TROPOCAL CYCLONE ACTIVITY SHOWN BY A NEW APPROACH TO ACCUMULATED CYCLONE ENERGY CONSIDERING TC SIZE AND ASYMMETRY

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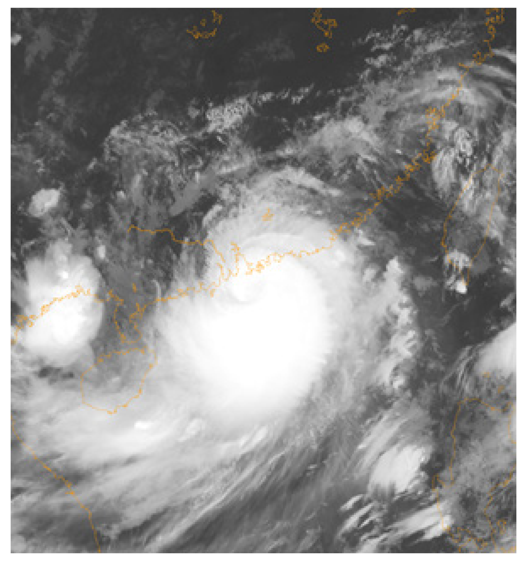
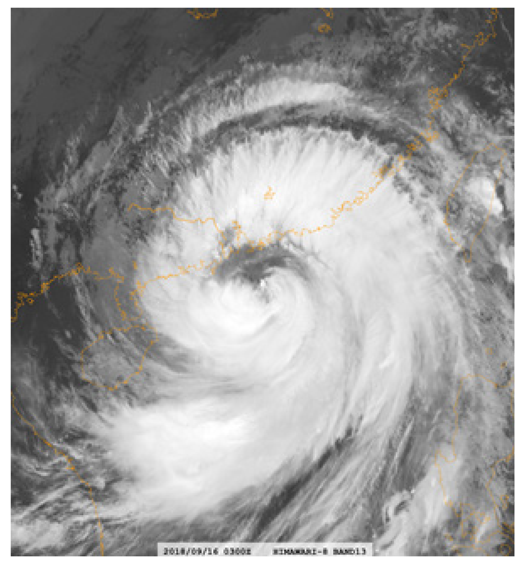
INTRODUCTION

Accumulated Cyclone Energy (ACE) has been widely used to estimate the accumulated tropical cyclone (TC) energy and TC activeness over different oceanic basins. However, ACE has its own limitation when being used as an index to infer the accumulated TC kinetic energy. The main reason is ACE solely depends on the TC maximum wind speed given by the meteorological agencies, while neglects the size and structure changes of TC. However, the accumulated kinetic energy for individual TCs varies largely regarding their sizes and structures. An example could be Hato (2017) and Mangkhut (2018). They have similar maximum wind speed but very different stucture as they were apporaching the coast of Guangdong, China (See figures below).



Hato (2017)



Mankghut (2018)

The trend estimations can be considerably shifted by using different datasets as different agencies have distinct methods for estimating the TC maximum wind speed (Song et al., 2010; Knapp and Kruk, 2010; Yu and Chiu, 2012). It is also worth noting that TCs' average sizes vary largely betwwen different basins (Chavas and Emanuel, 2010).

JTWC		JMA		HKO	
Period	ACE	Period	ACE	Period	ACE
1975-1989	279	1975-1989	220	1975-1989	224
1990-2004	305	1990-2004	264	1990-2004	226
% of Increase	9.32%	% of Increase	20.00%	% of Increase	0.89%

Additionally, Studies (e.g., Wong and Chan, 2004, Musgrave et al., 2012) show that the TC size, asymmetric structure, and intensity are closely related with each other. Hence, these links should be considered by taking TC size and structure into account when designing a metric for demonstrating TC accumulated energy and activeness.

Using wind radii data from the up-to-date global best track datasets, a new index, the structural accumulated cyclone energy (SACE), is proposed in this study to invesitigae TC activity in Western North Pacific (WNP) and North Atlantic (NA). SACE is defined as the integral of the empirical wind speed profile at each angle in the TC polar coordinate. By considering TC's size and asymmetry, SACE provides a more accurate estimate of accumulated TC energy than ACE. The primary goal of this study is to introduce a new index, named structural accumulated cyclone energy (SACE), to more accurately estimate the TC accumulated energy and activeness.

