Classification systems for wave energy resources and WEC technologies

Vincent Neary, Ryan Coe, Giorgio Bacelli, Victor Nevarez, Water Power Technologies, Sandia National Labs, NM, USA
Joao Cruz, Yannick Debruyne, Cruz-Atcheson, Consulting Engineers, Portugal
Kevin Haas, Seongho Ahn, Georgia Tech, GA, USA

Wave Resource Characterization 4 (#973)
Civil Engineering Building, Room G10
August 29, 2017
Motivation

- **Resource classification**
  - Reduce time and costs for siting, scoping studies and project planning

- **Technology classification**
  - Reduce design and manufacturing costs

---

**Wind Resource Classification**

| Wind Power Class | Resource Potential | Wind Power Density at 50 m W/m² | Wind Speed at 50 m m/s | Wind Speed at 50 m mph |
|------------------|--------------------|--------------------------------|------------------------|------------------------|
| 1 Poor           | 0 - 200            | 0.0 - 0.0                 | 0.0 - 0.0              |
| 2 Marginal       | 200 - 300          | 6.0 - 6.0                 | 6.0 - 6.0              |
| 3 Fair           | 300 - 400          | 6.8 - 6.8                 | 6.8 - 6.8              |
| 4 Good           | 400 - 500          | 7.5 - 7.5                 | 7.5 - 7.5              |
| 5 Excellent      | 500 - 600          | 8.1 - 8.1                 | 8.1 - 8.1              |
| 6 Outstanding    | 600 - 800          | 8.6 - 8.6                 | 8.6 - 8.6              |
| 7 Superb         | > 800              | > 9.0                     | > 9.0                  |

Wind speeds are based on a Weibull k of 2.4 at 50 m.

---

**Wind Turbine Classification**

| Wind turbine class | I | II | III | S |
|-------------------|---|----|-----|---|
| $V_{ref}$ (m/s)   | 50| 42.5| 37.5|   |
| A                 | 0.16|   |   |   |
| B                 | 0.14|   |   |   |
| C                 | 0.12|   |   |   |

Values specified by designer.

TC88 Design document, 61400-1 Ed. 3, © IEC:2005
Resource classification: Wave power density

- Omni-directional power density – opportunity for wave energy extraction

\[ J = \frac{\rho g}{16} H_S^2 C_g(T_e, h) \]  [KW/m]

- Annual available energy (AAE) density

\[ AAE = J(8766h/year) \]  [KW-h/m]

Geographic distribution of mean omni-directional power density and AAE density in US
Resource classification: Data source

**Source**: NOAA’s 30-year WAVE III hindcast (Chawla et al., 2013)

Third generation, spectral wave model providing wave hindcasts

(4min resolution ≈ 7km)

**Data**: 1. Complete directional wave spectra $S(f, \theta)$ at limited grid points

2. Bulk and partition wave parameters ($H_s$, $T_p$, $\theta_m$, at each grid point)

Spectra $S(f, \theta)$ - 1,951 locations

Partition - 70,386 locations
Resource classification: Partitioned $J$

1. Calculate partition wave power densities in peak period and direction bins

\[ J(T_p, \theta) \]

2. Sum all direction bins

\[ J(T_p) = \sum_{\theta} J(T_p, \theta) \]

3. Sum all to get total $J$ and annual available energy ($AAE$) density

\[ J = \sum_{T_p} J(T_p) \quad \text{and} \quad AAE = T_{year} \times J \]

$T_{year} = \text{number of hours in a year (8,766 hrs)}$
Resource Classification: Class delineation

### Frequency/period band classes (4)

| Band    | Band 1 (local wind sea) | Band 2 (short, moderate and long period swell) | Band 3 | Band 4 |
|---------|-------------------------|-----------------------------------------------|--------|--------|
| Period, $T_p$ | $0 < T_p < 7$          | $7 < T_p < 10$                               | $10 < T_p < 14$ | $14 < T_p$ |
| Frequency, $f$  | $f < 0.14$              | $0.1 < f < 0.14$                             | $0.07 < f < 0.1$ | $0 < f < 0.07$ |

(1) Local wind sea, period ($0 < T_p < 7$)
(2) Swell, short period ($7 < T_p < 10$)
(3) Swell, moderate period ($10 < T_p < 14$)
(4) Swell, long period ($14 < T_p$)

### Power classes (4)

| Class | 0 | 1 | 2 | 3 |
|-------|---|---|---|---|
| Power(KW/m) | J<1.14 | 1.14<J<5.7 | 5.7<J<22.8 | 22.8<J |
| AAE(MWh/m) | AAE<10 | 10<AAE<50 | 50<AAE<200 | 200<AAE |

0 – small (P<10 KW), homes, farms, remote
1 – intermediate (10 – 500 KW), village, hybrid systems, distributed
2, 3 – intermediate to large (P>500 KW), commercial, utility scale

Sample: Hawaii, 22.7N 160.5W
### Four power classes
- **0**: small (P<10 KW), homes, farms, remote
- **1**: intermediate (10 – 500 KW), village, hybrid systems, distributed
- **2, 3**: intermediate to large (P>500 KW), commercial, utility scale

