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Ride on the Geospatial Revolution

ASPRS 2011 Annual Conference
Milwaukee, Wisconsin, May 1- 5

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Coastal Applications of WorldView-2 High Resolution Multi-Spectral Imagery

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F. Pacifici, C. Padwick

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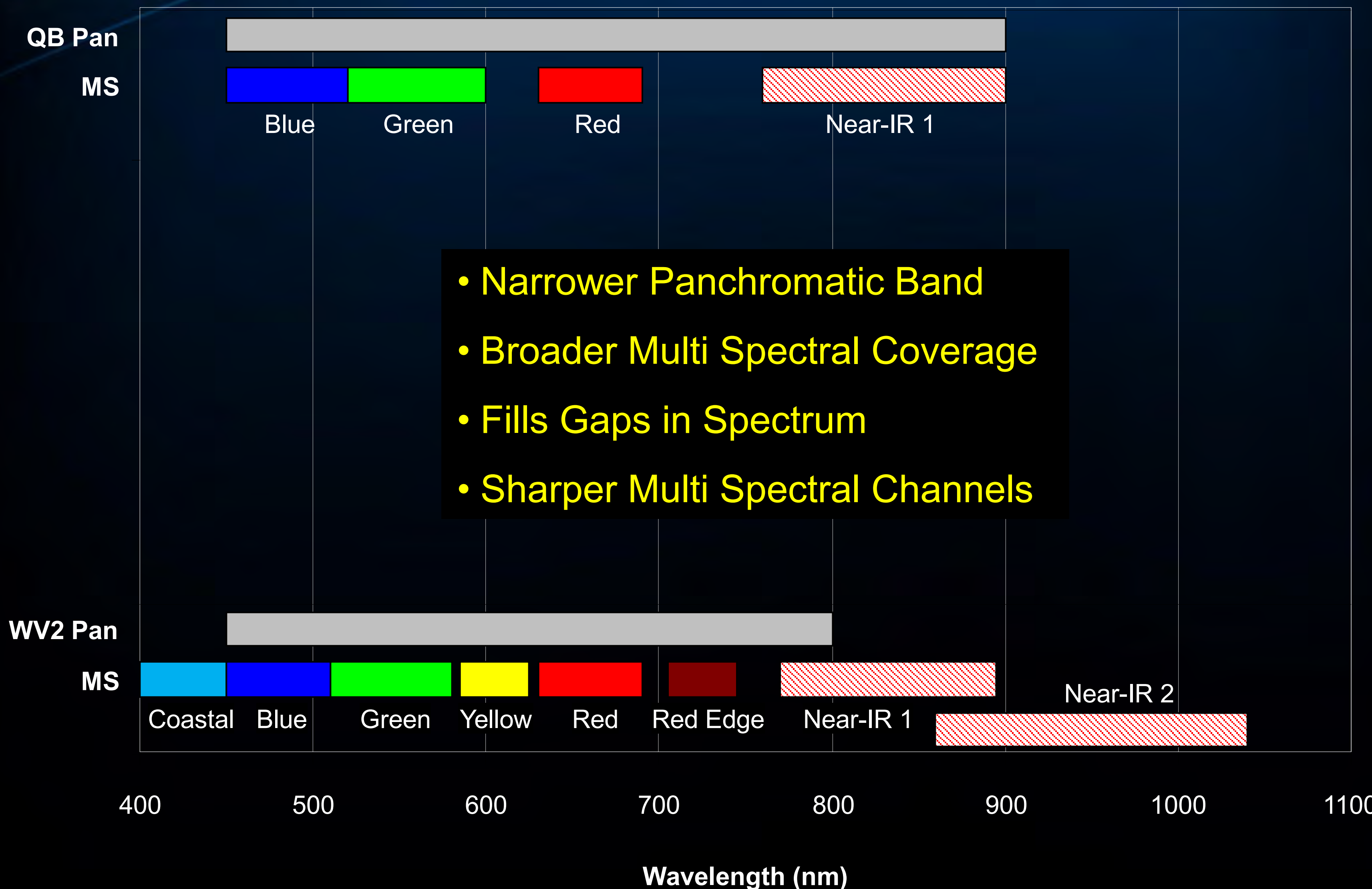
Overview

- Information content of WV-2 bands, as applicable to bathymetric retrievals
  - Spectral characterization of WV-2 MS bands
  - Qualitative assessment of WV-2 MS bands
- More that one approach to optical bathymetry
  - Machine learning approach (mono imagery)
  - Rigorous radiative-transfer modeling combined with Bayesian error estimation (mono imagery)
  - Photogrammetric techniques (stereo imagery)
- Will answer the following questions:
  - How accurate?
  - How deep?
  - Which bands?
  - What about sea floor reflectivity?
- Conclusions

Spectral Response Comparison with Quickbird



Information content in shallow water imagery

- The following sequences of slides illustrate qualitatively how the combination of:
  - » Broader spectral coverage
  - » Continuous spectral coverage
  - » Sharper spectral channels

available in WorldView-2 provide a finer level of spectral penetration than is otherwise achievable with traditional VNIR sensors

- We show this progressive transition at different locations

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WorldView-2 First Images

4 band 2m Image

November 23, 2009

Aitutaki Lagoon

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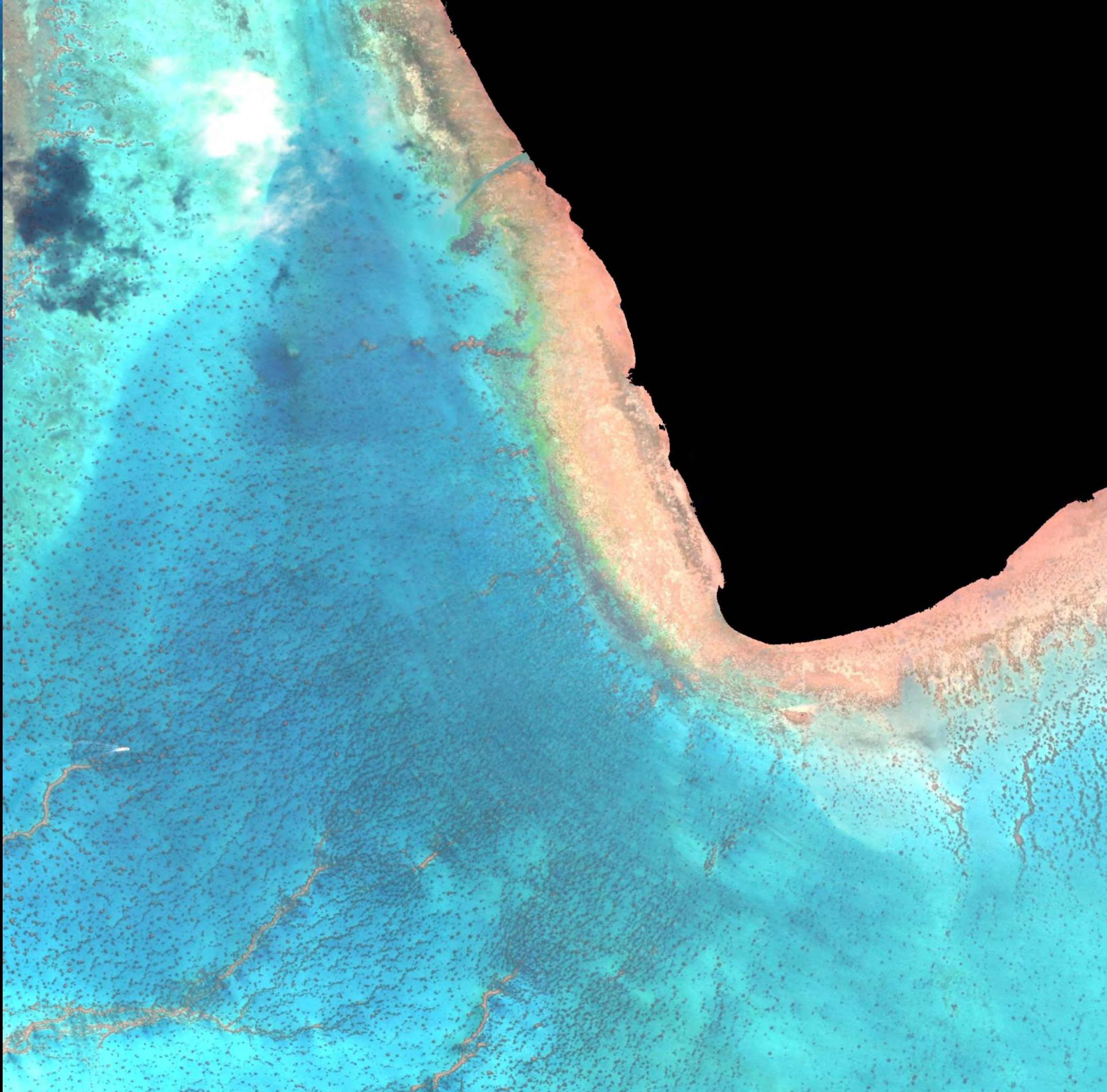
WorldView-2 First Images

4 band 2m Image

November 23, 2009

Aitutaki Lagoon



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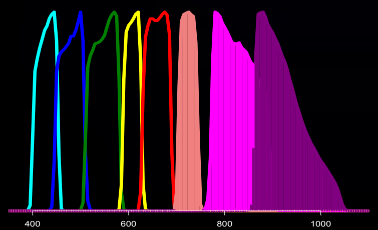
WorldView-2 First Images

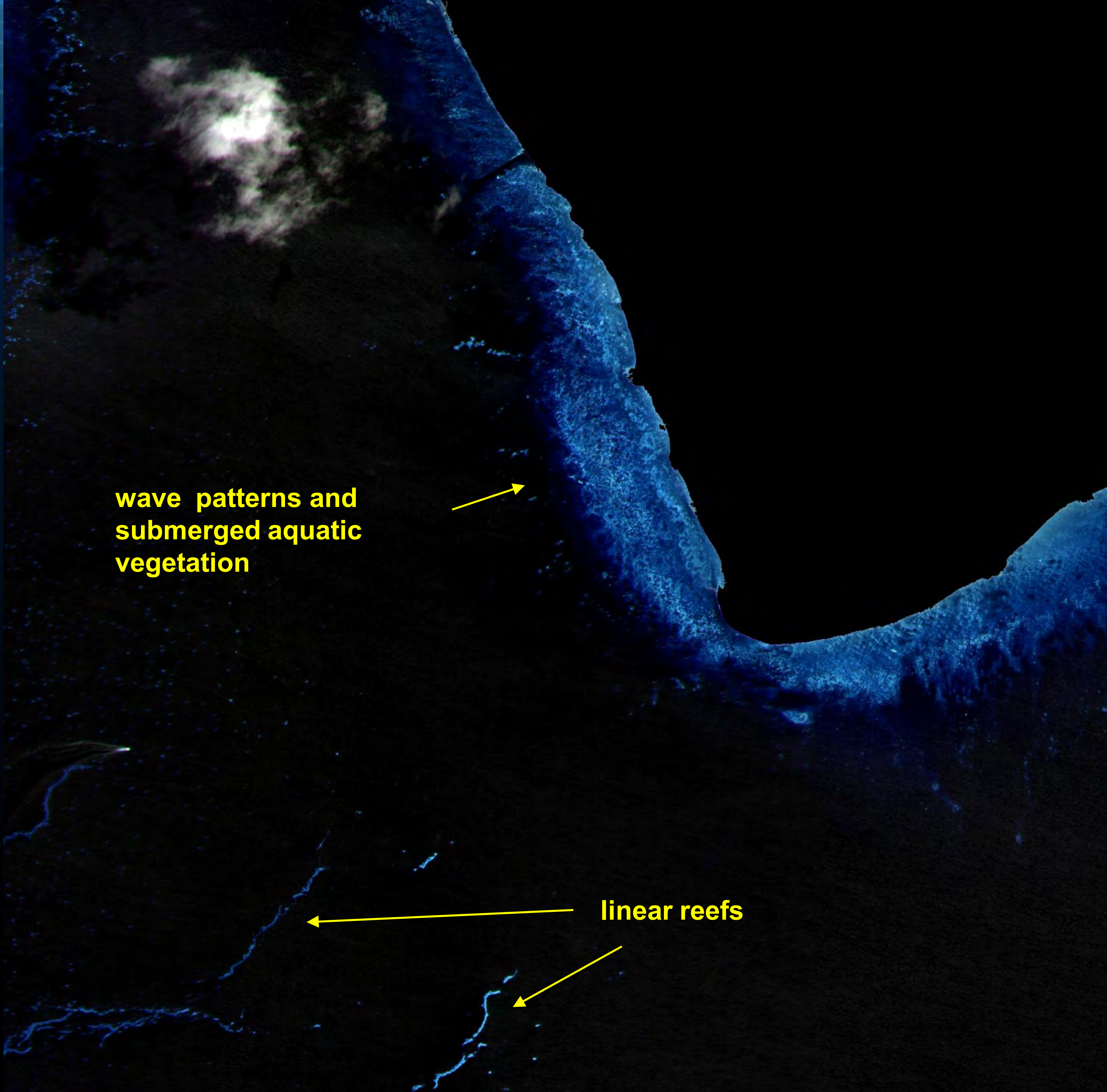
RE, NIR1, NIR2

2m Image

November 23, 2009

Aitutaki Lagoon





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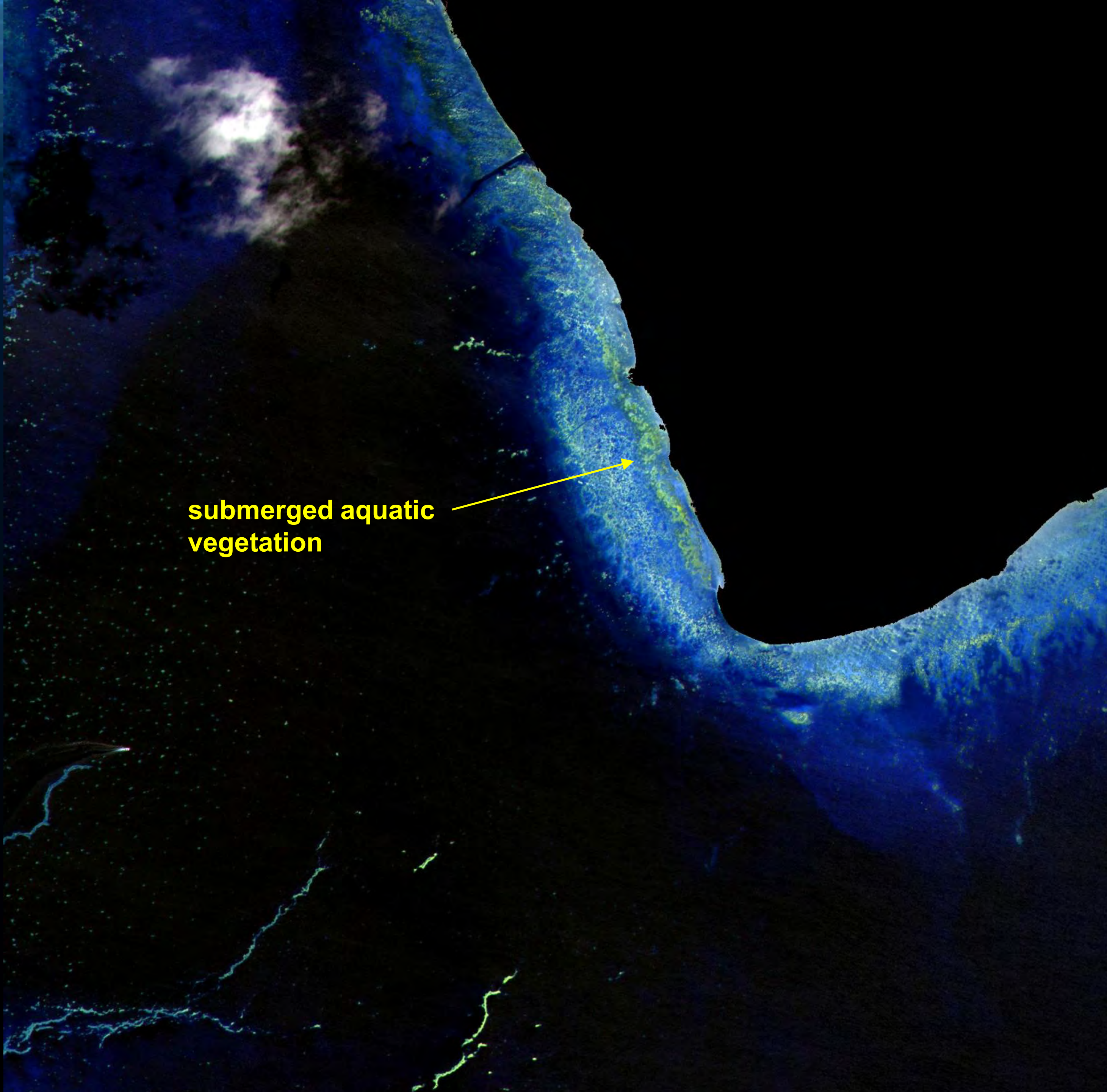
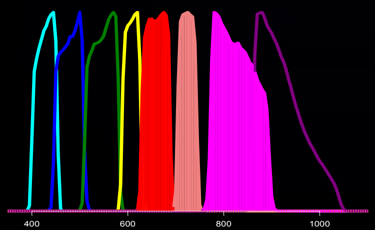
WorldView-2
First Images
R, RE, NIR1
2m Image
November 23, 2009

