NRC Publications Archive
Archives des publications du CNRC

Appraisal of IEC standards for wave and tidal energy resource assessment

Cornett, Andrew; Toupin, Mathieu; Baker, Scott; Piche, Steffanie; Nistor, Ioan

This publication could be one of several versions: author’s original, accepted manuscript or the publisher’s version. / La version de cette publication peut être l’une des suivantes : la version prépublication de l’auteur, la version acceptée du manuscrit ou la version de l’éditeur.

NRC Publications Archive Record / Notice des Archives des publications du CNRC :
https://nrc-publications.canada.ca/eng/view/object/?id=16c91e09-eebd-4b94-857e-3c7cf1ab37e9
https://publications-cnrc.canada.ca/fra/voir/objet/?id=16c91e09-eebd-4b94-857e-3c7cf1ab37e9

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at
https://nrc-publications.canada.ca/eng/copyright
READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L’accès à ce site Web et l’utilisation de son contenu sont assujettis aux conditions présentées dans le site
https://publications-cnrc.canada.ca/fra/droits
LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D’UTILISER CE SITE WEB.

Questions? Contact the NRC Publications Archive team at PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

Vous avez des questions? Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n’arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.

National Research Council Canada
Conseil national de recherches Canada

ICOE 2014
INTERNATIONAL CONFERENCE ON OCEAN ENERGY
NOVEMBER 4-6, 2014
Halifax, NS Canada

Appraisal of IEC Standards for Wave and Tidal Energy Resource Assessment

Andrew CORNETT[1], Mathieu TOUPIN[2],
Scott BAKER[1], Steffanie PICHE[2], Ioan NISTOR[2]

[1] National Research Council, Ocean Coastal & River Engineering, Ottawa, Canada
[2] University of Ottawa, Dept. of Civil Engineering, Ottawa, Canada

ABSTRACT

This paper describes research in progress for which the main objective is to appraise the new IEC technical specifications (TS) for assessment of wave and tidal energy resources through pilot application of the procedures set forth therein to sites in the Bay of Fundy and off the west coast of Vancouver Island. The new IEC TS for tidal current resource assessment is being appraised through application to the FORCE project site located near the north shore of Minas Passage in the upper Bay of Fundy, Canada. In parallel, the new IEC TS for wave energy resource assessment is being appraised through application to the waters off the west coast of Vancouver Island, British Columbia, Canada. In both cases, the accuracy of the resulting resource estimates is being assessed through comparison with direct measurements obtained using ADCP units and directional wave buoys. Moreover sensitivity analyses are being undertaken to determine the main sources of error and uncertainty impacting the precision of resource assessments conducting following the IEC methodologies. Preliminary results indicate that the new IEC technical specifications can be applied with a moderate level of effort to develop reasonable estimates of tidal and wave energy resources.

INTRODUCTION

Through a collaborative international effort, Technical Committee 114 of the International Electro-technical Commission (IEC TC-114) is working to develop a set of technical specifications (precursors to standards) for the emerging field of marine energy systems. Two of the new technical specifications (TS) concern methods and procedures for determining, objectively and reliably, the scale and character of the wave and tidal energy resources in a region [9,10]. The proposed methods for assessing these resources are complex and involve sophisticated computer modelling of wave conditions and tidal flows, validated by field measurements. Moreover, since resource assessment typically progresses in stages, depending on the purpose and the desired level of accuracy, the new standards specify different methods and procedures appropriate for several different stages of assessment (reconnaissance, feasibility or design). More extensive measurements and more detailed modelling are required as the resource assessment attempts to become more refined and precise. Furthermore, an increasing number of complex secondary factors, such as turbulence, velocity shear, spectral width and directionality must be taken into consideration.

The International Electro-technical Commission (IEC) is the world's leading organization that prepares and publishes International Standards for all electrical, electronic and related technologies. The IEC provides a platform to companies, industries and governments for meeting, discussing and developing the International Standards they require. International standards play an important enabling role by helping to ensure products and services are safe, reliable and of good quality. They help harmonize practices around the world and remove technical barriers to trade, fostering increased trade and economic growth. They lend credibility to emerging industries, help increase investor confidence and contribute to the social license that is essential for the growth and success of the emerging marine renewables sector. The IEC technical specifications discussed in this paper are intended to become international standards, once sufficient industry experience in their application has been developed.

Many of the new IEC technical specifications for marine energy systems are based on a relatively limited amount of research and industry experience. The new TS's covering wave and tidal energy resource assessment have only been partially applied in real world situations, and it is uncertain whether the prescribed methodologies are appropriate or will lead to the desired outcomes. This paper describes research currently in progress that aims to appraise the new IEC standards for assessment of wave and tidal energy resources through pilot application of the procedures set forth in the draft documents to sites in the Bay of Fundy (in Atlantic Canada) and in the Pacific Ocean near the west coast of Vancouver Island. The research effort aims to investigate to what extent the new IEC TS's are clear, easy to follow and implement, and whether following the prescribed methodologies will lead to resource estimates which have the desired level of precision and reliability. Moreover, it aims to investigate the main sources of uncertainty and determine which factors/choices most influence the precision and reliability of the resource assessment.

IEC RESOURCE ASSESSMENT METHODOLOGY

Wave Resource Assessment

The IEC methodology for wave energy resource assessment is complex and involves sophisticated computer modelling of wave conditions that are well validated by field measurements [9]. A simplified summary of the procedure is presented in Figure 1. The TS recognizes that the quality and completeness of the resource information required from a study varies depending on whether the main goal is preliminary reconnaissance to identify promising sites, a more detailed feasibility assessment of one or more sites, or detailed design of a wave energy farm at a specific location. More extensive measurements and more detailed modelling are required as the resource assessment attempts to become more refined and precise. However, due to a general lack or research and industry experience, it remains unclear whether the procedures specified in the new TS will lead to the desired outcomes; whether the level of precision that is hoped for can be achieved using the prescribed methods.

