The Meteorological Magazine

December 1990

Impact of two observations on a model forecast
Battle of Britain weather
Road slipperiness

HMSO

Met.O.992 Vol. 119 No. 1421

First published 1990

HMSO

HMSO publications are available from:

HMSO Publications Centre
(Mail and telephone only)
PO Box 276, London, SW8 5DT
Telephone orders 071-873 9090
General enquiries 071-873 0011
(queuing system in operation for both numbers)

HMSO Bookshops
49 High Holborn, London, WC1V 6HB 071-873 0011 (counter service only)
258 Broad Street, Birmingham, B1 2HE 021-643 3740
Southey House, 33 Wine Street, Bristol, BS1 2BQ (0272) 264306
9–21 Princess Street, Manchester, M60 8AS 061-834 7201
80 Chichester Street, Belfast, BT1 4JY (0232) 238451
71 Lothian Road, Edinburgh, EH3 9AZ 031-228 4181

HMSO's Accredited Agents
(see Yellow Pages)

and through good booksellers

The
Meteorological
Magazine

December 1990
Vol. 119 No. 1421

551.509.52:551.507.2:551.508.822

The impact of surface and radiosonde observations from two Atlantic ships on a numerical weather prediction model forecast for the storm of 25 January 1990

J.T. Heming
Meteorological Office, Bracknell

Summary

At 1200 UTC on 24 January two Atlantic ships, positioned near the centre of a developing depression, reported surface and upper-air observations. In the next 24 hours the depression deepened explosively and caused much damage as it crossed the United Kingdom. The impact of these ships' data on a forecast from a numerical weather prediction model is examined with particular reference to the storm's development.

1. Introduction

The storm of 25 January 1990 tracked across the United Kingdom causing extensive damage and loss of life throughout a wide area (McCallum 1990). The depression reached its greatest intensity during the late afternoon, having earlier crossed southern Scotland. As a result, most of England and Wales experienced severe gale-force winds at times throughout the day and in some coastal areas winds reached storm force.

During the late afternoon and early evening of 24 January the Meteorological Office issued warnings to the military and civilian population of the severity of the impending storm and of possible structural damage. Numerical weather prediction (NWP) models are a vital source of guidance to forecasters and on this occasion they had products from the 1200 UTC run of the limited-area (fine-mesh) model, which covers Europe and the North Atlantic, and the 1200 UTC run of the global model.

The UK operational global and fine-mesh models each have 15 levels and a grid spacing of approximately 150 km and 75 km respectively. The principles of the 15-level model are described by Gadd (1985). The global model produces a 5-day forecast every 12 hours from 0000 and 1200 UTC starting analyses, whereas the fine-mesh model produces operational forecasts for the period up to 36 hours ahead and is run on a 12-hour cycle as follows:

0000/1200 UTC	Global analysis interpolated onto the fine-mesh grid
0300/1500 UTC	Assimilation
0600/1800 UTC	Intermediate assimilation and 36-hour forecast
0600/1800 UTC	Update assimilation including data received after the intermediate assimilation
0900/2100 UTC	Assimilation
1200/0000 UTC	Assimilation and 36-hour forecast.

Each fine-mesh assimilation accepts data within a time window of ± 90 minutes from the nominal analysis time. The assimilation method, known as the 'Analysis

Correction Scheme', gives each observation its maximum weight in the assimilation at its validity time. It is described in more detail by Lorenc *et al.* (1991).

The facility exists for forecasters to reject or correct observations before each run of the global and fine-mesh models. It is also possible for them to create 'bogus' observations for use in data-sparse areas or as support for existing observations. Such manual action is known as Intervention and is part of the continual monitoring of data in the Central Forecasting Office (CFO) at Bracknell.

This article assesses the impact of the surface and upper-air observations from two Atlantic ships on the fine-mesh forecast from data time 1200 UTC on 24 January. Both ships were positioned close to the developing depression, one just to the north and the other just to the south, at the time of the 1200 UTC analysis.

2. Summary of the life of the storm

On Tuesday 23 January the depression was part of a complex shallow area of low pressure moving slowly eastwards off the eastern seaboard of North America. Late in the day, the associated baroclinic wave engaged a short-wave upper trough and the depression began to deepen. During Wednesday 24 January the depression centre deepened by 37 mb in 24 hours and moved rapidly east in a powerful westerly jet, nearing the west coast of Ireland by the end of the day. On 25 January the storm tracked across Ireland and southern Scotland reaching its greatest intensity over the North Sea of 949 mb at approximately 1600 UTC. Most of England and Wales experienced severe gales. Mean wind speeds were in excess of 50 kn in many coastal areas and gusts in excess of 90 kn were reported. Fig. 1 is an analysis of the observed mean-sea-level pressure valid at 1200 UTC on 25 January. During 26 January the storm continued

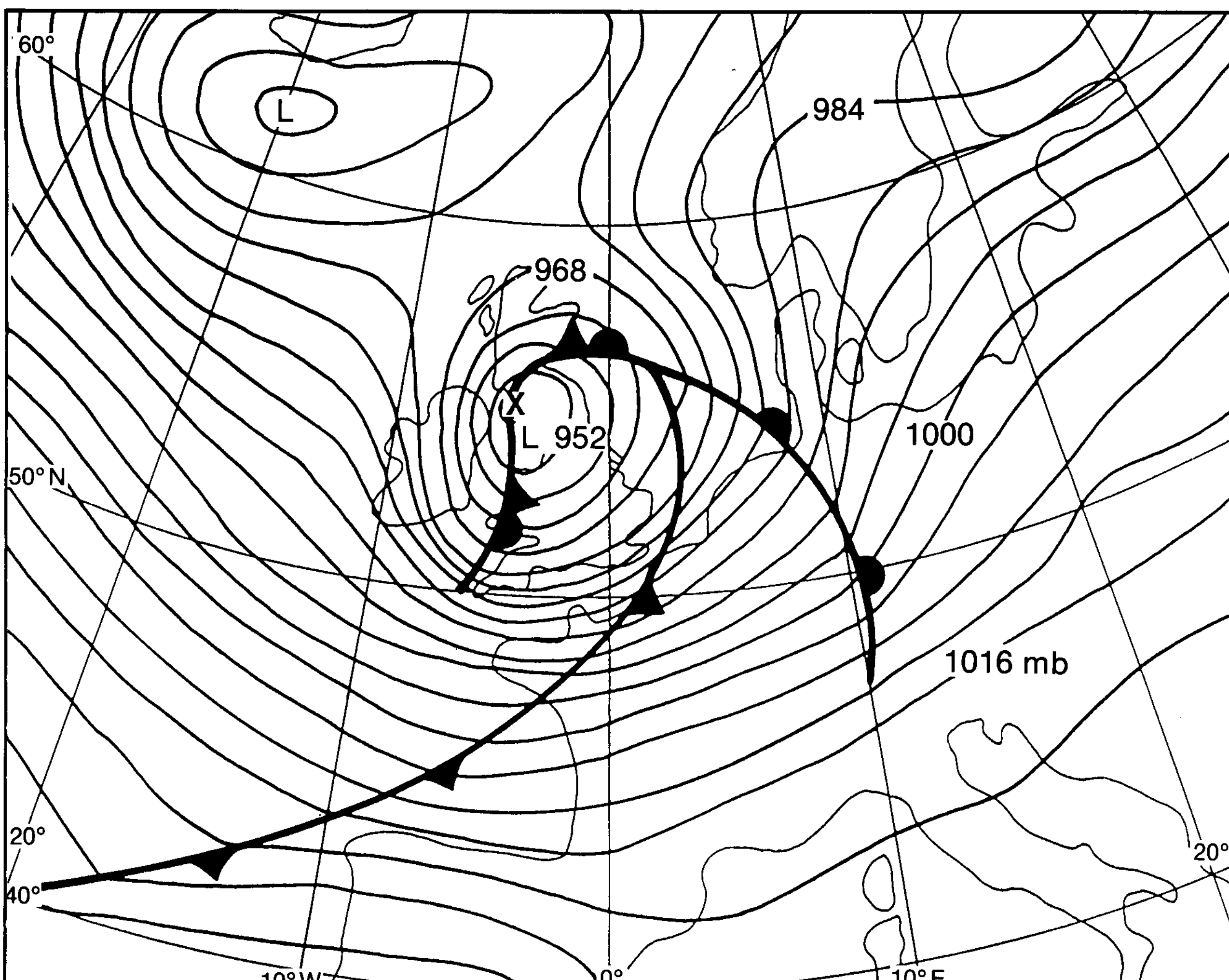

Figure 1. Analysis of observed mean-sea-level pressure for 1200 UTC on 25 January 1990.

its rapid eastward movement towards Denmark, then filled as it moved across southern Scandinavia.

3. Numerical model guidance for the storm

3.1 Forecasts before 1200 UTC on 24 January

The UK operational global model provided good guidance beyond 4 days ahead as to the development of the Great Storm of October 1987 (Gadd and Morris 1988). On this occasion the global model gave guidance during the 5 days preceding the storm which indicated that a depression would cross the United Kingdom on 25 January. Of particular interest is the 108-hour forecast from the 0000 UTC global analysis on the 21st verifying at 1200 UTC on the 25th (Fig. 2) which was used to warn of stormy conditions on Thursday the 25th in the farming forecast on television presented on the previous Sunday (21st). Mean surface winds of up to 50 kn were forecast in the approaches to south-west Ireland by this particular run.

The earliest operational fine-mesh forecast valid for 1200 UTC on the 25th, when the storm was expected at its greatest intensity, was the 36-hour forecast from data time 0000 UTC on the 24th (Fig. 3). This forecast runs the depression across the south of England as a relatively shallow wave, and both the depth of the depression and the strength of the surface winds are greatly underpredicted. Indeed, this forecast is considerably inferior to the global-model forecast 3 days earlier.

Operational fine-mesh forecasts from intermediate analyses at 0600 and 1800 UTC are available for guidance in the CFO. On this occasion the 30-hour forecast from the 0600 UTC analysis on the 24th showed a marked improvement on the previous forecast as can be seen in Fig. 4. The depression has a distinct centre and is some 8 mb deeper than in the previous forecast. This improvement was found to be due to a wide range of observational data valid between 0130 and 0730 UTC, and also the use of the 0000 UTC global analysis as a start field for the subsequent 12-hour fine-mesh assimilation cycle (Heming 1990). However, this forecast is still poor when compared with the verifying analysis for 1200 UTC on the 25th (Fig. 1).

3.2 Data in the North Atlantic

At 1200 UTC on the 24th there were many merchant ships in the North Atlantic reporting surface observations. There were three Ocean Weather Ships (OWSs) operating at the time, reporting surface and upper-air observations. Two of these, situated at stations Charlie and Lima (hereafter referred to as OWS C and OWS L), were positioned to the west of the United Kingdom. Upper-air reports were also received from some merchant ships which are part of the Automated Shipborne Aerological Program. These are commonly known as ASAPs. Fig. 5 shows the distribution of marine surface and upper-air observations at 1200 UTC

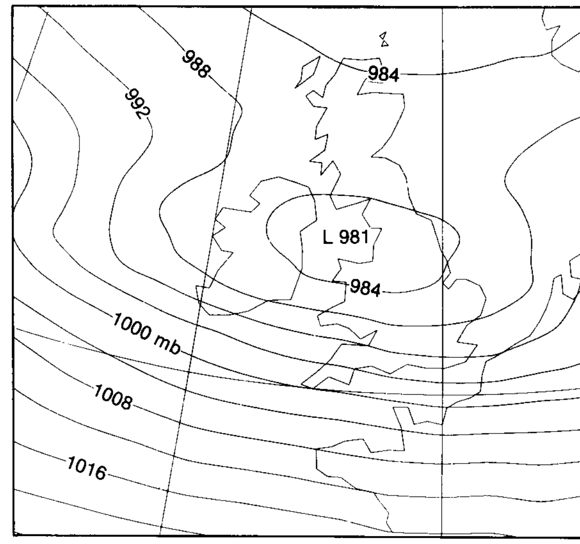

Figure 2. T+108 global model forecast of mean-sea-level pressure. Data time 0000 UTC on 21 January 1990.

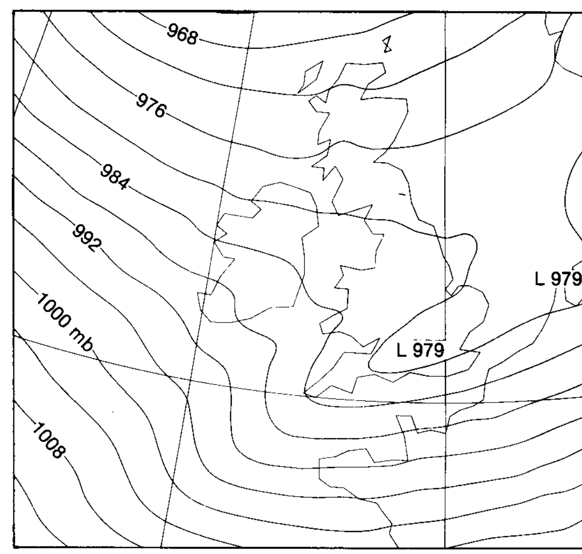

Figure 3. T+36 operational fine-mesh forecast of mean-sea-level pressure. Data time 0000 UTC on 24 January 1990.

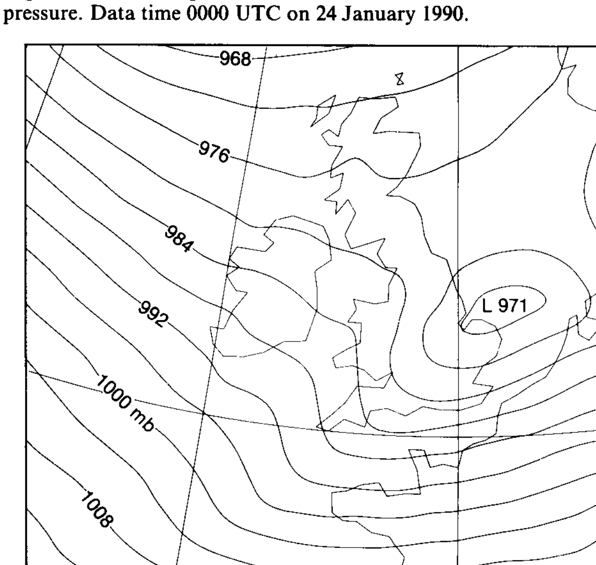

Figure 4. T+30 operational fine-mesh forecast of mean-sea-level pressure. Data time 0600 UTC on 24 January 1990.

on the 24th. Upper-air data in the North Atlantic were fairly sparse and just two ships were reporting upper-air observations in the vicinity of the developing storm. These were OWS C positioned just to the north of the depression and the ASAP with call-sign ONDA positioned just to the south. In addition to surface and upper-air data from ships, data was also available from aircraft, drifting buoys and land stations within the fine-mesh area at 1200 UTC. No satellite sounding data were received by the 1355 UTC fine-mesh data cut-off.

