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Thermal Infrared (TIR) Remote Sensing of Volcanic Plumes with MODIS and VIIRS

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TIR Remote Sensing of Volcanic Plumes

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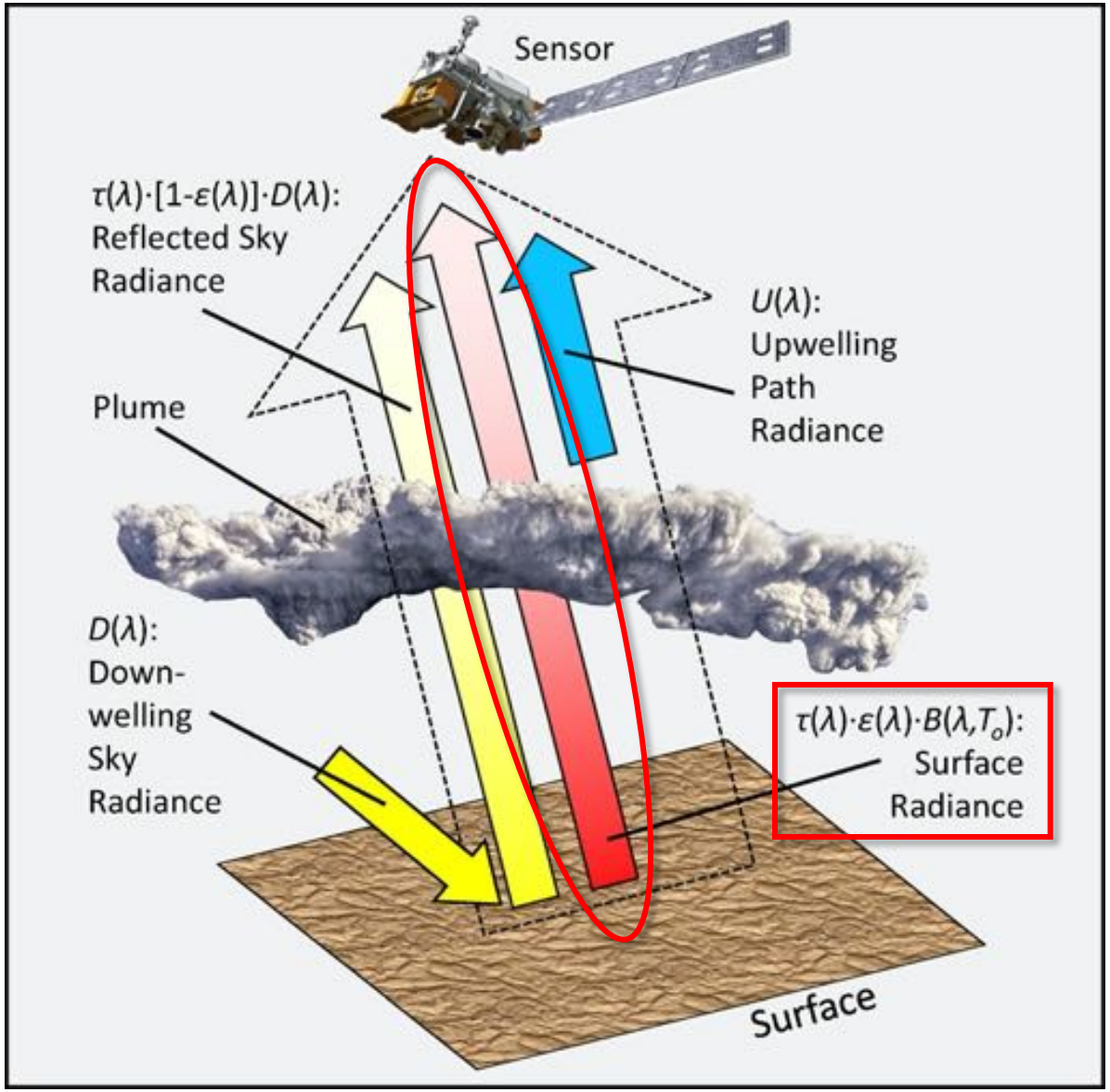
Detect plumes through transmission [$\tau(\lambda)$]:
the attenuation of surface radiance [$\varepsilon(\lambda) \cdot B(\lambda,T_o)$]
passing through the plume enroute to the sensor

$$L(\lambda,T_o) = \{\varepsilon(\lambda)\, B(\lambda,T_o) + [1 - \varepsilon(\lambda)]\, D(\lambda)\}\, \tau(\lambda) + U(\lambda)$$

The observed radiance [$L(\lambda,T_o)$; outlined arrow] includes the surface radiance (red arrow), reflected downwelling sky radiance [$D(\lambda)$, yellow arrow], and upwelling path radiance [$U(\lambda)$, blue arrow]

Reconstruct Observed Radiance:

1) Transmission, sky radiance, and path radiance are estimated through radiative transfer (RT) modeling, cached, and re-used
2) Surface emissivity [$\varepsilon(\lambda)$] available from lab spectra, product archives, or calculated within scene
3) Surface temperature [T_o] estimated from radiance observations



RT-Based Plume Detection and Mapping: Bardarbunga Volcano (Iceland) 2014-09-05

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a) Surface temperature estimation does not consider volcanic plumes or met. clouds

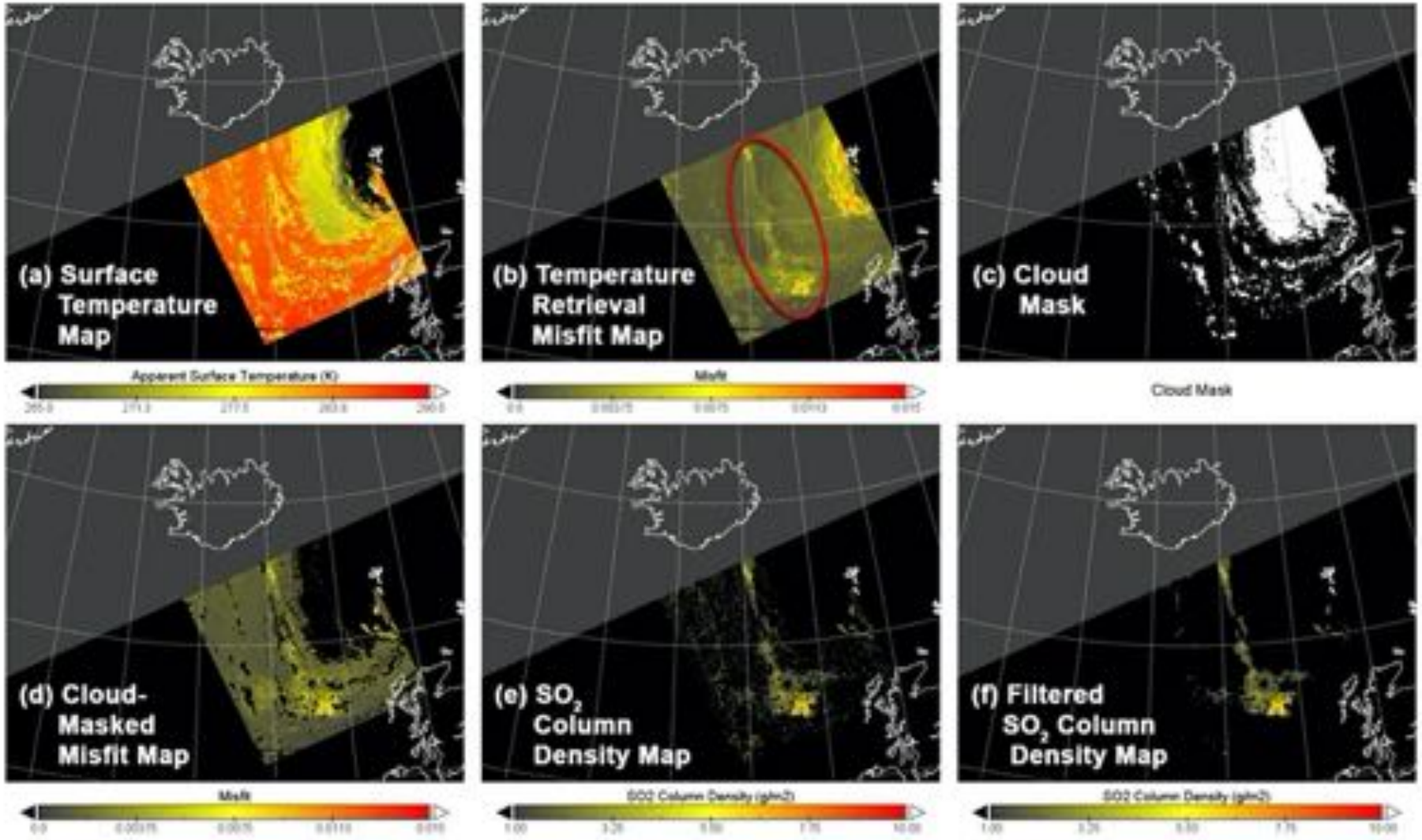
b) Misfit map shows the locations of plumes (red oval) and met clouds

