The Application of SBG-Class Observations to Monitor Volcanic Gas and Aerosol Plumes in Hawaii

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HyspIRI/SBG 2018 Science Workshop

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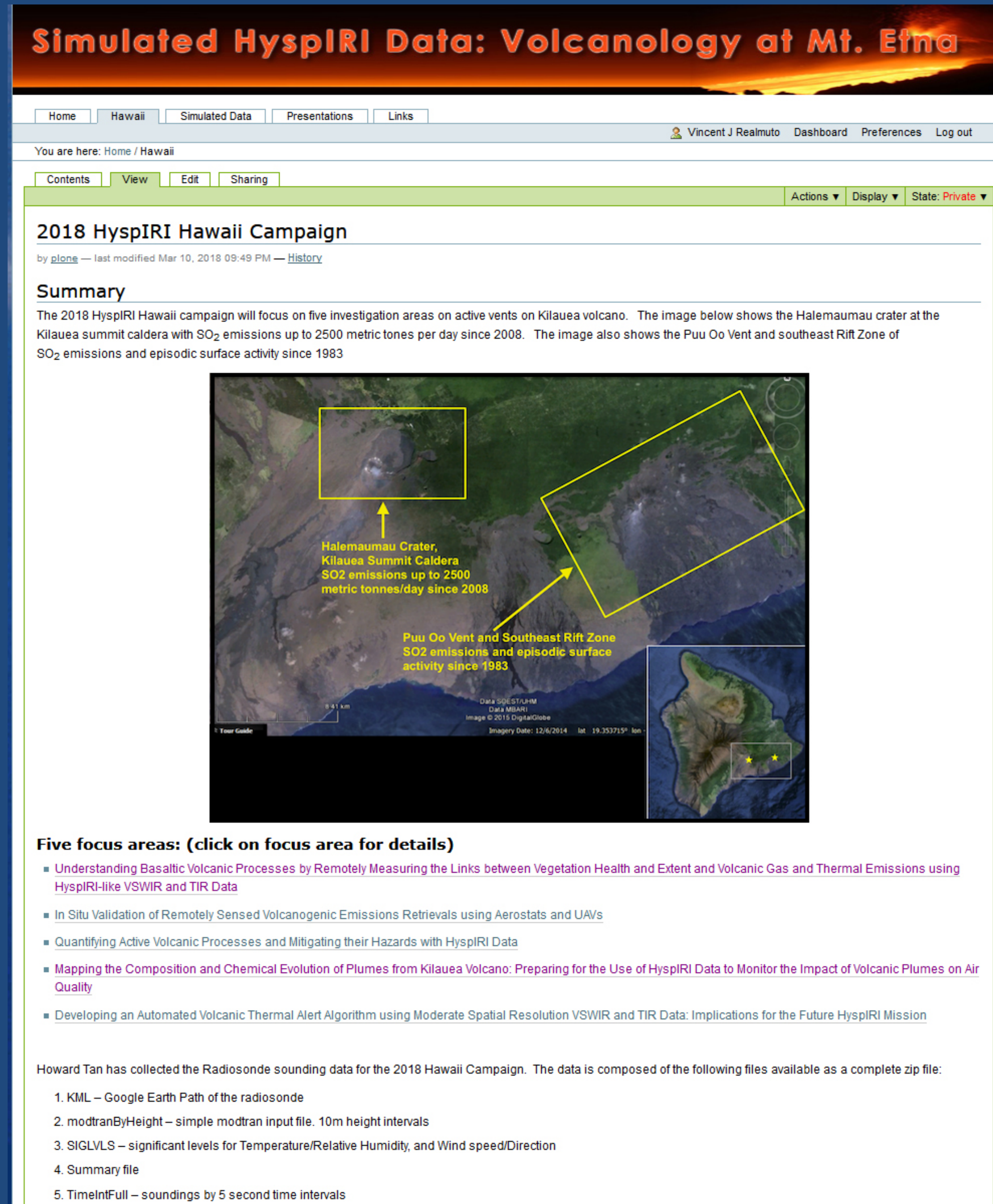
HyspIRI-Hawaii Volcanology Website

- https://volcanology-hyspiri.jpl.nasa.gov
- Links to Archived AVIRIS, MASTER, and HyTES Data
- Repository for High-Level Data Products (e.g., radiosonde)
- Links to Current PI Investigations



Simulated HyspIRI Data: Volcanology at Mt. Etna

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2018 HyspIRI Hawaii Campaign

by plone — last modified Mar 10, 2018 09:49 PM — History

Summary

The 2018 HyspIRI Hawaii campaign will focus on five investigation areas on active vents on Kilauea volcano. The image below shows the Halemaumau crater at the Kilauea summit caldera with SO_2 emissions up to 2500 metric tones per day since 2008. The image also shows the Puu Oo Vent and southeast Rift Zone of SO_2 emissions and episodic surface activity since 1983

Five focus areas: (click on focus area for details)

- Understanding Basaltic Volcanic Processes by Remotely Measuring the Links between Vegetation Health and Extent and Volcanic Gas and Thermal Emissions using HyspIRI-like VSWIR and TIR Data
- In Situ Validation of Remotely Sensed Volcanogenic Emissions Retrievals using Aerostats and UAVs
- Quantifying Active Volcanic Processes and Mitigating their Hazards with HyspIRI Data
- Mapping the Composition and Chemical Evolution of Plumes from Kilauea Volcano: Preparing for the Use of HyspIRI Data to Monitor the Impact of Volcanic Plumes on Air Quality
- Developing an Automated Volcanic Thermal Alert Algorithm using Moderate Spatial Resolution VSWIR and TIR Data: Implications for the Future HyspIRI Mission

Howard Tan has collected the Radiosonde sounding data for the 2018 Hawaii Campaign. The data is composed of the following files available as a complete zip file:

1. KML – Google Earth Path of the radiosonde
2. modtranByHeight – simple modtran input file. 10m height intervals
3. SIGLVLS – significant levels for Temperature/Relative Humidity, and Wind speed/Direction
4. Summary file
5. TimeIntFull – soundings by 5 second time intervals

Kīlauea Airborne Science Campaigns Jan – March 2017, Jan – Feb 2018

MODIS/ASTER Airborne Simulator (MASTER) TIR Observations to Map SO_2 Emissions at Summit of Kīlauea

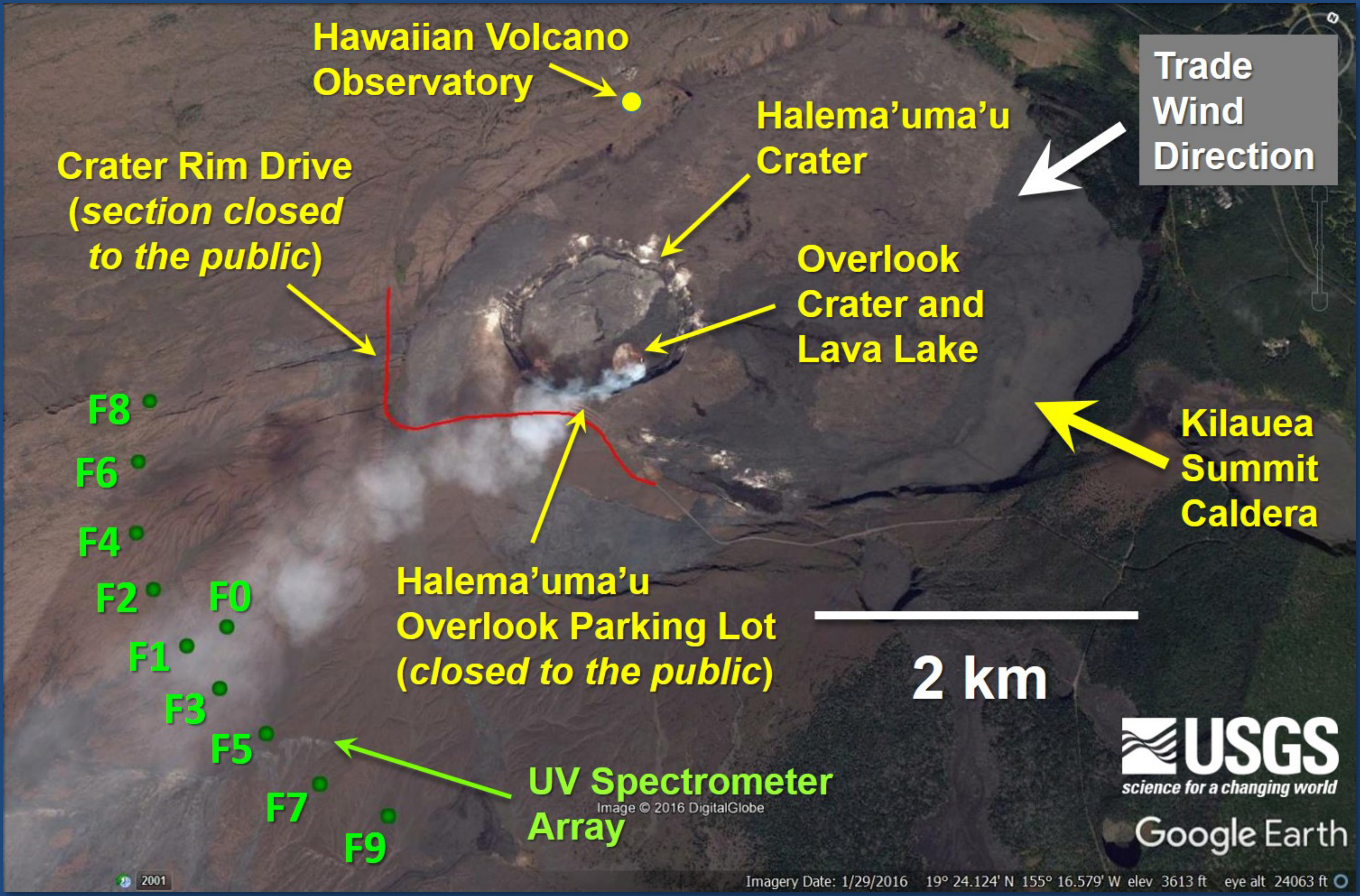
Airborne Visible-Infrared Imaging Spectrometer (AVIRIS) VSWIR Observations to Map Changes in Optical Depth Related to SO_4 Aerosols

In 2018 - Hyperspectral Thermal Emission Spectrometer (HyTES) to Map SO_2 and SO_4 Aerosols

