



# **Short-range Forecasting Research**

**Short Range Forecasting Division**

**Technical Report No.18**

**QUANTIFYING THE LOW-LEVEL  
WINDSHEAR AVIATION HAZARD  
FOR THE UK:  
SOME RESEARCH PROPOSALS**

**by**

**R.J. GRAHAM and R.W. LUNNON**

**May 1992**

**Meteorological Office  
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United Kingdom**



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# Quantifying the low-level windshear aviation hazard for the UK: some research proposals

## 1. Introduction

Encounter with windshear on approach or take-off has been identified as the main cause of weather-related aircraft accidents in the USA (Johnston, 1986). As a result a great deal of effort has been directed, in that country, towards understanding the structure of extreme low-level windshears, and in designing systems capable of detecting them (see e.g. Bowles and Hinton, 1990). Much of this effort has been focused on the microburst phenomenon (see e.g. Fujita, 1985), which is well established as the principle windshear hazard in the USA. In comparison, relatively little is known about the risk posed by low-level windshear to aviation operations in the U.K. It is generally believed that the risk in the U.K is much smaller than in the USA - primarily because of the lack of documented examples of microburst events in this country. However, significant shears can be associated with a variety of other meteorological phenomena (some examples are discussed in Woodfield and Woods (1983) and later in this report) all of which pose a potential threat to aircraft safety.

In light of the above, the aim of this paper is to review the results of existing studies of low-level windshear in the U.K., and to identify areas where further research to quantify the risk would be valuable. Published statistics on windshear in the U.K are reviewed in section 2. In section 3 the possibility of using the U.K. Met. Office mesoscale model to identify geographical regions which may be prone to topographically forced windshear is discussed. Ways of assessing the risk from convection-related windshear, which may include microburst-type events, are discussed in section 4.

Before proceeding further it will be useful to list the meteorological phenomena associated with low-level windshear and to comment briefly on the factors affecting the perceived severity of the hazard to aviation. Low-level windshear (hereafter referred to simply as windshear) can be associated with any of the following six meteorological phenomena (Annex 3 of the ICAO convention);

- a) thunderstorms
- b) cold or warm fronts
- c) strong surface winds coupled with local topography
- d) sea breeze fronts



- e) mountain waves
- f) low-level temperature inversions.

At the suggestion of the Aircraft Accident Investigation Branch (AAIB), a seventh is added to the list, namely;

- g) inaccurate measurement of surface wind, arising from inappropriate siting of anemometer(s).

Several attempts have been made to define a windshear severity scale in which windshear characteristics are related to the severity of the effect on aircraft control. A simple scale, in which windshear severity is related to head wind changes over a fixed distance of 600m, is shown in Table.1. Woodfield and Woods (1983) have warned, however, that use of a fixed distance to classify windshear severity can result in a misleading assessment of the effect on aircraft control; they stress that the two factors of overriding importance are the following;

- 1) The rate of change of head wind encountered with respect to the acceleration achievable (about 3kn/s for a B747 in approach configuration).
- 2) The total change in head wind with respect to the airspeed margin above stall speed (about 20% or 25kn for a B747).

## 2. Review of existing statistical studies

Published statistics on windshear frequency at U.K airfields are scarce. The only study to date which specifically addresses the probability of encountering windshear on approach is that of Woodfield and Woods (1983) (hereafter referred to as WW), whose paper on worldwide windshear statistics includes a separate analysis of data for Heathrow. Further information on windshear, albeit of a less direct form, is available from studies of the local horizontal variability of the surface wind performed at Heathrow (Roach and Forrester, 1984) and Gatwick (Marklow and Lunnon, 1990). Information of a more qualitative nature is also available, for Heathrow, from an unpublished Met. Office paper on the verification of windshear forecasting rules against pilot reports (Forrester, 1981). The main results of these studies are reviewed below.

### Aircraft encounters with windshear on approach

WW have analysed data collected from 9135 landings by 26 British Airways



B747 aircraft at 71 airports worldwide between 1981-82. For each landing, data were collected at 1s intervals for the final 2mins before touchdown. Of the 9135 landings, 2365 were at Heathrow airport. An interesting result of the study is that Heathrow appears to have a high frequency of large shears on short length scales - as discussed below.

