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The Current State and Future Developments for the inclusion of Waves in Coastal flooding forecasting in Newfoundland and Labrador

14th International Workshop on wave Hindcasting & forecasting and 2nd international Storm Surge Symposium, Key West, Florida

Devon Ross Telford
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Motivation

- During 1978, AES in the Atlantic Region assumed the responsibility for alerting the public whenever coastal sea levels appeared likely to be significantly higher (0.6 m for example) than normal, and this practice has continued for areas without flood stage information.
- However, numerous cases of coastal flooding have occurred that, if the forecaster had relied solely on storm surge models, would have been missed.
- The inclusion of waves and the impact of wave set-up in conjunction with the storm surge model has improved the forecasting of coastal flooding.
- This presentation will outline the guidance and techniques currently used by operational forecasters at the Newfoundland and Labrador Weather Office.

A Rogue Wave Event at Middle Cove Beach, Newfoundland

Devon Ross Telford

Newfoundland and Labrador Weather Office, Gander, Newfoundland

Introduction

On the afternoon of Sunday, August 31, 2008, large shoaling waves that were described by observers as 'rogue' occurred at Middle Cove Beach, Newfoundland. These waves washing over beach-goers and effectively pulling four of them out into the cove where they were rescued by bystanders. The raw wave data obtained for this study shows that rogue waves were present in the wave field. However, even in the absence of these waves the significant wave height and peak period of the wave field was the important contributor to the event. Through this study an operational nomogram was developed to give proposed warning thresholds for similar events based on significant swell height, peak period and tide height. With the knowledge of this synoptic event and with the use of the nomogram perhaps similar situations may be accurately forecasted and appropriate action may be taken to inform the public.

Site Survey

Middle Cove Beach is located ~10 km north of the city of St. John's, Newfoundland and faces northeast. Its rugged and scenic U–shaped bay is surrounded by a steep cliff making it popular among tourists and residence alike. The beach is composed of gravel and sand with the largest clast sizes distributed half way up the beach creating a berm dividing the foreshore from the backshore and denoting the high tide mark. The parking lot is found at the south end of the beach at an elevation of 7.3 m above the mean sea level, which for this site is 60 cm above the lowest low mean water level.

Figure 1. Middle Cove Beach, looking North from the a hill on the East side of the beach

Figure 2. bathymetry of Middle Cove Beach

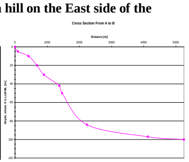

Figure 3. Cross section of water depth from Middle Cove Beach to a point 5.25 km to the Northeast

Analysis

On Thursday, August 28, 2008 a quasi-stationary low south of the Denmark Strait had its central pressure rapidly deepen from 1000 to 970 mb over the next 30 hrs **(Fig 4 and 5)**. By the morning of Friday, August 29, 2008 **(Fig 5 and 6)** the storm began to slowly weaken only filling by 17 mb over the next 24 hrs.

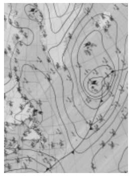

Figure 4. 2008-08-28 12Z

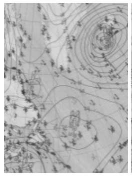

Figure 5. 2008-08-29 12Z

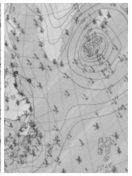

Figure 6. 2008-08-30 12Z

On the evening of Thursday, August 28, 2008, QuikScat images observed a wind field with a fetch approximately 120 nm wide across the Denmark Strait and 300 nm long with an average wind speed of ~30 kts from the northeast. The winds over the fetch strengthened to upwards of 60 kts by the following evening-pass on Friday, August 29, 2008 **(Fig 7)**. By the morning of Saturday, August 30 2008 **(Fig 8)**, the winds had begun to subside and the effective fetch had grown to 550 nm in length.

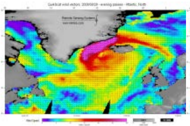

Figure 7

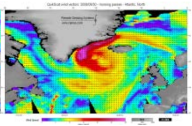

Figure 8

By the evening of Friday, August 29, 2008, the fetch had created a sea state with a significant wave height of ~13.5 m and a peak period of ~16 seconds in the generation area **(Fig 9)**. These waves left the generation region as swell and travelled southwestward. Located ~1200 nm to the southwest, the northern Avalon Peninsula of Newfoundland and the Northern Grand Banks first started to observe the bulk of the wave energy late in the afternoon local time on Sunday, August 31, 2008. The swell's significant wave height peaked to ~3.5 m @ 16 sec after midnight **(Fig 10)**.

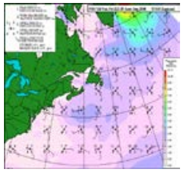

Figure 9

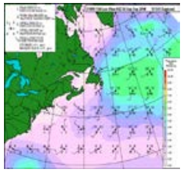

Figure 10

Methods

Upon examining the bathymetry surrounding Middle Cove Beach three distinct slopes are observed.

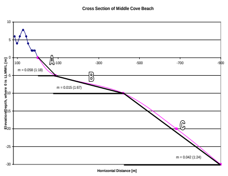

Figure 11. Cross section of bathymetry and topography from Middle Cove beach from the parking lot into the cove along the same line as figure 2.

The wave set-up for waves breaking over each section can be solved in terms of near shore slope, significant wave height and peak period.

$$Wave\_set-up = 1.15 * H_s\left[.575m^{0.031}\left(\frac{H_s}{1.56*T^2}\right)^{-0.254}\right]$$

Wave height observations from both the Terra Nova and SeaRose buoys did show individual waves that where twice the size of the significant wave height during the event. However, even in the absence of these waves one would expect the set-up from the significant waves to be a threat in this situation **(Fig 12)**.

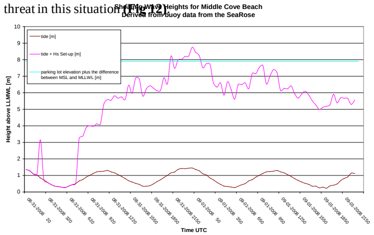

Figure 12. A time series of perturbed sea level using the near shore slope, the tide gage in St. John's Harbour and the peak periods and significant wave heights observed at the SeaRose located ~340 km to the East-Southeast of Middle Cove Beach.

Using the height of the parking lot, 7.9 m above the lowest low mean water level, as a proposed warning criterion for height of the wave set-up to reach, an equation for significant wave height as a function of near shore slope and peak period is derived.

$$H_S = \left(\frac{Wave\_set-up}{1.15*.575m^{0.031}}\left(1.56*T^2\right)^{-0.254}\right)^{1/0.746}$$

By subtracting the tide height from the parking lot height this equation can then be solved for differing levels of tide height and plotted as a nomogram **(Fig 13)**.

Conclusions

With the knowledge of this synoptic event and the use of the nomogram perhaps similar situations may be accurately forecasted and appropriate action may be taken to inform the public. For a forecasted northeasterly swell over the northern half of the East Coast a forecaster could determine the coastal hazard at Middle Cove Beach using this nomogram **(Fig 13)**.

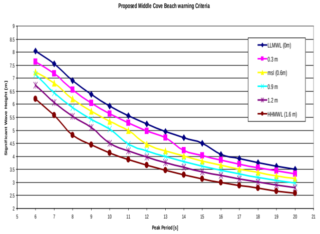

Figure 13

This study also raises additional questions that may be worth further investigation. What is the frequency for a similar event to occur at Middle Cove Beach? Are there other popular beaches in Newfoundland that are at risk and what would their warning criteria be?

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Acknowledgments

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Environment Canada
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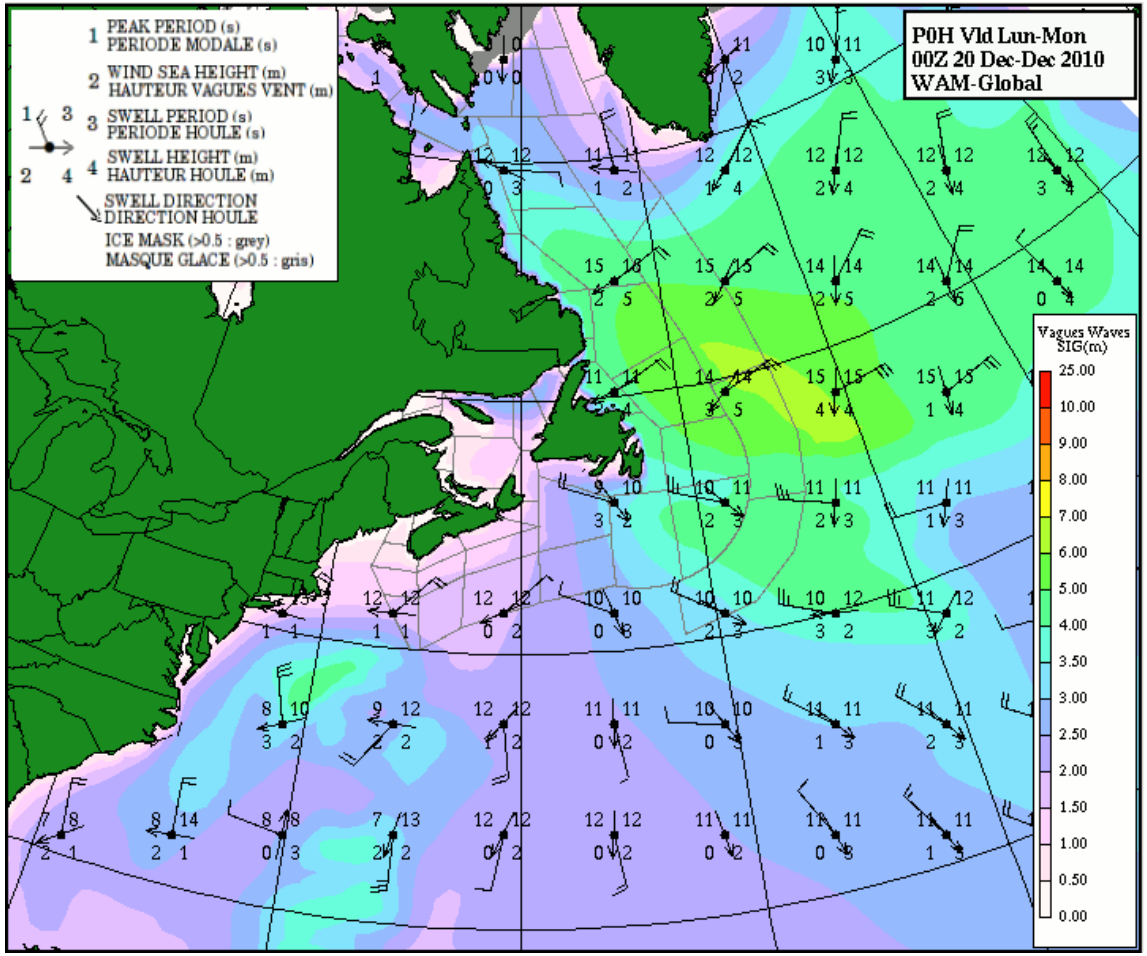
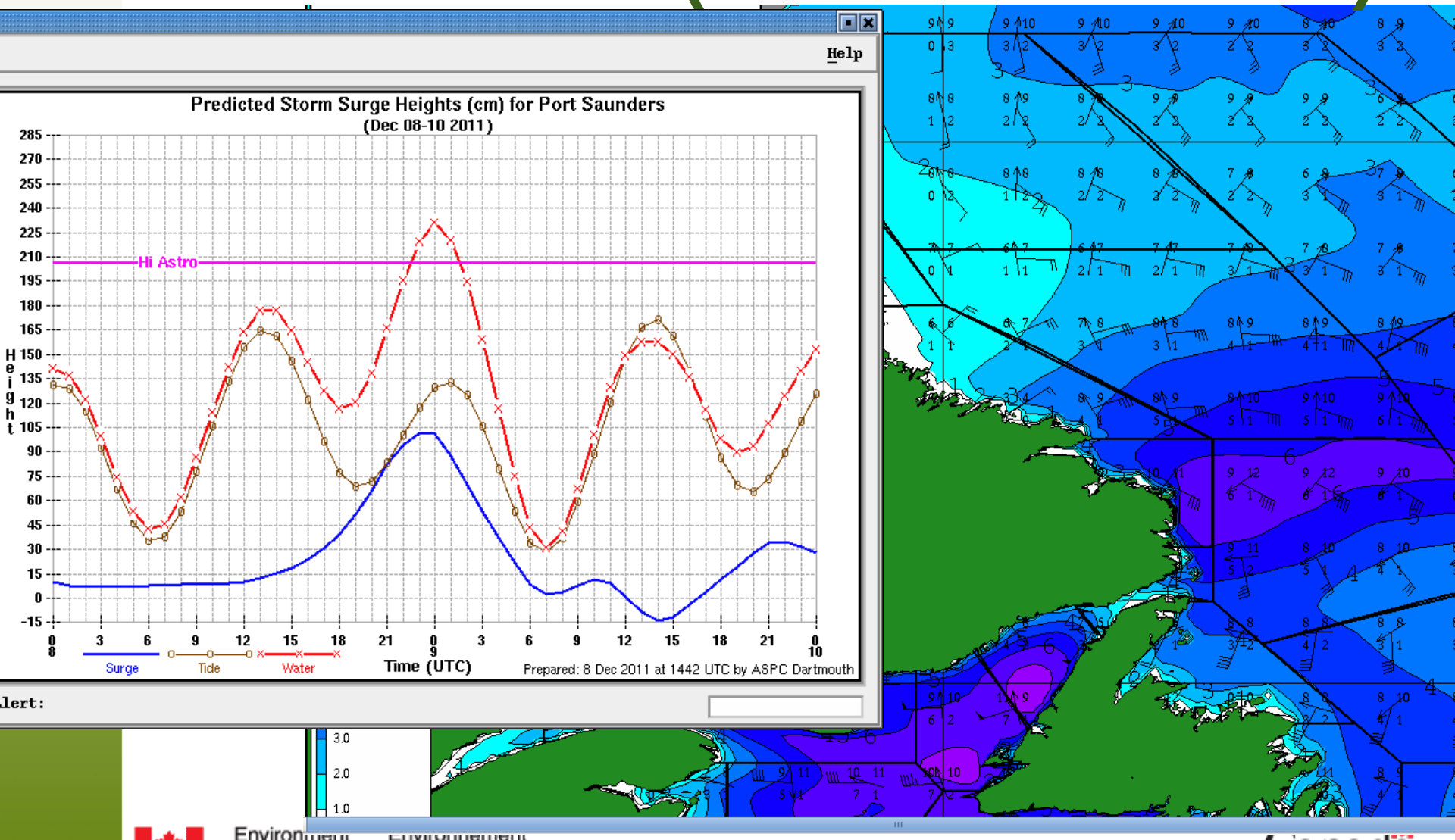
Dec 21-25, 2010
Northeast Coast of Newfoundland