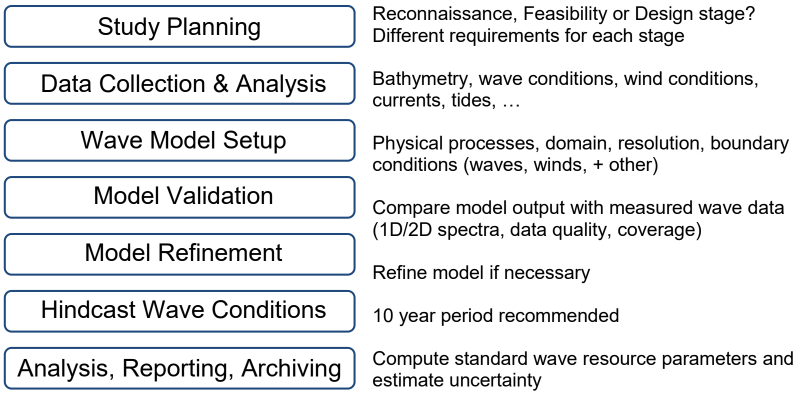

Figure 1. Simplified summary of the IEC methodology for wave energy resource assessment.

Tidal Resource Assessment

The IEC methodology for tidal current energy resource assessment is complex and involves sophisticated computer modelling of tidal flows that are well validated by field measurements [10]. A simplified summary of the procedure is presented in Figure 2. The tidal resource assessment TS also recognizes the need for a range of approaches matched to the purpose and desired precision. Again, whether the level of precision that is hoped for can be achieved using the prescribed methods remains uncertain.

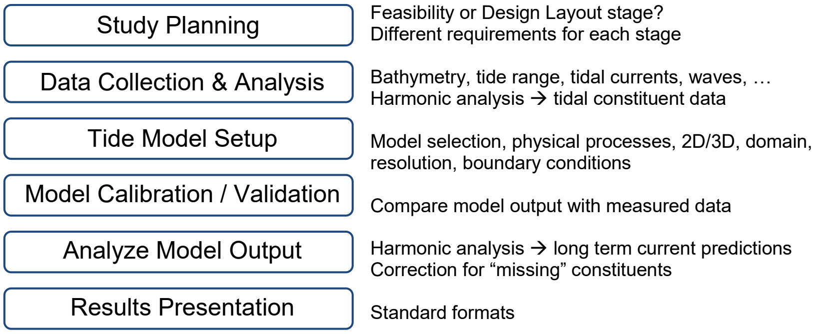

Figure 2. Simplified summary of the IEC methodology for tidal energy resource assessment.

PILOT APPLICATION OF IEC TS FOR WAVE ENERGY RESOURCE ASSESSMENT

Methodology

The new IEC TS for wave energy resource assessment [9] is being appraised through application to the coastal waters near the town of Ucluelet on the west-central coast of Vancouver Island, in the Canadian province of British Columbia. The wave energy resource in this area has been previously investigated by several authors, including [2,3,13]. In this work a series of wave propagation models based on the SWAN model [14] are being developed and used to predict wave conditions throughout the near-coast region. The accuracy of the resulting resource estimates are being compared with data from several wave measurement buoys, including a directional wave buoy deployed at Station "Beverley" by the West Coast Wave Initiative [1], a collaborative research effort led by the University of Victoria. Station Beverly is ~6 km from shore in 45m water depth (Latitiude: 48°52.82', Longitude:125°37.08', see Figure 3). A sensitivity analysis is being undertaken to investigate the main sources of error and uncertainty affecting the assessment of wave energy resources when using the methodologies specified in the IEC TS.

Three different SWAN models are being developed and applied to predict the temporal and spatial variation in coastal wave conditions over the model domain for the nine year period from 2005 to 2013. The SWAN models feature unstructured grids (with triangular elements) and a computational domain that includes a 280 km stretch of the Pacific coast of North America, centred on the community of Ucluelet. The relatively simple *reconnaissance* model features 4,300 nodes and a 1.5 km resolution over the study area whereas the more detailed *feasibility* model features 16,000 nodes and a 300 m resolution over the same area. The grid for the feasibility model is shown in Figure 3. A more detailed *design* model will be developed and applied in future work.

The boundary conditions for both models are derived from the WaveWatch III global wave hindcast database developed by the Marine Modelling Branch of the National Oceanographic and Atmospheric Administration (NOAA-MMB) [6,15]. Both SWAN models are forced using a time varying wind field combined with a time varying estimate of the directional wave spectrum along the offshore model boundary. For the relatively simple reconnaissance model, the wind field at each time step is assumed to be spatially non-varying, and the wave boundary conditions are specified in terms of three characteristic parameters: significant wave height, peak wave period and dominant direction; combined with an assumed directional spreading. Hence, all directional spectra used to force the simple reconnaissance model feature a single lobe of wave energy. In contrast, the more detailed feasibility model is forced using a spatially varying wind field and a more realistic spatially varying directional spectrum. The boundary spectra synthesized for the feasibility model generally feature multiple lobes of wave energy propagating in various directions, which is a more complex and more realistic representation of reality. Combined seas and swells approaching the coast from different directions can be simulated in the more detailed feasibility model, but not in the simpler reconnaissance model.

