Constraining Aerosol Vertical Profile in the Boundary Layer Using Hyperspectral Measurements of Oxygen Absorption

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Importance of Aerosols I

- **Directly impact Earth's radiation budget by scattering and absorbing solar radiation and by interacting with clouds**

- **Offset some of the radiative forcing from greenhouse gases**

- **Contribute largest uncertainty to total radiative forcing estimate**

- **Adversely affect human health**

Importance of Aerosols II

- **Aerosol vertical distribution crucial in determining area impacted by them**
  - **aerosols transported to the free troposphere or stratosphere will be horizontally transported over a large distance, impacting large regions**
  - **aerosols confined to the boundary layer are removed quickly by rain.**

- **Aerosols and their vertical distribution also impact remote sensing observations by varying photon path length**
  - **observations of atmospheric trace gases or surface parameters such as ocean color need to be corrected for aerosol effects**

Decadal Survey Designated Observable

TARGETED OBSERVABLE	SCIENCE/APPLICATIONS SUMMARY	CANDIDATE MEASUREMENT APPROACH	Designated	Explorer	Incubation
Aerosols	**Aerosol properties, aerosol vertical profiles, and cloud properties** to understand their direct and indirect effects on climate and air quality	Backscatter lidar and multi-channel/multi-angle/polarization imaging radiometer flown together on the same platform	X		

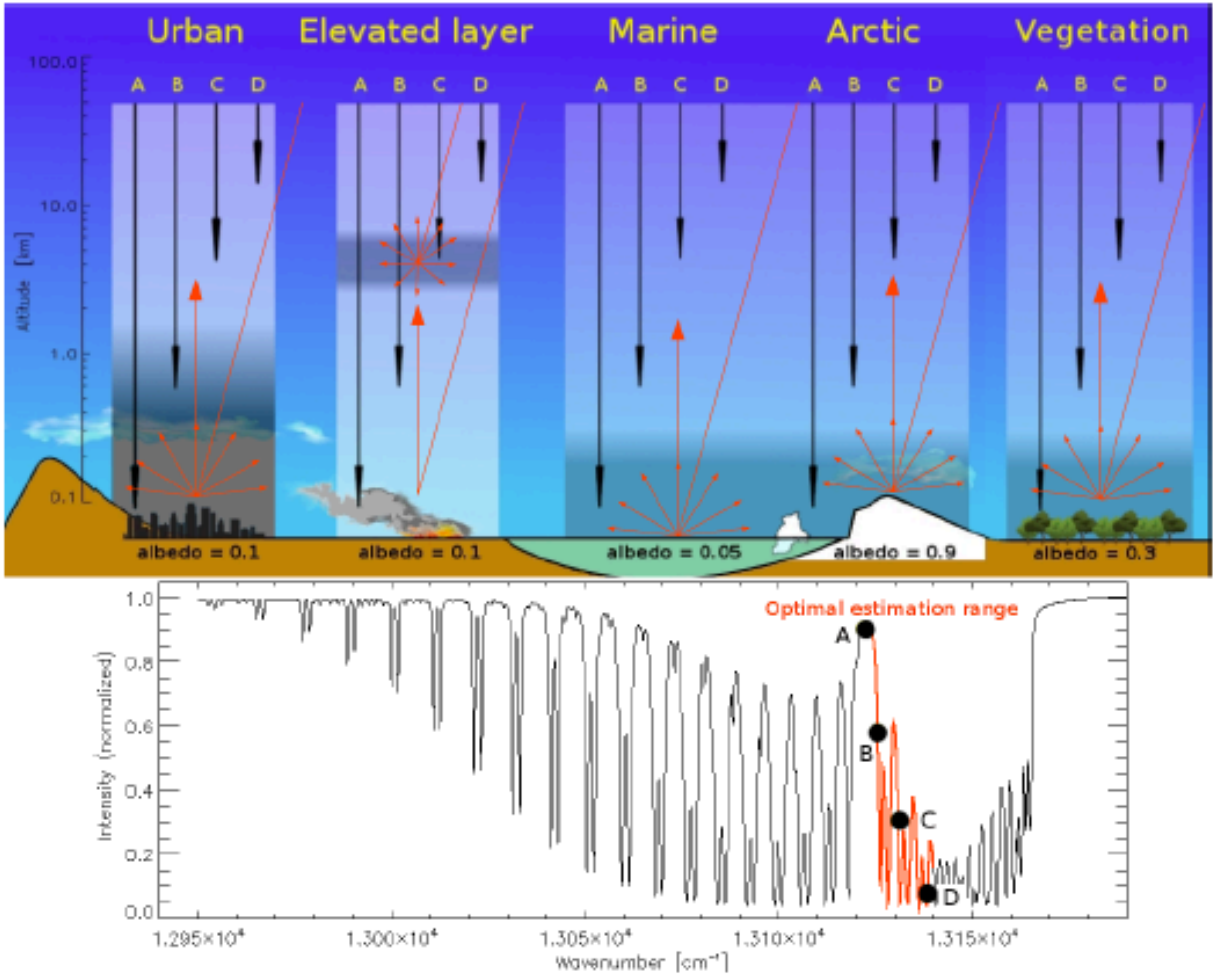
- QUESTION C-2. How can we reduce the uncertainty in the amount of future warming of the Earth as a function of fossil fuel emissions, improve our ability to predict local and regional climate response to natural and anthropogenic forcings, and reduce the uncertainty in global climate sensitivity that drives uncertainty in future economic impacts and mitigation/adaptation strategies?

- QUESTION C-5. A. How do changes in aerosols (including their interactions with clouds which constitute the largest uncertainty in total climate forcing) affect Earth's radiation budget and offset the warming due to greenhouse gases? B. How can we better quantify the magnitude and variability of the emissions of natural aerosols, and the anthropogenic aerosol signal that modifies the natural one, so that we can better understand the response of climate to its various forcings?

- QUESTION W-6. What processes determine the long-term variations and trends in air pollution and their subsequent long-term recurring and cumulative impacts on human health, agriculture, and ecosystems?

