Explosive cyclogenesis and an atmospheric river

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On 20/21 September 2021, an autumnal low pressure system in the North Atlantic deepened explosively as it approached and crossed Iceland during the afternoon of the 21st, with its central pressure of dropping from 991hPa at 1200 UTC on 20th to 951hPa at 0600 UTC on the 22nd (Atlantic surface synoptic chart for midday on each day of September can be seen on pages *ii* and *iii* of this issue's *Weather log*). According to local sources,[1] it was the deepest low pressure system to traverse Iceland during September since 2004. Directly after the passage of the storm centre, wind speeds reached hurricane force 12 at a number of well-exposed coastal and mountain sites, with a peak 10min mean windspeed of 67kn (77mph) measured at *Stórhöfði* (alt: 118m) on the southwestern tip of *Heimaey* [population: 4500], the largest island of the *Vestmannaeyjar* [Westman Islands] archipelago, off the southwest coast of Iceland. One isolated mountain site was reported to have measured a maximum 3s wind gust of 120kn (150mph) at the peak of the windstorm.[2]

The storm marked a sudden reversion to zonal conditions across the North Atlantic Ocean (with gales recorded as far south as Stornoway on the same day) and followed a prolonged spell of meridional airflow across the region during the spring and summer of 2021. The explosive cyclogenesis was linked to a strong '*atmospheric river*' (Figure 1) which advected a large amount of water vapour poleward from the sub-tropics during the 20th and 22nd. This feature can be clearly identified on the Meteosat satellite image for 1400 UTC on the 21st (Figure 2), close to the time of landfall of the storm over the Westman Islands.

Although the term 'atmospheric river' has been in use for at least a generation (Newell *et al.*, 1992), it has not been become mainstream in the meteorological vernacular (at least on the European side of the Atlantic) until recently. For comments on the use of this term and on early studies in the UK, see Browning (2018). Whilst atmospheric rivers share commonalities with the traditional warm conveyor belt airstream of a depression, they describe instead the entire flux of water vapour through the whole atmospheric column in three dimensions (mass transport through space and time) and are not bounded by the frontal delineation boundaries of a surface warm-sector, as would be drawn on a traditional surface synoptic chart.

The concurrence of atmospheric rivers and explosive cyclogenesis was first noted by Zhu and Newell (1994). More recently, Eiras-Barca *et al.* (2018) have highlighted the role they play in the deepening of North Pacific and North Atlantic cyclones due to their intense latent heat flux in the lower troposphere. In this particular case, features of a sting jet cyclone can be identified in satellite imagery around the time of the extreme wind gusts recorded over Iceland (Figures 2 and 3). These include distinct filamentation of the cloud head (for example, see Smart and Browning, 2014) and the erosion of the medium-high cloud associated with the warm conveyor belt due to the descending sting jet airstream. Preliminary analysis of a Weather Research and Forecasting (WRF) model run supports the interpretation of a sting jet being present (not shown), but, as in other cases, direct attribution of the strongest gusts to the transport of momentum down to the surface from the sting jet is uncertain. The extreme winds reported here appear to have occurred during the wind veer from southwest to west as the cold conveyor belt jet started to arrive (see the METAR observa-

