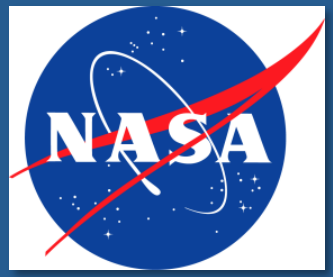
Validation of ASTER-Based Maps of Volcanic Sulfur Dioxide Plumes: A Preparatory Activity for the HyspIRI TIR Mission

V. J. Realmuto

Jet Propulsion Laboratory,
California Institute of Technology



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

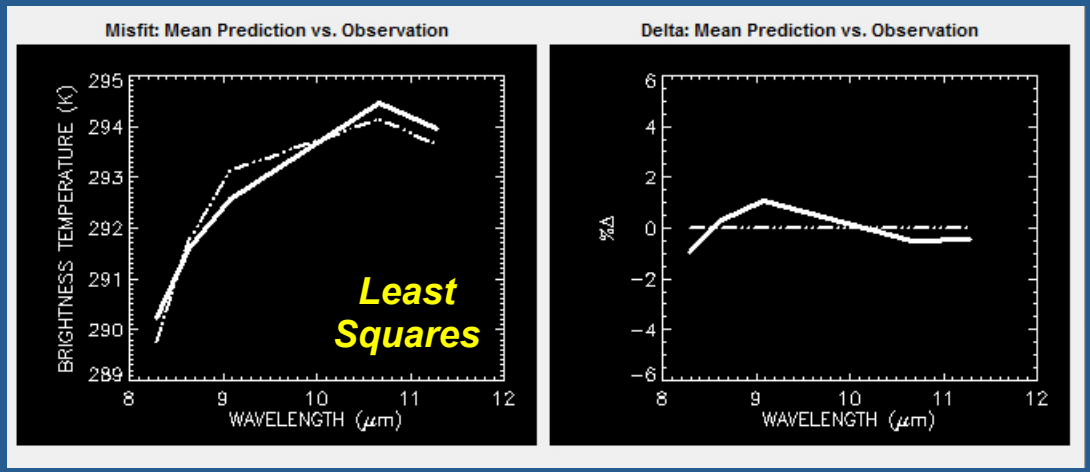
Least Squares:

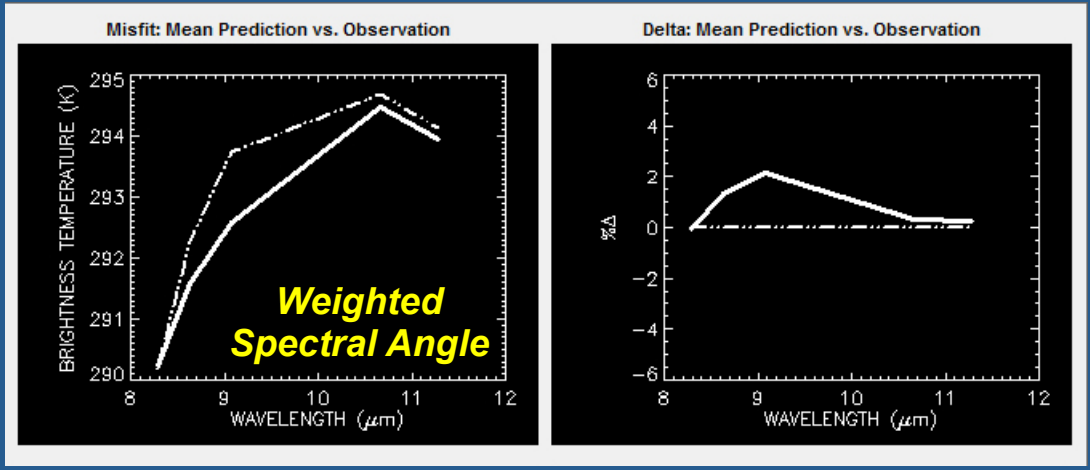
- Optimal Fit to Noisy Data
- Equal Weight to all Outliers
- Not Ideal for Temperature Estimation

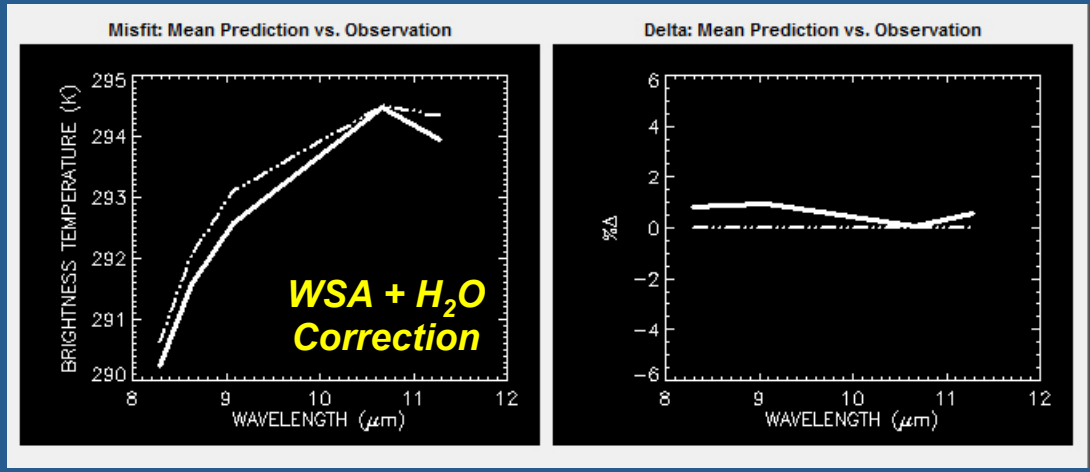
Spectral Angle:

- 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







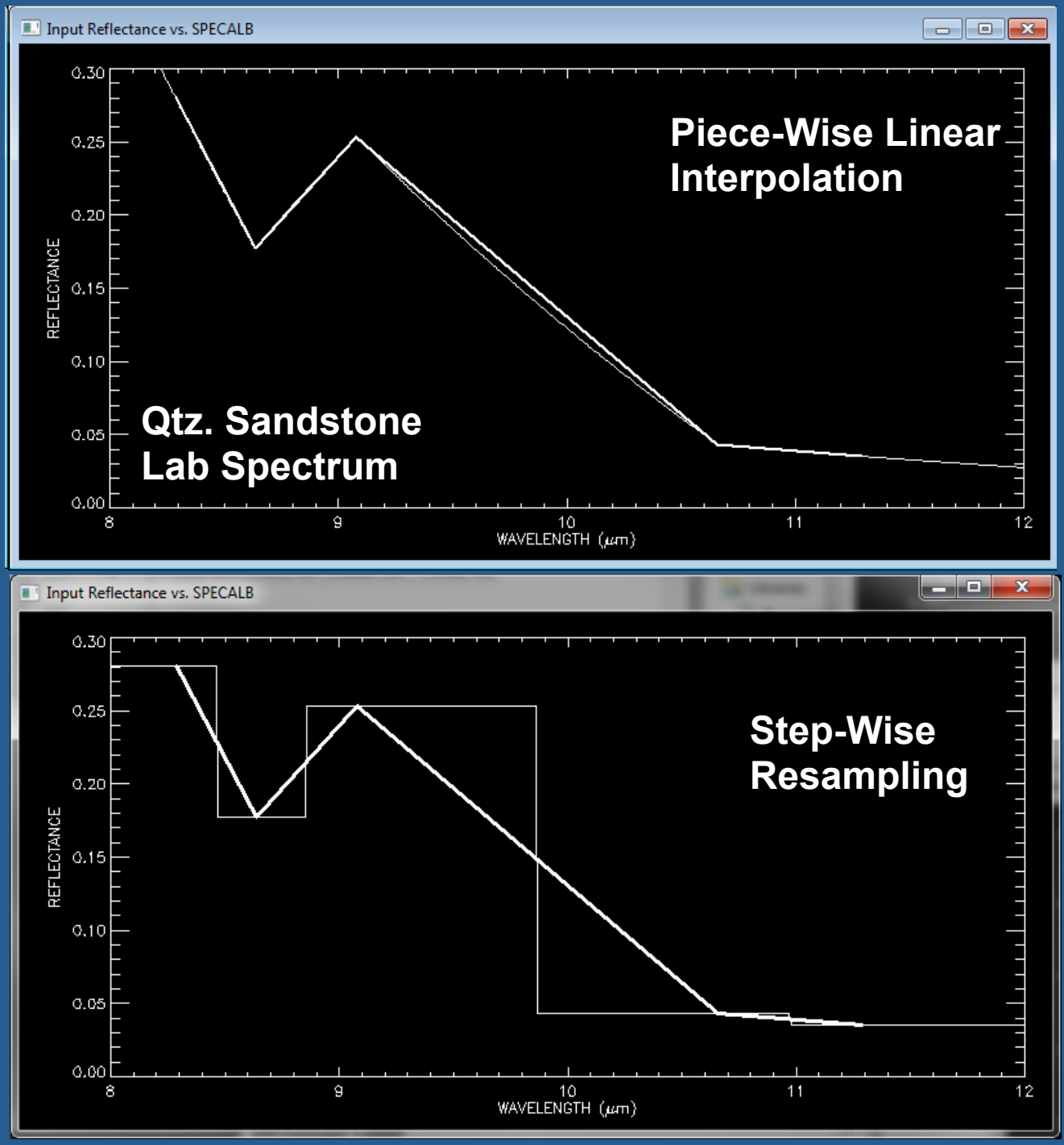
Interpolation of Reflectance Spectra

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

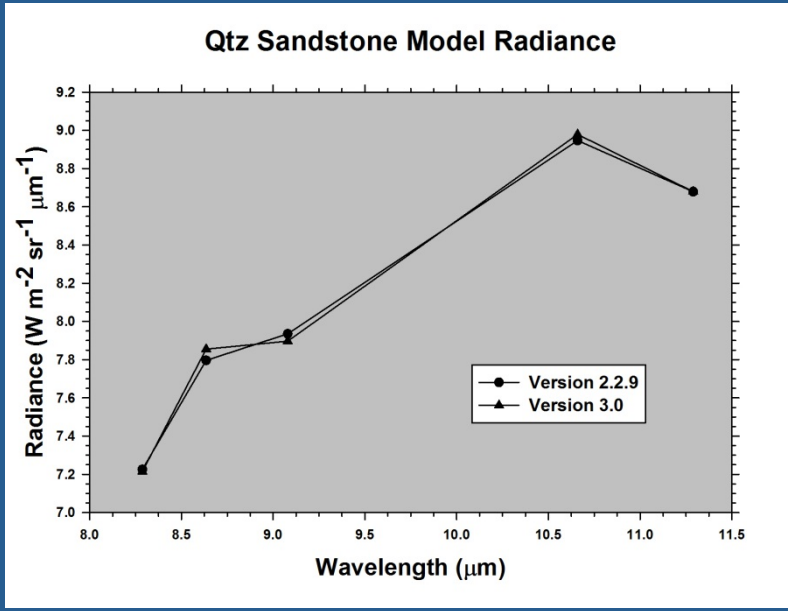
No “Gaps” in Re-sampled Spectrum

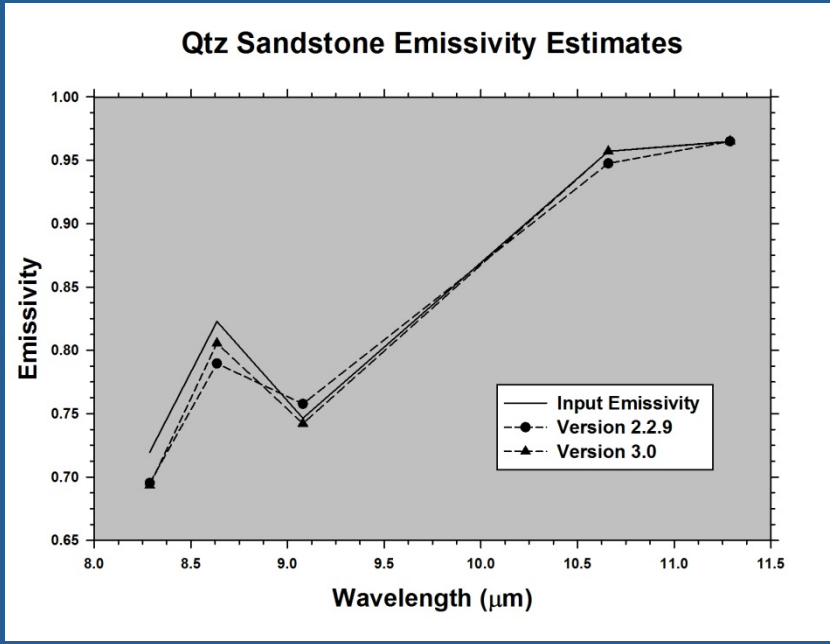


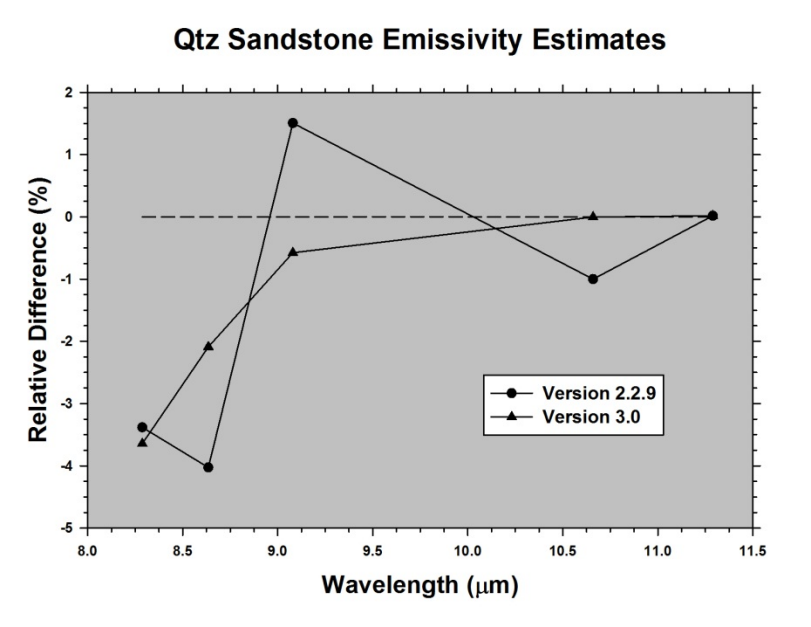
Simulations with Quartz Sandstone Lab Spectrum

