Anticipated Contributions of HyspIRI to the Remote Sensing of Volcanic Plumes

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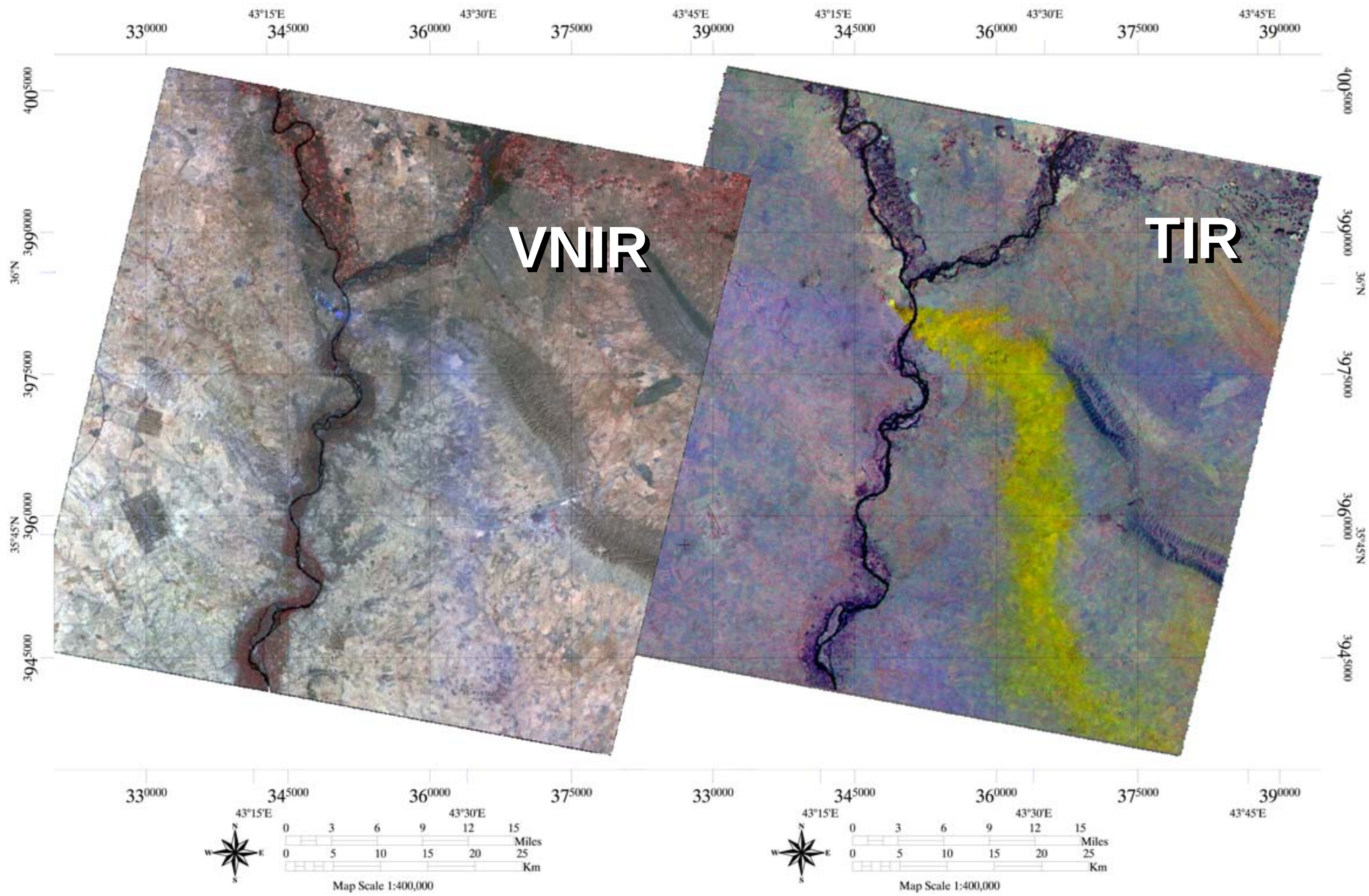
TQ1: How can we help predict and mitigate earthquake and volcanic hazards through the detection of transient thermal phenomena?

Do volcanoes signal impending eruptions through changes in surface temperature and gas emission rates and are such changes unique to specific types of eruptions? **[DS 227]**

→ Map SO_2 Content of Plumes

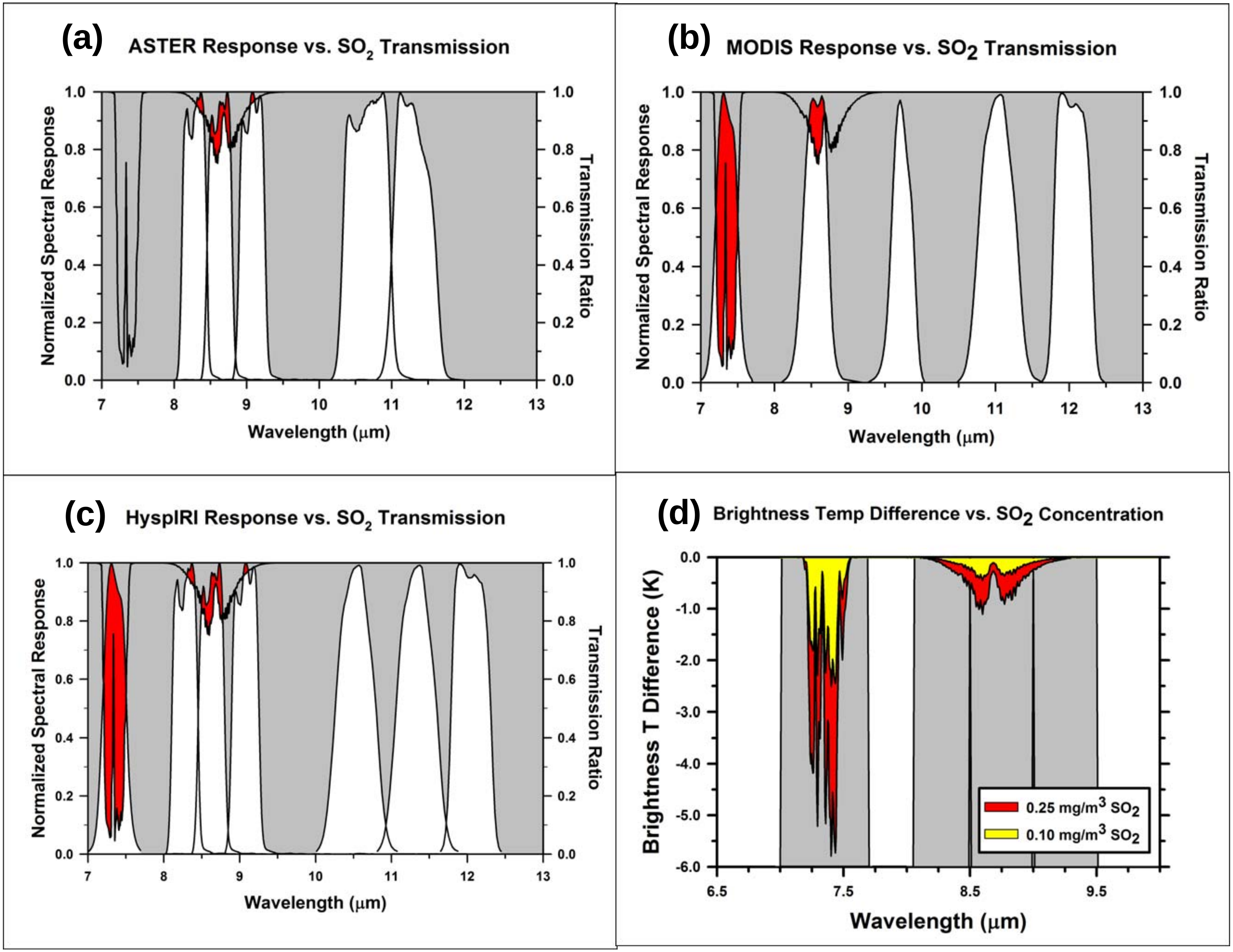
What are the characteristic dispersal patterns and residence times for volcanic ash clouds and how long fo such clouds remain a threat to aviation? **[DS 224]**

→ Detect Plumes and Track Positions over Time



Al Mishraq Sulfur Plant Fire, Iraq, 14 July 2003

~720 kt of SO2 released between 24 June – 21 July 2003 *[Carn et al., 2004]*


(a)
ASTER Response vs. SO2 Transmission
Normalized Spectral Response
Transmission Ratio
Wavelength (μm)
(b)
MODIS Response vs. SO2 Transmission
Normalized Spectral Response
Transmission Ratio
Wavelength (μm)
(c)
HyspIRI Response vs. SO2 Transmission
Normalized Spectral Response
Transmission Ratio
Wavelength (μm)
(d)
Brightness Temp Difference vs. SO2 Concentration
Brightness T Difference (K)
Wavelength (μm)
0.25 mg/m3 SO2
0.10 mg/m3 SO2

