Predictability of long-term change in global wave energy resources based on wind and wave climate variability

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MOTIVATION

The development of ocean renewable energy (ORE) can assist additional sources in tackling the impact of changing climate. However, ocean resources are highly affected by climate change impact themselves.

Hence, it is important to investigate such impact and consider the climate change impact in sustainability criteria for planning, site selection, and technology development of OREs.

In order to assess the sustainability of global wave energy, we utilized five decades of historical re-analysis wave climate to first, investigate the long-term change of wave resources in different time scales, and, second, to show the relation between the change of different wind and wave parameters.

Defining such a relationship can be used in the prediction of future changes in wave resources based on change in various wind and wave characteristics for sustainable development purposes.

METHOD

Data

- 60 years of modelled wave characteristics (1960-2019)
- Model: Simulating WAves Nearshore (SWAN)
- Wind input: re-analysis wind field: JRA-55 (spatial resolution: 60 km, and temporal resolution: 6 hours)
- Bathymetry: GEBCO (spatial resolution: 30 arc-sec)

Model Setup

- Computational grid coverage: global
- Frequency domain: 0.03-1 Hz with 36 bins (logarithmic) Directional resolution of the computational grid: 10
- Spatial resolution of the computational: 1 degree
- Computational time steps: 30 min
- Spatial resolution of the output grid: 1 degree
- Temporal resolution of the output grid: 6 hours

Wave power was calculated based on the deep-water approximation formula: ($P \approx 0.49 \times Hs^2 \times T_e$)

Validation

A) Comparison with buoy data

Comparison with 64 buoys distributed around the world with various recording periods (1978-2019), obtained from Copernicus Marine Environment Monitoring Service (CMEMS)

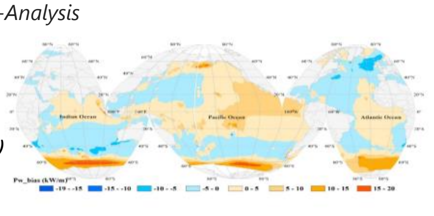
$$\mathrm{RMSE}=\sqrt{\frac{1}{N}\sum_{i=1}^{N}(P_i-M_i)^2}\;,\quad \mathrm{SI}=\frac{\mathrm{RMSE}}{\frac{1}{N}\sum_{i=1}^{N}M_i}\quad \mathrm{bias}=\sum_{i=1}^{N}\frac{1}{N}(P_i-M_i)\quad \mathrm{Nbias}=\frac{1}{\frac{1}{N}\sum_{i=1}^{N}(M_i)}\sum_{i=1}^{N}\frac{1}{N}(P_i-M_i)$$

M_i is the measured value, P_i is the predicted value, and N is the number of data.

Summary of error statistics in the estimated H_s and mean periods [1]

	H_s					T_{m02}					Distance from the closest grid point (°)
	R	SI	bias (m)	N.Bias	RMSE (m)	R	SI	bias (s)	N.Bias	RMSE (s)	
Lowest	0.81	0.17	0.02	-0.51	0.27	0.51	0.13	0.01	-0.41	0.69	0.00
Mean	0.89	0.29	0.22	-0.03	0.58	0.72	0.21	0.67	-0.08	1.24	0.40
Largest	0.95	0.46	-1.27	0.24	1.73	0.83	0.40	-2.59	0.11	3.12	0.69

B) Comparison with Re-Analysis

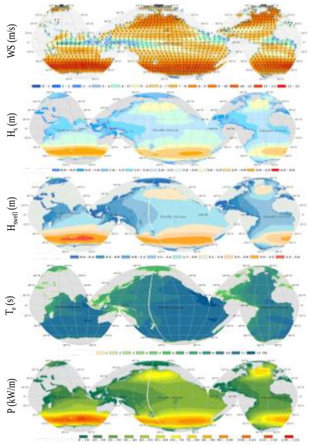


Bias for Mean annual P (kW/m) SWAN output- ERA-5 [1]

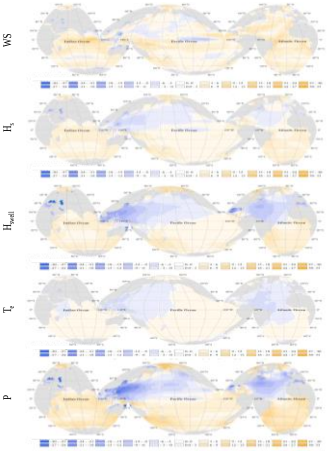
RESULTS

Change in 30-yearly mean annual wind and wave

(Per_1: 1960-1989, and Per_2: 1990-2019)

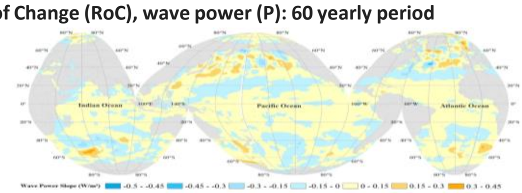


Annual mean values of different parameters in Per_1 [1]



Relative change of annual mean values of different parameters in Per_2 compared to Per_1 (%) [1]

Rate of Change (RoC), wave power (P): 60 yearly period

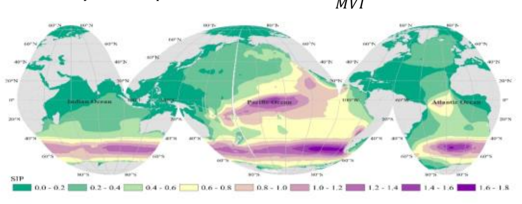


Priority coasts considering the variation and change in resources

Ideal condition:

- Highest P
- Lowest MVI
- Lowest rate of change (negative or positive)

Sustainability Index: $SI_P = \dfrac{\dfrac{P_{annual\ mean}}{\max(P_{annual\ mean})} \times \cos\dfrac{Rate\ of\ change}{\max|Rate\ of\ change|}}{MVI}$



Sustainability Index (SI_p) [1]

CONCLUSIONS

- Selection of different assessment periods can cause up to ±25% difference in wave resource assessment in deep waters.
- The long-term change in wave power appears to be a function of change in swell wave height rather than the combination of swells and seas.
- The long-term RoC for wave power showed spatial variation. It should be investigated in various time scales to detect the decadal changes, as well.
- The classification based on SI_p revealed the priority areas mainly in the southern hemisphere. The priority areas in the northern hemisphere are the west coasts of North America, east of Japan and Russia, west of Europe, Iceland, and south of Greenland.

REFERENCE

[1] Kamranzad B*, Amarouche K, Akpinar A. (2022) Linking the long-term variability in global wave energy to swell climate and redefining suitable coasts for energy exploitation. ***Scientific Reports***. 12, 14692. https://doi.org/10.1038/s41598-022-18935-w