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

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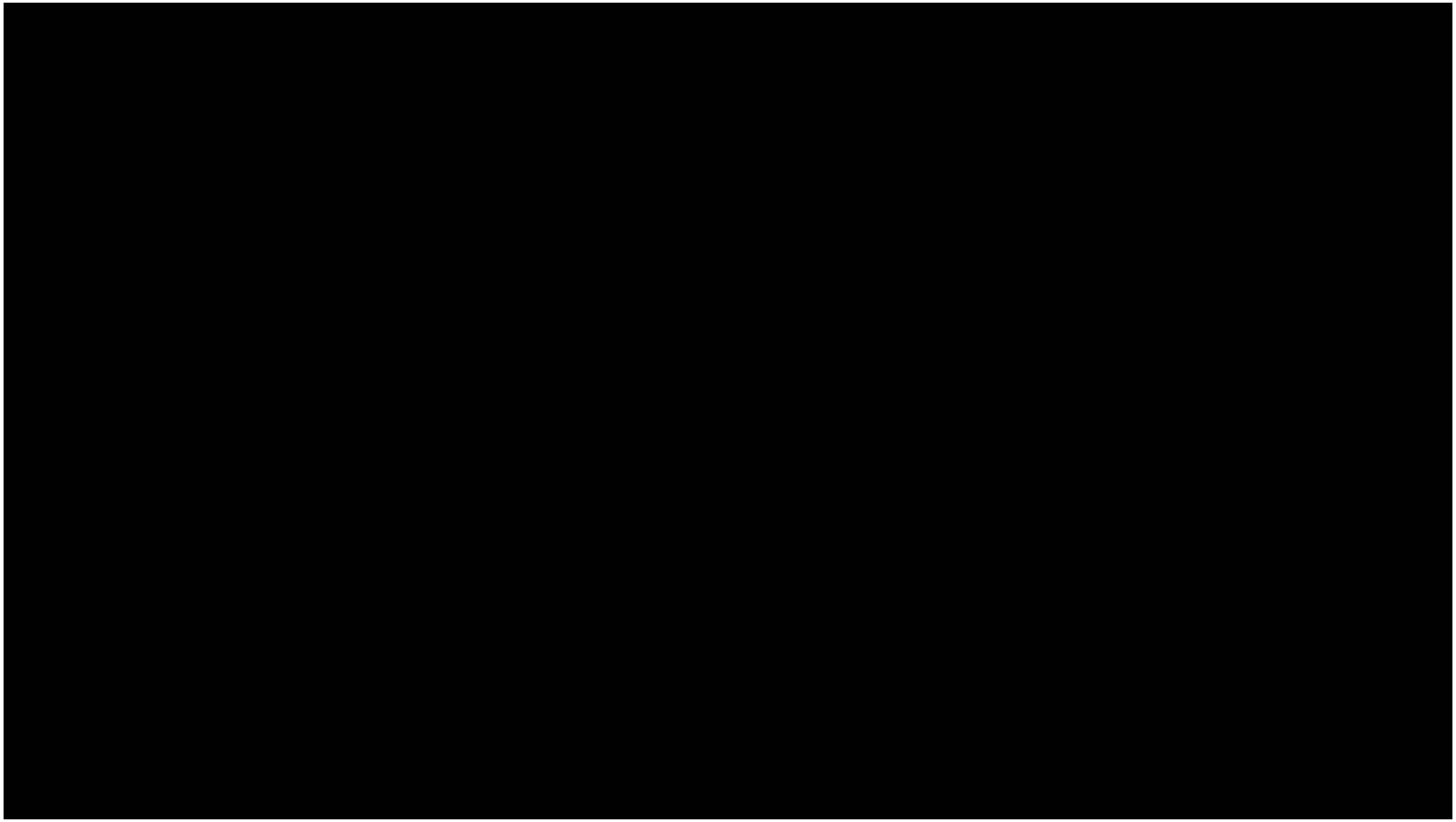
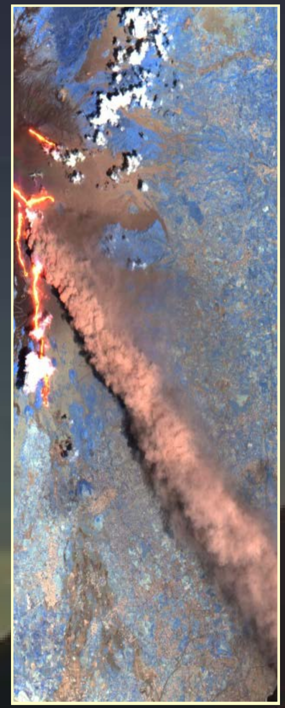
NASA Goddard SPACE FLIGHT CENTER

— Est. 1987 —
30TH ANNUAL AIAA/USU CONFERENCE ON SMALL SATELLITES
small SATELLITE AIAA/Utah State University

