

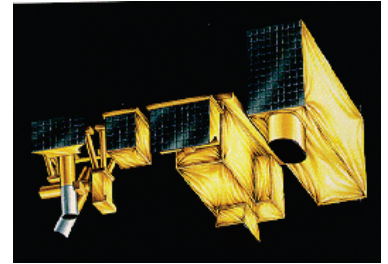
Using Multispectral Remote Sensing To Better Understand Modern Carbonate Environments *-for Improved Subsurface Reservoir Modeling-*

Jim Ellis, Ph.D.

Ellis GeoSpatial
www.ellis-geospatial.com



Presentation Outline



What's the Problem?

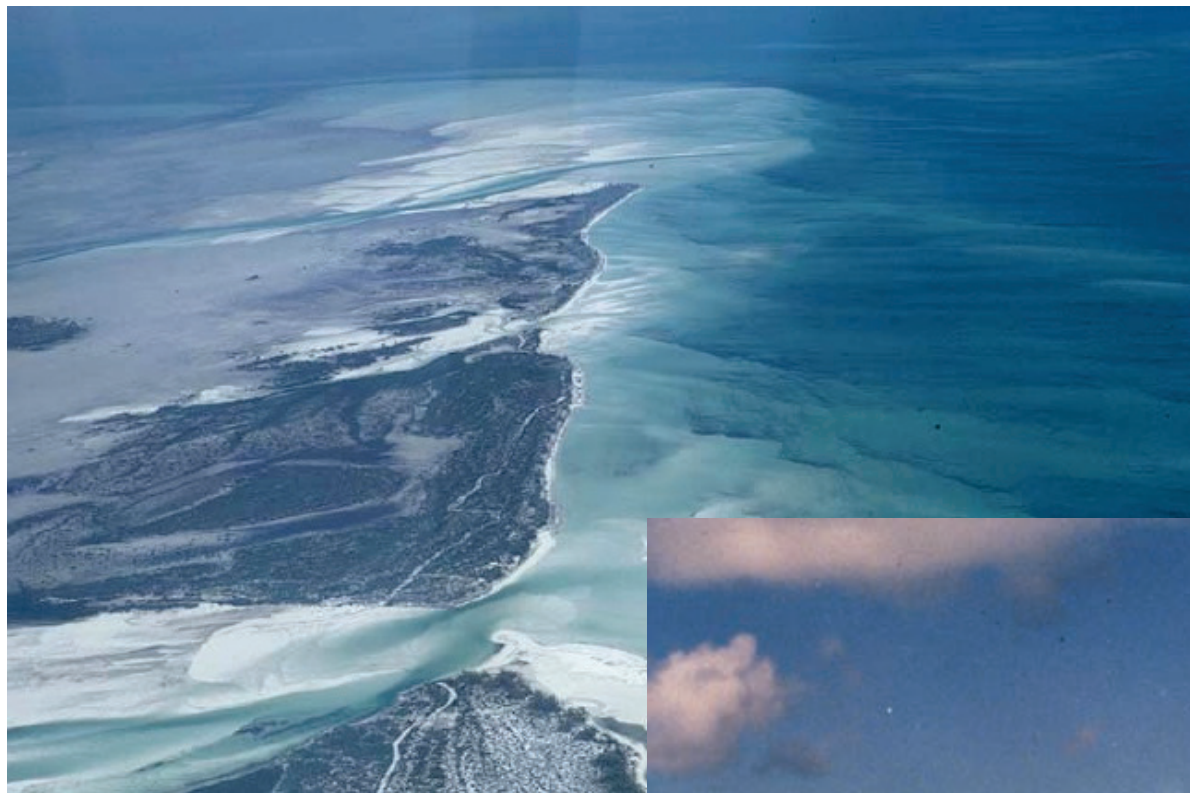
Multispectral Primer

**Using Remote Sensing & GIS to Develop
Accurate Shapes & DEMs of Landforms**

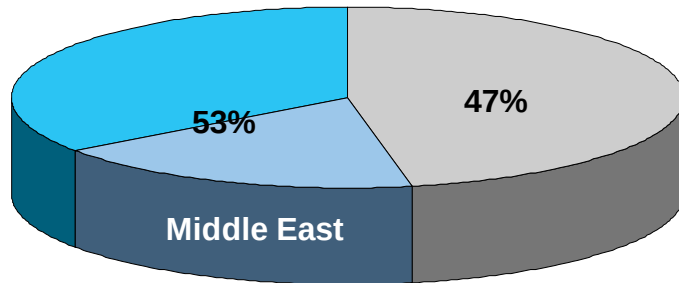
Developing Geostatistics for Geologic Models

Distributing Data in User-Friendly Formats

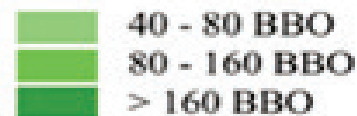
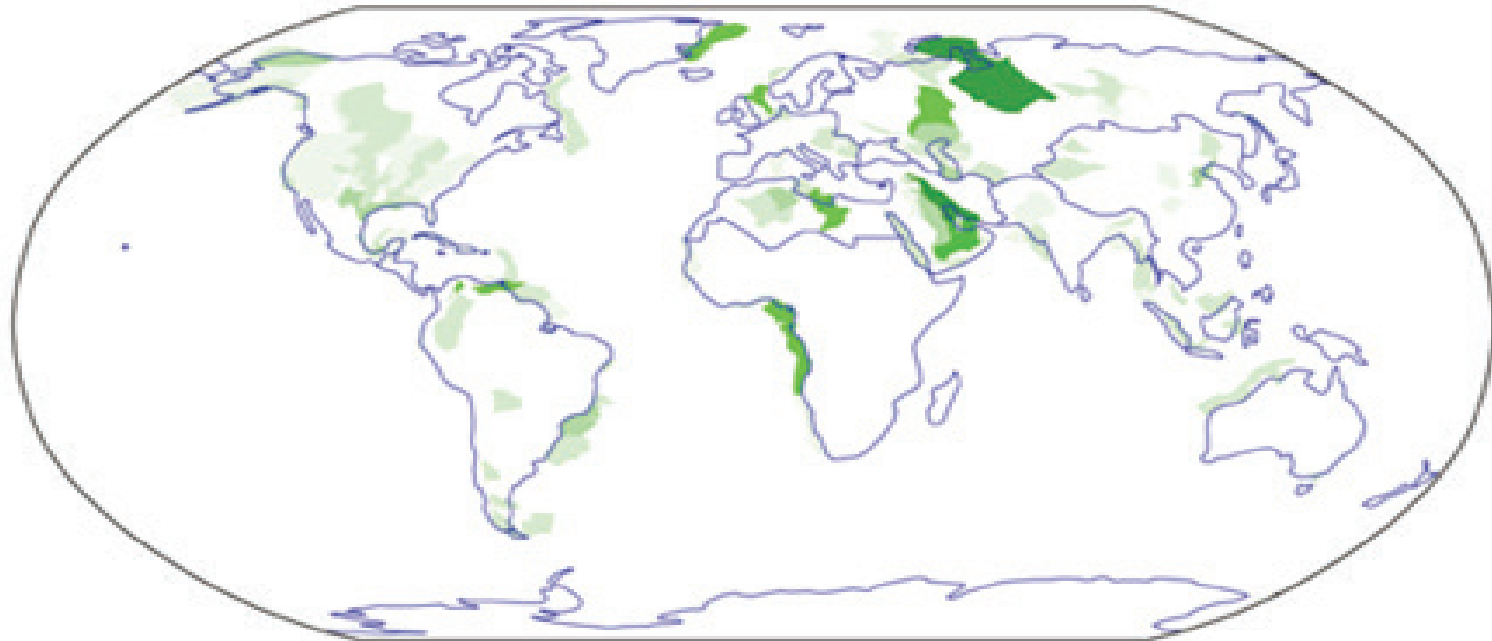




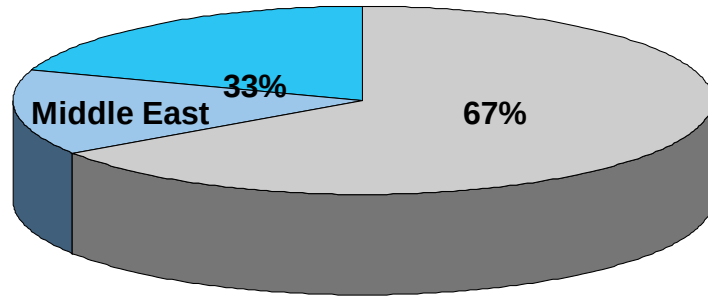
Over Half of the World's Oil Comes from Carbonate Reservoirs



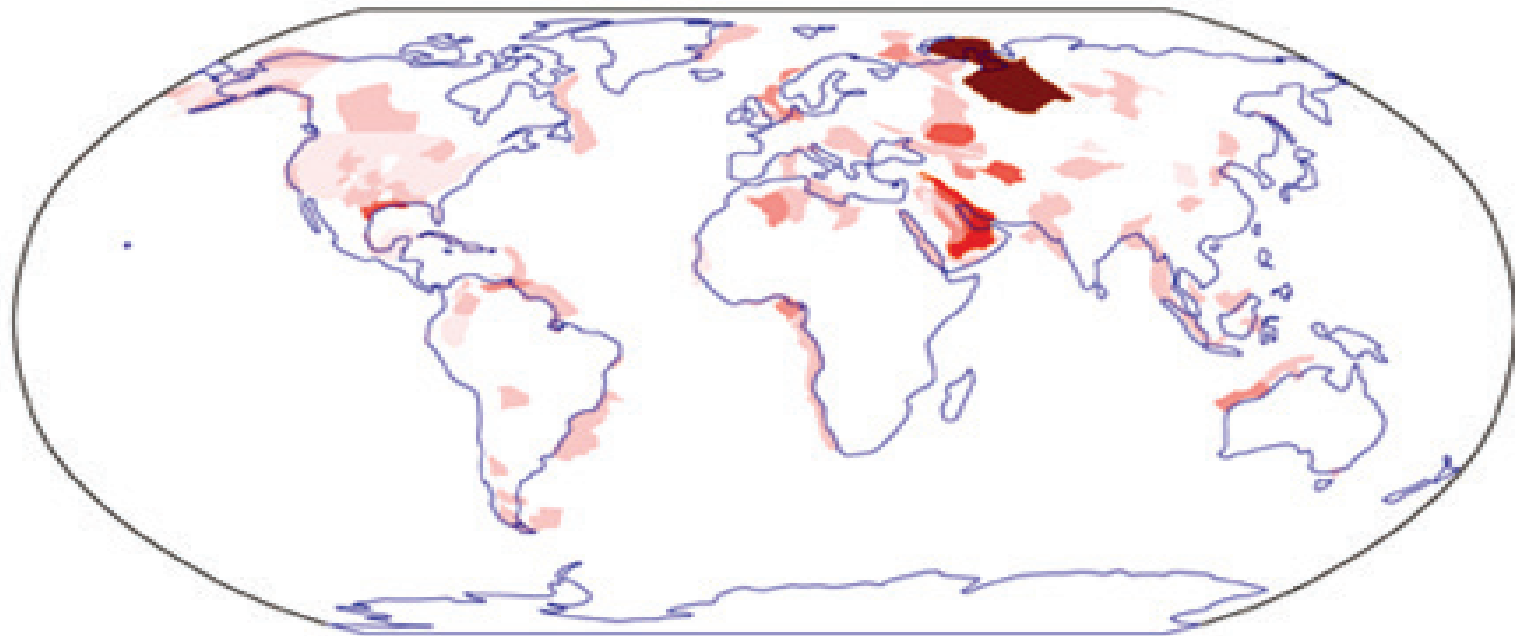
Based on Data from 17 Giant Provinces Accounting for 80% of World Oil Reserves



One Third of the World's Gas Comes from Carbonate Reservoirs



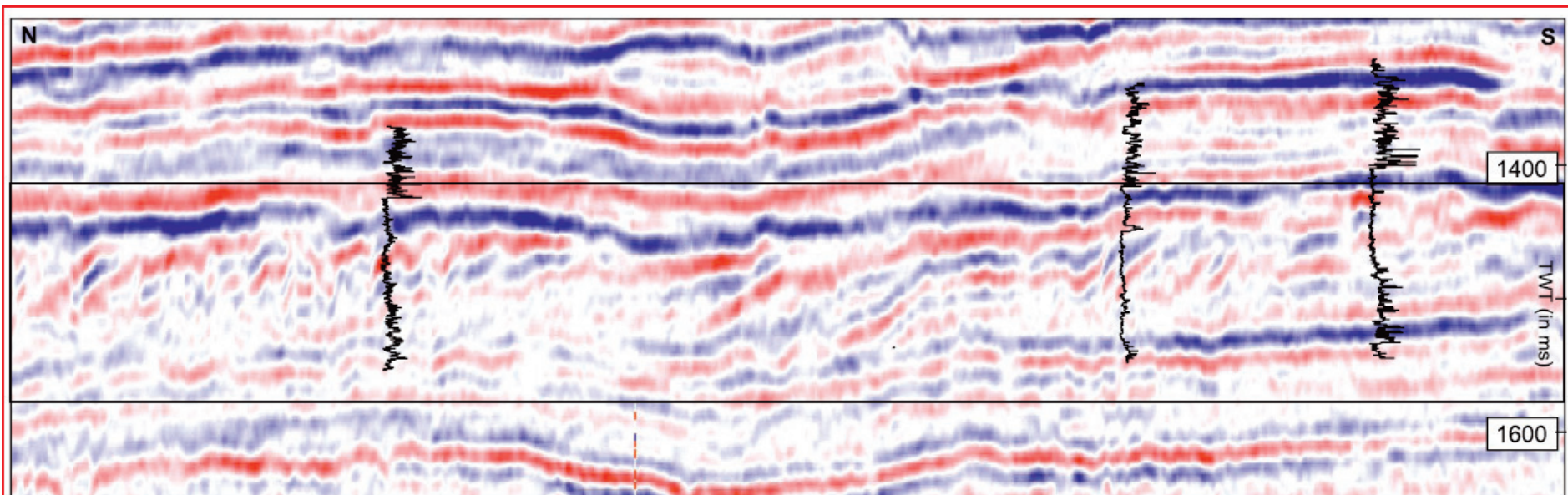
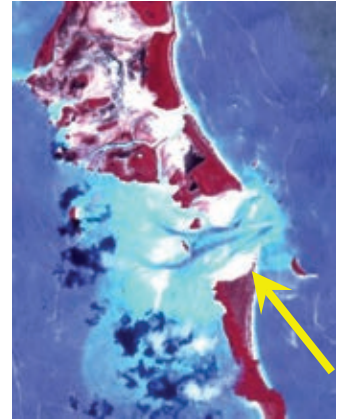
Based on Data from 16 Giant Provinces Accounting for 80% of World Gas Reserves



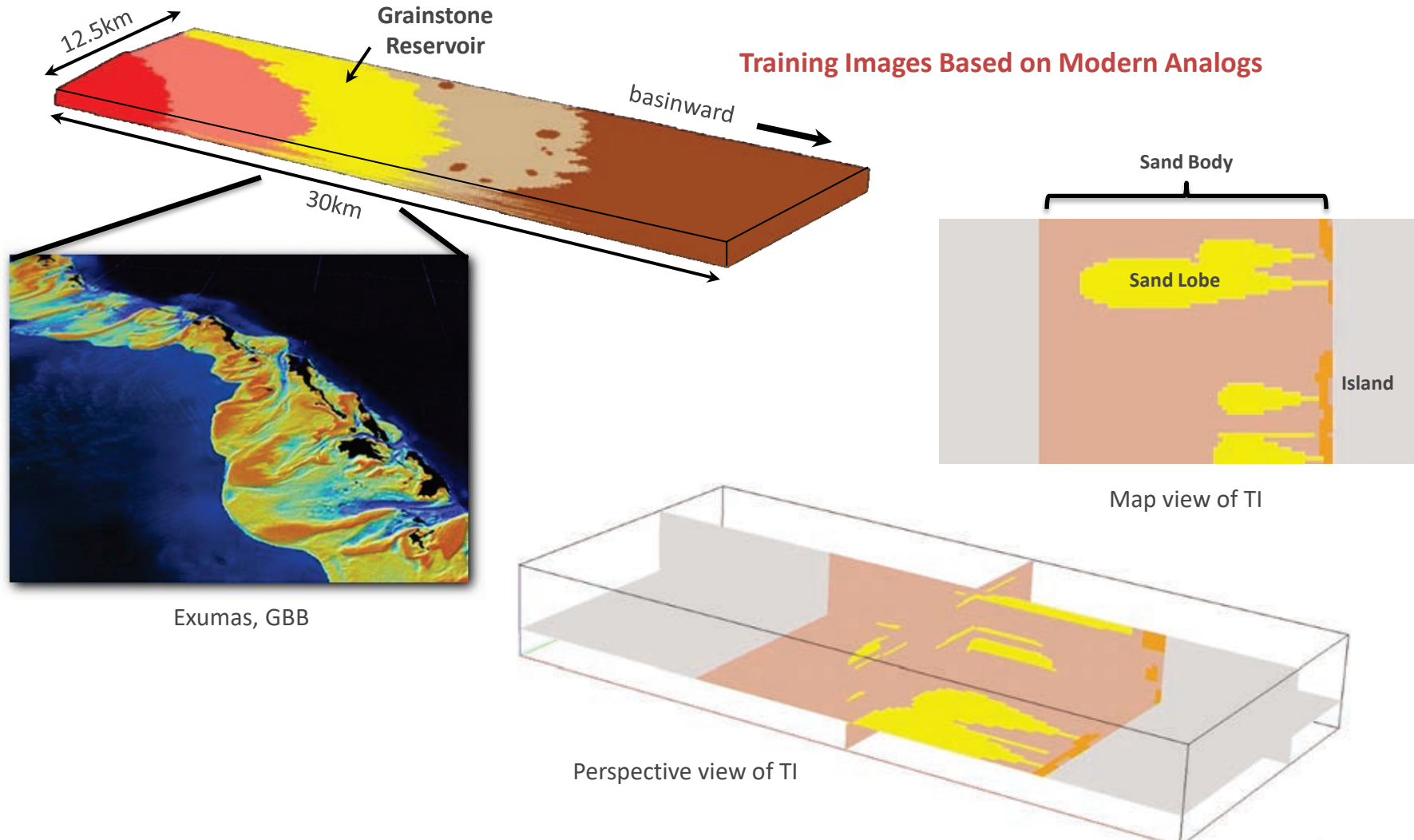
 < 6 Trillion Cubic Feet (TCF)
 6 - 120 TCF
 120 - 240 TCF

 240 - 480 TCF
 480 - 960 TCF
 > 960 TCF

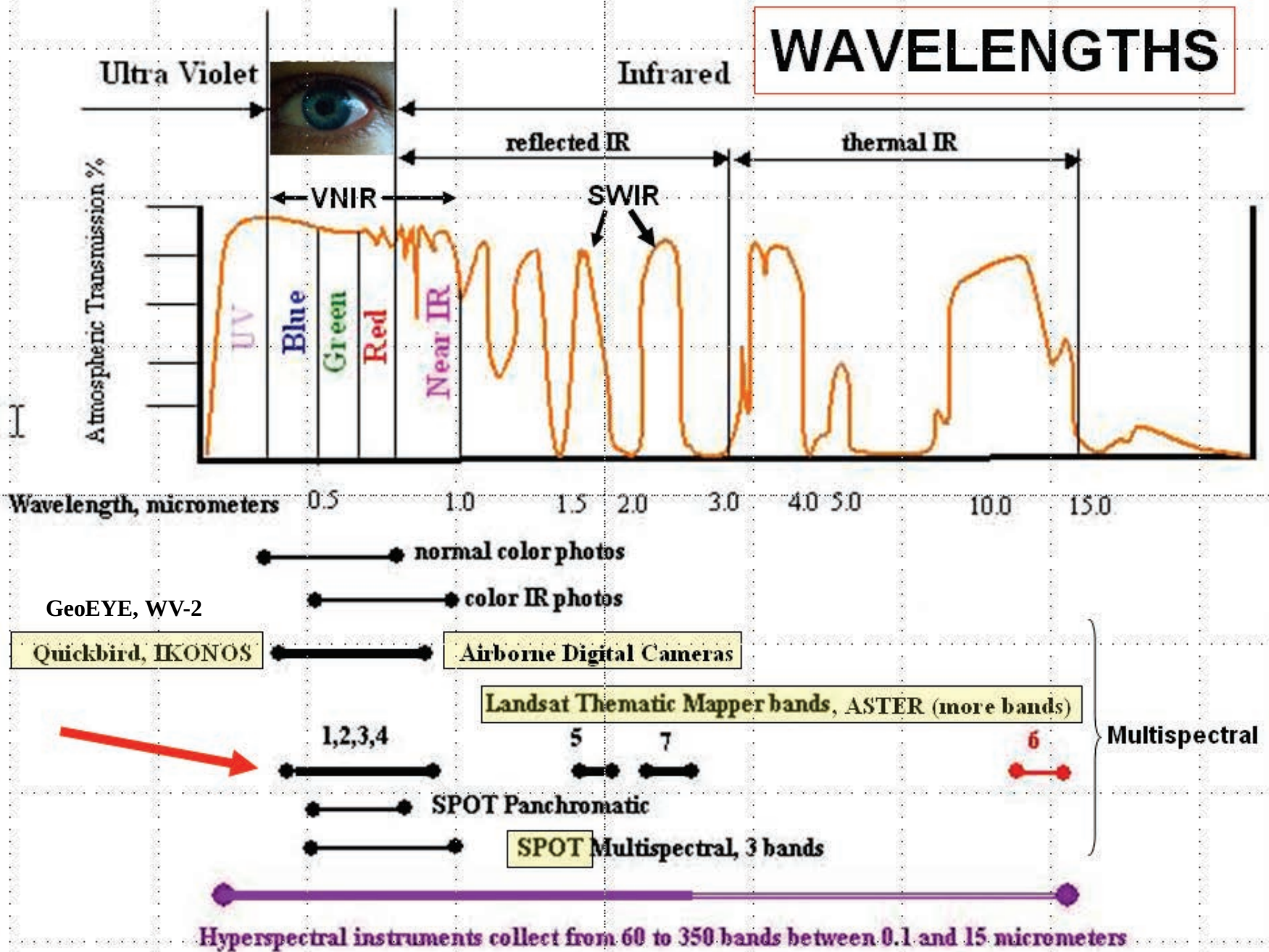
Modern Analogs Help Refine Subsurface Interpretations



Modern Analogs Can Provide Key Inputs for Reservoir Modeling



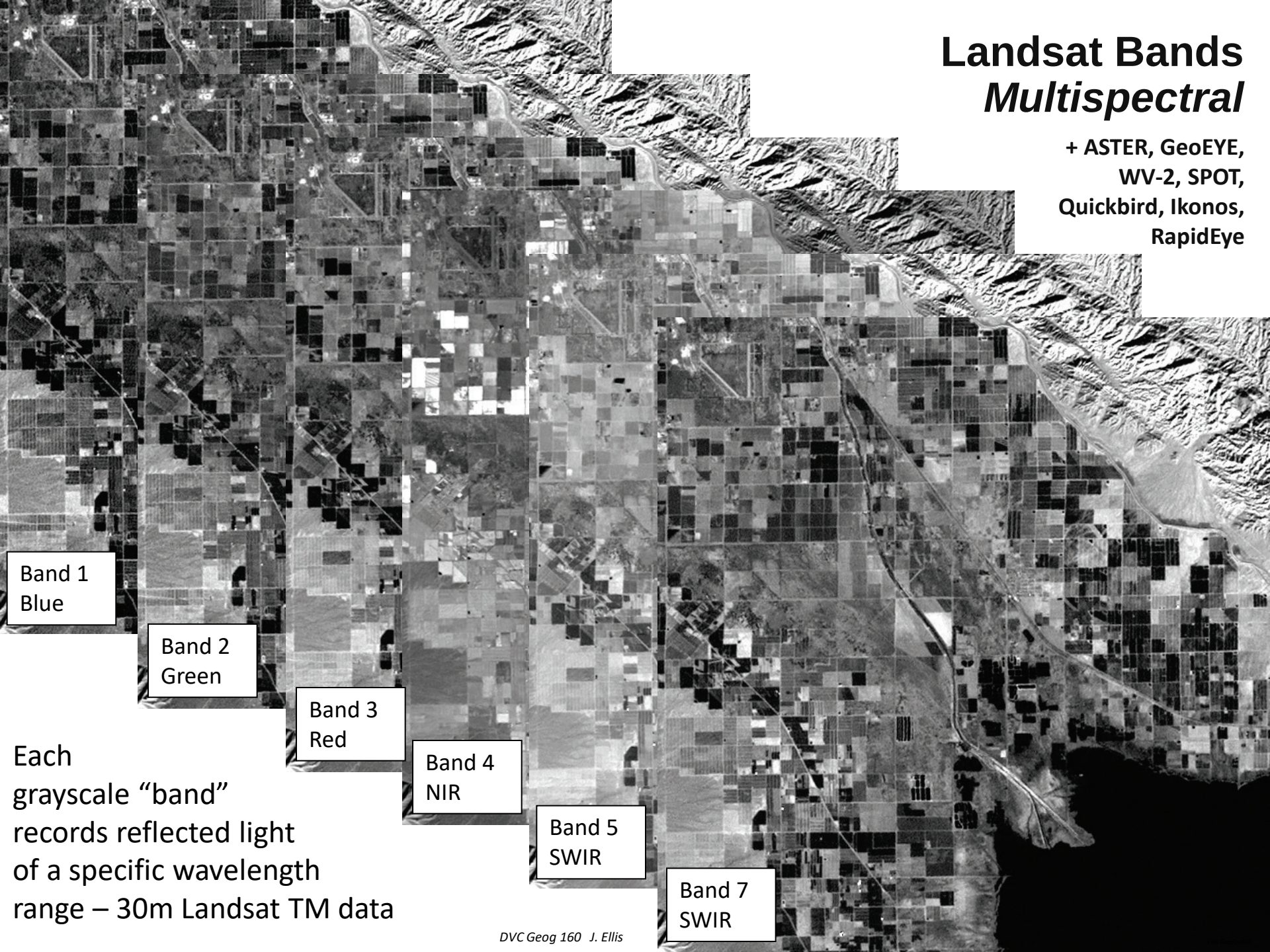
WAVELENGTHS



Landsat Bands

Multispectral

+ ASTER, GeoEYE,
WV-2, SPOT,
Quickbird, Ikonos,
RapidEye



Band 1
Blue

Band 2
Green

Band 3
Red

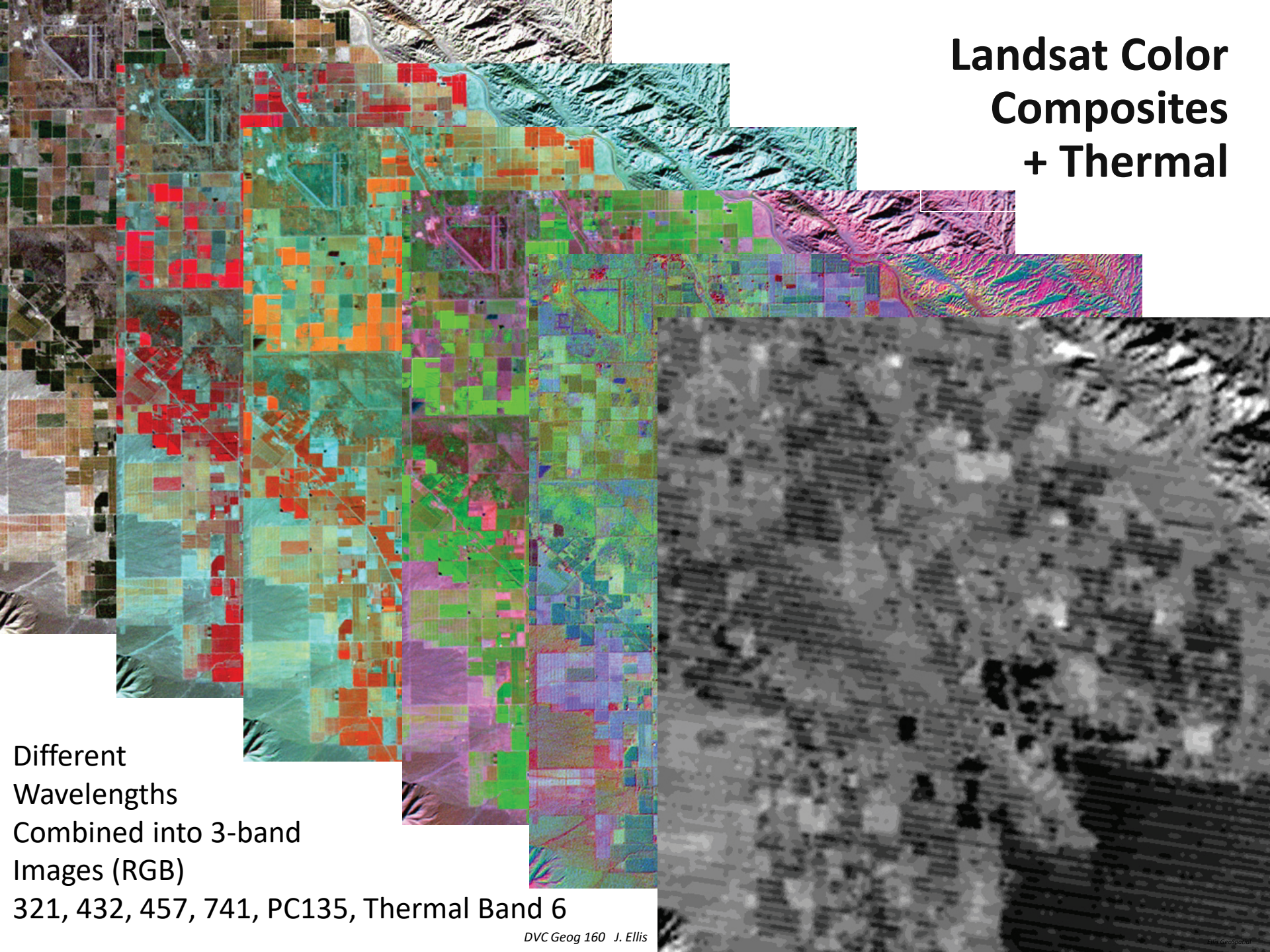
Band 4
NIR

Band 5
SWIR

Band 7
SWIR

Each
grayscale “band”
records reflected light
of a specific wavelength
range – 30m Landsat TM data

Landsat Color Composites + Thermal



Different
Wavelengths
Combined into 3-band
Images (RGB)

321, 432, 457, 741, PC135, Thermal Band 6

MODERN CARBONATE ENVIRONMENTS

FLORIDA

Miami

ATLANTIC OCEAN

*THE
EXUMAS*

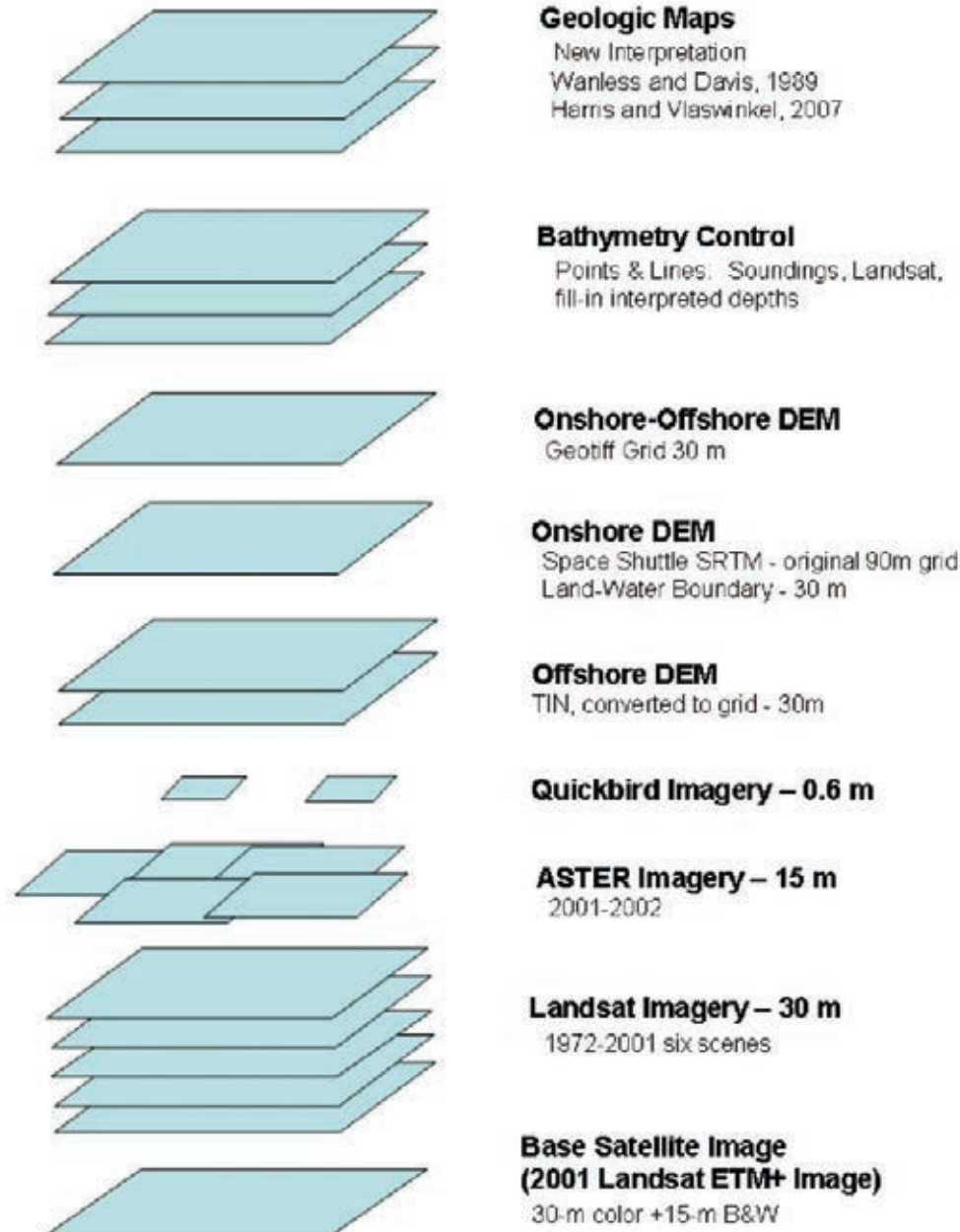
GREAT BAHAMA BANK

CUBA

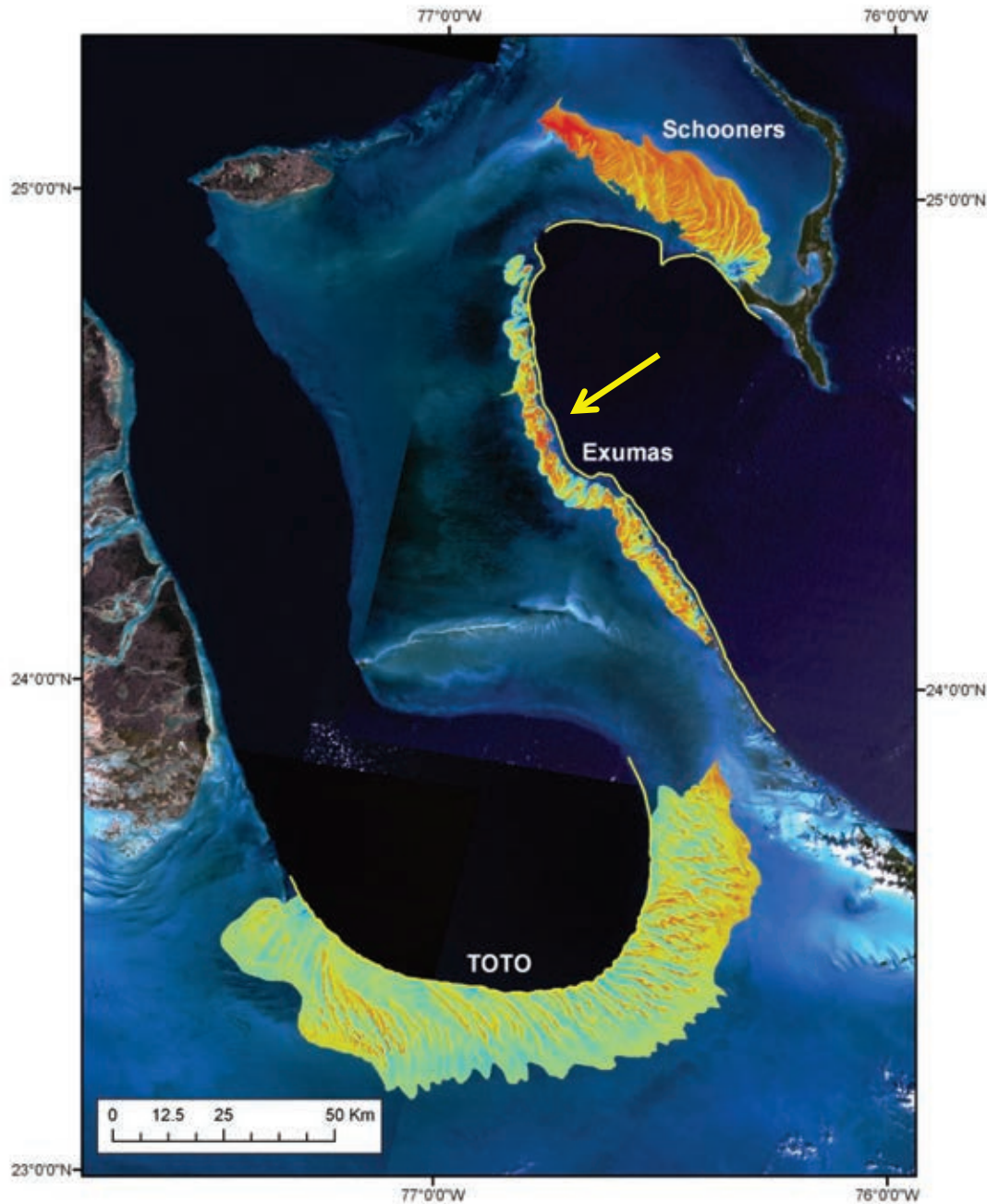
USE GIS TO ORGANIZE IMAGES & MAPS

Enables
Integration
Attributes
GeoStatistics
Change-Detection,
Spatial Analysis
GeoPDFs

