Best practices in topo-bathymetric lidar collection & processing

Tim Webster, Nathan Crowell, Kevin McGuigan, Candace MacDonald, Kate Collins + many

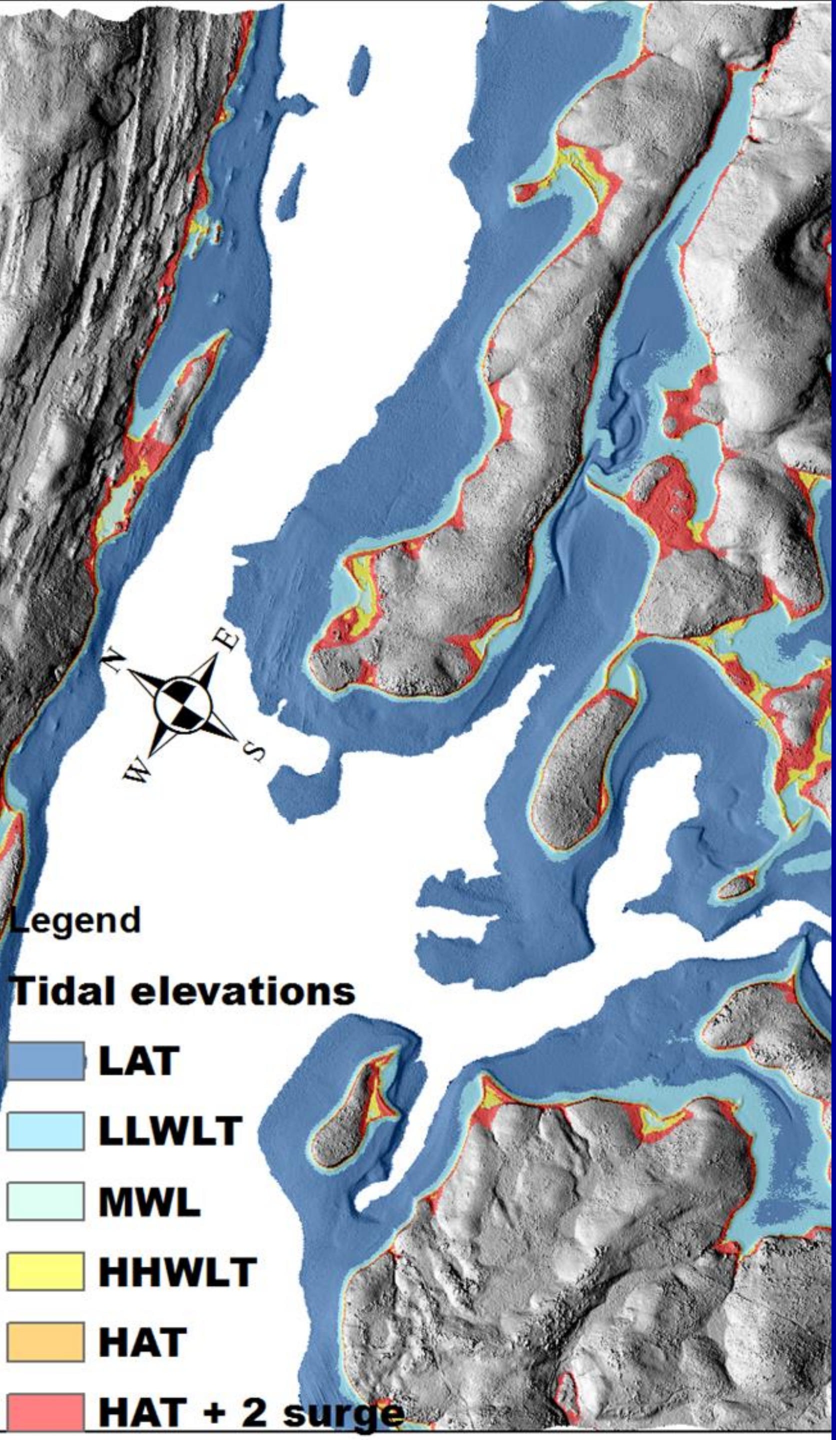
Tim.Webster@nscc.ca

Research Scientist

Applied Geomatics Research Group

Centre Of Geographic Sciences

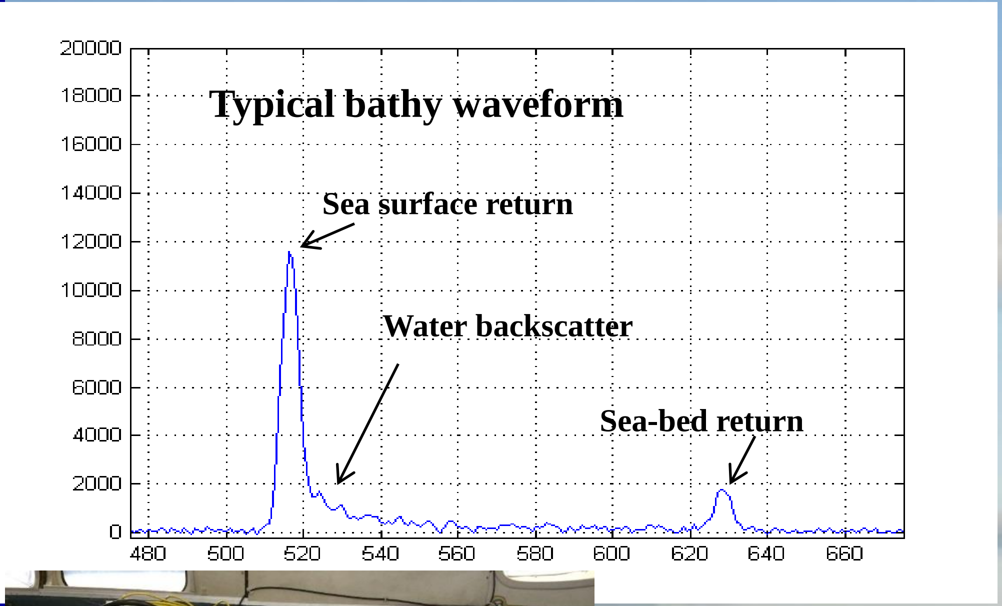
Nova Scotia Community College



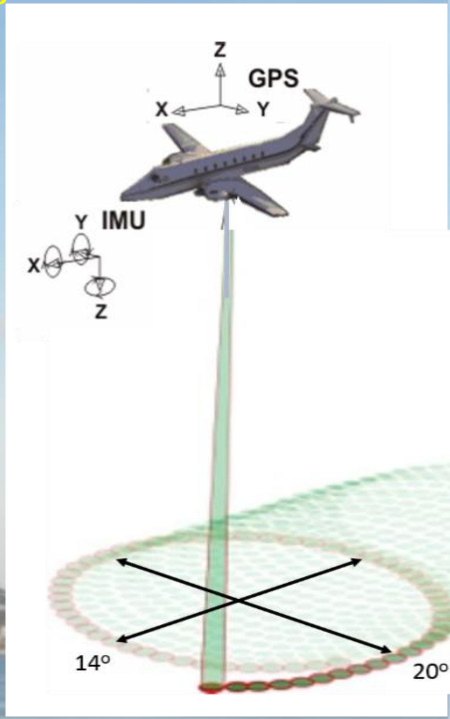
Outline

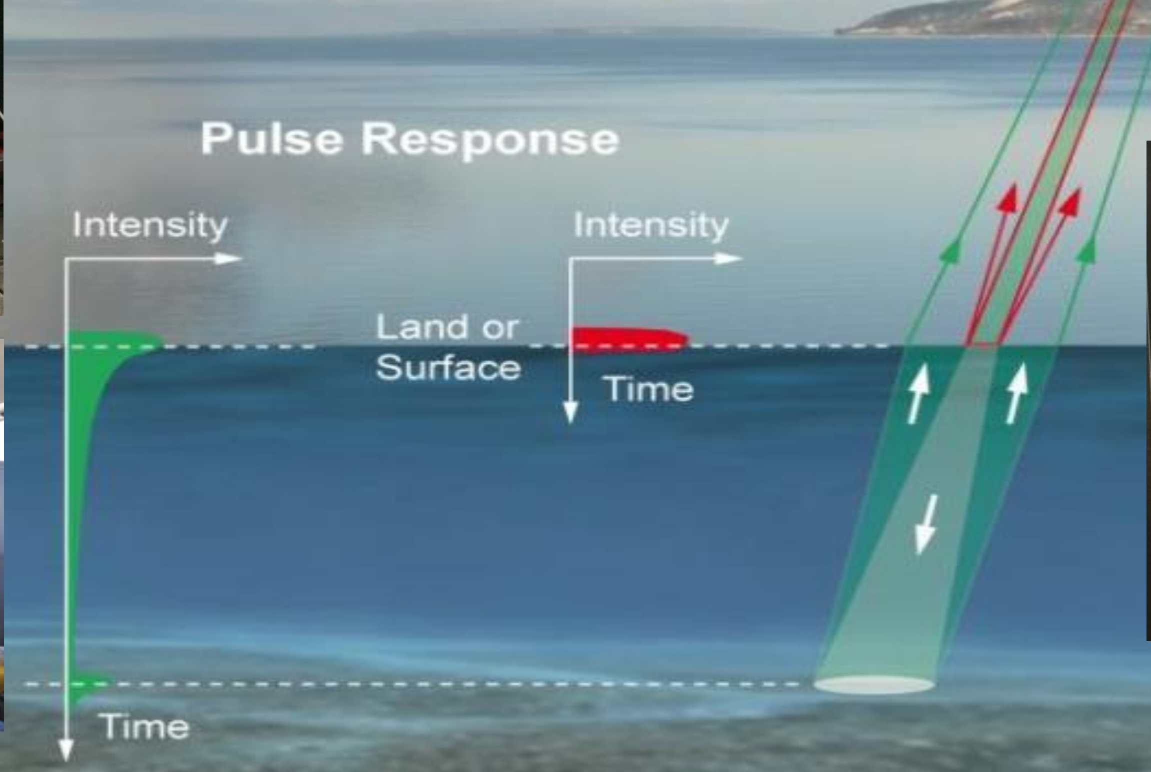
- Quick intro to CH2 topo-bathymetric lidar Processing flowchart/research products
- Real-time turbidity buoys
- Detection of 1 x 1 m cubes
- Variable AGL 300 vs. 400 m + overlap
- Multi-use products from the topo-bathy survey
- Conclusions

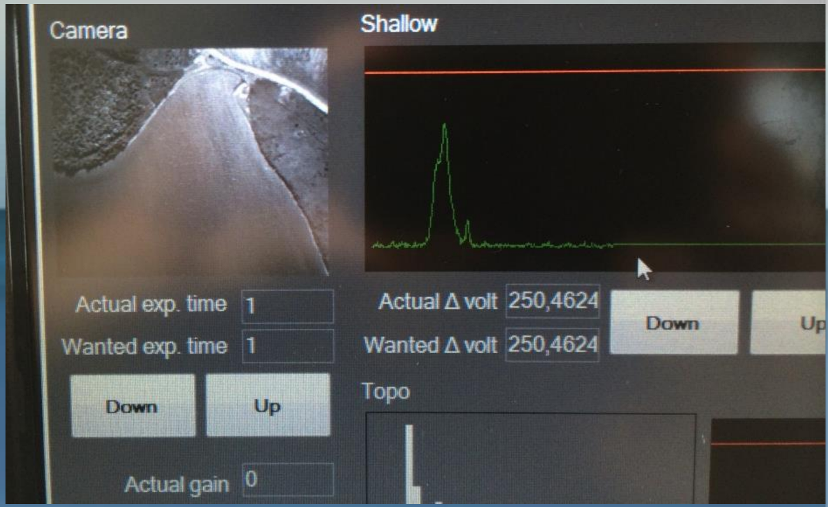
Chiroptera$_{II}$ – Lidar principles



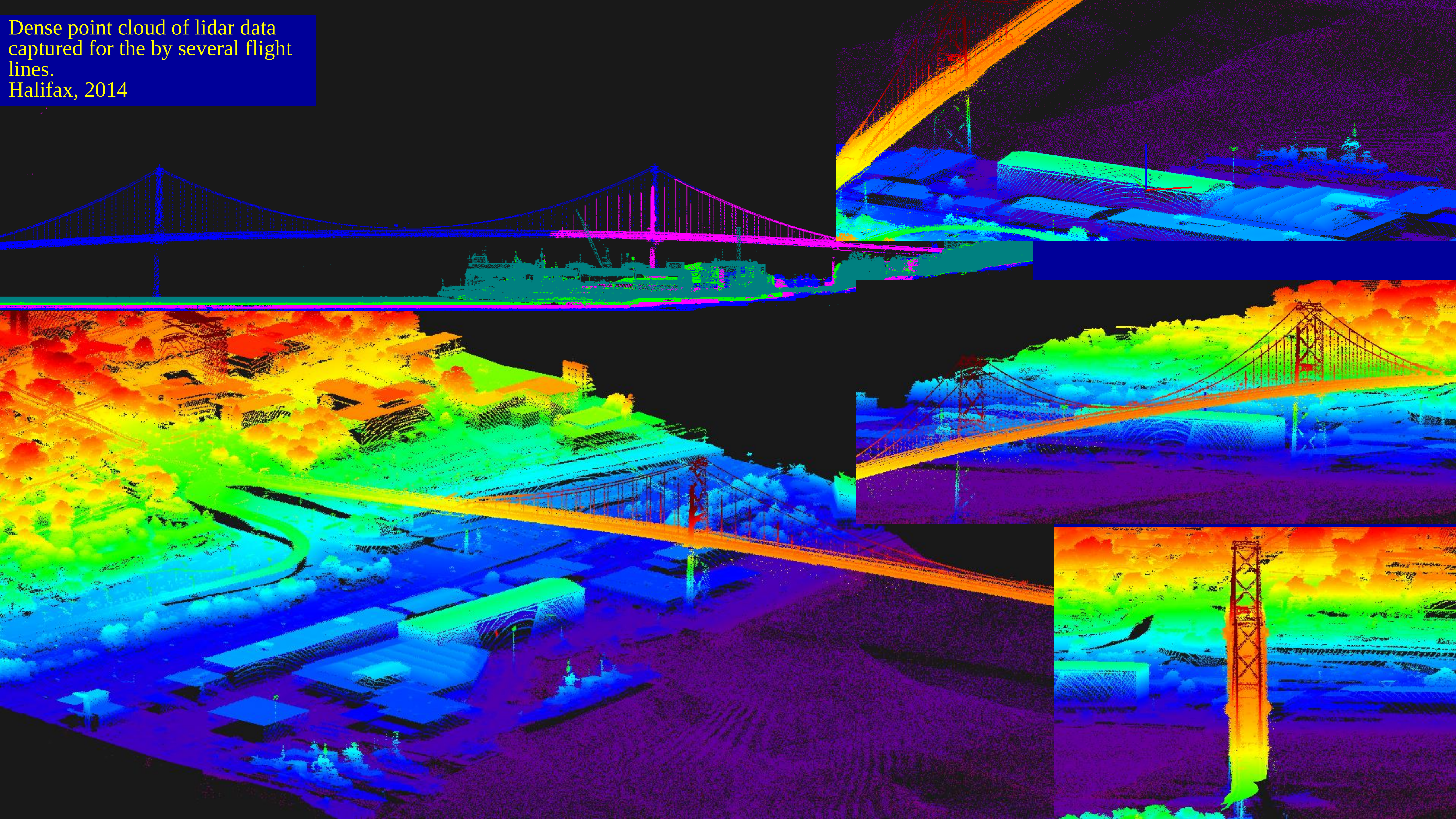
4 sensors
NIR laser 500kHz
Green laser 35 kHz
RCD30 60 MP RGB, NIR
5 MP QA camera



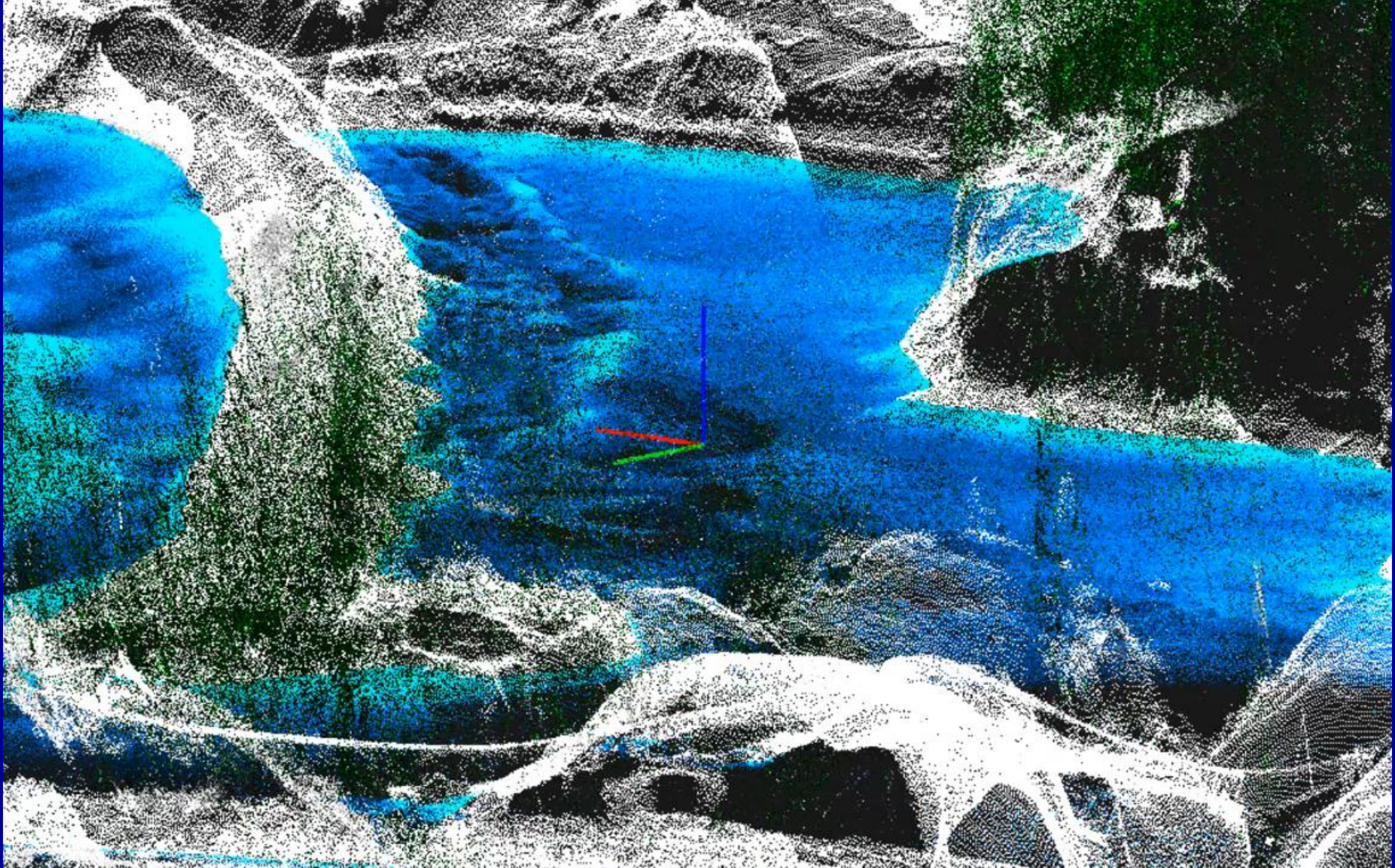


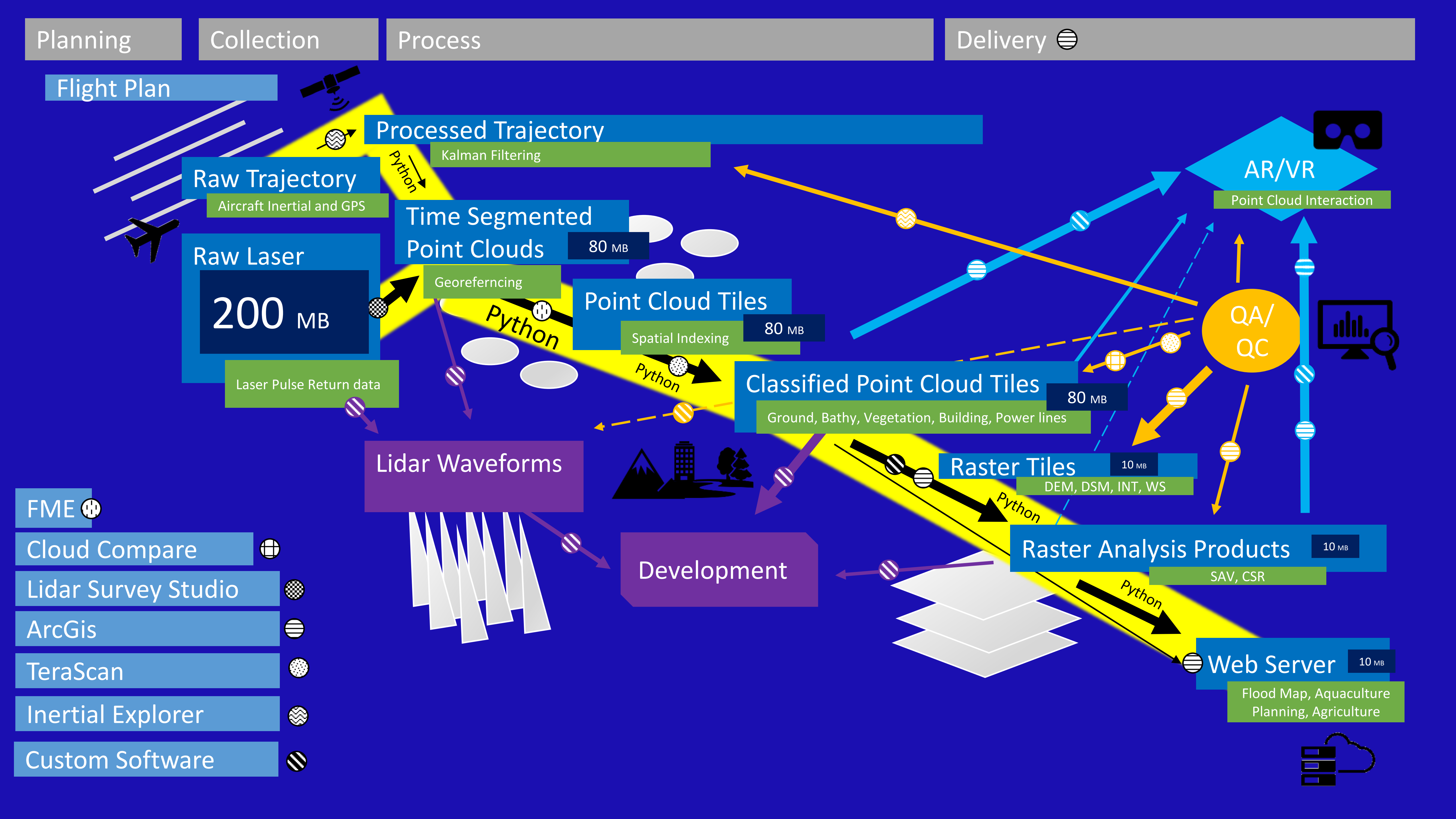


Source: Leica Geosystems

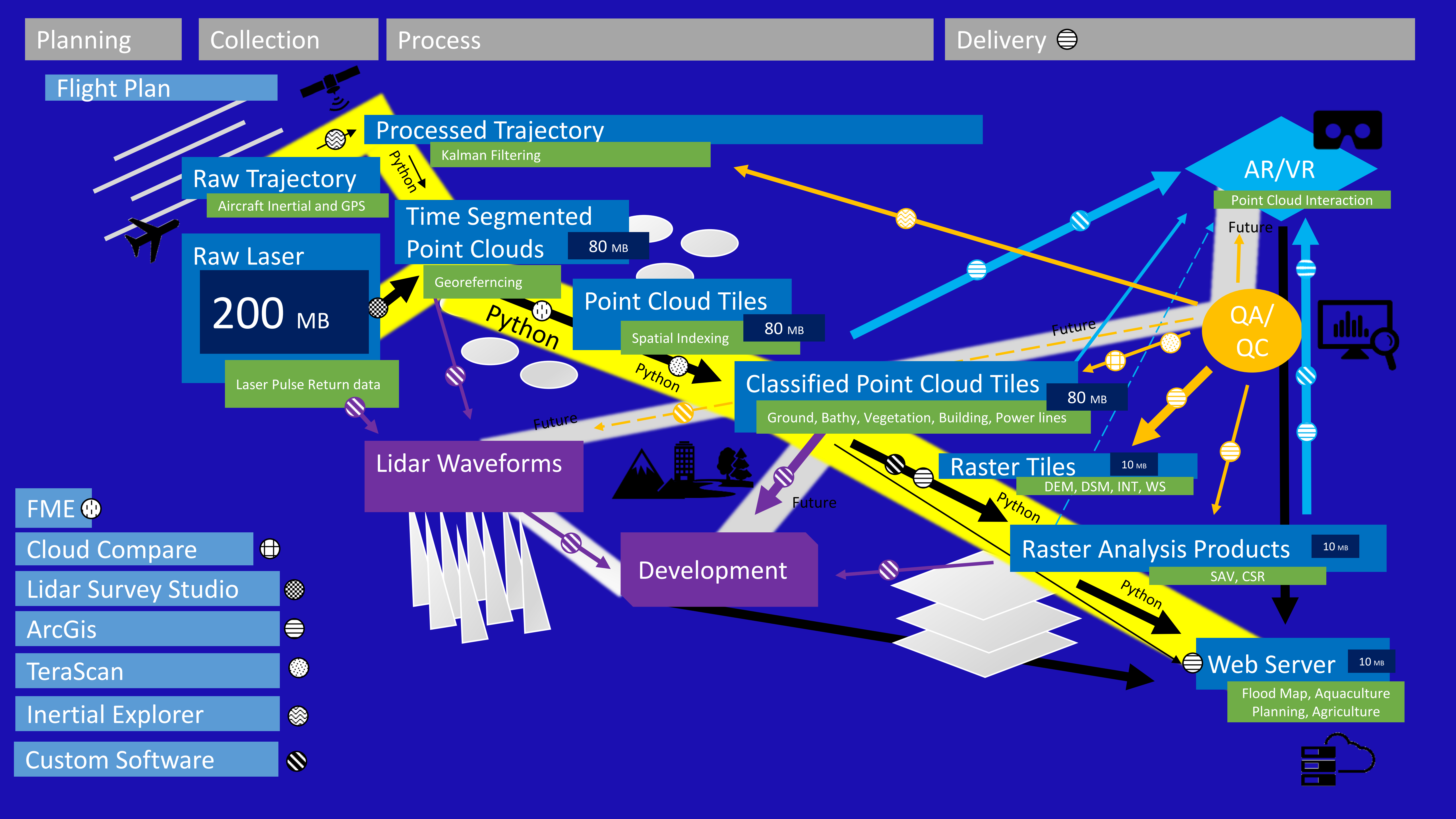


Dense point cloud of lidar data captured for the by several flight lines.
Halifax, 2014





Planning
Collection
Process
Delivery
Flight Plan
Processed Trajectory
Kalman Filtering
Python
Raw Trajectory
Aircraft Inertial and GPS
Time Segmented Point Clouds
80 MB
Georeferncing
Raw Laser
200 MB
Laser Pulse Return data
Python
Point Cloud Tiles
Spatial Indexing
80 MB
Python
AR/VR
Point Cloud Interaction
QA/ QC
Classified Point Cloud Tiles
80 MB
Ground, Bathy, Vegetation, Building, Power lines
Lidar Waveforms
Raster Tiles
10 MB
DEM, DSM, INT, WS
Python
FME
Cloud Compare
Lidar Survey Studio
ArcGis
TeraScan
Inertial Explorer
Custom Software
Development
Raster Analysis Products
10 MB
SAV, CSR
Python
Web Server
10 MB
Flood Map, Aquaculture Planning, Agriculture



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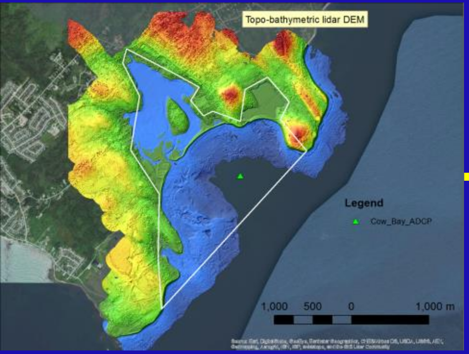
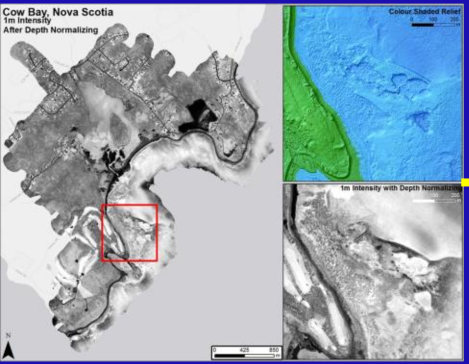
Cloud Compare
Lidar Survey Studio
ArcGis
TeraScan
Inertial Explorer
Custom Software

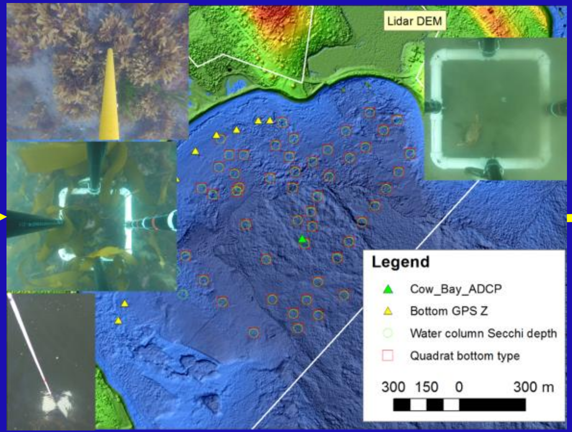
Research & Development of additional map products

