ATMOS 2024
July 1, 2024

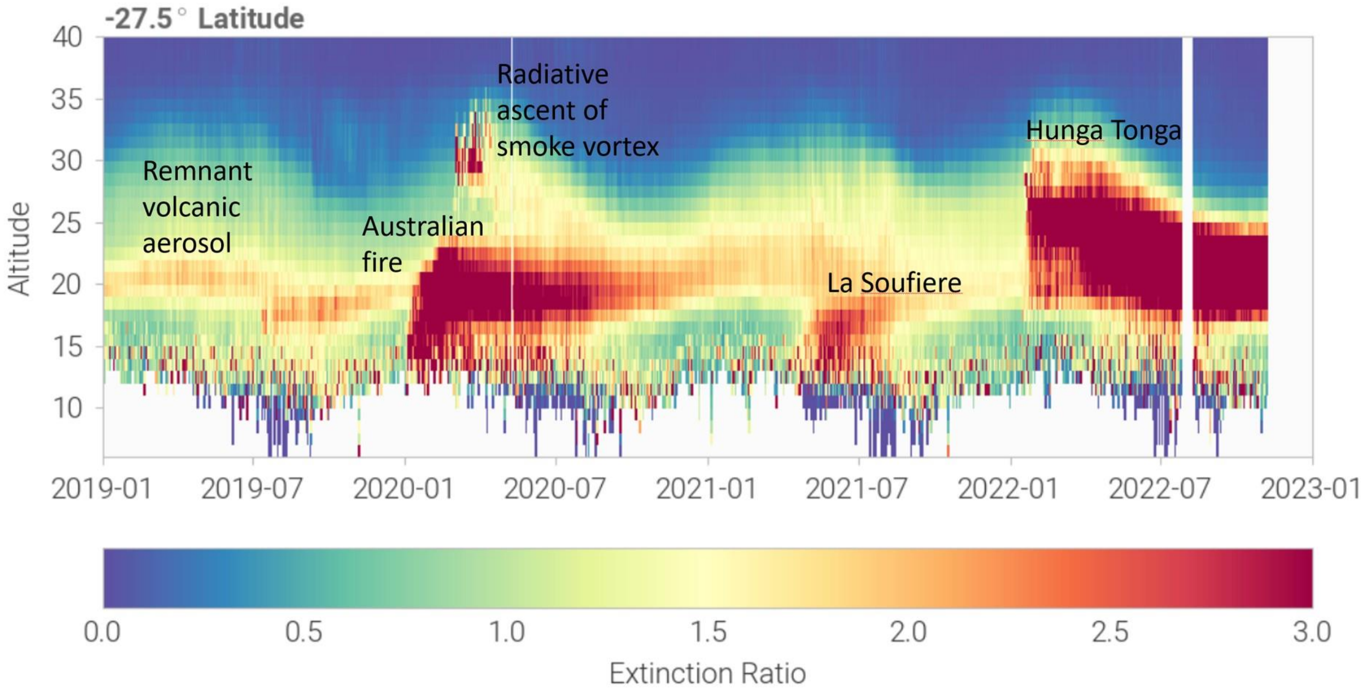
The ALTIUS Stratospheric Aerosol Data Product

Doug Degenstein, Adam Bourassa, Bion Larson, Daniel Zawada

University of Saskatchewan

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 volcanic and forest fire activity