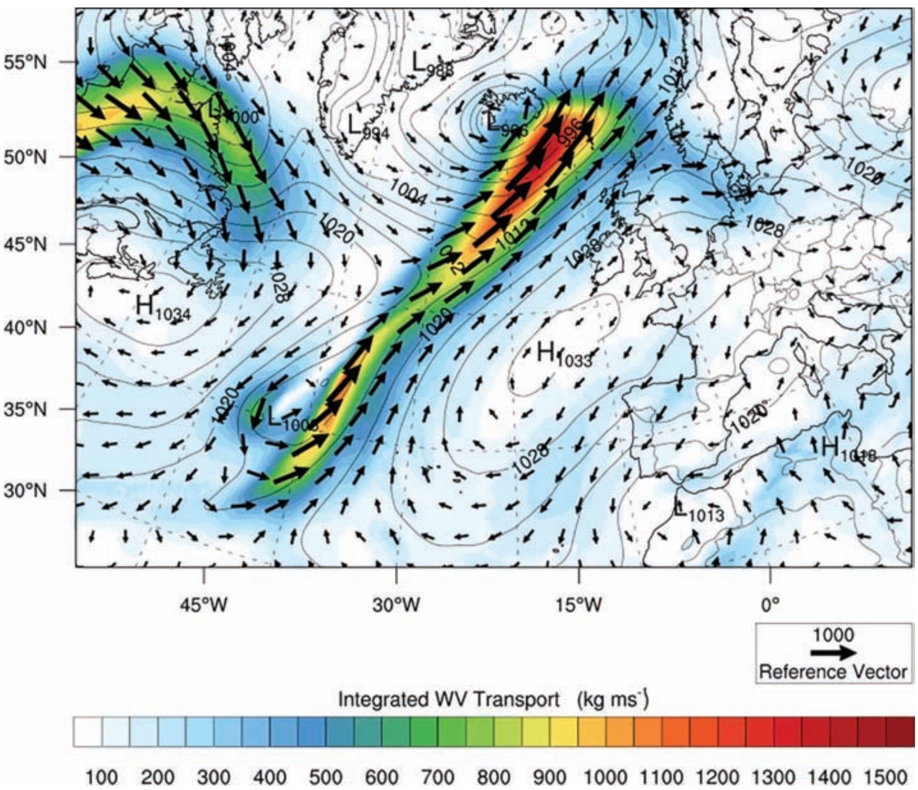

Figure 1. Integrated water vapour transport (IVT) from 1000 to 300hPa in the North Atlantic region 1200 UTC 21 September 2021 obtained from a Weather Research and Forecasting (WRF) model run initialised with Global Forecast System (GFS) operational analysis data.

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RMetS Royal Meteorological Society

