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DEVELOPMENT OF MULTI-SENSOR SO_2 PRODUCTS FOR JPSS

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JPSS Science Team Meeting
11 August 2016

Outline

- Importance of SO_2 monitoring
- Strengths and weaknesses of different satellite measurements
- Measurement integration plan
- Collaboration

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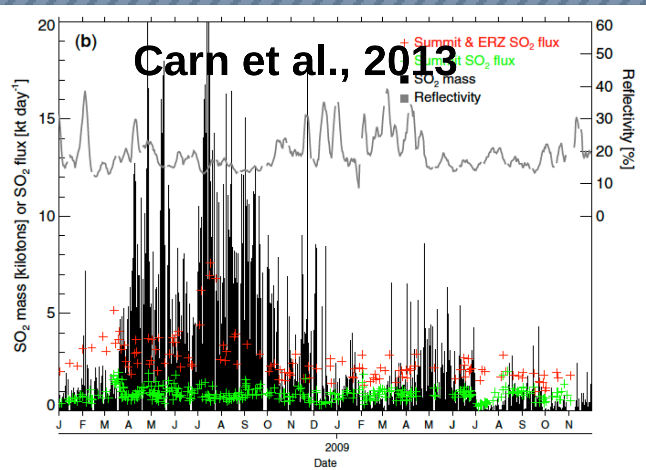
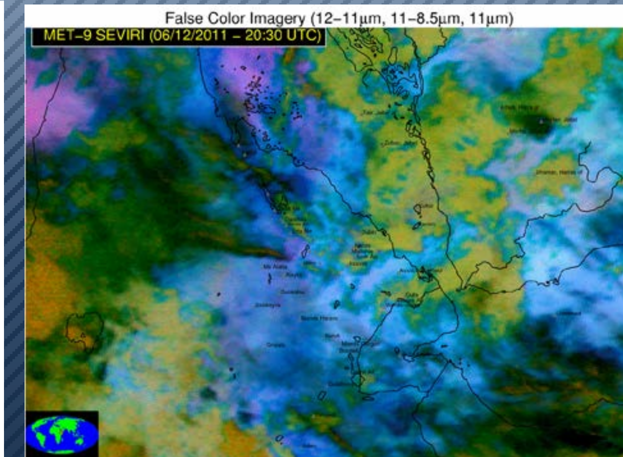
Motivation

Volcano Monitoring

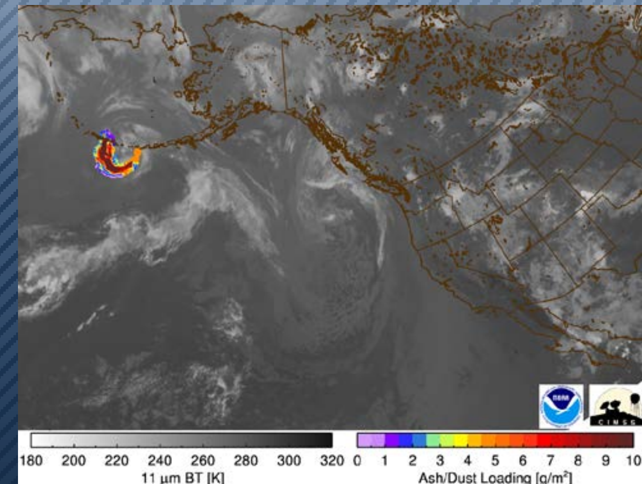


Hazard Avoidance

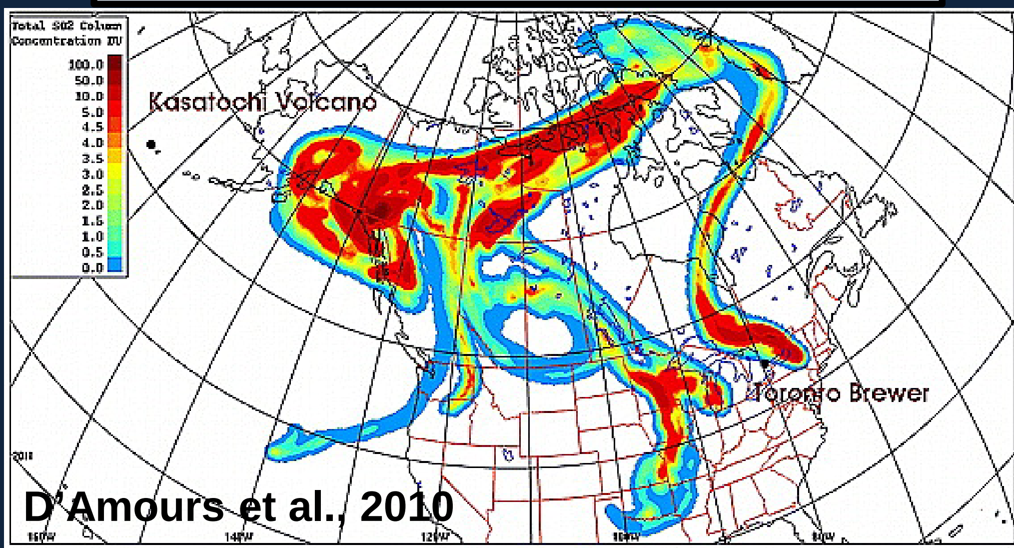


2011 Nabro Eruption

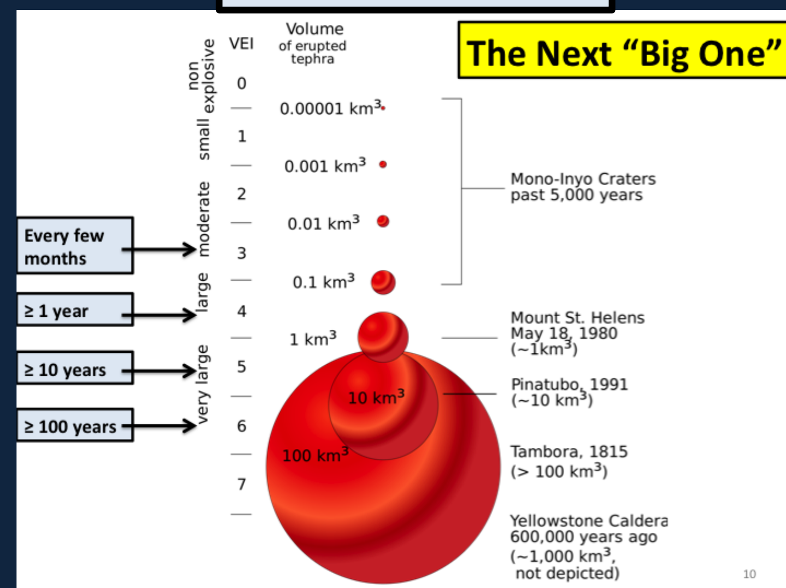
Volcanic Ash Tracking



Dispersion and Transport Modeling



Climate



End Users

- Volcanic Ash Advisory Centers
- Meteorological Watch Offices
- Weather Forecast Offices
- Volcano Observatories (including the USGS)
- Military
- Operational modeling community (dispersion, weather, and climate)
- Research Community

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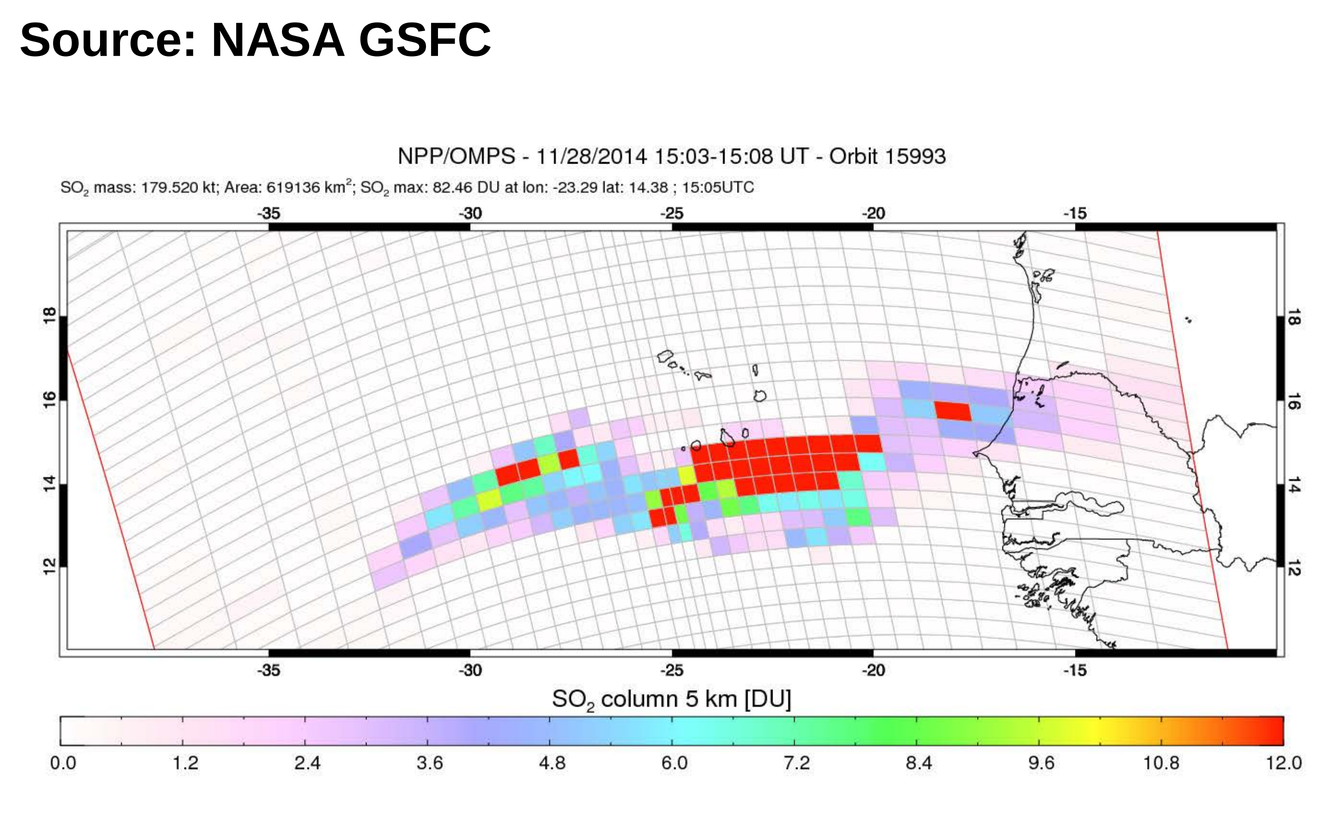
Ultra-Violet (OMPS)



<u>**Major Strengths:**</u>

- **Very sensitive to the presence of SO_2 under many conditions including in the presence of clouds (liquid, ice, and aerosol) and over bright surfaces**

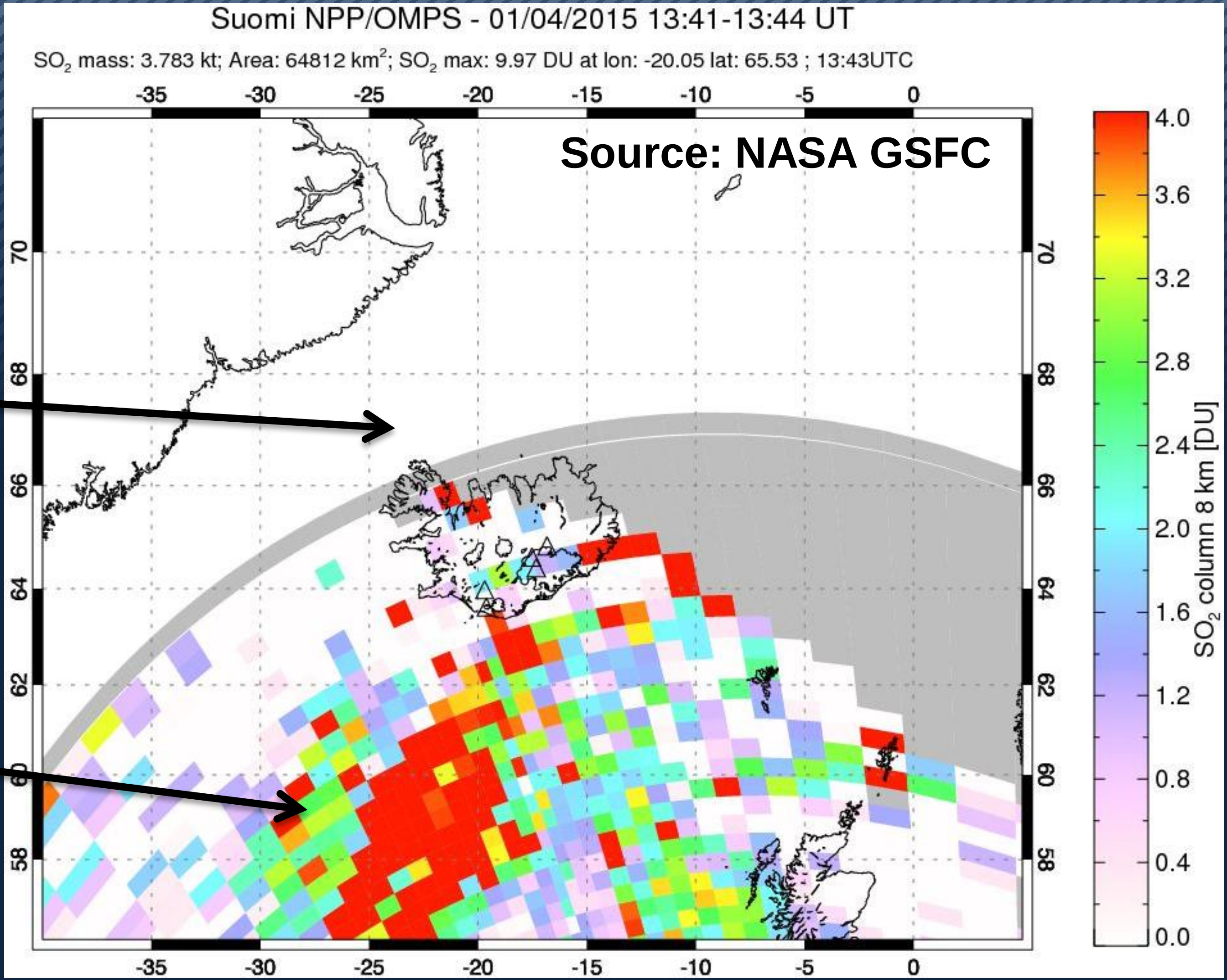
- **Sensitive to SO_2 loading, some sensitivity to SO_2 height**

Ultra-Violet (OMPS)

Weakness: Sensitive to solar zenith angle

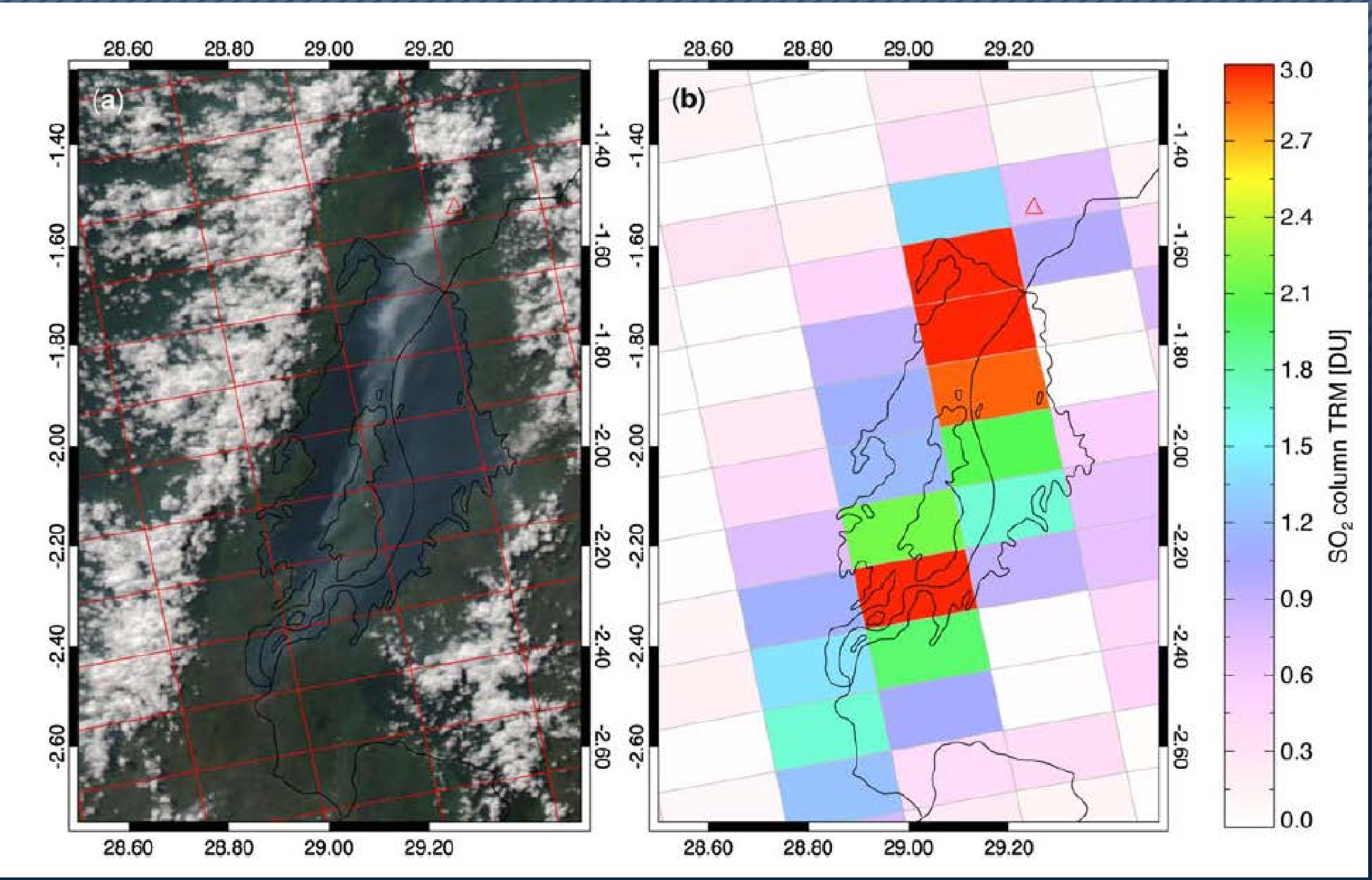
No information when SZA > 90º

Increased noise as SZA increases to 90º



Ultra-Violet (OMPS)

