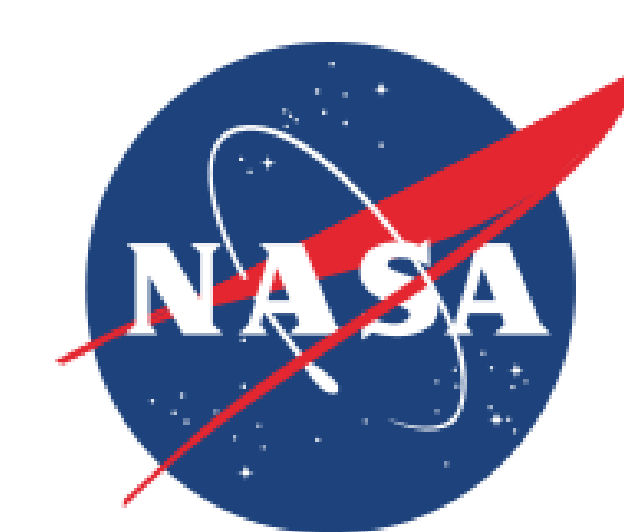




Why HSRL?

S.P. Burton, C.A. Hostetler, J.W. Hair, R.A. Ferrare, K.A. Powell, X. Liu, S. Starnes, T. Thorsen, M.A. Vaughan
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What is HSRL?

The High Spectral Resolution Lidar (HSRL) technique adds a second detector channel with a high precision filter that can separate the backscattered returns from particles from the frequency-broadened molecular signal. This second channel means there are two equations for two unknowns, making the lidar equation fully determined, unlike a single-channel system.

The boxes on this poster discuss the particular advantages of HSRL for products and applications.

2 equations

$$\left\{ \begin{array}{l} P_p(r) = \frac{C_p}{r^2} [\beta_m(r) + \beta_p(r)] \exp \left\{ -2 \int_0^x [\alpha_m(r') + \alpha_p(r')] dr' \right\} \\ P_m(r) = \frac{C_m}{r^2} [\beta_m(r)] \exp \left\{ -2 \int_0^x [\alpha_m(r') + \alpha_p(r')] dr' \right\} \end{array} \right.$$

2 unknowns

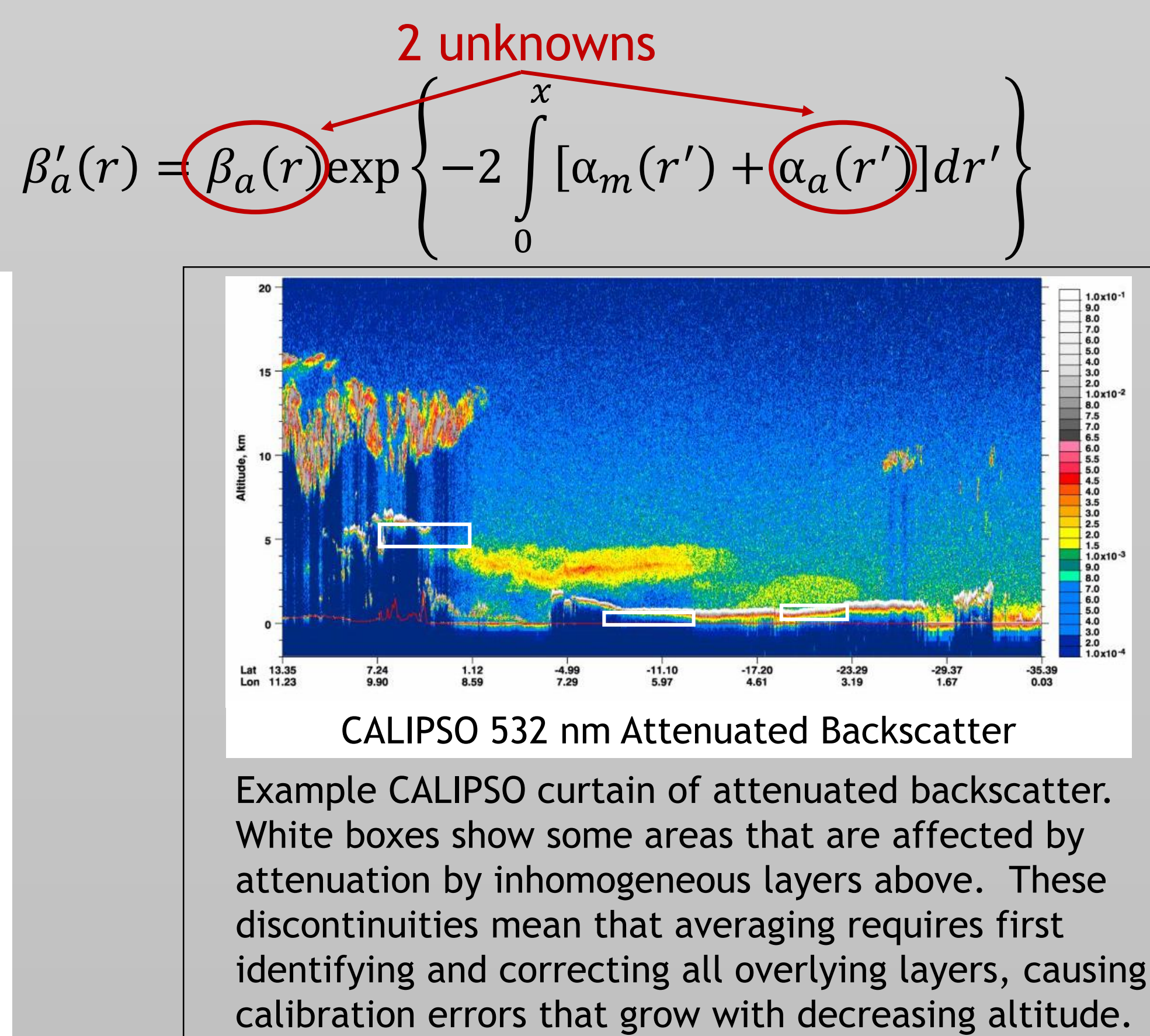
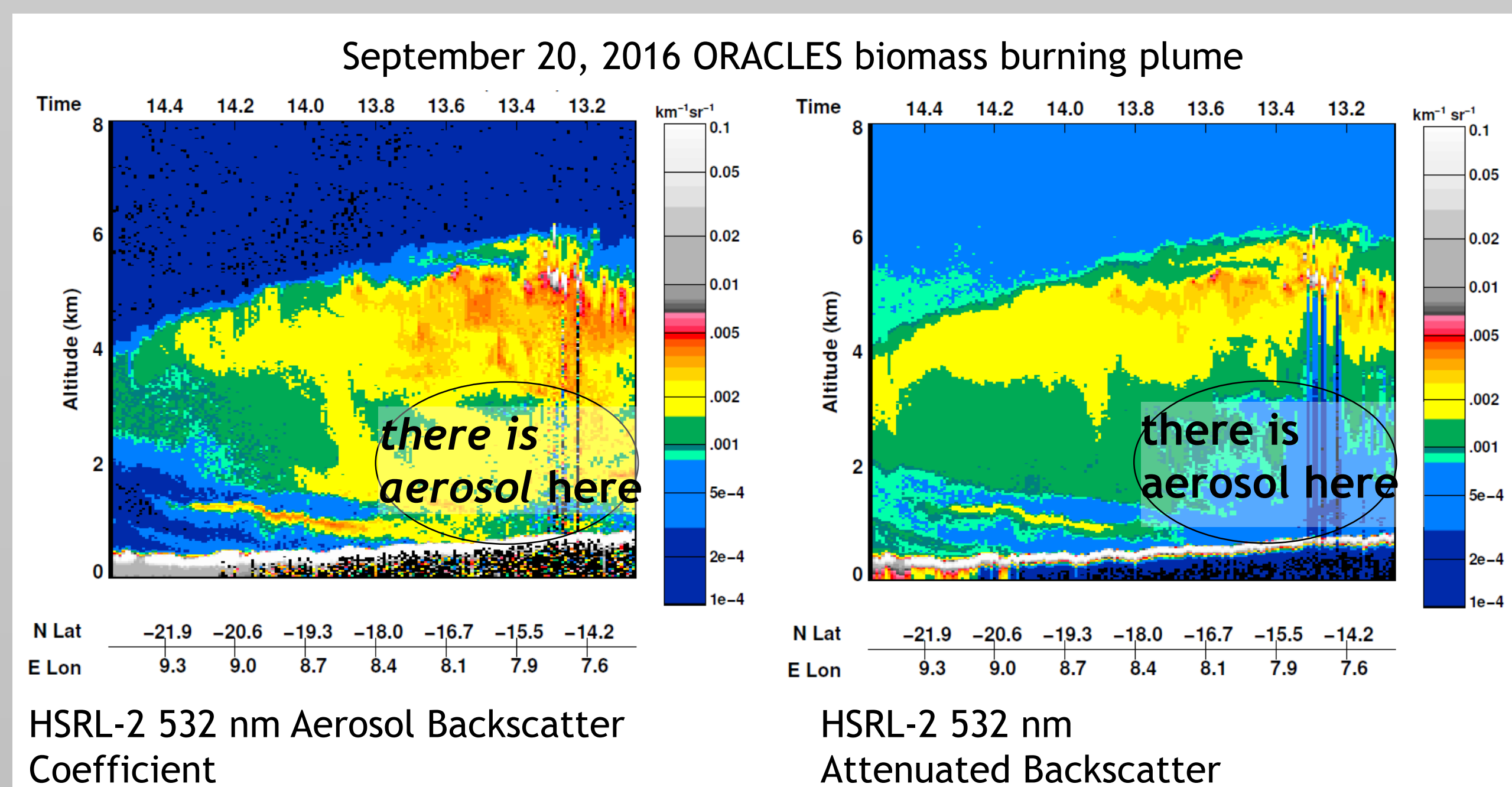
particle backscatter