Results for Heathrow, taken from WW, are shown in Fig.1 for 4 layers below 1500ft. In this example only simple shear patterns are considered, in which the head wind decreases without a subsequent recovery. Results for three length scales (or "ramp" lengths) are shown: the ordinate gives the number of exceedances, per ramp length travelled, of a given speed change; the abscissa shows the normalised speed change,  $\Delta v/H^{1/3}$ , where H is the ramp length. The interpretation of Fig.1 is aided by considering, as an example, the question: what is the largest speed decrease, over a ~300m air distance, likely to be encountered once in 1000 landings? To answer this question, first note that for an approach duration of 2mins at a speed of  $75\text{ms}^{-1}$  an exceedance of once in 1000 landings is equivalent to once in  $10^{4.5}$  ramp lengths; extrapolating the 301m ramp length curve (for the 250-500ft layer) to the  $10^{-4.5}$  exceedance level indicates that, at Heathrow, a head wind decrease in excess of ~16kn ( $\Delta v/H^{1/3} \sim -1.2$ ) may be expected once in 1000 landings (note that a shear of this size would be considered "severe" according to the scale given in Table.1). A similar analysis, based on the world wide dataset, indicates that a head wind decrease in excess of 12-15kn may be encountered once in 1000 landings on global routes. The lower figures obtained from the world wide dataset suggest that, compared with other airports, Heathrow will tend to pose more of a threat to aircraft with low approach speeds than to those with relatively high approach speeds - the former being more sensitive to shorter length shears.

The reason for the high frequency of strong shears on short length scales at Heathrow is uncertain. Reference to Fig.1 shows that the effect extends to the 1000-1500ft layer - suggesting that the influence of airport buildings, which might be expected to be confined to the lowest layers, is unlikely to be the main cause.

It is possible that shears due to thunderstorm activity are under represented in the data used by WW, and this will be an important factor to address in any future research. It is not known, for instance, how aircraft avoidance of thunderstorm activity may have biased the statistics. Furthermore, the period of observation was relatively short, and is unlikely to sample the full range of convective conditions climatologically "possible"



at Heathrow. This may be an important omission, since the likelihood of severe convective storms is highest in the south and east of England. A program of windshear monitoring by DWR would provide the database necessary for a more complete assessment of the risk of large windshears associated with convective activity (see section 4). Further to the above, WW do not address the problem of how the risk is distributed amongst the various relevant meteorological phenomena. Such information would be useful in devising schemes for forecasting windshear.

#### **Spatial variability of the surface wind at Heathrow and Gatwick**

Studies of the horizontal variability of the surface wind between two airfield anemometers at different sites have been performed by Roach and Forrester (1984) for Heathrow, and Marklow and Lunnon (1990) for Gatwick. The studies were designed to assess the probability of the wind at the ATC anemometer being significantly different to that that might be experienced by an aircraft at touchdown or take-off. It is difficult to derive information on the probability of head wind shears, on approach or take-off, from the statistics on surface wind variability. However, the possibility of unrepresentative ATC wind reports is a related cause for concern, and for this reason the results are reviewed below.

For both Heathrow and Gatwick the horizontal variability was found to contain systematic elements, due to airfield buildings causing differences in exposure between the two sites, in addition to the variability resulting from local weather conditions. The effect of buildings on the wind variability is most striking in the study for Heathrow, in which Roach and Forrester concluded that the interference of buildings increased wind speed differences by a factor of 2-5 and could, on some occasions, generate wind direction changes of over  $30^{\circ}$  for periods of several hours. Exposure problems at Heathrow were exacerbated when the winds were strong and gusty, with about half the wind differences in excess of 20kn occurring when the wind speed exceeded 20kn. Nevertheless, there were some occasions when differences of 10-15kn were recorded while the wind speed at one site was less than 5kn. At both Heathrow and Gatwick significant wind variability (i.e. vector wind differences between the two sites of 15kn or more) was found to be associated with the passage of cold fronts, low pressure troughs and with ambient shower or thunderstorm activity. However, as indicated above, moderate to strong, gusty winds - coupled with exposure differences due to airport buildings -



contributed more large differences than any other single factor.

