

A High-Resolution, Wave and Current Resource Assessment of Japan: The Web GIS Dataset

Adrean Webb*, Takuji Waseda*, Wataru Fujimoto*, Kazutoshi Horiuchi[‡], Keiji Kiyomatsu[‡], Kazuhiro Matsuda[§], Yasumasa Miyazawa[†], Sergey Varlamov[†], and Jun Yoshikawa[§]

*Department of Ocean Technology, Policy, and Environment

The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba, Japan

webb@isea.k.u-tokyo.ac.jp, waseda@k.u-tokyo.ac.jp, fujimoto@isea.k.u-tokyo.ac.jp

[†]JAMSTEC-APL, 3173-25 Showa-machi, Kanazawa-ku, Yokohama-city, Kanagawa, Japan

miyazawa@jamstec.go.jp, vsm@jamstec.go.jp

[§]Web-Brain, 2-3-6 Sotokanda, Chiyoda-ku, Tokyo, Japan

kzmat@web-brain.jp, jun@web-brain.jp

[‡]Forecast Ocean Plus, 2-2-5 Kudanminami, Chiyoda-ku, Tokyo, Japan

horiuchi@forecastocean.com, kiyomatsu@forecastocean.com

Abstract—The University of Tokyo and JAMSTEC have conducted state-of-the-art wave and current resource assessments to assist with generator site identification and construction in Japan. These assessments are publicly-available and accessible via a web GIS service designed by WebBrain that utilizes TDS and GeoServer software with Leaflet libraries. The web GIS dataset contains statistical analyses of wave power, ocean and tidal current power, ocean temperature power, and other basic physical variables. The data (2D maps, time charts, depth profiles, etc.) is accessed through interactive browser sessions and downloadable files.

Index Terms—wave resource assessment, ocean and tidal current resource assessment, ocean temperature resource assessment, web GIS, NOAA WAVEWATCH III, JCOPE-T

I. INTRODUCTION

With an extensive coastline and close proximity of the Kuroshio current, Japan is an ideal candidate for wave and ocean current energy extraction. Supported by New Energy and Industrial Technology Development Organization (NEDO), The University of Tokyo and JAMSTEC have conducted state-of-the-art wave and current resource assessments for the reconnaissance and feasibility study stages of marine renewable energy development (to assist with generator site identification and construction in Japan). These marine renewable energy assessments are now publicly-available and accessible via a web GIS service designed by WebBrain and maintained by The University of Tokyo.

An English interface of the web GIS dataset is located at http://www.todaiww3.k.u-tokyo.ac.jp/nedo_p/en. The resource assessments can be accessed via the ‘Marine Energy Web GIS’ menu button on the left side (http://www.todaiww3.k.u-tokyo.ac.jp/nedo_p/en/webgis). Useful information and references can also be found within the menu button categories ‘Manual’, ‘FAQ’, and ‘Papers’.

TABLE I
LIST OF RELEVANT VARIABLES AND DEFINITIONS.

Terminology	Unit	Long name
P_{w1}	kW m^{-1}	Deep-water wave power density
P_{w3}	kW m^{-1}	Doppler-shifted wave power density
h_{m0}	m	Spectral significant wave height
f_p	Hz	Peak frequency
t_{-1}	s	Wave energy period (inverse moment)
θ_w	deg	Mean wave direction (meteorological)
U_{10}, U_{10}, V_{10}	m s^{-1}	10 m wind vector and components
P_c	W m^{-2}	Ocean current power density
u, u, v	m s^{-1}	Current vector and components
θ_c	deg	Current direction (oceanographic)
m_c	%	Current flow direction stability
P_T	W m^{-2}	Ocean temperature power density
T	$^{\circ}\text{C}$	Water temperature
ΔT_{20}	$^{\circ}\text{C}$	Water temperature difference with 20 m depth
$J[X, Y]$	%	Discrete joint probability distribution of X and Y
$F[X]$	%	Discrete frequency distribution of X
$F_c[X \geq x]$	%	Relative cumulative frequency of X greater than or equal to x

II. RESOURCE ASSESSMENTS

For full details of the resource assessments, please see [2] and [3], and other references listed under the ‘Papers’ category (http://www.todaiww3.k.u-tokyo.ac.jp/nedo_p/en/papers). To facilitate easy reference, relevant variables and definitions from the assessments are tabulated in Table I.

