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CHARACTERIZATION OF EXTREME WAVE HEIGHTS AND RELATIVE RISK RATIOS FOR US COASTAL REGIONS

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MOTIVATION

- Wave resource characterization provides essential data for the design, test planning, installation, operation, maintenance, and decommissioning of marine energy converters (MECs) and other ocean and coastal engineering applications
- Characterization of the long-term project risks and extreme wave loads are necessary to ensure the integrity and safe operation of MECs which requires understanding of the extreme wave heights occurring on average every *n*-years
    - Extreme wave loads for WEC design load cases characterized by *n*-year significant wave height [IEC TS 62600-2]
    - Relative risk ratio, $H_{s(n)}/H_{s(mean)}$ has been proposed as metric to characterize WEC or WEC project risk relative to opportunity for wave energy harvesting [Neary et al. 2018]
- Buoy data in US coastal regions for estimating extreme wave heights is sparse and multi-decade measurement histories are limited

TS 62600 IEC. *Marine Energy – Wave, Tidal and Other Water Current Converters – Part 2: Design Requirements for Marine Energy Systems*. International Electrotechnical Commission, Geneva, Switzerland, 2015.
Neary, V. S., Coe, R. G., et al., (2018) Classification systems for wave energy resources and WEC technologies. Int. Marine Energy Journal, 1(2), 71-79.
Neary, V. S., Ahn. S., et al. (2020). Characterization of extreme wave conditions for wave energy converter design and project risk assessment. *Journal of Marine Science and Engineering*, *8*(4), 289.

INTRODUCTION & OBJECTIVE

- International Electrotechnical Commission (IEC) provides standards for marine energy systems
  - IEC 62600-2: Marine Energy – Wave, Tidal and Other Water Current Converters – Part 2: Design Requirements for Marine Energy System requires estimation of 1-, 5-, and 50-year extreme wave heights
  - DNV-RP-C205 outlines best practices for the estimation of the *n*-year return period extreme wave heights

WECs

6) Parked/survival conditions	6.1	1,35(ULS) 1,00 (SLS)	ESS $H_{m0}=H_{m50}$	ECM $U=U_5$	EWLR	Wind: EWM ($V=V_5$)	Extreme
	6.2	1,10 (ULS) 1,00 (SLS)	ESS $H_{m0}=H_{m50}$	ECM $U=U_5$	EWLR	Wind: EWM ($V=V_5$) Grid loss	Abnormal

TECs

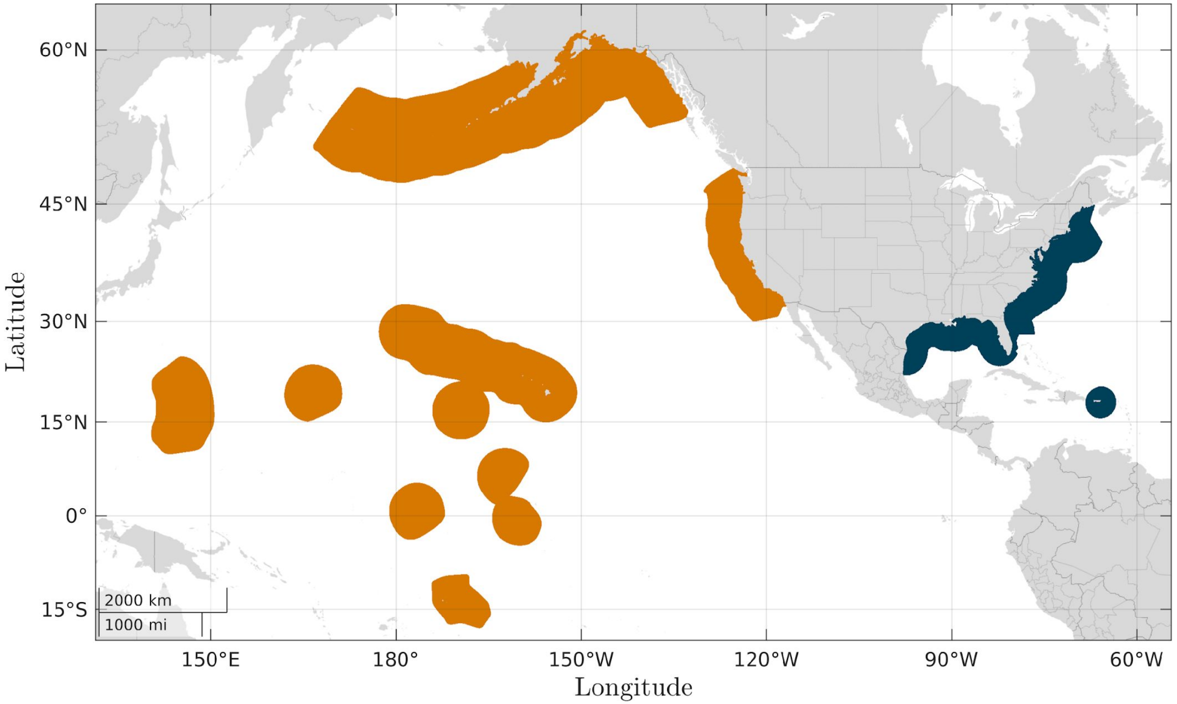
6) Parked/ survival conditions	6.1a	1,35 (ULS) 1,00 (SLS)	ECM $U=peak\ spring$ flood, ebb, OE	ESS $H=H_{m5}$ most probable direction(s)	EWLR	Wind: EWM ($V=V_5$)	Extreme
	6.1b	1,35 (ULS) 1,00 (SLS)	ECM $U=peak\ spring$ flood, ebb, OE	ESS $H=H_{m50}$ most probable direction(s)	EWLR	Wind: EWM ($V=V_{50}$)	Extreme
	6.2	1,10 (ULS) 1,00 (SLS)	worst combination of current and wave	worst combination of	EWLR	Wind: EWM ($V=V_5$)	Abnormal