Dec 21-25, 2010
Northeast Coast of Newfoundland

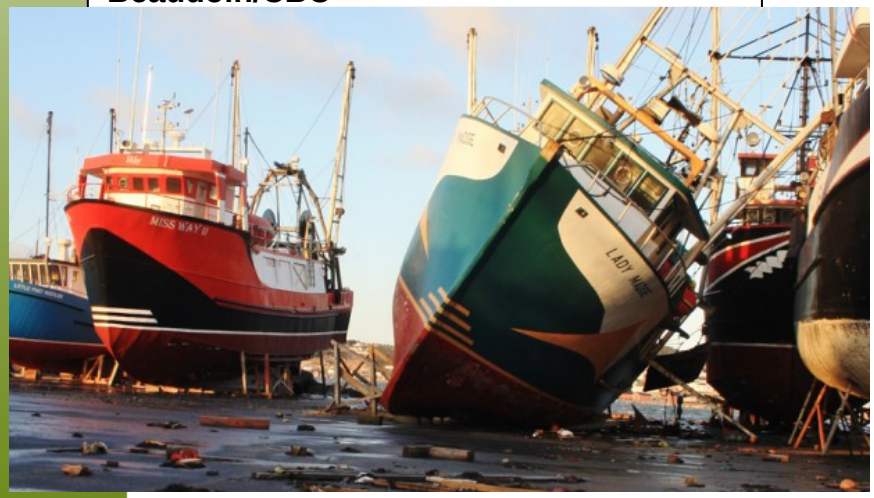
Dec 21-25, 2010
Northeast Coast of Newfoundland

Dec 12, 2011
Port Saunders (near Port au Choix)

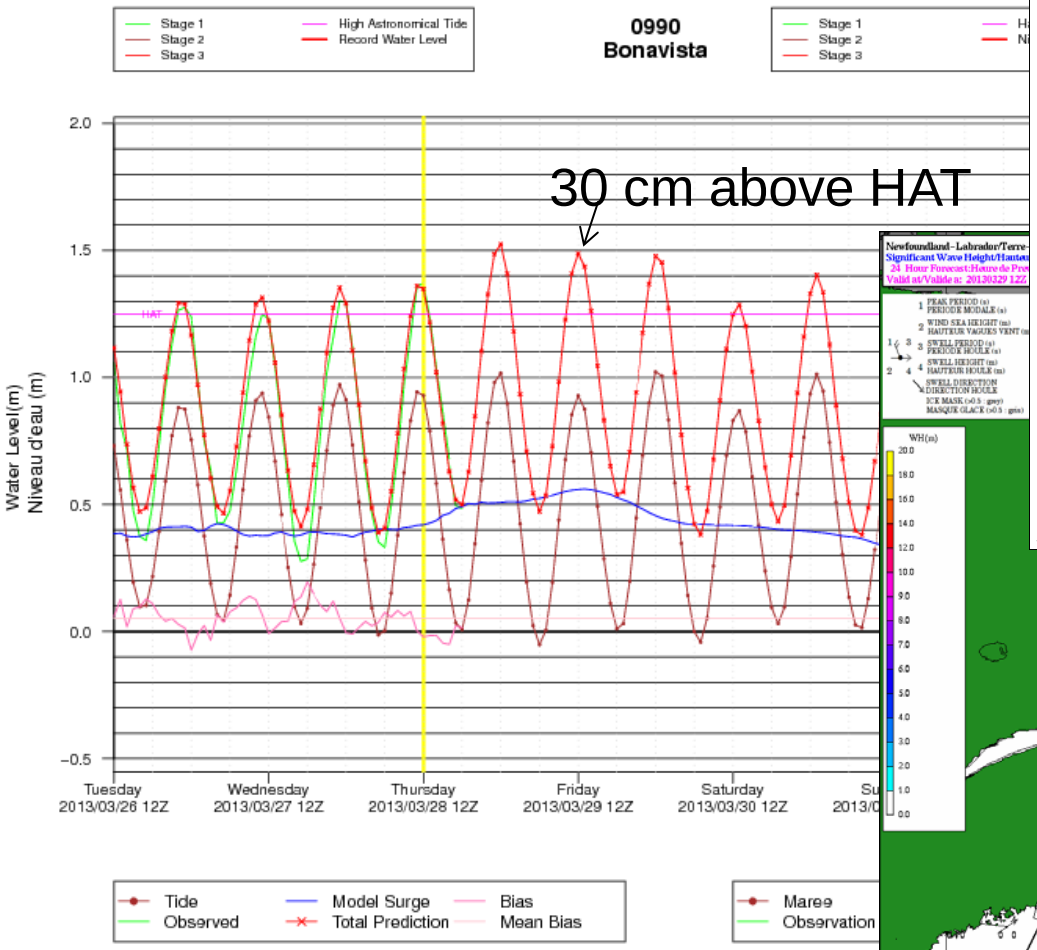


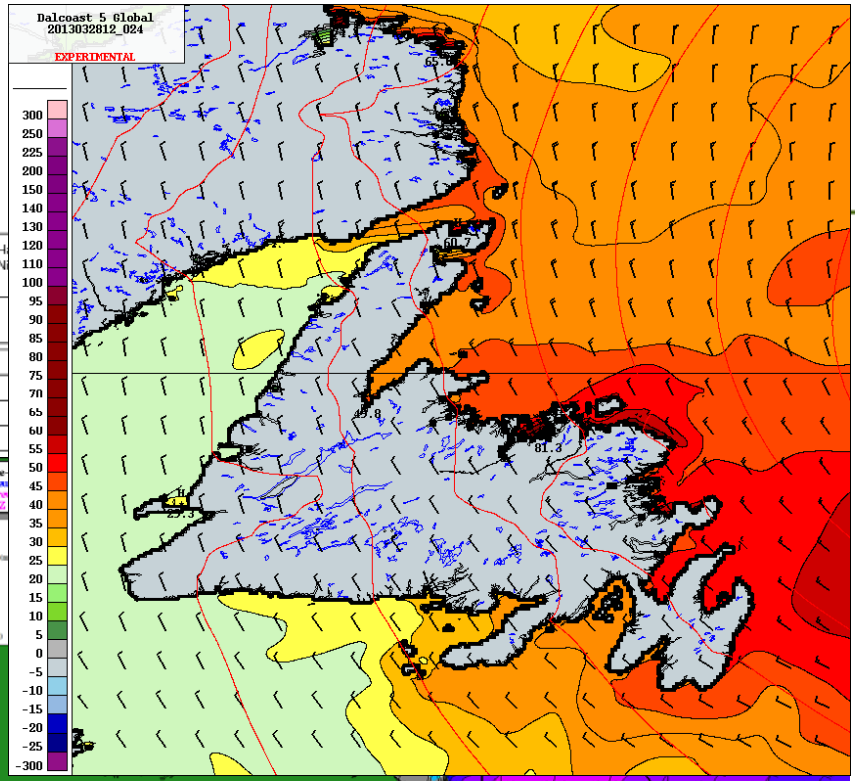
Dec 12, 2011
Port Saunders (near Port au Choix)

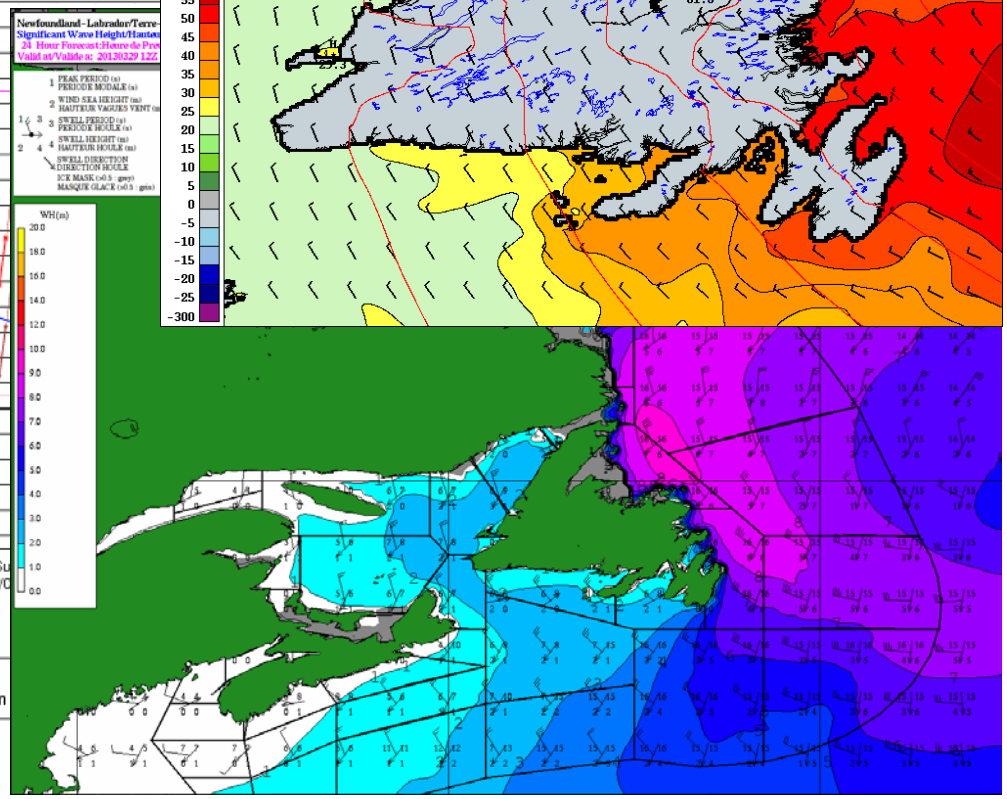
The storm raised water levels and made beaches treacherous places to be. Leila Beaudoin/CBC



