Anticipated Contributions of HyspIRI to the Remote Sensing of Volcanic Plumes

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13 August 2009
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 SO₂ Content of Plumes**

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

- **Detect Plumes and Track Positions over Time**
Al Mishraaq 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. SO\textsubscript{2} Transmission

(b) MODIS Response vs. SO\textsubscript{2} Transmission

(c) HysplIRI Response vs. SO\textsubscript{2} Transmission

(d) Brightness Temp Difference vs. SO\textsubscript{2} Concentration

- 0.25 mg/m\textsuperscript{3} SO\textsubscript{2}
- 0.10 mg/m\textsuperscript{3} SO\textsubscript{2}
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. SO₂ Concentration

Can We Estimate Surface Temperature When Looking Through a Plume?

Ground Temperature has Stronger Influence on IRAD Than SO₂ Concentration

Simultaneous Retrieval of Temperature and SO₂ is Difficult; Cascading (Serial) Retrieval is a Better Option:

a) Evaluate Effect of Last SO₂ Estimate on Current Temperature Estimate

b) Exit When \( \Delta T < \text{Threshold} \)
Notional HyspIRI TIR Response vs. Spectra of Plume Materials

Real World Example:
Etna Eruption Plume
28 Oct 2002

Model SO₂ Difference Spectra
0.25 mg/m³
0.50 mg/m³

Model Ash Difference Spectra
OD 0.22
OD 0.44

Model Sulfate Difference Spectra
OD 0.22 @ 11 μm

Thermal IR Response vs. SO₂ Transmission
Normalized Spectral Response
Transmission Ratio

Thermal IR Response vs. Silicate Ash Transmission
Normalized Spectral Response
Transmission

Thermal IR Response vs. Sulfate Aerosol Transmission
Normalized Spectral Response
Transmission
Passive Degassing of $\text{SO}_2$
- 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
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 SO₂ Retrievals: Dependant on Uniformity of Plume

AIRS Misfit is 10X Higher Than MODIS Misfit: High Sensitivity to Water Vapor
Mt Etna: 28 Oct 2002
MODIS-Aqua B28

HyspIRI 7.3 μm Channel
Very Strong H$_2$O Vapor and SO$_2$ Absorption
Can We Separate Effects of H$_2$O 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

HyspIIRI/MODIS Results Were Identical for H₂O; Small Variations (~ 0.05 K) Between Temperature Estimates

H₂O and Temperature were Over-Estimated; Estimated Temp Within 0.1 K of True Temperature
Simulated Retrievals of Water Vapor + SO₂

True Water Factor = 0.65

HyspIRI Results Worse Than MODIS Results:
  • Under-Estimated the SO₂ Conc. Below 5.5 mg/m³
  • Over-Estimated the Corresponding H₂O and Temperature
  • Water Estimate Improved with Higher Conc. of SO₂

Good Agreement Between HyspIRI and MODIS SO₂ Results (< 0.5 mg/m³), Despite Wide Disagreements between H₂O 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 H₂O 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 H₂O and SO₂
- Additional Channel Between 7.5 and 8 μm(?)
- Shift the Positions of Bands 2 and 3 to Narrow the Intervening Gap