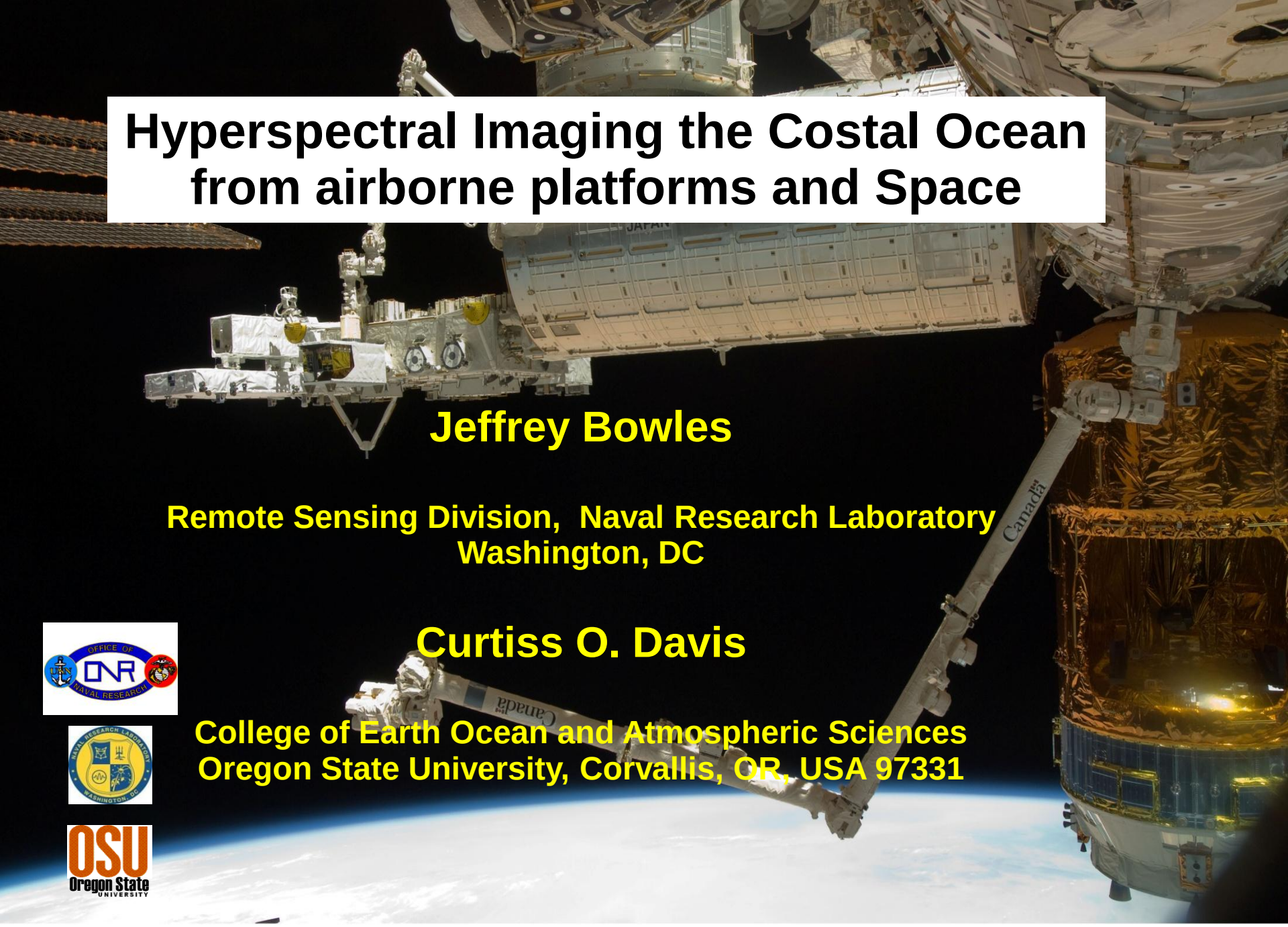

Hyperspectral Imaging the Costal Ocean from airborne platforms and Space

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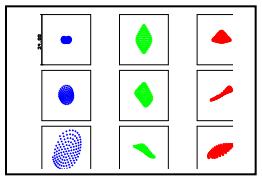
Introduction and Outline

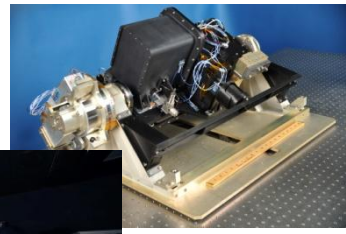
- The Hyperspectral Imager for the Coastal Ocean (HICO)
  - How it came to be
  - The challenge of operating on the International Space Station (ISS)
- HICO data collections
- Data Processing flow
- On-orbit Calibration
- Example data products

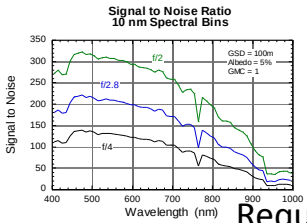
Airborne Coastal Hyperspectral Program at NRL

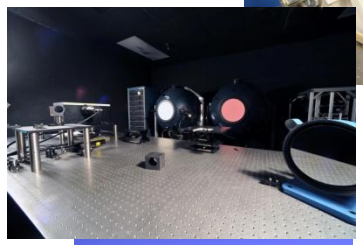
20 years end-to-end development of airborne coastal hyperspectral imaging

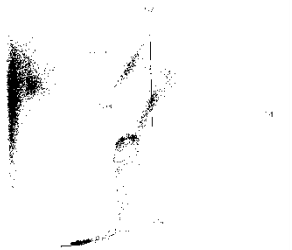
Sensor Performance Modeling











Nonlinear Manifold Analysis

Sensor Development

Sensor Calibration

Flight Campaigns

Ground / Water Truth

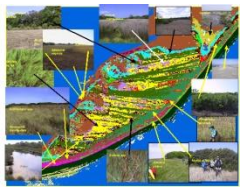
Data Processing

Product Extraction

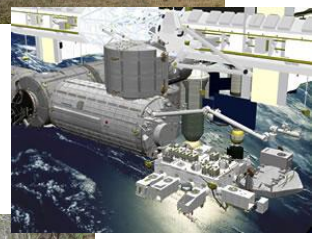
Product Evaluation

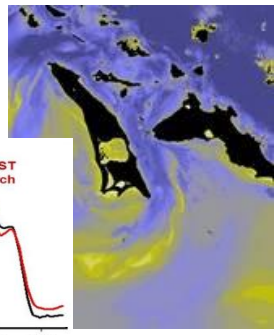
Requirements Evaluation

Spiral Development

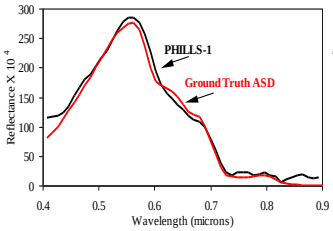


Pattern Recognition / Classification





Spectral Identification / CWST Products



Atmospheric Removal

HICO based on experience with PHILLS

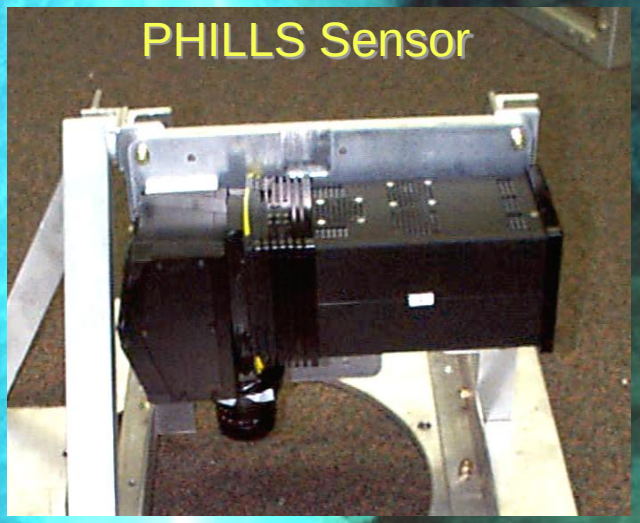
AN-2 Aircraft

PHILLS image of shallow water features near Lee Stocking Island, Bahamas as part of CoBOP Experiment

Airborne Experiments with the Portable Hyperspectral Imager for Low-Light Spectroscopy (PHILLS) demonstrated:

- Sensor design.
- Processing algorithms.
- Shallow water bathymetry, hazards to navigation, and beach trafficability from hyperspectral remote sensing data.