March 28-29 2013
Northeast Coast







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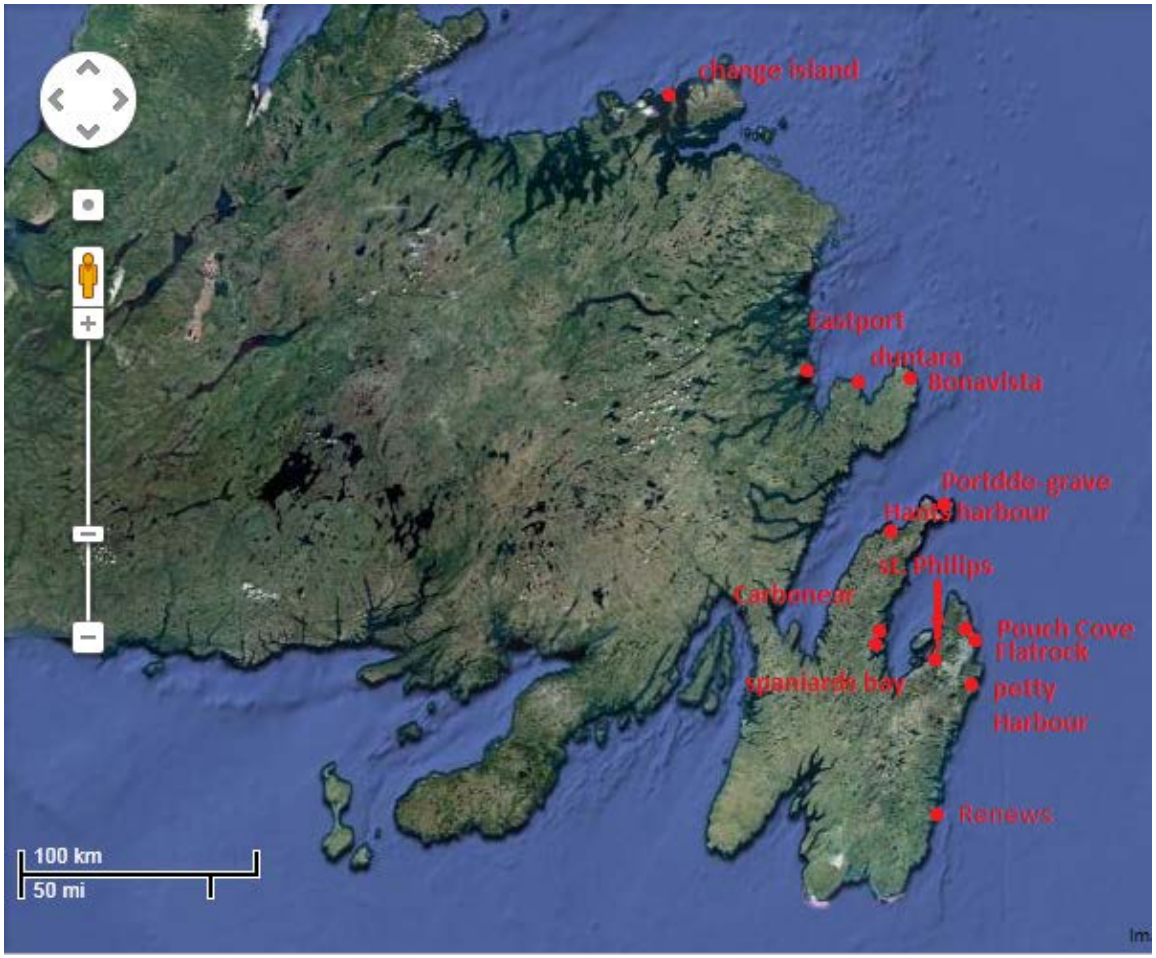

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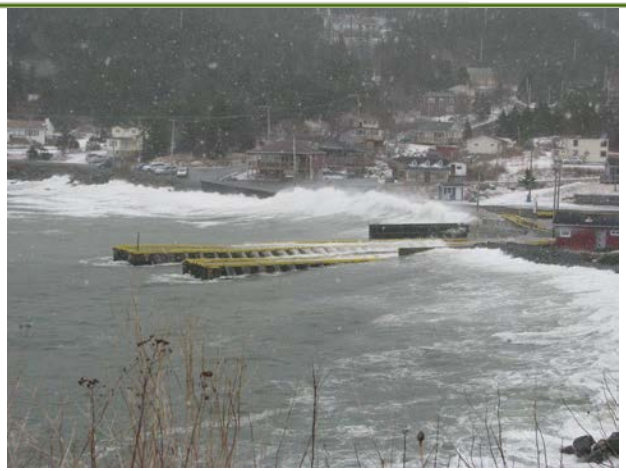


St. Philips

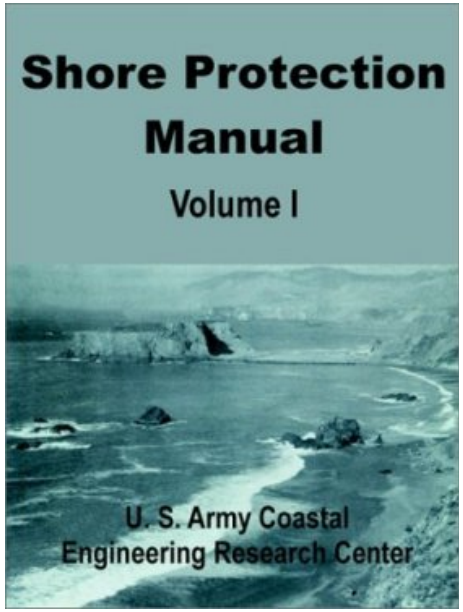
Petty Harbour

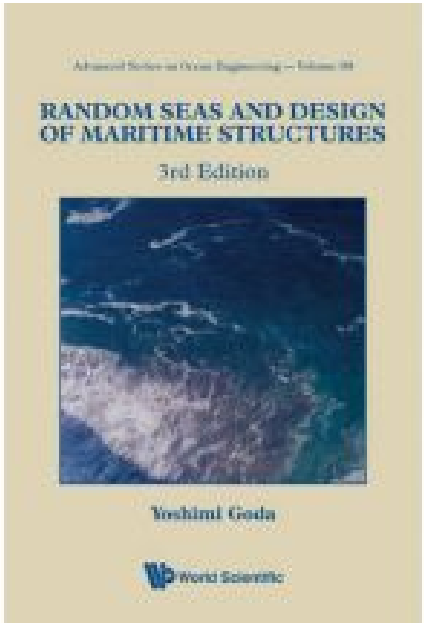
Duntara

Duntara

What tools and techniques can you use to try and predict wave set-up?

- In the Newfoundland and Labrador Weather Office we use a parameterized engineering method for forecasting wave set-up.
- This can be found outlined in the Shore Protection Manual where much of methods used were obtained from the research of Yoshimi Goda.





What tools and techniques can you use to try and predict wave set-up?

Parameterized Engineering Method

- Wave set-up is on the order of 10% of the equivalent deep water wave height.
  - which is the deep water significant wave height after wave refraction and diffraction have been taken into consideration.

- Whereas COMET suggested using 10-20% of the Breaking wave height.

- "*If the wave setup and set-down are calculated with the regular wave theory, they both are evaluated excessively large*" – Yoshimi Goda

$$n_s = H_b \left[-\frac{\gamma_b}{16} + \frac{1}{\gamma_b \left(1 + \frac{8}{3\gamma_b^2}\right)} \right]$$

Too big

10 m @ 13 sec => 2.26 m set-up???

What tools and techniques can you use to try and predict wave set-up?

Parameterized Engineering Method

- Goda (2008) used a reliable random wave breaking model, PEGBIS, that numerically computed values for breaking wave height.

- Curves for specific bathymetry slopes were generated and empirical formulas for these curves obtained.

$$(H_{1/3})_{\text{peak}}/H_0' = b_0 + b_1 x + b_2 x^2 \ : \ x = \ln(H_0'/L_0)\,, \tag{3.37}$$

$$\left.\begin{aligned} b_0 &= 0.8119 - 0.1470y - 0.0136y^2\,, \\ b_1 &= 0.1509 - 0.0711y - 0.0070y^2 \quad : \ y = \ln(\tan\theta)\,, \\ b_2 &= 0.1127 + 0.0186y + 0.00227y^2\,. \end{aligned}\right\} \tag{3.38}$$

What tools and techniques can you use to try and predict wave set-up?

Parameterized Engineering Method

- So what do we need to know to try and forecast wave set-up?
  - What are the deep water characteristics of the impinging waves?
    - the direction of the wave trains in the sea state.
    - significant wave height
    - peak period
  - What are the characteristics of the coastline?
    - This requires a lot of ‘hand waving’
    - Most bathymetry maps available in the region are too coarse but work done on past events in Newfoundland and Labrador indicated that most areas susceptible to waves have very steep slopes: ~1:10

What tools and techniques can you use to try and predict wave set-up?

Parameterized Engineering Method

- Noting the sum the predicted tide, predicted storm surge and predicted wave set-up for the threat area and determine if the sum will be equal or greater than 100 cm above High Astronomical Tide (HAT).

Tide + Surge + Set-up > 100 cm above HAT ???

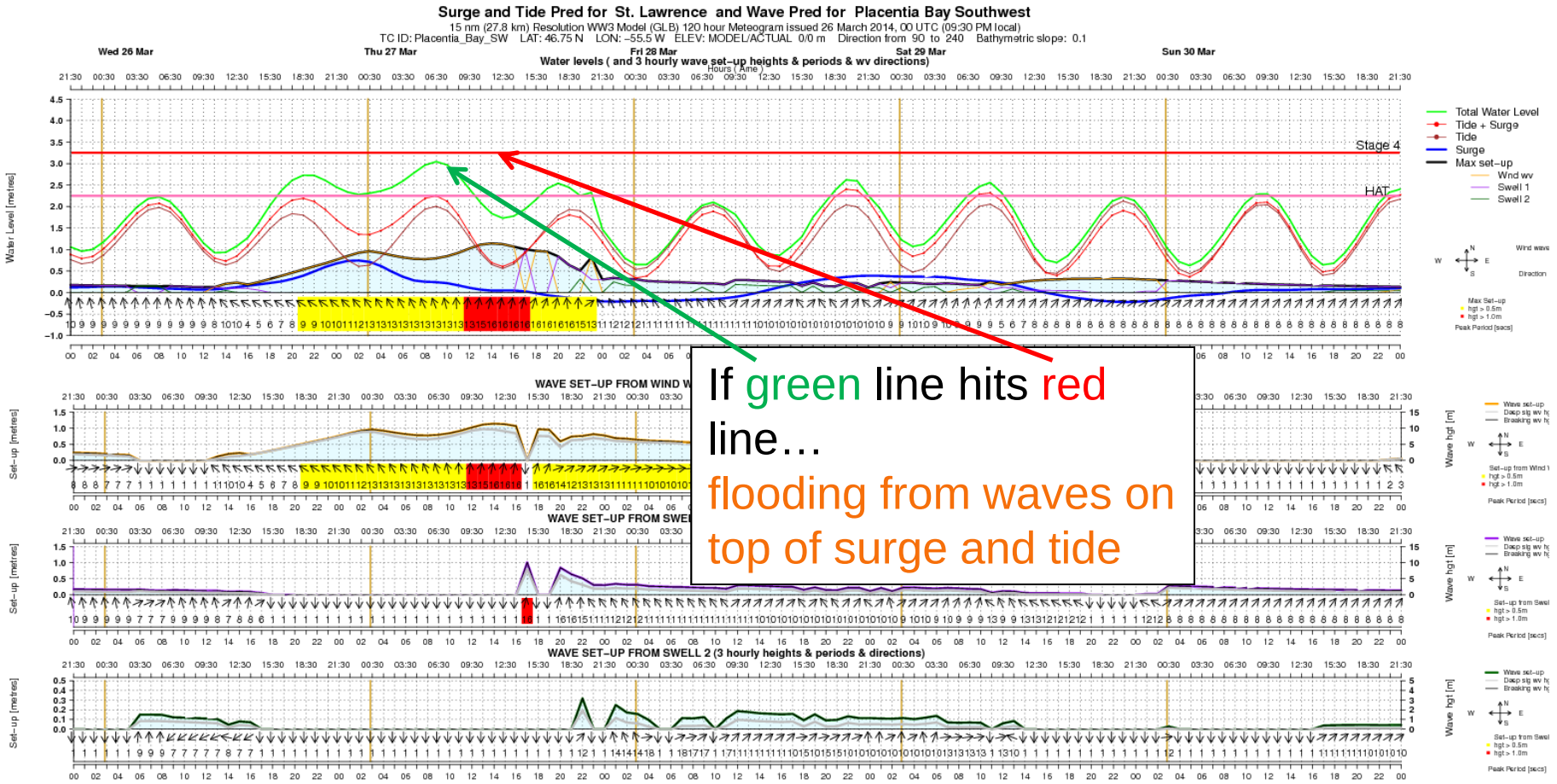
  - Note that the tide usually has the largest effect, and most severe flooding occurs during a spring tide.

