Evolution of the stratospheric aerosol enhancement following the Kasatochi eruption: Odin-OSIRIS measurements

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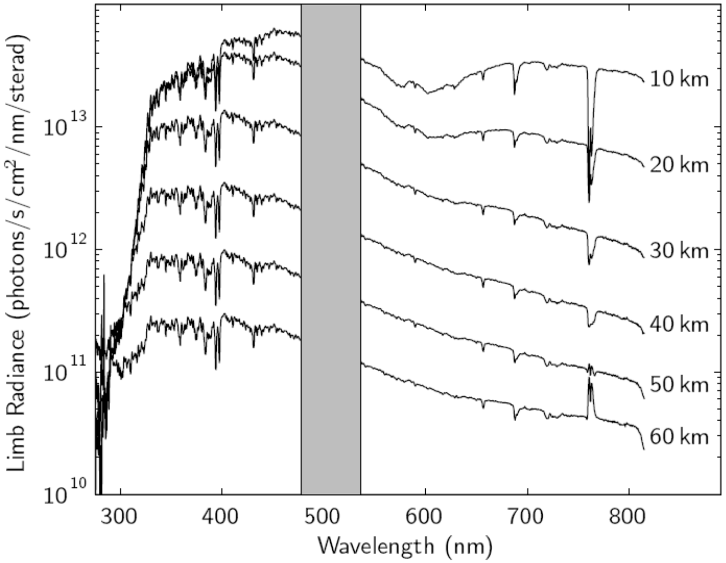
5th Limb Workshop, Helsinki, Finland

November 17, 2009

Optical Spectrograph and Infrared Imager System (OSIRIS)

OSIRIS does limb scanning and limb imaging

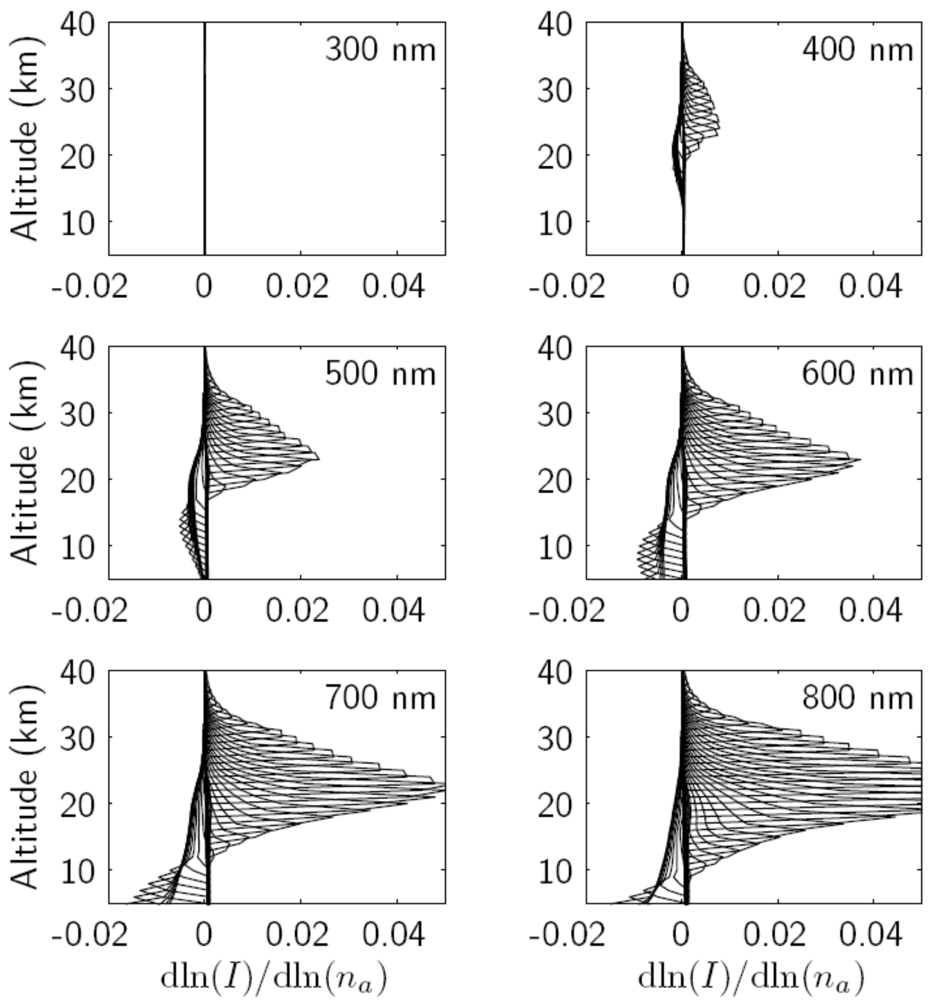
1) Optical Spectrograph
   - Single line of sight, narrow horizontal slit
   - Grating spectrograph, 280-810 nm, 1 nm res
   - Auto-exposed limb scan
2) Infrared Imager
   - Three channel filtered vertical imager
   - 1.26 and 1.27 micron singlet delta O_2
   - 1.53 micron OH Meinel



Eight years of data – the last 2 have been 100% aeronomy
New version of the MART processing underway