PHILLS Sensor



Two Previous Attempts

- Naval EarthMap Observer (NEMO)
  - Late 90's
  - Joint Government/Industry collaboration
  - VNIR/SWIR free flyer
  - Terminated do to funding problems on industry side

- HyGEIA
  - Meant for ISS but in the Window Observational Research Facility (WORF)
  - Terminated after break up of Columbia

- HICO
  - Successfully built and launched

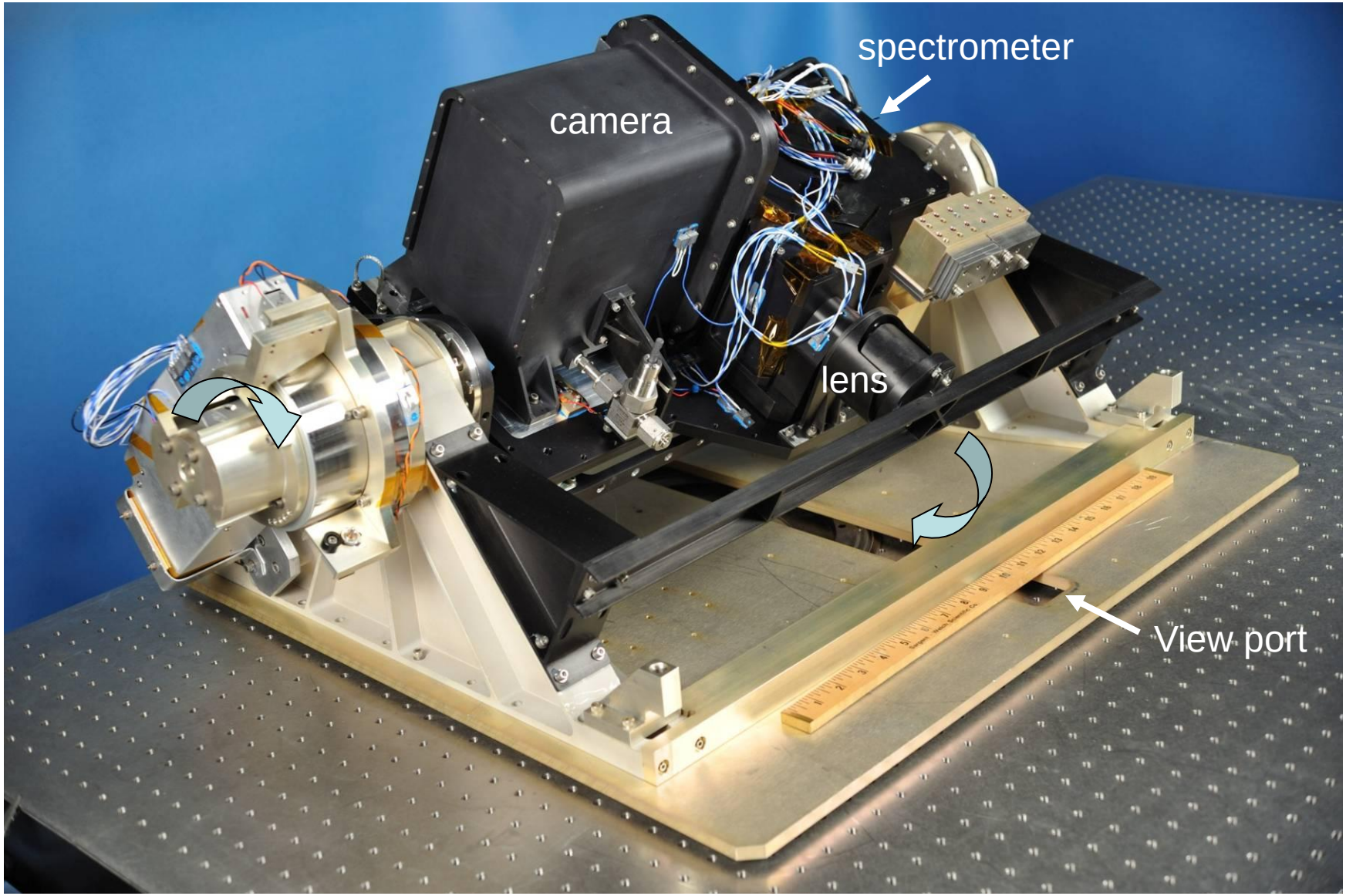
What is the Hyperspectral Imager for the Coastal Ocean (HICO)?

- HICO is an experiment to demonstrate the expected benefits gained by imaging the coastal ocean at higher resolution from space.+
- The HICO sensor:
  - first spaceborne imaging spectrometer for coastal oceans
  - samples coastal regions at <100 m GSD (400 to 900 nm: at 5.7 nm)
  - high signal-to-noise ratio to resolve the complexity of the coastal ocean
- Instrument was developed with funding from the Innovative Naval Prototype (INP) program by the Office of Naval Research
- Launch and early operations funded by the Space Test Program
- Additional ONR funding has paid for operations since HICO's first image

HICO image of Hong Kong, October 2, 2009.