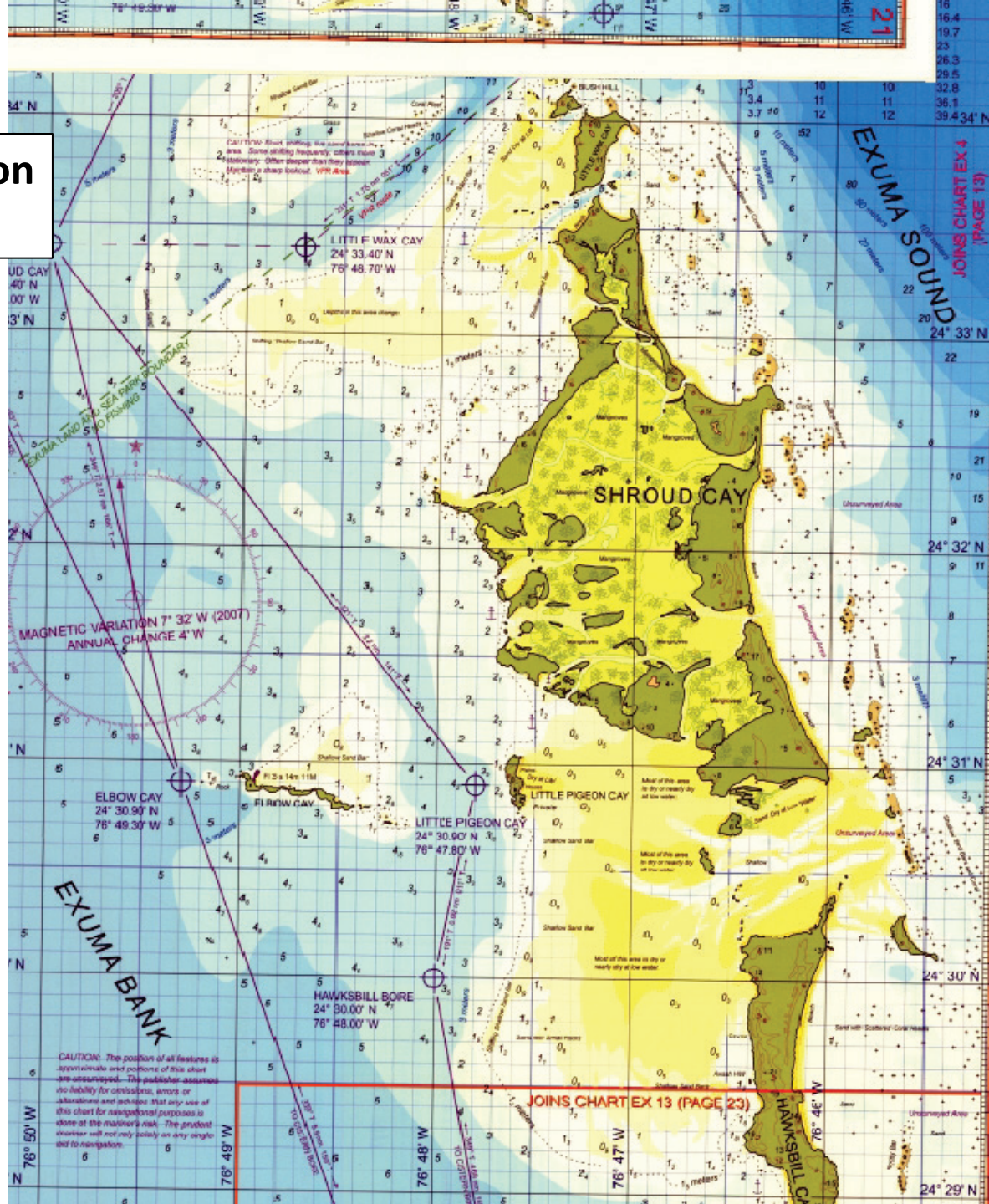
GIS Stack of Images & Maps for Caicos Platform



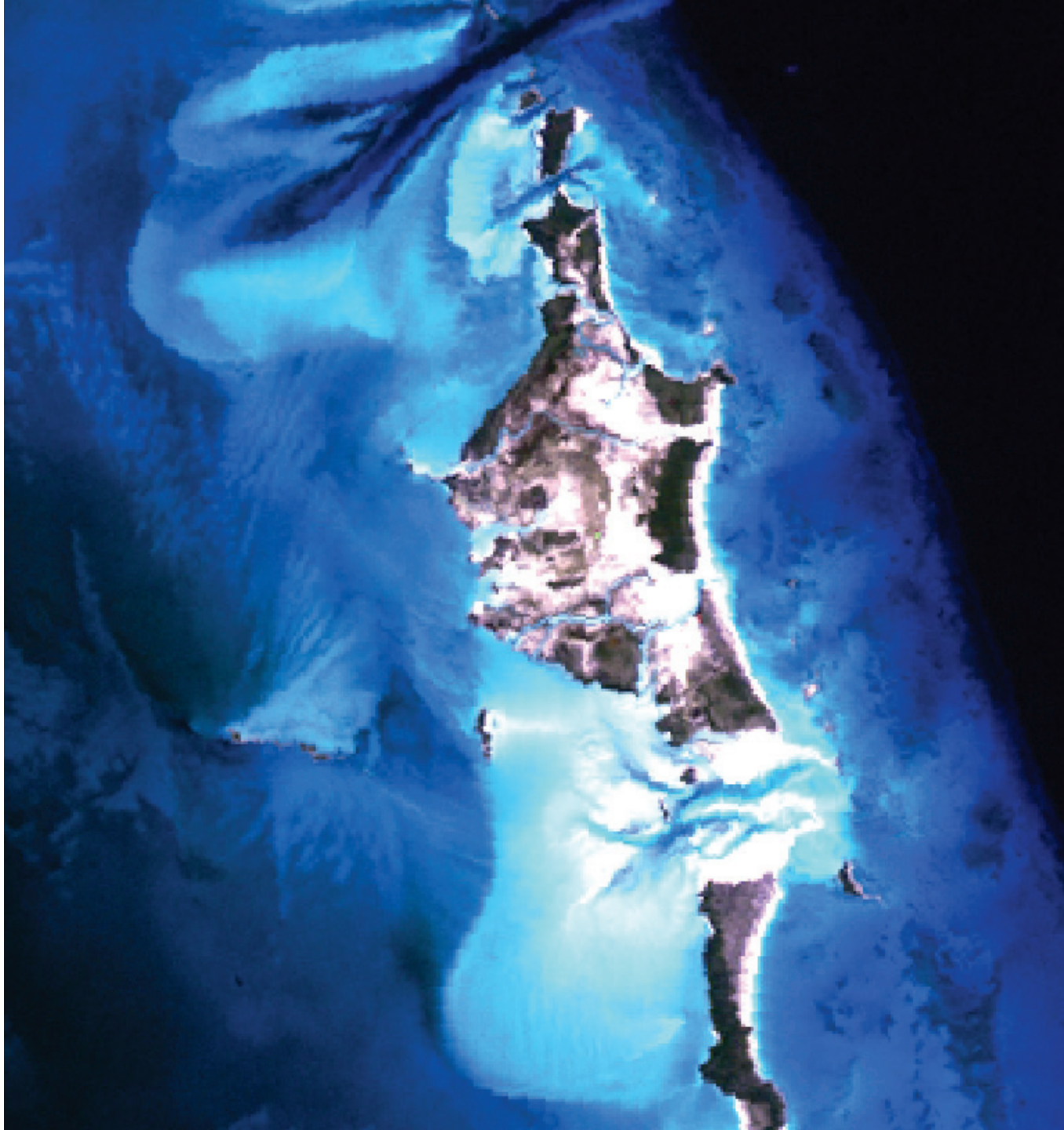
What can be
done with
Multispectral
Images?



Navigation Chart

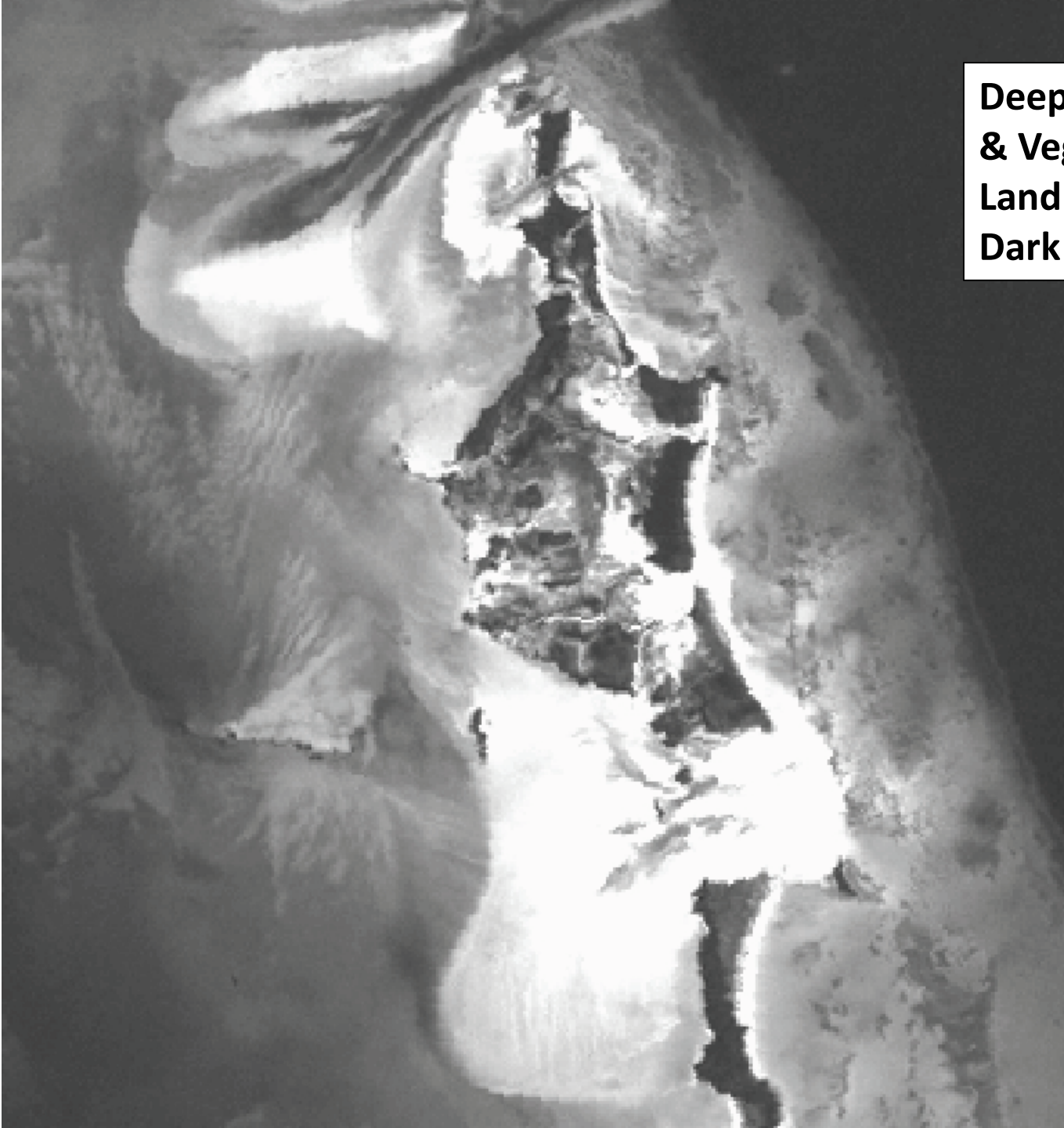


**Landsat
Color
Bands
321 as
RGB**



**Landsat
Band 1**

**Deep Water
& Vegetated
Land have
Dark Pixels**



**Landsat
Total
Infrared
Bands
457 as
RGB**



**Land-
Water
Mask**

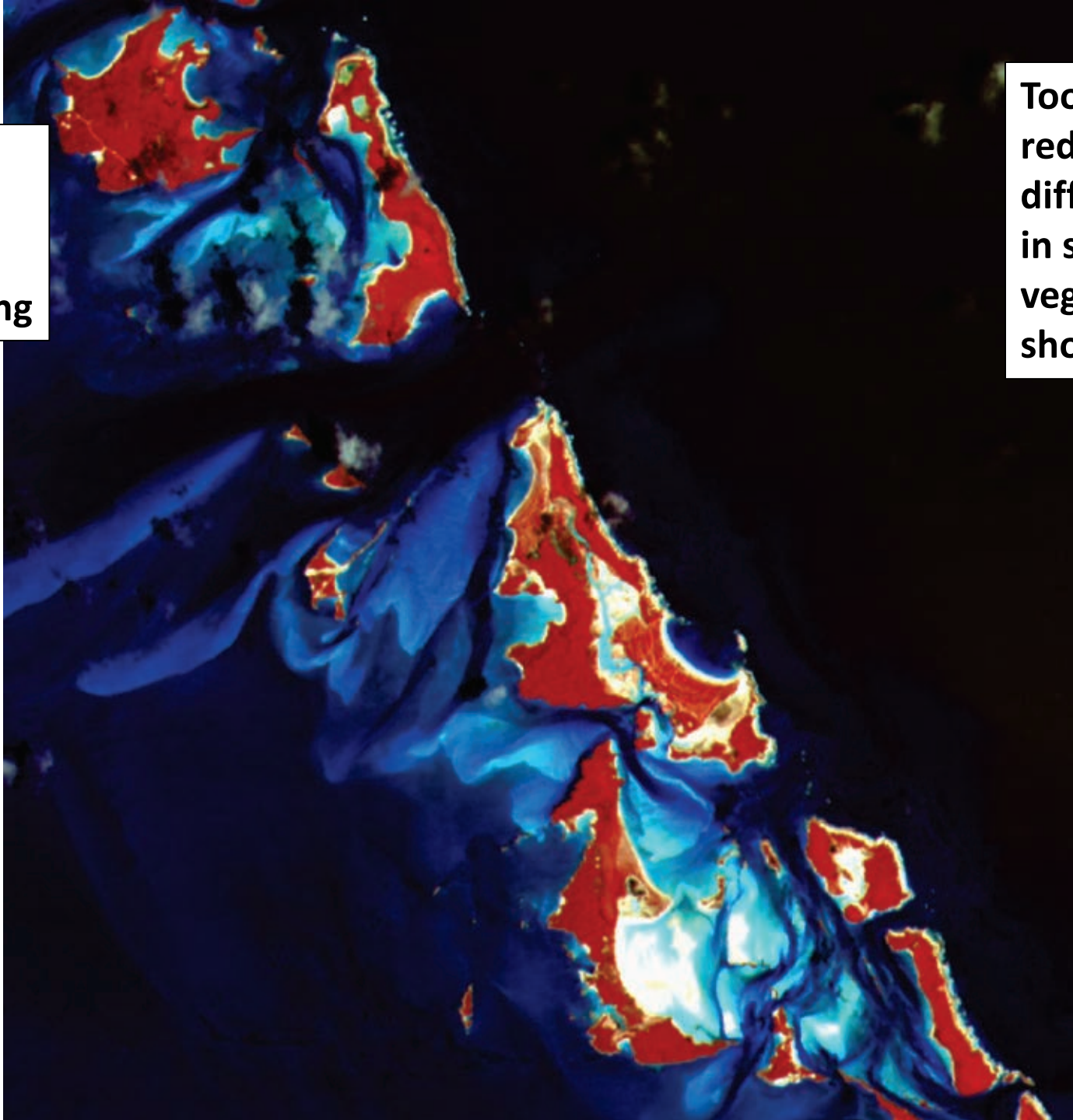


**Shoreline
Derived from
Land-Water
Mask**



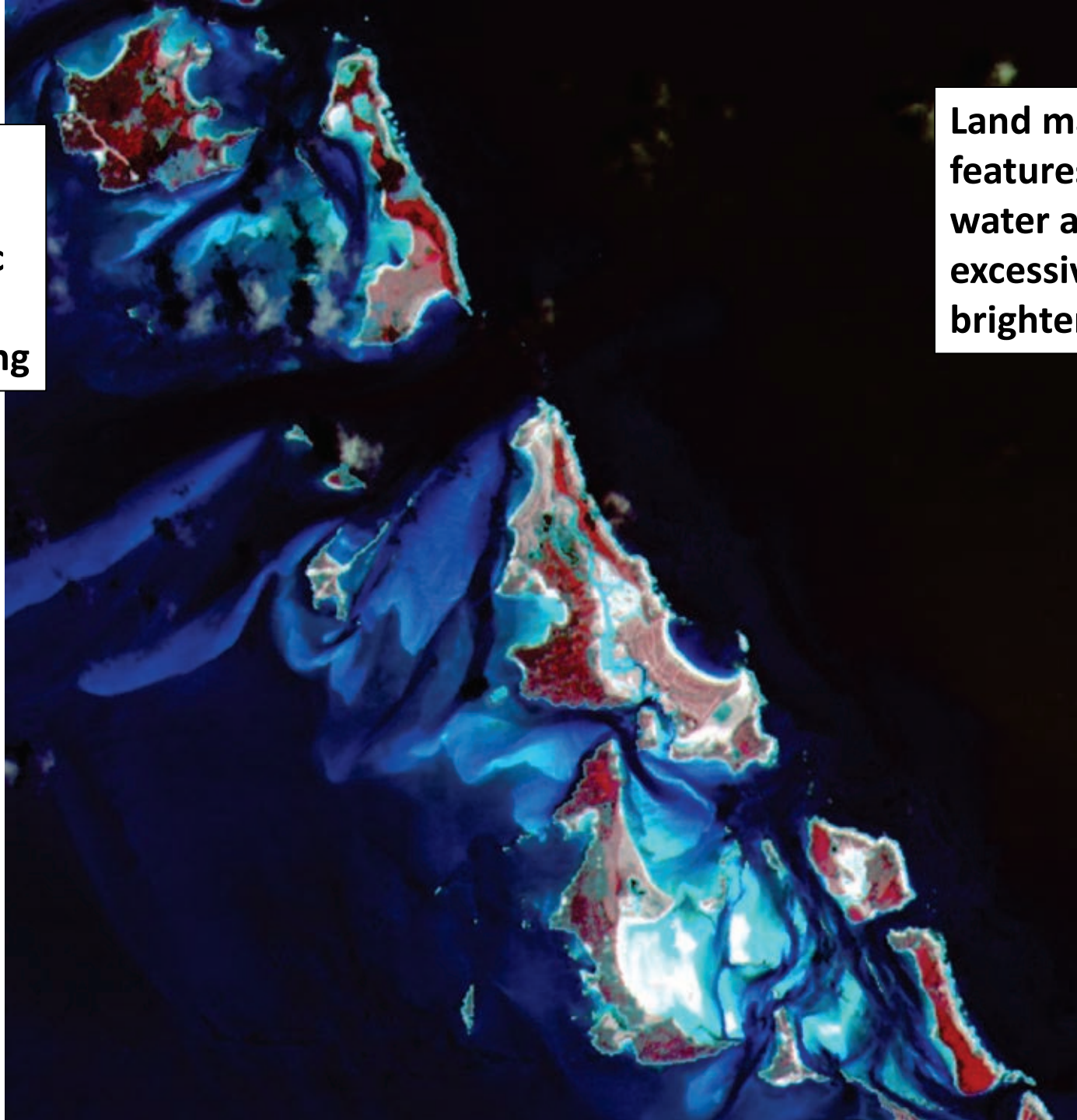
ASTER
CIR
Normal
Processing

Too much
red...little
difference
in soils or
vegetation
shown



ASTER
CIR
Geologic
Contrast
Stretching

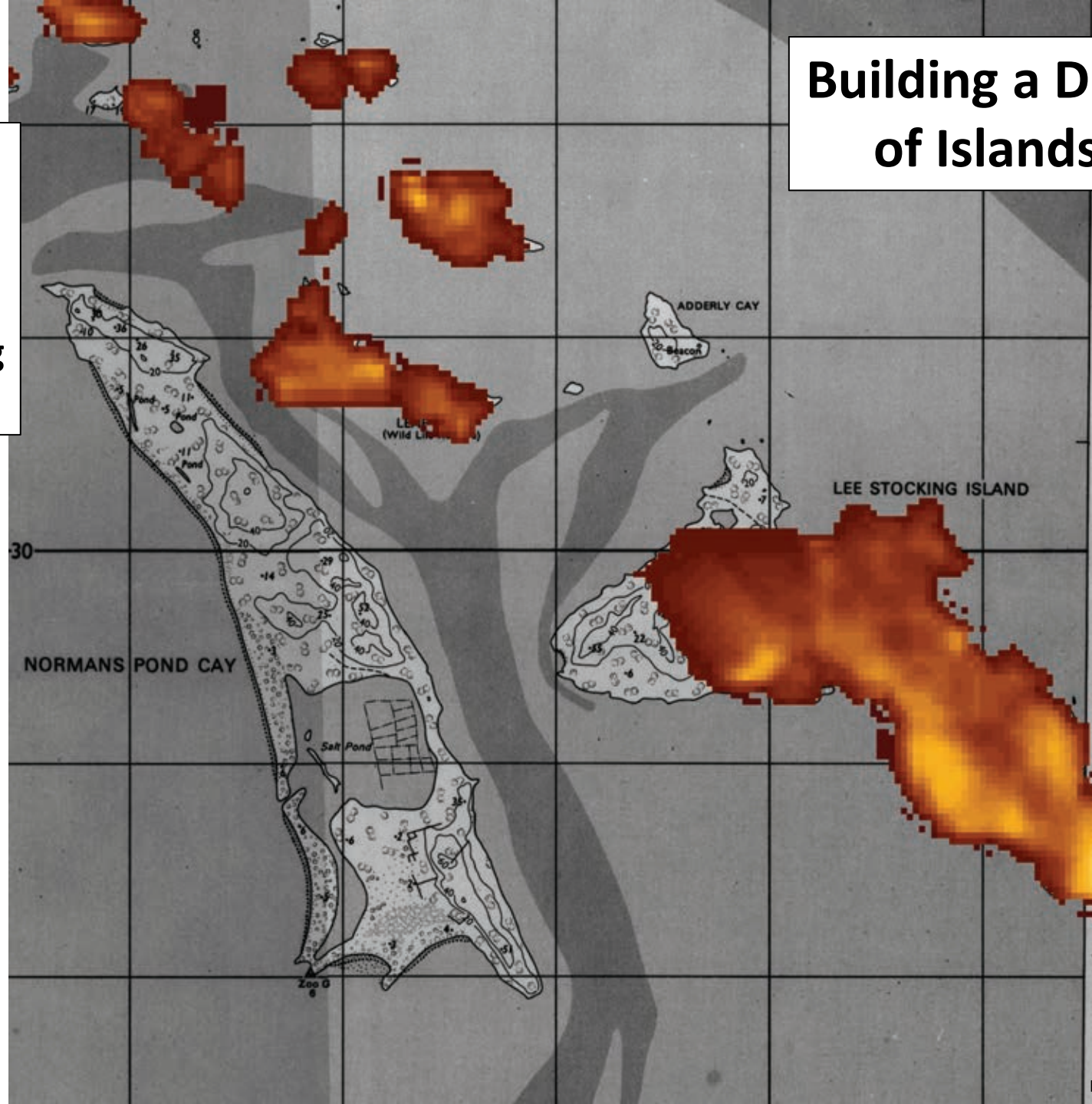
Land masked so
features under
water are not
excessively
brightened



Space
Shuttle
SRTM

Missing
Islands

Building a DEM of Islands



Map of the Florida Keys National Marine Sanctuary showing the distribution of the Caribbean monk seal. The map includes the Florida peninsula, the Gulf of Mexico, and the Atlantic Ocean. The distribution is indicated by a color scale from dark red (high density) to light yellow (low density). Key locations labeled include Normans Pond Cay, Leaf Cay (Wild Life Reserve), Adderly Cay, and Lee Stocking Island. A legend in the top left corner shows the color scale and a scale bar.

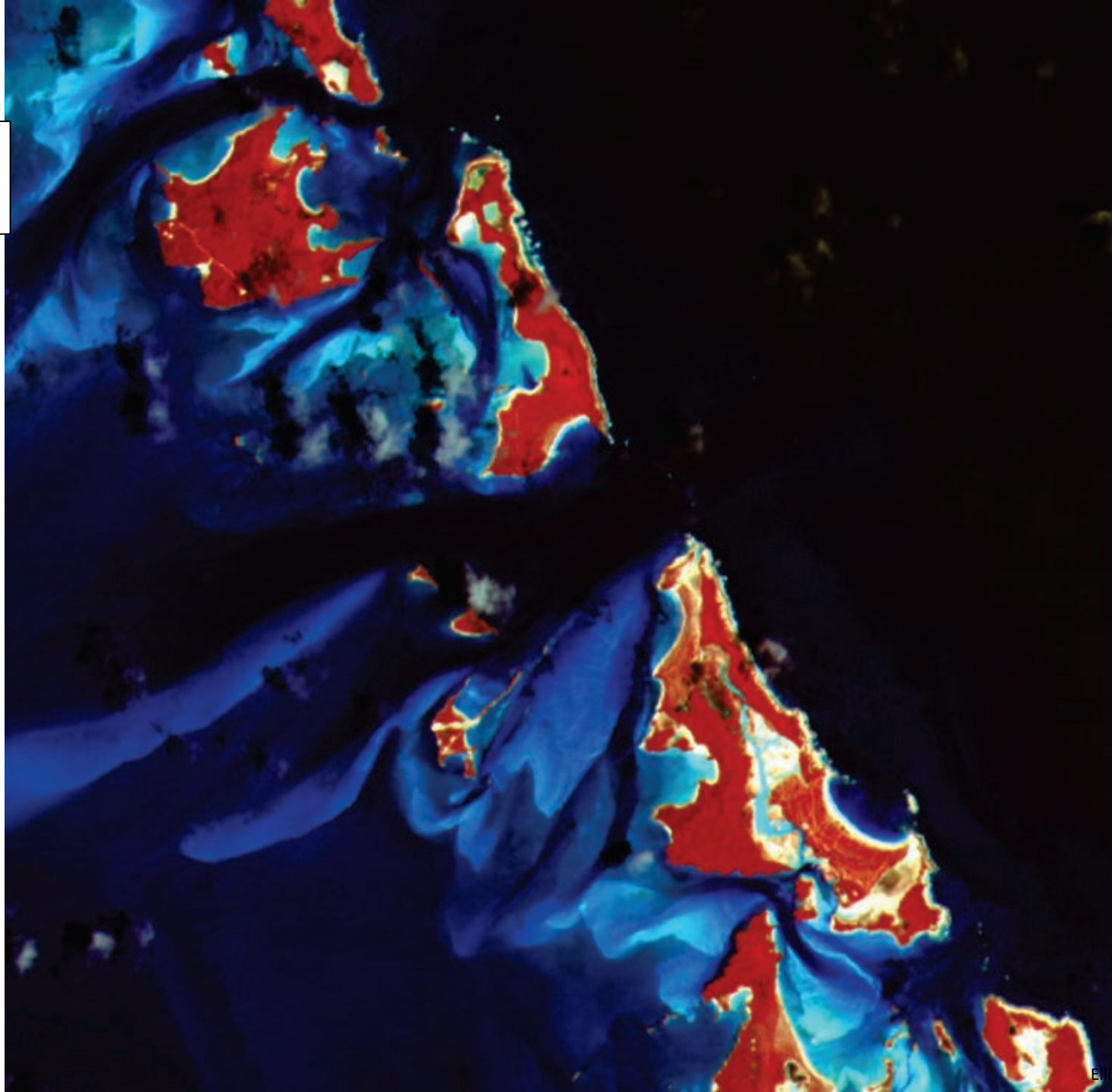
**STRM Island Extent
Too Large**



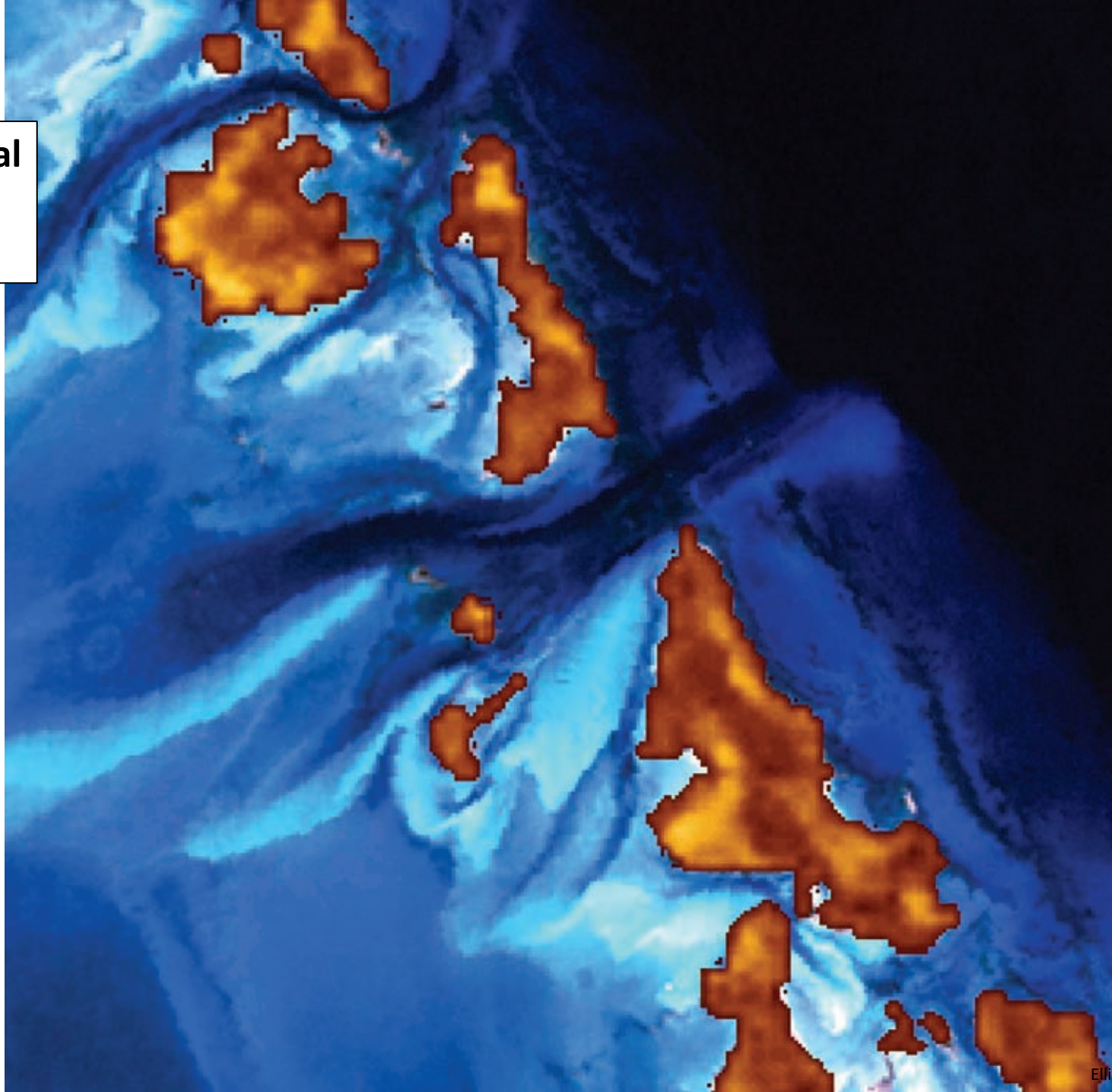
**STRM Island Trimmed
With Landsat Land-Water Mask**