particulate extinction

True backscatter coefficient

- Direct measure of backscatter (geophysical quantity) rather than attenuated backscatter (integrated quantity)
- Accurate at all altitudes; errors do not accumulate with range
- Can be averaged more than attenuated backscatter (if necessary) since there is no dependence on overlying layers

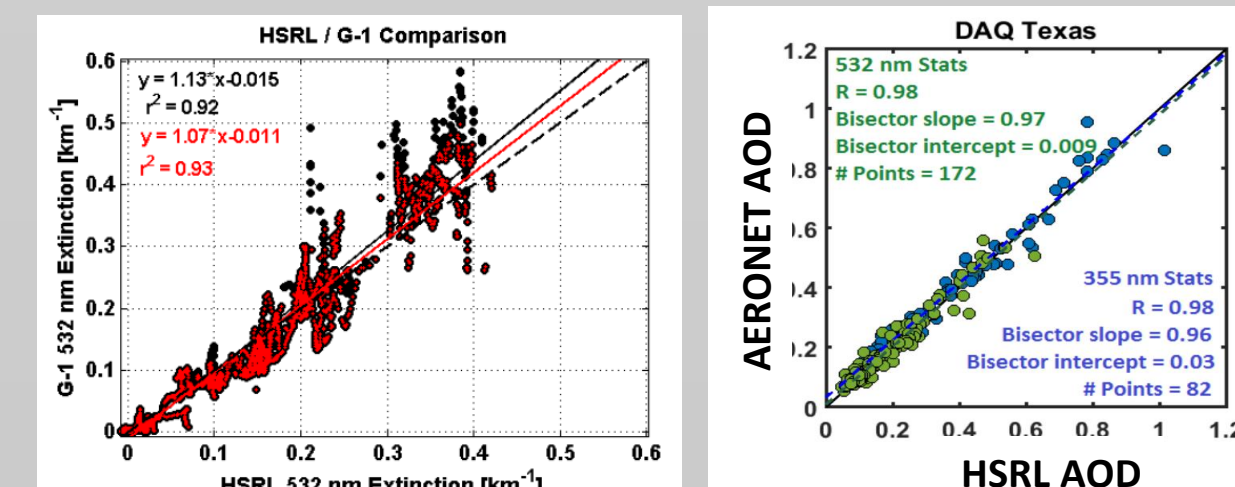
Attenuated backscatter is the quantity measured directly by a backscatter lidar (e.g. CALIPSO). It is the true aerosol backscatter coefficient times an exponential attenuation factor, which represents light that is lost along the optical path.



