

Volcanic Cloud and Aerosol Monitor (VOLCAM) for Deep Space Gateway

N. Krotkov¹, P. K. Bhartia¹, O. Torres¹, C. Li^{2,1}, S. Sander³, V. Realmuto³, S. Carn⁴, J. Herman⁵
¹NASA/GSFC, Nickolay.A.Krotkov@nasa.gov ²UMD/ESSIC ³NASA/JPL ⁴MTU ⁵JCET/UMBC

Frequent (~15 min) imaging of reflected solar ultraviolet (UV) and thermal infrared (TIR) radiation of the whole Earth from cislunar vantage point offer unique possibilities to answer NASA's Earth System Science (ESS) questions and further advance volcanic ash (VA) and sulfur dioxide (VSO₂) aviation safety applications. We propose complementary ultraviolet (UV) and thermal Infrared (TIR) filter cameras for a dual-purpose whole Earth imaging with complementary natural hazards applications and Earth System science goals.

Our proposed UV imager is similar to the DSCOVR/EPIC filter camera currently observing Earth from the L1 vantage point¹, but with more rapid color sampling to mitigate scene motion artifacts. The baseline configuration includes 4 narrow band (1-2nm) UV interference filters (317.5, 325, 340, and 388 nm) to obtain atmospheric composition retrievals: total column ozone O₃ and volcanic sulfur dioxide SO₂, UV scene reflectivity (cloud fraction), and UV absorbing aerosol properties (ash, smoke and dust). Visible filters near the oxygen absorption A band can be added to measure cloud and aerosol plume heights. The Earth disc image is projected onto 2048 x 2048 pixel CCD detector to produce a nadir ground resolution ~10x10 km² at nadir. Figure 1 shows Mt. Etna VSO₂ cloud measured by the EPIC UV camera at ~20km resolution in 2 hours.

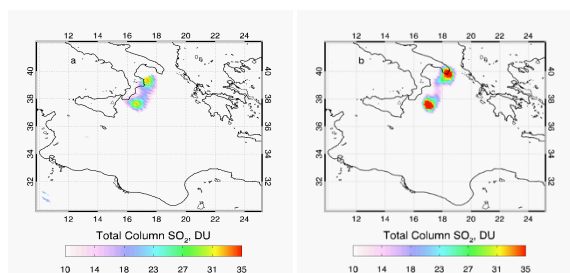


Figure 1. EPIC volcanic sulfur dioxide (VSO₂) map for the December 3 2015 eruption of Etna volcano (Sicily, Italy; triangle) in two consecutive EPIC exposures at (a) 08:16UTC; (b) 10:04 UTC. Total column SO₂ amount is measured in Dobson Units (1DU = 2.69x10¹⁶ molecules SO₂/cm²). Background and anthropogenic SO₂ is far below EPIC detection limit of ~10 DU, while VSO₂ is generally less than 1000 DU.

Large horizontally extended layers of smoke and desert dust are routinely generated by agriculture-related biomass burning and wild fires as well as by the wind lifting effect in the world deserts. These plumes are mobilized thousands of kilometers away from their original sources, often reaching densely populated centers and affecting air quality. Because of the known absorption properties of carbonaceous and desert dust aerosols, near UV observations will make possible the detection of smoke and desert dust plumes (Fig.2). The high temporal frequency of the observations will enable a predictive capability to minimize adverse effects on the population. Such whole disk UV measurements, including polar regions, will not be available from GEO satellites.