ASTER
CIR

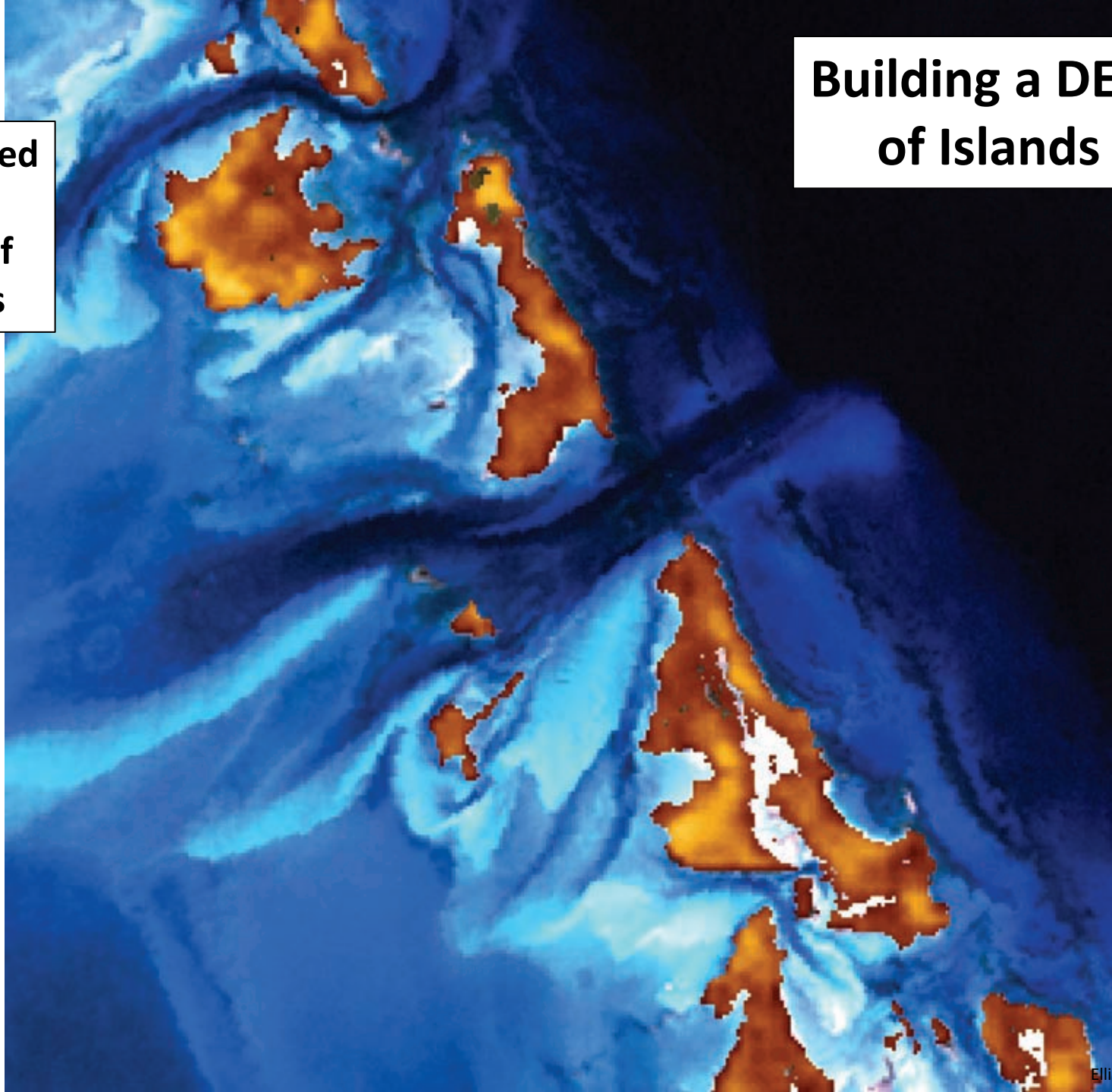


Original
SRTM
DEM



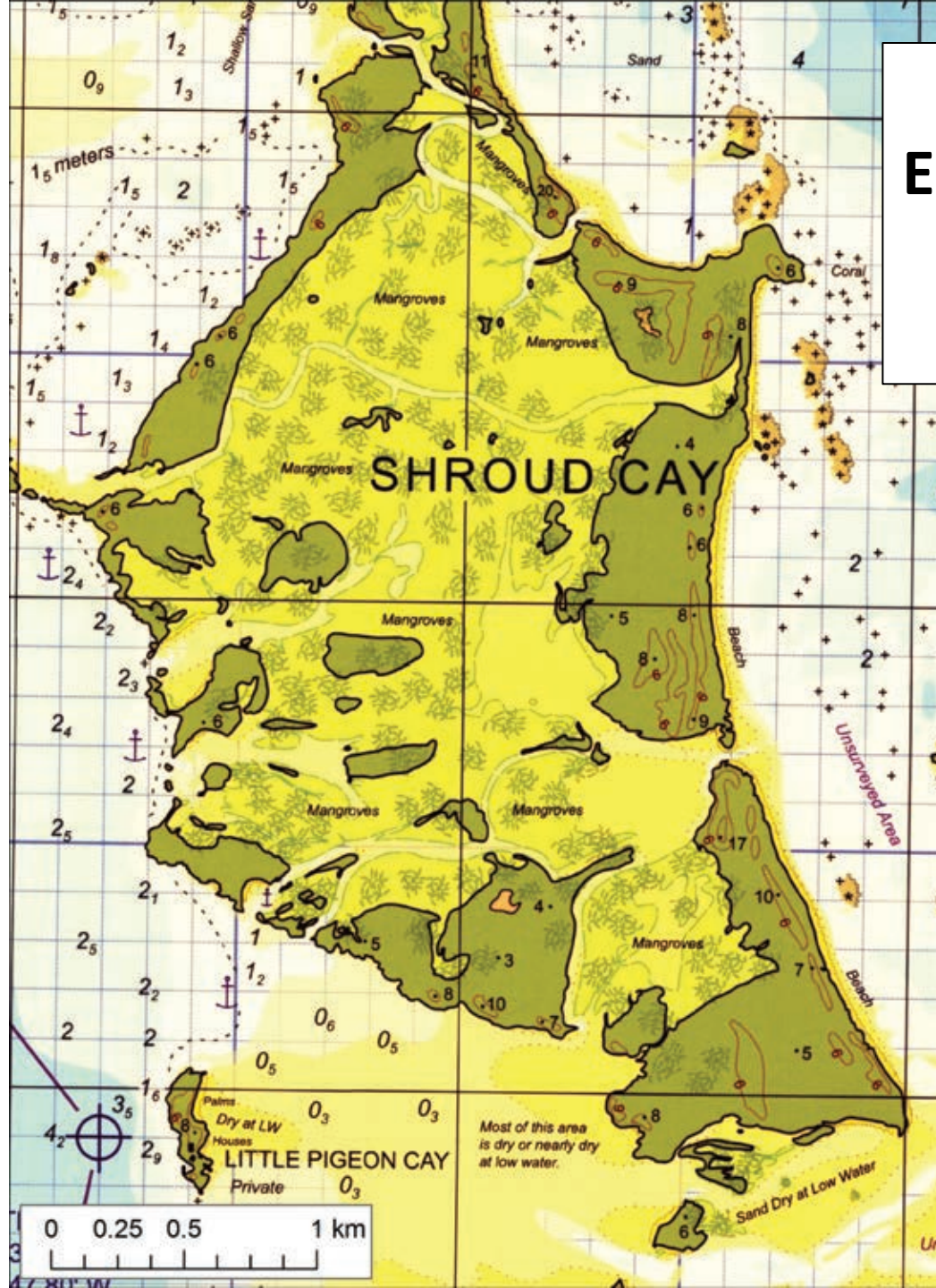
**Trimmed
SRTM
DEM of
Islands**

**Building a DEM
of Islands**



Navigation Chart

Land Cover Environmental Mapping of Islands



**Quickbird
2.6 meter
Color Image**

**Four
Multispectral
Bands**

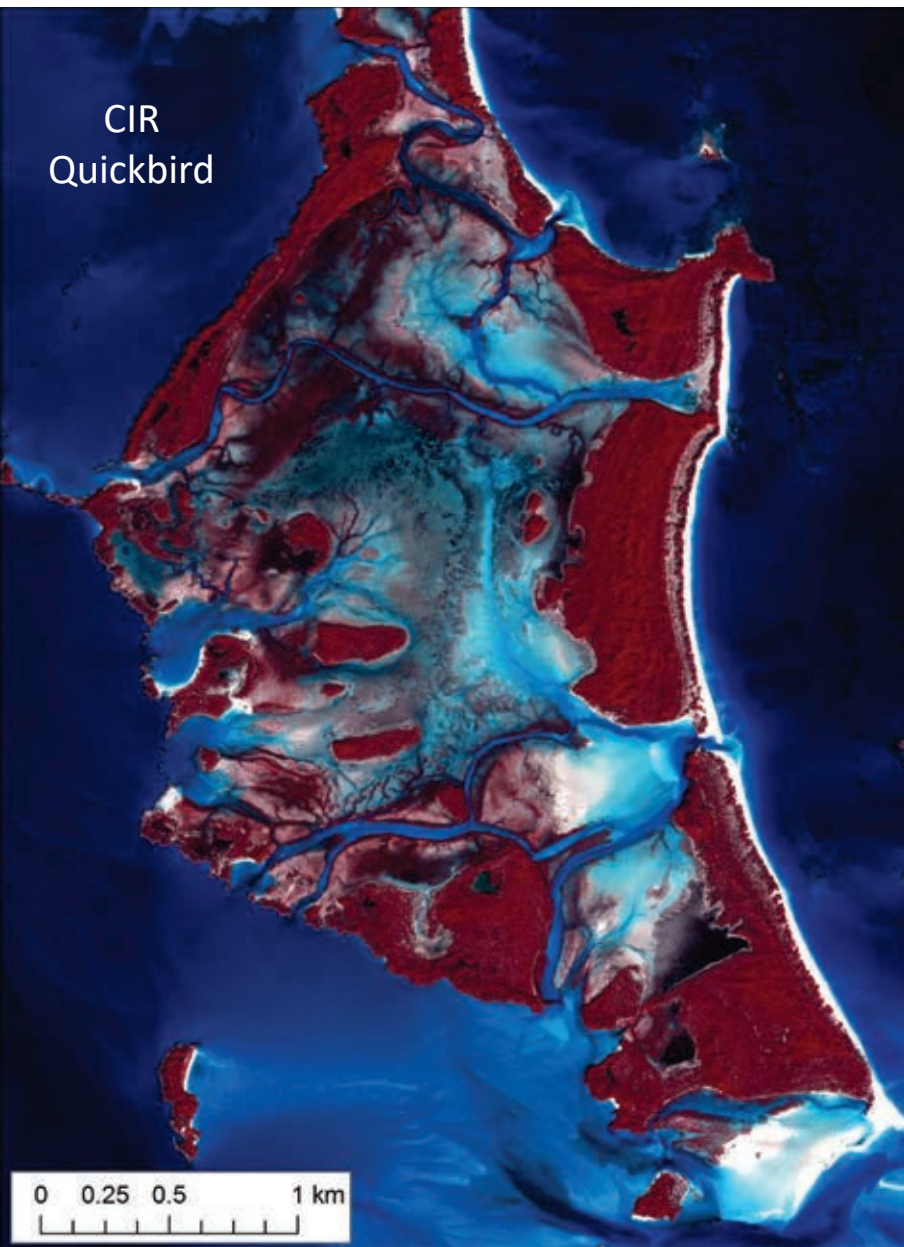
B, G, R, NIR



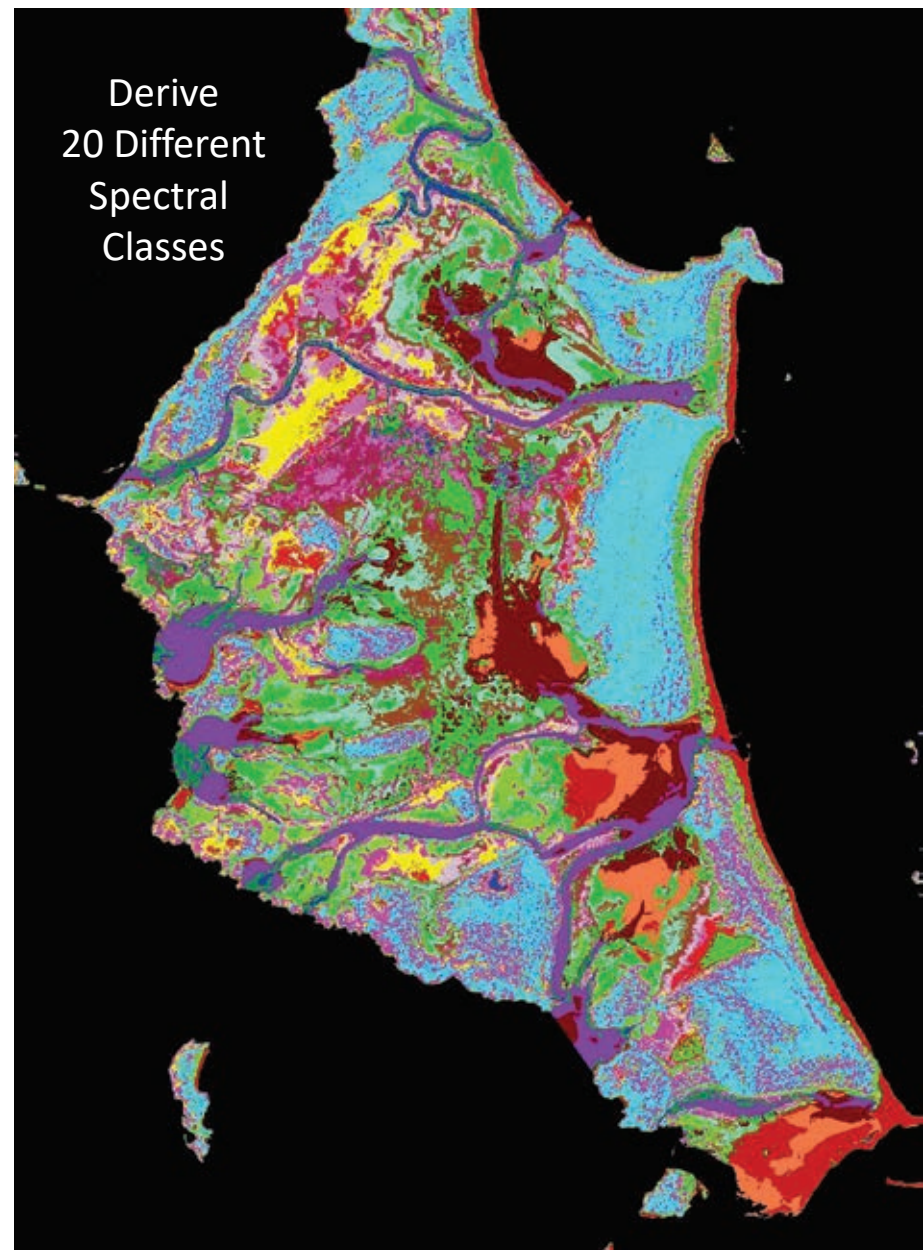
**Mask to Separate
Land from Water
For Land Cover
Mapping**



Shroud Cay – Sand Flats Mapping

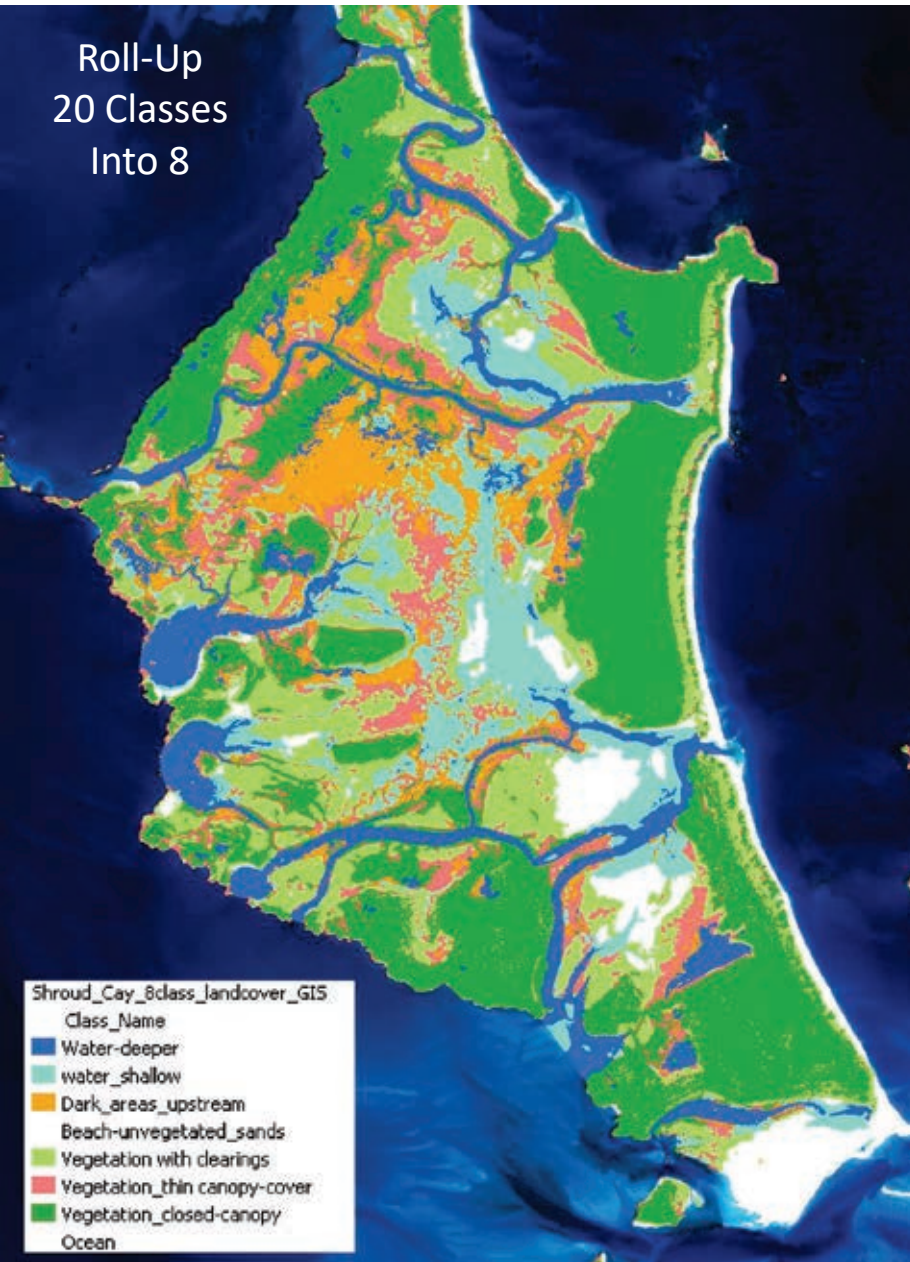


Spectral Classification

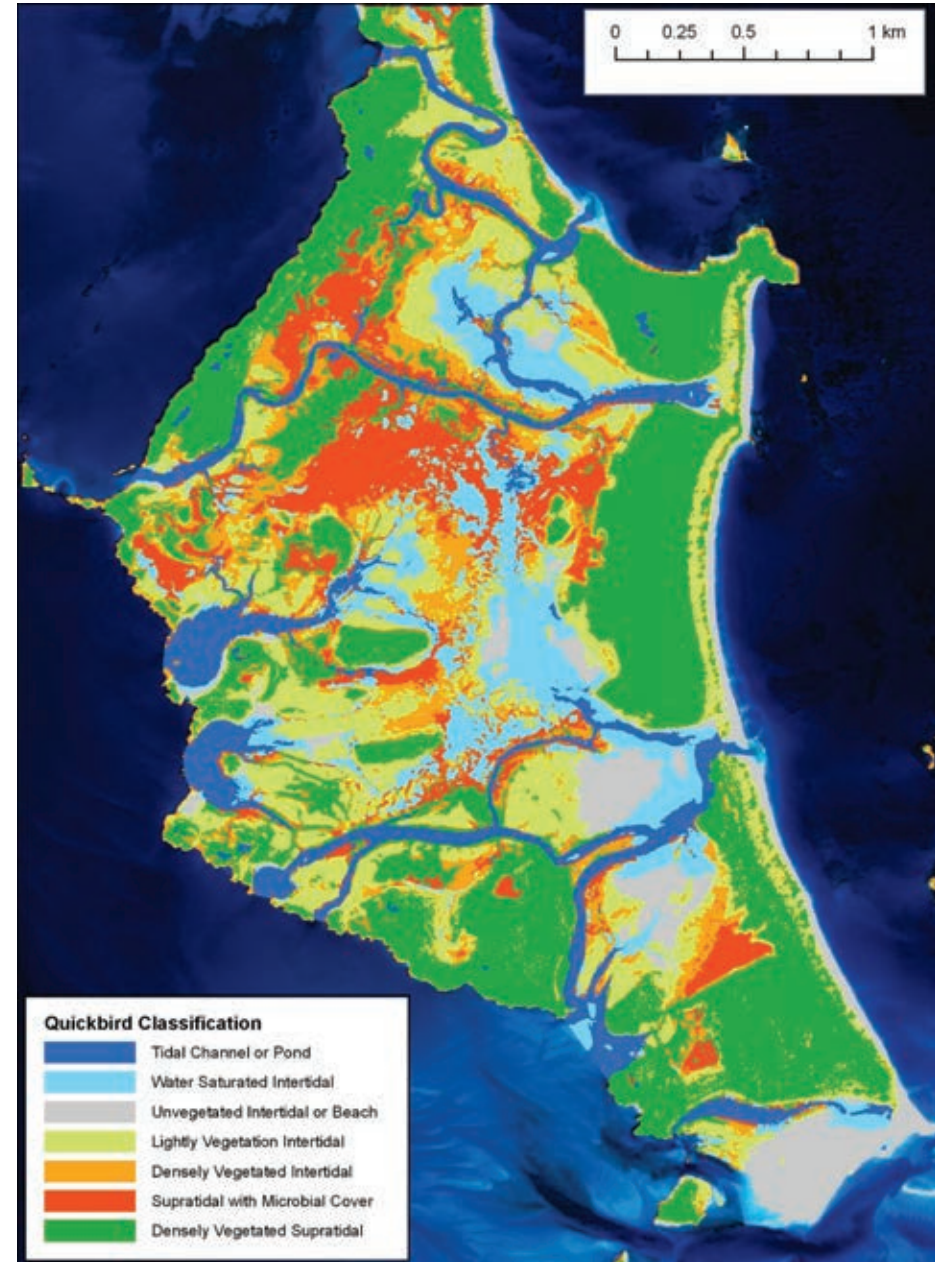


Analyst Map – ?

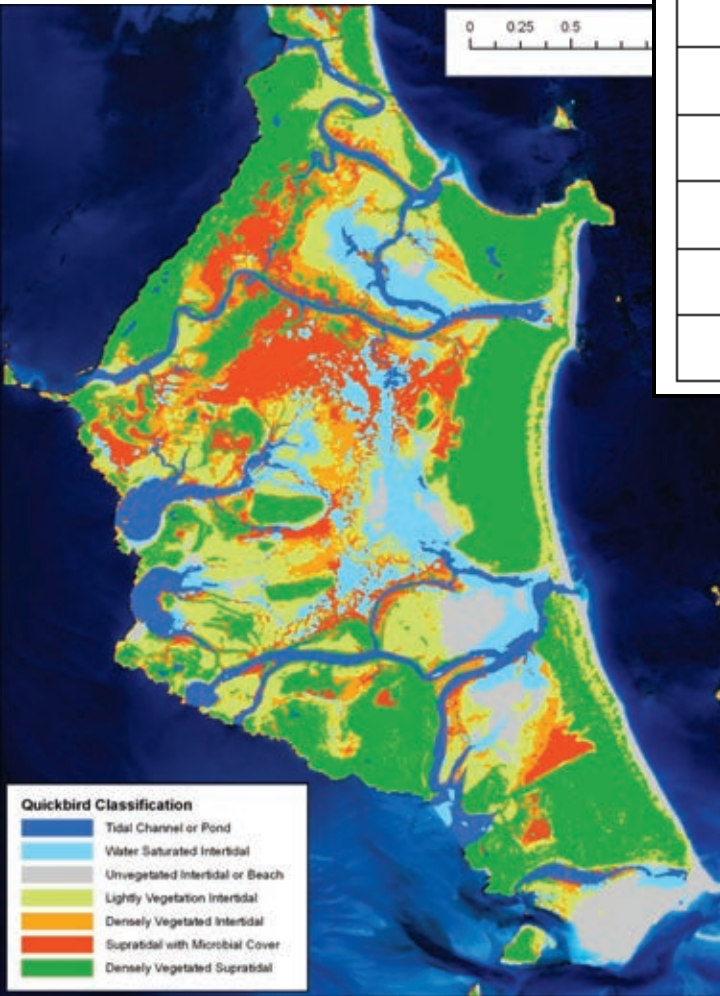
Roll-Up
20 Classes
Into 8



Carbonate Geologist Map



Distribution Of Onshore Landcover Types



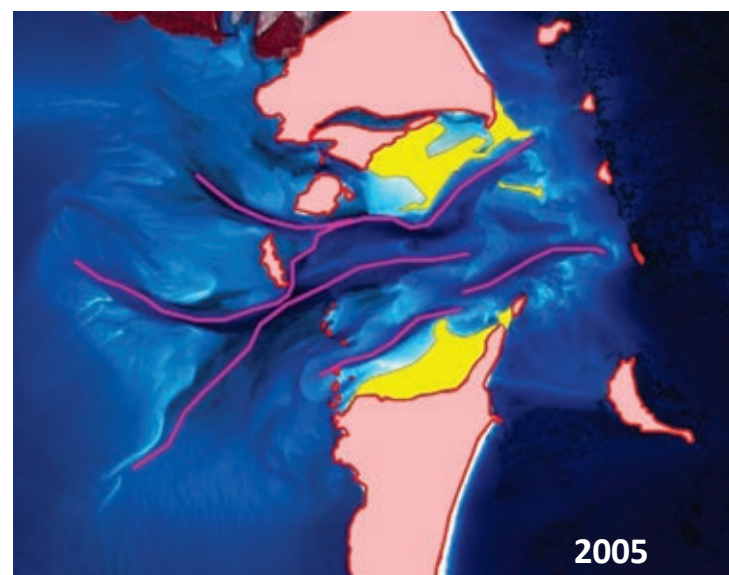
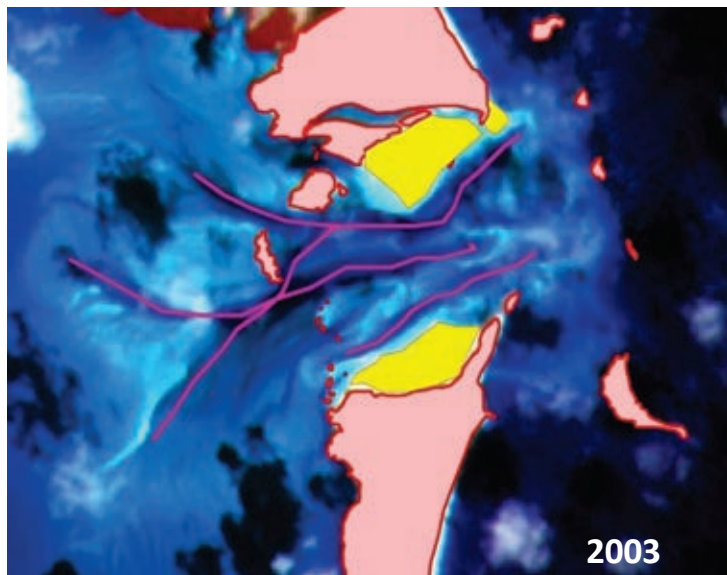
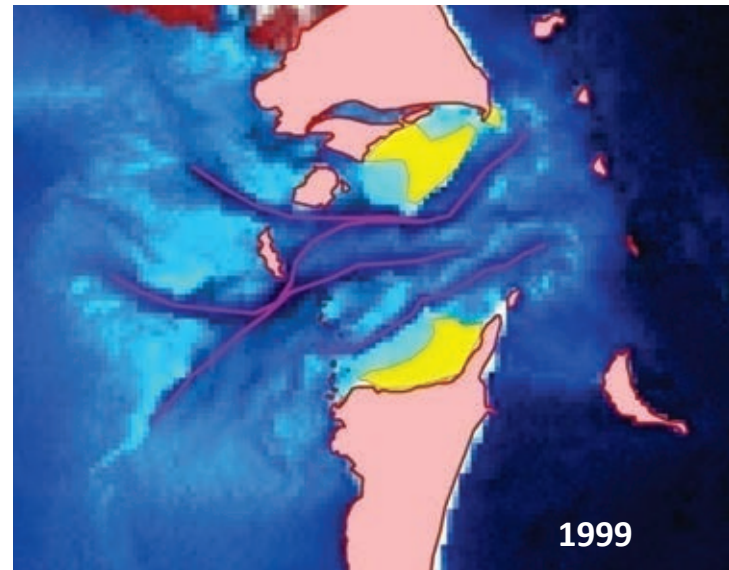
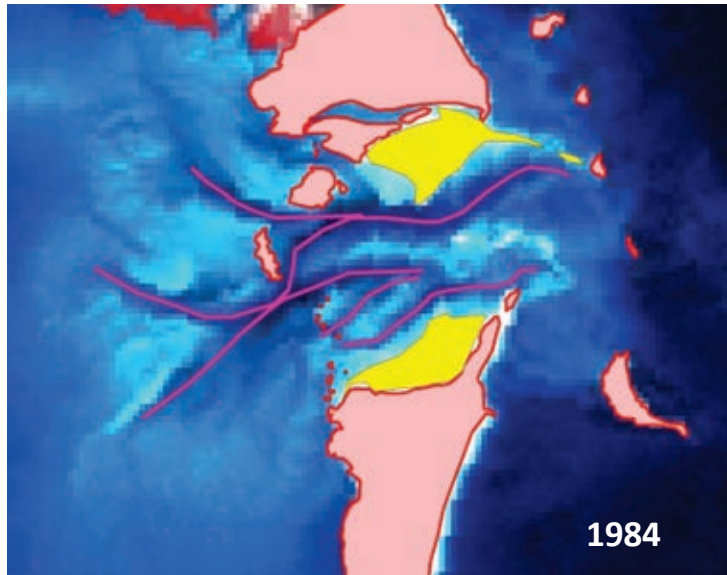
Spectral Classification of Onshore Landcover Types

Landcover Type	Color on Fig. 31F	Area (m ²)	Area (%)
Tidal Channel or Pond	Blue	712,552	9.1
Water Saturated Intertidal	Light Blue	819,360	10.5
Unvegetated Intertidal or Beach	Light Gray	532,045	6.8
Lightly Vegetated Intertidal	Light Green	1,431,510	18.3
Densely Vegetated Intertidal	Orange	873,919	11.2
Supratidal with Microbial Cover	Red	759,842	9.7
Densely Vegetated Supratidal	Green	2,700,046	34.5
TOTAL		7,829,274	100.0

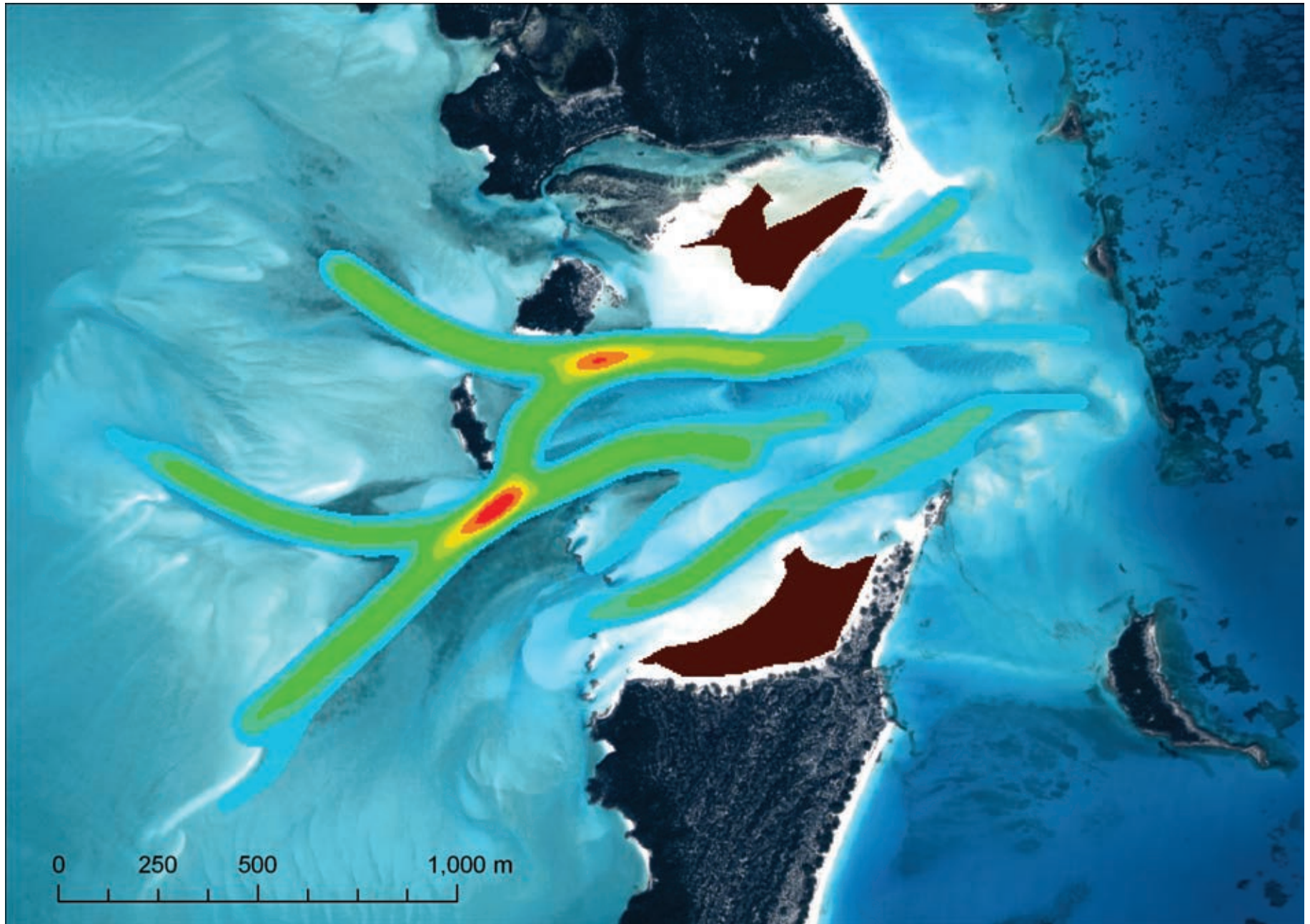
*9310 polygons in
the classification
map...*

Tidal Channels and Change Detection

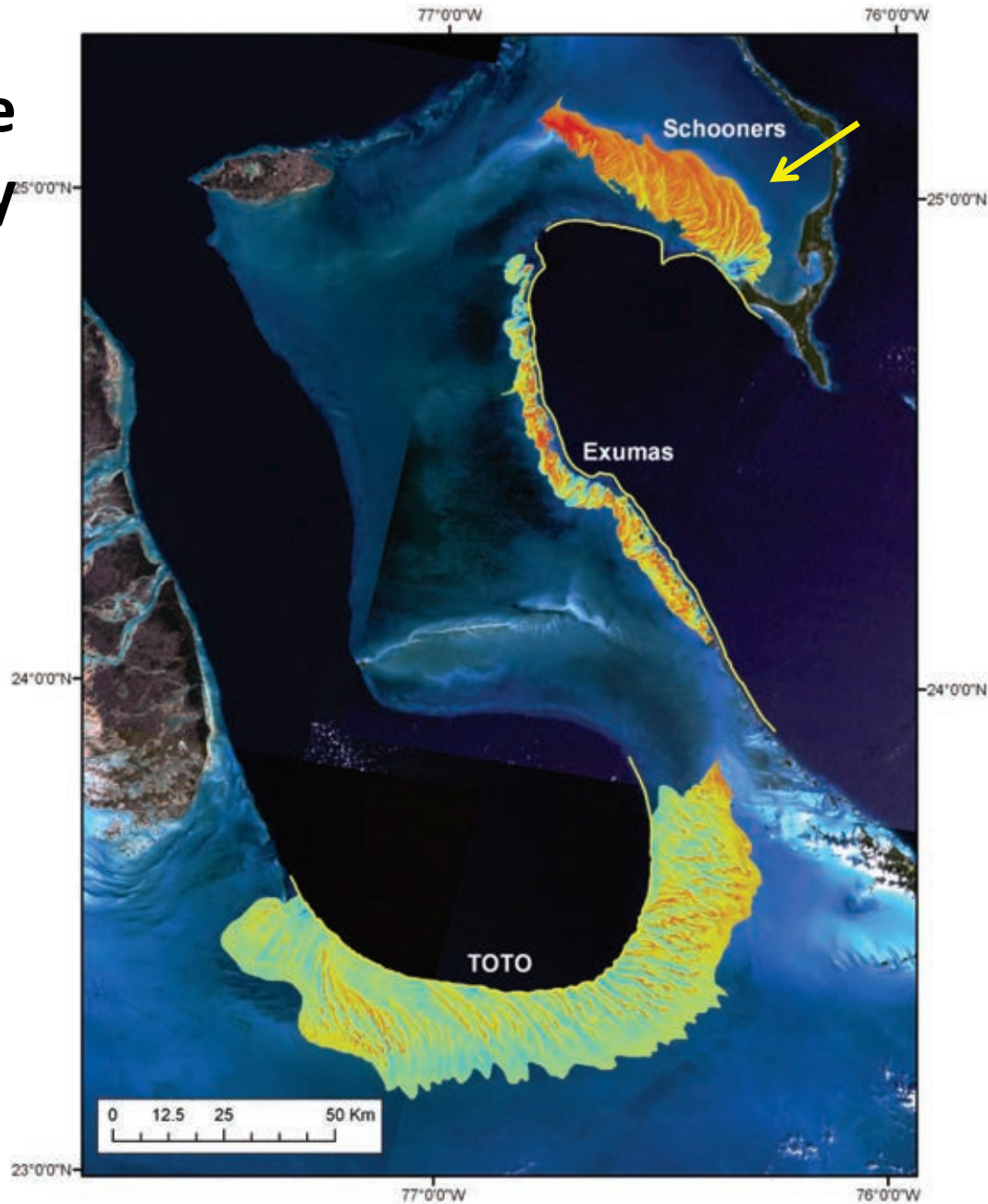
Changes in channels and associated sand bodies



