UV Remote Sensing of Volcanic Ash

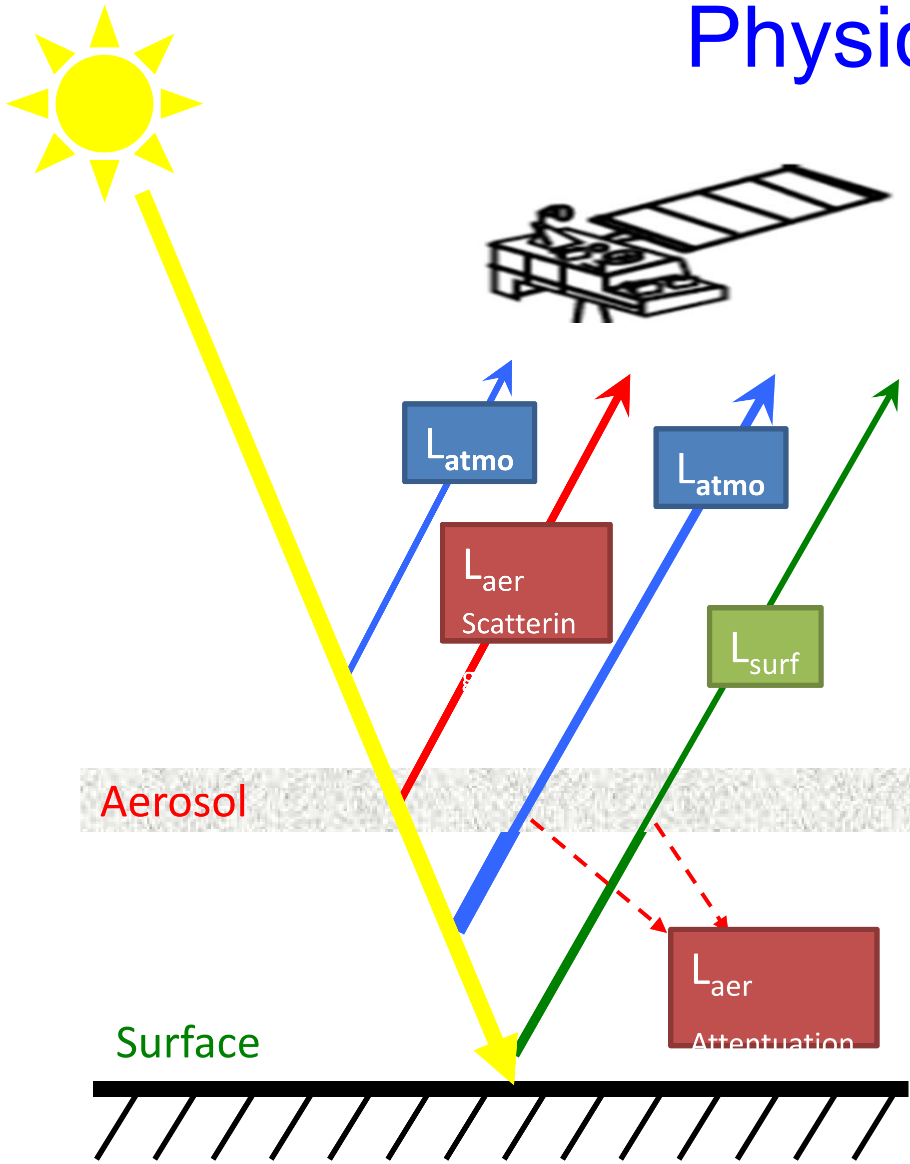
Kai Yang

University of Maryland College Park

WMO Inter-comparison of Satellite-based Volcanic Ash Retrieval Algorithms Workshop

June 26 – July 2, 2015, Madison, Wisconsin

Remote Sensing of Aerosols: Physical Basis



The top-of-atmosphere radiance (L_{TOA}) can be separated into three different contributions for an aerosol laden atmosphere.

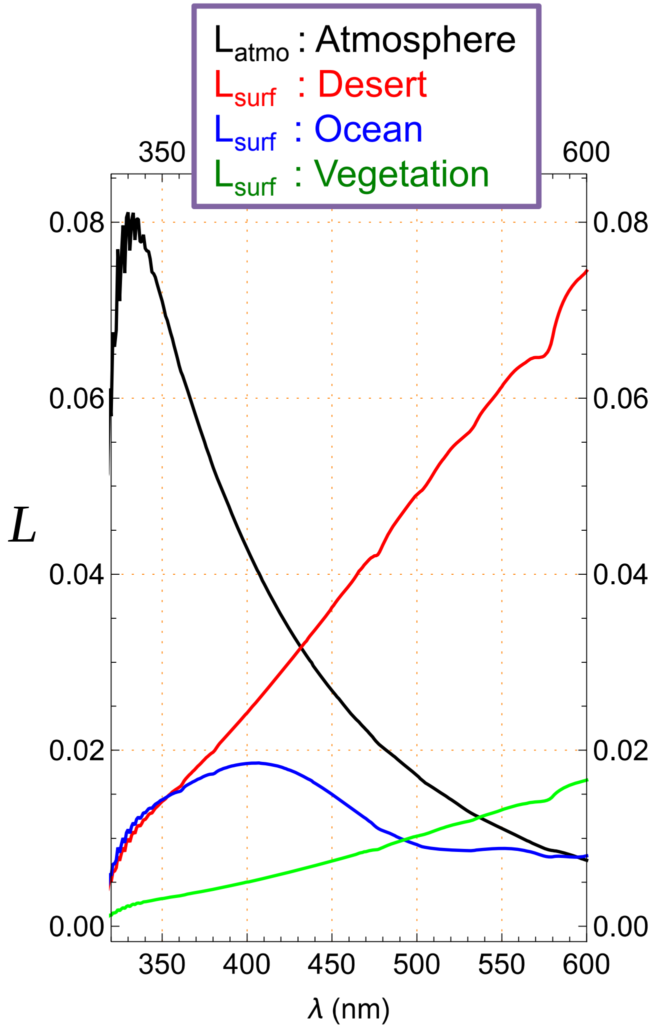
Backscattered radiance by air molecules: Rayleigh scattering + gas absorption