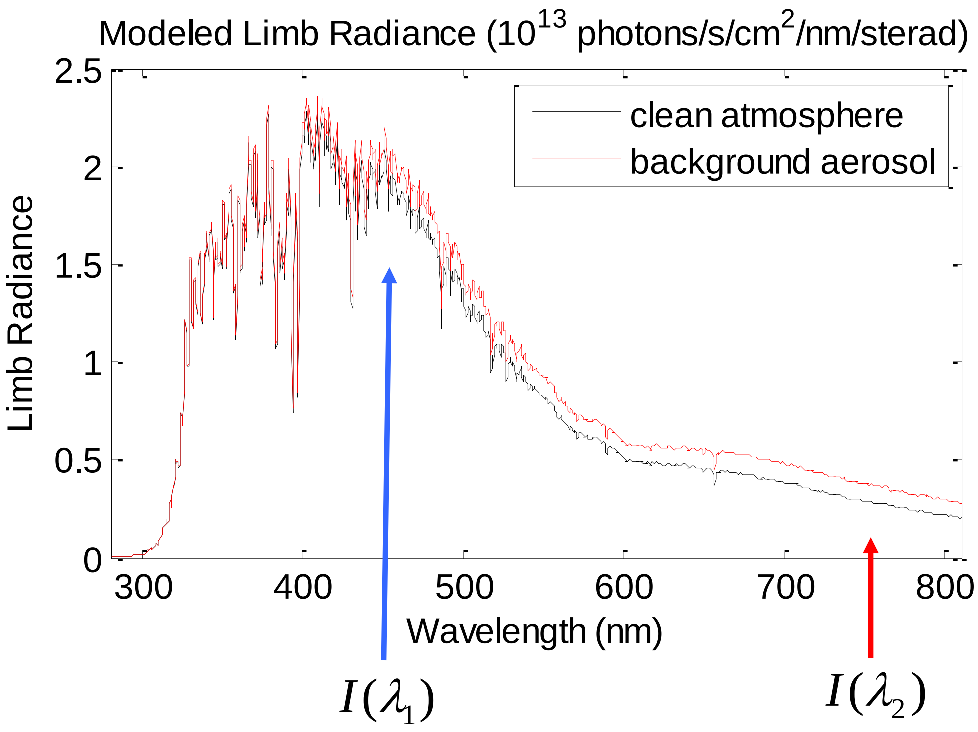
The Limb Scatter Signature of Stratospheric Aerosol

Aerosol Weighting Functions (Jacobian)



- Visible/NIR stratospheric aerosol signal is well characterized by Mie scattering (liquid droplets around 0.1 to 0.3 micron radius)
- Cross section spectrum is a relatively weak function of wavelength
- Enhancement and attenuation effects that depend on (aerosol) optical depth

Typical limb spectrum at 22 km tangent altitude



The Measurement Vector

$$y = \log\left(\frac{I(\lambda_2)}{I(\lambda_1)}\right) - \log\left(\frac{I_R(\lambda_2)}{I_R(\lambda_1)}\right)$$

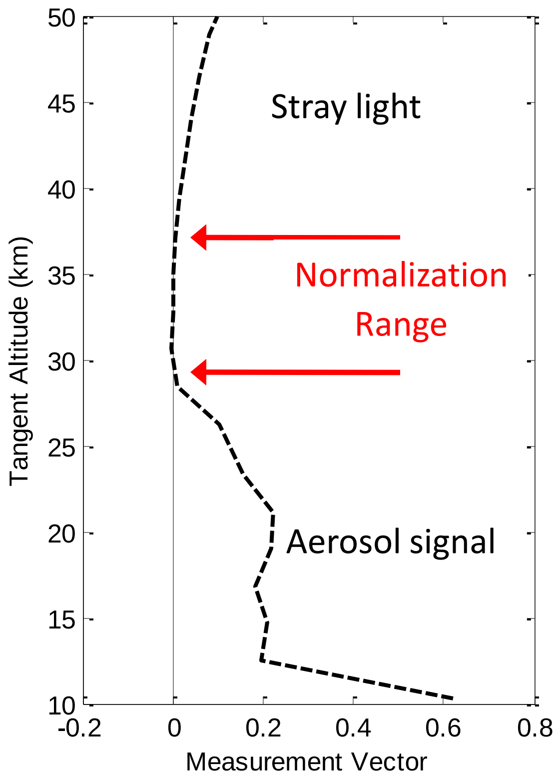
$I_R(\lambda) \equiv$ Model with no aerosol

Effectively a measure of the residual scattering (positive Jacobian required)

This is always a positive quantity even in the presence of a gas absorption

** No tangent altitude normalization in a traditional sense, rather a *shift* of the measurement vector profile.

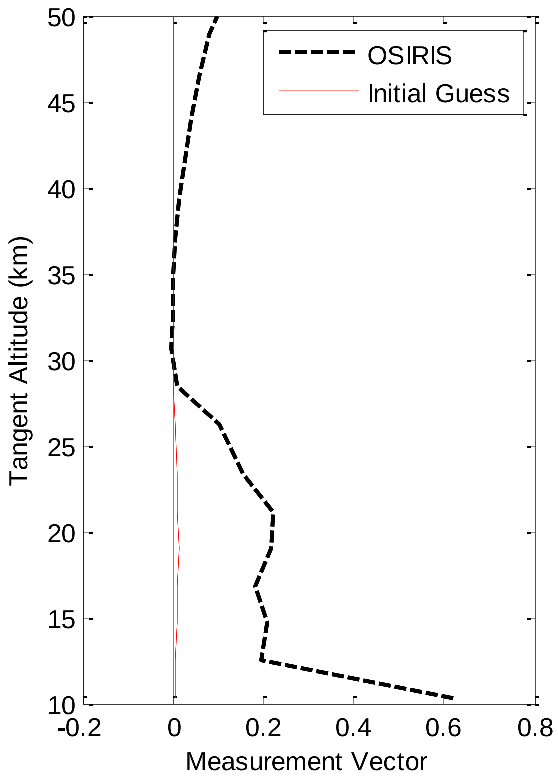
The Measurement Vector for a typical mid-latitude OSIRIS limb scan



