

Inferring Profiles of Aerosol Small Mode Fraction from CALIOP

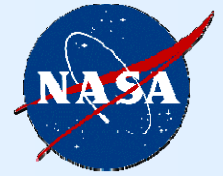
Richard Ferrare¹, Sharon Burton¹, Damien Josset², Marian Clayton³, Chris Hostetler¹

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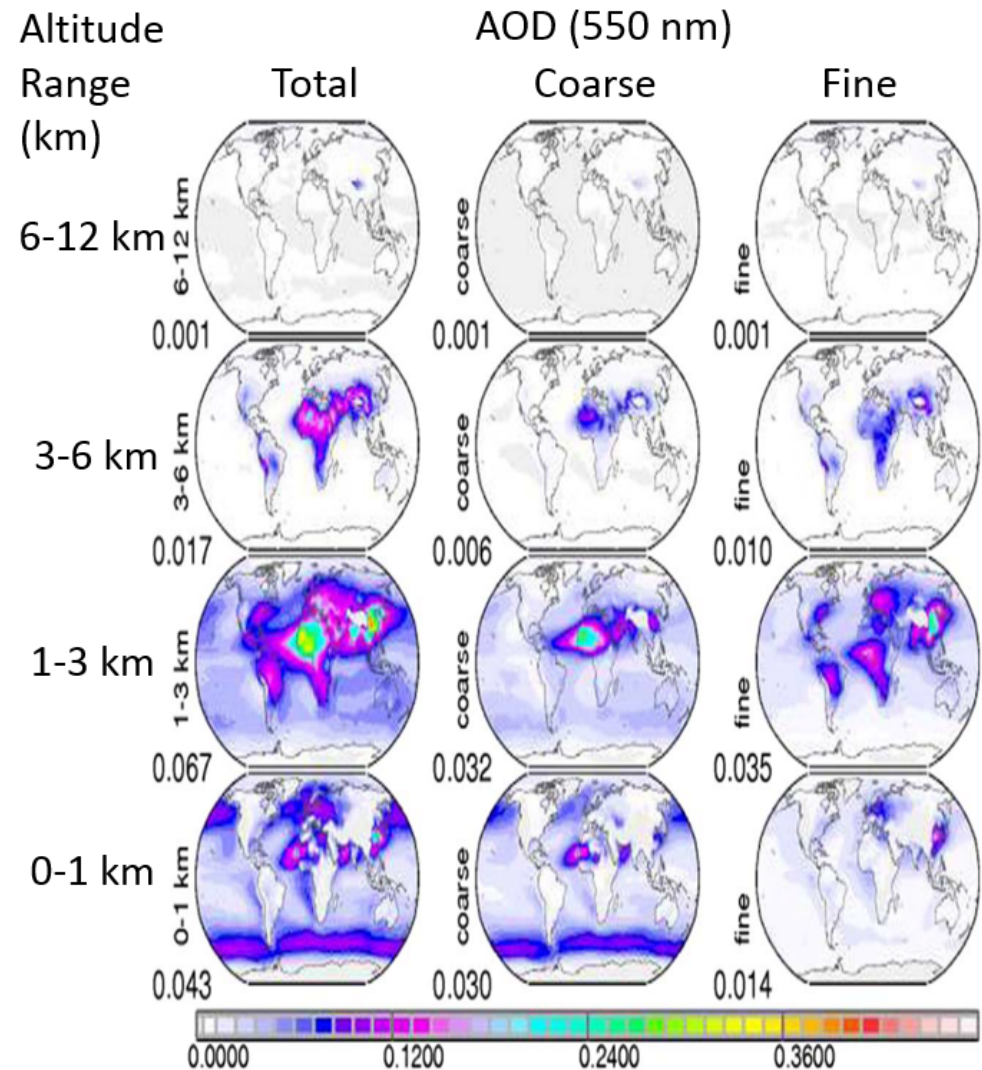
²NRC/Naval Research Laboratory, Stennis Space Center USA

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Motivation



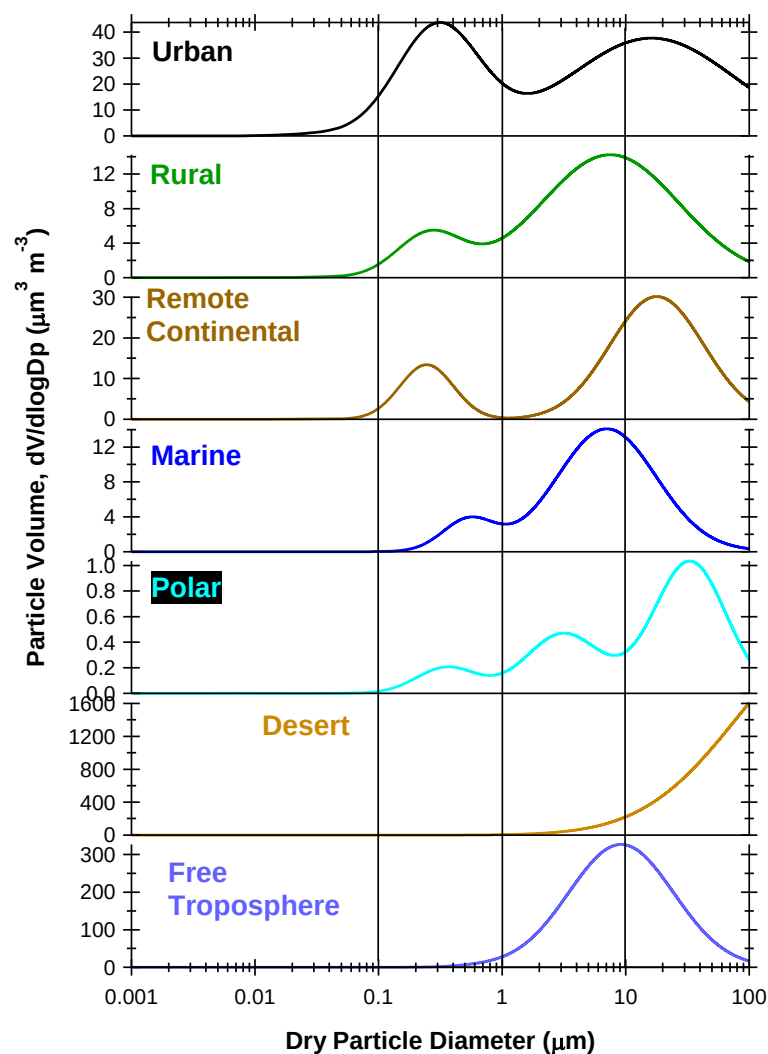
- Aerosol Small Mode Fraction (SMF)
 - Important for assessing aerosol impacts on clouds and precipitation
 - Often used as a tool for deriving estimates of anthropogenic aerosol loading and associated aerosol radiative forcing
- Models show SMF varies considerably with altitude
- Measurements (retrievals) of SMF vertical profiles are required to assess these model simulations
- Can CALIOP aerosol extinction profiles (532 and 1064 nm) be used to infer SMF?



Small Mode and Fine Mode Fractions



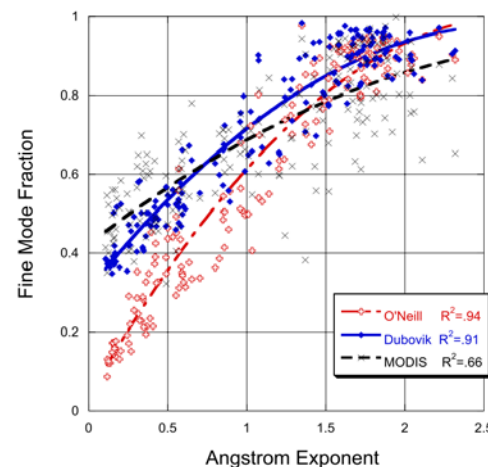
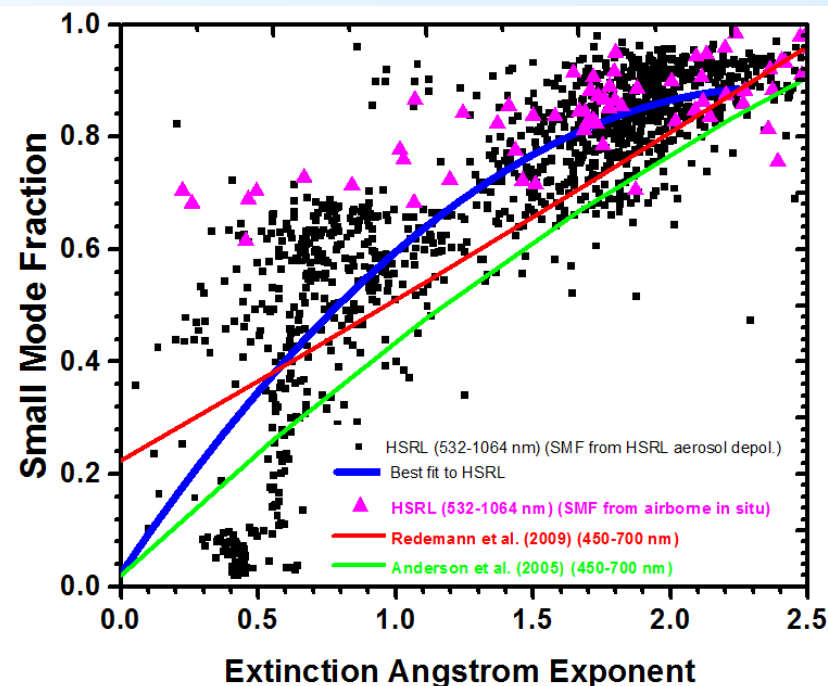
- Note: Fine Mode Fraction (FMF) and Small Mode Fraction (SMF) are closely related
- FMF (and SMF) typically vary with different aerosol types
- Typically there is a strong wavelength dependence of visible light extinction for fine mode aerosols but not for coarse mode
- SMF and FMF are related to the Extinction Angstrom Exponent (EAE)
- Can we infer FMF (SMF) profiles using CALIOP profiles of aerosol extinction Angstrom exponent EAE (532-1064 nm)?