The probability of vector wind differences exceeding a given magnitude is shown in Fig.2 for both Heathrow and Gatwick. In both cases the differences were calculated from 2min average winds. The smaller probabilities at Gatwick, for the whole range of differences, is undoubtedly related to the smaller separation between the anemometers (3.2km at Heathrow, 1.25km at Gatwick). By way of an example, Fig.2 shows that the probability of a vector difference between the two sites exceeding 15kn is about 1 in 10,000 at Heathrow and about 1 in 30,000 at Gatwick. Similar probabilities may be assumed to apply for the differences between the surface wind disseminated by ATC, and the wind experienced by an aircraft at touchdown or take off.

Horizontal shears in the surface wind will usually extend some distance above the surface, and the exceedance probabilities shown in Fig.2 will therefore be correlated with the probability of vector differences along equivalent sections of the approach path. However, vector shears along the approach path which are dominated by vertical gradients in the wind field will not be reflected in surface wind variability and use of Fig.2, will therefore tend to under estimate the probability of encounter with vector wind shears on approach. The use of vector wind differences (rather than differences in the wind component along the runway) make it difficult to relate the statistics to equivalent changes in head wind component. In addition, the fixed separation of the anemometers make it difficult to comment on the length scale of the changes.

Marklow and Lunnon have given examples of along-runway wind differences on a case study basis, and it is notable that, at Gatwick, the largest recorded difference in the along-runway wind component was 18.2kn and occurred on a day marked by showery activity. The wind speed differences between the anemometers on this occasion did not exceed 10kn, the large vector differences being associated with occasions when direction differences exceeded  $90^{\circ}$ .

One limitation of the above studies is that they were, of necessity restricted to studying the variability of the wind between two sites only. It is planned to increase the number of anemometers at Heathrow from two to four and it would be useful to repeat the Heathrow study, using all four anemometers, when this has been implemented.

#### **Trial of windshear forecasting rules**

An operational trial of windshear forecasting rules took place at



Heathrow during the period 16 May to 30 Nov. 1981. The efficacy of the rules was tested by verifying forecasts of windshear against pilot reports. The results of the trial yield some information on the meteorological phenomena with which windshear at Heathrow is most frequently associated. The results also highlight some of the difficulties in inferring the presence of windshear - of sufficient strength to affect aircraft performance - from conventional meteorological data alone (i.e. without dedicated wind-finding equipment).

In the trial, windshear warnings were issued if one or more of the following conditions was satisfied;

- a) Mean surface wind speed greater than or equal to 17kn.
- b) The magnitude of the vector difference between the mean surface wind and the gradient wind (an estimate of the 2000ft wind) greater than or equal to 45kn.
- c) Thunderstorms or heavy showers within about 10km of the airfield.
- d) A recent pilot report of windshear.

Results of the study are summarised below;

- Pilot reports confirming windshear were received in 4.5% of warning periods. This implies that 95.5% of the warnings were false alarms; the apparently large false alarm rate may be over pessimistic, however, since pilots may well be less likely to report windshear when it is expected (i.e. when there are thunderstorms in the vicinity, or when a warning is in force).
- Pilot reports of windshear were received in 0.3% of non-warning periods.
- Warnings occupied 6% of the time.

The high false alarm rate is undesirable since it may give rise to a tendency for pilots to disregard warnings. The study clearly suggests that more research is required to increase the skill with which windshear can be forecast without also increasing the false alarm rate.

A rule which called for windshear to be forecast if a frontal surface was in the vicinity of the airfield was dropped after a preliminary trial found no correlation between frontal surfaces and pilot reports of windshear. This finding is in apparent contradiction to the studies of Roach and Forrester and Marklow and Lunnon, discussed above. However, cold fronts crossing southern England typically replace a southwesterly airstream with a northwesterly airstream and consequently any windshear associated with cold front passage will tend to appear mainly in the cross-runway wind component. (Two of the



three runways at Heathrow are oriented 280/100. Those at Gatwick are oriented 260/080.). Such shears would have little effect on the descent/ascent rate of the aircraft, and may therefore not have been reported. The preliminary trial also found that rule (a) (with a threshold wind speed of 25kn rather than 17kn) was the rule most highly correlated with pilot reports of windshear - which is consistent with the results of the afore mentioned studies. Rule (b) was also successful - but did not apply very often. Rule (c) produced considerable over warning in summer, and was difficult to apply because of the lack of weather radar.

