A train of cloud heads associated with multiple cold fronts

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Abstract

Satellite images of a North Atlantic extratropical cyclone in the early stages of rapid cyclogenesis are presented. A simple interpretation of the imagery is suggested with the aid of a brief analysis of output from a Numerical Weather Prediction model. The analysis indicates the presence of a number of cold fronts beneath an overrunning tropopause depression. These *micro*-cold fronts evolve in conjunction with multiple baroclinic leaves which subsequently go on to form cloud heads.

Keywords: *extratropical cyclone; cold front; cloud head; NWP model; satellite imagery*

Cloud heads are hook-shaped areas of cloud (Bottger *et al*. 1975) that form in rapidly deepening extratropical cyclones undergoing frontal fracture (Shapiro and Keyser 1990). Interest in the cloud head phenomenon arises because damaging surface winds can occur near the tip of a cloud head. Sometimes a cloud head can be a single entity (Browning and Roberts 1994), albeit with embedded fine-scale bandedness, but occasionally they occur as multiple structures. A fairly extreme example of a train of cloud heads was observed recently in a cyclone that developed over the North Atlantic on 5 February 2016. The Met Office surface analysis for 0000UTC on 6 February (Figure 1) shows the cyclone, with central pressure 974 hPa, to the west of the southern part of Ireland.

Figure 2 shows satellite infra-red images at 2-hour intervals from 1900 to 2300 UTC as the cyclone deepened from 984 hPa at 1800 UTC 5 February to 974 hPa at 0000 UTC 6 February. The image at 1900 (Figure 2(a)) shows several cloud bands that were associated with a sequence of cold fronts, *ie.* more than were represented in the operational analysis in Figure 1. Four of these micro-cold fronts are highlighted by dashed lines (a, b, c and d). Cloud heads can be seen forming at their northern ends but at this stage in their development they are what Weldon (1979) called 'baroclinic leaves' rather than fully fledged cloud heads. Figure 3, depicting the water vapour (WV) imagery corresponding to Figure 2(a), shows so-called 'dark zones' in the vicinity of the cold frontal cloud bands. This is an indication of subsided dry air associated with an overrunning tropopause depression. As the tropopause depression advanced above the micro-cold fronts it induced an increasing cyclonic circulation at lower levels, and distorted the set of cold fronts. Figures 2 (b and c) show that, where the dry descending air overran fronts `c' and `d' it suppressed the cloud along much of their length, and the baroclinic leaf clouds took on the hook-shaped form of cloud heads. Meanwhile cold front `a' showed no sign of forming a similar cloud head, presumably because it was too far ahead of the influence of the tropopause depression.

The above interpretation of the satellite imagery is supported by a forecast from the WRF model * run at fairly high resolution. Figure 4 shows the model forecast for a time corresponding to the cloud observations in Figure 2(c) and just 1 hour before the surface analysis in Figure 1. The location and depth of the cyclone centre is well represented. The simulated cloud imagery also corresponds reasonably well to that shown by the satellite, albeit with a slightly different disposition of the cloud heads The green contours in Figure 4 depict the height of the tropopause as inferred from the potential vorticity (PV = 2 PV units). These contours show that the leading edge of the overrunning tropopause depression is just to the south of cloud head ‘d’.† An analysis of the height of the PV=1 surface shows that near-tropopause air extends below 700 hPa at the leading edge of the tropopause depression, at a position roughly corresponding to the position of the WV dark zone in the satellite imagery. The model cross-section in Figure 5 depicts the structure along the dashed red line AA' in Figure 4.

The bold black line shows the tropopause depression (*ie.* where the PV=2 surface has descended to 500 hPa) and the thinner black line shows dry near-tropopause air (PV=1) descending to much lower levels in the vicinity of the columns of moist air associated with the cold fronts labelled ‘b’, ‘c’ and ‘d’ . Fronts ‘c’ and ‘d’ are surface based cold fronts but ‘b’ is an upper cold front over-running a warm frontal zone.

In summary, we have presented a case of North Atlantic extratropical development where satellite imagery displayed evidence for multiple cold fronts, baroclinic leaves and cloud heads. An operational run of the WRF model represents the essential features well and depicts the way in which a tropopause depression interacts with a series of cold fronts to create a train of discrete cloud heads. Our study demonstrates the utility of a combined analysis of routinely available satellite images with output from a moderately sophisticated computer model.

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***(Footnote 1)**

The model used was version 3.8.0 of the WRF (Weather Research and Forecasting) mesoscale model. The domain was designed to cover much of the north-east Atlantic region at the highest resolution possible (horizontal grid spacing 7.5 km and 48 levels in the vertical) given modest computational resources (the simulation was performed on a desktop computer workstation). The model run was initialised from GFS (Global Forecast System model) operational data. The model physics configuration was conventional for WRF apart from the treatment of deep and shallow cumulus clouds. As the horizontal grid spacing lies in the awkward convective `grey-zone', a scale-aware convection scheme recently introduced into WRF was selected (the Multi-Scale Kain-Fritsch scheme).