- A tangent altitude normalization creates a measurement vector value of zero at the normalization
- Use the error in the radiance to define a detectable aerosol signal threshold
- Use all tangent altitudes less than the threshold to normalize, i.e. shift the mean to zero

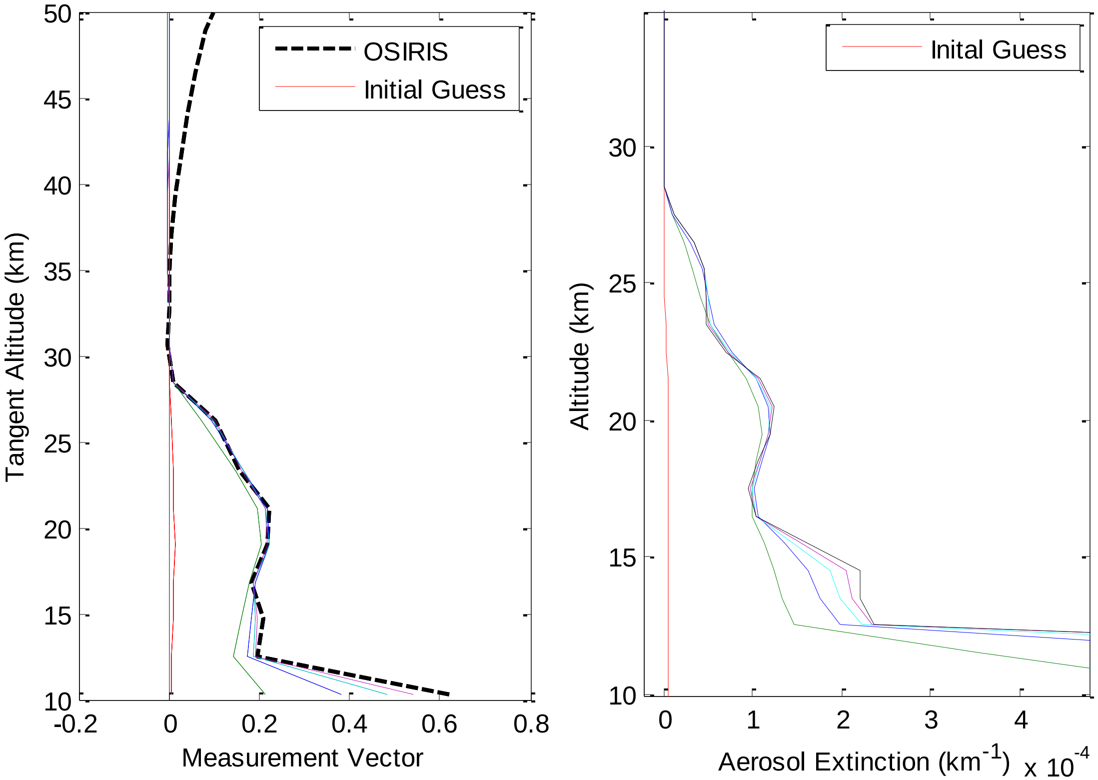
The OSIRIS Aerosol Retrieval: Methodology

The Measurement Vector for a typical mid-latitude OSIRIS limb scan



- Assume a particle size distribution to calculate phase functions and cross section ratio
- Choose an initial guess profile that represents a very low aerosol load
- This ensures a positive Jacobian at all tangent altitudes for the first iteration
- For a multiple wavelength retrieval, do the longest wavelengths first
- Iterate using the MART inversion (one spectral dimension, i.e. k=1)

