Assessment of the origin of moisture for the precipitation of North-Atlantic extratropical cyclones

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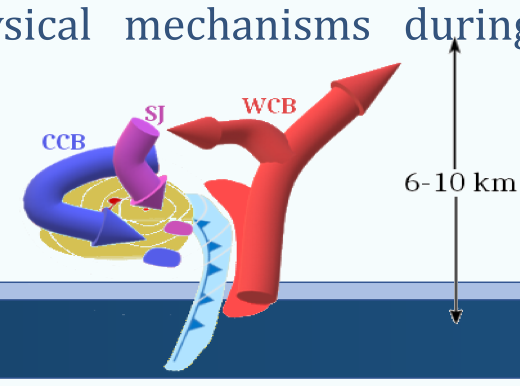
Background

Few meteorological phenomena have captured as much attention in the meteorological community as extratropical cyclones (ECs). The geographical distribution of precipitation within cyclonic circulation is not homogeneous, resulting in different intensities and impacts across different ECs' areas. The upward moisture sources for this rainfall can vary significantly, as the precipitating masses may not respond to the same physical mechanisms during their development.

Notably, variations in moisture transport primarily arise from differences between precipitation near the cyclone center and precipitation in its outer regions.



Objectives

This study aimed to conduct an assessment of the moisture sources for precipitation in North Atlantic ocean (NATL) ECs using a multi-structural EC approach. We addressed our goal by studying the deepest NATL ECs during extended winters (October to April) from 1985 to 2022 in a dataset obtained via dynamic downscaling of ERA5 using the mesoscale Weather Research and Forecasting model [1].

Models

WRF (v.4.2) forced by ERA5 reanalysis data (updated each 6h)

Horizontal resolution: 20 km

FLEXPART *WRF · TRansport Of VApour (TROVA)

[1,2,3]

ExCyclone-TRAMO

The storm track dataset ExCyclone-TRAMO (EXtratropical Cyclone TRAcks and MOisture), derived from WRF simulations, was used in this study and is publicly available at https://doi.org/10.5281/zenodo.13844378.

ECs Detection and Tracking

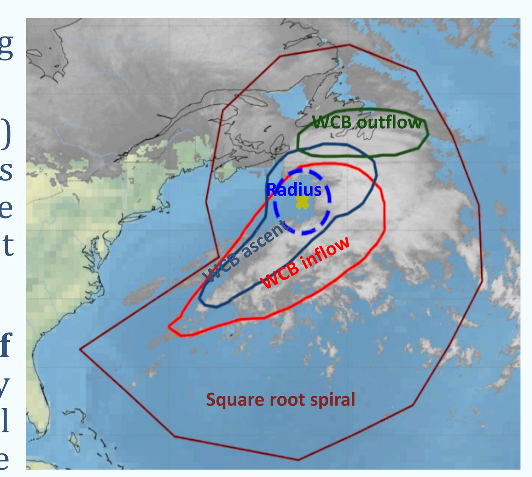
MSLP minima/1000km radius for paring centres in continuous 6h time steps.

ECs structure detection

Radius: We determined the **outer radius** following three distinct approaches based on: i) MSLP (RG07; Rudeva&Gulev [4]), ii) Laplacian of the MSLP (LS06; Lim&Simmonds [5]), iii) Gaussian approximation using the geopotential height (SBF10; Schneidereit et al. [6]).

WCB: **Inflow, ascent and outflow footprints of the probable WCB** were determined by ELIAS 2.0 CNN models [7]. The WCB physical predictors needed as input data were derived from our WRF outputs.

Spiral: Following Gautschi [8], to produce the 17 vertices of the **square root spiral**. In the MSLP field, the angles and hypotenuses of the spiral were adjusted to MSLP drop.



EC shape modelling. The background shows the IR brightness temperature from the geostationary GridSat-B1.

Acknowledgements

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XUNTA DE GALICIA

Lagrangian moisture tracking

Moisture source attribution was conducted using the **Lagrangian source diagnostic** proposed by Sodemann et al. [9], **applied to precipitating particles** within the target regions (radius, WCB, and spiral).

Precipitating particles were characterised as those experiencing a reduction in specific humidity exceeding 0.1 g/kg prior to reaching the designated region. We backtracked parcels up to 10 days.

