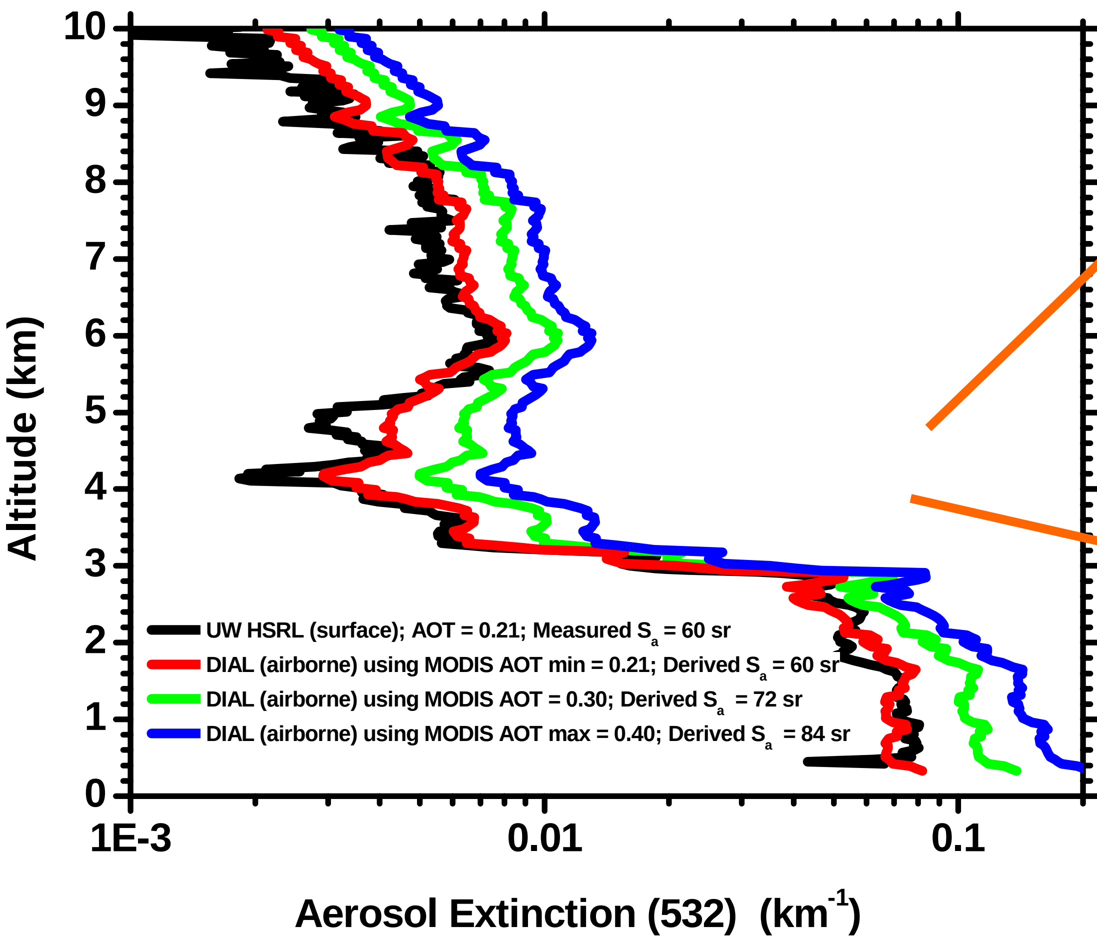


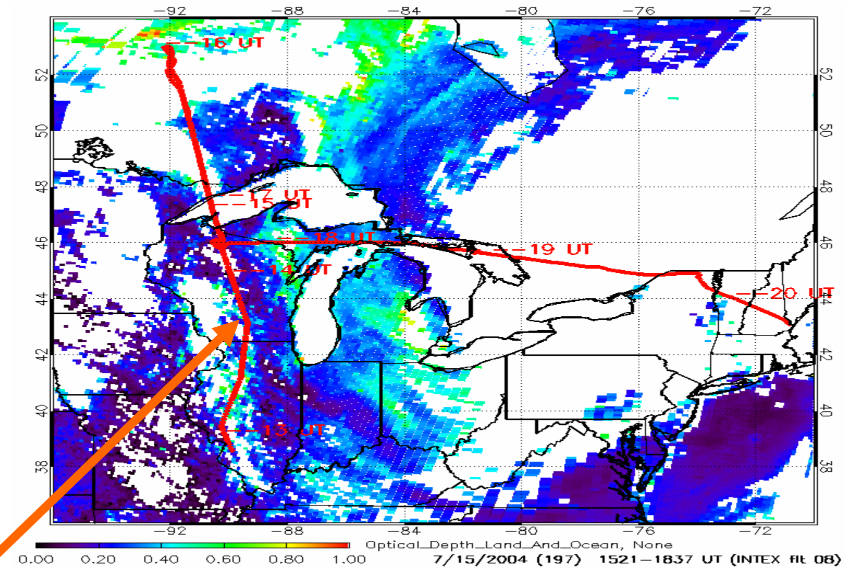
MODIS AOT (550 nm)

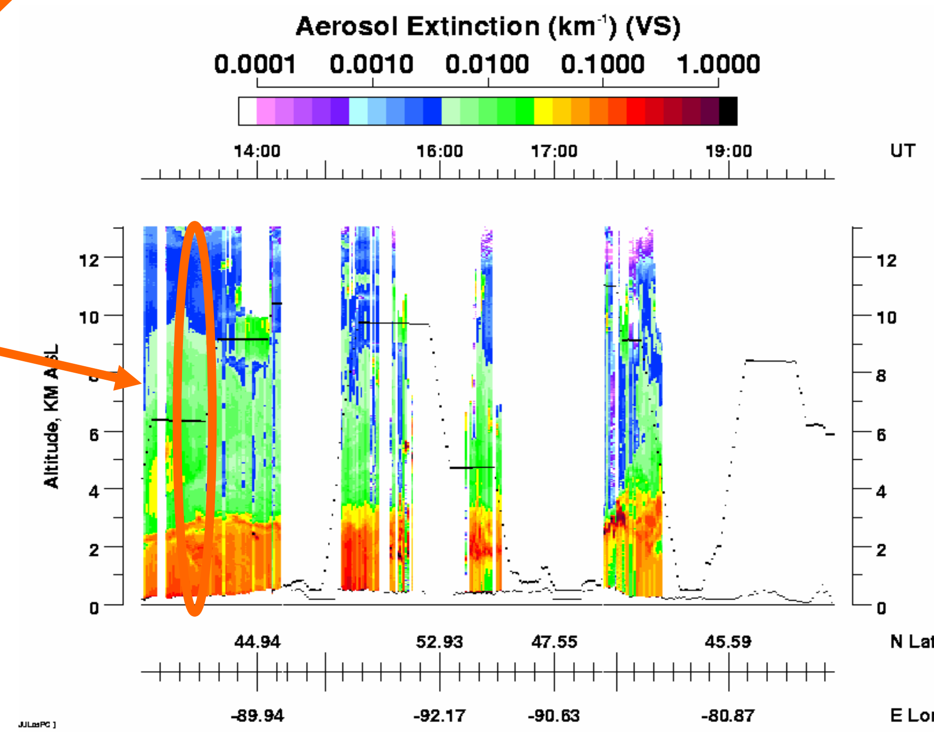


Aerosol Extinction Comparison – July 15, 2004

- Comparison with ground-based Univ. of Wisconsin HSRL lidar that measures backscattering and extinction directly
- UV DIAL retrieval constrained using MODIS AOT (land)
- Better agreement when using lower error bound of MODIS AOT which supports investigations that indicate MODIS AOT over land is biased slightly high

