Characterizing the Near Shore Wave Energy Resource on the West Coast of Vancouver Island, Canada

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WEST COAST VANCOUVER ISLAND SWAN MODEL

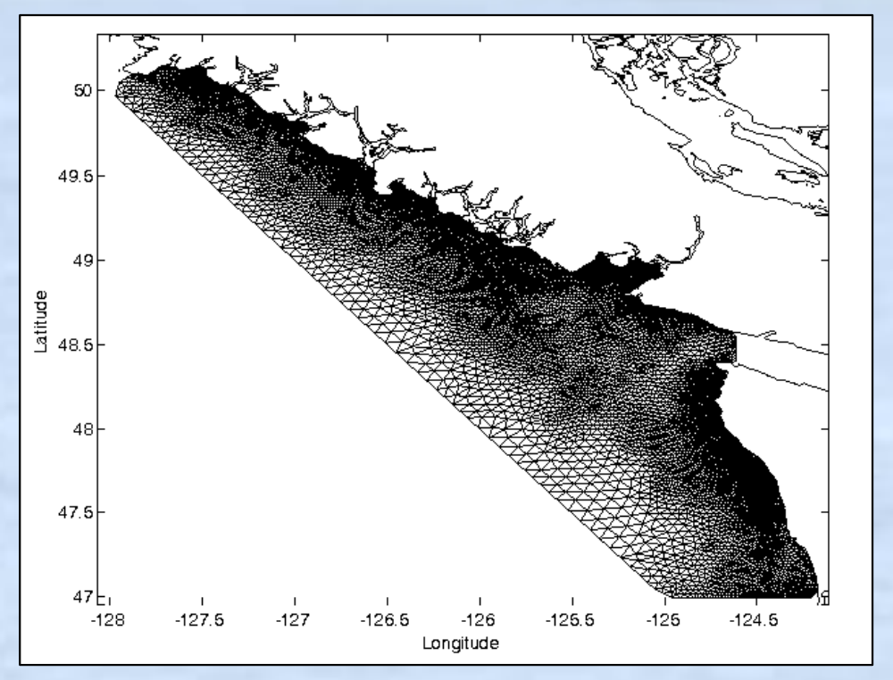
Global wave energy inventories have shown the West Coast of Vancouver Island (WCVI) to possess one of the most energetic wave climates globally, yet efforts to quantify this resource have been limited. UVic's West Coast Wave Initiative (WCWI) endeavors to investigate, measure and quantify this resource for wave energy development by running a SWAN version 40.91AB model executed in non-stationary model using 3 hour time steps. The model hindcasts wave conditions over the 2005 to 2012 target period.

In order to maintain computational efficiency, while retaining high resolution in near shore when small scale wave seafloor interaction transformations occur, an unstructured grid of 9,945 points was developed. The spatial grid distribution was determined a convergence analysis on the basis of H_{mo}, and has a lower spacing limit of 75m.

SWAN Model Set-up

Unfortunately, directional wave measurements appropriate for boundary conditions are not available for the WCVI region. The best alternative was to synthesize boundary conditions based on publically available FNMOC and NCEP Wave Watch 3 (WW3) nodes. Assuming a JONSWAP spectrum, and using the parametric H_{mo} and T_p WW3 results, 30 individual frequency variance density spectrums were synthesized by varying the peakiness factor, γ, from 1 to 7, in 0.2 increments. The final JONSWAP spectrum was determined by minimizing the RMSE between the synthesized spectrums and those directly measured at the Brooks buoy. These were converted into directional spectra by assuming $\cos^2\theta$ directional spreading - this process was completed for both WW3 models. For wind input conditions for the SWAN model, the FNMOC WW3 results are paired with the COAMPS wind model, while the NCEP WW3 results feature their own wind model.