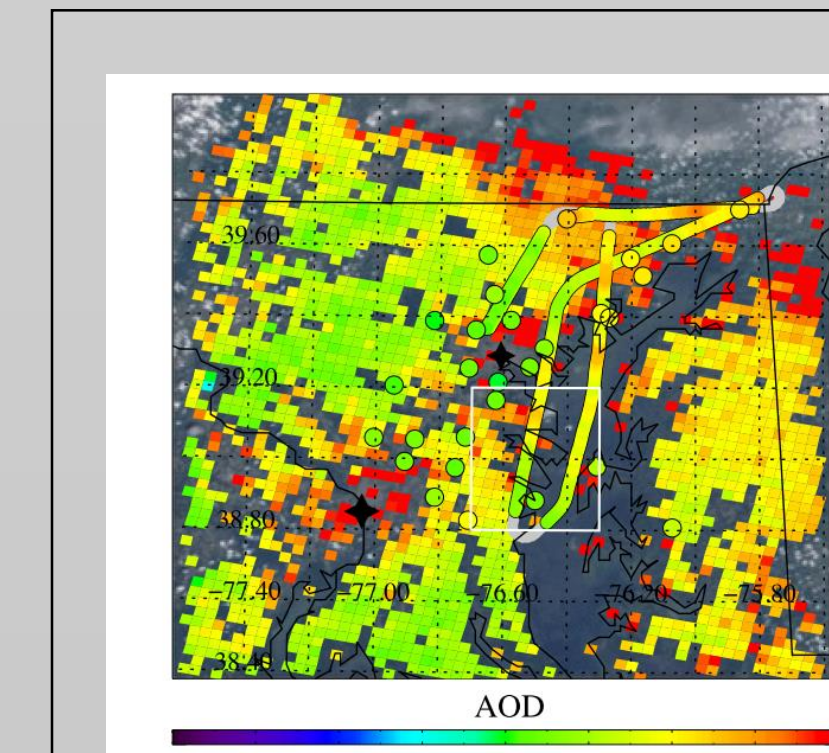
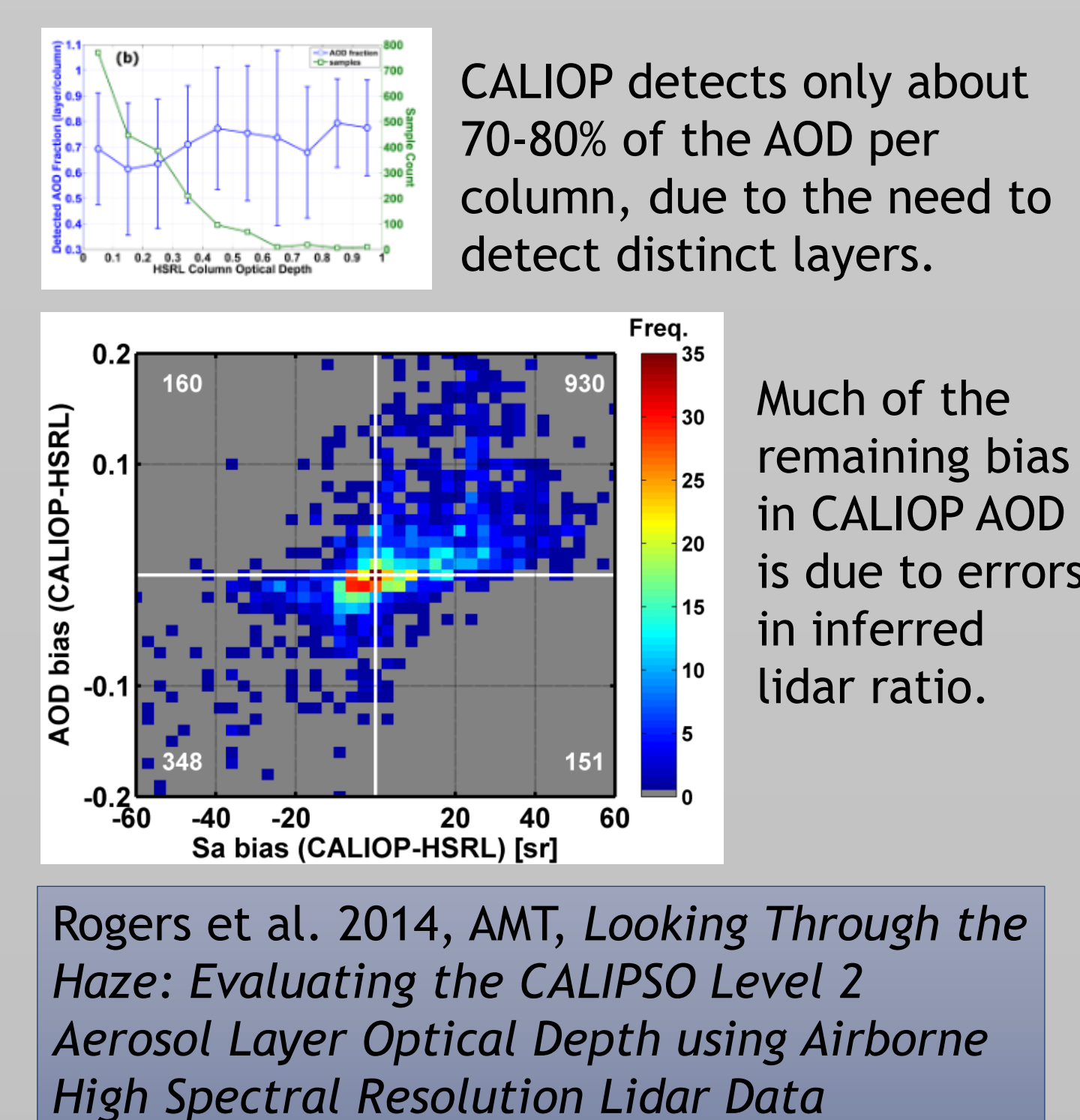
Independent measure of extinction

- No need for inferred/modeled lidar ratio or external constraint.
- No accumulation of error from bootstrapping down into the atmosphere.
- Molecular channel provides direct measure of AOT at higher resolution than passive, without cloud adjacency or surface artifacts.
- No need for layer detection. Extinction can be retrieved (with error bars) even if it is near zero.

Airborne HSRL extinction has been validated against in situ measurement and sun-photometer measurements with bias difference less than 3% (0.01 km⁻¹) and RMS differences less than 50% (532 nm).

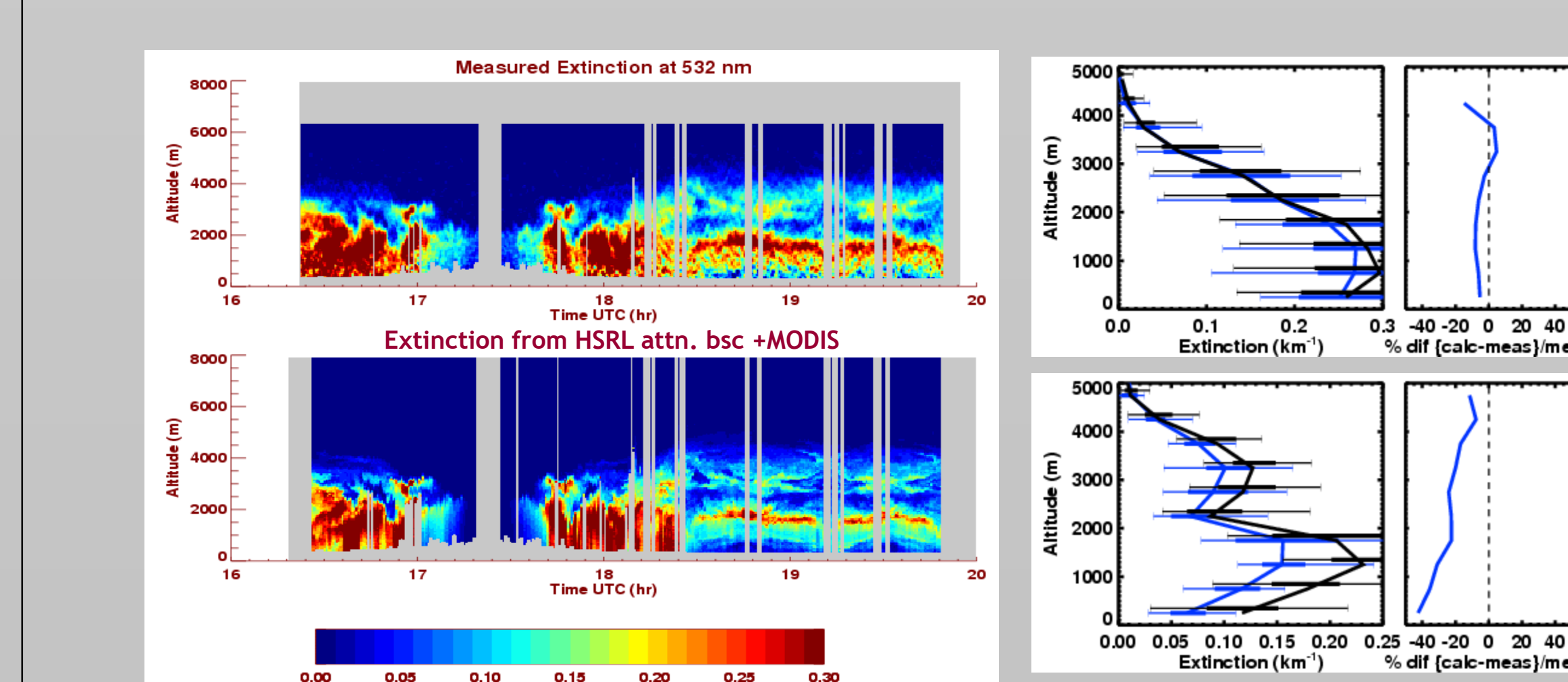


Rogers et al. 2009, ACP, NASA LaRC airborne high spectral resolution lidar aerosol measurements during MILAGRO: observations and validation



Airborne HSRL AOD from extinction was used to validate MODIS 3 km AOD product.