Developmental Work

- Steps towards an automated guidance.

- A display that would allow the forecaster can see the timing or onset of:
  - Tide
  - Surge
  - Wave partitions

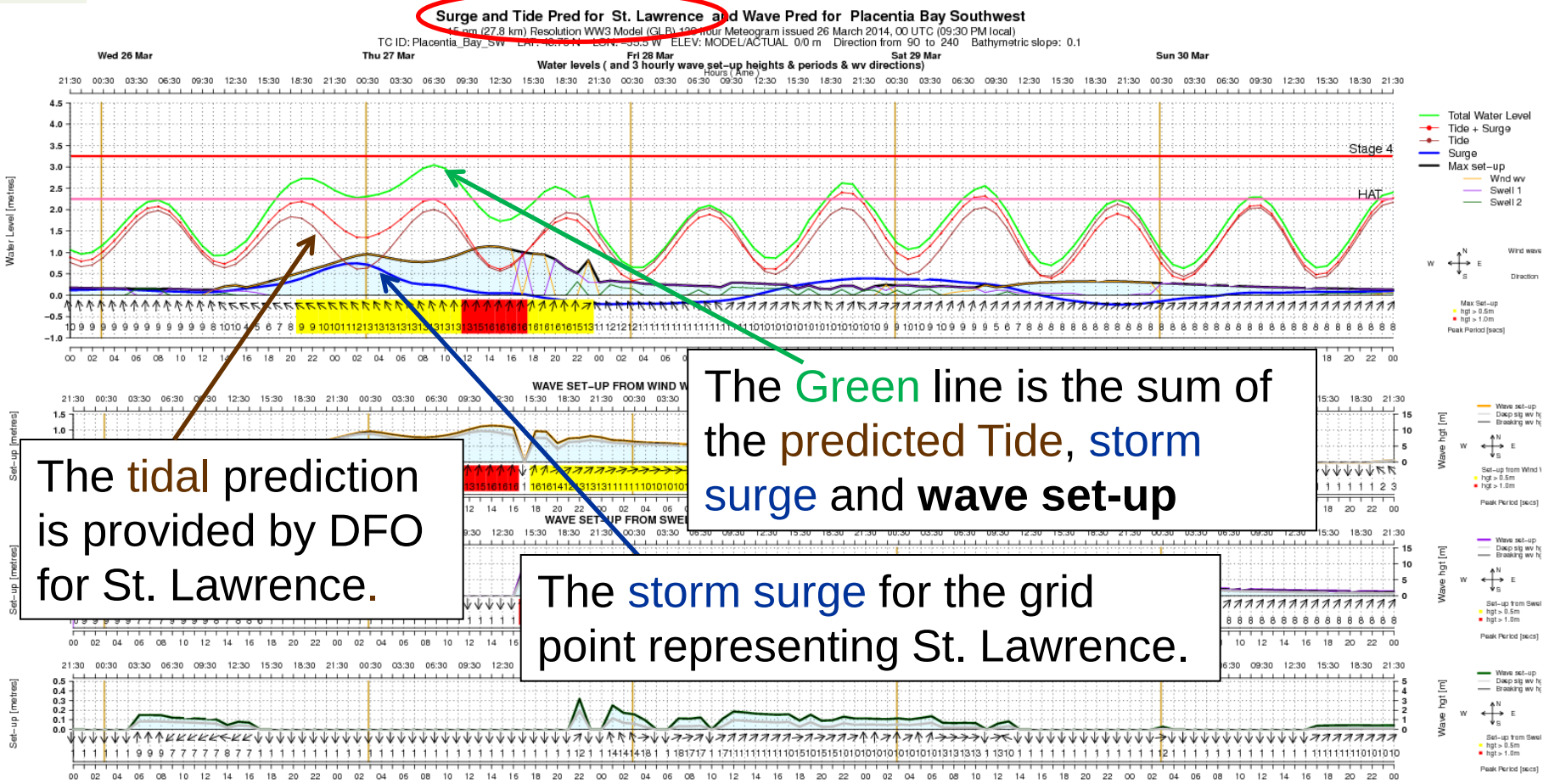
Developmental Work



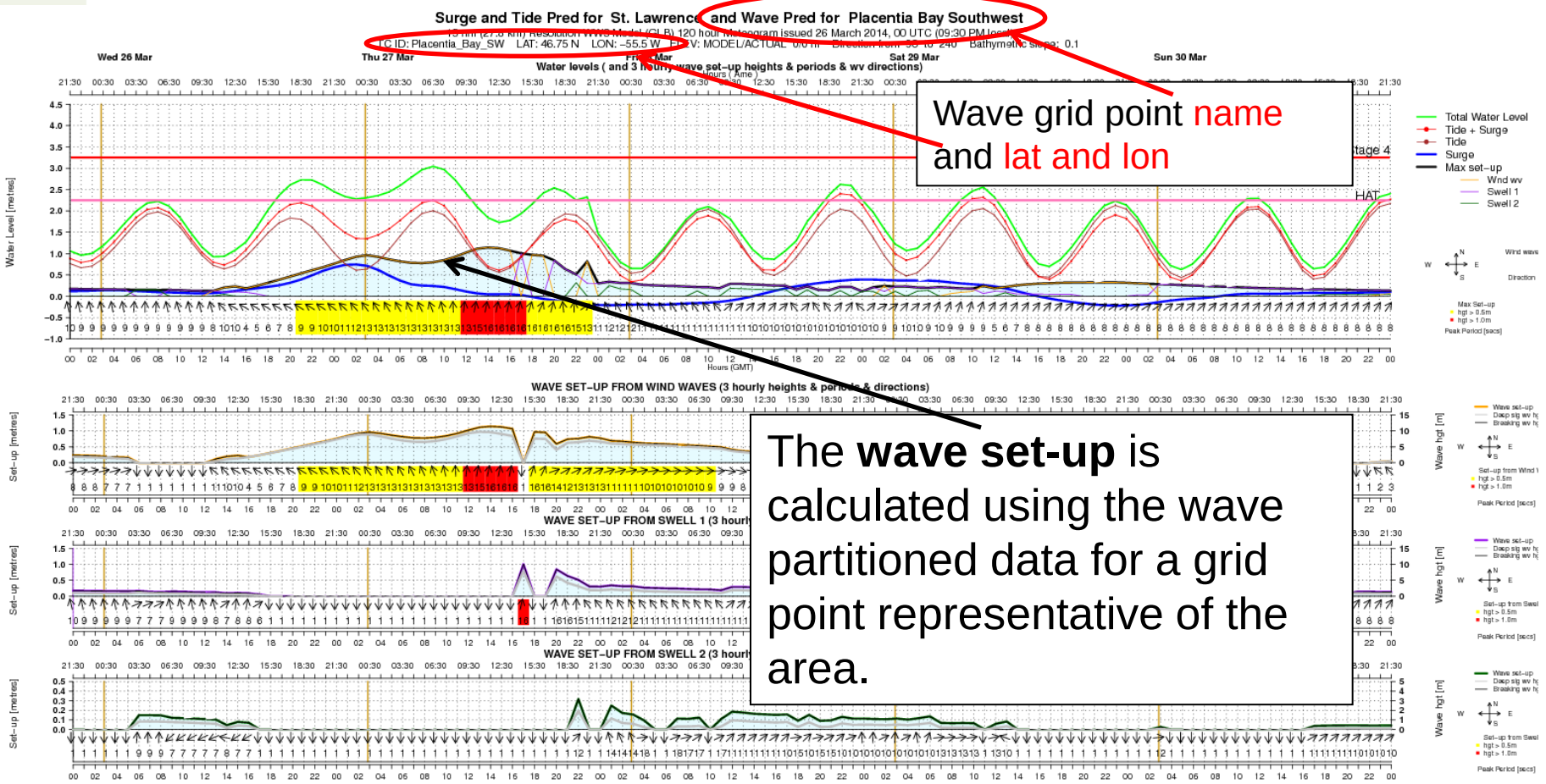
If green line hits red line…

flooding from waves on top of surge and tide

Developmental Work



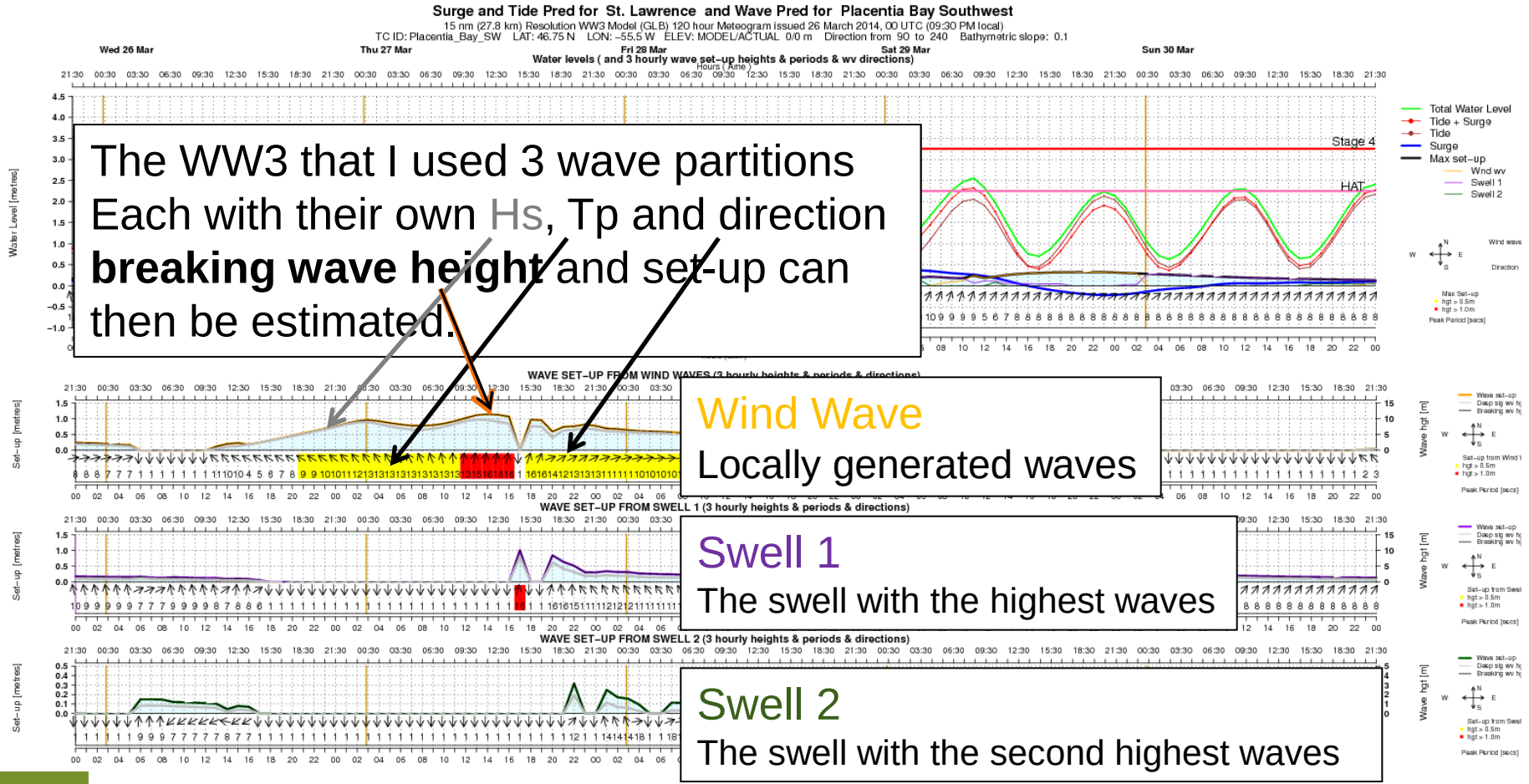
Developmental Work



Wave grid point name and lat and lon

The **wave set-up** is calculated using the wave partitioned data for a grid point representative of the area.

Developmental Work



The WW3 that I used 3 wave partitions Each with their own Hs, Tp and direction **breaking wave height** and set-up can then be estimated.

