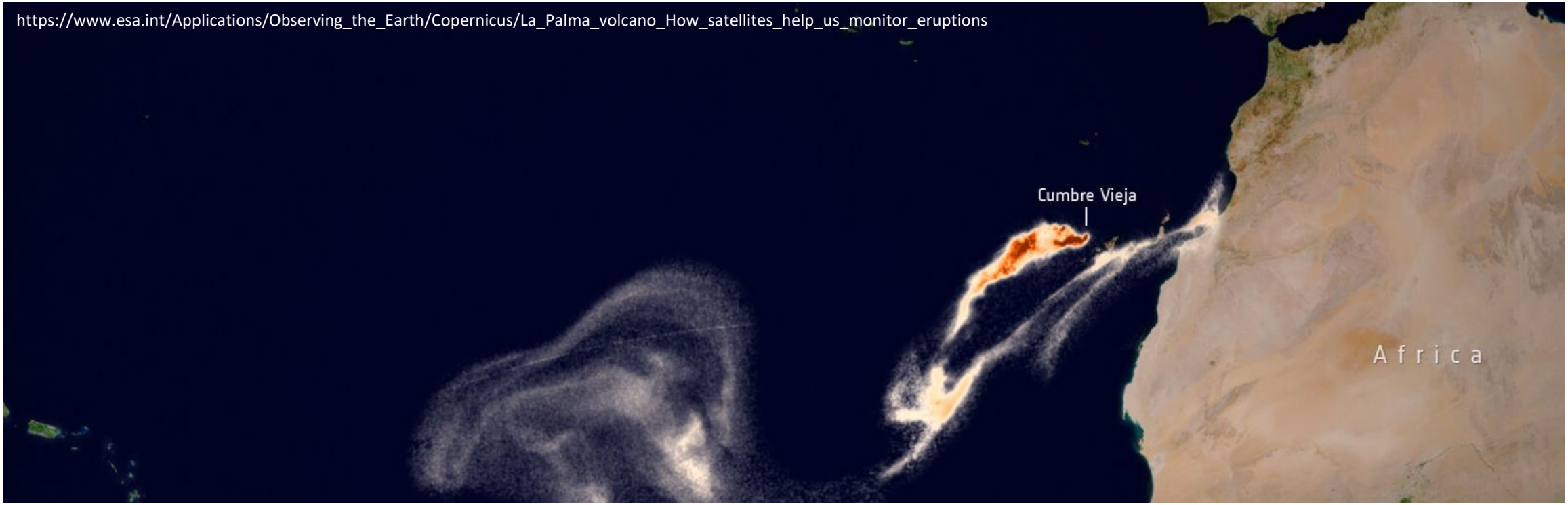

MONITORING VOLCANIC EMISSIONS WITH A GEO-LEO FUSION APPROACH

2021 Cumbre Vieja (La Palma, Canary Islands) Volcanic Eruption

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INTRODUCTION

- Objectives are (1) to increase the utilization of LEO and GEO assets through data fusion of imager radiances (e.g., VIIRS, ABI) with sounder and trace gas measurements and products (e.g., from CrIS, TROPOMI), and (2) to provide a GEO hyperspectral sounder-like perspective of atmospheric changes in time.
- Instruments (utilized in a spatial-temporal fusion approach):

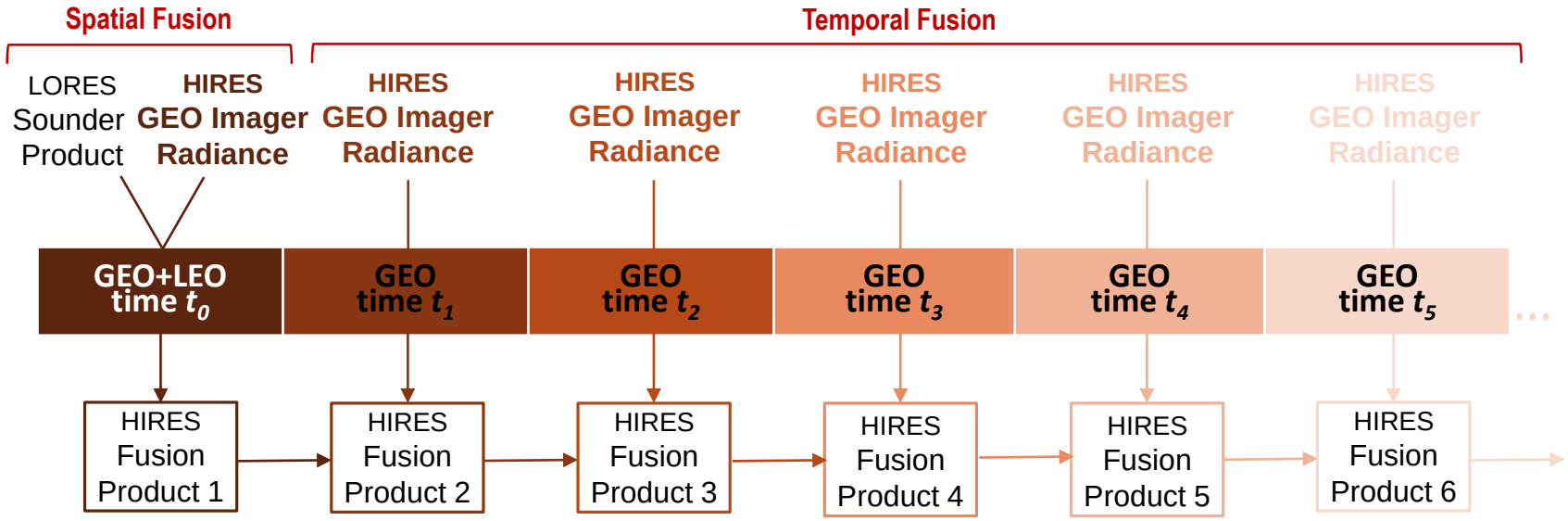
Instrument	Platform Agency	Orbit	Spectral Range	Spatial Resolution	Temporal Resolution	Primary variables
VIIRS Visible Infrared Imaging Radiometer Suite	SNPP, NOAA-20 NOAA & NASA	LEO	412 nm–12 µm (VIS,NIR,IR,DNB)	750 m (for IR bands)	Twice daily global coverage	Imagery and retrievals of clouds and earth surface parameters
CrIS Cross-track Infrared Sounder	SNPP, NOAA-20 NOAA & NASA	LEO	3.92–15.4 µm (hyperspectral IR)	14 km	Twice daily global coverage	Temperature and moisture profiles, surface/cloud/trace gas concentrations
TROPOMI TROPOspheric Monitoring Instrument	Sentinel-5P ESA	LEO	270–2385 nm (UV-VIS, NIR, SWIR)	3.5 km x 5.5 km	daily global coverage	Trace gas concentrations (e.g., O_3, NO_2, SO_2, CO, CH_4)
ABI Advanced Baseliner Imager	GOES-16 NOAA & NASA	GEO	0.47–13.3 µm (2 Vis, 4 NIR, 10 IR)	2 km (for bands > 2µm)	10 minutes (for Full Disk)	Imagery and retrievals of temperature, water vapor, ozone, cloud properties …

