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ALTIUS Stratospheric Aerosol Retrieval Algorithms: Overview, Development, and Results

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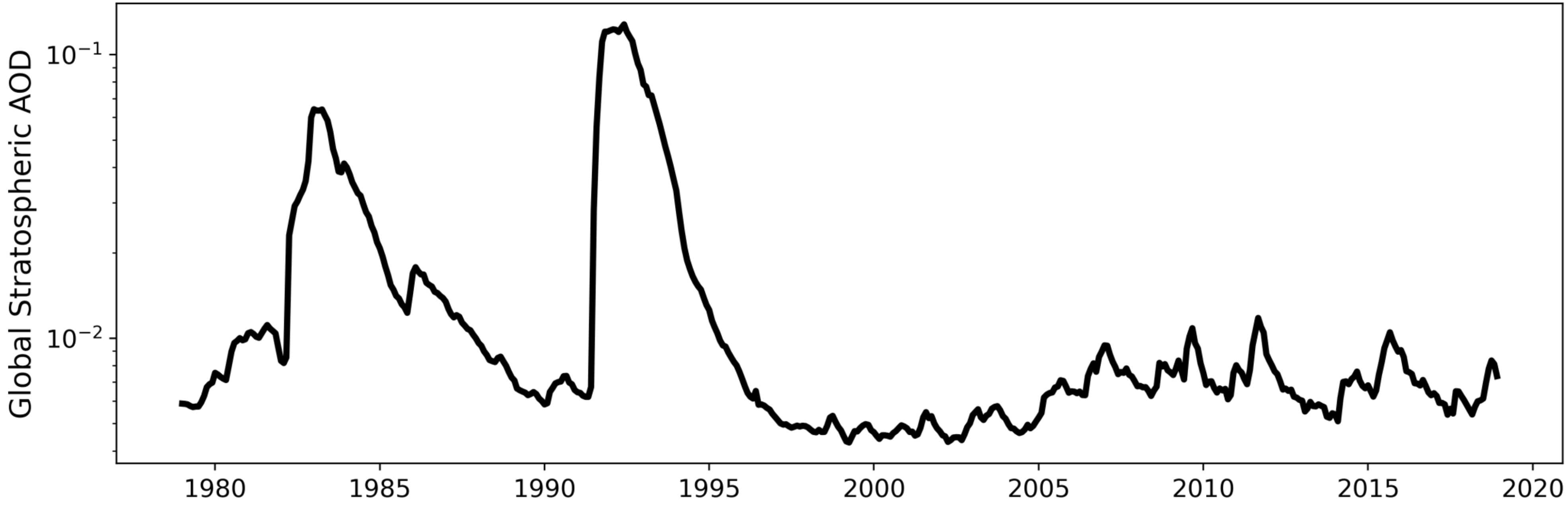
Stratospheric Aerosol

- Sub-micron sized droplets that are primarily sulphuric acid
- Important for chemical, dynamical, and radiative balance
- Background layer perturbed by large-scale events
  - Small and large volcanic eruptions
  - Recently large forest-fire activity



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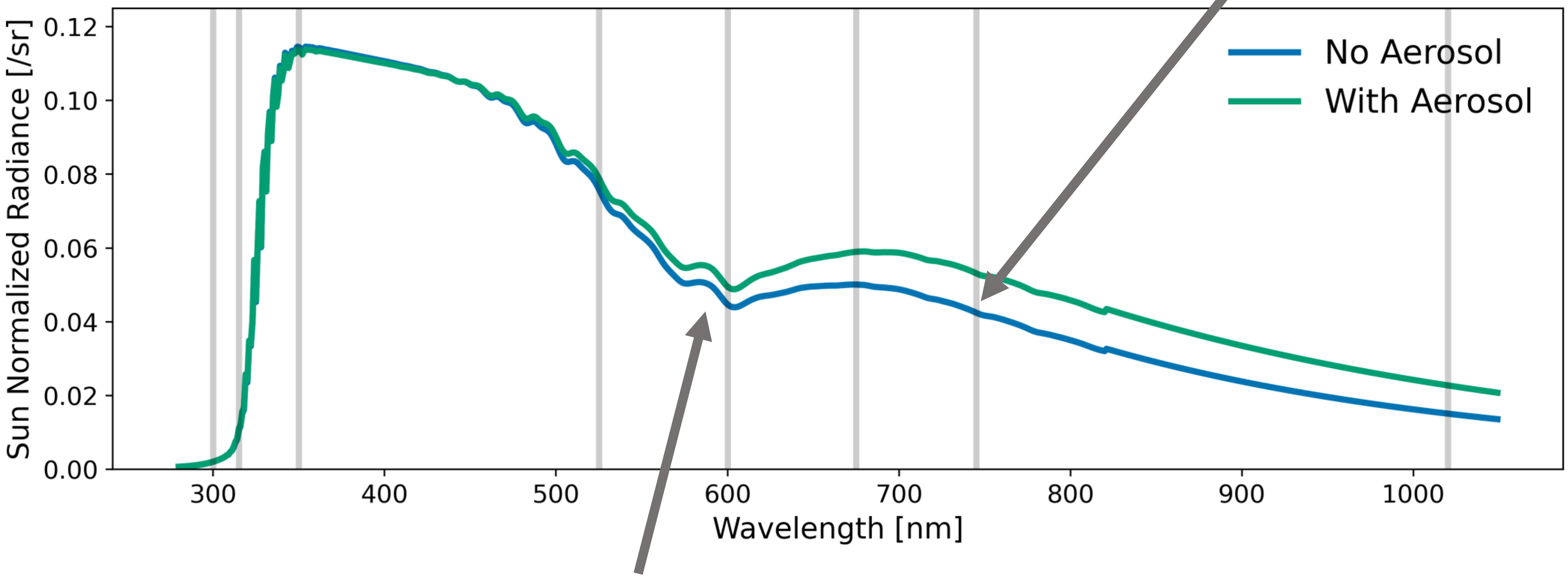
Stratospheric Aerosol with ALTIUS

- Contributes significant scattering to visible/near infrared wavelengths
  - Ozone interference in the Chappuis absorption band

- Two ways that ALTIUS can contribute to stratospheric aerosol science
  - A significant role in continuing the stratospheric aerosol record
    - Potential for “self-validation” comparing ALTIUS occultation measurements with limb scatter measurements
  - The imaging nature of ALTIUS can provide more information on the horizontal extent of stratospheric plumes
    - Several recent injections have been highly localized in the stratosphere (Australian wildfires, Hunga Tonga)

