Onboard Instrument Processing Concepts for the HyspIRI Mission

Steve Chien, Dorothy Silverman,
Ashley Gerard Davies, David Mclaren
Jet Propulsion Laboratory, California Inst. of Technology
Pasadena, CA, USA
steve.chien@jpl.nasa.gov

Daniel Mandl, Jerry Hegemihle
Goddard Space Flight Center and Microtel LLC
Greenbelt, MD, USA

***Abstract*—Future NASA missions will have instruments that generate enormous amounts of data. We describe an onboard processing mission concept for a possible Direct Broadcast capability for the HyspIRI mission – a mission under consideration for launch in the next decade carrying visible to short wave infrared (VSWIR) and thermal infrared (TIR) instruments. The VSWIR and TIR instruments will produce over 800 x 10^6 bits per second of data however the Direct Broadcast downlink rate will be approximately 10x10^6 bits per second, allowing only 1/80th of the data to be rapidly downlinked.**

Our onboard processing concept under development spectrally and spatially subsamples the data as well as generates science products onboard to enable return of key rapid response science and applications information despite limited downlink bandwidth. This rapid data delivery concept focuses on wildfires and volcanoes as primary applications but also has applications to vegetation, coastal, flooding, dust, and snow/ice applications.

Keywords imaging spectroscopy, hyperspectral imaging, onboard processing, data reduction

I. Introduction

HyspIRI [HyspIRI] is a proposed mission to carry a VSWIR hyperspectral instrument with 220 bands from 0.5 to 2.4 microns at 60m/pixel resolution and a TIR instrument with 8 bands in the 4 and 8-12 micron range, also with 60m/pixel resolution. With a VSWIR instrument swath of approximately 150 km and TIR swath of approximately 600 km these instruments will have a 19 and 5 day repeat coverage. The data acquisition rate is 800 x 10^6 bit per second. The normal data downlink path is to downlink at a high data rate when overlying polar ground stations with complete data processing and delivery in a 1-2 week timeframe. To enable more rapid data delivery, the mission is studying an option of including an X-band direct broadcast using heritage equipment providing continuous 10 x 10^6 bit per second downlink.

Volcanism – Active volcanism also produces a distinctive thermal signature that can be detected onboard to enable spatial sub-sampling (a large eruption may cover 100 pixels compared to 1.5x106 pixels/s acquired). Onboard algorithms [Davies et al. 2006] and ground-based algorithms suitable for onboard deployment [Wright et al. 2003, 2004, Harris et al. 2000] are mature: the latter examples use TIR bands. On HyspIRI, the algorithm would perform a table-driven temperature inversion from several spectral TIR bands and then trigger downlink of the entire spectrum for each of the hot pixels identified.

Many other rapid delivery applications exist. Rapid delivery data to feed vegetation and plant stress products would be of use in drought and crop tracking. These approaches can use plant color and are amenable to spatial snd spectral subsampling (e.g. [Perry & Roberts 2008] evaluation of 14 which require in total 22 VSWIR-range bands) and thermal models [Anderson and Kustas 2008] using TIR-band data. Ocean and coastal applications include sea surface temperature (using a small spectral subset of TIR (often only two bands) data but requiring considerable ancillary data) and ocean color applications to track biological activity such as harmful algal blooms. Measuring surface water extent to track flooding is another rapid response product leveraging VSWIR spectral information [Brakenridge and Anderson 2005, Carroll et al. 2009] which has been demonstrated onboard EO-1 [Ip et al 2006]. Again these only require the use of two spectral bands. Tracking of large-scale dust storms and cryosphere [Doggett et al. 2006] applications of snow and ice represent additional applications areas with small spatial area and require a small number of spectral bands.