Raster Products

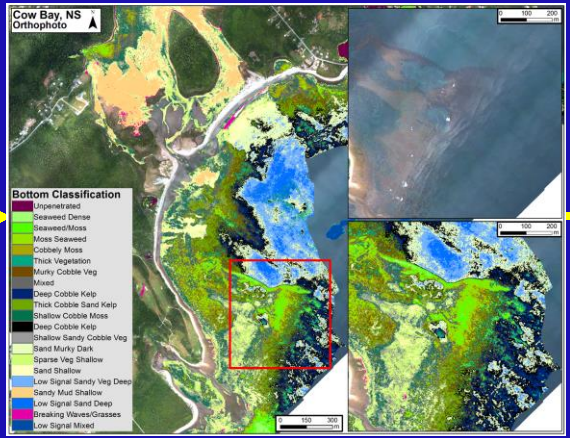




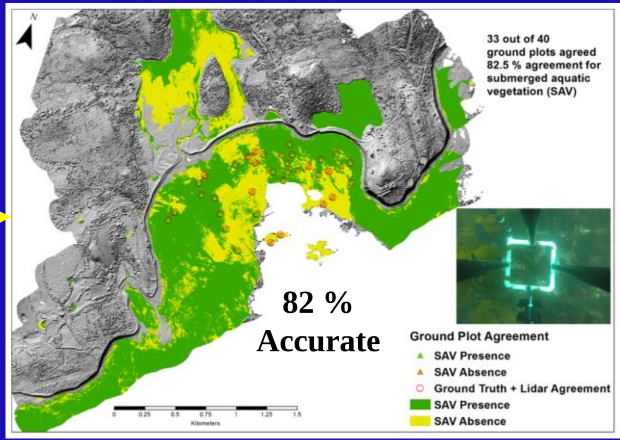
Ground Truth Support



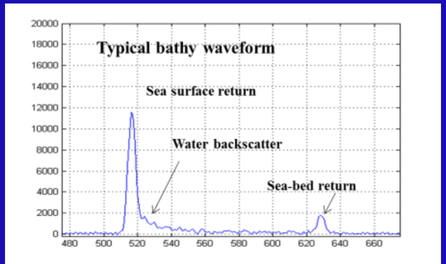
Bottom "benthic habitat" Map

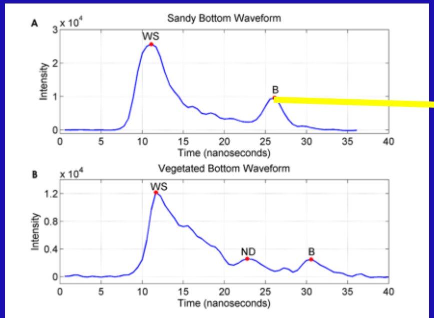


Submerged Aquatic Vegetation Map



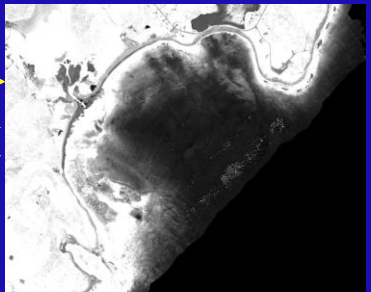
Development





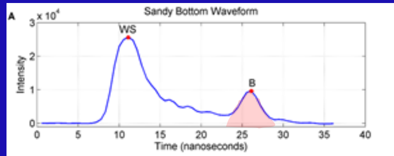
Photo

Peak Intensity

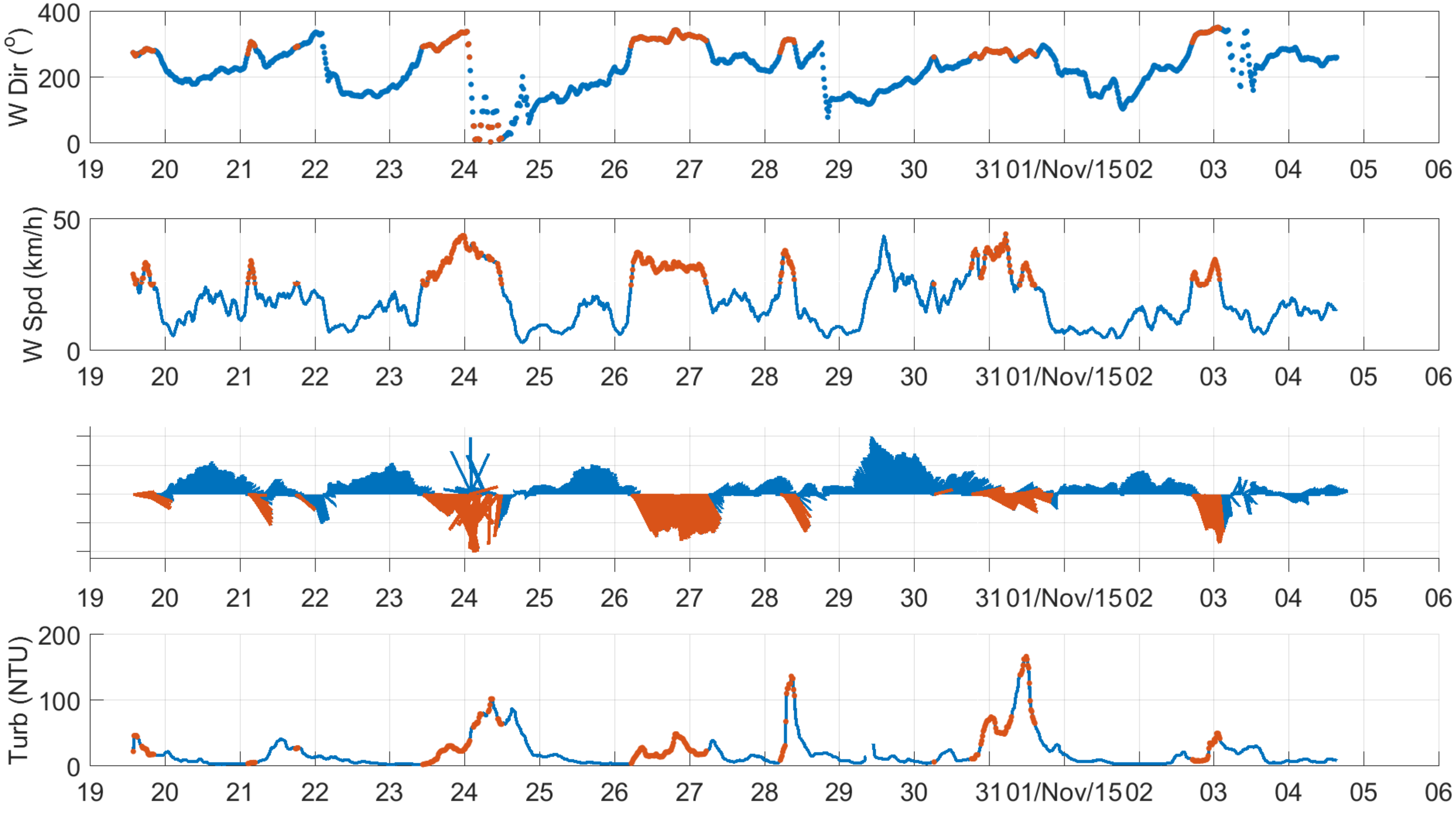


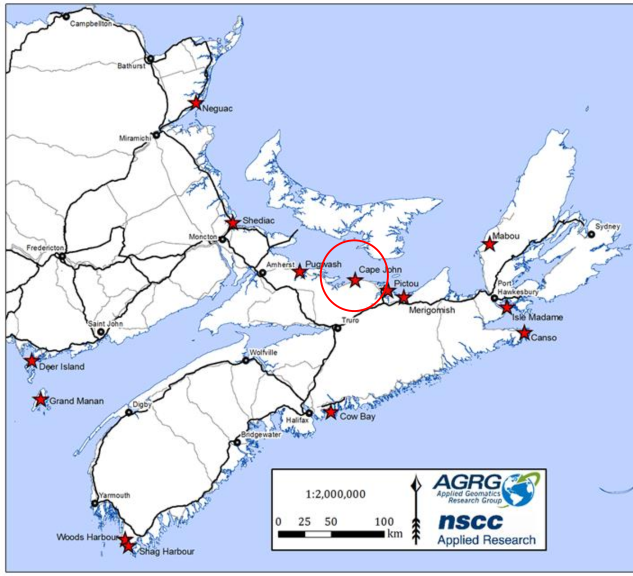
Area Under the Curve

Area Under the Curve Normalized by Depth



Turbidity & Wind Direction, Cape John



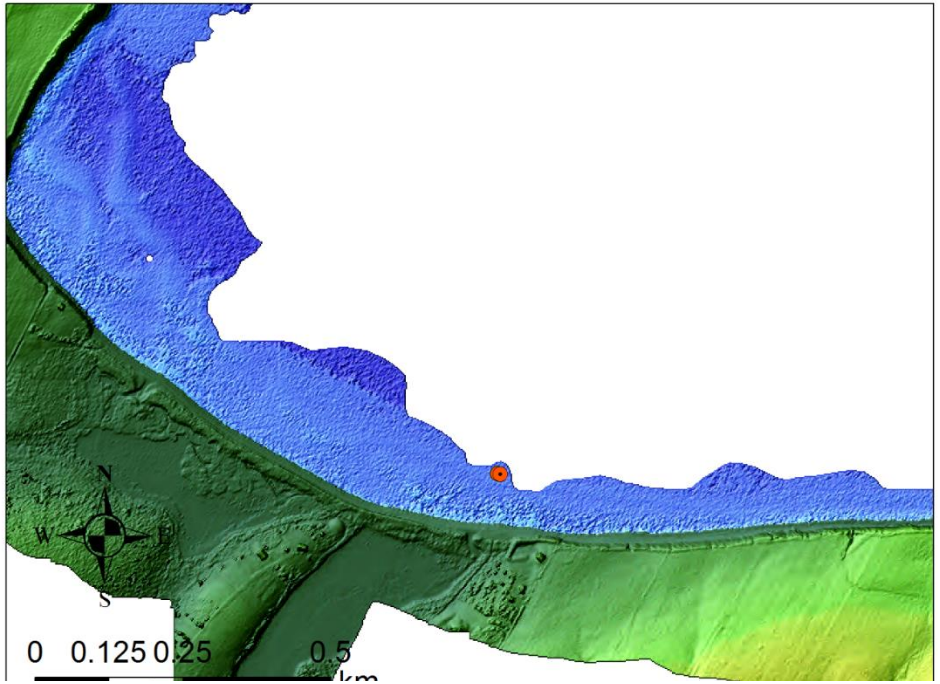


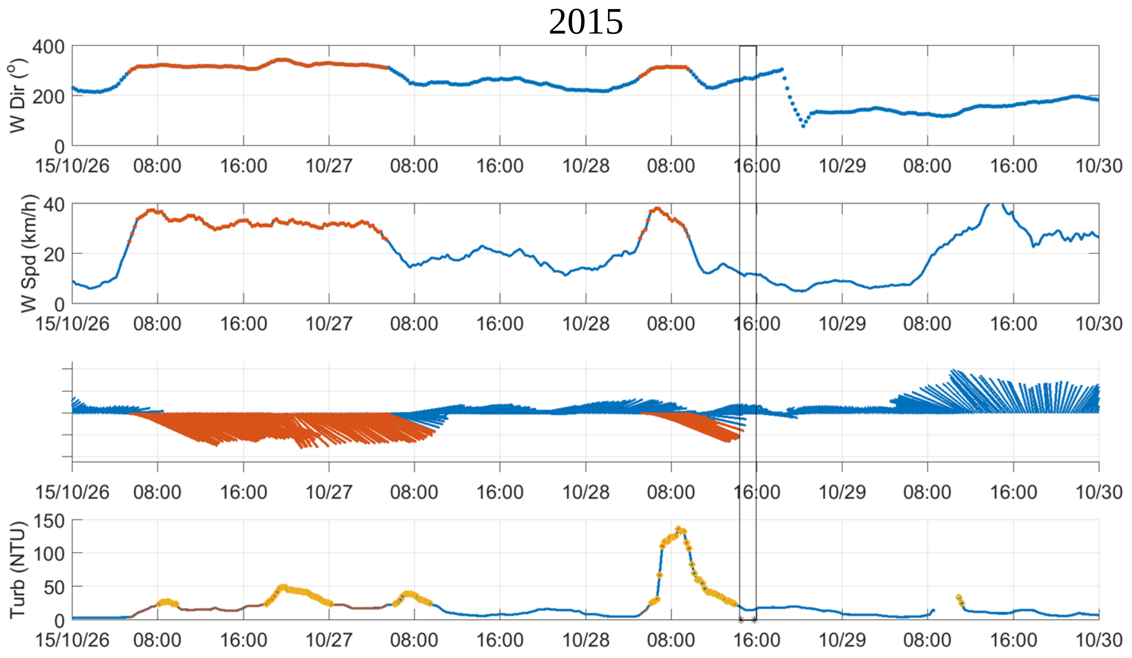
If wind is blowing between 270 and 90 degrees (from NW or NE)

&

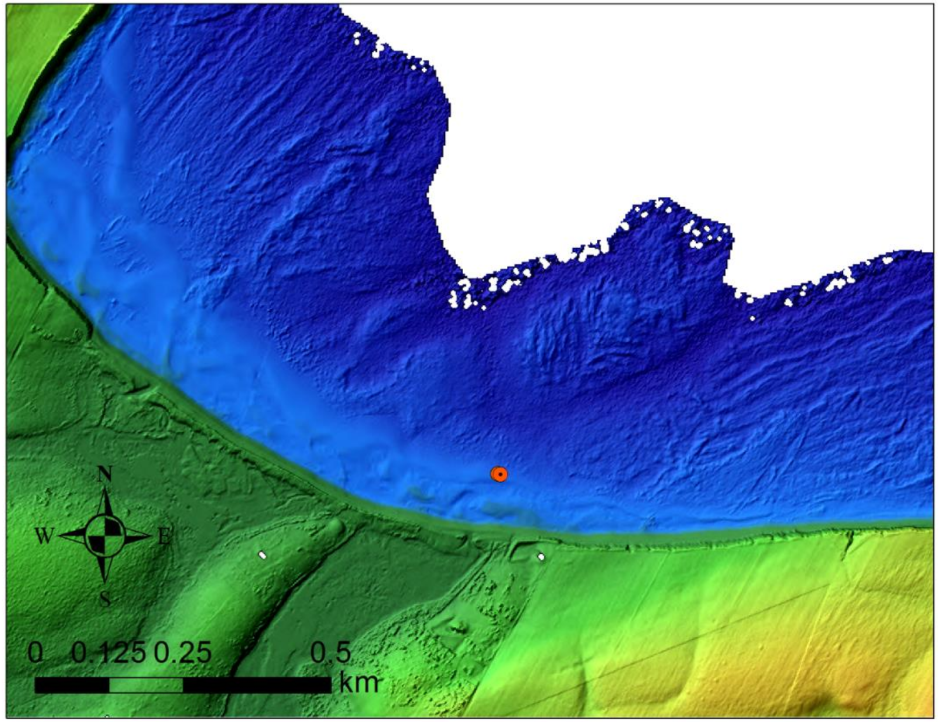
Wind speed is > 25 km/hr

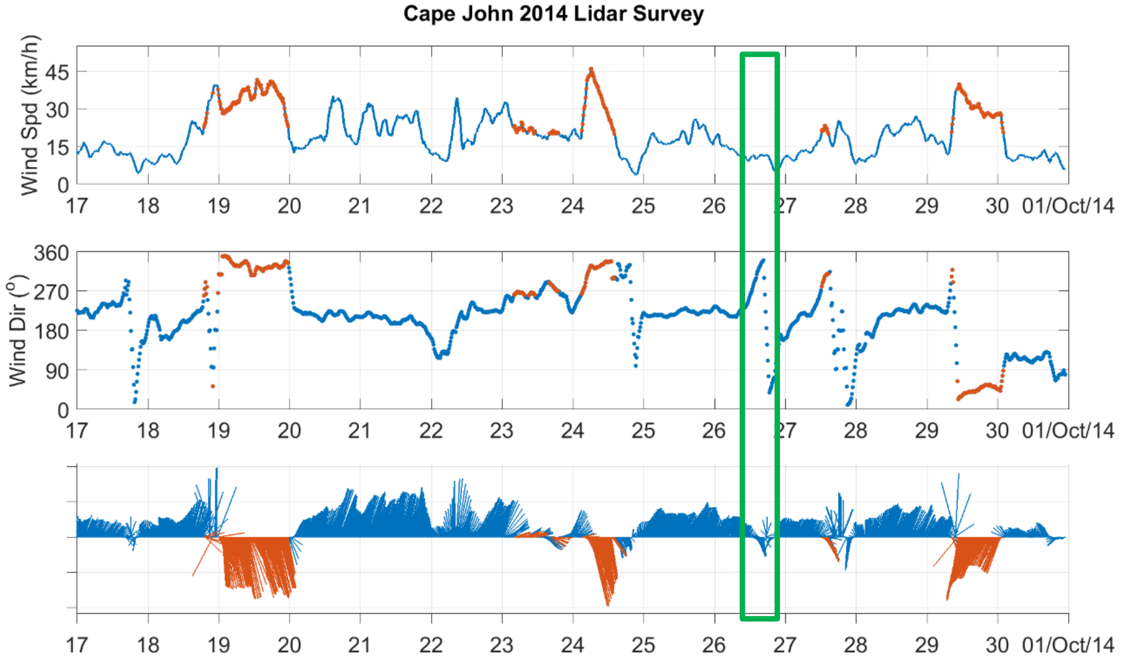
Water can take between 8 and 16 hours to clear





Oct. 2015
Max. Depth
4 m



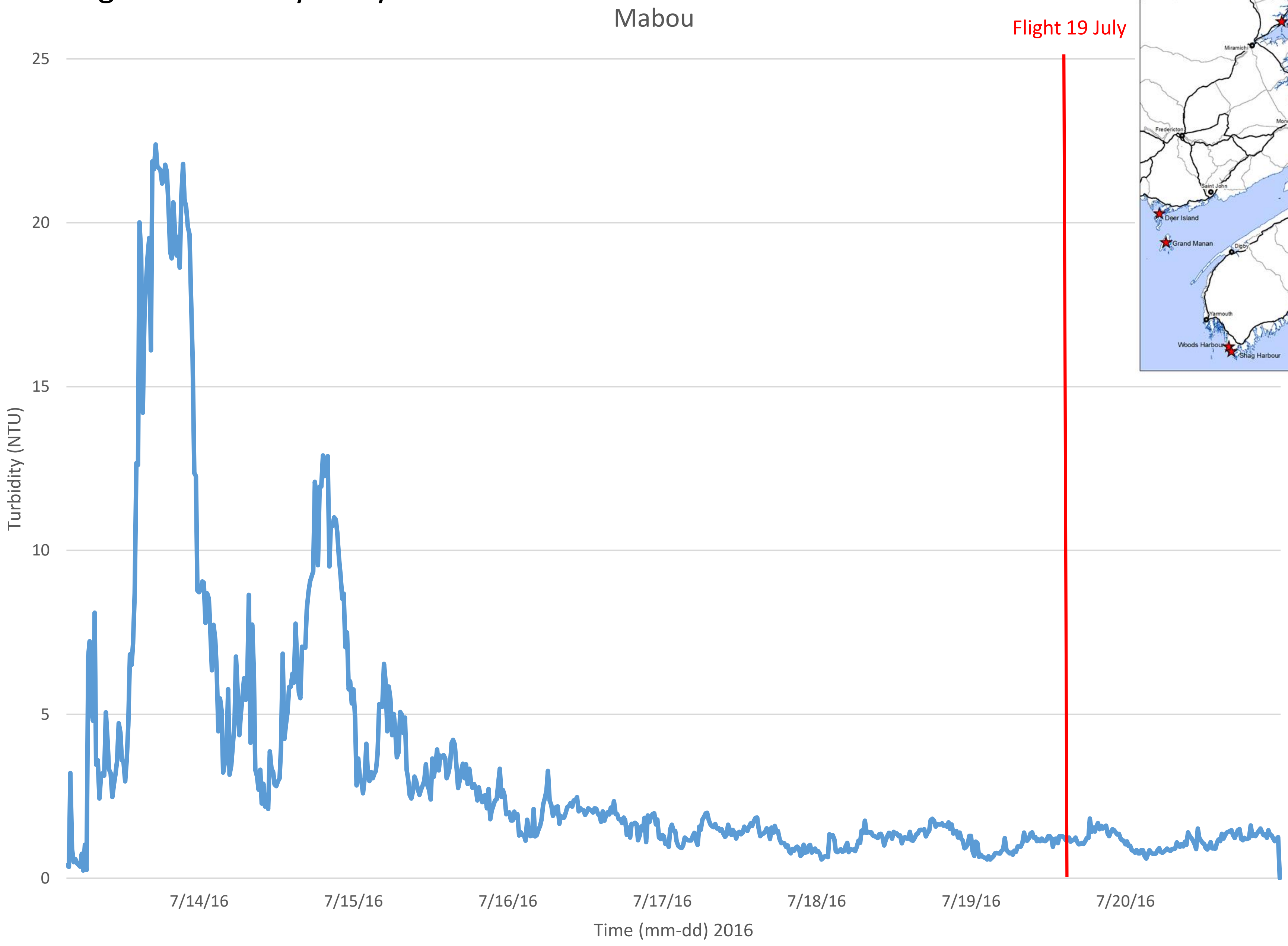


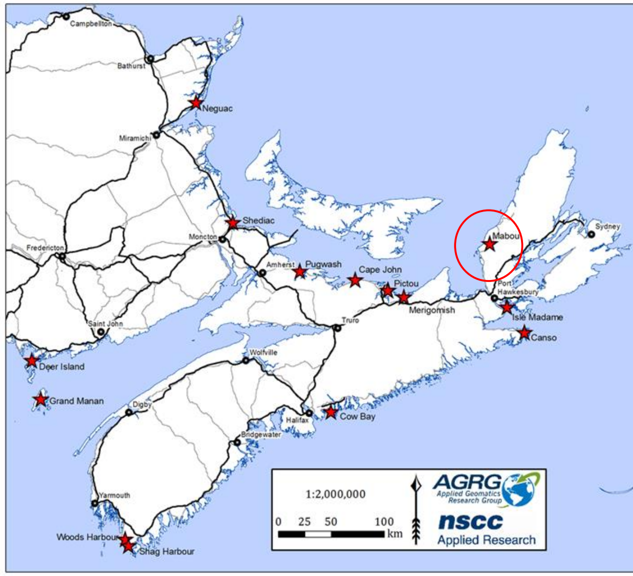
Sept. 2014
Max. Depth
6 m

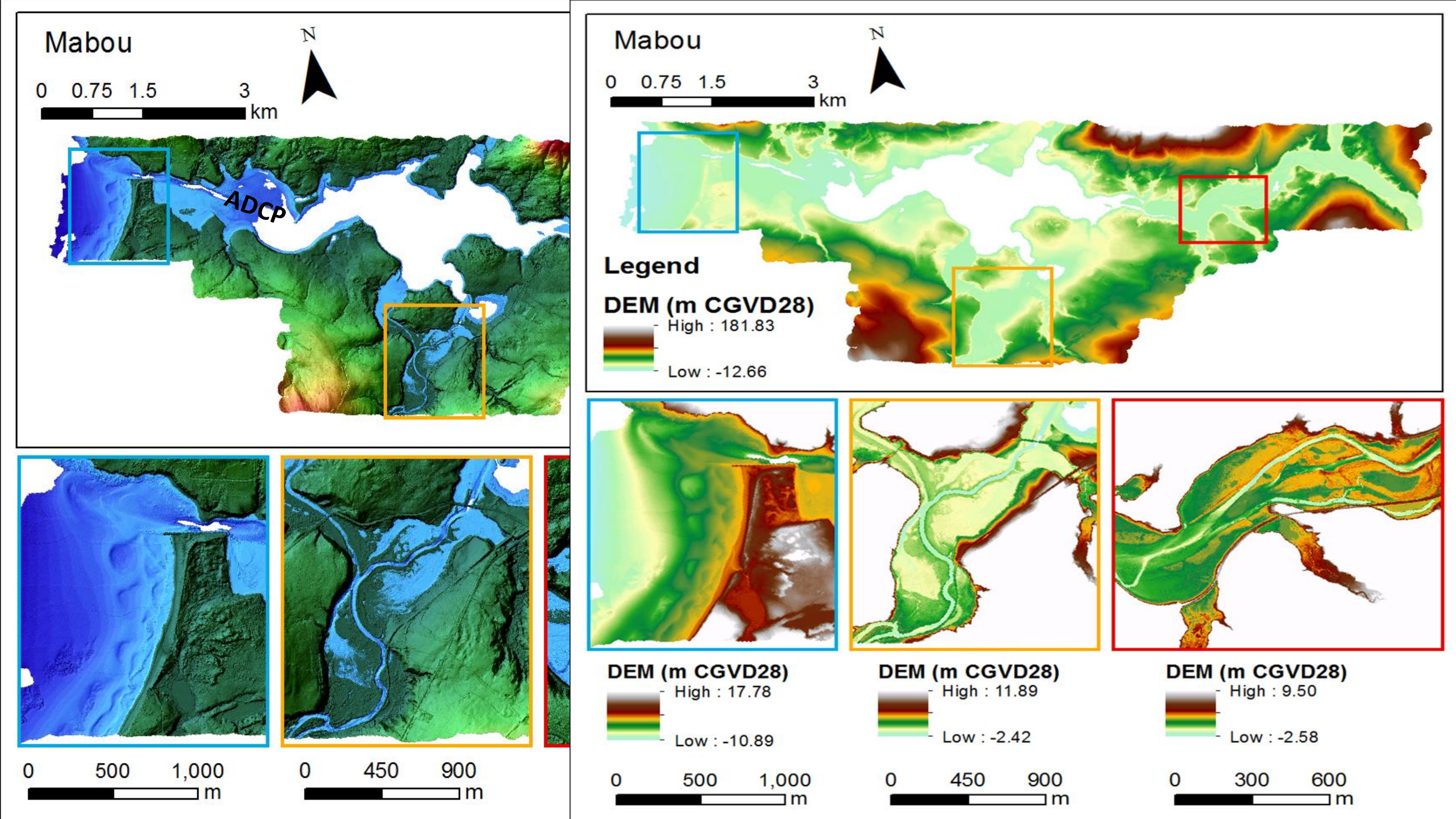
3 CB-50s D-cell batteries
+
Modem
+
Turbidity

1 CB-150
Solar Panel
+
Modem
+
Wind
Temp
+
Turbidity

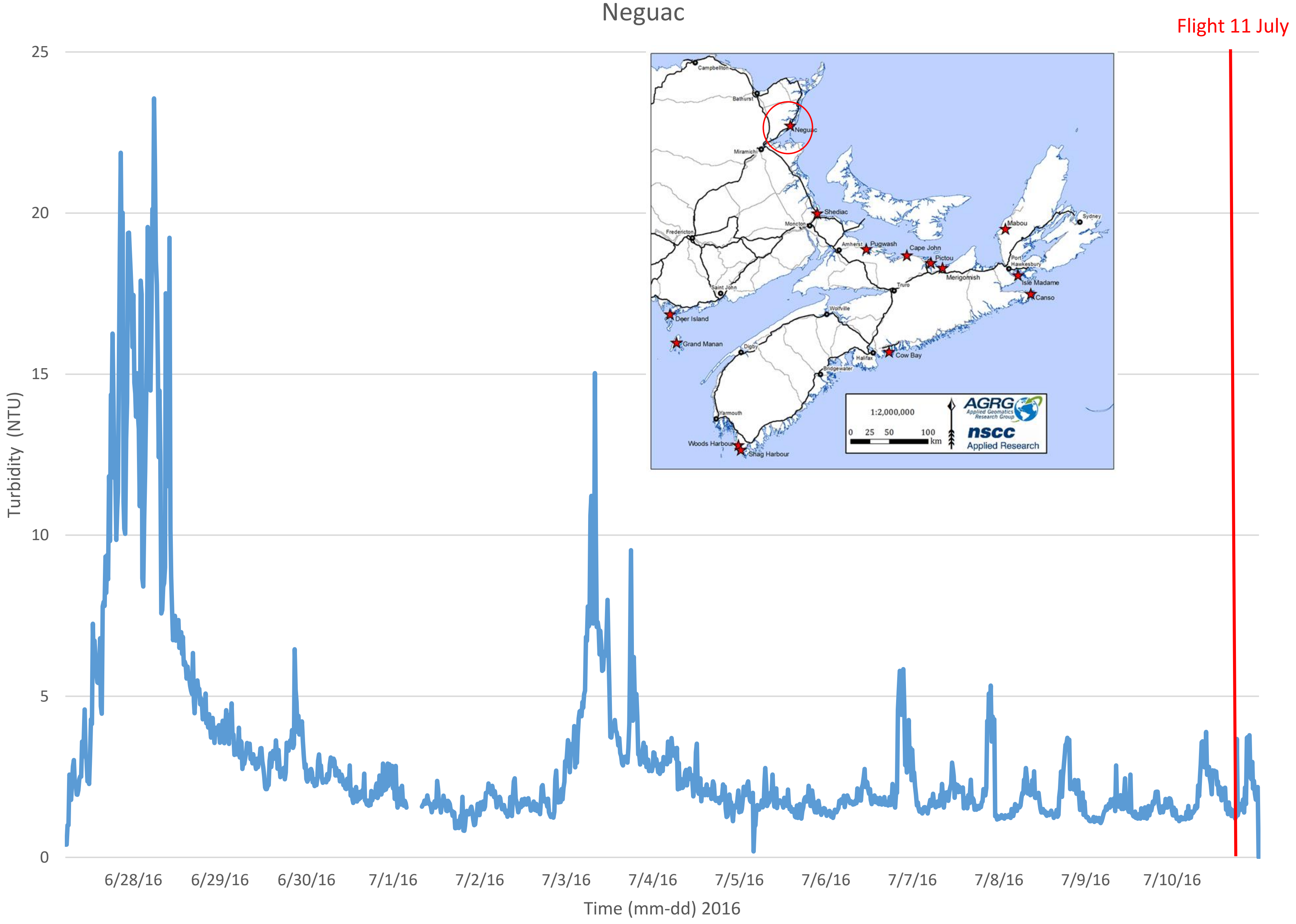
2016 Mission utilizing the Turbidity Buoys

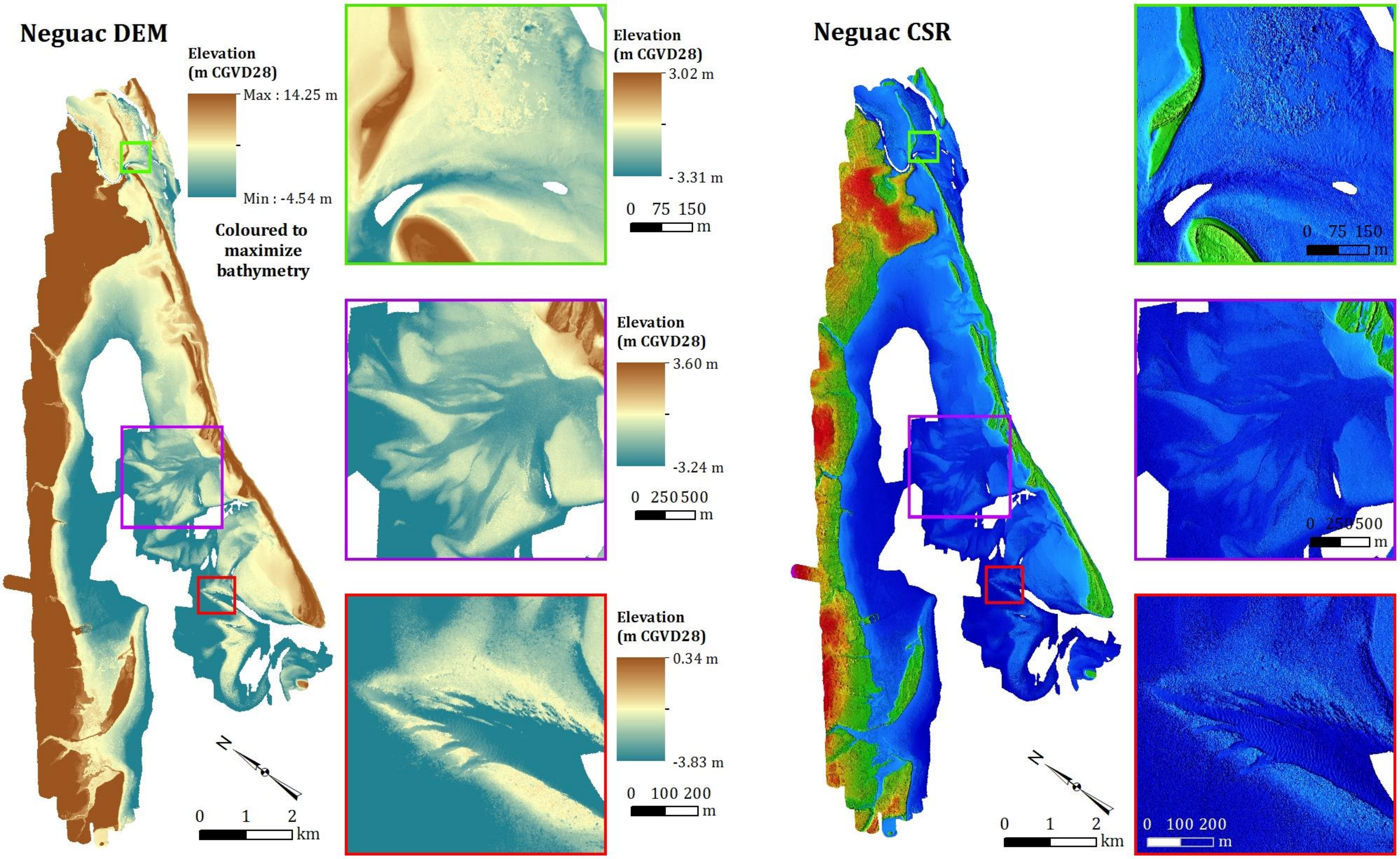




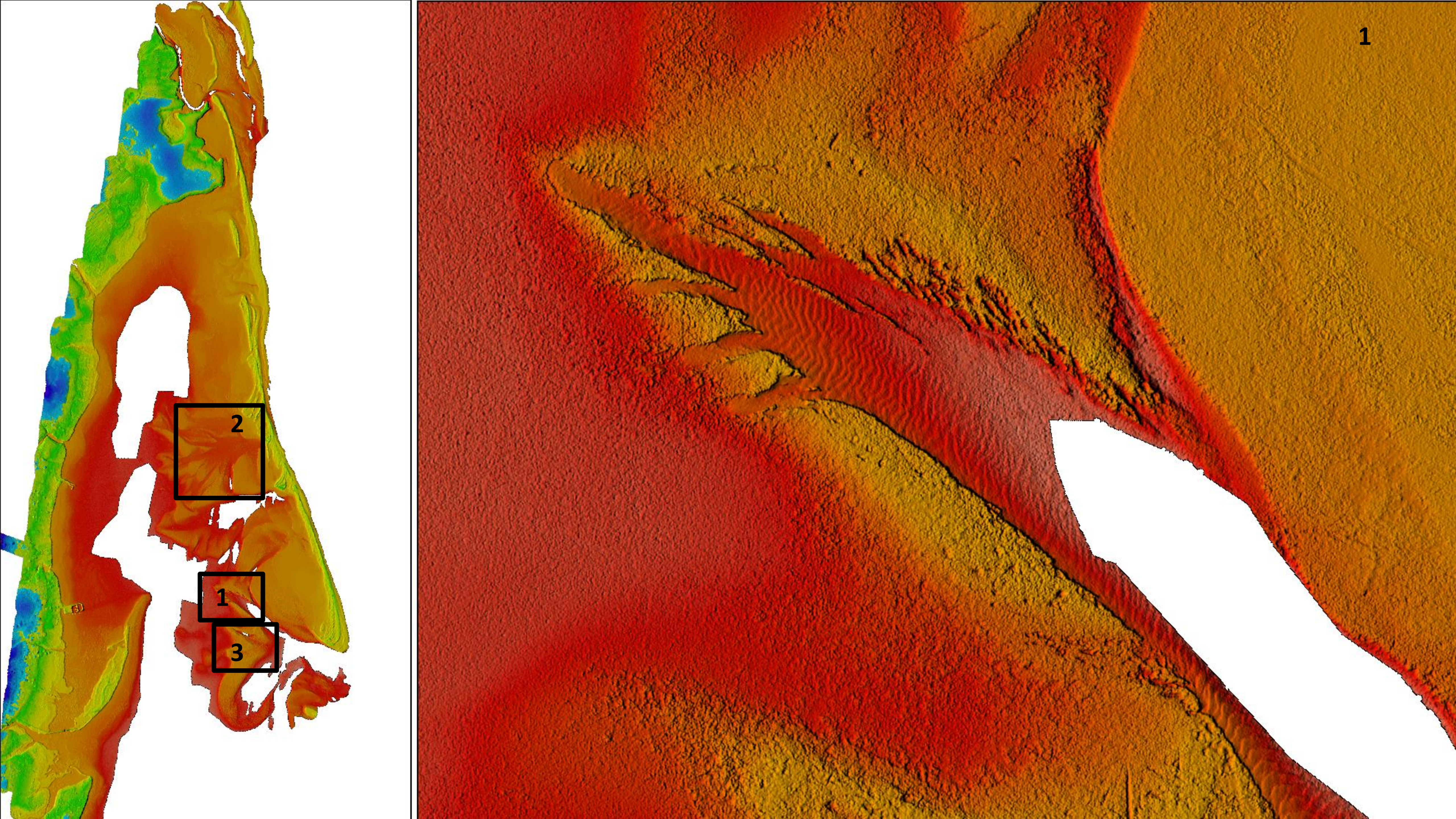

Mabou
N
0 0.75 1.5 3 km
ADCP
0 500 1,000 m
0 450 900 m
Mabou
N
0 0.75 1.5 3 km
Legend
DEM (m CGVD28)
High : 181.83
Low : -12.66
DEM (m CGVD28)
High : 17.78
Low : -10.89
0 500 1,000 m
DEM (m CGVD28)
High : 11.89
Low : -2.42
0 450 900 m
DEM (m CGVD28)
High : 9.50
Low : -2.58
0 300 600 m