Aitutaki Lagoon





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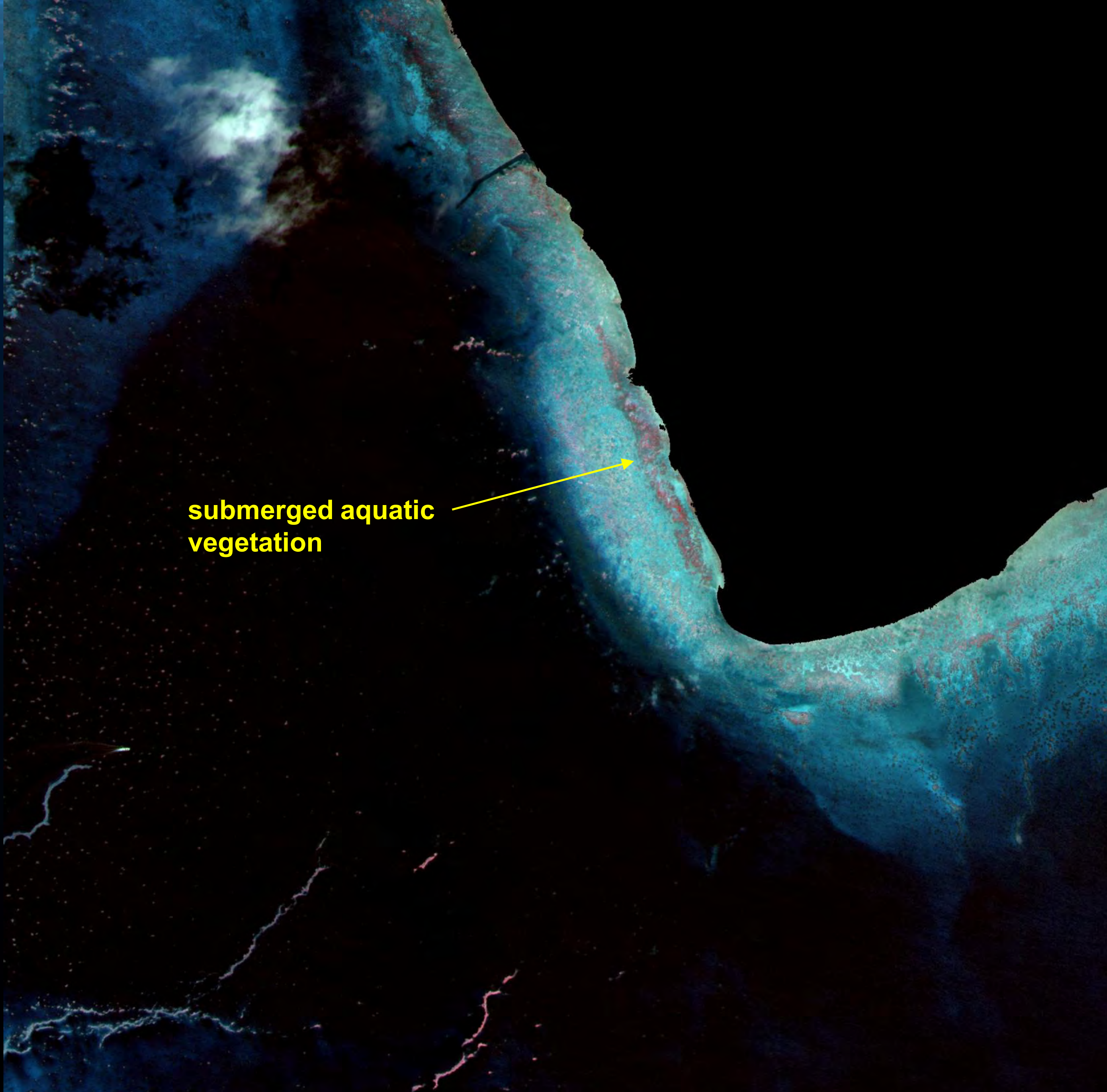
WorldView-2 First Images

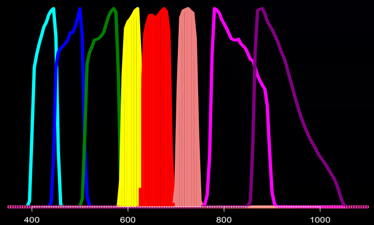
Y, R, RE

2m Image

November 23, 2009

Aitutaki Lagoon





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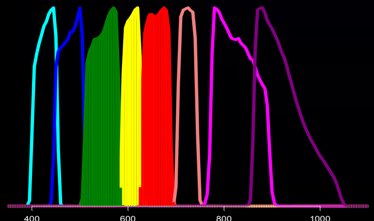
WorldView-2 First Images

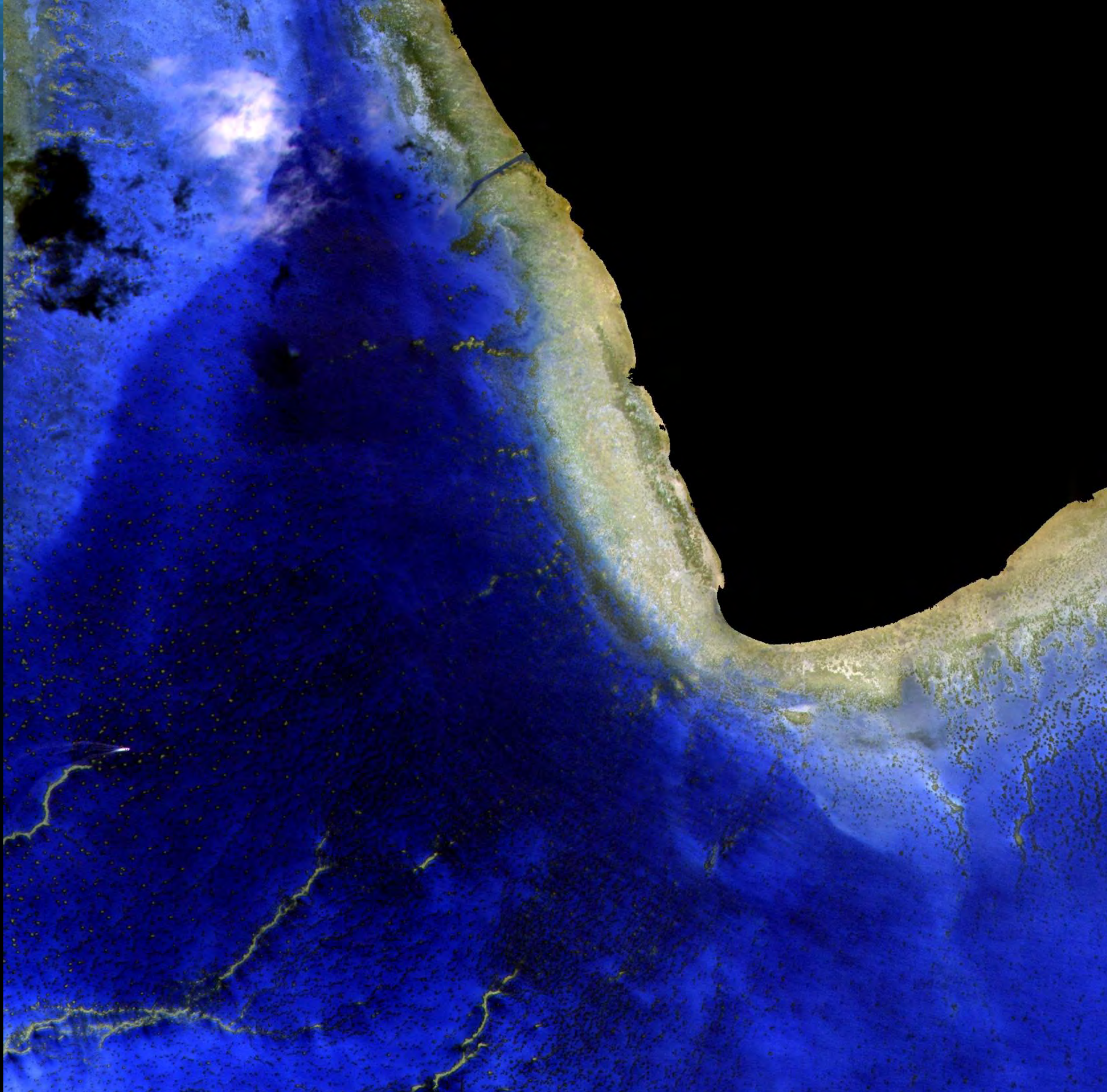
G, Y, R

2m Image

November 23, 2009

Aitutaki Lagoon





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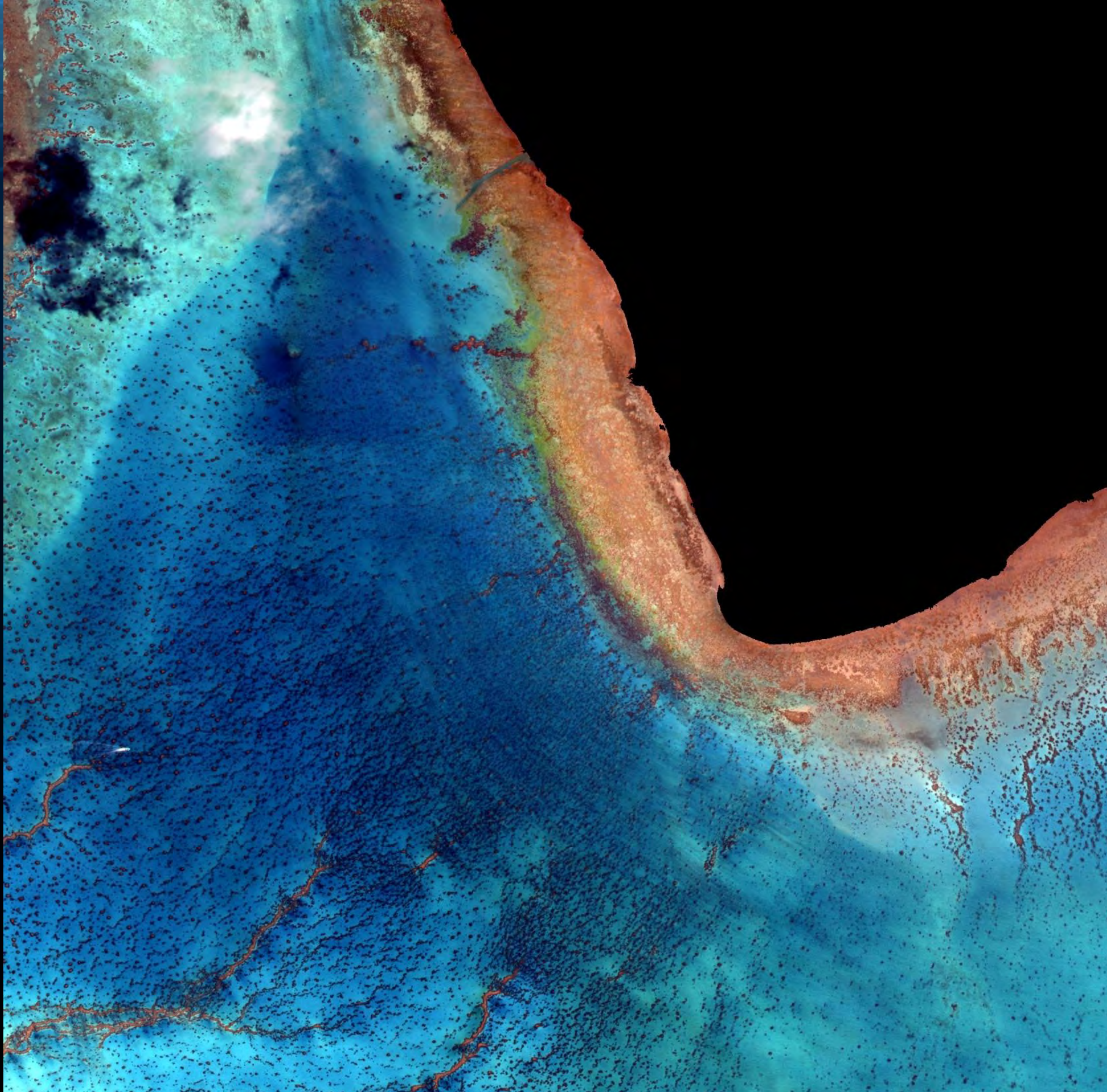
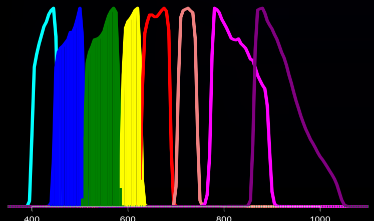
WorldView-2
First Images
B, G, Y
2m Image
November 23, 2009

Aitutaki Lagoon





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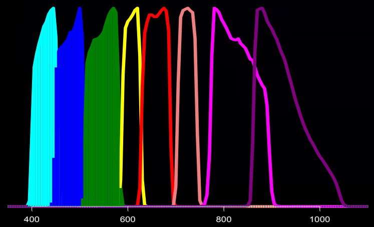
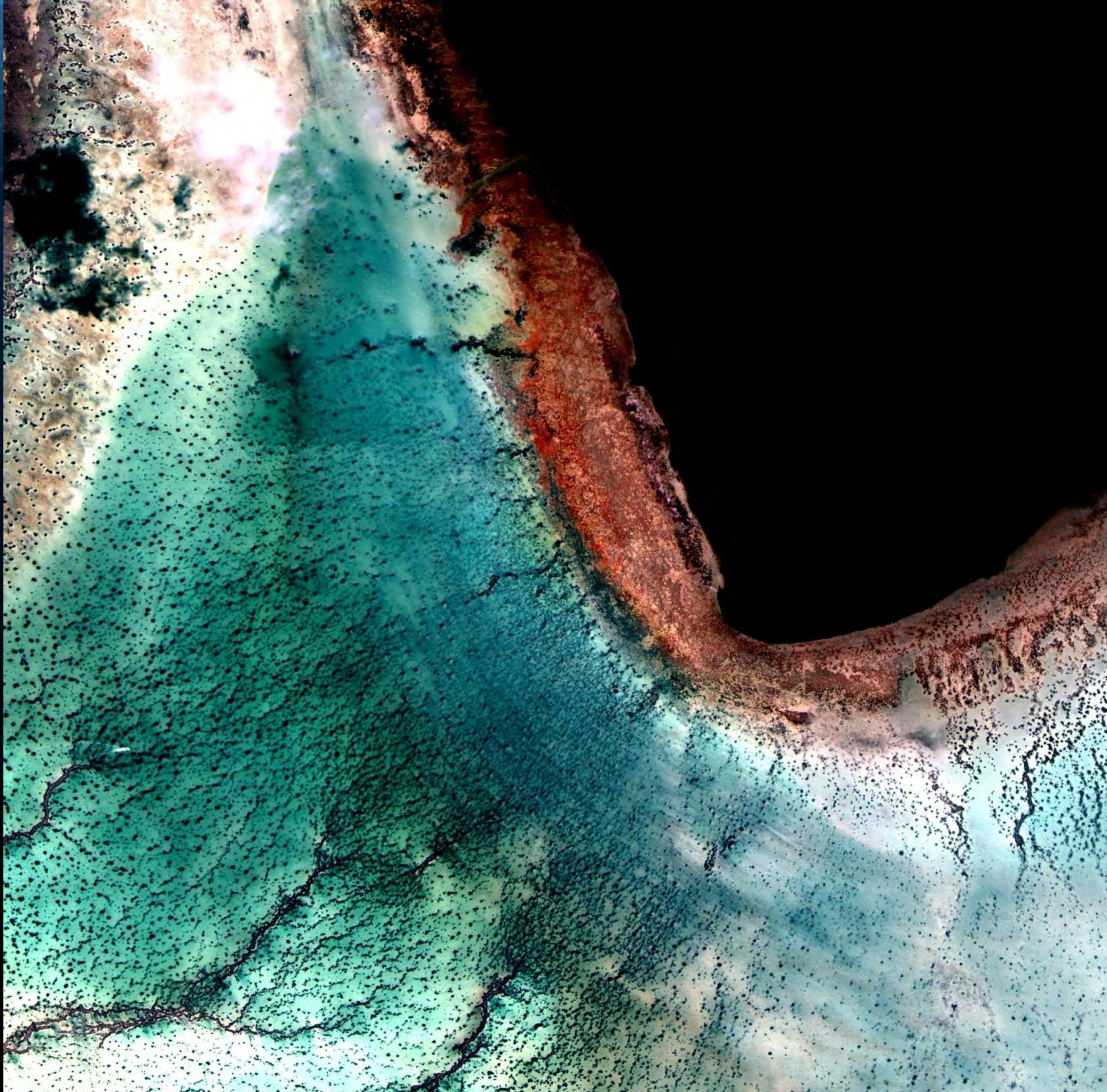
WorldView-2
First Images
C, B, G
2m Image
November 23, 2009