Using Historic Imagery to Document Channel Stability

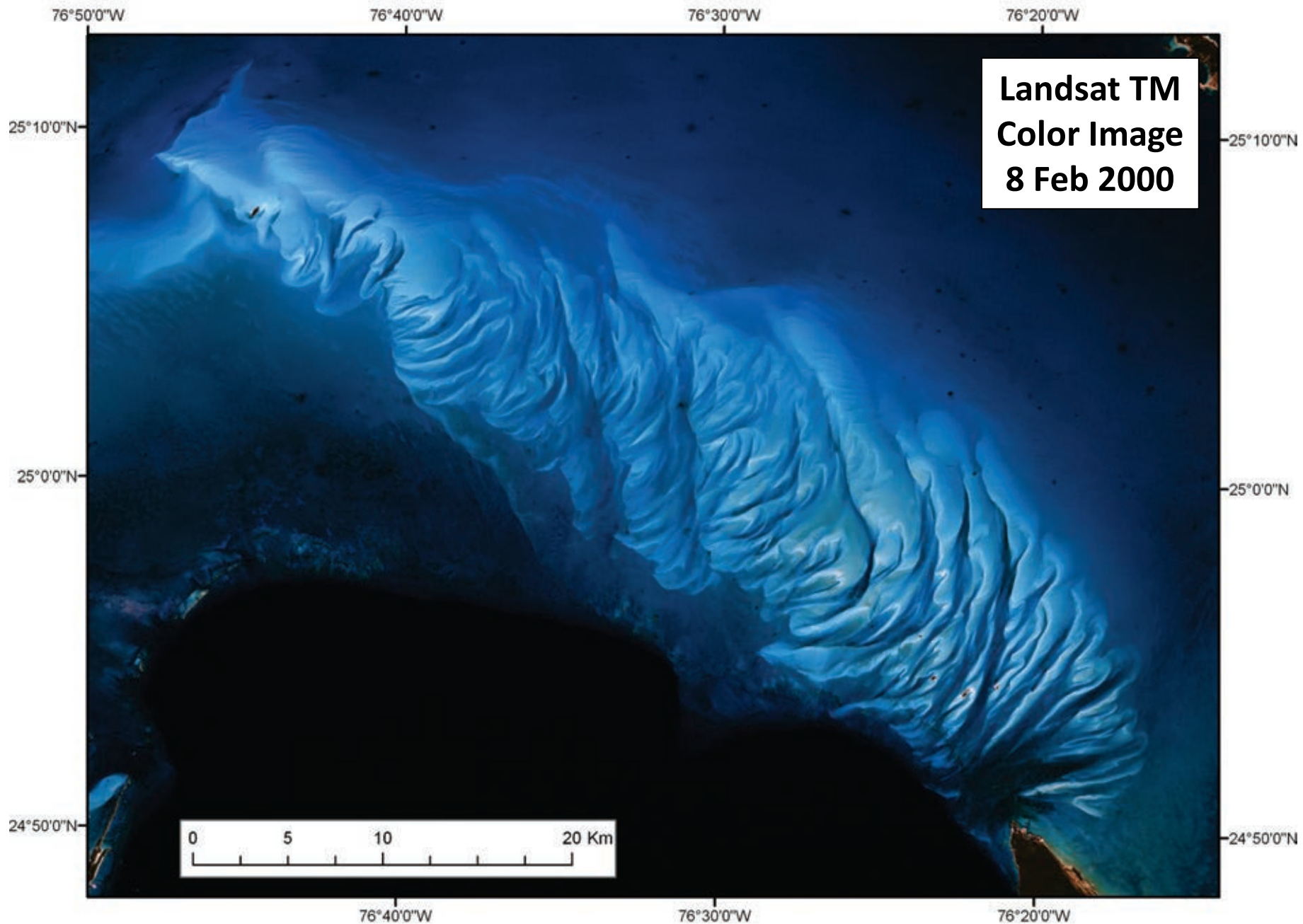


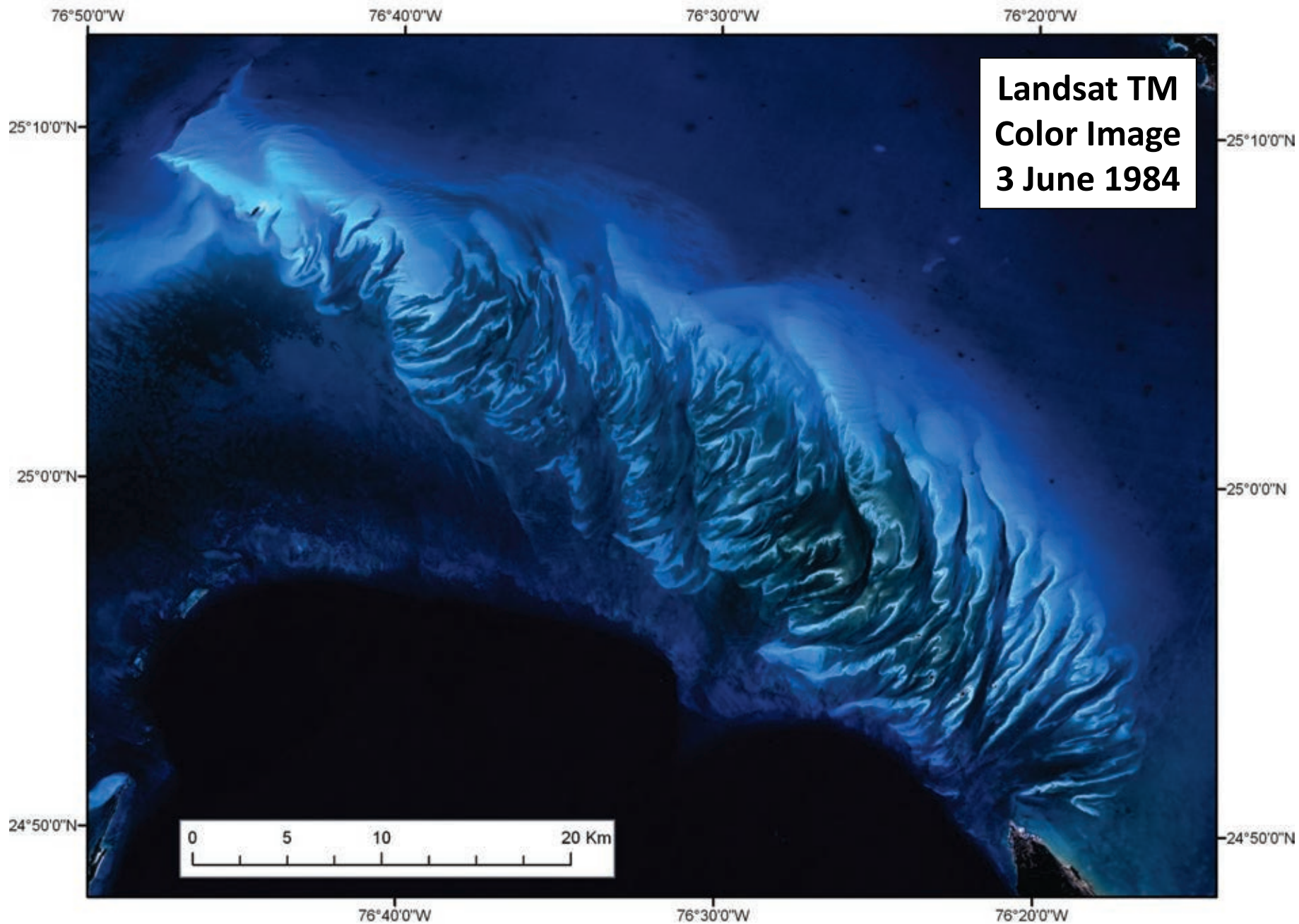
Developing an Offshore Bathymetry DEM

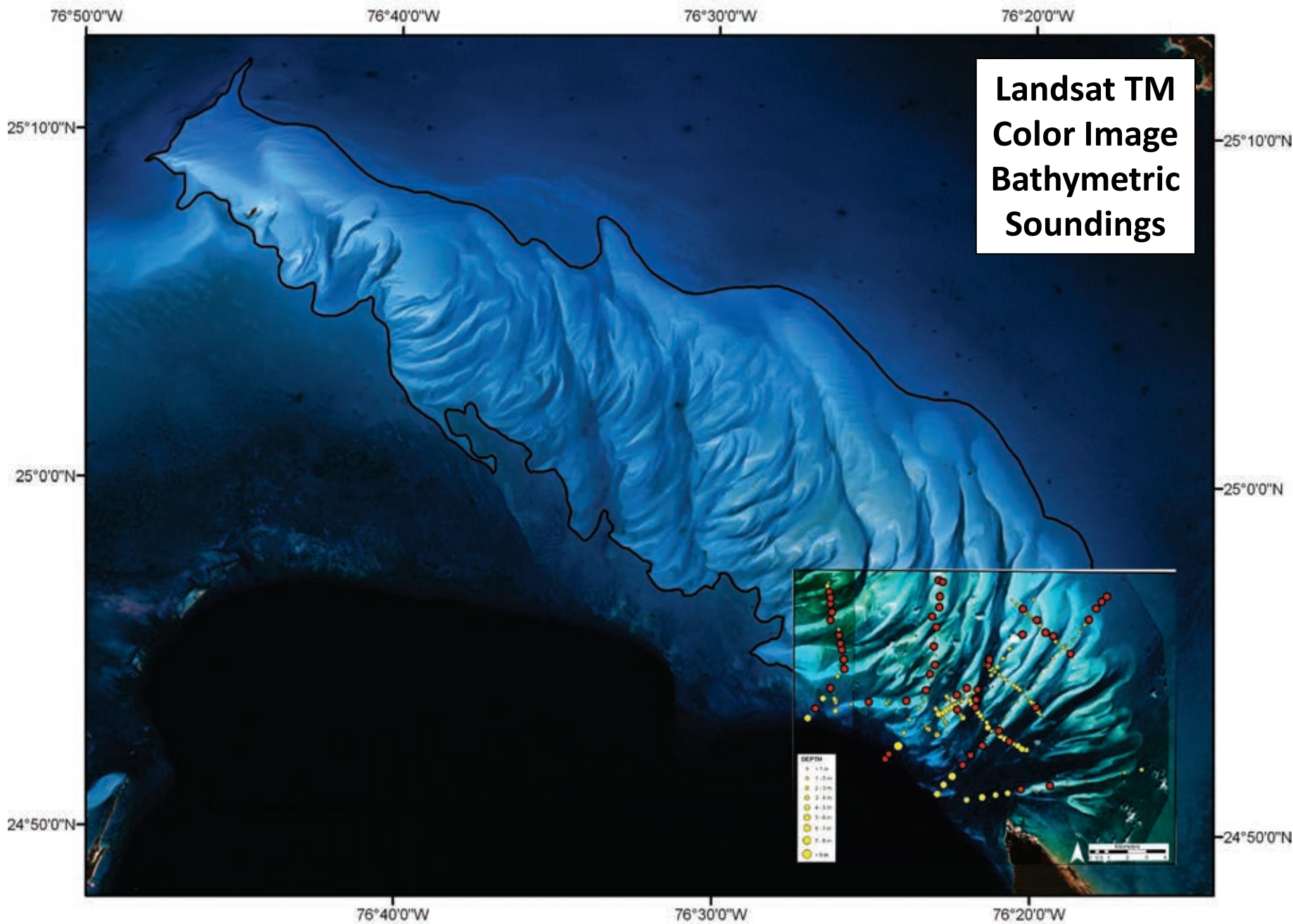


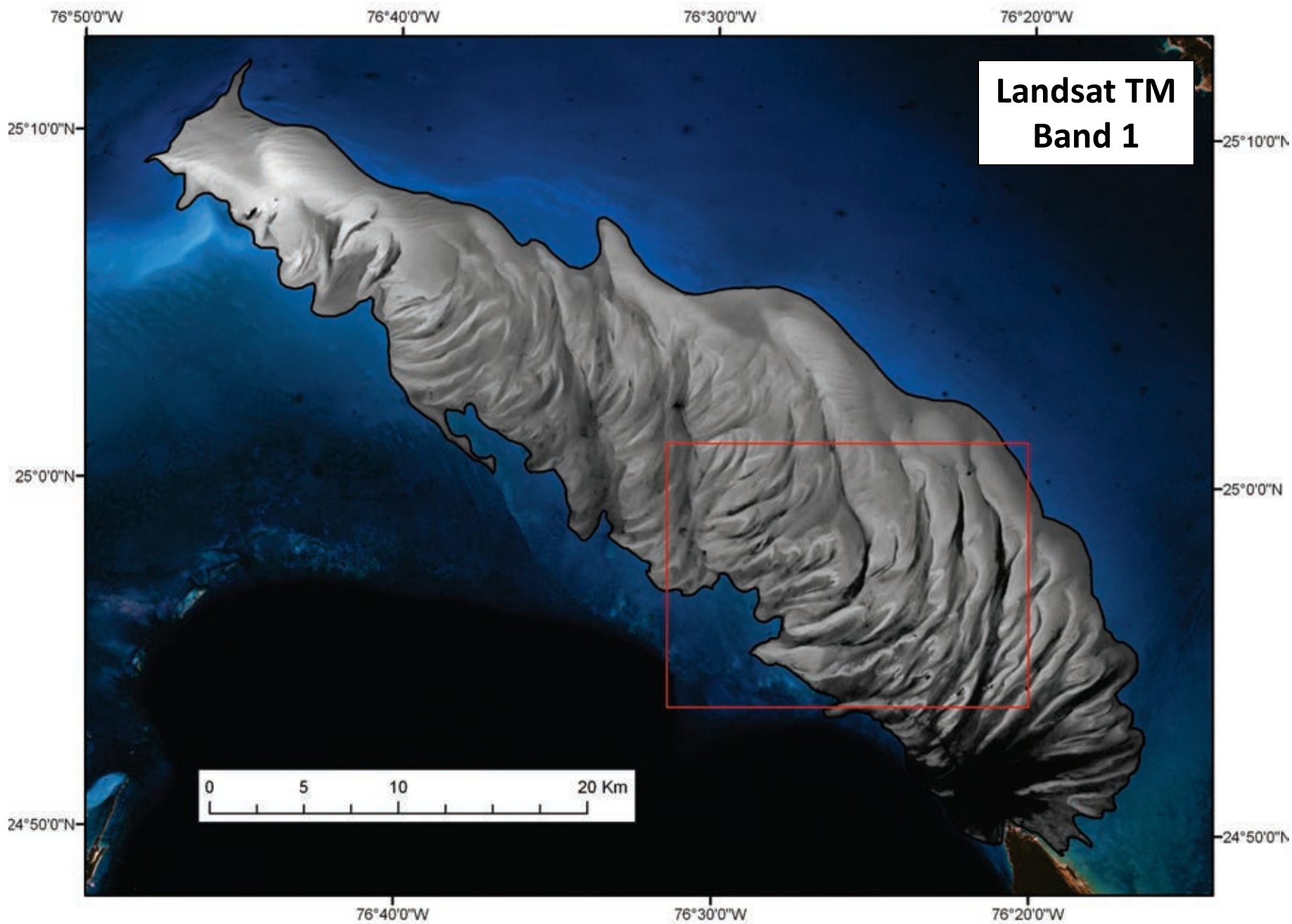
Navigation Chart

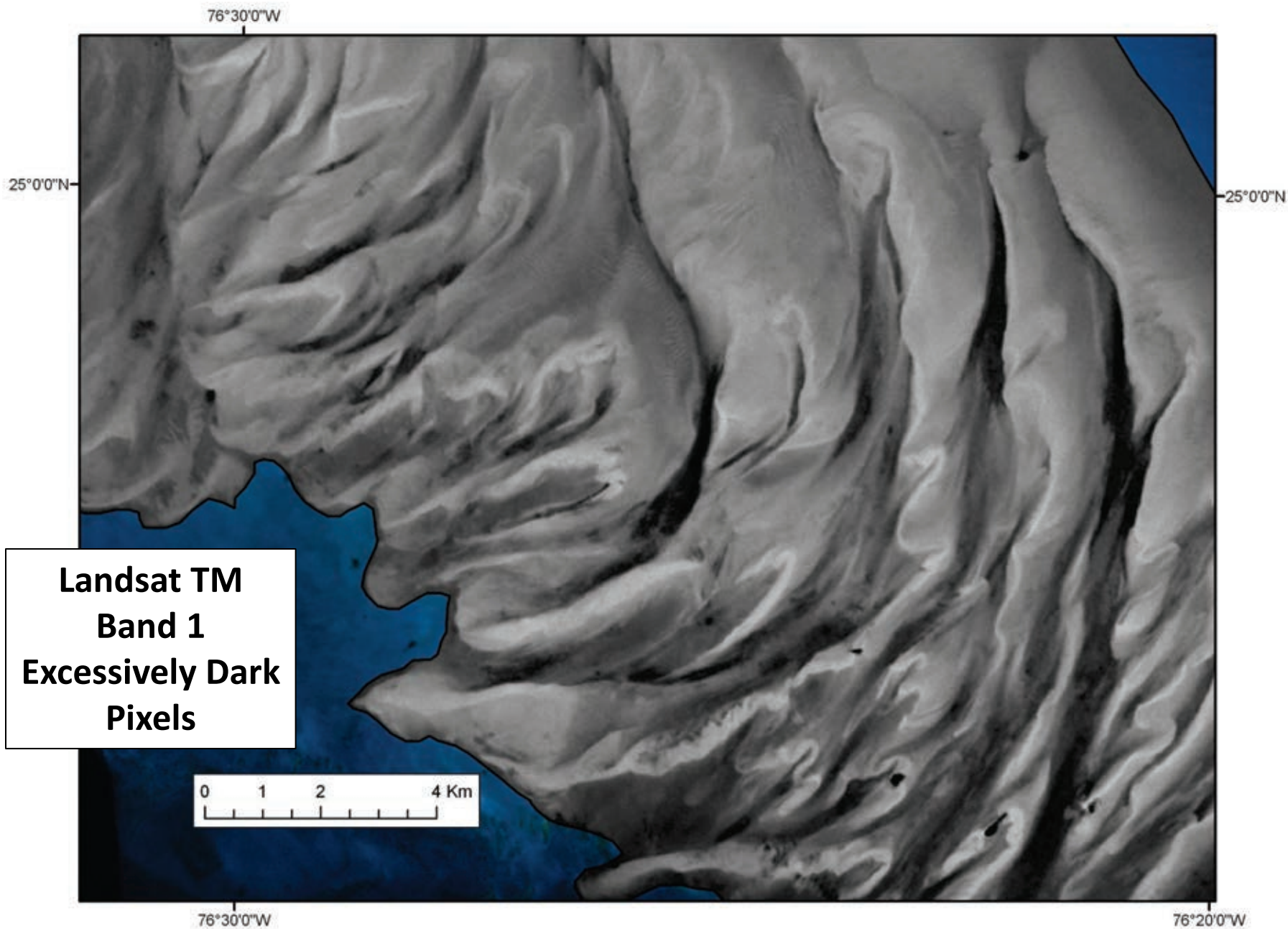


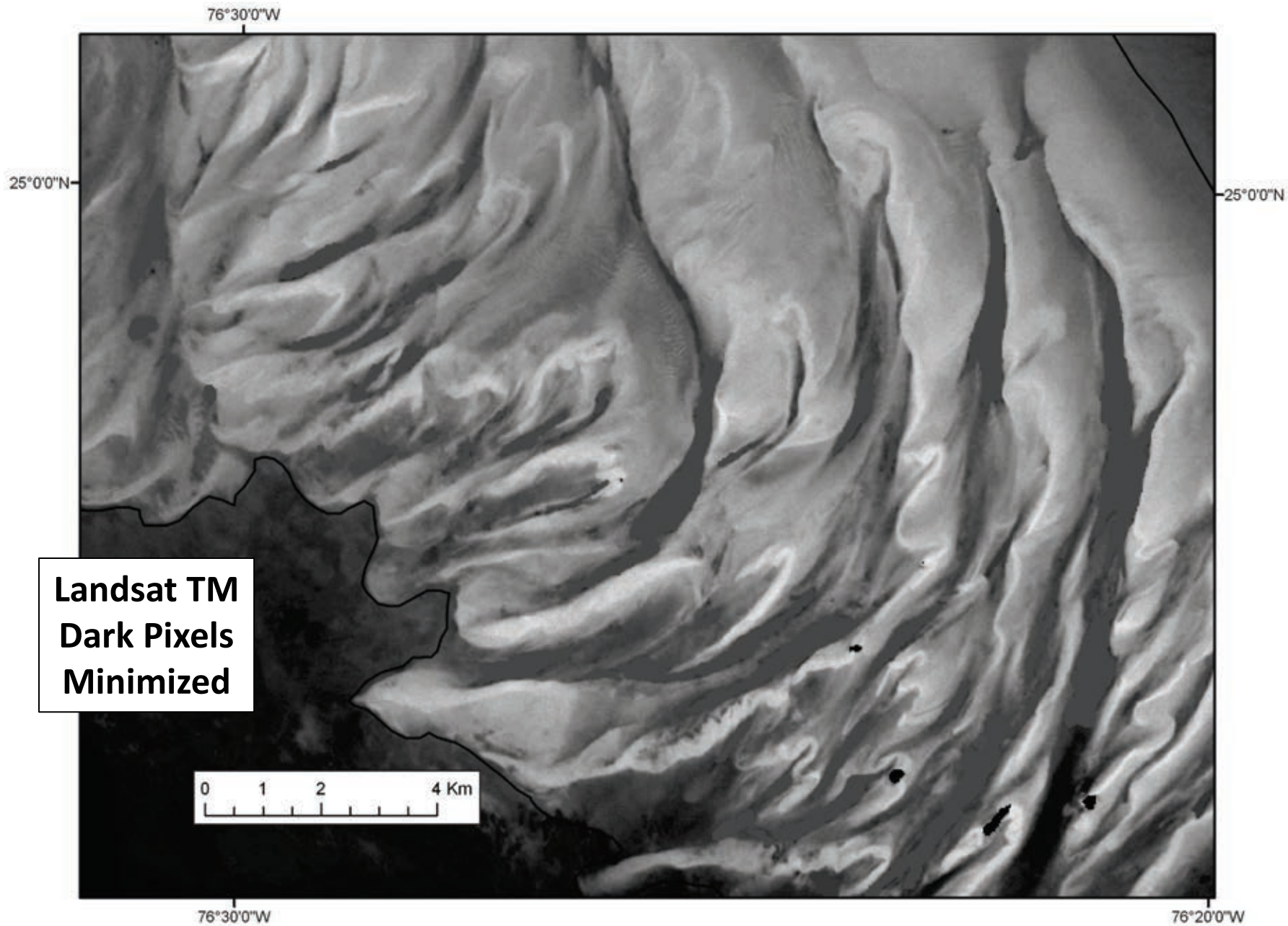




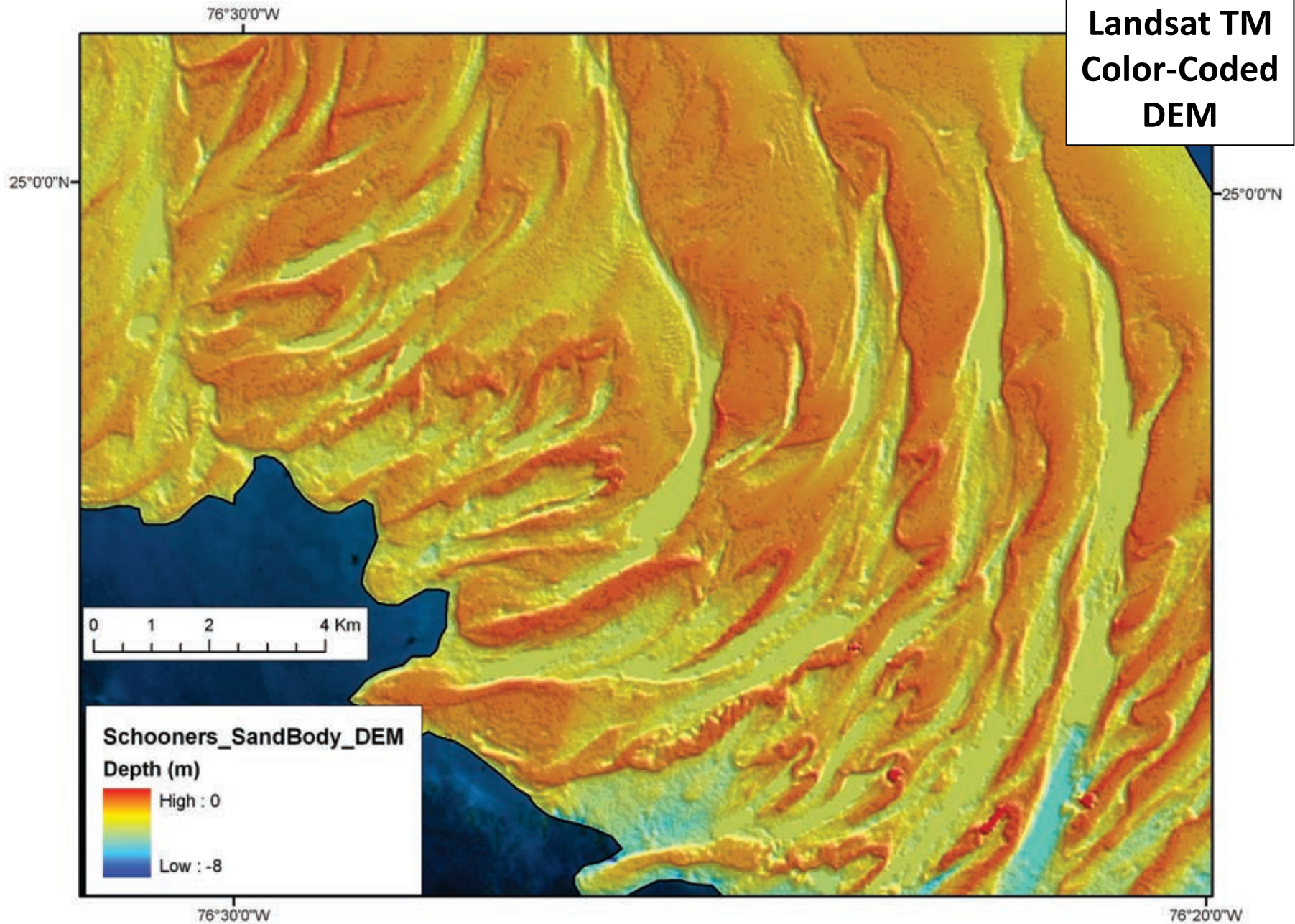




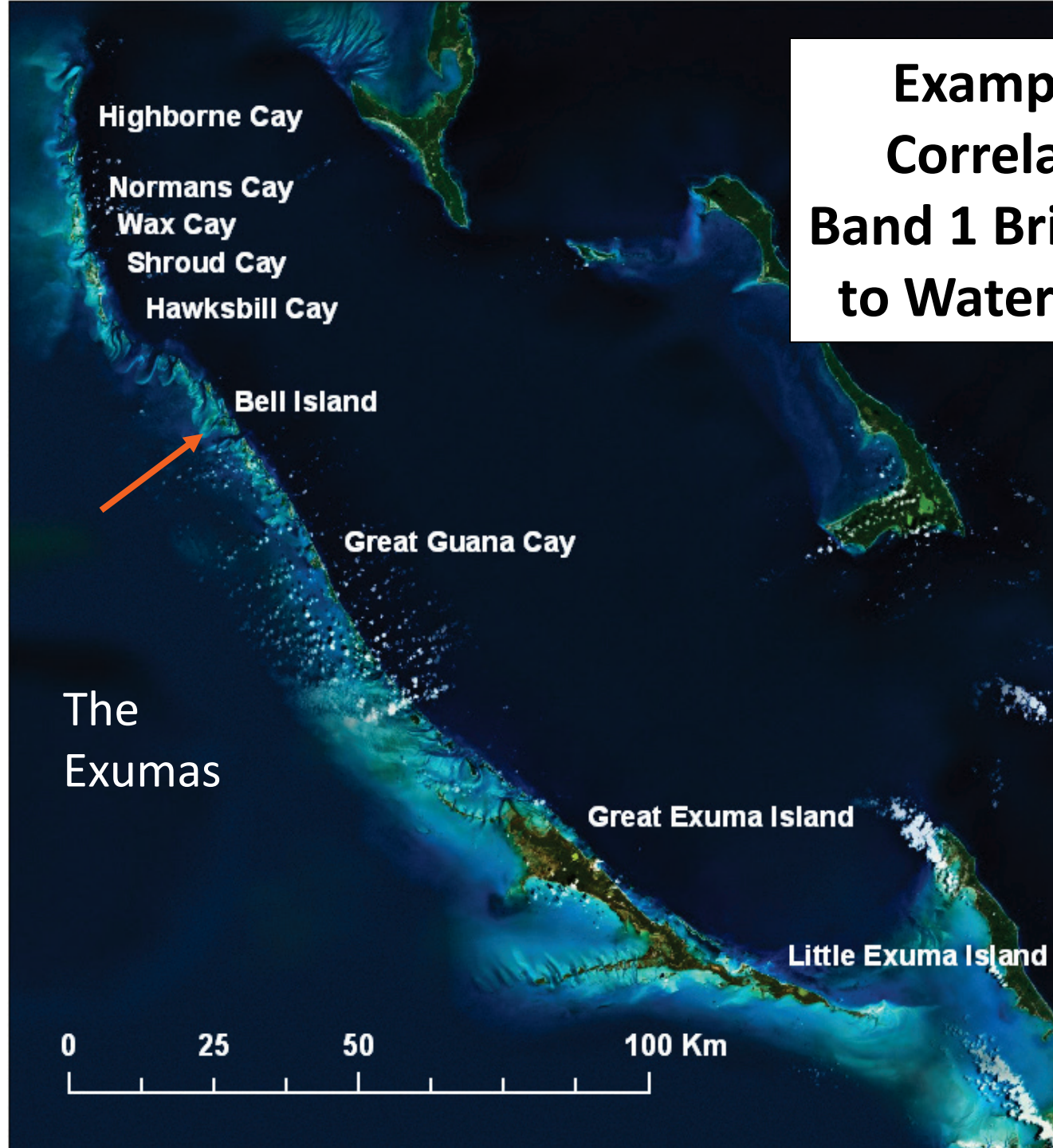




**Landsat TM
Color-Coded
DEM**



Example of Correlating Band 1 Brightness to Water Depth



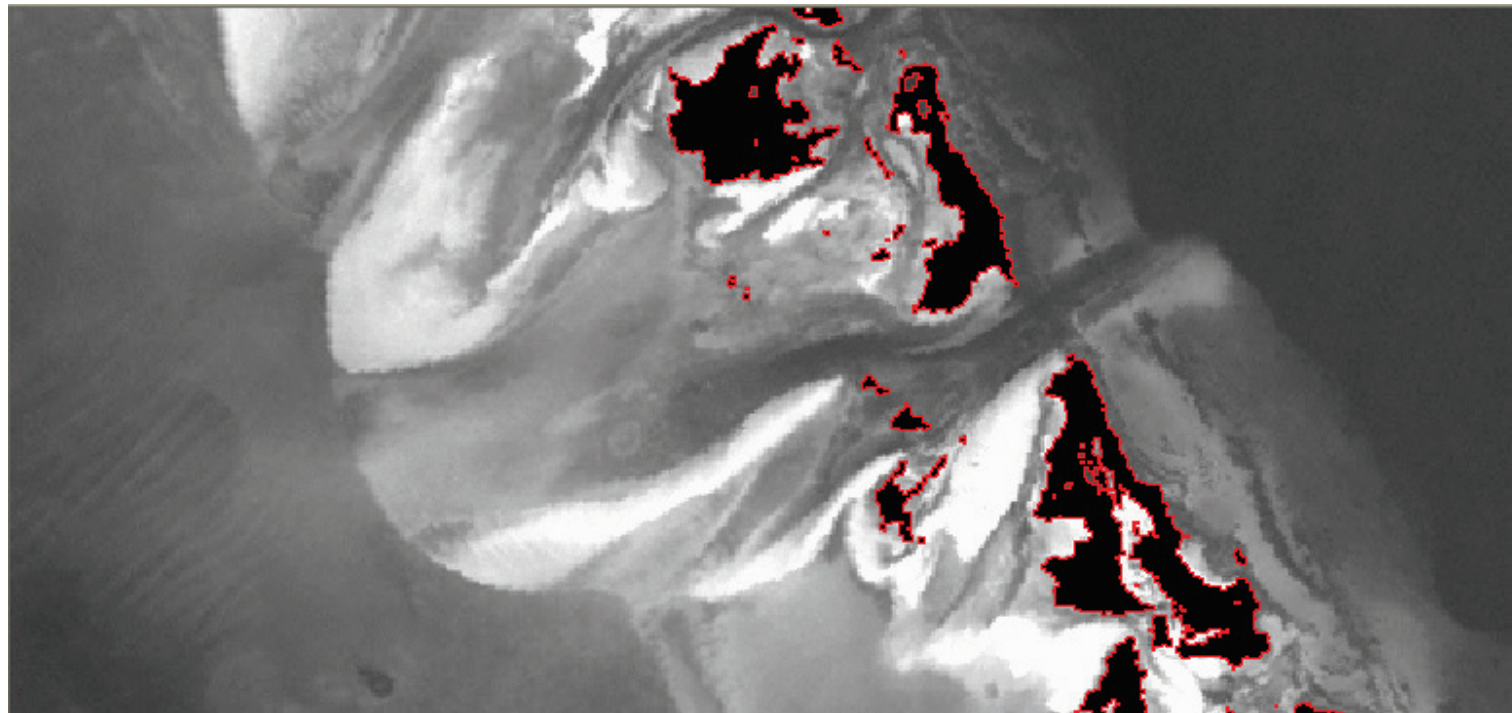
Some Areas had Navigation Charts

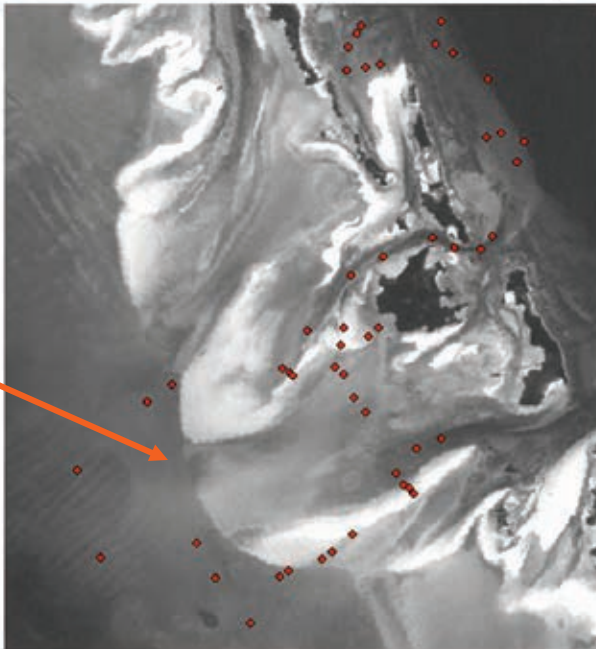
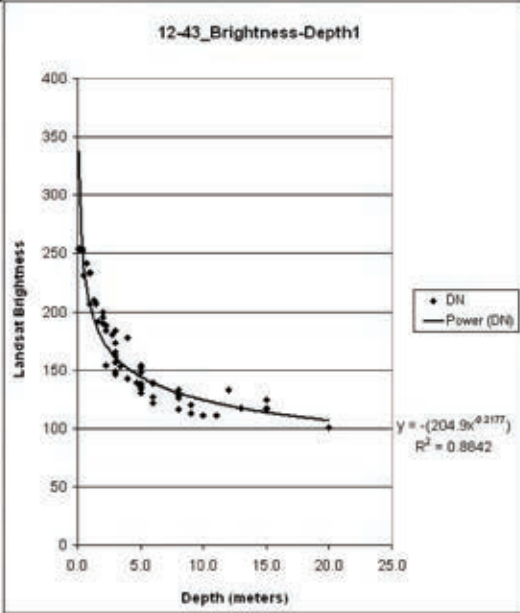
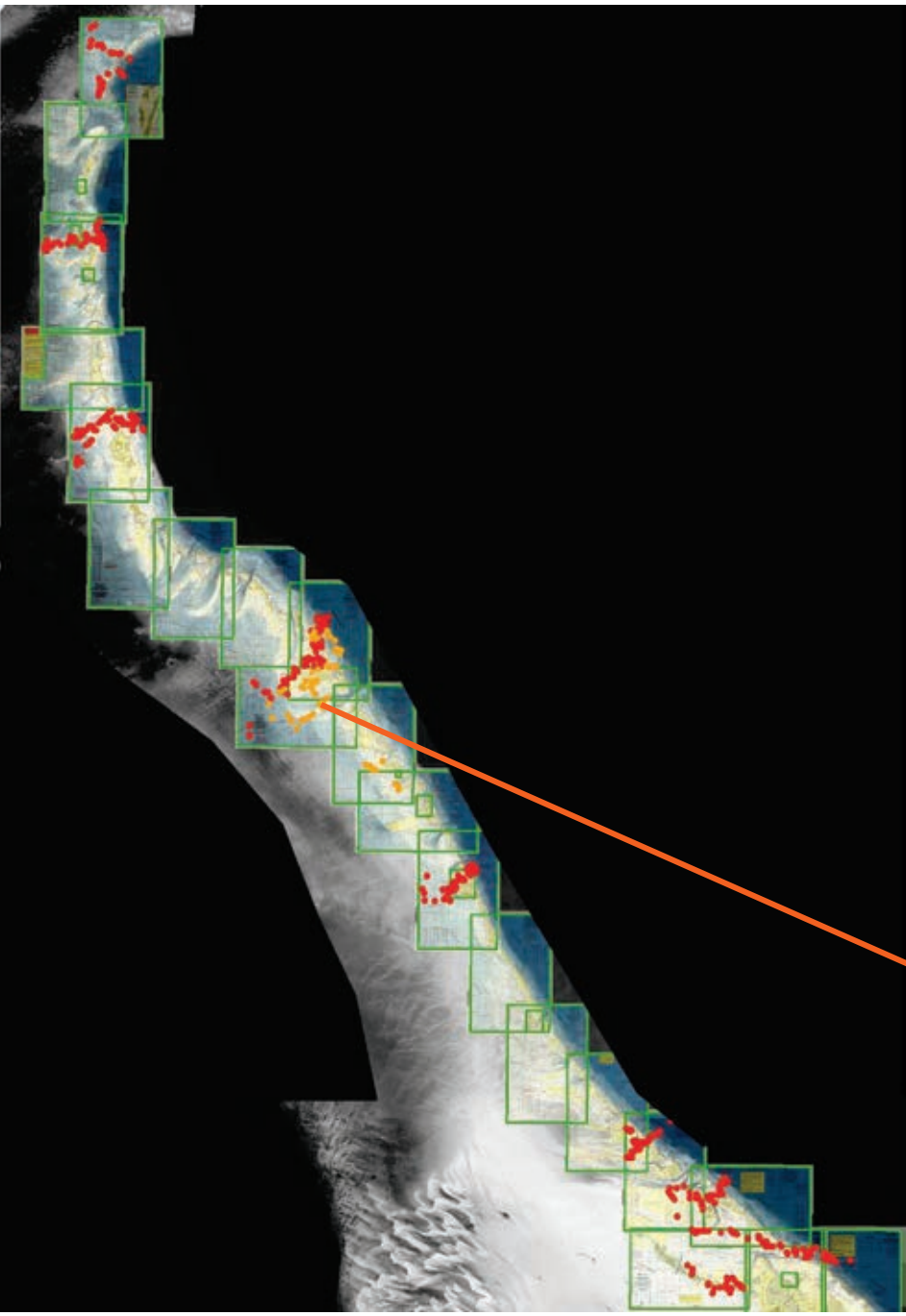
Navigation Chart with Soundings (1:32,000)