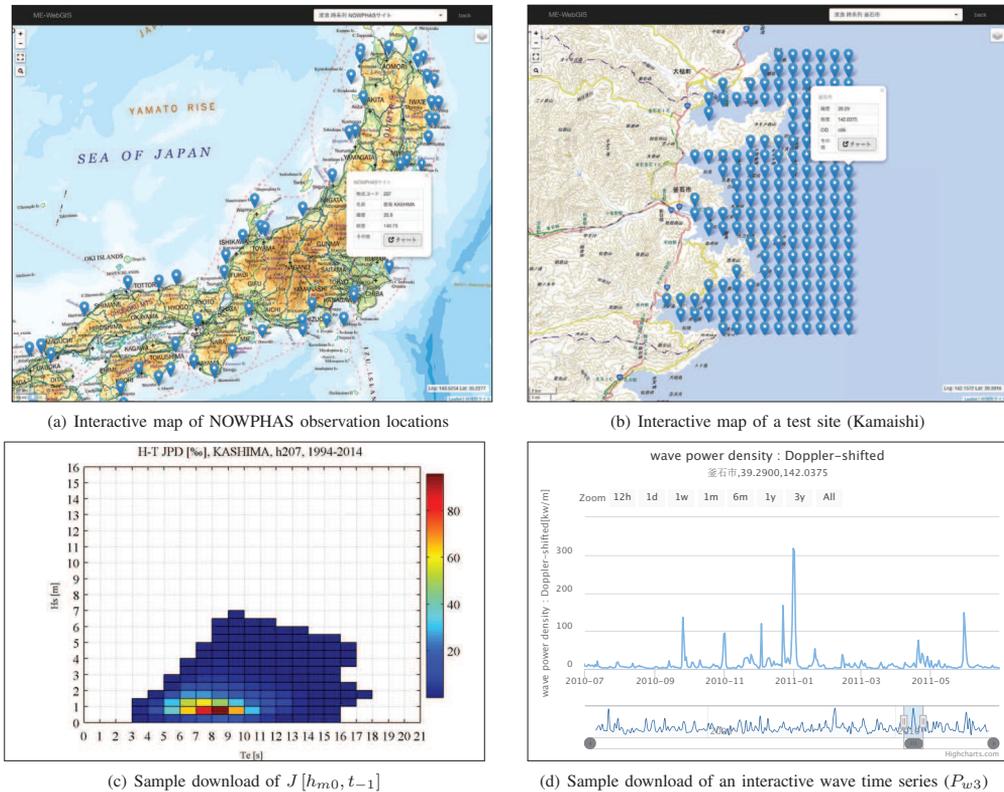


Fig. 1. Sample of TodayWW3 time series data available for 21 years (1994–2014). Screenshots of interactive maps are shown in (a) and (b) for the 82 NOWPHAS locations and 11 test sites (respectively). Sample file downloads (for the selected sites) are shown in (c) joint probability distribution of significant wave height and wave energy period and (d) interactive time series of P_{w3} .

A. Wave resource assessment

The wave resource assessment (University of Tokyo) is based on a large-scale NOAA WAVEWATCH III (version 4.18) simulation that includes several key components to improve model skill, such as a four-nested-layer approach for high resolution and the addition of current effects in all wave power density calculations. The nearshore resolution of each coastal model grid (24 in total) is approximately 1 km, with a latitude-longitude grid cell size of $0.010^\circ \times 0.0125^\circ$. Data from all the grids are post-processed and assembled into a single grid (banded artifacts from overlapping grids are visible in some regions as a result), referred to as *TodayWW3* here. The main simulation covers a 21-year period (1994/01/0 to 2014/12/31) to reduce aleatory uncertainty [1] and required approximately 3 million parallel process hours to run on The University of Tokyo FX10 supercomputer.

B. Current and temperature resource assessments

The ocean and tidal current and ocean temperature resource assessments (JAMSTEC) are based on a high-resolution sim-

ulation using JCOPE-T – a regional, $1/36^\circ$ tide-resolving model with 47 sigma levels (approximately 3 km in the horizontal) that is nested within the data-assimilating, $1/12^\circ$ non-tidal JCOPE2 model. The simulation covers a 10-year period (2002/01/01 to 2011/12/31) and required approximately 25 thousand parallel process hours to run on a JAMSTEC NEC SX-9 supercomputer. Both assessments are referred to as *JCOPE-T* here.