Aitutaki Lagoon





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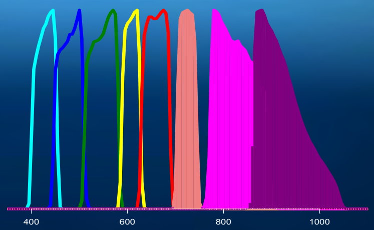
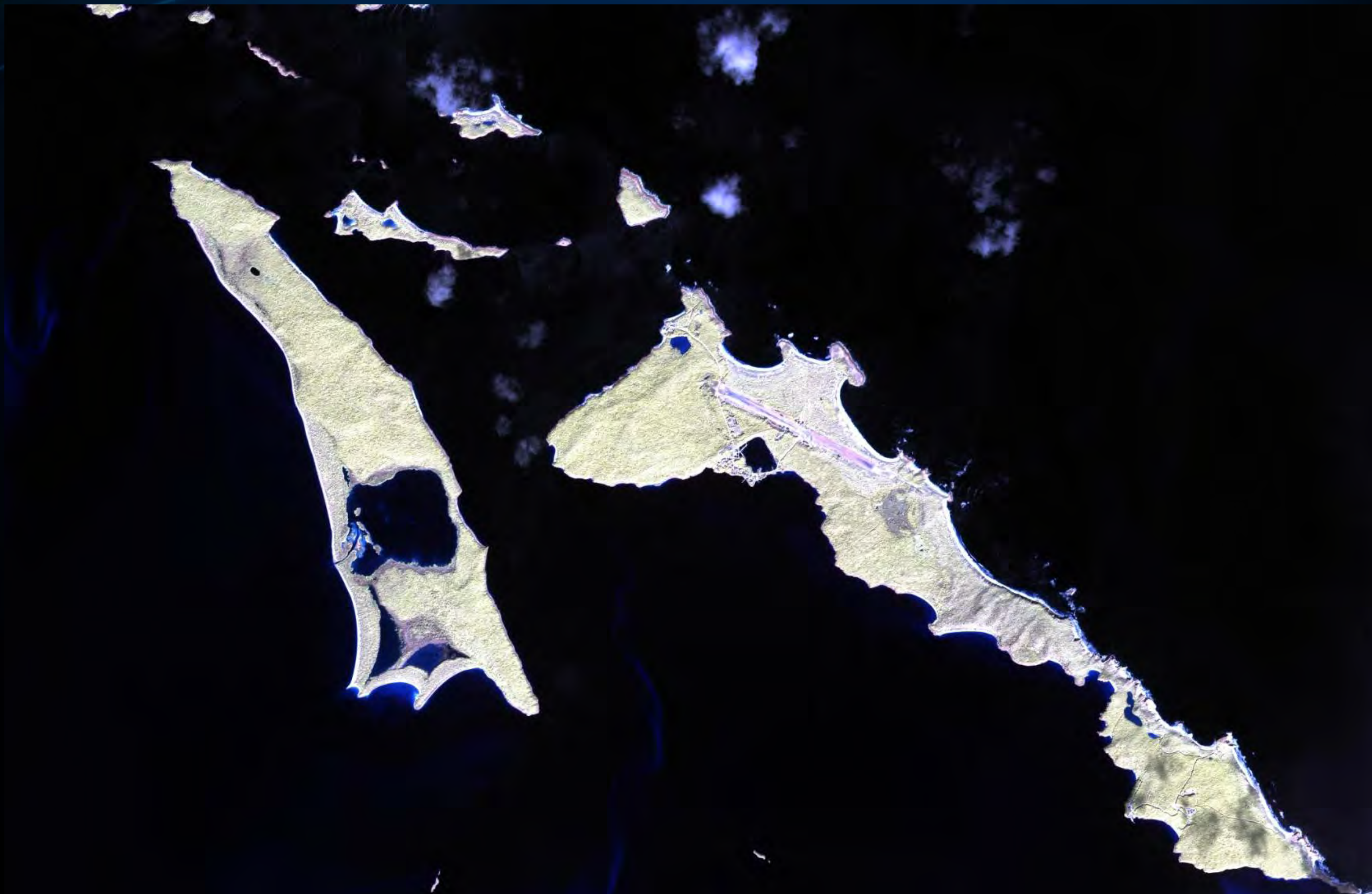


WorldView-2
2m Image
LSR
Dec 26, 2010



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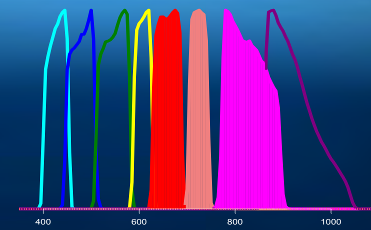
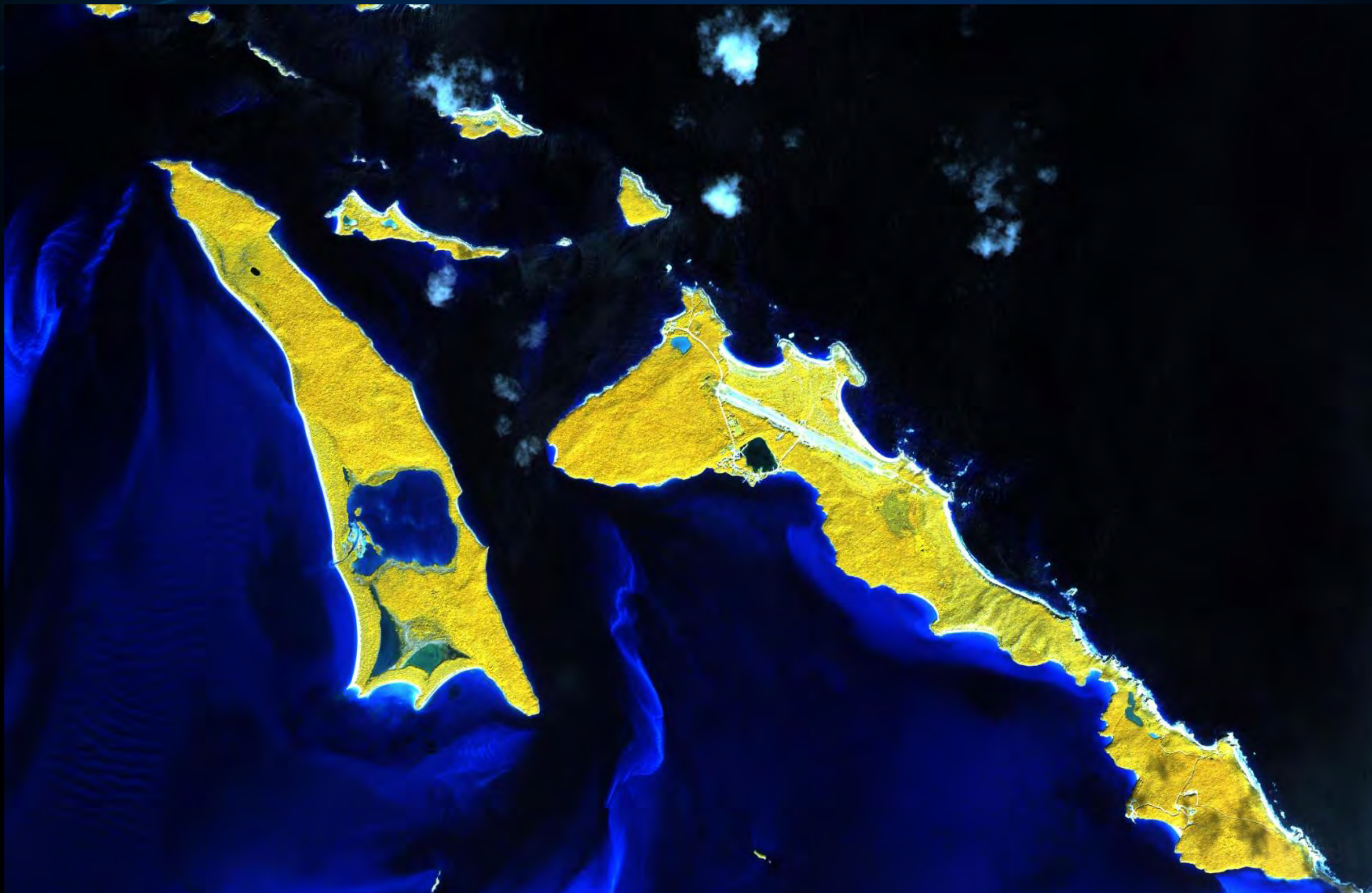


WorldView-2
2m Image
LSR
Dec 26, 2010



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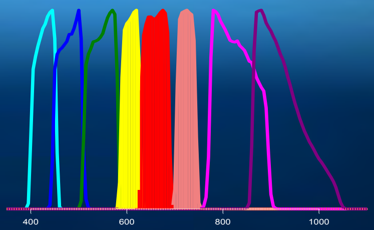
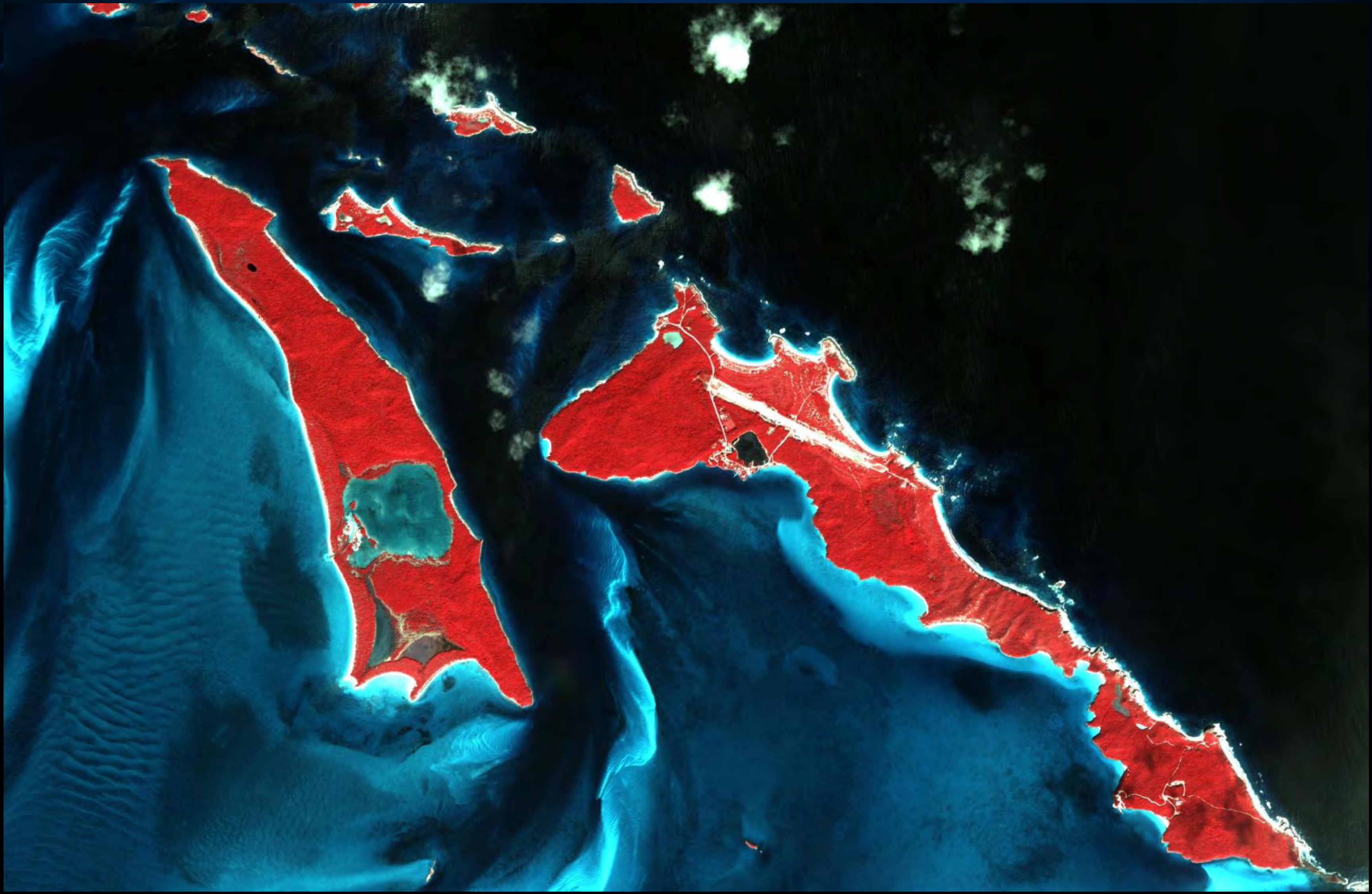


WorldView-2

2m Image

LSR

Dec 26, 2010



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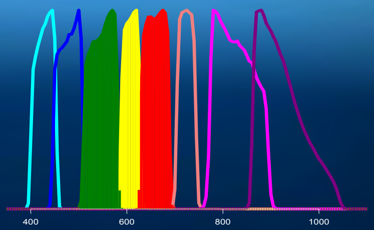

WorldView-2
2m Image
LSR
Dec 26, 2010

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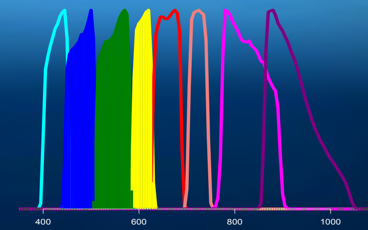

WorldView-2

2m Image

LSR

Dec 26, 2010

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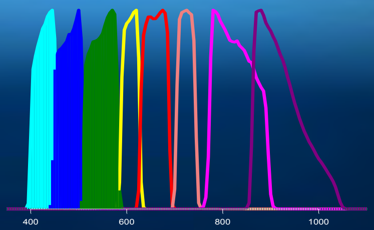
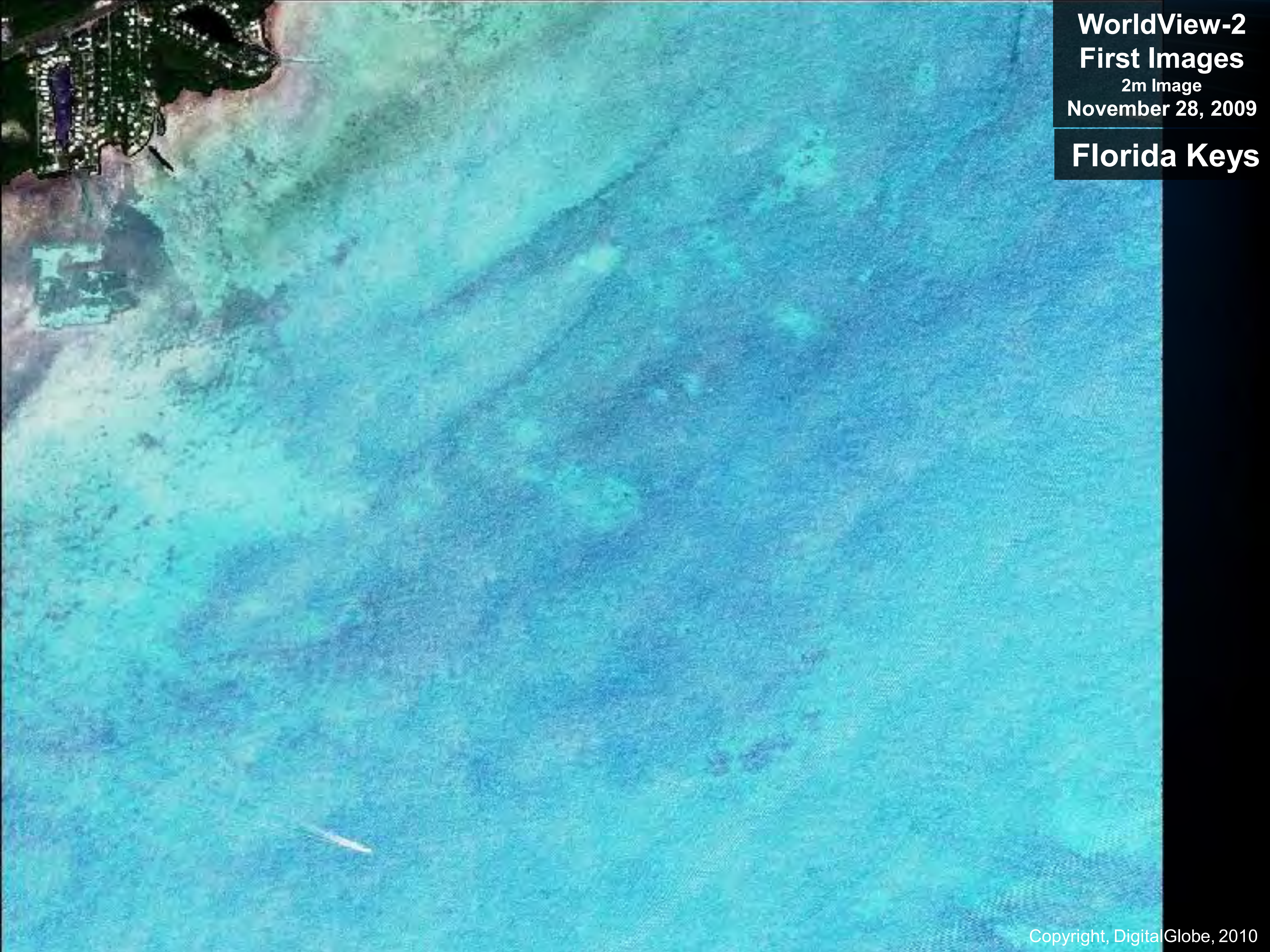