HICO is integrated and flown under the direction of DoD's Space Test Program

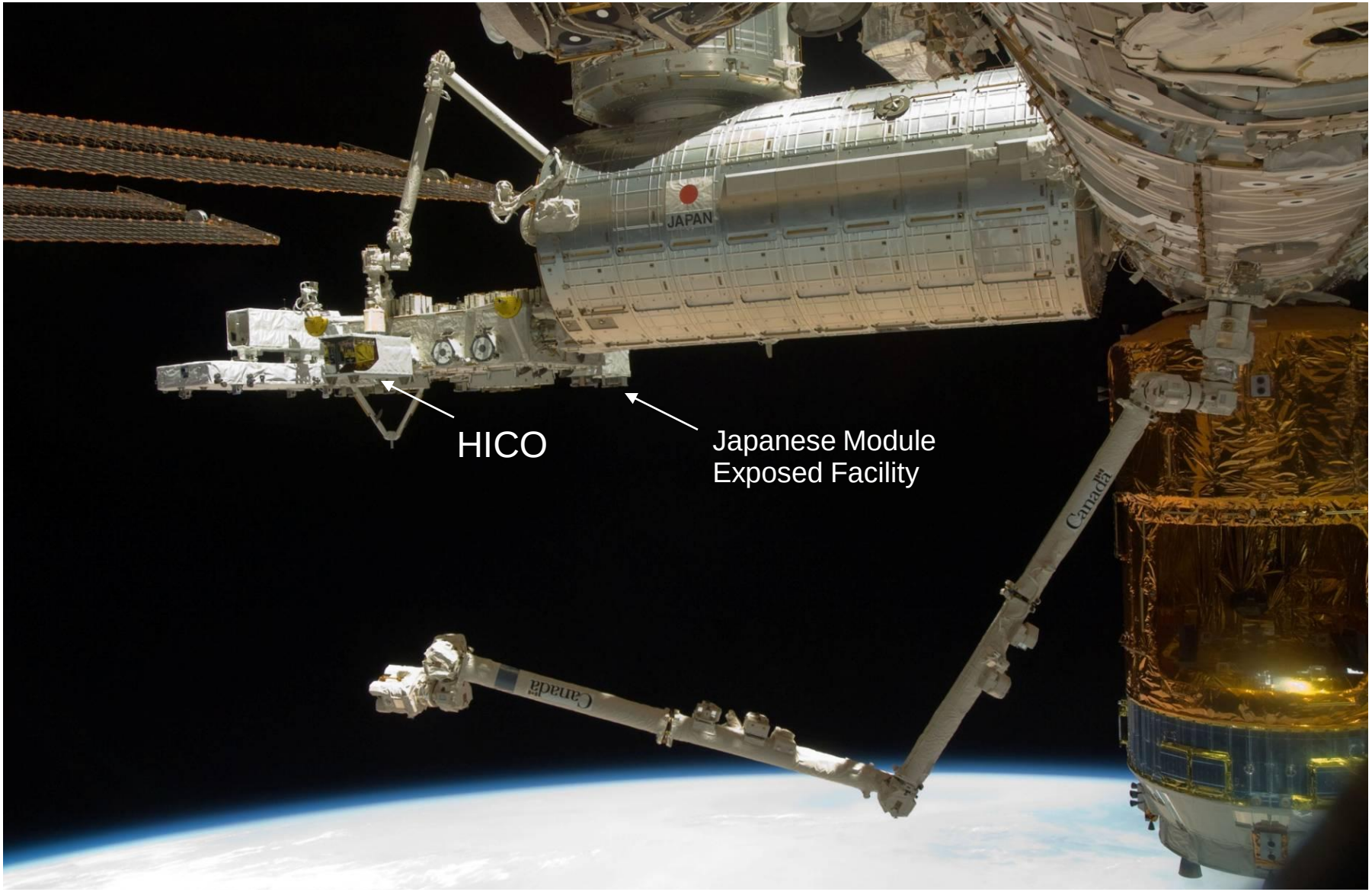
HICO Flight Sensor - Stowed position



HICO meets Performance Requirements

Parameter	Performance	Rationale
Spectral Range	380 to 960 nm	All water-penetrating wavelengths plus Near Infrared for atmospheric correction
Spectral Channel Width	5.7 nm	Sufficient to resolve spectral features
Number of Spectral Channels	102	Derived from Spectral Range and Spectral Channel Width
Signal-to-Noise Ratio for water-penetrating wavelengths	> 200 to 1 for 5% albedo scene (10 nm spectral binning)	Provides adequate Signal to Noise Ratio after atmospheric removal
Polarization Sensitivity	< 5% (430-1000 nm)	Sensor response to be insensitive to polarization of light from scene
Ground Sample Distance at Nadir	92 meters	Adequate for scale of selected coastal ocean features
Scene Size	42 x 192 km	Large enough to capture the scale of coastal dynamics
Cross-track pointing	+45 to -30 deg	To increase scene access frequency
Scenes per orbit	1 maximum	Data volume and transmission constraints

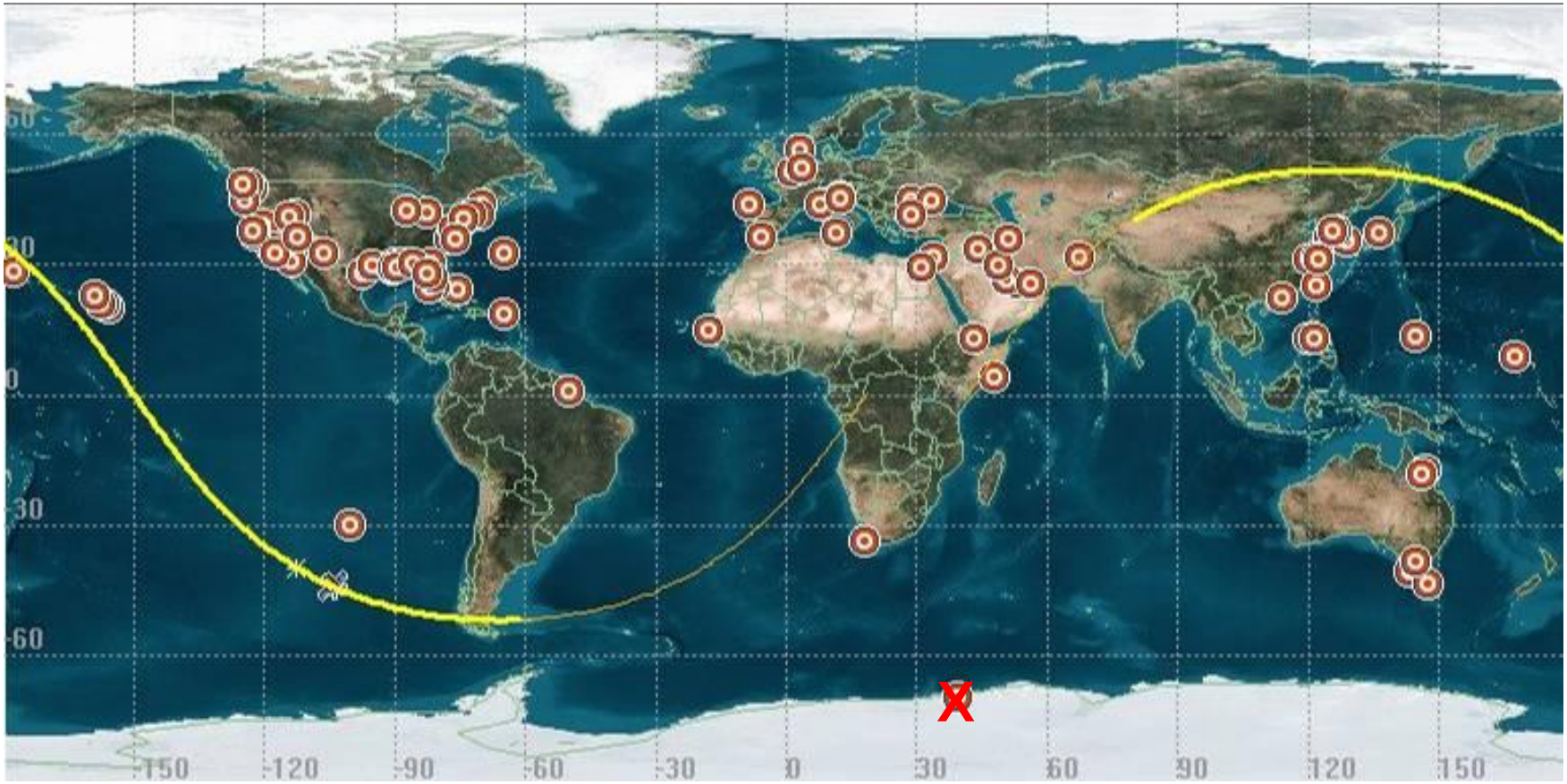
HICO Installed on the ISS on September 24, 2009