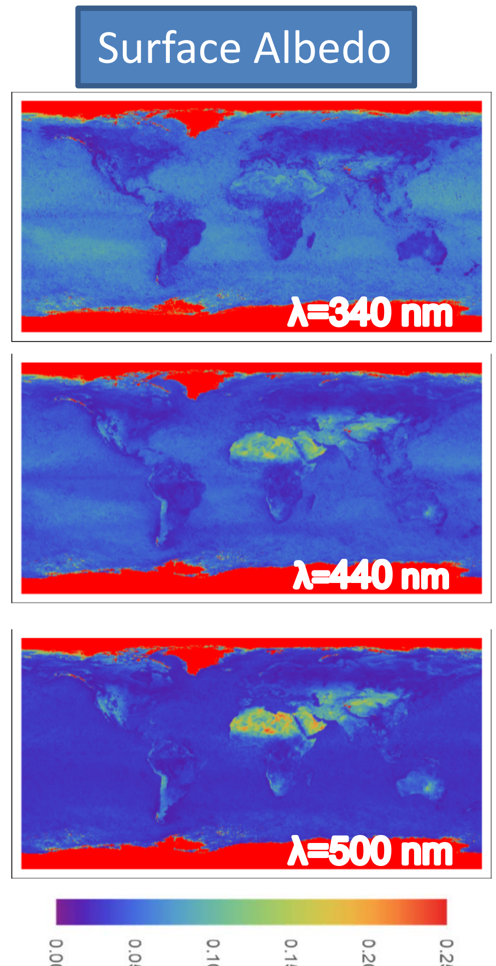
Radiance change due to aerosol scattering and absorption

$$L_{TOA} = L_{atmo} + L_{surf} + L_{aer}$$

Radiance reflected from underlying surface

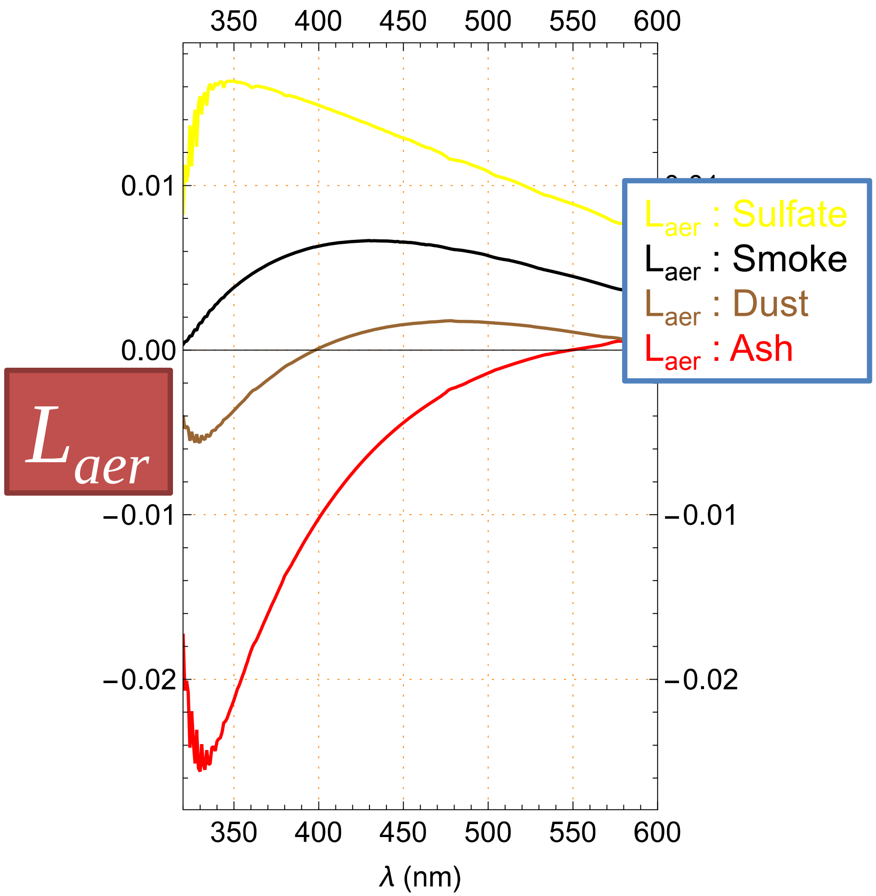
Spectral Dependence of Radiance contributions: Atmospheric Backscattering and Surface Reflection





Spectral Dependence of Aerosol Effects: L_{aer}

L_{aer} : Radiance change due to aerosols



$$L_{aer}(\lambda) \approx AS + (L_{surf} + L'_{atmo})(1\text{-}AA)$$

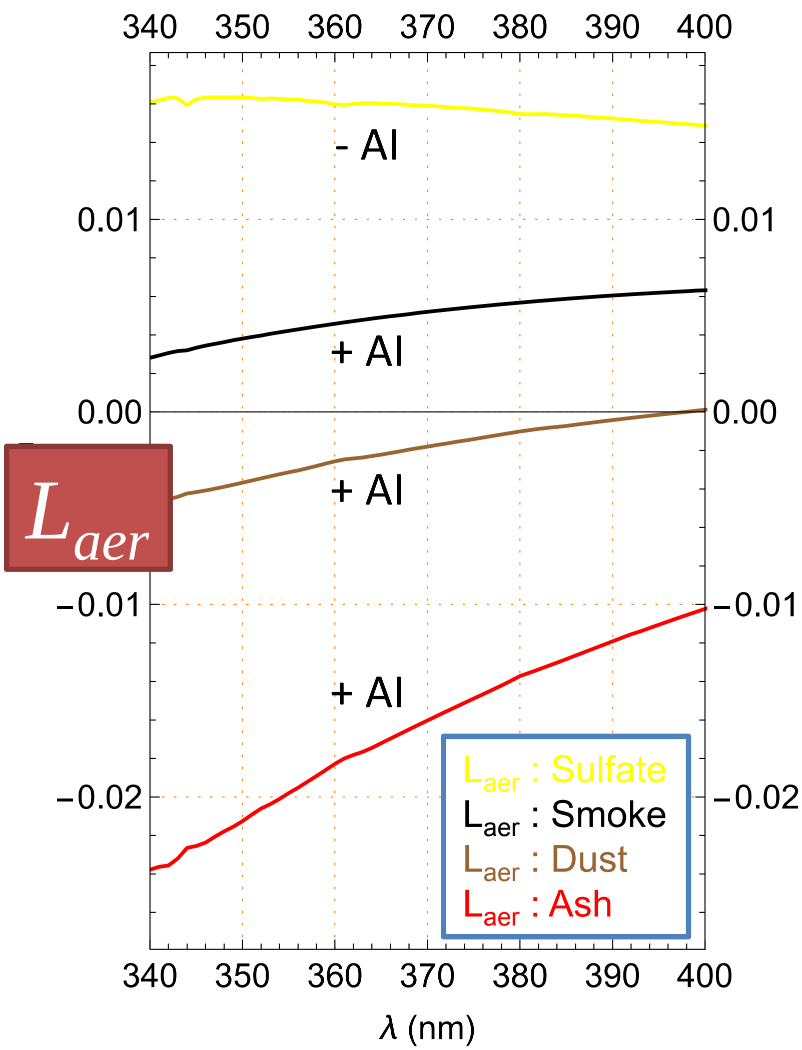
where AS is aerosol scattering,

AA is aerosol absorption,

L'_{atmo} is atmospheric radiance from under the aerosol layer.

