HURRICANE - GENERATED OCEAN WAVES

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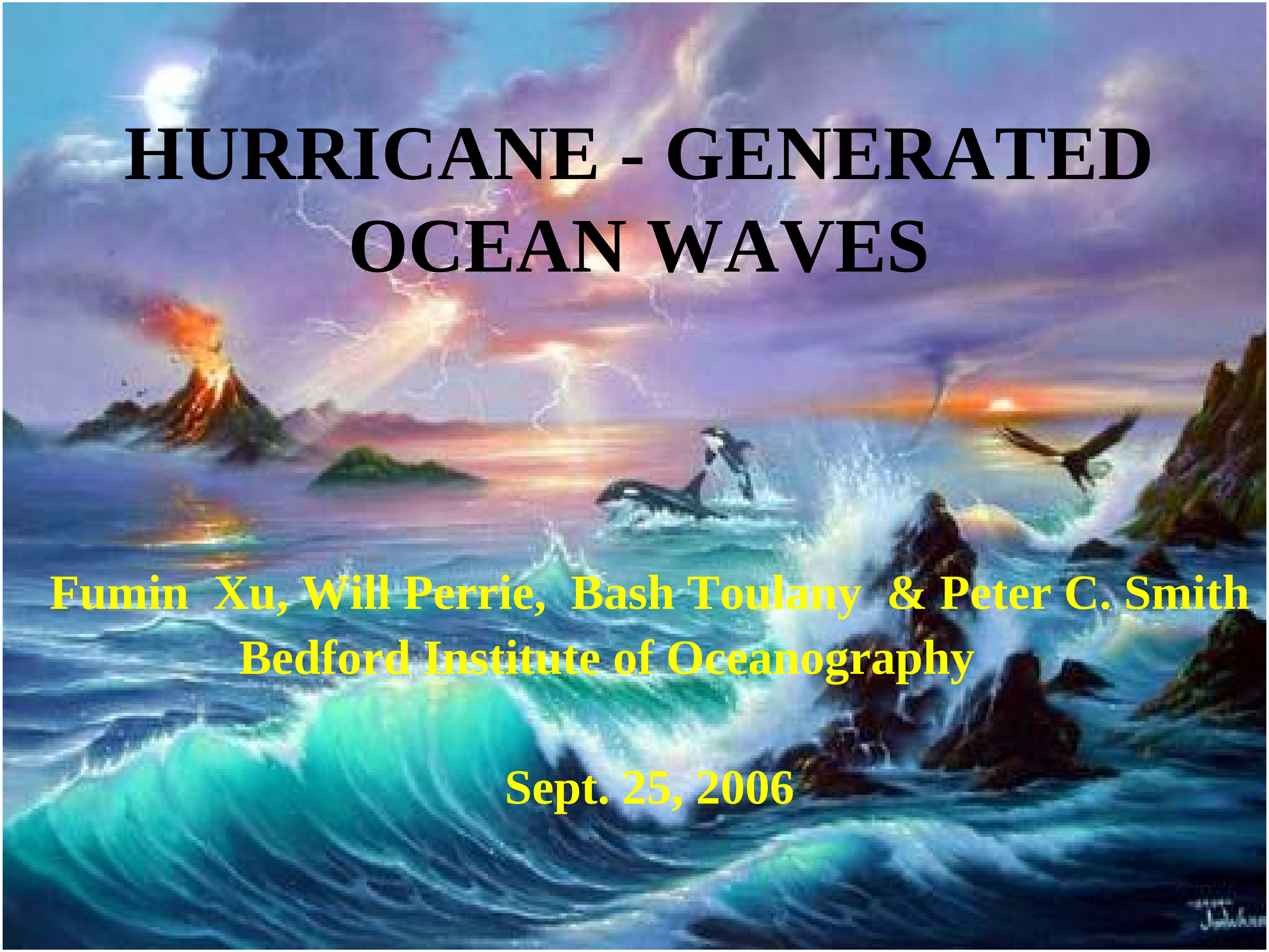


Outline:

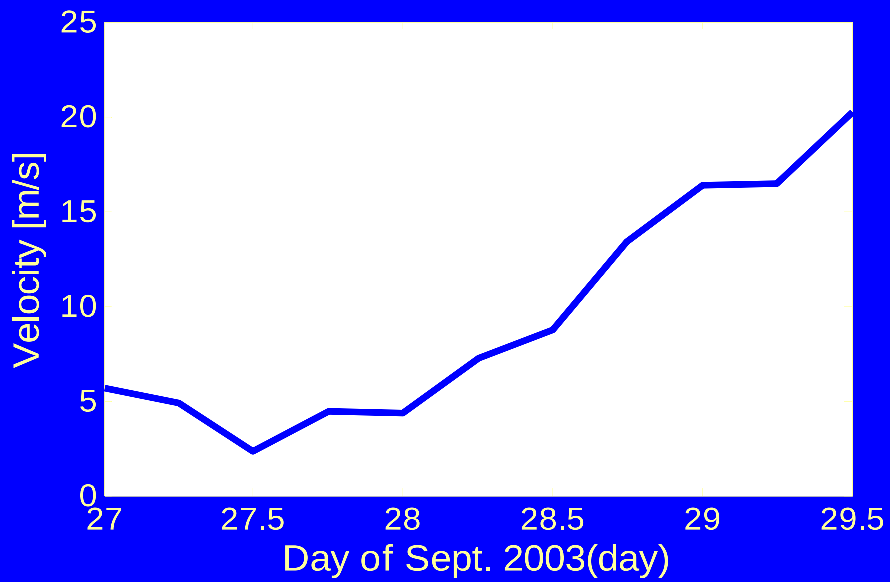
- Introduce hurricane Juan
- Wave Spectral Observations Around Juan's Track
- Large domain Wave Model Simulation(WW3)
- Juan Generated Waves simulation in Coastal Shallow Water (SWAN)
- Improvement of 2D Spectral Boundary conditions
- Summary
- analysis