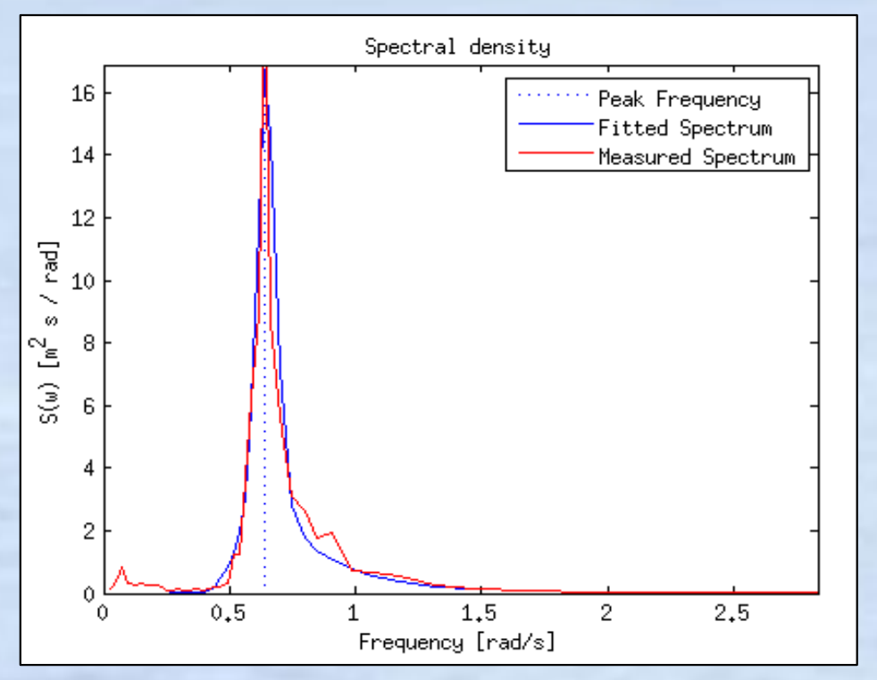
To determine the optimum SWAN boundary conditions, both combinations of synthesized wave boundary conditions and local winds were run for the entire 2010/2011 test period and the modeled H_{mo} and T_p were compared against those directly measured at the Brooks and La Perouse buoys. The FNMOC/COAMPS boundary condition combination consistently preformed better than the NCEP model and hence was used for all future computations.



SWAN UNSTRUCTURED GRID

Correlation Coefficient			NCEP	FNMOC/COAMPS
2010	La Perouse	H_{m0}	0.95	0.96
		T_p	0.35	0.46
	Brooks	H_{m0}	0.96	0.97
		T_p	0.37	0.43
2011	La Perouse	H_{m0}	0.89	0.95
		T_p	0.37	0.51
	Brooks	H_{m0}	0.85	0.92
		T_p	0.47	0.50

BOUNDARY CONDITION CORRELATION



SYNTHESIZED VS. BUOY SPECTRUM

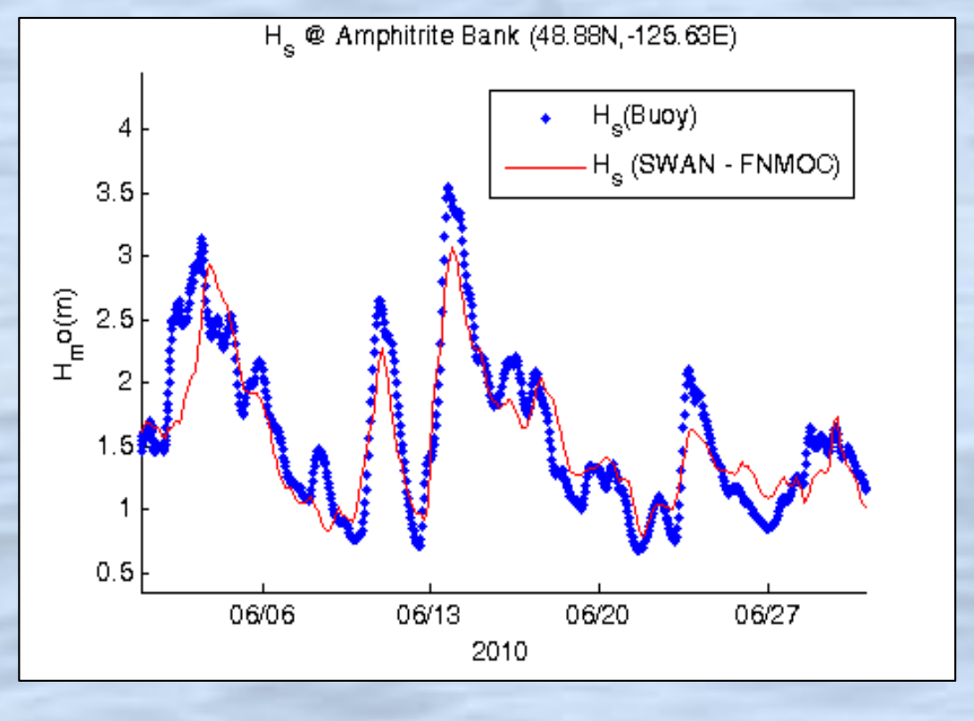
Additionally, the SWAN model allows for three different wave growth, white capping and quadruplet wave interaction solver methods. In order to determine optimum performance for the WCVI region, the SWAN model was rerun using all three solvers over the 2010/2011 test period. The method of Westhuysen et al. was found to consistently find better correlation with buoy measurements and hence was used for all future runs.

