Applications of AIRS to the Study of Heterogeneous Volcanic Plumes

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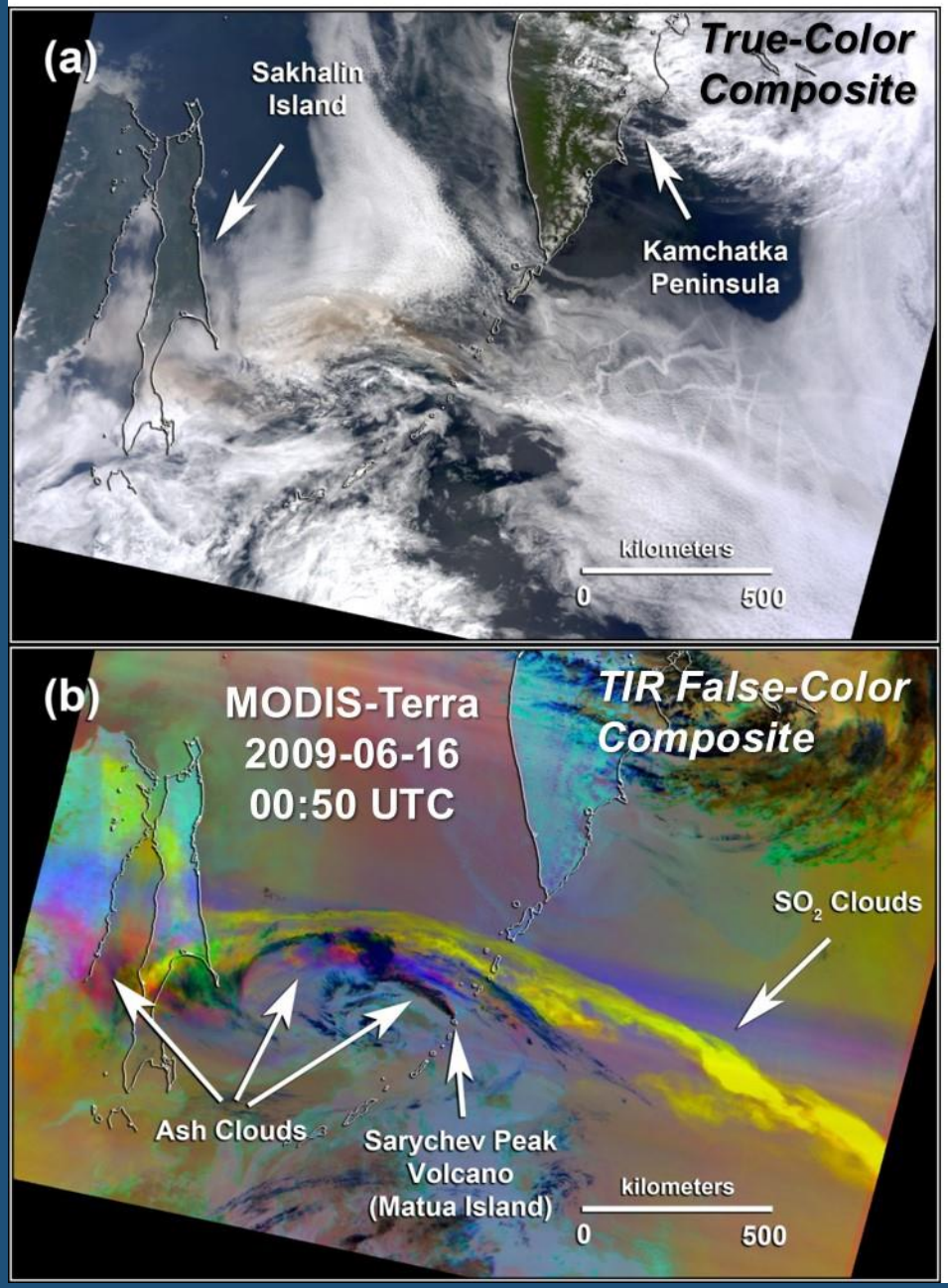
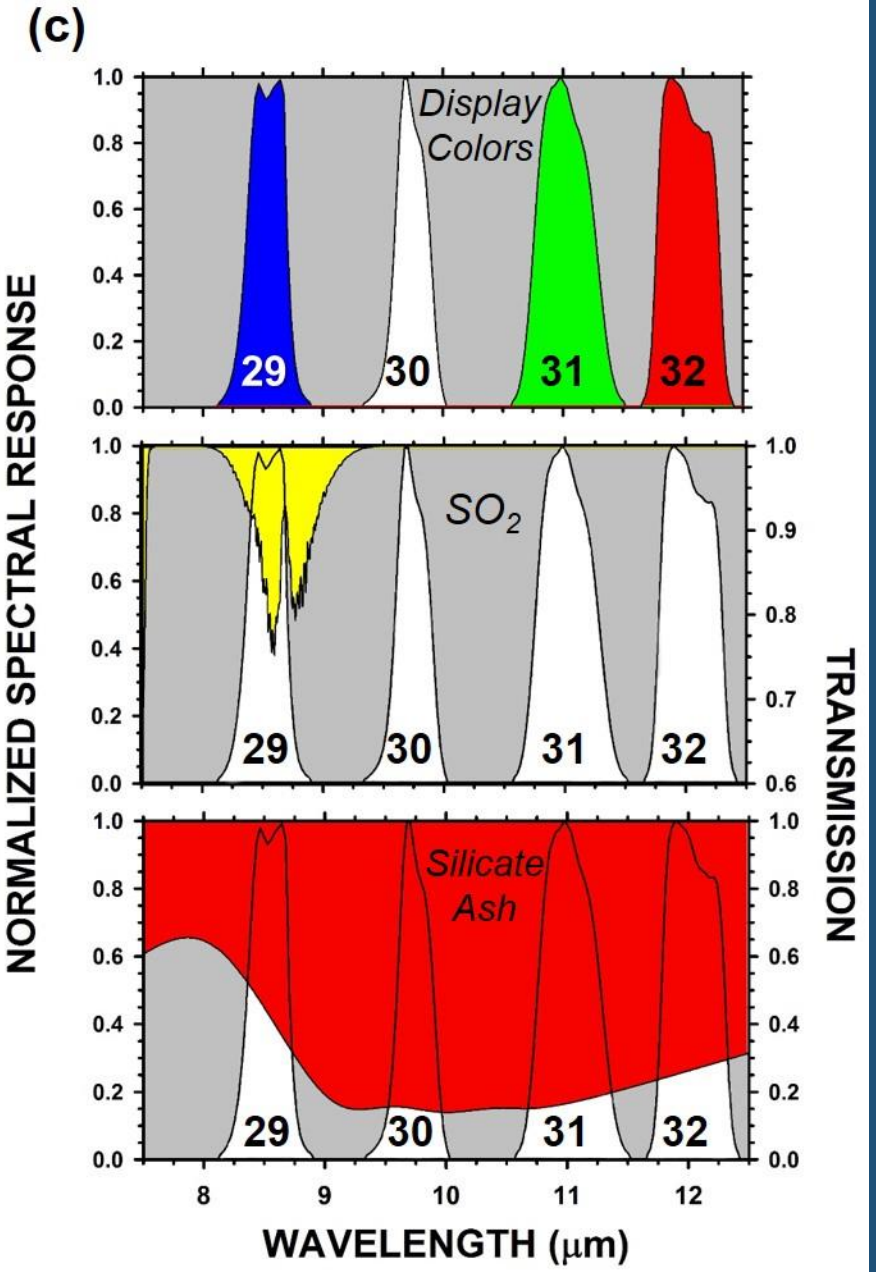
Government sponsorship acknowledged.

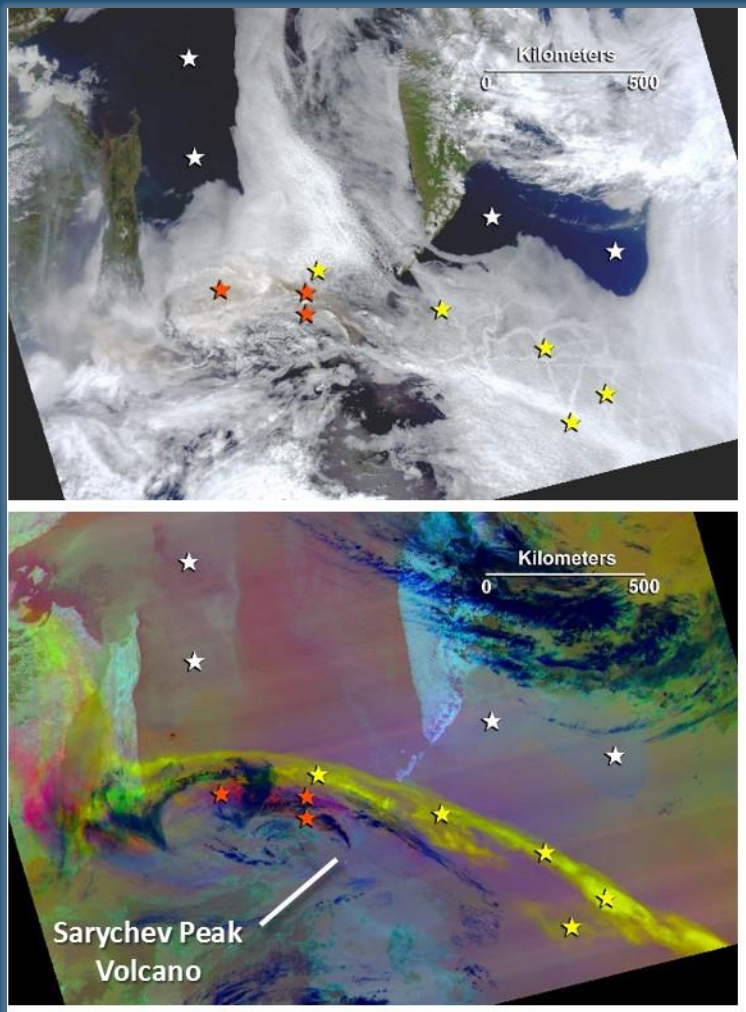
Spectroscopy of Volcanic Plumes:

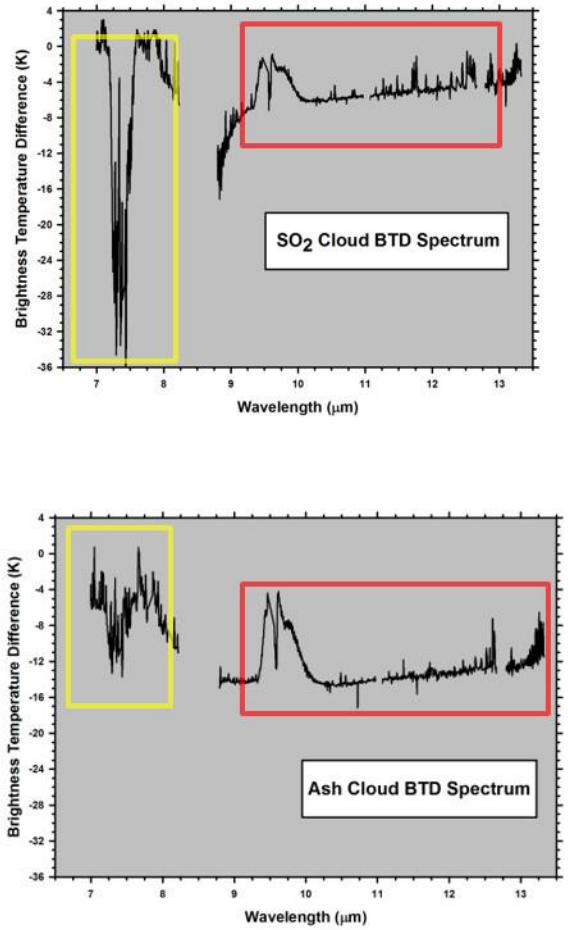
Sarychev Peak Eruption

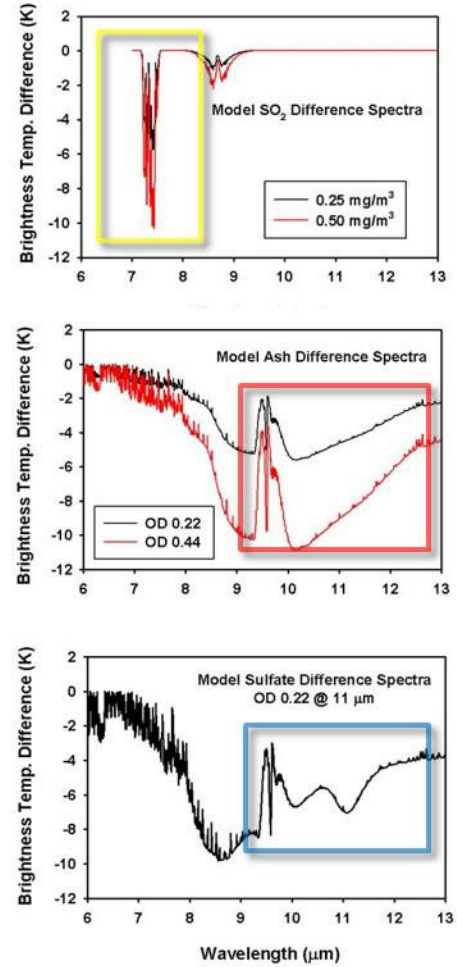
June 2009


(a)
True-Color Composite
Sakhalin Island
Kamchatka Peninsula
kilometers
0
500
(b)
MODIS-Terra
2009-06-16
00:50 UTC
TIR False-Color Composite
SO2 Clouds
Ash Clouds
Sarychev Peak Volcano (Matua Island)
kilometers
0
500


(c)
Display Colors
SO2
Silicate Ash
29
30
31
32
NORMALIZED SPECTRAL RESPONSE
TRANSMISSION
WAVELENGTH (μm)
8
9
10
11
12







(a) MODIS-Aqua 2009-06-16

(b) AIRS BTD Spectra 2009-06-16

(c) Model BTD Spectra

Heterogeneous Plumes from Sarychev Peak Eruption, Kurile Islands, Russia

Sample Locations:
- ☆ Clear Path
- ★ Ash Plume
- ★ SO_2 Plume

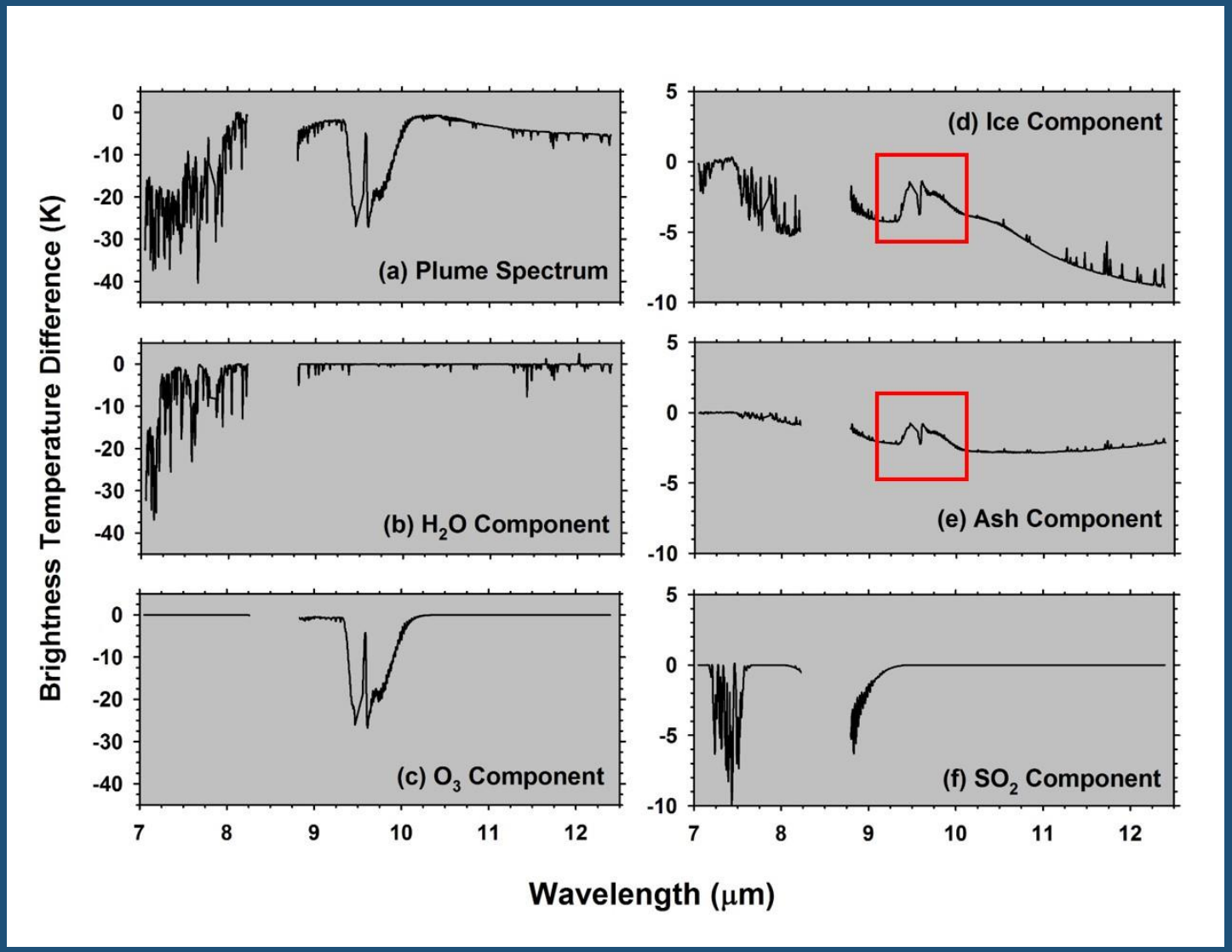
- Spectra of SO_2 plumes show evidence of ash
- Spectra of ash plumes show evidence of SO_2
- No spectral evidence for SO_4 aerosols

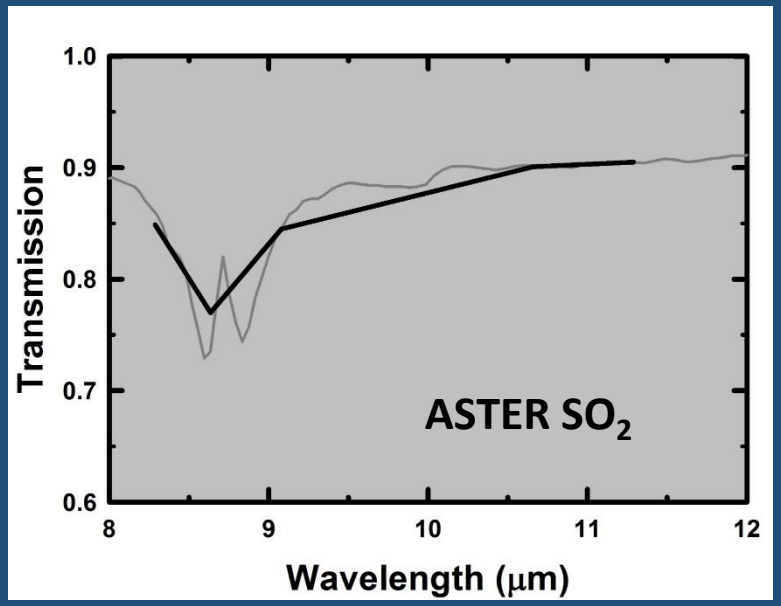
Spectrum of a heterogeneous volcanic plume, together with the spectra of individual components.

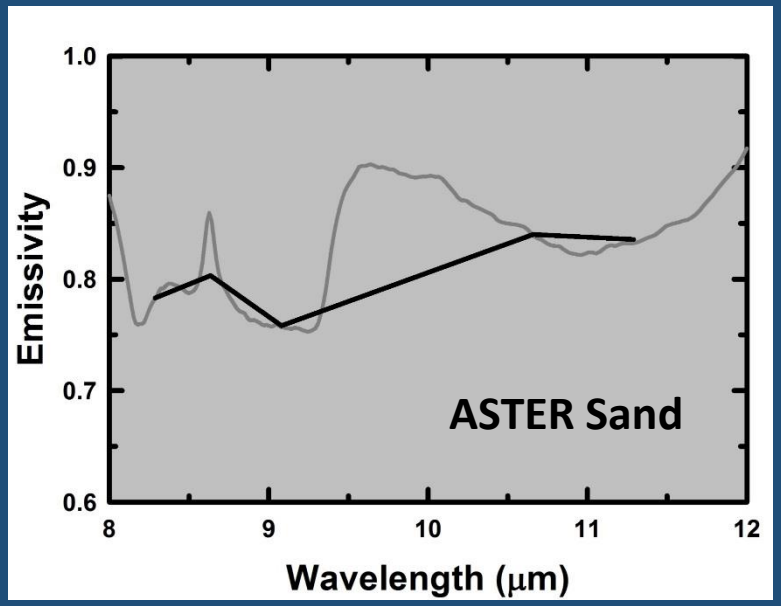
Spectra were generated with MOD5.3doe at 0.1 cm^{-1} resolution and convolved with the AIRS spectra response.

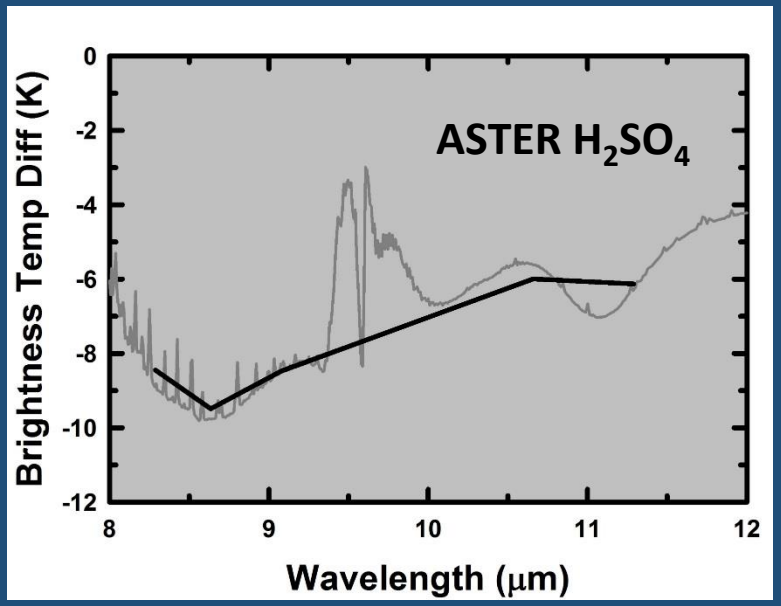
Note the change in the temperature scale between Spectra (a) – (c) and (d) – (e), and the gap in AIRS spectral coverage between 8.2 and 8.8 µm.

