ONBOARD PROCESSING OF MULTISPECTRAL AND HYPERSPECTRAL DATA OF VOLCANIC ACTIVITY FOR FUTURE EARTH-ORBITING MISSIONS

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Future space missions that monitor Earth's surface and environment will generate massive volumes of data. For example, the HyspIRI mission, in its current design, will generate 10^9 bits (1 gigabit, or 1.5 megapixels) per second of operation. Downlinking and processing these data in order to identify new volcanic eruptions, or changes in existing eruptions, in a timely manner to assist in the determination of volcanic risk and hazard, will be a major challenge [1]. Ideally, if data can be processed onboard the spacecraft, then the results of the analysis can be speedily downlinked and subjected to additional processing on the ground. The resulting products will be distributed to end-users, in this case, the relevant volcano observatory scientists and regional/local decision makers. Such an autonomous system has been successfully demonstrated. The Autonomous Sciencecraft (ASE) [2-4] is advanced software flying on the *Earth Observing-1* (*EO-1*) spacecraft since mid 2004. ASE consists of an onboard planner that manages available resources, a spacecraft command language that interprets commands from the planner to operate the spacecraft and instruments, and data classifiers that process Hyperion hyperspectral imagery (196 bands from 0.4 to 2.5 μm). It is not possible to rapidly (i.e., within a few hours) downlink the entire Hyperion observation, which may exceed 200 MB in size. Instead, the results of the onboard processing, a highly-compressed précis of the science content of the observation in a small file no larger than 20 KB, is downlinked during more frequent engineering contacts, typically within 90 minutes of data acquisition. For volcano observations, this file consists of the radiant flux at 12 wavelengths for each pixel containing anomalous thermal emission [3].

Thus, the location and extent of the ongoing volcanic activity is quickly available for distribution and additional analysis. Such operational advances have reduced the time taken for delivery and processing of the full Hyperion dataset from 2-3 weeks in 2003 to 24-36 hours in 2009. Ground-based processing now includes a pixel-by-pixel derivation of thermal emission, incorporating atmospheric correction, sunlight removal, correction for viewing geometry [5], and which now yield radiometrically corrected and geo-located products that identify the location of 'hot' pixels [Figure 1], maps of thermal emission and pixel fraction occupied by the thermal source, [Figure 2 and 3], and the integrated thermal emission, a quantity that can be used to estimate the eruption effusion rate [Table 1]. Additionally, the integrated thermal emission data are automatically added to any previously available data to produce a history of activity at the volcano to date, with calculations indicating if the current activity is statistically significant. These results can be used to prioritise eruption notifications and to act as a trigger for requests of additional observations not only by *EO-1* but other assets as well. The entire system is autonomous [4, 6]. The current system, based at NASA's Jet Propulsion Laboratory, has, at best, obtained and processed onboard *EO-1* an observation from a sensor web trigger in a mere two hours (Mt. St. Helens, July 2008).

It is therefore desirable to include such a capability on future missions. The HyspIRI mission in particular would benefit greatly from both an onboard processing capability and autonomous ground-processing of data. The broad wavelength range of HyspIRI instruments means that pre-eruption thermal anomalies may be identified at thermal infrared wavelengths. For ongoing eruptions, onboard classifiers can identify the style of volcanic activity, thus allowing the correct models of effusion to be used to quantify eruption processes. Recent analysis of terrestrial remote-sensing data identifies the following wavelength selection for best constraining temperature distribution for ongoing volcanic eruptions, including lava fountains, open-channel and insulated lava flows, active lava flows, lava domes and insulated highly-silicic lava flows [7]. Balancing a desire to return as much data as possible with constraints on product size and the available processing capability, the optimum minimum wavelength set for an onboard classifier would be 2, 5, 8, and 12 μm. Additional constraints for fits to the thermal emission spectrum would be possible with data at 3 μm. The number of thermally-active pixels is a tiny fraction of the total number in an observation (typically of order 10 to 100, out of 1.5 M pixels collected per second). The same classifier could also be used onboard a future mission to the volcanic jovian moon Io [7, 8] where long communication times means an onboard capacity to identify high-priority data would increase science return per returned byte, especially where there are constraints on downlink.