METHOD

Data Sources

In this study, the JMA best track dataset (Japan Meteorological Agency, 2020) is used to calculate the ACE and SACE over the WNP, and the extended best-track (EBT, Demuth et al., 2006) dataset is used for the NA TCs. This study focuses on the periods when wind radii data is available, which are 1977-2018 over the WNP, and 1988-2018 over the NA. In the JMA best track dataset, the 30 and 50 knot wind radii are calculated using 10-minute sustained wind speed, while the 34 and 50 knot wind radii are calculated using 1-minute sustained wind speed in the EBT. The radii unit in both datasets is nautical mile (nm).

Methodology

To resolve the empirical wind speed profile of TC, two well-known approximations, the modified Rankine vortex model and the Holland 80 models, are used here (e.g., Rankine, 1882; Hughes, 1952; Holland, 1980).

$$\begin{cases} v(r) = \left(\frac{V_{max}}{r_{max}}\right)\cdot r \ , & r \le r_{max} \\ v(r) = V_{max}\left(\frac{r}{r_{max}}\right)^{-a}, & r_{max} < r \le r_c \end{cases}$$

$$v(r) = V_{max}\cdot\sqrt{\left(\frac{r_{max}}{r}\right)^{B}\cdot\exp\left[1-\left(\frac{r_{max}}{r}\right)^{B}\right]},\quad r \le r_c$$

In order to include the impacts of TC's size and structure in the SACE, each angle in the TC polar coordinate is integrated to calculate the index. Quadrant data is used for EBT, and the below equation is used to approximate the angular variation of wind radii in the NWP:

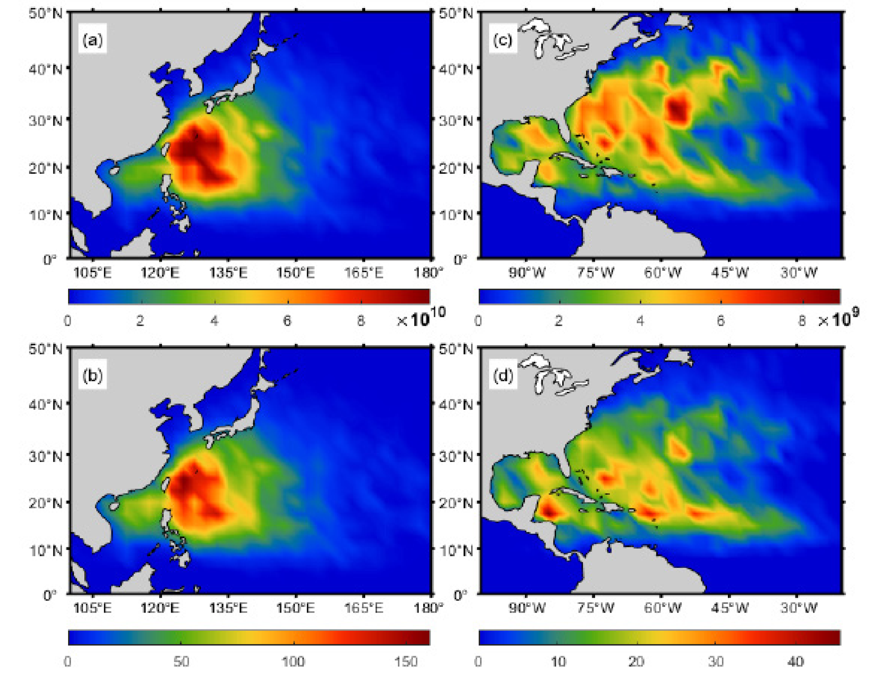
$$r(\theta) = r_t \sin\theta - \sqrt{r_t^2 \sin^2\theta + r_i \cdot r_s}$$

Lastly, the new SACE index in final form is defined as:

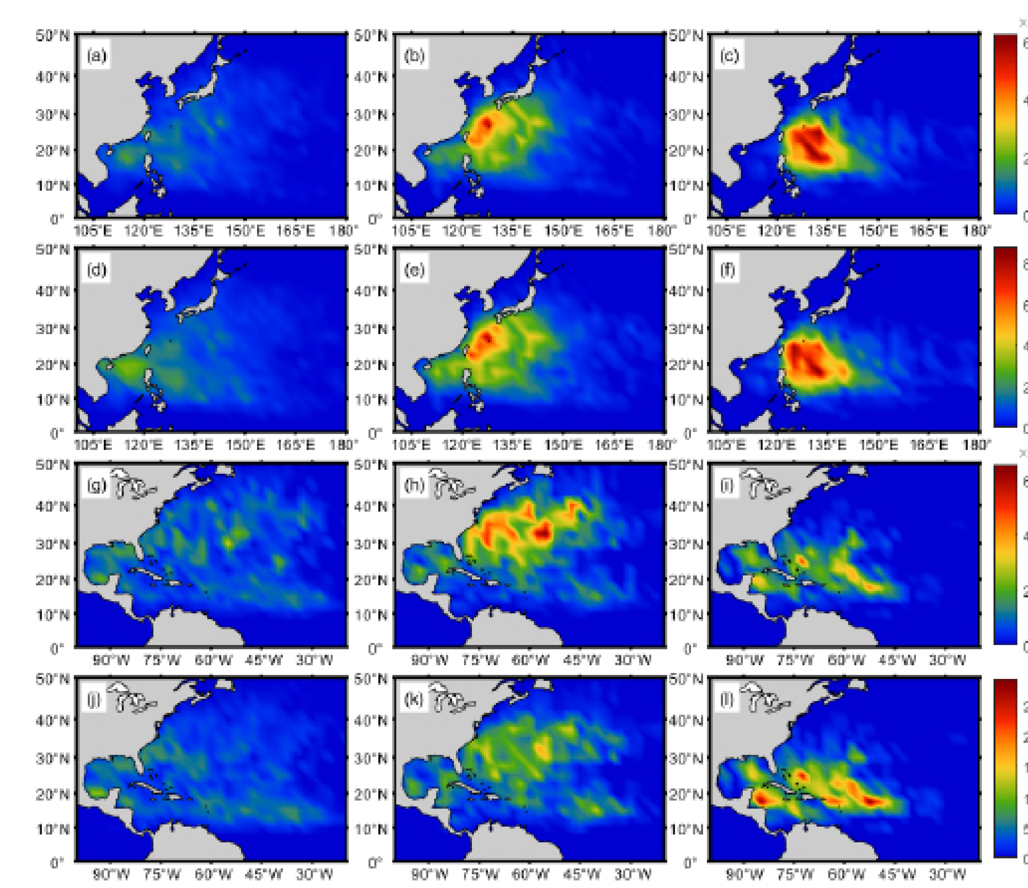
$$SACE = \int_0^{\tau}\int_0^{2\pi}\int_0^{r_c} \mathrm{v}(\mathrm{r})^2\cdot r\, dr\, d\theta\, dt$$

RESULTS AND CONCLUSION

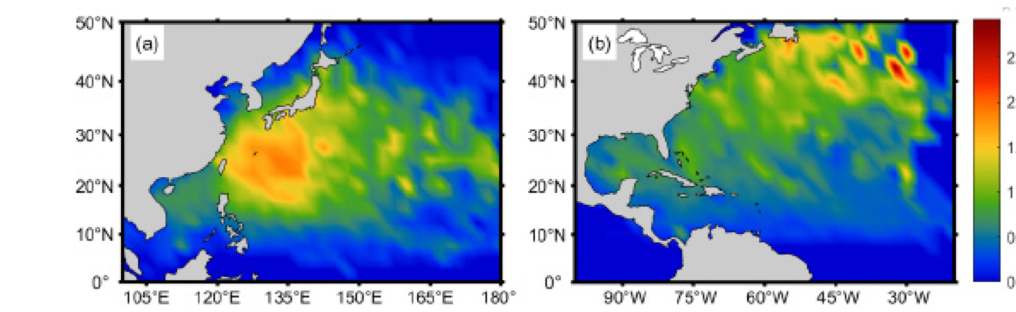
Spatial Distribution Images



(a-b) : The spatial distribution of SACE (a) and ACE (b) in WNP. (c-d): The spatial distribution of SACE (c) and ACE (d) in NA.