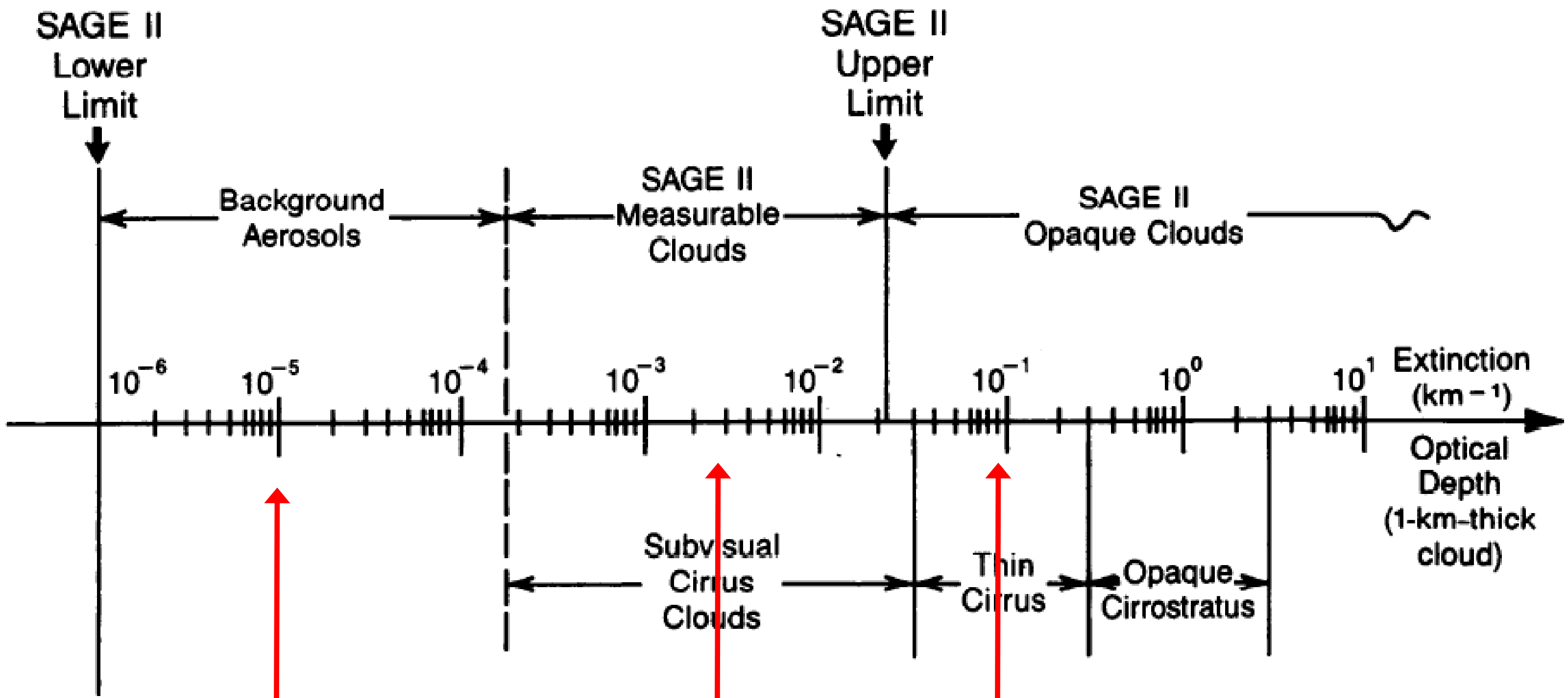
The first 5 iterations of the inversion



- •Typically attains convergence in the stratosphere within 6 to 8 iterations
- •Increasing optical depth at low altitude can lead to negative Jacobian
- •Clouds present a challenge
- •Effective surface reflectivity required to fit the measurements within the normalization range changes by up to 20-30% after the aerosol retrieval
- •Results are sensitive to radiative transfer assumptions (grid discritizations, multiple scattering)

OSIRIS Aerosol Retrieval: Dynamic Range

Figure 1 from Wang et al., JGR, 1996: The measurement range of the SAGE II 1-micron aerosol extinction coefficient



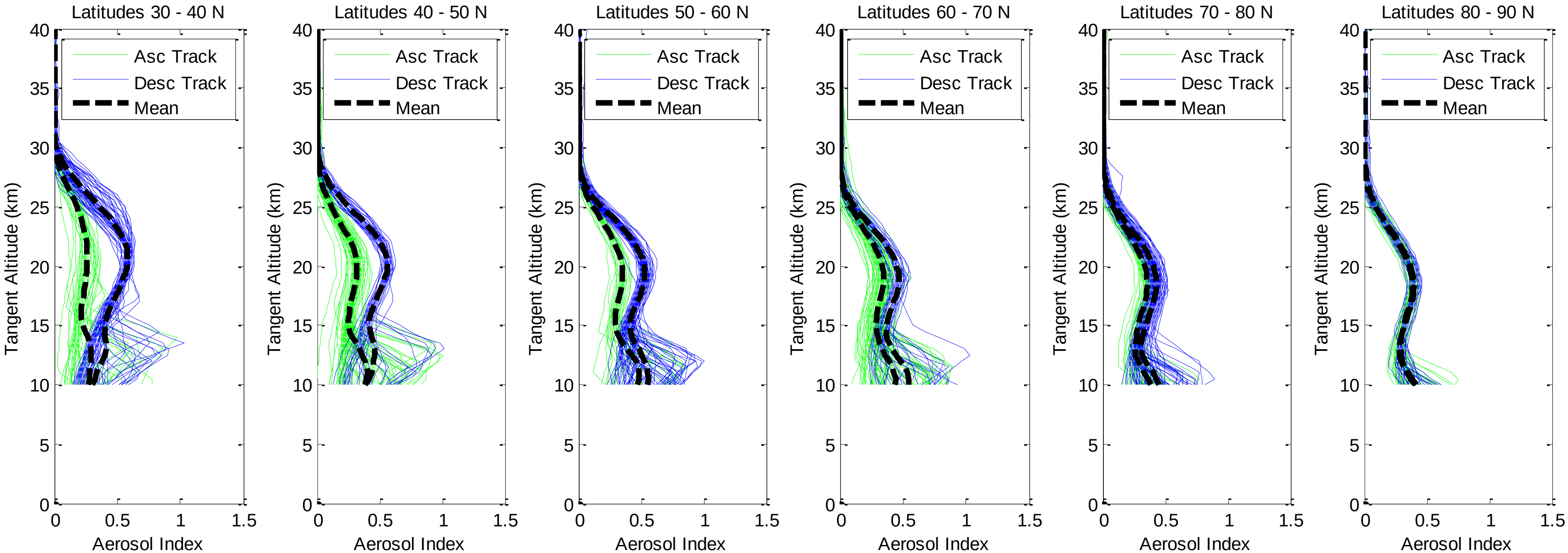
OSIRIS lower limit. Defined by signal to noise in the upper stratosphere. Converted from 750 nm to 1 micron using the assumed particle size distribution.