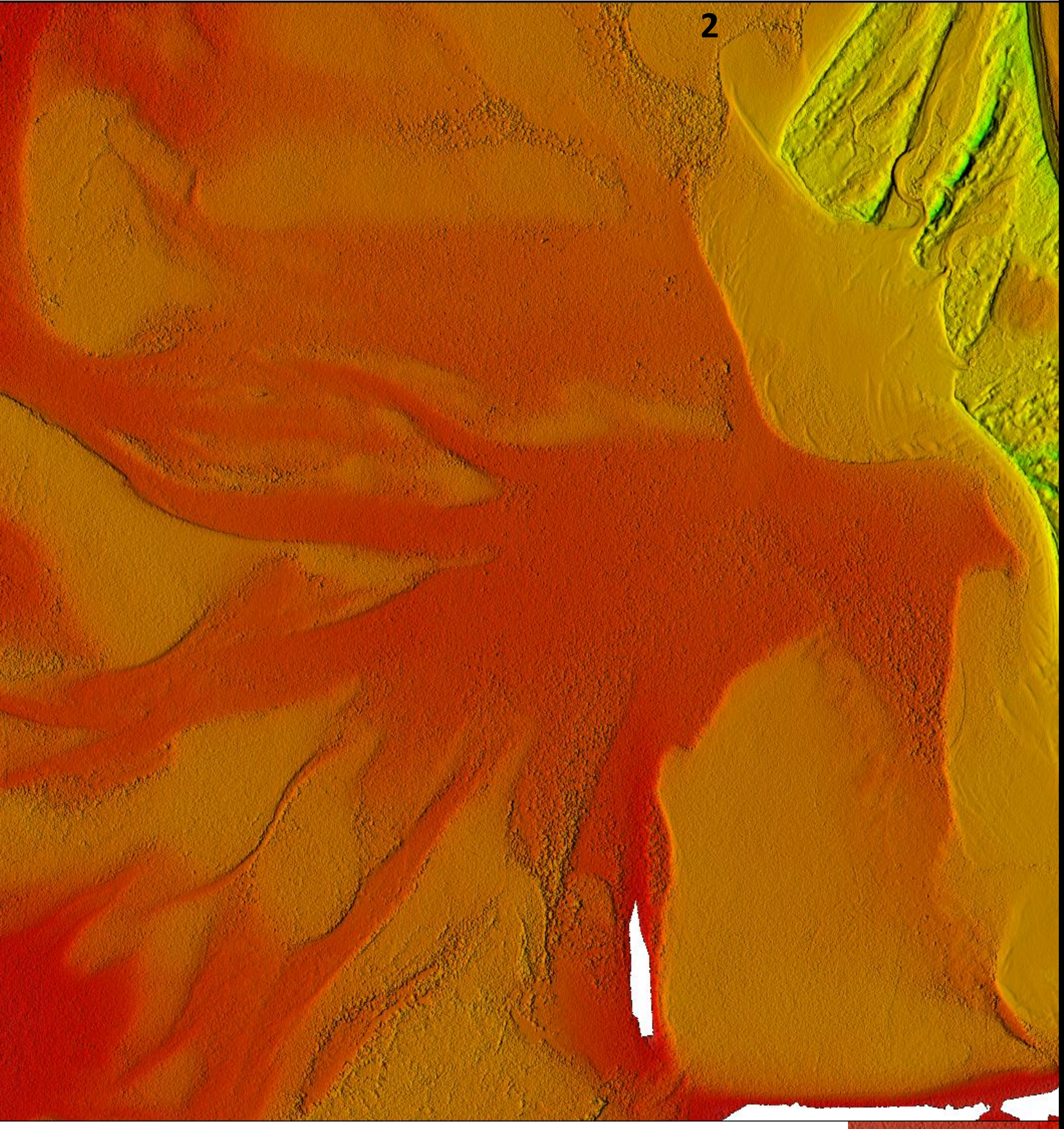
2016 Mission utilizing the Turbidity Buoys

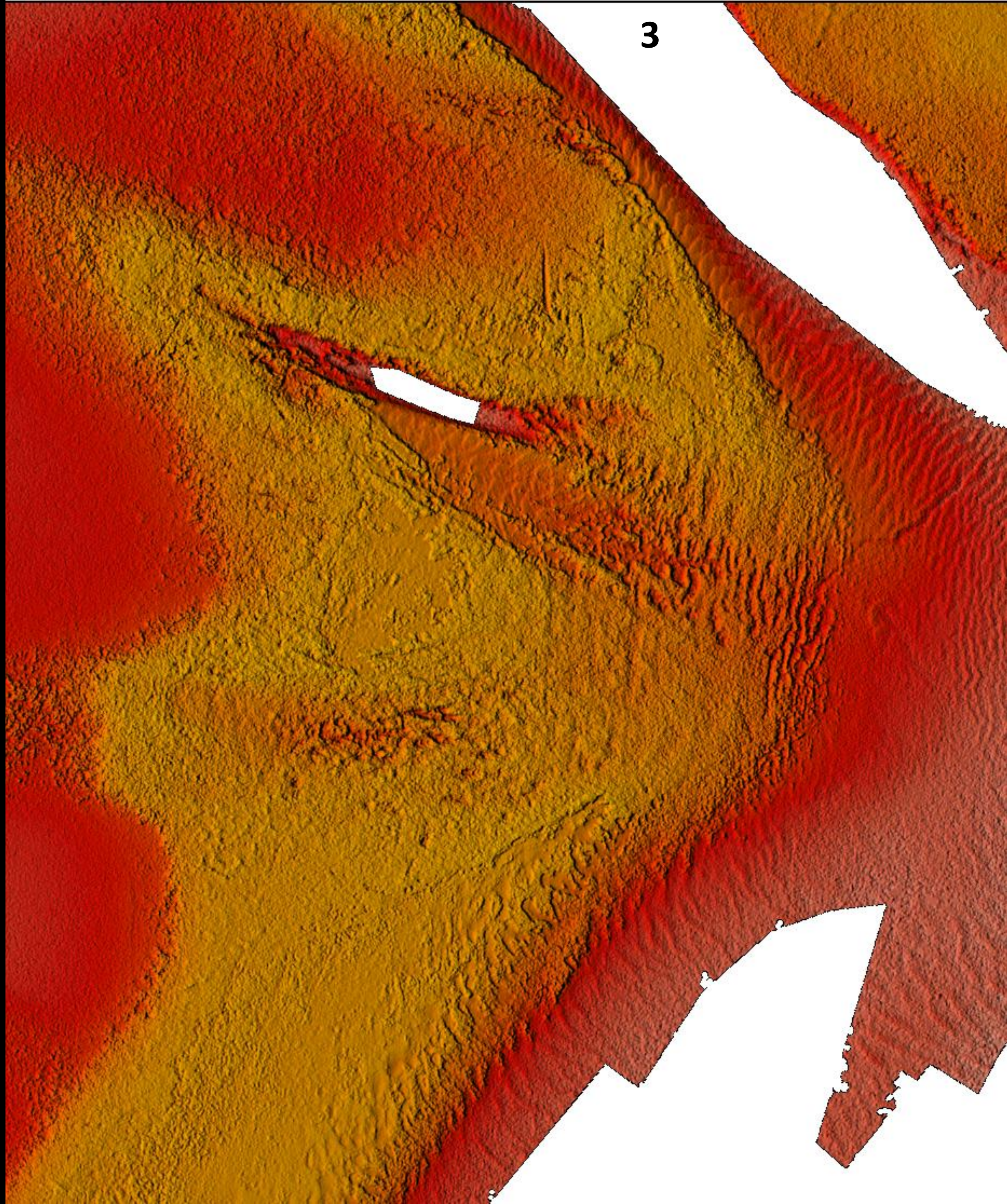


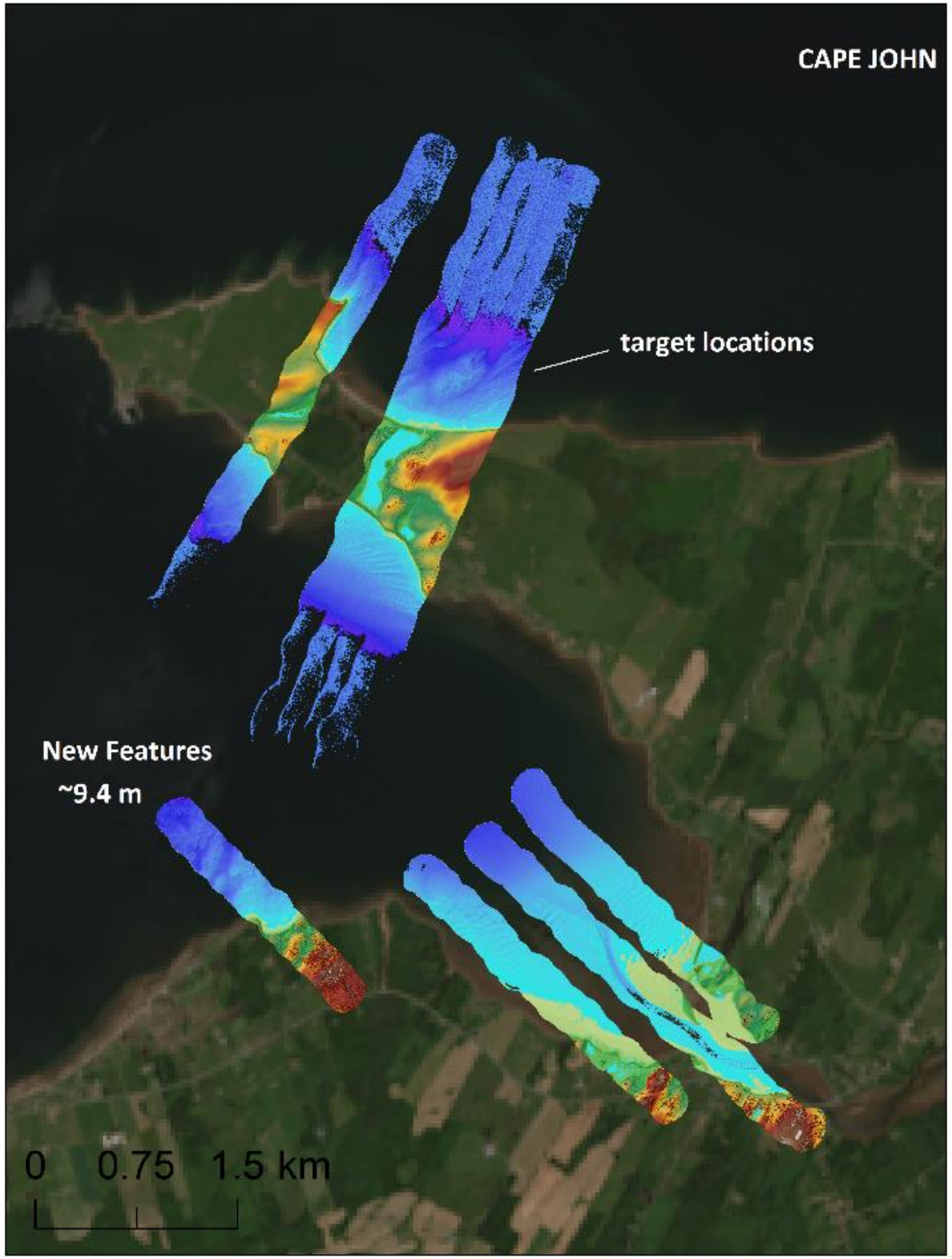


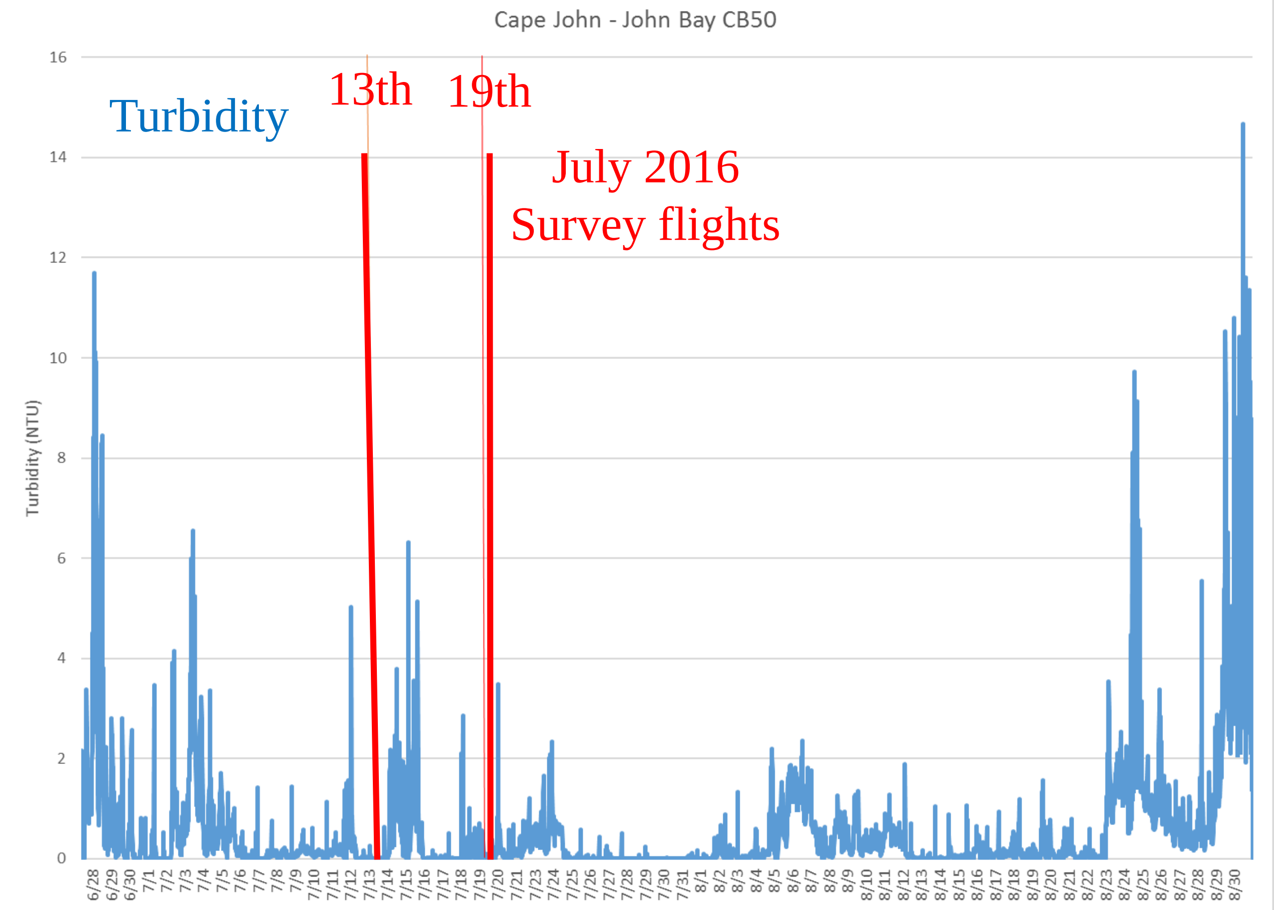
Neguac DEM
Elevation (m CGVD28)
Max : 14.25 m
Min : -4.54 m
Coloured to maximize bathymetry
0 1 2 km
Elevation (m CGVD28)
3.02 m
- 3.31 m
0 75 150 m
Elevation (m CGVD28)
3.60 m
-3.24 m
0 250 500 m
Elevation (m CGVD28)
0.34 m
-3.83 m
0 100 200 m
Neguac CSR
0 75 150 m
0 250 500 m
0 100 200 m
0 1 2 km


2
1
3
1

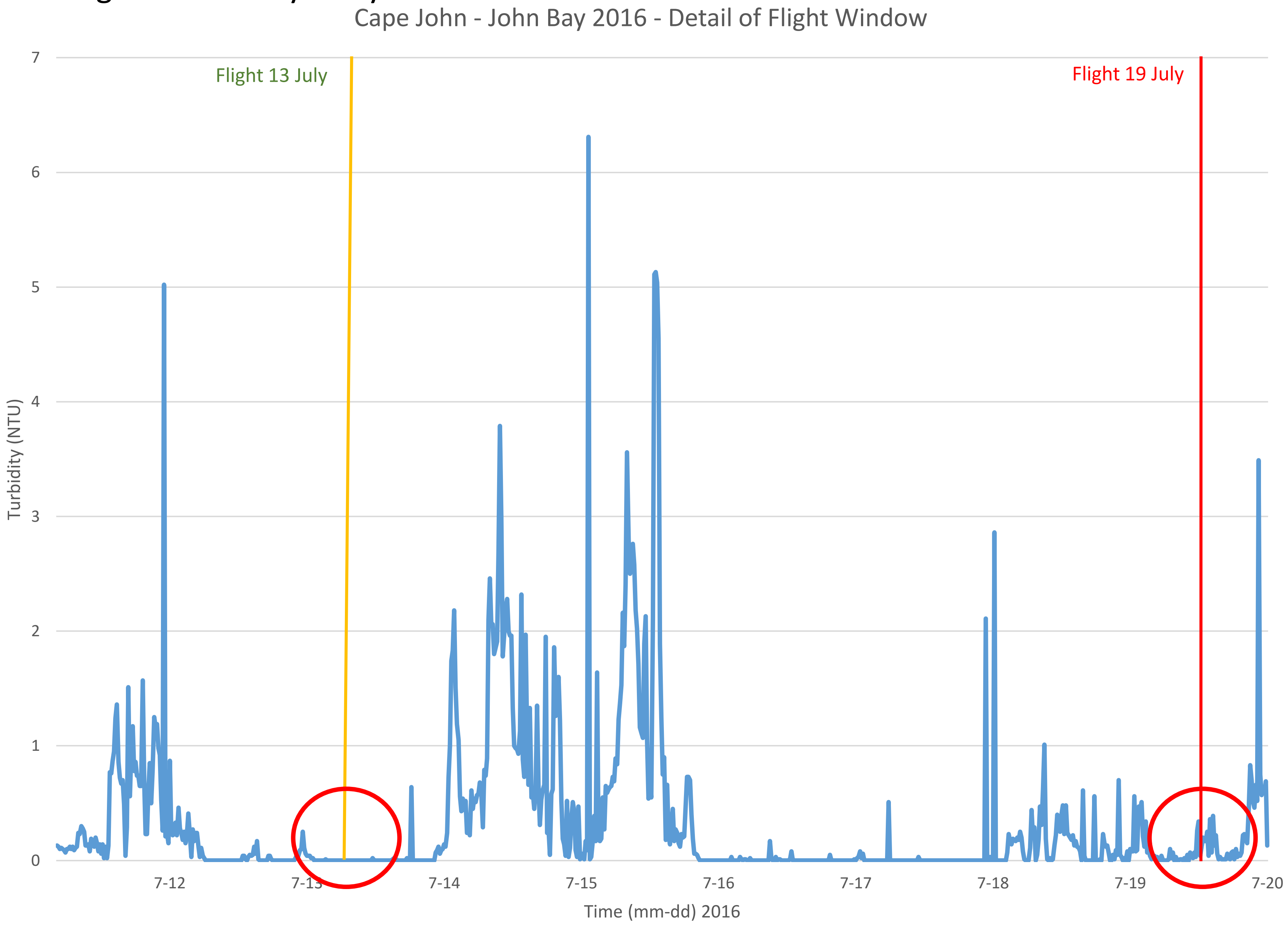

2

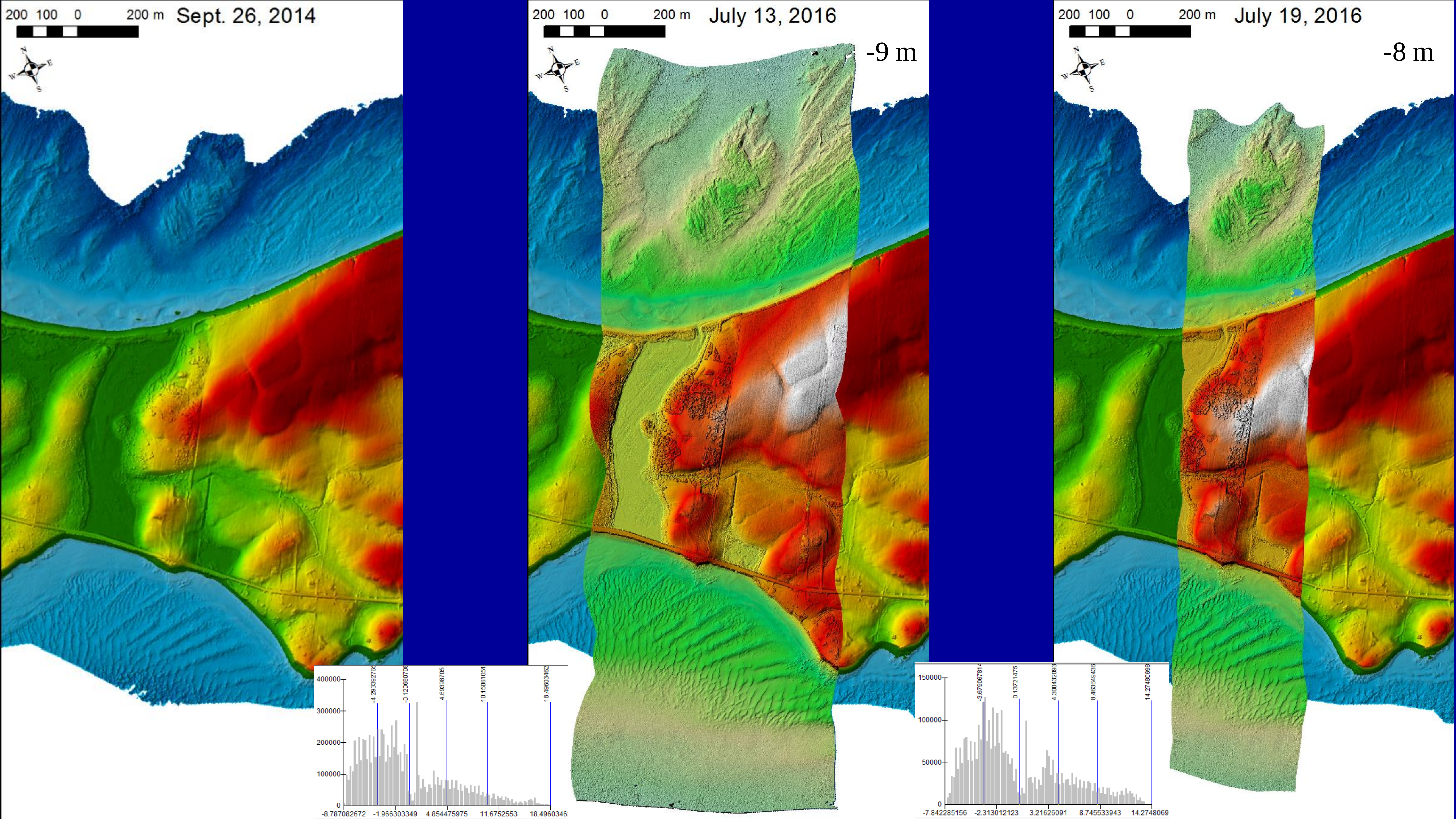

3

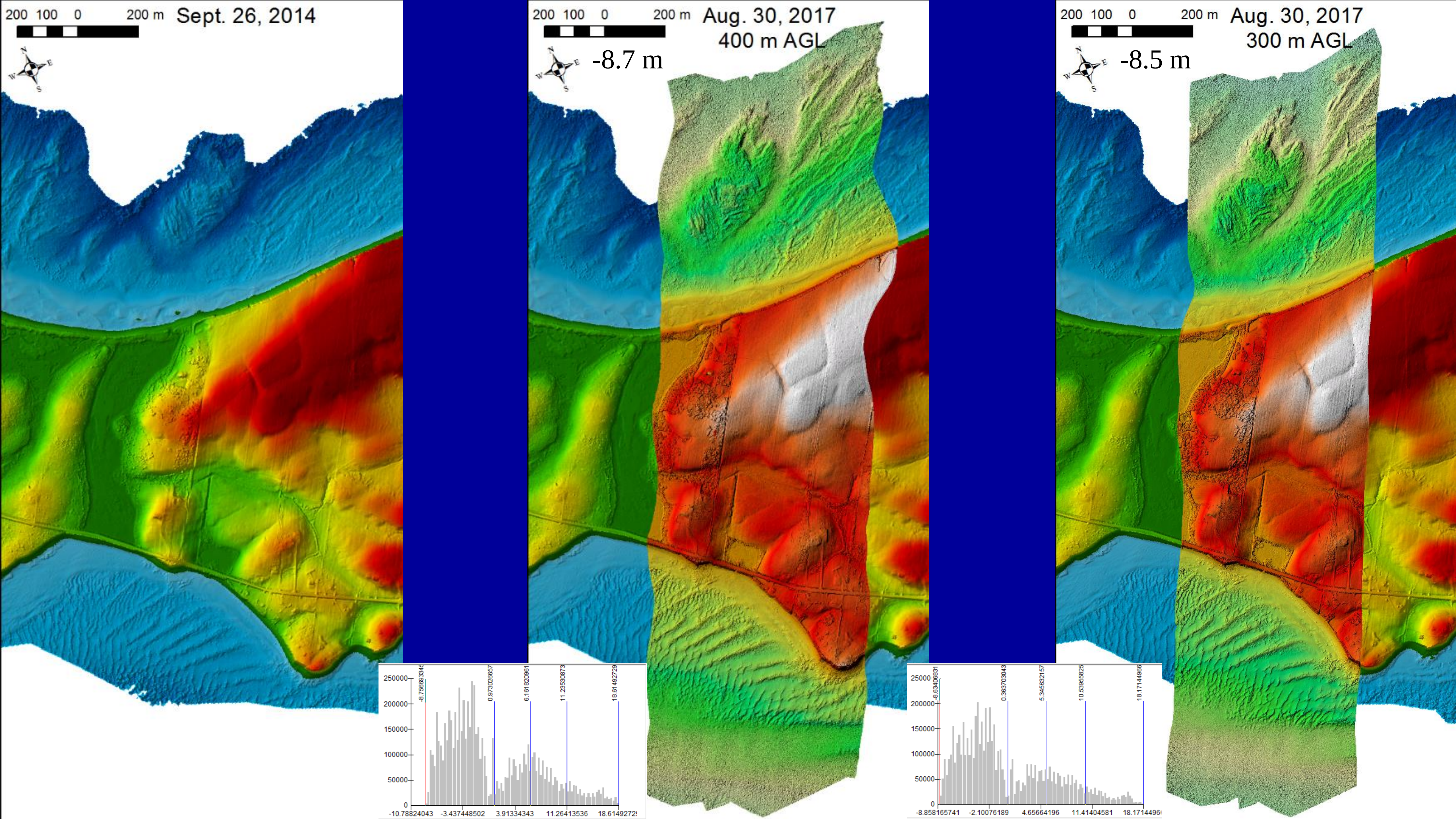

CAPE JOHN
target locations
New Features
~9.4 m
0 0.75 1.5 km


Cape John - John Bay CB50
Turbidity
13th
19th
July 2016
Survey flights
Turbidity (NTU)
16
14
12
10
8
6
4
2
0

2016 Mission utilizing the Turbidity Buoys




200 100 0 200 m
Sept. 26, 2014
200 100 0 200 m
July 13, 2016
-9 m
200 100 0 200 m
July 19, 2016
-8 m
400000
300000
200000
100000
0
-8.787082672 -1.966303349 4.854475975 11.6752553
150000
100000
50000
0
-7.842285156 -2.313012123 3.21626091 8.745533943 14.2748069



200 100 0 200 m
Sept. 26, 2014
N
E
S
W
200 100 0 200 m
Aug. 30, 2017
400 m AGL
-8.7 m
200 100 0 200 m
Aug. 30, 2017
300 m AGL
-8.5 m
250000
200000
150000
100000
50000
0
-8.75669334
0.973026657
6.161820961
11.23530873
18.6149272
-10.78824043
-3.437448502
3.91334343
11.26413536
18.6149272
25000
200000
150000
100000
50000
0
-8.63406831
0.363703043
5.345632157
10.53955825
18.1714496
-8.858165741
-2.10076189
4.65664196
11.41404581
18.1714496

Point Densities at 300m and 400m Altitude

	Nominal Point Density (pt/m²)		
300m Altitude Data Collection	**Single Line**	**Overlap**	**Double Overlap**
Bathymetry Points	2.1	3.6	6.5
Topo + Bathy Laser (Ground Points)	33.8	56.4	112.7
Topo Laser Only (Ground Points)	29.0	55.6	97.9

400m Altitude Data Collection	**Single Line**	**Overlap**	**Double Overlap**
Bathymetry Points	1.6	3.1	4.9
Topo + Bathy Laser (Ground Points)	20.6	47.4	80.9
Topo Laser Only (Ground Points)	19.3	46.7	79.9

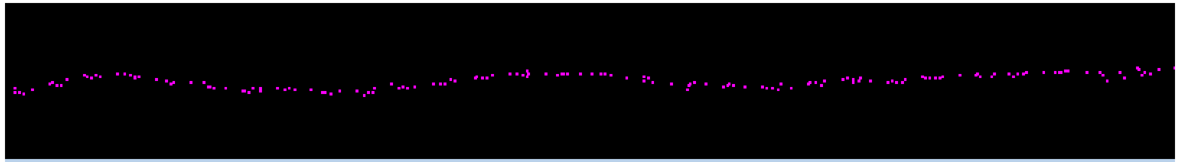
Point density increased on average of approximately 20% at 300 metre altitude over 400 metres.

Point Cloud gridded to 50cm resolution

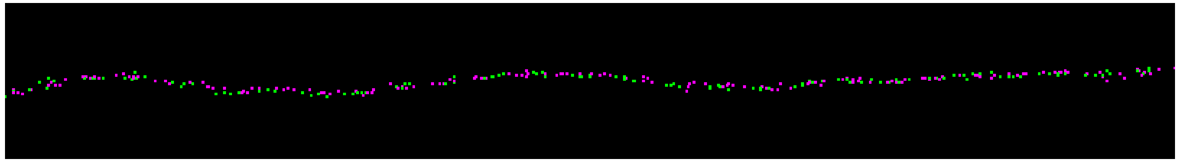
400m Single Flightline

400m Overlapping Flightlines

50m



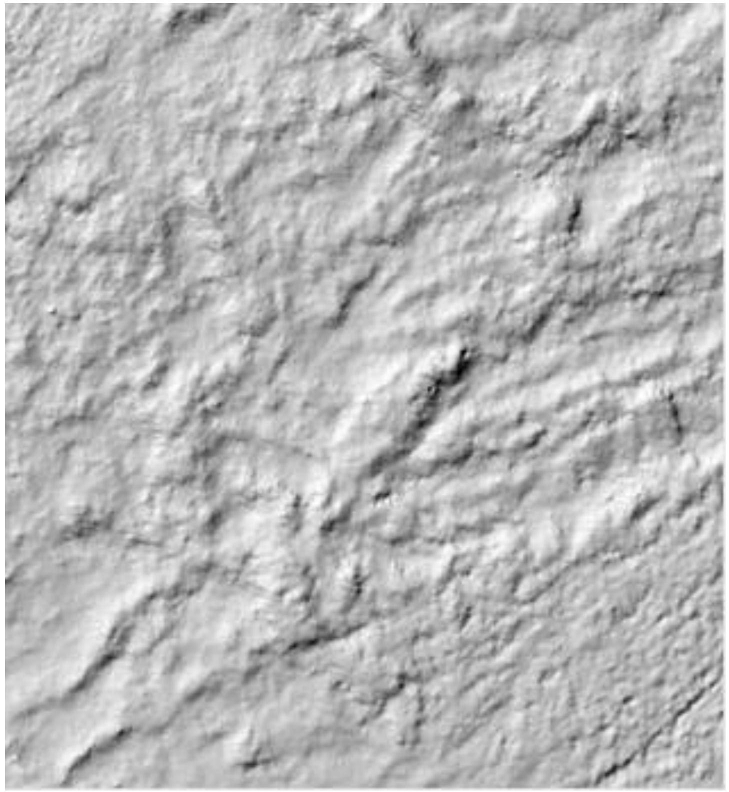
400m Single Flightline



400m Overlapping Flightlines

10m

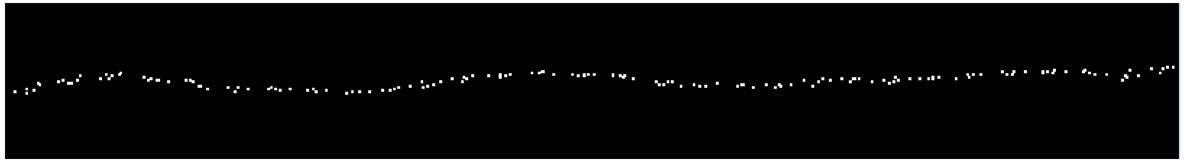
Point Cloud gridded to 50cm resolution



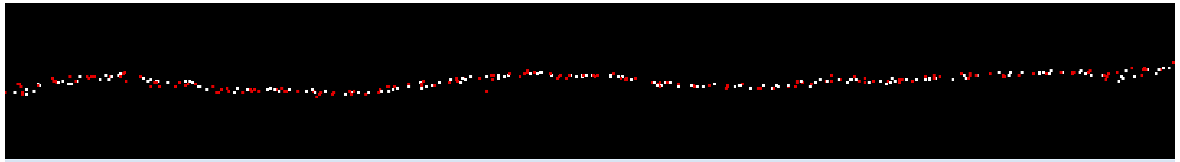
300m Single Flightline

300m Overlapping Flightlines

50m



300m Single Flightline



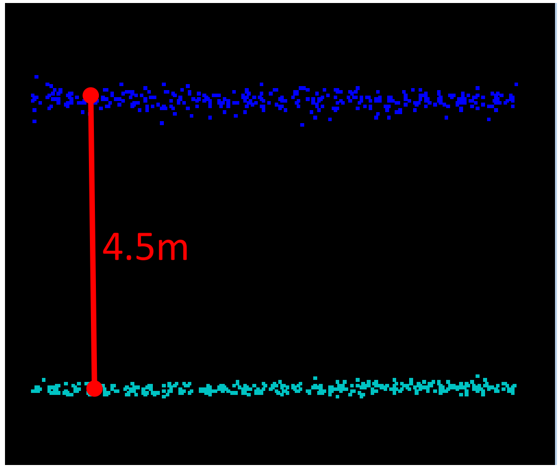
300m Overlapping Flightlines

10m

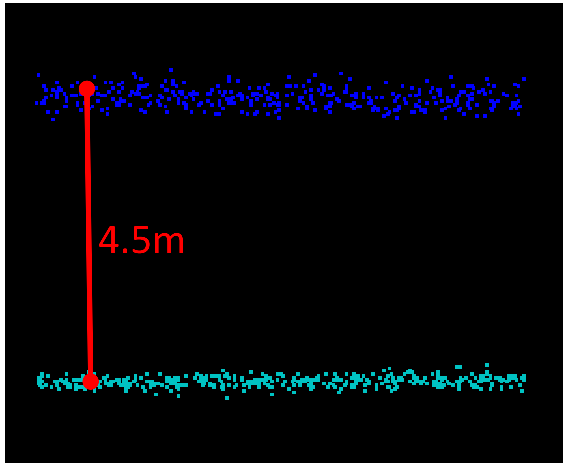
400 m 60% overlap

300 m 60% overlap

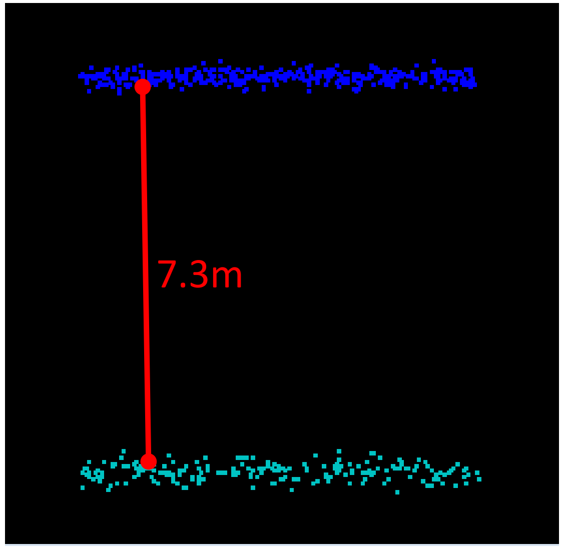
Bathymetry Standard Deviation vs AGL & Depth