- Case Study covers detection and tracking of volcanic sulfur dioxide (SO_2) and ash plumes from the Cumbre Vieja volcano (Canary Islands, Spain) eruptions on October 9 and 18, 2021.
- Fusion of VIIRS/TROPOMI, ABI/TROPOMI, and ABI/CrIS better spatial and temporal to monitor the variable dispersion of trace gas emissions, with ABI/CrIS expanding coverage into nighttime.

ABI and VIIRS/CrIS Level 1 data has been provided courtesy of the UW-Madison/SSEC data center and the UW SSEC Atmosphere SIPS, respectively. We acknowledge the use of TROPOMI trace gas data from the Copernicus Sentinel-5P mission (https://sentinel.esa.int/web/sentinel/data-products).

The Imager/Sounder Fusion Approach

- GEO/LEO spatial and temporal fusion[1,2] utilizes a multi-dimensional k-d tree search either between high spatial resolution (HIRES) and low spatial resolution (LORES) imager radiances (*spatial fusion*) or between imager radiances from subsequent time steps (*temporal fusion*). Trace gas fusion products are derived by using ABI 'B13 minus B15' (10.3–12.3 µm) BT differences in the search. Then the LEO sounder or trace gas product, which is either of low spatial and/or low temporal resolution, is averaged over closest neighbors – in radiance and geolocation space.



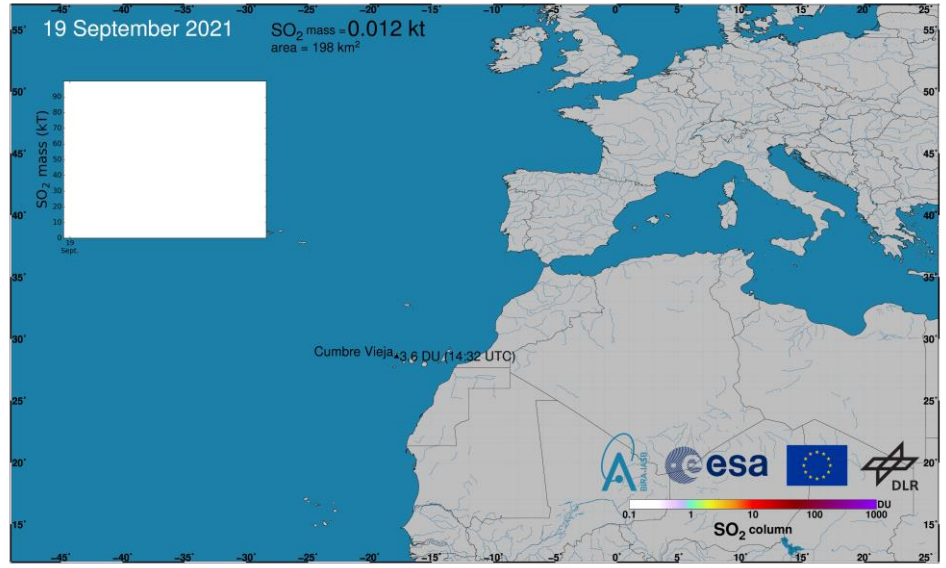
- When applied to TROPOMI trace gas products and SO_2-sensitive CrIS BT differences this GEO/LEO fusion approach allows the tracking of the trace gases in time sequences of the fusion products.

1. Weisz, E., Baum, B. A. & Menzel, W. P. (2017), Fusion of satellite-based imager and sounder data to construct supplementary high spatial resolution narrowband IR radiances. *Journal of Applied Remote Sensing*, *11*(3), 036022. https://doi.org/10.1117/1.JRS.11.036022

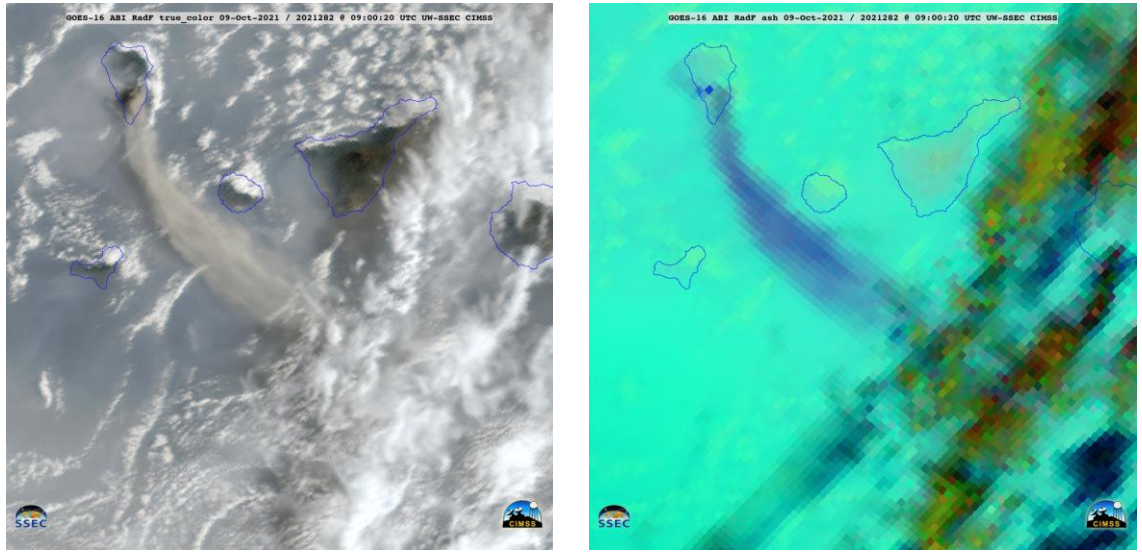
2. Weisz, E., & Menzel, W. P. (2020), Approach to enhance trace gas determinations through multi-satellite data fusion. *Journal of Applied Remote Sensing*, *14*(4), 044519. https://doi.org/10.1117/1.JRS.14.044519