- L'_{atmo} is large in UV, small in VIS/NIR.
- In UV, aerosol measurement is accomplished by quantifying its scattering and absorption effects.
- In VIS/NIR, aerosol measurement is primarily relied on quantification of aerosol scattering, when surface is dark or when surface reflection is properly accounted for.

UV Aerosol Index (AI): Quantification of Radiance Change



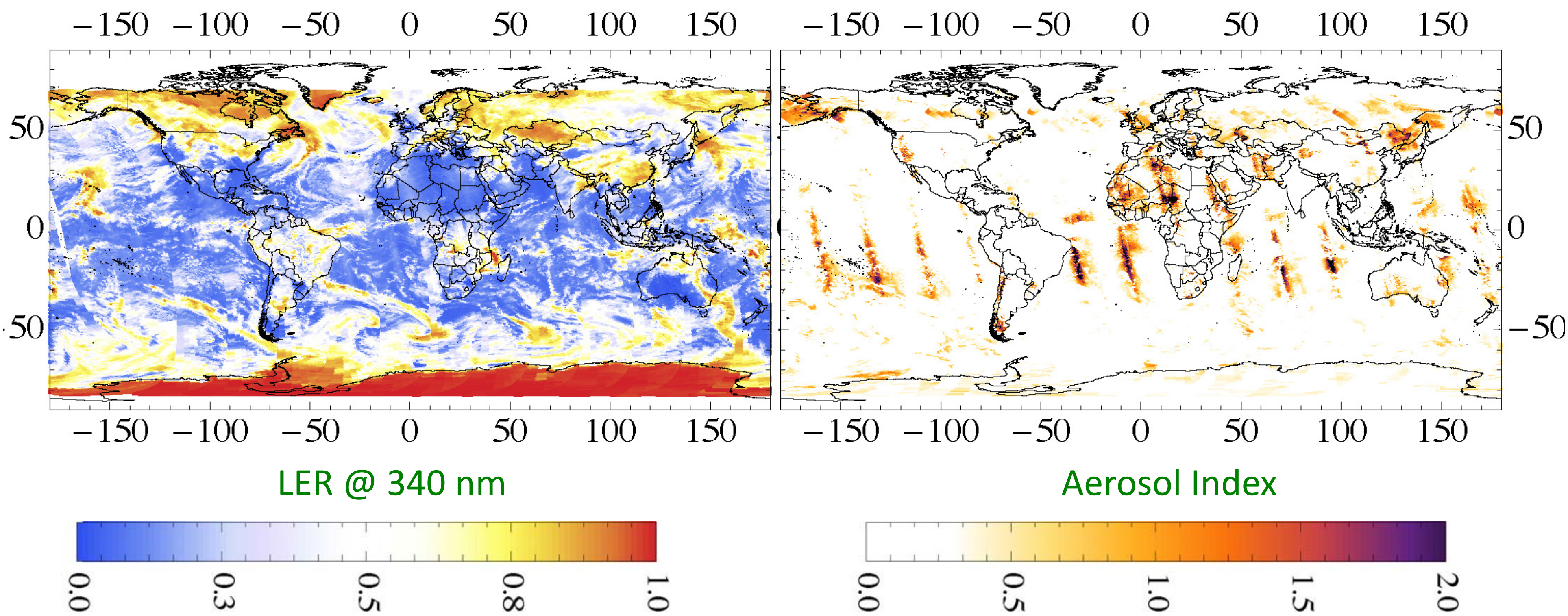
Spectral Contrast in Apparent Surface Reflectivity R_λ

- Definition of Aerosol Index (AI): Spectral slope of R_λ, proportional to AI value.
- The spectral dependence of TOA radiance change is most pronounced for UV-absorbing aerosols, which cause R_λ to increase with wavelength: +AI
- Non-absorbing aerosols, under certain conditions, can cause R_λ to decrease with wavelength: - AI

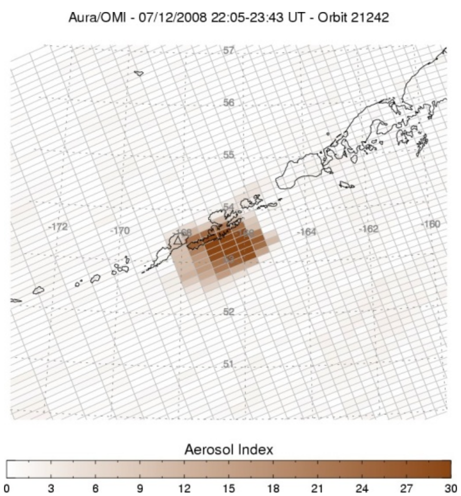
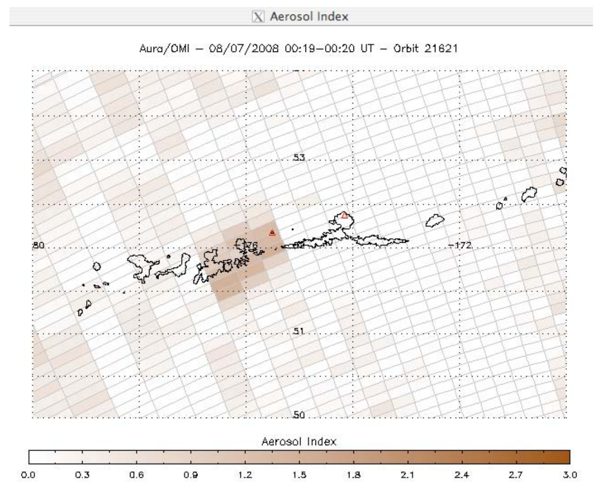
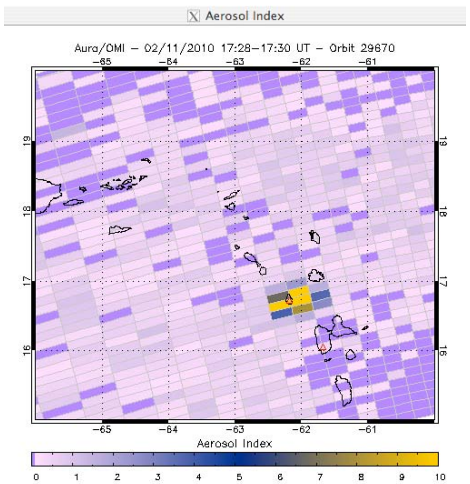
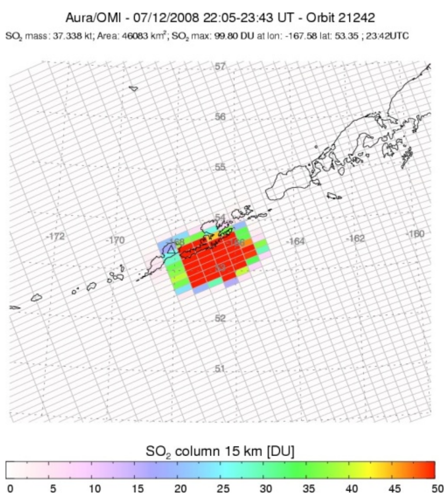
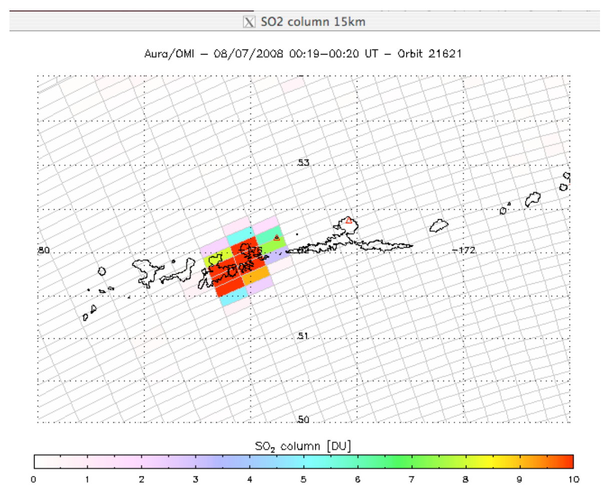
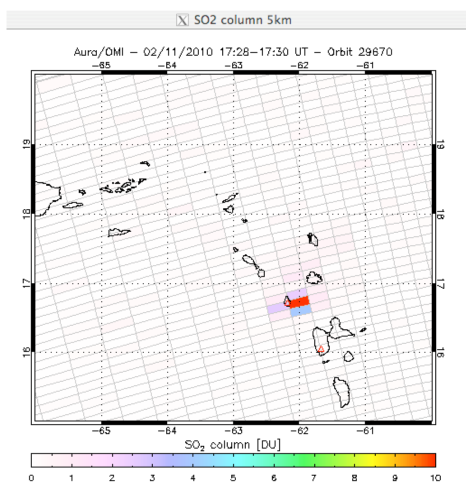
UV Aerosol Index (AI)