Imaging Spectroscopy for Earth Observations

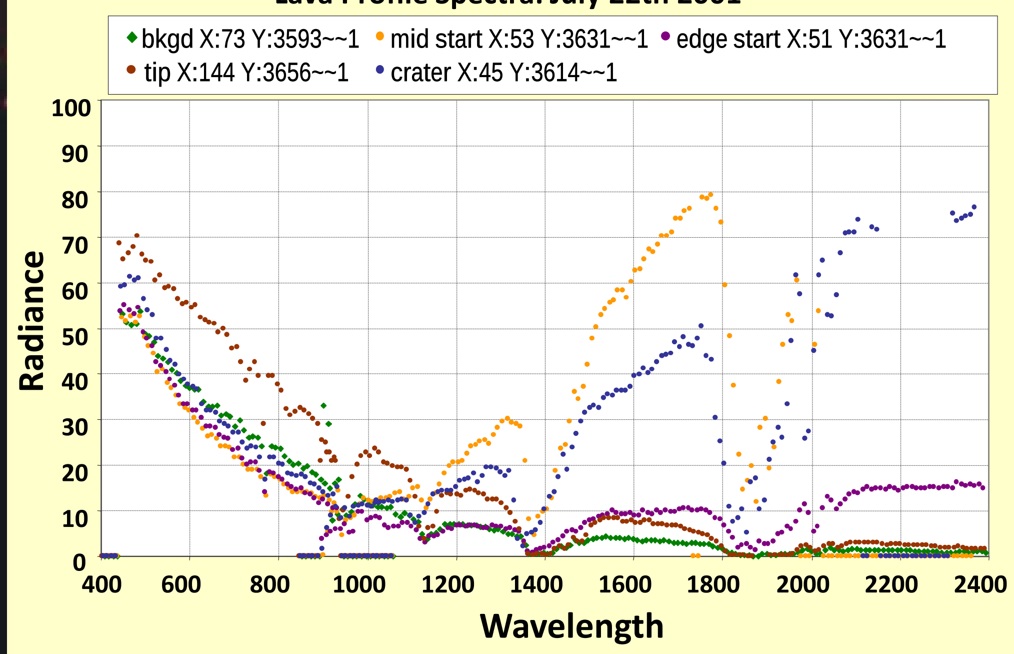


ALI Pan Enhanced Bands 3 -2-1	Hyperion 7-5- 4 Equiv	EO - 1 ALI Bands 7 -5-5’
		