For use in NWP models, radiosonde observations, at standard as well as special levels, are used to calculate mean values about each of the model levels as described by Atkins and Woodage (1985). The layer-mean values for the two ships' reports are shown in Tables I and II together with the background field values. The back-

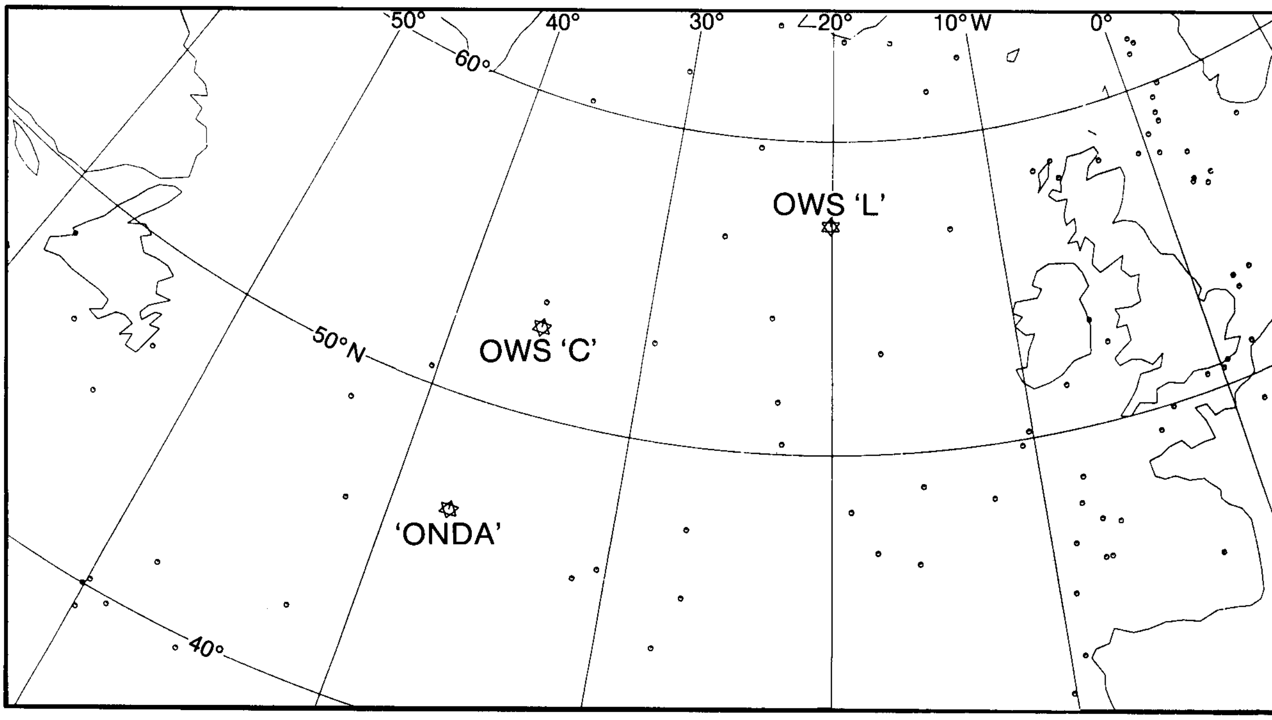

Figure 5. Distribution of surface and upper-air marine observations at 1200 UTC on 24 January 1990 marked by circles and stars respectively.

Table I. SYNOP (1200 UTC) and TEMP (1100 UTC) observations (Obs) from OWS C (52.7° N, 35.5° W) on 24 January 1990 as used by the model, with values of the background (Back) given alongside. Vertical averaging has been performed on the full observed profile to give values at each model level.

	Level (mb)	MSLP Back	Temperature (°C) Obs	Back	Wind (° / kn) Obs	Back
SYNOP	1001.3	1003.4	1.3	3.0	300/ 17	292/ 17
TEMP	1000.0	1003.6	1.2	2.9	295/ 14	292/ 17
	997.0		1.0	2.7	294/ 14	292/ 17
	974.9		−0.8	1.0	293/ 14	292/ 17
	934.8		−4.2	−2.3	292/ 15	294/ 18
	869.8		−10.0	−6.9	287/ 16	306/ 15
	789.9		−16.2	−12.6	271/ 20	299/ 14
	690.1		−18.3	−19.8	255/ 31	277/ 22
	590.1		−24.1	−24.0	249/ 49	263/ 36
	490.1		−33.9	−33.4	245/ 75	255/ 50
	390.0		−43.5	−44.1	238/117	247/ 66
	309.9		−54.0	−53.4	240/122	246/ 82
	249.8		−58.7	−55.7	244/114	247/ 93
	189.7		−59.6	−55.0	246/ 99	250/100
	124.8		−66.6	−62.0	250/ 92	255/106
	66.0		—	—	/	/
	25.0		—	—	/	/

Table II. As Table I, but observations from ONDA (46.5° N, 37.4° W) on 24 January 1990

	Level (mb)	MSLP Back	Temperature (°C) Obs	Temperature (°C) Back	Wind (°/kn) Obs	Wind (°/kn) Back
SYNOP	997.1	1006.2	14.1	11.7	230/ 50	261/ 33
TEMP	996.0	1006.7	13.2	11.1	230/ 51	265/ 34
	993.0		13.0	10.9	230/ 51	265/ 35
	971.0		11.7	9.1	234/ 53	266/ 38
	931.1		9.3	6.1	240/ 57	267/ 44
	866.3		5.3	2.1	247/ 66	267/ 49
	786.8		2.3	−1.9	247/ 75	264/ 55
	687.4		−1.8	−8.3	245/ 85	258/ 65
	587.8		−9.9	−12.2	245/ 95	253/ 85
	488.1		—	—	245/106	249/102
	388.4		—	—	/	/
	308.8		—	—	/	/
	249.0		—	—	/	/
	189.2		—	—	/	/
	124.5		—	—	/	/
	65.7		—	—	/	/
	24.9		—	—	/	/

ground field is the fine-mesh model's 3-hour forecast from the 0900 UTC analysis. Large differences between observations and background (increments) indicate large errors in the short-term forecasts at these locations and the data assimilation has to make large adjustments to the numerical field to accommodate the observation. In this case the surface pressure observation from both the SYNOP (surface observation) and TEMP (upper-air observation) from ONDA were flagged by the model's quality control and consequently not used in the fine-mesh model's data assimilation stage. The observations were flagged because these observations were substantially different from the background values and there were no nearby observations which supported such large increments. The 'Intervention' forecaster on duty at the time perceived these model rejections to be incorrect, since the depression was deepening more rapidly than the background field suggested, and so provided 'bogus' surface and upper-air data in the vicinity of ONDA to support the ship's observation and prevent it being rejected in the 1200 UTC run of the global model that followed. The principles of model data quality control and use of 'bogus' data are described by Atkins and Woodage (1985). It must also be noted that the ascent from OWS C reached the 100 mb level whereas that from ONDA only reached the 400 mb level.

3.3 Fine-mesh analyses with and without OWS C and ONDA

Figs 6(a) and 6(b) show the operational fine-mesh analyses at 1200 UTC on the 24th with the positions of OWS C and ONDA marked. A rerun of the model analysis without the TEMP and SYNOP reports from OWS C and ONDA show some small differences from the operational versions of the mean-sea-level pressure, 500 mb height and 1000–500 mb thickness fields (Figs 7(a) to 7(c)).

Despite the surface pressure observations from ONDA being rejected by the model, Fig. 7(a) shows that the effect of the remaining unflagged part of the TEMP report, together with OWS C's report, was to reinforce the western centre of the low pressure complex, although by not nearly as much as the surface observations indicated.

Fig. 7(b) shows differences between the two 500 mb height fields. The positive values to the south of the depression and negative to the north clearly indicate a tightening of the contour gradient in this region as a direct result of the inclusion of the two ships' data. Fig. 7(c) shows the differences between the two 1000–500 mb thickness fields. The negative values to the north and the positive values of even greater magnitude to the south indicate both a tightening of the thermal gradient and an amplification of the thermal ridge associated with the depression. The analysis differences for both these fields are consistent with the temperature and wind-speed increments for the observations from both OWS C and ONDA. Tables I and II show that the temperature increments from OWS C's ascent are nearly all negative and those from ONDA are all positive. The ascent from OWS C also shows a strong jet around 300 mb — absent in the background values — and positive wind-speed increments of up to 51 kn between the 700 and 250 mb levels.

3.4 Fine-mesh forecasts with and without OWS C and ONDA

Fig. 8(a) shows the operational fine-mesh 24-hour mean-sea-level pressure forecast verifying at 1200 UTC

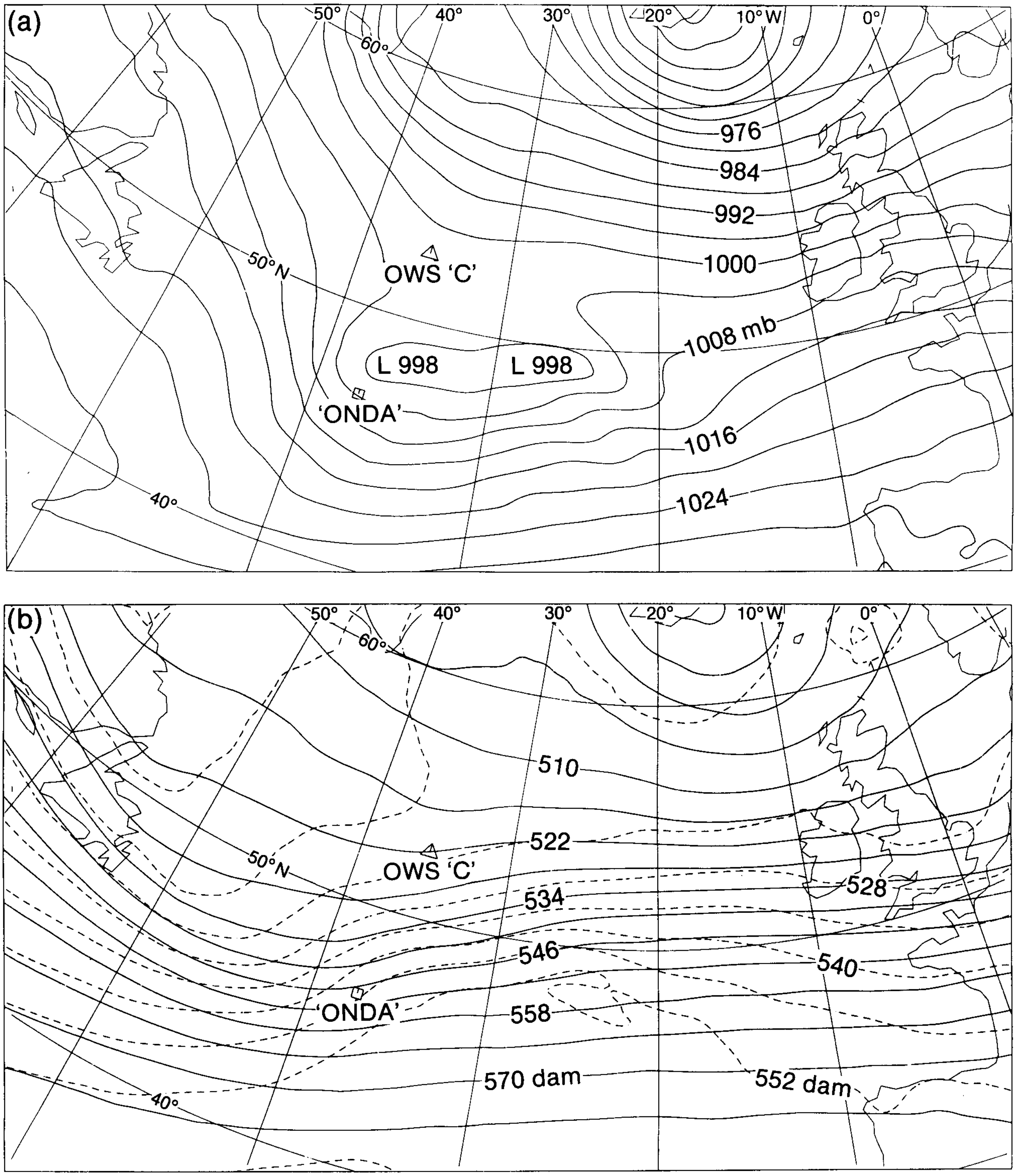

Figure 6. T+00 operational fine-mesh analysis for 1200 UTC on 24 January 1990, (a) mean-sea-level pressure, and (b) 500 mb height (full lines) and 1000–500 mb thickness (dashed lines).

on the 25th. Fig. 8(b) is the corresponding forecast from the analysis without observations from OWS C and ONDA. Whilst the operational forecast was still some 9 mb too shallow and too far south in its forecast of the low centre when compared with the verifying analysis (Fig. 1), it is clear that the inclusion of the two ships has had a beneficial impact. The forecast run from the analysis without OWS C and ONDA features a low centre which is much broader and 8 mb shallower than the operational forecast.

