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The *Braer* Storm Revisited

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ABSTRACT

The *Braer* storm of January 1993 was the deepest ever recorded cyclone outside of the Tropics with a minimum core pressure of 914 mbar, but due to its track between Scotland and Iceland it ensued little damage and was never intensively examined. Here we present a study on the dynamics of the storm using modern re-analysis data from the European Centre for Medium-Range Weather Forecasts (ECMWF) and sensitivity studies with the Weather Research and Forecasting (WRF) model to quantify influences of diabatic heating and Greenland's topography on the track and rapid deepening of the storm.

1. INTRODUCTION

In a 24-hour period between 9 and 10 January 1993, a storm system in the North Atlantic (Fig. 1a) underwent explosive cyclogenesis, deepening 78 mbar and setting a record minimum central sea level pressure of 914 mbar (Fig. 1b). The 24 hour deepening rate, 3.25 Bergerons[1], is the largest on record for an extratropical cyclone (see Lim and Simmonds, 2002). The storm is named after the oil tanker MV *Braer*, which was travelling from Bergen, Norway to Quebec, Canada. On the morning of 5 January 1993 the ship lost power and began to drift helplessly in the rough seas to the north of Scotland. It later ran aground at Garths Ness, 25 miles south of Lerwick on the Shetland Islands. The *Braer* storm produced wind gusts in excess of 100 knots (kn) over the Shetland Islands, which finally broke up the MV *Braer* and released 85,000 tonnes of light crude oil into the North Sea. Fortunately, no human lives were lost, however ca. 1,500 sea birds died. In contrast to heavier North Sea oil, the light crude oil the MV *Braer* contained was broken up quite easily by the turbulent sea and after 21 January there was no visible oil left on the sea surface. Further impacts included blizzards in Scotland and heavy rain and gales for the rest of Britain, however, the storm caused minimal other damage.

Two analyses of the *Braer* storm were published in *Weather* shortly after its occurrence (Burt, 1993; McCallum and Grahame, 1993). Both are mostly descriptive accounts of the storm, detailing observations from ships, buoys and land. Until now, however, an analysis of the state of the atmosphere at this time and how it conspired to produce a storm of such record breaking intensity has remained absent from the literature. This is probably mostly the result of the lack of damage wrought, owing to the storm's track between Iceland and Scotland (Fig. 1b). The 20th anniversary of the *Braer* storm in January 2013 motivated us to revisit this highly unusual cyclone using modern re-analysis data from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA-Interim dataset and high-resolution simulations with the Weather Research and Forecasting (WRF) model. In this article, we will focus on the main dynamical factors contributing to the rapid deepening of the cyclone (Section 2). We will then present results of sensitivity experiments to investigate the influence of orographic forcing by Greenland

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[1] 1 Bergeron corresponds to 24 mbar of mean-sea level pressure fall in 24 hours at 60 °N

and latent heat release within the cyclone's frontal cloud bands on the storm's track and intensity (Section 3). A short summary and conclusions will be given in Section 4.

2. SYNOPTIC EVOLUTION

a) Mean-sea level pressure, upper-level jet and baroclinicity

January 1993 was characterised by a very active storm track over the North Atlantic, leading to exceptionally mild, wet and windy conditions in the UK (Meteorological Office, 1995). During the first two weeks of the month, a succession of cyclones crossed the North Atlantic, three of which had minimum central pressures below 960 mbar (Fig. 2). They brought heavy rains, snow and gales to northern Britain. These deep baroclinic depressions formed in association with a sharp thermal gradient and strong upper-level jet streak over the western North Atlantic and north-eastern North America as further discussed below. This zone is located close to the northern edge of the Gulf Stream, where strong sea surface temperature gradients enhance lower-tropospheric baroclinicity and heat fluxes from the warm ocean surface aid destabilisation of the boundary layer, creating an environment favourable for cyclone development. The *Braer* storm was initiated in this region on 8 January and tracked rapidly north-eastward while deepening explosively (Fig. 3). It reached peak strength just south of Iceland on 10 January 1993, attaining what is the deepest core pressure of an extratropical cyclone ever recorded in the North Atlantic (Lim and Simmonds, 2002). Pressure at sea level was 914 mbar, something more typically found at the top of a 900 m (2950 ft) mountain. The path taken by the *Braer* storm was similar to that of the two intense cyclones crossing the North Atlantic in the first week of January 1993 (Figs. 2a and b) and close to the mean storm track of explosively deepening cyclones identified by Wang and Rogers (2001; see Fig. 3a). During the afternoon of 10 January and the morning of 11 January the *Braer* storm was almost stationary. The cyclone then filled slowly and drifted north-eastwards into the Norwegian Sea, where it lasted several more days.

Figure 4 shows the evolution of the upper-level jet and low-level baroclinicity between 7 and 10 January 1993 based on ECMWF ERA-Interim re-analysis data. On 7 January, large parts of eastern Canada, the Labrador Strait and Greenland are covered by cold Arctic air, while a warm subtropical air mass is found over the south-eastern USA (Fig. 4a). A jet maximum of over 140 kn is located to the east of Newfoundland. A secondary maximum, most likely associated with the subtropical jet (labelled 's' on Fig. 4a), is found over the eastern USA. There is considerable upper-level divergence associated with the right entrance regions of both jet maxima (dashed lines in Fig. 4a). By 8 January 1993, the two jet streaks have merged, forming a short, linear feature with a maximum speed of more than 200 kn and impressive zonal and meridional wind speed gradients (Fig. 4b). The temperature difference at 850 mbar between Newfoundland and Nova Scotia is nearly 40 °C over 1150 km (715 miles), roughly the distance between the north coast of Scotland and south coast of England. The *Braer* storm initially appeared at the surface on the morning of 8 January under the strong upper-level divergence associated with the right entrance region of the intensifying jet streak (blue ‘B’ in Fig. 4b). The surface cyclone crossed the upper-level jet in the early morning hours of 10 January, into the area of strong upper-level divergence associated with the left exit region of the jet (Fig. 4c). This is a well-documented characteristic of many explosively developing cyclones (Riviere and Joly, 2006). Initially, two separate surface circulations were evident in the ECMWF data; these merged early on the 10 January into one much stronger circulation. It was at this time, between 0000 and 0600 UTC on the 10 January that the core pressure of the *Braer* storm deepened most rapidly, falling 26 mbar in 6 hours (Fig. 3b) or more than 4 mbar hr^{-1}.