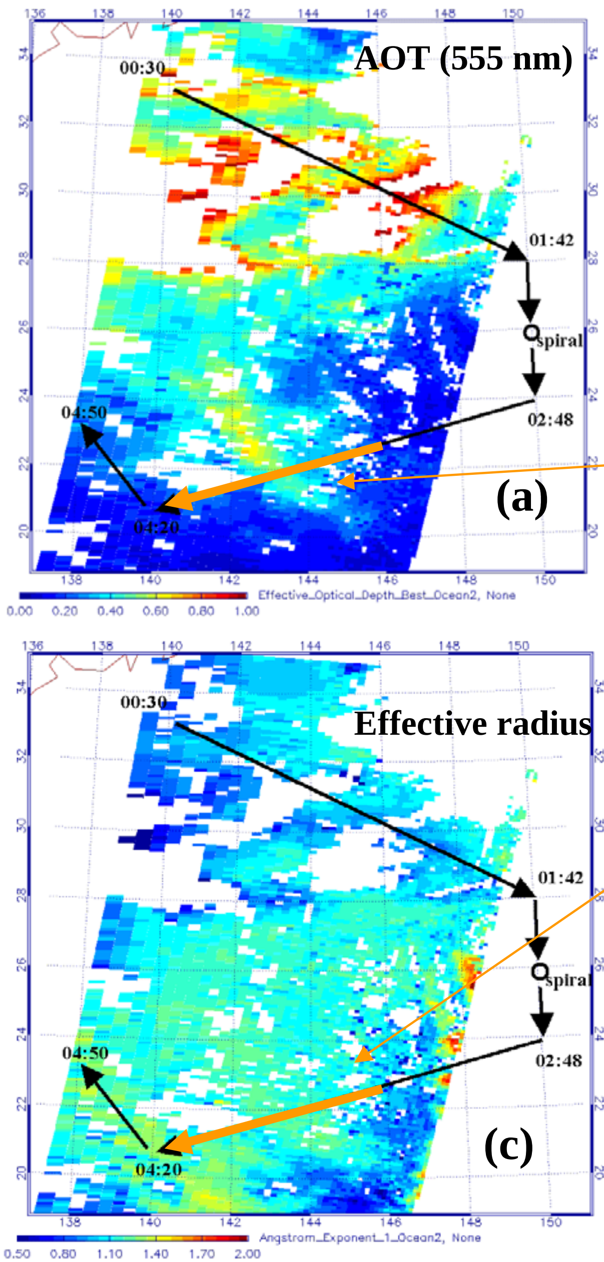




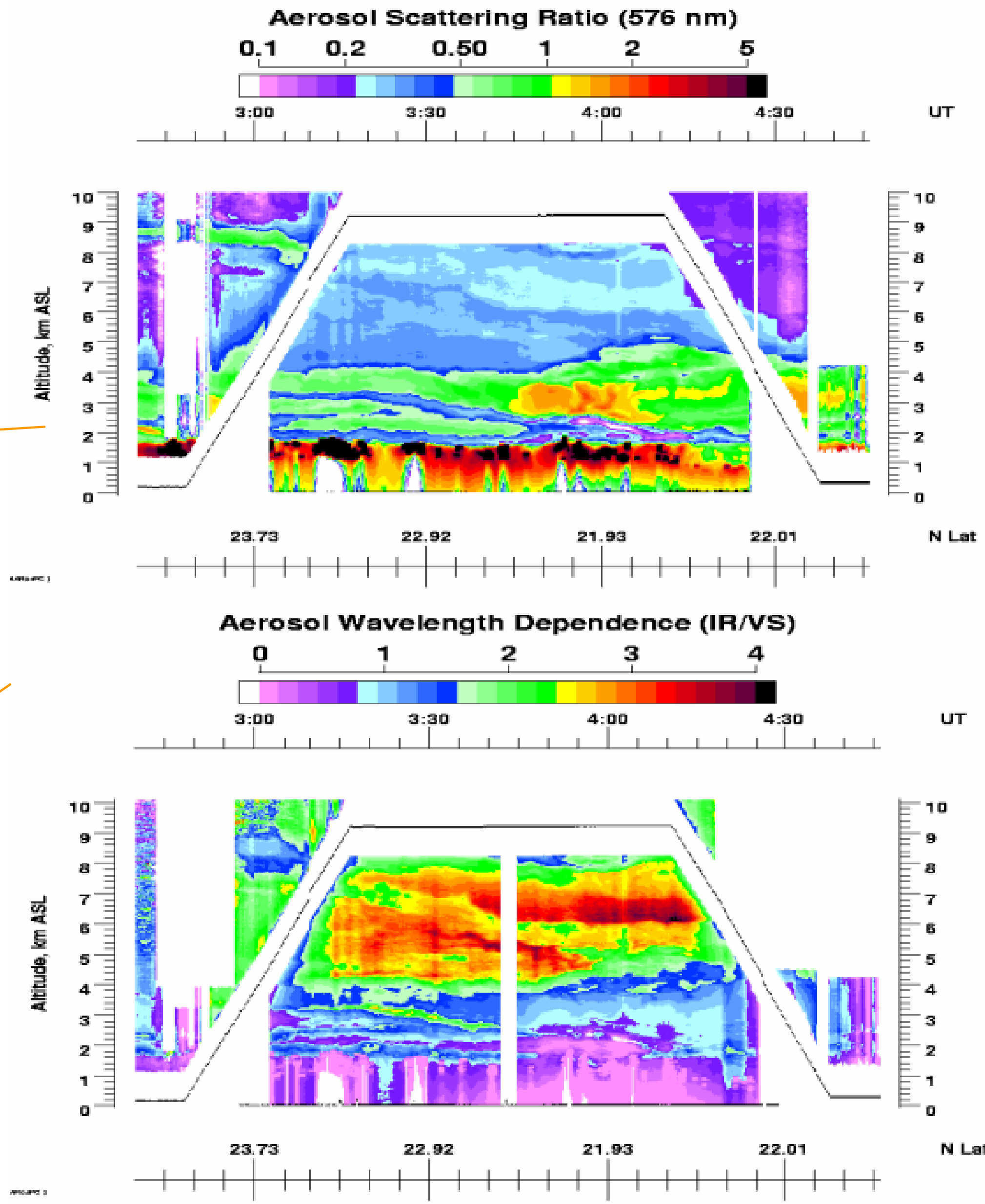


March 24, 2001 MODIS+GOCART

Terra MODIS

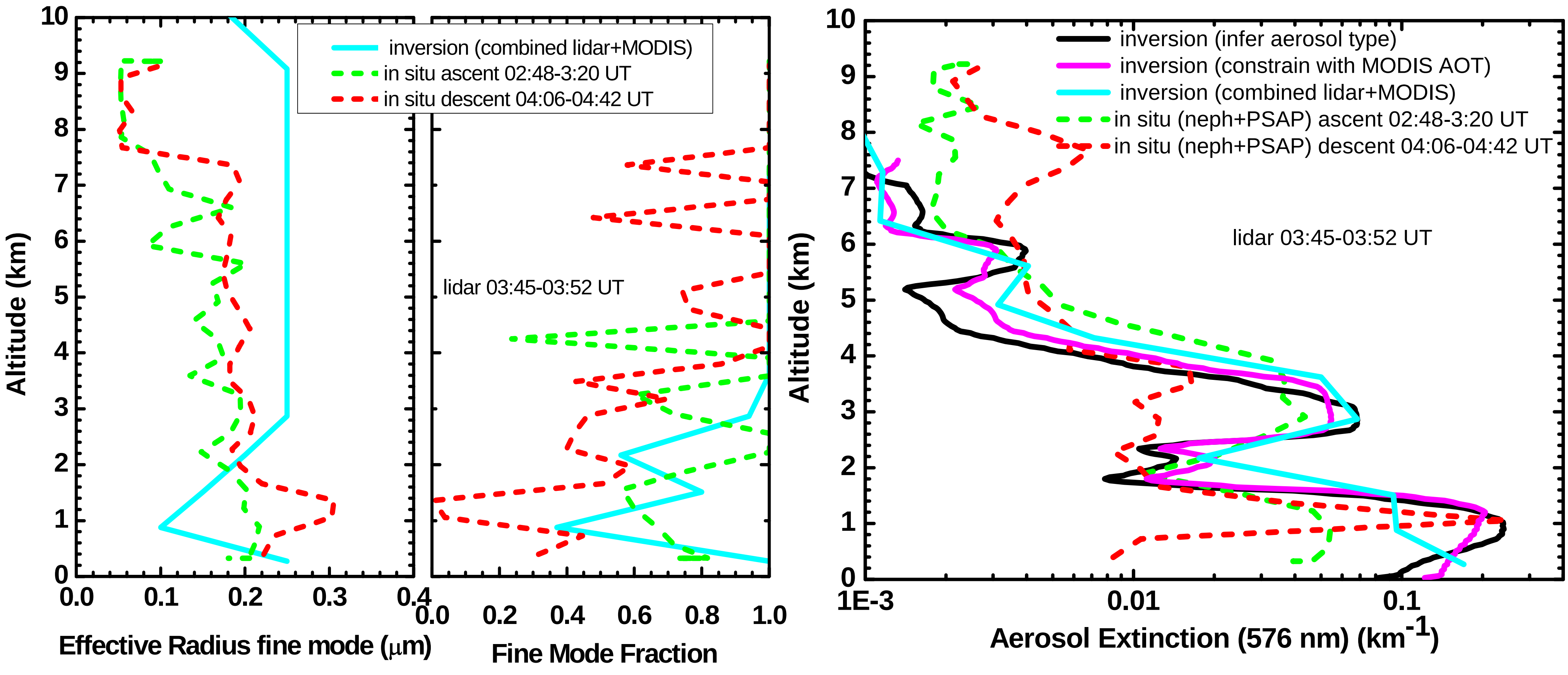


UV DIAL



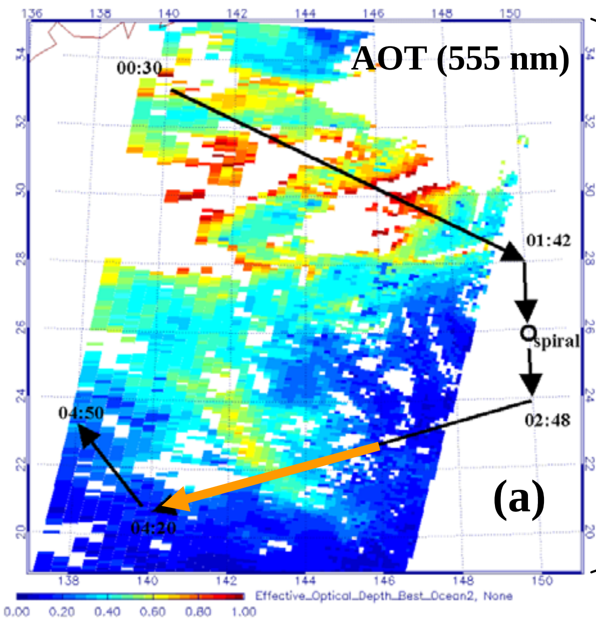
MODIS+lidar Aerosol Retrieval Example