Munchak et al. 2013, AMT, MODIS 3 km aerosol product: applications over land in an urban/suburban region



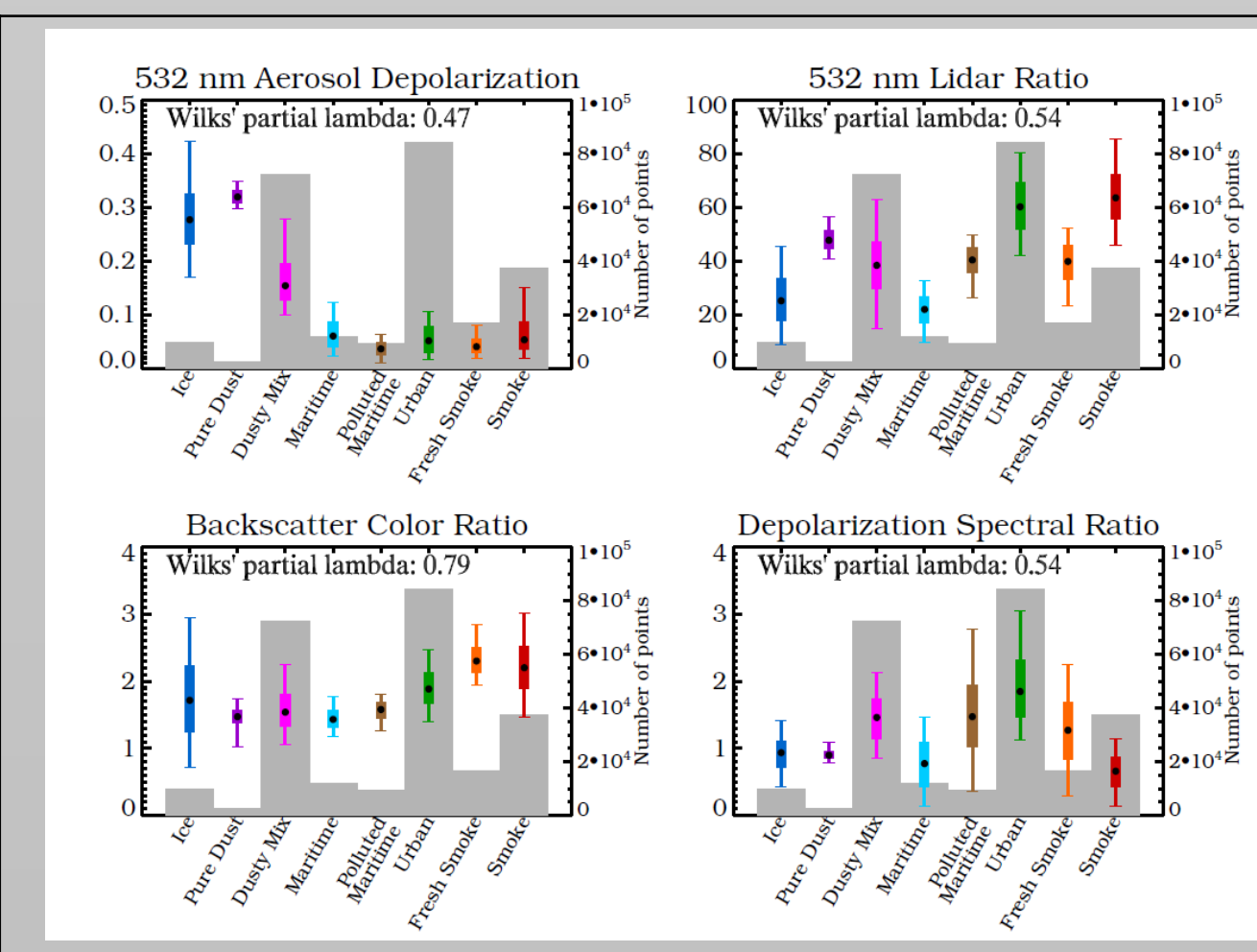
Burton et al., 2010, JGR Using airborne high spectral resolution lidar data to evaluate combined active plus passive retrievals of aerosol extinction profiles

Constrained retrieval (attenuated backscatter from HSRL instrument+ AOD constraint) produces errors in extinction due to inhomogeneity in lidar ratio. Note, error bars increase with decreasing altitude.

Vertically resolved aerosol type information

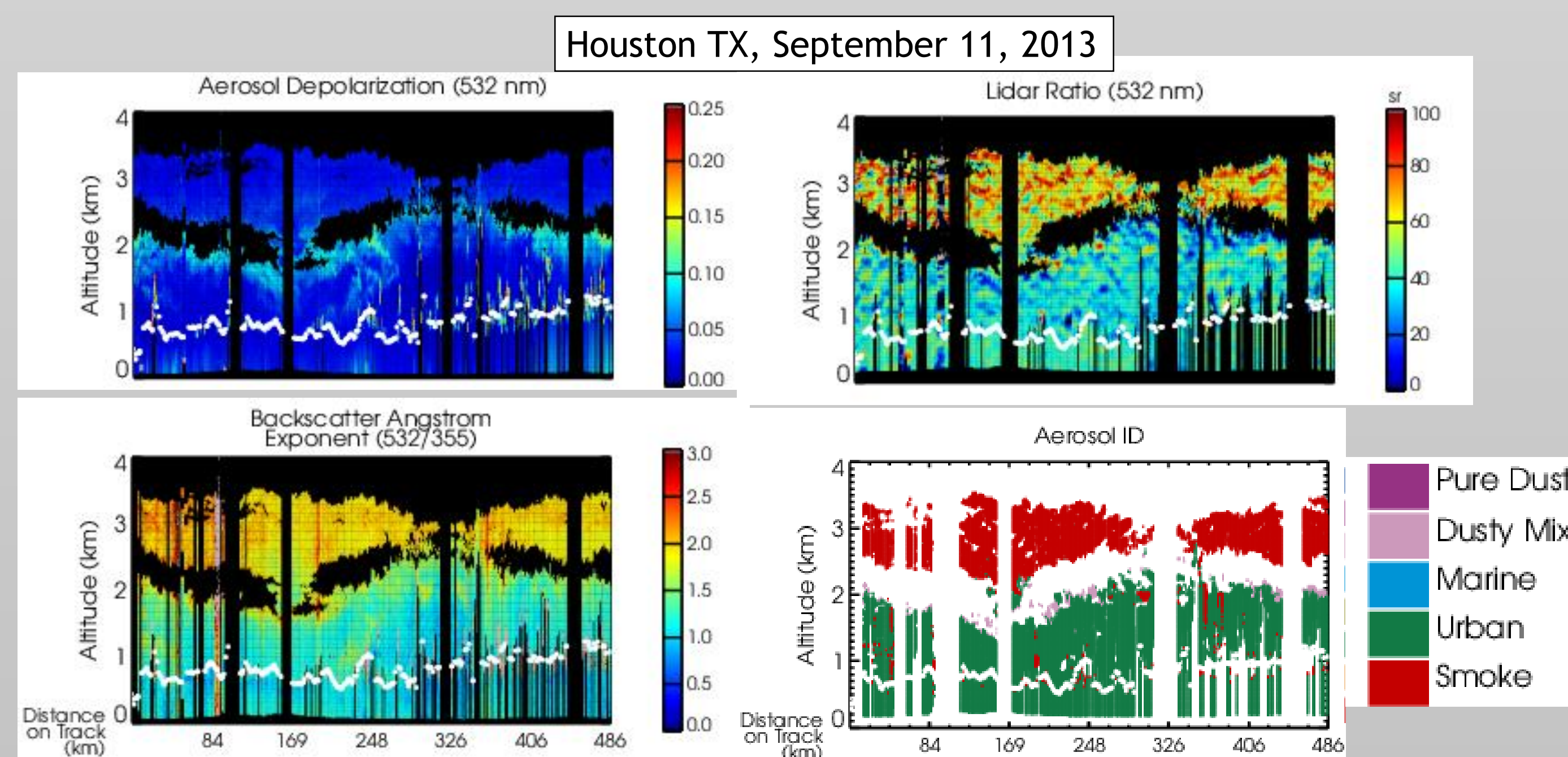
- Lidar ratio gives the most information of all intensive parameters about aerosol composition for aerosols other than dust.
- Particulate depolarization is also more accurate in HSRL system, since separating particulate and molecular parts requires accurate backscatter.
- Extinction angstrom exponent is more directly related to particle size than backscatter angstrom exponent.
- Backscatter angstrom exponent from HSRL is more accurate and precise than from single channel backscatter instrument.