In the reconnaissance model, directional wave spectra are resolved using 25 frequencies and 24 directions, whereas in the feasibility model, 40 frequencies and 36 directions are used. Both models are run in non-stationary mode.

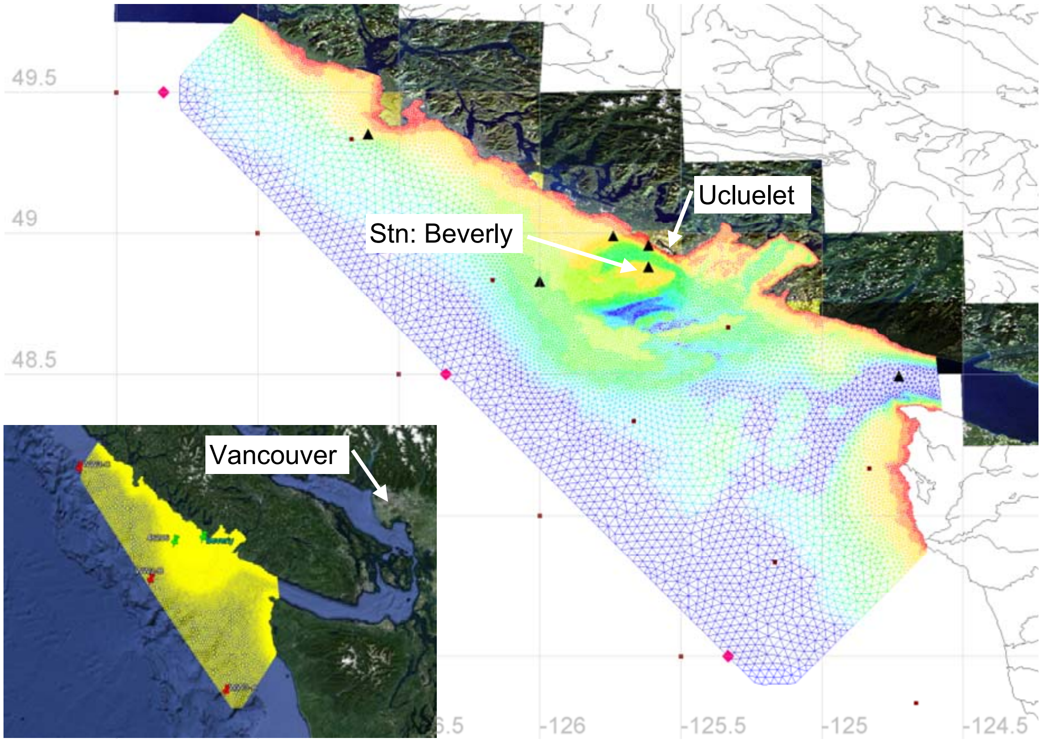

Figure 3. SWAN model domain and bathymetry with feasibility grid (300m resolution over area of interest).

Preliminary Results

Typical model output for a single time step is shown in Figure 4. Measured and modelled directional spectra at Station Beverley for this time are compared in Figure 5. Due to its greater resolution and more realistic boundary conditions, the feasibility model generally provides an improved simulation of the directional wave conditions throughout the study area. However, the feasibility model also requires greater effort to setup and takes longer to run. Figure 6a compares the measured and modelled significant wave height at station Beverley during September 2010, while Figure 6b compares the omni-directional wave power for the same period. While both models are able to predict the main trends in wave height and wave power, the more detailed feasibility model clearly delivers greater precision, as expected.

Following the IEC TS [9], wave energy resources are characterised in terms of the following parameters:

- Spectral estimate of significant wave height, H_{m0}
- Energy period, T_e
- Spectral width, ε_0
- Omni-directional wave power, J
- Maximum directionally resolved wave power, $J_{\theta max}$
- Direction of maximum directionally resolved power, θ_{Jmax}
- Directionality coefficient, d

Identical procedures have been developed and used to compute these key resource parameters from both the wave buoy data and from the SWAN model outputs. Several statistical measures, including bias, root-mean-square error (RMSE), scatter index (SI) and correlation coefficient (R^2) have been adopted to quantify how well the reconnaissance and feasibility models are able to estimate the wave energy resource at station Beverley. A sensitivity study is also underway to identify the main sources of error and uncertainty, and help identify ways of improving the accuracy and reliability of wave energy resource assessments based on wave propagation modelling. The results of these analyses will shed new light on the degree of accuracy or certainty that can be expected when applying the IEC wave energy resource assessment methodology. The results of these ongoing investigations will be presented and discussed in future publications.

