# NSERC Applied Research and Development grant with partner Leading Edge Geomatics: "Operational research of airborne topo-bathymetric lidar"



Tim Webster, Kate Collins, Nathan Crowell, Kevin McGuigan & Candace MacDonald + Contributions from Matt Roscoe,David Kristiansen, Calvin Gough, Tyler Yorke, Sean Dzafovic & Ariel Vallis

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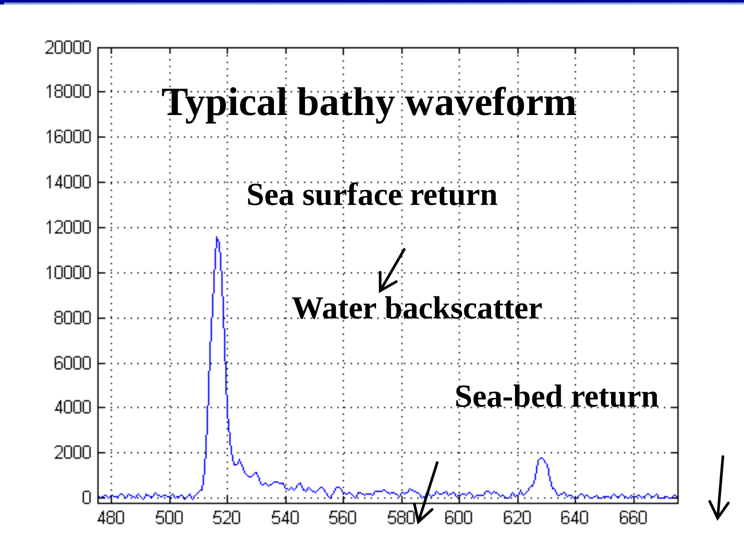
Research Scientist

Applied Geomatics Research Group

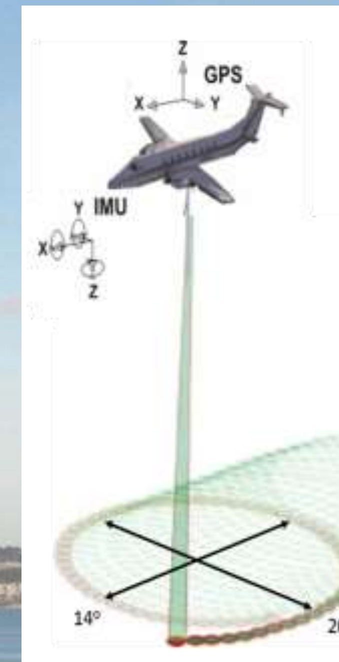
Centre Of Geographic Sciences

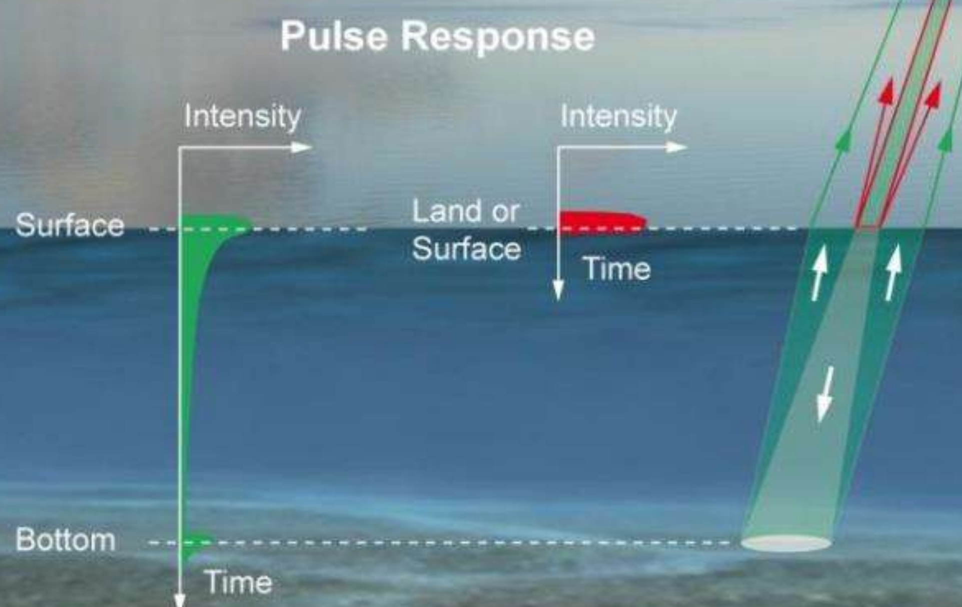
Nova Scotia Community College

# Chiroptera$_{II}$ – Lidar principles




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

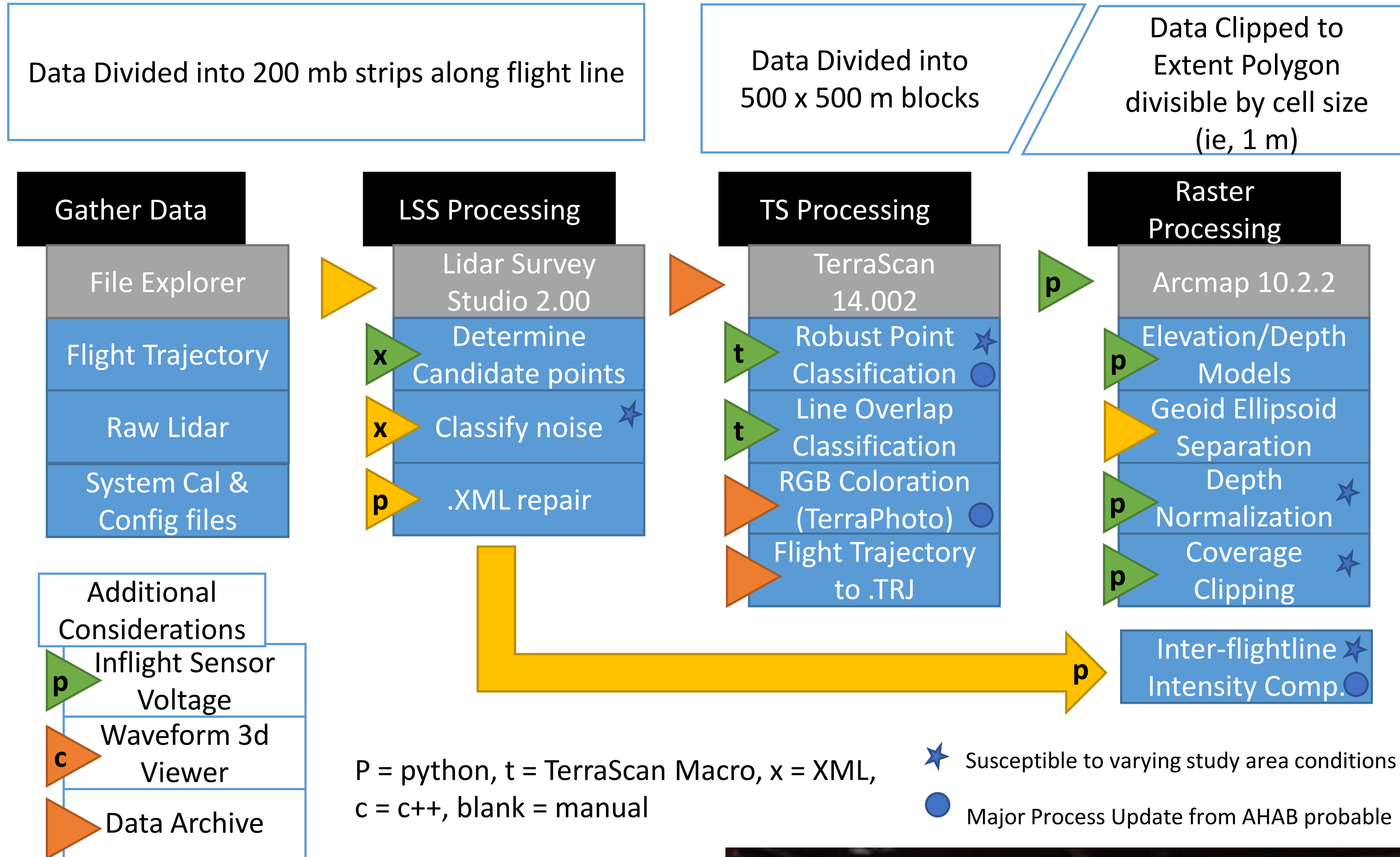



**Outline**

Intro Topo-bathy lidar
Lesson - Implementation
Turbidity management
Eelgrass mapping
Depth Normalization
Future surveys
Conclude

Source: Leica AHAB



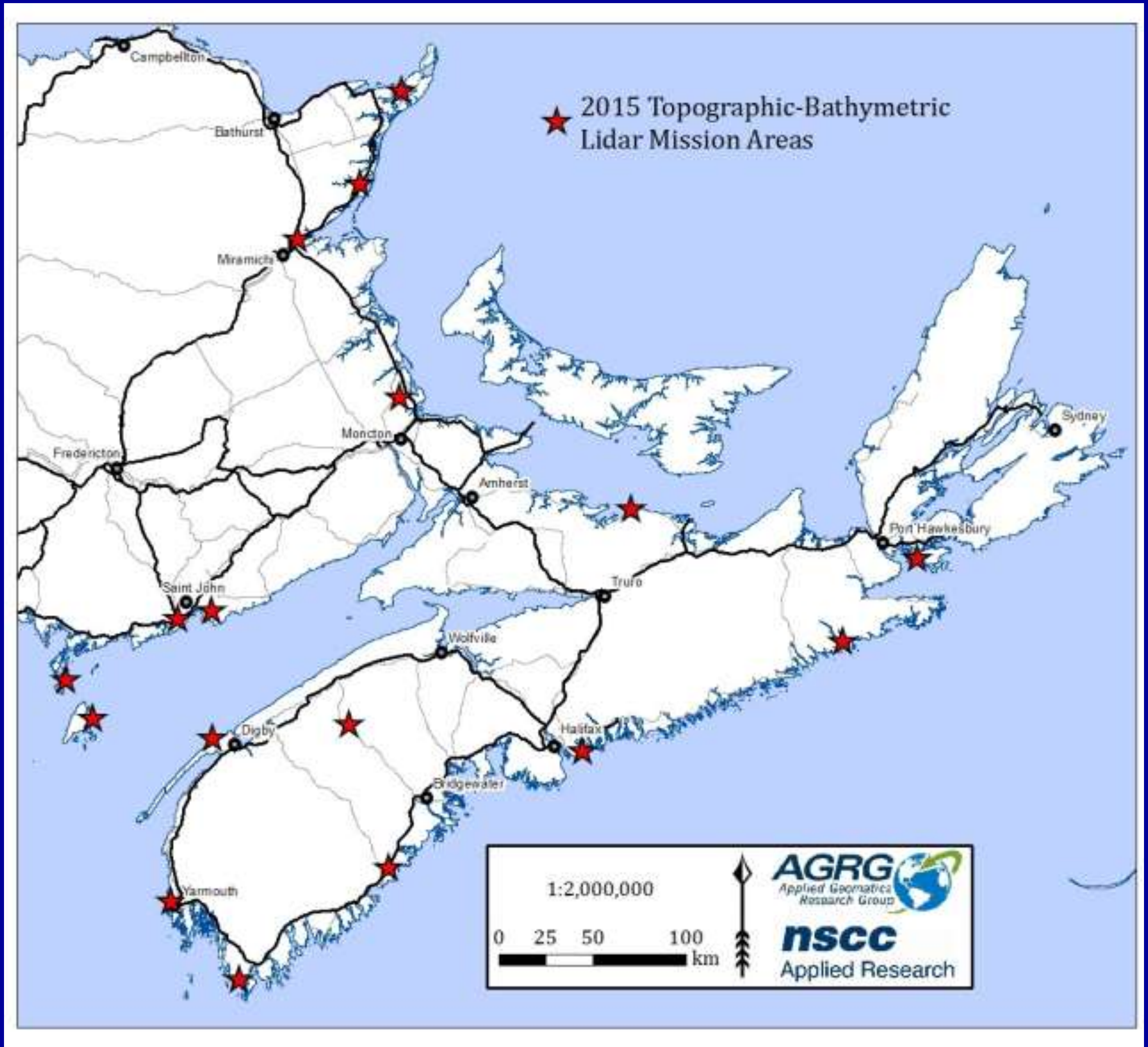

Project partner
Leading Edge Geomatics Aircraft



Leading Edge Geomatics

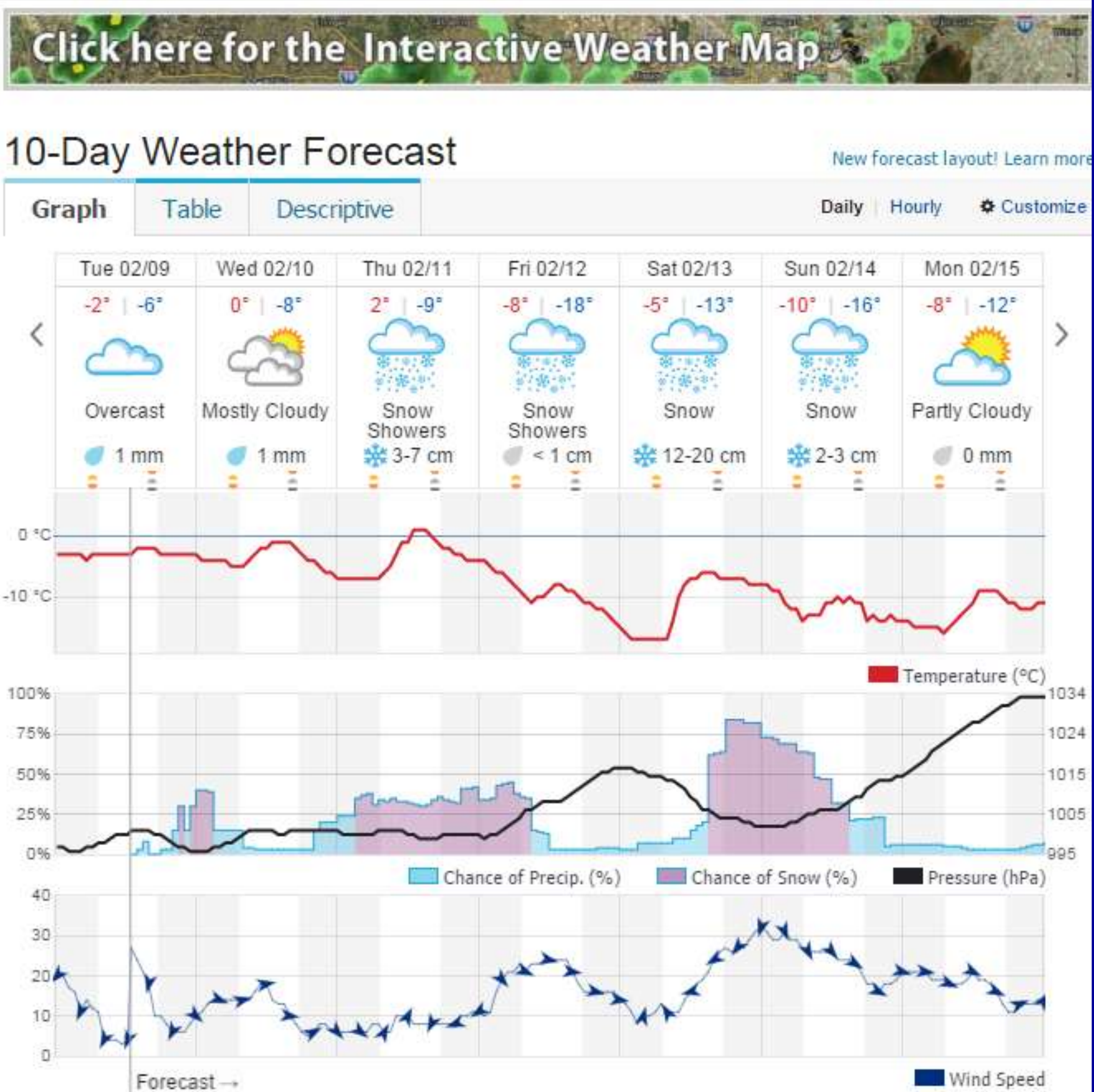
**We relied on weather forecasts and local knowledge for water clarity conditions, very challenging**

**Water clarity # 1 issue**
**Most surveys, better at low tide.**
**Most required good aerial photography (high sun angle to minimize shadow, but avoid glint)**



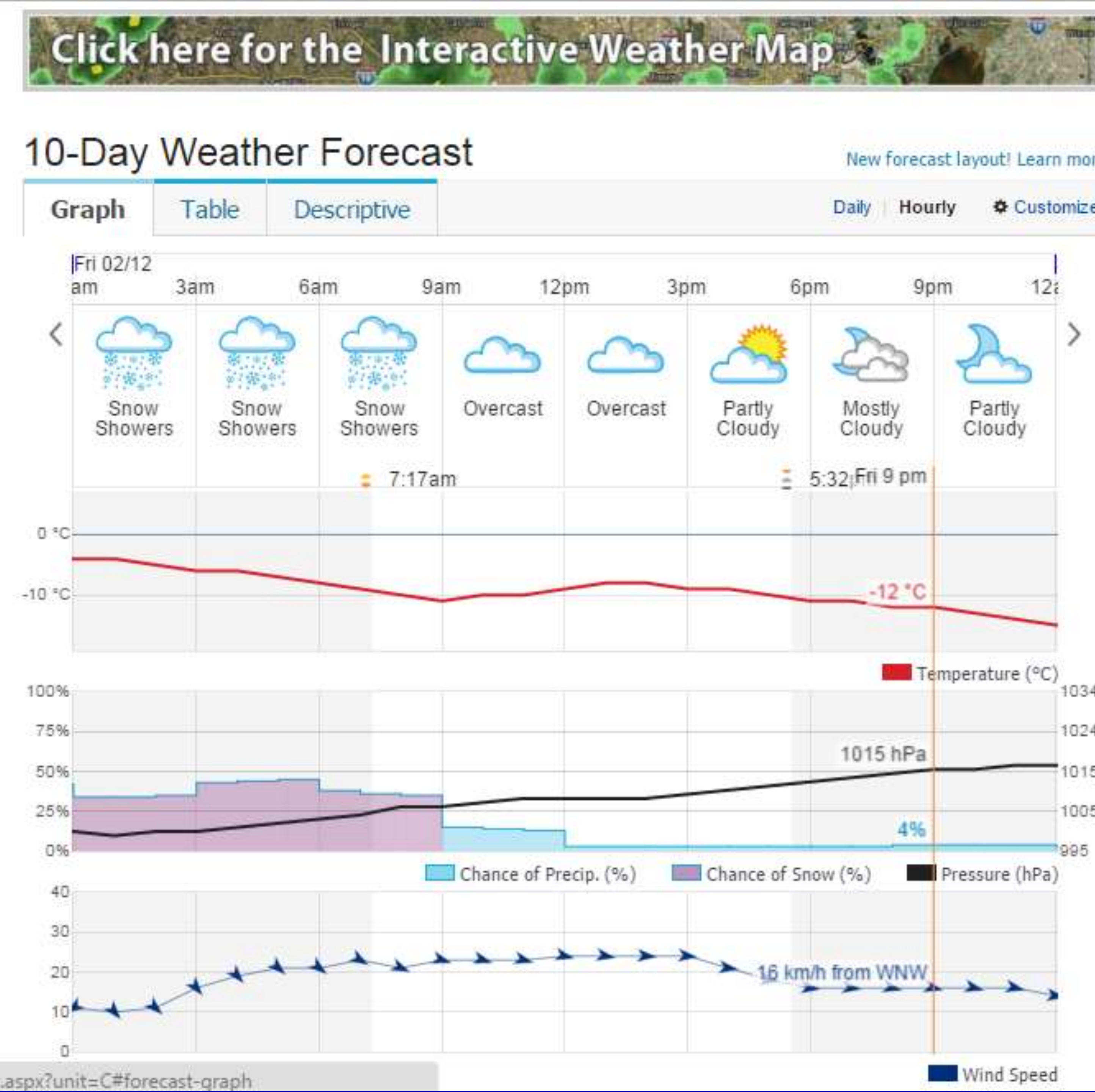

**Having multiple areas allowed us to choose optimal sites based on the:**

- **Forecast (wind, rain, cloud)**
- **Tide (tidal range)**
- **Orientation of the coastline (onshore or offshore wind)**
- **Exposure of the site**
- **Deployment of field crews**




