An Overview of the Remote Sensing of Heterogeneous Volcanic Plumes

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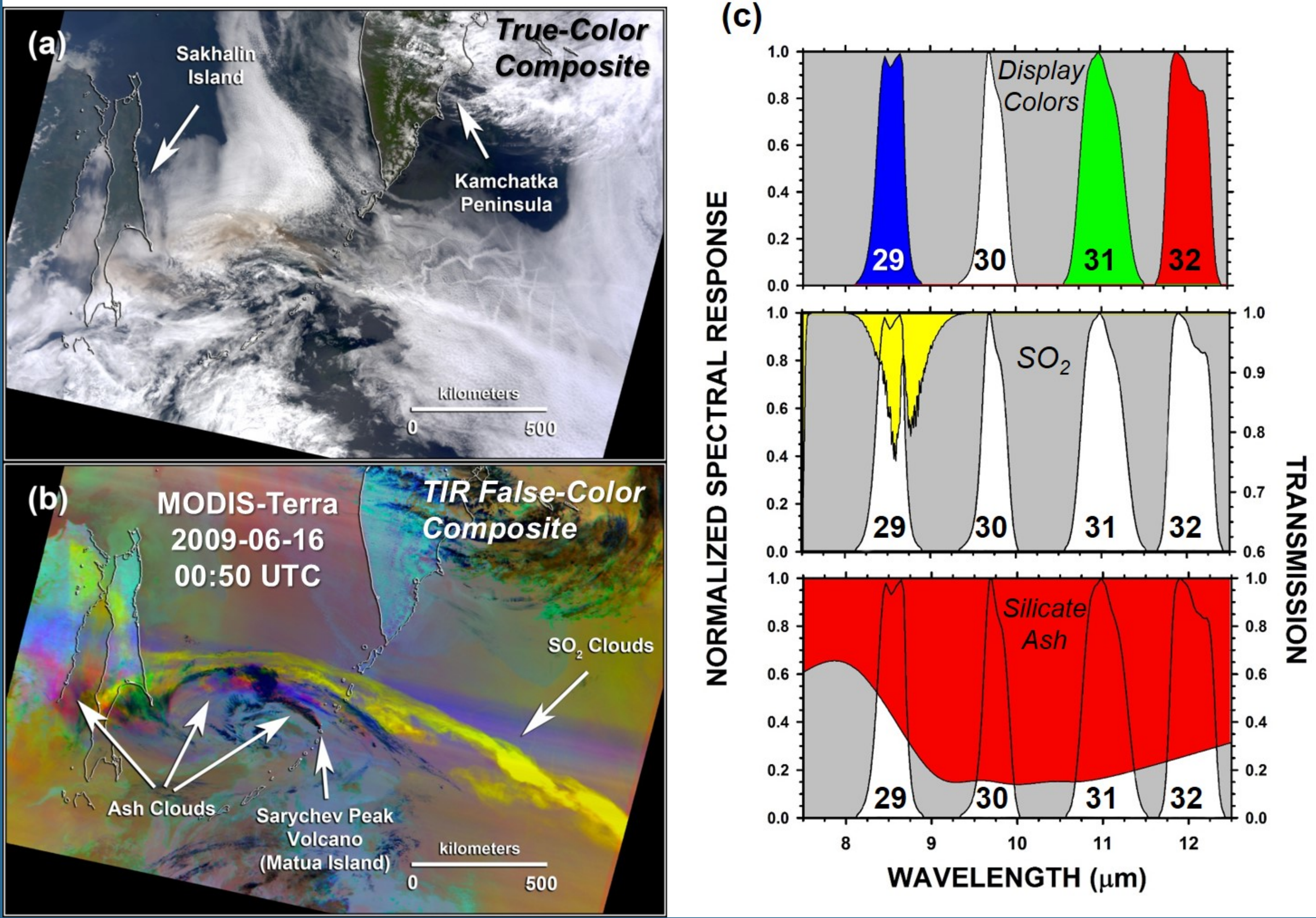
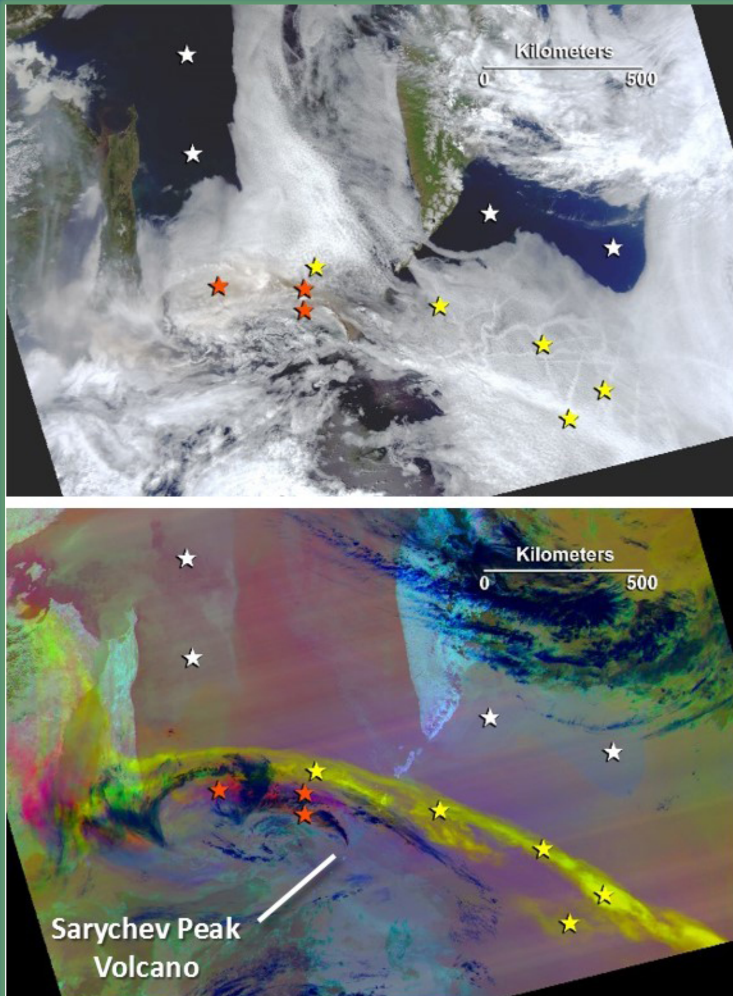
Spectroscopy of Volcanic Plumes:

Sarychev Peak Eruption

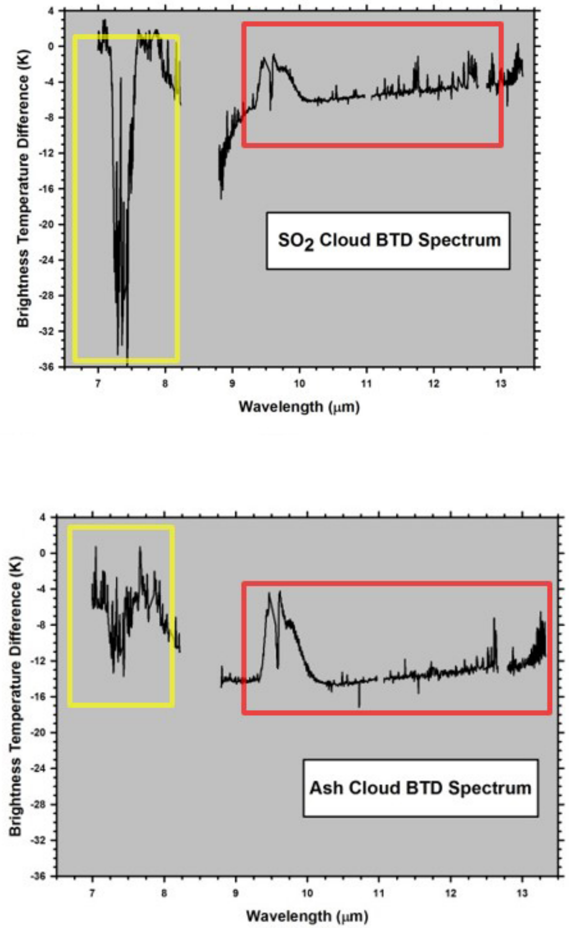
June 2009



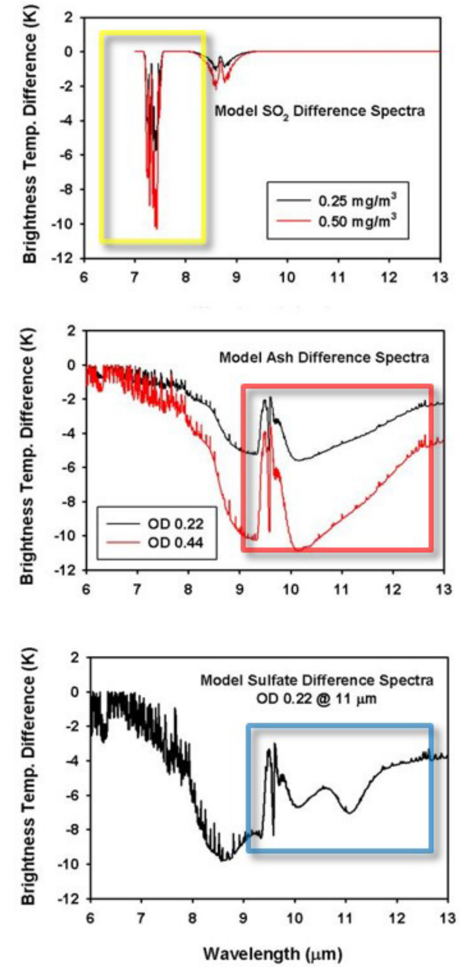
(a)
True-Color Composite
Sakhalin Island
Kamchatka Peninsula
kilometers
0
500
(b)
MODIS-Terra
2009-06-16
00:50 UTC
TIR False-Color Composite
SO2 Clouds
Ash Clouds
Sarychev Peak Volcano (Matua Island)
kilometers
0
500
(c)
Display Colors
SO2
Silicate Ash
29
30
31
32
NORMALIZED SPECTRAL RESPONSE
TRANSMISSION
WAVELENGTH (μm)
8
9
10
11
12
0.0
0.2
0.4
0.6
0.8
1.0
0.6
0.7
0.8
0.9



(a) MODIS-Aqua
2009-06-16



(b) AIRS BTD Spectra
2009-06-16



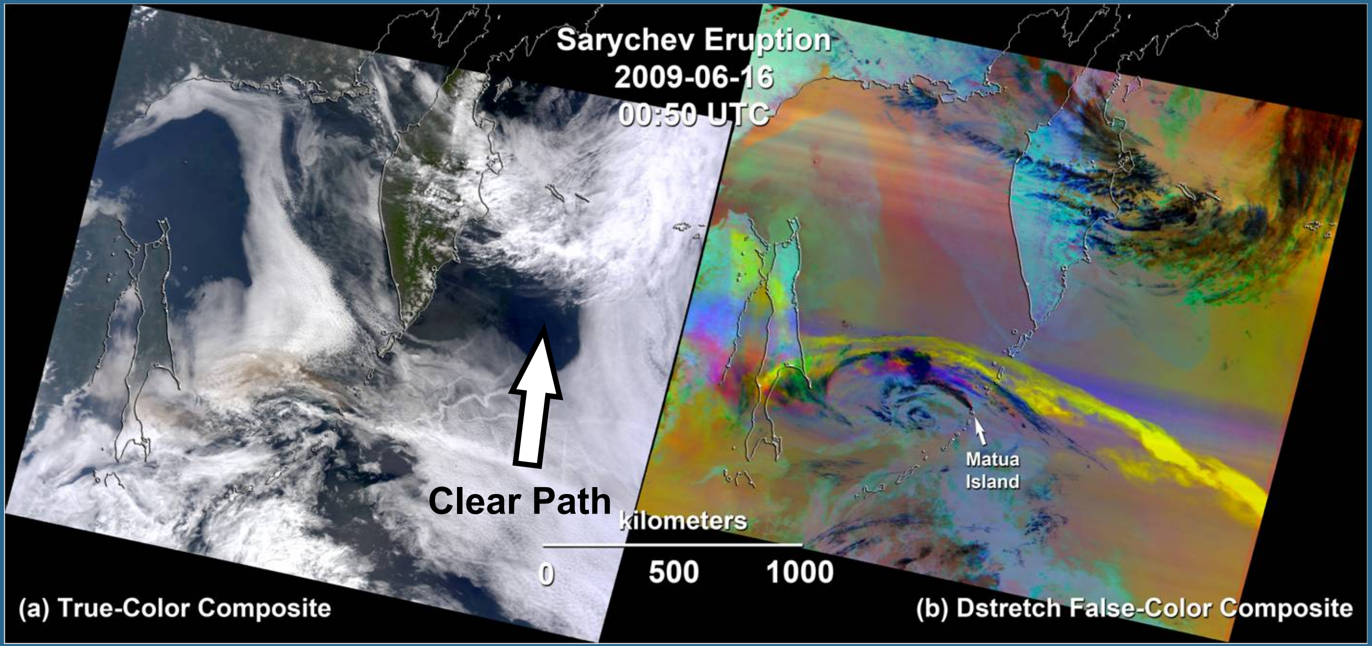
(c) Model BTD
Spectra

Heterogeneous Plumes from Sarychev Peak Eruption, Kurile Islands, Russia

Sample Locations: ★ Clear Path ★ Ash Plume ★ SO_2 Plume

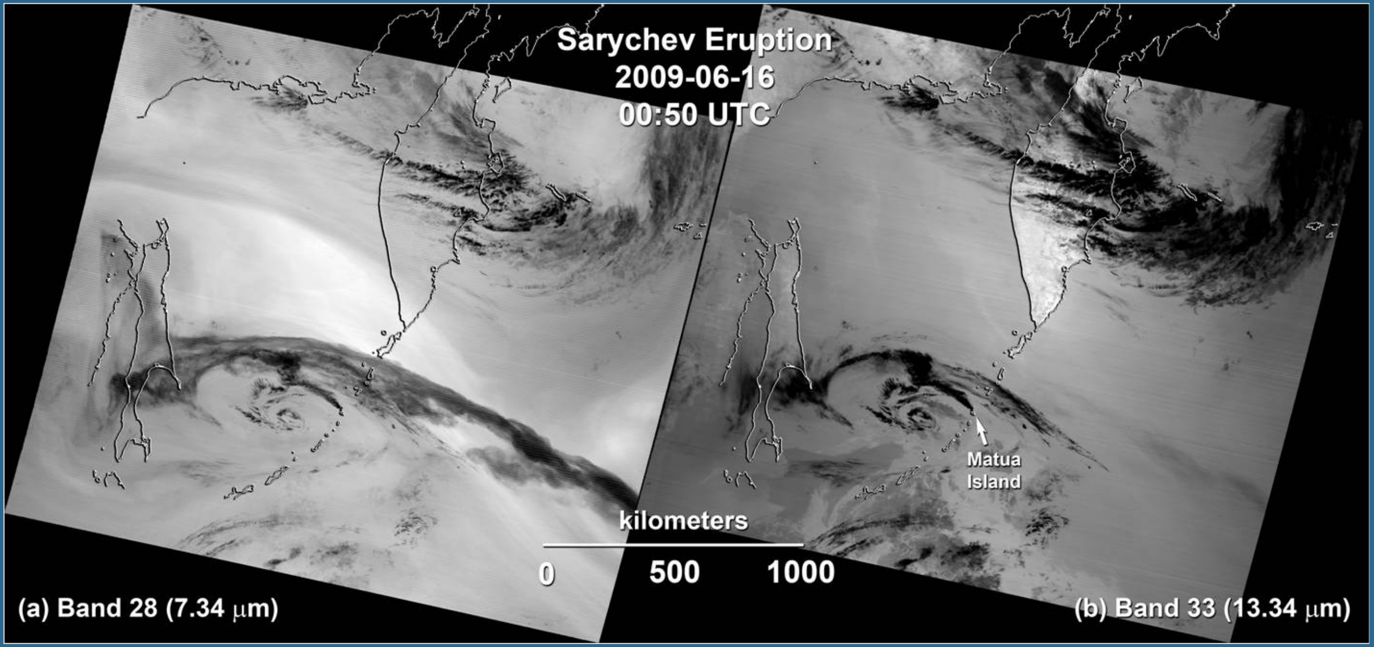
- Spectra of SO_2 plumes show evidence of ash
- Spectra of ash plumes show evidence of SO_2
  - No spectral evidence for SO_4 aerosols

Retrieval Procedure Requires Profiles of Atm. Temp, H_2O, and O_3 as Input



Radiance Spectra from Clear Path (Plume-Free) Regions are used to "Tune" the H_2O and O_3 Profiles

Tuning is a Time-Consuming Process: Retrieval of H_2O is More Efficient and a Better Characterization of Variations in H_2O