### 3. Future research

#### 3.1 Constructing U.K climatologies of topographically forced windshear

To advance skill in predicting windshear it will be necessary to increase knowledge of the risk attached to each of the various causes of windshear. For this reason, and to extend the limited scope of existing studies (which have concentrated on Gatwick and Heathrow) it would be useful to construct a climatology of the risk, for the U.K., posed by each of the relevant meteorological phenomena. Unfortunately, there is little information of a statistical nature on the occurrence of windshear at airports other than Heathrow and Gatwick: much of the information which does exist being in case study (e.g. Findlater, 1984) or anecdotal (e.g. Menzies, 1991) form. It would be prohibitively expensive to acquire the necessary data using a detailed observing program similar to that of WW, and a feasible alternative would be to base the climatologies on output from the Met. Office mesoscale model. The mesoscale model has sufficient resolution to model the geographical distribution of weather conditions typically associated with vertical windshear (e.g. temperature inversions and sea breeze flows), and could be used to identify regions which are climatologically prone to these weather phenomena. The climatologies of windshear risk produced by the mesoscale model could be checked against the case study and anecdotal evidence. In addition to exploring the risk of windshear on a nationwide basis, results from the mesoscale model would also serve to complement the information on windshear characteristics already available for Heathrow. At the major U.K. air fields data from aircraft fitted with aircraft to satellite data relay (ASDAR) equipment, which report every 10mb in the lowest 100mb of climb or descent, could be used to check the model performance.

An example will serve to illustrate the potential of the approach



described above. Menzies (1991) has suggested that the Forth/Clyde valley region may be prone to windshear (he cites a recent example in which a 2000ft wind of 260 50kn was encountered above a surface wind at take off of SE 5kn). It is possible that this and other instances of windshear in the Forth/Clyde region are related to the presence of low-level temperature inversions, which are common in valleys. It is well known that temperature inversions may be accompanied by low-level jet structures in the wind field - and therefore with vertical windshear. The mesoscale model can simulate much of the effect of geography on the formation of low-level temperature inversions (i.e. wind shelter, cold air drainage), and might therefore be used to confirm the association of low-level windshear with temperature inversions in this region. Other regions which might be prone to similar effects could also be identified. Of course, it is not suggested that it will be possible to predict the intensity of the windshear. However, it should be possible to calibrate selected model output - a combination of a low-level vertical temperature gradient and vertical windshear, for example - to give an indication of the risk of low-level windshear to aviation operations at particular airports. The risk from sea breeze flows at coastal airports such as Liverpool and Bristol could also be studied in a similar way.

Orographic lee waves and rotor flows are further potential sources of low-level windshear at U.K airports. Findlater (1984) has drawn attention to a number of cases reported at Inverness (Dalcross) airport, including one example when a BA 1-11 reported wind speed changes of +/-50kn on approach. Harrison (1992) has reported encounters with mountain waves at Aberdeen, Edinburgh, Newcastle, Teeside and Leeds/Bradford. Mountain waves effects could also be experienced at Prestwick and Glasgow airports, given the right flow conditions.

The current operational version of the mesoscale model has insufficient resolution to model lee wave activity. However, certain types of lee wave flow can be modelled by high resolution experimental versions of the model (Lorenc et. al. 1991), and future research may be able to make use of these models.

### 3.2 Windshear associated with convective activity

An important task for future research is to address the probability of an aircraft encounter with a microburst in the U.K. It is widely accepted that, for aviation operations in the USA, the risk of encounter with a microburst (see for example Fujita and McCarthy 1990) poses by far the greatest windshear



hazard. However, to date there is no well documented example of the microburst phenomenon in the U.K. Nevertheless, violent disturbances to the low-level wind field have been recorded, in this country, in association with strong convective activity and some of these may be associated with microburst-like events. An example of such a disturbance, which occurred during thunderstorm activity at Farnborough airfield in May 1989, is outlined later in this section, and may be a suitable case for further study to help determine the characteristics of windshear associated with such phenomena.