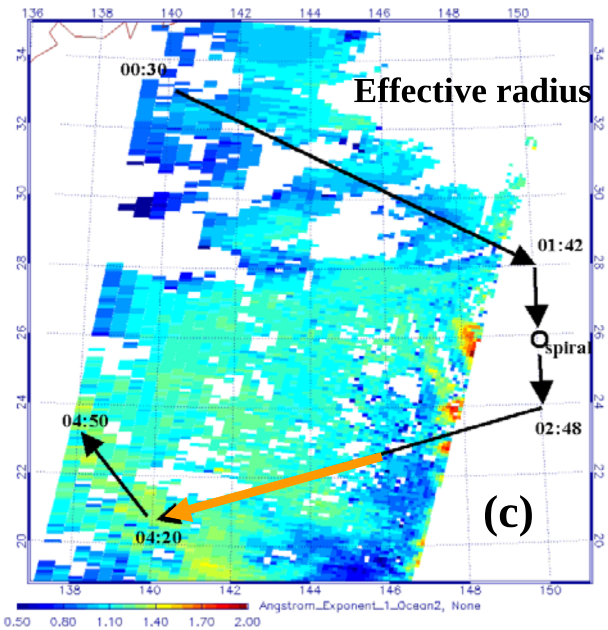
- TRACE-P Flight 14 March 23-24, 2001
- Good agreement between techniques for this test case
- Results show qualitative agreement with in situ measurements
- Plan to evaluate additional cases from TRACE-P, INTEX NA



