THE METEOROLOGICAL MAGAZINE

HER MAJESTY'S
STATIONERY
OFFICE

June 1986

Met.O.971 No. 1367 Vol. 115

METEOROLOGICAL OFFICE Met.O.971

THE METEOROLOGICAL MAGAZINE

No. 1367, June 1986, Vol. 115

551.509.313

The Meteorological Office fine-mesh data assimilation scheme

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Summary

The initial fields for the Meteorological Office operational forecast models are provided by a data assimilation scheme which uses a repeated insertion technique to adjust model fields towards the observations. This paper describes how the scheme is used in the limited-area fine-mesh version of the model. The results of several studies are presented which illustrate the beneficial aspects of fine-mesh analyses compared with analyses which have been interpolated from a coarser-mesh global data assimilation.

1. Introduction

Fine-mesh limited-area forecast models have been an important tool to the forecaster for more than a decade now, but for much of that period little attention has been paid to the problem of analysing fine-scale detail. The initial conditions for the fine-mesh model have generally been determined by interpolation from a coarser-mesh hemispheric or global analysis. The reasons for this reluctance to tackle the problem of objective analysis of small-scale features are not difficult to understand. Primarily the problem is one of data sparsity. It has long been thought that attempts to analyse on a scale which is smaller than that provided by the observing network would be doomed to failure. The introduction of high-resolution satellite data from the HERMES (High-resolution Evaluation of Radiances from MEteorological Satellites) system (Turner *et al.* 1985) has, however, provided one impetus for the development of a fine-mesh analysis system.

Another difficulty, which has slowed the development of fine-mesh analysis systems in operational numerical weather prediction centres, is the problem of initialization. Conventional non-linear normal mode initialization schemes have proved to be rather difficult to apply to limited-area models because their solution is complicated by the presence of lateral boundary conditions. Bourke and McGregor (1983) have developed techniques for overcoming these problems, but such complications do not in fact arise with the scheme adopted by the Meteorological Office. The repeated insertion scheme, which was first developed by Lyne *et al.* (1982) for global data assimilation, has been designed to minimize the excitation of spurious gravity waves. Small observation increments are added to the model fields, which are assumed to be sufficiently in balance, at each time-step, so that the model is not forced too far from a 'balanced state' and the requirement for any further initialization is eliminated. It is relatively simple to adopt such a scheme for use with a limited-area fine-mesh model.

Apart from the observations, the other component of any analysis scheme is, of course, the forecast model itself. The detail provided by fine-mesh forecasts is very impressive (Woodroffe 1984) and although spurious features are occasionally developed, there is now sufficient confidence in the fine-mesh fields to use them as the basic starting point of the analysis in preference to the smoother coarse-mesh fields. The fine-mesh forecast structure should be retained in subsequent analyses, especially in data-sparse regions. Better quality control of observations which define intense features might also be anticipated if those features were present in the first guess for the analysis. The important detailed structure of frontal regions cannot be determined from observations and can only be analysed using a fine-mesh first guess. By achieving a frontal analysis on a scale which is consistent with the forecast model being used, the 'spin-up' time during which the fields adjust to the scale of the model is much reduced. The elimination of this spin-up period implies that useful rainfall fields may be obtained from the early stages of a forecast and also that features which may be developing rapidly in those early stages would not have their development retarded.

The fine-mesh data assimilation scheme also allows the inclusion of a more detailed orography at the analysis stage. This makes the analysis of surface reports which are influenced by orographic effects more meaningful and also allows the full effects of a more detailed representation of a mountainous area to be felt from the start of the forecast. The alternative way of including a finer-mesh orography is to insert it gradually during the early stages of the forecast which, as well as generating 'noise', means that the full benefits are lost.

2. The fine-mesh data assimilation scheme

The techniques used for the analysis and assimilation of data for limited-area fine-mesh modelling are closely allied to those developed for the operational global data assimilation scheme, to the extent that both data assimilation systems share the same core computer code. Atkins and Woodage (1985) have given a brief descriptive account of the data assimilation scheme and Gadd (1985) has outlined the 15-level weather prediction model which is used for both data assimilation and forecasts. Full details of the coarse-mesh scheme can be found in Bell (1985) and to avoid undue repetition only a brief outline of the basic scheme is given here. Additional detail is given where the fine-mesh scheme differs from the global scheme.

(a) Intermittent assimilation

The first point to note is that the fine-mesh data assimilation is not a continuous cycle. The starting point for making a fine-mesh analysis of time T is an interpolated coarse-mesh analysis valid at T−12 hours. This uses a simple bi-linear interpolation to the latitude–longitude fine-mesh grid which has twice the resolution of the coarse-mesh model and has the same 15 levels and the same terrain-following vertical coordinate system. The fine-mesh domain is enclosed by longitude lines 80° W and 40° E and by latitude lines 80° N and 30° N. There are 129 grid points east–west and 67 north–south giving a horizontal resolution of about 75 km in the vicinity of the United Kingdom. Lateral boundary values are required to allow for the movement of synoptic features through the edges of the forecast region. The boundary tendencies for the prognostic variables are derived from a coarse-mesh forecast starting from the same coarse-mesh analysis at T−12 which is used to provide the interpolated fine-mesh field. These tendencies are applied throughout the assimilation period as well as the subsequent forecast. Fuller details of the boundary update scheme are given in Dickinson (1985), which also describes the integration scheme and the physical parametrizations. The necessity for lateral boundary updating is one reason why this intermittent assimilation cycle has been adopted for the fine-mesh model in preference to a continuous cycle. The boundary updating scheme involves the specification of interpolated coarse-mesh values at the fine-mesh boundary points and a continuous assimilation cycle would involve using boundary values from a succession of coarse-mesh forecasts. This procedure would introduce a shock to the fine-mesh model whenever the boundary values were introduced from a new coarse-mesh forecast since they would be incompatible with previous values. The gravity waves generated would make quality control of observations for the fine-mesh analysis rather difficult since the first-guess fields would be contaminated by noise. The intermittent assimilation cycle also makes the subjective monitoring of the analyses by the forecasters in the Central Forecasting Office rather easier because the coarse-mesh and fine-mesh solutions cannot diverge too far from one another.

The assimilation cycle consists of four separate 3-hour assimilation periods as illustrated in Fig. 1.

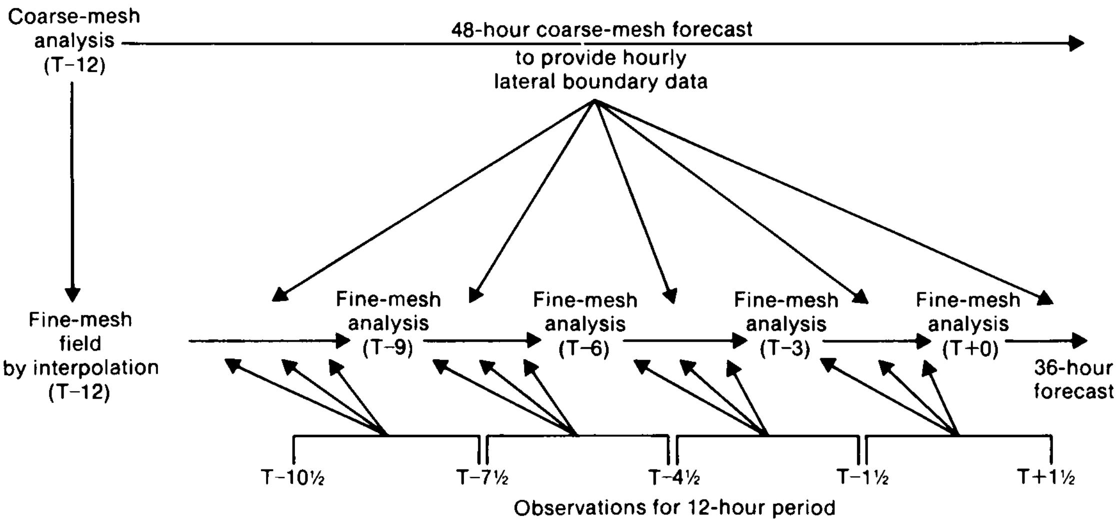

Figure 1. Schematic diagram of the operational fine-mesh data assimilation scheme.

The observations used in each period are those which are valid at T−9, T−6, T−3 and T+0 hours. An observation time window of ±1½ hours allows all observations which fall within that 3-hour window to be used, with the exception of surface data which are included only if verifying at the analysis time. This contrasts with the coarse-mesh assimilation cycle which is based on 6-hour assimilation periods each with a 6-hour time window for the observations. Thus, in the fine-mesh scheme, the asynoptic data, such as aircraft reports and satellite soundings, are used at a time which is closer to the observation time and also the surface observing network can be used at the intermediate hours (03, 09, 15 and 21 GMT). The adjustment of the model orography to fine-mesh values in the first period (03 or 21 GMT) does, however, preclude the use of surface pressure information at these stages. This more frequent insertion of data with a smaller time window is likely to be particularly beneficial when the observations are able to identify small-scale, rapidly moving features. The fine-mesh analyses also make use of a more comprehensive surface station network in Europe, whereas in the coarse-mesh analyses only a subset of the network is used for reasons of economy. To avoid unnecessary disturbance near the boundaries of the domain, observations are excluded from a zone near the boundary, where an enhanced diffusion is applied.

A single cycle of the assimilation is illustrated schematically in Fig. 2. The quality control, selection and weighting of observations for a fine-mesh analysis uses the same three-dimensional univariate optimum interpolation procedure as the coarse-mesh analysis, with only a few small modifications.

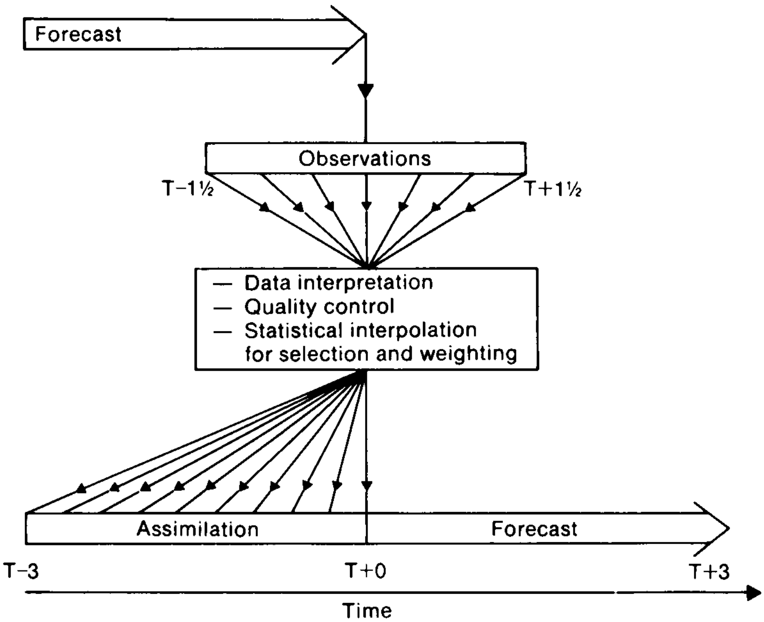

Figure 2. Schematic diagram of one data assimilation cycle (time in hours).