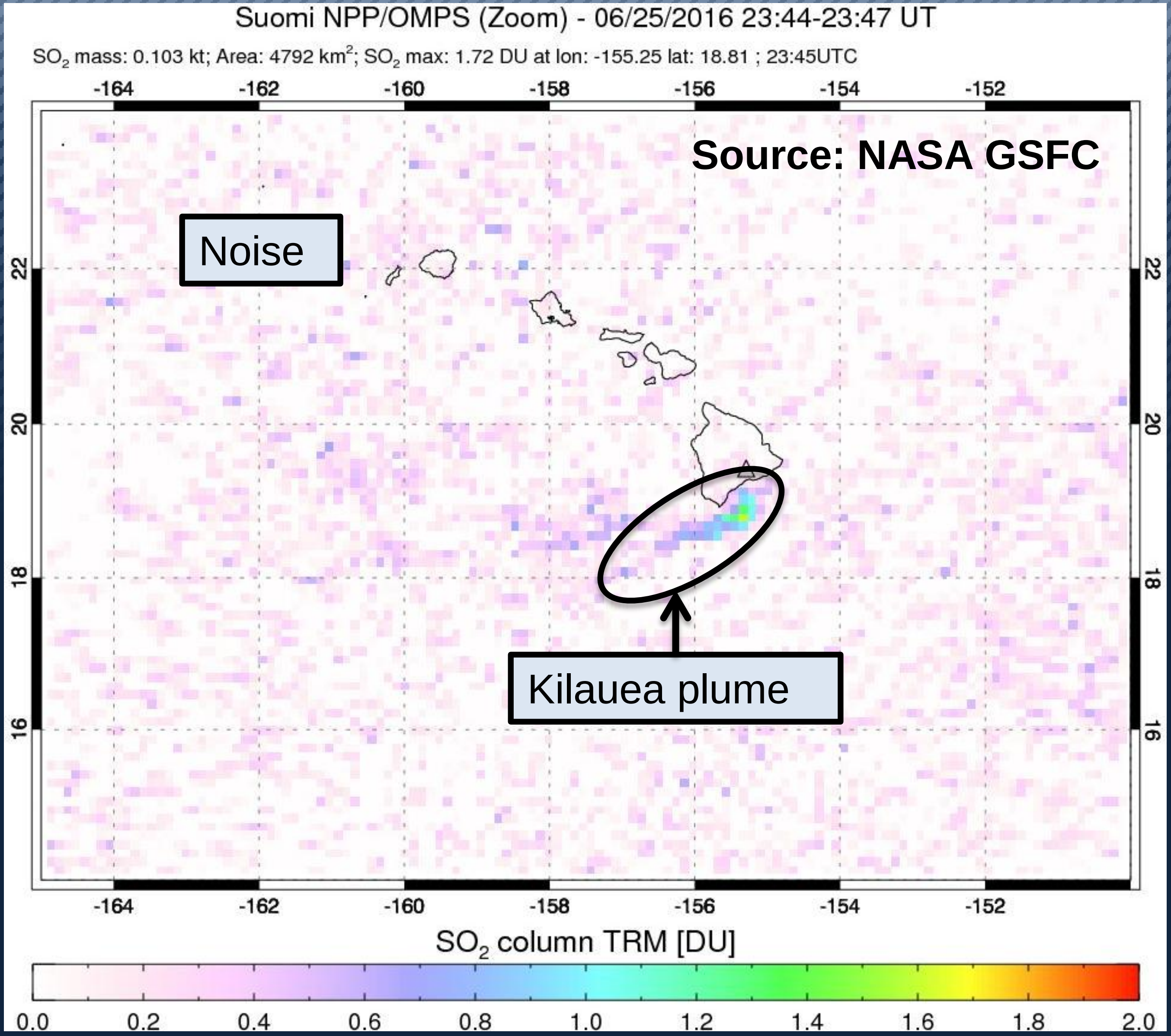
Weakness: Large footprint size relative to spatial scale of many SO_2 plumes



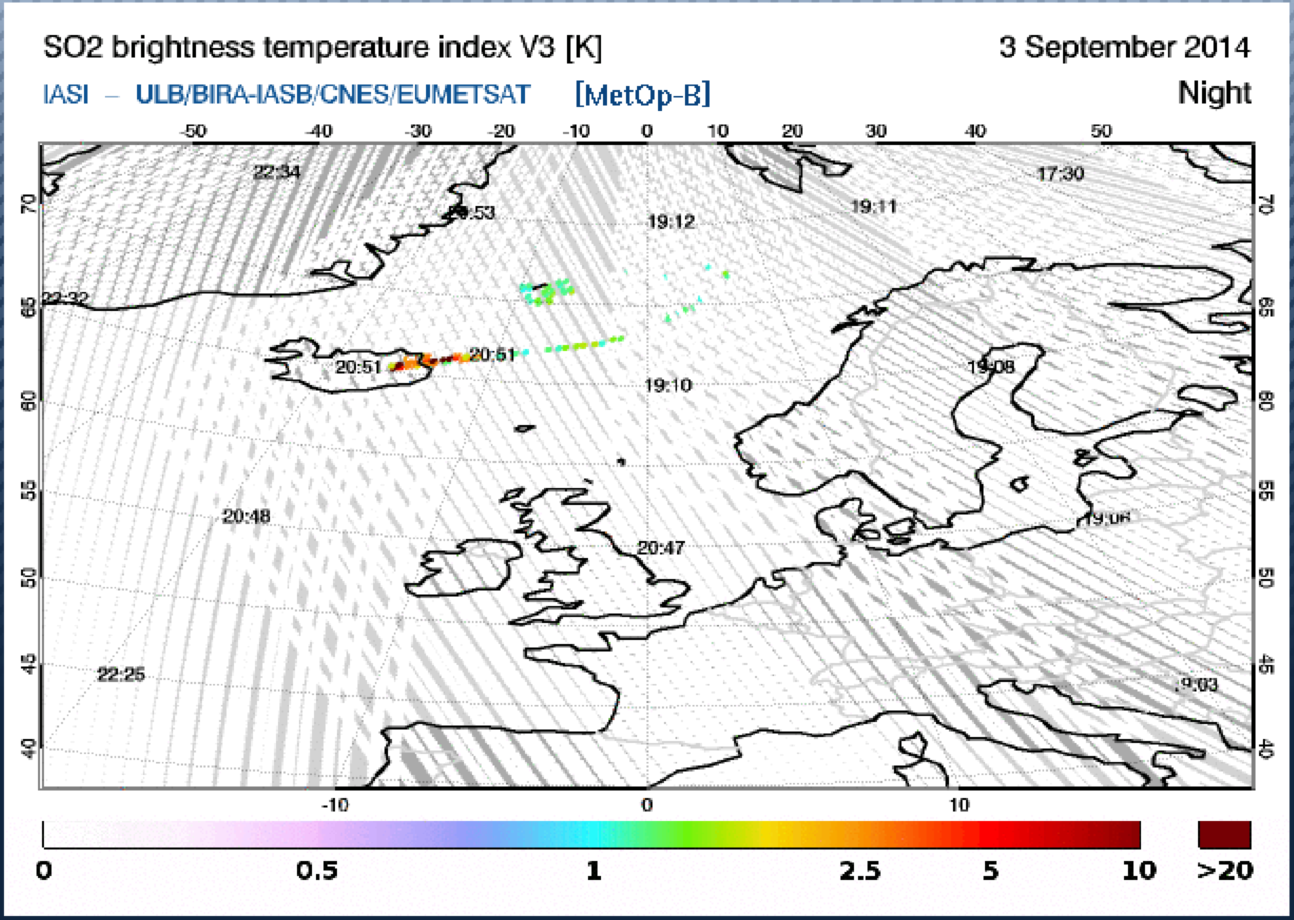
Carn et al., 2013

Ultra-Violet (OMPS)

Weakness: Noise



Hyperspectral Infrared (CrIS)

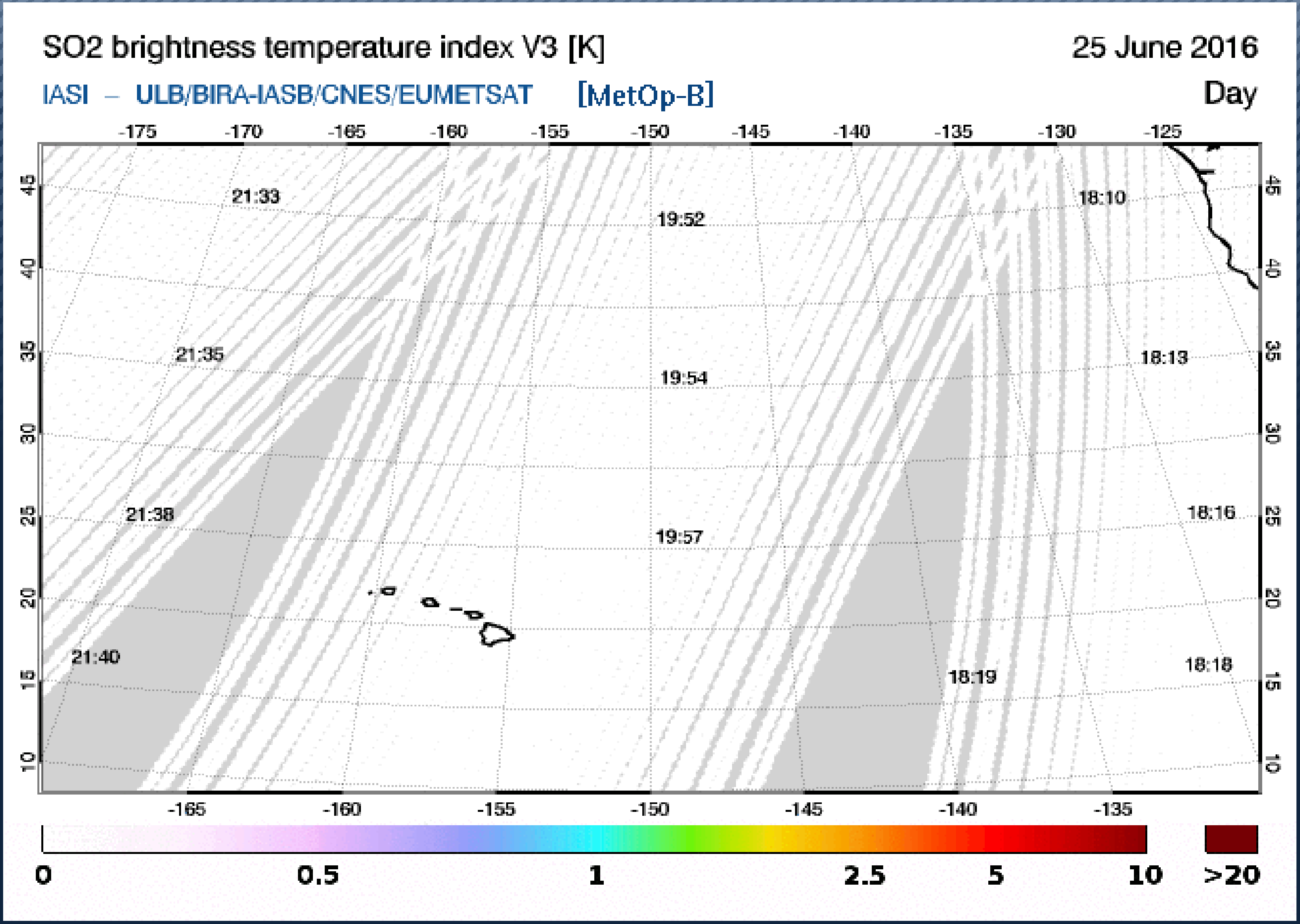


Major Strengths:

- **Provides information on SO_2 day and night**
- **Provides sensitivity to SO_2 loading and height**

Hyperspectral Infrared (CrIS)

Weakness: Less sensitive to lower tropospheric SO_2



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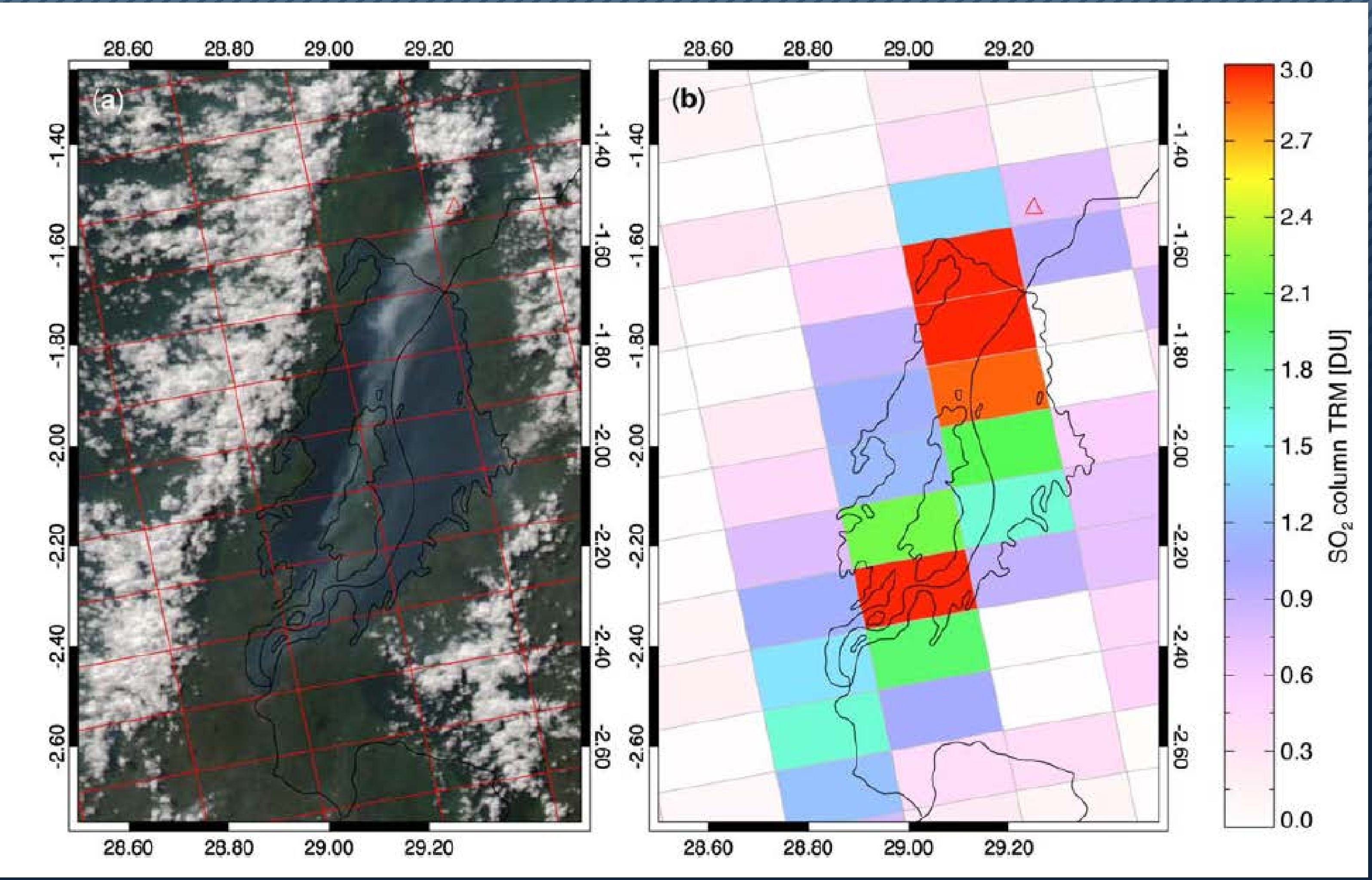
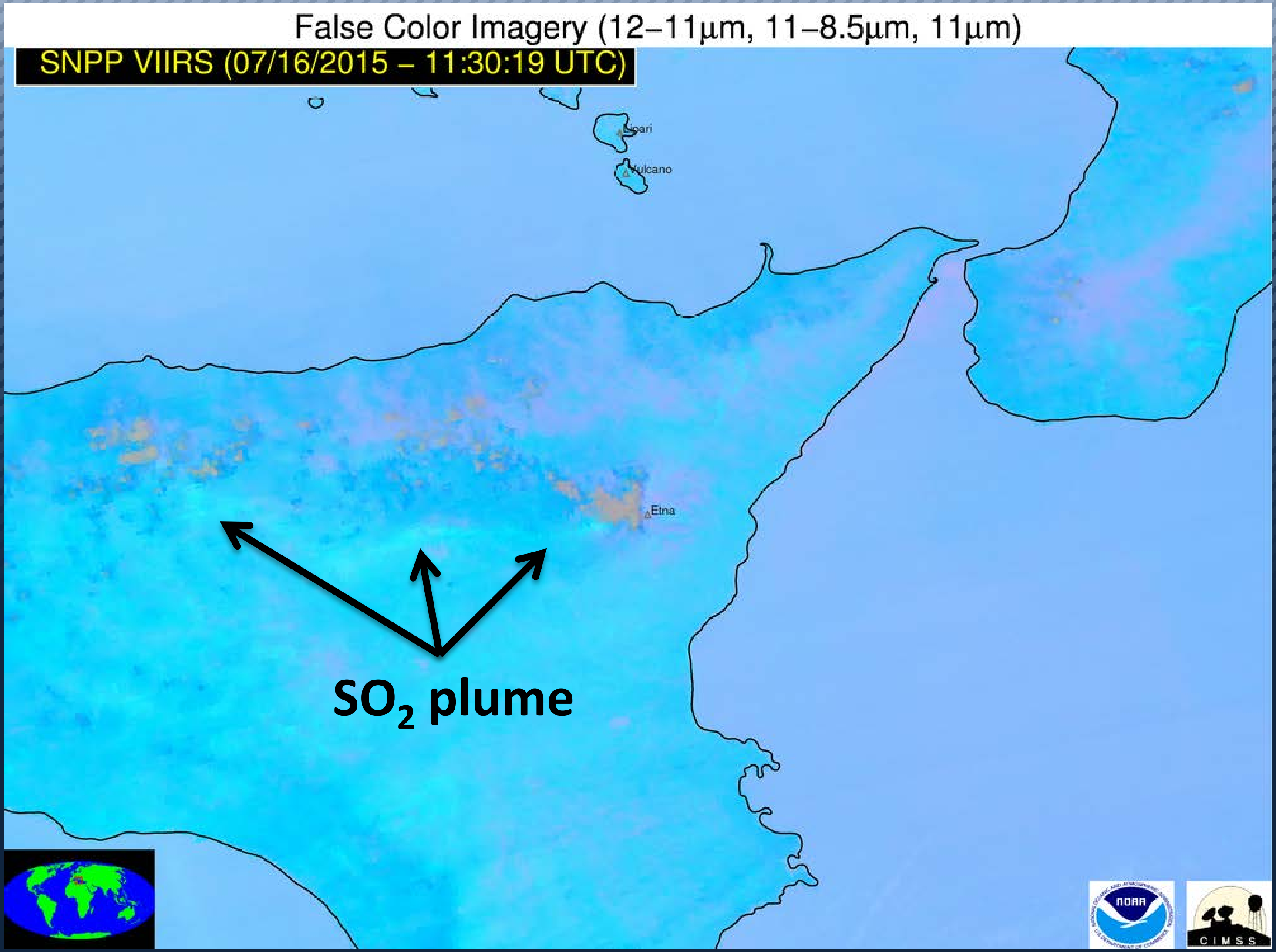