WorldView-2

2m Image

LSR

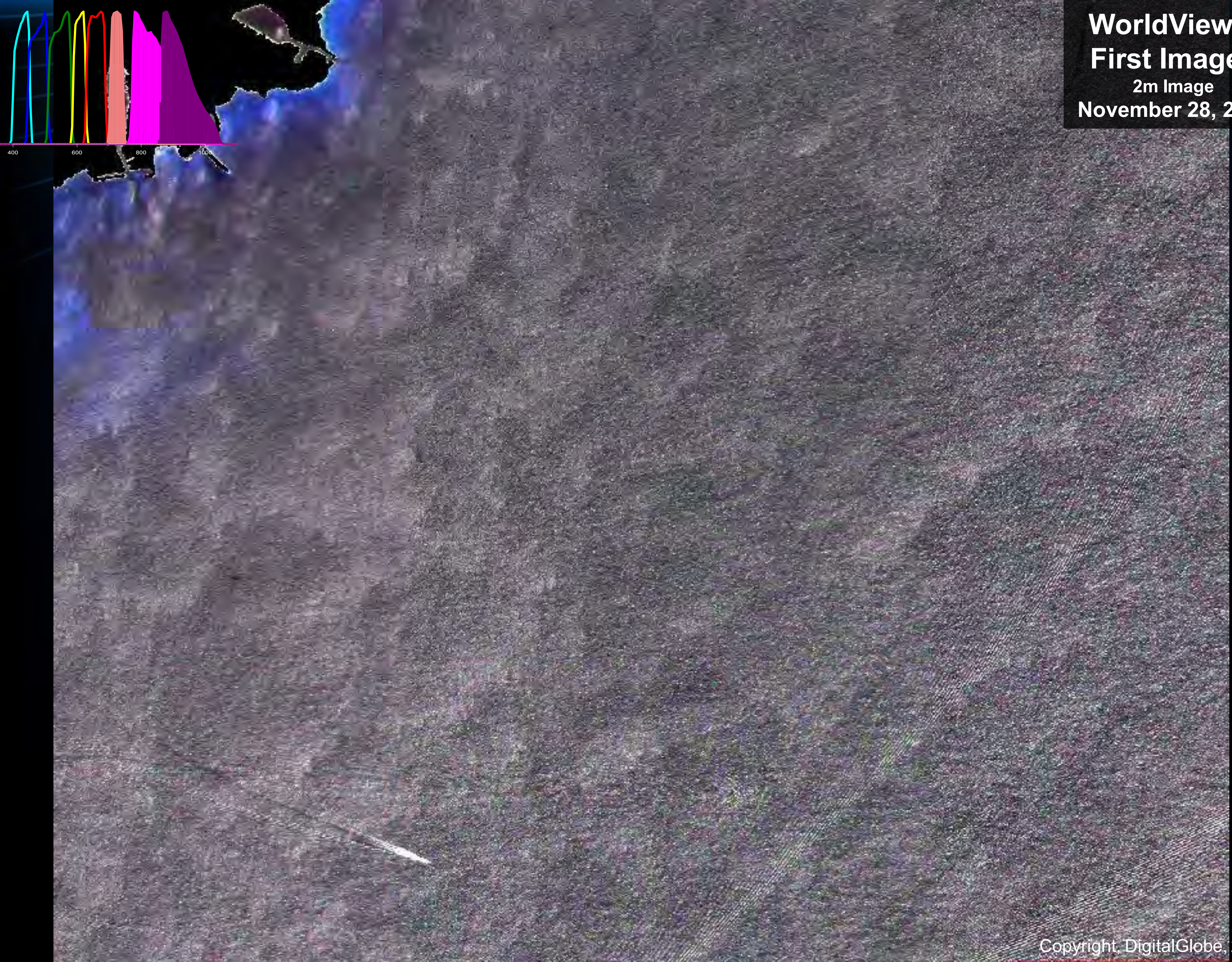
Dec 26, 2010


WorldView-2
First Images
2m Image
November 28, 2009
Florida Keys

WorldView-2 First Images

2m Image

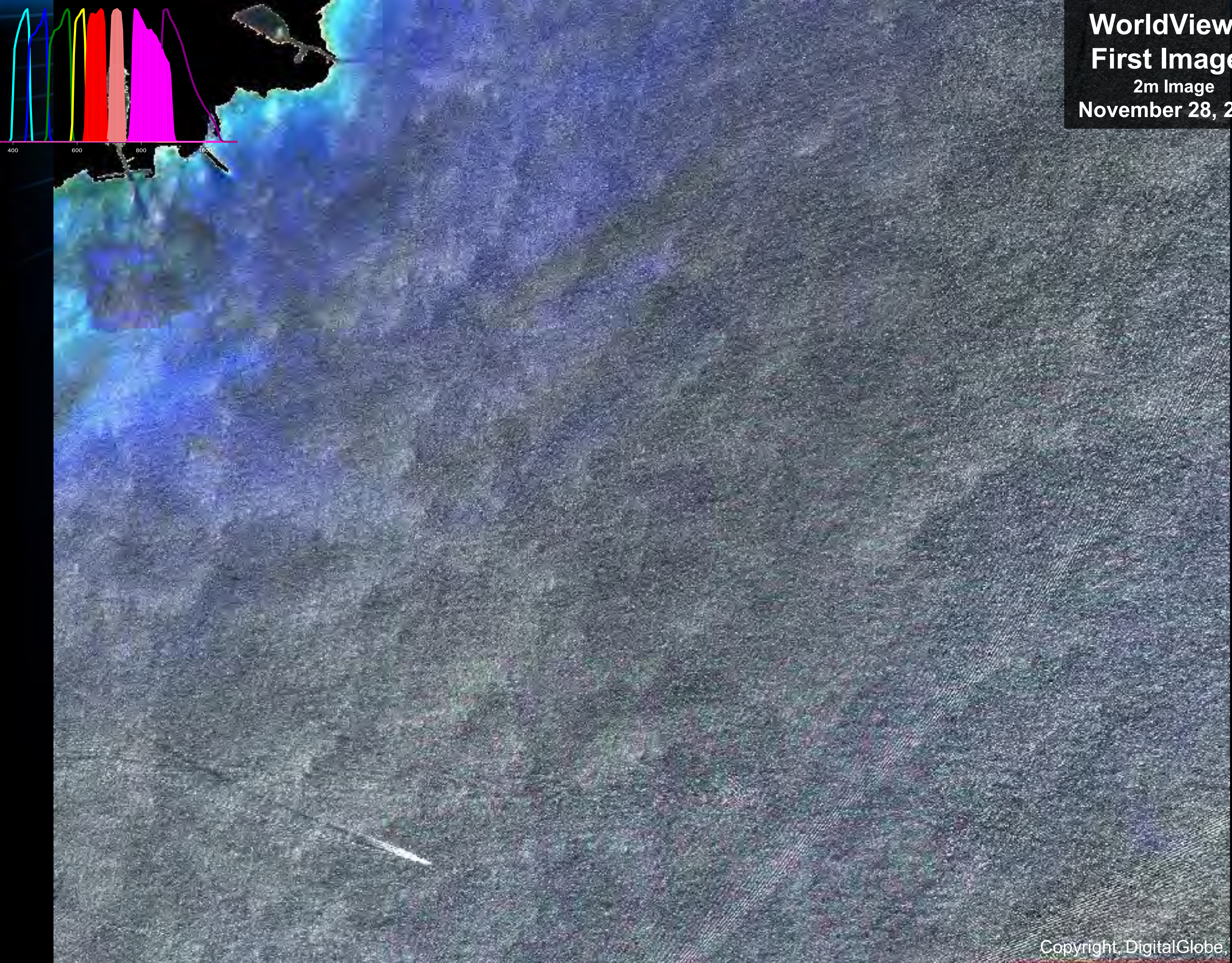
November 28, 2009



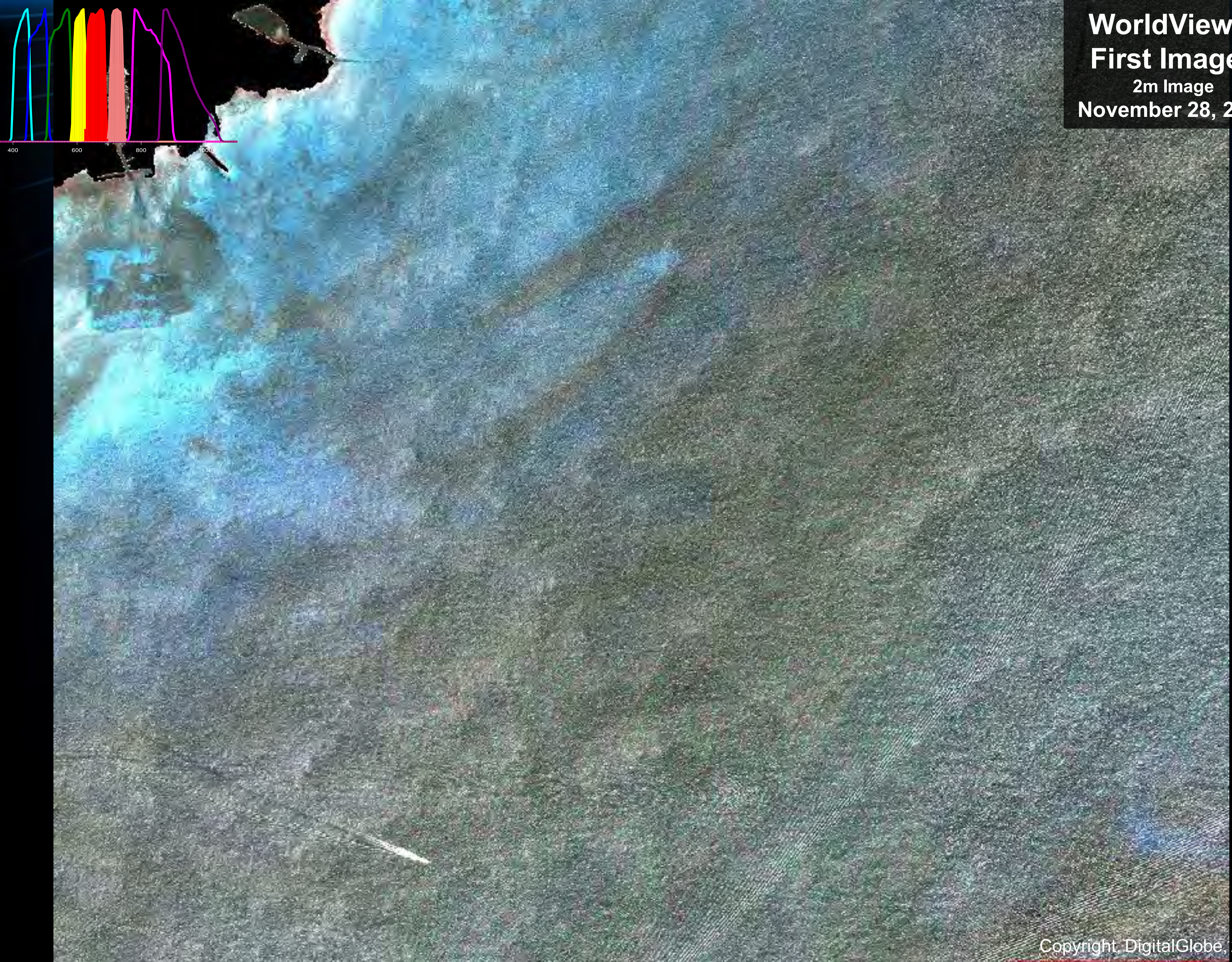
WorldView-2 First Images

2m Image

November 28, 2009



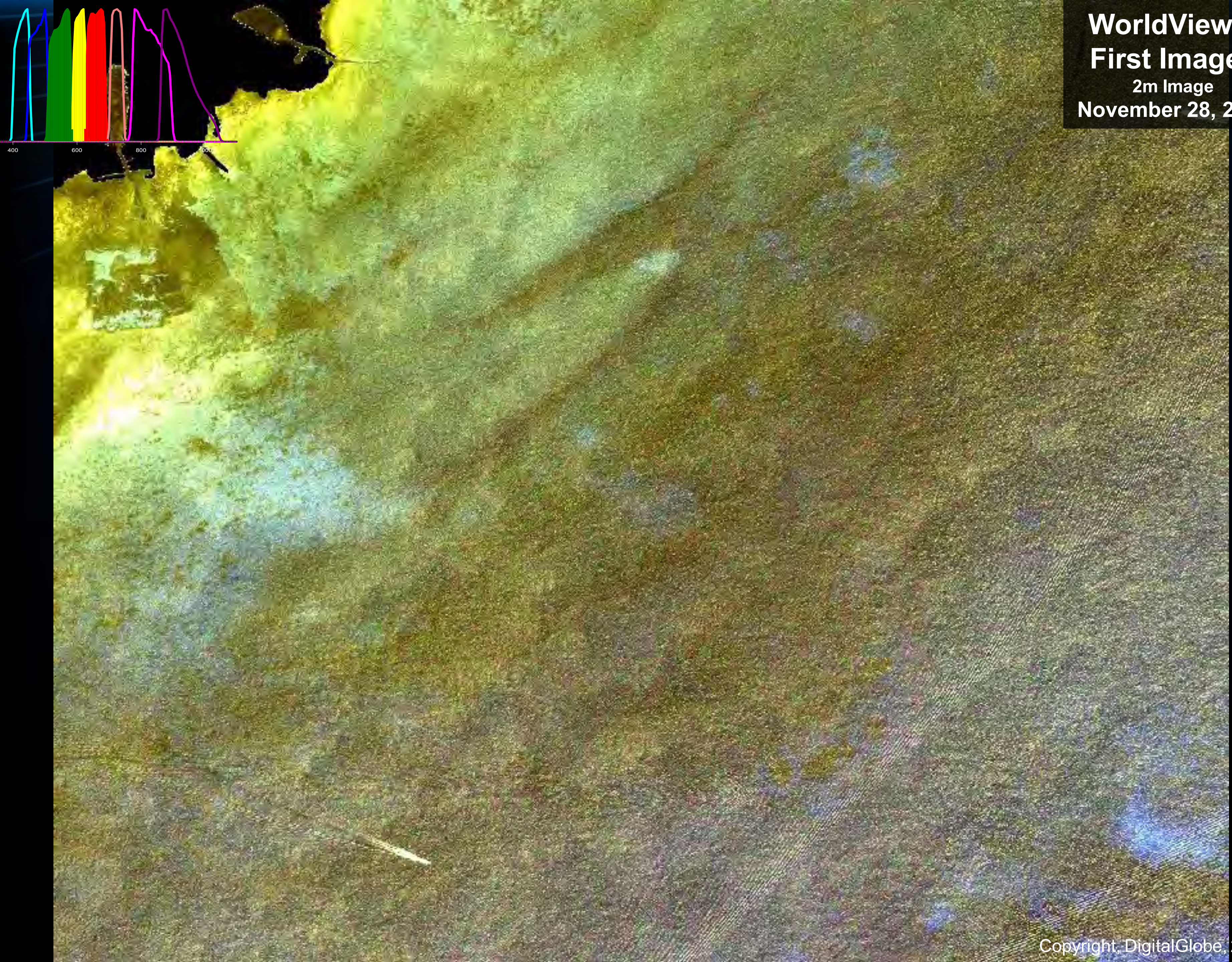
WorldView-2
First Images
2m Image
November 28, 2009

