Impact of Volcanic Eruptions on Sea Surface Temperature products

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GHRSST XXIII, 27 June – 1 July 2022, Institut de Ciencies del Mar, Barcelona, Spain

Abstract

The eruptions of the Raikoke volcano on 22 June 2019 and the Tonga volcano on 15 January 2022 sent plumes of volcanic ash to the stratosphere and higher with the potential to affect the reliability and accuracy of satellite derived Sea Surface Temperature (SST) retrievals. The current study looks at the impact of the eruptions on SST retrievals produced by the Naval Oceanographic Office (NAVOCEANO) using SST software developed at the Naval Research Laboratory (NRL) and using legacy GOES-13 SST software updated by NRL for compatibility with the Electro-optical Infrared Weather System Geostationary (EWS-G1) imager. Emphasis is on SST products distributed to the Group for High Resolution SST (GHRSST). We used Suomi National Polar-Orbiting Partnership (Suomi NPP) Visible Infrared Imaging Radiometer Suite (VIIRS) measurements over a higher latitude region that received a significant sulfur dioxide injection into the stratosphere from Raikoke. The NRL SST software produced fewer retrievals with moderately higher standard deviation following the Raikoke eruption compared to a previous year with low volcanic contamination. The plume from the Tonga volcano had a relatively low sulfur dioxide content, so its effects were more limited in time and space. In the Tonga case, the EWS-G1 SST retrievals using the legacy software are more affected by volcanic contamination than those produced by the NRL SST software using other satellites. In general, this study finds that the NRL SST software successfully excludes SST retrievals under higher volcanic contamination while allowing retrievals, with mild consequences, under conditions of lower contamination.

1. Introduction

Volcanic eruptions have the potential to affect the reliability of satellite-derived Sea Surface Temperature (SST) retrievals. This study examines the short-term impact on Naval Oceanographic Office (NAVOCEANO)-produced SST retrievals from two volcanic eruptions: Raikoke on 22 June 2019 and Hunga Tonga-Hung Ha'apai on 15 January 2022. As SST is assimilated into Navy models, we want to confirm the accuracy of NAVOCEANO SST retrievals and consider the recurring effects following episodes of volcanic activity.

NAVOCEANO produces SST retrievals from polar orbiting and geosynchronous satellites with the Naval Research Laboratory (NRL)-developed SST software suite. NAVOCEANO distributes to the Group for High Resolution Sea Surface Temperature (GHRSST) these derived SST products: Suomi National Polar-orbiting Partnership (SNPP) Visible Infrared Imaging Radiometer Suite (VIIRS), METOP Global Area Coverage (GAC), and Electro-optical Infrared Weather System Geostationary (EWS-G1). The present poster mainly examines the effect of the two volcanic eruptions on SNPP VIIRS SST.

2. NRL SST software suite

The NRL SST software suite is a collection of modular programs that allows for the processing of Sensor Data Record (SDR) data from various satellites/sensors. NAVOCEANO operationally runs the software to produce near real-time SST retrievals and distribute the SNPP VIIRS derived SST to GHRSST.

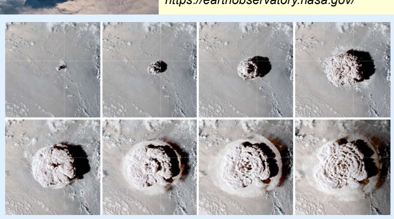
Coefficients for the non-linear SST equations are determined by regression with buoys over an initial calibration period. In the daytime equation below, T_{11} and T_{12} are the brightness temperatures (BT) respectively at 10.x µm and 11.x µm, T_f is the analyzed field, and θ is the satellite zenith angle:

$$a_0 + a_1 T_{11} + \left(a_3 + a_4 T_f + (a_5 + a_7 T_f)\left(\frac{1}{\cos(\theta)} - 1\right)\right)(T_{11} - T_{12}) + a_6\left(\frac{1}{\cos(\theta)} - 1\right)$$

Principal tests to identify and mask out contamination include:

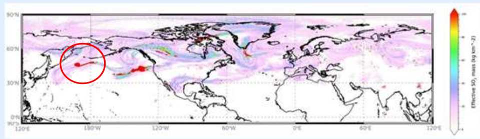
- Reflectance table test: based on thresholds corresponding to the 90th percentile of reflectance values from a training data set encompassing the valid range of satellite zenith and sun reflection angles. [daytime only]
- BT and reflectance correlation test: a lack of correlation is expected under conditions observing valid oceanic features (uncontaminated.) [daytime only]
- The BT's difference (T_{11} - T_{12}) test: relies on a threshold function of the estimated SST as derived from a training data set. [daytime and nighttime]
- 3.x µm BT (T_4) inter-comparison test: compares T_4 with the corresponding value as estimated from T_{11} and T_{12} using a repurposed daytime non-linear SST equation.
- Proximity to cloud test: potentially masks out borderline retrievals that are adjacent to previously identified clouds