Figs 9(a) and 9(b) show the 24-hour forecasts from the operational and rerun analyses respectively for the 500 mb height and 1000–500 mb thickness fields. The operational forecast features a significant amplification of the thermal ridge and the upper trough when compared with the forecast from the analysis without

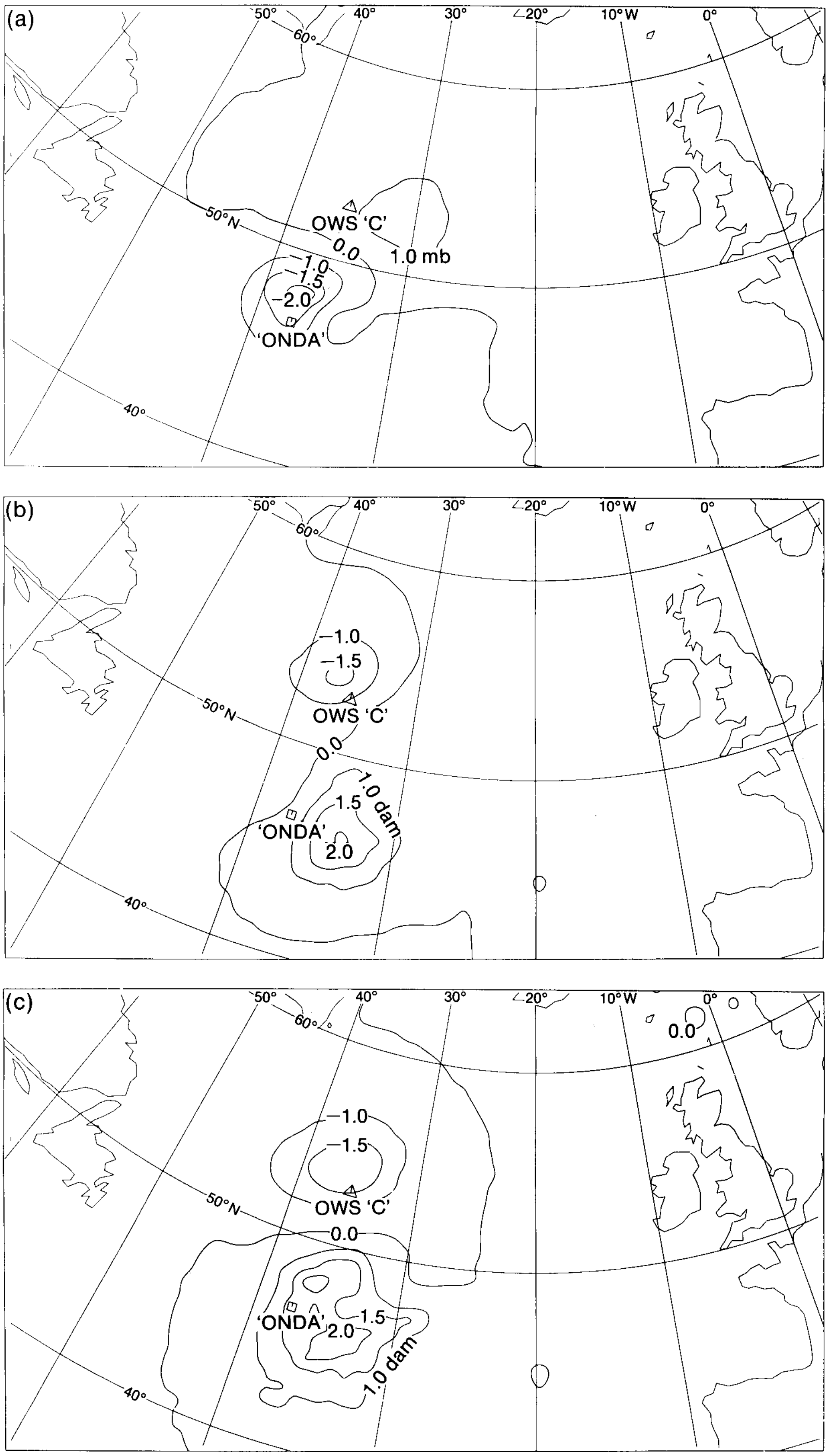

Figure 7. Difference between fine-mesh operational analysis and analysis without OWS C and ONDA for 1200 UTC on 24 January 1990, (a) mean-sea-level pressure, (b) 500 mb height, and (c) 1000–500 mb thickness. Positions of the two ships marked.

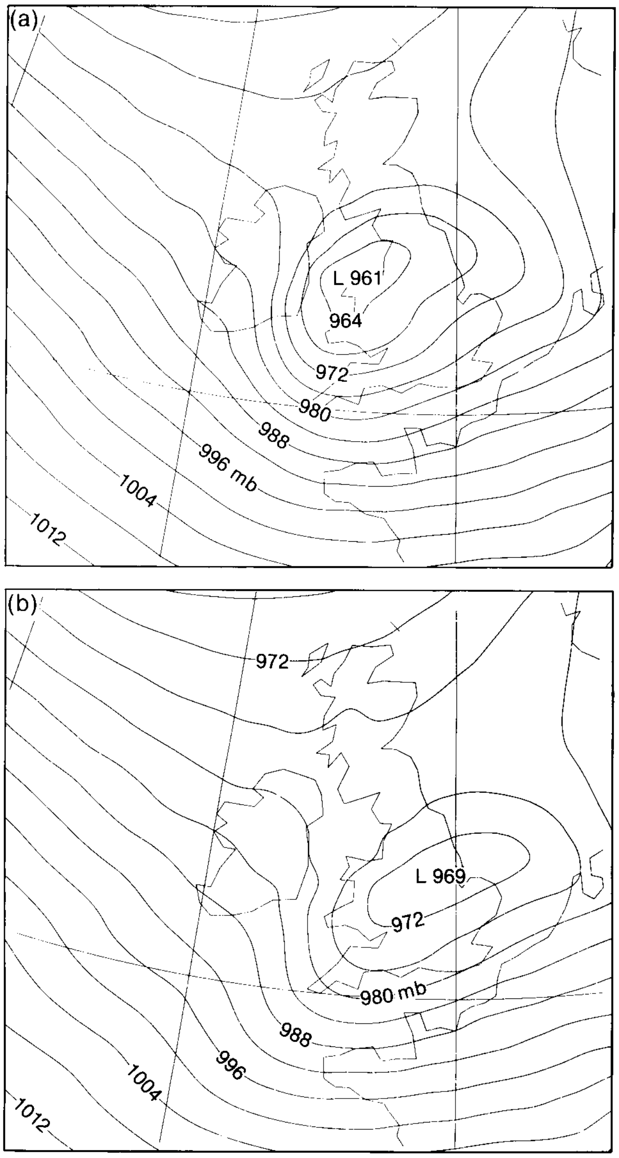

Figure 8. T+24 fine-mesh forecast of mean-sea-level pressure. Data time 1200 UTC on 24 January 1990, (a) operational run, and (b) rerun without OWS C and ONDA.

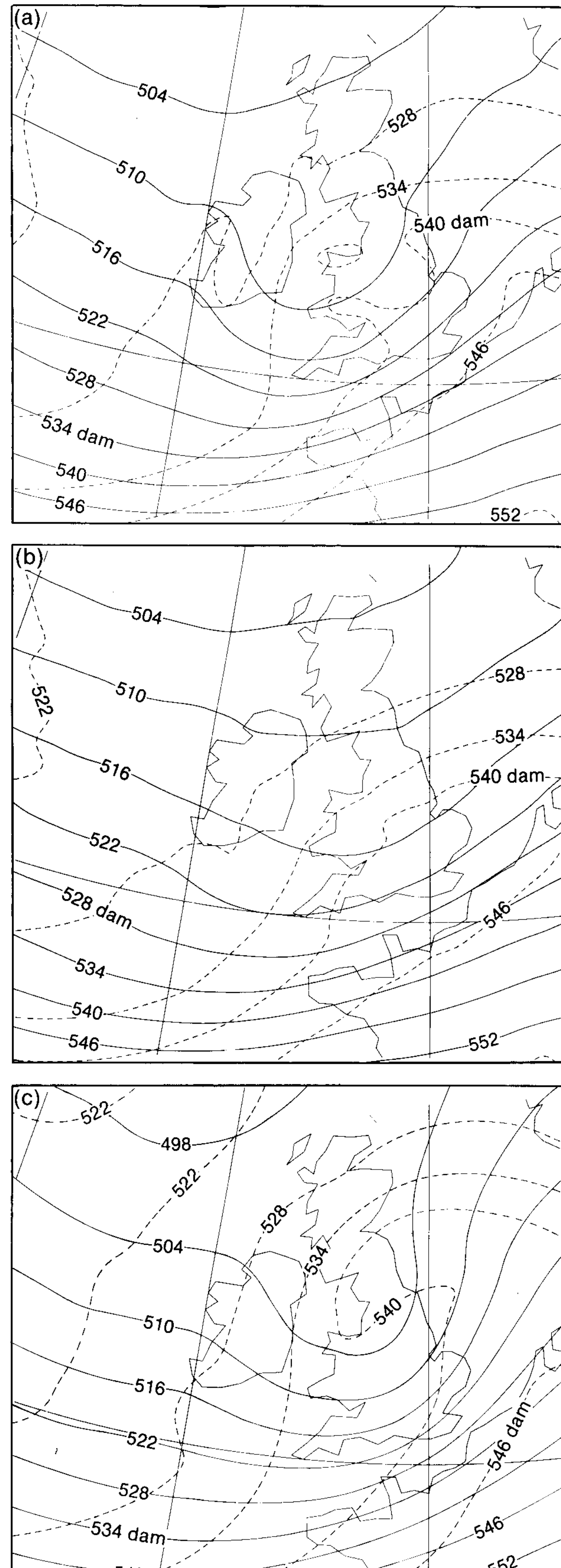

Figure 9. T+24 fine-mesh forecast of 500 mb height (full lines) and 1000–500 mb thickness (dashed lines). Data time 1200 UTC on 24 January 1990, (a) operational run, (b) rerun without OWS C and ONDA, and (c) verifying analysis for 1200 UTC on 25 January 1990.

OWS C and ONDA. This is clearly a much better forecast on inspection of the verifying model analysis (Fig. 9(c)).

To determine the impact of each ship separately, forecasts were run from an analysis without OWS C (Fig. 10(a)) and an analysis without ONDA (Fig. 10(b)). It appears that in both cases there is a similar impact on the depth of the low, although the observation from ONDA has the effect of correctly placing the centre about 200 km further west in the forecast. It is interesting to note that the sum of the individual impacts of OWS C (5 mb deepening) and ONDA (3 mb deepening and a 200 km movement of the centre) is equal to their combined impact (8 mb deepening and 200 km movement of the centre).

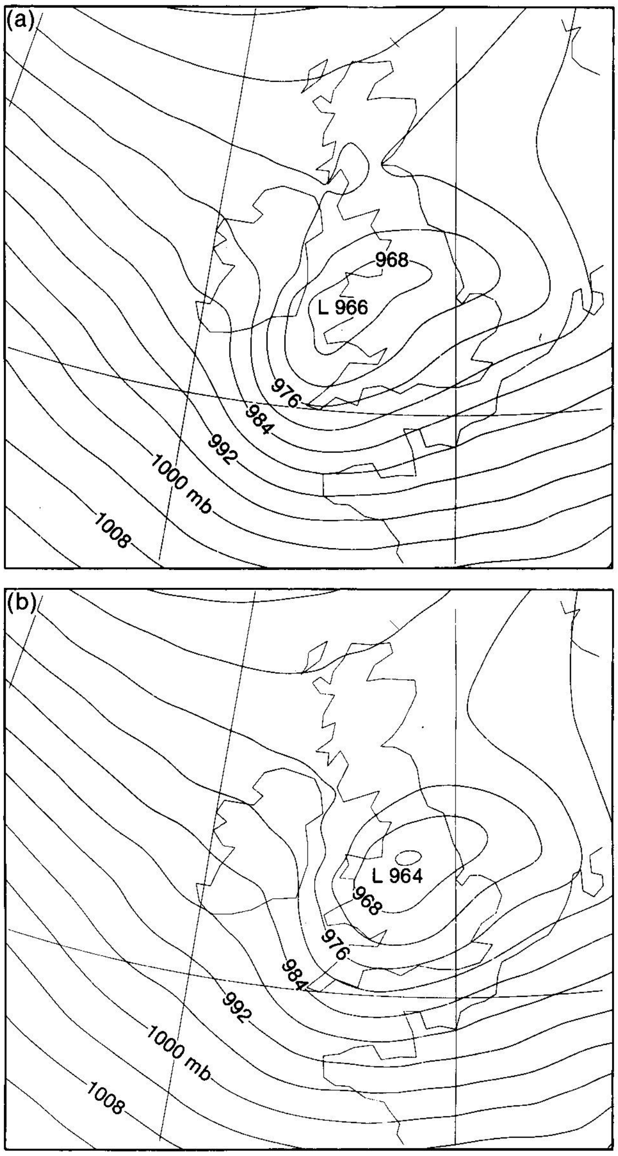

Figure 10. T+24 fine-mesh forecast of mean-sea-level pressure. Data time 1200 UTC on 24 January 1990, (a) rerun without OWS C only, and (b) rerun without ONDA only.

4. Surface winds over the United Kingdom

Of greatest importance to the civilian population was the surface wind which was at its most severe between 0900 and 1800 UTC on the 25th. Figs 11(a) to 11(c) show the operational forecasts of surface (10 m) wind speed verifying at 1200, 1500 and 1800 UTC on the 25th. These forecasts indicate mean wind speeds in excess of 40 kn over a wide area initially across the south-west of the United Kingdom, and later extending east and north along the English Channel and into Wales, eventually into the North Sea and the Low Countries by 1800 UTC. The forecast area of winds in excess of 50 kn moves up the Channel and just extends into south coast areas of England.

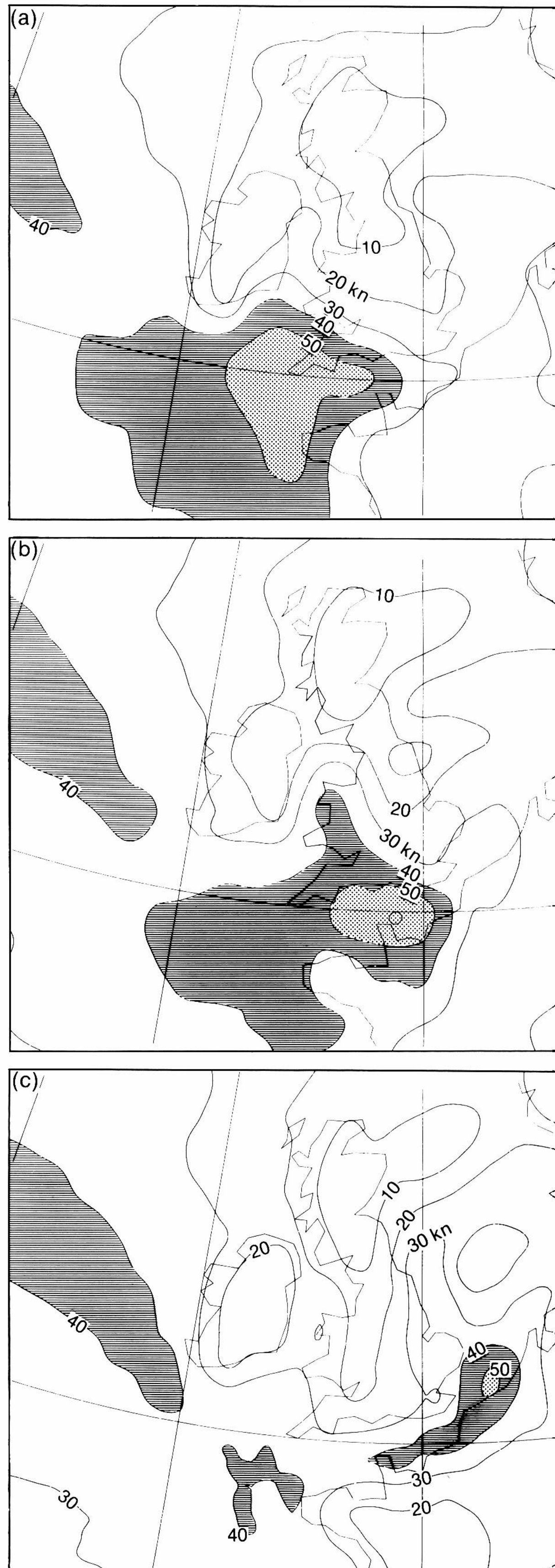

Figure 11. Operational fine-mesh forecast of surface (10 m) wind speed. Data time 1200 UTC on 24 January 1990, (a) T+24, (b) T+27, and (c) T+30. Hatched areas highlight the progression of the maximum winds.