Upper limit for trace gas retrieval. A conservative estimate that will be pushed in the future.

OSIRIS upper limit. Defined by saturation of the exposure. Requires correct cloud particle scattering – very approximate.

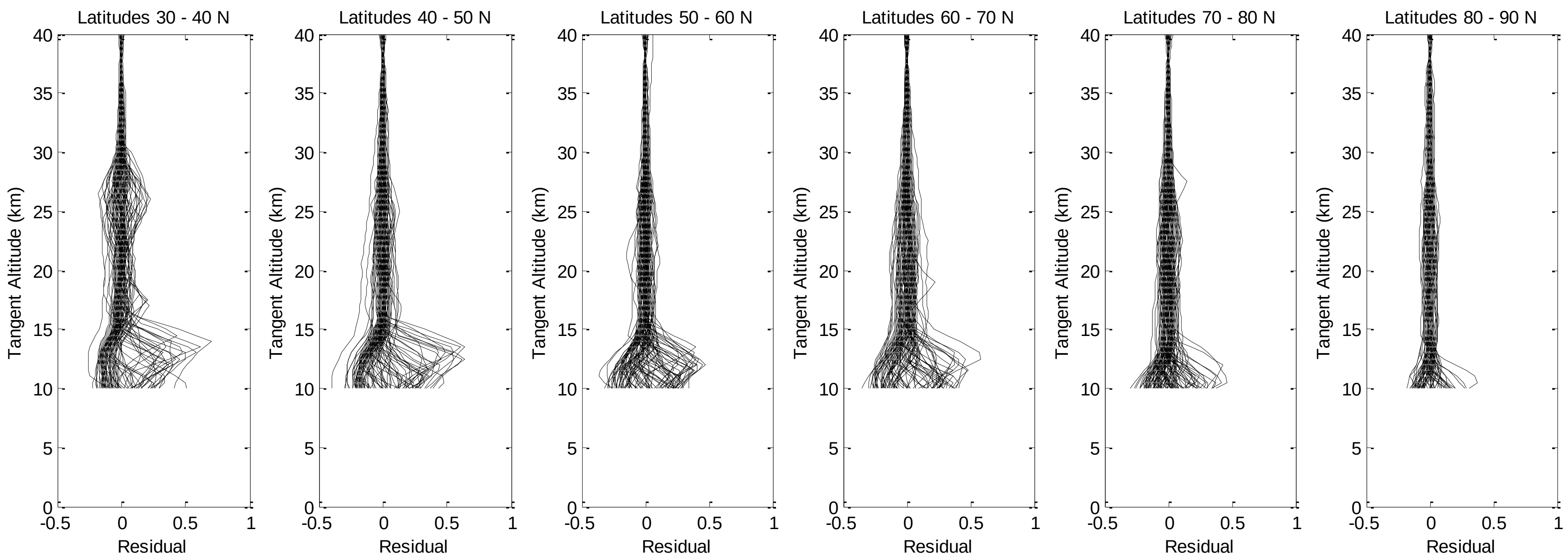
- Kasatochi volcano (52 N, 175 W) erupted August 8,2008 (perfect timing for observation with OSIRIS)
- Injection of 1.2 -1.5 Tg SO2 to altitude up to 16 km
- The largest (and one of the only significant) stratospheric volcanoes since 1991
- Opportunity: background perturbation, polar eruption, geo-engineering… a test of limb scatter algorithms

