8-2013

Satellite-derived bathymetry: A reconnaissance tool for hydrography

Shachak Pe'eri
University of New Hampshire, Durham, shachak.peeri@unh.edu

Christopher Parrish
University of New Hampshire, Durham

Lee Alexander
University of New Hampshire, Durham, lee.alexander@unh.edu

Andy Armstrong
University of New Hampshire, Durham

Satellite-Derived Bathymetry : A reconnaissance tool for hydrography

Shachak Pe'eri[1], Christopher Parrish[2,3], Lee Alexander[1], and Andrew Armstrong[1,3]

[1] Center for Coastal and Ocean Mapping, University of New Hampshire, Durham, NH, USA
[2] NGS Remote Sensing Division, NOAA/NOS, National Geodetic Survey, Silver Spring, MD, USA
[3] Joint Hydrographic Center, National Oceanic and Atmospheric Administration, Durham, NH, USA

SDB: Technical overview

- **Approaches:**
  - Inversion methods (e.g., Lyzenga 1978, 2006; Philpot 1989)
  - Ratio approaches (e.g., Dierssen et al. 2003; Stumpf et al. 2003)
  - Look-up tables (LUT) (e.g., Louchard et al. 2001)

Stumpf et al. 2003

$$Z = m_0 \cdot \frac{\ln(L_{obs}(\lambda_i))}{\ln(L_{obs}(\lambda_j))} - m_1$$

$L_{obs}(\lambda_i)$, $L_{obs}(\lambda_j)$-radiance values

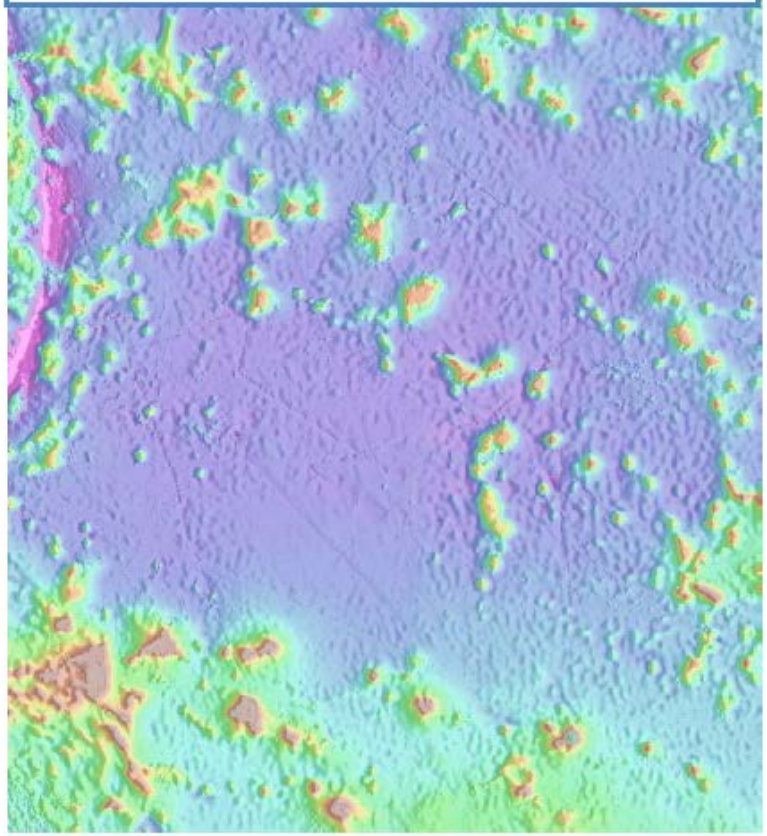
m_o- gain

m_1- offset

SDB: Study activities

- **Developed a satellite-derived procedure using ArcMap.**
- **Demonstrated proof of concept in US (MA), Nigeria and Belize.**
- **Estimate the product accuracy.**
- **Broadened our collaboration within NOAA (e.g., IOCM and OSC/CSDL).**
- **Evaluated imagery from different satellites over (Barrow, AK and Buck Island, USVI).**
- **Participated in an external evaluation study by NOAA over (Simeonof Island, AK; Saipan; St. Thomas, USVI).**
- **Published the procedure and our results.**

The IHO-IOC GEBCO Cook Book



February 2013

IHO Publication B-11
IOC Manuals and Guides, 63

Chapter 11.0 LANDSAT 7 Satellite-Derived Bathymetry

Contributed by S. Pe'eri, B. Madore and L. Alexander, Center for Coastal and Ocean Mapping, USA, C. Parrish and A. Armstrong, National Oceanic and Atmospheric Administration, USA, and C. Azuike, Nigerian Navy Hydrographic Office Lagos, Nigeria

Since the 1970's, satellite remote sensing has become increasingly recognized as a useful reconnaissance tool to map near-shore bathymetry, characterize a coastal area and to monitor seafloor changes that may have occurred since the last hydrographic survey was conducted. Satellites allow for the capturing of images over broad expanses of the Earth. The following procedure provides the user with an inexpensive and quick approach to derive bathymetry from satellite imagery. The data sources used in the procedure below are publicly-available imagery collected by LANDSAT 7 satellite using the Enhanced Thematic Mapper Plus (ETM+) instrument and chart soundings.

The key steps in the procedure include:

1. **Pre-processing** – Satellite imagery is downloaded based on the geographic location and environmental conditions (e.g., cloud coverage and sun glint) had to be used.
2. **Water separation** – Dry land and most of the clouds are removed.
3. **Spatial filtering** – 'Speckle noise' in the Landsat imagery is removed using spatial filtering.
4. **Applying the bathymetry algorithm** – The Stumpf et al. (2003) algorithm using the blue and green bands.
5. **Identifying the extinction depth** – The optic depth limit for inferring bathymetry (also known as, the extinction depth) is calculated.
6. **Vertical referencing** – A statistical analysis between the algorithm values to the chart soundings references the Digital Elevation Model (DEM) to the chart datum.

For more details on satellite-derived bathymetry and hydrographic applications, please refer to Pe'eri et al. (2013).

Pe'eri, S., C. Parrish, C. Azuike, L. Alexander and A. Armstrong, 2013. Satellite Remote Sensing as Reconnaissance Tool for Assessing Nautical Chart Adequacy and Completeness, *Marine Geodesy* (submitted).

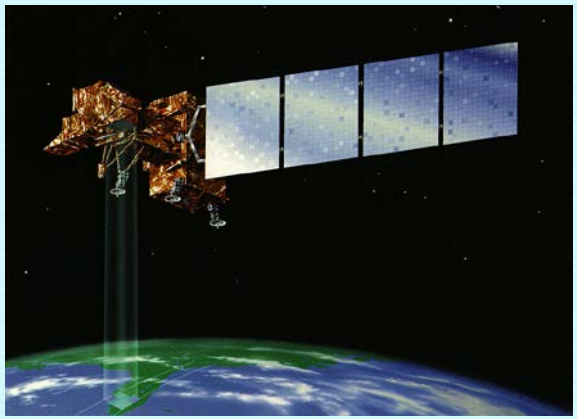
Stumpf, R., K. Holderied and M. Sinclair, 2003, Determination of water depth with high-resolution satellite imagery over variable bottom types, *Limnology and Oceanography*, **48,** 547-556.

http://ibis.grdl.noaa.gov/SAT/GEBCO_Cookbook/index.php

Directions over the past year

- Is the procedure limited spatially or can bathymetry be derived in other geographical locations, namely the Arctic?
- The water clarity is the main error source. Is it possible to reduce this error or at least identify the locations most affected by water clarity?
- Would this procedure work with imagery from other satellites?

Available resources



Landsat 7

Launch Date: 4/1999

Landsat 8 (LDCM)

Launch Date: 2/2011

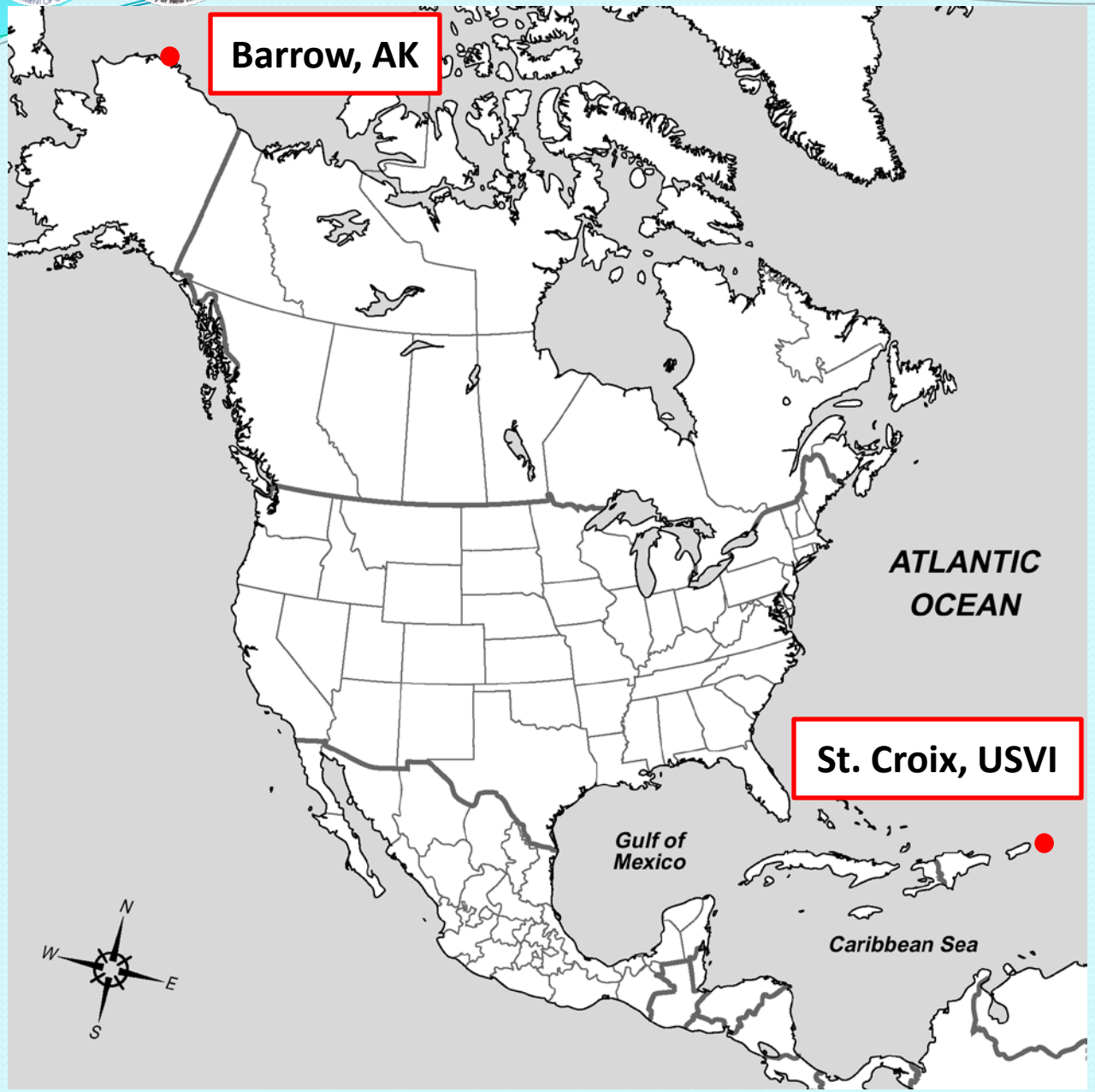
WorldView2

Launch Date: 10/2009

Organization: NASA/USGS program
Swath: 185km
Ground resolution: 28.5m

Company: DigitalGlobe
Swath: 18 km
Ground resolution: 2m

(Images from landsat.gsfc.nasa.gov and www.digitalglobe.com)