At 1200 UTC the operational 24-hour forecast verifies well with observations of mean wind speed in Wales and the south and west of England. These range from 20 kn in North Wales to 60 kn along the south coast. Further east the observations are up to 15 kn stronger than the forecast. At 1500 UTC the operational forecast predicts the position of the strongest winds with a high degree of accuracy. In the English Channel a maximum wind strength of 59 kn was forecast and winds of up to 65 kn were reported. The forecast wind speeds are generally less than 15 kn different from the observations, with a few observations up to 25 kn different. Fig. 12 shows the reports of mean wind speeds and maximum gusts reported at 1500 UTC. At 1800 UTC the wind speeds forecast across the south and east of the United Kingdom verify well against the observations. However, the forecast for the north of England was not so good; several observations were more than 25 kn stronger than the forecast values.

The forecasts from the analysis without OWS C and ONDA (Figs 13(a)–13(c)) show a much smaller area of winds in excess of 40 kn than obtained from the operational forecast; the maxima of 50 kn at some fine-mesh grid points in the English Channel at 1500 UTC compare with 59 kn operationally. These are clearly inferior to the operational forecasts (Figs 11(a)–11(c)).

Some of the strongest winds experienced in the United Kingdom on 25 January 1990 were at Aberporth in south-west Wales between 1400 and 1500 UTC where a mean speed of 65 kn and a maximum gust of 93 kn were reported. The operational 27-hour forecast verifying at 1500 UTC (Fig. 11(b)) indicates mean wind speeds of up to 45 kn at fine-mesh grid points nearest and to the north and east of Aberporth. The forecast wind speeds at these grid points from the analysis without the two ships are up to 25 kn less. Even the forecast from the analysis just without ONDA predicts winds some 20 kn less than the operational forecast in places.

5. Conclusions

It has been found that the improvement between the fine-mesh forecast from 0000 UTC on the 24 January 1990, which featured a shallow complex depression of 979 mb positioned in the area of East Anglia (Fig. 3), and the forecast from 1200 UTC on the 24th, which predicted a much deeper low of 961 mb positioned over North Wales (Fig. 8(a)), was due to the combined effects of many observation types in the area of development in the North Atlantic over the intervening 12 hours

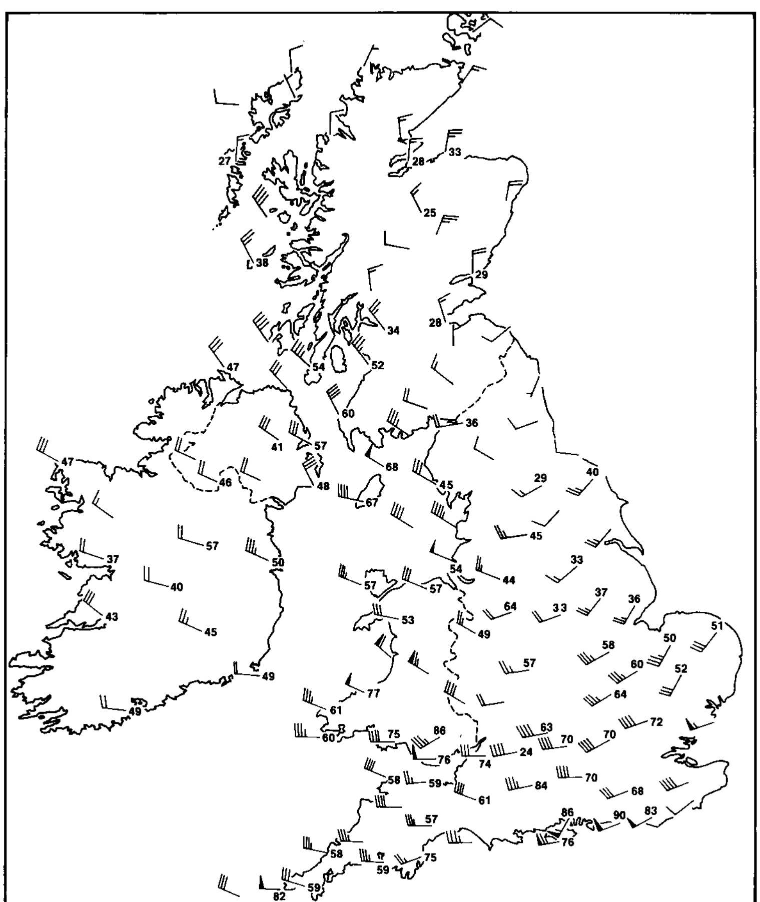

Figure 12. Observed 10-minute mean wind speeds (traditional wind arrows) and maximum gusts (if over 25 kn) within the previous hour at 1500 UTC on 25 January 1990.

(Heming 1990). The impact of two particular observations at 1200 UTC, the reports of OWS C and ONDA, has been studied in detail and it is shown that they make the largest single contribution to the improvement of the forecast. This clearly shows the value of upper-air data in the North Atlantic. Another important point to be made is that, on this occasion, small differences produced in the analysis, as a result of the inclusion of these two ships' observations, amplified to produce considerably larger differences in the 24-hour forecast.

Operationally, the forecaster was supplied with very good guidance from the fine-mesh model during the afternoon of 24 January with regard to the impending wind strengths, and warnings were issued to the military and civilian population in good time. The fine-mesh model is widely acclaimed in its ability to handle intense low-pressure systems owing to its high horizontal resolution. However, a limiting factor on forecast accuracy is the sparsity of observations in the North Atlantic, where most of the UK's weather systems originate. The problem is made worse in the fine-mesh model by its early data cut-off, mentioned earlier. It was found that the lack of observations in an area of explosive cyclogenesis was a contributary cause of the poor fine-mesh forecast of the Great Storm of October 1987. The inclusion of aircraft observations valid just outside the fine-mesh data time window made a vast improvement to the forecast (Lorenc *et al.* 1988). On 24 January 1990, two ships were positioned near one such area of low pressure in the North Atlantic that was set to deepen explosively. Their observations, received before the fine-mesh data cut-off, made a significant contribution to the quality of model guidance by providing vertical profiles of the atmosphere at a critical stage in the development of the severe storm which crossed the United Kingdom the following day.

Acknowledgements

The author would like to thank C.D. Hall for his assistance during this investigation and the preparation of this article, and E. McCallum for comments on a rough draft of the paper.

References

Atkins, M.J. and Woodage, M.J., 1985: Observations and data assimilation. *Meteorol Mag*, **114**, 227–233.

Gadd, A.J., 1985: The 15-level weather prediction model. *Meteorol Mag*, **114**, 222–226.

Gadd, A.J. and Morris, R.M., 1988: Guidance available at Bracknell for the storm of 15/16 October 1987, and the forecasters' conclusion at the time. *Meteorol Mag*, **117**, 110–117.

Heming, J.T., 1990: The impact of data on fine-mesh forecasts for the storm of January 25th 1990. (Unpublished, copy available in the National Meteorological Library, Bracknell.)

Lorenc, A.C., Bell, R.S., Davies, T. and Shutts, G.J., 1988: Numerical forecast studies of the October 1987 storm over southern England. *Meteorol Mag*, **117**, 118–130.

Lorenc, A.C., Bell, R.S. and MacPherson, B., (1991): The new Meteorological Office data assimilation scheme. (To be published in *Q J R Meteorol Soc.*)

McCallum, E., 1990: The Burns' Day storm, 25 January 1990. *Weather*, **45**, 166–173.

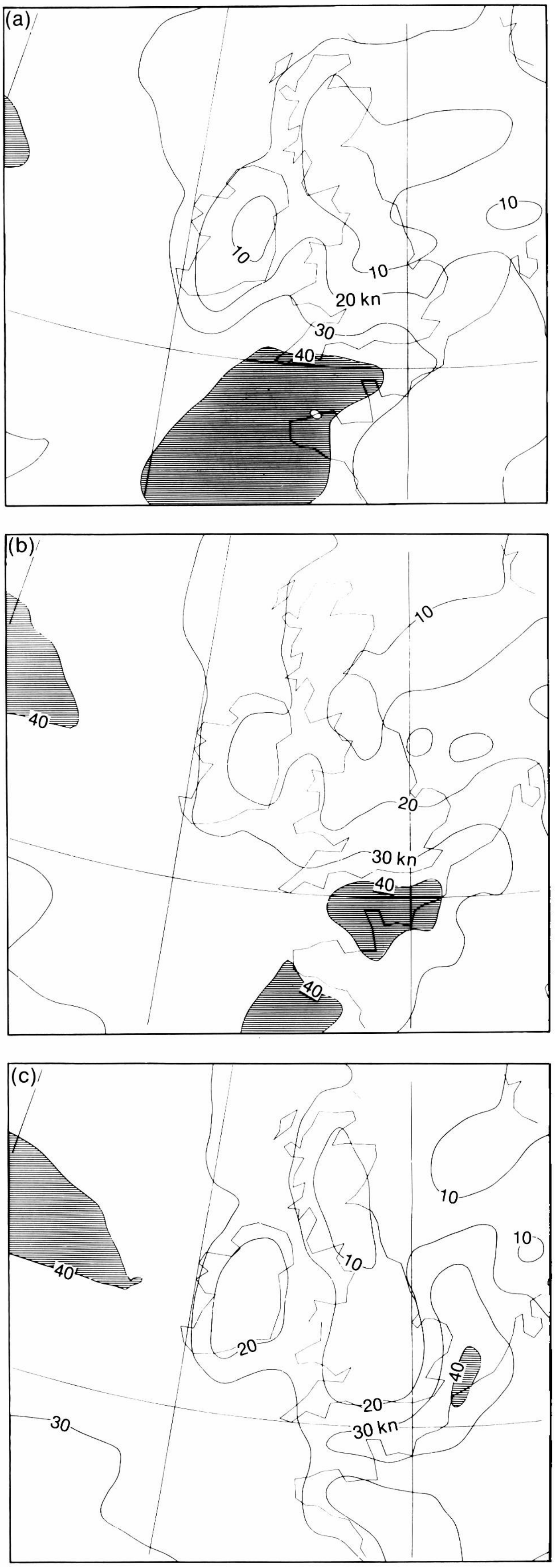

Figure 13. Fine-mesh forecast of surface (10 m) wind speed from analysis without OWS C and ONDA. Data time 1200 UTC on 24 January 1990, (a) T+24, (b) T+27, and (c) T+30.

The Battle of Britain — a meteorological retrospect

R.J. Ogden
Camberley, Surrey

Summary

To mark the 50th anniversary of the Battle of Britain, the meteorological services in RAF Fighter Command at that time are described, and reference is made to some of the difficulties faced and overcome. The weather during the core of the Battle is also analysed and is related to the pattern of air attacks.

1. The organizational background

In the tactical planning developed during the late 1930s under Air Chief Marshal Dowding, the first Air Officer Commanding-in-Chief of the newly formed RAF Fighter Command, it was envisaged that day-to-day control of fighter operations would rest at Group rather than Command level (Wright 1969). It was therefore decided that in the event of war, independent forecasting offices should be established at each Group Headquarters (HQ). The limited range of pre-war fighter aircraft such as the Gloster Gladiator originally suggested that airfield meteorological offices were unnecessary, but by the spring of 1939, with the emergence of the Hurricane and Spitfire that would be controlled in the air from Sector Operations rooms, it was recognized that small meteorological units should also be located at the key airfields designated as Sector HQ. These policies were implemented at the beginning of September 1939 or as soon as practicable thereafter; for information purposes a small office was also set up at HQ Fighter Command, but forecasting facilities were not introduced there until after the Battle of Britain when tactical considerations had changed (Air Ministry 1954).

Independent forecast offices were thus established at HQ 11 Group (Uxbridge), HQ 12 Group (Hucknall, later Watnall) and HQ 13 Group (Newcastle) at the outbreak of war, and at HQ 10 Group (Rudloe Manor, Wiltshire) shortly after that new Group was introduced in July 1940 to take over responsibility for south-west England and South Wales, leaving 11 Group to concentrate on the major task of covering London and the south-east. These four offices were all manned 24 hours a day by teams of civilian forecasters and civilian assistants. The forecasters provided meteorological advice for the air staff and controllers, and also originated all the forecasts needed by the Sector and other fighter airfields in the Group area; 11 Group additionally looked after HQ Fighter Command at Bentley Priory, Stanmore. Another important function was to prepare upper-wind and temperature forecasts for Army anti-aircraft (AA) batteries; for obvious reasons, the activities of AA Command had to be very closely co-ordinated with those of RAF Fighter Command, and to ensure this an Army AA liaison officer was always on duty with the Group controllers. The Group meteorological offices were also, to an extent, involved with RAF Balloon Command; although at this stage of the war small meteorological units were attached to most of the main balloon barrages (Air Ministry 1954), their resources were limited and Group forecasters provided advisory and back-up support. The assistants at the Group offices did all the chart and tephigram plotting and also the tedious 6-hourly ballistic wind computations for the AA batteries. In addition to many minor tasks including decoding observations for display in the operations room, they also operated the meteorological teleprinter switchboard, assembling the hourly Group collectives, passing these to Dunstable and sending routine area forecasts to all the outstations.

The Sector airfields in 11 Group were at Kenley, Biggin Hill, Hornchurch, Debden, North Weald, Northolt and Tangmere; each of these had its own subsidiary meteorological office as did RAF Hendon, RAF Manston (where there were also at first some dependent forecasters) and the pre-war civil airfields of Croydon, Heston, Lympne and Shoreham that had been taken over as RAF stations. Just outside the 11 Group area there were Sector meteorological offices at Middle Wallop (10 Group) and at Duxford and Coltishall (12 Group) (see Fig. 1). The staff complement at the outstation offices varied between three and five so that there was always at least one person on duty throughout the 24 hours. In most cases, the Officer-in-charge was a member of the pre-war Observer grade, his staff being a mixture of Observers, A IIIs, Royal Air Force Volunteer Reserve (RAFVR) (Met) airmen and a few Meteorological Assistants; although there were many Women's Auxiliary Air Force (WAAF) plotters in the Group and Sector operations rooms, the trade of meteorologist was not introduced in the WAAF until September 1941, so that there were no meteorological