- QUESTION C-3. How large are the variations in the global carbon cycle and what are the associated climate and ecosystem impacts in the context of past and projected anthropogenic carbon emissions?

Oxygen Absorption and Aerosol Vertical Profile



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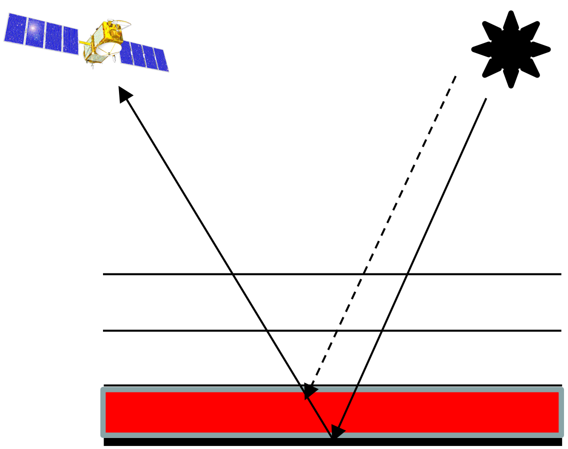

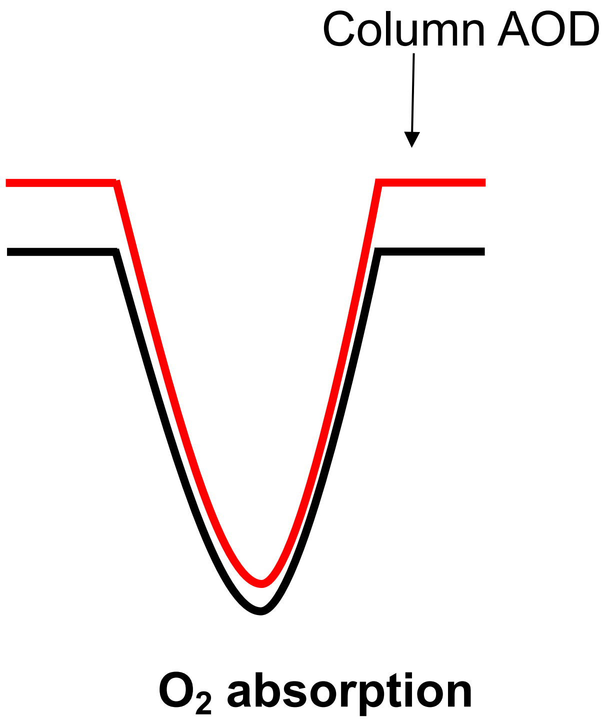

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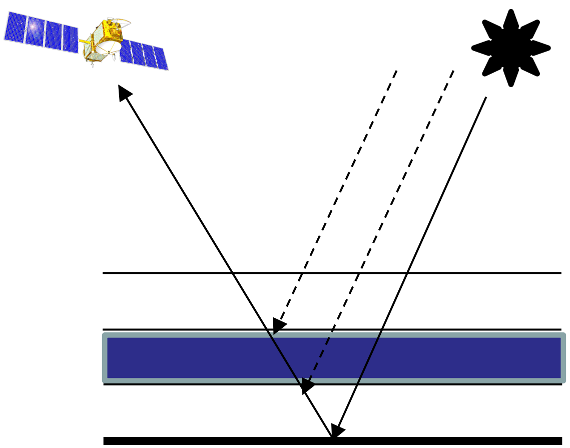

