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Wind-chill indices — a review

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Summary

A description is given of the background to the formulae most widely used for quantifying the chilling effects of strong winds combined with low temperatures. These are expressed in terms of wind-chill indices (or factors) and wind-chill equivalent (or apparent) temperatures. Their applications are discussed and a wind-chill climatology for various locations in the United Kingdom is presented.

1. Introduction

The term wind-chill is a familiar one that has been used (and occasionally misused) for many years, normally in connection with human comfort, i.e. the common experience that a person will feel colder when the wind is blowing than when it is not. However, it can be applied more generally to indicate enhanced heat loss from objects that are warmer than their surroundings.

Countries regularly experiencing severe winter weather such as Canada and the USA have, for a long time, taken account of the chilling effect of the wind in weather forecasts issued to the general public. It is only recently that wind-chill has been included in media forecasts in the United Kingdom, although forecasts of wind-chill have been issued in the past to farmers in connection with potentially stressful conditions for new-born lambs (Starr 1984). During the winter of 1984/85, and more especially that of 1985/86, wind-chill and wind-chill equivalent temperatures were quoted on television forecasts. This led to the receipt of enquiries by the Meteorological Office Advisory Services Branch and Weather Centres about wind-chill calculations and the situations to which they can be applied. Some enquirers did not realize the limitations of either the concept or its applications.

2. History

An object cools because of radiative, conductive and convective heat losses (plus evaporation if its surface is wet). Convective heat loss varies with wind speed, thus total heat loss from an object is greater when the wind is blowing than when it is not (other things being equal). Work describing this wind-enhanced cooling power of the atmosphere pre-dates the First World War.

A generalized heat-balance equation was produced by Hill (Stone 1943) for the cooling of a dry, heated body by convection and conduction to the air (an equilibrium between incoming and outgoing radiation was assumed) of the following format:

$$H = (a + b\sqrt{v})\,(t_s - t_a)$$

where the notation is as follows:

H = rate of heat loss
a = heat transfer coefficient of conduction
b = heat transfer coefficient of convection
v = wind speed
t_s = surface temperature of object
t_a = ambient air temperature.

Other workers produced various values for the coefficients using instruments such as the katathermometer (an alcohol thermometer with an oversized cylindrical bulb whose rate of cooling from 38 to 35 °C in different meteorological conditions was assumed to be proportional to the rate of human cooling) and the frigorimeter (a nearly solid copper sphere whose temperature was maintained at 37 °C, in various conditions, by electric current — the amount of current needed was assumed to be a measure of the cooling power of the atmosphere).

A first power wind-speed term was introduced into the generalized heat-balance equation by Plummer (1944) and by Siple and Passel (1945). It was Siple (1939) who first used the term 'wind-chill' to describe the wind-enhanced cooling power of the atmosphere while producing a comfort scale for workers and explorers in cold climates, and who promoted its use during work in Antarctica in the 1940s. The Siple–Passel formula is described in detail in Section 3. It became established as the major wind-chill formula, at least in the English-speaking world, mainly because of its ease of calculation. Other formulations based upon the Siple–Passel formula have also been proposed (Court 1948, Lyall 1981).

An entirely new formula was introduced by Steadman, based on the concept of thermal equilibrium, i.e. all heat generated by a body is balanced by heat lost, provided the body is covered by an adequate thickness of clothing (Steadman 1971). The Steadman formula, and its subsequent development (Steadman 1984) is described in detail in Section 4.

Additional factors influencing comfort were considered by Beal (1974). He produced an equation by considering the same heat losses as Steadman plus variables such as age, health, time of food digestion, time of day and psychological effects (e.g. length of darkness, snow and general state of mind). Because it is more complicated, Beal's equation is more difficult to implement.

A further formula, developed by Rodriguez, considers conductive heat transfer from the body core to the skin surface and then convective heat loss from the skin surface to the air (Rodriguez 1980). A fixed body-core temperature is used but the skin temperature is allowed to vary with air temperature and wind speed. However, he did not consider the vaso-constriction process, i.e. when the brain senses reduced skin temperature, blood is diverted from the exterior by the constriction of peripheral blood vessels in order to reduce heat loss. This process maintains the temperature of vital organs (brain, heart and lungs) at 37 °C at the expense of more 'superficial' areas such as hands and feet.

3. The Siple–Passel wind-chill formula

This wind-chill formula was developed from experiments conducted in Antarctica during 1941. Measurements were made of the time required to freeze 250 gm of water in a plastic cylinder (5.7 cm diameter and 15 cm high) in a variety of wind speeds and temperatures. The rate of heat loss was assumed to be proportional to the difference in temperature between the cylinder and the temperature of the surrounding air. Of the 89 separate results obtained, 56 were used to produce the following equation:

$$H = (12.12 + 11.6\sqrt{v} - 1.16\,v)\,(33 - t_a)$$

where the notation is as follows:

H = rate of heat loss (W m^{-2}) (to convert to Kcal m^{-2} h^{-1}, divide by 1.16)
v = wind speed (m s^{-1})
33 = bare-skin temperature (°C)
t_a = ambient air temperature (°C).

The original application of the Siple–Passel formula was to predict conditions likely to produce frost-bite during army exercises. Maps of wind-chill indices for the USA, Canada and, eventually, all continents were produced as a guide to clothing requirements. The formula is still widely used and forms the basis of wind-chill tables and nomograms in numerous textbooks and articles, e.g. Thomas and Boyd (1957), National Oceanic and Atmospheric Administration (1975), Anton (1981) and Schlatter (1981).

4. The Steadman wind-chill formula

This formula is based upon the concept of thermal equilibrium. Steadman assumes that a healthy adult (of height 1.7 m and with a body surface area of 1.7 m^2) whilst walking outdoors at 3 m.p.h. (1.3 m s^{-1}) would generate 188 W m^{-2} of heat. This is offset by heat losses from the body and to maintain thermal equilibrium in a variety of weather conditions, the amount of clothing worn has to be varied. The appropriate amount of clothing, expressed as clothing thickness, is the result obtained from Steadman's formula.