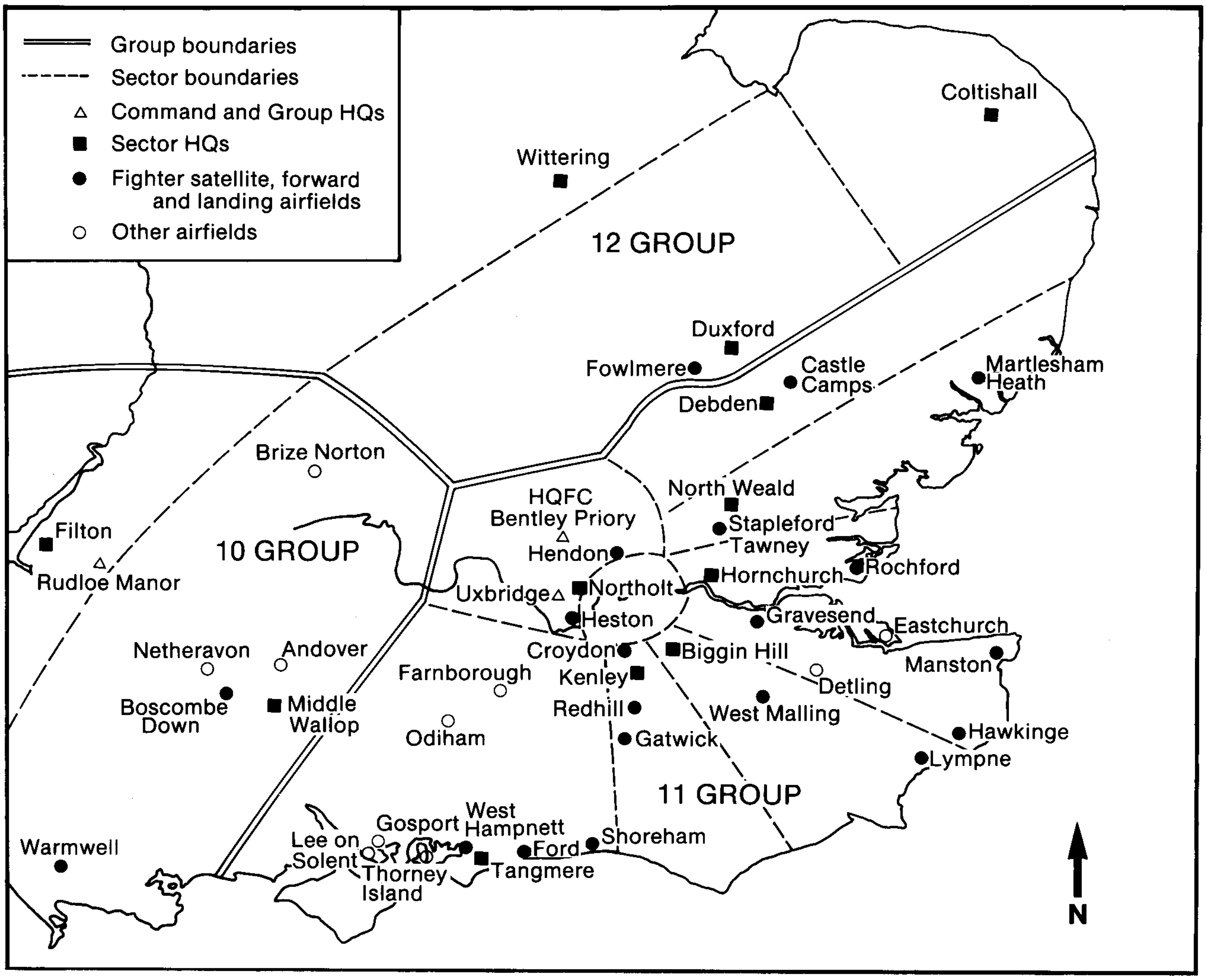

Figure 1. Group and Sector boundaries, Headquarters and airfields at the time of the Battle of Britain.

'WAAFs' during the Battle of Britain (Ogden 1986). The primary function of the outstation assistants was to observe the weather continuously, paying particular attention to surface wind, cloud and visibility; nephoscope observations also had to be made whenever suitable medium or high cloud was visible at those stations issued with this equipment. An important supplementary task was that of pilot-balloon work. In 11 Group, each outstation was allocated several specified times during the 24 hours at which ascents had to be made, cloud permitting, unless some overriding operational requirement turned up. In this way the Group forecasters were normally assured of a regular supply of upper-wind information to help with their aviation and AA forecasts. Secondly, the assistants maintained an up-to-date supply of decoded actual weather reports in the Sector operations rooms. Thirdly, the controllers and the Squadrons were provided with whatever forecasts they needed, these being obtained from the Group office. It was made clear to all concerned that the staff at the Sector offices were not themselves forecasters but that within this well understood constraint were always willing to help with advice and interpretation, and a good local rapport was normally established on that basis.

2. The Battle period and the relevant meteorological factors

Although the precise dates of the Battle of Britain are not clear cut, there is a general consensus that it started on 10 July 1940 and ran until around the end of October, by which time the large-scale daylight operations by bombers and fighters ceased, leaving for the most part just the night blitz. Within this 16-week period there were four distinct phases. At first the attacks were directed primarily at coastal convoys in the English Channel and the North Sea, with some raids also on south coast ports from Falmouth to Dover. The second phase, launched on 13 August, concentrated on the fighter airfields, both on the coast and well inland, and on the radar stations. On 7 September, in a switch of tactics, London and the Thames Estuary became the primary target by day, with heavy night raids as well. This phase continued until 30 September, with some attacks on Bristol, Plymouth and Southampton and at night on Merseyside. The final phase of fighter-bomber incursions in smaller formations, often at quite high levels, lasted through the month of October (Wright 1969). It was the second and third phases, i.e. from 13 August to 30 September, that formed the core of the Battle and which had the maximum impact on the meteorological services.

Hazy blue skies with many condensation trails are enduring folk memories of the Battle of Britain, but the records show a very mixed bag of weather; there were certainly some fine warm days, but equally others that were dull, cool, wet and much more typical of mid-autumn. Weather factors played a part on the operations of both sides, but in several ways the *Luftwaffe* (German Air Force) was affected more than the RAF.

The *Luftwaffe* bombers then operating had neither airborne radar nor radio-beam position-fixing techniques such as the *Knickebein* system which only became operational in their night bombing raids in late October (Saward 1985). Navigation was, therefore, a matter of dead reckoning (for which a knowledge of upper winds is vital) plus map reading. Moreover, as during the attacks on airfields and radar stations, the *Luftwaffe* orders specifically forbade indiscriminate bombing (Price 1988); success was contingent on visual identification of specific targets. For low-level daylight operations this was not too difficult given a reasonable cloud base and adequate visibility, though summer haze was sometimes a problem. However, after the heavy losses of Ju87 (*Stuka*) dive bombers in some of the early airfield attacks, that type of aircraft was largely withdrawn following the raids on 18 August (Saward 1985); admittedly, some low-level raids were also made by other aircraft, notably at Croydon, Kenley, Manston and Biggin Hill, but these were only a small minority of the total. The more general altitude for the *Luftwaffe* bombers was well above 10 000 feet, and for them the amount of cloud below that level was crucial, both for navigation and target identification; many attacks were broken up, misdirected or aborted because of cloud. The height and thickness of medium-cloud layers over northern France and the English Channel must also have had an effect on the practicability of assembling large formations of bombers and fighters. The forecasting of stratocumulus and cumulus cloud is notoriously difficult even today, but the British meteorologists had a significant advantage in that throughout almost the whole Battle period, the flow was predominantly from the quadrant between west and north, so that the fairly close network of hourly reporting stations over the British Isles gave them a much clearer picture of what was going on. The *Luftwaffe* had to rely on what their meteorologists could infer from the general weather situation, amplified by reports from their high-level weather and photographic reconnaissance aircraft that were regularly sent to England, and the Fw200 aircraft that operated long-range weather reconnaissance flights west of Ireland. Another problem was that the endurance of fighters at high level could be reduced by strong northerly winds.

By comparison, the meteorological requirements of the RAF fighter pilots and their controllers were modest. Acceptable weather was needed for take-off and landing, and all concerned required a general picture of the height, thickness and amount of the various cloud layers, together with warning of cumulonimbus cloud with severe up- or downdraughts. The upper airflow was also relevant, and if strong especially so for controllers when vectoring aircraft onto targets. Given that the weather was good enough for the *Luftwaffe* to mount a daylight raid during most of the Battle, the RAF fighters could almost certainly operate without serious meteorological problems, but difficulties did arise in October due to fog and low cloud at airfields.

Clearly neither side in the conflict wished to advertise their location by producing contrails, and during the Bomber Command offensive later in the war the prediction of contrails became a matter of considerable operational significance. But it was probably the introduction and widespread use of aircraft like the Hurricane, Spitfire and Messerschmitt with service ceilings above 30 000 feet that first alerted meteorologists to the problem; predictive techniques did not emerge until after the Battle (Parker 1942).

3. The fighter airfields under attack, 13 August to 6 September 1940

The German *Adlerangriff* (Eagle attack), designed to destroy the RAF as a prerequisite for invasion, was originally scheduled to start on 10 August, but the previous night it was postponed pending the arrival of better weather. By 12 August there was an anticyclone near the Isles of Scilly and the German meteorologists predicted good clear weather on the following day, which was then confirmed as *Adler Tag* (Eagle Day). With no more than small patches of stratocumulus over south-east England on 12 August, the *Luftwaffe* had no meteorological problems in sending preliminary raids to Lympne (twice), Manston, Hawkinge and six radar stations as well as maintaining pressure on ports and convoys. Cloud cleared that night, but by the morning of 13 August a weak warm front moving round the flank of the anticyclone had already reached Bristol, bringing thickening layers of cloud as the day wore on. The opening of the assault was disorganized by this cloud and some aircraft returned to base. Targets, including Odiham and Farnborough, could not be found and the bombers attacking Middle Wallop were so disoriented by cloud and harried by fighters that they dropped their bombs over three counties. Attacks were pressed home at Eastchurch and Detling and at Southampton but, thanks to the weather, it was a poor start to the campaign. During 14 August the anticyclone receded further and a weak cold front moved south-east across the country, followed by a more active one with rain, so that *Luftwaffe* activity was much reduced; Manston was hit again, also Middle Wallop, although the latter was attacked in the belief that it was Netheravon. The second cold front moved right across Britain during the night, leaving behind it a light north-westerly flow with generally clear weather in all eastern districts. This set the stage for the major onslaught of 15 August, the most wide-ranging series of attacks during the entire Battle.

The opening raids on Lympne, Hawkinge and the nearby radar stations were mounted in the late morning, that at Lympne being particularly severe. A pencilled note inside the cover of their *Observations Register* reads 'The enclosure was hit by a few bombs and everything destroyed except the rain-gauges and a minimum thermometer! Also, three 500 lb bombs landed just in front of the office making it unusable. During this period, which was the heaviest in the blitz, observations were only missed on occasions when bombs, AA or machine-gun fire made it very unsafe to venture in the open'. This dedicated approach seems to have been characteristic of the fighter airfield outstations. In surviving Registers, there are several examples of complete entries throughout periods when severe attack is known to have been taking place.

After the attack at Lympne, the meteorological office was re-established in the private house of the Observer, not far away. The Air Ministry agreed to pay rental for a room, the RAF installed a tie-line to Hawkinge to restore communication with 11 Group, replacement instruments were sent and when the airfield again became fully operational less than 48 hours after the raid, hourly reports recommenced (Meteorological Office 1941). Within an hour of this opening sally, bombers came from Norway to attack targets in north-east England; the formations were broken up by RAF fighters and failed to reach targets at Usworth, Linton and Dishforth, but did bomb Driffield. Shortly after this, the third attack was again in south-east England; among other airfields Manston was hit once more. Some three hours later the fourth raid came towards Portland and Portsmouth and yet again to Middle Wallop, but the meteorological office there appears to have been undamaged in all the raids.

The final raid of the day, in the early evening, appears to have been aimed at Biggin Hill and Kenley, but the force was split up by RAF fighters and had to seek alternative targets, one of these being West Malling which was bombed from high altitude. The other was Croydon which received a low-level attack by Me110s that caused many casualties and considerable damage, especially to a large and very busy aircraft maintenance hangar, a radio component works and the Bourjois perfume factory which were all on the industrial estate bordering the apron. The terminal building was also hit, but the meteorological office, just beneath the famous control tower, received only minor damage. However, in a second raid three days later, by stragglers from one of the Kenley attacks, the terminal was again hit, this time more seriously and the following morning the RAF decided the building was structurally unsafe and must be evacuated. Fortunately during July the RAF had requisitioned several private houses to the south of the airfield and one of these was allocated to the meteorological office. That afternoon and evening (19 August) all the records and instruments were moved and reinstalled and full observations recommenced the following morning (Meteorological Office 1941 and Cluett *et al.* 1984).

During 16 August there was a ridge across England with no more than broken cumulus and stratocumulus at 3000 feet. Manston and West Malling were again hit and there were heavy attacks on Brize Norton (then a training and maintenance airfield) and Tangmere. At Brize Norton, the office had to be evacuated because of delayed-action bombs outside, and was located for a time in a wooden hut pending repairs. At Tangmere there were broken windows, a hole in the roof and damage to instruments in the enclosure. Thereafter, the staff worked in the Watch Office after dark, but continued in their own office by day (Meteorological Office 1941). August 17 was a perfect summer day, but there was little *Luftwaffe* activity, no doubt while they prepared for the series of raids being planned for the morrow.

August 18 dawned fine and clear and the *Luftwaffe* opened the proceedings with both high- and low-level attacks at Kenley and Biggin Hill. First to arrive at Kenley was a formation of Do17s at very low level which caused many casualties, a great deal of damage and also fires, whose smoke was slow to clear in the stable light westerly flow, making the visibility so poor that the high-level force of Ju88s could not identify the airfield and diverted to an alternative target at West Malling instead. Some of the Do17s at high level did bomb the airfield, but others moved on to bomb Croydon instead (Price 1988). One of the many buildings destroyed at Kenley was Station Headquarters where the meteorological office had been located earlier in the year, but presumably it had been moved by this time to Sector Operations which were not hit though most of their communications were cut. The Kenley *Observation Registers* for this period have unfortunately not survived. By contrast, surprisingly little damage was caused at Biggin Hill on this occasion.

The second series of attacks on 18 August, also in good weather, were at Thorney Island, Ford and Gosport. Ford in particular was severely damaged and was abandoned by the Fleet Air Arm, being subsequently taken over by the RAF as another satellite field for the Tangmere Sector. Meteorologically, it was the third attack of the day that was the most interesting. During the morning a warm front had moved east across Scotland, followed by a cold front which moved steadily south-east as the ridge ahead of it gave way. By early afternoon, cloud and rain had spread as far south as North Wales and Lincolnshire, and three hours later, as the bombers were crossing the Essex and Kent coasts *en* *route* for Hornchurch and North Weald, both medium and low cloud layers were spreading into south-east England from the west; indeed it was raining in London by early evening. The raiders realized that there was no chance of being able to identify their primary targets from a high level and both attacks were aborted. The aircraft then returned to base, some of them bombing secondary targets in Shoeburyness and at Manston *en route* (Price 1988).

The cold front had moved down into the English Channel by the following morning, leaving behind a cloudy, showery airstream as a fairly deep depression moved south-east from Shetland to southern Sweden, introducing a strong north-northwesterly flow. A local teenager visiting Croydon Airport for some aircraft spotting recorded in his diary that 22 August was 'a very grey, dull typical autumn day and hardly weather to suite the *Luftwaffe*' (Cluett *et al.* 1984). This was a very fair assessment as, apart from a few minor raids at airfields, there was very little *Luftwaffe* activity for the five days from 19 to 23 August inclusive. However, the rise of pressure behind a cold front which cleared the south coast during the afternoon of 23 August soon damped out showers and next morning it was clear.

Manston was raided twice on 24 August, making a total of 9 raids in 13 days. After the second attack, hardly any buildings remained intact, all communications were cut and delayed-action bombs littered the airfield. Fighter Command decided that Manston should, for the time being, be evacuated and reduced to an emergency only airfield. Bombs had fallen within 20 yards of the meteorological office from which, in view of the RAF change of status, the dependent forecasters were withdrawn; alternative premises for an observing office were found on the other side of the airfield. There were also raids that afternoon at both North Weald and Hornchurch, but apart from the interruption of power supplies the meteorological offices appear to have been unaffected (Meteorological Office 1941).