Landsat image of reflected blue light as a grayscale image

Islands masked black using Space Shuttle Radar Image

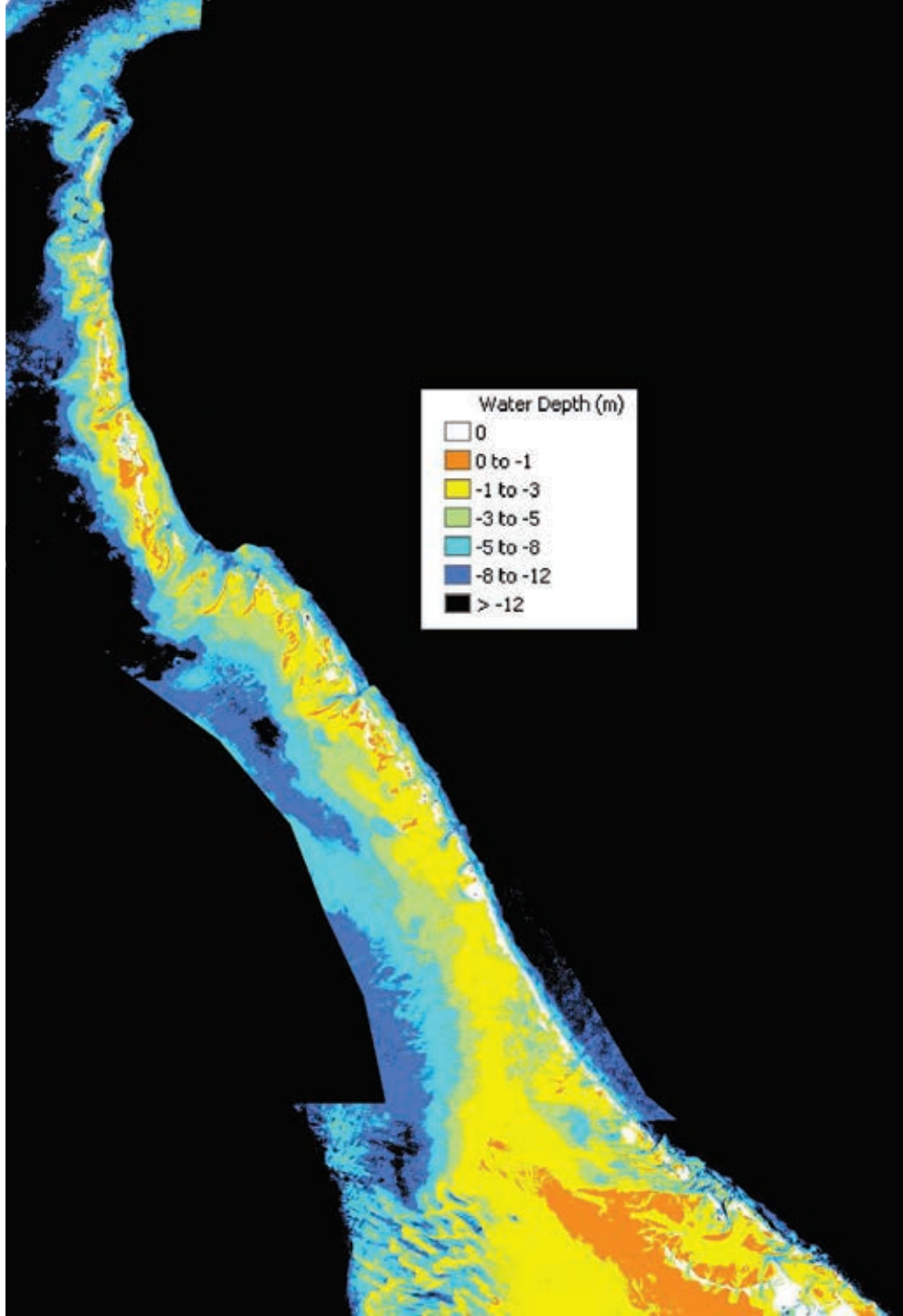




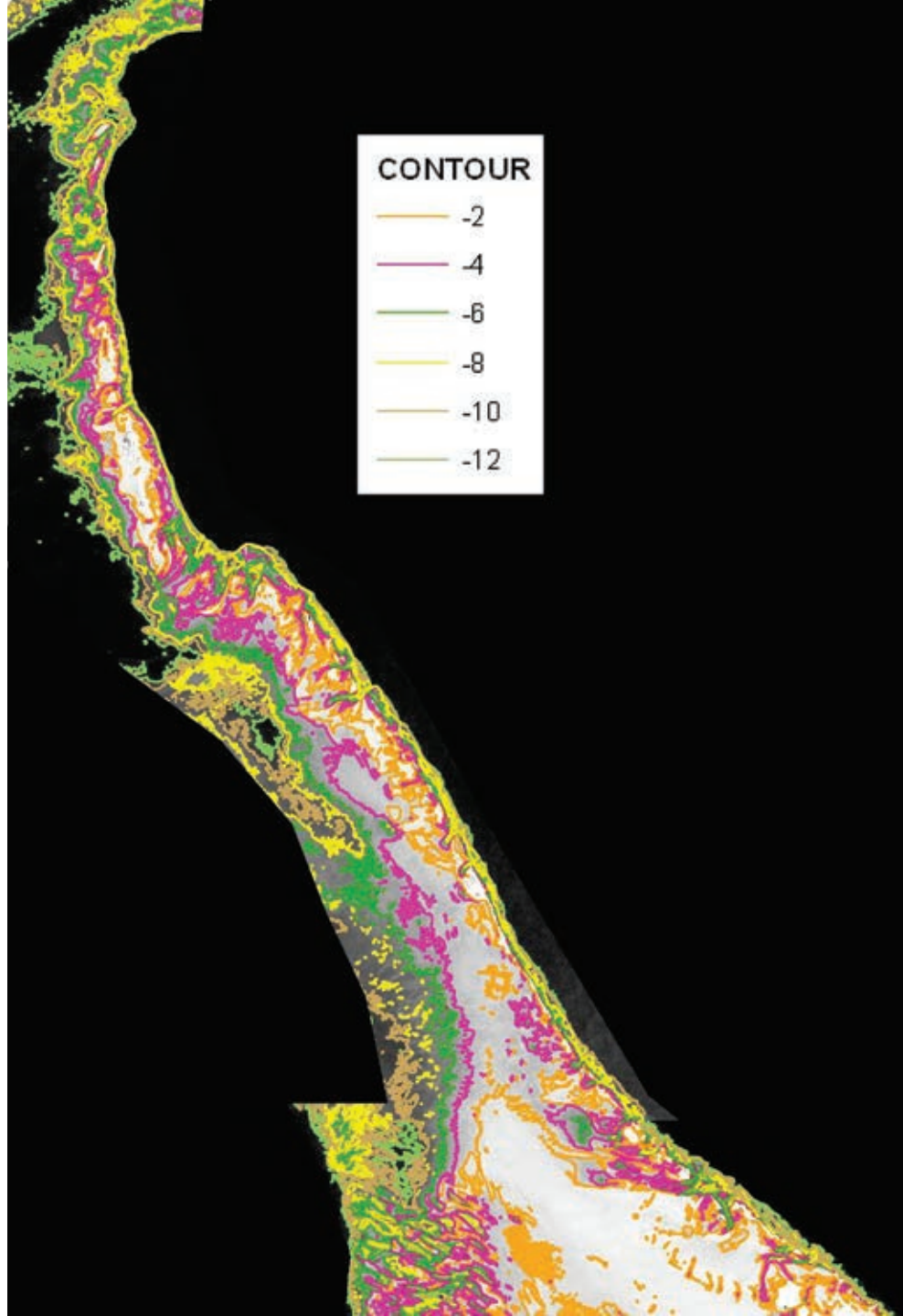
Depth	Brightness
0.1	254
0.2	254
0.4	252
0.5	254
0.7	231
1.0	242
1.0	207
1.0	233
1.0	234
1.3	210
1.4	209
1.5	207
1.6	192
2.0	195
2.0	190
2.0	200
2.3	154
2.3	184
2.3	188
2.8	180
3.0	184
3.0	165
3.0	157
3.0	162
3.0	149
3.0	173
3.0	146
3.4	153
4.0	178
4.0	143
4.7	139
4.8	138
5.0	152
5.0	130
5.0	138
5.0	134
5.0	136
5.0	148
5.0	154
5.0	138
6.0	122
6.0	138
6.0	139
6.0	127
8.0	133
8.0	126
8.0	116
8.0	129
9.0	113
9.0	120

Millions of x,y,z points in the offshore DEM

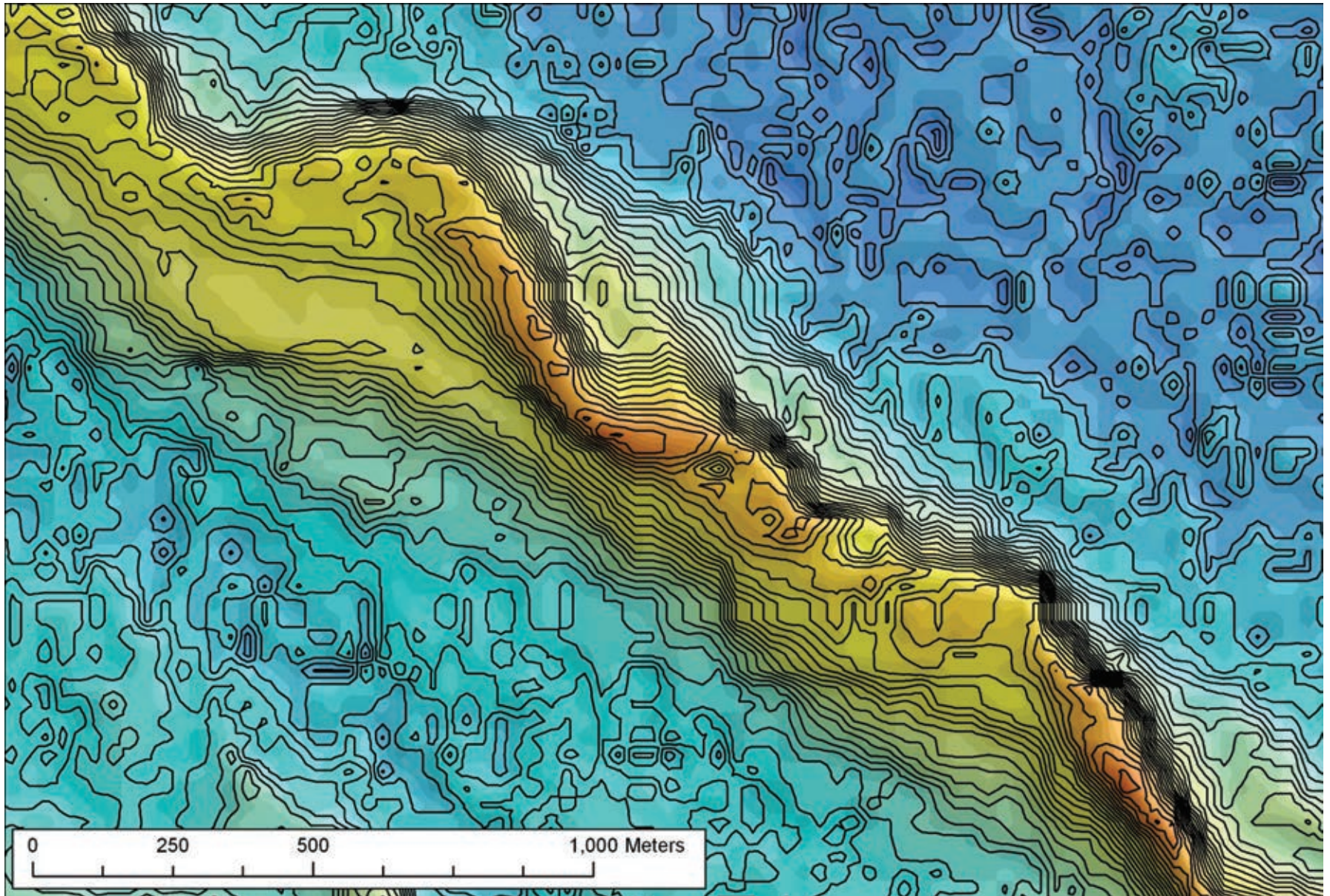
Color-Coded Offshore DEM



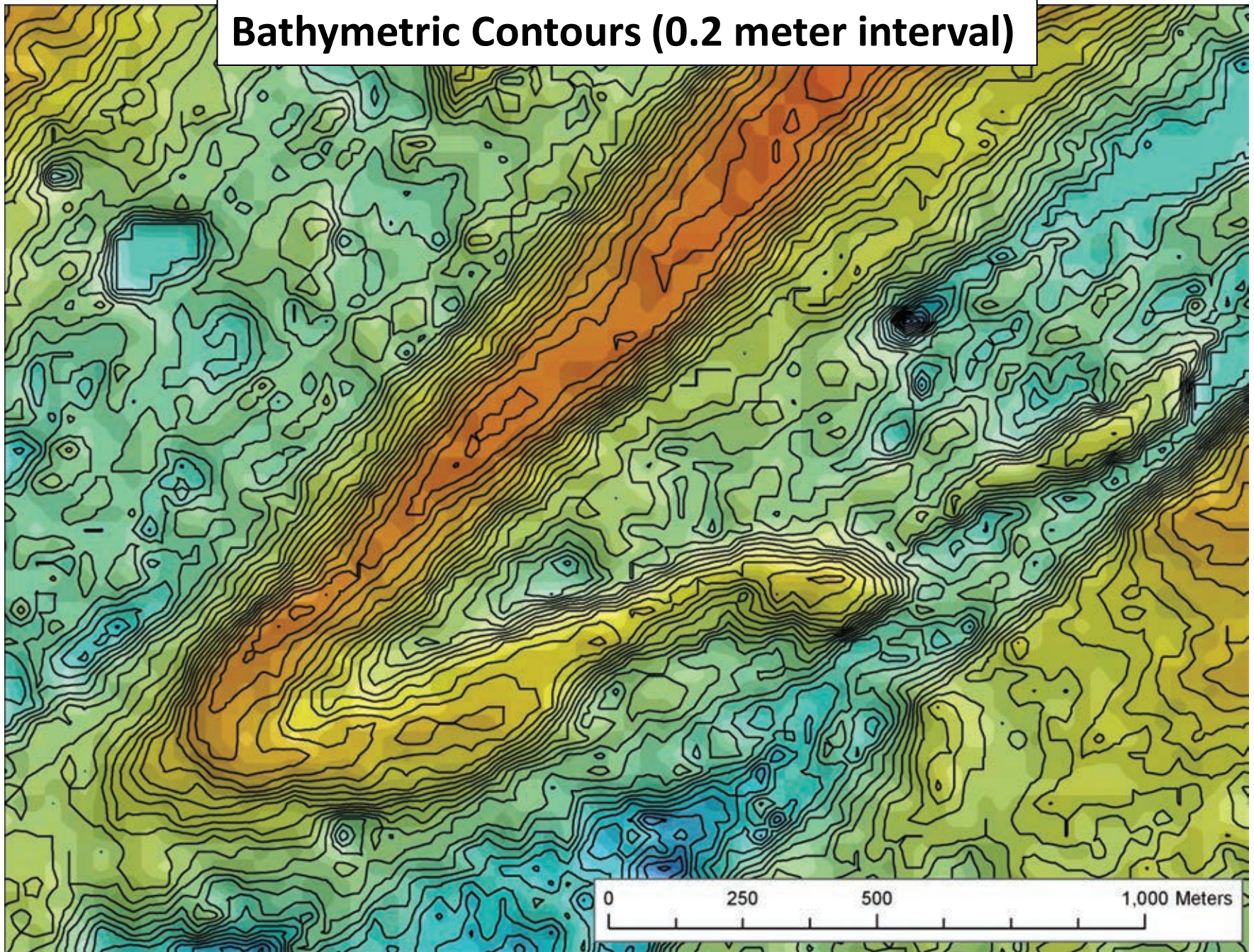
Color-Coded Offshore Contours



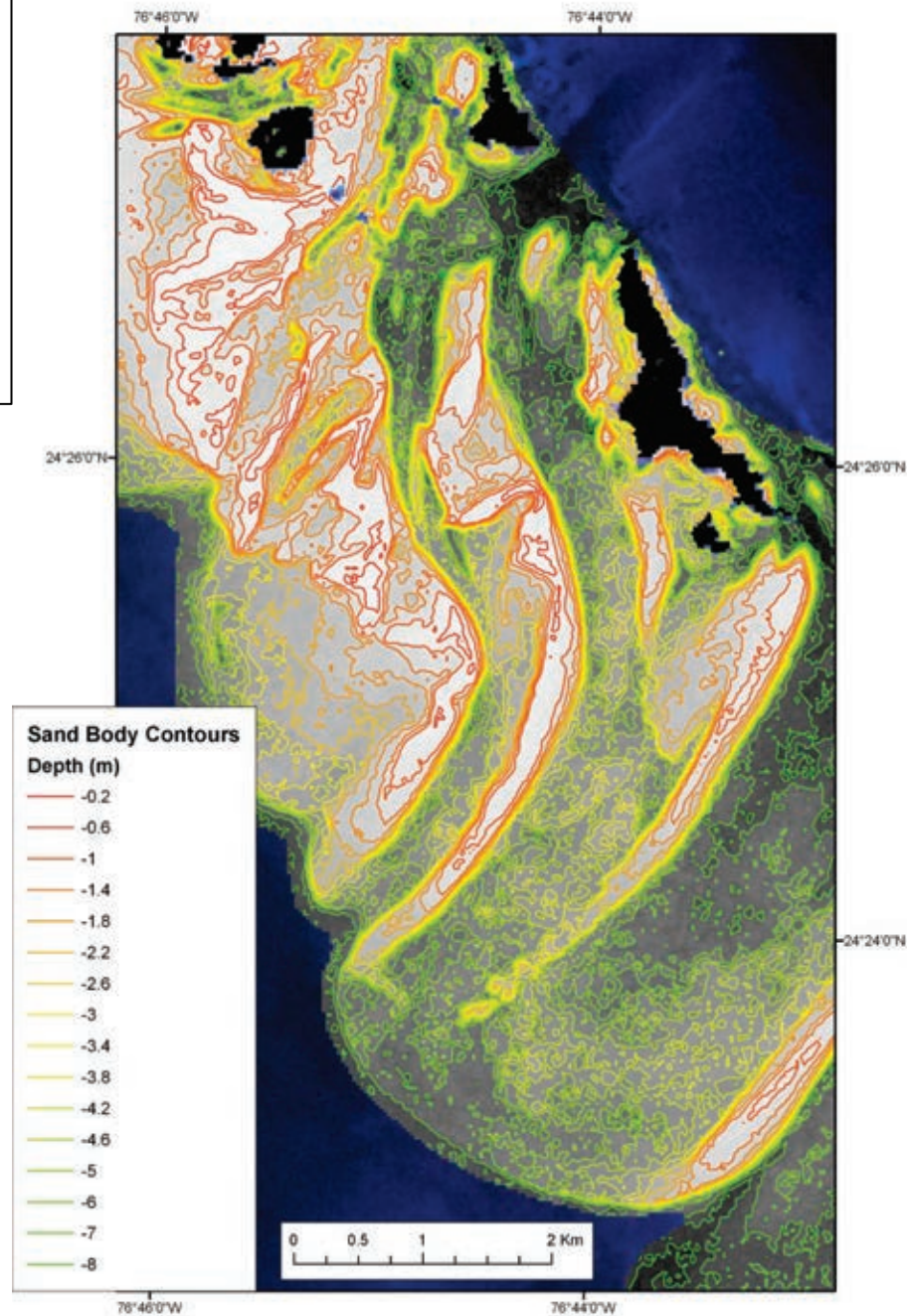
Bathymetric Contours (0.2 meter interval)



Bathymetric Contours (0.2 meter interval)



Bathymetric Contours (Selected Contours from 0.2 meter interval)



Drainage Model on Landsat TM DEM

RiverWorks Software

Identify

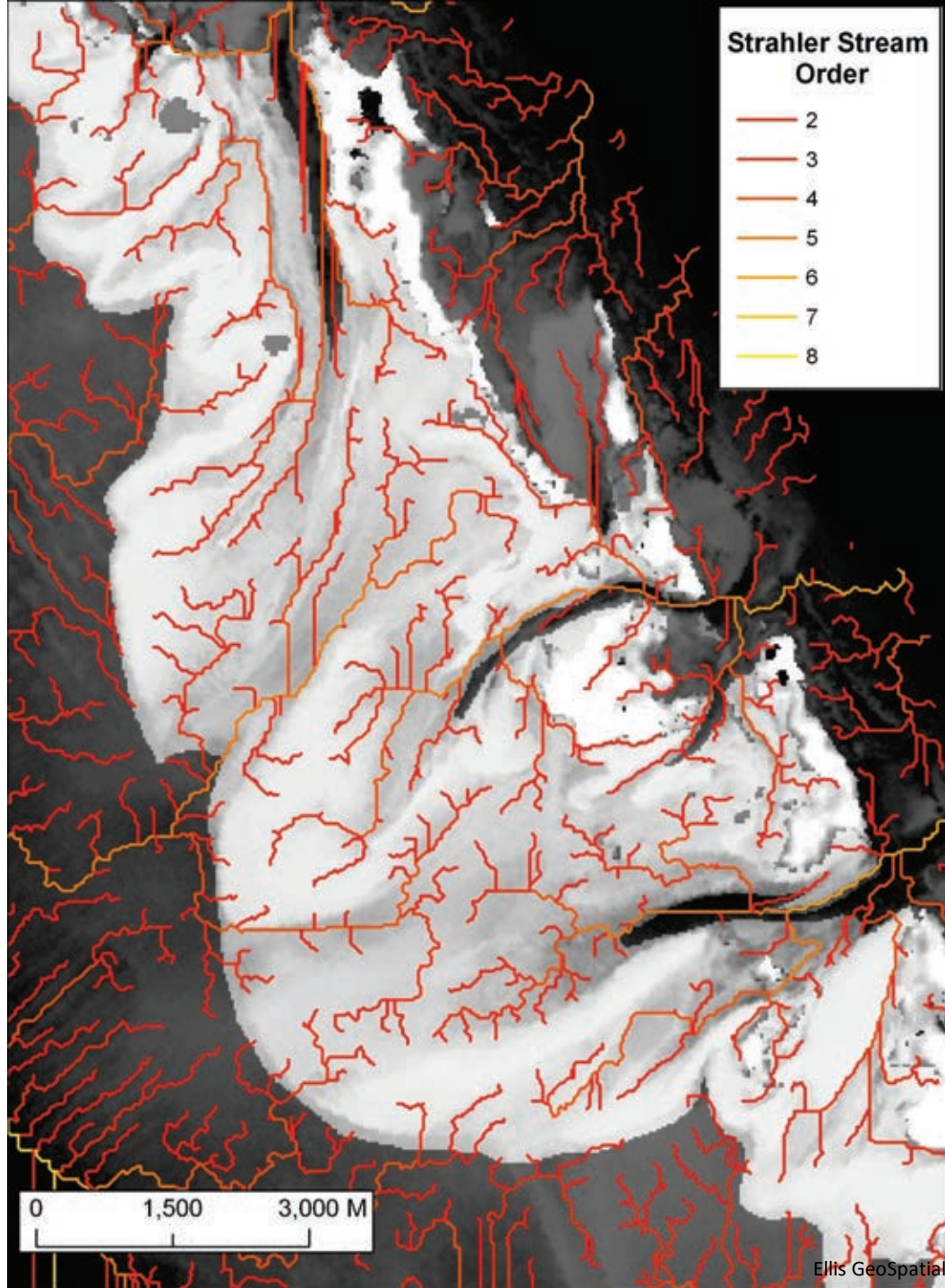
Identify from: High-Guana_Drainage_onshore-offshore1

☒ High-Guana_Drainage_onsl
 339563.25

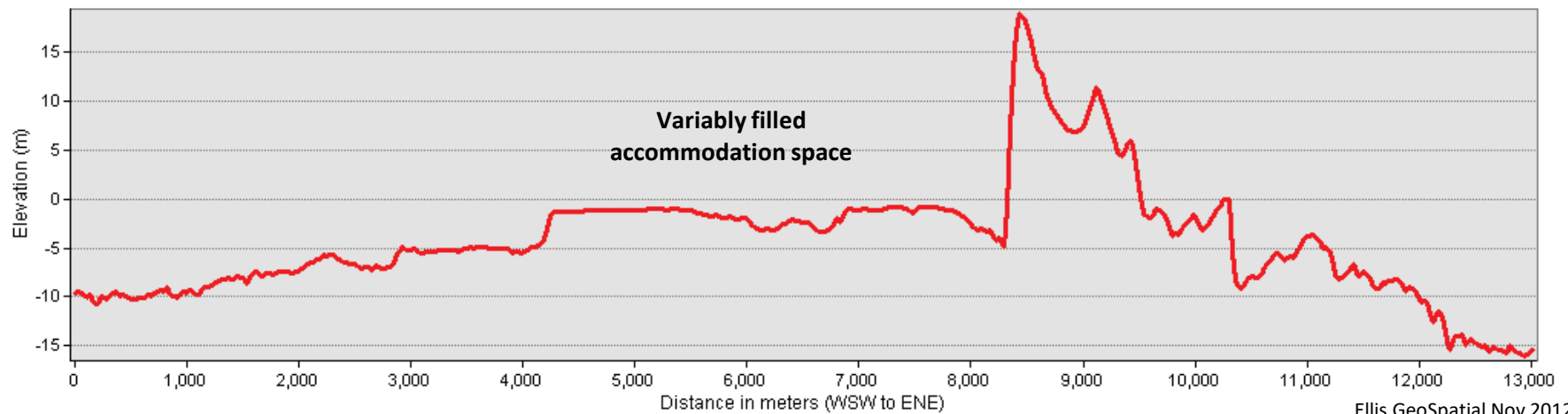
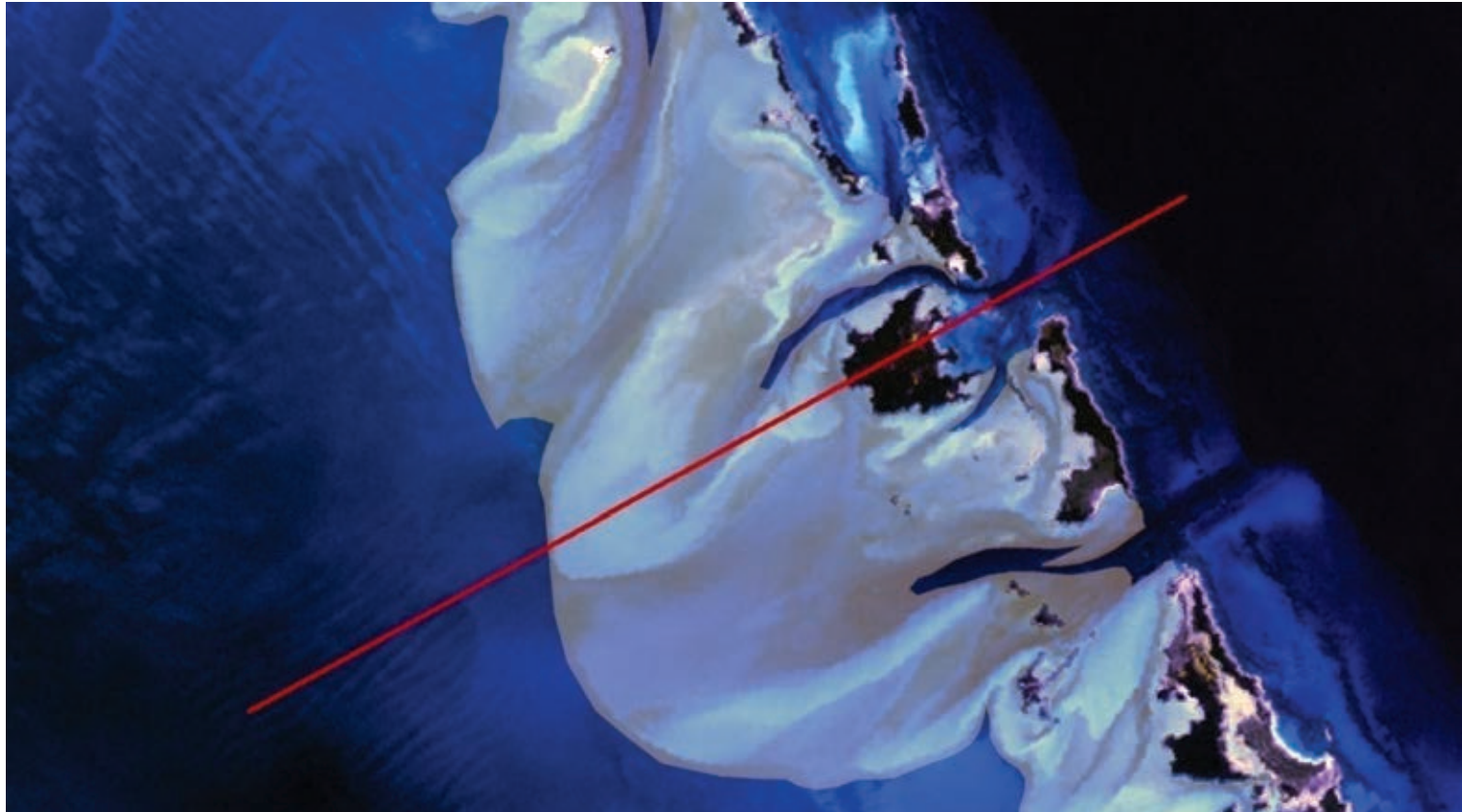
Location: 339,573.482 2,61

Field	Value
FID	8226
Shape	Polyline
Downstrm_X	339563.25
Downstrm_Y	2692893.75
Downstrm_Z	-2.4417
Dnstrm_ID	3311786
Upstrm_ID	3338497
HS_Order	3
Area_km2	0.2291
SL_Len_km	0.3876
Length_km	0.458
Drop_m	0.3177
SL_Slope	0.00082
Slope	0.000694
Tot_Len_km	1.5716
Magnitude	5
Max_Len_km	0.8354
Relief_km	0
Net_Diam	4
Sinuosity	1.1816
Drain_Dens	6.861
Source_Den	21.8289

Identified 1 Feature



Analysis of Sand Lobe Profile

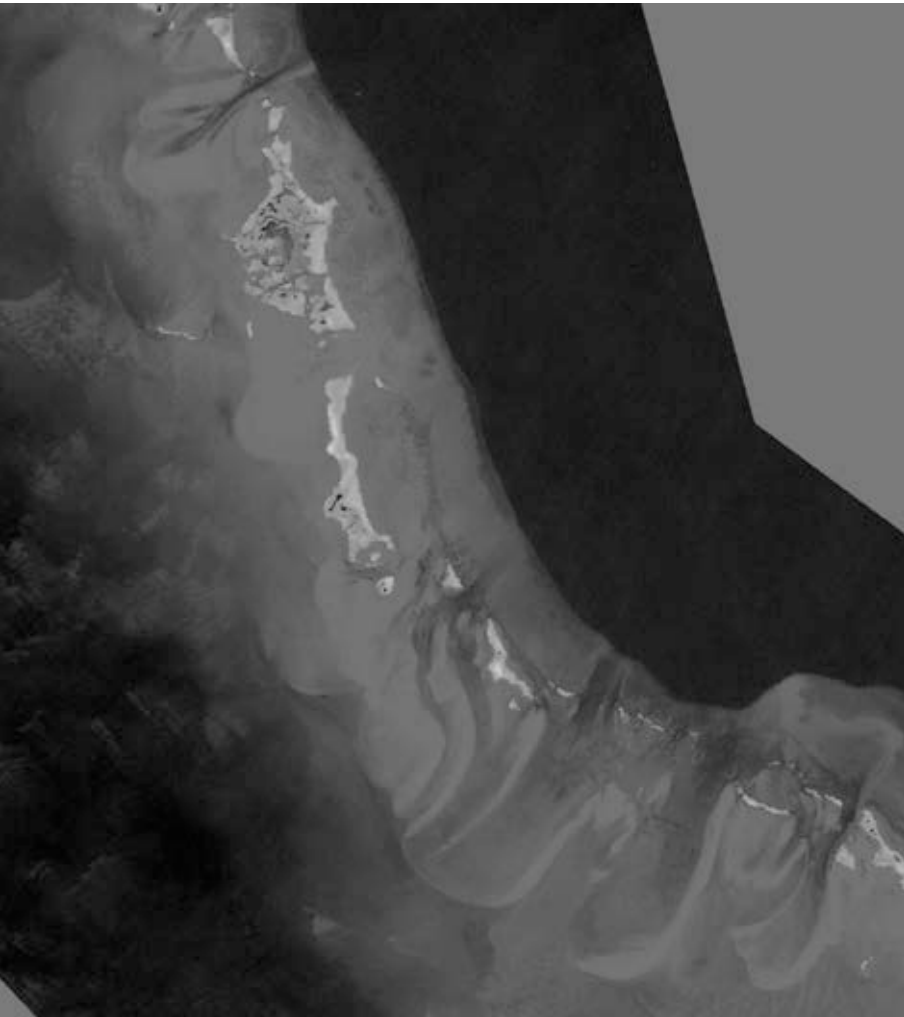


Sand Body Images, DEM, and Maps

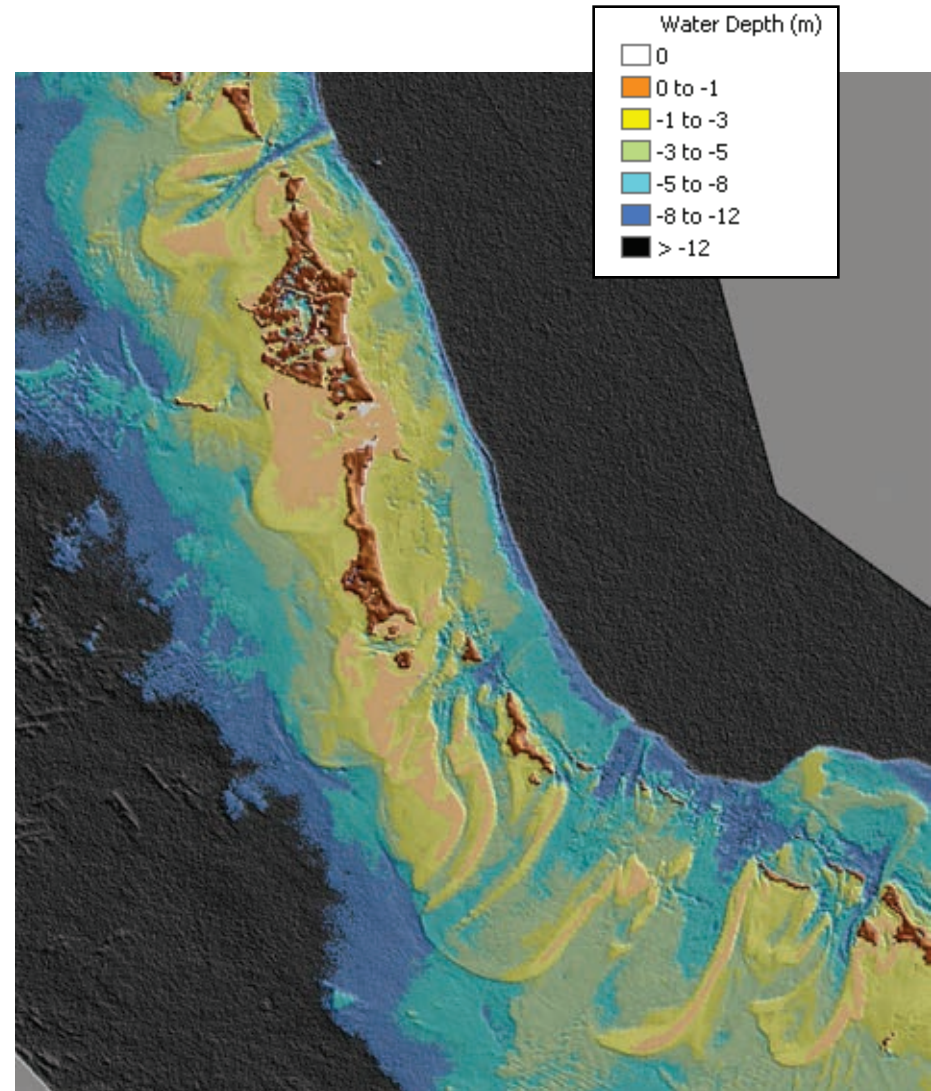


**Total Sand body =
Overall distribution of
modern carbonate
sands**

Offshore DEM (0 – 20 m water depth)