Steadman considered more variables than Siple and Passel and, consequently, the formula is more complex:

Heat generated = Heat lost
= evaporative loss in breath (1)
+ loss due to heating breath (2)
+ loss from uncovered skin (3)
+ loss from thinly clothed hands and feet (4)
+ loss from fully clothed areas (5)

$$188 = \underset{(1)}{16.29} + \underset{(2)}{0.22\,(37 - t_a)} + \underset{(3)}{\frac{0.13\,(30 - t_a)}{R_s}} + \underset{(4)}{\frac{0.5\,(30 - t_a)}{0.5 + R_s}} + \underset{(5)}{\frac{3.55\,(33 - t_a)}{R_f + R_s}}$$

where the following notation has been used:

188 = heat generated by a healthy adult walking outdoors and suitably clothed (W m^{-2})
t_a = ambient air temperature (°C)
37 = body-core temperature (°C)
33 = skin temperature adequately covered with clothing (°C)
30 = bare-skin temperature (°C)
R_f = clothing resistance (m^2 s °C cal^{-1})
= clothing thickness divided by thermal conductivity of the clothing

R_s = surface resistance (m^2 s °C cal^{-1}) = $\frac{1}{h_r+h_c}$

h_r = heat transfer coefficient of radiation (cal m^{-2} s^{-1} °C^{-1})

$$= 0.0135 \left\{ 4.0 \left(\frac{t_a+273}{100}\right)^3 + 0.3 \left(\frac{t_a+273}{100}\right)^2 \right\}$$

h_c = heat transfer coefficient of convection = 0.61 ($S^{0.75}$)
S = effective wind speed (m.p.h.), i.e. that measured at the conventional height of 10 m above the ground adjusted to represent the wind relative to a person walking at 3 m.p.h.

The effect of the walker's speed on the relative wind speed is only important in light winds, hence two equations exist to calculate the effective wind speed, namely:

$$S = (v_{10}^2 + 10)^{0.5} \text{ if } v_{10} \geqslant 6.4 \text{ m.p.h. } (2.9 \text{ m s}^{-1})$$

$$S = \{v_{10}^2 + 10 + 7(6.4 - v_{10})^{0.5}\}^{0.5} \text{ if } v_{10} < 6.4 \text{ m.p.h.}$$

where v_{10} is the 10 m wind.

An extra term can be incorporated into the heat-balance equation — a heat gain due to the insolation effects on a person in full sunshine. As a heat gain it must be deducted from the heat losses on the right-hand side of the thermal equilibrium equation:

$$\text{additional heat gain due to sunshine} = \alpha \text{PG}$$

where α, P and G are defined as follows:
α = absorptivity of the skin (or clothing)
P = proportion of the skin (or clothing) effectively receiving normally incident radiation
G = insolation (cal m^{-2} s^{-1}).

Subsequently, Steadman extended his work to cover all air temperatures from −40 °C to +50 °C, wind speeds up to 20 m s^{-1} and humidity effects, i.e. to consider both wind-chill effects and heat-stress effects (Steadman 1984). This new work contains several modifications to his earlier ideas, although these mainly concern heat-stress calculations.

5. Discussion of the Siple–Passel and Steadman formulae

The two most widely used wind-chill formulae in the English-speaking world are the empirical one due to Siple and Passel and the theoretical one due to Steadman. These two formulae approach the subject of wind-chill in different ways.

The Siple–Passel formula is based upon experiments to measure the time taken for water to freeze in a variety of weather conditions, i.e. the stronger the wind blows, the greater will be the convective heat loss and the less the time taken for the water to freeze. Objections have been raised about the observational procedures and the experimental basis (Court 1981, Molnar 1960). These relate particularly to the extrapolation to weather conditions other than those measured and the applicability to heat-generating humans, wearing clothing. It is not really possible to express the effect of the wind on heat loss from a person without referring to the amount of clothing being worn (Burton and Edholm 1955) and so the Siple–Passel formula should be applied to bare-skin areas only.

Steadman, however, bases his theory on the more realistic situation of a fully clothed person walking outdoors. In order to remain in thermal equilibrium in varying weather conditions, the amount of heat lost from a person must not exceed the heat generated, a balance being achieved by wearing appropriate thicknesses of clothing. Steadman's formula considers all forms of heat loss from a person as a whole. However, the 'wind-chill' part of his equation (term 3) can be isolated, and is applicable to bare-skin areas, assumed to be only the face. The output from the equation as a whole is a thickness of clothing (mm) — that which is necessary to maintain thermal equilibrium; the output from the 'wind-chill' part is an amount of heat loss (W m^{-2}).

In Steadman's formula the relationship between heat loss and wind speed is approximately linear and positive (Fig. 1). This contrasts with the Siple–Passel formula where a maximum amount of heat loss is obtained with a wind speed of 25 m s^{-1} (twice the strongest wind speed measured during their experiments) implying that higher wind speeds have little additional effect on heat loss (see Figs 1 and 2). This is not borne out in experiments (Currie 1951). Most tables or nomograms of wind-chill produced using the Siple–Passel formula do not give results for wind speeds greater than about 22 m s^{-1} (43 kn or 49 m.p.h.) because of the inconsistency.