Signature in ALTIUS Spectra

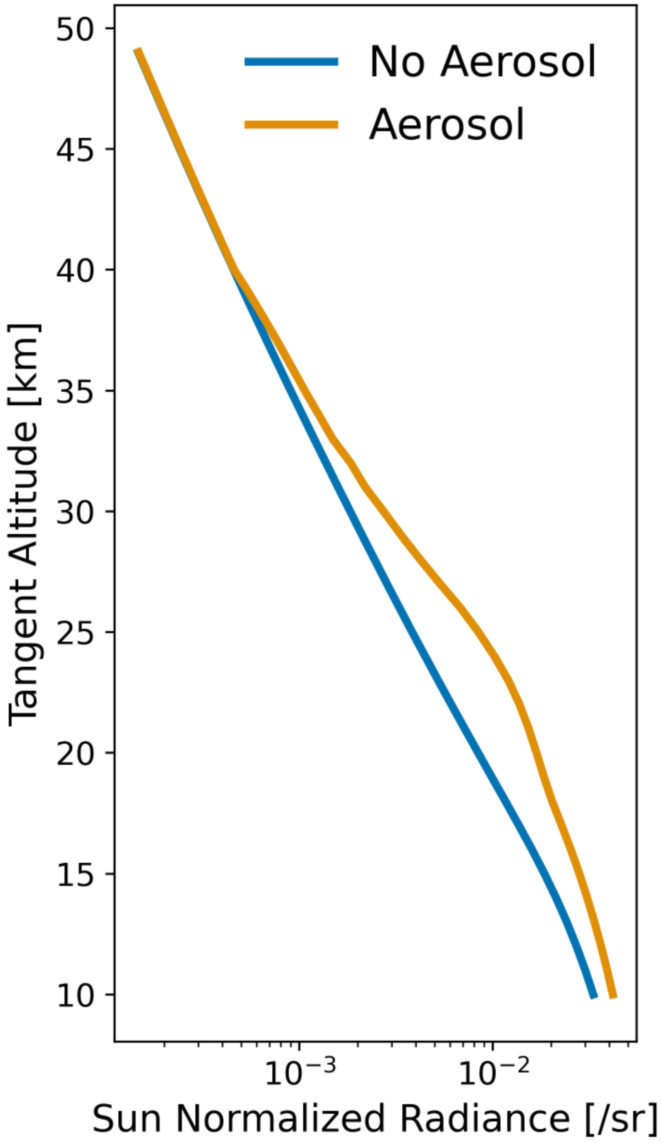
Stratospheric aerosol increases the signal in the red end of the spectrum



And changes the slope in the Chappuis absorption band

Challenges with Retrieving Aerosol

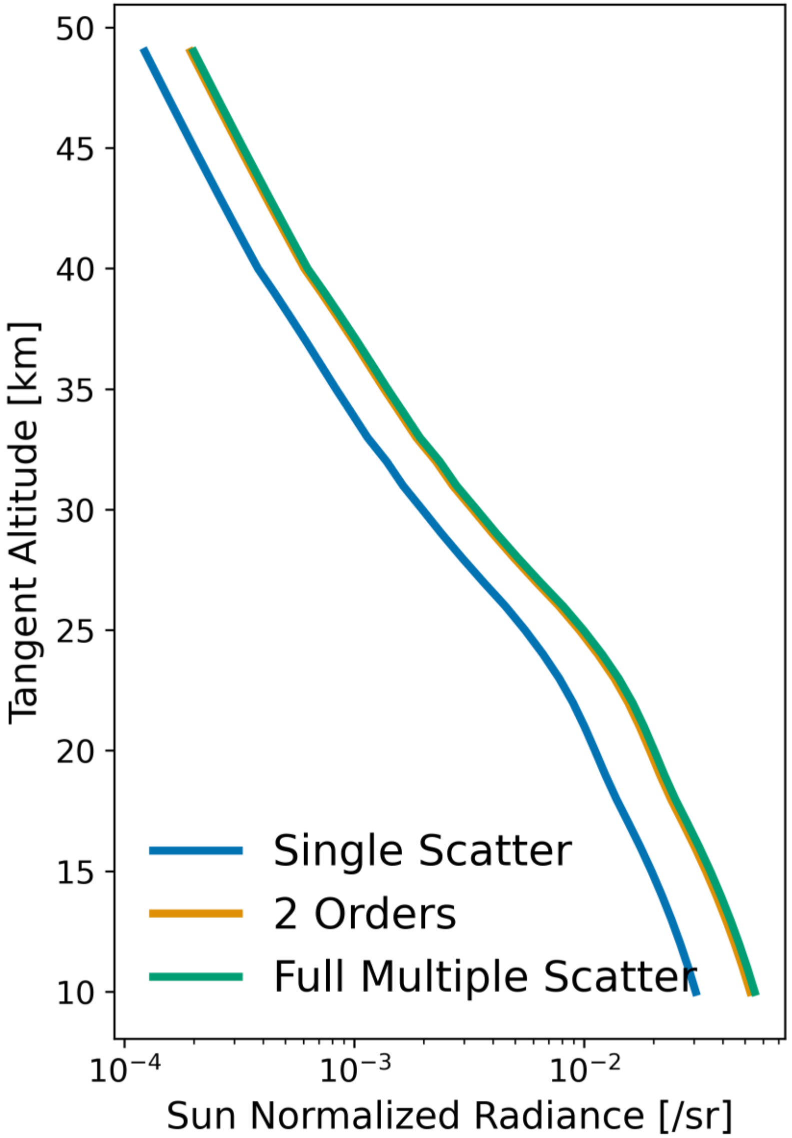
- A information-poor problem
  - A small spectrally smooth signal increase over Rayleigh scattering
  - Need confidence in our ability to model the radiative transfer
- For absorbing species, we would normally use differential absorption structure or ratios of sensitive to insensitive wavelengths
- Many parameters required to characterize
  - Number density, aerosol type, particle size distribution



Challenges with Retrieving Aerosol

- The signal that we observe is almost entirely from two orders of scattering
  - About 50% single scatter, 50% surface->atmosphere->instrument

- Half of our observed signal is “contaminated” by the troposphere
  - Clouds, surface BRDF, tropospheric aerosols