Burton et al. 2012 AMT Aerosol Classification of Airborne High Spectral Resolution Lidar Measurements - Methodology and Examples



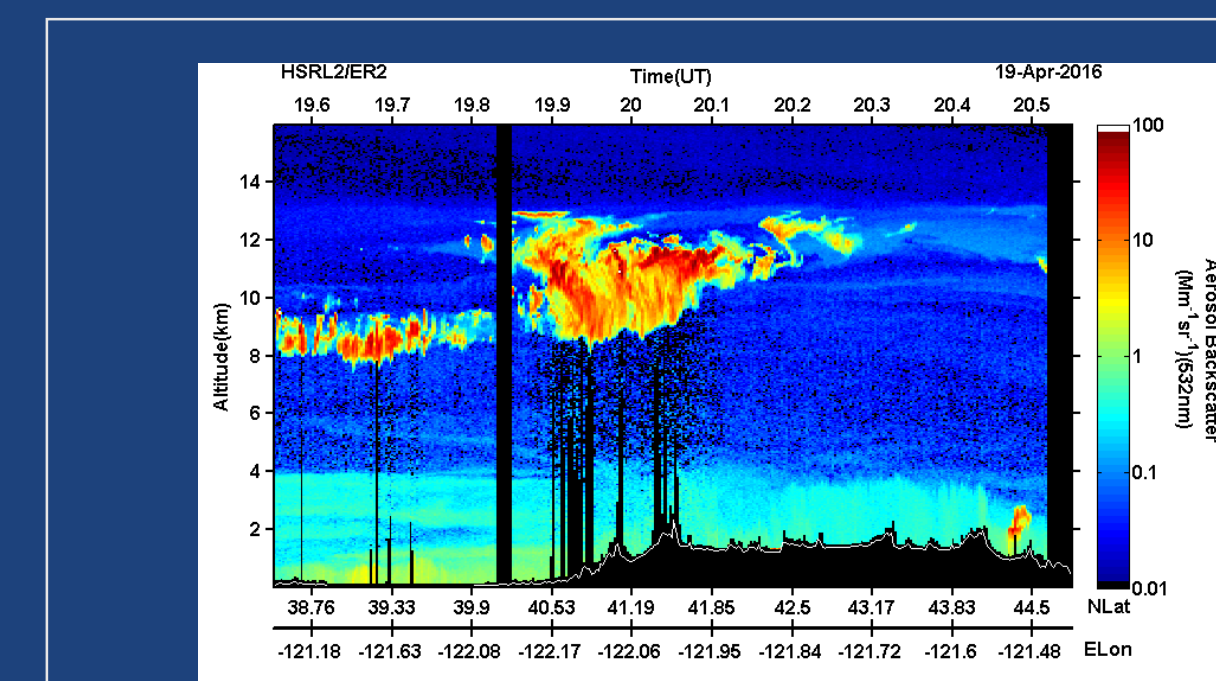
HSRL intensive properties are used to infer aerosol type. Box and whiskers charts demonstrate separability of types using each intensive parameter.

- Aerosol typing is useful for model assessment/assimilation since it gives information on which species in the model need to adjust to match observations, instead of changing all species proportionately.
- Relevant to direct radiative forcing because it gives a proxy for anthropogenic fraction.
- Relevant to indirect radiative forcing because it informs on particle type and activation potential.



