

Wetter tropical cyclones in the North Atlantic basin under global warming: Insights from a Lagrangian moisture tracking approach

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Summary

Future projections indicate a basin-wide increase of 9–20% in 6-hourly tropical cyclone (TC) moisture uptake, which translates to a 1.8% to 12.5% rise in TC-related precipitation. Notably, the thermodynamic scaling of this precipitation exhibits a complex and non-linear response. While mid-century rainfall increases follow the theoretical Clausius–Clapeyron relationship, precipitation sensitivity to warming degrades by the end of the century. In addition, future rainfall amplification relies predominantly on moisture contributions from sources near the TC, whereas the support from distant moisture sources decreases. For landfalling systems in the southeastern United States, TC-related precipitation is exacerbated by intensifying localised moisture transport from the Gulf of Mexico, the Caribbean Sea, and the western North Atlantic. Overall, these findings highlight an intensification of ocean-to-land moisture transport by TCs, emphasising a growing future threat of regional flooding.

Motivation

- Tropical cyclones (TCs) play a **critical role in the global and regional hydrological cycles**, while simultaneously ranking among the most destructive meteorological hazards in tropical regions. [1,2].
- Under global warming, TCs are projected to become **more intense** but **less frequent** overall [3]
- Multiple studies agree that TC-related **precipitation** will **intensify** [4]

This work aims examine changes in moisture sources of TC-related precipitation across the North Atlantic (NATL) basin under future scenarios

Historical period

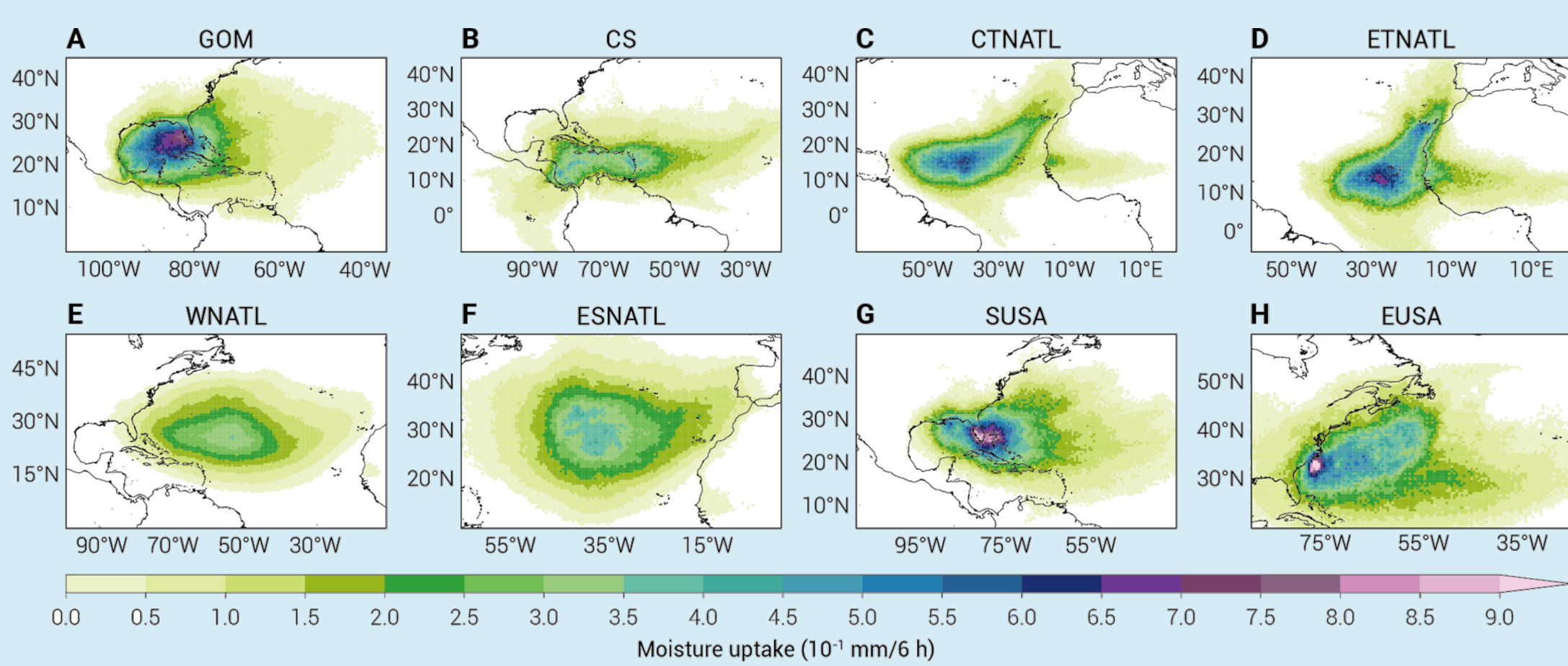


Figure 1. Spatial patterns of moisture source contributions during the historical period (1985–2014)

- The Gulf of Mexico (GOM) and Caribbean Sea (CS) act as **dominant moisture sources** for TCs within these regions.
- Moisture supply in the Central and Eastern Tropical NATL originates primarily **upstream**, driven continuously by prevailing trade winds and the subtropical high-pressure system.
- Landfalling TCs are fueled predominantly by oceanic moisture, highlighting their **critical role in ocean-to-land moisture transport**.