- **Objective:** Estimate the 1-, 5-, and 50-year extreme wave heights and relative risk ratios for the US EEZ following international standards and catalogue for hosting on the DOE's Marine and Hydrokinetic Data Repository and MHK Atlas following FAIR data principles

TS 62600 IEC. *Marine Energy – Wave, Tidal and Other Water Current Converters – Part 2: Design Requirements for Marine Energy Systems*. International Electrotechnical Commission, Geneva, Switzerland, 2015.
DNV-RP-C205. *Environmental conditions and environmental loads*. Det Norske Veritas, Oslo, Norway, 2014.
ISO, 2015. *Petroleum and Natural Gas for Offshore Structures — Part 1: Metocean Design and Operating Considerations*. Switzerland.
Wilkinson, M. D., Dumontier, M., et al. (2016). The FAIR guiding principles for scientific data management and stewardship. *Scientific Data*, 3(1), 1-9.

DATA | HINDCAST & BUOY

- Utilized validated, high-resolution 42-year hindcast data produced from a third-generation spectral wave model and following IEC 62600-101 [Yang et al. 2023 & references therein]
  - Feasibility-level wave energy resource characterization covering US EEZ (~200 m spatial resolution)
- Utilized NOAA NDBC buoy data
  - Within bounds of hindcast data over 200 with period of record (POR) > 2 years and over 45 with POR > 20 years



TS 62600 IEC. *Marine Energy – Wave, Tidal and Other Water Current Converters – Part 101: Wave Energy Resource Assessment and Characterization*. International Electrotechnical Commission, Geneva, Switzerland, 2015.
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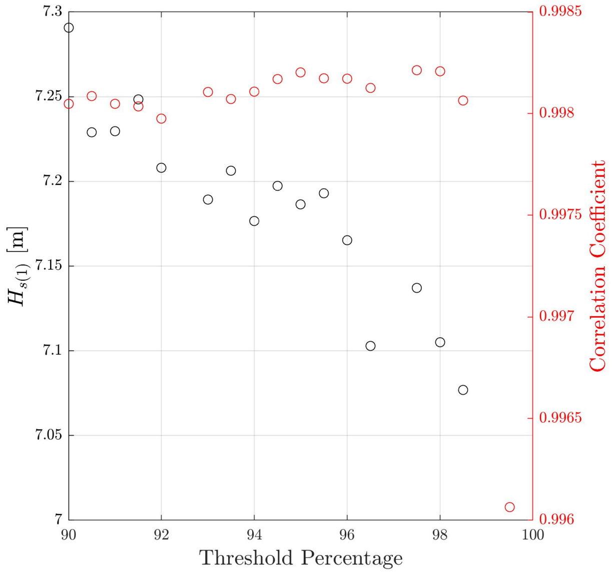
NOAA. National Data Buoy Center. https://www.ndbc.noaa.gov/.