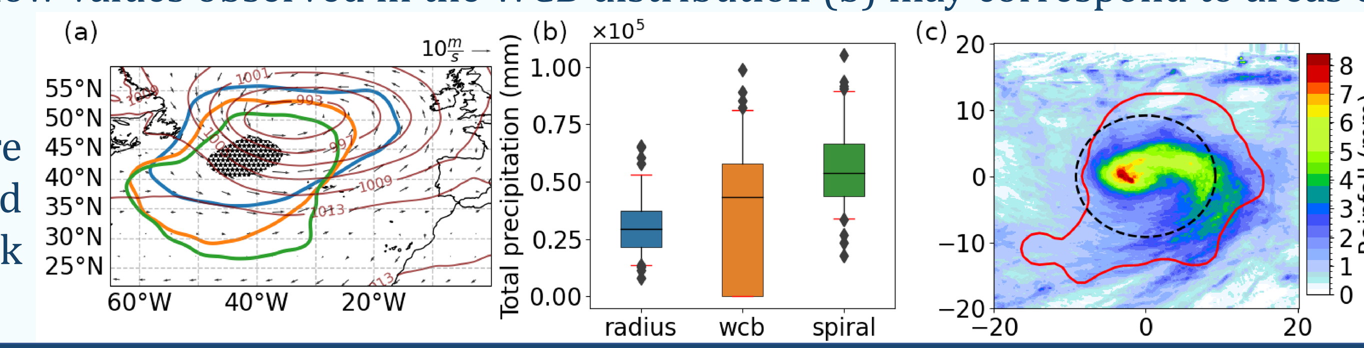
If specific humidity decreases, previous moisture uptakes are proportionally discounted to deduct precipitation losses during transport. [10]

Moisture Uptake Patterns

NATL

The sources of moisture for prec. in different target regions extended westward across the ocean, reaching only the subtrop. boundary for WCB and spiral. The union contour of WCB cases (c, red contour) extends SW. As shown in (a), this SW region is influenced by the subtrop. anticyclonic circulation. Therefore, the low values observed in the WCB distribution (b) may correspond to areas of WCB inflow with reduced precipitation efficiency.

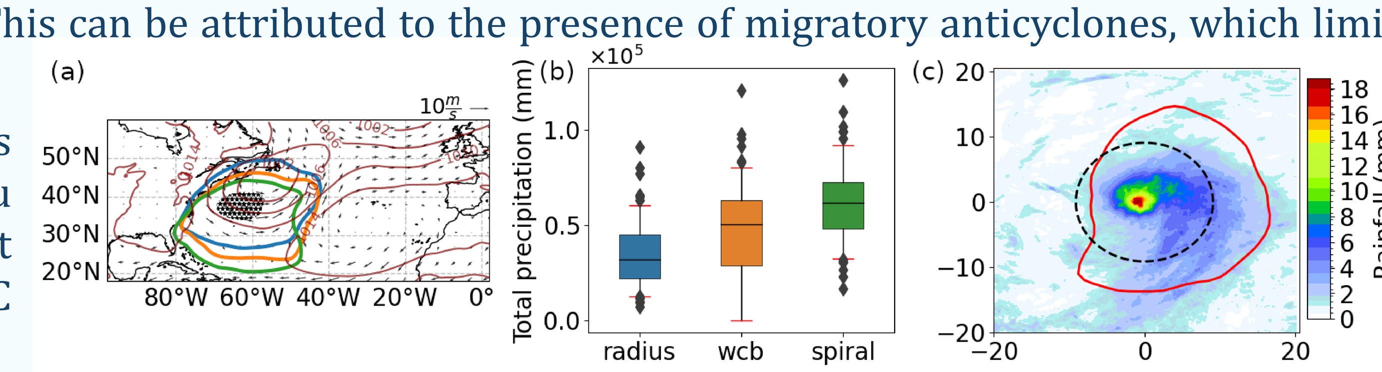
The highest moisture uptake was observed southwest of the EC (black markers in a).



WNATL

The moisture uptake (a) extend SW, into the subtropics, with moisture being sourced from further south for precipitation within the WCB and spiral structures. The region of consistently intense moisture uptake is positioned south of the centres. The Gulf of Mexico did not appear to be a major contributor to moisture. This can be attributed to the presence of migratory anticyclones, which limit the flow from this region.