Study sites

St. Croix, USVI

Site: Buck Island

Water: very clear

Bottom: Coral and sand

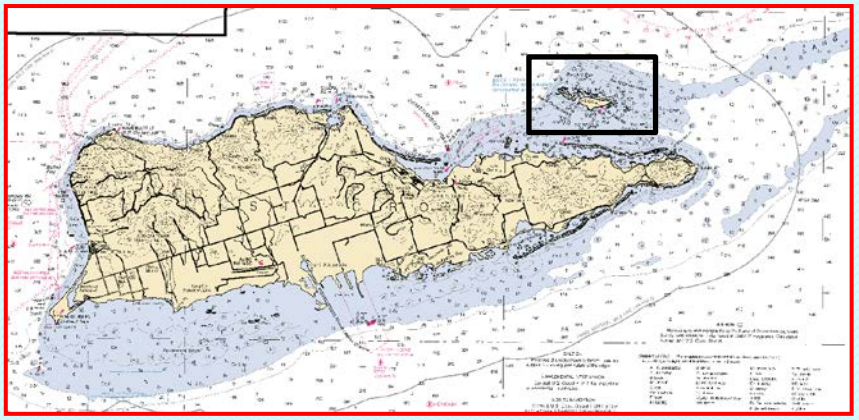
Barrow, AK

Site: Elson Lagoon

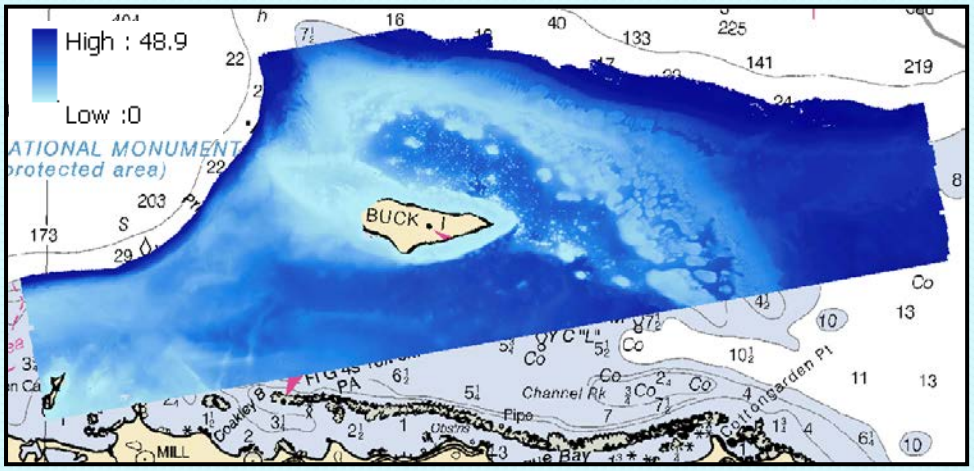
Water: Turbid

Bottom: mud, sand and gravel

Buck Island, USVI

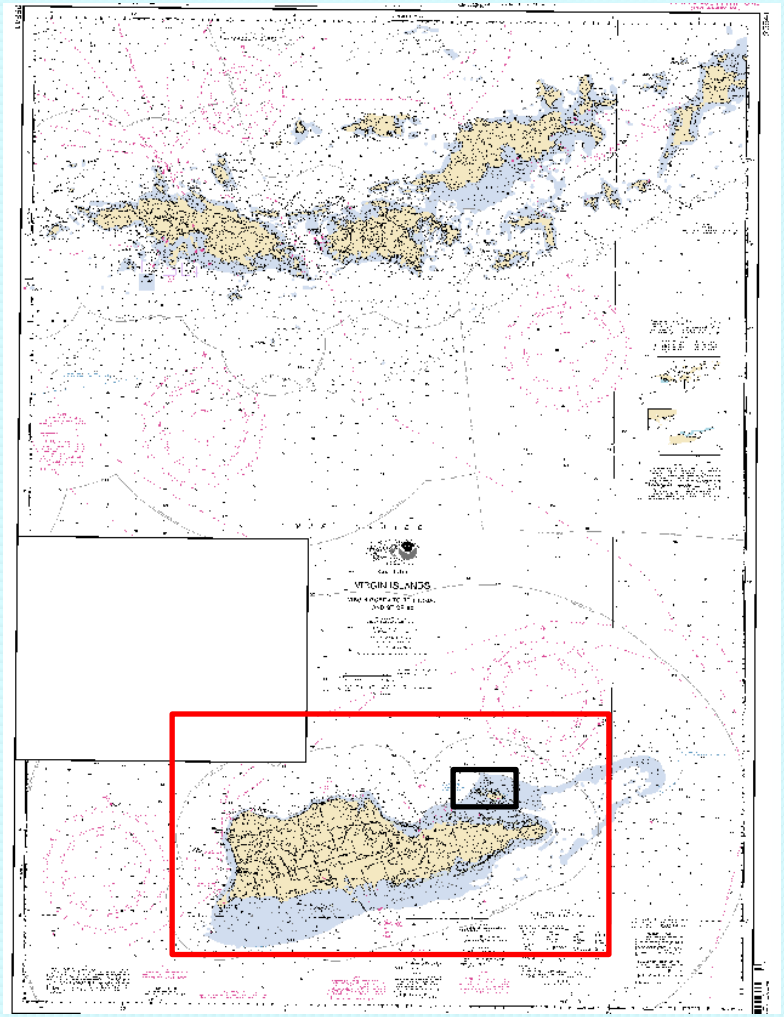


St. Croix, USVI



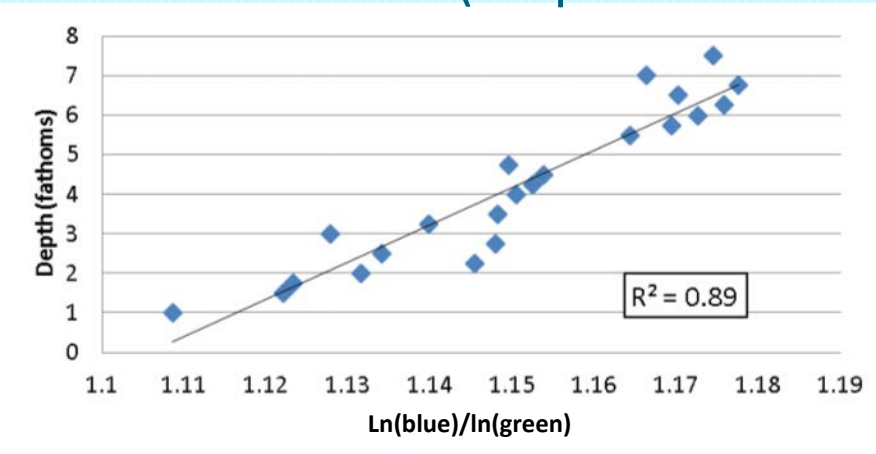
ALB reference dataset (LADS-MKII)

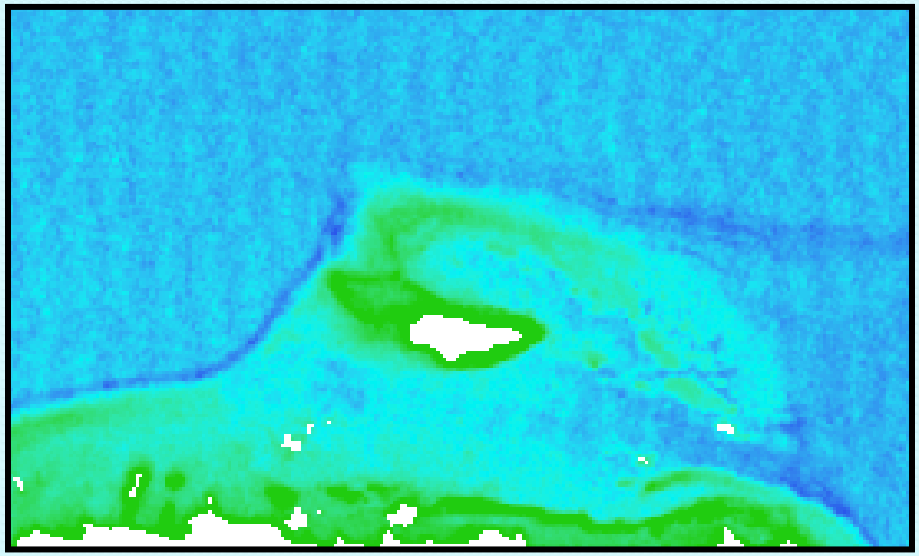
NOAA Chart 25641 (scale: 1:100,000)

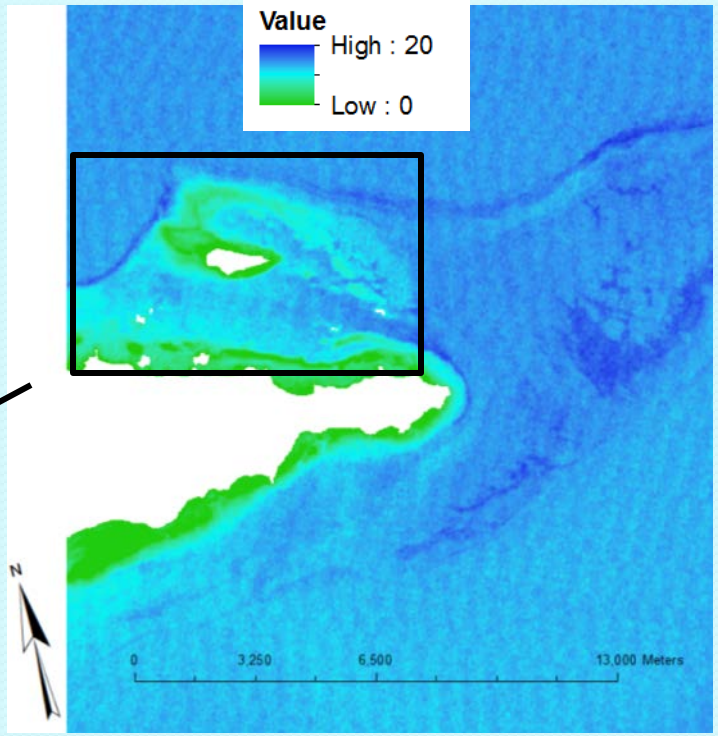


Landsat 7 results

(Acquisition date: January 8, 2003)







