Ocean Products and Atmospheric Removal in APS

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February 22, 2011

Outline

1. **Data Processing in the Automated Processing System (APS)**
2. HICO processing streams in APS
3. Vicarious Calibration in APS
4. HICO APS Data Products
5. HICO APS Data Processed through HOPE Algorithm
6. Summary

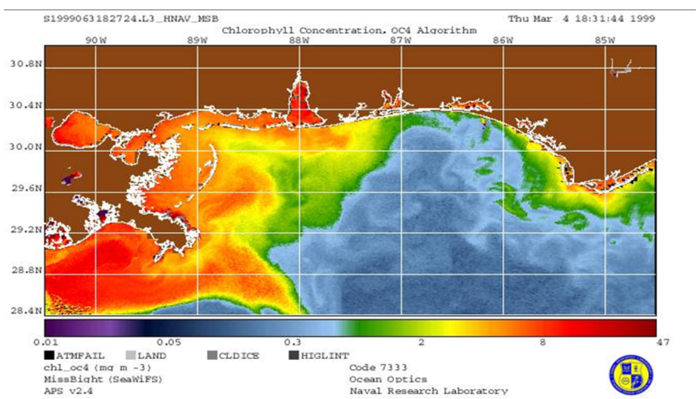
Automated Processing System (APS)

The Automated Processing System (APS) is a collection of UNIX programs and shell scripts designed to generate regional map-projected image data bases of satellite derived bio-optical products from a large flow of raw satellite input data in an automated fashion.

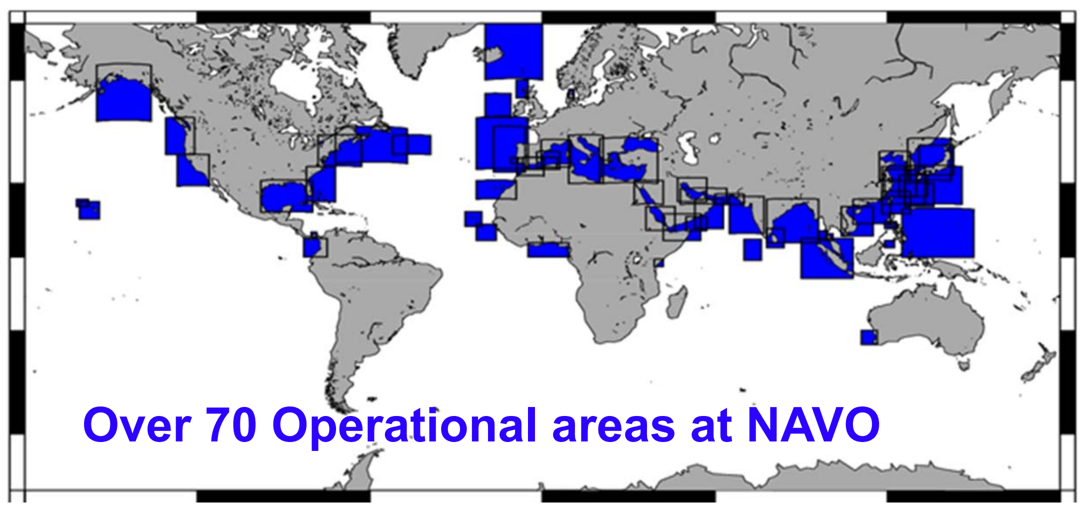
- Consistent with standard NASA processing code (SeaDAS 6.1) for SeaWiFS, MODIS, MERIS.
- Addition of Navy-specific algorithms and products (absorption, backscattering coefficients, diver visibility).
- No graphical user interface.
- Multiple platforms (Linux RH 7.1,RH 7.3/SGI IRIX 6.5).
- An SQL database is populated (web browsing).

APS Development

- Developed at NRL/Stennis
- End-to-end processing (radiometric, atmospheric, geometric correction → optical products) within several minutes
- Handles multiple satellites, algorithms, regions-of-interest
- Multiple input streams: NRL receiving system, NOAA, NASA – real time and archival data (global)
- Adding new products, sensors (euphotic depth, MERIS, HICO)
- Architecture in place to easily test algorithms, reprocess large imagery data bases



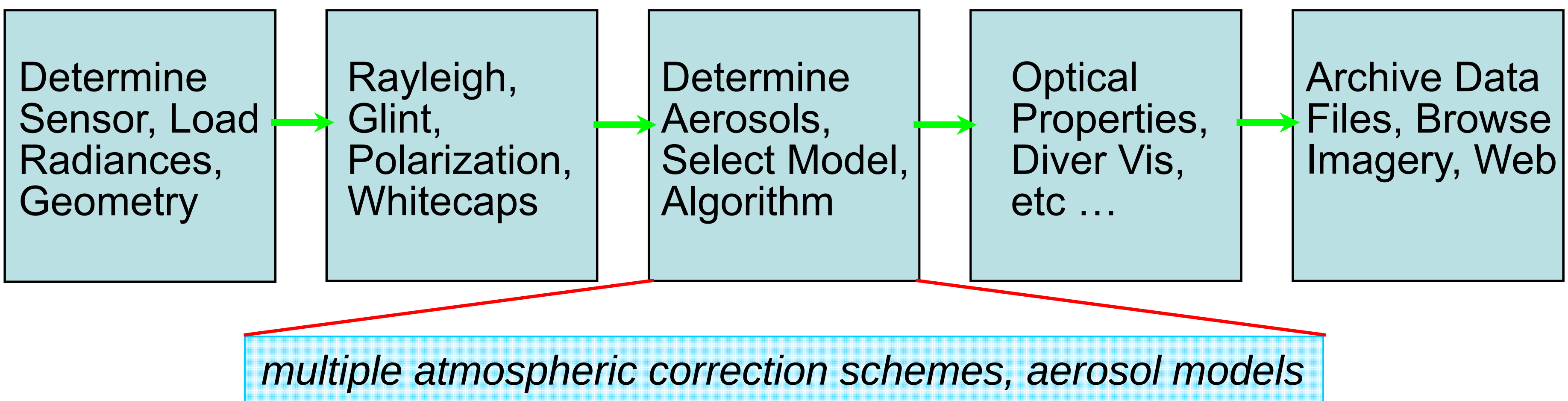
- *weekly, monthly composites*
- *data files*
- *browse imagery*



Data Transformation in APS

- Individual scenes are sequentially processed from the raw digital counts (Level-1) to radiometrically, atmospherically, and geometrically corrected (Level-3) products within several minutes.
- Data processed into several temporal (daily, 8-day, monthly, and yearly) composites or averages (Level-4).
- Quick-look “browse" images (PNG) are automatically generated and stored on a web.
- The Level-3 and Level-4 data (HDF v4) are archived in a directory-based data base that resides on a 40TB RAID array.

APS Processing Steps



Ocean Color Imagery

- **Multi-Year Image Archive**

  SeaWiFS - 1km, daily, 1997-present
  MODIS - 250m, 500m and 1 km, daily, 2002-present
  OCM – 350m, 8 bands
  MERIS – 1km (300m), 15 bands

- **Processed With Consistent Algorithms**

Daily, Weekly, Monthly
Bio-Optical Properties
1 km resolution

Bio-Optical Properties

- Radiances, Reflectances
- Chlorophyll
- Partitioned Absorption Coefficients *(detrital, sediment, CDOM, and phytoplankton)*
- Backscattering Coefficient
- Diffuse, Beam Attenuation Coefficients
- Suspended Particulate Concentrations *(total, organic, inorganic)*
- Euphotic Depth
- Diver Visibility

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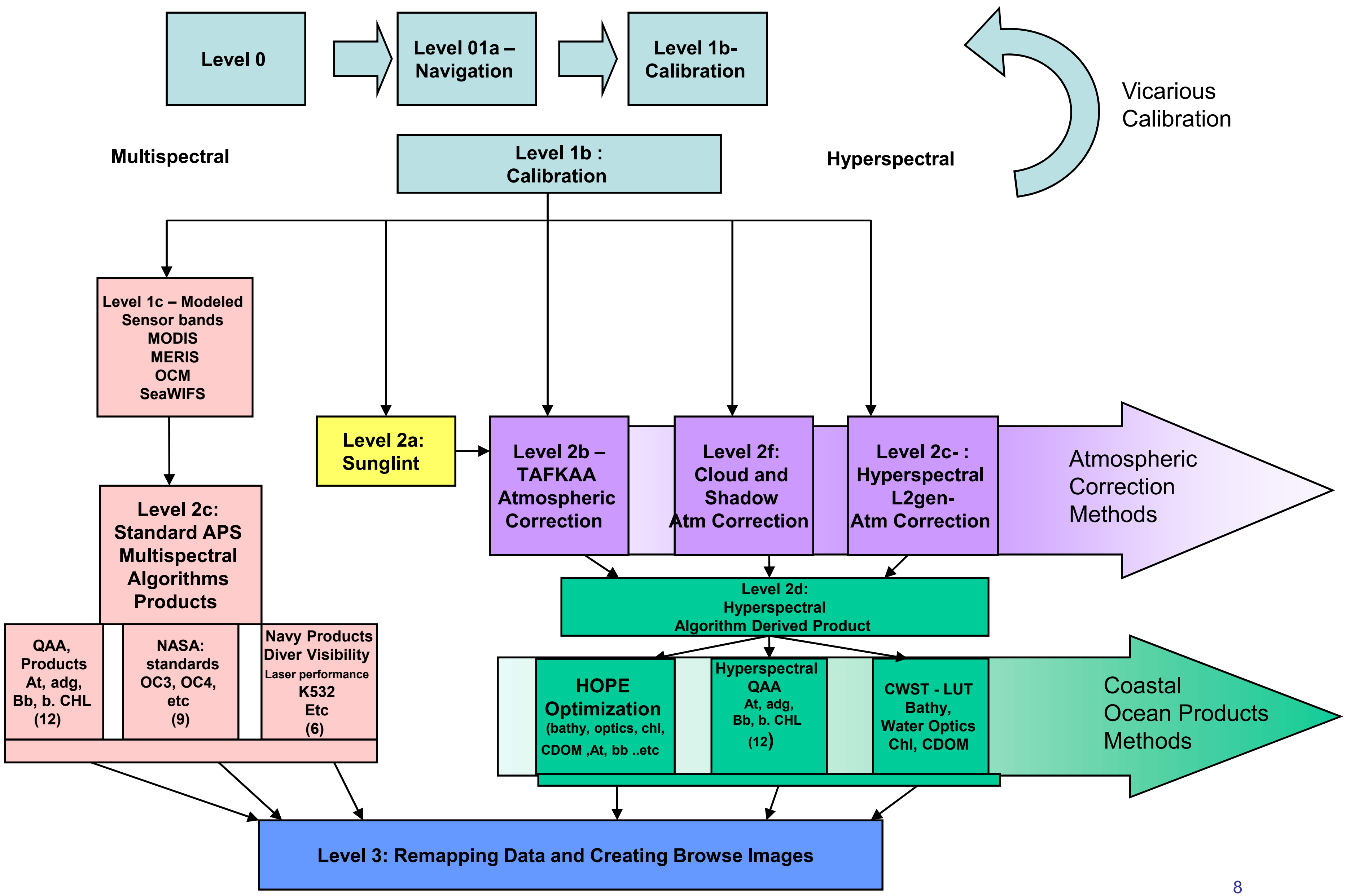
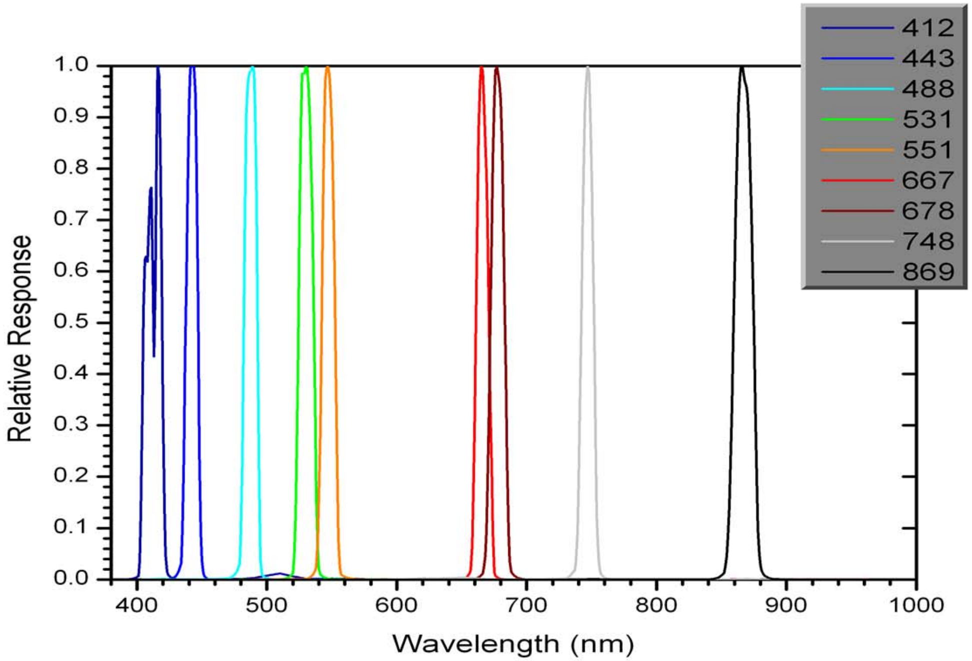
HICO Processing Activity in APS