b) Potential vorticity perspective

An alternative perspective on the storm evolution can be gained through the use of potential vorticity (PV), which combines aspects of vertical stability and absolute vorticity (Hoskins *et al.,* 1985). PV is a conserved variable for adiabatic motions in the atmosphere and is therefore very useful when tracking a disturbance. For example, if a developing cyclonic system crosses high topography, the air column is squashed, which causes a rapid reduction in relative vorticity and can mask the original disturbance. The pressure field is also distorted and it becomes difficult to track the depression until it reaches the lee side of the topography. PV, however, will not change in this situtation and therefore the disturbance can be followed more easily. As shown by Hoskins *et al.* (1985), positive PV anomalies can occur at upper levels and lower levels in the troposphere. When they favourably align in the vertical, the cyclonic circulation exerted by each anomaly can act to mutually amplify each anomaly. The lower anomaly is generated by a warm air moving polewards and the upper anomaly is produced by intrusions of stratospheric air (characterised by high PV) down into the troposphere. The upper anomaly can increase the lower anomaly by advecting more warm air from the south at low levels and the lower anomaly advects high PV air from the north into the upper anomaly. As the anomalies interact and *phase lock,* the cyclone intensifies and will deepen until they become vertically stacked and the cyclone begins to weaken.

Figure 5 shows upper-level PV (averaged between 250 and 450 mbar) together with the geopotential height of the 1000 mbar surface. Before 0600 UTC 9 January subsidence in broad-scale northwesterly flow forces the tropopause to descend on the downstream side of a strong North American ridge. As a result, upper tropospheric PV increases in a trench-like fashion over the east coast of Canada (purple ‘PV+’ in Fig. 5a). At this time, the *Braer* storm is forming to the southeast of Newfoundland, well south of the main upper-level PV gradient (‘B’ in Fig. 5). Another marked upper-level PV anomaly is generated by flow over Greenland’s orography (shown by the green ‘GPV+’ in Fig. 5a). The surface depression (‘B’) has a low-level PV anomaly associated with it (see figure 6). As discussed in Section 2, the surface cyclone ‘B’ tracks northeastward, crossing the upper jet during 9 January while the ‘PV+’ anomaly is advected zonally along the poleward side of the upper-level jet. At 1800 UTC on 9 January, the *Braer* storm is located just downstream of the descending upper PV anomaly, while ‘GPV+’ is almost stationary (Fig. 5b). Between 1800 UTC 9 January and 0600 UTC 10 January, ‘PV+’ acts as the central anomaly with ‘GPV+’ and the surface anomaly rotating cyclonically around it (Figs. 5b and c). The ‘GPV+’ anomaly splits into two, smaller anomalies (‘GPVa+’ and ‘GPVb+’, Fig. 5c). ‘GPVa+’ is wrapped into ‘PV+’, intensifying the overall upper-tropospheric anomaly. The circulation associated with the surface cyclone, which is located poleward of the upper PV at 0600 UTC on 10 January (Fig. 5c), can help to advect high PV air into the developing anomaly from upstream as discussed earlier in this section. This idea will be returned to below. Rotating around each other and becoming a singular, tropospheric-deep cyclonic wave, the upper and lower anomalies (‘PV+’ and ‘B’, respectively) become super-posed vertically by 1800 UTC 10 January (Fig. 5d). Concurrently, strong latent heating at the thermal ridge (see Fig. 4c) produces a low PV tongue that begins to cut off the ‘PV+’ anomaly from the supply of high PV air upstream (black arrow, Fig. 5d). This is found to occur in the post-mature phase of many strong winter cyclones (see Posselt and Martin, 2004).

Three-dimensional analysis of the PV field during 10 January 1993 reveals that indeed the surface cyclone ‘B’ and the upper anomaly (‘PV+’) do interact and phase lock (Figs. 6a and b). Whilst still out of phase vertically at 0600 UTC on 10 January (Fig. 6a) the circulation associated with the low level anomaly (‘B’) advects high PV air from the northwest (upstream) into the upper anomaly (‘PV+’). Simultaneously, warm air is advected from the southeast into the lower anomaly by the cyclonic circulation associated with ‘PV+’, leading to mutual amplification. Notice how the isentropes (lines of constant potential temperature) bow toward each anomaly, characterised by higher stability (Fig. 6). Conversely, a weakly stratified environment exists around the anomalies, allowing for a deep penetration depth of their circulations and explosive mutual amplification (see Fig. 5). At the peak of the *Braer* storms intensity (1800 UTC 10 January) the two anomalies formed a continuous vertical tower of PV throughout the depth of the troposphere (Fig. 6b). This has been shown to occur at the peak strength of many intense cyclones, e.g. the European windstorm *Lothar* (Wernli et al. 2002; Čampa and Wernli, 2012). As in many other cases, the lower-level PV anomaly was probably significantly enhanced by diabatic heating, without which a weaker interaction between upper and lower PV anomalies would have likely resulted.

