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Determination of a Diurnal Cycle in Subtropical Cyclones Using Persistent Homology

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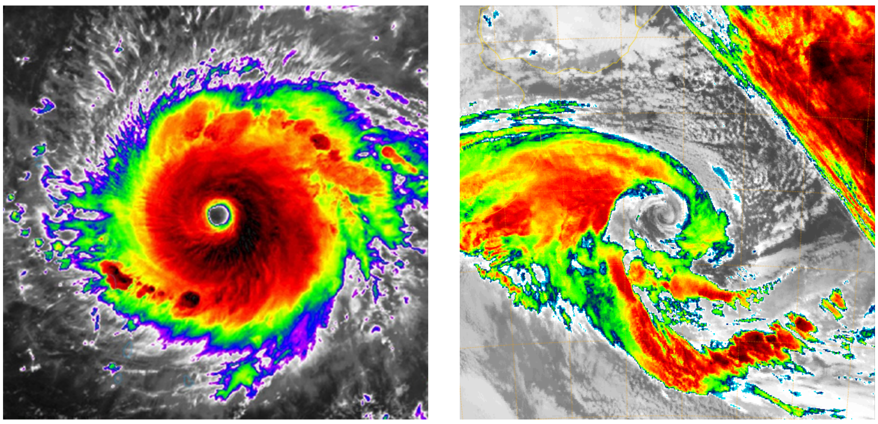
Diurnal cycles in tropical cyclones are cyclic pulses of brightness temperature that propagate radially from the center to the periphery in the brightness temperature field of the top of atmosphere [1]. While these diurnal cycles are well characterized in tropical cyclones, the same cannot be said for subtropical cyclones, whose diurnal cycle has yet to be determined. As part of this work, we utilize topological data analysis to investigate the characterization of the diurnal cycle in subtropical cyclones.

Attempts for characterization of diurnal cycles have been made using algebraic topology tools, particularly first-order homology [4]. However, the applicability of this methodology to subtropical cyclones presents a challenge because the geometric structure of the temperature field in these systems is not closed.

Figure 1 illustrates two cyclones: the first is a tropical cyclone, and the second is a subtropical cyclone. Upon examining the structure of both systems, it becomes evident that the subtropical cyclone lacks a closed structure. Consequently, the analytical algorithms commonly employed are generally ineffective for characterizing subtropical cyclones.



(a) (b)

Figure 1: (a) Typical tropical cyclones. Extracted from [3], (b) Typical subtropical cyclones. Extracted from [2]. Image generated by the authors.

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In this work, to address these problems, we employ a method to determine the radial temperature profile, zero-order homology and merge trees to characterize the cycles. The radial temperature profile is obtained for each time instant, t, as an integral function of the radius, $f(r)$, of the temperature field on a circle of radius, r, divided by the length of the circumference, p, as follows:

$$f(r) = \frac{1}{p} \oint T_{bb}(r)\, dp, \tag{1}$$

where T_{bb} is the brightness temperature field.

This function captures the behavior of the temperature field around a point referred to as the "eye". Consequently, discontinuities in the geometric structure of the field are ignored. This allows us to characterize the global temperature behavior at a certain distance, r, from the cyclone eye. This enables the radial mean temperature of the cyclone to be comparable in different instants. After calculating the temperature-profile difference, the resulting field is thresholded and a distance transformation is applied to quantify the separation between structures. Sub-level set filtering and merge trees determine the lifetimes of the dominant connected components (H_0). A time series of maximum persistence is constructed to capture the pulsating temperature field. Fourier transform is employed to quantify the cycle frequency.

Numerical experiments in subtropical cyclones indicate that the proposed methodology is consistent with what would be expected from a diurnal cycle, capturing quantitatively the underlying phenomenology, helping identify the existence of a diurnal cycle in subtropical cyclones.

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