II. Operations Concept

Operationally, the HyspIRI team would define a set of spatial regions of interest where specific algorithms would be executed [Chien et al. 2010a]. For example, known coastal areas would have certain products or bands downlinked, ocean areas might have other bands downlinked, and during fire seasons other areas would be processed for active fire detections. Ground operations would automatically generate the mission plans specifying the highest priority masks executable within onboard computation, setup, and data downlink constraints.

III. Science Applications

In the remainder of this abstract we briefly survey some of the products that are being evaluated for rapid data delivery. In our studies we are focusing on three baselines: (1) downlink the MODIS bands (to leverage strong heritage in MODIS analysis algorithms), (2) downlink spectral bands needed to produce a larger set of science products, or (3) product science

Portions of this work were performed by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

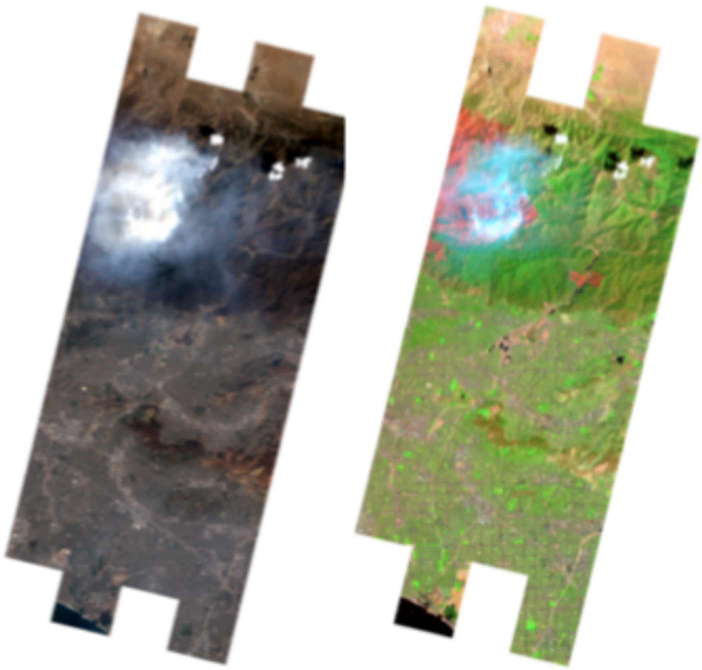

Figure 1: Advanced Land Imager (ALI) images of the Station Fire near Los Angeles, CA, August 2009. (L) Color (R) Burn Scar Product – Burn Scar in Red

products onboard (including spatial sub-sampling via onboard detection for small targets such as volcanoes or wildfires). For each discipline we are evaluating the bands needed as well as the ancillary data needed to produce end science products.

A. Fires and Burn Scars

One of the highest priority rapid data delivery applications is active fire and burn scar mapping. The thermal bands of the TIR instrument (e.g., [Justice et al. 2002] requiring 4μm and 11μm spectra only) can accurately detect the thermal signature of fires and send down alerts as well as the thermal and VSWIR data corresponding to the active fires . For day overflights the VSWIR data can also provide useful data for burn scar evaluation [van Wagtendonk et al. 2004] using spectral information from the 0.76-0.9μm and 2.08-2.35μm ranges. Thermal detections can be easily performed onboard and have been routinely performed onboard Earth Observing-1 (EO-1) [Davies et al. 2006] using algorithms processing data in the 0.4 - 2.4 μm range, and allows tremendous downlink savings as the spatial areas for even large fires (the areas currently burning, or hot) are a small fraction of total pixels acquired (more than 10^6 pixels/s). While burn scars are larger areas they still represent a small fraction of overflown landmass and only require a small fraction of the spectral information (typically only two bands).