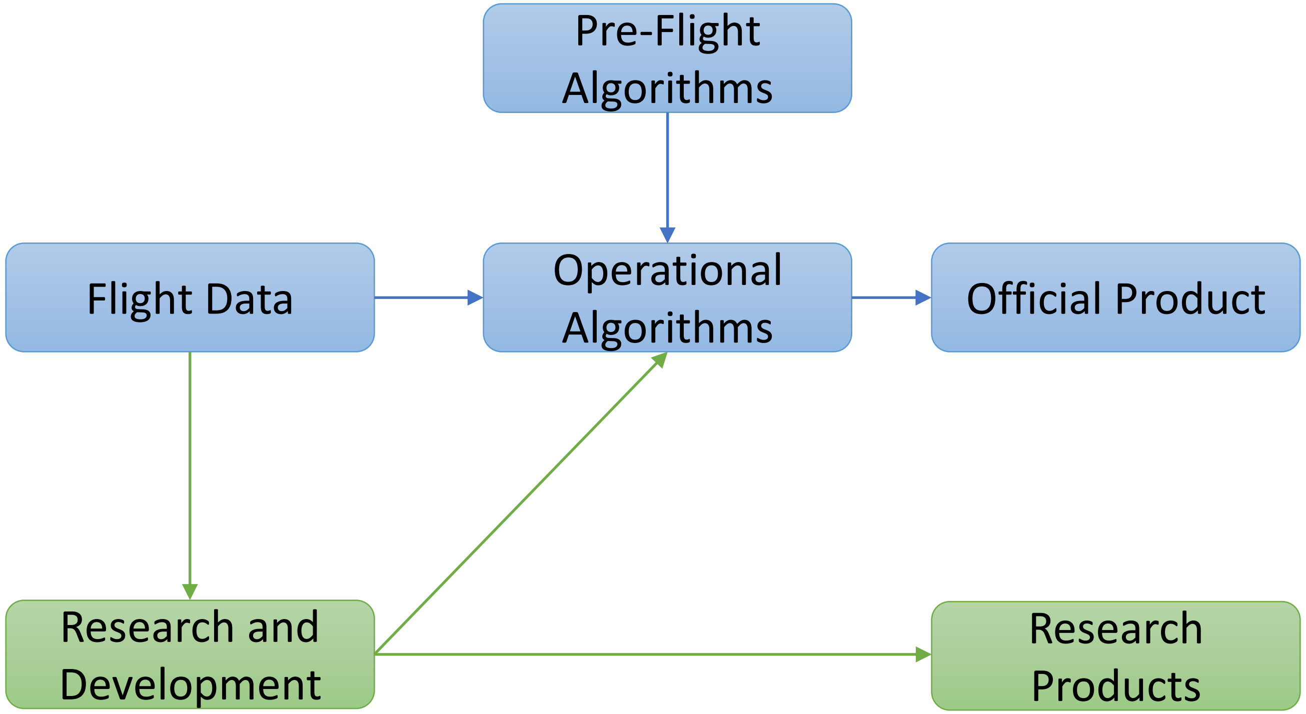
Stratospheric Aerosol with ALTIUS

- Contributes significant scattering to visible/near infrared wavelengths
  - Ozone interference in the Chappuis absorption band
  - Not what I am going to talk about today

- Today: The secondary product retrieval and how 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)

Aerosol Secondary Product Philosophy

- Our experience is that there are always unknowns with real flight data
- Having a well tested algorithm that is known to work with other instruments lets us get a useful data product out quickly
    - Aerosol secondary product is based upon decades of experience with OSIRIS + OMPS-LP
- Opportunity for future improvements in a more research sense



General ALTIUS Aerosol Retrieval Approach

- Based on heritage from the OSIRIS and USask OMPS-LP algorithms
- Assume:
  - Particle size distribution + Composition – 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 using radiances at **multiple wavelengths**
- Screen:
  - Cloud detection algorithm to set the lowest retrieved altitude
- Report:
  - Extinction coefficient at a reference wavelength (much less sensitive to assumption on size/composition)

Differences from Aerosol used for Ozone Correction

Aerosol Used in Ozone Correction		Secondary Product Aerosol
Single wavelength	→	Multiple wavelengths optimized to reduce sensitivity to particle size
Low vertical resolution, tied to ozone retrieval	→	Vertical resolution optimized for ALTIUS SNR/sampling
Horizontal resolution tied to ozone retrieval		Opportunities to perform higher horizontal resolution retrievals (depending on binning, etc) for extreme events

Multiple Wavelength Retrieval

- The original OSIRIS retrieval used 750 nm radiances normalized by 470 nm radiances
  - It was thought the normalization reduces sensitivity to Rayleigh scattering and particle size
- A study by Rieger et. al. (2018) showed that normalizing by 470 nm helps in backscatter, but is harmful in forward scatter
  - Different “regimes” of aerosol effects, in forward scatter the single scatter phase function is dominant, in backward scatter the “integrated” phase function is more important (multiple scatter)
- For OSIRIS V7 we developed a way to dynamically adjust this normalization on a scan by scan basis

