Directional Wave Changes Induced by the Expanding Tropics

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1 Motivation

A continued expansion of the tropics, defined by the poleward extent of the Hadley Cell (HC), is expected over the coming century with global warming. The expansion and strengthening of the HC has implications for the surrounding climatic zones under a changing climate. However, the implications on wave climate are not well understood. For wave-dominated, sandy coastlines even a small change in wave direction can have significant impacts for sand transport and shoreline erosion (Adams *et al.,* 2011; Goodwin *et al*., 2016). On this basis, the correlation of directional wave power with the width and strength of the Hadley Cell circulation is a variability indicator that should be exploited for future wave climate projections.

2 Objective

Quantify the impacts of Hadley Cell variability on wave climate (directional wave power) over the past ~40 yrs.

3 Data and methods

Data: Zonal winds (*U10*, m/s), mean wave direction (Dir_m, °), and wave power (P_w, kW/m) was calculated for regular waves as $P_w = \frac{\rho g^2}{32\pi} {H_s}^2 T_p$. From ERA5 reanalysis (ECMWF, 2017). From 1979 to 2018 (hourly and 0.5° resolution).

a) Classification of the global wave climate into Wave Climate Types (WCT)

a.1) Spatial-time multivariate (monthly values of Dir_m, P_w) *K-mean* clustering technique were used to classify the wave climate.

a.2) Indicators of variability (longitude, latitude of the mass center, Lon_{CS} and Lat_{CS}; *mean wave power, P_{wCS}; average of mean direction, Dir_{mCS}; total area, A_{TCS}*) of the WCT for each region were extracted. The regions were identified as Indian Ocean, North Pacific, Tropical Pacific, South Pacific, North Atlantic, Tropical Atlantic and South Atlantic.

b) The expanding tropics

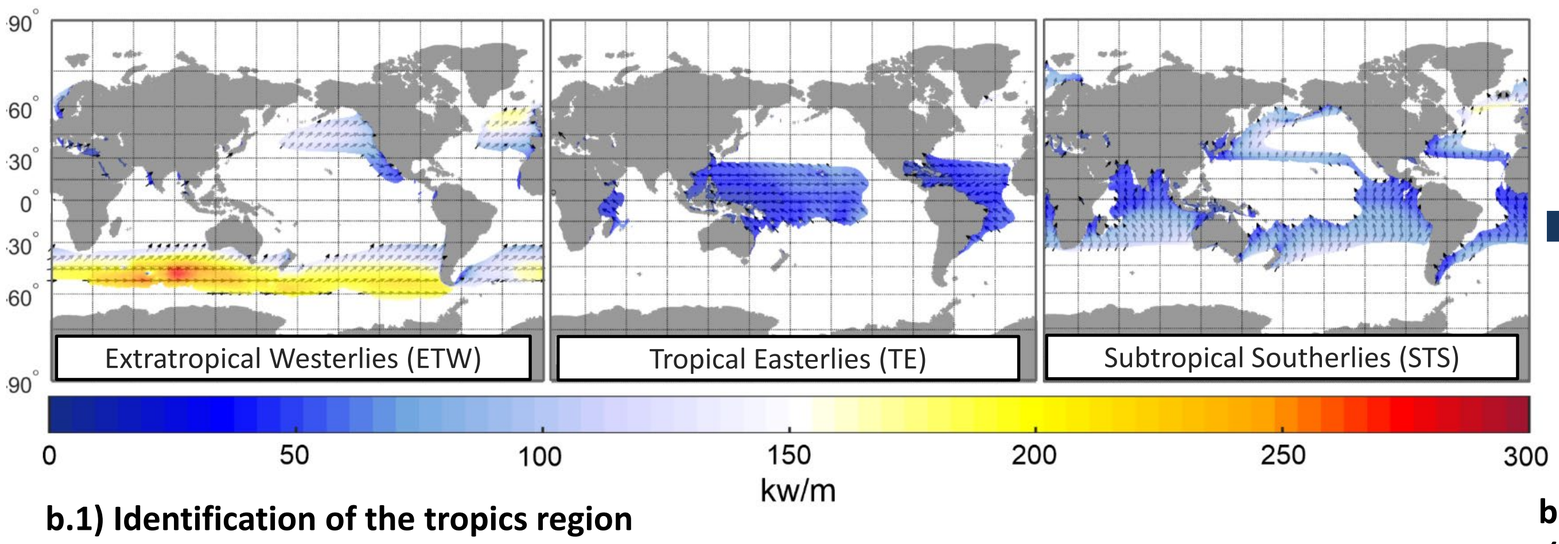
b.1) The limits of the tropics were identified as the latitude where the direction of the surface zonal wind switches sign.