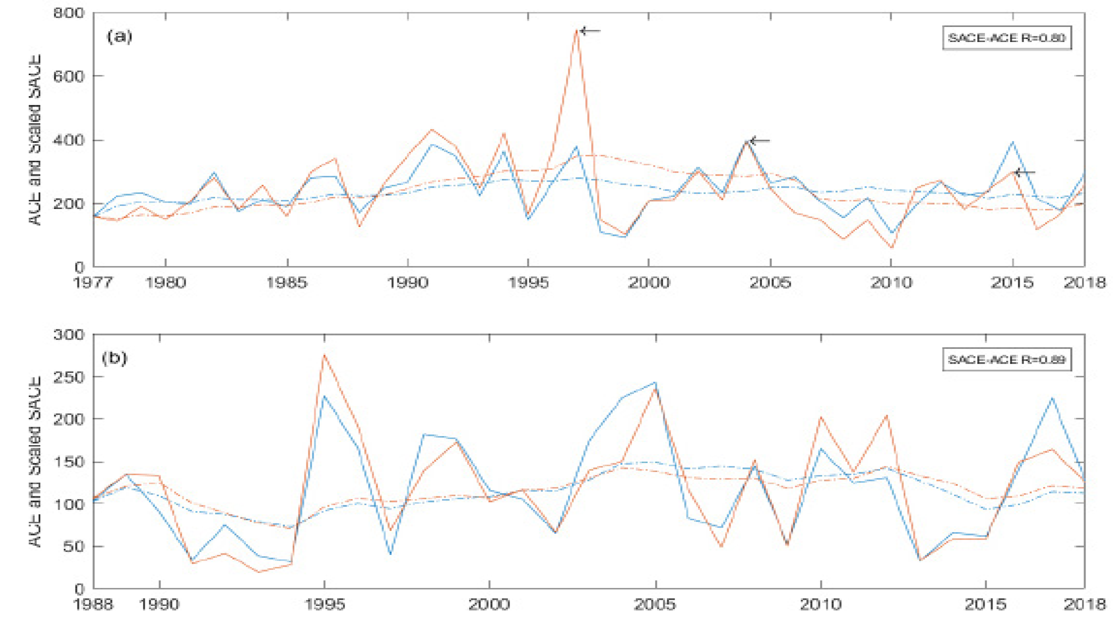


(a-c): SACE's distribution in WNP and (d-f): ACE's distribution in WNP. (g-i): SACE's distribution in NA and (j-l): ACE's distribution in NA. The right row: Tropical Cyclone (TS) category, the middle row: Cat. 1-2 TC category, and the left: Cat. 3+ T