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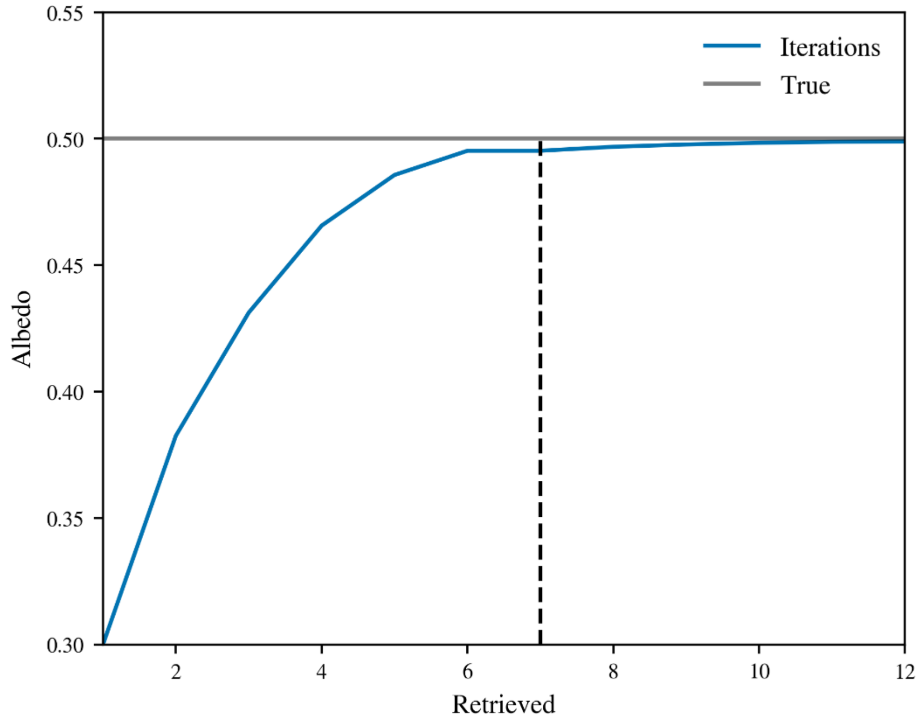
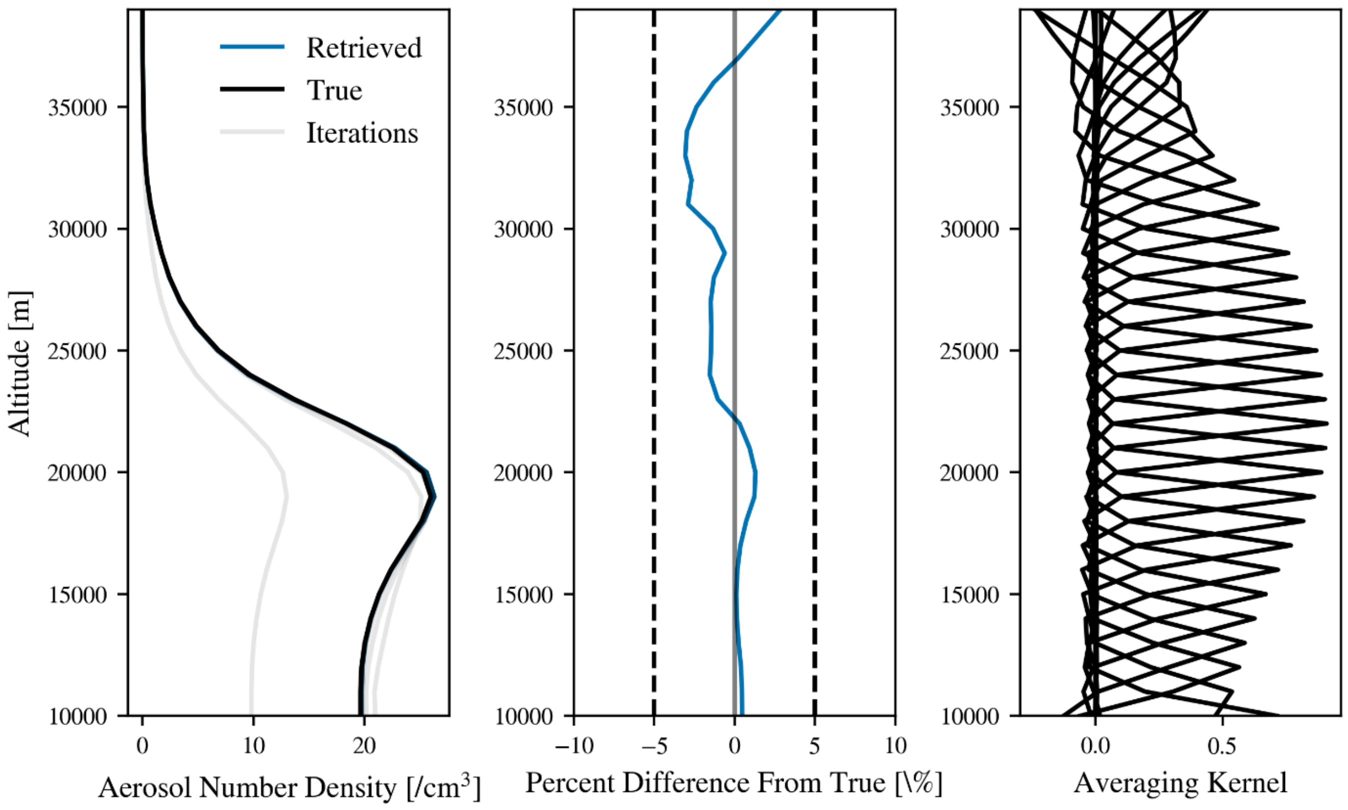
ALTIUS Aerosol Retrieval Approach

- Based on heritage from the OSIRIS and USask OMPS-LP algorithms
- Assume:
  - Particle size distribution – Representative single mode log-normal based on balloon in-situ measurements
- Retrieve:
  - Equivalent Lambertian surface reflectance by matching absolute limb radiances at 675 nm in upper stratosphere
  - Aerosol number density radiances at 745 nm (normalized to high altitude)
- Screen:
  - Cloud detection algorithm to set the lowest retrieved altitude
- Report
  - Extinction coefficient (much less sensitive to assumption on size)

