Changing Behaviors of Tropical Cyclones in a Warming World: Insight into Australia

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Track

Research Motivation :

- Tropical cyclones (TCs) are among the most destructive natural hazards. After losing their tropical characteristics, many evolve into post-tropical cyclones (PTCs) that can persist inland and deliver damaging impact.
- With climate warming, risks extend further into the post-tropical stage, yet PTC behavior remains poorly understood.
- **Our goal** is to develop a physical–machine learning hybrid algorithm to track TC–PTCs, monitor real-time impacts, and assess their future changes.

Results

Historical tracks:

- ✓ A physical-based semi-automatic algorithm has been developed by Deng (2024, 2025a) to track and identify PTC beyond the existing best track dataset (BT) for Australia based on IBTrACS and BoM best-track datasets, Infrared satellite imagery from GridSat-B1 and ERA5 reanalysis.
- ✓ Based on the algorithm, 69.2% of post-landfall TCs can be further tracked beyond the available BT while moving over land. Half of the post-landfall TCs move more than 1000–1500 km inland from the coast, but only one third (34.8%) of these are captured in the BT archives (Fig.1).

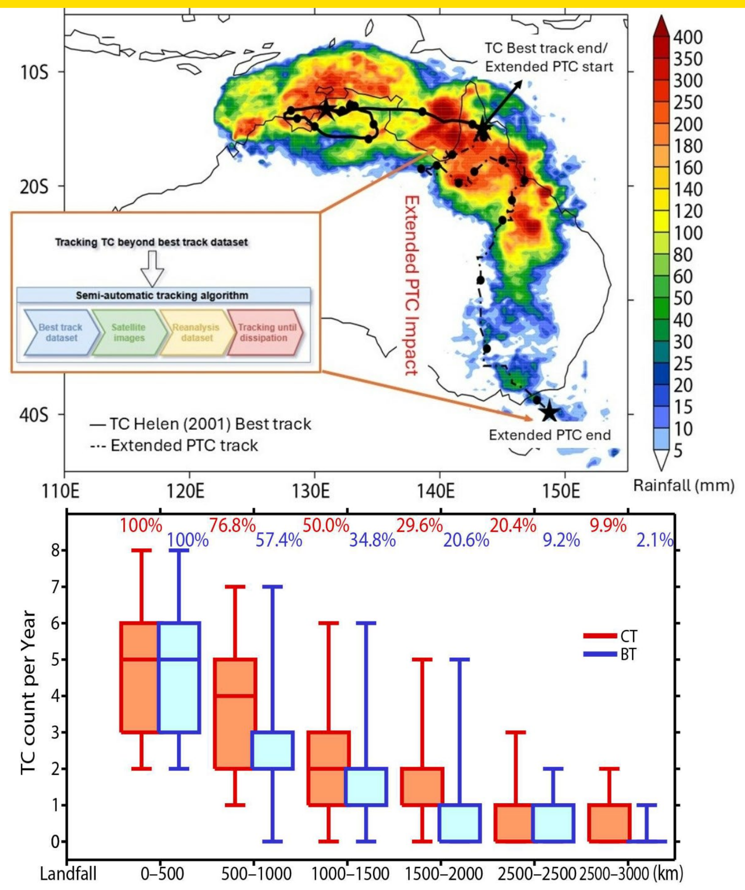

Figure 1: (upper) Track of TC Helen (2007) (black solid line) and its PTC (black dashed line), along with observed rainfall (shading, unit: mm), and (bottom) TC counts per year as a function of distance (km) from landfall (Deng 2025a)

Future tracks:

- ✓ Large-ensemble high-resolution simulations (d4PDF) under four warming scenarios show a robust poleward shift of TC genesis, driven by weakening Hadley circulation (Fig. 2).
- ✓ This shift, evident in Australia, is suggested to significantly affect overall TC–PTC overland behaviors.

