Characterization of Aerosols using Airborne Lidar, MODIS, and GOCART Data during the TRACE-P (2001) Mission

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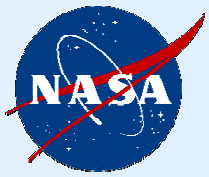
Outline

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

Motivation



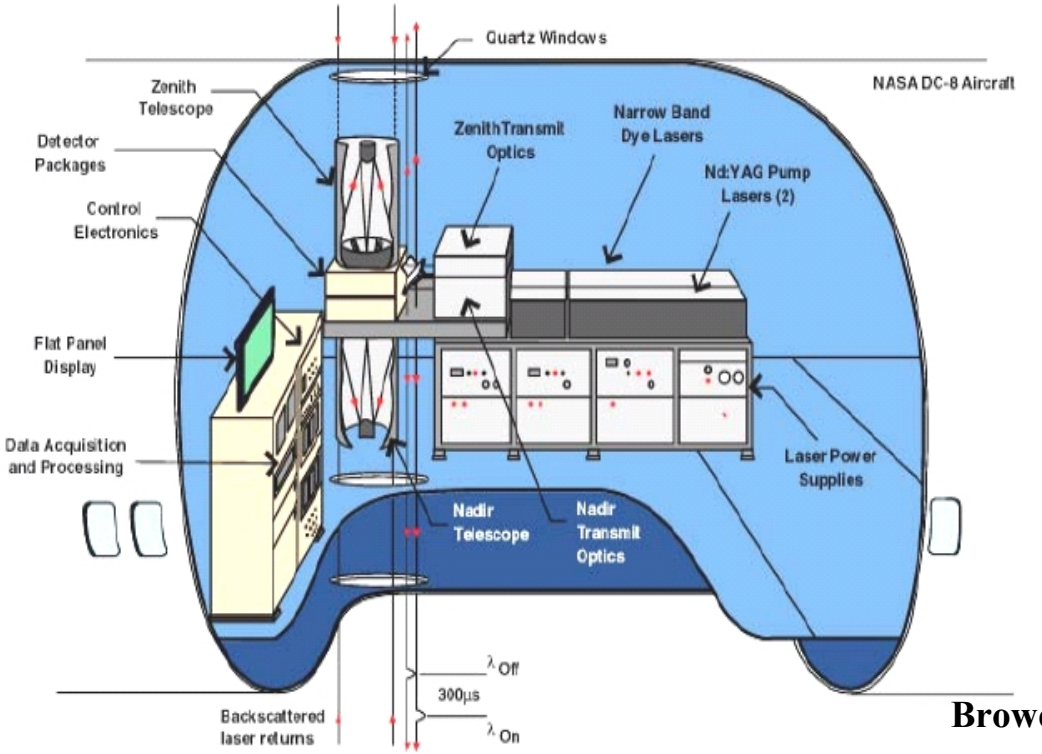
- Key aerosol parameters required for assessing anthropogenic impacts on radiative forcing
  - Vertical distribution
    - radiative forcing
    - surface temperature and climate responses
  - Aerosol size distribution
    - fine mode - biomass burning, pollution
    - coarse mode - desert dust, sea salt
- Methodology
  - Models
    - +Global coverage
    - - Large uncertainties in vertical distribution
  - MODIS
    - +Estimates of fine, coarse mode over ocean
    - - Column average – no profile information
  - Lidar
    - +High resolution vertical profiles
    - - Typically provide little quantitative information on size or composition

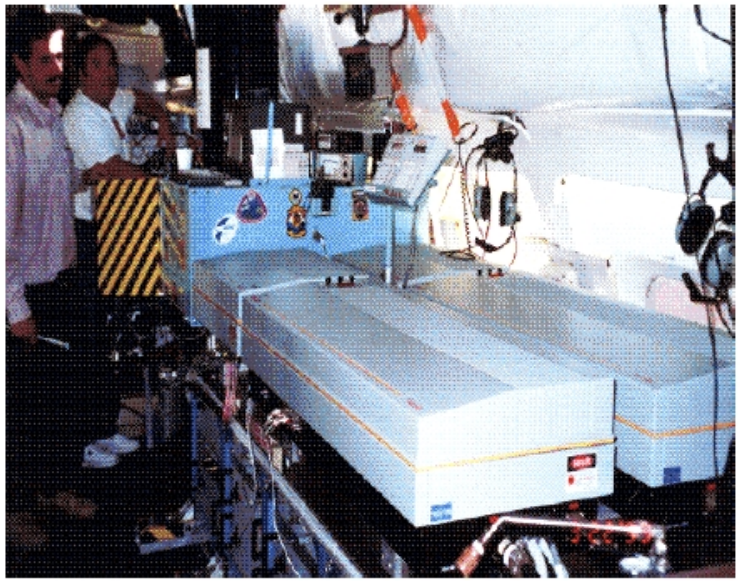
Objectives

- Use combination of airborne lidar and MODIS to provide information regarding the vertical distribution of fine vs. coarse aerosol modes
- Retrieve aerosol extinction and optical thickness profiles from lidar data
- Identify aerosol types vs. altitude
- Evaluate ability of GOCART model to simulate aerosol extinction profiles and simulate contributions to fine and coarse modes

NASA Langley UV DIAL Airborne Lidar

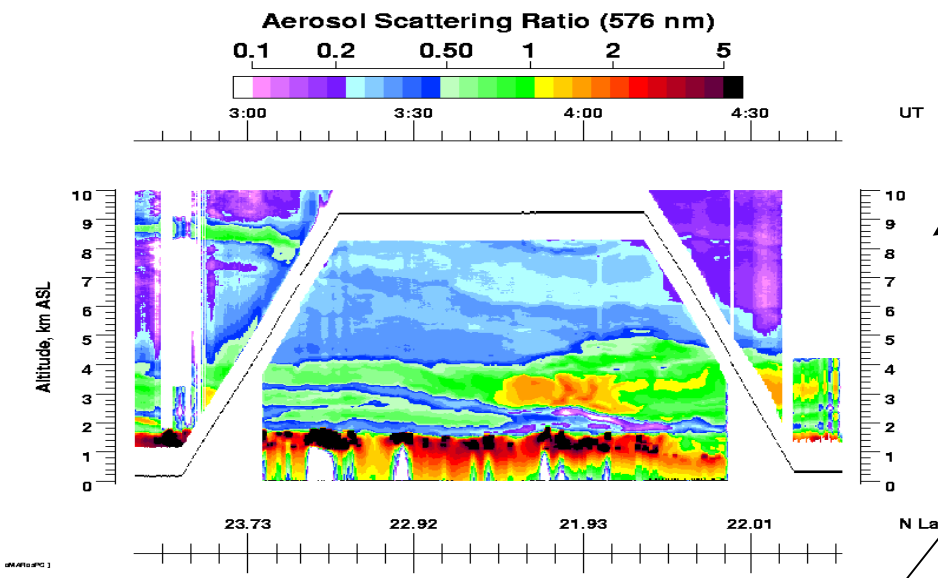
- **Ozone Differential Absorption Lidar (DIAL) Profiles (λ_{on}=289 nm & λ_{off} =300 nm)**
- **Aerosol & Cloud Scattering Ratio Profiles (300, 576, & 1064 nm)**
- **Simultaneous Nadir and Zenith Ozone & Aerosol Profiling**
- **Nadir Aerosol Depolarization Profiles (576 nm)**
- **Deployed on NASA DC-8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