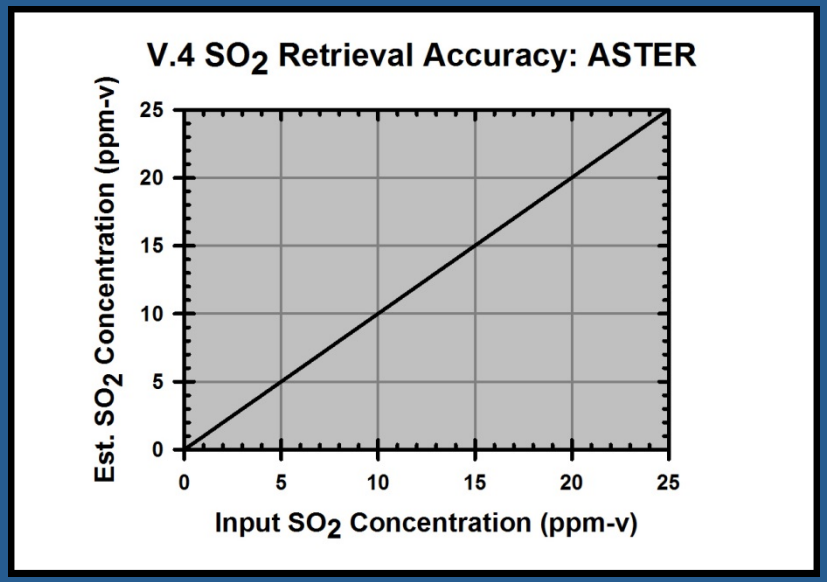
Step-Wise Resampling + WSA Misfit has Significant Impact on the Estimated Emissivity

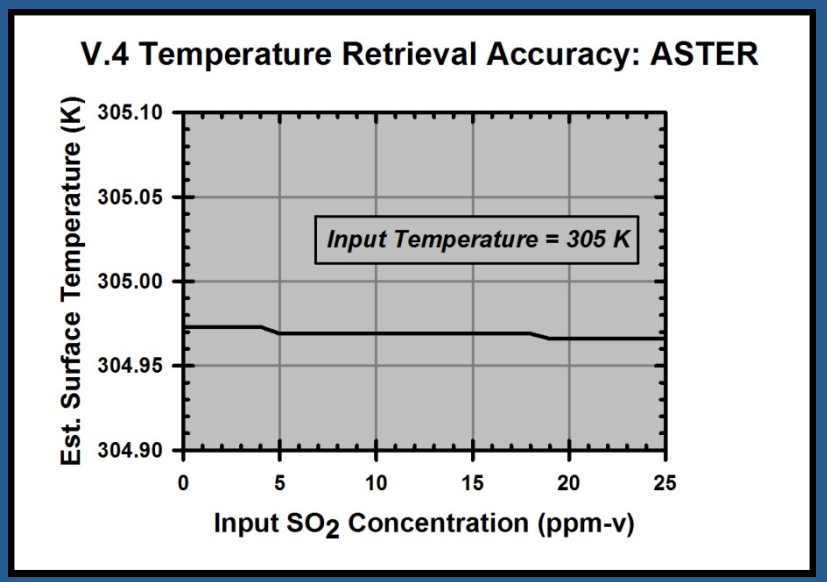
Significant Improvements in Estimates for ASTER Channels 11 – 13

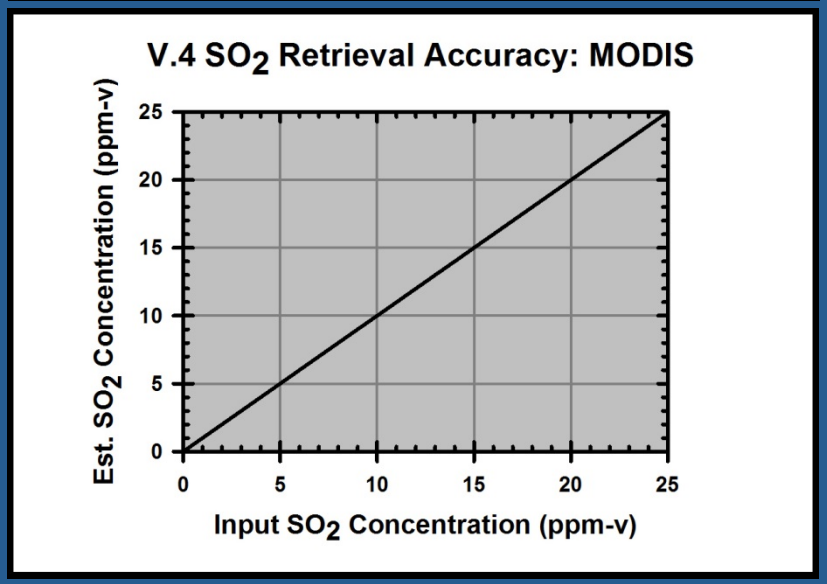


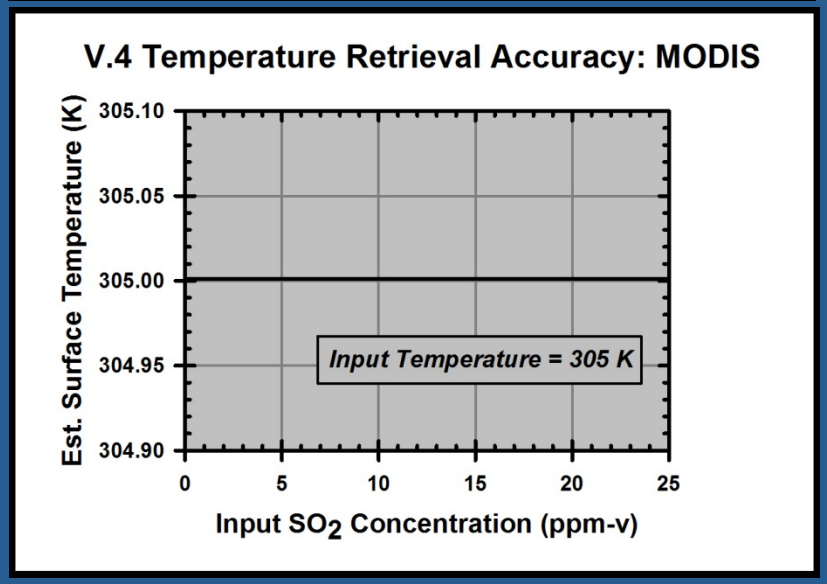






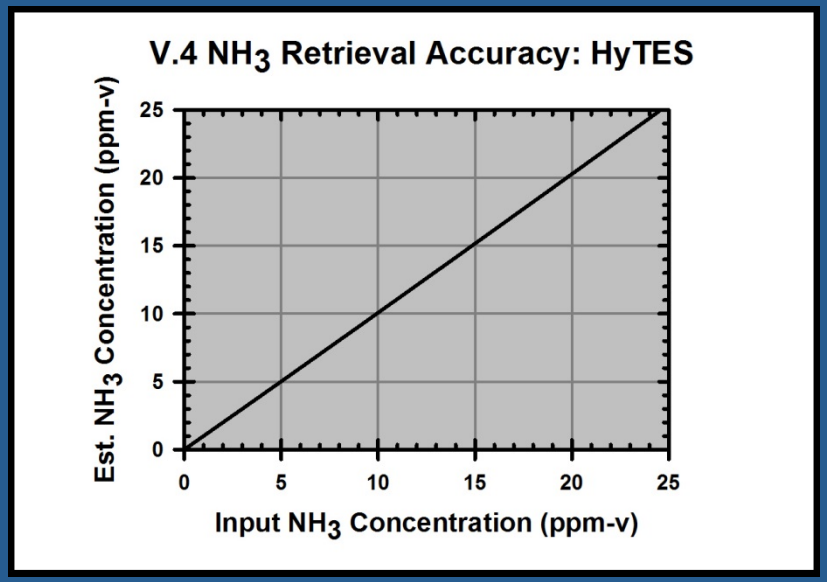


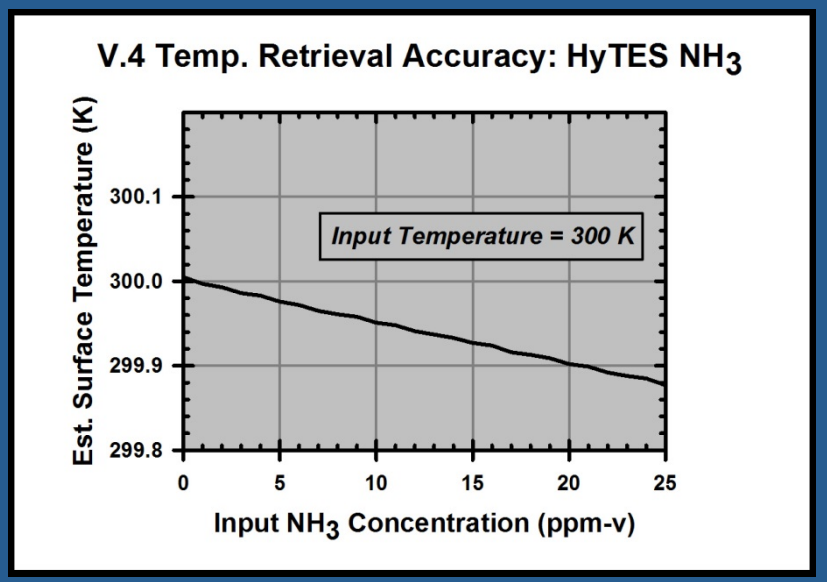


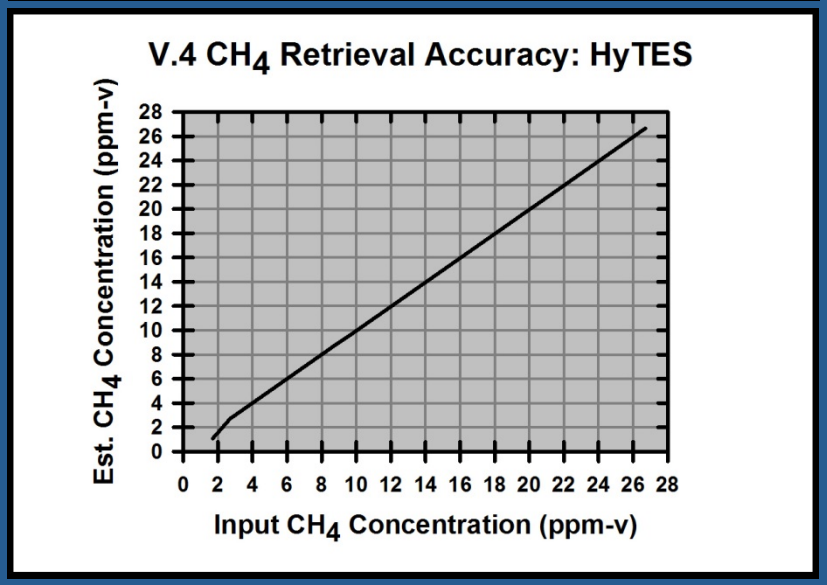


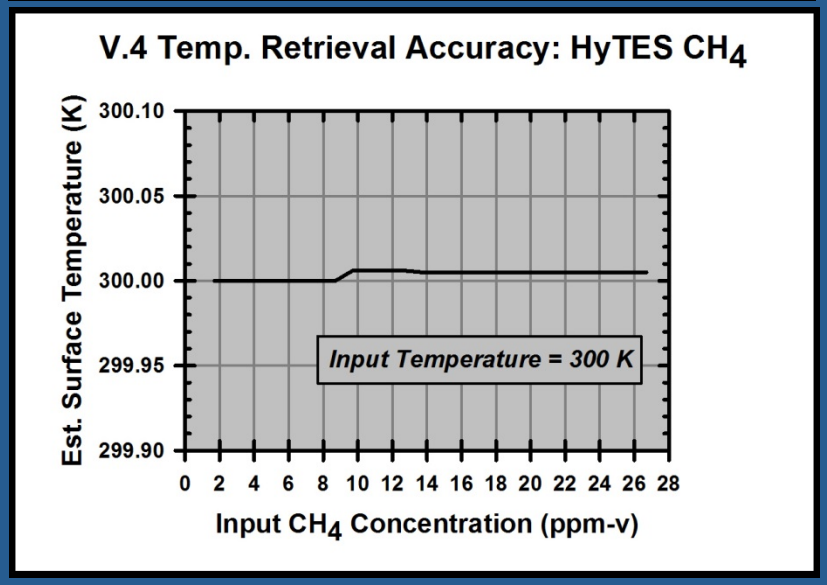
Version 4.0 Accuracy: ASTER and MODIS Simulations of SO_2

Simulated Radiance Spectra: Theoretical Limits on Retrieval Accuracy
Highly-Accurate Temperature Estimates: Independent of SO_2 Concentration