	Solver	$\overline{Hs}$	B	E_{rms}	SI	r
La Perouse	Komen	2.36	0.71	0.91	0.39	0.94
	Jannsen	2.36	0.038	0.62	0.26	0.94
	Westhuysen	2.36	0.35	0.59	0.25	0.95
Brooks	Komen	2.83	0.31	0.61	0.22	0.96
	Jannsen	2.83	0.18	0.56	0.20	0.95
	Westhuysen	2.83	0.19	0.53	0.18	0.96

SWAN NUMERICAL SOLVER COMPARISION

SWAN Model Validation

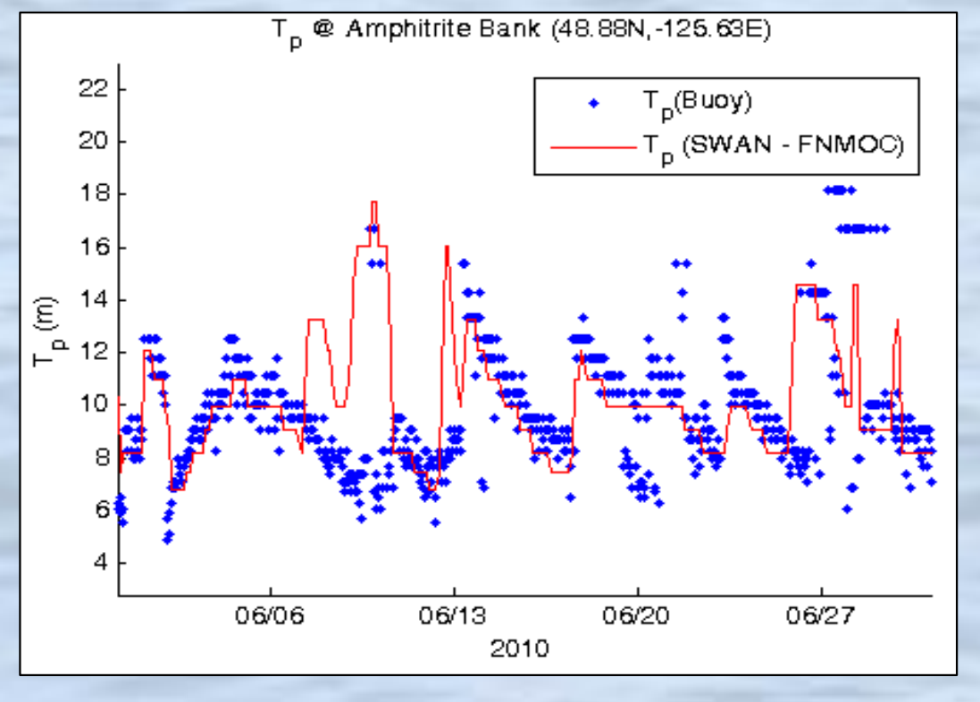
During the summer of 2010, WCWI deployed an AXYS Watchmate 500 wave measurement buoy on Amphitrite Bank. Given that this data was not used to train the model, it was used for validation purposes. As shown below, the correlation between the model and measured significant wave height and peak period are very good. Understanding that the Amphitrite buoy was only deployed between May and October, when locally generated seas dominate, the correlation is very encouraging and provided confidence in hincasted results for the longer target period (2005 – 2012).