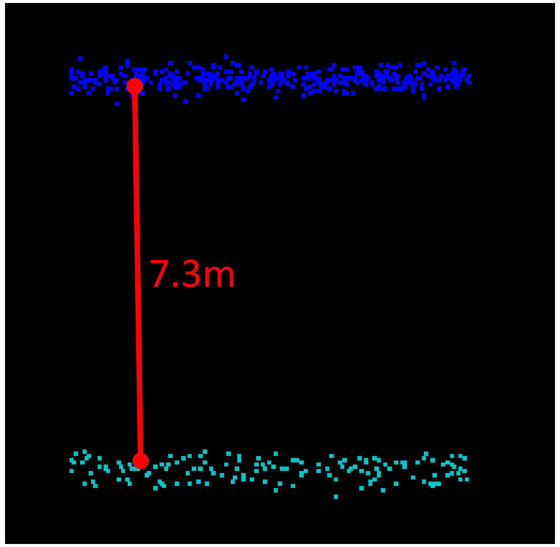
300m at depth of 4.5m:
368 Pts**, St Dev 0.07**
Bottom points



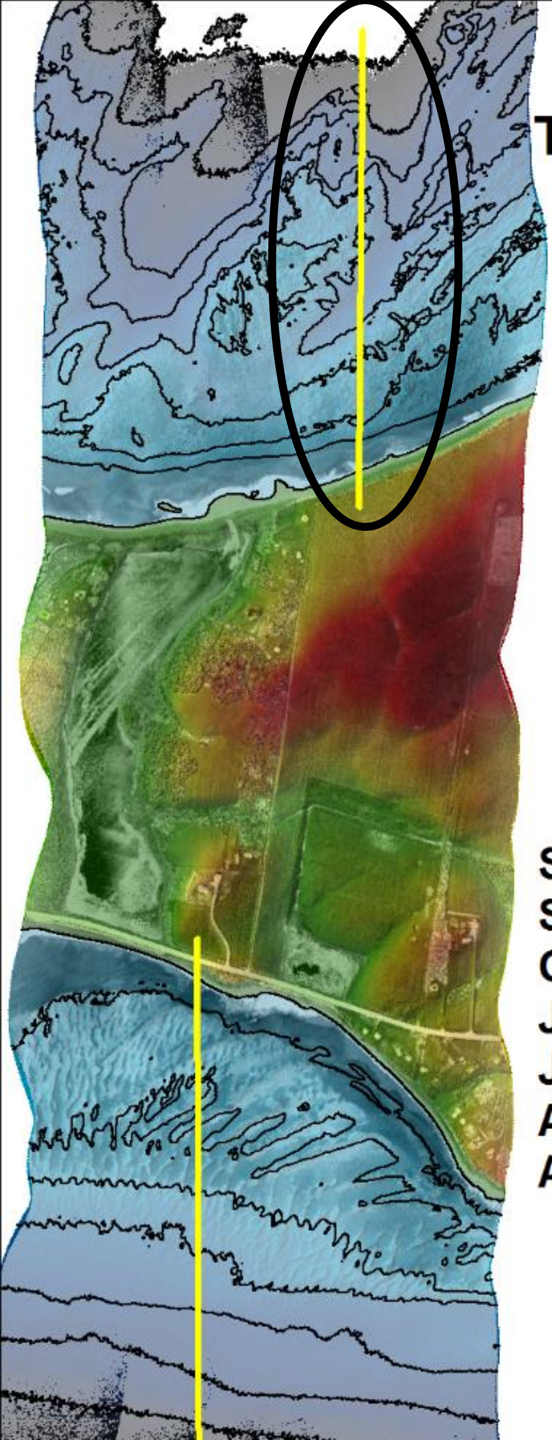
400m at depth of 4.5m:
385 Pts, **St Dev 0.10**
Bottom points



300m at depth of 7.3m:
209 Pts, **St Dev 0.20**
Bottom points



400m at depth of 7.3m:
155 Pts, **St Dev 0.25**
Bottom points



Cape John Topo-Bathymetric testing area

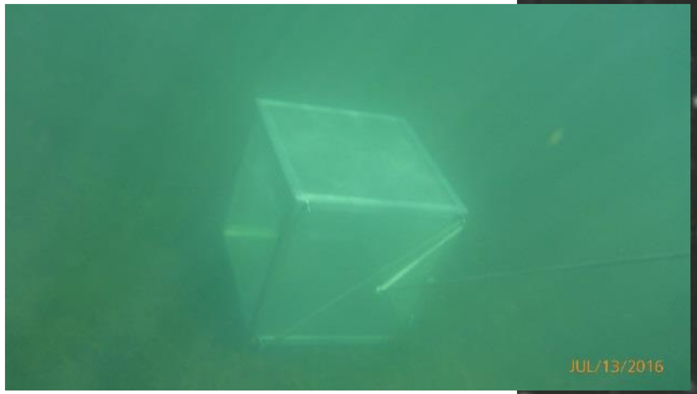
200100 0 200 m

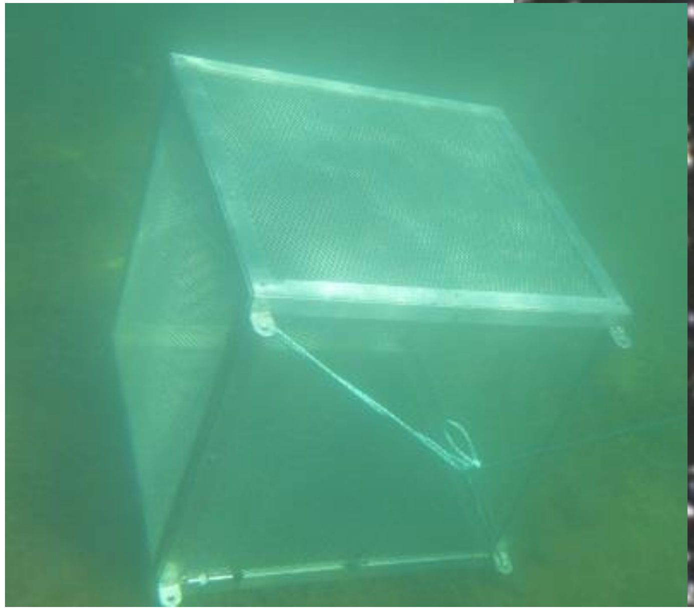
Legend

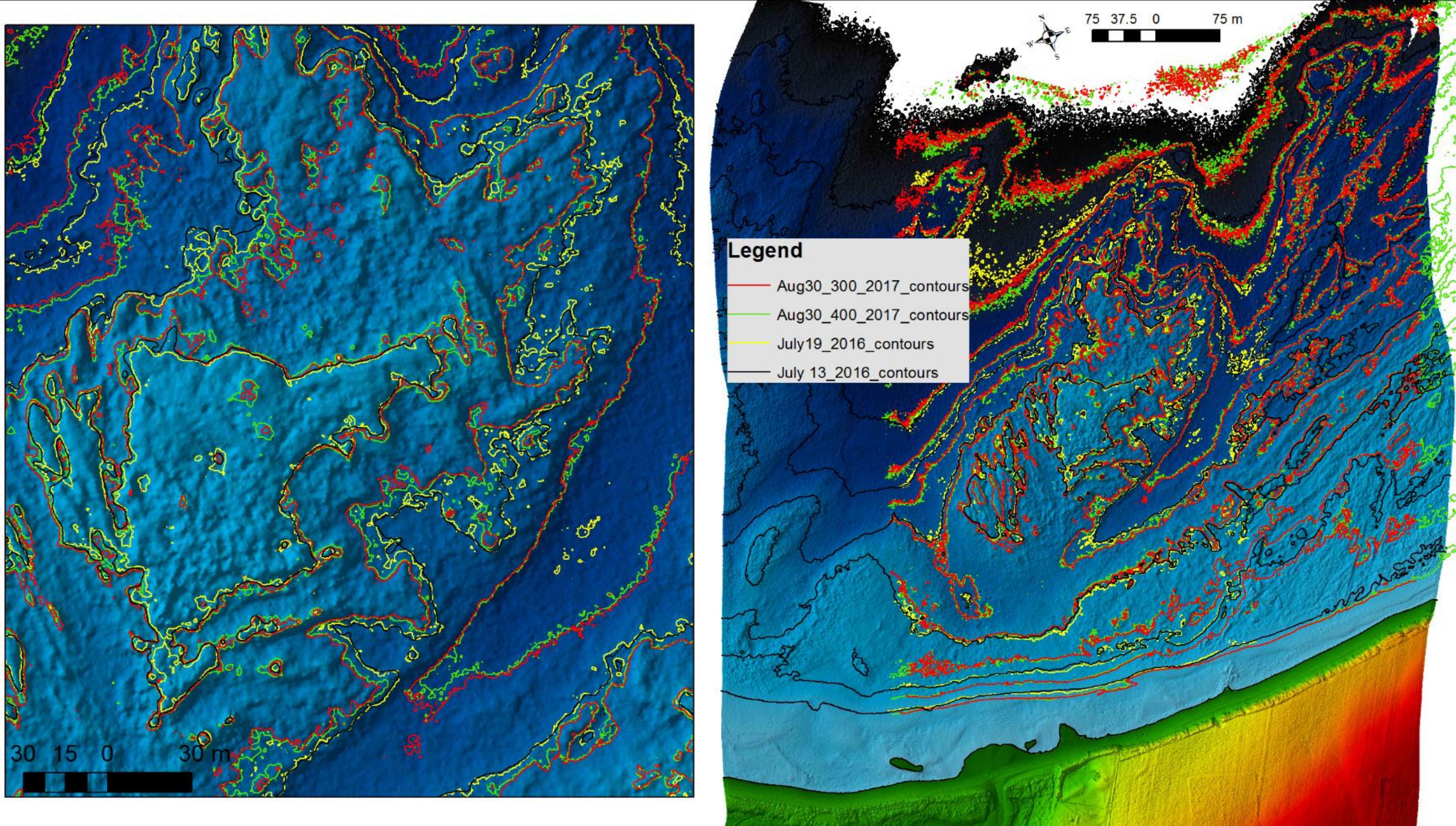
N_Profile

S_Profile

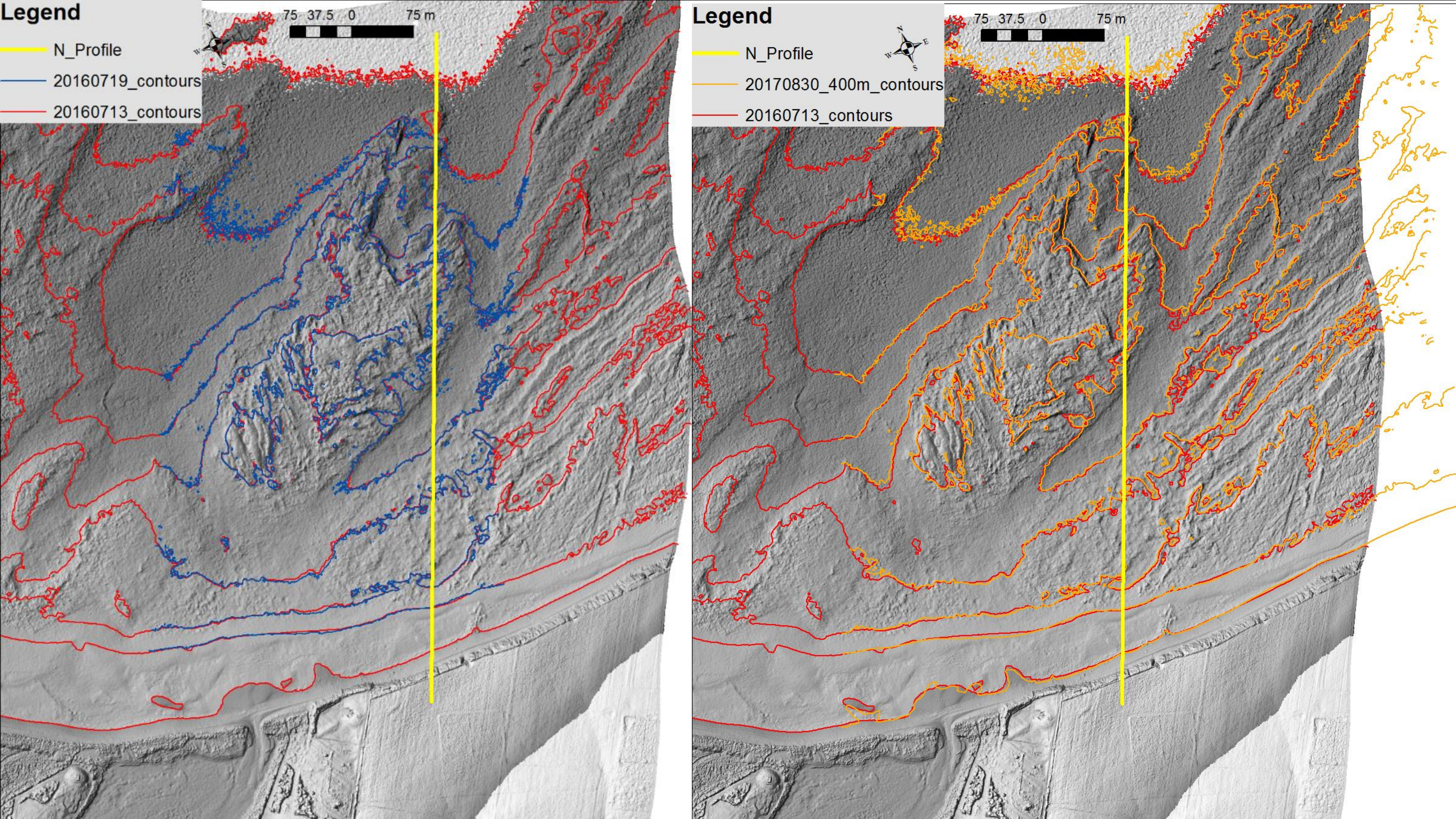
Surveys conducted
Sept. 26, 2014, 400 m 30%
Oct. 28, 2015, 400 m 30%
July 13, 2016, 400 m 30%
July 19, 2016, 400 m 30%
Aug. 30, 2017, 400 m, 60%
Aug. 30, 2017, 300 m, 60%

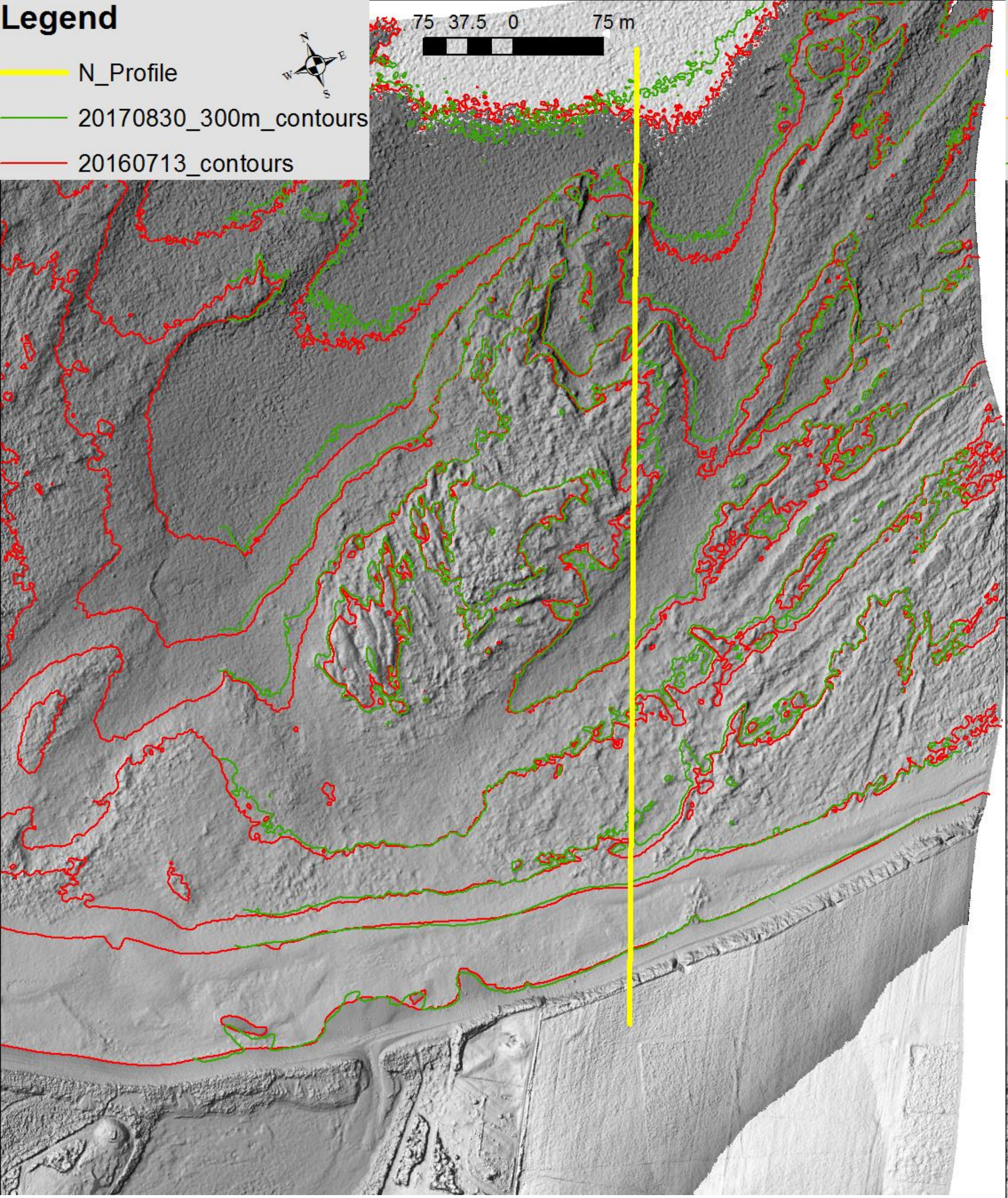
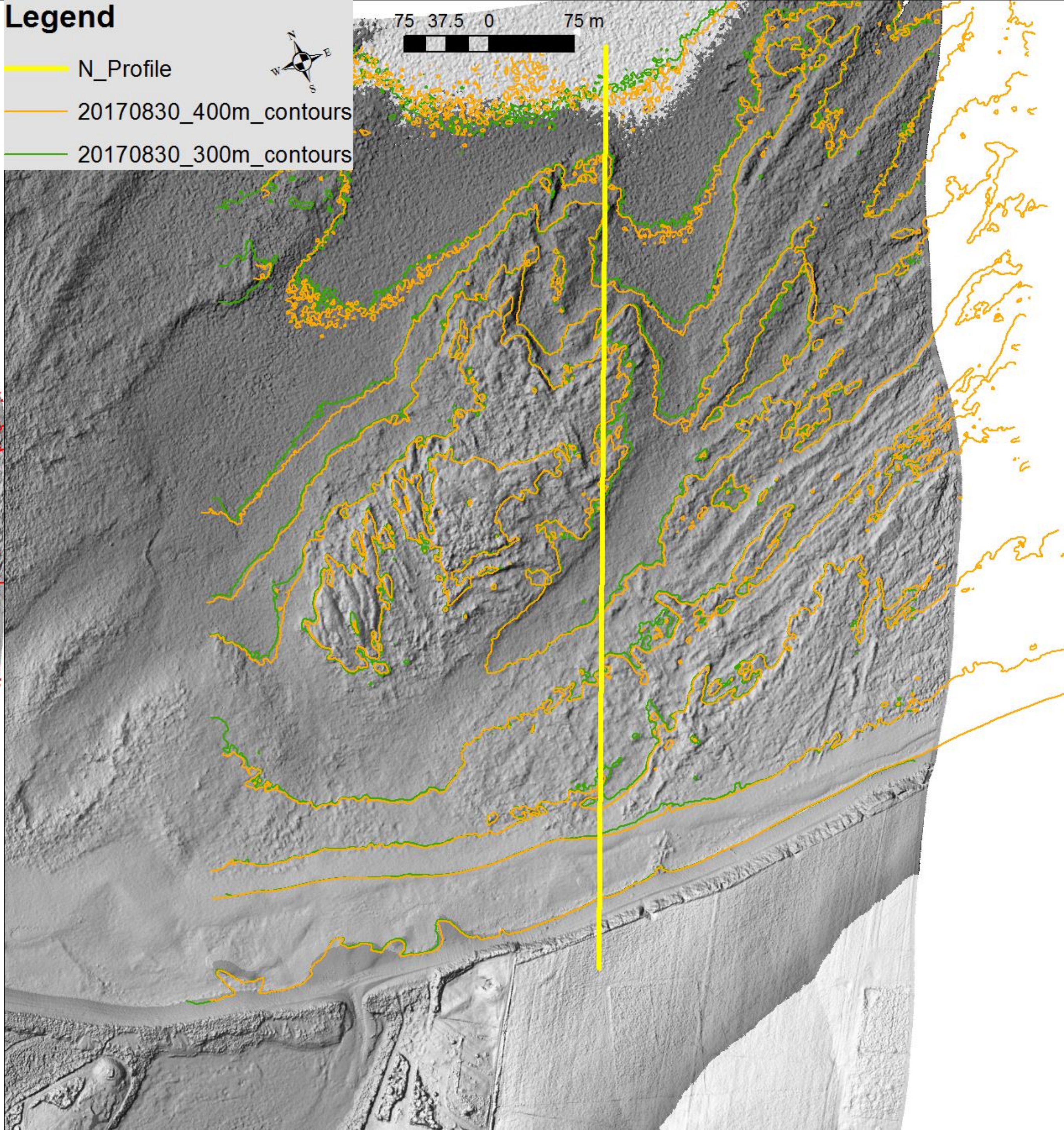


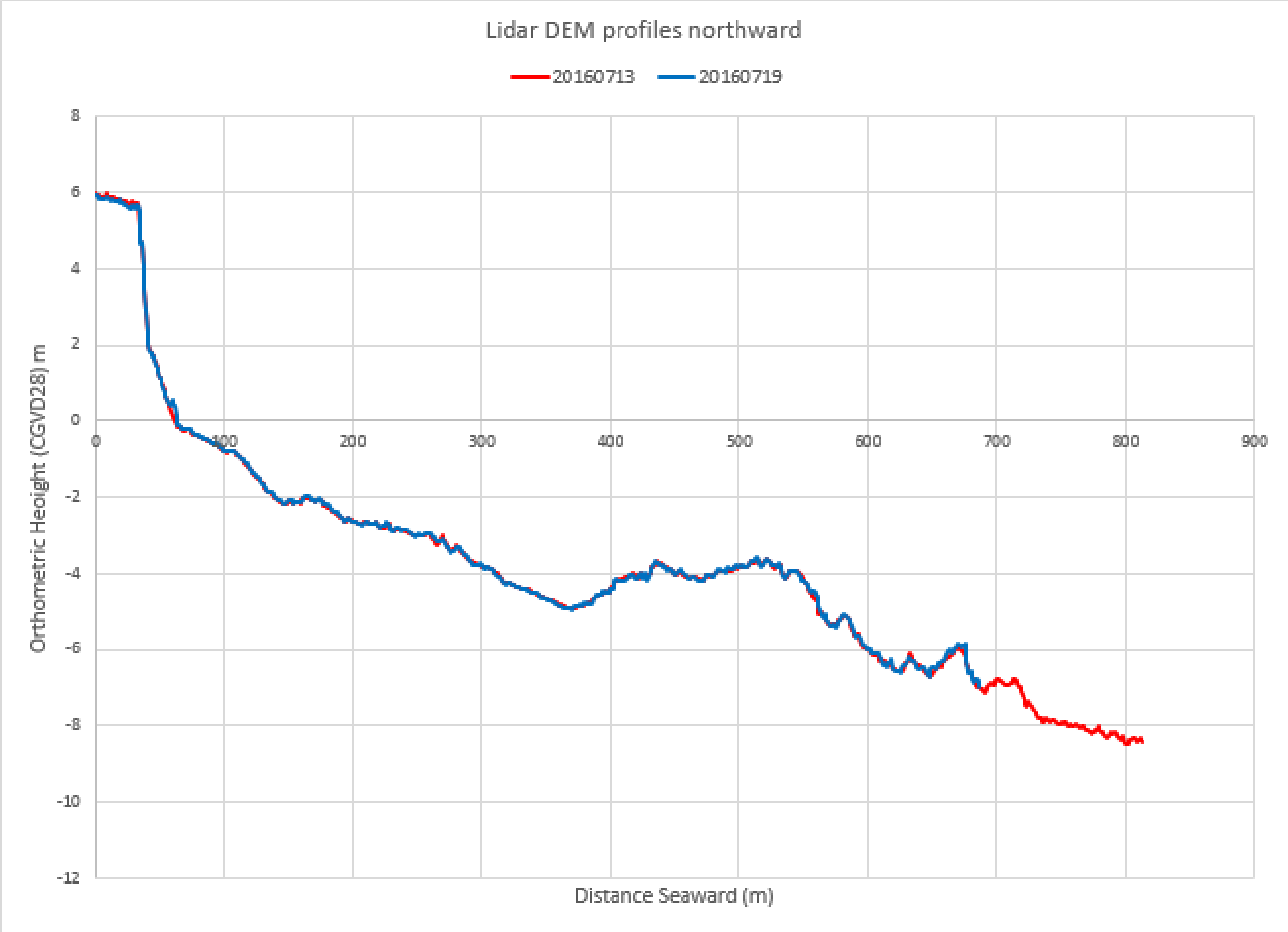


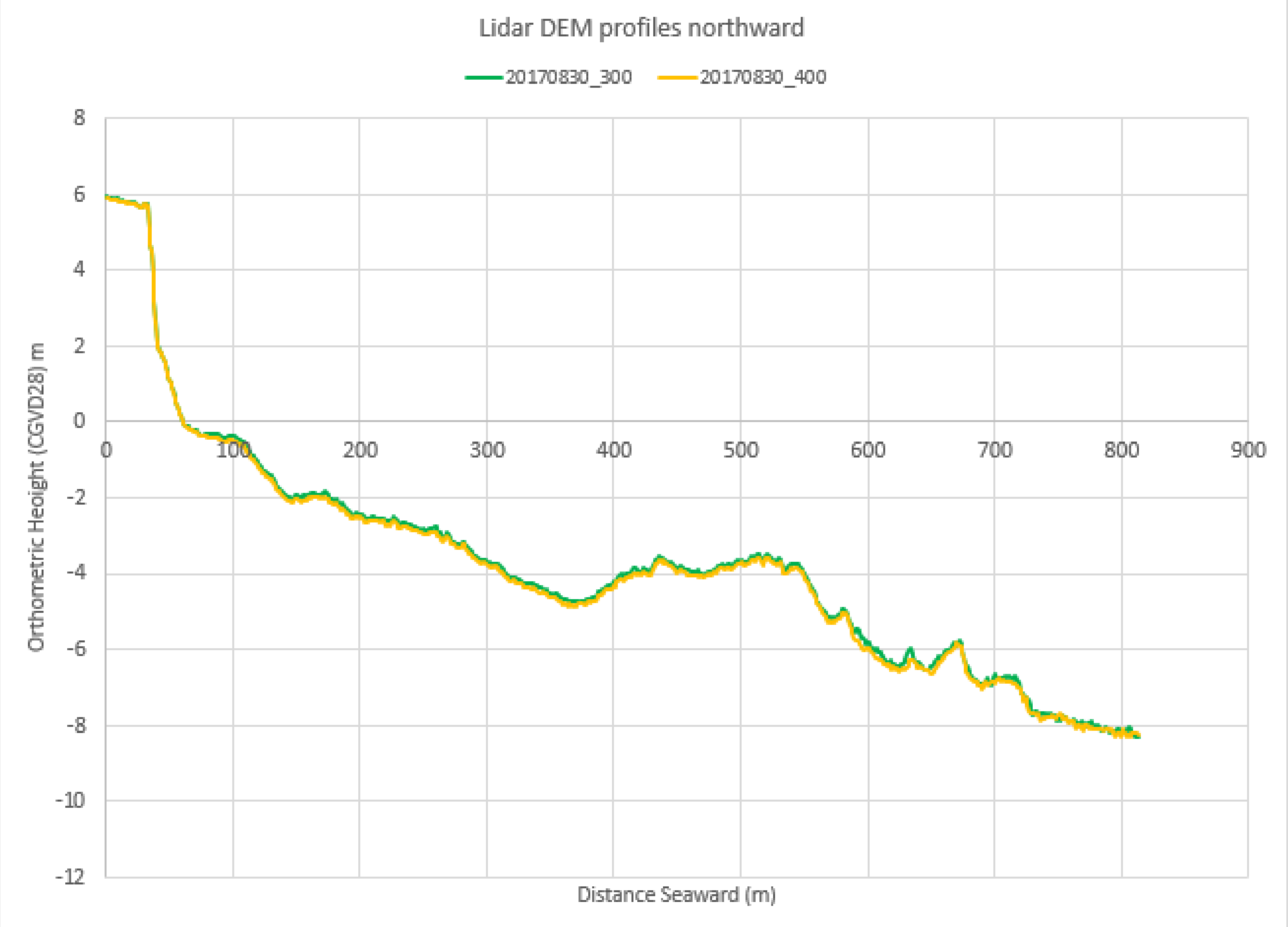


30 15 0 30 m
75 37.5 0 75 m
N
E
S
W
Legend
Aug30_300_2017_contours
Aug30_400_2017_contours
July19_2016_contours
July 13_2016_contours

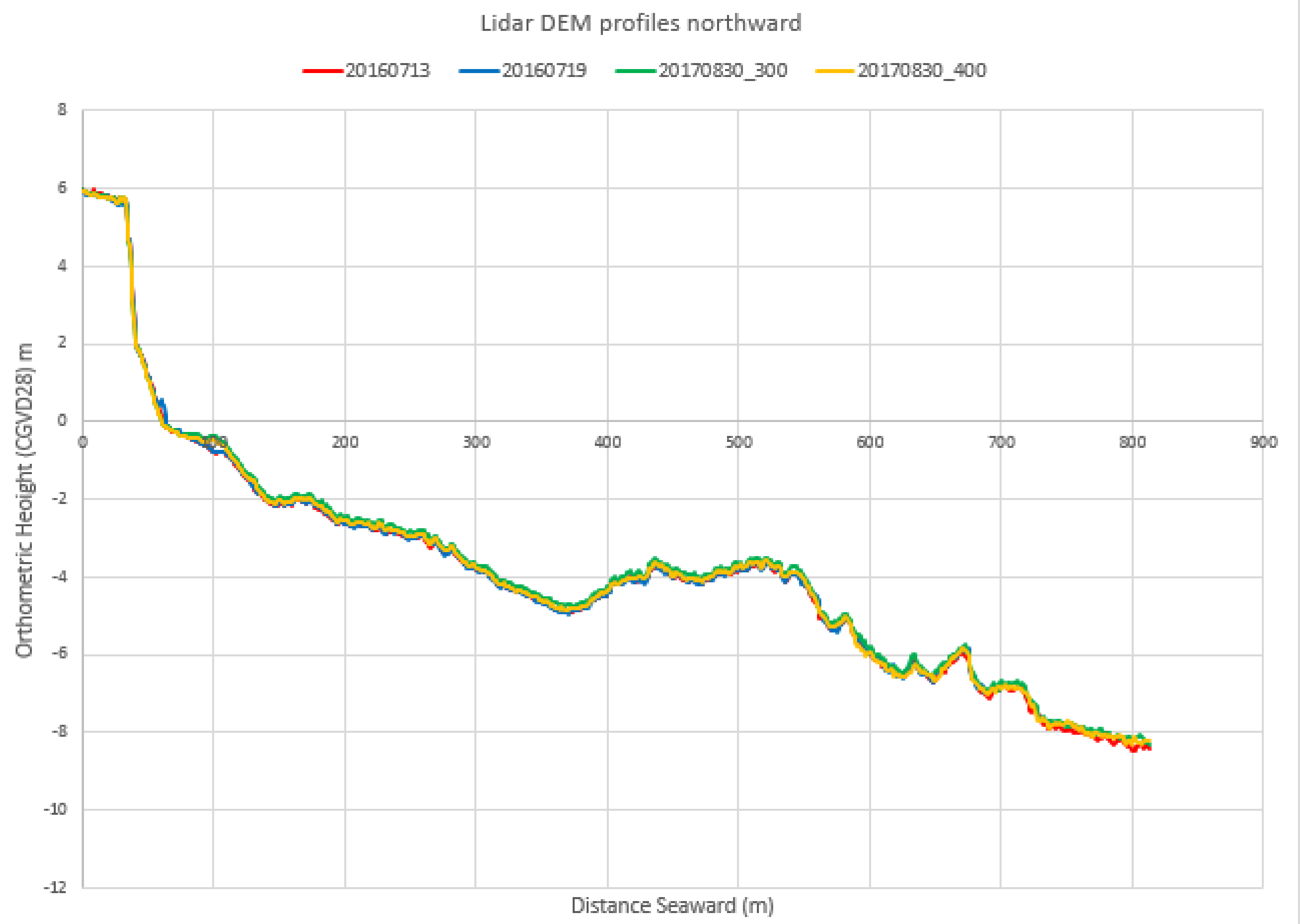

Legend
N_Profile
20160719_contours
20160713_contours
75 37.5 0 75 m
Legend
N_Profile
20170830_400m_contours
20160713_contours
75 37.5 0 75 m