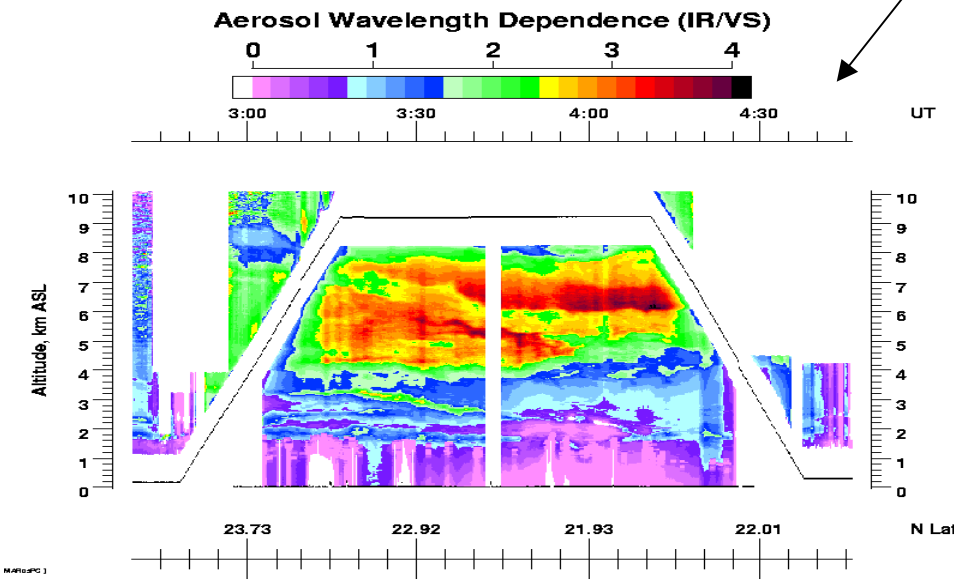


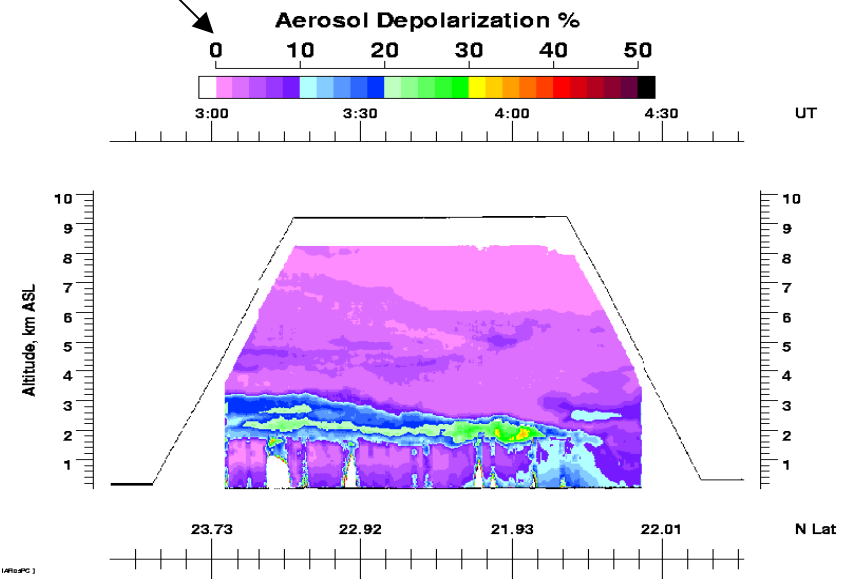
Browell et al., J. Geophys. Res, 108(D20), 8805, 2003.

UV DIAL Measurements



- TRACE-P Flight 14 March 23-24, 2001
- Extensive parameters (300, 576, 1064 nm)
  - aerosol scattering ratio
  - backscatter
  - extinction
- Aerosol intensive parameters
  - backscatter wavelength dependence
  - depolarization





Retrieval of Aerosol Extinction Profiles

- Backscatter lidar equation (2 unknowns)

Measured Signal
Range from Instrument
Calibration Constant
Molecular Backscatter Coefficient
Molecular Extinction Coefficient
← Known
Determined from measured signals and meteorological data

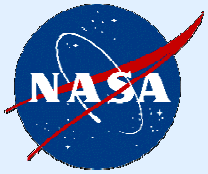
$$P(r) = \frac{C}{r^2}\left[\beta_m(r) + \beta_p(r)\right]\exp\left\{-2\int_0^r \left[\sigma_m(r') + \sigma_p(r')\right]dr'\right\}$$

Particulate Backscatter Coefficient
Particulate Extinction Coefficient
← Retrieved Parameters

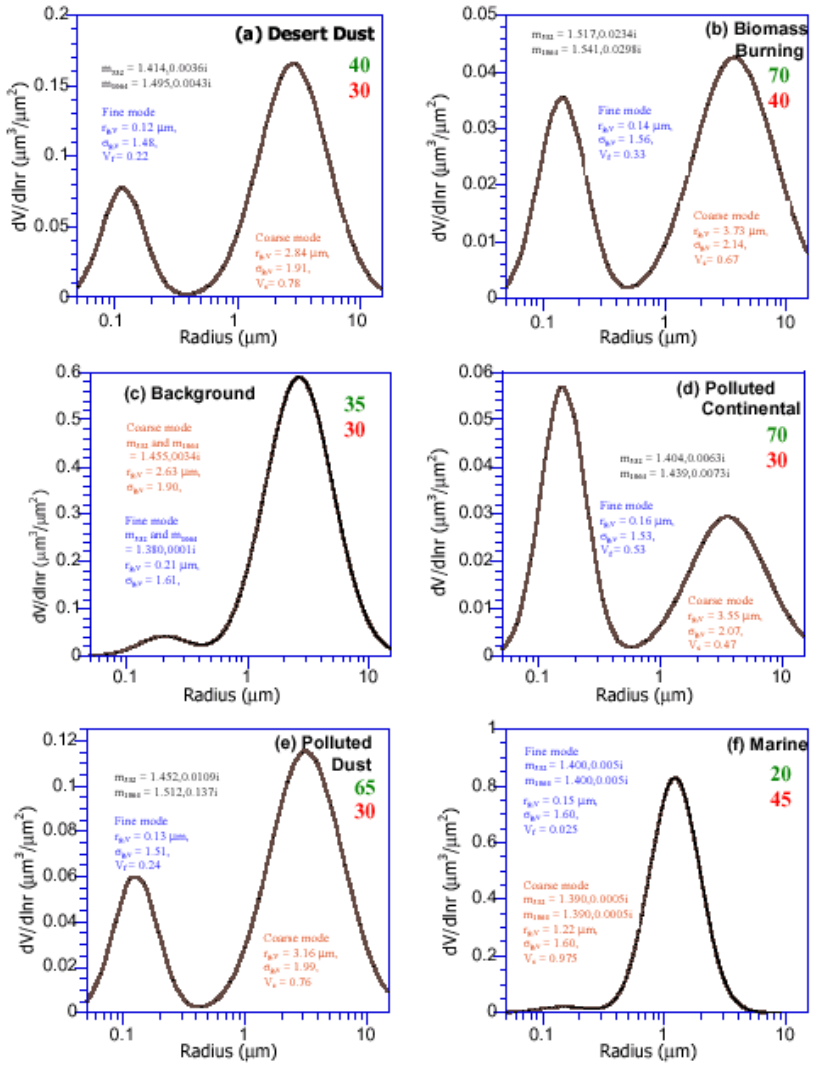
"Lidar Ratio" = $\frac{\sigma_p(r)}{\beta_p(r)} = S_p$ ← Assumption of value for extinction-to-backscatter (S_p) ratio required for backscatter lidar retrieval

- Solution approaches
  - Assume a priori aerosol types and S_p values and use lidar measurements of intensive parameters to determine aerosol types
  - Use external information to constrain solution (e.g. MODIS AOT)

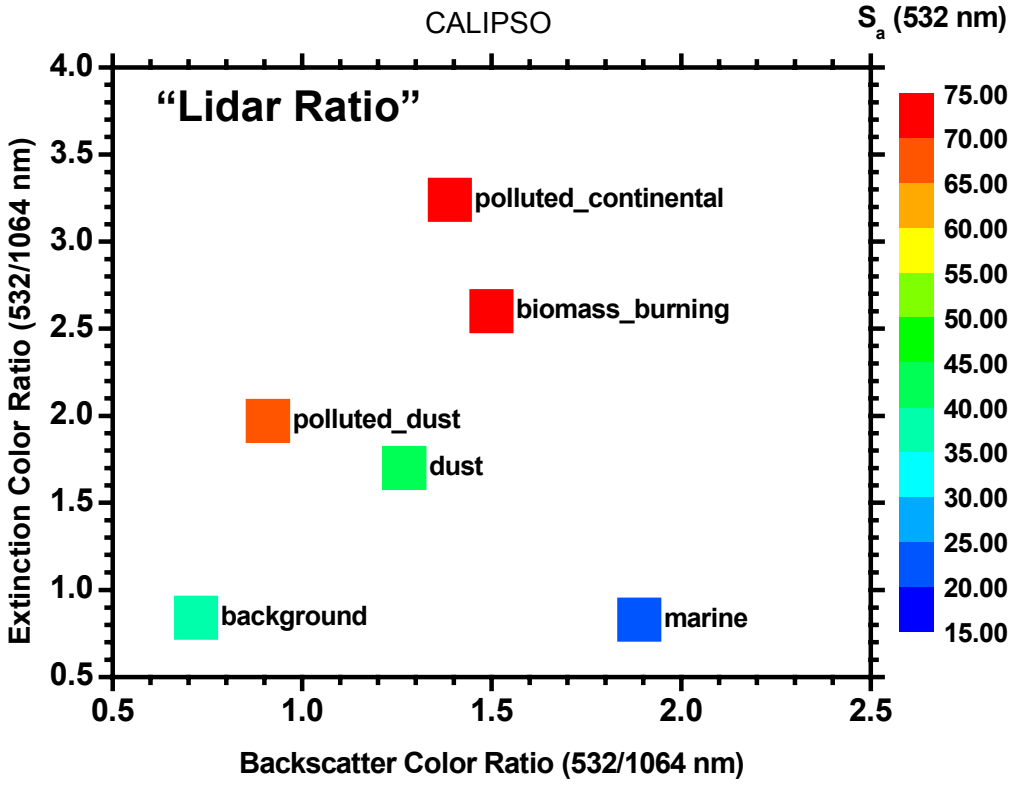
Retrieval of Aerosol Extinction Profiles



