Noise assessment model
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The Larkhill noise assessment model. Part II: Assessment and use

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Summary

Noise forecasting is a routine task performed operationally for a number of Ministry of Defence ranges in support of artillery training exercises and explosives testing. The forecasts are produced using a numerical model which is run on a desk-top computer. Part I of this paper published in the previous issue of the *Meteorological Magazine* described the current operational model and discussed the theoretical background. Part II assesses the model and describes its use. A simplified technique for providing noise assessments for remote sites using synoptic data is also presented.

1. Introduction

Over the last 30 years or so it has become well established that the noise generated by gunfire and explosions can travel long distances in the atmosphere. During the last 10 years there has been a growing demand for some assessment of when such noise is likely to be sufficiently loud so as to cause structural damage or lead to complaints. In response to this demand a numerical model to assess the likely noise levels around the ranges has been developed.

Part I of this paper (Turton *et al.* 1988) discussed the theoretical background to the problem and presented the current operational model. The results from the model suggested that the downwind enhancement is mainly due to differences in the wind speed over the lowest few hundred metres, whilst focusing is mainly due to the directional changes in the wind profile.

In Part II the accuracy, sensitivity and limitations of the model are assessed and some empirical results that allow noise assessments to be prepared using synoptic data are presented. For ease of reference, equations given in Part I are referred to with the prefix I (e.g. the equation used to predict the noise levels is referred to as equation (I8)).

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2. Assessment of the model

Since 1981 a number of trials have been conducted at various ranges to investigate the noise levels from artillery fire and explosives. Most of these trials were conducted on Porton Down (about 12 km south-east of Larkhill), although other investigations have been carried out at Sennybridge (Cowley 1983) and more recently at Lulworth (Lord *et al.* 1986).

The model-predicted noise levels have been compared to actual field measurements made during the Lulworth trials in order to assess the accuracy of the predictions. Fig. 1 shows the model-predicted noise field on 10 October 1985. On this occasion the surface wind was 7.2 m s^{-1} (14 kn) from 245° and the 150 m wind was 8.8 m s^{-1} (17 kn) from 247°. The sound enhancement region lies between 50 and 160° and is centred on a direction close to the 110° given by equation (19), with a shadow region in the opposite direction. A slight focus occurred to the south-east at about 10 km distance. As can be seen from the inset in Fig. 1, the direction of the focus was fairly well predicted by the wind shear vector determined from the 10 and 900 m winds. Also shown in the figure are the mean observed noise levels at various measurement sites; the measured values have been normalized to an equivalent 5 lb charge of plastic explosive, as used in the model prediction. In this example the largest difference is at 1575 m, 074° where the measured level was 123 decibels (dB) and the predicted value was 128 dB. Further away from the source the model-predicted 120 dB contour lies about 800 m too far out — the model is overpredicting the noise levels in the enhancement region.

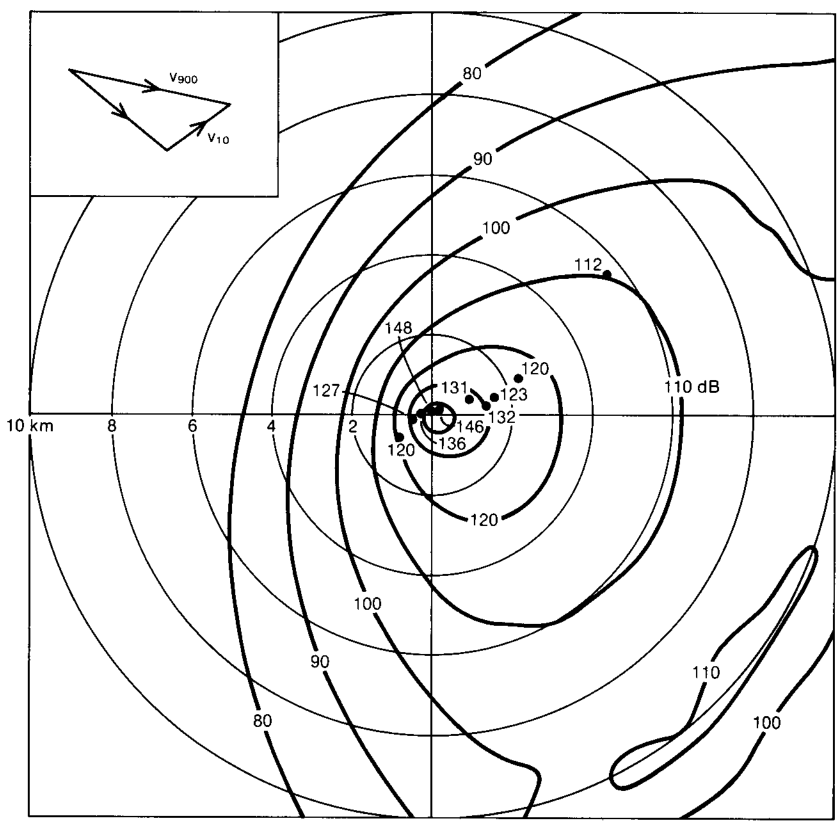

Figure 1. Polar diagram for Lulworth at 1010 GMT on 10 October 1985 showing model-predicted noise levels (dB) for a 5 lb charge. Mean measured noise levels at various locations are also shown. The inset shows how the surface (10 m) and upper (900 m) winds give an indication of the direction of the focus.

Fig. 2 shows the mean prediction errors at various distances from the source for the six Lulworth trial days, using the data of Lord *et al.* (1986). In the downwind direction (defined here as within 45° of the surface wind) the results given in Fig. 2(a) show considerable variation from day to day, although the prediction errors show no obvious dependence on distance. The root-mean-square (r.m.s.) error (of the plotted points) is 4 dB. Fig. 2(b) shows similar data, but upwind of the source; here the results suggest that the model has a tendency to underestimate the noise levels. In particular, on one day (9 November 1985) the model underestimates become exceptionally large with increasing distance from the source. On this occasion the weather was cloudy with heavy showers, and the surface wind was variable between 8 and 15 m s^{-1}. In the model forecast a surface wind of 9.8 m s^{-1} (19 kn) was specified; if this is increased to 12.9 m s^{-1} (25 kn) then the upwind predicted noise levels are significantly higher (e.g. at 2000 m the predicted levels are increased by about 20 dB) and the error is substantially reduced. However, this change has a detrimental effect on the downwind predictions (e.g. at 1625 m the levels are decreased by 5 dB and the error is increased). This illustrates an important aspect of the model in that the predicted noise levels can be very sensitive to the low-level winds specified; this is discussed more fully later. The r.m.s. error of the upwind plotted points is 14 dB, but is reduced to 7 dB if the data for 9 November are omitted.

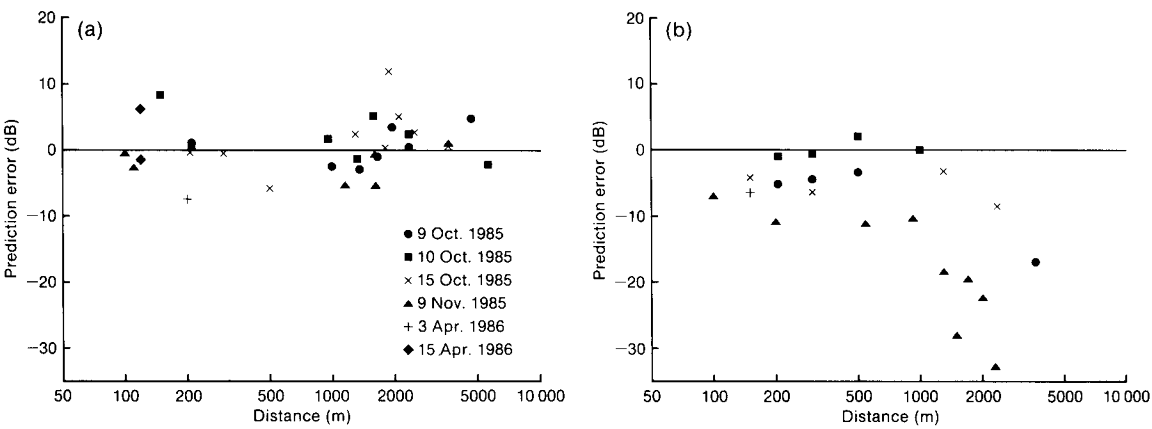

Figure 2. Comparison of model predictions with measurements made during the Lulworth trials for (a) downwind and (b) upwind directions.

All the measurements made to date have been in enhancement and shadow regions; no measurements have been made in a focus region. The main reason for this is that foci are caused by the shears aloft, often associated with frontal systems, which change with time as the front passes through. Consequently, identifying where a focus might occur at a particular time, so as to deploy instrumentation, is a problem.

The results suggest that on average (in the enhancement and shadow regions) the model predictions have a typical error of about ±6 dB, although there are wide variations from day to day. Whilst this might seem reasonably accurate, it should be noted that this is equivalent to an error in predicting the actual intensity of the sound wave by a factor of 4. Nonetheless, a prediction error of about 6 dB should be viewed against the effects of meteorology, which can lead to variations in noise level of about 30 dB, thus demonstrating that the model does have some skill. It should be emphasized that a 6 dB error in the noise levels in the enhancement region is more significant than a similar error in the shadow region because the levels are much higher. The predicted noise levels in the focus region would be expected to be much less accurate than this, as discussed in the following section.

There are a number of reasons why the model predictions are different from those measured:
(a) Errors introduced by the sensitivity of the model predictions to internal parameters (i.e. terms in the prediction equation (I8)) and external parameters (i.e. the quality and details of the input meteorological data).
(b) Deficiencies in the model formulation (i.e. the neglect of the effects of turbulence, interference and of the surface).
(c) Inaccuracies in the determination of the source level, L_0 (equation I10).
These factors are discussed in sections 3 and 4.

3. Sensitivity of the model

The sensitivity of the model-predicted noise levels has been investigated by examining:
(a) the effect of internal parameters which specify the incremental distance (Δr) and the incremental ray elevation (Δe), and
(b) the effect of changes in the atmospheric profiles.

3.1 *Sensitivity to internal parameters*

The choice of internal parameters Δr and Δe can affect the predicted noise levels in situations where sound rays are brought down to ground, i.e. in enhancement and focus regions. The term Δr introduces a degree of spatial averaging on the predicted noise levels; the computed values are only independent when their (radial) spacing exceeds $2\Delta r$. The example of 20 August 1985, described in Part I (Turton *et al.* 1988), was recomputed using differing values for these parameters, and the results are summarized in Table I.

Table I. *Predicted noise levels (dB) in enhancement and focus regions for different values of internal parameters Δr and Δe*

Parameters		Enhancement		Focus
Δr km	Δe degrees	2.5 km, 40°	5.0 km, 40°	11 km, 140°
1.00	1.00	128.3	115.4	106.0
1.00	0.10	128.6	116.3	104.3
0.10	0.10	128.3	115.4	114.0
0.10	0.01	128.8	116.5	113.8
0.01	0.01	130.0	115.4	114.0

The results show that adjusting the internal parameters changes the computed noise levels only slightly in the enhancement region, but quite markedly in the focus region. The largest differences arise by reducing Δr, which effectively reduces the averaging implicit in the computed values. Since the characteristic wavelength of artillery noise is a few tens of metres, this imposes a physical limit on the degree of spatial averaging that is sensible. However, in practice the choice of these parameters is constrained by the need to collect a significant number of ray returns, N, within the specified incremental distance, Δr. The resolution with which the computations are performed in the current operational model ($\Delta r = 1$ km, $\Delta e = 1°$) is limited by the computing power available at the range stations. Whilst the model does show an unhealthy sensitivity to these parameters in the focus region, it should be recognized that the empirical constant c_2 (see equation (I8)) was determined by comparing predictions from the model with measurements in enhancement regions. The model predictions have not been validated, however, in focus regions. The level of the increase in noise in the focus region in the model with $\Delta r = 1$ km is some 8–10 dB in the above examples; this increase is nearly doubled when Δr is reduced to

0.1 km. The predicted noise levels are also, obviously, dependent upon the values of the other empirical constants c_1 and c_3.