(b) Quality control

The first of two complementary quality-control checks involves the raising of a flag on every observation that departs substantially from the first-guess field, which in the fine-mesh scheme is a 3-hour fine-mesh forecast verifying at the observation time.

An observation ψ_{OB} is suspect if the inequality in the equation

$$(\psi_{OB} - \psi_{FG})^2 \geqslant N_1^2 (\epsilon_{OB}^2 + \epsilon_{FG}^2)$$

is satisfied, where ψ_{FG} is the first-guess value at the observation point, and ϵ_{OB} and ϵ_{FG} are the assumed errors for observation and first guess respectively.

The suspect observations are not allowed to quality control other observations in the second check, which consists of comparing an observation with the interpolated analysis ψ_{INT} using neighbouring observations. However, they may be reinstated if their departure from the interpolated analysis does not exceed a predetermined level as given by the equation

$$(\psi_{OB} - \psi_{INT})^2 \geqslant N_2^2 (\epsilon_{OB}^2 + \epsilon_{INT}^2)$$

where ϵ_{INT} is the expected analysis error. Conversely observations which satisfy this equation are rejected.

The parameters N_1 and N_2 in the above equations have been chosen in order that the scheme gives realistic quality-control decisions (values of 3 are typical). Optimum interpolation is used to calculate ψ_{INT} and ϵ_{INT}. The interpolated analysis is given by

$$\psi_{INT} = \psi_{FG} + \sum_i W_i (\psi_{OB} - \psi_{FG})_i$$

where the observation weights W_i are found by solving the set of equations determined by minimizing the expected analysis error variance ϵ_{INT}^2. To solve these equations the error characteristics of the observation and first-guess fields (i.e. the error covariances) have to be specified. Once the W_i have been found, ϵ_{INT}^2 is known. The summation in the above equation is taken over all selected data. Ideally all data should be used to interpolate to the analysis point, but for reasons of computational economy a selection of the best data is made. The best data are defined as those which, when taken singly, reduce the expected analysis error by the greatest amount.

(c) Interpolation increments for the analysis grid

The optimum interpolation procedure is performed twice. Once to provide an analysis at observation points for the purpose of quality-control checks as discussed above, then a second time to select the data and calculate the required weights for determining increments appropriate to the analysis grid. At this stage only those data which passed the two quality-control steps are available for selection. The optimum interpolation procedure is modified to allow for the higher resolution of the model in two respects. Firstly, the observation errors are reduced by 10% from the values used on the coarse mesh, on the basis that the component of the error which caters for the unrepresentativeness of the observation as an area average may be reduced; this implies a higher weight for the observations. Secondly, a narrower structure function is used as the basis for calculating the first-guess error covariance. The width of the Gaussian structure function is reduced by a factor $\sqrt{2}$ compared with that used on the coarse mesh. This achieves the aim of analysing small-scale features which are identified by the observations. An interpolation analysis is not actually required for the analysis grid, all that is needed are details of the selected observations and their weightings for use in the following assimilation stage.

(d) Assimilation of increments

During the assimilation stage, interpolation increments are recalculated for each time-step using the optimum interpolation weights W_i which have already been calculated. This is done during a 3-hour integration starting at the previous analysis time, using a repeated insertion technique. At each model time-step, the weighted average $\Delta\psi$ of the difference between the forecast values at that time-step ψ_M and the observed values ψ_i is calculated using the equation

$$\Delta\psi = \sum_i W_i (\psi_i - \psi_M)$$

and a small fraction of this is added into the model.

The assimilation equation is represented by

$$\psi_{n+1} = A(\psi_n) + D(\psi_n) + \lambda_n (\Delta\psi_n + G(\Delta\psi_n) + H(\Delta\psi_n))$$

where operator A represents the forecast equations, including all the physical parametrization processes, and operator D represents a damping term which is required to suppress gravity waves generated during the assimilation process. These gravity waves generally have a larger divergent wind component than meteorological motions, and divergence diffusion, which has no effect on the vorticity, is used to control them. A damping coefficient of 2.5×10^6 m^2 s^{-1} is used. The other three terms, which are all scaled by the relaxation coefficient λ_n, are the assimilation increment $\Delta\psi_n$ together with further increments (denoted by operators G and H) which are derived using geostrophic and hydrostatic relationships. During the assimilation period λ_n increases linearly with time. As indicated in Fig. 3, at the

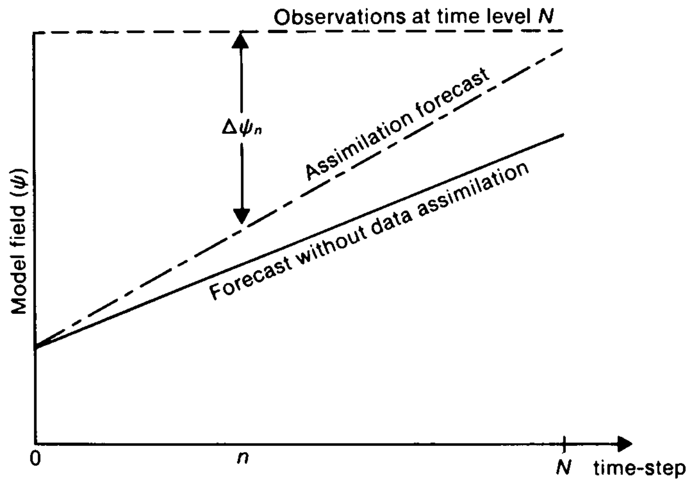

Figure 3. Variation of assimilation increment with time.

start of the assimilation period the assimilation increments may be large and are therefore given a small weight. As the fields adjust towards a state defined by the observations during the assimilation period, the assimilation increments become smaller and a larger relaxation coefficient may be used without generating too much noise. For mass field information the final value of λ is 0.175, but for wind data a smaller value is used during the last few time-steps of the period in order to suppress undesirable surface pressure oscillation at the start of the subsequent forecast. The geostrophically derived wind increments (operator G) and hydrostatically derived temperature increments (operator H) are designed to hasten the fit of mass field data and are fully described in Bell (1985). Geostrophic wind increments are easier to use in the fine-mesh scheme, because the narrower structure function for the first-guess error correlation gives a smoother temperature increment field upon which the geostrophic wind increments are based.

3. Some results of the scheme

(a) Direct impact of additional data

The same basic set of observations is used in any analysis whether coarse mesh or fine mesh. Both aim to make the best use of all available data. Two components of the observing network do, however, produce information on a scale which is equivalent to the fine-mesh model grid. These are the Local Area Sounding System (LASS) data (the locally retrieved satellite temperature soundings produced on the HERMES computer facility) and the European surface observation network. Unfortunately the potential for more detailed analyses based on the direct impact of such data has yet to be realized. Bell and Hammon (1985) have discussed the problems associated with LASS data in some depth. Although a lot of detail is evident in the observed thickness fields, it has proved difficult to identify what detail is real and what is spurious. Significant biases have been noted at low levels and near the tropopause, caused by cloud clearing problems and also the use in the retrieval process of a poor climatological first guess. All these factors contribute to the problem of analysing and adequately assimilating the information from LASS data. Lorenc *et al.* (1985) have described methods by which these weaknesses may be overcome.

The problem of extracting fine-scale information from the surface observing network is equally intractable. It is uncertain how representative the reports are of grid-box mean fields, particularly where local orographic effects may be large. It is also uncertain how to spread the surface information into the lower troposphere. Ideally one might wish to confine the influence of surface information to the boundary layer, but the required flexibility to do this has not yet been established. At the present time the only use made of surface synoptic reports is the surface pressure information. The indirect impact of the data is more significant. When one considers how the data interact with the fine-mesh forecast model and the fine-mesh orography the benefits are more obvious as the following sections will show.

(b) Impact on analysis of using a more detailed orography

Much fine-scale detail at the surface over land is a result of orographic influences and even if this detail is evident from observations on a 75 km fine-mesh scale, it is unlikely to be analysed correctly if a coarse orography is used. Fig. 4 illustrates the mean height for the coarse-mesh orography (150 km grid mesh) for western Europe. It is clear that only the largest features are resolved on this scale. The United Kingdom is only identifiable by a single high value representing the Scottish Highlands and another representing North Wales. The Alps are identified as a single high value of 1800 metres in Switzerland and there is no detail at all in France and Germany. In contrast the fine-mesh (75 km mean) orography in Fig. 5 shows substantially more detail. In particular, the Alps reach up above 2400 metres and four separate high points are clearly resolved, as is the Rhône valley between the Alps and the Massif Central.

The Alps present a considerable barrier to flow from a northerly direction as the example in Fig. 6 clearly shows. The subjective analysis in Fig. 6 has ignored many of the smaller features in the observations which have been influenced by orography on a scale much smaller than 75 km and which are essentially noise as far as the objective analyses are concerned. Even with small features ignored, it is clear that there is a substantial distortion of the flow around the Alps and through the Rhône valley with associated troughing in the region of the Po valley. Fig. 7 shows the objective analysis for the same data time after four cycles of the fine-mesh data assimilation with a coarse-mesh representation of the orography. The flow has only been disturbed slightly by the model Alps in this case and pressure is much too high in northern Italy where the model has been unable to adjust to the observations because of the inappropriate orographic forcing. Fig. 8 is similar to Fig. 7 but in this case a fine-mesh representation of the orography has been used. This shows a surface pressure field which more closely resembles the subjective analysis in terms of the flow around the Alpine barrier and the low pressure to the lee of the Alps.

(c) Aspects of quality control

Another potential advantage of the fine-mesh data assimilation scheme is the greater detail that may be available in the first-guess field which is used for quality controlling the observations. This is especially important at the surface, but may also be valuable near upper jets. An interesting example illustrating this point is an intense surface low which moved north-eastwards across Ireland and Scotland on 18 October 1984. The intensity of this low was not evident until it reached land, where pressure falls in excess of 20 mb in 3 hours occurred in south-west Ireland. The lowest observed pressure

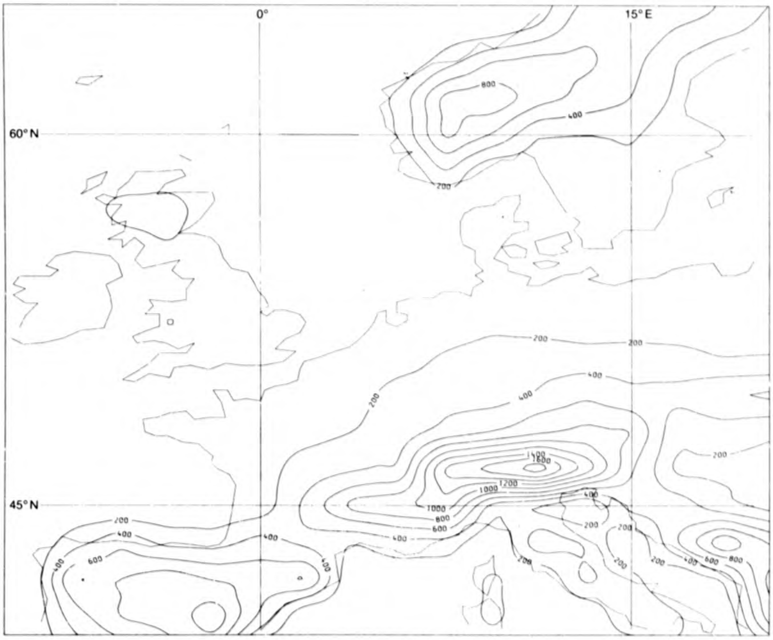

Figure 4. Coarse-mesh orography over north-west Europe. Contours are at 200 m intervals.