Eruption of Mt. Etna, Sicily

July 22, 2001

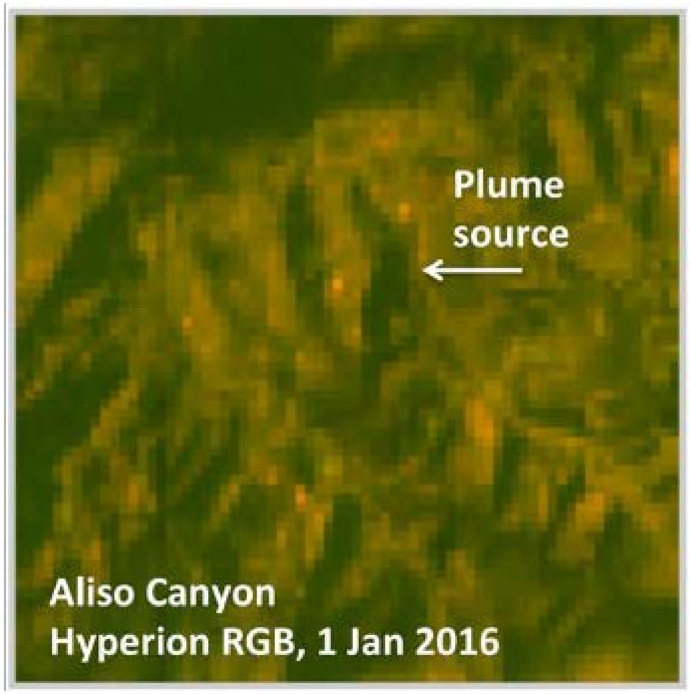
EO-1 Hyperion Spectra

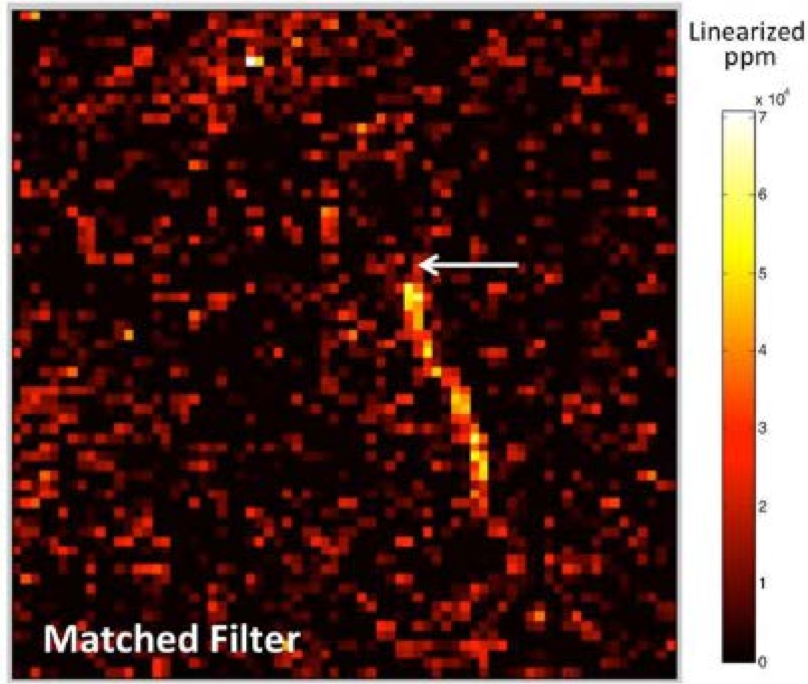


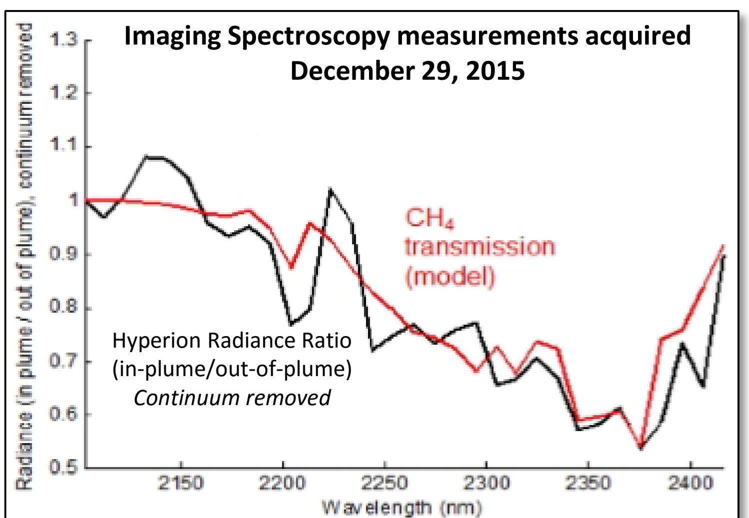
Hyperion Temperatures for Etna

Spectrum	Crust T°C	Hot ToC	Area Hot
J 13-CTB	346 C	994 C	0.0025
J 13-MM	874 C	876 C	0.45
J 13-CTS	976 C	978 C	0.47
J 13-TipX	210 C	900 C	0.00034
J 22-MS	726 C	1075 C	0.090
J 22-CX	487 C	1075 C	0.022
J 22-RS*	1054 C	1058 C	0.690

Hyperion Detects the California Methane Leak







On January 1, 2016, Hyperion imaged the massive methane leak in the Aliso Canyon region of California. David Thompson's (JPL) algorithm detected the methane leak within the Hyperion data and showed a pronounced plume trending to the south. Since then, six additional acquisitions have been made, thanks to EO-1's ability to rapidly schedule, reorient satellite attitude, and quickly process and distribute the data.

Hyperion Matched Filter Detection Technique Provided by
D. Thompson, A. Thorpe, R.O. Green and The Imaging Spectroscopy Team, JPL, CalTech