Table 1. Autonomous data processing output

Mass Effusion rate:	**130.19 kg/s**
Volumetric Effusion rate:	**0.05 m^3/s**
Total Power loss:	**3.91e+07 W**
Radiative Power loss:	**2.86e+07 W**
Convective Power loss:	**1.05e+07 W**
Look Angle:	**6.29 (deg)**
Range to Ground:	**692.77 (km)**

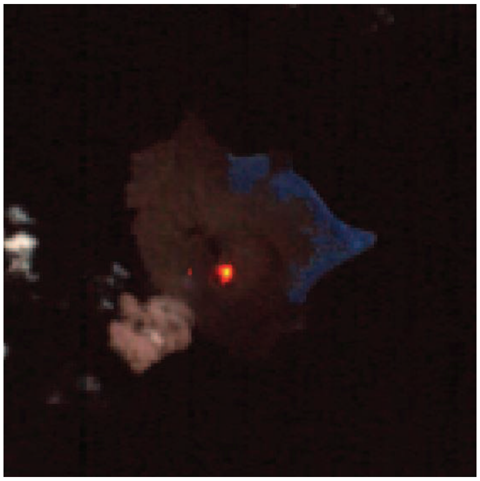

Figure 1 (left). Hyperion short wavelength infrared observation of Krakatau volcano (Indonesia) on 2009 August 23 showing an ongoing eruption in the summit crater. Spatial resolution is 30 m/pixel.

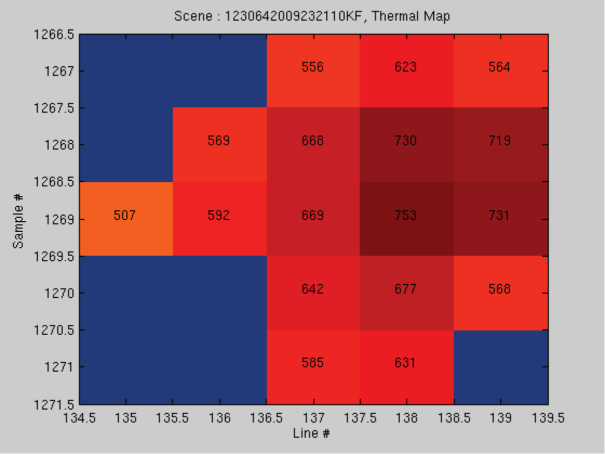

Figure 2. Thermal map of hot pixels identified by the thermal classifier flying on *EO-1* [5].

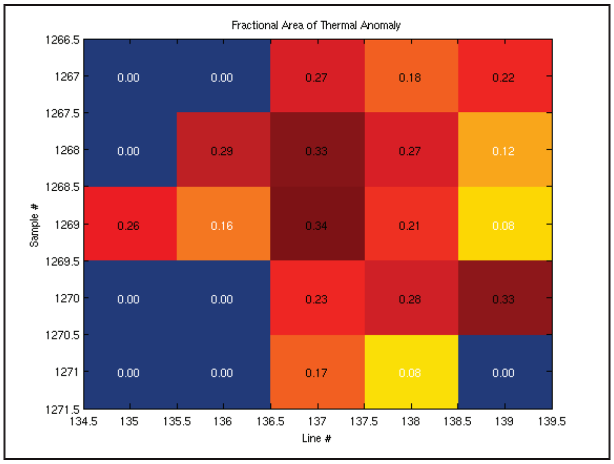

Figure 3. Fraction of pixels filled by thermal sources at temperatures given in Fig. 2 [5].

Acknowledgements: This work was performed at the Jet Propulsion Laboratory-California Institute of Technology, under contract to NASA. *EO-1* is managed by the NASA Goddard Space Flight Center. © 2009. All rights reserved.

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