Satellite-derived bathymetry

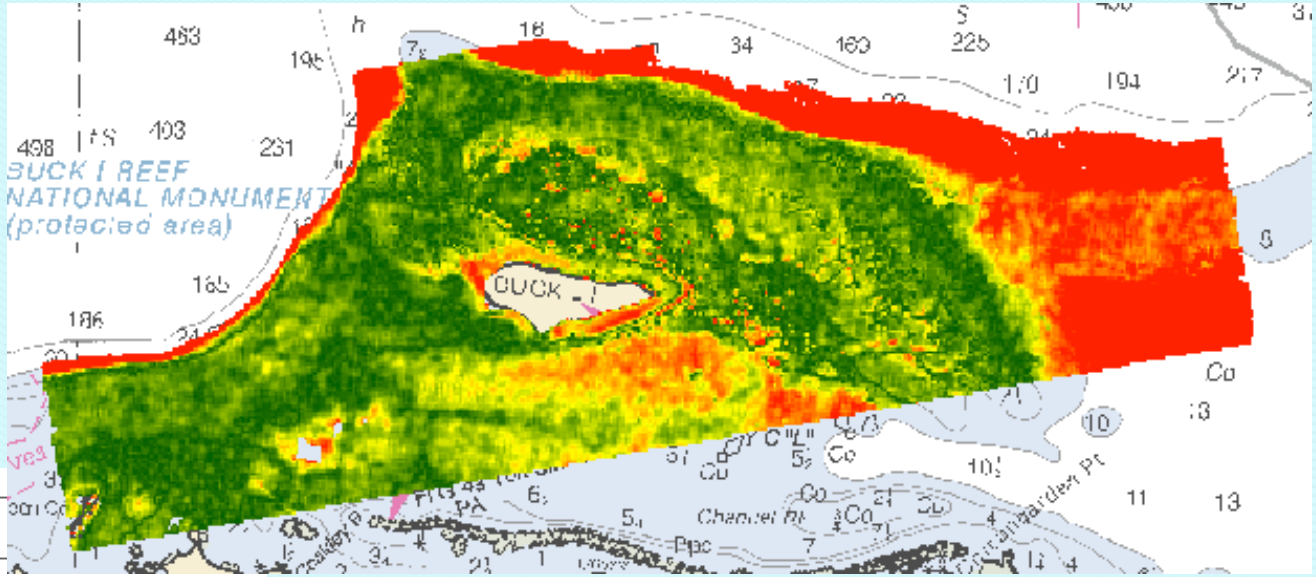
Landsat 7 results

(comparison to reference bathymetry)

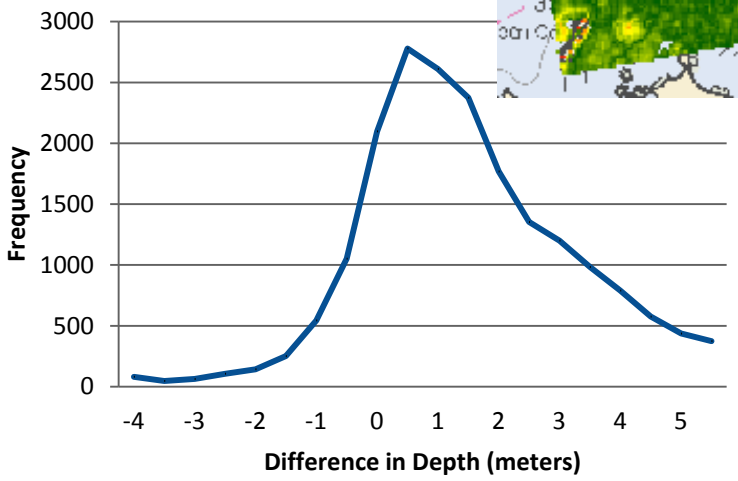
Absolute depth difference

±6 m

0 m



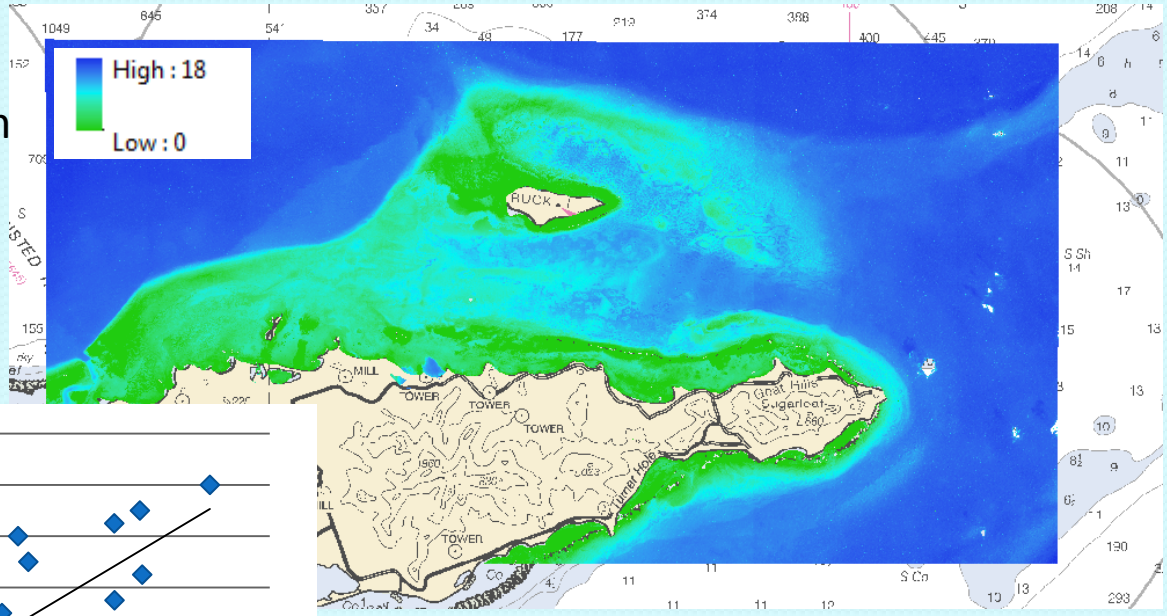
Grid resolution: 28.5 m

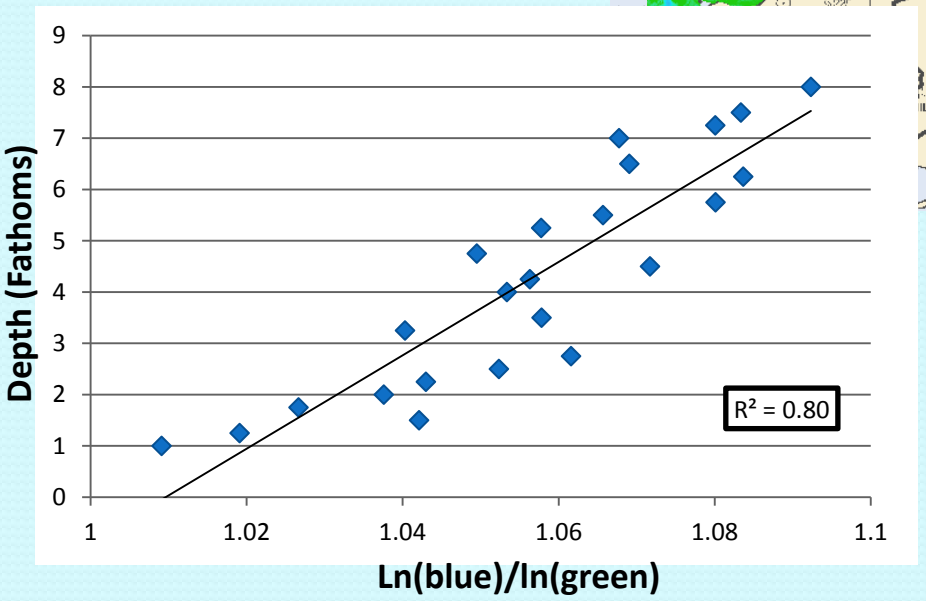


WorldView2 results

(Acquisition date: January 14, 2012)

Extinction depth: 14.5 m
(8 Fathoms)

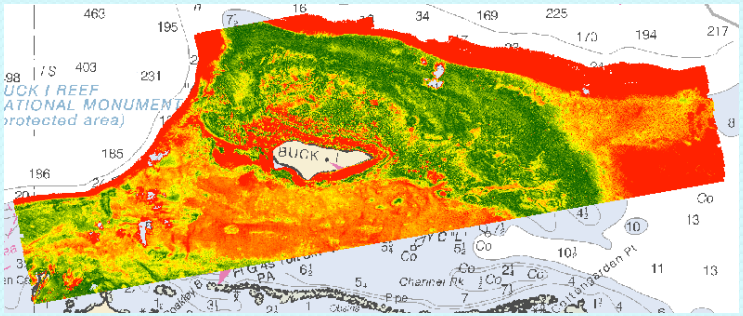




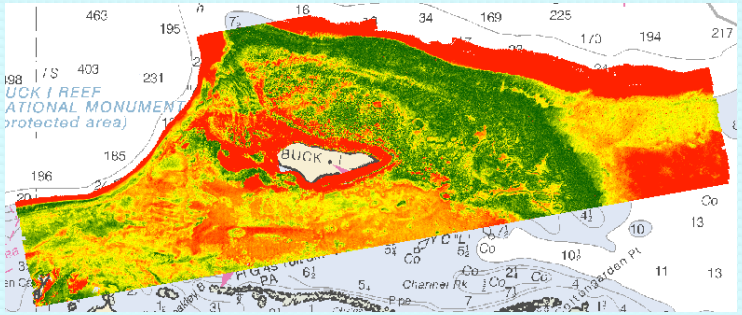
Satellite-derived bathymetry

WorldView2 results

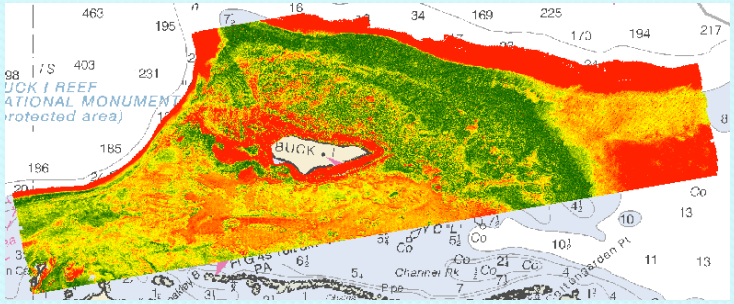
(comparison to reference bathymetry)



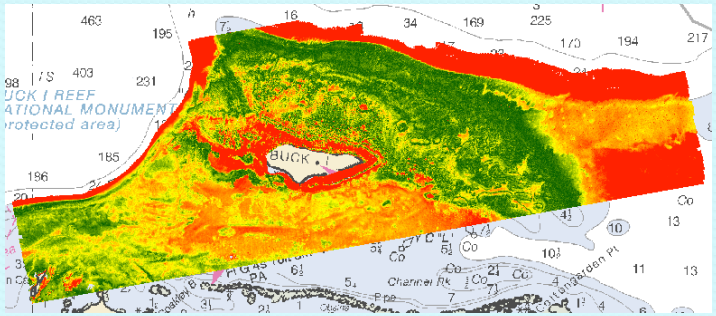
1126 - 12/8/2009
(15:11:26 GMT; off-nadir angle: 22.9°)



1716 - 1/14/2012
(15:17:16 GMT; off-nadir angle: 15.3°)

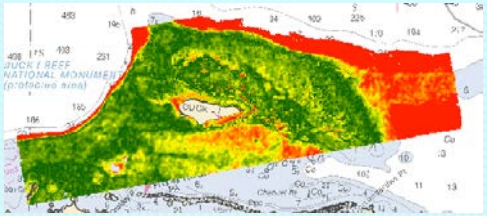


1706 - 1/14/2012
(15:17:06 GMT; off-nadir angle: 10.5°)



1730 - 1/14/2012
(15:17:30 GMT; off-nadir angle: 20.5°)