b.2) Indicators of variability (longitude, latitude of the mass center,Lon_{CS}; Lat_{CS}; *Total area A_{TCS}*) of the tropics for each ocean basin(Pacific, Atlantic and Indian Ocean) were calculated.

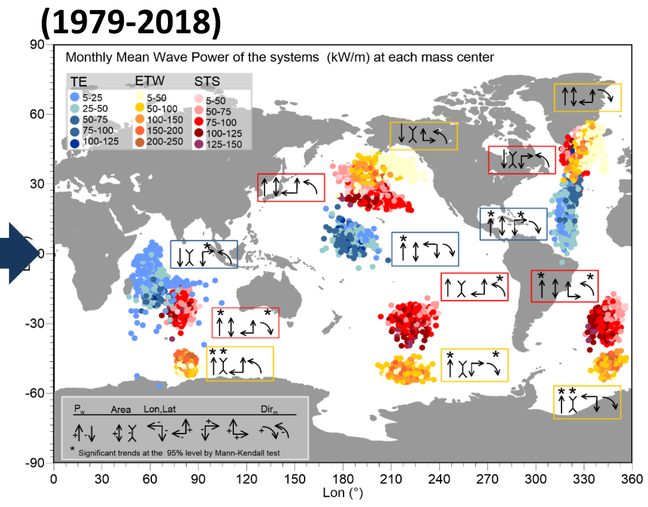
c) Impacts of expanding tropics on wave climate: Pearson's Correlation Coefficients were obtained, $R(A,B) = \frac{1}{N-1}\sum_{i=1}^{N}\overline{\left(\frac{A_i-\overline{x_A}}{s_A}\right)\left(\frac{B_i-\overline{x_B}}{s_B}\right)}$. When the probability was lower than 5% (P<0.05) the correlation coefficient was statistically significant. Time series were de-trended and de- seasonalized first.

4 Results

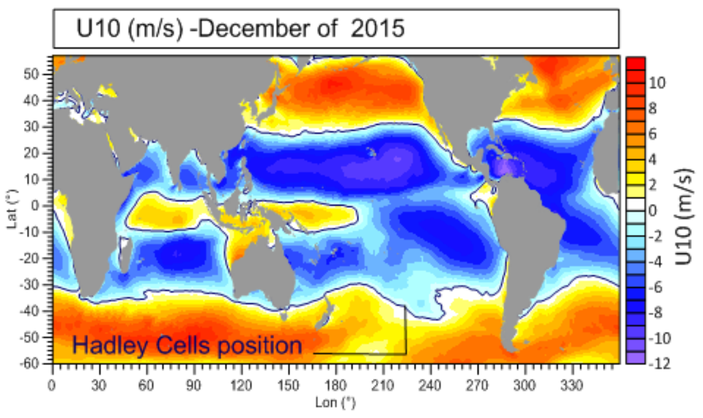
a) a.1) Wave Climate Types (WCT)



a.2) Indicators of variability of WCTs (1979-2018)



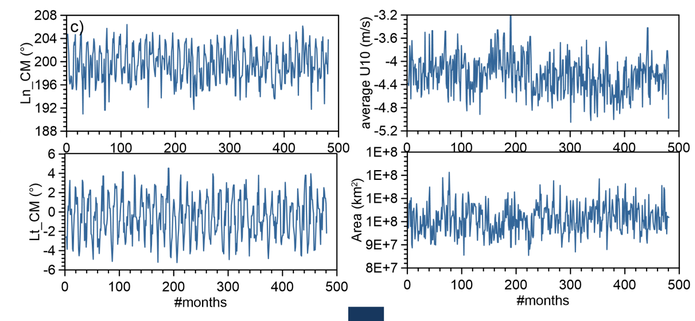
b) b.1) Identification of the tropics region