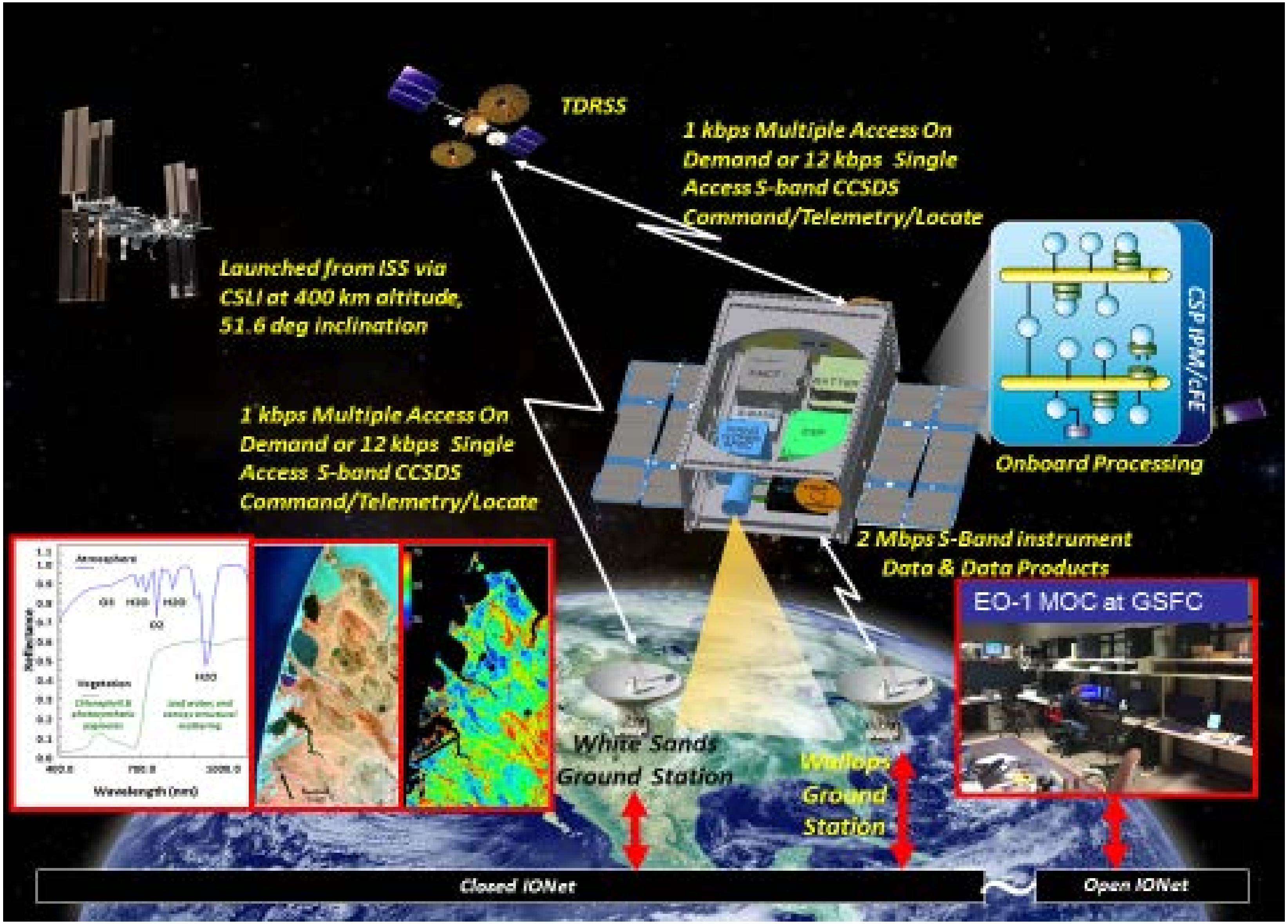
Overview

- Design viable constellation of cubesats with hyperspectral sensors which enable daily repeat observations
  - Emulate Earth Observing 1 (EO-1) operations which has a repeat capability of 2 to 3 days for any spot on Earth with slewing of up to 23 degrees
  - Need high performance onboard processing to mitigate reduced downlink capacities due to the use of cubesats
  - Identify potential orbit configurations
  - Identify sustainability issues such as orbit degradation and the ability to perform inclination maneuvers to maintain orbits
  - Identify radiation and thermal issues versus selection of cost-effective components
  - Design communications for continuous coverage and maximum downlink capacity
- Maintain open design to enable a collaborative approach to evolve better designs as new components or ideas emerge
- Original design was submitted to a NASA proposal call for funding, but was declined
- Desire is to resubmit to future calls

New Capabilities

- Daily or better repeat observations using an imaging spectrometer from space
  - ✓ Using constellation of low cost cubesats
  - ✓ Low cost pipeline of satellites that get launched every few months to maintain constellation formation without inclination maneuvers
- Low powered, high performance onboard processing of spectra which includes radiometric correction, atmospheric correction, geocorrection and classification of features or trait detection
- Continuous coverage of cubesat by Space Network via 1 kbps to maintain location knowledge to avoid losing satellite

Architecture to Emulate EO-1 Operations



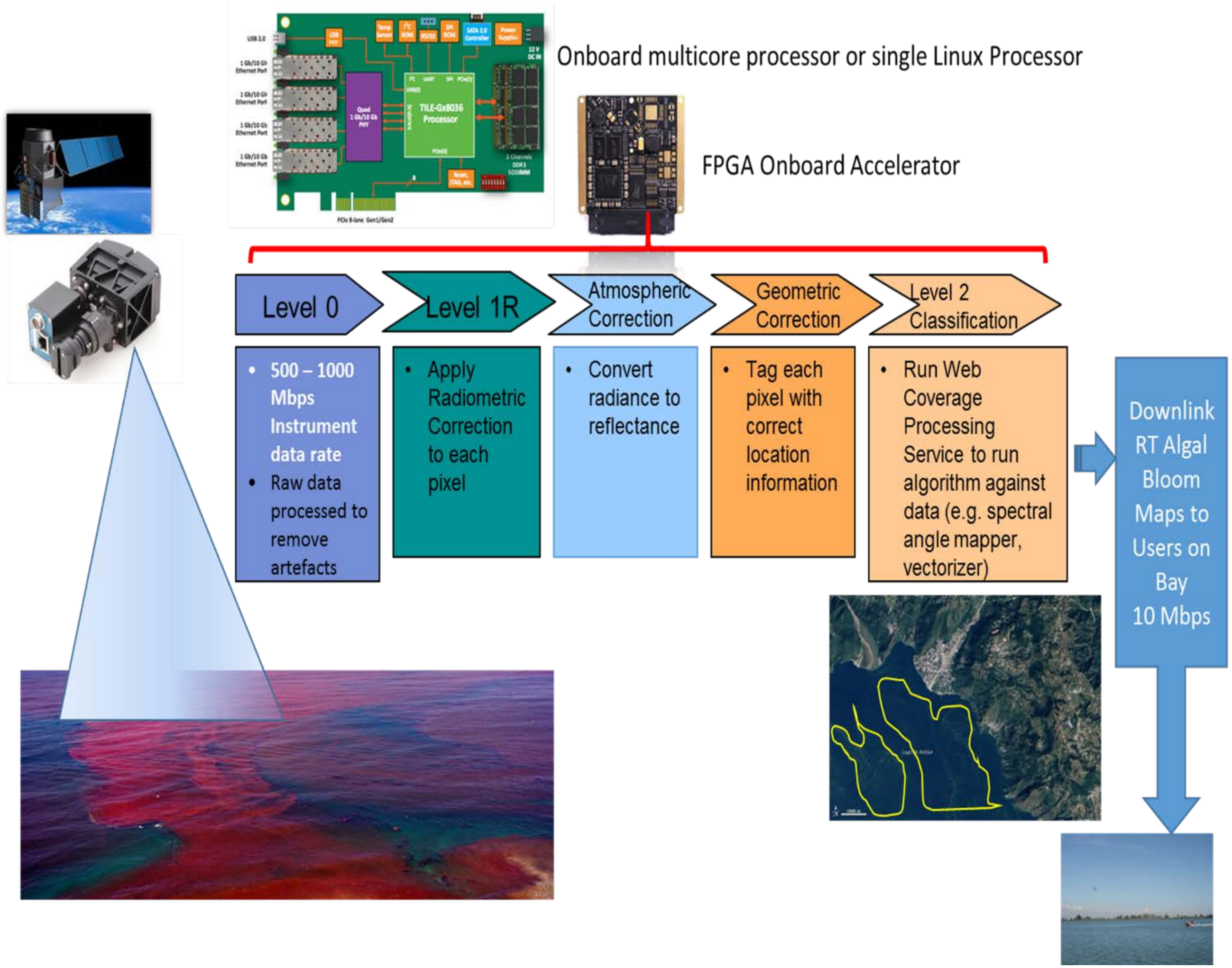
Preliminary Part Selection

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	

Software

- Core Flight Software (CFS)
- ASIST, ITOS or COSMOS for ground control software
- SensorWeb software which includes Intelligent Payload Module software
  - ✓ Some details at https://sensorweb.nasa.gov