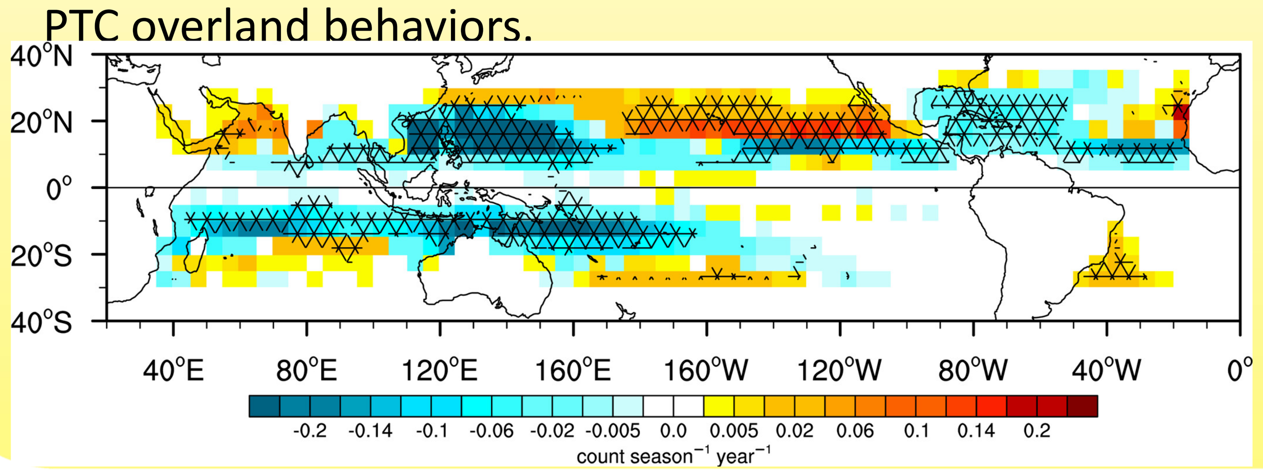

Figure 2: The contrast of TC genesis frequency between W4K and HST during JASO in Northern Hemisphere and JFMA in Southern Hemisphere based on the 100-member d4PDF ensemble for 32 years. The cross-hatched region denotes at the 95% confidence level (Cao et al. 2024)

Ongoing Study:

- ➢ Building on the developed TC/PTC dataset, we are developing a more efficient machine-learning PTC tracking algorithm for global TC extension to capture full cyclone lifecycles.
- ➢ Investigating TC changes under warming climates and identify emerging vulnerable regions, building on insights from out previous findings.

Precipitation

Research Motivation :

- TC winds typically weaken rapidly following landfall, but the rains can persist well inlands—as seen with TC Oswald (2013) over eastern Australia (Deng et al. 2021, 2025b).
- Evidence has shown TCs, both globally and regionally, have changed or are expected to change in the current or future warming climate. However, the impacts on overland TC/PTC rainfall remain unclear remains uncertain.
- **Our goal** is to quantify how overland TC/PTC rainfall patterns are shifting and identify regions increasingly at risk in Australia.

Results

Historical TC/PTC Rainfall:

- ✓ Although BT TC impact frequency changed little between 1990–2005 and 2005–2020, including PTC tracks shows that TC/PTC frequency has increased across most inland and mid–high-latitude regions, such as southern and southeastern Australia, previously rarely affected by TCs
- ✓ Combined with rainfall observations, we find that inland and poleward penetration of post-landfall TCs—including their rainfall—has already increased from 1990–2020 and is underestimated in widely used historical TC BT datasets (Fig. 3).