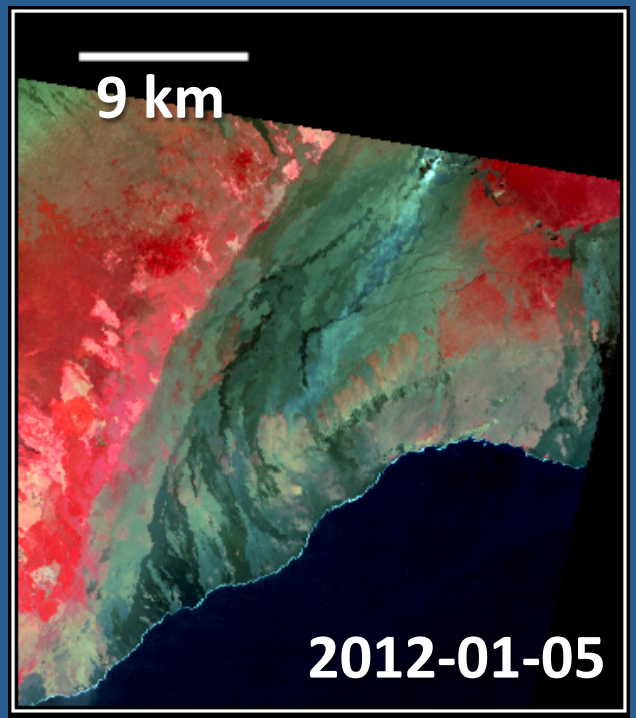


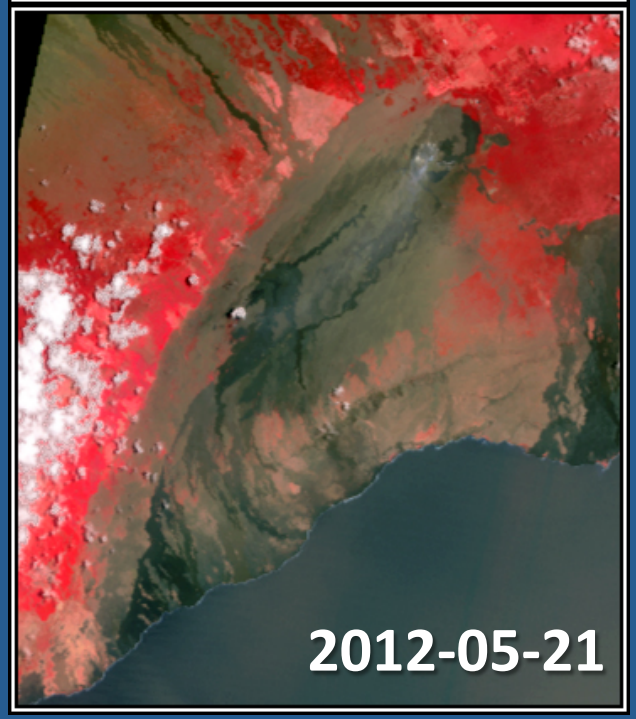


Version 4.0 Accuracy: HyTES Simulations for NH_3 and CH_4

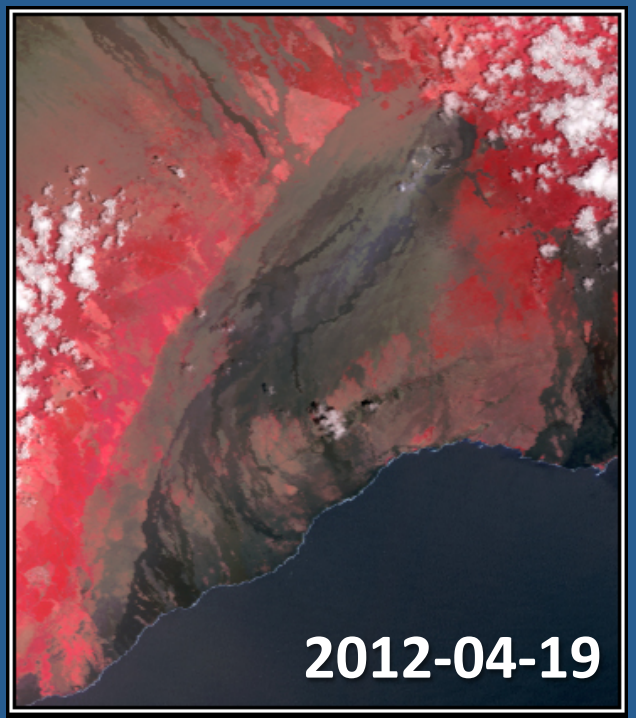
Validation Efforts at Kilauea Volcano, Hawaii

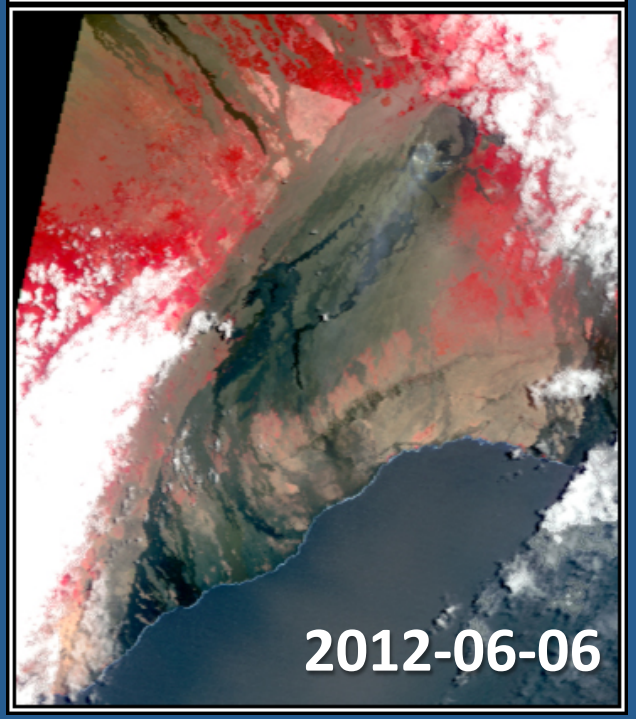
Collaboration with USGS Hawaiian Volcano Observatory and University of Hawaii