Sample Onboard Processing Data Stream

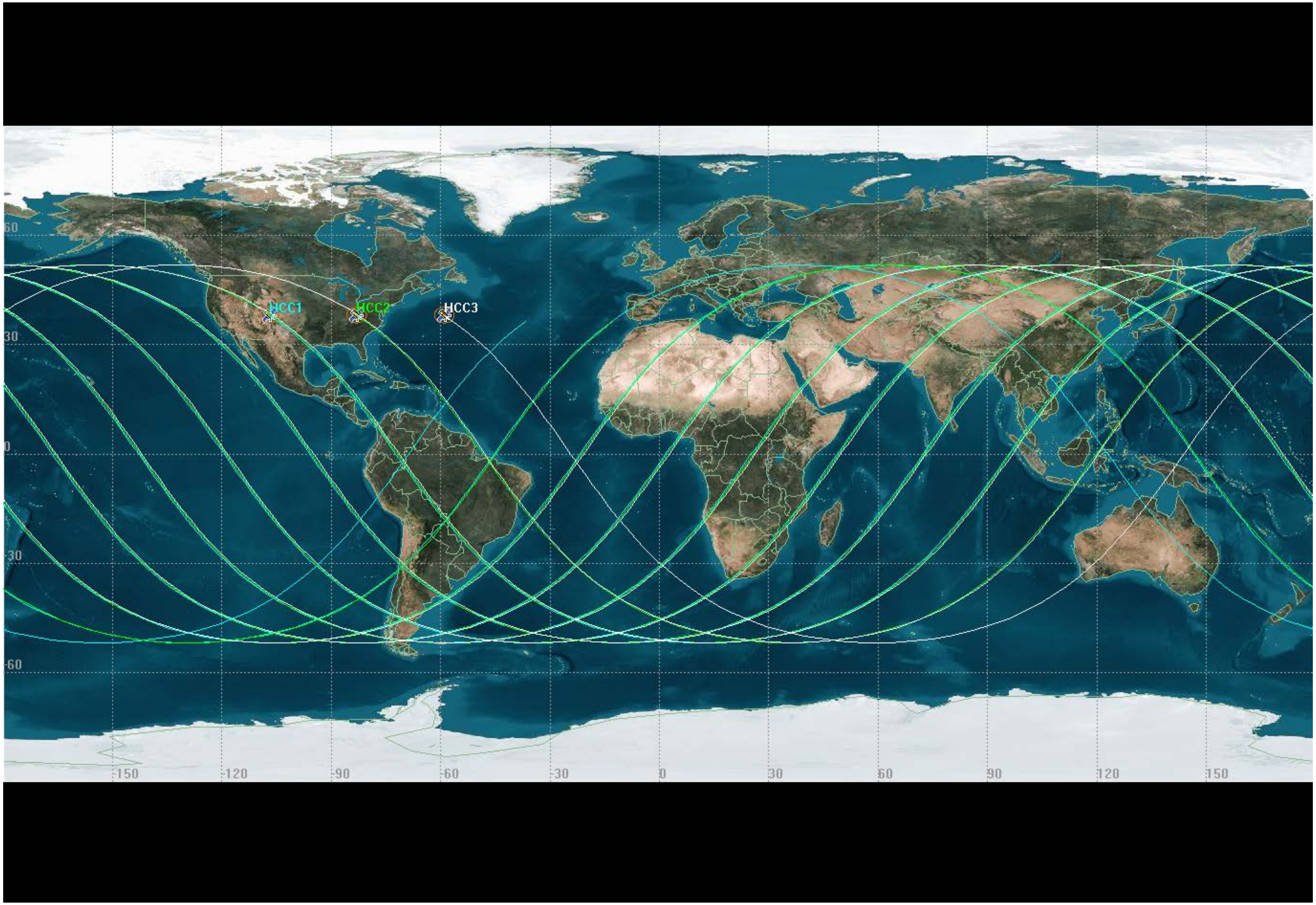


- ➢ Onboard data reduction and data product production thus reducing downlink capacity requirements
- ➢ Onboard processors consume less than 10 watts