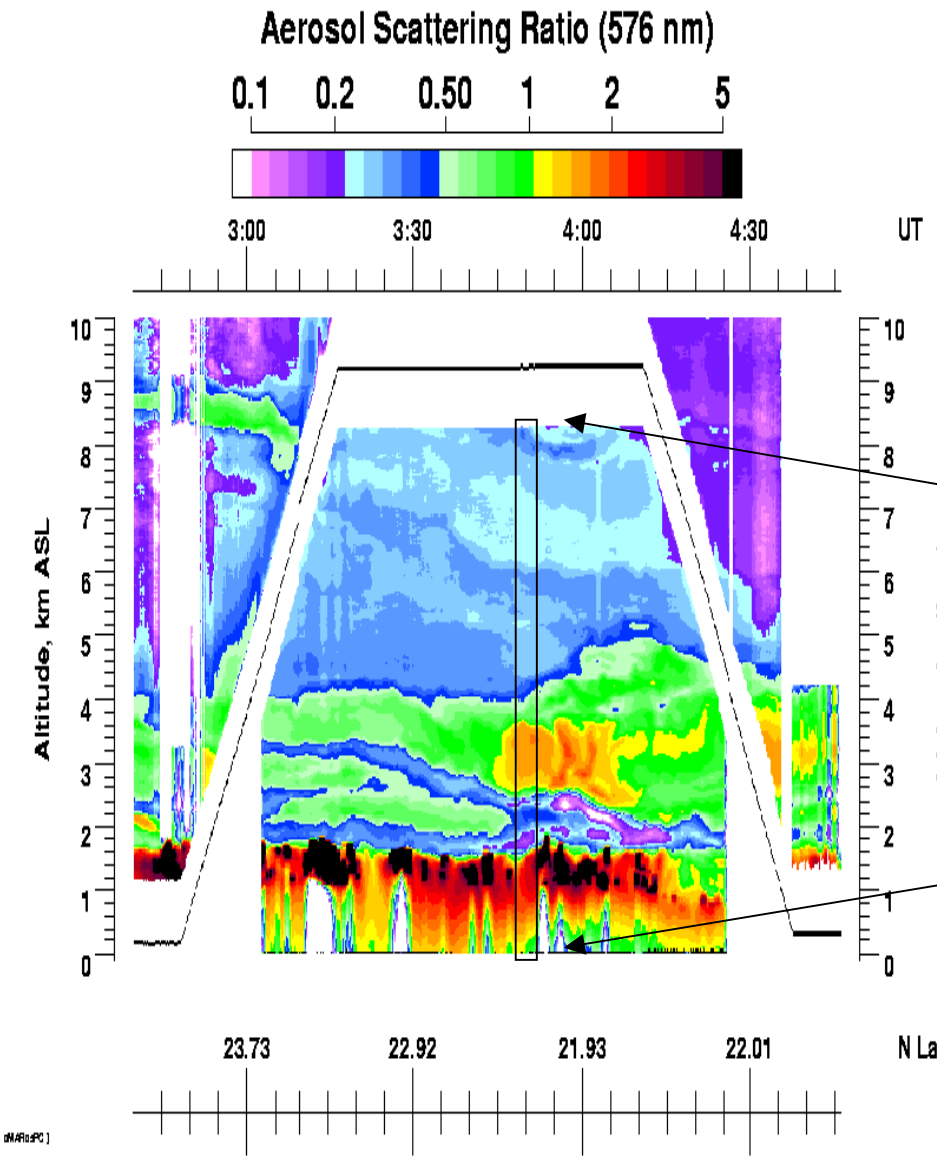
- Aerosol types determined from AERONET climatology used for CALIPSO retrievals (Omar et al., 2003)



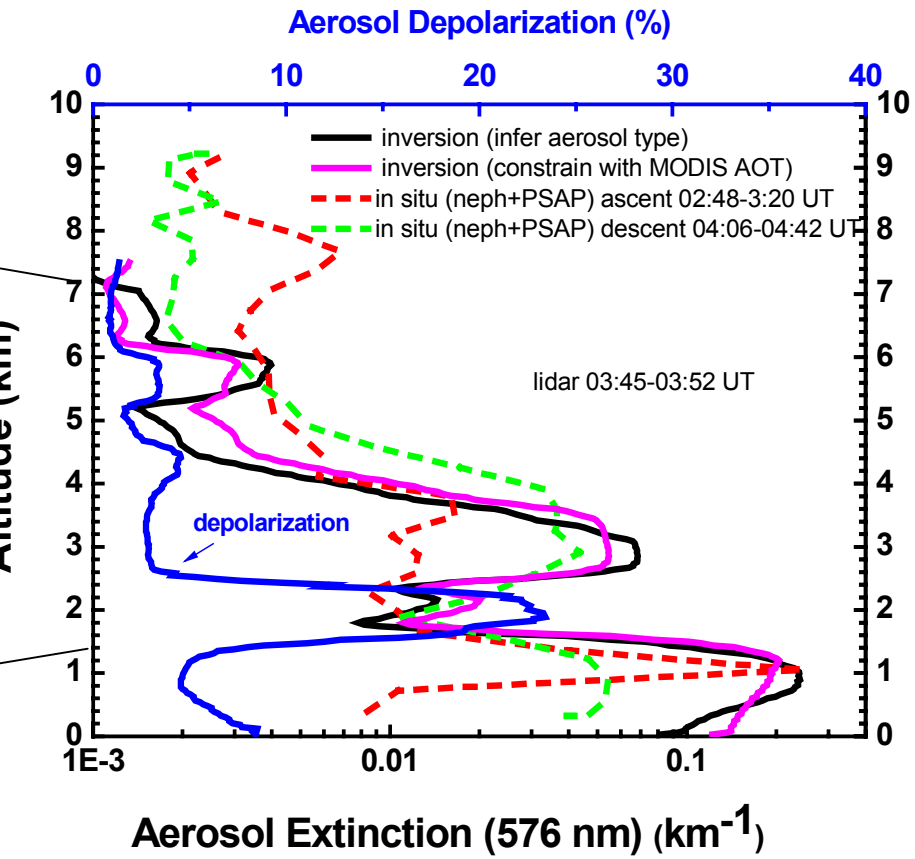
- Use backscatter and extinction "color ratios" to infer aerosol type and corresponding lidar ratio (Sasano and Browell, 1989; Reagan et al., 2004)



Retrieval of Aerosol Extinction Profiles



- TRACE-P Flight 14 March 23-24, 2001
- Good agreement between techniques for this test case