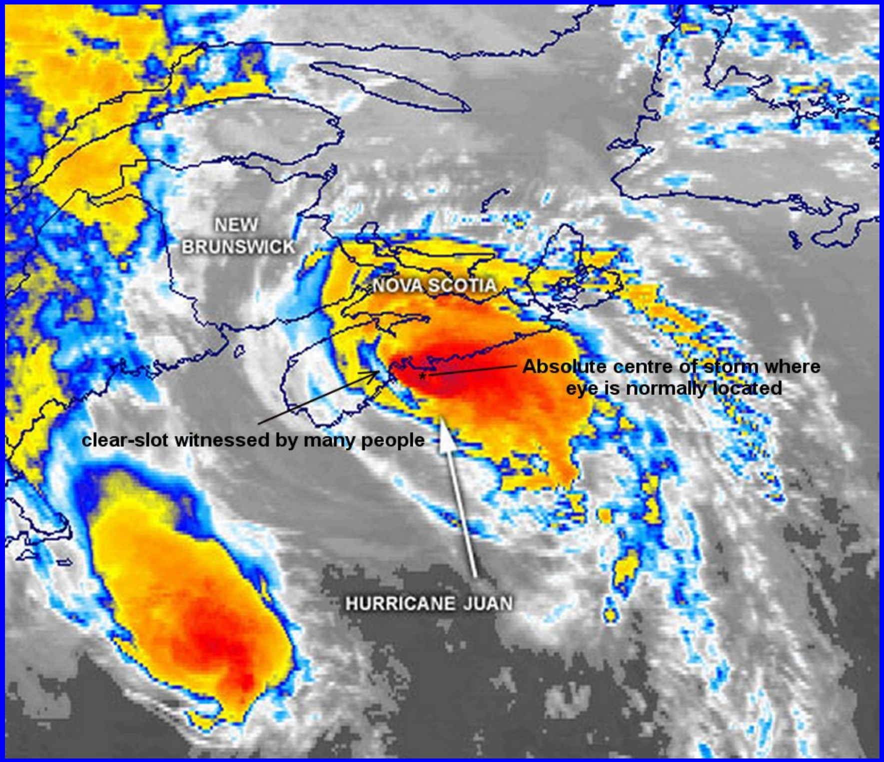
Goals:

- **Hurricane generated large scale ocean waves properties**
- **Costal shallow water hurricane generated waves simulation study**

1. Hurricane Juan

- Hurricane Juan was one of the most damaging storms in the modern history of Nova Scotia.
- Juan was a rapidly propagating accelerating hurricane.





Juan's translation speed

Satellite image at landfall

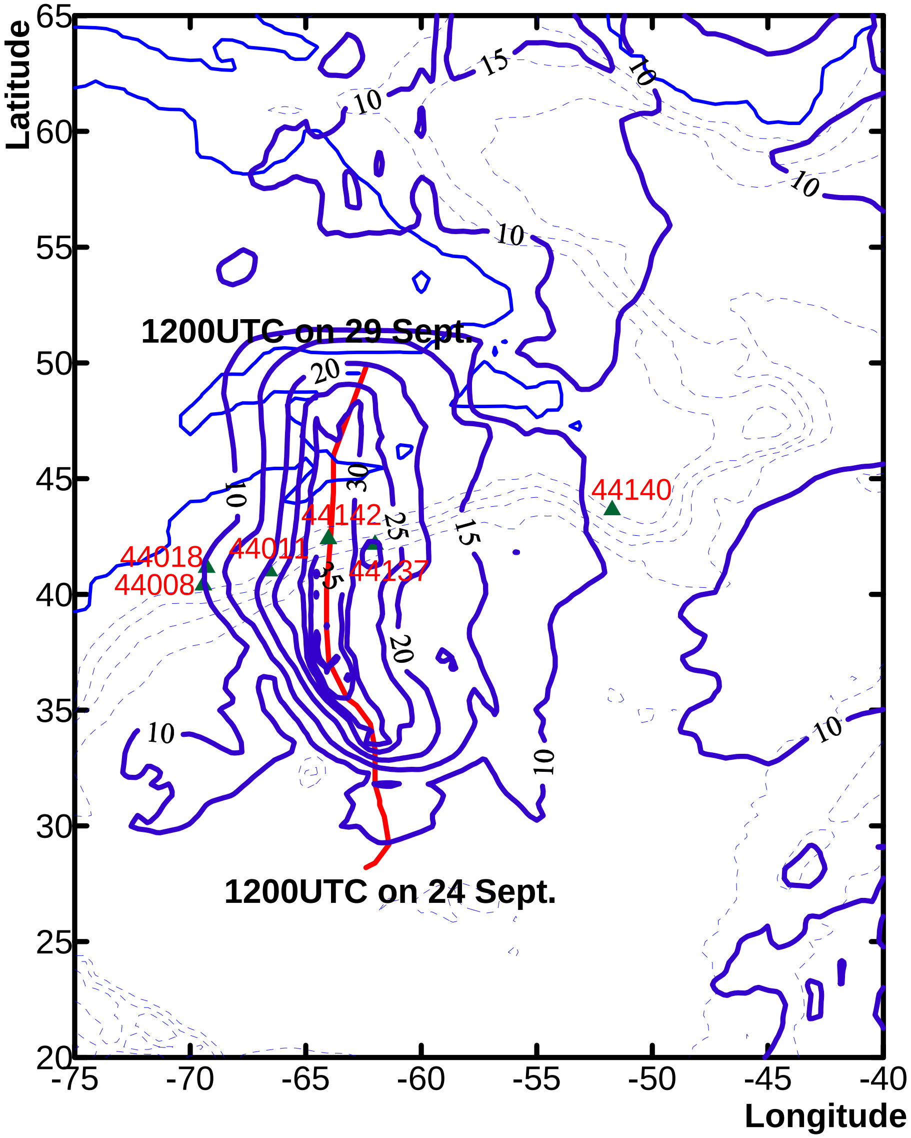
2. Wave Spectral Observations Around Juan's Track