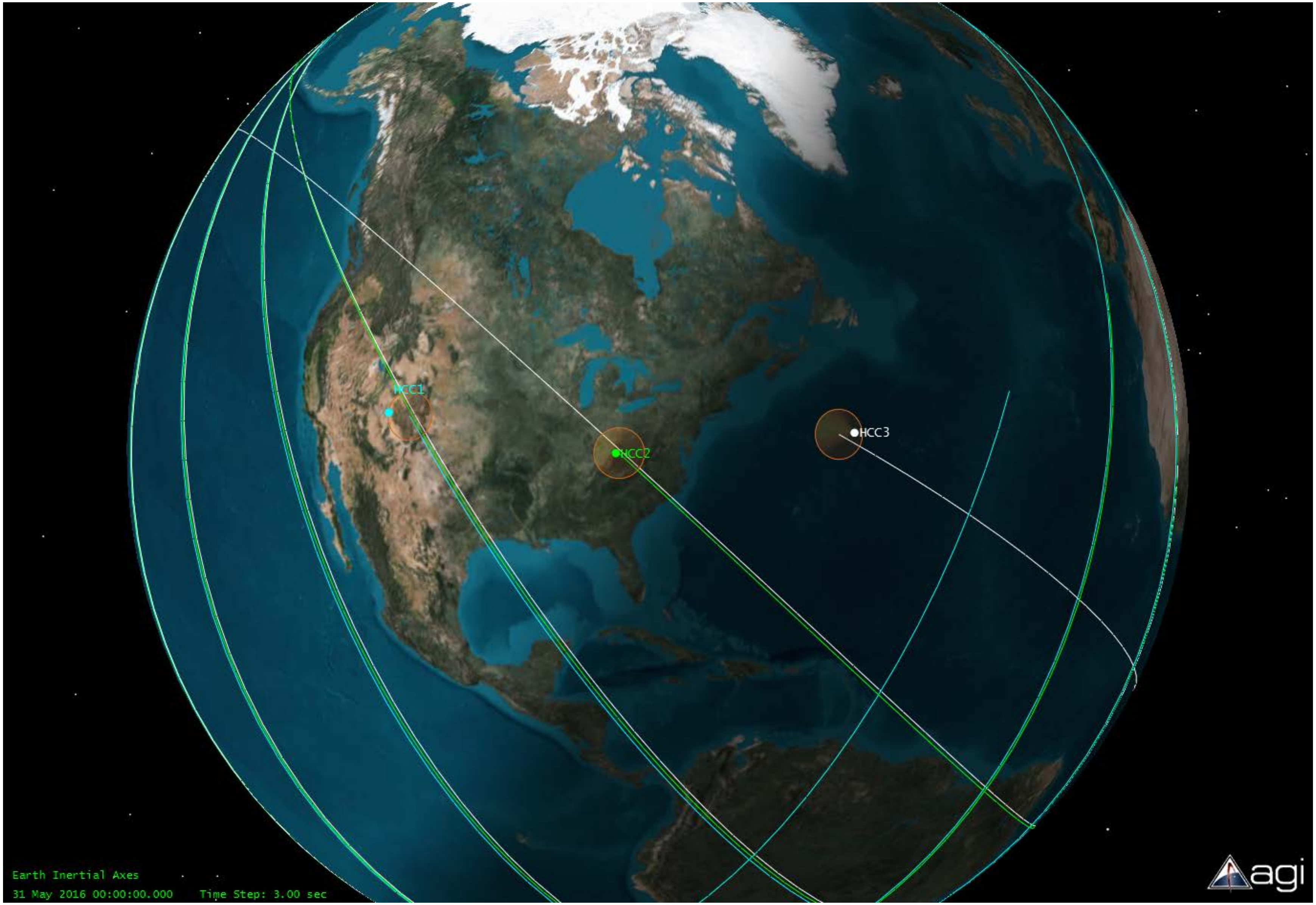
Preliminary Instrument - Headwall Nano-Hyperspec

- 640 spatial pixels
- 270 spectral bands (400 – 1000 nm)
- ~2.2nm spectral sampling interval
- 5nm spectral resolution (FWHM with 20-micron slit)
- 17mm lens (standard) – Use 1500 mm lens for Cubesat application
- 480GB storage capacity (~ 130 minutes at 100 fps)
- Connectivity: Gigabit Ethernet
- Size (exclusive of GPS): 3" x 3" x 4.72" (76.2mm x 76.2mm x 119.92mm)
- Weight: less than 1.5 lb. (0.68kg)

