HICO On-Line Atmospheric Correction

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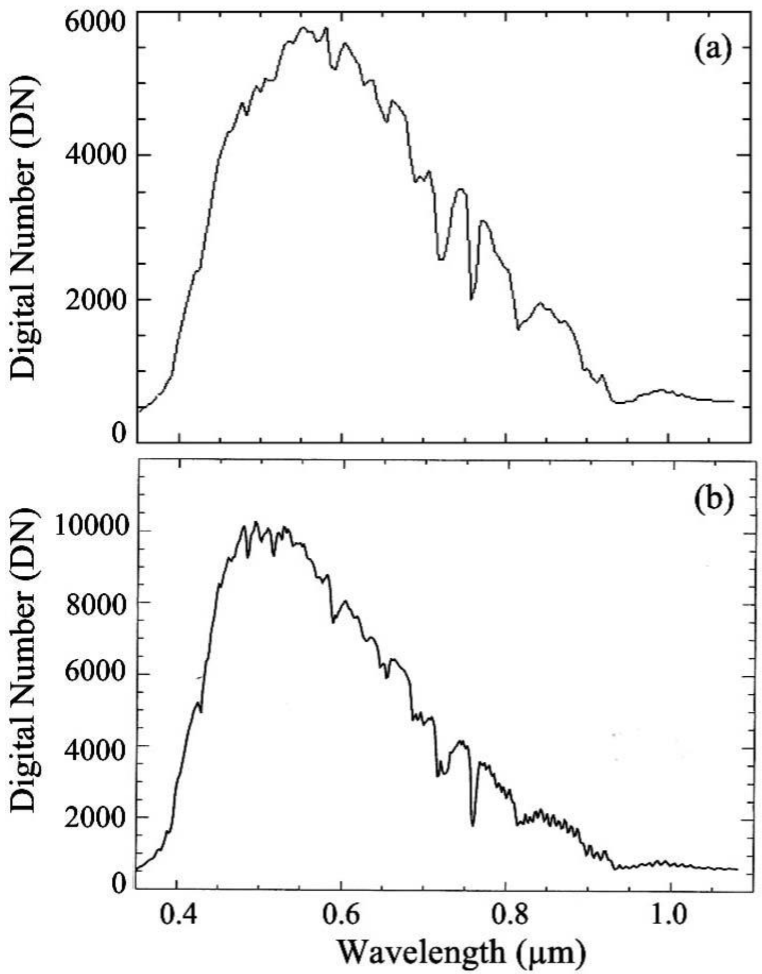
Introduction and Outline

- HICO the Hyperspectral Imager for the Coastal Ocean Operated on the ISS 2009 - 2014.
- HICO calibrated radiances
  - On orbit maintenance of calibration
- Atmospheric correction
  - Hyperspectral challenge
  - ATREM, Tafkaa 6S, Tafkaa Tabular
- OSU implementation of Tafkaa 6S
- Examples
  - San Francisco Bay
  - Monterey Bay
  - Lake Erie

Special thanks to NRL, ONR, the DoD Space Test Program, JAXA and NASA for their support of the HICO program.

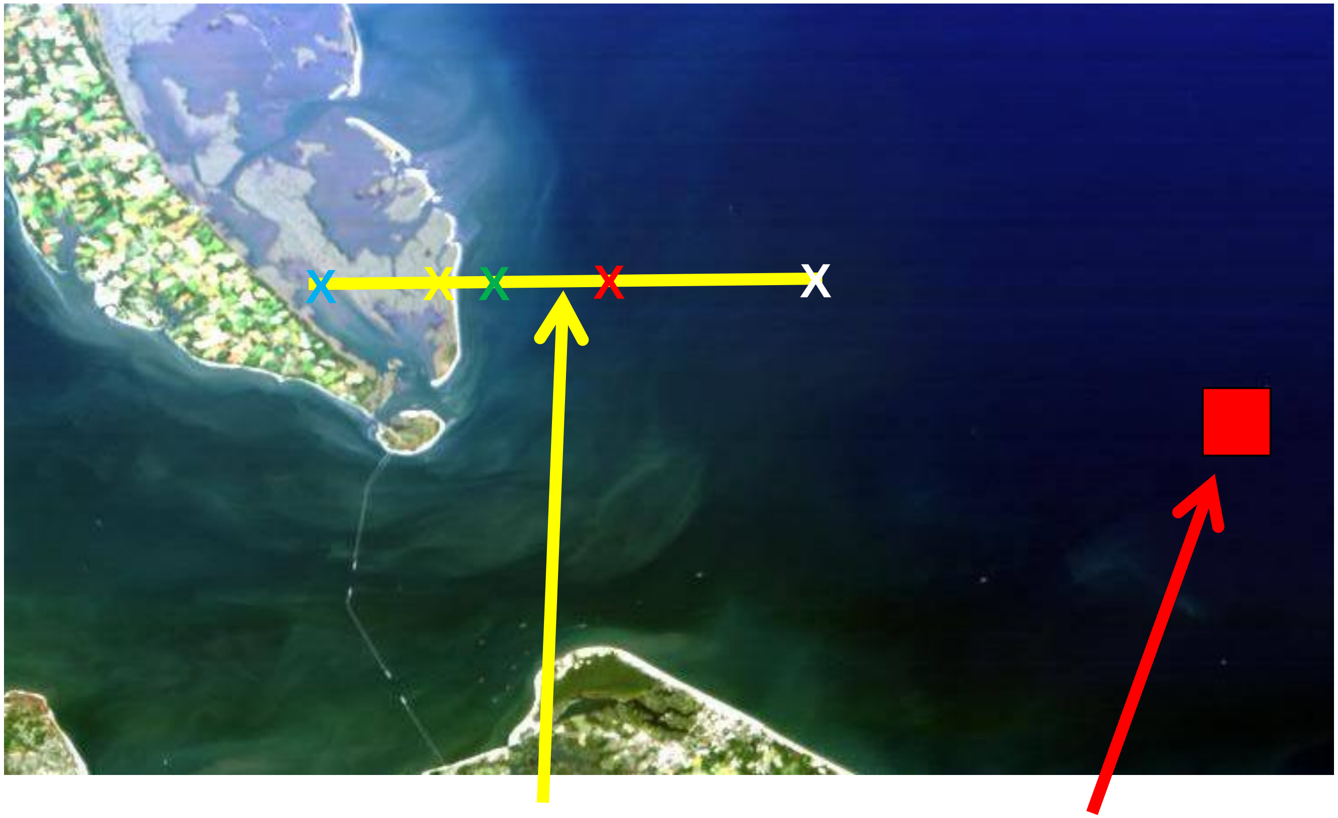
HICO On-Orbit Calibration

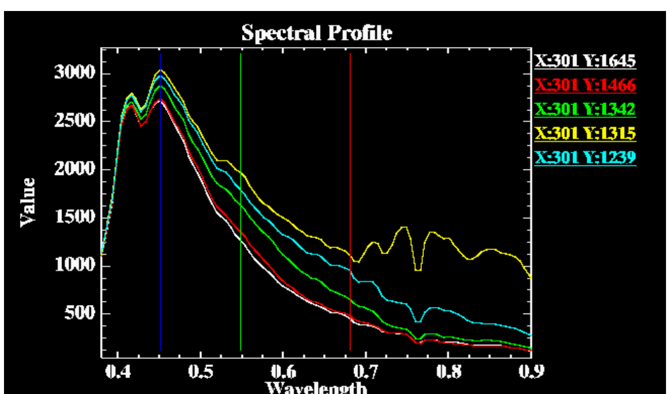
- HICO fully calibrated in the laboratory (Lucke et al, 2011)
  - Radiometric calibration
  - Spectral calibration
  - Dark current correction
  - Second Order correction
- HICO does not have a second order filter or an on-board calibrator.
- Cannot ask the ISS to rotate to point at the moon.
- On-orbit 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