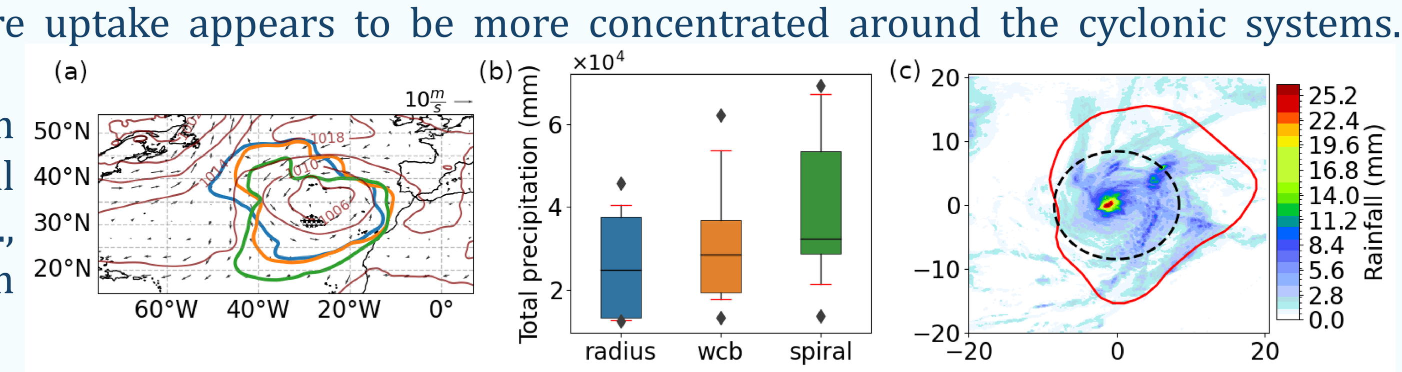
The prec. dist. (c) follows the characteristic tau shape, with the highest prec. amounts near the EC centre .



ENATL

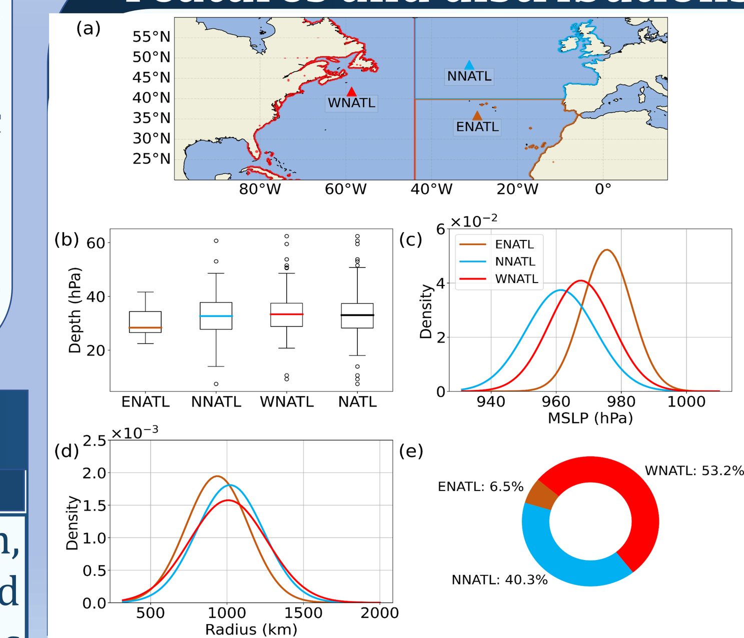
Moisture were primarily located in the surrounding ocean, with a well-defined NW extension. For the case of EC Daniel (December 2019), a case sample analyzed in [11], moisture transport from NW to the Iberian Peninsula was influenced by an atmospheric river. It is important to consider the composite effect, EC-relative moisture uptake appears to be more concentrated around the cyclonic systems.

Despite the ENATL ECs exhibiting a smaller mean radius, a substantial fraction of its total prec., remains contained within this region(c).