Carn et al., 2013

Narrow-band Imager (VIIRS)

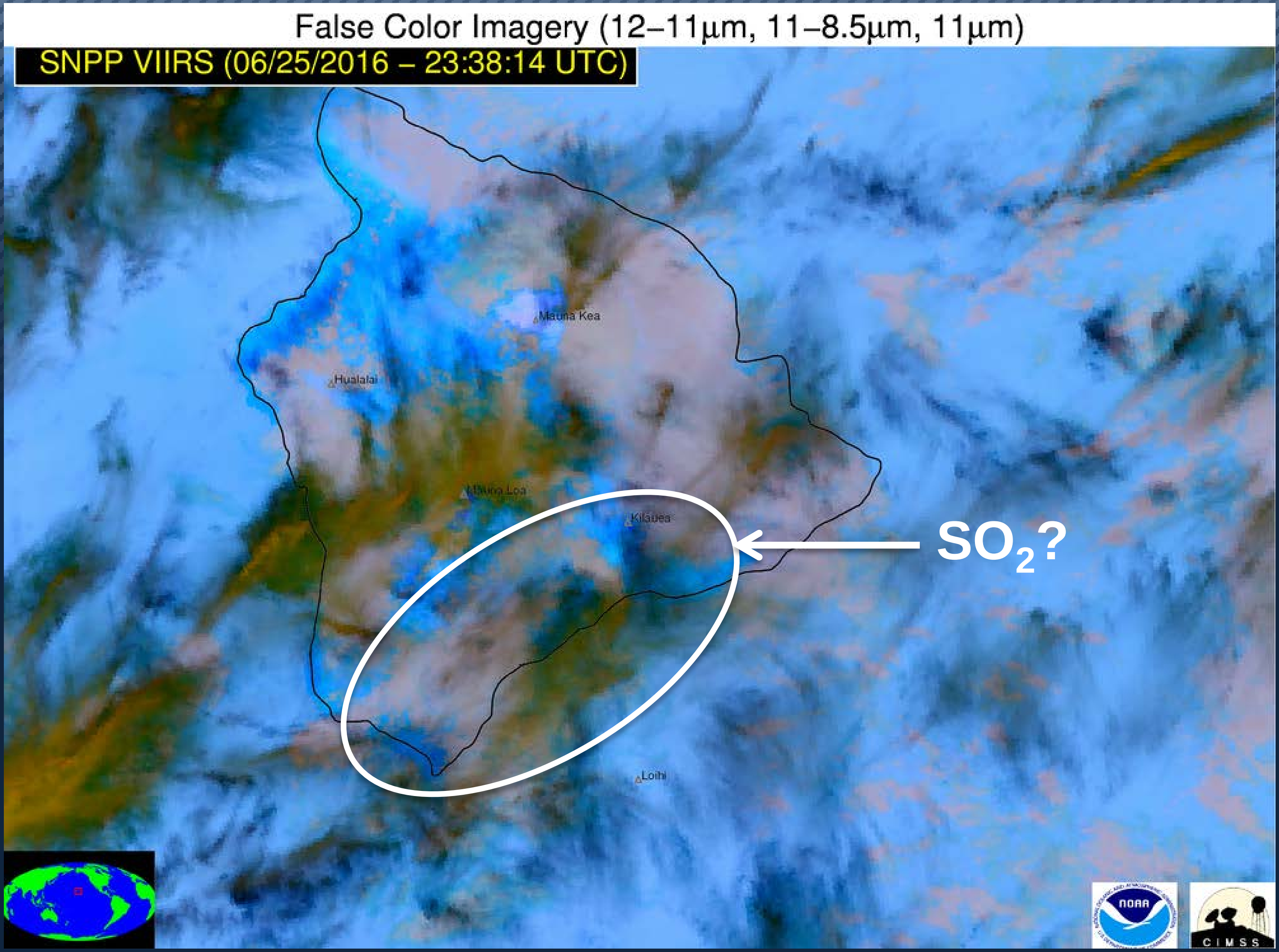


Major Strengths:

- **Provides high spatial resolution imagery of SO_2 clouds and plumes under many conditions day and night.**

Narrow-band Imager (VIIRS)

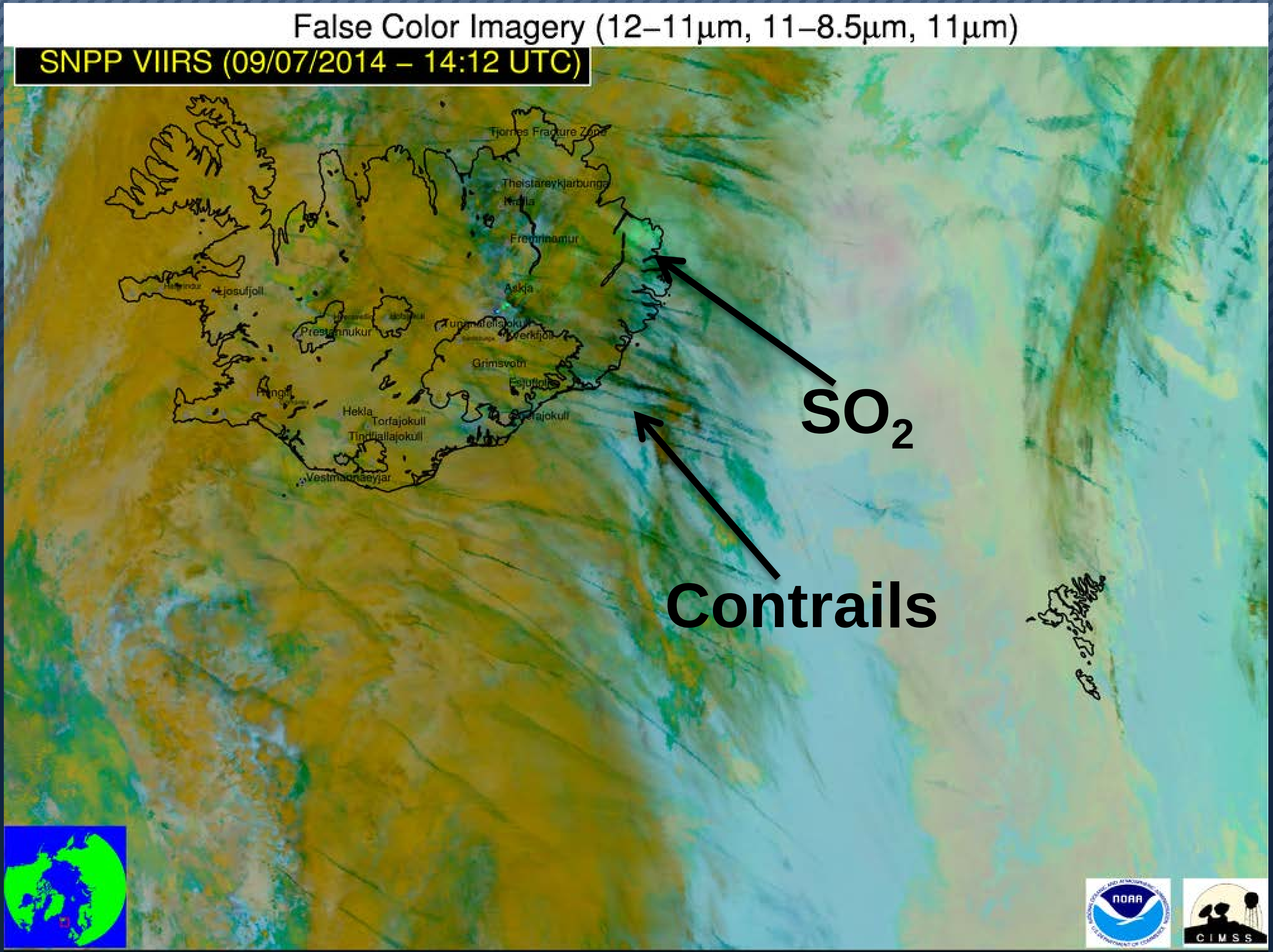
Weakness: Larger lower limit of detection, especially in the presence of clouds



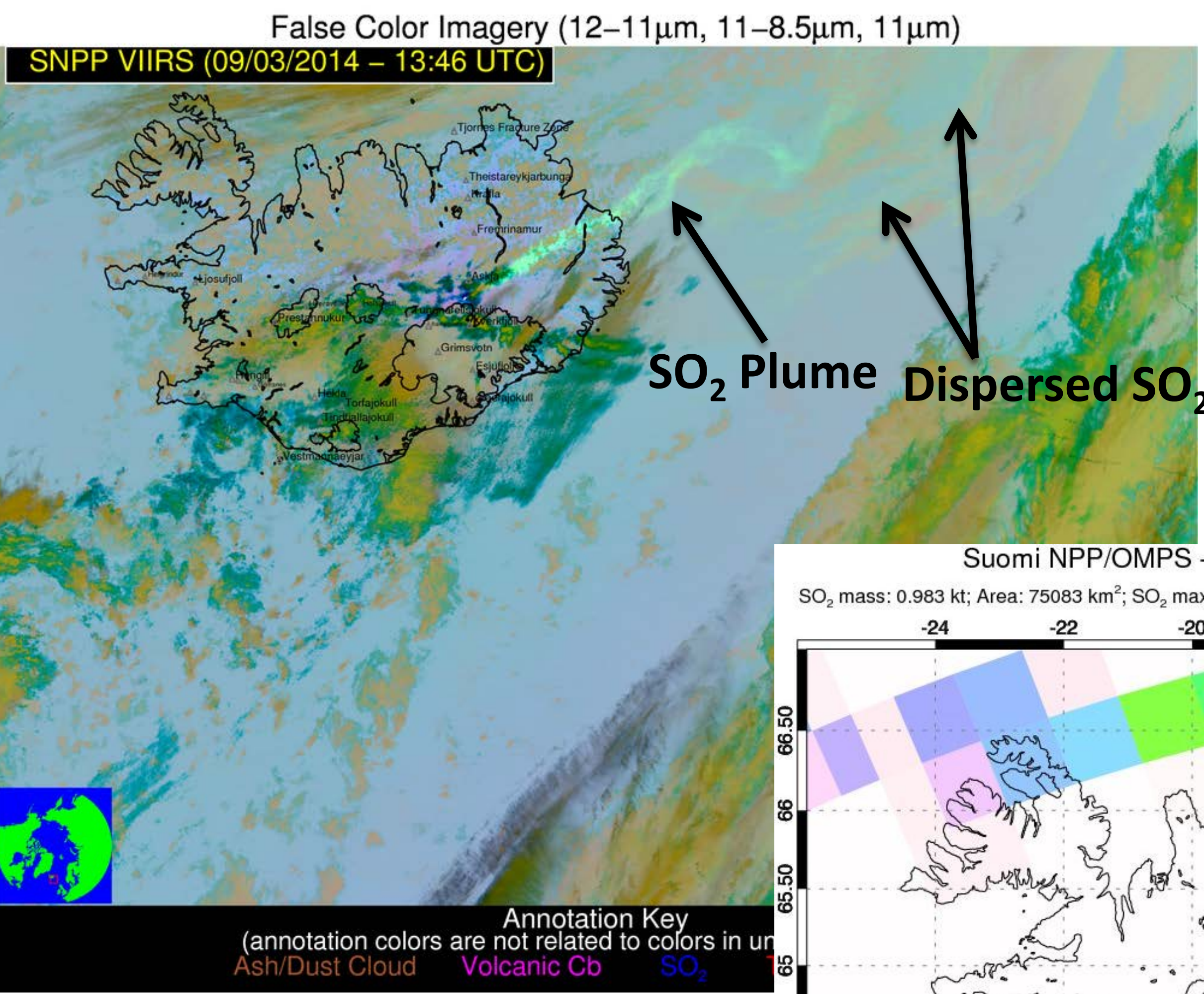
SO_2?

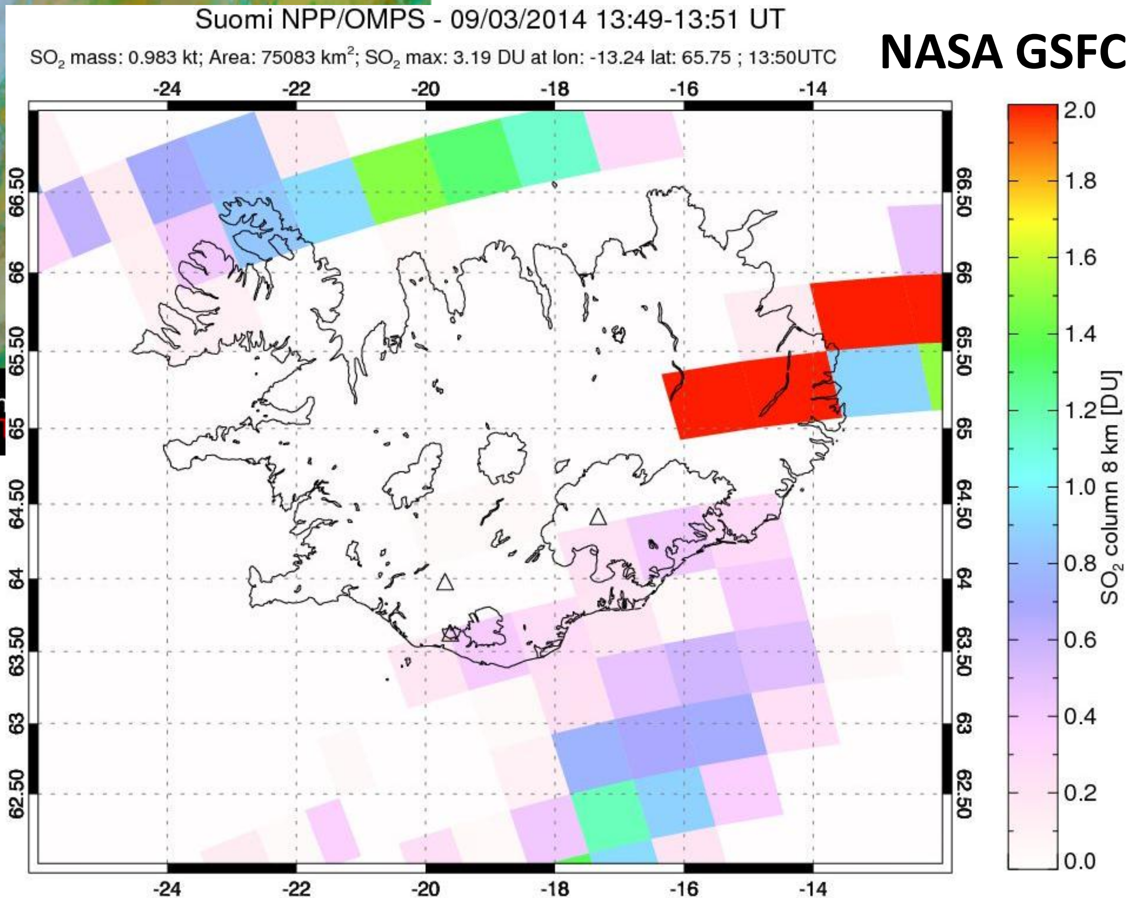
Narrow-band Imager (VIIRS)

Weakness: Challenging to extract quantitative information without additional constraints



A multi-sensor SO_2 analysis is needed





NASA GSFC

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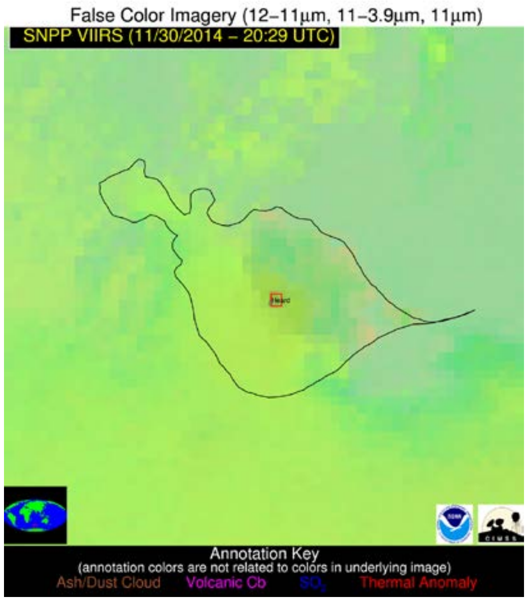
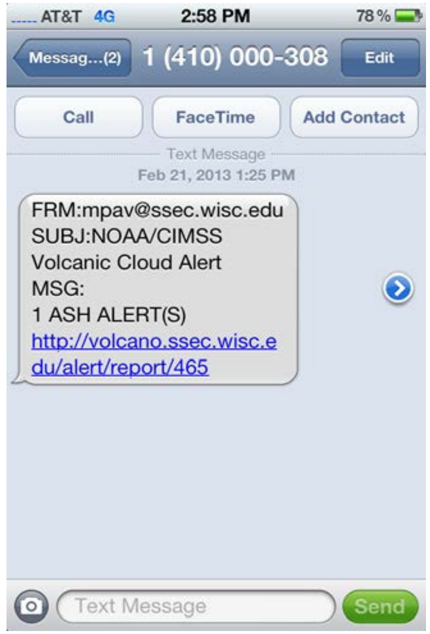
VOLcanic Cloud Analysis Toolkit (VOLCAT)