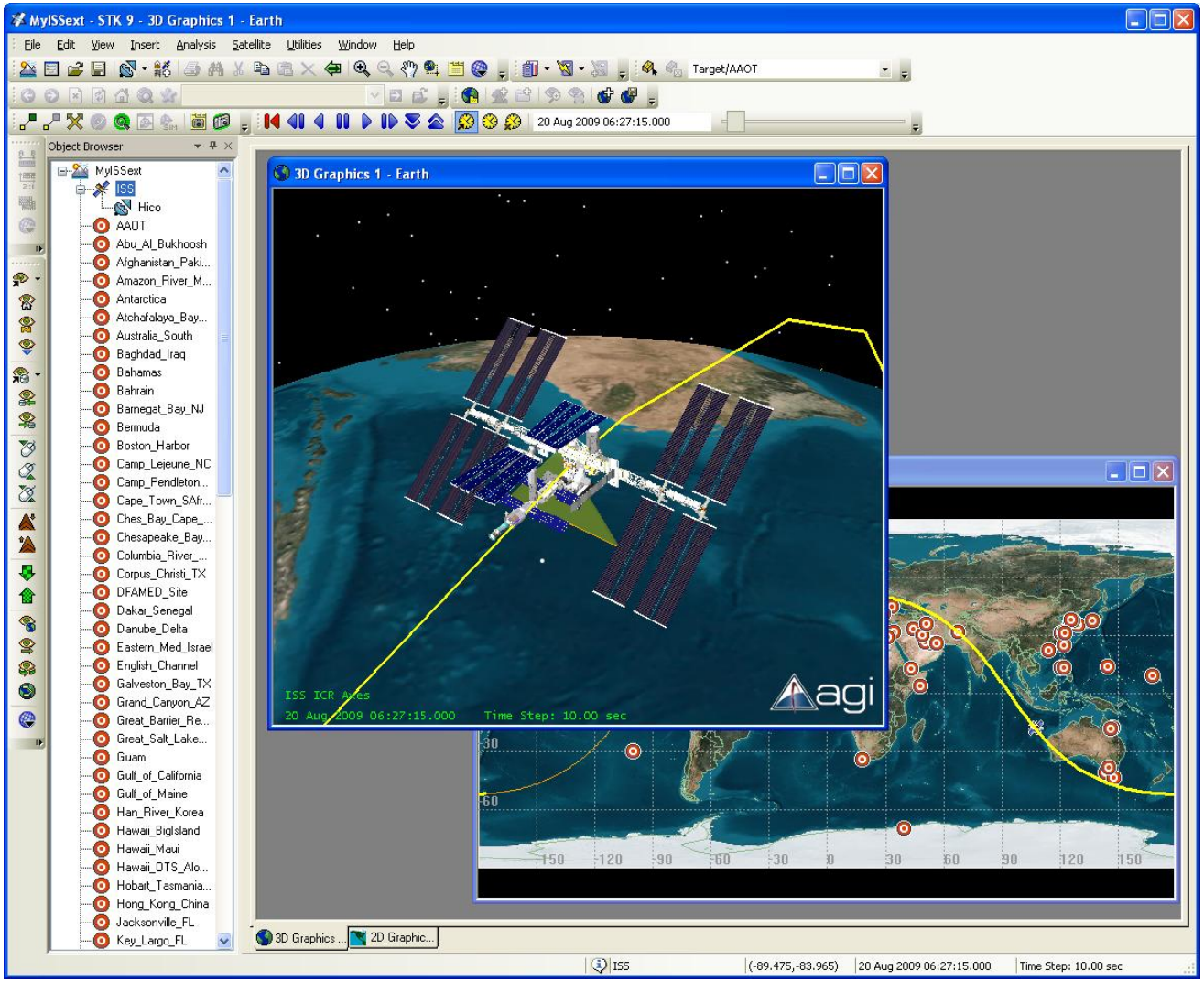
HICO Image Locations

Locations chosen based on:

1. Location – within latitude limits of ISS (~53.5N, ~52.5S)
2. Type – ocean, coast, land
3. Use – CalVal, Science, Navy, etc



Mission Planning with Satellite Tool Kit (STK)



Combines scene locations,
ISS attitude, ISS ephemeris, HICO pointing and constraints to produce list of all possible observations in particular time period

Scene Selection

- Once all possible targets that can be imaged are identified, the information is provided to the “science” team.

- Differences in priorities are worked out
  - Preference goes to images with simultaneous ground truth collection

- Once that happens, the pointing and timing information for each scene is collected and put into a form that can be used to command HICO
  - Commands originate at the NRL in DC

HICO Data Processing and Distribution

Process Image and ancillary data to Level 1b at NRL-DC

Processing to higher levels and archiving at NRL-DC and NRL-Stennis Space Center including using the Automated Processing System (APS)

Multispectral Image Data Emulation

Bin HICO data to emulate MODIS, MERIS, SeaWiFS spectral bands

Calibrate and geolocate image

Apply legacy MODIS, MERIS, SeaWiFS Algorithms to retrieve products (Often invalid when bottom is visible)

Retrieve familiar products at 90 m ground sample distance

Full Spectral Image Processing

Retain full hyperspectral data set of contiguous wavelength bands (~10 nm)

Calibrate and geolocate image

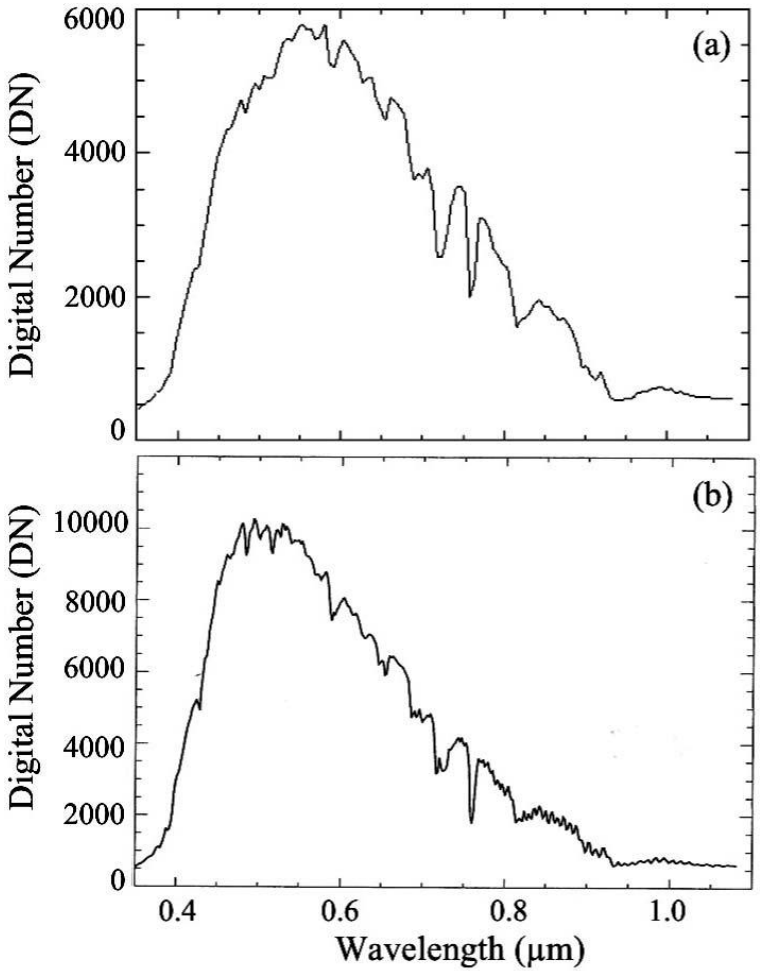
TAFKAA, Cloud and Shadow, or other algorithms for atmospheric removal

Apply spectral algorithms to retrieve coastal products not accessible with multispectral algorithms

Distribution to Naval and DoD researchers and product users and academic researchers