2021 Cumbre Vieja Volcano Eruption

- The 2021 eruption of the Cumbre Vieja volcanic ridge (La Palma, Canary Islands) began on 19 September 2021
- Lasted almost 3 months and produced extensive lava flows that destroyed thousands of homes and large areas of farmland
- Satellite-based remote sensing data and imagery proved fundamental in forecasting, detecting, and tracking eruptive activity
- One key source for trace gas information is TROPOMI on Sentinel-5P (note, only available once during daytime)
- Intermittent periods of ash-laden volcanic clouds were observed since the beginning of the eruption
- Airborne ash is tracked operationally by utilizing IR channels of geostationary satellite sensors like ABI
- From the UW CIMSS Satellite Blog: GOES-16 ABI True Color and RGB imagery from 9 Oct 2021



https://www.aeronomie.be/en/news/2021/tracking-cumbre-vieja-volcanic-sulphur-dioxide-space



https://cimss.ssec.wisc.edu/satellite-blog/archives/42806

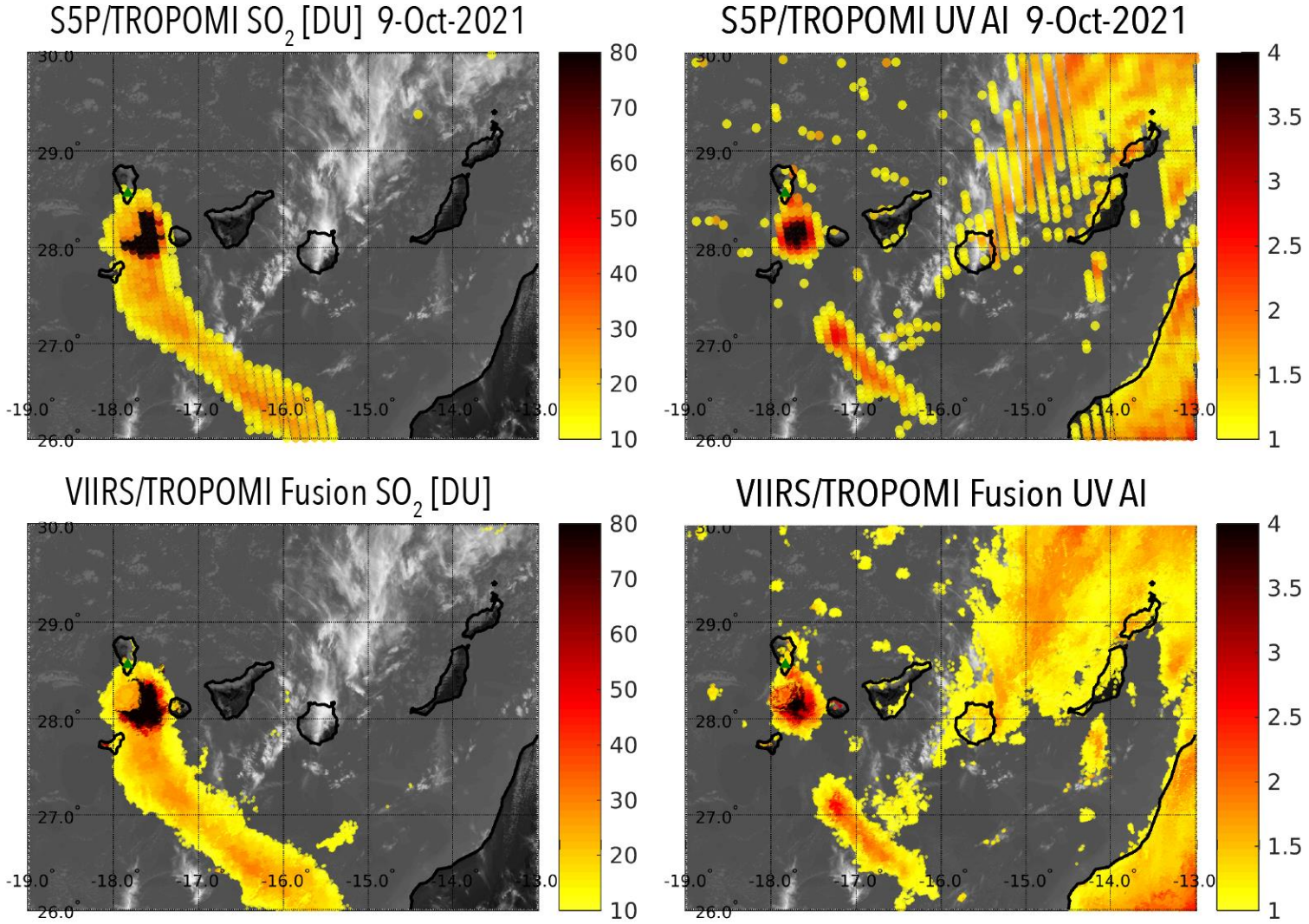
➢ Fusion adds more detailed depiction, improved temporal resolution (e.g., from once a day to hourly or better), and expansion into nighttime of the trace gas concentrations

VIIRS/TROPOMI SO_2 and Aerosol Index (AI) Fusion Results (9 Oct 2021)

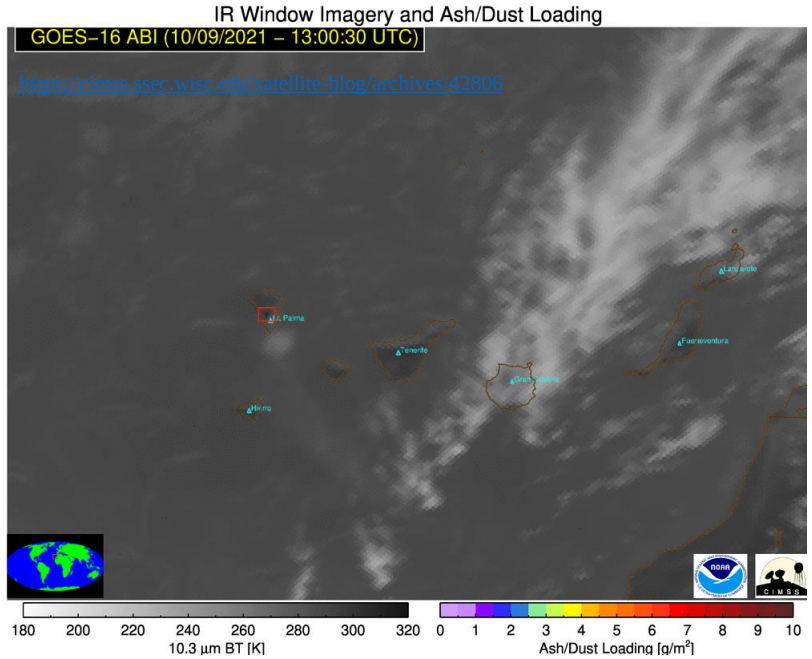
- TROPOMI (top) and J1-VIIRS/TROPOMI Fusion (bottom) of SO_2 and Aerosol Index (340-380 nm), superimposed on VIIRS Band 15 (10.7 µm) BTs
- TROPOMI and NOAA-20 overpass times over La Palma are approx. 1500 and 1400 UTC, respectively