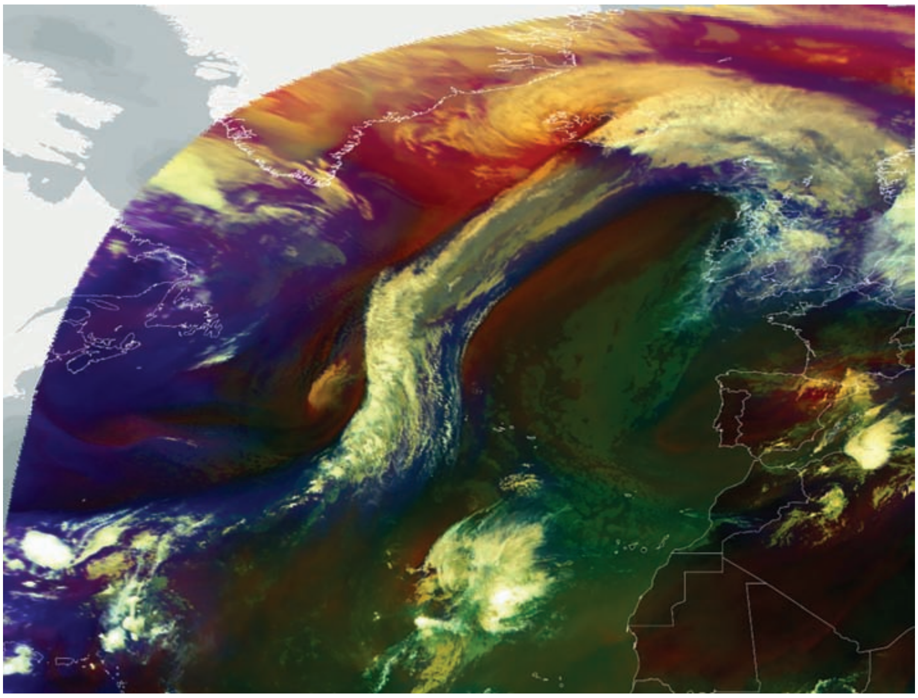

Figure 2. EUMETSAT Meteosat Second Generation (MSG) 'Airmass' image valid 1200 UTC on 21 September 2021. Relatively dry air in the troposphere is shaded orange and red. Moister air is shaded blue-green with cold cloud tops highlighted in white. The atmospheric river in question appears to originate from a cluster of convective clouds in the sub-tropical Atlantic Ocean and extends poleward towards Iceland where a 'cloud head' associated with the deep extratropical cyclone can be seen. A second low pressure system /frontal wave can be seen mid-way between the two. (©EUMETSAT, 2021.)

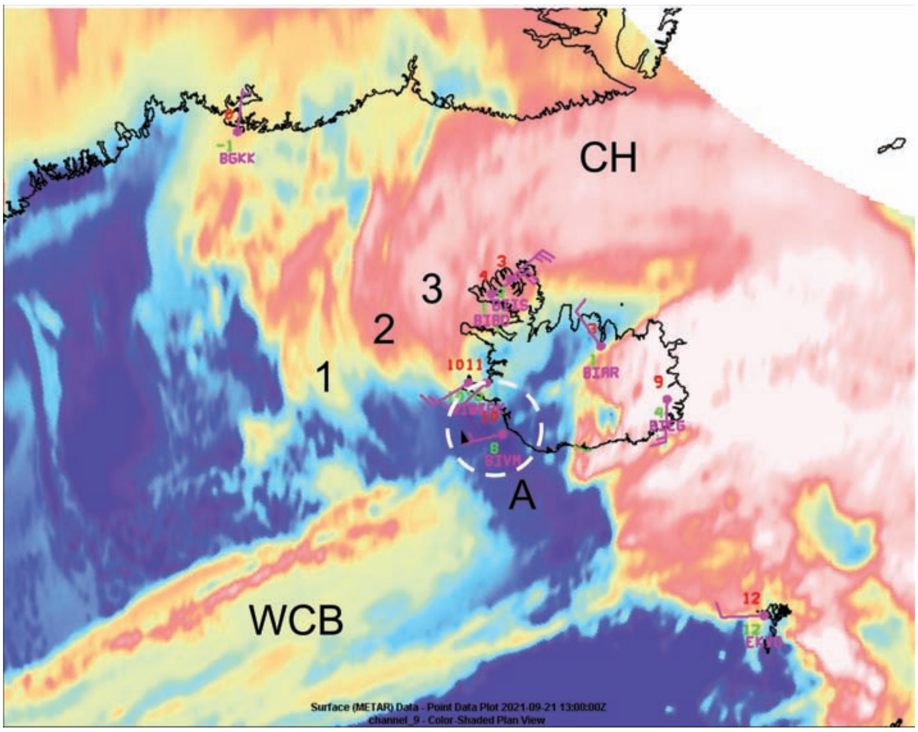

Figure 3. EUMETSAT MSG 10.8µm channel IR image, valid 1300 UTC on 21 September 2021, zoomed in over Iceland. Cold cloud tops are shaded in red, pink and white. Warmer cloud tops are shaded in blue. The following features are annotated: prominent cloud filaments (1,2,3) associated with a cloud head (CH); a warm conveyor belt (WCB), constituting the body of the atmospheric river and a thin line of colder convective cloud tops, marking the surface cold front, is visible along the western edge of the WCB; a warmer area (A) where cloud appears to have been eroded by descending air. METAR observations valid at the same time have been overlaid and the observation for BVIM (Vestmannaeyjar Airport) circled.
(*Source:* Original data- EUMETSAT, 2021.)

tion for BVIM (Vestmannaeyjar Airport, also shown in Figure 3).

Acknowledgements

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