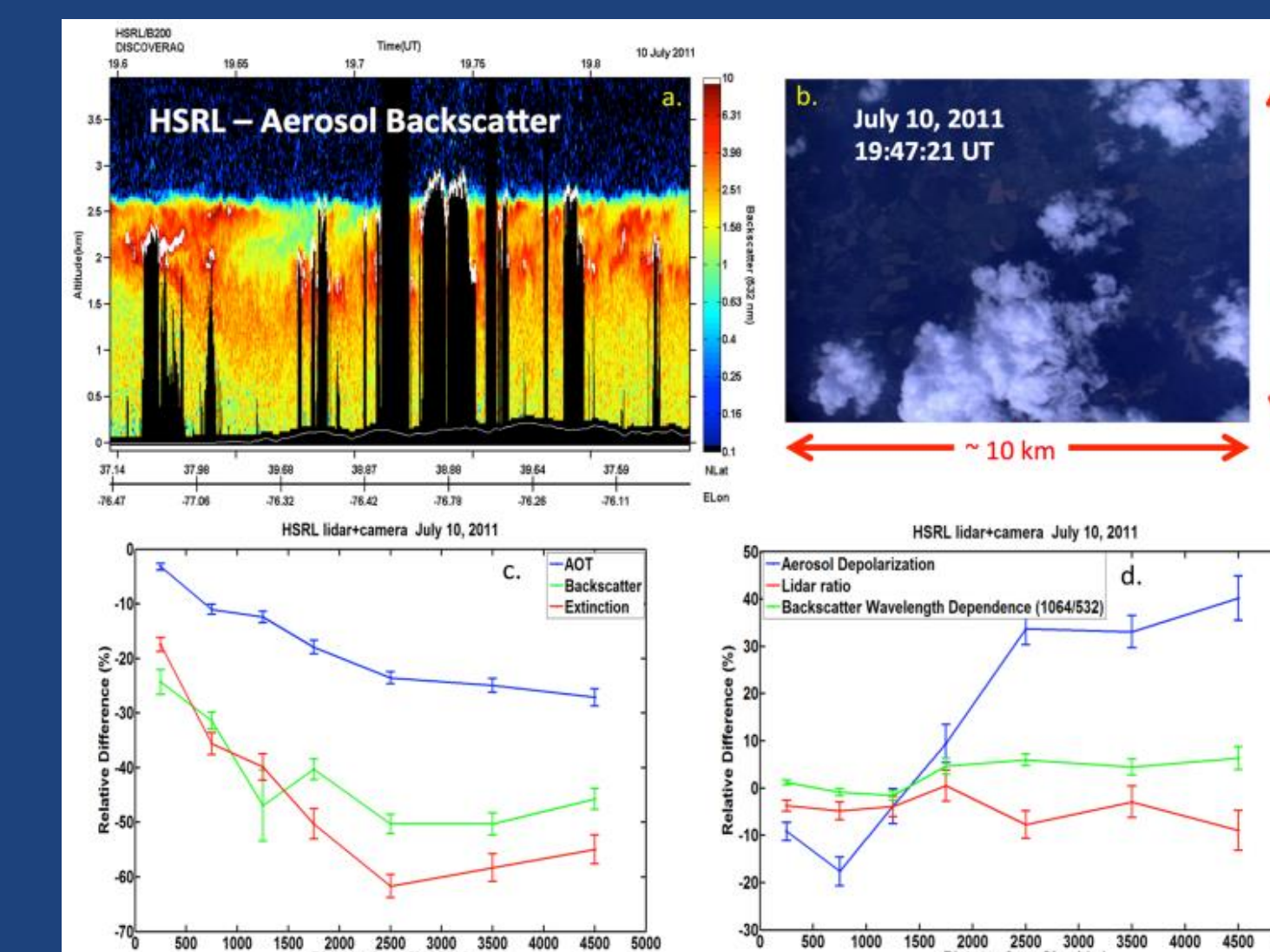
Aerosol-Cloud Interactions

- Better accuracy low in the atmosphere and in heterogeneous situations means more retrievals in proximity to clouds.
- Extinction and microphysical retrievals provide better proxies for vertically resolved CCN.
- High sensitivity to vertically resolved tenuous aerosol and cloud layers gives input (quantity, type) on ice nuclei (IN) in proximity to cirrus.



HSRL observation from April 19 2016 in Western U.S. of UTLS ice-nucleating aerosol intermixed with cirrus with fall streaks

See also Rich Moore's poster about inferring CCN from HSRL.

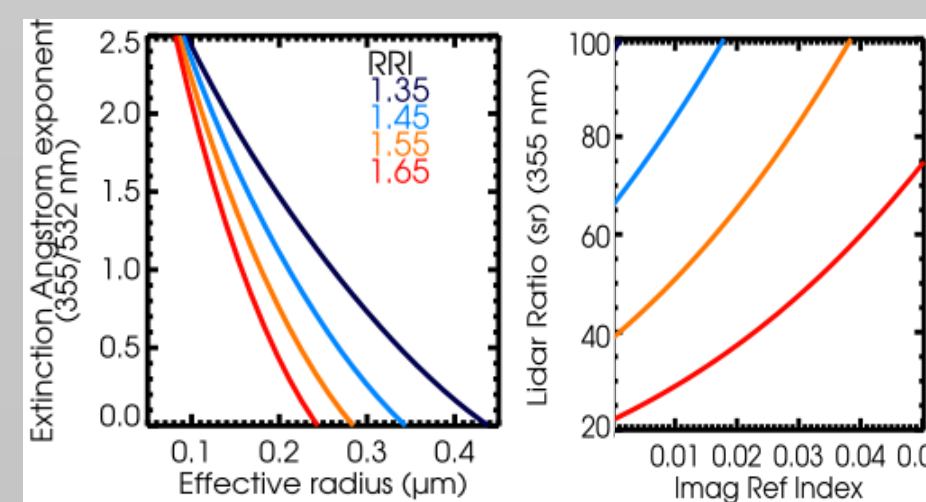


Eck et al., 2014, ACP, Observations of rapid aerosol optical depth enhancements in the vicinity of polluted cumulus clouds

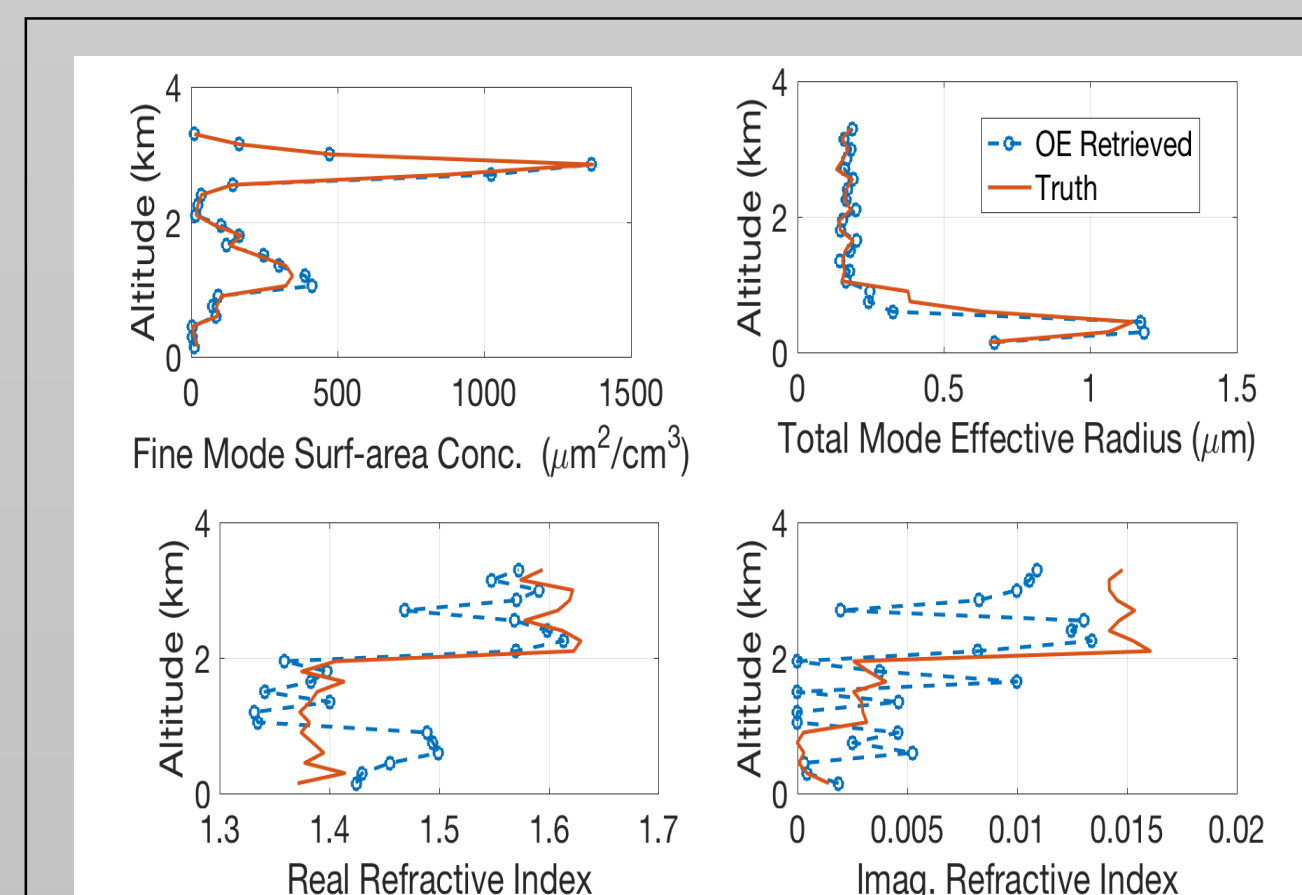
Contribution to combined active + passive retrievals, clouds and aerosols

- HSRL + polarimeter microphysical retrieval produces vertically resolved effective radius, particle concentrations and absorptions, relevant to aerosol-cloud interactions & air quality.
- The lidar provides vertical profile information. More channels = more information = better accuracy and less systematic error.
- HSRL products improve polarimeter column microphysical retrievals for both aerosol and clouds.
- A lidar-only microphysical retrieval can be done, given 2 wavelengths of extinction and 3 backscatter.