Microbursts, like tornados, are generally associated with severe convective activity, and it may not be unreasonable to assume that microburst frequency in the U.K is related to tornado frequency. The majority of tornadoes in the U.K occur east of the mountains of Wales and south of the mountains of northern England (Meaden 1976), and this area must be considered to be at greatest risk from the microburst. Roach and Findlater (1983) have estimated the likelihood of an aircraft encounter with a tornado, in the region described above, as between a factor of 10-100 less than that in the worst tornado regions of the USA. It may not be unreasonable to assume that a similar ratio applies for the risk of encounter with a microburst. In the USA the risk at individual airports is assessed using a simple algorithm based on the average number of thunderstorms observed at the airfield per year and the number of operations per day. The result is used to determine whether a low-level windshear alert system (LLWAS) should be installed. When applied to Heathrow the same algorithm indicates that the need for LLWAS is marginal. Preliminary considerations suggest, therefore, that the risk to aviation from microburst activity at the major airports within the U.K should be more rigorously assessed.

Doppler Weather Radar (DWR) is a powerful tool for the study of detailed structure in the wind field and has been used extensively in the study of microbursts in the USA (Hjelmfelt, 1988). To fully assess the frequency of microburst-like phenomena in regions of the UK would require the deployment of a DWR (preferably an array of such instruments) and a period of data collection and analysis. Although DWR is not currently deployed on a routine operational basis in the UK, DWR winds will shortly become available on completion of the planned addition of a Doppler facility to the existing weather radar installation at Cobbacombe, Exmoor (some experience with DWR has been gained from the Siemens Plessey Radar system located at Cowes, Isle of Wight (Lilley, 1990)). The maximum (on site) resolution of the Cobbacombe radar will be  $1^\circ$  of arc with 150m range gates, although some averaging of



range gate data is likely to take place before dissemination beyond site. To meet requirements for the study of low-level windshear, range gate averaging should be kept to a minimum (such that the spatial resolution is better than 500m, say). The Cobbacombe radar will produce a volume scan every 5mins, which is on the low side for sampling microburst activity - microburst intensities are typically maintained for only 10-15mins (Hjelmfelt, 1988). The forthcoming data from Cobbacombe will prove invaluable to the general study of windshear, however, the high elevation of the site may make it difficult to apply the derived windshear frequency statistics to terminal areas such as Heathrow. The best way of obtaining data specific to terminal areas would be to add a Doppler facility to one or more of the existing ATC radars, and this is probably the best option for assessing the risk to aviation from convective microbursts. Adding a Doppler facility to existing ATC radars would, in addition, provide independent datasets for comparative studies with the Cobbacombe data. Alternatively, data from multiple anemometer configurations, such as that planned for Heathrow, will yield site specific information - but the horizontal resolution of the data will not be ideal and the required period of data acquisition is excessive (e.g. to estimate the shear strength associated with an exceedance probability of  $10^{-8}$  would require ~20years of data).

To illustrate the potential hazard to aviation in the U.K. a case in which a severe disturbance in the surface wind was associated with thunderstorm activity at Farnborough in May 1989 is briefly presented below. As yet the specific cause of the disturbance (i.e. gust front or microburst) has not been identified. The radar derived precipitation rates at 1250GMT 24 May 1989 are shown in Fig.3, the location of Farnborough is marked ("F"). A large storm cell with precipitation rates in excess of 100mm/hr may be seen to the south-west of Farnborough. The anemograph record for the relevant period is reproduced in Fig.4. The record shows that during the period 1230 to 1250, when the storm cell was developing and approaching Farnborough from the south-west, the wind backed from NE'ly to SE'ly. At around 1240 the mean wind speed, previously below 10kn, increased to 15kn - and this increase was shortly followed at 1250 by a sudden gust of 46kn from the south. The strong gust will clearly be associated with strong horizontal windshear and further research to attempt to quantify the horizontal windshear implied by the time sequence information shown in Fig.4 would be valuable.

Simulations of convective storms such as the Farnborough storm, using numerical models capable of resolving microbursts-like features could be used



to relate the severity of windshear to synoptic factors affecting storm development, such as stability and low-level moisture content. The frequency with which synoptic conditions favoured convection-related windshear could then be assessed by analysis of the relevant synoptic parameters using past synoptic records.

#### 4. Summary of recommendations

Some of the possible avenues of research that might be pursued in order to advance understanding of the threat posed by low-level windshear in the U.K have been discussed above. Based on this discussion a summary of recommendations is given below.