OSIRIS Measurements: 10 days pre-eruption



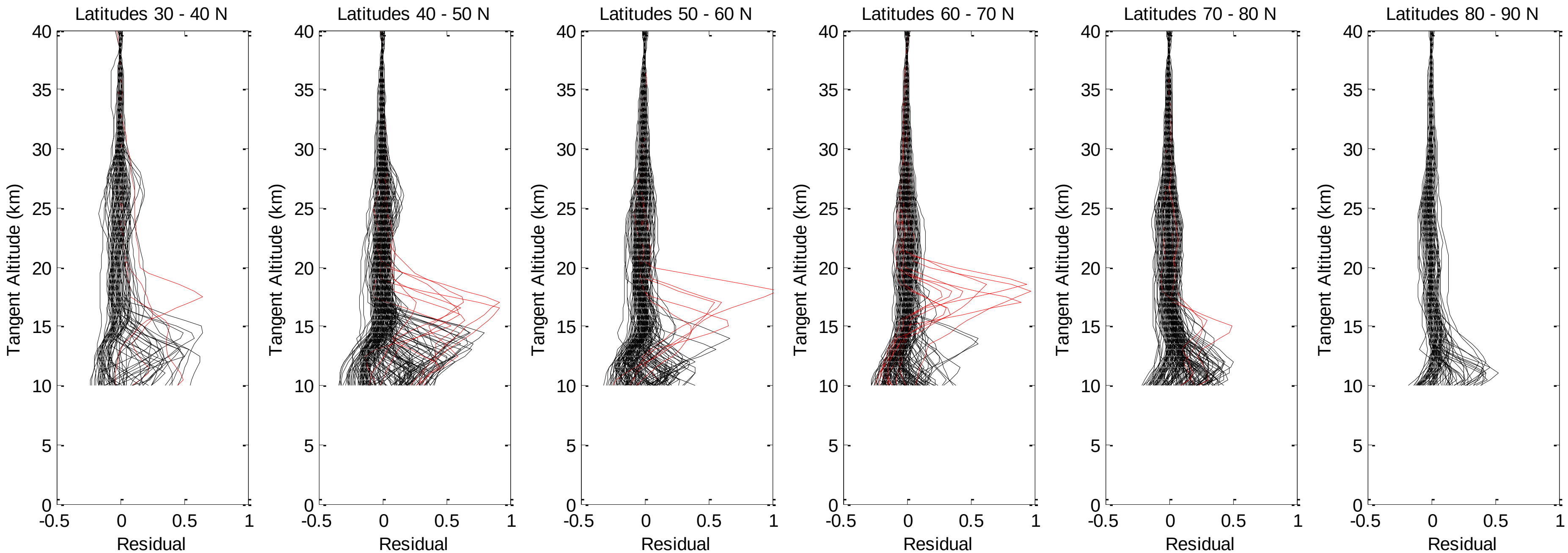
The aerosol measurement vector for mid to high latitude scans

OSIRIS Measurements: 10 days pre-eruption



The measurement vector minus the mean for each latitude range (ascending / descending seperated)

OSIRIS Measurements: 10 days post-eruption

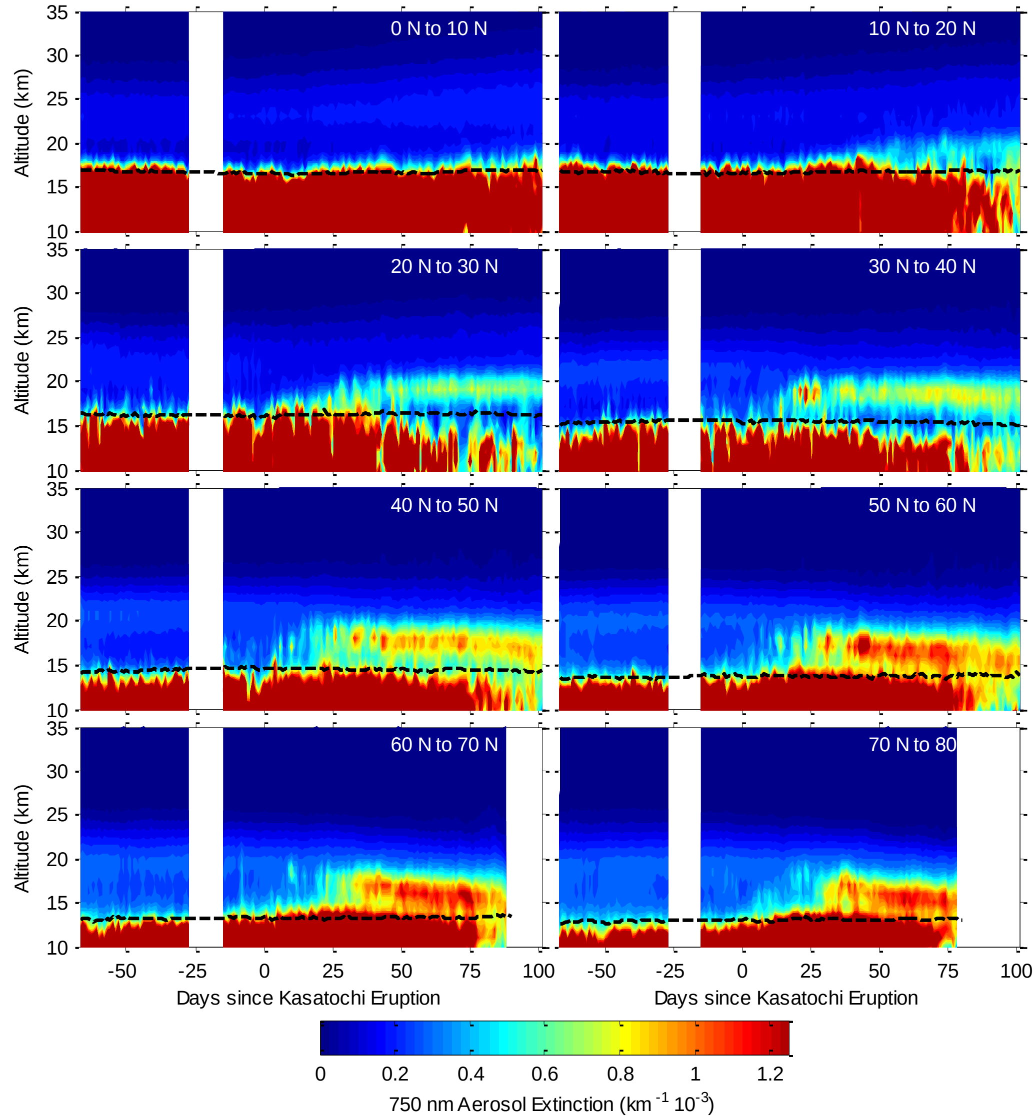


The measurement vector (post-eruption) minus the mean (pre-eruption) for each latitude range (ascending / descending seperated)

Successive time periods show more and more evidence of an aerosol enhancement in the lower stratosphere – conversion of SO2 to aerosol.