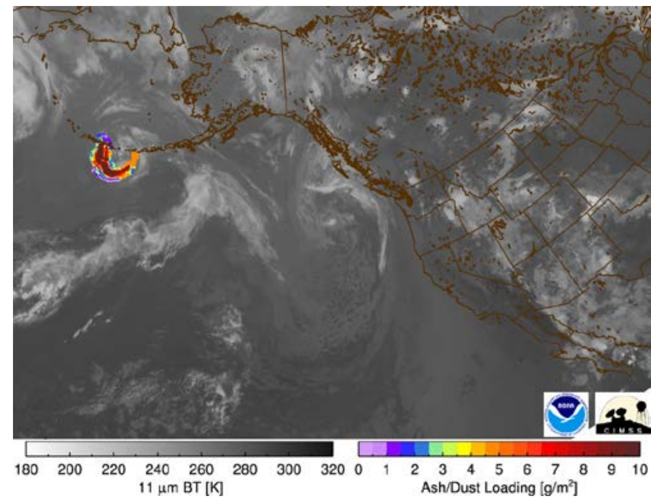
1). Unrest Alerts



2). Eruption Alerts



3). Volcanic Cloud Tracking



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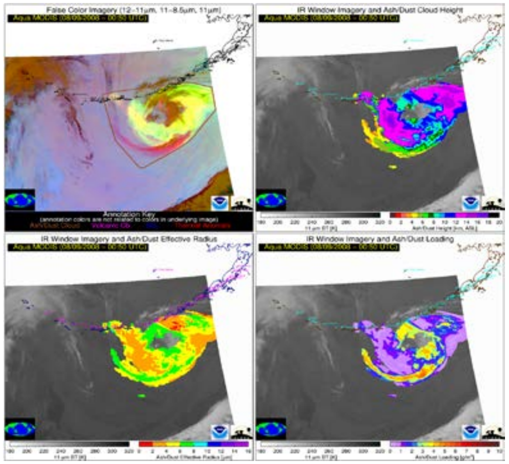
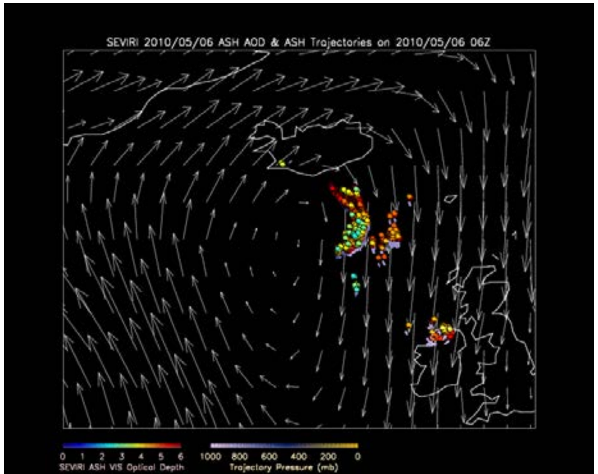


5). Dispersion Forecasting



Spectrally Enhanced Cloud Objects (SECO) Method for SO_2 Detection

- Automatically extract coherent SO_2features from OMPS and CrIS using cloud object analysis
- Construct an *a priori* probability from OMPS and CrIS and utilize it in VIIRS implementation of SECO method
- Final SO_2 detection results are at the VIIRS resolution and are overlaid on VIIRS imagery
- The fused JPSS SO_2 detection results can then be used to aid in SO_2 detection and tracking from GEO satellites

SO_2 Retrieval Options

- Utilize existing OMPS SO_2 loading products
- A variation on published methods (e.g. NUCAPS, Carboni et al. 2012; Clarisse et al., 2014) will be used to retrieve SO_2 loading and effective height from CrIS
- Optimal estimation readily allows the results from one sensor to influence another through the *a priori*. Thus, the result from OMPS or CrIS, which ever is deemed to be of higher quality, can be used to constrain the VIIRS retrieval, while allowing for small-scale spatial variability to be captured
- Many details TBD – this is R&D, not manufacturing!

References

- Pavolonis, M. J., W. F. Feltz, A. K. Heidinger, and G. M. Gallina, 2006: A daytime complement to the reverse absorption technique for improved automated detection of volcanic ash. J.Atmos.Ocean.Technol., **23**, 1422-1444.

- Pavolonis, M. J., 2010: Advances in Extracting Cloud Composition Information from Spaceborne Infrared Radiances-A Robust Alternative to Brightness Temperatures. Part I: Theory. Journal of Applied Meteorology and Climatology, **49**, 1992-2012, doi:10.1175/2010JAMC2433.1 ER.

- Pavolonis, M., A. Heidinger, and J. Sieglaff, 2013: Automated retrievals of volcanic ash and dust cloud properties from upwelling infrared measurements, J. Geophysical Research, **118(3)**, 1436-1458.

- Pavolonis, M., J. Sieglaff, and J. Cintineo (2015a), Spectrally Enhanced Cloud Objects (SECO): A Generalized Framework for Automated Detection of Volcanic Ash and Dust Clouds using Passive Satellite Measurements, Part I: Multispectral Analysis, Journal Geophysical Research, **120**, 7813-7841.

- Pavolonis, M., J. Sieglaff, and J. Cintineo (2015b) Spectrally Enhanced Cloud Objects (SECO): A Generalized Framework for Automated Detection of Volcanic Ash and Dust Clouds using Passive Satellite Measurements, Part II: Cloud Object Analysis and Global Application, Journal Geophysical Research, **120**, 7842-7870.

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Collaborations

- Fusing information from many sensors is challenging. Collaborations with hyperspectral UV and IR SO_2 remote sensing groups at NASA and in academia are needed.

- In addition, a collaborative effort with the USGS, academia, and international partners (e.g. IMO) is needed to validate the fused JPSS SO_2 analysis.

- International collaboration is needed to work towards best practices for combining measurements from multiple satellite sensors – connection to WMO SCOPE-Nowcasting.

- Collaboration with the dispersion, weather, and climate modeling communities are critical to ensure that the impact of the information is maximized

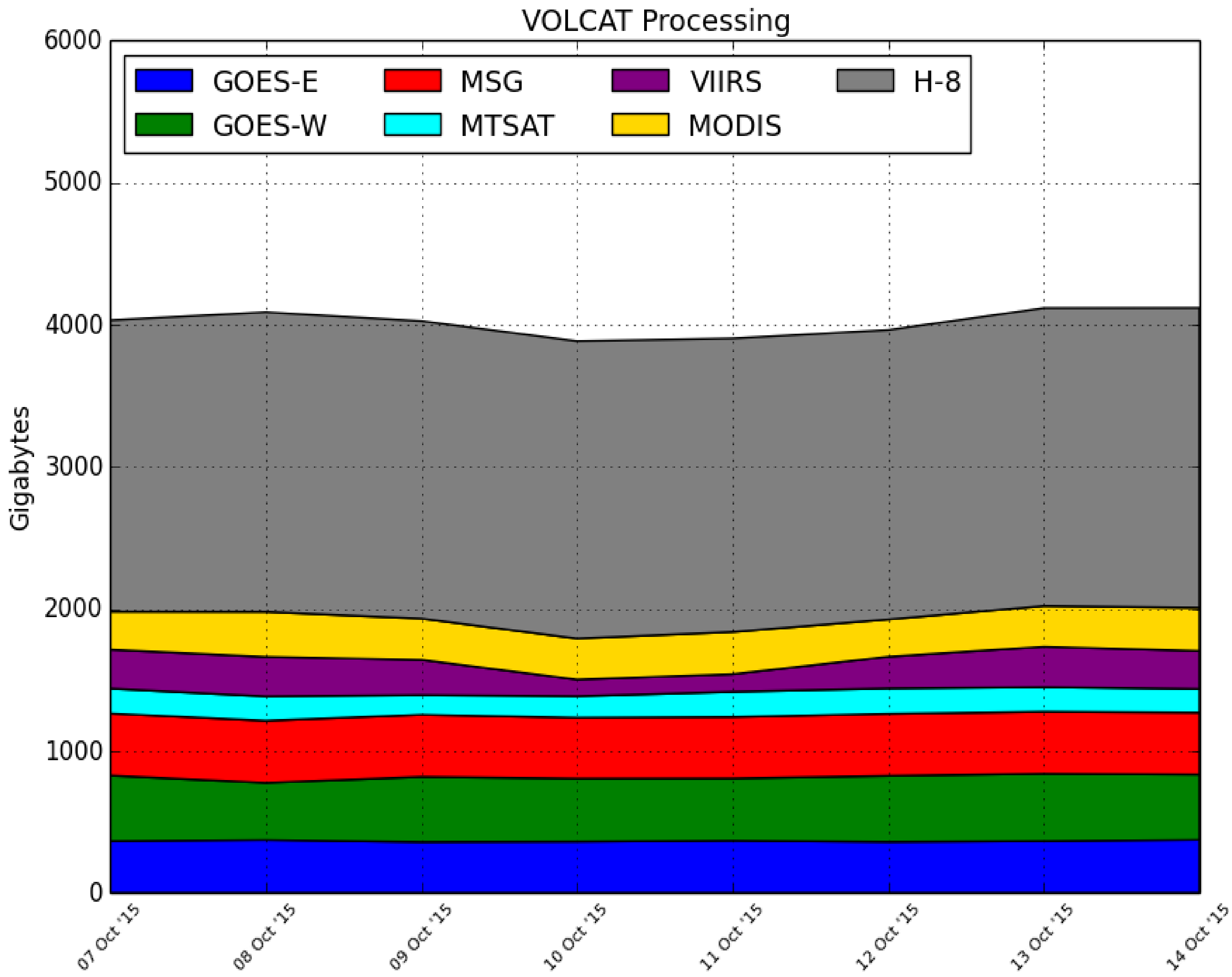
Summary

- In support of NOAA's mission, NOAA's role in generating environmental intelligence related to SO_2 needs to be expanded (and integrated with information on volcanic ash) in collaboration with NASA, USGS, and international partners.

- The JPSS satellite series is a critical component of the SO_2 observing system

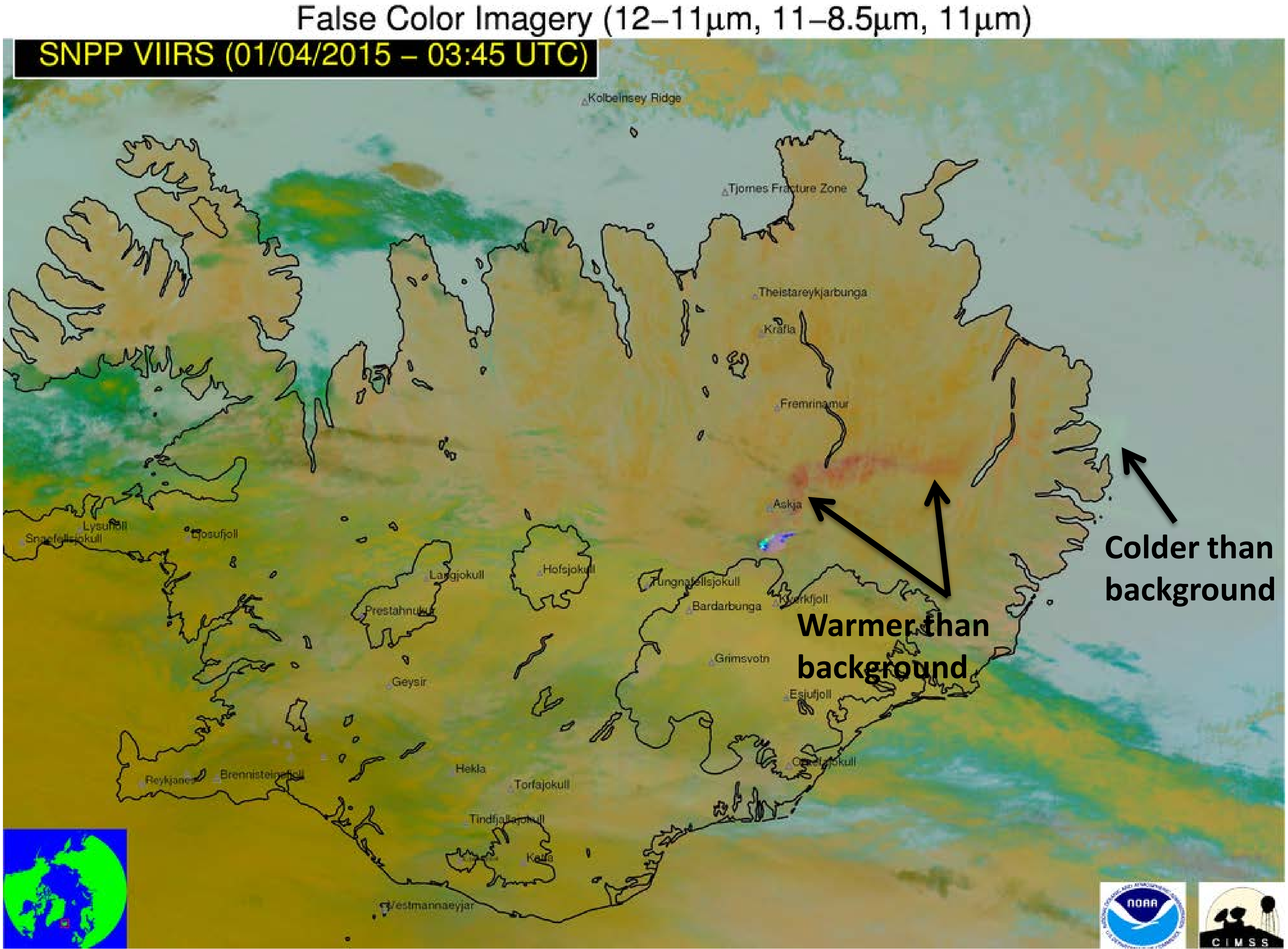
- A collaborative JPSS initiative is needed to ensure that the JPSS sensors are being fully utilized for SO_2 monitoring

"Big Data"

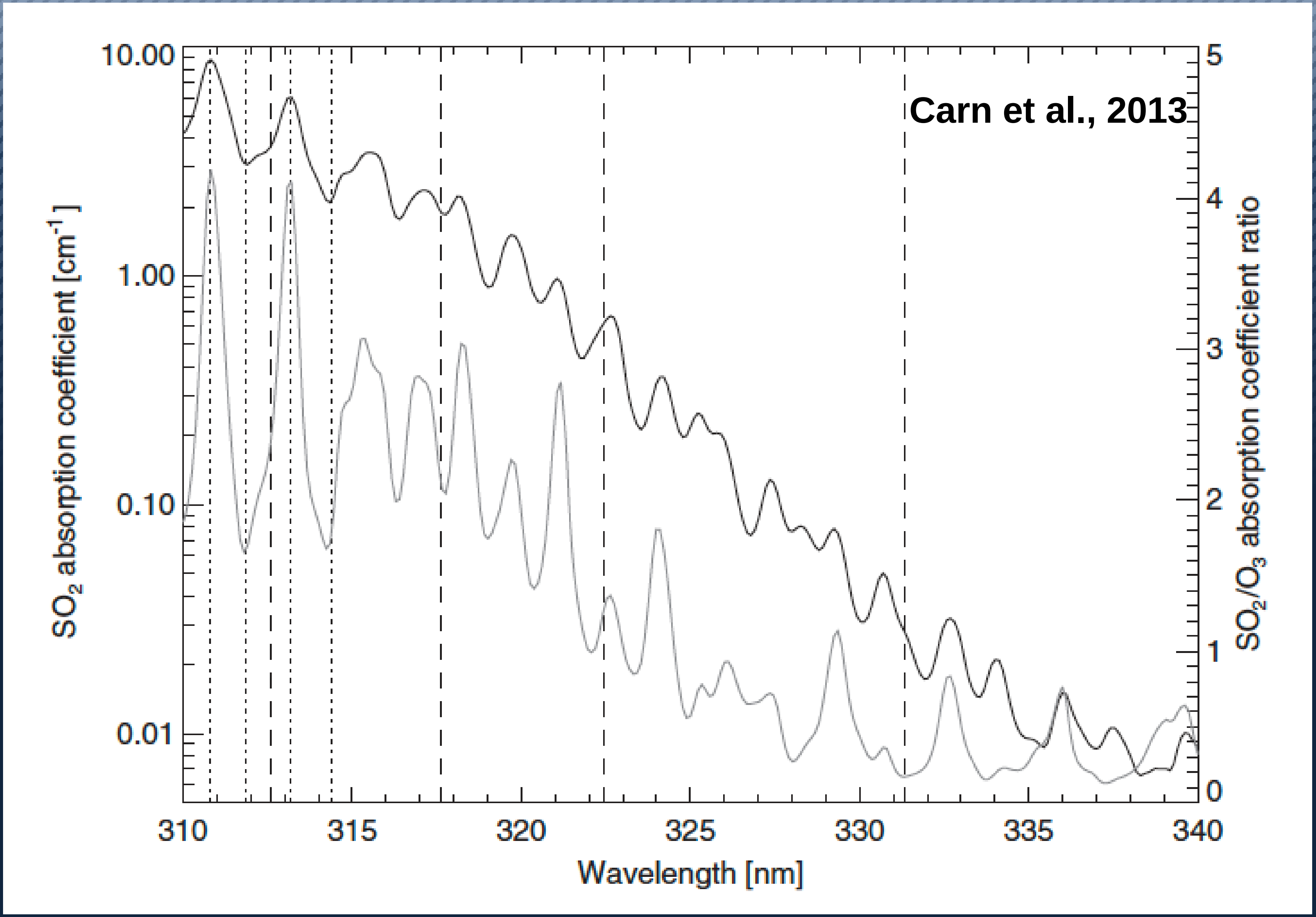

VOLCAT Processing
GOES-E
MSG
VIIRS
H-8
GOES-W
MTSAT
MODIS
Gigabytes
6000
5000
4000
3000
2000
1000
0
07 Oct '15
08 Oct '15
09 Oct '15
10 Oct '15
11 Oct '15
12 Oct '15
13 Oct '15
14 Oct '15