**www.intellicast.com/**

**Daily & hourly forecast, presented graphically or tables**

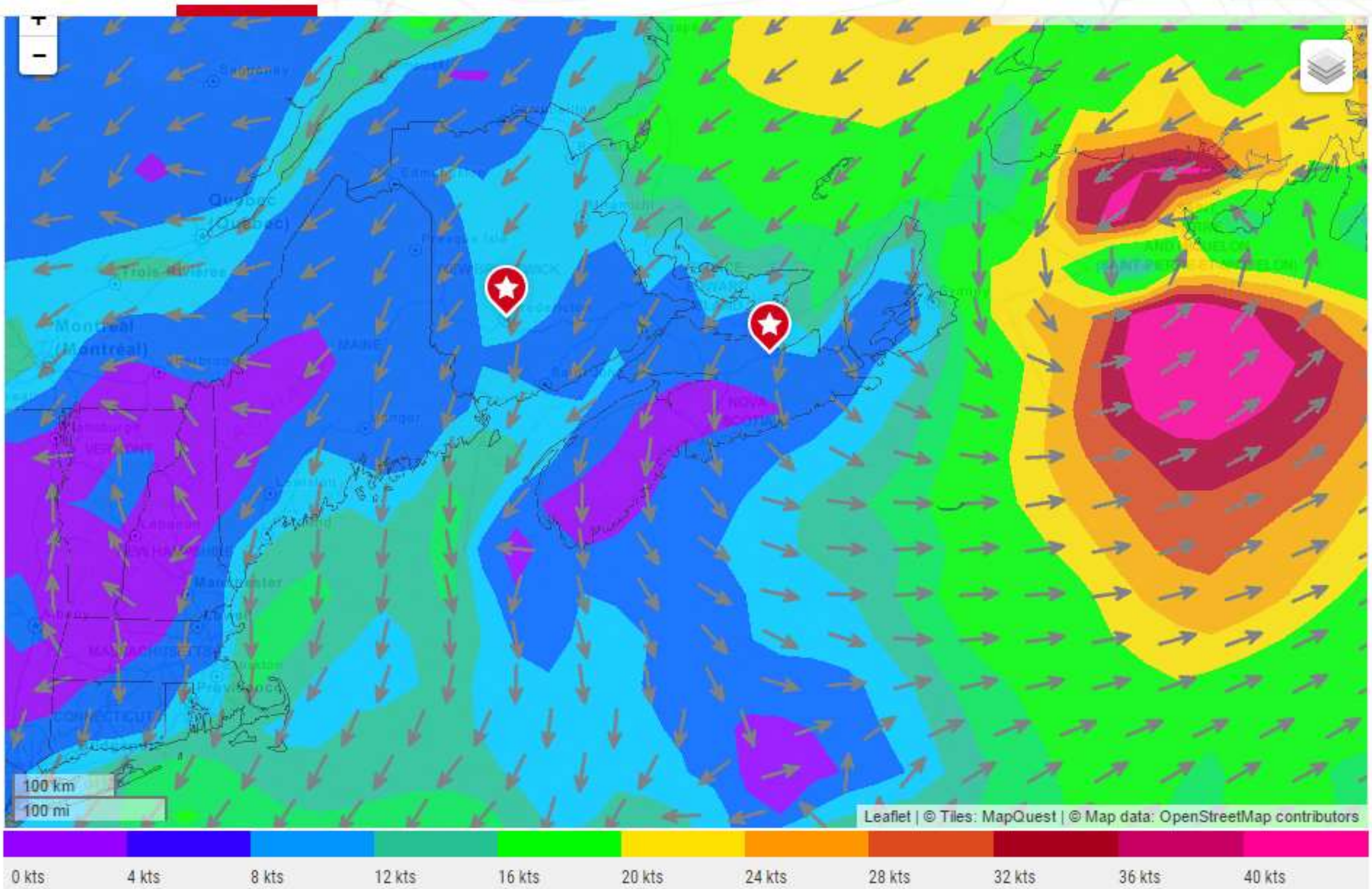



**Hourly forecast, Presented graphically or tables**

www.windfinder.com

**Can advance 3 hrs out to 6 days ahead**





## www.windfinder.com





Data based on our forecast model 7:21 AM 5:27 PM 1:11 PM (UTC -4) 39 m



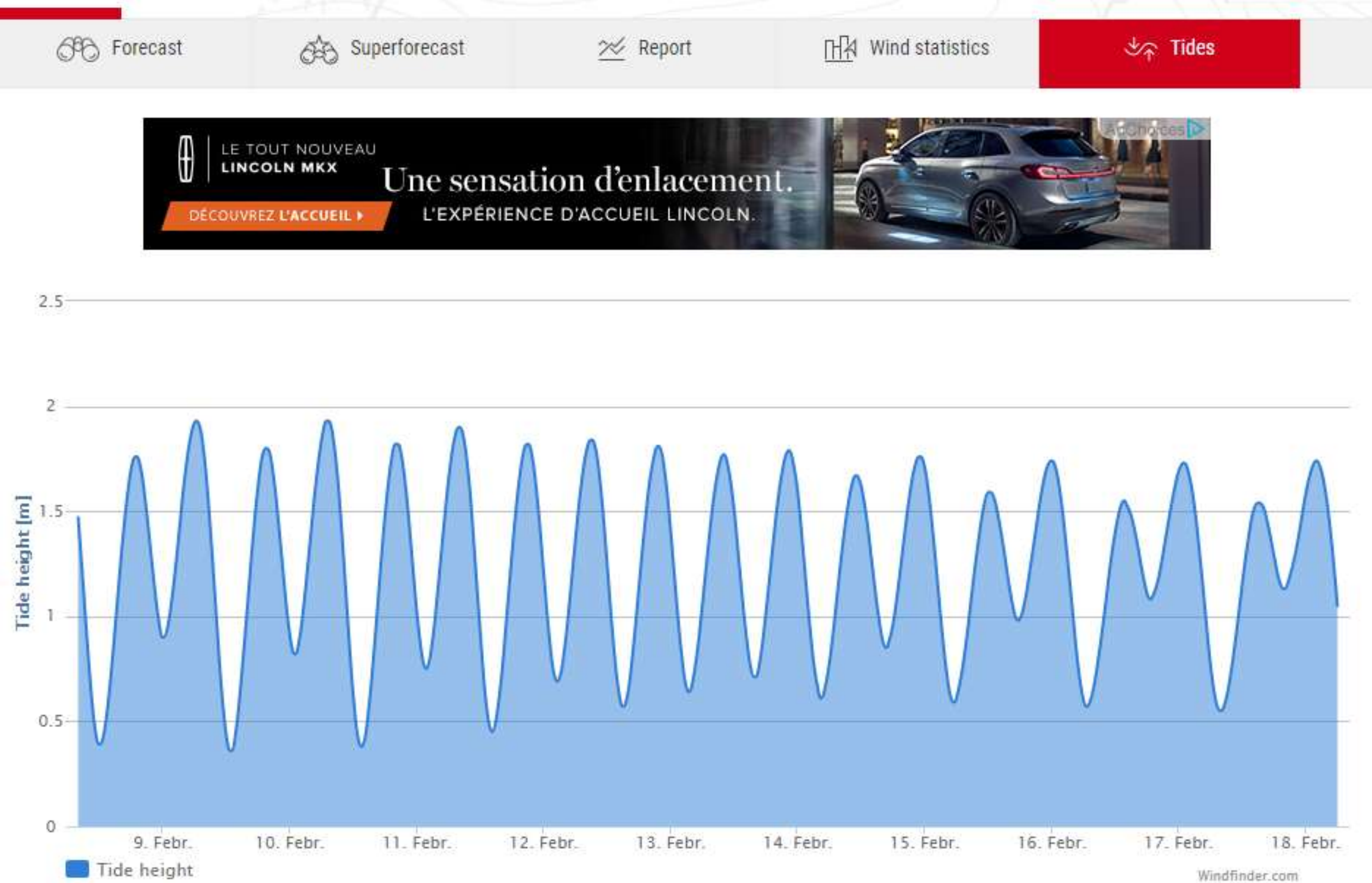
Last update: 12:38 local time

Print this forecast Embed this forecast

| Local date | Tuesday, Feb 09 | | | | | | | | Wednesday, Feb 10 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Local time | 02h | 05h | 08h | 11h | 14h | 17h | 20h | 23h | 02h | 05h | 08h | 11h | 14h | 17h | 20h | 23h |
| Wind direction | | | | | | | | | | | | | | | | |
| Wind speed (kts) | 19 | 16 | 15 | 10 | 7 | 4 | 3 | 5 | 8 | 9 | 7 | 10 | 8 | 4 | 1 | 2 |
| Wind gusts (max kts) | 32 | 26 | 25 | 17 | 12 | 6 | 4 | 8 | 14 | 18 | 15 | 17 | 12 | 5 | 1 | 3 |
| Cloud cover | | | | | | | | | | | | | | | | |
| Precipitation type | *** | ** | *** | ** | ** | | | | | | | | | | | |
| Precipitation (mm/3h) | 12 | 4 | 7 | 2 | 3 | | | | | | | | | | | |
| Air temperature (°C) | -2 | -2 | -2 | -2 | -1 | -3 | -4 | -3 | -3 | -4 | -5 | -3 | -2 | -3 | -11 | -8 |
| Air pressure (hPa) | 992 | 992 | 994 | 996 | 996 | 995 | 993 | 991 | 992 | 994 | 995 | 996 | 995 | 996 | 997 | 996 |
| Wave direction | | | | | | | | | | | | | | | | |
| Wave height (m) | 1.4 | 1.5 | 1.4 | 1.0 | 0.7 | 0.4 | 0.3 | 0.2 | 0.3 | 0.5 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 |
| Wave period (s) | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 |

# Can look at the predicted tides also



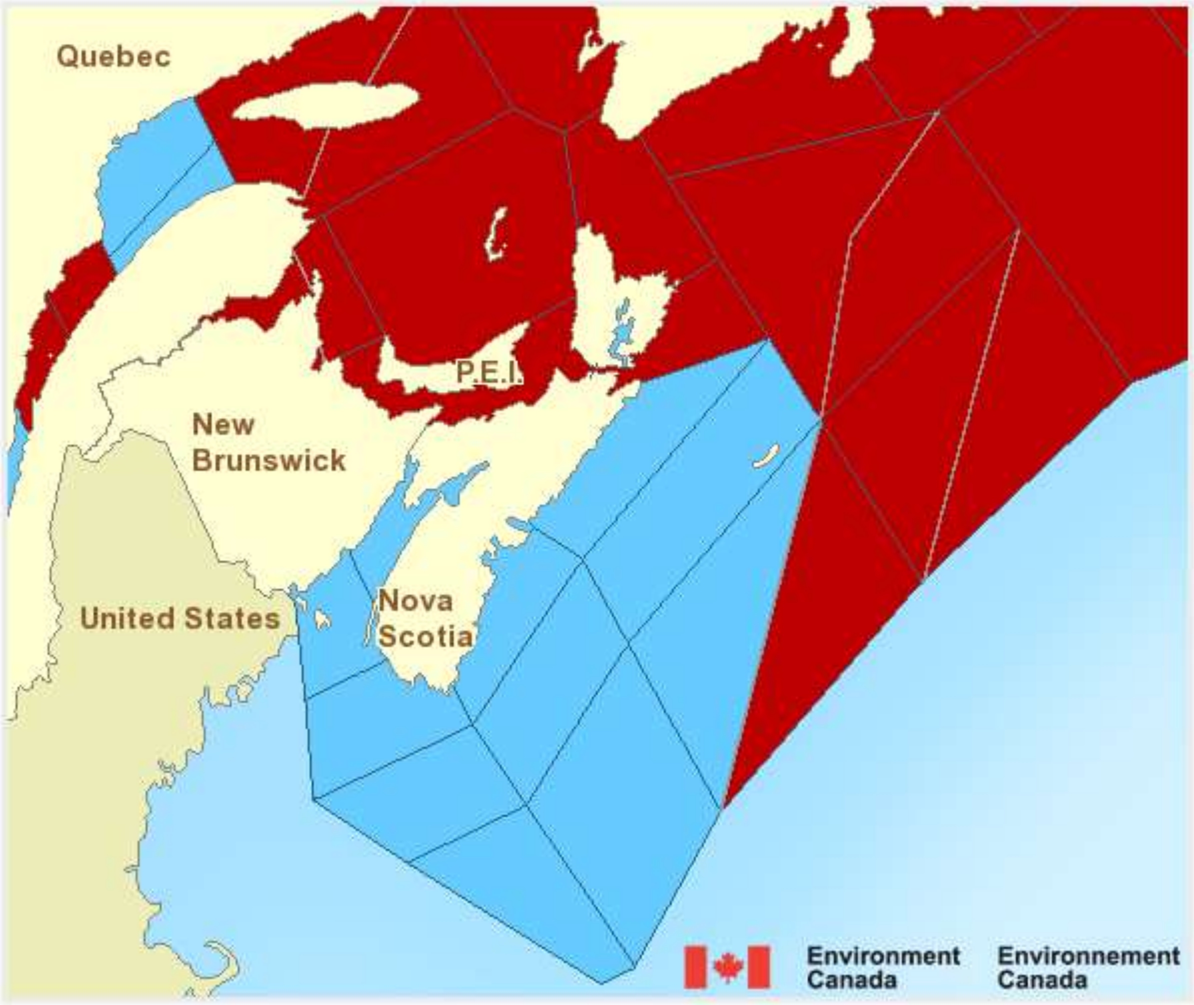


https://weather.gc.ca/marine/



# Marine Weather for: Atlantic - Maritimes

Click on the coloured marine region for which you would like the marine forecast or latest warning




Warning

Advisory

https://weather.gc.ca/marine/

**Marine forecast has more information on wind and waves**
**Can also access weather stations on land and buoys**



| | | | |
|---|---|---|---|
| Wind (**knots**) | NNE 18 gust 25 | Air temperature (°C) | -7 |
| Conditions | N/A | Relative humidity (%) | 91 |
| Visibility (km) | 1 | Dew point temperature (°C) | -8 |
| Pressure and tendency (kPa) | 100.6 ↓ | Wind Chill | -15 |
| Sunrise | 7:36 AST | Sunset | 17:31 AST |

**Select a location below:**

Select a Buoy or Land Station ▾ Go

# Can examine the past 24 hours for weather stations



Forecast | Weather Conditions | Ice Conditions | Warnings | Synopsis

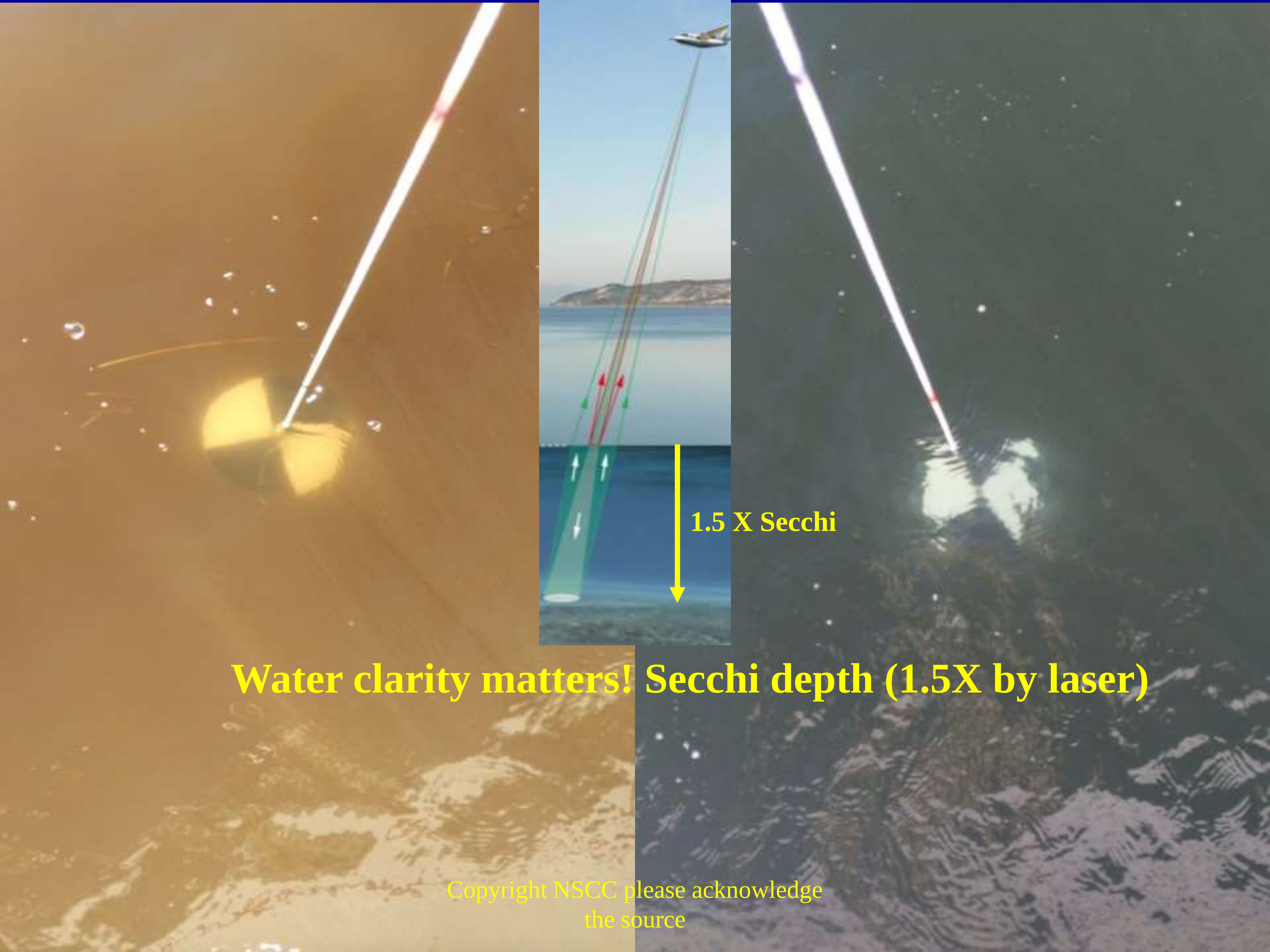
Current Conditions | Past 24 Hour Conditions | Regional Summary