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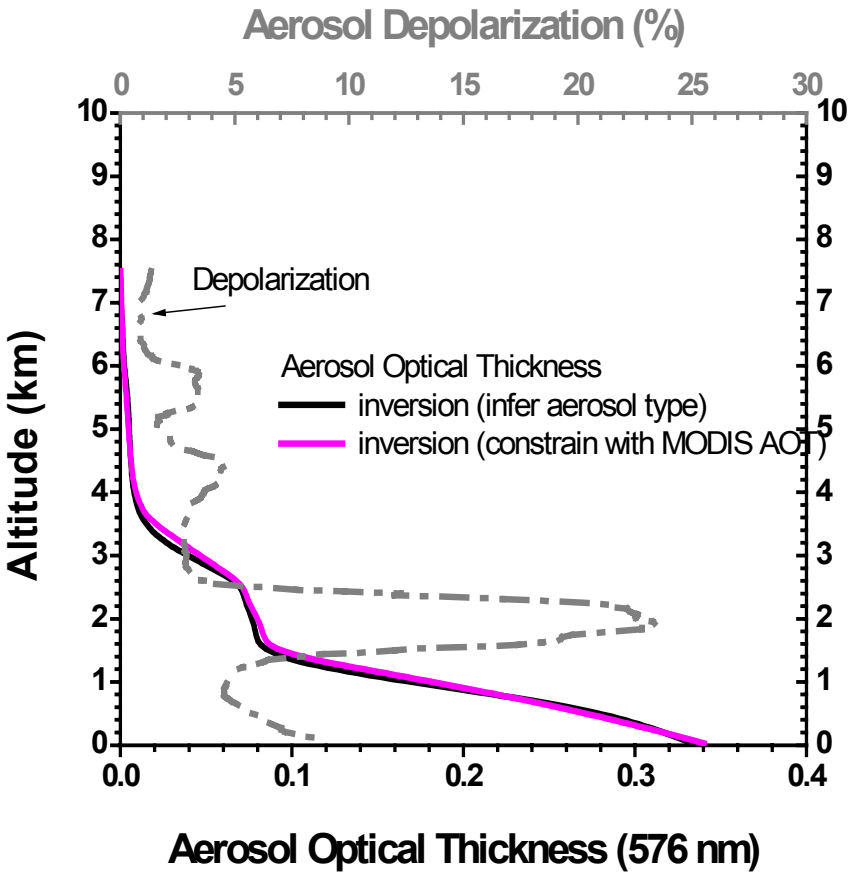
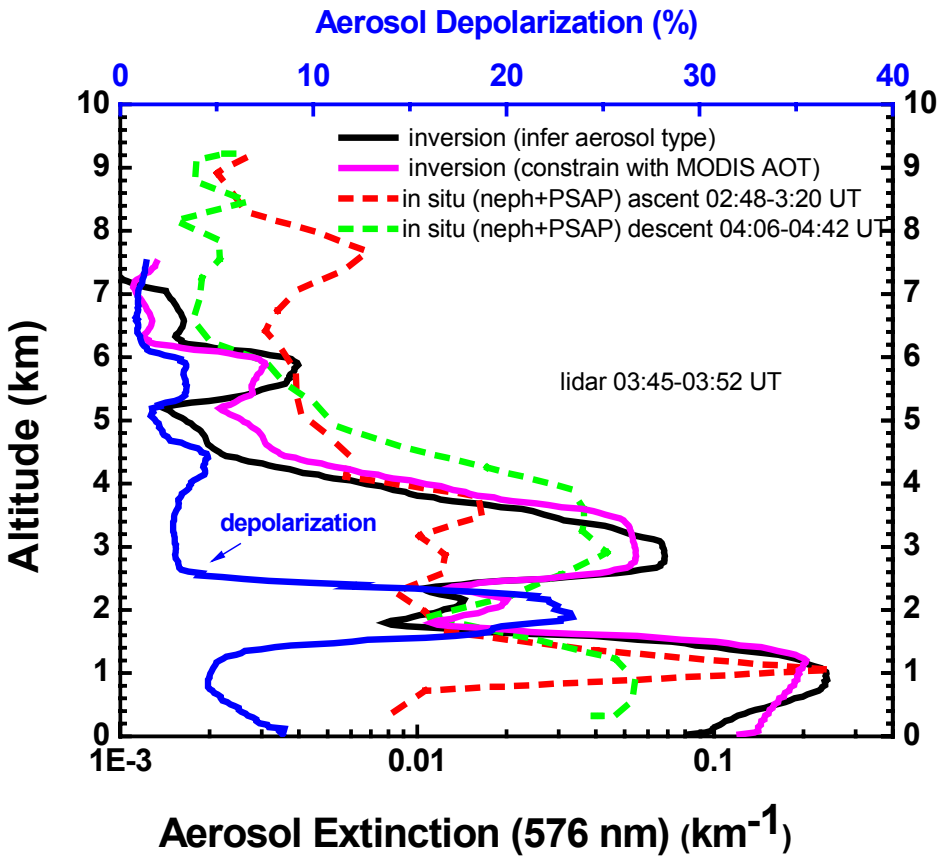
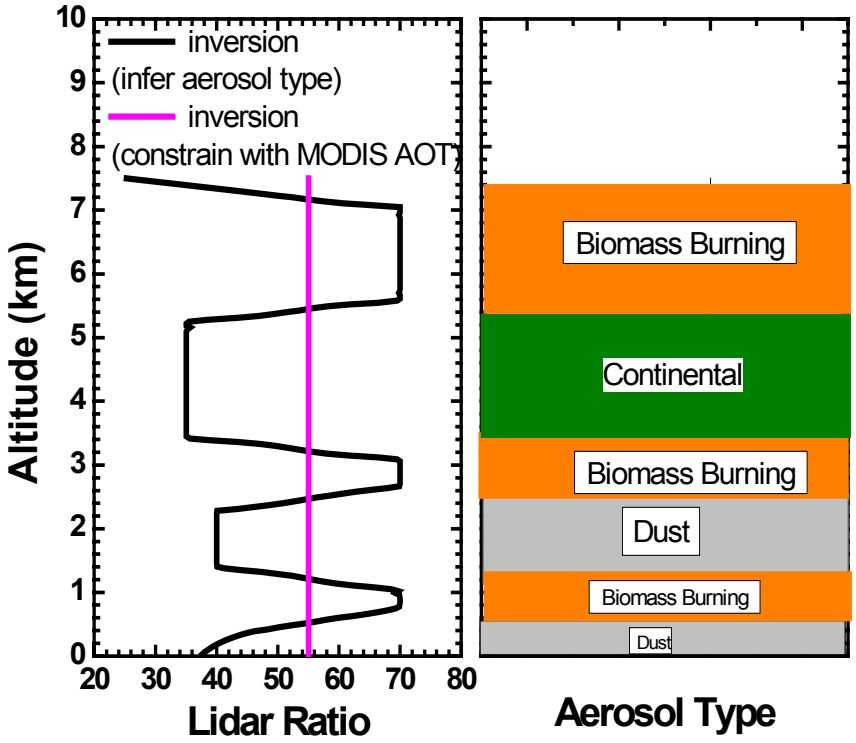
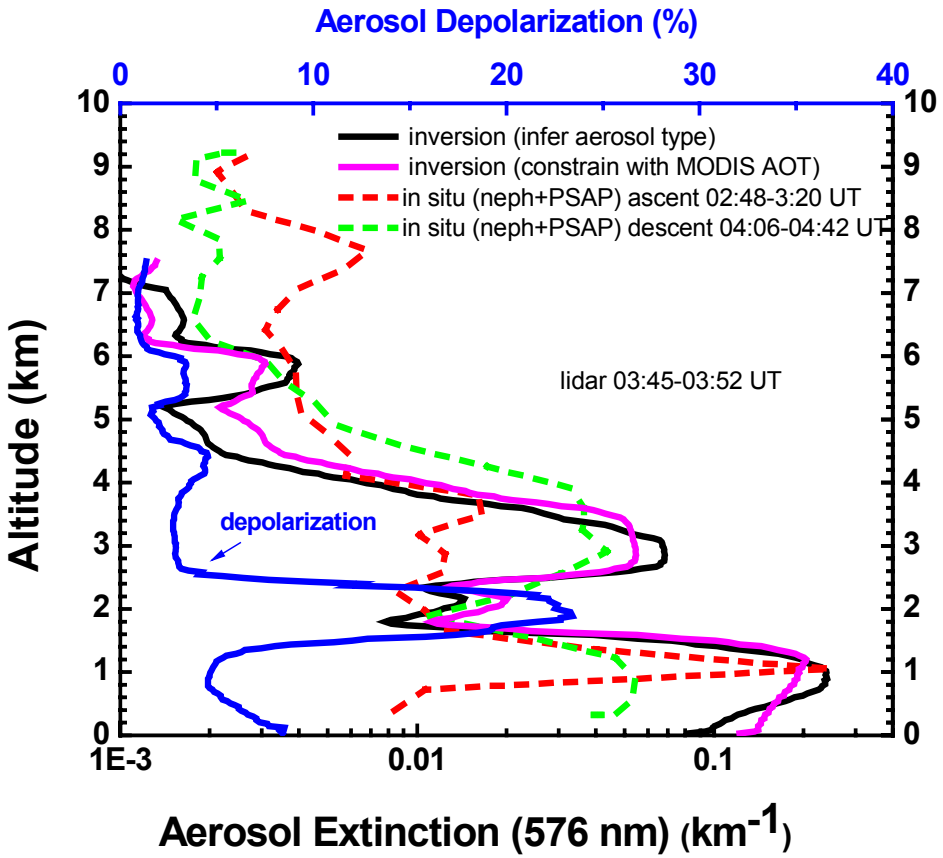