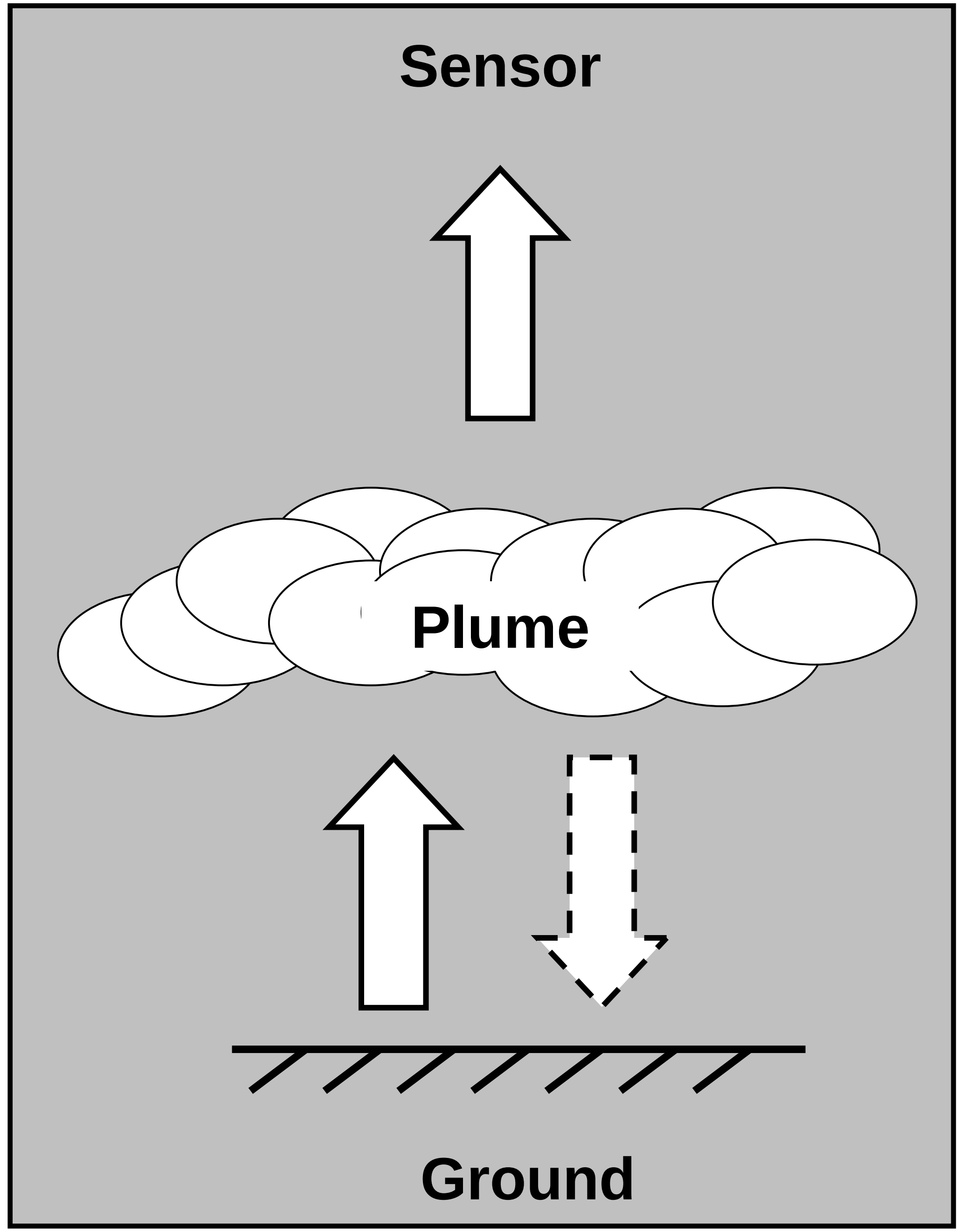
3-Slab Radiative Transfer Model

Slab 2 Radiance $= \varepsilon_3(\lambda, x_3)\ B(\lambda, T_3) + \tau_3(\lambda, x_3)$[Plume Radiance]

Plume Radiance $= \varepsilon_2(\lambda, x_2)\ B(\lambda, T_2) + \tau_2(\lambda, x_2)$[Slab 1 Radiance]

Slab 1 Radiance $= \varepsilon_1(\lambda, x_1)\ B(\lambda, T_1) + \tau_1(\lambda, x_1)$[Ground Radiance]

Ground Radiance $= \varepsilon_o(\lambda, x_o)\ B(\lambda, T_o) + [1 - \varepsilon_o(\lambda, x_o)]\ \varepsilon_1(\lambda, x_1)\ B(\lambda, T_1)$



Surface Temperature vs. SO_2 Concentration

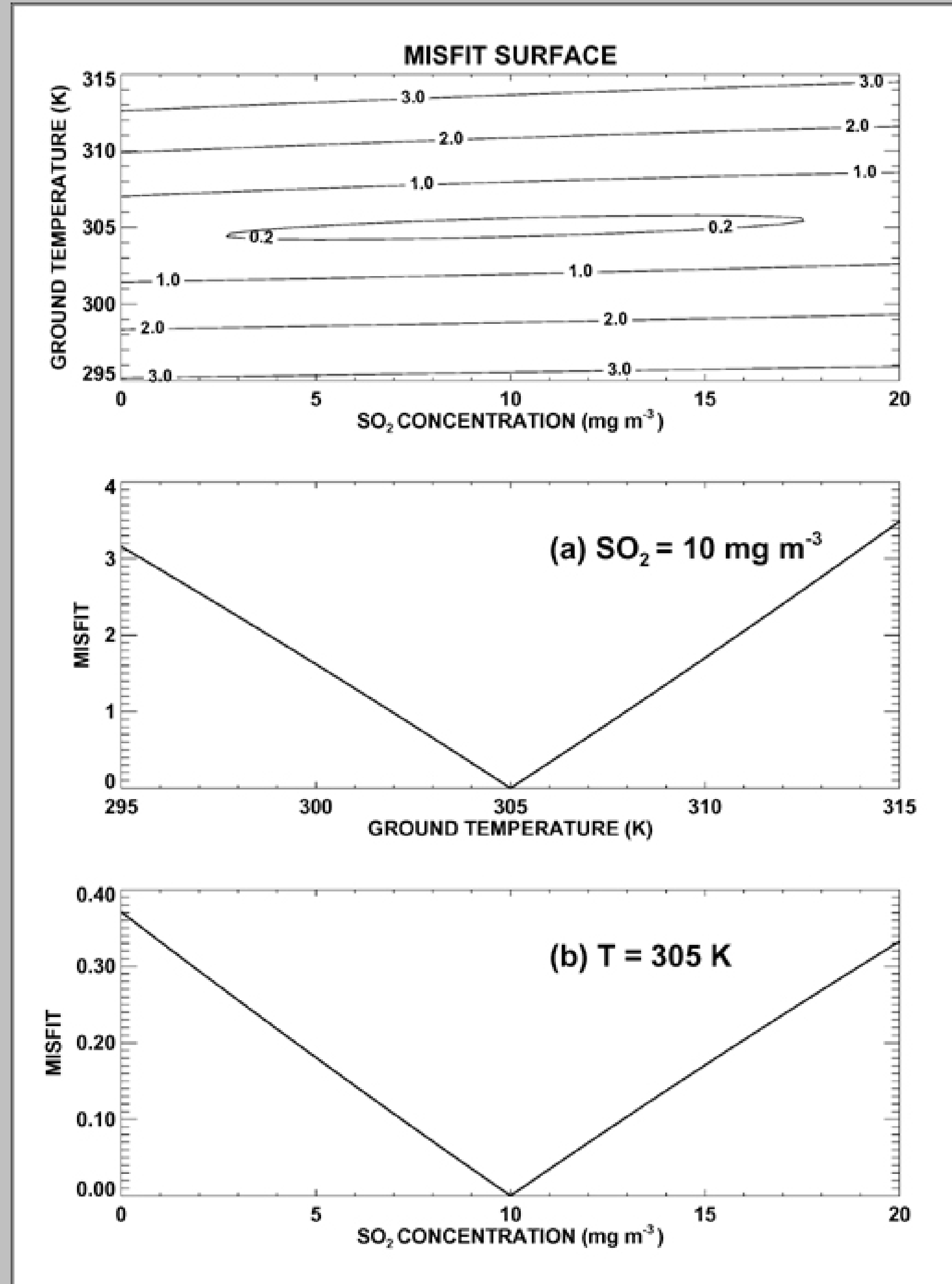
Can We Estimate Surface Temperature When Looking Through a Plume?

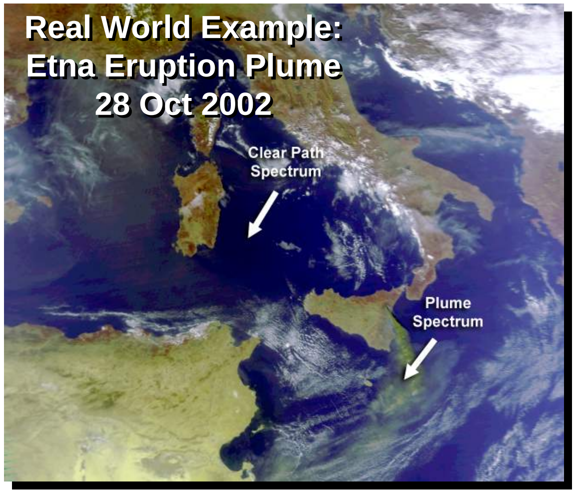
Ground Temperature has Stronger Influence on IRAD Than SO_2 Concentration