ALTIUS Aerosol Retrieval

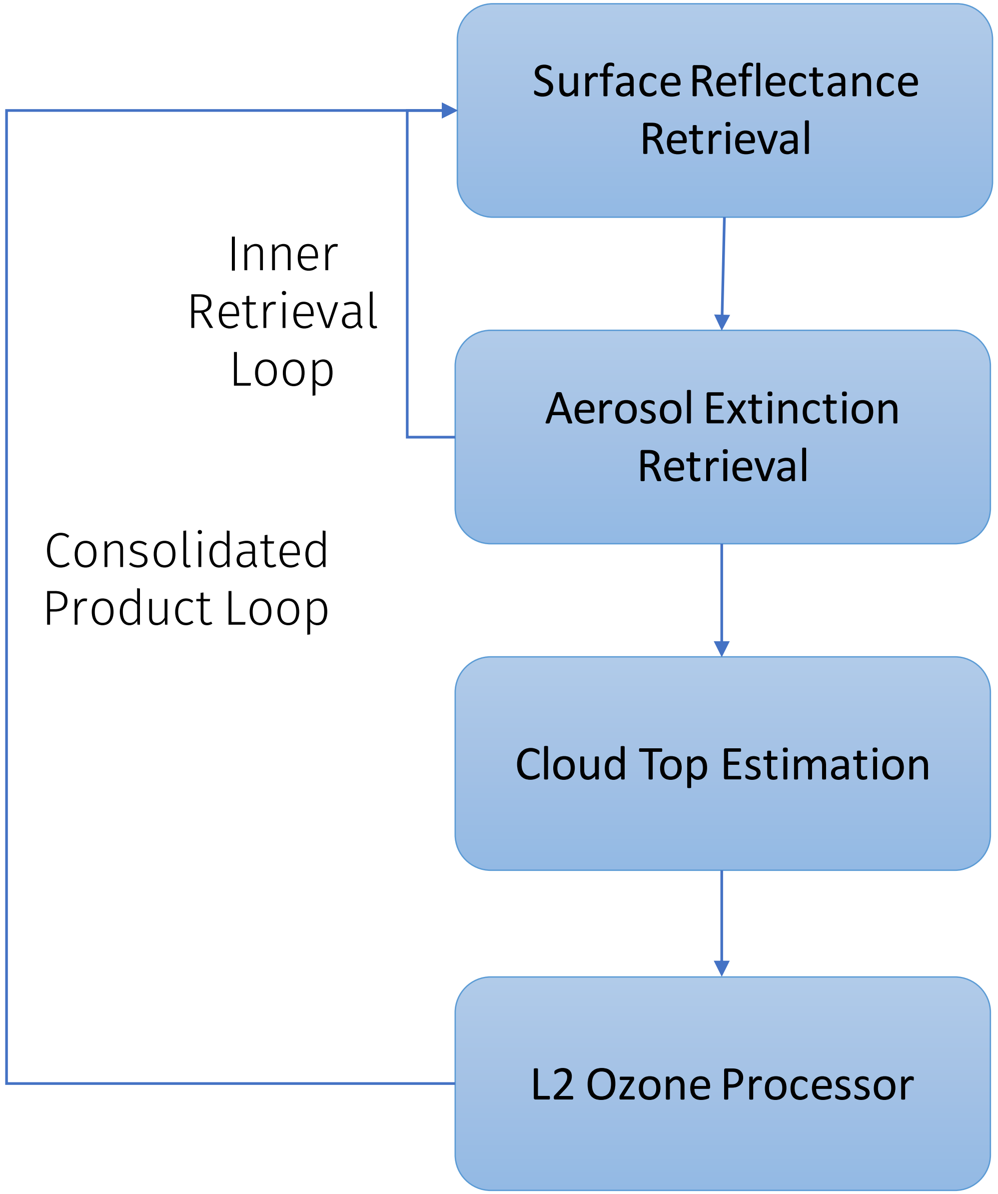
$$x_{i+1} = x_i + \left(K^T S_y^{-1} K + S_a^{-1} + \gamma diag\left(K^T S_y^{-1} K\right)\right)^{-1} \left[K^T S_y^{-1}\left(y - F(x_i)\right) - S_a^{-1}(x_i - x_a)\right],$$





Processing Chain

- First retrieve surface reflectance
- Then Aerosol
- Feed aerosol back into reflectance retrieval and repeat
- Estimate cloud top
- Provide results to L2 Ozone Processor
- For the consolidated product, the results of the ozone retrieval can be fed back and iterated