Retrieval of Aerosol Extinction Profiles

- TRACE-P Flight 14 March 23-24, 2001
- Inversion provides some indication of aerosol types
  - Planned modifications - examine layer averages to reduce sensitivity to noise in lidar profiles
  - Use in conjunction with GOCART results



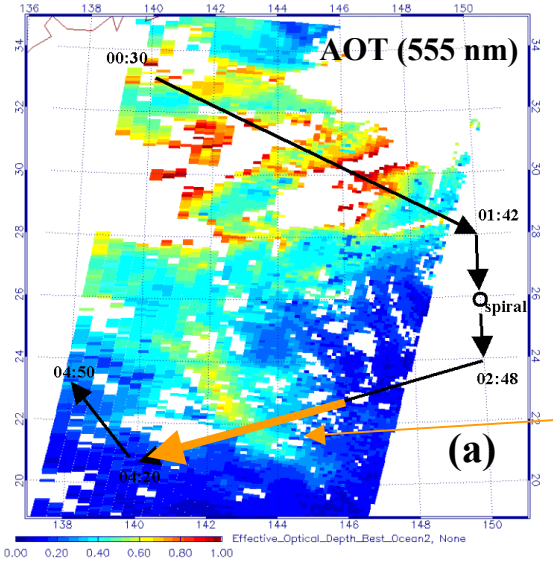


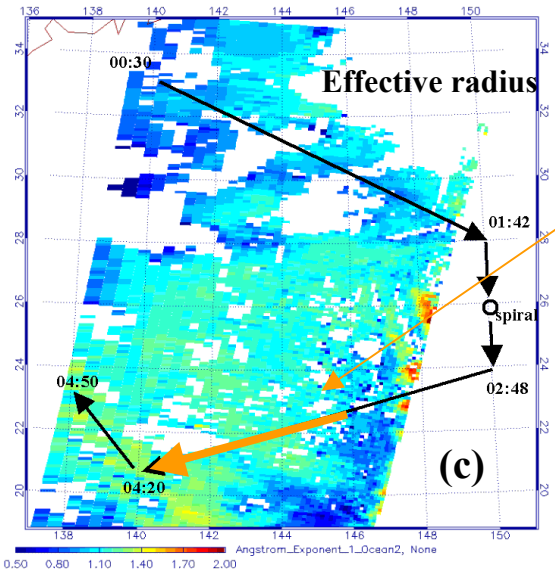
MODIS+lidar Aerosol Retrieval

- Retrieval algorithm
  - (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
  - UV wavelength (300 nm) – more information on fine particle size
  - Depolarization – adjust the backscatter phase function for nonsphericity