Legend
N_Profile
20170830_300m_contours
20160713_contours
75 37.5 0 75 m

Legend
N_Profile
20170830_400m_contours
20170830_300m_contours
75 37.5 0 75 m

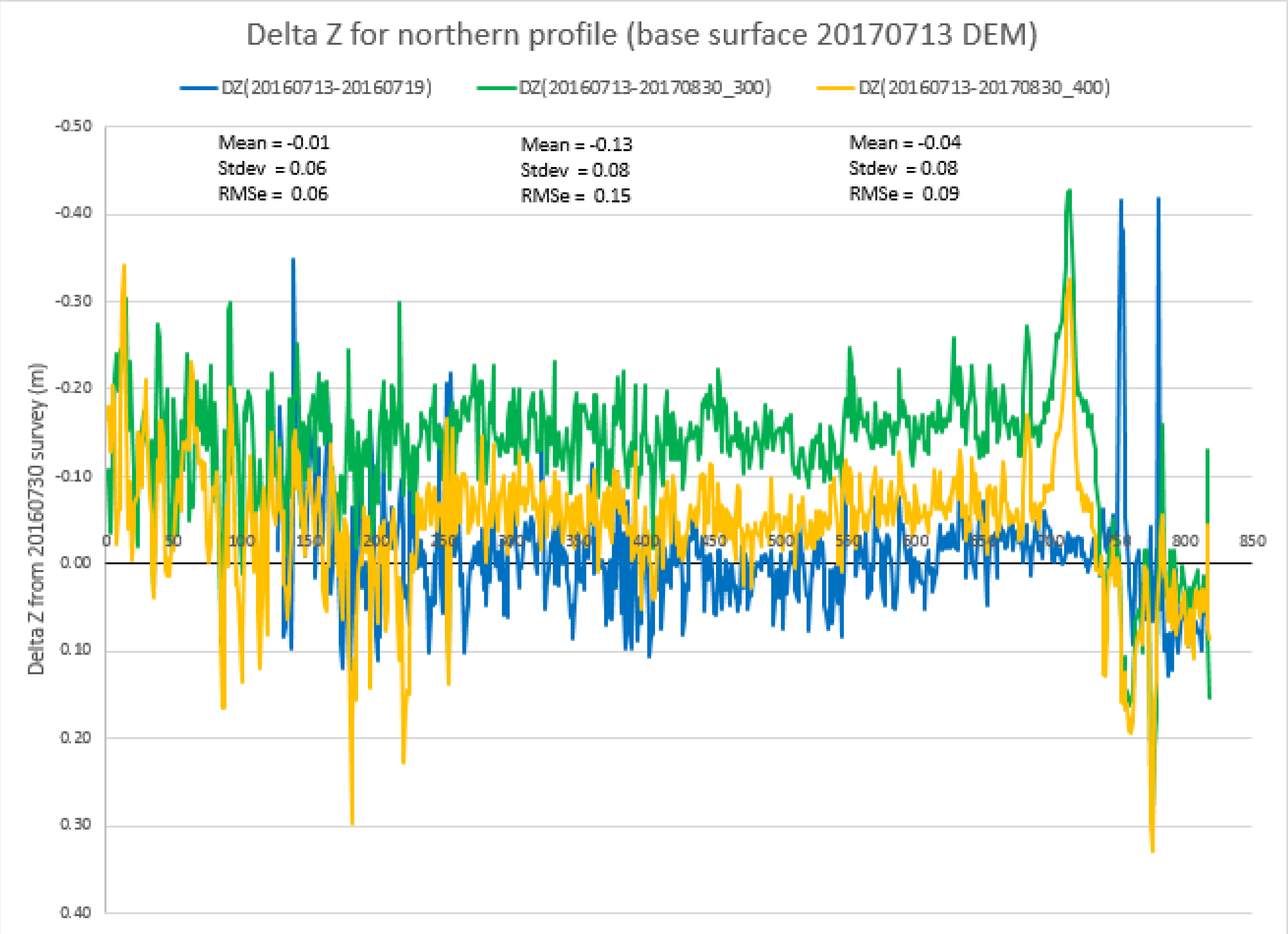

Lidar DEM profiles northward
20160713
20160719
Orthometric Height (CGVD28) m
Distance Seaward (m)
8
6
4
2
0
-2
-4
-6
-8
-10
-12
0
100
200
300
400
500
600
700
800
900



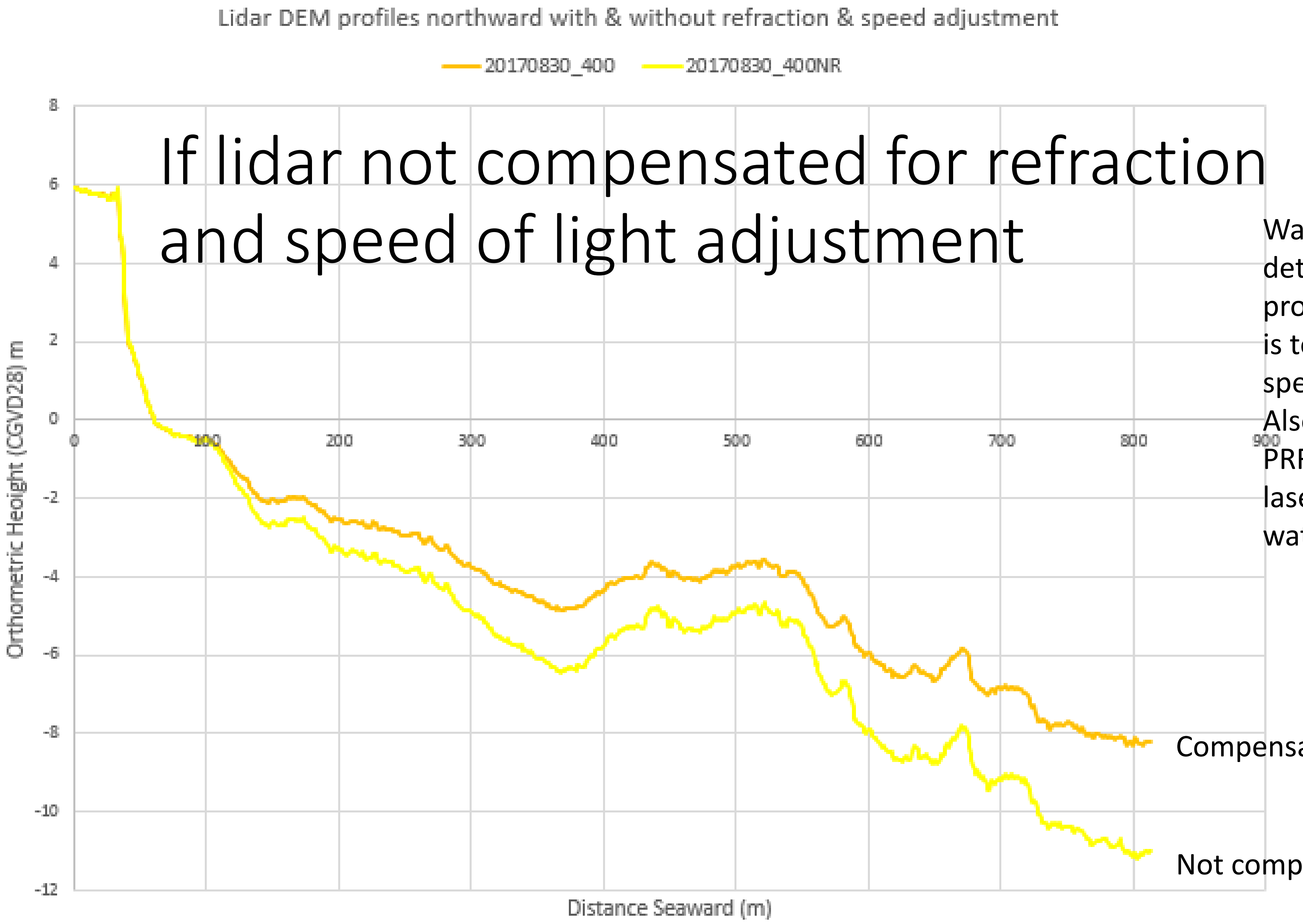
Lidar DEM profiles northward
20170830_300
20170830_400
Orthometric Height (CGVD28) m
Distance Seaward (m)
8
6
4
2
0
-2
-4
-6
-8
-10
-12
0
100
200
300
400
500
600
700
800
900



Lidar DEM profiles northward
20160713
20160719
20170830_300
20170830_400
8
6
4
2
0
-2
-4
-6
-8
-10
-12
0
100
200
300
400
500
600
700
800
900
Orthometric Height (CGVD28) m
Distance Seaward (m)


Delta Z for northern profile (base surface 20170713 DEM)
DZ(20160713-20160719)
DZ(20160713-20170830_300)
DZ(20160713-20170830_400)
Mean = -0.01
Stdev = 0.06
RMSe = 0.06
Mean = -0.13
Stdev = 0.08
RMSe = 0.15
Mean = -0.04
Stdev = 0.08
RMSe = 0.09
Delta Z from 20160730 survey (m)
-0.50
-0.40
-0.30
-0.20
-0.10
0.00
0.10
0.20
0.30
0.40
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850

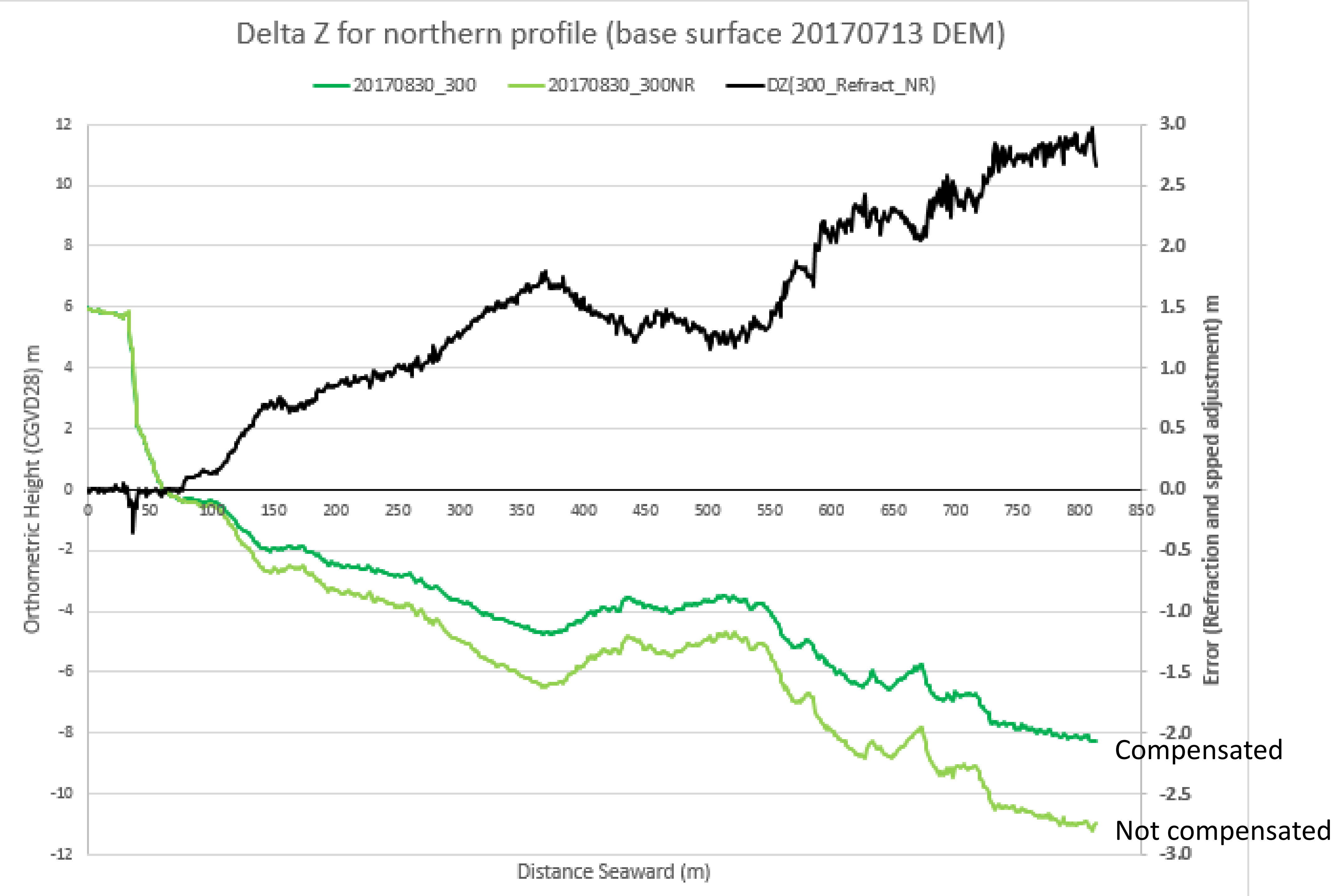
If lidar not compensated for refraction and speed of light adjustment



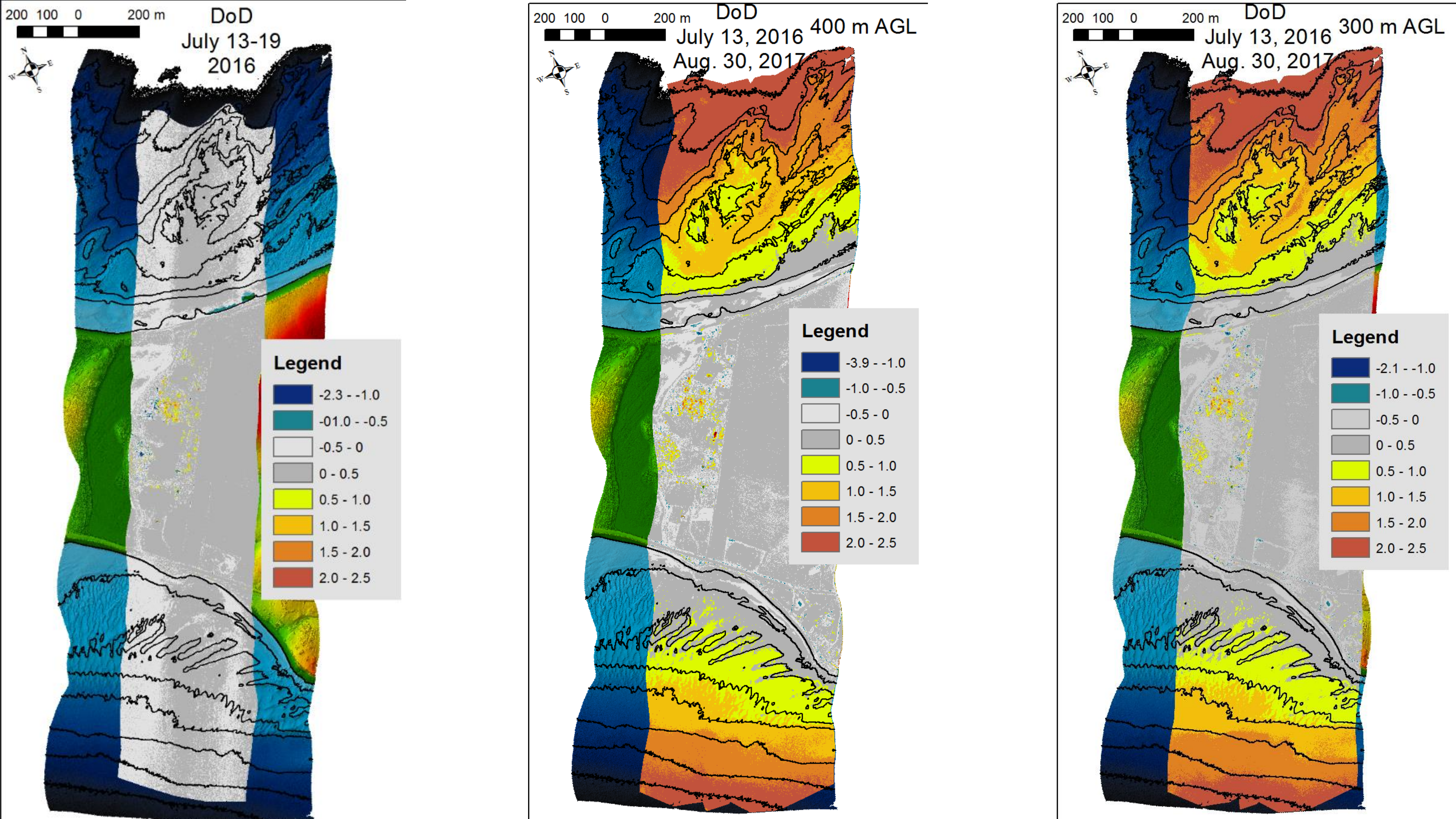
Compensated

Not compensated

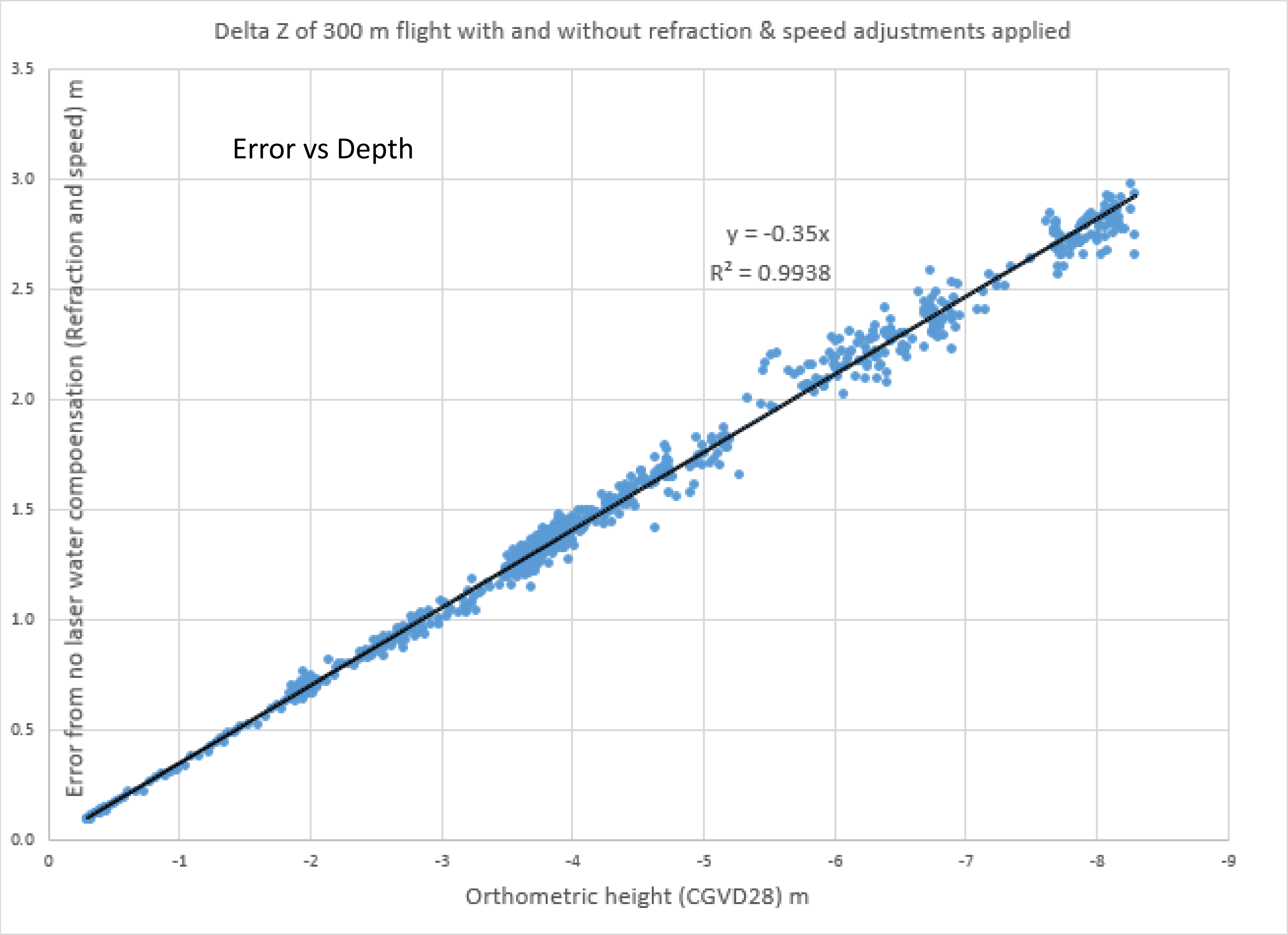
Water surface detection can be a problem if the water is too calm – flat specular reflector. Also have to monitor PRF & gain of the NIR laser, to ensure water surface returns



Delta Z for northern profile (base surface 20170713 DEM)
20170830_300
20170830_300NR
DZ(300_Refract_NR)
Orthometric Height (CGVD28) m
Error (Refraction and spped adjustment) m
Distance Seaward (m)
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
Compensated
Not compensated



200 100 0 200 m
DoD
July 13-19
2016
Legend
-2.3 - -1.0
-01.0 - -0.5
-0.5 - 0
0 - 0.5
0.5 - 1.0
1.0 - 1.5
1.5 - 2.0
2.0 - 2.5
200 100 0 200 m
DoD
July 13, 2016
Aug. 30, 2017
400 m AGL
Legend
-3.9 - -1.0
-1.0 - -0.5
-0.5 - 0
0 - 0.5
0.5 - 1.0
1.0 - 1.5
1.5 - 2.0
2.0 - 2.5
200 100 0 200 m
DoD
July 13, 2016
Aug. 30, 2017
300 m AGL
Legend
-2.1 - -1.0
-1.0 - -0.5
-0.5 - 0
0 - 0.5
0.5 - 1.0
1.0 - 1.5
1.5 - 2.0
2.0 - 2.5



Delta Z of 300 m flight with and without refraction & speed adjustments applied
Error vs Depth
y = -0.35x
R² = 0.9938
Error from no laser water componensation (Refraction and speed) m
Orthometric height (CGVD28) m
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
-1
-2
-3
-4
-5
-6
-7
-8
-9

Detecting Submerged Features

1m Metal Cubes placed within Survey Area

1m Metal Cubes as seen in Airborne Imagery

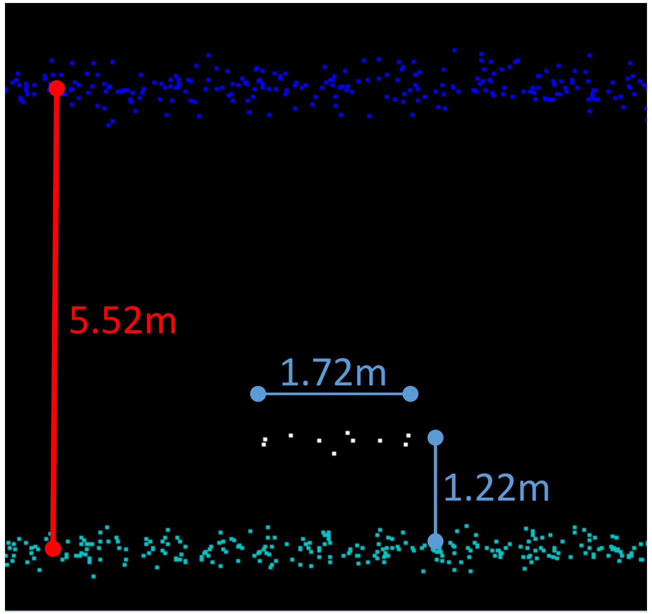
400m Altitude

300m Altitude

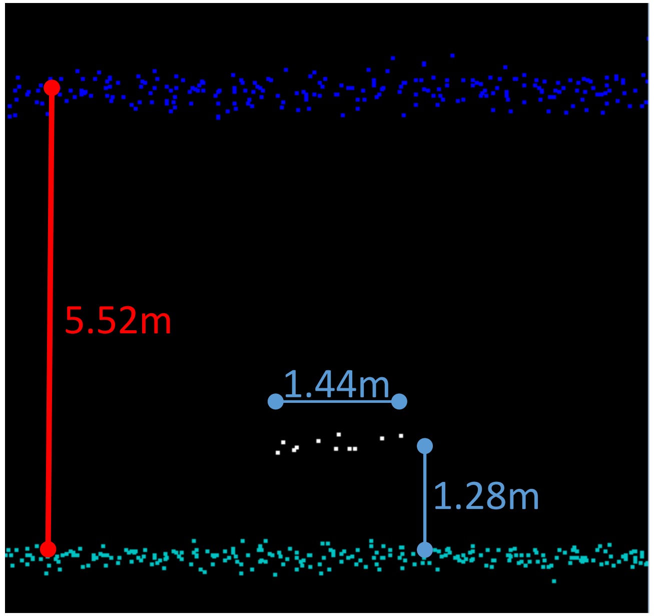
1m Metal Cubes in the Point Cloud:

Number of detected returns and effect of beam divergence on point distribution

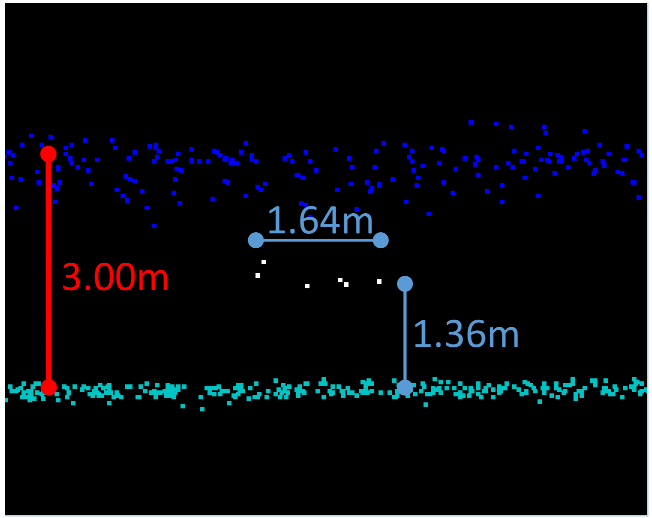
Light scattering with depth + beam divergence



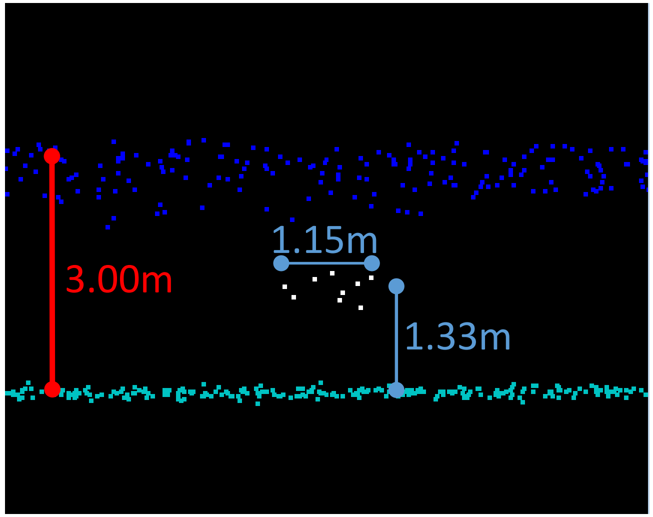
400m altitude: 10 returns from three flightlines (3, 4, and 3 returns on each pass)



300m altitude: 11 returns from two flightlines (4 and 7 returns on each pass)

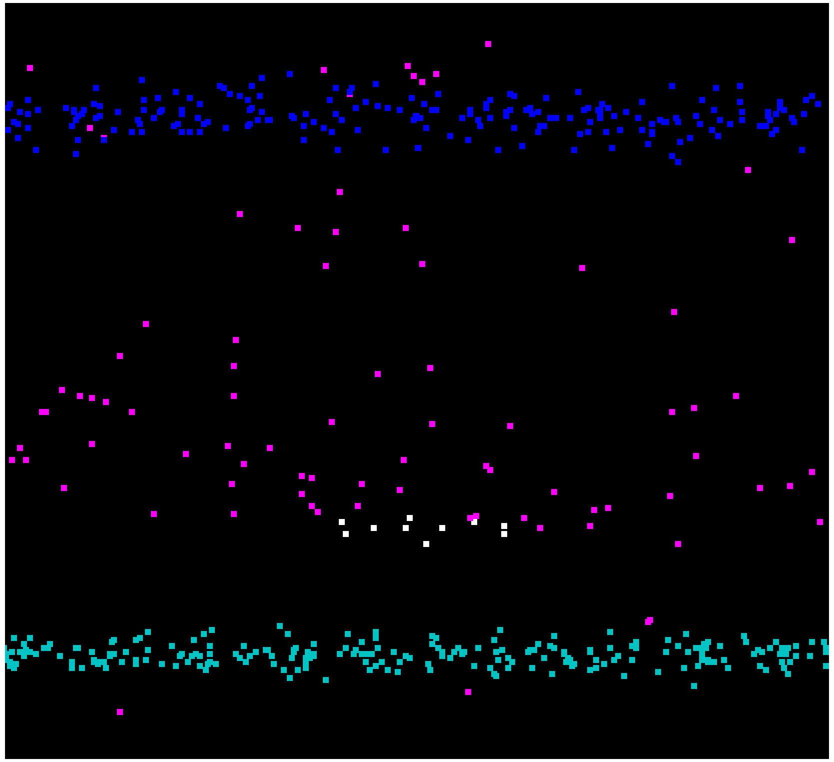


400m altitude: 6 returns from three flightlines (2, 2, and 2 returns on each pass)

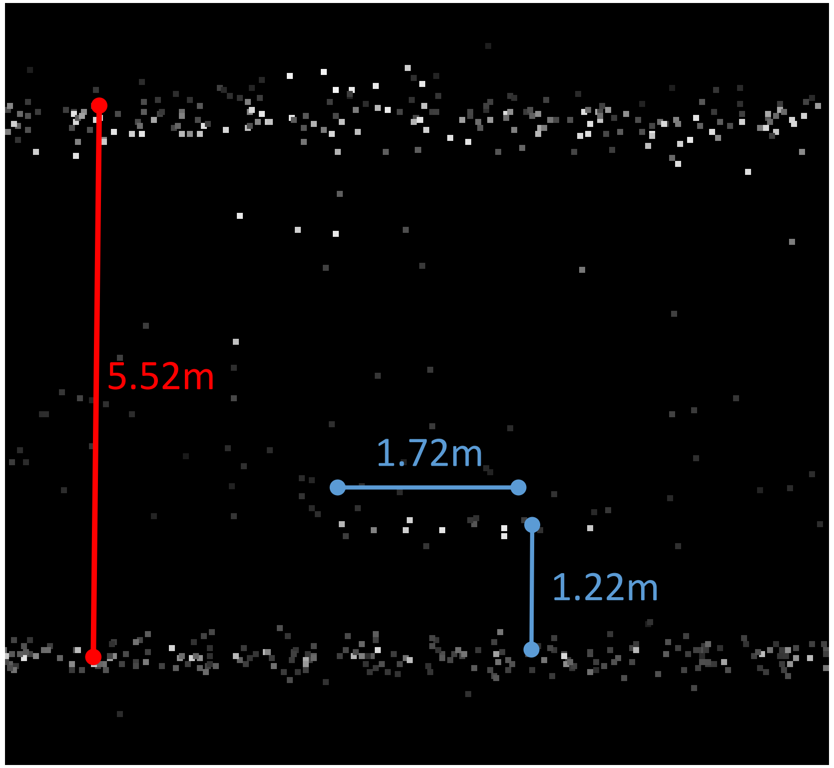


300m altitude: 9 returns from two flightlines (5 and 4 returns on each pass)

Classification of Submerged Features
Strength or Amplitude-Intensity of the Returns

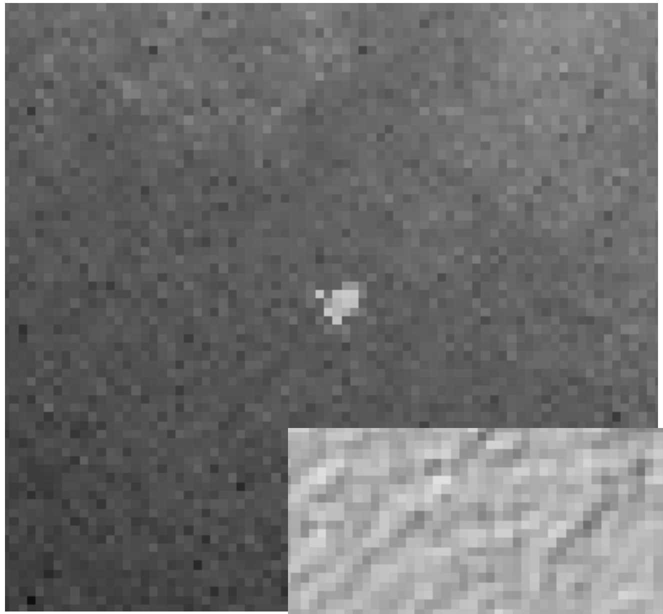


Spatially points returned off the 1m Metal Cube are indistinguishable from the surrounding water column noise

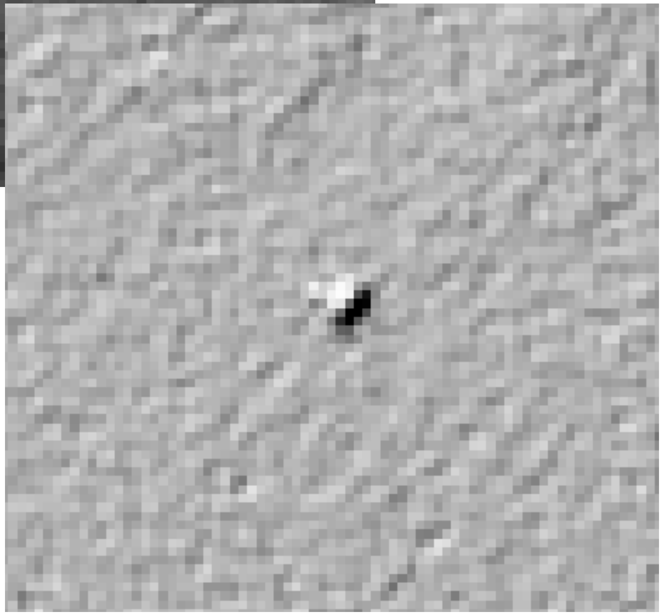


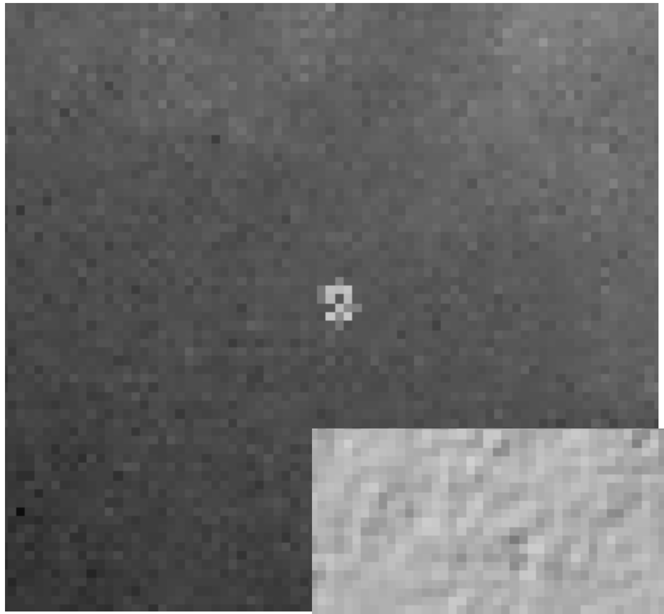
However, **intensity of these returns are much higher than the surrounding water column noise**. This noise can be filter out using intensity thresholds