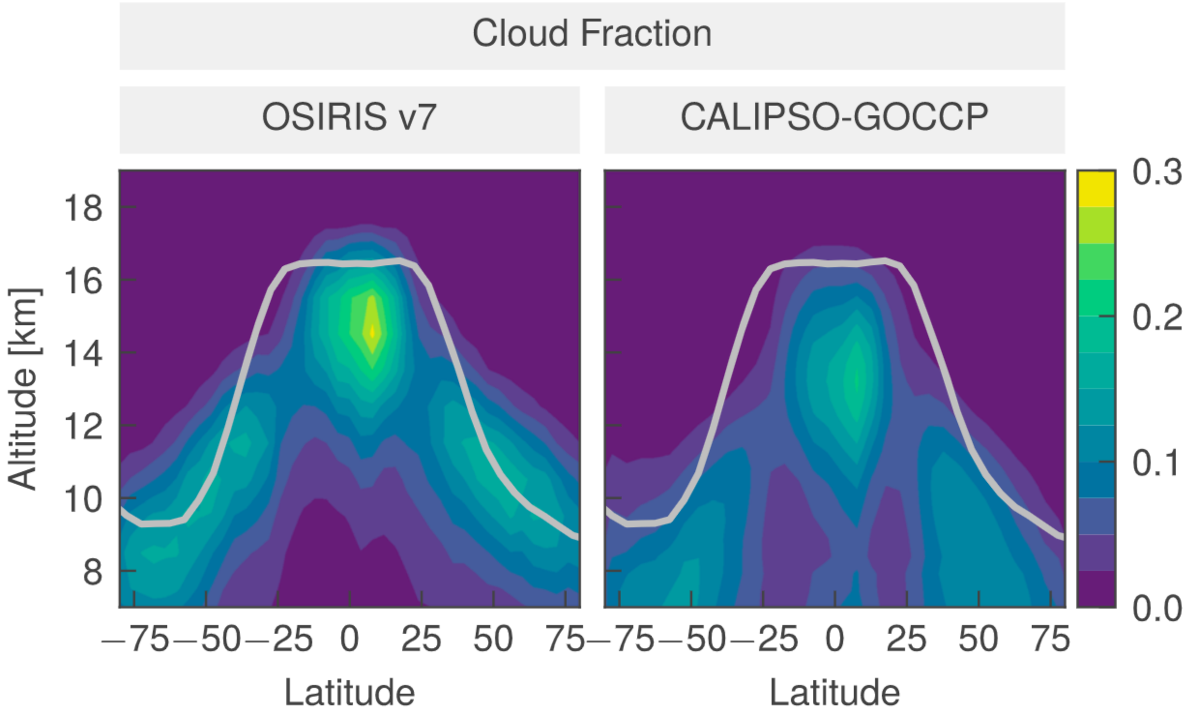
Cloud Detection

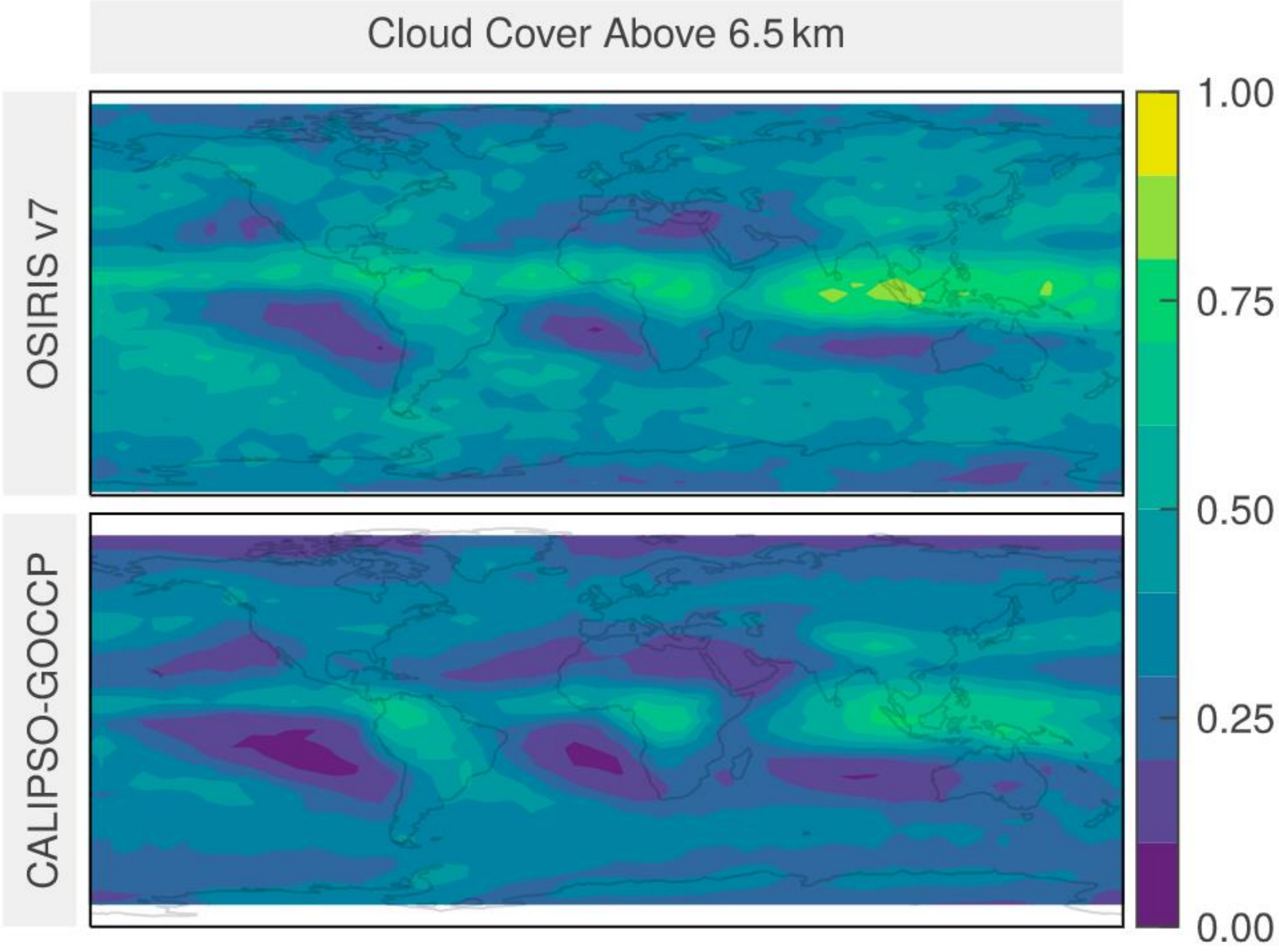
- Near tropopause, the aerosol signature is contaminated by clouds
  - Primarily cirrus (ubiquitous sub-visual in tropics)
- Cloud particles are large, and have a sharp vertical number density gradient

$$R = \frac{\partial \log I\,(745\,nm)}{\partial z} - \frac{\partial \log I\,(1020\,nm)}{\partial z}$$

- A threshold can be applied to R to detect clouds
  - False positives for large volcanic plumes
- Instead, we apply a threshold to $R \cdot (Retrieved\ Aerosol\ Extinction)$