Multiple Wavelength Retrieval

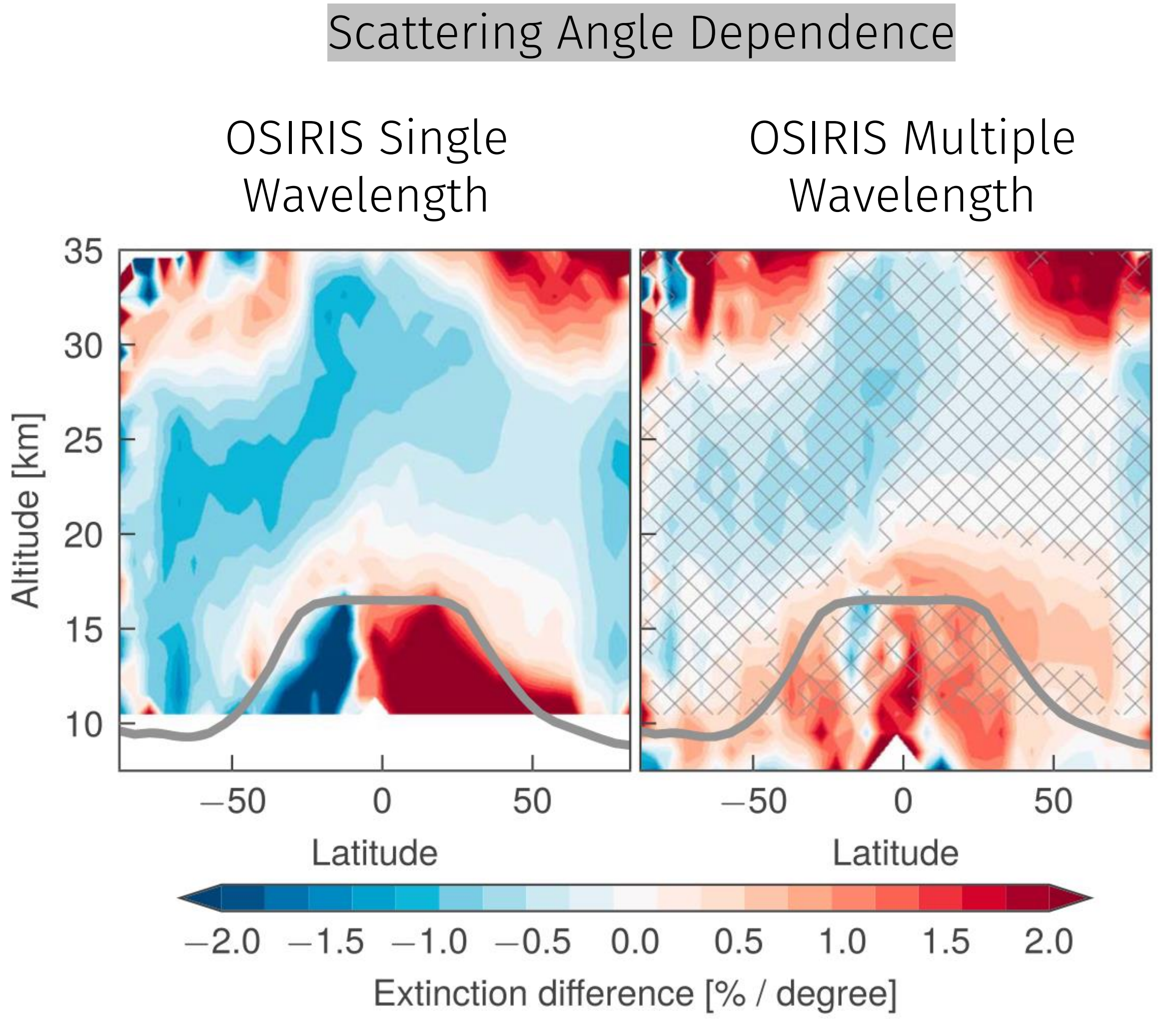
- At each altitude we calculate

$$y = w_1 \log(I(470nm)) + w_2 \log(I(675nm)) + w_3 \log(I(750nm)) + w_4 \log(I(805nm))$$

- The original OSIRIS retrieval was w = [-1, 0, 1, 0]
- The ALTIUS aerosol retrieval in the ozone retrieval is w = [0, 0, 1, 0]
- For the secondary product we maximize the information content of the retrieval by adjusting the weights for each measurements
  - Reduces sensitivity to measurement geometry
  - Tends to cancel some errors due to particle size
- The exact wavelengths used are flexible, and will be tailored to ALTIUS instrument performance
  - Baseline before the flight, easy to adjust during commissioning if necessary