SWAN vs. BUOY Hmo COMPARISION

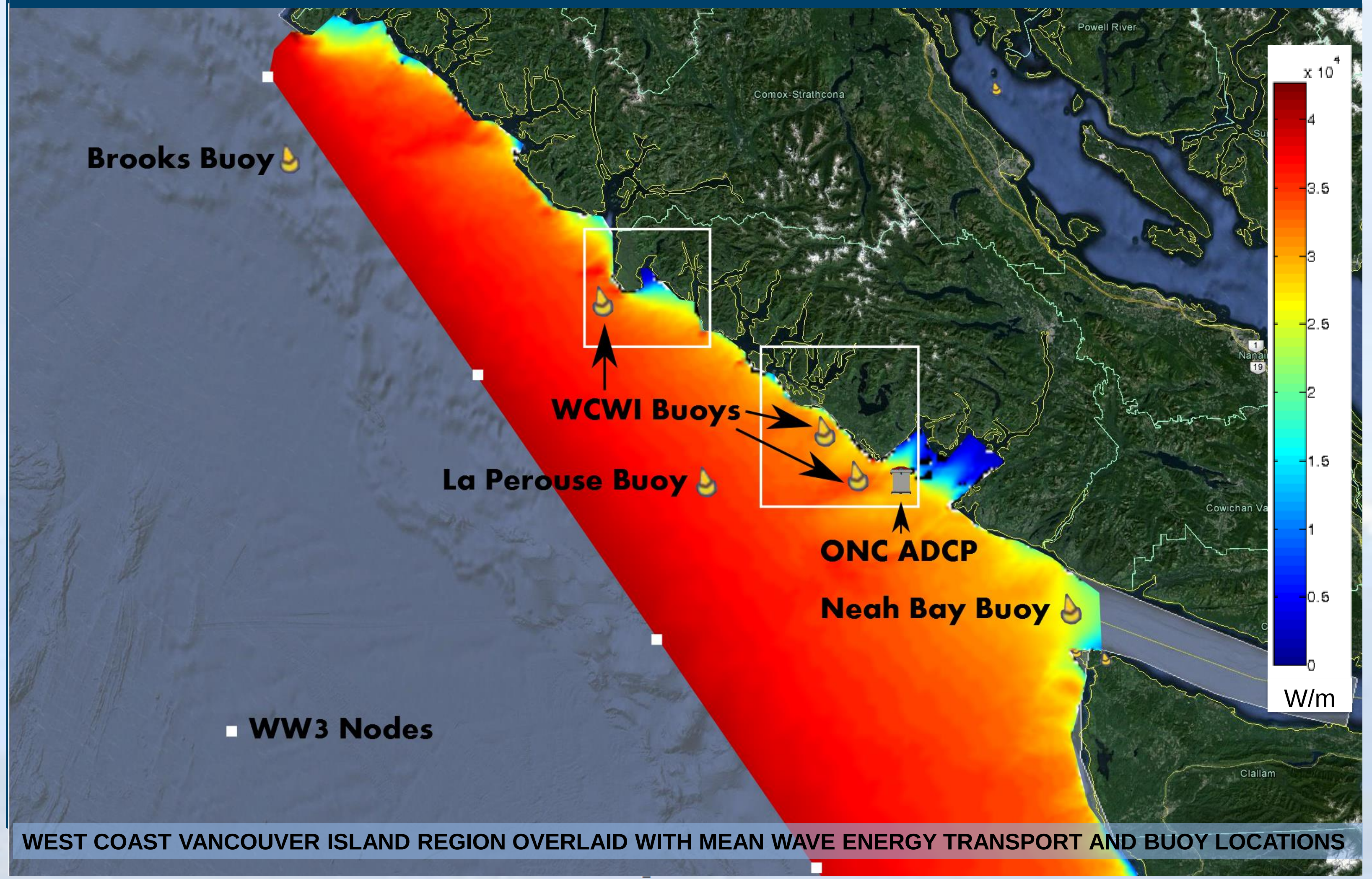
H_{mo}	B	SI	r
La Perouse	0.11	0.17	0.96
Amphitrite	-0.004	0.22	0.90
T_p			
La Perouse	0.87	0.31	0.46
Amphitrite	1.06	0.37	0.46

SWAN MODEL VALIDATION



SWAN vs. BUOY Tp COMPARISION

WCVI REGION AND MEASUREMENT DEVICES



WEST COAST VANCOUVER ISLAND REGION OVERLAID WITH MEAN WAVE ENERGY TRANSPORT AND BUOY LOCATIONS

CHARACTERISTIC QUANTITIES FOR WAVE ENERGY CONVERTERS

The SWAN model directly outputs many standard parameters for characterizing a sea state and wave resource; these include the significant wave height (H_{mo}), the peak wave period (T_p), the energy period (T_e), the spectral peak direction (θ_p) and the omnidirectional wave energy transport (J).