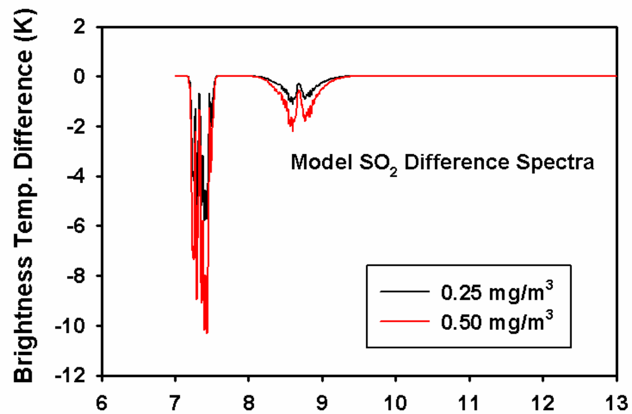
Simultaneous Retrieval of Temperature and SO_2 is Difficult; Cascading (Serial) Retrieval is a Better Option:

a) Evaluate Effect of Last SO_2 Estimate on Current Temperature Estimate

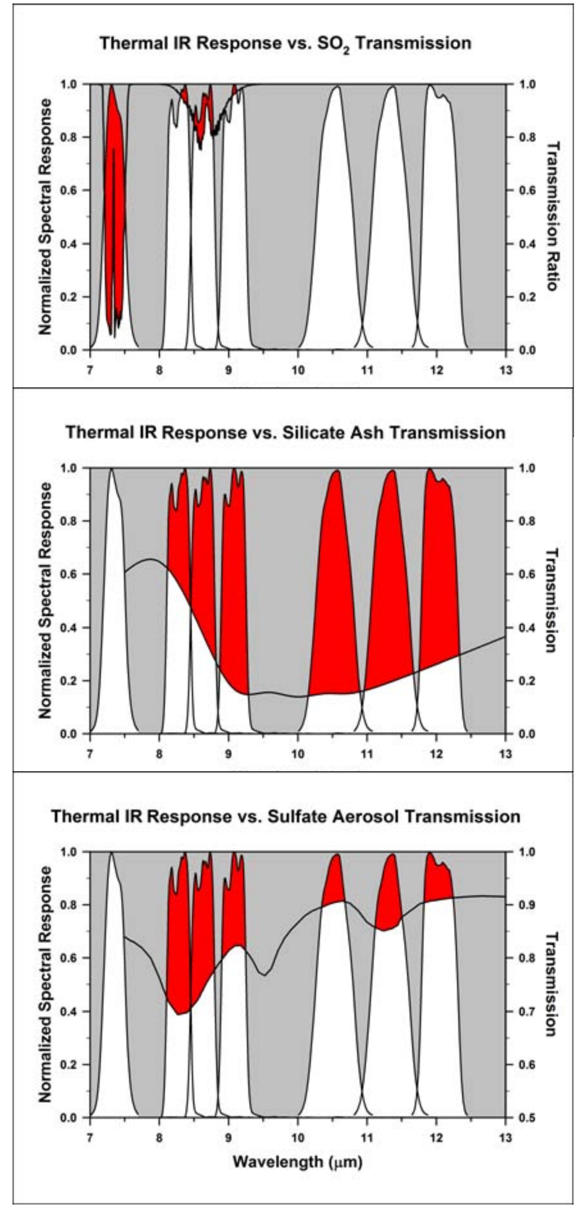
b) Exit When ΔT < Threshold

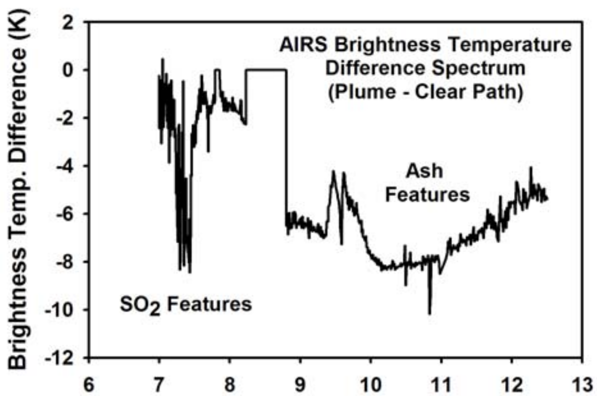


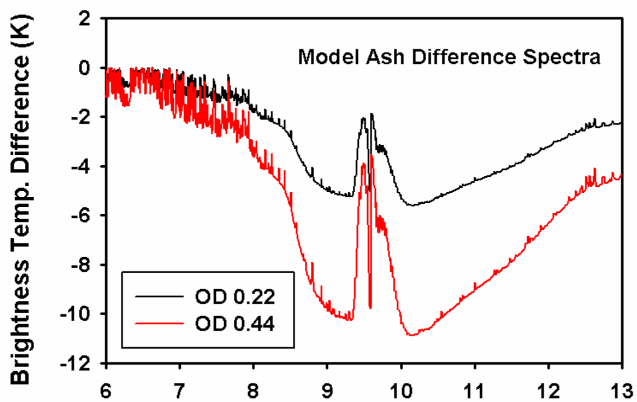


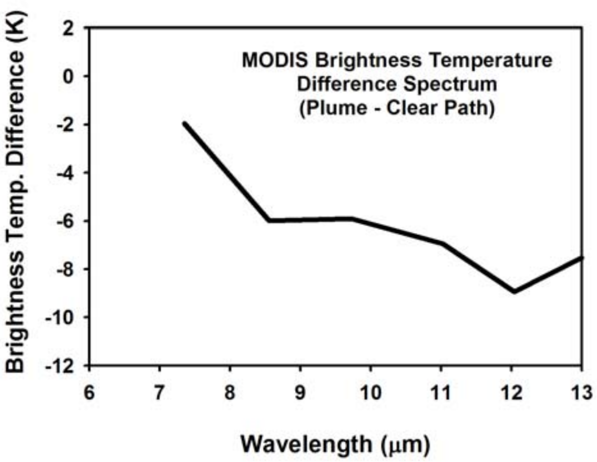


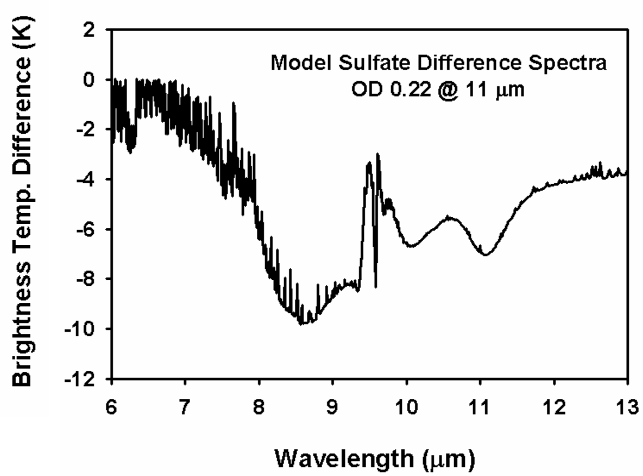
Notional HyspIRI TIR Response vs. Spectra of Plume Materials