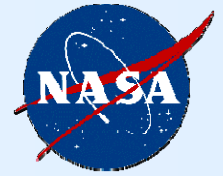
Small Mode Fraction estimated from extinction Angstrom exponent



- We attempt to infer SMF using profiles of aerosol extinction Angstrom exponent EAE (532-1064 nm)
- Airborne HSRL measurements are used to derive a relationship between EAE and SMF
 - EAE profiles are derived using HSRL aerosol extinction profiles (532, 1064 nm)
 - SMF is inferred from HSRL measurements of aerosol depolarization, backscatter, and extinction (532 nm) [Sugimoto and Lee (2006); Tesche et al. (2009)]
 - Derived relationship is similar to those found using AERONET, airborne Sun photometer, and in situ measurements
- Profiles of SMF are then derived using CALIOP aerosol extinction profiles (532, 1064 nm)



Lidar ratio required for retrieving aerosol extinction from CALIOP aerosol measurements

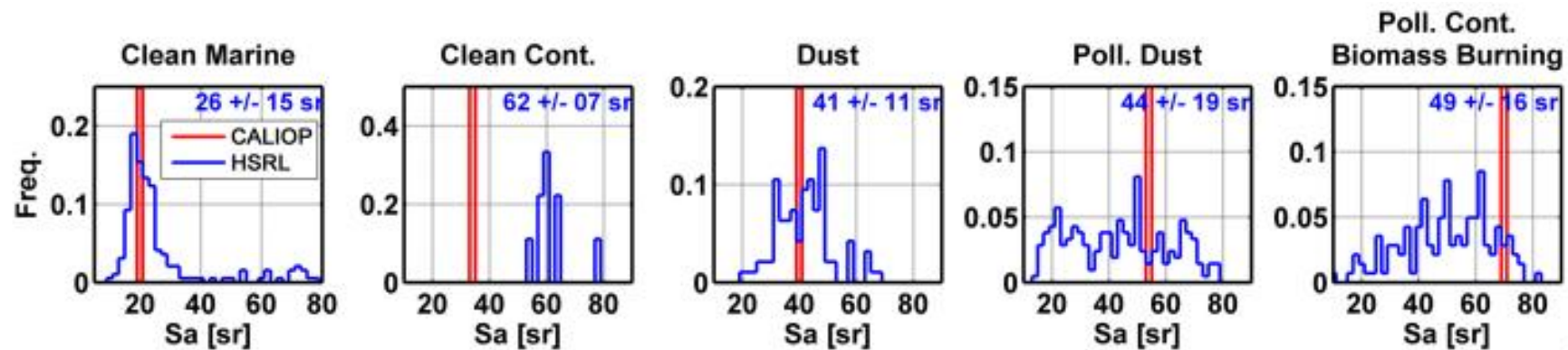


Aerosol Backscatter and Extinction Retrievals

- CALIOP retrievals of aerosol backscatter and extinction profiles rely on accurately specifying the extinction/backscatter (“lidar”) ratio
- CALIOP algorithms use location, altitude, integrated backscatter, depolarization to infer a specific aerosol type which is assigned a specific lidar ratio

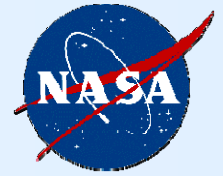
Problems

- Inferred aerosol type may be incorrect
- Lidar ratios assigned to aerosol types may be incorrect
- Aerosols are often mixtures of aerosol types so that real distribution of lidar ratio is continuous, not discrete
- Uncertainty in lidar ratio leads to $\sim > 30\%$ uncertainties in extinction and AOD

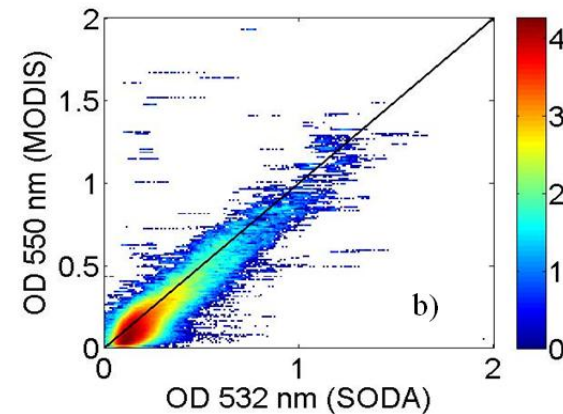


Rogers et al., AMT, 2014

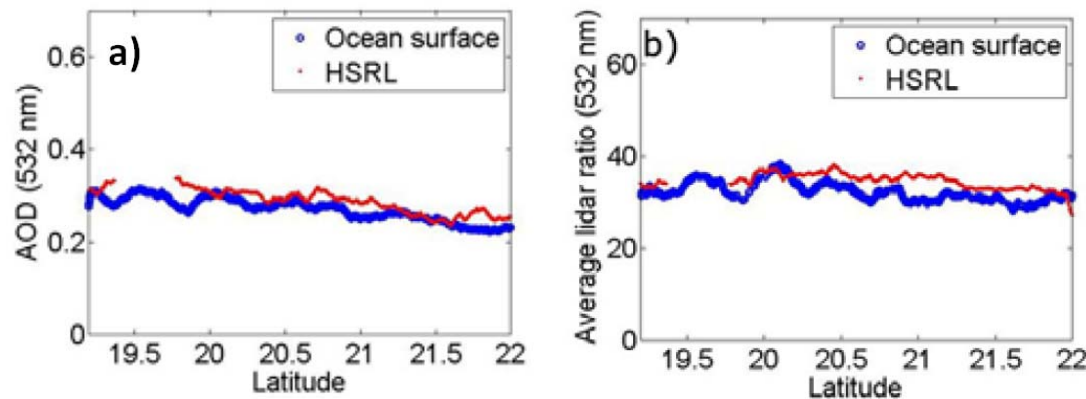
SODA Technique provides constraint on AOD and total column lidar ratio



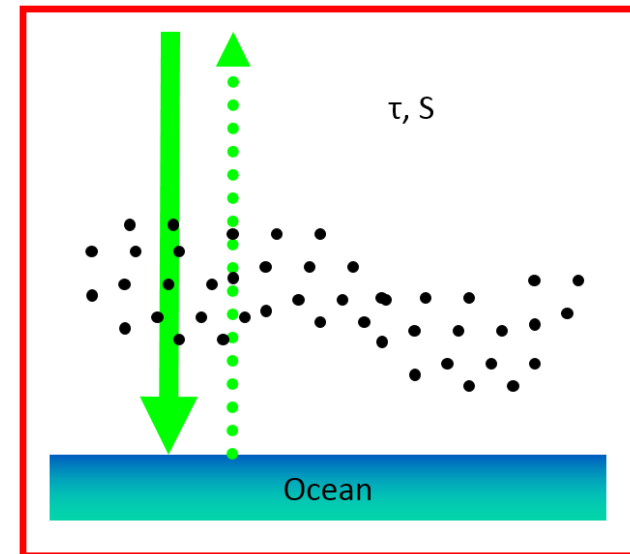
- SODA
 - Synergized Optical Depth of Aerosol (SODA) method uses coincident CloudSat measurements of ocean surface to determine atmospheric transmission and AOD which is used as a constraint
 - “effective” lidar ratio can be retrieved directly and used to categorize aerosols (single layer) or constrain inversions (multiple layers)



Josset et al., GRL, 2008



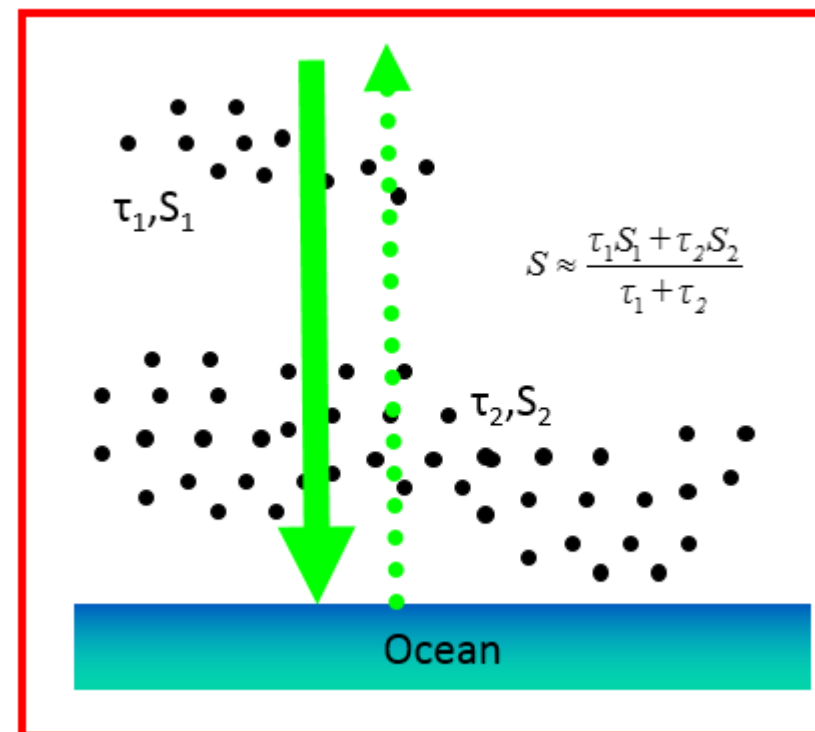
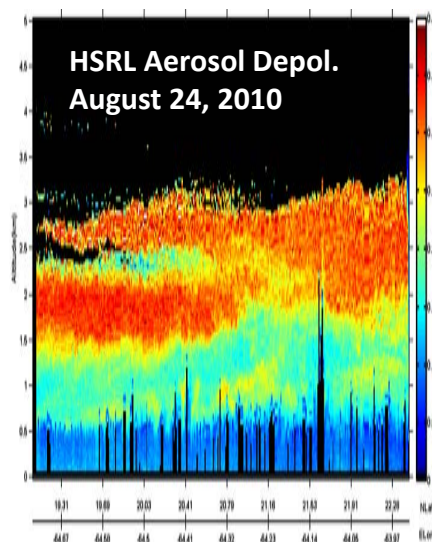
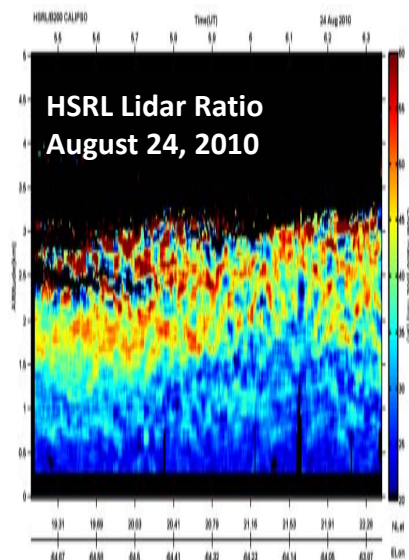
Josset et al., GRL, 2008