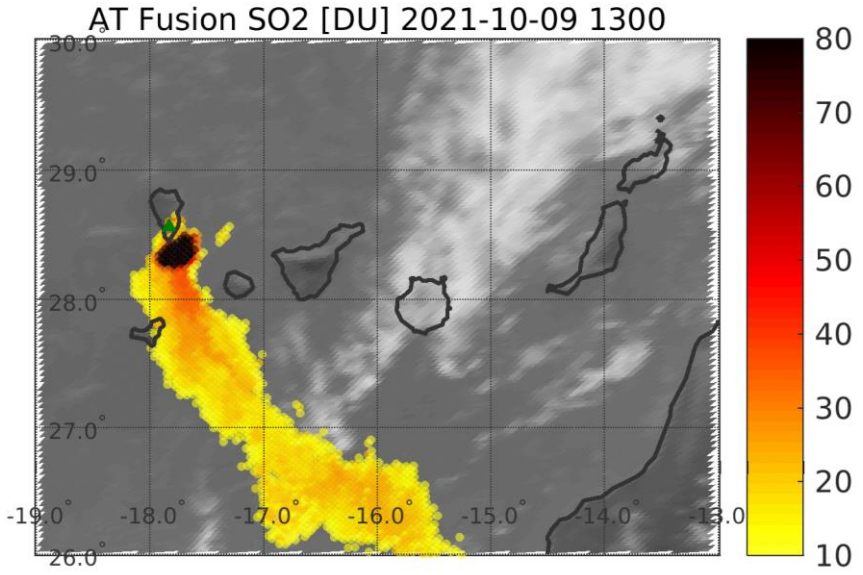
TROPOMI L2 →

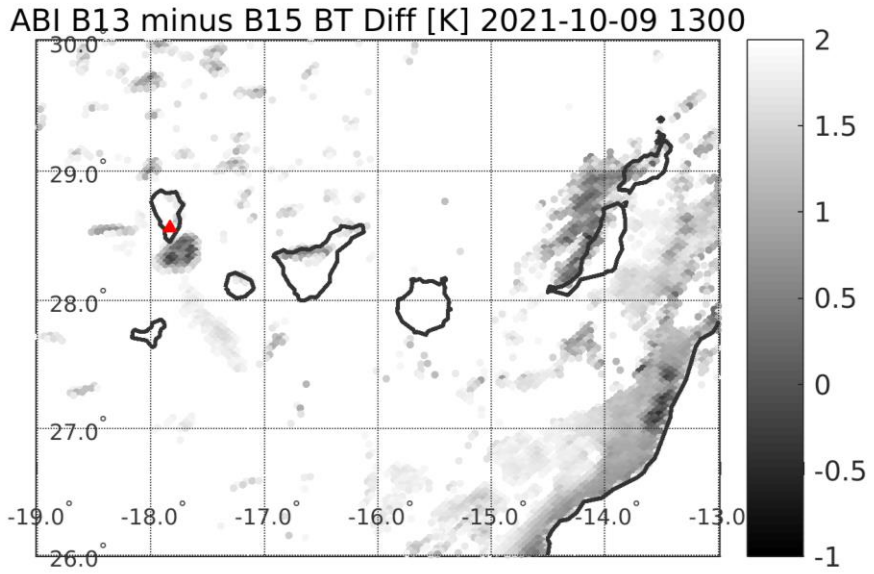
VIIRS/TROPOMI FUSION →

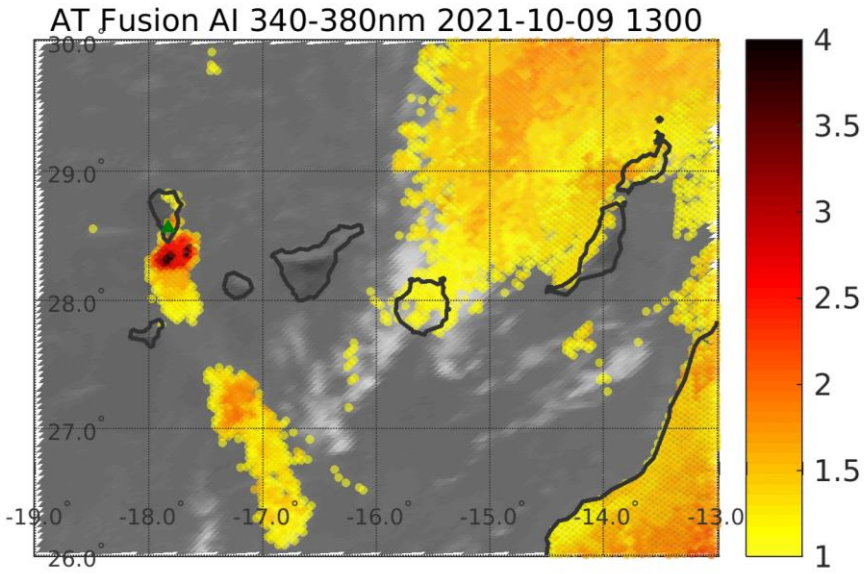


ABI/TROPOMI SO_2 and AI Fusion Results (9 Oct 2021, 1300-1500 UTC)