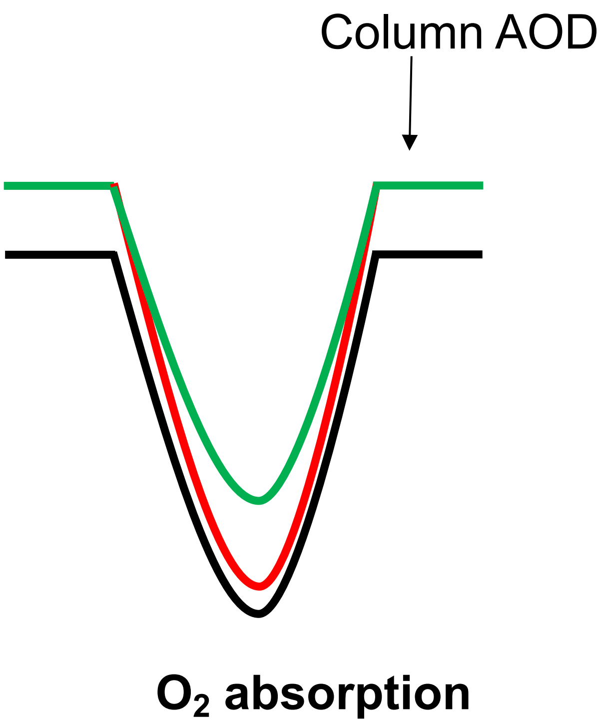

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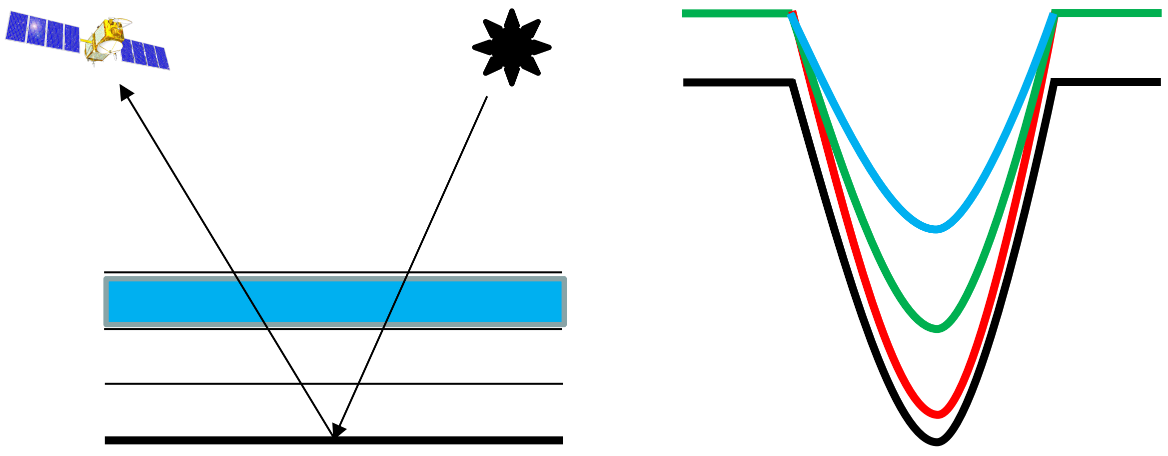
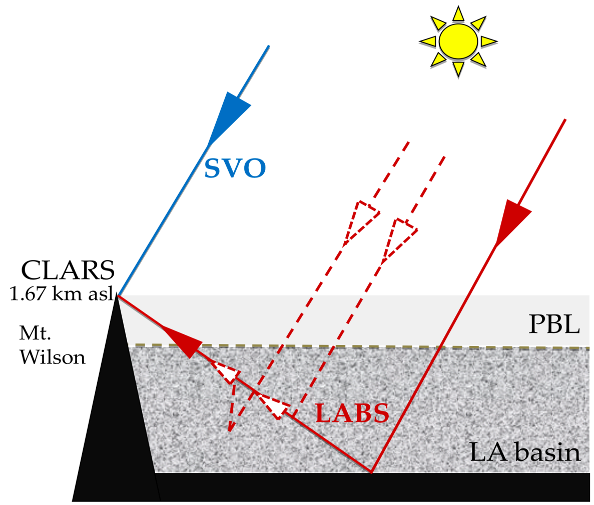
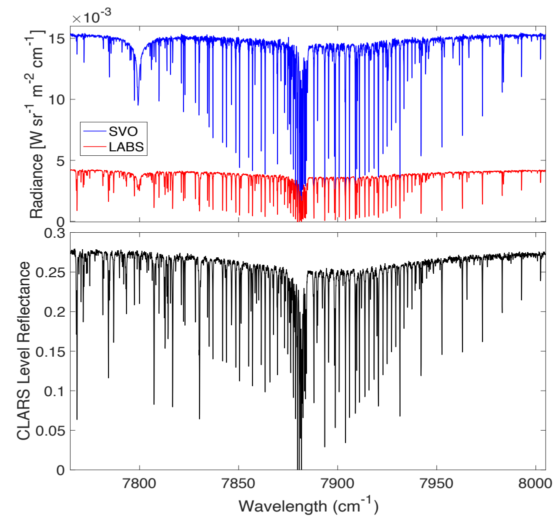