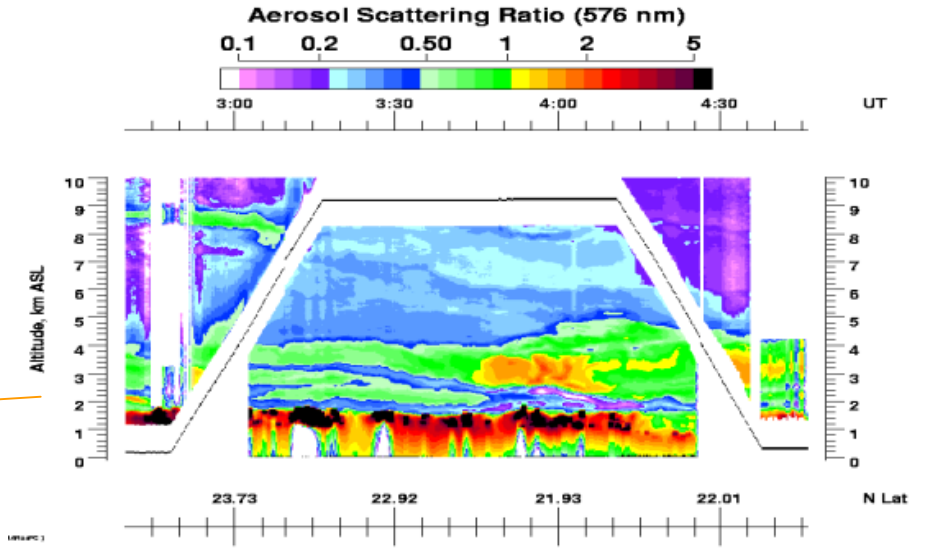
March 24, 2001 MODIS+GOCART

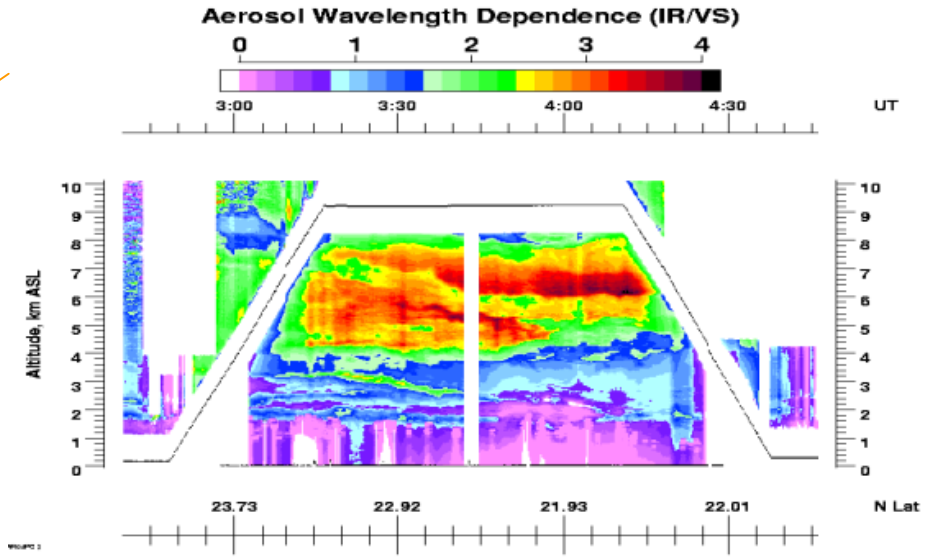
Terra MODIS





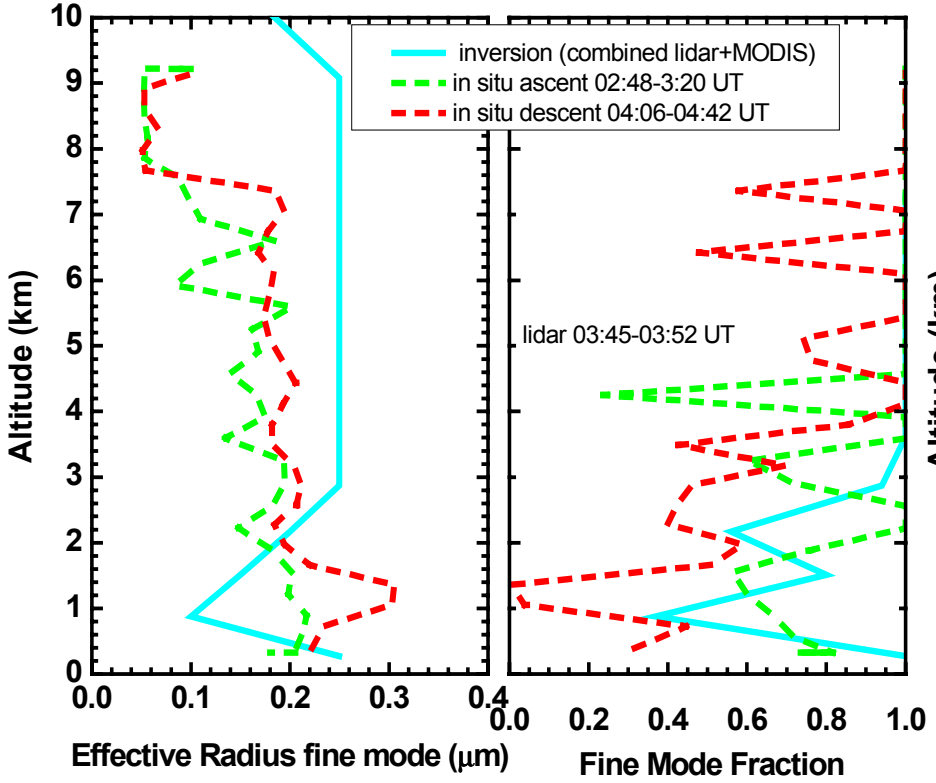
UV DIAL

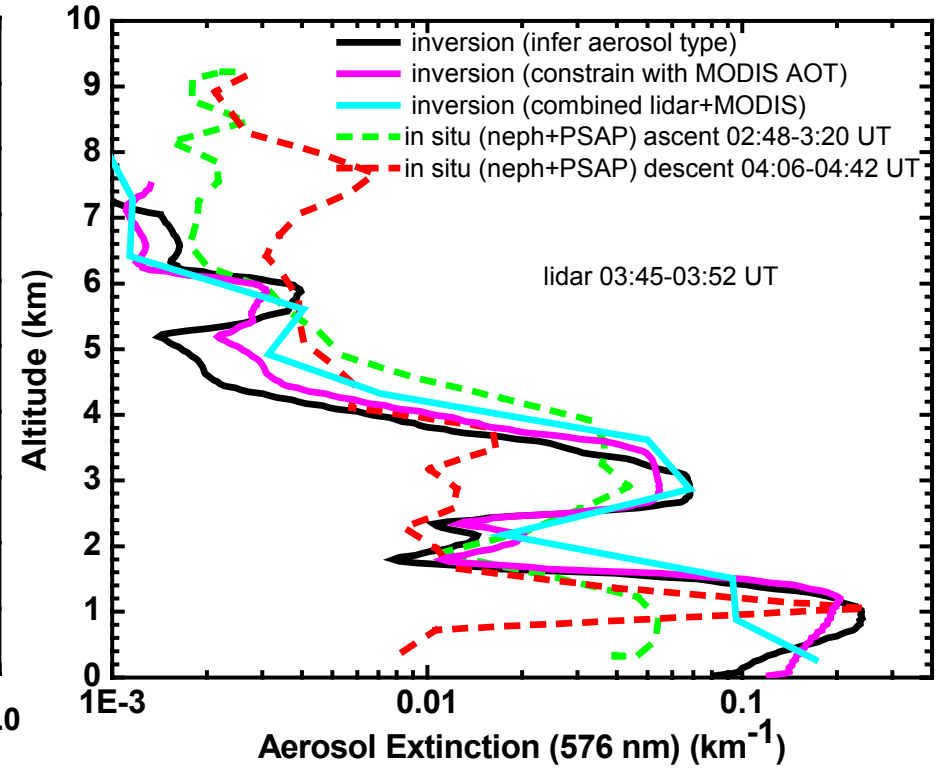




MODIS+lidar Aerosol Retrieval Example

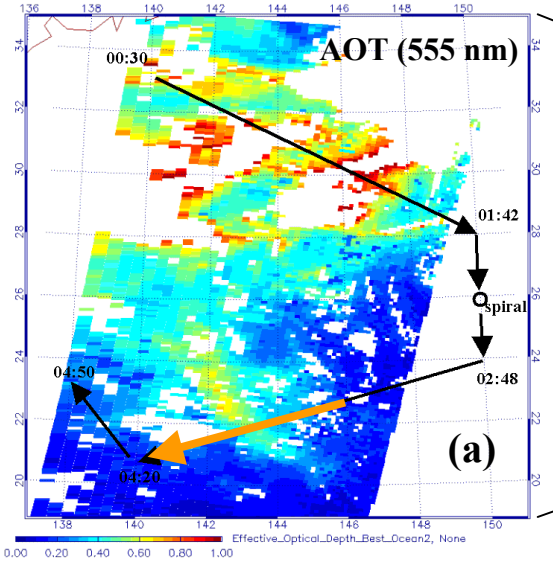
- TRACE-P Flight 14 March 23-24, 2001
- Good agreement between techniques for this test case
- Results show qualitative agreement with in situ measurements
- Plan to evaluate additional cases from TRACE-P, INTEX NA

