The origins of Storm Ciarán: From diabatic Rossby wave to warm-seclusion sting-jet cyclone

Contact information Email: a.volonte@reading.ac.uk

Ambrogio Volonté [1,2], Jacopo Riboldi [3]

1 Department of Meteorology, University of Reading, Reading, UK | 2 National Centre for Atmospheric Science, University of Reading, Reading, UK | 3 Institute for Atmospheric and Climate Science, ETH Zurich, Zurich, Switzerland

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Storm Ciarán

- **Storm Ciarán was an extratropical cyclone 'bomb' (Sanders and Gyakum, 1980) and deepened rapidly as it crossed the N Atlantic towards the UK, with min MSLP dropping from 987 to 957hPa from 0 to 21 UTC on 1 November (Gray and Volonté, 2024).**
- **Ciarán caused substantial damage and disruption in the UK and continental Europe, with at least 16 people killed.**
- **Gusts of over 100 knots (51 m s^{-1}) were reported in several locations in Brittany (N France). Jersey (Channel Islands) experienced a severe hailstorm (Wells et al., 2025) and a tornado which, with estimated winds of 71–83 m s^{-1}, was likely the strongest reported in the British Isles since 1954 (Knightley et al., 2024).**
- **Storm Ciarán was a severe windstorm that prompted several studies, including a pioneering one on the performance of machine-learning forecast models in simulating it (Charlton-Perez et al., 2024).**
- **Here our interest focuses on its evolution, starting from its origin as Diabatic Rossby Wave (DRW).**

What are Diabatic Rossby Waves?

1. **Low-level systems near a strong baroclinic zone, with circulation and high wind shear usually confined to low levels.**
2. **Driven by latent heat release, particularly strong downstream of the low centre (where moist air ascends at the baroclinic zone).**
3. **Propagate rapidly along the baroclinic zone, via a mechanism independent from the jet stream and involving a continuous storm regeneration in latent heat release region (Boettcher et al., 2013).**

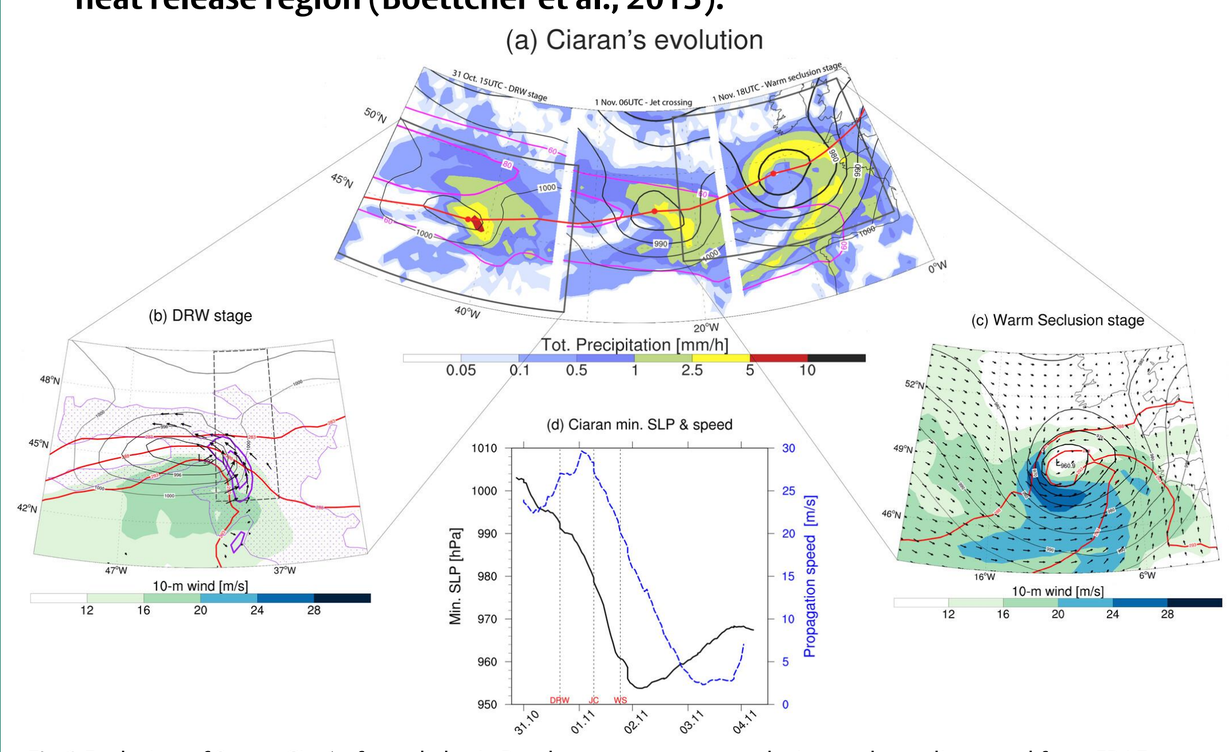

Fig.1 Evolution of Storm Ciarán from diabatic Rossby wave to warm-seclusion cyclone, diagnosed from ERA5 Reanalysis data (Hersbach et al., 2020), from Volonté and Riboldi (2024).