- Further studies of the horizontal variability of the surface wind should be performed at Heathrow after the installation of the two additional anemometers.
- Strategies should be developed to calibrate relevant variables in mesoscale model output against probable risk of windshear. The main purpose would be to identify regions which may be prone to windshear. However, the utility of the mesoscale model as a forecasting tool in real time forecasting of windshear could also be assessed.
- Steps should be taken to ensure that data at sufficiently high spatial resolution for windshear studies will be available from the Cobbacombe DWR.
- We recommend that the addition of a Doppler facility to the ATC radar at Heathrow should be considered.● A statistical analysis of windshear frequency should be carried out on data from the Cobbacombe radar when it comes on line, and on data from Dopplerised ATC radar, should it become available. Comparative studies of data from the two sites would be valuable.
- The event at Farnborough described in section 4 should be analysed to estimate the likely horizontal wind shear associated with the event.
- Studies of numerical simulations of severe storms should be performed to look for a relationship between convection-induced windshear and synoptic scale parameters such as stability.

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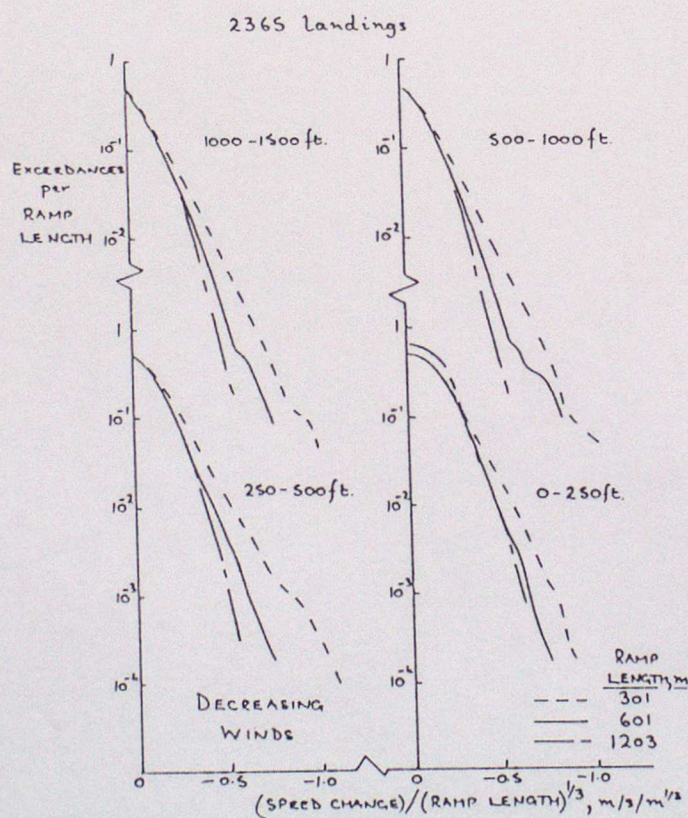


Intensity of Shear	Effect on Aircraft Control	Head Wind Shear in 600 m*
Light	Little	0 to 2 m/s (0 to 3.9 kn)
Moderate	Significant	2 to 4 m/s (4 to 7.8 kn)
Strong	Considerable difficulty	4 to 6 m/s (7.9 to 11.7 kn)
Severe	Hazardous	>6 m/s (11.7 kn)

\*Described separately as change for 600 m horizontally and 30 m in height, but this is equivalent to 600 m travelled on a 3° flightpath

#### WINDSHEAR SEVERITY SCALE PROPOSALS TO ICAO

TABLE. 1 (from Woodfield + Woods, 1983)



London (Heathrow). Variation of single ramps with height

Fig. 1 (from Woodfield and Woods, 1983)