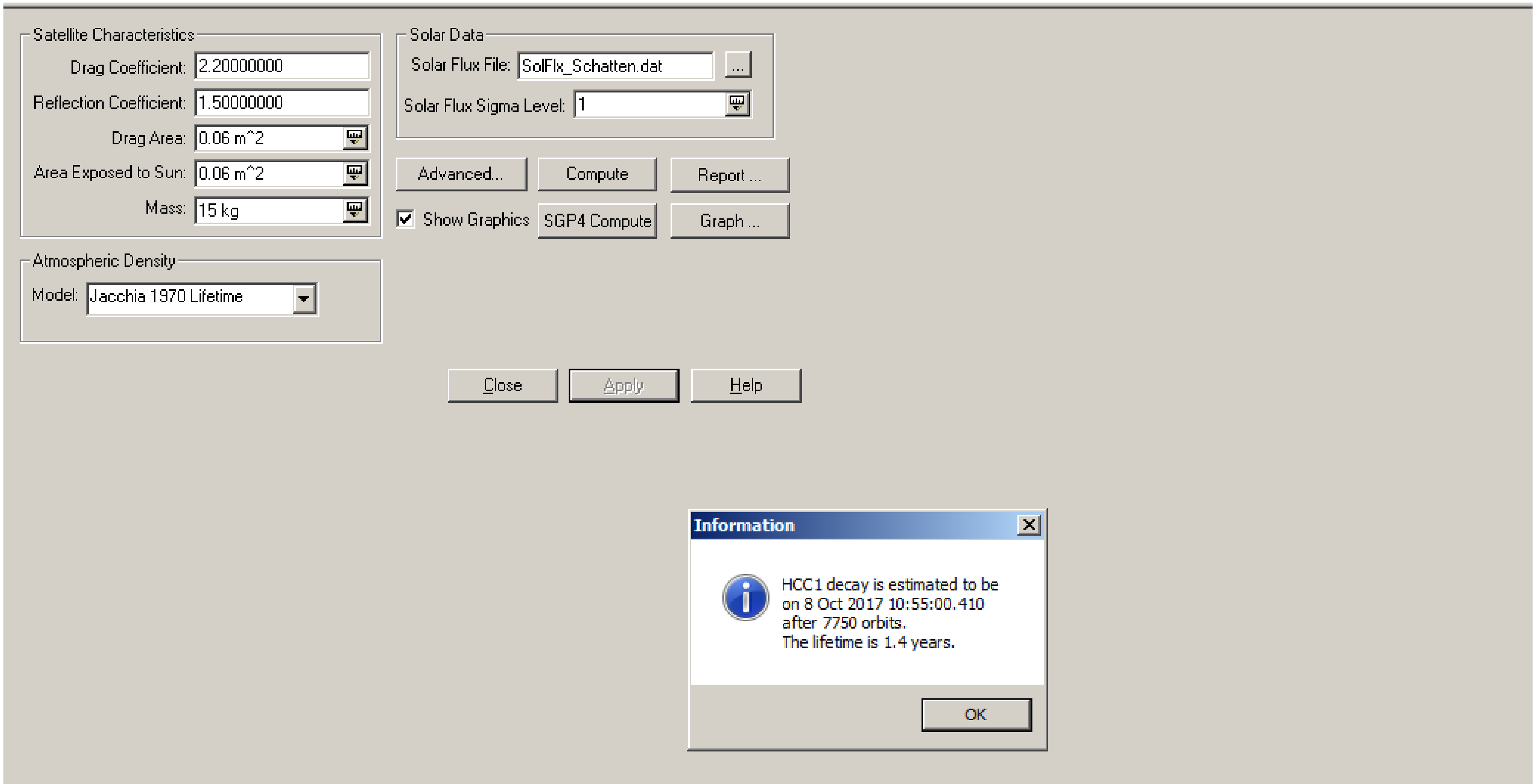
Orbit Which Provides Daily Coverage for Selected Spots on Earth



