

Hyperspectral Cubesat Constellation for Rapid Natural Hazard Response

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Abstract

Earth Observing 1 (EO-1) satellite has an imaging spectrometer (hyperspectral) instrument called Hyperion. The satellite is able to image any spot on Earth in the nadir looking direction every 16 days. With slewing of the satellite and allowing 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 is sought is the ability to image natural hazards in a daily time series for space based imaging spectrometers. The Hyperion can not provide this capability on EO-1 with the present polar orbit. However, a constellation of cubesats, each with the same imaging spectrometer, positioned strategically in the same orbit, can be used to provide daily coverage, cost-effectively.

Overview

New onboard processing capability is enabling more rapid response for satellites with imaging spectrometers. Figure 1 depicts a Field Programmable Gate Array (FPGA) based onboard processing that performs a data processing chain on raw data from an imaging spectrometer and is able to download the finished products directly to the user. As an example, using a CHREC Space Processor (CSP) which is based on the Zynq chip (2 Arm processors and FPGA circuits) 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.

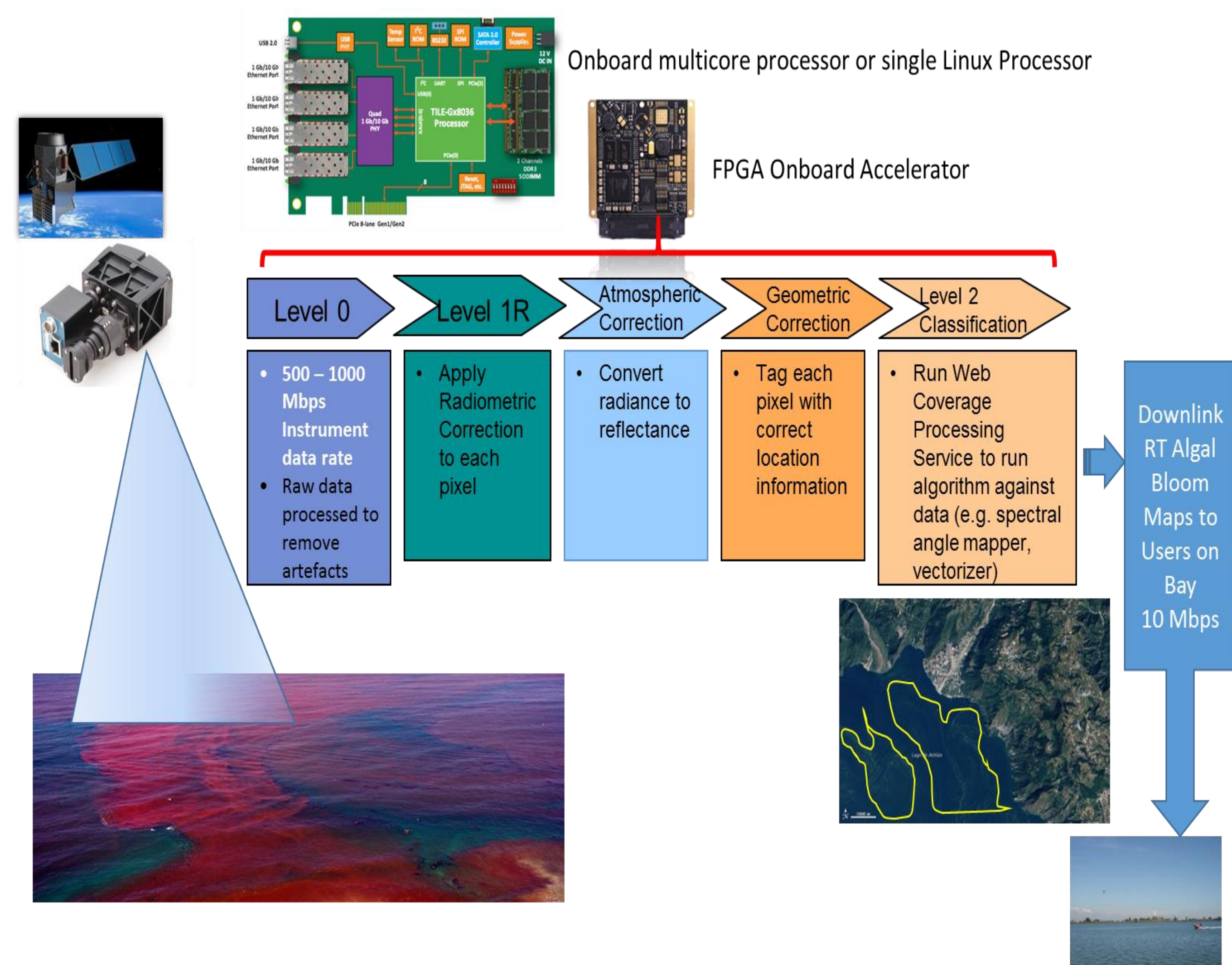


Figure 1 Basic data processing steps for a space-based imaging spectrometer that typically was done on the ground, but can now be done onboard, in realtime at low power consumption with new onboard processing technology. In this example, the data processing chain is used to detect harmful algal blooms.

Concept of Operations

In this concept of operations, a number of cubesats are placed in the same orbit so as the earth rotates under the constellation, at least one of the satellites will have the target in its view. Figure 2 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 and the limited power capacity.