Landsat 7



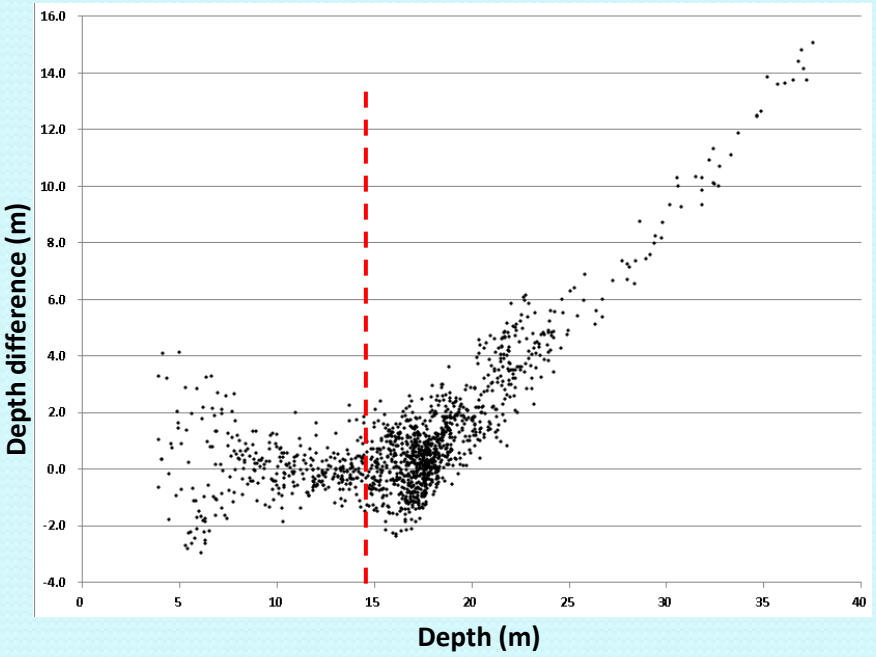
Absolute depth difference

±6 m

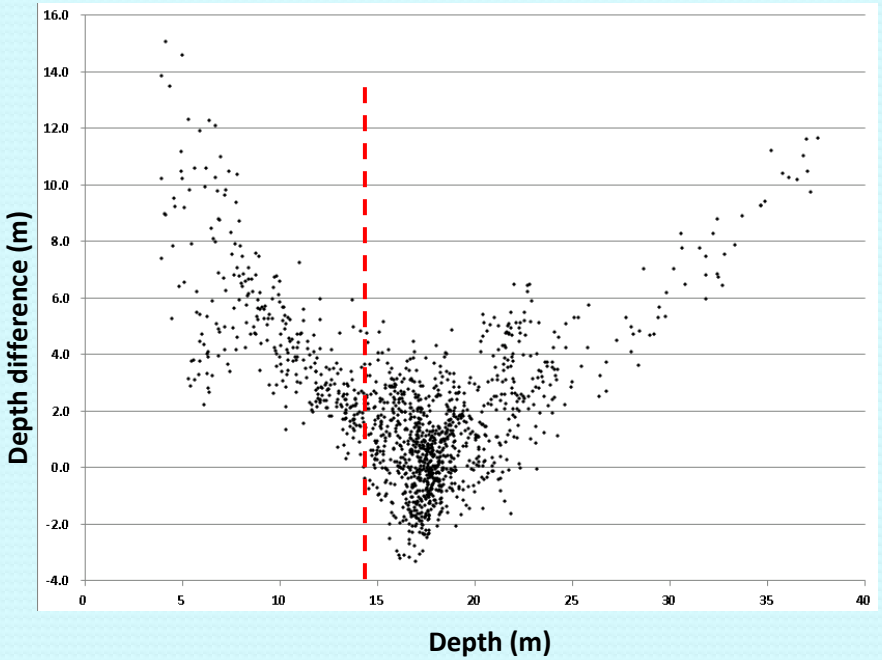
0 m

Reference sources

Elevation difference over Buck Island study site between satellite-derived bathymetry (Landsat 7) and the lidar reference bathymetry (LADS MK-II)



Referencing to chart datum using lidar



Referencing to chart datum using chart soundings

Extinction Depth (14.5 m)

Elson Lagoon, Ak

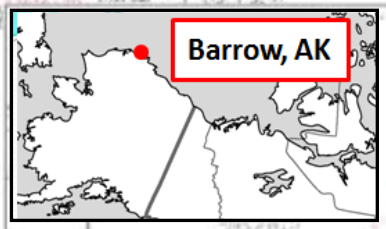
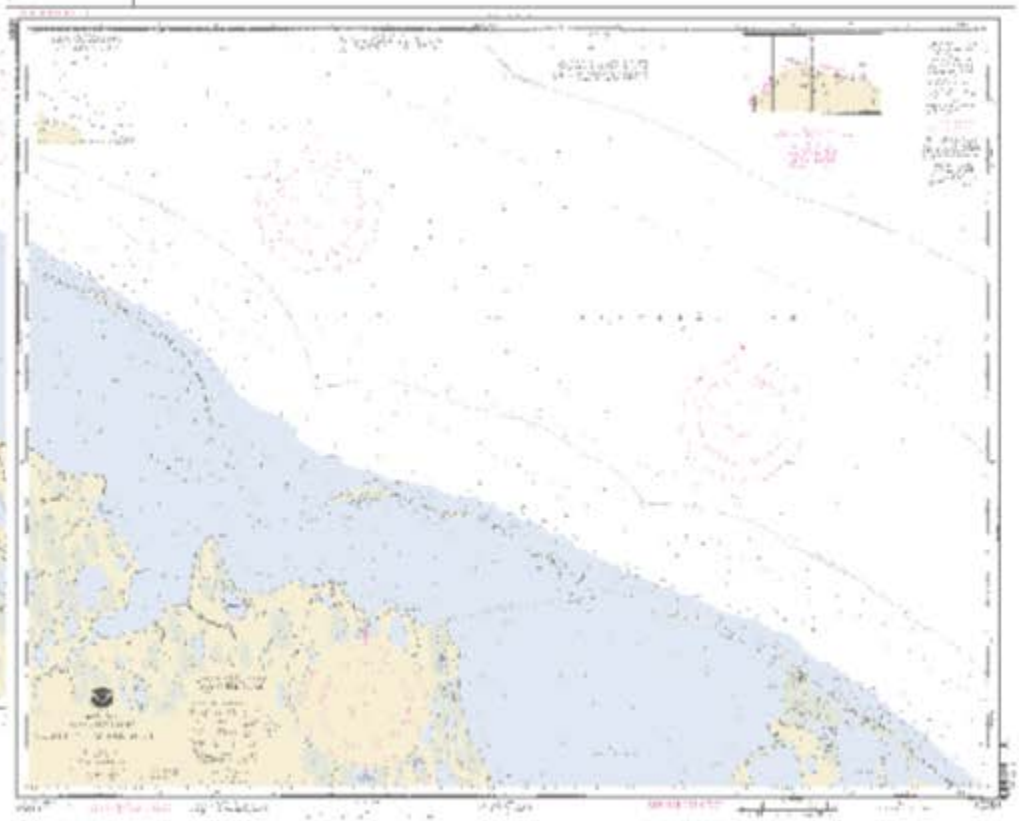


Chart 16082 (Scale 1:47,943)

NOAA Chart 16081 (scale 1:48,149)



Reference depth measurements

Diag'd on Diag. Ch. No. 9400

Form 504

U. S. COAST AND GEODETIC SURVEY

DEPARTMENT OF COMMERCE

DESCRIPTIVE REPORT

Type of Survey Hydrographic

Field No. AR-2345 Office No. H-7071

LOCALITY

State ALASKA

General locality ARCTIC OCEAN

Locality POINT BARROW (ELSON LAGOON)

1945

CHIEF OF PARTY

R. W. Woodworth

LIBRARY & ARCHIVES

DATE MAR 11 1946

NOS Survey H07071 - HYD93 Format Header

Format	Ngdc Id		Params	Create Date	Source Institution	Seq
HYD93	03F11278		SF	19791231	National Ocean Survey, N.O.A.A.	01

	Platform Name	Plat Type	Chief Hydrographer(s)	Seq
	Field/Shore Party	1SHIP	R.W. WOODWORTH	02

Type of Survey	Strt Yr	End Yr	Scale of Survey	Seq
	1945	1945	20,000	03

of Survey	Area (Specific) of Survey	Seq
AN	PT. BARROW (ELSON LAGOON)	04

Description	Processing Status Description	Seq
		05

nation	Seq
	06

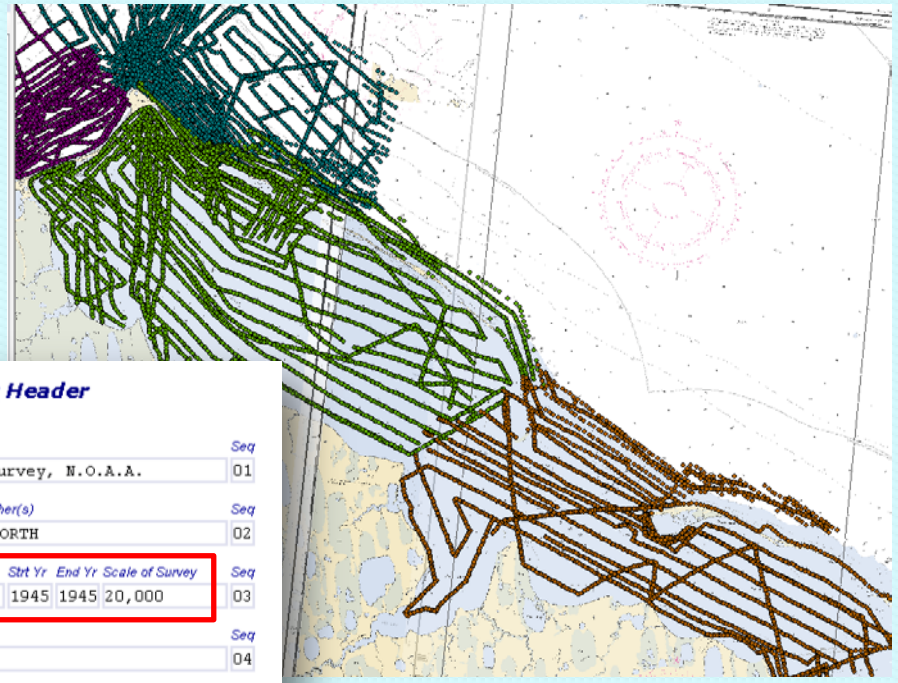
ntal Datum of Records	Code	Original Horizontal Datum	Seq
NO551 North American Datum 1983	MGGAL	Early Alaska Datums	07

code Vertical Datum		tide	Original Sounding Units	Seq
04	Mean Lower Low Water		feet	08