August 25 also started clear over south-east England, but during the day medium and low cloud spread in as a weak cold front approached from the north, reaching Norfolk by evening. Warmwell was attacked but *Luftwaffe* activity was curtailed. However, the front became quasi-stationary and then returned northwards for a time, leaving southern England in a westerly on 26 August with little more than patchy cloud at 3000 feet. Raids were directed to Kenley, Biggin Hill, Hornchurch, North Weald and Debden, but the first four of these were broken up by RAF fighters before the targets were reached. Debden was hit, causing both damage and casualties, though not in the meteorological office. After this interlude, the front again moved south, bringing showers right down to the English Channel coast by the evening of 27 August. The same front appears to have restricted *Luftwaffe* activity for two more days, because it remained stationary over the English Channel on 28 August, then returned north on 29 August linked to a warm front over Scotland, and brought stratocumulus at 2000 feet back into south-east England. Although the weather on 28 August was ideal for bombing, *Luftwaffe* flights must have been hampered by cloud to the south, and on 29 August they were no more than fighter sweeps.

On 30 August, however, it was a very different story. The front had at last cleared through into Europe, the cloud dispersing as the pressure rose behind it, and the anticyclone, which since 12 August had been near or well to the south-west of the British Isles, moved east to dominate the English Channel and northern France, later settling over Germany. This introduced the longest spell of fine summer weather during the entire Battle, lasting for 9 days from 30 August to 7 September.

The primary target during this period was Biggin Hill which received 9 attacks in 7 days, the evening raids on both 30 and 31 August being particularly severe. The former wrecked workshops, equipment section, hangars, motor transport section, barracks, dining halls and camp roads. Electricity, gas, water, sewerage and telephone services were all cut and three air raid shelters received direct hits (Ogley 1990). Among those killed were the observer-in-charge, N.A. Roberts, and two RAFVR (Met) Leading Aircraftmen, Buttfield and Brunning, i.e. three of the four meteorological staff on the strength at the time. The RAF decided that with swift remedial action to restore services, the airfield could remain fully operational, but that all personnel whose presence there was not essential should move away. Three new meteorological staff were immediately posted in as replacements for those killed, and although for a short time they had no office, observations were maintained from a point near the Sector Operations building. But on the evening of 31 August this received a direct hit and an Emergency Operations room was at once set up in an empty shop in Biggin Hill village. The meteorological office was allocated a house on the northern edge of the airfield (Meteorological Office 1941 and Ogley 1990). On 31 August Croydon, Detling, Debden and Hornchurch were also attacked, but the meteorological offices do not seem to have been directly affected on this occasion.

During the first 6 days of September the airfield attacks continued in glorious weather. On 3 September North Weald was severely damaged and the meteorological office was reduced to a total wreck. It was moved to a new position near Sector Operations, and, as the meteorological teleprinter had been badly damaged, RAF Signals staff had to send the observations to Uxbridge (this second location was also wrecked in October and the office then had to move again). On 6 September, three large attacks were directed at the five Sector airfields round London, but all of these were broken up and few of the bombs reached their targets. On the following morning, however, the meteorological staff at Hornchurch had to move their screen to a new location.

4. The location of Fighter Command meteorological offices

At Group HQ, the forecasting offices were established in the Operations blocks which were purpose-built concrete bunkers, well underground; these became known to all who worked in them as 'The Hole'. The original Command policy for the Sector meteorological offices was that they should be housed in the Sector Operations buildings (Air Ministry 1954), but this was not implemented for some time and a more usual location was near the watch office, from which there was a good view across the airfield. Perhaps surprisingly, when the Battle of Britain started, the Sector Operations blocks were usually above ground at one side of the airfield, protected only by blast walls and camouflage netting. Air Chief Marshall Dowding commented that 'it would have been admirable if fine underground installations could have been built, but there simply was not time for that. The system had to be brought into being as quickly as possible, and the best was done in the time available' (Wright 1969). Emergency arrangements were, however, made in case the above-ground locations on the airfields became untenable.

As noted above, when Biggin Hill Operations was hit on 31 August, an immediate move was made to a shop in the village, and when communications to the Operations block at Kenley were cut on 18 August, a similar move was made to a butcher's shop in Caterham High Street, chosen because it was immediately over the main Post Office telephone cable in the area (Price 1988). In these very cramped emergency conditions there was certainly no room for the meteorological offices which normally remained for a time on or alongside the airfields. However, steps were taken as soon as possible to prepare more suitable alternative operations rooms well away from the airfields. In many cases, large buildings were requisitioned and converted; Biggin Hill for example took over a large mansion in Keston Mark (Ogley 1990), Kenley chose the Vicarage in Old Coulsdon, Duxford moved to Sawston Hall and Hornchurch to a building in Romford. In other cases, temporary buildings were erected as at Debden which went to the outskirts of Saffron Walden, and at North Weald which moved to Ongar.

Once these alternative Operations rooms were fully established, in almost all cases the meteorological offices moved to them, and having done so remained there until 1944 when they moved back to the airfields. These relocations of the Sector meteorological offices no doubt brought a feeling of some relief at being less adjacent to primary target areas, but were sometimes rather cramped (Kenley for example was in the butler's pantry). The moves did however bring about the intended close contact and integration of the meteorological work into the activity of the Operations rooms. As a further precaution against any more disasters, emergency alternatives to the alternative Operations rooms were earmarked and the meteorological offices were invited to make contingency planning for a sudden move if this ever became necessary; in the event it is believed that this never happened. One minor problem that arose from the relocation of the meteorological office well away from the airfield, is that the observations are supposed to refer to the latter. When the two sites were at similar heights within a mile or so of each other (as at Kenley), the differences were not normally significant, but when the sites were several miles apart and at quite different altitudes (as at Debden), the observer had to telephone the Duty Pilot in the Watch Office and accept his values for cloud and visibility whenever there was a chance that these were significantly different.

5. London becomes the major target, 7–30 September 1940

On 7 September the weather was still clear in the south-east and heavy attacks were made throughout that day and the following night. But this was the end of the 9-day spell of summer weather, as by next morning a cold front had brought rain as far south as East Anglia; some morning raids were sent to fighter airfields, but to little effect. With the switch of objectives from specific targets like airfields and radar stations to a very large area such as London, the need for precision in navigation and target identification diminished, so that cloud amounts below the aircraft were from here on of less account. On the following day, 9 September, a very showery northerly airstream at first restricted *Luftwaffe* activity; but convection quickly died down as the ridge collapsed ahead of the next frontal system, and afternoon raids were sent to London. The fronts crossed the country during 10 September bringing thick cloud, rain and a largely peaceful day. It was mainly clear in the north-northwesterly behind the cold front on 11 September, allowing raids to London, Southampton and Portsmouth, and that night to London and Merseyside. But then the weather intervened once more, another warm front brought rain across the country on 12 September, with cloud bases down to 500 feet in the warm sector, and the cold-frontal clearance the next day was only partial. Interestingly, around midday on 13 September, radio monitoring of *Luftwaffe* transmissions reported that an enemy aircraft over Kent was sending messages that cloud was only 7/10 at 1500 metres and that attack was possible. Some raids were indeed mounted that afternoon, but the reconnaissance was over-optimistic and they achieved little. The cloud and showers persisted through the next day as well, and the true clearance did not develop until the early hours of 15 September, when a more active cold front with rain had moved through to the continent.

September 15 has come to be known as Battle of Britain Day, largely because of heavy *Luftwaffe* losses in a series of raids on London on a similar scale to those of 7 September. The weather was by no means clear, but with only half cover or less of cumulus cloud it proved to be the best day for over a week. Next morning an active warm front was sweeping rain across the country, and when the cold front cleared around midday on 17 September, it left behind a very strong westerly circulation round the parent low near Shetland which had a central pressure as low as 970 mb. The gradient had eased by 18 September and with broken cloud some raids were mounted both day and night, but by then upper cloud ahead of yet another frontal system was spreading in to give a wet day on 19 September, the rain intensifying that night as a wave developed on the cold front near the Isles of Scilly and moved up the English Channel. Despite these most unfavourable conditions, some *Luftwaffe* bombers did penetrate to London shortly before the wave arrived in south-east England, and a parachute mine descended on Heston, then the home of the Photographic Reconnaissance Unit, which damaged the roof and windows of the first floor meteorological office there. A few days earlier, an AA shell had fallen through the roof and floor of this office before exploding in the room underneath. All this damage was repaired in due course, but the offices at Heston, Hendon and Northolt, being on the fringe of the London area, were all damaged further during October and November, though fortunately without serious effects on the meteorological work.

The next 3 days, 20–22 September, were dominated by a second wave on the cold front moving up the English Channel, followed by an active frontal system associated with the next depression in the family which tracked from west of Ireland to north Scotland; *Luftwaffe* activity on these days was confined to reconnaissance and a few fighter sweeps. However, the cold frontal clearance during the late evening of 22 September was sharp, and by midnight, in the words of Lord Alanbrooke 'London was like Dante's Inferno', as indeed it was on the following night as well. No doubt because of the commitment to these two very heavy night raids, the *Luftwaffe* mounted no more than fighter sweeps during daylight hours on 23 September, despite only well broken cumulus at 3000 feet. Around this time a large anticyclone became established north-west of Ireland, and for the rest of the month the flow over Britain was predominantly from the north, with troughs bringing cloudy spells and showers, especially on 28 and 29 September. During this period, cloud was more broken in the west, and for the most part raids were concentrated on Portsmouth, Southampton, Bristol and Plymouth. Some bombers did reach London on 27, 28 and again on 30 September, but this last occasion proved to be the final large-scale engagement of the daylight Battle.

6. Conclusions

Two facts emerge clearly from this meteorological look back at the Battle of Britain. Firstly, there is no doubt that the pattern of German air attacks was considerably affected by the weather. Secondly, the civilian meteorological staff played a full part alongside their RAF colleagues at Groups, Sectors and other airfields, and despite very exacting working conditions the service was maintained.

Acknowledgements

My thanks are due to Maurice Crewe, Meteorological Office Librarian, who drew my attention to the invaluable M O 7 damage report of 1941 which is in his care; also to Michael Wood, Meteorological Office Archivist, who gave me free access to the 6-hourly synoptic charts of the Battle period, also to the station histories and all the surviving *Observation Registers* of the Fighter Command Stations.

Except where otherwise specified, all the day-to-day operational details of the Battle are drawn from *A summer for heroes* by Wood and Dempster, which is based on a 1961 book by the same authors called *The narrow margin*.

References

Air Ministry (Air Historical Branch), 1954: The Second World War 1939–1945: Meteorology. (Unpublished, copy available in National Meteorological Library, Bracknell.)

Cluett, D., Bogle, J. and Learmonth, B., 1984: Croydon Airport and the battle for Britain 1939–1940. London Borough of Sutton, Libraries and Arts Services.

Meteorological Office, 1941: Damage by enemy action to M O 7 outstations. (Unpublished, copy available in National Meteorological Library, Bracknell.)

Ogden, R.J., 1986: Meteorological Office training of assistant staff: 1939–51. *Meteorol Mag*, **115**, 200–213.

Ogley, B., 1990: Biggin on the bump. Westerham, Froglets Publications.
Parker, A.E., 1942: On the formation of condensation trails. London, Air Ministry, Meteorological Office, Synoptic Division Technical Memorandum No. 42.

Price, A., 1988: The hardest day. Arms and Armour Press.

Saward, D., 1985: Victory denied. Buchan and Enright.

Wood, D. and Dempster, D., 1990: A summer for heroes. Shrewsbury, Airlife Publications.

Wright, R., 1969: Dowding and the Battle of Britain. MacDonald.

551.574.42:625.7(485)

Road slipperiness during warm-air advections

T. Gustavsson and J. Bogren
University of Gothenburg

Summary

This article deals with two cases of road slipperiness in Sweden caused by sublimation during warm-air advections. The weather preceding frontal movements causes differences in local climate to occur which affect the geographical distribution of the occurrence of slipperiness.

1. Introduction

Formulae for forecasting road surface temperatures and the risk of road slipperiness have traditionally been developed for conditions with falling temperatures during evenings and nights when there could be a possibility of road icing (e.g. Parmenter and Thornes 1986, Rayer 1987). However, analyses of recordings from field stations in the Swedish Road Weather Information System (VVIS) have shown that road slipperiness, caused by sublimation, also occurs during rapid weather changes, chiefly during warm-air advections (Gustavsson 1985, Bogren and Gustavsson 1986 and 1989, Gustavsson 1990). (This type of road slipperiness could be dangerous for road users as it appears very unexpectedly.) The variation in warming between the air and the road surface, in addition to the advection of warm, humid air, leads to an intense deposit of rime on the road surface. Great local variations in sublimation risk occur in complex terrain as a result of varying local topography and other factors. The effects of local climatological factors on the risk of road slipperiness have earlier been documented by Lindqvist (1975, 1982).

This study is part of a project concerned with the analysis of temperature variations in complex terrain and their association with the occurrence of local slipperiness. In this paper the topographical factors which control the local risk of slipperiness during warm-air advections are identified and the variations in sublimation due to the weather situation preceding the warming illustrated.

2. Data

The climatological data used in this study are recordings from 48 field stations in the VVIS in the counties of Bohuslän, Älvsborg and Jönköping in the south-western part of Sweden (see Fig. 1) with additional information from synoptic maps to determine the prevailing weather conditions. Each station is equipped with sensors for the measurement of air temperature and humidity at a level of 2 m, and a probe at the surface for the measurement of the road surface temperature. Additional sensors at some selected stations measure wind speed, wind direction, precipitation and residual salinity on the road surface. The measured variables are recorded every half hour during the winter season and stored on a computer. Thus it is possible to analyse the interaction between such factors as temperature development and prevailing weather.

The most important parameter giving information about the variation between field stations when there is a risk of slipperiness due to sublimation is the actual time when the dew-point temperature is higher than the road surface temperature. This parameter has therefore been analysed in relation to such factors as local topography, distance between field stations, and the temperature development during the warm-air advection. However, this parameter is only of interest when the road surface temperature is below 0 °C.

3. Results

To illustrate the effects of local topography on temperature development during warm-air advections, two types of weather situations have been studied. The first situation is characterized by clear, calm conditions preceding the warm-front movement, and the second situation is marked by cloudy, windy weather preceding the rise in temperature.

3.1 Case-study of 18 January 1986

The weather events of 18 January 1986 were characterized by clear, calm conditions preceding a warm front.