3.2 *Sensitivity to external parameters*

The results from the model are particularly dependent upon the specified low-level winds; these influence the results in several ways, as discussed below.

Examination of equations (18) and (19) shows that the low-level winds directly determine the extent and direction of the sound shadow region (this was illustrated by the Lulworth predictions for 9 November 1985). More importantly, they affect the extent and direction of the sound enhancement region. To illustrate this the case of 20 August 1985 was recomputed, but with adjusted surface and 150 m winds; the changes made were comparable with the likely errors in the winds. The results are summarized in Table II.

Table II. *Maximum noise levels (dB) at 2.5 km and 5.0 km in enhancement region with adjusted low-level winds*

Surface wind		150 m wind		Maximum noise level	
degrees	kn	degrees	kn	2.5 km	5.0 km
215	20	217	29	128.8	115.4
210	17	217	29	131.7	115.4
220	23	217	29	126.6	121.0
215	20	212	24	124.9	126.5
215	20	222	34	131.7	113.6

The table shows that relatively small adjustments in the specified low-level winds can give rise to significant changes in the computed noise levels because they lead to changes in the vertical gradient of the speed of sound. In situations with light winds, comparable changes would be expected to have an even larger effect. This suggests that the accuracy of the low-level data will limit the reliability of the model predictions in the enhancement region. However, these changes do not make a significant difference to the predicted focus region.

In the model the low-level winds are only defined at two levels (10 m and 150 m); clearly this is insufficient to resolve any detail in the boundary-layer wind profile. An important question is whether the lack of detail near the surface has much effect on the predicted noise levels. To examine this, hypothetical wind profiles for neutral conditions were determined from a simple model (Smith 1977). The profiles were derived by specifying a geostrophic wind of 20 kn, a roughness length of 10 cm (appropriate to open countryside) and a Coriolis parameter of 1.1×10^{-4} s^{-1}. The temperature profile specified was dry adiabatic with a surface temperature of 10 °C. Two predictions were made, one with winds and temperatures at the standard model levels 10, 150 ... 3000 m, and one with values at 10 m intervals up to 150 m. Whilst the wind speed shows a considerable difference in structure up to 150 m, the wind direction profile is virtually unchanged. Increasing the resolution of the low-level data has a marked effect on the sound enhancement region; at 2.5 km the maximum noise level is reduced by 3.4 dB, whilst at 5 km it is reduced by 1.8 dB, and the 120 dB contour lies about 900 m closer in. The changes in the predicted noise levels result because the trajectories of the sound rays are different.

It is also probable that the strong wind shears found below 10 m have some effect on the propagation of sound. However, uncertainties in the definition of the noise source (as discussed later), and the degree of spatial averaging implicit in the current model, make such detail superfluous at present.

These results suggest that the current operational model predictions would be changed (but not necessarily improved) if more detailed low-level data were available. However, a more sophisticated model would almost certainly require better data, particularly near the surface where the shears are greatest. Wessels and Velds (1983) have shown that similarity theory can be applied to the problem of sound propagation in the surface layer and such an approach could be used to supplement the available data.

4. Deficiencies in the model formulation

The main deficiencies in the model are the neglect of the effects of turbulent diffusion, wave-form interference, and the underlying surface.

4.1 *Effects of turbulence*

Turbulence has an important role in the propagation of sound. Turbulent fluctuations in wind, temperature and humidity, which can occur on scales from a few millimetres to several hundred metres, are associated with variations in acoustic refractive index. If the scale of these fluctuations is larger than, or comparable to, the wavelengths of interest then they cause scattering of the sound waves. The main consequence of this is that the noise levels at a particular point can be variable, another effect is that sound can be spread into shadow regions. Because there is relatively little back-scatter, any attenuation of the sound energy is small, and is generally much less than that due to atmospheric absorption. For low-frequency impulsive noise both the attenuation due to absorption and turbulence are negligible.

4.2 *Interference effects*

Within a shock wave there are both over- and under-pressures, as illustrated in Fig. 3(a) which shows the type of wave-form which results from artillery fire. If two sound rays come together as shown in Fig. 3(b) then the two waves combine and there is a considerable increase in the noise level. However, if the two waves are out of phase then the resulting wave-form shape changes; in the example shown in Fig. 3(c) the duration of the shock wave is increased. The noise at a particular point, near the surface, is related to the resultant pressure change due to the direct wave, the ground reflected wave(s) and (in the enhancement and focus regions) the refracted wave(s). Depending on the phase of each of these, either constructive or destructive interference effects may be possible, as illustrated in Fig. 3. The details of the interference process are not considered in the present model.

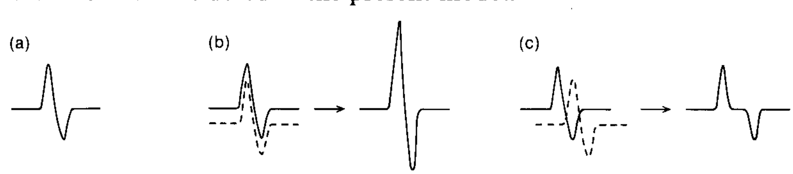

Figure 3. Schematic of (a) typical wave-form shape and possible interference effects that occur when two combining waves are (b) in phase and (c) out of phase.

4.3 *Effects of surface and terrain*

In Part I (Turton *et al.* 1988) the propagation of sound in the atmosphere was described by geometric optics methods. Such techniques can also be used to describe the reflection of sound waves at ground/sea surfaces provided the wavelengths of the sound waves are large compared with the scale of undulations in the surface. If this is so then the angles of the incident and reflected sound rays are equal. For artillery noise the basic wavelengths are a few tens of metres, thus water surfaces are usually acoustically flat and so geometric methods apply. However, land surfaces may be sufficiently rough for diffraction effects, rather than reflection, to occur. Also, the character of the surface is important; acoustically 'hard' surfaces (such as a water surface, which has a reflection coefficient close to unity) are good reflectors, whilst 'soft' surfaces (which may result from vegetation) can absorb much of the incident sound energy and so reflect much less of it. However, for the low-frequency noise resulting from explosions or gunfire, it is suspected (but not established) that the reflection coefficient over land surfaces may still be significant, perhaps even as large as 0.8.

Furthermore, the situation is not quite so simple as suggested above because the wave-front is spherical rather than plane. The consequence of this is the so-called 'ground wave', which is required mathematically to match the boundary conditions as the spherical wave-front is distorted by the (plane) boundary; see, for example, Chessell (1977) and Piercy *et al.* (1977). Although the physical interpretation of the ground wave is not well understood, it is believed that it has an important role in propagating energy away from the source at low levels.

In addition to the effects of the actual surface, topography can also have a significant effect. If sound rays are reflected off sloping surfaces then the reflected and incident rays have different angles to the horizontal and this will affect where the rays next come down to ground. Complex terrain also has an important effect on the propagation of sound because the boundary-layer wind and temperature gradients are significantly modified from those found over flat surfaces (e.g. by cold air drainage and lee eddies over hills).

The effect of sea surfaces in reflecting sound waves is one of some importance, and is believed to be a particular problem at the Proof and Experimental Establishment range at Shoeburyness. Complaints of noise, evidently originating from Shoeburyness (suggesting levels in excess of 120 dB), have been made at Margate, some 50 km away across the Thames estuary. The explanation for these anomalously high noise levels is believed to be the 'bouncing' of sound waves across the estuary. At present any assessment of bounce is made subjectively by a forecaster since there is no explicit inclusion of surface reflections in the current model; this is an important aspect in which the present operational model is deficient.

4.4 *Determination of noise levels in focus regions*

It can be seen from equation (I8) that the predicted increase in noise levels, for a particular density of returning sound rays, is greater further away from the source. In reality the opposite is true. Because the wave-front diverges, the intensity of sound rays returning to ground further away from the source is reduced. This is not reflected in equation (I8), which clearly does not conserve energy. As the empirical constant c_2 has been determined from measurements made in the enhancement region closer to the source, the predicted noise levels in the focus region are likely to be much less certain than those for the enhancement region.

4.5 *Determination of the source level*

The peak over-pressure of the shock wave resulting from gunfire or explosions, which initially propagates supersonically, decreases rapidly as the wave diverges. By the time the shock wave has travelled about 100 m from the source, the peak over-pressure is small, and the wave propagates at nearly the speed of sound, i.e. it effectively becomes a sound wave.

As noted in Part I, L_0 is determined by equation (I10), which has been determined from, and validated for, a limited range of explosive charge weights (0.2–37 lb). In the model the noise source is assumed to be omnidirectional, but for artillery guns this is not so. The measurements made at Lulworth (Lord *et al.* 1986) showed that the noise levels, to the rear and side of the guns at 100 m distance, were on average up to 6 dB different; for obvious reasons no measurements were made in front of the guns. These differences result partly because the effective noise source is somewhere in front of the gun, and partly because wind effects can still occur within 100 m of the source. No account of this difference is made in the model when predicting the noise levels.

5. Meteorological data as used in the model

In order to compute the sound-ray trajectories, the model considers the atmosphere as a series of layers of 150 m thickness. These data are currently provided from the Mark 3 radiosonde, details of which are given by Pettifer (1979). At the range stations radiosonde flights are made every 2 hours, and the data may be supplemented by radiowind flights between radiosonde ascents. The radiosonde measures temperature (every 2 seconds), humidity (every 4 seconds) and pressure (every 8 seconds), i.e. with an approximate vertical resolution of 12, 24 and 48 m respectively.

Values of (virtual) temperature are determined (by interpolation) at the designated model levels 150, 300 ... 3000 m. The surface temperature in the model is based on the hourly screen measurements. If the screen temperature changes between flights then the forecaster adjusts the upper temperatures to maintain an appropriate lapse rate.

Winds are determined by radar tracking of a target suspended from a balloon. Mean winds are evaluated for 150 m thick layers centred on the designated levels. However, since reliable winds from the radar cannot be obtained below about 200 m, the wind at 150 m is usually estimated by the forecaster from comparison of the surface (10 m) wind and the mean wind around 300 m.

As discussed earlier, the model-predicted noise levels are particularly sensitive to the low-level winds. Unfortunately this is the area in which the data are least reliable. Also the surface wind at the anemometer may well differ from that at the point of firing/detonation; at Larkhill the two locations can be up to 13 km apart, so the influence of local terrain and surface obstacles may lead to significant differences in the winds.

The winds aloft, which are layer means, are probably adequate since the model assumes horizontal homogeneity and sound waves traversing these layers will be (as their height increases) further away from the source.

Since the model results are less sensitive to temperature, the temperature data should, in general, be adequate. However, changes in the thermal stucture of the boundary layer need to be taken into account (together with any accompanying changes in wind shear).

6. A simplified method for noise assessments

Whilst the noise assessment model described in this paper has been found to be a valuable tool for predicting noise levels at the range stations, there is on occasions a need for noise forecasts at remote sites where few data are available. A simplified method of producing assessments using synoptic data has been developed, which may be applicable for use at such sites.

The results from the model have shown that the low-level wind shear and wind direction are the main factors that determine the extent and direction of the sound enhancement region. This suggests that, with some knowledge of the winds, it should be possible to provide guidance towards the likely direction and degree of enhancement. For remote sites the only available information is the geostrophic wind (which may be determined from a synoptic chart). Using this, and a surface (10 m) wind (either forecast from the geostrophic value or estimated from the nearest observation), it is possible to make an assessment of the likely noise enhancement. In practice the ranges usually require to know to what distance are the noise levels likely to be sufficiently loud so as to cause complaints or nuisance, i.e. the distances from the source of the 130 dB and 120 dB levels.