MODIS-like (Multispectral) HICO Data Creation

- Perform convolution over 412, 443,488, 531, 547, 667,678,748, 869 nmeter MODIS Aqua spectral response
- Generate 9 band data set and store within simple format and also envi file format
- Write data readers for APS to ingest data into APS
- Process according using usual MODIS processing algorithms
- Compare products to MODIS derived products



MODIS Spectral Response (MSR)

Band Convolution performed by:

$$\textbf{ML HICO}_i = \frac{\sum \textbf{MSR}_{ik} * \textbf{HICO\_data}_k}{\sum \textbf{MSR}_{jk}}$$

ML HICO$_i$: MODIS-Like HICO data for *ith* MODIS band
HICO_data$_k$: Hyperspectral data for *kth* wavelength
MSR$_{ik}$: MODIS Spectral Response for *ith* MODIS band and *kth* wavelength

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Vicarious Calibration Option in APS

- Purpose is to fit nLw computed by APS to in situ data
  - Sensor gains/offsets unique for NIR atmospheric correction of APS
  - Also unique to parameters used (designated wavelengths, etc)

- Forward atmospheric correction computation
  - Perform standard atmospheric correction over in situ site
  - Store rayleigh/aerosol radiances and absorption terms
  - Compute normalized water leaving radiance (nLw)

- Inversion of atmospheric correction
  - Substitute in situ (nLw) into level 2 nLw record
  - Add computed atmospheric terms to in situ nLw to get vicarious Lt
  - Vicarious Lt is the Lt value needed to compute in situ nLw
  - Store original Lt and vicarious Lt values

- Linear regression over sample sites generates sensor gains/offsets

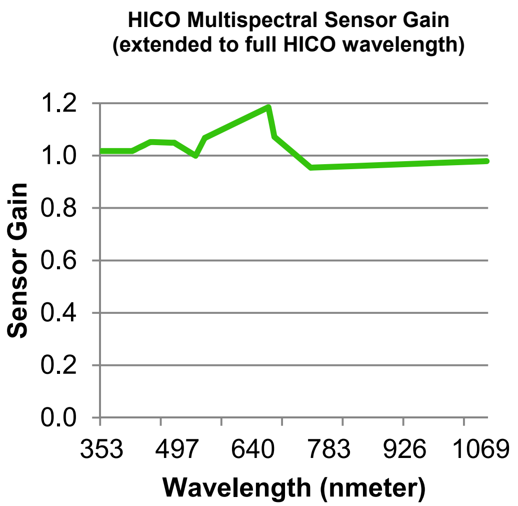
Vicarious Calibration Activity

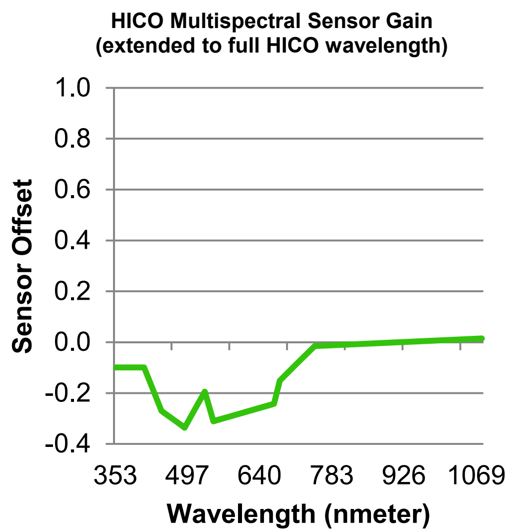
- Multispectral (MODIS-Like) HICO Data
  - 7 Aeronet sites (Seaprism data) included AAOT, LISCO, LJCO locations from 12/10/09 to 10/02/10
  - Seaprism data interpolated for MODIS 531nm and 678nm bands

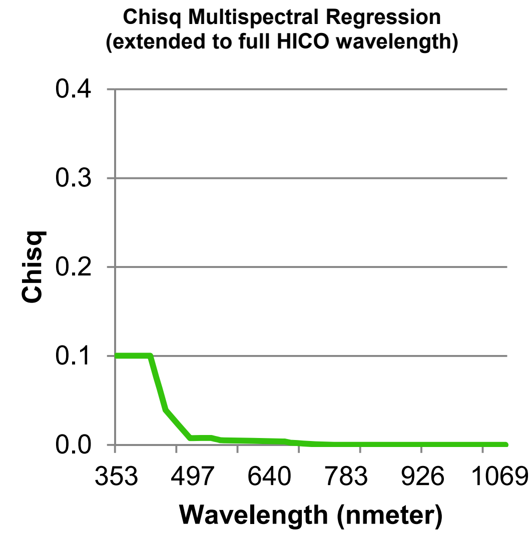
- Hyperspectra Data
  - 3 LISCO (Hypersas) dates included from Sep/Oct 2010
  - Hypersas data interpolated to HICO wavelengths

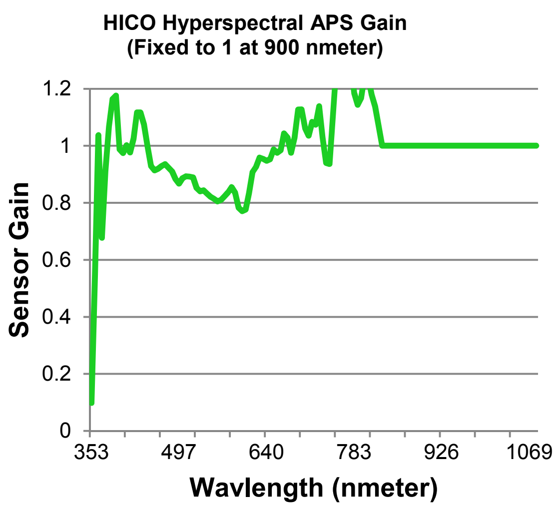
- Common processing
  - vLt values computed by APS inverse atmospheric correction
  - Measured Lt and vLt stored
  - Vicarious gains and offsets set by linear regression of Lt to vLt

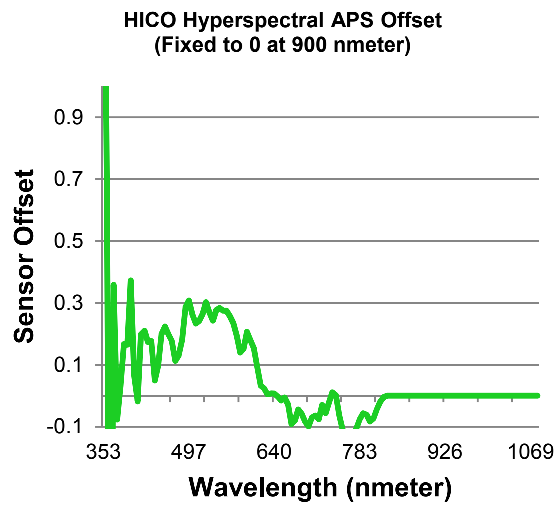
Vicariously Calibrated Gain/Offset Values