B. Volcano Monitoring

The HyspIRI TIR and VSWIR instruments have great applicability to volcano monitoring. The HyspIRI instruments can be used to measure the thermal signature of volcanic sources. While significant prior work has tracked thermal signatures of volcanic activity from space using MODVOLC (using MODIS sensor bands B21/22 (3.959 mm) and B32 (12.02 mm) and GOES/AVHRR 4, 11-12 μm [Harris et al. 2000, Wright et al. 2003, 2004]). However, HyspIRI offers more sensitive detection capability with the TIR instrument providing 4 and 8-12 μm spectra. The EO-1 Hyperion instrument has been used operationally with onboard software to track volcanic thermal activity using spectral slope in the 0.4-2.5 μm range [Davies et al. 2005] and automatically downlink full spectra of thermally active pixels. HyspIRI could use a similar capability to detect and summarize volcanic activity enabling the spacecraft to pick out the few key pixels of data out of literally billions of non-relevant pixels. Such an algorithm would use several TIR bands to estimate surface temperature and flag pixels likely to be hot due to volcanic activity. When such pixels are detected a notification with TIR and selected VSWIR data would be downlinked for each flagged pixel. The HyspIRI TIR instrument also could potentially detect volcanic SO_2 emissions using the SO_2 absorption band in the 8-9 μm range.

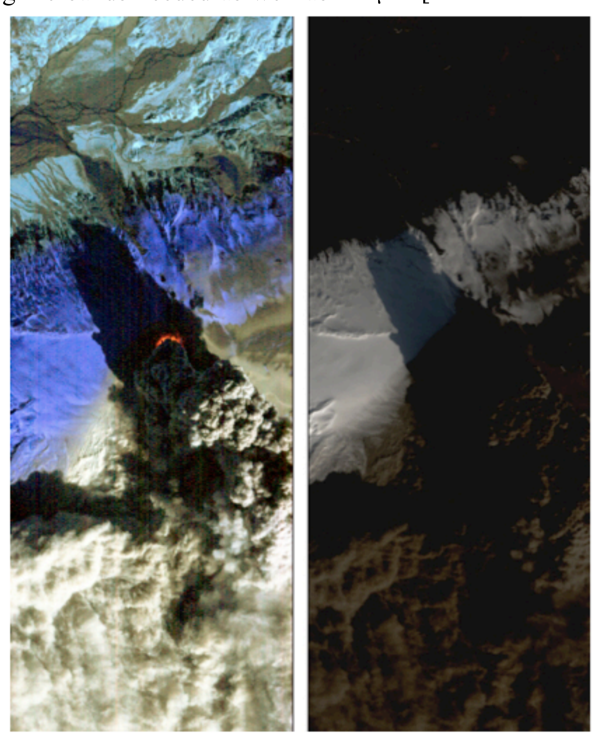

Figure 2:
Hyperion 17 April 2010 imagery acquired via volcano sensorweb.
Left – thermal false color
Right – True color

Image courtesy EO-1/NASA GSFC Volcano Sensorweb JPL/A. Davies

Onboard processing of volcanic data represents a huge win from both a data volume and timeliness perspective. Because volcanic eruptions represent a small number of pixels (even a major eruption might only cover a few hundred pixels), localization of the volcanic activity means analysis can focus on a relatively small fraction of pixels). Volcanic activity also represents an extreme example of timeliness. Given the large number of people living close to volcanoes, accurate and timely information is critical to informed assessment of current and future risk to both lives and property.

C. Other Applications

Snow and Ice Products - The Hyspiri instruments (both VSWIR and TIR) will be useful for studying and monitoring Snow, Water, Ice, and Land (SWIL) phenomena. SWIL classification is important for monitoring climate change, assessing environmental sustainability, and regulating both land-based and sea traffic. Ice and snow products have been developed on the ground using a range of instruments including MODIS [MODIS Snow Ice] using 0.4-12 μm and onboard spacecraft using Hyperion bands at 0.43, 0.56, 0.66, 0.86 and 1.65 μm [Doggett et al. 2006]. Because of the impact of snow and ice on commercial activities rapid delivery of this remote sensed data is important.