CLARS: California Laboratory for Atmospheric Remote Sensing



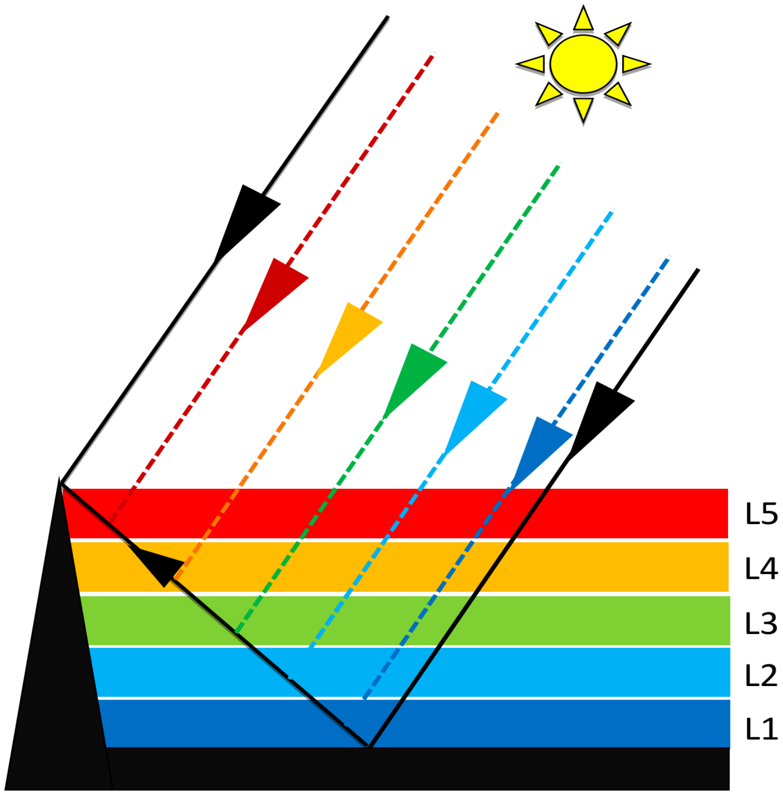


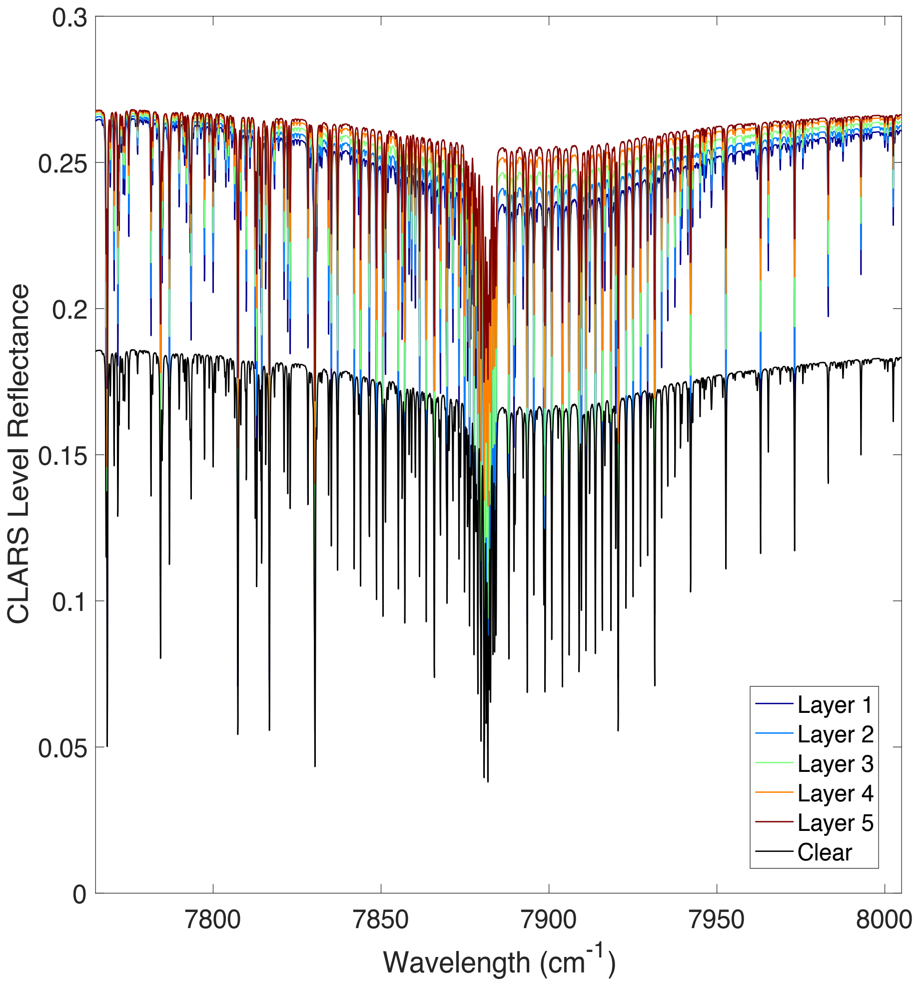
Source: megacities.jpl.nasa.gov

Reflected sunlight from 33 surface sites

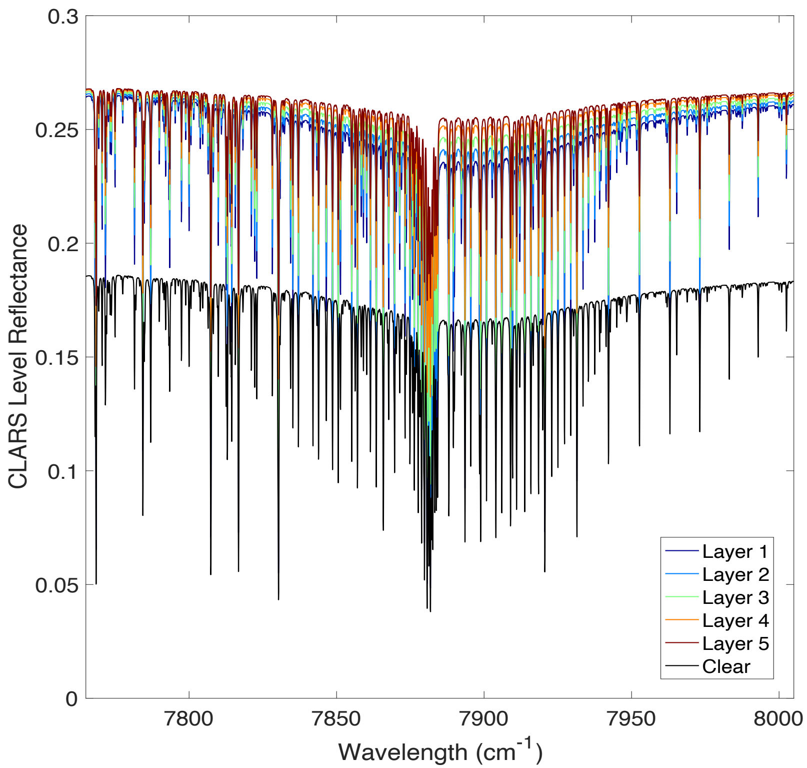
Oxygen $^1\Delta$ band at 1.27 µm

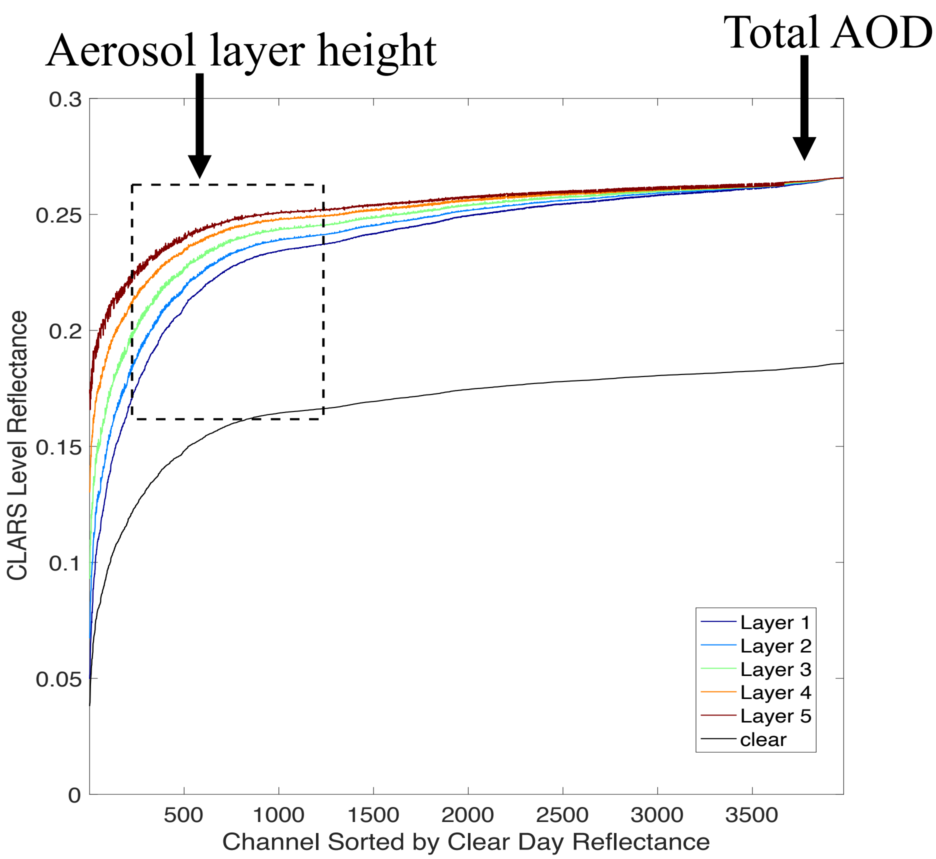
Sensitivity to Aerosol Vertical Structure