- AI is computed without any information about the aerosol particles (e.g., the refractive index and particle size distribution), and is determined by the deviation from Rayleigh atmosphere.
- AI can be used to determine their location and the relative amount of UV absorbing aerosols, even over bright surfaces, such as snow/ice or meteorological clouds.

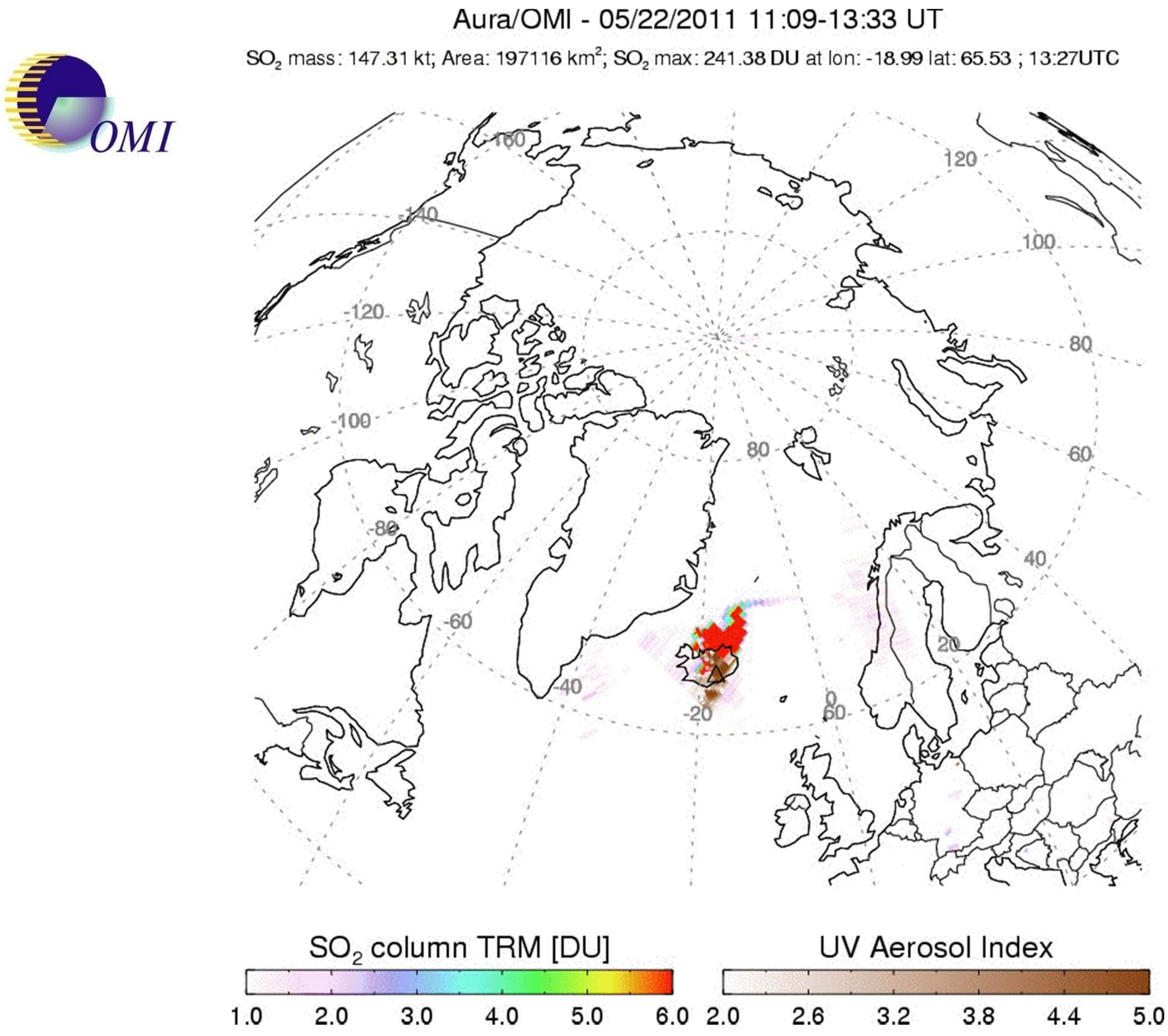
Mapping of UV Absorbing Aerosols: Sample AI Data from SNPP/OMPS