Flooding - HyspIRI instruments are useful for tracking surface water extent with applications to flooding and disaster response. Because flooding is the greatest natural hazard (both in terms of lives lost and property damage), any real-time capability to assist in humanitarian efforts is of tremendous importance. MODIS has been used for ground processing for near real-time flood mapping by both the Dartmouth Flood Observatory [Brakenridge and Anderson 2005] and the University of Maryland [Carroll et al. 2009] (using MODIS bands 1,2,5,7 (0.62-2.155 μm). EO-1 Hyperion has also been employed to detect floods using onboard software that enables rapid alert generation and retasking [Ip et al. 2006] (using 0.86 and 0.99 μm). Because of the tremendous human and economic impact of flooding, rapid delivery of flooding data is critical.

Dust Products - HyspIRI instruments can be used to track large-scale dust storms using both color (VSWIR) and thermal (TIR) information. These dust storms are hundreds of kilometers in extent and threaten human health and aircraft safety as well as having significant environmental impacts. Because of these major impacts and the dynamic nature of dust storms rapid delivery of relevant satellite data is key.

Vegetation - The HyspIRI instruments can be used to measure plant stress [Perrry and Roberts 2008] as well as identify plant species. Monitoring vegetation pigment levels with VSWIR in the 500-1200 nm range can identify plant stress to assist in predicting crop failures – a key rapid response application. VSWIR can also identify plant species with rapid response applications for disease risk estimation. Thermal plant stress as measured by the TIR instrument can also be used to estimate evapotranspiration (ET) [Anderson & Kustas 2008], a key indicator in predicting crop failure. Timely products from MODIS are currently being used by the USDA to assess crop health and yield (e.g., as affected by drought, fires, volcanic eruptions, or storms). For example, the U.S. Department of Agriculture's Foreign Agricultural Service (FAS) is using MODIS data to estimate predicted crop yields. This data enables FAS to make accurate crop-yield estimations, which ultimately affect decisions impacting U.S. agriculture, trade policy and food aid. All of the above applications would benefit from timely delivery of data for decision making based on crop and disease models.

Ocean/Coastal - The HyspIRI VSWIR and TIR instruments are useful for studying a wide range of oceanographic applications, many of which significantly benefit from rapid data delivery. Ocean color measurements using VSWIR can be used to detect and track harmful algal blooms (HAB's) and other biological events, and sediments that pose a threat to both exposed people and wildlife. Because of these hazards, rapid data delivery is of great value. For example, the Maximum Chlorophyll Index has been developed for rapid data delivery using EO-1/Hyperion data from the 660, 681, 711, & 752 nm bands to track activity in Monterey Bay. Ocean and coastal applications present unique challenges because of the subtlety of the ocean signals. Image corrections (e.g., atmospheric correction) are critical and present tremendous challenges for onboard processing.

IV. CONCLUSIONS

We have discussed a concept under development for Direct Broadcast for the HyspIRI mission. Because the HyspIRI TIR and VSWIR produce 800×10^6 bits per second of data and the heritage X band direct broadcast link can only downlink approximately 10×10^6 bits per second, onboard data reduction is required. We have presented a hybrid approach that uses scientist specified regions of interest, onboard processing and event detection, and product generation all as methods to reduce the amount of data for downlink. This approach is currently under refinement and evaluation using the EO-1 mission as a testbed.

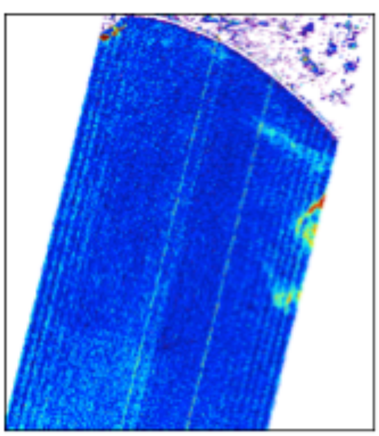

Figure 3: Maximum Chlorophyll Index product of Monterey Bay derived from Hyperion imagery acquired 21 October 2008.