Sounding Method	Seq
Digital Echo Sounder w/ Graphical Record assumed	09

c Sound Velocity Correction	Seq
1 Corrected for actual sound velocity	10

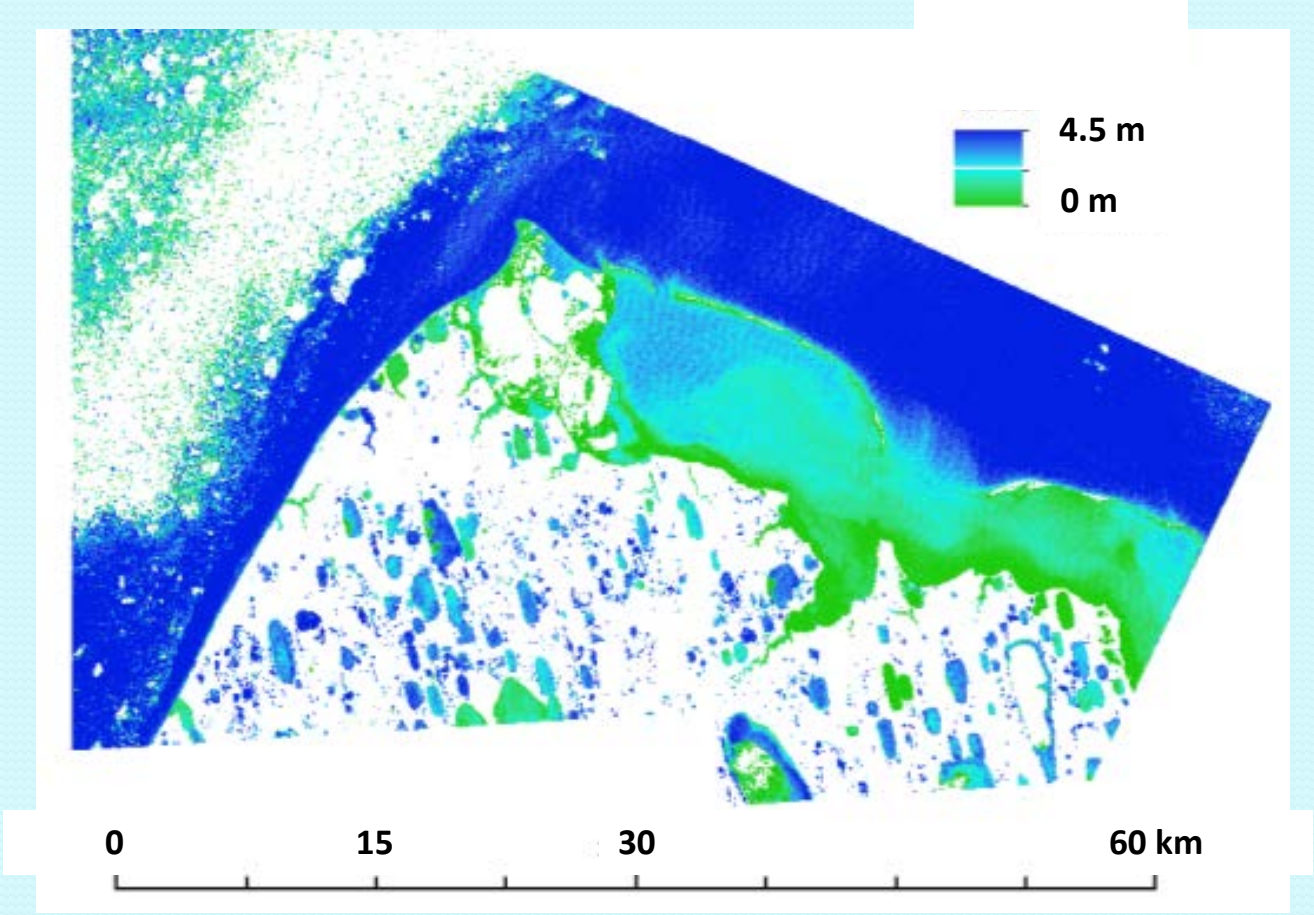
Data Processing Methodology	Seq
Smooth sheets digitized for N.O.S. under Ashville Contract	11



Digitized soundings

Landsat 7 results

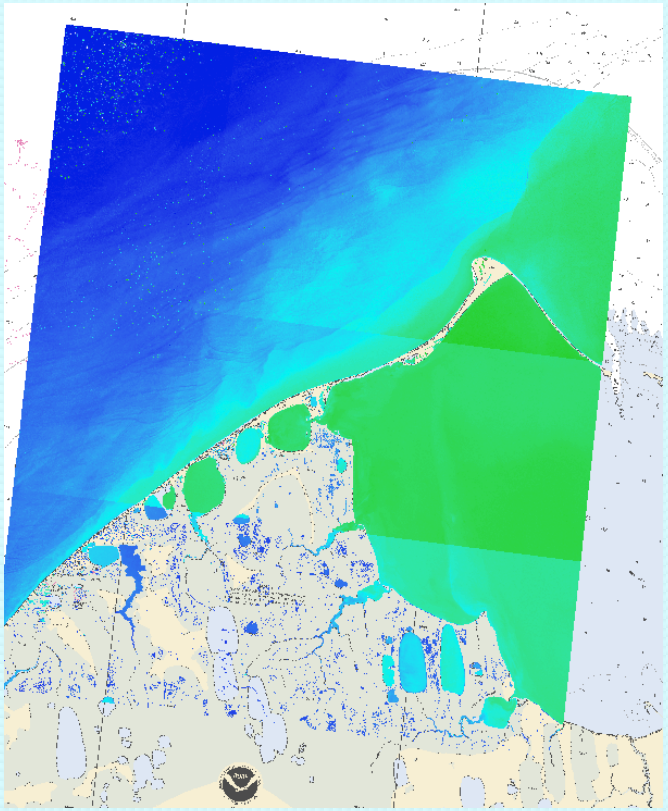
(Acquisition date : July 18, 2002)



Extinction depth: 4.5 m (15 ft)

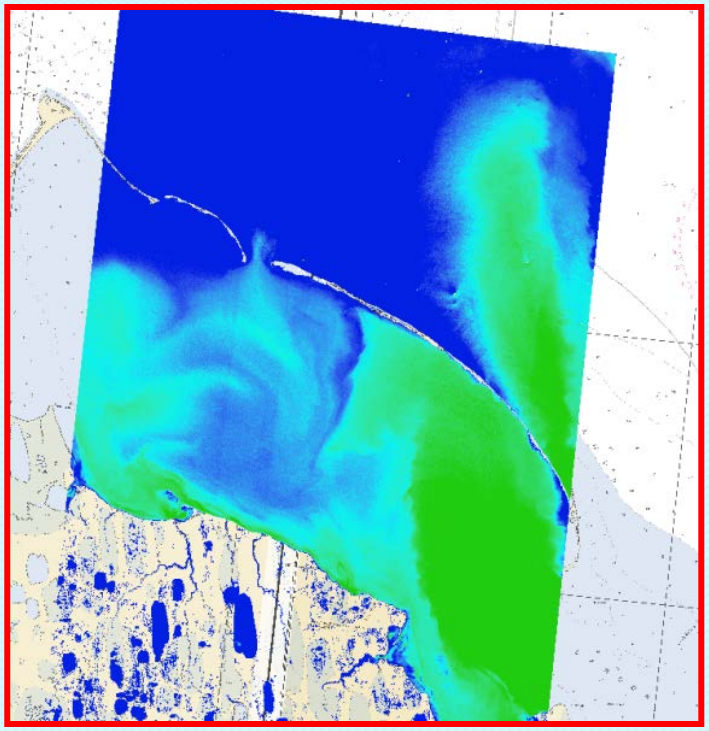
WorldView2 results

(Acquisition date: July 21, 2010 through August 10, 2010)

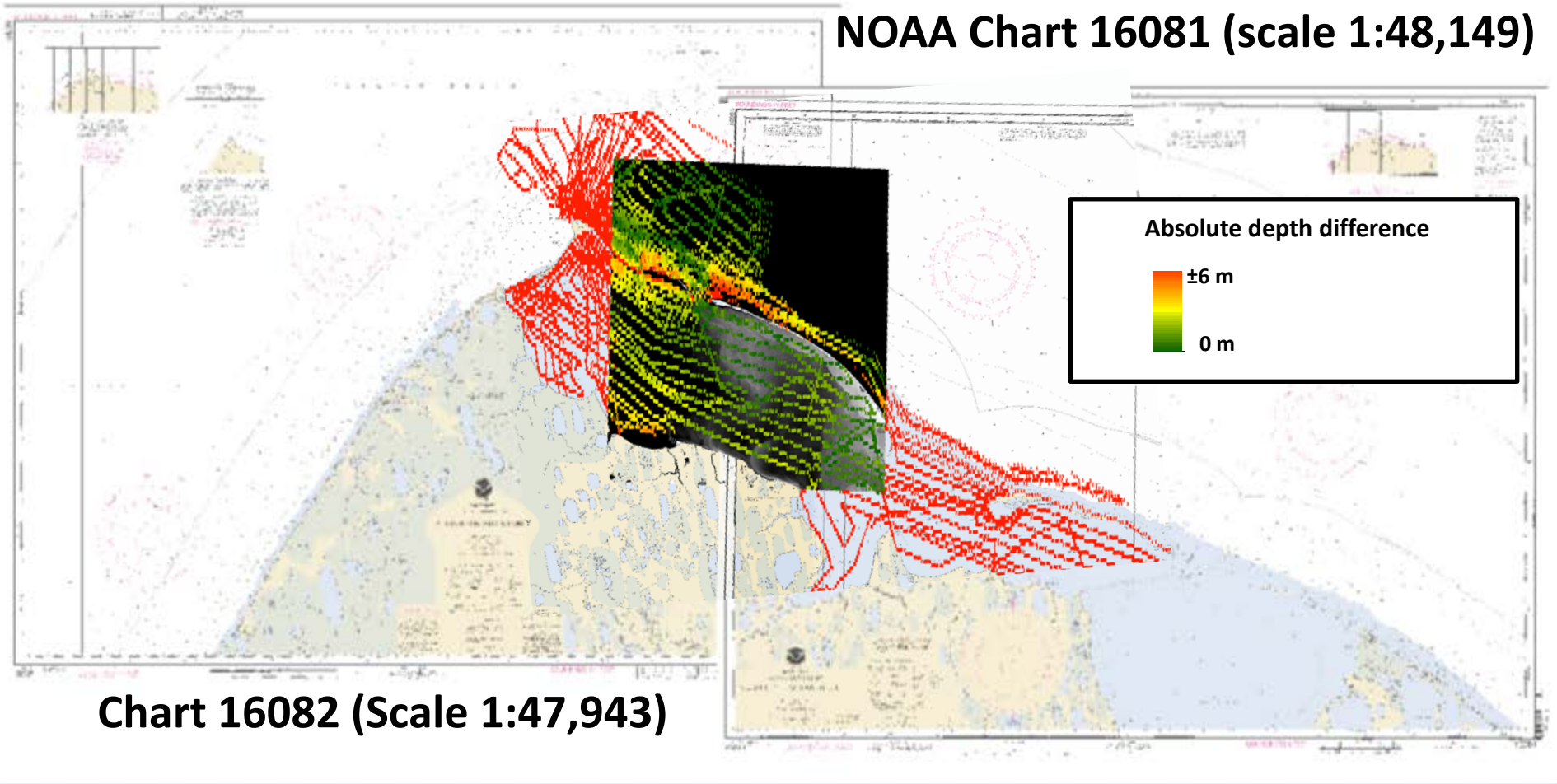


Extinction depth: 3.9 m (13 ft)

Extinction depth: 4.3 m (14 ft)

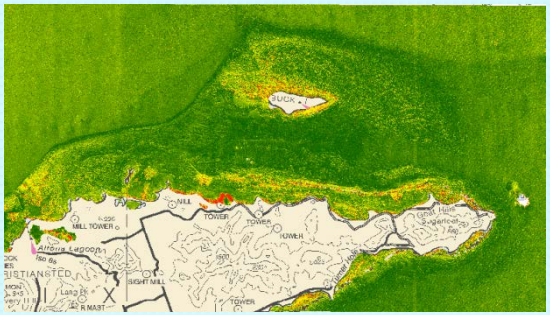


Comparison to the chart soundings (WV2)