Strong H_2O Absorption in MODIS 28 Obscures the Surface

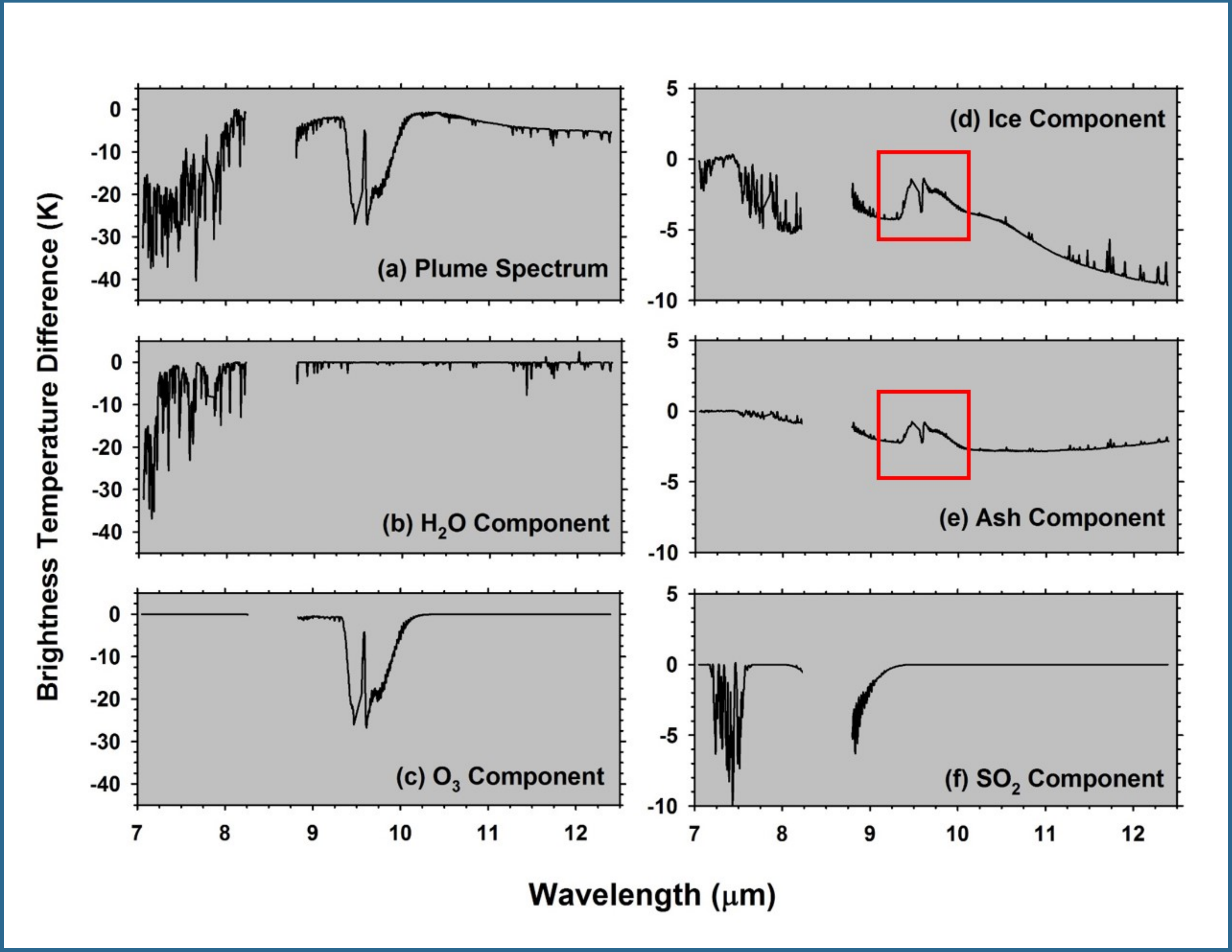
Moderate H_2O Absorption in MODIS 33 Does Not Obscure the Surface

Composite Spectrum of a Heterogeneous Volcanic Plume

Spectra were generated with MOD5.3doe at 0.1 cm^{-1} resolution and convolved with the AIRS spectra response.

Note the change in the temperature scale between Spectra (a) – (c) and (d) – (e), and the gap in AIRS spectral coverage between 8.2 and 8.8 μm.

O_3 "artifact" (red boxes) is common to difference spectra



Preparing for the Use of HyspIRI to Monitor the Impact of Volcanic Plumes on Air Quality

Co-Investigators and Collaborators:

F. Schwandner, UCLA/JIFRESSE

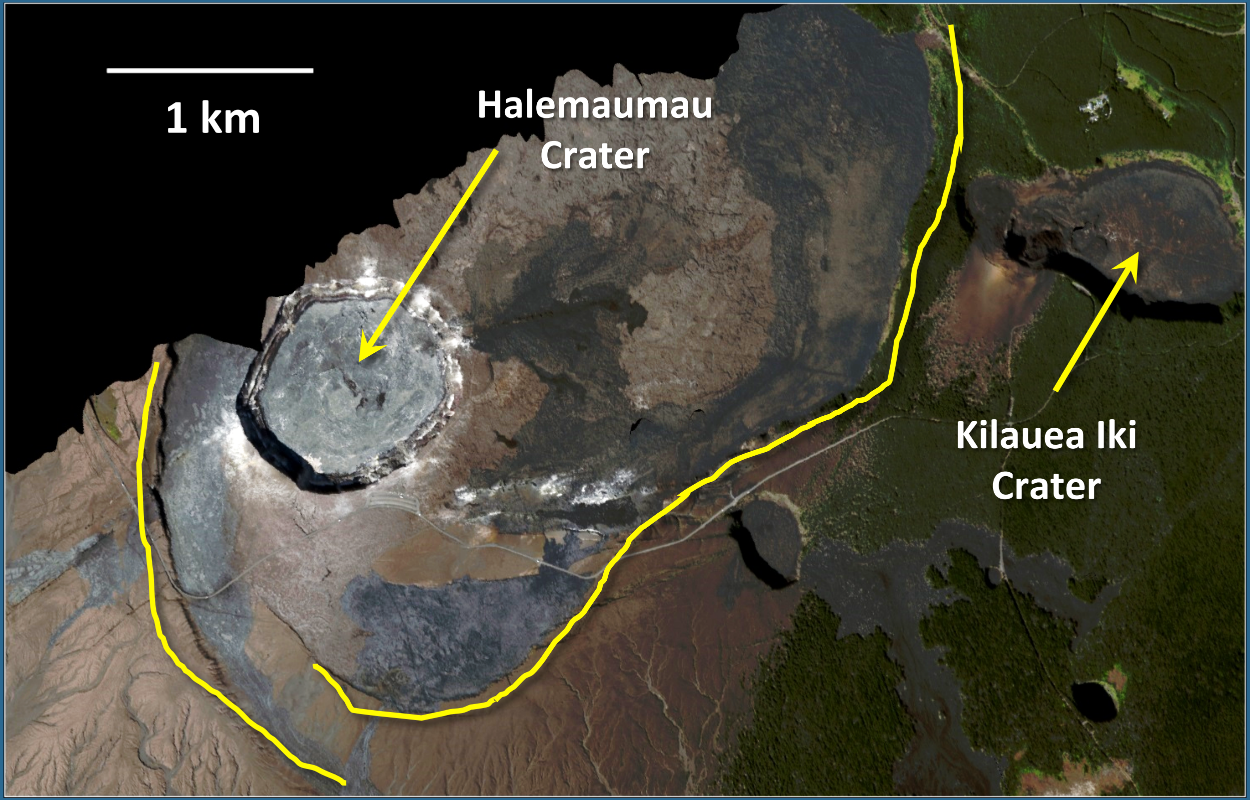
A.J. Sutton, USGS-HVO

T. Elias, USGS-HVO

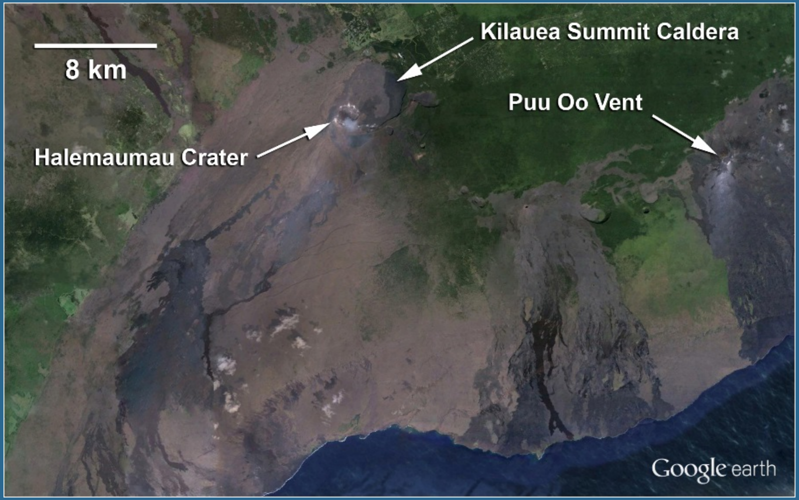
S. Businger, UH-Manoa

K. Horton, FlySpec, Inc.

Production of Vog has Intensified Since Start of Summit Eruption in 2008

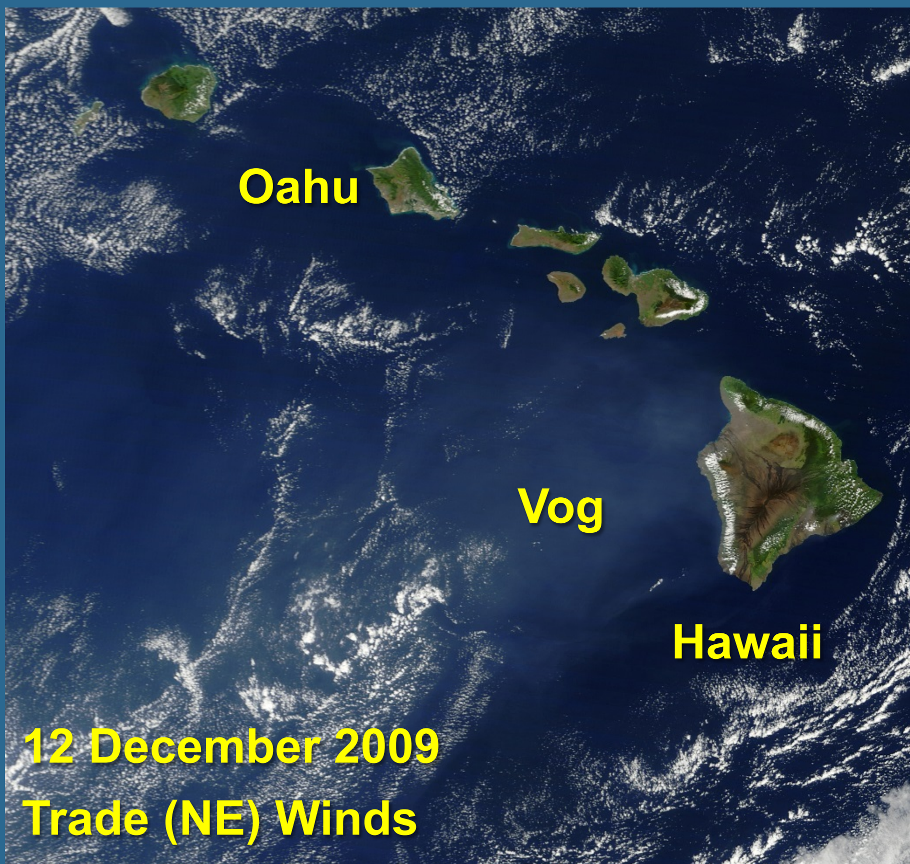


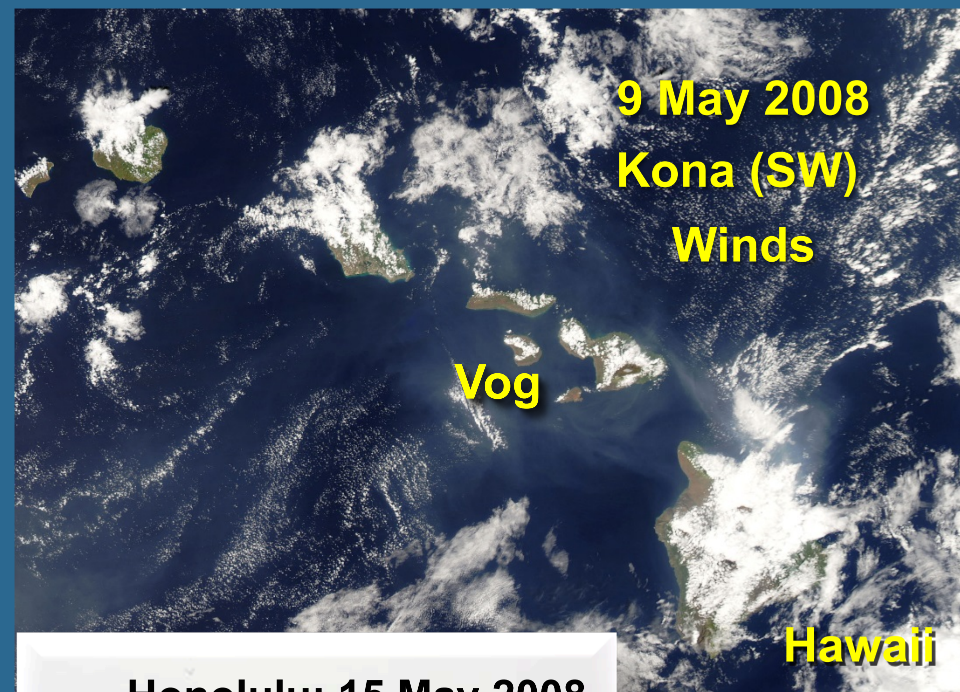
- SO_2 Emissions Increased from 140 to 2500 mt/day in March, 2008
- Annual Averages of SO_2 and $PM_{2.5}$ Exceeded Air Quality Standards (2011 & 2012)
- Increased Cases of Respiratory Disease and Hypertension in Downwind Communities
- Federal Disaster Relief to Farmers/Ranchers since 2008



Volcanic Smog (Vog): Suspension of Sulfate (SO_4) Aerosols, Sulfur Dioxide (SO_2), and H_2O vapor/droplets

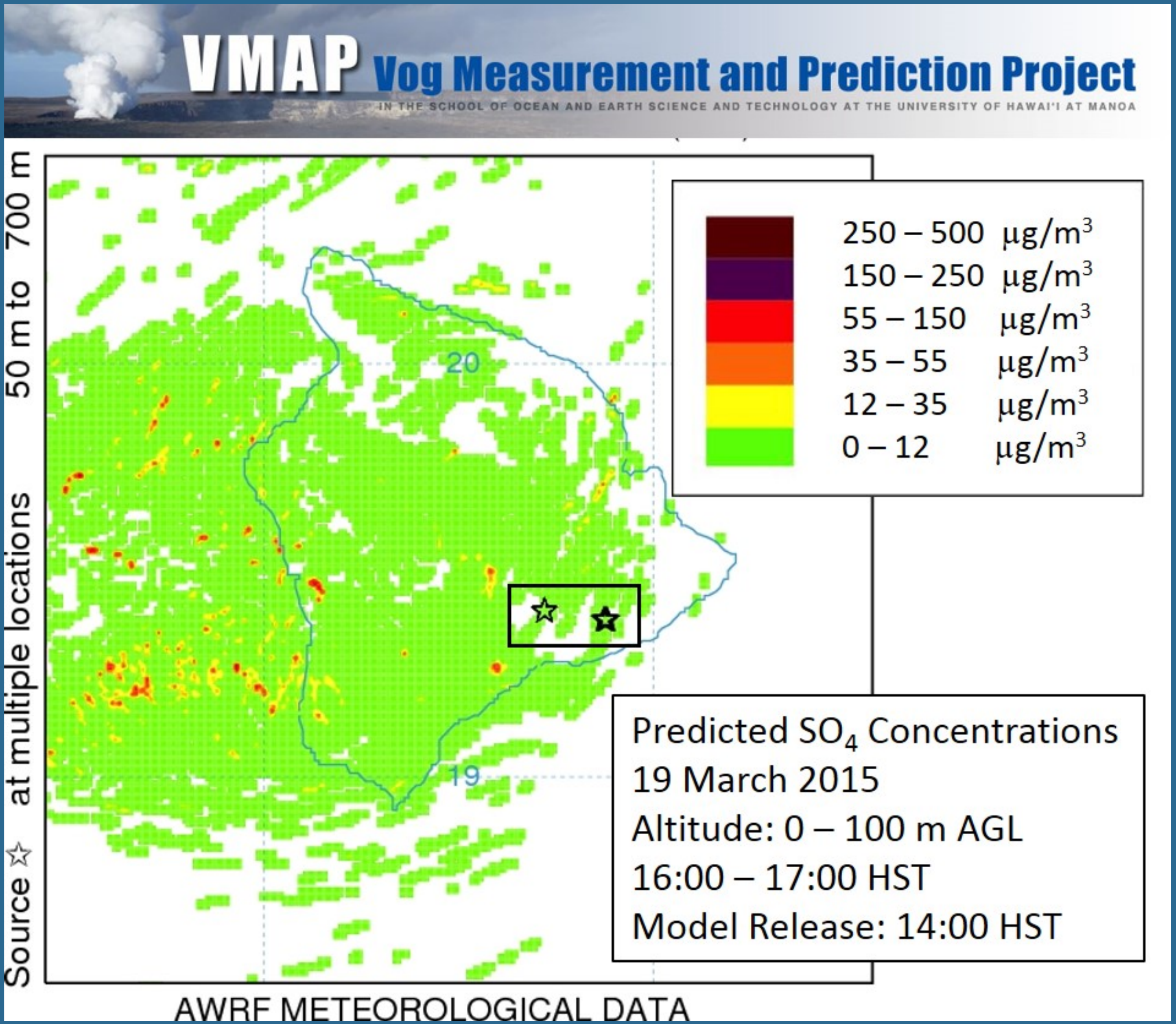
- Particulate Matter < 2.5 μm Diameter ($PM_{2.5}$) is a Respiratory Hazard
- Corrosive Pollution Damages Crops and Property