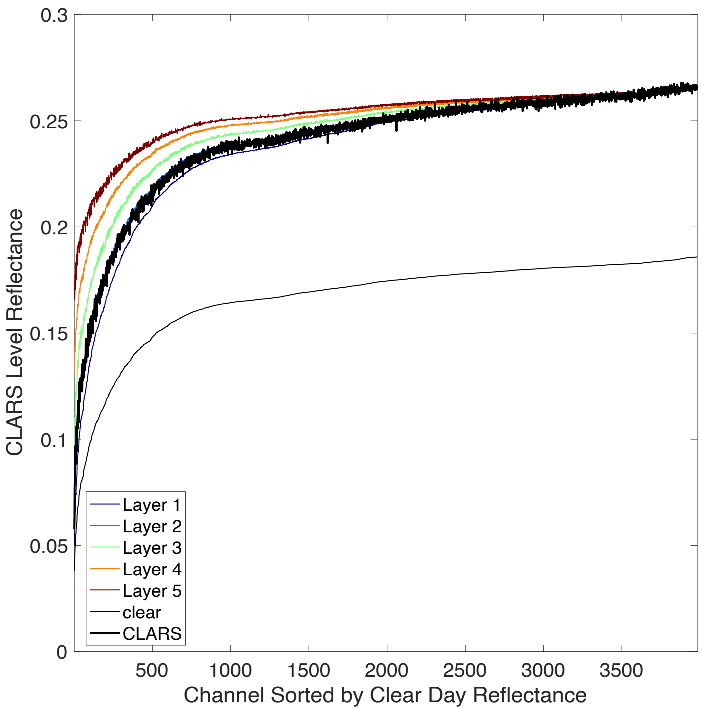
Spectral Sorting

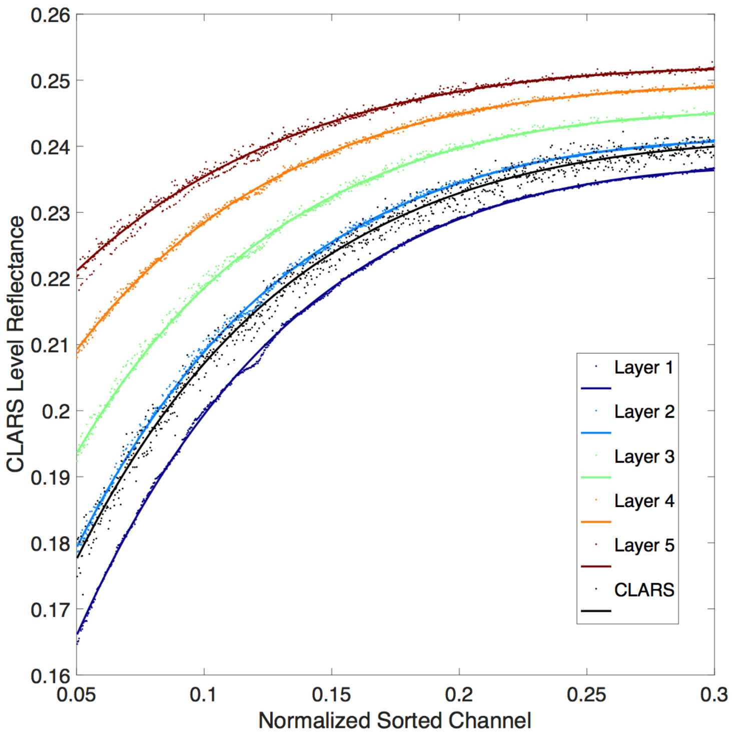




Liou (2002)
Richardson et al. (2016)