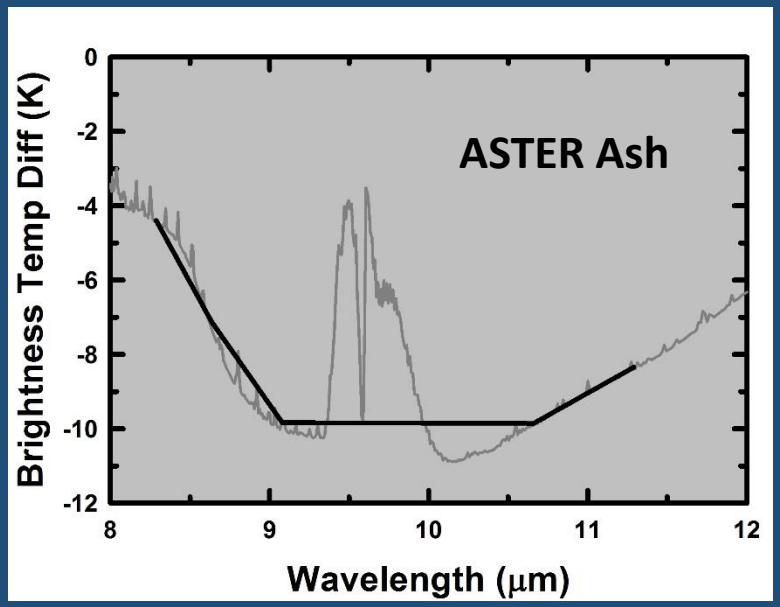
O_3 "artifact" (red boxes) is common to difference spectra

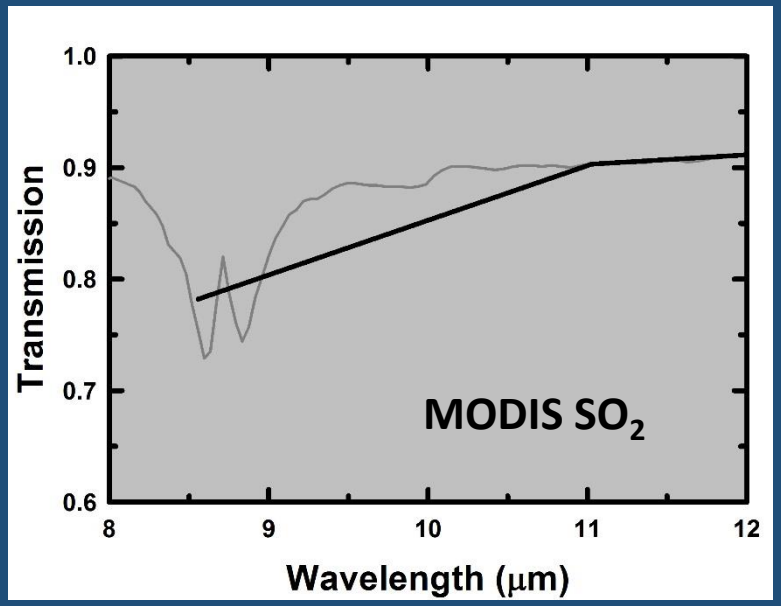


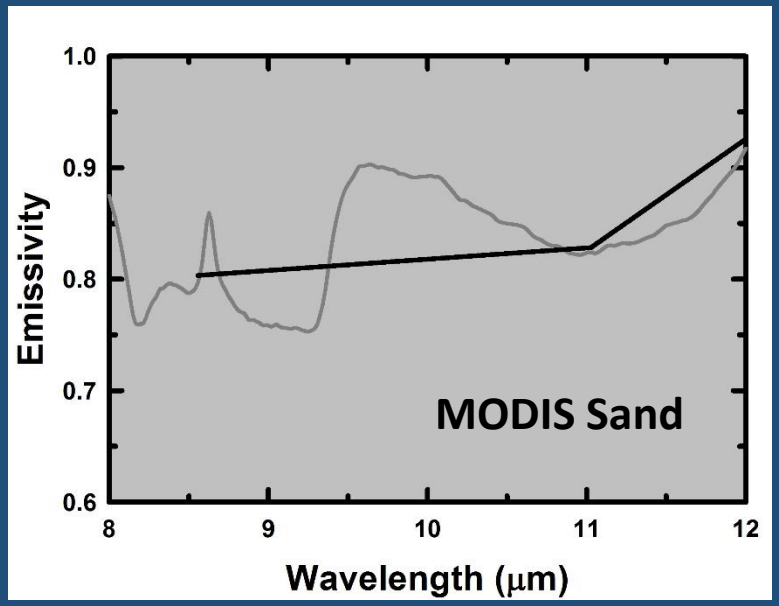

ASTER SO_2
Transmission
Wavelength (μm)
1.0
0.9
0.8
0.7
0.6
8
9
10
11
12

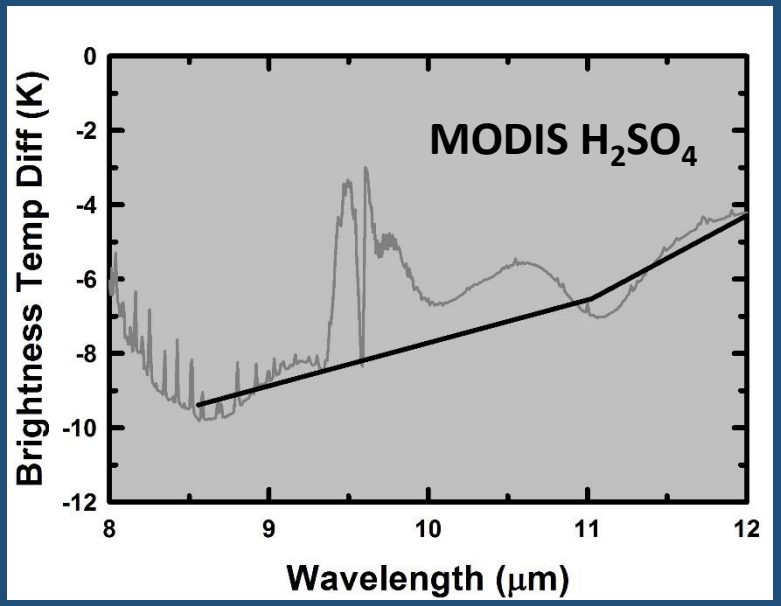

ASTER Sand
Emissivity
Wavelength (μm)
1.0
0.9
0.8
0.7
0.6
8
9
10
11
12

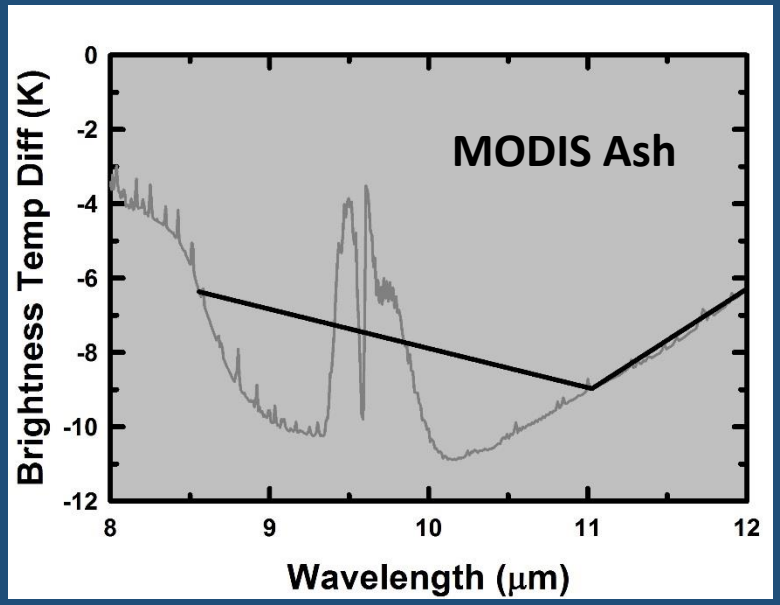

ASTER H_2SO_4
Brightness Temp Diff (K)
Wavelength (μm)
0
-2
-4
-6
-8
-10
-12
8
9
10
11
12


ASTER Ash
Brightness Temp Diff (K)
Wavelength (μm)
0
-2
-4
-6
-8
-10
-12
8
9
10
11
12


MODIS SO_2
Transmission
Wavelength (μm)
1.0
0.9
0.8
0.7
0.6
8
9
10
11
12


MODIS Sand
Emissivity
Wavelength (μm)
1.0
0.9
0.8
0.7
0.6
8
9
10
11
12


MODIS H_2SO_4
Brightness Temp Diff (K)
Wavelength (μm)
0
-2
-4
-6
-8
-10
-12
8
9
10
11
12


MODIS Ash
Brightness Temp Diff (K)
Wavelength (μm)
0
-2
-4
-6
-8
-10
-12
8
9
10
11
12