The vector wind difference (i.e. the thermal wind speed) can be related to the predicted noise enhancement. Fig. 4 shows the model-predicted maximum distances from the source of the 130 and 120 dB noise levels, from operational predictions made at Larkhill over a 6-month period. The curves are simple exponential least square fits to the data and enable the forecaster to estimate the maximum distance from the source of the 130 and 120 dB noise levels. The regression equations for the curves are

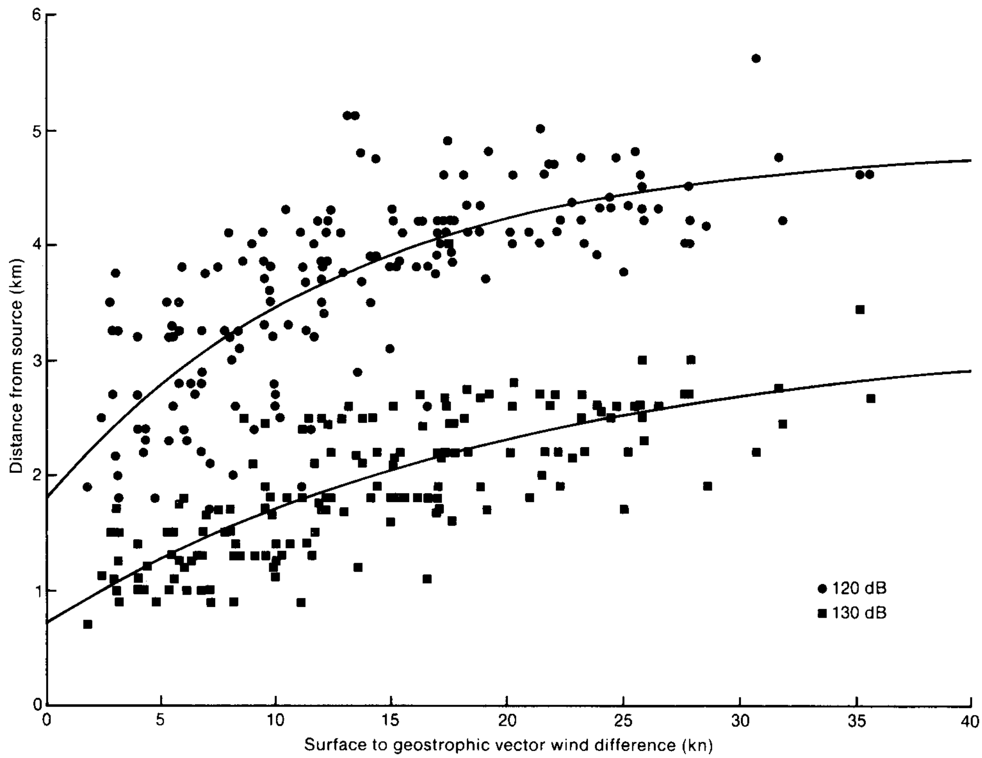

Figure 4. Model-predicted maximum distances from the source of the 130 and 120 dB noise levels for various surface to geostrophic vector wind differences. The curves are exponential least square fits.

$$d_{130} = 3.240 - 2.536 \exp\{-0.050\,(v_G - v_{10})\}, \quad \ldots \quad (1)$$

$$d_{120} = 4.860 - 3.075 \exp\{-0.078\,(v_G - v_{10})\}, \quad \ldots \quad (2)$$

where v_G and v_{10} are the geostrophic and 10 m winds given in knots, as is practised at the range stations. As an example, for a velocity difference of 20 kn the 130 and 120 dB levels would be expected to occur at approximately 2.3 and 4.2 km from the source. Fig. 4 shows that the distances determined from equations (1) and (2) are generally within 1 km of those predicted by the model; the standard errors of the fits are 390 m (d_{130}) and 540 m (d_{120}). The figure is valid only for an effective charge weight of 5 lb; however, a correction to the distances obtained, based on the noise-level decay rate, can be made for different charge weights. The corrected distances are obtained by multiplying d_{130} and d_{120} by a factor, F, which is given by

$$\log_{10} F = 1.1 \log_{10}(W/5) \log_{10}(d_{120}/d_{130}), \quad \ldots \quad (3)$$

where W is the equivalent charge weight (in pounds).

Forecasters should also be aware that, in conditions when there is a low-level inversion (perhaps a nocturnal inversion, or an inversion capping a cloud layer), the noise levels are likely to be higher and so the relevant distances will be increased.

The direction in which the noise enhancement is greatest usually veers some 10–30° from the surface wind direction, and depends on the turning of the low-level wind, which would usually be expected to be less than that between $\mathbf{v}_{10}$ and $\mathbf{v}_G$. As a rough guide the enhancement region might be expected to occur within a sector centred on the average wind direction and extending by about 50° to the side of the surface and geostrophic wind directions.

Because there is no detailed information about the wind profile, the method can give only a very rough indication of focusing. However, the model suggests that focusing is most likely when the directional shear is large, and is again related to the thermal wind speed. Fig. 5 shows the percentage occurrence of focusing for various wind speed classes. The figure shows that when the thermal wind speed is less than 10 kn the likelihood of focusing is low. For thermal winds greater than this, the likelihood of focusing increases with increasing speed. It should be noted that any focusing indicated by this method is caused by the turning of the wind within the boundary layer; such focusing tends to occur 5–10 km from the source. Overall, the model suggests that boundary-layer focusing would occur on about 45% of all occasions.

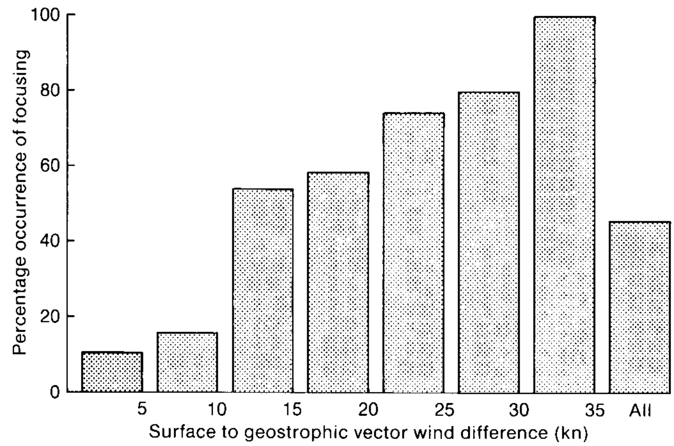

Figure 5. Percentage occurrence of focusing for various surface to geostrophic vector wind differences.

In the example for 20 August 1985 (see Part I, Fig. 7) the direction of the focus region is related to the directional shear in the wind profile. The wind shear in the layer, between the surface and the geostrophic wind is given by the thermal wind, which can be used as an indicator of the focus direction as illustrated in Fig. 1. In the model the predicted foci generally extend over a range of azimuth, typically 60°. When the boundary-layer foci were forecast to occur within 60° of the thermal wind direction, then this agreed with the model predictions on about 80% of occasions.

Focusing can also occur as a result of directional shears above the boundary layer. Obviously the method cannot give any guidance to this type of focusing. Forecasters should assess the likelihood of such focusing from the directional changes in the winds shown by an upper-air ascent. Foci due to shears above the boundary layer tend to occur further away from the source, at 10–20 km distance.

7. Concluding remarks

This paper has reviewed the current noise assessment model used operationally at a number of Ministry of Defence ranges. Use of the model has proved valuable to the ranges in identifying, and avoiding, occasions when noise levels are likely to be high, so producing a decrease in the number of complaints received by the Ministry of Defence for nuisance and damage. Complaints do still arise, however, and indicate both a reluctance by the ranges to curtail activities in marginal conditions and the limitations in the accuracy of the current model, in particular the neglect of surface reflection effects. Trials have suggested that the mean r.m.s. accuracy of the model is about 6 dB, but there are very wide variations from this value day to day. However, this figure should be viewed against the overall effects of meteorology which can cause differences of about 30 dB in the noise levels.

The results from the model are also somewhat dependent upon the resolution at which the calculations are performed, especially in regions where focusing is predicted. The results also suggest that low-level winds have a major influence on the propagation of sound and on the resulting noise levels, particularly in the enhancement region. Limitations on the quality and representivity of the data used in the model can lead to significant errors in the forecast.

The demand for noise forecasts for various activities, in addition to artillery training and explosives testing, is increasing (e.g. demolition, quarrying, and wind turbine noise). The Meteorological Office is in a unique position to provide such forecasts which, in the future, might also form the basis of a commercial service using data from the observational network and/or products from the mesoscale model. However, before such a service could be established, more confidence is needed in the predictions.

Further modelling work needs to be done to include important effects (e.g. surface reflections) not presently considered. However, any potential improvements in the current model will probably be limited because of its empirical nature. A more sophisticated model based on firm theoretical principles, which takes account of the most important effects, would be necessary to produce more reliable forecasts. In addition, such a model would benefit from better quality data on winds and temperatures in the lowest few hundred metres of the atmosphere.

Noise forecasts are increasingly needed at sites remote from the observational network. To provide guidance for such sites, a simple method for making noise assessments has been developed. This method is now being used for several ranges where on-site meteorological support is not available.

Acknowledgements

We would like to thank Mr G. Kerry and Dr D.J. Saunders of the Department of Applied Acoustics, University of Salford, for their contributions in the development of the operational model.

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The identification of rainfall type from weather radar data

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Summary

A method of identifying rainfall type (frontal or convective) using data from a weather radar is described. The basis of the method is the use of pattern-recognition information, derived from space–time correlation surfaces, as local rainfall type indicators. The potential of this method for real-time implementation is discussed.

1. Introduction

Estimates of rainfall may be made by using radar. Precipitation particles back-scatter a proportion of the radar energy which can be quantified as a radar reflectivity, Z. Use is normally made of an empirical relationship between Z and the rainfall rate, R, of the form $Z=AR^B$, the values of A and B being dependent upon the distribution of precipitation particle sizes and hence rainfall type. In the UK radar system (Collier and James 1986) the values are A=200 and B=1.6, although many values of A and B are possible (see Battan 1973). The value of B does not vary as much as that of A, and therefore the factor A is modified in real time using data from a few telemetering rain-gauges.

The real-time adjustment procedure involves the fully automatic recognition of rainfall type (frontal rain, rain shadow, convective rain and bright band‡), and the modification of the factor A is made in different ways for different topographic areas dependent upon the rainfall type (see Collier *et al.* 1983). This technique has been shown to significantly improve the accuracy, relative to gauge-only measurements of areal rainfall, of the radar estimates of rainfall (Collier 1986). Nevertheless, the technique of objectively recognizing rainfall type was shown to be unreliable in particular circumstances.

The procedure of using different R:Z relationships for different rainfall types has been investigated in several countries (see, for example, Attmannspacher 1976, Wilson and Brandes 1979, Calheiros and Zawadzki 1987). In principle, a reliable method of identifying rainfall types could produce useful improvements in rainfall measurement accuracy. More recently, it has become evident that estimates of wet deposition, either of radioactivity (reference Chernobyl) or of pollutants such as acid rain, depend upon knowledge of wash-out efficiency which is related to rainfall type (Monk and Jonas 1986). Hence, there are good reasons for considering whether it is possible to objectively estimate rainfall type. Collier *et al.* (1983) proposed a technique based upon a time series analysis of ratios of radar estimate to rain-gauge estimate. However, if a procedure could be found that was independent of rain-gauge data, then it would be possible to analyse in real time the spatial variations of rainfall type in much finer detail.

This paper outlines a rainfall-type analysis procedure that uses radar data alone, and is capable of real-time operation. Limited case-studies are presented to demonstrate the success of the procedure and highlight areas of difficulty.

