

CycloPhaser: A Python Package for Detecting Extratropical Cyclone Life Cycles

Danilo Couto de Souza¹, Pedro Leite da Silva Dias¹, Carolina Barnez Gramscianinov², and Ricardo de Camargo¹

¹ Institute of Astronomy, Geophysics and Atmospheric Sciences of the São Paulo University, Rua do Matão, 226, Cidade Universitária, 05508-090, São Paulo, Brazil ² Institute for Coastal Systems – Analysis and Modeling, Helmholtz-Zentrum Hereon, Geesthacht, Germany

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Summary

CycloPhaser is a Python package designed to detect and analyze extratropical cyclone life cycles from central relative vorticity data. It enables researchers in meteorology and atmospheric sciences to automatically identify key stages of cyclone development, such as intensification, decay, and mature phases, using the vorticity series and its derivatives. By leveraging vorticity data, CycloPhaser helps scientists study cyclones across various regions and timeframes, contributing to improved understanding of cyclone energetics and behavior.

Statement of Need

Extratropical cyclones are key features of the climate system. In South America, they are especially important due to the presence of cyclogenesis hotspots in southeast Brazil (SE-BR), the La Plata River basin (LA-PLATA), and southeastern Argentina (ARG) (C. Gramscianinov et al., 2019). These cyclones can cause extreme precipitation, intense winds, high sea waves, and landslides, significantly impacting communities (Cardoso et al., 2022; C. B. Gramscianinov et al., 2023; D. C. de Souza et al., 2024; D. de Souza & Silva, 2021). Understanding their temporal and spatial development and evolution is crucial for improving forecasts, ultimately aiding in the adoption of mitigation and adaptation strategies.

Accurately identifying the regions where cyclones are positioned throughout their distinct life cycle stages remains a significant challenge in atmospheric sciences. Seminal works by @bjerknes1922life, @shapiro1990fronts, and @neiman1993life described extratropical cyclone life cycles in terms of structural changes and large-scale dynamics. However, these classifications were based on manual analysis of satellite imagery and synoptic charts, limiting their applicability to large datasets with multiple cyclone cases. Recent research has sought to objectively define cyclone life cycle stages using techniques such as normalizing the life cycle duration (Rudeva & Gulev, 2007; Schemm et al., 2018) or bisecting the cycle into “intensification” and “decay” phases by focusing on periods before and after peak vorticity or the lowest central pressure (Azad & Sorteberg, 2014; Booth et al., 2018; Dacre & Gray, 2009; Michaelis et al., 2017; ?). While these approaches support the study of cyclone intensification and decay, they tend to overlook critical phases such as the incipient stage — where environmental dynamics are still adapting to the developing low-level disturbance and surface isobars are not yet fully closed. Additionally, they treat the mature phase as a single time step, failing to account for the possibility that it may encompass multiple time steps during which the cyclone exhibits homogeneous features.

The pioneering work by @couto2024new was the first to offer a comprehensive analysis of extratropical cyclone life cycles, dissecting systems into distinct life cycle phases and enabling

the detection of multiple configurations across different systems. This study presents the Python package that facilitated such work. The method allows for an automated classification of cyclone life cycle stages, enabling the efficient processing of large datasets with minimal computational cost. This tool opens new avenues for research, such as analyzing cyclone life cycle behavior in climate change projections, enabling comparisons with present-day climates, and providing insights into how cyclone life cycles may evolve in response to climate variability. Additionally, it offers potential for assisting model validation by comparing the spatial positioning of life cycle phases across different models and reanalysis datasets. The package is both flexible and fully customizable, making it adaptable to a wide range of datasets and research needs.