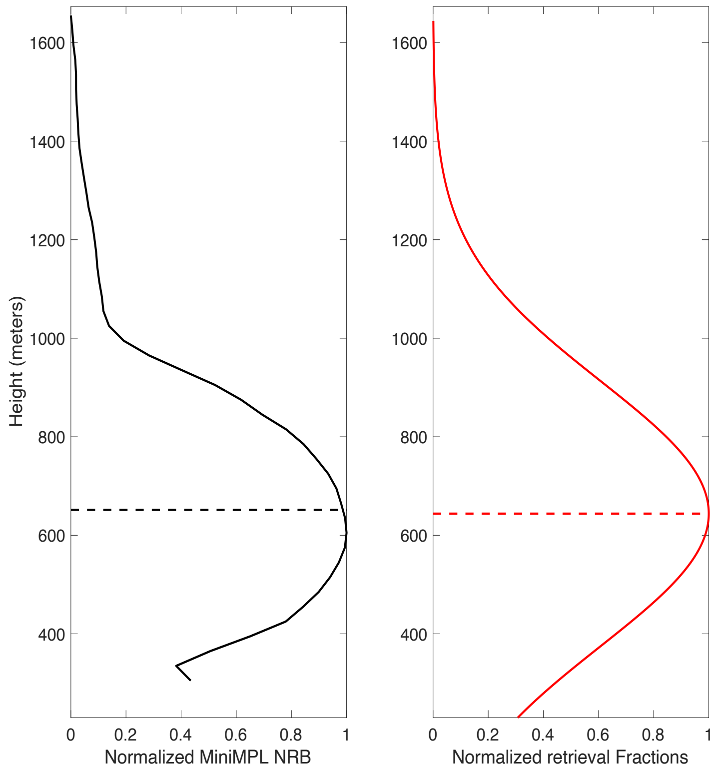
Look-up Table for Aerosol Layer Height



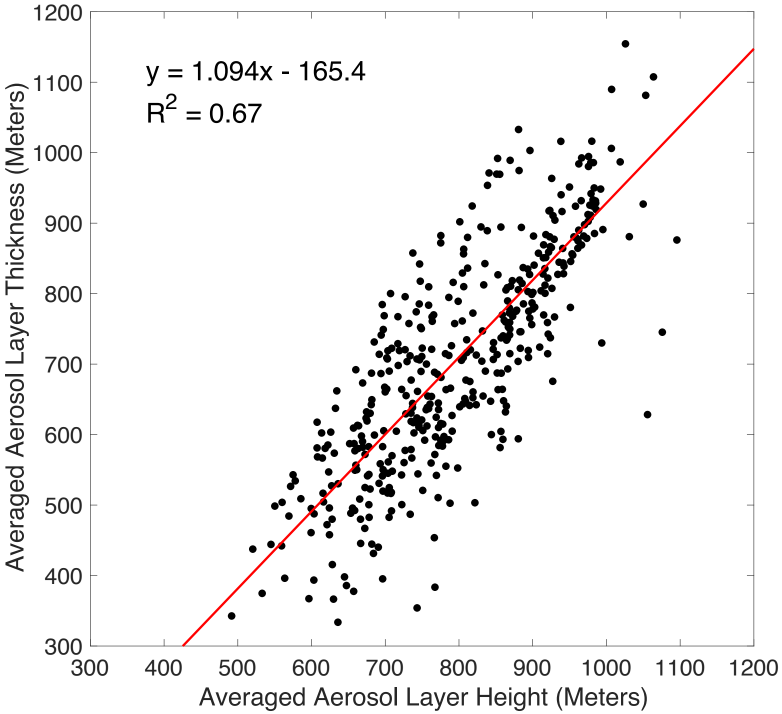


$$f(x) = a_1 - a_2 * (1 - x) - a_3 * \exp(-a_4 * x)$$

Aerosol Vertical Structure



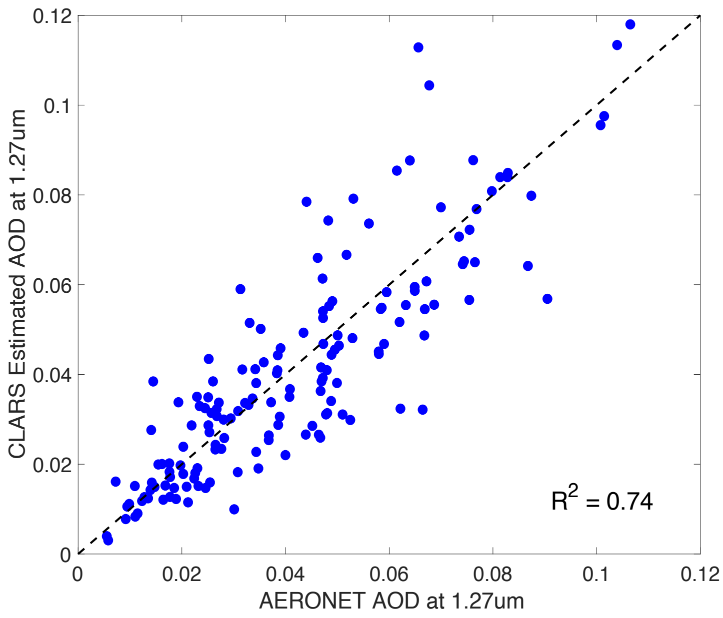
Empirical correlation between aerosol layer height and the geometric thickness of aerosol layer



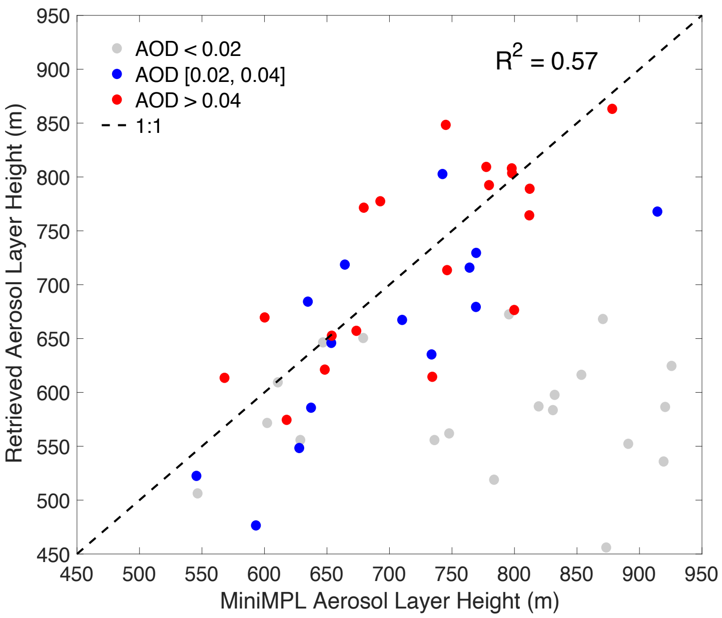
Physically correlated with effective ALH driven by expansion and collapse of the PBL.

Validation

RMSE = 0.013



RMSE = 67.01 m



Application to Satellite Measurements

- **Spectral sorting method can be applied to hyperspectral O_2 A-band measurements from satellites, such as the OCO-2 and the OCO-3 missions**

- **Accuracy of ALH retrieval shows a certain dependence on SSA and phase function (can be simultaneously retrieved by combining hyperspectral oxygen absorption and polarimetric measurements)**

- **ALH likely to be underestimated for relatively clean days. However, for very low aerosol loadings, the bias in GHG retrievals will be negligible.**

Conclusions

- **Boundary layer aerosol profiling method for hyperspectral remote sensing measurements of oxygen absorption to retrieve total AOD and effective ALH**

- **Demonstration using CLARS-FTS measurements to profile aerosols in the LA Basin**