These patterns are consistent with earlier findings, indicating that the historical moisture source simulations provide a robust baseline for assessing projected future changes

Data and Methods

WRF-CMIP6

FLEXPART-WRF

CyTRACK

LATTIN
Lagrangian Atmospheric moisture and heat tracking

METHODS

- The study focuses on the MID (2041–2070) and END (2071–2100) of the century under SSP2-4.5 and SSP5-8.5 scenarios.
- TCs were identified in the WRF simulations using CyTRACK [5]
- Moisture sources were identified using LATTIN [6] by applying TC-specific thresholds.

Acknowledgements

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References

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The current study can be found at

Pérez-Alarcón et al (2026). Ocean-Land-Atmosphere Research, doi: 10.34133/olar.0145

Future Scenarios

- The analysis of 6-hourly area-averaged moisture uptake reveals a highly heterogeneous response across the NATL basin.
- Basin-wide moisture uptake is projected to increase robustly under all scenarios, with median values rising by +9.7% to +19.4% relative to the historical period
- This enhanced moisture uptake translates directly into wetter storms, as confirmed by consistent increases in both Lagrangian precipitation estimates (+1.8% to +10.3%) and WRF-simulated precipitation (+1.2% to +12.5%).



These consistent projections of wetter TCs underscore the heightened risk of extreme precipitation from future storms.