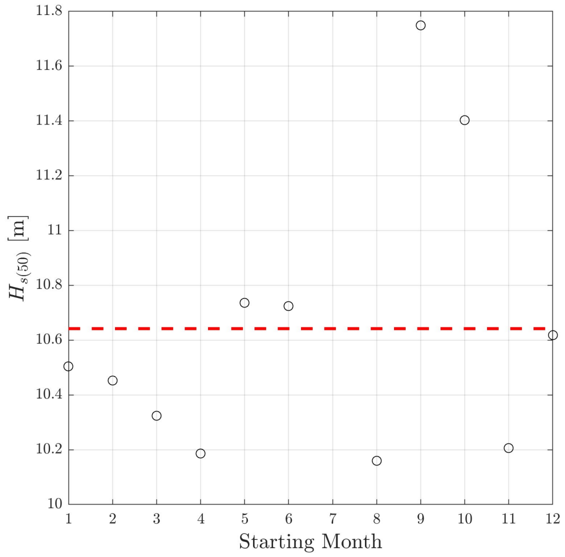
METHODS | ESTIMATING EXTREME WAVE HEIGHTS

- Utilizing two different methods for estimating $H_{s(n)}$ depending on return period [Coles 2001, Holthuijsen 2007]:
  - 1-year – peak-over-threshold (POT)
  - 5- and 50-year – annual maxima (AM)
- Peak-over-threshold
  - Threshold level required for estimating $H_{s(n)}$ is site specific (and automated) [Neary et al. 2020]
- Annual maxima
  - Estimated $H_{s(n)}$ based on mean value of twelve different annual windows [Ahn et al. 2024]

$H_{s(1)}$



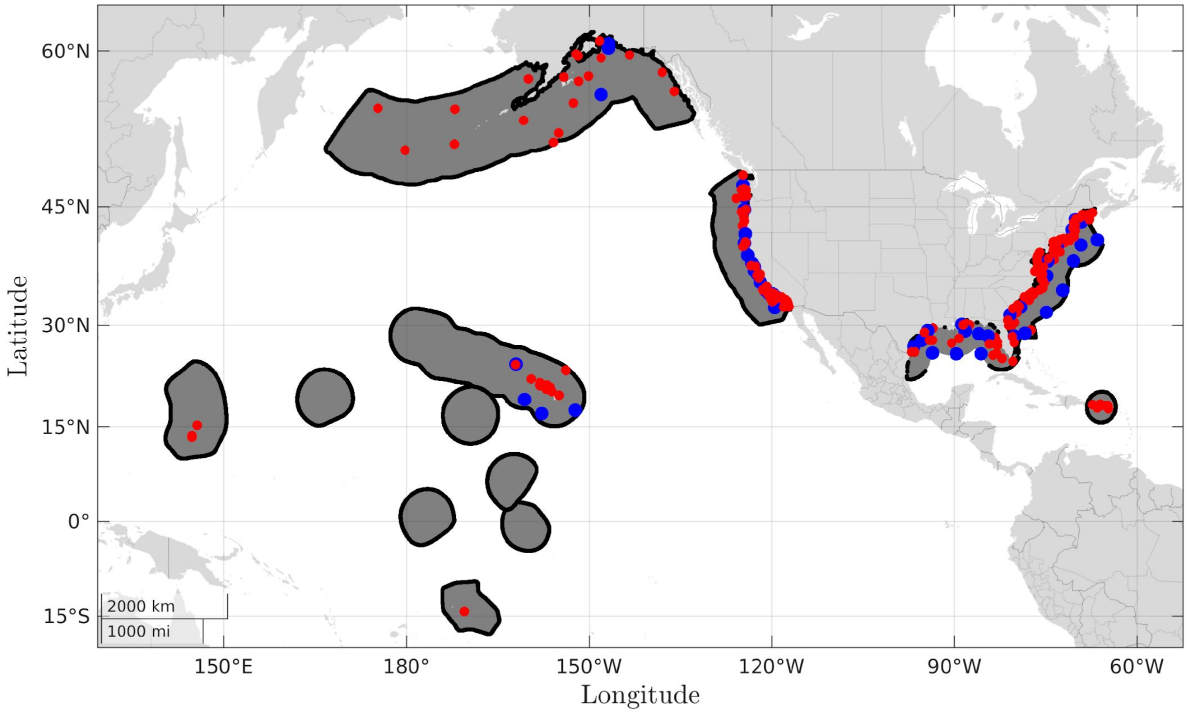
$H_{s(50)}$



Coles, S., (2001). An introduction to statistical modeling of extreme values, Springer-Verlag.
Holthuijsen, L.H., (2007). Waves in oceanic and coastal waters, Cambridge University Press.
Neary, V.S., Ahn, S., et al. (2020). Characterization of extreme wave conditions for wave energy converter design and project risk assessment. *Journal of Marine Science and Engineering*, *8*(4), 289.
Ahn, S. & Neary, V. S., (2024). High-resolution atlas of extreme wave height and relative risk ratio for US coastal regions. *Ocean Engineering*, *314*, 119684.