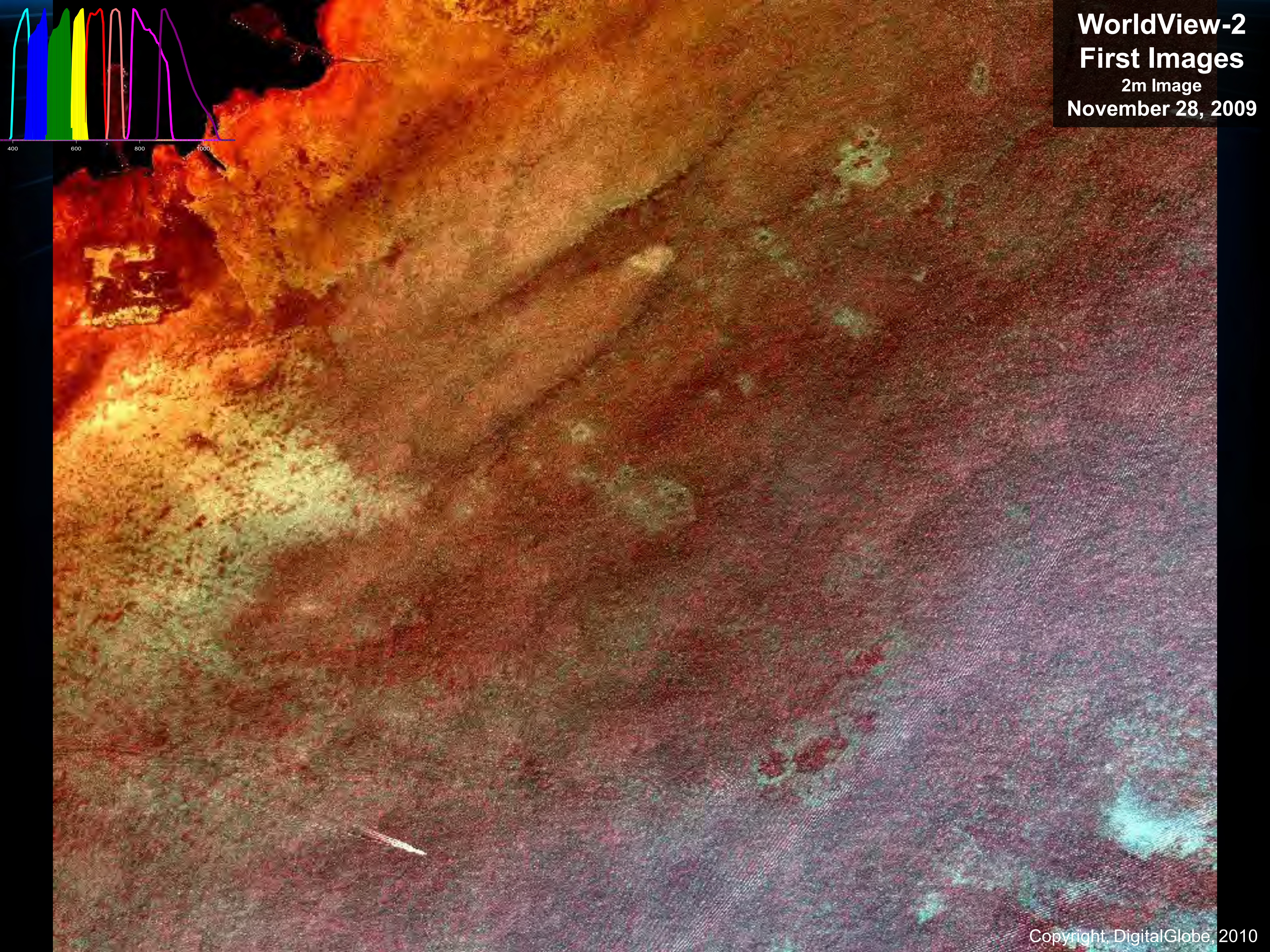


WorldView-2 First Images

2m Image

November 28, 2009

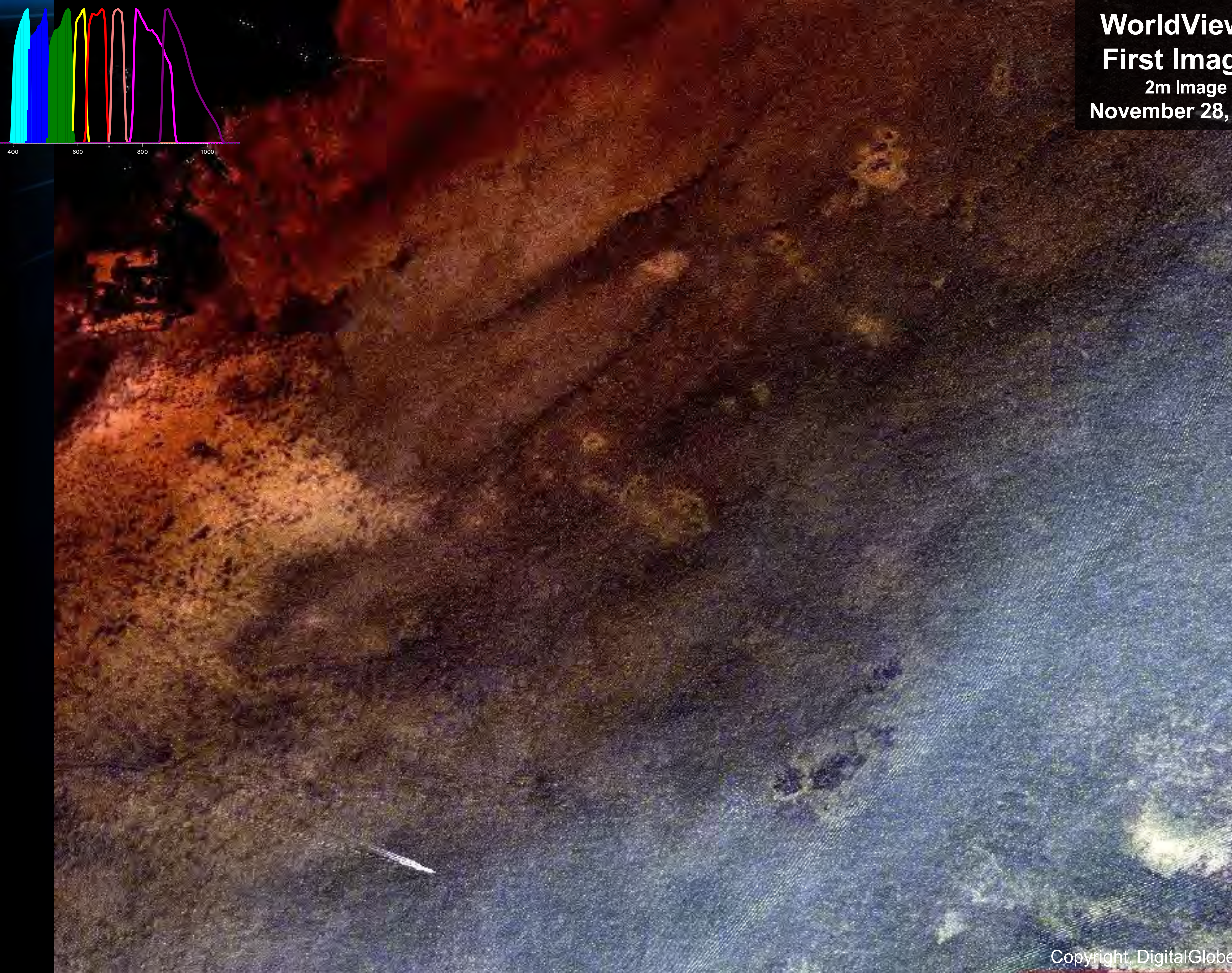



WorldView-2
First Images
2m Image
November 28, 2009
400
600
800
1000

WorldView-2 First Images

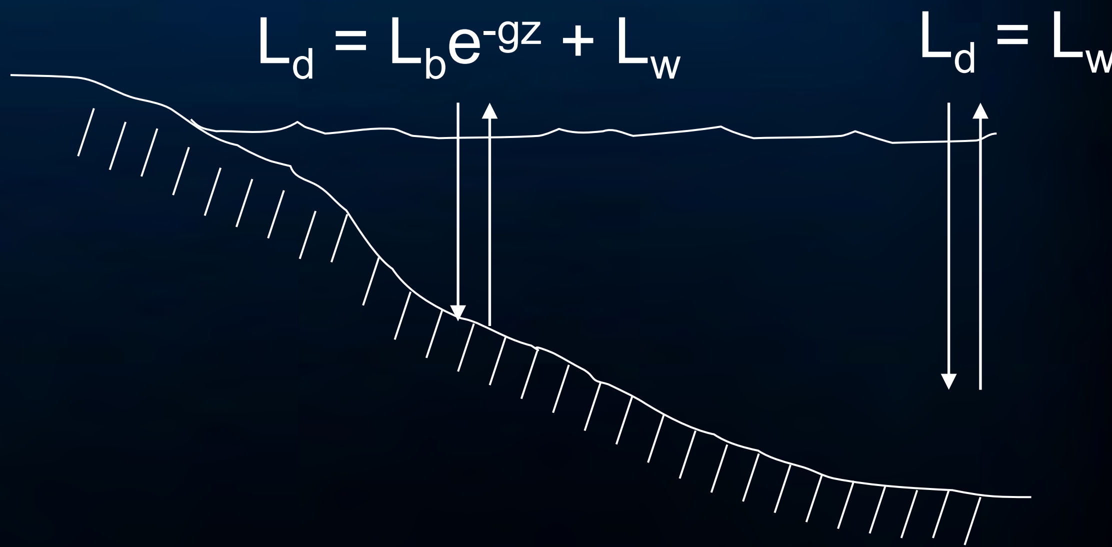
2m Image

November 28, 2009



Bathymetry Using Worldview2 Spectral Bands

Governing Equation:
Ld - radiance at detector
Lb - radiance sensitive to bottom
g - two way attenuation coefficient
z - depth
Lw - radiance over deep water



Source: Lyzenga, 1978, Applied Optics. 17:379-383, and generalized by Philpot, 1989, Applied Optics. 28:1569-1578.

- Water absorptivity varies spectrally from band to band
- As the depth increases, the reflected irradiance decreases faster in the high-absorptivity spectral band (e.g. green band) than in the low-absorptivity band (e.g. blue band)

Bathymetry Using Worldview2 Spectral Bands

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Governing Equation:

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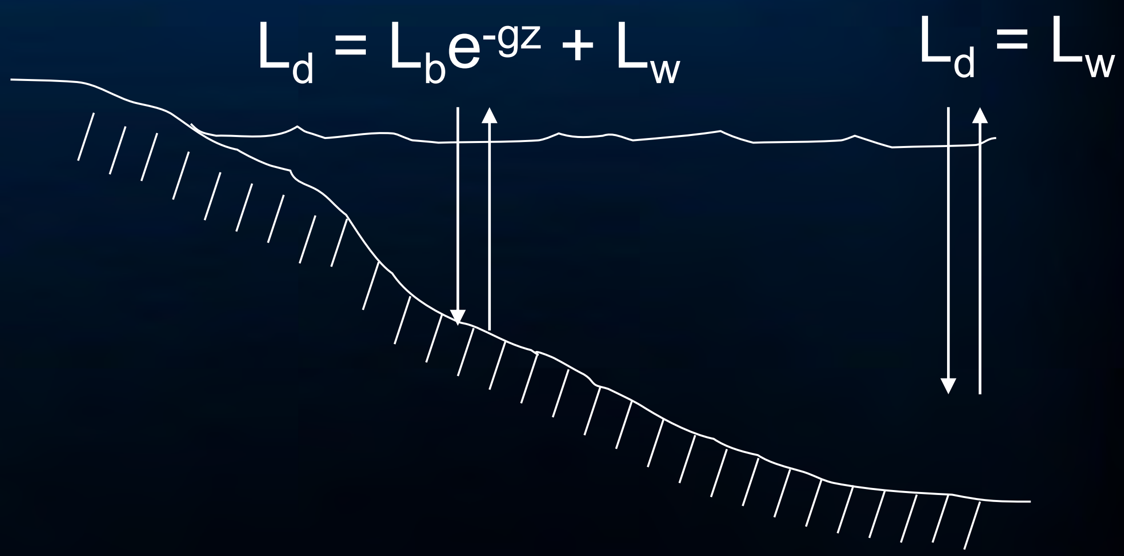


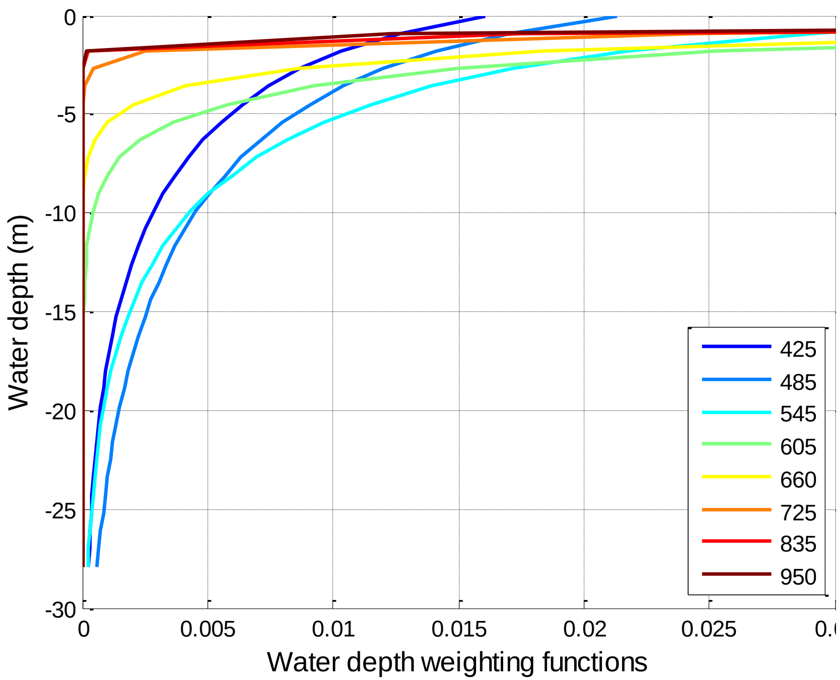
Source: Lyzenga, 1978, Applied Optics. 17:379-383, and generalized by Philpot, 1989, Applied Optics. 28:1569-1578.

Observed spectrum is a function of:

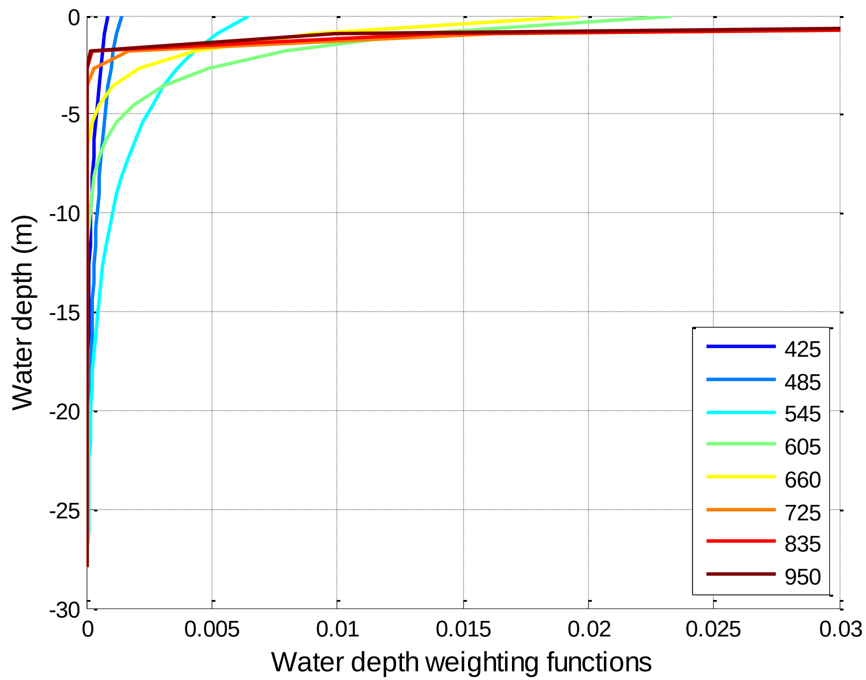
1. water depth
2. bottom reflectance spectra
3. water column inherent optical properties (IOPs)
4. viewing geometry

Sensitivity of WV02 bands to seafloor type

Ooid sand – large reflectivity



Coral – small reflectivity



Sensor right above the water surface
Clear water
1m/s wind speed

Generated from lookup tables provided by Anthony Vodacek , Rochester Institute of Technology

Machine Learning Assessment of Worldview2 Potential for Bathymetry Studies

- Input a stack of WV-2 spectral features:
  - Converted radiance values from the 8 WV-2 bands
  - 28 unique pairs of NDVI-style band ratios computed from the above
- Apply supervised machine learning methods:
  - Logistic Regression
  - Classification Trees with k-fold Cross-Validation
  - Tree Ensembles
  - Neural Networks
- Train and validate on independent ground truth
- Generate confusion matrices
- Perform predictor ranking

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WorldView-2
First Images
natural color
2m Image
November 23, 2009

Aitutaki Lagoon

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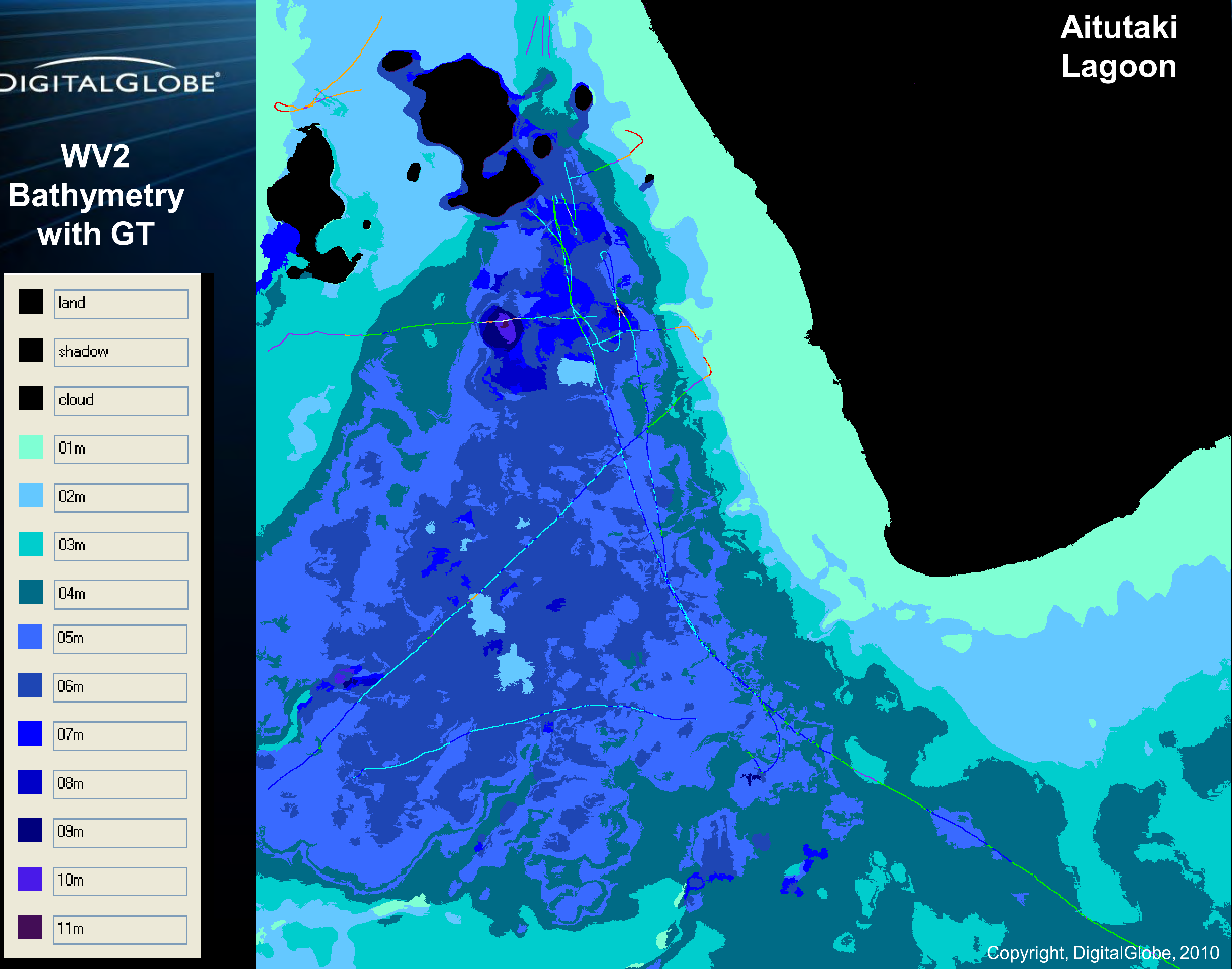
WV2 Bathymetry with GT



Classification Agreement

	01m	02m	03m	04m	05m	06m	07m	08m	09m	10m	11m	Acc(%)	Acc[1 m]
01m	105	14	0	0	0	0	0	0	0	0	0	88.24%	100.00%
02m	1	317	24	2	3	4	0	0	0	0	0	90.31%	97.44%
03m	0	5	357	38	2	0	0	0	0	0	0	88.81%	99.50%
04m	0	0	10	594	200	3	0	0	0	0	0	73.61%	99.63%
05m	0	0	0	72	1172	201	2	0	0	0	0	81.00%	99.86%
06m	0	0	1	6	179	1041	14	0	0	0	0	83.88%	99.44%
07m	0	0	0	0	7	146	289	0	0	0	0	65.38%	98.42%
08m	0	0	0	0	0	8	21	22	0	0	0	43.14%	84.31%
09m	0	0	0	0	0	0	0	0	23	0	0	100.00%	100.00%
10m	0	0	0	0	0	0	0	0	0	20	0	100.00%	100.00%
11m	0	0	0	0	0	0	0	0	0	0	7	100.00%	100.00%
Acc(%)	99.06%	94.35%	91.07%	83.43%	74.98%	74.20%	88.65%	100.00%	100.00%	100.00%	100.00%	80.39%	98.05%
Acc[1 m]	100.00%	100.00%	99.74%	98.88%	99.23%	98.93%	99.39%	100.00%	100.00%	100.00%	100.00%	99.65%	99.23%