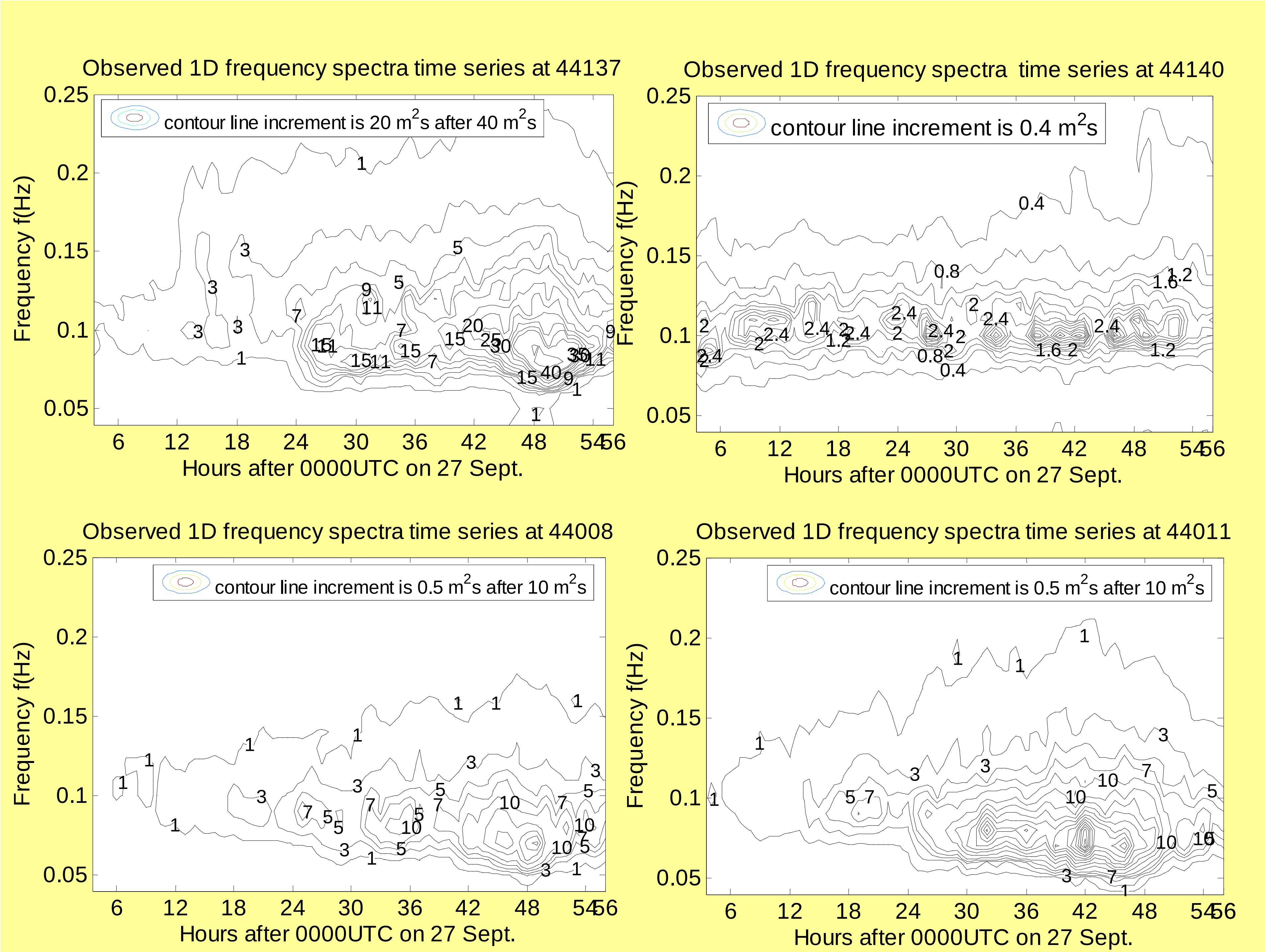
What is in the map?

- Juan's wind swath isolines;
- Six buoys within or near the 10m/s wind swath isoline.

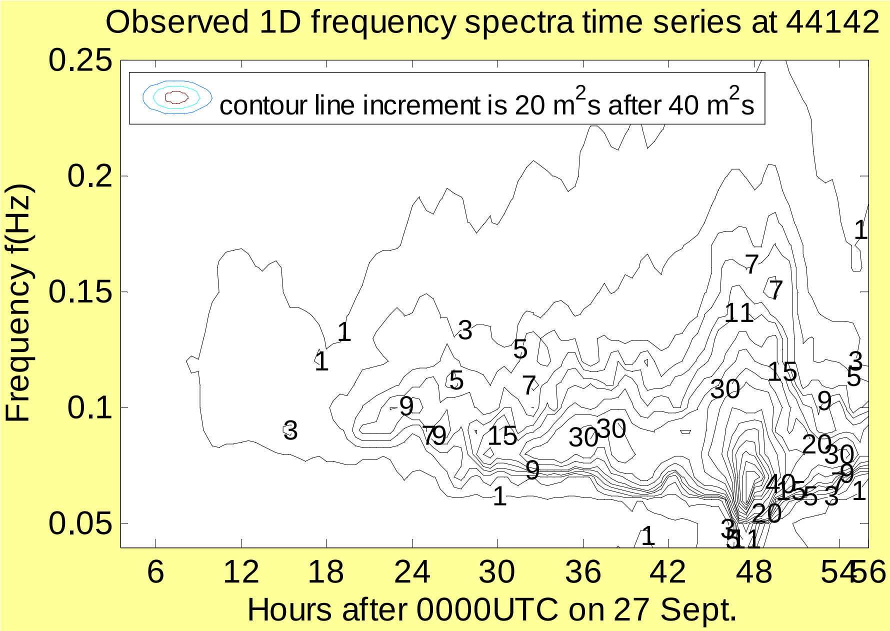
Buoys' information:

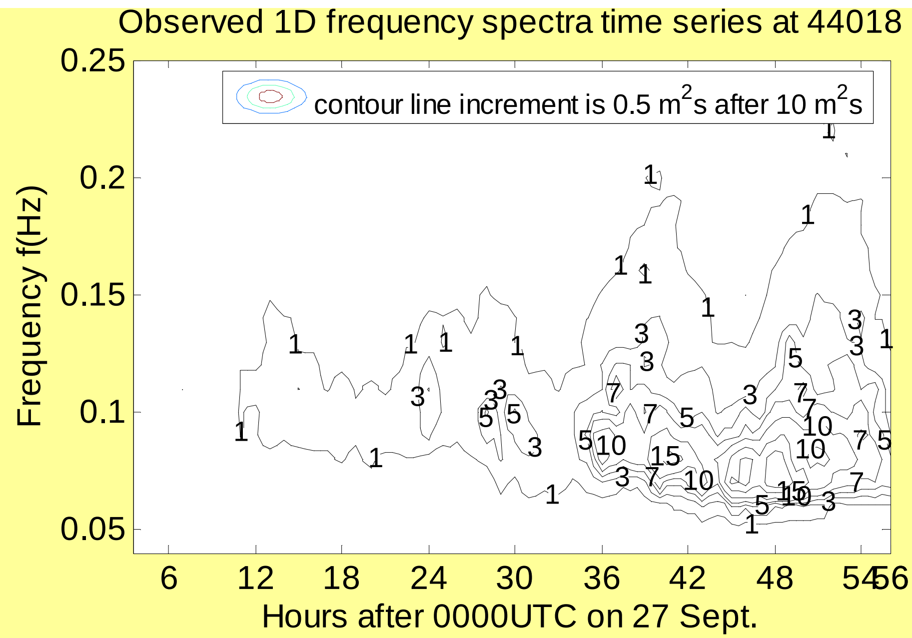
- **Intermediate water depth: 44140, 44008, 44018 and 44011;**
- **Deep water: 44142, 44137 .**
- **Buoys' location near the track:**
  44142: on the storm track;
  44137: on the right side of the track, outside maximum wind radius;
  44140(right), 44008 and 4018(left): on the 10m/s wind swath isoline;
  44011(left): on 20m/s wind swath isoline.





Observed 1D frequency spectra time series at 44137
contour line increment is 20 m2s after 40 m2s
Frequency f(Hz)
Hours after 0000UTC on 27 Sept.
Observed 1D frequency spectra time series at 44140
contour line increment is 0.4 m2s
Frequency f(Hz)
Hours after 0000UTC on 27 Sept.
Observed 1D frequency spectra time series at 44008
contour line increment is 0.5 m2s after 10 m2s
Frequency f(Hz)
Hours after 0000UTC on 27 Sept.
Observed 1D frequency spectra time series at 44011
contour line increment is 0.5 m2s after 10 m2s
Frequency f(Hz)
Hours after 0000UTC on 27 Sept.