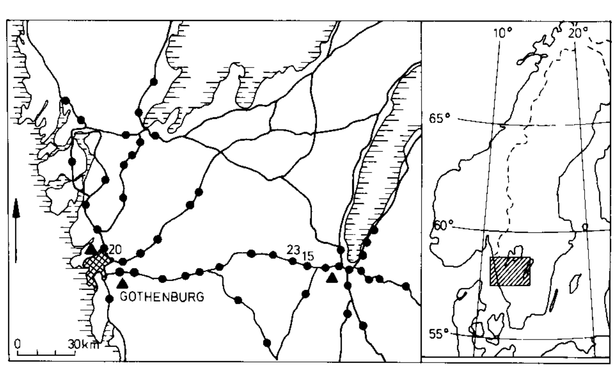

Figure 1. Map of the study area.

Recordings of temperature, cloudiness and wind from synoptic weather stations in the area show that this was a stable situation with minimum air temperature ranging from −11 °C to −24 °C within the region, a cloud cover not exceeding 2 oktas and almost no wind. During the early morning of the 18th, however, a warm front moving north-eastwards from the British Isles reached the south-western parts of Sweden (Fig. 2) and the weather changed rapidly. Owing to the warm-air advection, the temperature rose markedly while the degree of cloudiness changed from clear to completely overcast and the wind increased from 0 m s^{-1} to 7 m s^{-1} in a primarily south-westerly direction.

The effect of the weather change on the distribution of the time at which the risk of slipperiness occurred in the study area is illustrated by three VVIS stations, numbers 15, 20 and 23. These represent three different types of location. Station 20 is located close to the coast in a flat, open, wind-exposed area and station 15 is sited 115 km inland in a small, shallow valley, with gentle slopes admitting pooling of cold air yet surrounded by a forest which provides wind shelter. Station 23 is located 110 km inland in a large valley surrounded by open areas where cold air could pool during stable weather conditions, but the openness also creates great wind exposure.

The temperature development and the time of the risk of sublimation for stations 15, 20 and 23 are shown in Fig. 3. The shaded area indicates risk of slipperiness, i.e. the dew-point temperature is higher than the road surface temperature and a flux of humid air develops towards the surface.

As a result of the variation in the ability of cold air to pool around the stations, the night minimum temperature differs between the sites. The lowest temperature

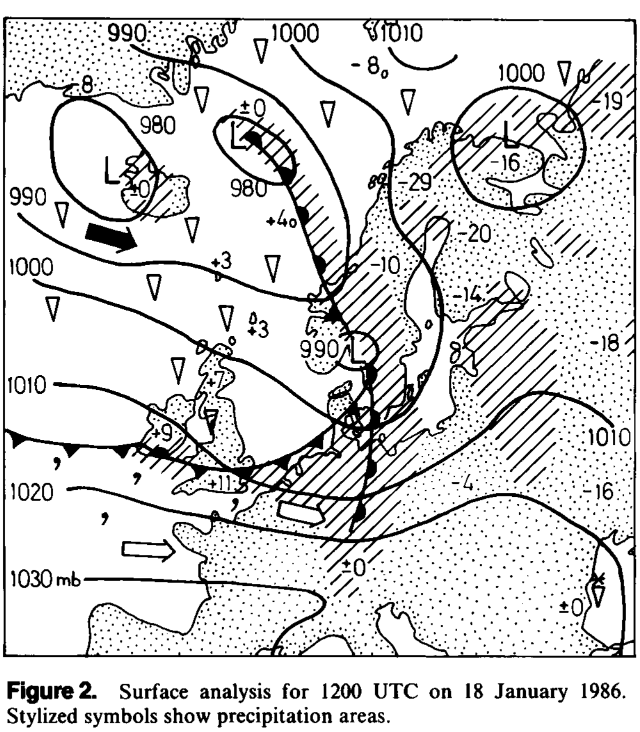

Figure 2. Surface analysis for 1200 UTC on 18 January 1986. Stylized symbols show precipitation areas.

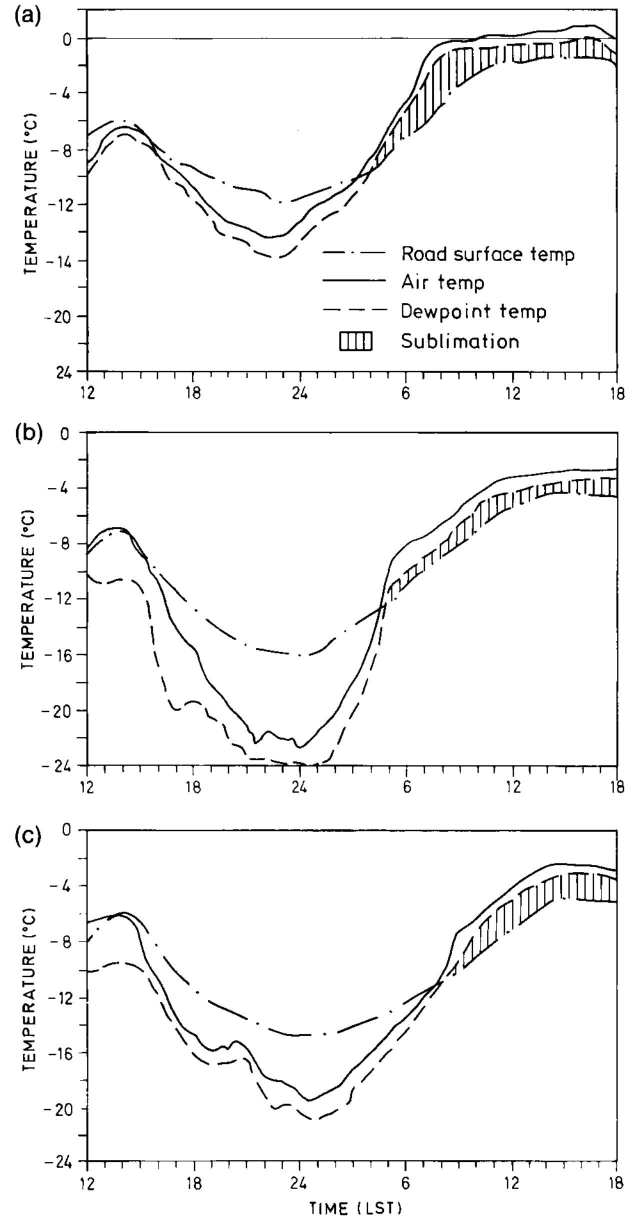

Figure 3. Temperature curves at three VVIS stations during 17 and 18 January 1986, (a) station 20, (b) station 23, and (c) station 15.

occurred at station 23, where the minimum air temperature was −23 °C. Station 15 had a minimum temperature of −19 °C and station 20 −13 °C, i.e. 10 °C warmer than station 23. Recordings from the synoptic stations in Fig. 1 have been used to confirm that there were no differences in the regional weather in the area studied.

Station 20 was first reached by the warm air at 2300 Local standard time (LST) on 17 January and the air temperature rose from −13 °C to 0 °C by 0800 LST the following day, showing a warming rate of 1.4 °C h^{-1}. The warm air reached the two inland stations 1.5 hours later, at 0030 LST. The reaction to the warm air at station 23 was immediate. The air temperature started to rise at a rate of 3.0 °C h^{-1} during the first 5 hours of the warming trend, until 0500 LST, and continued thereafter at a more modest rate. At station 15 the rise in air temperature was slower, 1.5 °C h^{-1}, due to the surrounding forest which provided a wind shelter for the pooled cold air.

The variation in the onset of the risk of slipperiness is associated with the rapid rise of both the air and dew-point temperature in relation to the less responsive road surface temperature. As a result of the rapid rise of the air temperature, the risk of slipperiness occurred almost simultaneously at stations 20 and 23, at 0400 LST and 0430 LST, respectively, in spite of the large regional distance between the sites. But not until 0830 LST was station 15, in the sheltered valley, exposed to risk of slipperiness, i.e. a difference of 4 hours between the valley stations (numbers 15 and 23) although they are sited less than 10 km apart from each other.

3.2 Case-study of 20 January 1986

Weather conditions on 20 January were characterized by low air temperatures, an overcast sky and a strong prevailing wind chiefly from the north-east. In the course of the afternoon, a rise in temperature and a change in the wind direction from north-east to south-west took place when the area under study was reached by a warm front moving from the west towards Scandinavia (Fig. 4).

The conditions on the 20th were quite different from those of the 18th owing to the cloudiness and prevailing winds which effectively prevented the development of large local temperature variations. The temperature recordings in Fig. 5 show how the three sites were reached by the warm air during the day resulting in a risk of slipperiness in the afternoon. Because of its westerly position, station 20 was reached first by the warm air, resulting in a warming rate of 1.6 °C h^{-1}, and at 1530 LST there was a risk of slipperiness. The two inland

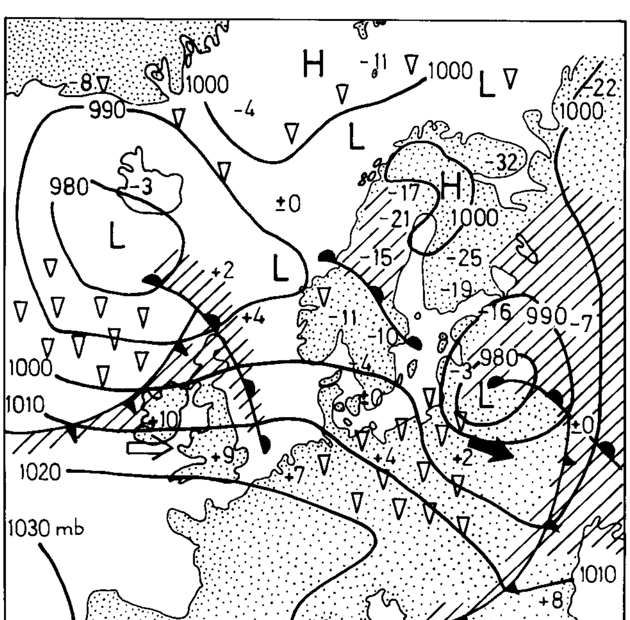

Figure 4. As Fig. 2, but for 20 January 1986.

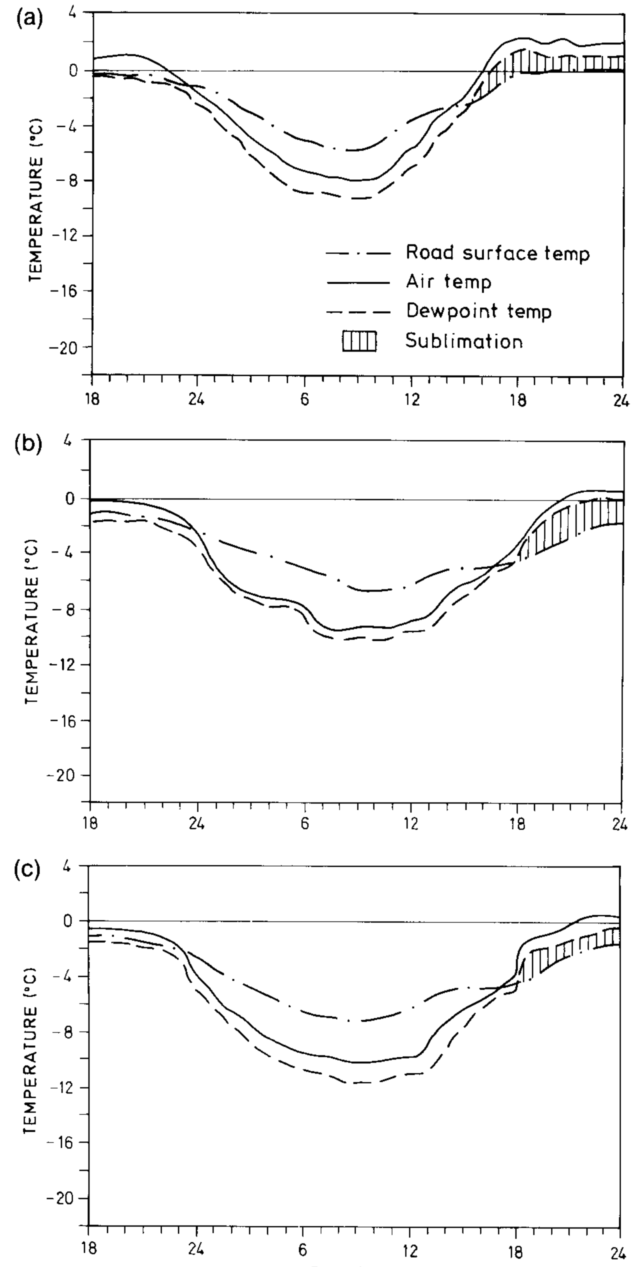

Figure 5. Temperature curves at three VVIS stations during 19 and 20 January 1986, (a) station 20, (b) station 23, and (c) station 15.

stations were not affected by the warming until 1230 LST; with a warming rate close to 1.0 °C h^{-1}, they were not exposed to a risk of sublimation until 1800 LST, i.e. 2.5 hours later than at the coastal site. The maximum temperature at station 20 was approximately 1.5–2 °C higher than at the other two stations, which could partly explain the variation in the warming rate between the two inland stations. The higher maximum temperature at station 20 was a result of the variation in altitude between the three stations, which is approximately 250 m. The difference in time of commencement of risk of slipperiness under these conditions of these sites was a result of the relation of the region positions versus the frontal movement direction.

4. Discussion

The frontal movements on both the 18 and 20 January were from the south-west to the north-east, which means that they reached the study area in the coastal zone first and then moved inland. The difference in the reactions of the sites within the study area to the warm air advections is illustrated by Figs 6 and 7. The relative difference in time for the start of slipperiness is calculated in relation to the station which was first exposed to slipperiness. This time difference is plotted against the position of the station expressed as distance from the coast. The scatter in the figures is a reflection of the different weather conditions preceding the frontal movements. During 18 January, the time at which a site was affected by a risk of slipperiness was a result of the local 'climate' which developed at each site, and hence great time differences between sites which were located quite near to one another occurred. During 20 January, the time at which the risk of slipperiness began is closely correlated to the position of the site in relation to the frontal movement.

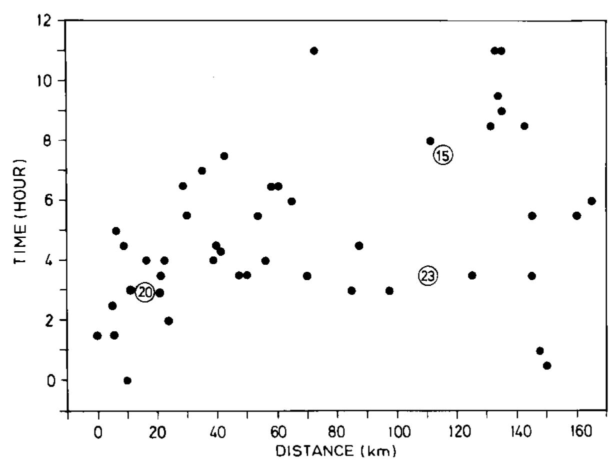

Figure 6. Relative time difference between the 48 field stations in the VVIS for start of sublimation versus distance from the coast on 18 January 1986.