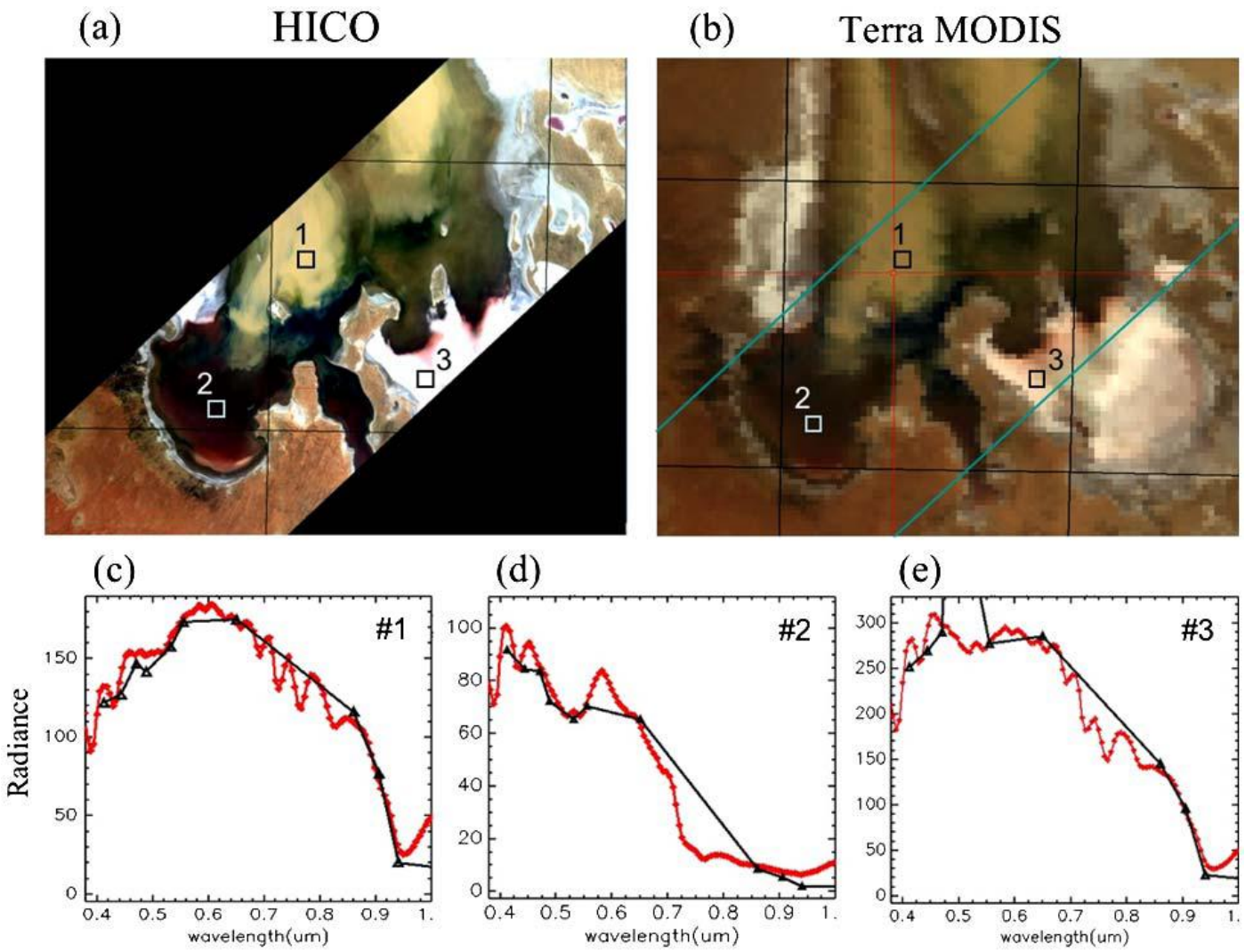
HICO On-Orbit Calibration

- HICO fully calibrated in the laboratory (Lucke et al, 2011)
  - Radiometric calibration
  - Spectral calibration
  - Dark current correction
  - Second Order correction
- HICO does not have a second order filter or an on-board calibrator.
- Cannot ask the ISS to rotate to point at the moon.
- On-orbit calibrations using natural scenes (Gao et al, 2012)
  - Spectral calibration using Fraunhofer lines and oxygen line
  - Radiometric calibration using land calibration targets
  - Second order correction using water scenes



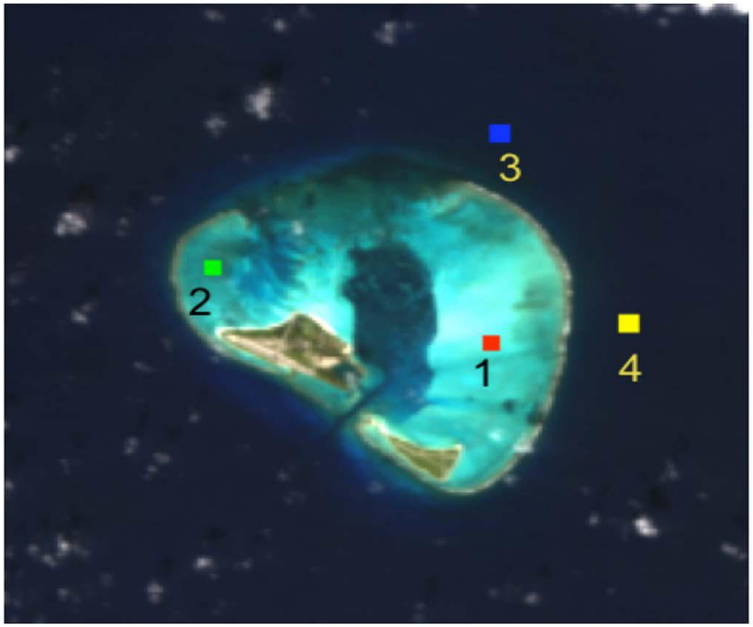
HICO spectra a) normal (5.7 nm) resolution and b) at full (1.9 nm) resolution used for spectral calibrations.

Cross Calibration with MODIS

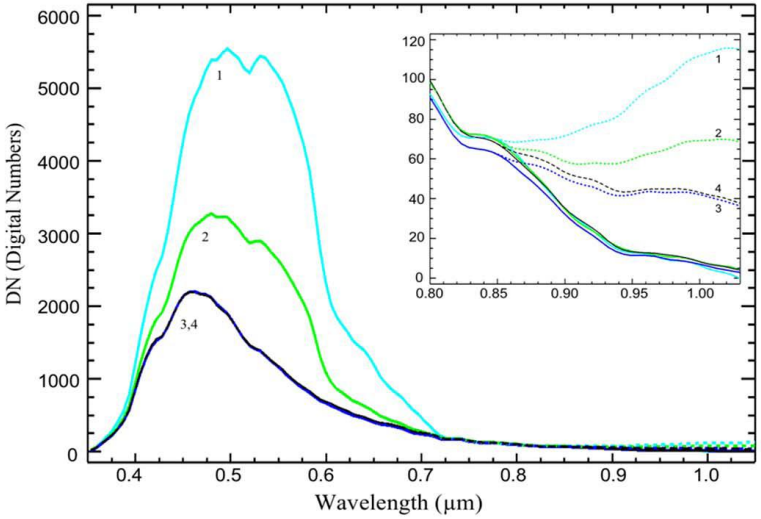


HICO true color image (a) acquired over Lake Eyre, Australia on May 11, 2010, the corresponding Terra MODIS true color image (b) acquired less than 1 hour earlier on the same day, and comparisons between HICO and MODIS data acquired over Area 1, 2, and 3, as marked in (a) and (b).