c) Met clouds are identified by comparing surface temperature estimates with air temperature at surface

d) Combination of cloud mask and misfit map improves the detection of volcanic plumes

e) Estimation of SO_2 column density is confined to the locations identified by the masked misfit map

f) SO_2 map is filtered/repaired to minimize the “holes” corresponding to the locations of met clouds.



Calibration/Validation: Bardarbunga Example

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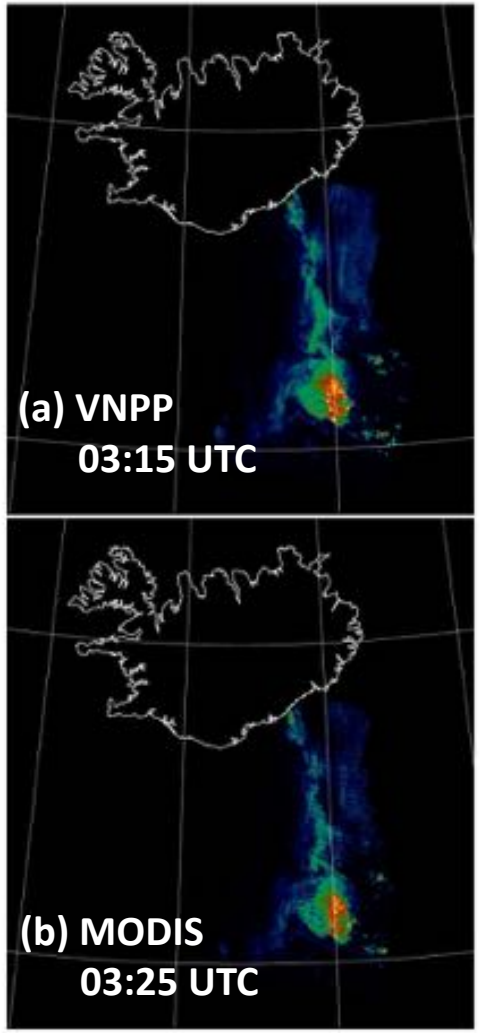
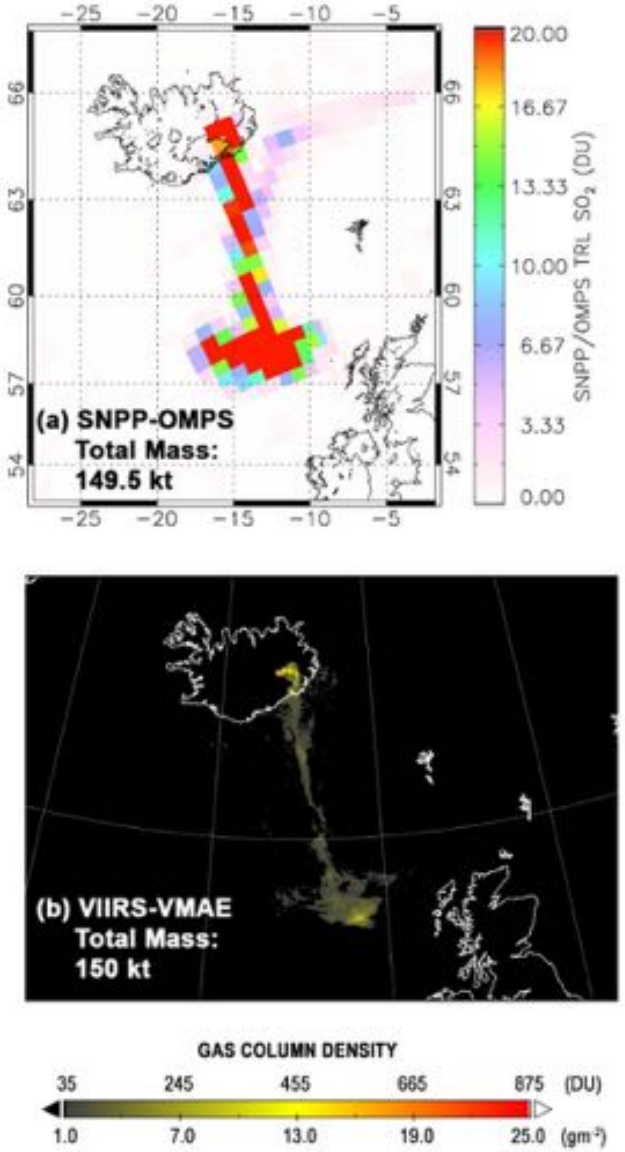


2014-09-05
03:15/03:25 UTC
(Night-time)

SO_2 retrievals based on (a) VNPP and (b) MODIS-Aqua observations are virtually identical

Validates the use of VNPP data to augment and extend MODIS-based data records



2014-09-05
13:06 UTC
(Daytime)

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 kt)

Calibration/Validation: Mt. Etna Example

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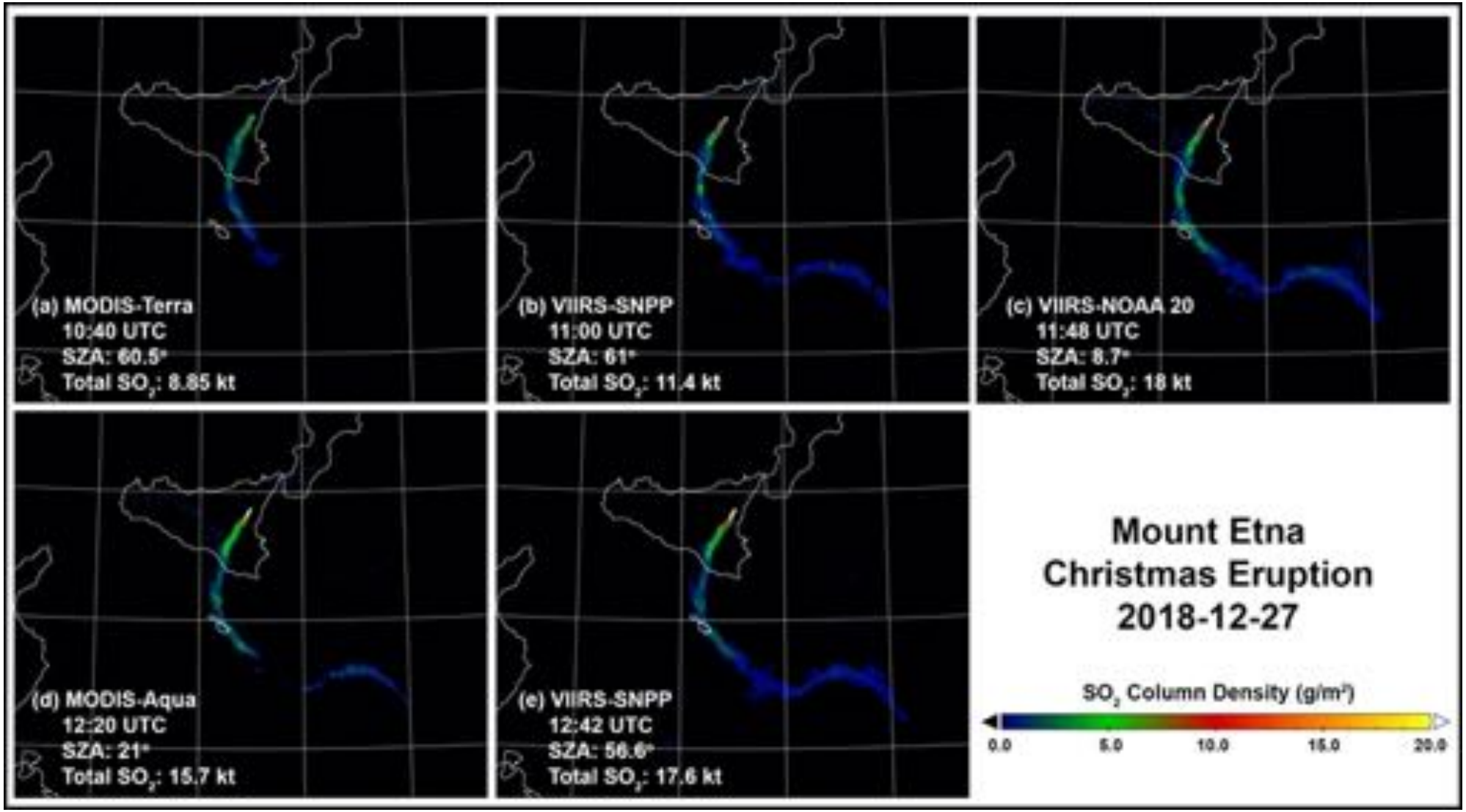
Five Daytime Observations Within Period of ~120 min (average of 36 min between observations)