OSIRIS Cloud Detection

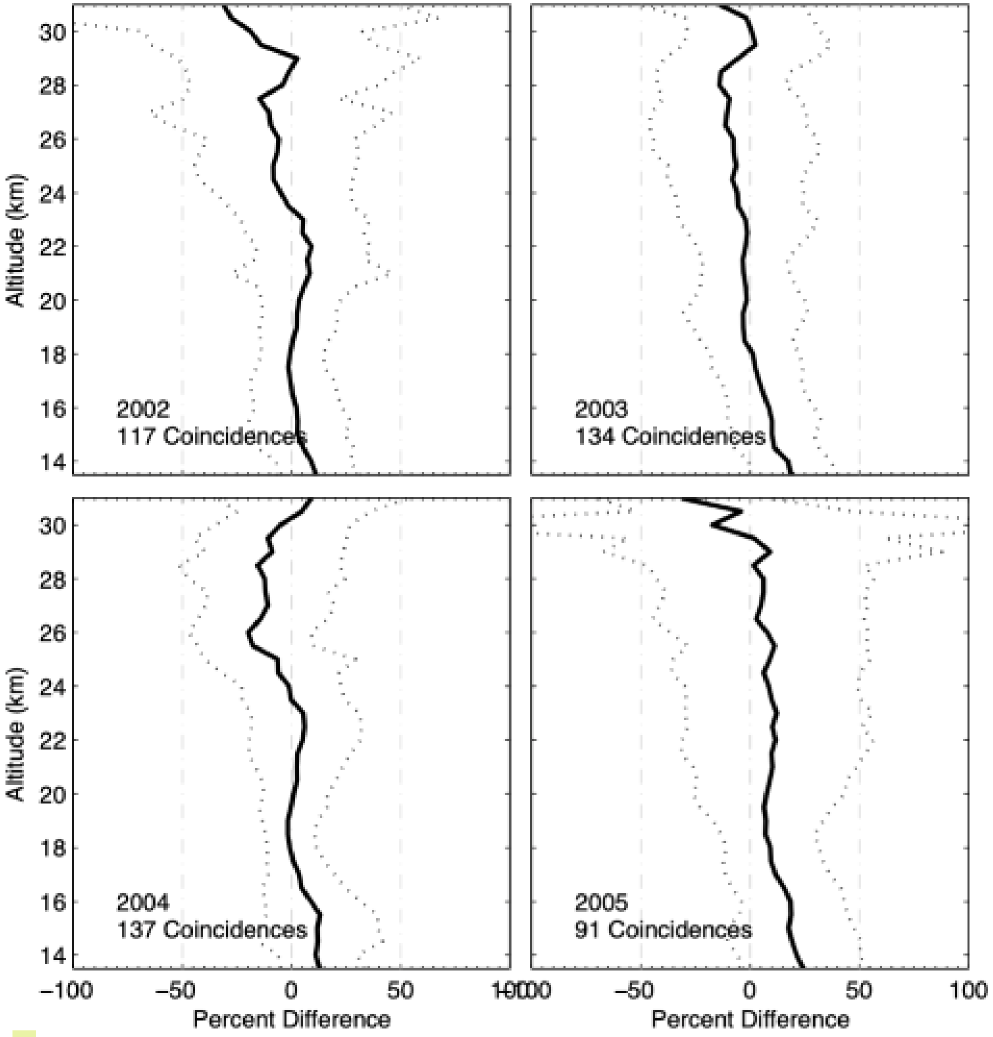




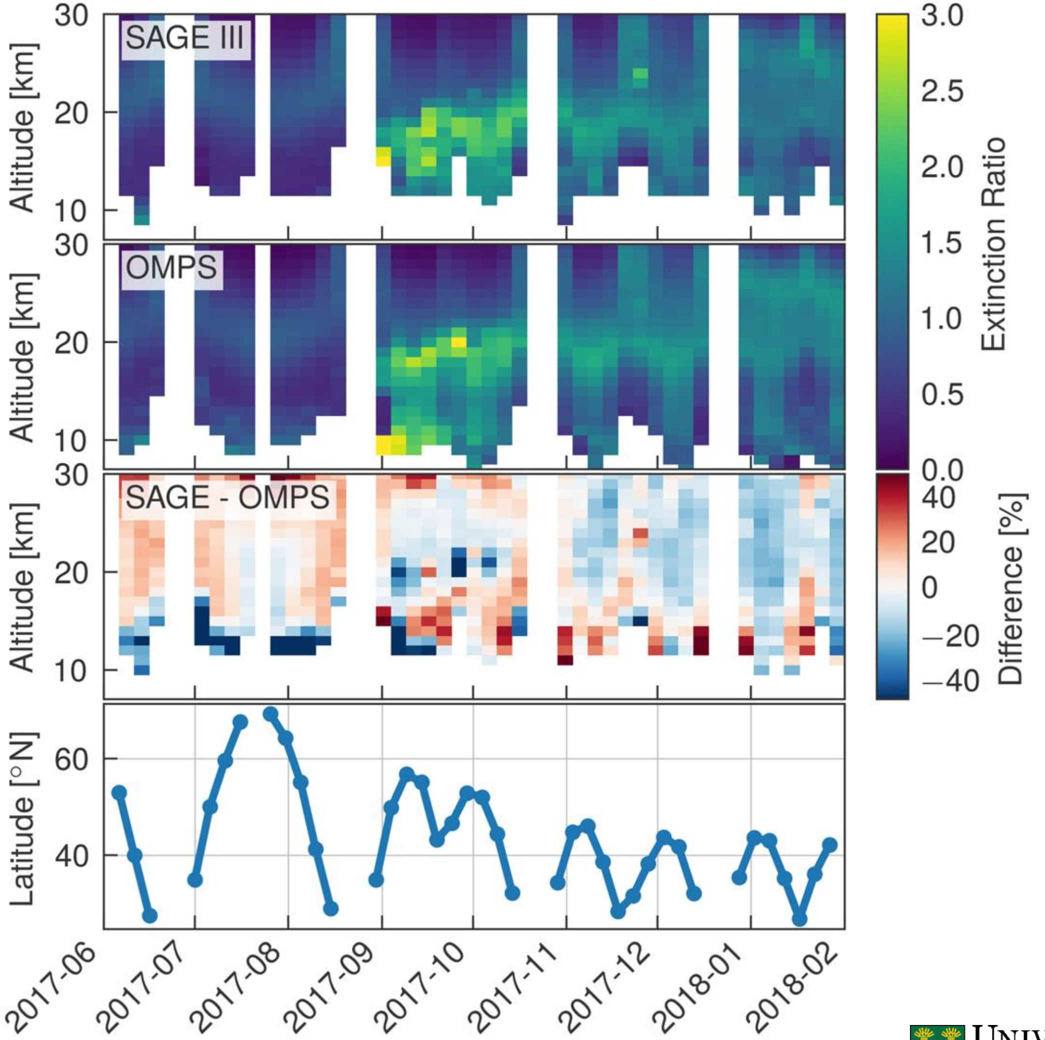
- Generally, detects clouds at a slightly larger frequency and higher altitude than CALIPSO-GOCCP
- Could be from higher sensitivity of limb scatter technique
- Mask aerosol extinction below the cloud top

Expected Performance

OSIRIS Compared to SAGE II in Quiet Period 2002-2004 (Best Case)



OMPS-LP Compared to SAGE III After 2017 Canadian Forest Fire (Worst Case)



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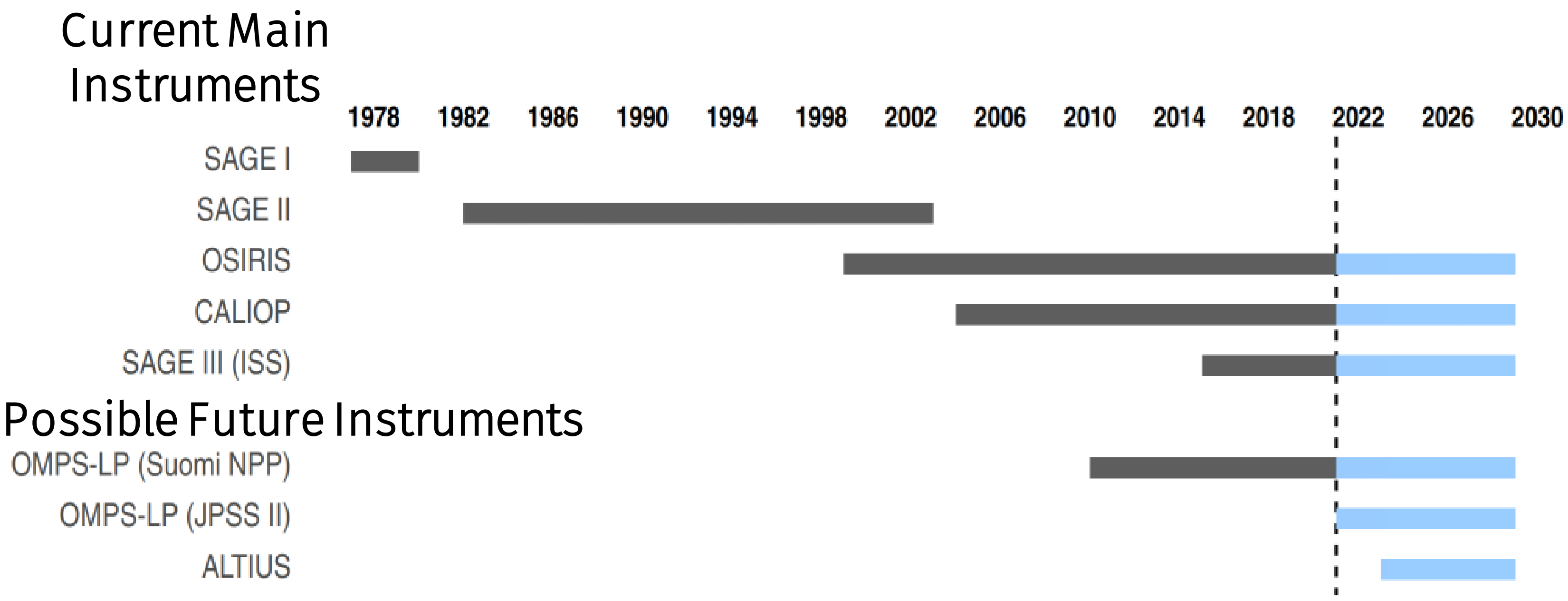
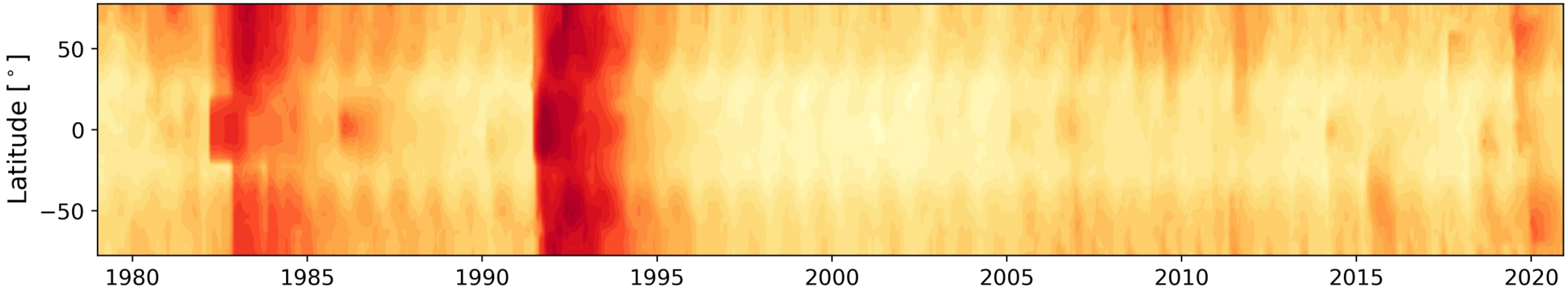
Contribution to Global Aerosol Record