HICO On Orbit Second Order Correction

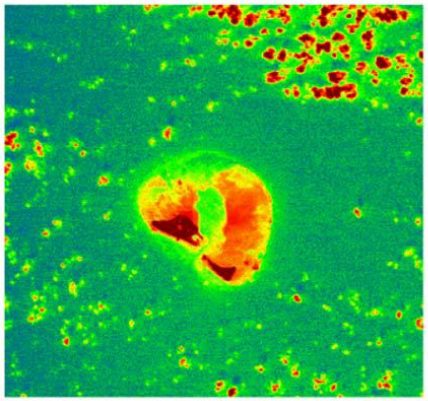


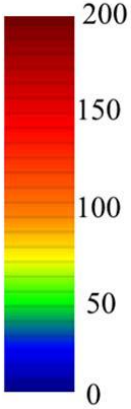
(a)



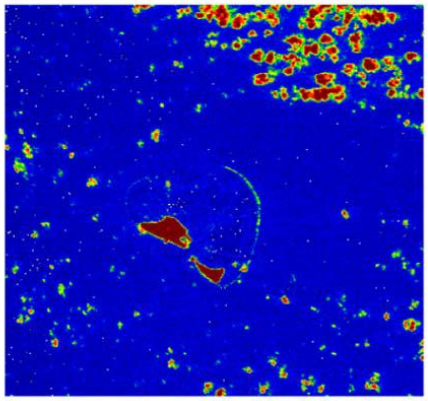
(b)

Before Correction (1μm)





After Correction (1 μm)



HICO image of Midway Islands on October 20, 2009 used for second order light correction (Li, et al, 2012).

Radiometric Comparison of HICO to MODIS (Aqua)

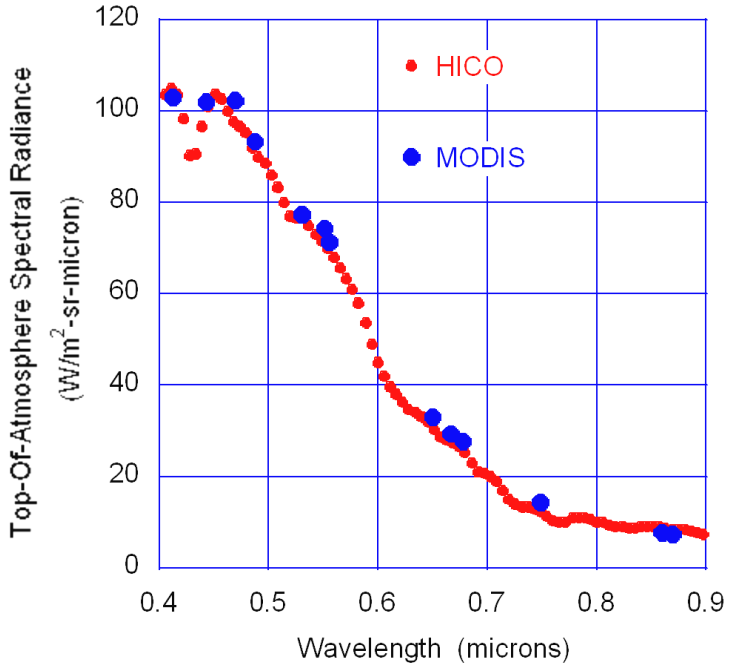
Nearly coincident HICO and MODIS images of turbid ocean off Shanghai, China demonstrates that HICO is well-calibrated

HICO	MODIS (Aqua)
Date: 18 January 2010	Date: 18 January 2010
Time: 04:40:35 UTC	Time: 05:00:00 UTC
Solar zenith angle: 53°	Solar zenith angle: 52°
Pixel size: 95 m	Pixel size: 1000 m