Cockpit of ER-2

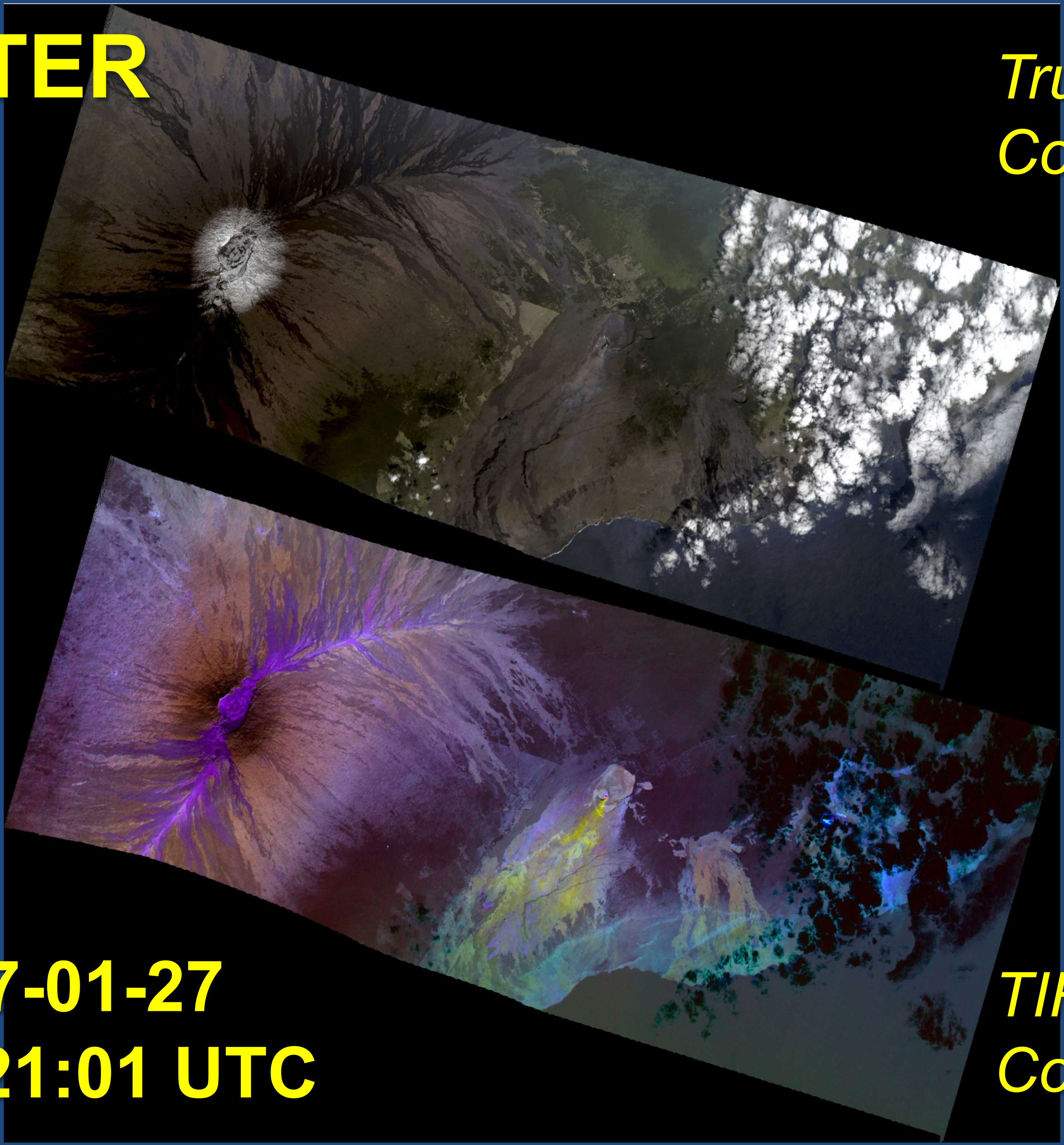
Photo Courtesy of Stu Broce

Kīlauea Summit: Location Map



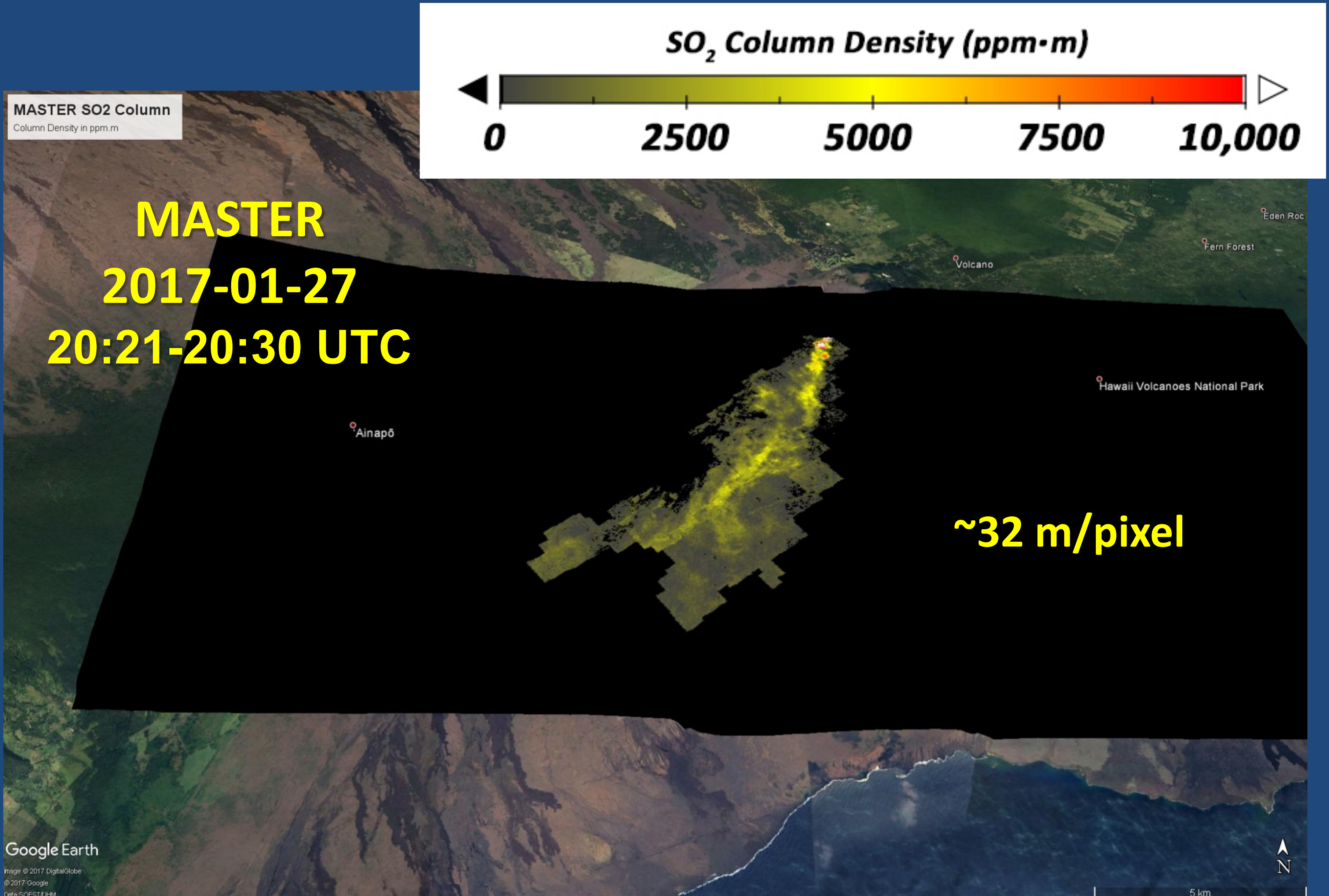
MASTER

True-Color Composite



TIR Composite

2017-01-27
20:54-21:01 UTC



SO2 Column Density (ppm·m)
0
2500
5000
7500
10,000
MASTER SO2 Column
Column Density in ppm.m
MASTER
2017-01-27
20:21-20:30 UTC
Volcano
Fern Forest
Eden Roc
Hawaii Volcanoes National Park
Ainapō
~32 m/pixel
Google Earth
Image © 2017 DigitalGlobe
© 2017 Google
Data SOEST/UHM
N
5 km

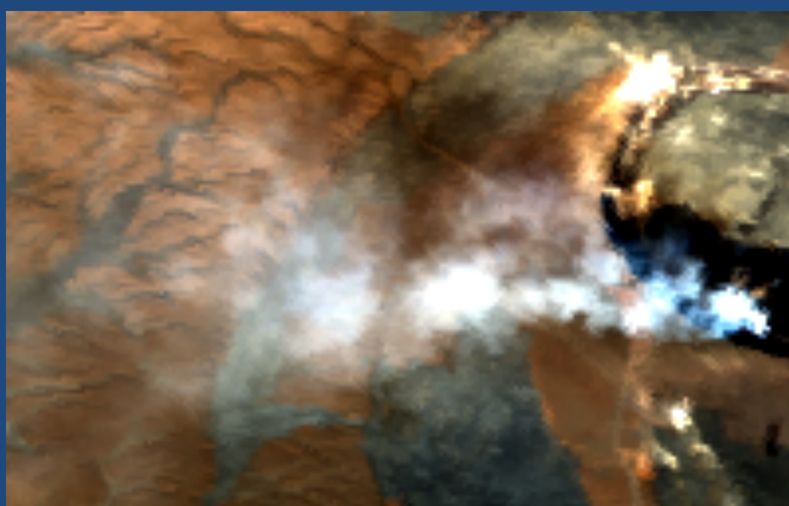
5 km

Optimal Estimation for Iterative Fitting of Surface and Atmospheric Spectra

Combined Parametric Models for Surface, Atmosphere, and Instrument Properties

Makes optimal, weighted use of *a priori* knowledge of instrument and domain

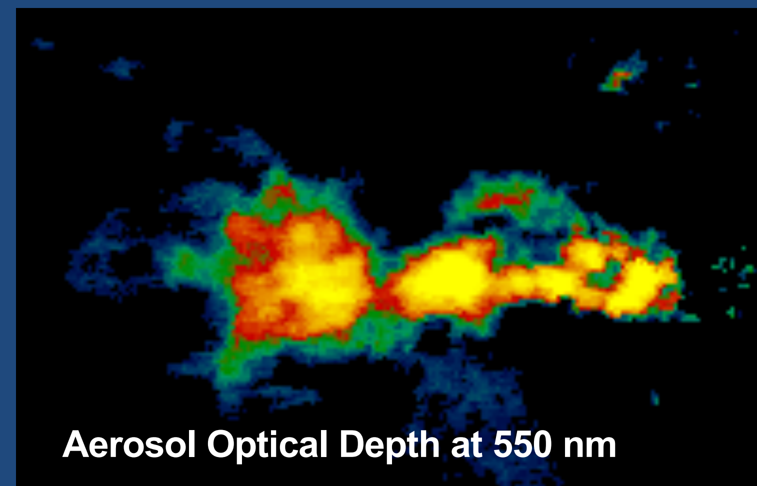
- Tropical Atmospheric Temperature/Humidity Profiles
- Scattering Aerosol Model
- Surface Reflectance Sampled In-Scene

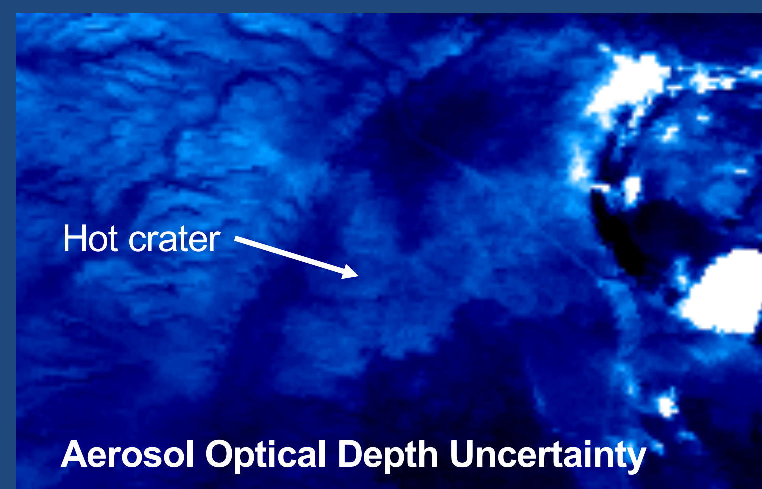


AVIRIS-C f170127t01p00r16 (subset, visible bands)

Combined estimate of H_2O vapor, AOD, surface reflectance and temperature

Down-wind Changes in AOD are Proxies for Formation of SO_4 Aerosols





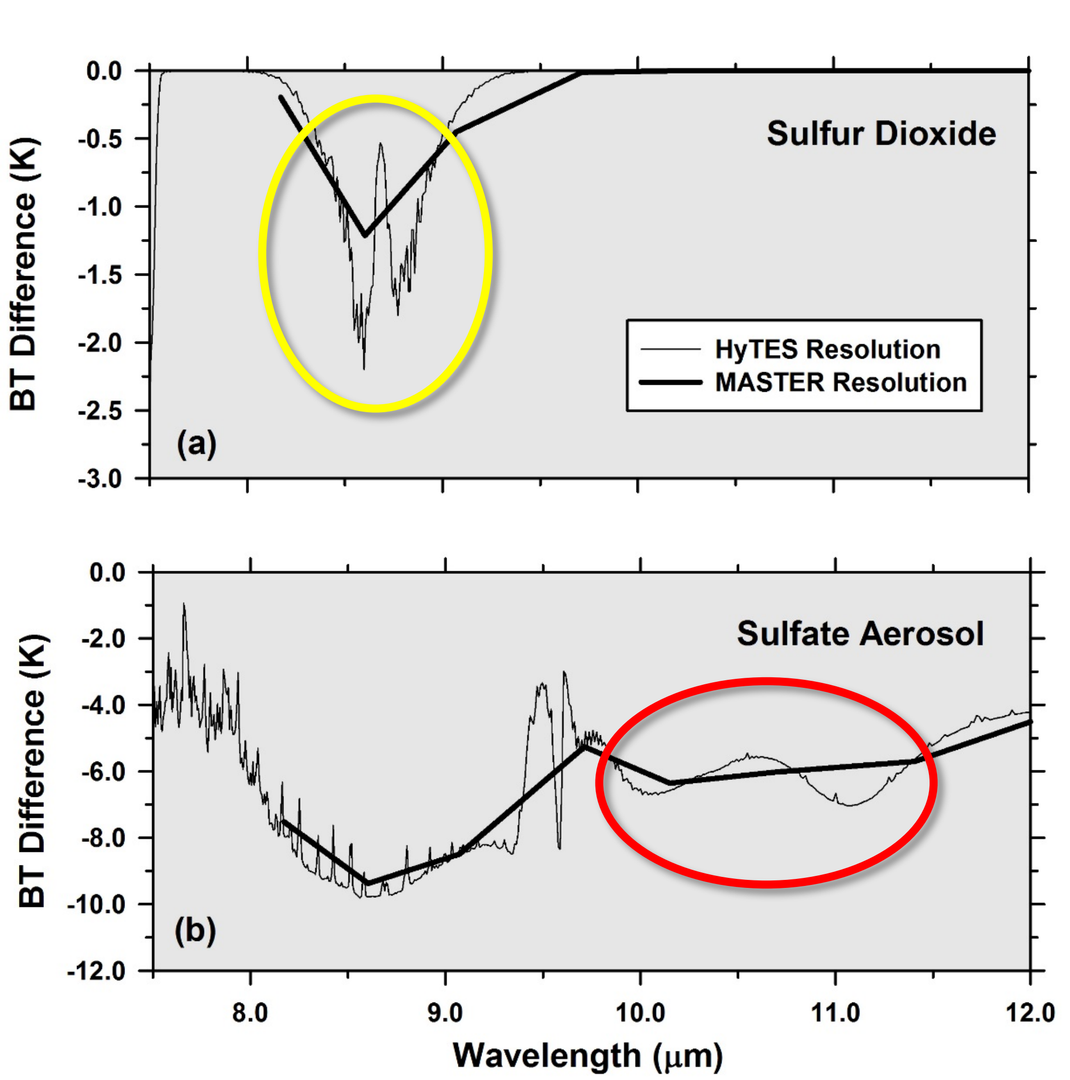
HyTES Deployment in 2018 Enables Unique Identification of Plume Components