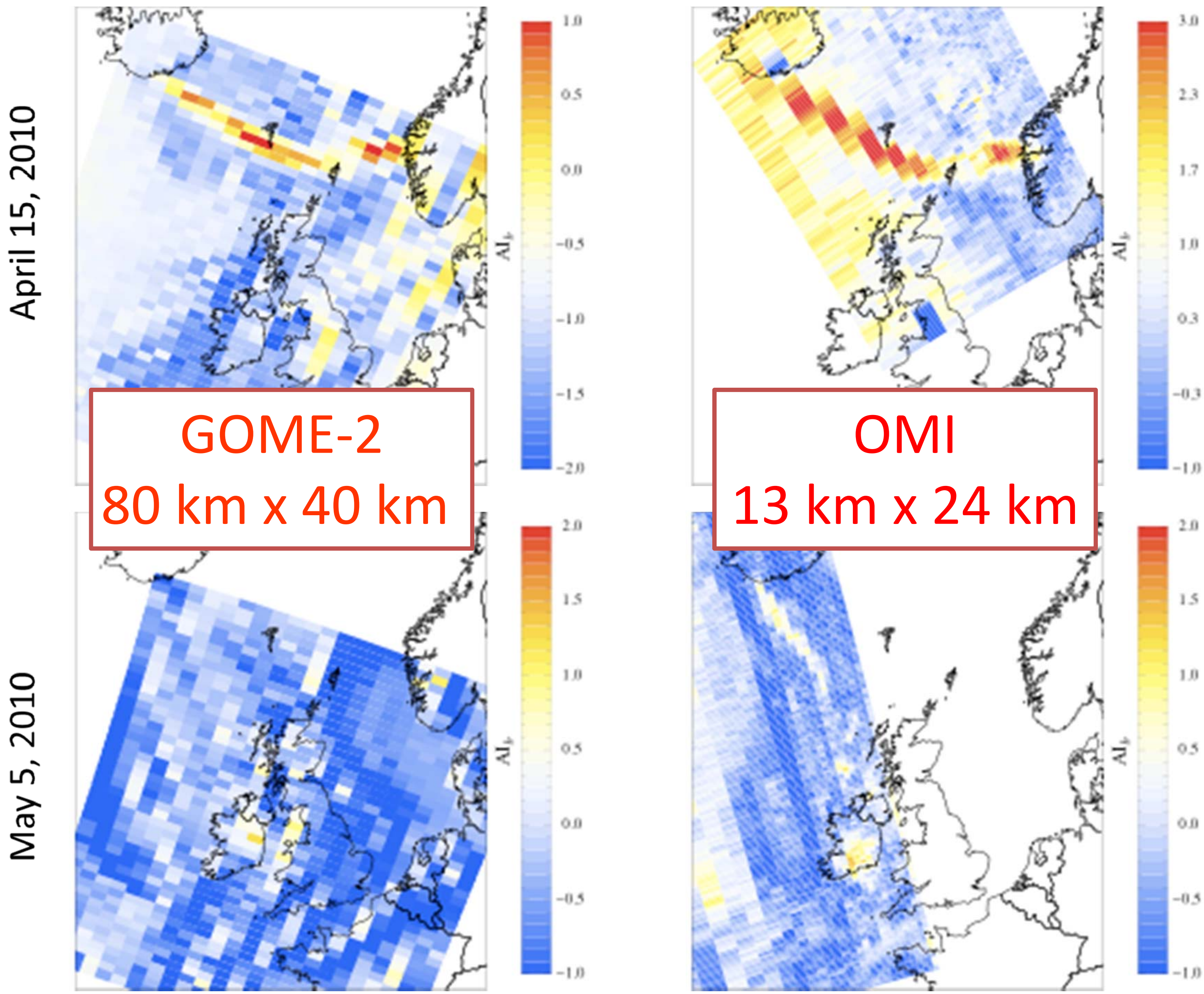
Volcanic Ash Detection: Fresh Eruption Clouds