BACKUP SLIDES

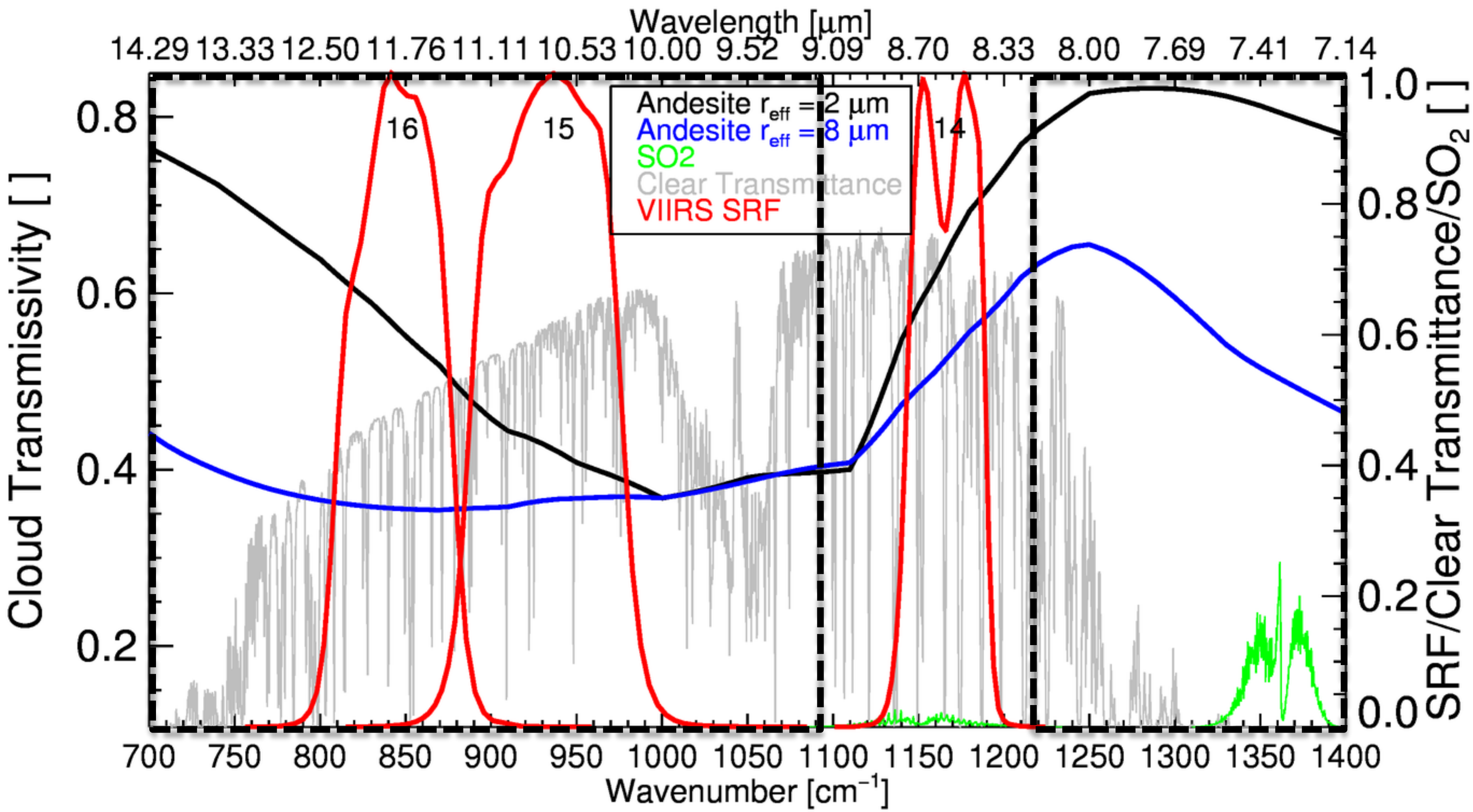
Nuances/Exceptions are Prevalent



UV Sensitivity



Infrared Sensitivity



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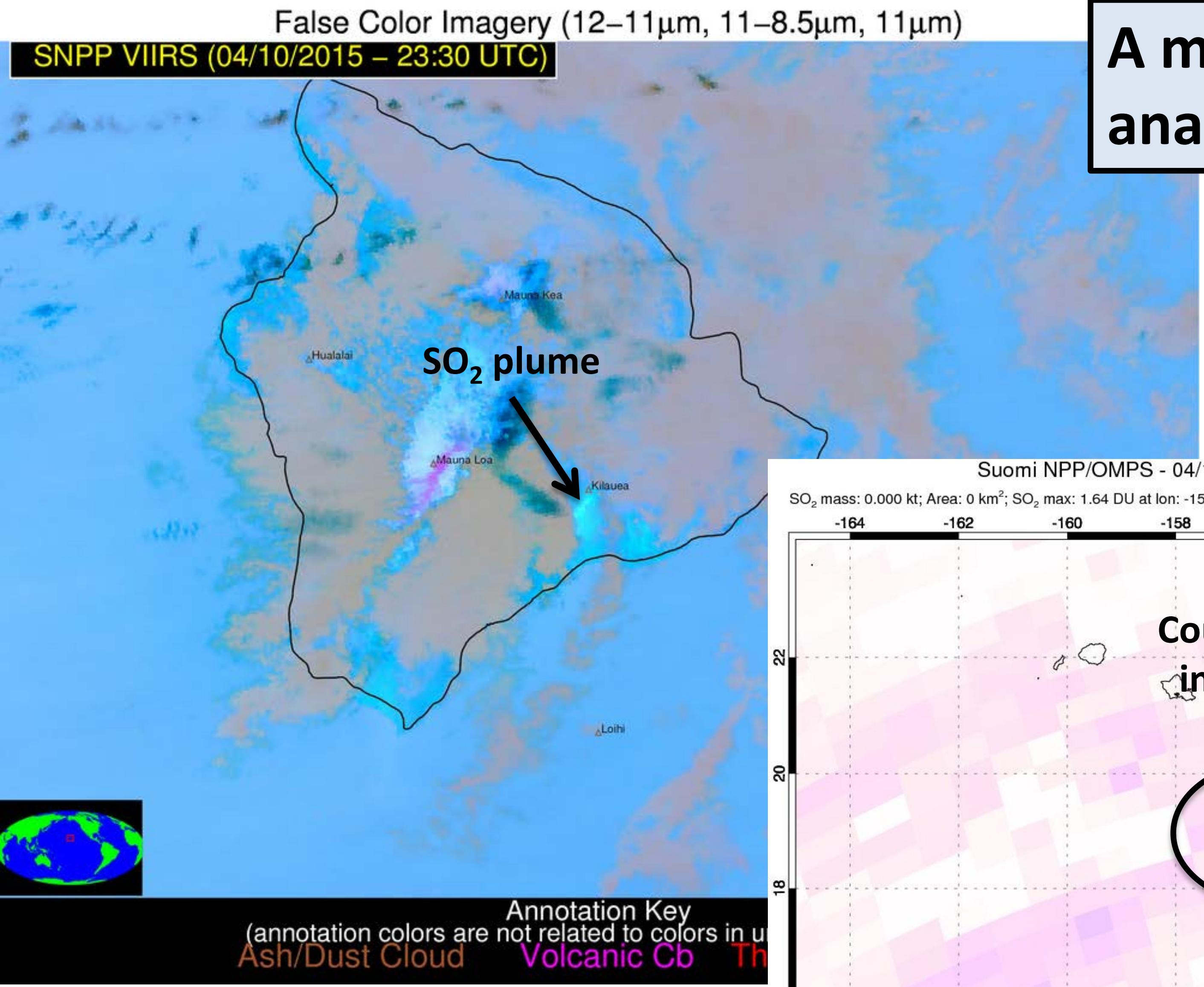
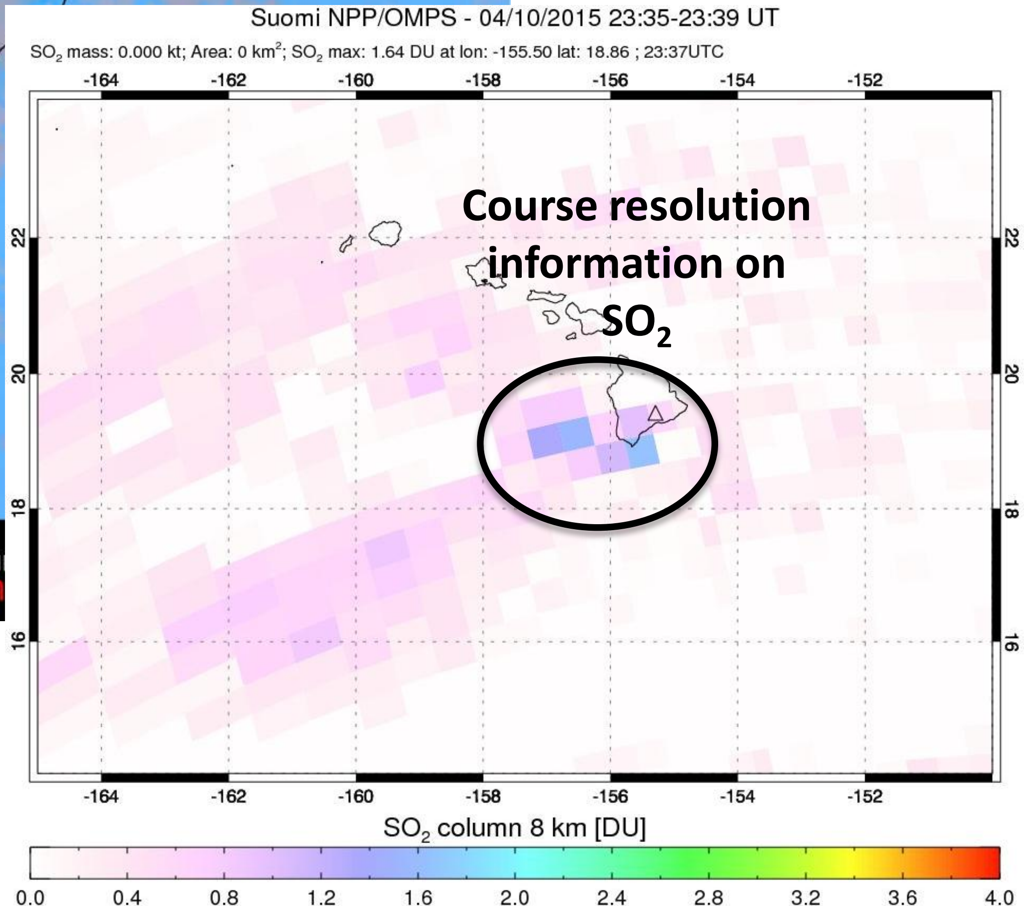




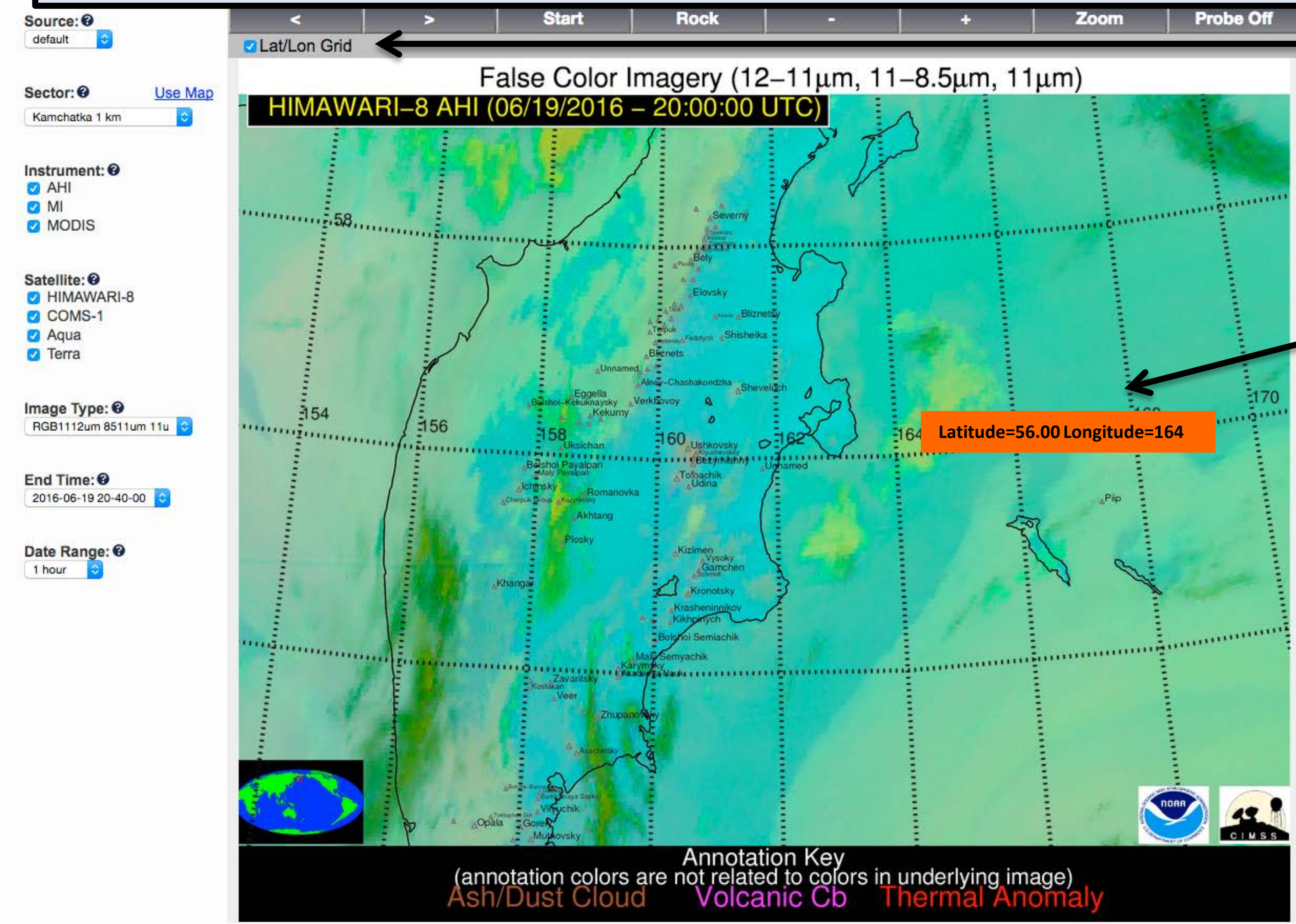
Optional Overlay Options: lat/lon grid, volcanoes, coast lines, VAAC boundaries, automated feature annotations

Image Probe: cursor readout of lat/lon and data value

Image Markup Tools: users can generate and export polygons and annotated images

SO_2: alerting, tracking, and characterization

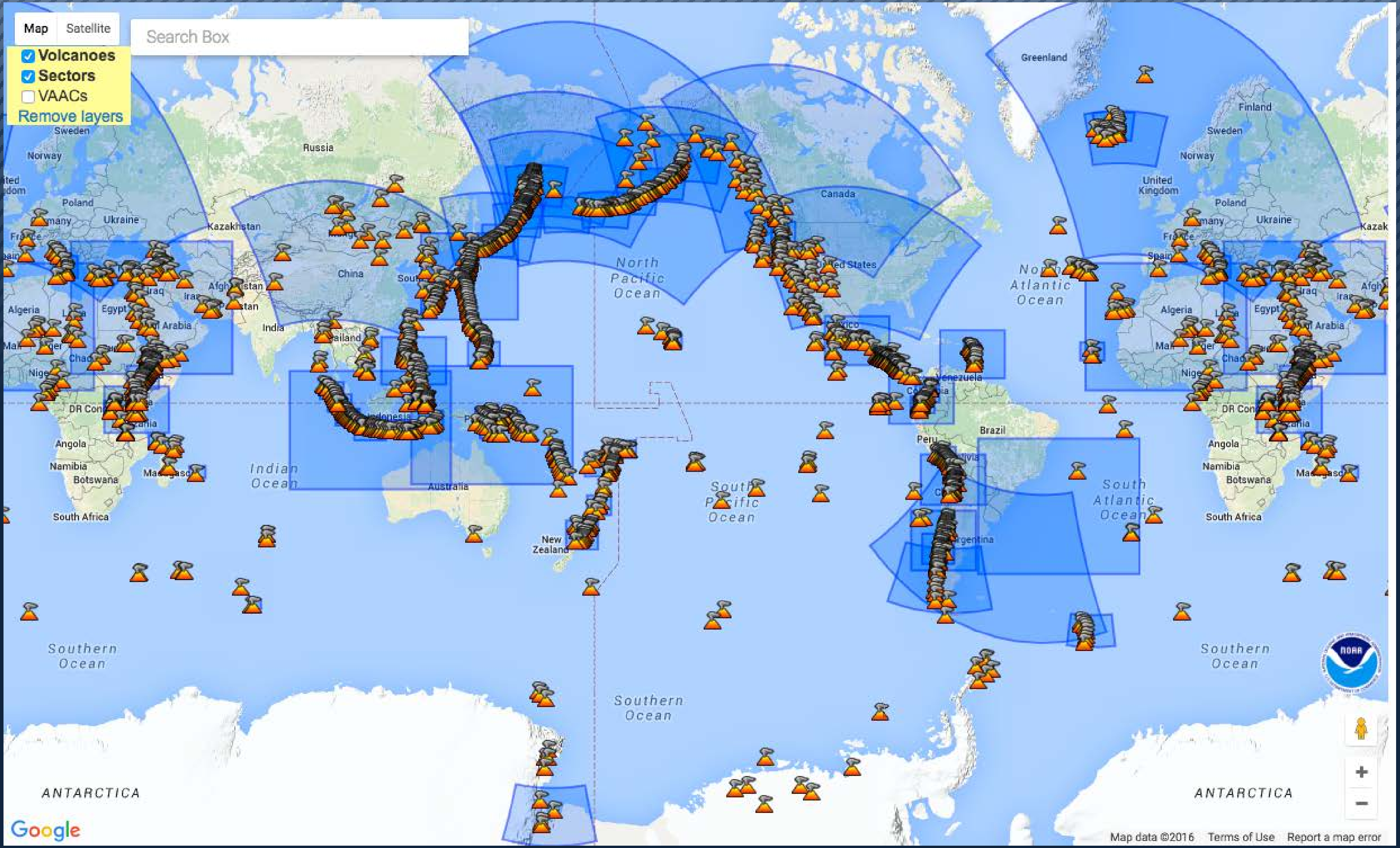
Incorporation of Non-Satellite Tools: volcano web cameras, dispersion/trajectory modeling, and infrasound