†(Footnote 2)

Although not important to the present study, note that the green contours show the level of only the *main* tropopause: air from above the tropopause extends at lower levels to the south of the red dashed line within a descending tropopause fold.

References

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Figure legends

Figure 1. Met Office surface analysis valid 0000 UTC, 6 February 2016. (Courtesy and copyright UKMO)

Figure 2. Sequence of Meteosat infra-red images at (a) 1900, (b) 2100 and (c) 2300 UTC, 5 February 2016. Cloud bands associated with a sequence of cold fronts are highlighted by dashed lines, labelled ‘a’, ‘b’, ‘c’ and ‘d’. (Courtesy and copyright EUMETSAT)

Figure 3. Meteosat water vapour image for 1900 UTC, 5 February 2016. The cold fronts are highlighted as in Fig 2(a). (Courtesy and copyright EUMETSAT)

Figure 4. WRF model forecast for 2300 UTC, 5 February 2016 (T+17h). MSL pressure is shown by the blue contours at intervals of 4 hPa. The shading represents simulated WV channel imagery (white, moist mid-troposphere). Green contours show the height of the tropopause (PV=2) at intervals of 50 hPa. Dashed cyan lines represent cold fronts and the labels, ‘b’, ‘c’ and ‘d’ correspond to the positions of the cloud heads developing at the northern ends of these fronts. The dashed red line shows the position of cross-section AA'.

Figure 5. WRF model cross-section along AA' in Figure 4. Shading represents relative humidity from <10% (dark blue) to >90% (yellow). The thick blue contour shows where cloud mixing ratio exceeds 0.001 g/kg. The tropopause (PV=2) is shown by the bold black line; the thinner black line corresponds to PV=1. Green contours represent isopleths of wet-bulb potential temperature at intervals of 0.5 C. Fronts ‘b’, ‘c’ and ‘d’ are denoted by cold-frontal symbols. Note that front ‘b’ is depicted as an *upper* cold front.

Figure 1

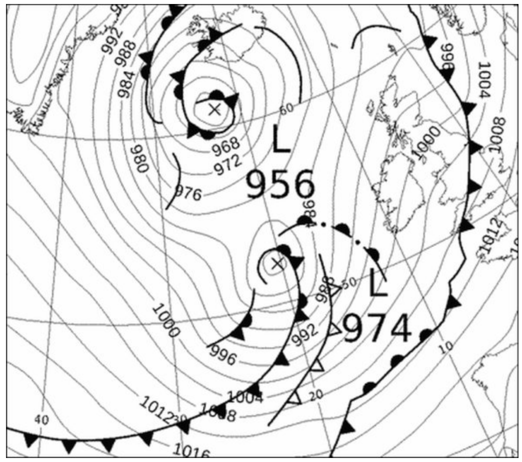

Figure 1. Met Office surface analysis valid 0000 UTC, 6 February 2016. (Courtesy and copyright UKMO)

