# Trends in Storminess Over the West Antarctic Peninsula: A Multi-Method Analysis of ERA5 Reanalysis Data (1979-2021)

Evan Quinter[1*], Mary Stack[2*], Dr. Kevin Grise[2], Dr. Scott Doney[2], Carlos Moffat[1]
[*] Co-first authors
[1] University of Delaware, [2] University of Virginia

**Key Words**
Storms, Extreme Weather, West Antarctic Peninsula, Wavelet Analysis, Storm Tracking

**Introduction**

The West Antarctic Peninsula (WAP) is among the most rapidly warming regions on Earth, with significant implications for the ocean, cryosphere, and ecosystems. Warming ocean and atmospheric temperatures have led to widespread glacial melt and ecosystem restructuring. While previous studies have focused on oceanographic and ecological signals, the impacts and long-term changes of extreme weather along the WAP remain poorly understood. Storms can influence sea-ice dynamics, air-sea exchange, ocean stratification, and coastal terrestrial habitats, making it essential to understand how storm characteristics are evolving in this vulnerable region.

**Objective**

This study investigates long-term trends in synoptic storm events over the WAP from 1979 to 2021 using two complementary approaches: Eulerian wavelet-based analysis and Lagrangian storm tracking. By comparing these methods, we aim to provide a robust assessment of how storm characteristics have changed over the past four decades and what these changes may imply for the region's future.

**Methods**

We analyzed ERA5 reanalysis output of 6-hourly wind speeds over a 43-year period (1979 - 2021). Storm events were quantified using two distinct methods. Eulerian wavelet analysis was applied to ERA5 wind speed data, with scaled wavelet power computed within two frequency bands: mesoscale (12 - 48 hour) and synoptic-scale (2 - 7 day). The Eulerian approach identified storm events as concurrent positive anomalies in either wavelet frequency band and wind speeds, indicating both high wind speed and high band-passed variance. The Lagrangian method detected discrete storm events using the Hodges storm-tracking algorithm (Hodges, 1994, 1995, 1999) with filtering criteria from Grise et al. (2013, 2014). Storms were identified based on thresholds for minimum vorticity, lifespan, track length, and peak vorticity to robustly identify well-defined storm events. Storms were analyzed within a defined area of interest (AOI) centered on the Palmer Long-Term Ecological Research (LTER) region, as well as within an extended buffer zone (AOI + 200 km) that encompasses the AOI and adjacent areas potentially influencing local conditions. Trends were assessed independently for the AOI and the full buffer region inclusive of the AOI.

**Results**

We found good agreement between the two methods, with similar number of storm days and strong correlation between the two approaches on the annual and seasonal scales. We also analyzed individual storms as case studies for the agreeability of the methods (Figure 1).