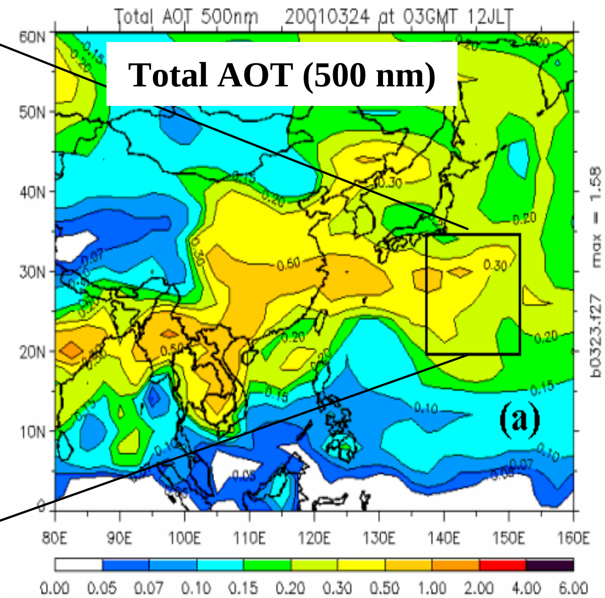
March 24, 2001 MODIS+GOCART

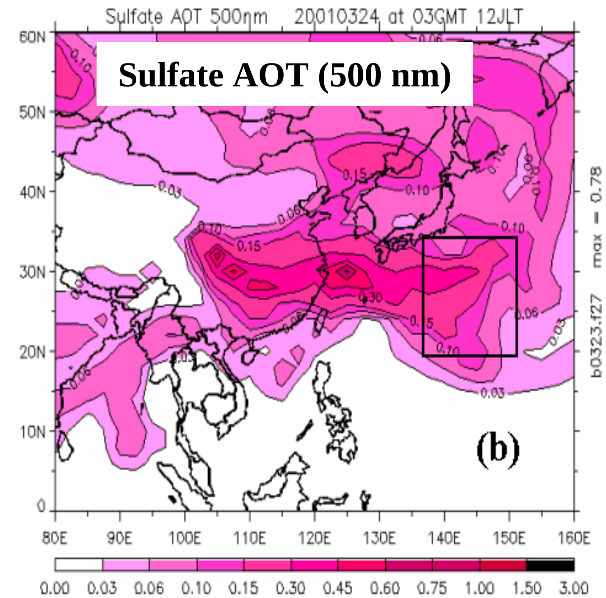
Terra MODIS

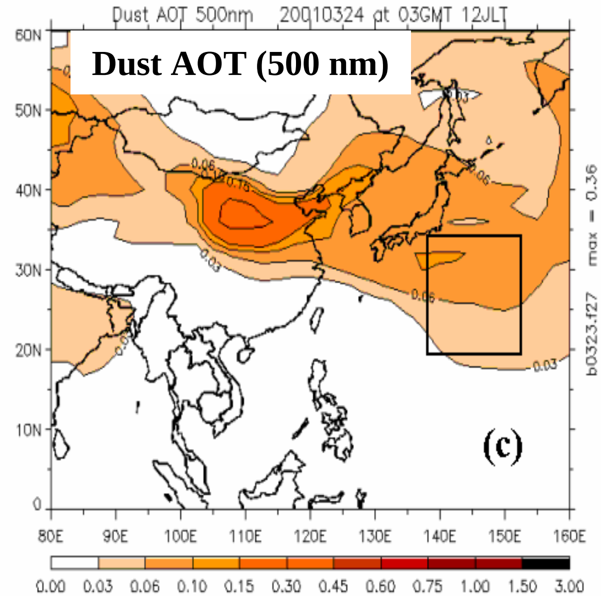


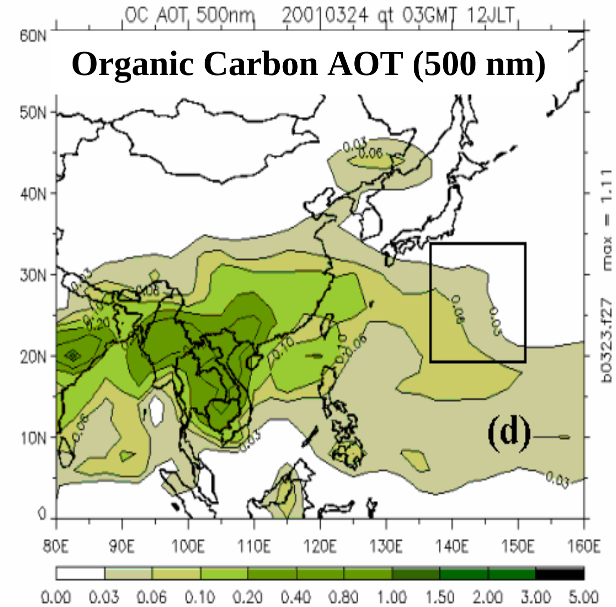


GOCART





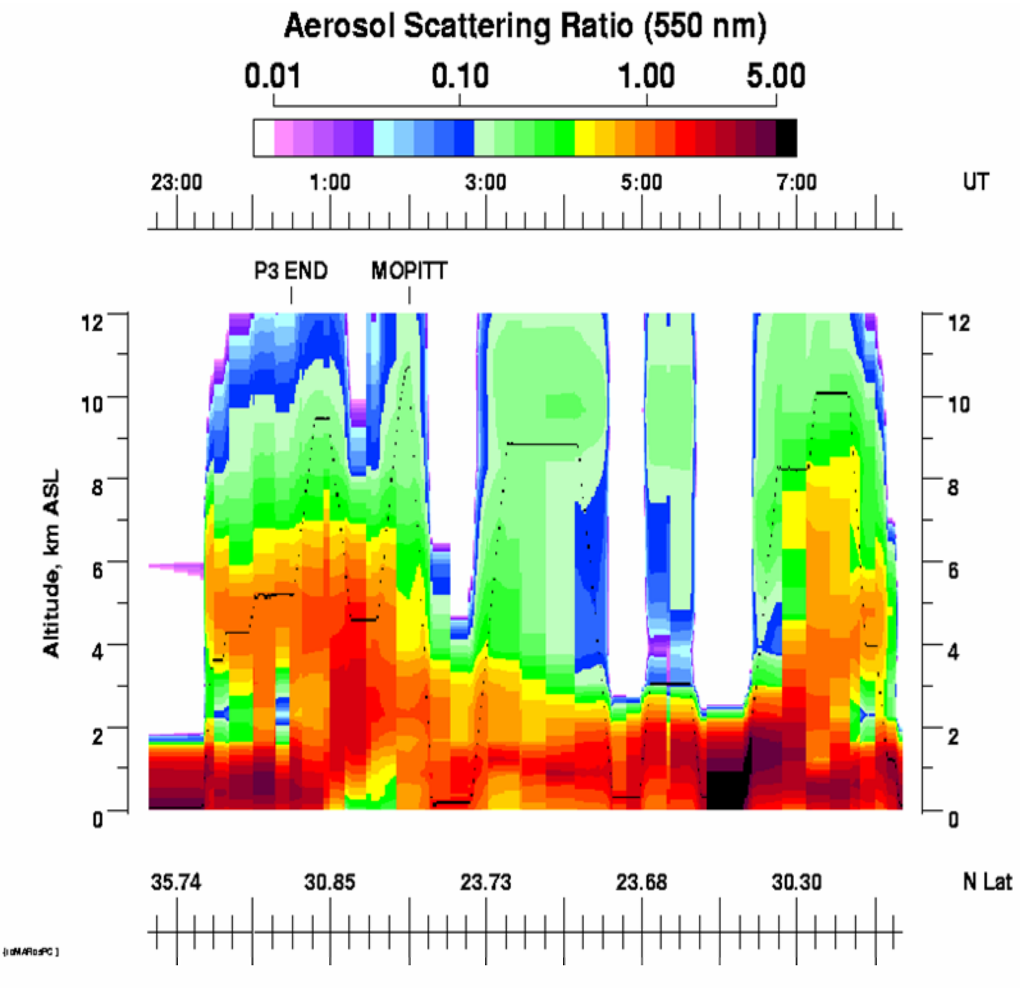