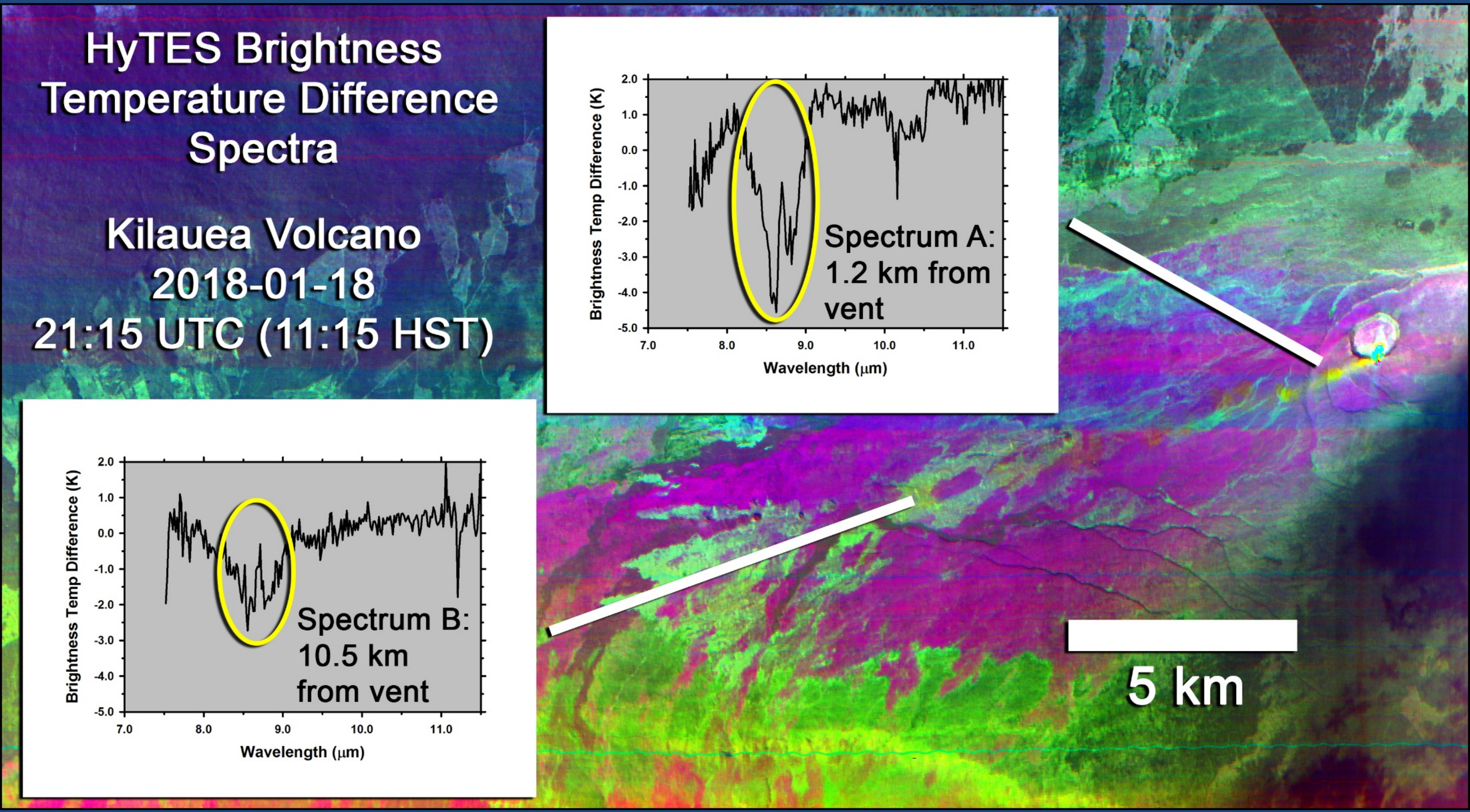
MASTER Resolution

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

HyTES Resolution

- Resolves “Doublet” in SO_2 Spectrum
- Detect SO_4 Absorption Features at 10 and 11 μm

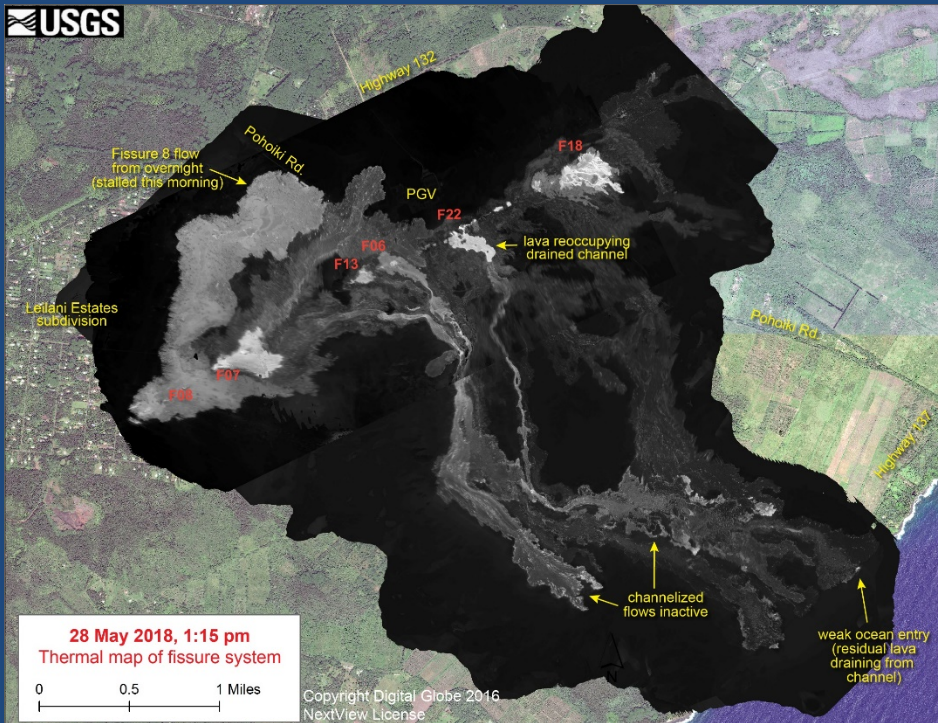




- Imaging Spectroscopy: Fine spectral resolution of HyTES (0.02 μm) enables unique identification of SO_2
- Spectrum A indicates stronger SO_2 absorption than Spectrum B
- Absence of SO_4 Spectral Features - Decrease in SO_2 result of dispersion, rather then conversion of SO_2 gas to SO_4 aerosols (conversion rate of ~8% /hr)

Summit - Lower East Rift Zone (LERZ) Eruption

- Fissures open in Leilani Estates on May 3
- SO_2 emission rates in excess of 15,000 t/d
- Ash eruptions at Summit began May 15
- Ash plumes heights up to 10 km




Published 17 May 2018, Getty Images


Published 16 May 2018, Vice News

500 + meters of subsidence at Summit

Towards an Automated Implementation of TIR-Based Retrieval Procedures for Terra, Aqua, SNPP, NOAA-20, ECOSTRESS, and SBG…

Plume Tracker Interactive Analysis Tool

- Radiative Transfer (RT) - Based Retrieval Procedures for Surface Temperature and Gas Concentration
- RT Processing is Computationally-Expensive
- Focus Computations on User-Defined Regions-of-Interest

Automated Procedures Should Integrate Plume Detection with Retrieval Algorithms

Surface Emissivity is a Confounding Factor for SO_2 Detection

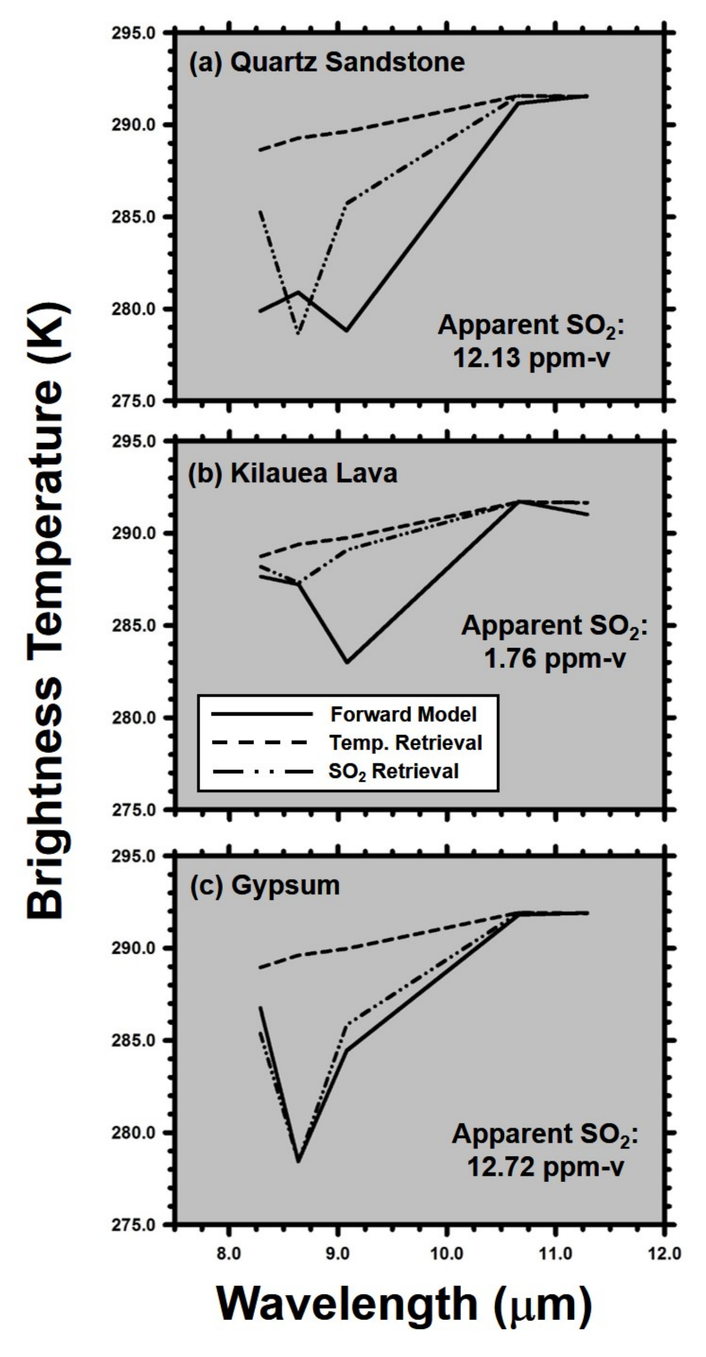
Solid Lines: Forward model spectra generated for SO_2-free atmospheric profiles.
Surface compositions of (a) quartz sandstone, (b) pahoehoe lava from Kilauea Volcano, and (c) gypsum

Estimate Surface Temperature and SO_2 Concentration Assuming ε = 1 (Blackbody)

Retrieval Algorithm has Two Steps:
Step 1 (Dashed Lines): Temperature Retrieval Finds the Lowest Surface Temperature with the Constraint that Model Spectra ≥ Observed Spectra

Step 2 (Broken Lines): SO_2 Retrieval based on Estimated Surface Temperature.
Retrieval Attempts to "Fit" Emissivity Minima by Adding SO_2
The false detections are largest for (a) quartz sandstone and (c) gypsum, due to the overlap between emissivity minima and SO_2 absorption (8 – 9.5 μm)

As a rule, the assumption of blackbody emissivity for exposed (non-vegetated) surfaces will lead to false detections of SO_2

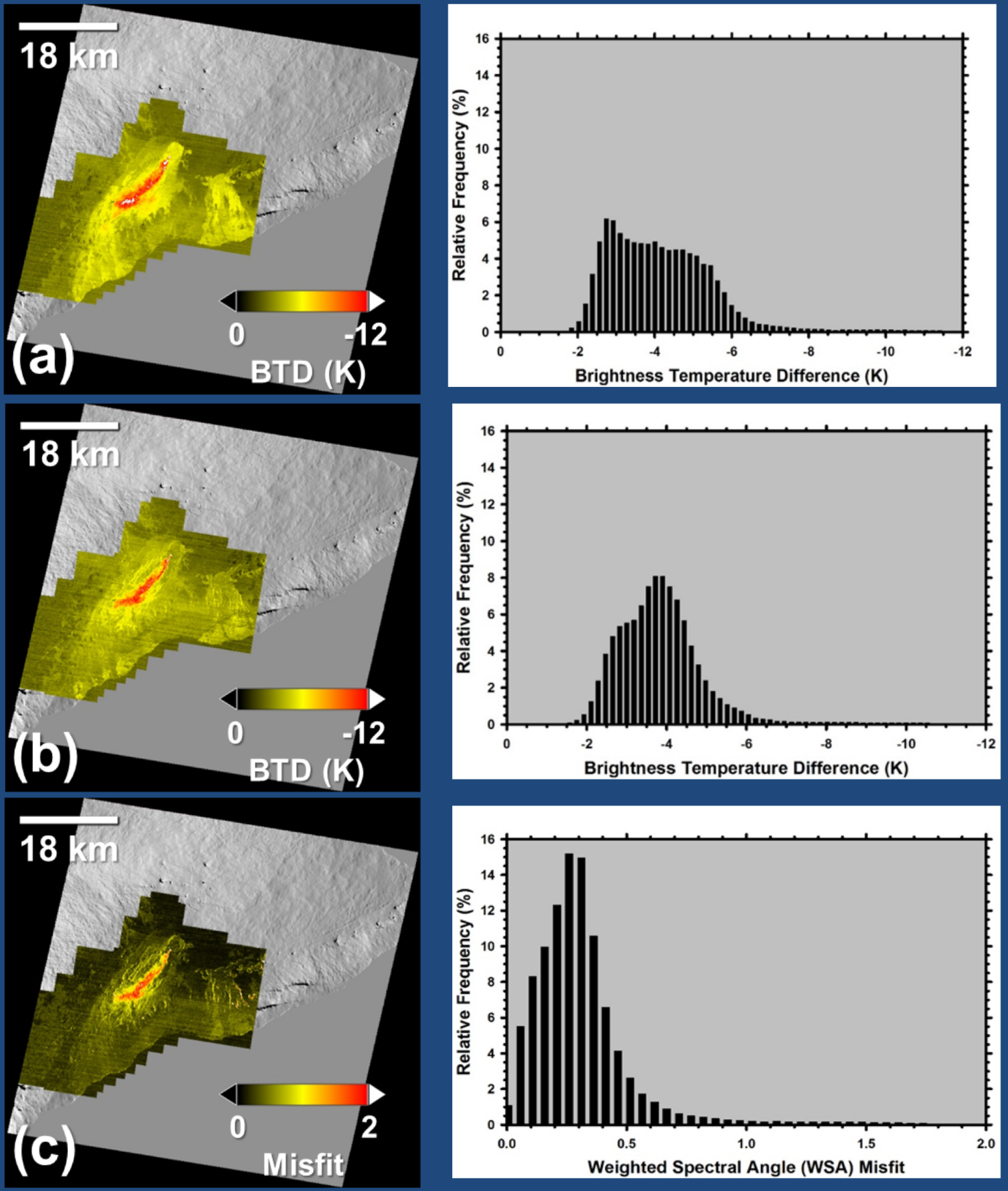


Plume Detections Improve with Corrections for Surface Emissivity and Atmospheric Effects