Problem - often there is large vertical variability in aerosol types



- Vertical variability in aerosol types leads to:
 - Significant variability in lidar ratio
 - Significant uncertainties in aerosol extinction profiles derived using single, “effective” lidar ratio

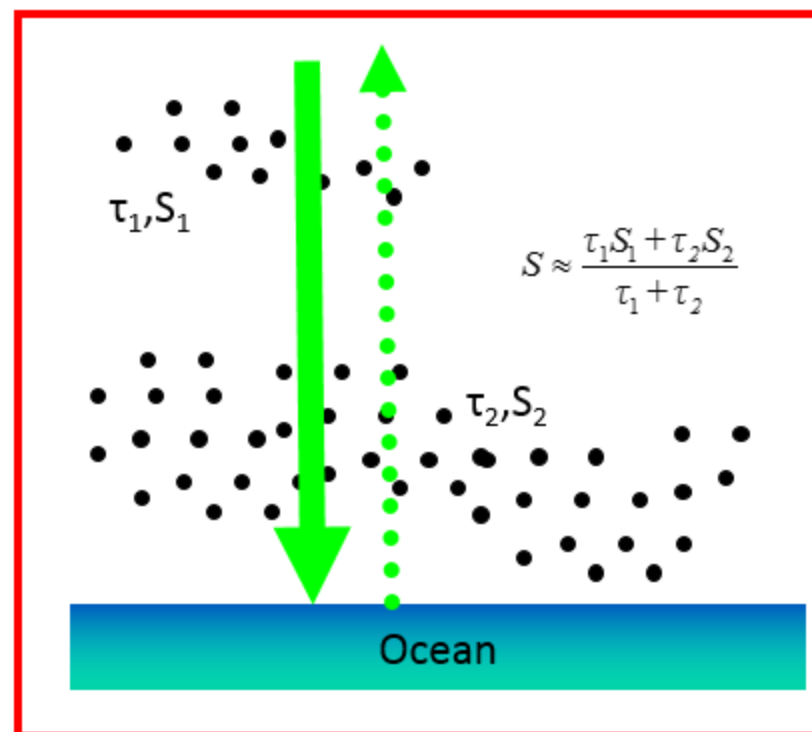


Modified SODA Technique attempts to account for vertical variability of aerosol type and lidar ratio

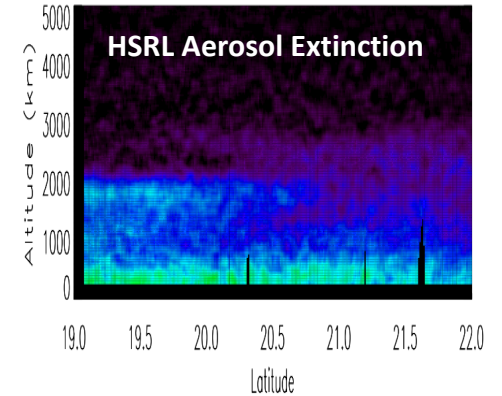
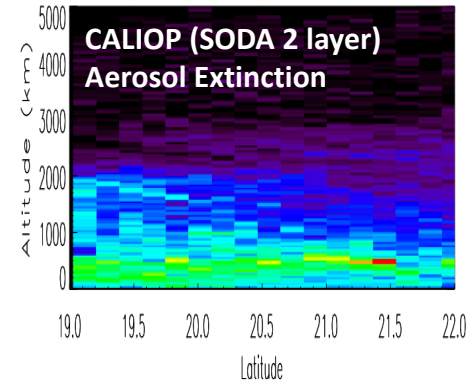
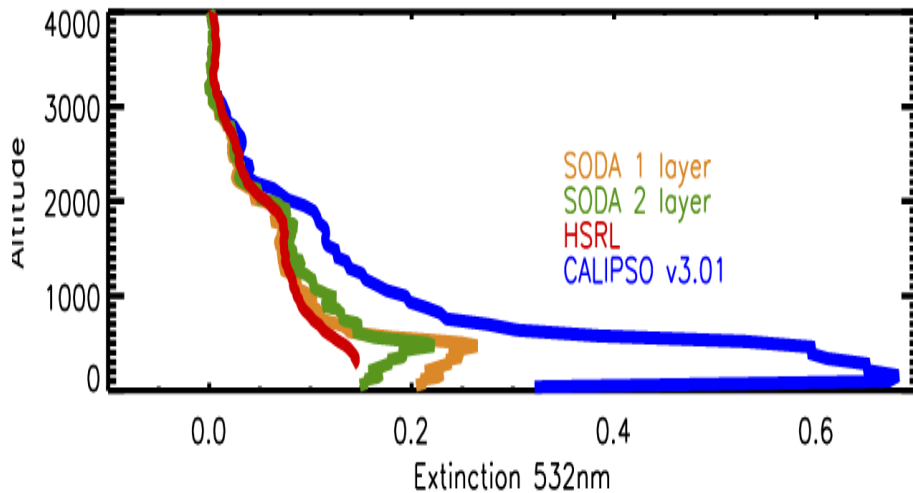
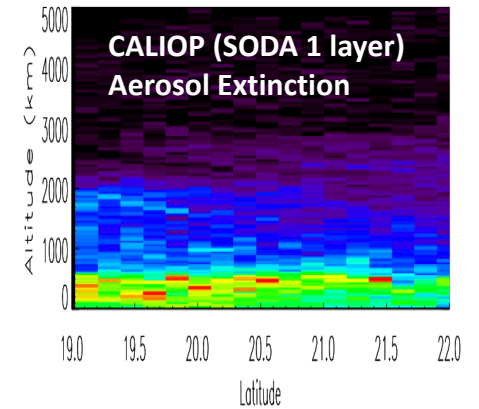
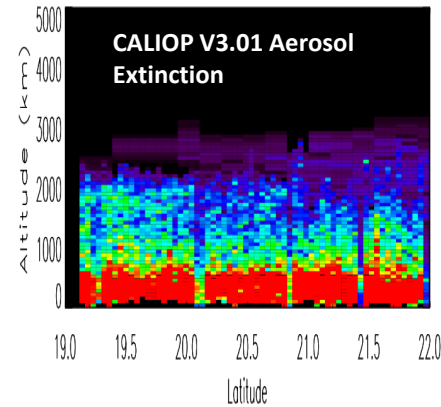
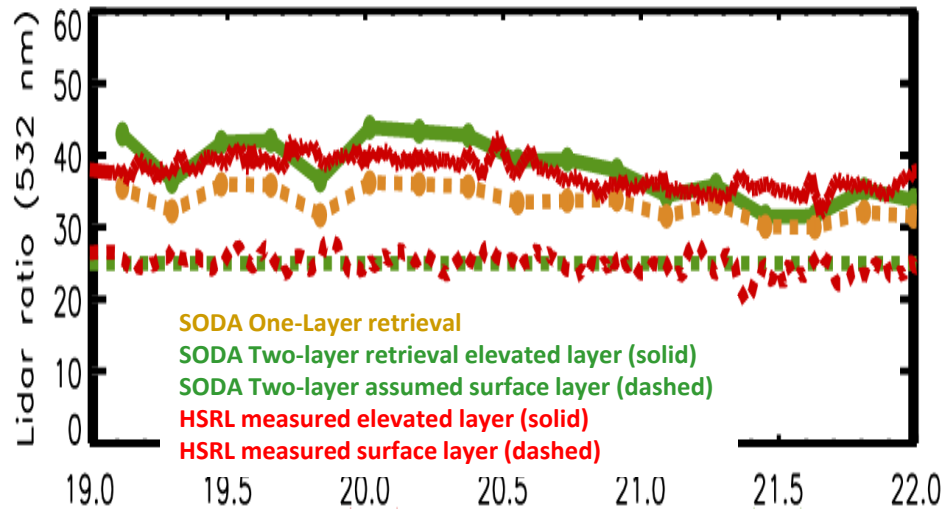
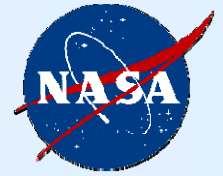


Modified technique:

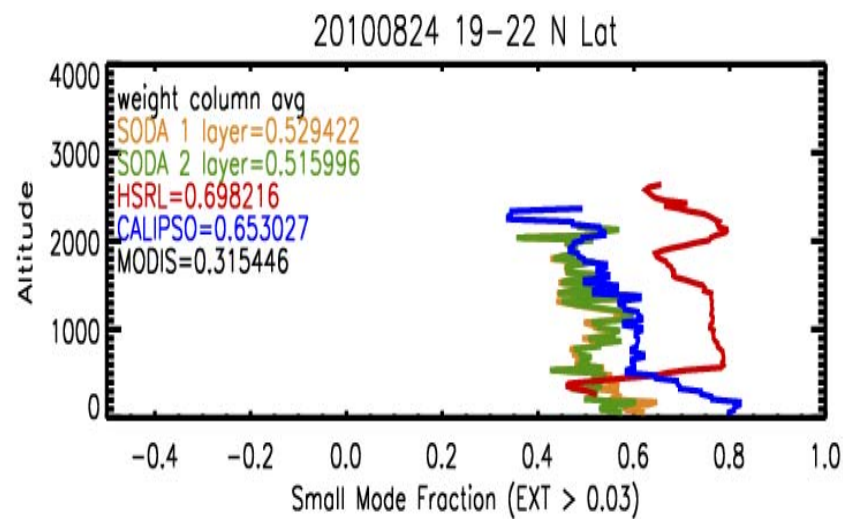
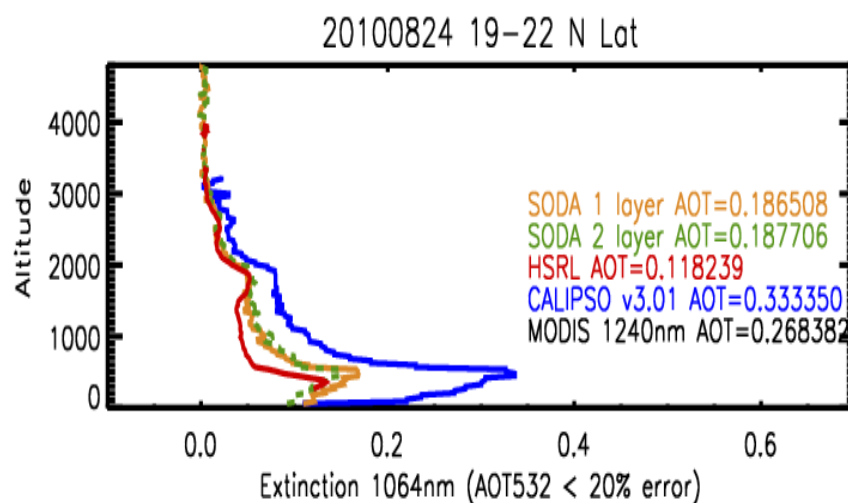
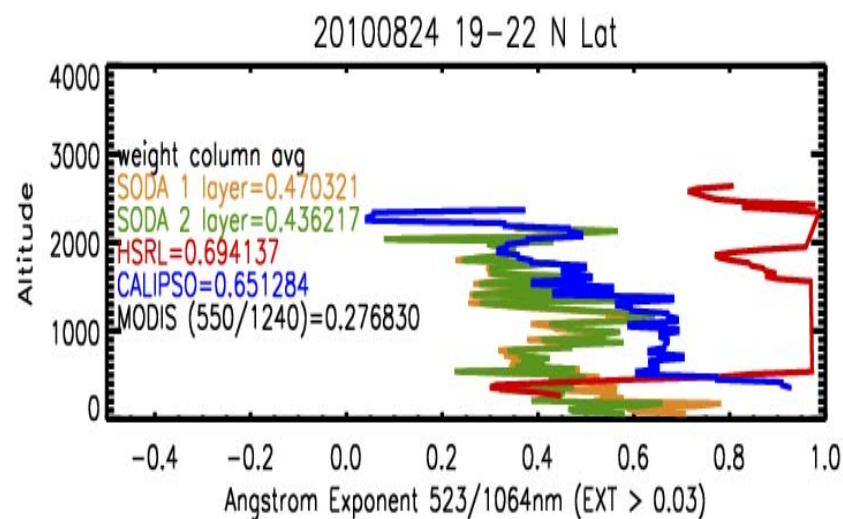
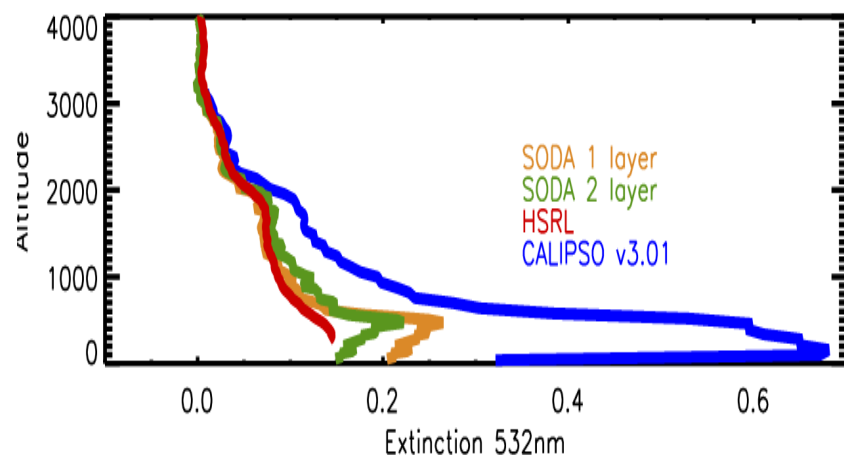
- Assume lower layer contains marine aerosols with known lidar ratio based on measurements from NASA LaRC HSRL, ground based Raman lidar, SODA (single layer)
 $S_a(532) = S_a(1064 \text{ nm}) \sim 25 \text{ sr}$
- Estimate height of lower layer based on PBL height from GMAO model data
- Use total column AOT from SODA
- Derive AOT and lidar ratio of elevated layer in iterative fashion from CALIOP attenuated backscatter profiles



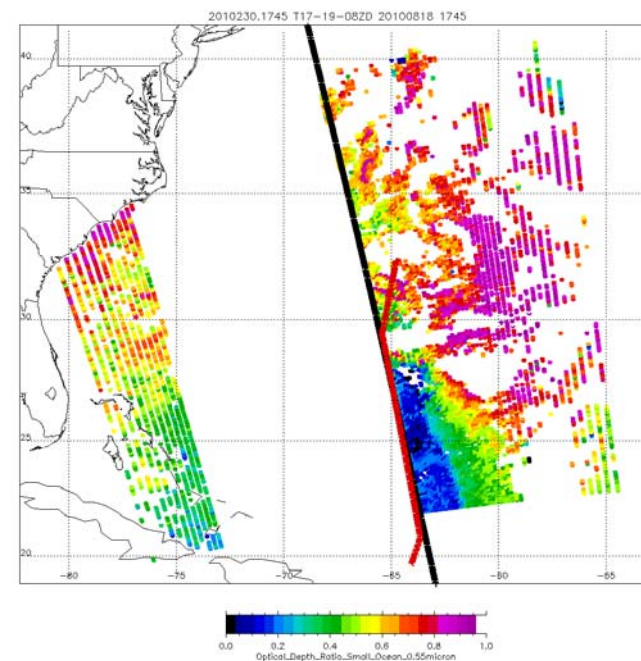
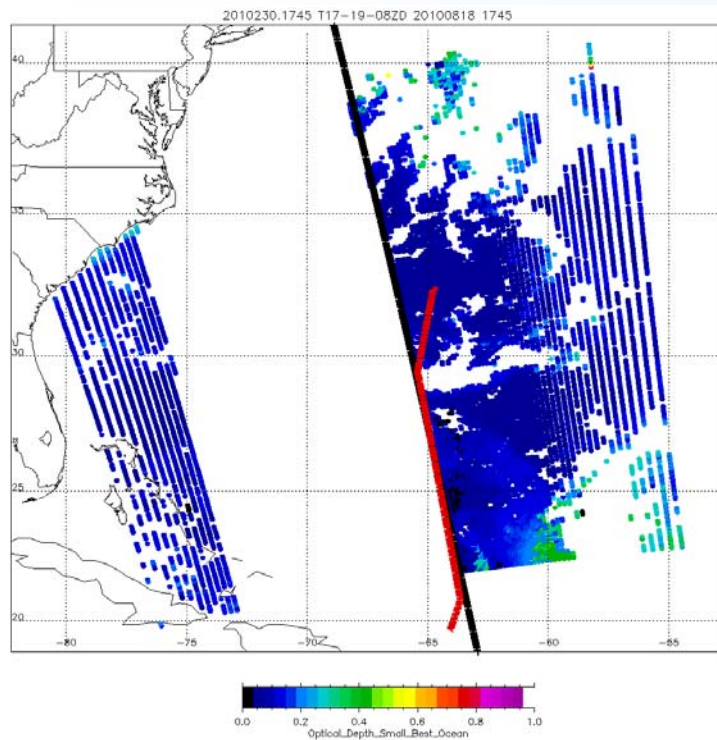
August 24, 2010 test case with HSRL