More than 99% of the 4,910 validation samples are in the {+/-1 m} accuracy

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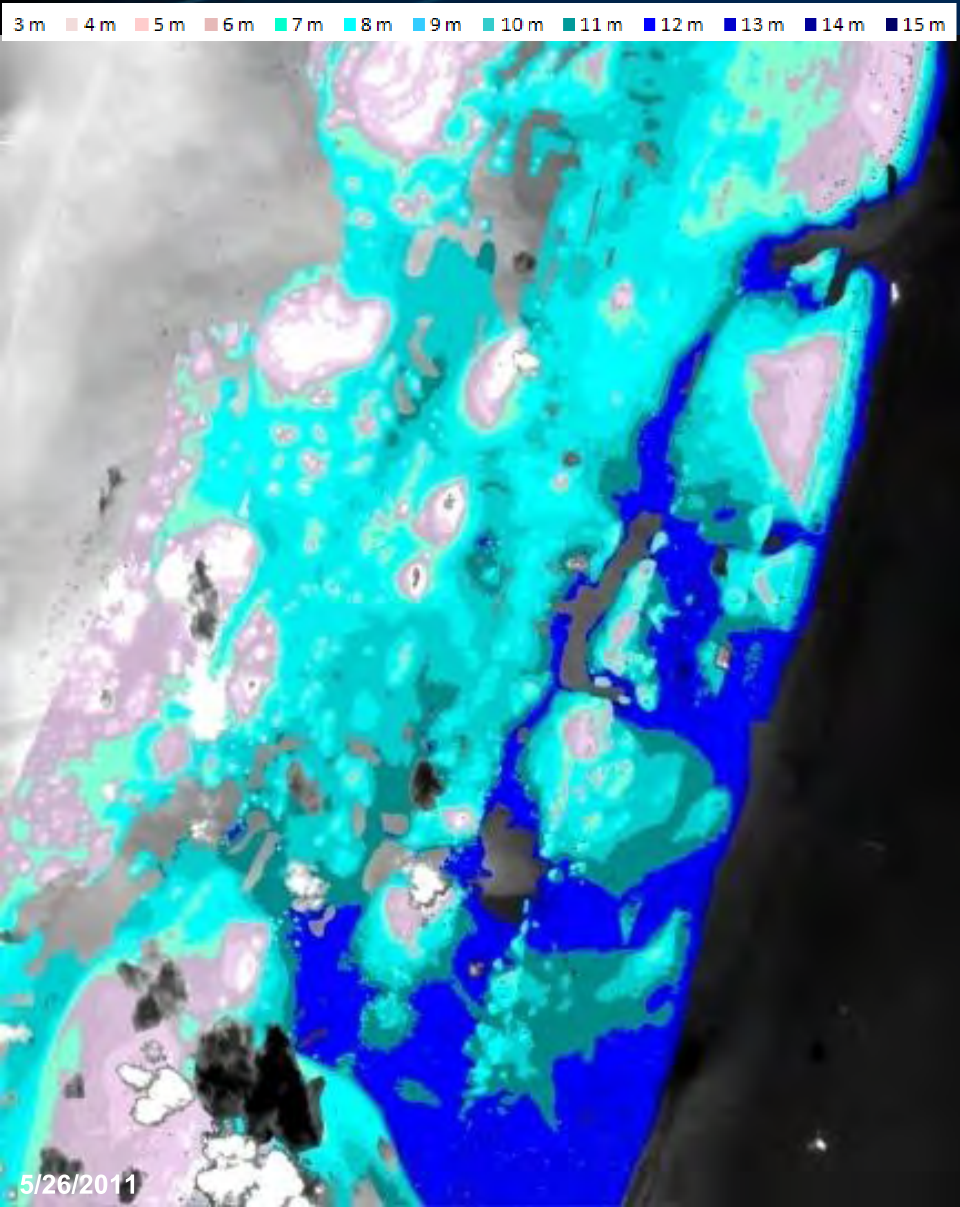
LIDAR GT



WV2 Bathymetry

5/26/2011

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Classification Agreement for Bathymetry (Against LIDAR GT – Florida)

	3	4	5	6	7	8	9	10	11	12	13	14	15	Acc (%)	Acc[1 m]	Acc[2 m]
3	179612	13256	60	5	0	0	0	0	0	0	0	0	0	93.10	99.97	100.00
4	27665	352906	28206	1539	191	66	0	0	0	0	0	0	0	85.95	99.56	99.94
5	615	27430	333128	31600	687	95	5	0	0	0	0	0	0	84.64	99.64	99.97
6	215	2630	48827	430157	36937	1120	117	8	3	0	0	0	0	82.72	99.21	99.93
7	454	3329	8229	90985	556612	108822	10320	1654	335	135	35	6	0	71.28	96.86	99.24
8	6	1096	1818	4131	59775	598783	127239	5496	528	442	407	0	0	74.87	98.26	99.46
9	40	447	575	1240	6348	80149	674765	59474	1628	0	0	0	0	81.82	98.75	99.72
10	15	167	356	1384	6232	31926	253858	970762	83048	830	13	0	0	71.98	96.97	99.39
11	0	55	296	500	1598	9255	26054	138817	630299	121000	7355	1192	210	67.29	95.03	98.60
12	0	0	0	14	75	512	1875	4924	39824	524400	35399	296	0	86.35	98.73	99.59
13	0	0	0	1	14	216	612	1643	6140	54961	314355	34659	2138	75.80	97.40	99.40
14	0	0	0	0	0	37	254	287	217	520	3727	25748	2748	76.77	96.08	97.63
15	0	0	0	0	0	3	11	19	33	31	120	1134	5771	81.03	96.95	98.64
Acc (%)	86.09	87.94	79.03	76.6	83.27	72.06	61.62	82.05	82.71	74.67	86.98	40.85	53.11	77.00	97.96	99.35
Acc[1 m]	99.36	98.08	97.31	98.43	97.73	94.80	96.42	98.81	98.83	99.72	97.81	97.63	78.39	96.41		
Acc[2 m]	99.65	98.73	99.28	99.44	98.79	98.77	99.74	99.69	99.85	99.91	99.87	98.10	98.07	99.22		

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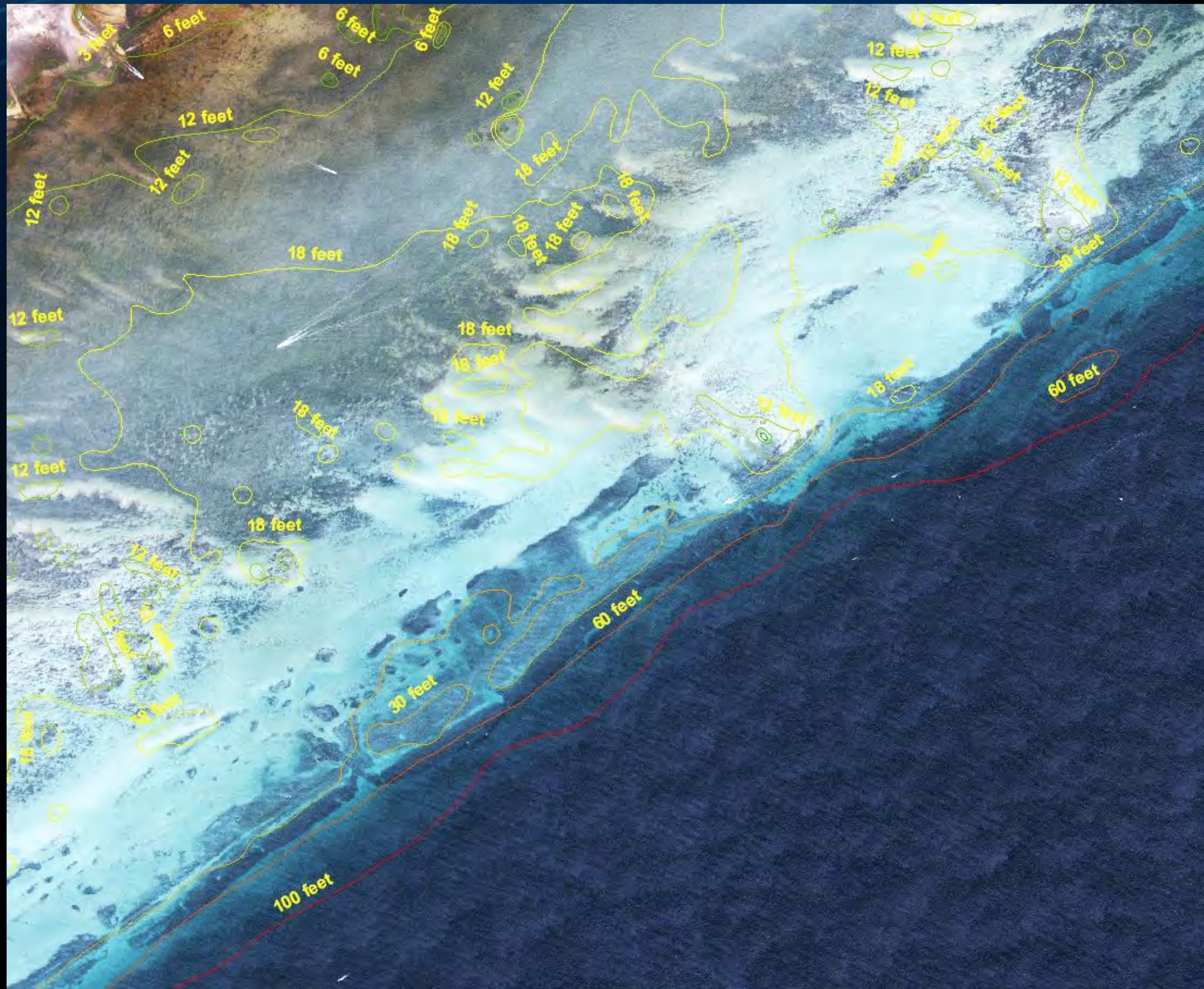
WorldView-2 First Images

4 band

2m Image

November 28, 2009

Florida Keys



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Bathymetry and Sea Bed Modeling

WorldView-2
First Images
4 band
2m Image
November 28, 2009

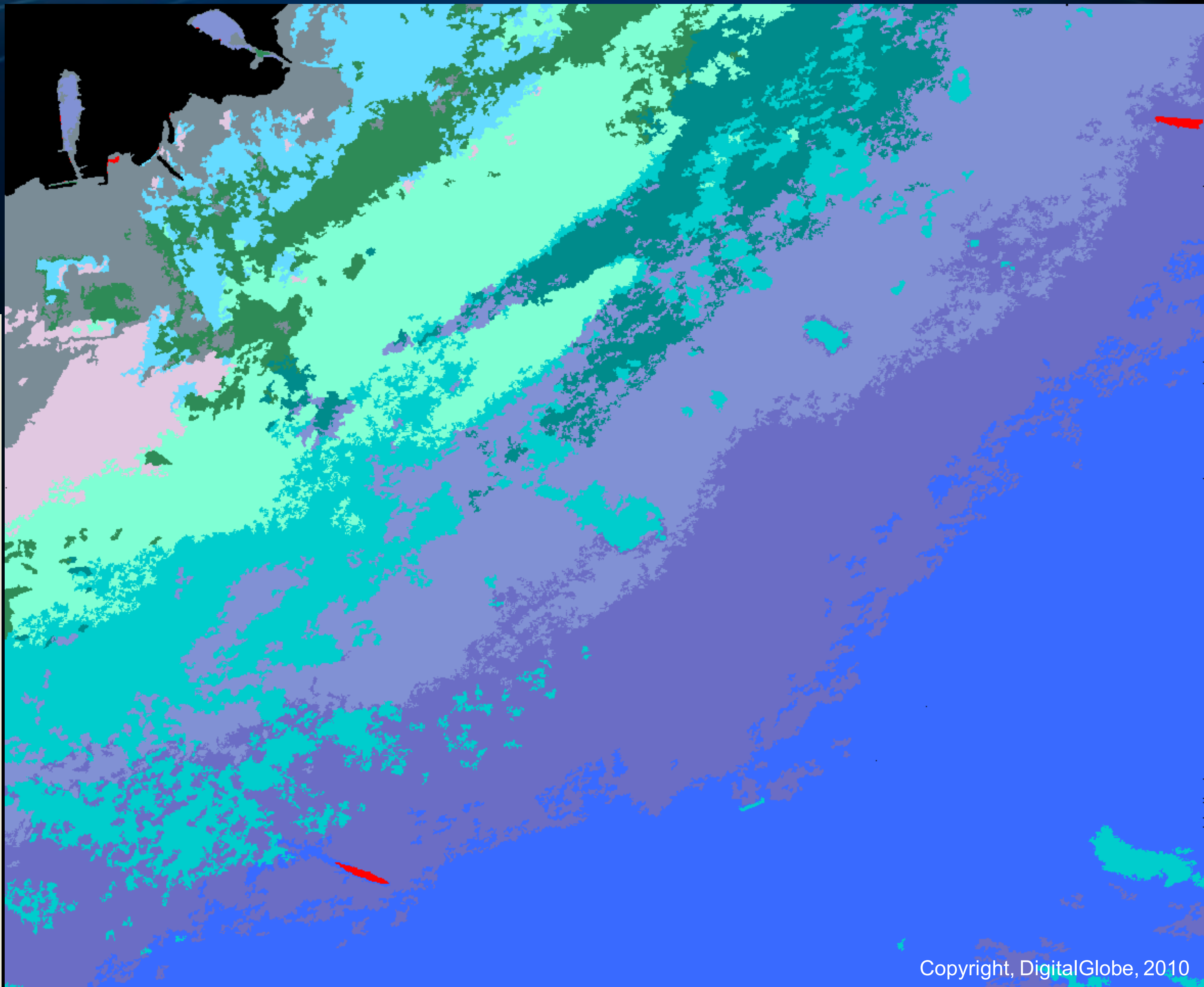
Florida Keys

Bathymetry and Sea Bed Modeling

DIGITALGLOBE

WorldView-2
First Images
4 band
2m Image
November 28, 2009

Florida Keys



Classification Agreement for Bathymetry + Sea Bed

Input Node - Predict: Tree Ensemble (363)

		Predicted												Totals
		01_A	02_B	03_C	04_D	05_DEPTH3	06_DEPTH6	07_DEPTH9	08_DEPTH12	09_DEPTH15	10_DEPTH15	11_DEPTH18	12_shiptrac	
Observed	01_A	1285	8	0	0	0	0	0	0	0	0	0	0	1293
	02_B	0	1300	0	0	0	0	0	0	0	0	0	0	1300
	03_C	0	7	1727	0	6	0	0	0	0	0	0	0	1740
	04_D	3	0	0	683	0	0	0	6	0	0	0	0	692
	05_DEPTH3	5	0	3	0	1093	0	0	0	0	0	0	0	1101
	06_DEPTH6	0	0	7	0	0	2504	21	0	0	0	0	0	2532
	07_DEPTH9	0	0	0	1	0	1	1502	3	0	0	0	0	1507
	08_DEPTH12	0	0	0	12	0	0	0	3584	39	0	0	0	3635
	09_DEPTH15	0	0	0	0	0	0	0	7	2595	1	0	0	2603
	10_DEPTH15	0	0	0	0	0	0	0	0	4	2136	11	0	2151
	11_DEPTH18	0	0	0	0	0	0	0	0	0	15	2779	0	2794
	12_shiptrac	0	0	0	0	0	0	0	0	0	0	0	245	245
Totals		1293	1315	1737	696	1099	2505	1523	3600	2638	2152	2790	245	21593

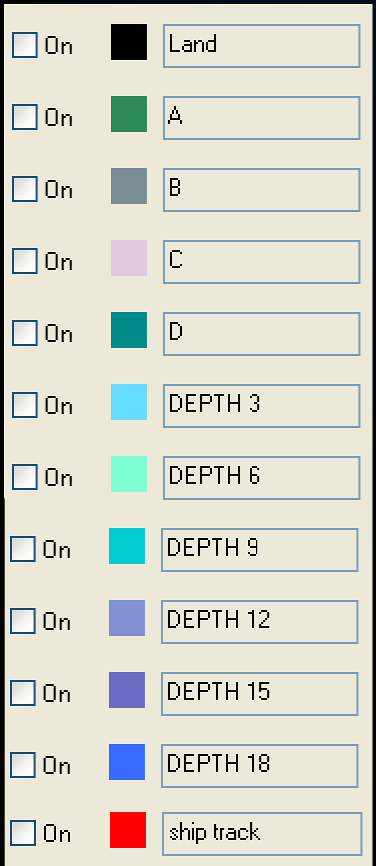
	Observed												Overall
	01_A	02_B	03_C	04_D	05_DEPTH3	06_DEPTH6	07_DEPTH9	08_DEPTH12	09_DEPTH15	10_DEPTH15	11_DEPTH18	12_shiptrac	
% Agree	99.4%	100.0%	99.3%	98.7%	99.3%	98.9%	99.7%	98.6%	99.7%	99.3%	99.5%	100.0%	99.3%