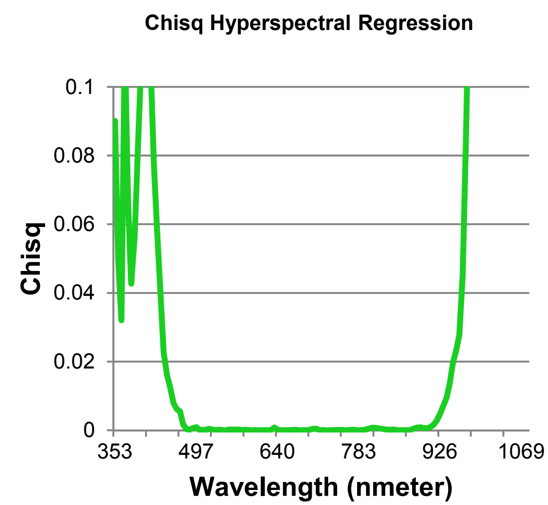






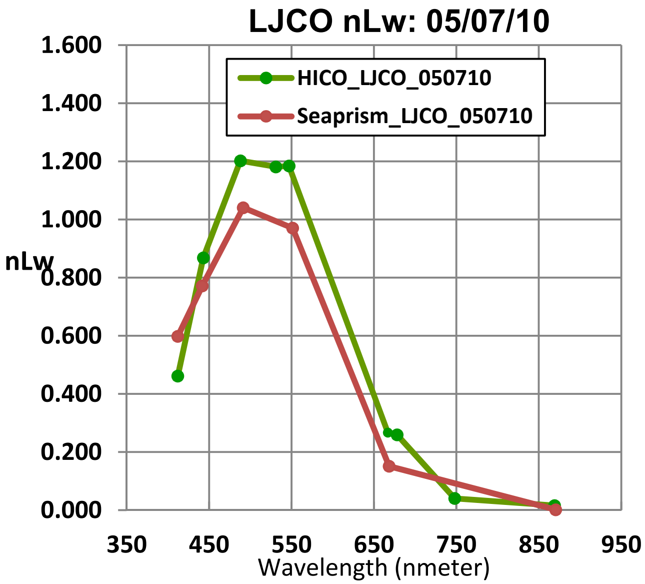


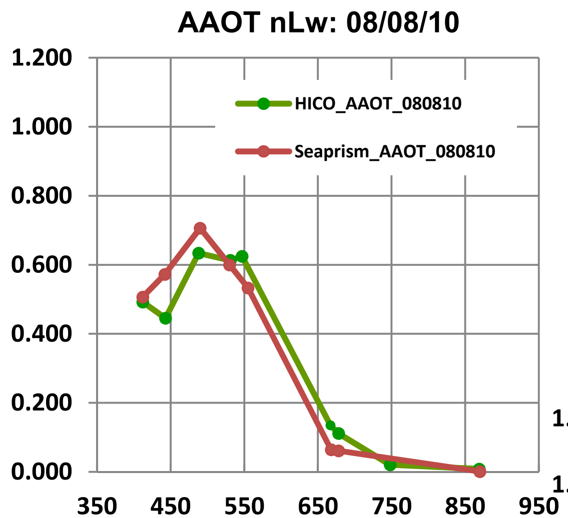


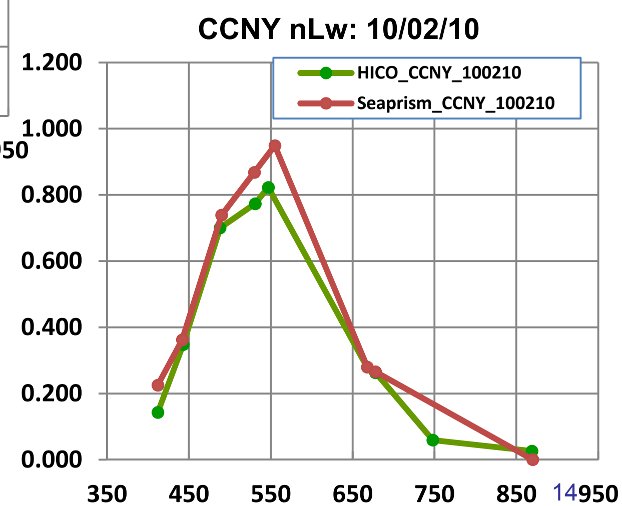


Multispectral Vicarious Gain Validation

- Data reprocessed with new sensor gain/offsets
- APS processed HICO spectral overlaid on in situ data for comparison

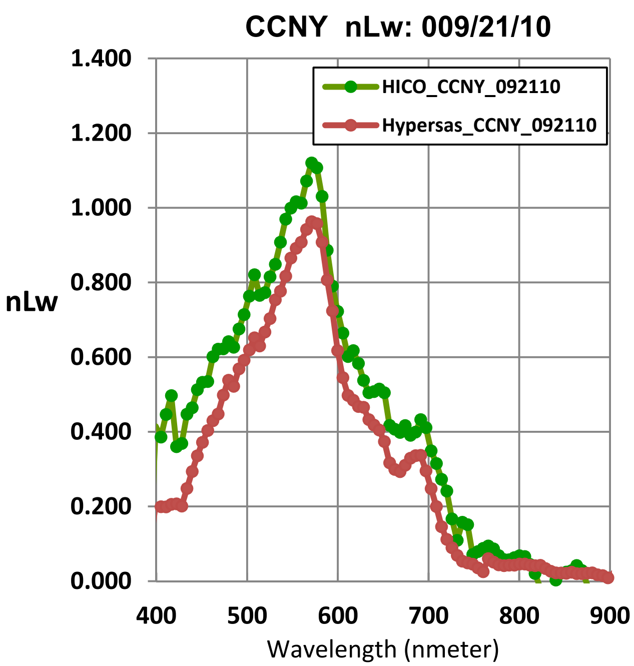


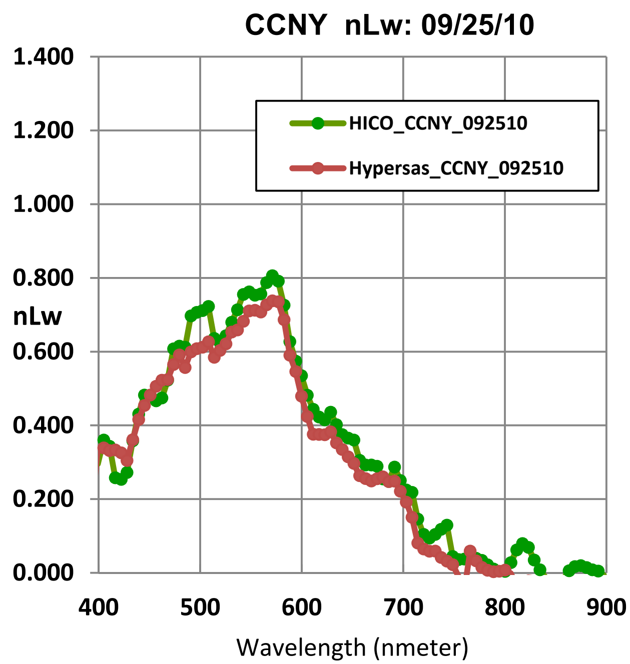


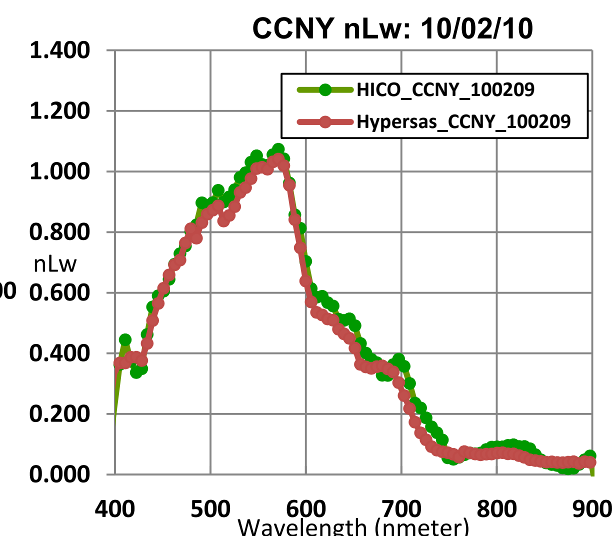


Hyperpectral Vicarious Gain Validation

- Data reprocessed with new sensor gain/offsets
- APS processed HICO spectral overlaid on in situ data for comparison







Vicarious Calibration Activity Summary

- 7 MODIS-like HICO (9 band) scenes in multispectral study
- 3 HICO scenes in hyperspectral study
- In Situ AERONET data used to compute vicarious Lt values
- Linear regression between HICO measured Lt and vicarious Lt values used to set gains and offsets
- Scenes reprocessed with new gains/offsets to determine new nLw at AERONET location
- Results unique to APS atmospheric correction inputs

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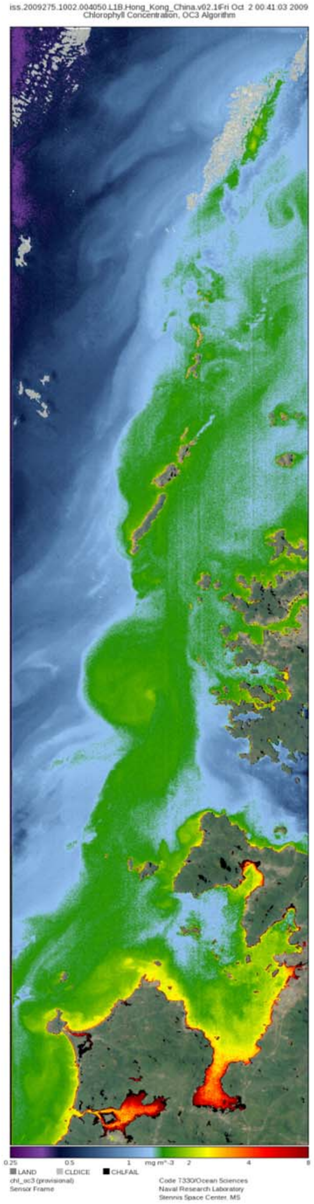
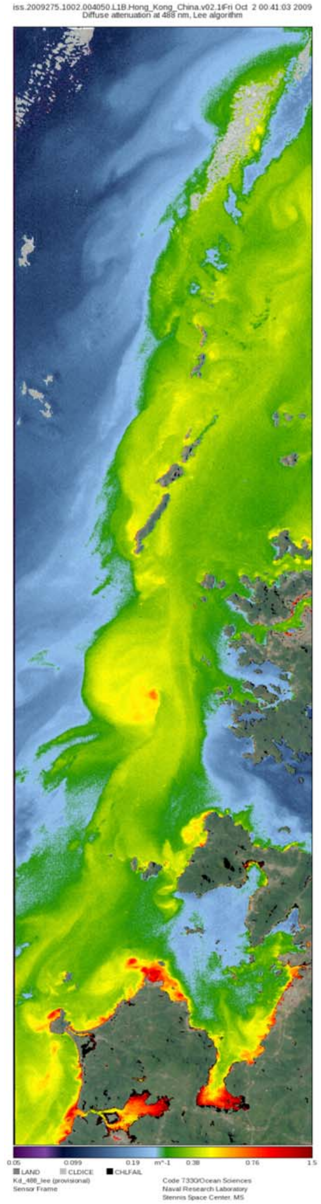
Hong Kong, 2 October 2009

True Color

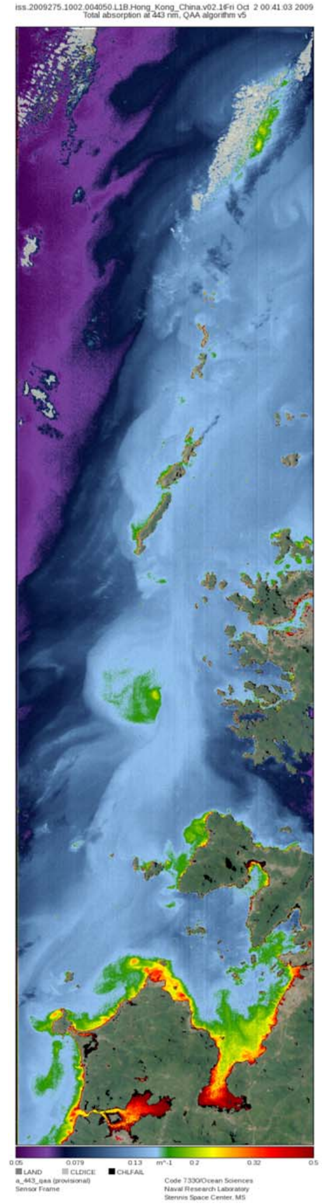
Chlorophyll (oc3)