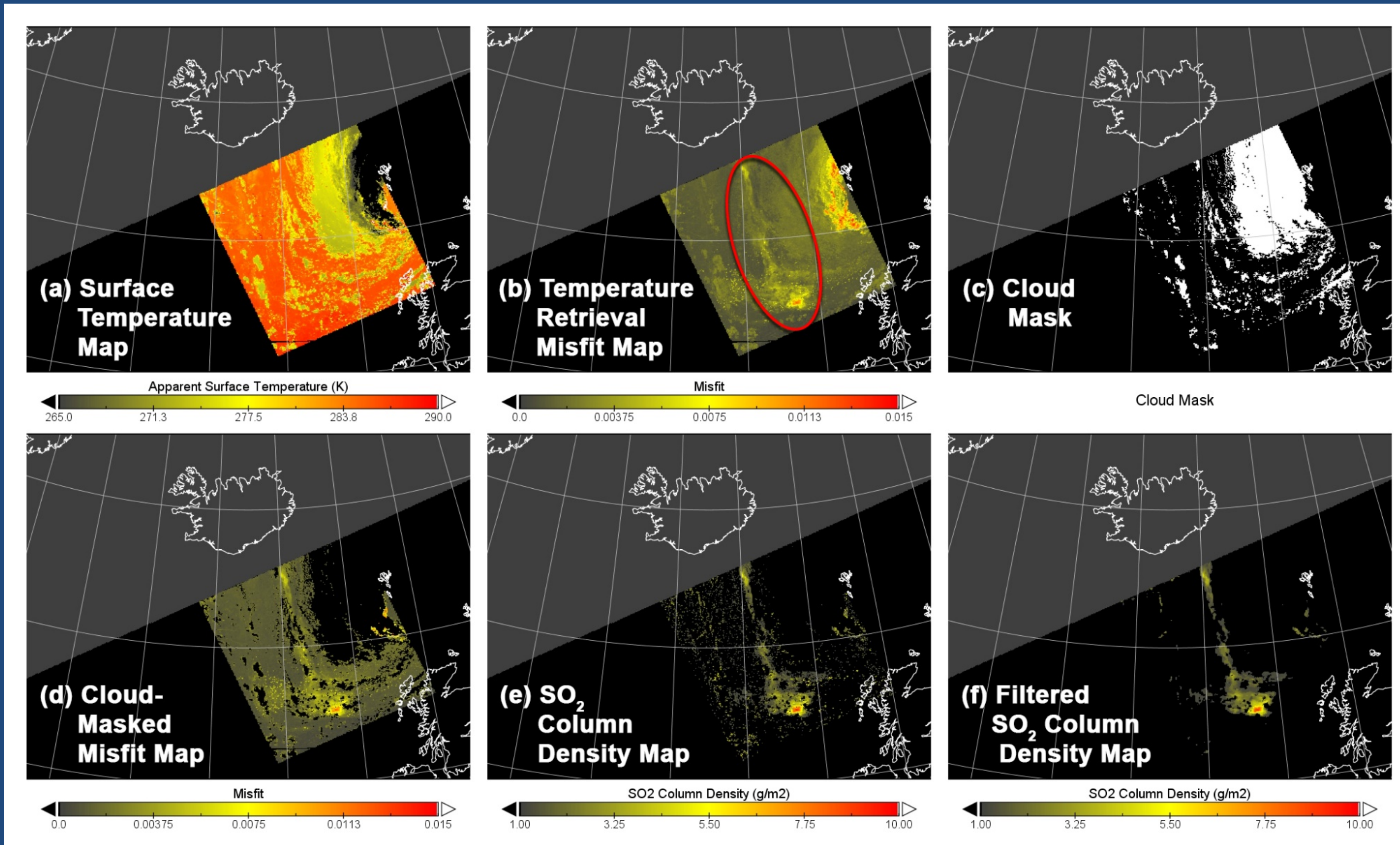
(a) Brightness Temperature Difference (BTD) in ASTER Channel 11.
Plume marked by BTD of -12 K or larger
Emissivity effects result in BTD as large as -6 K outside of the plume.
The histogram shows an offset of -2 K.

(b) BTD following a correction for surface emissivity.
Emissivity effects suppressed, but the BTD remains non-zero outside of the plume.
The histogram shows an offset of -2 K.

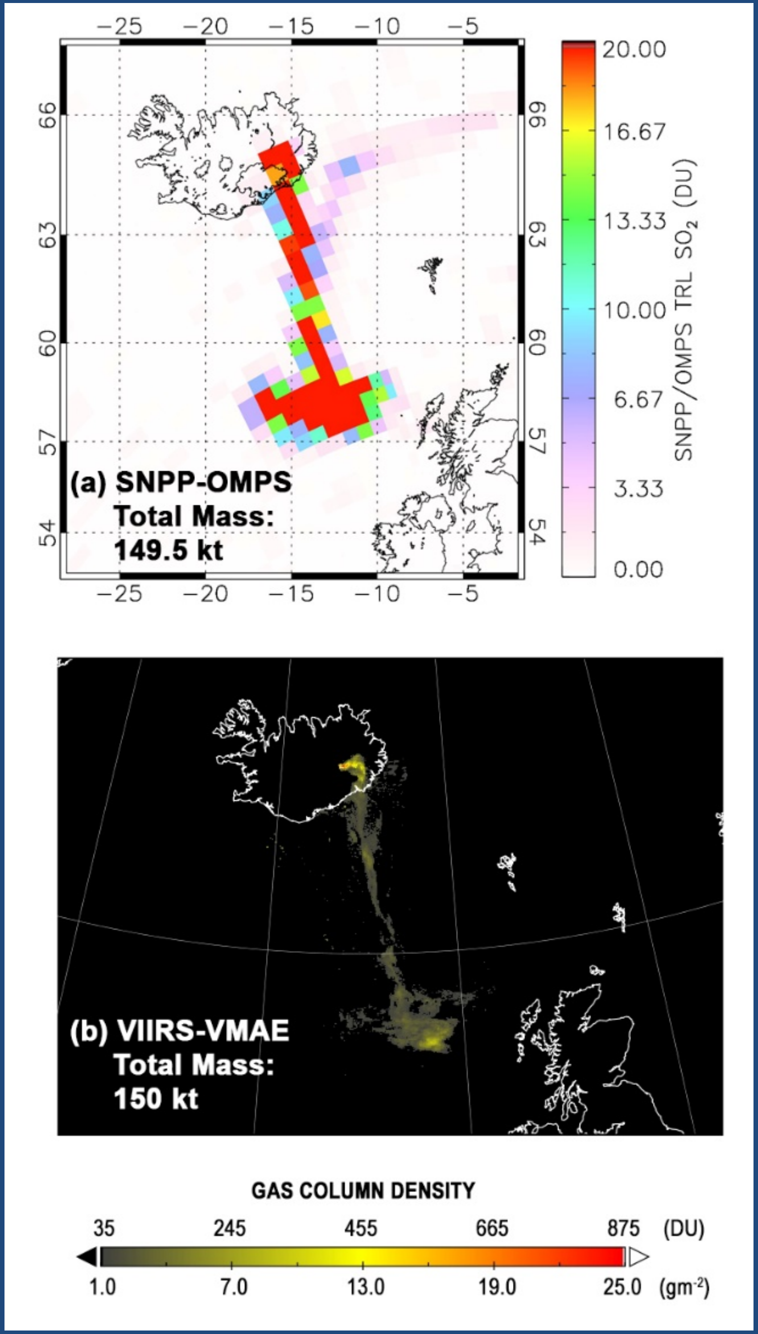
(c) Misfit map resulting from retrievals of surface temperature.
Retrievals take emissivity and atmospheric effects into account.
Plume is delineated by the highest misfit (≥ 1.0), and the misfit approaches zero outside of the plume.
The histogram shows no offset, and over 90% of the misfit values are less than 0.5.



Bardarbunga Volcano (Iceland), 5 September 2014



a) Surface temperature estimation does not consider volcanic plumes or meteorological (met) clouds
b) Misfit map shows the locations of plumes (red oval) and met clouds
c) Met clouds are identified by comparing surface temperature with air temperature at plume altitude
d) Combination of cloud mask and misfit map improves the discrimination of volcanic plumes
e) Estimation of SO_2 column density is confined to the locations, or pixels, identified by the masked misfit map
f) SO_2 map is filtered to minimize the “holes” corresponding to the locations of met clouds.



New Retrieval Procedure Successful

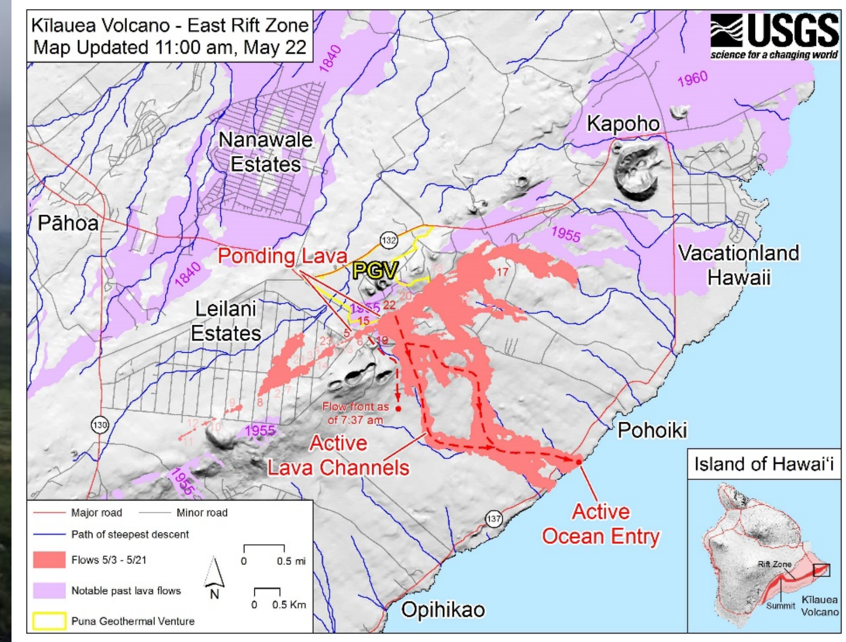
- Moderate to High SO_2 Concentrations
- Plume Altitude > 3 km ASL
- Arctic Atmospheric Environment (Atmosphere is Cool and Dry)

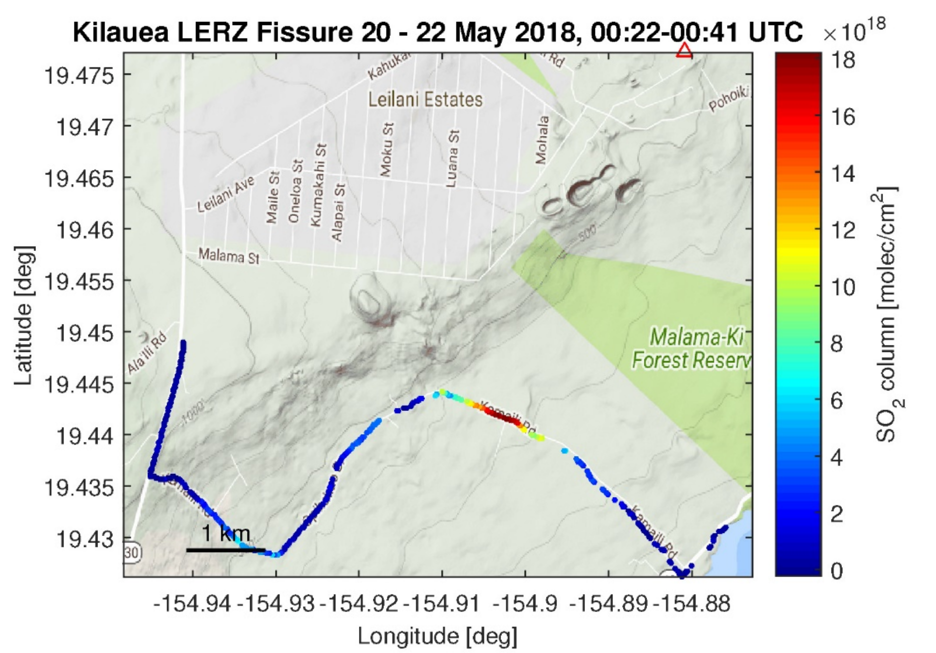
What About Low-lying Plumes in Tropical Environments?