Eruption of

Eyjafallajökull Volcano

Iceland

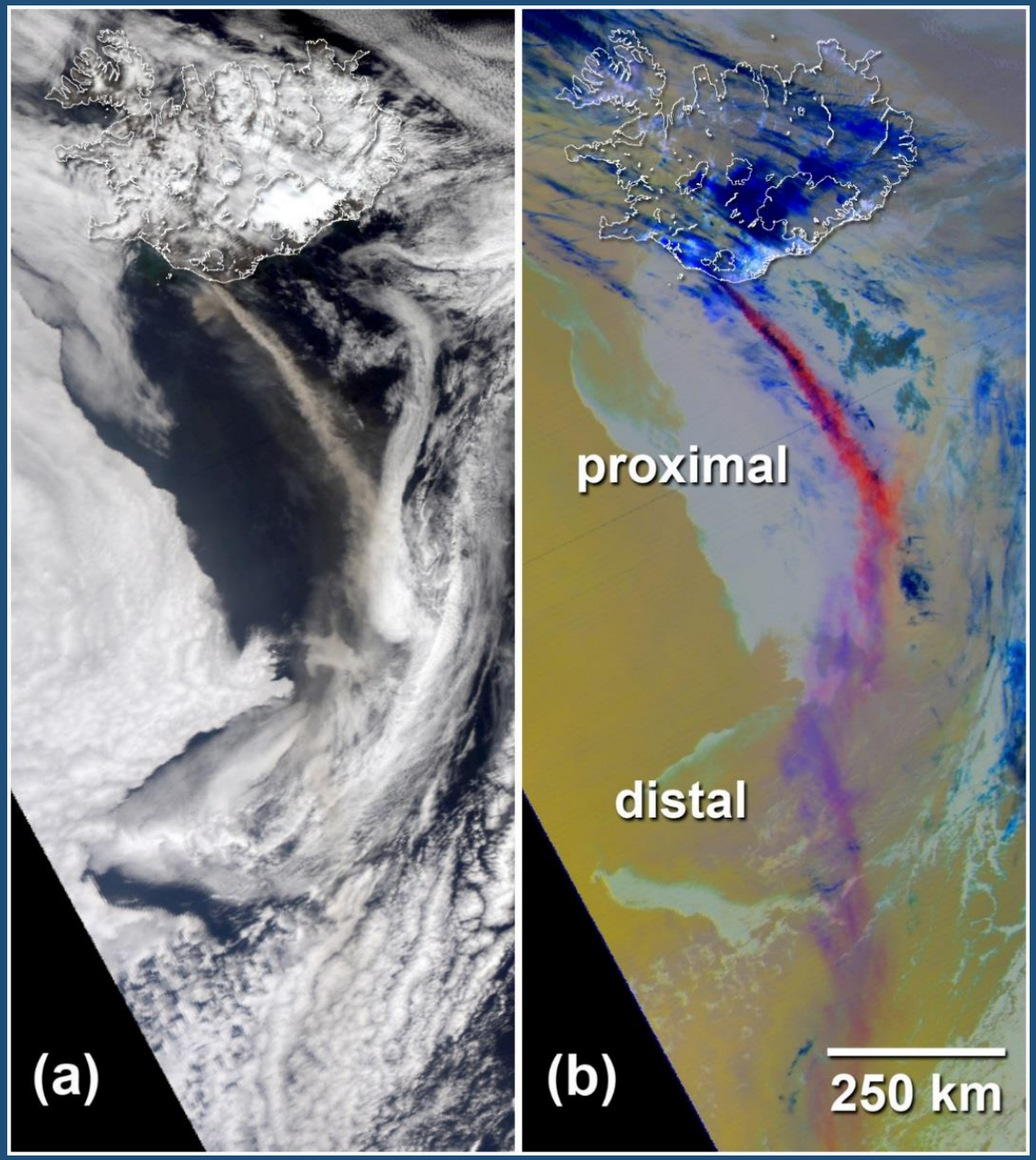
2010-03-19 &

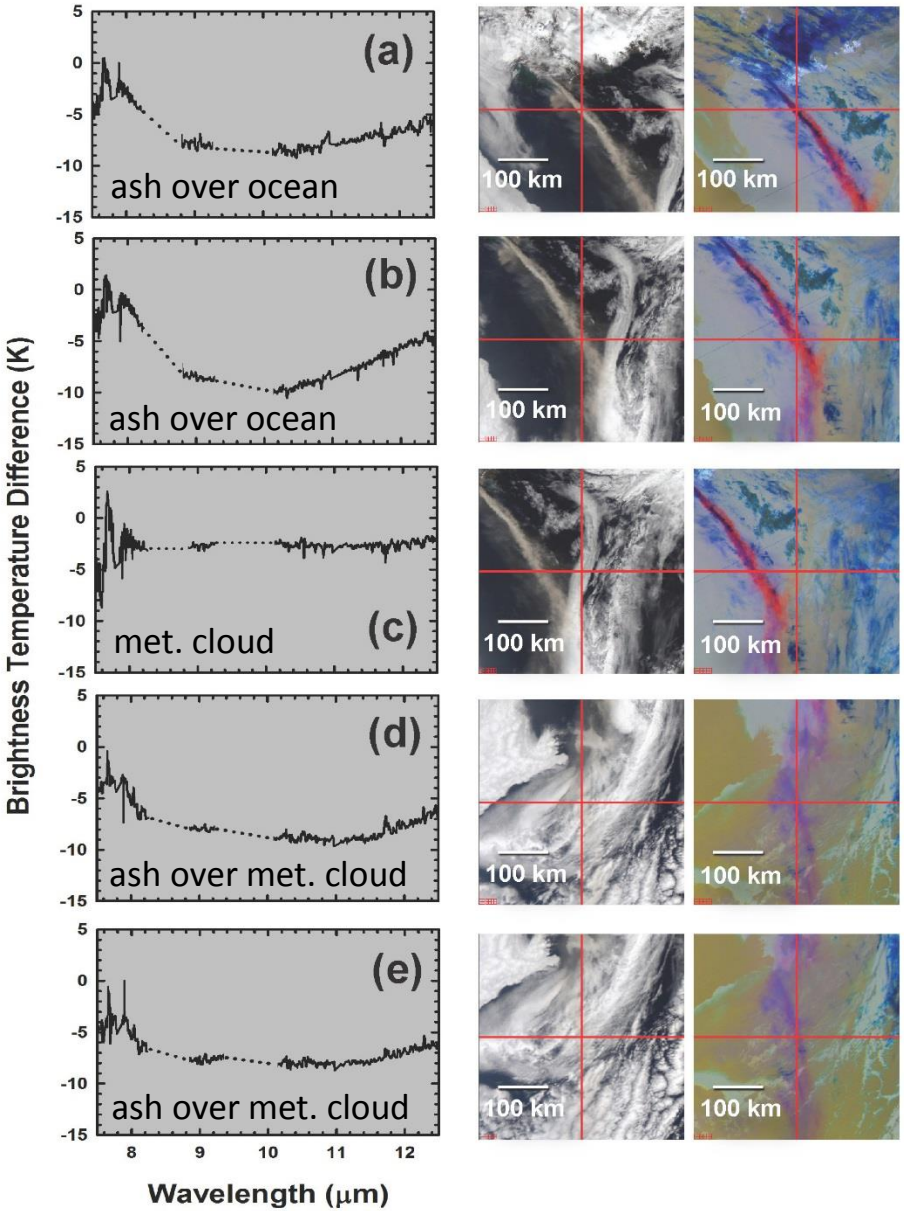
2010-05-07

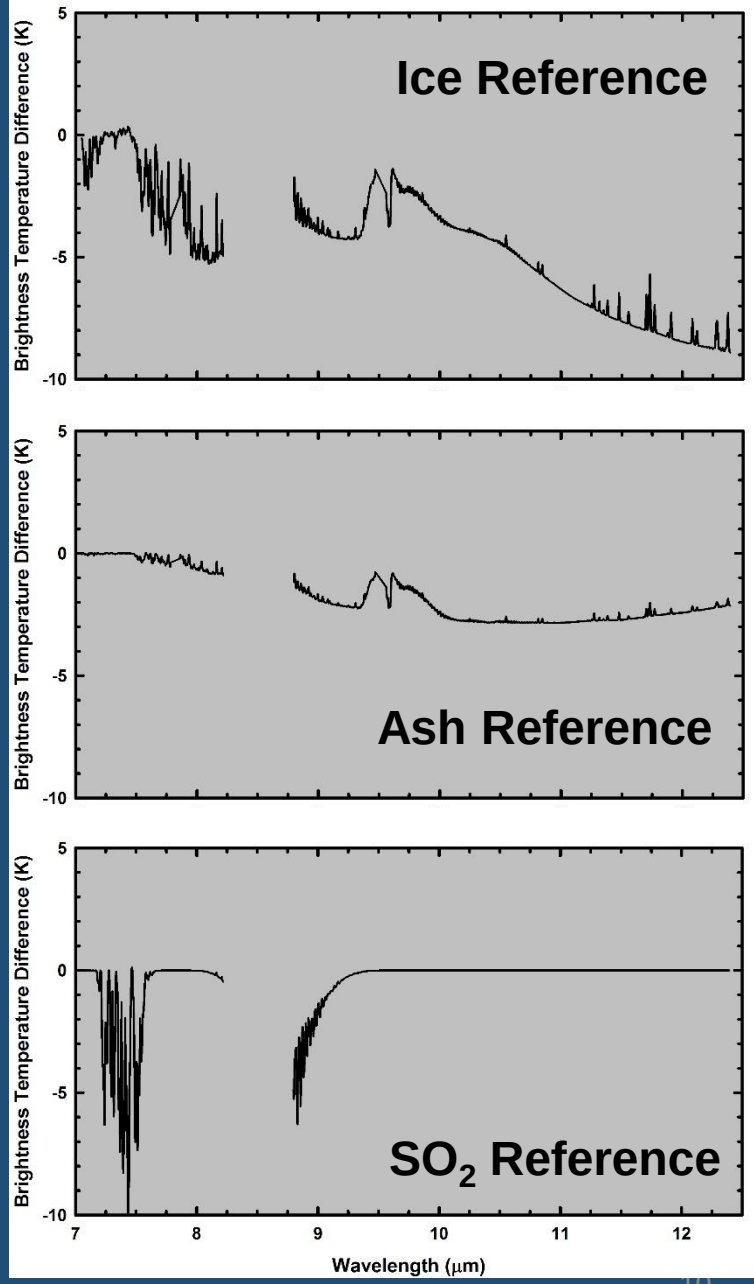
The spectral signature of volcanic plumes is a function of plume composition and background.

(a) On 7 May 2010 the proximal portion of the Eyjafallajökull plume was located over the open ocean, while the distal portion was located over meteorological clouds

(b) In the TIR we see the distinct change between the spectral radiance of the proximal and distal portions of the plume. RT modeling is required to discriminate changes in plume composition from changes in the background



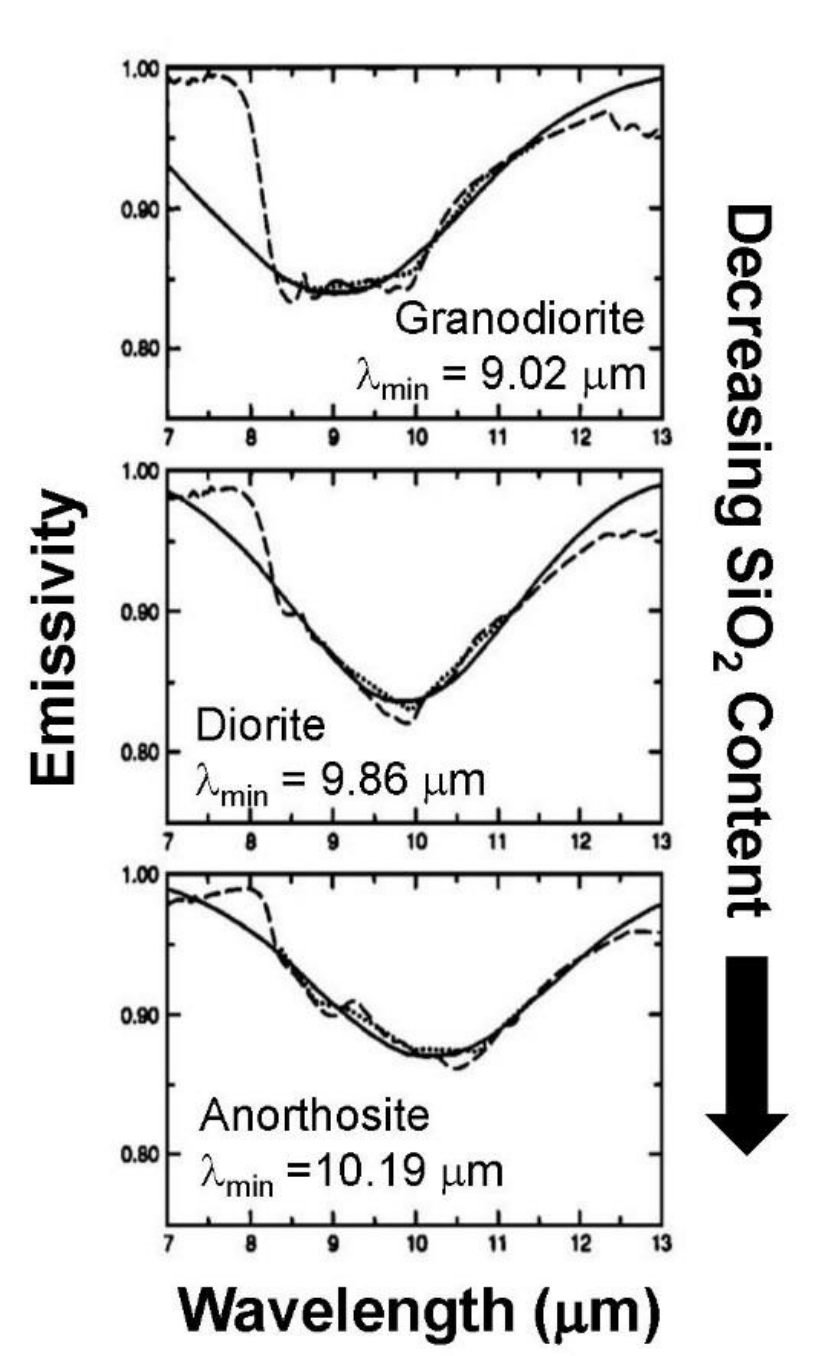

(a)
ash over ocean
(b)
ash over ocean
(c)
met. cloud
(d)
ash over met. cloud
(e)
ash over met. cloud
100 km
Brightness Temperature Difference (K)
Wavelength (μm)