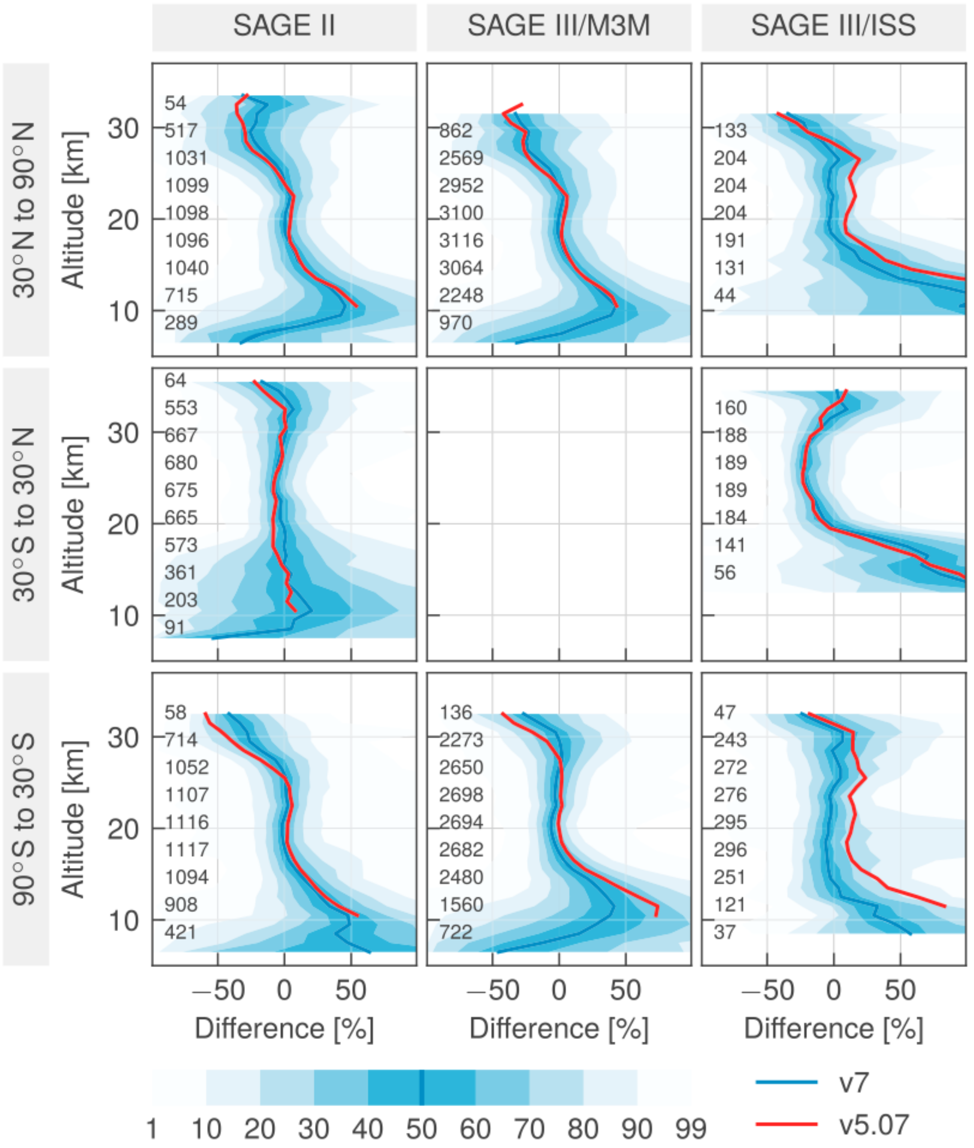
Example Improvement

- Extinction should be relatively insensitive to scattering geometry
- For OSIRIS we measure the same air mass each day with different scattering angles
  - Multiple wavelength retrieval reduces biases between these two measurements
- We hope to validate ALTIUS similarly using limb/occultation matching



Expected Performance/Improvement

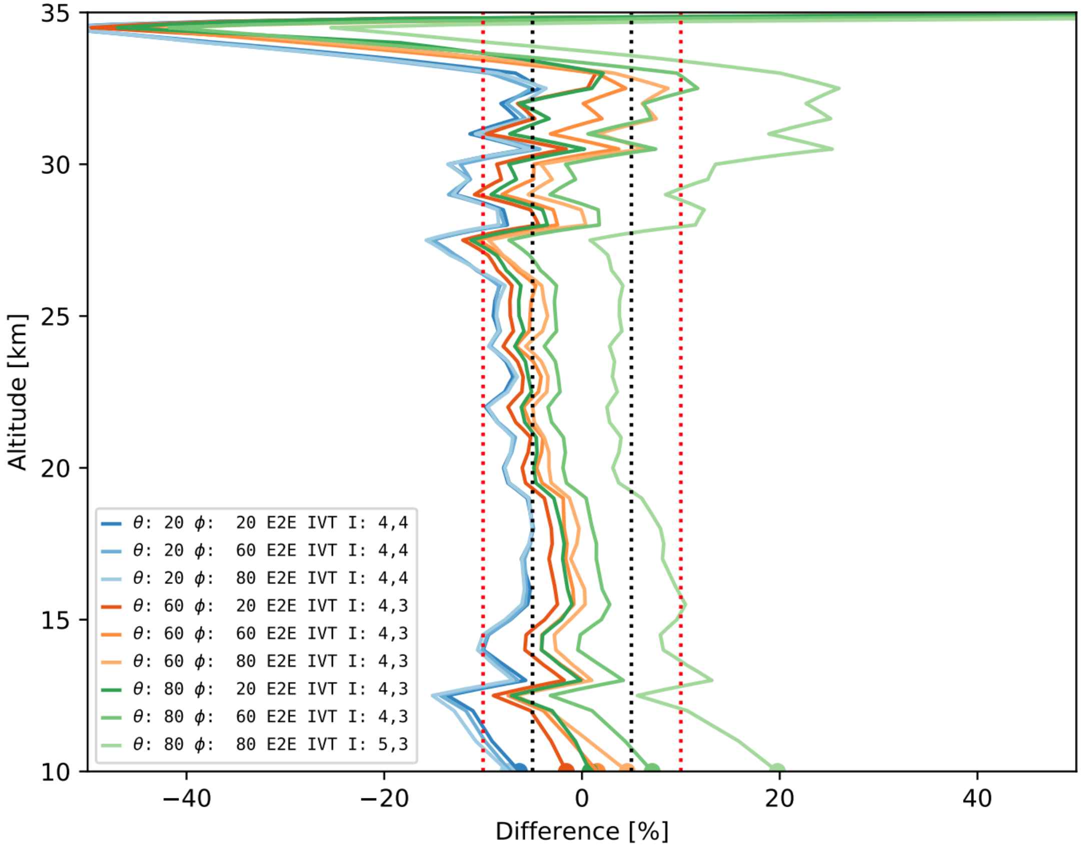
- For OSIRIS we see overall improvement in the multiple wavelength retrieval
  - Largest improvement with respect to SAGE III where the scattering geometry may not be uniformly distributed
- Impact on ALTIUS is expected to be larger because of the more extreme scattering geometries viewed