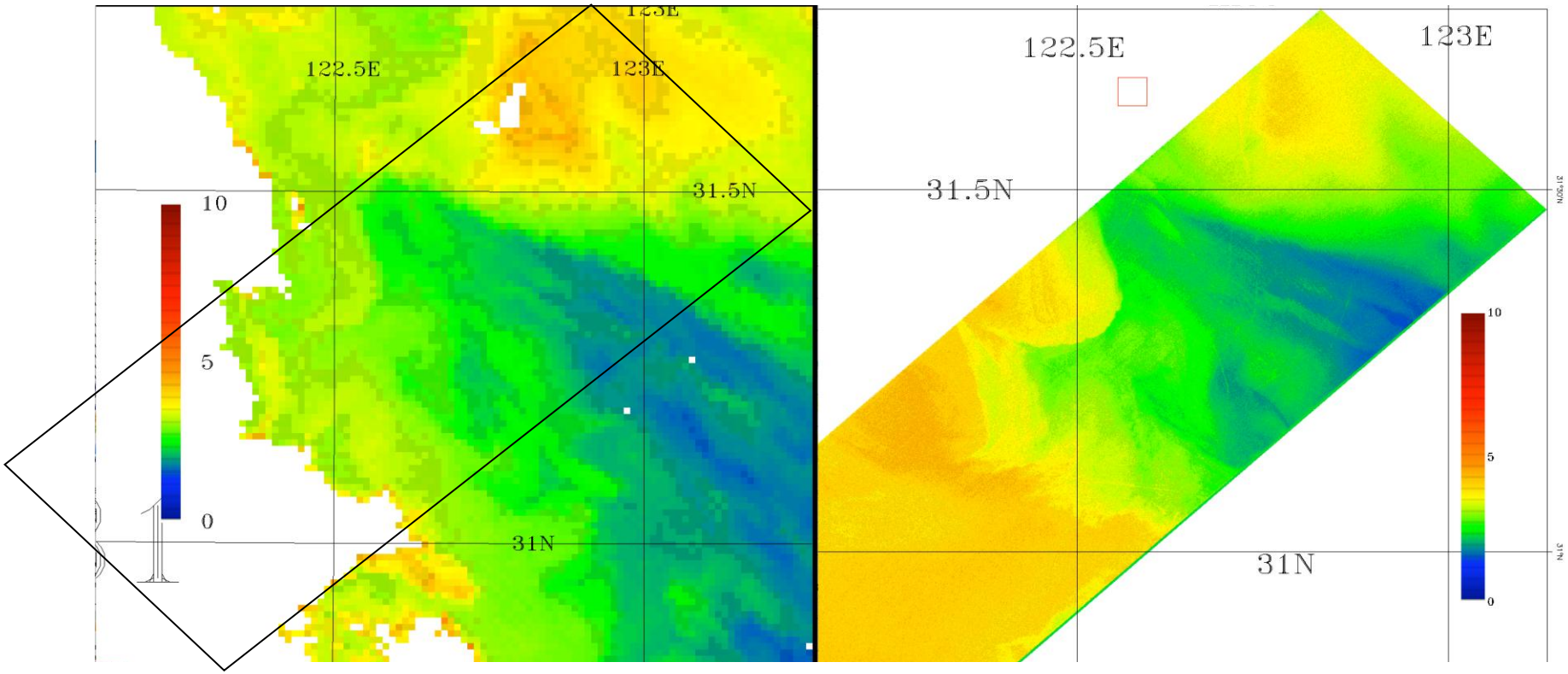
East China Sea off Shanghai

R.-R. Li, NRL

Top-Of-Atmosphere Spectral Radiance



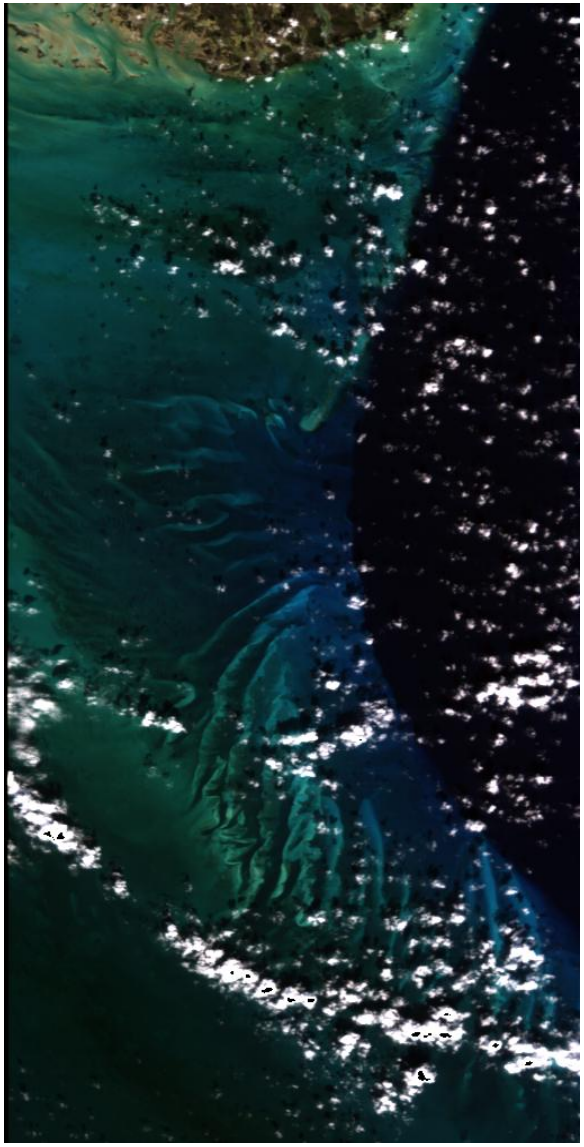
Chlorophyll Comparison of HICO to MODIS (Aqua)



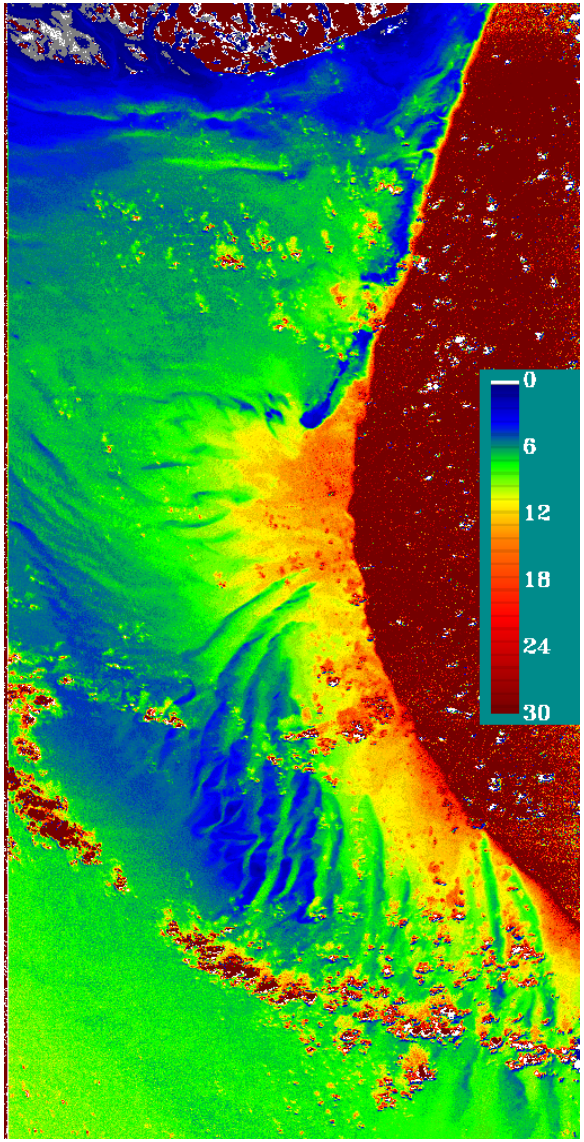
Nearly coincident MODIS and HICO™ images of the Yangtze River, China taken on January 18, 2010. Left, MODIS image (0500 GMT) of Chlorophyll-a Concentration (mg/m3) standard product from GSFC. The box indicates the location of the HICO image relative to the MODIS image. Right, HICO™ image (0440 GMT) of Chlorophyll-a Concentration (mg/m3) from HICO™ data using ATREM atmospheric correction and a standard chlorophyll algorithm. (R-R Li and B-C Gao.)