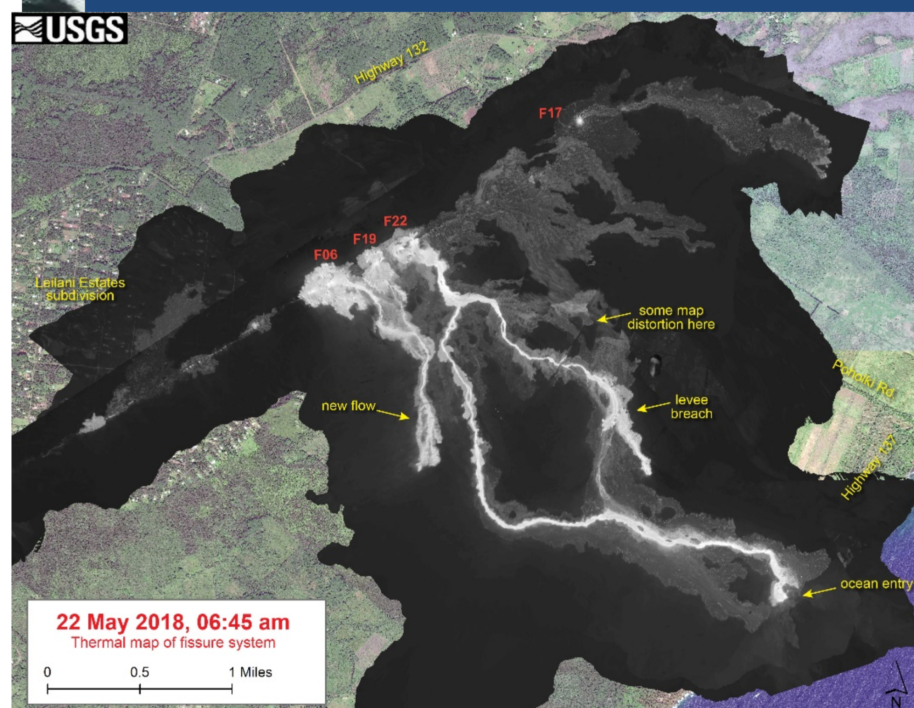
OMPS (UV) and VIIRS (TIR) Collocated on S-NPP and NOAA-20 Platforms

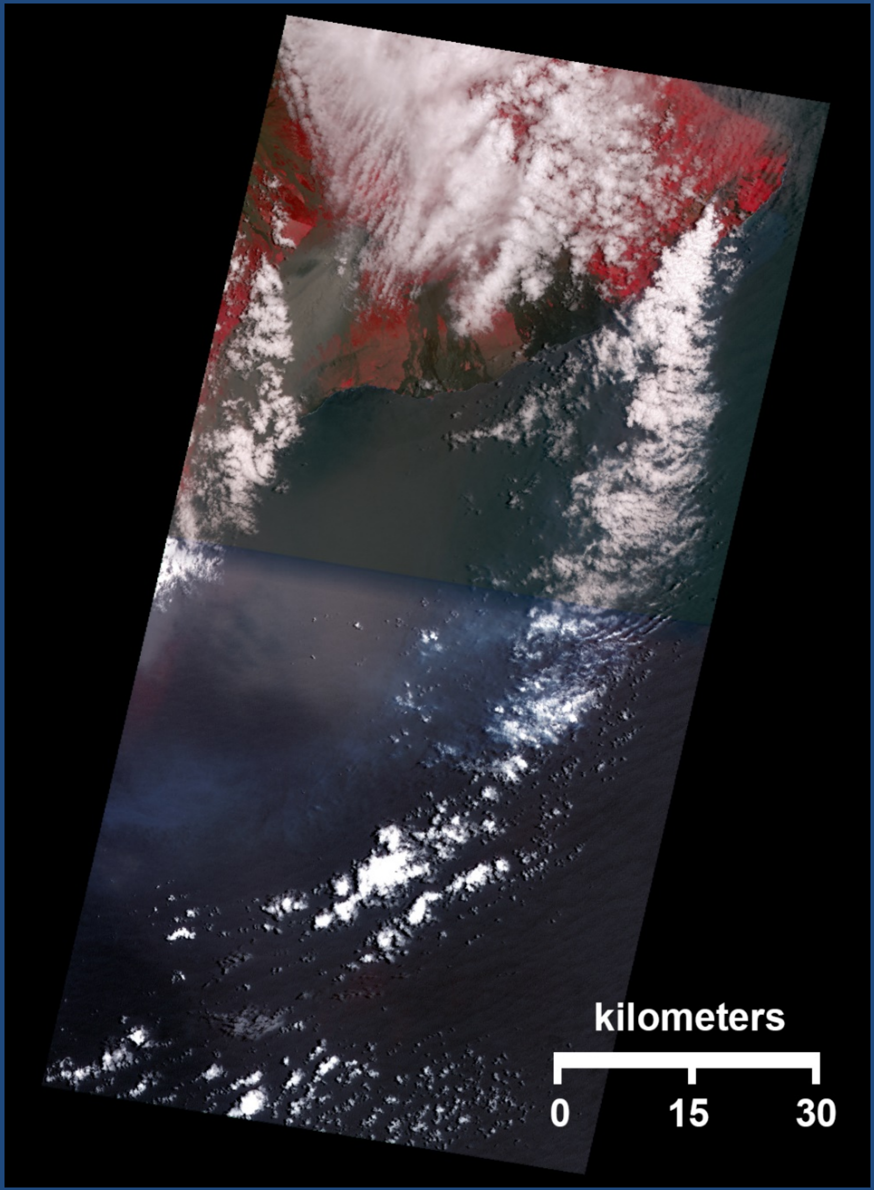
Contemporaneous Retrievals of Total SO_2 Mass from S-NPP are in Excellent Agreement (149.5 vs. 150 kilotonnes)

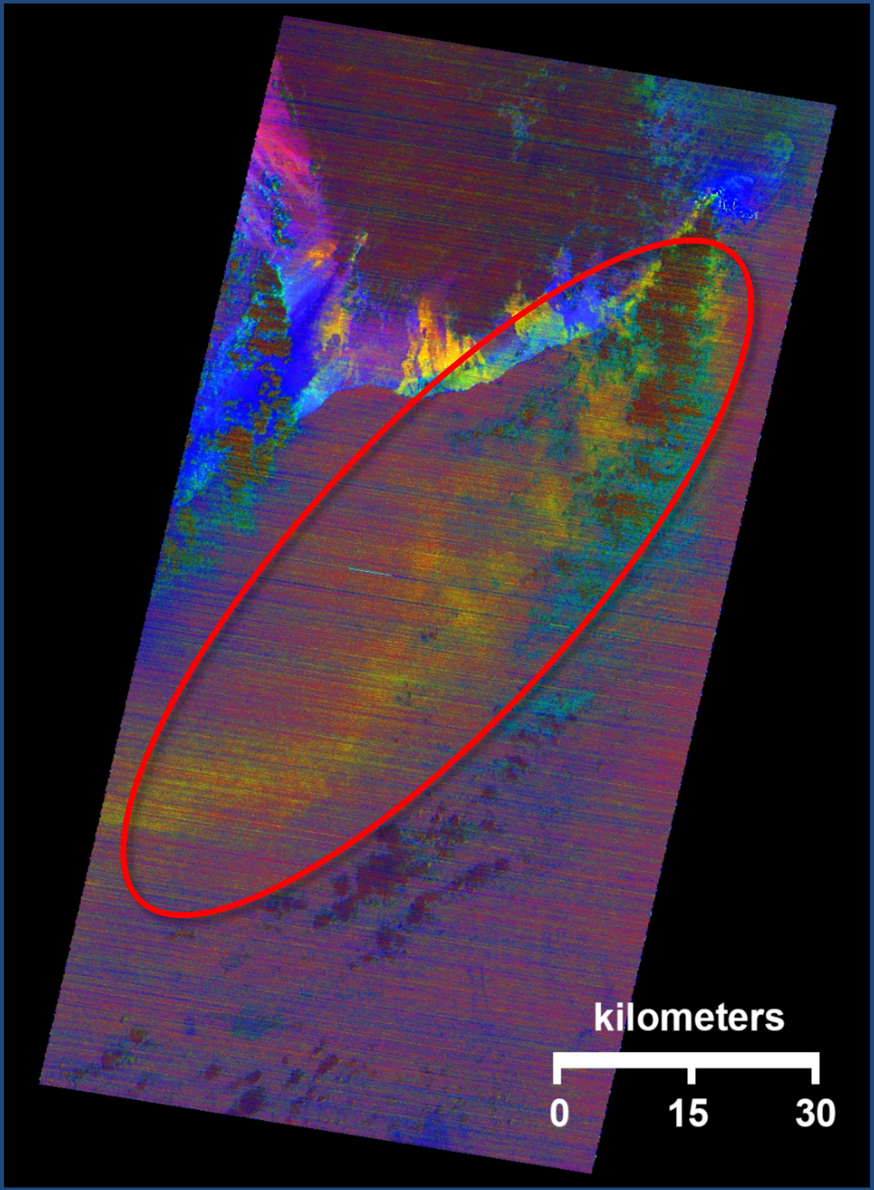

22 May 2018


Kīlauea Volcano - East Rift Zone
Map Updated 11:00 am, May 22
USGS
science for a changing world
Nanawale Estates
Kapoho
Pāhoa
Ponding Lava
PGV
Leilani Estates
Vacationland Hawaii
Flow front as of 7:37 am
Active Lava Channels
Pohoiki
Island of Hawai'i
Active Ocean Entry
Opihikao
Major road
Minor road
Path of steepest descent
Flows 5/3 - 5/21
Notable past lava flows
Puna Geothermal Venture
0 0.5 mi
0 0.5 Km
N
Rift Zone
Summit
Kīlauea Volcano
1840
1960
1955


Kilauea LERZ Fissure 20 - 22 May 2018, 00:22-00:41 UTC
Leilani Estates
Leilani Ave
Malama St
Moku St
Luana St
Mohala
Malama-Ki Forest Reserv
1 km
Latitude [deg]
Longitude [deg]
SO$_2$ column [molec/cm^2]
$\times 10^{18}$
19.475
19.47
19.465
19.46
19.455
19.45
19.445
19.44
19.435
19.43
-154.94 -154.93 -154.92 -154.91 -154.9 -154.89 -154.88
18
16
14
12
10
8
6
4
2
0


USGS
Highway 132
F17
F22
F19
F06
Leilani Estates subdivision
some map distortion here
new flow
levee breach
Pohoiki Rd
Highway 137
ocean entry
22 May 2018, 06:45 am
Thermal map of fissure system
0 0.5 1 Miles
N