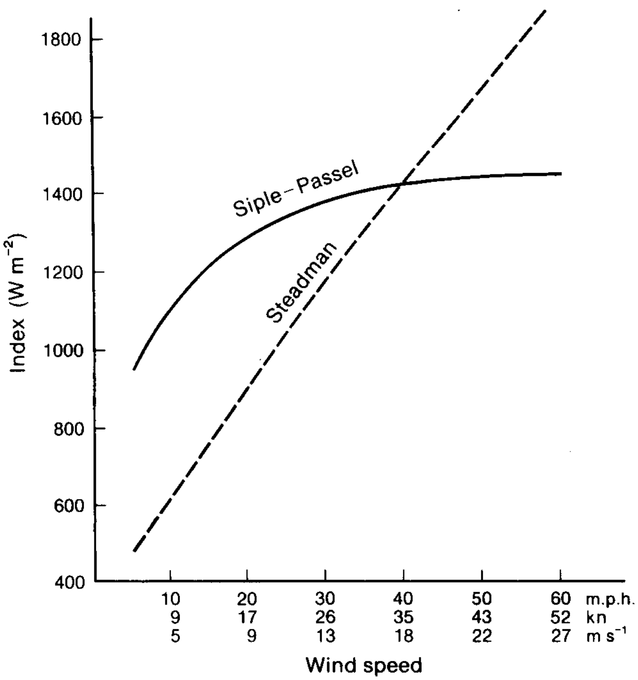
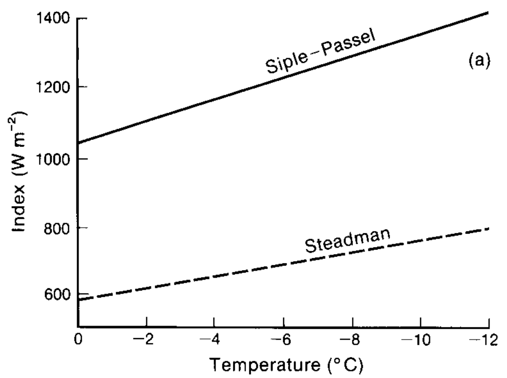


Figure 1. Values of the Siple–Passel and Steadman wind-chill indices for a fixed air temperature of −2 °C at various wind speeds.

The temperature chosen to represent that of bare skin is different in the two formulae. Siple and Passel chose 33 °C to be consistent with the 'clo' unit used for clothing requirements (Gagge *et al.* 1941), but Steadman believed this value to be too high and chose a value of 30 °C (Steadman 1971). However, Rodriguez (1980) stated that if the bare-skin temperature remained at these values (30 or 33 °C) then no discomfort would be felt. One of the major differences between Steadman's 1971 and 1984 work is the calculation of the bare-skin temperature for every occasion, using the body-core temperature of 37 °C and the weather conditions prevailing, i.e. the bare-skin temperature is no longer a fixed value of 30 °C.



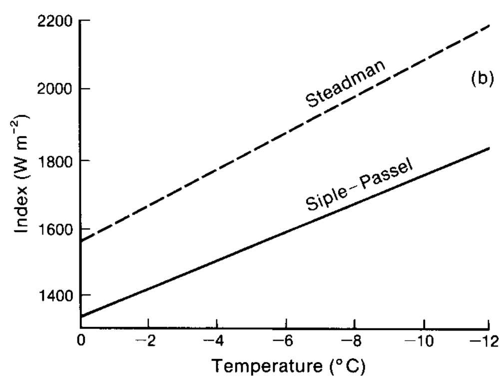


Figure 2. Values of the Siple–Passel and Steadman wind-chill indices at various temperatures for (a) 10 m.p.h. and (b) 50 m.p.h. wind speed.

However, Steadman does not recommend calculating this if the air temperature is less than 0 °C because of the uncertain response of the skin temperature to the vaso-constriction process.

The output from the Siple–Passel equation is a rate of heat loss for each combination of wind speed and temperature. As part of his work on a bioclimatic classification for the USA, Terjung (1966) adopted the sensation categories given in Table I, based upon the development by Siple and Passel of proposals made by Gold (1935).

Table I. *Wind-chill ranges corresponding to the sensation felt by the majority of people (after Terjung 1966). To convert Kcal m^{-2} h^{-1} to cal m^{-2} s^{-1}, divide by 3.6.*

Wind-chill		Sensation felt by majority
W m^{-2}	Kcal m^{-2} h^{-1}	
348–696	300–600	cool
697–929	601–800	very cool
930–1160	801–1000	cold
1161–1390	1001–1200	very cold
1391–1625	1201–1400	bitterly cold
> 1625	> 1400	exposed flesh freezes

However, criticism of the formula has thrown doubt on the absolute values obtained; even though a value of 1625 W m^{-2} calculated from the formula may correspond to conditions when exposed flesh freezes, the rate of heat loss is not necessarily 1625 W m^{-2}. Siple himself recognized the limitations of his formula (and its application to circumstances other than those originally intended) and recommended dropping the units and regarding the results as simply numbers for empirical purposes (Molnar 1960).

6. Wind-chill equivalent temperatures

Wind-chill equations produce values for the rate of heat loss from a body. However, often a more useful product is the wind-chill equivalent temperature. A certain combination of wind speed and temperature is associated with a certain rate of heat loss. The same heat loss may also be produced by combining a reference speed (e.g. a person's walking speed) with a different temperature, known as the wind-chill equivalent temperature or apparent temperature. By using this, the chilling effects of the wind may be expressed in terms of the lower temperature needed to produce the same sensation for a person walking in calm conditions.

The Siple–Passel equivalent temperatures relate to bare skin only and are easy to calculate by rearranging the wind-chill equation given in Section 3.

For wind speed v and air temperature t_a, the wind-chill is H. The equivalent temperature t_e is the air temperature required to give the same wind-chill, but for a given wind speed v_o. The most often quoted value of v_o is 5 m.p.h. (2.6 m s^{-1}), a person's walking speed. Use of this value yields the following expression for t_e in terms of v and t_a:

$$t_e = 33 - \frac{(12.12 + 11.6\sqrt{v} - 1.16v)(33 - t_a)}{27.81} .$$

Steadman's equivalent temperatures are based on the thickness of clothing required to insulate 85% of the body surface and to keep the body in thermal equilibrium. These temperatures are difficult to calculate from Steadman's 1971 equation, but in his 1984 paper he gives simplified equations for calculating equivalent temperatures for any combination of air temperature, humidity, wind speed and solar radiation.

