DEVELOPMENT OF MULTI-SENSOR \( \text{SO}_2 \) PRODUCTS FOR JPSS

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11 August 2016
Outline

• Importance of $\text{SO}_2$ monitoring

• Strengths and weaknesses of different satellite measurements

• Measurement integration plan

• Collaboration
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Motivation

Volcano Monitoring

Carn et al., 2013

2011 Nabro Eruption

Hazard Avoidance

Dispersion and Transport Modeling

D'Amours et al., 2010

Volcanic Ash Tracking

Climate

The Next “Big One”
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)

Major Strengths:

- 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

Increased noise as SZA increases to 90°

No information when SZA > 90°

Source: NASA GSFC
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

Source: NASA GSFC

Suomi NPP/OMPS (Zoom) - 06/25/2016 23:44-23:47 UT

SO₂ mass: 0.103 kt; Area: 4792 km²; SO₂ max: 1.72 DU at lon: -155.25 lat: 18.81; 23:45 UTC

Source: NASA GSFC

Noise

Kilauea plume
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$_2$
Hyperspectral Infrared (CrIS)

Weakness: Large footprint size relative to spatial scale of many SO$_2$ plumes

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

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

SO$_2$?
Narrow-band Imager (VIIRS)
Weakness: Challenging to extract quantitative information without additional constraints
A multi-sensor SO$_2$ analysis is needed.
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VOLcanic Cloud Analysis Toolkit (VOLCAT)

1). Unrest Alerts

2). Eruption Alerts

3). Volcanic Cloud Tracking

4). Volcanic Cloud Characterization

5). Dispersion Forecasting
Spectrally Enhanced Cloud Objects (SECO) Method for SO$_2$ Detection

- Automatically extract coherent SO$_2$ features 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!


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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 SO₂ 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 SO₂ observing system.

• A collaborative JPSS initiative is needed to ensure that the JPSS sensors are being fully utilized for SO₂ monitoring.
“Big Data”

VOLCAT Processing

- GOES-E
- MSG
- VIIRS
- H-8
- GOES-W
- MTSAT
- MODIS

Gigabytes

BACKUP SLIDES
Nuances/Exceptions are Prevalent

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

SNPP VIIRS (01/04/2015 – 03:45 UTC)

Warmer than background

Colder than background
UV Sensitivity

Carn et al., 2013
Infrared Sensitivity

![Graph showing infrared sensitivity with wavenumber, wavelength, and corresponding transmittance values for Andesite with different effective radii and SO2.](image-url)
A multi-sensor SO$_2$ analysis is needed.
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
LEO and GEO satellite imagery are routinely generated for numerous geographic sectors that cover nearly every volcano in the world.
1). Unrest Alerts
VOLCAT Goals

1). Unrest Alerts

2). Eruption Alerts
1). Unrest Alerts

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3). Volcanic Cloud Tracking
VOLCAT Goals

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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]
Spectrally Enhanced Cloud Objects (SECO)

JGR - Pavolonis et al. (2015a)
JGR – Pavolonis et al. (2015b)
B). False Color Imagery (12–11 μm, 11–3.9 μm, 11 μm)

Terra MODIS (02/19/2001 - 23:10 UTC)
B). False Color Imagery (12–11μm, 11–3.9μm, 11μm)

Terra MODIS (02/19/2001 – 23:10 UTC)

Weak multispectral signature

Strong multispectral signature
Automated Determination of Source Volcano

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 16:16:13 UTC
Radiative Center (Lat, Lon): 56.060 °, 160.640 °

Nearby Volcanoes (meeting alert criteria):
- Kiyuchevskoy (0.00 km) [Thermal Anomaly Present]
- Kamen (5.00 km) [Thermal Anomaly Present]
- Bezymphanny (9.80 km) [Thermal Anomaly Present]
- Ushkovsky (10.40 km)
- Zmina (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

Annotation Key
(Annotation colors are not related to colors in underlying image)

- Ash/Dust Cloud
- Volcanic Cb
- Thermal Anomaly

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