Image of the 22 June 2019 eruption of Raikoke (left) taken from the International Space Station and a time series image of the 15 Jan 2022 eruption of the Tonga volcano (below) derived from GOES 17 data. Courtesy of the NASA Earth Observatory https://earthobservatory.nasa.gov/

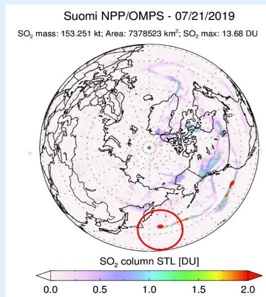


3. Raikoke

The Raikoke volcano is on the Kuril Islands in the Sea of Okhotsk, north-east of Japan at 48.35°N, 153.23°E. An eruption from Raikoke occurred on 22 June 2019, producing a plume of volcanic ash and SO_2 that reached the stratosphere.



Volcanic SO_2 from MetOp Infrared Atmospheric Sounding Interferometer (IASI), on 21 July 2019. Original image provided by Dr. Michael Fromm, NRL Code 7227.



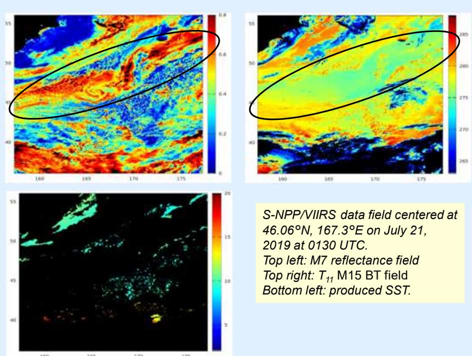
Volcanic SO_2 for 21 July 2019 from SNPP Ozone Mapping and Profiler Suite (OMPS). Original image by NASA Atmospheric Chemistry and Dynamics Laboratory

One month later, on 21 July 2019, SO_2 can be found throughout the northern hemisphere, mostly at latitudes greater than 30°N. A sub-plume (shown in red circles on figures above and to the left) with high effective SO_2 mass is also seen at 46.06°N, 167.3°E from both METOP IASI and SNPP OMPS data.

Additionally, data from S-NPP/VIIRS on 21 July 2019 at 0130 UTC show the effect of the strong contamination around 46.06°N, 167.3°E on the reflectance (M7) and BT (M15).

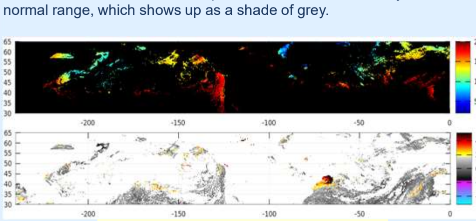
In the top left panel below, red indicates high reflectance (contaminated) while blue indicates low reflectance (probably clear). The semi-circular feature in the center of the image (shown in a black circle) corresponds to the strong sub-plume described above, extending diagonally from the west side of the region at 45°N to the east side of the region at 52°N.

The BT field in the top right panel below shows a green area which corresponds to the high reflectance area from the top left panel. The BT values to the north and south of the sub-plume are only 5 to 6°K colder than expected and are associated with a smooth BT field, whereas cloud contaminated areas generally have much colder and more variable BT values.



S-NPP/VIIRS data field centered at 46.06°N, 167.3°E on July 21, 2019 at 0130 UTC.
Top left: M7 reflectance field
Top right: T_{11} M15 BT field
Bottom left: produced SST.

A broader image of the S-NPP/VIIRS SST fields on 21 July 2019 from 30°N to 65°N and 120°E to 0°W is shown in the top panel of the figure below. The region mostly includes weak contamination. The resulting SST field is as expected with contaminated data being masked out. The K10 field (NAVOCEANO analyzed field) is used to assess the validity of the VIIRS SST retrievals. As shown in the bottom panel of the figure below, deviations of the SST field compared to the K10 field mostly fall within a normal range, which shows up as a shade of grey.