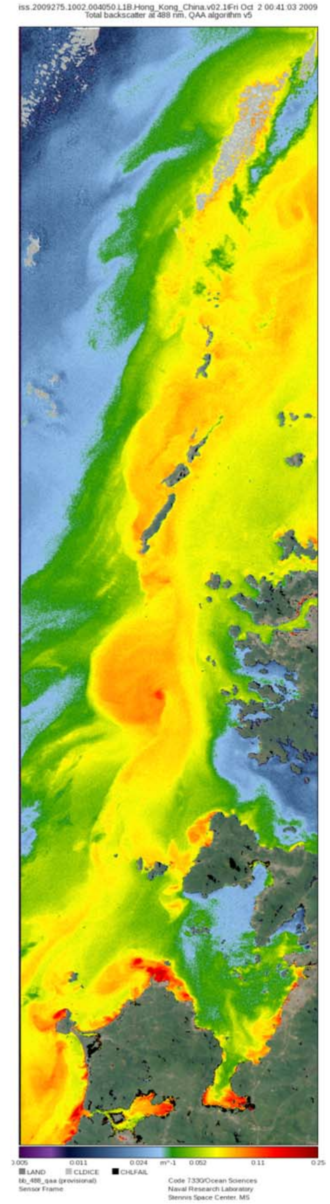
K_d (488)



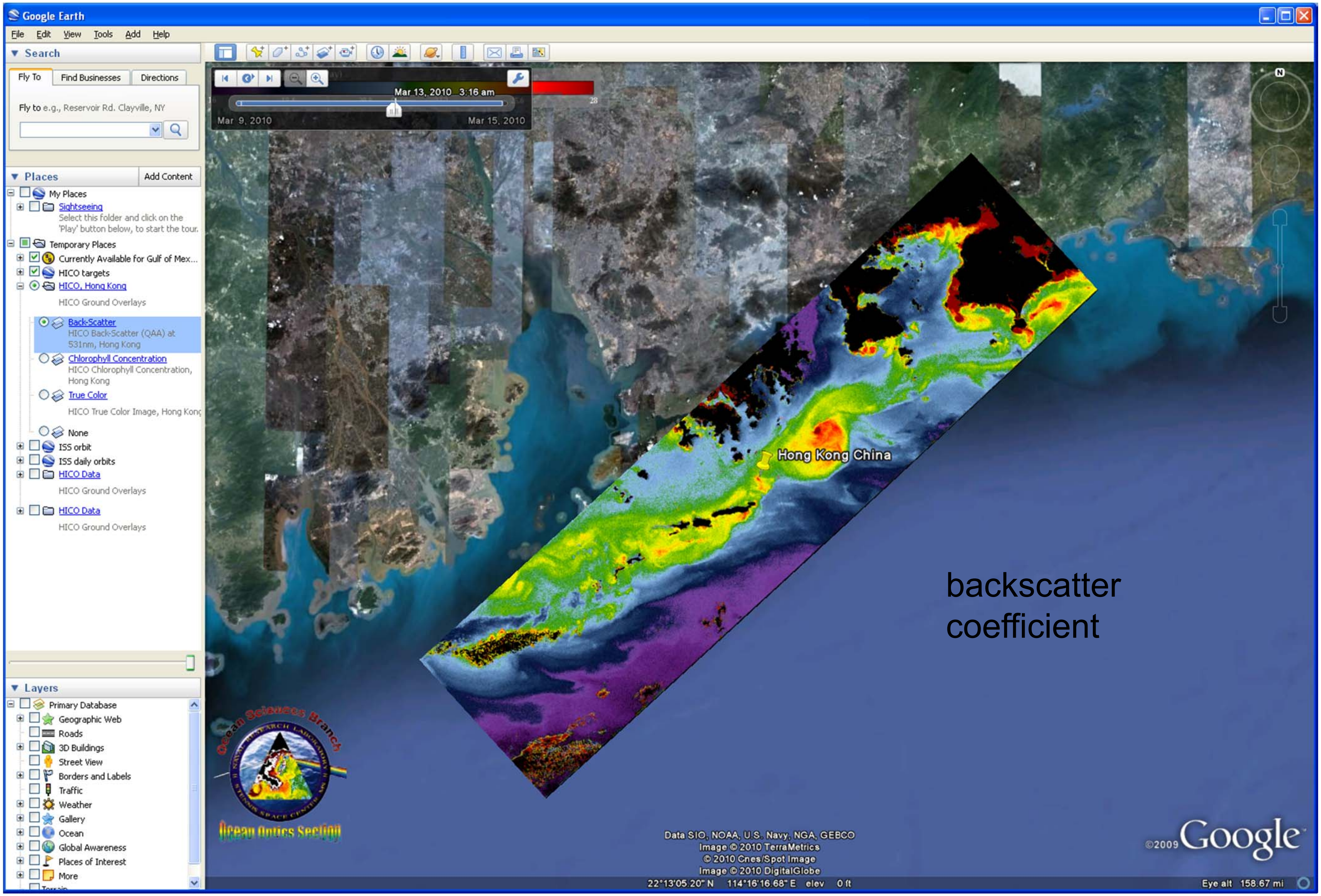
a (443)



b_b (488)



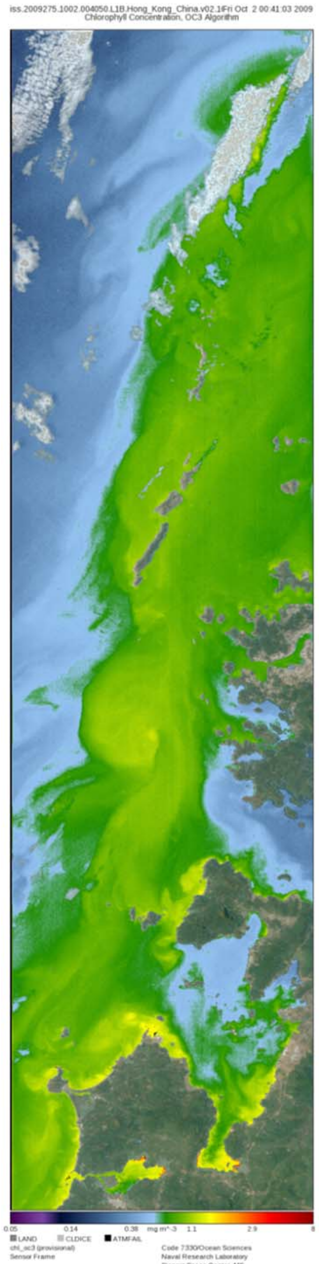
Hong Kong: 10/02/09: HICO Products over Google Earth Background



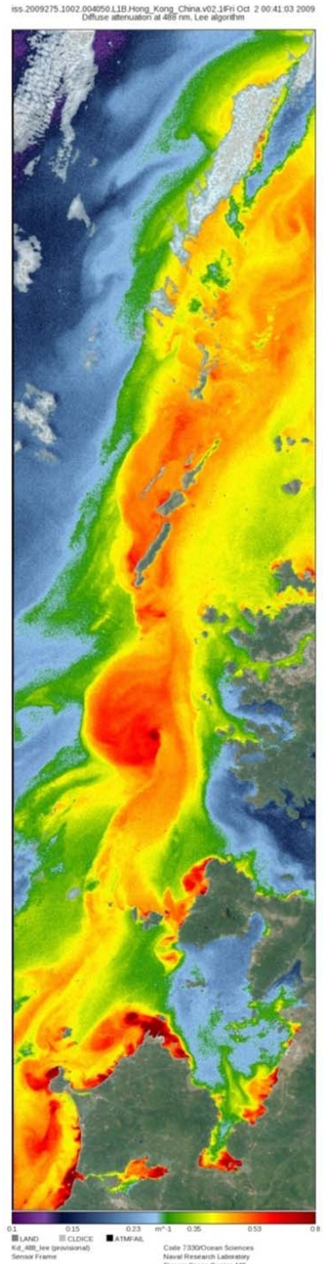
Hong Kong, 2 October 2009

True Color

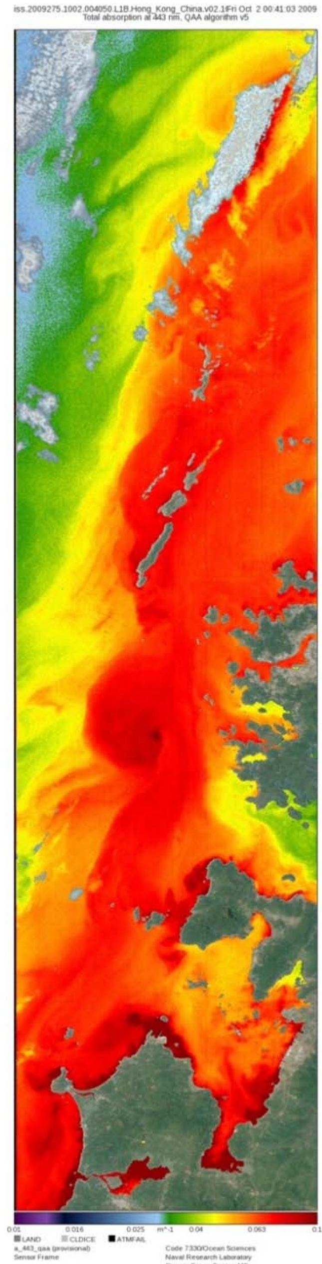
Chlorophyll (oc3)



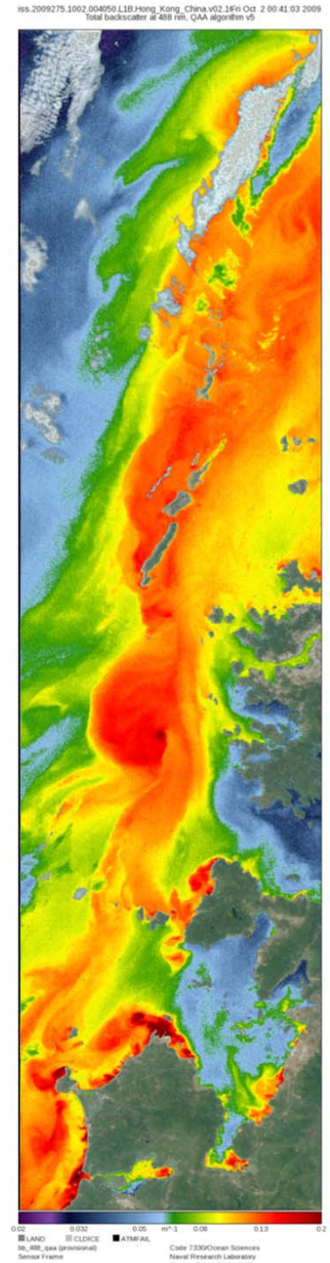
K_d (488)



a (443)



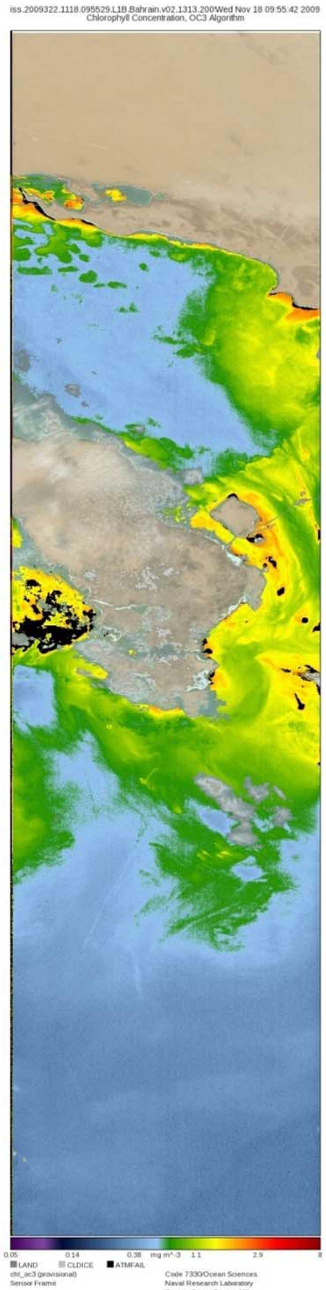
b_b (488)