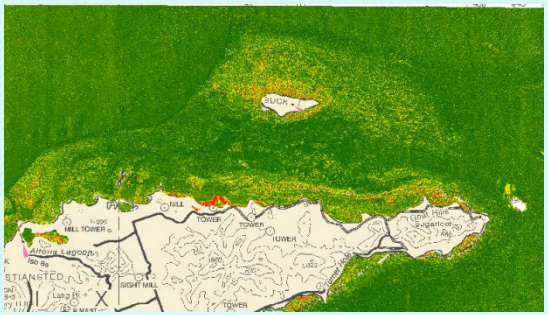


Time series over Buck Island

1718_1730 (Δt=12 min)

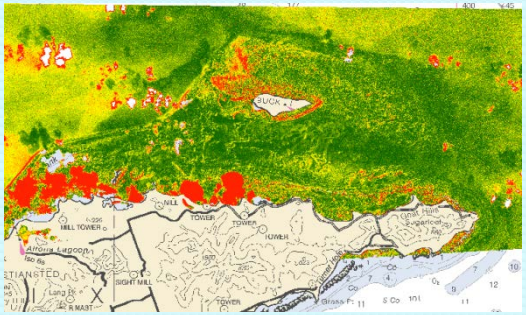


1706_1730 (Δt=24 min)

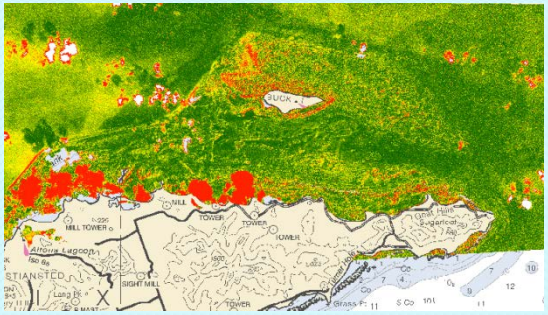


1706_1718 (Δt=12 min)

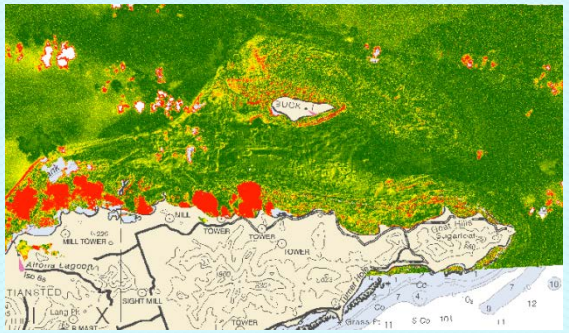
1126_1718 (Δt=2y1m6d)



1126_1706

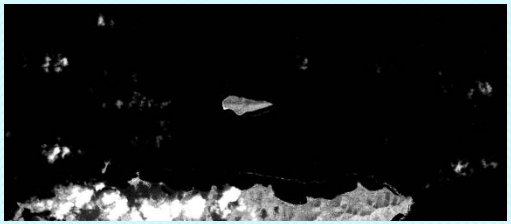


1126_1730



(Δt = 2 years 1 month 6 days)

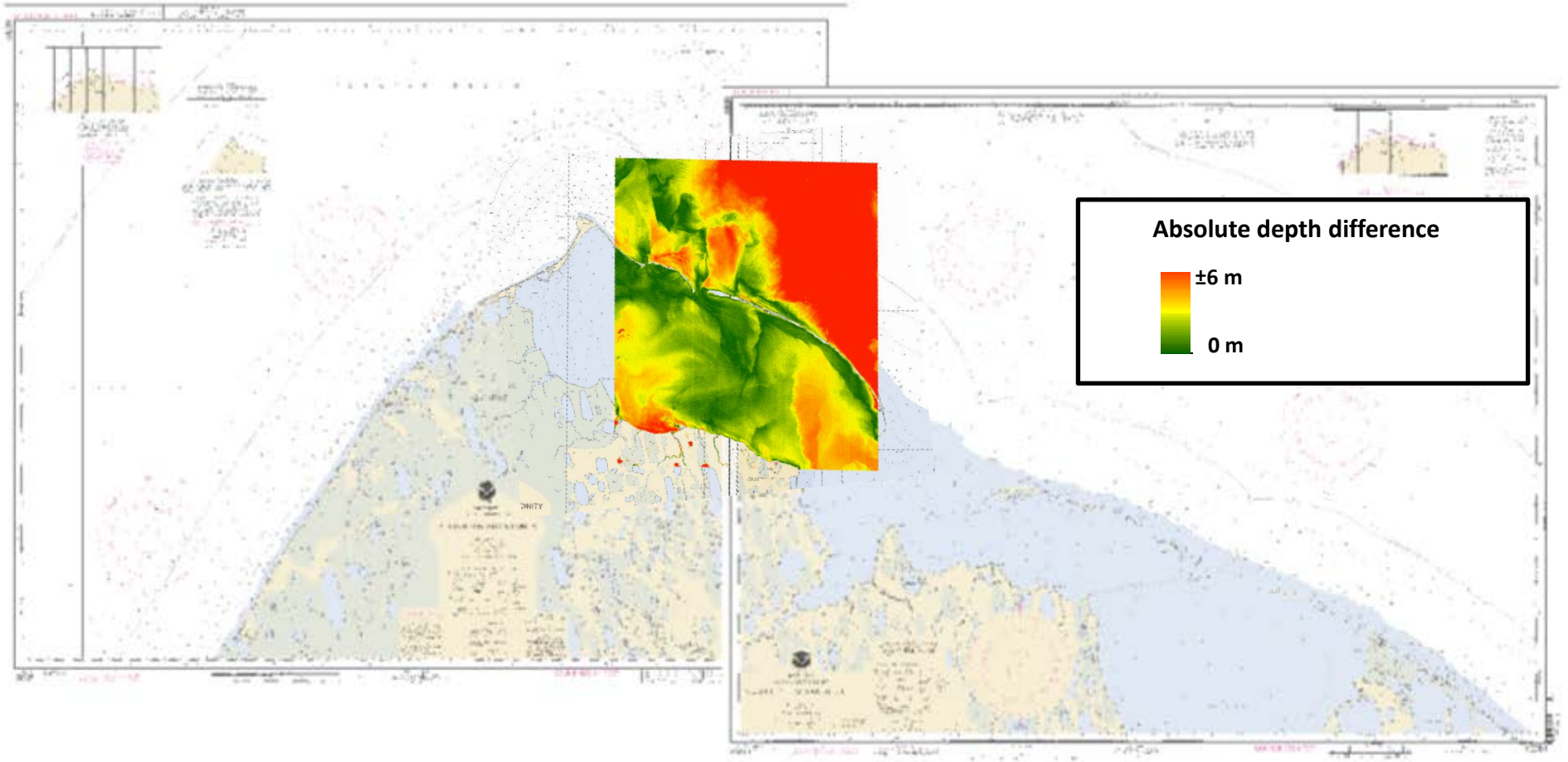
Absolute depth difference



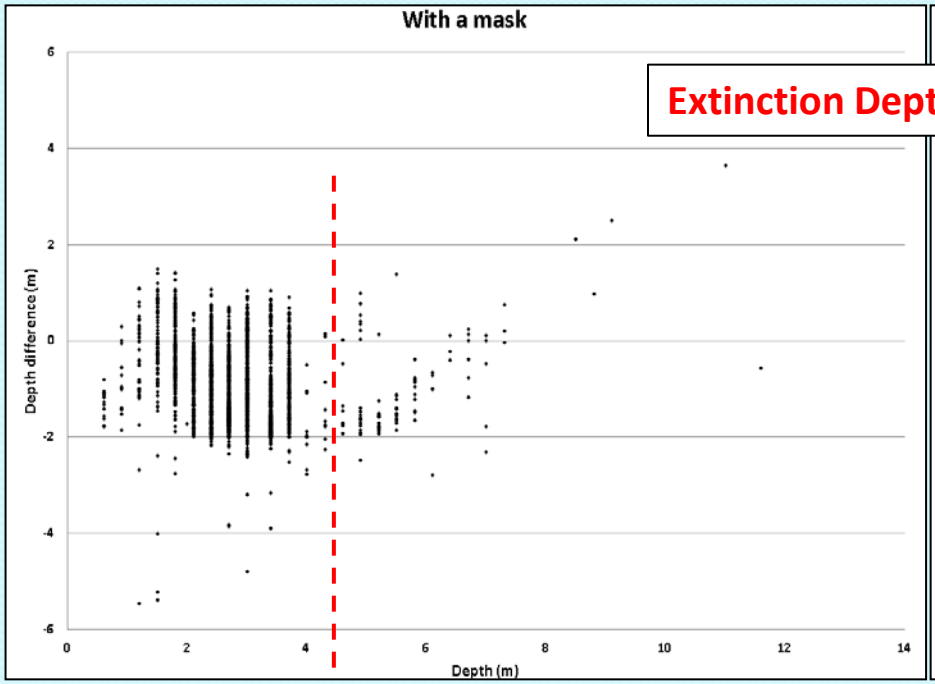
NIR band 6

Up to 14 m misalignment between the images

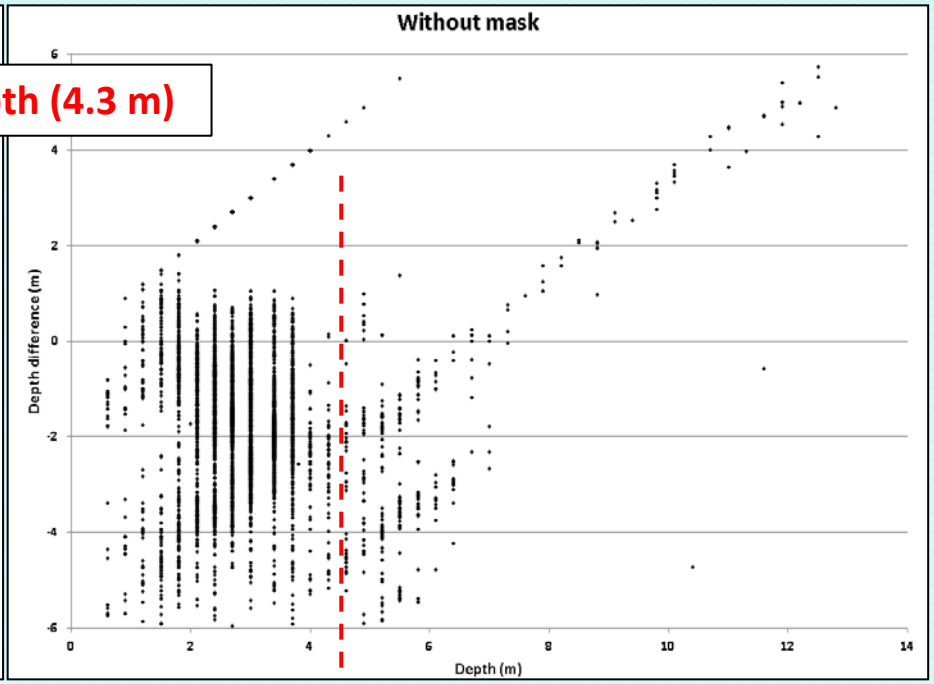
Time series over Elson Lagoon



Results (WorldView2)



Extinction Depth (4.3 m)



Statistics (≤ 4.3 m):