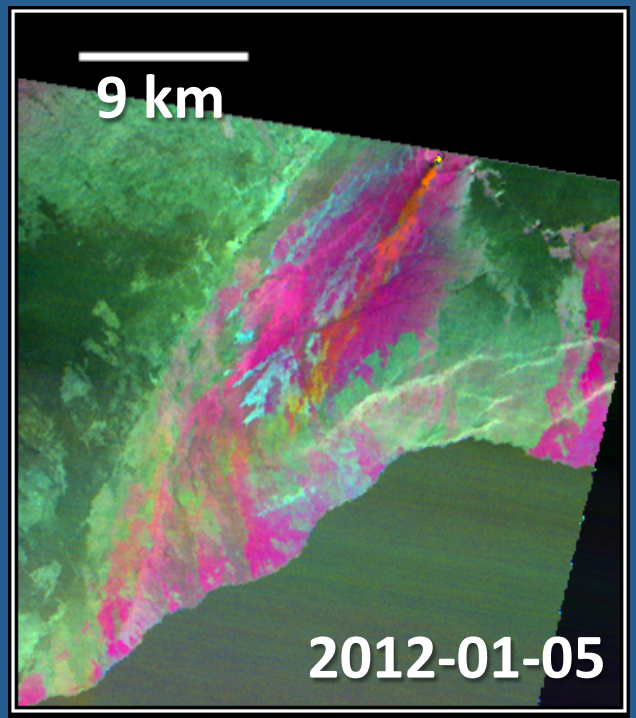


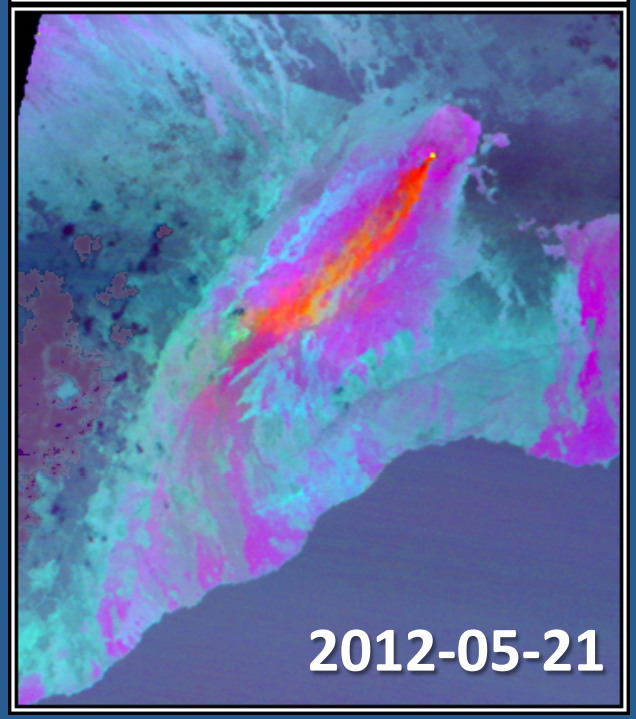


ASTER VNIR False-Color Composites

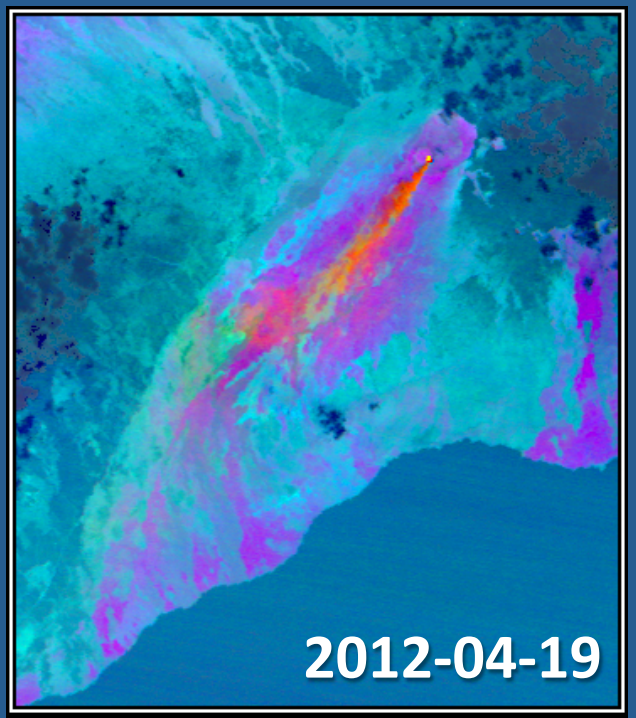


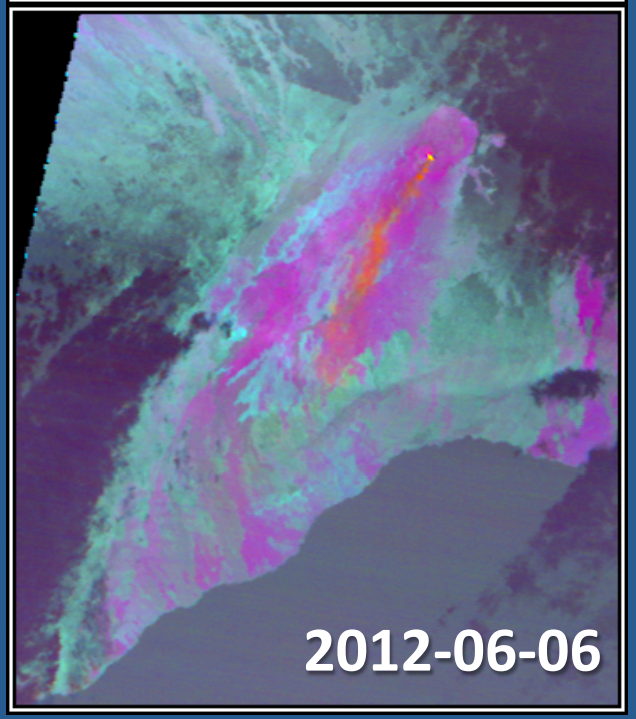


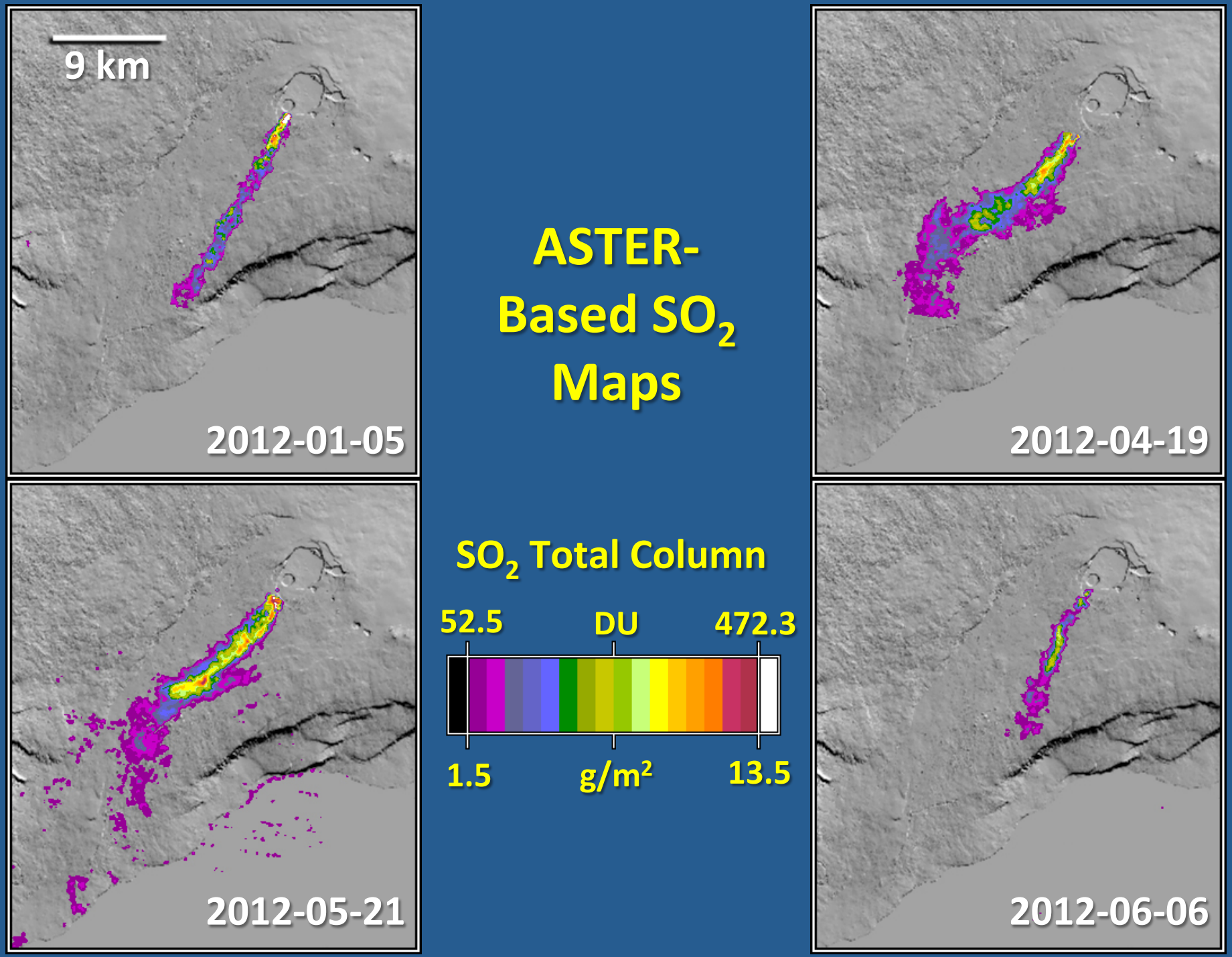




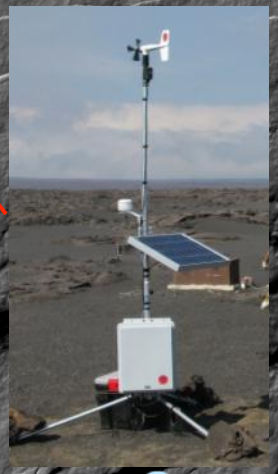
ASTER TIR False-Color Composites





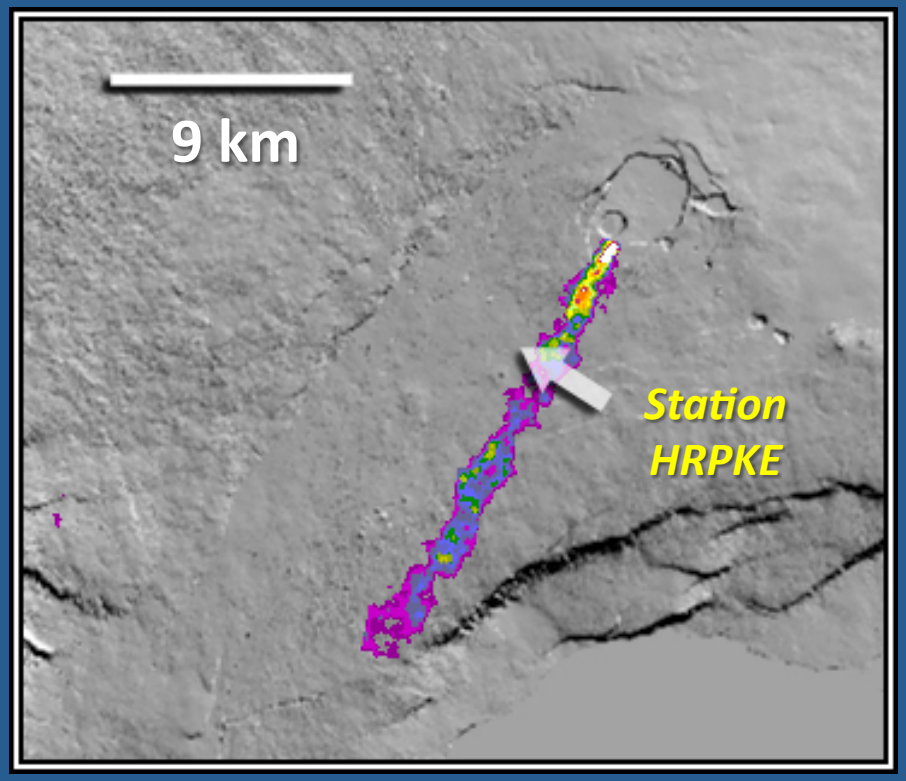

9 km
2012-01-05
2012-04-19
2012-05-21
2012-06-06
ASTER-Based SO_2 Maps
SO_2 Total Column
52.5
DU
472.3
1.5
g/m²
13.5

USGS-HVO Automated Ground Sensor Network



Station HRPKE

USGS



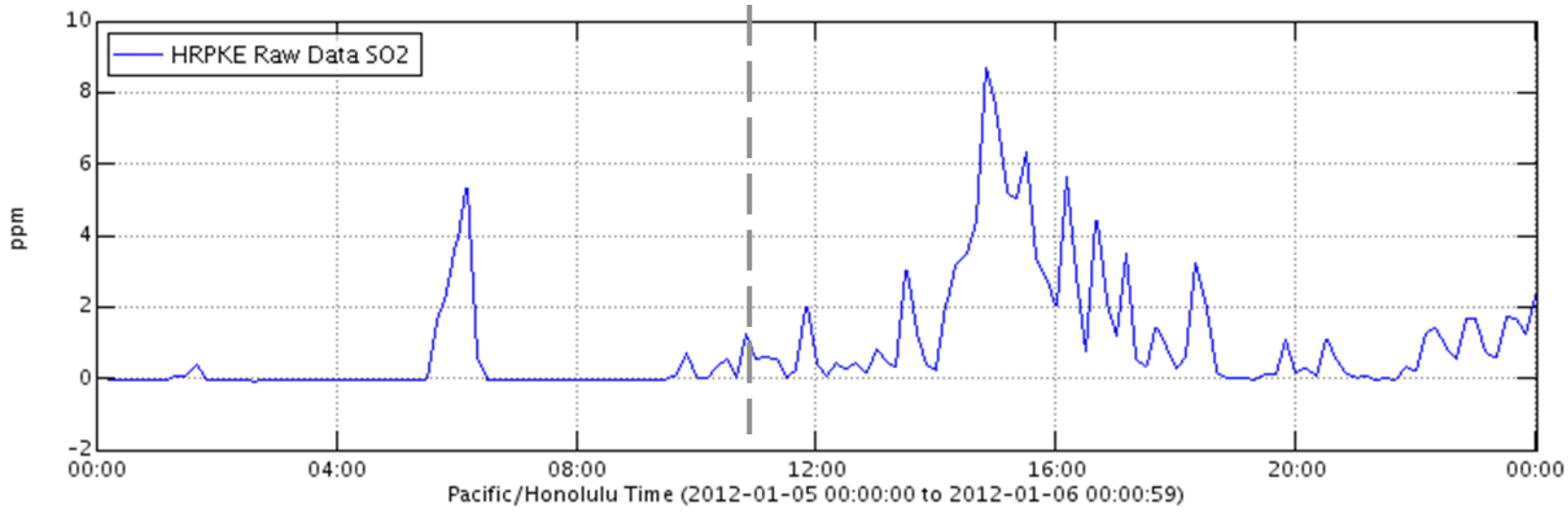
2012-01-05
11:06 HST

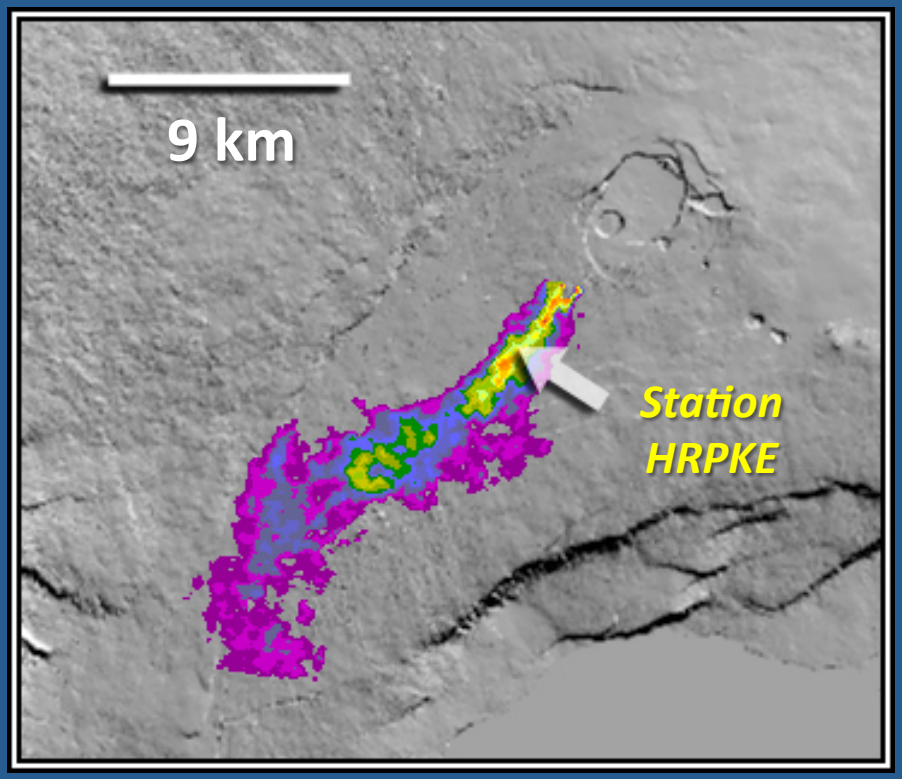
SO_2 Column (g/m^2)

1.5 7.5 13.5

2.1 10.7 19.2

SO_2 Conc. (ppm-v)





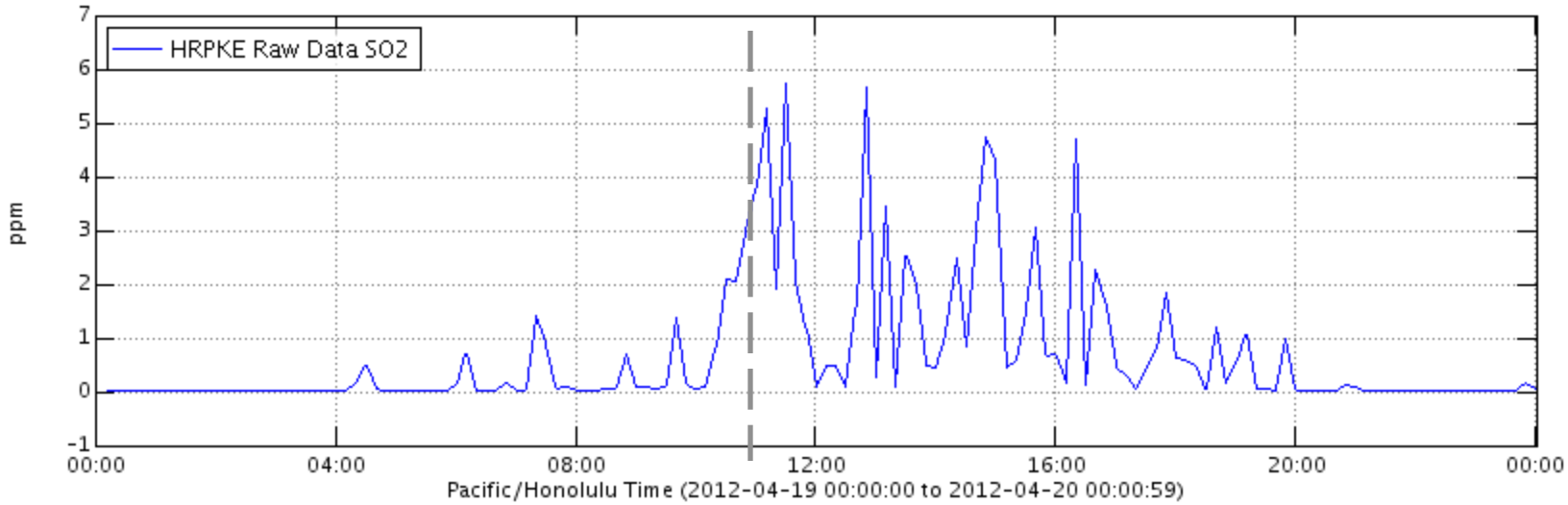
2012-04-19
10:59 HST

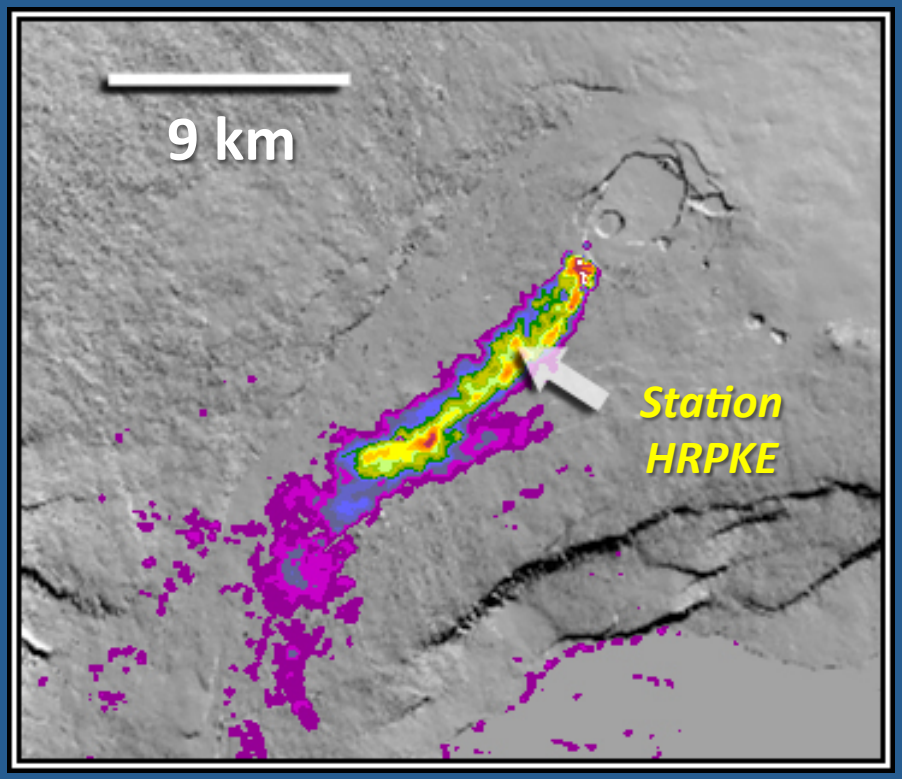
SO_2 Column (g/m^2)

1.5 7.5 13.5

2.1 10.7 19.2

SO_2 Conc. (ppm-v)





2012-05-21
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SO_2 Column (g/m^2)

