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Moisture Transport by Extratropical Cyclones in High-Resolution Climate Change Simulations

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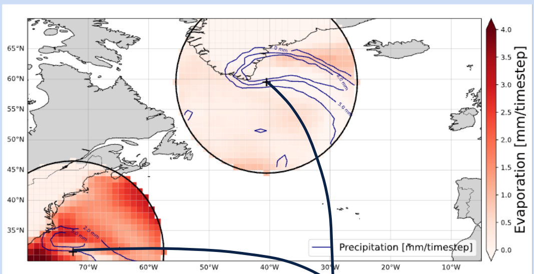
Motivation

Extratropical cyclones (ETCs) play a pivotal role in hydrological processes of the atmosphere, such as moisture transport and precipitation. Long-term changes in the hydrological contribution of ETCs will therefore have important impacts on shifts in precipitation patterns, droughts, and extreme events. Here, **we analyze how ETC contributions in the North Atlantic depend on resolution and global warming in climate model simulations.**

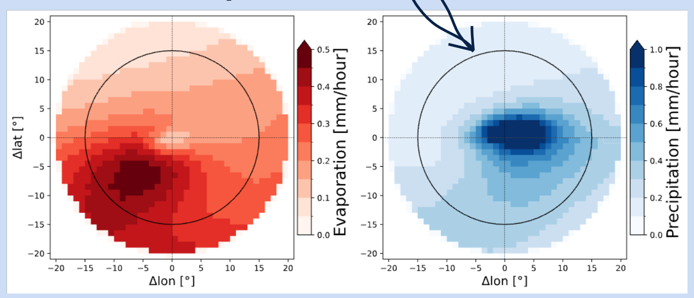
Methods

- Analysis of MESACLIP CESM1 simulations[1]: low and high resolution (LR: 1°, HR: 0.25°), both for the historical period (1970-2000) and RCP-8.5 (2071-2100) at 6h intervals, 8 ensemble members
- ETC-tracking[2] inside the domain of the North Atlantic (30-70°N, 5-80°E), definition of impact area[3] of ETCs by 15° circles around cyclone center
- Analysis via 2 accumulation methods:

geographical flux maps:



cyclone-centered composites:

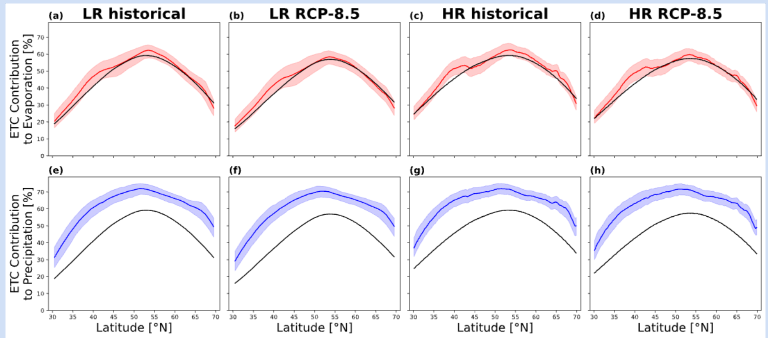


$\sim 10^6$ cyclone timesteps per composite

Results

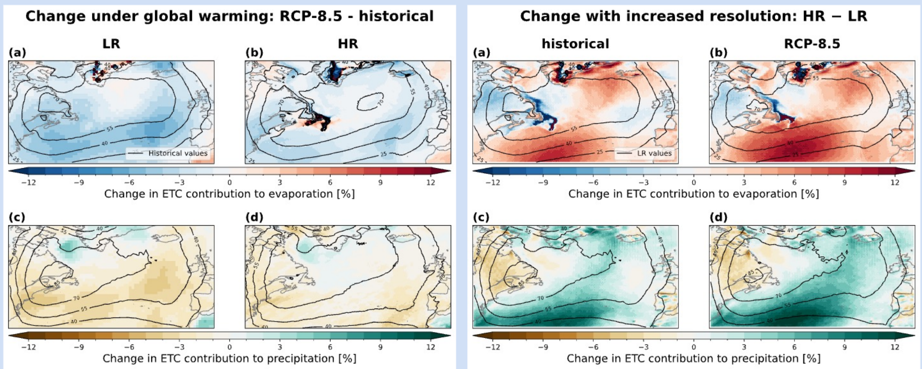
1. Yearly ETC contributions to fluxes (zonal mean):