Mean = -0.49 m

Standard deviation = 0.64 m

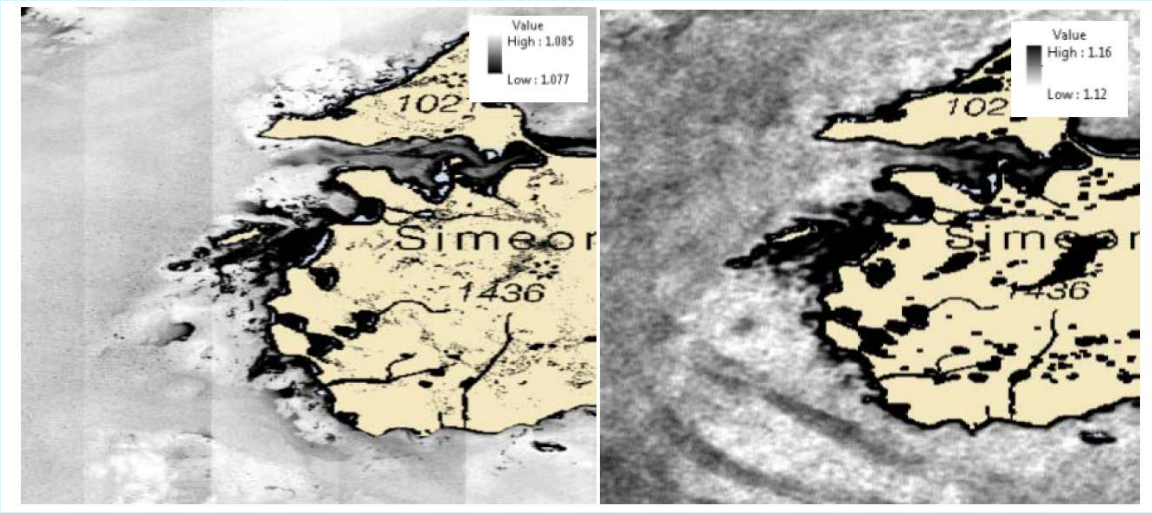
Statistics (≤ 4.3 m):

Mean = -0.95 m

Standard deviation = 0.81 m

SDB: Issues with product results

Image quality

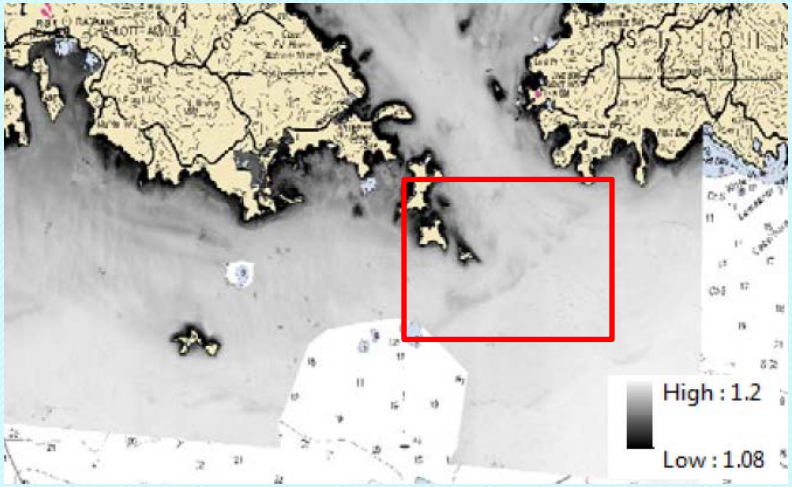


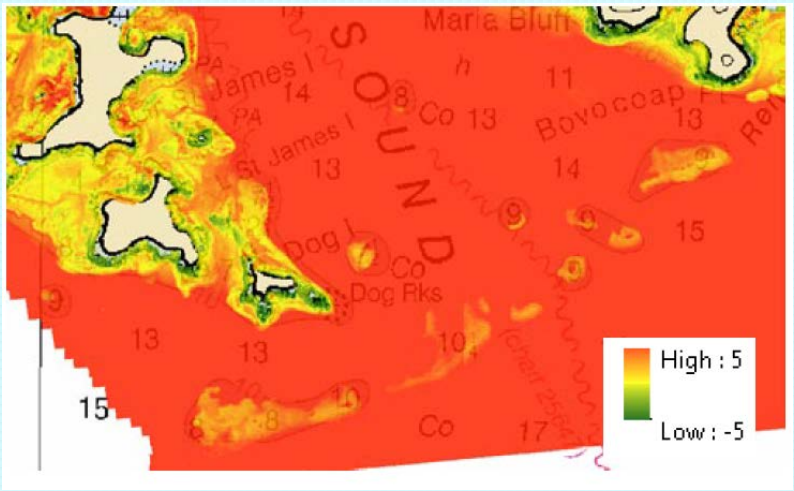
WV2 (also with Landsat8) **Landsat7**

Depth

Site	WV2_eff	L7 _eff	WV2 _rec	L7_rec
Barrow, AK	4.5 m	4.3 m	6 m	6 m
Simeonof Island, AK	4.5 m	4.2 m	12.5 m	12.5 m
Saipan	12 m	6 m	23 m	10 m
St. Thomas, USVI	10 – 11 m		17 m	

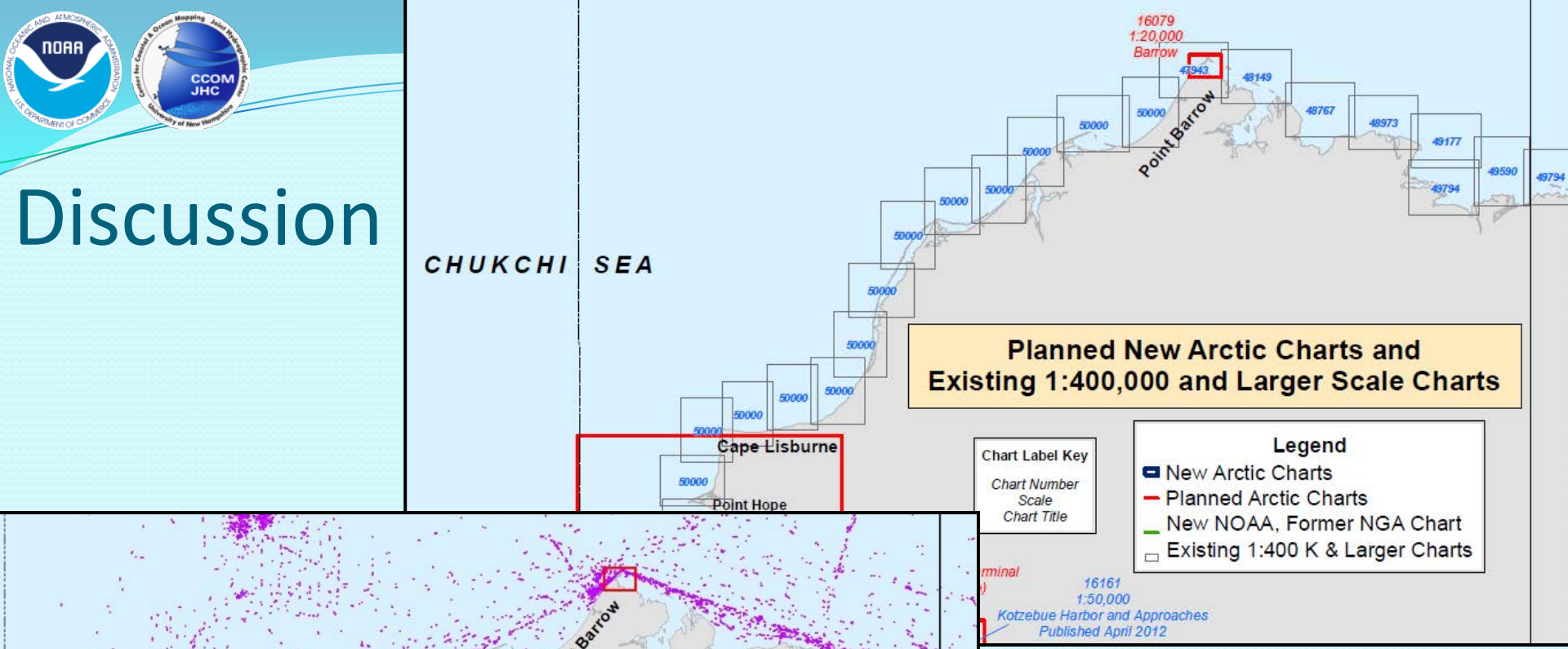
SDB: Discussion

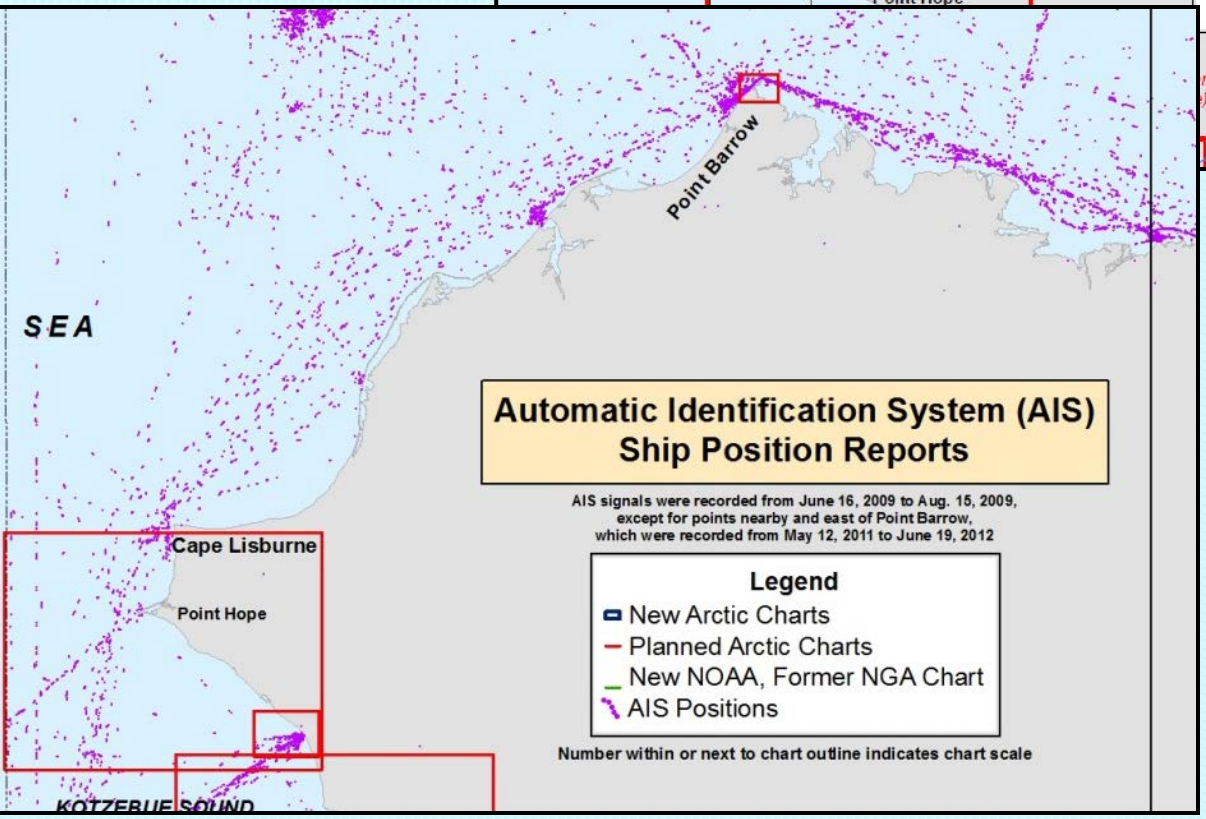




(Right image) Algorithm result image. (Left image) Difference map in meters between the satellite-derived bathymetry and the ALB reference dataset in depths greater than the extinction depth (11.5 m). The difference map is overlaid on NOAA Chart 25641 (soundings are in fathoms).