Figure 2

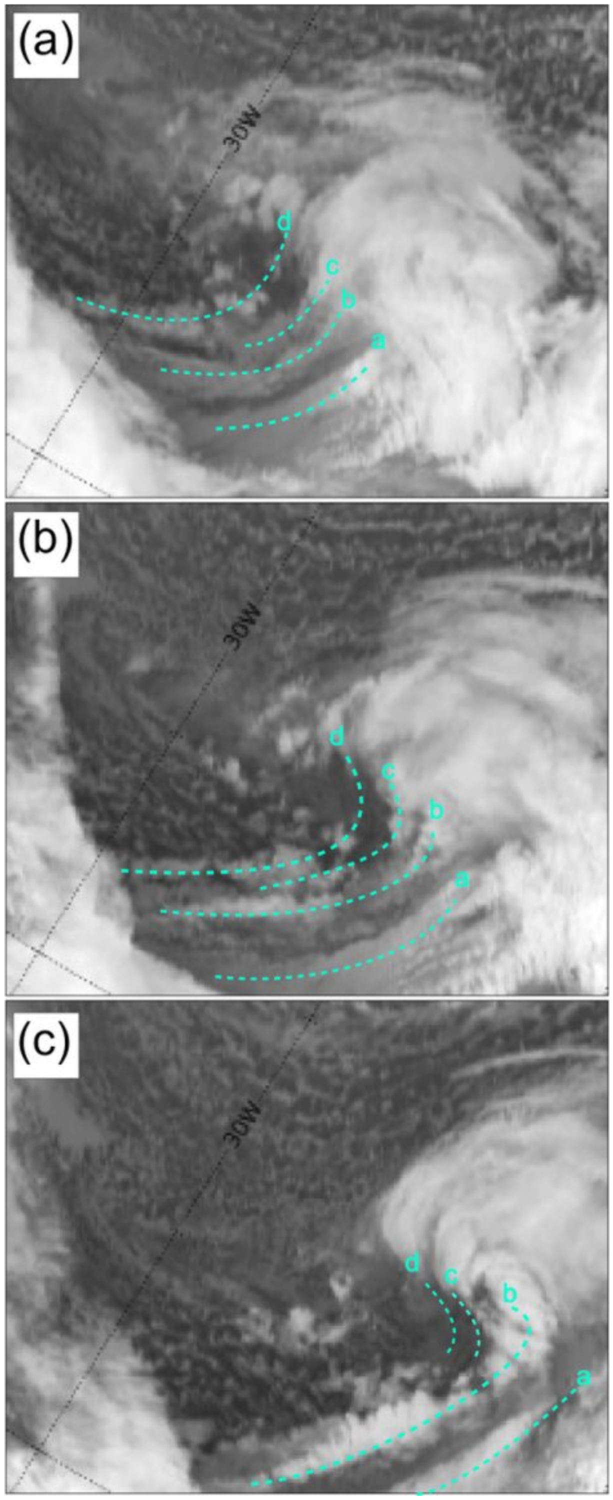

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Figure 3

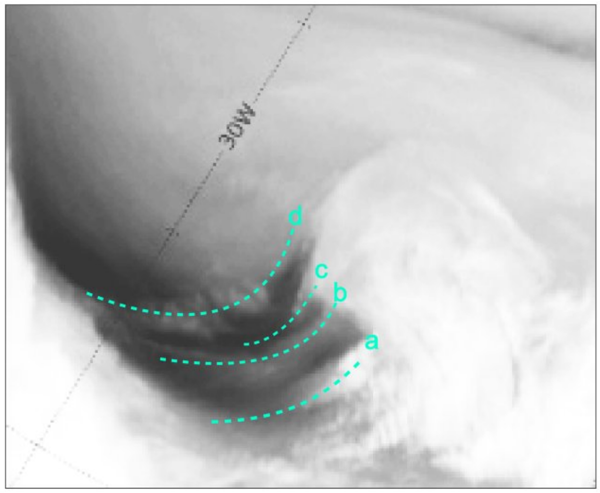


Figure 3. Meteosat water vapour image for 1900 UTC, 5 February 2016. The cold fronts are highlighted as in Fig 2(a). (Courtesy and copyright EUMETSAT)

Figure 4

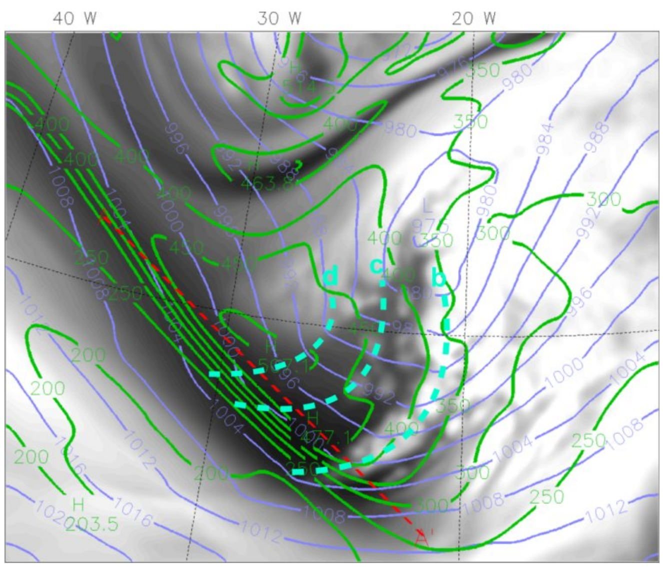
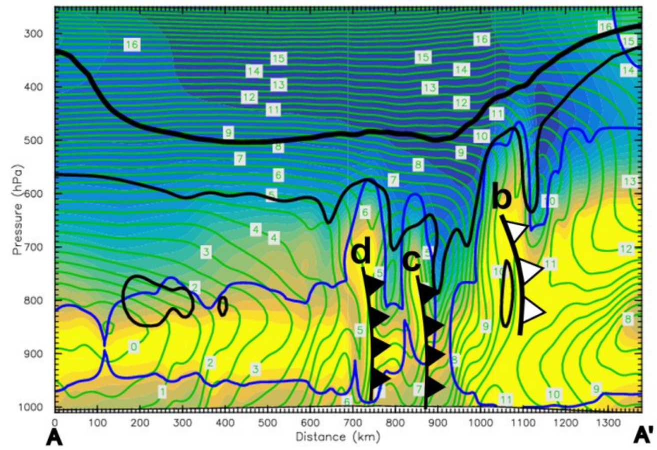


Figure 4. WRF model forecast for 2300 UTC, 5 February 2016 (T+17h). MSL pressure is shown by the blue contours at intervals of 4 hPa. The shading represents simulated WV channel imagery (white, moist mid-troposphere). Green contours show the height of the tropopause (PV=2) at intervals of 50 hPa. Dashed cyan lines represent cold fronts and the labels, 'b', 'c' and 'd' correspond to the positions of the cloud heads developing at the northern ends of these fronts. The dashed red line shows the position of cross-section AA'.

Figure 5



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