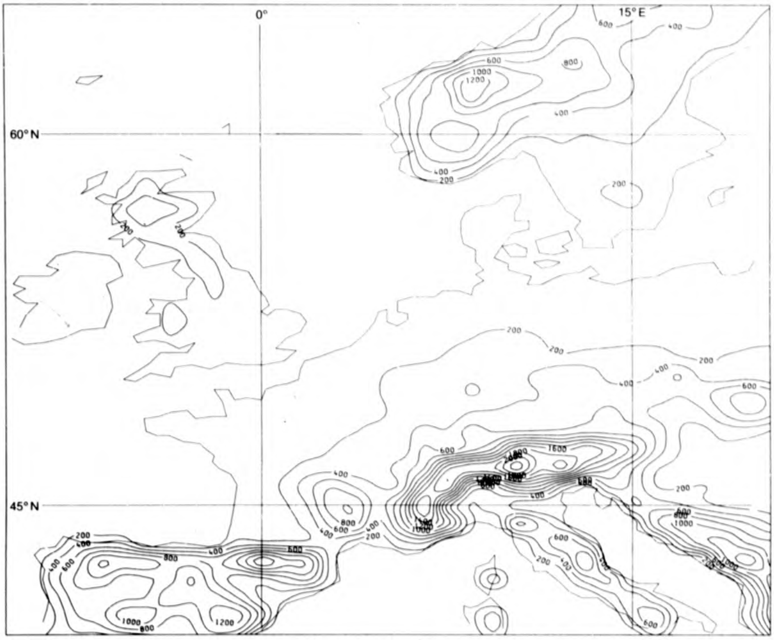

Figure 5. As Fig. 4 but for the fine-mesh.

was 966 mb at Valentia, but the coarse-mesh analysis (Fig. 9) could only achieve 979 mb with the centre shown as nothing more than a trough extending from the main Atlantic low and too far north. Part of the problem was a poor first guess which caused the rejection of several observations and made the fitting of the remaining observations more difficult. The fine-mesh data assimilation of the same case is illustrated in Fig. 10. Although the fine-mesh scheme was unable to adjust towards the Valentia observation which was still rejected, two other previously rejected Irish observations were accepted and the resulting analysis was 6 mb deeper with the centre correctly placed further south. At 18 GMT the low had moved to the north of Scotland and central pressures in the fine-mesh forecasts were 963 and 959 mb from coarse-mesh and fine-mesh analyses respectively, compared with an observed value of 956 mb. The track of the low in the forecast based on the coarse-mesh analysis (Fig. 9) was much too far west of the observed track whereas the forecast and observed tracks in Fig. 10 almost coincide and, perhaps more important, the forecaster could place more credence in this solution because the analysis was better.

(d) Impact of a higher-resolution assimilation model

In addition to making the assimilation of observations rather easier, as the previous example has shown, it would be hoped that a higher-resolution model would provide more detail in data-sparse areas. An example of this is the analysis based on data for 00 GMT on 10 October 1985. The subjective analyst's chart for that date is given in Fig. 11. The main feature of interest is the system in the Atlantic where surface reports are completely lacking. The analyst has drawn a low of central pressure 998 mb at 30° W, based on continuity and satellite imagery, with a warm front extending towards Ireland. Figs 12 and 13 show objective analyses for the same data time from the coarse-mesh and fine-mesh data assimilation systems respectively. The fields of surface pressure, 1000 mb wind and 700 mb vertical velocity are superimposed. The fine-mesh solution is closer to the truth in several respects. It correctly puts the centre of gravity of the system back near 30° W and it has a sharper definition of the frontal structure as indicated by the vertical motion field. The wind vectors match the subjective analysis with regard to the sharp trough which marks the cold front at 30° W, the sudden decrease in strength of the south-westerly flow at 15° W at the surface warm front and also south-westerly flow in the warm sector which is rather too anticyclonic in the coarse-mesh analysis. The different characteristics of the two analyses are very obvious in Fig. 14 which shows cross-sections through the system along the 52° N line of latitude. The horizontal wind shear is much greater in the fine-mesh analysis (Fig. 14(a)) at 28° W near the cold front. At 850 mb the northerly component of the wind changes from northerly 10 m s^{-1} to southerly 20 m s^{-1} across the frontal zone in the fine-mesh analysis, whereas the comparable values for the coarse-mesh analysis are northerly 5 m s^{-1} changing to southerly 15 m s^{-1}. There is a much stronger thermal contrast in the fine-mesh analysis, as indicated by the pecked contours, especially at low levels. The fine-mesh solution also gives much stronger vertical motions as indicated by the arrows.

The best test of the analyses is to determine how good the subsequent forecasts are. Figs 15 and 16 show the evolution of two fine-mesh forecasts one starting from an analysis produced by the fine-mesh data assimilation system (a) and the other starting from an interpolated coarse-mesh analysis (b). Fig. 15 shows T+0, T+6 and T+12 surface pressure charts for the two forecasts, the left-most charts corresponding with Figs 12 and 13. The centre pair of charts indicate a 6 mb difference in the central pressure of the Atlantic low by T+6 and the two forecasts diverge further by T+12 so that (a) is 9 mb deeper than (b) with a correspondingly more vigorous circulation. This trend continues in the later stages of the forecasts, shown in Fig. 16, with differences in central pressure of 12 mb, 12 mb and 8 mb at T+18, T+24 and T+30 respectively. The speed and track of the forecast low is similar in both runs. In fact, as regards position both runs verified very well, as indeed did a coarse-mesh forecast from the

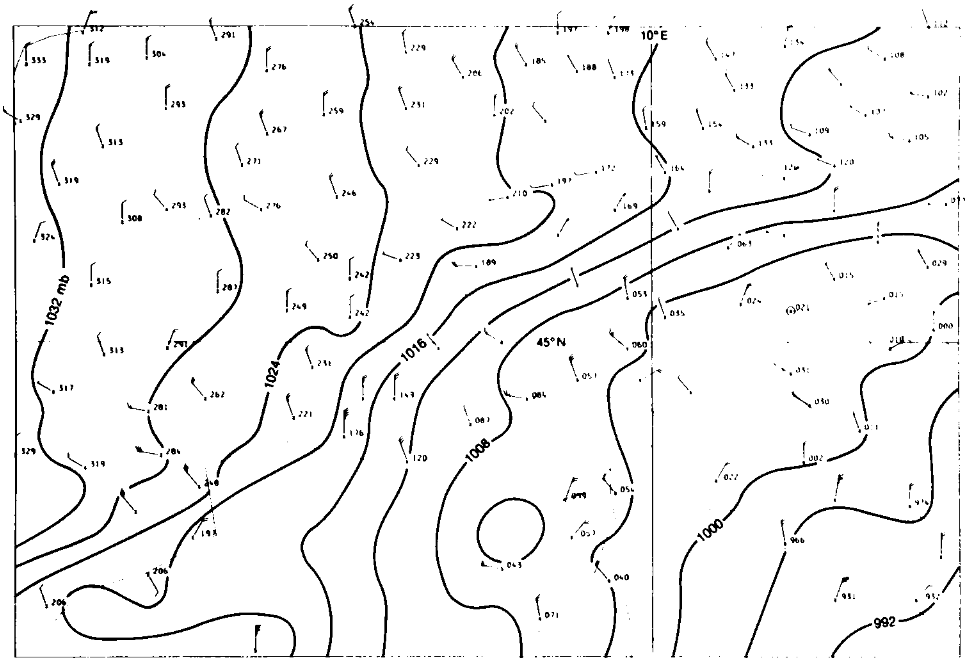

Figure 6. Subjective analysis of surface pressure at 12 GMT 9 February 1984.

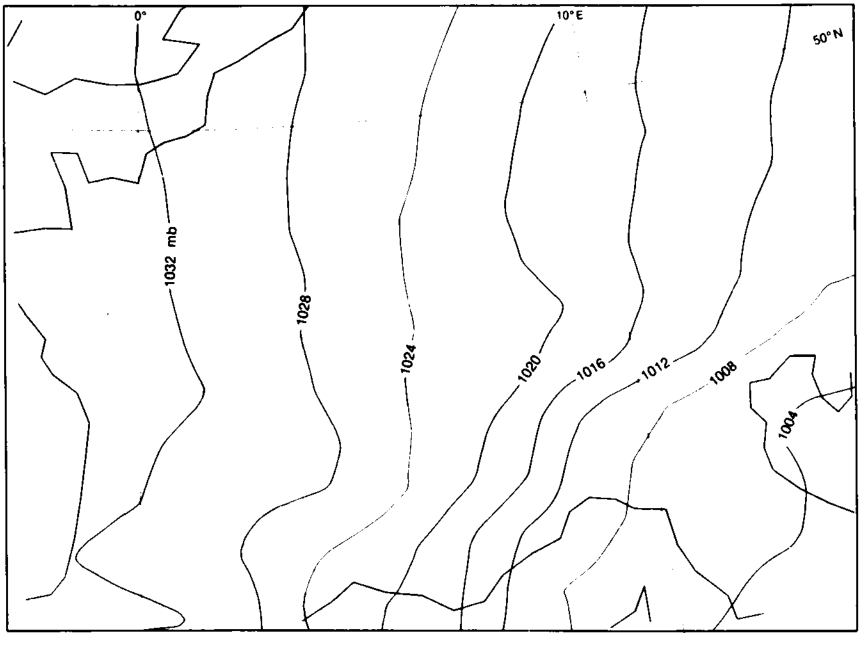

Figure 7. Objective analysis of data in Fig. 6 using fine-mesh data assimilation scheme with coarse-mesh orography.