III. DATA DISTRIBUTION

The marine renewable energy resource assessments are distributed using web GIS, a newly-developed web mapping service. The web GIS engine is a THREDDS Data Server (TDS) that provides remote access to the datasets (<http://doi.org/10.5065/D6N014KG>). Topographical data is handled using GeoServer, an open geospatial information server (<http://geoserver.org>), and the user interface utilizes ‘Leaflet’, a browser and mobile mapping library (<http://leafletjs.com>). The server comprises a 12-Core 2.5 GHz CPU (Xeon E5-2680v3), 64 GB RAM, 800 GB SSD, and

TABLE II

HOURLY TODAIWW3 TIME SERIES DATA IS AVAILABLE FOR 82 NOWPHAS LOCATIONS AND 11 NEDO TEST SITES FOR 21 YEARS (1994–2014). DURATION OF THE TIME SERIES IS ADJUSTABLE AND DOWNLOADABLE. IN ADDITION, THE JOINT PROBABILITY DISTRIBUTION OF SIGNIFICANT WAVE HEIGHT AND WAVE ENERGY PERIOD IS PROVIDED AND DOWNLOADABLE.

Variable	NOWPHAS		Test sites	
	Histogram	Series	Histogram	Series
h_{m0}		○		○
f_p		○		○
t_{-1}		○		○
θ_w		○		○
P_{w1}		○		○
P_{w3}		○		○
$J[h_{m0}, t_{-1}]$	○		○	

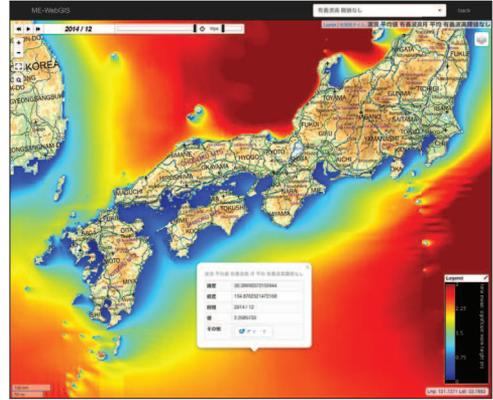
5×4TB HD (RAID5) hardware unit running CentOS 6.6; it is projected to handle a 10 concurrent user load.

The web GIS dataset is accessed through interactive browser sessions and downloadable files, and consists primarily of NetCDF files (COARDS convention). These files contain the mean and climatology data (and other related variables) that are used to create the interactive 2D maps. Location-specific analyses are also available, such as time series, joint probability distributions, time charts, and depth profiles.

Within each interactive 2D map session, drop-down menus in the top right corner are used to access or change the relevant analyses (mean period type, depth, etc.). A layer icon in the same corner is used to select the desired variable and background geographical map. For some outputs, a time display navigator in the top left corner is used to select the desired time period and can be used to automatically cycle through all periods. Clicking on any location will reveal in a pop-up display the coordinates, time (if relevant), and value ('none' if on land or outside the domain). Location-specific analyses can be accessed via the link in these displays. A search bar in the top left corner can also be used to search for locations by name. See Figs. 2–4 for sample screenshots of interactive sessions.

IV. WAVE TIME SERIES INFORMATION

Access to the TodaiWW3 time series data is located within the subcategory 'Wave Time Series Information' (/webgis# Wave_Time_Series_Information). Within it, hourly time series data is available for 82 observational locations and 11 NEDO test sites. The observational locations chosen coincide with a coastal observational network maintained by Nationwide Ocean Wave Information for Ports and HarborS (NOWPHAS). Observational data is distributed by NOWPHAS (<http://nowphas.mlit.go.jp>) and is not included in the web GIS dataset. Respectively, each NEDO test site covers a 0.2° × 0.2° latitude-longitude region (approximately 300 grid cell locations).