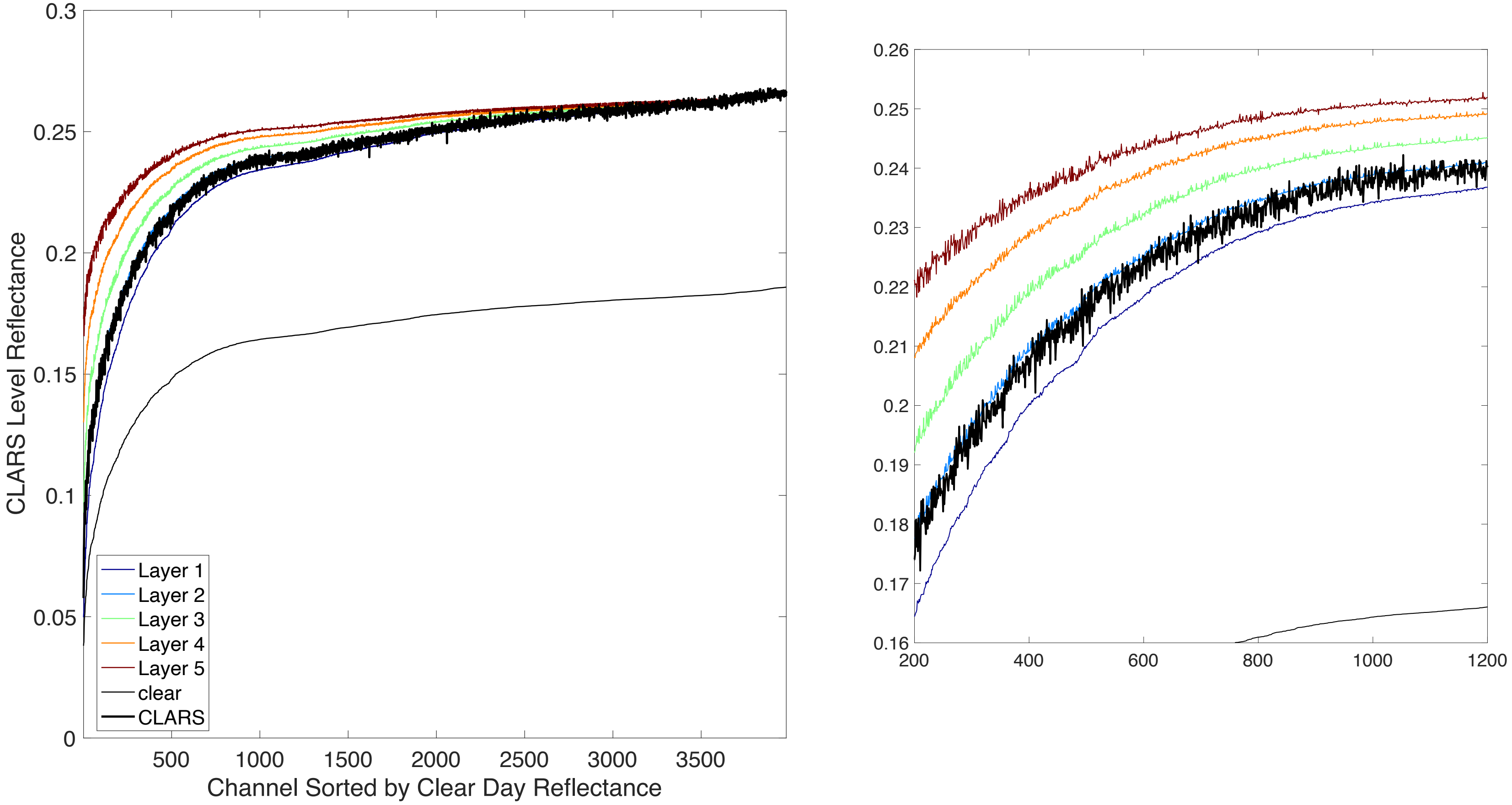
- **Straightforward way to extract information on aerosol loading and its vertical structure from observed radiance**

- **Spectral region with greatest sensitivity to geophysical parameter(s) to be retrieved can be easily identified**

