Hyperspectral Cubesat Constellation for Natural Hazard Response (Follow-on)

Daniel Mandl, Gary Crum, Vuong Ly, Matthew Handy
NASA\GSFC
Code 580
Greenbelt, MD 20771
(301)286-4323
daniel.j.mandl@nasa.gov

Karl F. Huemmrich, Lawrence Ong
NASA\GSFC
Code 618
Greenbelt, MD 20771
(301)614-6663
karl.f.huemmrich@nasa.gov

Ben Holt, Rishabh Maharaja
HTSI – NASA\GSFC
Code 428; Greenbelt, MD. 20771
(301)286-2686
benjamin.holt@nasa.gov

ABSTRACT

The authors on this paper are team members of the Earth Observing 1 (E0-1) mission which has flown an imaging spectrometer (hyperspectral) instrument called Hyperion for the past 15+ years. The satellite is able to image any spot on Earth in the nadir looking direction every 16 days and with slewing, of the satellite for up to a 23 degree view angle, any spot on the Earth can be imaged approximately every 2 to 3 days. EO-1 has been used to track many natural hazards such as wildfires, volcanoes and floods. An enhanced capability that has been sought is the ability to image natural hazards in a daily time series for space-based imaging spectrometers. The Hyperion cannot provide this capability on EO-1 with the present polar orbit. However, a constellation of cubesats, each with the same imaging spectrometer, positioned strategically can be used to provide daily coverage or even diurnal coverage, cost-effectively. This paper sought to design a cubesat constellation mission that would accomplish this goal and then to articulate the key tradeoffs.

INTRODUCTION

Remote sensing scientists that use image spectroscopy from space have been testing various techniques to monitor farming, ecology, forestry, biodiversity and natural hazards. Typically, these applications require a spectral range of 400 – 2400 nm, which is what the Hyperion on Earth Observing 1 returns. For all of these phenomena, there is a need in the science community to sample measurements in a time series, especially on a daily basis, or even better would be multiple observations of the same spot on each day, diurnal. In the past, hyperspectral sensors were expensive given the required spectral range of 400 – 2400 nm and the typical spatial requirements of 30 m for land applications such as that used for the Hyperion on EO-1. The EO-1 mission cost approximately $200 million to get to launch in November 21, 2000. A potential follow-on survey NASA hyperspectral mission named HyspIRI is estimated to cost in the neighborhood of $500 million for the complete mission including three years of operations. In the case of HyspIRI, gathering survey data for all land surfaces requires management of large data sets in the Terabit range for each orbit. A hyperspectral cubesat constellation solution has many constraints which includes low power on the satellite, relatively low bandwidth for the space to ground link, limited onboard space to host instruments and other satellite components. Thus some of the tradeoffs translate to lower spectral bandwidth, lower signal to noise ratio but greater temporal resolution and at a much lower cost. Thus, the lower cost enables partial capability and allows for more hyperspectral data sets to fulfill some science but can be sufficient for monitoring of natural hazards. Small hyperspectral instruments typically span 400 – 1000 nm and are small enough to fit in a cubesat.

SELECTED CONCEPT OF OPERATIONS

In our selected concept of operations, a number of cubesats are placed in a space station orbit at an altitude of approximately 400 km although a similar polar orbit to EO-1 could be employed. Figure 1 shows the basic architecture components of the mission. Note that in this architecture, there are two modes to communicate to the cubesats. The first is via S-band to the ground network at about 2 Mbps to handle the higher level data products. The second is 1 kbps S-band to TDRSS via the Space Network to enable total coverage for commanding and basic telemetry for health and safety of the cubesats.

This model of operations emulates the EO-1 concept of operations whereby there is a high speed data downlink and low rate for command and telemetry. In the case of EO-1, X-band is used at 100 Mbps downlink rate for the instrument data. But due to power limitation, the cubesats use S-band at 2 Mbps for their high data downlink channel to stay within power constraints. The low rate for EO-1 is either to the Ground Network at 32 kbps or 8 kbps to TDRSS via Space Network. In the case of the cubesats, it would be 1 kbps to TRDRSS via Space Network to stay within the power constraints of the smaller antennas, limited power capacity and thus being able to fulfill the link margin.