(a) Monthly mean of h_{m0} for 2014/12 (no threshold)



(b) Monthly standard deviation of h_{m0} for 2014/12 (no threshold)



(c) Time chart of h_{m0} monthly means and standard deviations

Fig. 2. Sample of TodaiWW3 mean data available for each of the 21 years (1994–2014). Screenshots of interactive monthly outputs of h_{m0} are shown for (a) mean and (b) standard deviation. (c) Means and standard deviations can be viewed as time charts at each map location.

TABLE III

2D MAPS AND TIME CHARTS (AT EVERY MAP LOCATION) OF TodaiWW3 DATA ARE CALCULATED FOR SELECT PERIOD TYPES AND SIGNIFICANT WAVE HEIGHT THRESHOLDS. DIFFERENT MEAN/CLIMATOLOGY TYPES (YEAR/SEASON/MONTH) ARE CALCULATED FOR EACH/ALL OF THE 21 YEARS (1994–2014). MEAN/CLIMATOLOGY OF U_{10} REFERS TO $((U_{10}), (V_{10}))$. SEE SECTION V FOR DETAILS.

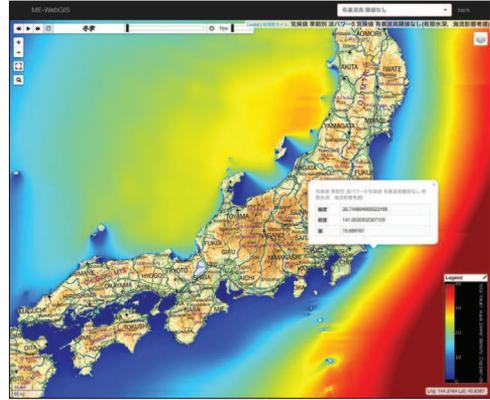
Variable	Mean / Climatology							
	Type			Threshold (h_{m0} ; m)				
	Year	Season	Month	None	3	5	7	9
h_{m0}	○	○	○	○	○	○	○	○
f_p	○	○	○	○	○	○	○	○
t_{-1}	○	○	○	○	○	○	○	○
θ_w	○	○	○	○	○	○	○	○
U_{10}	○	○	○	○				
U_{10}	○	○	○	○				
V_{10}	○	○	○	○				
P_{w1}	○	○	○	○	○	○	○	○
P_{w3}	○	○	○	○	○	○	○	○

Observational and test site locations are chosen via interactive browser sessions such as the sample screenshots shown in Figs. 1a–b. Each selected location contains six time series with adjustable durations in UTC format. See Table II for a full list of variables and Fig. 1d for a sample download. The 21-year joint probability distributions of significant wave height and the wave energy period are also provided; see Fig. 1c for a sample download. The time series data can be downloaded as ‘png’, ‘jpeg’, ‘pdf’, ‘svg’, and ‘csv’ files while the joint probability distributions can be downloaded as ‘png’ and ‘csv’ files.

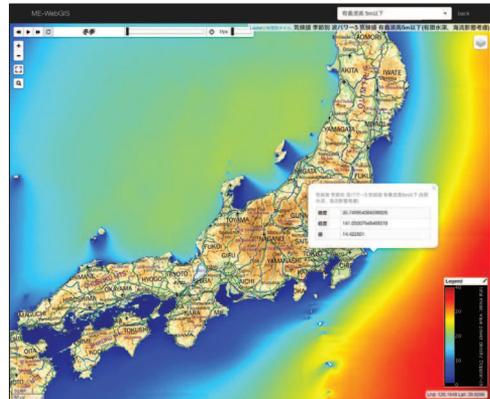
V. WAVE MAP INFORMATION

Access to the TodaiWW3 mean and climatology data is located within the subcategory ‘Wave Map Information’ (./webgis#Wave_Map_Information) and is further subdivided by means and climatologies. Nine variables are chosen and analyzed for online distribution; see Table III for a full list. Since there is a high variability in wave power density near Japan, five significant wave height thresholds – 3 m, 5 m, 7 m, 9 m, and none – are applied when calculating each statistic and any corresponding value above this limit is ignored (see Table III for applicability). As an example, winter climatologies of the Doppler-shifted wave power density are shown both with a 5 m threshold and without in Figs. 3a–b.