Andros Island, Bahamas, Oct 22, 2009

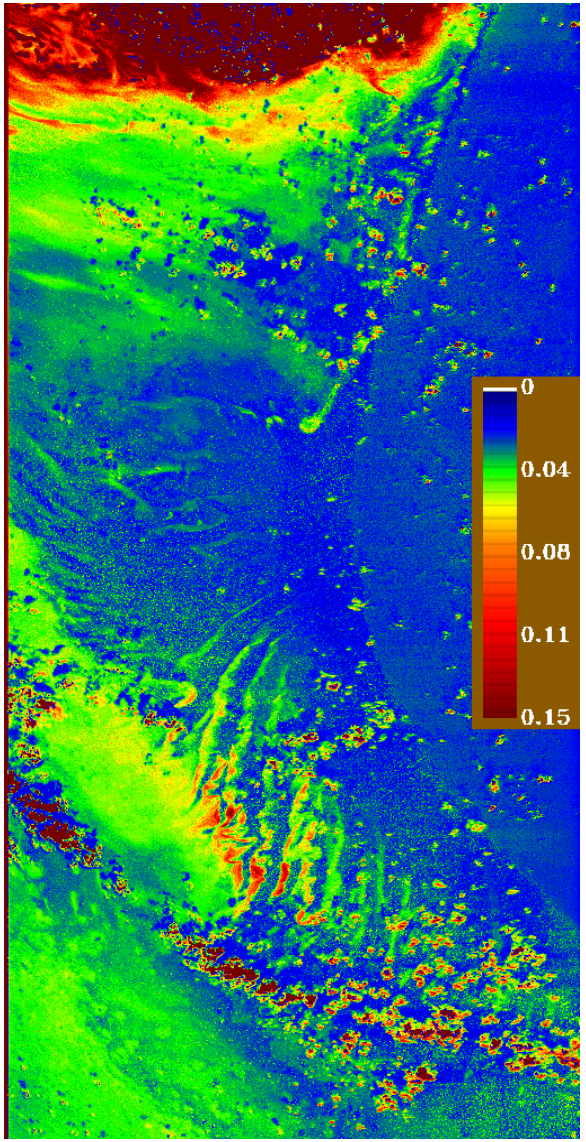
RGB image



Bathymetry



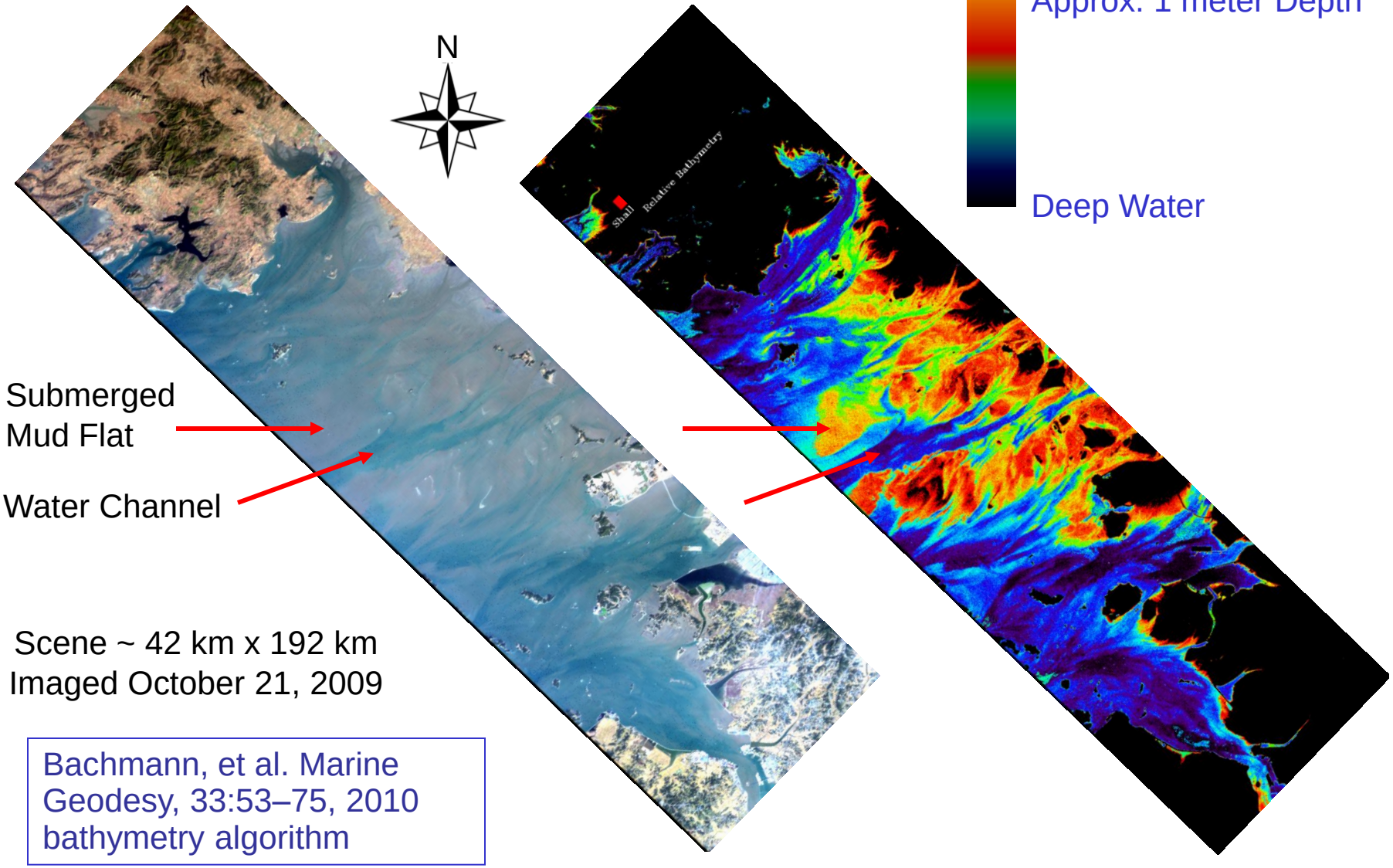
Absorption



Relative Bathymetry of Han River Area Mud Flats

HICO Image off Korean Peninsula

Relative Bathymetry Map Retrieved from HICO Image



Bachmann, et al. Marine Geodesy, 33:53–75, 2010 bathymetry algorithm

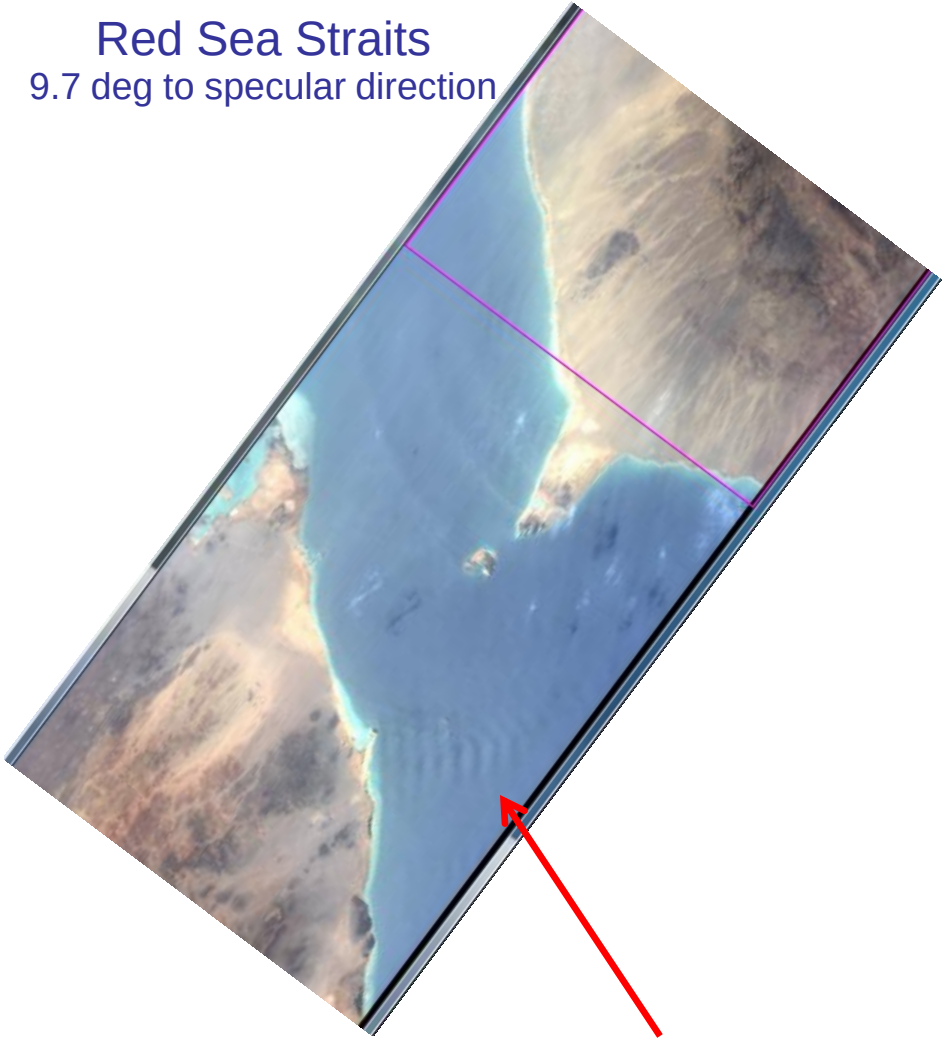
Issues

- HICO data has a couple of outstanding issues that have not been fully resolved
  - Data has “etaloning“ in the 700 to 950 nm region of the spectrum
    - Data is convolved to 20 nm band pass in the areas most affected
  - Data is inconsistent
    - Some data looks great and processes with little trouble
    - Some data has trouble with calibration resulting in negative blue radiances after atmospheric correction
    - Second order correction does not always work
    - Likely a polarization sensitivity issue. Actively being work but resolution time unknown
  - Geolocation is not as accurate as is possible
    - Largely traceable to timing errors on the space station
    - Two possible solutions 1) use NASA supplied timing correction or 2) use Broadcast Ancillary Data (BAD) to geocorrect data directly
    - Expect this to be resolved in the near term one way or the other

HICO Is Unique

- Only coastal hyperspectral instrument in orbit
- Should exploit the unique features of HICO including its orbit, which allows many combinations of sun/view angles
- Also has a high spectral resolution mode allowing 1.9 nm spacing

Red Sea Straits
9.7 deg to specular direction



Thought to be the effects of atmospheric gravity waves
Wavelength ~2 km

HICO Summary (HICO Docked on the ISS)

- **Built and launched in 28 months**
- **Over 6000 scenes collected**
- **Slot on ISS until July 2014**
- **Data from OSU HICO website**
- **http://hico.coas.oregonstate.edu**