Potential Contributions of HyspIRI to the Remote Sensing of Volcanic Plumes

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H₂O Vapor vs. SO₂ Absorption

H₂O Vapor Absorption Affects the Entire 8-12 µm Atmospheric Window:

Add Channel Sensitive to H₂O to Facilitate Atm. “Corrections”

Considerable Variation in H₂O Within a Scene:

Can We Characterize These Variations?

Very Strong H₂O Vapor and SO₂ Absorption in HyspIRI 7.3 µm Channel:

Can We Separate Effects of H₂O and SO₂?

7.3 µm Not Suitable for Mapping Plumes Below 5 km? [Prata et al., 2003]
Heritage for HyspIRI Spectral Response

(a) ASTER Response vs. SO₂ Transmission

(b) MODIS Response vs. SO₂ Transmission

(c) HyspIRI Response vs. SO₂ Transmission

(d) Brightness Temp Difference vs. SO₂ Concentration

- Brightness Temp Difference (K)
  - 0.25 mg/m³ SO₂
  - 0.10 mg/m³ SO₂
ASTER D-Stretch Depicting the Passive Emission of SO$_2$

ASTER D-Stretch Depicting Ash, water/ice, and SO$_2$ Released by Explosive Eruption
Real World Example: Etna Eruption Plume 28 Oct 2002

Notional HyspIRI TIR Response vs. Spectra of Plume Materials

- **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
Thermal IR Response vs. Silicate Ash Transmission
Thermal IR Response vs. Sulfate Aerosol Transmission
Retrieval of Surface Temperature and SO$_2$ Concentration

Ground Temperature has Stronger Influence on Perceived Radiance Than the SO$_2$ Concentration

Simultaneous Retrieval of Temperature and SO$_2$ is Difficult; Temperature is Well-Constrained but SO$_2$ is Poorly-Constrained

Cascading (Serial) Retrieval is a Better Option:

Estimate Surface Temperature

*(Estimate H$_2$O Vapor Factor)*

Estimate SO$_2$ Concentration

Repeat Temperature Estimation w/ Prior H$_2$O and/or SO$_2$ Estimates

Repeat H$_2$O and/or SO$_2$ Estimation with New Temperature

Exit When $\Delta T < $ Threshold
Retrieval Procedure Requires Profiles of Atm. Temp, H$_2$O, and O$_3$ as Input

Radiance Spectra from Clear Path (Plume-Free) Regions are used to “Tune” the H$_2$O and O$_3$ Profiles

Tuning is a Time-Consuming Process: Retrieval of H$_2$O is More Efficient and a Better Characterization of Variations in H$_2$O

Two Candidates for H$_2$O Channel:
MODIS 28 (7.3 $\mu$m) and MODIS 33 (13.3 $\mu$m)

Strong H$_2$O Absorption in MODIS 28 Obscures the Surface

Moderate H$_2$O Absorption in MODIS 33 Does Not Obscure the Surface
Simulated Retrievals of H$_2$O and SO$_2$

Evaluate Five Configurations of Channels
ASTER, HyspIRI, MODIS 29-32, MODIS 28-32, and MODIS 29-33

Synthetic Radiance Spectra as “Observations”
Surface Temp = 275 K, SO$_2$ Conc = 2.5 mg/m$^3$, H$_2$O Factor = 0.75
Plume Altitude = 15 km, Sea Surface Background, Sarychev Atm. Profiles

Three Retrieval Modes/Configuration
Temperature: Assume SO$_2$ = 0, H$_2$O = 0.75 (Tuning Mode)
H$_2$O Factor: Assume SO$_2$ = 0 (Potential New Tuning Mode)
H$_2$O + SO$_2$: Potential New Retrieval Mode
ASTER Simulation Results

Temperature Under-Estimated, Misfit Spectrum 4 – 10%

\( \text{H}_2\text{O} \): Misfit Spectrum < 6%

\( \text{H}_2\text{O} + \text{SO}_2 \): Misfit Spectrum < 2%

\( \Delta\% \) Axis Range = 24%
HyspIRI Simulation Results

Temperature Over-Estimated, Misfit Spectrum ~75% at 7.3 µm

H₂O: Misfit ~20% at 7.3 µm

H₂O + SO₂: Misfit Spectrum < 2%

Δ% Axis Range = 100%
MODIS 29-32 Simulation Results

Temperature Under-Estimated, Misfit Spectrum Between 5 – 11%

H₂O: Misfit Within ±3%

H₂O + SO₂: Misfit Spectrum < 1%

Δ% Axis Range = 19%
MODIS 28-32 Simulation Results

Temperature Over-Estimated, Misfit Spectrum ~80% at 7.3 µm

H₂O: Misfit ~20% at 7.3 µm

H₂O + SO₂: Misfit Spectrum < 10%

Δ% Axis Range = 120% (Worst Misfit)
MODIS 29-33 Simulation Results

Temperature Under-Estimated, Misfit Spectrum < 6%

H$_2$O: Misfit < 3%

H$_2$O + SO$_2$: Misfit Spectrum < 1%

Δ% Axis Range = 8% (Best Misfit)
Retrieval Accuracy

ASTER: Best Overall Performance

MODIS 28-32: Worst Overall Performance

MODIS 29-32/MODIS 29-33: Roughly Equal Performance; Slightly Better Than HyspIRI

Presence of 7.3 µm Channel Degrades Performance

Note: All Configurations Produced Exact Retrievals in Traditional (TBound + SO₂) Mode
MODIS-Based Retrievals of H$_2$O and SO$_2$

Evaluate Three Configurations of Channels
MODIS 29-32, MODIS 28-32, and MODIS 29-33

Compare Temperature and SO$_2$ Retrievals with Fixed and Free H$_2$O Factors
Region-of-Interest Included SO$_2$, Ash, and Clear-Path Pixels
MODIS 29 – 32 Results

Fixed H$_2$O Factor

Free H$_2$O Factor

Improved Fit: Δ%
Range Reduced from 2% to 0.5%
TBound Estimates Decreased ~0.5%
SO$_2$ Estimates Decreased 5 – 10%
MODIS 28 – 32 Results

Fixed H$_2$O Factor

Improved Fit: $\Delta\%$

Range Reduced from 8% to 1%

TBound Estimates Increased $\sim$1.5%

SO$_2$ Estimates Increased $\sim$ 50%

Free H$_2$O Factor
MODIS 29 – 33 Results

Fixed H₂O Factor

Free H₂O Factor

Improved Fit: Δ% Range Reduced from 3% to 0.7%

TBound Estimates Decreased < 0.5%

Problematic Interpretation of SO₂ Results:
Reduction in Estimates < 10% ?

Spike @ -100% is Significant!

Spike @ 0 Change Significant?
Summary Remarks

Single Channel @ 7.3 µm Does Not Provide Sufficient Resolution to Separate the Effects of H₂O and SO₂

Characterizing Spatial Variations in H₂O Has Broader Science Impact than SO₂ Detection:

- Shift Channel to Longer Wavelength (~ 8.0 µm)
- Definitive Solution to Channel Position Requires HyTES Data

Adopting 13.3 µm Channel (MOD 33) for MODIS-Based Plume Mapping

- Not Necessary for HyspIIRI Due to High Spectral Resolution Between 8 and 9 µm

Food For Thought: HyspIIRI Channel Between 9.5 and 10 µm Would Help Discriminate Sulfate Aerosols from SO₂ or Ash