The characteristics of the Siple–Passel and Steadman's 1971 wind-chill equations are reflected in the equivalent temperatures given in Tables II and III, e.g. Siple and Passel's formula produces equivalent temperatures that are more sensitive to changes in the lower wind-speed ranges, than those in the higher ranges.

Table II. *Wind-chill equivalent temperatures (°C) using Siple–Passel equation (using a reference wind speed of 5 m.p.h.)*

Wind speed kn	m.p.h.	m s^{-1}	Air temperature °C 0	−1	−2	−3	−4	−6	−8	−10	−12	−14	−18
4	5	2	0	−1	−2	−3	−4	−6	−8	−10	−12	−14	−18
9	10	5	−6	−7	−8	−9	−11	−12	−14	−17	−20	−22	−26
13	15	7	−9	−11	−12	−13	−14	−16	−19	−22	−24	−28	−32
17	20	9	−12	−13	−14	−16	−18	−19	−22	−25	−28	−31	−35
22	25	11	−14	−15	−16	−18	−19	−21	−24	−28	−31	−34	−38
26	30	13	−15	−16	−18	−19	−21	−23	−26	−29	−33	−36	—
30	35	16	−16	−17	−19	−21	−22	−24	−27	−31	−34	—	—
35	40	18	−17	−18	−20	−22	−23	−25	−28	−32	—	—	—

Table III. *Wind-chill equivalent temperatures (°C) using Steadman's 1971 equation (using a reference wind speed of 5 m.p.h.)*

Wind speed kn	m.p.h.	m s^{-1}	Air temperature °C 0	−1	−2	−3	−4	−6	−8	−10	−12	−14	−18
4	5	2	0	−1	−2	−3	−4	−6	−8	−10	−12	−14	−18
9	10	5	−3	−4	−5	−6	−7	−9	−11	−13	−16	−18	−22
13	15	7	−4	−6	−7	−8	−10	−11	−14	−17	−19	−22	−26
17	20	9	−6	−8	−9	−11	−12	−13	−17	−19	−22	−25	−30
22	25	11	−8	−9	−11	−13	−14	−16	−19	−22	−25	−28	−33
26	30	13	−10	−11	−13	−14	−16	−17	−21	−24	−28	−31	—
30	35	16	−11	−12	−14	−16	−18	−19	−23	−27	−31	—	—
35	40	18	−12	−14	−16	−17	−19	−21	−25	−29	—	—	—

The two formulae produce different equivalent temperatures for the same combinations of wind speed and temperature, e.g. at −6.0 °C and 9 m s^{-1} the Siple–Passel equivalent temperature is −19 °C, whereas the Steadman (1971) equivalent temperature is −13 °C.

Equivalent temperatures are not quoted when the wind speed is less than the reference walking speed as the equivalent temperature that is calculated is warmer than the air temperature. This unrealistic result does not occur with the equivalent temperatures derived from the Steadman 1984 equation as the reference wind speed adopted is zero, i.e. the full effect of the wind is taken into account. The gain in equivalent temperature due to sunshine is also calculated, plus a humidity increment, although this is small at low temperatures. Tables IV and V give these equivalent temperatures and the sunshine correction. A nomogram has been prepared (Fig. 3) to enable other combinations of wind and temperature to be assessed.

Forecasts of equivalent temperatures are issued regularly in North America where the often harsh winter weather warrants a relevant indication of how cold it will feel outdoors. However, because of differences in people's age, activity, state of health, metabolic rate, etc., not everyone will experience the

Table IV. *Wind-chill equivalent temperatures (°C) using Steadman's 1984 equation – rounded to the nearest 0.5 °C*

Wind speed kn	Wind speed m.p.h.	Wind speed m s^{-1}	Air temperature °C 20	18	16	14	12	10	8	6	4	2
4	5	2	19.5	17.5	15.5	13.5	11.5	9.5	7.5	5.0	3.0	1.0
8	9	4	18.0	16.0	14.0	12.0	9.5	7.5	5.0	3.0	1.0	−1.5
12	13	6	17.0	14.5	12.5	10.5	8.0	5.5	3.5	1.0	−1.0	−3.5
16	18	8	16.0	13.5	11.0	9.0	6.5	3.0	2.0	−0.5	−3.0	−5.5
19	22	10	15.0	12.5	10.5	8.0	5.5	3.0	0.5	−2.0	−5.0	−7.0
23	27	12	14.5	12.0	9.5	7.0	4.5	2.0	−1.0	−3.5	−6.0	−8.5
29	33	15	13.5	11.0	8.5	6.0	3.5	0.5	−2.0	−5.0	−7.5	−10.0
39	45	20	12.5	10.0	7.0	4.5	1.5	−1.5	−4.0	−7.0	−10.0	−12.5

Wind speed kn	Wind speed m.p.h.	Wind speed m s^{-1}	0	−5	−10	−15	−20	−25	−30	−35	−40
4	5	2	−1.0	−6.0	−11.0	−16.0	−21.5	−26.5	−31.5	−36.5	−41.5
8	9	4	−3.5	−9.0	−14.5	−20.0	−25.0	−30.5	−36.0	−41.5	−46.5
12	13	6	−6.0	−11.5	−17.5	−23.0	−28.5	−34.0	−40.0	−45.5	−51.0
16	18	8	−8.0	−14.0	−20.0	−25.5	−31.5	−37.5	−43.0	−49.0	−54.5
19	22	10	−9.5	−16.0	−22.0	−28.0	−34.5	−40.0	−46.0	−52.0	−58.0
23	27	12	−11.0	−17.5	−24.0	−30.5	−36.5	−42.5	−49.0	−55.0	−61.0
29	33	15	−13.0	−19.5	−26.5	−33.0	−39.5	−45.5	−52.0	−58.5	−64.5
39	45	20	−15.5	−22.5	−29.5	−36.5	−43.0	−50.0	−56.5	−62.5	−69.5