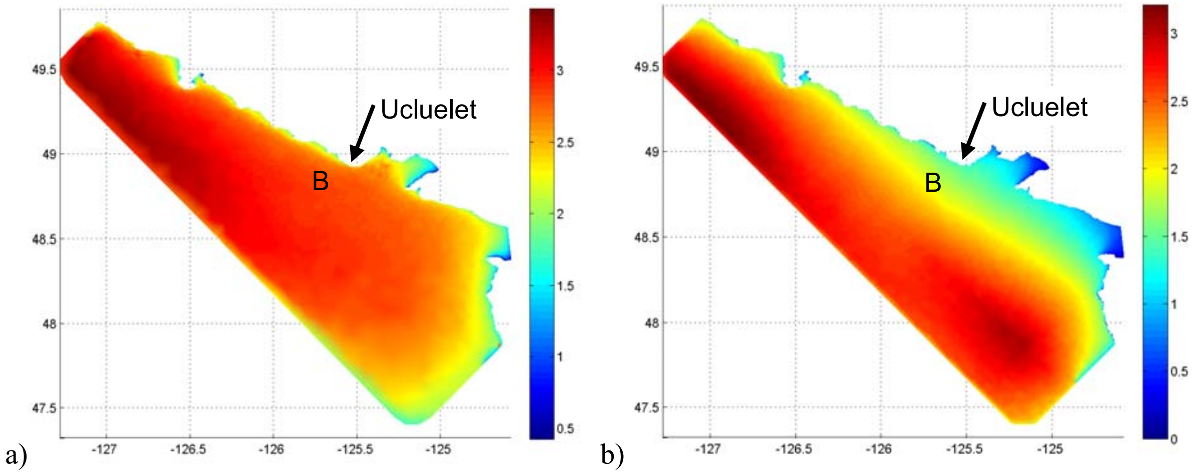

Figure 4. Predicted wave heights for 15:00/23/09/2010: a) reconnaissance model; b) feasibility model.

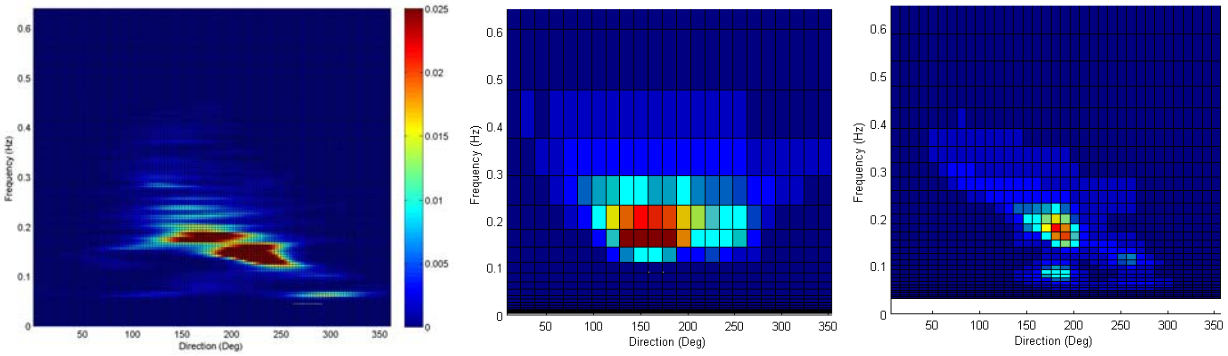

Figure 5. Measured and modelled wave spectra at station Beverley, 15:00/23/09/2010.

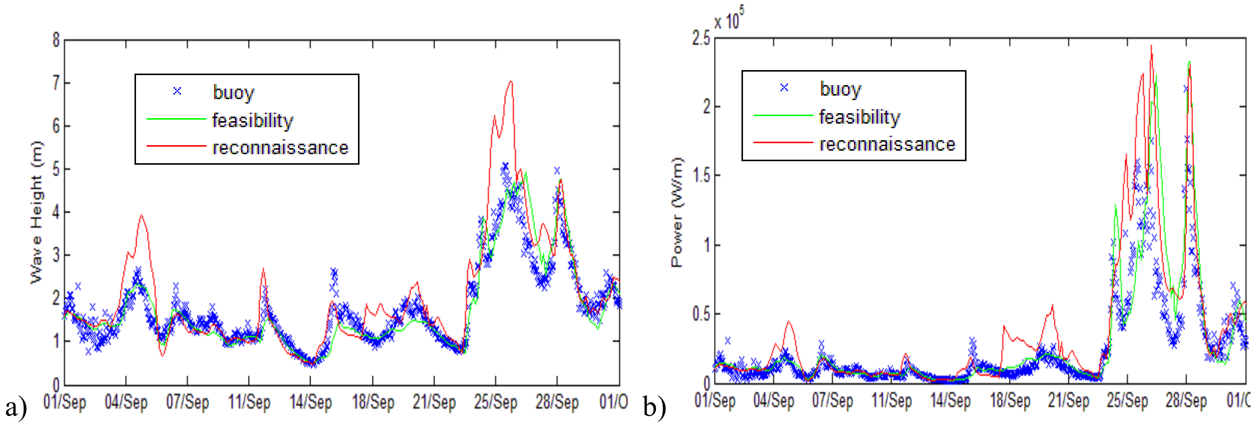

Figure 6. Measured and modelled wave conditions at station Beverley during September 2010: a) significant wave height; b) omni-directional wave power.

PILOT APPLICATION OF IEC TS FOR TIDAL ENERGY RESOURCE ASSESSMENT

Methodology

The new IEC TS for tidal current resource assessment is being appraised through application to the Fundy Ocean Research Center for Energy (FORCE) project site located near the north shore of Minas Passage in the upper Bay of Fundy (see Figure 7). The tidal energy resource in this area has been previously investigated by several authors, including [4,11] among others. The tidal resource is being modelled using a series of progressively more detailed models based on the open source TELEMAC modelling system [7,8]. The accuracy of the resulting resource estimates are being assessed by comparison with direct measurements acquired near the four technology demonstration berths between August and December 2011 using bottom-mounted ADCP units. Moreover, a sensitivity analysis is being undertaken to determine the main sources of error and uncertainty impacting the precision of the various resource assessments.