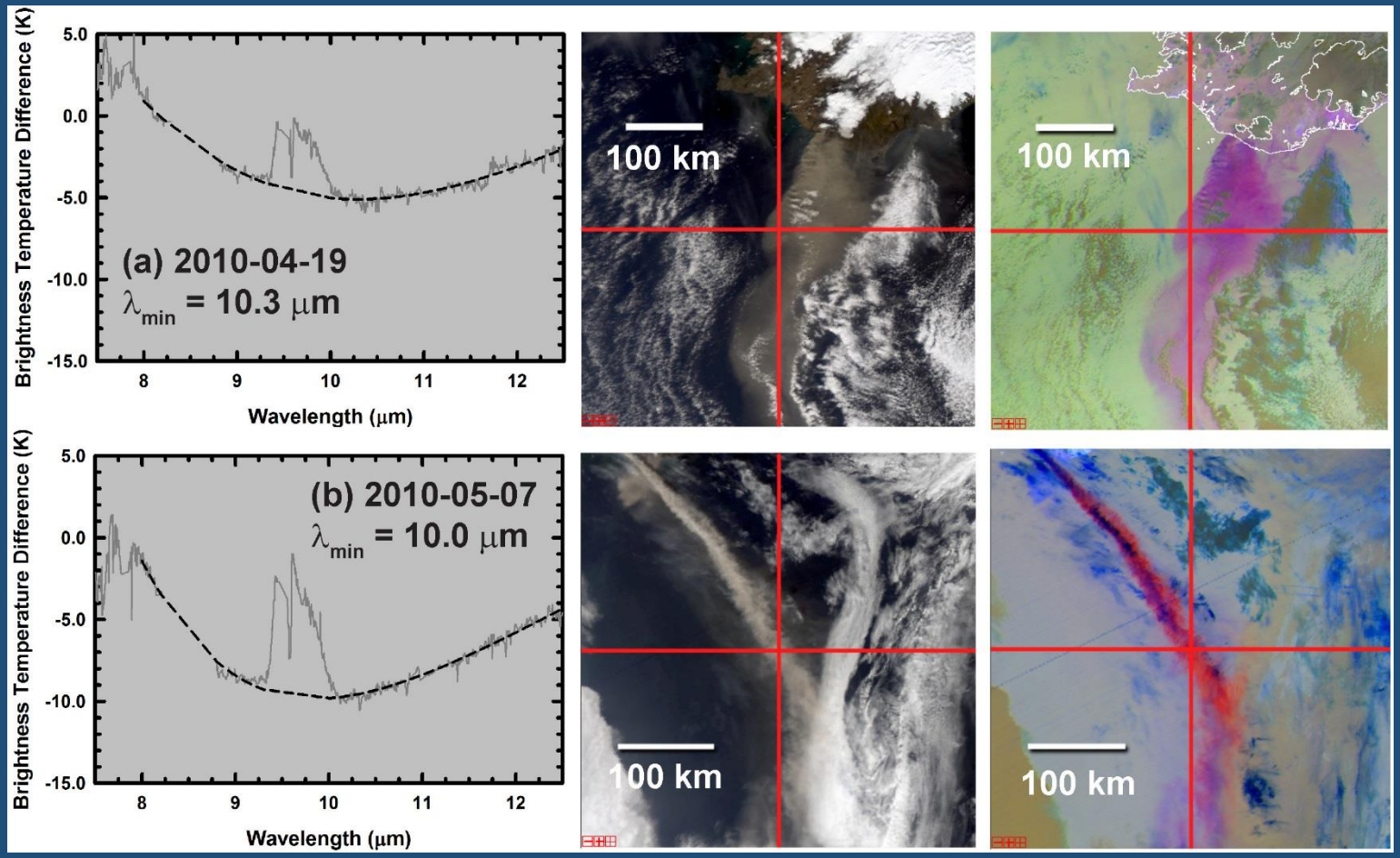

Ice Reference
Ash Reference
SO_2 Reference
Brightness Temperature Difference (K)
Wavelength (μm)

Position of minimum emissivity (λ_{min}) for igneous rocks is sensitive to SiO_2 content.

The emissivity minima are parameterized as minima of Gaussian functions (solid lines) fit to laboratory spectra (broken lines).

Note the shift of λ_{min} to longer wavelengths with the decrease in SiO_2. [modified from *Sabine et al.*, 1994]





The Eyjafallajökull melt became more silicic (increasing SiO_2) over the course of the eruption, and here we see that λ_{min} shifted from 10.3 to 10.0 µm between (a) 19 March and (b) 7 May 2010.

RT modeling is necessary to remove the O_3 artifact between 9 and 10 µm, as this spectral region is critical to locating the emissivity minimum.

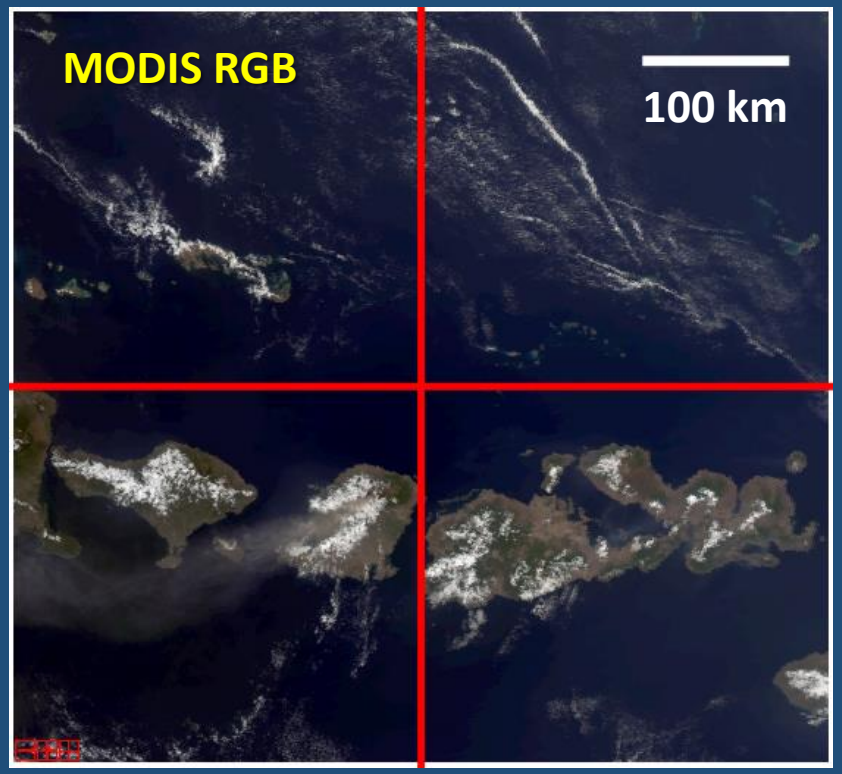
Rinjani Eruption

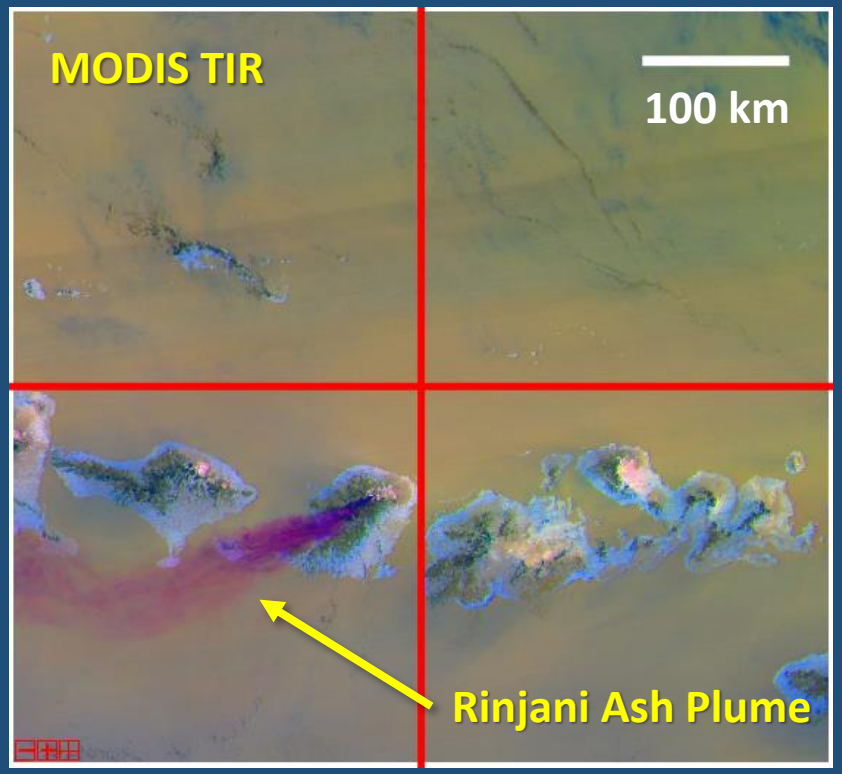
2015-11-04

Granule 60
6:00 UTC

Plume Spectroscopy

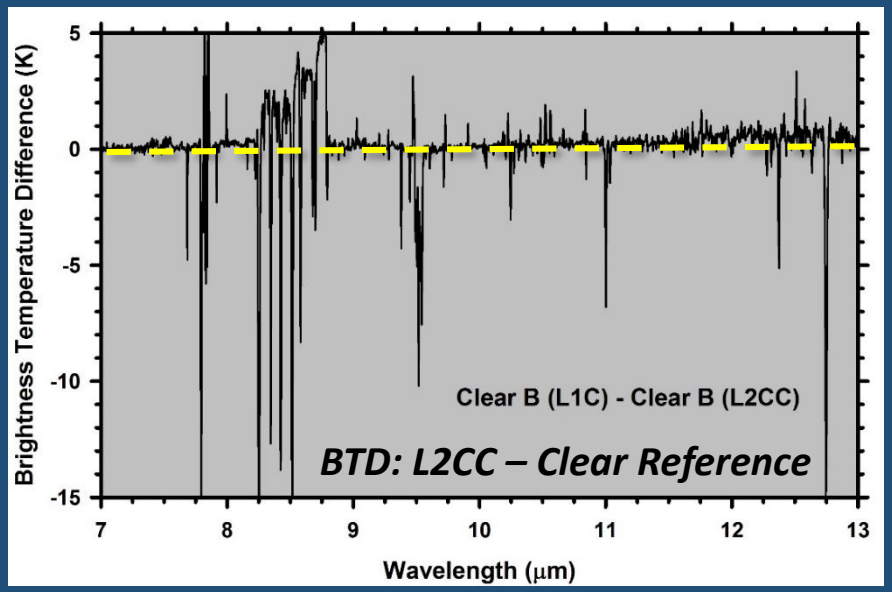
- Our Goal is to Isolate the Spectral Signatures of Plume Constituents
- Common Practice is to Identify a Plume-Free 'Background' or 'Reference' Spectrum and Compare Plume Spectra to this Background
- Alternate Approach: Compare Plume Spectrum to Forward Model that Excludes the Plume Constituents
- Evaluate Use of L2 Cloud-Cleared (L2CC) Radiance as Proxy for Forward Model