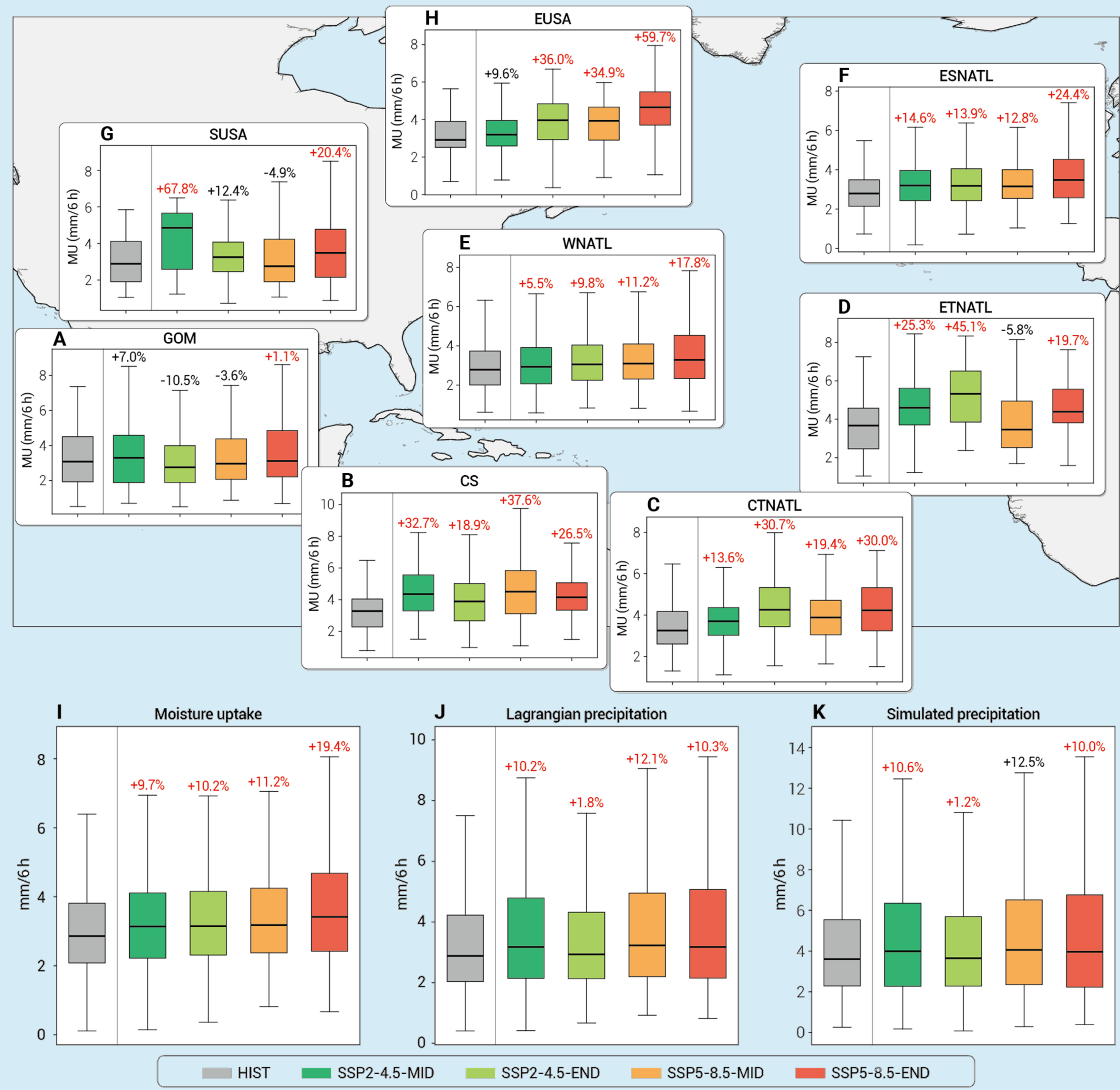


Figure 2. Projected future changes in area-averaged 6-hourly moisture uptake in each region (A–H) and basin-wide (I–K)

C-C scaling

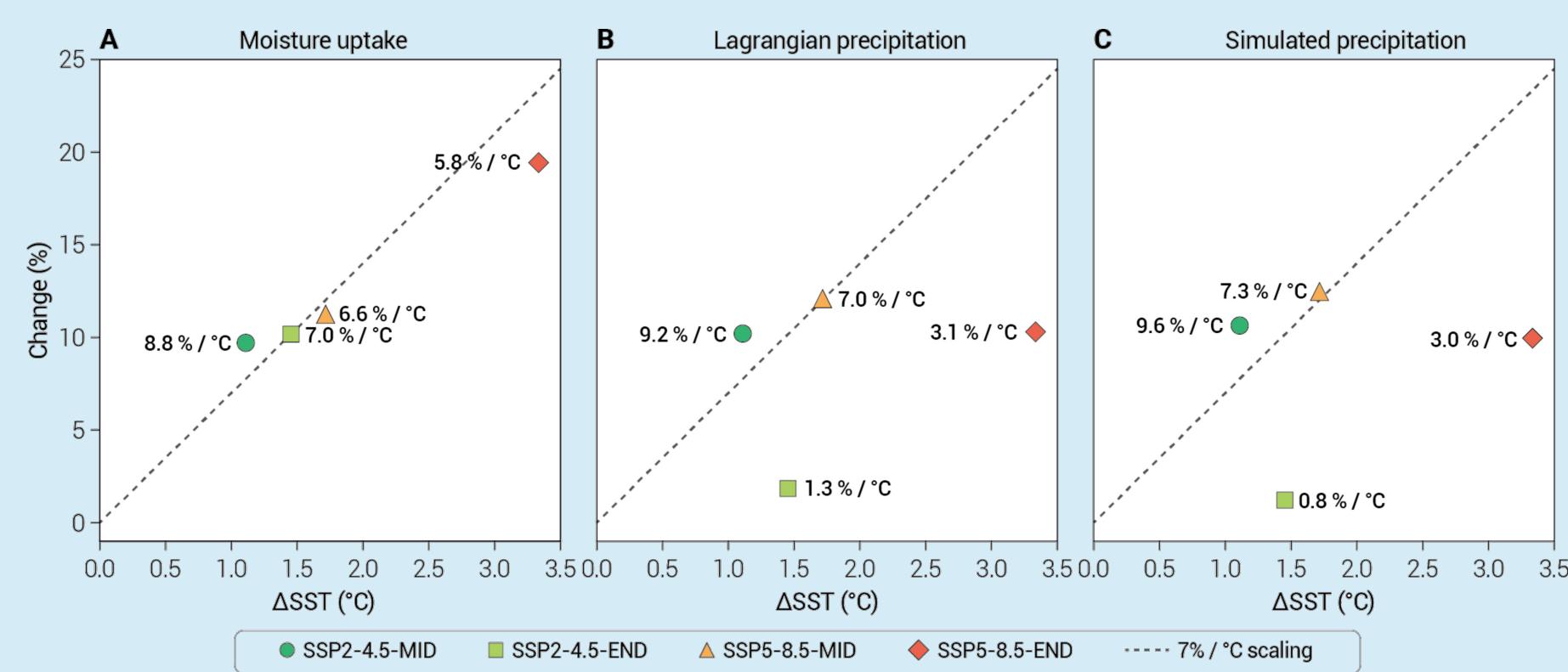


Figure 3. Scaling rates of TC-related moisture uptake and precipitation changes

The increase in moisture and precipitation closely follows the expected $\sim 7\%$ per $^{\circ}\text{C}$ warming rate (C–C relationship) by mid-century, but this scaling weakens with further warming by the end of the century.

Conclusions

Global warming will intensify TC moisture uptake and precipitation across the NATL, shifting storms to rely more on local moisture sources. This significantly heightens the risk of extreme rainfall over land, even though precipitation scaling with temperature weakens at higher warming levels by the end of the century.