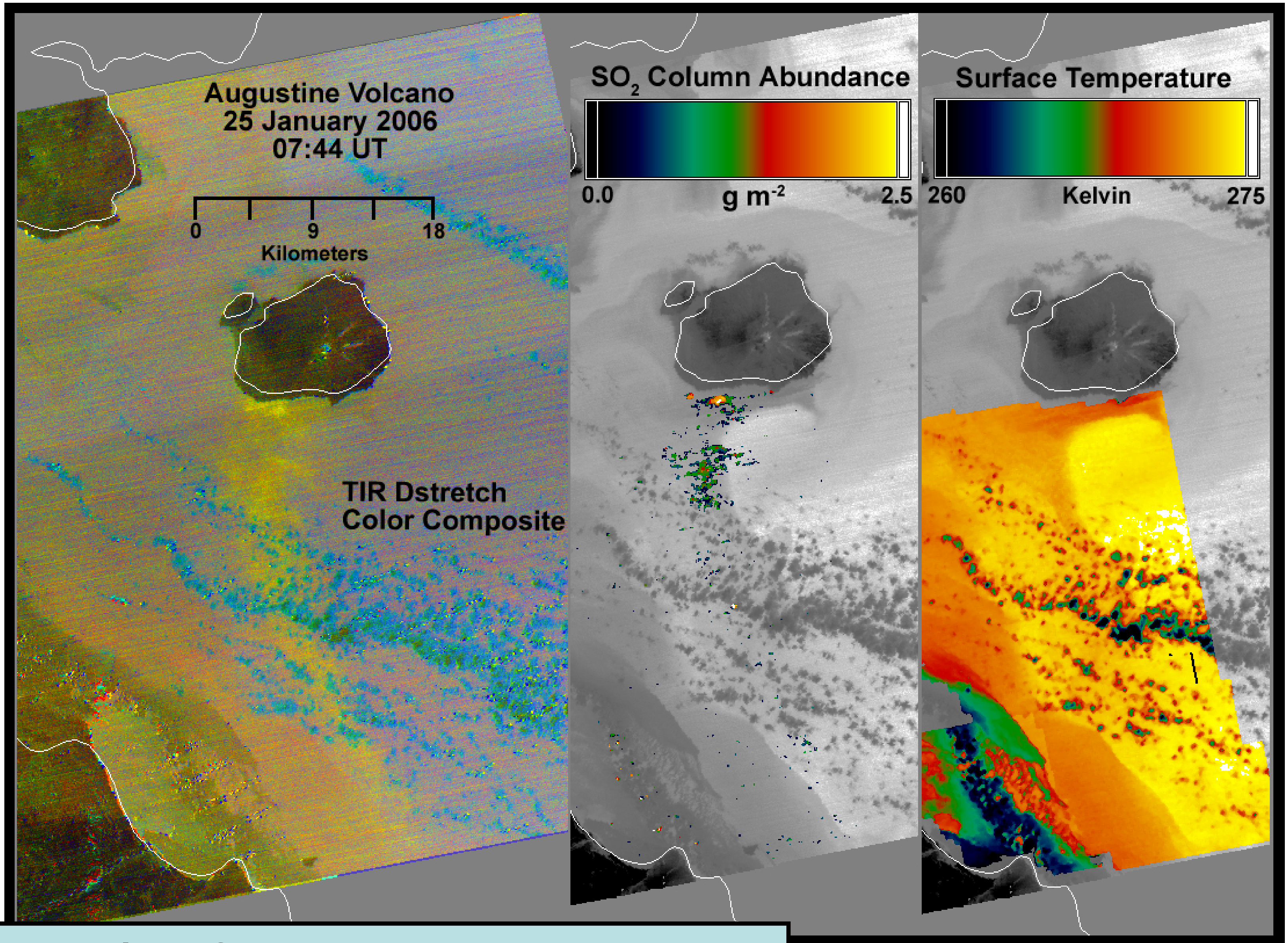






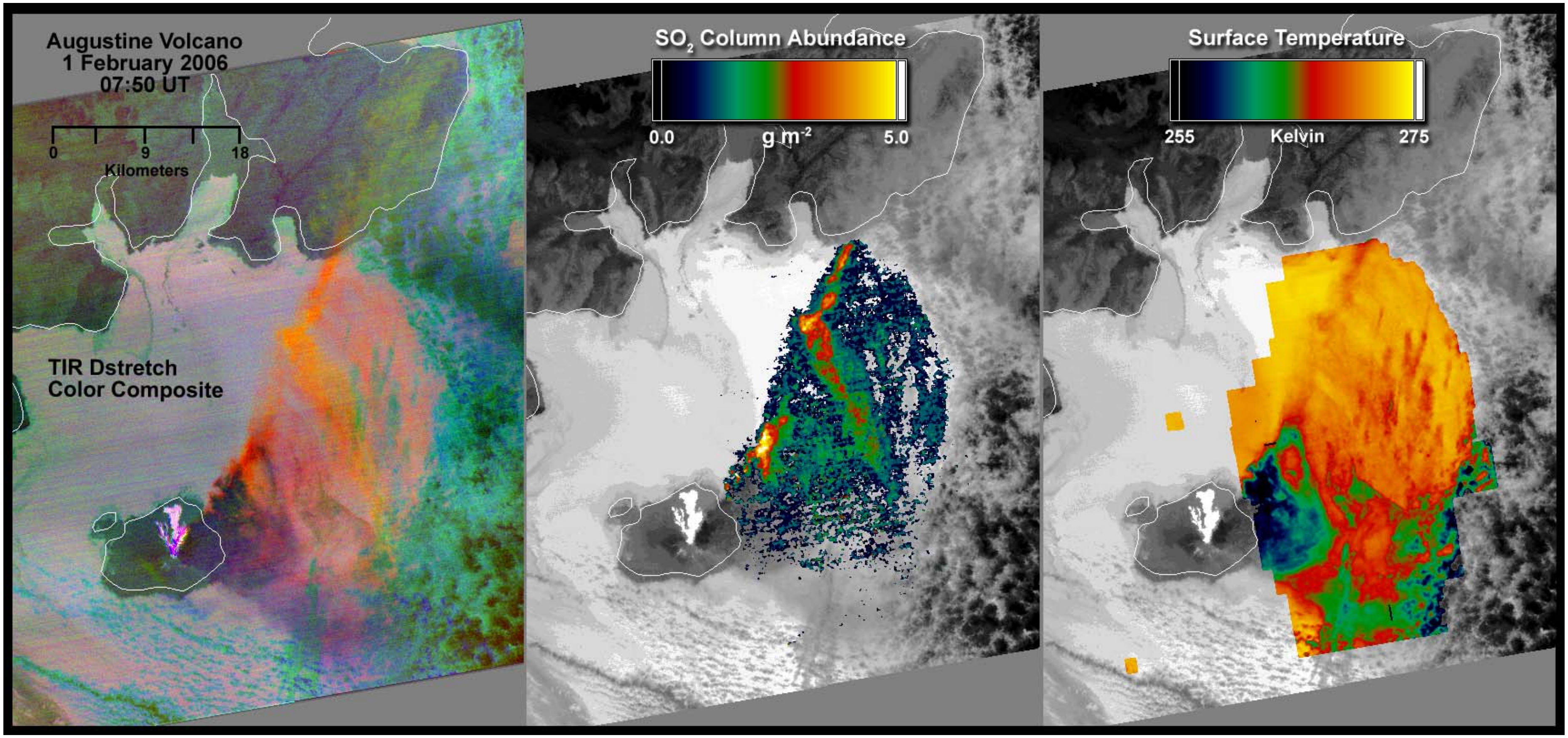






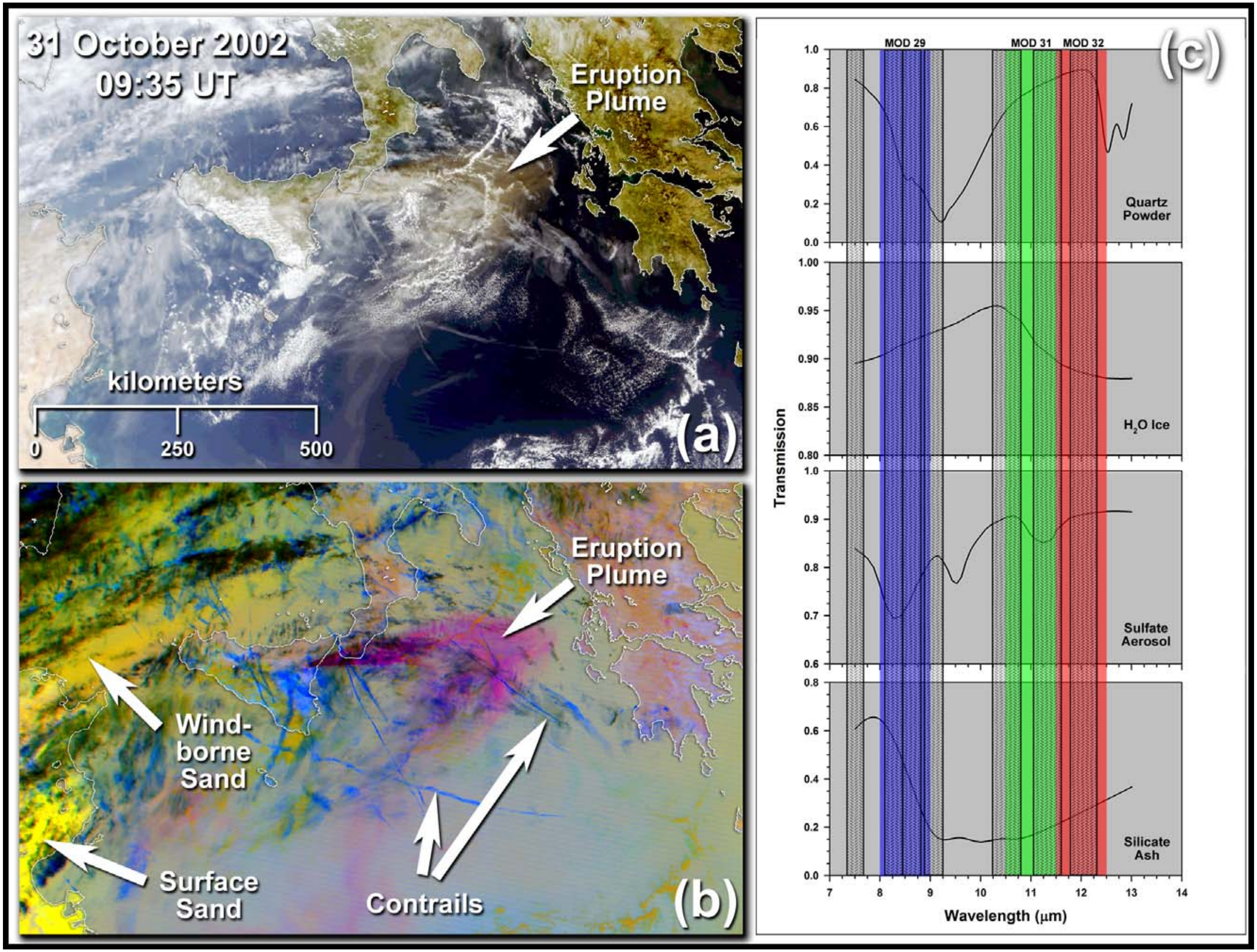
Passive Degassing of SO_2

- **Plume Transparent to TIR Radiance**
- **No Anomalies in Apparent Surface Temperature**