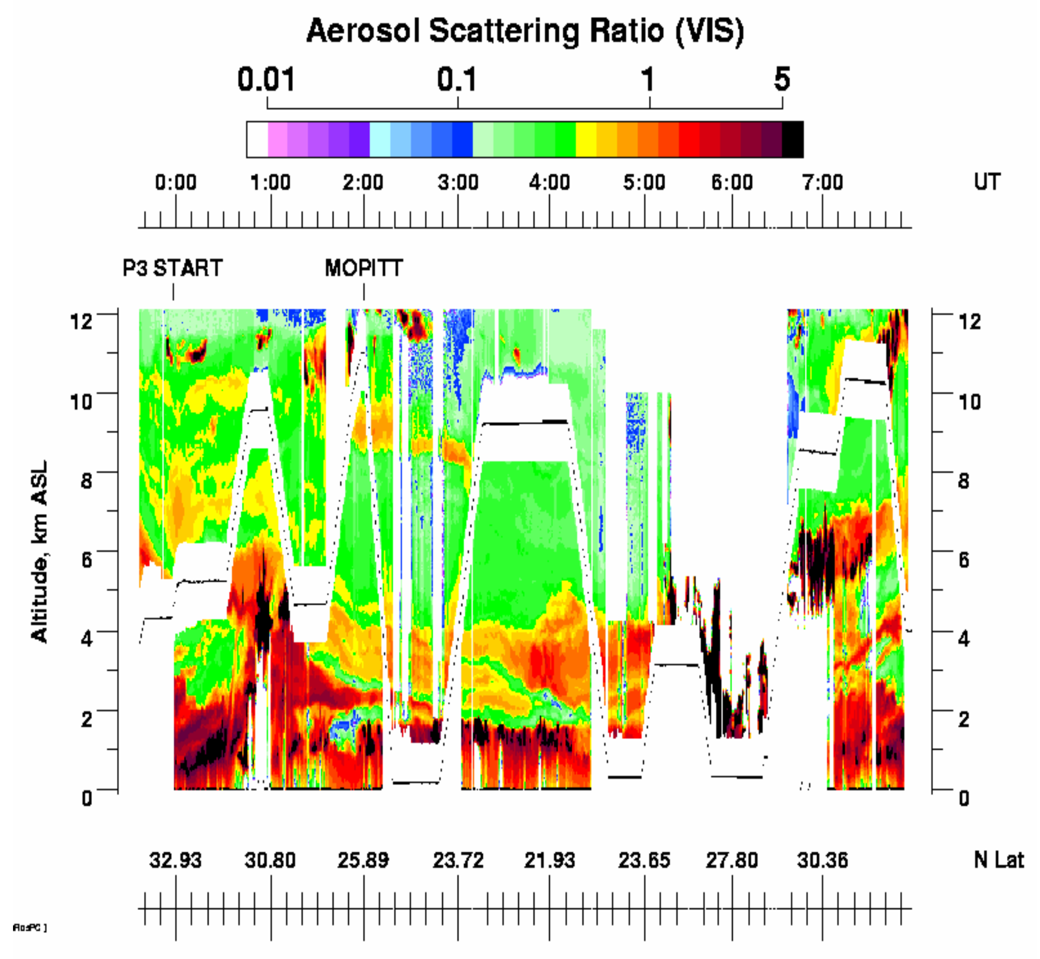
Comparison with GOCART

- TRACE-P Flight 14 March 23-24, 2001
- Attenuated aerosol scattering ratio

GOCART



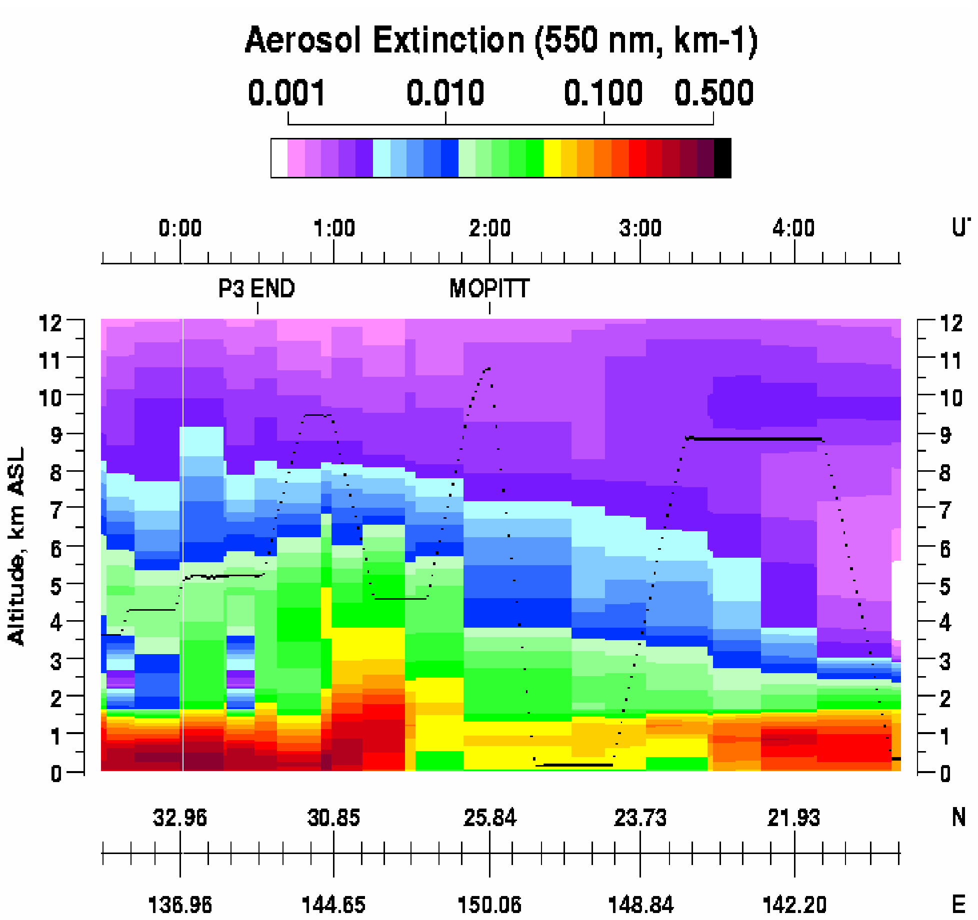
UV DIAL



Comparison with GOCART