## Bas Caraquet

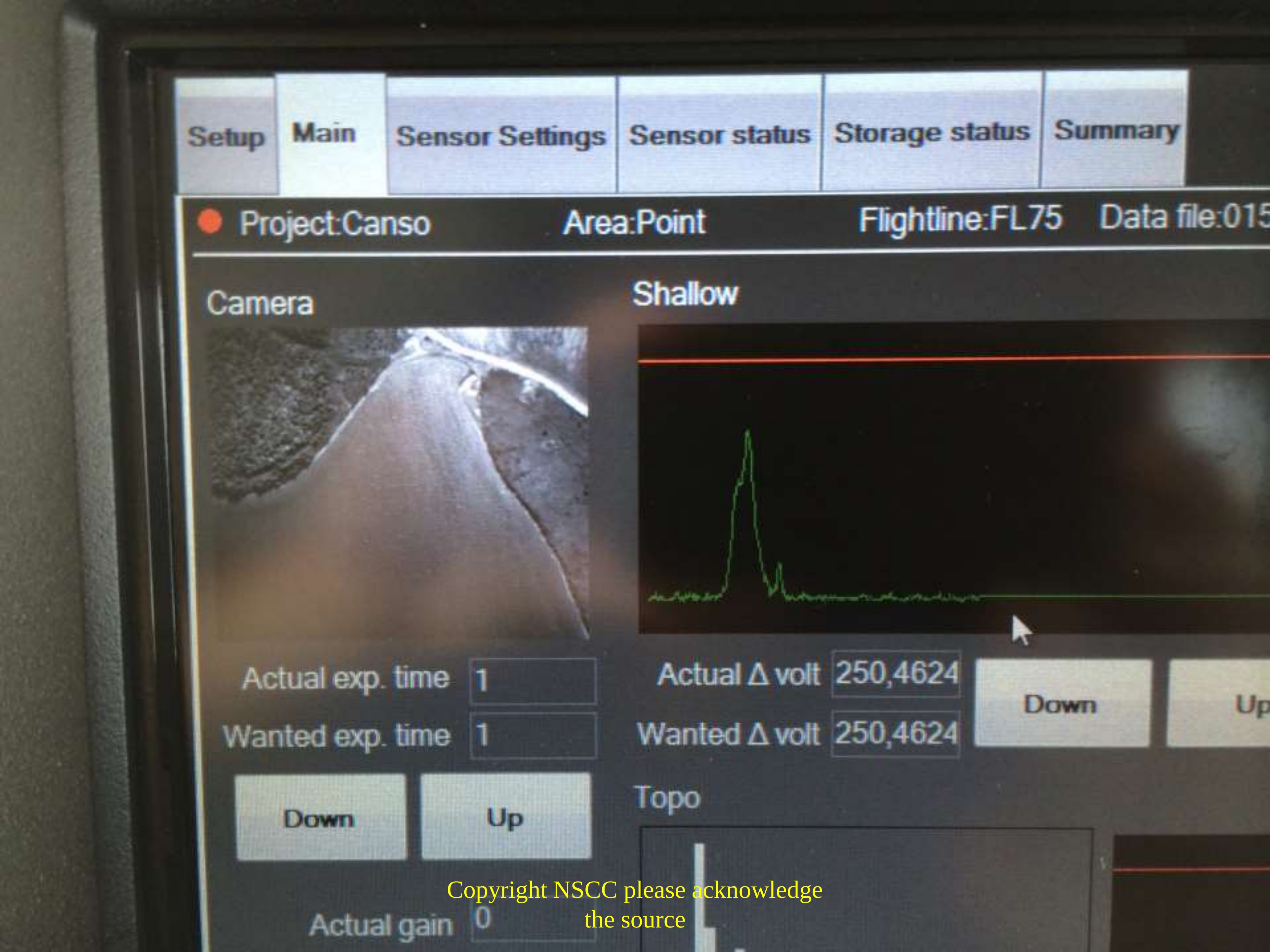
12:00 PM AST 09 February 2016

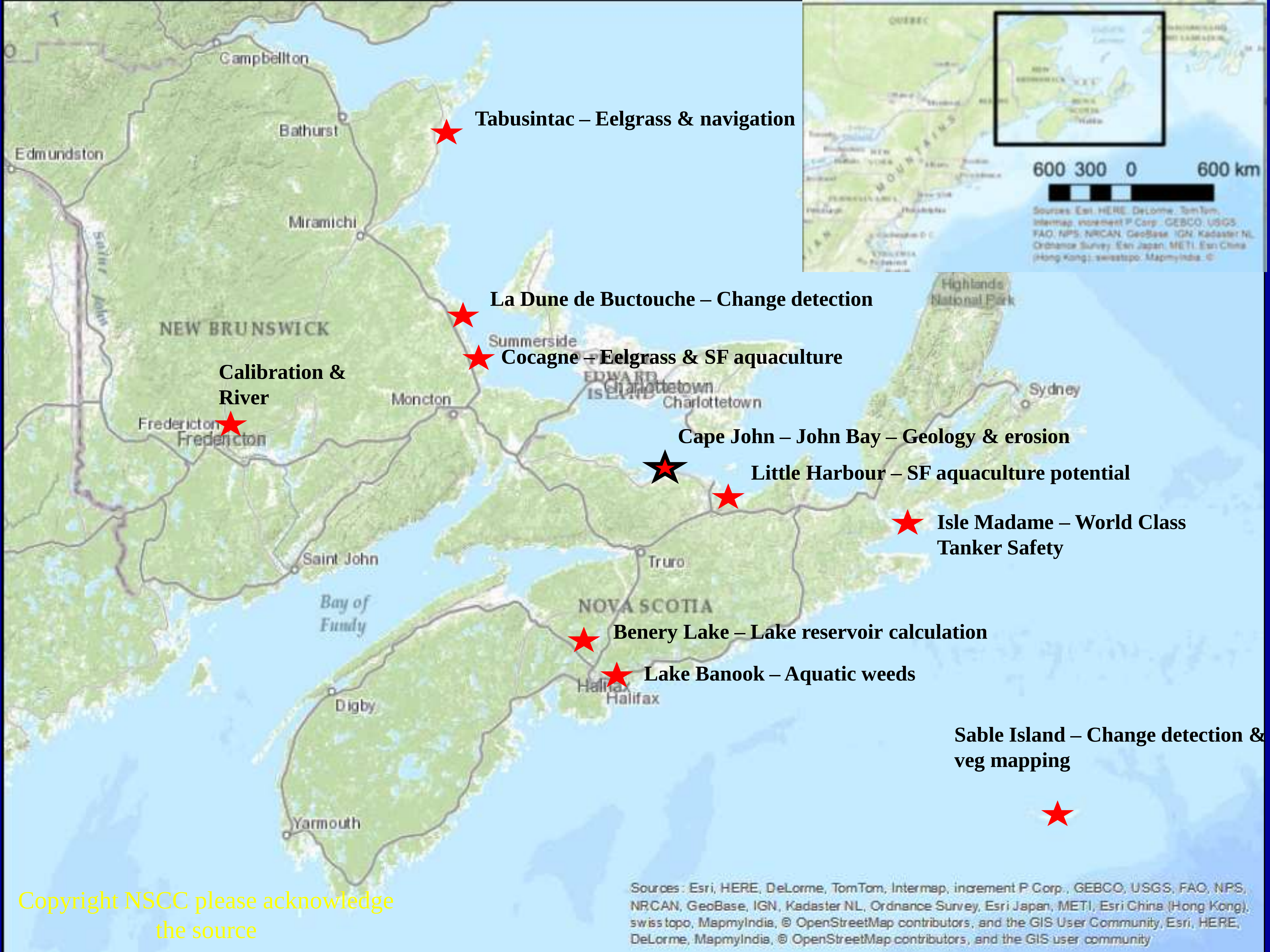
**This table is a summary of hourly weather conditions for the past 24 hours.**
**Please note that these observations might not always be representative of weather conditions over their associated marine area.**

| Date / Time (AST) | Wind **(knots)** | Conditions | Visibility (km) | Pressure (kPa) | Air temp (°C) | Relative humidity (%) | Dew point (°C) | Wind Chill |
|---|---|---|---|---|---|---|---|---|
| 09 February 2016 | | | | | | | | |
| 12:00 | NE 23 gust 29 | N/A | 0.9 | 100.7 | -7 | 91 | -8 | -17 |
| 11:00 | NE 21 gust 27 | N/A | 1 | 100.7 | -7 | 91 | -8 | -16 |
| 10:00 | NE 20 gust 32 | N/A | 1 | 100.7 | -7 | 91 | -8 | -16 |
| 9:00 | NNE 23 gust 33 | N/A | 0.5 | 100.7 | -7 | 91 | -8 | -17 |
| 8:00 | NE 21 gust 32 | N/A | 0.3 | 100.8 | -7 | 92 | -8 | -16 |
| 7:00 | NE 24 gust 31 | N/A | 0.4 | 100.8 | -7 | 91 | -8 | -17 |
| 6:00 | NE 26 gust 35 | N/A | 0.3 | 100.9 | -7 | 91 | -8 | -17 |

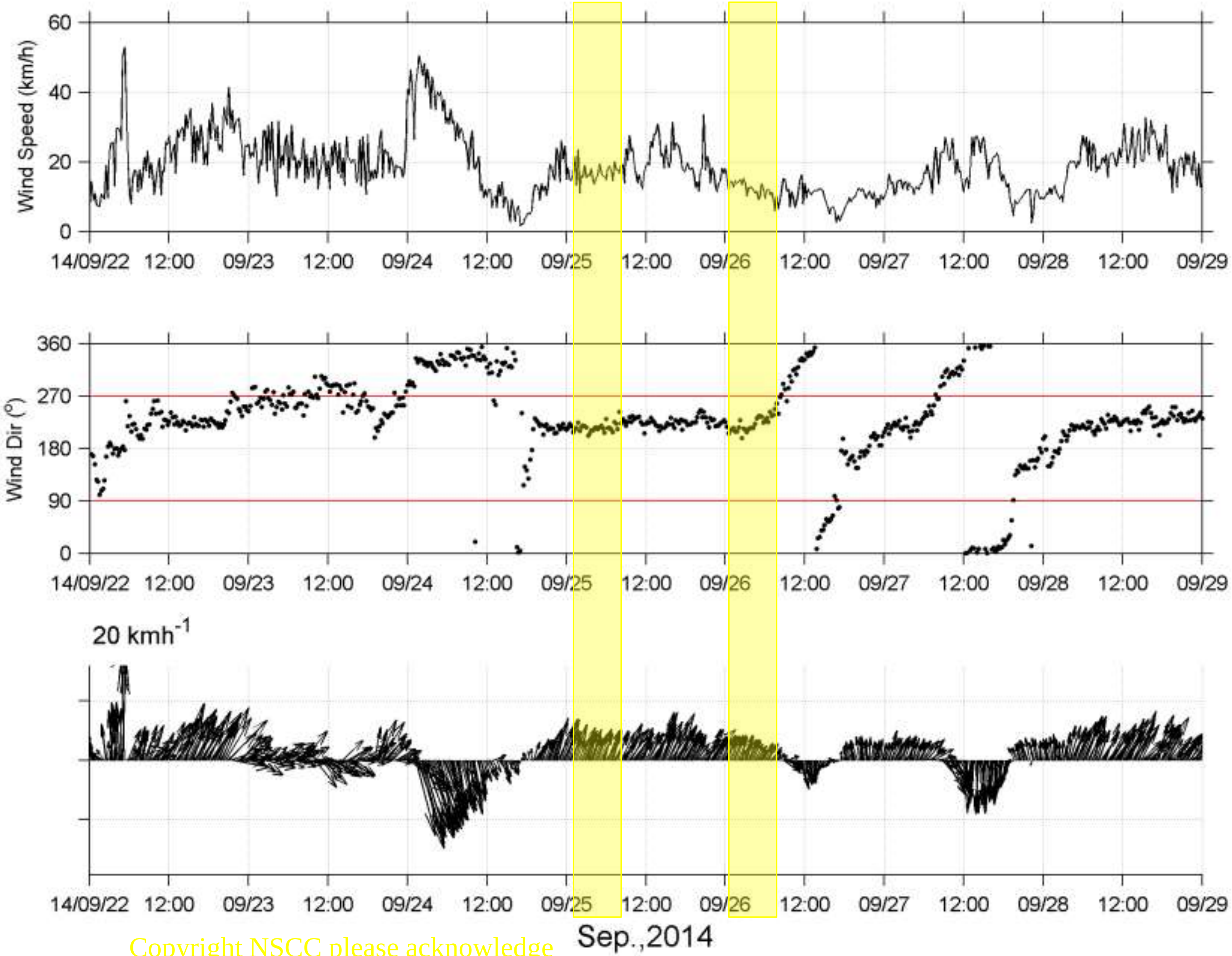


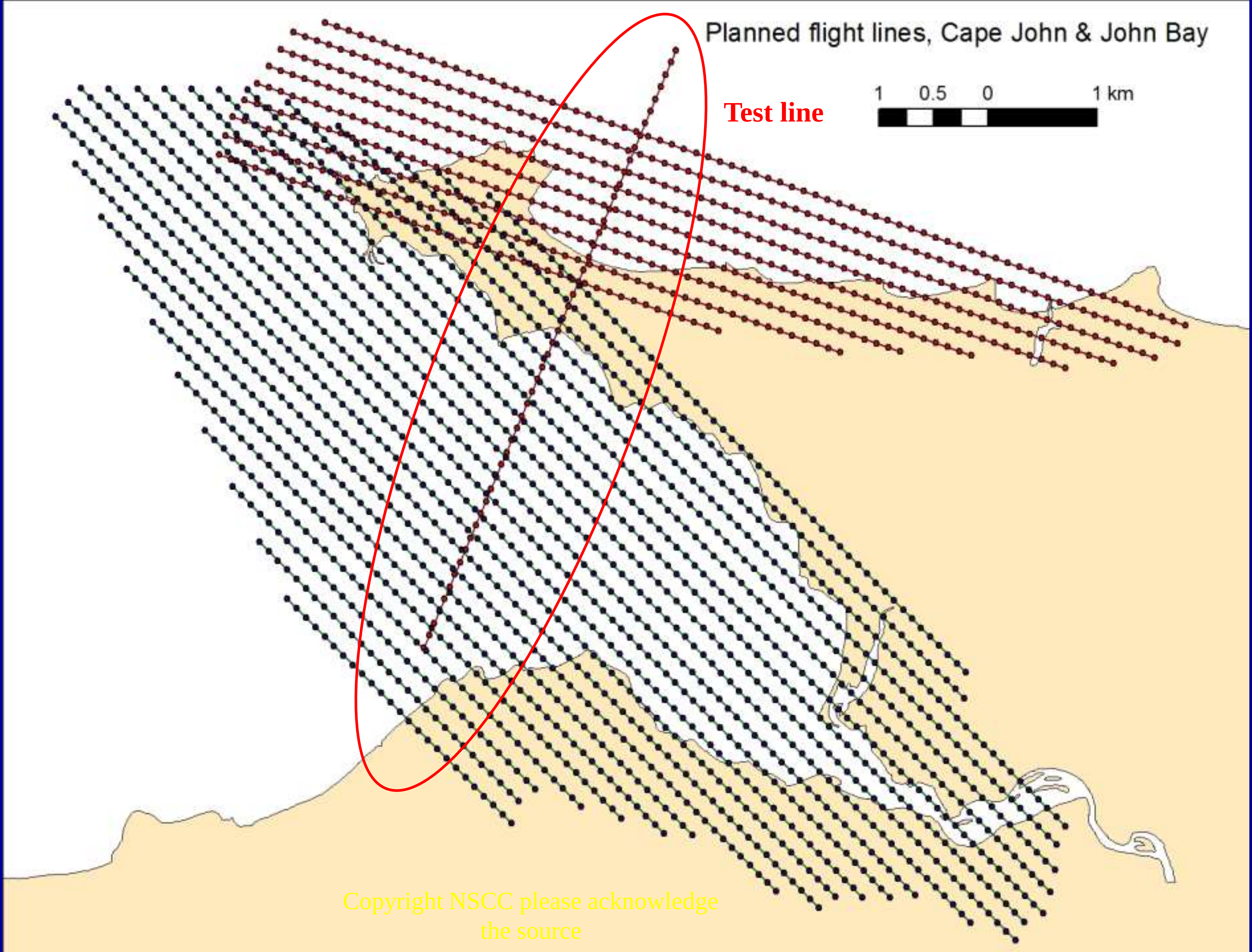

# Water clarity matters! Secchi depth (1.5X by laser)


Setup
Main
Sensor Settings
Sensor status
Storage status
Summary
Project:Canso
Area:Point
Flightline:FL75
Data file:015
Camera
Shallow
Actual exp. time
1
Wanted exp. time
1
Actual Δ volt
250,4624
Wanted Δ volt
250,4624
Down
Up
Down
Up
Topo
Actual gain
0

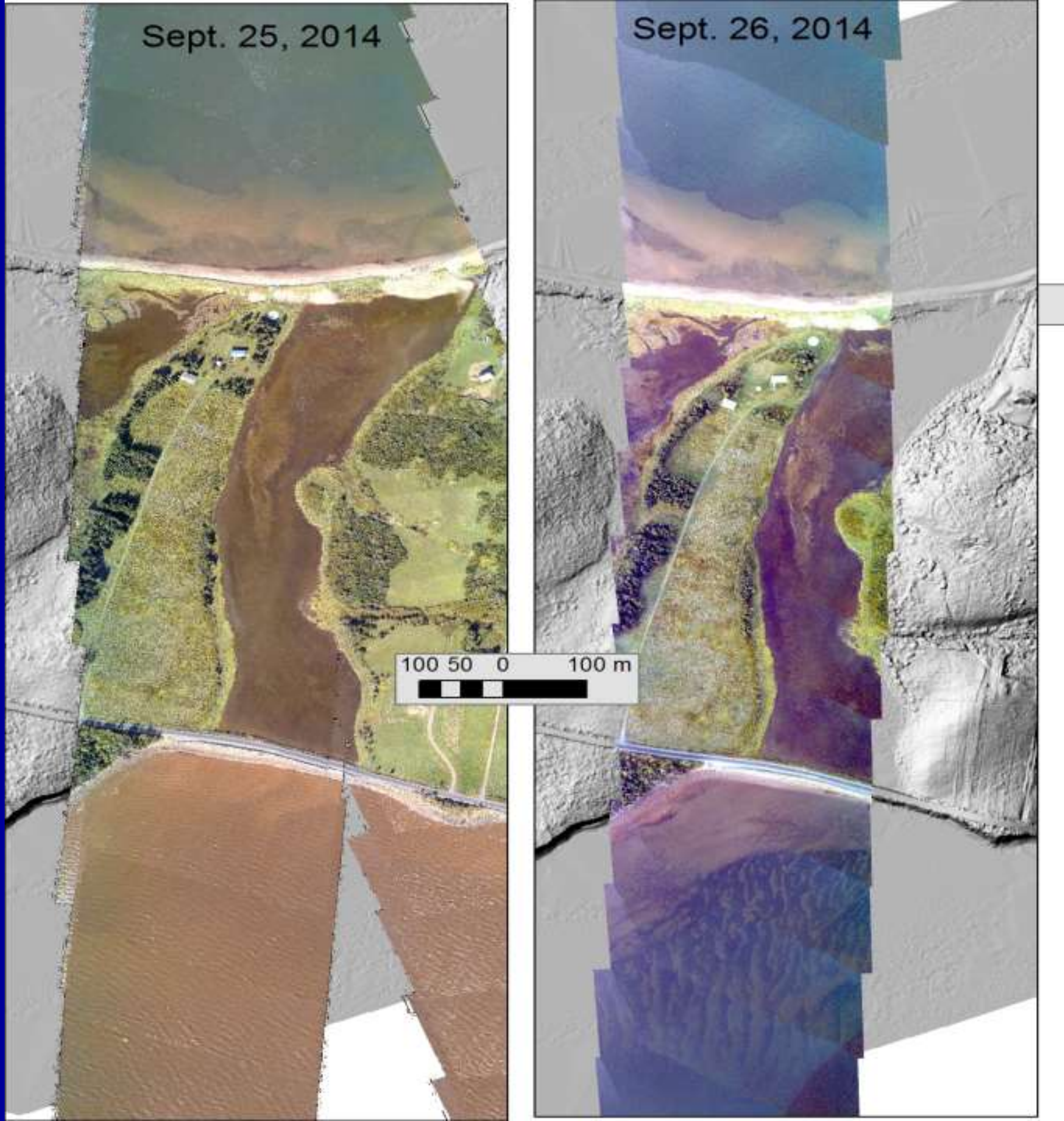

Tabusintac – Eelgrass & navigation
La Dune de Buctouche – Change detection
Cocagne – Eelgrass & SF aquaculture
Calibration & River
Cape John – John Bay – Geology & erosion
Little Harbour – SF aquaculture potential
Isle Madame – World Class Tanker Safety
Benery Lake – Lake reservoir calculation
Lake Banook – Aquatic weeds
Sable Island – Change detection & veg mapping
Campbellton
Bathurst
Edmundston
Miramichi
NEW BRUNSWICK
Summerside
Moncton
Fredericton
Charlottetown
Sydney
Highlands National Park
Saint John
Truro
Bay of Fundy
NOVA SCOTIA
Halifax
Digby
Yarmouth
600 300 0 600 km
Sources: Esri, HERE, DeLorme, TomTom, 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, Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