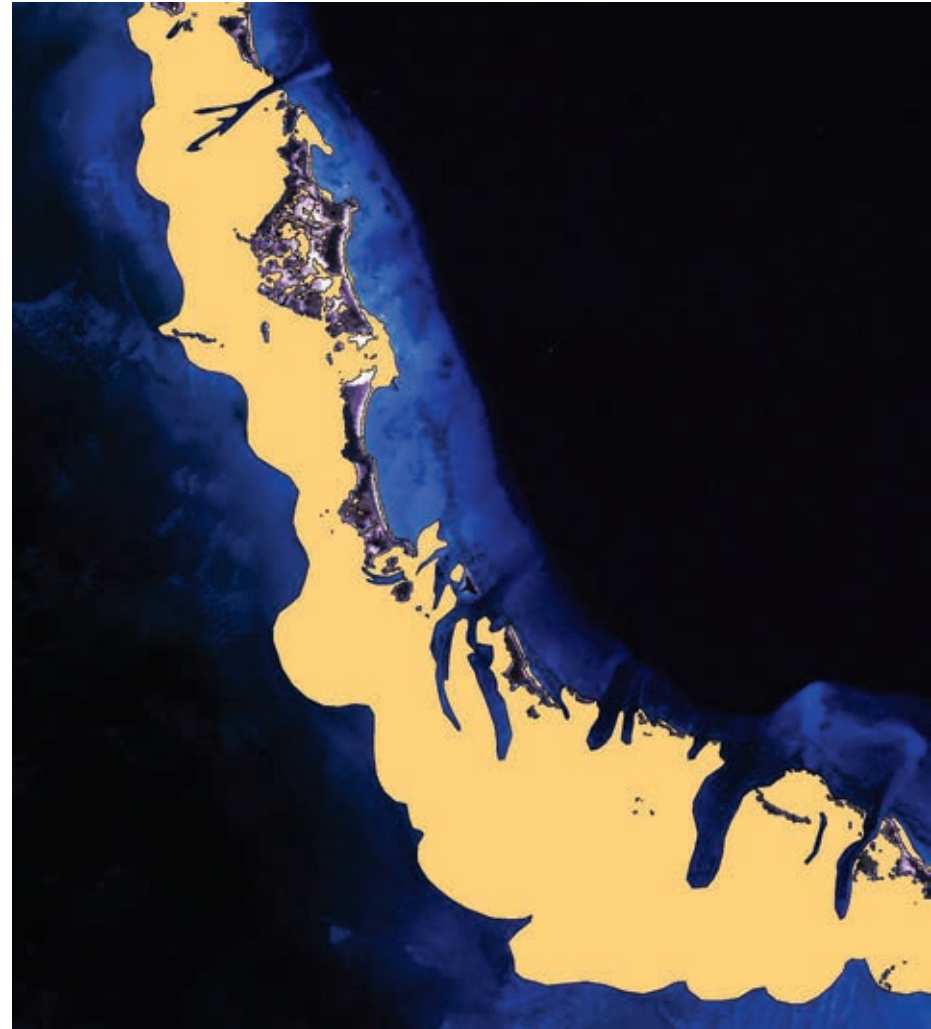
**DEM shaded and color-coded
For water depth**



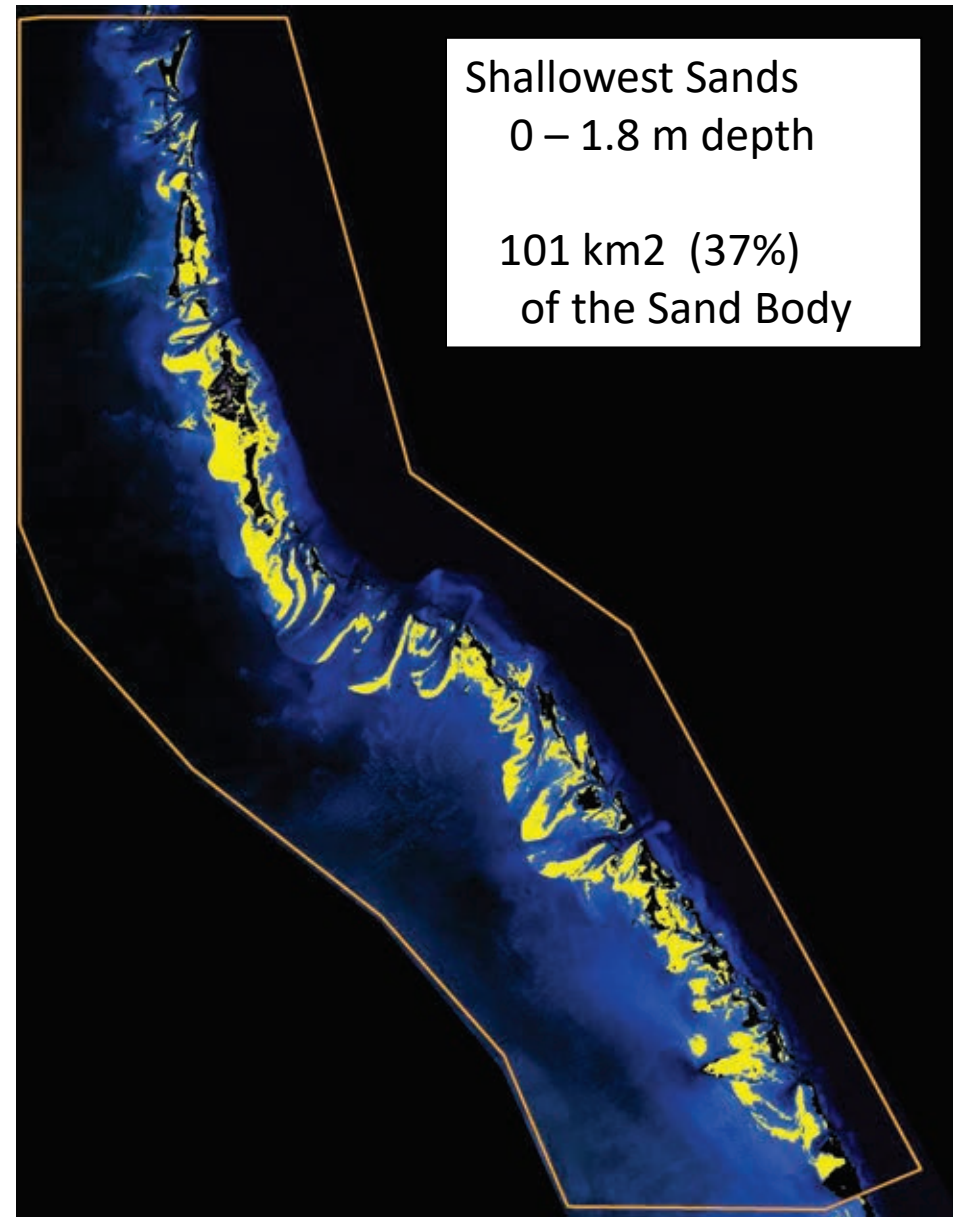
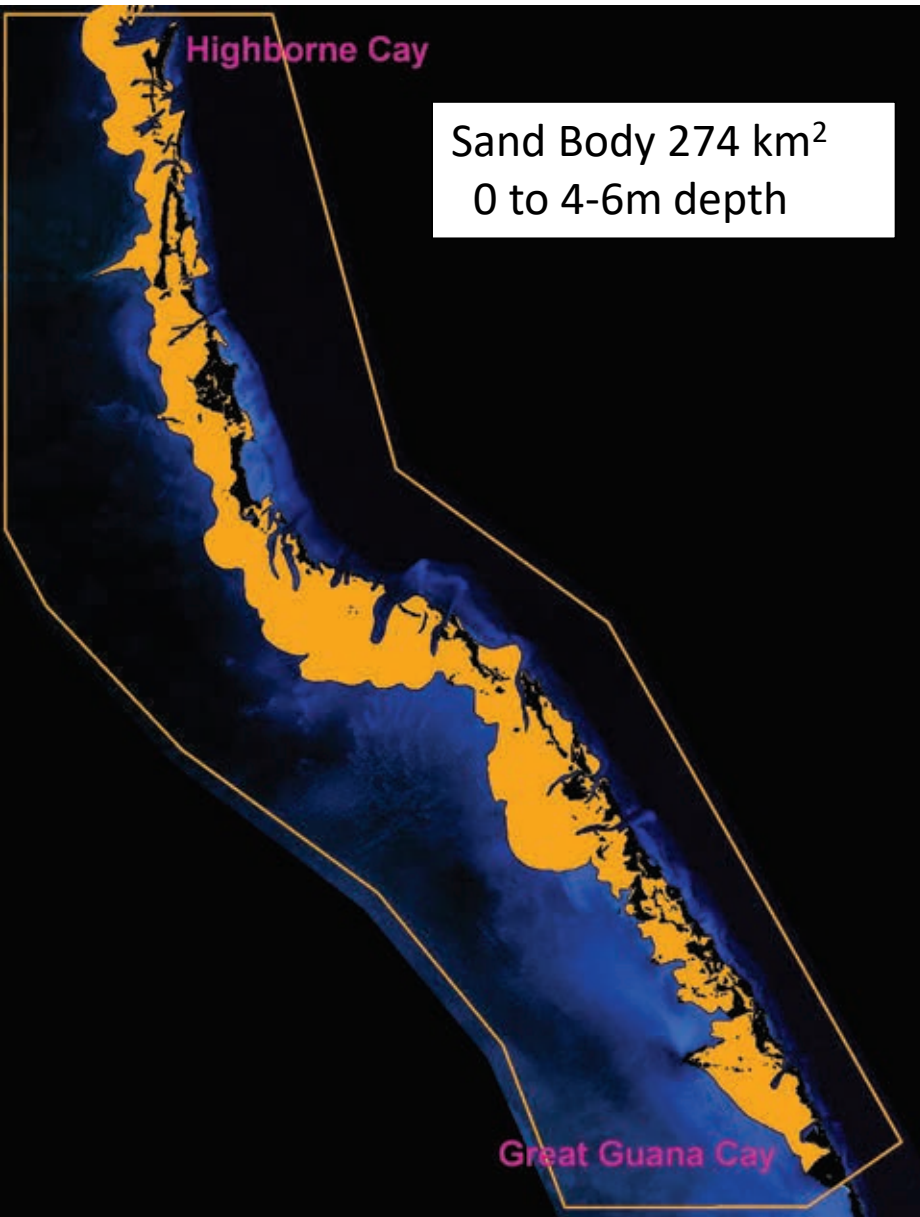
**Sand Body interpretation faded onto
shaded offshore DEM**



Sand Body interpretation

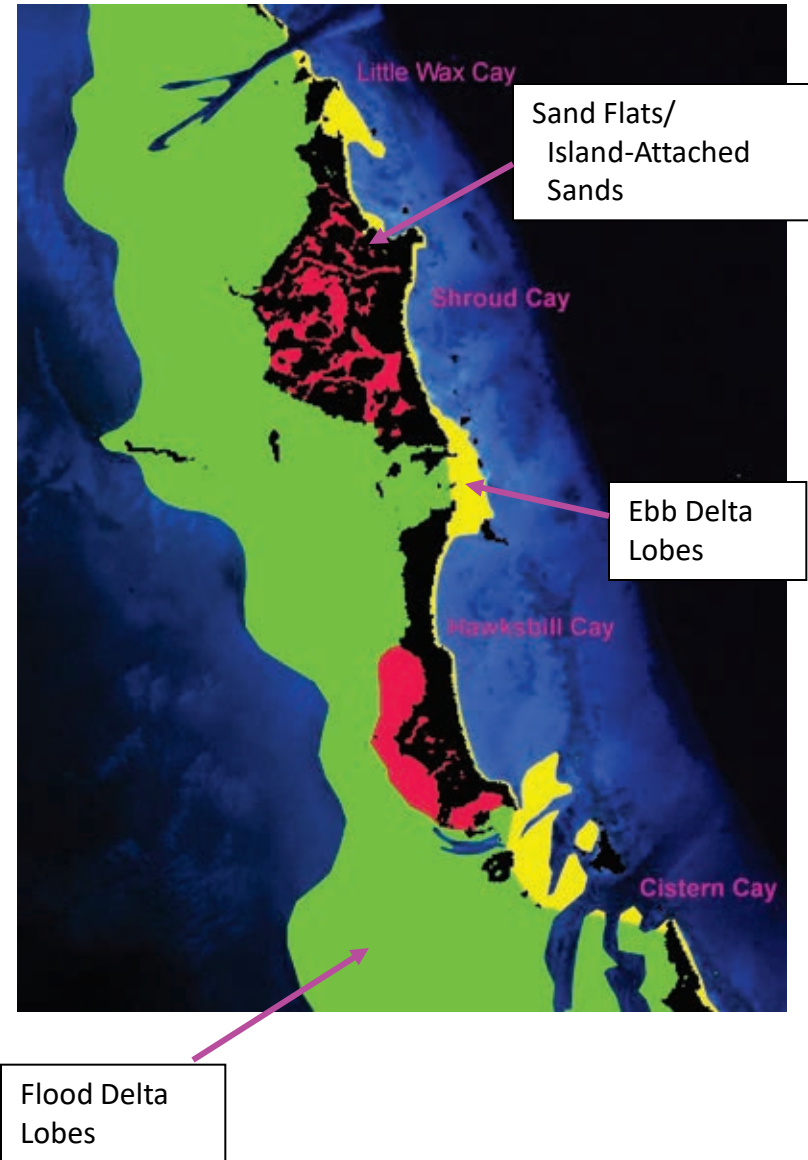


Subdividing the Sand Body using Water Depth

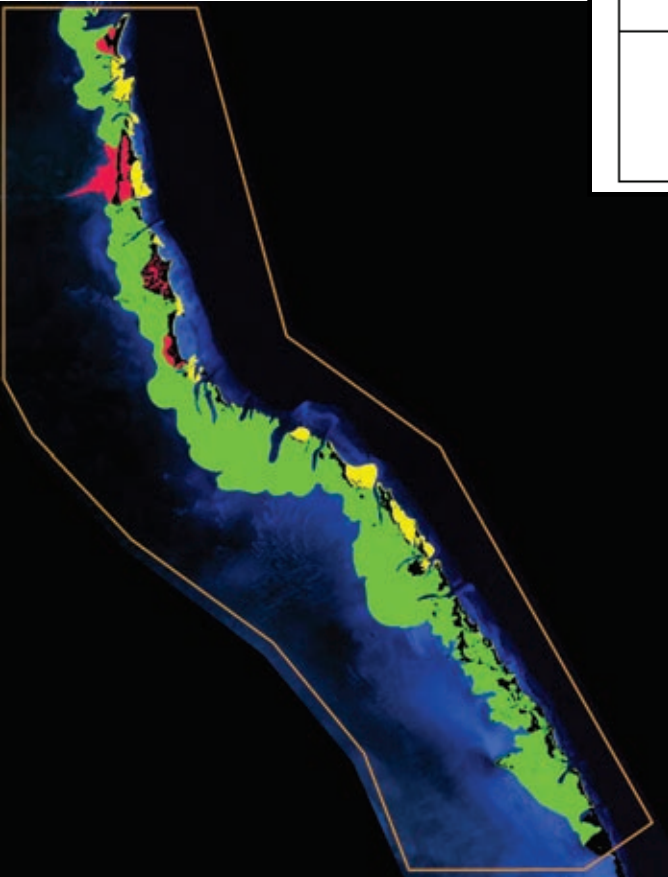


Sand Body Depositional Settings

Using GIS to Separate
Flood Tidal Delta Lobes
Ebb Tidal Delta Lobes
Sand Flats/
Island-Attached Sands



Sand Body Depositional Settings

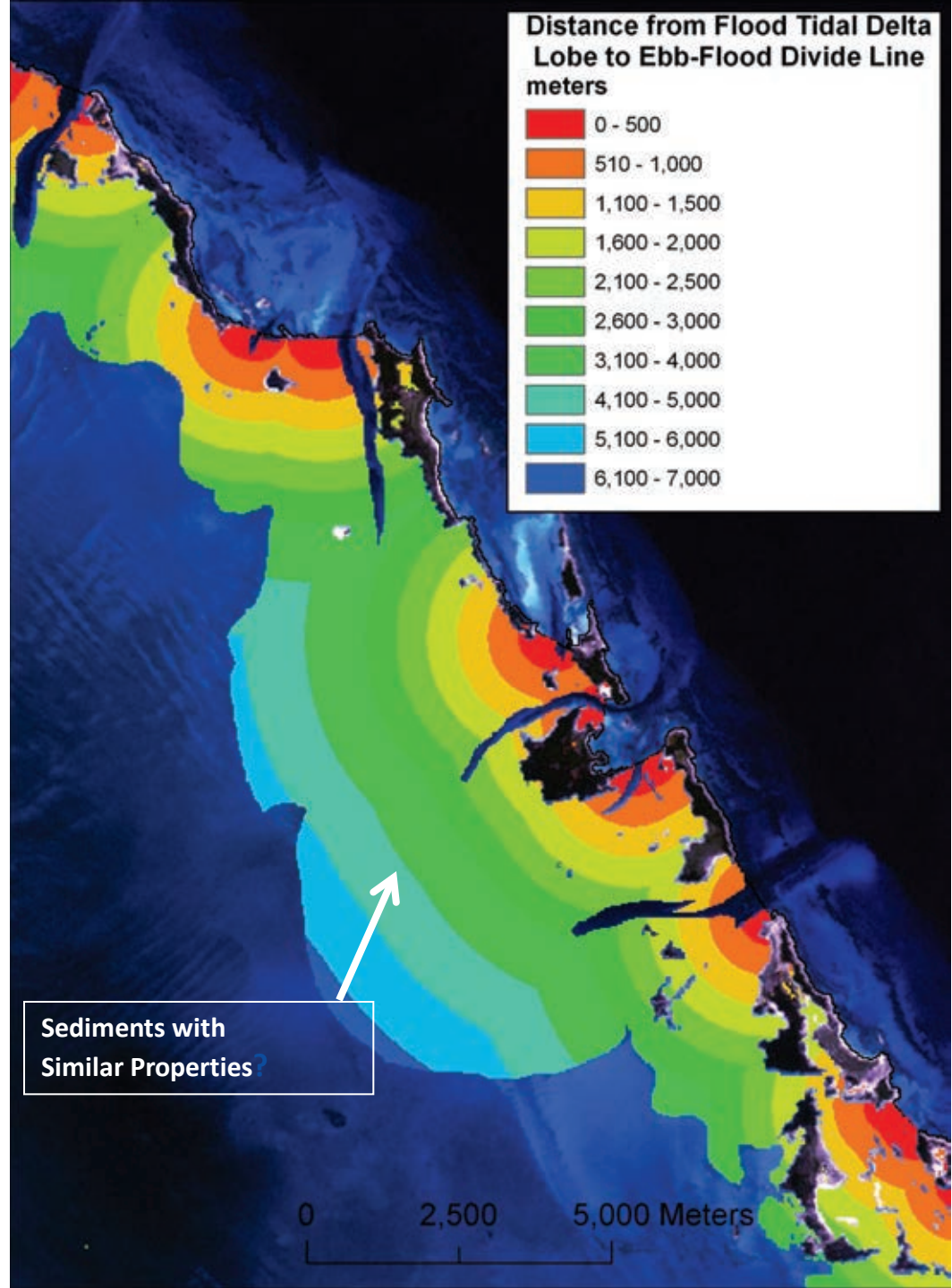


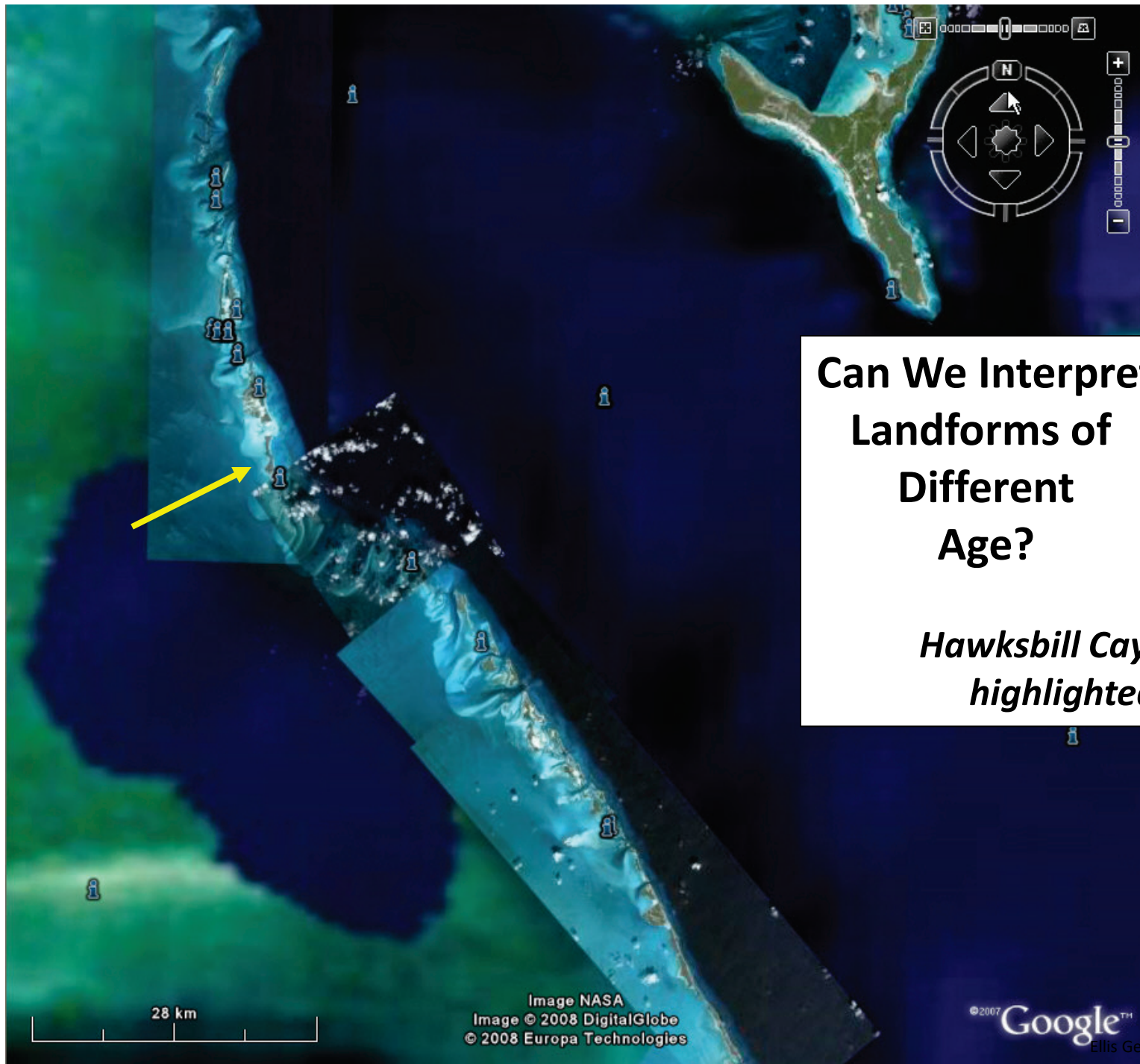
Area & Percentage of 3 Depositional Settings

Color on Figure	Depositional Setting	Area (km ²)	Area (%)
Green	Flood Tidal Delta Lobes	273.2	85.3
Yellow	Ebb Tidal Delta Lobes	29.6	9.2
Red	Sand Flats and island-attached sands	17.4	5.4

67% of the flood tidal delta lobes lie between 1-4 km from the channel openings

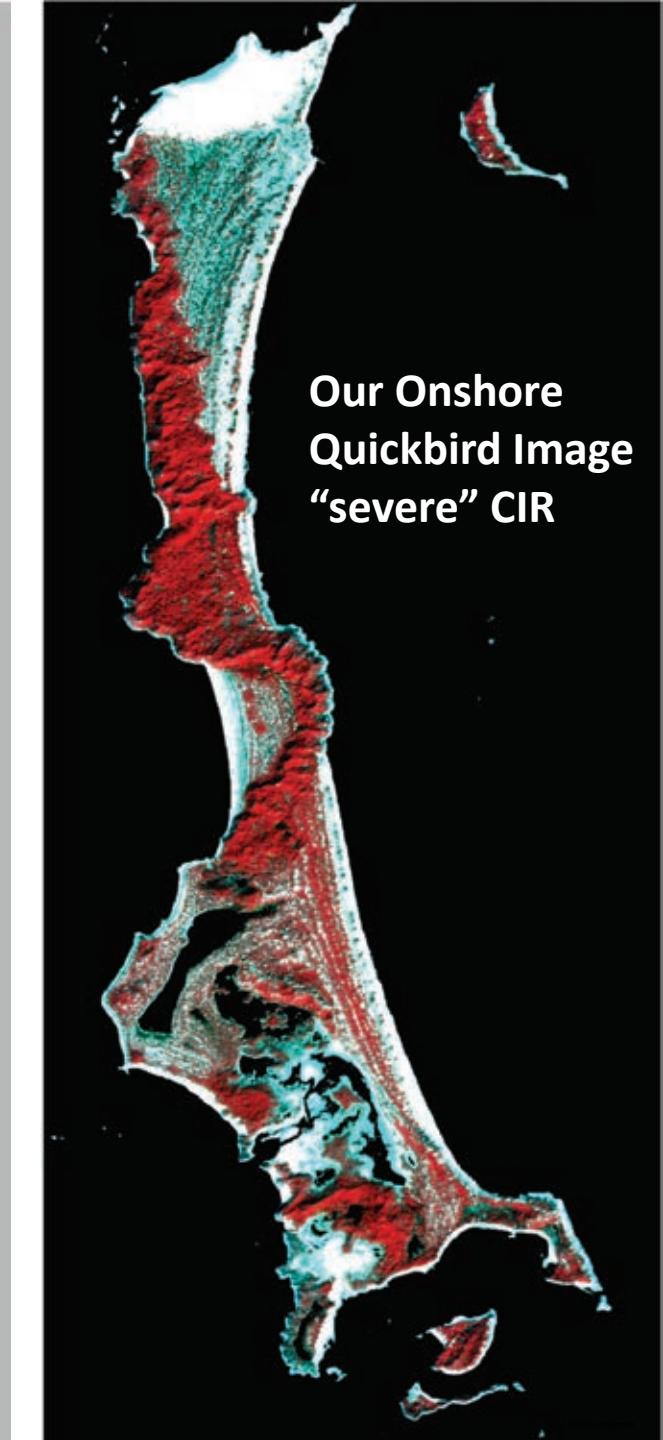
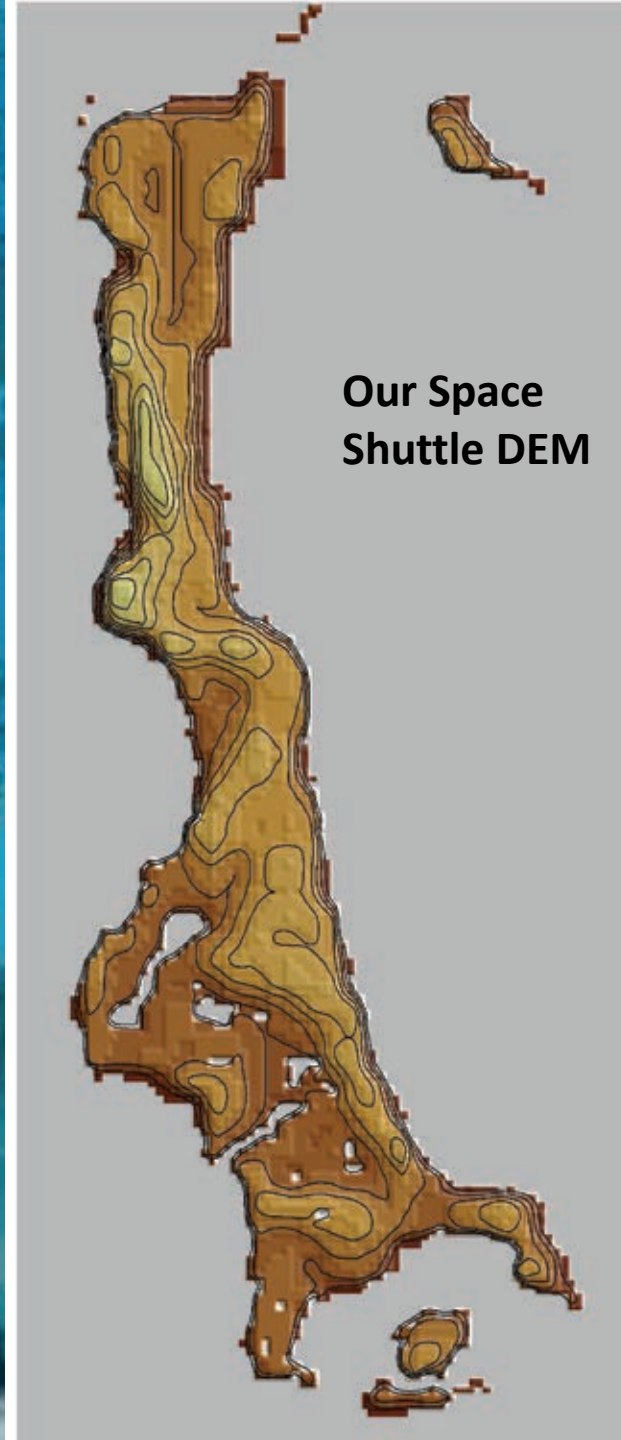
Average distance is 2.7 km (+/- 1.5 km) with a range from 0 to 7.3 km





**Can We Interpret
Landforms of
Different
Age?**

*Hawksbill Cay
highlighted*

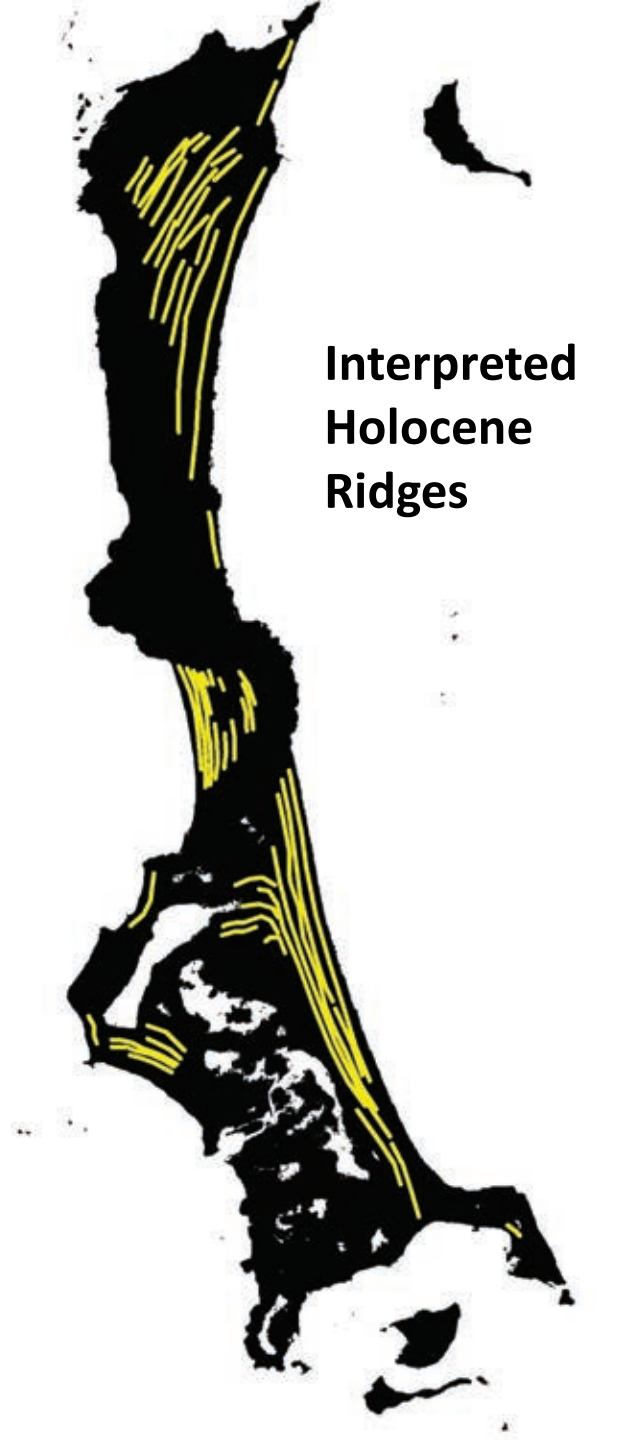


An aerial photograph of a coastal area, likely a bay or inlet. A large, irregularly shaped area along the shoreline is highlighted in red, indicating a 'severe' CIR. The surrounding water is dark blue, and the land is a mix of green and brown. The red area follows the curve of the bay and extends into several smaller inlets.

**Our Quickbird
"severe" CIR**

An aerial photograph of the same coastal area as the first image. A large, irregularly shaped area along the shoreline is highlighted in yellow, indicating interpreted Pleistocene. The yellow area follows the curve of the bay and extends into several smaller inlets, similar to the red area in the first image but with a different color and possibly different underlying data.

**Interpreted
Pleistocene**

An aerial photograph of the same coastal area as the first two images. The image is mostly black, with yellow lines and patterns overlaid, indicating interpreted Holocene Ridges. The yellow lines are concentrated in the upper and lower portions of the bay, following the general shape of the coastline but with more specific, linear features.