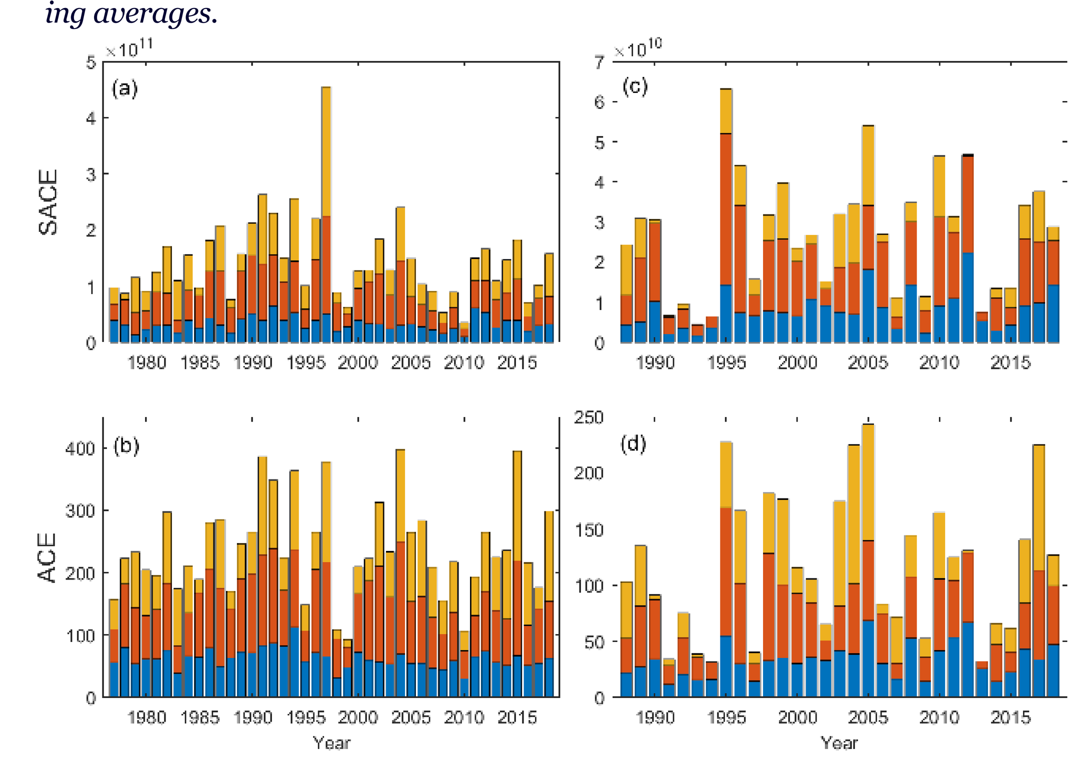


(a-b) : The spatial distribution of average TC size in WNP (a) and NA (b)