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‡ When the radar beam intersects the region where snow melts to form rain, the radar reflectivity is enhanced and a 'bright band' is observed.

2. The possible technique

Sharon (1974) describes the application of space–time correlation analysis to rain-gauge data (see also Huff and Shipp 1969). A similar procedure may be applied to radar data. Consider the correlation coefficient, C_{ij}, which is defined as a function of pairs of points in the radar reflectivity field, Z. For any two points, (x_i, y_i) and (x_j, y_j), the correlation coefficient is given by

$$C_{ij} = \frac{\overline{Z'_i Z'_j}}{\sigma_i \sigma_j}$$

where Z'_i and Z'_j are deviations of the measurements of Z at the points specified from their respective long-term average, and σ_i, σ_j are the standard deviations in time of the measurements of Z at the same points (the overbar indicates a time mean). Assuming the field of radar reflectivity to be homogeneous and isotropic with respect to the correlation coefficient, then C_{ij} becomes a function of the distance d_{ij} between the respective points where

$$d_{ij} = \{(x_i - x_j)^2 + (y_i - y_j)^2\}^{1/2}.$$

For a given type of precipitation and a given area, the sample correlation function, $r(d_{ij})$, is derived from estimates of r_{ij} obtained from the reflectivity data using

$$r_{ij} = \frac{\overline{Z'_i Z'_j}}{S_i S_j}$$

where S_i, S_j are estimates of σ_i, σ_j respectively. This expression for r_{ij} may be written as

$$r_{ij} = \frac{\sum_{t=1}^{n} (Z_{it} - \overline{Z_i})(Z_{jt} - \overline{Z_j})}{\{\sum_{t=1}^{n} (Z_{it} - \overline{Z_i})^2 \sum_{t=1}^{n} (Z_{jt} - \overline{Z_j})^2\}^{1/2}} \quad \ldots \ldots \ldots \ldots (1)$$

where t takes values from 1 to n with n the number of sets of data acquired over the period considered (1 hour or 12 sets in the present work).

Once the r_{ij} have been computed a set of correlation fields can be constructed by considering each data point in turn as being the 'key point' relative to which the correlations are plotted. Thus if there are N data points there would be N fields each consisting of $(N-1)$ plotted correlations. If the reflectivity field is regarded as homogeneous, the correlation function depends only on the distance d_{ij} between points and not on the specific locations. In this case the N fields can be combined with each key point being at the centre of the composite. The result is a field with $N(N-1)$ plotted correlations, each at an appropriate distance and direction relative to the original key point. Each computed correlation is included twice at diametrically opposed points relative to the centre. The correlation surface is constructed by plotting contours of equal correlation on the composite surface. It should be noted that the spatial distribution of values on this surface does not map onto the topography underlying the area under consideration; vector distances from the centre of the field simply indicate the relative positions of points whose correlations have been calculated.

The approach outlined is only valid if the variance is constant throughout the field (Gandin 1965). This is an appropriate assumption for convective systems, but may not be appropriate for rainfall in which orographic effects vary significantly. In such circumstances the correlation surfaces may become very variable in space, although this variation will be closely linked to orographic features. For situations in which orographic effects are small, and rainfall patterns are dominated by mesoscale frontal dynamics, one might expect characteristic correlation surfaces, provided that areas over which the analysis is carried out are small compared to the synoptic scale (hundreds of kilometres). It is evident that the correlation surfaces can perhaps be used to describe objectively the spatial structure of the storm rainfalls. In what follows this possibility is investigated.

3. Analysis of rainfall patterns

Examples of radar data associated with events which produced local river flooding have been studied. The effects of the automatic calibration procedure applied in real time were removed before the data were analysed. All the data considered were recorded with the Hameldon Hill radar in north-west England as part of the North West Weather Radar Project (Collier *et al.* 1980).

Four areas each containing 100 data elements in a 10 × 10 array with a 2 km grid were selected around the locations of the existing telemetered rain-gauges. Only three of these locations are considered in this paper and these are shown in Fig. 1.

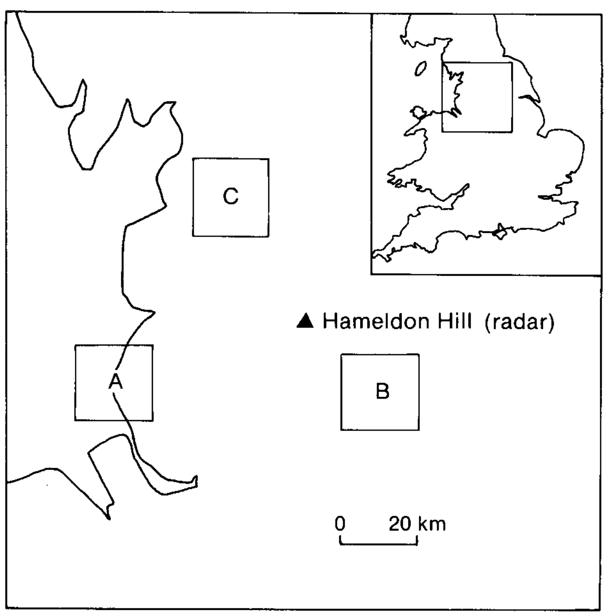

Figure 1. Locations of the space–time correlation windows A, B and C.

The space–time correlation surface technique was applied to each set of radar elements, one hour's data (12 scans at 5-minute intervals) being used for the time series. After the sets of data had been analysed, a contour-plotting routine was used to display the surfaces. The results of this analysis agreed with the findings of Sharon (1974) for convective rainfall and of Marshall (1980), in that definite forms of pattern were produced by different weather conditions detected by the weather radar. Samples of these contours during the passage of a convective trough are shown in Fig. 2. In general terms, the shapes of these surfaces confirm that under showery conditions the data elements have very poor correlation with their immediate neighbours, the contours enclosing almost circular areas (Fig. 2(a)). In the region of the convective trough there is much higher correlation between data elements lying along

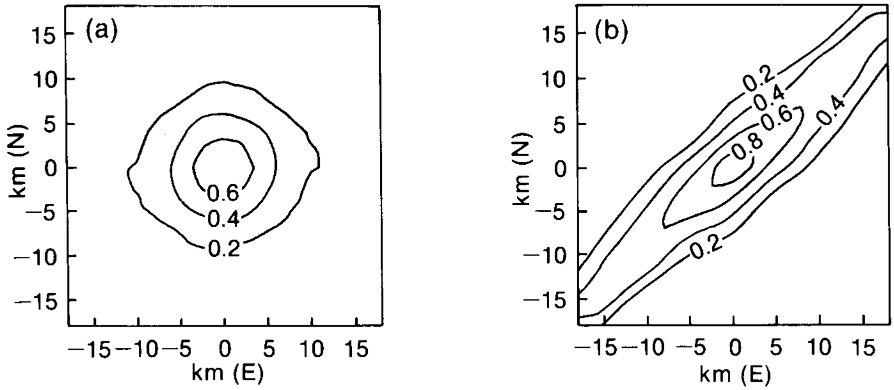

Figure 2. Correlation surfaces for (a) box A (see Fig. 1) for 0847 to 0947 GMT on 19 October 1984 (showery conditions) and (b) box B (see Fig. 1) for 0802 to 0902 GMT on 19 October 1984 (frontal conditions).

the axis of the trough (Fig. 2(b)). This supports the idea of using such a pattern-recognition algorithm to discriminate between various rainfall types.

Although visual discrimination between patterns is automatic, some more basic property was sought that would enable numerical values to be computed which described the pattern characteristics of the space–time correlation surface. An initial attempt was made in which the values of the correlation surface were summated in the expectation that the elliptical patterns, indicative of frontal rainfall, would produce a different order of value than would a circular pattern. However, it became evident that this solution would not produce a unique numeric property possessing high discrimination between rainfall types.

In an attempt to define the shape of the contours making up the space–time correlation surface, the ratio of the summated value of the data lying on the major axis of the shape to that of the data on the minor axis was extracted. This ratio is referred to as the 'rectangular ratio' for the correlation surface (see Fig. 3).

The space–time correlation surface is symmetrical about its diagonal. This symmetry enables the ratio of the two data axes to be extracted very simply since it is only necessary to operate on half of the data. A series of ratios was produced by successively discarding the oldest data scan and including an extra one

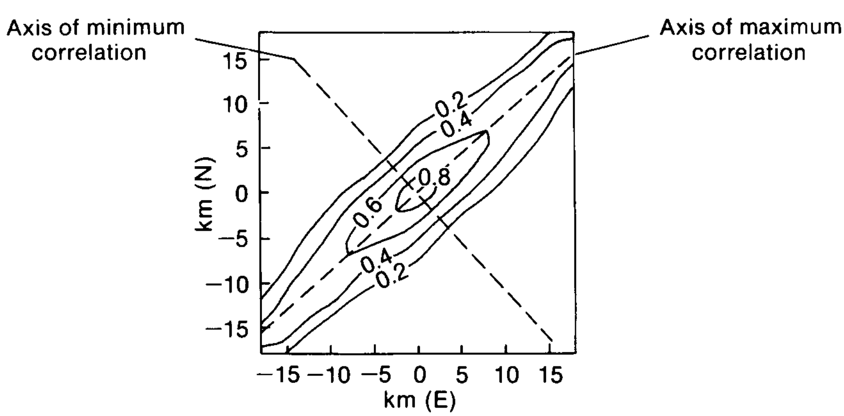

Figure 3. Illustration of the axes of maximum and minimum correlation used in the calculation of the 'rectangular ratio'.

from the data file. The continuous analysis of one day's data produces 288 values for this parameter; however, the structure of the available data meant that the first hour of the day was used to establish the first ratio. In real-time application, data for the previous day would be included in the analysis of the first 11 scans in any day. Examples of the values of this ratio are shown in Fig. 4 together with corresponding synoptic maps showing the analysed weather type.

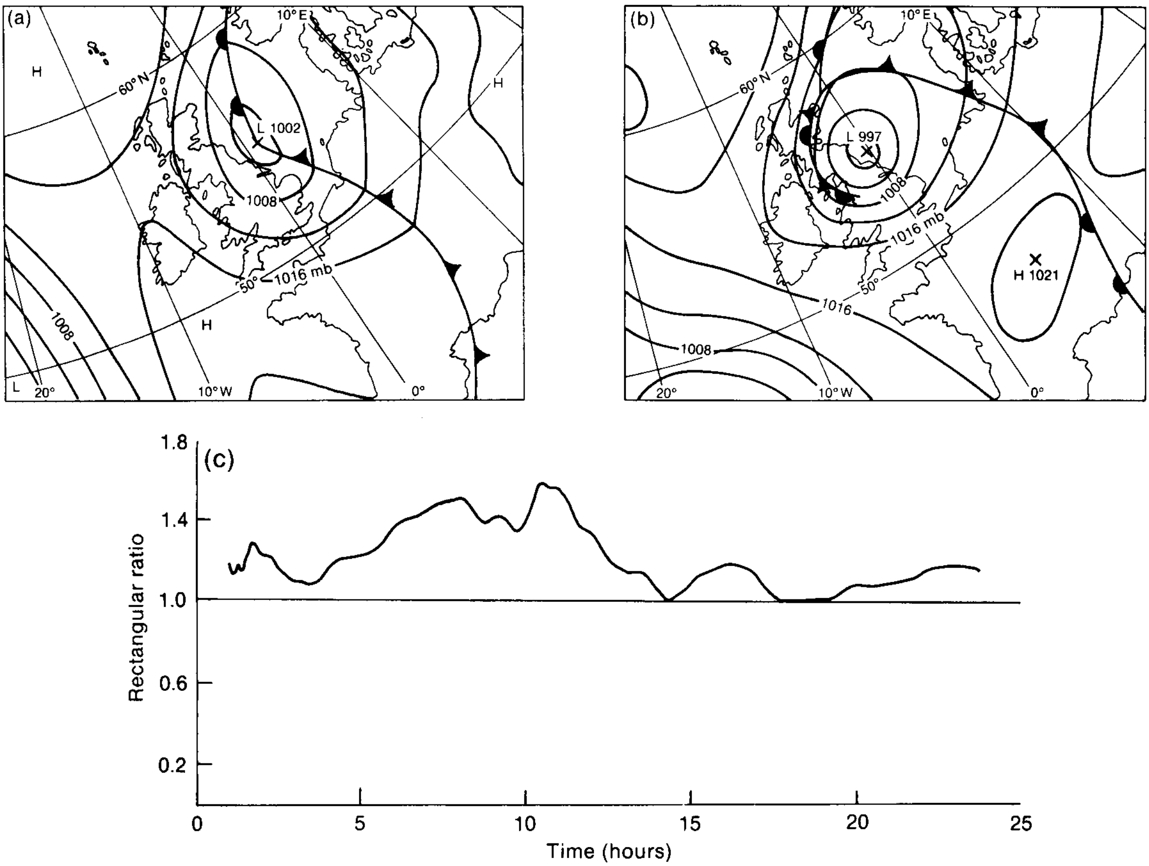

Figure 4. Illustration of (a) the synoptic situation over the United Kingdom at 0600 GMT on 3 November 1984, (b) the synoptic situation at 1800 GMT on 3 November 1984, and (c) the variation of rectangular ratio calculated for box C (see Fig. 1) during the period 0100 to 2400 GMT on 3 November 1984.