The ADCP data was first screened to remove erroneous records and correct for spurious anomalies such as drop-outs and abrupt changes in mean velocity and/or direction, likely caused by movement of the instrument platform. Following this, the corrected data was analyzed to produce standard outputs such as velocity time histories, tidal ellipses and vertical velocity profiles (see Figure 8). An estimate of the depth-averaged velocity at each site was obtained by integrating the velocity data over the water column, accounting for the time-varying free-surface elevation. Harmonic analysis, as implemented in T-Tide [12] was used to derive harmonic constants for both surface elevation and the orthogonal velocity components in the east and north directions, *u(t)* and *v(t)*. The tidal currents at FORCE are significantly stronger near the free surface than near the seabed, and considerably stronger in the easterly direction (during flood) than in the westerly direction (during ebb). The high-frequency fluctuations in the ADCP data indicate that the tidal flows at FORCE include considerable turbulence.

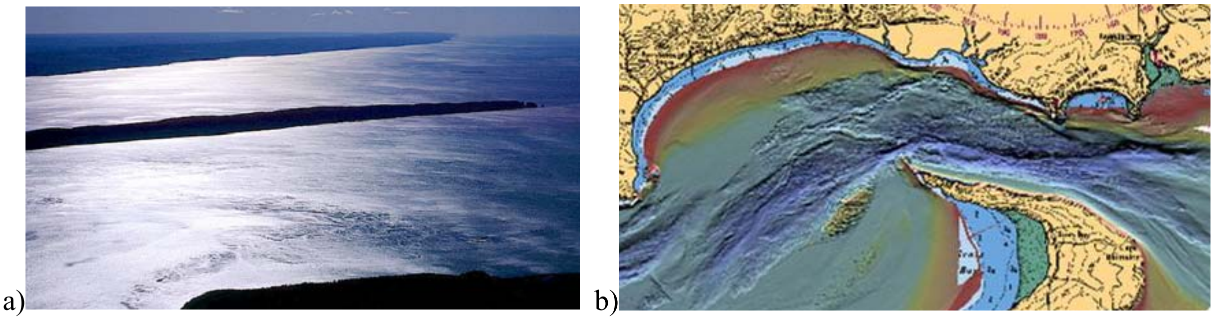

Figure 7. Minas Passage: a) aerial view from NE; b) bathymetry.

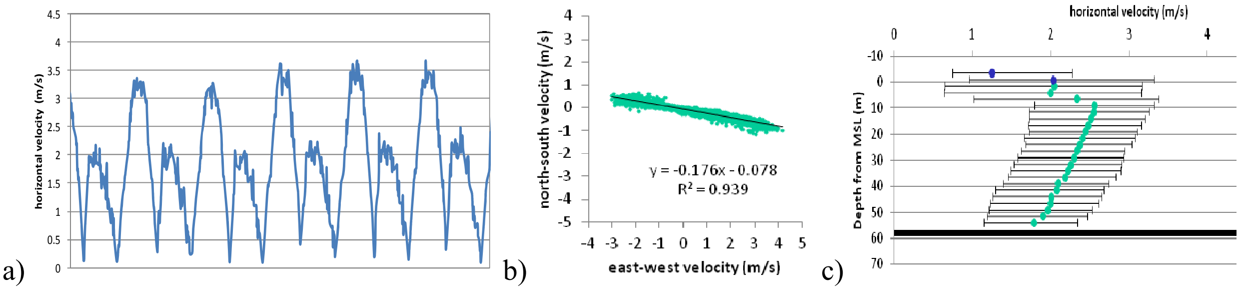

Figure 8. Typical outputs from ADCP data analysis: a) velocity time history; b) tidal current ellipse; c) vertical velocity profile.

All the tide models developed for this study are based on the Telemac-2D finite-element hydrodynamic solver for free-surface flows. Using finite element techniques, Telemac-2D solves the vertically averaged shallow water (Saint-Venant) equations in two horizontal dimensions. Telemac-2D uses an unstructured triangular mesh enabling complex shorelines and bathymetries to be represented in a highly realistic manner. Areas of particular interest can be modelled with very high resolution while regions of lesser interest can be represented with coarser resolution. All the tide models shared the 8,500 km^2 domain shown in Figure 9, however the grid resolution in Minas Passage and at the FORCE crown lease area varied from 20 m up to 500 m (see Figure 10). The model bathymetry was based largely on high resolution (5 m) multi-beam survey data supplied by FORCE and the Canadian Hydrographic Service (CHS). The models were forced using boundary conditions derived from CHS tidal constituent data for Dipper Harbour West and Deep Cove. The number of leading tidal constituents used to establish the boundary conditions varied from one (M2 only) up to eight (M2 + 7 others).

The tide models were calibrated by adjusting the bottom roughness throughout the domain to minimize the error between the model predictions and observations for 15 CHS tide stations distributed throughout the domain, considering both the amplitude and timing of high and low tides, as well as the amplitude and phase of eight leading harmonic constants. Typical results are presented in Figure 11. The calibrated models are able to simulate the tides in the Upper Bay of Fundy with good accuracy.