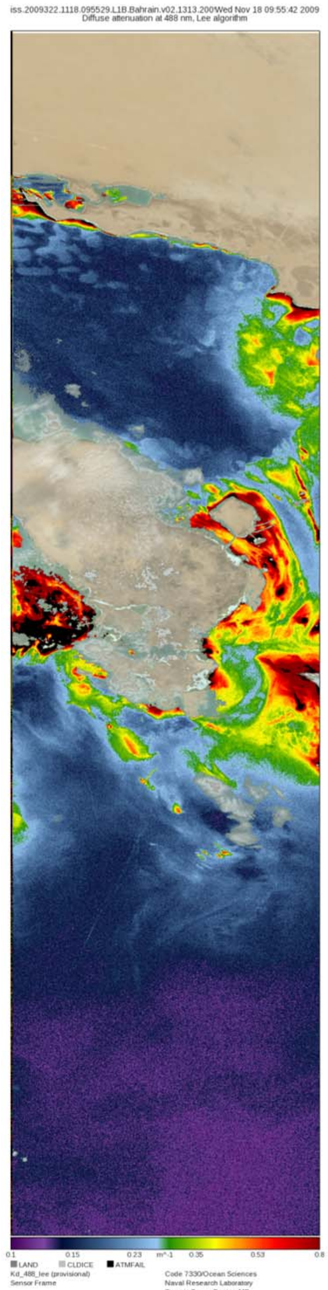
Bahrain, 18 November 2009

True Color

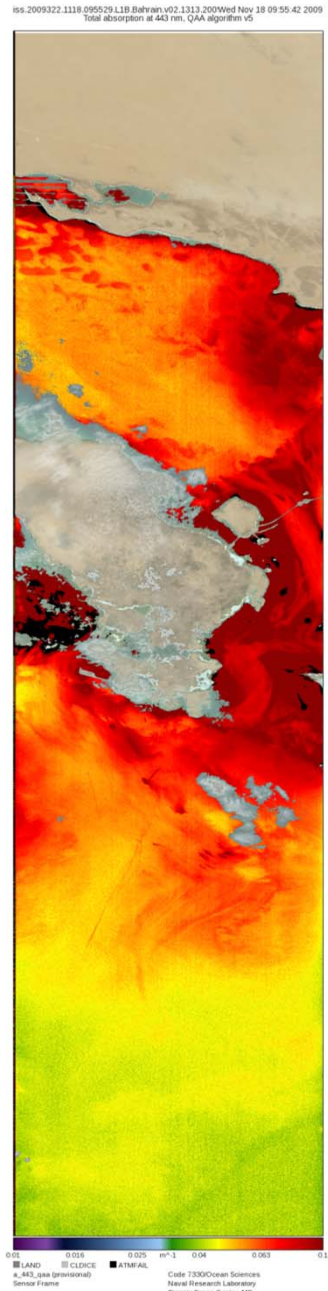
Chlorophyll (oc3)



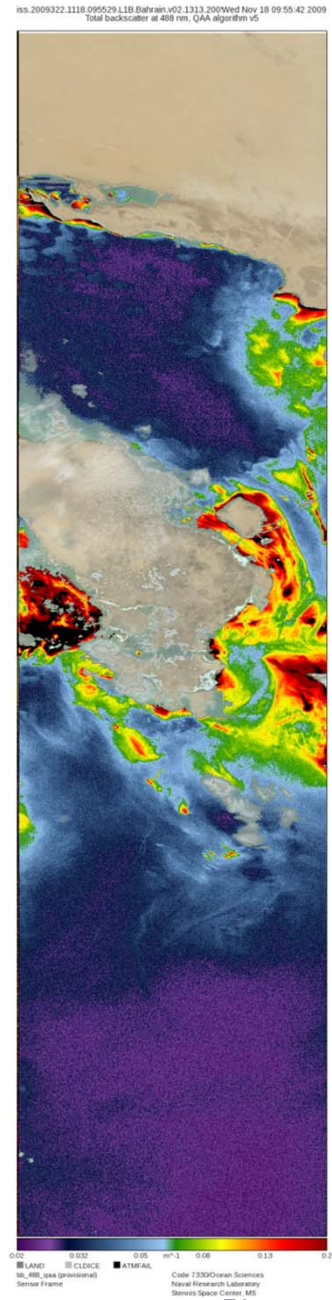
K_d (488)



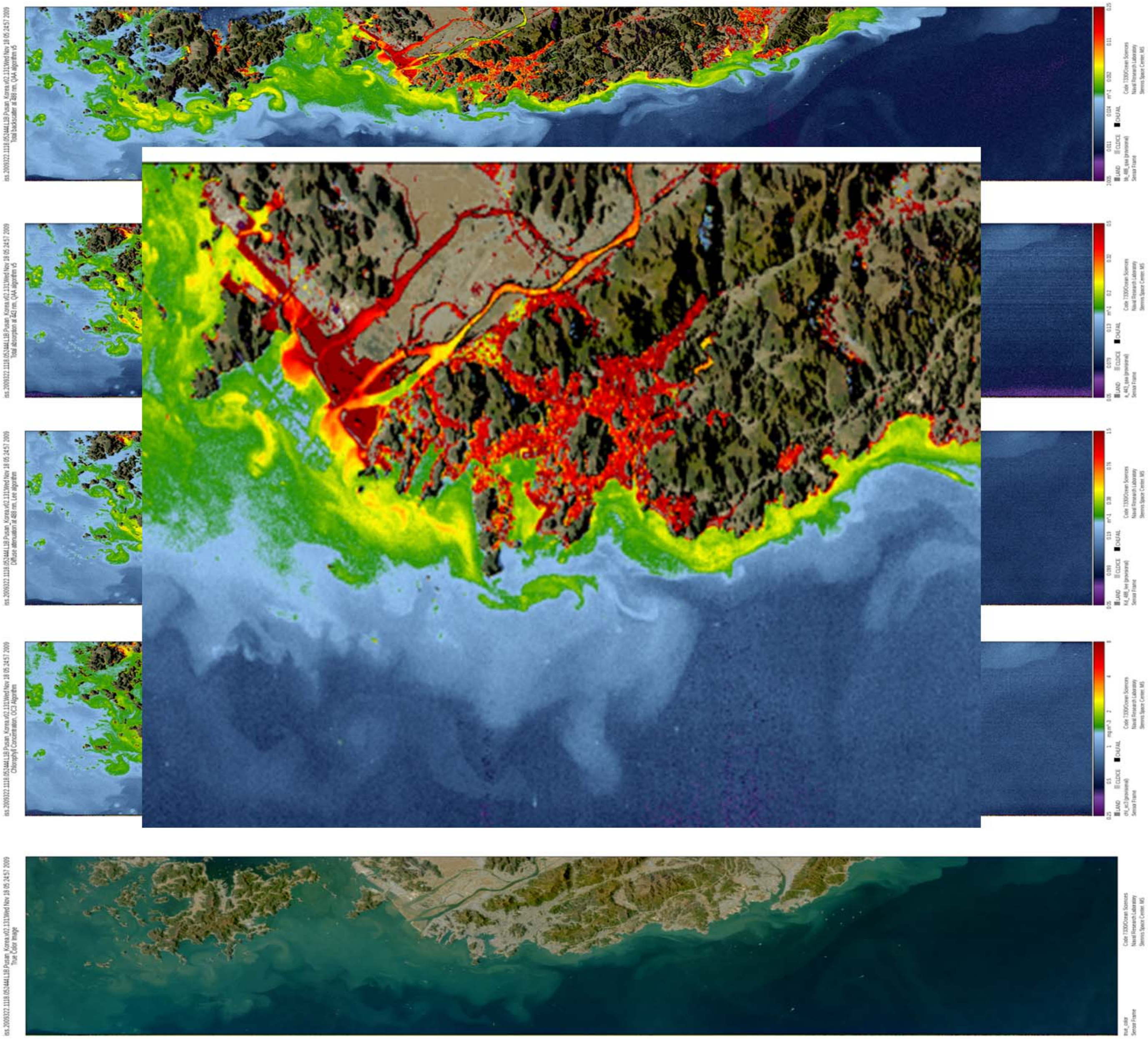
a (443)



b_b (488)



Pusan, Korea, 18 November 2009



b_b (488)

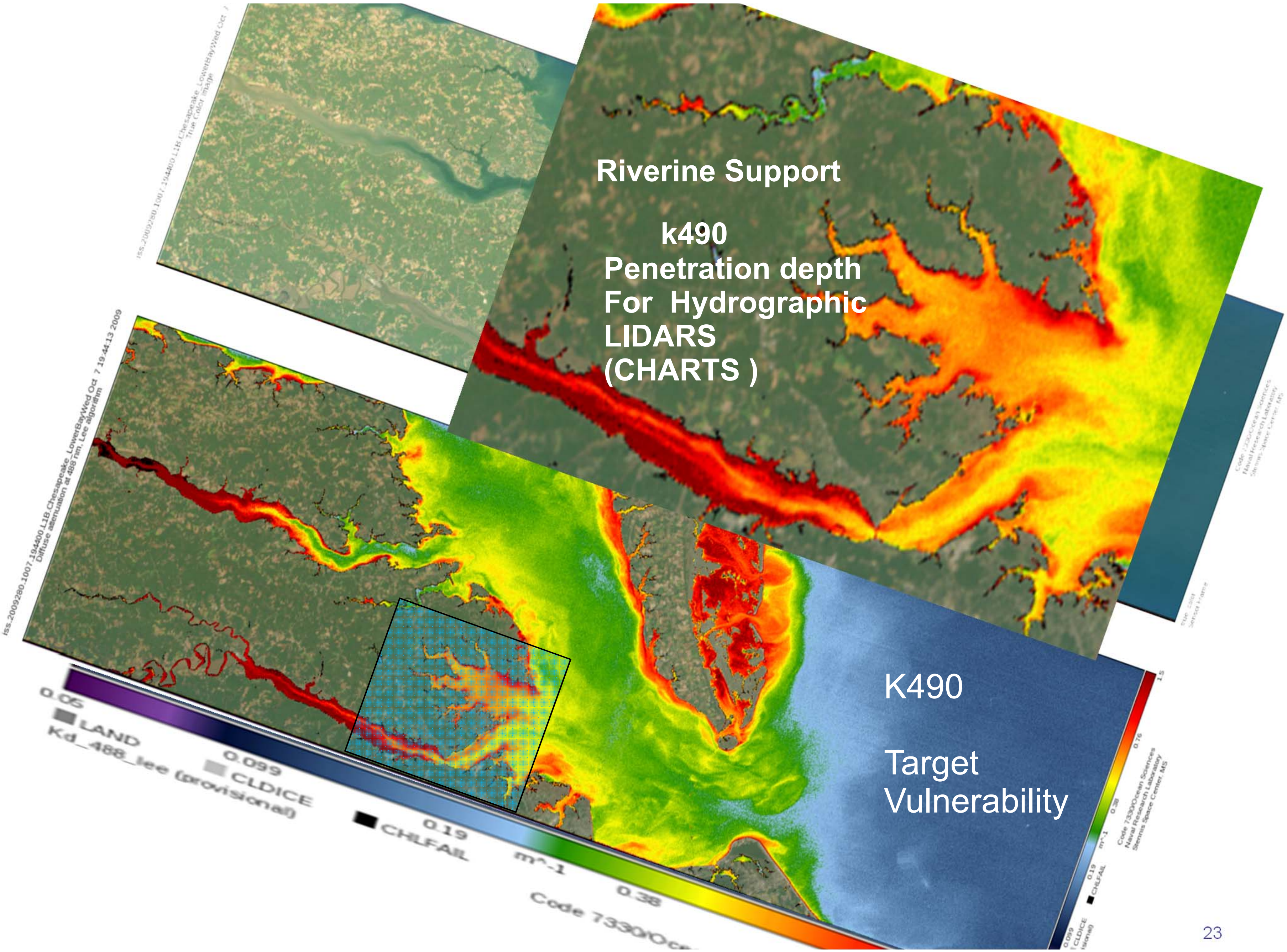
a (443)