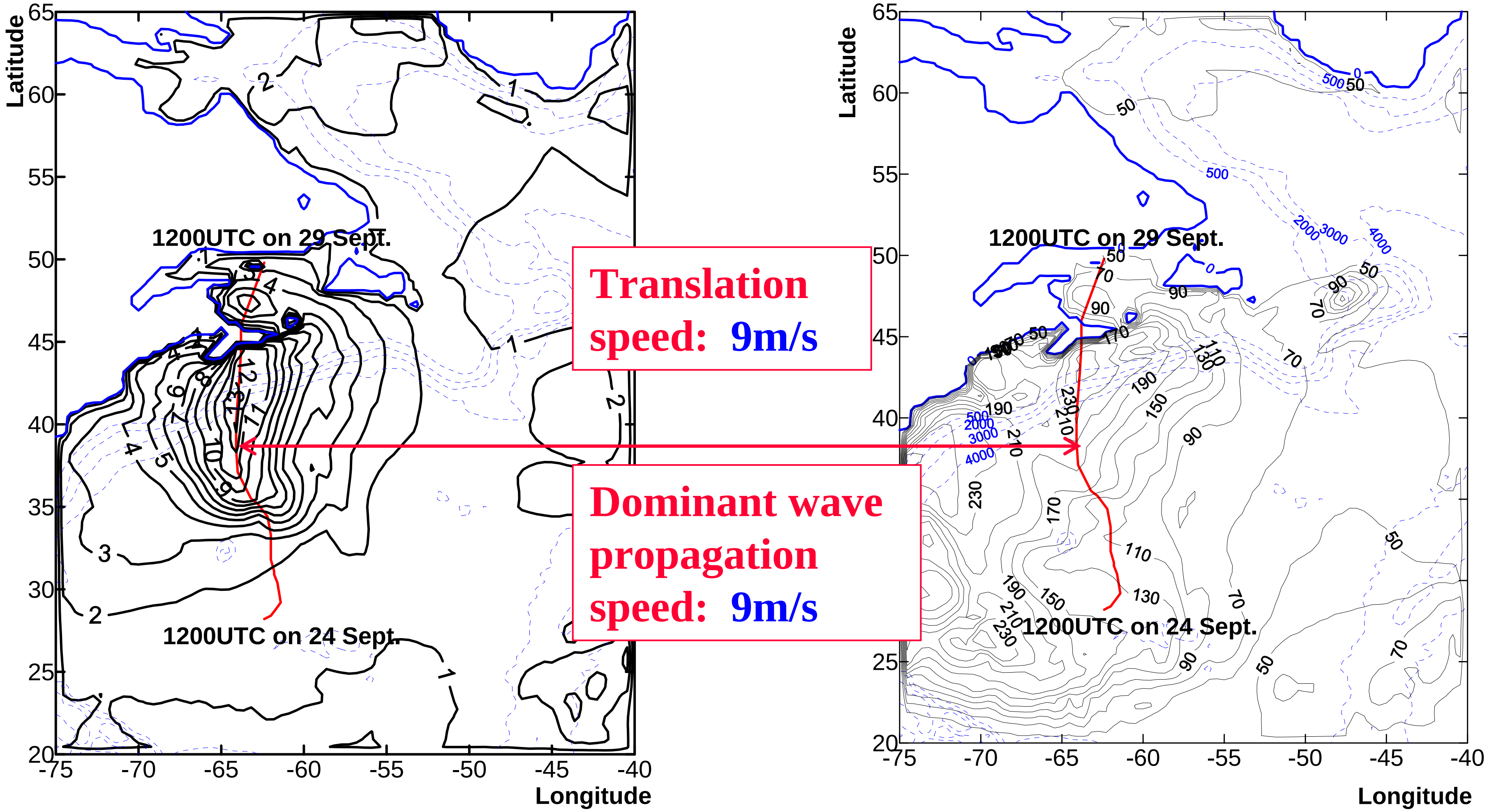


- **Waves at different locations show totally different behaviours in strength, duration and spectral pattern;**
- **In areas along the track and on the left of the track, dominant swell existed almost over 24 hours, before, during and after Juan's passage (44142, 44137, 44011, 44008 and 44018).**

44140: very slightly influenced;

- **44008 and 44018: obviously influenced by Juan-generated waves, swell dominated;**
- **44011: dominant swell existed over 24 hours;**
- **44142: extremely low frequency strong waves last for about two hours, during peak waves;**
- **44137: swell existed over 24 hours, until peak waves (last for about 3 hours).**

3. Wave Model Simulations



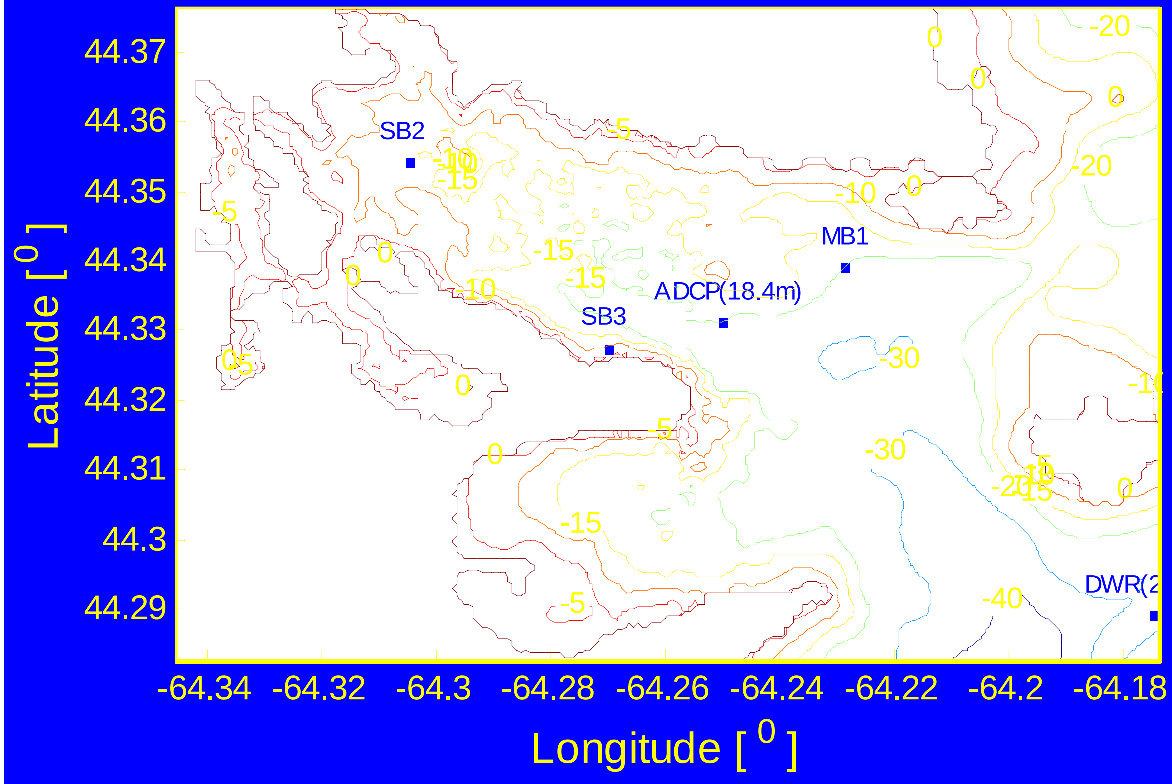
WW3(2.22) simulated significant height (Hs) swath isolines (units in m)

WW3(2.22) simulated average wave length (L) swath map (units in m)

1. **Hs and L swath distributions:** more **asymmetric** than Juan's wind swath distribution, especially L;
2. **Hurricane-generated waves range:** cover **far larger** area than hurricane wind range;
3. **Maximum Hs:** occurs on right side near the track;
4. **L on left of track:** is larger and more complex than that on right side;
5. **Swell:** Swell dominates, and propagates outside of Juan's wind range on left of track. On the right side of Juan's track, less swell exists even within the 10m/s wind swath isoline;
6. **Translation speed effect:** Strong waves occur along the track, when translation speed reached and surpassed dominant wave group velocity.