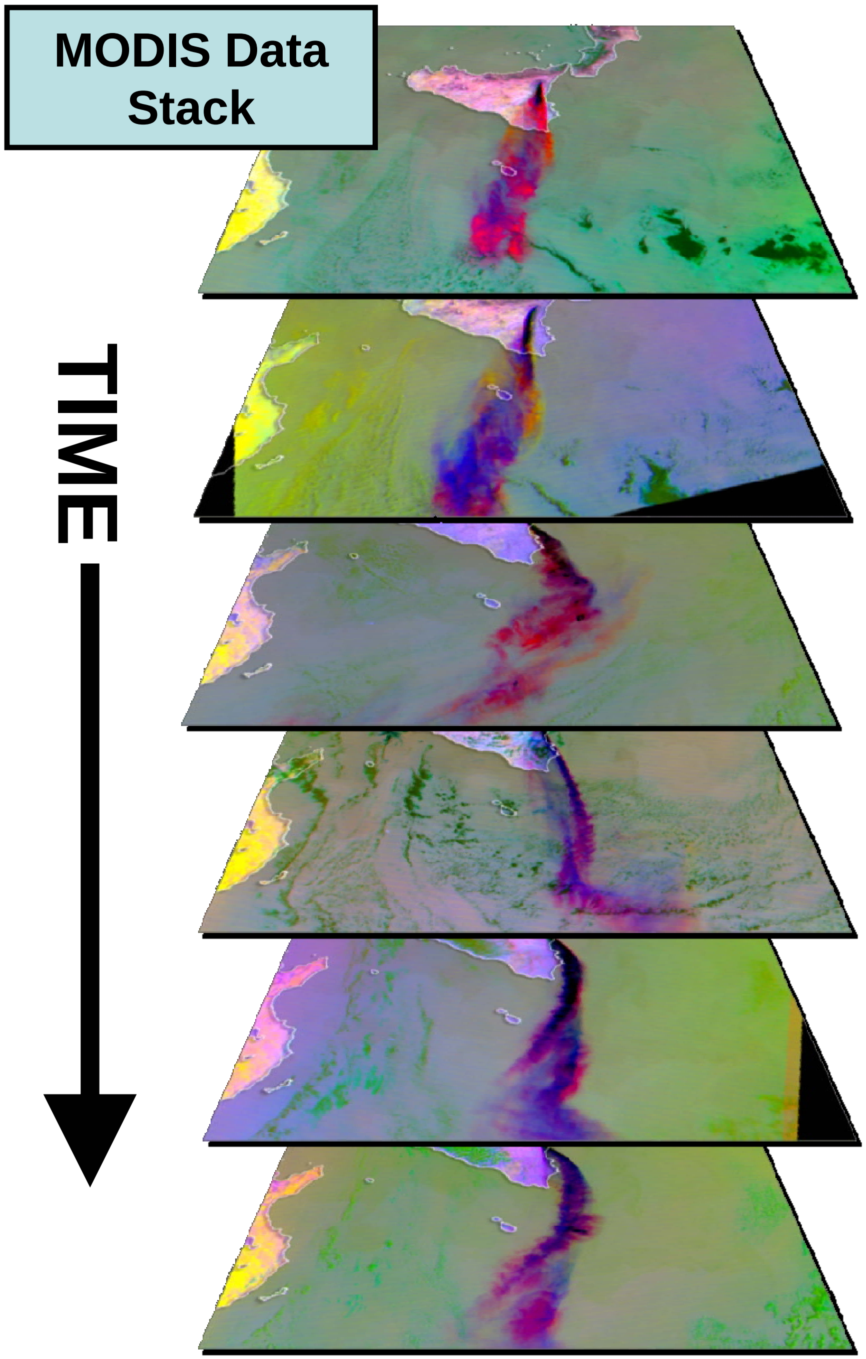


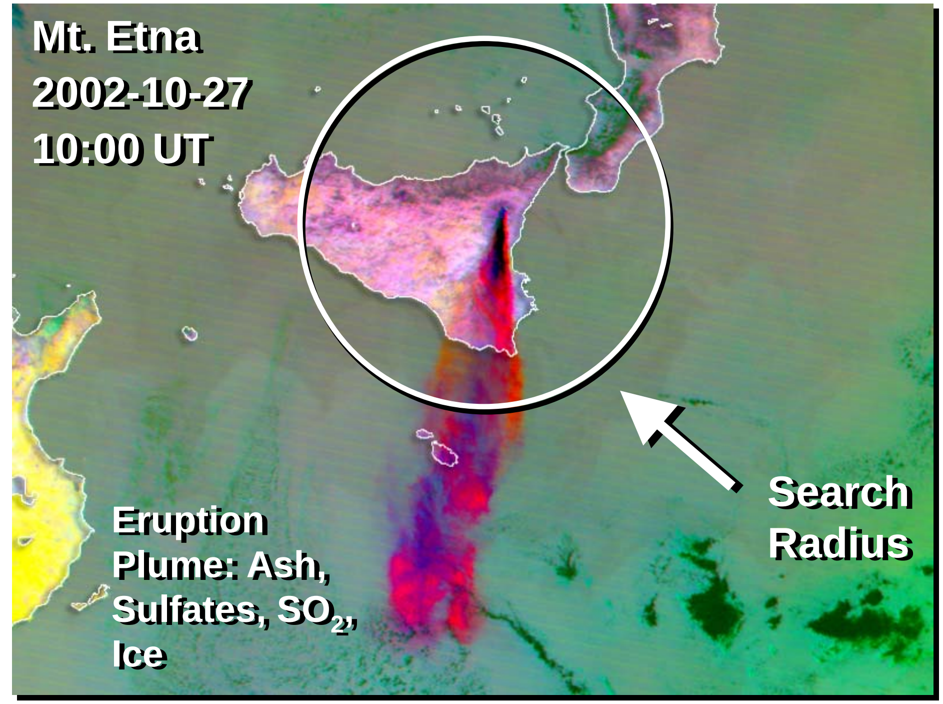
Explosive Eruption: Heterogeneous Plumes

- Plume Records Explosive Episodes
- High Opacity to TIR Radiance
- Anomalies in Apparent Surface Temperature



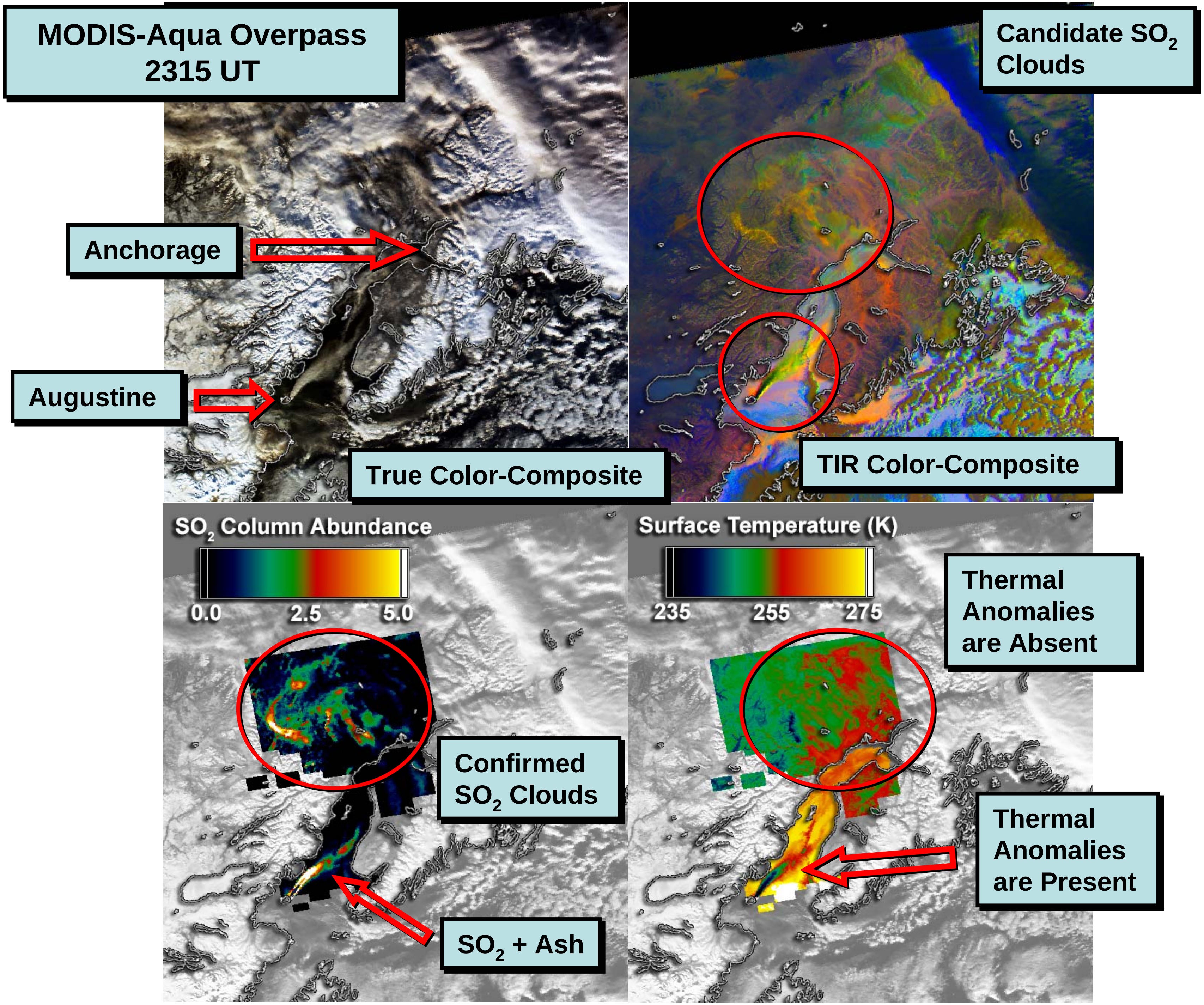
Plume Detection Based on Multispectral TIR Remote Sensing

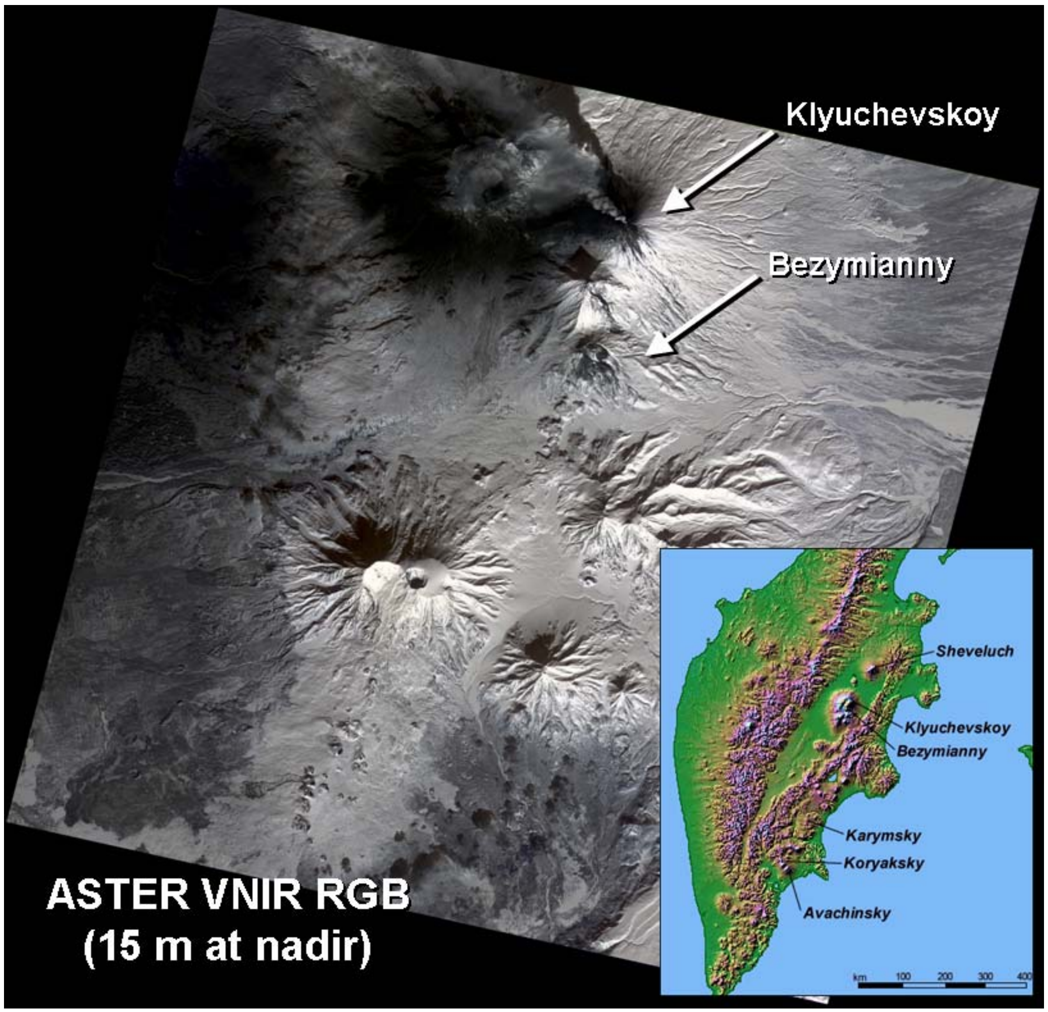




Plume Tracker Project

- Automated Detection of Eruption Plumes Based on Machine Learning Techniques
- Define Search Radius Centered on Volcano
- Exploit Unique Spectral Characteristics of Eruption Plumes
- Exploit Persistence of Plumes over the Course of an Eruption