4. Discussion and conclusions

The magnitude of the rectangular ratio, which is always greater than 1, is typically less than 2. However, this value may be exceeded when, for example, very narrow bands of rain, such as line convection, are observed (James and Browning 1979). Large values may also be produced by orographic rainfall associated with extensive upland areas. Negative values of the ratio occur when the data element value Z_{it} used in equation (1) is less than the mean value $\overline{Z_i}$ for the series. Such negative values causing these excursions could be indicative of bright band or large gradients of rainfall since under these conditions the rainfall within the area of the data elements can vary by an order of magnitude. However, it is unlikely that this technique would provide a method of identifying bright band which was more reliable than that described by Smith (1986).

Fig. 4 shows examples of showery and frontal rainfall with the corresponding rectangular ratios. The movement of an occlusion across northern England is marked by changes in the value of the rectangular ratio. The choice of window size is very important. If the window is too small a front may not be recognized, as the convective elements in the front dominate the calculation of the value of the rectangular ratio. Insufficient data have been analysed to make reliable identification of the relationship between the rectangular ratio of correlation and the rainfall type. Nevertheless, the examples shown in Figs 2 and 4 give the authors sufficient confidence that the procedure may be reliable enough for operational use. Work has begun to investigate further the operational performance that can be expected. The following conclusions may be made, albeit tentatively at this stage.

(a) The use of space–time correlation surfaces may be applied to radar data in the same way as proposed for rain-gauge networks.

(b) The use of space–time correlation surfaces to identify the statistical structure of storm rainfall is a practical method and deserves further detailed investigation. More detailed consideration should be given to the most appropriate size for the windows used.

(c) The rectangular ratio of space–time correlation surfaces shows variations that are a function of the shape of the data contours and therefore provide a means of identifying storm type for the data window analysed. This procedure is inherently related to pattern-recognition techniques, and would therefore benefit from developments in this field.

(d) The use of the rectangular ratio may provide a method of identifying local storm type within small areas of a data field, thereby reducing the temporal errors and also allowing the individual analysis of topographic features.

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The achievements of COST-43*

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Summary

The history of the COST-43 Agreement — a project to set up an experimental European network of ocean stations — is described from its origins in the late 1960s, through to the two formal phases which occurred from 1979 to the present day. It is shown that many of the aims and objectives of the project have been achieved.

1. Introduction

In the Report of the Political Working Group for Scientific and Technical Research established by resolution of the Council of the European Communities on 31 October 1967 the birth certificate of 'Action 43' is registered in the descriptive notice 'Oceanography, Action 43: Setting up of a network for oceanographic and meteorological measuring stations in European waters'. One of the initial aims was 'the common development of a complete network of automatic measuring stations allowing the collection and transmission of oceanographic and meteorological observations both along the coast and in the open sea' — a bold and far-seeing objective.

However, it was rapidly realized that the technology was not at that time sufficiently developed, and that the most likely way of making progress was by a policy of short steps via *action concertée* by the interested parties.

In 1970 the creation of the COST (Co-operation in Science and Technology) framework resulted in a number of Consultants Groups, amongst which was the Oceanography/Meteorology Technical Committee. Initially chaired by Dr A. Nyberg of Sweden, this group was charged in April 1970 with defining in one year the technical content of a concerted project between the governments which were

* Based on a paper presented to the COST-43 Seminar on Operational Ocean Station Networks — COST Project 43, Institute Français de Recherche pour l'Exploitation des Mers, Brest, France, 16–18 June 1987.

interested. It took a little longer than that, but by autumn 1972 the Senior Officials Committee of COST had received the required report. One of the aims of COST is to promote co-operation between industrial companies in the field of research and development projects, and so the Senior Officials discussed the report with various commercial and industrial companies only to find that the proposals for organization and finance were not sufficiently well defined, and the technical specifications insufficiently detailed for the manufacturers to be confident that progress could be made within a reasonable budgeting framework.

By June 1973 it was clear that there was a need for a consultant to define the detailed specification of the project and to estimate the amounts of money that would be required to implement it. To that end Professor J.P.G. Martinais of the Centre Océanologique de Bretagne was appointed to produce a report.

Professor Martinais' (1976) report is still well worth reading today. First he addressed the requirement in terms that recognized the interdependence of the global atmospheric and oceanographic circulations, which he called 'Marine meteorology' and 'Global oceanography', tempering this requirement by the perspective and constraints of the economic context.

Second he considered the state of the art in marine meteorological measurements, making an inventory of the technical problems which he could see would be posed in implementing an established network of ocean stations. He found a mismatch between the parameters that needed to be measured and those sensors that existed at that time, and came up with the idea of 'pilot networks' in which 'new instruments could be tried, tested and evolved as technical progress is made and scientific knowledge increased'. His basic concepts involved:

(a) sensors,
(b) buoy transmit terminals,
(c) the transmission unit,
(d) the structure, and
(e) one or several onshore stations,

and he gives us the excellent advice that 'some day, every piece of equipment at sea will either be damaged or lost; therefore, it must be simple, robust, uncomplicated and cheap.' I am sure that today we all recognize all these concepts and we have learnt the truth of the advice one way or another.

Third, and most important, Professor Martinais made some proposals as to the way ahead as he saw it in 1975. These involved:

(a) Pilot networks — these would require Ocean Data Acquisition Stations and onshore data reception to be organized for limited areas or regions at a reasonably low cost. Comparisons of a number of such networks would allow technical and financial solutions to be tested.

(b) Concrete proposals for data transmission systems via polar-orbiting and geostationary satellites, and via high frequency.

(c) Concrete proposals for structures and various types of buoy ranging from fixed platforms through moored buoys to drifting buoys.

(d) A plea for some standardization both in the area of structures and with regard to sensors as soon as the developing technologies allowed.

Lastly he made a plea for European nations to pool some of their technical and scientific efforts for the greater good of the whole, since he saw that it was only in this way that the efforts of the COST countries could come together to complement each other and to provide the European/Atlantic-wide network that was required. To quote from the final words in his report — dated January 1976 — 'The efforts to co-ordinate the investigations are difficult, the long-term programme is ambitious, but today a realistic and constructive stage is possible.'

2. COST-43 — the First Agreement

By mid-1975, therefore, the Technical Committee on COST-43 had seen its early ideas for an intergovernmental Agreement drift back in time by several years. The hopes of some that a European industrial consortium could be set up to run the whole network had foundered because of a downturn in the economic situation and it was becoming clearer that *action concertée* via co-ordinated national programmes was the only way ahead. During 1975 it became clear that the ideas for pilot networks of Ocean Data Acquisition Systems (ODAS) in five regions were feasible, based on national contributions, and it was agreed that a Project Co-ordinator would be required to help the work. In January 1976 Dr T. Kvinge was first named as the Project Co-ordinator.

It was now necessary for the Memorandum of Understanding (MOU) and Technical Annexes of the Agreement to be prepared. This took some time, but by October 1976 Dr K. Holberg (Norway), who was then the Chairman of the Technical Committee, was able to put the document describing COST-43 to the Committee of Senior Officials.

There was then an 'interim' period while the lawyers got to work, but I am glad to say that this did not stop buoy instrumentation development and installation work continuing on a national basis. The final document was dated 29 July 1977 (COST/60/1/77) and was entitled 'COST-43 — a project to set up an experimental European Network of Ocean Stations (ENOS) for the purpose of providing meteorological and oceanographic data on a real time basis.'

The project was to be implemented in two phases:

(a) Evaluation, testing and further development of existing and/or new systems (sensors, structures, transmission systems) provided in national programmes.

(b) Setting up of pilot networks in selected test sea areas, i.e. the Azores, Bay of Biscay, Faeroes/Shetland, North Sea/Baltic and Mediterranean.

The project was intended to form an opinion on whether an integrated European regional network would be feasible and politically practical, and was to take 4 years by *action concertée*. The initial signatories to the Instrument included Denmark, France, Ireland, Norway, Portugal, Finland, Sweden and the United Kingdom. (Other countries now participating such as Belgium, Iceland, Italy, The Netherlands and Spain signed later, and the Federal Republic of Germany has been a regular Observer.)

It was now necessary to await ratification before the Agreement could come into force, and in the meantime an Interim Management Committee was set up (Chairman, P.M. Vitureau of Centre National pour l'Exploitation des Océans, France). This Committee dealt with the administrative problems whilst continuing to make some progress towards the objectives of the project. From 4 to 6 December 1978 the first Technical Seminar under the auspices of COST-43 was held at the Instituto Dofesu Nacional in Lisbon. During the seminar, attended by 42 participants, 23 papers were presented covering a wide range of ODAS-related topics.

The Agreement entered into force on 29 June 1979 when ratifications had been obtained from the necessary seven countries, and the first meeting of the Management Committee was held in Brussels on 6 July 1979 under the chairmanship of the author. The budget for the first 4 years was some 12.5 million Belgian francs. The majority of this sum was required to cover the meetings and to support the Head of Project and a small Technical Secretariat located in the Christian Michelsen Institute (CMI) of Bergen, Norway.

In September 1980 a second COST-43 Seminar was held at the CMI, which was devoted to the practical problems of ODAS development and applications that were then uppermost — in particular ODAS sensors, their calibration and stability, the reliability of data retrieved from ODAS, and of the ODAS structures and moorings, and the future of the COST-43 project. By that time it was becoming clear that COST-43 was moving steadily towards an operational phase and the need for planning beyond 1983 was already being considered. The words of T. Hovberg and U. Karstrom (Sweden) at this time are noteworthy:

> It will not be possible to cover future needs for meteorological and oceanographical data from European waters by ships and satellite observations only. Buoy and platform stations will also be needed.
>
> An ocean station network in European waters must — to a large extent — be designed and run in common. Otherwise it will be inefficient and expensive!
>
> Different national projects get a little extra push from the existence of a formal international agreement.

These remarks are still true today.