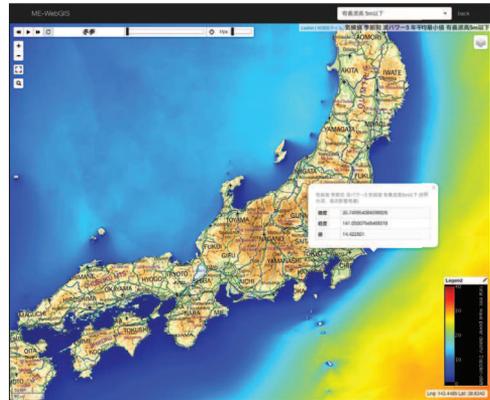
For each variable and threshold in Table III, three different types of means or climatologies – annual, seasonal, and monthly (referred to as *year*, *season*, and *month* hereafter) – are calculated for each or all of the 21 years. Winter, spring, summer, and autumn seasons are classified as months December–February, March–May, June–August, and September–November respectively. Means and standard deviations (for select variables) are available both as 2D maps and time charts (at map locations); see Table IV for a list and Figs. 2a–c for examples. The 21-year climatologies



(a) Winter climatology of P_{w3} with no h_{m0} threshold



(b) Winter climatology of P_{w3} with a 5 m h_{m0} threshold



(c) Winter mean minimum of P_{w3} with a 5 m h_{m0} threshold

Fig. 3. Sample of TodaiWW3 climatology map data available for a 21-year period (1994–2014). Screenshots of interactive seasonal outputs of P_{w3} are shown for two thresholds for (a) climatology (none), (b) climatology (5 m), and (c) mean maximum (5 m).

TABLE IV

LIST OF 2D MAPS AND TIME CHARTS (AT EVERY MAP LOCATION) AVAILABLE FOR TODAIWW3 MEAN AND CLIMATOLOGY DATA. ‘STD’ AND ‘CLIM’ ARE SHORTHAND FOR STANDARD DEVIATION AND CLIMATOLOGY; ‘MAX’ AND ‘MIN’ REFER TO THE MEAN MAXIMUM AND MINIMUM AT EACH LOCATION. SEE SECTION V AND TABLE III FOR FURTHER DETAILS.

Variable	Mean				Climatology		
	Map		Chart		Map		
	Mean	Std	Mean	Std	Clim	Max	Min
h_{m0}	○	○	○	○	○	○	○
f_p	○	○	○	○	○	○	○
t_{-1}	○	○	○	○	○	○	○
θ_w	○	○	○	○	○	○	○
U_{10}	○	○	○	○	○	○	○
U_{10}	○	○	○	○	○	○	○
V_{10}	○	○	○	○	○	○	○
P_{w1}	○	○	○	○	○	○	○
P_{w3}	○	○	○	○	○	○	○

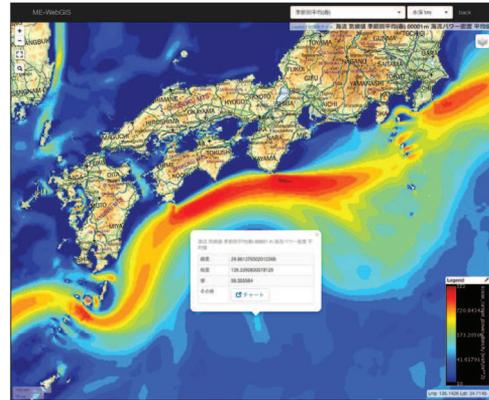
are available as 2D maps. In addition, mean maximums or minimums (at each map location) are available (for select variables) for their respective period type (year/season/month); see Table IV for a list and Fig. 3c for a mean maximum example.

VI. CURRENT AND TEMPERATURE MAP INFORMATION

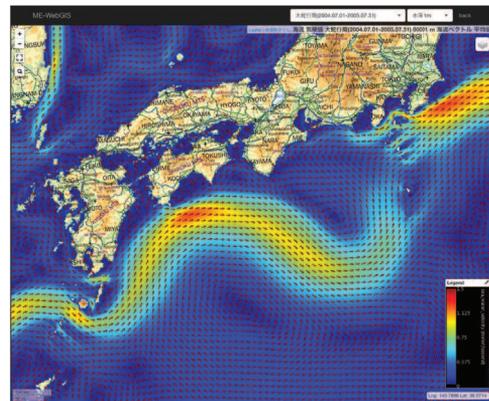
The ocean and tidal current and ocean temperature resource assessments are accessible within the subcategory ‘Current and Temperature Map Information’ (/webgis# Current_and_Temperature_Map_Information). Six and three variables from each resource assessment (respectively) are chosen and analyzed for online distribution. In each assessment, each statistic is calculated for nine depths, given by $D_c=[1, 50, 100, 200, 400, 500, 700, 1000]$ and $D_T=[5, 50, 100, 200, 400, 500, 700, 1000]$ (respectively). See Table V for a full list of variables.