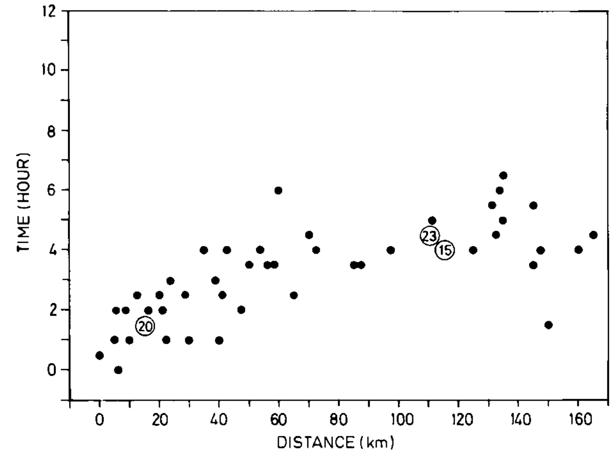

Figure 7. As in Fig 6, but for 20 January 1986.

5. Conclusions

The two cases show that the spatial distribution of slipperiness is controlled by the weather situation preceding the warm-air advection. If the preceding weather is characterized by clear, calm conditions, it is possible for local temperature differences to develop at the sites, according to their topographical environments. Due to the individual variations in local climate between the sites there are great differences in how rapidly they react to the warming and there thus lies a different pattern of when a risk of slipperiness will occur. This implies that there can be considerable time differences between adjacent sites as regards their exposure to the risk of slipperiness. On the other hand, the effect of local topography is not as important when the warm front is preceded by cloudy, windy conditions, making the warming and the risk of slipperiness at each site more dependent upon the progressing frontal movement.

Acknowledgements

This project is financially sponsored by the Swedish Transport Research Board and the Swedish National Road Administration. Adviser for the project is Professor S. Lindqvist. Linguistic revision was done by B. Kroeber and J. Vesterlund. S. Svensson drew the figures.

References

Bogren, J. and Gustavsson, T., 1986: A method for the development of a local climatological model for prediction of slipperiness on roads. GUNI rapport 20, Department of Physical Geography, Gothenburg.

—, 1989: Modelling of local climate for prediction of road slipperiness. *Phys Geogr*, **10**, 147–164.

Gustavsson, T., 1985: Tillämpad vägklimatologi — förstudie. M. Sc. Thesis. Department of Physical Geography, Gothenburg.

—, 1990: Analyses of local climatological factors controlling risk of slipperiness during warm-air advections. Accepted for publication in *Int J Climatol.*

Lindqvist, S., 1975: Vaghalkans beroende av mikro-och lokalklimatiska faktorer. GUNI rapport 8, Department of Physical Geography, Gothenburg, (summary in English).

—, 1982: Neue Methoden der Glatteisüberwachung in Schweden. GUNI rapport 16, Department of Physical Geography, Gothenburg, (summary in English).

Parmenter, B. and Thornes, J.E., 1986: The use of a computer model to predict the formation of ice on road surfaces. Crowthorne, Berkshire, TRRL Research Report RR71.

Rayer, P.J., 1987: The Meteorological Office forecast road surface temperature model. *Meteorol Mag*, **116**, 180–191.

Correspondence

551.578.45(430.1)551.578.46:551.515

Comments on 'A heavy mesoscale snowfall event in northern Germany'

Pike (*Meteorol Mag*, **119**, 187–195) draws attention to the convergence line during 11–12 January 1987 near the coast of north Germany (see Figs 1, 7 and 8 of his article). However, this feature does not explain why the heaviest snowfall, as shown in Fig. 5, occurred 40–80 km inland, downwind from the Lübeck Bight. The width of the associated snow belt was about the same as the width of the Bight itself. Kresling (referenced in Pike) states that weather radar showed that new shower cells were being continually generated in the Bight during the 24 hours up to 1200 UTC on the 12th. It is therefore probable that convergence of land-breeze components (not necessarily actual land-breezes) over the Bight, within the flow of unstable air from the Baltic, played an important part in producing the heavy snowfall east and north-east of Hamburg. Many of the shower cells, on crossing the southern shore of the Bight, would still be in the developing stage, with upcurrents predominating. Consequently, given the fairly strong wind speed in the unstable layer (about 50 km h^{-1}) they deposited most of their snow content well inland.

F.E. Lumb

41 York Road
Camberley
Surrey GU15 4HS

Reply by W.S. Pike

Unfortunately, in 1987, the Hamburg Offices were not archiving their radar data which could have verified this 'continued-snow-shower-generation' over the Lübeck Bight (southern waters of the Mecklenburg Bight) referred to by Anders Kresling. Nevertheless, I have no reason to doubt his first-hand observations.

At risk of offending mariners, there is no really satisfactory way of confirming the snowfall maxima which radar tells us are occurring at sea! Andersson and Nilsson (*Weather and forecasting,* **5**, 299–312) summarize that, in the majority of cases 'heavy snowfall does not extend far inland' and 'all available radar evidence indicates that the maximum snowfall occurs over the sea'. However, over northern Germany during 11–12 January 1987 we find that, in conditions of strong onshore windflow at cloud levels, a mesoscale 'coastal' snowfall maximum has been swept some 50–60 km inland.

Such extreme events may be defined as 'the currently known limits to general rules', and I welcome Frank Lumb's erudite comments which form a well-considered and logical postscript to this particular investigation.

W.S. Pike

19 Inholmes Common
Woodlands St. Mary
Newbury RG16 7SX

Notes and news

Extending the reach — the Defence Oceanology International 91 conference and exhibition.

The theme of the Admiralty Research Establishment (ARE) sponsored Defence Oceanology International 91 conference and exhibition, being held on 6–8 March 1991 at the Brighton Metropole, reflects the defence requirements that represent the new order of the 1990s.

In choosing the theme 'Extending the Reach', the increasing importance to navies throughout the world of flexibility, both in out-of-area operations and in response to the changing nature of the threat, is recognized, as is the importance of new technology and new operational concepts and operational costs.

A call for papers has now been published. Papers are invited on surface and sub-surface issues under the following headings: sonar and acoustics; communications, command, control and information; signature measurement; environment monitoring and control; power, propulsion and manoeuvrability; oceanography and climatology; vulnerability/durability/survivability; new concepts and systems; and defence technology transfer. Copies of the Call for Papers and full details on all aspects of DOI 91 are available from:

The Spearhead Group
Rowe House
55/59 Fife Road
Kingston upon Thames
Surrey KT1 1TA
United Kingdom
Tel: 081-549 5831 Fax: 081-541 5657
Telex: 928042 SPEARS G.

Books received

The listing of books under this heading does not preclude a review in the Meteorological Magazine at a later date.

Weather watch, by R.F. File (London, Fourth Estate Ltd, 1990) is a multi-faceted investigation of British weather, but in the context of the world's weather. Weather lore is tested and descriptions of a multitude of phenomena are included.

Television weathercasting; a history, by R. Henson (London, McFarland and Company, 1990) describes the progress of weather presentation on American television, including all the variety of personalities involved.

Radar image — 19 October 1990 at 0600 UTC

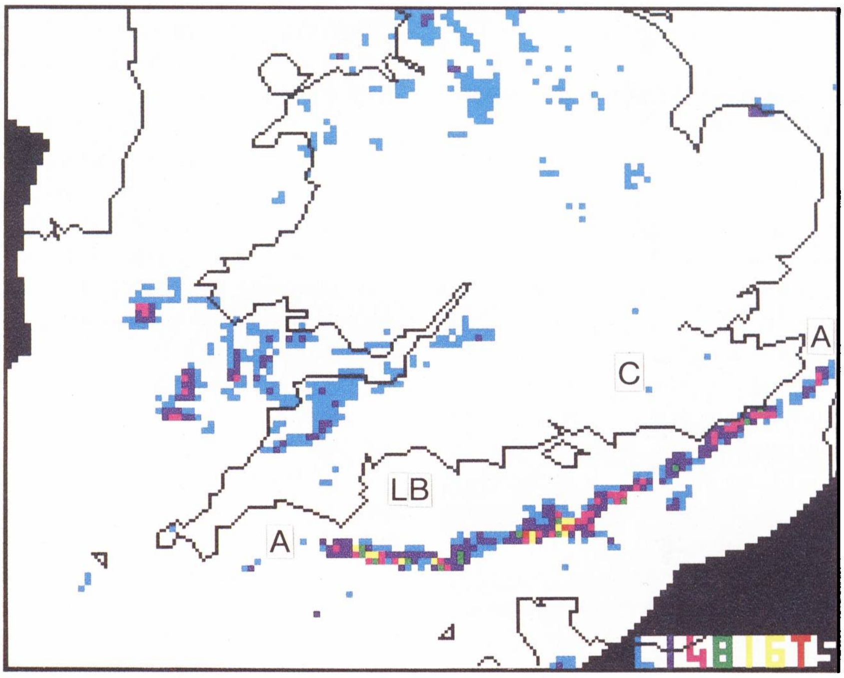

Figure 1. Rainfall intensity (mm h^{-1}) from the UK weather radar network for 0600 UTC on 19 October 1990. Blue < 1, purple > 1, pink > 4, green > 8, yellow > 16, and red > 32. Black areas are outside radar coverage. See text for explanation of lettering.

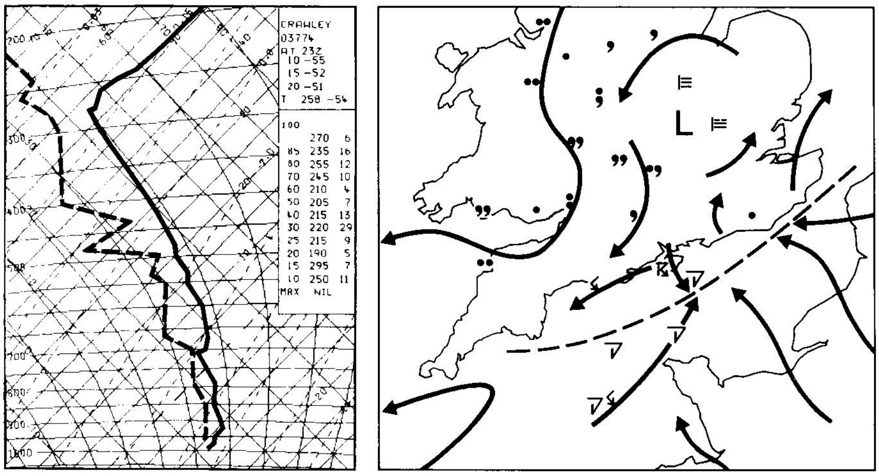

Figure 2. Surface wind streamlines (arrowed) and present weather including sferic location reports (conventional symbols) for 0600 UTC on 19 October 1990. The dashed line shows the position of the convergence zone. The radiosonde sounding for Crawley for 0000 UTC on 19 October 1990 is incorporated on the left.

The main feature on this image from the UK weather radar network (Fig. 1) is the narrow band of precipitation extending almost the entire length of the English Channel (A — A). Embedded cells of heavy rain are evident, particularly towards the west of the band, and some were associated with thunderstorms.

The band developed along a low-level convergence zone in the circulation of a shallow slow-moving low pressure area centred over south-east England (L in Fig. 2). The convergence zone acted as a focus for preferential shower development to sea surface temperatures of the order of 15 °C. The upper-air sounding from Crawley (C in Fig. 1 and insert to Fig. 2) implied deep convection was possible to around 300 mb.

The first main cells formed in the central part of Lyme Bay (LB in Fig. 1) as early as 2300 UTC the previous evening with convergence possibly being locally enhanced by the focusing of offshore land-breeze circulations. The band subsequently extended towards the east, persisting as a marked feature until mid morning, but then tending to fragment. However over extreme south-east England the band reformed in the afternoon when surface temperatures had risen sufficiently for deep land-based convection to develop.

A.J. Waters

GUIDE TO AUTHORS

Content

Articles on all aspects of meteorology are welcomed, particularly those which describe results of research in applied meteorology or the development of practical forecasting techniques.

Preparation and submission of articles

Articles, which must be in English, should be typed, double-spaced with wide margins, on one side only of A4-size paper. Tables, references and figure captions should be typed separately. Spelling should conform to the preferred spelling in the *Concise Oxford Dictionary* (latest edition). Articles prepared on floppy disk (Compucorp or IBM-compatible) can be labour-saving, but only a print-out should be submitted in the first instance.

References should be made using the Harvard system (author/date) and full details should be given at the end of the text. If a document is unpublished, details must be given of the library where it may be seen. Documents which are not available to enquirers must not be referred to, except by 'personal communication'.

Tables should be numbered consecutively using roman numerals and provided with headings.

Mathematical notation should be written with extreme care. Particular care should be taken to differentiate between Greek letters and Roman letters for which they could be mistaken. Double subscripts and superscripts should be avoided, as they are difficult to typeset and read. Notation should be kept as simple as possible. Guidance is given in BS 1991: Part 1: 1976, and *Quantities, Units and Symbols* published by the Royal Society. SI units, or units approved by the World Meteorological Organization, should be used.

Articles for publication and all other communications for the Editor should be addressed to: The Chief Executive, Meteorological Office, London Road, Bracknell, Berkshire RG12 2SZ and marked 'For Meteorological Magazine'.

Illustrations

Diagrams must be drawn clearly, preferably in ink, and should not contain any unnecessary of irrelevant details. Explanatory text should not appear on the diagram itself but in the caption. Captions should be typed on a separate sheet of paper and should, as far as possible, explain the meanings of the diagrams without the reader having to refer to the text. The sequential numbering should correspond with the sequential referrals in the text.

Sharp monochrome photographs on glossy paper are preferred; colour prints are acceptable but the use of colour is at the Editor's discretion.

Copyright

Authors should identify the holder of the copyright for their work when they first submit contributions.

Free copies

Three free copies of the magazine (one for a book review) are provided for authors of articles published in it. Separate offprints for each article are not provided.

Contributions: It is requested that all communications to the Editor and books for review be addressed to the Chief Executive, Meteorological Office, London Road, Bracknell, Berkshire RG12 2SZ, and marked 'For *Meteorological Magazine*'. Contributors are asked to comply with the guidelines given in the *Guide to authors* which appears on the inside back cover. The responsibility for facts and opinions expressed in the signed articles and letters published in *Meteorological Magazine* rests with their respective authors.

Subscriptions: Annual subscription £30.00 including postage; individual copies £2.70 including postage. Applications for postal subscriptions should be made to HMSO, PO Box 276, London SW8 5DT; subscription enquiries 071–873 8499.

Back numbers: Full-size reprints of Vols 1–75 (1866–1940) are available from Johnson Reprint Co. Ltd, 24–28 Oval Road, London NW1 7DX. Complete volumes of *Meteorological Magazine* commencing with volume 54 are available on microfilm from University Microfilms International, 18 Bedford Row, London WC1R 4EJ. Information on microfiche issues is available from Kraus Microfiche, Rte 100, Milwood, NY 10546, USA.

December 1990

Editor: F.E. Underdown
Editorial Board: R.J. Allam, R. Kershaw, W.H. Moores, P.R.S. Salter

Vol. 119
No. 1421

Contents

ISSN 0026–1149

ISBN 0-11-728672-9

9 780117 286726

Printed in the United Kingdom for HMSO
Dd 0291241 12.90 C13 503 12521