Table V. *Increase in equivalent temperatures (°C) due to full sunshine (Steadman 1984)*

Temperature °C	Wind speed m s^{-1} 0	2	4	6	8	10	12	15	20
−40	7.2	6.8	5.7	4.7	4.0	3.2	3.0	2.9	2.4
−20	7.4	7.0	5.9	5.0	4.3	3.6	3.4	3.1	2.7
0	7.4	7.0	6.0	5.2	4.5	3.8	3.6	3.4	3.0
20	8.5	8.3	7.4	6.5	5.5	4.6	4.3	3.8	3.3
30	8.3	8.1	7.2	6.6	6.2	5.9	5.6	5.3	4.9

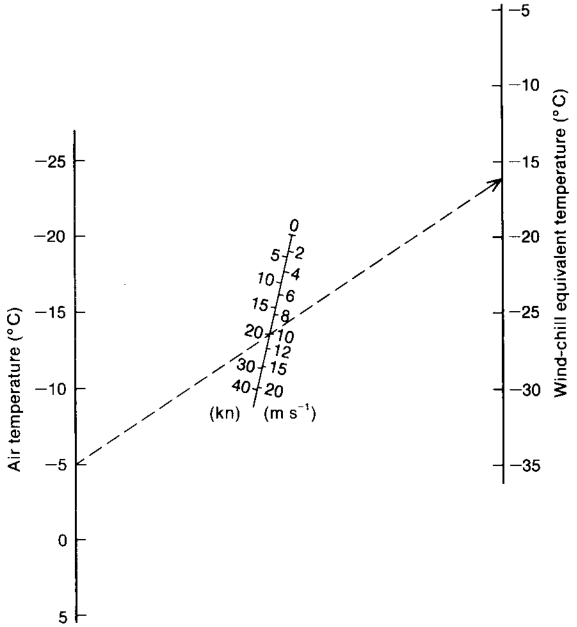


Figure 3. Nomogram for obtaining the wind-chill equivalent temperatures for various combinations of air temperature and wind speed at 10 m (after Steadman 1984). The example shows an equivalent temperature of −16 °C resulting from an air temperature of −5 °C and a wind speed of 20 kn.

same level of discomfort at the same equivalent temperature. No experimental evidence exists to suggest whether Steadman's or Siple and Passel's equivalent temperature is more applicable to the majority of people.

During the winter of 1984/85, weather forecasters in the United Kingdom started quoting equivalent temperatures. The Meteorological Office favours the more realistic approach adopted by Steadman (1984) for assessing wind-chill and uses his equivalent temperatures in forecasts during severe weather.

7. Applications

During and after the cold spell of February 1986, the Meteorological Office received many requests for information about wind-chill for a wide variety of reasons. The subjects that came to the attention of the authors included:

(a) alleged mistreatment of animals,
(b) inadequate heating of office blocks,
(c) interference with outdoor construction (effects both on materials and on operatives),
(d) effects of exposure for soldiers on exercise,
(e) damage to car engines and
(f) damage to crops.

Wind-chill indices do have a role to play for the types of application illustrated by subjects (a) to (d), either in the traditional sense of heat loss from bare skin or simply in terms of a measure of severe weather. For example, when materials need to be maintained at temperatures above that of their surroundings, chilling winds have an adverse effect. Daines (1985) describes how wind can reduce the time available for the compaction of bituminous materials used in road construction and how tables of wind speed versus temperature can be used to assess this effect. Strong cold winds can also increase the energy needed to maintain comfortable temperatures in buildings, particularly those that are poorly insulated or very exposed. Analyses of the frequency of wind-chill indices by wind direction can be used when deciding upon the design and layout of buildings to enable protective measures, e.g. the placing of shelter belts, to be taken (Dodd 1985). These and other applications of wind-chill calculations in the construction industry have already been described by the authors (Dixon and Prior 1986). The enhanced heat loss from young lambs (Starr 1984) is one example of the stress that wind-chill can cause animals, especially when they are wet.

The main misconception about wind-chill is the application of wind-chill equivalent temperatures to unheated, inanimate objects such as machinery, storage tanks or crops. When the wind is blowing, any dry, unheated, inanimate object cannot cool below the ambient air temperature; an object with a wet surface could, of course, cool to somewhat below the ambient air temperature due to evaporative heat loss. However, a heated object, for example a running car engine, will lose heat more quickly by convection when the wind is blowing. Once the engine is switched off and heat is no longer being generated, the engine will quickly cool towards the ambient air temperature as described above, but will be unable to cool below this temperature. Rodriguez (1980) quotes a typical misuse of the wind-chill concept with regard to sales of anti-freeze solution — 'One can be told that although the temperature is going down to −23 °C, one should protect the automobile engine down to −51 °C because of expected high winds'.

For human applications, the wind-chill index has its roots in assessing the comfort of military personnel spending prolonged periods outdoors in harsh climates. Even in the United Kingdom, the decrease of mean temperature with altitude coupled with an increase in mean wind speed leads to severe conditions in many upland areas for significant parts of each winter. Considerable use of such areas is now also made for sport and recreation, and the proper planning of these can be assisted by considering wind-chill indices and the associated clothing requirements (Baldwin and Smithson 1979).

When used as a comfort index for the general public, the great variety of personal circumstances (such as dress, activity and state of health) somewhat lessens the applicability of the wind-chill equivalent temperature to that of a general, although still useful, indicator.