4. Juan Generated Waves in Shallow Water

4.1 Lunenburg Bay computation domain, observation stations



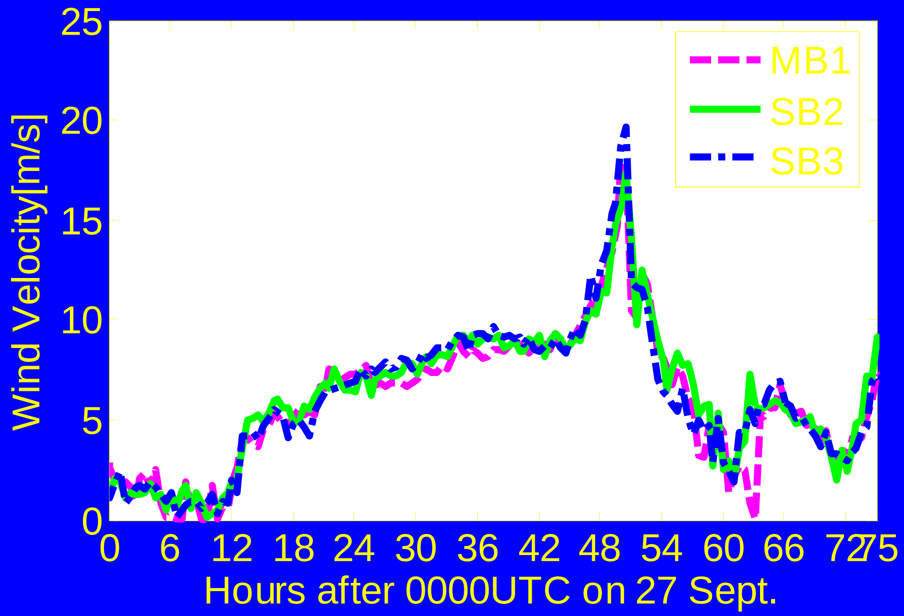
Computation Domain:
(64.35°W ~ 64.17°W, 44.28°N ~ 44.38°N);
Spatial resolution: 60m;

Direction resolution: 4°;
frequencies range : from 0.04Hz to 0.58Hz, with neighbouring frequencies defined as: $f_{n+1} = 1.0434 f_n$;

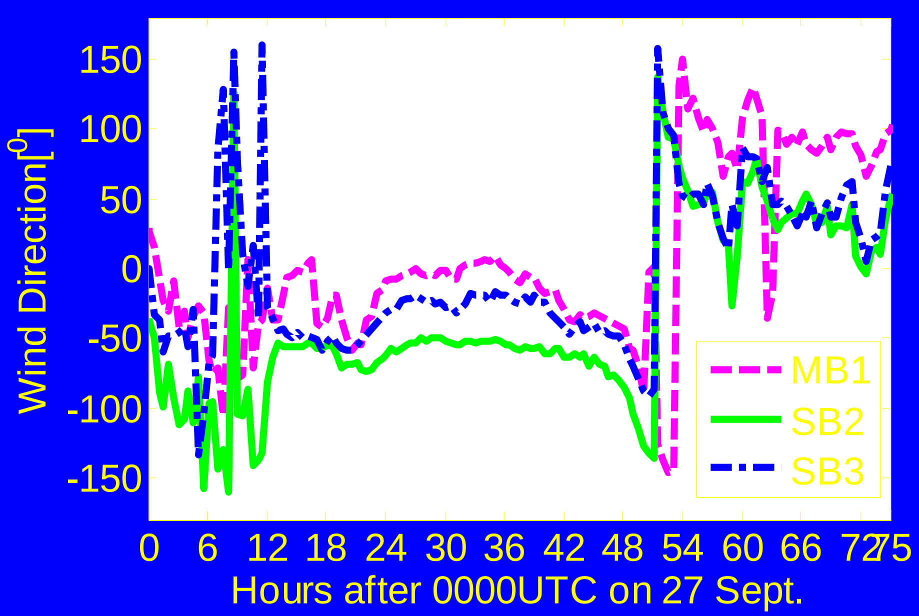
Location of lunenburg Bay:

On the left side of Juan's track, swell dominates for almost over 24 hours, before, during and after Juan's passage.

4.2 Wind Observations at SB2, SB3 and MB1



wind velocity



wind directions

4.3 Improved in 2D Spectral Boundary conditions

Reality: Only 2D observed spectra recorded every half hour at DWR.

Method: Construct correlation between DWR and open boundary points of Lunenburg Bay domain.

(a): Multiple-nested wave simulation:

(SWAN) Mahone Bay → nested within → (SWAN) fine-resolution domain (65ºW~63ºW, 43ºN~45ºN)

fine-resolution domain → nested within → (WW3) intermediate-resolution domain (71º W~55ºW, 42ºN~62ºN)

intermediate-resolution domain → nested within → (WW3) coarse-resolution domain (75º W~40ºW, 20ºN~65ºN)

Spatial Resolutions: 130m, 1', 5', and 15', respectively;

Directional resolution: 6°;

Frequencies range: from 0.03094Hz to 0.5939Hz, with neighbouring frequencies defined as $f_{n+1} = 1.1\, f_n$;