K_d (488)

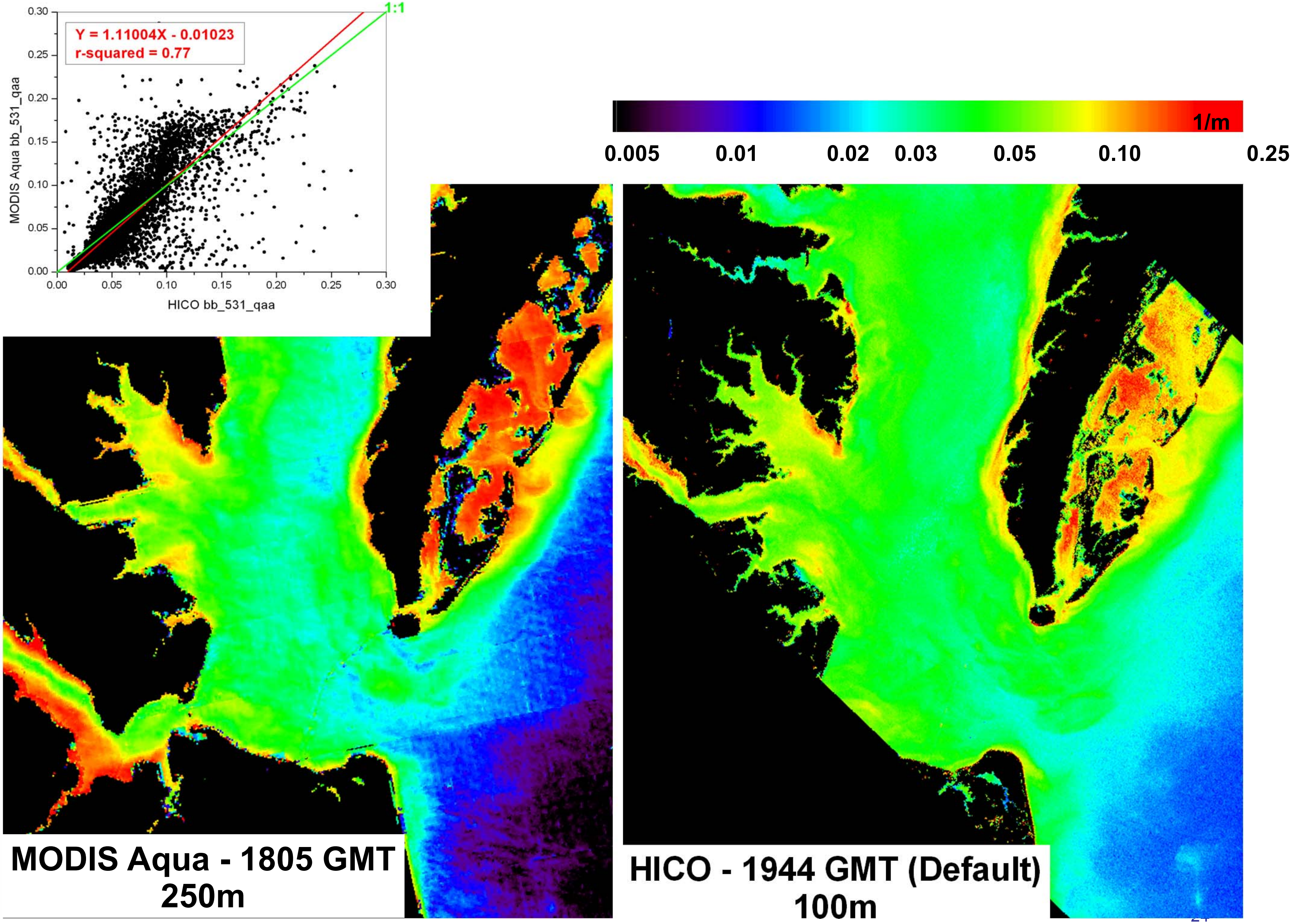
Chlorophyll (oc3)

True Color

Chesapeake Bay: 10/07/09: Diffuse Attenuation

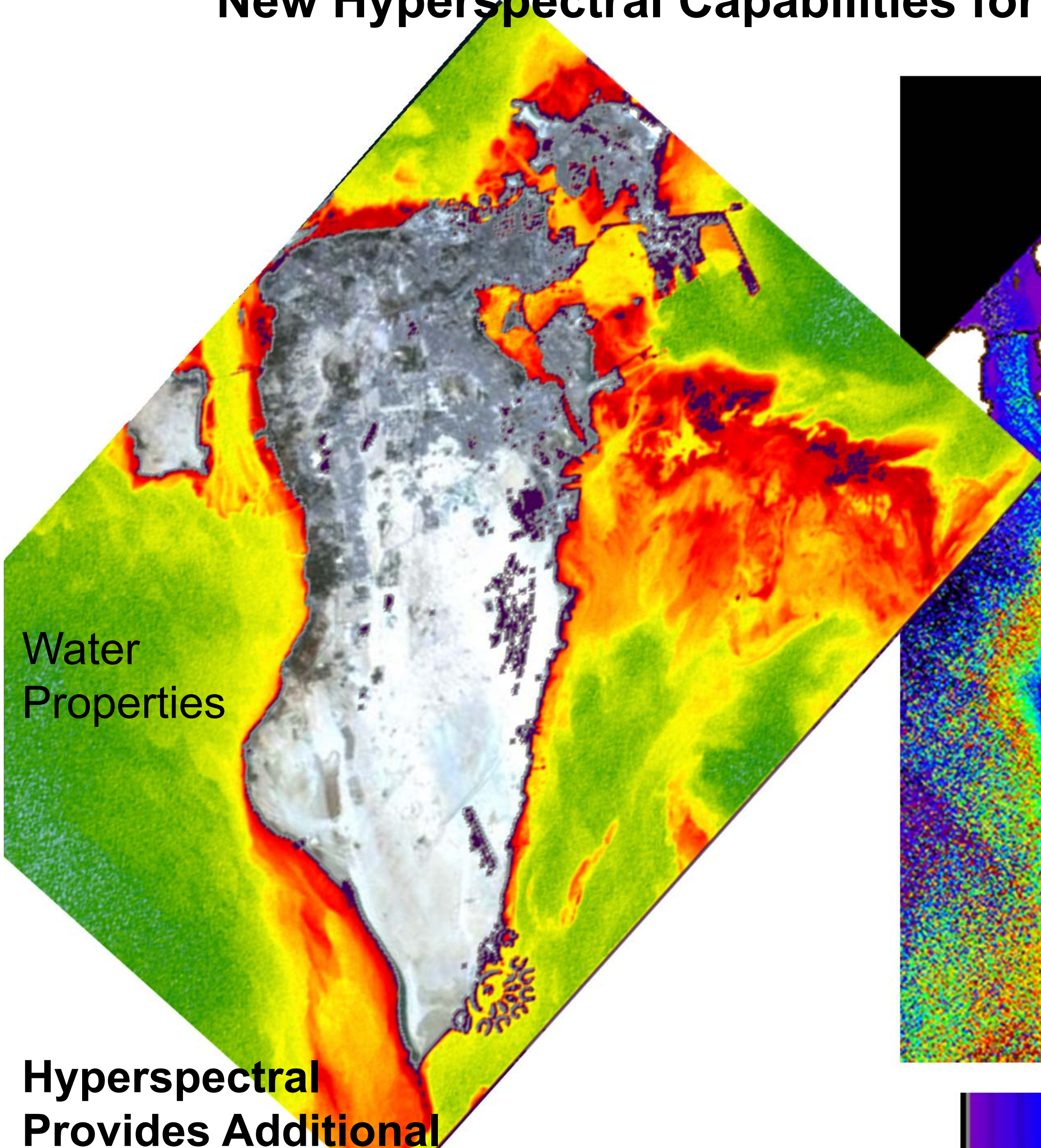


Chesapeake Bay: 10/07/09: Backscatter @ 531nm (QAA)