8. Climatology

The spatial and temporal variability of wind-chill in the United Kingdom has been commented upon by Smithson and Baldwin (1978). They presented maps for the months January, April, July and October showing 18-year averages of wind-chill index and of the clothing thickness required to maintain the body in thermal equilibrium, using the work of Steadman. Essentially, these maps relate to altitudes less than about 100 m above mean sea level, since almost all the stations used in the analyses were below this level. The analyses were based upon monthly averages of temperature and wind speed, thus both masking the true range of conditions during a month and introducing problems concerned with the co-variance of wind and temperature over the United Kingdom. To overcome these difficulties, Mumford (1979) proposed an alternative approach using a 5% random sample of 1200 GMT observations over 15 years to produce seasonal maps of both mean and absolute maximum wind-chill, again for lowland Britain. Data from six sites in upland Britain have been processed by Baldwin and Smithson (1979), in terms of the frequency of wind-chill and required clothing thickness.

Several workers have calculated the wind-chill indices during particular cold spells, notably Howe (1962), Lyall (1981) and Giles (1986); the last named has discussed the severe weather at Birmingham in February 1986 in the context of the previous 45 Februarys.

Extensive computer archives of hourly temperature, mean wind speed and mean wind direction are now available for the network of weather observing stations administered by the Meteorological Office.

The more populous parts of the United Kingdom are well represented, with some records spanning 30 years or more. Thus it is now possible to examine hourly mean wind-chill indices and equivalent temperatures easily and over relatively long periods. A standard computer program is available to produce frequency distributions of temperature versus wind speed and a program has been written to calculate wind-chill indices on a monthly or seasonal basis, in terms of 30° wind direction sectors, from either the Siple–Passel or the Steadman (1971) formulae.

Since the wind-chill information given in public weather forecasts relates to low equivalent temperatures, an indication of their frequency in various parts of the United Kingdom will be of interest. Figs 4–10 show frequency distributions for seven stations (see Fig. 18 for their locations) whose hourly data during the 'winters' (October–April) of the years 1965–85 have been analysed in terms of Steadman (1984) equivalent temperatures. Only equivalent temperatures of 0 °C or less were considered, the average proportion of the 'winter' with such values varying typically from about a quarter in southern England (Figs 4 and 5) to about a half in lowland Scotland (Figs 8 and 9) to almost three quarters in the Shetlands (Fig. 10). The distributions suggest that the most frequent winter equivalent temperature is above 0 °C in most parts of the United Kingdom, with one exception being the Shetlands where values as low as −4 °C to −5 °C are common (Fig. 10). It should be noted that almost all the wind speeds used were measured by anemometers with a standard exposure (effective height 10 m), so the values will overestimate wind-chill effects for more sheltered sites in the vicinity, e.g. urban areas, and underestimate them for more exposed locations, e.g. over hills or near coasts. The Steadman equivalent temperature calculation incorporates a wind speed adjustment to 2 m above ground level.

An alternative presentation is given in Figs 11–17, in terms of indices from the 'wind-chill' term in the 1971 Steadman formula that are greater than 500 W m^{-2}. This threshold corresponds roughly to an index of 900 W m^{-2} produced by the Siple–Passel formula, a value associated with the human sensation 'cold' by Terjung (1966). The average proportion of the winter deemed 'cold' or worse varies from about one third in south-east England (Fig. 11) to about three quarters in the Shetlands, where the shape of the frequency distribution again reflects the harsh climate (Fig. 17). At most of the locations the proportion of 'cold' hours is only slightly greater than that for hours with an equivalent temperature 0 °C or less; notable exceptions are Plymouth (Figs 5 and 12) and Stornoway (Figs 9 and 16) where the windy, relatively mild, climate leads to many more hours qualifying when the less rigorous wind-chill index criterion is chosen.

Fig. 18 shows the contributions to the total number of hours with indices above 800 W m^{-2} from each 30 ° wind direction sector at the seven locations. The influence of topography is evident at several locations, with preferred directions for wind-chill corresponding to those from which winter winds are either enhanced by passage over the sea or funnelled by extensive high ground. The London analysis provides an example of high wind-chill associated with directions other than that of the prevailing wind.

More detailed directional information is given in Fig. 19. This indicates the tendency for high wind-chill indices to be associated mainly with cold continental airstreams in south-east Britain but also with stronger, less cold winds of maritime origin over other parts of the country.

The frequency and directional pattern of chilling winds will vary with location and in this respect it is important to bear in mind the local influence, particularly on wind speed, of terrain roughness, altitude and topography.

9. Concluding remarks

Wind-chill indices are a useful way of quantifying the various detrimental effects of chilling winds. The Siple–Passel wind-chill formula still appears to be the most widely used, despite its shortcomings. The Steadman formula considers criteria that are more realistic for people outdoors and consequently the Meteorological Office favours this more theoretically satisfactory approach.

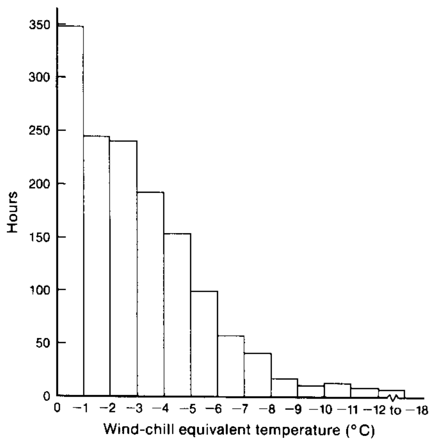


Figure 4. The average number of hours during October–April at London/Heathrow (anemometer effective height 10 m) with Steadman (1984) wind-chill equivalent temperatures in various ranges. The proportion of the period with equivalent temperature 0 °C or less is 28%.

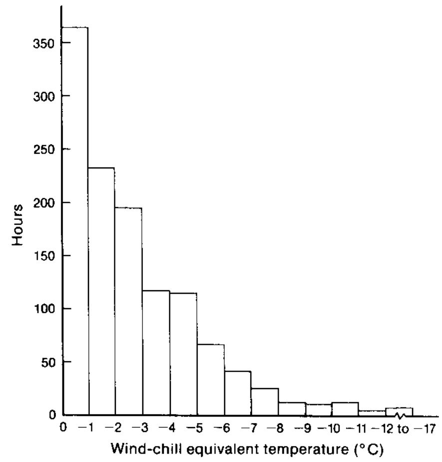


Figure 5. As Fig. 4 but for Plymouth/Mount Batten (anemometer effective height 13 m). The proportion of the period with equivalent temperature 0 °C or less is 24%.