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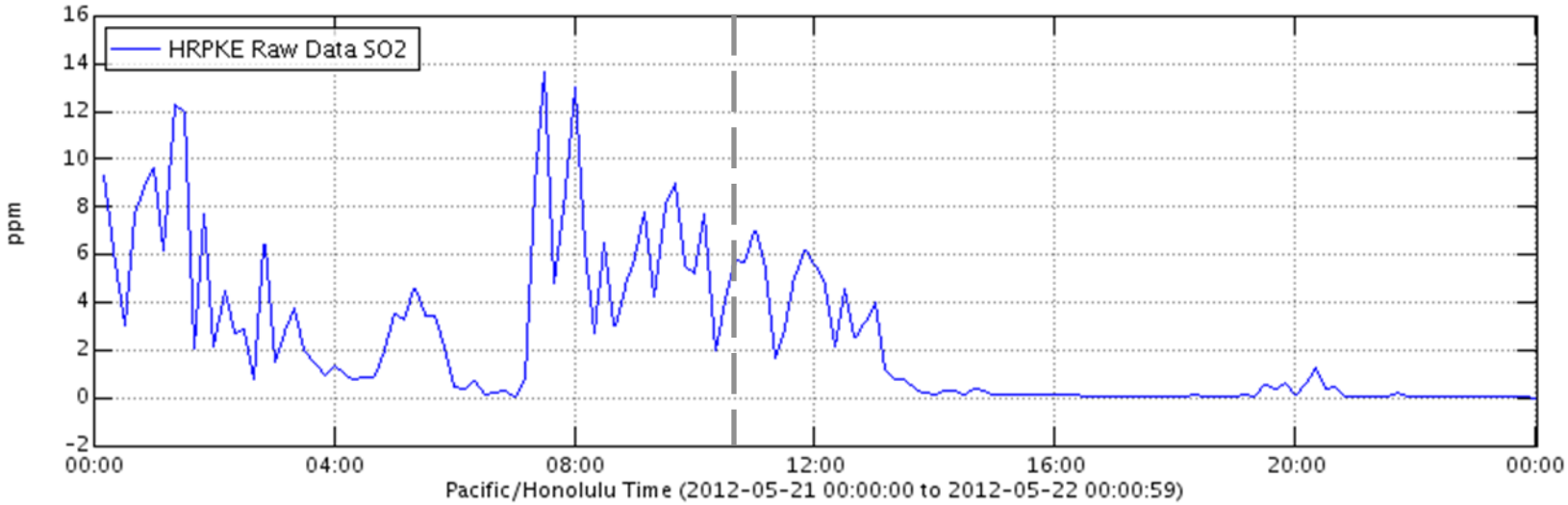
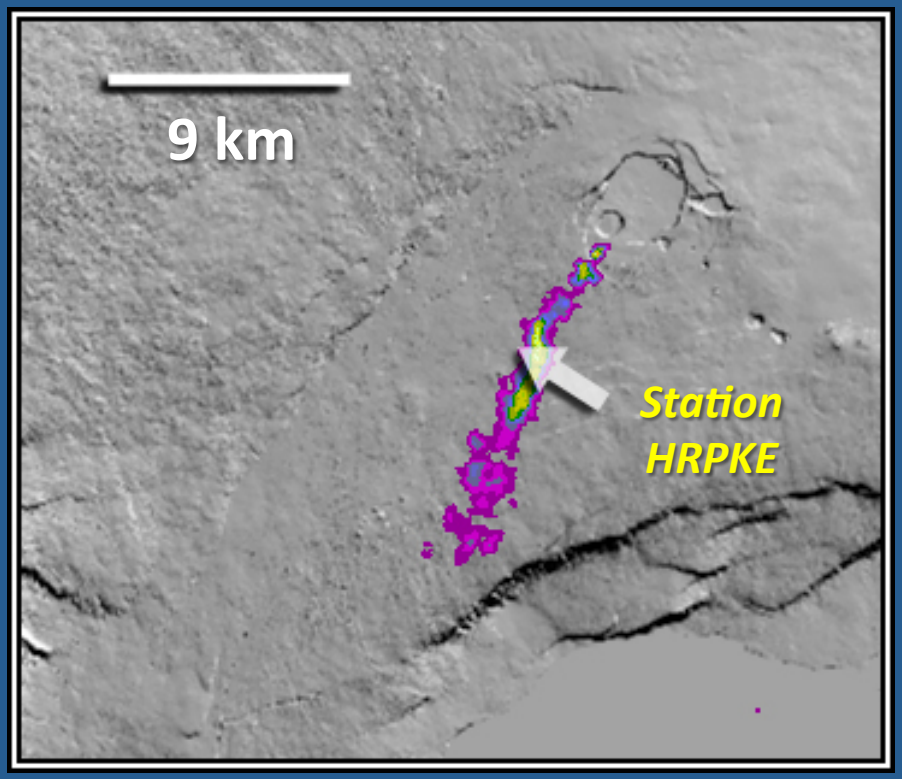
2.1 10.7 19.2

SO_2 Conc. (ppm-v)





2012-06-06
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SO_2 Column (g/m^2)

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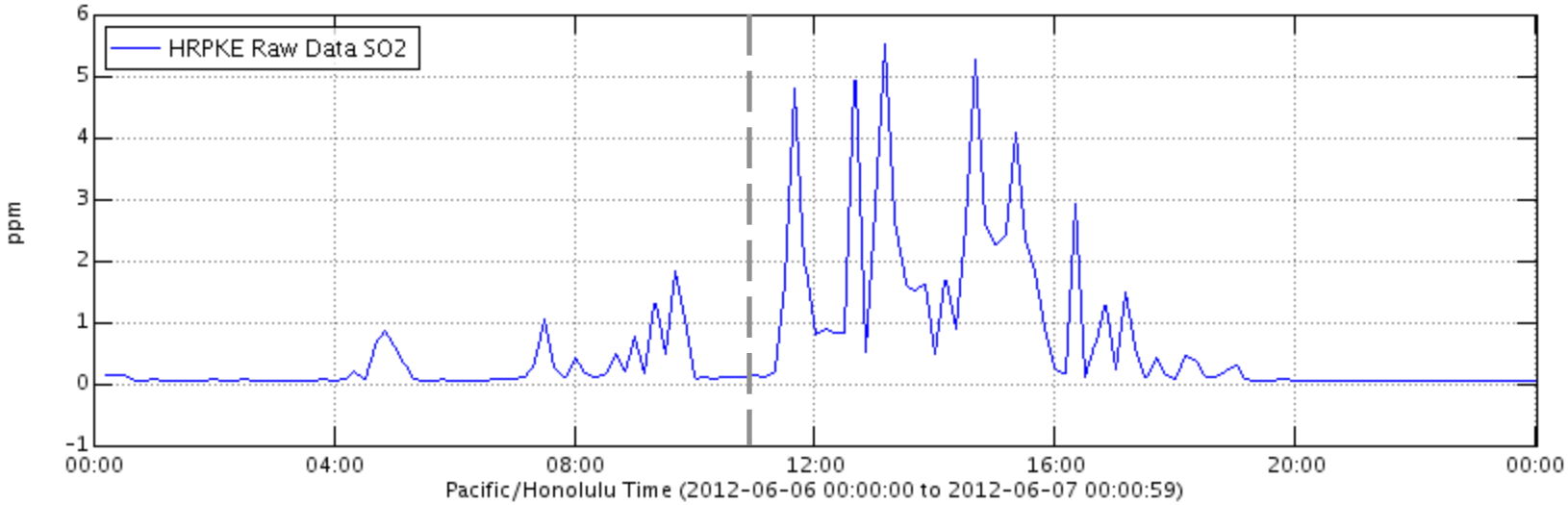
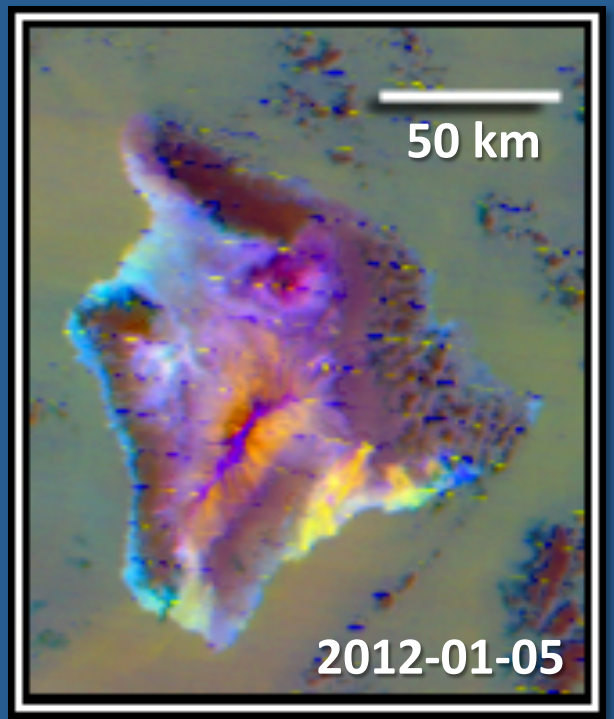
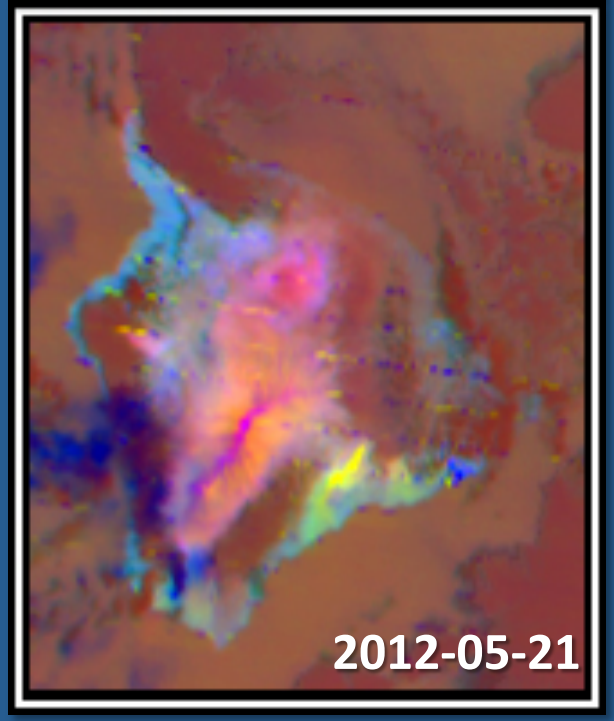
2.1 10.7 19.2

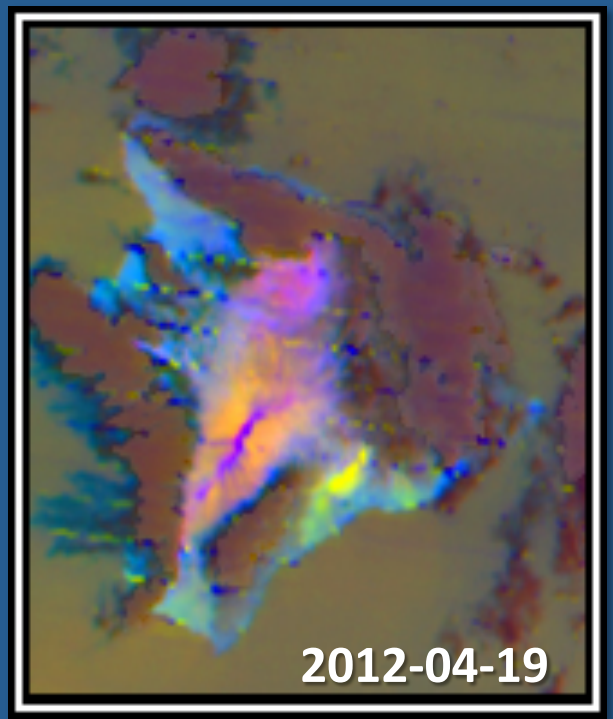
SO_2 Conc. (ppm-v)