Wind Wave

Locally generated waves

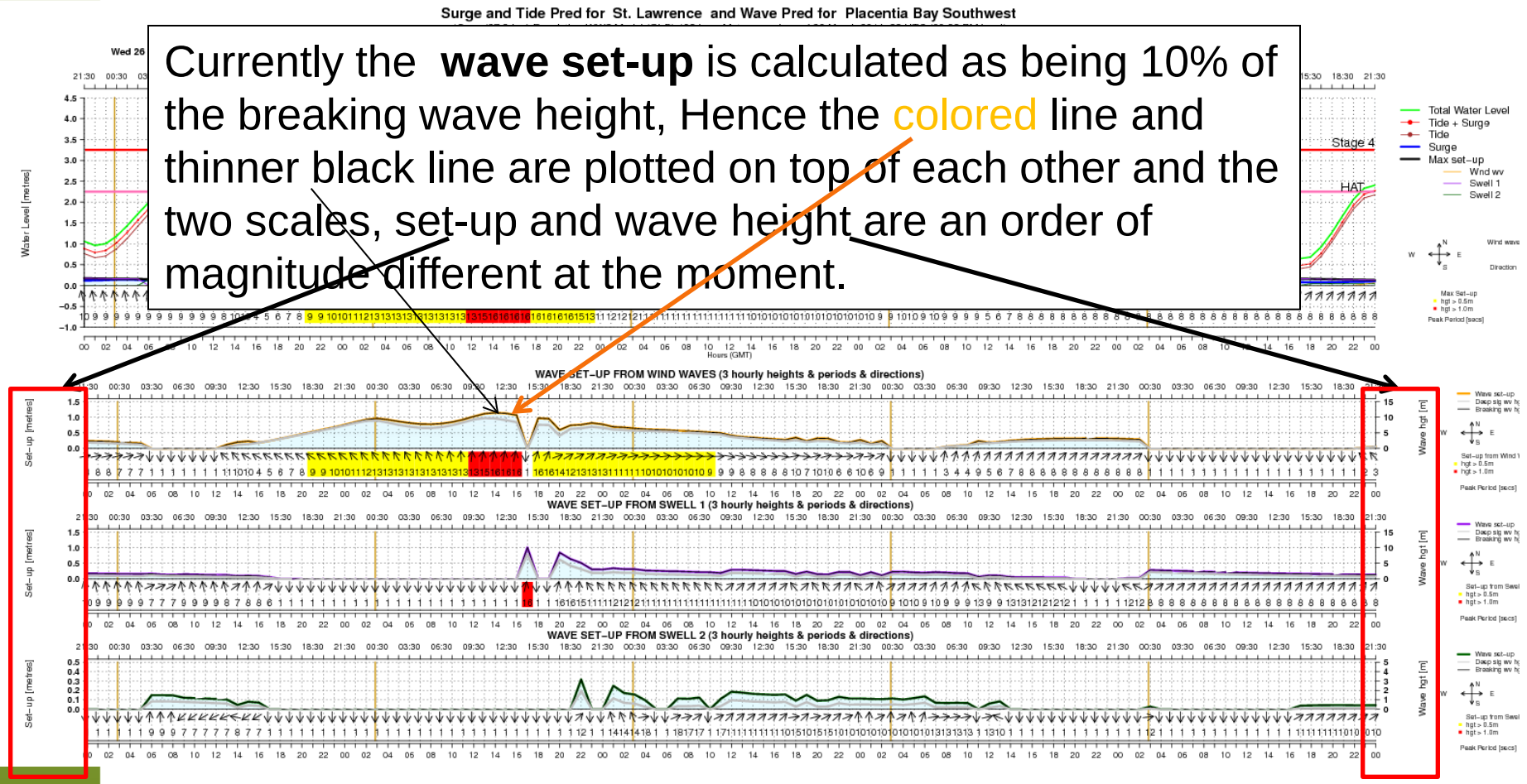
Swell 1

The swell with the highest waves

Swell 2

The swell with the second highest waves

Developmental Work



Currently the **wave set-up** is calculated as being 10% of the breaking wave height, Hence the colored line and thinner black line are plotted on top of each other and the two scales, set-up and wave height are an order of magnitude different at the moment.

Developmental Work

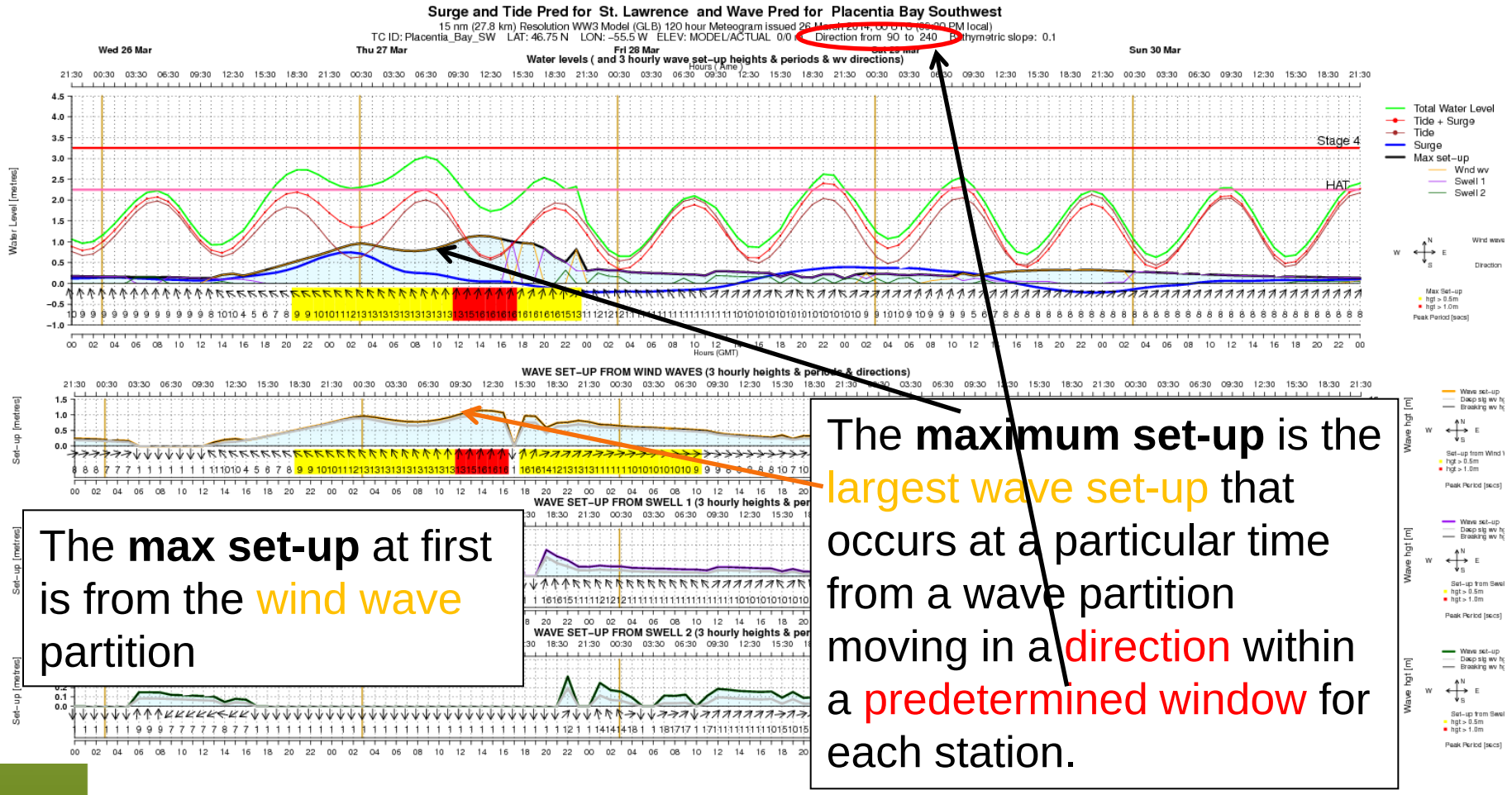
- The **breaking wave height** for each swell partition is calculated using empirical formulas for specific bathymetry slopes obtained Goda (2008).

the **slope** is defined for each station

$$(H_{1/3})_{\text{peak}}/H_0' = b_0 + b_1 x + b_2 x^2 \;:\; x = \ln(H_0'/L_0)\,, \qquad (3.37)$$

$$\left.\begin{aligned} b_0 &= 0.8119 - 0.1470y - 0.0136y^2\,, \\ b_1 &= 0.1509 - 0.0711y - 0.0070y^2 \;:\; y = \ln(\tan\theta)\,, \\ b_2 &= 0.1127 + 0.0186y + 0.00227y^2\,. \end{aligned}\right\} \qquad (3.38)$$

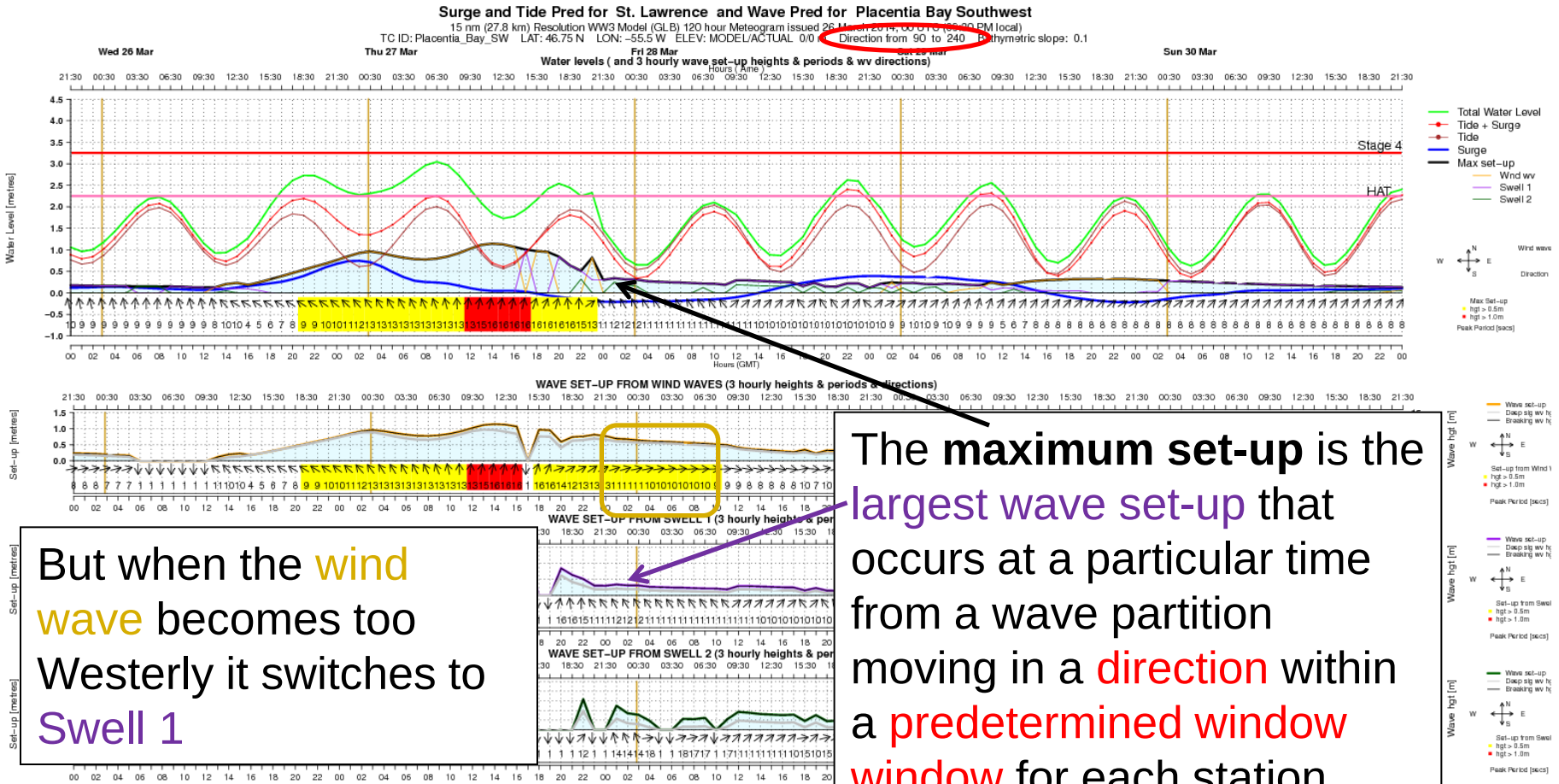
Developmental Work



The **max set-up** at first is from the wind wave partition

The **maximum set-up** is the largest wave set-up that occurs at a particular time from a wave partition moving in a direction within a predetermined window for each station.