MODIS-Aqua Overpass
2315 UT
Candidate SO_2 Clouds
Anchorage
Augustine
True Color-Composite
TIR Color-Composite
SO_2 Column Abundance
0.0
2.5
5.0
Surface Temperature (K)
235
255
275
Thermal Anomalies are Absent
Confirmed SO_2 Clouds
Thermal Anomalies are Present
SO_2 + Ash



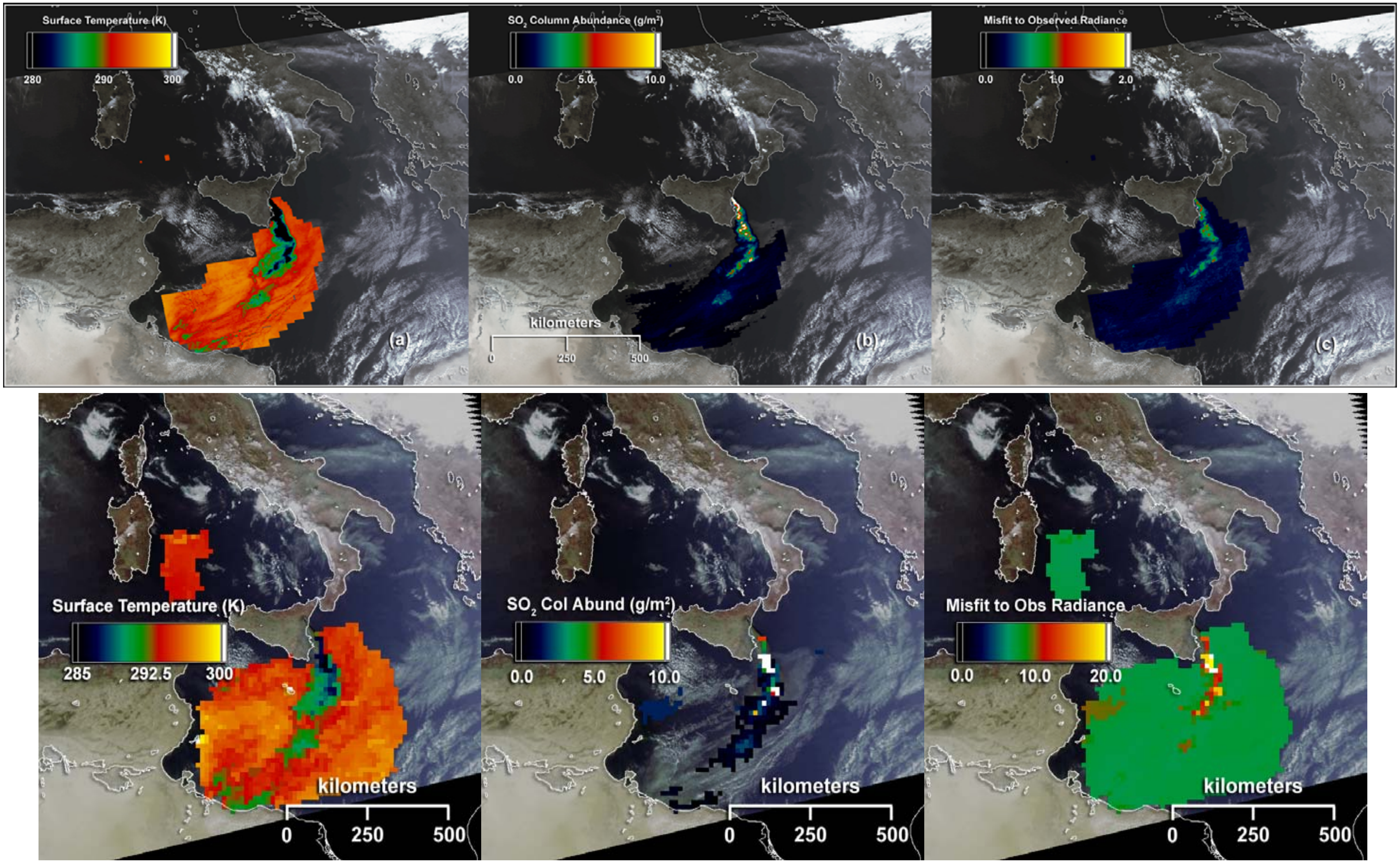
Eruption of Klyuchevskoy Volcano: 12 March 2005

Observed by AIRS, MODIS (Terra + Aqua), MISR, and ASTER

- **AIRS: 17 km at nadir**
- **MODIS: TIR 1 km at nadir**
- **ASTER: TIR 90 m at nadir**

Dilution: SO_2 mass/area scales with the spatial resolution of the instrument

ASTER vs. MODIS: mass/area decreases by ~ 2 orders of magnitude



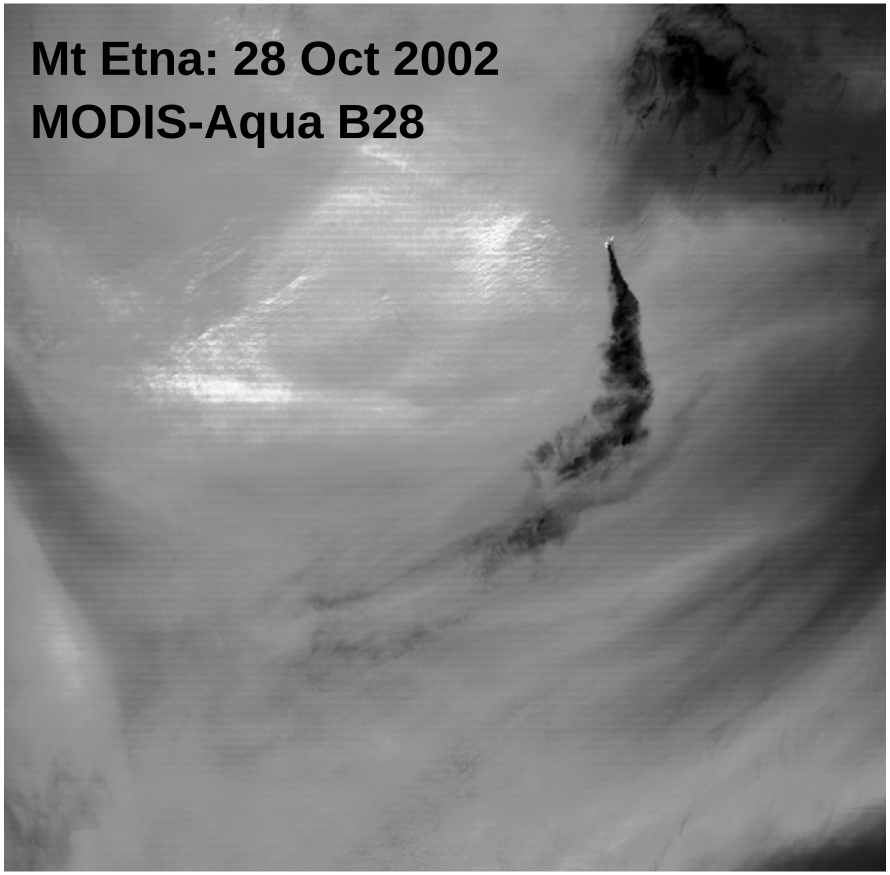
Comparison of Retrievals from MODIS-Aqua (Top Row) and AIRS (Bottom Row) Data

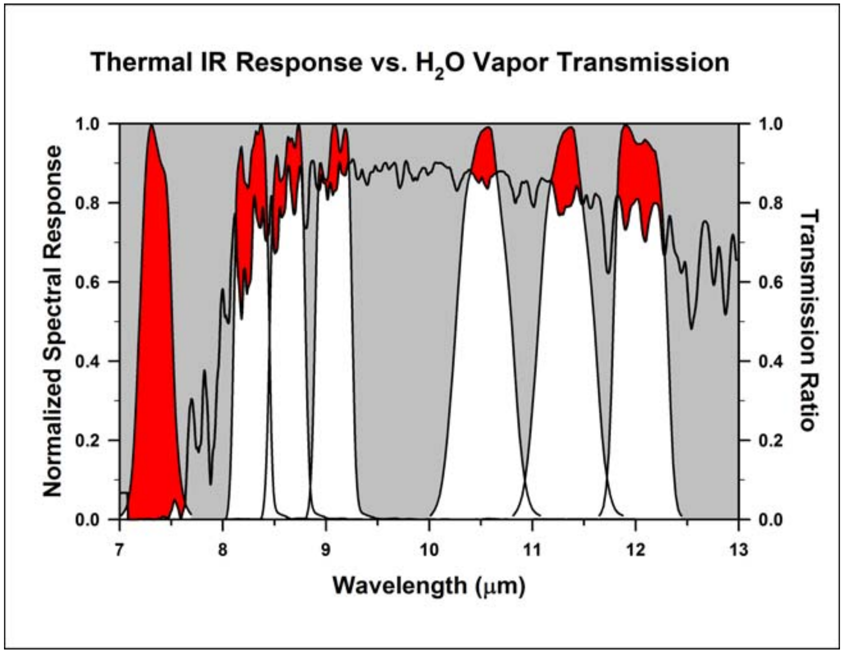
Spatial Resolution at Nadir: 1 km for MODIS vs. 17 km for AIRS