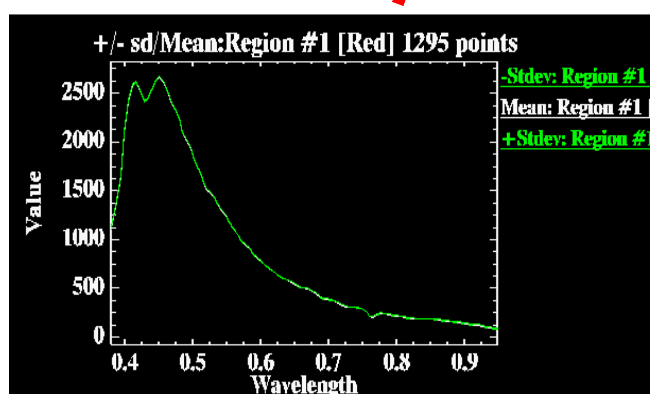


HICO spectra a) normal (5.7 nm) resolution and b) at full (1.9 nm) resolution used for spectral calibrations.

Calibrated Spectral Radiances







Left: Spectra extracted from pixels along the east-west transect shown in yellow. Approximate locations of the spectra are indicated by same color Xs on the image. Spectra are scaled calibrated at-sensor radiances.

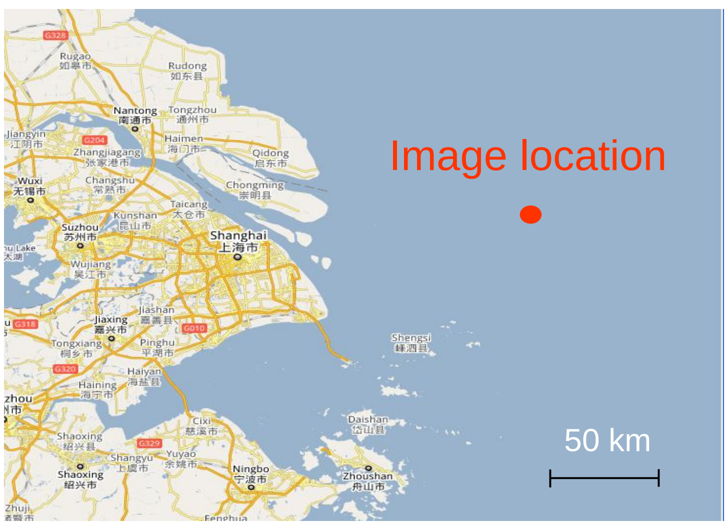
Right: Mean and standard deviation of 1295 pixels in the red Region of Interest. The SNR (μ/σ including all sensor and environmental variations) is >300:1 for much of the spectra. Spectra are scaled calibrated at-sensor radiances.

Radiometric Comparison of HICO to MODIS (Aqua)

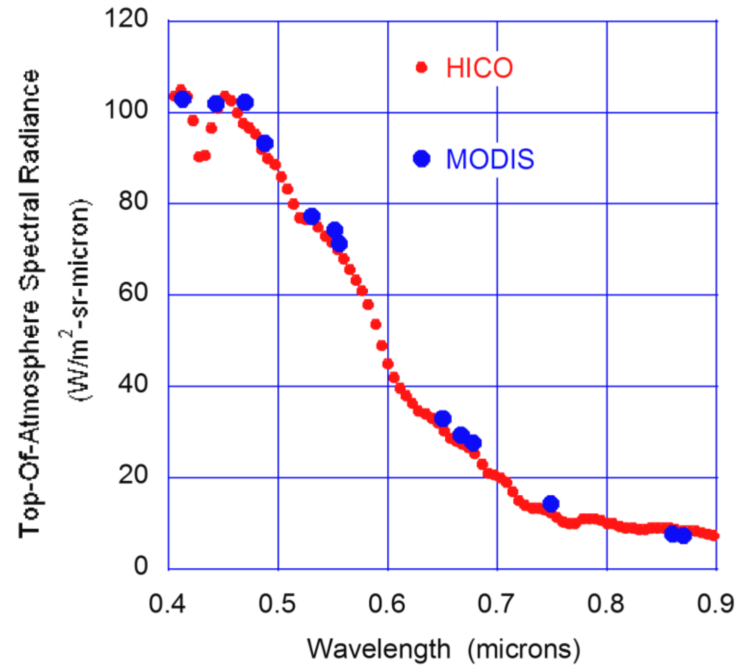
Nearly coincident HICO and MODIS images of turbid ocean off Shanghai, China demonstrates that HICO is well-calibrated