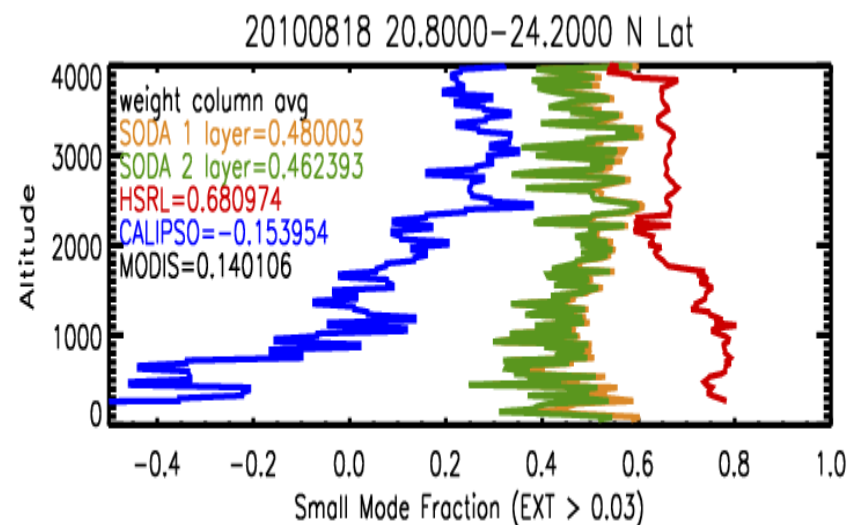
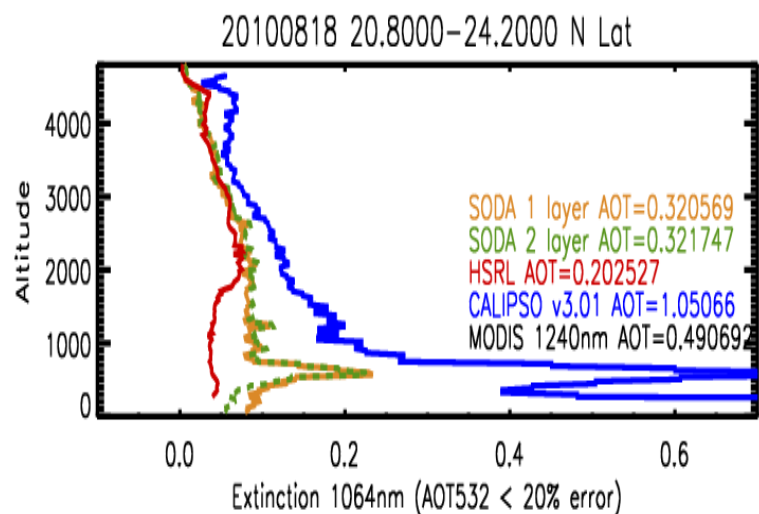
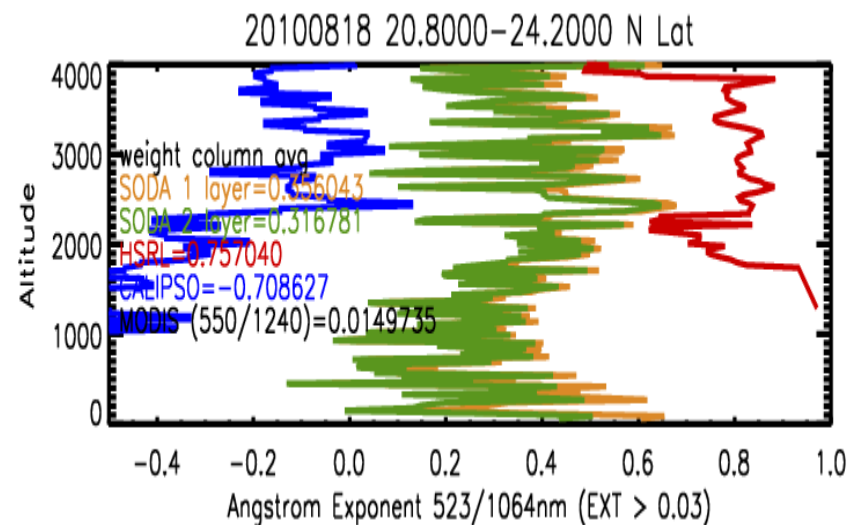
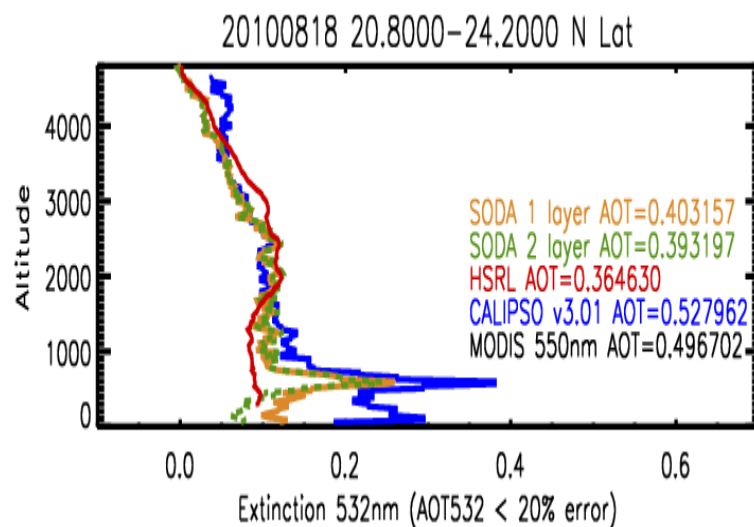
August 24, 2010 test case with HSRL and CALIPSO



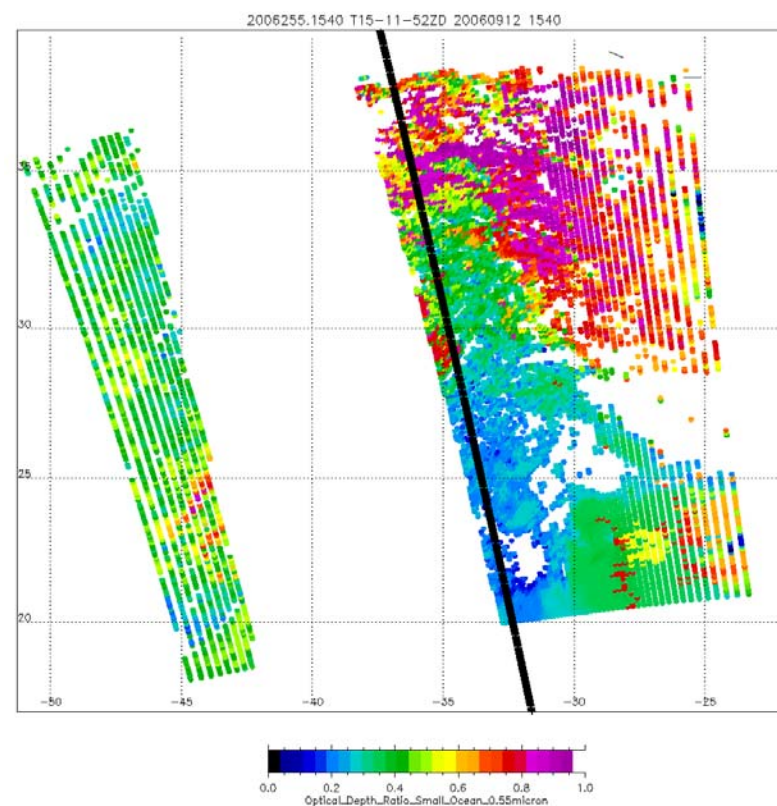
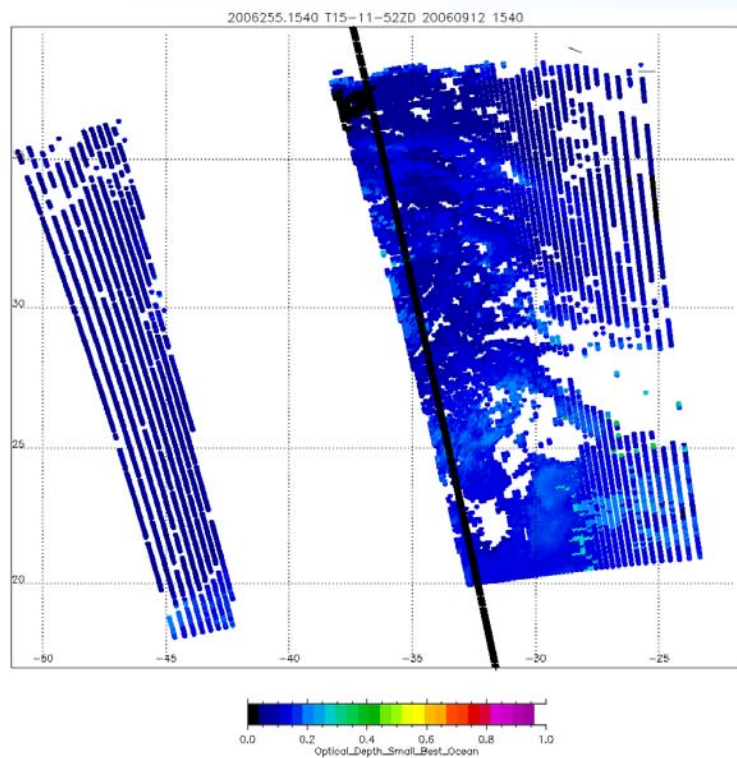
Aug. 18 2010 test case (airborne HSRL, MODIS, CALIPSO) over Atlantic Ocean