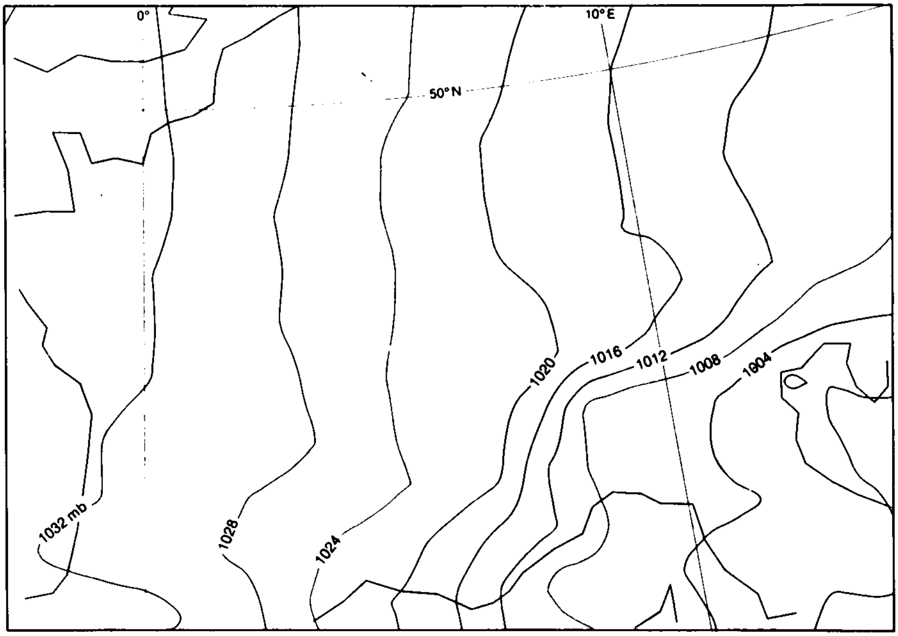

Figure 8. As Fig. 7 but using fine-mesh orography.

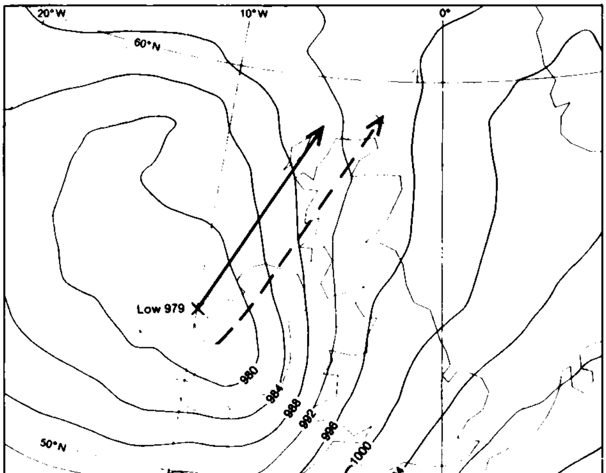

Figure 9. Objective analysis of surface pressure at 00 GMT 18 October 1984 using coarse-mesh data assimilation with the observed (dashed line) and forecast (solid line) tracks of the low centre superimposed.

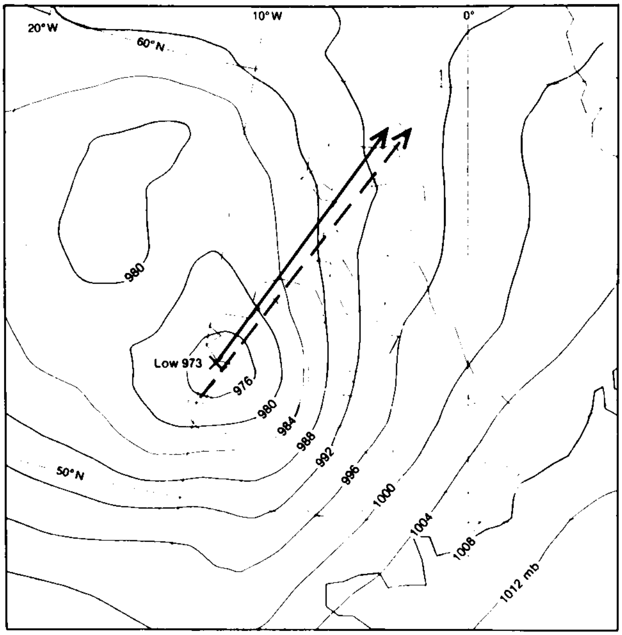

Figure 10. As Fig. 9 but using fine-mesh data assimilation.

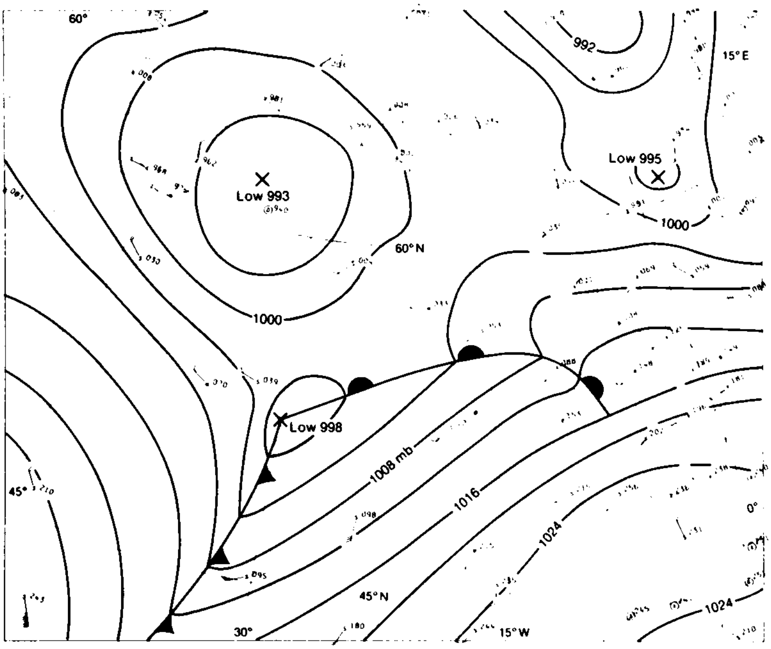

Figure 11. Subjective analysis of surface pressure at 00 GMT 10 October 1985.

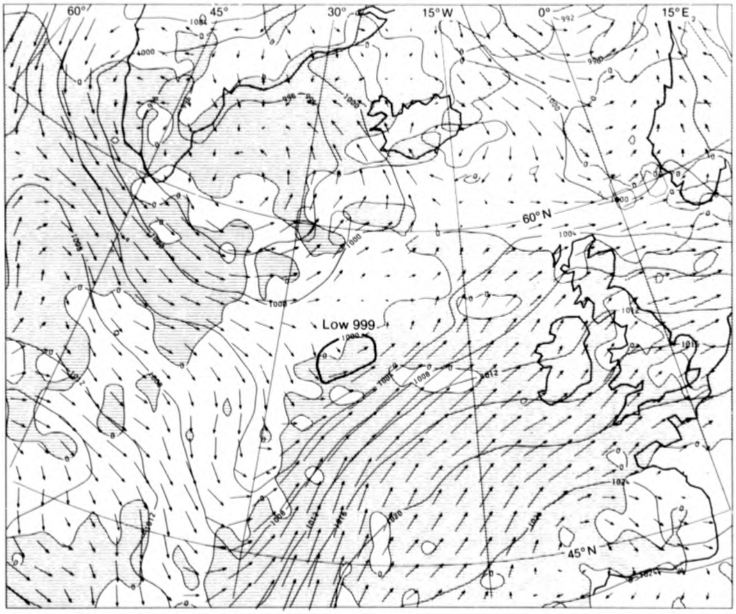

Figure 12. Objective analysis of data in Fig. 11 using coarse-mesh data assimilation. Shaded areas indicate upward motion and arrows show wind direction at 1000 mb level (the length of the arrow is proportional to the wind speed). Isobars are at 4 mb intervals.

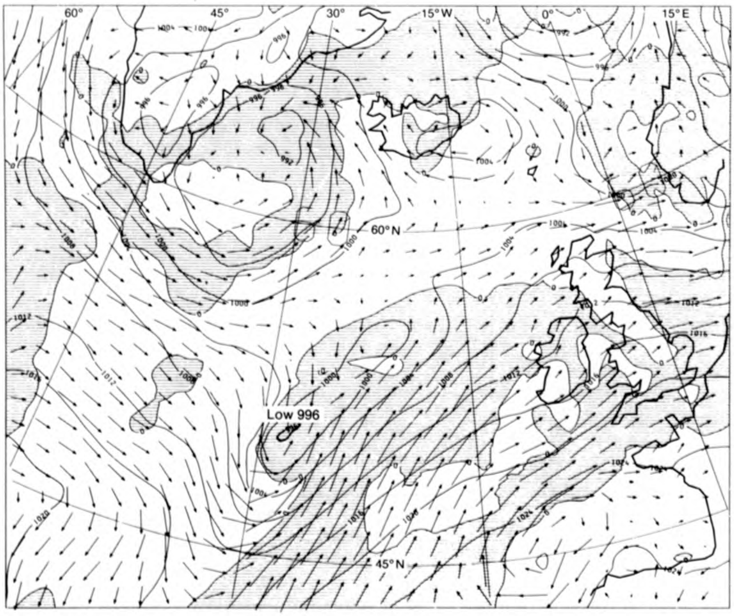

Figure 13. As Fig. 12 but using fine-mesh data assimilation.