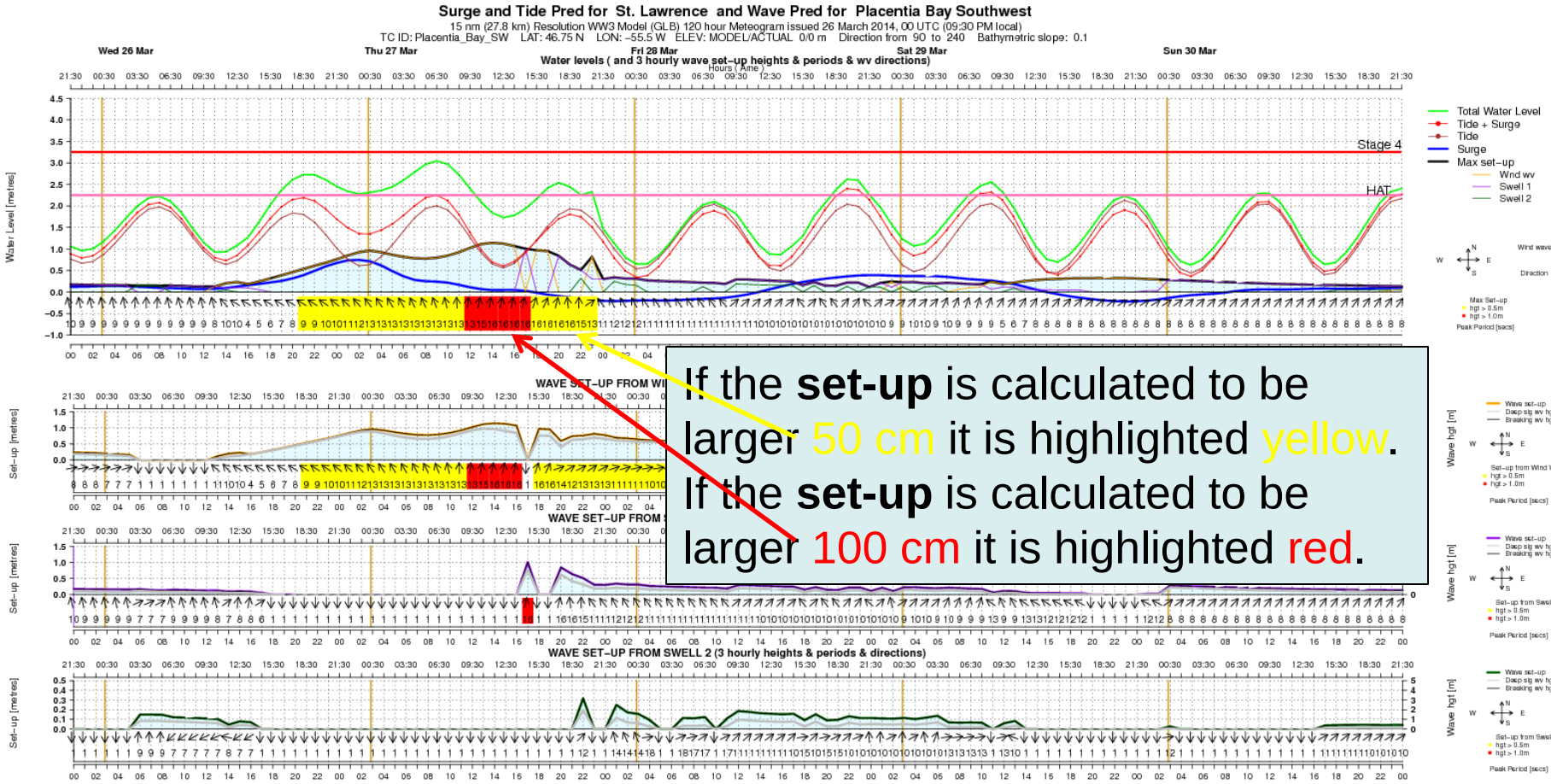
Developmental Work



But when the wind wave becomes too Westerly it switches to Swell 1

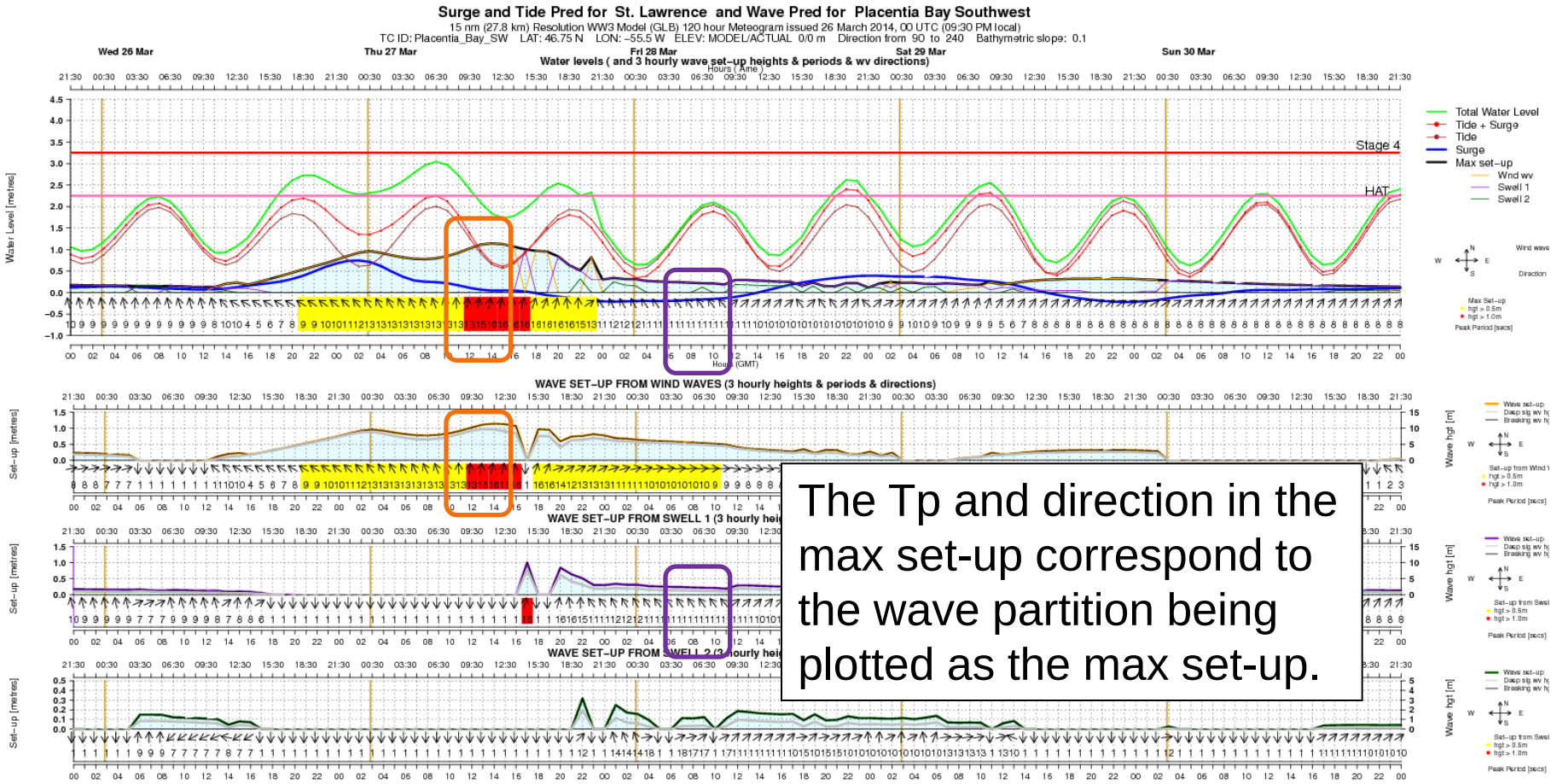
The **maximum set-up** is the largest wave set-up that occurs at a particular time from a wave partition moving in a direction within a predetermined window window for each station.

Developmental Work



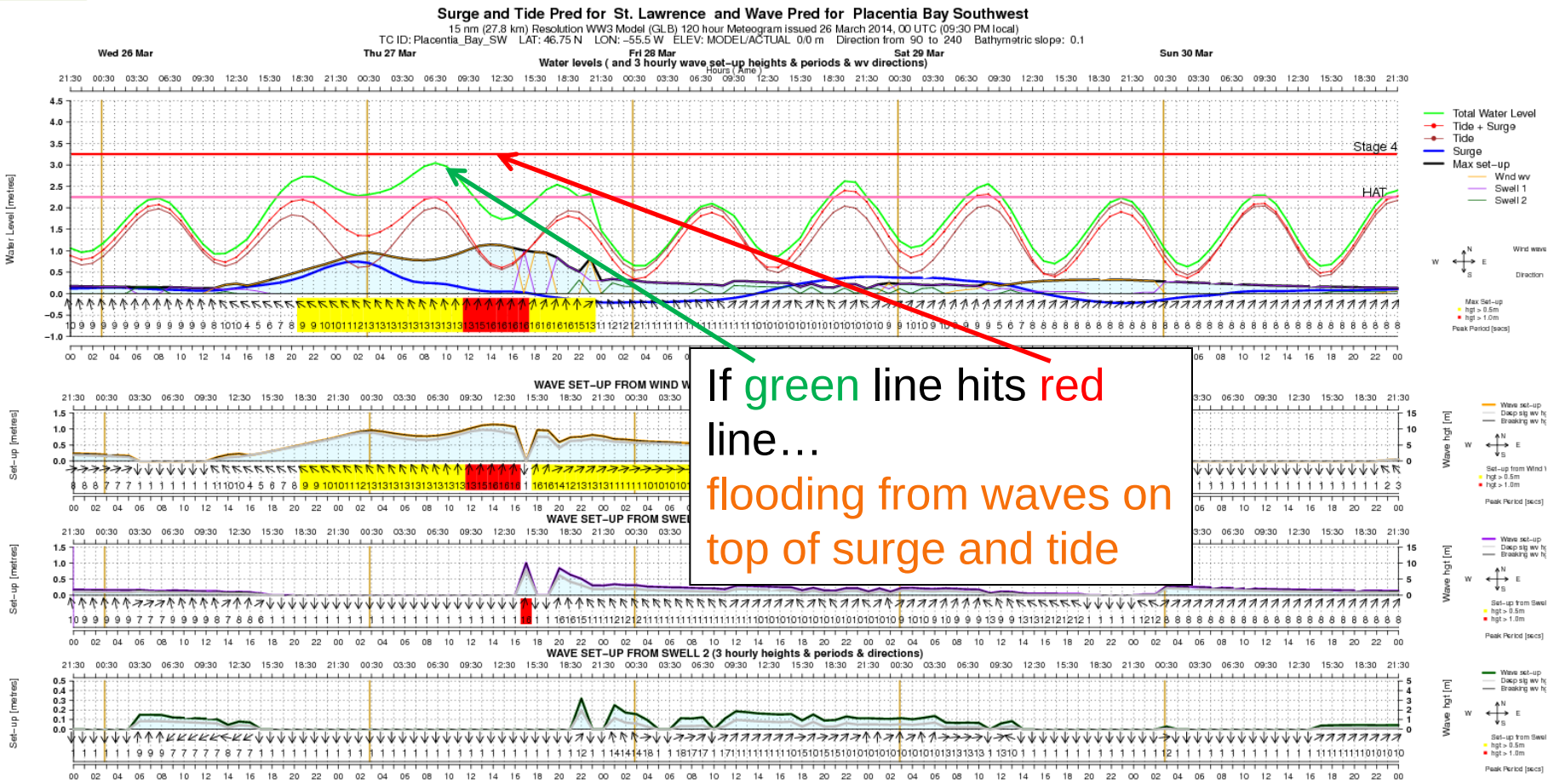
If the **set-up** is calculated to be larger 50 cm it is highlighted yellow. If the **set-up** is calculated to be larger 100 cm it is highlighted red.

Developmental Work



The Tp and direction in the max set-up correspond to the wave partition being plotted as the max set-up.