3D View of Orbit

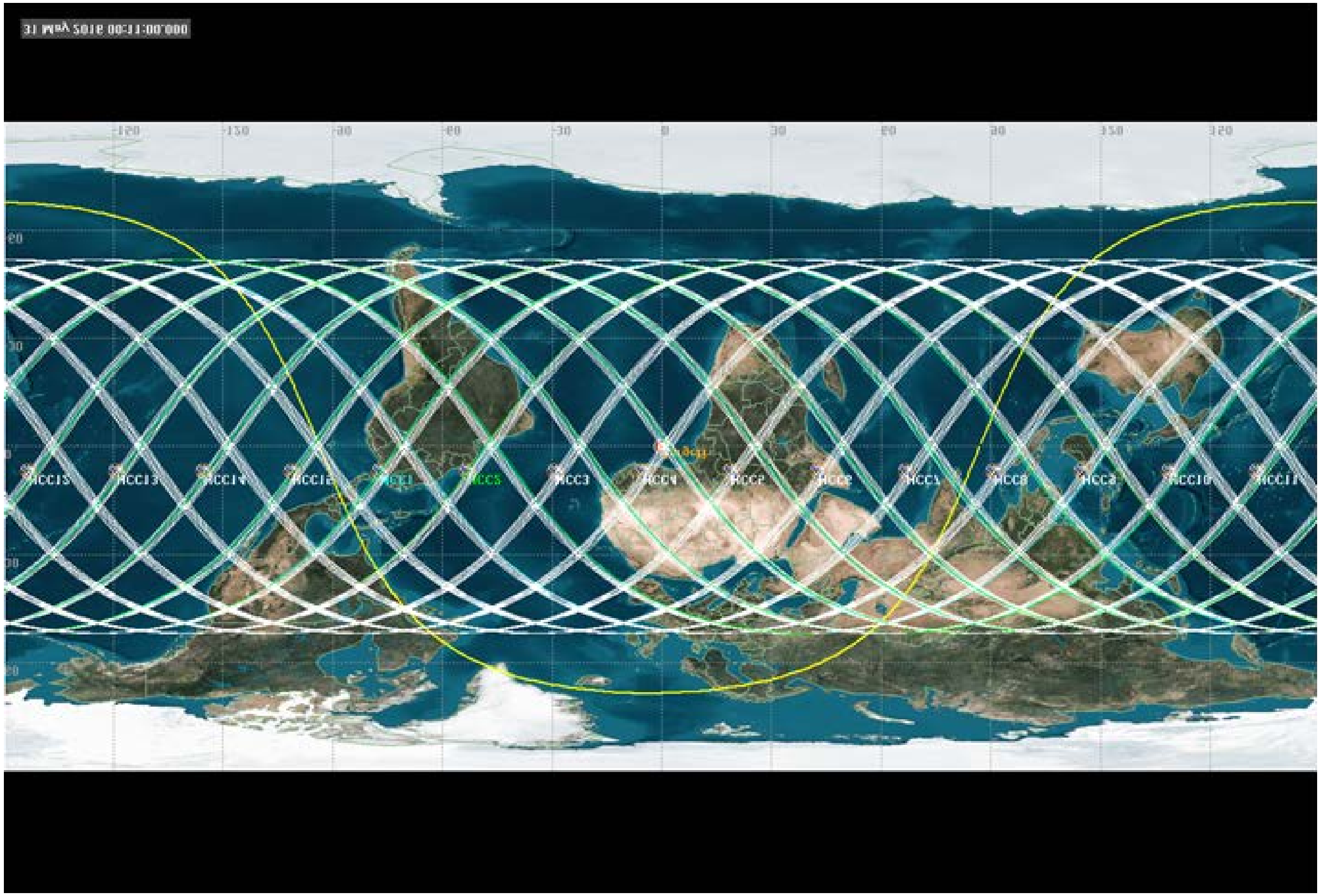


Orbital Decay with No Propulsion



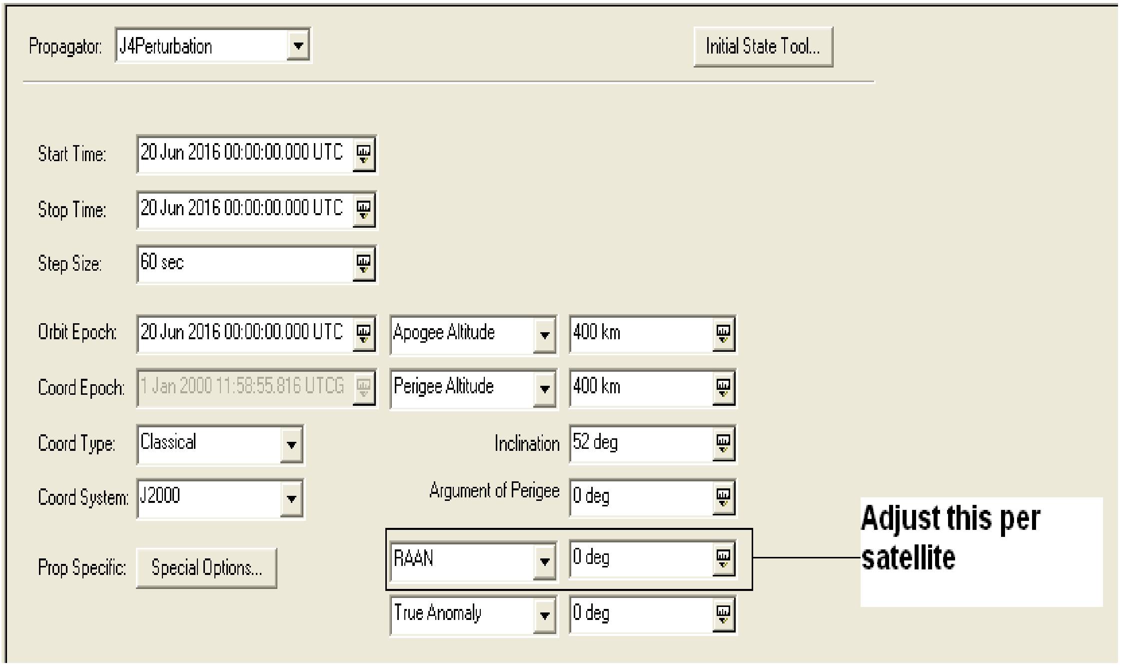
- Assumptions
  - Each Cubesat is 15 Kg (6U configuration)
  - Surface area is about 0.06 m^2
  - Orbit stays at Space Station orbit (400 km) with 90% of elevation for 1.4 year

Alternative Orbit Configuration



- Assumptions
  - Each Cubesat is 15 Kg (6U)
  - 15 cubesats at 400km elevation

Setup Parameters for this Orbit Configuration



- Assumptions
  - 15 Cubesats provide coverage for selected portions of Earth approximately every 42 minutes thus enabling hyperspectral observations diurnally
  - Need 3 sets of 15 cubesats to enable any spot on Earth to be observed approximately every 42 minutes, minus the polar regions

Programmatic Approach

- Cost per cubesat estimated at about $500K or less once non recurring engineering costs subtracted
  - ➢ Operations costs not included, but original plan was to piggyback on EO-1 operations
  - ➢ This won't be viable in future since EO-1 operations ends in 2017
- Operations emulates EO-1 operations
  - ➢ Makes use of TDRSS for continuous coverage at 1 kbps
  - ➢ Makes use of NASA Ground Stations to downlink data products at 2 Mbps
- Preliminary orbital design assumes 3 cubesats at 400 km elevation and that the orbit degrades to 90% in 1.4 years
  - ➢ Launch new cubesat every 4 months
  - ➢ After one year, cubesat replaces first cubesat launched
  - ➢ Maintain 3 satellite constellation at $1.5 million per year plus operations costs
  - ➢ As time goes on, cubesat costs reduced and increase capability by folding in new improved technology
- Sustainable approach is also expandable
  - ➢ Could launch additional cubesat that make use of additional spectral bandwidth such as greater than 1000 nm
  - ➢ Additional sensors could be added on ongoing basis once process begun, cost-effectively

Conclusion

- Hyperspectral Cubesat Constellation approach provides sustainable pipeline to obtain hyperspectral daily observations, thus making it optimal for observing natural hazards where time series are typically desired
- Approach would engage a large science and applications community since at present, typical hyperspectral missions costs are in the hundreds of millions of dollars. Therefore, launches are infrequent, minimizing data that scientists can work on.
    - ➢ Small hyperspectral instruments do not provide the quality of the larger instruments and at present do not provide the same spectral bandwidth
    - ➢ Smaller hyperspectral instruments quality are improving