Fig. 2

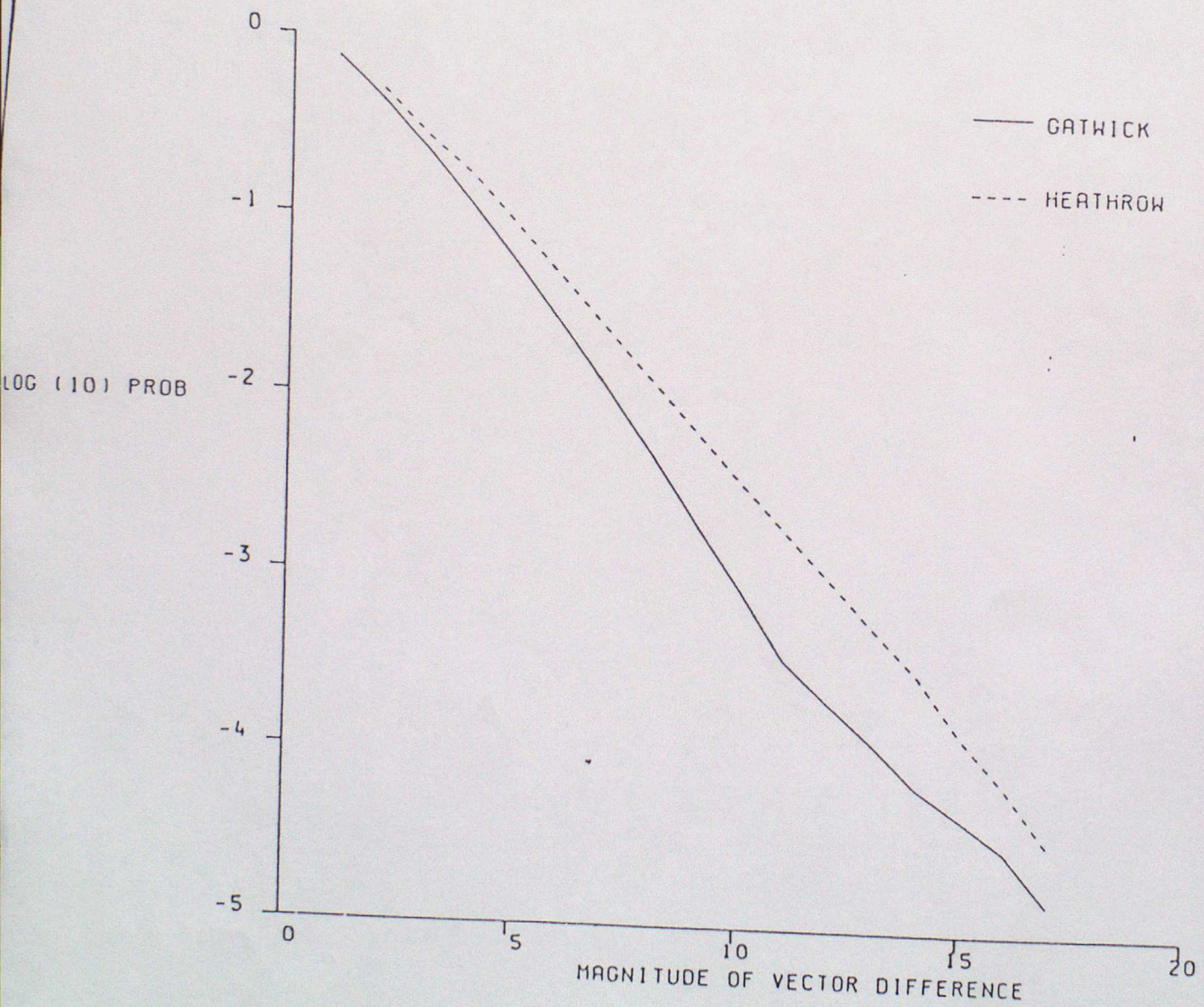
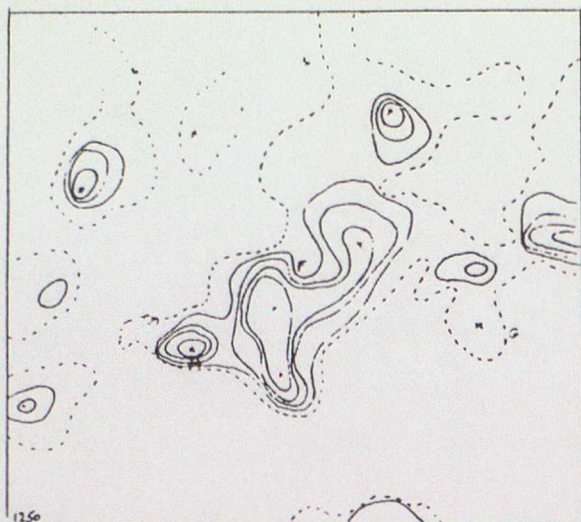


Fig.2

(from Marklow and Lunnon, 1990)





----- 5.0 m.k.-1  
 ————— depths at 25 m.k.-1 interval  
               50 m.k.-1  
               75 m.k.-1  
               100 m.k.-1

F - Farnborough  
 G - Guelphford

Fig. 3

SOUTH FARNBOROUGH - AUTOGRAPHIC RECORDS.