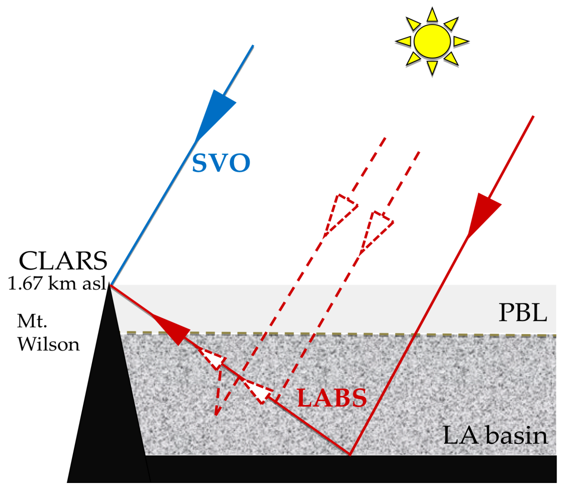
Backup Slides

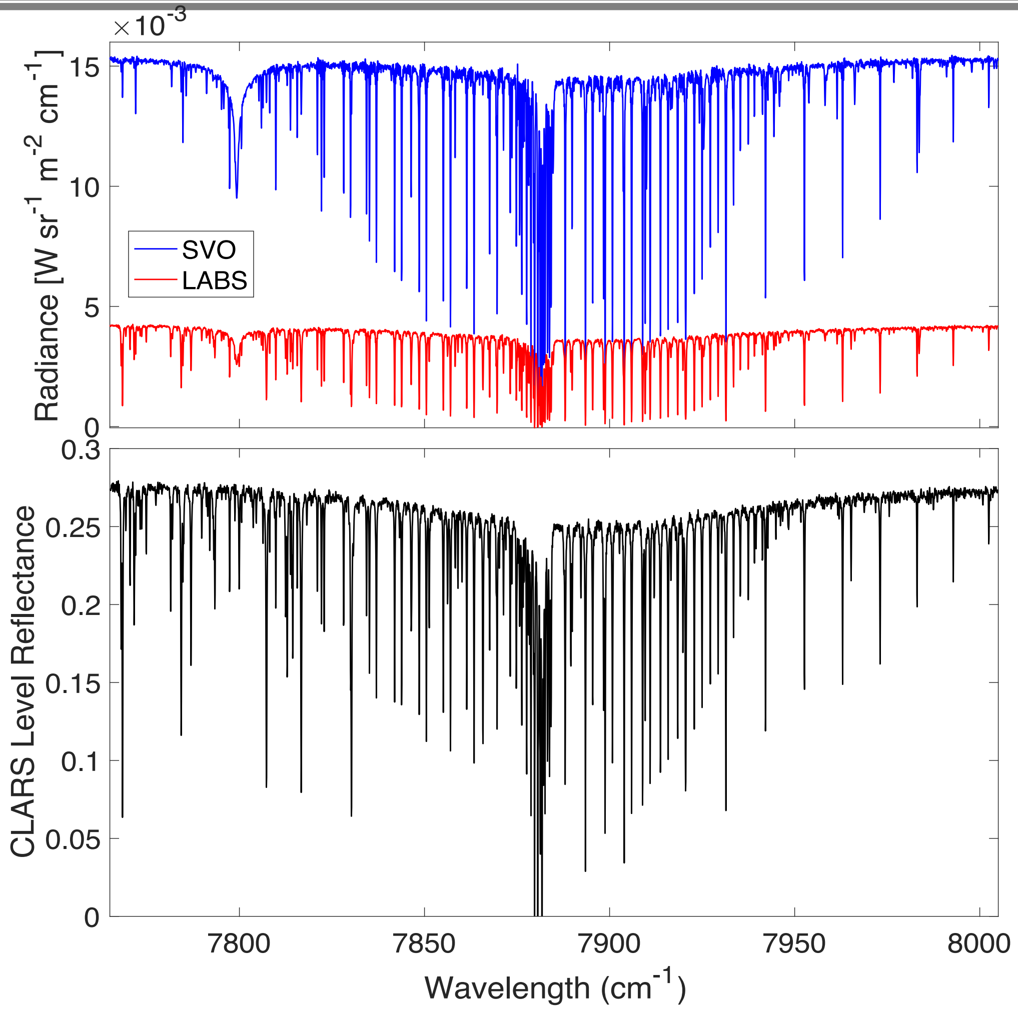
Sorting Applied to CLARS Measurements

What about the real measuements?



SVO and LABS Spectra





Retrieval Uncertainties

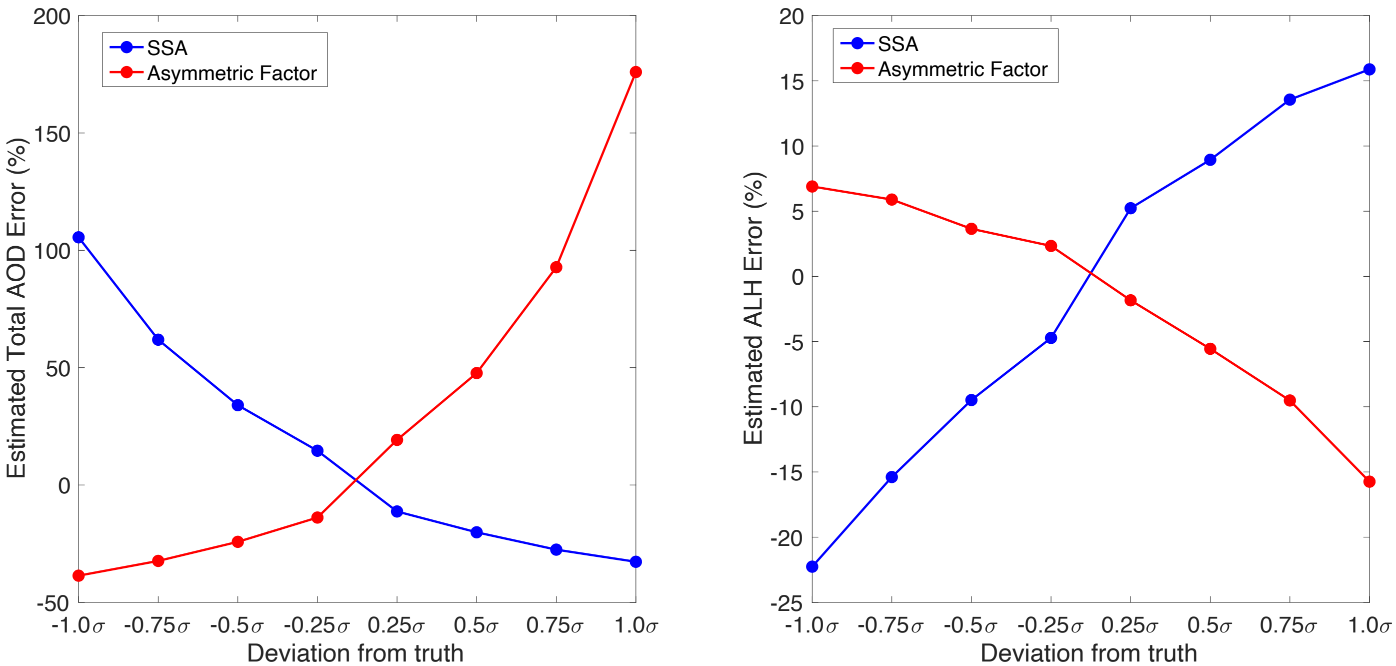


Figure 4. The uncertainty of total AOD and effective ALH retrievals from CLARS measurements caused by the errors in the input aerosol optical properties of SSA and phase function. Synthetic radiance observation is first generated with a RT model with the same CLARS and solar geometries as in Figure 2, with aerosol in the middle layer (ALH=706 meters), and the averaged total AOD (0.0541), SSA (0.8592), and asymmetric factor (0.8120) derived from long term AERONET measurements at Caltech. The corresponding standard deviations (σ) for SSA (0.1459) and asymmetric factor (0.0877) are used as the errors. The total AOD in (a) and ALH in (b) are then retrieved by applying the proposed method to the synthetic spectra data using RT model with perturbed SSA or asymmetric factor by a certain error (-1.0σ, -0.75σ, -0.5σ, -0.25σ, 0.25σ, 0.5σ, 0.75σ, 1.0σ). The estimation error of total AOD and asymmetric factor are calculated as the deviation (in percentage) from the known truth.