Overlay options

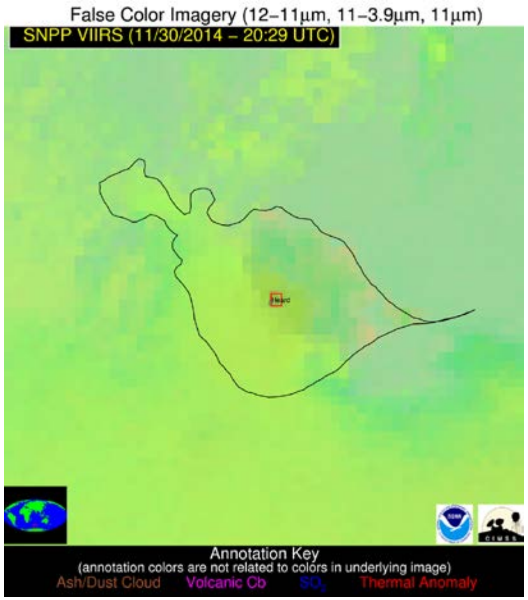
Image Probe

LEO and GEO satellite imagery are routinely generated for numerous geographic sectors that cover nearly every volcano in the world



VOLCAT Goals

1). Unrest Alerts



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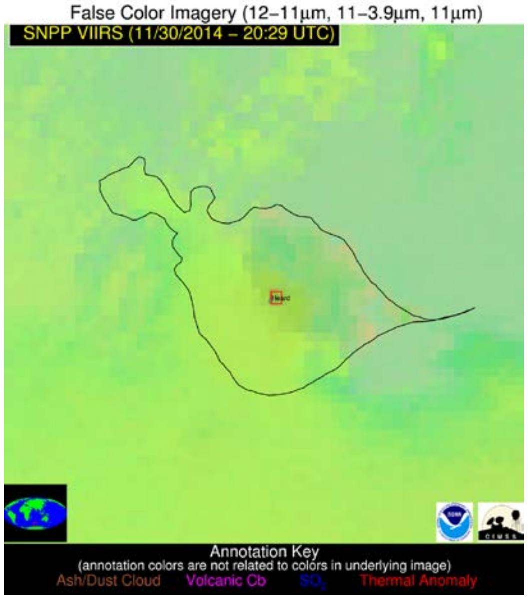

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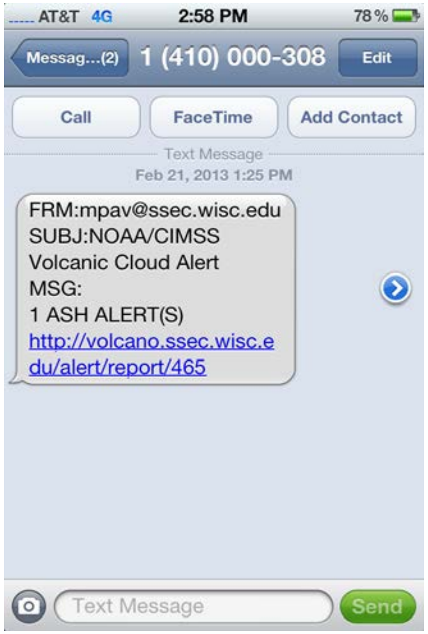

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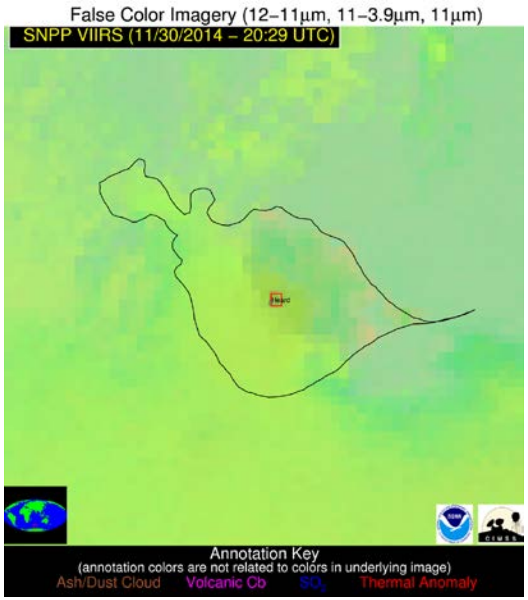

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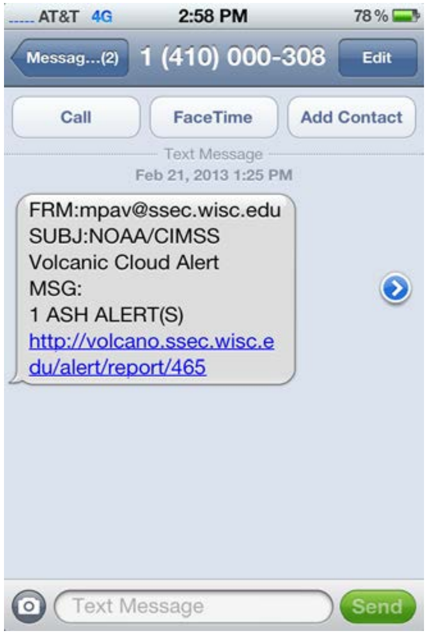

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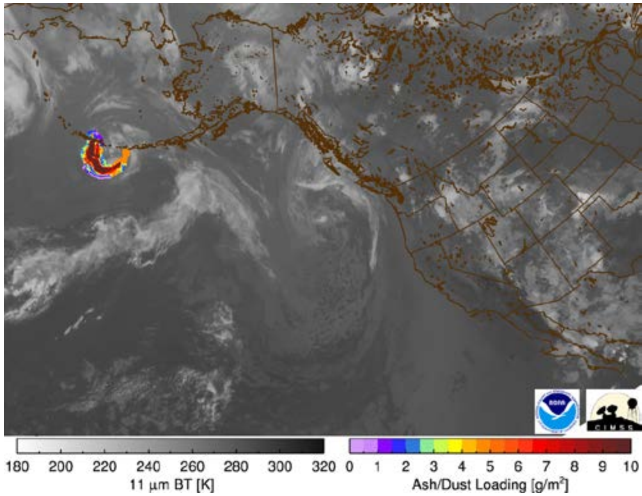

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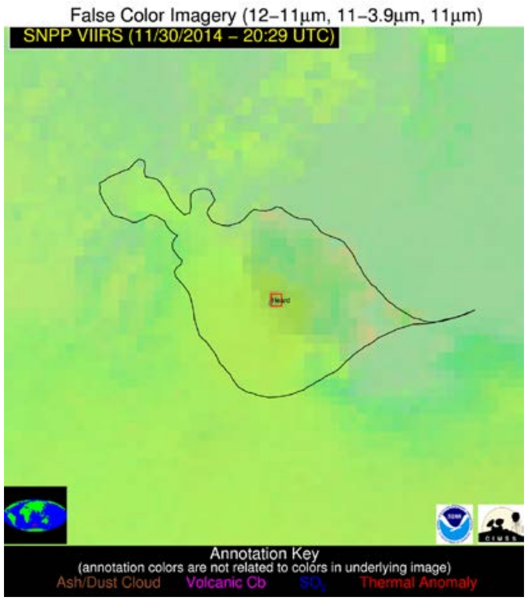

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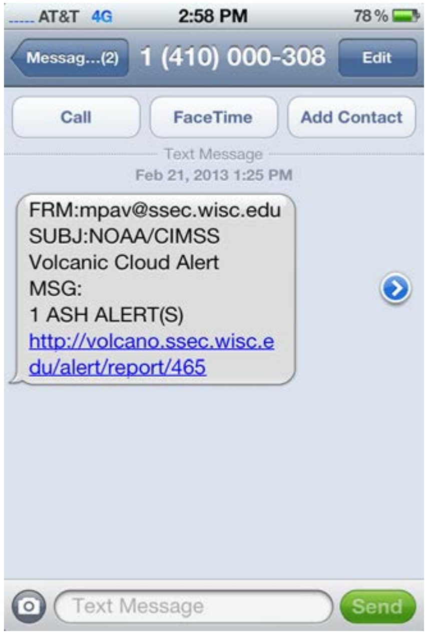

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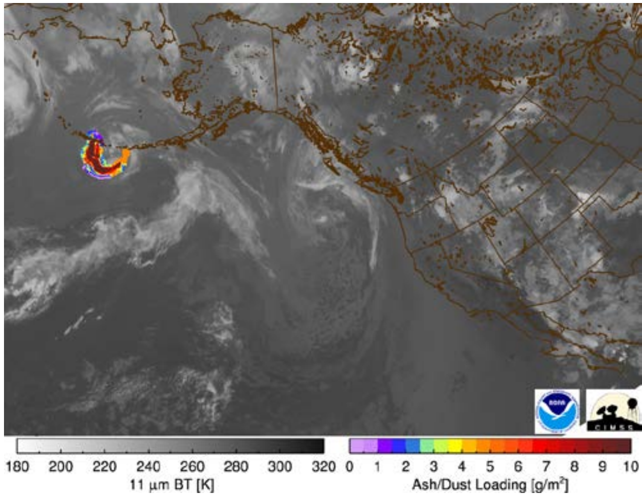

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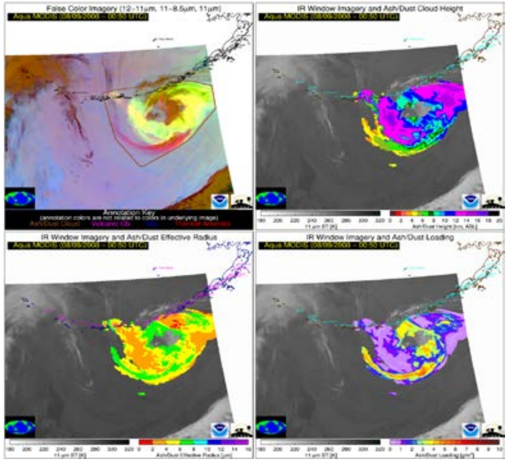

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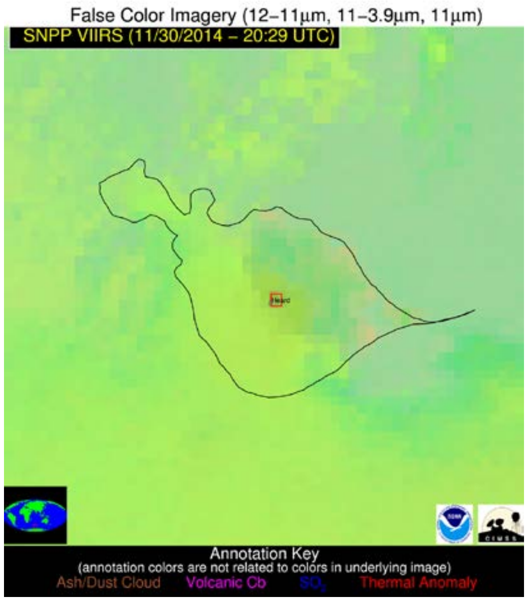

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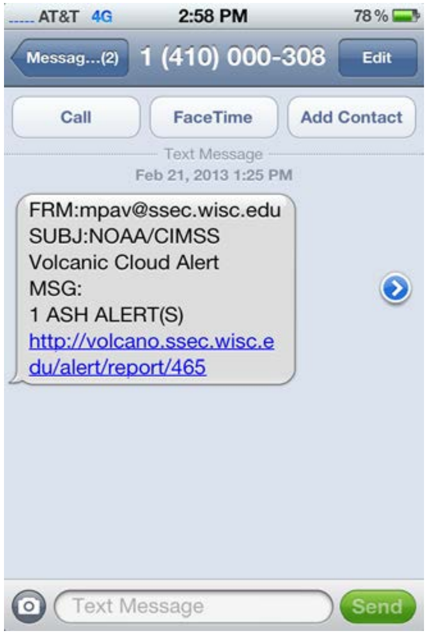

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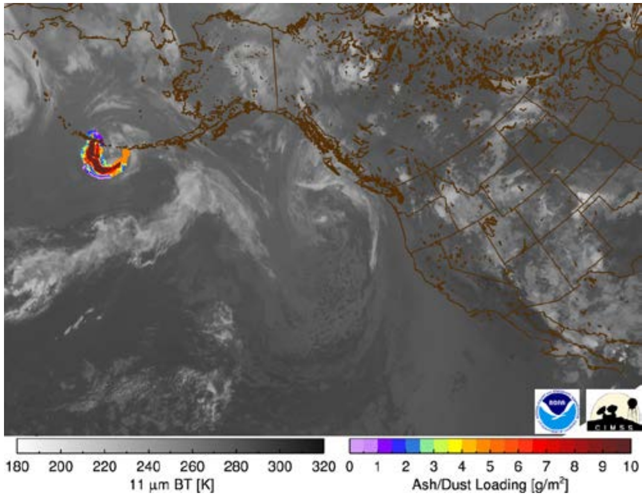

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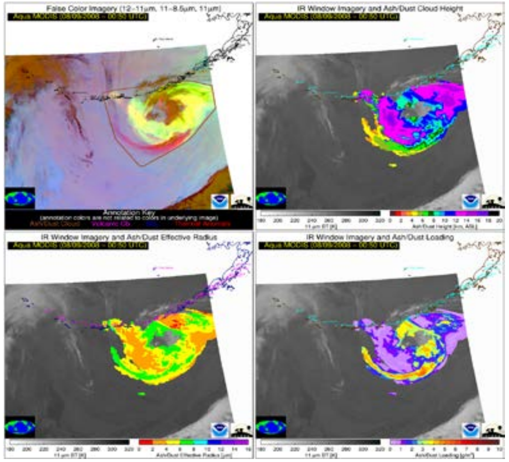

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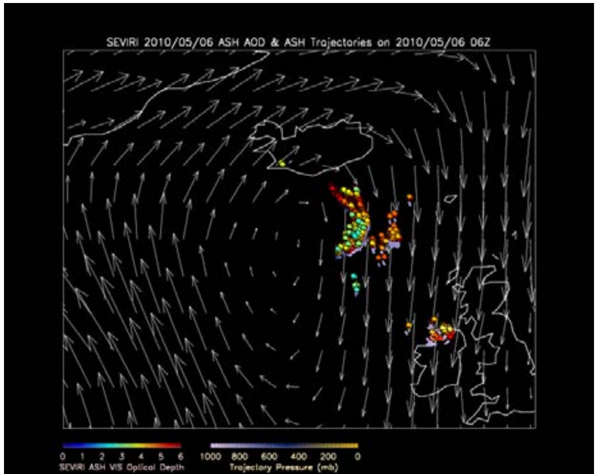

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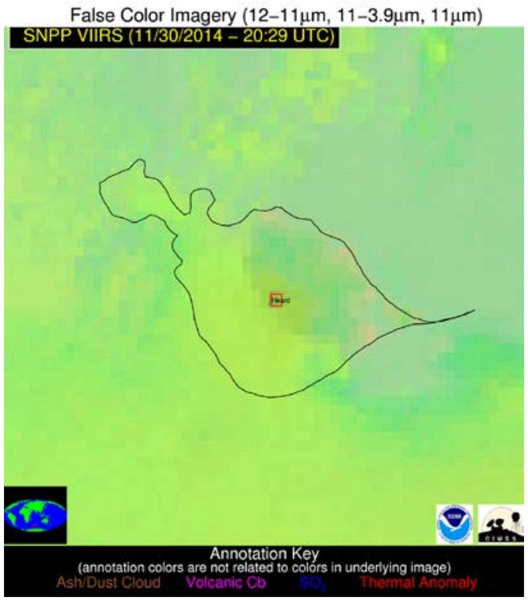

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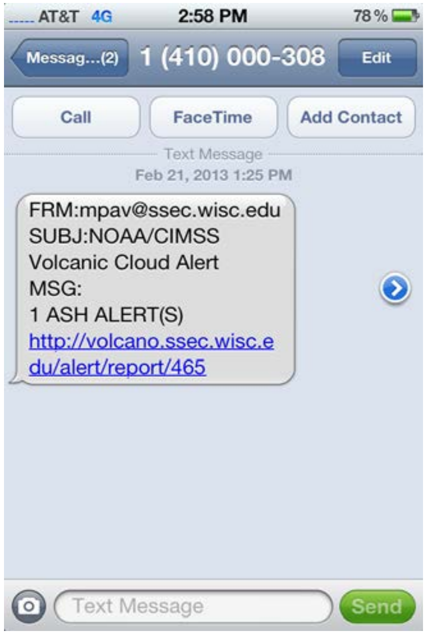

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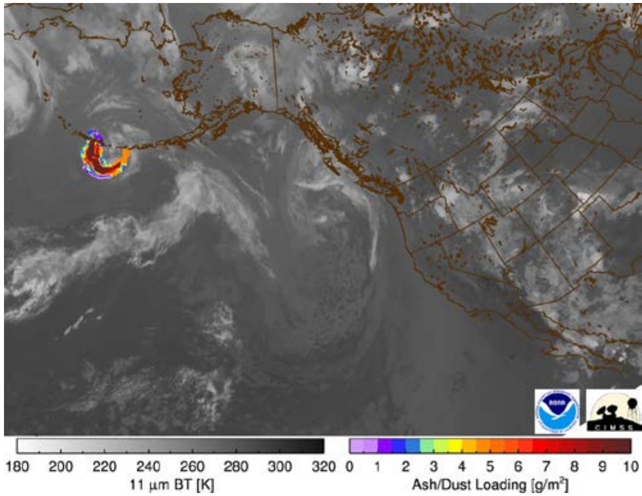

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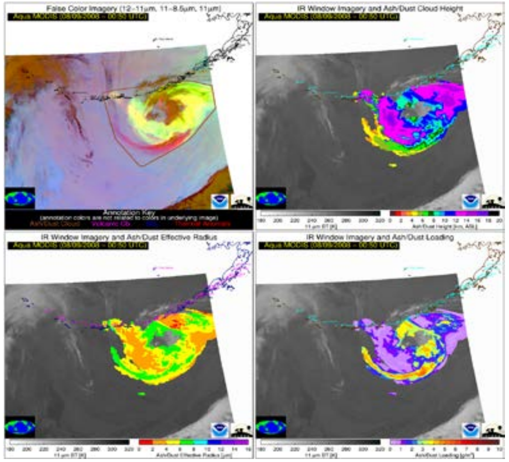