Identification of "early Ciarán" as DRW

- **Closed mean sea level pressure min (Fig 1b) co-located with low-level potential vorticity max (Fig 3b), indicating the presence of a surface cyclonic feature.**
- **Substantial low-level baroclinicity to the east of the low (Fig 1b).**
- **Fast propagation of the cyclone (Fig 1d).**
- **High low-level relative humidity around the cyclone (Fig 1c).**
- **Very weak upper-level-induced ascent forcing on mid-level vertical velocity over the cyclone (Fig 2) (Volonté and Riboldi, 2024).**

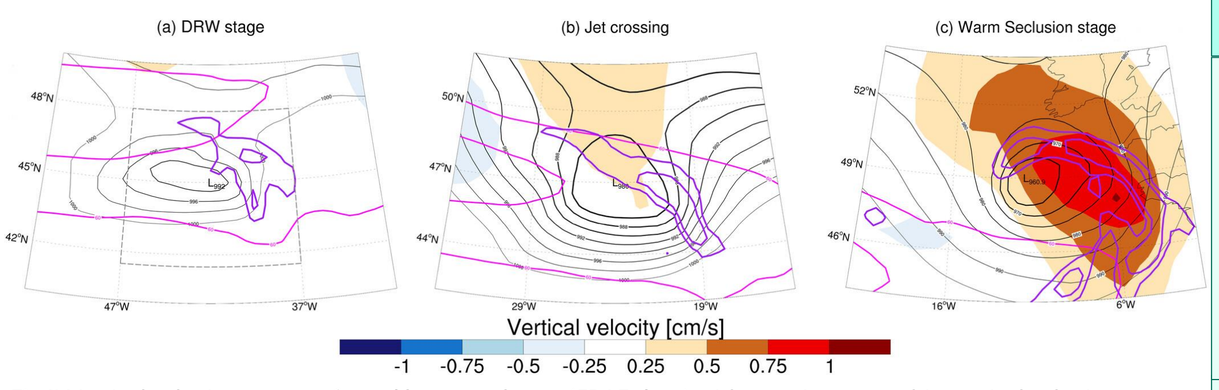

Fig.2 Vertical velocity patterns forced by upper layers (ERA5 data) with quasi-geostrophic vertical velocity at 700hPa due to upper-layer vorticity and temperature advection (in cms^{-1}, shaded) and full vertical velocity at 700hPa (purple contours, only 10, $20cms^{-1}$) at the same time steps as in Fig.1. Overlaid are sea-level pressure and 250hPa wind (black and magenta contours, respectively). From Volonté and Riboldi (2024).

The evolution into a warm-seclusion cyclone

Ciarán deepened rapidly once it started favourably interacting with a strong upper-level jet and evolved into an intense warm-seclusion extratropical cyclone (Fig 3), capable of producing sting jets (Volonté and Riboldi, 2024).