	Okmok; 7/12/2008	Kasatochi; 8/8/2008	Montserrat; 2/11/2010
Ash			
SO_2			

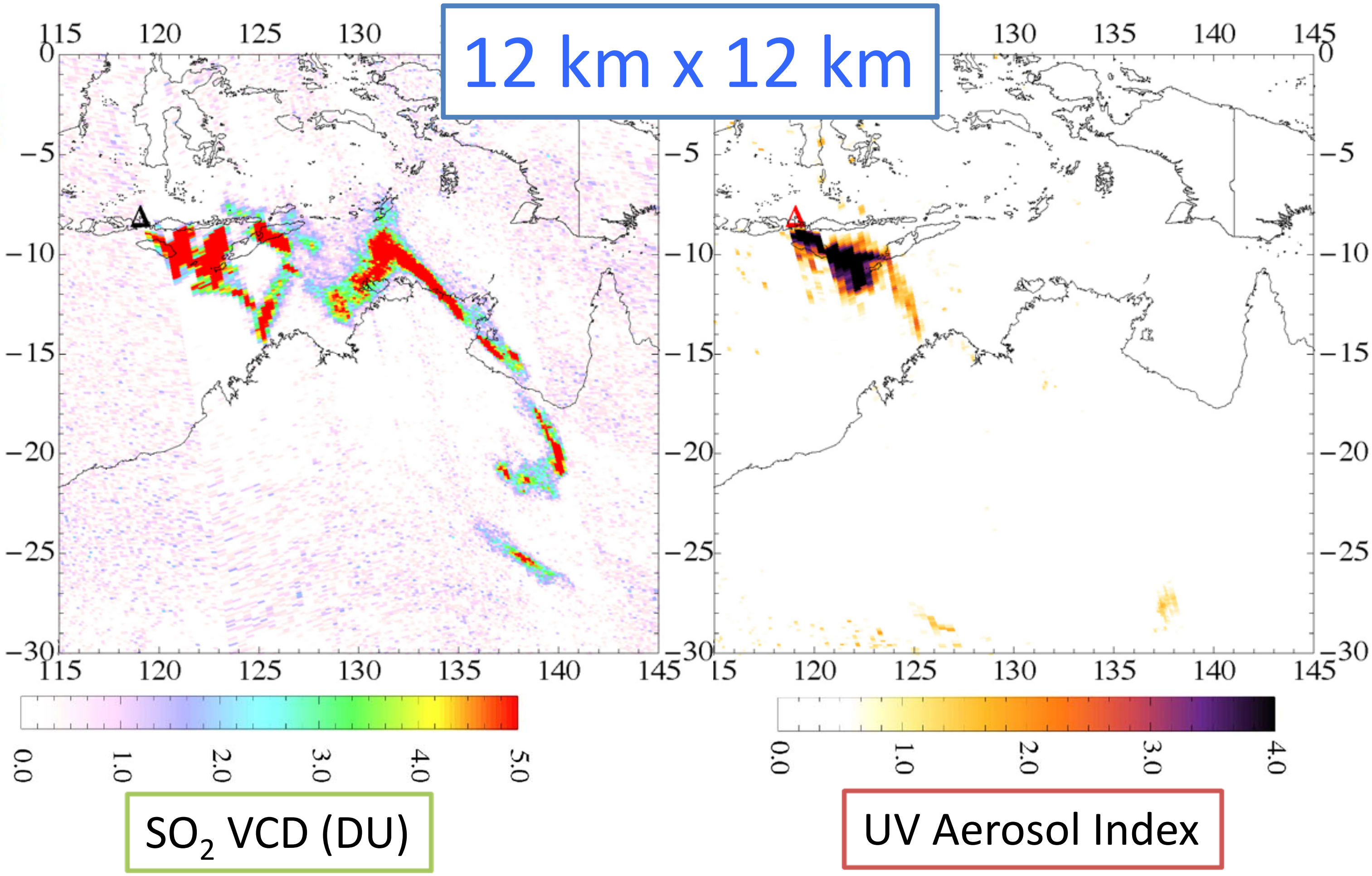
Ash and SO_2: Grímsvötn, May 2011



Eyjafjallajökull Ash: Pixel Size Effect



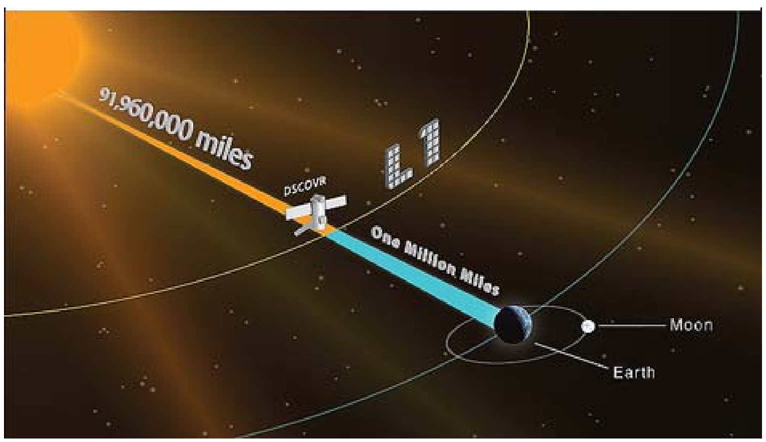
SNPP/OMPS @ High Spatial Resolution Mode
Future JPSS-1&2 will have similar high resolution



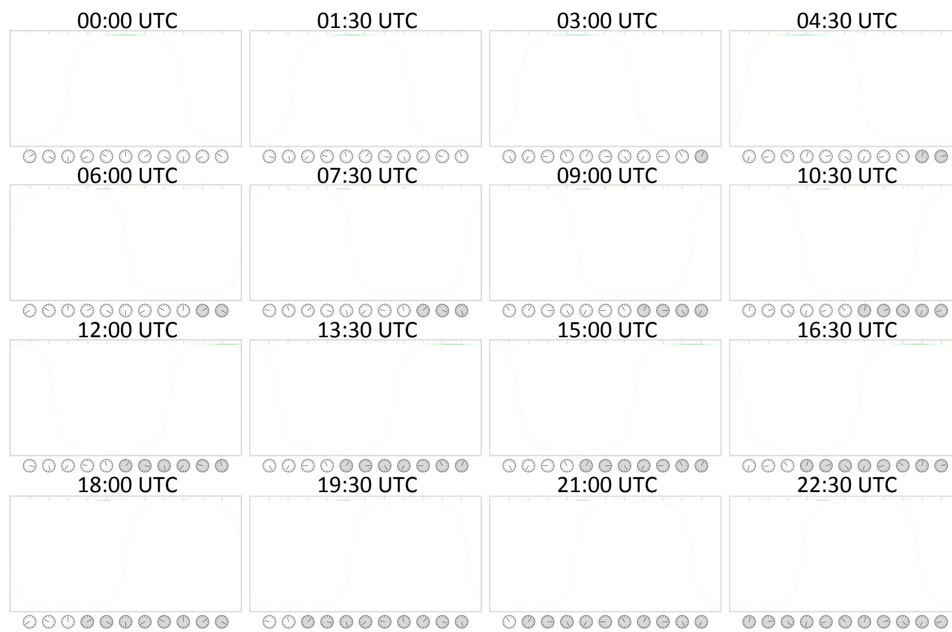
Eruption of Sangeang Api (Indonesia) 05/31/2014

Near Future Enhancements from New Satellite Mission: DSCOVR (2015)

EPIC on NOAA/NASA DSCOVR at L-1 point, observes sunlit side of the Earth (UV/VIS discrete channels) at a spatial resolution of 24 km x 24 km, provides ash/SO_2.



September 2, 2015

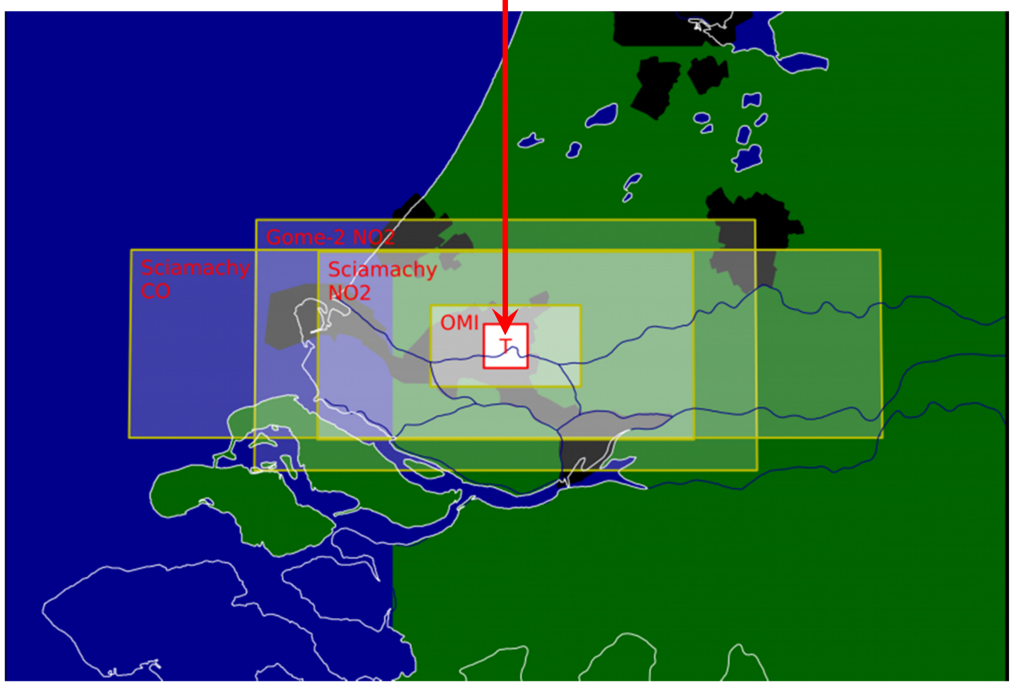


Multiple (>= 5) views in 24 hours

Near Future Enhancements from New Hyperspectral UV/VIS Satellite Mission: TROPOMI (2016)

TROPOMI

- TROPOMI on ESA polar orbiting Sentinel-5 Precursor, provides ash/SO_2 at a spatial resolution of 7 km x 7 km .