However, when investigating potential wave energy development sites, a series of additional metrics are used to further describe the sea state for wave energy conversion. These include:

- Directionally Resolved Wave Energy Transport:

$$J_\theta = \rho g \sum_{i,j} S_{i,j}\Delta f_i \Delta\theta_j \cos(\theta-\theta_j)\delta \qquad \delta = \begin{cases} 0 & if \ \cos(\theta-\theta_j) < 0 \\ 1 & if \ \cos(\theta-\theta_j) \geq 0 \end{cases}$$

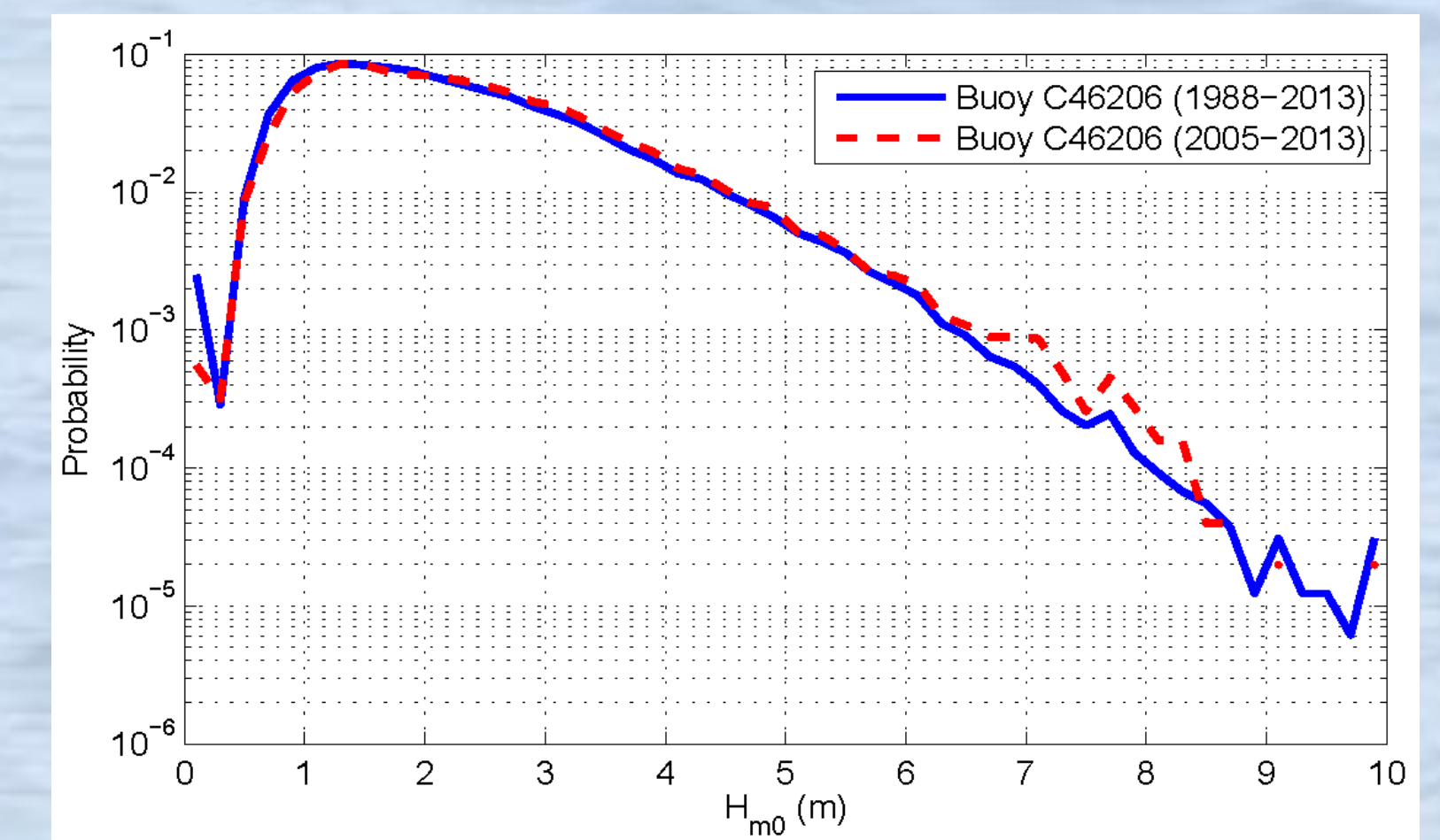
- Frequency Spectrum Width:
- Direction of Maximum Energy Transport:
- Directionality Coefficient:

$$\epsilon_0 = \sqrt{\frac{m_o m_2}{m_1^2} - 1} \qquad J_{\theta_J} = \max\ (J_\theta) \qquad d = \frac{J_{\theta_J}}{J}$$