**Interpreted
Holocene
Ridges**

Pleistocene



Holocene Ridges

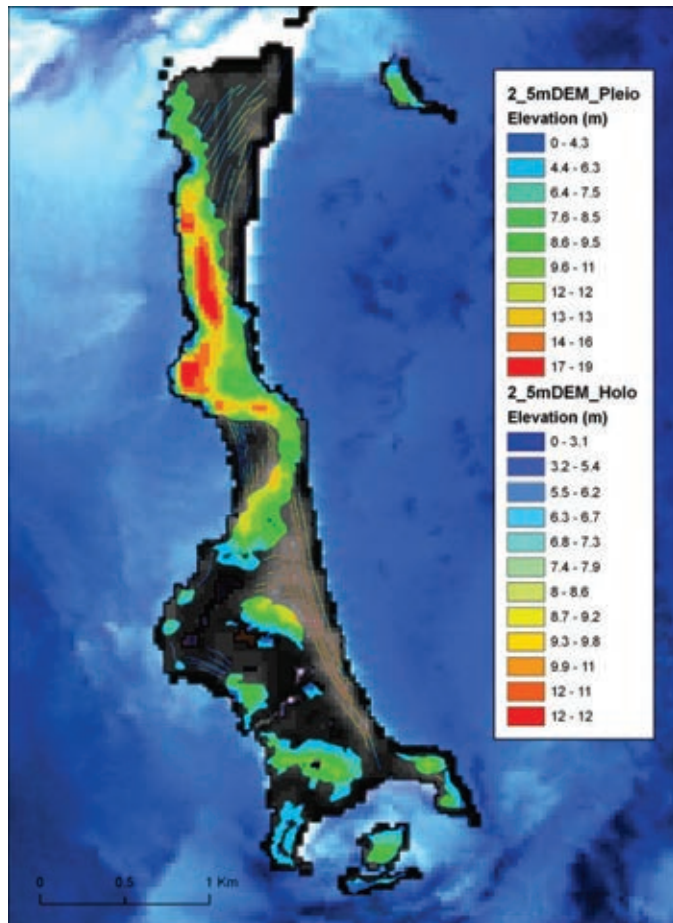


Pleistocene & Holocene Statistics

Hawksbill Cay

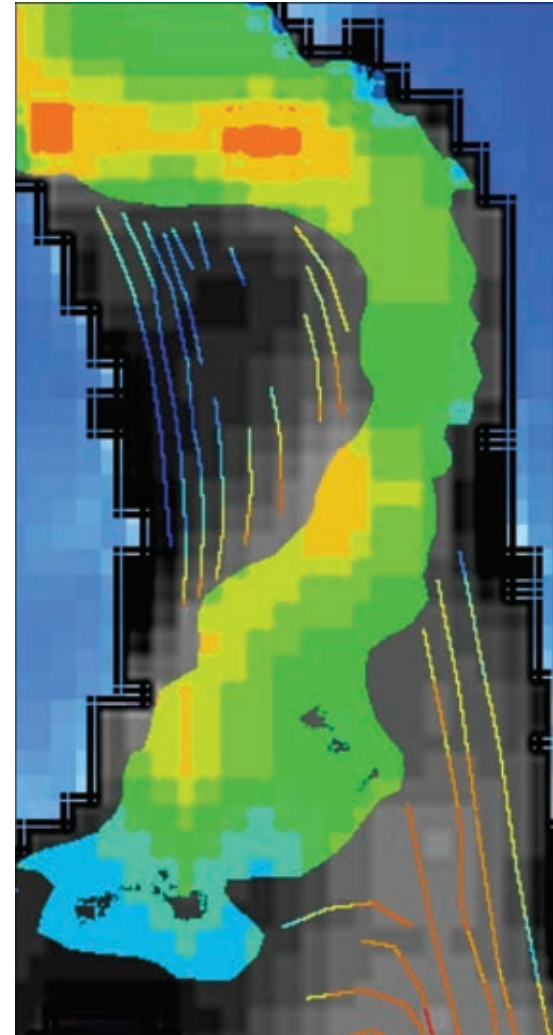
Land Area	2.8 km ²
Pleistocene	1.07 km ² (38%)
Holocene	1.73 km ² (62%)
Holocene Ridges	17.6 km total length ~320 m average length

Analysis of Island Topography



Pleistocene landforms have elevations from near sea level to 19 m (mean elevation of 9.3 ± 3 m)

Holocene ridges have elevations from near sea level to 12 m (mean elevation of 7.7 ± 2.5 m)

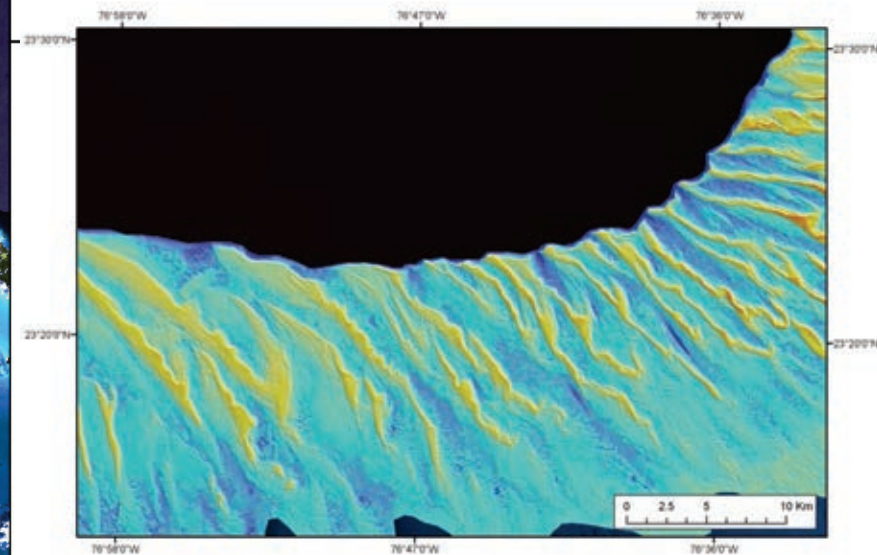
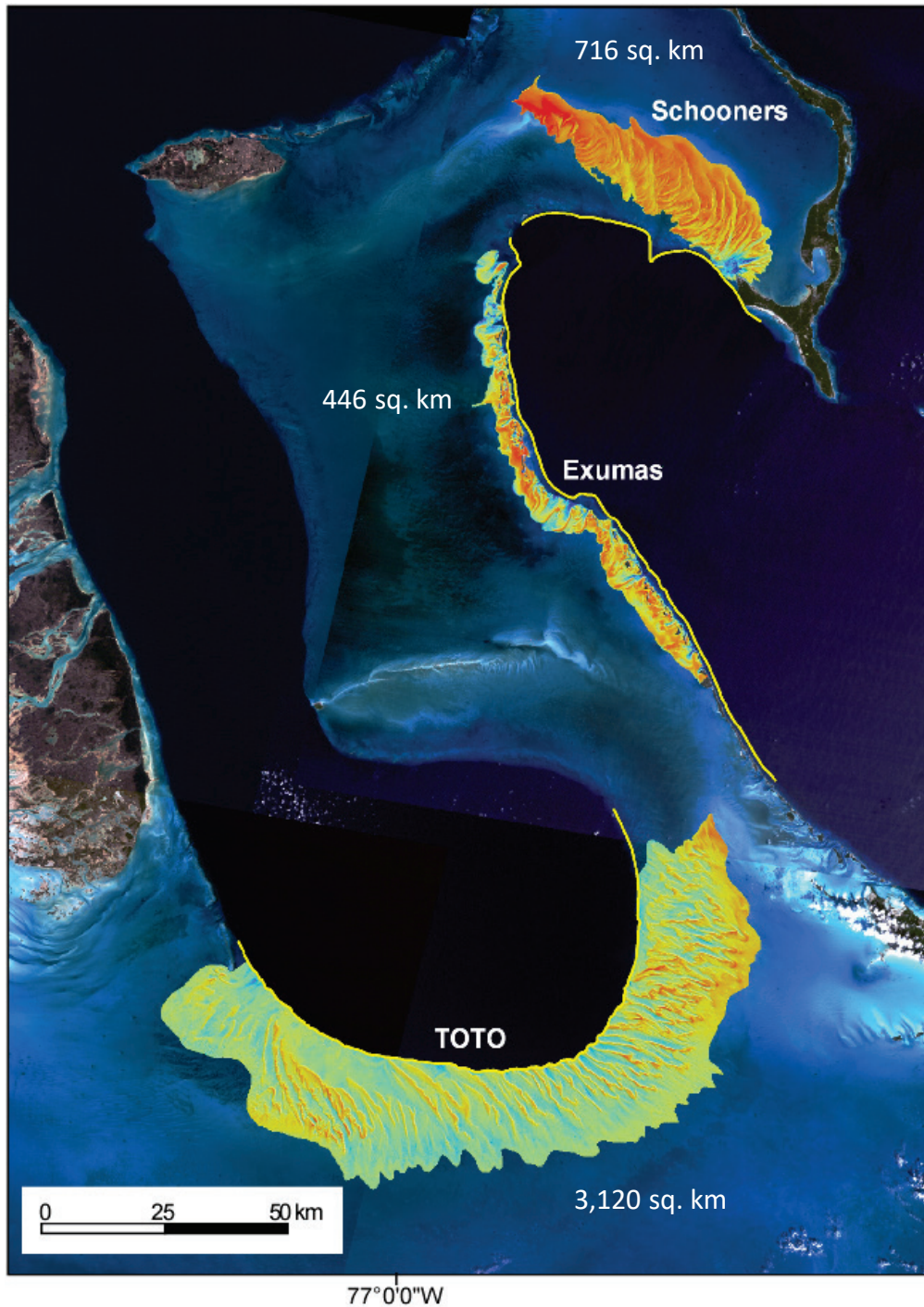


Sand Bars

3 sites

4,282 sq. km

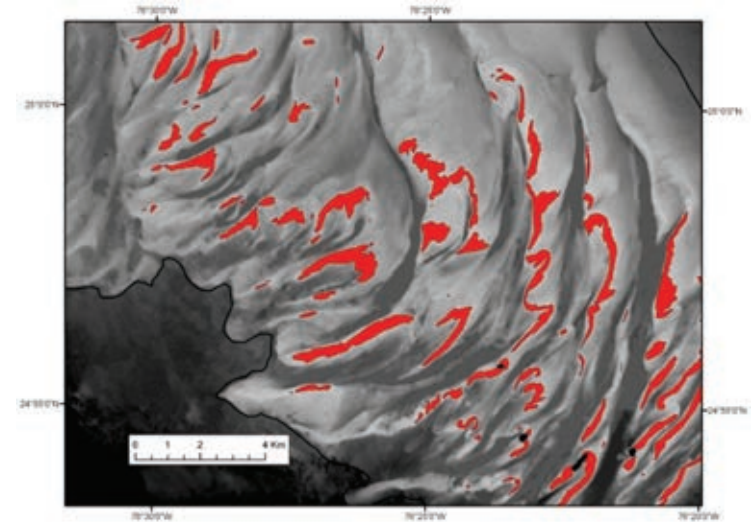
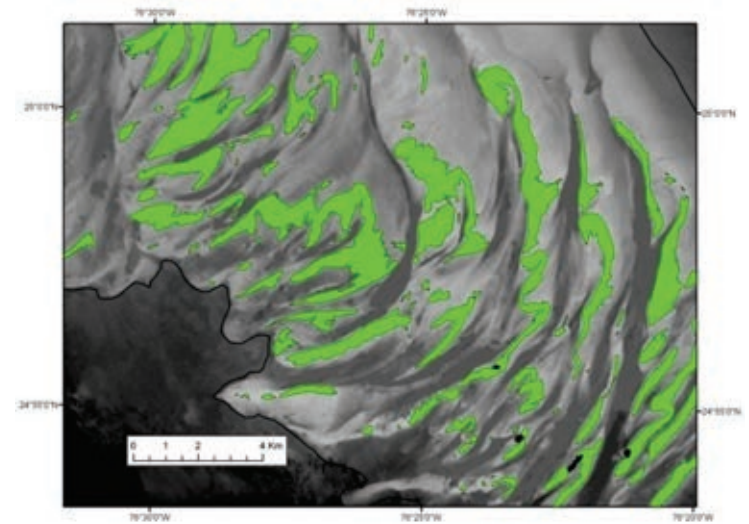
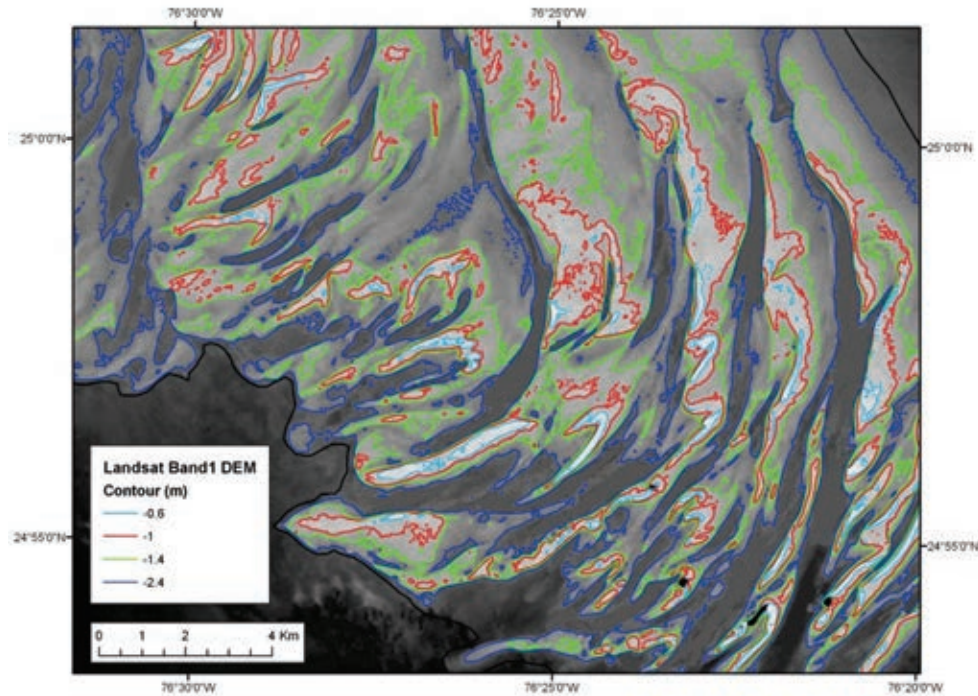
1,175 GIS polygons
partitioned to:
Sandbars (547) and Bar-crests (628)



Sandbars and Bar Crests

Sandbars

Select Contours of DEM



Bar Crests

Level 1 Shape Metrics, Hand-Measured

[1] Form Factor (FF)

$$FF = \frac{4\pi A}{Pr^2}$$

[2] Sinuosity (S)

$$S = \frac{L - DMG}{L}$$

[3] Aspect (As)

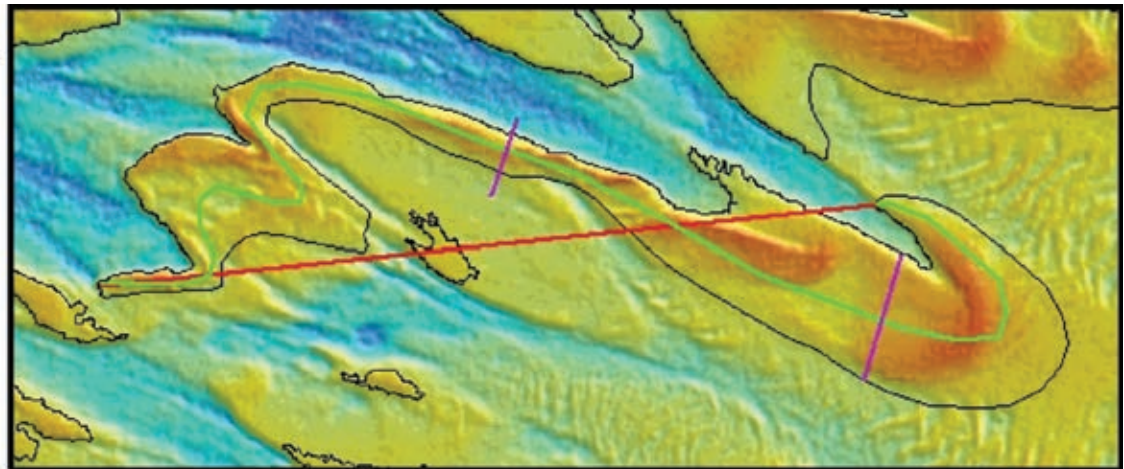
$$As = \frac{L - W_a}{L}$$

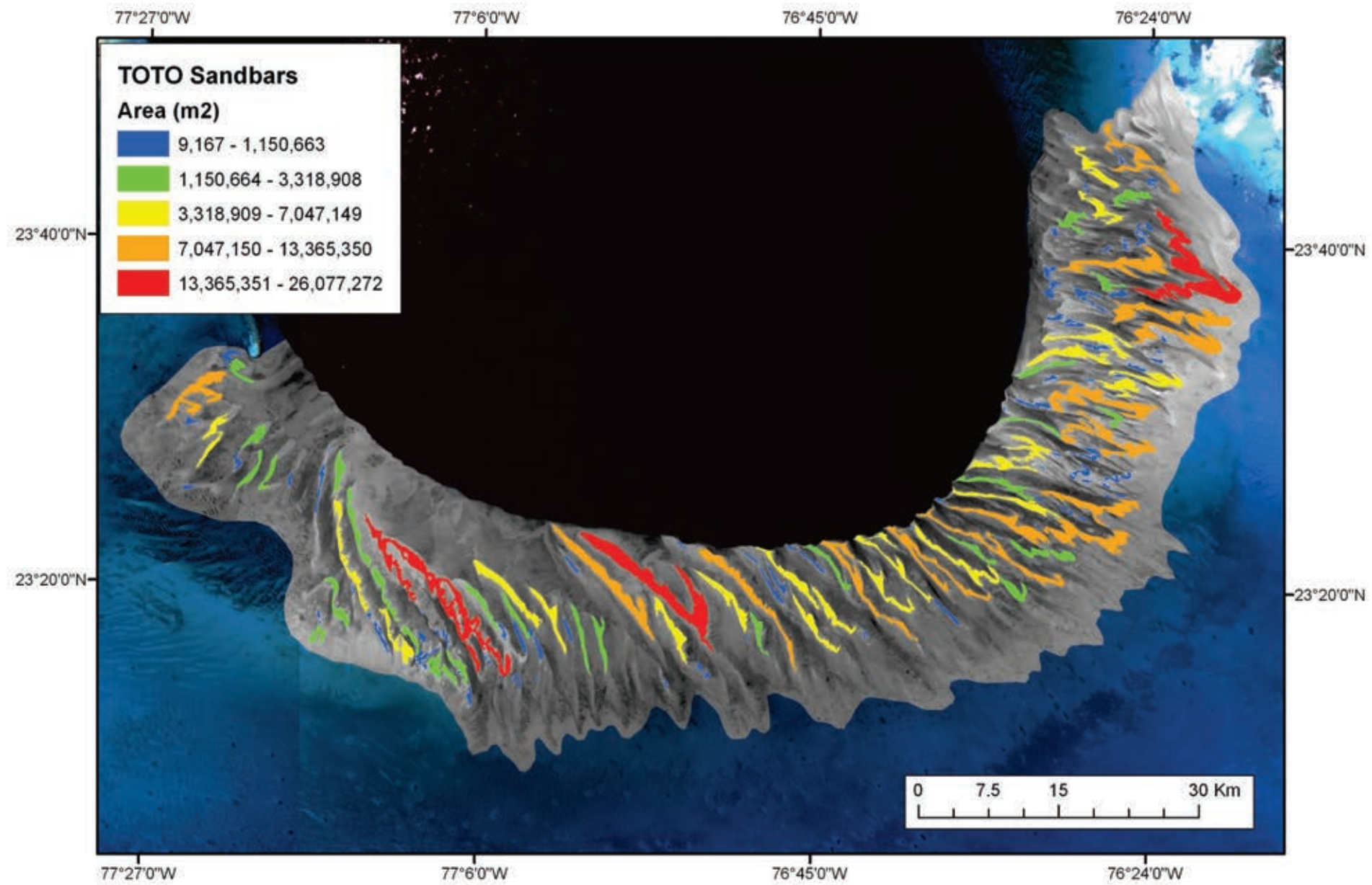
[4] Roundness (also termed elongation) (R)

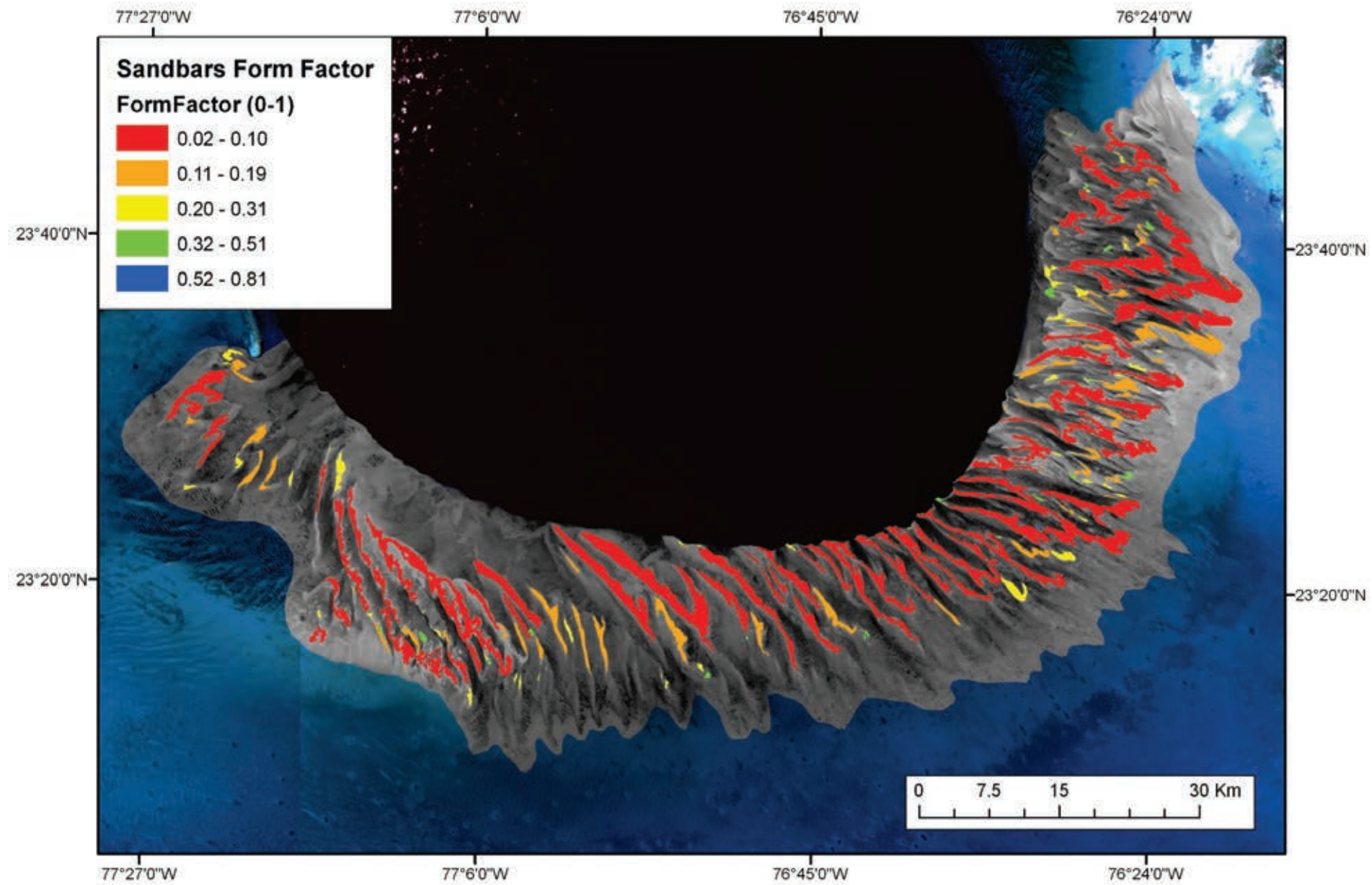
$$R = \frac{DMG - W_m}{DMG}$$

where, A is the area of a sandbar polygon, Pr is the perimeter, L is length, W_a and W_m are average and maximum widths, respectively, and DMG is 'distance made good'.

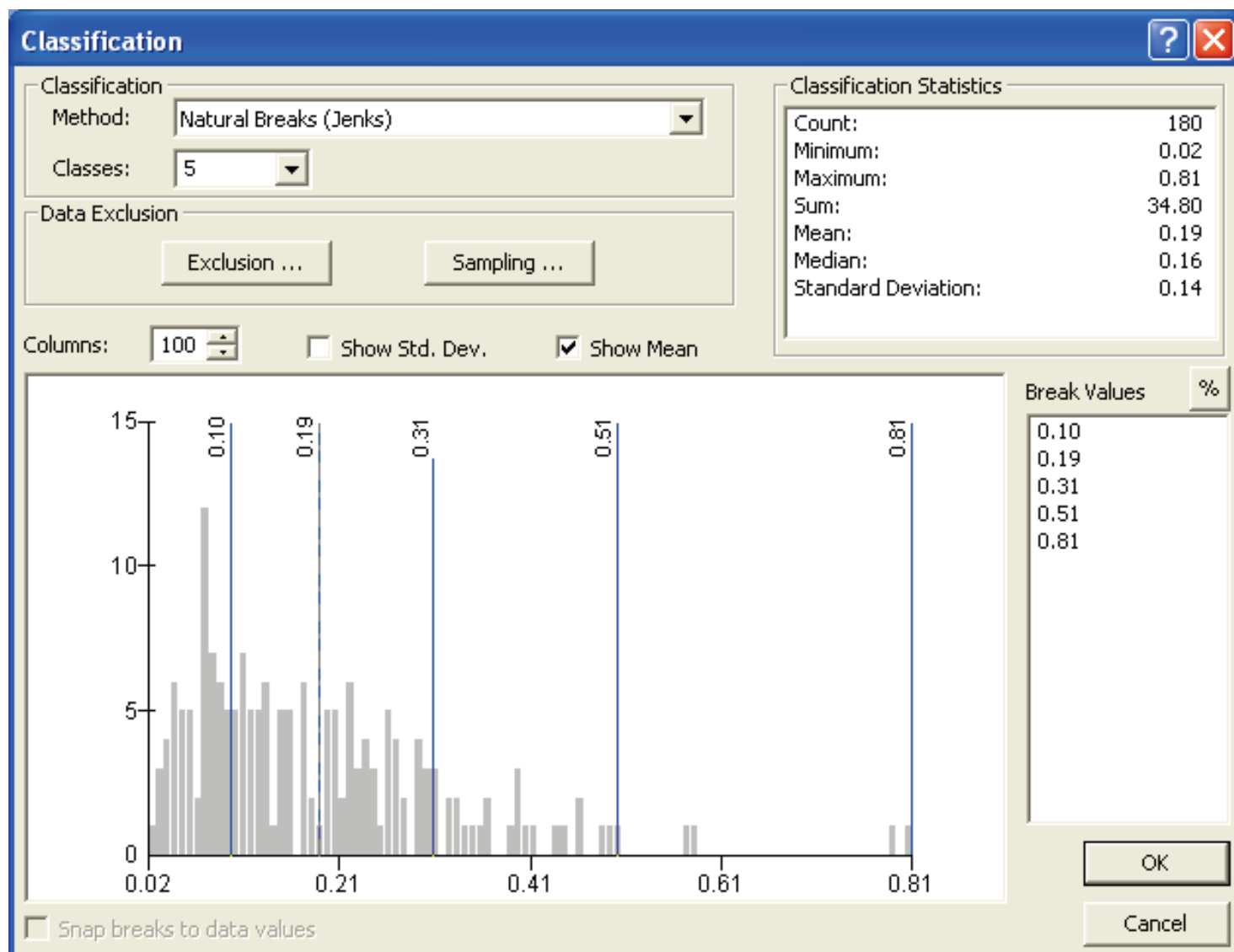
Total length (L - green line), distance made good (DMG - red line), maximum width (W_m - longer purple line) and estimated average width (W_a - shorter purple line) for an irregular-shaped sandbar.