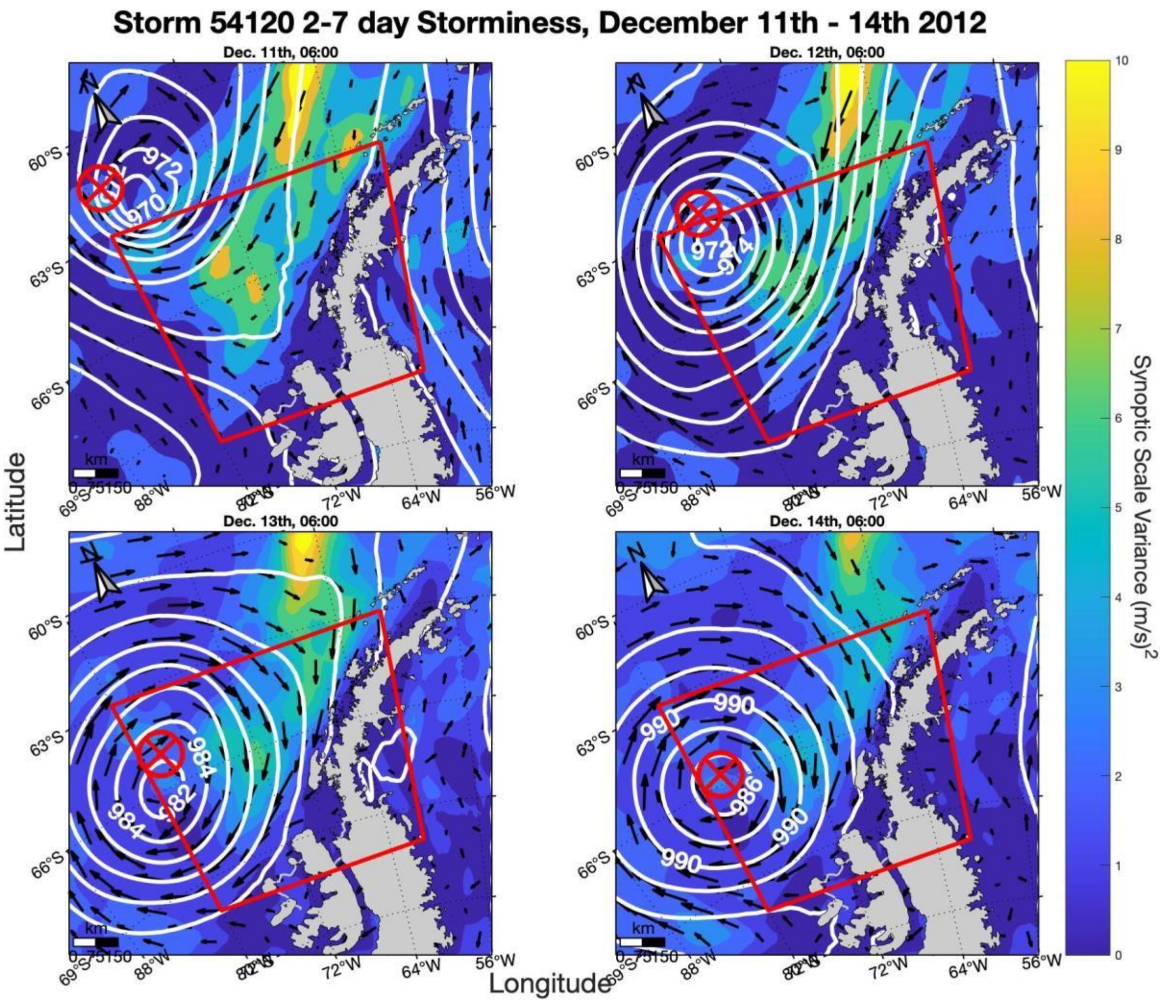


*Figure 1.* The four panels depict a storm identified as "Storm 54120" as it transits across the West Antarctic Peninsula from December 11th - 14th, 2021. The Lagrangian method depicts the storm center (red circle with an X), as well as the AOI used for trend analysis (red box). The Eulerian method plots the synoptic-scale wind-speed variance (heat map), along with the pressure fields (white contour lines) and wind direction (black arrows).

The number of annual storm days increased for the mesoscale Eulerian storms (slope = 0.216 days/year, $R^2$=0.089, $p$ = 0.049), while the synoptic-scale Eulerian storms and Lagrangian storm tracks showed no significant trends.

Seasonally, the summer storm days increased over the past 43 years in both the Eulerian synoptic-scale method (slope = 0.109 days/year, $R^2$= 0.090, $p$ = 0.048) and Lagrangian extended buffer zone (slope = 0.238 days/year, $R^2$= 0.091, $p$ = 0.049). Fall also showed a significant increase in storm days for the Lagrangian buffer zone (slope = 0.216 days/year, $R^2$= 0.104, $p$ = 0.035).

The Lagrangian method showed a significant decrease in winter storm days for the buffer zone (-0.271 days/year, $R^2$= 115, $p$ = 0.026) and in winter storm frequency for both the AOI (slope = -0.096 storms/year, $R^2$= 0.092, $p$ = 0.049) and the buffer zone (slope = -0.141 storms/year, $R^2$= 0.094, $p$ = 0.046). In contrast, Lagrangian summer storm frequency increased in the buffer zone (slope = 0.165 storms/year, $R^2$= 0.145, $p$ = 0.012).

The Eulerian method showed increased power in the fall (slope = 0.011 $(m/s)^2$/year, $R^2$= 0.0997, $p$ = 0.036). The mean power of Eulerian storm days also showed an increase in the fall (slope = 0.0165 $(m/s)^2$/year, $R^2$= 0.104, $p$ = 0.033).

**Discussion**

The results indicate a seasonal shift in storm activity over the West Antarctic Peninsula, with increasing storm days and frequency during the summer and fall. These changes may reflect broader atmospheric circulation shifts linked to regional climate warming, with summer circulation changes particularly influenced by Antarctic ozone depletion which alters stratospheric temperatures and drives a poleward shift in the frequency of cyclones.

The observed increase in summer and fall storm frequency and fall storm power could have significant implications for the WAP environment. Stronger and more frequent storms may enhance upper-ocean mixing, influence sea ice timing, and increase precipitation, all of which can alter marine and terrestrial ecosystems. The decline in winter storm frequency, particularly in the Lagrangian analysis, may suggest a weakening of storm tracks during the cold season.

**Conclusion**

This study provides a comprehensive assessment of synoptic storm events trends over the West Antarctic Peninsula using two complementary analytical methods. The findings reveal a clear increase in storm activity during the summer and fall seasons. Increases in storm frequency and severity could affect the entire WAP environment: higher winds may reduce sea ice coverage; more rainfall and surface mixing may alter upper oceanographic layers; and stronger storms could negatively impact seabird colonies on land. The integration of Eulerian and Lagrangian approaches offers a comprehensive understanding of how WAP storms have changed over time and for monitoring atmospheric extremes in polar regions. As climate change continues to reshape the Southern Hemisphere's storm systems, understanding these evolving patterns will be critical for anticipating future environmental impacts in the Antarctic.

**References**

Grise KM, Son S-W, Gyakum JR (2013) Intraseasonal and Interannual Variability in North American Storm Tracks and Its Relationship to Equatorial Pacific Variability. *Monthly Weather Review* 141:3610–3625

Grise KM, Son S-W, Correa GJP, Polvani LM (2014) The response of extratropical cyclones in the Southern Hemisphere to stratospheric ozone depletion in the 20th century. *Atmospheric Science Letters* 15:29–36. https://doi.org/10.1002/asl2.458

Goodell E, Stammerjohn S, Meredith M, et al. (2024) Expanding Understanding of the Western Antarctic Peninsula Sea-Ice Environment Through Local and Regional Observations at Palmer Station *JGR Oceans* 129:11. https://doi.org/10.1029/2023JC020453

Hodges KI (1994) A general method for tracking analysis and its application to meteorological data. *Monthly Weather Review* 122:2573–2586

Hodges KI (1995) Feature tracking on the unit sphere. *Monthly Weather Review* 123:3458–3465

Hodges KI (1999) Adaptive constraints for feature tracking. *Monthly Weather Review* 127:1362–1373

Schofield O, Cimino M, Doney S, et al. (2024) Antarctic pelagic ecosystems on a warming planet. *Trends in Ecology & Evolution* 39:1141-1153. https://doi.org/10.1016/j.tree.2024.08.007