LONG TERM CLIMATE VALIDATION

The SWAN model target period hindcast used measured sea state conditions, for boundary conditions, over the 8 year period between 2005–2012. As a result, it is important to ensure this period is representative of the long term wave climate.

The combined probability density functions for the target period and the full dataset for the La Perouse buoy shows excellent correlation. Above 7m, the two curves diverge slightly yet this condition corresponds to < 1% of total energy transport. However, these conditions are important when looking at survivability and extreme loading events.

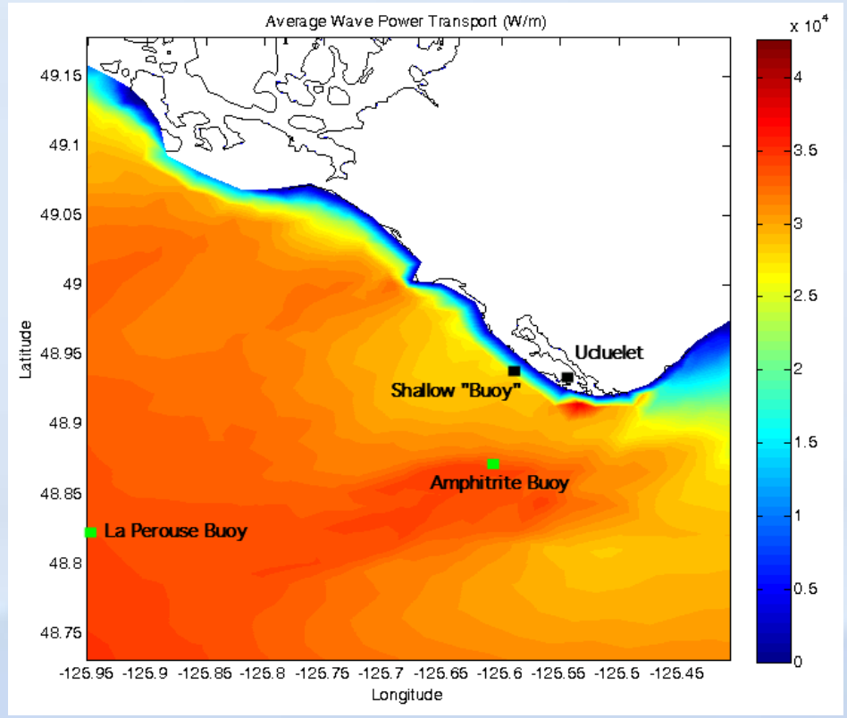


QUANTIFYING THE WAVE CLIMATE

West Coast Climate Characteristics

The WCVI region is an extremely energetic wave environment and features approximately 45 kW/m of energy transport along the continental shelf. However, this study reveals the significant spatial variation of wave energy transport in near shore locations.

Ucluelet, British Columbia is often noted as an area of high wave energy transport, due to interaction with the seafloor, and as a result is of great interest to many wave energy developers.