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

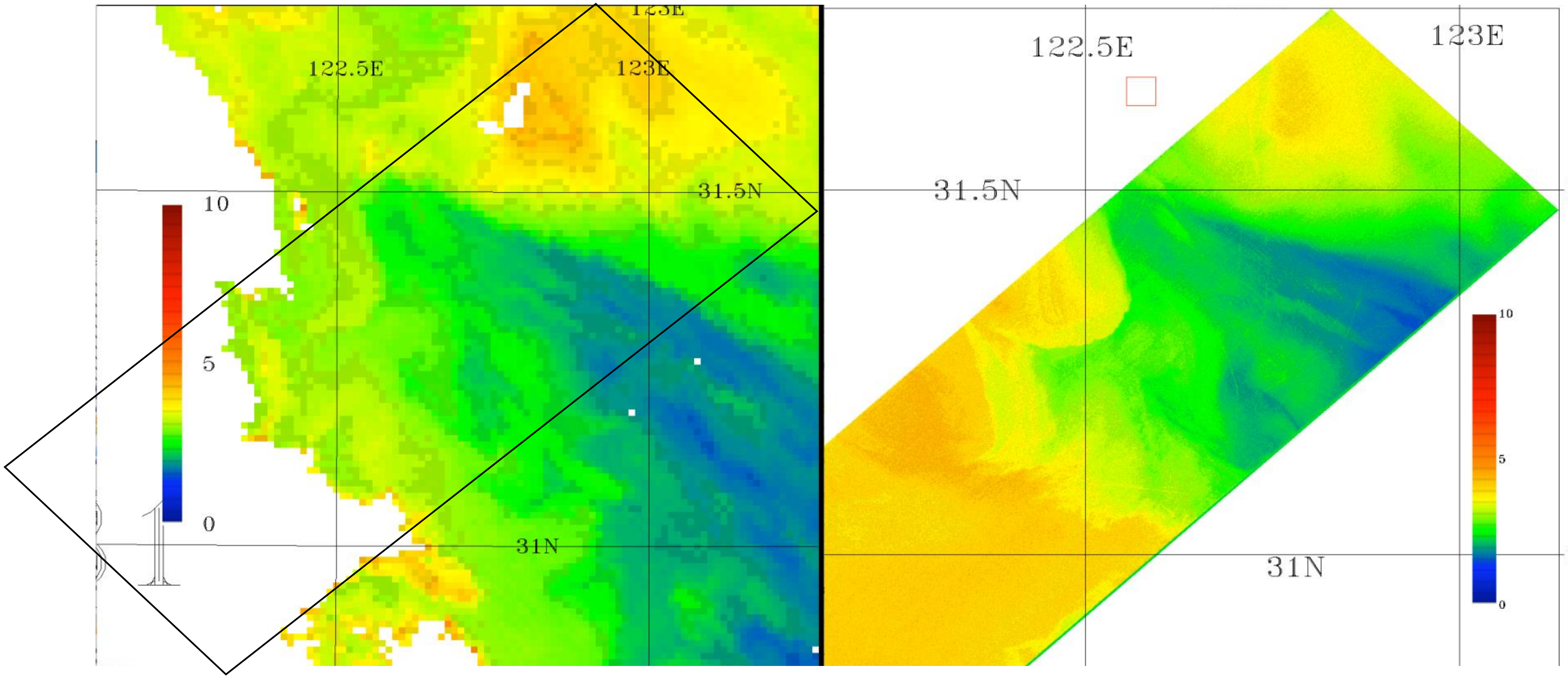


Top-Of-Atmosphere Spectral Radiance



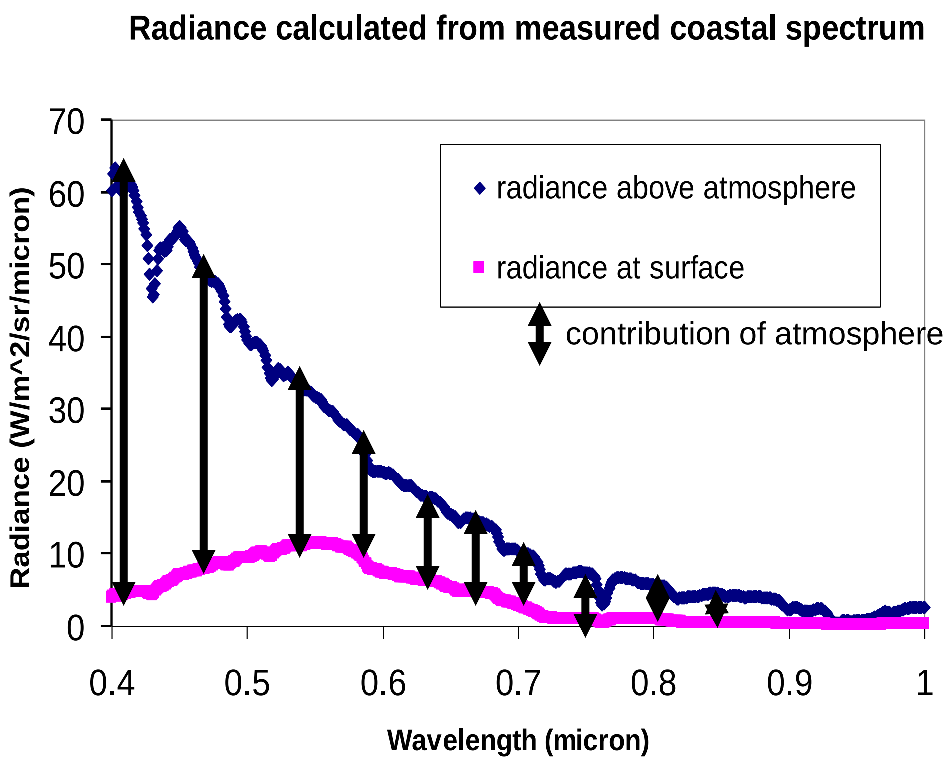
R.-R. Li and B.-C. Gao, NRL

Chlorophyll Comparison of HICO to MODIS (Aqua)



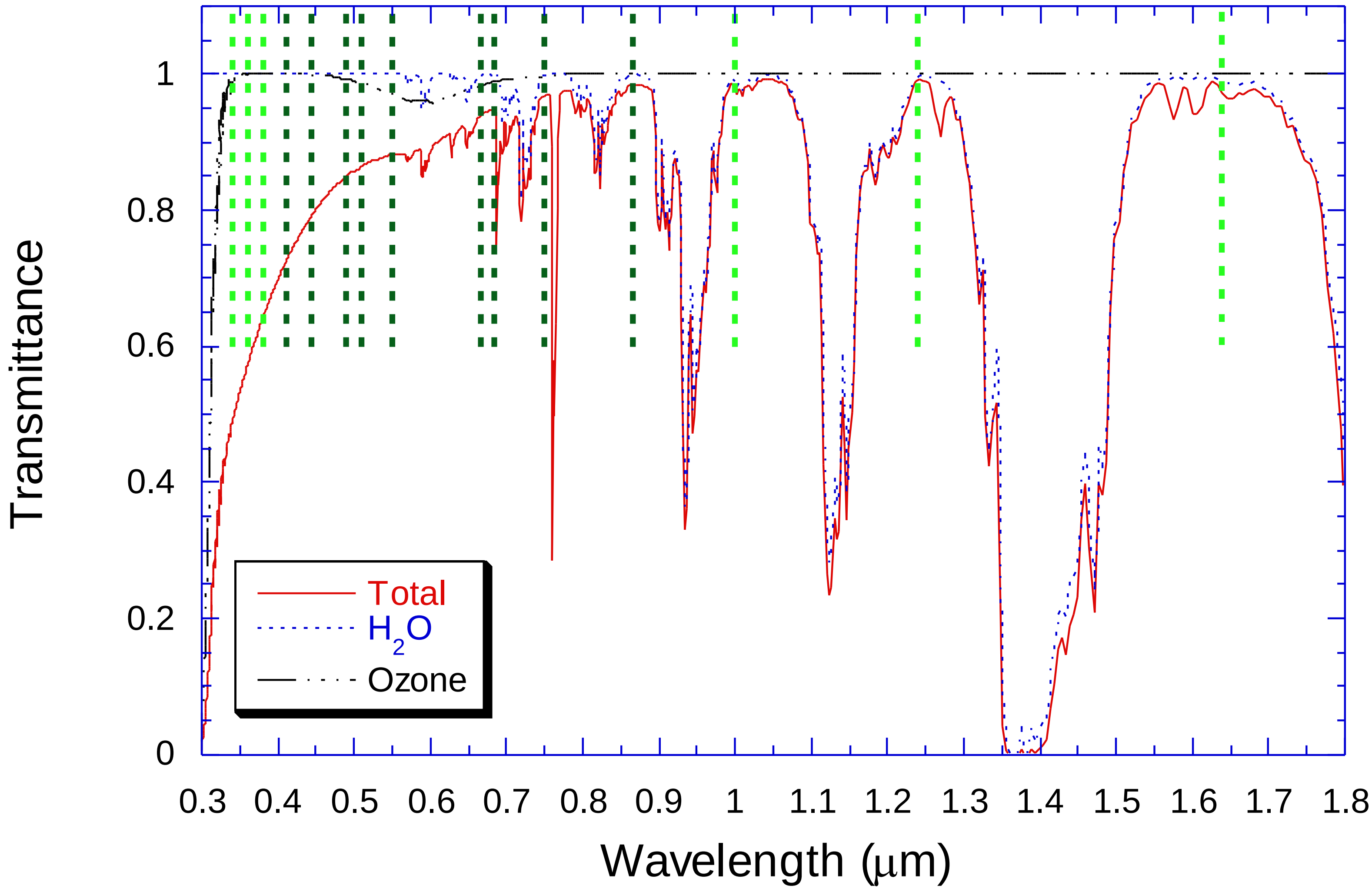
Nearly coincident MODIS and HICO™ images of the Yangtze River, China taken on January 18, 2010. Left, MODIS image (0500 GMT) of Chlorophyll-a Concentration (mg/m3) standard product from GSFC. The box indicates the location of the HICO image relative to the MODIS image. Right, HICO™ image (0440 GMT) of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