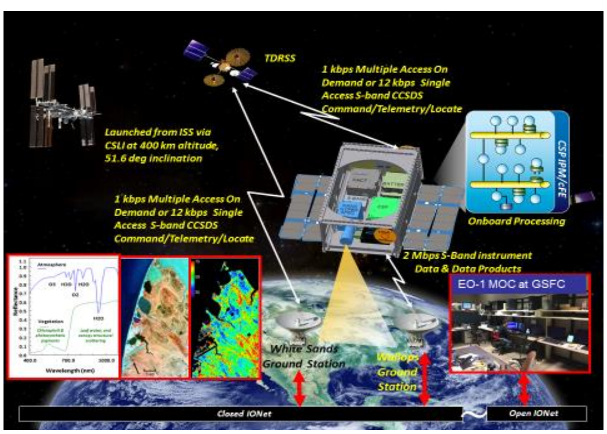

Fig 1 Basic cubesat architecture for each hyperspectral cubesat used in the constellation

ONBOARD DATA PROCESSING

New onboard processing capability is enabling more rapid response for satellites with imaging spectrometers. Figure 2 depicts a Field Programmable Gate Array (FPGA) augmented processor that enables real time onboard processing on raw data from the hyperspectral instrument at Gbps speeds. This enables onboard data reduction to higher level data products from an imaging spectrometer and thus reduces that data volume required to be downlinked. As an example, we selected the Center for High Performance Reconfigurable Computing (CHREC) Space Processor (CSP) which is based on the Zynq chip (2 Arm processors and FPGA circuits) which can provide realtime onboard processing support of the raw data at rates of 1 Gbps. The cubesats with the instruments can be built for under $1 million each.

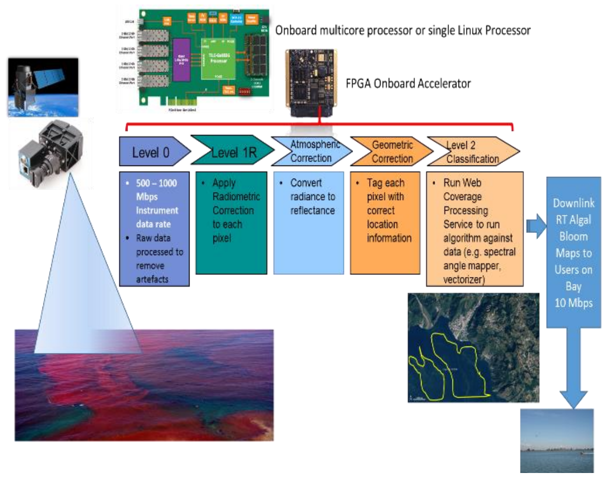

Fig 2 Basic data processing steps for a space-based imaging spectrometer that typically was done on the ground, but can now be done onboard, in realtime at low power consumption with new onboard processing technology. In this example, the data processing chain is used to detect harmful algal blooms.

INTERNAL COMPONENTS IN EACH CUBESAT

All of the components selected for our initial design are readily available commercially. Figure 3 is a preliminary list of the estimated cost for the key components. The present plan, if funded, would be to use Blue Canyon Technologies to integrate the majority of components and to purchase a Headwall Nano-Hyperspec instrument. Note that the overall cost falls in the range of $500K - $1 Million per cubesat depending on the extra system engineering and integration effort. Furthermore, we assumed that there might be additional cost to making the Nano-Hyperspec more radiation tolerant. The Nano-Hyperspec has a spectral bandwidth of 400 to 1000 nm. With 150 mm lens, it can support 60 m resolution and with a slightly larger lens, can support potentially 30 m resolution. The pitch of the Nano-Hyperspec is 7.4 microns and would require a cm aperture to avoid distortion of the spectra based on the size of the detectors.

Component Name	Vendor	Dimensions	Mass	Count	Cost	TRL	Power
30 Wh Battery	Clyde Space	95.885mm x 90.170 mm x 20.440mm	256g	1	$3,850	9	
6U CubeSat Side Solar Panel	Clyde Space			2	$14,300	9	
3U 2-Sided Double Deployed Solar Panel	Clyde Space			1	$32,750	9	
SCR-102 S-Band radio	Innoflight	(82 X 82 X 35) mm	290g	1	$80,000	9	8W
3G Flex EPS (Electrical Power System)	Clyde Space	(90.80 x 85.08x14.95) mm	148g	1	$13,500	9	.39W
Nano-Hyperspec	Headwall	76.2mm x 76.2mm x 119.92mm)	.68 kg		$200,000 Estimate w/upgrade	9/Aerial, 6/Space	10W
XACT Attitude Determination System	Blue Canyon Tech	10 x 10 x 5 cm	850g	1	$250000	9	Max 2.83W
SGR-05U Space GPS Receiver (antenna included)	Surrey Satellite Technologies US LLC	70x46x12 mm	20g	1	$26,300	9	0.8W
CHREC Space Processor	Space Micro	88 x 89 x 15mm	72g	2	$30,000	9	2.5W
6U Box					$10,000	9	