Validate data products through comparison with field measure-ments and compli-mentary satellite data products (including SEVIRI, IASI, and TROPOMI) provided by Italian National Institute of Geophysics and Volcanology (INGV)



RGB Plume Detection Strategy

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Problem:

Plume Detection Requires RT-Based Temperature Estimation

Solution:

“Rapid” Plume Detection Based on Spectral Properties and Brightness Temperature

Confine RT-Based Temperature and SO_2 Estimates to Plumes

Plume Spectroscopy: Sarychev Peak Volcano

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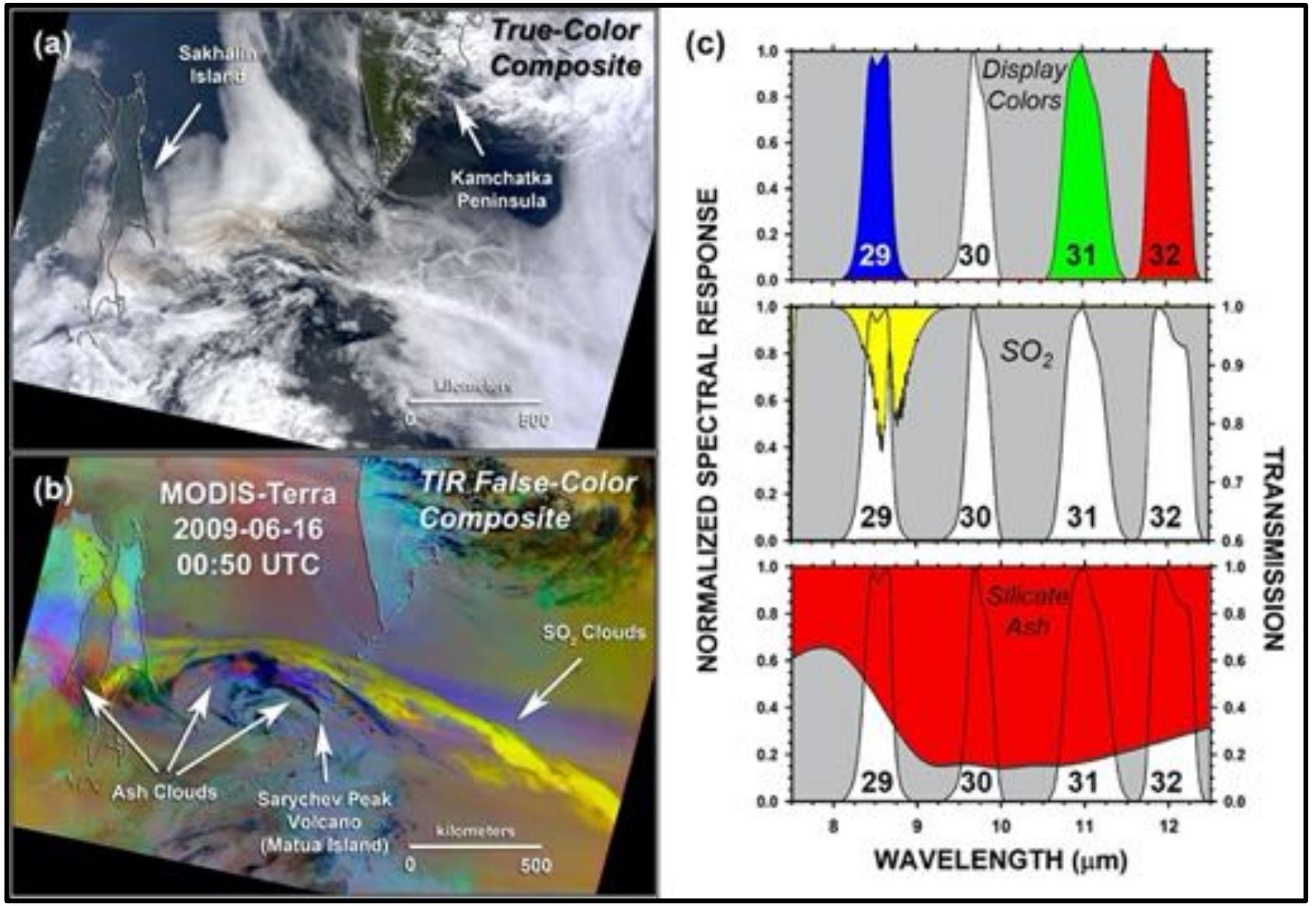
a) MODIS-Terra True-color composite. Volcanic plumes and meteorological clouds have similar appearance at visible wavelengths

b) False-color composite of TIR data from Channels 32, 31, and 29, displayed in red, green, and blue. SO_2 plumes appear yellow, while the display colors of ash plumes range between red and magenta

c) Transmission spectra of SO_2 (middle) and silicate ash (bottom), superimposed on the spectral response of MODIS Channels 29, 30, 31, and 32



RGB Plume Detection Strategy: De-Correlation Stretch (D-Stretch)