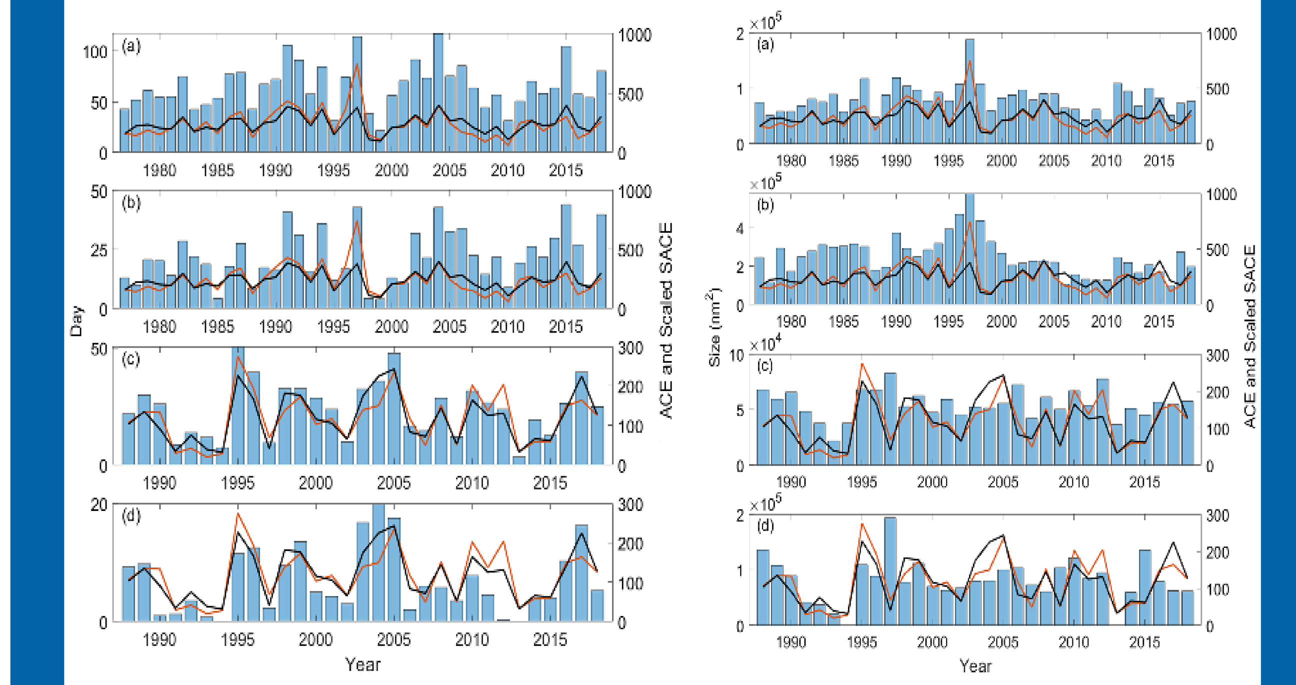
Temporal Variability Images



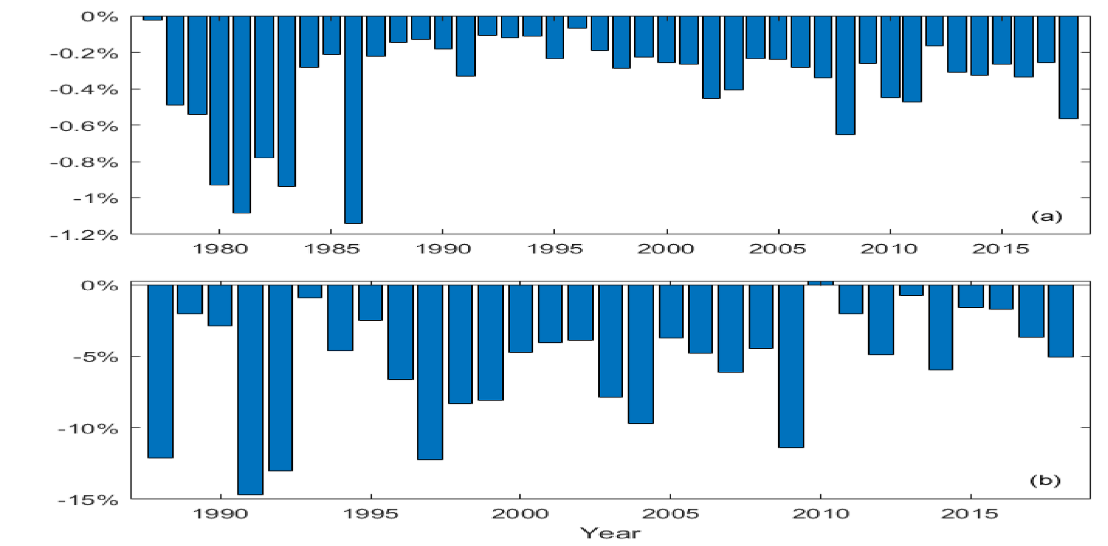
(a): ACE vs scaled SACE in WNP with their 10-year moving averages. The arrows highlight three ENSO years. (b): ACE vs scaled SACE in NA with their 10-year moving averages.



(a-b): Contribution of each TC intensity category to SACE (a) and ACE (b) in WNP. (c-d):in NA. From bottom to top in the stacked bars: TS, Cat. 1-2 TC, and Cat. 3+ TC



Left figure: (a-b) ACE and scaled SACE (right axis) with Cat. 1+ TC day (a) and Cat. 3+ TC day (b) in WNP. (c-d) in NA. Right figure: ACE and scaled SACE (right axis) with average TC size (a) and average Cat. 3+ TC size (b). (c-d) in NA.



(a-b) : Difference between asymmetric structure and symmetric sturcture using SACE method in WNP (a) and NA (b)

Conclusion

- SACE shows differences in spatial distribution compared to ACE. In WNP, the larger values shift to the open ocean and are more concentrated. In NA, larger values shift to highere latitudes and Cat. 1-2 TC is the main contributor. It could be explained by the average size distribution.
- The new index SACE shows differences in temporal variability compared to ACE. In WNP, compared to ACE, SACE has a more obvious downward trending after 1997 and 2005. In NA, The 2005 Atlantic hurricane season is not the maximum value in SACE. SACE is very well correlated with TC day parameters and TC size. ACE is poorly correlated with TC size. Additionally, three WNP SACE values in 3 ENSO years indicate complexity in the relationship between TC energy and climatalogical environment.
- Assymetry could potentially deducts the accumulated TC energy assuming size unchanged.

CITATION

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