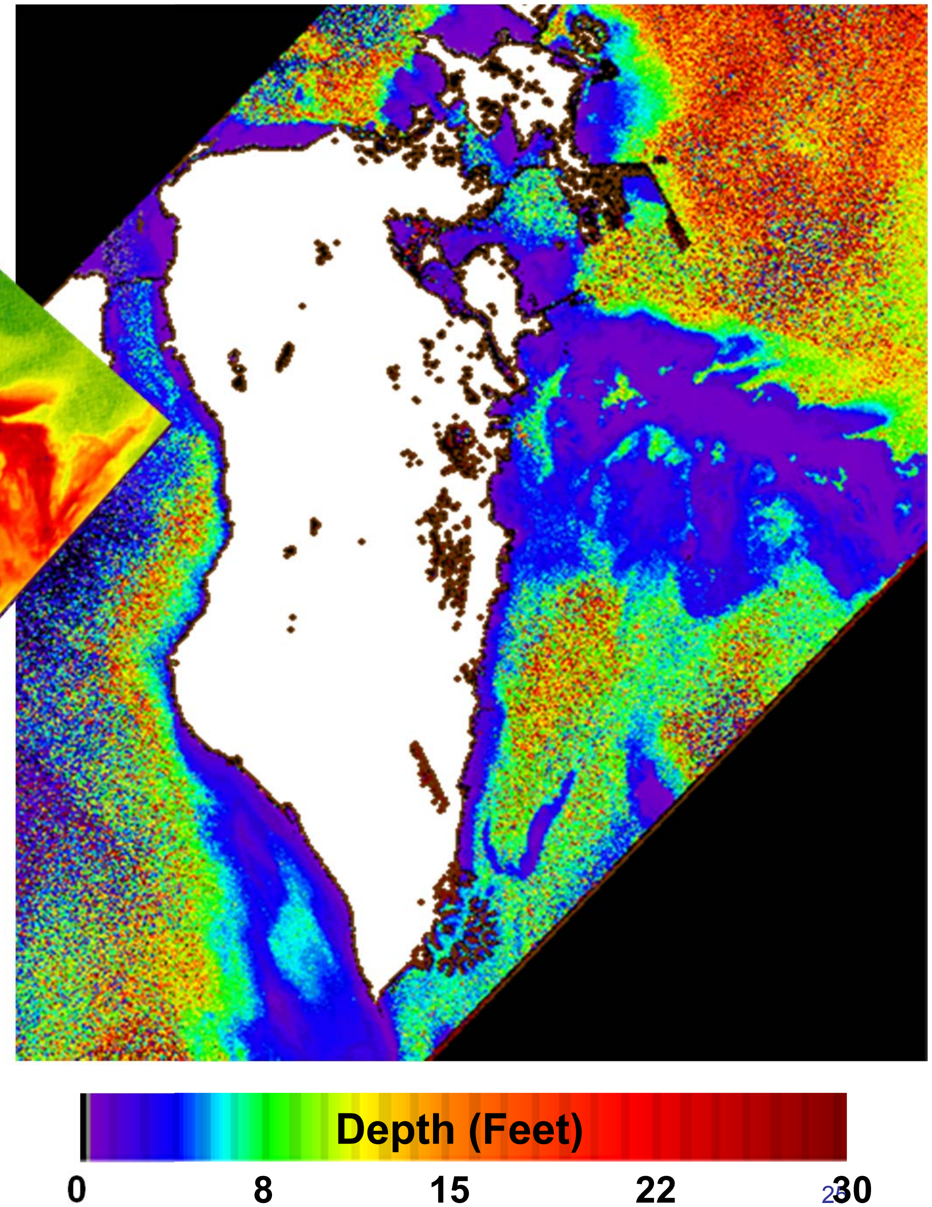
HICO Image – Bahrain 10/02/09

New Hyperspectral Capabilities for extracting bathymetry



Water
Properties

**Hyperspectral
Provides Additional
Bathymetry Capabilities**



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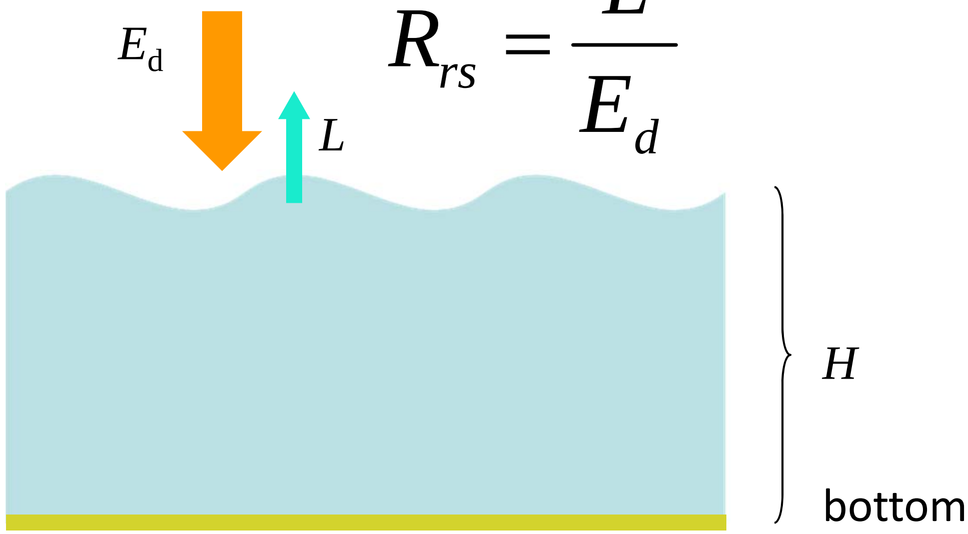
1. Some basics of HOPE

(**H**yperspectral **O**ptimization **P**rocess **E**xemplar)

$$R_{rs} = \frac{L}{E_d}$$



$$R_{rs}(\lambda) = F[\underbrace{a(\lambda), b_b(\lambda)}_{\text{Water property}}, \underbrace{\rho(\lambda), H}_{\text{bottom property}}]$$

Water property

bottom property

HOPE Algorithm

$$R_{rs}(\lambda) = F[a(\lambda), b_b(\lambda), \rho(\lambda), H]$$

Explicit Analytical Function

for water column — for bottom

$$r_{rs} \approx r_{rs}^{dp}\left[1 - e^{-\left(D_0 + 1.03(1+2.4u)^{0.5}\right)kH}\right] + \frac{\rho}{\pi} e^{-\left(D_0 + 1.04(1+5.4u)^{0.5}\right)kH}$$

$$u = bb/(a + bb), \quad k = a + bb$$

$D_0 \approx 1/\cos(\theta_{sun})$

a: a_w – pure water
a_ϕ – phytoplankton pigments
a_g – gelbstoff/detritus

b_b: b_{bw} – pure water/molecules
b_{bp} – particles

(*Lee et al* 1998, 1999, from Hydrolight runs)

HOPE Algorithm

<u>Have to</u> know the spectrum shapes for analytical derivation!

<u>Global</u> default parameterization:

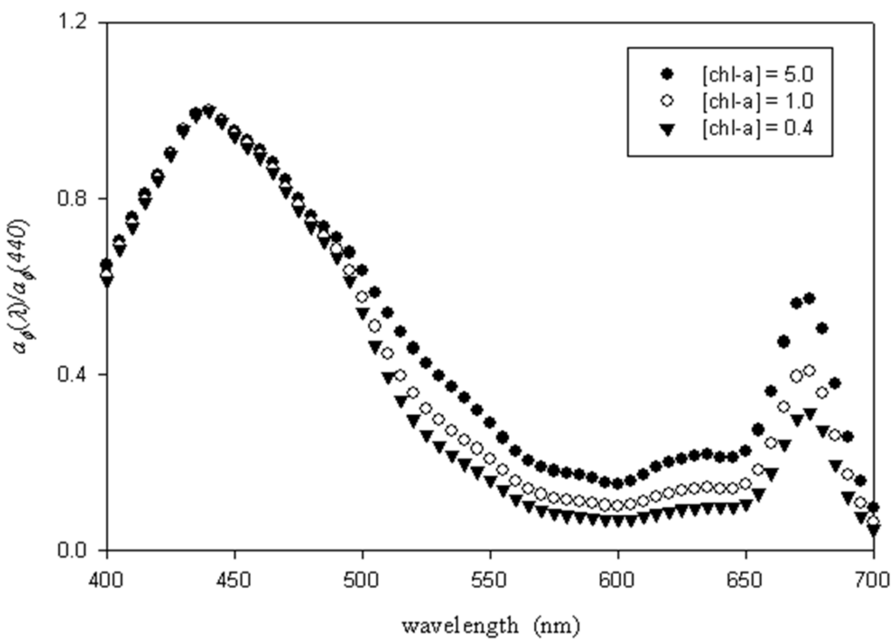
(no access to local information, e.g. Iran, North Korea)

1. Pigment absorption spectrum

$$a_\phi(\lambda) = \left(a_0(\lambda) + a_1(\lambda)\ln(\boldsymbol{P})\right)\boldsymbol{P}$$

$P = a_\phi(440)$

$a_0(\lambda)$ and $a_1(\lambda)$ values are available (*Lee* 1994)



Examples of $a_\phi(\lambda)$ simulation.

HOPE Algorithm

Global default parameterization (cont.):

2. CDOM absorption spectrum

$$a_g(\lambda) = \boldsymbol{G}\, e^{-0.015(\lambda - 440)}$$

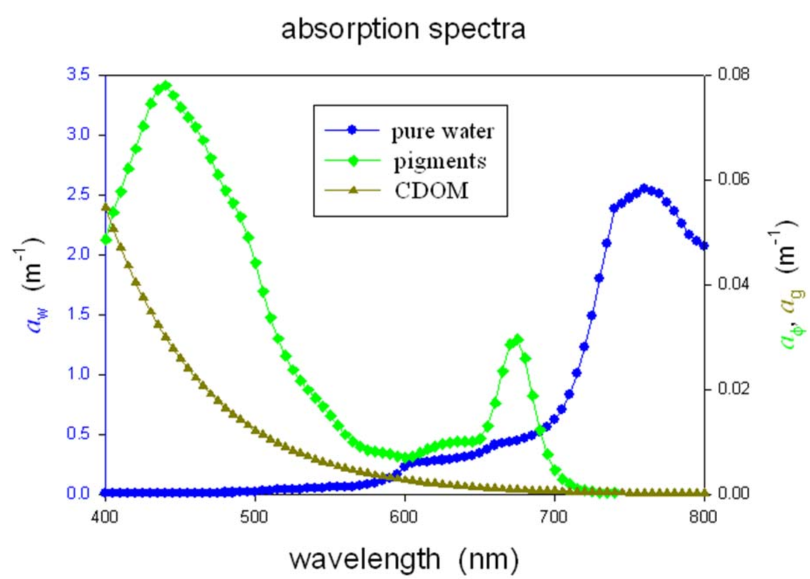
$G = a_g(440)$

3. Particle backscattering spectrum

$$b_{bp}(\lambda) = \boldsymbol{X}\left(\frac{555}{\lambda}\right)^{Y}$$

$X = b_{bp}(555)$

$$Y \approx 2.2\left(1 - 1.2\, e^{-0.9\frac{r_{rs440}}{r_{rs555}}}\right)$$



HOPE Algorithm

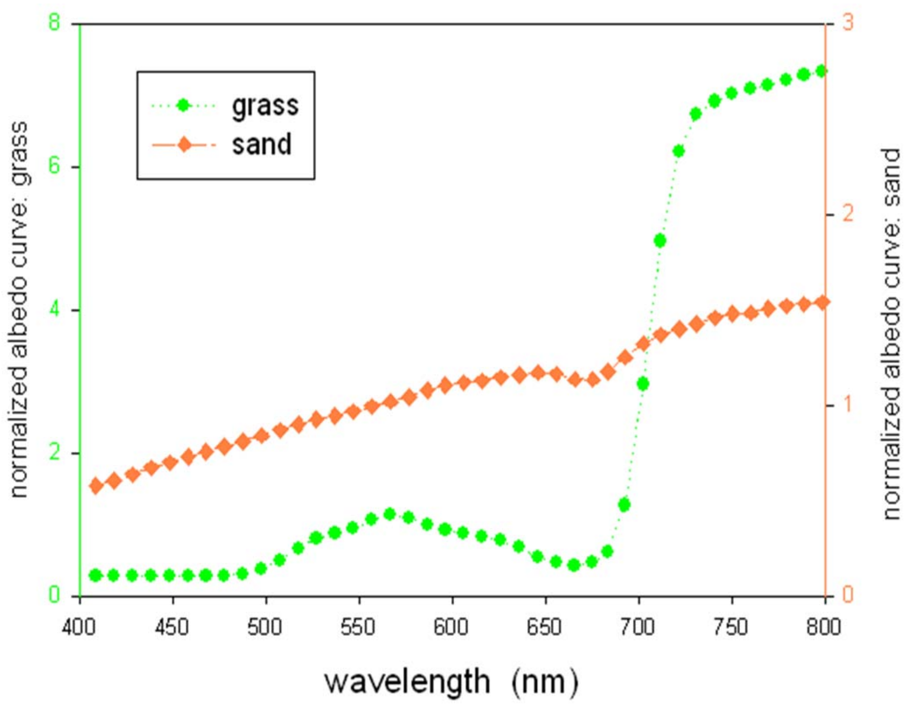
Global default parameterization (cont.):

4. Bottom reflectance spectrum

$$\rho(\lambda) = B * \rho^{+}_{bott}(\lambda)$$

$B = \rho(550)$

$\rho^{+}_{bott}(\lambda) = \rho(\lambda)/\rho(550)$, spectral curvature of bottom reflectance



<u>Selection criterion</u>:

If Rrs(550) < 0.01 sr^{-1}
<u>and</u> Rrs(710)/Rrs(670) > 1.2,
Grass bottom is assumed;

Otherwise, sandy bottom is assumed.