3. MODEL SENSITIVITY EXPERIMENTS

To better understand the rapid intensification and why the storm took the track it did, like the majority of other explosively deepening cyclones over the North Atlantic (Fig. 3a), sensitivity experiments using the WRF model were conducted. The WRF model is a terrain-following, non-hydrostatic numerical model applied widely in atmospheric research. WRF was run at a 4 km grid spacing over a domain between 90 ^{o}W – 20 ^{o}E and 20 ^{o}N – 80 ^{o}N. WRF was initialised at 0000 UTC 7 January 1993 in each simulation and ran for 144 hours ending at 0000 UTC 13 January. This set-up was chosen after a number of tests with other configurations, as it showed the best reproduction of the evolution of the storm compared to ERA-Interim data. Three simulations were designed: (a) A *Control* experiment to show that WRF can reproduce a realistic storm of similar intensity and track. (b) A *‘No Latent Heat’ (NOLH)* experiment, in which the energy released through phase changes of water was set to zero and in which the convection scheme was deactivated, to quantify contribution of diabatic processes to the *Braer* storm's depth. (c) A '*No Greenland' (NOGL)* experiment, in which all grid points over Greenland were set to land points at 1 m elevation, to test the sensitivity of the *Braer* storm to effects of Greenland's steeply sloped topography. The importance of latent heat release (diabatic heating) on the intensification of a developing cyclone has been well documented in the literature (e.g. Stoelinga, 1996; Wernli *et al.*, 2002). The effects of Greenland's topography on the evolution of individual cyclone developments and the northern hemispheric stormtracks have also been investigated in a number of studies (e.g. Kristjansson and McInnes, 1999; Petersen *et al.,* 2004). The results are not clear-cut and show both damping and enhancing effects on cyclone development over the North Atlantic.

In the *Control* experiment, surface pressure began to fall in a broad area off of the east coast of the USA on the morning of 8 January with a closed 1012 mbar isobar evident by 0900 UTC. The subsequent track and deepening rate follows closely that of reality through 8 and 9 January (compare Figs. 3 and 7). Crossing the upper jet the depression deepened to 998 mbar by 0600 UTC 9 January (Fig. 7). The deepening rate steadily increased during 9 January but lagged slightly behind the observed rate. By 0000 UTC 10 January, the *Braer* storm is at 972 mbar, weaker than the 960 mbar found in ECMWF data at this time. In the next 6 hours, however, the core pressure falls 32 mbar (more than 5 mbar hr^{-1}), with a marked drop of 20 mbar between 0300 UTC and 0600 UTC 10 January (Fig. 7). This is the time when the upper and lower PV anomalies discussed in Section 2b phase-lock at approximately 55 ^{o}N/ 20 ^{o}W. This is well reproduced by WRF, which, as is the case in reality, merges two surface circulations at this time corresponding to the two initially separate waves. Progressing almost due north, the *Braer* storm in *Control* reaches peak intensity of 915 mbar at 1800 UTC just south of Iceland (Fig. 8a), very similar to ECMWF data (Fig. 3a). A lee cyclone (see explanation further down in this section) with a minimum pressure of 956 mbar occurs just east of Greenland throughout the development of the *Braer* storm in *Control* and appears to interact with the storm at peak intensity during 10 January as was shown for the associated PV anomalies in Section 2b. The track of the *Control* cyclone between 10 and 11 January deviates slightly from the observed path. Remaining south of Iceland it does a loop on itself before progressing east on 12 January, tracking closer to Scotland than in reality (Fig. 7a). Overall the reproduction of the *Braer* storm in WRF is satisfactory with a maximum depth within 1 mbar of the re-analysis data and closely correlated path across the North Atlantic until 10 January, which gives confidence that the sensitivity experiments are meaningful.

The track of the *NOLH* cyclone is very similar to *Control* although displaced slightly to the north throughout (Fig. 7a). Despite a slower start, the deepening of the *Braer* storm in *NOLH* during 8 and 9 January is comparable to *Control*, with a central pressure at 0000 UTC 10 January of 974 mbar (Fig. 7b). It is in the next 6 hours that the depression in *NOLH* deepens considerably less than *Control* and ECMWF, such that by 0600 UTC the *NOLH Braer* storm is only 961 mbar, significantly weaker than the 940 mbar *Control*. This offers support for the hypothesis that the lower-tropospheric PV anomaly was significantly enhanced by diabatic heating. With a weaker lower level anomaly, the circulation near the surface would have been weaker and the amplification of the upper anomaly would have been suppressed. In addition, a lack of condensational heating of the middle troposphere would keep the stability higher and reduce the strength of the coupling between the two waves. A maximum intensity of 946 mbar is reached by the *Braer* storm in *NOLH* slightly further north (over the southern coast of Iceland) than the *Control*. This suggests that diabatic processes contribute about 30 mbar to the overall deepening of the *Braer* storm.

Removing Greenland from WRF in the *NOGL* experiment allows cold air at low levels to cross the landmass and push further east across the North Atlantic Ocean. It also removes the lee cyclone from the eastern side of Greenland (Fig. 8b) that was seen in the *Control* simulation and therefore reduces the positive PV signature seen in Fig. 5 (not shown). The Greenland lee cyclone is a semi-permanent atmospheric phenomenon that exists because prevailing westerly flow is forced to subside along the eastern side of the ice sheet. Vortex stretching in the lee increases an air parcel's vorticity and subsidence warms the parcel, creating a favourable environment for cyclogenesis. In a model study of the entire Northern Hemispheric circulation in which Greenland was removed, Petersen *et al.* (2004) found a significant reduction in the number of cyclones between Greenland and Europe. The effect of Greenland on depth and track of explosively developing cyclones is not fully understood. It is hypothesized here that the Greenland lee cyclone (and associated PV anomaly) might have been at least partly responsible for retarding the eastward propagation of the *Braer* storm, keeping it further north and therefore away from the British Isles when it was most powerful.

The initial development of the *NOGL* cyclone is almost identical to *Control*. Forming around 36 ^{o}N just off the east coast of the USA, the storm tracks north-eastward along a similar line (displaced slightly to the south). WRF produces a cyclone with the same central pressure of 998 mbar at 0900 UTC 9 January (Fig. 7a). Continuing to deepen at a similar rate to *Control,* the core pressure of the *Braer* storm is 970 mbar at 0000 UTC 10 January (Fig. 7b), at a similar position to *Control* of 53 ^{o}N and 24 ^{o}W (Fig. 7a). From this point forward through 10 and 11 January, the *Braer* storm has a faster evolution and deepens more rapidly in *NOGL*. The centre remains further south, doing a much smaller loop, and tracking almost due east by the end of 10 January (Fig. 7a). As the storm passes just to the south of the Faroe Islands at 0300 UTC on 11 January, the cyclone is still an unprecedented 918 mbar and is closer to Scotland than *Control* (Figs. 8c and d) or re-analysis data at this time. In addition, *NOGL* clearly has a broader and warmer core than *Control*, but has slacker gradients in temperature around the centre (Figs. 8c and d). Cold air comes from the northwest behind the *NOGL* cyclone as opposed to the west in *Control*. At the same time, warmer air is advected further poleward on the eastern side of the *NOGL* storm.