For each variable and depth in Table V, climatologies are calculated for four different periods – year, season, LM, and NLM. As previously, ‘year’ and ‘season’ refer to annual and seasonal climatologies and cover the 10-year simulation. ‘LM’ is shorthand for the large-meander Kuroshio path and covers the period 2004/07/01 to 2005/07/31; ‘NLM’ is shorthand for the non-large-meander Kuroshio path and covers the simulation period 2002/01/01 to 2011/12/31 which excludes LM.

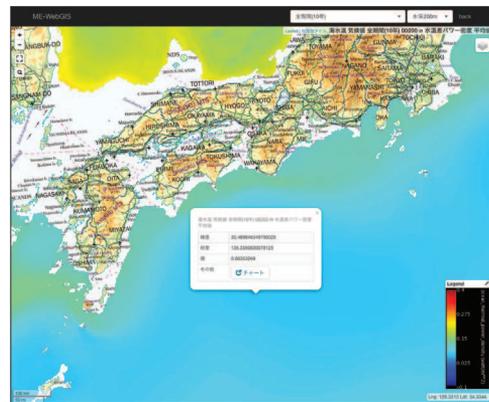
The four different ocean current and temperature climatologies are accessible as interactive 2D maps and depth profiles (at map locations); examples are shown in Figs. 4a–c and Fig. 5a. In addition, standard deviations, maximum and minimum values (within the different periods), and relative cumulative frequencies (greater than or equal) are available for select variables; see Table VI for a list and the values used for F_c . And finally, frequency distribution histograms are also available for select variables and can be downloaded as ‘png’ and ‘csv’ files. See also Table VI for a list and Fig. 5b for a sample download.



(a) Spring climatology of P_c at a 1 m depth



(b) Large-meander climatology of u at a 1 m depth



(c) Annual climatology of P_T at a 200 m depth

Fig. 4. Sample of JCOPE-T climatology map data available, covering up to a 10-year period (2002–2011). Screenshots of interactive climatologies are shown in (a) and (b) at 1 m depths for P_c (10-year-seasonal) and u (large-meander) respectively, and (c) at a 200 m depth for P_T (10-year-annual).

TABLE V

2D MAPS AND DEPTH PROFILES OF JCOPE-T DATA ARE CALCULATED FOR SELECT PERIOD TYPES AND DEPTHS. DIFFERENT CLIMATOLOGY TYPES (YEAR/SEASON/LM/NLM) COVER UP TO A 10-YEAR PERIOD (2002–2011); ‘LM’ AND ‘NLM’ ARE SHORTHAND FOR THE LARGE-MEANDER AND NON-LARGE-MEANDER KUROSHIO PATHS. SELECTED DEPTHS ARE REPRESENTED BY ‘D_c’ AND ‘D_T’. CLIMATOLOGY OF \mathbf{u} REFERS TO $(\langle u \rangle, \langle v \rangle)$. SEE SECTION VI FOR DETAILS.

Variable	Climatology				Depth	
	Year	Type		D _c	D _T	
		Season	LM	NLM		
$ \mathbf{u} $	○	○	○	○	○	○
\mathbf{u}	○	○	○	○	○	○
u	○	○	○	○	○	○
v	○	○	○	○	○	○
m_c	○	○	○	○	○	○
P_c	○	○	○	○	○	○
T	○	○	○	○		○
ΔT_{20}	○	○	○	○		○
P_T	○	○	○	○		○