Difficulty of Atmospheric Removal Over Water



- Atmosphere most of signal
- Atmospheric gases are well mixed, well understood
- Water is variable but well understood
- Aerosols variable in space & time
- Accurate aerosol models and radiative transfer necessary

Full Spectral Atmospheric Correction



- Multispectral channels selected to avoid water vapor and other absorptions
- Must correct the full spectrum for hyperspectral data

Figure From Menghua Wang, NOAA/NESDIS/STAR

Tafkaa Atmospheric Corrections

- Tafkaa-6S (Available for HICO data on the OSU HICO website)
  - Based on ATREM (Gao & Davis 1997 PROC SPIE)
  - Uses 6-S atmospheric model
  - User selects aerosol model and optical depth
  - Handles data from all altitudes
  - Uses absorption features to correct water vapor at all wavelengths
  - Changes from ATREM include ability to parse image header file, improved speed, uses larger set of aerosol models
- Tafkaa-Tabular (not generally available, needs further support)
  - Much of the code based on ATREM (Gao & Davis 1997, PROC SPIE)
  - Uses a large look-up table for the aerosol correction
    - Table created using Zia Ahmed's full vector radiative transfer model
    - Can use dark pixel assumption for open ocean scenes
  - Includes a correction for reflections off of the sea surface
  - Only works for near sea-level data
  - Originally described in (Gao, Montes, Ahmad, & Davis, Applied Optics 2000), modifications in several SPIE proceedings