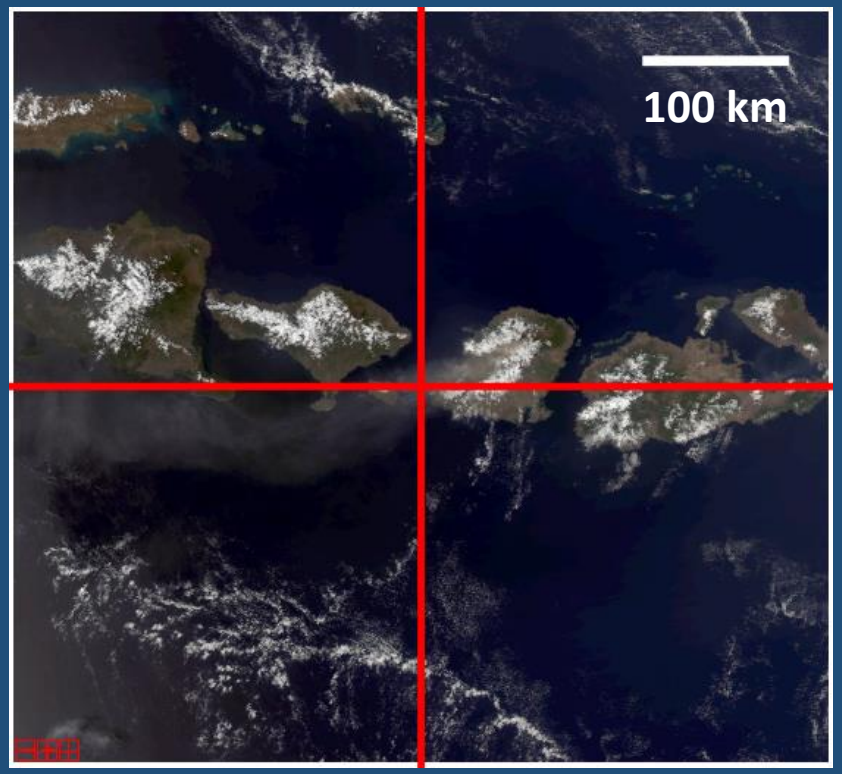
Clear Path B

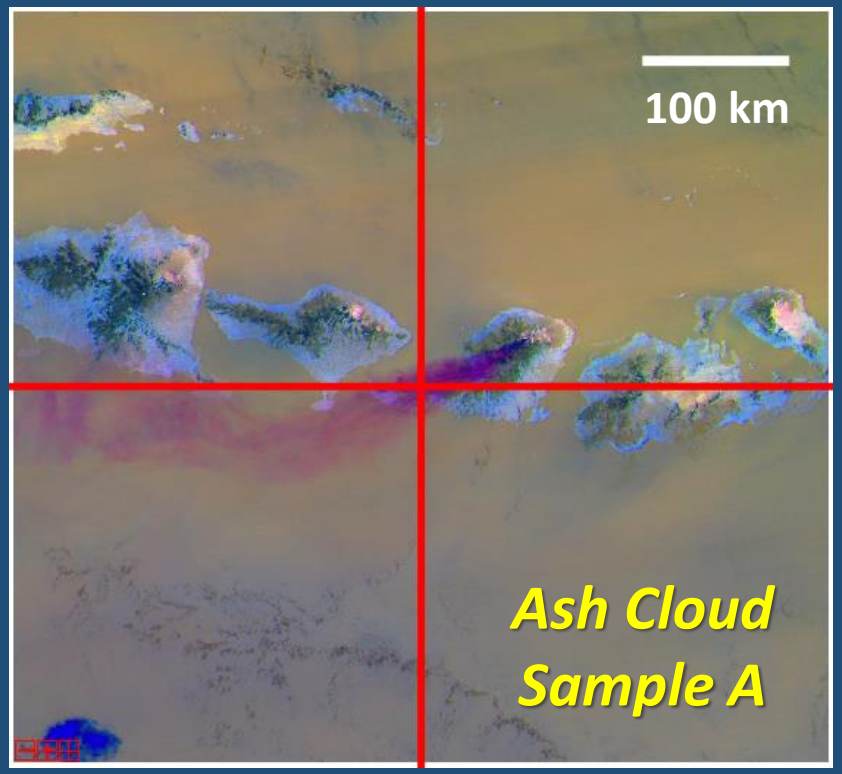
- Reference Spectrum for Background
- Close Agreement Between L1C and Cloud-Cleared (L2CC) Spectra

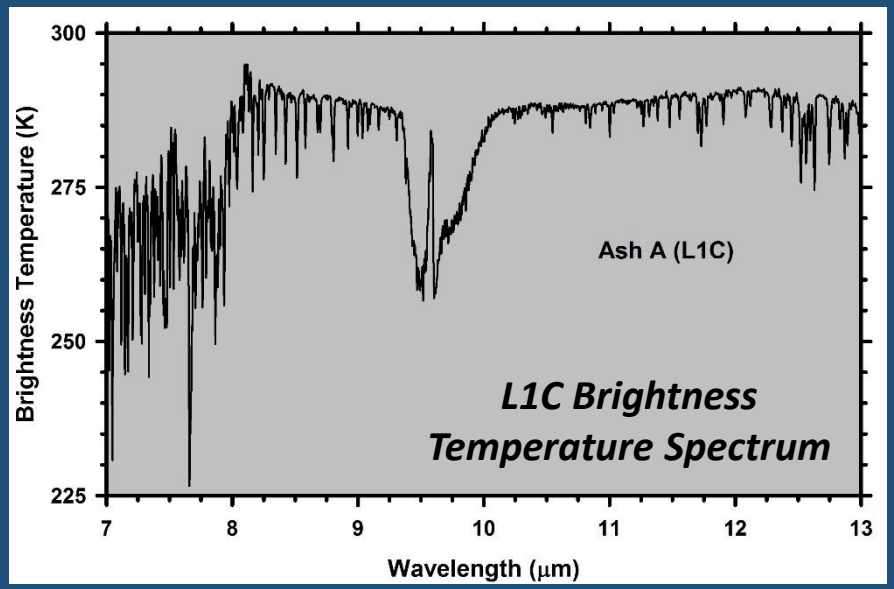


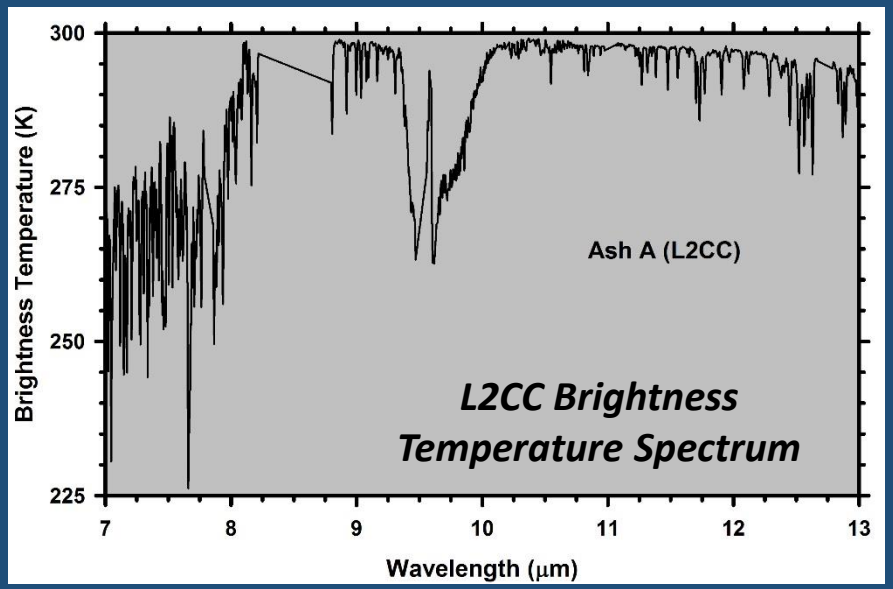
Ash Cloud Sample A

- High Concentration of Ash (High Optical Depth)
- ‘Concave’ Difference Spectra Indicative of Silicate Ash: Max. BTD ~ 12 K
- L2CC Spectrum is Good Approximation of Clear Path: Minor Negative Slope in L2CC–Reference BTD Spectrum

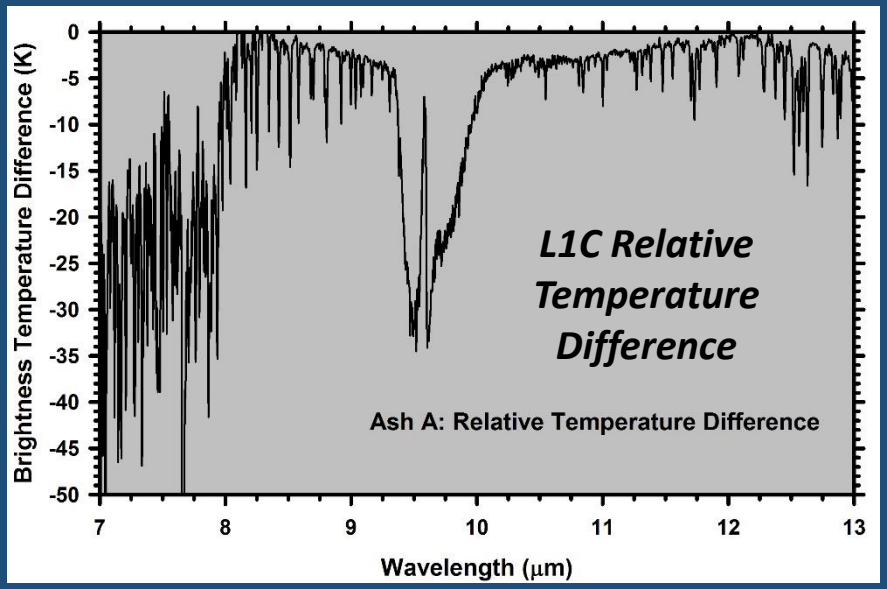

100 km

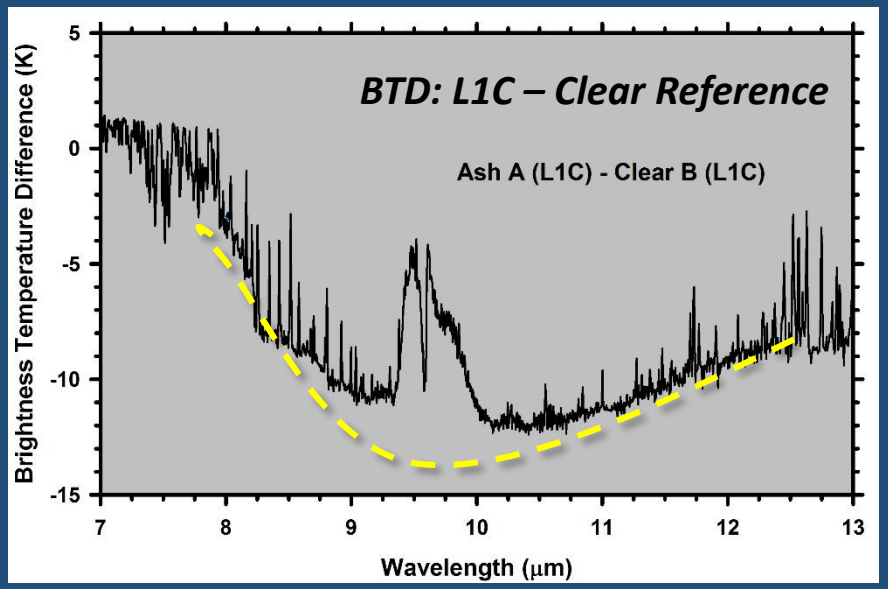

100 km
Ash Cloud
Sample A

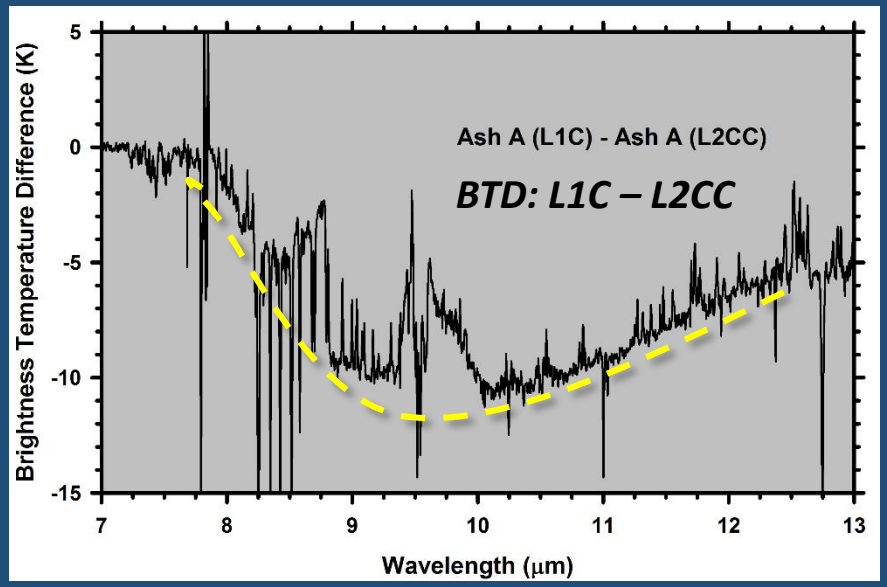

Brightness Temperature (K)
300
275
250
225
7
8
9
10
11
12
13
Wavelength (μm)
Ash A (L1C)
L1C Brightness
Temperature Spectrum