University of Saskatchewan

Algorithm Status

- Initial version of the algorithm has been implemented into the ALTIUS processing chain
- Full End-to-End simulations are being done with realistic instrument models to assess expected errors
- Currently expect instrumental errors on the order of ~5-10% primarily from straylight
  - Considering algorithm updates to improve the performance

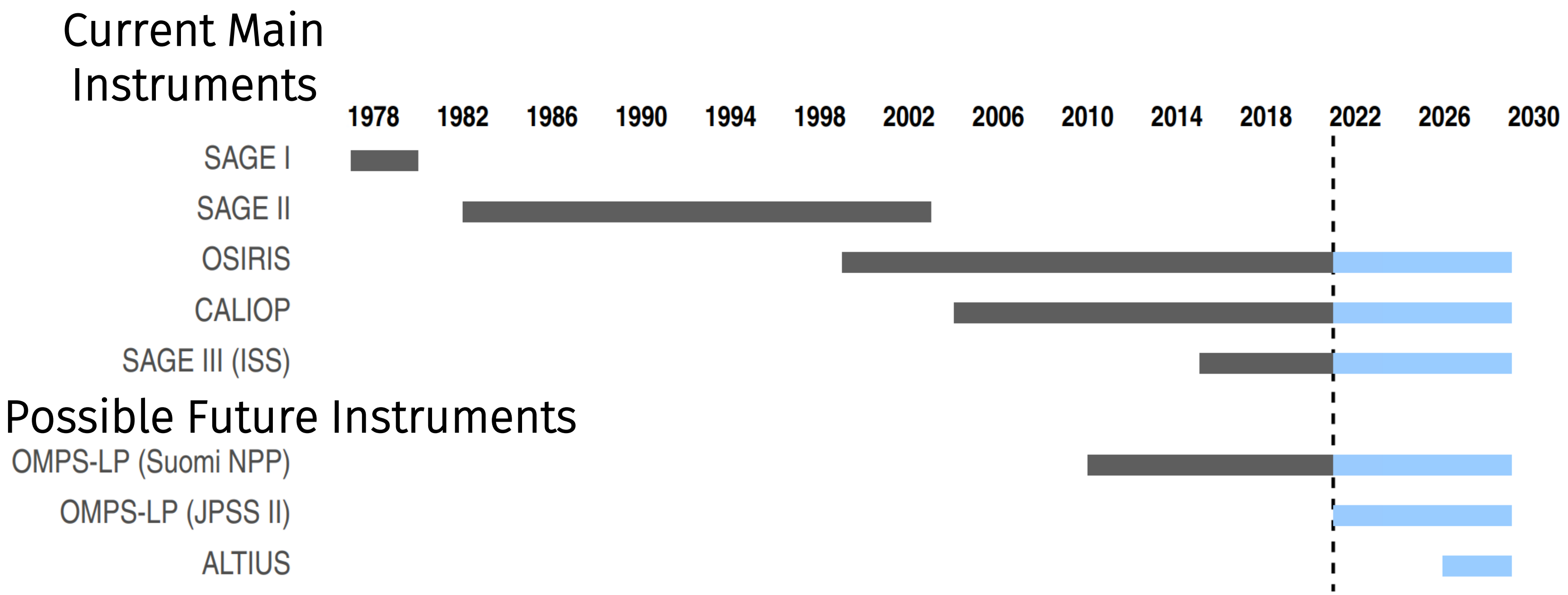


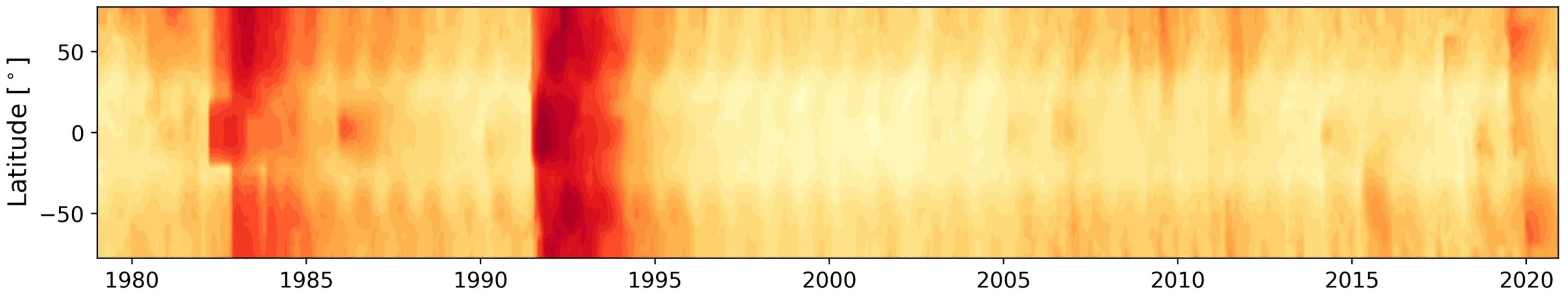
University of Saskatchewan

ALTIUS Aerosol Science Contributions

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



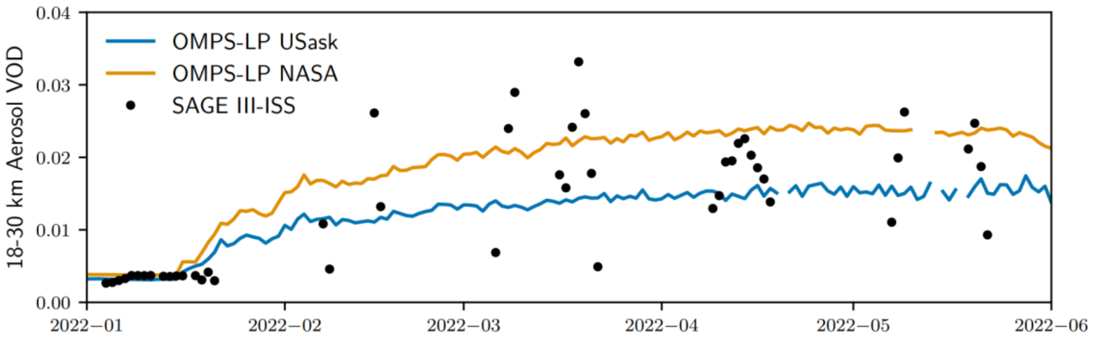


University of Saskatchewan

ALTIUS Contribution to Uncertainty Understanding

- This will be the first time period we have two super dense sampling aerosol instruments (ALTIUS + OMPS-LP)
  - + ALTIUS occultation
- There are still very large uncertainties on estimating AOD injections from large events
  - Different retrievals from the same instrument can have factors of 2 differences
- Potential to learn a lot about what is possible with limb scatter aerosol