(Less computation time; less ambiguity)

HOPE Algorithm

$$R_{rs}(\lambda) = F(P, G, X, B, H)$$

Or

$$R_{rs}(\lambda_1) = F(P, G, X, B, H)$$

$$R_{rs}(\lambda_2) = F(P, G, X, B, H)$$

.

.

$$R_{rs}(\lambda_n) = F(P, G, X, B, H)$$

5 unknowns for each $R_{rs}(\lambda)$ spectrum!

HOPE Algorithm

Error function:

$$err = \frac{\left[\sum_{400}^{675}\left(R_{rs} - \hat{R}_{rs}\right)^2 + \sum_{750}^{800}\left(R_{rs} - \hat{R}_{rs}\right)^2\right]^{0.5}}{\sum_{400}^{675}\hat{R}_{rs} + \sum_{750}^{800}\hat{R}_{rs}} = f(P, G, X, B, H)$$

P, G, X, B and *H* are derived when *err* reaches a minimum (HOPE).

Initial values for HOPE:

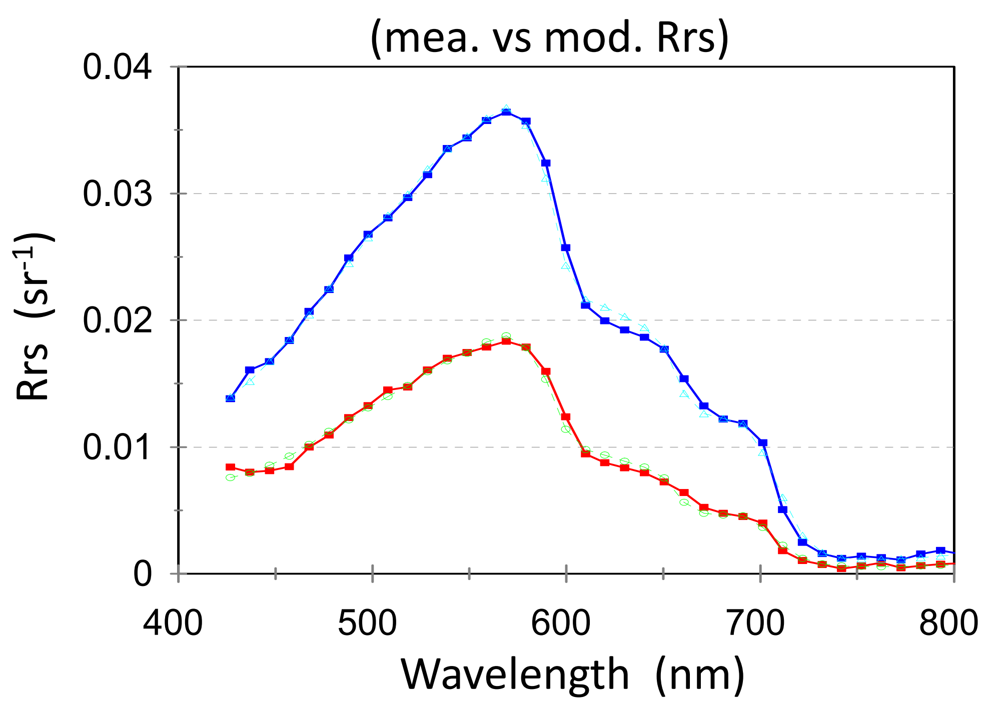
$P = 0.05\,(Rrs(443)/Rrs(555))^{-1.7}$

$G = 1.5\,P$

$X = 8\,Rrs(660)$

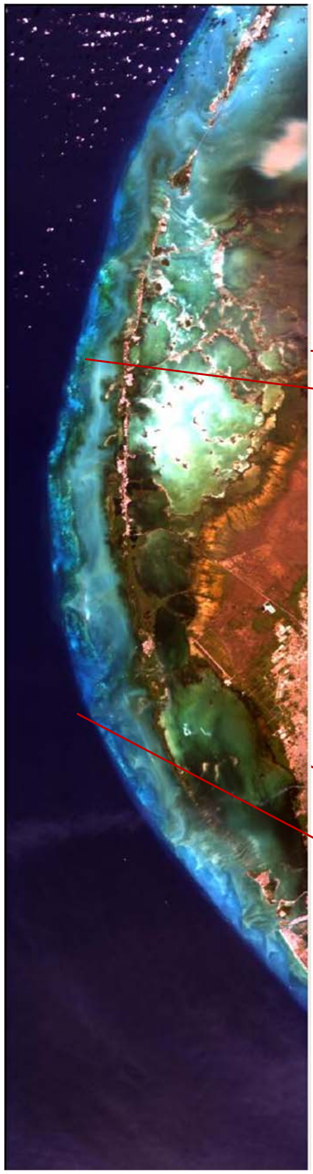
$B = 4\,Rrs(490)$

$H = 1/(6.5\,P)$

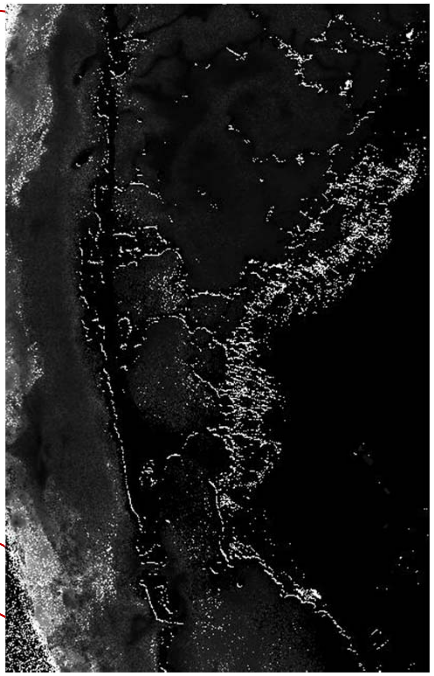


Key Largo HOPE Bathymetry Estimation using HICO

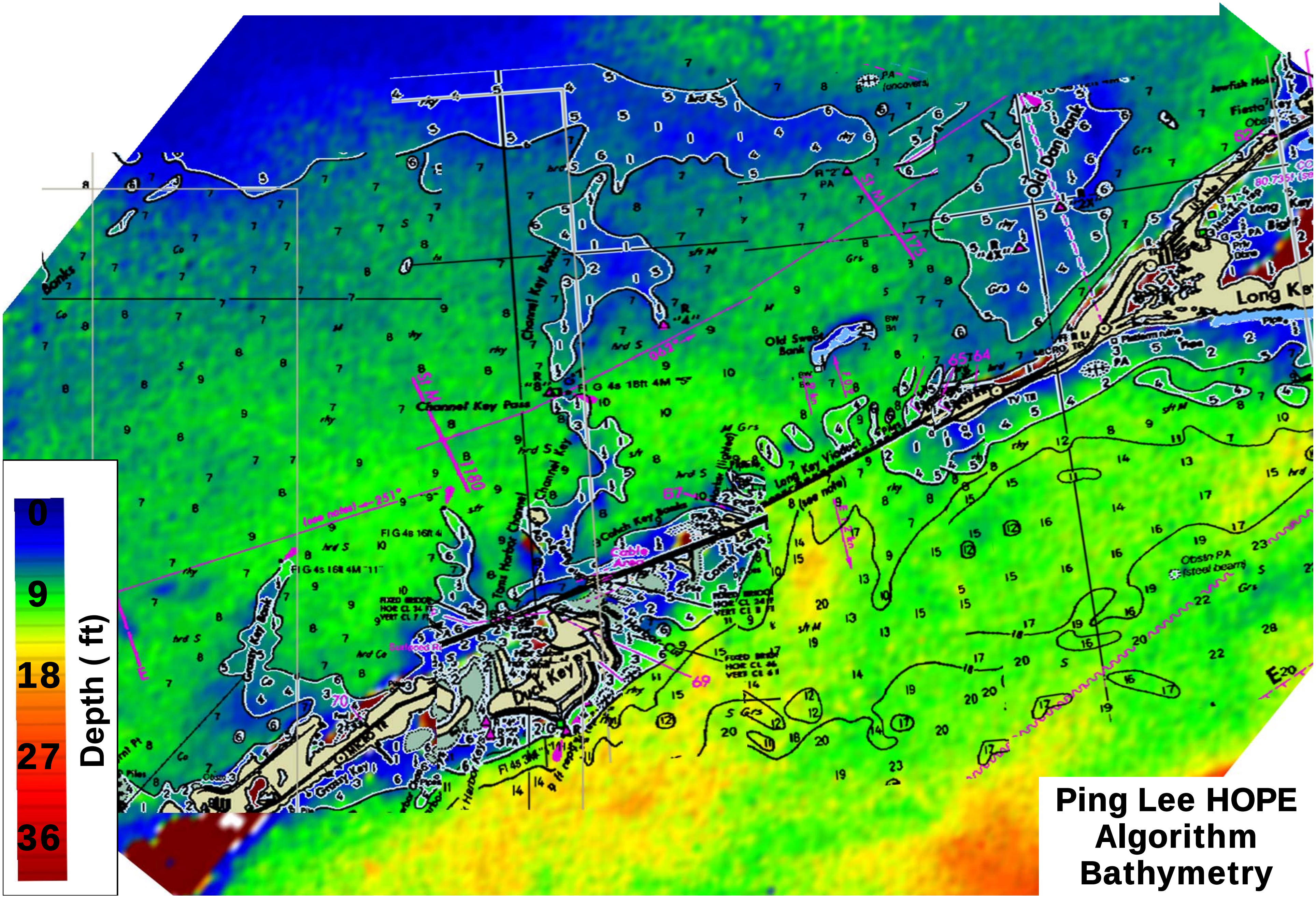
Key Largo 11/13/2009



Bathymetry Estimates from HOPE Algorithm



HICO Image - Key Largo, Florida: 11/13/09



Ping Lee HOPE Algorithm Bathymetry

Summary

- MODIS-Like (multispectral) data set is convolved from MODIS SRF and full hyperspectral HICO data set
- APS has been modified to process multispectral and hyperspectral HICO data
- Vicarious Calibration activity is being explored to refine Level 1B data to APS atmospheric correction method
- APS processed HICO data when received at NRL-SSC
- HICO APS has been processed through HOPE algorithm for parameters including bathymetry