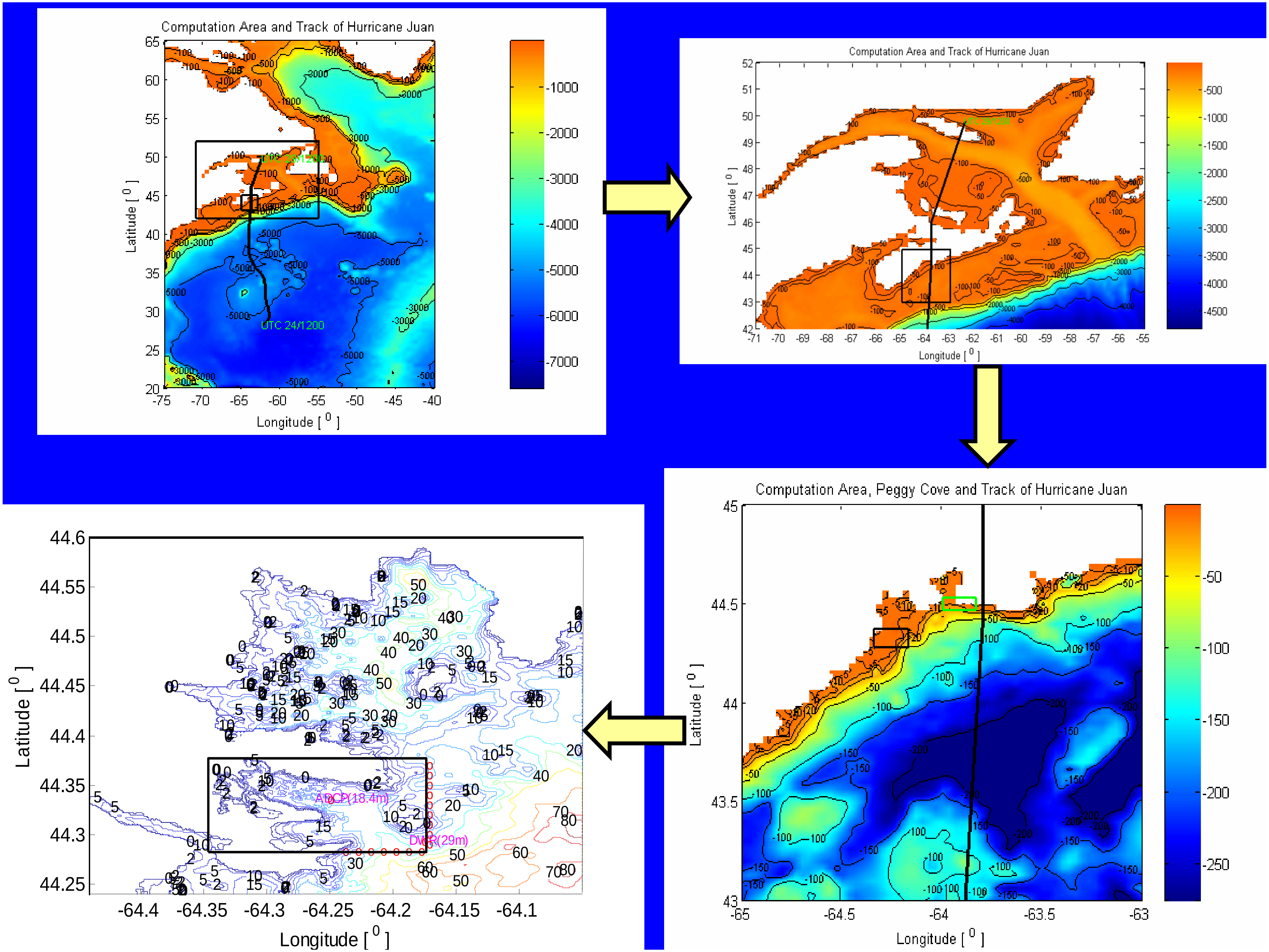
(b) wind fields: Blended winds (Xu, et al. 2006) applied in these domains.

(c) Wave Relations: Lunenburg Bay open boundary-DWR

- **Assume**: 2D wave spectra have similar spectral shapes at each grid point on the east and south boundaries and at the DWR location;
- **Because**: spectra at these points experience almost same winds and swell;
- **Therefore**: 2D spectra at open boundary points of the Bay are obtained by :

$$S_P(f,\theta) = \kappa^2 S_{DWR}(f,\theta) \quad \text{in which} \quad \kappa = Hs / Hs_{DWR}$$

Position	South boundary points							East boundary points								
Points	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16
Long.	64.24	64.23	64.22	64.21	64.20	64.19	64.18	64.17	64.17	64.17	64.17	64.17	64.17	64.17	64.17	64.17
Lat.	44.28	44.28	44.28	44.28	44.28	44.28	44.28	44.29	44.30	44.31	44.32	44.33	44.34	44.35	44.36	44.37
k	0.85	0.92	0.90	0.93	0.97	1.01	1.02	1.02	1.07	0.90	0.85	0.86	0.89	0.85	0.81	0.80


Computation Area and Track of Hurricane Juan
Latitude [0]
Longitude [0]
UTC 24/1200
Computation Area and Track of Hurricane Juan
Latitude [0]
Longitude [0]
Computation Area, Peggy Cove and Track of Hurricane Juan
Latitude [0]
Longitude [0]
Latitude [0]
Longitude [0]
ADCP(18.4m)
DWR(29m)

5. Shallow water wave Simulation

Motivation:

- **Accurate winds and incoming 2D open boundary spectra;**
- **Use state-of-the-art operation models → accurate model physics;**
- **expect: accurate simulation results.**