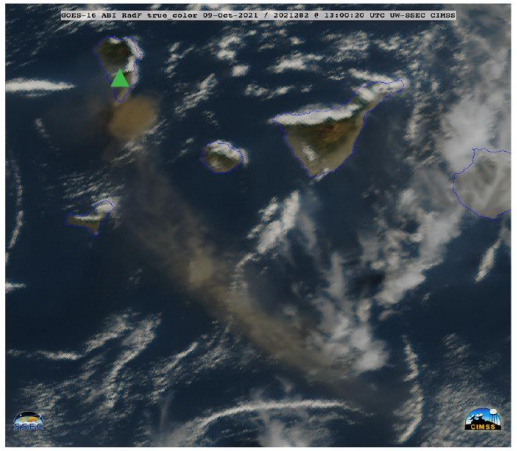




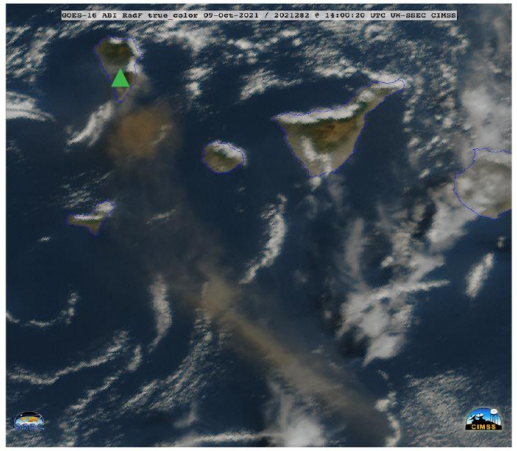
ABI/TROPOMI SO_2 Fusion Results (9 Oct 2021, hourly at 1300-1600 UTC)

- GOES-16 ABI True Color RGB images (adapted from https://cimss.ssec.wisc.edu/satellite-blog/archives/42806) and ABI/TROPOMI SO_2 [DU] fusion results (superimposed upon ABI 10.3 µm brightness temperatures)
- Fusion starts at 1500 UTC (i.e., the approximate time of the TROPOMI overpass), i.e., works forward and backward in 10 minutes increments