The near surface (10 m) winds clearly demonstrate the southward shift of the *Braer* storm at its peak intensity (Figs. 8e and f). A clear wind maximum is visible on the southern side of the cyclone centre with mean 10 m wind speeds exceeding 35 m s^{-1} (78 mph) and 30 m s^{-1} (67 mph) along the northern coast of Scotland in *NOGL*. Note the dramatic decrease of winds over land in Fig. 8e. Previous studies have indicated some issues with WRF to realistically represent high winds over land (Nawri *et al.,* 2012), suggesting that the results presented here are likely to be an underestimation. As an illustration of the differences between *Control* and *NOGL*, Fig. 9 shows the evolution of the mean 10 m wind speeds at grid points closest to Edinburgh and Lerwick on the Shetland Islands. The change is more pronounced at Lerwick, where 10 m wind speeds peak 5 m s^{-1} greater in *NOGL* at close to 30 m s^{-1} (Fig. 9a). Over the central belt and most densely populated region of Scotland the 10 m winds peak around 23 m s^{-1} and remain at or above 17 m s^{-1} for at least 24 hours between the afternoon of 10 January and morning of 11 January, as opposed to *Control,* in which winds exceed 17 m s^{-1} for less than 10 hours and peak at around 20 m s^{-1} (Fig. 9b). In other words, Edinburgh would have experienced what is officially tropical storm category wind speeds for a full 24 hours, had the Greenland lee cyclone not steered the *Braer* storm away from the British Isles.

4. CONCLUDING REMARKS

Here we have presented an investigation into the *Braer* storm of January 1993, the most explosively deepening extratropical cyclone on record. Deepening 78 mbar in 24 hours and attaining a minimum core pressure of 914 mbar, the *Braer* storm was a remarkable meteorological phenomenon. The *Braer* storm formed in the right entrance region of an exceptionally strong upper-level jet just off the east coast of the USA, near the northern edge of the Gulf Stream, and crossed the jet into the highly divergent left exit region. Interactions of two upper-level PV anomalies and diabatically generated PV at low levels contributed to the rapid storm intensification, ultimately creating a vertical PV tower during the mature phase. Many of these attributes are structurely similar to previous intense cyclones over the North Atlantic. Sensitivity experiments with WRF show that diabatic processes contributed more than 30 mbar to the deepening of the *Braer* storm and shifted the track slight southward. A removal of Greenland's topography does not affect the storm's intensity much, but the lack of a steering lee cyclone leads to a track closer to the British Isles, which would have potentially caused much more serious damage than the real-world storm. In the future we would like to carry out a piece-wise inversion of the PV field to show the contribution from each PV anomaly to the circulation. In addition, we found unusually large geopotential height tendencies across large parts of the stratosphere that deserve further investigation.

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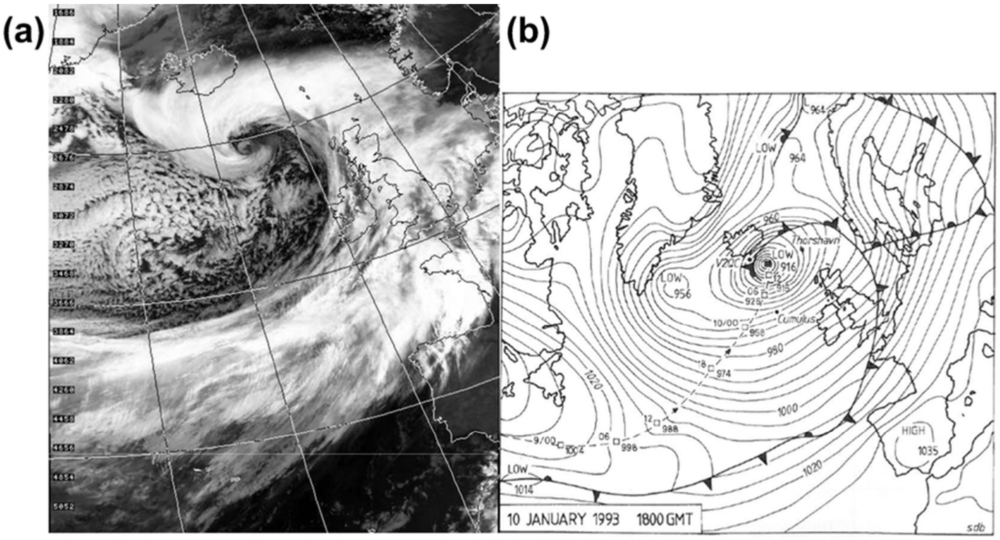

The Braer storm near peak strength on 10 January 1993. (a) Infrared image taken from the AVHRR satellite on a westerly pass over the UK (courtesy of www.satdundee.ac.uk) at 0920 UTC. (b) Surface analysis chart at 1800 UTC taken from Burt (1993).
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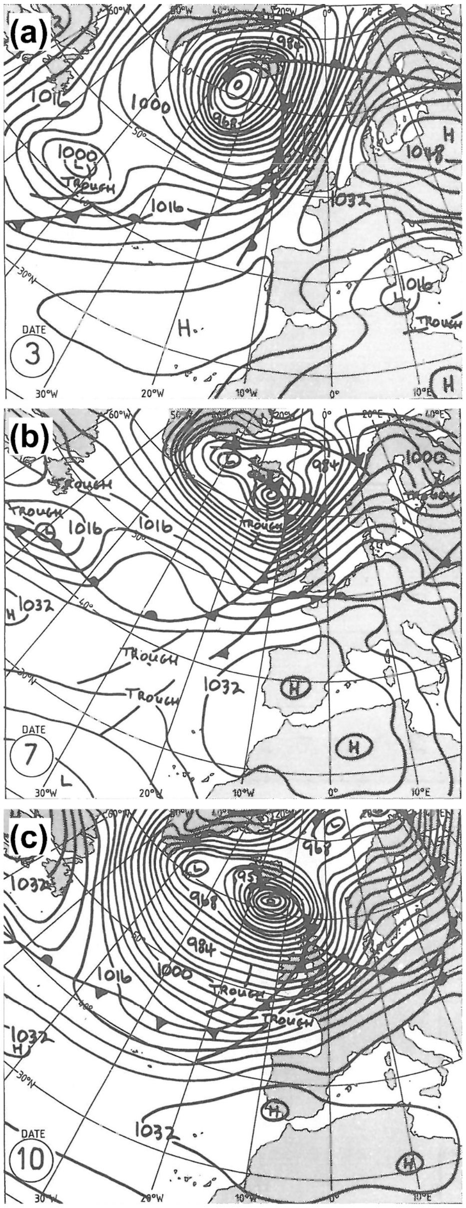