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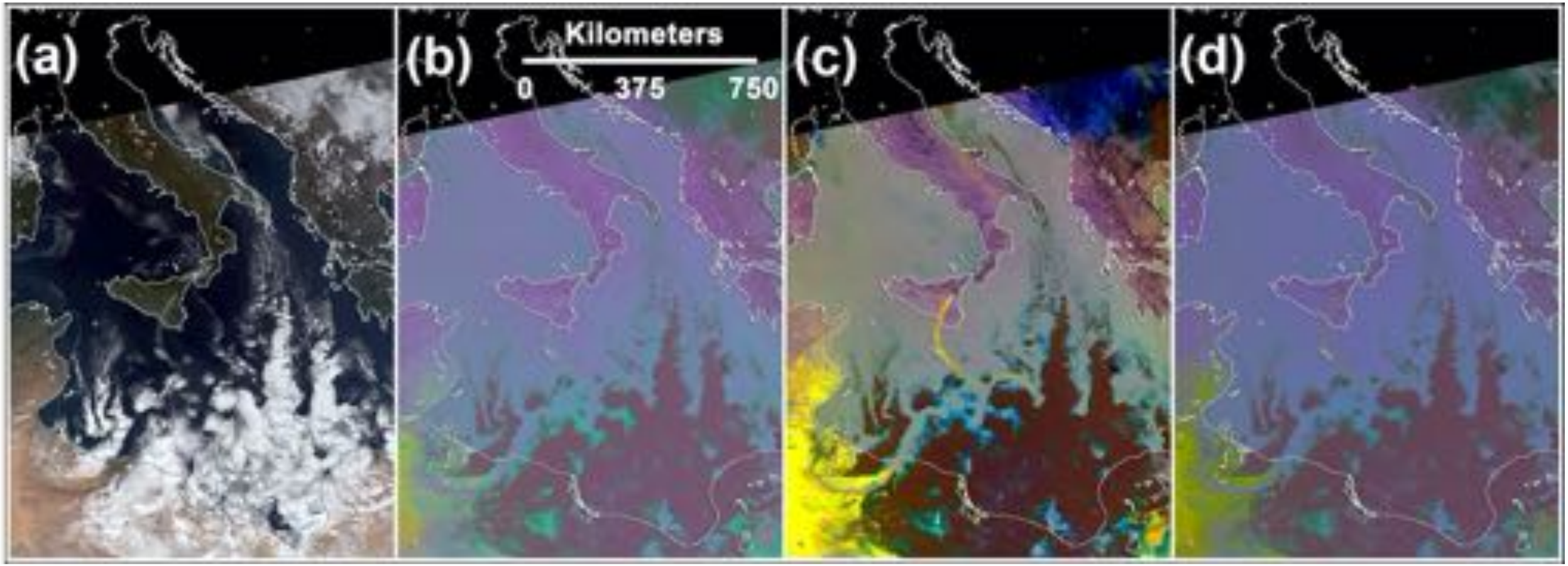

D-Stretch based on PCA – Results Depend on Scene Statistics Used to Calculate PC

(a) True-Color Composite; **(b)** TIR D-Stretch based on Global Scene Statistics

(c) D-Stretch based on Statistics for User-Defined Sub-scene

(d) D-Stretch Minima based on Quadrant Statistics

VIIRS RGB Plume Products:
Raikoki Volcano | 2019-06-22 | 1430 UTC

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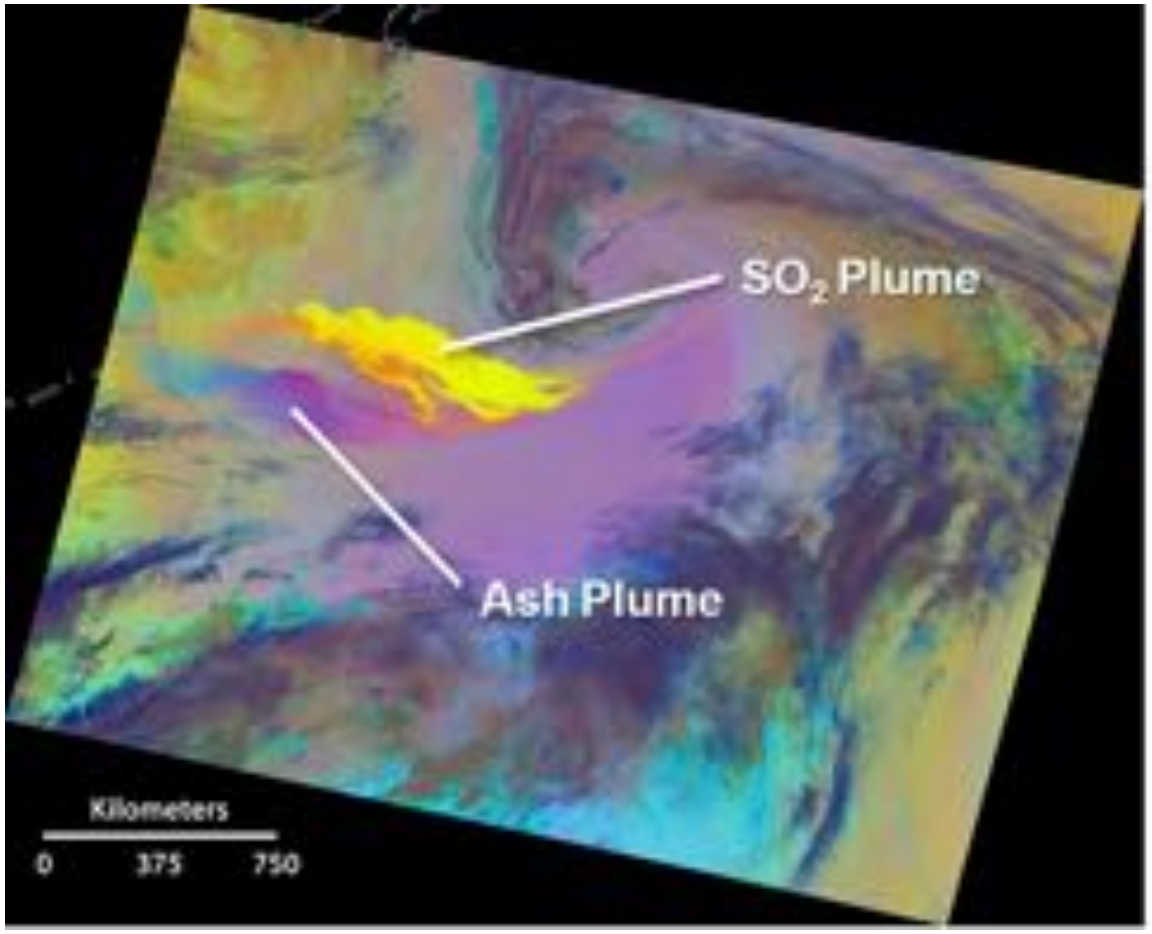
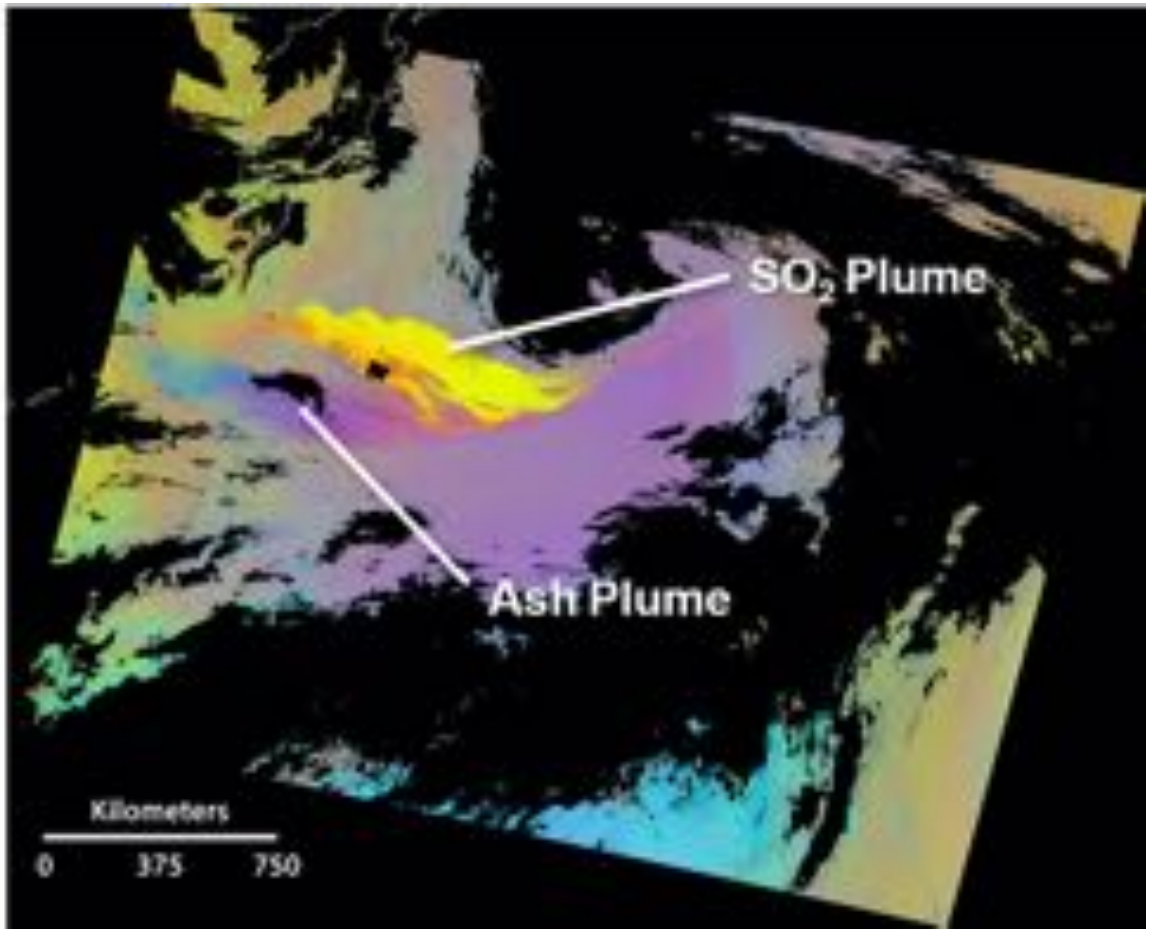