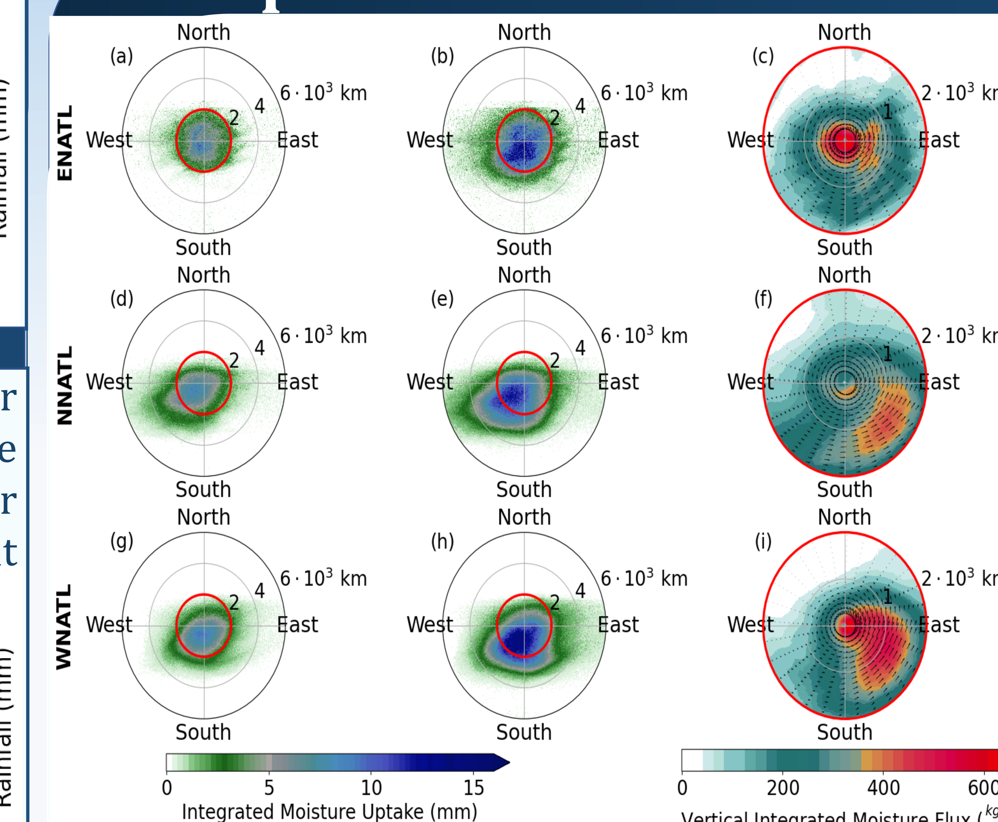
For ECs at the deepest time: (a) Composite data on the MSLP (contours in red, labelled in hPa) and 900 hPa wind fields (vectors, arrows). The blue contours indicate the 95th percentile contours of the composited moisture uptake fields where precipitation occurs within the radius, while the orange contours represent the WCB (Warm Conveyor Belt) target regions, and the green contours denote the spiral target regions. The black shaded areas indicate the intersections of the 99th percentile contours of moisture uptake composites for each target region. (b) Distribution of a total of 6h accumulated precipitation within the target region. (c) The composite 6h precipitation distribution within a 20°×20° box centred on the EC, in dashed black contour the mean radius, and solid red the union contour of the WCB targets.

Features and distributions of the deepest ECs across the NATL



- Cyclones were selected if they reached their deepest phase over the NATL occurred at least 24 h from genesis and lysis phases (the representativeness of cyclones in the mature phase)
- The cyclones were then ranked according to their maximum depth, and the top 237 cyclones were selected, representing 2% of the total ECs from the ExCyclone-TRAMO dataset.

Composite of Moisture Flux and Uptake



From left to right, composites of moisture uptake associated with prec. within the WCB, the spiral target region, and composites of the vertically integrated moisture flux (VIMF), all panels for the time of maximum depth of ECs in the NATL regions. A red contour indicating a radius of 2,000 km is included for reference.

ENATL:

M.U. is more evenly distributed around the cyclone centre and well constrained within a 2,000 km radius. The most intense moisture flux concentrated within the innermost 500 km radius.

NNATL:

M.U. in the spiral region was most pronounced, the maximum uptake occurring within 3,000 km. The highest moisture flux was typically within the E-S quadrant, forming a comma-shaped pattern.

WNATL:

SW source contributes substantially to prec. within the spiral and extends radially up to 4,500 km. A moisture source emerges from the SE, forming a filament of M.U. that suggests transport from the ascending western branch of the oceanic anticyclone.

Conclusions

The radius-based approach effectively captures precipitation maxima, and the innermost radial rainbands. The WCB-based target provides a more comprehensive representation of the full extent of these rainbands. Based on the radius approach, moisture sources for the EC over the W/NNATL are distributed over the western NATL (aligning with [12]). When accounting for prec. areas within WCB and the spiral, M.U. pattern shows an expansion into the subtropics, between 10° and 15° latitude. EC-relative M.U. exhibits a pronounced maximum SW of the EC centre, varying in intensity and spatial extent.

The importance of factors such as moisture availability also varies across regions. The WNATL hosts significant baroclinic zones linked to the Gulf Stream. Evaporation over these regions has been identified as a key mechanism for moisture to reach the initiation points of the WCB [13]. Additionally, cyclones propagating towards the warm, moist side of the SST front associated with the Gulf Stream exhibit increased values of total column water vapour [14]. In contrast, the lower M.U. rates for ECs located farther N, appear to be linked to reduced moisture availability in these regions. At these latitudes, weaker surface evaporation limits the moisture supply and may even hinder WCB formation [13].

References

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