1m Metal Cubes in gridded surface (50cm resolution), 5m depth

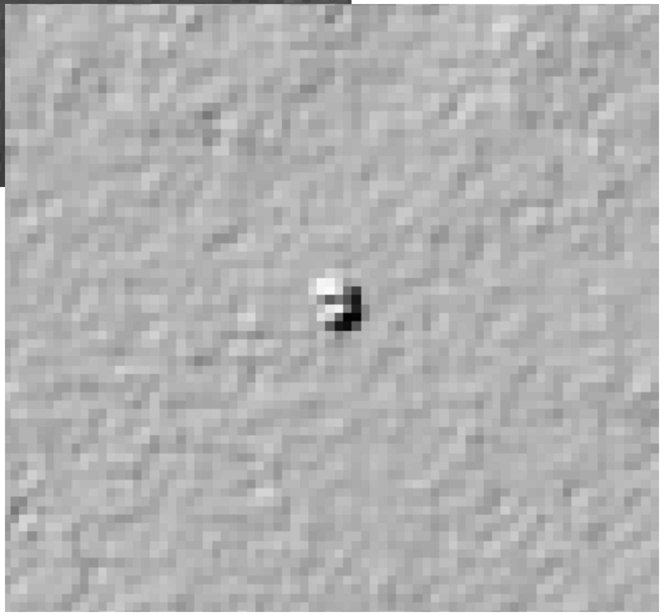


Intensity
Bathymetry & Cubes





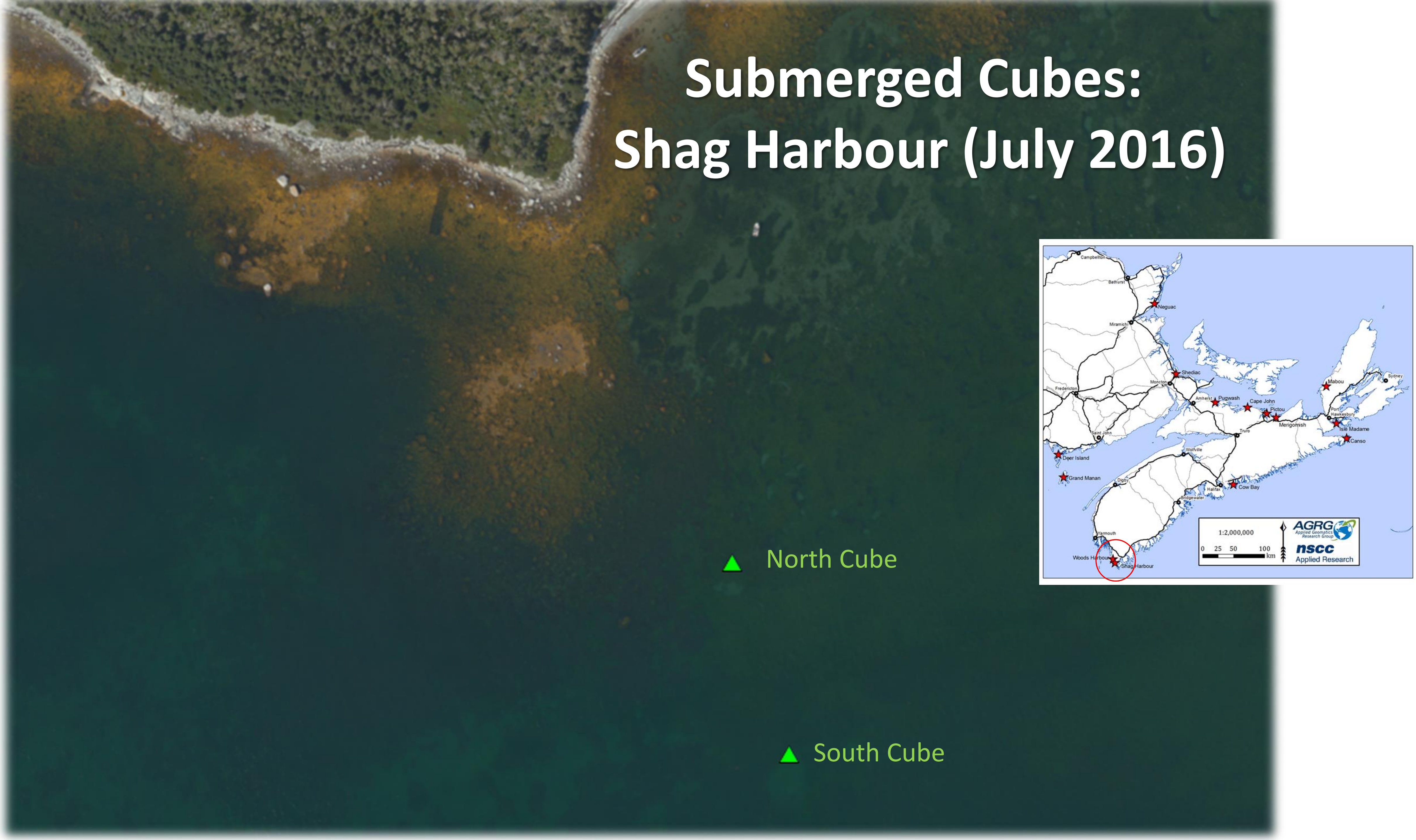
Hill Shade
Bathymetry & Cubes

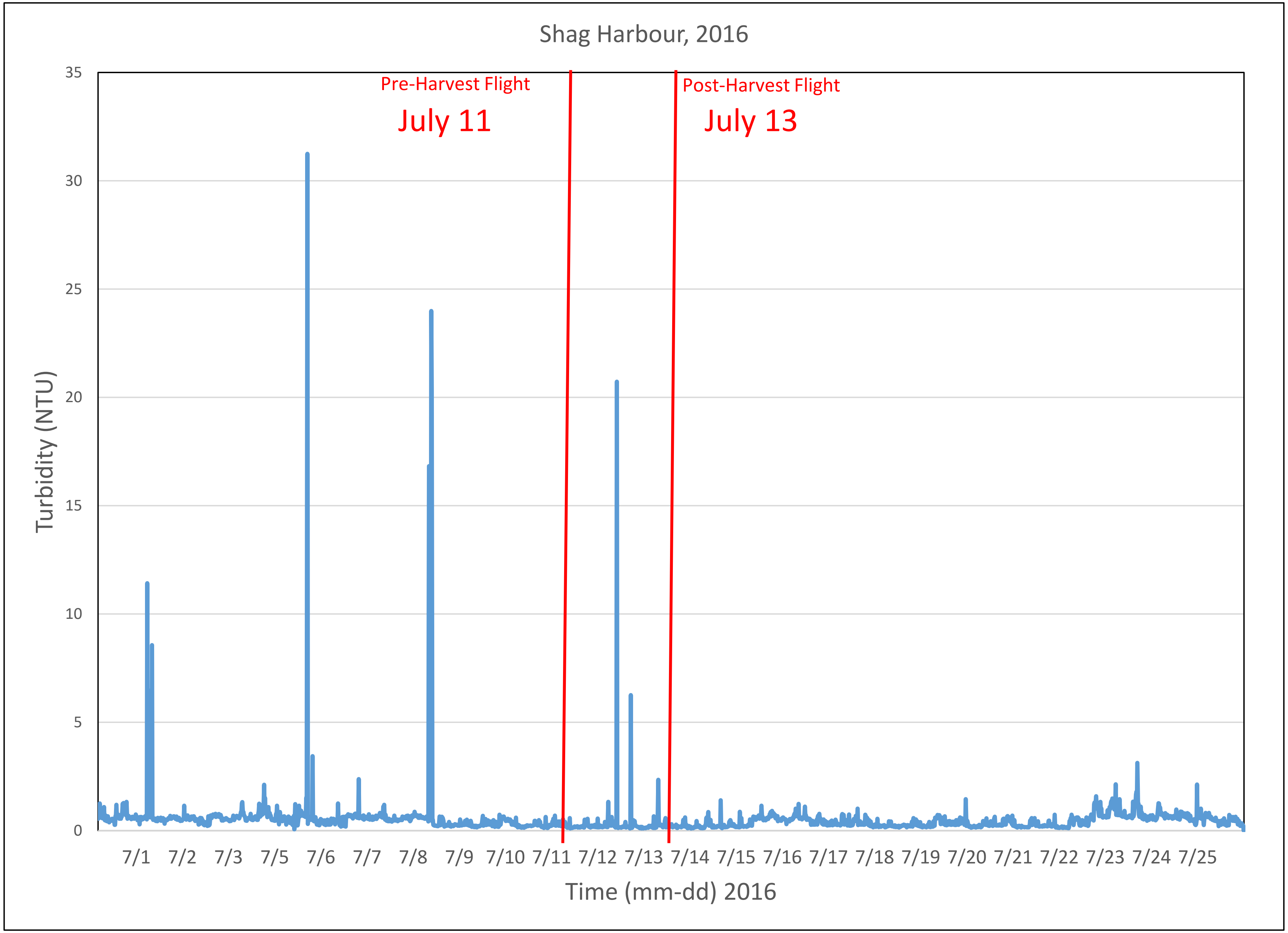


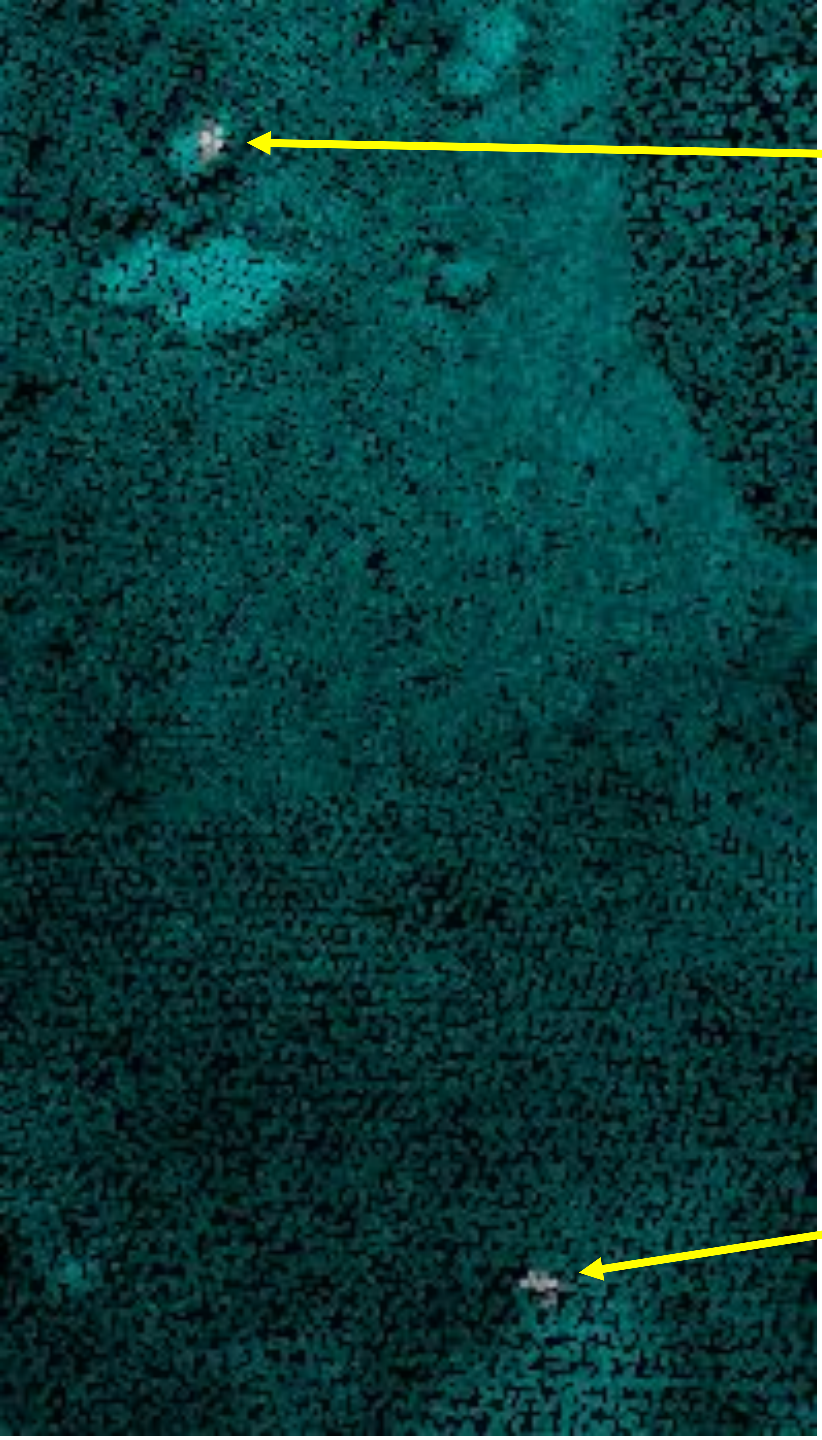
400m Altitude

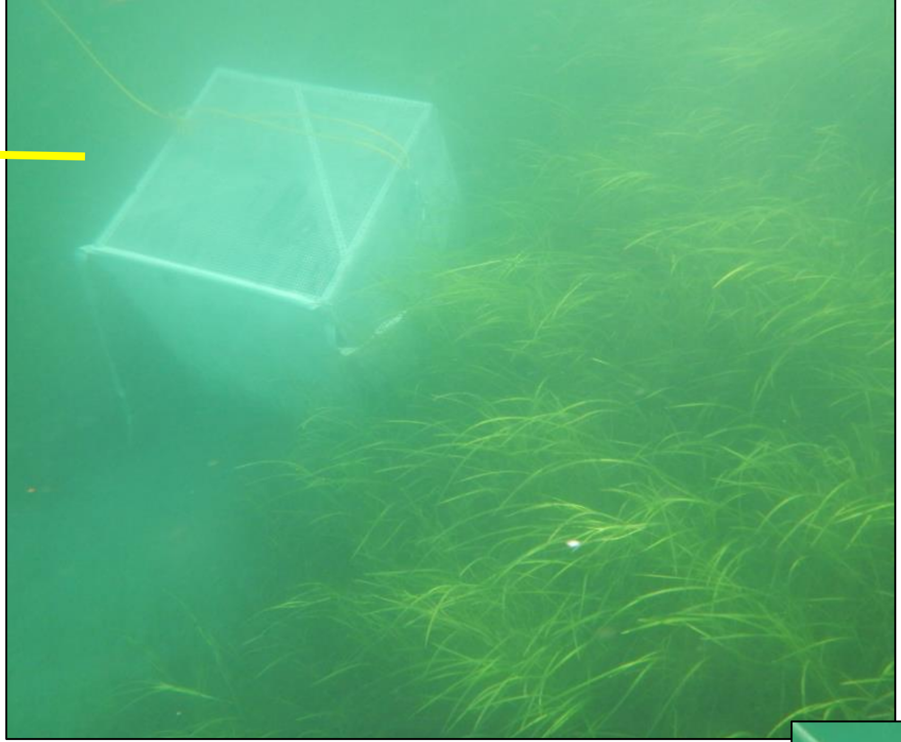
300m Altitude

Submerged Cubes: Shag Harbour (July 2016)



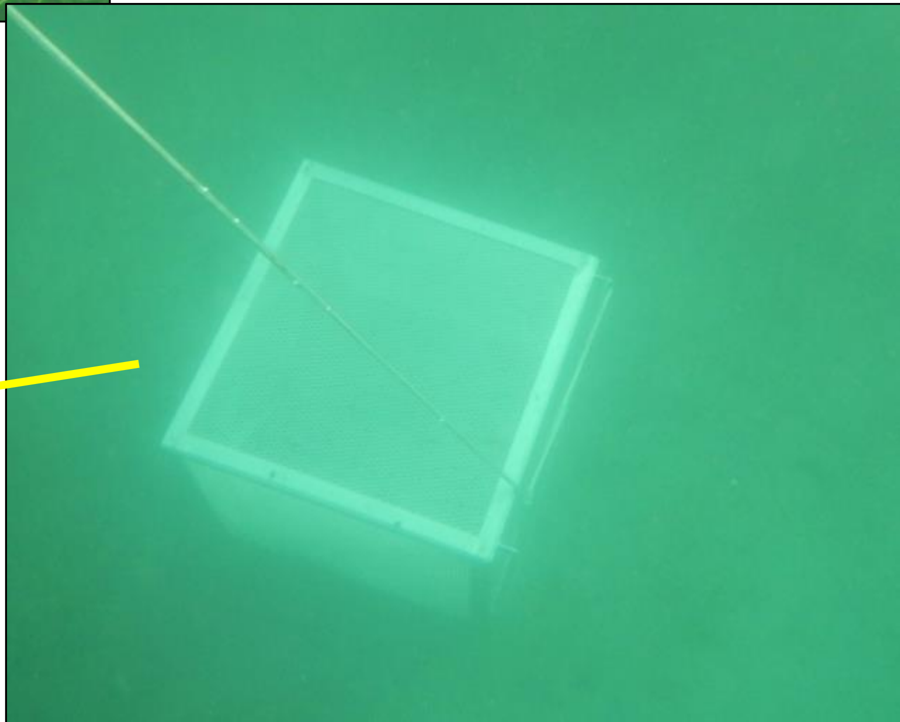

Shag Harbour, 2016
Pre-Harvest Flight
July 11
Post-Harvest Flight
July 13
Turbidity (NTU)
35
30
25
20
15
10
5
0
7/1 7/2 7/3 7/5 7/6 7/7 7/8 7/9 7/10 7/11 7/12 7/13 7/14 7/15 7/16 7/17 7/18 7/19 7/20 7/21 7/22 7/23 7/24 7/25
Time (mm-dd) 2016





~4.5 m water
Surrounded by
eelgrass

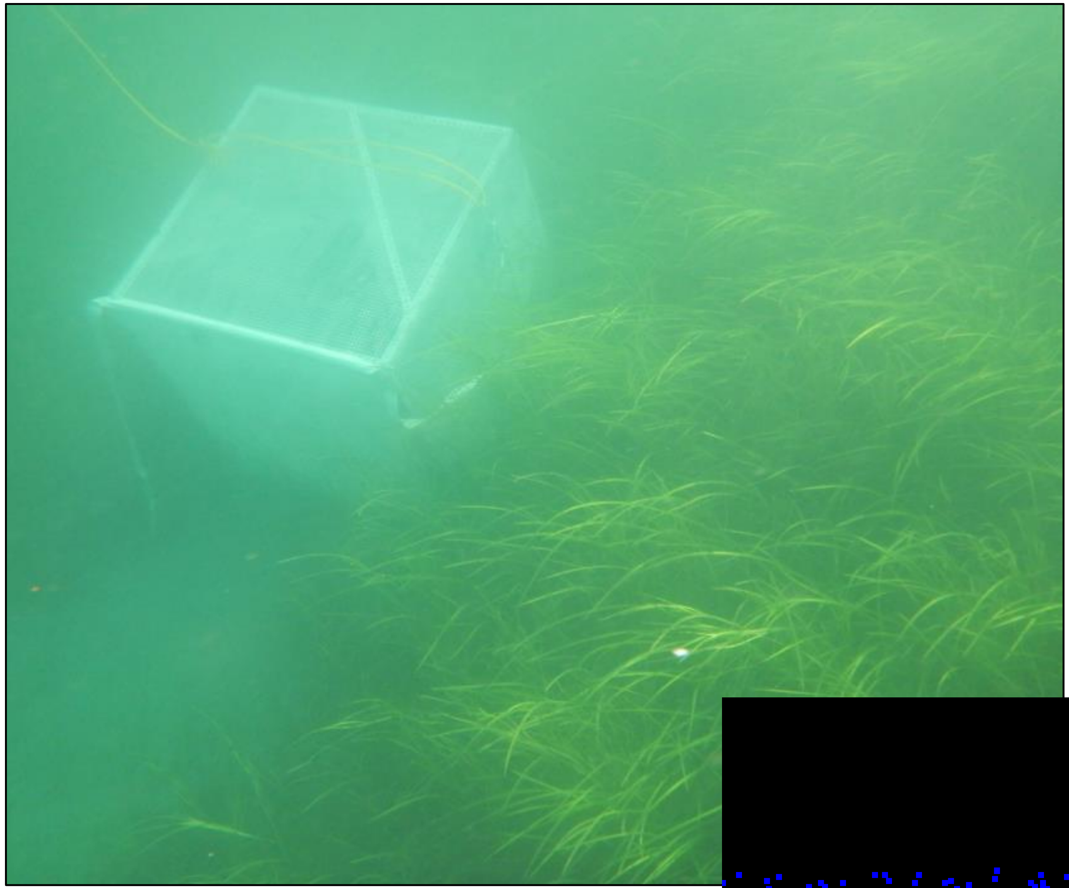
~5.8 m water
Surrounded by
??

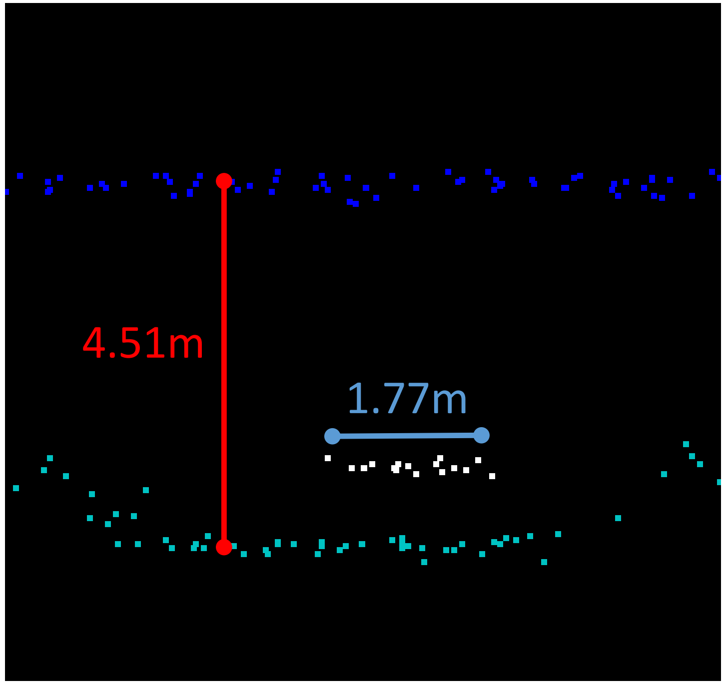


July 11 survey

North Cube

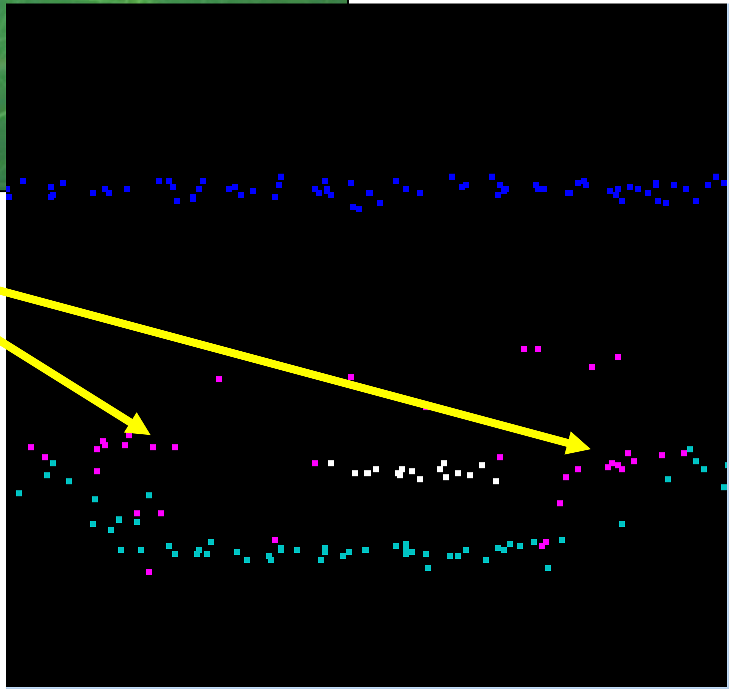
Increased wind-fetch on the 11th, glint effects the photos and obstructs seeing the cube

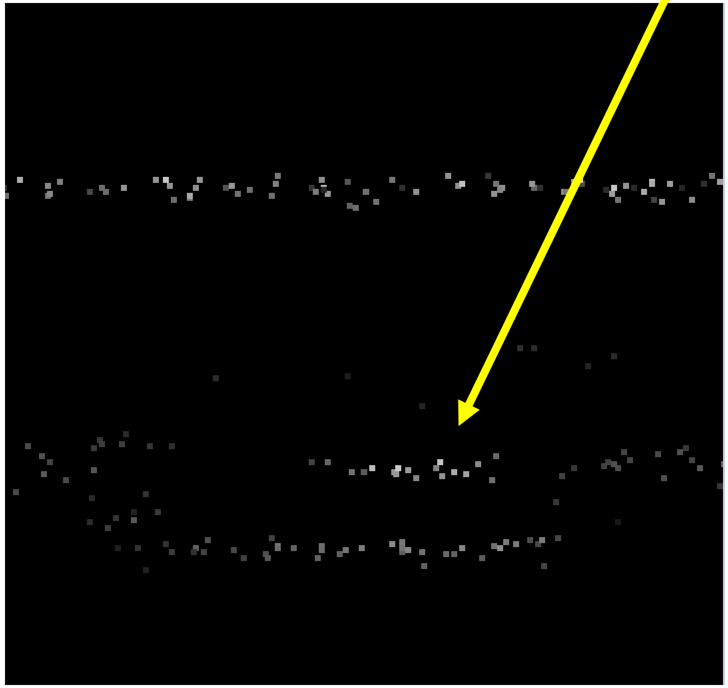




Intensity difference highlights the cube

Eelgrass



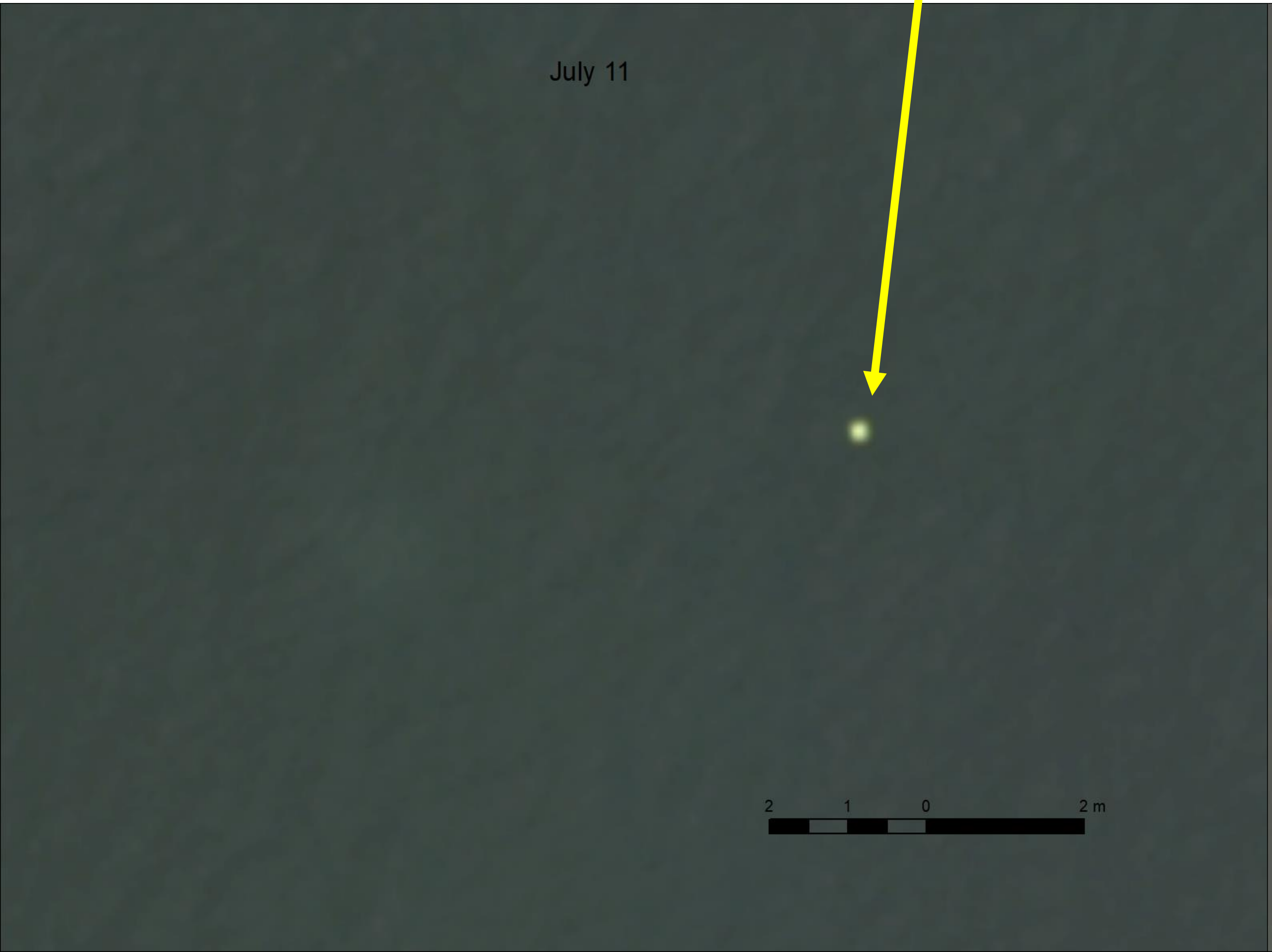


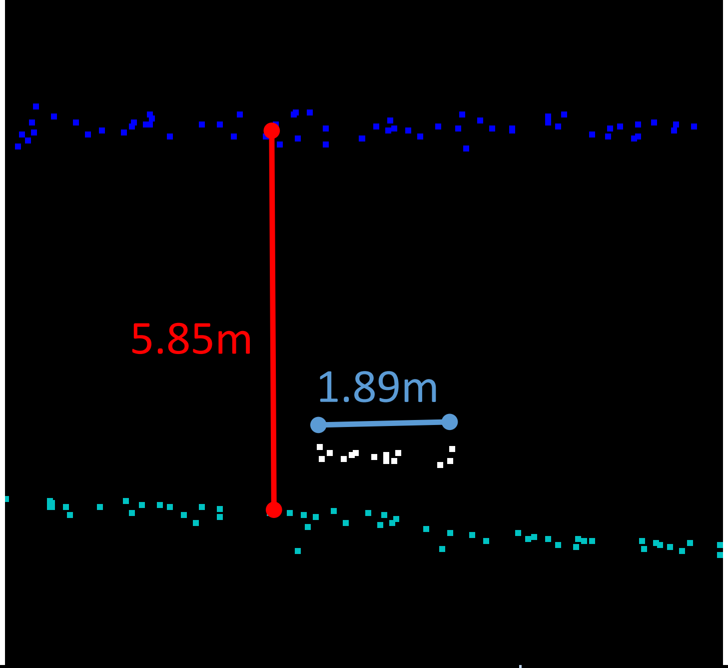
North Cube

Southern Cube, too deep to see

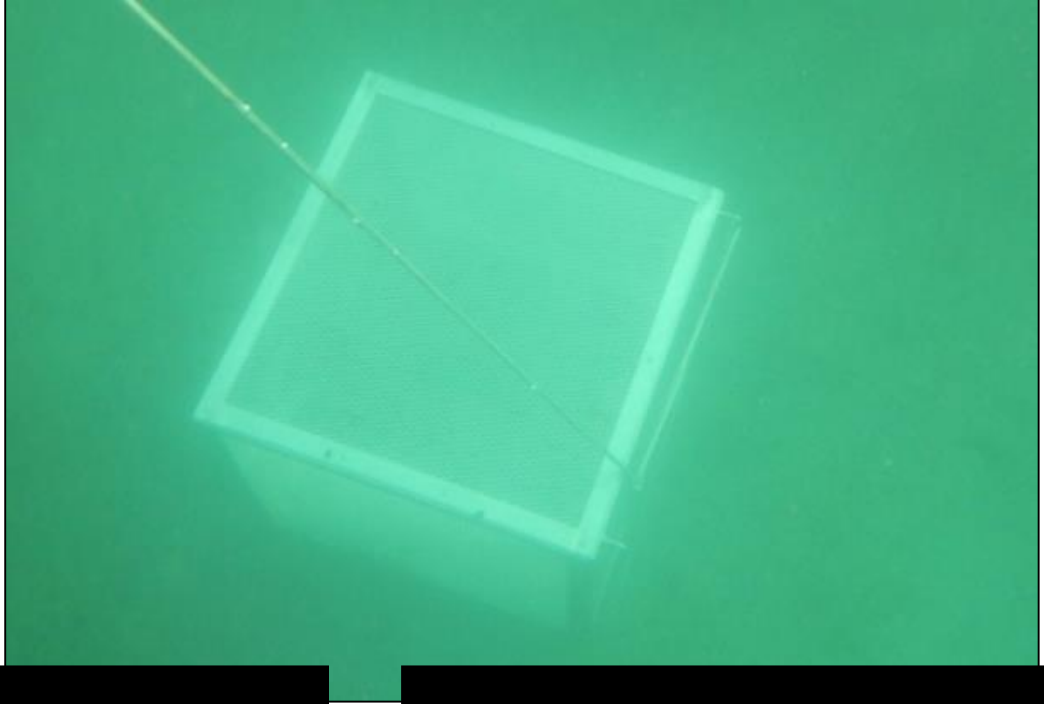
Buoy of cube

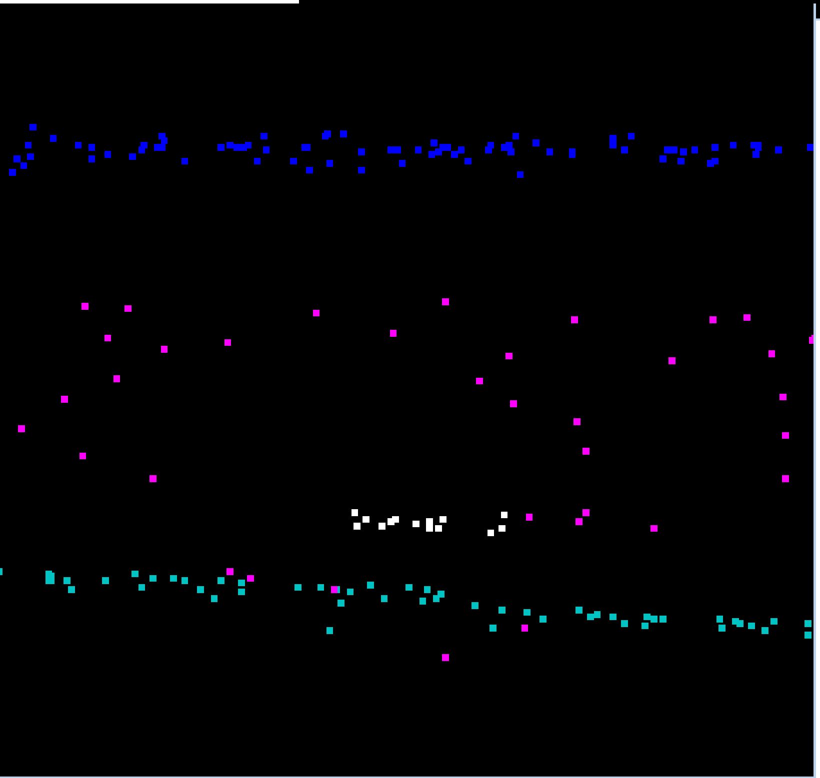
Southern cube redeployed prior to second flight on July 13