# AGRG Weather Stn. Cape John, Sept. 22-29




Planned flight lines, Cape John & John Bay
Test line
1 0.5 0 1 km

**Flight on the 25th aborted do to poor lidar returns**

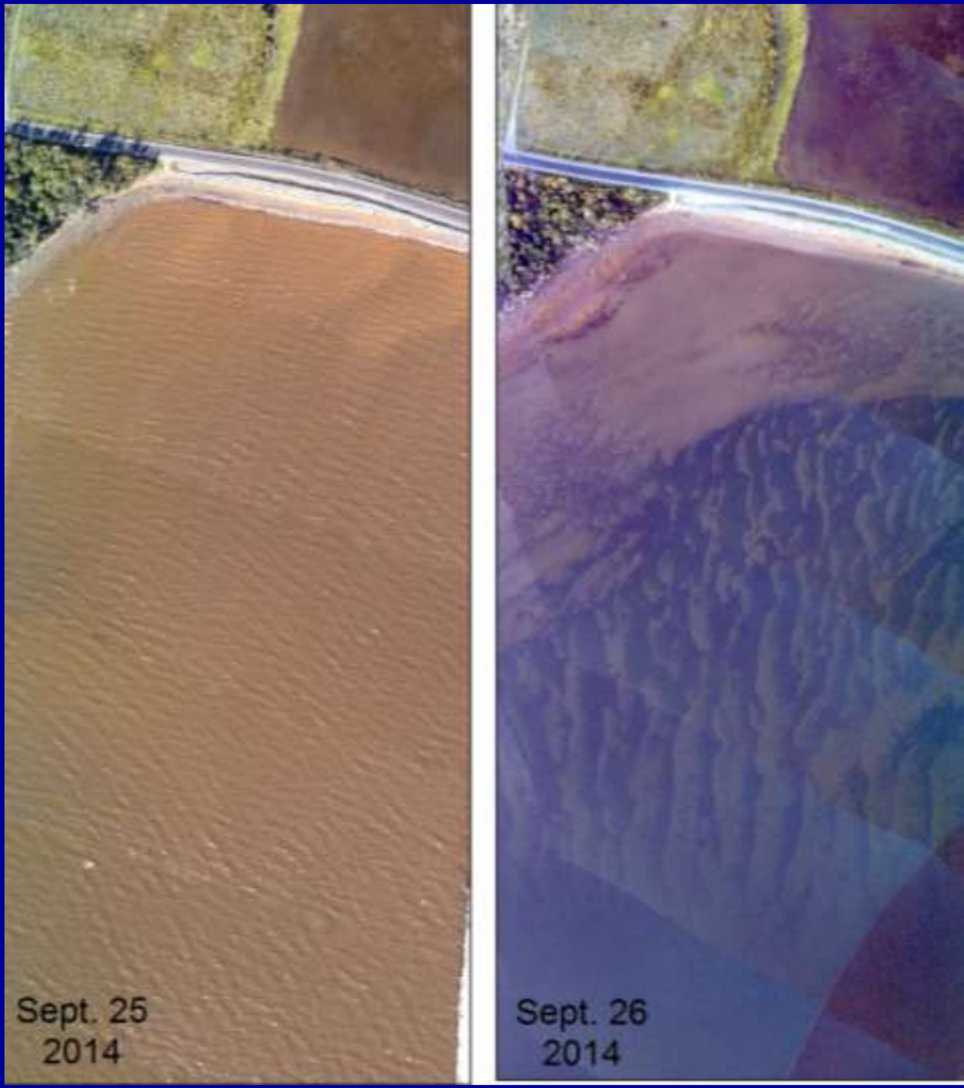


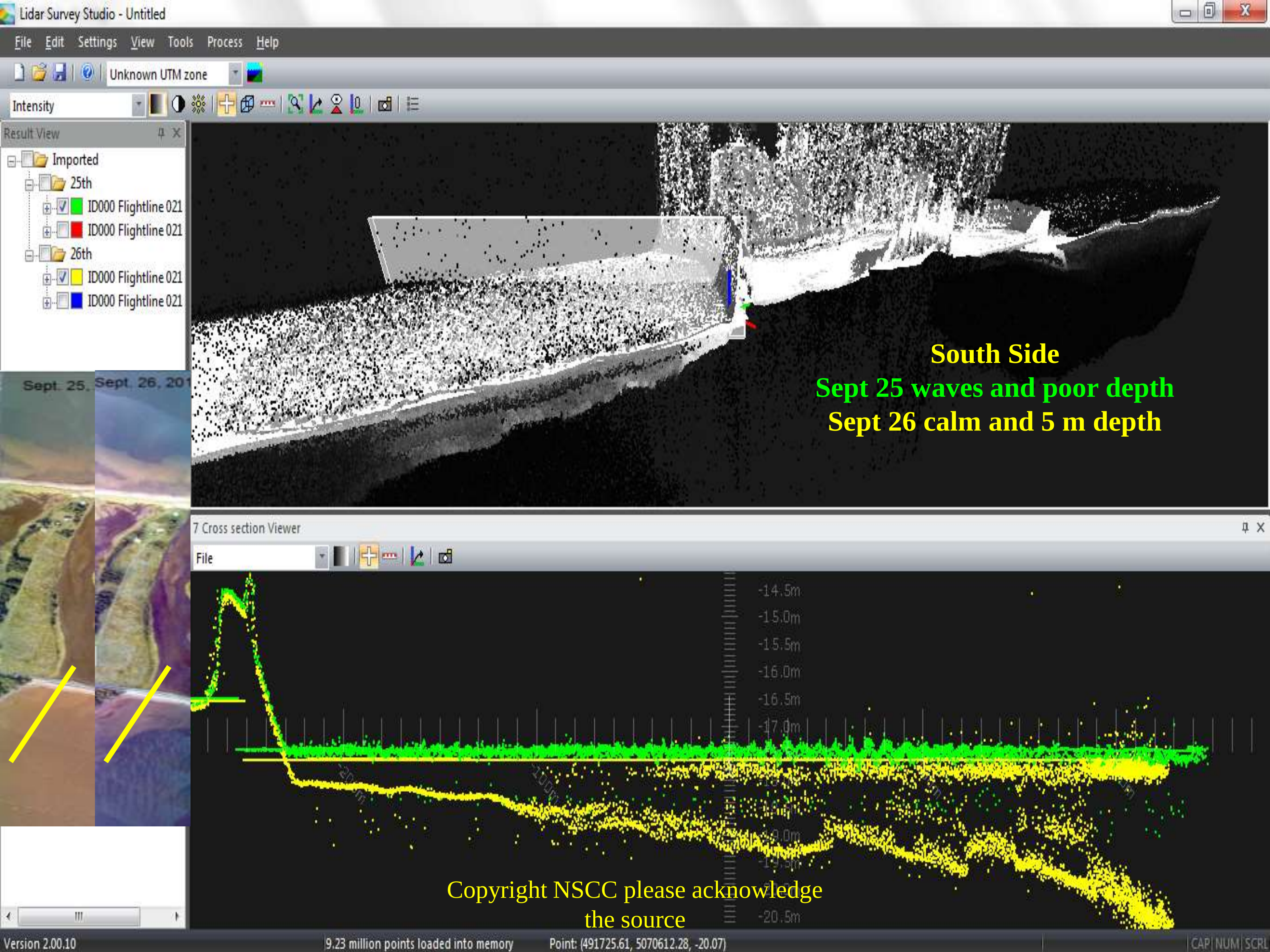

**Flight on the 26th proceeded with improved water quality**

# What a difference a day makes

## Turbidity management

- Cape John/John Bay had to be aborted Sept 25 due to poor water quality & surveyed Sept 26

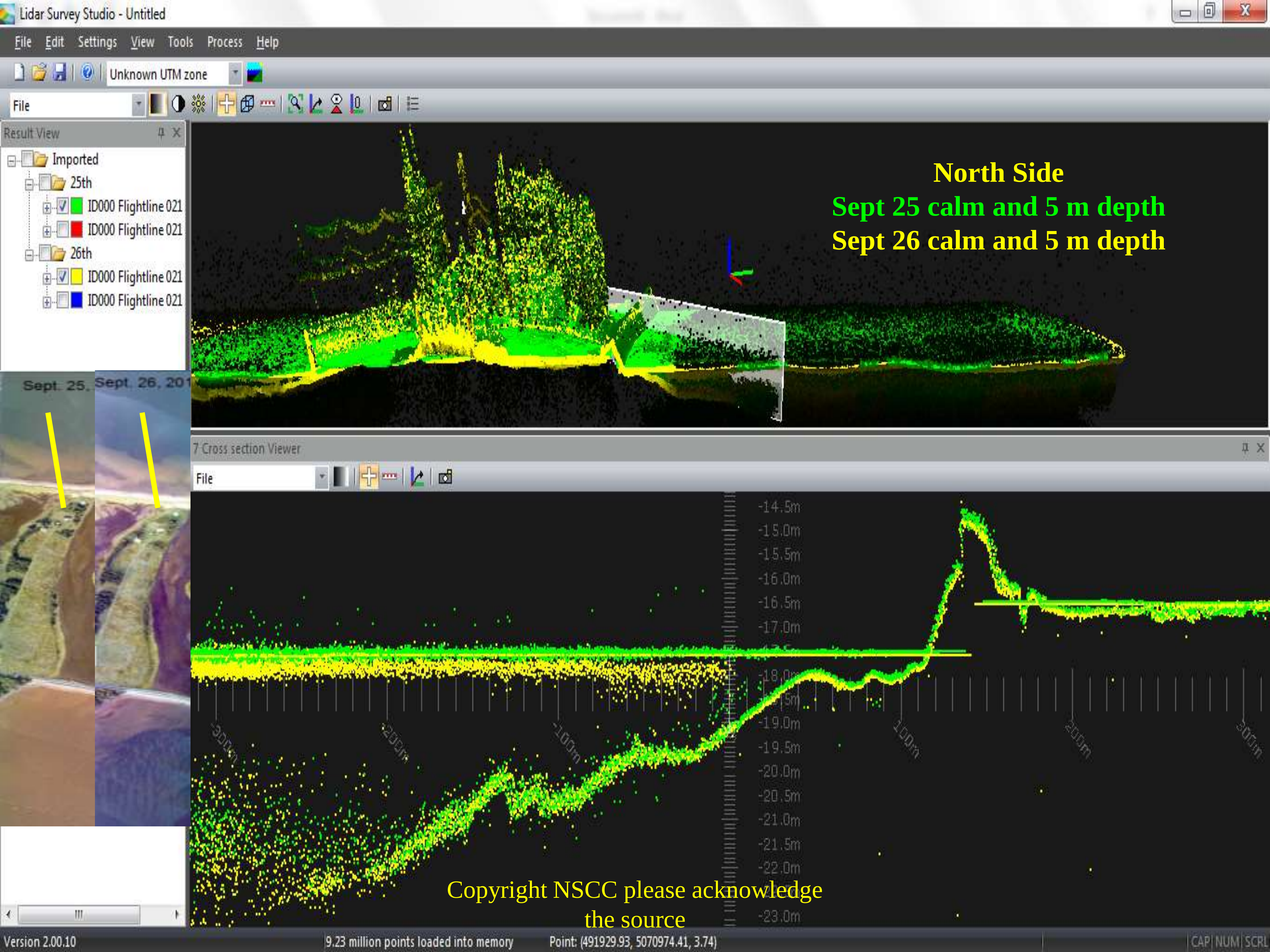


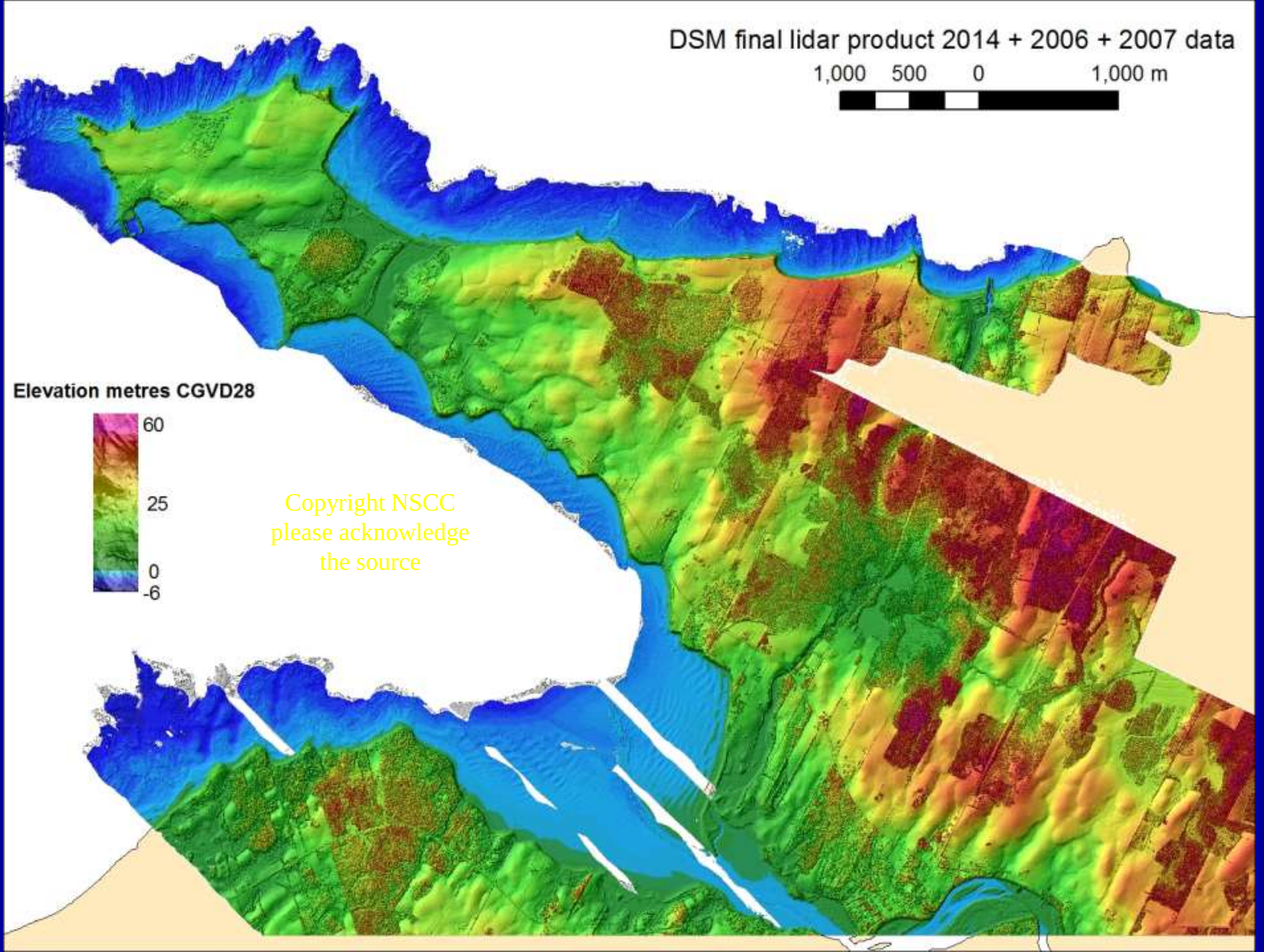

Lidar Survey Studio - Untitled
File Edit Settings View Tools Process Help
Unknown UTM zone
Intensity
Result View
Imported
25th
ID000 Flightline 021
ID000 Flightline 021
26th
ID000 Flightline 021
ID000 Flightline 021
Sept. 25
Sept. 26, 201
South Side
Sept 25 waves and poor depth
Sept 26 calm and 5 m depth
7 Cross section Viewer
File
-14.5m
-15.0m
-15.5m
-16.0m
-16.5m
-17.0m
-20.5m
Copyright NSCC please acknowledge
the source
Version 2.00.10
9.23 million points loaded into memory
Point: (491725.61, 5070612.28, -20.07)
CAP NUM SCRL

North Side

Sept 25 calm and 5 m depth

Sept 26 calm and 5 m depth




DSM final lidar product 2014 + 2006 + 2007 data
1,000 500 0 1,000 m
Elevation metres CGVD28
60
25
0
-6

# Optimization of data collection and refinement of post-processing techniques for Maritime Canada's first shallow water topographic-bathymetric lidar survey

**Timothy Webster[†], Kevin McGuigan[†], Nathan Crowell[†], Kate Collins[†] and Candace MacDonald[†]**

[†] Applied Geomatics Research Group, Nova Scotia Community College
Middleton, NS B0M 1M0, Canada

**New publication in a special issue "Advances in Topobathymetric Mapping, Models, and Applications"**

www.JCRonline.org

**ABSTRACT**

Webster, T.; McGuigan, K., Crowell, N., Collins, K., and MacDonald, C. 2016. Optimization of data collection and refinement of post-processing techniques for Maritime Canada's first shallow water topographic-bathymetric lidar survey *In:* Roberts, T.M., Rosati, J.D., and Wang, P. (eds.), *Advances in Topobathymetric Mapping, Models, and Applications*. Journal of Coastal Research, Special Issue, No. XX, pp. 7–14. Coconut Creek (Florida), ISSN 0749-0208.

An airborne topographic-bathymetric lidar survey was conducted for five coastal study sites in Maritime Canada in the fall of 2014 using the shallow water Leica AHAB Chiroptera II sensor. The sensor utilizes near infrared (NIR) and green lasers to map the topography, water surface and bathymetry, and is equipped with a 60 MPIX camera which results in 5 cm resolution colour and NIR orthophotos. Depth penetration of the lidar sensor is limited by water clarity, and because the coastal zone is vulnerable to reduced water clarity/increased turbidity due to fine-grained sediment suspended by wind induced waves, several techniques were employed to obtain maximum depth penetration of the sensor. These included monitoring wind speed, direction, and water clarity at study locations, surveying a narrow pass of the study area to assess depth penetration, and quickly adapting to changing weather conditions by altering course to an area where water clarity was less affected by wind induced turbidity. These techniques enabled 90% depth penetration at all five of the shallow embayments surveyed, and up to 6 m depth penetration in the exposed coastal region. Synchronous ground truth surveys were conducted to measure water depth and clarity and seabed cover during the surveys. GPS checkpoints on land indicated that the topographic lidar has an accuracy of better than 10 cm RMSE in the vertical. The amplitude of the green laser bathymetric returns provides information on bottom type and can be useful for generating maps of vegetation distribution. However, these data are not automatically compensated for water depth attenuation and signal loss in post-processing, which results in difficulties in interpreting the amplitude imagery derived from the green laser. We present an empirical approach to generate a depth normalized amplitude image which is merged with elevation derivatives to produce a 2 m resolution map product that is easily interpreted by end users. An eelgrass distribution model was derived from the bathymetric elevation parameters with 80% producer's accuracy.