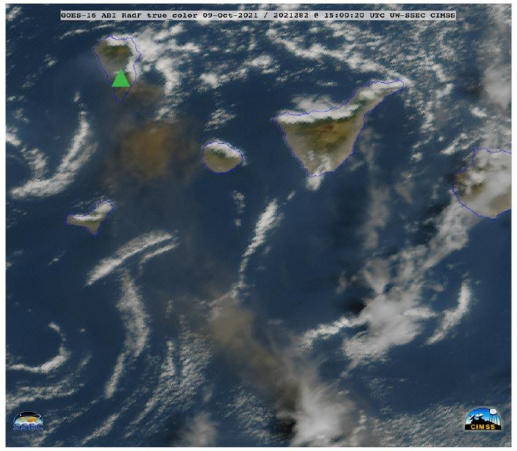
ABI True Color 9-Oct-2021 1300 UTC



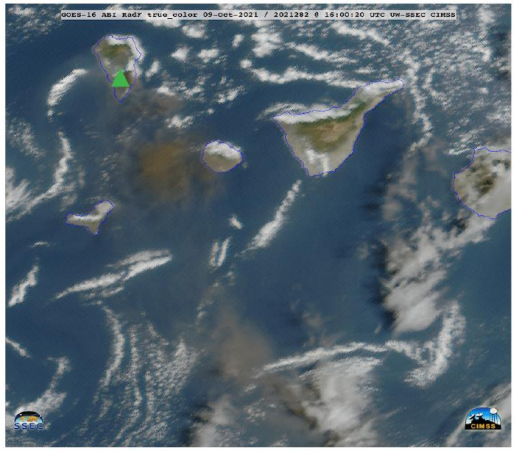
ABI True Color 9-Oct-2021 1400 UTC



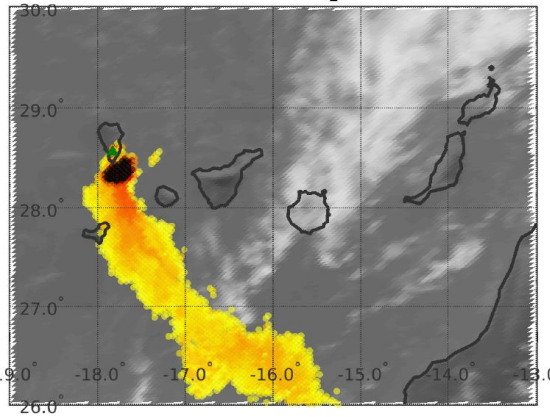
ABI True Color 9-Oct-2021 1500 UTC



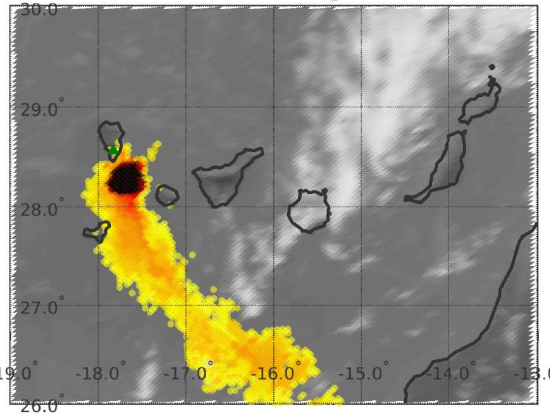
ABI True Color 9-Oct-2021 1600 UTC



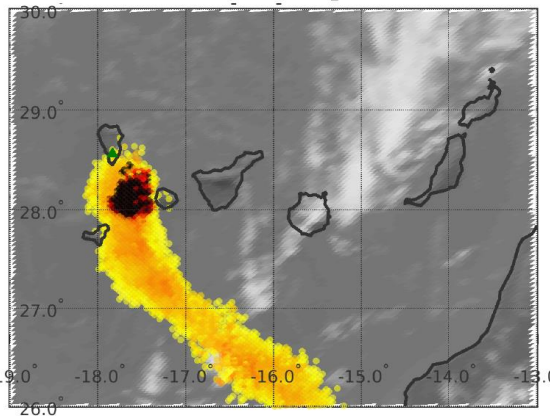
ABI/TROPOMI Fusion SO_2 [DU] 1300 UTC



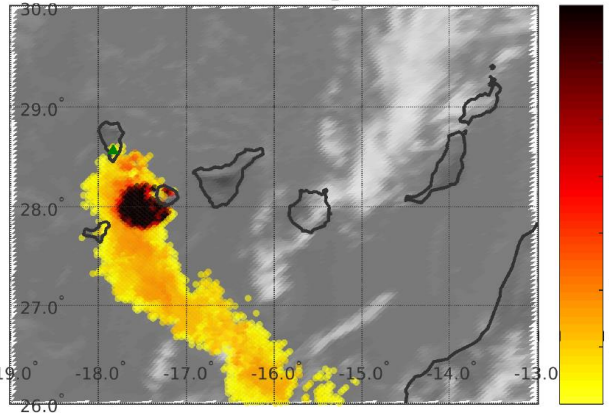
ABI/TROPOMI Fusion SO_2 [DU] 1400 UTC



ABI/TROPOMI Fusion SO_2 [DU] 1500 UTC

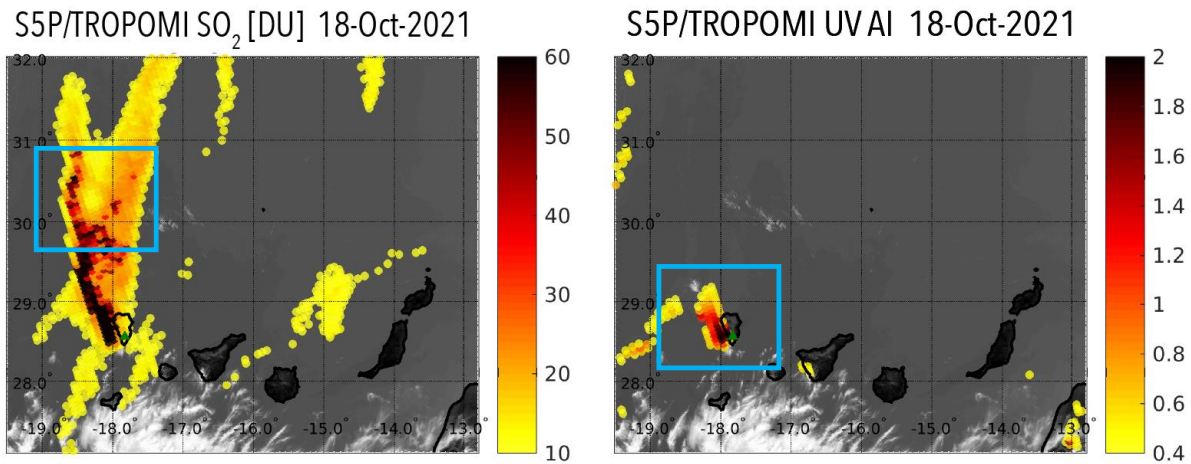


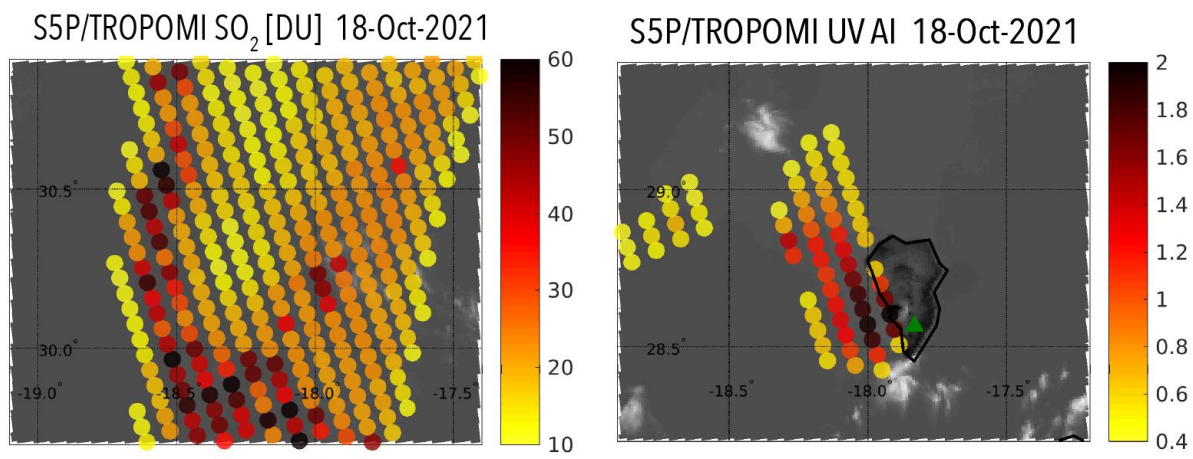
ABI/TROPOMI Fusion SO_2 [DU] 1600 UTC



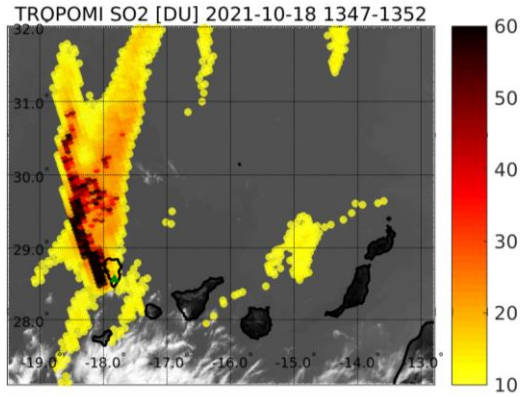
VIIRS/TROPOMI SO_2 and AI Fusion Results (18 Oct 2021)

- TROPOMI (top) and J1-VIIRS/TROPOMI Fusion (bottom) of SO_2 and Aerosol Index (340-380 nm), superimposed on VIIRS Band 15 (10.7 µm) BTs
- TROPOMI and NOAA-20 overpass times over La Palma are approx. 13:50 UTC and 14:30 UTC, respectively