METHODS | BIAS & DEPTH LIMITED CORRECTION

- Hindcast data has been found to underpredict extreme wave heights when compared to measured buoy data [Neary et al. 2020, Neary et al. 2023, Ahn et al. 2024]
- Evaluating different methods of bias correction:
  - Regional average correction [Neary et al. 2020]
  - Spatial interpolation correction
- Depth limited correction based on empirical model based on breaking depth limits [Goda 2010]



Red: POR > 2 years
Blue: POR > 20 years

Neary, V.S., Ahn, S., et al. (2020). Characterization of extreme wave conditions for wave energy converter design and project risk assessment. *Journal of Marine Science and Engineering*, *8*(4), 289.
Neary, V. S. & Ahn, S., (2023). Global atlas of extreme significant wave heights and relative risk ratios. *Renewable Energy*, *208*, 130-140.
Ahn, S. & Neary, V. S., (2024). High-resolution atlas of extreme wave height and relative risk ratio for US coastal regions. *Ocean Engineering*, *314*, 119684.
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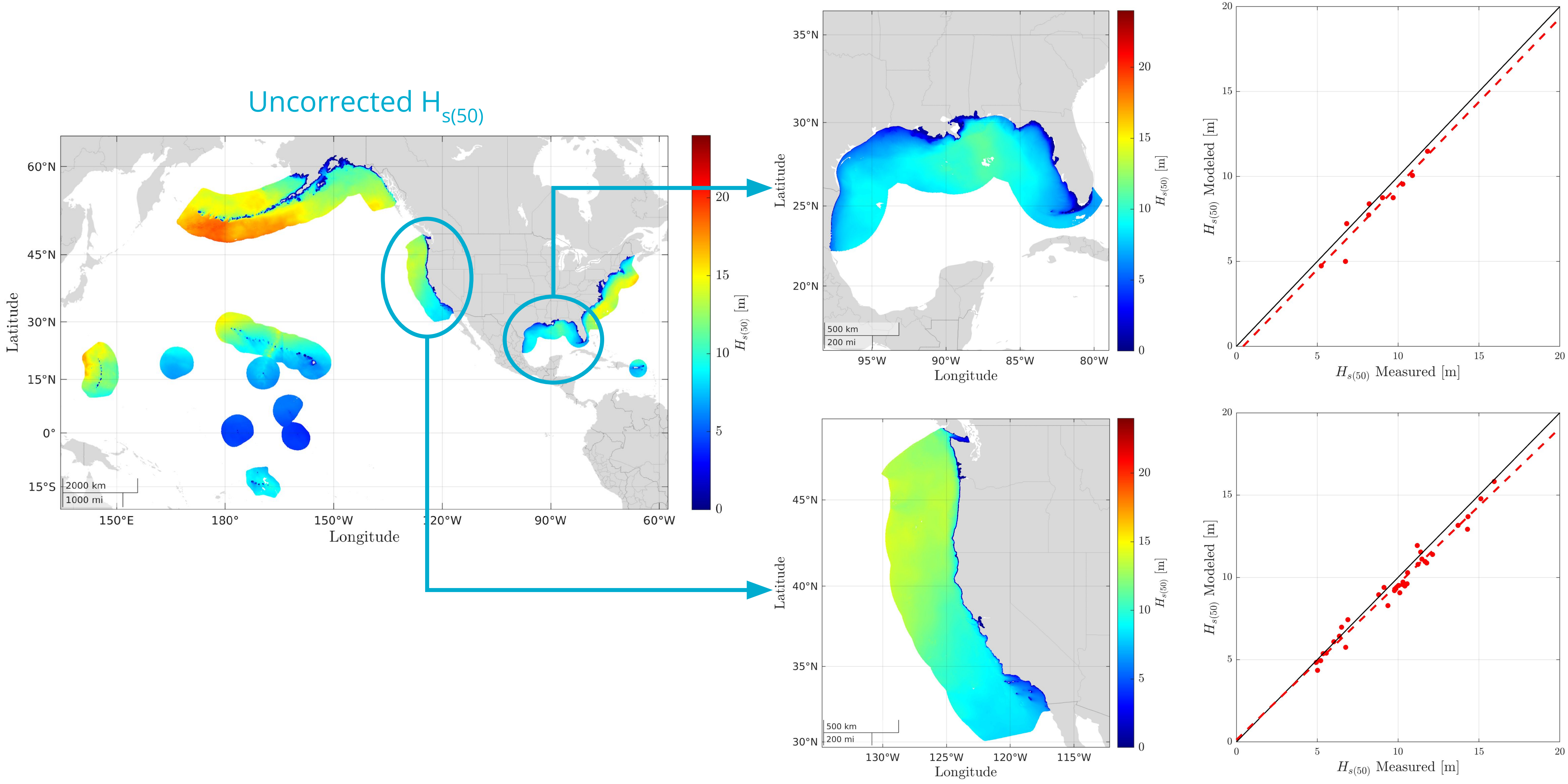
James, G., Witten, D., et al. (2023). An introduction to statistical learning, Springer Nature.
Goda, Y., (2010). Reanalysis of regular and random breaking wave statistics. *Coastal Engineering Journal*, 52, 71-106.