Fig 3 List of commercial components that can be put on Hyperspectral Cubesat with estimated cost and Technology Readiness Level (TRL)

SELECTED ORBIT DESIGN

In this section we present two potential configurations that provide daily coverage for any spot on the Earth within the coverage area of the Space Station. Therefore, for this configuration, there is no coverage for the poles. We used STK to calculate orbit possibilities. This was selected because one of the launch options is the use of the Cubesat Deployer mechanism on Space Station.

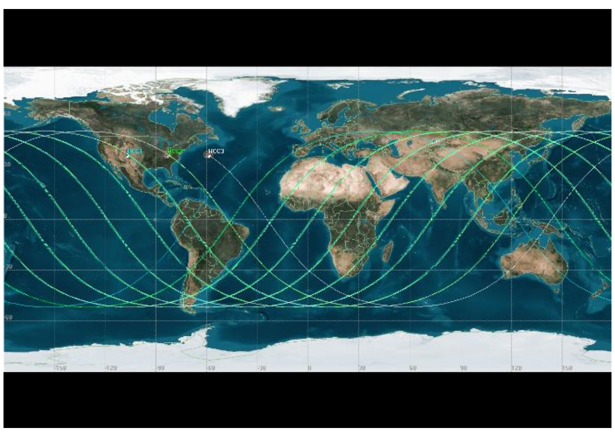

Fig 3 Consists of three Cubesats, HCC1, HCC2 and HCC3 deployed 4 month and 1 day apart. This sets a concept of operations whereby a new HCC is launched every approximately 4 months to replenish the Cubesats that lower beyond specifications.

Figure 4 shows that same orbit design in 3D. Note that in this orbit design, only three cubesats are needed. The assumption is that the cubesat will slew up to 30 degrees. The field of view for the Nano-hyperspec is 640 pixels at 30 meters per pixels for a total of 19.2 km looking nadir. For worst case, which means slewing 15 degrees, the 30 degree cone would cover approximately 460 Km on the ground, only imaging a portion of that area. So for this example, it is assumed that if the satellite slewed 30 degrees, there would be an overlap of about 9.6 Km with the next orbit over.

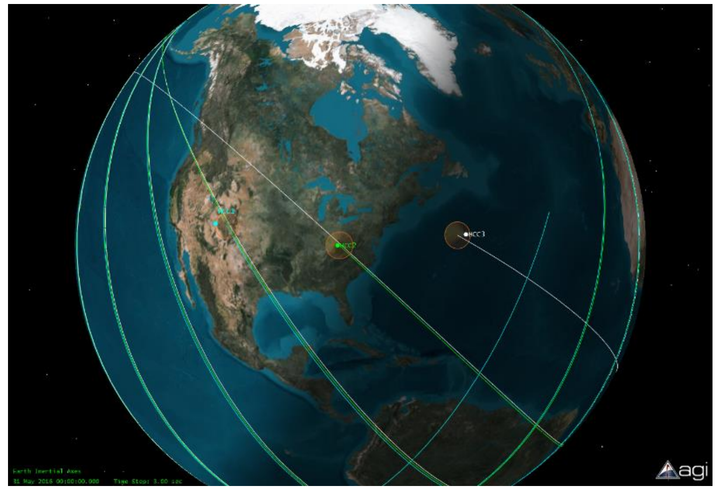

Fig 4 3D view of the proposed orbit

Note that when STK is used to estimate the amount of time the orbit would decay by 10%, to 360km, the estimate is 1.4 years as shown in Figure 5 below.