False color added by J. Ryan/MBARI

Image courtesy [Chien et al. 2009]

Acknowledgment

The authors gratefully acknowledge inputs from many science and applications specialists including members of the HyspIRI Science working group. Special thanks are due to: M. Anderson, R. Brakenridge, P. Campbell, I. Csiszar, A. Davies, R. Furfaro, L. Giglio, G. Glass, J. Kargel, F. Kogan, R. Kudela, J. Mars, E. Middleton, S. Miller, F. Muller-Karger, A. Prakash, V. Realmuto, D. Roberts, J. Ryan, R. Sohlberg, and R. Wright. However, full responsibility for any errors or omissions lies with the authors.

References

[1] M. Anderson and W. Kustas, "Thermal Remote Sensing of Drought and Evapotranspiration," Eos, Vol. 89, No. 26, 24 June 2008, pp. 233-234.

[2] G.R. Brakenridge and E. Anderson, "MODIS-Based Flood Detection, Mapping, and Measurement: The Potential for Operational Hydrological Applications," Transboundary Floods, Proc. NATO Adv. Rsch Wkshp, Springer, 2005, pp. 1–12.

[3] M. Carroll et al., "A New Global Raster Water Mask at 250 Meter Resolution,"Int'l J. Digital Earth, vol. 2, no. 4, 2009.

[4] S. Chien, D. Silverman, A. Davies D. Mandl, Onboard Science Processing Concepts for the HyspIRI Mission, IEEE Intellgent Systems, Nov/Dec 2009, pp. 12-19.

[5] S. Chien et al., "Using Autonomy Flight Software to Improve Science Return on Earth Observing One," J. Aerospace Computing, Information, and Communication, vol. 2, no. 4, 2005, pp. 196–216.

[6] S. Chien et al., "An Autonomous Earth- Observing Sensorweb," IEEE Intelligent Systems, vol. 20, no. 3, 2005, pp. 16–24.

[7] A.G. Davies et al., "Monitoring Active Volcanism with the Autonomous Sciencecraft Experiment (ASE) on EO-1," Remote Sensing of Environment, vol. 101, no. 4, 2006, pp. 427–446.

[8] T. Doggett et al., "Autonomous Detection of Cryospheric Change with Hyperion Onboard Earth- Observing 1," Remote Sensing Env, vol. 101, no. 4, 2006, pp. 447–462.

[9] A. Harris et al., "Real-Time Satellite Monitoring of Volcanic Hot Spots,"Geophysical Monograph, vol. 116, 2000, pp. 139–159.

[10] HyspIRI Mission Web site, hyspiri.jpl.nasa.gov

[11] F. Ip et al., "Flood Detection and Monitoring with the Autonomous Sciencecraft Experiment Onboard EO-1," Remote Sensing of Env, v. 101, n. 4, 2006, pp. 463–481.

[12] C.O. Justice et al., "The MODIS Fire Products," Remote Sensing of Environment, vol. 83, no. 1, 2002, pp. 244–262.

[13] E. Perry and D. Roberts, "Sensitivity of Narrow-Band and Broad-Band Indices for Assessing Nitrogen Availability and Water Stress in an Annual Crop, Agronomy Journal, vol. 100 Issue 4, 2008, pp. 1211-1219.

[14] van Wagtendonk, J.W., Root, R.R. & Key, C.H. (2004). Comparison of AVIRIS and Landsat ETM+ detection capabilities for burn severity. Remote Sensing of Environment, 92(3), 397-408.

[15] R. Wright et al., "Automated Volcanic Eruption Detection Using MODIS," Remote Sensing of Environment, vol. 82, no. 1, 2003, pp. 135–155.

[16] R. Wright et al., "MODVOLC: Near- Real-Time Thermal Monitoring of Global Volcanism," J. Volcanology & Geothermal Research, vol. 135, n. 1–2, 2004, pp. 29–49.