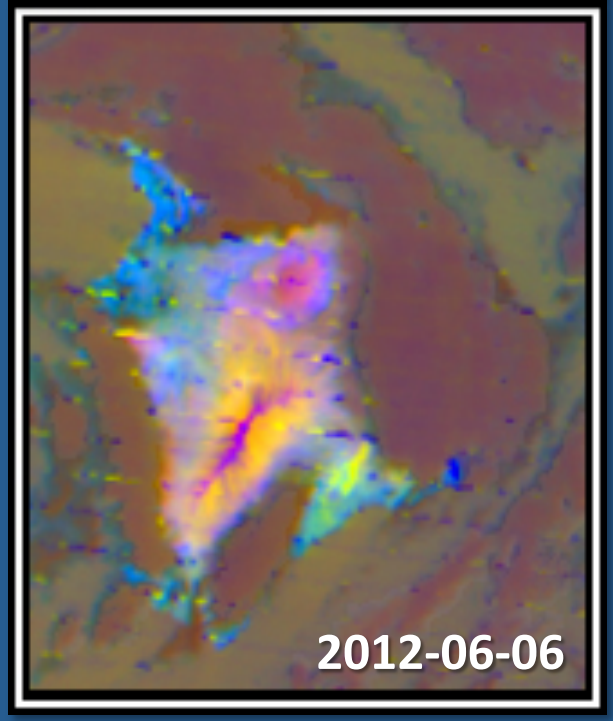


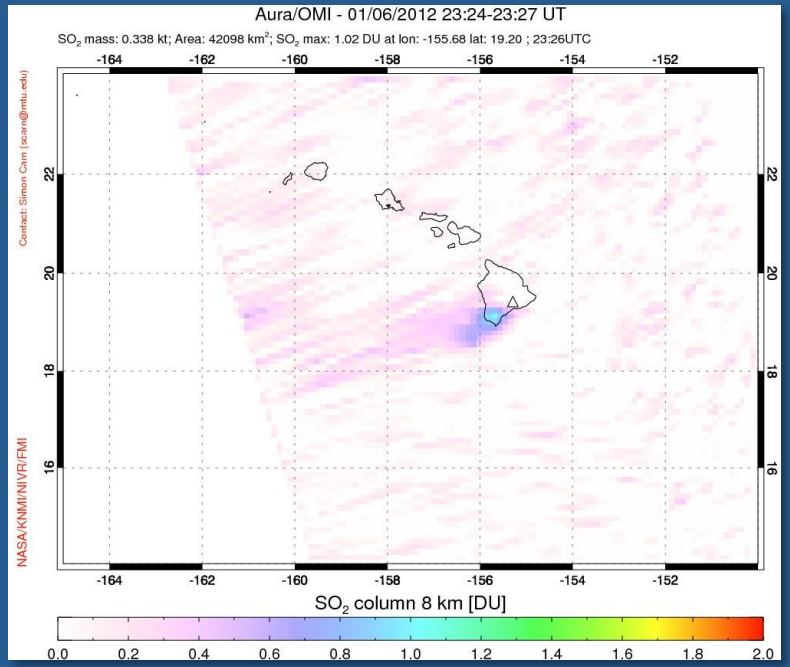


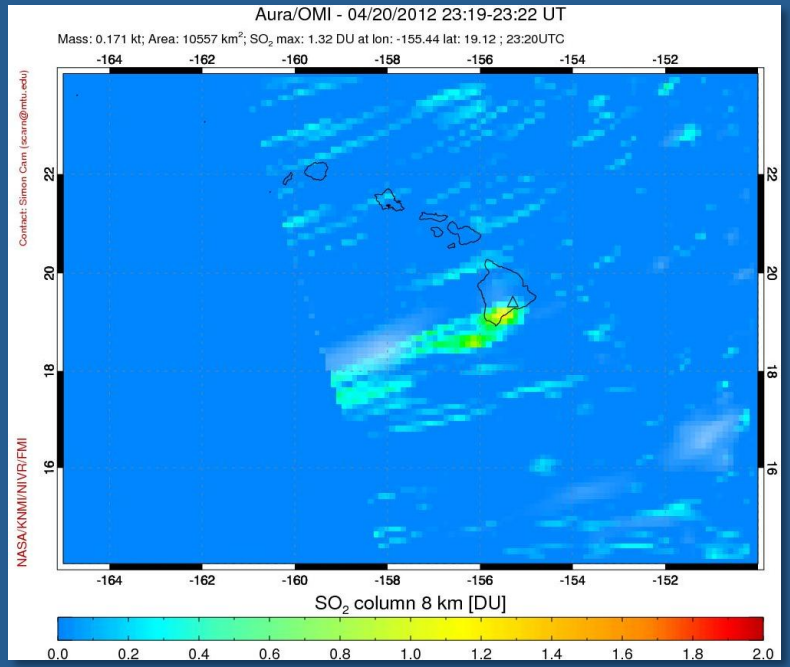


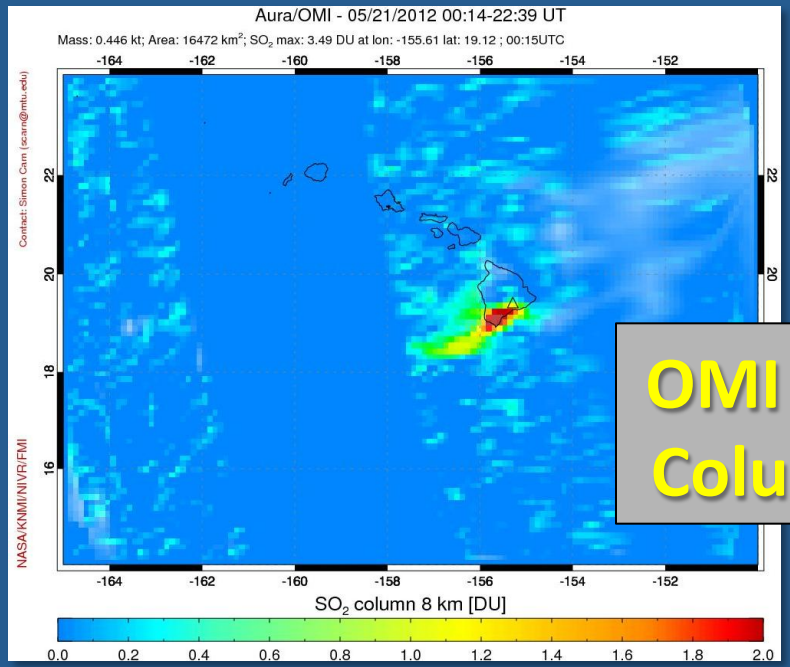
MODIS TIR False-Color Composites

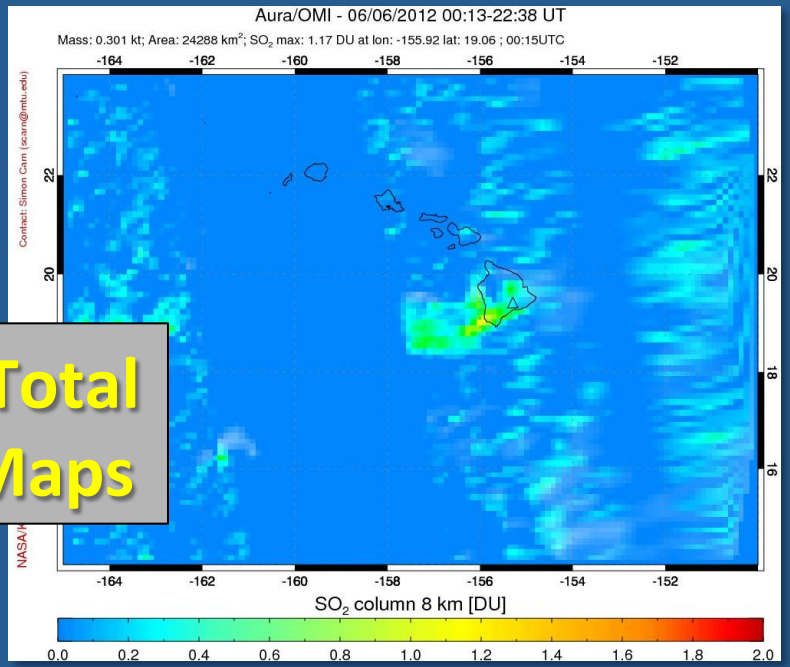




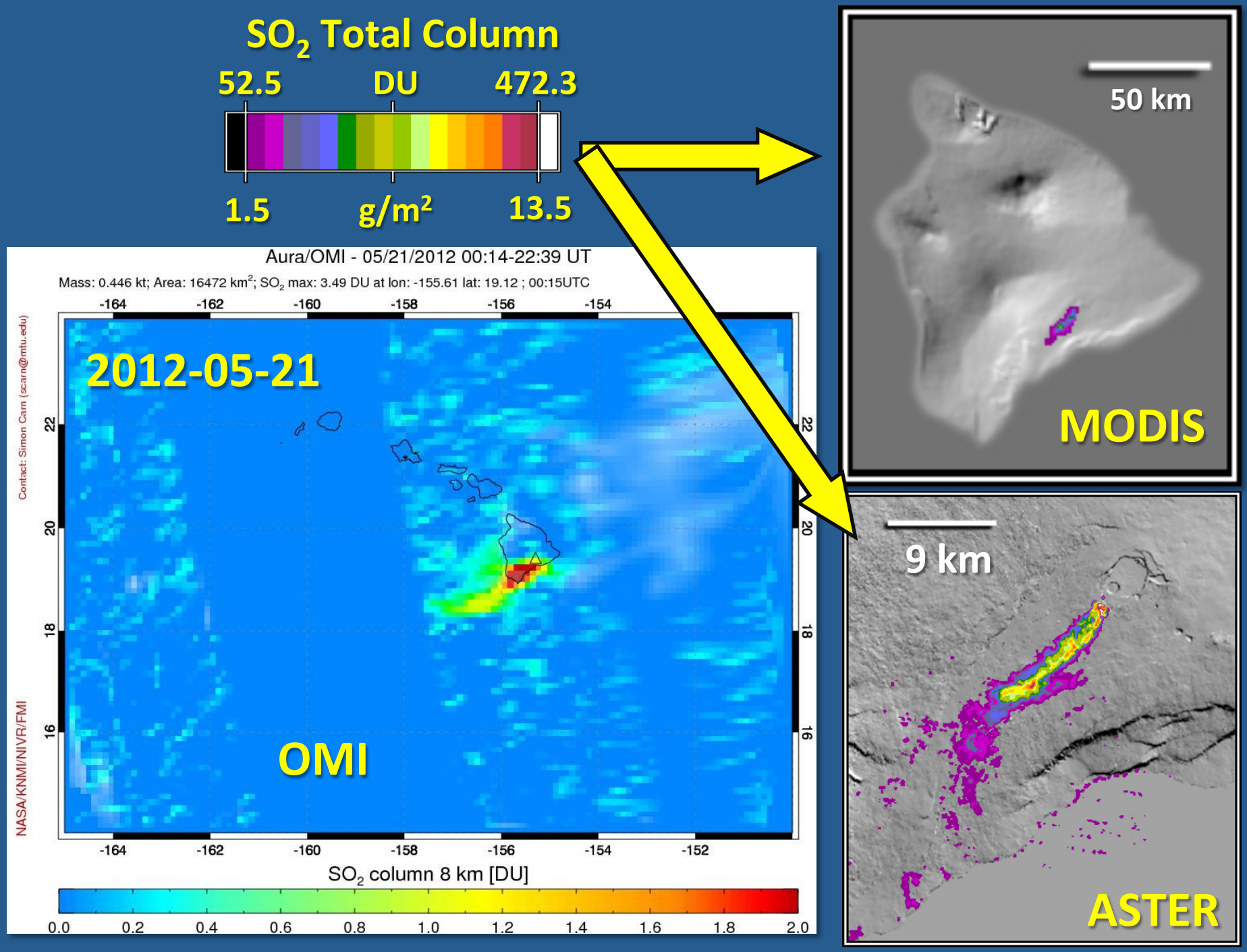








OMI SO_2 Total Column Maps


SO2 Total Column
52.5
DU
472.3
1.5
g/m2
13.5
Aura/OMI - 05/21/2012 00:14-22:39 UT
Mass: 0.446 kt; Area: 16472 km2; SO2 max: 3.49 DU at lon: -155.61 lat: 19.12 ; 00:15UTC
2012-05-21
OMI
Contact: Simon Carn (scarn@mtu.edu)
NASA/KNMI/NIVR/FMI
SO2 column 8 km [DU]
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0
50 km
MODIS
9 km
ASTER

Total Mass SO_2 on 2012-05-21

Instrument	Spatial Resolution	Total Mass SO_2 (metric tons)	Plume Area
OMI	13 x 25 km	0.446 kt	16,472 km^2
MODIS	1 km (at nadir)	0.231 kt	67 km^2
ASTER	90 m	0.259 kt	71.15 km^2

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

SO_2 will be Under-Estimated if

- Plume does not fill a Pixel (IFOV)
- Distribution of SO_2 not Uniform within a Pixel

OMI Reports 2X Mass and 235X the Area: If "Background" SO_2 (< 0.5 DU) were Removed the Mass would Decrease

Validation Efforts Continue at Kilauea:

Coordinating HVO Field Campaigns with ASTER Overpasses

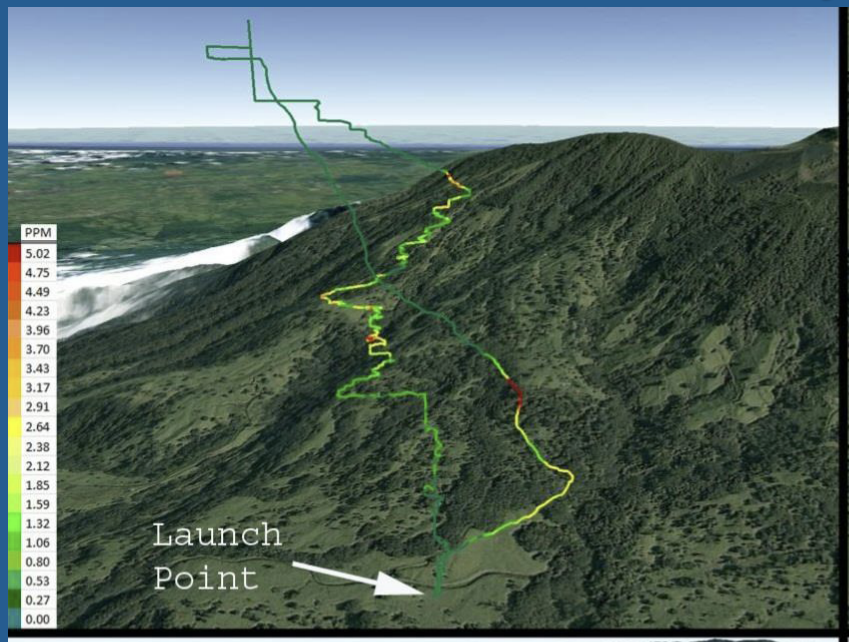
Urgent ASTER Status for Kilauea since May 2013

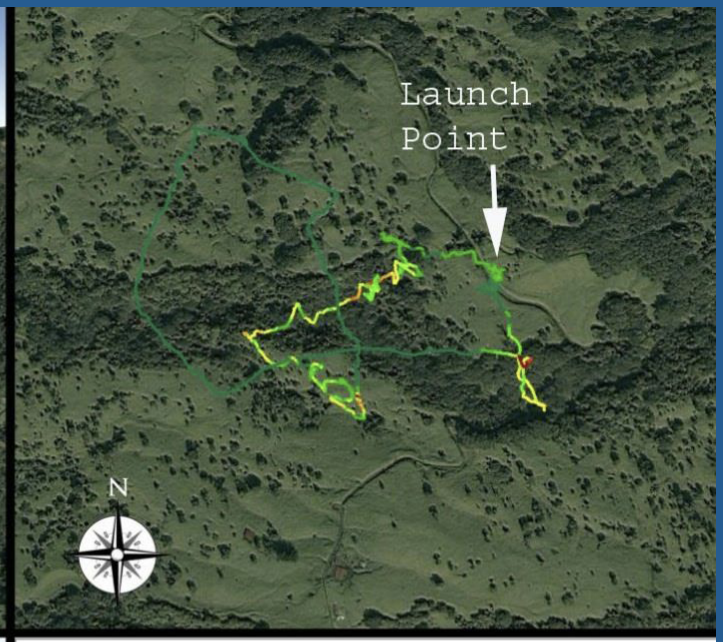
Validation Efforts at Turrialba Volcano, Costa Rica