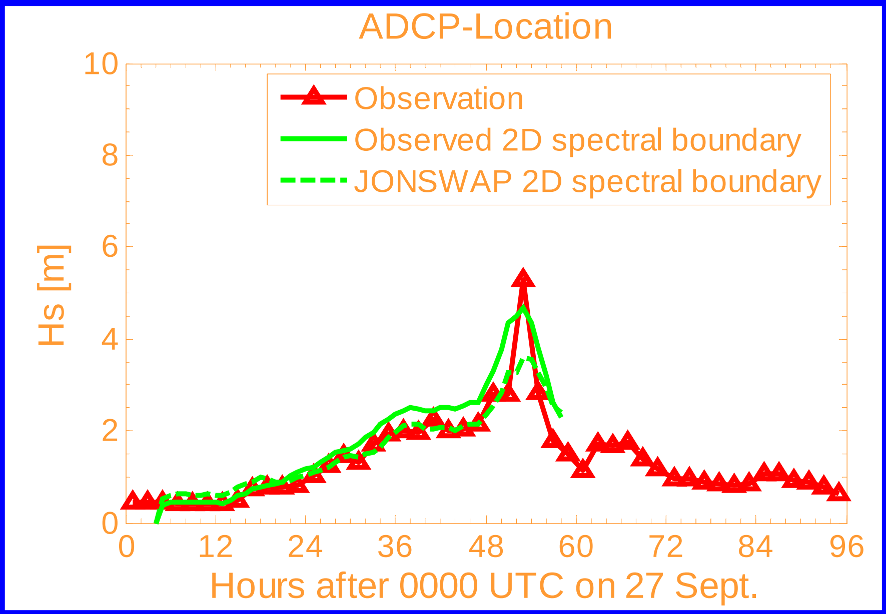
5.1 Effectiveness of JONSWAP-type 2D spectral boundary

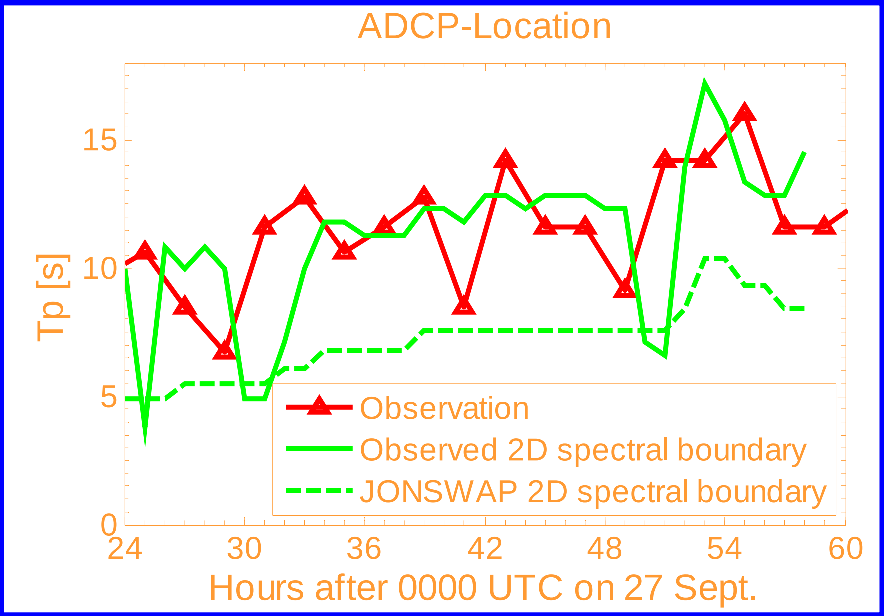
- **Prescribed JONSWAP-type 2D spectral boundary conditions: based on observed Hs, Tp, and Pdir (spectral peak enhancement: 7; directional spreading factor: 8);**
- **Describe: extremely narrow frequency and directional incoming waves.**

5.2 Model physics

- **Wind input, whitecapping and nonlinear wave-wave interactions (triad and quadruplet): default settings are applied;**
- **Bottom friction:** $C_{bottom} = 0.038 m^2 s^{-3}$ **;**
- **Depth-induced breaking: switched off.**

5.3 Calibration results





- **Simulated Hs and Tp using improved 2D boundary spectra compare better with ADCP data than using prescribed JONSWAP 2D boundary spectra, especially the peak period Tp**

  → the dominant swell is therefore simulated reasonably;

- **At ADCP: simulated Hs is still lower than wave observations, during peak waves, and a little higher than observations <u>before</u>, <u>after</u> peak waves.**

6. Summary

- Wave range: Wave range influenced by hurricane-generated waves is far larger than the wind vortex range;
- Different locations: Different locations within Juan's vortex show totally different wave strength, duration and spectral pattern;
- Swell: Swell dominates on the left side of the track, the track and the right side near the track, before, during and after Juan's passage;
- Waves around the track: Highest waves occur near the track on the right side; waves on far left of track are larger than those at same distance on the right side;
- 2D spectral boundary conditions: Resolved by building relationships between 2D wave spectra at open boundary points and observed 2D spectra
  - **through SWAN→SWAN→WW3 → WW3 multiple-nesting from coastal domain to largest domain;**

  → improved results are obtained.
- Waves in the Bay: Dominant swell is simulated reasonably; the simulated Hs is somewhat lower than the observations, during peak waves, and a little higher than observations before and after peak waves.

7. Analysis

- DIA formulation: DIA is applied in Lunenburg Bay, with frequency increment factor $\Delta f = 1.0434$, to ensure enough spectra resolution for extremely narrow band swell

  → Deviation from SWAN model biases more energy transfer to lower frequencies;

- Depth-induced breaking was switched off: Gives better results during peak waves and slight overestimations before and after peak waves;

- Other ocean dynamic factors: Currents from tides, wind, storm surge and waves combine to influence the waves, and need to be taken into account;

- JONSWAP formulation: JONSWAP-type 2D spectra are not adequate to describe the extremely narrow frequency and directional band wave spectra;

- Peak waves simulation: need further research, to be presented in future paper.

- SWAN model behaviour: What will happen? when very shallow water meets extremely narrow low frequency and directional band waves, generated by hurricane.

- Biases in ADCP wave measurements are a problem.