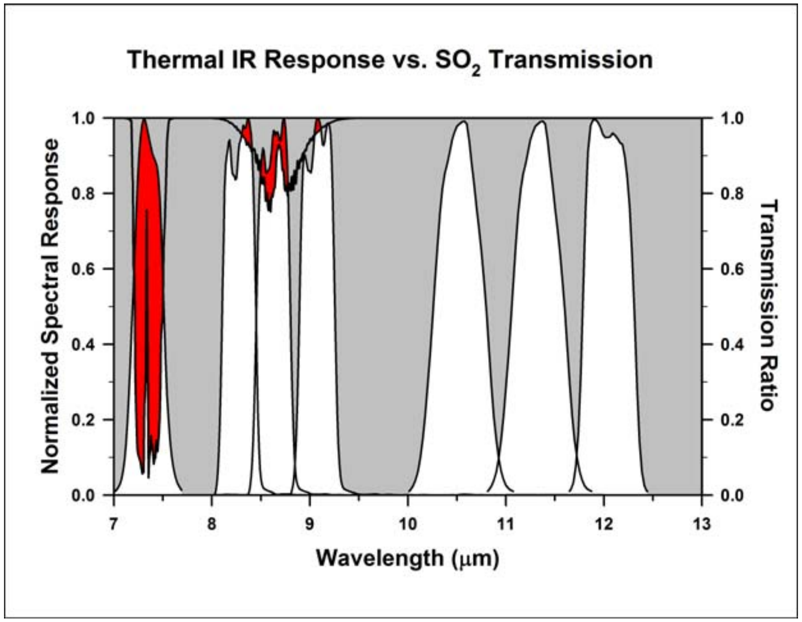
Excellent Agreement for Surface Temperature

Good Agreement for SO_2 Retrievals: Dependant on Uniformity of Plume

AIRS Misfit is 10X Higher Than MODIS Misfit: High Sensitivity to Water Vapor





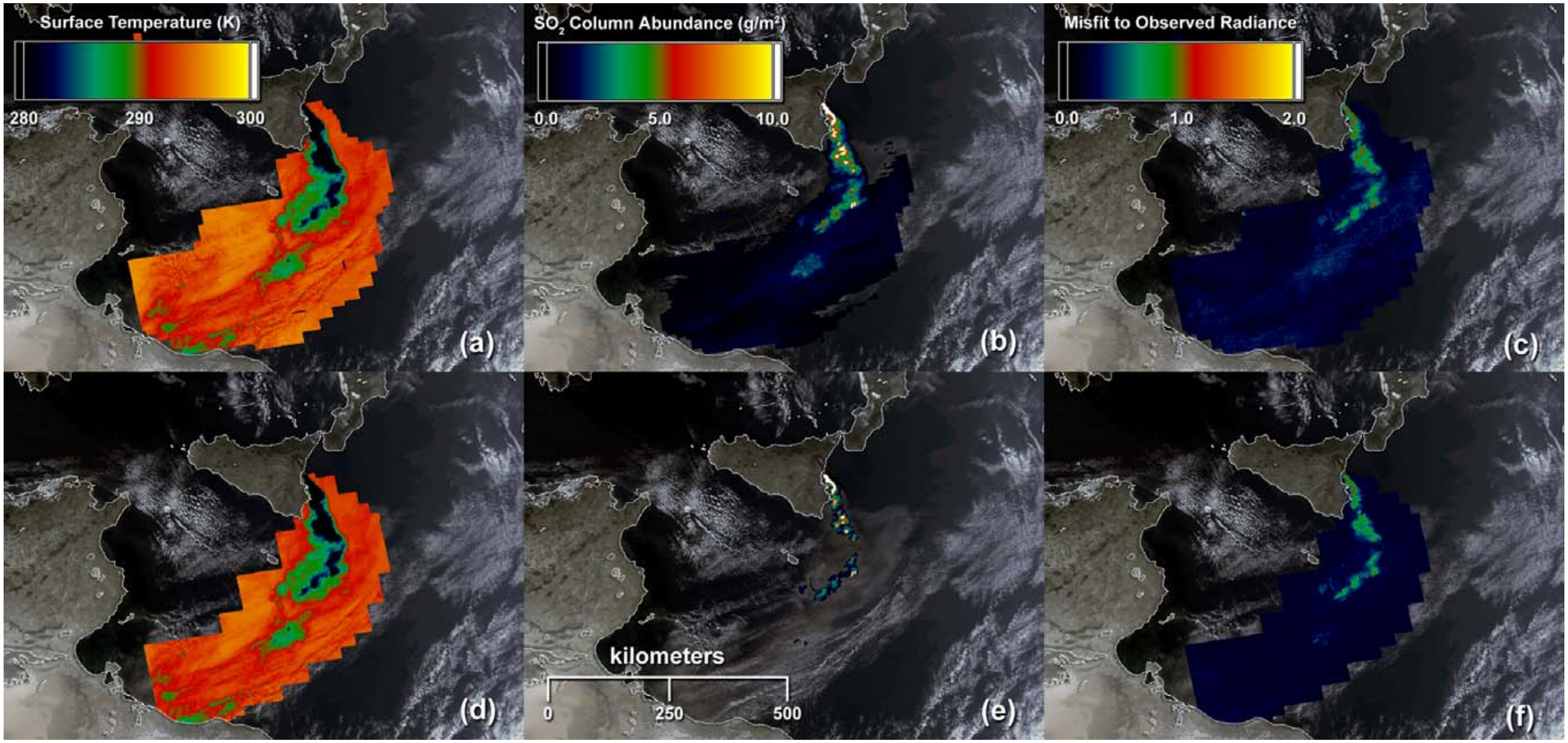


HyspIRI 7.3 μm Channel

Very Strong H_2O Vapor and SO_2 Absorption

Can We Separate Effects of H_2O and SO_2?

Not Suitable for Mapping Plumes Below 5 km? [Prata et al., 2003]

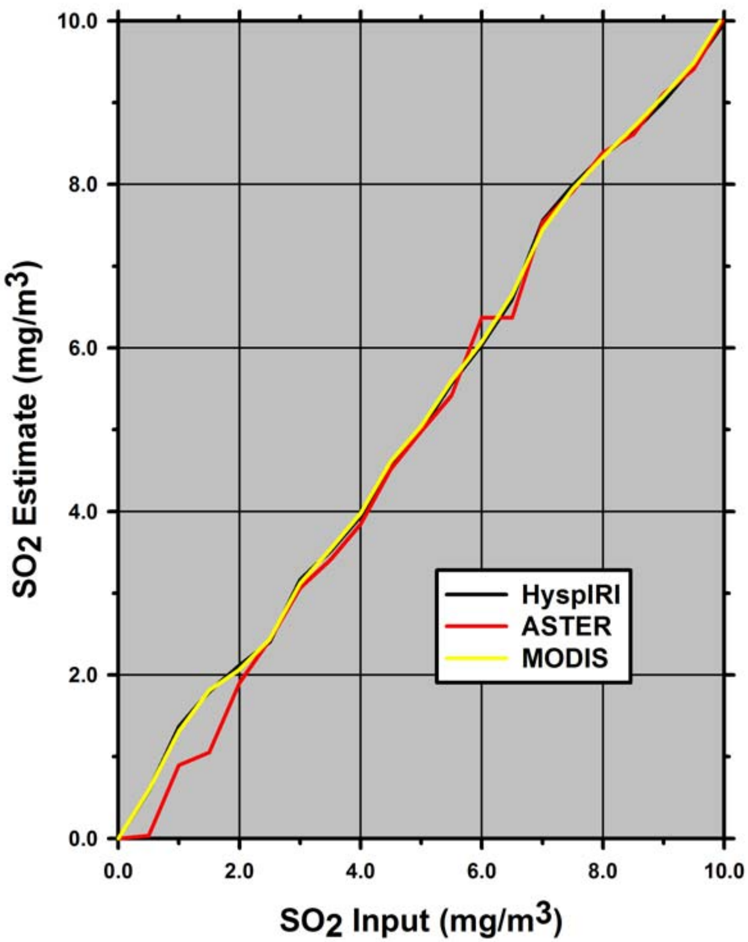


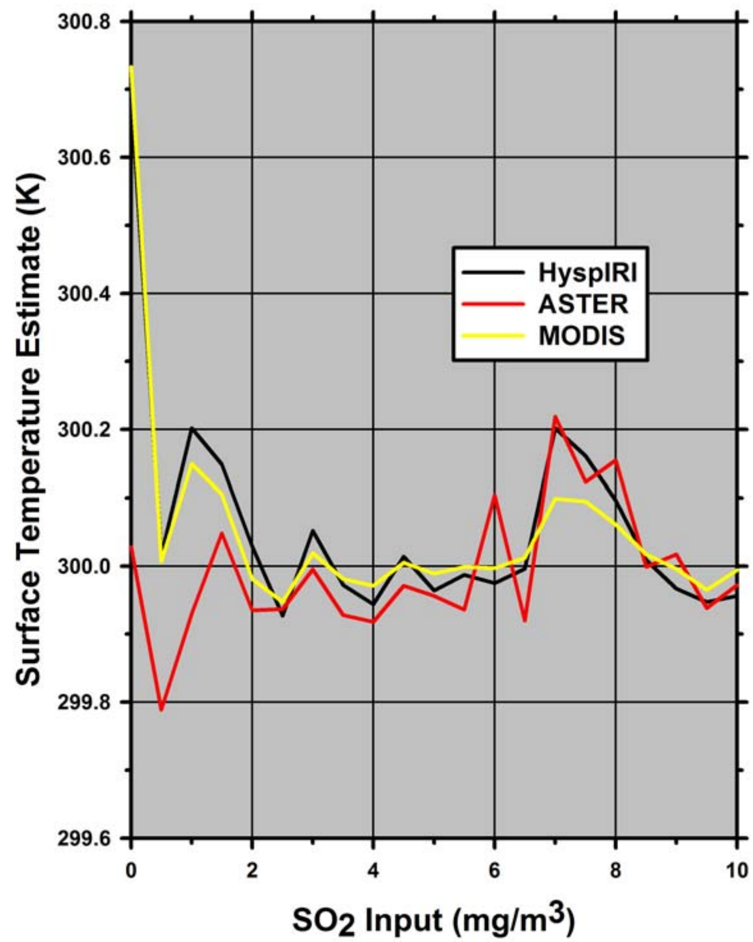
MODIS-Based SO_2 Retrievals: 28 October 2002

Comparison of Retrievals with 5-Band (Top Row) and 4-Band (Bottom Row) Surface Temperatures

Improved Sensitivity to Low Concentrations of SO_2

Increased Influence of Water Vapor on SO_2 Estimates – Requires Better Descriptions of Atm. Water Vapor (NCEP Reanalysis or AIRS L2?)