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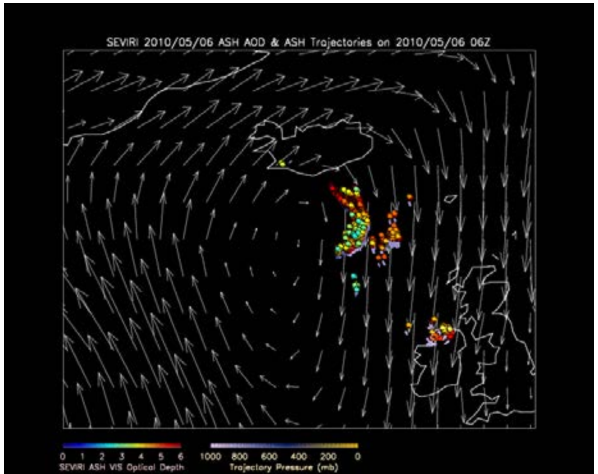
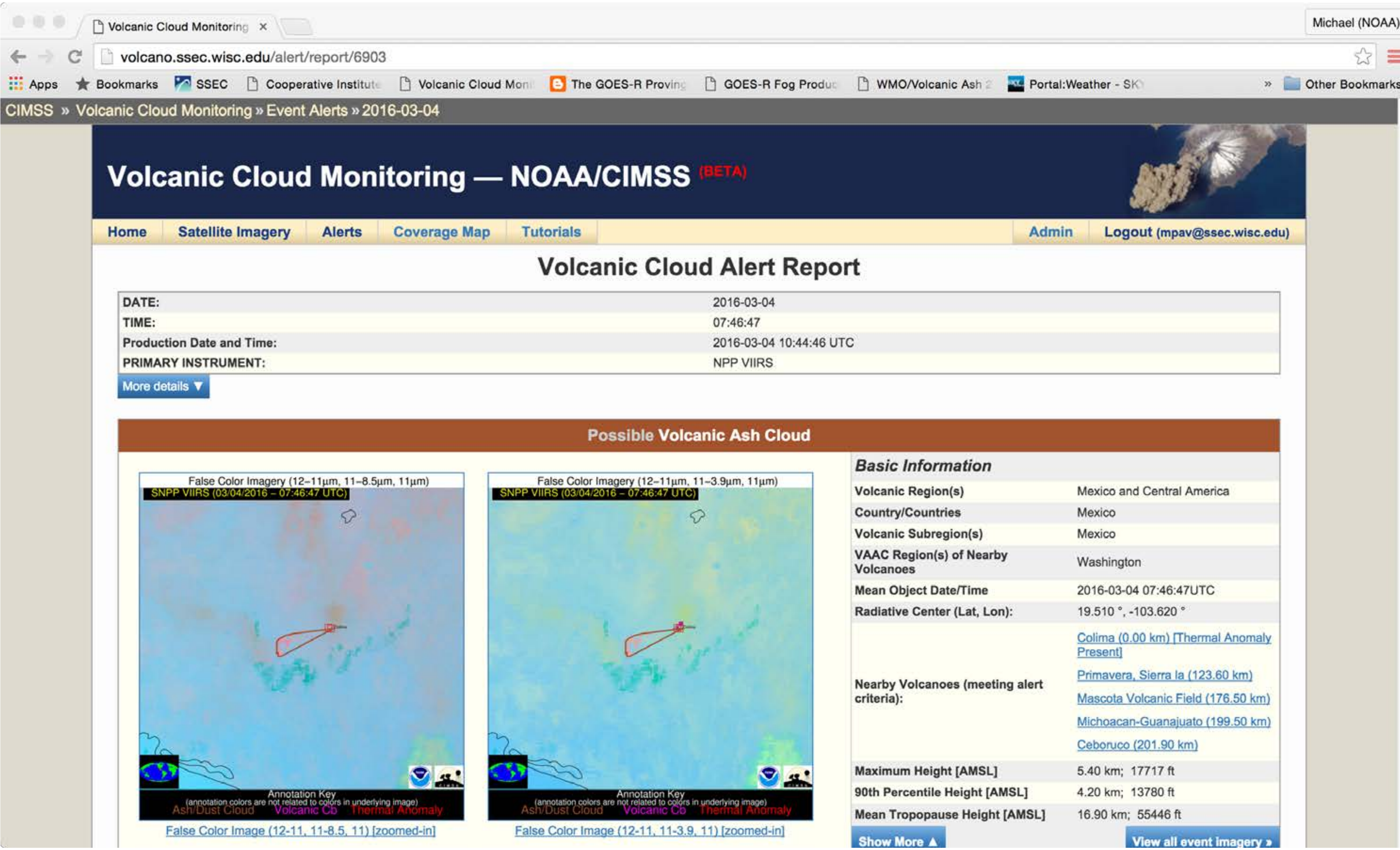


http://volcano.ssec.wisc.edu



Volcanic Cloud Detection

The VOLCAT detection approach is multi-faceted and employs several different conceptual models to identify volcanic clouds across the spectrum of eruption cloud types.

- Spectral cloud objects [spectral signature]
- Plume [spectral signature + geometric properties]
- ~~Puff [some spectral signature + cloud growth]~~
- ~~Major Explosion [cloud growth~~]
- Tracking in time [spectral signature + feature tracking]



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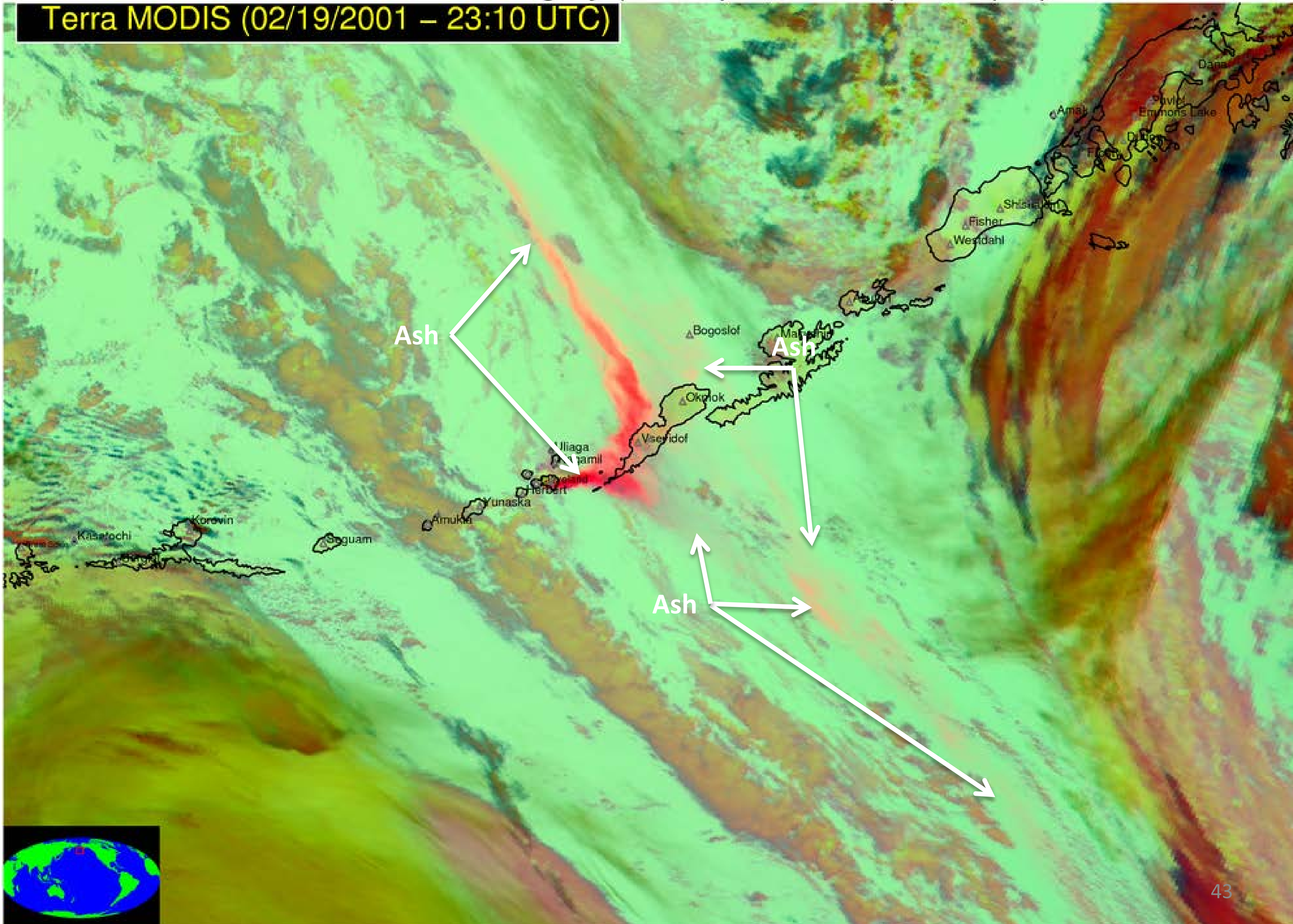
Spectrally Enhanced Cloud Objects (SECO)

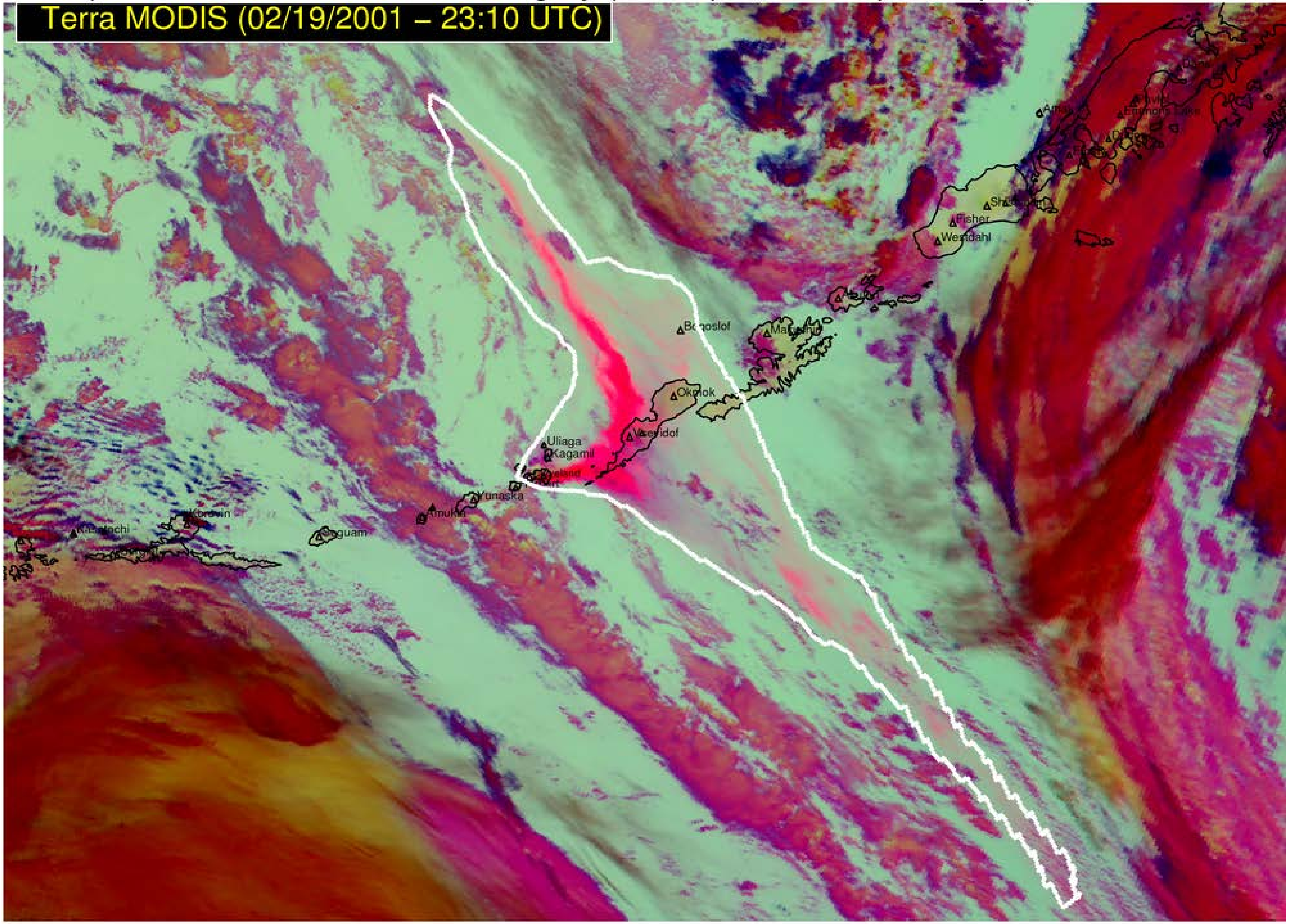
JGR - Pavolonis et al. (2015a)

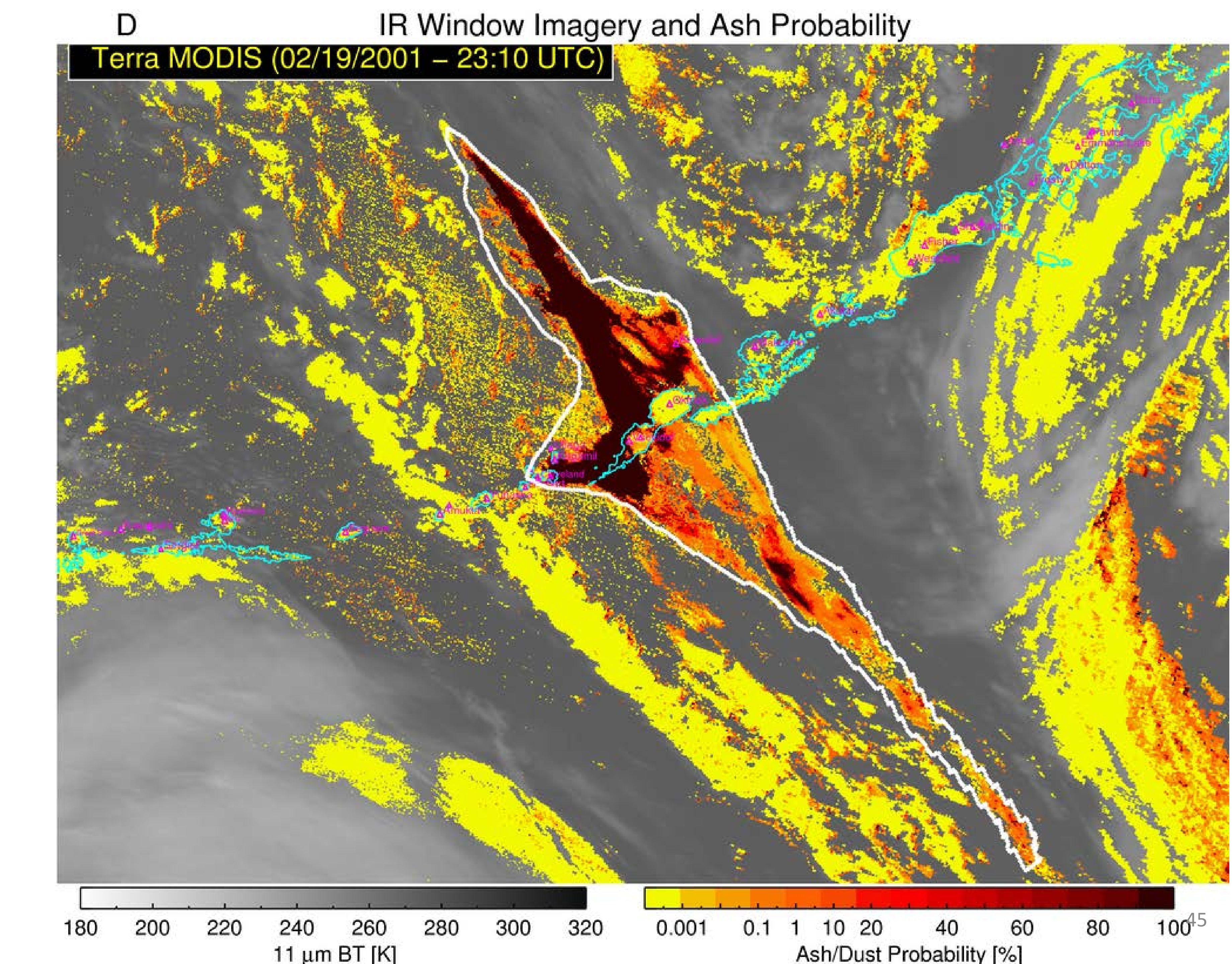
JGR – Pavolonis et al. (2015b)

False Color Imagery (12–11μm, 11–3.9μm, 11μm)



B). False Color Imagery (12–11μm, 11–3.9μm, 11μm)