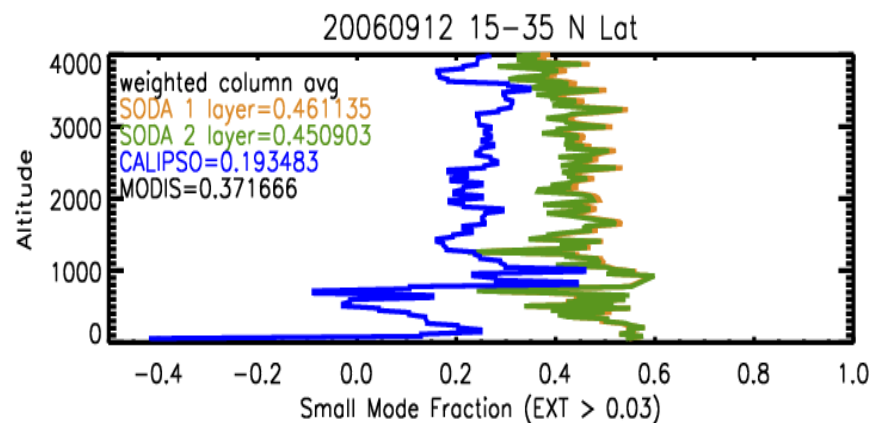
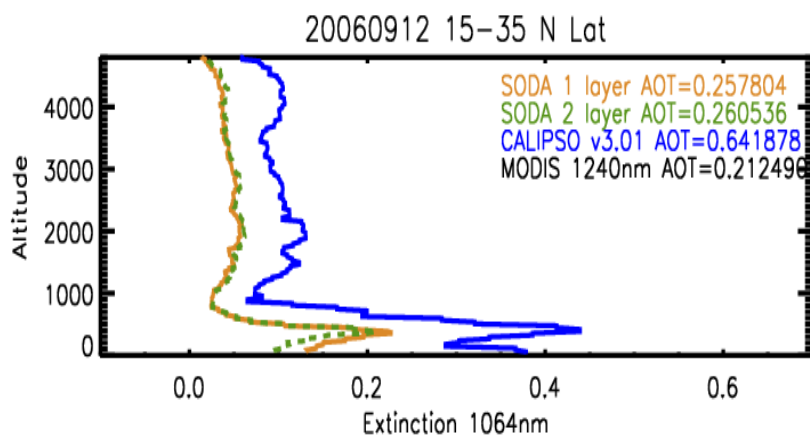
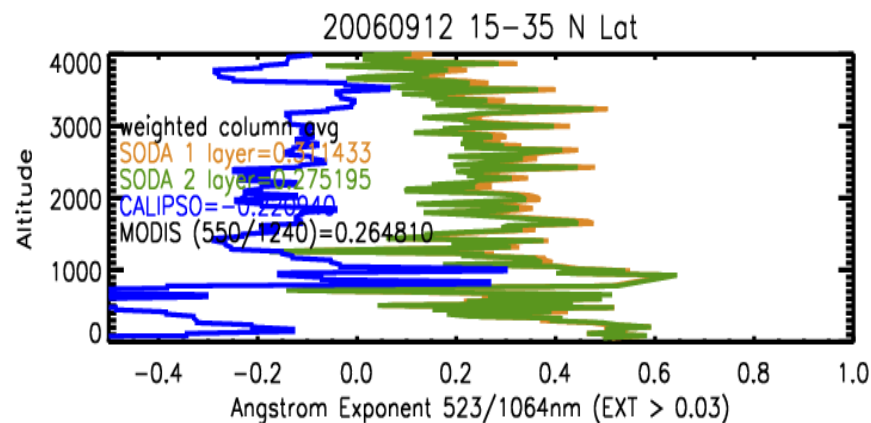
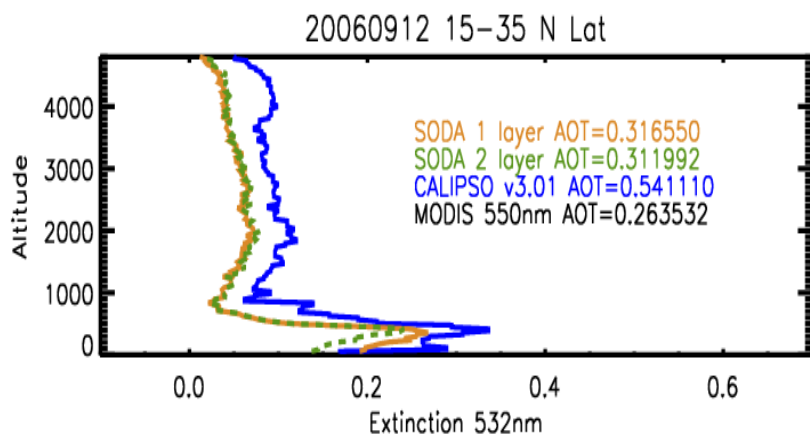
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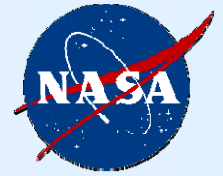
Sept. 12, 2006 test case with dust outbreak over Atlantic Ocean



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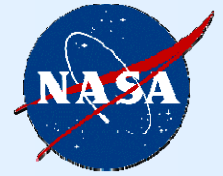


Summary

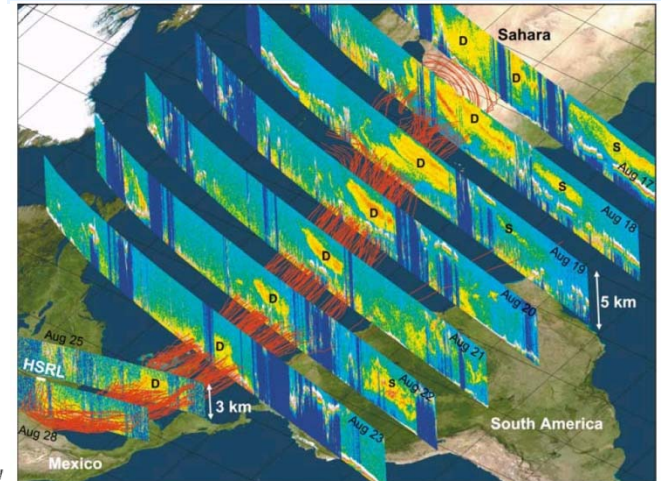
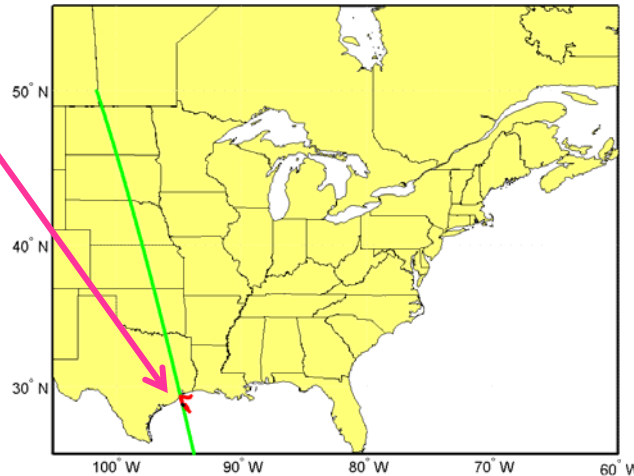


- SODA method combines CALIOP and CloudSat measurements to derive column AOD and total column effective lidar ratio
- Modified SODA method attempts to account for vertical variability of aerosol type and lidar ratio
- Test cases show modified SODA method provides:
 - Aerosol extinction profiles in better agreement with HSRL data
 - Profiles of extinction Angstrom exponents and Fine Mode Fraction
 - Column average extinction Angstrom exponents and Fine Mode Fraction in better agreement with MODIS retrievals
- Profiles of extinction Angstrom exponent derived from CALIOP using modified SODA method may be valuable for providing profiles of Aerosol Index for inferring CCN

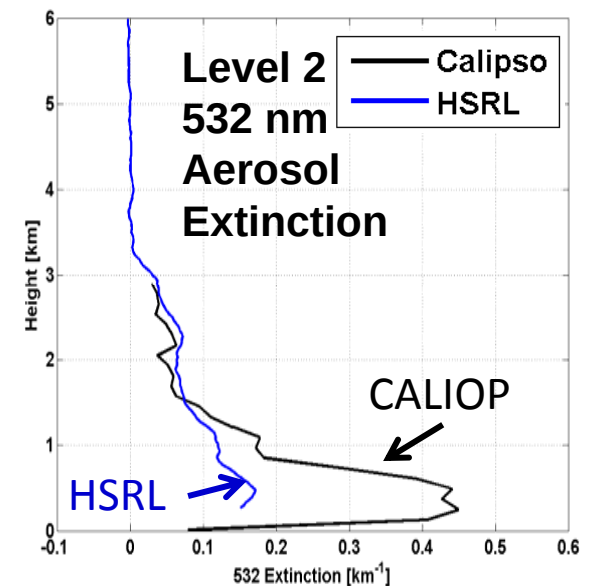
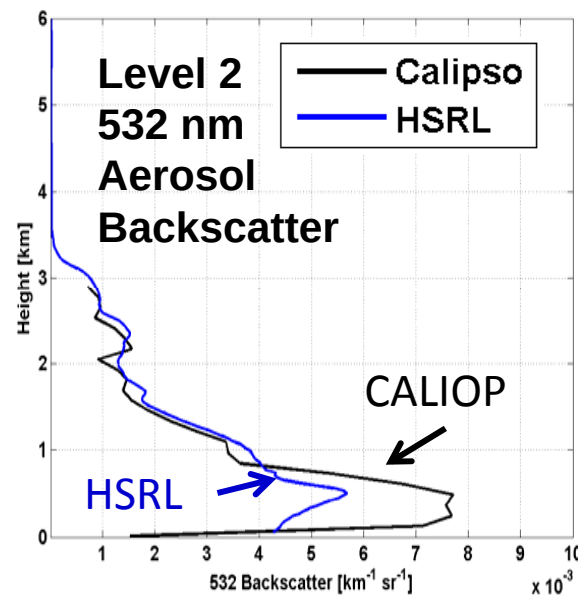
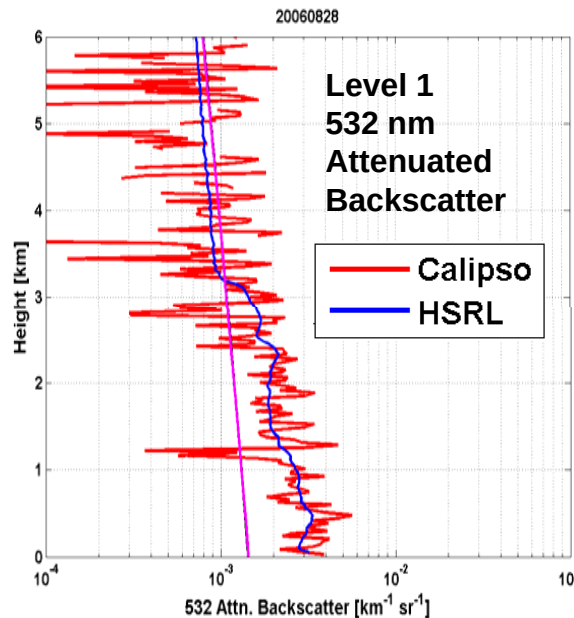
Constrained Retrieval using CALIOP Backscatter Example – August 28, 2006