Developmental Work



If green line hits red line…

flooding from waves on top of surge and tide

EC/NOAA Marine Collaboration

- I gave a presentation at the 2014 Atlantic and Eastern Arctic Weather Workshop, Dartmouth, NS in February 2014.

- During the workshop, Rich Okulski (NWS) presented John Cannons Presentation on their Wave Run Up Project.

EC/NOAA Marine Collaboration

Overwash

Splashover

Rule of thumb from BOX:

Along exposed coast, overwash and splashover can become important when waves about 10 miles offshore reach 20 feet or more

NART Wave Run Up Project

- It was apparent that both services where working on a similar problem so I was presented an opportunity to attend an upcoming the NART Wave Run Up Project and a "Train The Trainer" workshop at WFO Taunton April 16 and 17, 2014.

- Part of the workshop is classroom instruction on how to develop the wave run up program and the rest is "hands on" training at field sites.

- This would be more inline with what our colleagues at the NWS are also working on.
  - Thanks to Bob Cannon at BOX and Tony Mignone at CAR for hosting and organizing the NE wave run-up workshop.

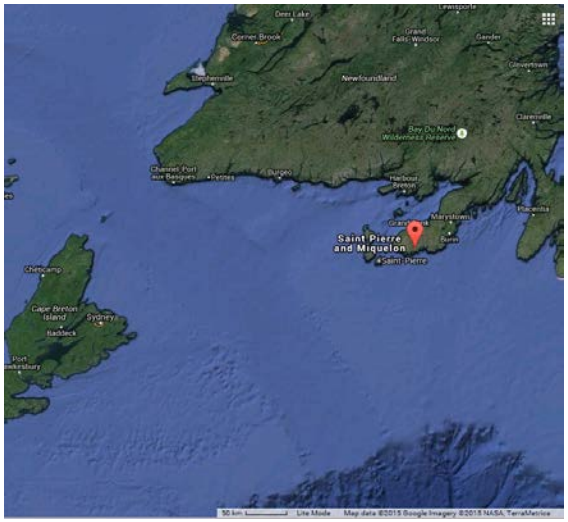
NART Wave Run Up Project

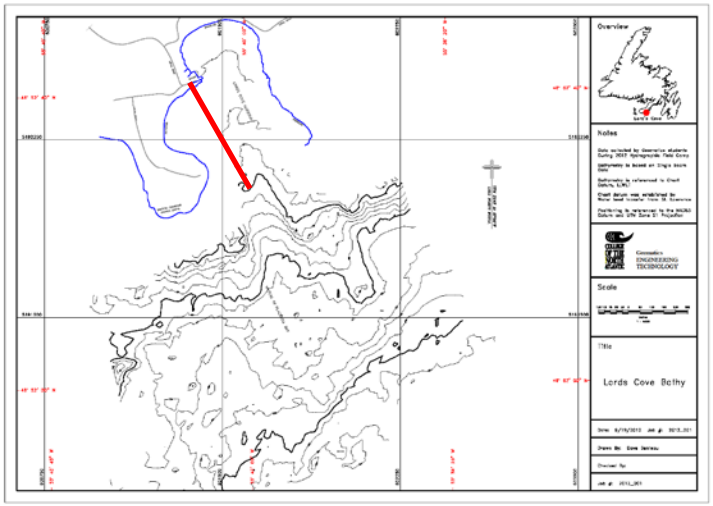
- 3 different parameterization dependent on the shore
  - Stockdon Parameterization
  - Sallenger scaling model
  - J.P. de Wall & J.W. van der Meer Parameterizations
- These parameterization require an
  - estimate of the near shore slope
  - Significant wave height and wave length for waves at the 20 meter isobath.
- This means we have to go to the beach and take some measurements.

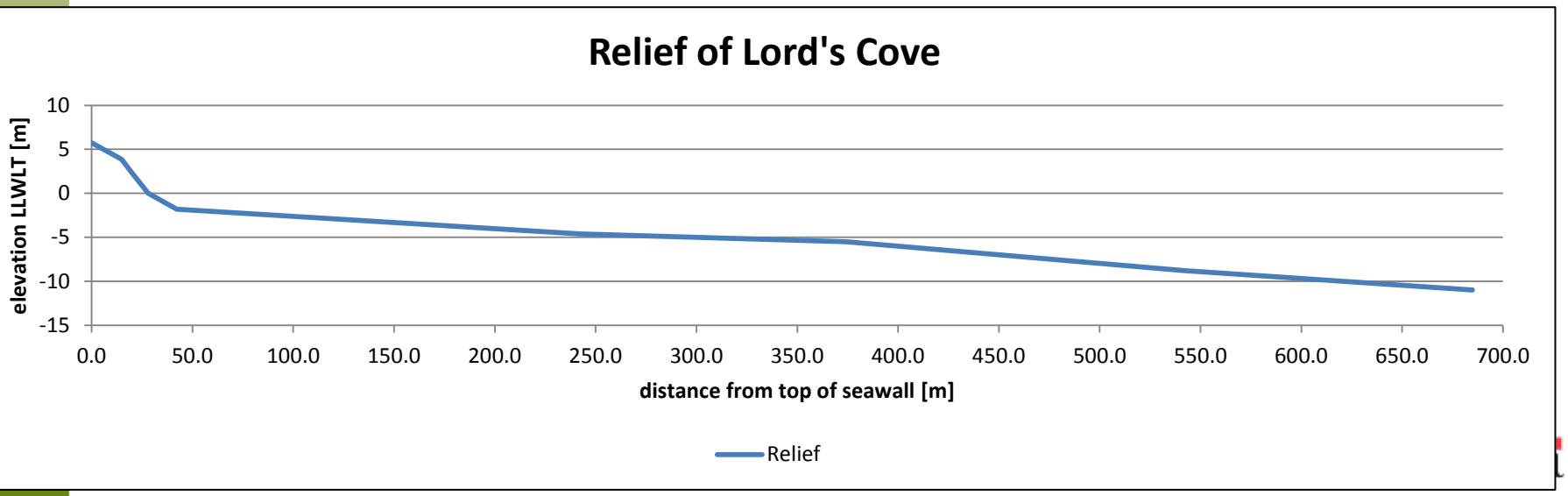
NART Wave Run Up Project

–Duxbury Beach survey

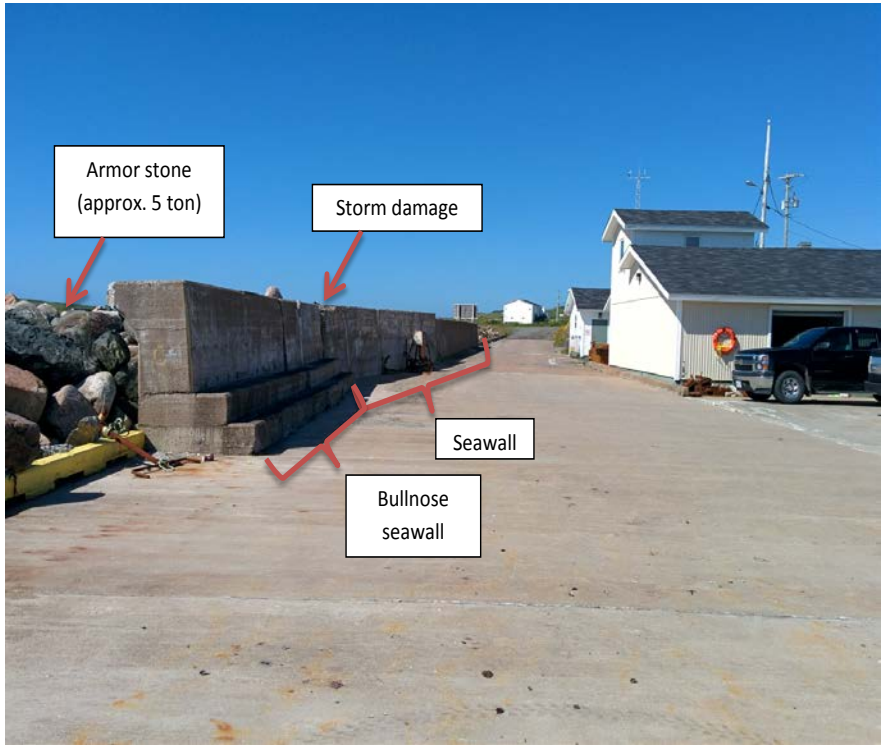
Lord's Cove, NL



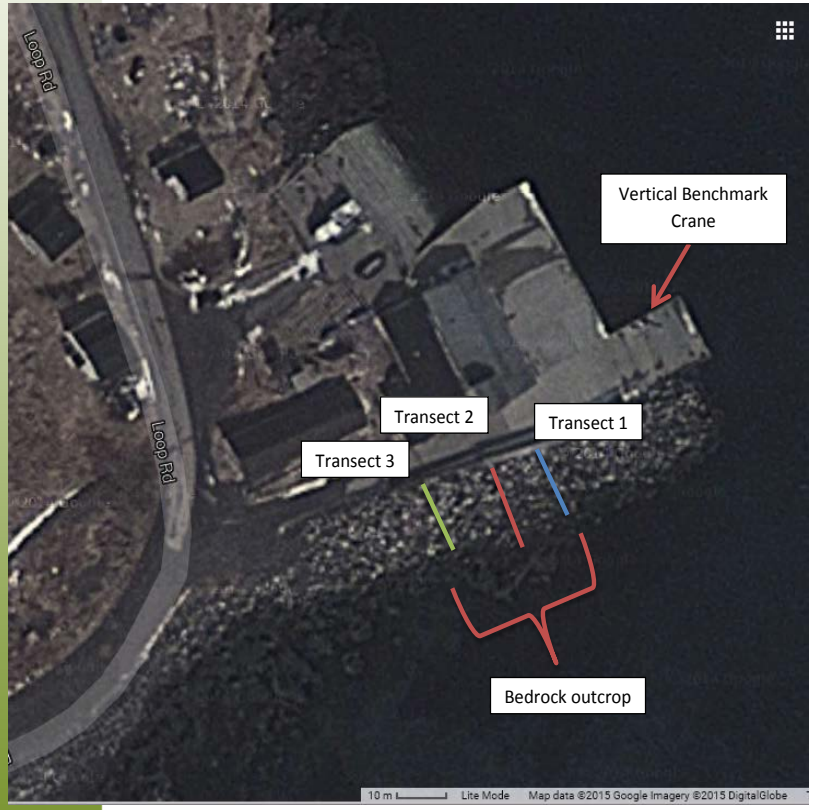




Lord's Cove, NL
- Survey



Lord's Cove, NL
- Survey



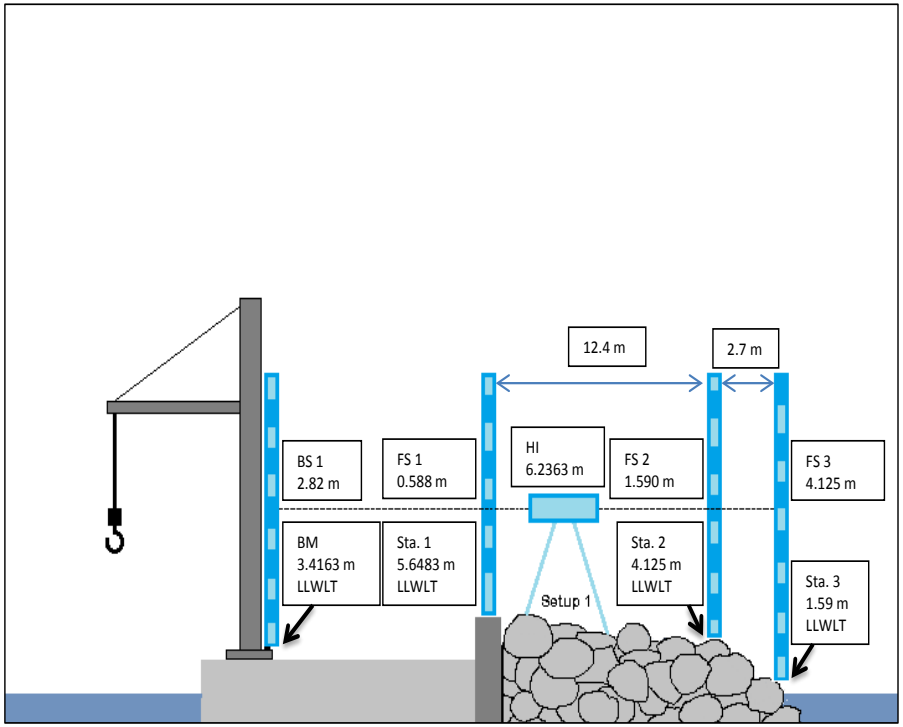


Figure 15. Diagram of transect 3.