- GloSSAC is a multi-instrument continuous stratospheric aerosol data-record that is used for many applications including the CMIP6 model runs
- Many of the included instruments are beyond their designed lifetime





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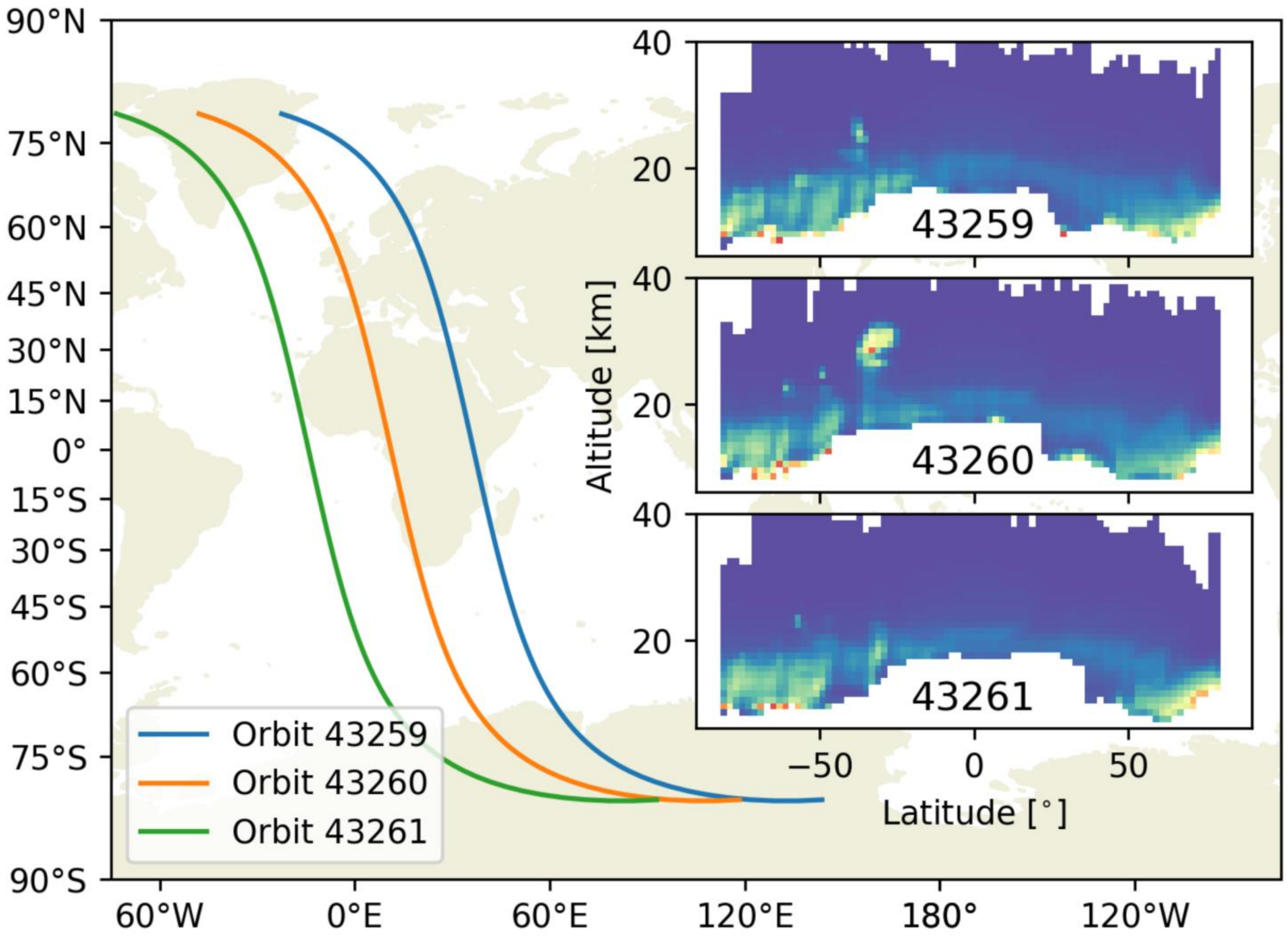
ALTIUS Imaging Benefits

- Three consecutive orbits of measurements from OMPS-LP
- Horizontal (cross-track) imaging of ALTIUS will provide a new and novel view of localized plumes