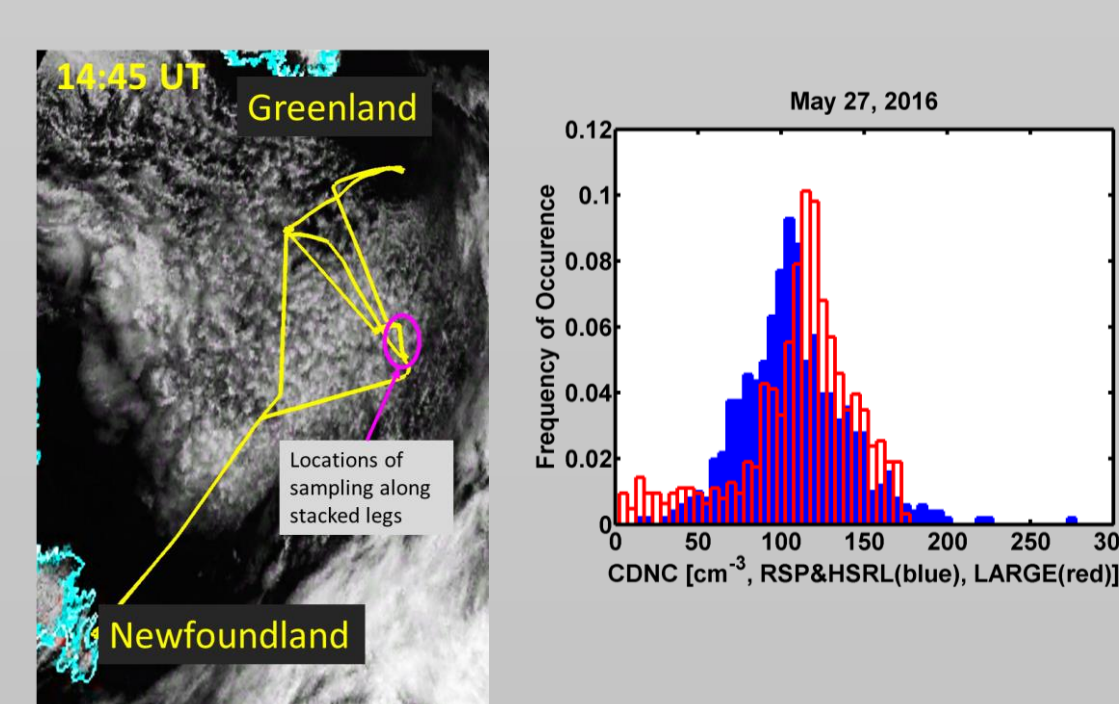
Dependence of effective radius and imaginary refractive index on HSRL products



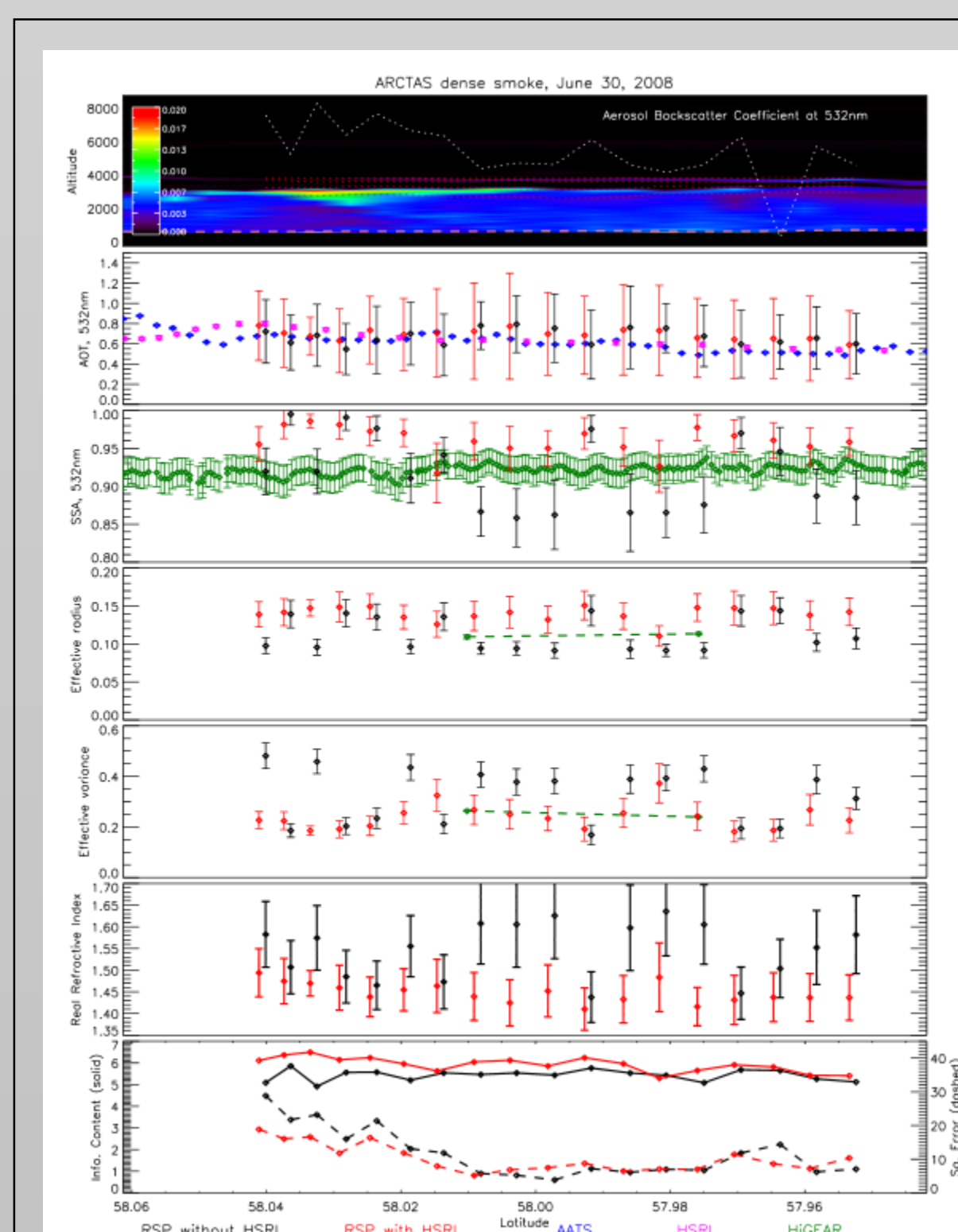
Burton et al., 2016, AMT, Information content and sensitivity of the 3B + 2a lidar measurement system for aerosol microphysical retrievals



HSRL gives information about vertical shape of microphysical properties including absorption, in combined HSRL + RSP retrieval. See Xu Liu's poster.



Retrieval of cloud number droplet concentration from NAAMES compares well with in situ (LARGE). Uses extinction from HSRL lidar and cross section from RSP polarimeter. See John Hair's poster.