Lord's Cove, NL

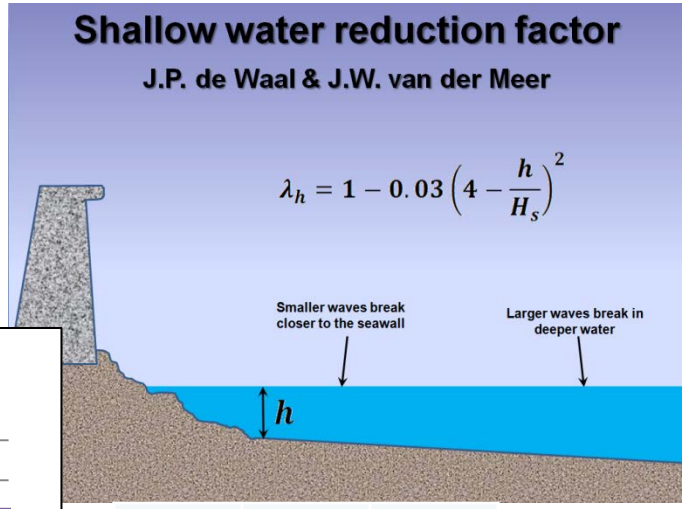
- March 22, 2015 Event

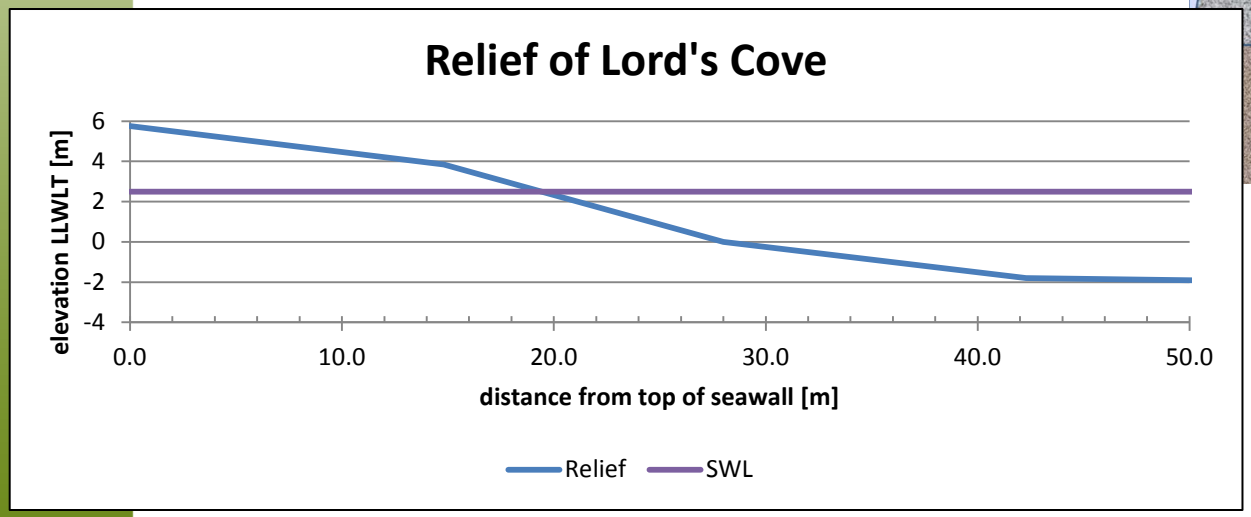
https://www.facebook.com/WERCCNA/videos/927397180614103/?video_source=pages_finch_main_video

Lord's Cove, NL
- Survey

Lord's Cove, NL - March 22, 2015 Event

- So we can "know" everything but the depth of the water when the waves break again right before the revetment.
- But we can estimate it from the video and picture.





h [m]	q (cu m)	q (cu ft)
1	0.04135	1.460
1.5	0.04718	1.666
2	0.05525	1.951
2.5	0.06388	2.256
3	0.07303	2.579
3.5	0.08264	2.918
4.000	0.09266	3.272

Overtopping Rate Validation

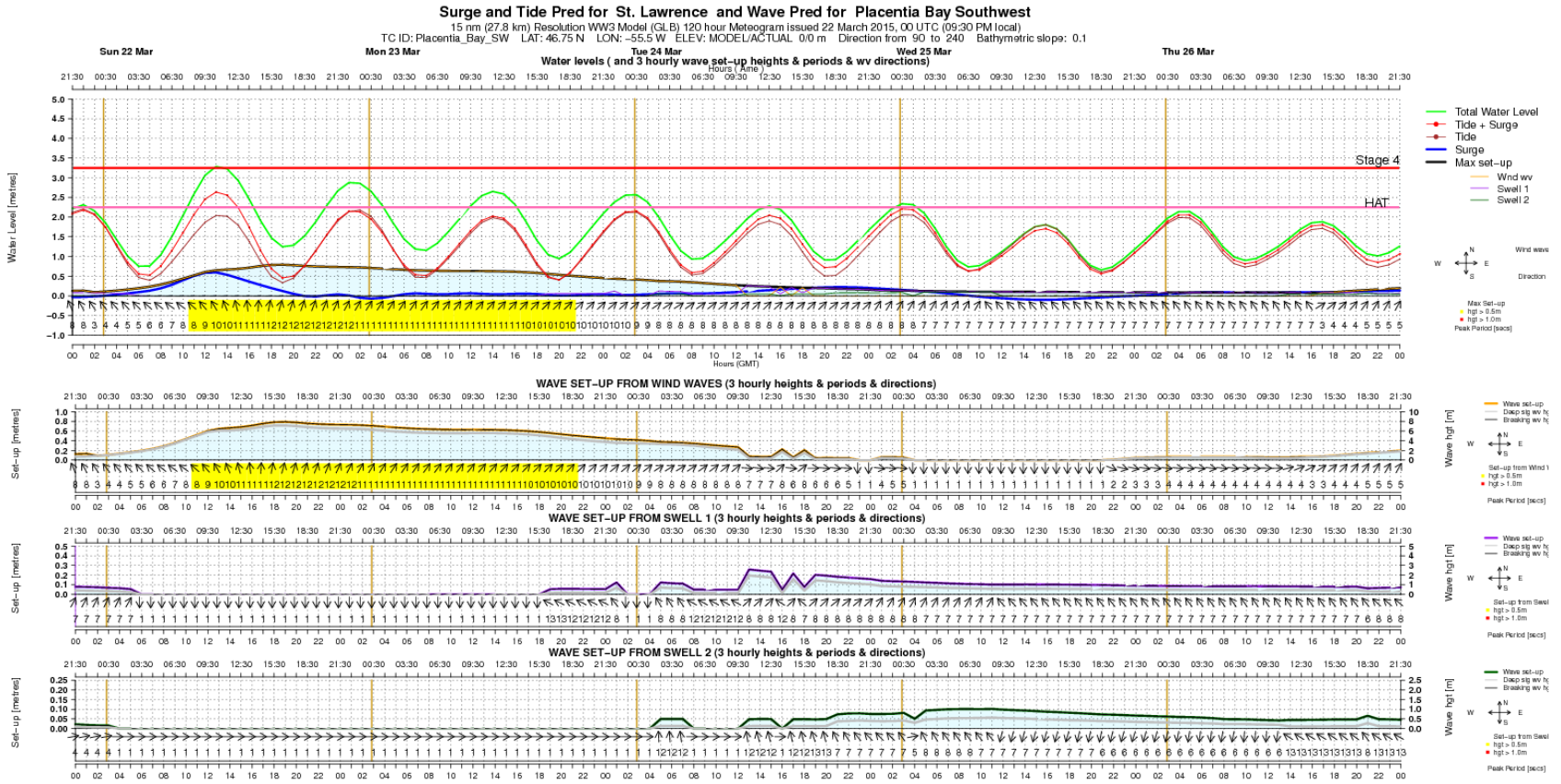
Now what?

- This EC/NOAA collaboration is starting to leave my group of Predictions and Services and is starting to look a lot more like Science and Research.

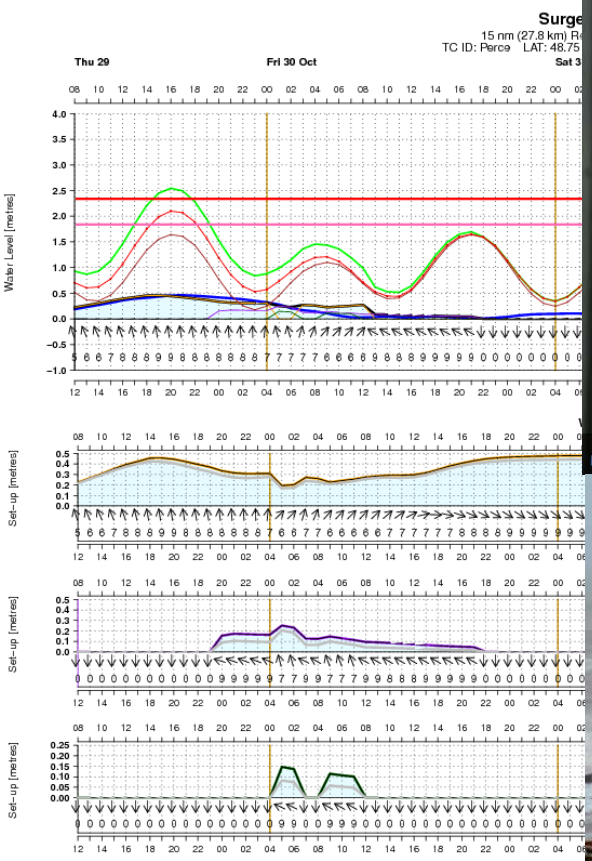
- Overtopping rate may be too ambitious at this time for Atlantic Canada and we might have to take a step back and look at wave run-up instead.

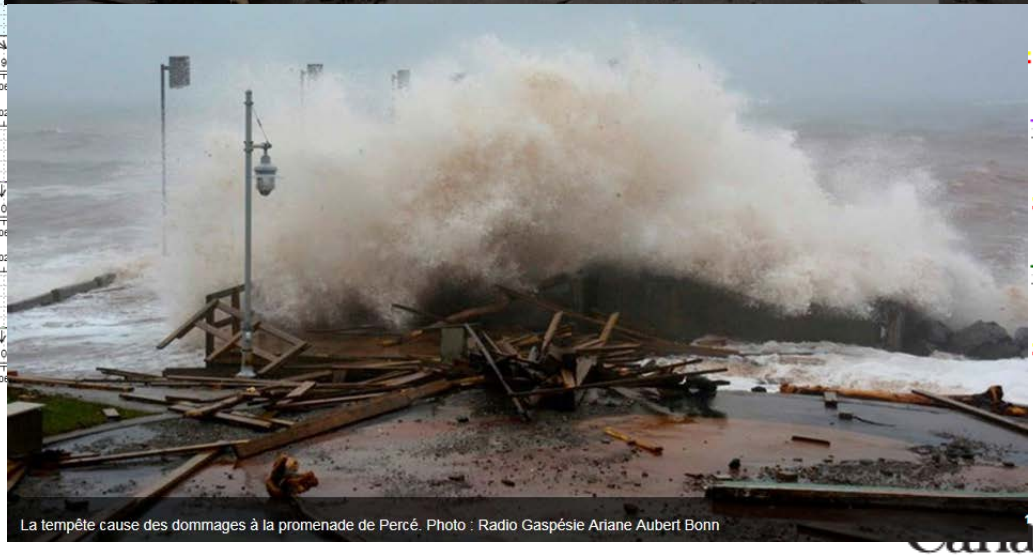
- In the mean time, forecasters still have the wave, surge, tide progs to use.

Lord's Cove, NL
- March 22, 2015 Event



Perce, QC
- Oct 29, 2015 Event





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- Global and Planetary Change Special Issue Extreme Climate Events, 57, 139-150.
- This presentation was put together from various Comet Modules including;
  - **Shallow-Water Waves**
- As well as the following NOAA and CDIP websites

  http://cdip.ucsd.edu/?nav=documents&sub=index&xitem=waves

  http://www.ndbc.noaa.gov/wavecalc.shtml

  https://www.mfe.govt.nz/publications/climate/preparing-for-coastal-change-guide-for-local-govt/html/page8.html

Thanks!

NLWO Wave Set-up

Questions / Comments?