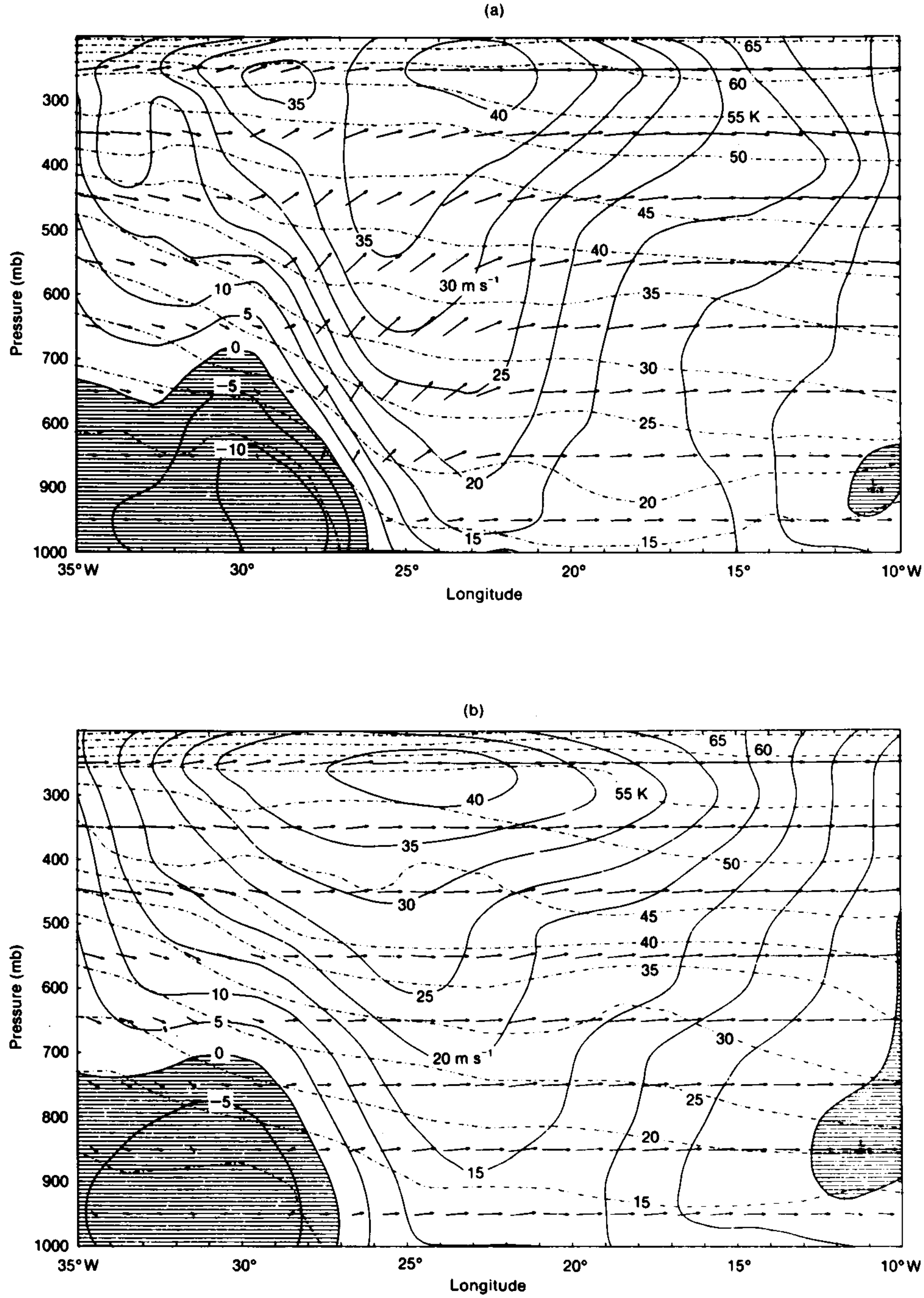

Figure 14. Vertical cross-sections through latitude 52° N of potential temperature (pecked line), southerly wind component (solid line with northerly winds shaded) and motion in the plane of the section (arrows with length proportional to wind speed) from (a) fine-mesh analysis and (b) coarse-mesh analysis for 00 GMT 10 October 1985.

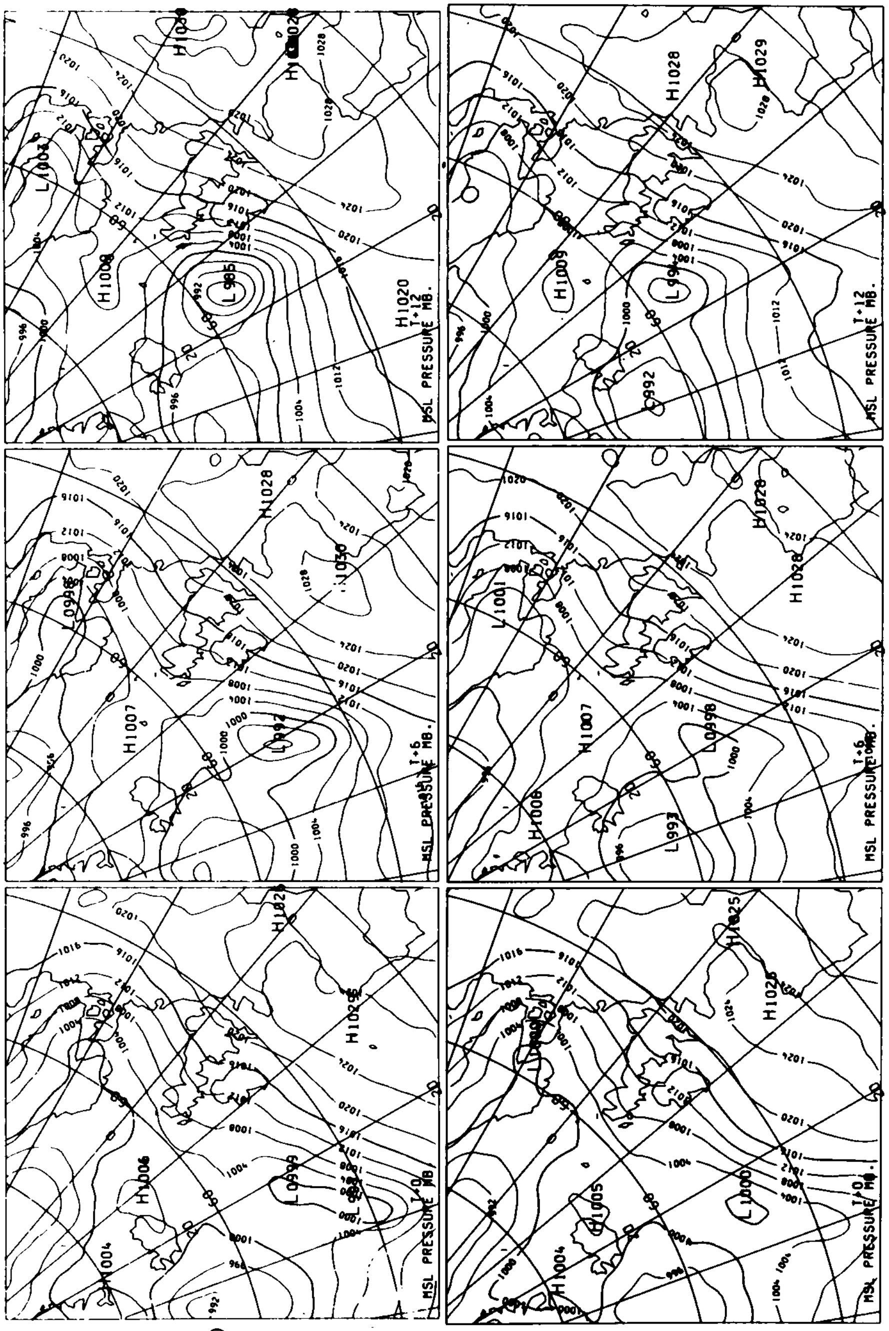

Figure 15. Surface pressure forecasts at T+0, T+6 and T+12 using fine-mesh forecast model starting from (a) fine-mesh analysis and (b) interpolated coarse-mesh analysis from data time 00 GMT 10 October 1985.

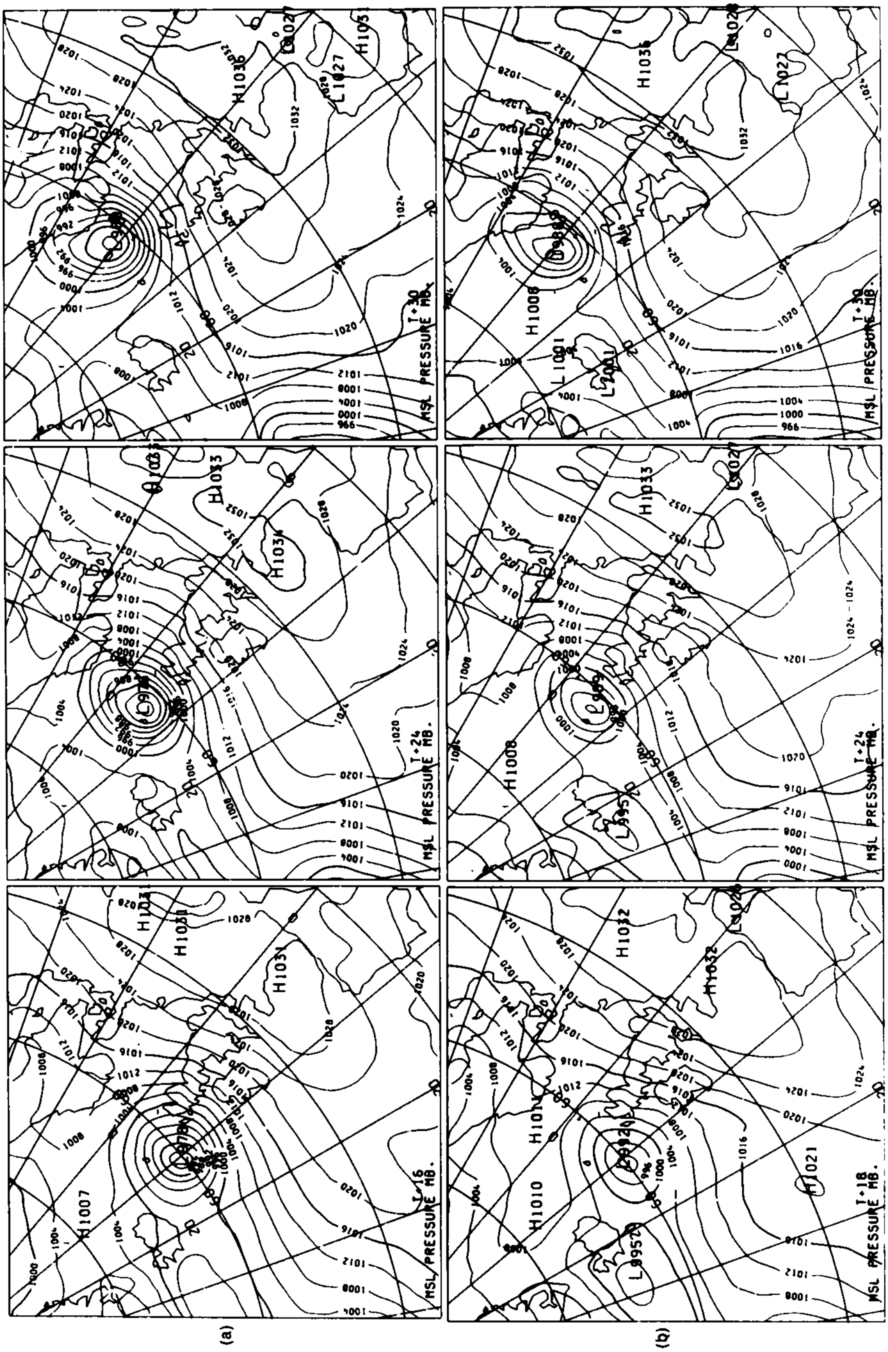

Figure 16. As for Fig. 15 but for forecast times T+18, T+24 and T+30.

coarse-mesh analysis. Table I shows the depth of the low at 6-hour intervals from three forecasts with the same data time and also from the verifying subjective analysis. Forecast (b) does not depart significantly from the coarse-mesh forecast based on the same analysis until T+12. This gives some indication of the time-scale needed for the model fields to adjust from the coarse-mesh solution to the fine-mesh solution. Had the major deepening of this feature taken place later in the forecast period, then the differences between forecasts (a) and (b) would have been much less. This case demonstrates that substantial improvements in the detail of a forecast are likely when using a fine-mesh data assimilation system, particularly if significant developments occur in the early stages of the forecast.

Table I. *Pressure of low centre at 6-hour intervals from subjective analysis and three computer forecasts.*

Date	Verifying time GMT	Coarse-mesh analysis, coarse-mesh forecast mb	Coarse-mesh analysis, fine-mesh forecast mb	Fine-mesh analysis, fine-mesh forecast mb	Subjective analysis mb
10 Oct.	00	1000	1000	998	997
	06	998	998	992	—
	12	996	994	985	985
	18	996	991	979	—
11 Oct.	00	995	998	976	974
	06	994	988	980	—
	12	996	990	986	984

4. Concluding remarks

It is hoped that the discussion in the preceding section has demonstrated the viability of a fine-mesh data assimilation scheme. Observations can be successfully assimilated into a fine-mesh limited-area numerical model so that an objective analysis appropriate to the scale of the model is produced, and useful improvements in the quality of subsequent forecasts can be achieved. As well as providing the initial conditions for operational fine-mesh forecasts, a tool suitable for investigating the potential of new high-resolution data sources such as that generated by the HERMES system is available.