At the end of 1980 Dr R.E.W. Pettifer (United Kingdom) became the new Chairman, and during 1981 and 1982 Belgium, France, Iceland, The Netherlands and Spain acceded to the Agreement, bringing the total number of countries in COST-43 to 12. The COST-43 ODAS network as at 30 June 1980 is shown in Fig. 1 (COST-43 1981). Further progress was made as more ODAS were brought into operational status. For the first time joint multilateral projects became part of the plan (e.g. Iceland, Norway and the United Kingdom in the south-west of Iceland; France and Portugal in the Azores; Finland and Sweden in the Baltic). At the same time drifting buoys and wave riders (Portugal) were being considered. A highlight of 1982 was the COST-43 Project Review and Proposals for the Future (COST-43 1982a) which was put forward to the COST Senior Officials by the Management Committee. This document proposed a further 4 years' extension to the existing Agreement with organization and funding broadly staying the same so that the co-operative development of the European ODAS network within the individual programmes of participating countries could be continued via the encouragement and guidance of the COST framework. Member states supported these proposals and, following a questionnaire, a diagram showing the areas of national interest was produced (Fig. 2, COST-43 1982b). On the technical side a third COST-43 Seminar was held at the European Centre for Medium-range Weather Forecasts (ECMWF) in Reading, England from 14 to 16 June 1983. There were 86 participants

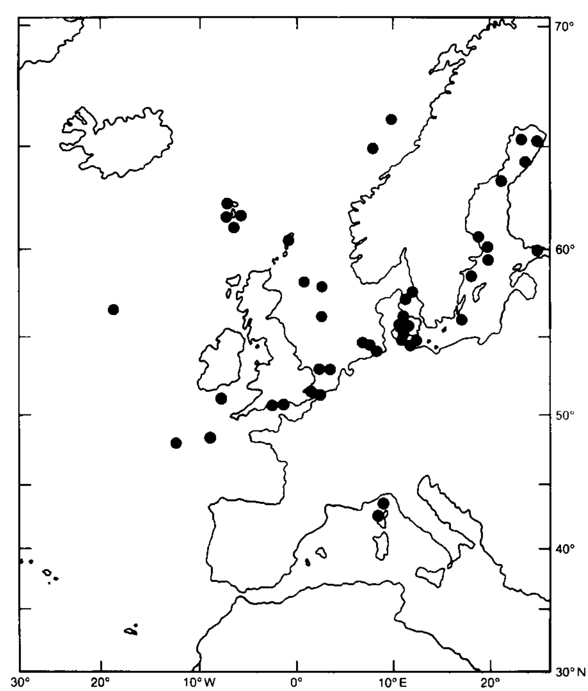

Figure 1. COST-43 ODAS network on 30 June 1980 (from COST-43 1981).

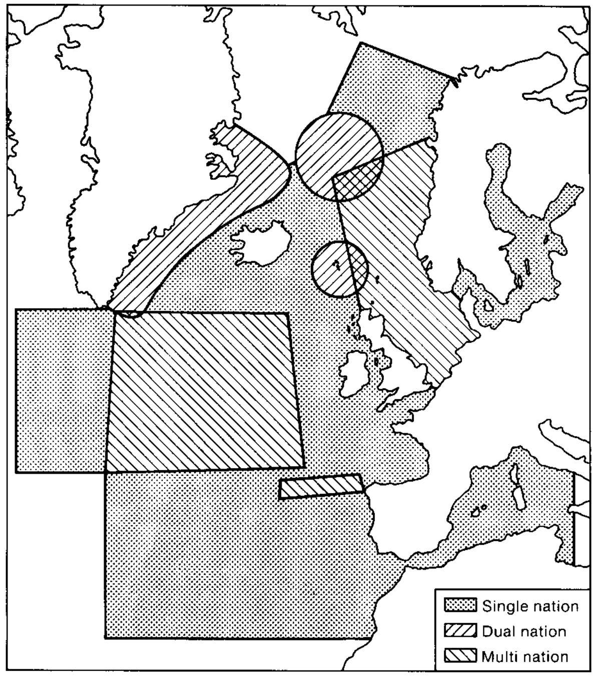

Figure 2. Areas of national interest for ODAS location (from COST-43 1982b).

from 8 countries and 27 papers were presented. ODAS manufacturers from Finland, Norway and the United Kingdom made an appearance at this seminar giving a scientific and industrial session.

3. COST-43 — the second phase 1984–88

The aims for the second 4-year period were clear. Firstly there was a continuing need to complete experimental development in respect to buoy technology and sensor technology, particularly in the area of drifting buoys. Secondly there was a need to define and agree an achievable programme of specific ODAS in a suitable network over the European/North Atlantic area. Fig. 3 (Pettifer 1983) identified the areas and sites of common interest and it also showed the existing ODAS sites in early 1983. Other aims included the maintenance of close co-operation with the World Meteorological Organization (WMO) and Intergovernmental Oceanographic Commission (IOC) programmes, and the desire to encourage and if possible implement a programme of drifting buoys in the North Atlantic.

The new second phase of the COST-43 Agreement was signed on 21 November 1983 and came into force a year later on 1 December 1984. It is therefore valid for a period of 4 years until 1 December 1988. During the period from June 1983 until December 1984 an Interim Management Committee was formed to carry on the good work. The project continued to make progress. In particular, and perhaps most importantly, an *ad hoc* Working Group was set up to plan the implementation of a major co-operative drifting buoy programme in the northern part of the North Atlantic. At the same time the Project Leader was specifically instructed to start investigating the possibilities for the development of another drifting buoy programme in the southern part of the North Atlantic.

It was during this period that the first Joint Venture Programme — System of Operational (drifting) Buoys in the Atlantic (SOBA) was planned and started operation. Six nations — France, Iceland, Ireland, The Netherlands, Norway and the United Kingdom participated.

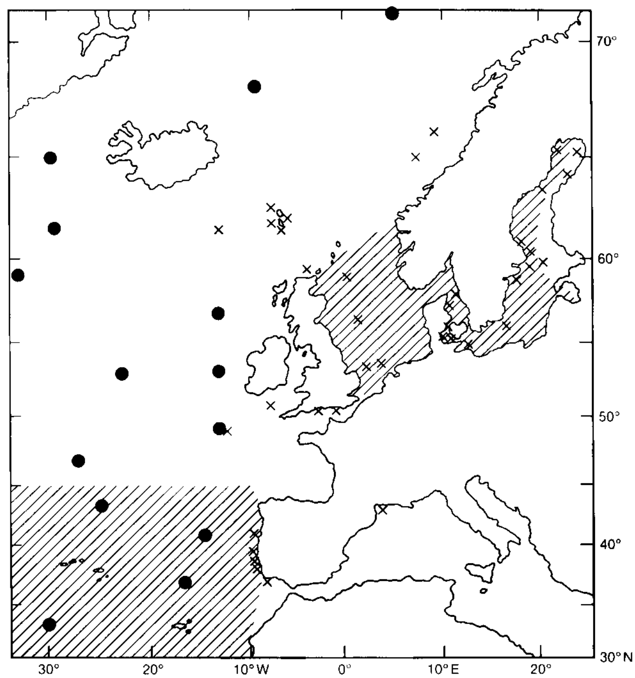

Figure 3. Areas (hatched) and sites of common interest for the establishment of new ODAS stations (solid circles) compared with those in place on 30 June 1983 (crosses) (from Pettifer 1983).

The basic elements of the SOBA programme are as follows:

(a) A minimum of two drifting buoys are kept operating in a specified area 55–63° N, 25–45° W at all times over a period of 3 years.

(b) The data are transmitted via the Argos system and received by local user terminals, from where they are disseminated in near real-time in DRIBU code via the Global Telecommunication System (GTS).

It was also during this period that COST-43 was able to send a representative to the Informal Meeting on Observing Systems with particular emphasis on the North Atlantic which was held at ECMWF in October 1984. This led on to COST-43 participating in the Operational World Weather Watch Systems Evaluation for the North Atlantic (OWSE–NA) which is currently under way.

On 5 December 1984 the new Management Committee held its first meeting under the new Agreement and continued, at first under the continuing leadership of Dr R.E.W. Pettifer and later with Dr W.A. Oost (The Netherlands) as Chairman.

While the co-ordinated programmes for measurements from moored buoys and marine platforms have continued to be important elements of the COST-43 programme in its second phase, perhaps the most important (and exciting) new venture has been the genesis and implementation of the co-operation between European nations to establish the SOBA and the SCOS (Southern COST-43 Operational System) operational drifting buoy programmes.

As stated above it was possible to implement the SOBA programme from October 1984. The SOBA programme has now been operational for 2½ years. The statistics show that during the first 14 months of operations a total of 7 buoys were deployed giving some 60 'buoy months' of accumulated buoy deployment time with an average buoy coverage in the SOBA area of 1.3 buoys. Early in 1986 it was decided to increase the target number of buoys in the SOBA area from two to three, and to make greater efforts to ensure that the data from the buoys were being recovered and received into the GTS.

In general the SCOS programme for drifting buoys in the southern area of the North Atlantic has followed the operational procedures of the SOBA programme. In this case two deployment areas, 40–45° N, 30–35° W and 35–40° N, 20–30° W, were chosen to be used alternately with fixed time intervals. Due to the southerly position, the number of useful passes of the TIROS polar-orbiting satellites are significantly lower for this area than for the SOBA area, and the idea of using buoys with a Meteosat transmitter as well as the Argos system (used for position location) has been developed. For the SCOS programme France, Ireland, The Netherlands, Portugal, Spain and the United Kingdom have participated. The SCOS programme began in July 1986.

4. Achievements of COST-43

4.1 *ODAS and drifting buoys*

So far the emphasis has been on the activities of the COST-43 project, and this is natural since it is through the activities that the achievements can be demonstrated. The initial aim was the establishment of an experimental network of ODAS providing oceanographic and meteorological data in real time. Back in 1979 there were very few established ODAS within the COST-43 area, apart from the highly expensive ocean weather ships. During the ensuing years over 60 ODAS stations have been established under the aegis of COST-43. Some have only been deployed for a short period, but many are maintained to be fully operational (see Fig. 4, COST-43 1986). Further, we now have two programmes in which drifting buoys are routinely seeded into chosen weather-sensitive areas of the North Atlantic.

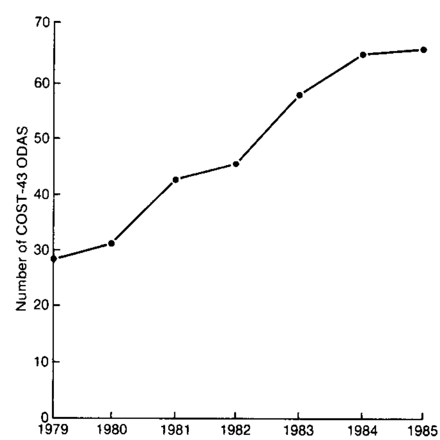

Figure 4. Operational COST-43 ODAS from 1979 to 1985 (from COST-43 1986).

4.2 *Technology development and transfer*

Through the proceedings of the four major Technical Seminars run by the project, and via many (approximately 150) further Technical Documents as well as personal contacts brought about by the existence of the project, there has been extensive European-wide exchange of technical ideas and information concerning the difficult problems of the engineering and technology of ODAS deployment and routine operation. Inter-calibrations between the different national systems and sensors have been carried out under the project to ensure the consistency and value of the data provided by the ODAS. Successful long-term deployment of ODAS in European North Atlantic waters is now a part of the operational data-gathering scene.

At the same time the development of marine buoy/ODAS industries has been aided through the various COST-43 national programmes, particularly in Norway, France and the United Kingdom.

4.3 *North Atlantic Ocean data*

International liaison between the Technical Secretariat of COST and international bodies such as WMO and IOC has ensured that the data generated under the auspices of COST-43 have contributed to the wider requirement for real-time and archival data. Ocean data are now available which were not there before, and they have only become available through the encouragement of COST-43 ventures and the guidance of the COST-43 Management Committee.