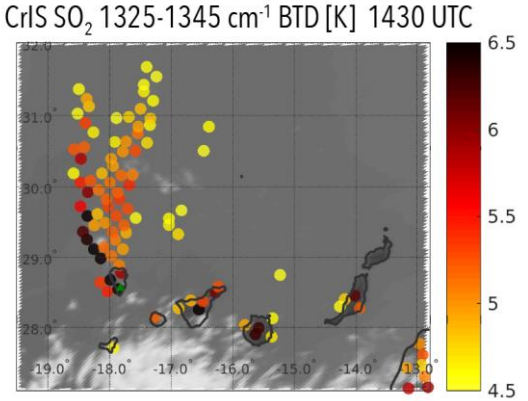




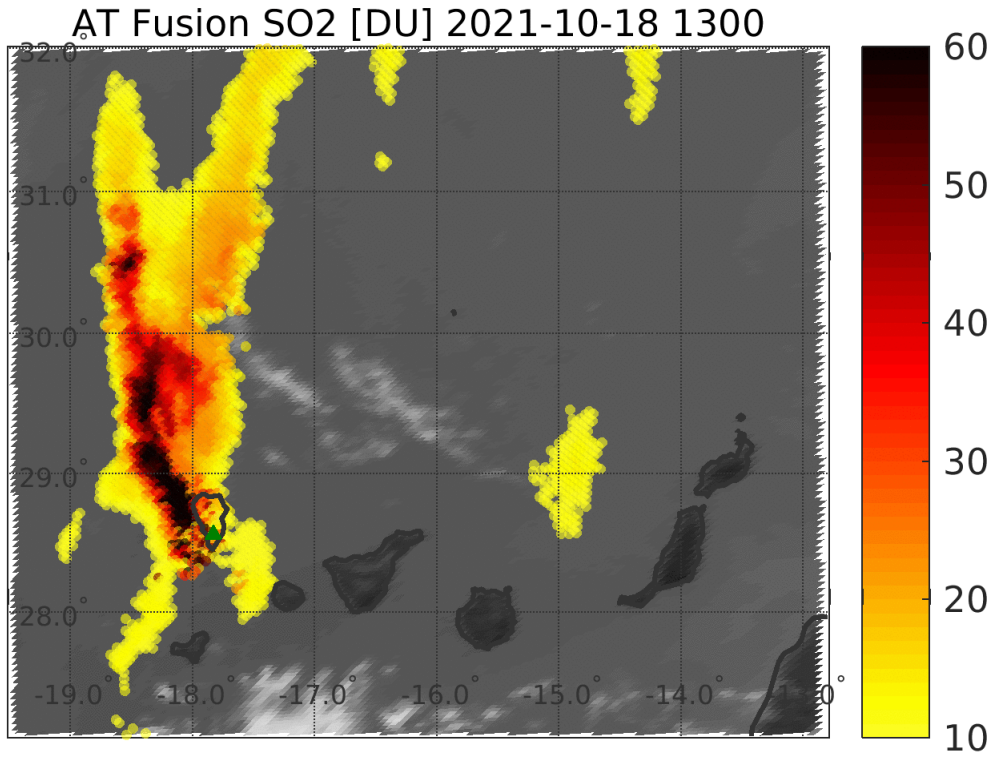
ABI/TROPOMI and ABI/CrIS SO_2 Fusion Results (18 Oct 2021, 1300-1600 UTC)

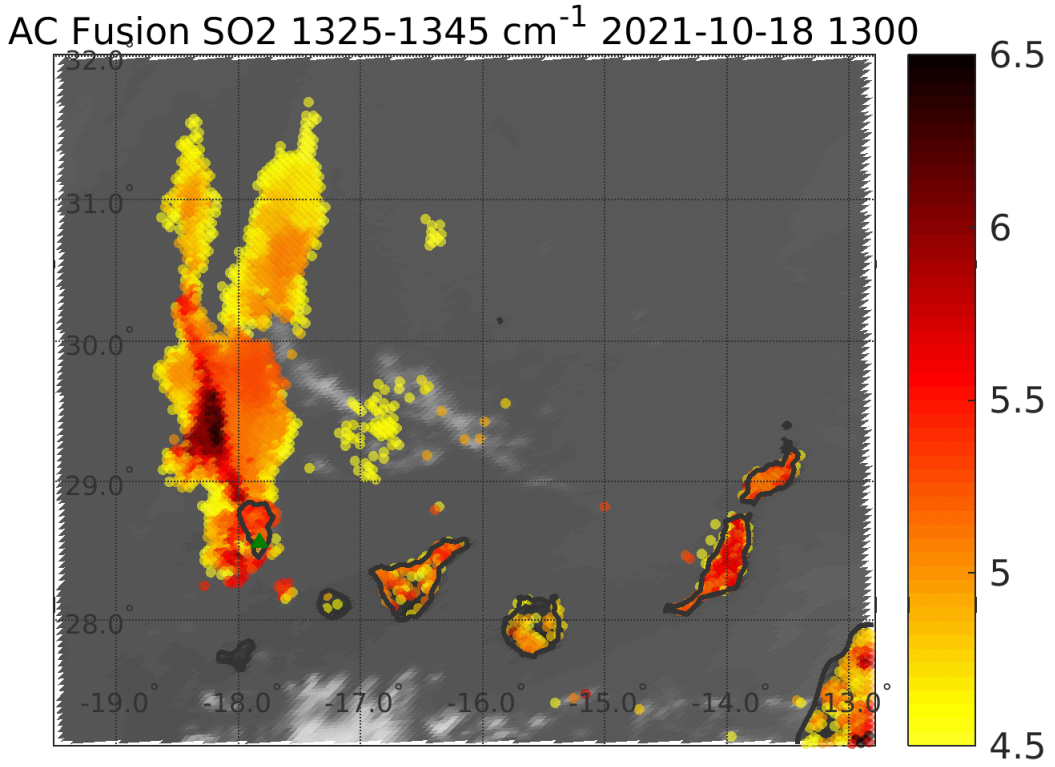


TROPOMI SO_2 [DU]
at ~1350 UTC (fusion start)

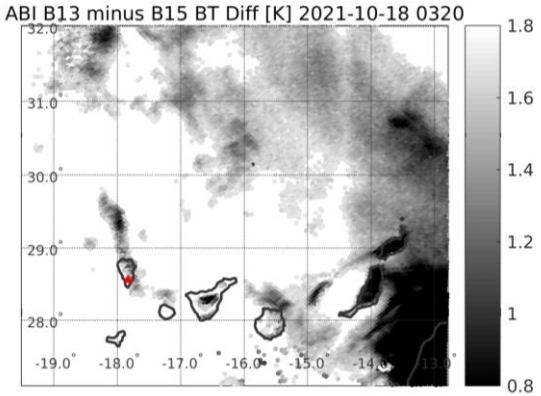


CrIS 1325-1345 cm^{-1} BTD [K]
at ~1430 UTC (fusion start)