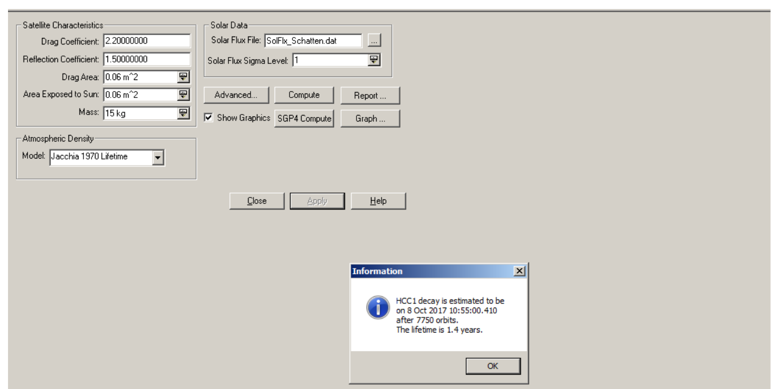

Fig 5 Orbit decay estimate by STK

Thus, the constellation of three satellites could be maintained with margin for at least one year. Then the cubesats could be replaced in some pattern such as replacing one cubesat every 4 months or replacing all three annually. As new cubesats are deployed, either the cost would come down for future cubesats, or the capability would increase or possibly both. The annual cost would be $1 million to $3 million per year amortized over the life of the mission.

Another interesting orbital configuration is shown in Fig 6. The configuration consists of 15 cubesats and would allow selected spots in the Space Station field of view to be viewed by one of the satellites in the constellation approximately every 46 minutes. We assume that only the daylight hours would be viable, but that would still leave at least 6-10 observations per day during daylight hours.

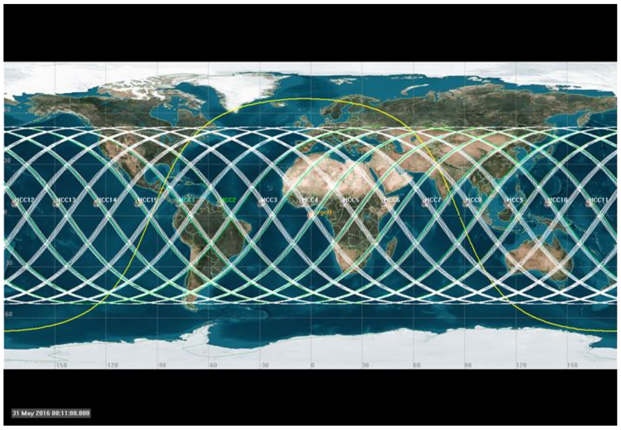

Fig 6 15 cubesat configuration that enables observations for selected spots on the earth every 46 minutes

If the desire is to be able to select any spot on the earth (minus the polar regions that Space Station cannot view) to be observed by one of the constellation cubesats, it would require 3 sets of 15 satellites for a total of 45 cubesats. Figures 7 show the key parameters for these orbits.

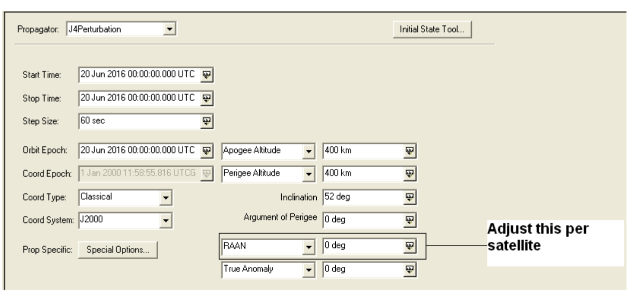

Fig 7 Setup parameters to propagate orbit for the cubesats in this configurations.

There are other desirable orbits similar to the Earth Observing 1 polar orbit which originally was at 705 km. They will be explored at a later date. The key advantage to an orbit emulating the Space Station is that the temperature variation

CONCLUSION

The main goal of this effort was to find a cost-effective way to serve the disaster community with daily repeat measurements with space-based imaging spectrometers. There are numerous ways to use spectral measurements to enhance responsiveness to disaster scenarios. Off-the-shelf components for cubesats offer a way to build a cost-effective constellation and thus provide a portion of the hyperspectral capability of a full hyperspectral mission at a fraction of the cost.

References

1. Mandl et al., Hyperspectral Cubesat Constellation for Rapid Natural Hazard Response AGU2015, Poster, Session: Near Real Time Data for Earth Science and Space Weather Applications III., December 15, 2015, San Francisco, CA.