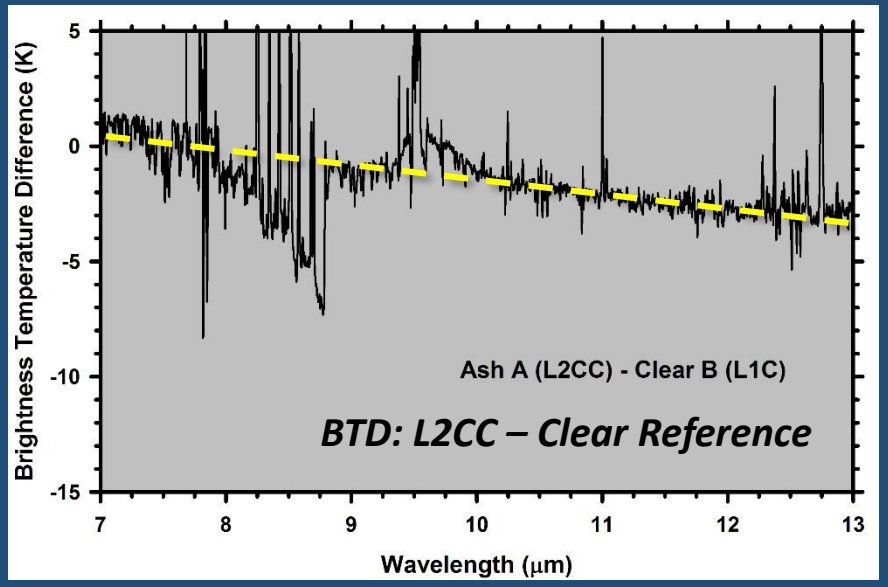

Brightness Temperature (K)
300
275
250
225
7
8
9
10
11
12
13
Wavelength (μm)
Ash A (L2CC)
L2CC Brightness
Temperature Spectrum

Ash Cloud Sample A









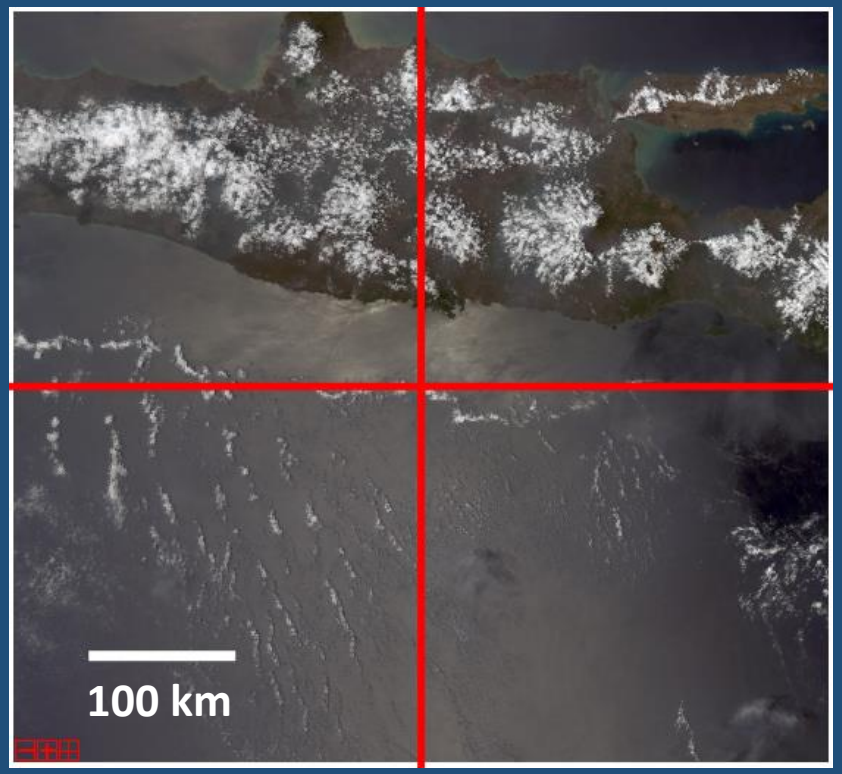
Ash Cloud Sample G

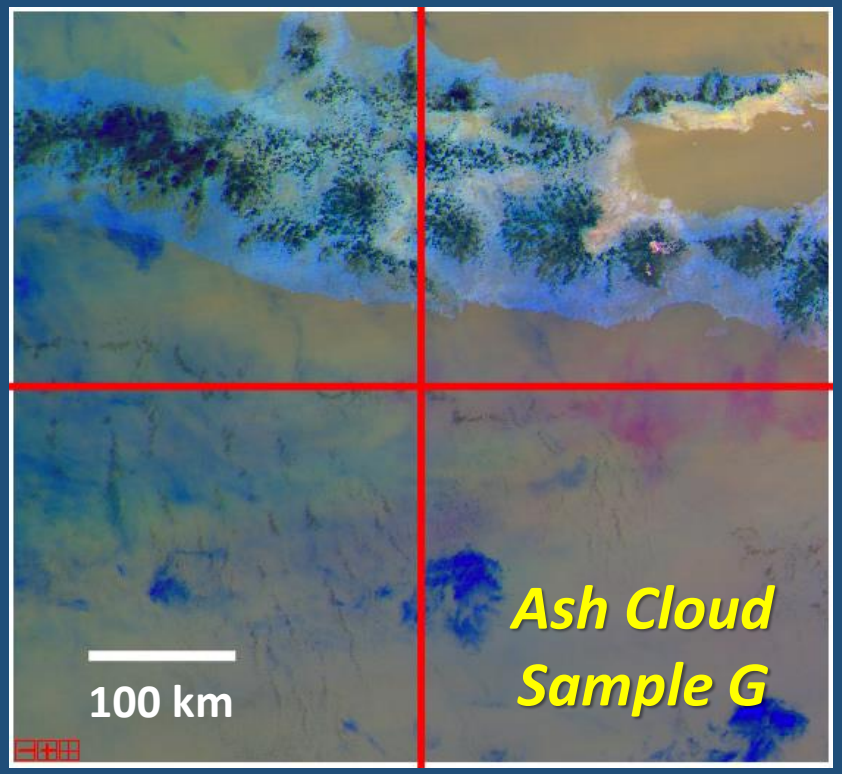
- Ash Concentration ~ 0; L1C and L2CC Spectra (Virtually) Identical

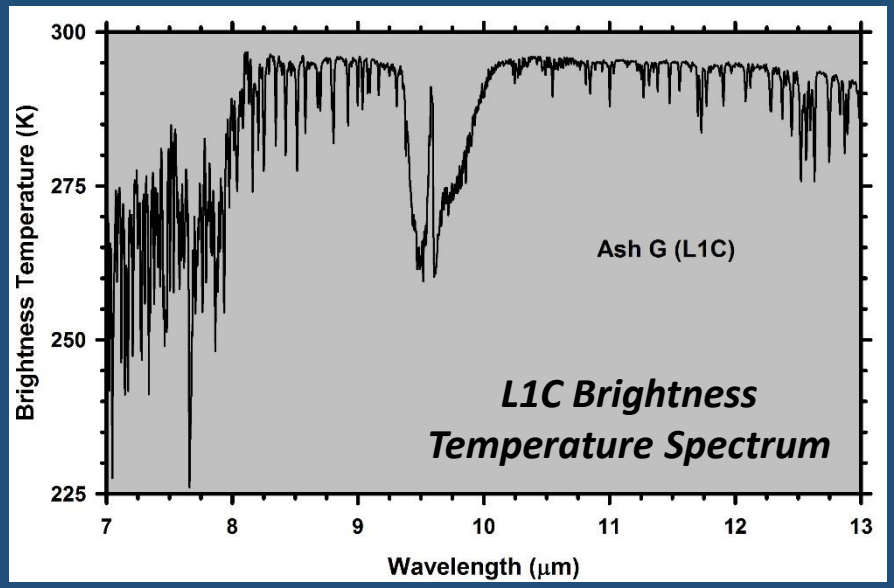
- Concave Difference Spectra Based on Clear Path:
  L1C – Clear: Max. BTD ~ 5 K
  L2CC – Clear: Max. BTD ~ 5 K

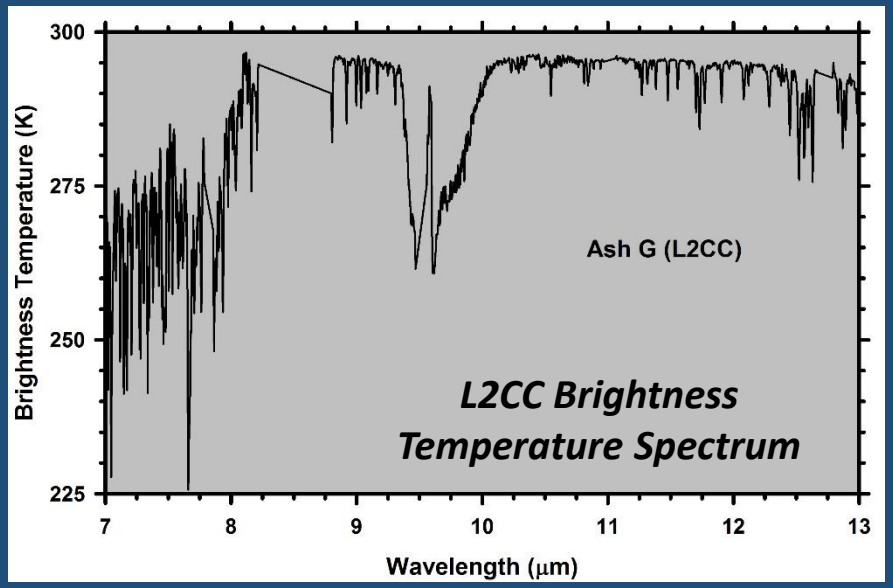
- L1C – L2CC Spectrum is Linear (Slight Negative Slope) and ~ 0.0