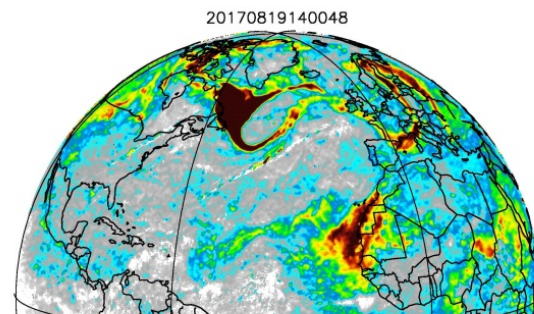


Figure 2. Spatial distribution of desert dust (over western Africa and Atlantic) and biomass burning aerosols (over Canada and north Atlantic) as shown by EPIC UV Aerosol Index (UVAI) measured on August 18, 2017. The UVAI is calculated from EPIC observations at 340 nm and 388 nm (red and black colors indicate high aerosol mass and height). TIR measurements will allow discriminating between ash (large particles), smoke (fine particles) and ash (using VSO₂ as a proxy).

Nighttime observations of volcanic and aerosol plumes will be obtained with a TIR camera capable of ~20km spatial resolution. The baseline configuration is similar to the previously proposed geostationary VOLCAM TIR camera² with 4 spectral channels centered at 8.5, ~11,12 and 13.3 μ m. This selection allows imaging of VSO₂ (8.5 μ m)³, meteorological cloud property retrievals⁴, and ash mass and particle effective radius(11,12 μ m)⁵⁻⁶. Adding 13.3 μ m (e.g., GOES-R/ABI channel 16) would allow retrieval of volcanic ash height⁵. The original VOLCAM TIR detector was a 640 x 480 noncooled microbolometer 2D array², which could be upgraded with an advanced microbolometer technology⁷.

From cislunar orbit VOLCAM UV-TIR cameras will periodically observe movement of the large scale weather systems and transient volcanic and aerosol clouds over polar regions not visible from the equatorial GEO orbit.

Simultaneous, frequent measurements of cloud evolution (by O2-A band and TIR bands) and aerosol properties (by UV and TIR bands) will provide unique opportunities to study the interaction between cloud system and several important aerosol species (smoke, dust, and VSO₂). This will help to better understand the indirect effects of aerosols on climate, as well as the invigoration/suppression of convective clouds by aerosols.

The TIR measuring capability will help to unambiguously differentiate volcanic sulfate aerosols from ash and desert dust plumes, and from smoke layers, providing accurate characterization of the optical depth and mass concentrations for hazard alert decisions. In addition TIR imaging will detect major “hot spots” due to forest fires and volcanic activity.

The combined use of UV and TIR cameras will allow volcanologists and atmospheric scientists to document the life cycle of volcanic sulfur in the atmosphere and map radiative forcing (RF) of volcanic clouds and aerosols above land, water and meteorological clouds. The RF calculations would allow interpretation of the absolute whole Earth radiation measurements to quantify the input from clouds, volcanic events and aerosols (smoke and dust) to the Earth’s radiation balance.

Synergetic use of UV and TIR capabilities of VOLCAM will yield more accurate retrievals of SO₂ discharged from volcanic eruptions, by combining the greater SO₂ sensitivity afforded by UV measurements and information about SO₂ height provided by TIR measurements. This will lead to more accurate quantification of volcanic input of sulfur (SO₂ and sulfate aerosols) into the atmosphere and their climate impacts.

The high-frequency, day-and-night monitoring capabilities of VOLCAM for volcanic ash will be critical for aviation safety applications, particularly for airliners taking the polar routes over the Arctic that is not observed by GEO instruments.

Frequent measurements of volcanic ash size will also help to determine the sedimentation rate of volcanic ash, providing better constraints for numerical models.

DSG requirements:

- 1) External instrument stabilization platform for accurate Earth pointing;
- 2) External science data downlink antenna for high speed transmission of frequent measurements (e.g., ~10 wavelengths every 15 minutes from a 2048 x 2048 detector).

VOLCAM instrument characteristics

- 1) Mass (without pointing platform) ~30 kg
- 2) Power ~ 30 Wt
- 3) Volume < 0.5 m³
- 4) Data rate (without compression) ~350 kb/sec
- 5) Independent thermal management

With the near autonomous operation of the VOLCAM instrument, the uplink commands are infrequent during normal operation and should not exceed a few kilobits per day.

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