2020 Australian Forest Fires Event



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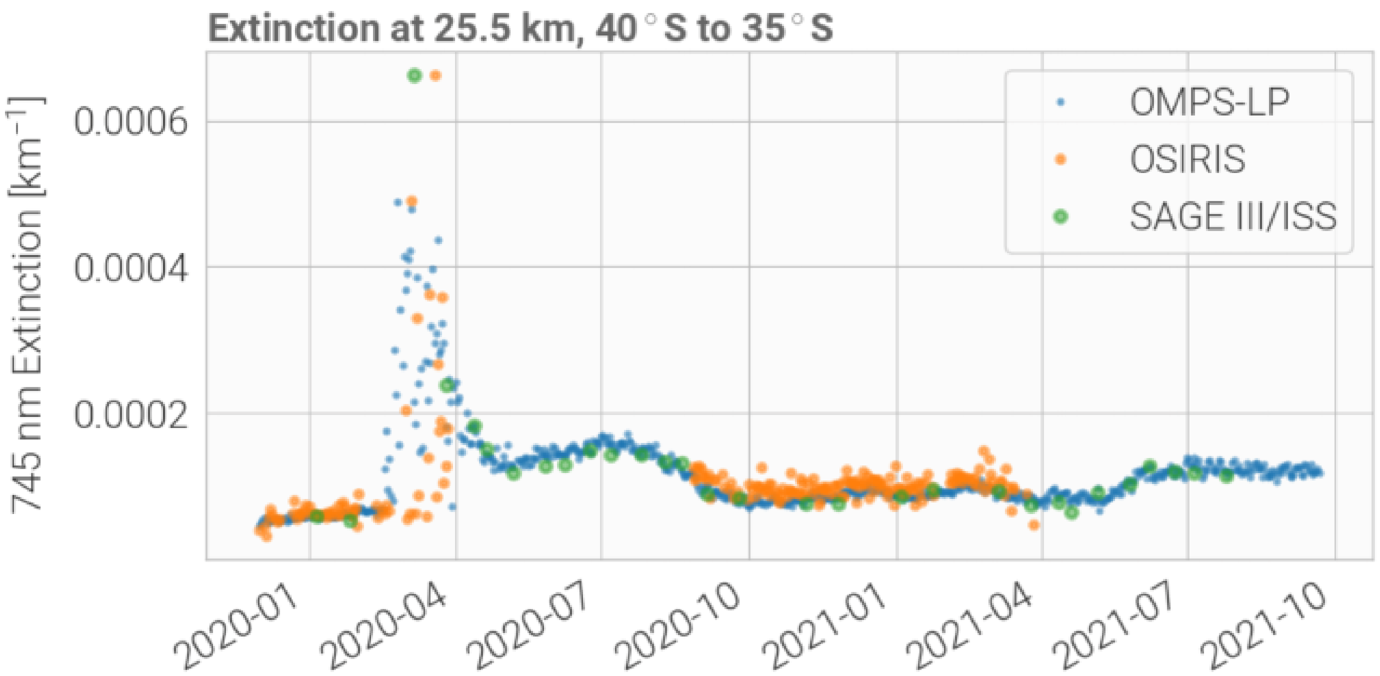
Conclusions

- Stratospheric aerosol both has large impacts on the atmosphere and interferes with the ozone retrieval
- A stratospheric aerosol retrieval has been implemented for ALTIUS based on OSIRIS/OMPS-LP algorithms – quite good performance expected
- ALTIUS can play a significant role in extending and maintaining the global stratospheric aerosol time series
- The imaging nature of ALTIUS will be helpful in understanding the horizontal and vertical extent of localized plumes

Back-up slides

Uncertainties in Localized Plumes

- Recent stratospheric aerosol events have large uncertainties at the time of injection
- Generally good agreement between different instruments before the injection and a few months after the injection
- Large standard deviation of the OMPS-LP measurements suggests that it is a sampling issue
  - OMPS-LP densely samples the along track dimension, must be a across-track (zonal) sampling issue



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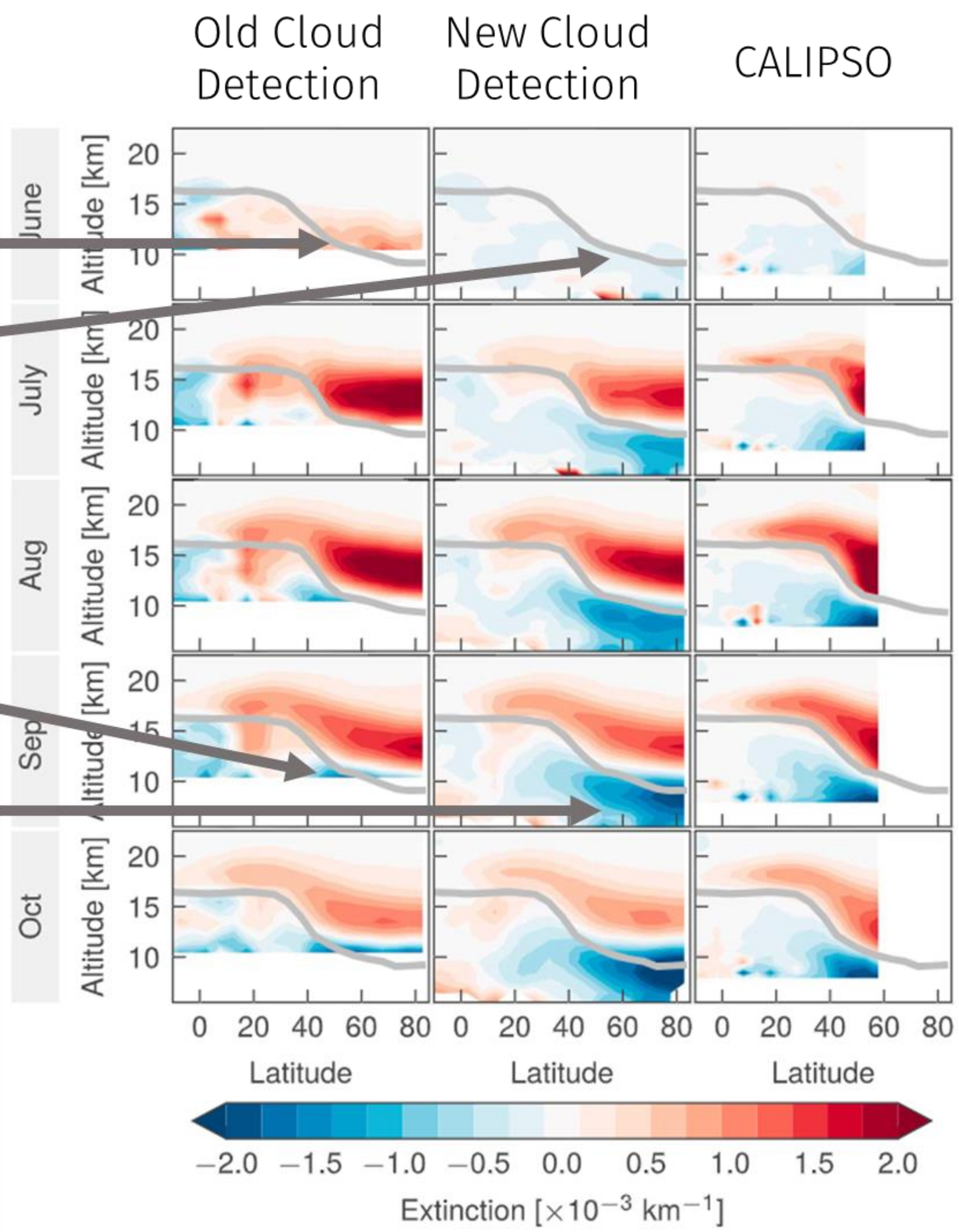
Evolution of Sarychev Eruption (OSIRIS)

- New cloud detection method has less contamination at the lower altitudes

- And pushes the retrieval farther into the UTLS



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