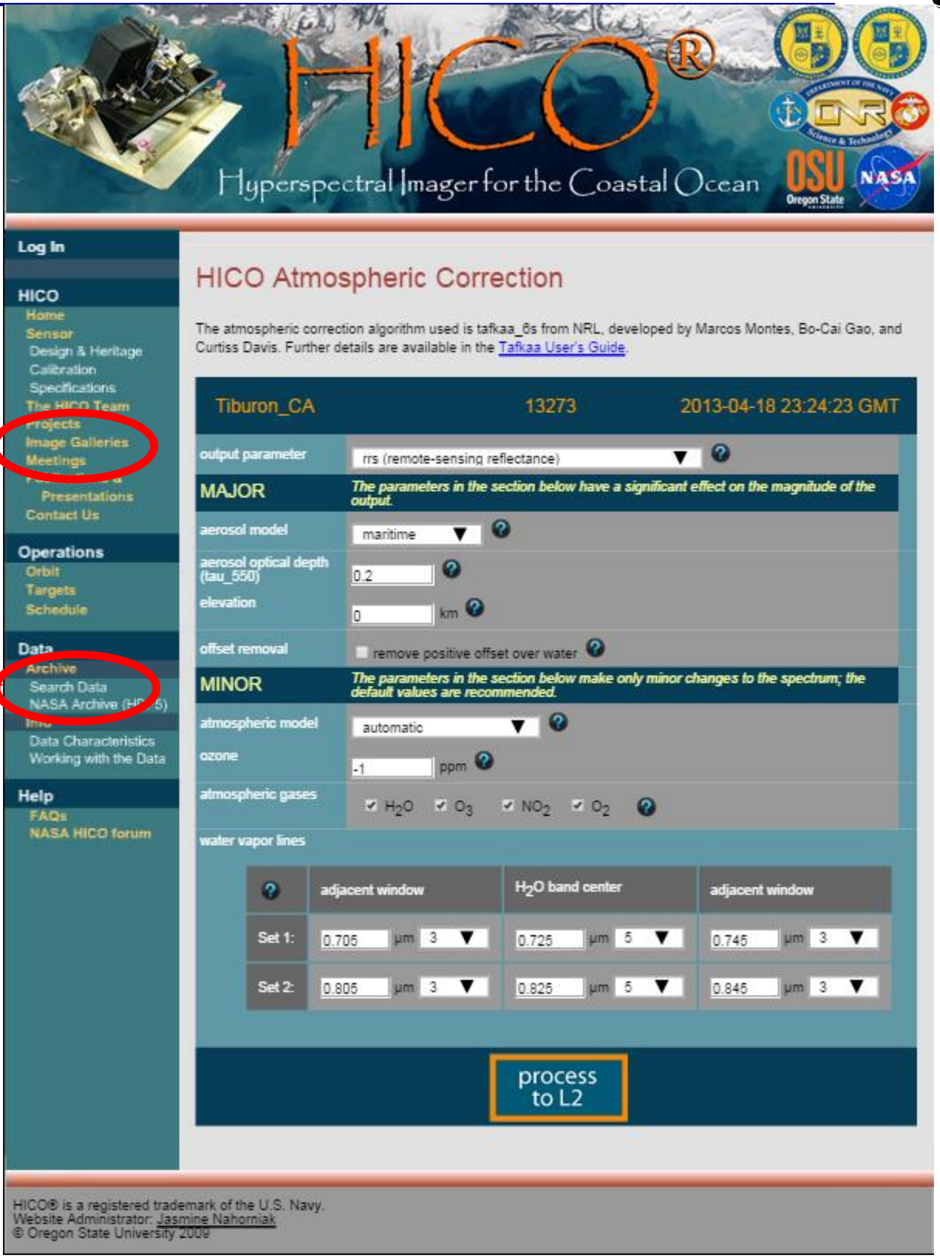
HICO atmospheric correction tool

- OSU HICO website tool
- uses Tafkaa 6S

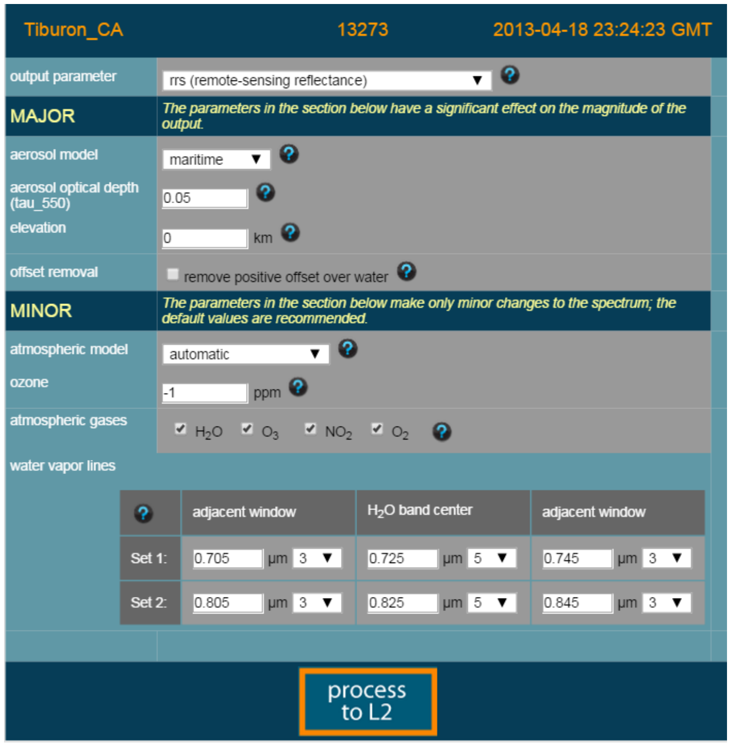
Tool access types

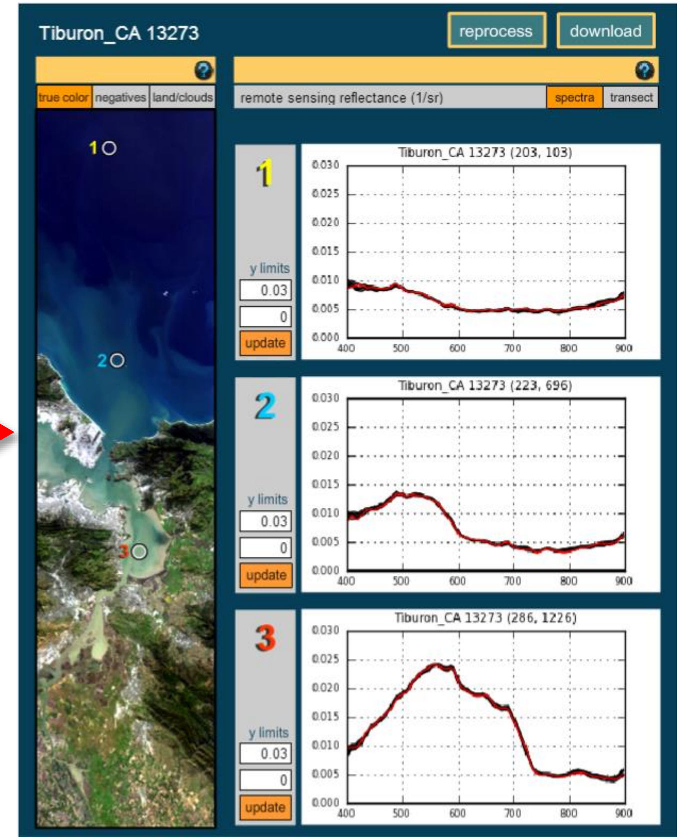
1) public access
- from “Image Galleries”
- select scenes only

2) full access (*available on request*)
- from “Search Data” results
- all scenes