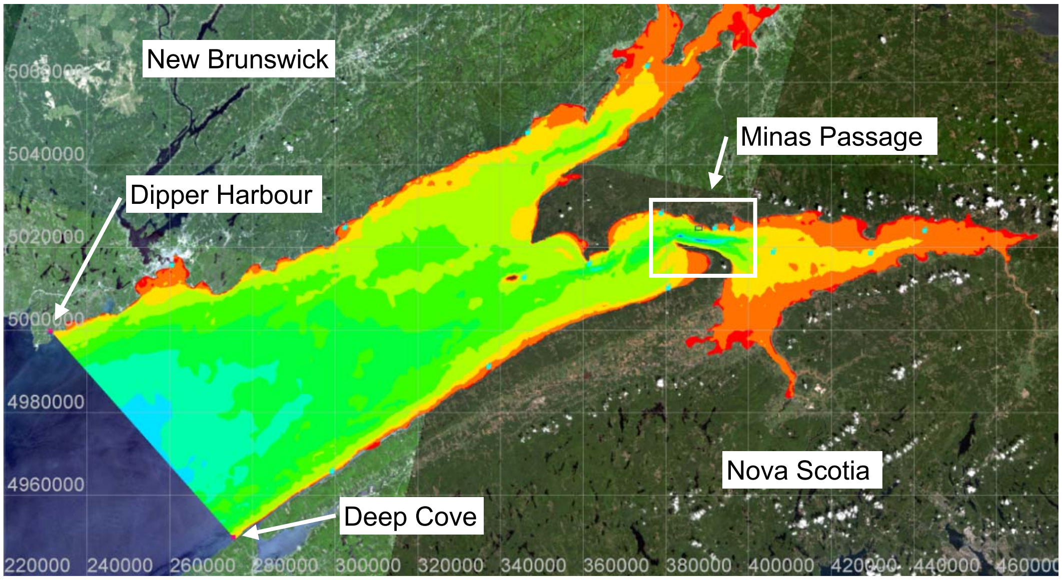

Figure 9. Hydrodymamic model domain and bathymetry.

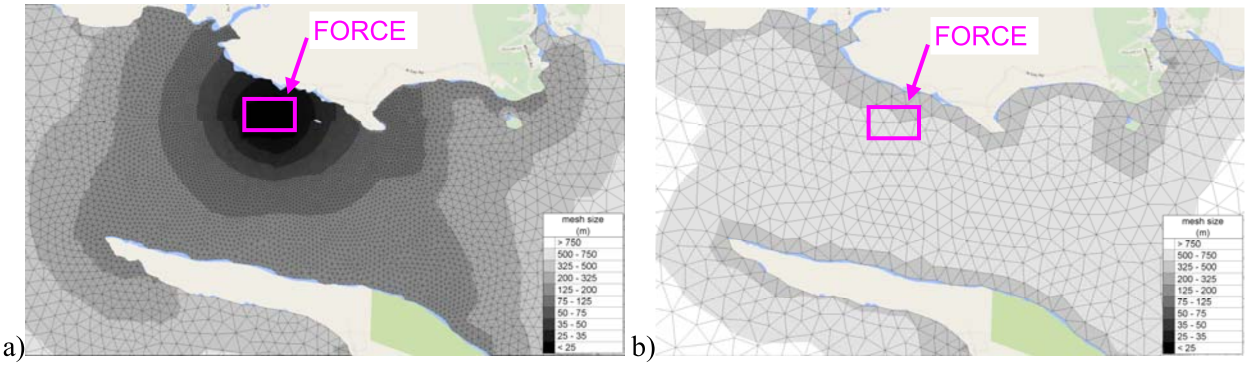

Figure 10. Model grids with a) 20m and b) 500m resolution in Minas Passage.

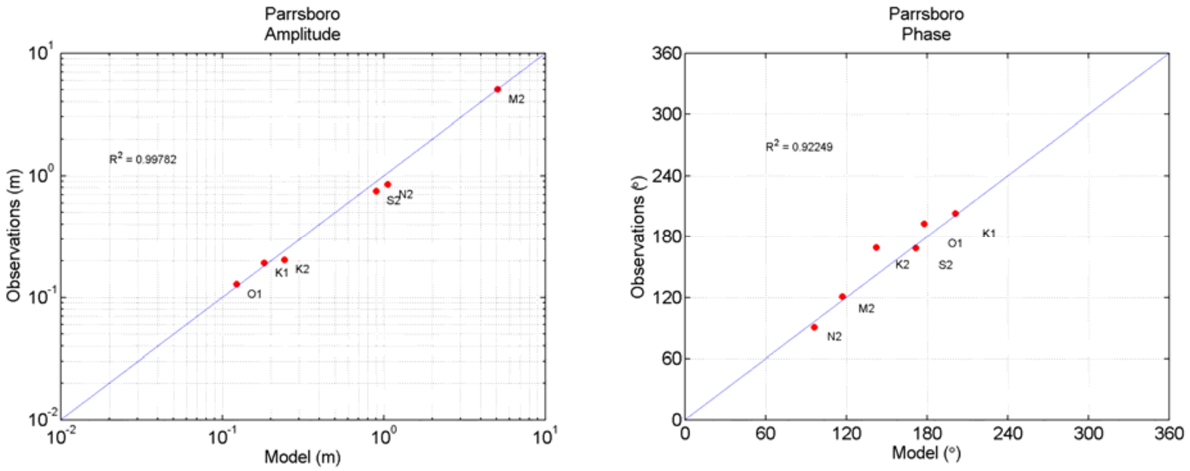

Figure 11. Comparison of modelled and published harmonic constants for CHS station Parrsboro.

Preliminary Results

The family of tide models featuring different grid resolutions ranging from 20m to 500m were used to predict the tidal flows in Minas Passage during the ADCP deployments. Following the methodology prescribed in the IEC TS [10], the model outputs for a month long simulation period have been analysed to obtain depth-averaged estimates of the tidal energy resource at each of the four FORCE berths. The ADCP data for each berth has been analysed in an identical manner to support comparisons between the measured and modelled data. This process involves the following steps.