$$\text{ETC contribution} = \frac{\text{ETC-induced flux}}{\text{Total flux}}$$



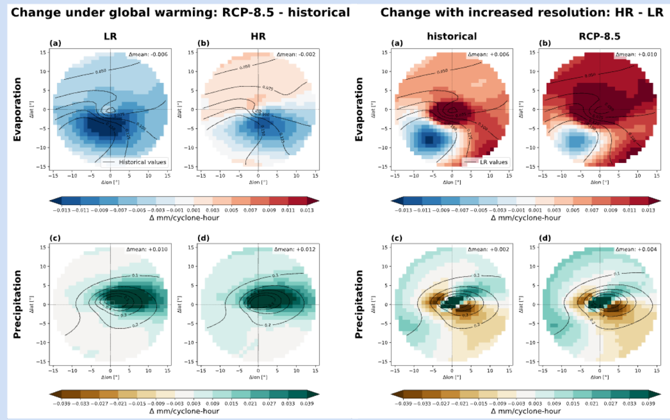
ETCs contribute more to precipitation than evaporation.

2. Changes in ETC contributions to moisture fluxes



ETC contributions to evaporation (E) & precipitation (P) decrease in a warmer climate but increase with higher resolution.

3. Cyclone-centered moisture flux changes :

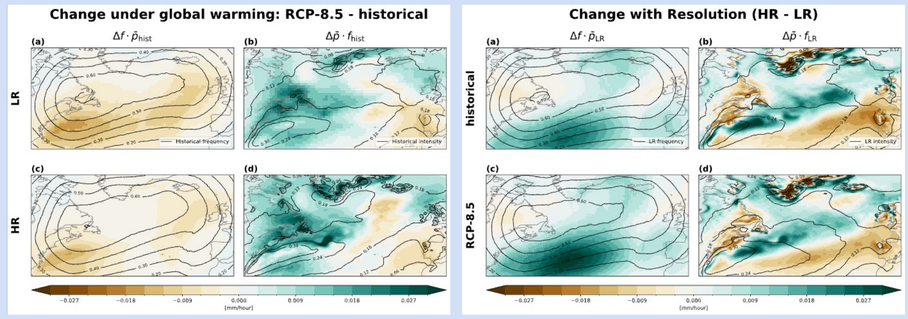


Warmer climate:
ETC-induced E declines & P increases in warm sector

Higher resolution:
E decreases at its hotspot and increases elsewhere, P bands intensify and become narrower

4. Decomposition of P into cyclone frequency f and precipitation intensity $\bar{p}$:

$$\Delta p = \Delta(f \cdot \bar{p}) = \Delta f \cdot \bar{p}_{control} + f_{control} \cdot \Delta\bar{p}$$



Under global warming, f decreases but $\bar{p}$ increases. With HR, f increases and high $\bar{p}$ bands intensify and become narrower.

References

1. Chang, P. et al, 2020: An unprecedented set of high-resolution earth system simulations for understanding multiscale interactions in climate variability and change. Journal of Advances in Modeling Earth Systems, 12, e2020MS002298, https://doi.org/10.1029/2020MS002298
2. Sprenger, M. et al, 2017: Global Climatologies of Eulerian and Lagrangian Flow Features based on ERA-Interim. Bull. Amer. Meteor. Soc., 98, 1739–1748, https://doi.org/10.1175/BAMS-D-15-00299.1
3. Givon, Y. et al, 2026: Contrasting impact of different Mediterranean cyclones on the hydrological cycle and ocean heat content. WCD, 7, 567–582, https://doi.org/10.5194/wcd-7-567-2026

Take Home Messages

- ETCs intensify precipitation (i.e., contribute more to precipitation), but this is less true for evaporation
- Resolution impacts on ETC-induced moisture fluxes are larger than the climate change signal
- LR and HR often agree on the sign and magnitude of change with global warming, suggesting that LR simulations remain a valuable tool to assess changes in ETC-induced moisture fluxes in a warmer world