Surface analysis charts for 1200 UTC on (a) 3, (b) 7 and (c) 10 January 1993 (taken from Weather Log, 1993). The extremely deep cyclone in (c) is the Braer storm.
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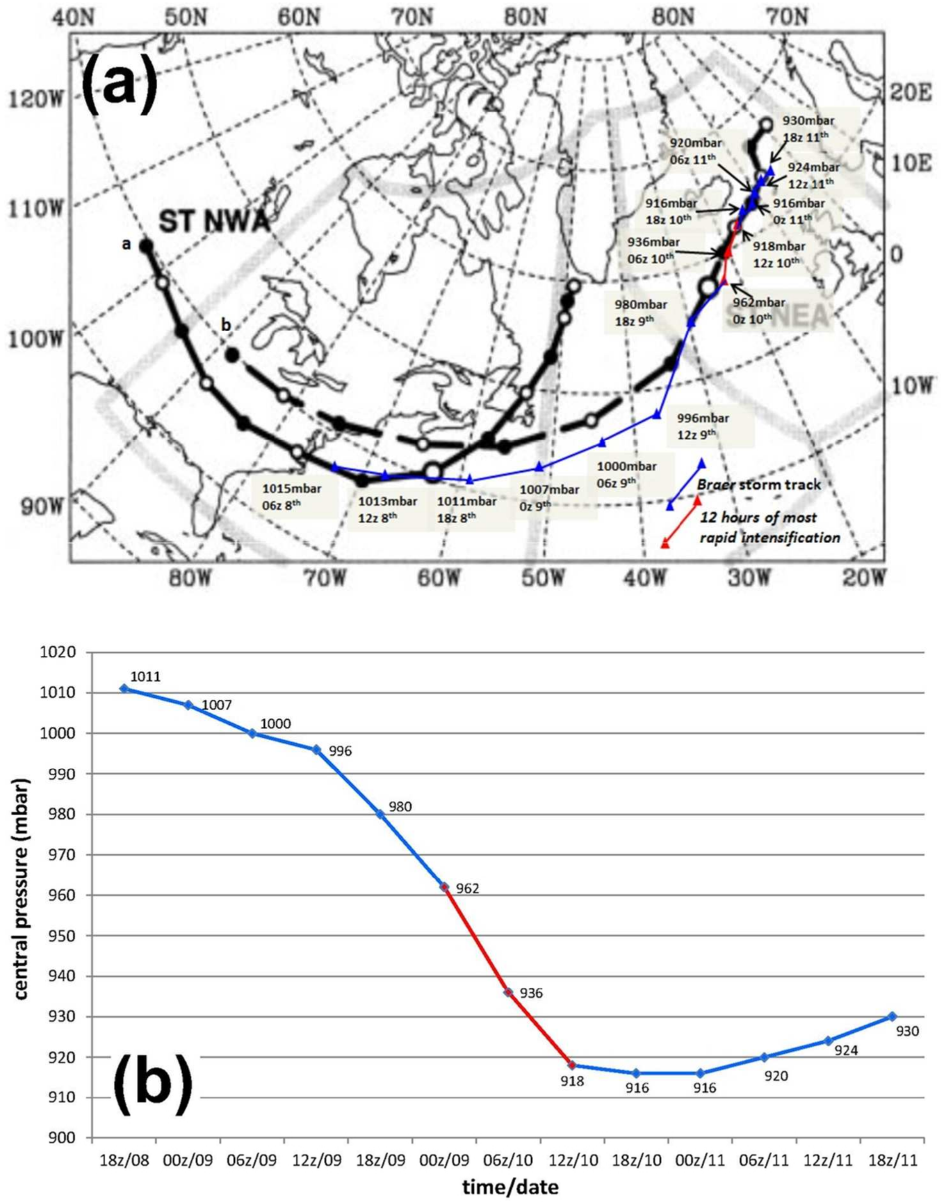
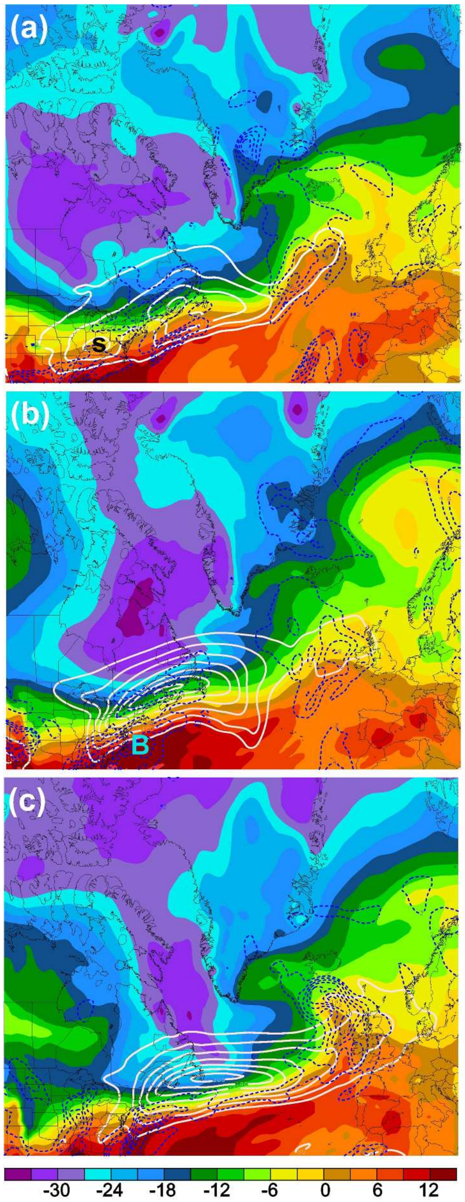