Aggregate D-Stretch Composite



Cloud-Masked D-Stretch Composite

VIIRS RGB Plume Detection
Raikoki Eruption | 2019-06-22 | 1430 UTC

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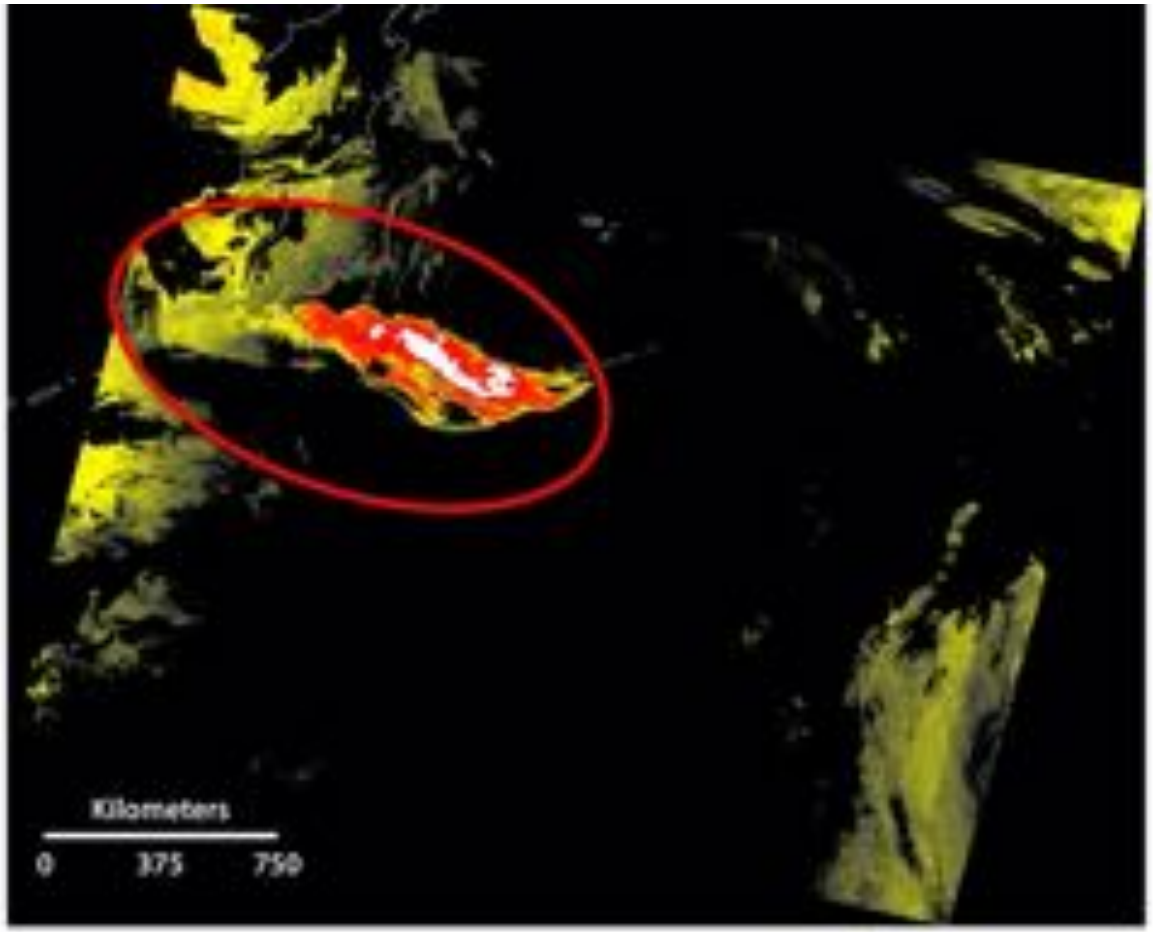

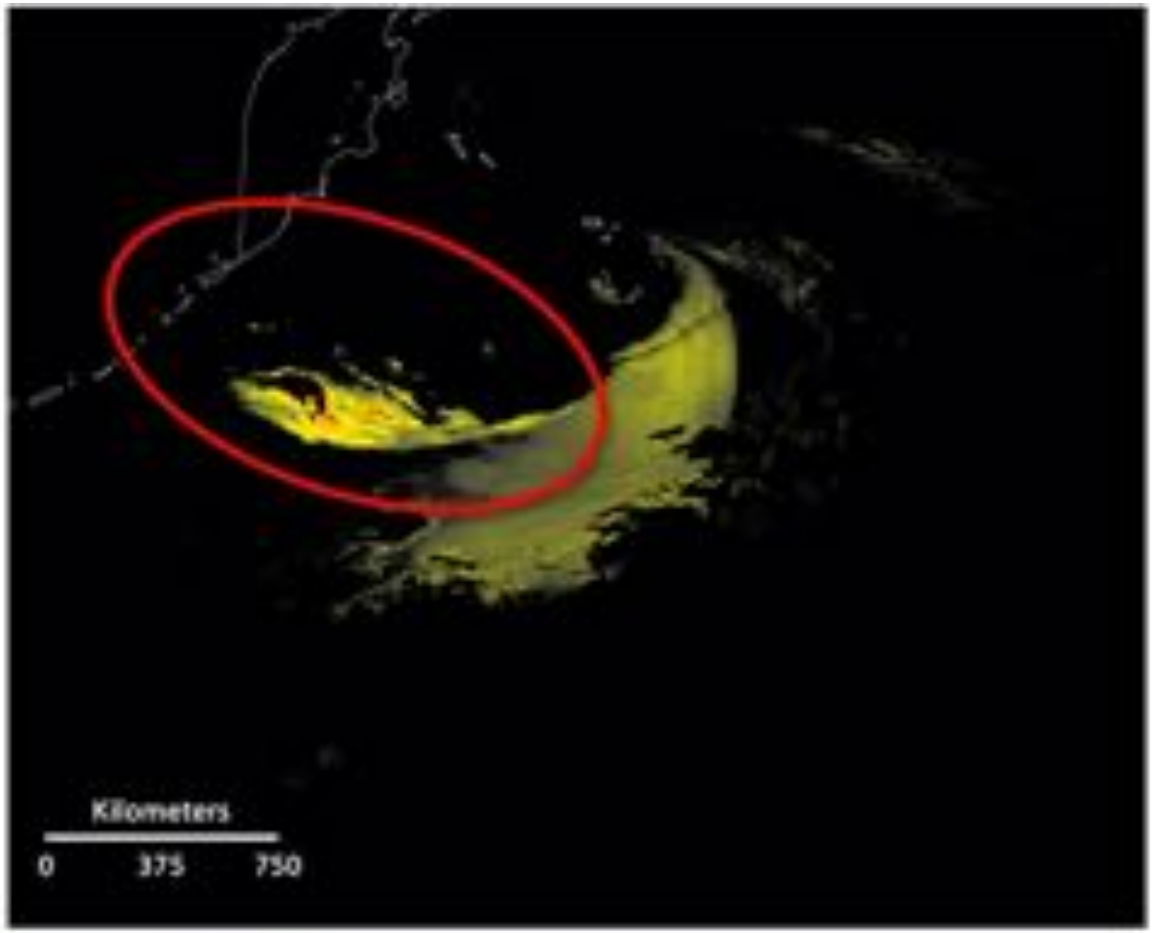

SO_2 Index Map
(D-Stretch of M14)