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

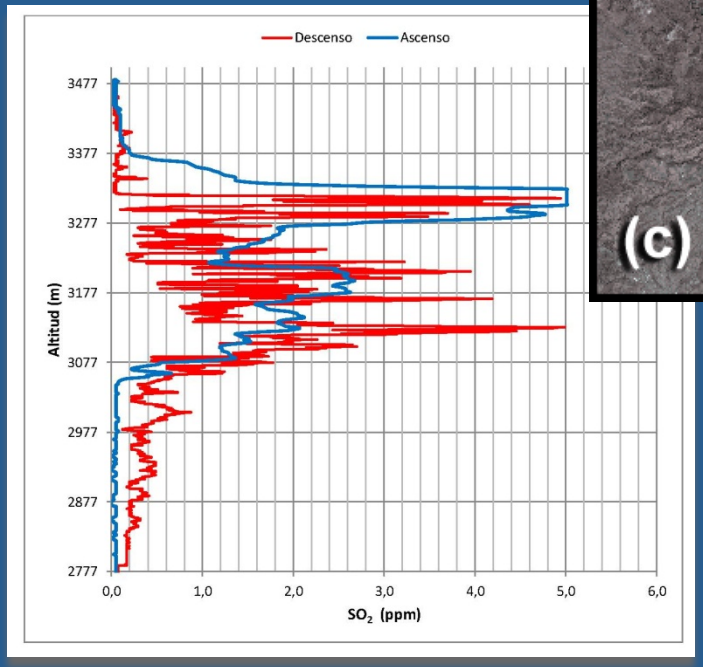


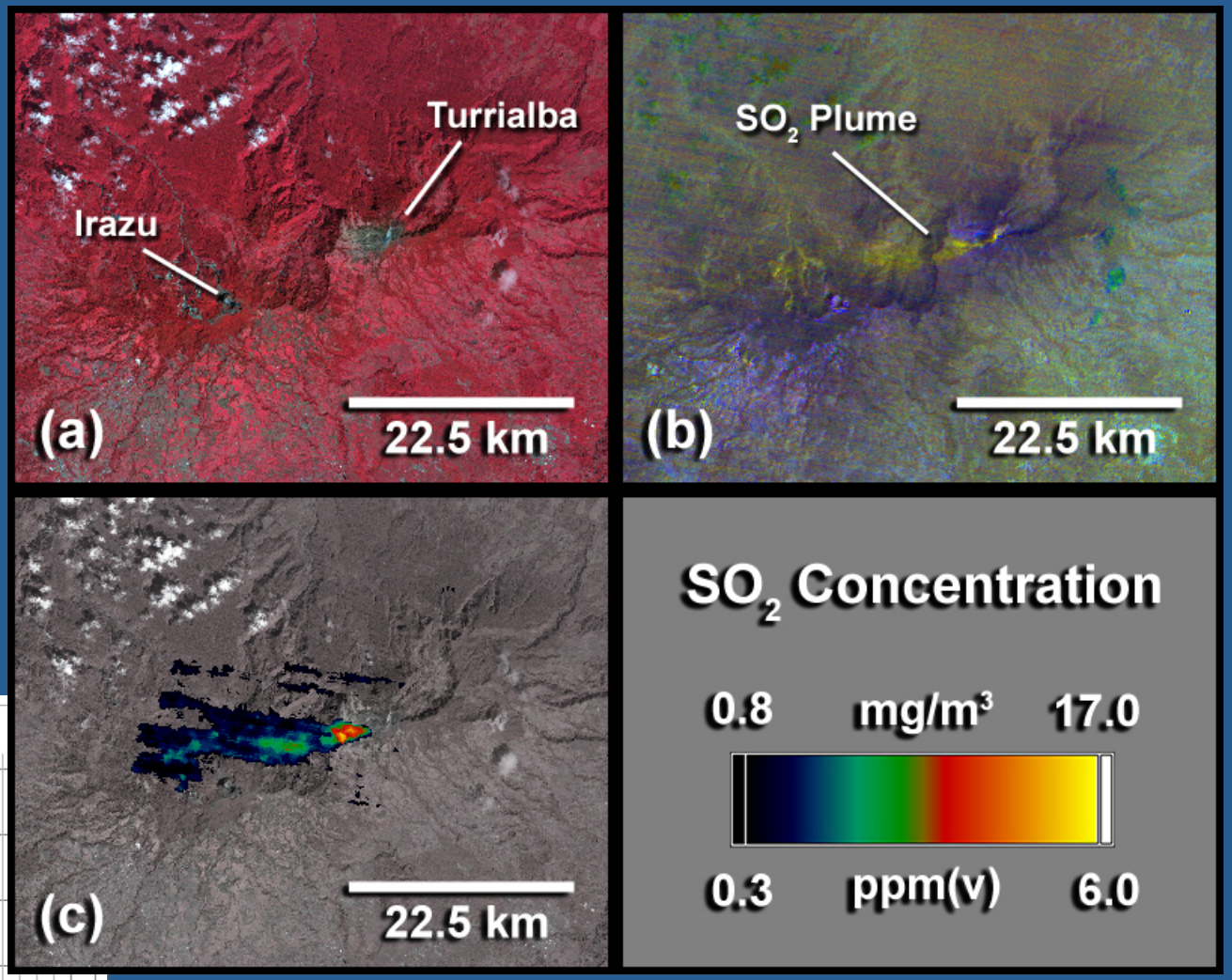


Version 3.0.2 Applied to ASTER Data

Turrialba Volcano, Costa Rica

21 Jan 2012

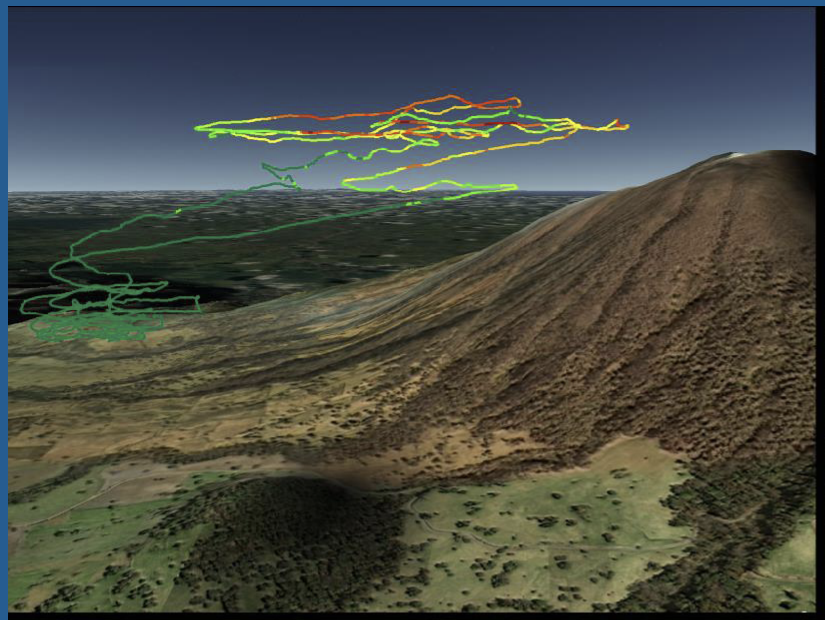


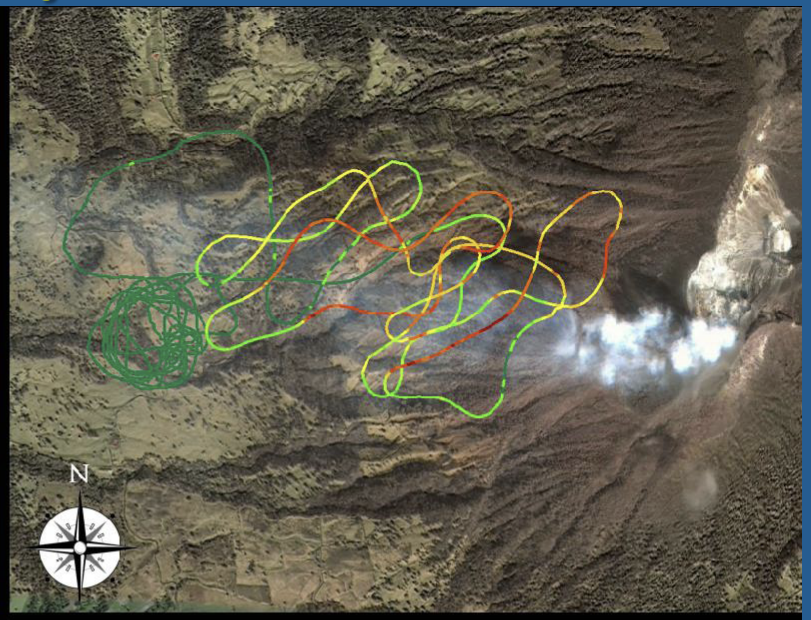


Challenging Conditions for SO_2 Retrieval: Humid Atmosphere, Low-Altitude Plume

Excellent Agreement With In-Situ (Tether-sonde) Measurements from 01 Feb 2012

Micro-UAV Deployment
Turrialba Volcano, Costa Rica
08 February 2013



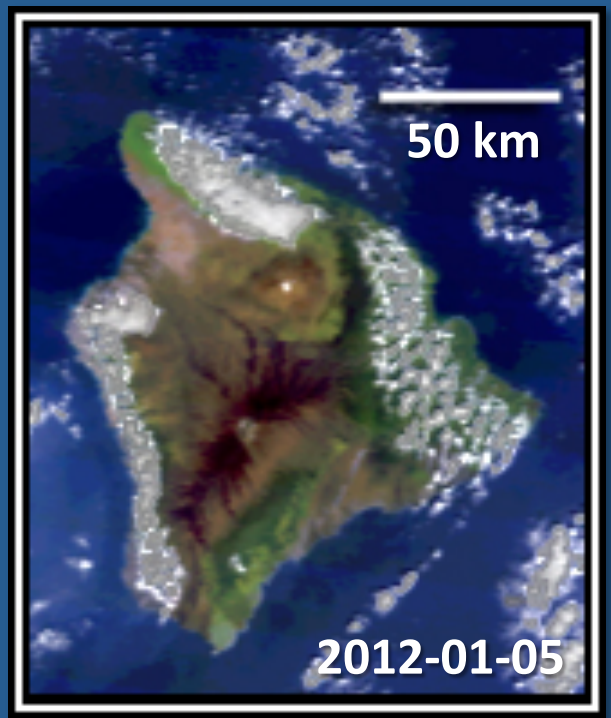


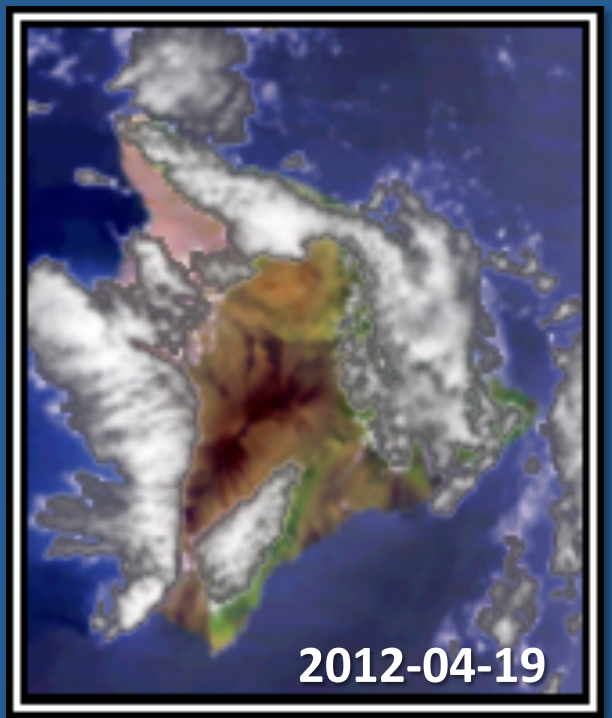
Pieri et al., 2013

Shameless Plugs:

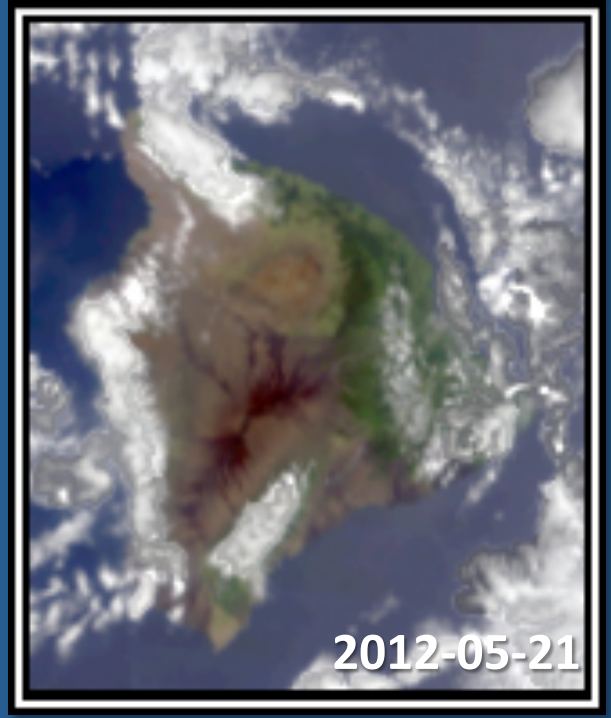
Plume Tracker Demonstration on Wednesday (16 October) @ 7:00 PM