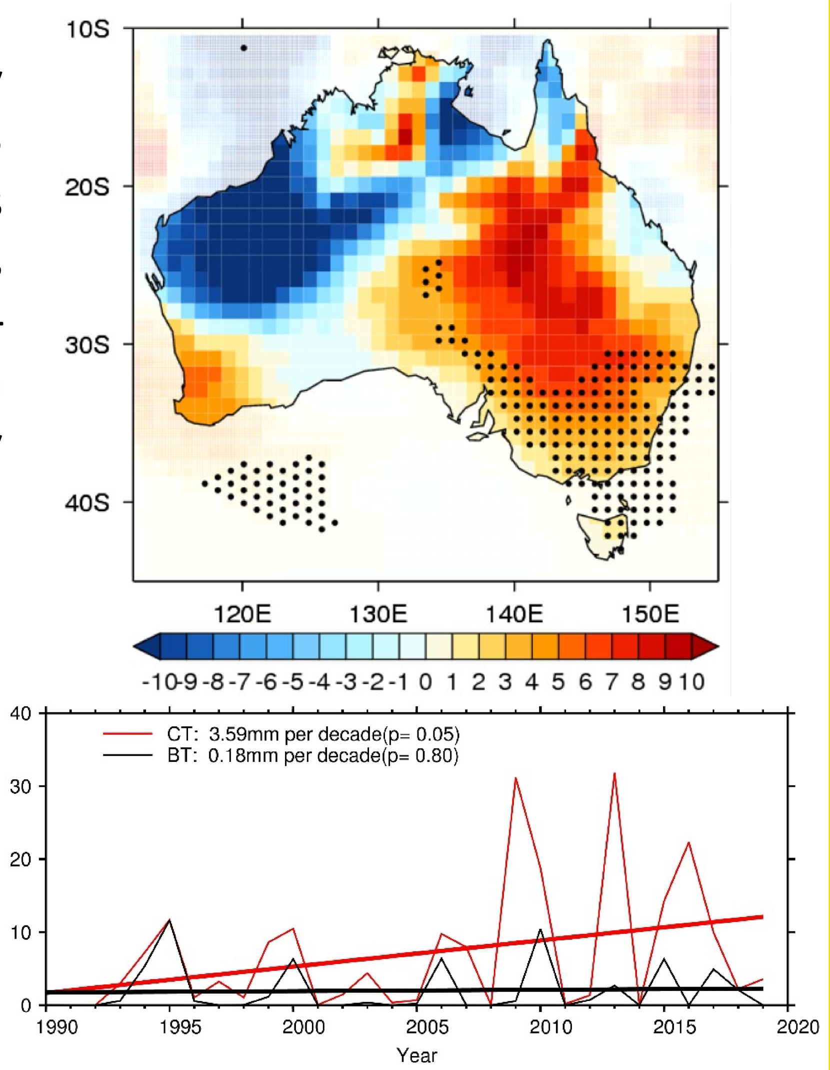

Figure 3: (Upper) The difference of TC/PTC impact frequency between 2005-2020 and 1990-2005. The dotted region denotes at 90% confidence level, and (Bottom) time series of TC/PTC-related annual rainfall over the south and southeast of inland Australia within 125°–145°E, south of 25°S (Deng 2024).

Ongoing study:

- ➢ Determining whether poleward and inland shifts in TC/PTC rainfall are driven by changes in TC internal processes or by environmental factors, or both.
- ➢ Studying future TC/PTC rainfall impacts in Australia—one of the highest TC-rainfall regions near the coast and the driest continent inland.

Collaborators and Research Group:

Our team brings together leading experts in tropical cyclone and machine learning :

- Elizabeth A. Ritchie – School of Earth, Atmosphere & Environment and ARC Centre of Excellence for Weather of the 21st Century, Monash University, Australia
- Christopher A. Davis – NSF National Center for Atmospheric Research, USA
- Noel E. Davidson – Bureau of Meteorology, Australia
- Nan Sun– School of Systems and Computing, UNSW Canberra
- UNSW Canberra TC Research Group – Lan Phuong Le, Holly Huang, Panpan Lu, Marin Akter
- **Contact: difei.deng@unsw.edu.au**

Intensity changes

Research Motivation :

- Under global warming, landfalling TCs may decay more slowly, persist longer, and penetrate further inland, amplifying impacts (Li & Chakraborty, 2020), though uncertainties remain.
- Australia, despite fewer landfalls, records the highest number of inland TC maintenance/intensification worldwide.
- **Our goal** Our goal is to quantify nearshore TC intensity changes historically, assess their shifts under future warming, and extend the analysis to overland TC/PTC longevity for Australian regions.