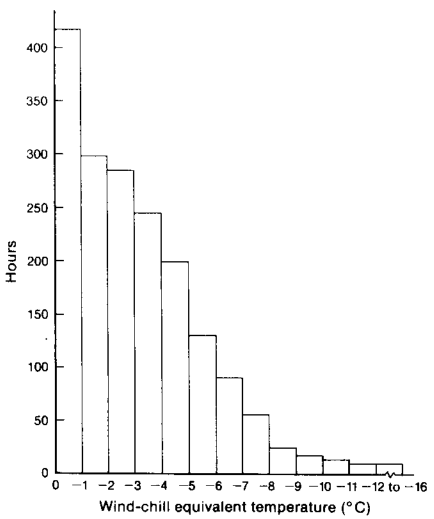


Figure 6. As Fig. 4 but for Manchester/Ringway (anemometer effective height 10 m). The proportion of the period with equivalent temperature 0 °C or less is 35%.

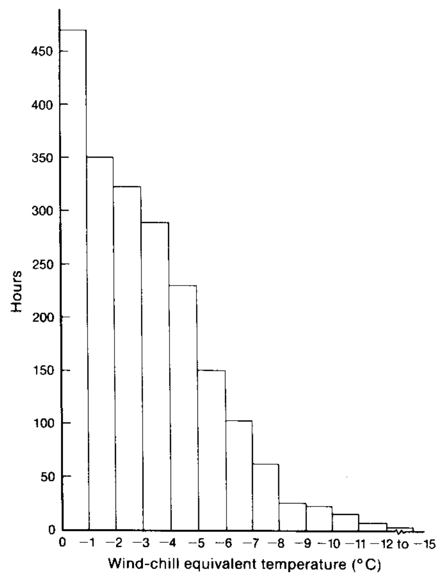


Figure 7. As Fig. 4 but for Belfast/Aldergrove (anemometer effective height 17 m). The proportion of the period with equivalent temperature 0 °C or less is 41%.

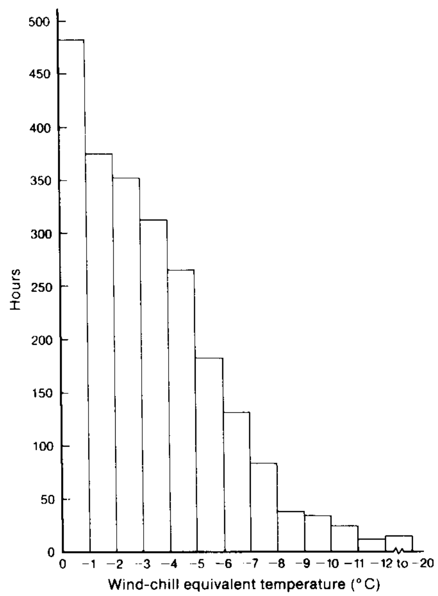


Figure 8. As Fig. 4 but for Edinburgh/Turnhouse (anemometer effective height 10 m). The proportion of the period with equivalent temperature 0 °C or less is 45%.

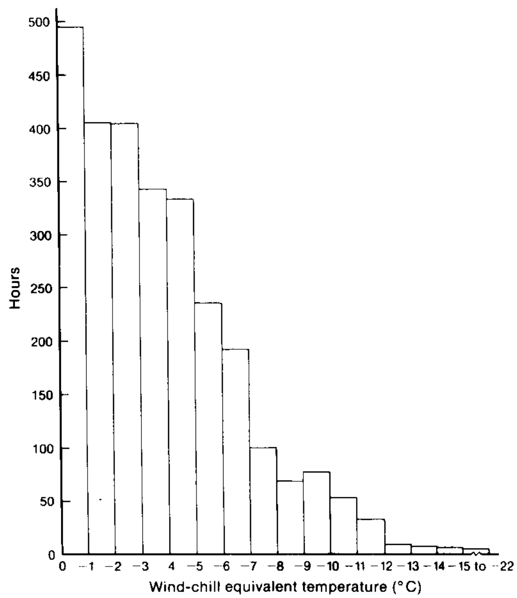


Figure 9. As Fig. 4 but for Stornoway (anemometer effective height 10 m). The proportion of the period with equivalent temperature 0 °C or less is 54%.

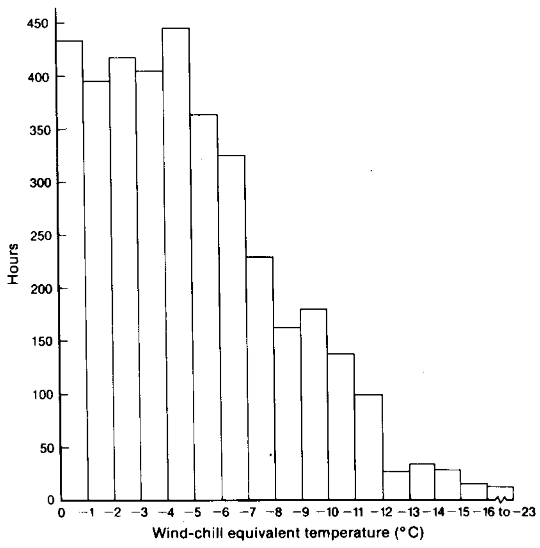


Figure 10. As Fig. 4 but for Lerwick (anemometer effective height 10 m). The proportion of the period with equivalent temperature 0 °C or less is 72%.

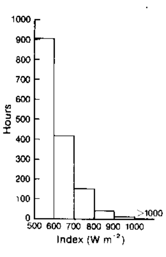


Figure 11. The average number of hours during October–April at London/Heathrow with Steadman (1971) wind-chill indices in various ranges. The proportion of the period with index 500 W m^{-2} or more is 31%.