- TRACE-P Flight 14 March 23-24, 2001
- Aerosol Extinction

GOCART



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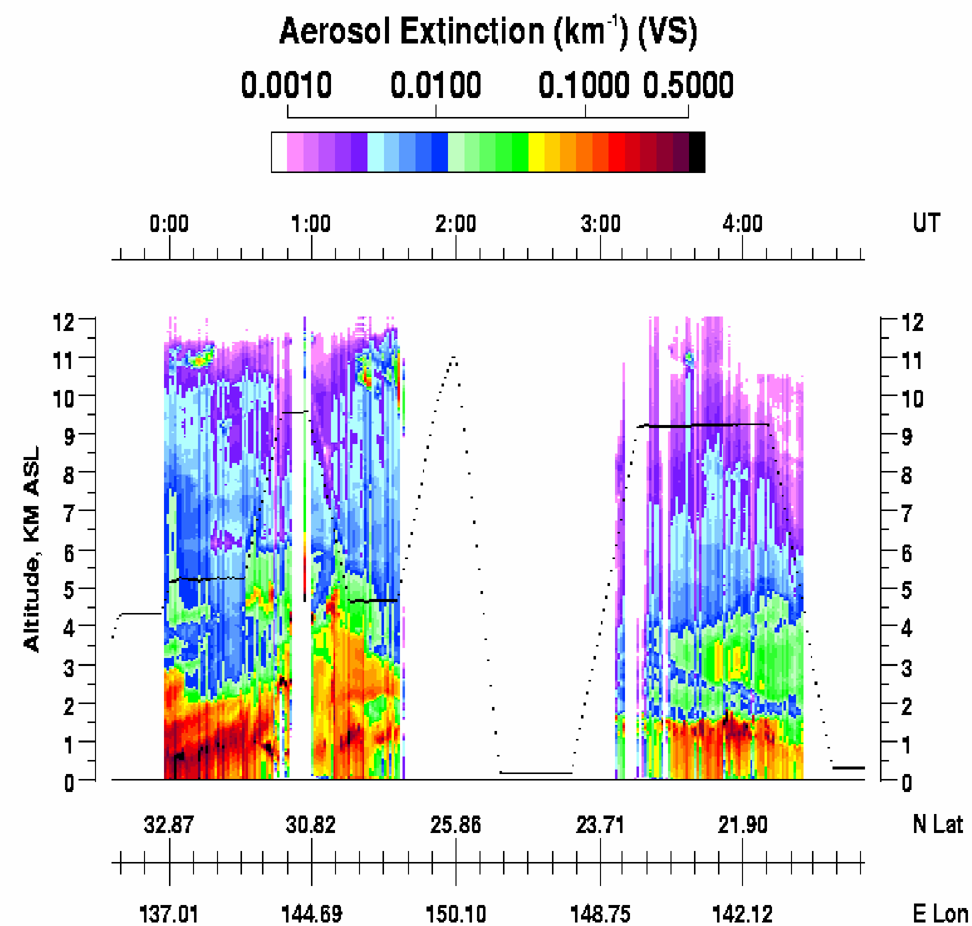
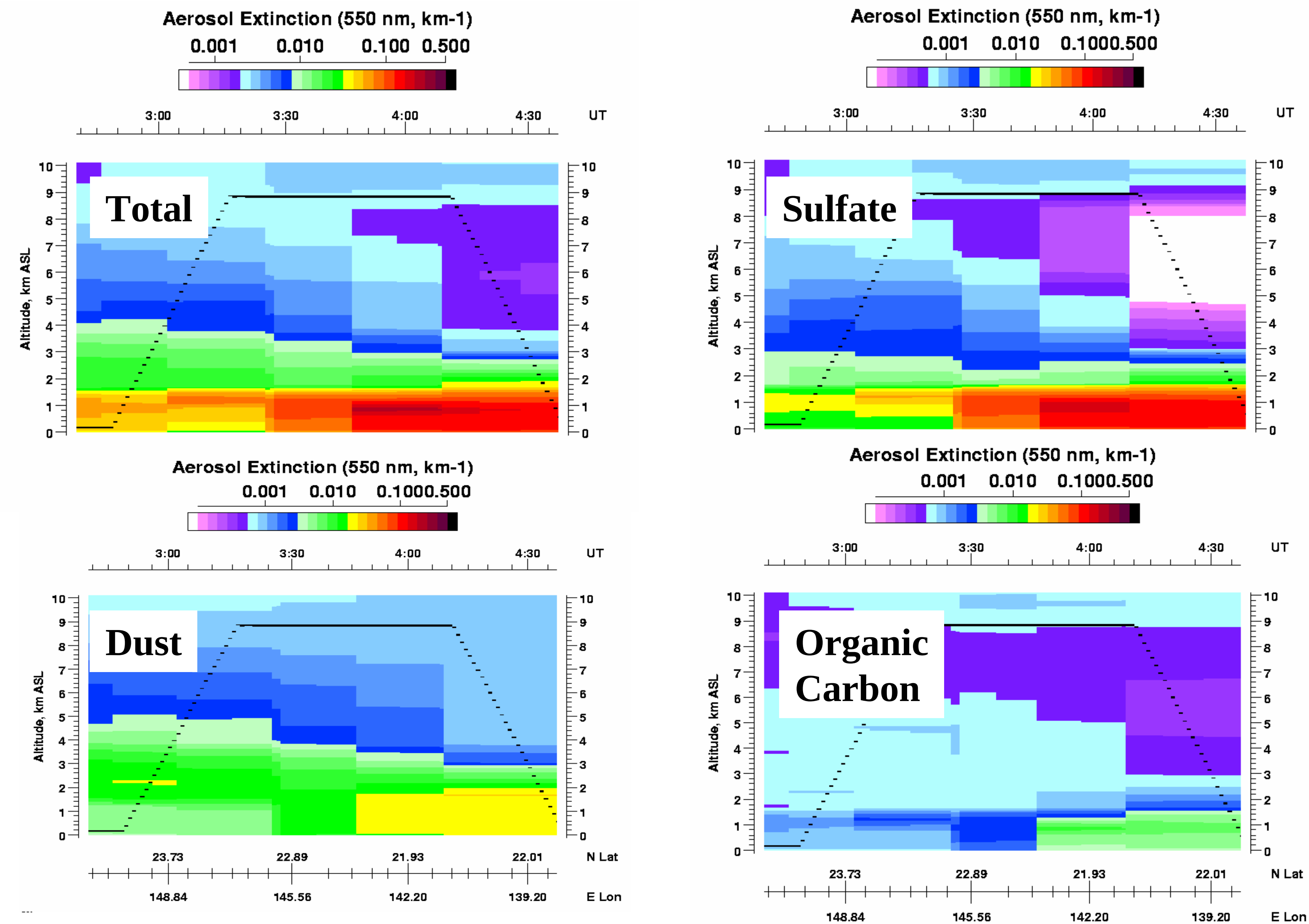
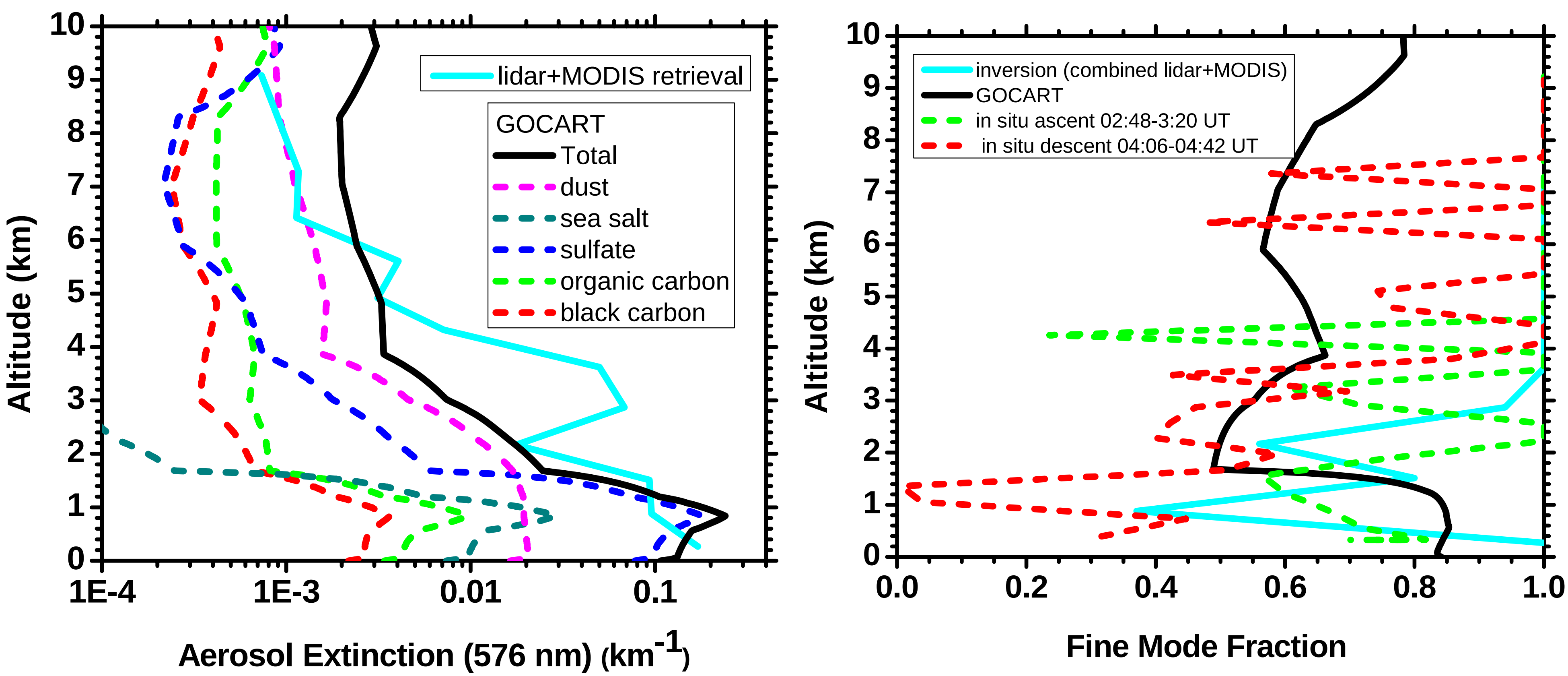