Evolution of the Braer storm based on ECMWF ERA-Interim re-analysis data. (a) Track (blue line) superimposed over mean storm track of explosively deepening cyclones over the North Atlantic (black lines a - North West Atlantic and b - North East Atlantic) as found by Wang and Rogers (2001). Triangles mark the centre of the Braer storm at time shown. Core pressures are also given. (b) Core pressure evolution, labels are core pressure in mbar. The 12 hours of most rapid deepening are indicated by red lines in (a) and (b). Dates are all in January 1993.
89x115mm (300 x 300 DPI)



200 mbar wind speeds (white contour every 20 kn from 80 kn) plotted over 850 mbar temperatures (colour fill) and divergence at 300 mbar (blue dashed contour every 2.10-5 s-1 starting from 2.10-5 s-1) for (a) 0000 UTC 7 January, (b) 1800 UTC 8 January and (c) 0600 UTC 10 January 1993. ‘s’ is the region of high winds likely part of the sub-tropical jet and the blue ‘B’ in panel (b) marks the location where the Braer storm first appeared at the surface. Maximum jet speeds exceed 200 kn in (b) and (c). The plots are based on ECMWF ERA-Interim re-analysis data.
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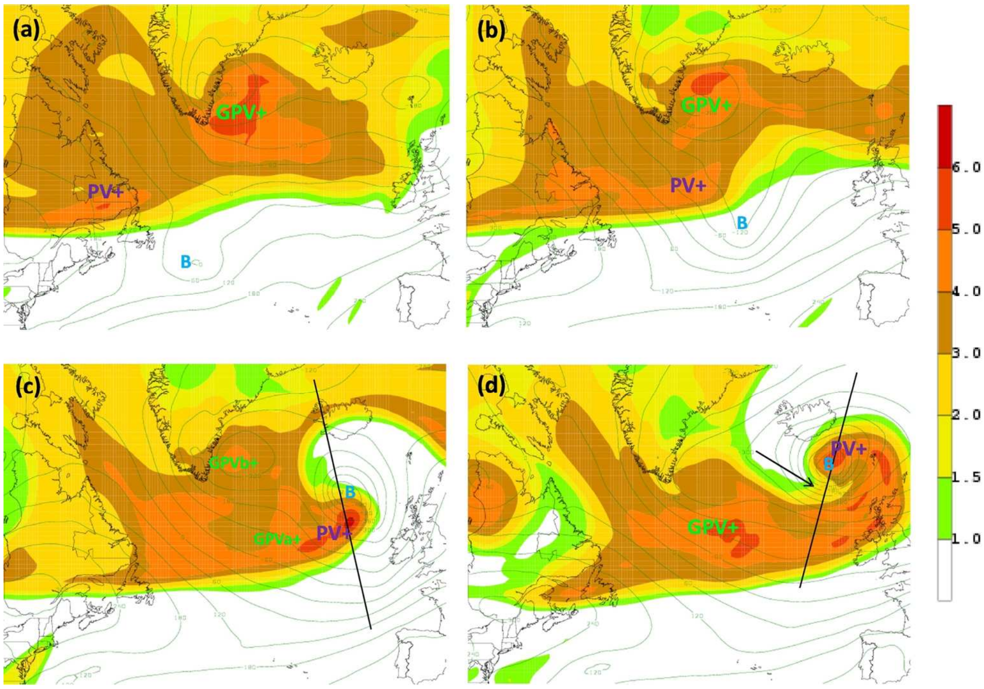