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Comparison of wind speeds recorded simultaneously by a pressure-tube anemograph and a cup-generator anemograph

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Summary

Wind speeds recorded concurrently by a pressure-tube anemograph and an electrical cup-generator anemograph over a period of 1 year are compared. For 60-minute mean speeds, agreement between the two instruments is generally good. For maximum gust speeds in a 60-minute period it is found that the cup-generator anemograph records 6–7% lower than the pressure-tube instrument.

1. Introduction

The standard instrument for the measurement of wind speed and direction in the Irish Meteorological Service is the Dines pressure-tube anemograph. In recent years, rotating-cup anemometers, which are more adaptable for remote and digital displays, have come into use, mainly at airports, and the question of the comparability of the two types of instrument has become important.

Smith (1981) has compared wind speeds measured by pressure-tube and cup-generator anemographs at a number of stations in Britain but was hampered by the lack of a series of simultaneous observations by both instruments at the same site. A cup-generator anemograph is at present installed on the same mast as a Dines anemograph at Galway. In this paper, a comparison is made between values of both mean wind speed and maximum (gust) speed recorded by the two instruments. Following Smith, the cup-generator anemograph will hereafter be referred to as the CGA and the pressure-tube anemograph as the PTA.

2. Exposure of the instruments

Both anemometers are installed on a 9.1 m mast which has its base on the roof of a small hut about 2.5 m high. The head of the PTA is at the top of the mast. The speed and direction sensors of the CGA are mounted on opposite ends of a cross-arm which is fixed 1.0 m below the PTA head in the direction 035–215°. The cups are 0.3 m and the vane 0.4 m above the level of the cross-arm and each is 1.2 m distant from the mast with the cups on the south-western extremity. The PTA recorder is in the hut while the CGA recorder is in the nearby meteorological station building.

Galway synoptic weather station is situated about 3 km east of Galway city on the north shore of Galway Bay (53° 17'N, 9° 01'W). The ground around the anemometer hut is 18 m above mean sea level and slopes southwards towards the shoreline 0.9 km distant. The exposure is reasonably open despite the suburban location. The station building, 5.4 m high, is situated 59 m to the north-north-east of the anemometer mast. A housing estate to the south and south-east comes within 70 m of the mast at its nearest point but, because of the fall in ground level, the roofs of the houses are below that of the hut. There is a wooded area about 500 m to the east-north-east but, apart from this, there are few trees in the vicinity. Beyond 200 m in various directions there are a few scattered, mostly largish, buildings; beyond 500 m in the sector 240–030° are large housing estates interspersed with open spaces.

The effects of some of these topographical features may be traced in Fig. 1 which shows the variation of gust ratio with direction as given by the PTA. The ratios are high for a near-coastal location (L. Burke, personal communication) and reflect the suburban situation. The variation with direction is moderate compared to other stations. Fig. 1 refers to the period 1978–84. Because of the large variability of gust ratios, individual years do not provide sufficiently large samples to enable the variation of gust ratio with direction to be determined accurately. However, data for the year in which the wind comparison was done (1984) agree with Fig. 1 in a general way.

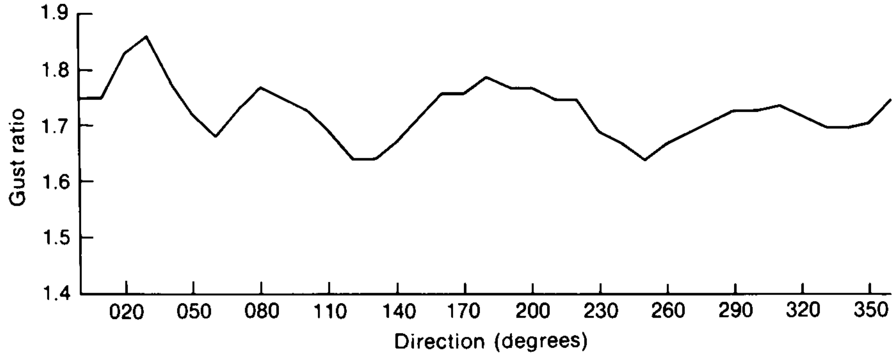

Figure 1. Median gust ratio in overlapping 30° sectors as given by the PTA, 1978–84 (gust ratio = maximum daily gust/10- minute mean centred on gust, mean speeds 7–37 kn only).

3. Characteristics of the Dines anemograph

The Dines PTA is described in the *Handbook of meteorological instruments, part I* (Meteorological Office 1956). The pressure difference between a 'pressure tube', whose opening is kept facing directly into the wind, and a 'suction tube', connected to a set of holes drilled in the vertical tube supporting the head of the instrument, is measured by means of a sensitive float manometer. This is connected to a chart recorder and the float is so designed that the wind-speed record is on a linear scale. The starting speed of the instrument is about 1.5 kn (Smith 1981).

The pressure difference Δp produced by the head of the PTA is related to the wind speed u by

$$\Delta p = \tfrac{1}{2} K \rho u^2 \qquad \text{(1)}$$

where ρ is the density of air. The instrument is calibrated on the assumption that the constant $K = 1.49$. However, it was discovered that turbulence associated with the bends in the pressure and suction tubes where they join the head caused variations in the value of K (Bilham 1927). This defect was finally corrected by enclosing the base of the head in a cylindrical shield with a conical top thus making K approximately equal to the theoretical value (Simmons and Johansen 1929). Wieringa (1980), citing work by Veryard (1925) and Giblett *et al.* (1932) as well as experiments carried out in 1952 in the Dutch National Aeronautics Laboratory, concluded that the correct value of K is 1.37 and that the PTA underestimates wind speeds by about 4%. However, this appears to be the result of a misunderstanding. The experiments described by Veryard were carried out on PTA heads without vanes or shields (Bilham 1927), and Giblett *et al.* (1932) applied corrections to data from instruments with an old type of hemispherically topped shield but not to data from a PTA with a modern-type shield. It is not clear whether the Dutch experiments were performed with or without vanes or what type of shield (if any) was used. For this reason, no correction was applied to the PTA wind speeds in the present study.

The lag in the response of the PTA to varying wind speeds is governed mainly by the movement of air through the pressure and suction tubes. According to Sanuki (1952), the indicated speed, v, is related to the actual speed, u, with respect to time, t, by the differential equations

$$\frac{dv}{dt} = C\sqrt{(u^2-v^2)} \text{ when } u^2 \geqslant v^2 \qquad \ldots \ldots \ldots \ldots \ldots \ldots (2)$$

and

$$\frac{dv}{dt} = -C\sqrt{(v^2-u^2)} \text{ when } u^2 < v^2 \qquad \ldots \ldots \ldots \ldots \ldots \ldots (3).$$

The constant C is determined by the length, diameter and other characteristics of the tubes connecting the head of the instrument to the recorder. The *Handbook of meteorological instruments, part I*, (Meteorological Office 1956) gives data on the response to various applied air speeds of a PTA which had pressure and suction tubes of length 2 m and diameter 25 mm. These are in fair agreement with the theory and imply a value of C of around 0.7 s^{-1}. Sanuki's own experimental results for a PTA with 17 m tubes of diameter 17 mm give $C = 0.35\ s^{-1}$ (C decreases with increasing length and decreasing diameter). In the case of the Galway PTA the length of the tubes is 11 m and their diameter 25 mm so it is reasonable to assume that the appropriate value of C lies between the two values given above.

Because of its non-linear response, the PTA slightly overestimates mean speeds in fluctuating winds. Sanuki (1952) calculated the amount of this overestimation for a sinusoidally fluctuating air speed and found that, unlike the overspeeding of a cup anemometer, it is independent of the mean speed. He also found that the overestimation by the PTA was less than that by a standard cup instrument except possibly at high wind speeds. This conclusion should apply more strongly to the Galway PTA which has better piping conditions than Sanuki's instrument.

4. Characteristics of the cup-generator anemograph

The rotating-cup instrument is a Mk 2 electrical cup-generator anemometer and is the same type as the Mk 2 instrument referred to by Smith (1981). The rotating cups drive an a.c. generator the voltage output of which operates a Mk 4 chart recorder. Both anemometer and recorder are described in the second edition of the *Handbook of meteorological instruments, volume 4* (Meteorological Office 1981) and the recorder is described by Hartley (1955). The system has a high starting speed (about 5 kn) and the scale is highly compressed and non-linear below about 10 kn. These facts represent serious drawbacks in climatological use in view of the high frequency of winds of 10 kn or less.

The response time of a cup anemometer varies inversely with the wind speed so that the response distance (the product of speed and response time) is approximately constant. A graph in the *Handbook of meteorological instruments, volume 4* showing the variation of response time with speed for the Mk 4 CGA implies a response distance of 6–7 m. Smith (1981) states that the cups of the Mk 2 have a greater inertia than those of the Mk 4 but he is also of the opinion that observations from the two are compatible. The response time of the recorder used with the CGA is about 0.2 s (Pearce 1974) so that the recorder contributes very little to the lag of the overall system.

The overestimation of the mean speed of a turbulent airflow by cup anemometers is due to two factors sometimes referred to as 'u-error' and 'w-error' (MacCready 1966). The u-error is associated with turbulent fluctuations along the direction of the mean wind and is due to the variation of response time with speed, which implies a non-linear response. The magnitude of the error increases with the width of the speed trace and decreases, in percentage terms, with increasing mean speed. MacCready estimated the u-error to be about 1% for an anemometer of response distance 1 m at a height of 5 m and found that it was proportional to the response distance and inversely proportional to the height. This would imply that the *u*-error for a CGA with response distance 6 m at a height of 10 m would be about 3%. The *w*-error is associated with the vertical component of turbulence and increases with the variance of the vertical angle of the wind. In unstable conditions the error may be a few per cent.

5. Data

The comparison between the CGA and the PTA is based on wind speeds recorded during 1984. The data extracted from the CGA chart record consisted of the mean speed and direction and the highest gust speed in 60-minute periods ending at 12 and 24 GMT. Wind speeds were estimated to the nearest knot. The hours chosen are those at which time-marks were made on the chart and the timing uncertainty was thus minimized. Because of the high starting speed of the anemograph and compression of the lower part of the scale, only winds of Beaufort force 3 (7–10 kn) or greater were used.

Trouble was experienced with the CGA recorder on a few occasions, particularly in September and October, owing to the chart coming off its sprockets and to irregular movement of the chart. It was found necessary to reject the record from 9 September to 20 October. The zero error of the recorder was found to fluctuate slightly but averaged almost exactly zero over the portion of the record used. The average zero error did not exceed a few tenths of a knot in any month and it was not considered necessary to correct the tabulated speeds.