HICO atmospheric correction sequence



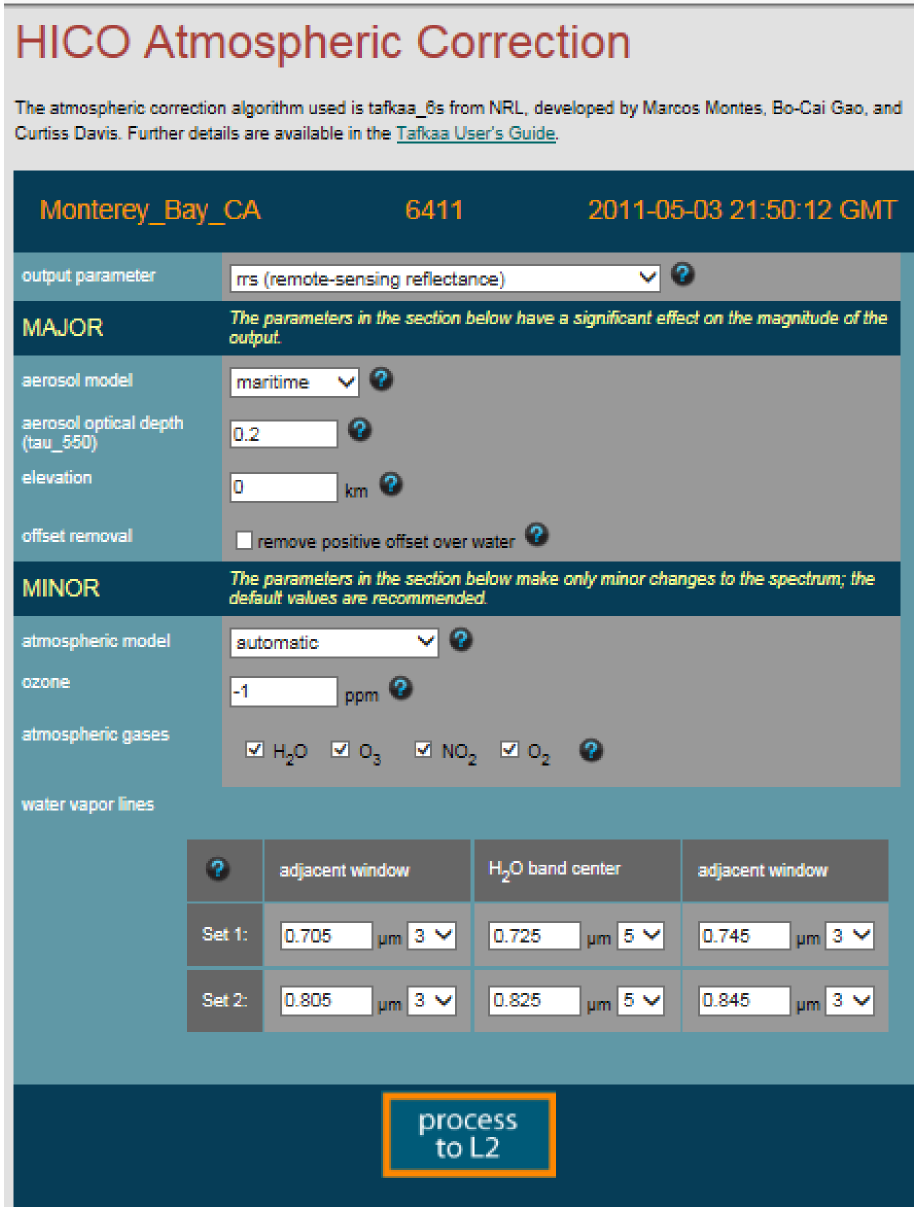


1. On the OSU HICO website, find a HICO scene and click

2. Select appropriate atmospheric values for the scene.

3. Examine the spectra at user-selected locations within the scene. Reprocess as needed, then download the data.

The HICO atmospheric correction screen



The tool includes two sections that have Major and Minor Effects.

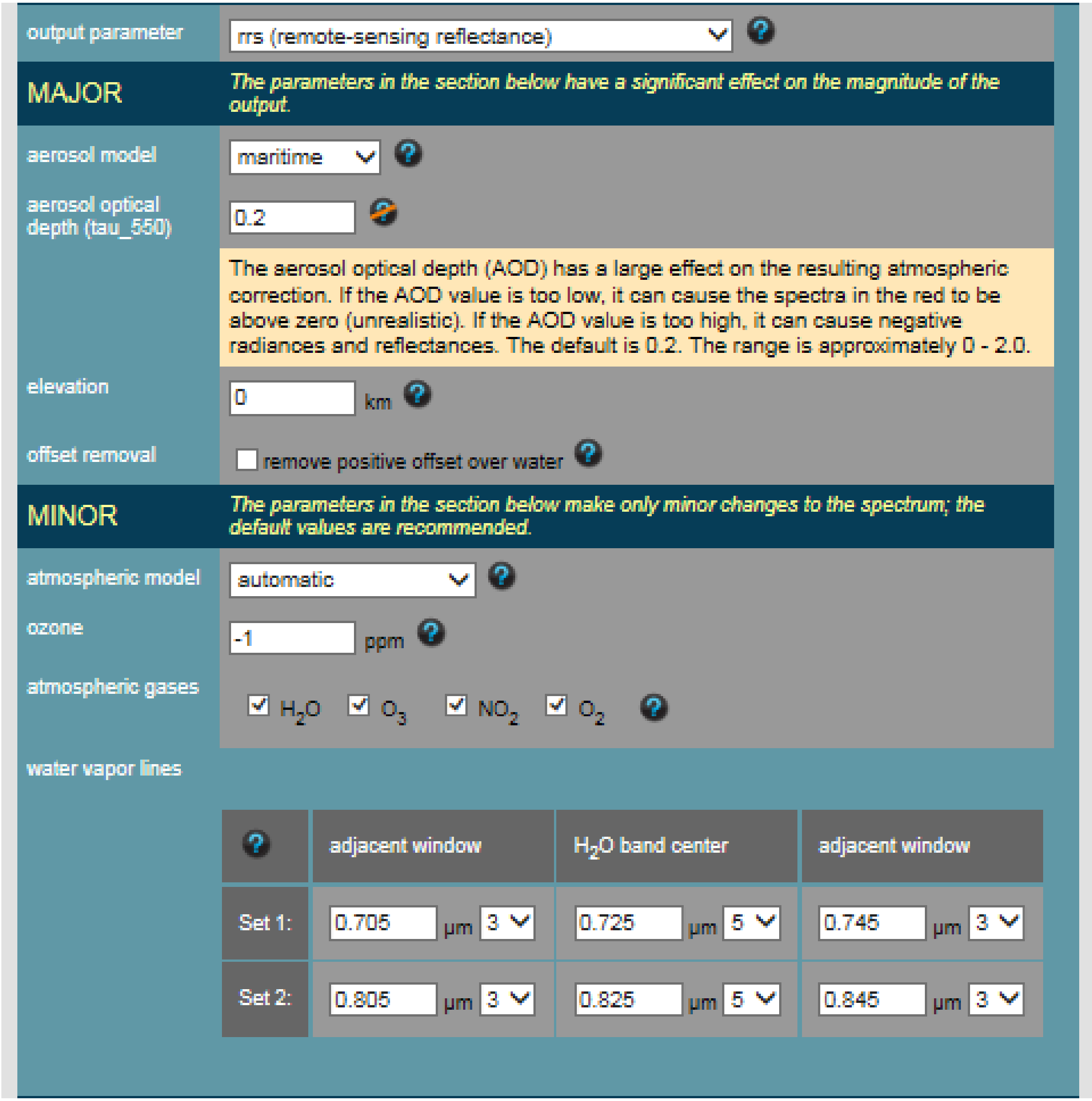
Major:

- **Aerosol Model**
- **Aerosol Optical Depth**
- **Elevation**
- **Offset Removal** (assume Rrs from 740-785 nm = 0)

Minor:

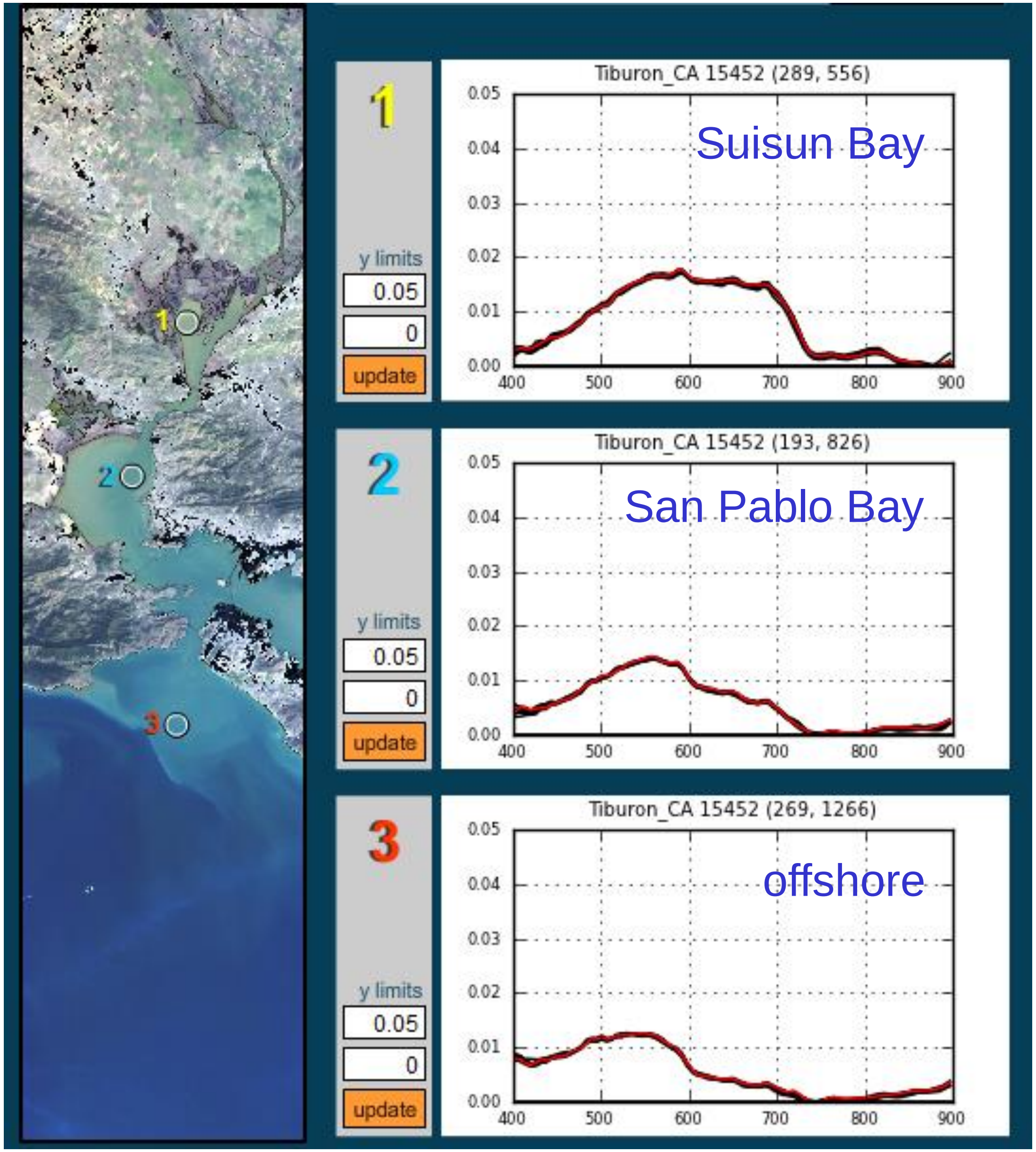
- **Atmospheric Model** (automatically selected for location and season)
- **Ozone** (use climatology or input a value from your data)
- **Water Vapor** (uses the selected absorption lines)

Atmospheric Correction Help Buttons



There is a help button for each topic; click on it to get help and then click again to remove the help screen.

HICO image: Tiburon, California (2014)



Remote sensing reflectance spectra from February 19, 2014 for:

(1) Suisun Bay,

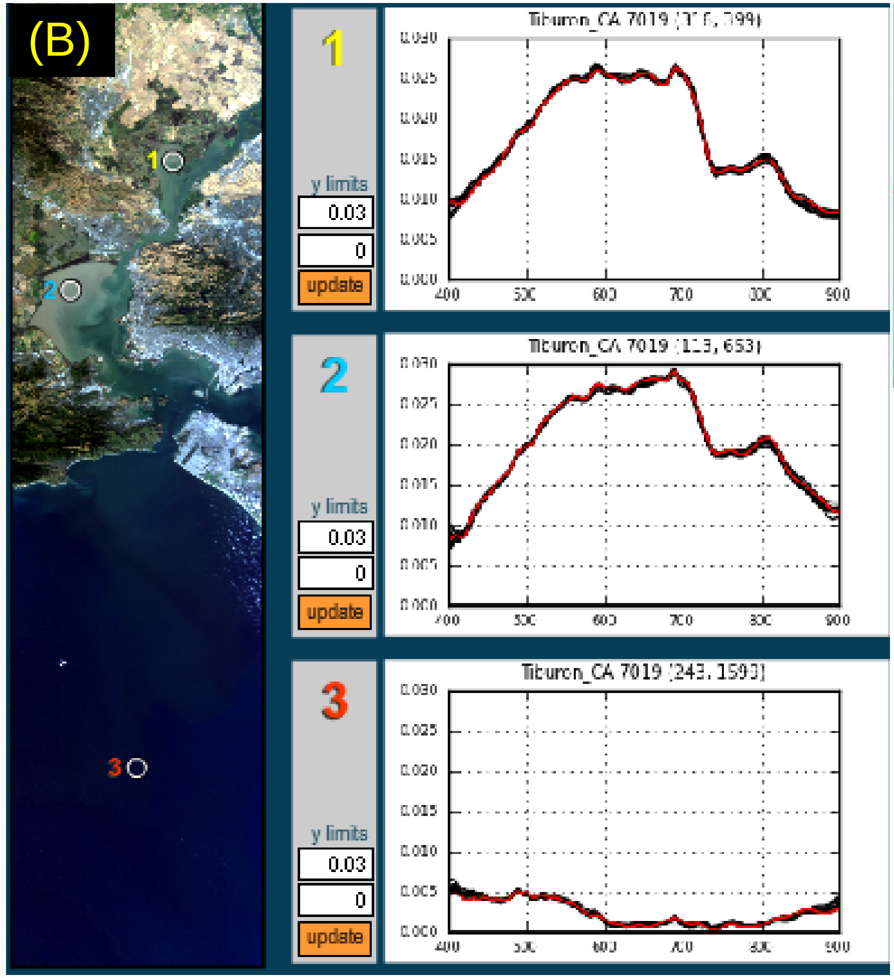
(2) San Pablo Bay, and

(3) offshore

showing outflow from the bays even during low flow drought conditions.

HICO image: Tiburon, California (2011)