RESULTS | 50-YEAR RETURN PERIOD UNCORRECTED HS: US EEZ

Uncorrected $H_{s(50)}$



Gulf of Mexico

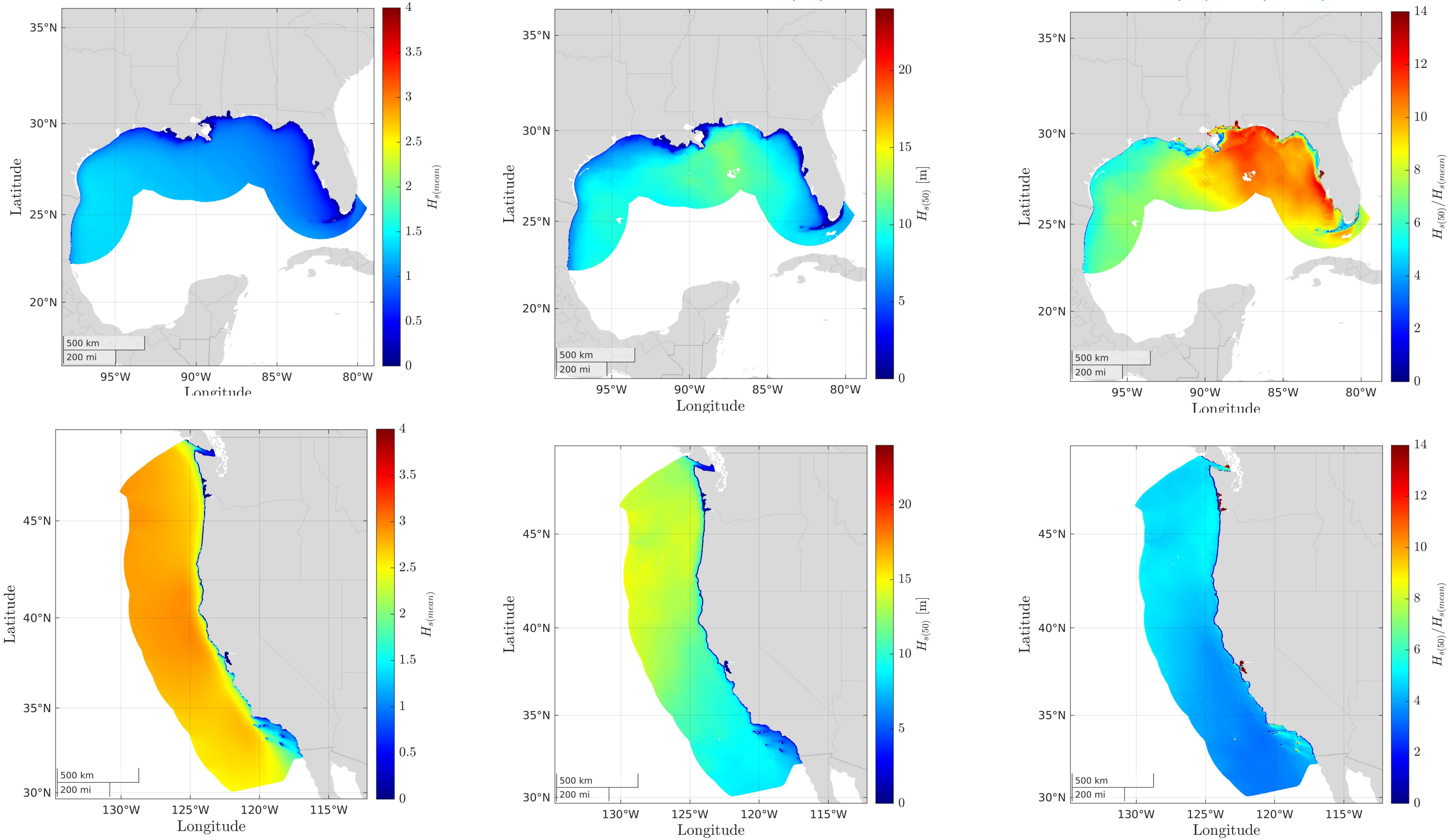
West Coast

RESULTS | MEAN HS, 50-YEAR RETURN PERIOD CORRECTED HS, & RELATIVE RISK RATIOS: GULF OF MEXICO & WEST COAST

$H_{s(mean)}$ | Corrected $H_{s(50)}$ | $H_{s(50)} / H_{s(mean)}$

Gulf of Mexico

West Coast



CONCLUSIONS & FUTURE WORK

- Estimated the uncorrected 1-, 5-, and 50-year extreme wave heights for the US EEZ following international standards
- Presented $H_{s(mean)}$, preliminary bias corrected $H_{s(50)}$, and relative risk ratios for the Gulf of Mexico and West Coast regions
- Future work:
  - Further evaluation of regional average and spatial bias correction approaches
  - Bias corrections for the US EEZ and estimation of $H_{s(n)}$ and relative risk values
  - Cataloguing and documenting $H_{s(n)}$ values and relative risk ratios following FAIR data principles for hosting on the DOE's Marine and Hydrokinetic Data Repository and MHK Atlas

MHK

https://mhkdr.openei.org/home

THANK YOU

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REFERENCES

- Ahn, S. & Neary, V. S., (2024). High-resolution atlas of extreme wave height and relative risk ratio for US coastal regions. *Ocean Engineering*, *314*, 119684.
- Coles, S., (2001). An introduction to statistical modeling of extreme values, Springer-Verlag.
- DNV-RP-C205. *Environmental conditions and environmental loads*. Det Norske Veritas, Oslo, Norway, 2014.
- Goda, Y., (2010). Reanalysis of regular and random breaking wave statistics. *Coastal Engineering Journal*, 52, 71-106.