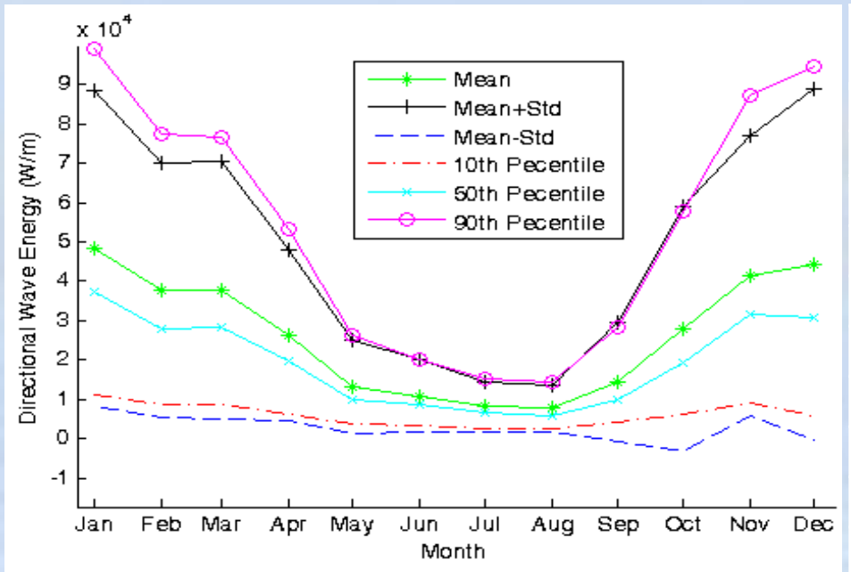


UCLUELET REGION ENERGY TRANSPORT

Amphitrite Bank Temporal Characteristics

The seasonal variability of the wave climate surrounding Ucluelet, BC is dramatic and has significant consequences on energy production and WEC design. As a result, a detailed understanding of the temporal wave climate is paramount. From the 8 year hindcast, the mean monthly wave characteristics provide some interesting results:

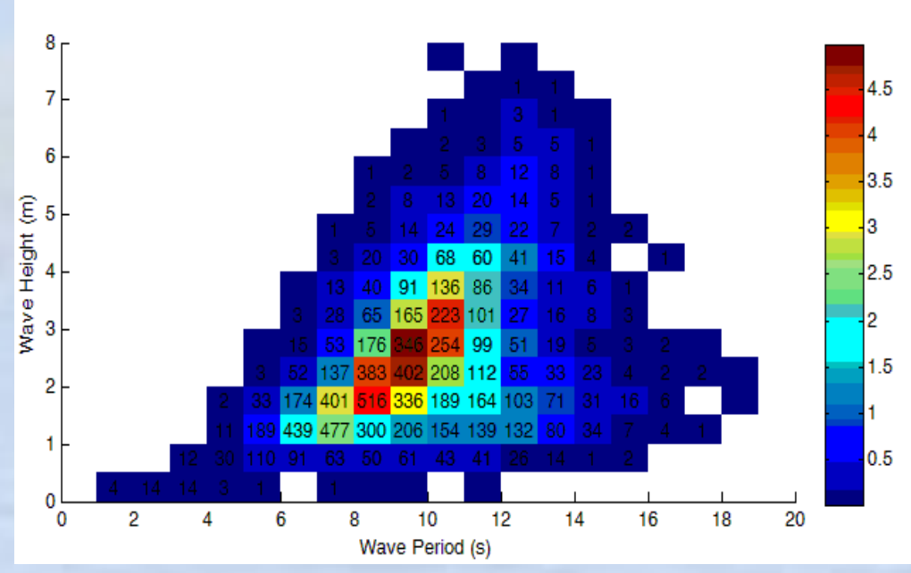
- Directional wave energy transport has a maximum of 49 kW/m in January, while August features only 10 kW/m.
- Energy period values remain relatively constant throughout the year, varying from 10.2 sec (Dec) - 8.5 sec (Jul)
- Direction of max. directional transport remains constant at ~ 250° throughout the year, while directional spectrum peak directions vary between 160°- 285°.
- The directionality co-efficient varies very little and remains constant around 0.84.



SEASONAL ENERGY TRANSPORT

	Directional Energy Transport	Wave Height	Energy Period	Wave Direction
	(kW/m)	(m)	(sec)	(degrees)
Winter				
Mean Value	41.9	2.70	9.84	250
Mean 10th %	8.70	1.50	7.56	215
Mean 90th %	87.0	4.07	12.1	275
Summer				
Mean Value	10.8	1.51	8.78	246
Mean 10th %	2.10	0.98	6.21	201
Mean 90th %	28.0	2.14	12.1	275