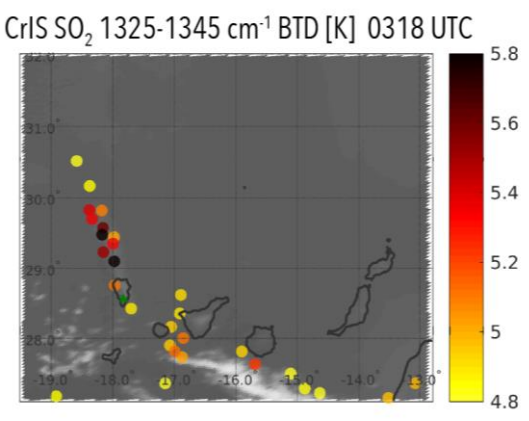




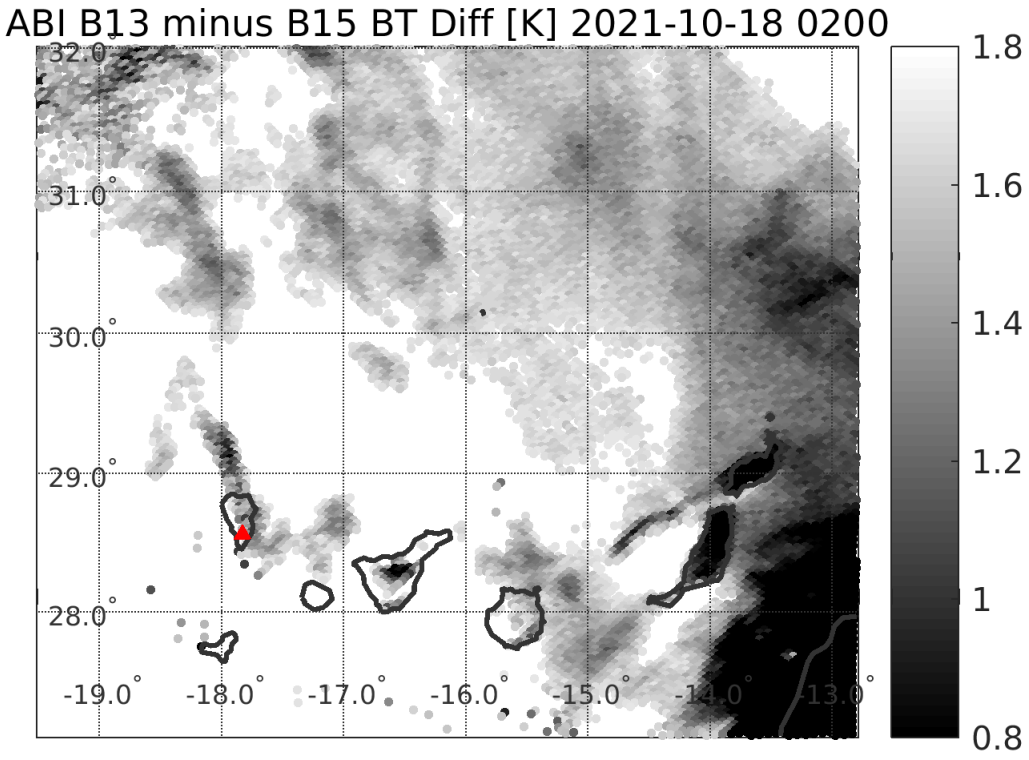
ABI/CrIS SO_2 Fusion Nighttime Results (18 Oct 2021, 0200-0500 UTC)

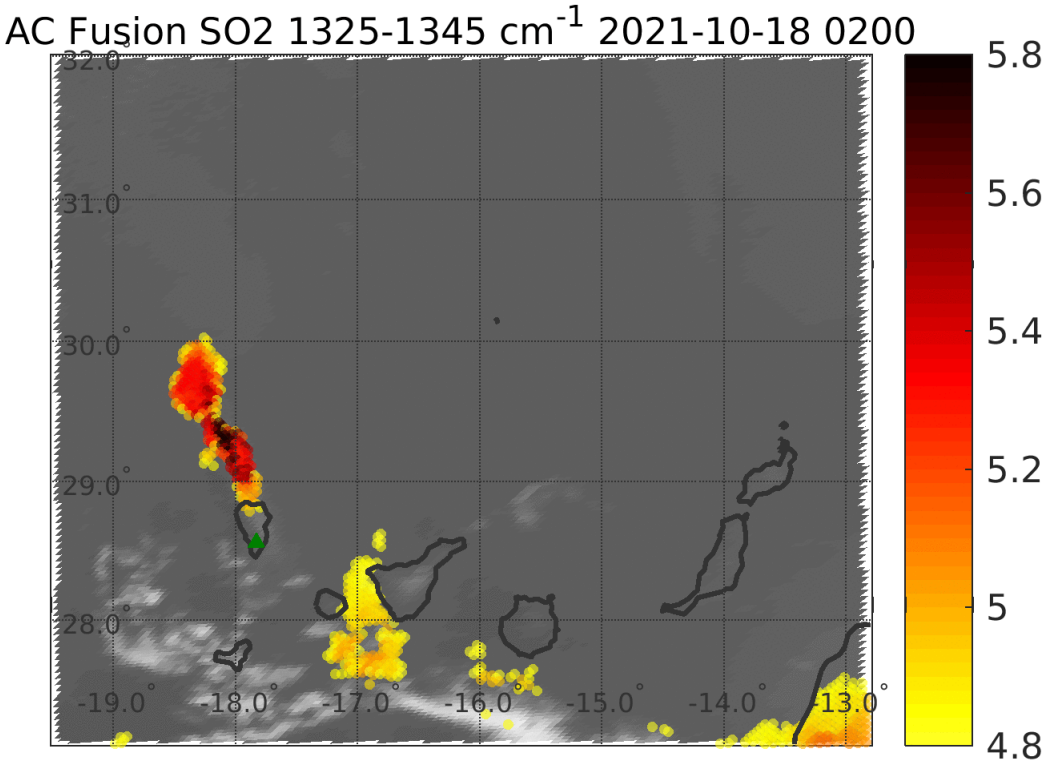


ABI B13-B15 BTD [K]
at 0320 UTC (fusion start)



CrIS 1325-1345 cm^{-1} BTD [K]
at ~0320 UTC (fusion start)





SUMMARY

- Emission and dispersion of volcanic SO_2 and ash plumes from the Cumbre Vieja volcano eruptions on October 9th and 18th, 2021 are investigated.
- Fusion results show increased spatial and temporal detail, and growth and directionality of the volcanic ash plumes are realistically depicted
- SO_2 detection at nighttime is demonstrated with ABI/CrIS fusion (utilizing SO_2-sensitive CrIS channels; BTD of 6 K corresponds ~60 DU SO_2)
- Three instrument pairings (VIIRS/TROPOMI, ABI/TROPOMI, and ABI/CrIS) are presented; fusion algorithm is computationally efficient and stable
- Potential benefits range from improved air quality monitoring to better aircraft safety systems
- Fusion work suggests potential changes for the scanning and spectral design of future LEO instruments
- Provides an early indication of the anticipated impact of geostationary high spectral resolution sounders on trace gas monitoring and warning operations (and other applications)