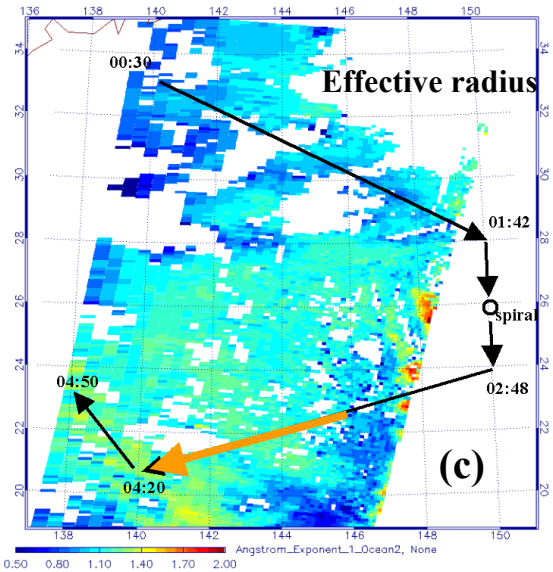




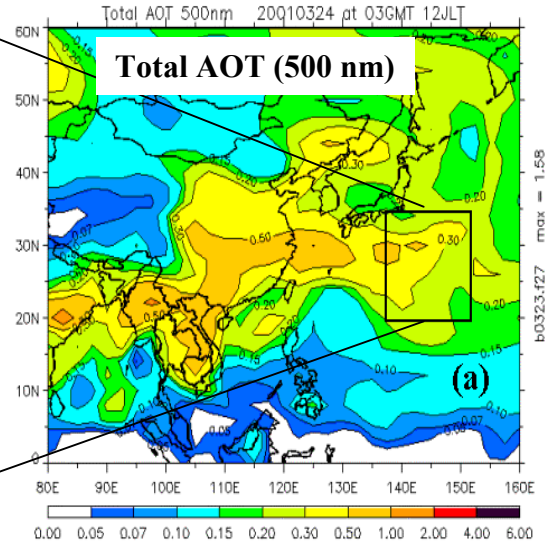
March 24, 2001 MODIS+GOCART

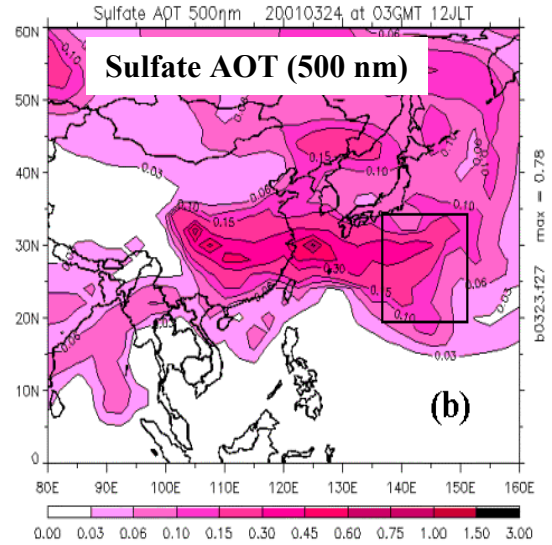
Terra MODIS

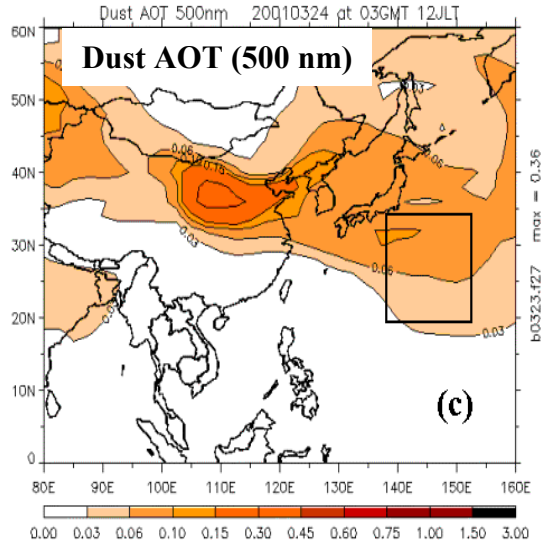


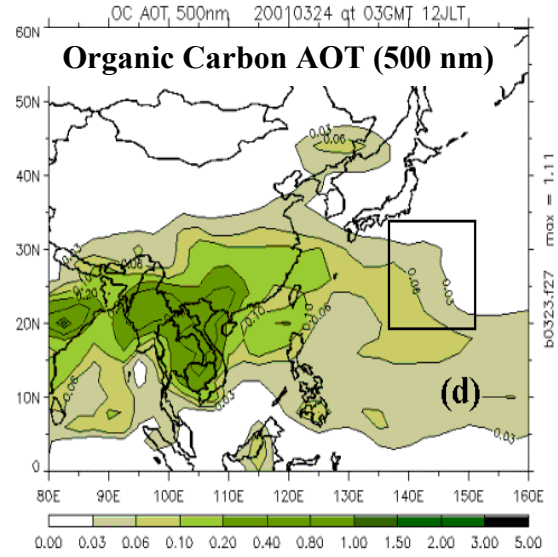


GOCART





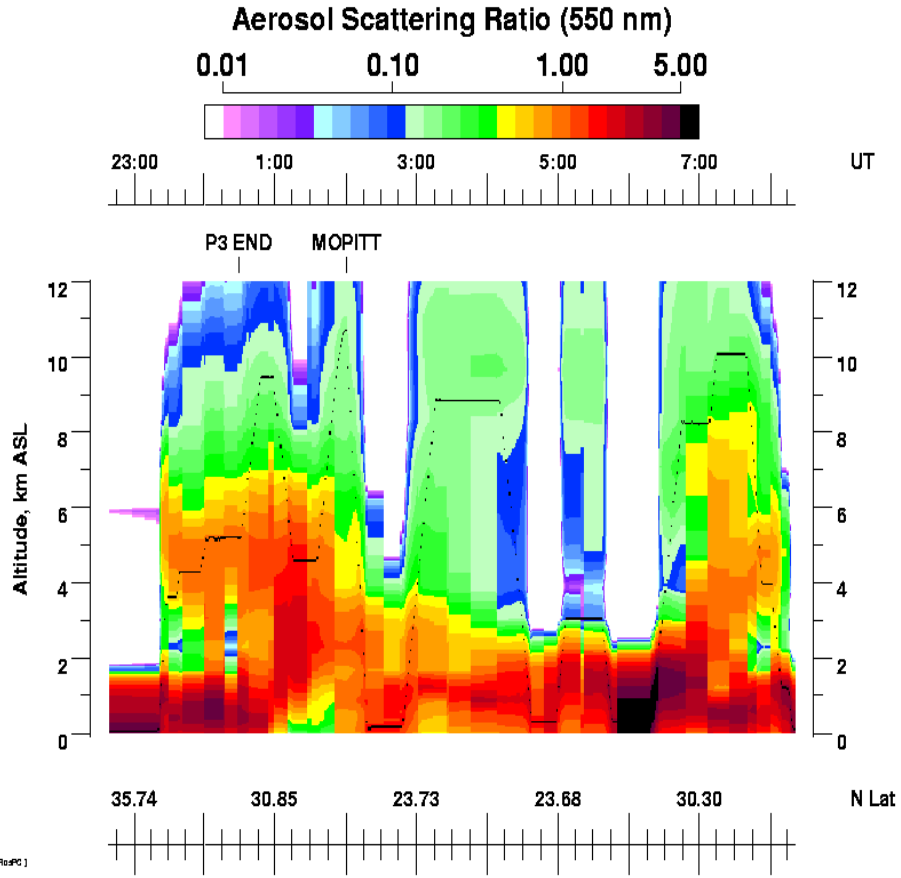




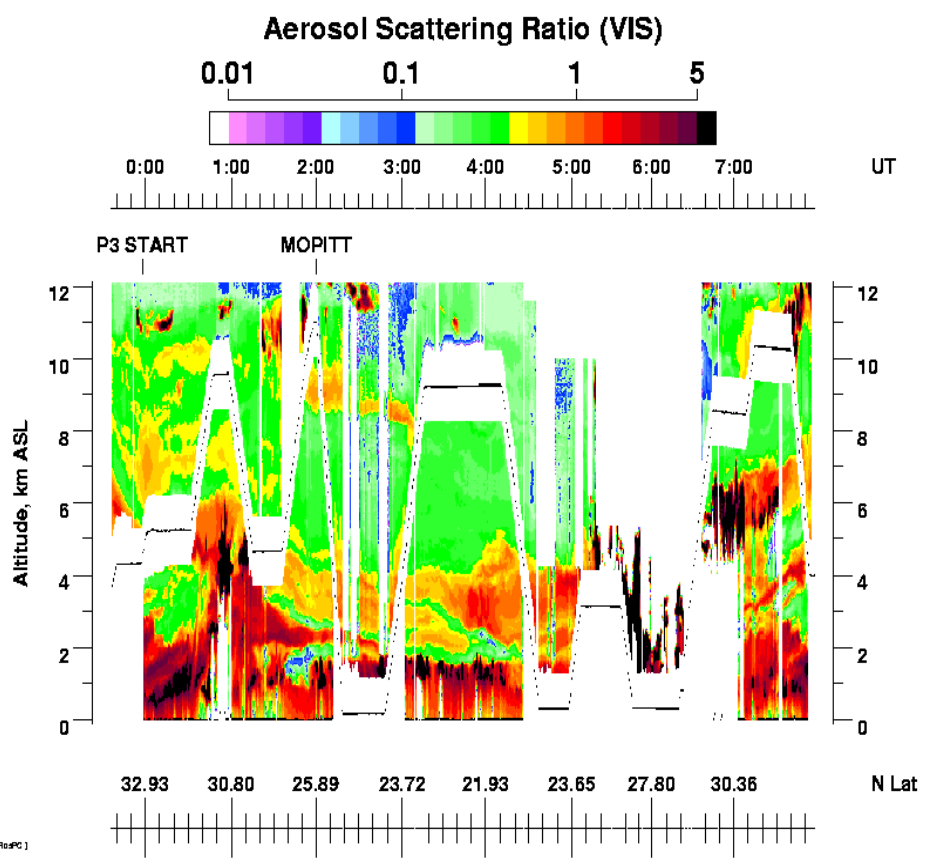
Comparison with GOCART

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

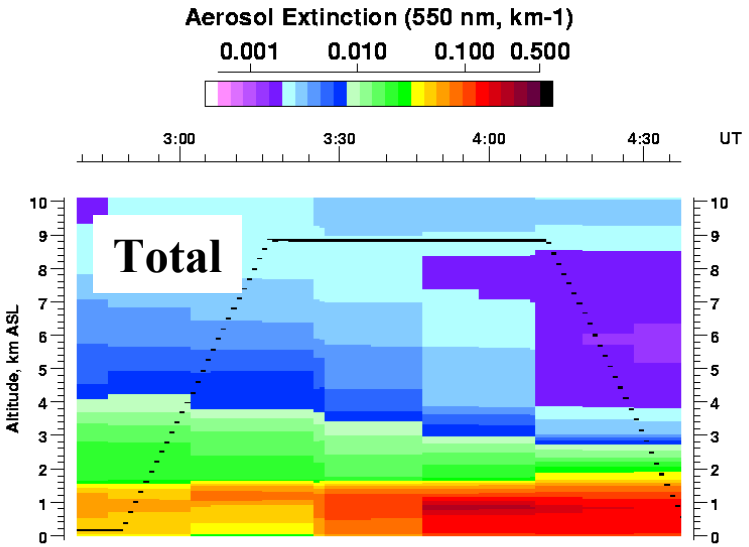
GOCART

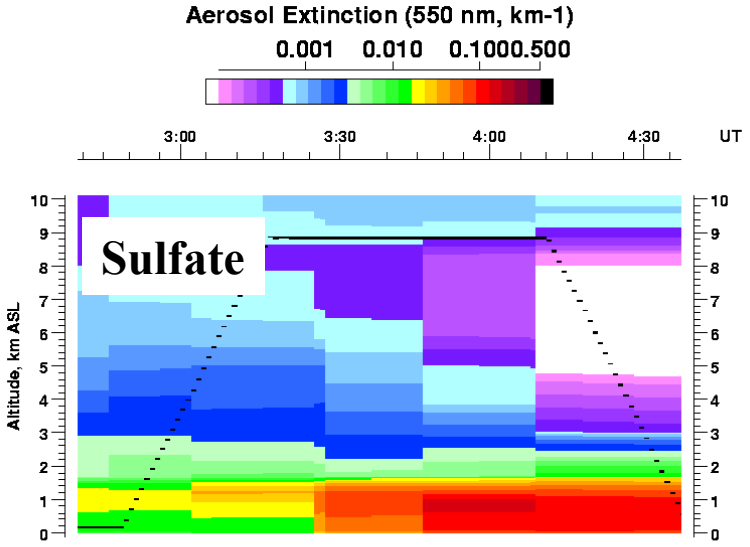


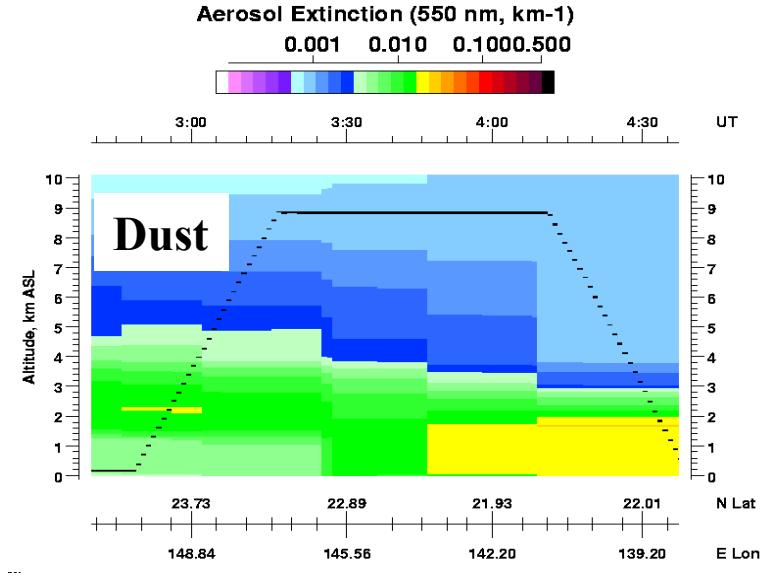
UV DIAL

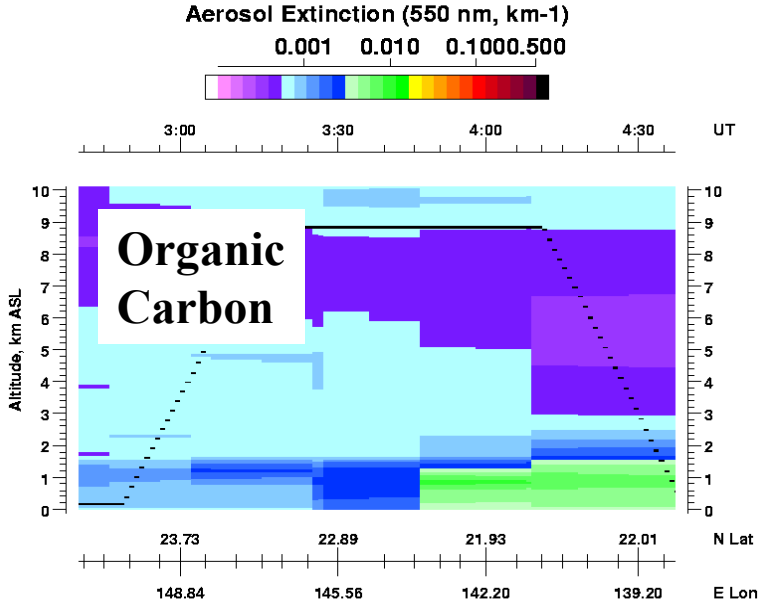


GOCART March 24, 2001









Comparison with GOCART

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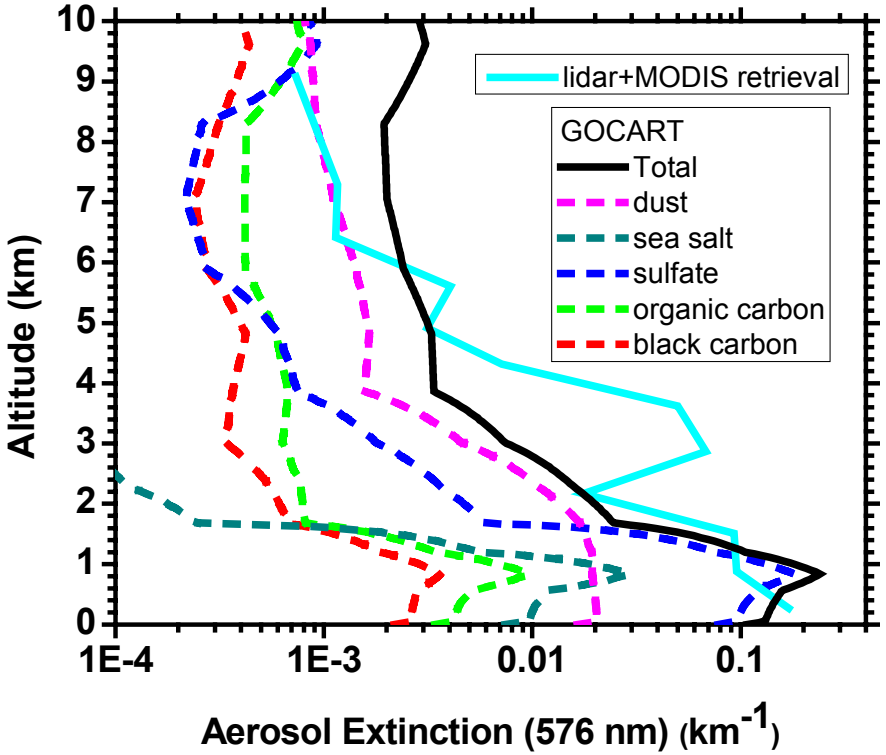