In addition to the above data, 60-minute means and gusts were extracted for 59 hours during periods of strong winds. This was done to increase the sample size for the higher wind-speed categories (force 5 and greater) and to spread the observations for these categories as evenly as possible over the 12 months. The winds for these 'selected' hours are less likely to be statistically independent than those for the fixed day and night hours. However, they were generally separated from each other by at least 3 hours.

The PTA is the official anemometer for the station and 60-minute means of wind speed and direction recorded by it are routinely tabulated for each hour. In addition, for the purposes of the present investigation, the highest gust in each hour for which data for the CGA had been extracted was obtained. Data for 6 hours had to be rejected because of partially defective traces. Because of the practice adopted of taking the highest gust in the hour regardless of its exact time of occurrence, the CGA and PTA gust speeds compared do not necessarily refer to the same gust.

The calibration of both anemometers was checked in October 1983 and the PTA was tested for possible leaks. The calibration of the PTA consisted of checking indicated speed against applied pressure differences using a sensitive manometer. In the case of the CGA, the voltage output of the generator was checked for known rates of rotation of the cup wheel and speeds indicated by the recorder were checked against known voltages. Facilities were not available to test the anemometer heads in a wind-tunnel. Apart from the faults in the CGA recorder previously mentioned, it is believed that both instruments were in excellent working order throughout 1984.

For the purpose of comparison, all winds with directions in the sector 335–095° were disregarded. This sector contains the directions for which the CGA vane and the tubes supporting the PTA head are upwind of the cups and also the directions for which the station building is upwind of the mast. Of a possible 732 observations (2 per day), 108 were rejected because of instrumental defects (mostly in the CGA in September/October), 198 because the wind was less than force 3, and 94 because the wind direction lay in the sector 335–095°, leaving 186 useful observations at 12 GMT and 146 at 24 GMT. To these must be added the 59 observations at the selected hours. For each of these hours, the ratio of the mean speed given by the CGA to that given by the PTA was calculated and also a similar ratio for the gust speeds. These ratios are hereafter denoted by R and R' respectively.

Because of the importance of extreme gust speeds, all daily maximum gusts in excess of 55 kn were read off the records of both instruments. There were seven such days, six in January and one in February.

6. Results

In order to investigate possible variations with wind direction, mean values of R and R' were calculated for each 30° sector from 095 to 335° for the 'day' (11–12 GMT) and 'night' (23–24 GMT) cases separately. No significant variation with direction was found for either ratio and data for all directions were therefore combined.

The observations were divided according to mean speed (as given by the PTA) into Beaufort forces 3 (7–10 kn), 4 (11–16 kn), 5 (17–21 kn), 6 (22–27 kn), and 7 or greater (28 kn or more). Average values of the ratios R and R' were then calculated for each month. Fig. 2 shows these ratios for the force 4 winds

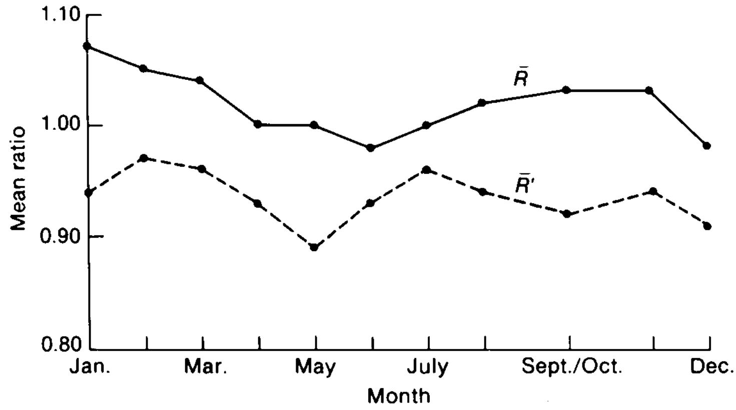

Figure 2. Monthly mean ratios (CGA/PTA) of mean wind speeds ($\bar{R}$) and maximum (gust) speeds ($\bar{R}'$) for 1984. Data are for force 4 winds only, day and night cases combined.

(the data for September and October have been combined because of the fact that the record for a large portion of these months had to be rejected). It may be seen that there is some variation in the ratios with time. The variation must be considered significant because, taking the extreme cases, the differences between the January and December values of $\bar{R}$ and the annual mean are statistically significant at the 1% level. Broadly similar variations were found in the case of the force 3 winds; there were insufficient observations of force 5 or more to enable reliable monthly averages to be calculated. Generally speaking, R and R' were above average in the period January–March and below average in April–June and in December. The variation does not appear to be related to seasonal meteorological factors and the small variation in the zero error of the CGA is insufficient to explain it. It may be due to drift in the calibration of the instruments or possibly to variation in the subjective error associated with manual tabulation. In any case, the data for the full year, when combined, cannot be considered to constitute independent, homogeneous samples.

Fig. 3 shows the average values of R and R' for the whole year for each wind force. The day and night observations are shown separately; 'all' indicates the combined day, night and selected cases. If we were to assume that the data were independent and homogeneous, the difference in $\bar{R}$ between day and night for force 3 winds would be significant at the 1% level and the difference in $\bar{R}'$ would be significant at the 5% level. This result is not likely to be very much affected by the month-to-month variation in the ratios since the frequency of occurrence by day and night of force 3 winds is rather evenly distributed over the months. Also, for force 3 winds, the night values of $\bar{R}$ and $\bar{R}'$ are less than the day values for each of the four quarters of the year. The day/night difference in the force 4 and 5 ratios are not significant at the 5% level and neither is the difference in $\bar{R}$ (day) between forces 3 and 4.

The mean CGA/PTA ratio for daily maximum gust speeds exceeding 55 kn was 0.947 with a standard error of the mean of 0.013. The speed of the gusts (as given by the PTA) ranged from 58 to 68 kn with a mean of 62 kn.

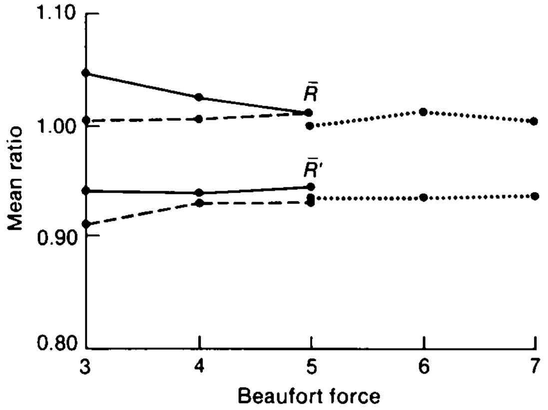

Figure 3. Mean ratios (CGA/PTA) of mean wind speeds ($\bar{R}$) and maximum (gust) speeds ($\bar{R}'$) for 1984. Solid line indicates day (11–12 GMT), pecked line night (23–24 GMT) and dotted line all (including selected) observations.

7. Discussion

Hartley (1955), from a comparison between a CGA Mk 1B and a remote-recording PTA mounted on the same tower, concluded that the instruments showed 'close agreement in both mean and maximum values'. On the other hand, Smith (1981) found that mean speeds derived from the CGA (Mk 2 and Mk 4) exceeded those from the PTA by 1–2 kn and that the greatest differences occurred at speeds below 8 kn and above 20 kn. This investigation was based on a study of records from five stations where there had been a change-over from a PTA to a CGA without change of site. The data were adjusted by reference to control stations with homogenous records spanning the times of change-over. Smith concluded that the differences at low speeds were due to observer error in reading the compressed, non-linear scale of the CGA and those for higher speeds were due to overspeeding of the cups.

Rijkoort (1955) compared a PTA with a cup anemometer and found that, for mean speeds below 5 m s^{-1} (10 kn), the PTA underestimated the mean wind compared to the cup instrument, but that for speeds exceeding that limit the opposite was the case. The difference between the two instruments was found to increase with the width of the trace and, for the higher speeds, overestimation by the PTA was as much as 10%. A feature of Rijkoort's experiment was that mean speeds from the PTA were estimated by eye from the charts whereas those from the cup anemometer were calculated from the number of contacts made in a given time. It is thus possible that the differences found were partially due to a systematic error in the estimation of the PTA winds and Rijkoort did in fact find some evidence of this. In the investigations of Hartley and Smith, as in the present study, both CGA and PTA mean speeds were estimated by eye.

For the higher wind-speed categories, Fig. 3 shows that agreement between the CGA and PTA on mean speeds is quite good despite the fact that the basic data were tabulated in whole knots. This disagrees with the findings of Smith on the one hand and Rijkoort on the other but agrees with Hartley's conclusions as regards mean wind speeds. The higher CGA/PTA ratios found for the day observations of force 3 and, to a lesser extent, force 4 may be due to overspeeding by the CGA which is expected to be most serious, relative to the PTA, at low mean speeds. Both Smith and Rijkoort also found overestimation by the CGA at low speeds. The difference between day and night may be due to the fact that overspeeding by the CGA is greatest in highly turbulent conditions which are most common in the daytime. However, caution is necessary in interpreting the force 3 results because of the large scatter in the ratios which are quotients of small whole numbers. While, as previously discussed, the difference between the day and night values of $\bar{R}$ for force 3 is probably significant, no great reliance should be placed on the amount of the difference. Also, the fact that a similar difference is found in the case of the force 3 gust ratios raises the possibility that some factor other than the response lag of the instruments may be involved.

It is clear from Fig. 3 that maximum gust speeds are significantly underestimated by the CGA relative to the PTA. This is to be expected at low mean speeds because of the large response time of the CGA but it is surprising to find it also at high mean speeds where the response time is much less.

To compare the actual results with theoretical expectations, use was made of Wieringa's (1973) model which gives the maximum (sinusoidal) gust in a given time interval as a function of gust period, mean speed, height above ground and roughness length. A roughness length of 0.5 m for Galway was assumed. The gust speed recorded by an anemometer is the product of the actual gust speed (which, according to the model, decreases with increasing gust period t) and the response factor of the anemometer (which increases with t) so that a maximum recorded speed is found at some value of t. For the PTA, the maximum recorded gust was obtained by integrating equations (2) and (3) numerically for sinusoidal inputs of various periods and of amplitudes given as a function of mean speed and period by Wieringa's model. A value of $C = 0.5\ s^{-1}$ was assumed. In the case of the CGA, the response factor was calculated assuming a response distance of 6.3 m for the anemometer and a response time of 0.2 s for the recorder (Pearce 1974). The results of the computations were that the CGA should record gusts about 7% lower than the PTA at a mean speed of 5 m s^{-1} (10 kn) but 3% higher at 20 m s^{-1} (39 kn).

Incidentally, the computations also show that, at high mean speeds, the value of t appropriate to the PTA maximum gust is 6–7 s. This is not inconsistent with the frequently quoted figure of 3 s for gust duration (positive departure from mean speed only). It confirms Wieringa's (1980) conclusion which was based on data from Giblett *et al.* (1932) and assumed a first-order, linear response for the PTA.

One possible explanation for the experimental result that the PTA records higher gusts than the CGA even at high mean speeds is that the PTA over-records the gusts owing to resonance phenomena. Borges (1968), in wind-tunnel experiments with a PTA, found a resonance peak at high mean speeds for a sinusoidal input of 0.2 to 0.3 Hz ($t = 3$ to 5 s) and concluded that the frequency response of floater-type anemographs is inadequate for the study of maximum gust speeds.