- L2CC Spectrum < Clear Path Spectrum

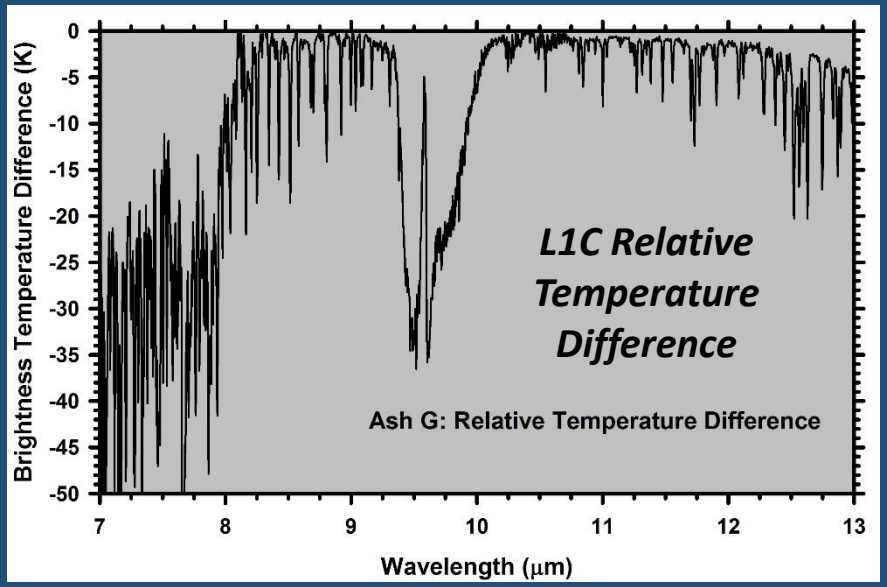

100 km

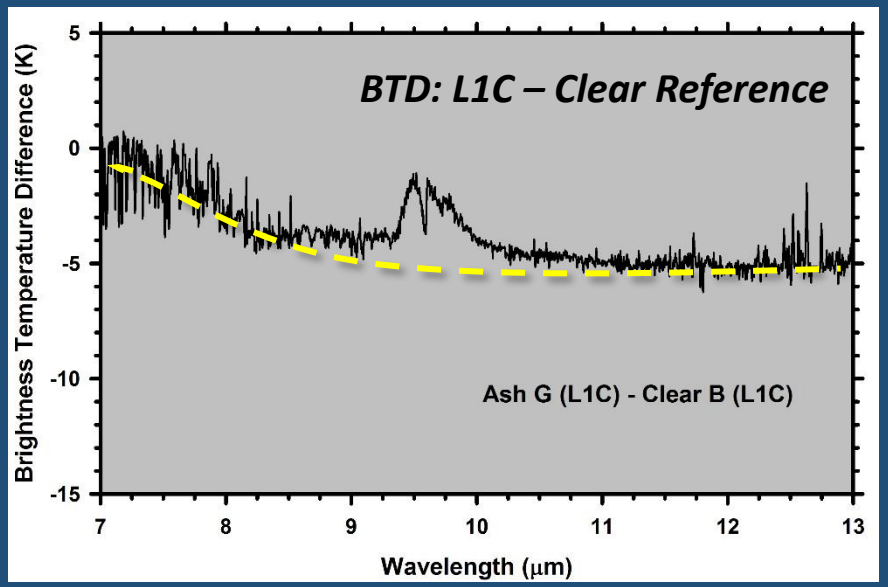

100 km
Ash Cloud
Sample G

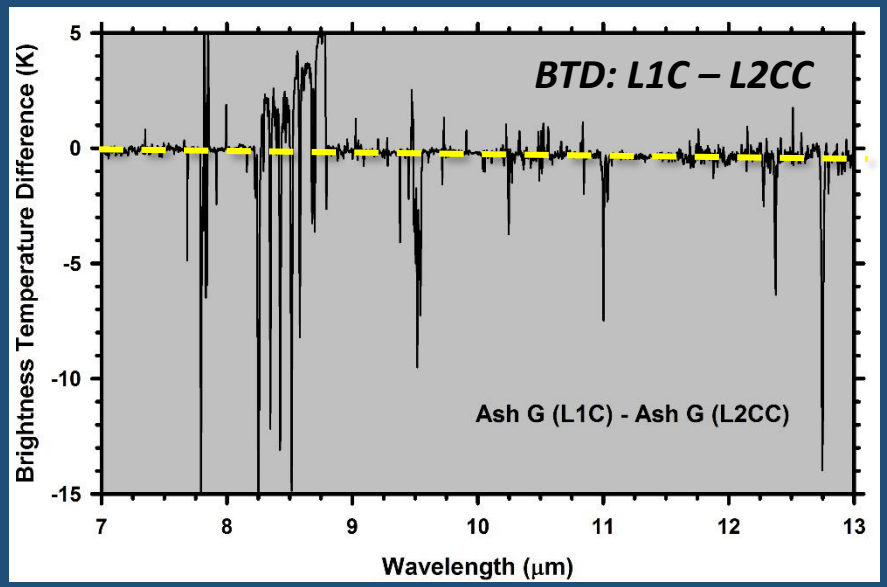

Brightness Temperature (K)
300
275
250
225
7
8
9
10
11
12
13
Wavelength (μm)
Ash G (L1C)
L1C Brightness
Temperature Spectrum

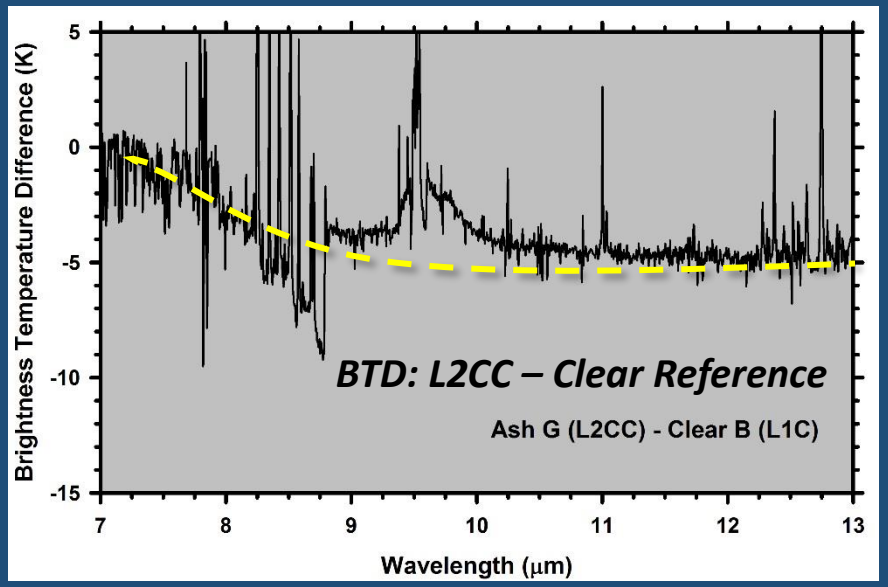

Brightness Temperature (K)
300
275
250
225
7
8
9
10
11
12
13
Wavelength (μm)
Ash G (L2CC)
L2CC Brightness
Temperature Spectrum

Ash Cloud Sample G









Preliminary Conclusions

- Cloud-Clearing Does Not Screen Low Concentrations of Ash (Low Optical Depth)
  - L2CC Reference ≈ Clear Path Reference for Samples A, B, D, F
  - L2CC Reference < Clear Path Reference for Samples C, E, G
  - SO_2 Also Below Screening Threshold?
  - Adjust/Modify Screening Threshold?
- Need to Evaluate Use of L2CC for Plumes Over Land Surface
- Need for Tools to Resample/Interpolate L2CC Spectra for Comparison with L1C or L1B Spectra

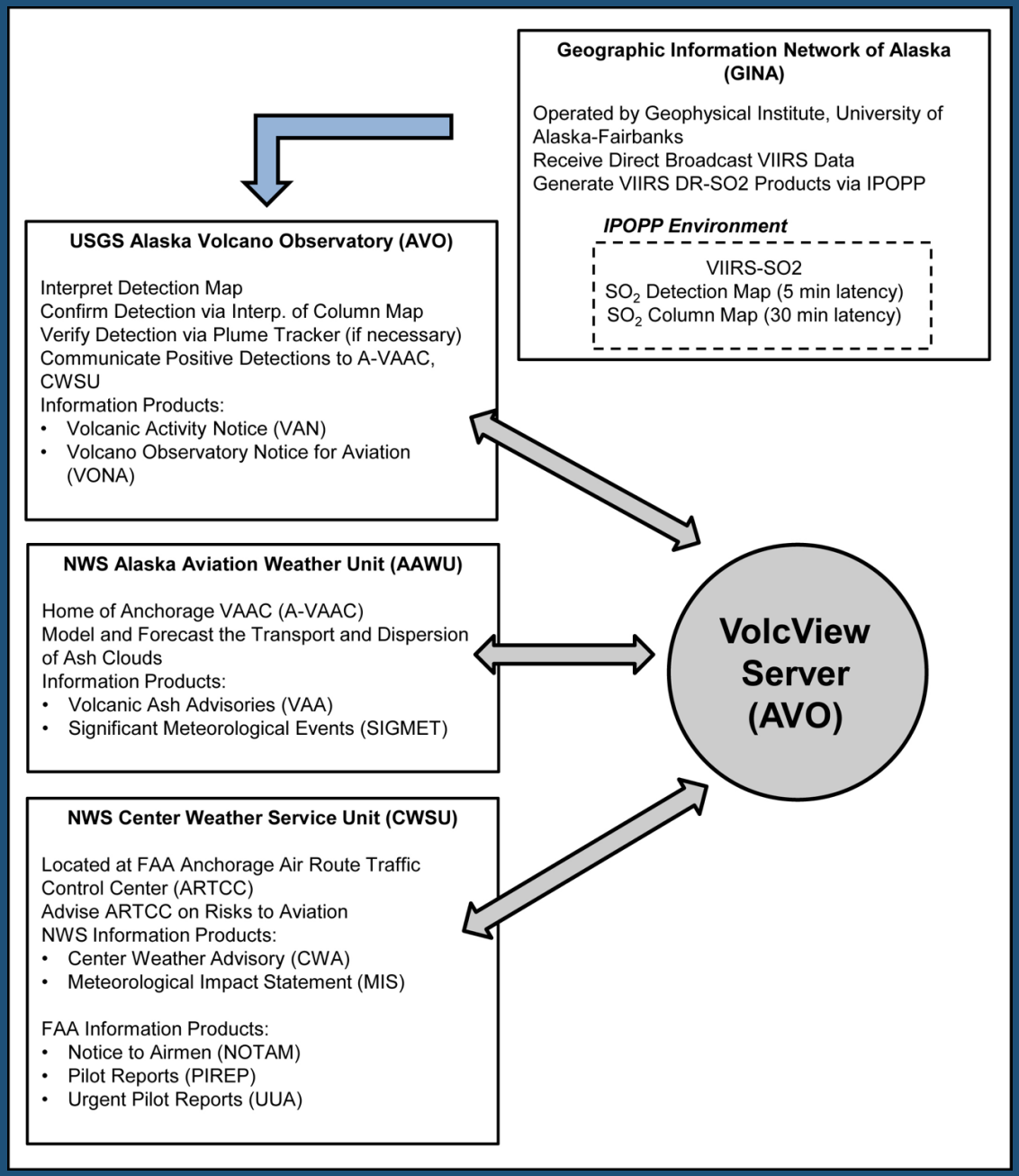
Spectral Analysis Tool

- Public-Facing Web Tool
  - Event-Driven Data Archive: Volcanic, Dust, Smoke, or Chemical Plumes
  - AIRS L1B (L1C?) Spectra + Corresponding MODIS RGB and TIR
  - Background Spectra vs. Cloud-Cleared Spectra?
  - Visual Comparisons with Library Spectra
- Evaluation of New SO_2 and Dust Products
  - Temperature and H_2O Profiles (L2, L3, or Climatology)
  - Surface Emissivity
  - Averaging Kernels
- Suggestions and Wish Lists?

Use Case

Volcanic Ash Hazards in North Pacific

USGS: Monitor Volcanic Activity

NWS: Forecast Ash Mass Concentration and Dispersion

FAA: Manage Air Traffic