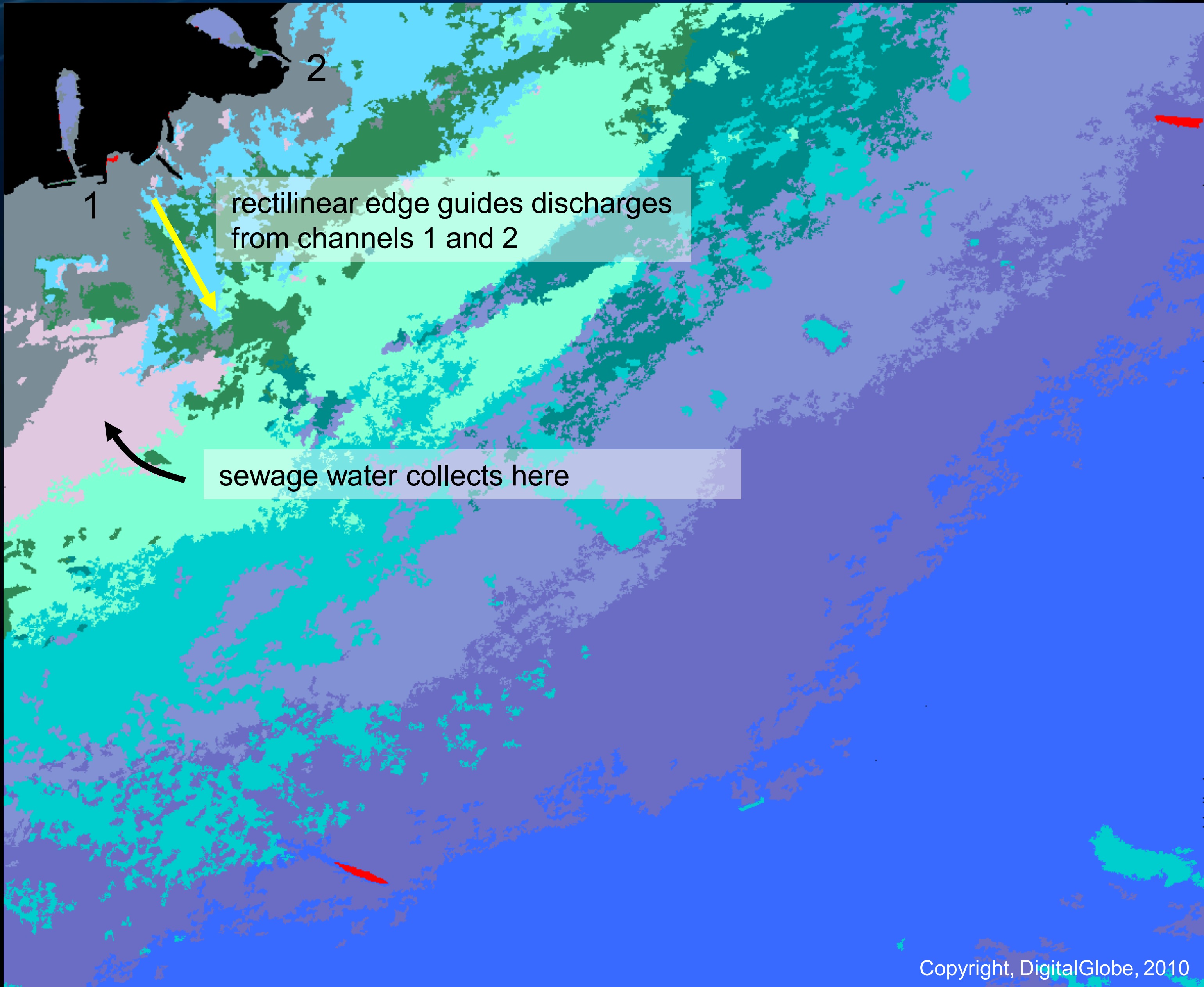
Bathymetry and Sea Bed Modeling

DIGITALGLOBE

WorldView-2 First Images
4 band
2m Image
November 28, 2009

Florida Keys

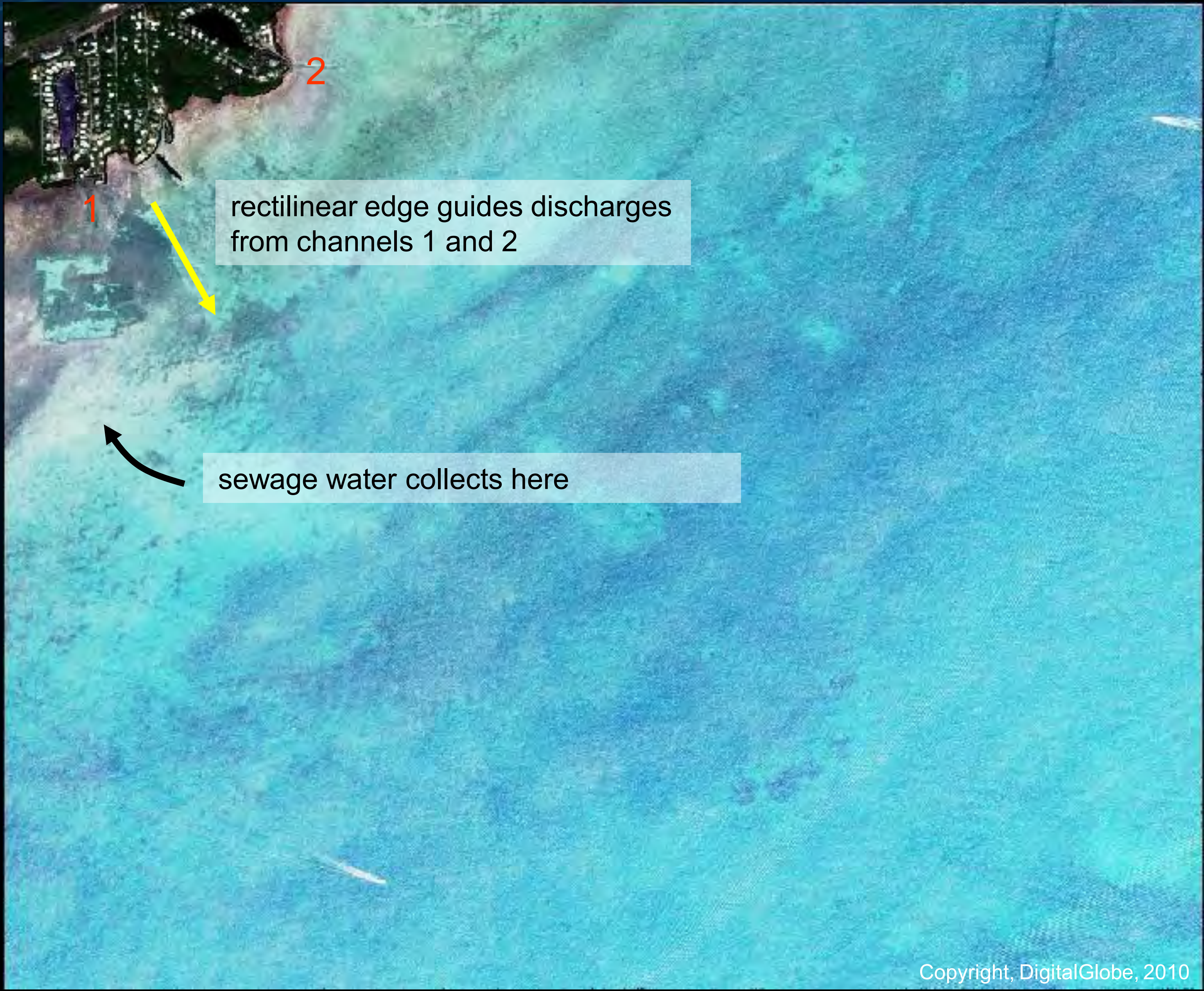




Bathymetry and Sea Bed Modeling

WorldView-2
First Images
4 band
2m Image
November 28, 2009

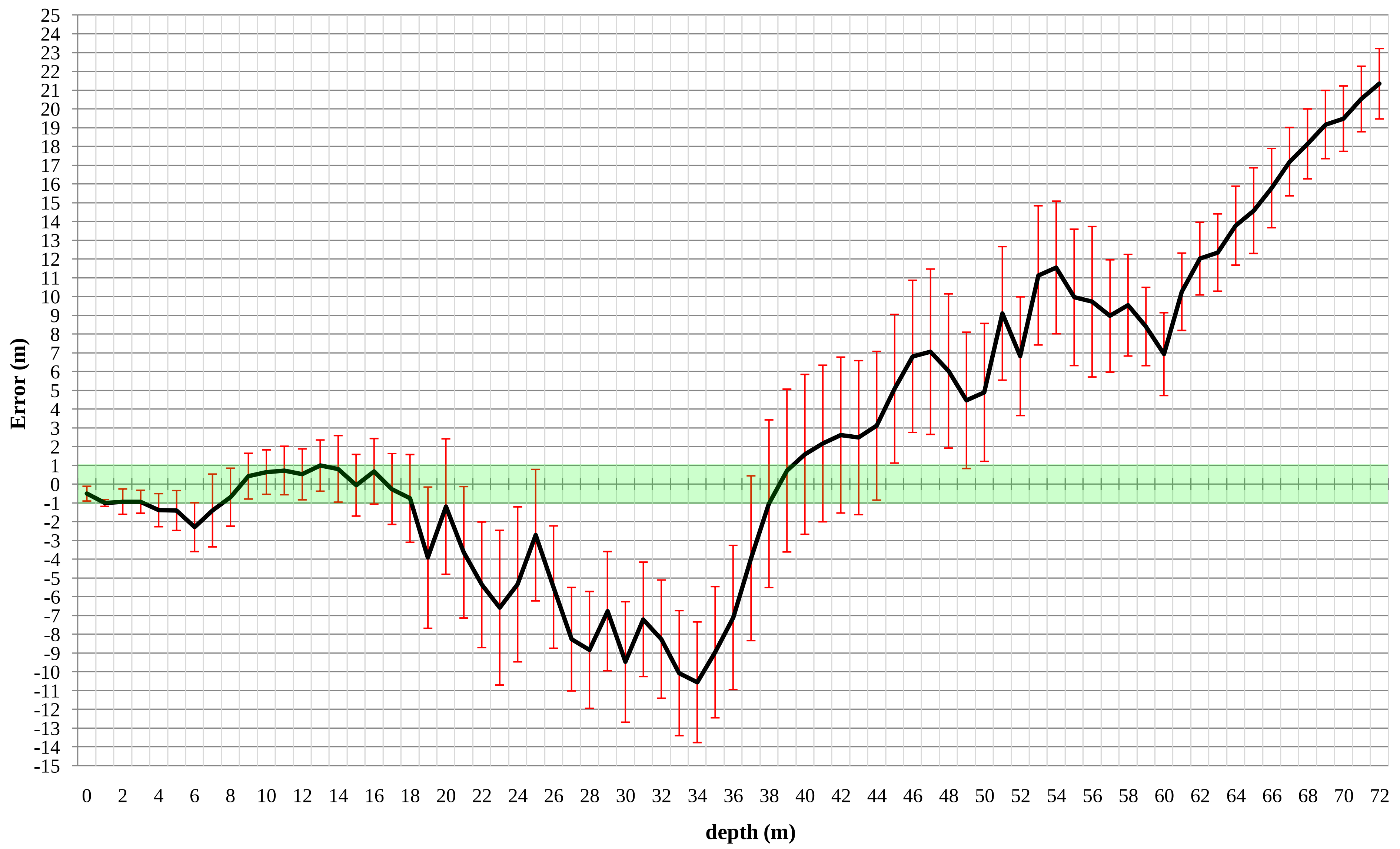
Florida Keys



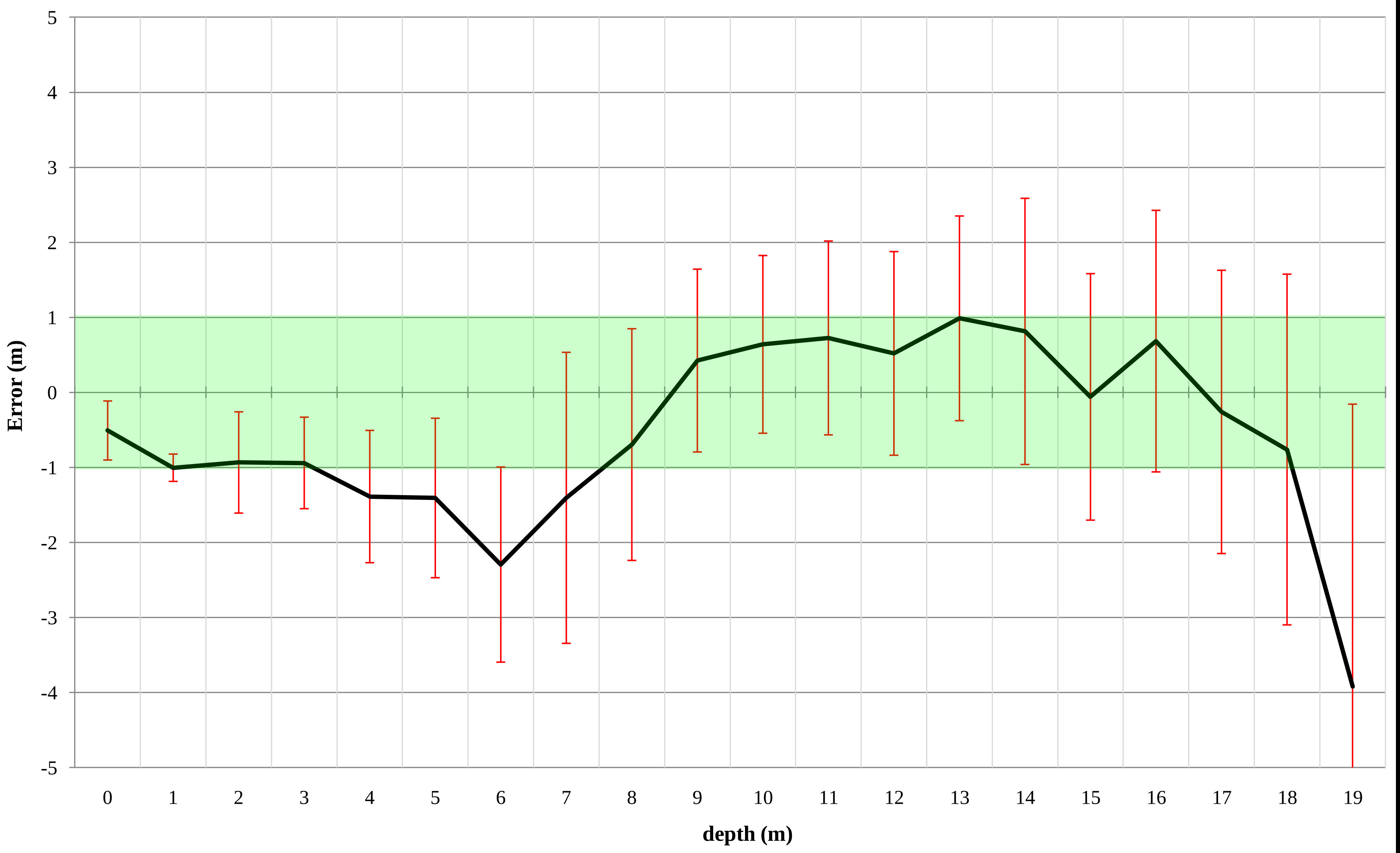
How Deep Can We See?

WorldView-2
true color image
San Diego, CA
February 14, 2010

Cumulative Error for Bathymetry



Cumulative Error for Bathymetry (20 m depth)



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Where is Most of the Predictive Power?

- NIR bands play little role except in the near surface
- C, B, G most useful for pure bathymetry
- Y, R, RE track submerged aquatic vegetation and coral, which in turns correlate with depth levels

	LC	ACCURACY				TOP PREDICTORS (best 4 out of 8 bands)							
		LR	CT	TE	NN	C	B	G	Y	R	RE	N1	N2
SCENE 1	depth 2m	94.4	99.1	97.6	96.1	■			■	■		■	
	depth 4m	79.0	86.5	83.4	80.9	■			■		■	■	
	depth 6m	94.6	83.5	83.1	85.4	■	■	■	■				
	depth 8m	56.5	92.6	93.2	94.9	■	■	■	■				
	depth 10m	83.7	99.8	95.7	89.1	■	■	■			■		
SCENE 2	sandy1	99.8	98.1	98.5	97.2		■	■	■	■			
	sandy2	99.8	99.8	99.0	98.7	■		■	■	■			
	coral1	99.7	96.5	96.5	96.4	■	■		■	■			
	coral2	97.3	98.3	98.5	96.1	■	■	■	■				
	depth 3m	99.9	98.7	98.5	99.3	■	■	■	■				
	depth 6m	99.9	98.6	93.5	99.2		■	■	■	■			
	depth 9m	99.8	98.9	98.6	99.8	■	■	■	■				
	depth 12m	99.0	97.3	89.8	91.4		■	■	■	■			
	depth 15m	93.3	99.0	92.2	95.7	■	■	■	■				
	depth 18m	99.7	98.4	96.0	93.6	■	■	■	■				
SCENE 3	depth 3m	99.2	99.7	99.7	99.8		■	■	■		■		
	depth 5m	84.2	97.7	97.3	99.6	■	■		■		■		
	depth 7m	73.8	83.9	90.6	93.3	■	■	■	■				
	depth 9m	73.0	84.6	88.0	80.6	■	■	■		■			
	depth 11m	89.0	85.5	92.1	83.6	■	■	■		■			
	depth 13m	93.3	93.8	95.3	83.1	■	■	■			■		
	depth 15m	94.9	95.8	98.6	95.2	■	■	■			■		

Physical Modeling vs. Machine Learning

- Machine learning models need to be retrained with GT for each individual scene making it currently impractical for automated and unsupervised application.

- Radiative-transfer approach combined with optimal estimation retrieval methodology offers more flexibility.
  - Top of the atmosphere (TOA) radiances are modeled using rigorous radiative transfer equations in water (HYDROLIGHT) and atmosphere (MODTRAN).
  - Bayesian approach, with real (TOP radiances) and pseudo (*a-priori*) measurements is used to derive unknown water depth.