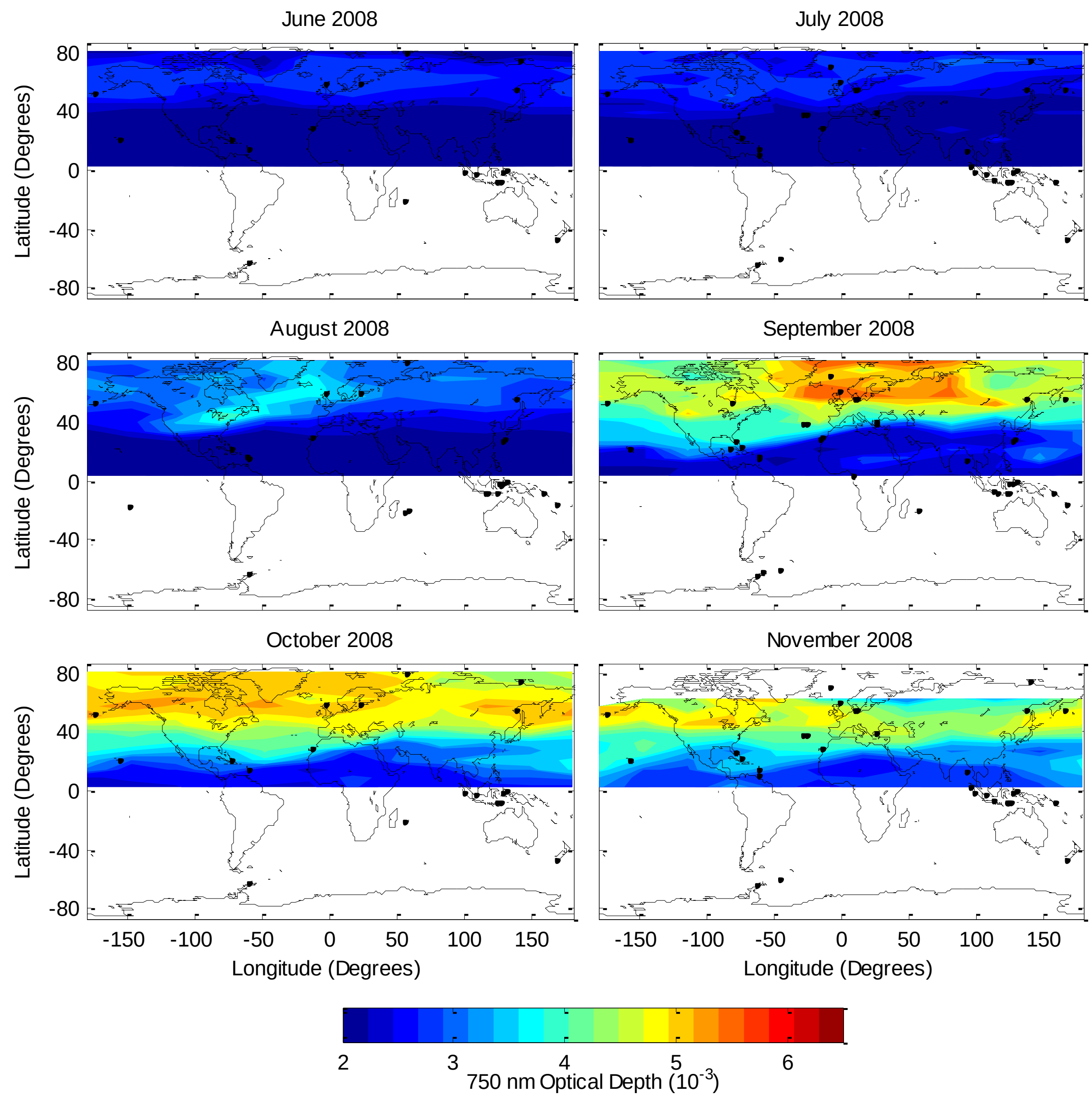
Retrieved Aerosol Extinction: Daily Time Series

- The 380 K level of potential temperature delineates the tropical tropopause layer and the lowermost stratosphere from the deep stratosphere
- Focus analysis above 380 K
- Pre-eruption: typical background state (no effect of Okmok eruption on July 12?)
- 10 to 30 days post eruption: clear evidence of an enhanced layer with significant variability (streamers?)
- 40 days post eruption: a stable enhanced layer between 15 and 22 km at mid to high latitudes (typical e-folding conversion time of 30 days)
- No clear enhancement in the deep tropics
- 80 days post eruption: decay of the stable layer (high-latitude aerosol lifetime is less than 1 year)