➢ HICO provides 90 m GSD, hyperspectral data, and high SNR

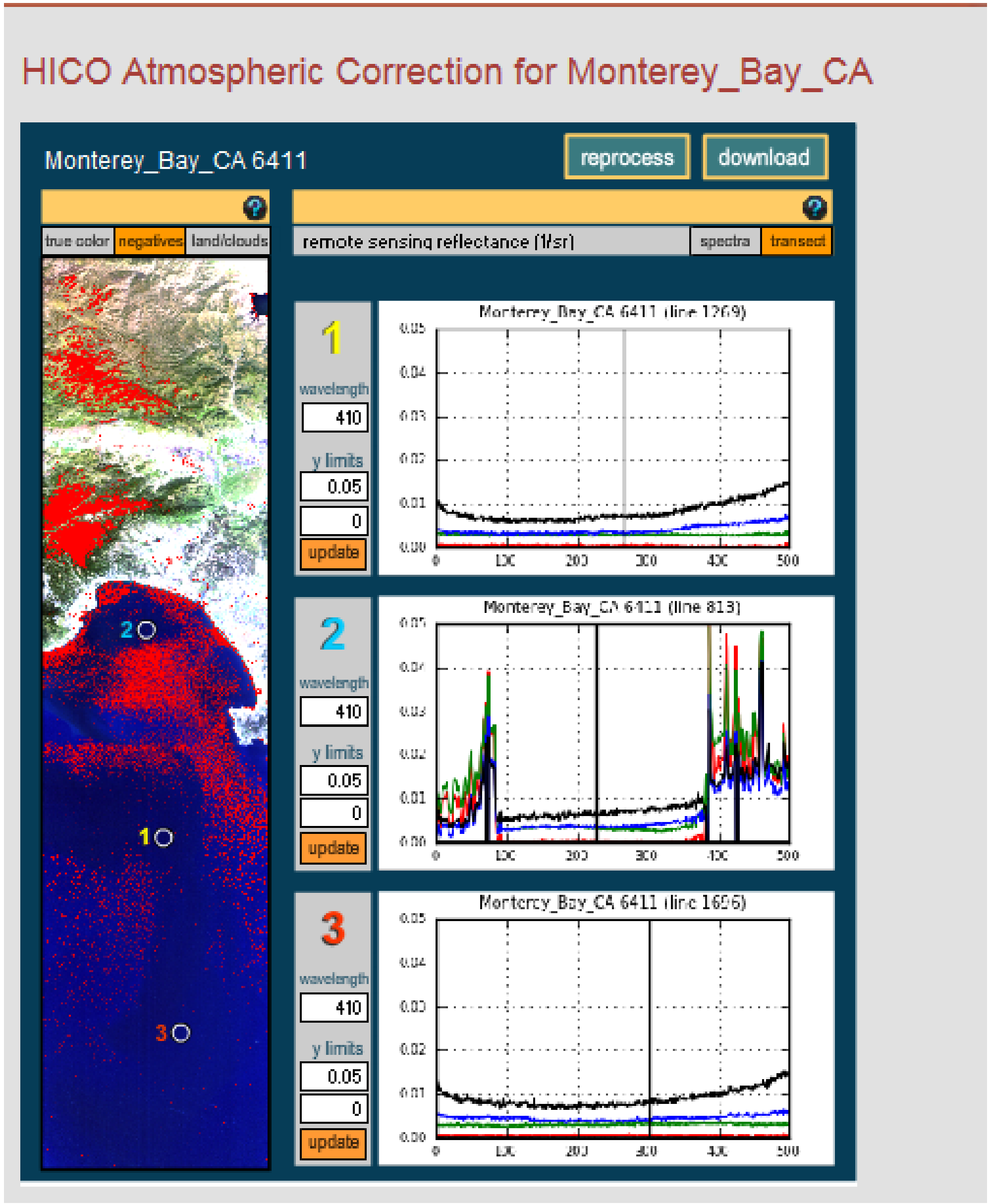


(A) HICO RGB image from June 24, 2011.

(B) Select spectra from the scene.

(C) Close-up of the box in (A).

Assessment tools, cross track blue issue



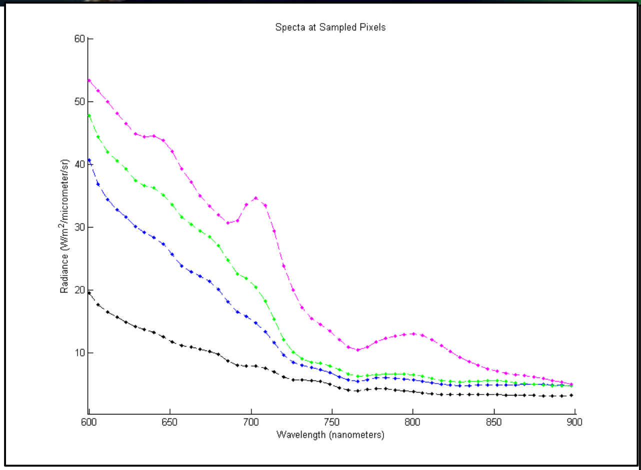
Additional tools to examine your data:

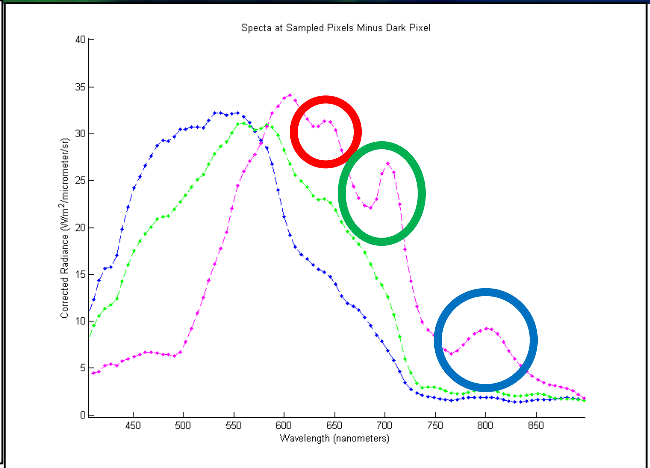
Image showing negatives
Move the circles to any location in the image
Change scales and reset the spectra
Across Scene Transect
Includes one selected channel.

Using 410 highlights an issue with enhanced blue at the scene edges for some open ocean scenes

Microcystis bloom in Lake Erie

HICO Image of a massive *Microcystis* bloom in western Lake Erie, September 3, 2011 as confirmed by spectral analysis.





Hyperspectral Imager for the Coastal Ocean (HICO)

- ONR Innovative Naval Prototype
- Built and launched in 28 months
- Installed September 24, 2009 on the ISS
  - > Operated for 5 years
  - > 10,000 scenes
  - > 50 projects

OSU Tafkaa 6S atmospheric correction

Data from NASA: http://oceancolor.gsfc.nasa.gov
and at: http://hico.coas.oregonstate.edu

Backup

Tafkaa Atmospheric Correction

The apparent reflectance ρ^*_{obs} at a hyperspectral sensor for a given wavelength is

$$\rho^*_{obs} = \pi L_{obs}/(\mu_o F_o) \qquad (1)$$

where L_{obs} is the radiance of the ocean–atmosphere system measured by the sensor, μ_o is the cosine of the solar zenith angle, and F_o is the extraterrestrial downward solar irradiance at the top of the atmosphere. Then ρ^*_{obs} can be expressed as:

$$\rho^*_{obs} = T_g\,[\rho^*_{atm+sfc} + \rho_w t_d t_u/(1 - s\rho_w)] \qquad (2)$$

where T_g is the total atmospheric gaseous transmittance on the sun-surface–sensor path, $\rho^*_{atm+sfc}$ is the reflectance resulting from scattering by the atmosphere and specular reflection by ocean surface facets, t_d is the downward transmittance (direct + diffuse), t_u is the upward transmittance, s is the spherical albedo that takes into account the reflectance of the atmosphere for isotropic radiance incident at its base, and ρ_w is the water- leaving reflectance. Solving (2) for ρ_w yields

$$\rho_w=\rho^*_{obs}/T_g-\rho^*_{atm+sfc}/[t_d t_u+s\,(\rho^*_{obs}/T_g-\rho^*_{atm+sfc})] \quad (3)$$

Given L_{obs}, the water-leaving reflectance can be derived according to (1) and (3) and the other quantities in the right hand side of (3) modeled theoretically.