	Trend		
	Pacific	Atlantic	Indian Ocean
Area (km2/yr)	2112.93*	777.28*	-173.09
$Ln_{CS\ U10}$ (°/yr)	3.8E-4	3.5E-4*	4.5E-4
$Lt_{CS\ U10}$ (°/yr)	-3.5E-4	-2.6E-4	-2.5E-4

* Significant at 95% confidence level by Kan Medell

b.2) Indicators of variability of the tropics (1979-2018)



c) Impacts of expanding tropics on wave climate

- Wave climate types are generated by the high and low-pressure belts of the lower structure of the Hadley, Ferrel and Polar Cells with the effects of Coriolis at the surface.
- The low-pressure belt (ascending branch of the Hadley Cells) is one of the atmospheric mechanisms that generate the **Tropical Easterlies**, while the high-pressure belts of the descending branches contribute to the generation of the **Subtropical Southerlies** and **Extratropical Westerlies**.
- Wave power of each WCT was positively (negatively) correlated with the total area of the Hadley Cells in the Northern (Southern) Hemisphere.
- Wave power variability of each WCT results from changes in pressure gradients induced by the ascending and descending branches of each atmospheric cell. Variability in wave direction is due to their relative position. Variability in the strength and position of each cell is associated with the width of the Hadley Cell.

Pearson's Correlation Coefficients (R) of P_w and Total Area of HC				
Region	**WTC**	**Pacific Ocean**	**Atlantic Ocean**	**Indian Ocean**
North Hemisphere	ETW	0.19*	0.35*	-
	STS	0.18*	0.17*	-
Tropical Region	TE	0.20*	0.16*	-0.45*
Southern Hemisphere	ETW	0.09	-0.24*	-0.70*
	STS	-0.16*	-0.30*	-0.76*

Pearson's Correlation Coefficients (R) of Dir_m and Total Area of HC				
Region	**WTC**	**Pacific Ocean**	**Atlantic Ocean**	**Indian Ocean**
North Hemisphere	ETW	0.28*	-0.14*	-
	STS	0.30*	0.14*	-
Tropical Region	TE	-0.43*	-0.18*	-0.58*
Southern Hemisphere	ETW	0.43*	0.31*	0.49*
	STS	-0.28*	-0.30*	-0.35*

* Significant at 95% confidence level

5 Conclusions

- The classification of the global wave power climate into high-level directional types allows correlation of wave conditions with planetary atmospheric phenomenon as the tropics continue to expand under anthropogenic warming (Lucas et al., 2014).
- With tropical expansion, the wave fields of coastal areas affected by **Extratropical Westerlies** rotate clockwise with the exception of the North Atlantic, and those affected by **Tropical Easterlies** and **Subtropical Southerlies** in the Southern Hemisphere rotate anti-clockwise.
- This work confirms the expanding tropics should be exploited for global coastal hazards projections under a changing climate.
- Future work will be addressed in the differentiation of both Northern and Southern Hemisphere Hadley Cell as results clearly distinguish different wave power impacts.

6 References

Adams, P.N., Inman, D.L., and Lovering, J.L. (2011), Effects of climate change and wave direction on longshore sediment transport patterns in Southern California. Clim. Change, 109, 211-228.

European Centre for Medium-Range Weather Forecasts. 2017, updated monthly. *ERA5 Reanalysis*. Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory. https://doi.org/10.5065/D6X34W69. Accessed 01 Feb 2019.

Goodwin, I.D, Mortlock, T.R. and Browning, S. (2016), Tropical and extratropical-origin storm wave types and their influence on the East Australian longshore sand transport system under a changing climate. J. Geophys. Res. Oceans, 121, 4833 – 4853.

Lucas, C., Timbal, B. and Nguyen, H. (2014) 'The expanding tropics: A critical assessment of the observational and modeling studies', *Wiley Interdisciplinary Reviews: Climate Change*, 5(1), pp. 89–112. doi: 10.1002/wcc.251