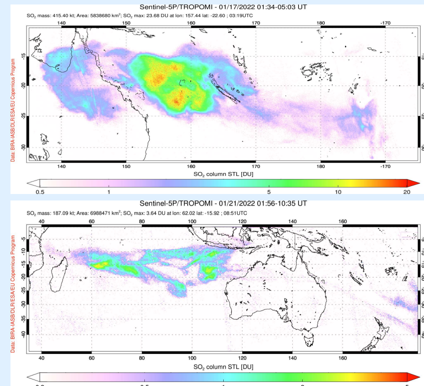


Top: S-NPP/VIIRS SST field on 21 July 2019
Bottom: corresponding SST – K10 difference field

For the SST field above, the number of SST retrievals is approximately 14 million while the standard deviation of the retrievals, as measured by the orbital overlap evaluation method, is 0.64°K. For comparison, the SST fields for the same area on 14 July 2014 contained 16 million retrievals with a standard deviation of 0.52°K. Although not strongly significant these results could indicate contamination from the Raikoke volcanic eruption, leading to fewer retrievals and larger standard deviation in 2019.

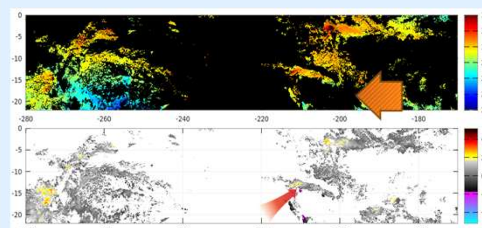
4. Hunga Tonga Huga Ha'apai (HT-HH)

The HT-HH volcano is an undersea volcano between the Hunga Tonga and Hunga Ha'apai islands in the Kingdom of Tonga. It is located in the SW Pacific at 20.54°S, 175.38°W. HT-HH started to erupt in December 2021 but quieted by early January. Then on 15 January 2022 there was an explosive eruption, lasting an estimated 6 hours, that sent a plume of volcanic ash and SO_2 high in the stratosphere. As such, the total amount of SO_2 injected into the stratosphere was limited. The SO_2 cloud can be followed in Sentinel-5 TROPOMI imagery (figures below), highlighting the decreasing amount of SO_2 over time, especially after going over Australia.



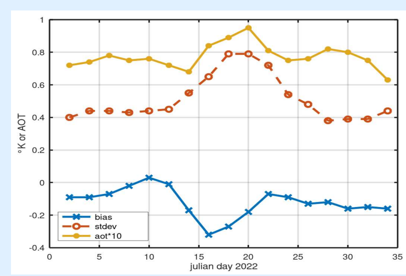
Volcanic SO_2 images for 17 (top) and 21 (bottom) of January 2022. Original images by NASA Atmospheric Chemistry and Dynamics Laboratory

The S-NPP/VIIRS SST fields for 17 January 2022 from 22°S to 0°N and 100°E to 170°W are depicted in the top panel of the figure below. The contaminated data seem mostly masked out with, in particular, the cloud in the volcanic SO_2 image on the right panel. The K10 field (NAVOCEANO analyzed field) is used to confirm the validity of the VIIRS SST retrievals: In bottom panel, deviations of the SST field compared to the K10 field mostly fall within a normal range which shows up as a shade of grey.



S-NPP/VIIRS SST field on 17 January 2022 (top) and corresponding SST – K10 difference field (bottom). The orange arrow in the top panel points to the masked SO_2 cloud. The red arrow points to some potential contamination at the edge of SO_2 cloud.

SST to buoy matchups for the region above during the whole month of January 2022 provide additional hindsight. The figure below includes a plot of the mean difference between SST and buoy temperature, the standard deviation and the corresponding Navy Aerosol Analysis and Prediction System (NAAPS) total aerosol optical thickness (AOT). The plots indicate mild contamination for a few days after the eruption and also correlation between the level of aerosol and the mean difference and the standard deviation.



Time series of S-NPP/VIIRS SST to buoy matchups for January 2022 over the downwind vicinity of HT-HH, 22°S to 0°N and 100°E to 170°W

5. Conclusion

While distinguishing among different sources or types of contamination, the SST suite successfully flags contamination from the volcano eruption, especially when the contamination is heavy and more likely to affect the estimated SST values. When the contamination is lighter, there is a higher probability for the data to be accepted, contributing to lower overall reliability when the light contamination is widespread.

Acknowledgements

This research was made possible in part by the Office of Naval Research through their support of the Multi-sensor Improved Sea Surface Temperature: continuing the GHRSST partnership and improving Arctic data.