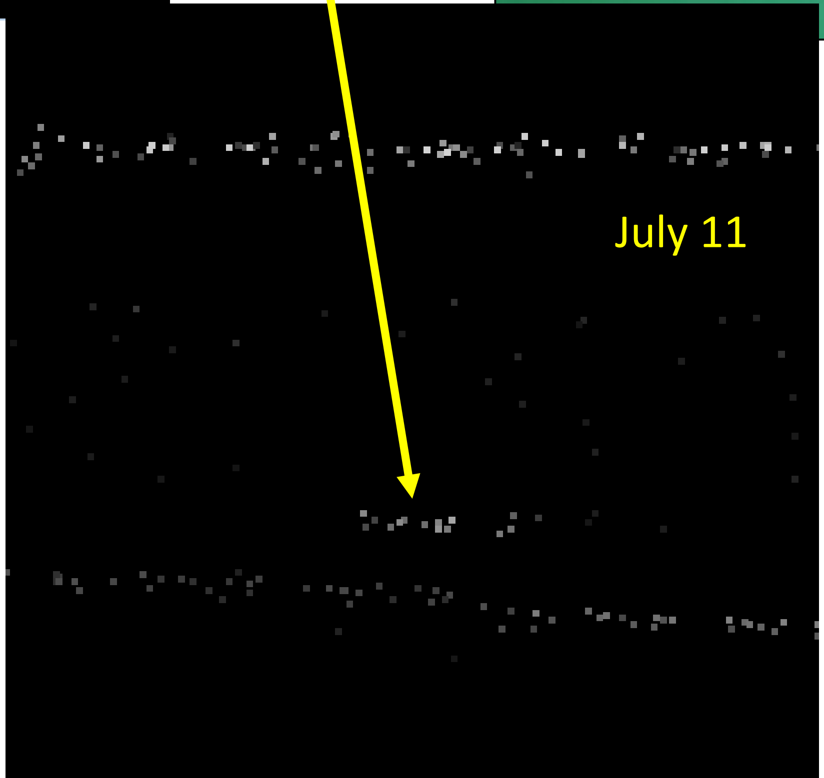




Intensity difference highlights the cube







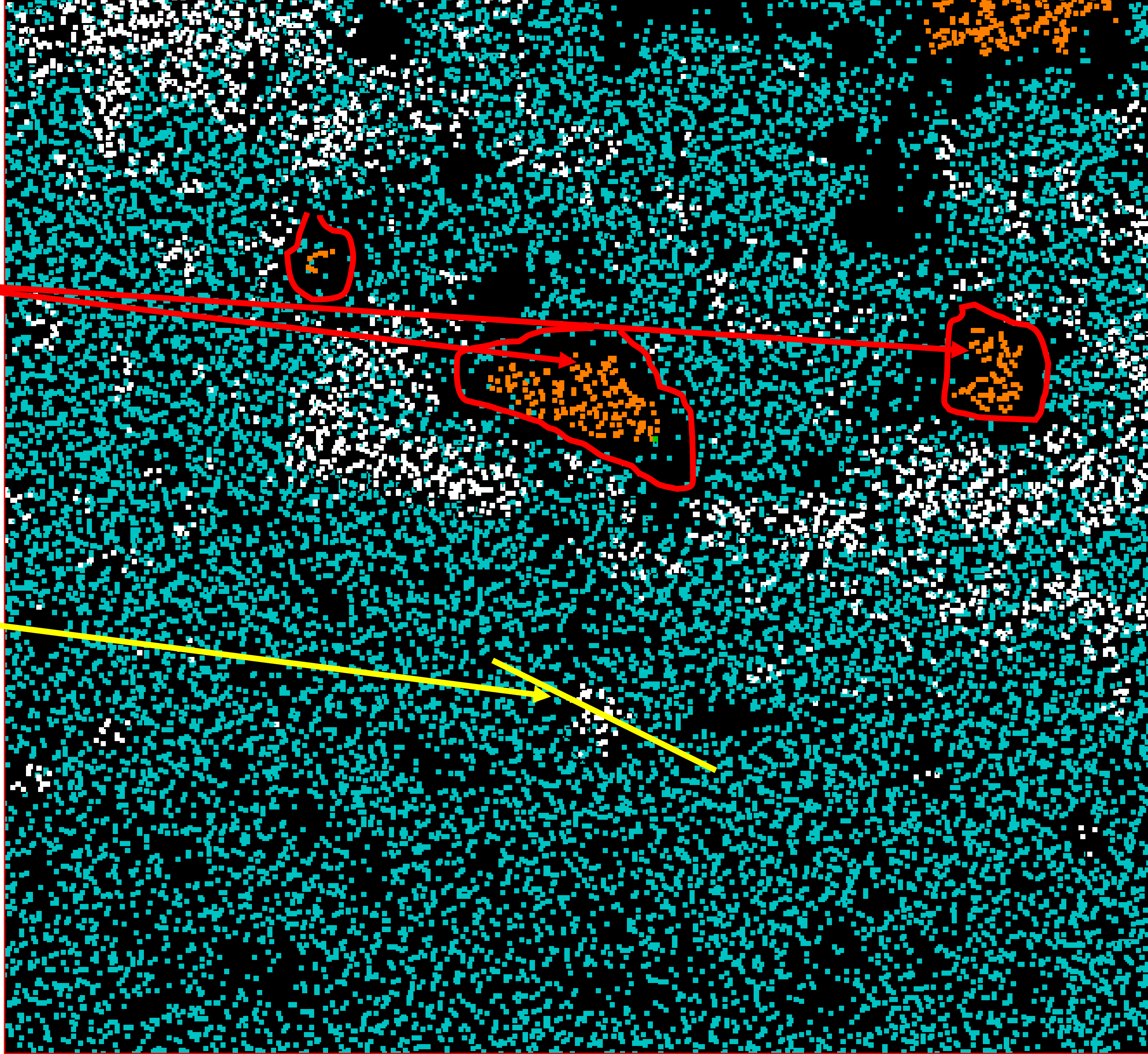
Can we detect boulders in such an environment?

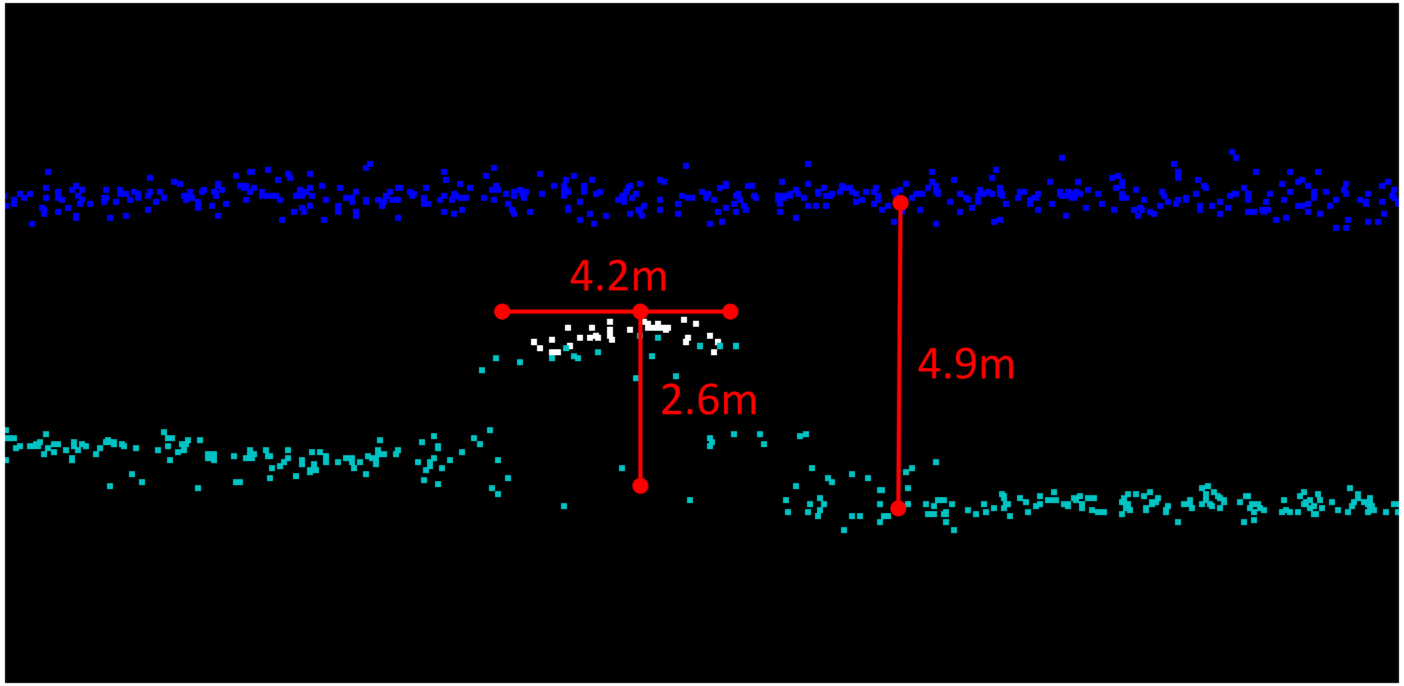
Can we detect boulders in such an environment?

Lidar point cloud

Exposed ground

Cross-Section




4.2m
2.6m
4.9m

Stronger return
From shallower real target, less scattering in the water column

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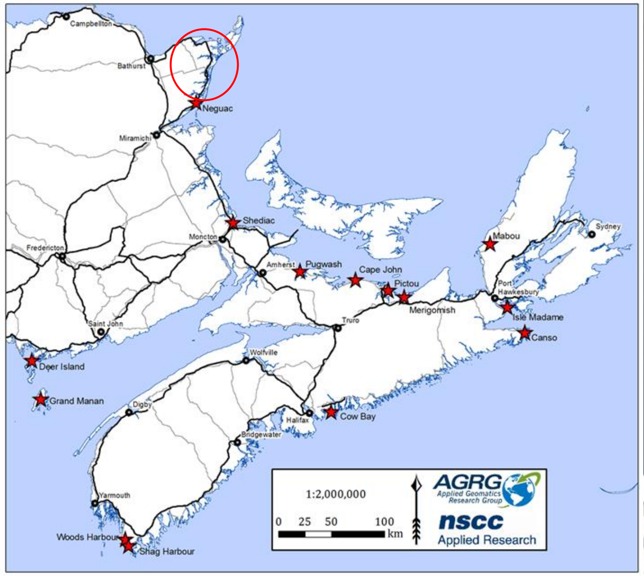
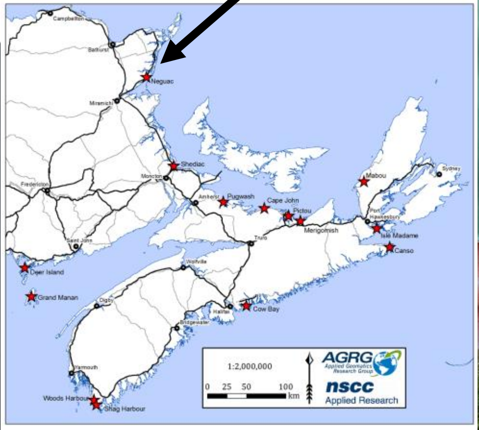
Canada › NB › Photo Galleries

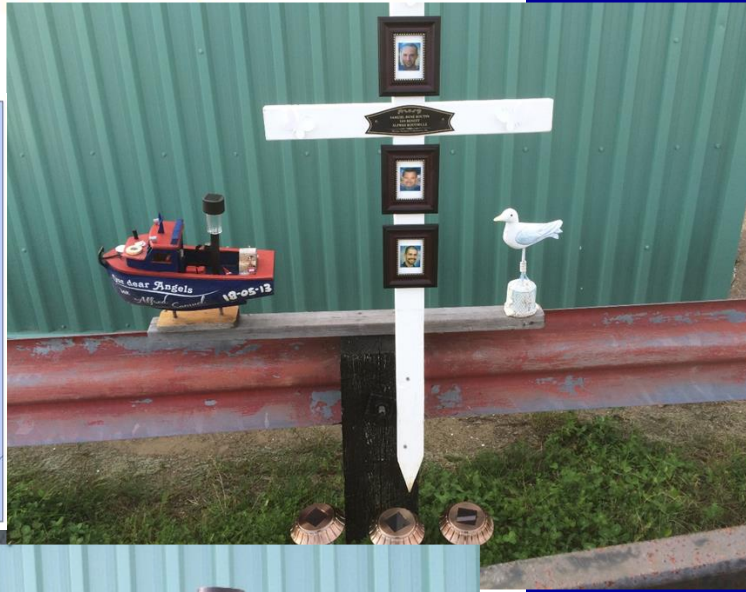
TSB report into deaths of 3 fishermen in Tabusintac released

2 recommendations stemming from grounding, sinking of Marie J in May 2013 made after previous incidents

CBC News   Posted: Nov 13, 2014 12:52 PM AT | Last Updated: Nov 13, 2014 3:55 PM AT

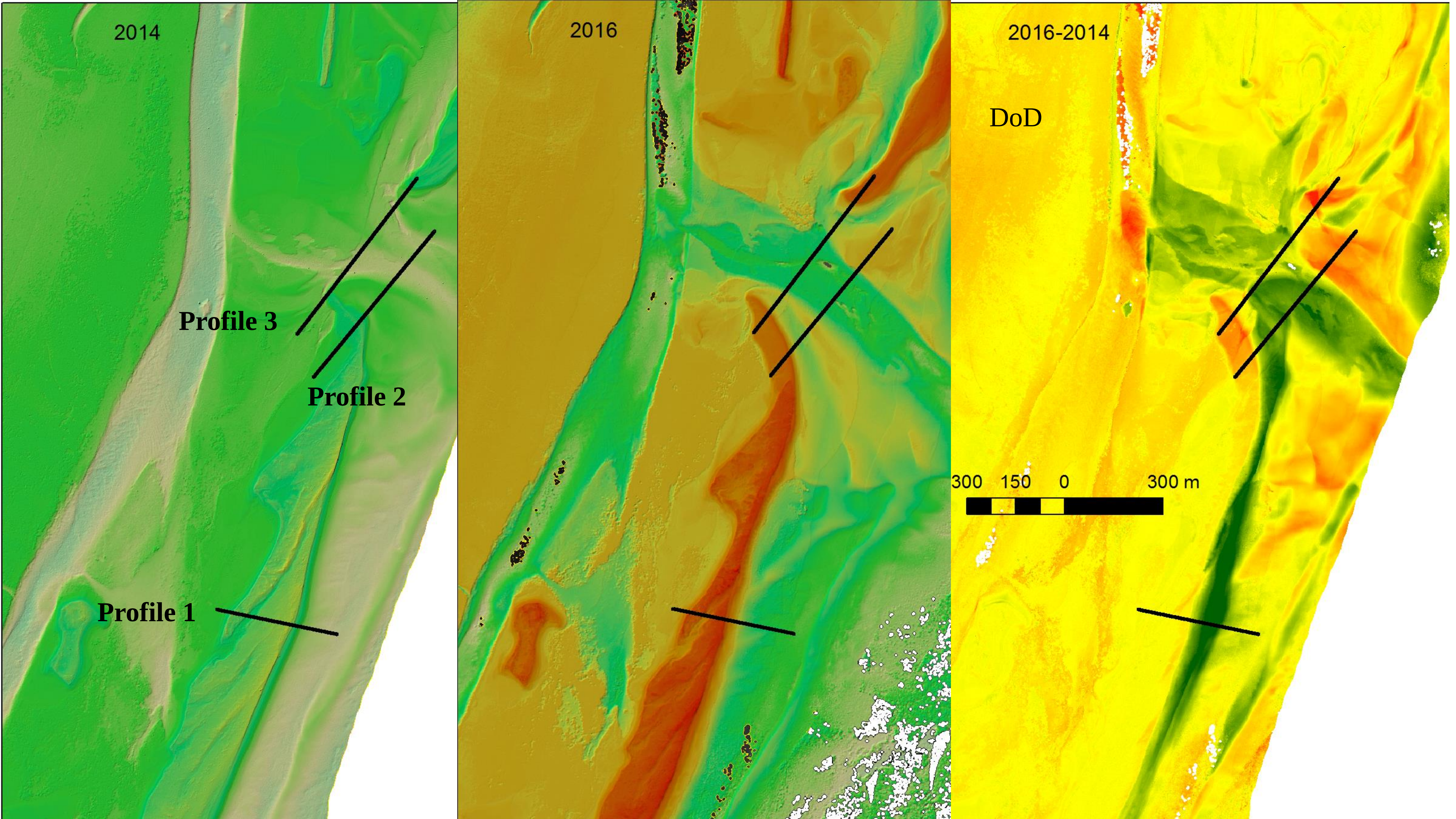


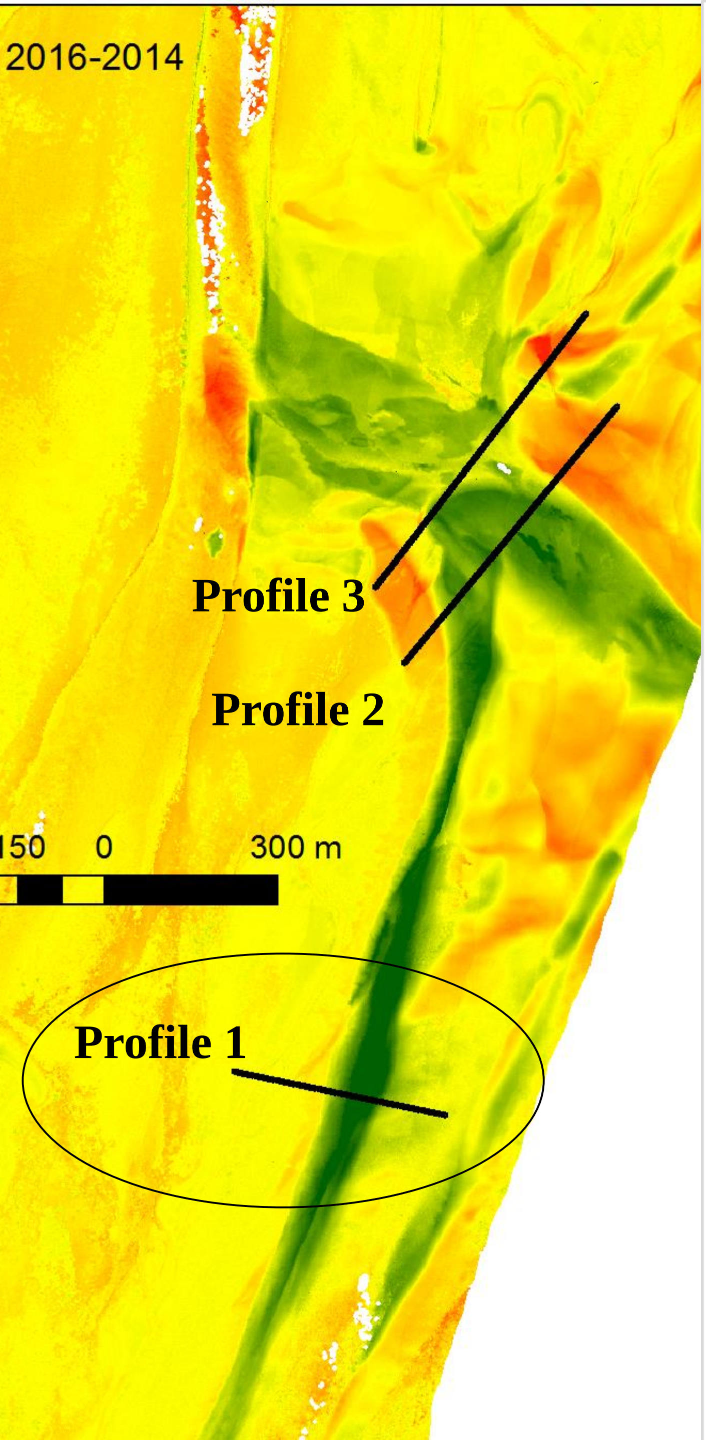


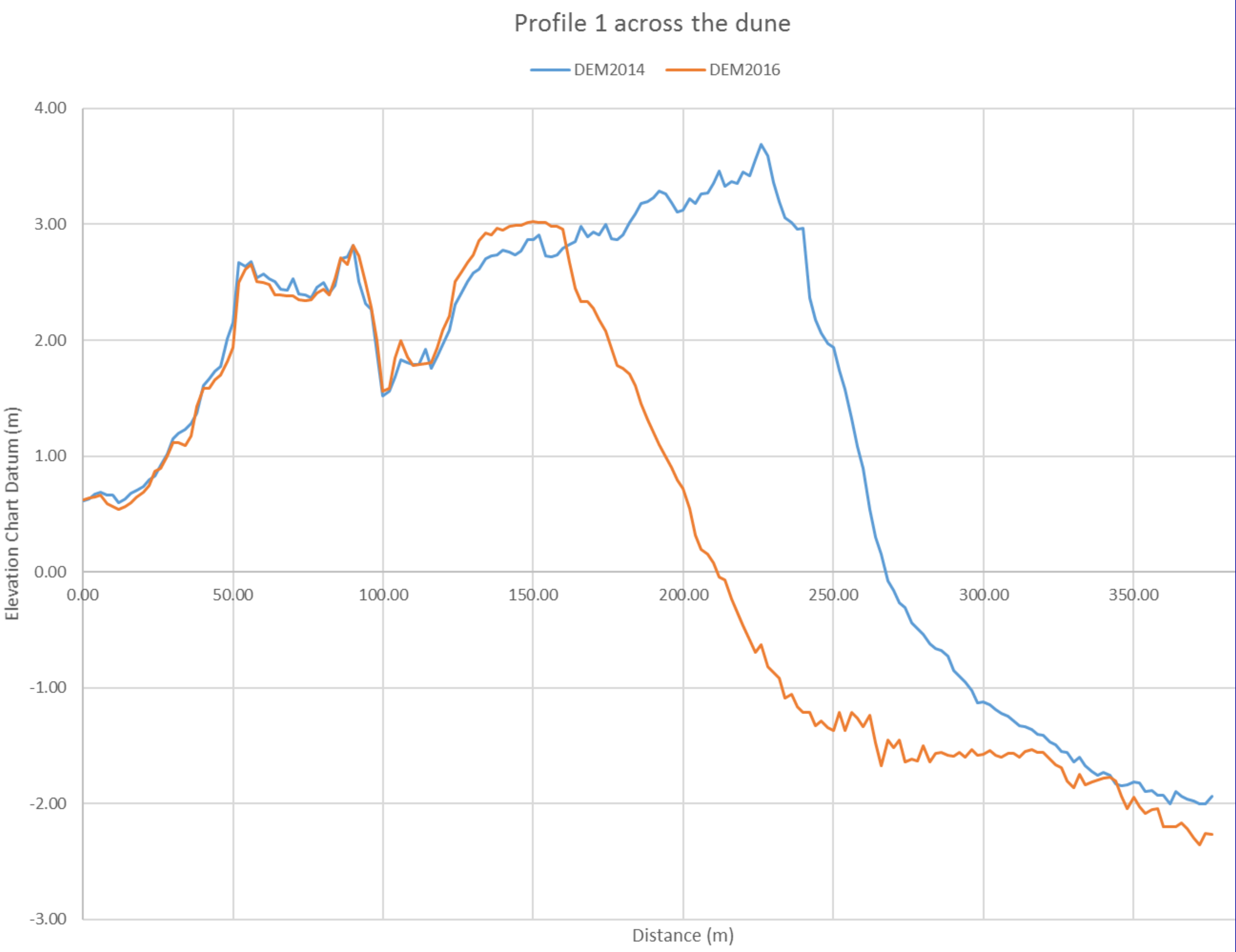


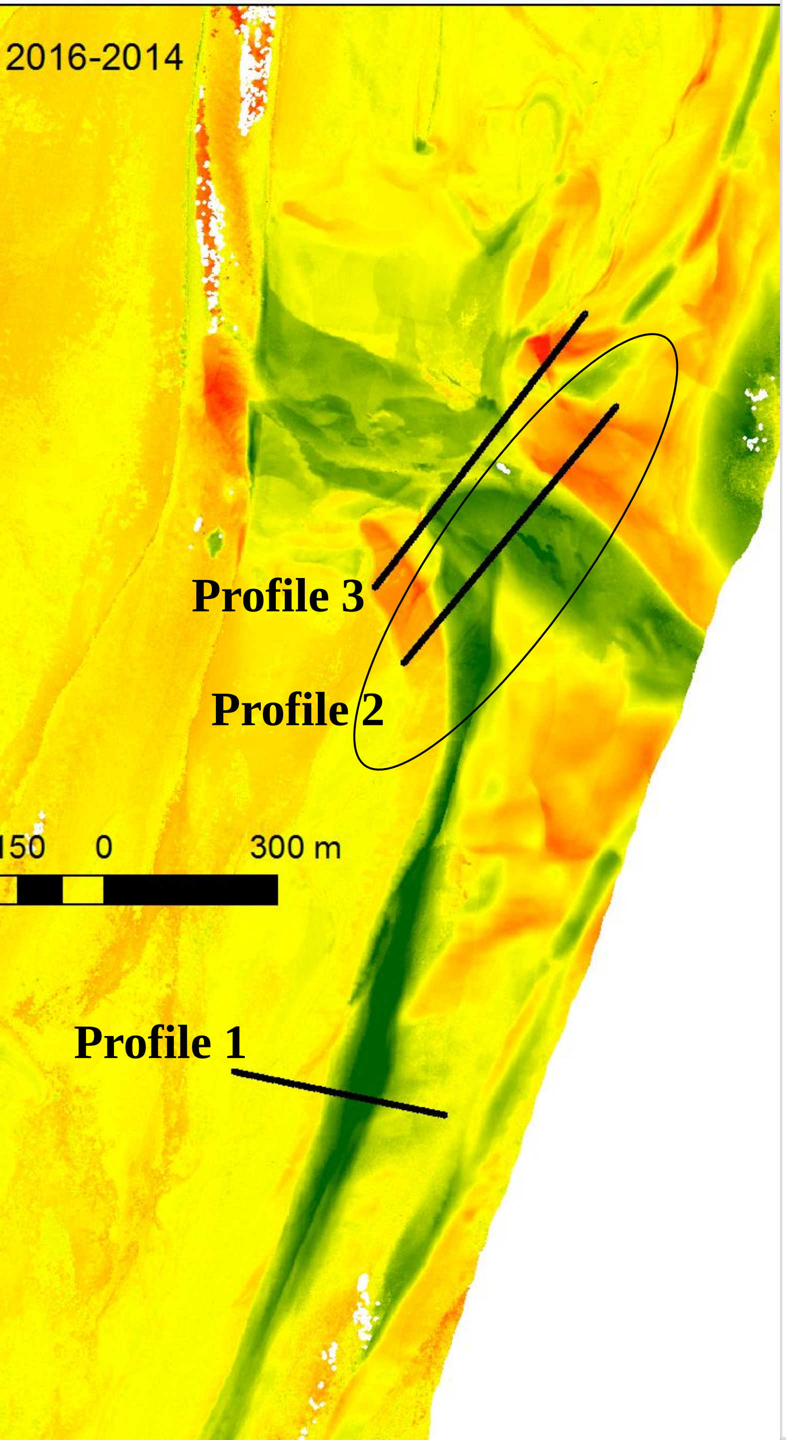
a sandbar in bad weather on May 18, 2013, and eventually sank, while
on Safety Board)

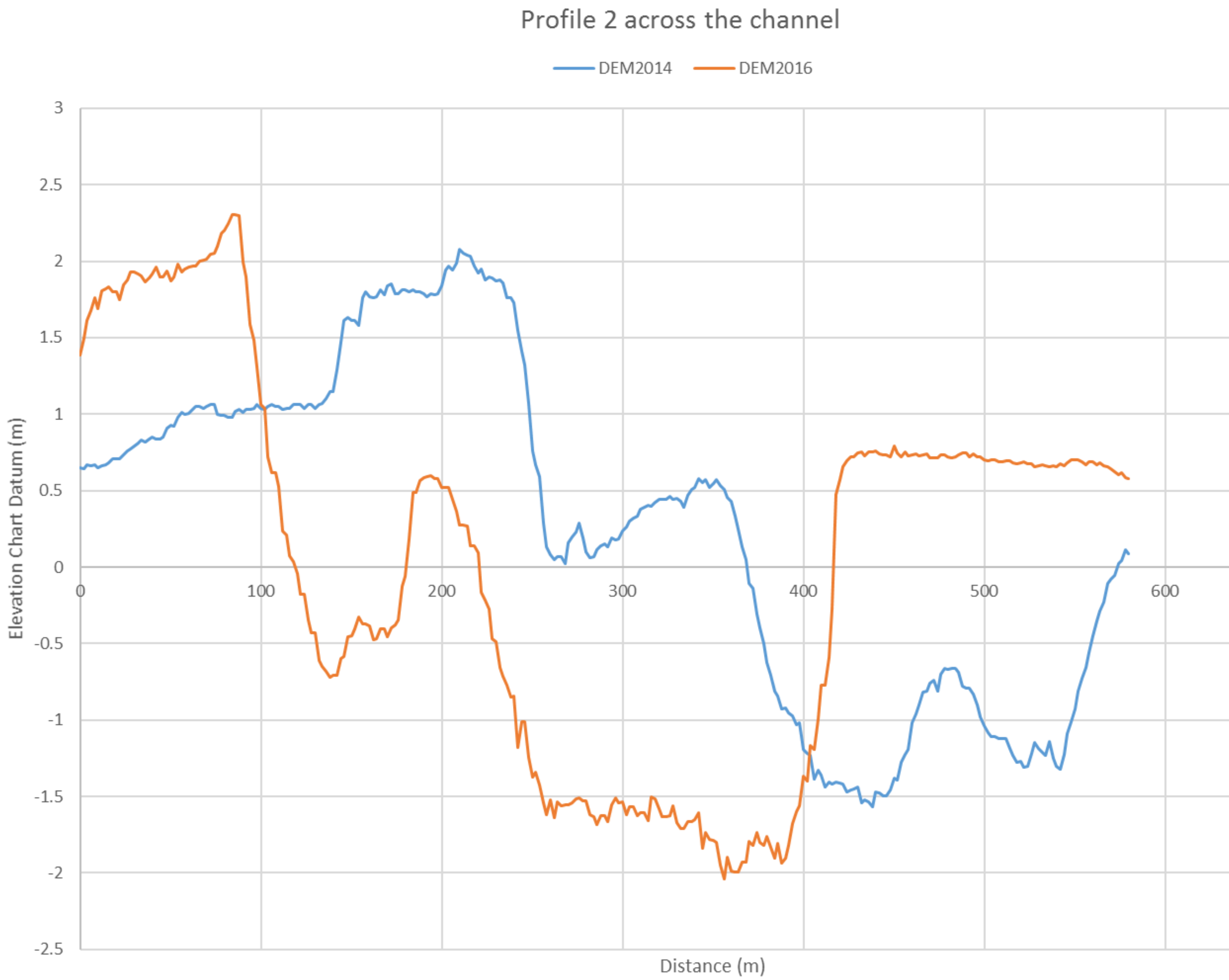
http://www.cbc.ca/news/canada/new-brunswick/tsb-report-into-deaths-of-3-fishermen-in-tabusintac-released-1.2833664