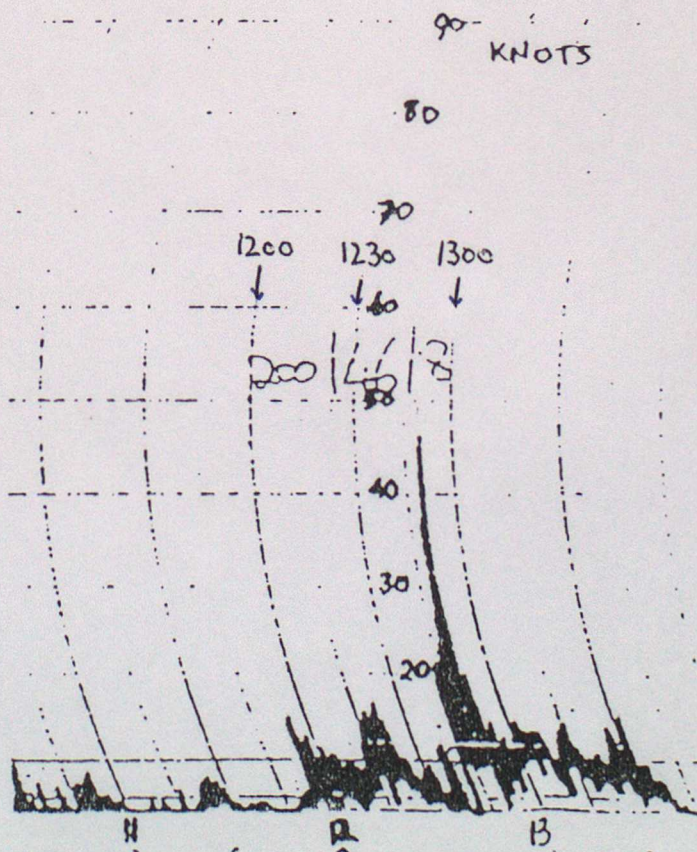
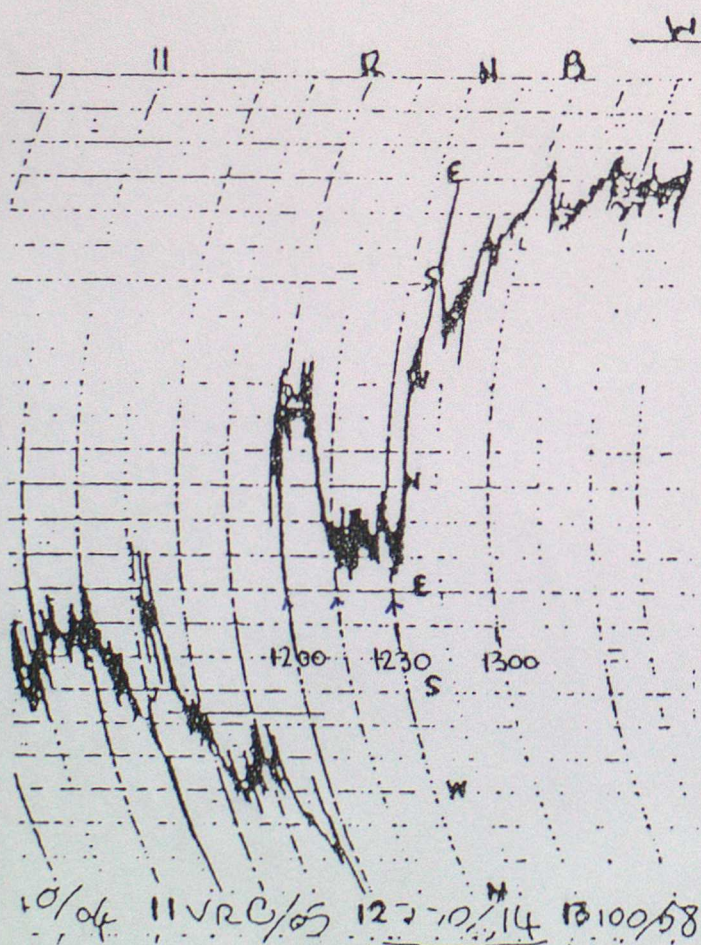


Fig. 4