Upper tropospheric potential vorticity averaged over the 250 mbar to 450 mbar layer (colour fill, in PVU) and 1000 mbar height (contoured every 50 gpm) at 0600 UTC 9 January (a), 1800 UTC 9 January (b), 0600 UTC 10 January (c) and 1800 UTC 10 January 1993 (d). Blue 'B' marks position of the Braer storm at the surface at each time, 'PV+' marks the location of the upper PV anomaly and 'GPV+' marks the upper PV anomaly generated by Greenland's orography. Thin black lines in (c) and (d) are roughly the location along which the cross sections in Fig. 6 were taken. Black arrow indicates the developing low PV tongue. The plots are based on ECMWF ERA-Interim re-analysis data.
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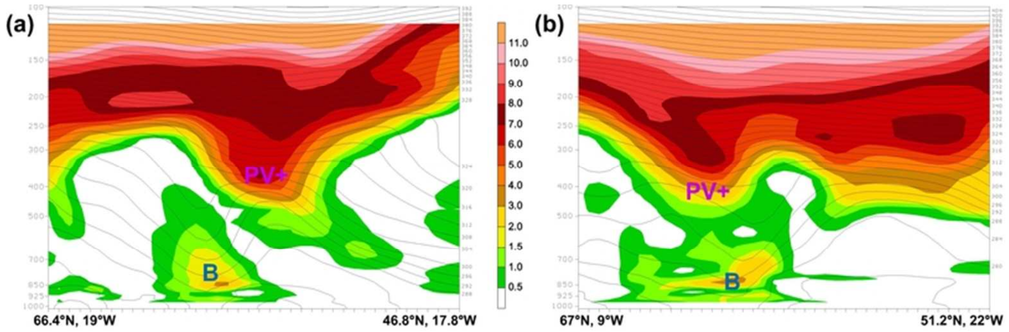
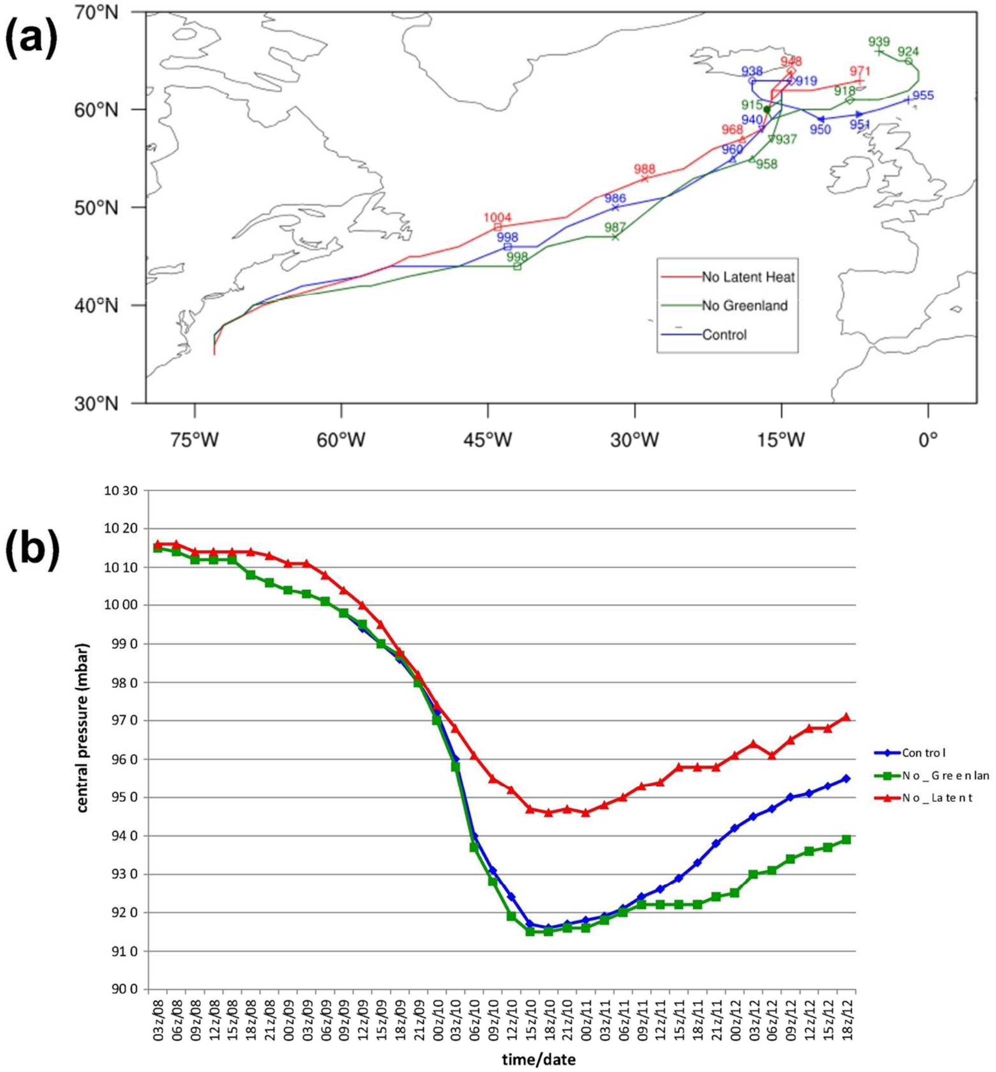
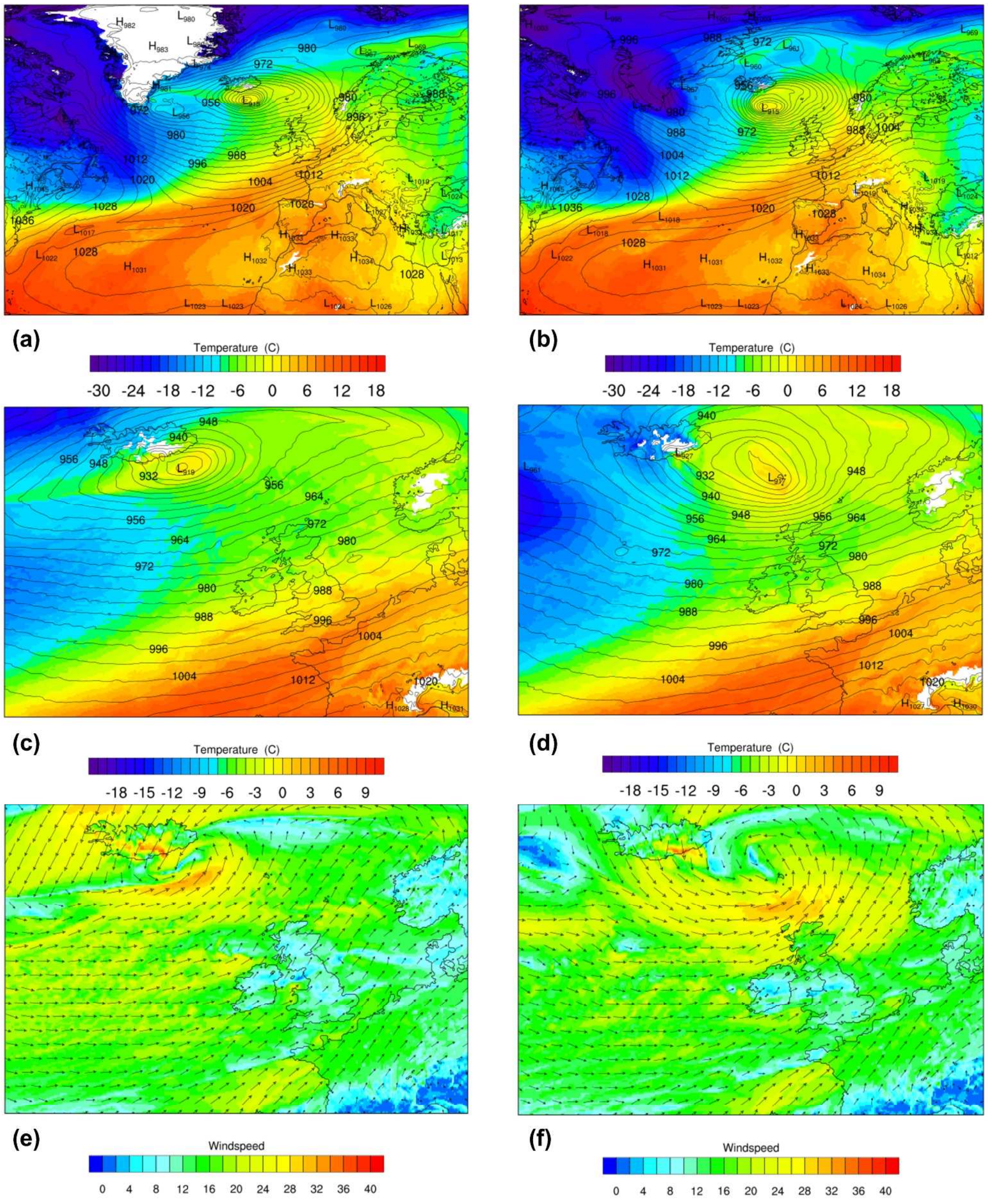