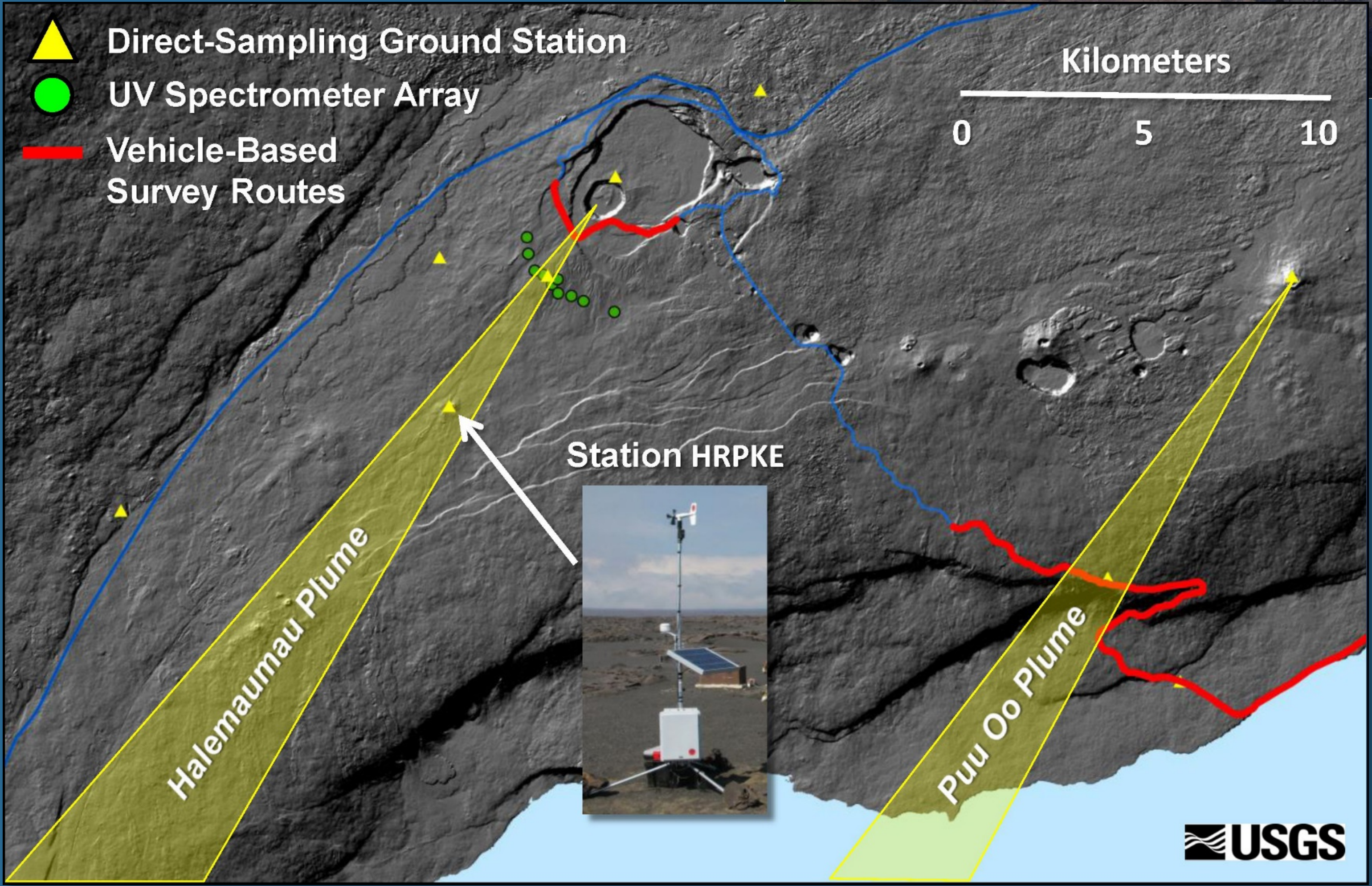
UH VMAP Project: Hourly Forecasts of $PM_{2.5}$

- Initialized by HVO Measurements of SO_2 Emission Rate
- Prediction Skill (Training) via Comparison with DOH Stations
- High Resolution of Model Domain (1 km Grid Spacing) + Sparse DOH Network = Most of the Forecast Field <u>Cannot be Validated</u>



USGS-Hawaii Volcano Observatory Gas Geochemistry Network

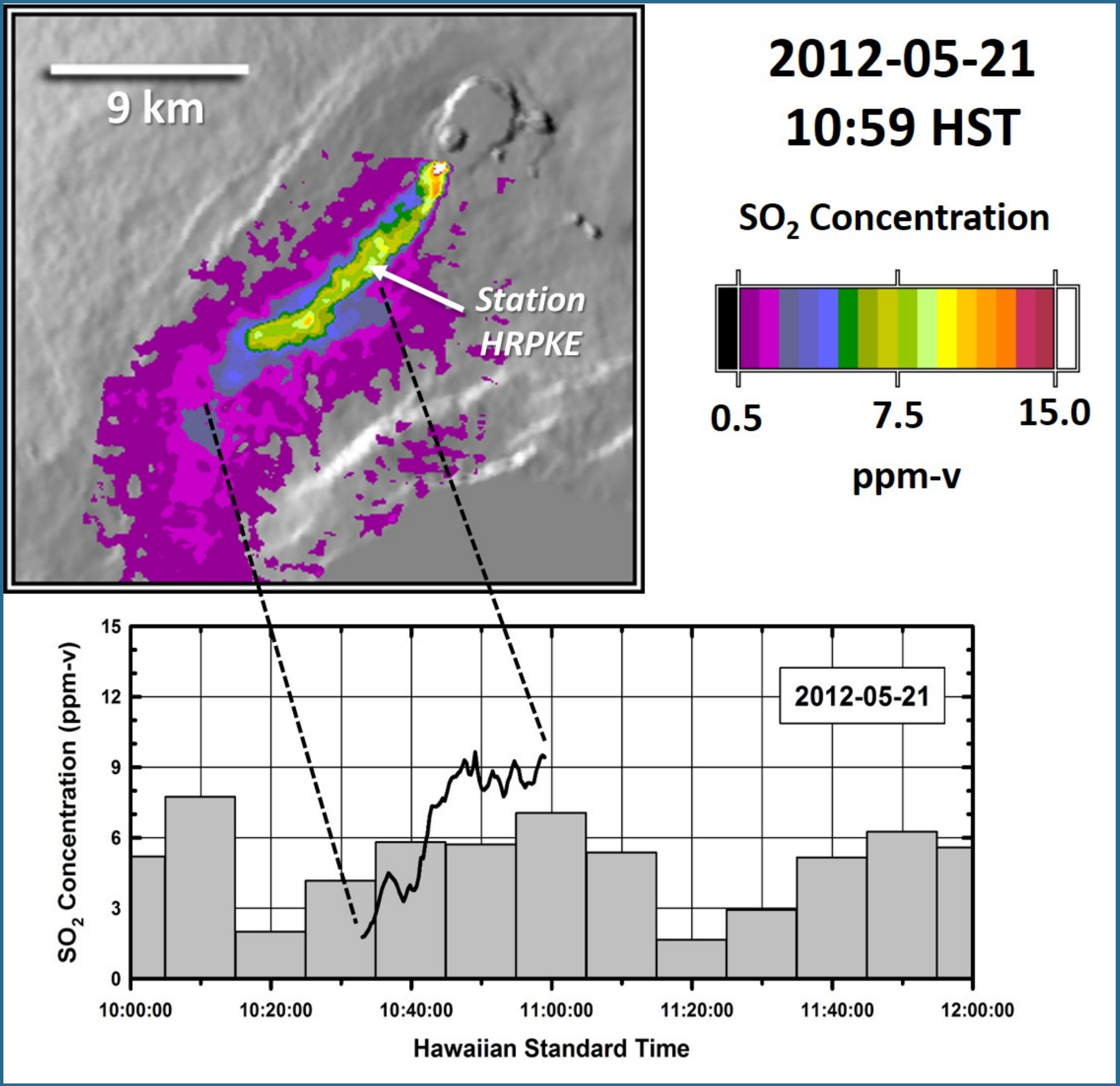
- Comprehensive Network of Direct-Sampling Ground Stations, UV Spectrometer Array, and Vehicle-Based Spectrometer Surveys
- SO_2 Emission Measurements Used to Initialize the Univ. Hawaii Vog Model



Plume Tracker Analysis of ASTER TIR Data

SO_2 Retrievals at High Spatial Resolution (90 m) Provide Important Input Parameters for Vog Model

- 2-D Maps of SO_2 Source is Superior to Line Source Model
- Longitudinal Profiles Record the Chemical Evolution of Plume - Constrain SO_2 Loss Rates
- Spatial Resolution of MODIS (1 km) and VIIRS (750 m) TIR Data are Finer than Vog Model (1 km)