GOCART March 24, 2001



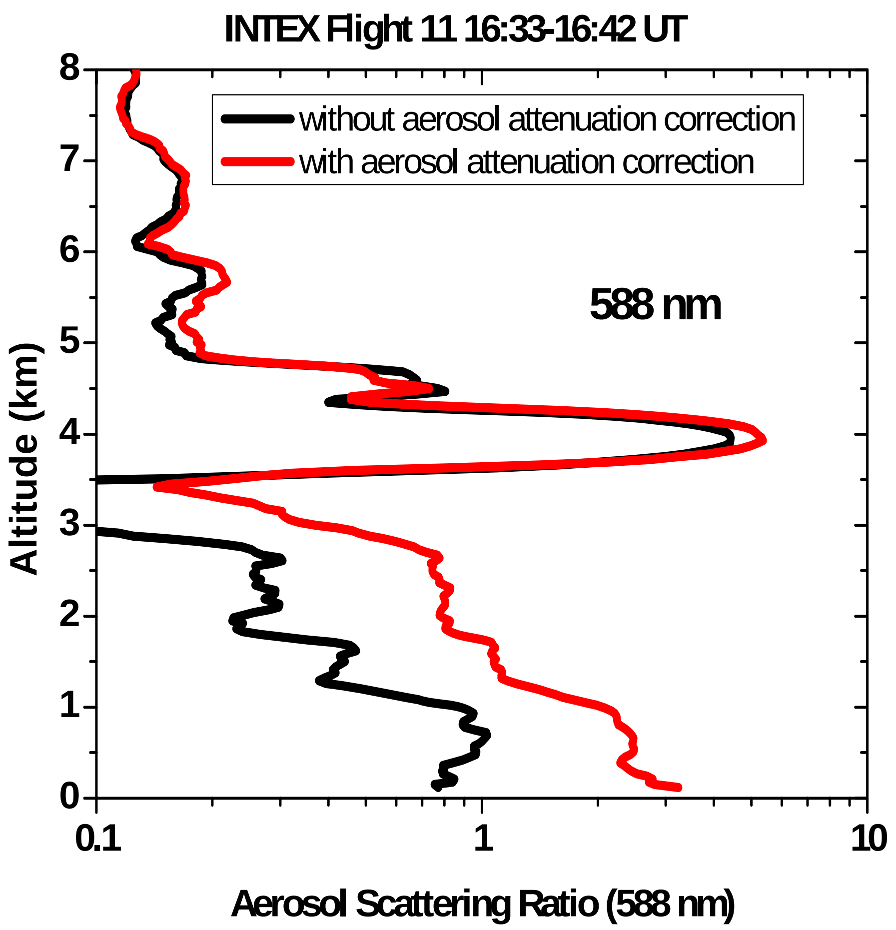
Comparison with GOCART

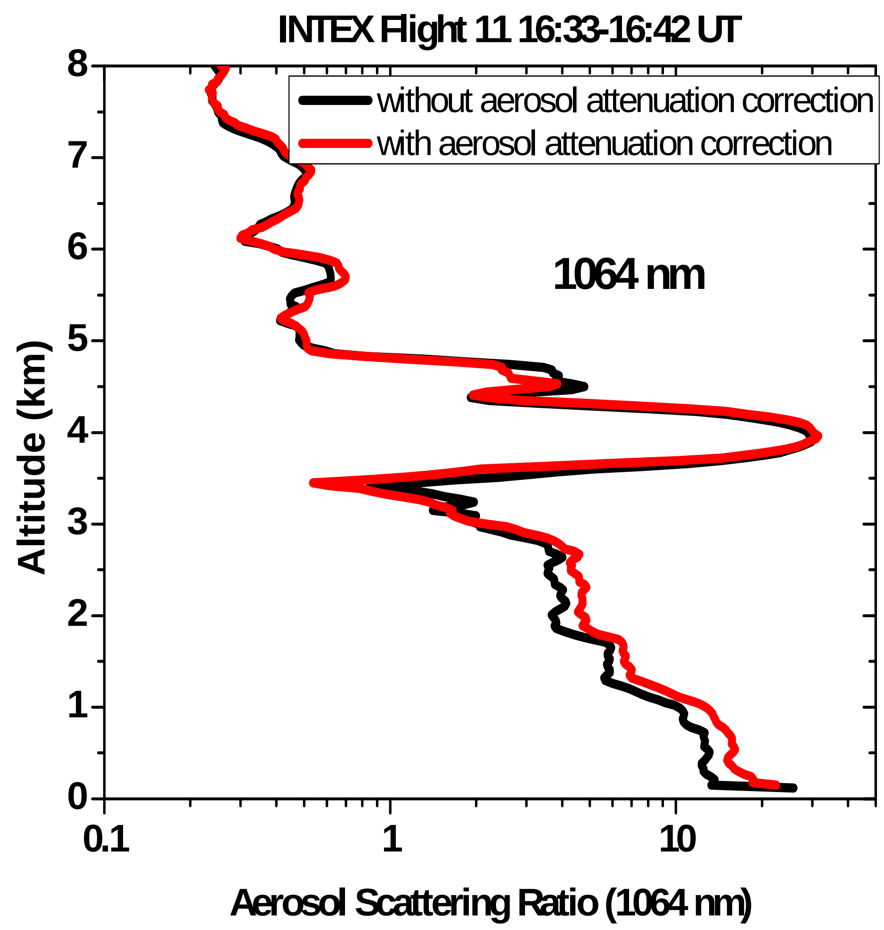
- TRACE-P Flight 14 March 23-24, 2001



Aerosol Profile Retrieval – July 22, 2004

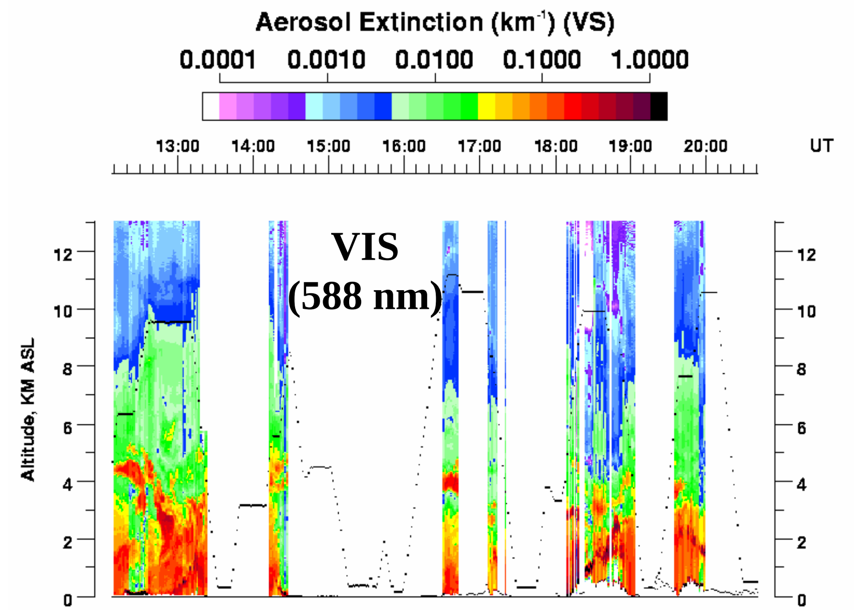
- Attenuation corrected applied using MODIS AOT constraint