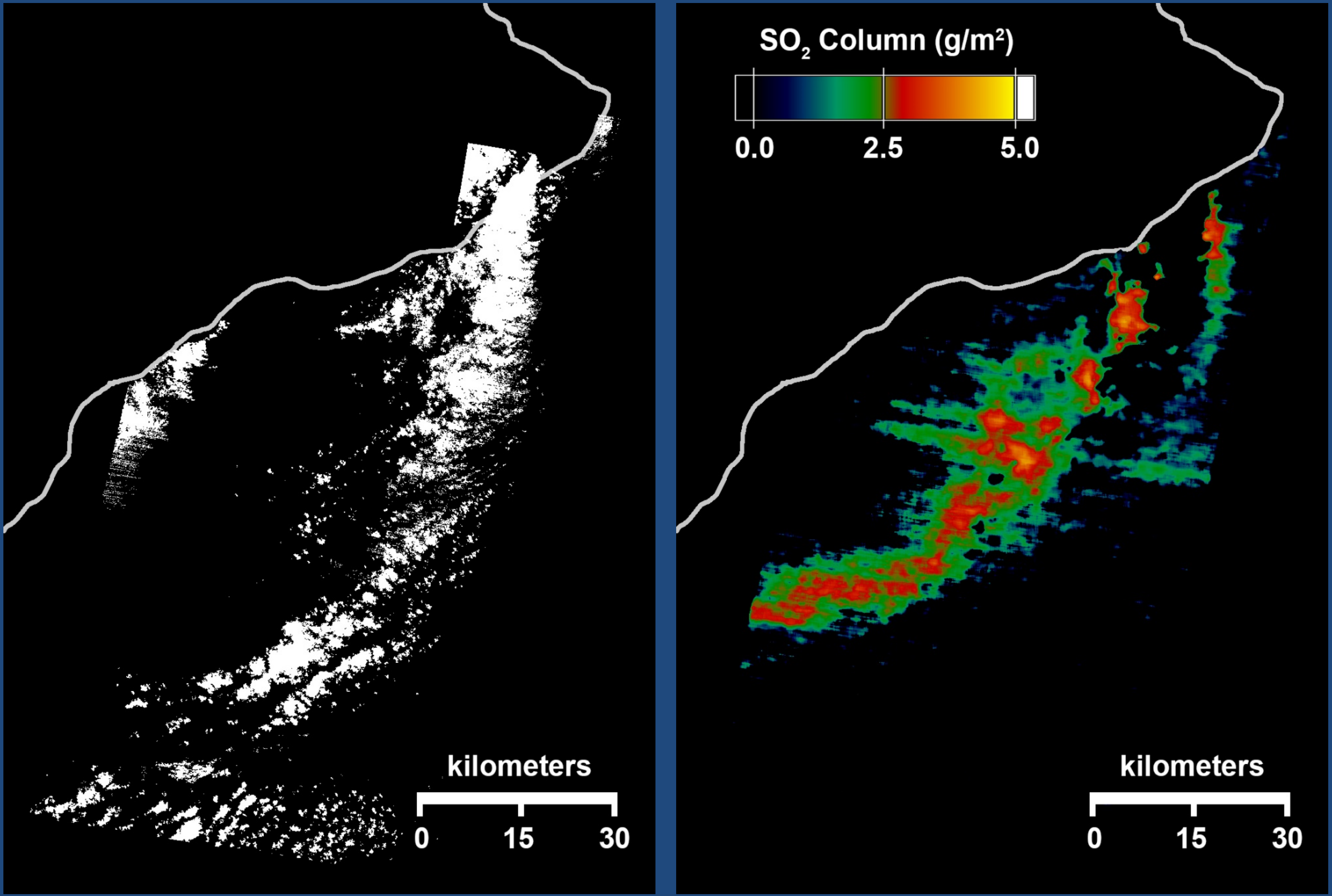


ASTER VNIR

2018-05-22

21:01 UTC

ASTER TIR

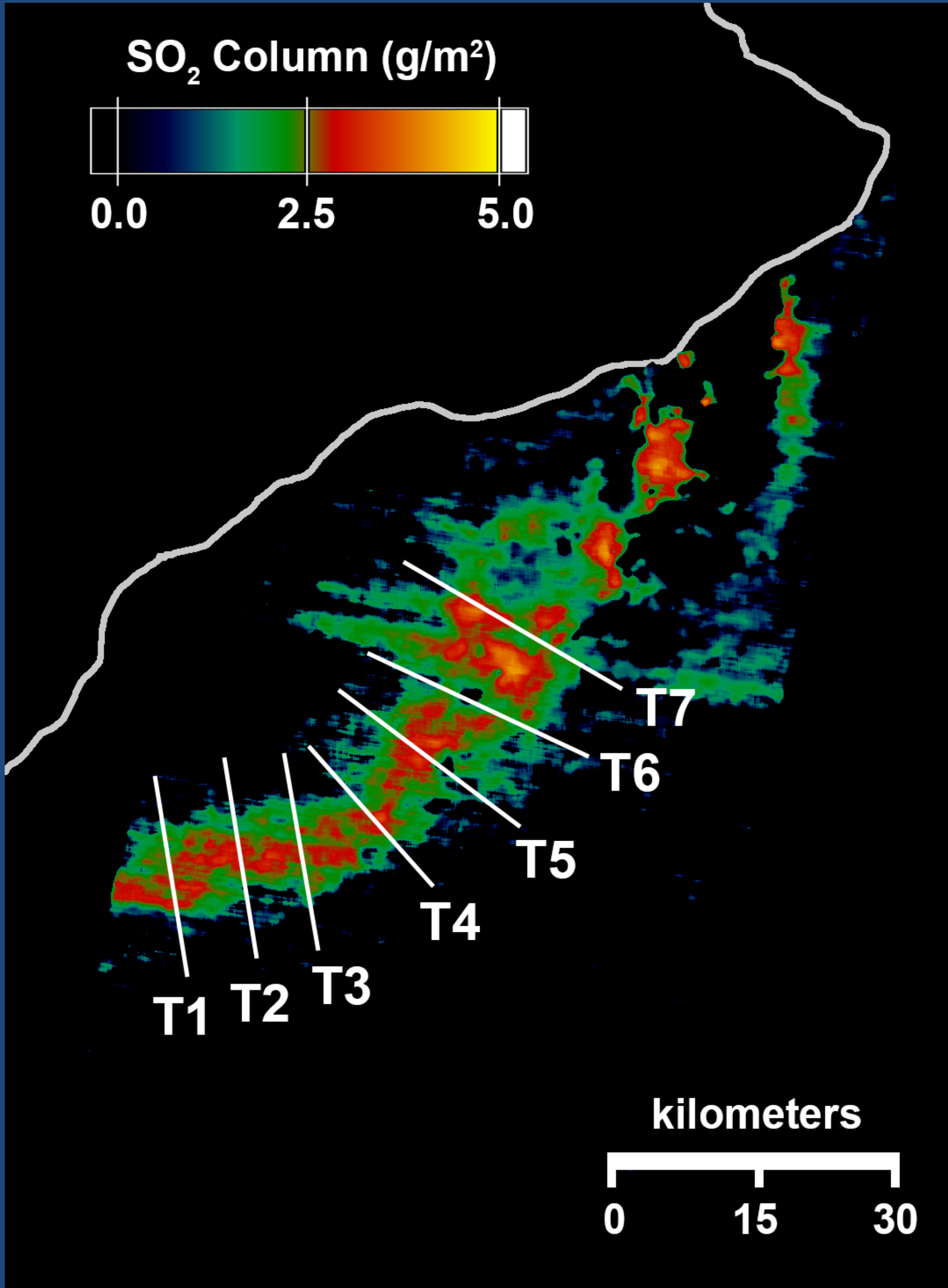


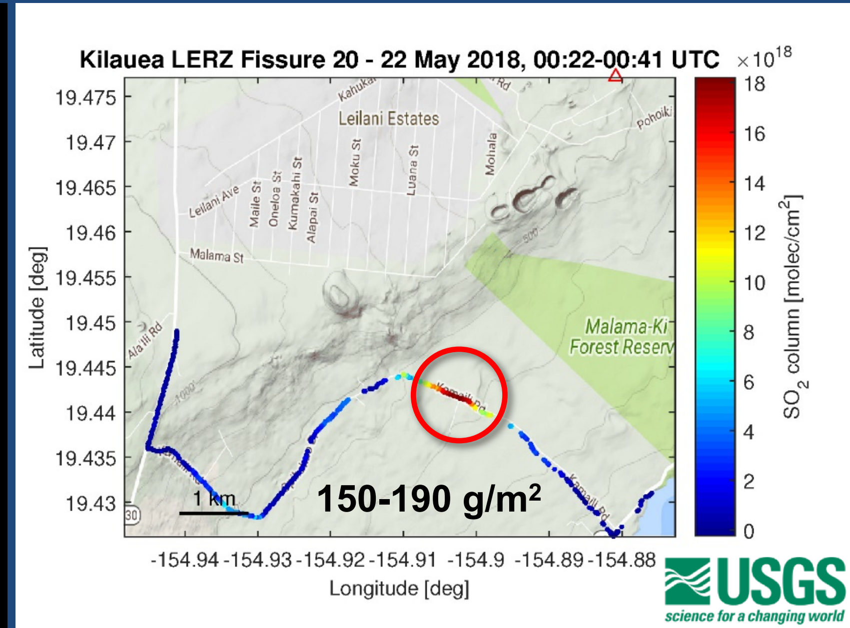
Cloud Mask

2018-05-22

21:01 UTC

SO$_2$ Column Density

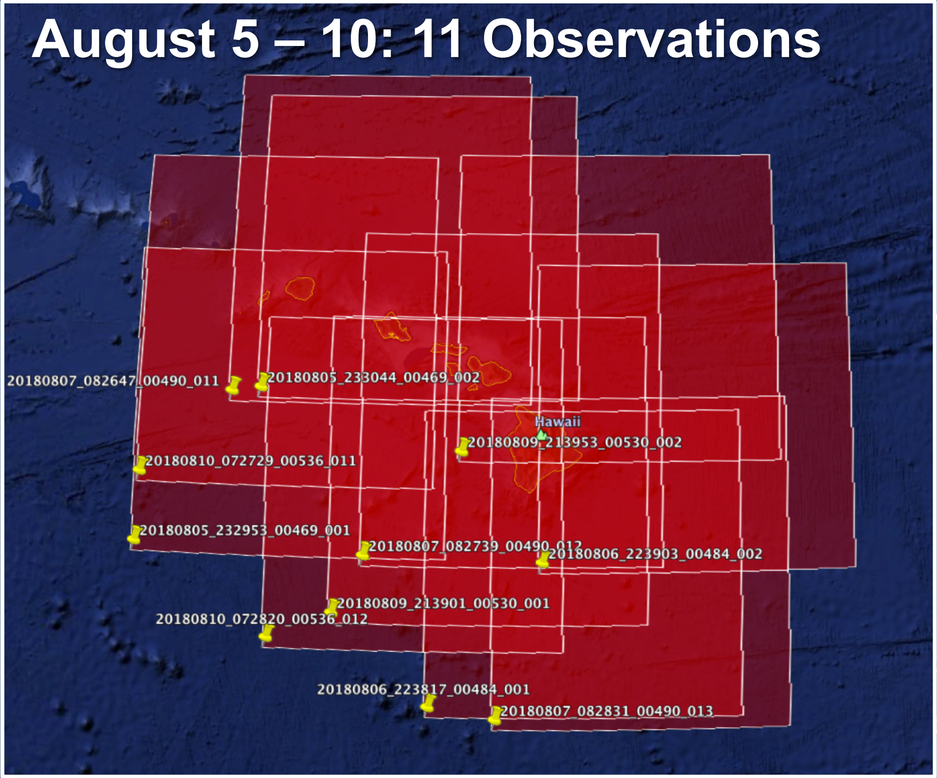


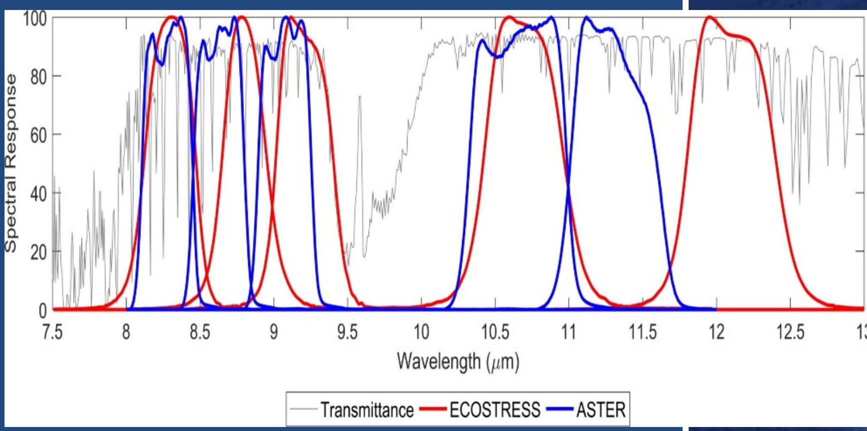


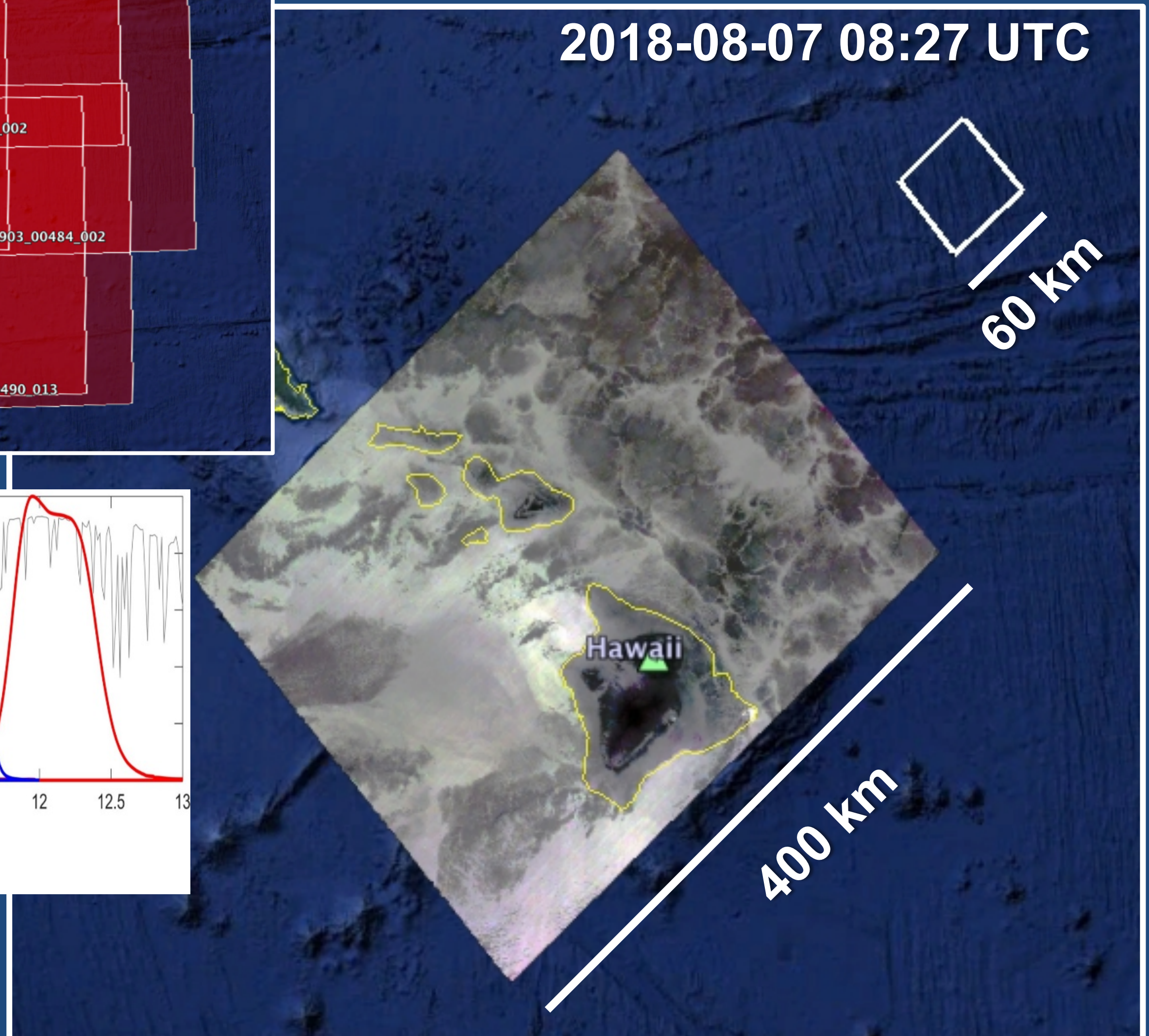
HVO Integrated Transects (kg/m)*	ASTER Integrated Transects (kg/m)
37.52	T1: 25.37
30.34	T2: 20.75
45.03	T3: 24.20
38.10	T4: 19.94
Ave: 37.75 ± 5.2	T5: 25.90
	T6: 23.98
	T7: 41.00
	Ave: 25.88 ± 6.5

**USGS/HVO data analyses are preliminary, and not for distribution*

ECOSTRESS Deployment on ISS Affords Multiple Opportunities to Observe Hawaii!