PARTIAL AMPHITRITE BANK RESULTS



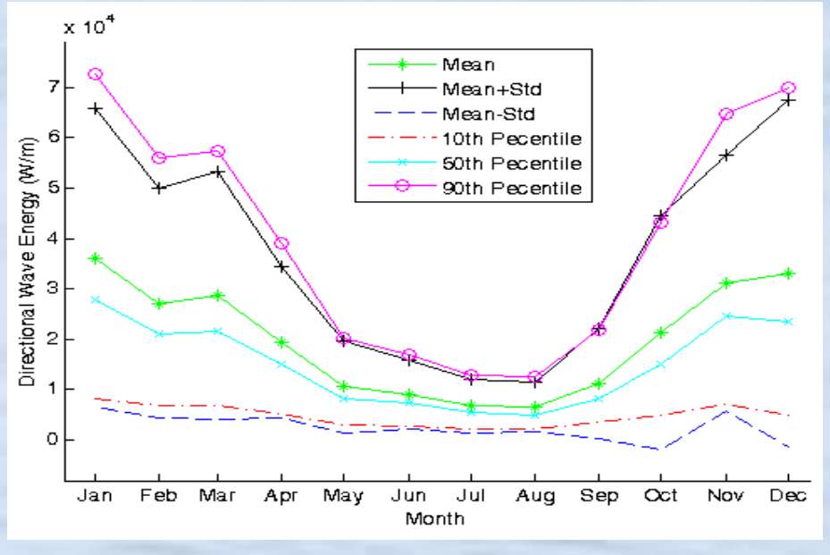
BIVARIATE DISTRIBUTIONS

Shallow Depth Characteristics

As shallow water locations are of great interest to WEC developers, the WCWI team is "prospecting" for high energy locations very close to shore. One initial shallow water location (see above image) provided some interesting comparative results against those recorded at Amphitrite Bank, only 7 km away.

- Directional wave energy transport is reduced to 38 kW/m in January, while August remains ~ 10 kW/m.
- Energy period values remain relatively constant throughout the year, varying from 10 sec (Jan) - 8.2 sec (Dec)
- Direction of max. directional transport is reduced to ~ 238° throughout the year, with reduced variation against the spectral peak.
- The directionality co-efficient varies improves considerably and remains constant at ~ 0.91.

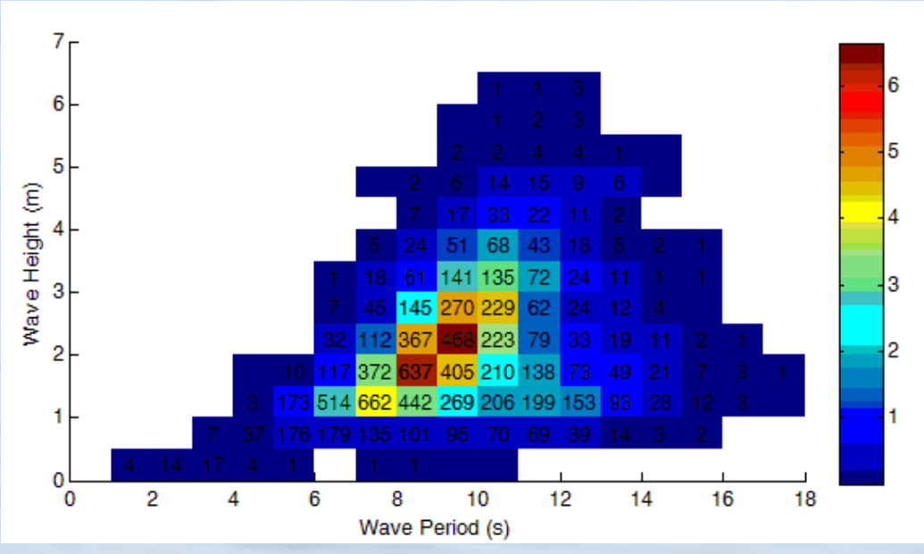
The mean energy transport values may be smaller in shallow areas, yet the reduced energy transport variability and directional spread may be beneficial and indicate preferred operating locations for certain WEC devices.



SEASONAL ENERGY TRANSPORT

	Directional Energy Transport	Wave Height	Energy Period	Wave Direction
	(kW/m)	(m)	(sec)	(degrees)
Winter				
Mean Value	31.2	2.30	9.51	236
Mean 10th %	6.82	1.28	7.49	211
Mean 90th %	64.2	3.45	11.55	255
Summer				
Mean Value	8.85	1.34	8.56	238
Mean 10th %	2.70	0.89	6.15	205
Mean 90th %	16.9	1.87	11.8	261

PARTIAL SHALLOW LOCATION RESULTS



BIVARIATE DISTRIBUTIONS

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* *For all presented tables, the parameter bias (B), scatter index (SI) and correlation coefficient (r) are used to quantify the accuracy of the model with respect to buoy measurements. .*