Constellation Coverage

The assumption is that a number of cubesats are placed somewhere between a space station and a high polar orbit at an elevation of approximately 400 km. The cubesat that was designed for this effort call for a 30 meter pixel resolution with a 640 pixel swath using a push broom imaging spectrometer. Each image is approximately 19 km wide. The circumference of the earth is approximately 40000 km. So the question is, what is the relationship with the required slew angle to get total coverage. Table 1 below shows how many satellites are required for three allowable slew angles to obtain total daily coverage:

# of cubesat satellites	Allowable view angle
20	68 deg
40	51 deg
160	32 deg

Table 1 Shows some tradeoffs between allowable view angle and the number of cubesats needed in the a constellation to achieve total daily coverage.

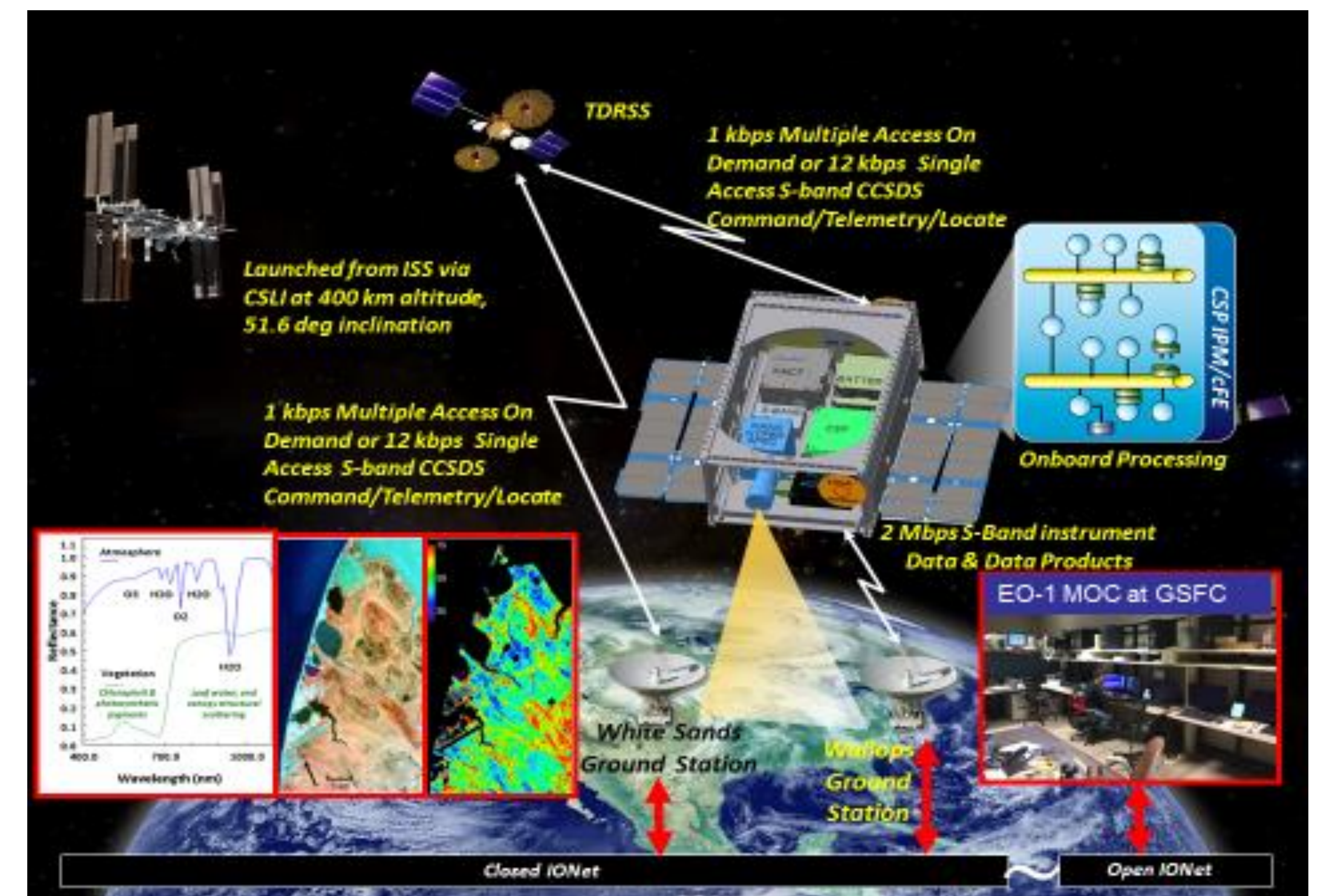


Figure 2 Basic data processing steps for a space-based imaging spectrometer that typically was done on the ground, but can now be done onboard, in realtime at low power consumption with new onboard processing technology. In this example, the data processing chain is used to detect harmful algal blooms.

Internal Components

Table 2 below shows how a 6U cubesat can be assembled with an imaging spectrometer and off the shelf components to create satellites that will cost under \$1 million each. Therefore, when you compare the cost of typical imaging spectrometer missions which range from \$200-\$500 million for a single satellite, there is motivation to consider this design. It should be noted that the quality of the imaging spectrometers used for NASA mission such as EO-1 and HypSPIRI are of much higher quality. For example, in this constellation example, a Headwall Nano-Hyperspec is specified which only has a spectral bandwidth of between 400-1000 nm whereas the VSWIR specified for HypSPIRI has a spectral bandwidth of 400 – 2500 nm. Also, there is a whole host of other quality parameters that the Nano-Hyperspec can not match. But if daily time series for rapid response are required, then this architecture becomes compelling.

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	

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.