**ADDITIONAL INDEX WORDS:** *Eelgrass, lidar seabed reflectance, depth normalization, seabed classification.*

# Light & Water

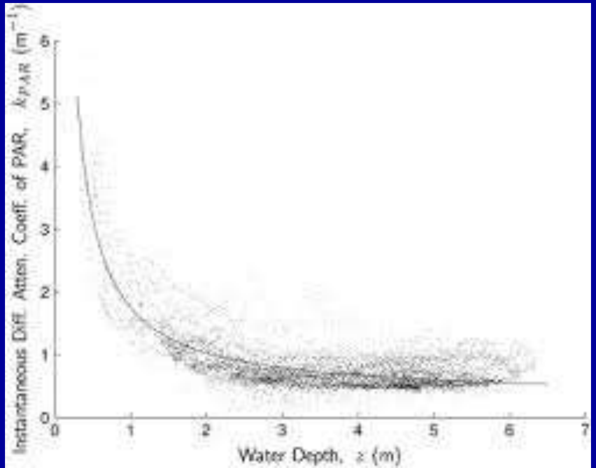
**One of the most common descriptors of the penetration of sunlight in water is the diffuse attenuation coefficient, K(λ), or Kd(λ)**

**K = K water + K dissolved organics + K particulates**

$$I_d = I_0 \, e^{-Kd}$$

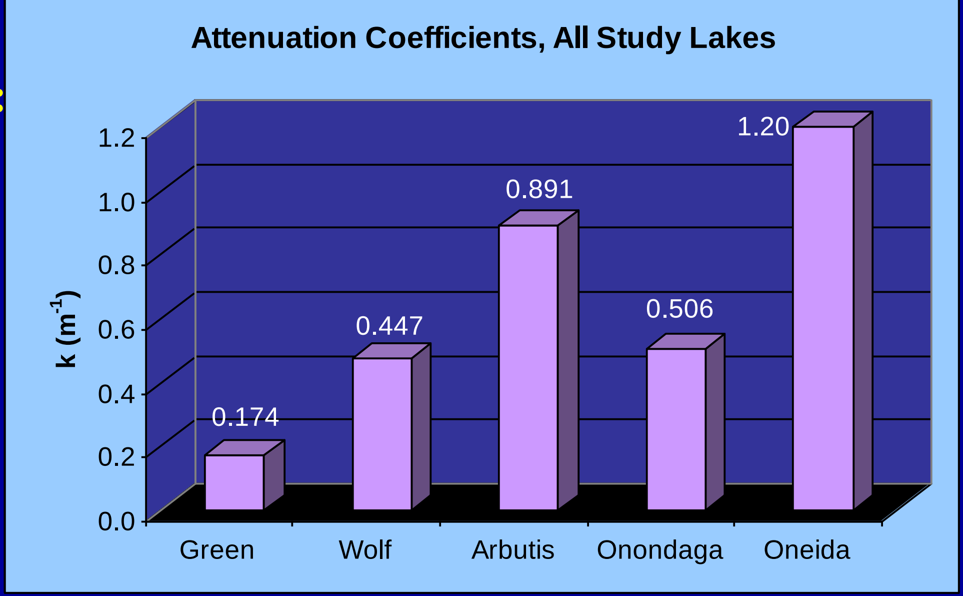
**$I_d$ – Intensity of light at water depth d (m)**
**$I_0$ – Intensity of light at surface**
**K – Diffuse attenuation coefficient**
**d - Water depth (m)**

***Exponential loss of light intensity with depth***
***K changes with turbidity***



## Relation between Secchi depth and K value:

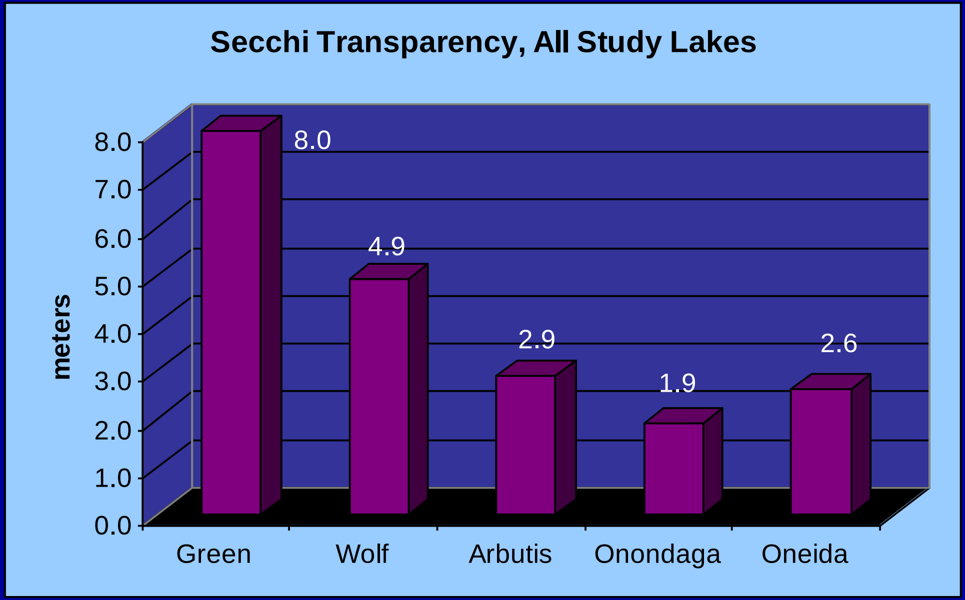
- **Empirical:**
  - ***K* = diffuse attenuation coeff.**
  - **$Z_s$ = Secchi depth**
  - **Drinking water K ≈ 0.06**




- **K = 0.1 → Secchi 16 m**
- **K = 0.5 → Secchi = 3.2 m**

$$Zs = \frac{1.6}{K}$$

**Zs = Secchi depth**




**Source: Leica AHAB**

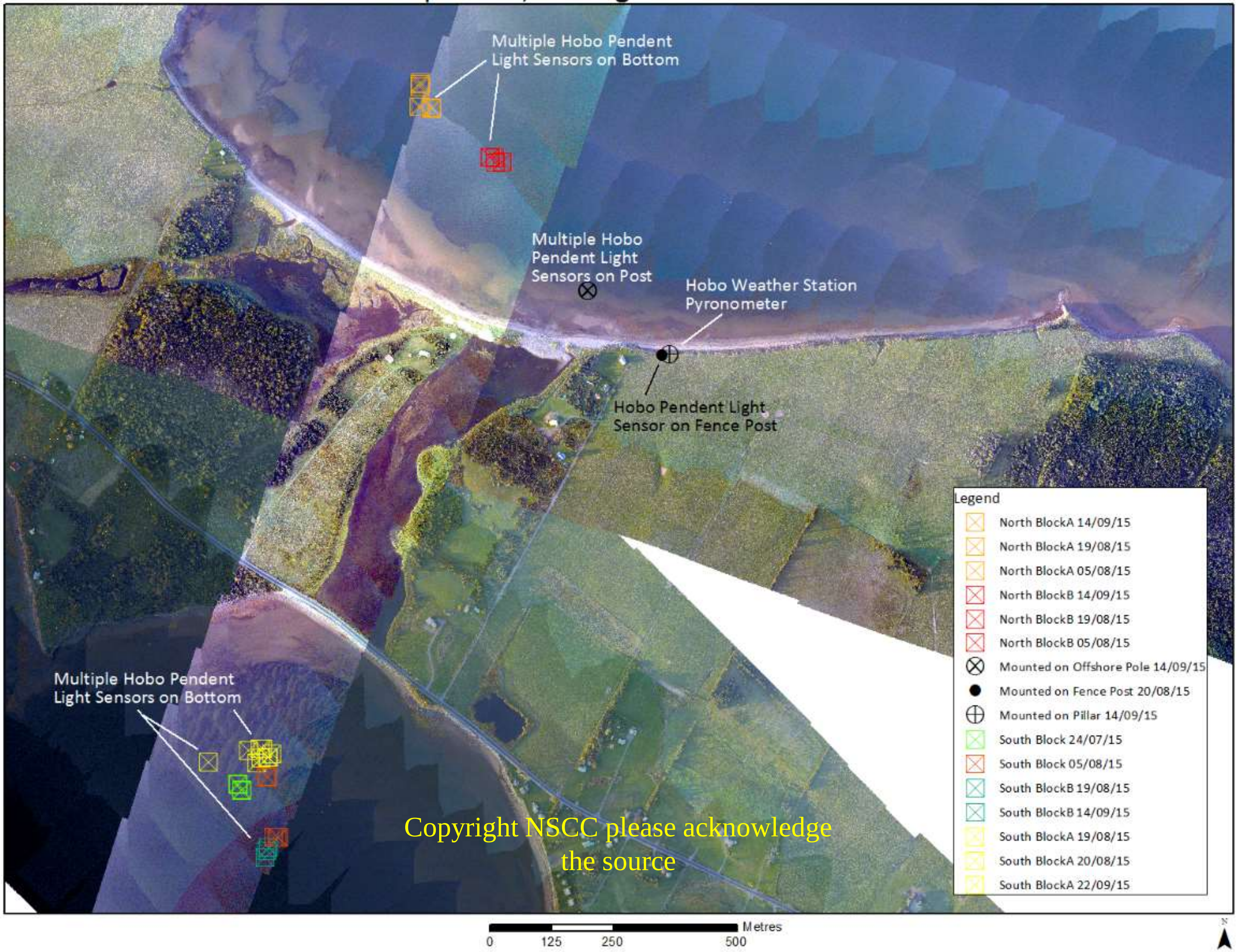
- k = 0.174 $m^{-1}$
- Secchi: 8 m

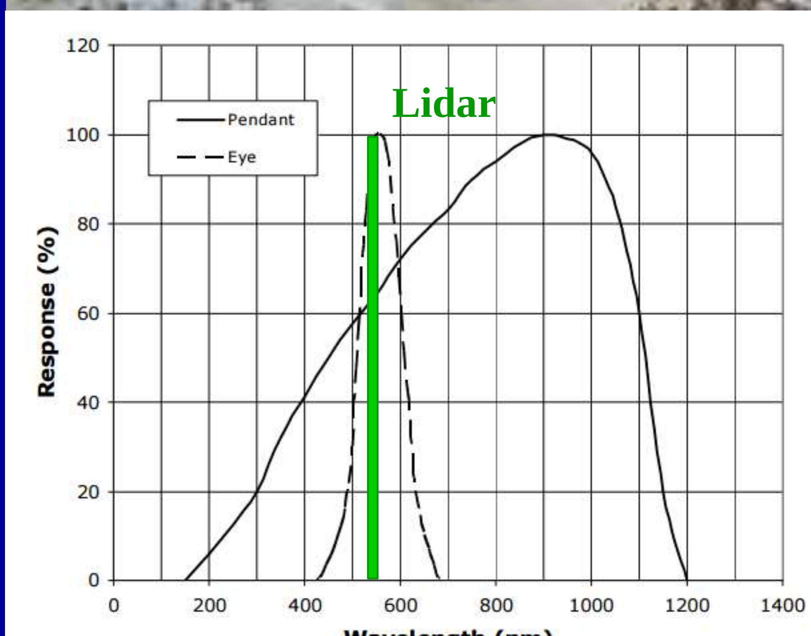
- k = 0.477 $m^{-1}$
- Secchi: 4.9 m

- k = 0.891 $m^{-1}$
- Secchi: 2.9 m

**Source www.earsel.org/Advances/4-1-1995/4-1_11_Gilabert.pdf**

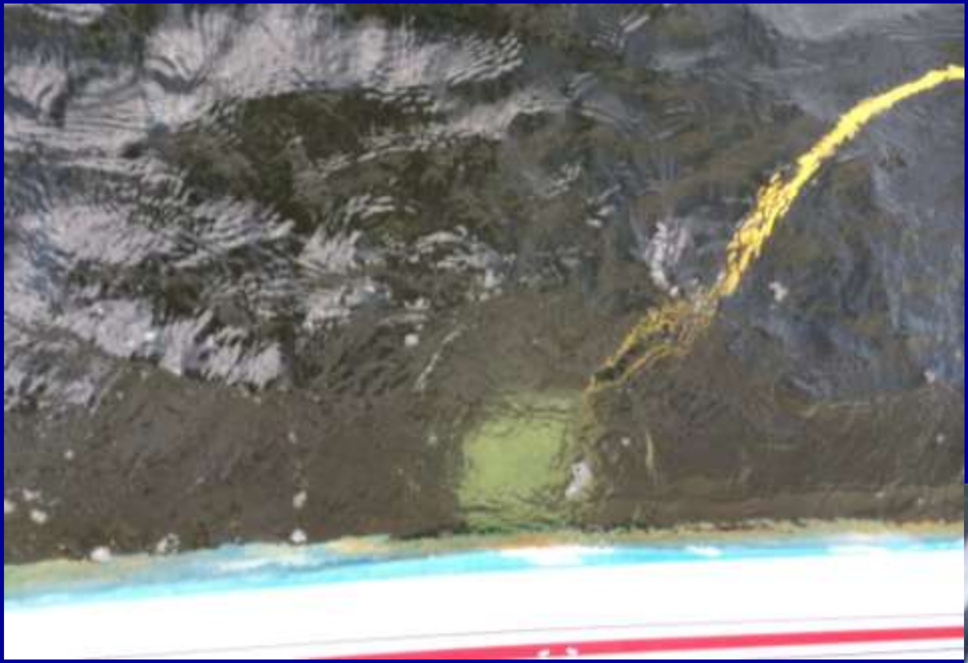
# Cape John, N.S. Light Sensor Locations