Knobelspiesse et al., 2011 ACP, Combined retrievals of boreal forest fire aerosol properties with a polarimeter and lidar

HSRL adds information content to polarimeter microphysical retrieval of smoke plume properties during ARCTAS, improving effective radius and SSA retrievals.

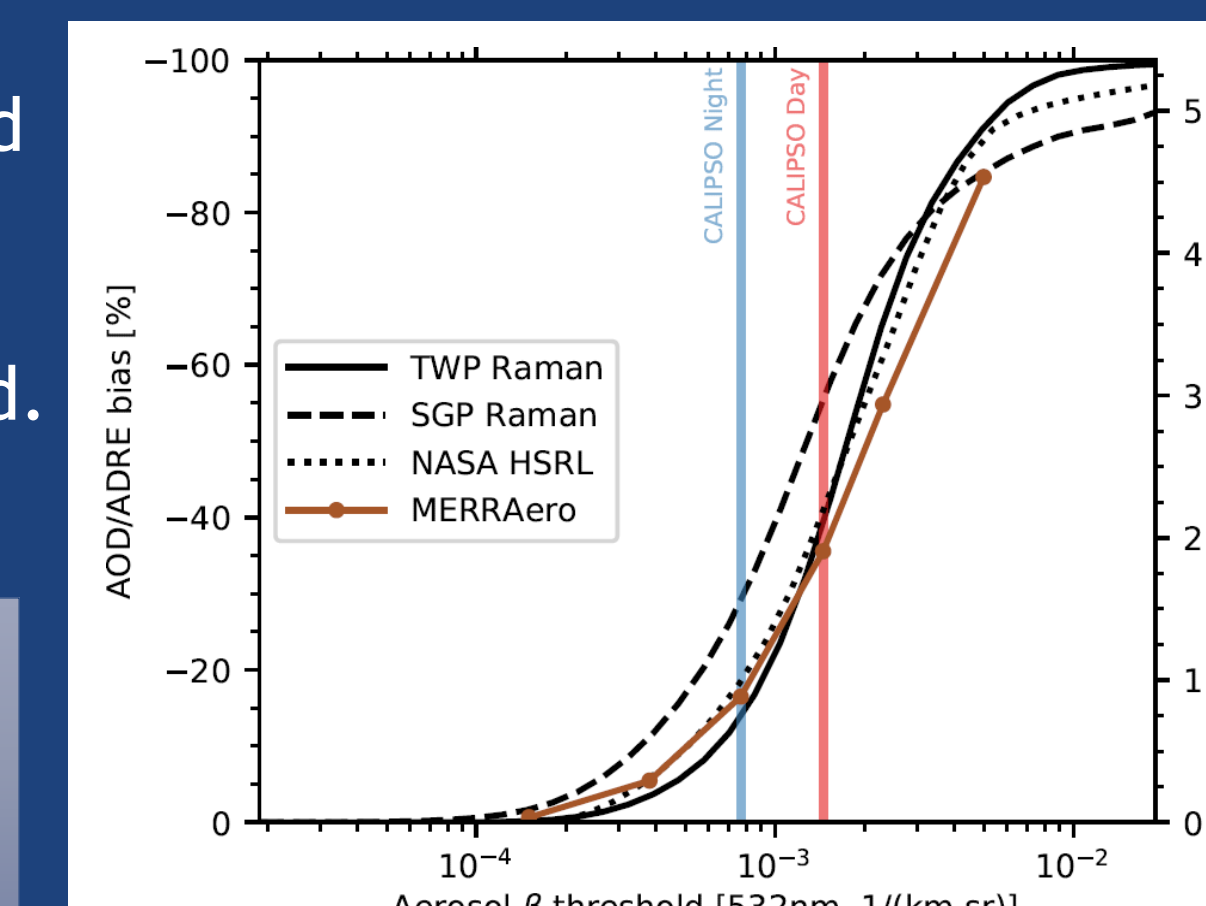
Direct radiative forcing

- Active measurements mean more coverage.
- Vertically resolved measurements mean DRE can be obtained near clouds or at the surface.
- HSRL extinction means better sensitivity to all radiatively important aerosol.
- Info about aerosol type and properties improves radiative transfer calculation and estimations of anthropogenic fraction.

See Tyler Thorsen's poster.

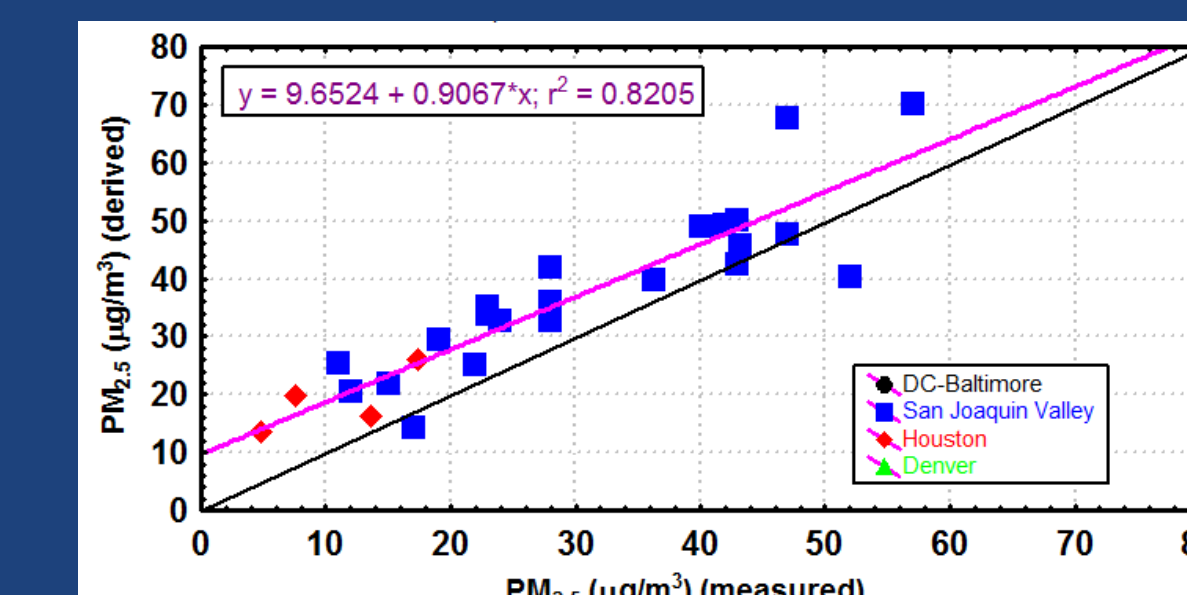
The bias in AOT and direct radiative effect depends on detection threshold.

Thorsen et al. 2017 GRL The impact of lidar detection sensitivity on assessing aerosol direct radiative effects



Air Quality

- Because HSRL backscatter and extinction don't suffer from increased calibration error at low altitudes, HSRL allows accurate retrievals in the boundary layer where aerosol is relevant to air quality and human health.
- Vertically resolved extinction gives a better proxy for PM_{2.5} than AOD divided by boundary layer height
- Microphysical retrievals from HSRL alone or HSRL + passive provide number concentration and size information which give still better proxies for PM_{2.5}



PM_{2.5} concentrations were derived from HSRL-2 multiwavelength retrievals of fine mode volume concentration and have high correlation with measured PM_{2.5}