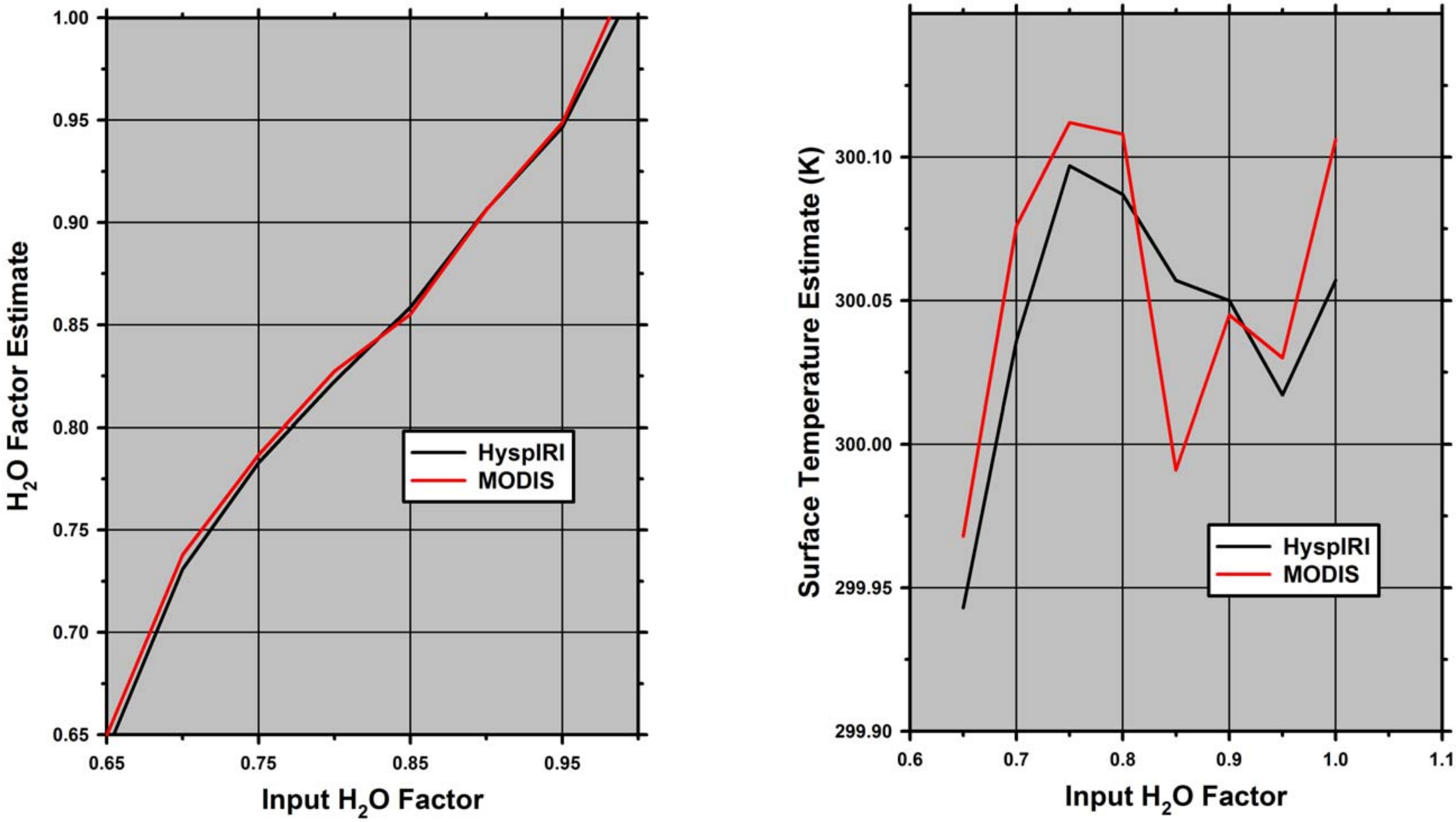
Simulated Plume Retrievals

Plume Altitude 6 km, NCEP Atm Profile, Mid-Latitude Winter Climatology, Ocean Background @ 300 K

"Perfect Knowledge" of Concentration and Distribution of Water Vapor

HyspIRI/MODIS More Sensitive than ASTER at Lowest Concentrations of SO_2

Worst HyspIRI/MODIS Temperature Retrievals (+ 0.8 K) at Zero Conc. SO_2!!

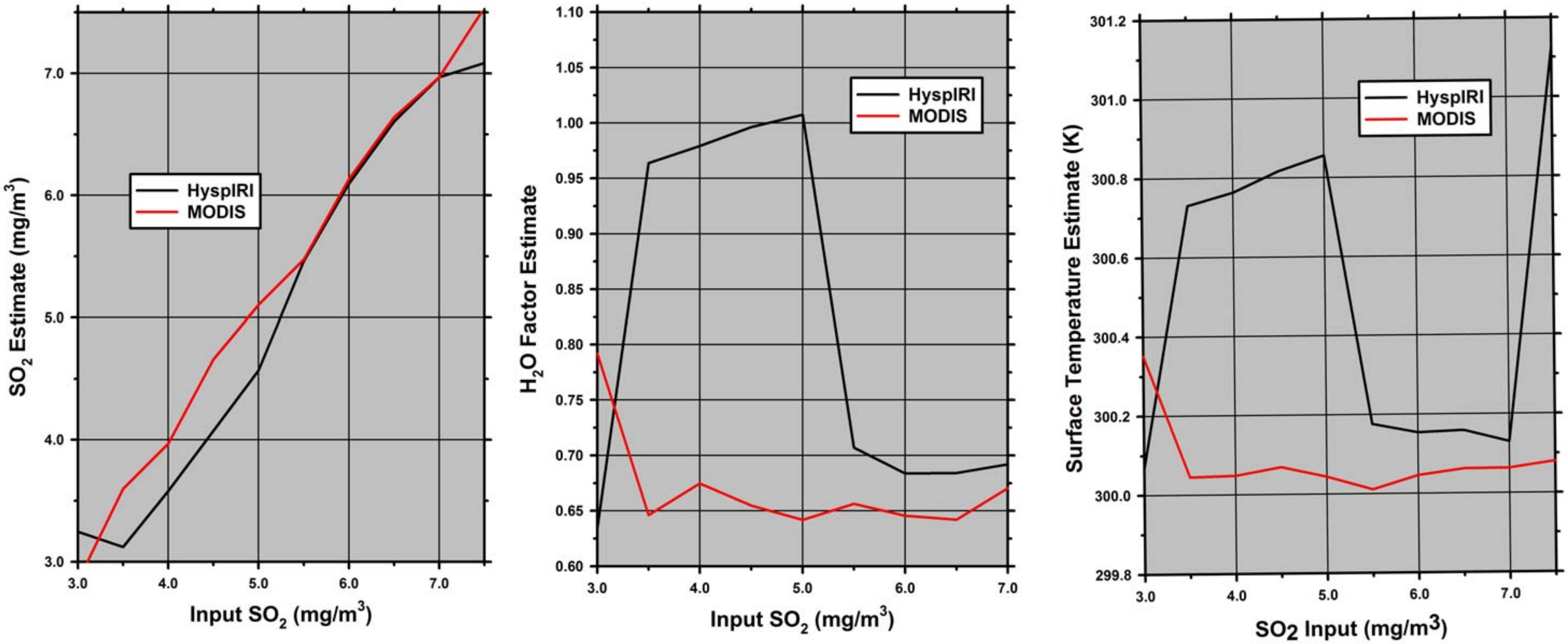


Simulated Retrievals of Water Vapor

Water Factor: Multiplicative Scaling Factor Applied to Entire Profile

HyspIRI/MODIS Results Were Identical for H_2O; Small Variations (~ 0.05 K) Between Temperature Estimates

H_2O and Temperature were Over-Estimated; Estimated Temp Within 0.1 K of True Temperature



Simulated Retrievals of Water Vapor + SO_2

True Water Factor = 0.65

HyspIRI Results Worse Than MODIS Results:

- **Under-Estimated the SO2 Conc. Below 5.5 mg/m^3**
- **Over-Estimated the Corresponding H_2O and Temperature**
- **Water Estimate Improved with Higher Conc. of SO_2**

Good Agreement Between HyspIRI and MODIS SO2 Results (< 0.5 mg/m^3), Despite Wide Disagreements between H_2O and Temperature Results

Summary Remarks

Inferior Hyspiri Results in Combined Retrieval are Counter-Intuitive

- HyspIRI Should Have More Leverage due to Higher Spectral Resolution
- More Analysis Necessary to Verify that Current Results are Repeatable

Success of H_2O Retrievals Bodes Well for Land Surface Products

In Practice, the Retrievals w/ 7.3 μm Channel have Been Problematic

- Technique Applied to MODIS and AIRS Data
- Too Much Variability in (Actual) Conditions within a Pixel? Need Increased Spatial Res?
- Restrict Application to Plumes at Altitudes >> 5 km?

Need Channels that will not Saturate in the Presence of H_2O and SO_2

- Additional Channel Between 7.5 and 8 μm(?)
- Shift the Positions of Bands 2 and 3 to Narrow the Intervening Gap