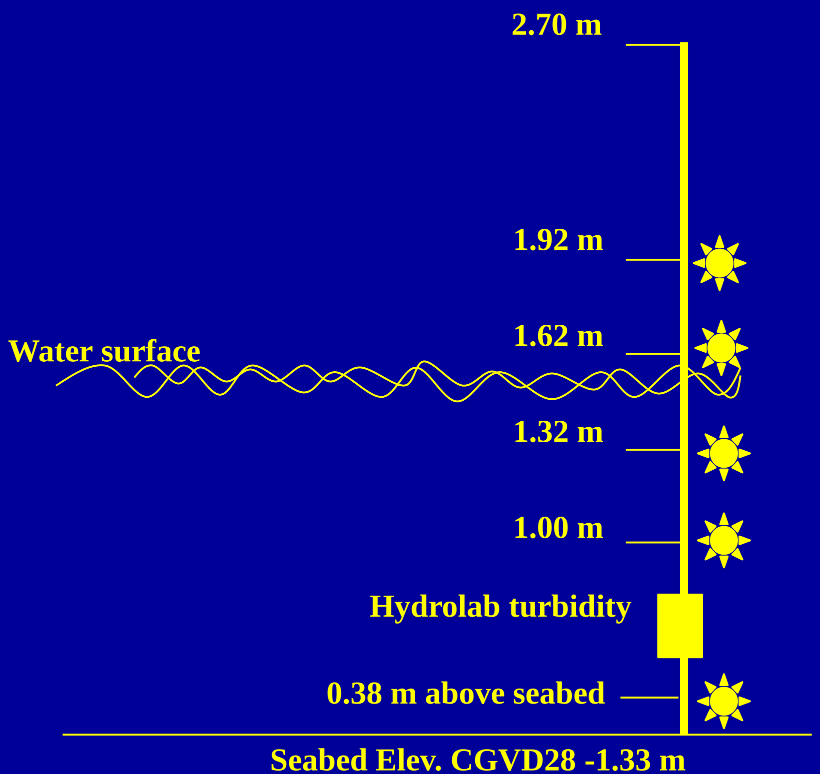




**Light sensor on dirty cinderblock post deployment**

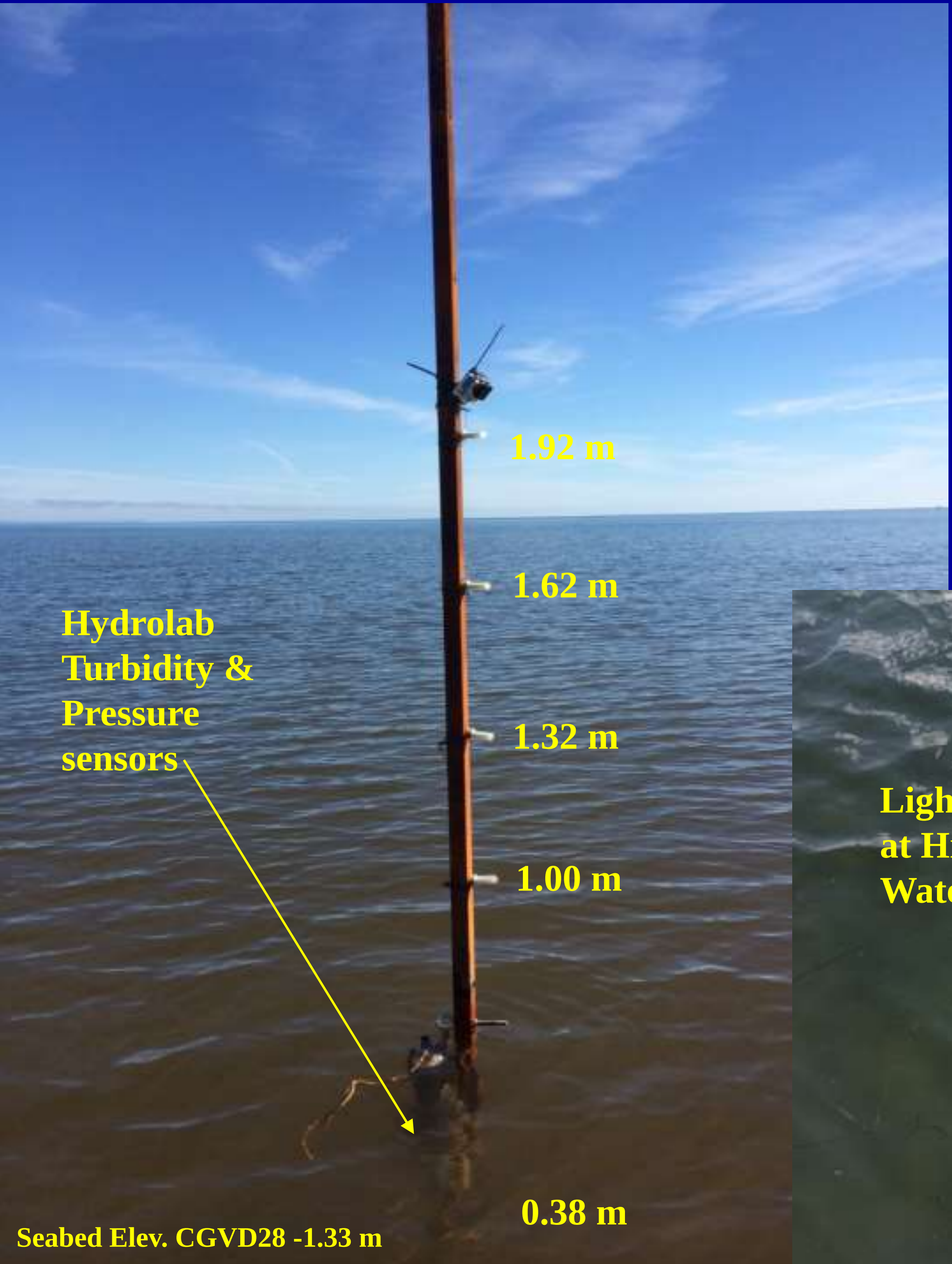
# Deploying light sensors

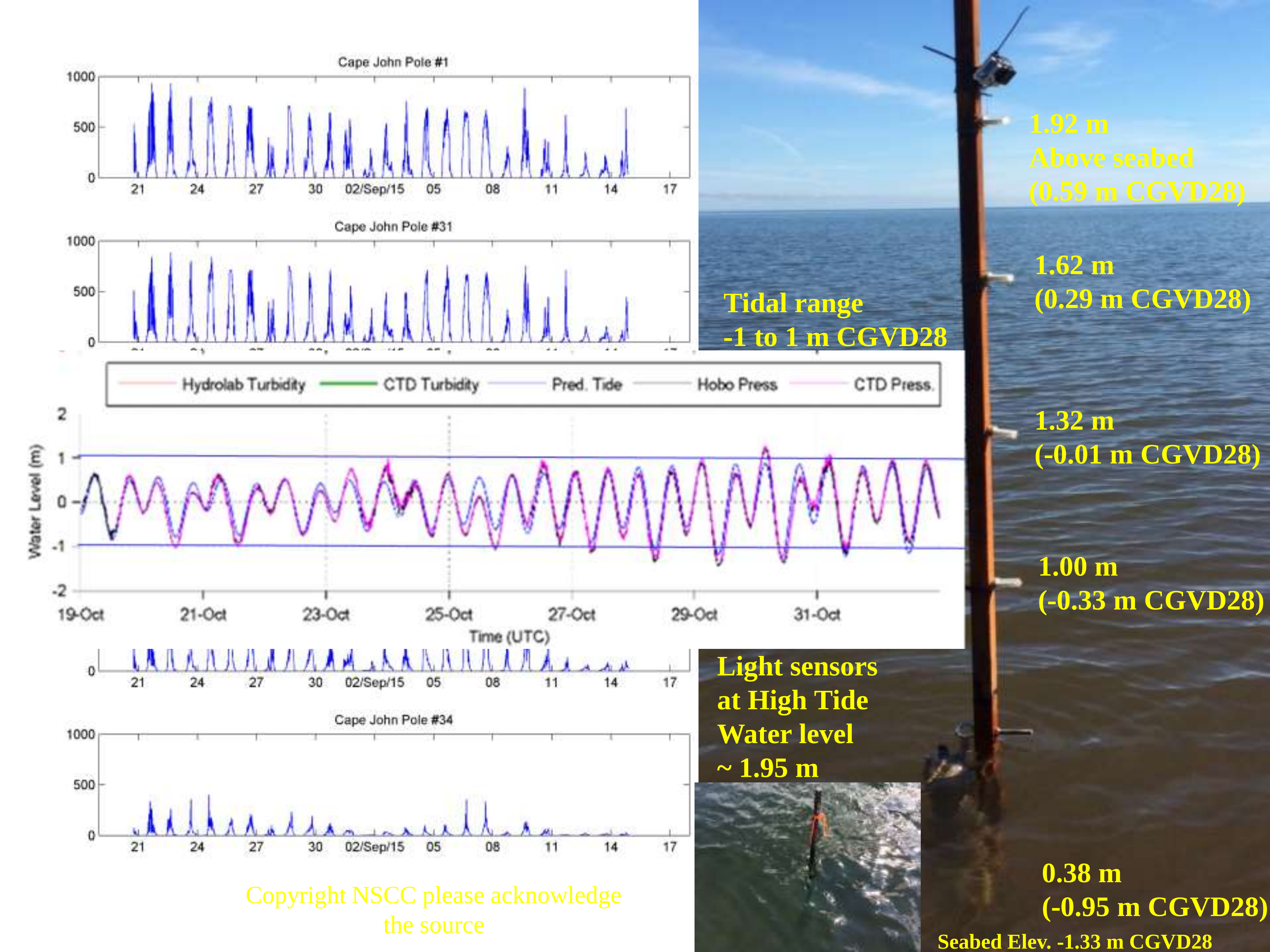


# Multiple hobo pendent light sensors on pole

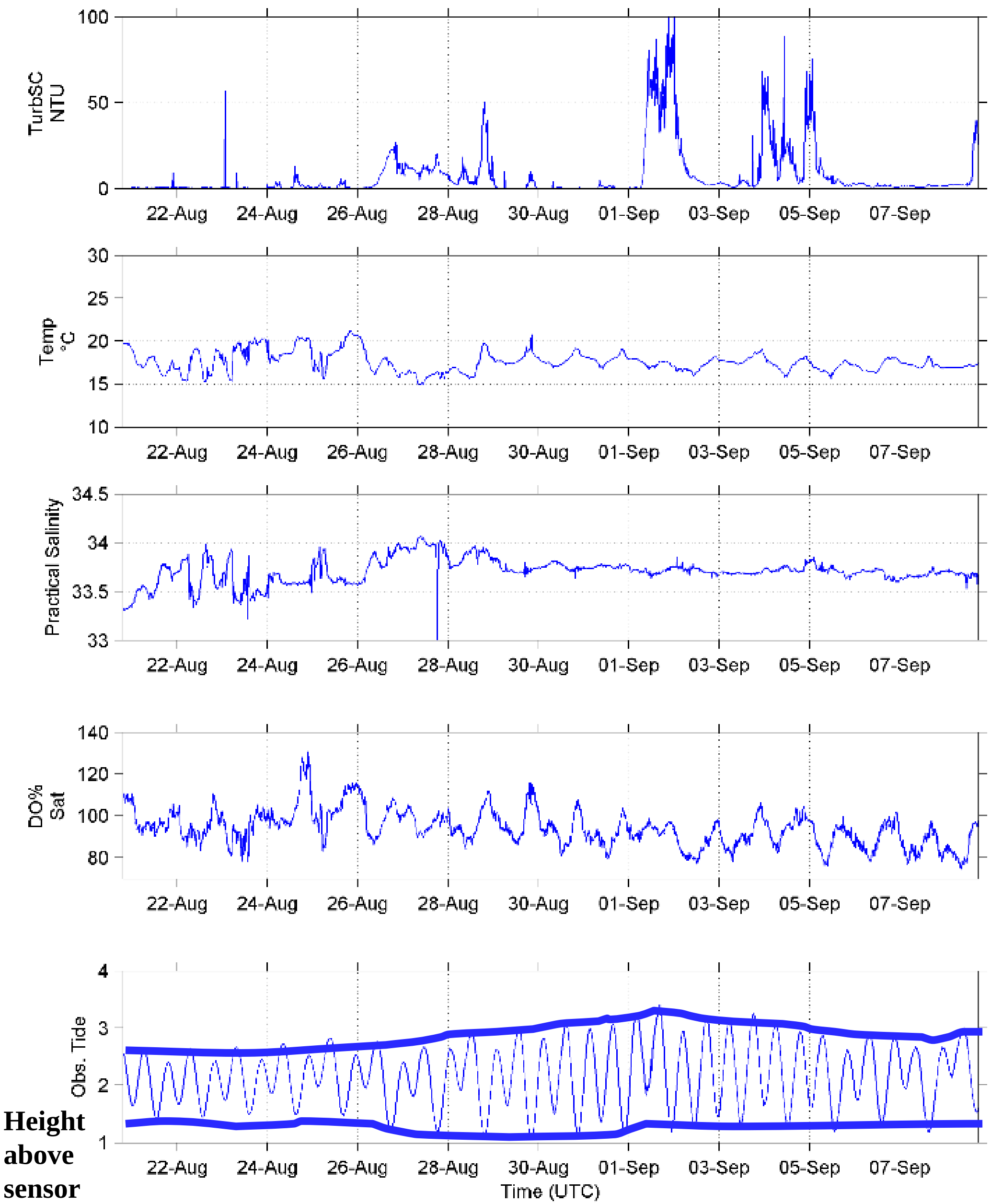
# Hobo pendent light sensors on pole



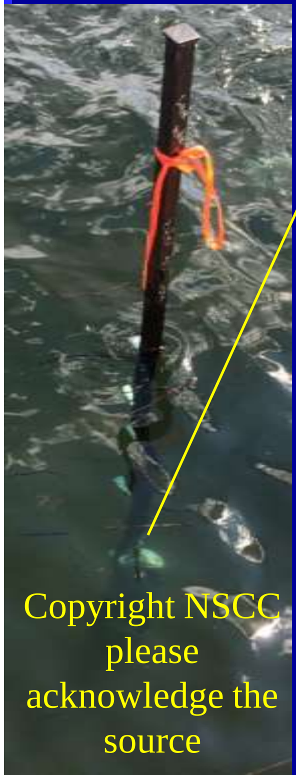



Cape John Pole #1
Cape John Pole #31
Cape John Pole #34
Hydrolab Turbidity
CTD Turbidity
Pred. Tide
Hobo Press
CTD Press.
Water Level (m)
Time (UTC)
19-Oct
21-Oct
23-Oct
25-Oct
27-Oct
29-Oct
31-Oct
02/Sep/15
1.92 m
Above seabed
(0.59 m CGVD28)
1.62 m
(0.29 m CGVD28)
Tidal range
-1 to 1 m CGVD28
1.32 m
(-0.01 m CGVD28)
1.00 m
(-0.33 m CGVD28)
Light sensors
at High Tide
Water level
~ 1.95 m
0.38 m
(-0.95 m CGVD28)
Seabed Elev. -1.33 m CGVD28

# Hydrolab Water Probe - Turbidity




**Height above sensor**

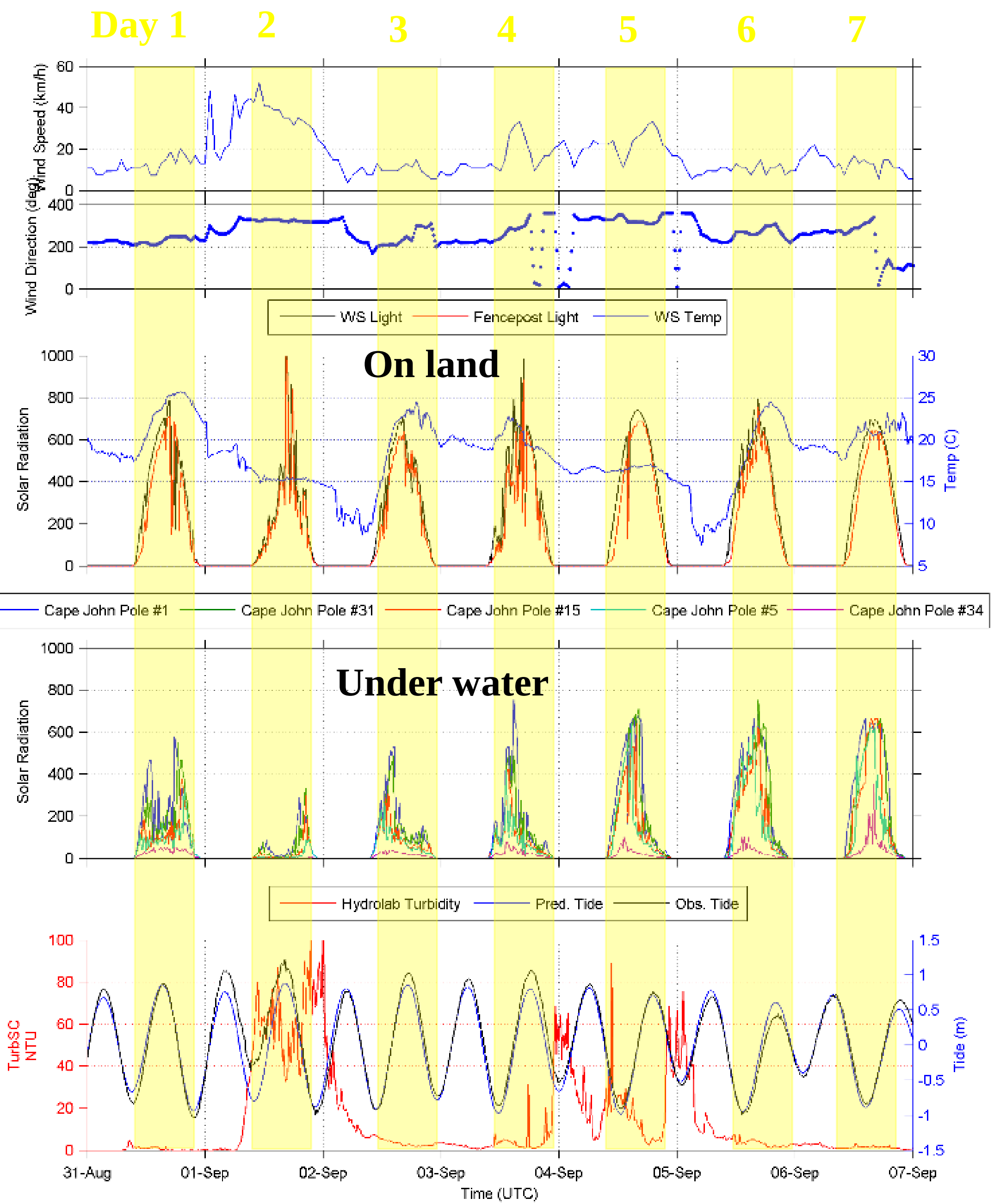





## Variable tidal range – lunar cycle


Time Lapse Camera
Weather Station
GPS
Pillar
Light Sensor
on land
HOBO

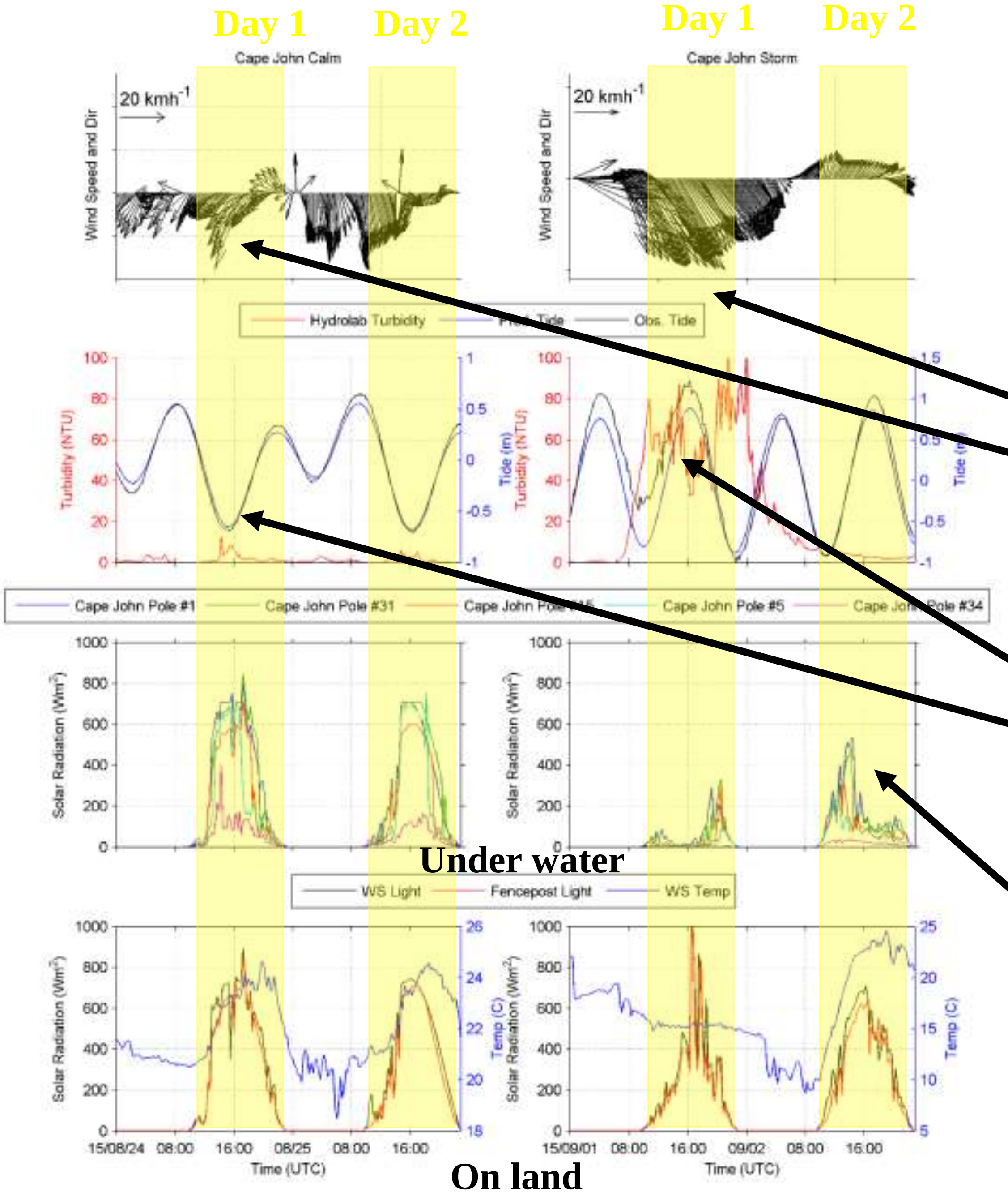
Weather Station – wind, solar, rain
Light sensors
Hydrolab-AML water turbidity
Tide gauges






# Comparing calm and stormy conditions at Cape John

Aug. 24-25
Sept. 1-2




50 km/hr for a longer period

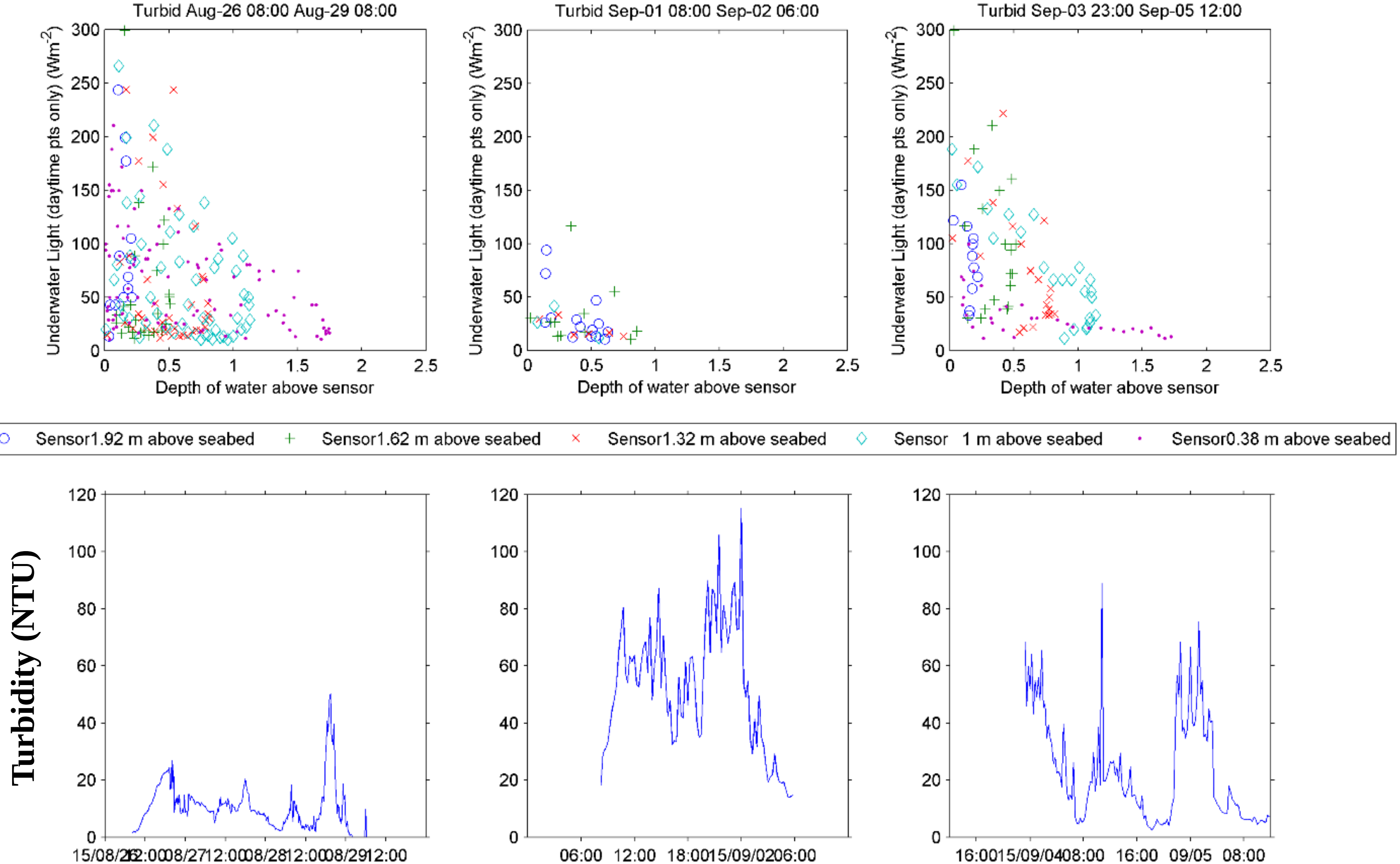
20 km/hr short lived

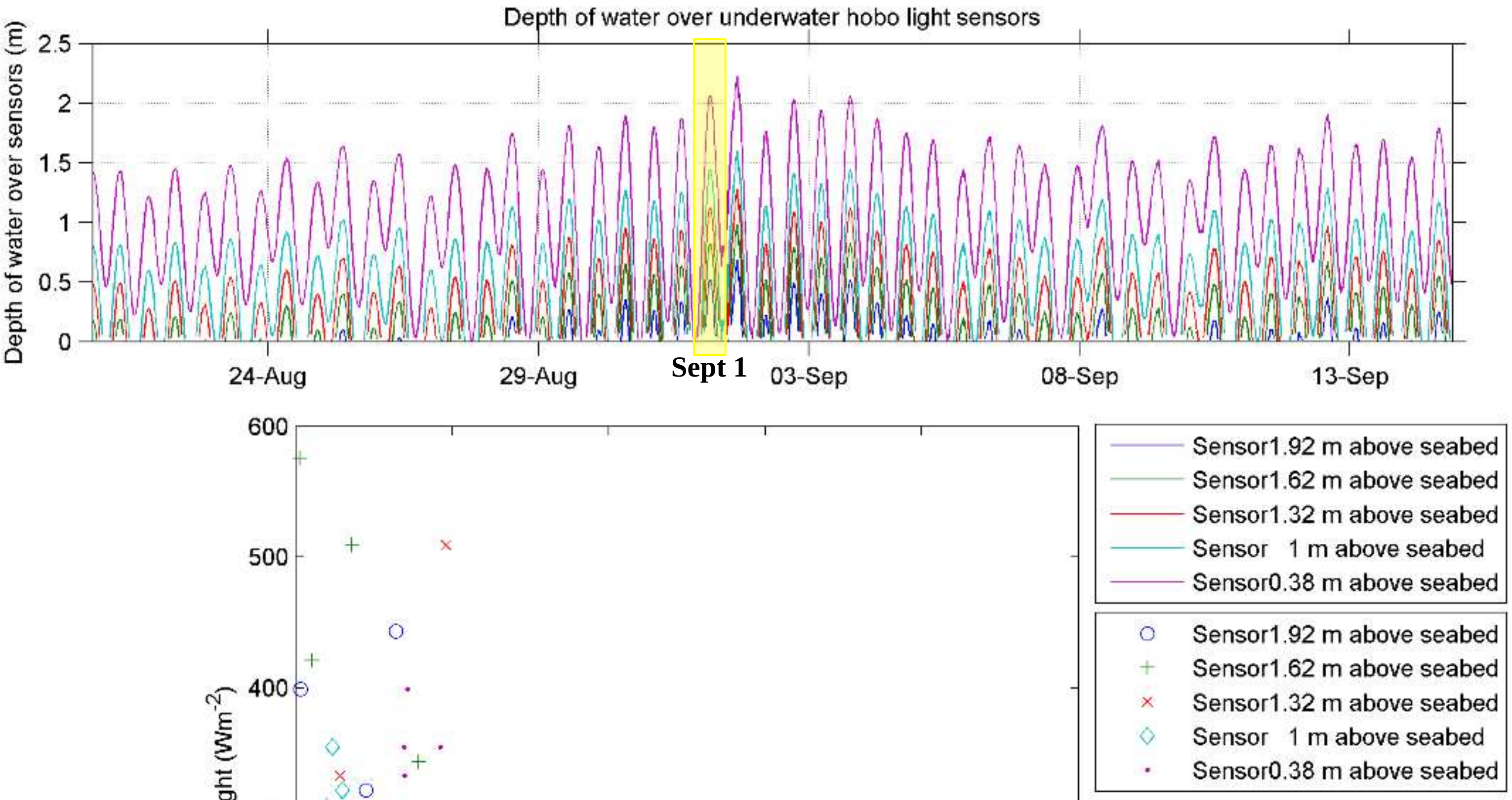
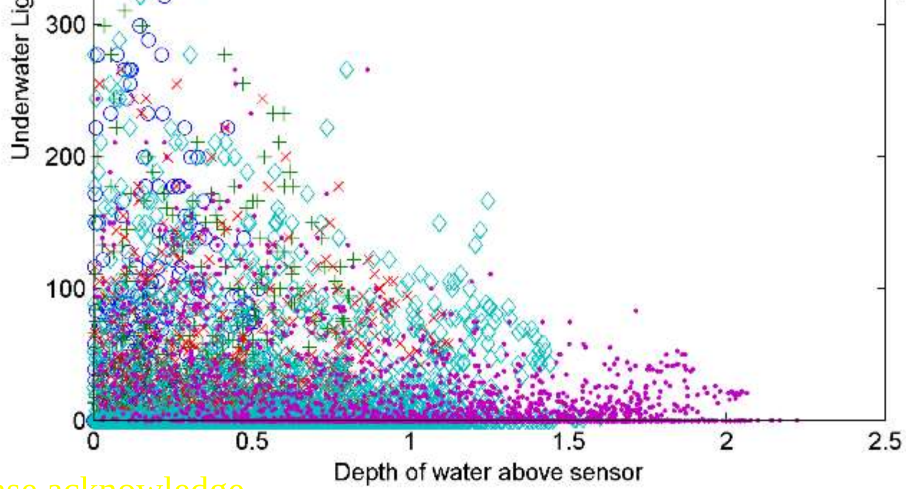
High tide , high turbidity