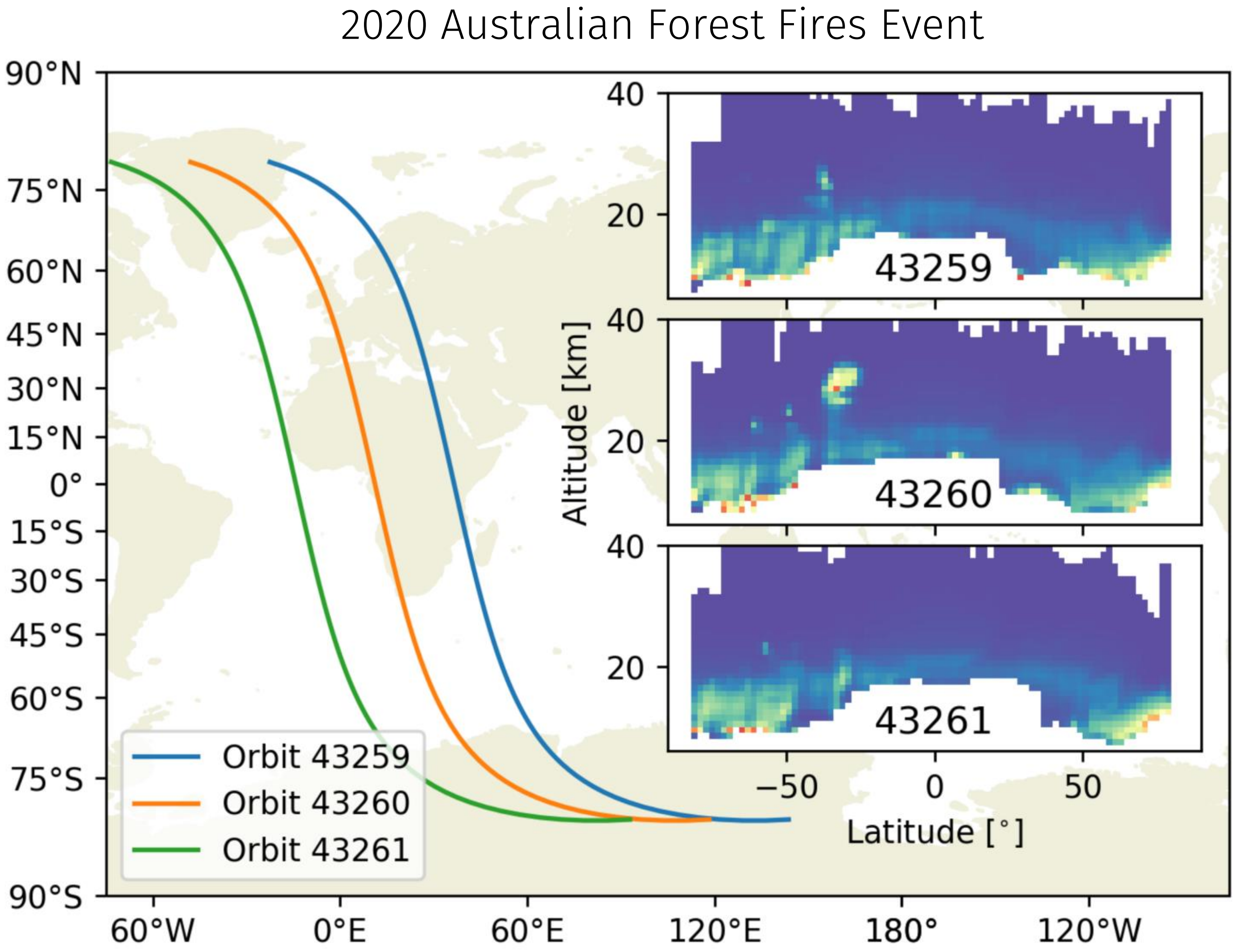
Hunga Tunga Eruption SAOD



UNIVERSITY OF SASKATCHEWAN

ALTIUS Imaging Benefits

- Recent events have caused highly localized horizontal structures
- Three consecutive orbits of measurements from OMPS-LP
- Horizontal (cross-track) imaging of ALTIUS will provide a new and novel view of localized plumes



UNIVERSITY OF SASKATCHEWAN

Conclusions

- Stratospheric aerosol both has large impacts on the atmosphere and interferes with the ozone retrieval
- A multi-wavelength retrieval algorithm is proposed for an aerosol secondary product based on state of the art OSIRIS algorithms
  - Will also be used as auxiliary input to improve the ozone retrieval
- ALTIUS can play a significant role in extending and maintaining the global stratospheric aerosol time series
  - Comparisons with OMPS-LP will offer a wealth of information on what is possible with limb scatter aerosol retrievals
- The imaging nature of ALTIUS will be helpful in understanding the horizontal and vertical extent of localized plumes

Conclusions

- Stratospheric aerosol both has large impacts on the atmosphere and interferes with the ozone retrieval
- A multi-wavelength retrieval algorithm is proposed for an aerosol secondary product based on state of the art OSIRIS algorithms
  - Will also be used as auxiliary input to improve the ozone retrieval
- ALTIUS can play a significant role in extending and maintaining the global stratospheric aerosol time series
  - Comparisons with OMPS-LP will offer a wealth of information on what is possible with limb scatter aerosol retrievals
- The imaging nature of ALTIUS will be helpful in understanding the horizontal and vertical extent of localized plumes

Thank you!