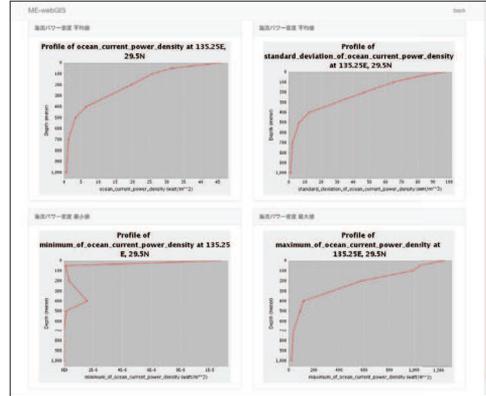
TABLE VI

LIST OF 2D MAPS, DEPTH PROFILES, AND HISTOGRAMS AVAILABLE FOR JCOPE-T DATA. ‘CLIM’ AND ‘STD’ ARE SHORTHAND FOR CLIMATOLOGY AND STANDARD DEVIATION; ‘MAX’ AND ‘MIN’ REFER TO THE MAXIMUM AND MINIMUM VALUES WITHIN THE DIFFERENT PERIODS. VALUES USED FOR F_c ARE LISTED IN THE TABLE AND FREQUENCY DISTRIBUTION FOR HISTOGRAMS ARE DOWNLOADABLE. SEE SECTION VI AND TABLE V FOR FURTHER DETAILS.

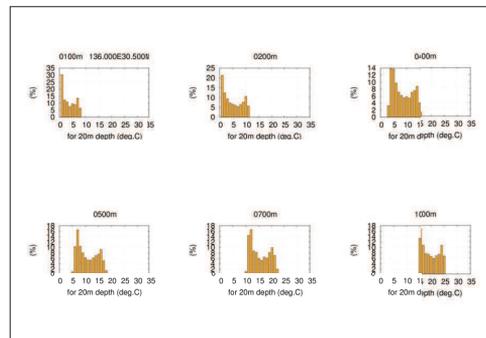
Variable	Climatology				F_c	Frequency
	Clim	Map / Profile		Std		Histogram
		Max	Min			F
$ \mathbf{u} $	○	○	○	○	1, 1.5	
\mathbf{u}	○					
u	○		○	○		
v	○		○	○		
m_c	○					
θ_c						○
P_c	○	○	○	○		
T	○	○	○	○		○
ΔT_{20}	○	○	○	○	20	○
P_T	○	○	○	○		

VII. SUMMARY

Marine renewable resource assessments conducted by The University of Tokyo and JAMSTEC are now publicly-available online at http://www.todaiww3.k.u-tokyo.ac.jp/nedo_p/en. The data is distributed by a web GIS service that utilizes TDS and GeoServer software with Leaflet libraries. The web GIS dataset contains statistical analyses of wave power (21 years), ocean and tidal current power (10 years), and ocean temperature power (10 years) that are accessed through interactive browser sessions and downloadable files.



(a) Spring depth profiles of P_c



(b) Spring frequency distribution of ΔT_{20}

Fig. 5. Sample of JCOPE-T climatology profile and histogram data available at map locations for a 10-year period (2002–2011). Screenshot of depth profiles is shown in (a) for seasonal P_c . Sample file download is shown in (b) of the seasonal ΔT_{20} frequency distribution histograms at specific depths.

ACKNOWLEDGMENT

This work was supported by the NEDO project titled, “Research on the Framework and Infrastructure of Marine Renewable Energy; an Energy Potential Assessment.” All sample screenshots utilize Geographical Survey Institute (GSI) English tile maps (<http://www.gsi.go.jp>).

REFERENCES

- [1] Y. Kidoura, R. Wada, and T. Waseda, “On the aleatory and epistemic uncertainty of the wave resource assessment in the Northwest Pacific,” in *ASME 2014 33rd Int. Conference, American Society of Mechanical Engineers*, 2014.
- [2] T. Waseda, A. Webb, K. Kiyomatsu, W. Fujimoto, Y. Miyazawa, S. Varlamov, K. Horiuchi, T. Fujiwara, T. Taniguchi, K. Matsuda, and J. Yoshikawa, “Marine energy resource assessment at reconnaissance to feasibility study stages; wave power, ocean and tidal current power, and ocean thermal power” (in Japanese), *Journal of the Japan Society of Naval Architects and Ocean Engineers*, in press, 2016.
- [3] A. Webb, T. Waseda, and K. Kiyomatsu, “A 21-year high-resolution wave resource assessment of Japan: Model setup and validation”. *Ocean Dynamics*, in preparation, 2016.