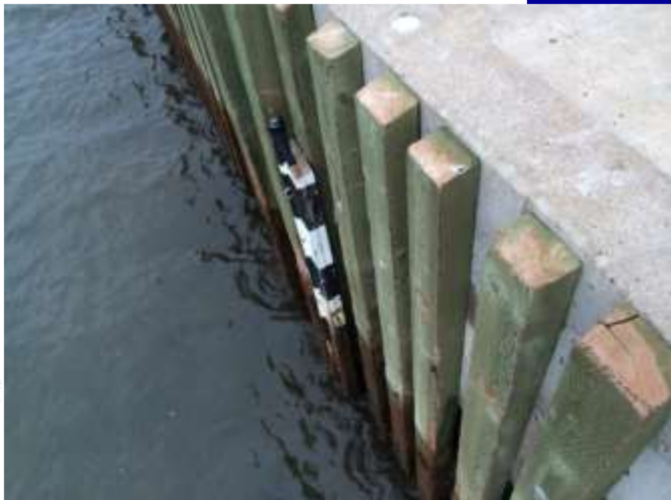
Low tide, minor turbidity

Recovery of water clarity from the storm after 1 day, but only at 70% in surface water, 25% near the bottom compared to before the storm

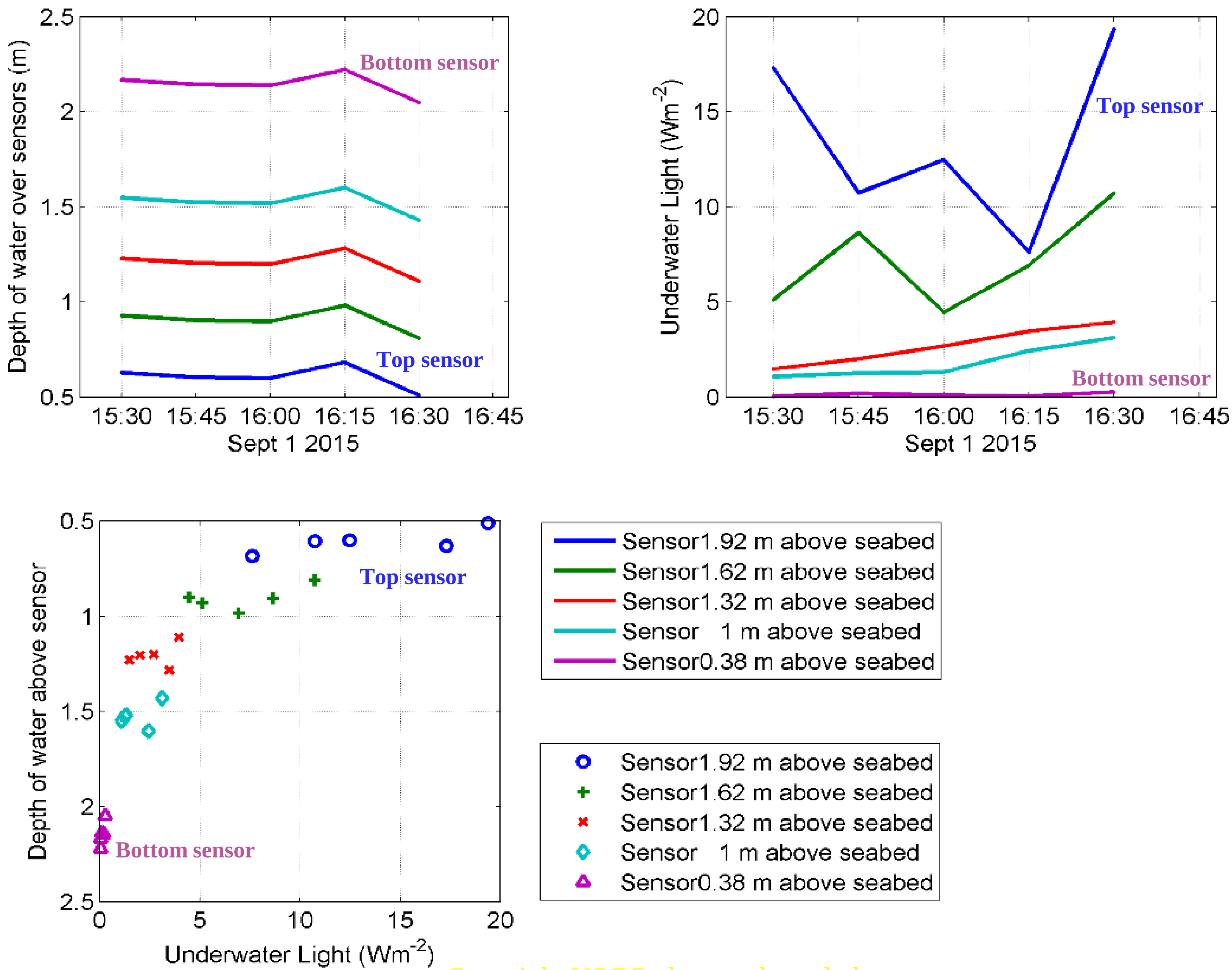
# Clear vs turbid water & storms

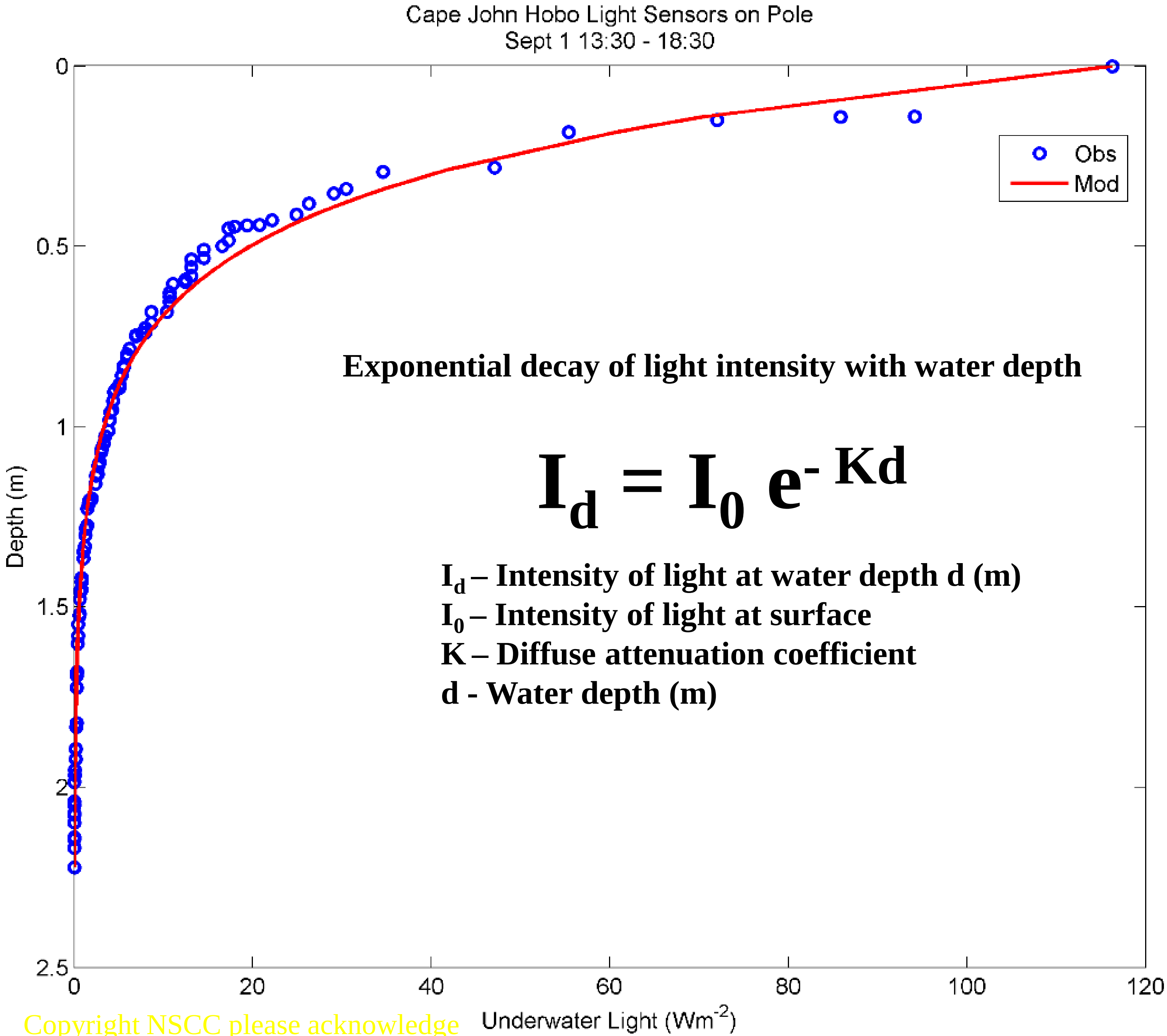



Depth of water over underwater hobo light sensors
Depth of water over sensors (m)
2.5
2
1.5
1
0.5
0
24-Aug
29-Aug
Sept 1
03-Sep
08-Sep
13-Sep
Underwater Light (Wm-2)
600
500
400
300
200
100
0
0
0.5
1
1.5
2
2.5
Depth of water above sensor
Sensor1.92 m above seabed
Sensor1.62 m above seabed
Sensor1.32 m above seabed
Sensor 1 m above seabed
Sensor0.38 m above seabed
Sensor1.92 m above seabed
Sensor1.62 m above seabed
Sensor1.32 m above seabed
Sensor 1 m above seabed
Sensor0.38 m above seabed