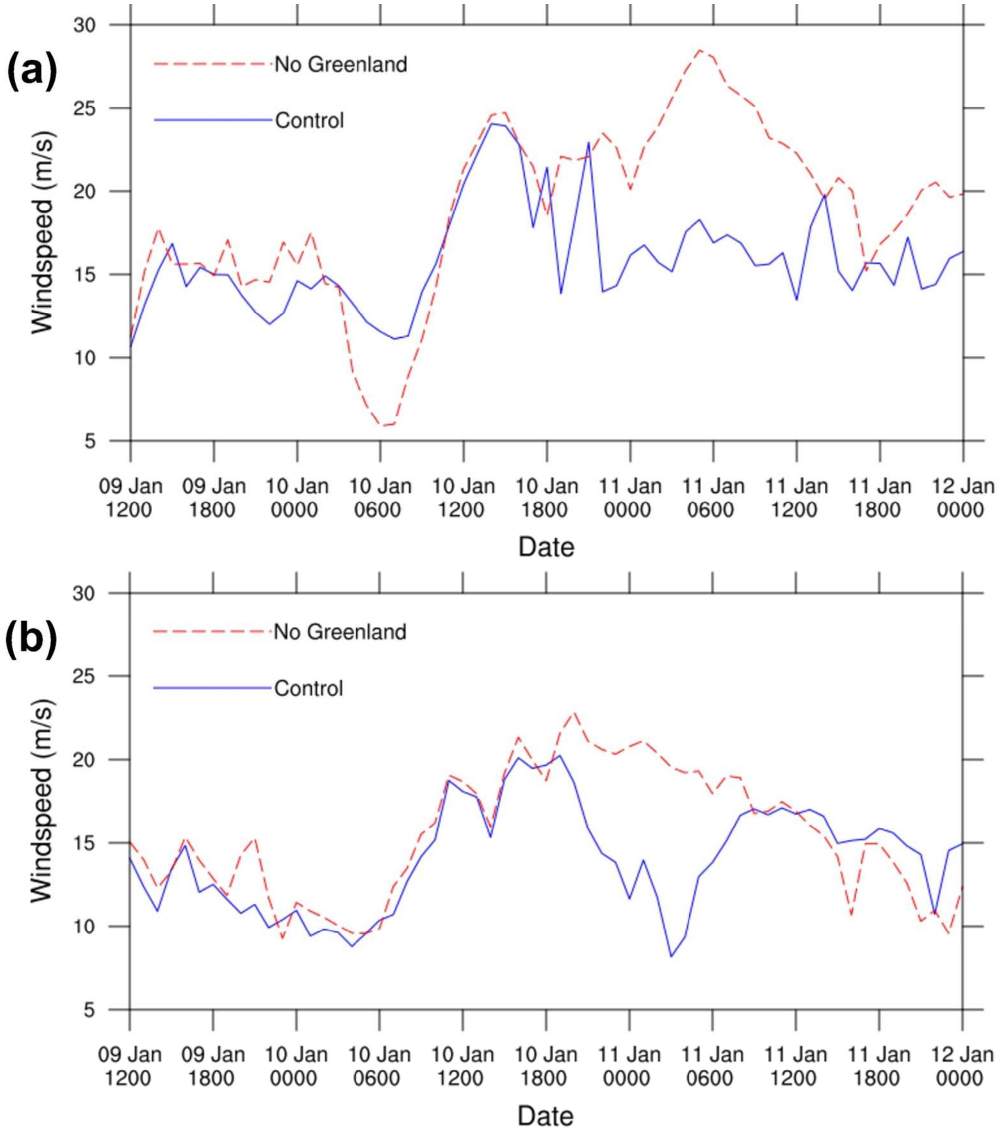
Cross sections through the centre of the Braer storm along the black lines marked in Fig. 5, showing potential vorticity (colour fill, in PVU with the same scale as in Fig. 5) and potential temperature (contours every 4K, dark blue) at 0600 UTC 10 January (a) and 1800 UTC 10 January 1993 (b). ‘PV+’ is the upper PV anomaly as in Fig. 5, ‘B’ is the centre of the surface cyclone as in Fig. 5. The plots are based on ECMWF ERA-Interim re-analysis data.
68x22mm (300 x 300 DPI)



WRF sensitivity experiments. (a) Tracks and core pressures of the modelled Braer storm in the control, no latent heat and no Greenland experiments. (b) Corresponding evolution of the core pressure (in mbar). 118x127mm (300 x 300 DPI)



Control (left side; (a), (c) and (e)) and No Greenland (right side; (b), (d) and (f)) sensitivity experiments with WRF. Panels (a) and (b) are 850 mbar temperatures (colour fill) and sea level pressure (contoured every 4 mbar) for 1800 UTC 10 January 1993; panels (c) and (d) are the same for 0300 UTC 11 January 1993 and zoomed in over the United Kingdom. Panels (e) and (f) are 10 m wind speeds (colour fill) and wind vectors (black arrows) for 0300 UTC 11 January 1993.
255x309mm (300 x 300 DPI)



Model time series of 10 m wind speed at two grid points close to (a) Lerwick and (b) Edinburgh. Blue is the control run and red dashed is the sensitivity experiment with Greenland's orography removed.
130x147mm (300 x 300 DPI)