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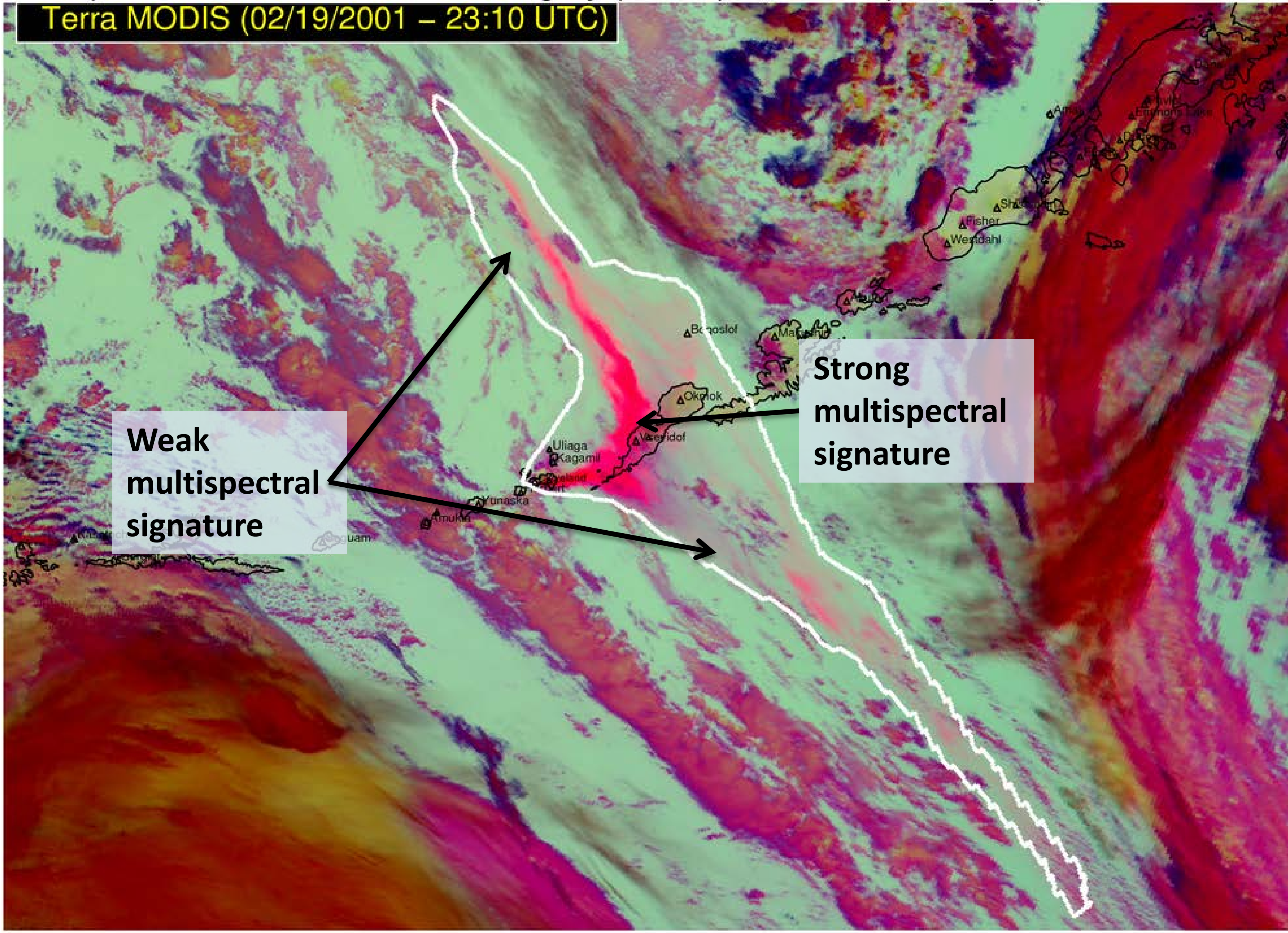
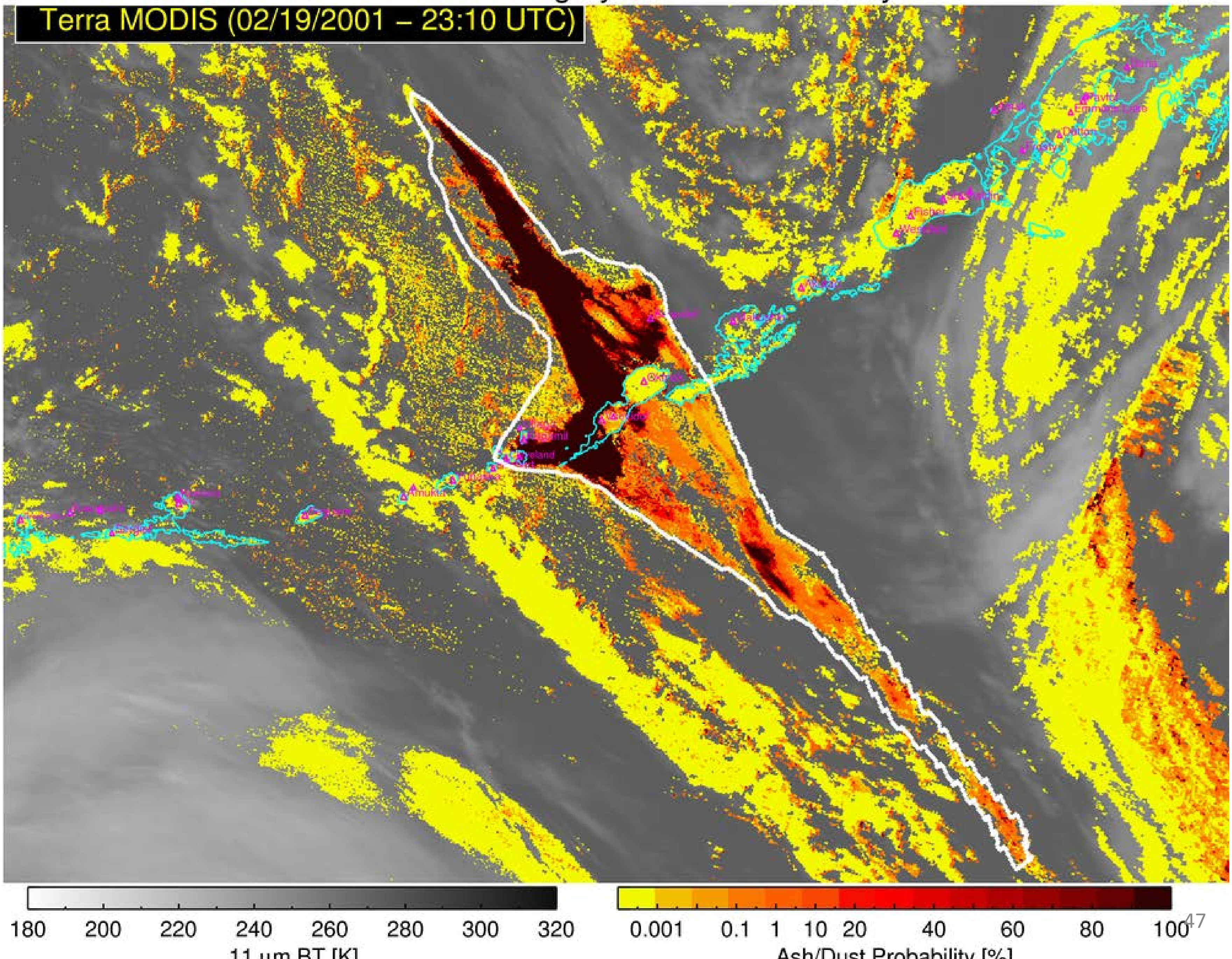
IR Window Imagery and Ash Probability
Terra MODIS (02/19/2001 – 23:10 UTC)
180
200
220
240
260
280
300
320
11 µm BT [K]
0.001
0.1
1
10
20
40
60
80
100
Ash/Dust Probability [%]

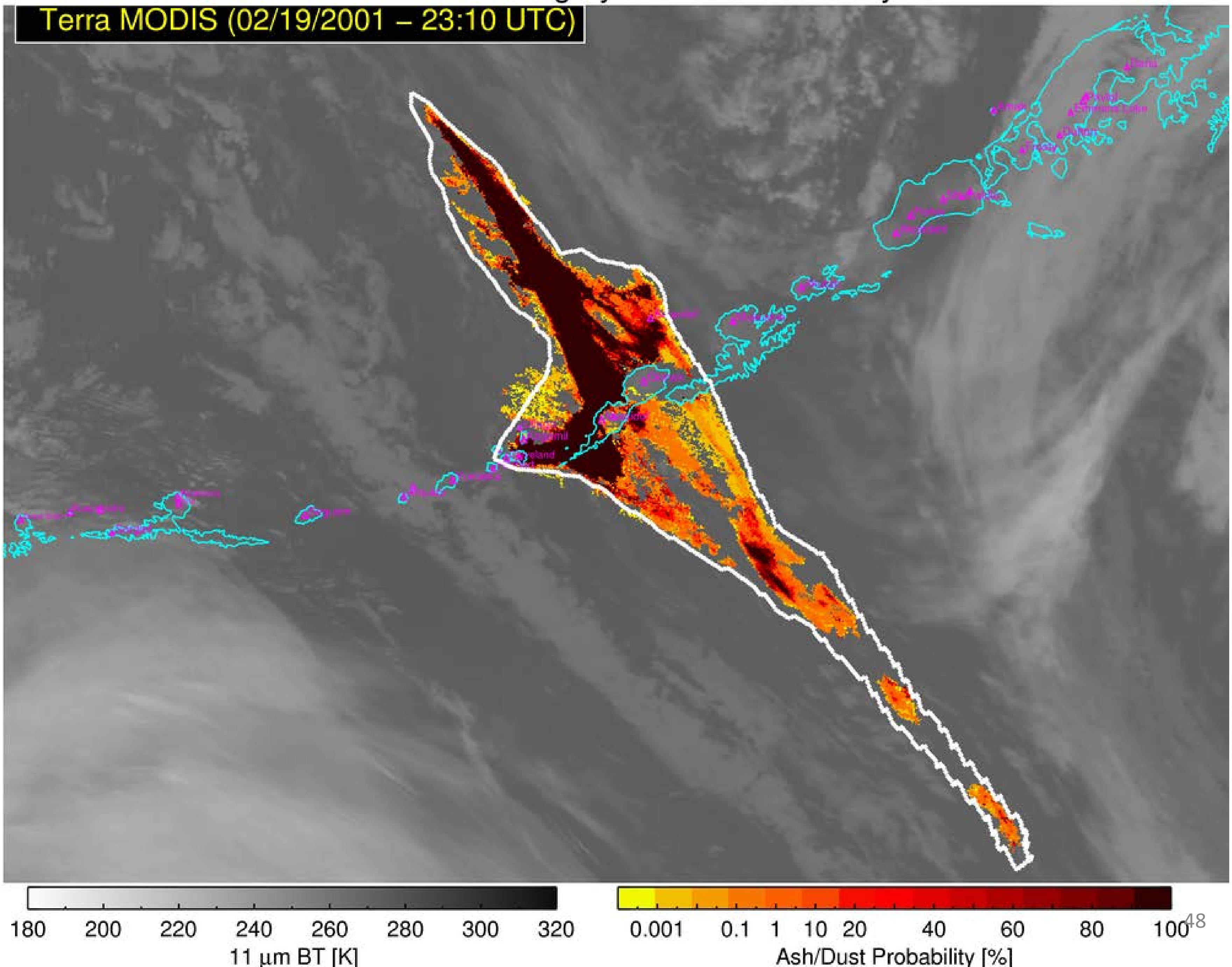
B). False Color Imagery (12–11μm, 11–3.9μm, 11μm)



D IR Window Imagery and Ash Probability

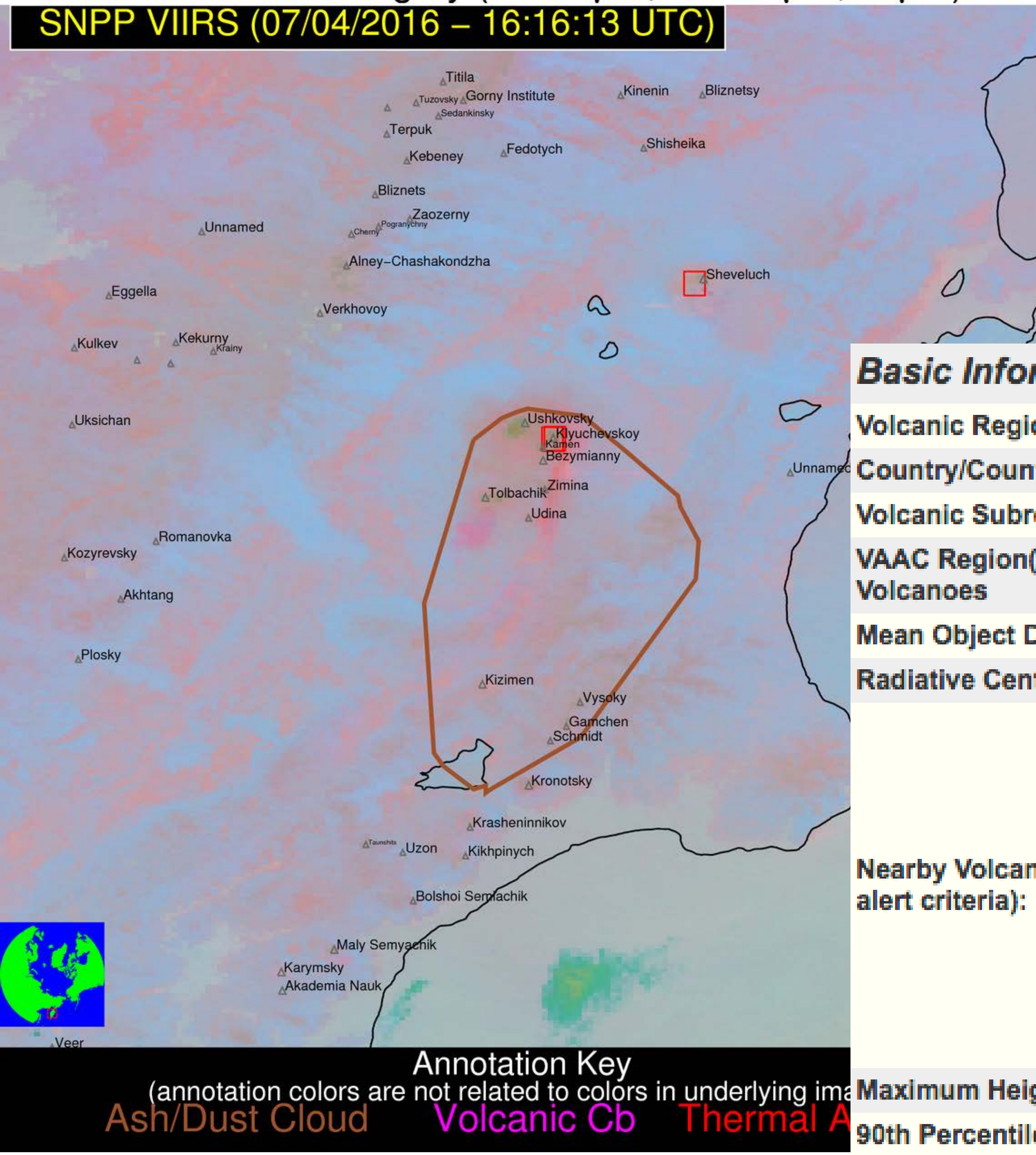


D IR Window Imagery and Ash Probability



Automated Determination of Source Volcano

False Color Imagery (12–11µm, 11–8.5µm, 11µm)



Basic Information

Volcanic Region(s)	Kamchatka and Mainland Asia
Country/Countries	Russia
Volcanic Subregion(s)	Kamchatka Peninsula
VAAC Region(s) of Nearby Volcanoes	Tokyo
Mean Object Date/Time	2016-07-04 16:16:13UTC
Radiative Center (Lat, Lon):	56.060 °, 160.640 °
Nearby Volcanoes (meeting alert criteria):	Klyuchevskoy (0.00 km) [Thermal Anomaly Present] Kamen (5.00 km) [Thermal Anomaly Present] Bezymianny (9.80 km) [Thermal Anomaly Present] Ushkovsky (10.40 km) Zimina (21.70 km)
Maximum Height [AMSL]	6.70 km; 21982 ft
90th Percentile Height [AMSL]	4.40 km; 14436 ft
Mean Tropopause Height [AMSL]	12.00 km; 39370 ft

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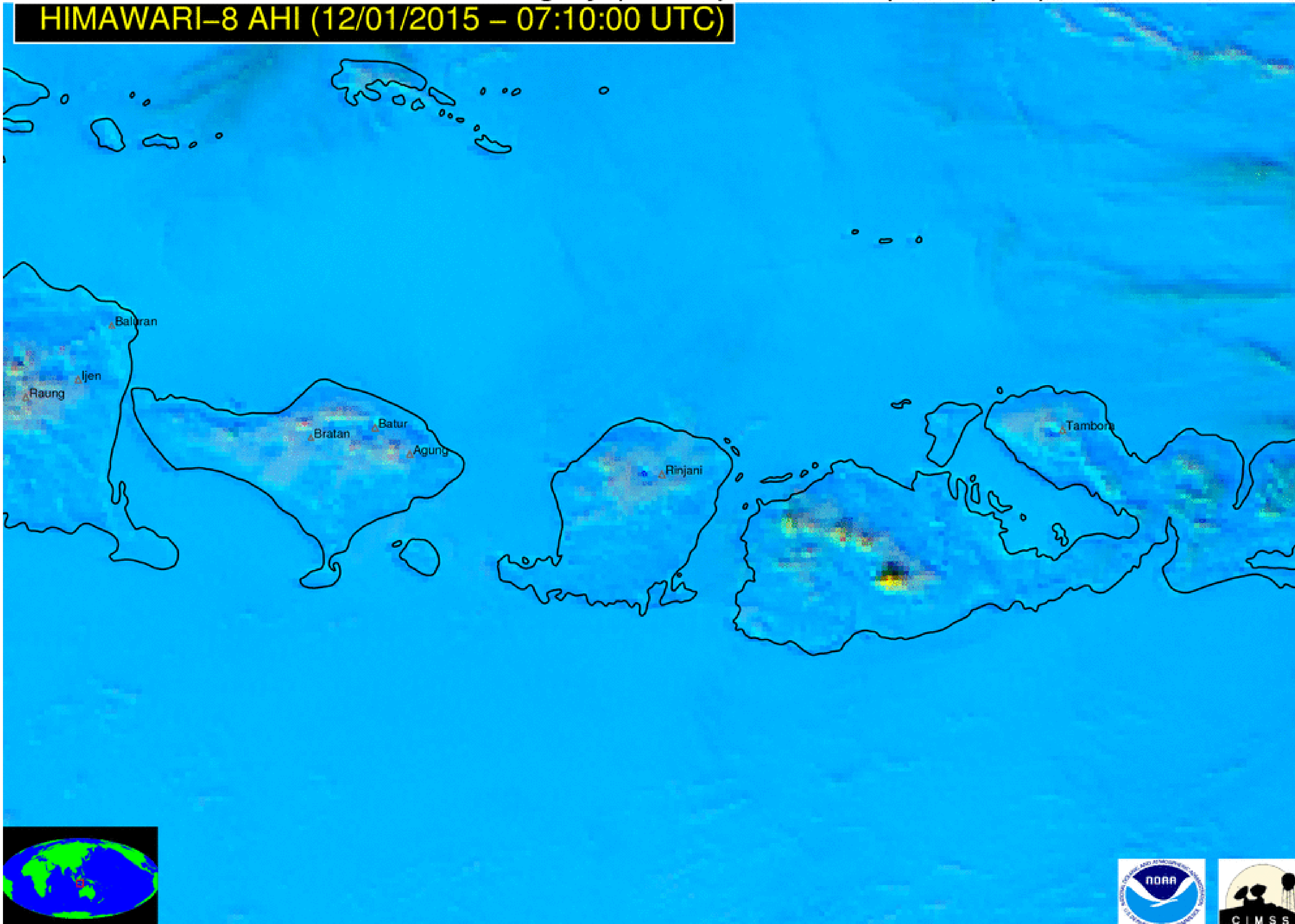
False Color Imagery (12–11µm, 11–8.5µm, 11µm)



Annotation Key
(annotation colors are not related to colors in underlying image)
Ash/Dust Cloud Volcanic Cb Thermal Anomaly