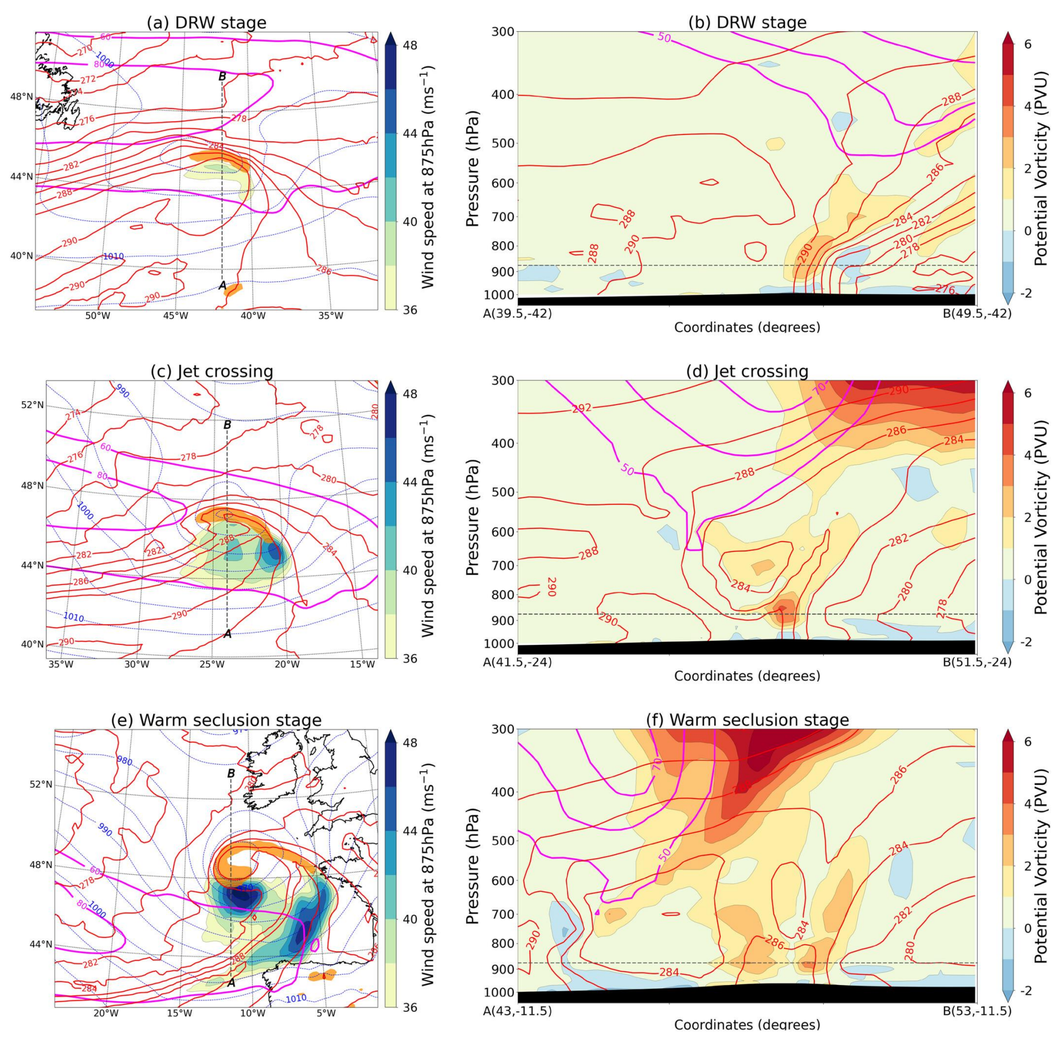

Fig.3 Maps and sections of Storm Ciarán evolving across stages (ERA5 data). Maps: wind speed (shading), potential vorticity (values above 2 PVU, orange) and wet-bulb potential temperature (red contours), all at 875hPa, 250hPa wind speed (magenta contours) and mean sea level pressure (blue contours). AB vertical sections across the cyclone centre: potential vorticity (shading), wet-bulb potential temperature (red), wind speed (magenta). From Volonté and Riboldi (2024).

See Gray and Volonté (2024) for more details on the presence of sting jets in Storm Ciarán, their dynamics and interaction with the dry intrusion.

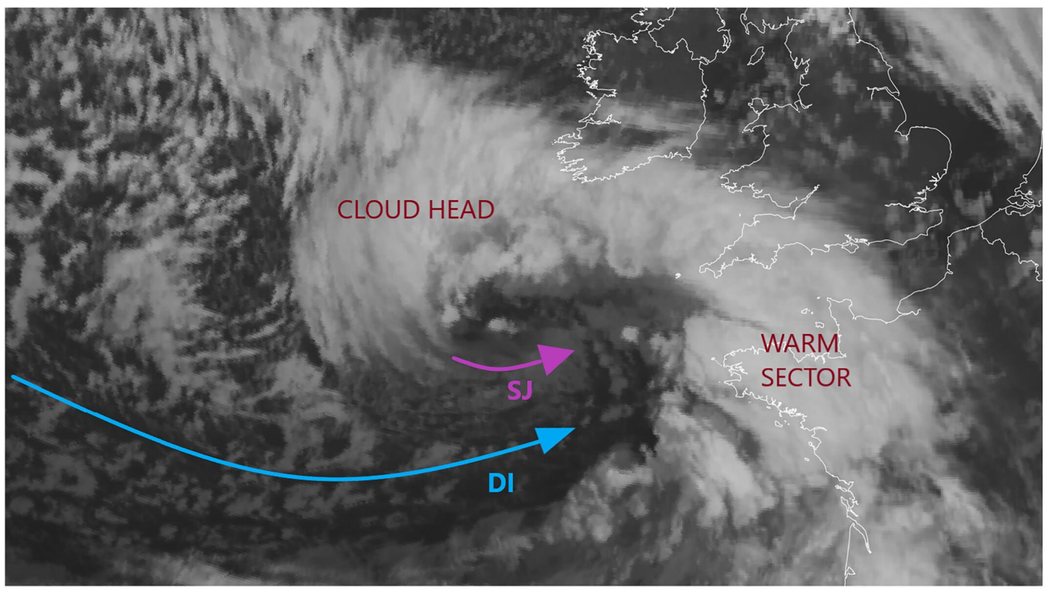

Fig.4 Infrared (10.8µm channel) High Rate SEVIRI image from the Meteosat second-generation 0° satellite referring to 1730UTC on 1 November 2023 (©EUMETSAT [2023]), with added indications of the paths of sting jet and dry intrusion and the locations of cloud head and warm sector. From Volonté and Riboldi (2024).

- **The evolution of Storm Ciarán was different from what is commonly attributed to windstorms affecting northwest Europe.**
- **Ciarán is an example of an extreme windstorm following the "DRW to warm-seclusion explosive sting-jet cyclone" pathway.**
- **This pathway seems linked to the genesis of some of the most extreme European windstorms (see e.g. Storm Lothar and its sting-jet-capable status in Gray et al., 2024).**
- **A systematic study of the role of this pathway in our warming climate is now needed.**

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