8. Conclusions

For winds of Beaufort force 3 to 7 inclusive (7–33 kn) the 60-minute mean wind speeds recorded by the cup-generator anemograph agree well, generally speaking, with those recorded by the pressure-tube anemograph. However, there is some evidence that, for force 3 and possibly force 4 winds, the CGA records a few per cent higher than the PTA during the daytime. The CGA Mk 2 underestimates maximum gust speeds compared to the PTA by 6–7% regardless of mean speed. This is contrary to the theoretical expectation that it should record higher than the PTA at high mean speeds.

Acknowledgements

This research was supported by the Irish Meteorological Service. I am grateful for the assistance of my colleagues in the Service particularly Messrs J. Kearney, L. Burke and U.N. Egan.

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Notes and news

Editor of the *Meteorological Magazine*

On 2 April 1986, R.P.W. Lewis, who had been Editor of the *Meteorological Magazine* for 12 years, retired from the Meteorological Office. During his period as Editor there were important changes in the appearance, style and content of the magazine with the aim of making it more attractive, readable and informative. The new Editor is R.W. Riddaway, with F.E. Underdown remaining as Assistant Editor. Nearly two years ago an Editorial Board was set up, and this will continue to advise the Editor on the content and presentation of articles. At present the Editorial Board consists of the following members:

R.W. Riddaway (Editor and Chairman)
D.A. Bennetts (Defence Services)
T. Davies (Forecasting Research)
W.R. Sparks (Observational Requirements and Practices)
P.G. Wickham (Meteorological Office College)

World Meteorological Day

In 1973, the world meteorological community celebrated a century of organized international collaboration in meteorology. One hundred years before that date, the First International Meteorological Congress met in Vienna and prepared the ground for the establishment of the International Meteorological Organization. This organization ceased to exist in 1951 and was replaced by an intergovernmental body known as the World Meteorological Organization (WMO). The Convention of WMO came into force on 23 March 1950 and this date has been celebrated annually since 1961 as World Meteorological Day.

To mark the occasion, the WMO Congress and Executive Committee (now Executive Council) recommended that all Members of the Organization should make a particular effort on this day to bring the importance of meteorology to the attention of everyone concerned. To facilitate this task, it was decided that a specific theme should be designated each year in order to ensure the co-ordination of activities and efforts. The theme for the year 1986 is 'Climate variations, drought and desertification'.

Although each Member of WMO celebrates the day independently, it is customary for the WMO Secretariat to prepare and distribute in advance information pertaining to the theme of the year. This year the material includes a booklet (WMO - No. 653) by F. Kenneth Hare, University of Toronto, entitled *Climate variations, drought and desertification* which aims to present a balanced perspective regarding the role of climate in the uses made of the arid zone by human society.

Mr W.A.L. Marshall, MBE

We regret to record the death, on 31 January 1986, of William Arthur Lewis Marshall, MBE at the age of 88. He retired from the Meteorological Office in 1959 after thirty-nine years of service. He was much respected both personally and professionally by the meteorological fraternity of his time.

'Curly Marshall' as he was called in his younger days joined the Office in 1920 as a Technical Assistant. In the mid-30s he was selected for sideways transfer to the Technical Officer grade. Until 1939 his duties were spent almost entirely within the Forecasting Division of M.O.2 in Kingsway. Following assignments away from London in the early part of World War II, one of these being on the initial trials of forecasting for smoke screens over factories, he returned in 1941 to take charge of the London Forecasting Office (later to become the London Weather Centre) where he remained for the next twelve years. With the upsurge of public interest in the weather and weather forecasting at the end of the war, following the wartime black-out of such information, he often appeared on radio and television and was interviewed frequently by the Press. It was during his time on the 'Victory House roof' that he prepared the first edition of *A century of London weather*. He wrote various articles that appeared in the *Meteorological Magazine* whilst his paper on the 'Comparison of wind recorded by anemograph with the geostrophic wind' still appears in meteorological bibliography to this day. He was appointed a Member of the Most Excellent Order of the British Empire in the New Year's Honours of 1952.

With the establishment of the new Scientific Civil Service at the end of World War II, Bill Marshall, as he was now more commonly known (the 'curls' long having disappeared) was regraded as a Senior Experimental Officer (SXO). However, with the introduction of the Chief Experimental Officer grade in 1953 he was one of the first SXOs so to be promoted and with this became Head of Communications, based at Dunstable.

His home on retirement remained at Totternhoe, a village just outside Dunstable. He is survived by his wife Lucy, and two sons the younger of whom, Tom, also entered the meteorological profession and retired as Deputy Director of Naval Oceanography and Meteorology at the Ministry of Defence in 1979. W.A.L. Marshall died on his 65th wedding anniversary. He was buried with deep snow on the ground. He would not have chosen this environment for the occasion but he would at least have taken satisfaction that the snow had been forecast.

Obituary

Dr A.E. Gill

We regret to record the death of Dr A.E. Gill, FRS, Senior Principal Scientific Officer in the Dynamical Climatology Branch who died, aged 49, after a very short illness on 19 April 1986.

Adrian Gill came to this country in 1960 as a research student at Trinity College, Cambridge where he worked with George Batchelor and became influenced by the famous Cambridge tradition in fluid dynamics set up by G.I. Taylor. Then followed a year at the Massachusetts Institute of Technology after which he returned to Cambridge. He was in Cambridge for the next 20 years pursuing research on various aspects of fluid dynamics particularly as applied to the atmosphere and the ocean. During the years in Cambridge Adrian built up a great research reputation and also built up, through students and many visitors, a strong and renowned research group.

Adrian was very much an international scientist. He travelled a great deal not just to conferences and the like but to work for substantial periods in other laboratories. Working summer vacations were spent at the Scripps Institute in La Jolla, in Vancouver, in Melbourne, in the Geophysical Fluid Dynamical Laboratory in Princeton (with which he had a particularly close relationship), in Boulder, Colorado, in Durban, South Africa, in Woods Hole, at the University of Washington, Seattle, in the Oceanographic Institute at Malaga in Spain and so on. He knew the whole world community in his subject extremely well — rather like an old-style travelling scholar. Through all these visits and interactions Adrian had an enormous influence on the subject and was of course himself influenced and sharpened so that he became a world leader if not the world leader in his field.

Adrian was of course a very able mathematician. But he was always keen to apply his mathematics to real problems. You might think that he could hardly have chosen more complex subjects to study than the ocean and the atmosphere. But unlike some mathematicians who seem to make easy things appear difficult, Adrian's genius was to break problems down to the simplest picture possible and then apply to that elementary model, simple and elegant mathematics. He always asked the simplest questions; with unusual insight he would isolate the bare essentials of a problem. Some of his papers are classics of their kind and will long be remembered. How does the dense water at the bottom of the ocean in the region of the Antarctic get there? What happens when a range of mountains rising from the ocean floor disturbs the flow? And no doubt most of all he will be remembered for his severe but effective simplification of the way in which the ocean and the atmosphere work together in the tropics. From this work was born the TOGA project — short for Tropical Ocean and Global Atmosphere — a very large international project concerned with the way atmosphere–ocean interaction influences climate. It turns out that there are strong connections between the state of the Pacific Ocean and the character of the climate elsewhere in the world, for instance, the occurrence of droughts in Africa or floods in South America. Adrian was most enthusiastic not only about this fascinating scientific problem but also about the way it related to important problems of the real world. He put a great deal of energy and time into his position as Chairman of the Scientific Steering Committee of the TOGA project.

In 1984 Adrian joined the Meteorological Office where he became an individual merit scientist. Together with his research group he moved from Cambridge to Oxford — not a very easy transition! In Oxford he set up a substantial group on ocean modelling and he helped to found the Robert Hooke Institute for Cooperative Atmospheric Research — a joint enterprise between the University, the Meteorological Office and the Natural Environment Research Council. There, with access to more people and greater resources, he was well on the way to leading the most effective scientific group in the world in coupled atmosphere–ocean models.

We can be thankful that Adrian has left us with a huge contribution to the science; in his way of working he has left an example of scientific dedication and a particularly effective way of pursuing the scientific enterprise. He has passed on his ideas and methodology to many students who he fostered so carefully and who are carrying on his work in various parts of the world. He has also left us with a superb textbook — *Atmosphere–ocean dynamics* — in which we can get the feel of Adrian's own inimitable style. Its concluding sentence is 'Nature is complex, there is much to be learnt'. We were all very much delighted, as he was, when he was elected a Fellow of the Royal Society just a month before his death.

In the last book of the Bible, the Revelation, we are told that in the heavenly city there will be no more sea. I do not think this is meant to imply that oceanographic skill will not be recognized in heaven — after all we are assured that life there will be more full than we can possibly imagine. But the writer of Revelation was imprisoned on an island — the sea was all around him, it meant barriers, separation. Adrian had a deep and thoughtful Christian faith and we can be glad for him that he has gone to that fuller life promised by no other than Jesus Himself. We can look forward — as I am sure even more do Helen, Jane, Simon and Adrian's family — to that time and place where the separation we feel so strongly today will no longer exist.

Mr J.L. Cadman

It is with regret that we record the death on 21 January 1986 of Mr J.L. Cadman, Professional and Technological Officer (PTO) I, of the Telecommunications Branch (Met O 5).

Jim Cadman joined Met O 5c in May 1978 as a PTO II from the Ministry of Defence Procurement Executive (MOD(PE)) and in January 1981 he was promoted to PTO I. From the start of his career in the Office he was deeply involved in the specification, procurement, and production of the major message-switching computer systems AUTOCOM Phase III and IV.

The Ferranti Phase III occupied his attention for his first three years in Met O 5 and the years since 1981 were mainly concerned with the detailed planning and implementation of Phase IV Tandem computers. For much of this time he wore 'two hats' having the additional responsibility of acting as the representative of the MOD(PE) Project Office.

Outside office hours Jim was a keen outdoor activity man, cycling to work most days, rambling at weekends and playing badminton indoors when he could. He was a musician of considerable talent and played the trombone with the Glenn Miller style band, the Millstones, at many social events.

Jim was a quiet man with a wry sense of humour and well liked within the Branch. He will be sadly missed.

Correction

Meteorological Magazine, April 1986, p.106, fourth line from bottom of section 3 should read 'E_{rg} represents the error of unadjusted radar rainfall values' not 'adjusted radar rainfall values'.

Meteorological Magazine

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Meteorological Magazine

June 1986

Vol. 115
No. 1367

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Contributions: it is requested that all communications to the Editor and books for review be addressed to the Director-General, 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. Authors wishing to retain copyright for themselves or for their sponsors should inform the Editor when submitting contributions which will otherwise become UK Crown copyright by right of first publication.

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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.

ISBN 0 11 727834 3 ISSN 0026–1149

Printed for HER MAJESTY'S STATIONERY OFFICE
by Delco Printing Co Ltd 6/86 Dd. 739131 C13