Quantification of Volcanic Ash

Model and Mie Calculations

Volcanic Cloud: Mixtures of Water/Ice Clouds and Ash Particles

Micro-physical properties of each component:

Particle shape (e.g. sphere/spheroid/irregular), mass density (e.g, ρ_{ash}=2.75 g/cm^3)

Size distribution (e.g., Log-normal for ash particles, r_{eff} = 2μm, σ=1.6),

Refractive index (e.g. real = 1.5, imag = 0.005, independent of λ)

↓

Volcanic Cloud: Optical Properties

Mass Coefficients: Scattering (K_{sca}), Absorption (K_{abs}),
Extinction ($K_{ext}=K_{sca}+K_{abs}$), Single Scattering Albedo ($\omega_0=K_{sca}/K_{ext}$),
and Scattering Phase Function

Measurements and Retrievals

Vertical Distribution of Particles:

Layer height estimated from radiance measurements or trajectory analysis

Surface Albedo

Estimated from radiance measurements or based on climatology

→

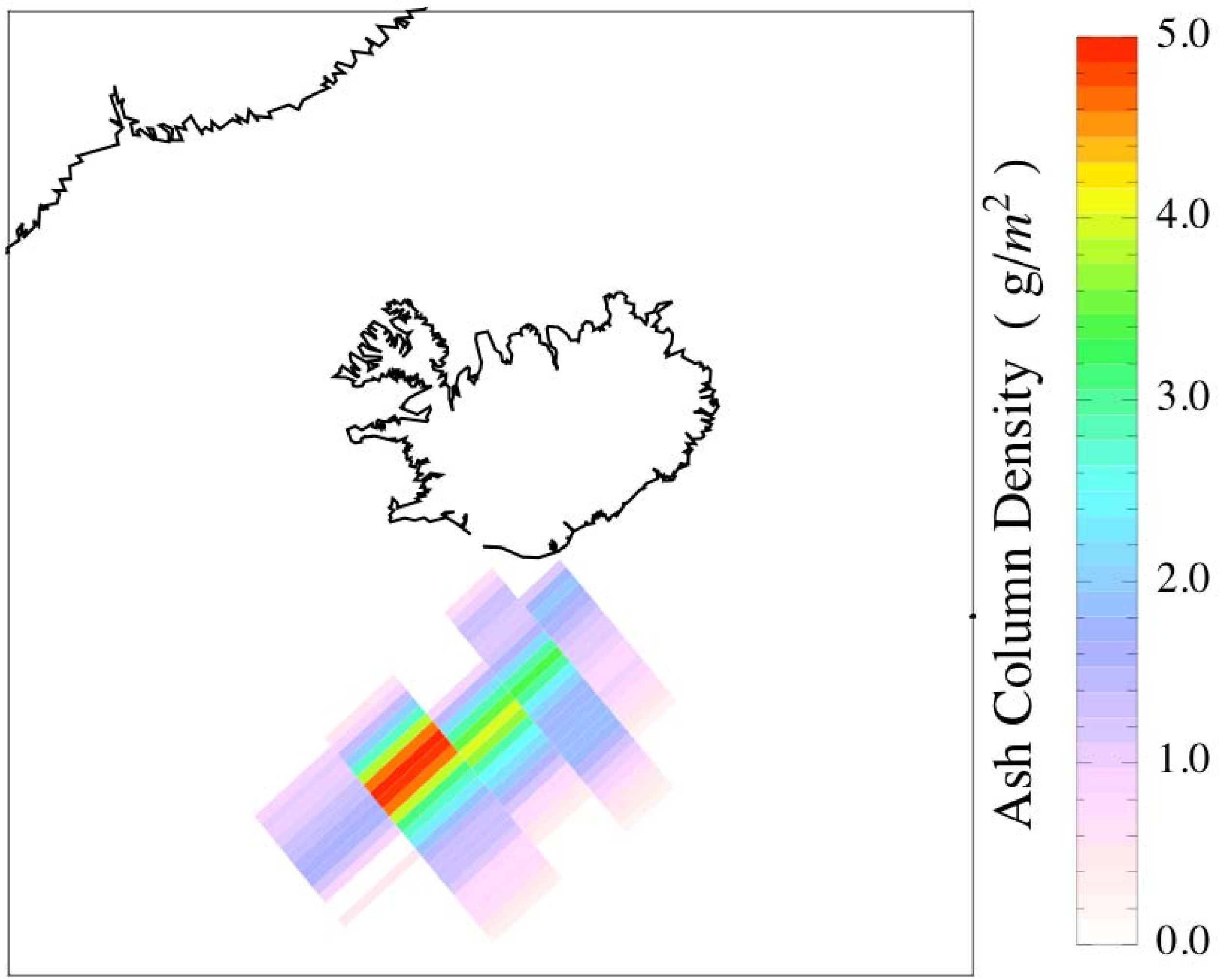
Extinction Optical Depths for Each Components: estimated from satellite radiance spectra

↓

Ash Mass Concentration (g/m^2)