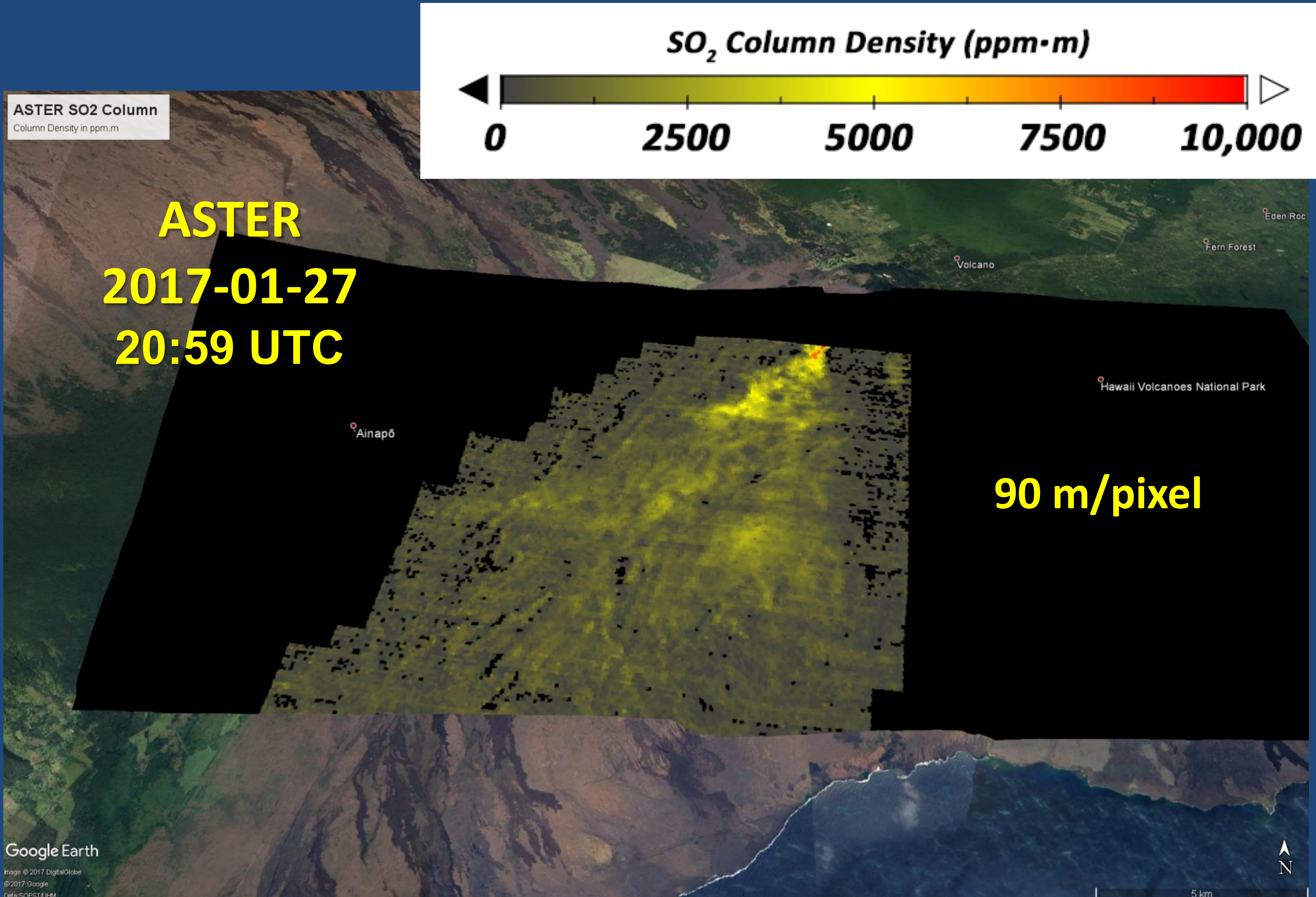






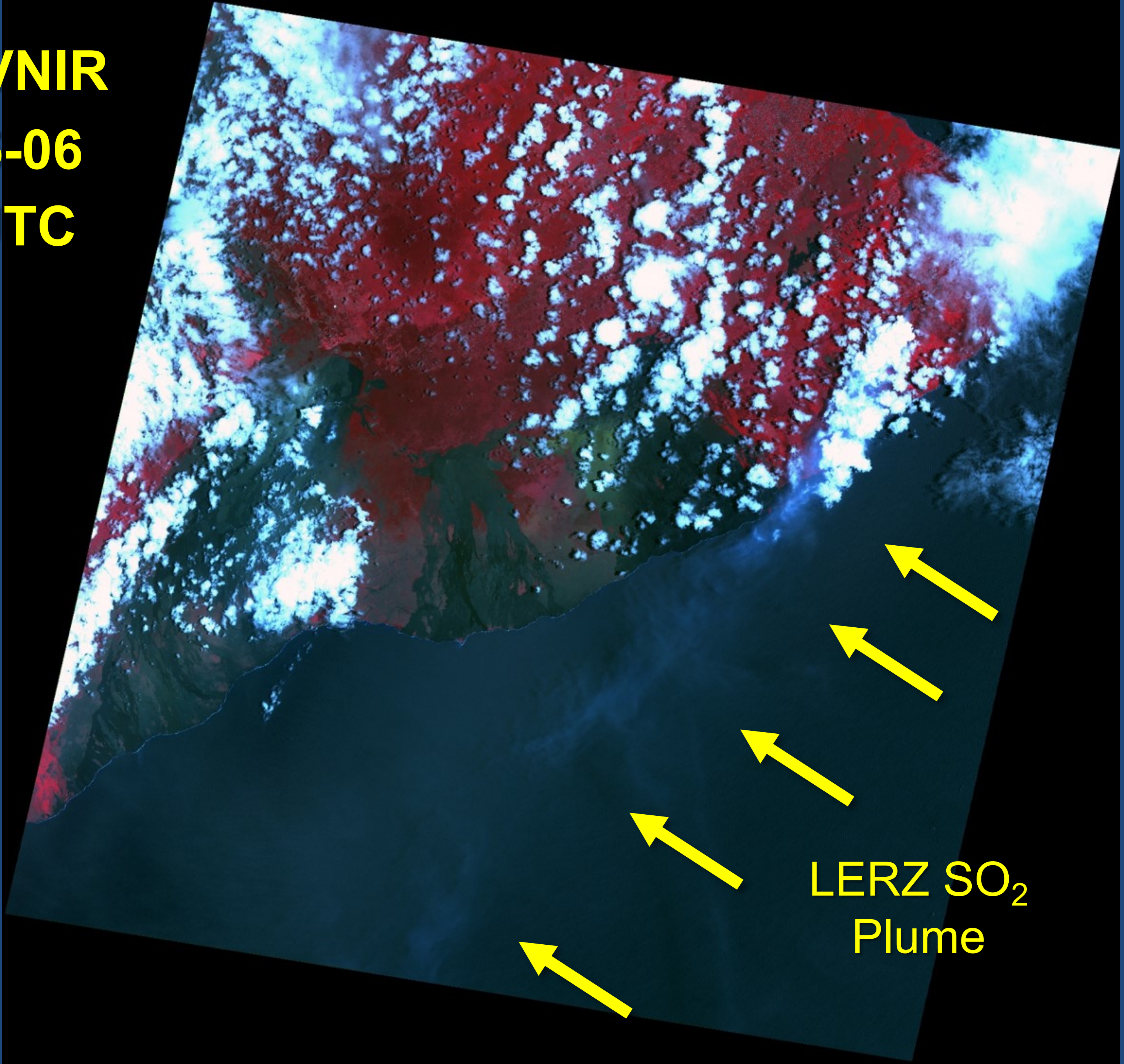
Spatial Resolution	**L1: 38 X 67 m**
	L2: 70 X 70 m

Thank You for
Your Attention.

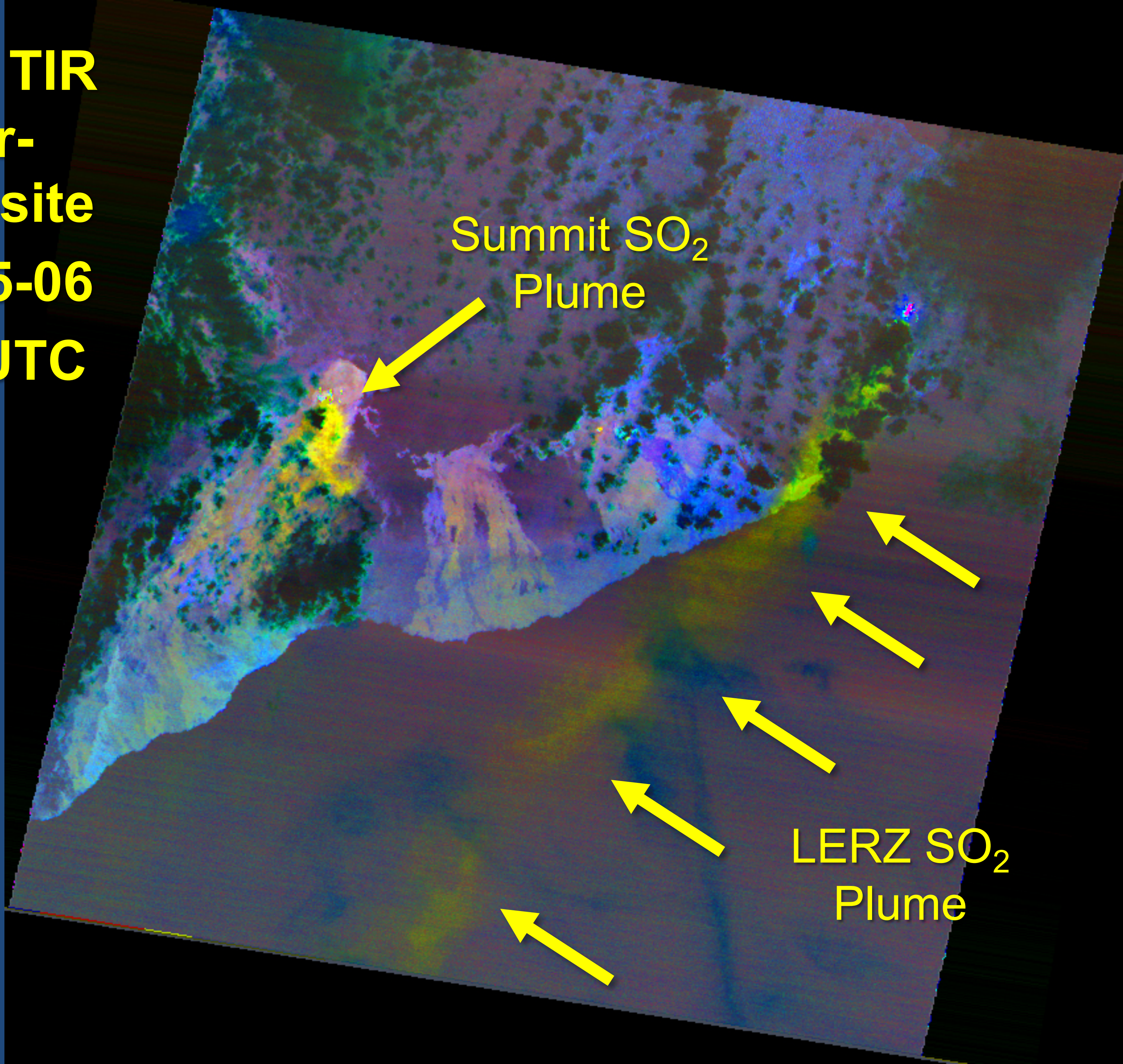

SO2 Column Density (ppm·m)
0
2500
5000
7500
10,000
ASTER SO2 Column
Column Density in ppm.m
ASTER
2017-01-27
20:59 UTC
Eden Roc
Fern Forest
Volcano
Hawaii Volcanoes National Park
Ainapō
90 m/pixel
Google Earth
Image © 2017 DigitalGlobe
© 2017 Google
Data SOEST/UHM
N
5 km