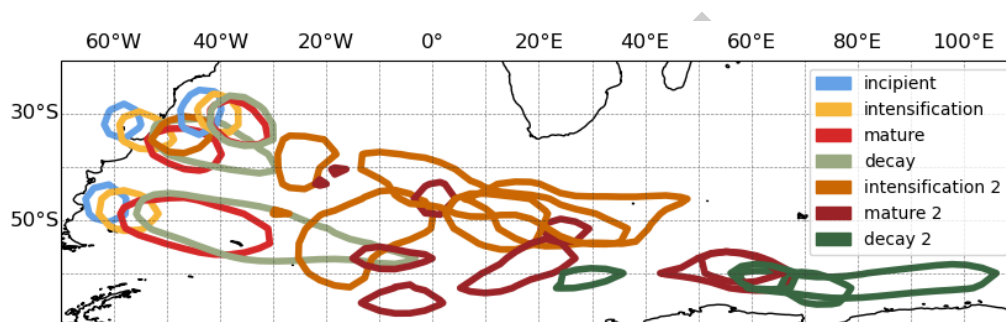


Figure 1: Yearly cyclone track densities normalized for the three cyclogenesis regions along the South American coast (SE-BR, LA-PLATA, and ARG). Contours represent normalized track densities above 0.8, plotted individually for each region. Details regarding the genesis regions, tracking procedures, and analysis techniques are discussed in @couto2024new.

Features

The program includes optional pre-processing steps, such as applying a Lanczos filter to remove noise from the series and a Savitzky-Golay filter for smoothing, ensuring sinusoidal patterns in the data for phase detection. Key cyclone phases — intensification, decay, and mature — are identified through peaks and valleys in the vorticity time series. The intensification phase spans from a vorticity peak to the next valley, while the decay phase covers the opposite. The mature phase is defined as the period between a vorticity valley and neighboring derivative peaks. The pre-processing steps, as well as peaks and valleys detection in the vorticity series, are computed using Scipy's package (Virtanen et al., 2020).

Thresholds for phase detection were rigorously calibrated using a representative set of cyclone tracks, ensuring accurate phase identification while filtering out noise. CycloPhaser also includes a residual phase to account for tracking anomalies, such as post-decay re-intensification without returning to maturity. A post-processing step further refines the phase boundaries by correcting gaps and isolating single time-step phases. Finally, the incipient stage is detected by missing labels in the series or by selecting the initial time steps. More details are discussed in @couto2024new.

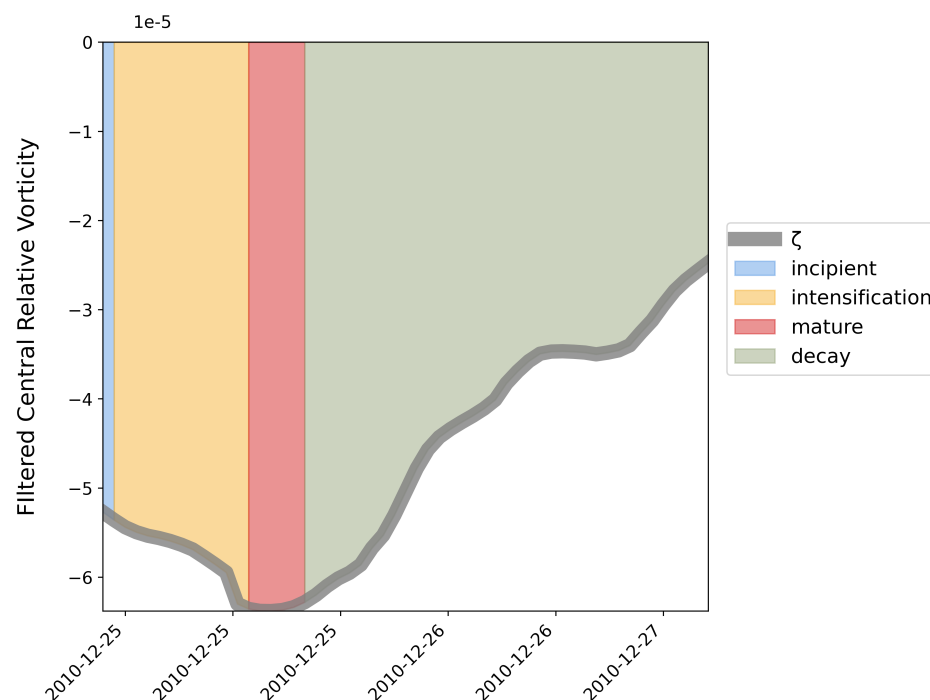


Figure 2: Representative example of a cyclone life cycle exhibiting an incipient-intensification-mature-decay configuration.