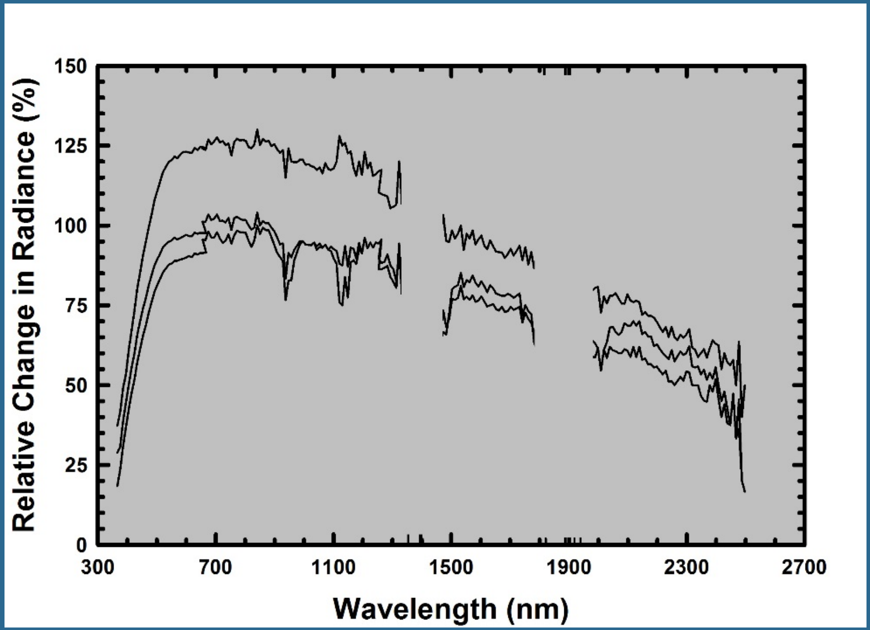
AVIRIS-Based Mapping of Aerosol Optical Depth

Compare Spectra of Surfaces Outside and Beneath Aerosol Plumes

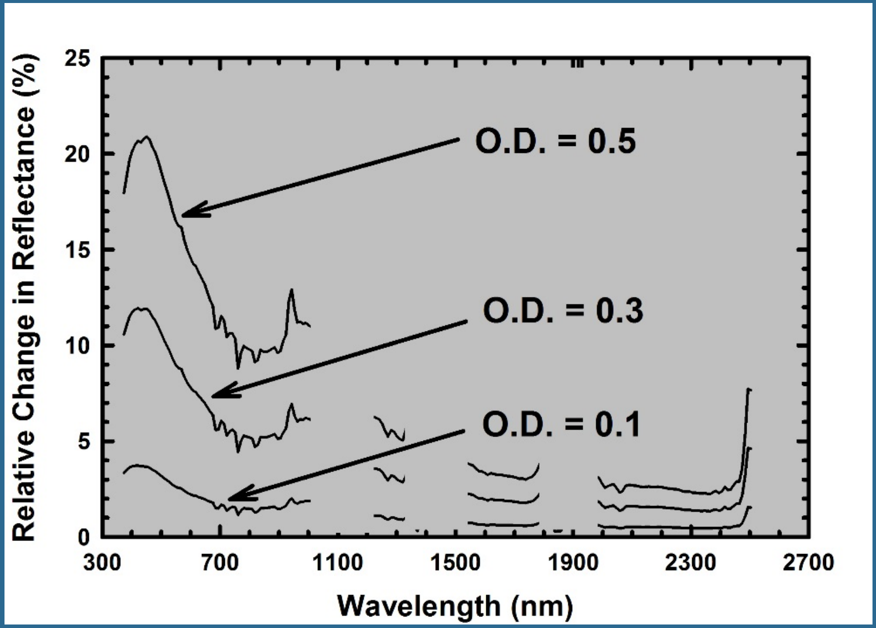
- Measure Increase in Radiance Due to Aerosol Scattering
- Standard Reflectance Product: Apparent Increases in Reflectance Attributed to Increase in AOD

Validate Retrievals with Sun Photometer Measurements

(a)



(b)



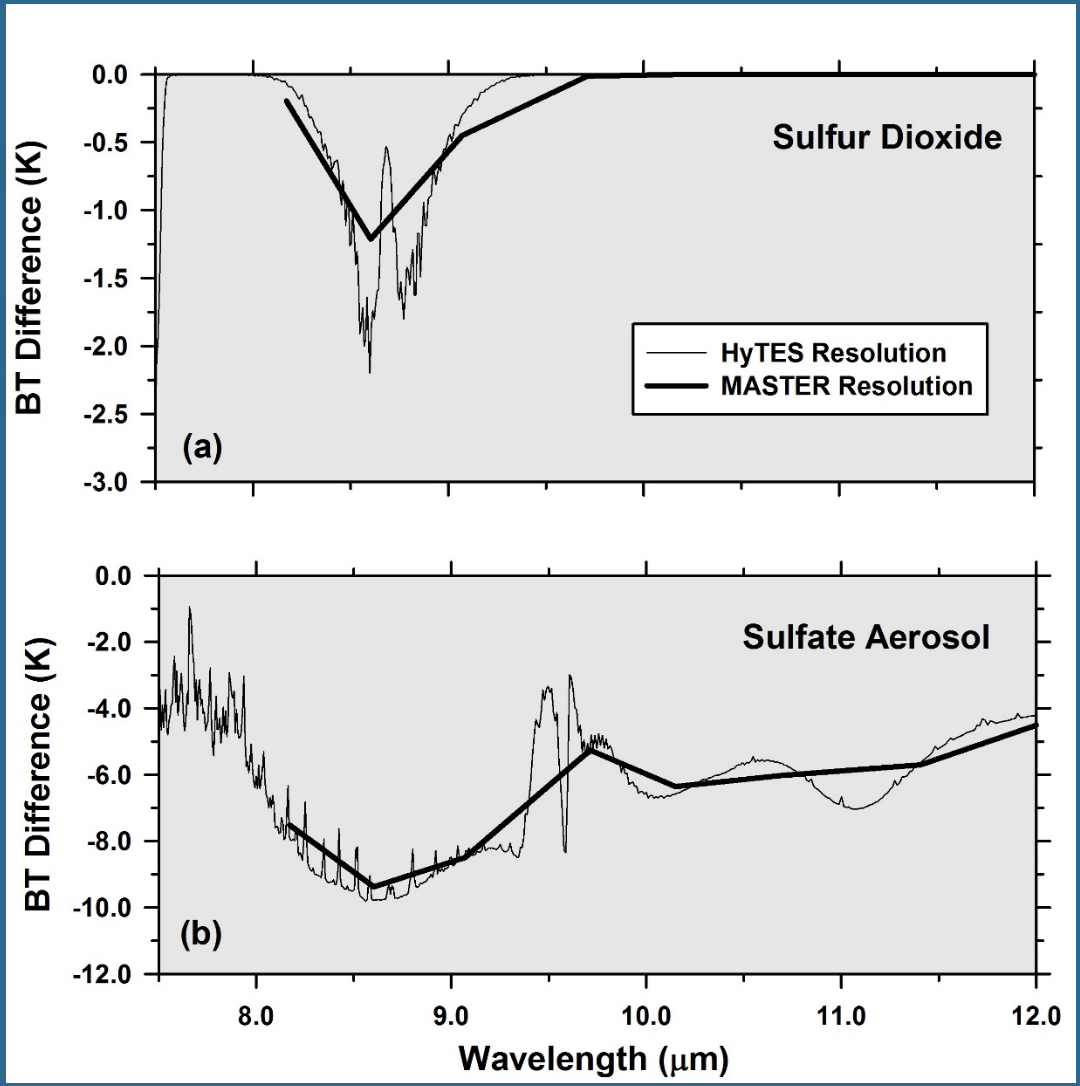
HyTES Deployment will Enable Unique Identification of SO_4 Aerosol