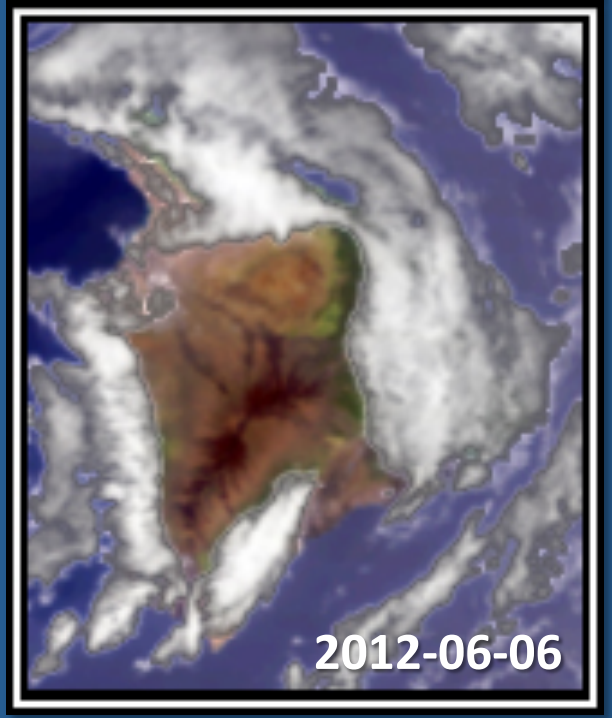
A New GPU-Enabled MODTRAN Thermal Model for the PLUME TRACKER Volcanic Emission Analysis Toolkit **- Alexander Berk, Spectral Sciences, Inc**





MODIS True-Color Composites





Sensitivity to SO_2 is a Function of Temperature Contrast

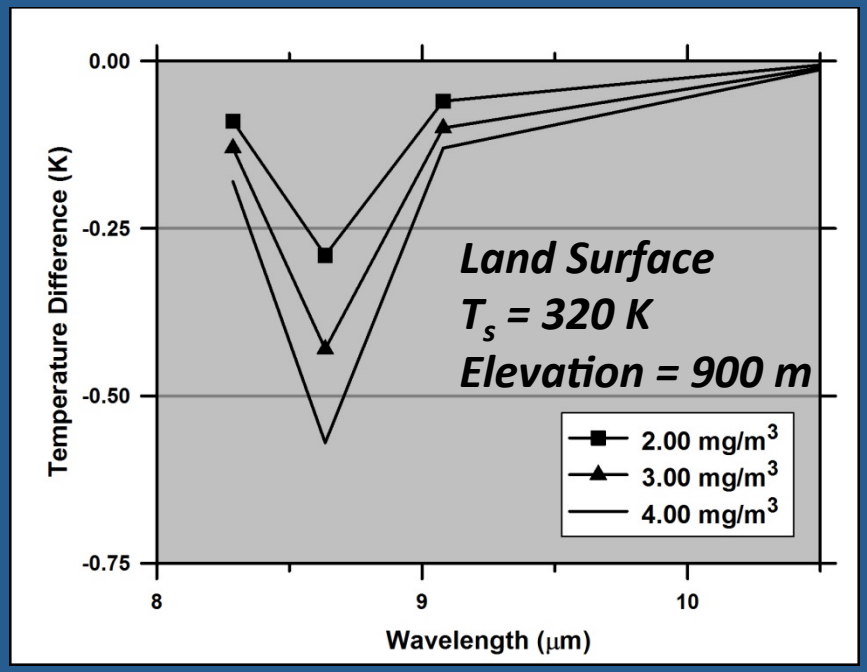
Plot Brightness Temperature Difference Relative to Clear Path (SO_2 = 0)

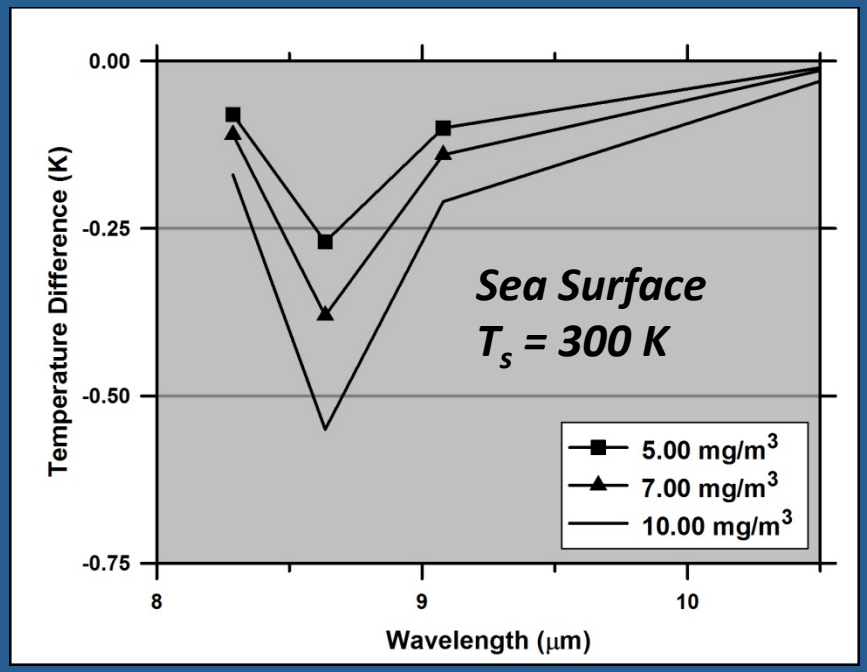
NEΔT 0.25 – 0.5: Realistic Temperature Sensitivity for ASTER or MODIS

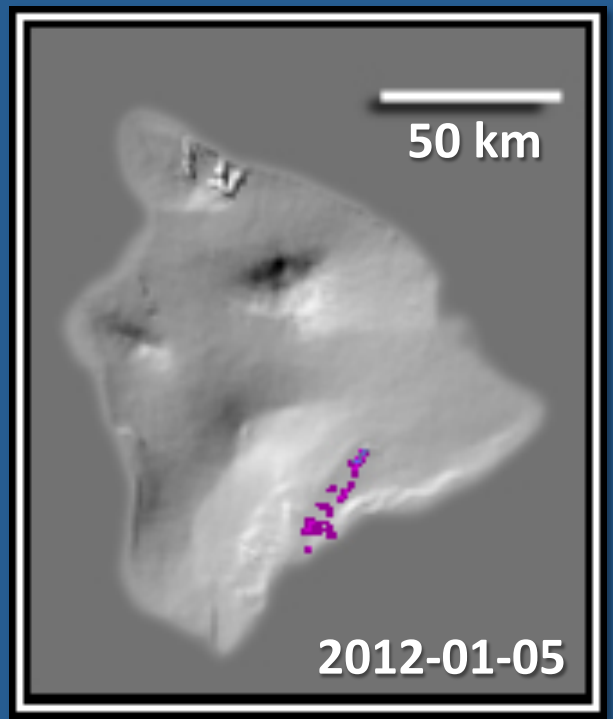
Land Surface (T_s = 320 K): SO_2 Detection Threshold ~ 3.0 mg/m^3

Sea Surface (T_s = 300 K): SO_2 Detection Threshold ~ 7.0 mg/m^3

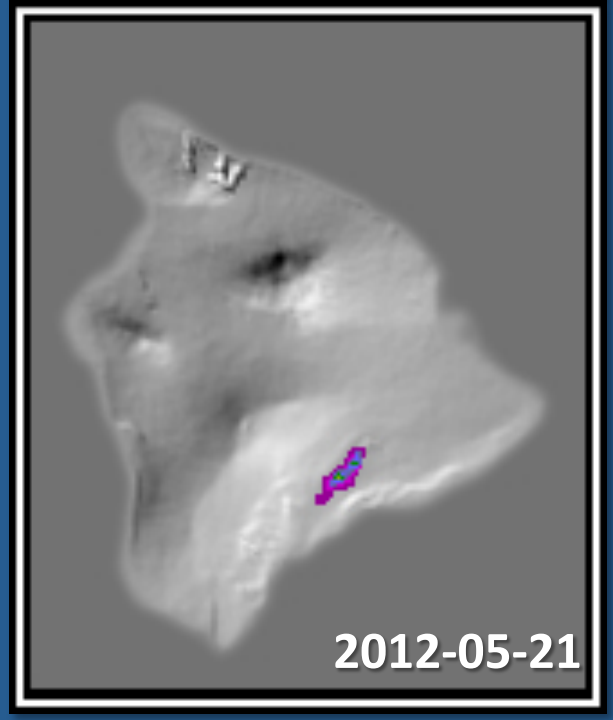
(Temperatures, Emissivity Spectra, and Elevation from ASTER Data over Kilauea Volcano)

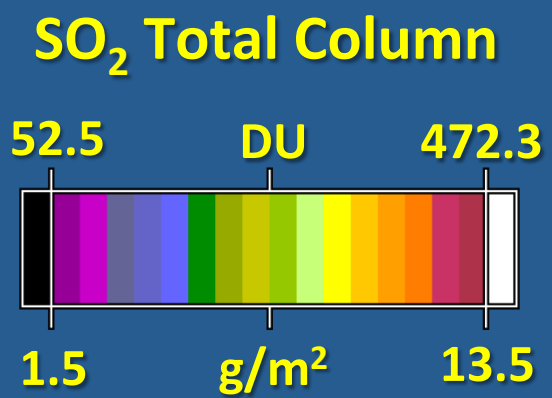


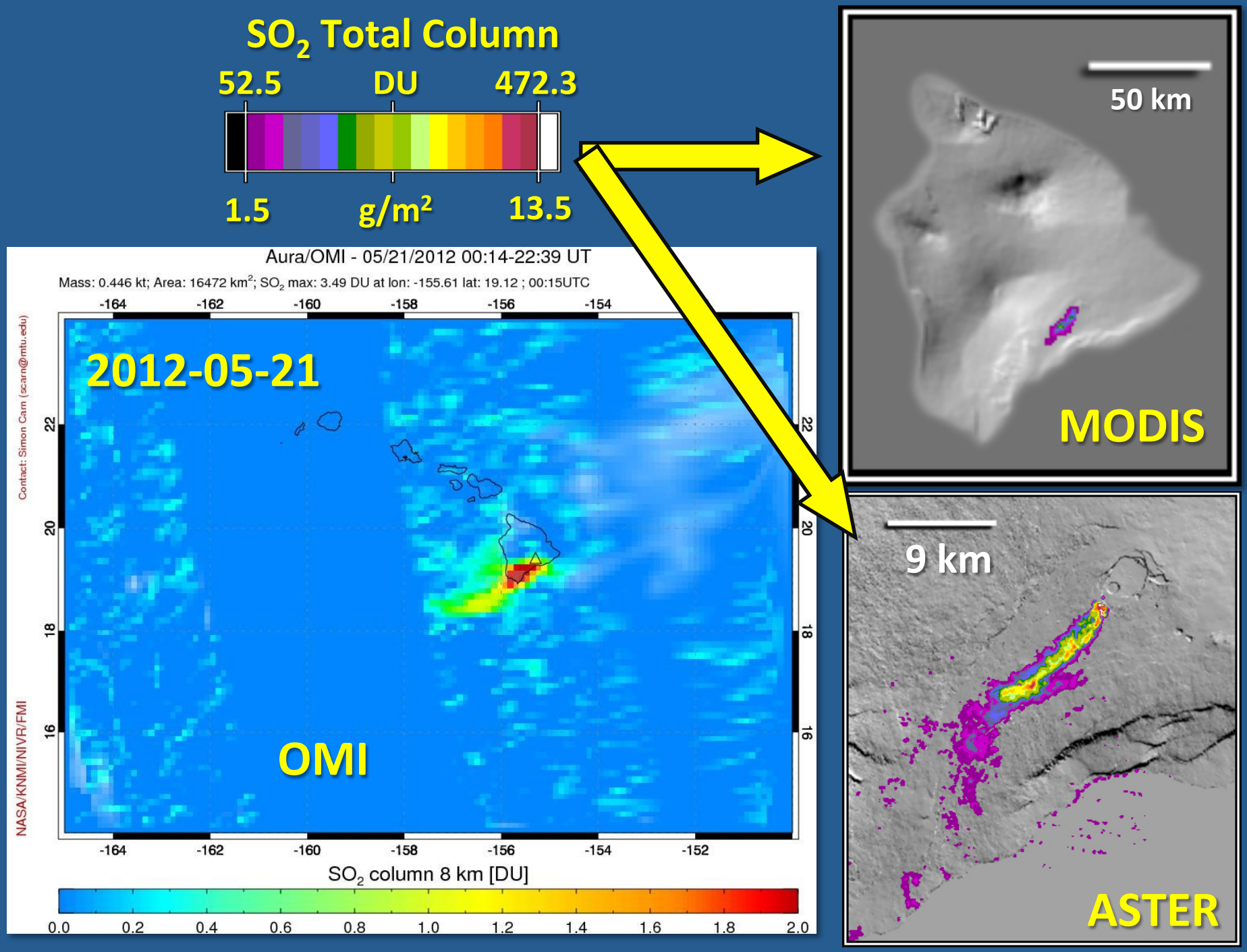




MODIS-Based SO_2 Maps






SO2 Total Column
52.5
DU
472.3
1.5
g/m2
13.5
Aura/OMI - 05/21/2012 00:14-22:39 UT
Mass: 0.446 kt; Area: 16472 km2; SO2 max: 3.49 DU at lon: -155.61 lat: 19.12 ; 00:15UTC
2012-05-21
OMI
Contact: Simon Carn (scarn@mtu.edu)
NASA/KNMI/NIVR/FMI
SO2 column 8 km [DU]
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0
50 km
MODIS
9 km
ASTER

Hash Table (Associative Array): Acceleration of Retrieval Algorithm

Key(1)	*MODTRAN Spectrum(1)*
Key(2)	*MODTRAN Spectrum(2)*
Key(3)	*MODTRAN Spectrum(3)*
Key(4)	*MODTRAN Spectrum(4)*
…	…

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

Retrieval Algorithm Time-Trials: Domain Refinement (V.2.2.9) vs. Brent's Method (V.3.0)

	Domain Refinement	***Brent's Method***
Calls to MODTRAN *(ROI = 1296 pixels)*	*264,398*	*144,508*
No Hash Table	*6.4 sec/pix*	*3.2 sec/pix*
Hash Table	*1.6 sec/pix*	*0.8 sec/pix*
Success Rate *(Hash Table Hits vs. Misses)*	*77.4 %*	*77.0%*
Cached Radiance *(All Calls to MODTRAN Use Hash Table)*	*0.2 sec/pixel*	*0.0086 sec/pix*