# Effect of water on light intensity

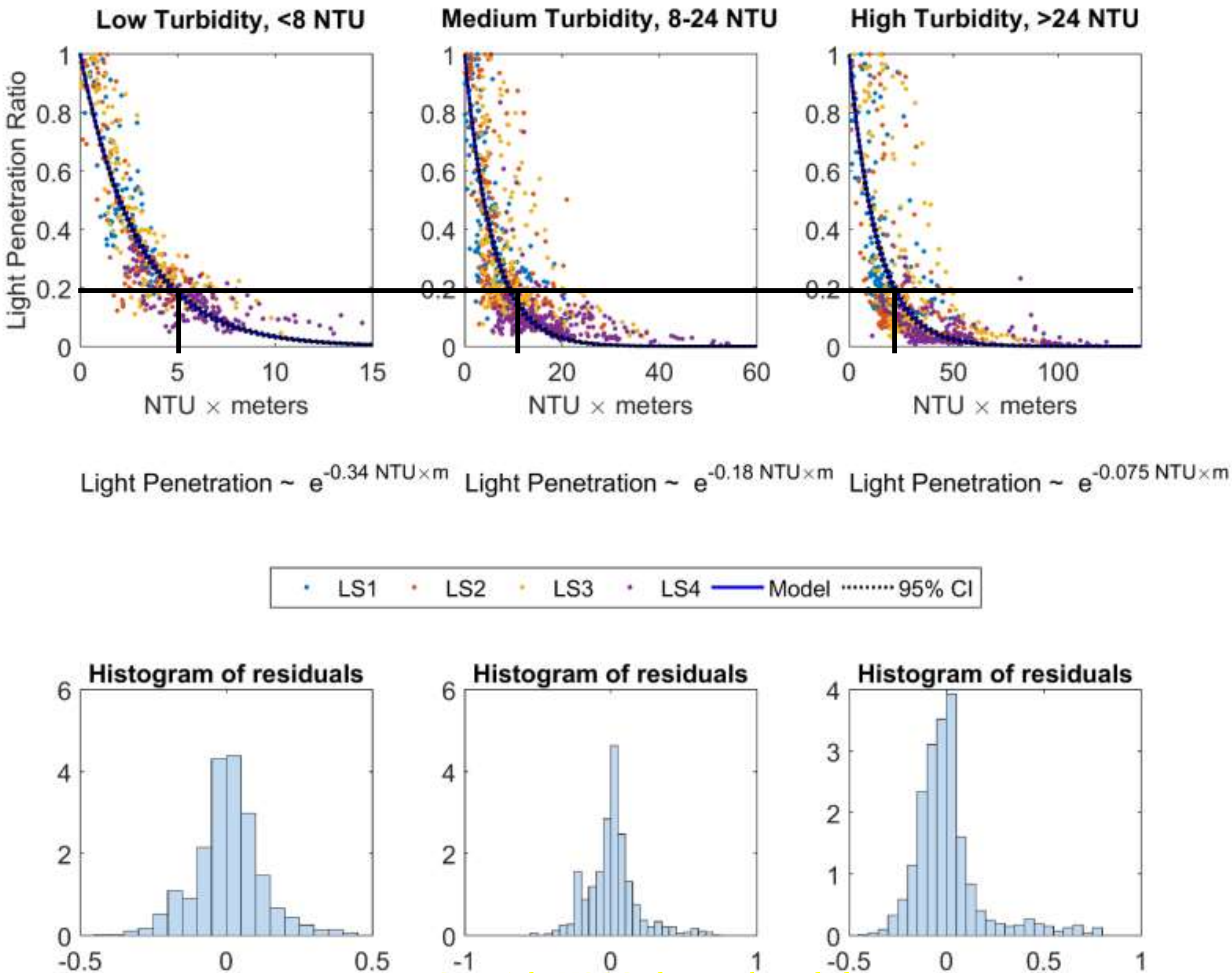


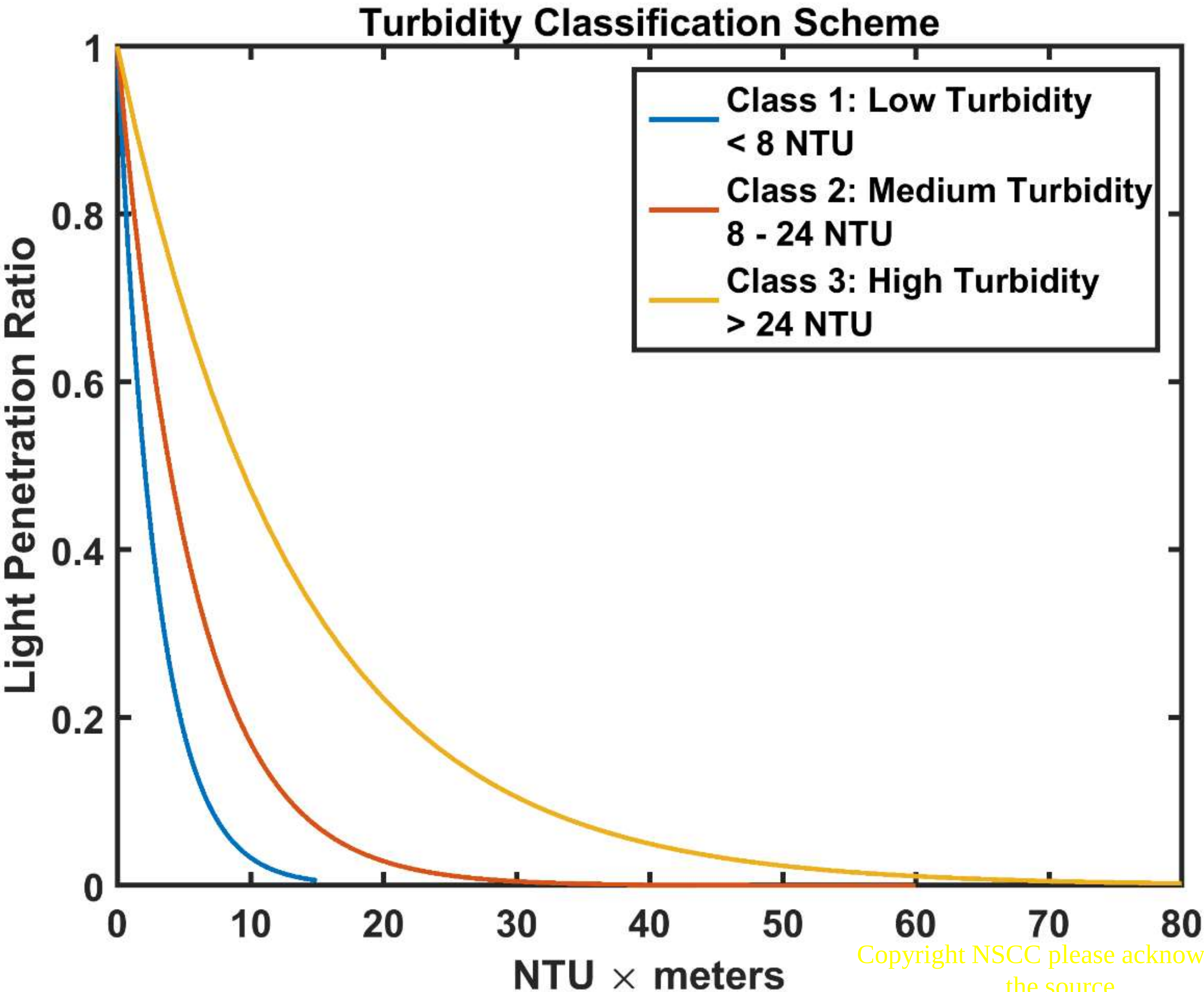


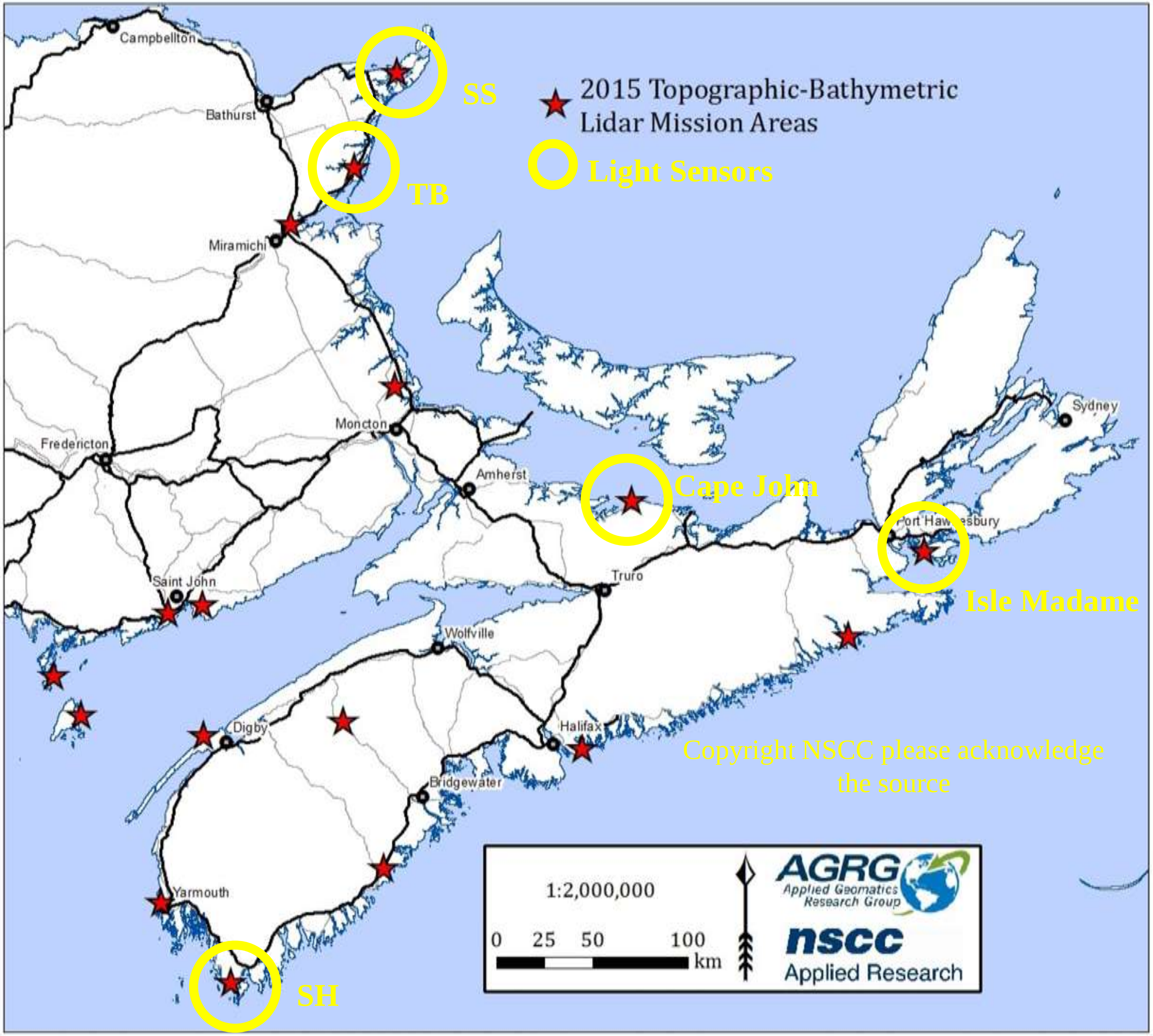

**Exponential decay of light intensity with water depth**

$$I_d = I_0 \, e^{-Kd}$$

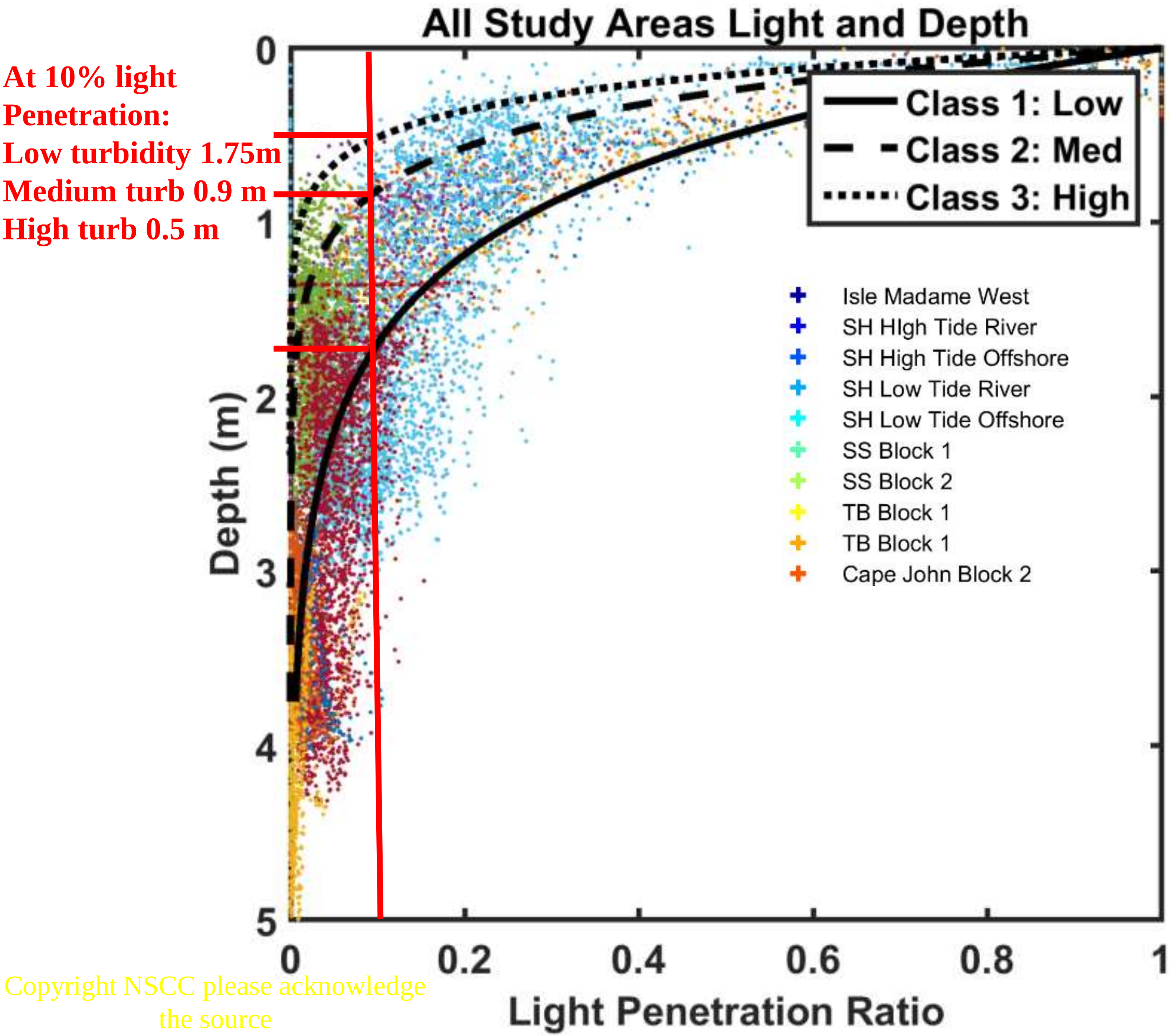
**$I_d$ – Intensity of light at water depth d (m)**
**$I_0$ – Intensity of light at surface**
**K – Diffuse attenuation coefficient**
**d - Water depth (m)**

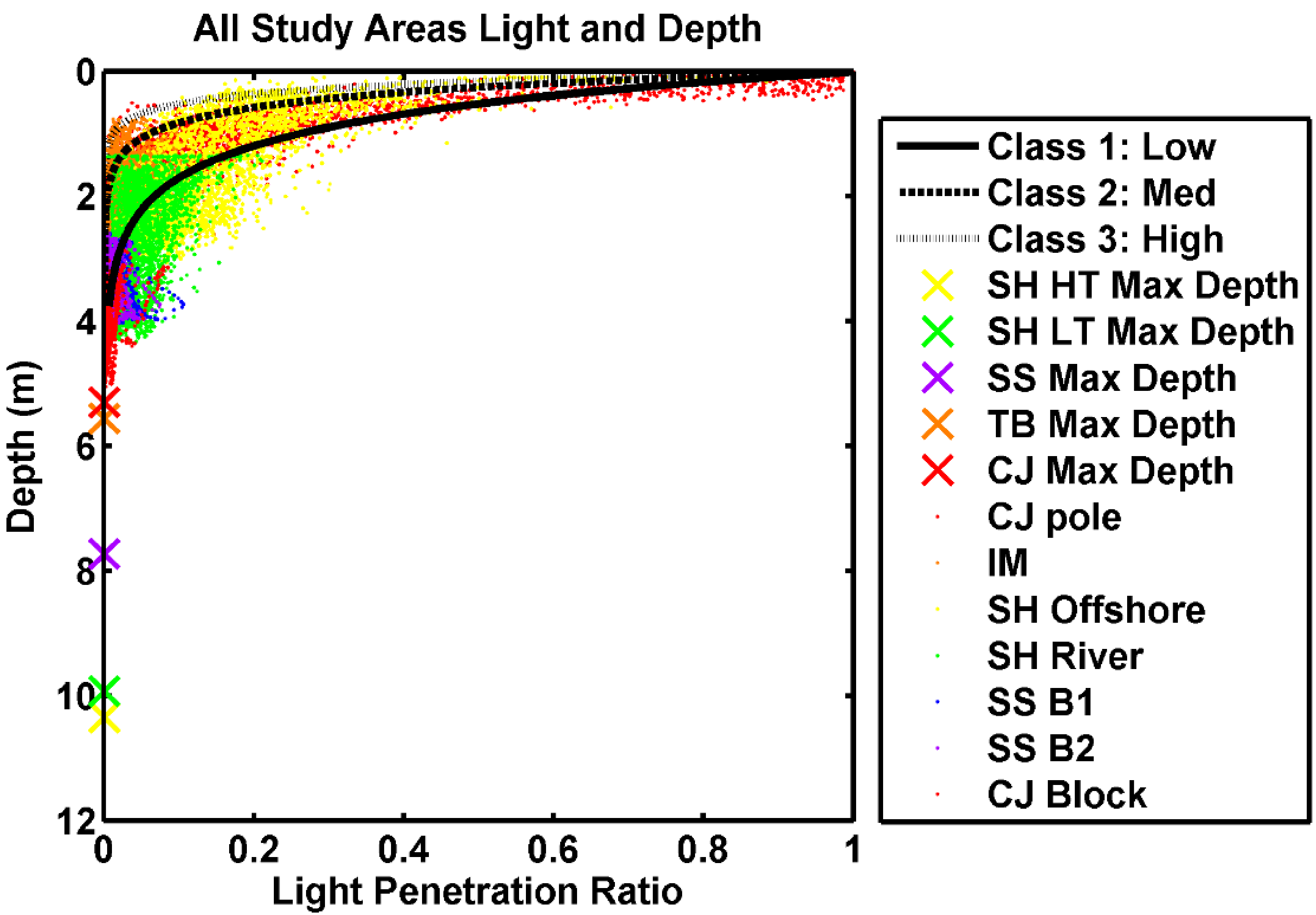

Low Turbidity, <8 NTU
Medium Turbidity, 8-24 NTU
High Turbidity, >24 NTU
Light Penetration Ratio
NTU × meters
NTU × meters
NTU × meters
Light Penetration ~ $e^{-0.34\ NTU \times m}$
Light Penetration ~ $e^{-0.18\ NTU \times m}$
Light Penetration ~ $e^{-0.075\ NTU \times m}$
LS1
LS2
LS3
LS4
Model
95% CI
Histogram of residuals
Histogram of residuals
Histogram of residuals

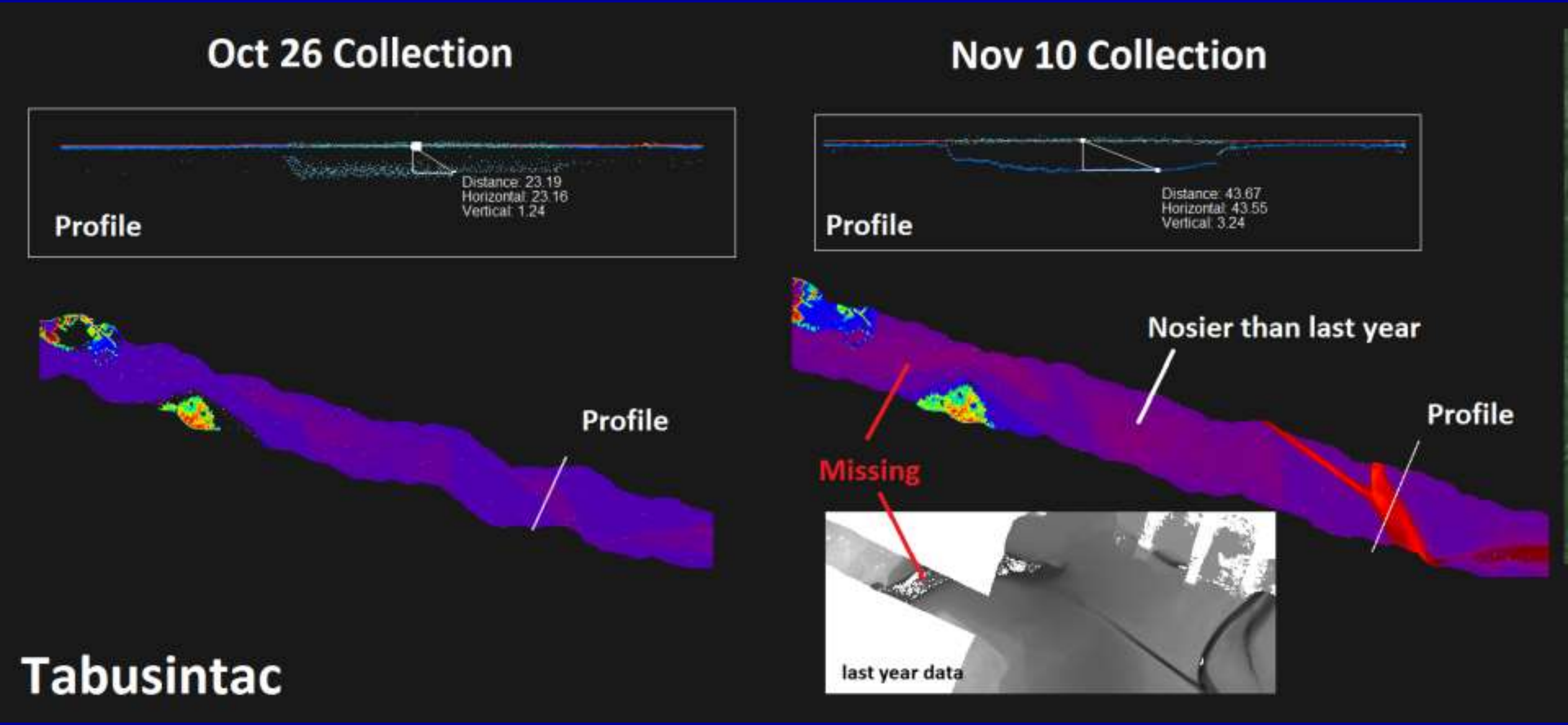

Turbidity Classification Scheme
Class 1: Low Turbidity
< 8 NTU
Class 2: Medium Turbidity
8 - 24 NTU
Class 3: High Turbidity
> 24 NTU
Light Penetration Ratio
NTU × meters
0
0.2
0.4
0.6
0.8
1
0
10
20
30
40
50
60
70
80



Campbellton
Bathurst
Miramichi
Moncton
Fredericton
Amherst
Saint John
Truro
Wolfville
Digby
Halifax
Bridgewater
Yarmouth
Sydney
Port Hawkesbury
SS
TB
Cape John
Isle Madame
SH
2015 Topographic-Bathymetric Lidar Mission Areas
Light Sensors
1:2,000,000
0 25 50 100 km
AGRG Applied Geomatics Research Group
nscc Applied Research

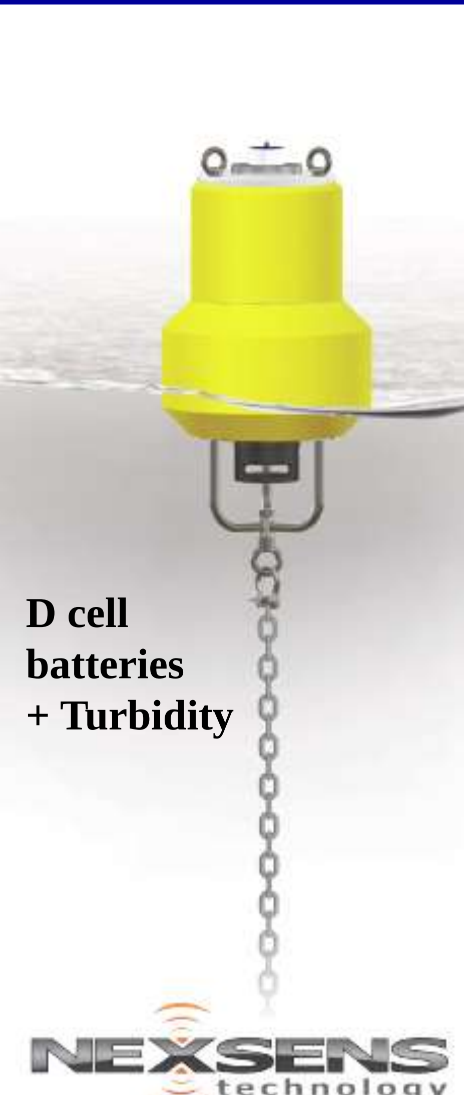

All Study Areas Light and Depth
At 10% light Penetration:
Low turbidity 1.75m
Medium turb 0.9 m
High turb 0.5 m
Class 1: Low
Class 2: Med
Class 3: High
Isle Madame West
SH HIgh Tide River
SH High Tide Offshore
SH Low Tide River
SH Low Tide Offshore
SS Block 1
SS Block 2
TB Block 1
TB Block 1
Cape John Block 2
Depth (m)
0
1
2
3
4
5
0
0.2
0.4
0.6
0.8
1
Light Penetration Ratio


All Study Areas Light and Depth
Depth (m)
0
2
4
6
8
10
12
0
0.2
0.4
0.6
0.8
1
Light Penetration Ratio
Class 1: Low
Class 2: Med
Class 3: High
SH HT Max Depth
SH LT Max Depth
SS Max Depth
TB Max Depth
CJ Max Depth
CJ pole
IM
SH Offshore
SH River
SS B1
SS B2
CJ Block


Oct 26 Collection
Nov 10 Collection
Distance: 23.19
Horizontal: 23.16
Vertical: 1.24
Profile
Distance: 43.67
Horizontal: 43.55
Vertical: 3.24
Profile
Profile
Nosier than last year
Profile
Missing
last year data
Tabusintac

# This upcoming field season will allow for
# Cellular modem communication for real-time monitoring options

## CB-50




## CB-150


## CB-450


## CB-650

# Acquisition of real-time turbidity monitoring

## CB-50 x 3 Funded by NSERC


D cell
batteries
+ Turbidity

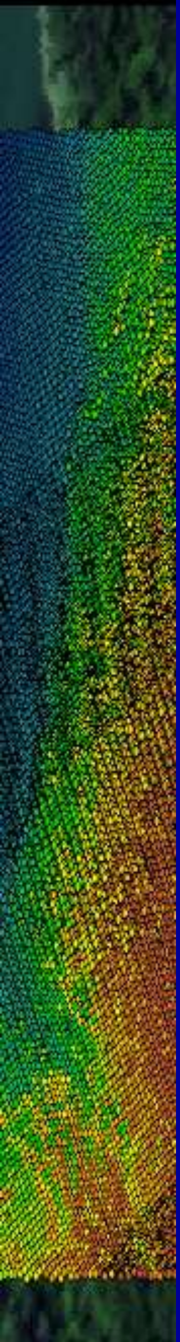
## CB-450 x 1

Funded by DFO
World Tanker Safety
Program


Solar
powered
batteries
+ Turbidity
+ Weather
station


**Airmar 200 WX:**

Wind speed & direction
Solid-state compass
10 Hz GPS
3-axis accelerometer
3-axis rate gyro
Barometric pressure
Ultrasonic wind readings



# Conclusions

- The wind speed and direction play a significant role in wave development and turbidity in coastal environment, more so than runoff
- Development of time series relating water clarity and weather conditions will hep become more operationally efficient
- Hobo light sensors measure differences in water clarity, hydrolab – turbidity, pressure sensor – water level, weather station – wind speed & direction, Hobo & weather station for atmospheric light conditions
- Real-time turbidity sensors deployed in bays will allow assessment for bathy-lidar flights

**Acknowledgement: equipment support**

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NSRIT
Nova Scotia Research and Innovation Trust