1) Use the calibrated tide model to simulate tidal flows for a period of one month.
2) Using harmonic analysis [12], determine the leading harmonic constants for $u(t)$ and $v(t)$ for all locations of interest.
3) Use the harmonic constants obtained in step 2 to construct one-year long depth-averaged time histories for $u(t)$, $v(t)$ and current speed, U, where $U(t)=[u^2(t)+v^2(t)]^{0.5}$.
4) Compute the annual distribution of depth-averaged flow speed and the associated exceedance probability curve from the time histories obtained in step 3.
5) Obtain the annual distribution and exceedance curve for the kinetic power density, p, where $p(t)=0.5\rho U^3(t)$.
6) Compute the annual kinetic energy per unit area, AE, obtained by summing the instantaneous power density from step 5 over the year.

The annual histogram of depth averaged flow speed derived from model output for one of the FORCE berths using this methodology is shown in Figure 11a, while the measured and modelled exceedance curves for depth-average flow speed are compared in Figure 11b. In this case, since the modelled and measured exceedance curves are very similar, we conclude that the TELEMAC-2D model provides a reliable prediction of the depth-averaged tidal resource for this site.

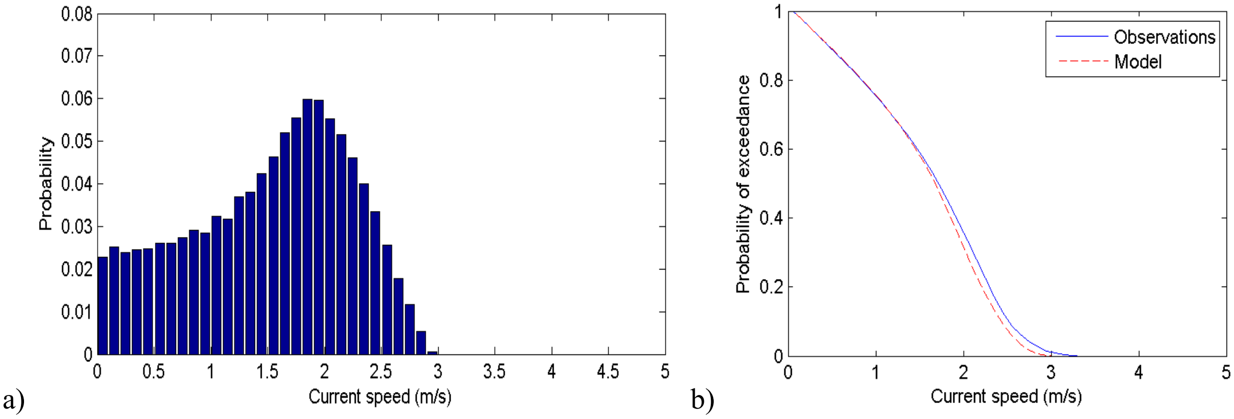

Figure 12. Annual distribution of depth averaged current speed: a) modelled histogram; b) modelled and measured exceedance probability.

The sensitivity of the tide model's predictive skill to the following variables and factors has also been assessed:

- The resolution of the model grid near the study area;
- The resolution of the bathymetric data used to develop the model bathymetry at the study area;
- The number of tidal constituents used to force the tidal model boundary;
- The simulation duration;
- The number of harmonics considered in harmonic analysis;
- The type of turbulence model implemented within Telemac-2D; and
- Whether Coriolis forces are included within Telemac-2D.

Due to space restrictions, only the sensitivity of the resource assessment to grid resolution will be discussed in this paper. Figure 13 shows an example of how refining the model mesh around the study area improves the estimation of depth-averaged velocity. It is evident that both the magnitude and the character of the velocities are significantly improved.

Results from ten different TELEMAC-2D tide models with grid resolutions near the FORCE crown lease ranging from 20 m to 500 m are compared in Figure 14. A linear relationship with $R^2 = 0.88$ is found between increasing grid resolution and improved predictive accuracy. These results show clearly the importance of adequate grid resolution when modelling and assessing kinetic energy resources.

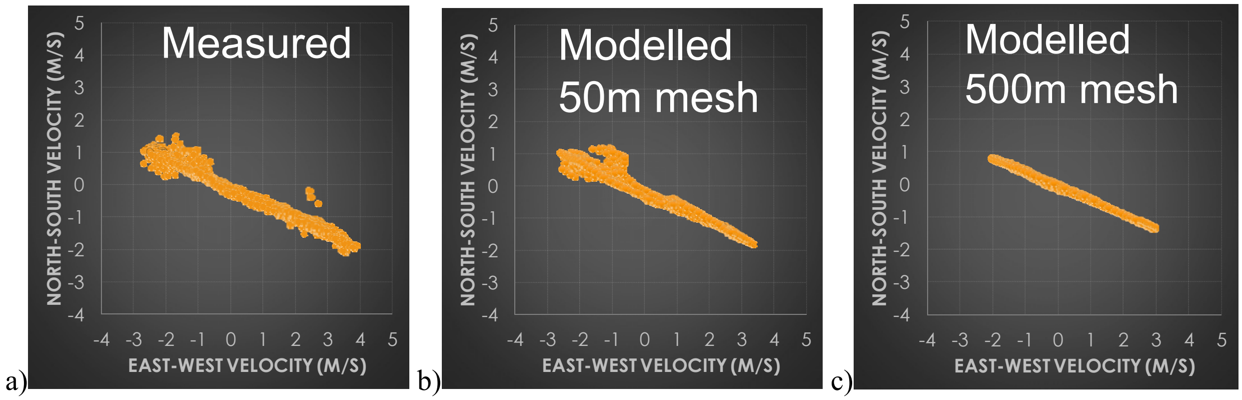

Figure 13. Comparison of measured and modelled velocity ellipses for mesh resolutions of 50m and 500m.