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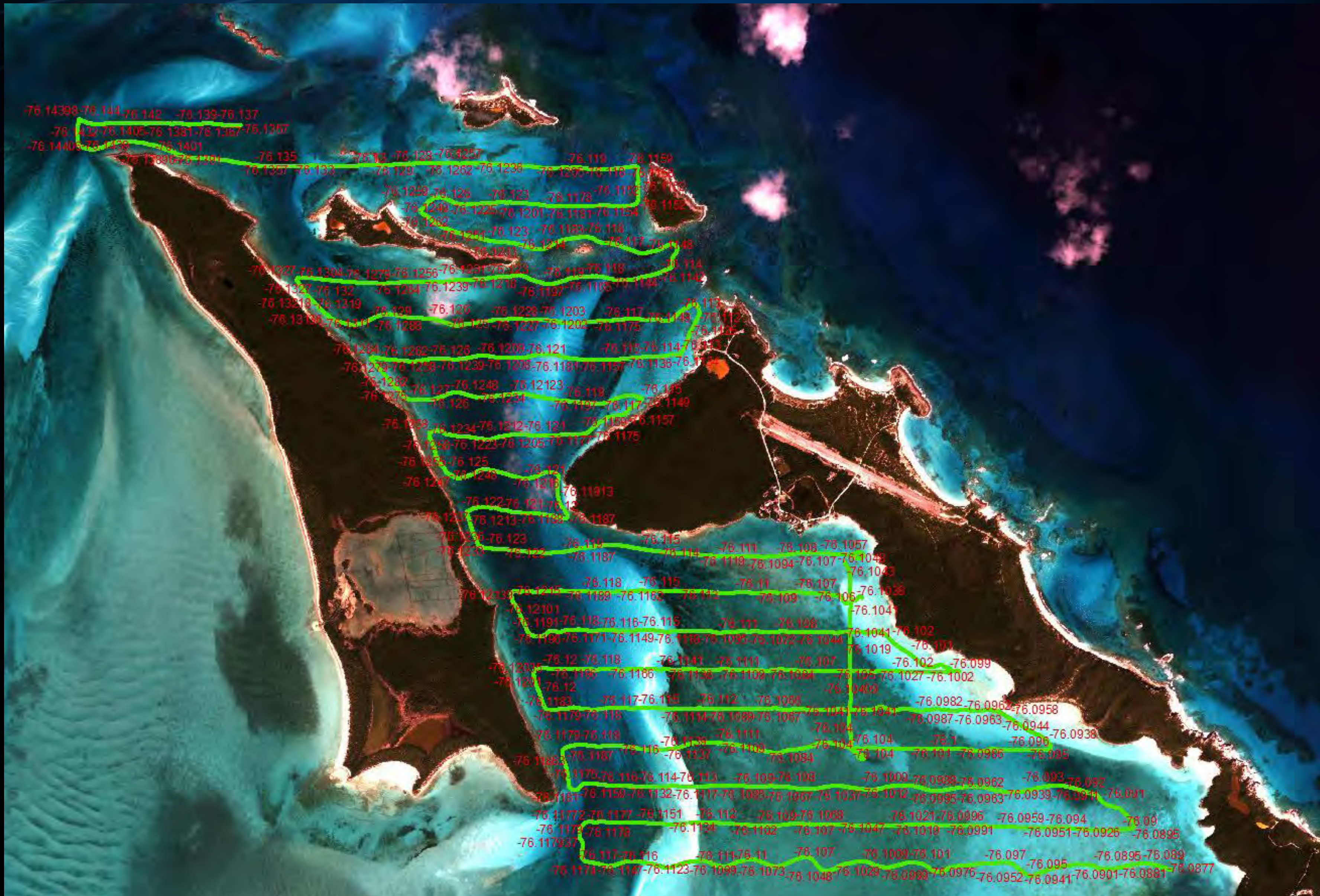
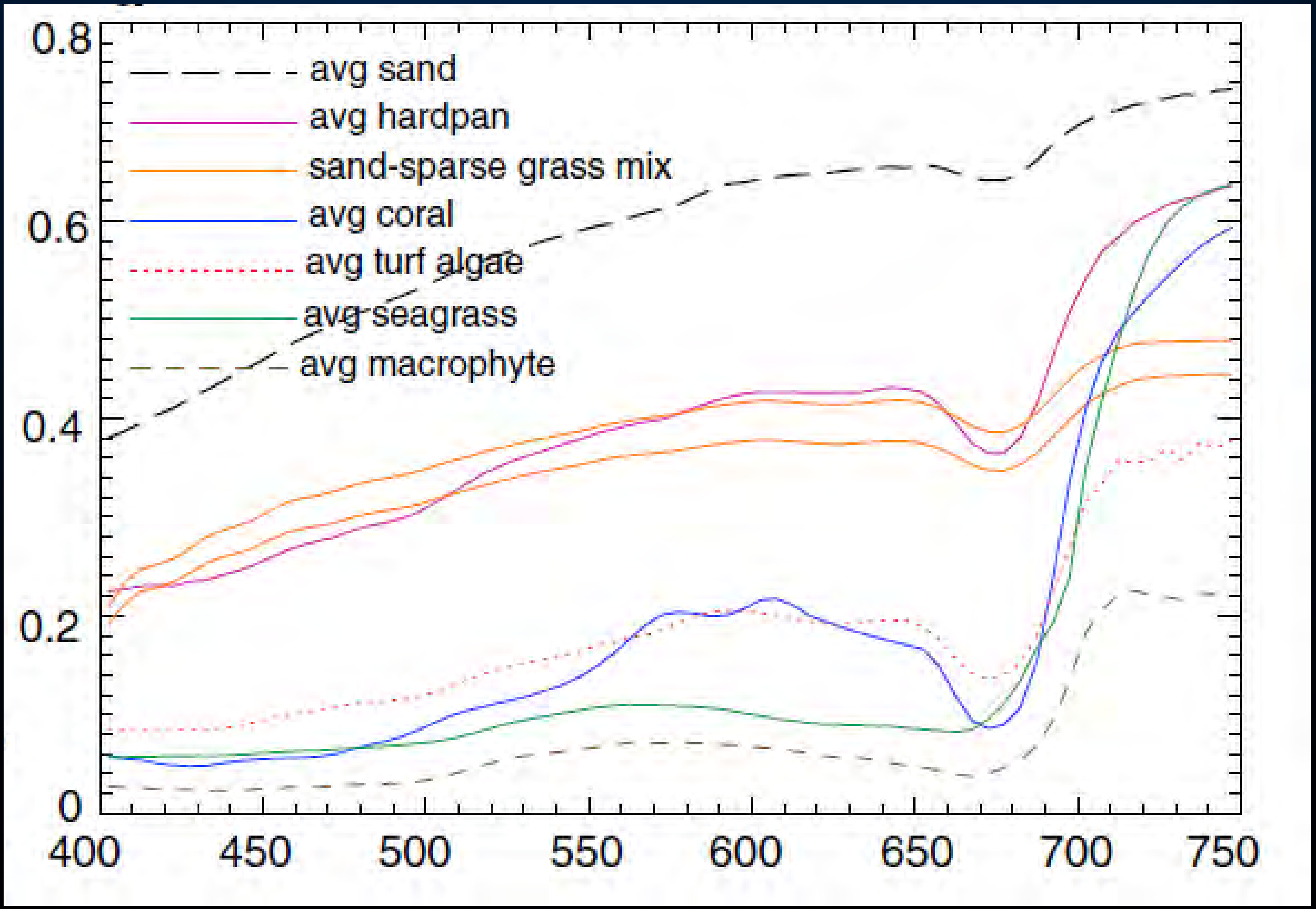
Lee- Stocking Island test site

Sounding data acquired in June 2001
Image collected in December 2010

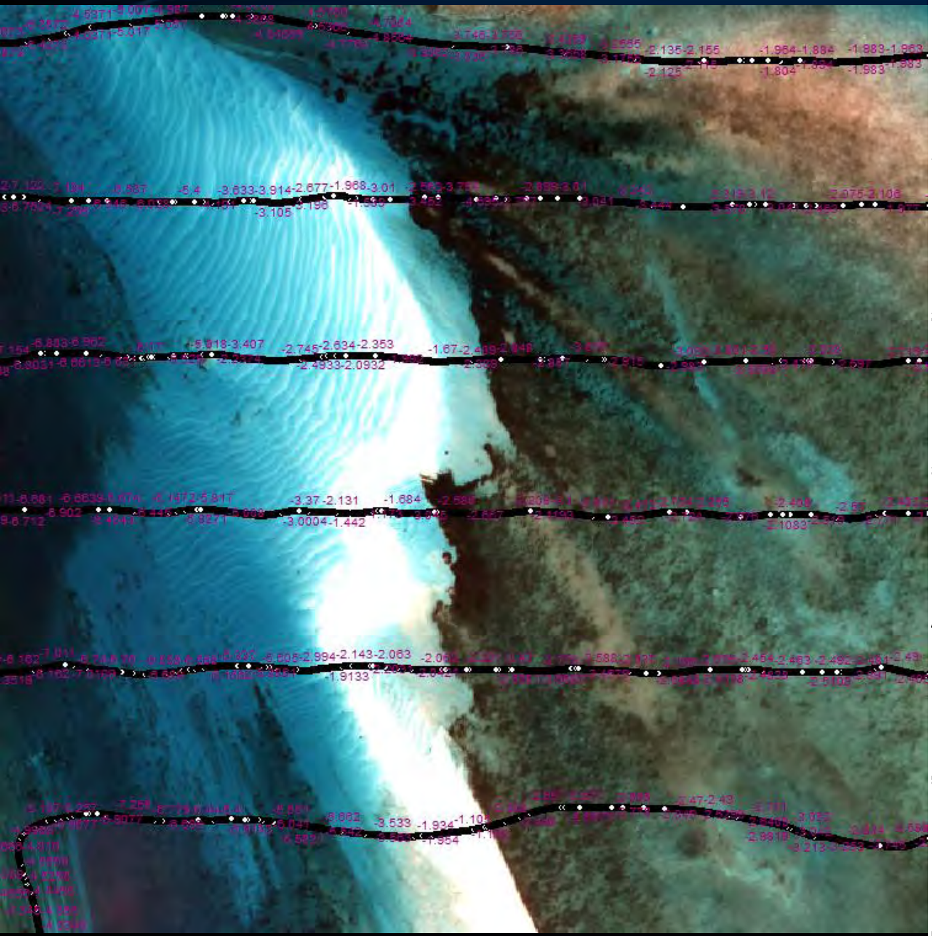


Spectral libraries from Lee-Stock Islands used to simulate the environment

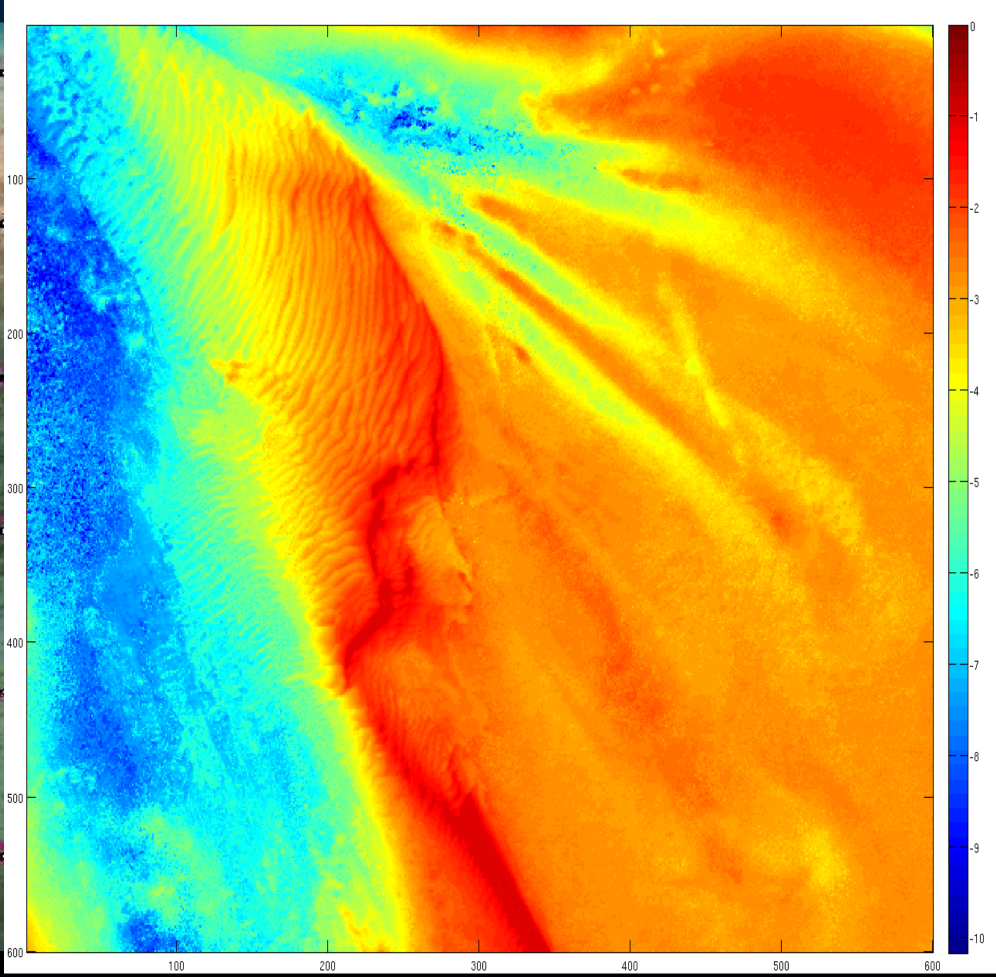


Source: Lesser & Mobley, 2007, Coral Reefs. 26:819:829

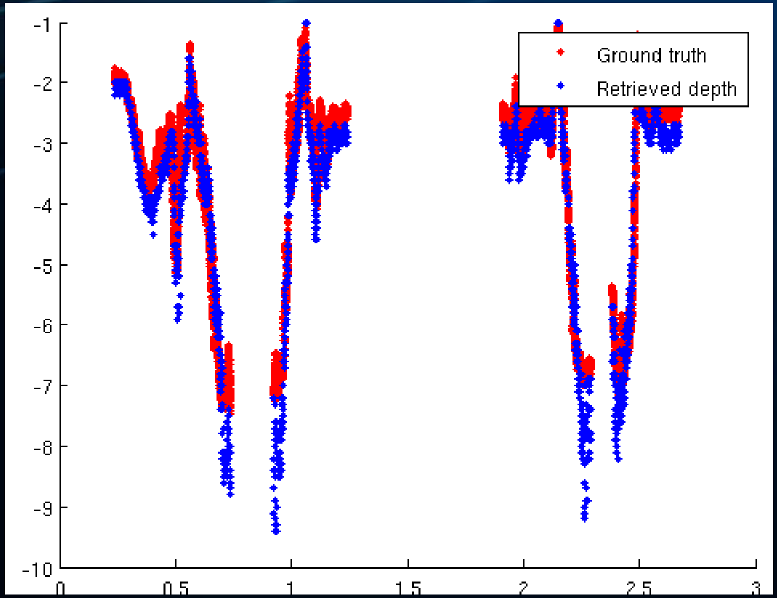
SONAR GT

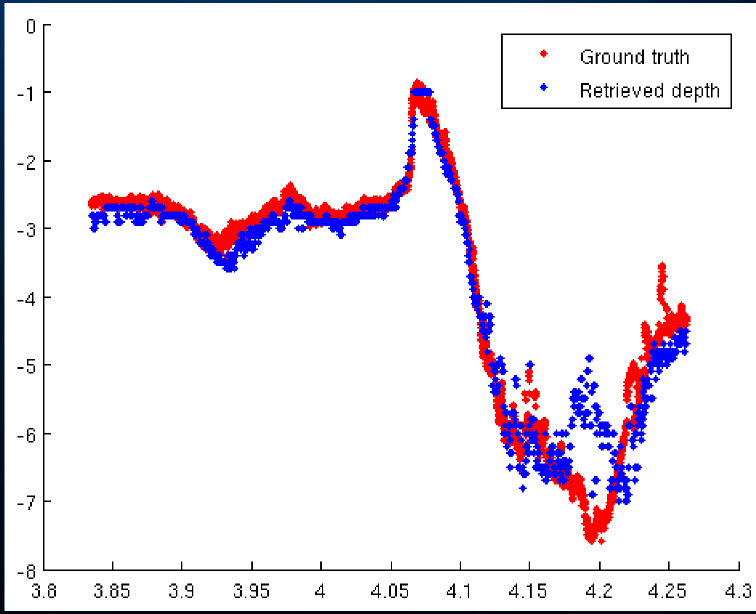


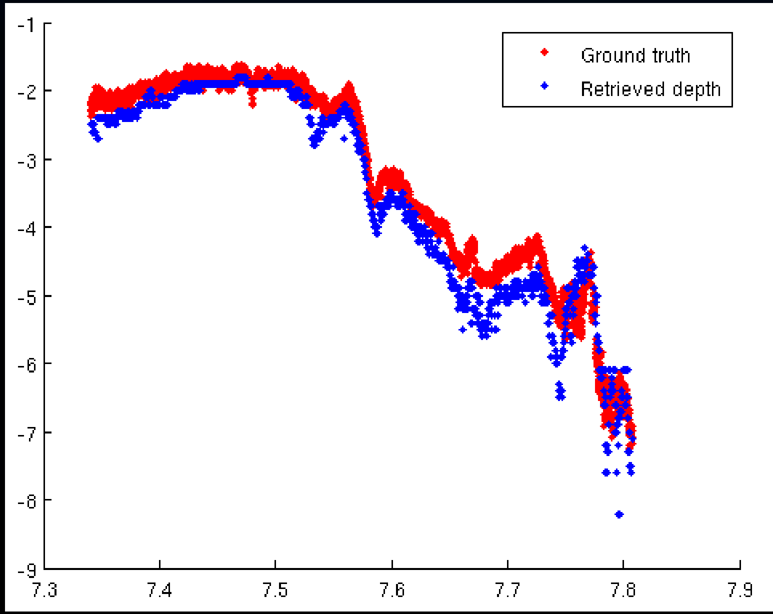
WV2 Bathymetry

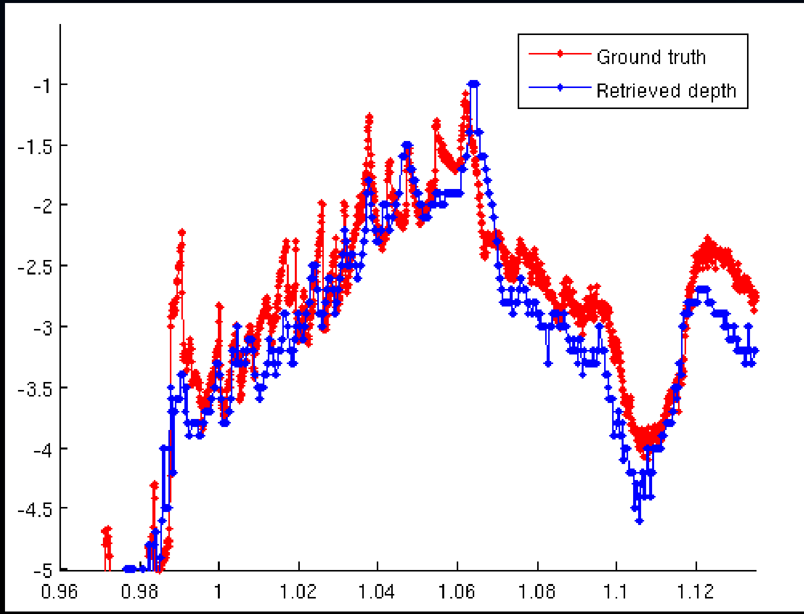


Accuracy (RMS error < 30 cm)









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Conclusions

- There is sufficient information content in WV02 spectral bands to retrieve water depths with 1-2m errors for waters as deep as 18 m.

- Coastal, Green, and Blue bands help with near-shore bathymetry
- Coastal, Green, Yellow and RE bands help with Benthic Habitat and Substrate/Sea Floor Mapping
    - Habitat maps can have accuracy ~90%

- Accuracy may not be high as Lidar or Sonar but wider geographic coverage and high refresh rate at a fraction of the cost

- Physical retrievals require very small training set (bottom reflectance and water IOP) compared with supervised classification methods.
    - Rich spectral libraries are available
    - Spectral libraries are typically representative of millions of square kilometers.