Characterization of aerosols using airborne lidar and MODIS

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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

• Simultaneous Nadir and Zenith Ozone & Aerosol Profiling
• 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)

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

“Lidar Ratio” = \[ \frac{\sigma_p(r)}{\beta_p(r)} = s_p \] \( \leftarrow \) 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
• 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
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
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

INTEX Flight 11 16:33-16:42 UT

With correction

Without correction

Aerosol Scattering Ratio – 588 nm

Attenuation correction applied using MODIS AOT constraint. Correction at low altitudes ~ 200-300% at 588 nm, 20-40% at 1064 nm.
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
• UV DIAL
• NASA Ames Airborne Sun Photometer (AATS14) on J-31 aircraft
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 $r_{\text{eff}}$
- 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
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?

- General agreement near surface
- DIAL shows more vertical variability

Backscatter Color Ratio
Extinction Color Ratio

Depol
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
Summary

- 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

INTEX Flight 16:33-16:42 UT

- Without correction
- With correction
NASA Langley Airborne UV DIAL Measurements

- Ozone Differential Absorption Lidar (DIAL) Profiles ($\lambda_{on}=289$ nm & $\lambda_{off}=300$ nm)
- Aerosol & Cloud Scattering Ratio Profiles (300, 576, & 1064 nm)
- Simultaneous Nadir and Zenith Ozone & Aerosol Profiling
- Nadir Aerosol Depolarization Profiles (576 nm)

GOCART and MODIS AOT Comparisons

**MODIS vs GOCART for TRACEP (VS)**
- Least-Sq Slope = 0.603
- Least-Sq Intercept = 0.100
- Least-Sq R = 0.865
- rms error = 0.161 (48.0 %)
- Bias diff = 0.0407 (11.5 %)
- N = 115

**MODIS vs GOCART for INTEX (VS)**
- Least-Sq Slope = 0.265
- Least-Sq Intercept = 0.112
- Least-Sq R = 0.373
- rms error = 0.207 (85.8 %)
- Bias diff = 0.103 (35.1 %)
- N = 123
Aerosol Extinction and Color Ratio Profiles – July 22, 2004

- Example retrievals constrained with MATCH AOT

**Aerosol Extinction (km^-1) (588 nm)**

```
0.000   0.001   0.01   0.1   1
```

**VIS (588 nm)**

**Aerosol Extinction Color Ratio (vis/ir)**

```
0   1   2   3   4   5
```

**ASR (588 nm) > 0.5, ASR (1064 nm) > 1**

**IR (1064 nm)**

**Aerosol Backscatter Color Ratio (vis/ir)**

```
0   1   2   3   4   5
```

**ASR (588 nm) > 0.5, ASR (1064 nm) > 1**
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
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 similar chemical signature
Flight 11, case 1, July 22, 2004 revised extinction, fine mode effective radius, JF

- DIAL
- In situ 550 nm

Effective Radius
- DMA+OPC
- OPC

Angstrom Exponent
- DIAL (575-1064 nm)
- In situ (450-702 nm)

- Lidar (3-wavelength)+MODIS
- Lidar (2-wavelength)+MODIS

Depolarization

Aerosol Small Mode Fraction

Single Scattering Albedo (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
**MODIS+lidar Aerosol Retrieval Example**

- 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

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![Graphs showing aerosol properties](image-url)
March 24, 2001 MODIS + GOCART

Terra MODIS

- AOT (555 nm)
- Effective radius

GOCART

- Total AOT (500 nm)
- Sulfate AOT (500 nm)
- Dust AOT (500 nm)
- Organic Carbon AOT (500 nm)
Comparison with GOCART

- Attenuated aerosol scattering ratio

**GOCART**

**UV DIAL**

![Graphs comparing Aerosol Scattering Ratio (550 nm) and Aerosol Scattering Ratio (VIS)]
Comparison with GOCART

- Aerosol Extinction

GOCART

UV DIAL

Aerosol Extinction (550 nm, km^-1)

0.001 0.010 0.100 0.500

Aerosol Extinction (km^-1) (VS)

0.0010 0.0100 0.1000 0.5000

Altitude, km ASL

32.96 30.85 25.84 23.73 21.93

32.87 30.82 25.86 23.71 21.90

P3 END MOPITT

32.96 30.85 25.84 23.73 21.93

32.87 30.82 25.86 23.71 21.90

E Lon
Comparison with GOCART

• TRACE-P Flight 14 March 23-24, 2001

Graphs showing aerosol extinction and fine mode fraction as functions of altitude.
• Attenuation corrected applied using MODIS AOT constraint
• Correction at low altitudes $\sim$ 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