5 km

ASTER VNIR
2018-05-06
21:01 UTC

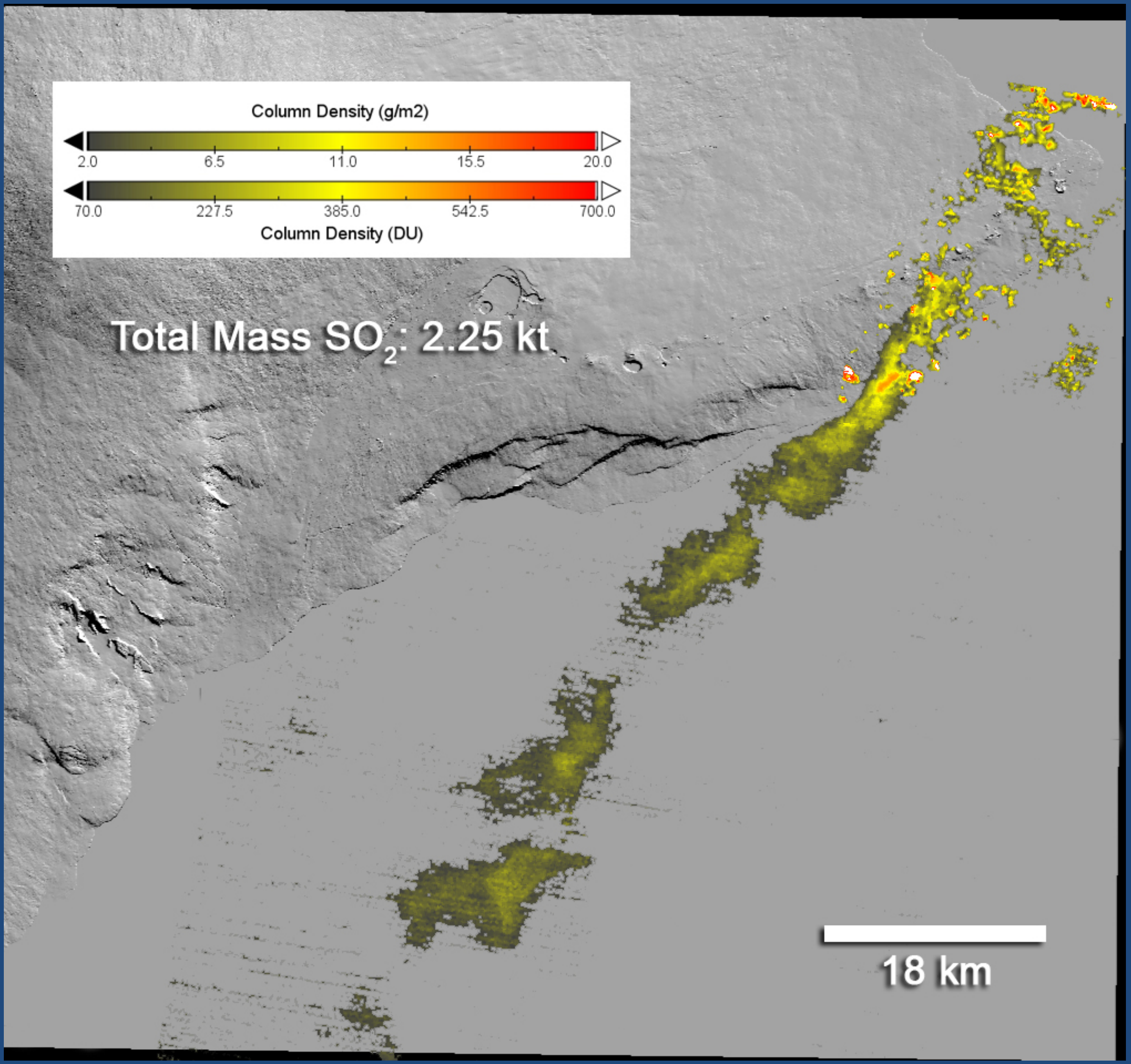


ASTER TIR Color-Composite 2018-05-06 21:01 UTC



ASTER-Based Estimates of SO_2 Column Density

- Column Density can scale inversely with size of IFOV (pixel)
- Total Mass is sum of Column Density over all pixels
- Total Mass useful for comparing SO_2 retrievals based on different airborne or satellite instruments
- How do we compare against field spectrometer measurements?

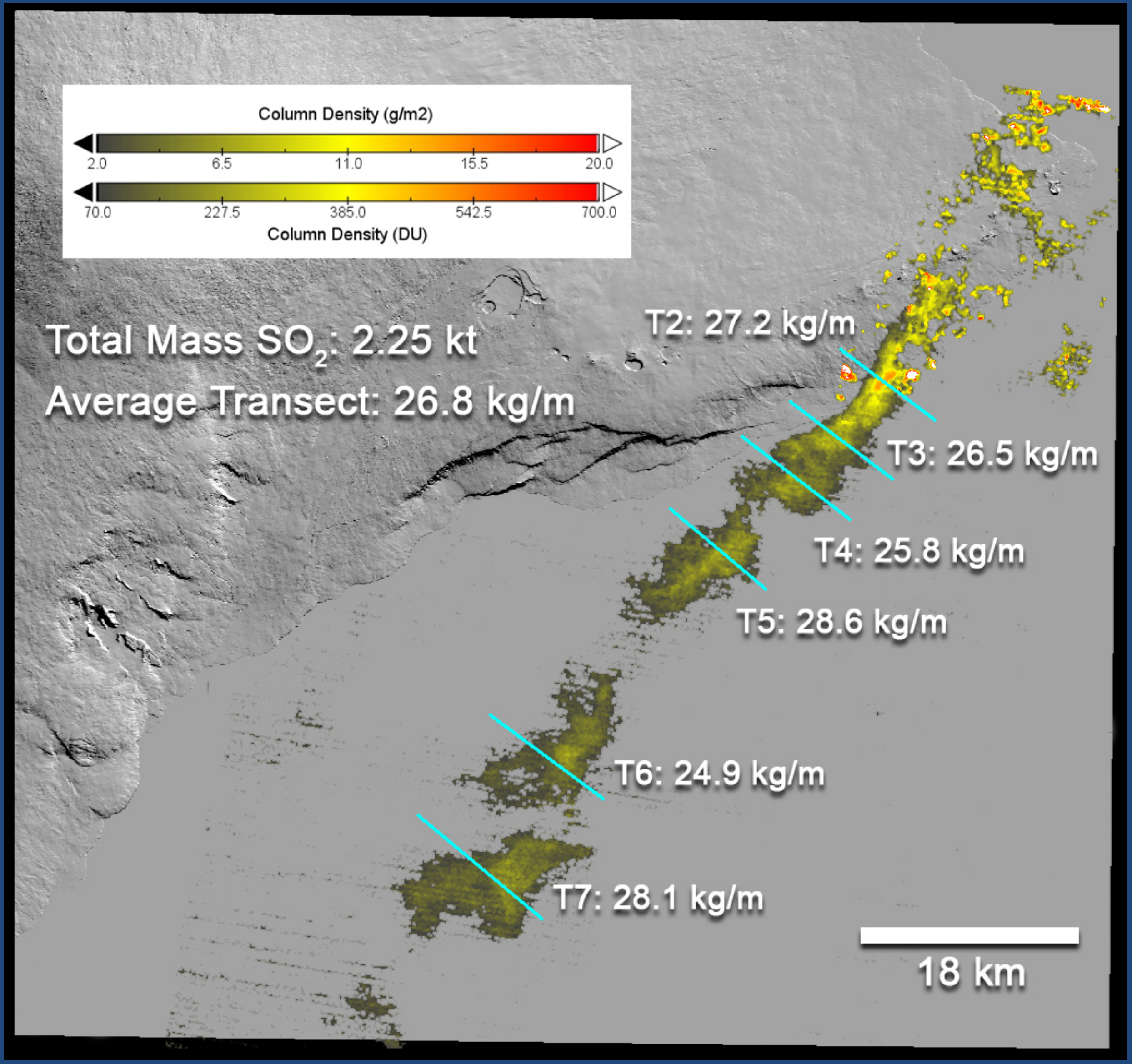


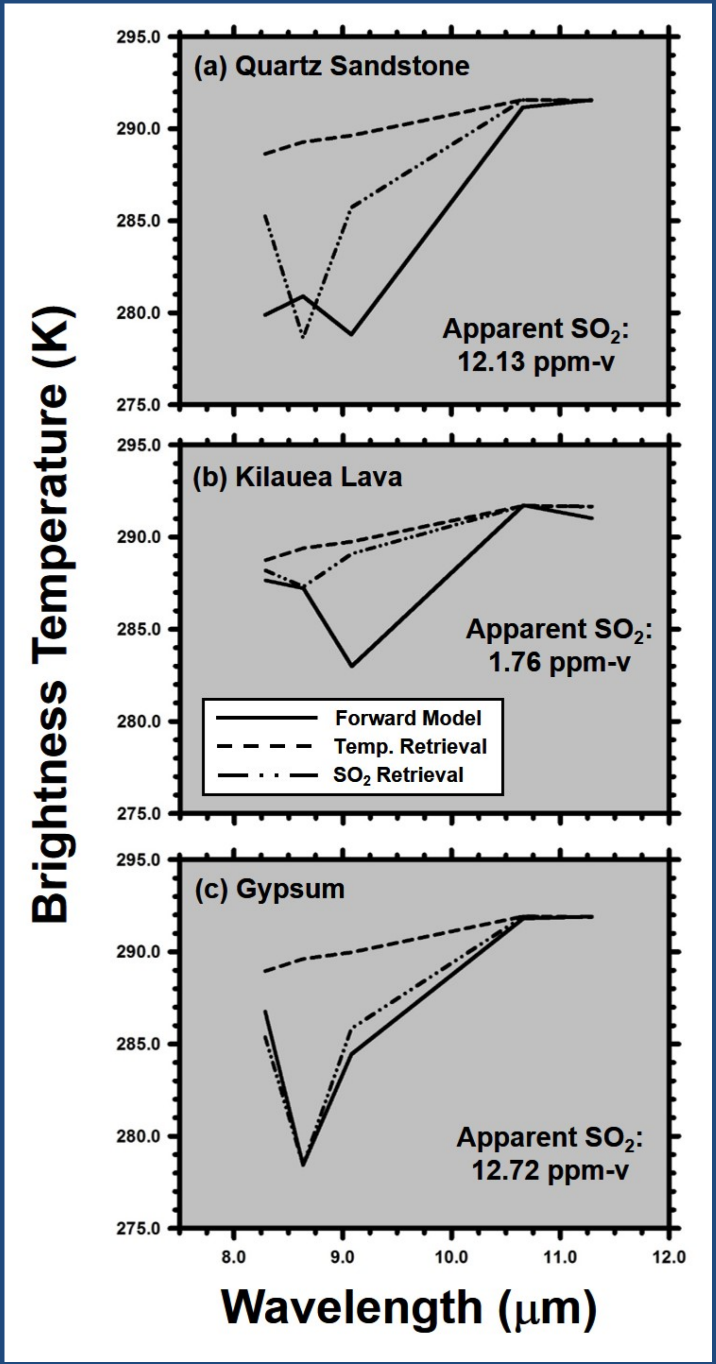
Agreement Between ASTER-Based Transects of SO_2 Plume and Vehicle Traverse Beneath Plume

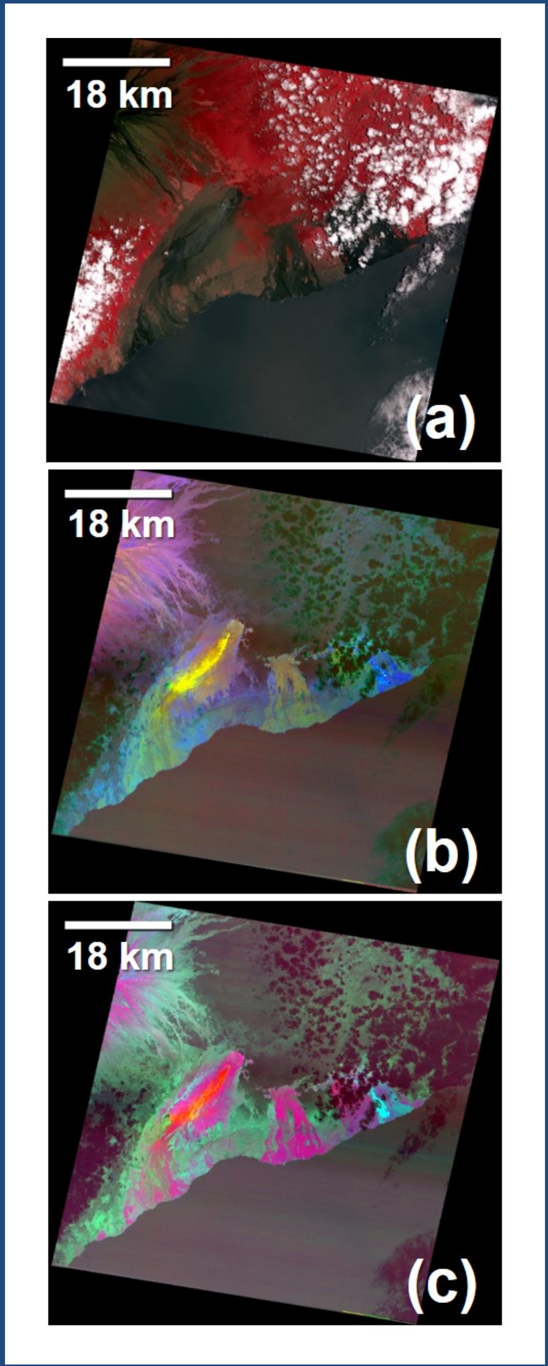
- Average ASTER Transect:
  26.8 ± 1.4 kg/m
  (11:01 AM local time)

- HVO Vehicle Traverse:
  32.8 kg/m (4:28 PM)*

** USGS/HVO results are preliminary and not for distribution*




Brightness Temperature (K)
295.0
290.0
285.0
280.0
275.0
(a) Quartz Sandstone
Apparent SO2:
12.13 ppm-v
(b) Kilauea Lava
Apparent SO2:
1.76 ppm-v
Forward Model
Temp. Retrieval
SO2 Retrieval
(c) Gypsum
Apparent SO2:
12.72 ppm-v
8.0
9.0
10.0
11.0
12.0
Wavelength (μm)


18 km
(a)
18 km
(b)
18 km
(c)