Weaker Absorption

Stronger Absorption

Ash Index Map
(D-Stretch of M15)

VIIRS RGB Plume Detection
Bardarbunga Eruption | 2014-09-05 | 0454 UTC

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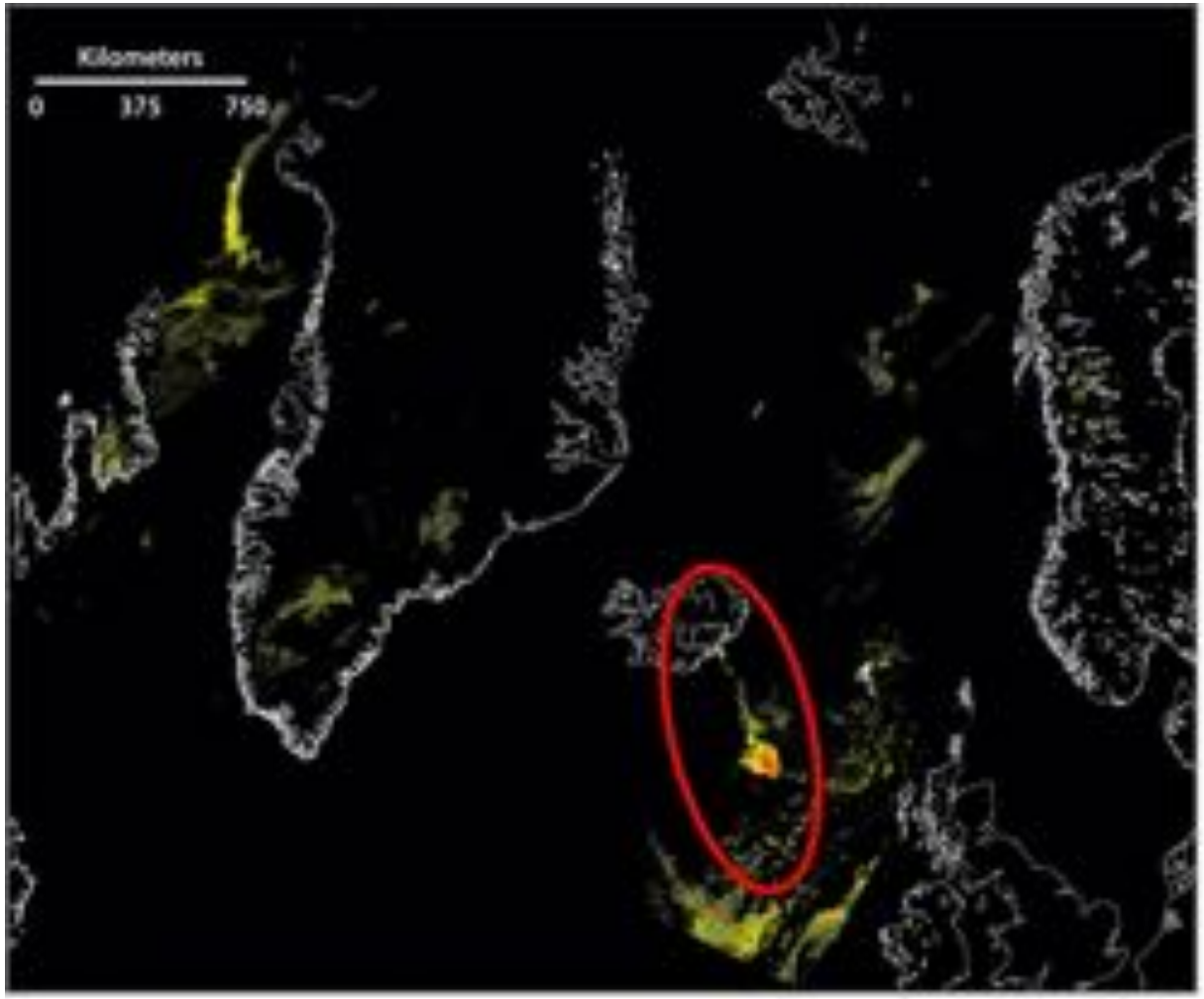

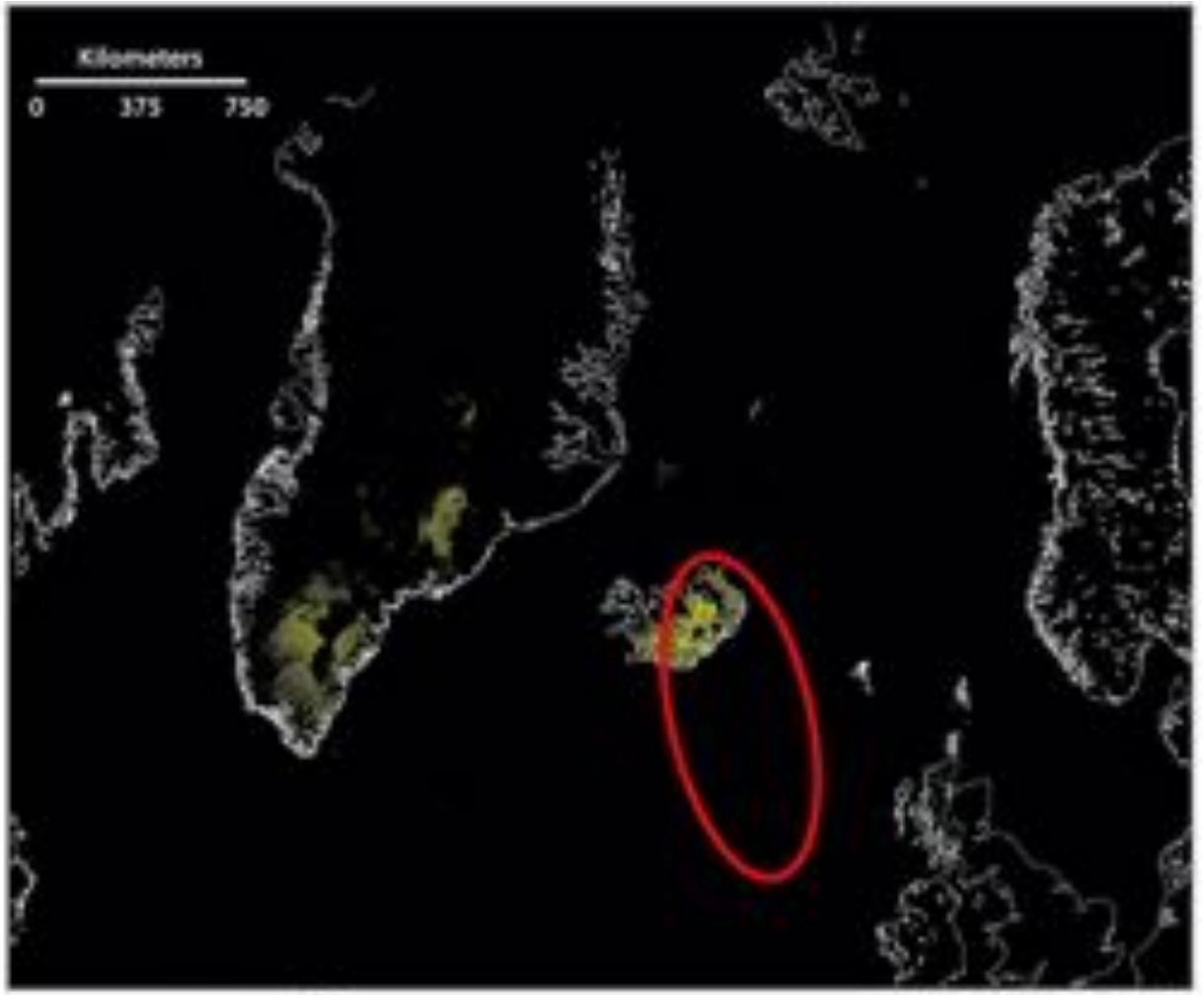

SO_2 Index Map
(D-Stretch of M14)