Although the package was initially devised for detecting life cycle phases using relative vorticity, it can be applied to any time series used as a proxy for cyclone detection, such as sea level pressure and geopotential height. Also, the program was designed for use in the Southern Hemisphere, but it can be applied to Northern Hemisphere vorticity series by multiplying by minus one.

References

- Azad, R., & Sorteberg, A. (2014). The vorticity budgets of north atlantic winter extratropical cyclone life cycles in MERRA reanalysis. Part i: Development phase. *Journal of the Atmospheric Sciences*, 71(9), 3109–3128. <https://doi.org/10.1175/jas-d-13-0267.1>
- Booth, J. F., Naud, C. M., & Jeyaratnam, J. (2018). Extratropical cyclone precipitation life cycles: A satellite-based analysis. *Geophysical Research Letters*, 45(16), 8647–8654. <https://doi.org/10.1029/2018gl078977>
- Cardoso, A. A., Rocha, R. P. da, & Crespo, N. M. (2022). Synoptic climatology of subtropical cyclone impacts on near-surface winds over the south atlantic basin. *Earth and Space Science*, 9(11), e2022EA002482. <https://doi.org/10.1029/2022ea002482>
- Dacre, H. F., & Gray, S. L. (2009). The spatial distribution and evolution characteristics of north atlantic cyclones. *Monthly Weather Review*, 137(1), 99–115. <https://doi.org/10.1175/2008mwr2491.1>
- Gramscianinov, C. B., Camargo, R. de, Campos, R. M., Guedes Soares, C., & Silva Dias, P. L. da. (2023). Impact of extratropical cyclone intensity and speed on the extreme wave trends in the atlantic ocean. *Climate Dynamics*, 60(5-6), 1447–1466. <https://doi.org/10.21203/rs.3.rs-995499/v1>
- Gramscianinov, C., Hodges, K., & Camargo, R. de. (2019). The properties and genesis

- 90 environments of south atlantic cyclones. *Climate Dynamics*, 53, 4115–4140. <https://doi.org/10.1007/s00382-019-04778-1>
- 91
- 92 Michaelis, A. C., Willison, J., Lackmann, G. M., & Robinson, W. A. (2017). Changes
93 in winter north atlantic extratropical cyclones in high-resolution regional pseudo-global
94 warming simulations. *Journal of Climate*, 30(17), 6905–6925. <https://doi.org/10.1175/jcli-d-16-0697.1>
- 95
- 96 Rudeva, I., & Gulev, S. K. (2007). Climatology of cyclone size characteristics and their
97 changes during the cyclone life cycle. *Monthly Weather Review*, 135(7), 2568–2587.
98 <https://doi.org/10.1175/mwr3420.1>
- 99 Schemm, S., Sprenger, M., & Wernli, H. (2018). When during their life cycle are extratropical
100 cyclones attended by fronts? *Bulletin of the American Meteorological Society*, 99(1),
101 149–165. <https://doi.org/10.1175/bams-d-16-0261.1>
- 102 Souza, D. C. de, Crespo, N. M., Silva, D. V. da, Harada, L. M., Godoy, R. M. P. de,
103 Domingues, L. M., Luiz, R., Bortolozo, C. A., Metodiev, D., Andrade, M. R. M. de,
104 & others. (2024). Extreme rainfall and landslides as a response to human-induced
105 climate change: A case study at baixada santista, brazil, 2020. *Natural Hazards*, 1–26.
106 <https://doi.org/10.1007/s11069-024-06621-1>
- 107 Souza, D. de, & Silva, R. R. da. (2021). Ocean-land atmosphere model (OLAM) performance
108 for major extreme meteorological events near the coastal region of southern brazil. *Climate*
109 *Research*, 84, 1–21. <https://doi.org/10.3354/cr01651>
- 110 Virtanen, P., Gommers, R., Oliphant, T. E., Haberland, M., Reddy, T., Cournapeau, D.,
111 Burovski, E., Peterson, P., Weckesser, W., Bright, J., & others. (2020). SciPy 1.0:
112 Fundamental algorithms for scientific computing in python. *Nature Methods*, 17(3),
113 261–272. <https://doi.org/https://doi.org/10.1038/s41592-019-0686-2>