MASTER Resolution

- Spectra of SO_2 and SO_4 are Similar
- Broad Absorption Centered near 8.7 μm

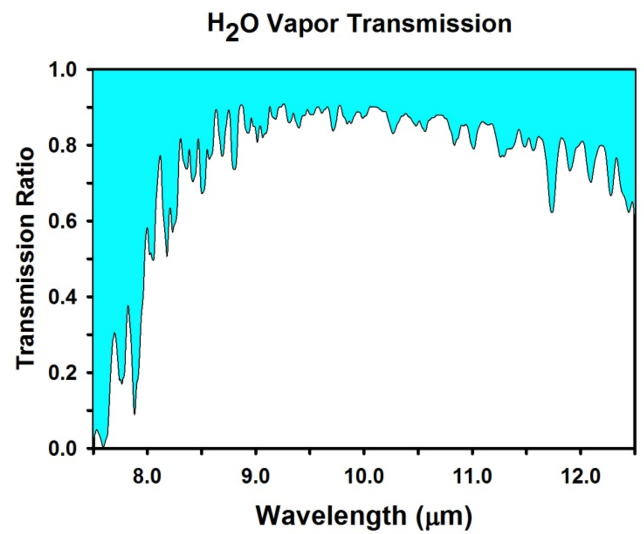
HyTES Resolution

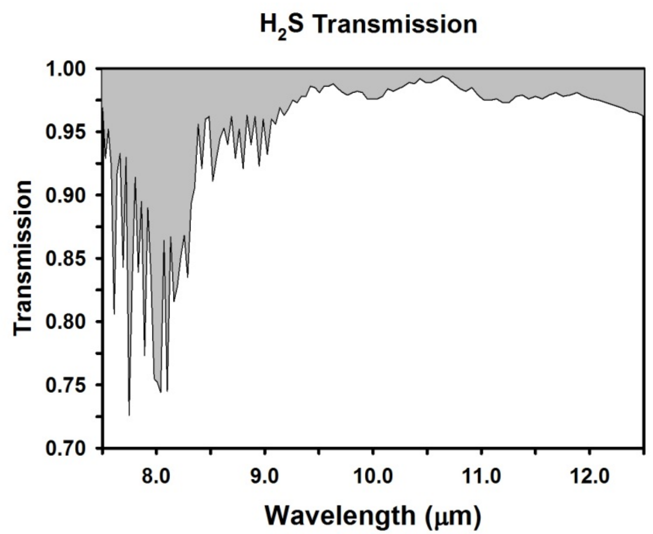
- Detect SO_4 Absorption Features at 10 and 11 μm

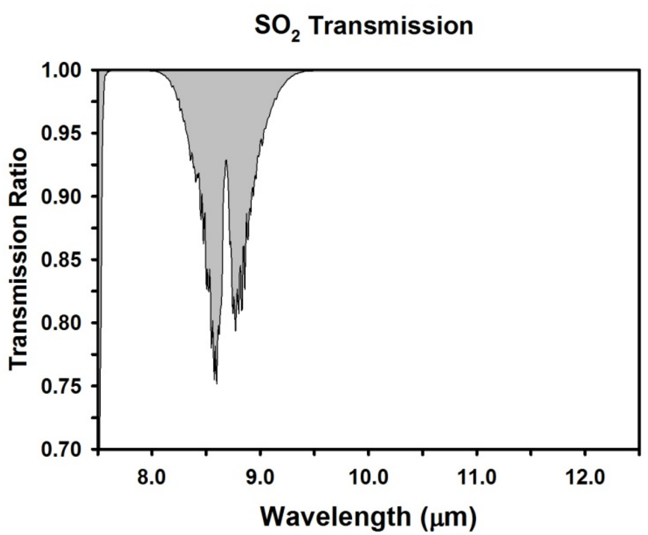


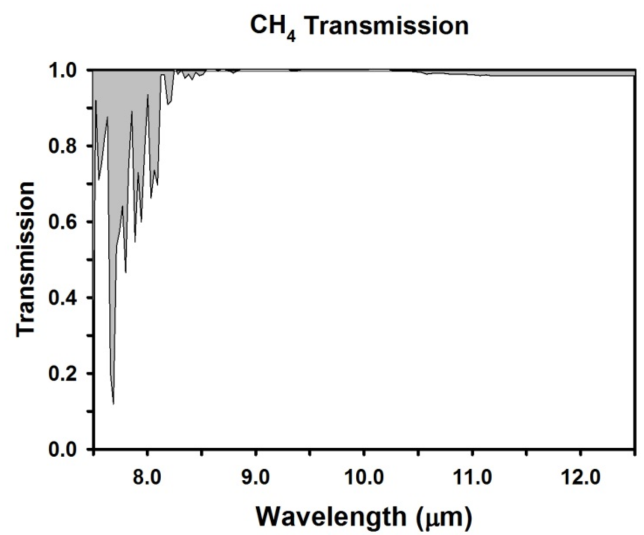
Evolution of Plume Tracker

- Hyperspectral Radiance Observations
- Extend Retrieval Procedures to “New” Gas Targets