Weaker Absorption

Stronger Absorption

Ash Index Map
(D-Stretch of M15)

VIIRS RGB Plume Detection
Mt. Etna Eruption | 2018-12-28 | 1148 UTC

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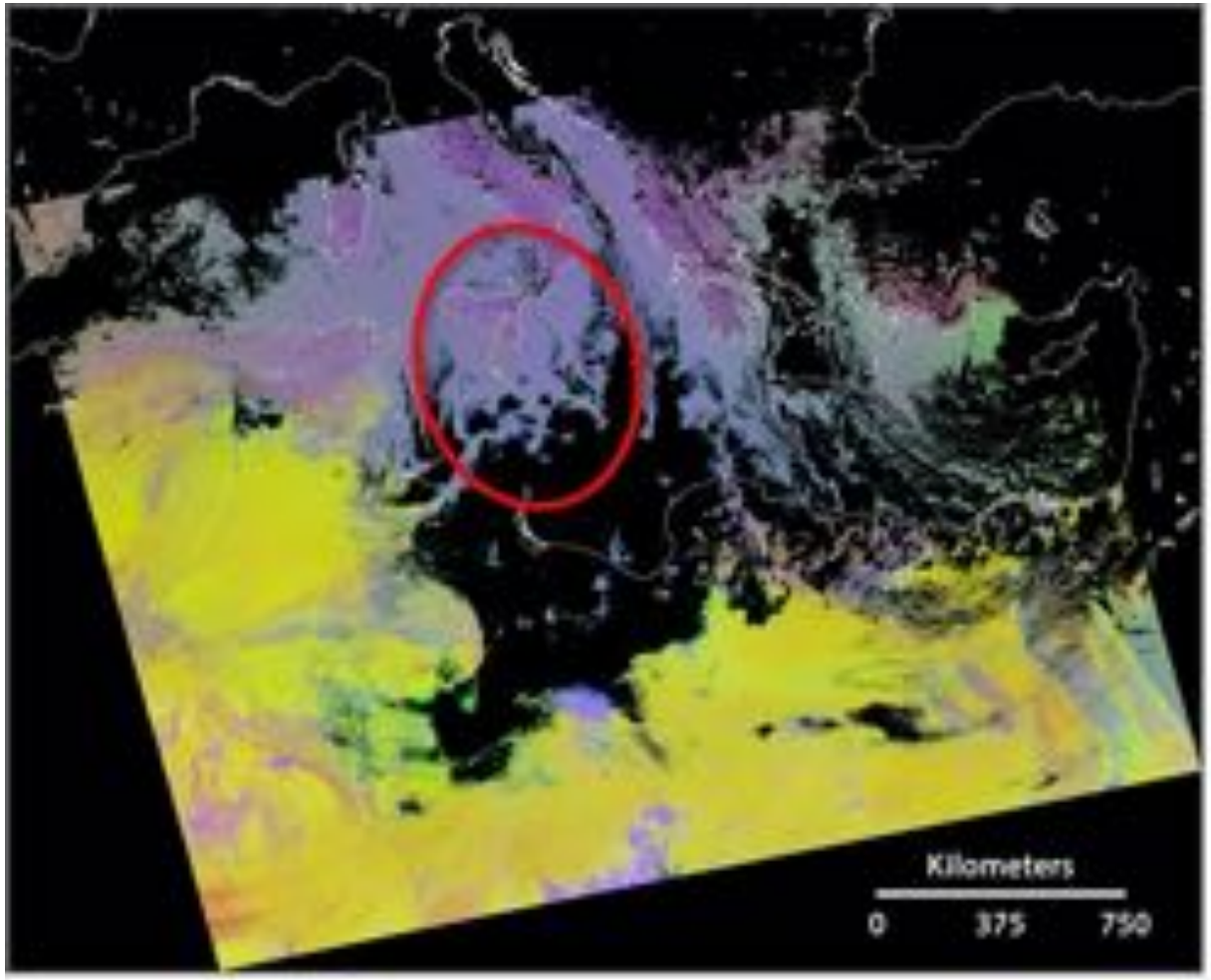

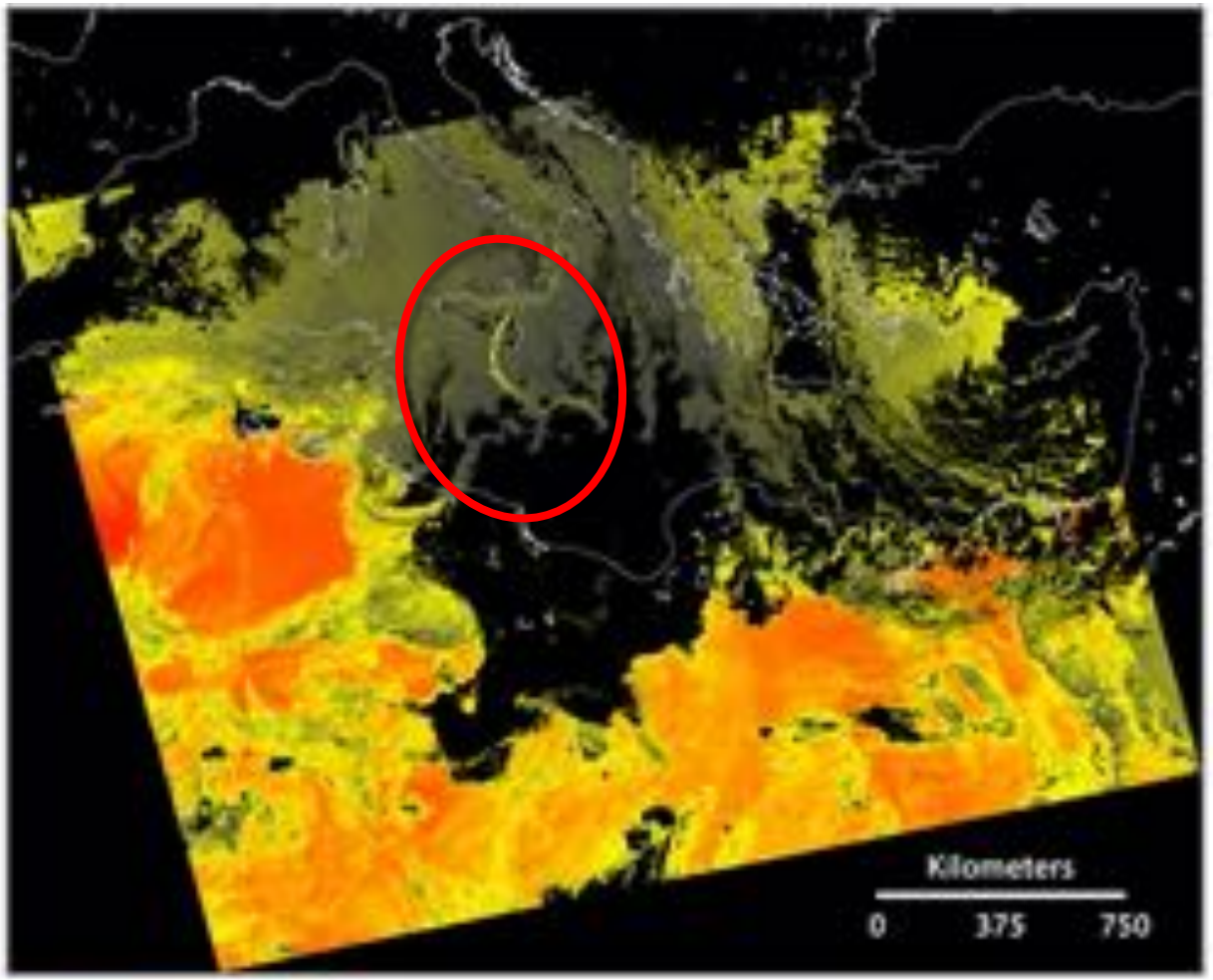

Cloud-Cleared Aggregate DS

Weaker Absorption — Stronger Absorption

SO_2 Index Map (D-Stretch of M14)