- Correction at low altitudes ~ 200-300% at 588 nm, 20-40% at 1064 nm

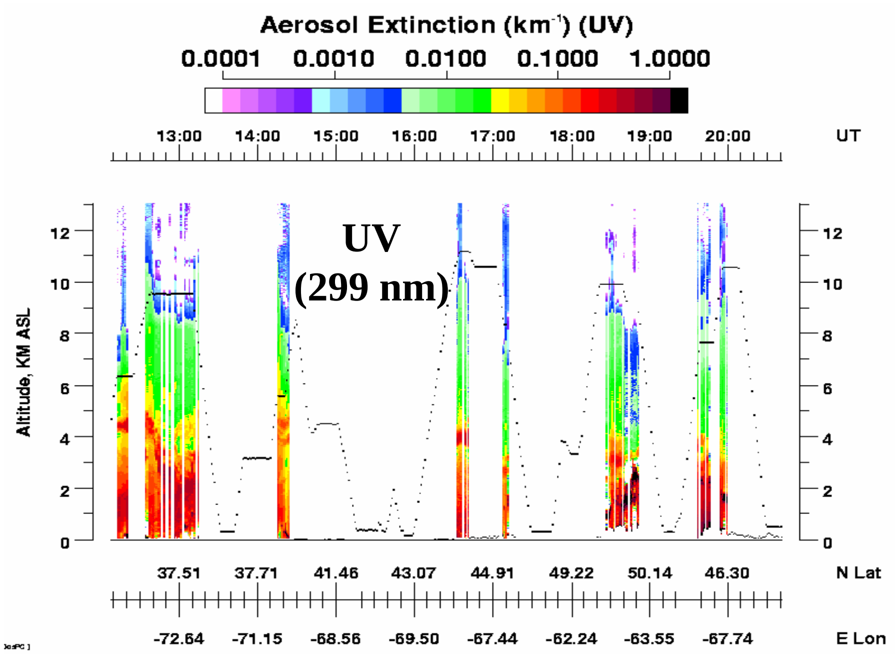


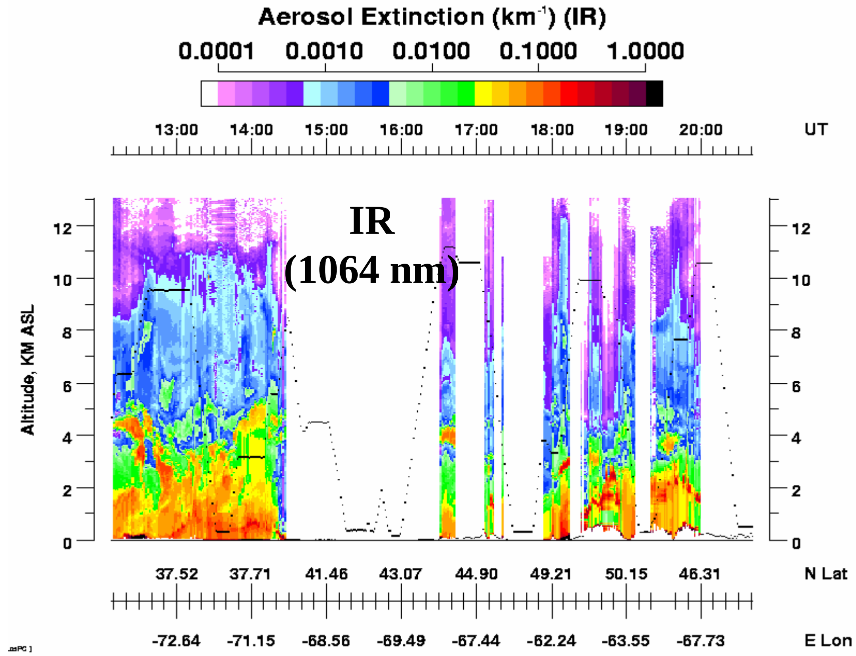


Aerosol Extinction Profiles – July 22

- Retrievals used constrained with MODIS AOT
- Currently limited to locations where satellite retrievals of AOT are present







AOT and Aerosol Extinction Profiles – July 22