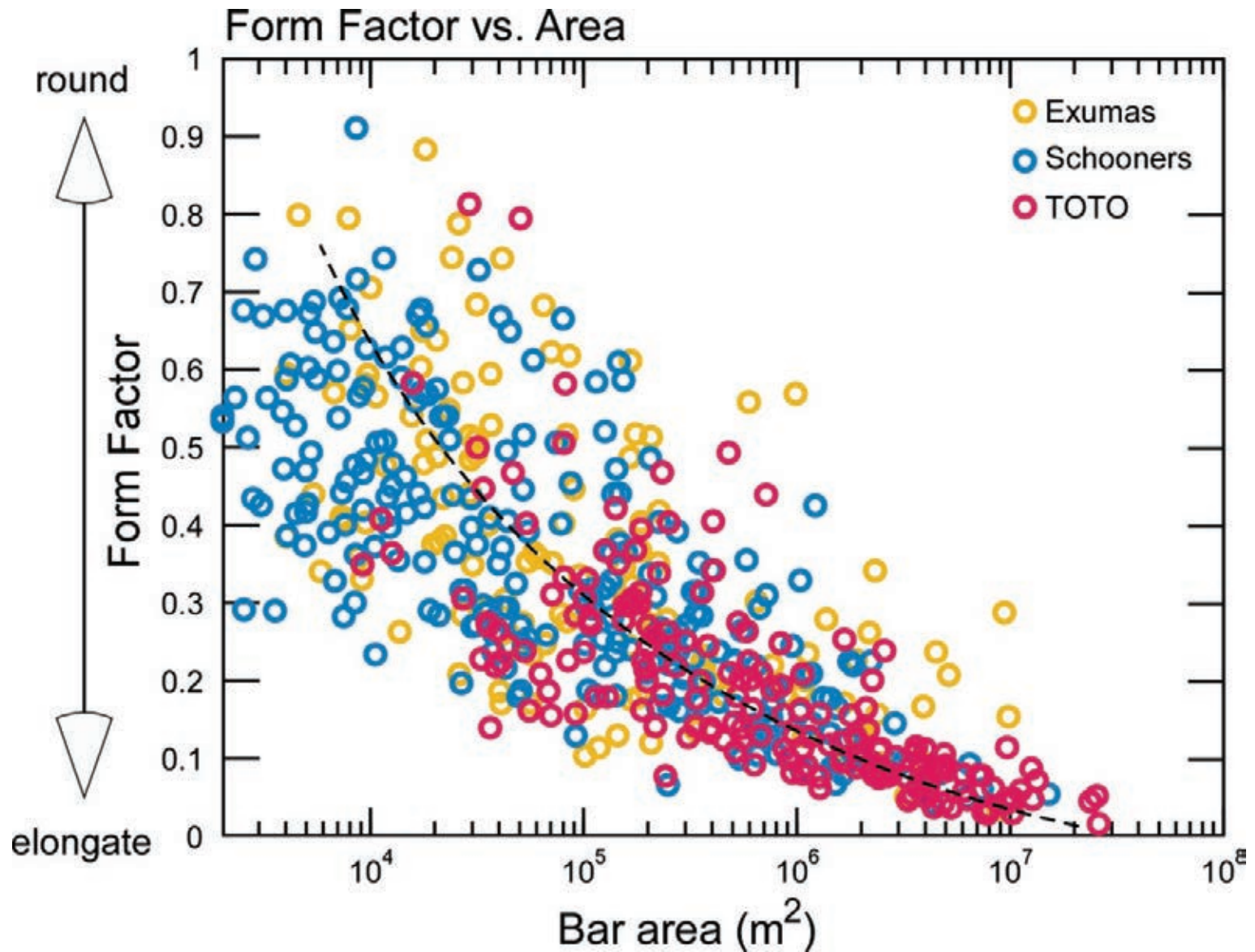


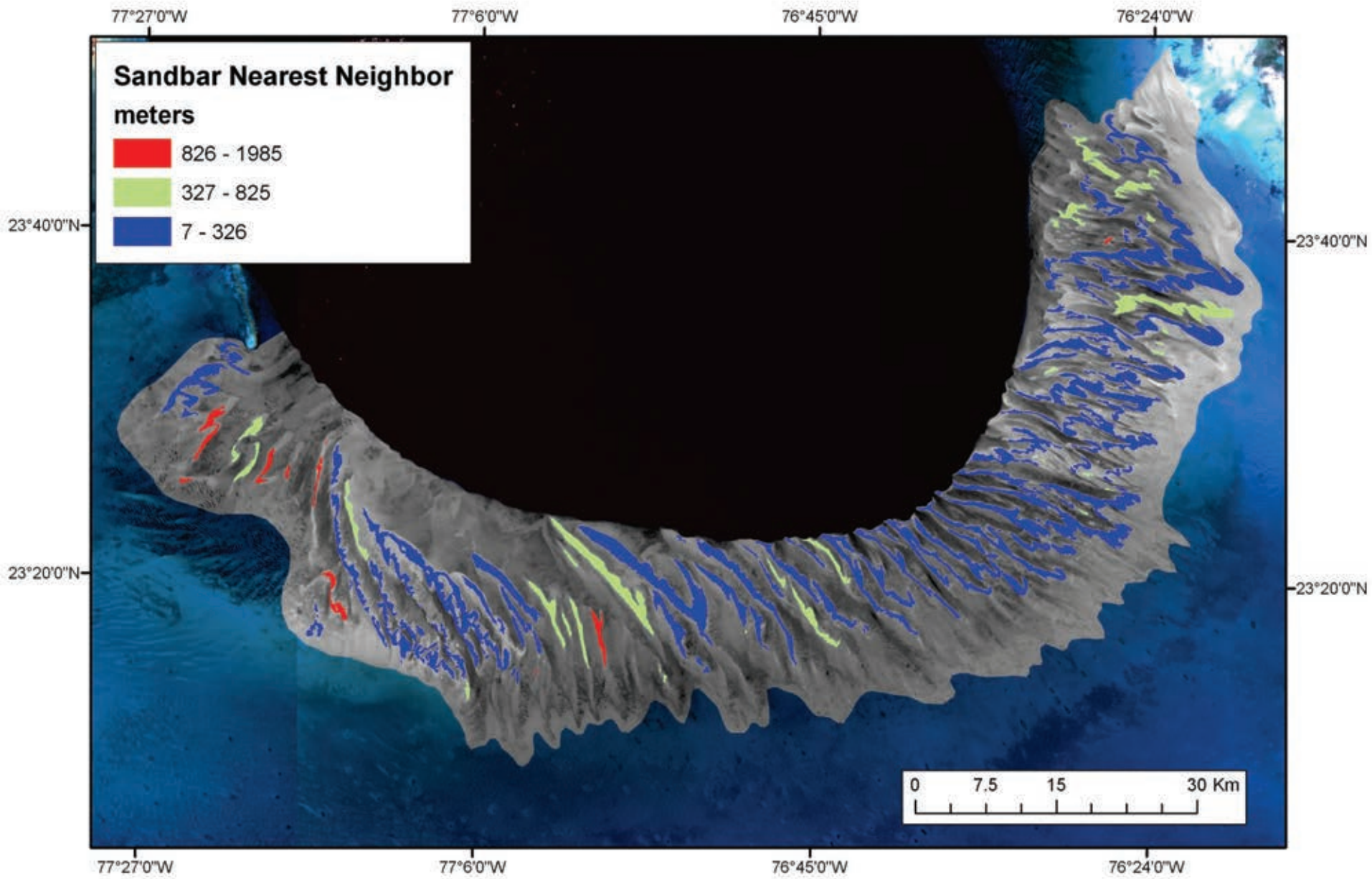


Form Factor Statistics from Sand Bar Attribute Table

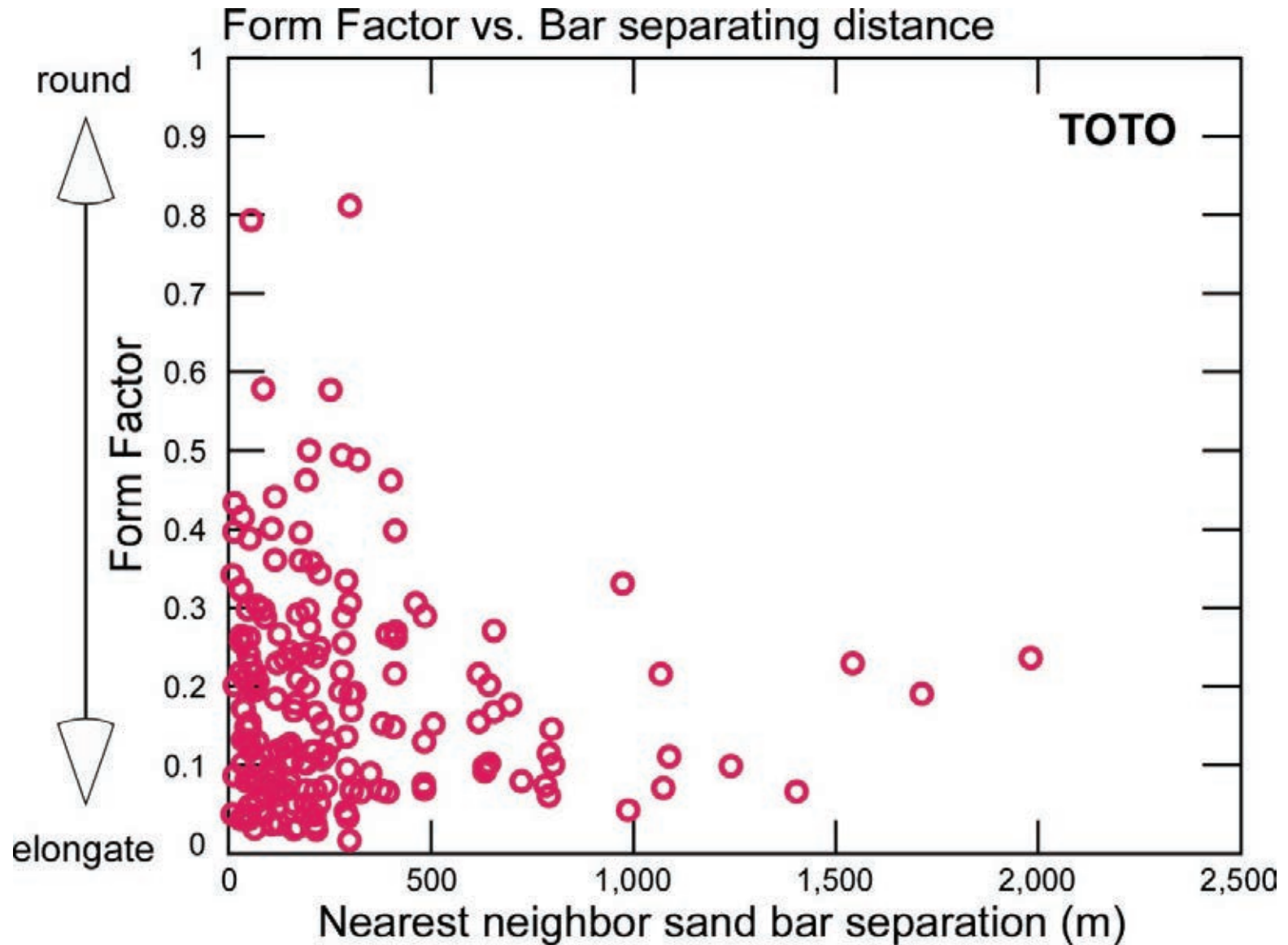


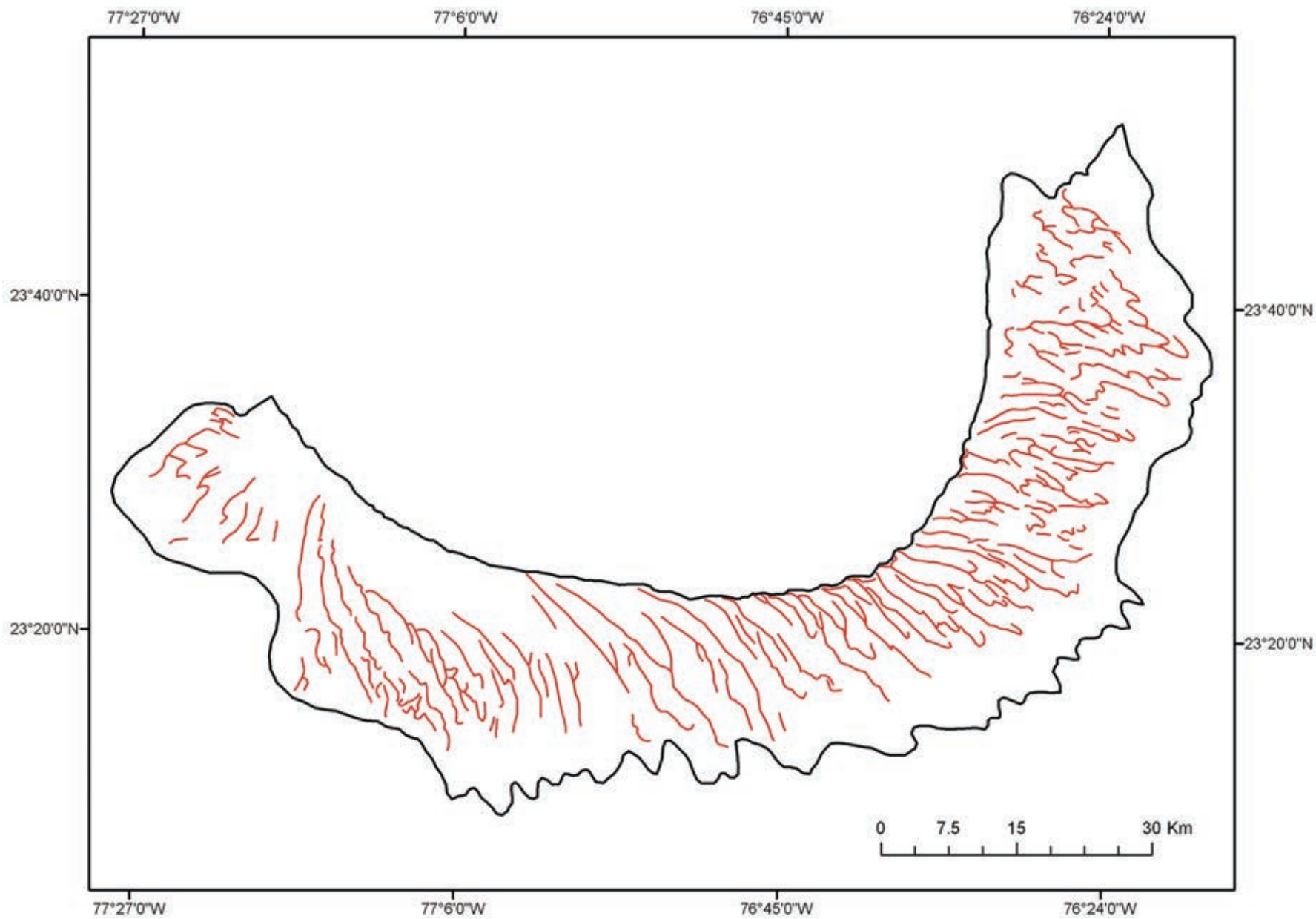
GeoStatistics

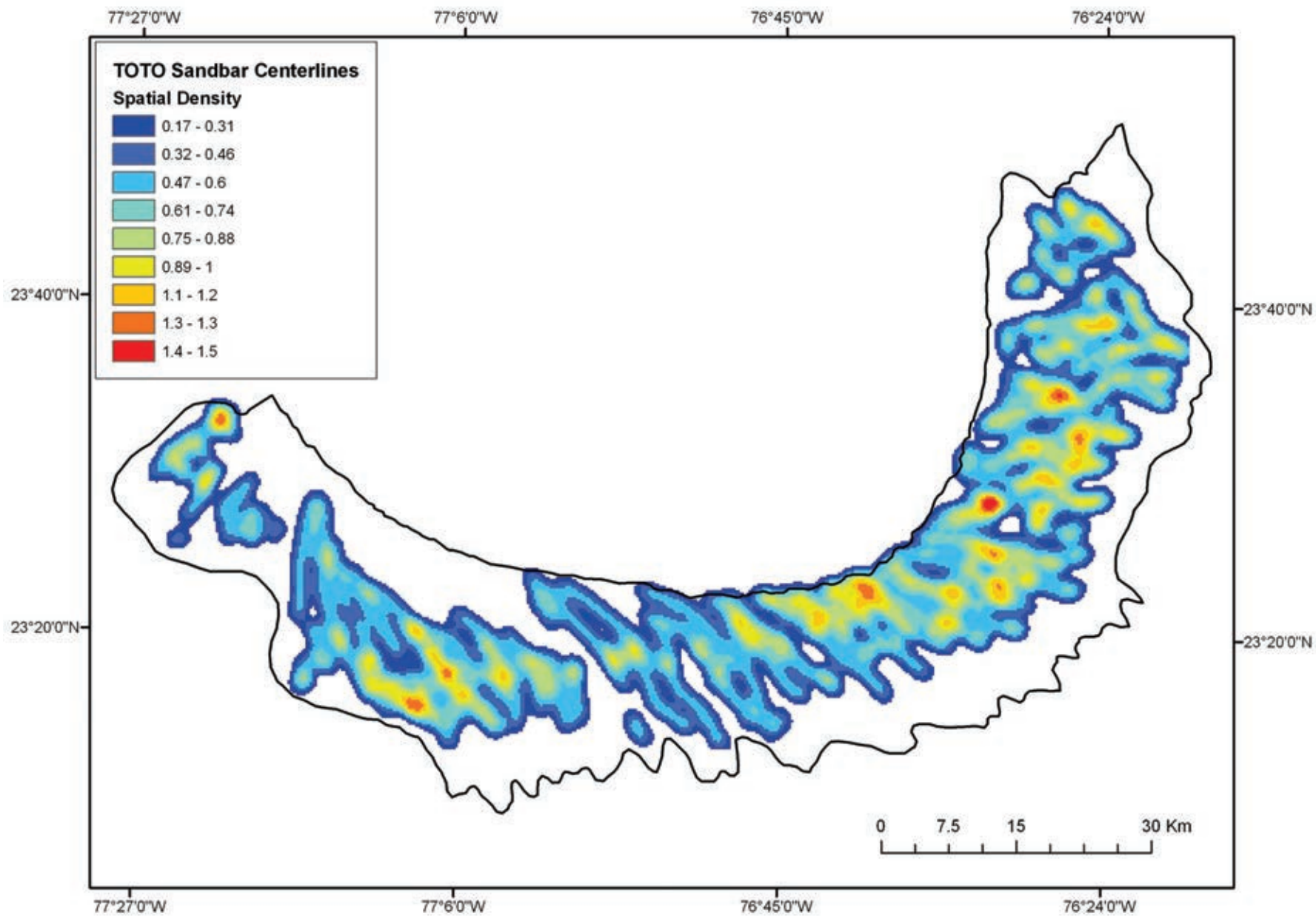


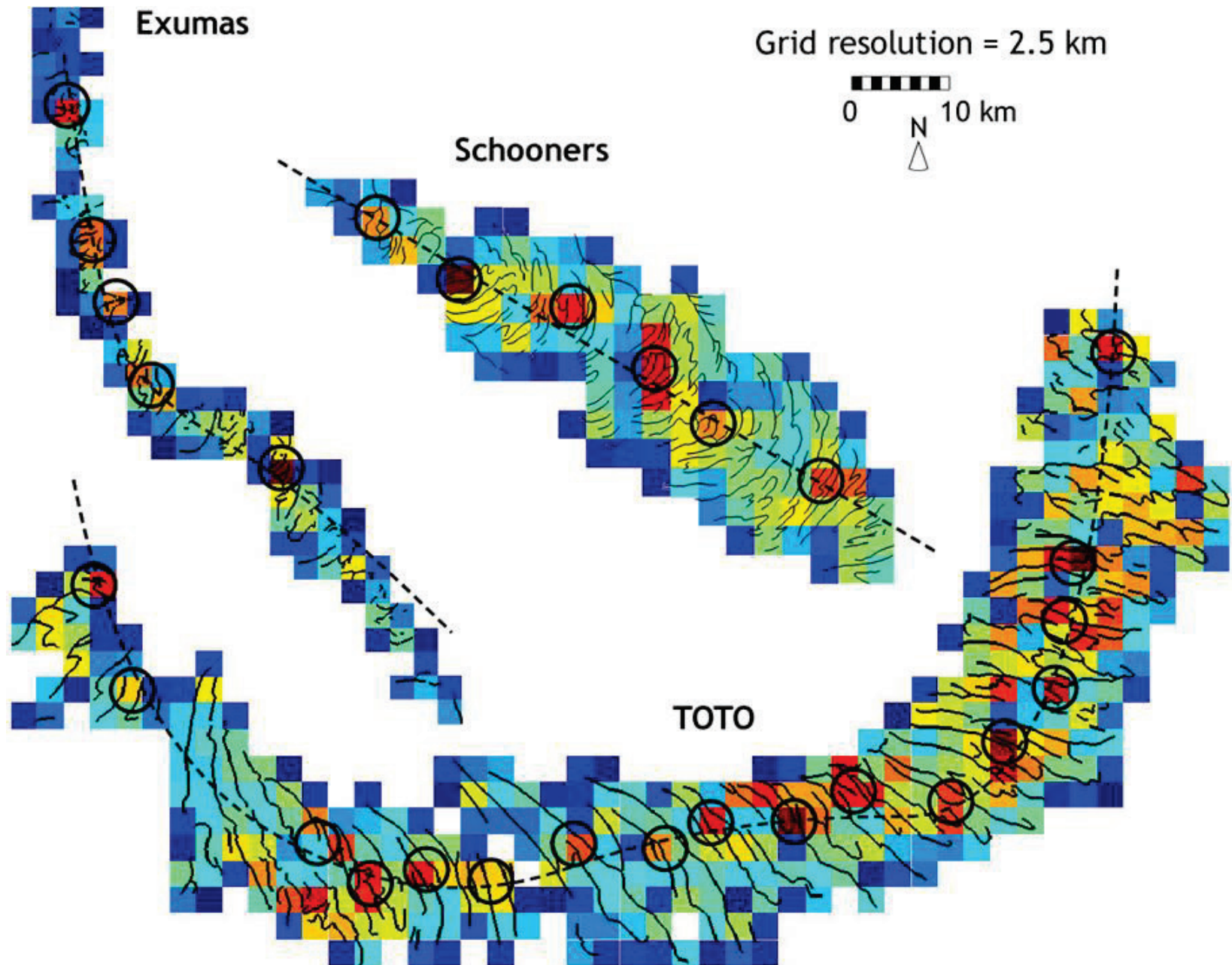


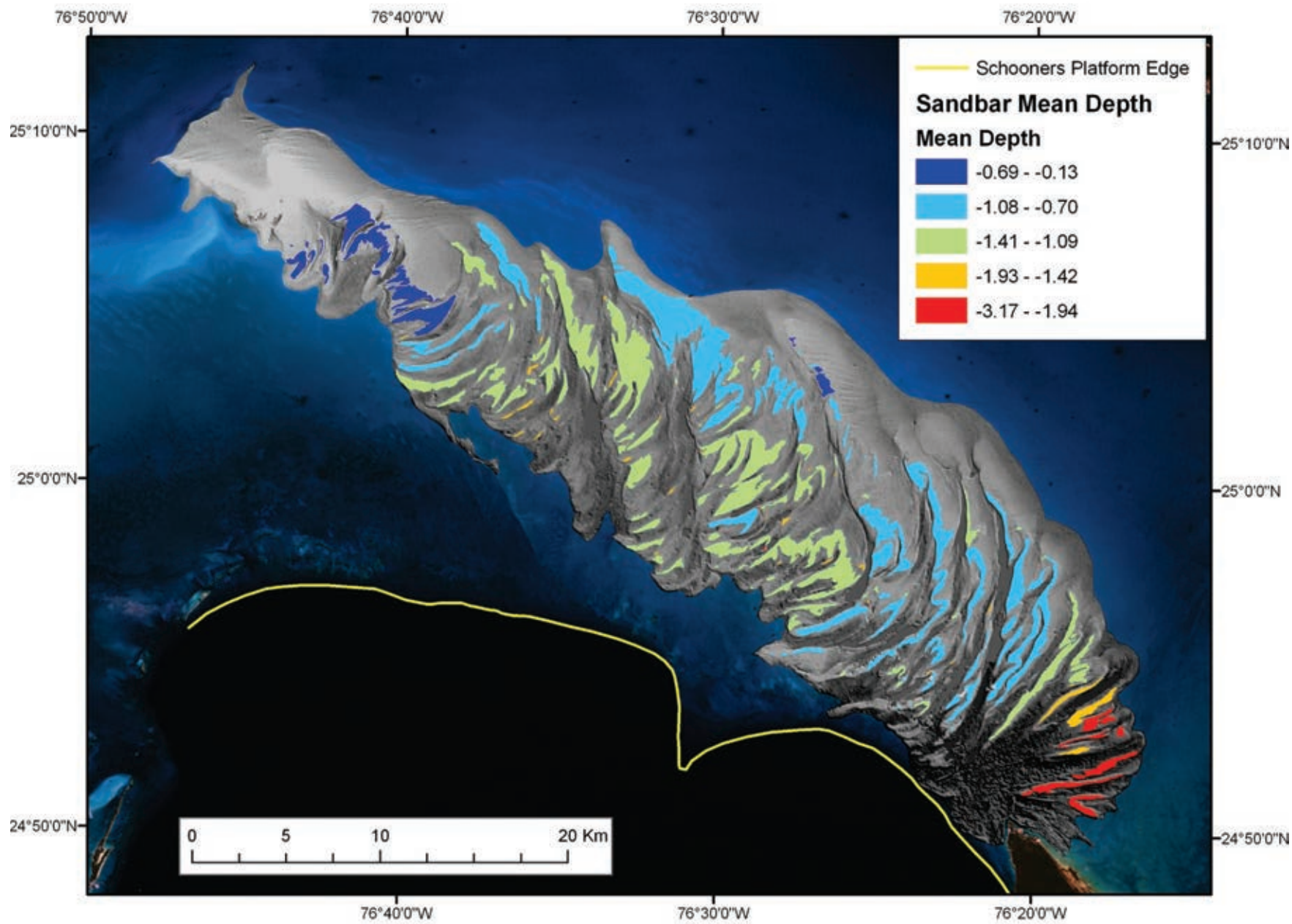
GeoStatistics

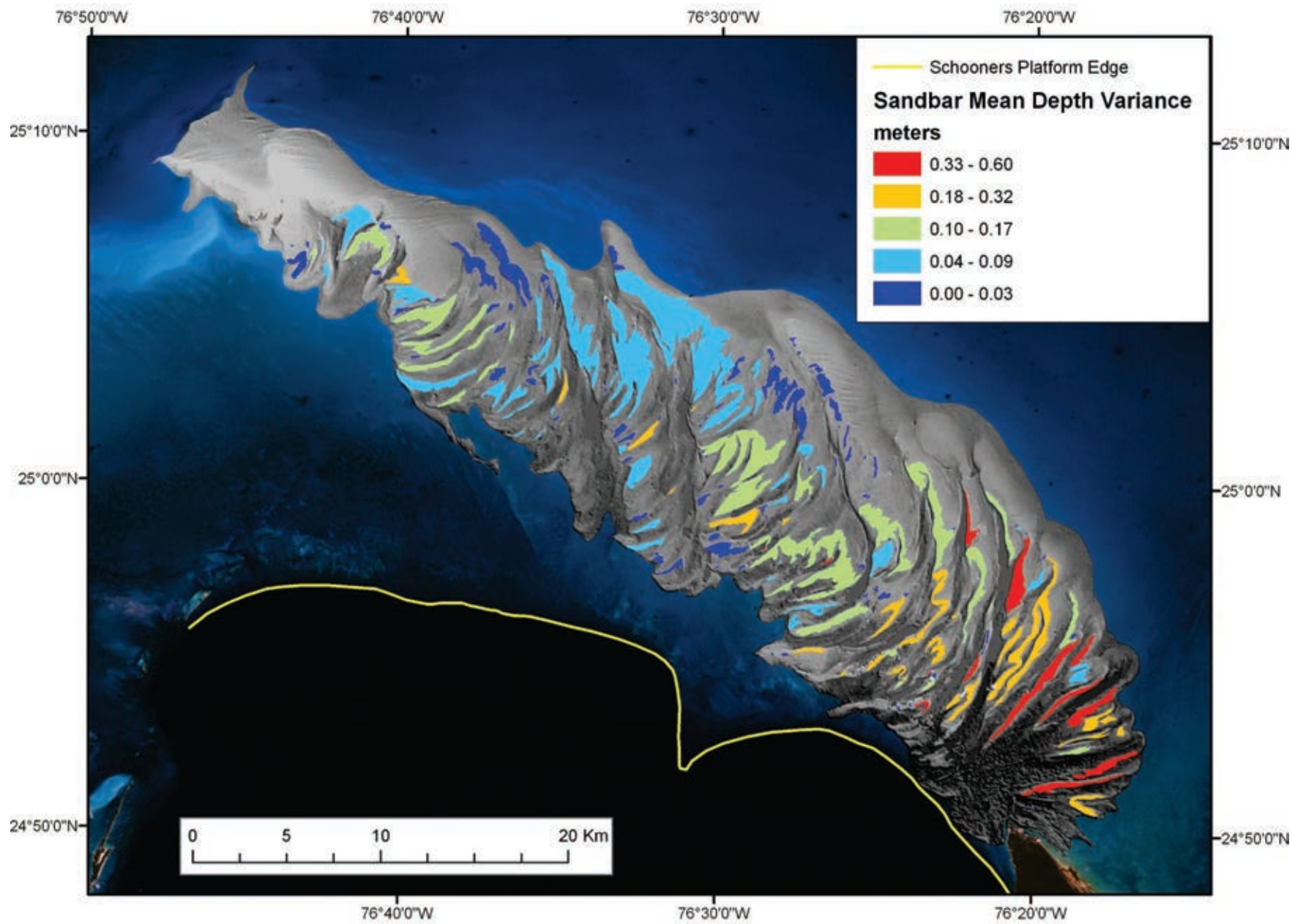


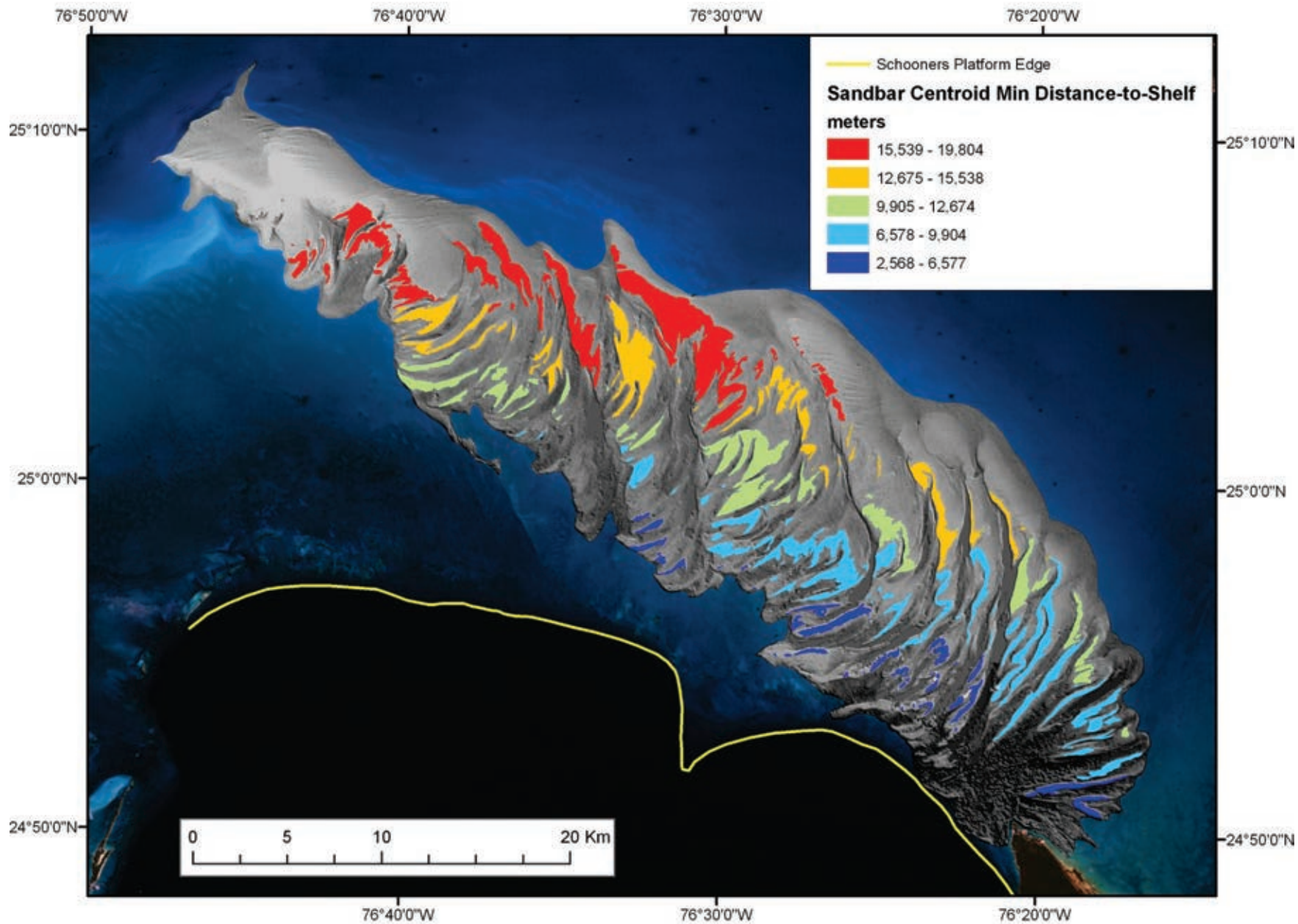




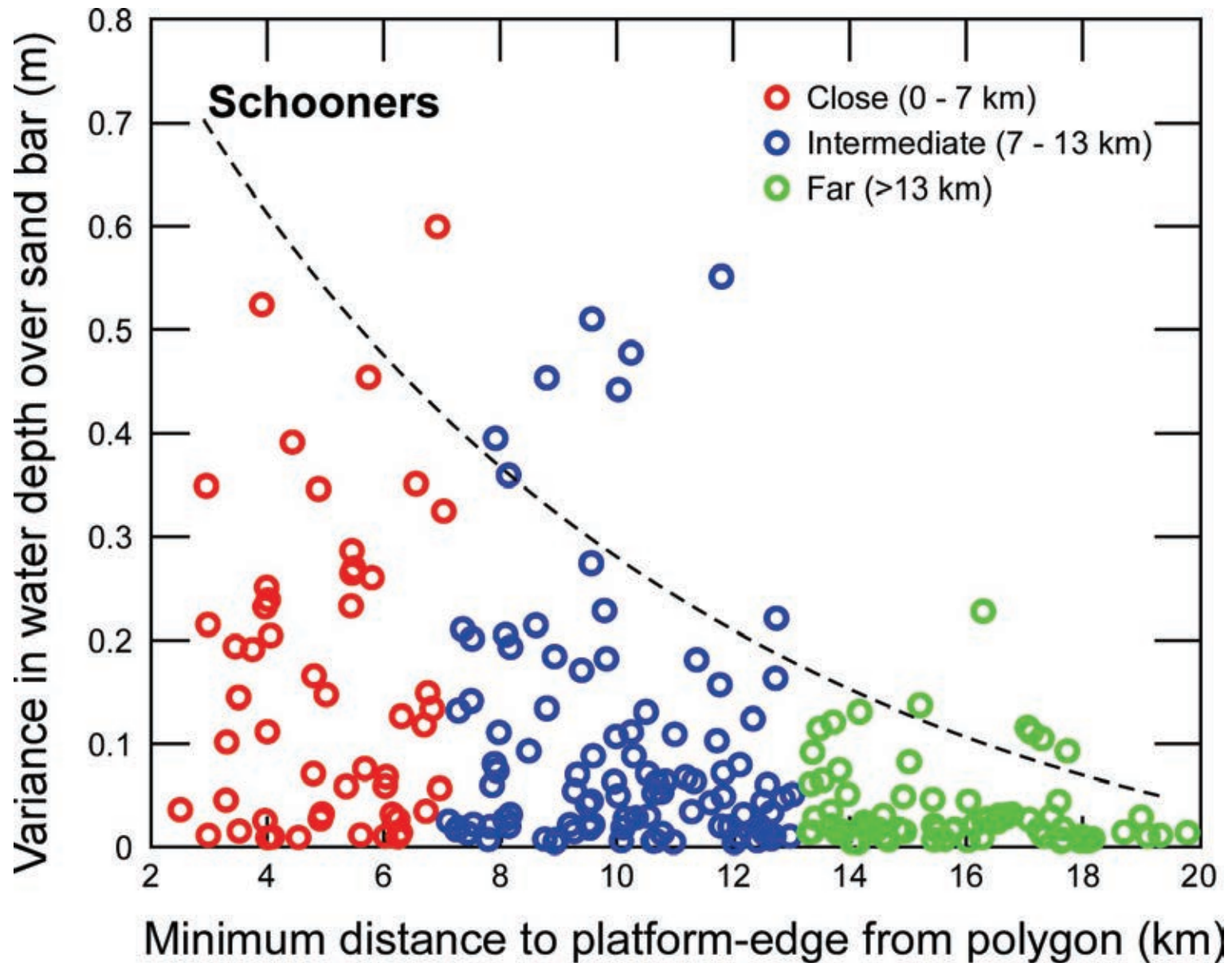




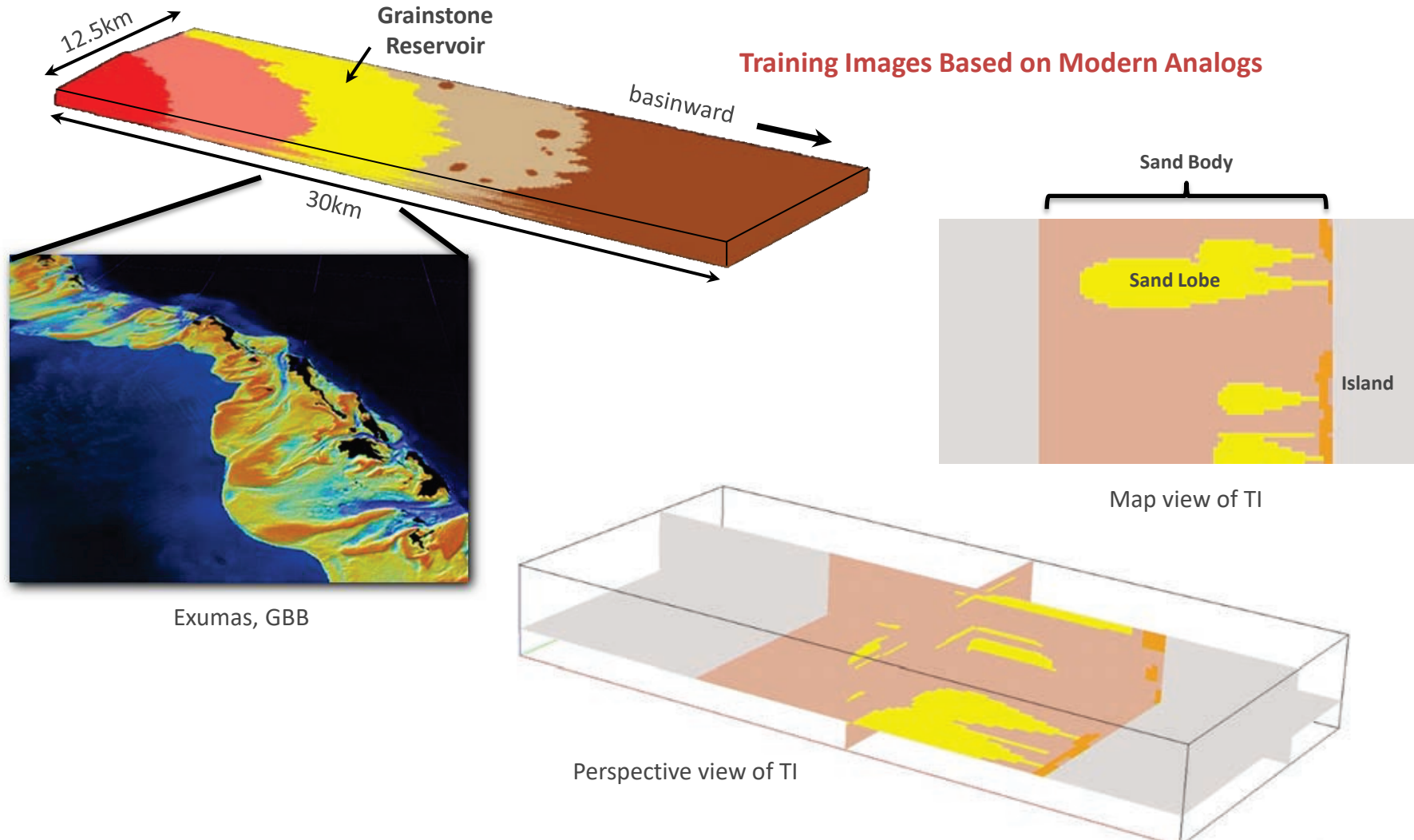




GeoStatistics

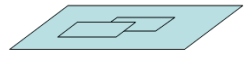


Modern Analogs Can Provide Key Inputs for Reservoir Modeling



Information Distribution

GIS Stack of Images & Maps for Exumas



New Geologic Maps

Regional
Local



Bathymetric/Topographic Contours

Derived from DEMs



GIS Hyperlinked References

Descriptions of specific sites



Integrated Images & Maps

For visualization of select areas



Bathymetry Control

Depths from Nautical Charts



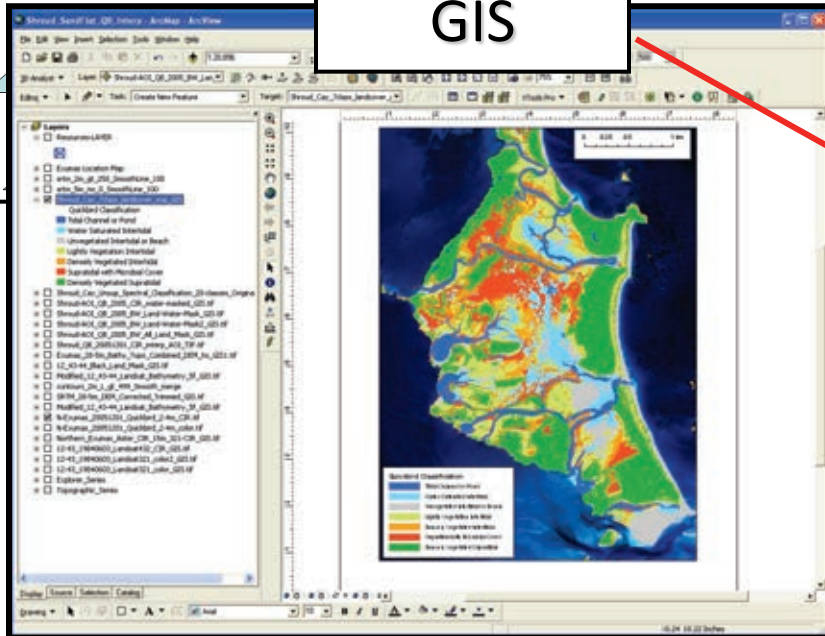
Land-Water Boundary

30 m - derived from Landsat



Onshore DEM

Complex
GIS



For the past 30 some years, the Caicos Platform has been an important area for studies of Holocene and Pleistocene carbonate successions and a destination for numerous geoscientists interested in learning about modern carbonate sedimentary systems. During the past few years there has been a renewed interest in understanding the geology of the platform, stemming in large part from recognition in the petroleum industry that more refined reservoir models of carbonate systems are needed both in exploration and development. The impetus for this workshop and this volume was a desire to bring together both present and past Caicos Platform workers with those not familiar with the Platform to share knowledge on the Holocene to Pleistocene sedimentology, diagenesis, platform evolution, and the applicability of the platform as an analogue for ancient isolated carbonate platforms.

This volume includes a broad array of papers and is divided into five sections:

- Introduction
- Holocene, Platform-Scale Surficial Sediment and Facies Distribution
- Holocene Subsurface Studies
- Holocene Sedimentology, Reservoir and Source-Rock
- Pre-Holocene Platform Evolution Sedimentology, and

William Morgan and Paul (Mitch) Harris

The DVD contains an extensive program. If the DVD does not automatically run when inserted, please open the file "CaicosW512300" file. An Internet browser and Adobe Reader are required to view the files. If there are any questions contact SEPME.

Developing Models and Analogs for Isolated Carbonate Platforms and Pleistocene Carbonates of Caicos Platform, BIR
SEPME Core Workshop 22, Copyright © 2008
SEPME (Society for Sedimentary Geology), Digital Version, ISBN



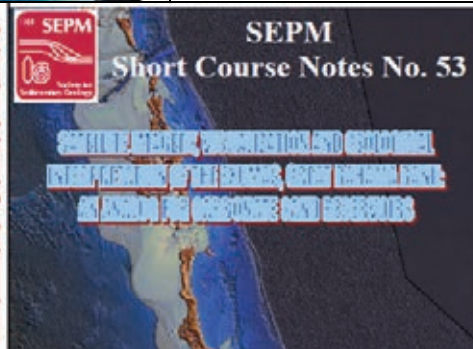
The Exuma Islands and surrounding carbonate sand bodies of Great Bahama Bank are an important training venue, an area of interest to researchers of modern carbonates, and a valuable modern analog for understanding carbonate sand bodies in the subsurface. We hope to promote this interest by making readily available a set of processed satellite images, offshore/onshore digital elevation model (DEM), and interpretation maps organized into a GIS, along with several examples of how this data can be visualized and used for geological interpretation.

Our application of spatial analysis techniques to the Exumas and its carbonate sand bodies provides new insights into this modern carbonate setting and potentially provides data that can have value as an analog in reservoir characterization and modeling. To increase accessibility, improve learning, and promote spatially accurate feedback, the stack of images, color-coded DEM, and geologic maps were exported out of GIS into easier and more flexible viewing programs such as GeoPDFs, GoogleEarth, and Animations.

PAUL M. (MITCH) HARRIS and JAMES ELLIS

DVD #1 contains an extensive program. If the DVD does not automatically run when inserted, please open the file "ExumaW512300" file. An Internet browser and Adobe Reader are required to view the DVD. Other programs are required for the supplemental information on DVD #2. If there are any questions contact SEPME.

Satellite Imagery, Visualization, and Geological Interpretation of the Exumas, Great Bahama Bank: An Analog for Carbonate Sand Reservoirs
SEPME Short Course Notes 53, Copyright © 2009
SEPME (Society for Sedimentary Geology), ISBN 978-1-56576-195-2



Processed satellite images, derived bathymetry (Digital Elevation Models), and sand body interpretation maps of three key areas of modern carbonate sand deposition on Great Bahama Bank (GBB) are organized into a GIS to develop morphometric data. The results of the sand body and sandbar interrogation imply that certain architectural properties of high-energy sand deposits are generic. We think such results broaden our perspective of the types of information that can be derived from studies of the modern and hopefully will stimulate further studies.

Collectively, the sand deposits show a range of depositional facies patterns. Rimming the southern end of Tongue of the Ocean (TOTO) is the broadest expanse of "high-energy" sands found in the Bahamas characterized by narrow sandbars separated by wide, deep channels and a lack of islands. A variation of the tidal bar motif with broader and more irregular sandbars, relatively narrow channels, and few small islands occurs at the northern end of Exuma Sound (Schooners). Sands associated with tidal channels and the numerous islands of the Exumas chain along the western edge of Exuma Sound occur primarily as flood tidal deltas.

An objective of this study is to move the geospatial data from a high-end GIS (GBB DVD 2) into lower cost and more readily available viewers, i.e., GeoPDF, Google Earth, animation, and ArcExplorer, to support training and improve communication. Examples of these types of files, as well as a detailed and well-illustrated summary paper and appendix, are included on GBB DVD 1.

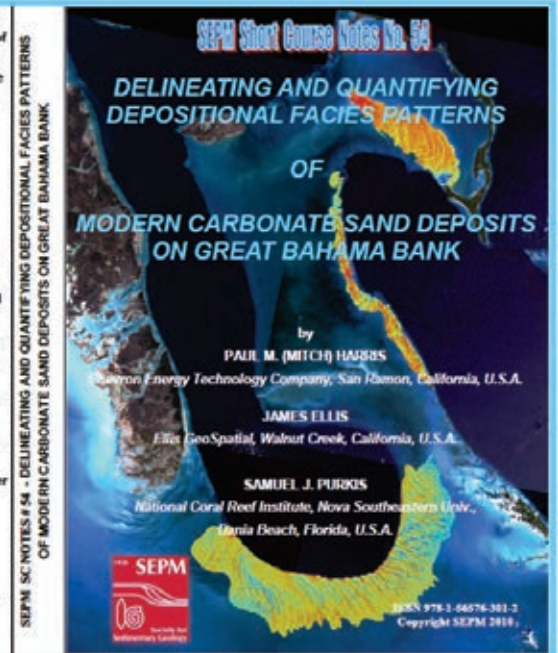
PAUL M. (MITCH) HARRIS, JAMES ELLIS, and SAMUEL J. PURKIS

Note: GBB DVD-1 contains an extensive program. If your computer security does not allow it to run, please open the GBB DVD 1 folder and then file -GBB Paper.pdf. GBB DVD-2 contains high-end GIS files for those that want to access them and are described in the paper and appendix on DVD-1. To access the files open the appropriate folders on DVD-2.

SEPME 2-DVD Sets with Entire GIS Database, GeoPDFs, kmz, ArcGIS Explorer, Animations, & Research Paper

2-Day Workshops at
2011 & 2012
AAPG National Conferences

Examples available via DropBox

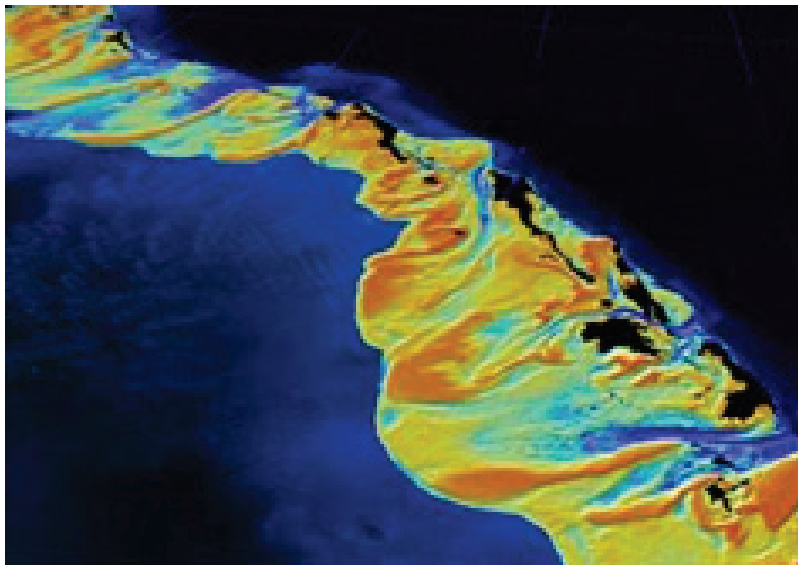


SUMMARY

Multispectral imagery is highly versatile

Remote Sensing & GIS provide unique, cost-effective, and timely information on surface features

Much multispectral data – but where's the low-cost, entry-level software to process it? (*ASPRS RSAD*)



The End

Jim Ellis

Ellis GeoSpatial

www.ellis-geospatial.com