- HSRL flight near Houston observed Saharan dust (Liu et al., JGR, 2007)
- HSRL and CALIOP profiles
 - CALIOP Level 1 attenuated backscatter profile in good agreement with HSRL
 - CALIOP Level 2 backscatter and extinction profiles significantly larger than profiles measured by HSRL



Liu et al. JGR, 2007



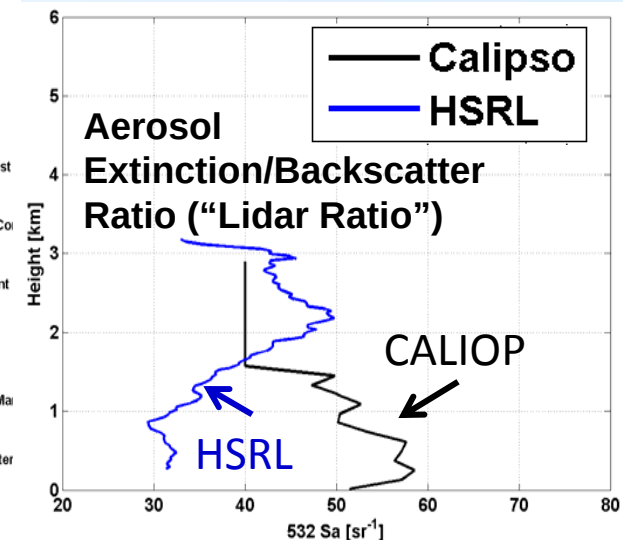
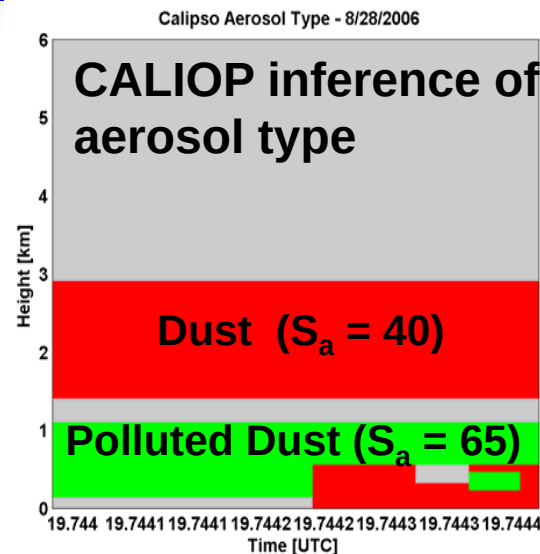
Constrained Retrieval using CALIOP

Backscatter Example – August 28, 2006

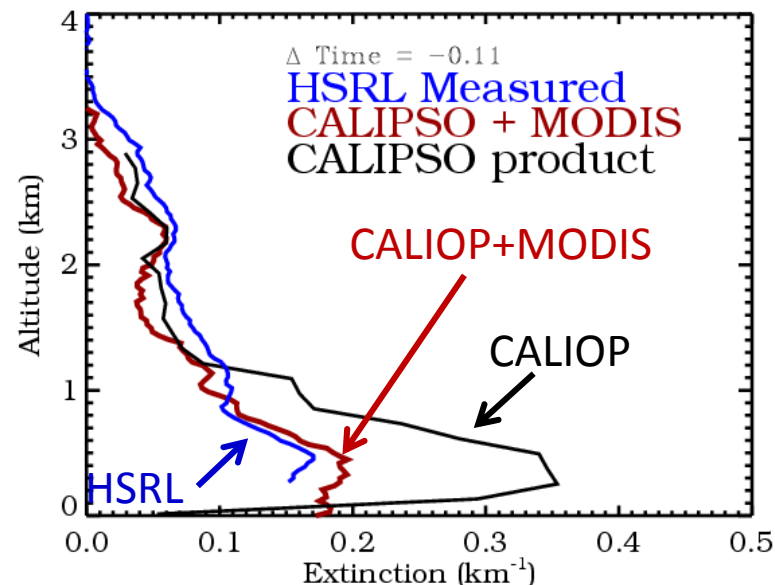


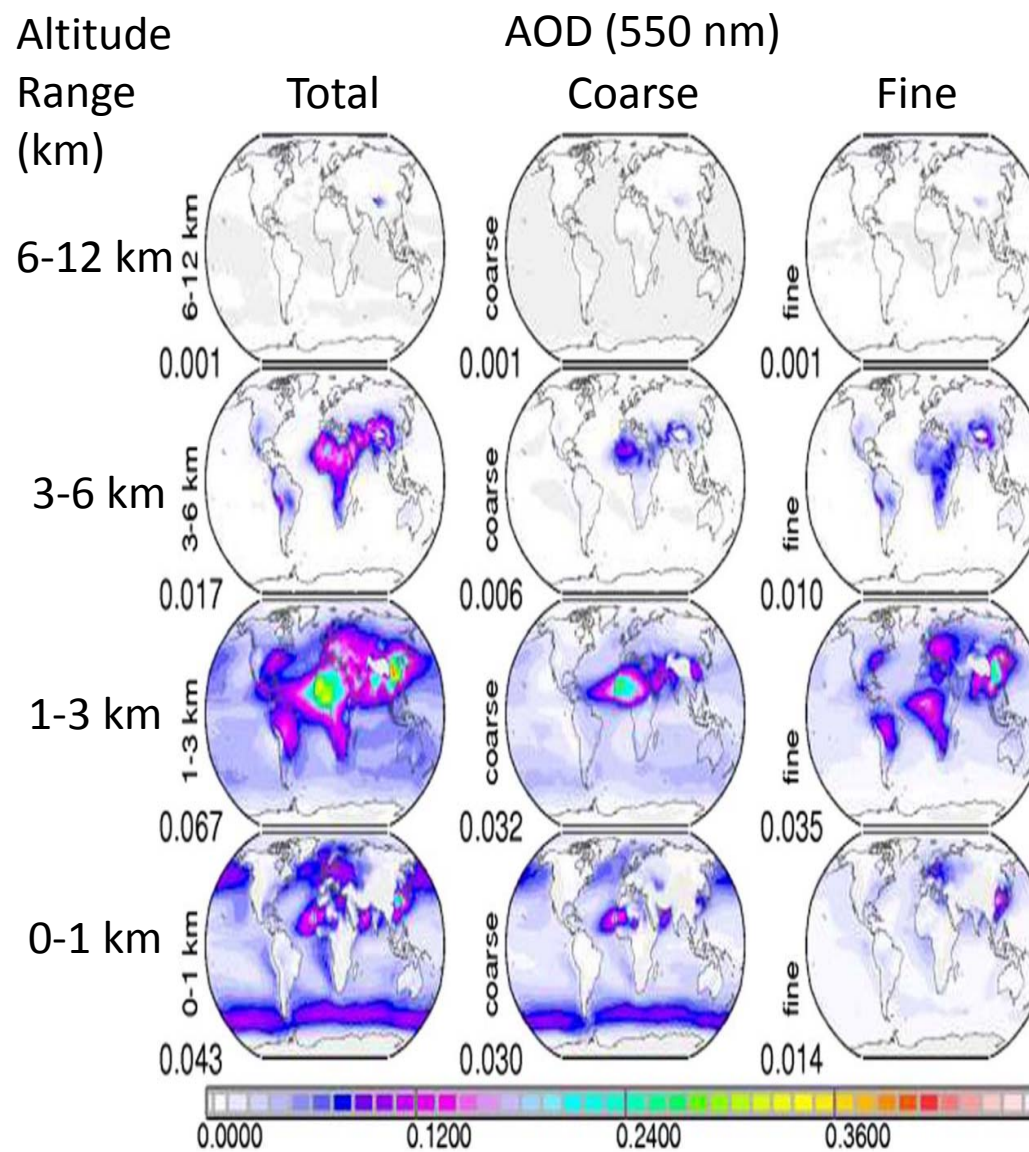
- CALIOP overestimates aerosol backscatter and extinction in the lowest layer due to incorrect assignment of aerosol extinction/backscatter (“lidar”) ratio

- CALIOP chooses “polluted dust” ($S_a = 65$)
- HSRL data indicate mixture of dust and maritime ($S_a \sim 30-40$)



CALIOP+MODIS retrieval produced aerosol extinction profile in much better agreement with HSRL