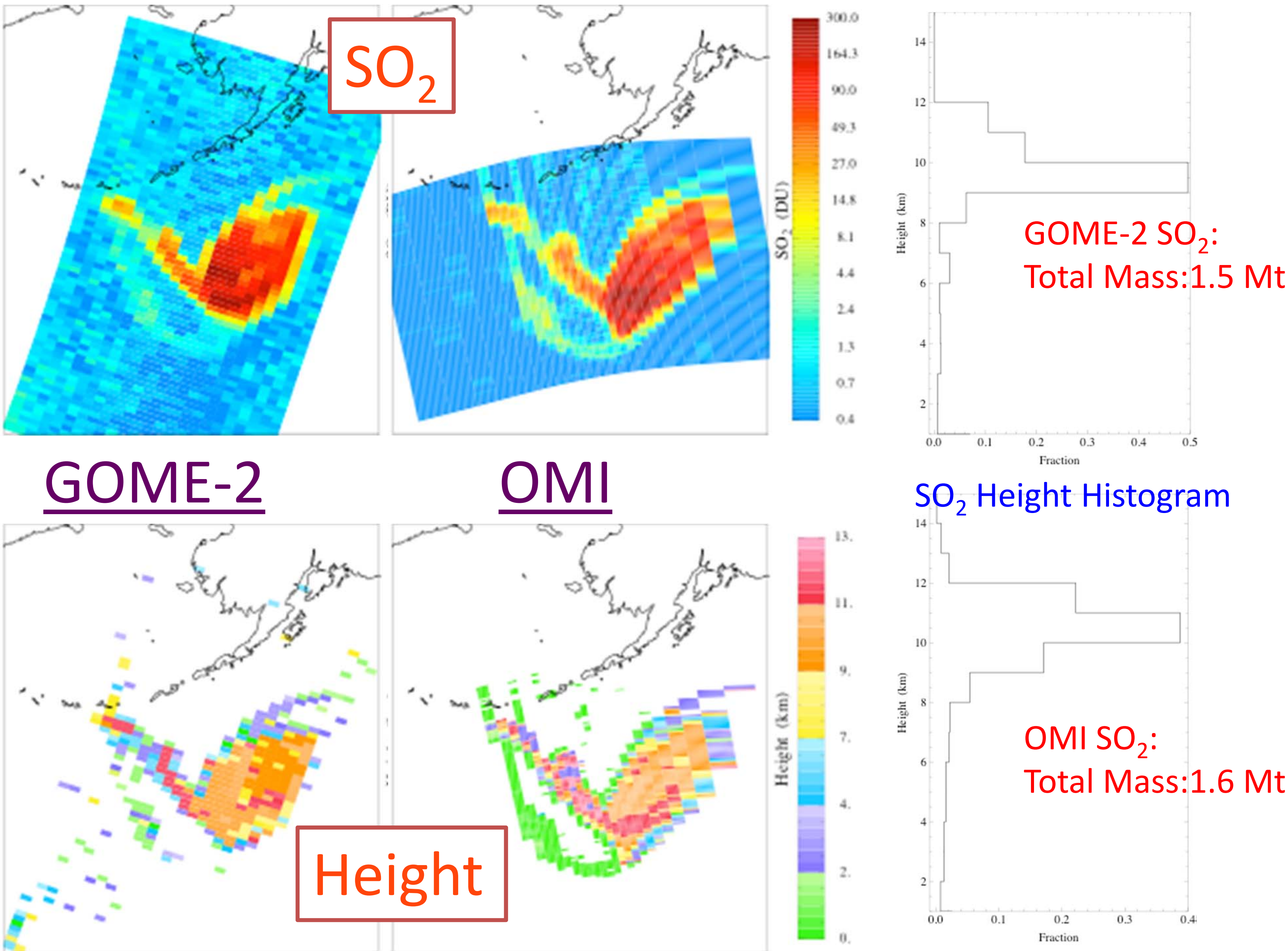
Ash Concentration Estimation

Grimsvötn, 05/23/2011 OMI



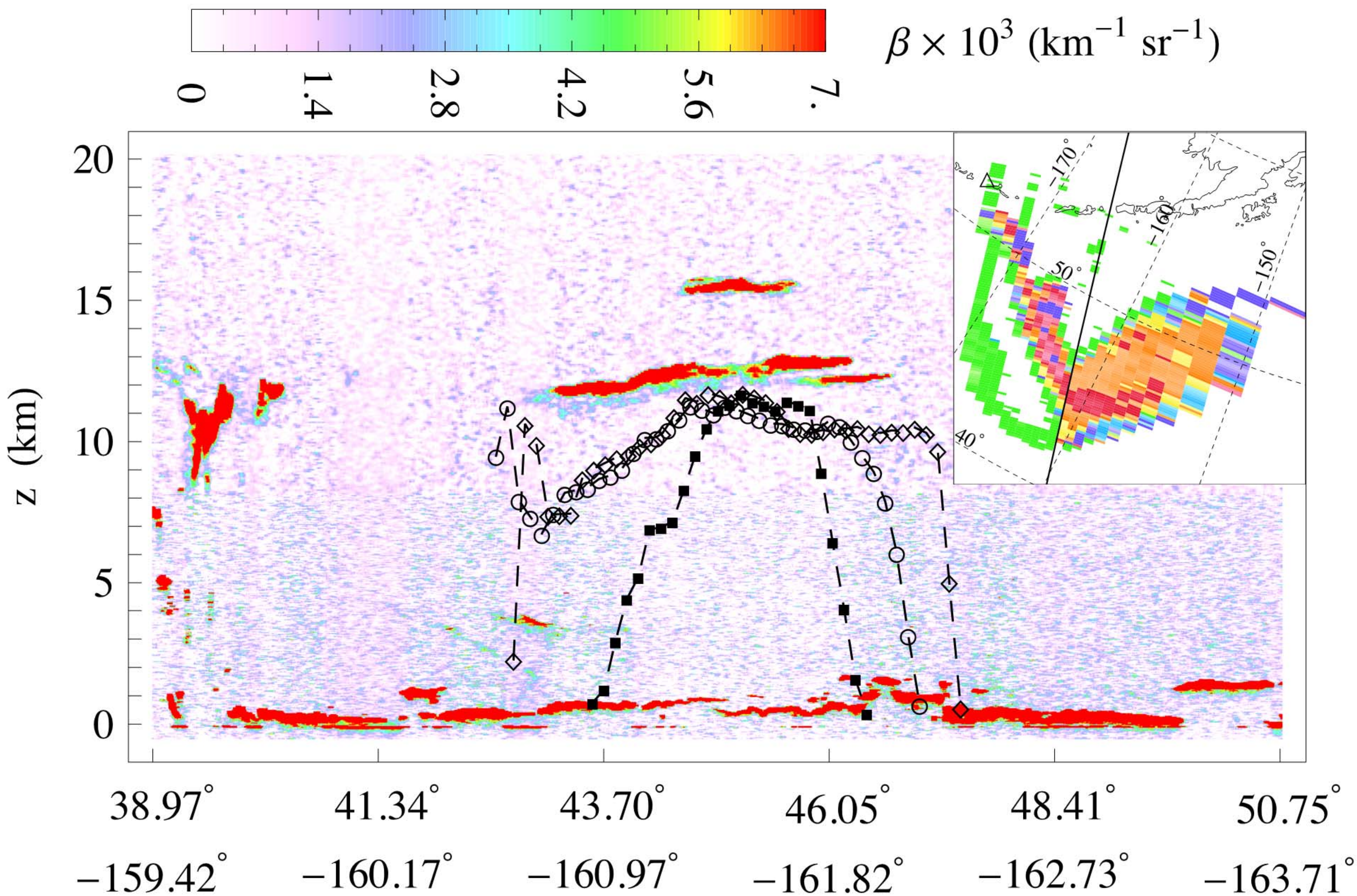
Plume Height Retrieval

Kasatochi SO_2 Plume: August 9, 2008



August 2008 Kasatochi Eruption

Comparisons with CALIPSO



Value of UV Data

UV spectra are highly sensitive to ash (absorbing aerosols) and SO_2 in the atmosphere.

Volcanic clouds under a wide range of conditions:

- Detectable independent of water/ice content or surface conditions
- Detectable for fresh (dense) plumes
- Detectable for aged (weak) SO_2 plumes: long-term tracking
- Detectable down to the lower troposphere, including SO_2 from degassing: volcanic unrest
- Plume height from SO_2 measurements
- Ash amount given ash cloud particle properties

Synergy of UV and IR

- Both UV and IR measurements are sensitive to ash particle size and composition, and its vertical location.
- Combining hyper-spectral UV (OMI, GOME2, OMPS) and IR (AIRS, IASI, CrIS) measurements provides greater constraints to a retrieval algorithm, and likely leads to more accurate estimates of volcanic ash particle size, plume height and loading.