### Four period band classes
- **(1) Local wind sea, period (0 < T_p <7)**
- **(2-4) Swell, period = (2) short (7 < T_p<10), (3) moderate (10 < T_p<14), (4) long (14 < T_p)**
Geographic distribution of wave power classes:

- **Class 0** (AAE<10 MWh/m)
- **Class 1** (10<AAE<50 MWh/m)
- **Class 2** (50<AAE<200 MWh/m)
- **Class 3** (200<AAE MWh/m)

- **Class 0** (J<1.14 KWh/m)
- **Class 1** (1.14<J<5.7 KWh/m)
- **Class 2** (5.7<J<22.8 KWh/m)
- **Class 3** (22.8<J KWh/m)
Technology Classification: Feasible?

- Energy capture/cost: Evaluate distribution of optimal designs within each resource class
- Extreme loads: Evaluate the distribution of extreme WEC load responses within each region

\[
\lambda = 1
\]

RM3 Point Absorber
Technology Classification: Design optimization

Ten (10) representative sites each region
Technology Classification: Design optimization

Class 1
Gulf Coast ~ 0.56

Class 2
East Coast ~ 0.68

Class 3
West Coast ~ 0.95

Design optimization

$\lambda_{opt}$

Site
Technology Classification: WEC load response

- Inter-regional variation of extreme loads (surge-excitation, $r = 100$-years) 2.7-4.3 MN

Coe et al. 2016. WDRT: A toolbox for design-response analysis of wave energy converters WEC design response toolbox (WDRT), METS 2016.
Conclusions

- Resource classification
  - Distinct regional trends in wave energy characteristics (deep and intermediate depths only)

- Technology classification
  - Energy/cost optimization indicates standard design classes suitable for broad regional wave climates
  - Extreme load response study for only 3 sites, but shows large inter-region variation
  - Limited to point absorber
ACKNOWLEDGEMENTS:

The project presented was supported by the Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy (EERE), Wind and Water Power Technologies Office (WWPTO). Special thanks to Dr. Joel Cline (DOE) for his continued support as lead for the DOE’s marine energy program’s resource characterization and assessment work.

Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy’s National Nuclear Security Administration under contract DE-NA0003525

THANK YOU

Contact: vsneary@sandia.gov
EXTRA SLIDES
Resource classification: Regional trends

**West Coast**
Class 3(3)
High power density
Most energy btw. $10 < T_p < 14$
Moderate period swell (band 3)
Directionally focused

**East Coast**
Class 2(2)
Moderate power density
Most energy btw. $7 < T_p < 10$
Short period swell (band 2)
Directionally spread

**Gulf Coast**
Class 1(1)
Low power density
Most energy btw. $0 < T_p < 7$
Local wind sea (band 1)
Directionally spread
Resource: Class delineation

### Frequency/period band classes (4)

| Band     | Band 1 (local wind sea) | Band 2 (short, moderate and long period swell) | Band 3 | Band 4 |
|----------|-------------------------|-----------------------------------------------|--------|--------|
| Period, $T_p$ | $0 < T_p < 7$             | $7 < T_p < 10$                              | $10 < T_p < 14$ | $14 < T_p$ |
| Frequency, $f$ | $f < 0.14$               | $0.1 < f < 0.14$                            | $0.07 < f < 0.1$ | $0 < f < 0.07$ |

### Power classes (4)

| Class | 0     | 1     | 2     | 3     |
|-------|-------|-------|-------|-------|
| Power (KW/m)       | $J < 1.14$ | $1.14 < J < 5.7$ | $5.7 < J < 22.8$ | $22.8 < J$ |
| AAE (MWh/m)        | $AAE < 10$ | $10 < AAE < 50$ | $50 < AAE < 200$ | $200 < AAE$ |

Sample: Hawaii, 22.7N 160.5W
Geographic distribution of relative risk classes: low ($R \leq 5$), medium ($5 < R < 8$), high ($8 \leq R$).
Technology: Methods, load response

- Selected 3 buoy sites West Coast for inter-region comparison
- Full sea state approach – select 200 sea states to represent design load cases (DLC) for analysis
- WEC-Sim predicts WEC load response
- Generate extreme survival response functions

Coe et al. 2016. WDRT: A toolbox for design-response analysis of wave energy converters
WEC design response toolbox (WDRT), METS 2016.
Non-dimensionalized loads

\[ F^* = \frac{F}{\rho g A_c \eta_r} \]

- \( \rho \) is the water density
- \( g \) is the constant of gravity
- \( A_c \) is the characteristic projected area of the device
- \( \eta_r \) is the r-yr return period value of the wave elevation
Next steps

- Resource classification
  - Extend to shallow sites (New DOE high-resolution hindcasts completed in 2019)
  - Review by industry (Marine Energy Council, US TAG: IEC, project steering committee)

- Technology classification
  - Extend the extreme load response study to thirty sites used in optimization study
  - Extend to other WEC archetypes