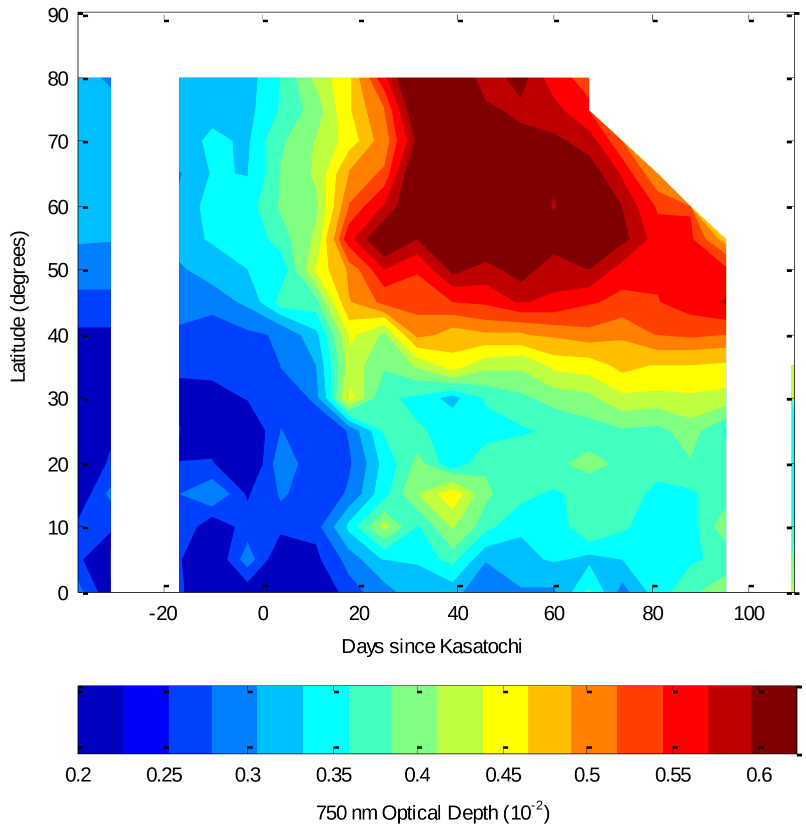


OSIRIS Aerosol Optical Depth: Monthly Average Maps

- Total vertical stratospheric aerosol optical depth (from 380 K to 40 km)
- Maximum enhancement in September of approximately a factor of 3 above background
- Stronger localized enhancements over Northern Europe and Greenland
- Decay evident in November

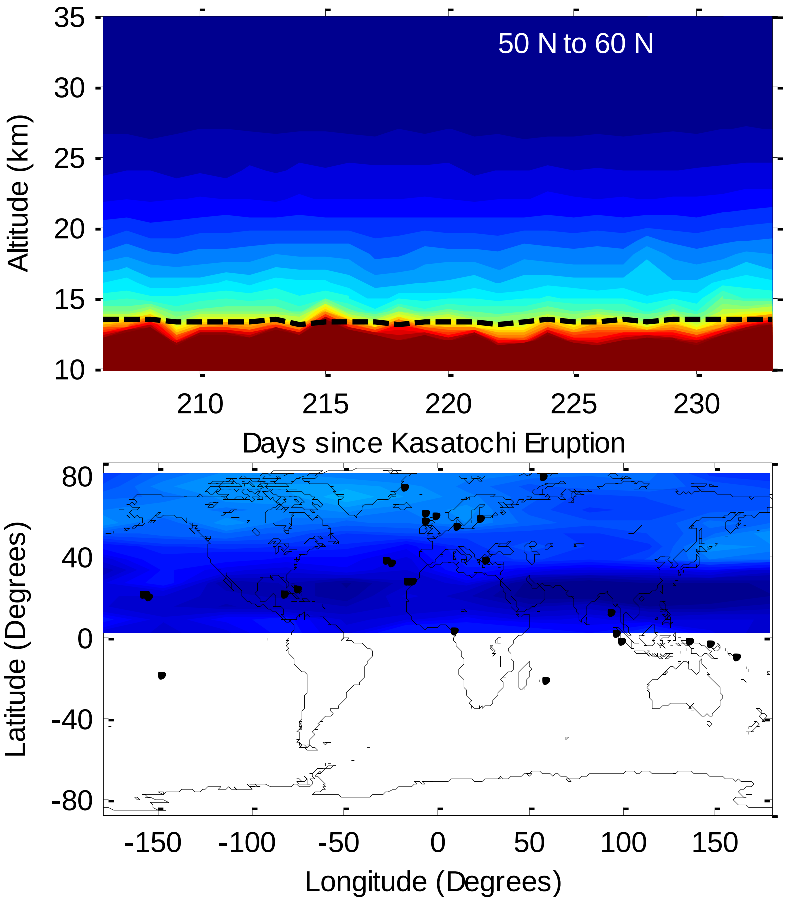


Optical Depth Time Series



OSIRIS retrievals of vertical stratospheric aerosol optical depth also as a zonal average time series (weekly as opposed to monthly)

- OSIRIS regains coverage of mid- to high northern latitudes in late-February
- Retrievals for the month of March show no evidence of an enhanced layer with very slightly larger values of extinction just above 380 K
- Vertical optical depth back to background levels



Submitted to JGR special issue (Bourassa et al.)

The Early Plume: Water Vapour?