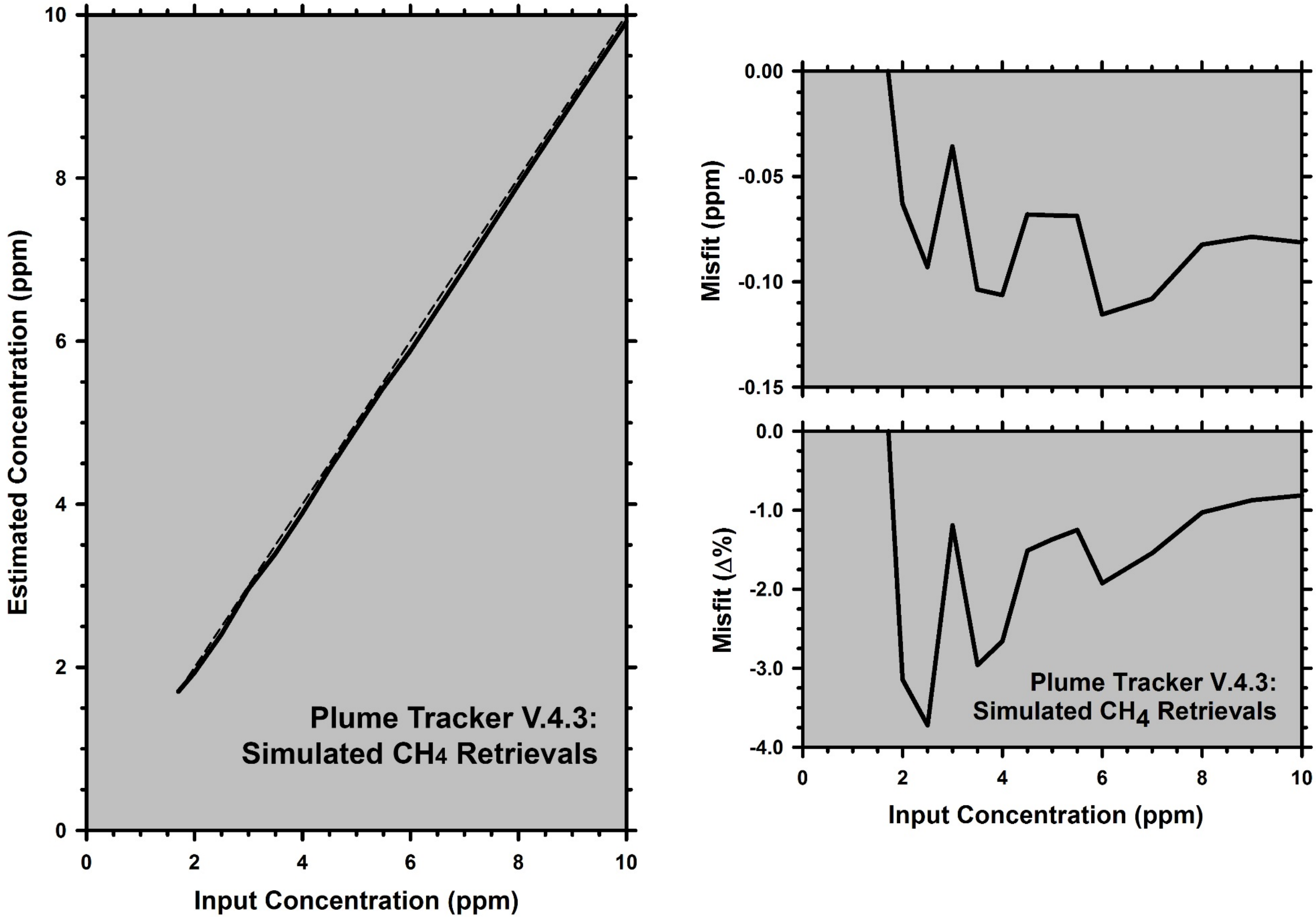


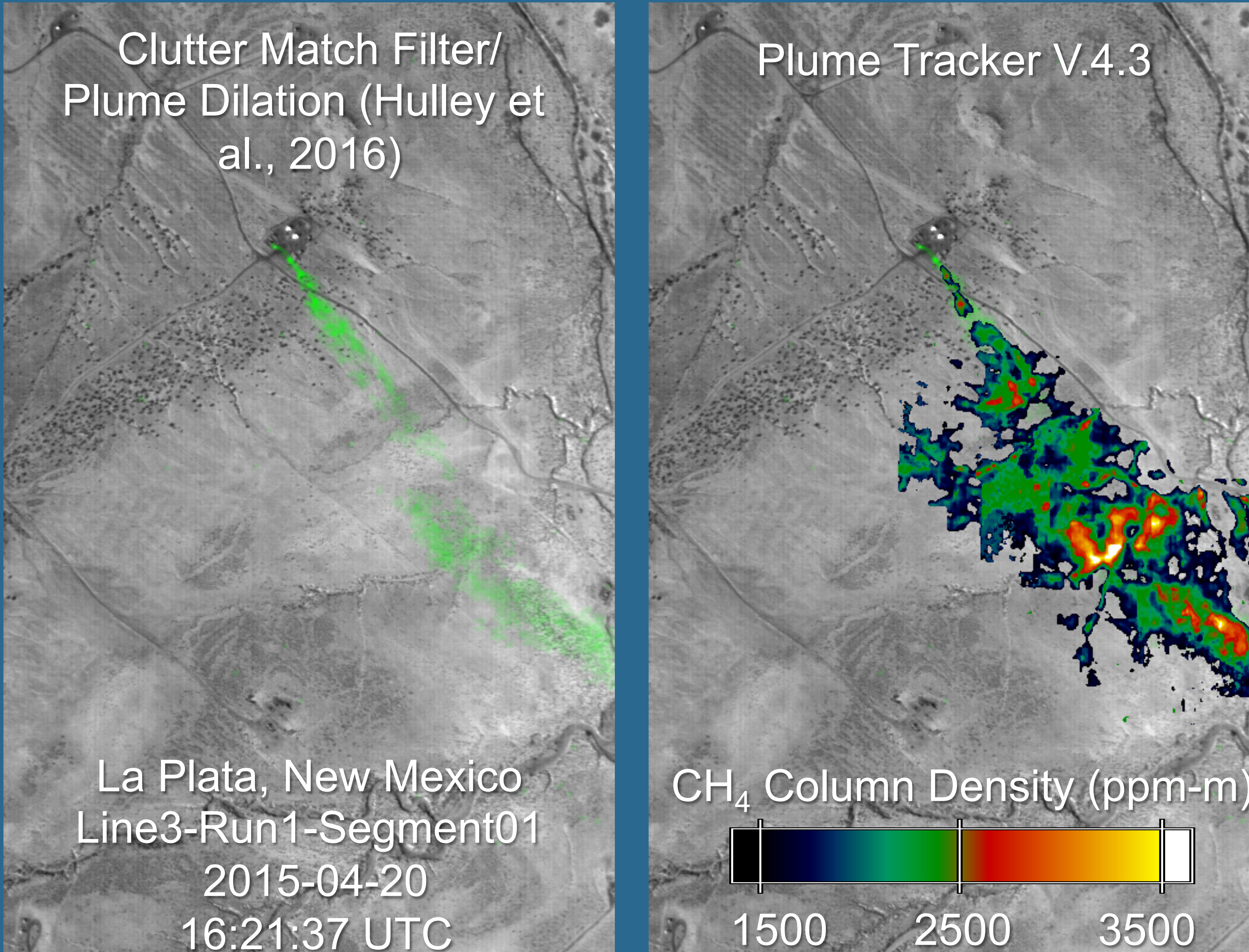
MODTRAN Output

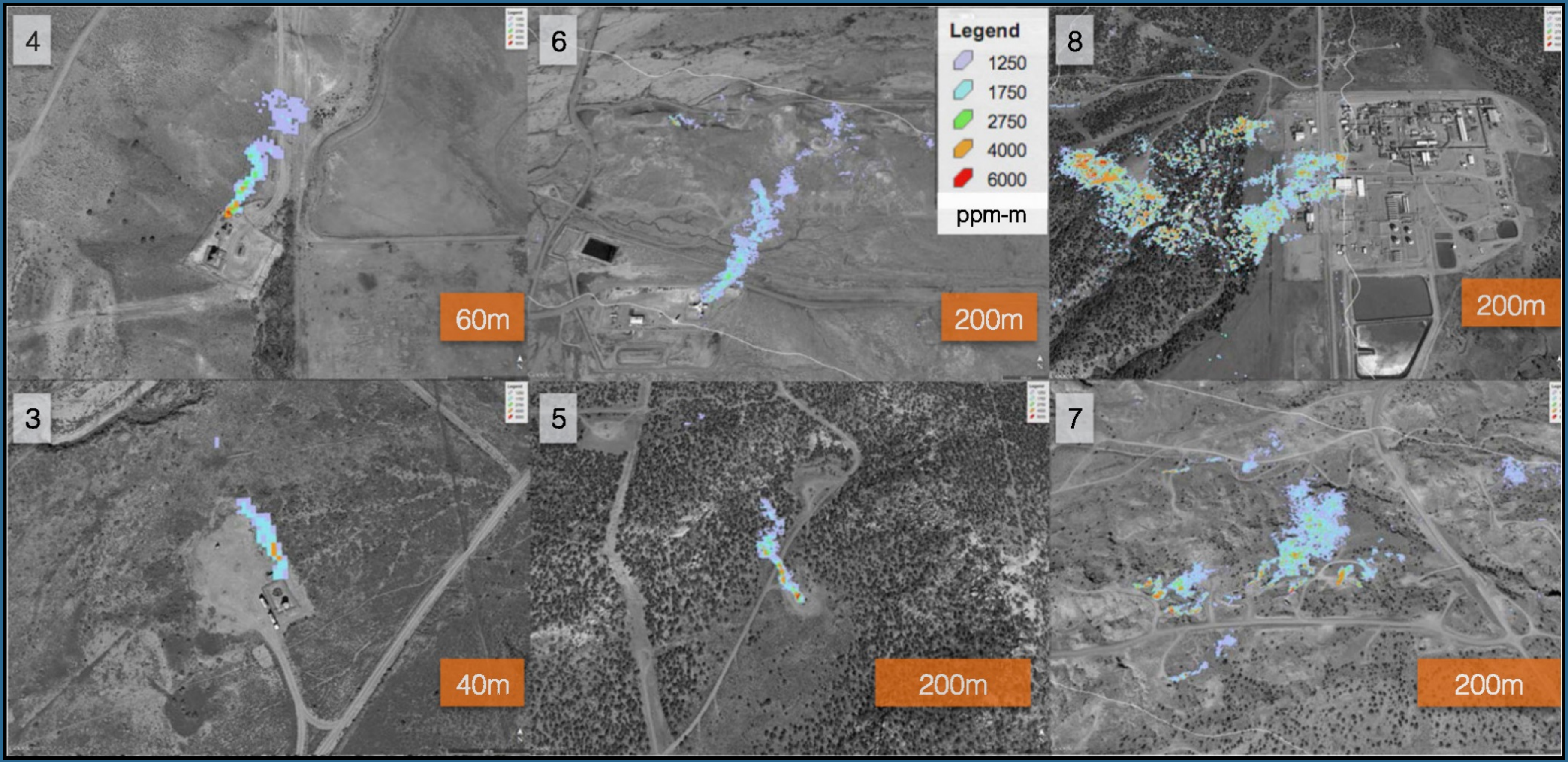
2 cm^{-1} ≈ HyTES Resolution

NIST Spectra

~ 4 cm^{-1}


Estimated Concentration (ppm)
Input Concentration (ppm)
0
2
4
6
8
10
Plume Tracker V.4.3:
Simulated CH4 Retrievals
Misfit (ppm)
0.00
-0.05
-0.10
-0.15
Misfit (Δ%)
0.0
-1.0
-2.0
-3.0
-4.0
Plume Tracker V.4.3:
Simulated CH4 Retrievals
Input Concentration (ppm)


Clutter Match Filter/
Plume Dilation (Hulley et
al., 2016)
La Plata, New Mexico
Line3-Run1-Segment01
2015-04-20
16:21:37 UTC
Plume Tracker V.4.3
CH_4 Column Density (ppm-m)
1500
2500
3500



AVIRIS-NG CH_4 Retrievals from Four Corners Survey
(Modified from Frankenberg et al., 2016)

Local Gas Plume in Plume Tracker 5

- Eliminates approximation of plume gas as semi-infinite layer
- Upgrades thermal scatter model
  - Replaces 2-stream Isaacs with N-stream DISORT
  - No added computational time when N is set to 2
- Allows ambient concentrations to be retained
- Decouples plume profile from atmospheric layering
  - Introduces option to define detailed plume profile when available
- Current implementation allows modeling of all HITRAN line compilation species (key species highlighted in red)

1=H_2O, 2=CO_2, 3=O_3, 4=N_2O, 5=CO, 6=**CH_4**, 7=O_2, 8=NO, 9=**SO_2**, 10=NO_2, 11=**NH_3**, 12=HNO_3, 13=OH, 14=HF, 15=HCl, 19=OCS, 20=H_2CO, 22=N_2, 23=HCN, 24=CH_3Cl, 25=H_2O_2, 26=C_2H_2, 27=C_2H_6, 28=PH_3, 29=COF_2, 31=**H_2S**, 32=HCOOH, 33=HO_2, 36=NO+, 37=HOBr, 38=C2H4, 39=CH_3OH, 40=CH_3Br, 41=CH_3CN, 43=C_4H_2, 44=HC_3N, 45=H_2, 46=CS, 47=SO_3

Thank You for
Your Attention.