4.4 *European co-operative structures*

As has been said before, one of the most important achievements of the COST-43 project has been to discover new ways in which nations (National Meteorological and Oceanographic Services and Institutes) can come together in joint projects in their common interest with the minimum of legal and bureaucratic procedures. COST-43 has acted as an 'umbrella' under which new precedents and simple procedures have been created for co-operative ventures. The use of simple Letters of Intent between Directors of National Meteorological Services is now an agreed method of procedure. Joining the COST-43 Agreement has not bound the signatories to specific (perhaps expensive) joint actions, it has instead created a favourable climate for co-operation through which individual national institutions have been able to take part in the establishment of an ODAS network which would have been outside their financial reach acting alone.

5. Conclusion

It is clear that this project has already been a major influence in drawing the European nations together to establish a network of over 60 ODAS and that the amount of data has increased by over 1500 reports a day. The essential nature of the Technical Secretariat and Project Leader has been demonstrated both in giving guidance and encouragement and also in forming a focal point for technical co-ordination of programmes. Simple procedures for multilateral international co-operation in establishing joint ODAS programmes have now been established, and it is my view that the way is now clear to obtain general agreement to extend the networks into a more fully operational and long-lasting context within a continuing regional umbrella organization.

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The refurbishment of the Central Forecasting Office, Bracknell

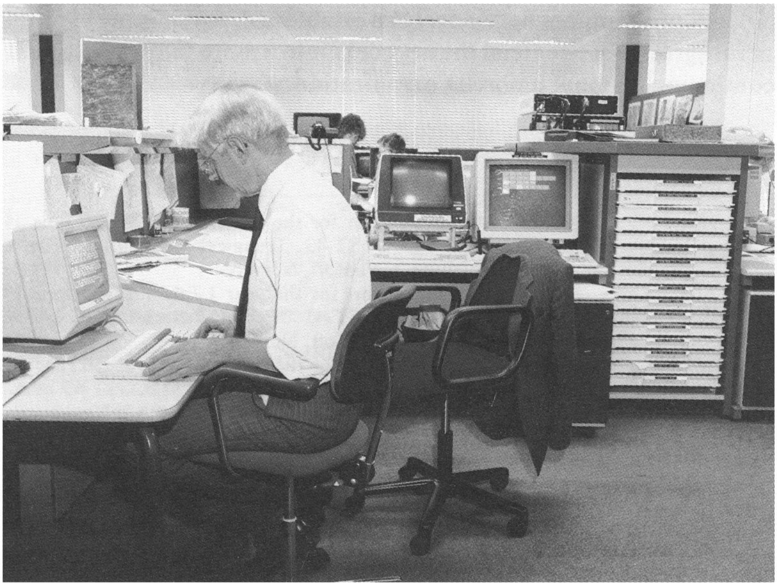
R.M. Morris

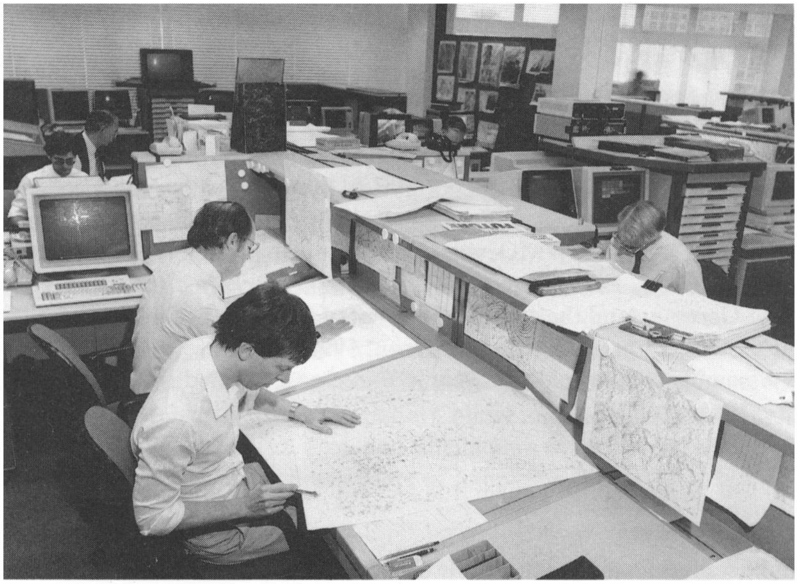
Assistant Director (Central Forecasting), Meteorological Office, Bracknell

Following a decision taken in the summer of 1986 to transfer the civil aviation Principal Forecasting Office from Heathrow to the Central Forecasting Office (CFO) at Bracknell, a major refurbishment programme for CFO was set in motion to culminate with the transfer of the Heathrow team at the end of March 1988. The transfer in fact occurred on 23 March and, although there were some difficulties with the communications, the aviation unit was operational at 1200 GMT.

The refurbishment was planned with the 1990s in mind. Working positions were designed as single movable units with greater use of VDUs envisaged than ever before, although it is recognized that persuading forecasters to use screens rather than paper will be a slow process. (This slowness is not necessarily due to forecasters' conservatism; the versatility of the software and the speed of keyboard response have to reach acceptable standards before it becomes more efficient and effective to use the VDUs rather than paper.) The increased use of VDUs meant that a false floor had to be inserted in CFO to take the cables and the ceiling had also to be lowered in order to accommodate a more efficient air-conditioning system to cope with the extra staff and machines! It was necessary therefore to evacuate CFO for about 6 months.

By dispersing staff in adjacent offices, it was possible to relocate CFO temporarily in accommodation that was just adequate if rather cramped and lacking in air-conditioning. (Visitors would have noticed numerous electric fans during the summer and numerous radiators during the winter although fortuitously the summer was not hot and neither was the winter very cold!) The temporary accommodation was occupied from July 1987 till early February 1988 and as we all know this period





contained some exceptional weather events. On a positive note the return to the refurbished accommodation was marked in style by the prediction of the deepest February depression ever recorded to affect the United Kingdom. This proved to be a good forecast.

The new CFO includes the Storm Tide Warning Service unit for the first time, and the Metroute and Prestel units are also firmly established as integral parts.

The fact that the refurbished CFO is functioning smoothly and that the integration of the Heathrow team into the system also occurred fairly smoothly — and on schedule too — was due to the combined efforts of several Branches in the Office, Property Services Agency and the private contractors, and also to the whole-hearted, unselfish and positive attitude of the staff directly concerned.

There is still much work to be done; the display and storage of paper has to be accomplished in the most efficient manner and the lines of communication (human as well as data) have to be thoroughly effective. It is a huge organization and it will take time and resources to meet these objectives.

Notes and news

European Geophysical Society

The European Geophysical Society (EGS), for active research workers of all ages, is run entirely by its members, with no official backing from governments. Its 13th Assembly was held from 21 to 25 March 1988 in Bologna, Italy, as part of the celebrations of the 900th anniversary of the foundation of the university in that city. The three sections of the Society (Solid Earth Geophysics; Atmospheric Sciences, Oceanography and Hydrology; and External Geophysics) organized a variety of symposia, workshops, general sessions and review lectures, including meetings and lectures on general meteorology, the physics and dynamics of the ocean circulation, climatic variations during the historical and instrumental periods, variational methods in meteorology and oceanography, the physics of low-frequency internal atmospheric variability, interaction of scales in weather systems, moisture and water in the soil and atmosphere, space oceanography, air–sea–ice interaction, large-scale general circulation modelling, results from ALPEX (Alpine Experiment), oceanography in WOCE (World Ocean Circulation Experiment) and POEM (Physical Oceanography of the Eastern Mediterranean) and numerical weather prediction and predictability. Amongst the 1000 participants was Dr Raymond Hide, FRS, head of the Geophysical Fluid Dynamics Laboratory in the Meteorological Office and sixth president (1982–84) of EGS, who was awarded honorary membership in recognition of 'his excellence in original and stimulating contributions to the field of geophysical hydrodynamics and his valuable efforts in the promotion and growth of the Society'. Dr Axel Wiin-Nielsen of Denmark, formerly Director of ECMWF and Secretary-General of WMO, was elected as ninth president of EGS (to serve from 1988 to 1990) and Dr W. Ian Axford, FRS, Director of the *Max-Planck-Institut für Aeronomie* at Lindau, Federal Republic of Germany and the current president of COSPAR (Committee on Space Research), was elected as the tenth EGS president (to serve from 1990 to 1992).

The 14th EGS Assembly will be held next year in Barcelona, Spain during the now 'traditional' week before Easter, 13–17 March 1989.

Retirement of Mr D. Forsdyke

Donald Forsdyke was educated at Dunstable Grammar School and followed his father's footsteps in joining the Meteorological Office. He entered in 1949 as a Scientific Assistant, the forerunner of the present ASO grade. His first appointment was to the CRDF or Sferics unit at Dunstable but that did not last long because he was called up for national service in January 1950 and posted first to Changi (Singapore) with the Far East Air Force and later to Upavon which he left on release from the Royal Air Force in 1951. As other successful members of the Office have done, he then obtained special leave without pay to further his education, taking an honours physics course at Imperial College. He rejoined the Office as a Scientific Officer in the Instrument Development Branch at Harrow, his first paper there being written on the digitalization of meteorological information, a pretty avant-garde topic at that time. In the late 1950s he saw the new cloud-base recorder through its trial phase before turning his hand in 1960, as a Senior Scientific Officer, to forecasting at Prestwick, directly joining the Senior Forecasters' roster at a time when Prestwick was an independent forecasting office for the transatlantic air routes.

In 1964 Don progressed to the Principal Forecasting Office at Heathrow, still forecasting for civil aviation. In 1966 he returned to instrument work for a time, running the operational radiation equipment at Easthampstead Park, near Bracknell, and working on the development of an instrument designed to measure the distribution of solar radiation in fifteen different spectral bands. He had made good progress with a task that others had found very troublesome when he was transferred back to forecasting in 1968, on promotion to Principal Scientific Officer, this time as Senior Forecaster in the Central Forecasting Office. Less than two years later he was posted overseas to Bahrain to be Chief Meteorological Officer with the Royal Air Force in the Arabian Gulf. It was in Bahrain that a flair for military staff work and planning began to be evident and he was involved, as a UK delegate, in the negotiations with the Government of Bahrain for the withdrawal of the permanent British military presence from the Arabian Gulf.

Another sharp change of career direction came with a posting on repatriation in 1971 into the field of agrometeorology. This took him to Bristol where he was Principal Meteorological Officer with the Agricultural Development and Advisory Service of the Ministry of Agriculture, Fisheries and Food. During five years at Bristol he thrived on the applied side of this work and gained a high reputation with his agricultural colleagues as their specialist adviser. In 1968 Don returned to work with the Royal Air

Force, this time as Chief Meteorological Officer at the Headquarters of the Royal Air Force in Rheindahlen. In Germany, he showed himself again to be very effective in the administration of meteorological services and he was highly regarded within the Headquarters for his appreciation of the military need and his ability to organize the resources under his control to meet it. Few were surprised when he was promoted as Senior Principal Scientific Officer to the post of Chief Meteorological Officer, Headquarters Strike Command (HQSTC) in 1979 on completion of his tour in Germany. At HQSTC his ability to work within the framework of the Royal Air Force system continued to stand him in good stead and he did particularly well during the Falklands crisis. He represented his Commander-in-Chief on relevant NATO Committees at this time.

For his final appointment Don returned in 1985 to Heathrow and civil aviation. As Chief Meteorological Officer there he has seen through the transfer of Heathrow's major forecasting responsibilities to Bracknell and retired on 31 March 1988 as the last of an illustrious line, extending back to the Second World War, of characterful officers-in-charge at the Heathrow forecasting office.

Don met his wife, Sheila, whilst studying at Imperial College and they have a daughter and a son, both now launched on their independent paths. Don and Sheila plan to retire to Dorset where the very best climate is to be found and we wish them many years of happiness there.

D.H. Johnson

Reviews

Geophysical fluid dynamics, second edition, by J. Pedlosky. 155 mm × 234 mm, pp. xiv + 710, *illus.* New York, Heidelberg, Berlin, London, Paris, Tokyo, Springer-Verlag, 1987. Price DM 89.00.