MODIS RGB Plume Detection
Sierra Negra Eruption | 2005-10-26 | 1940 UTC

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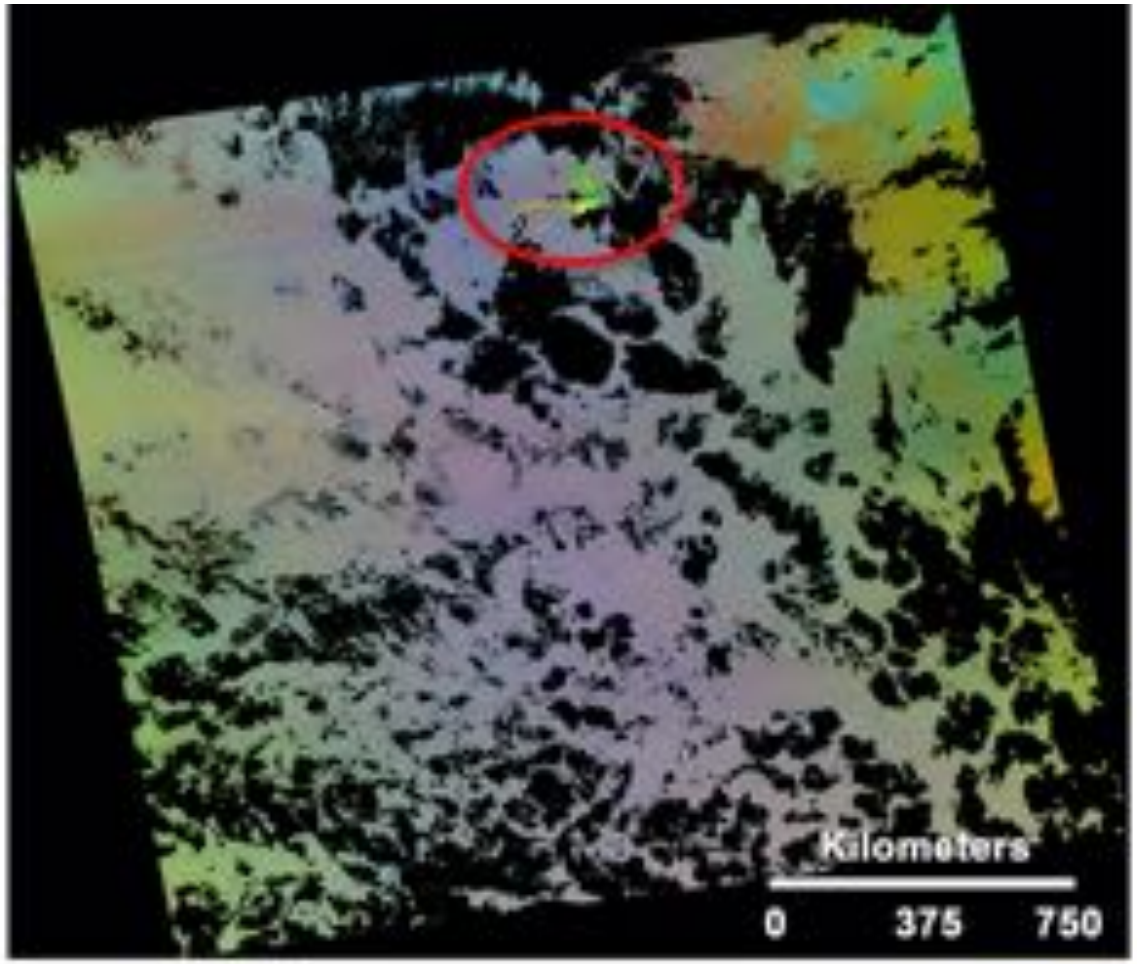
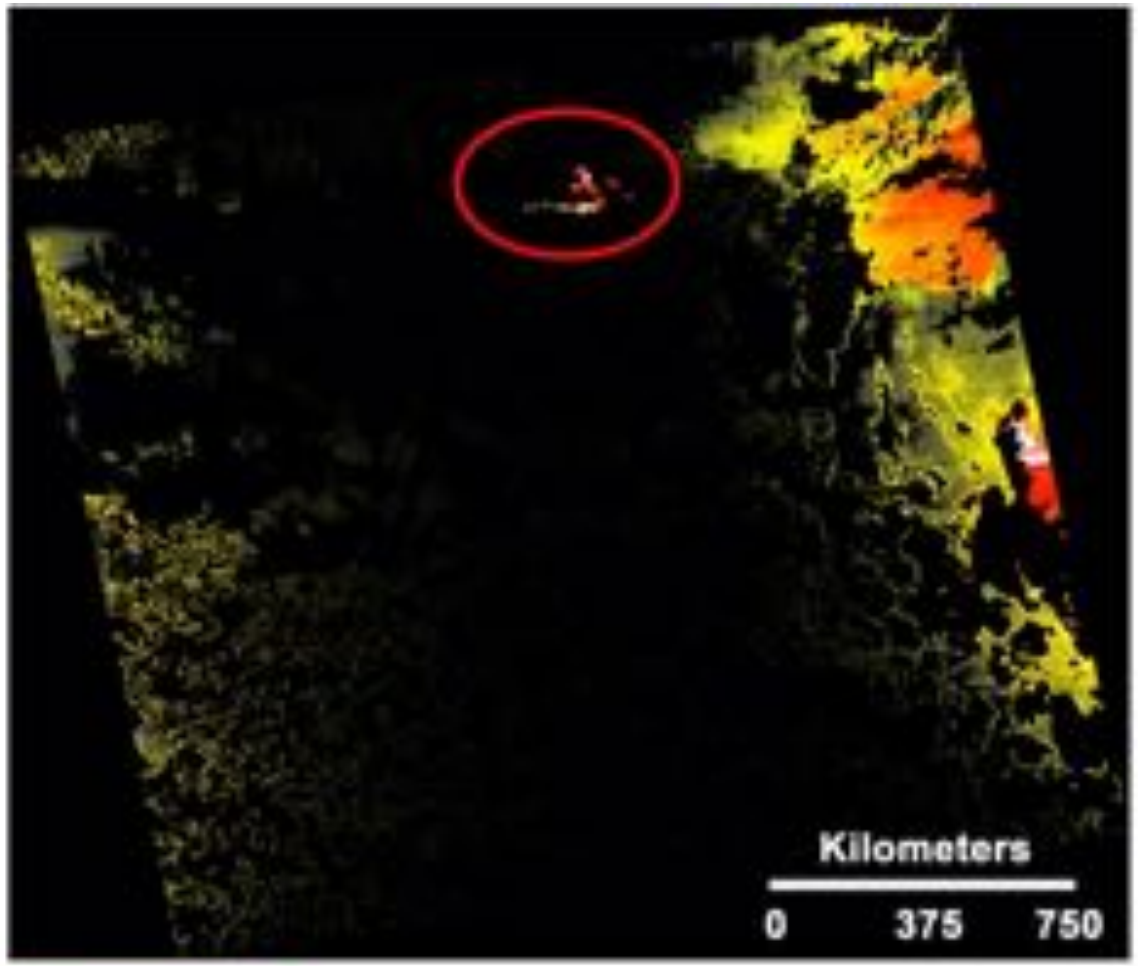


Cloud-Cleared
Aggregate DS



SO_2 Index Map
(D-Stretch of B29)

Resources for TIR Plume Detection and Mapping

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L1B Data Products	Additional Data Products	Additional Resources
Radiance-at-Sensor	Atmospheric Profiles	Radiative Transfer Model
Satellite Zenith/Range	Emissivity Spectra	Access to L2/L3 Data
DEM		Access to External Data Servers
Latitude		Recursive Processing
Longitude		

Thanks for Your Attention!