Validation of ASTER-Based Maps of Volcanic Sulfur Dioxide Plumes: A Preparatory Activity for the HyspIRI TIR Mission

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Plume Tracker was the Principal Tool Used in the Following Analyses

Brief Review of Plume Tracker Developments Since October 2012
Misfit Calculation:
Least Squares vs. Weighted Spectral Angle

Least Squares:
• Optimal Fit to Noisy Data
• Equal Weight to all Outliers
• Not Ideal for Temperature Estimation

Spectral Angle:
• Observed and Model Radiance Spectra Represented as Vectors in Data Space
• Minimize Angle Between Vectors (Spectral Angle)
• Minimization Weighted to Favor Solutions with Model Spectrum > Observed Spectrum

Optimum Temperature Estimate Given Imperfect Knowledge of Atmospheric Composition
Interpolation of Reflectance Spectra

ASTER Resolution to MODTRAN Resolution

Linear Interpolation Results in Spectral Variation within Response Functions of Individual Channels

Step-Wise Resampling Ensures Uniform Reflectance w/in a Channel

No “Gaps” in Resampled Spectrum
Simulations with Quartz Sandstone Lab Spectrum

Step-Wise Resampling + WSA Misfit has Significant Impact on the Estimated Emissivity

Significant Improvements in Estimates for ASTER Channels 11 – 13
Version 4.0 Accuracy: ASTER and MODIS Simulations of SO$_2$

Simulated Radiance Spectra: Theoretical Limits on Retrieval Accuracy
Highly-Accurate Temperature Estimates: Independent of SO$_2$ Concentration
Version 4.0 Accuracy: HyTES Simulations for NH$_3$ and CH$_4$
Validation Efforts at Kilauea Volcano, Hawaii

Collaboration with USGS Hawaiian Volcano Observatory and University of Hawaii
ASTER VNIR False-Color Composites
ASTER-Based SO$_2$ Maps

SO$_2$ Total Column

1.5 g/m$^2$ 52.5 DU 472.3
2012-01-05
11:06 HST

SO₂ Column (g/m²)

1.5   7.5   13.5
2.1   10.7  19.2

SO₂ Conc. (ppm-v)

Station HRPKE

HRPKE Raw Data SO₂

Pacific/Honolulu Time (2012-01-05 00:00:00 to 2012-01-06 00:00:59)
2012-04-19
10:59 HST

SO₂ Column (g/m²)

1.5  7.5  13.5

2.1  10.7  19.2

SO₂ Conc. (ppm-v)

9 km

Station HRPKE
OMI SO₂ Total Column Maps
Total Mass $\text{SO}_2$ on 2012-05-21

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Spatial Resolution</th>
<th>Total Mass $\text{SO}_2$ (metric tons)</th>
<th>Plume Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>OMI</td>
<td>13 x 25 km</td>
<td>0.446 kt</td>
<td>16,472 km$^2$</td>
</tr>
<tr>
<td>MODIS</td>
<td>1 km (at nadir)</td>
<td>0.231 kt</td>
<td>67 km$^2$</td>
</tr>
<tr>
<td>ASTER</td>
<td>90 m</td>
<td>0.259 kt</td>
<td>71.15 km$^2$</td>
</tr>
</tbody>
</table>

Higher Spatial Resolution = Less “Dilution”
Total Mass Should Decrease as Resolution Decreases (Coarsens)

$\text{SO}_2$ will be Under-Estimated if

- Plume does not fill a Pixel (IFOV)
- Distribution of $\text{SO}_2$ not Uniform within a Pixel

OMI Reports 2X Mass and 235X the Area: If “Background” $\text{SO}_2$ ($< 0.5$ DU) were Removed the Mass would Decrease
Validation Efforts Continue at Kilauea:

Coordinating HVO Field Campaigns with ASTER Overpasses

Urgent ASTER Status for Kilauea since May 2013
Validation Efforts at Turrialba Volcano, Costa Rica

Collaboration with University of Costa Rica

Site for Development of UAV-Based Plume Monitoring Technology (PI: D. Pieri, JPL)
Tethered Balloon Deployment
Turrialba Volcano, Costa Rica
01 February 2012

Pieri et al., 2013
Version 3.0.2
Applied to ASTER Data
Turrialba Volcano, Costa Rica
21 Jan 2012

Challenging Conditions for SO₂ Retrieval: Humid Atmosphere, Low-Altitude Plume
Excellent Agreement With In-Situ (Tethersonde) Measurements from 01 Feb 2012
Micro-UAV Deployment
Turrialba Volcano, Costa Rica
08 February 2013

Pieri et al., 2013
Shameless Plugs:

Plume Tracker Demonstration on Wednesday (16 October) @ 7:00 PM

MODIS True-Color Composites
Sensitivity to SO$_2$ is a Function of Temperature Contrast

Plot Brightness Temperature Difference Relative to Clear Path (SO$_2$ = 0)

$\Delta T$ 0.25 – 0.5: Realistic Temperature Sensitivity for ASTER or MODIS

Land Surface ($T_s = 320$ K): SO$_2$ Detection Threshold $\sim$ 3.0 mg/m$^3$

Sea Surface ($T_s = 300$ K): SO$_2$ Detection Threshold $\sim$ 7.0 mg/m$^3$

(Temperatures, Emissivity Spectra, and Elevation from ASTER Data over Kilauea Volcano)
MODIS-Based SO₂ Maps

SO₂ Total Column

<table>
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<tr>
<th>DU</th>
<th>g/m²</th>
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<tbody>
<tr>
<td>52.5</td>
<td></td>
</tr>
<tr>
<td>472.3</td>
<td></td>
</tr>
</tbody>
</table>

Values: 1.5 g/m², 13.5 g/m²
Key(i) = [zenith angle][surface elevation][surface T]
[H_2O factor][O_3 factor][SO_2 factor]

Scan Hash Table for Matches to Existing Keys
Associated Spectrum used for Matching Keys;
New Table Entry for Unique Keys

Time Trials (1296 pixels):
1.6 seconds/pixel w/ Hash Table
6.0 seconds/pixel w/o Hash Table

Hash Table (Associative Array): Acceleration of Retrieval Algorithm
## Retrieval Algorithm Time-Trials: Domain Refinement (V.2.2.9) vs. Brent’s Method (V.3.0)

<table>
<thead>
<tr>
<th></th>
<th>Domain Refinement</th>
<th>Brent’s Method</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Calls to MODTRAN</strong> (ROI = 1296 pixels)</td>
<td>264,398</td>
<td>144,508</td>
</tr>
<tr>
<td><strong>No Hash Table</strong></td>
<td>6.4 sec/pix</td>
<td>3.2 sec/pix</td>
</tr>
<tr>
<td><strong>Hash Table</strong></td>
<td>1.6 sec/pix</td>
<td>0.8 sec/pix</td>
</tr>
<tr>
<td><strong>Success Rate</strong> (Hash Table Hits vs. Misses)</td>
<td>77.4%</td>
<td>77.0%</td>
</tr>
<tr>
<td><strong>Cached Radiance</strong> (All Calls to MODTRAN Use Hash Table)</td>
<td>0.2 sec/pixel</td>
<td>0.0086 sec/pix</td>
</tr>
</tbody>
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