Results

Historical TC near shore intensify :

- ✓ Although post-landfall intensity is generally independent of pre-landfall intensity, our analysis shows that in Australia near-shore pre-landfall intensity changes significantly influence post-landfall TC decay rate, suggesting that the post-landfall decay rate can likely be predicted before landfall and the importance of offshore processes(Fig. 4).

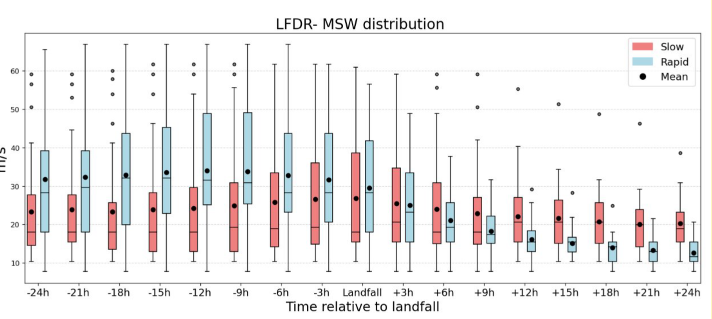

Figure 4: 10-m sustained maximum winds for slow and rapid decaying TCs, based on post-landfall dissipation rat (LFDR), for all Australian landfalling TCs since 1980.

Future offshore rapid intensification:

- ✓ Using high-resolution modelling, we examine mechanisms behind rapid offshore intensity changes (Deng et al., 2023). For TC Debbie, pseudo-global warming projections show competing environmental effects—higher SSTs versus stronger vertical wind shear—but intensification is projected, driven by enhanced inner-core processes offshore (Fig.5).

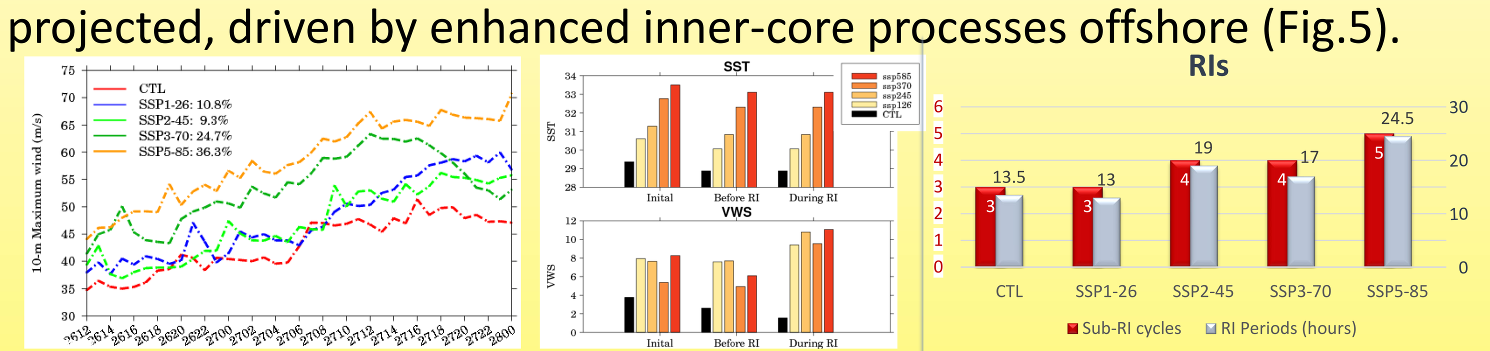

Figure 5: (Left) Intensity, (Middle) environmental fields, and (Right) internal eyewall mixing cycles of TC Debbie under different warming scenarios.

Ongoing study:

- ➢ Developing a model to predict near shore TC intensity changes
- ➢ Studying inland TC longevity under a warming climate, including both intense and weaker but still impactful systems

Join us in advancing TC research—bring your expertise, ideas, and curiosity to help unravel the mysteries of TC impacts in Australia's warming future!

References:

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