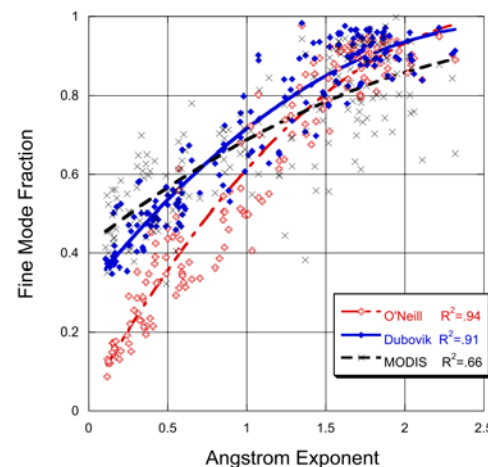
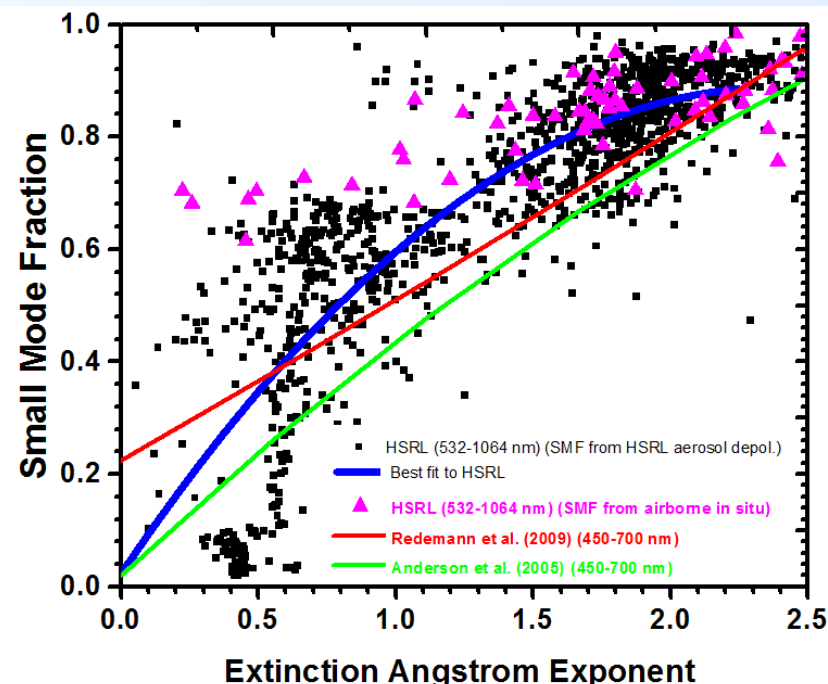


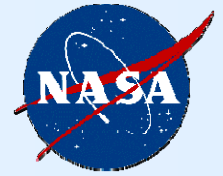


Small Mode Fraction estimated from extinction Angstrom exponent



- We attempt to infer SMF using profiles of aerosol extinction Angstrom exponent EAE (532-1064 nm)
- Airborne HSRL measurements are used to derive a relationship between EAE and SMF
 - EAE profiles are derived using HSRL aerosol extinction profiles (532, 1064 nm)
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 - Derived relationship is similar to those found using AERONET, airborne Sun photometer, and in situ measurements
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Aerosol Backscatter and Extinction Retrievals

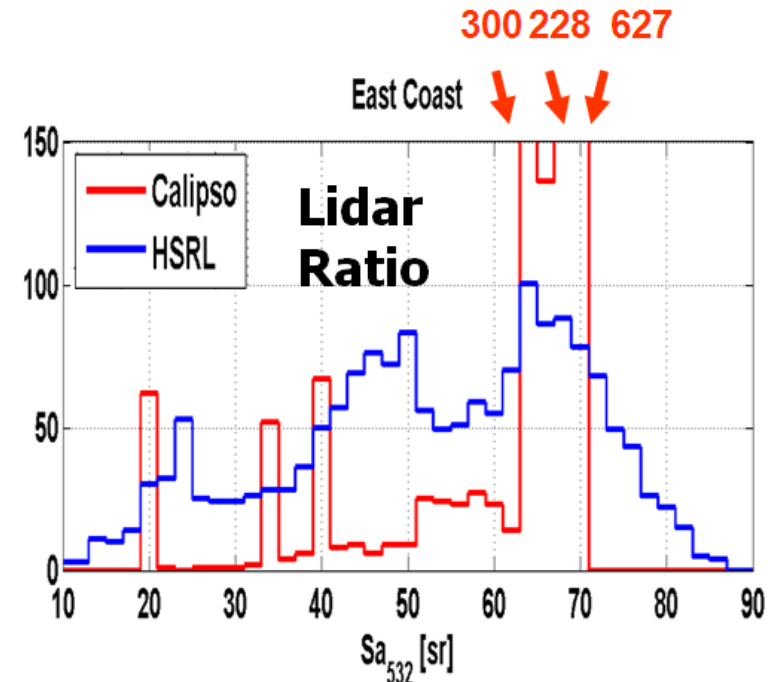
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Problems

- Inferred aerosol type may be incorrect
- Lidar ratios assigned to aerosol types may be incorrect
- Aerosols are often mixtures of aerosol types so that real distribution of lidar ratio is continuous, not discrete

Result

- -20% bias, 43% rms differences between CALIOP and HSRL lidar ratios
- 6% (backscatter) and -17% (extinction) bias differences between CALIOP and HSRL
- Bias errors are systematic and remain after averaging

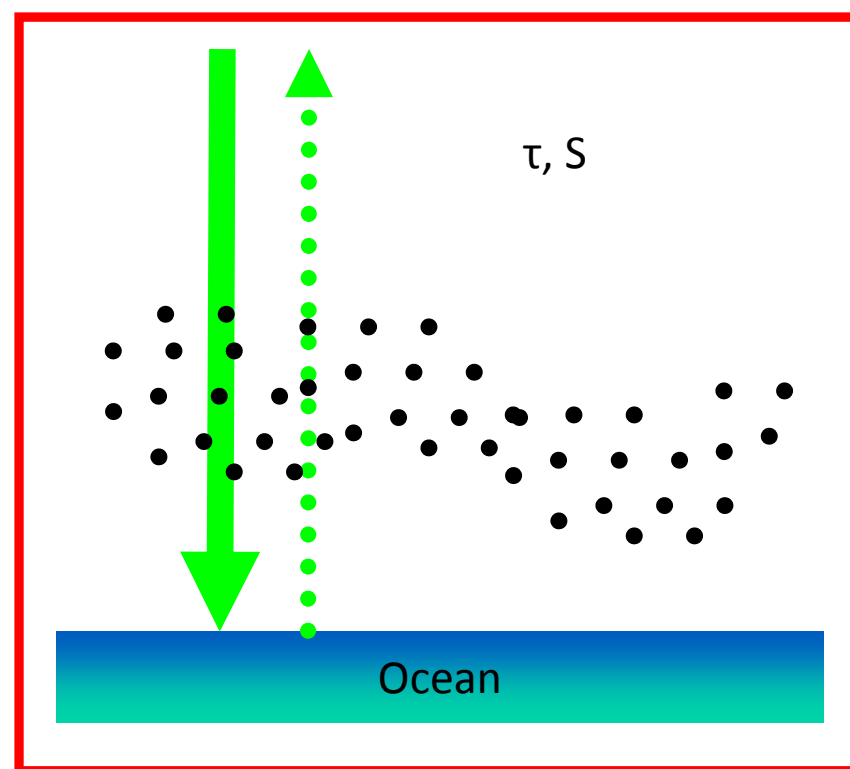
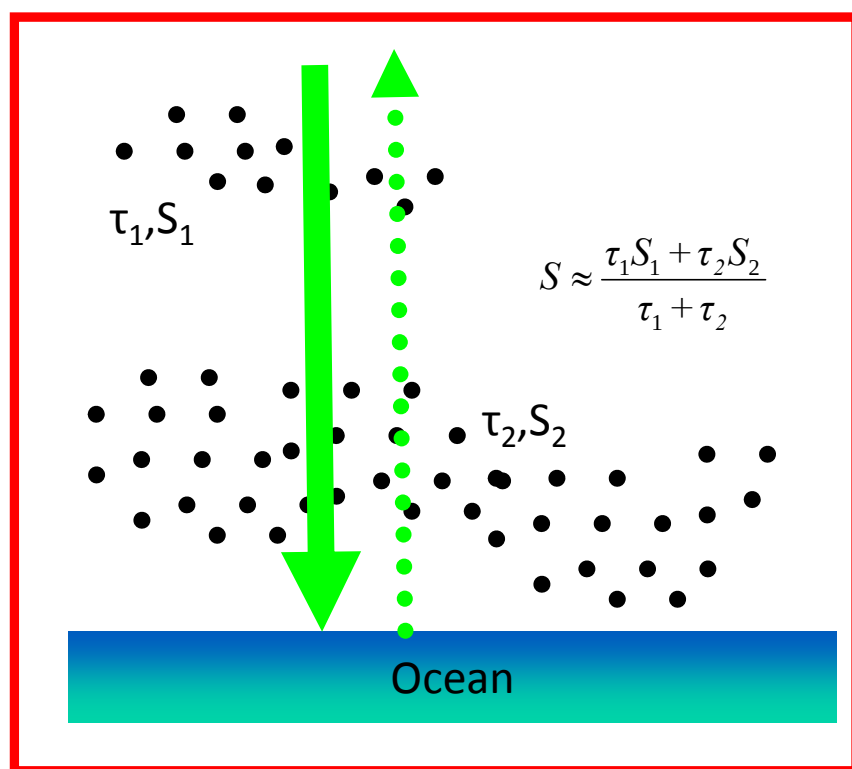


See Ray Rogers et al. poster

Total column lidar ratio



To simplify the interpretation of the results the VFM can be used to select monolayer scenes.



- SODA (v2) retrieves a TOTAL column effective lidar ratio (important to differentiate from R. Ferrare ongoing research, see perspectives)
- VFM: not perfect but is the current state of the art (vertical information and depolarization)
- Unique asset is the global scale retrieval over the ocean