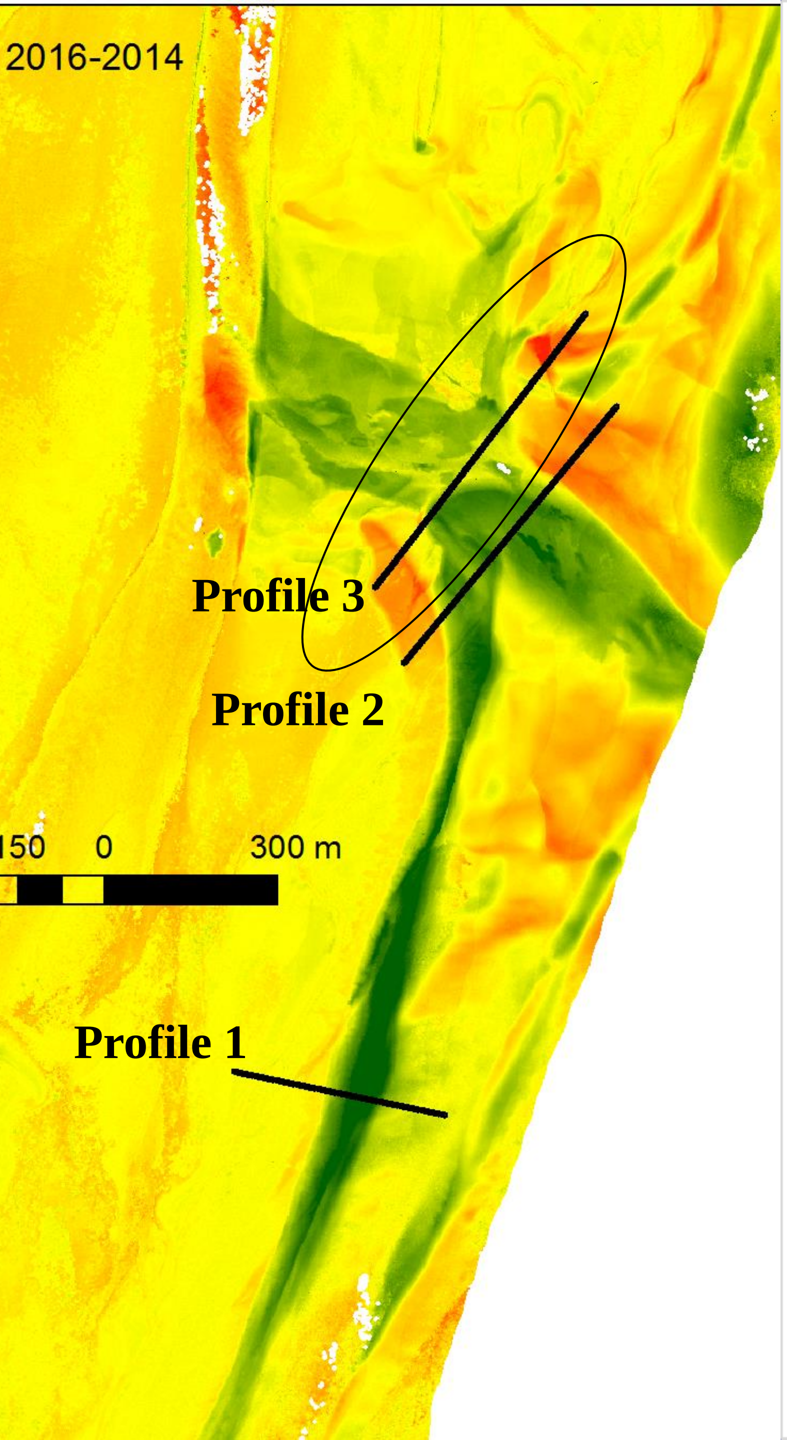

2014
Profile 3
Profile 2
Profile 1
2016
2016-2014
DoD
300
150
0
300 m


2016-2014
Profile 3
Profile 2
Profile 1
150
0
300 m

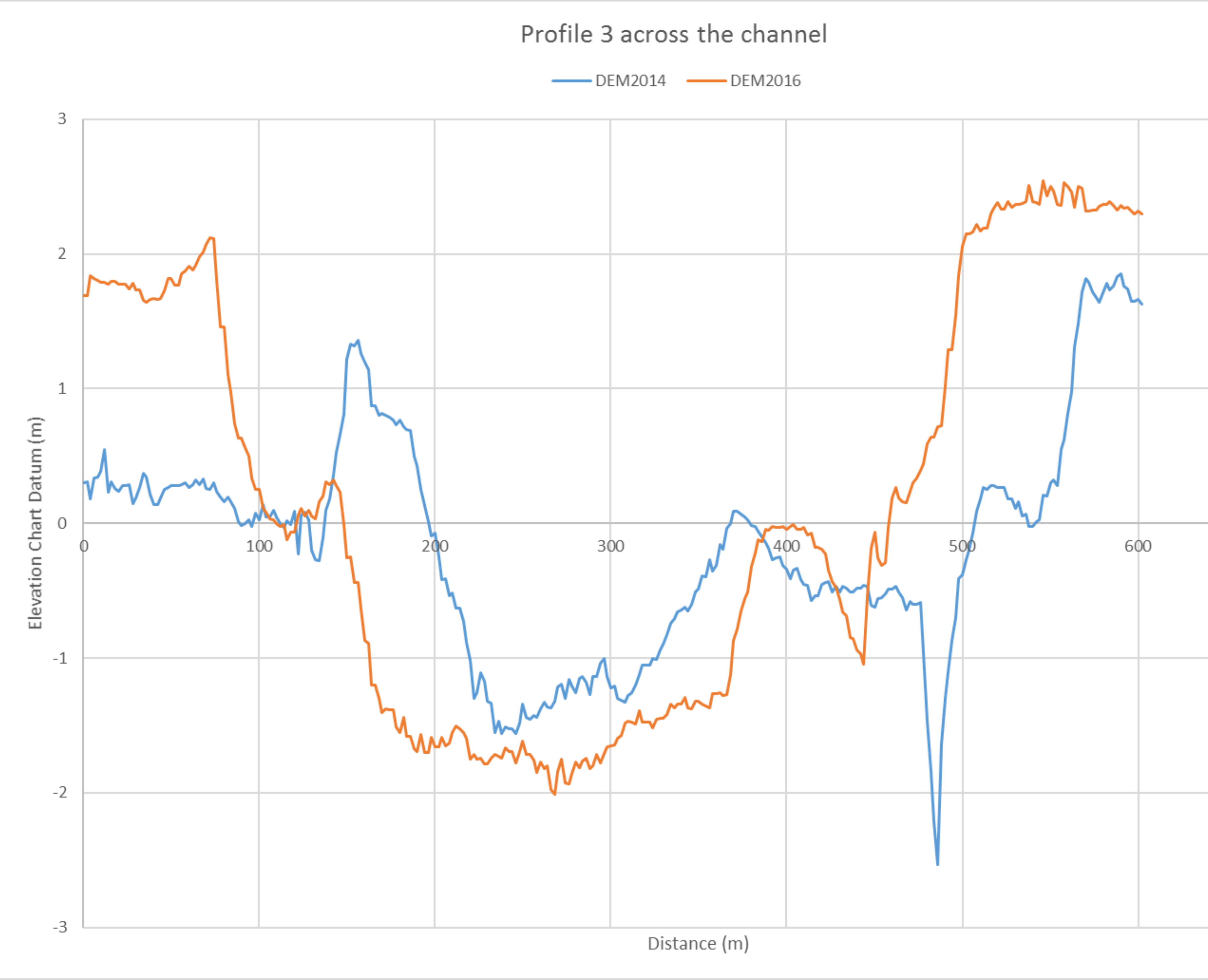

Profile 1 across the dune
DEM2014
DEM2016
Elevation Chart Datum (m)
Distance (m)
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00


2016-2014
Profile 3
Profile 2
Profile 1
150 0 300 m

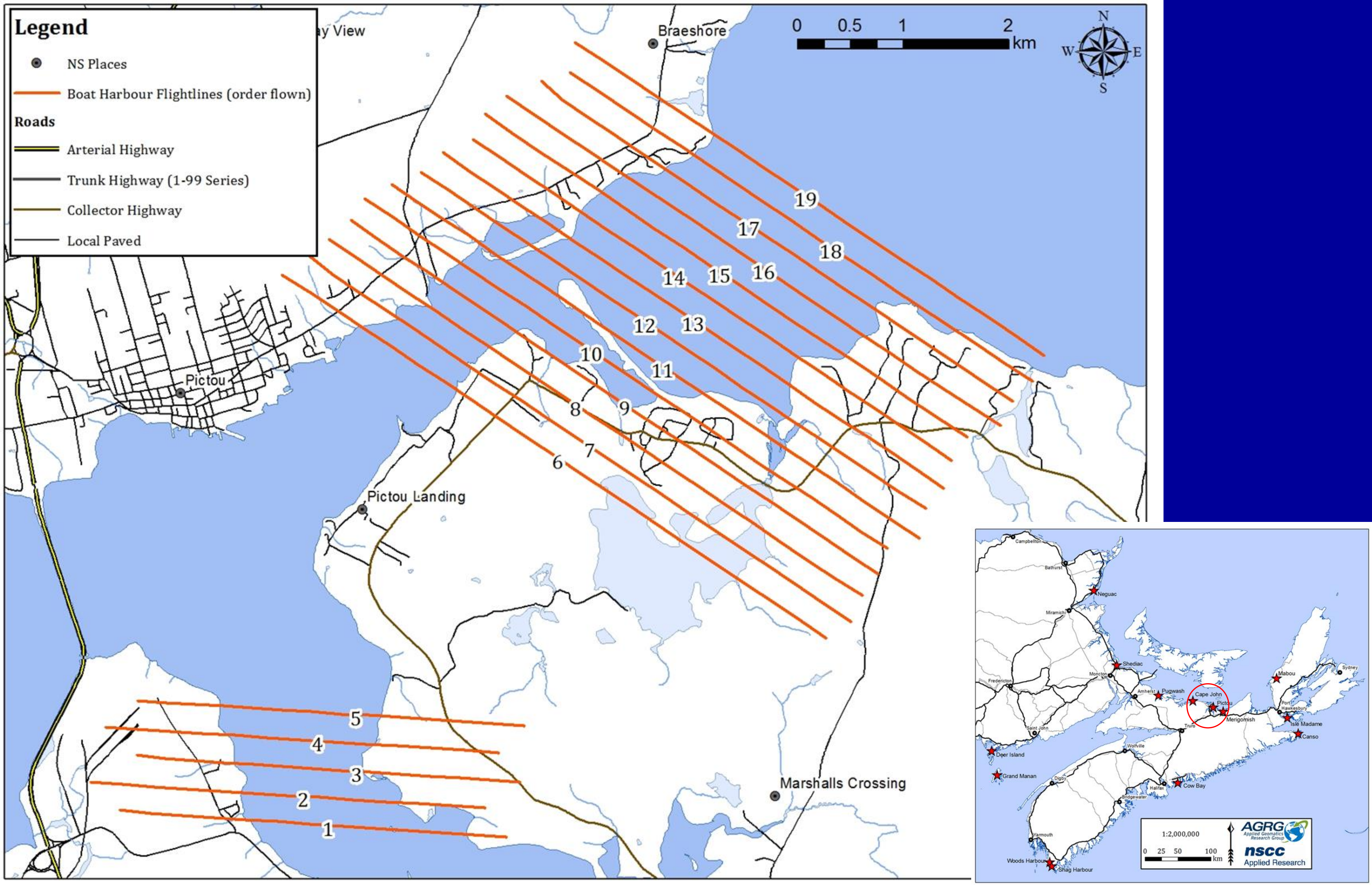

Profile 2 across the channel
DEM2014
DEM2016
Elevation Chart Datum (m)
Distance (m)
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
0
100
200
300
400
500
600

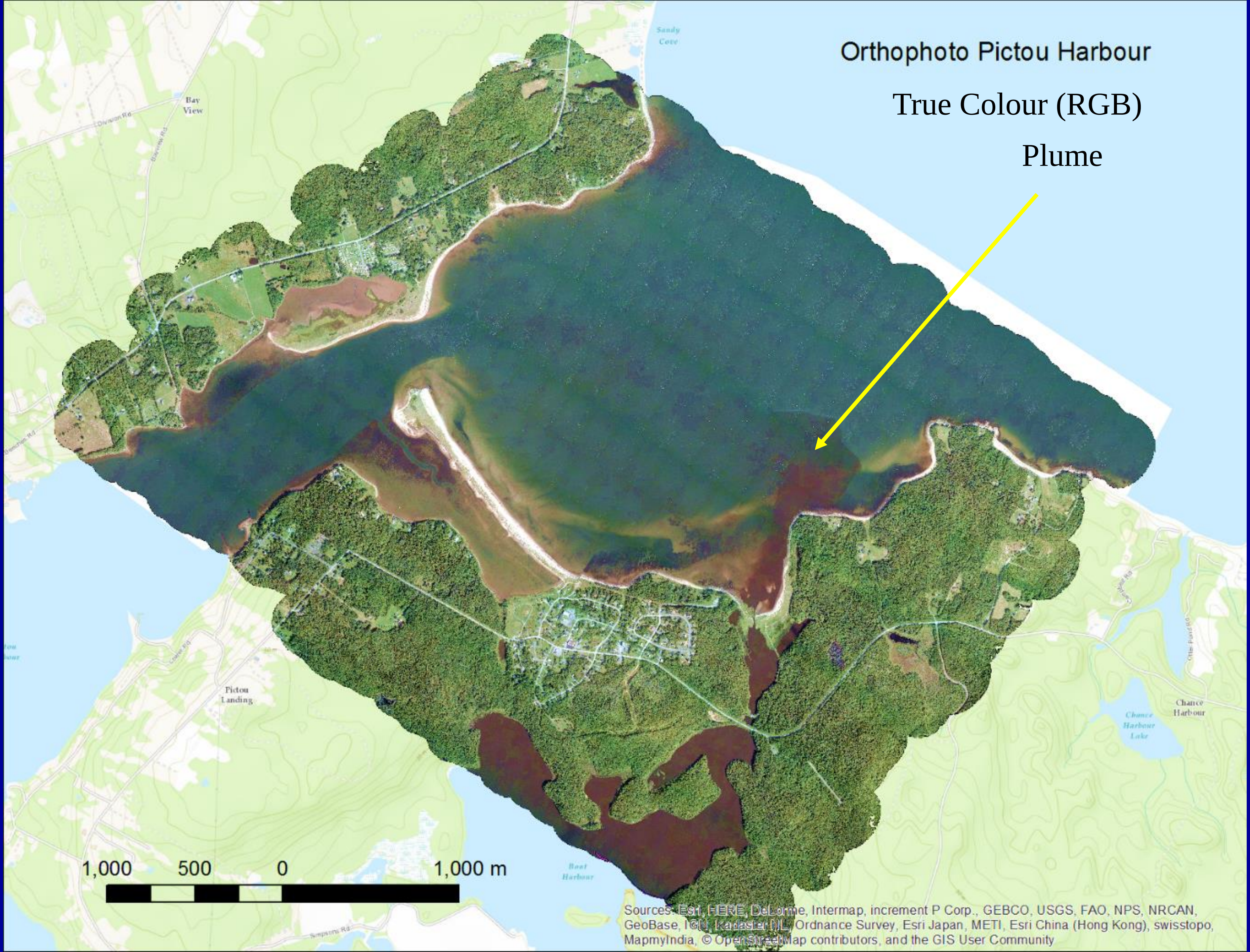


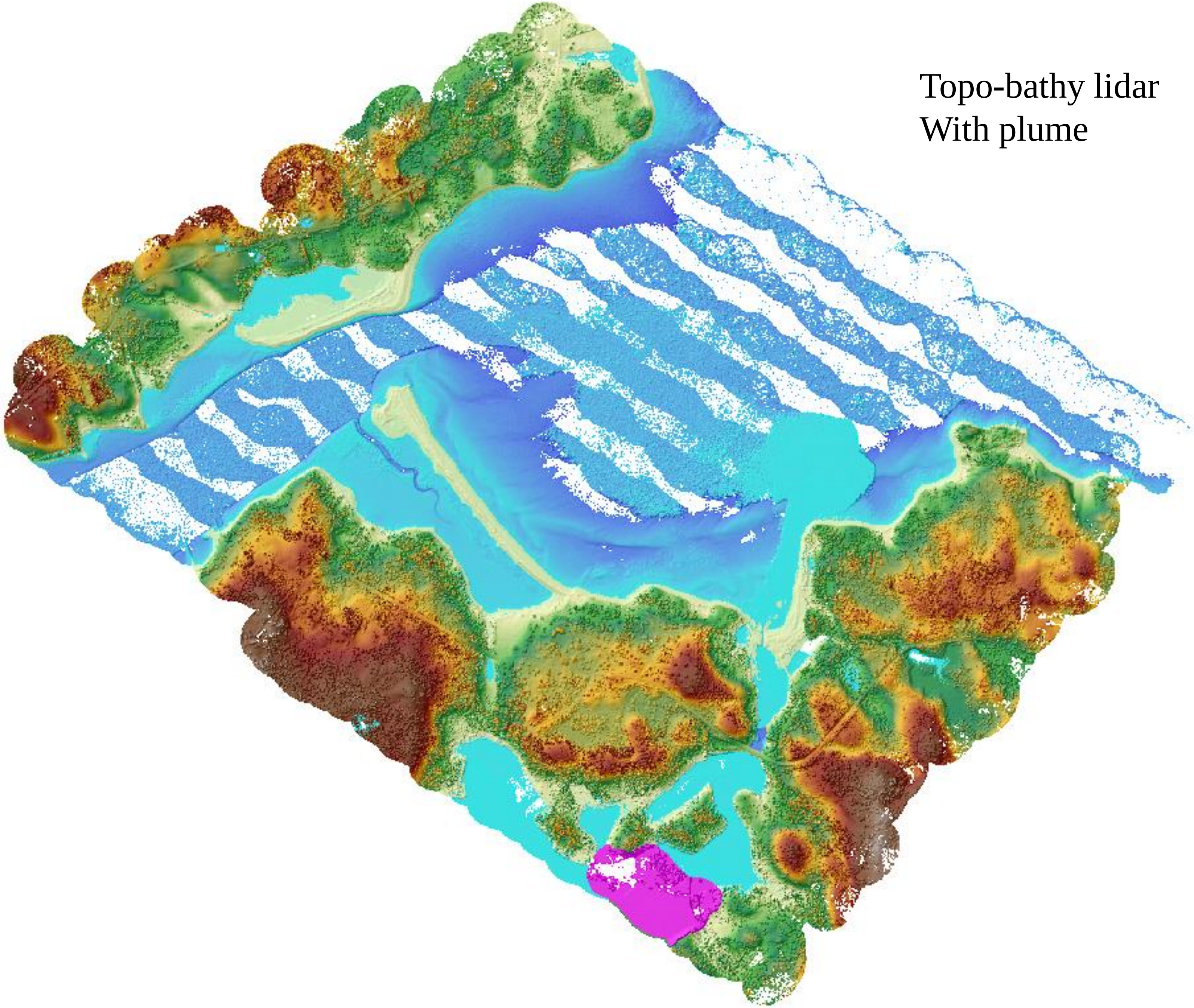
2016-2014
Profile 3
Profile 2
Profile 1
150
0
300 m



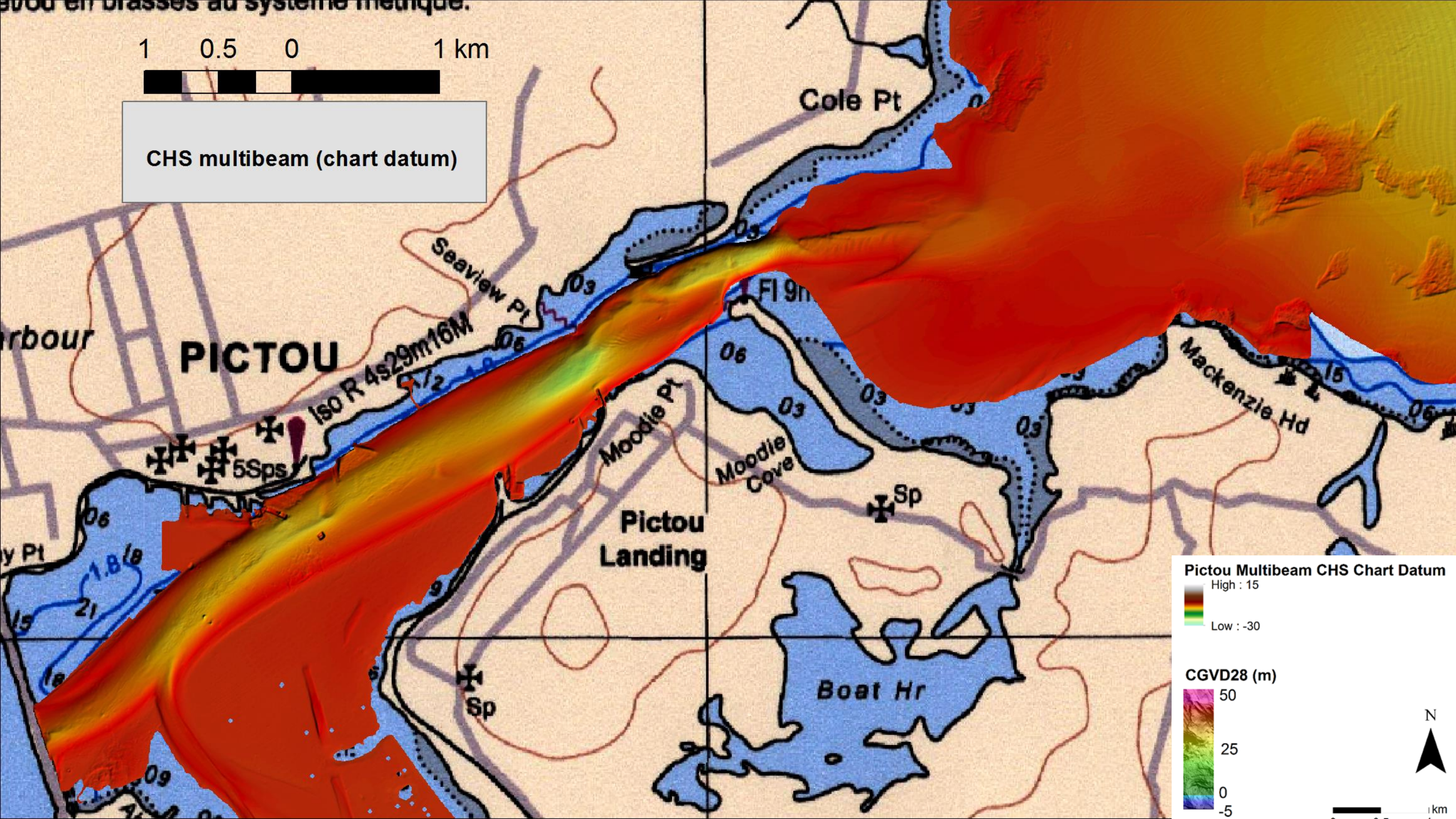
Profile 3 across the channel
DEM2014
DEM2016
Elevation Chart Datum (m)
Distance (m)
3
2
1
0
-1
-2
-3
0
100
200
300
400
500
600


Legend
NS Places
Boat Harbour Flightlines (order flown)
Roads
Arterial Highway
Trunk Highway (1-99 Series)
Collector Highway
Local Paved
0 0.5 1 2 km
N
W
E
S
Braeshore
Pictou
Pictou Landing
Marshalls Crossing
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
Campbellton
Bathurst
Neguac
Miramichi
Shediac
Moncton
Fredericton
Amherst
Pugwash
Cape John
Pictou
Merigomish
Mabou
Sydney
Port Hawkesbury
Isle Madame
Canso
Truro
Saint John
Deer Island
Grand Manan
Wolfville
Digby
Halifax
Cow Bay
Bridgewater
Yarmouth
Woods Harbour
Shag Harbour
1:2,000,000
0 25 50 100 km
AGRG
Applied Geomatics Research Group
nscc
Applied Research

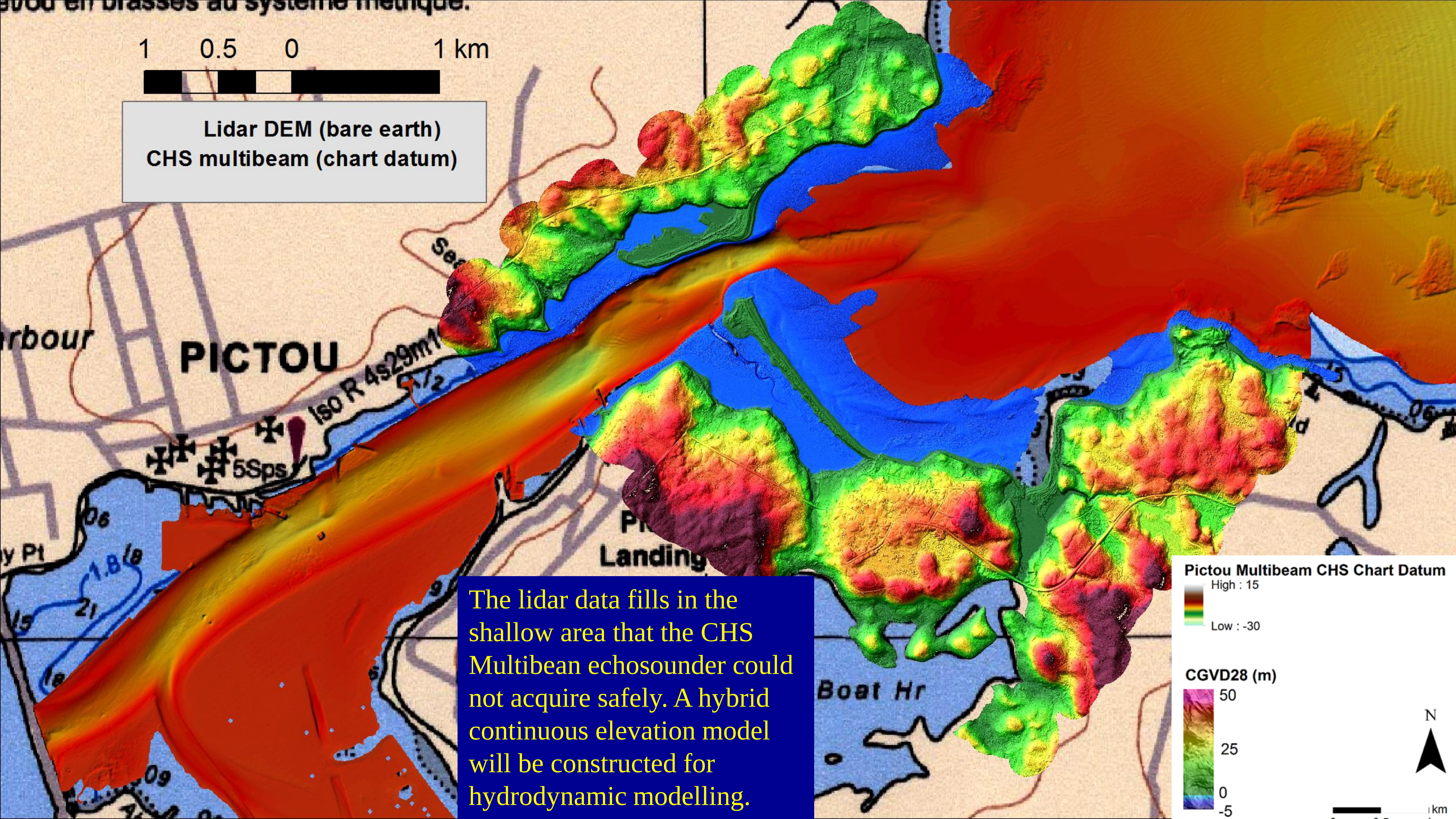

Orthophoto Pictou Harbour
True Colour (RGB)
Plume
1,000 500 0 1,000 m
Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Pictou Landing
Chance Harbour
Bay View
Sandy Cove



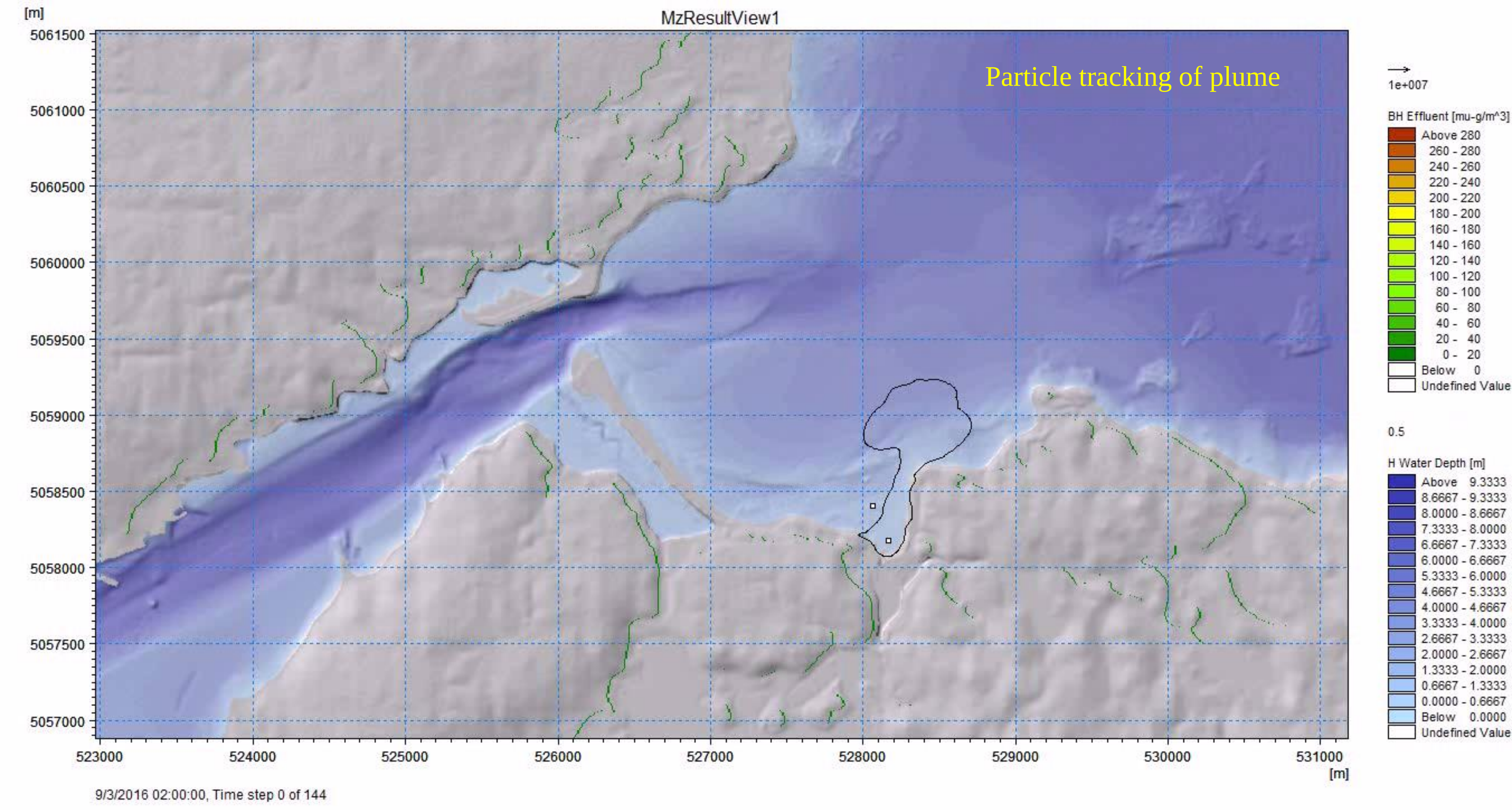
Topo-bathy lidar
With plume



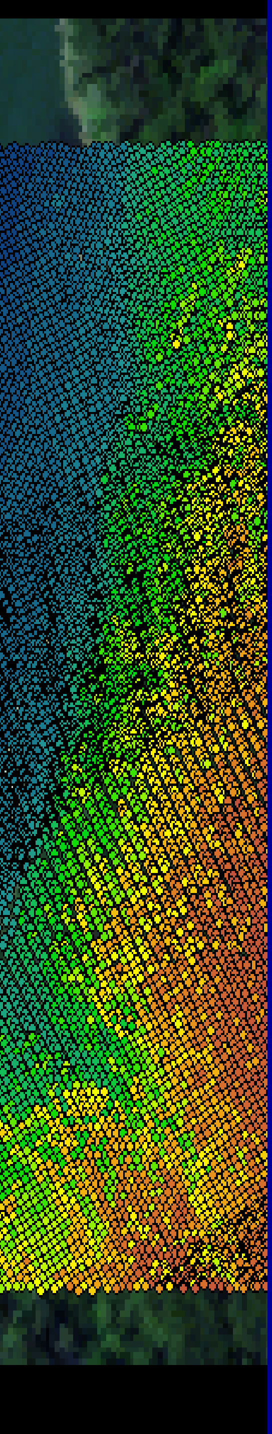
1 0.5 0 1 km
CHS multibeam (chart datum)
Cole Pt
Seaview Pt
PICTOU
Iso R 4s29m16M
5Sps
Moodie Pt
Moodie Cove
Pictou Landing
Sp
Sp
Boat Hr
Mackenzie Hd
Pictou Multibeam CHS Chart Datum
High : 15
Low : -30
CGVD28 (m)
50
25
0
-5
N



The lidar data fills in the shallow area that the CHS Multibean echosounder could not acquire safely. A hybrid continuous elevation model will be constructed for hydrodynamic modelling.



MzResultView1
Particle tracking of plume
[m]
5061500
5061000
5060500
5060000
5059500
5059000
5058500
5058000
5057500
5057000
523000
524000
525000
526000
527000
528000
529000
530000
531000
[m]
9/3/2016 02:00:00, Time step 0 of 144
1e+007
BH Effluent [mu-g/m^3]
Above 280
260 - 280
240 - 260
220 - 240
200 - 220
180 - 200
160 - 180
140 - 160
120 - 140
100 - 120
80 - 100
60 - 80
40 - 60
20 - 40
0 - 20
Below 0
Undefined Value
0.5
H Water Depth [m]
Above 9.3333
8.6667 - 9.3333
8.0000 - 8.6667
7.3333 - 8.0000
6.6667 - 7.3333
6.0000 - 6.6667
5.3333 - 6.0000
4.6667 - 5.3333
4.0000 - 4.6667
3.3333 - 4.0000
2.6667 - 3.3333
2.0000 - 2.6667
1.3333 - 2.0000
0.6667 - 1.3333
0.0000 - 0.6667
Below 0.0000
Undefined Value



Conclusions

- Processing workflow scripted for improved automation, still need human inspection, now includes export of point clouds and raster models to virtual reality and mixed reality devices. Great QA tools
- Continued research into benthic habitat mapping using lidar-orthophoto combination – 85% range, + additional waveform metrics
- Best practice around turbidity management for optimal surveys
- 1 x 1 m cubes detectable at depths of 5-6 m on lidar, deeper = wider
- 2017 experiment with standard 400 m AGL vs. 300 m and 60% flight line overlap vs. standard 30% - point density increased 20% @ 300m
- Depth effects bottom variance, can use intensity to differentiate real targets vs. water column noise
- Multiple applications of the surveys beyond charting – benthic habitat, hydrodynamic models …

Acknowledgement: equipment support

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