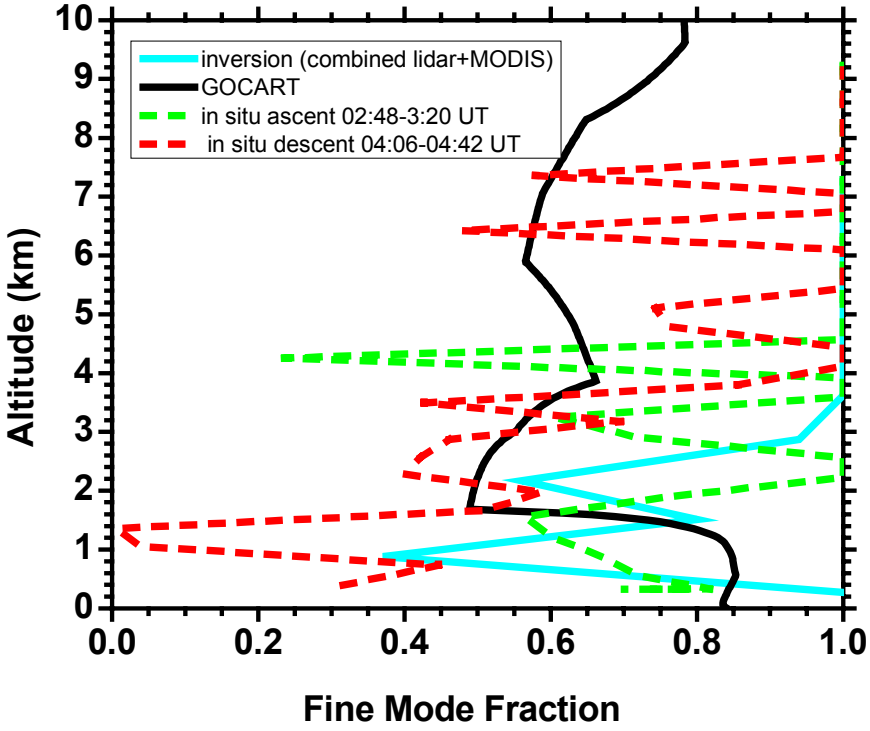
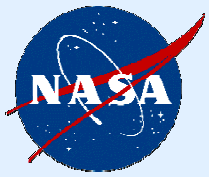




Summary



- Currently developing and evaluating algorithms to:
  - Retrieve profiles of aerosol extinction, optical thickness from airborne lidar and MODIS data
  - Infer profiles of aerosol type
- Begun evaluating GOCART results using lidar, MODIS, in situ data
  - Initial comparisons show qualitative agreement
- Future
  - Refine and implement algorithms for retrieving aerosol profiles from lidar data – with and without MODIS data
  - Evaluate algorithms using data from other TRACE-P, INTEX NA flights
  - Infer aerosol types as a function of altitude using lidar, MODIS, GOCART
  - Derive vertical distributions of fine, coarse mode particles for TRACE-P and INTEX NA