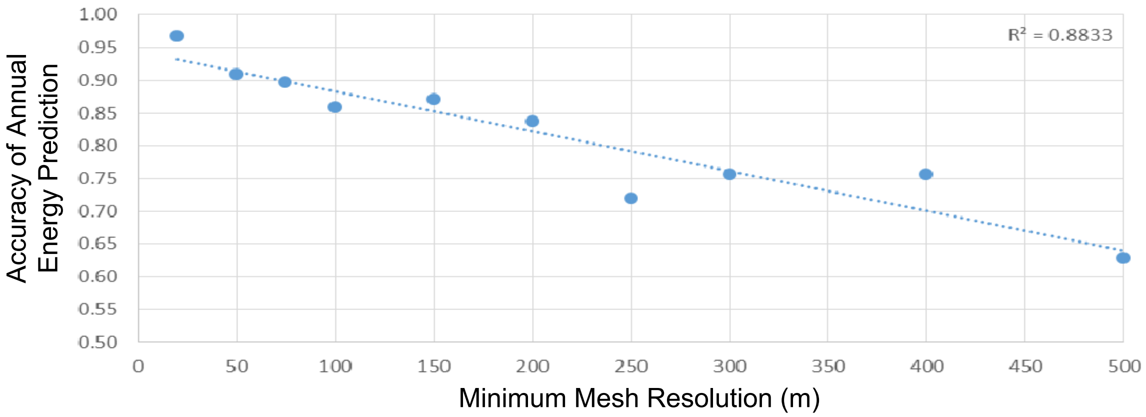

Figure 14. Influence of model resolution (minimum mesh size) on predictive skill.

CONCLUSIONS

Preliminary results are presented from an ongoing research study whose main objective is to appraise the new IEC technical specifications (TS) for assessment of wave and tidal energy resources through pilot application of the IEC methodologies to sites in the Bay of Fundy and off the west coast of Vancouver Island, Canada. The research aims to investigate to what extent the new IEC TS's are clear, easy to follow and implement, and whether following the prescribed methodologies will lead to resource estimates which have the desired level of precision and reliability. Moreover, it aims to investigate the main sources of uncertainty and determine which factors/choices most influence the precision of the wave and tidal resource estimates. Through this work, the performance, ease of use, and appropriateness of two new IEC standards will be assessed, and several refinements to improve future revisions may be identified.

Preliminary results indicate that the new IEC standards can be applied with a moderate level of effort to develop reasonable estimates of tidal and wave energy resources. However, the precision of the resource assessment is sensitive to a large number of factors and variables, including the resolution of the model grids used to simulate the wave conditions and tidal flows. Plentiful high-quality input data, reliable field observations, sophisticated modelling tools and careful attention to detail are essential in order to achieve resource assessments having a high level of precision and accuracy.

ACKNOWLEDGEMENT

The authors gratefully acknowledge financial support from Natural Resources Canada delivered through the eco-Energy Innovation Research and Development Fund.

REFERENCES

[1] Buckham, B. (2013) The West Coast Wave Initiative - A Strategic Approach to Wave Energy Development. Presented at the Marine Renewables Canada Annual Conference, Ottawa, Canada, November 2013.

[2] Clayton, H., Buckham, B, Wild, P., Robertson, B. (2014) Wave energy resources near Hot Springs Cove, Canada. *Renewable Energy*. **71**: 598–608.

[3] Cornett, A., Zhang, J. (2008) Nearshore Wave Energy Resources, Western Vancouver Island, B.C., National Research Council Technical Report CHC-TR-51. Ottawa, Canada.

[4] Cornett, A., Durand, N., Serrer, M. (2010) 3-D Modelling and Assessment of Tidal Current Resources in the Bay of Fundy, Canada. Proc. 2010 Int. Conf. on Ocean Energy (ICOE), Bilbao, Spain.

[5] Folley, M., Cornett, A., Holmes, B., Lenee-Bluhm, P. and Liria P. (2012) Standardising resource assessment for wave energy converters. Proc. 2012 Int. Conf. on Ocean Energy (ICOE), Dublin, Ireland.

[6] ftp://polar.ncep.noaa.gov/pub/history/waves. Accessed 10 October 2014.

[7] Galland, J.C.; Goutal, N.; Hervouet, J.M. (1991), "TELEMAC: A New Numerical Model for Solving Shallow Water Equations", *Advances in Water Resources* AWREDI 14 (3): 138–148.

[8] Hervouet, J.-M; Lang, P. (2000) Telemac-2D version 5.0, Validation Document, Rapport Électricité de France-DER, HP-73/2000/042/A.

[9] International Electrotechnical Commission (2014) Wave Energy Resource Assessment and Characterization. IEC/TS 62600-101.

[10] International Electrotechnical Commission (2014) Tidal Energy Resource Assessment and Characterization. IEC/TS 62600-201.

[11] Karsten, R., McMillan, J., Lickley, M., Haynes, R. (2008): Assessment of tidal current energy in the Minas Passage, Bay of Fundy. *J. Power and Energy*, **222(5)**: 493-507.

[12] Pawlowicz, R., Beardsley, B., Lentz, S. (2002) Classical Tidal Harmonic Analysis with Error Analysis in MATLAB using T_TIDE. *Computers and Geosciences*. **28**: 929-937.

[13] Roberston, B., Clayton, H., Buckham, B. (2014) Characterizing the near shore wave energy resource on the west coast of Vancouver Island, Canada. *Renewable Energy*. **71**: 665–678.

[14] The SWAN Team (2013), SWAN User Manual. Delft University of Technology. The Netherlands.

[15] Tolman, H. L. (2014) User manual and system documentation of WAVEWATCH III version 4.18. NOAA / NWS / NCEP / MMAB Technical Note 316.