Since the first edition of this book appeared in 1979 it has become established as one of the foremost texts in its field. In the 1980s (so far!) perhaps only the late Adrian Gill's *Atmosphere–Ocean Dynamics* has had as great an impact on theoretical meteorology and oceanography. This is not to say that Professor Pedlosky's book suits all tastes, even amongst theoreticians, for its detailed treatment of fundamentals (as perceived by the author) co-exists with some surprising omissions. For example, there is no discussion of the hydrostatic primitive equations which, of course, form the basis of most modern weather forecasting and climate simulation models. The meteorologist working with such models finds in the book much useful geostrophic theory to aid his understanding of their behaviour, but gains no insight into the justification for, or the properties of, the hydrostatic primitive equations themselves. This restriction of interest — which, sadly, is sometimes considered to define the scope of geophysical fluid dynamics — becomes increasingly uncomfortable as meteorological theory progresses. Within its own confines, however, the book is a recognized authority which has proved invaluable to both students and research workers. It gives clear, vigorous and detailed accounts of wave motions in rotating fluids, wave kinematics, geostrophic flow models, instability theory, boundary-layer techniques, conceptual models of ocean circulations and many other basic aspects of geophysical fluid dynamics.

What changes does the second edition show? At a superficial level, its red, white and blue livery presents a striking contrast to the rather dull green shades of the original; one can imagine mathematically innocent browsers being attracted to it in university bookshops (with results best not contemplated). As for content, the eight chapter headings are unchanged, but the text is 80 or so pages longer than before and revisions are evident as well as additions. The first two chapters, on the general dynamics of rotating fluids, are virtually unchanged, as is the chapter on 'Ageostrophic motion'. The chapters on 'Inviscid shallow water theory' and 'Friction and viscous flow' contain new sections on the theory of geostrophic turbulence, whilst the treatment of the effects of bottom topography (in the chapter on 'Homogeneous models of the wind-driven oceanic circulation') has been revised and expanded. The two chapters on quasi-geostrophic models and instability theory contain the most extensive changes. Sections on wave-mean flow interactions and thermocline models have been extended (or multiplied) to take account of recent developments, and a new multi-scale derivation of the quasi-geostrophic formulation is offered. The section on Charney's baroclinic instability problem has been redrafted, and there is a new section dealing with the instability of non-parallel flows. Weakly non-linear baroclinic instability theory is illustrated by a more fruitful example than before.

Of the new or revised sections, those on geostrophic turbulence are particularly helpful, and the new treatment of non-linear baroclinic instability is a great improvement. The section on Charney's problem is also improved, a conceptual framework now being more clearly discernible; it is a pity, however, that J.S.A. Green's elegant approximate treatment of short-wave instabilities is not included. The section on non-parallel flow instability sets out the fundamentals well, but leaves a misleading impression by failing to note the tendency of finite domains to promote the stability of Rossby waves.

The second edition of this book adheres to the structure and philosophy of the first, its new sections all conforming to the standards of clear and detailed exposition set by the author in 1979. Text, equations and diagrams are well presented (although the new sections, perhaps inevitably, bring their own crop of misprints). It will be of interest to all those meteorologists who recognize the value of conceptual models and thought-experiments in developing physical understanding of large-scale motions in the atmosphere.

A.A. White

Weather radar and flood forecasting, edited by V.K. Collinge and C. Kirby. 154 mm × 235 mm, pp. x + 296, *illus*. Chichester, New York, Brisbane, Toronto, Singapore, John Wiley and Sons Ltd, 1987. Price £39.00.

This book is based on the proceedings of a symposium that marked the completion of the North West Radar Project in 1985. More than 20 research workers reviewed the results of the project and other related work on flood forecasting and on the use of radar in meteorological forecasting.

A continuous programme of research and development on weather radar commenced in the 1950s and has now led to the commissioning and operation of a national radar network providing real-time precipitation data. This is an achievement of which the Meteorological Office can be proud, since it is a world leader in this field. Although many of the authors of this volume have contributed papers to learned journals and conference symposia, this is the first book which details what has been achieved and charts how weather radar technology might be further developed in the future.

The contents are divided into four parts, the first two of which consider the technical development and operational experience of weather radar. Hydrologists then consider how runoff can be modelled using radar data, and finally future developments in the technology are assessed. Each paper is well illustrated with clear maps and diagrams, and the book greatly benefits from a series of full coloured plates of specific radar images which are considered in detail in the text.

Although nearly three years old, the volume brings together a lot of material previously scattered through meeting reports and technical memoranda, and should provide hydrologists and other radar users with a useful overview of how the present network has been achieved and how it will develop. The recent announcement that there is now a fair prospect of at least three radar stations in Scotland brings overall coverage of the British Isles significantly closer, and it is interesting to note that it is the winter maintenance of highways rather than flood forecasting which looks likely to derive the greatest benefit north of the Border. One issue that the authors, and meteorologists concerned with radar, have not fully addressed is how this exciting, visually stimulating real-time data can best be marketed and brought to a wide section of the community that could benefit from it.

A. Perry

Satellite remote sensing, by R. Harris. 155 mm × 235 mm, pp. xi + 220, *illus*. Chichester, Ellis Horwood Ltd, 1987. Price £35.00.

This book should carry a government health warning: 'Reading chapter 2 could seriously damage your understanding of electromagnetic radiation.' To be fair, the rest of the book is much better and makes no reference to the radiation fundamentals which are so confusingly described in the second chapter. Some examples from this chapter include a diagram to define wavelength, phase and amplitude, only one of which is correctly defined, a table with inconsistent wavelength and frequency values, a careful definition of micrometer and nanometer followed by a version of the Planck function using ångströms as the wavelength unit, and the statement 'The earth and the sun are black bodies.' Enough of chapter 2, what of the rest of the book? It is intended as an introduction to remote sensing for undergraduates in environmental science. The first half covers basics: radiation, sensors, satellite systems, image processing and, unusually, ground data collection. The second half describes the applications of remote sensing in different areas of environmental science — agriculture, geology, the atmosphere and hydrosphere. The book concludes with a summary of developments planned for the next decade.

The author is particularly good at collating information from a number of sources and presenting it concisely. The sections on sensors, satellite systems and applications are examples of this. The more technical sections on radiation and image processing are weaker, and in the latter the lack of criticism or comparison between techniques leads to a very simplistic view of the problems involved. Each of the sections on applications of remote sensing is quite detailed and draws on a large number of references. There is, however, an imbalance introduced by the lack of criticism as in, for example, citing a paper which derived wind speeds from cloud tracking which differ from rawinsonde winds by about 4 m s^{-1} but were then used to calculate low-level divergence and convergence.

The book is well produced with clear diagrams, readable text and a very extensive reference list (over 200 items). There is a useful two-page list of acronyms, but the index is poor. It contains many geographical entries such as Wales or Bangladesh but few like 'sea temperature', 'snow', 'water quality', 'soil water content', and 'agriculture', all of which are section headings within the book.

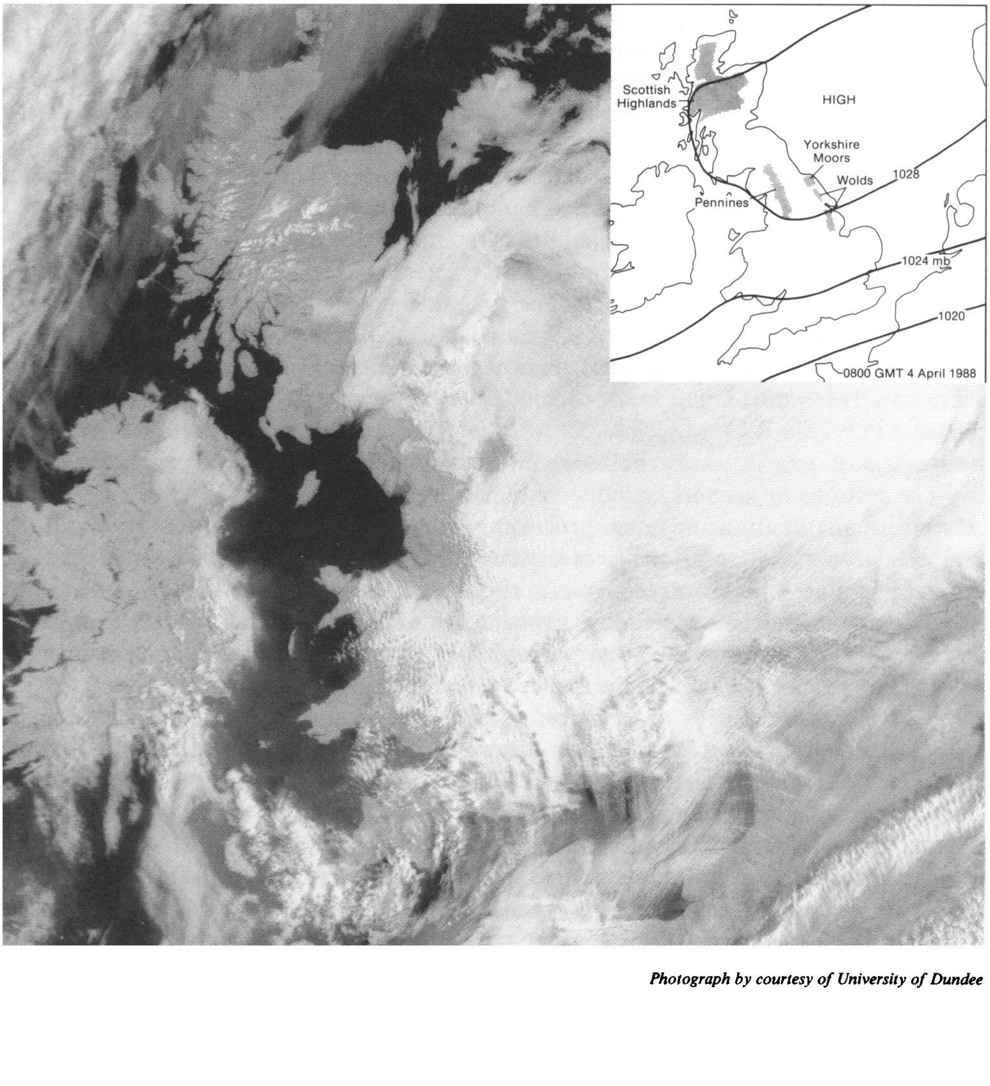
With these criticisms in mind, it would be difficult to recommend this book. It is certainly not suitable as the main text for an undergraduate course, but it does contain useful information and could be interesting to a newcomer to remote sensing if considered as a sort of 'Observer's book of remote sensing' — omitting chapter 2.

C. Duncan

Satellite photograph — 4 April 1988 at 0805 GMT

This visible image from NOAA-10 shows considerable detail within a sheet of low cloud in an east-north-easterly airstream beneath a subsidence inversion at about 500 m above sea level. Over the North Sea most of the cloud has a cellular structure, although near The Netherlands it is composed of a series of narrow, parallel bands. Over the land of eastern and central England, lee waves predominate. They appear to be triggered by relatively low hills such as the Yorkshire and Lincoln Wolds (100–200 m). The cloud dissipated on descent from hills of comparable height to that of the inversion (e.g. Pennines and Yorkshire Moors). The amorphous areas over Northern Ireland and parts of central Scotland are the remnants of overnight radiation fog.

During the day, much of western Britain enjoyed unbroken sunshine with temperatures reaching around 13 °C, whilst in the sunless eastern England, maxima were only 6 °C near coasts and 9 °C well inland where the cloud broke during the afternoon. Highest temperatures of the day were 15 °C in the Scottish Highlands — despite the mountain snow cover seen in the photograph.



Photograph by courtesy of University of Dundee

Meteorological Magazine

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Spelling should conform to the preferred spelling in the *Concise Oxford Dictionary*.

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

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