- Holthuijsen, L.H., (2007). Waves in oceanic and coastal waters, Cambridge University Press.
- ISO, 2015. *Petroleum and Natural Gas for Offshore Structures — Part 1: Metocean Design and Operating Considerations*. Switzerland.
- James, G., Witten, D., et al. (2023). An introduction to statistical learning, Springer Nature.
- Li, J. & Heap, A. D., (2014). Spatial interpolation methods applied in the environmental sciences: A review. *Environmental Modeling & Software*, 53, 173-189.
- Neary, V. S., Coe, R. G., et al., (2018) Classification systems for wave energy resources and WEC technologies. Int. Marine Energy Journal, 1(2), 71-79.
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- Neary, V. S. & Ahn, S., (2023). Global atlas of extreme significant wave heights and relative risk ratios. *Renewable Energy*, *208*, 130-140.
- NOAA. National Data Buoy Center. https://www.ndbc.noaa.gov/.
- TS 62600 IEC. *Marine Energy – Wave, Tidal and Other Water Current Converters – Part 101: Wave Energy Resource Assessment and Characterization*. International Electrotechnical Commission, Geneva, Switzerland, 2015.
- TS 62600 IEC. *Marine Energy – Wave, Tidal and Other Water Current Converters – Part 2: Design Requirements for Marine Energy Systems*. International Electrotechnical Commission, Geneva, Switzerland, 2015.
- Wilkinson, M. D., Dumontier, M., et al. (2016). The FAIR guiding principles for scientific data management and stewardship. *Scientific Data*, 3(1), 1-9.
- Yang, Z., García-Medina, G., et al. (2023). Multi-decade high-resolution regional hindcasts for wave energy resource characterization in US coastal waters. *Renewable Energy*, *212*, 803-817.