Back-up slides

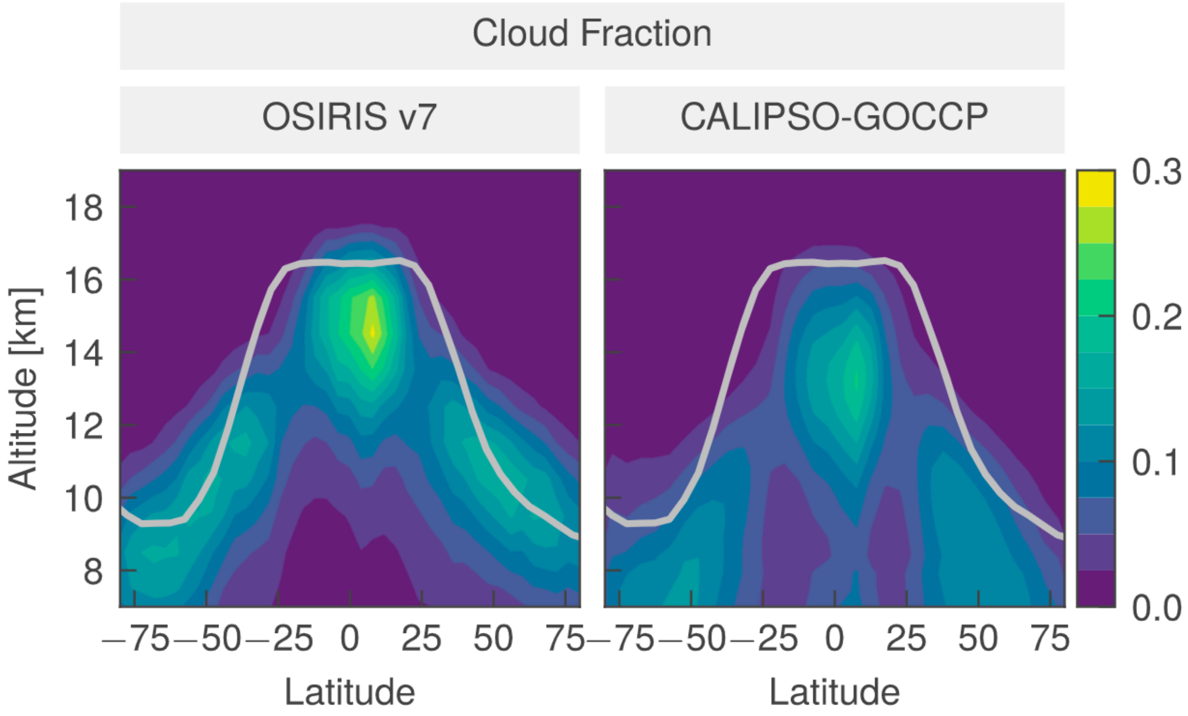
Cloud Detection

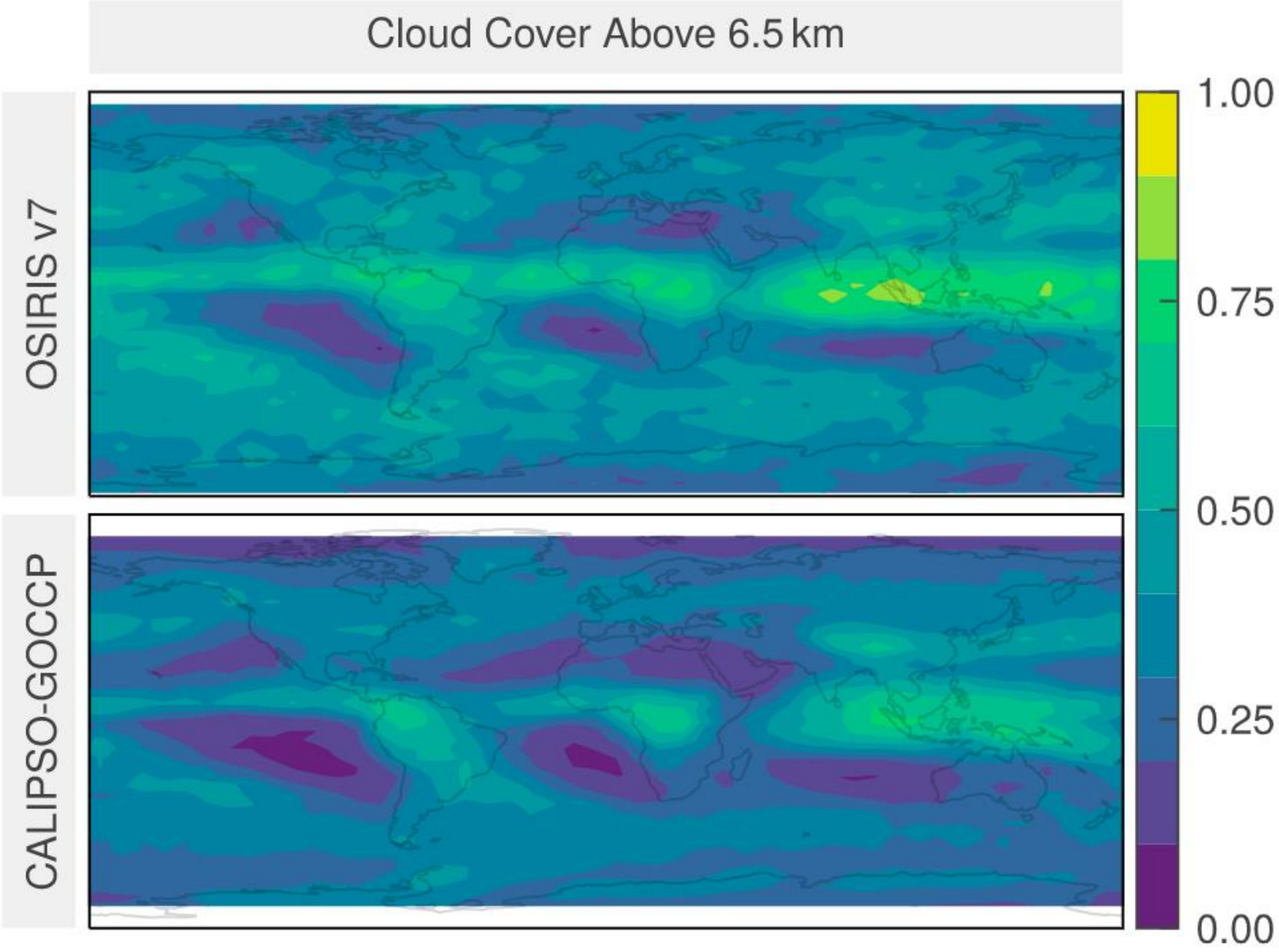
- Near tropopause, the aerosol signature is contaminated by clouds
  - Primarily cirrus (ubiquitous sub-visual in tropics)
- Cloud particles are large, and have a sharp vertical number density gradient

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

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

Cloud Detection Applied to OSIRIS





- 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

University of Saskatchewan

Lower Bound Improvements

- Typically we only consider aerosol information useful above the cloud top
- The normal way to handle this is to retrieve to a low altitude (~6-10 km) and then screen the data for clouds afterwards
- Retrieving into a thick cloud can cause problems at higher altitudes
  - Influences the radiative upwelling
  - Retrieval sometimes adds oscillations at upper altitudes to better match the low altitude cloud viewing lines of sight