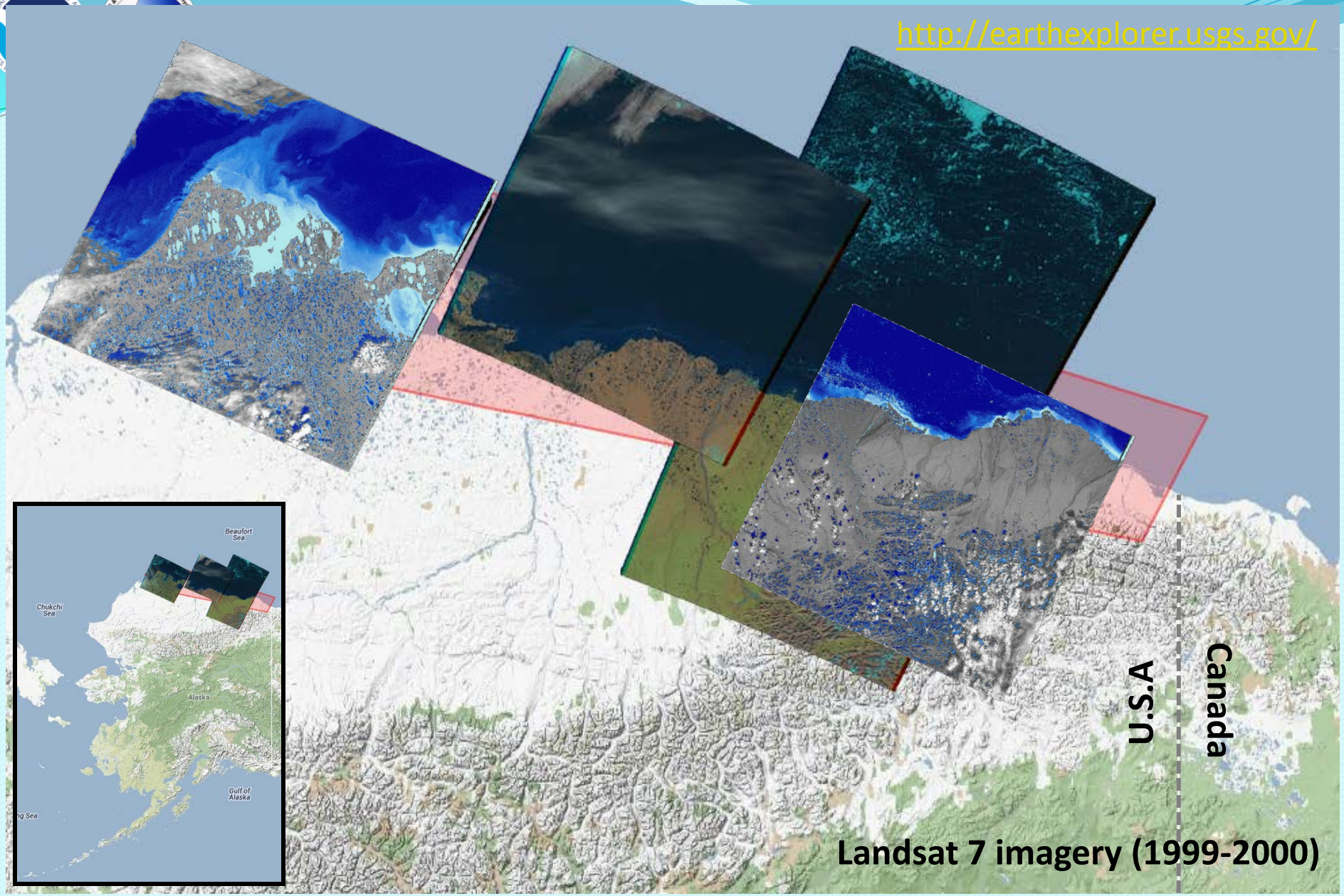
Discussion





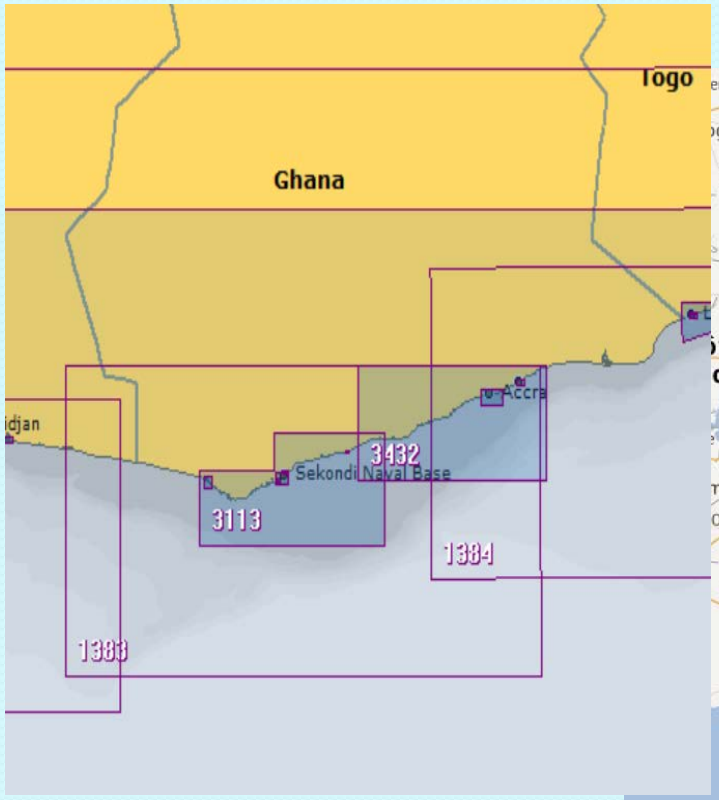
Images from:
Arctic Nautical Charting Plan – a plan to sustainable marine charting transportation in Alaska (Feb. 15, 2013)

(www.nauticalcharts.noaa.gov/mcd/docs/Arctic_Nautical_Charting_Plan.pdf)


http://earthexplorer.usgs.gov/
Beaufort Sea
Chukchi Sea
Alaska
Gulf of Alaska
U.S.A
Canada
Landsat 7 imagery (1999-2000)

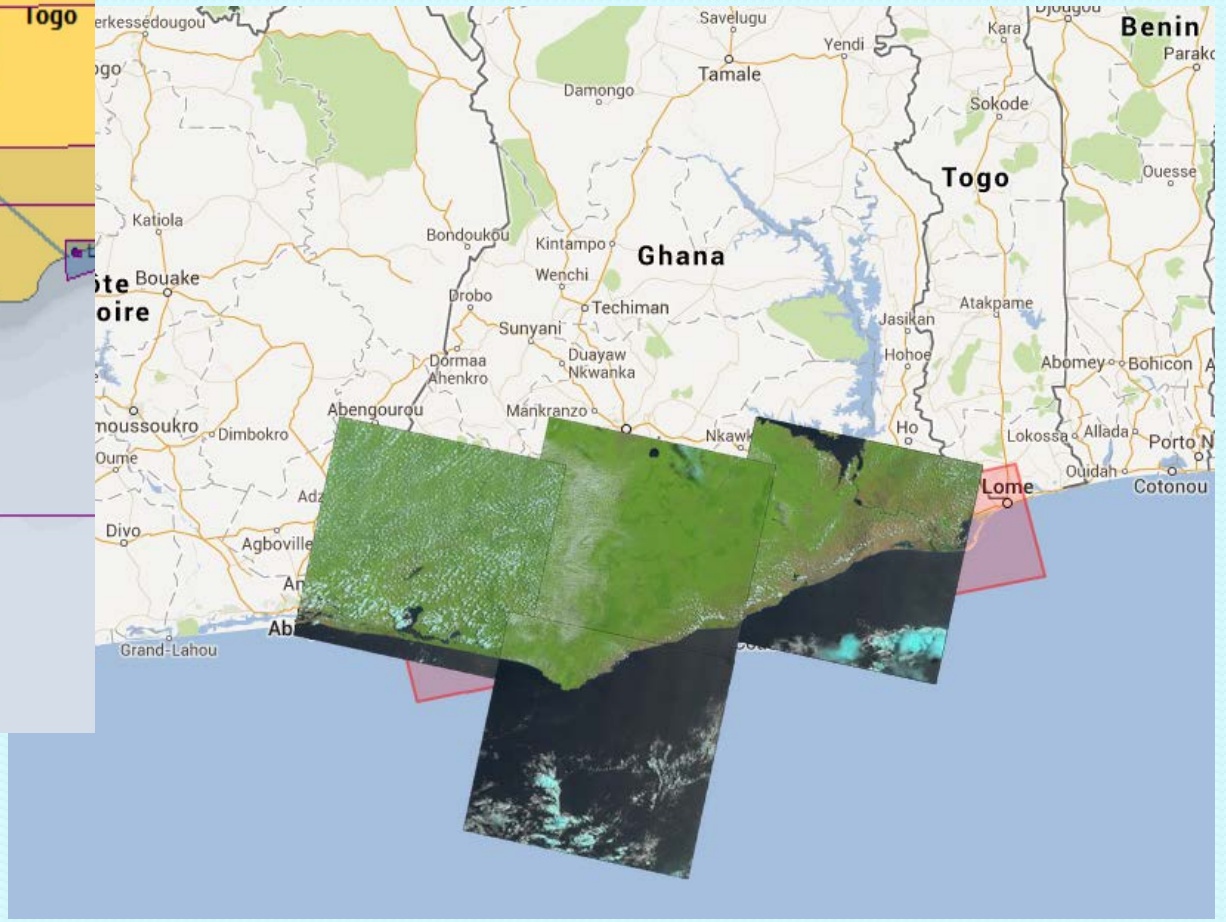
Current work

GEBCO project (Eunice Tetteh, Marine Research Div., Fisheries Ministry, Ghana)



BA Charts over coverage

Landsat 8 imagery (April-June, 2013)



Summary

- Landsat 7 and WorldView2 images were investigated over St. Croix, USVI and Barrow, AK.
- WorldView2 imagery proved high resolution imagery (2 m) that can be used as a reconnaissance tool for large-scale charts (i.e. 1:4,000 to 1:50,000).
- However, the WorldView2 swath is relatively small (18 km), which will require more images and may delay the production.
- Landsat 7 is useful as a reconnaissance tool for charts of 1:60,000 or smaller scales.

Thanks ☺

Acknowledgements:

- **UNH/NOAA Joint Hydrographic Center grant NA05NOS4001153.**
  - **Brian Madore (CCOM/JHC)**
    - **Capt. Robert Ward (International Hydrographic Bureau)**
      - **Jeff Ferguson and Dave Scharff (NOAA/OCS/)**
        - **Karen Marks (NOAA and IHO-IOC GEBCO program)**
          - **Mike Aslaksen and Maryellen Sault (NOAA/NGS)**
            - **Ashley Chappell (NOAA IOCM program)**
              - **Fugro LADS and Fugro Palegos**