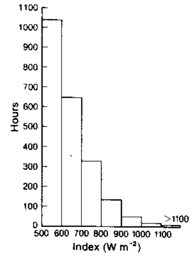


Figure 12. As Fig. 11 but for Plymouth/Mount Batten. The proportion of the period with index 500 W m^{-2} or more is 44%.

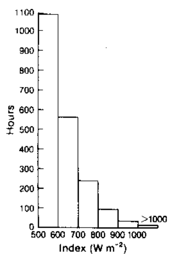


Figure 13. As Fig. 11 but for Manchester/Ringway. The proportion of the period with index 500 W m^{-2} or more is 40%.

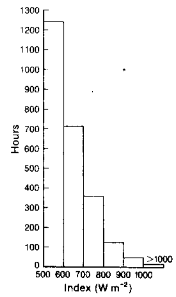


Figure 14. As Fig. 11 but for Belfast/Aldergrove. The proportion of the period with index 500 W m^{-2} or more is 48%.

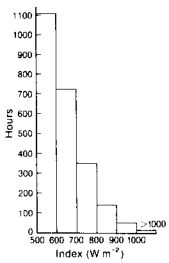


Figure 15. As Fig. 11 but for Edinburgh/Turnhouse. The proportion of the period with index 500 W m^{-2} or more is 47%.

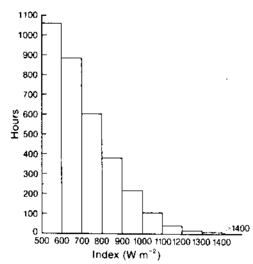


Figure 16. As Fig. 11 but for Stornoway. The proportion of the period with index 500 W m^{-2} or more is 65%.

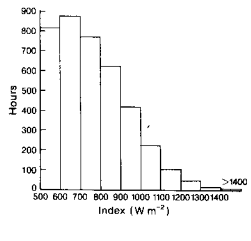


Figure 17. As Fig. 11 but for Lerwick. The proportion of the period with index 500 W m^{-2} or more is 77%.

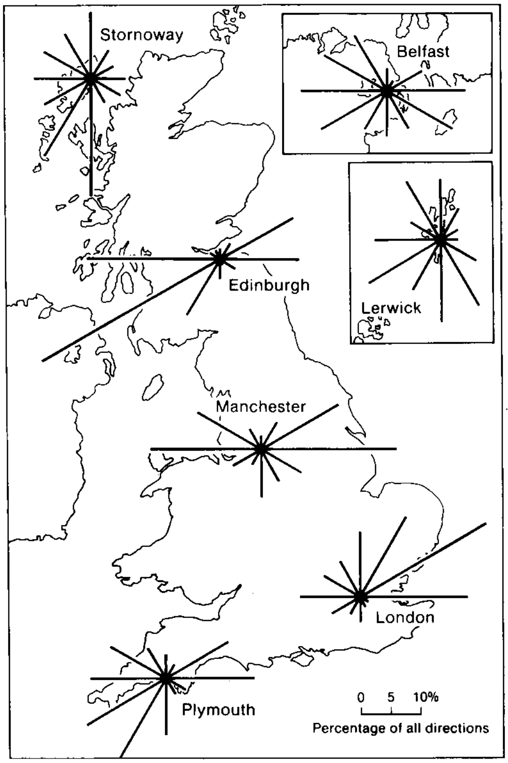


Figure 18. Wind-chill roses of Steadman (1971) indices greater than 800 W m^{-2}.

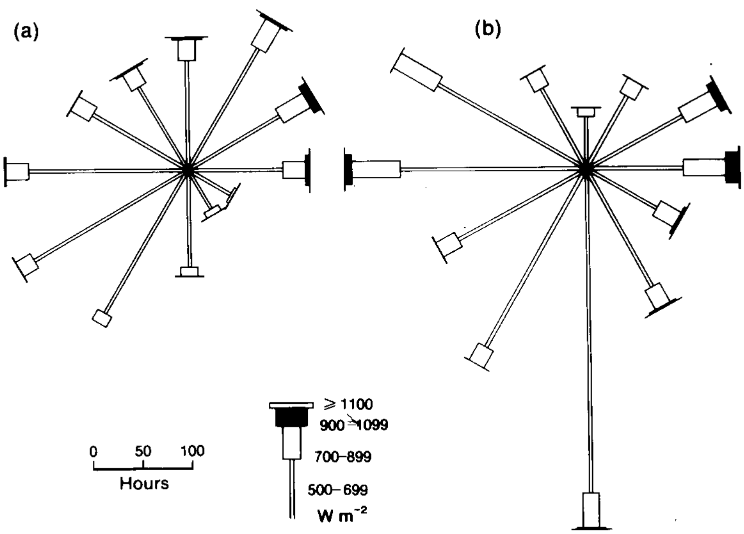


Figure 19. The average number of hours during October–April with Steadman (1971) wind-chill indices in various ranges and by 30° sectors at (a) London/Heathrow and (b) Manchester/Ringway.

It is likely that the demand for wind-chill information (and perhaps for summer-comfort indices as well) will grow, both for operational day-to-day use, and for design and planning purposes. It will be important to bear in mind the circumstances for which the advice is required.

Acknowledgements

The authors would like to thank E.J. Keeble of the Building Research Establishment for stimulating their interest in wind-chill and colleagues in the Advisory Services Branch of the Meteorological Office for their subsequent support and encouragement.

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551.509.313:551.515.13

The fine-mesh forecast of severe weather for 25 August 1986

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Monday 25 August 1986 was a public holiday in England, Wales and Northern Ireland, and the day was notable for the severity of the weather, particularly in areas bordering the Irish Sea. A depression spawned by the remnants of hurricane Charley deepened as it moved into the south-west approaches and brought gale force winds, heavy rain and flooding to many regions. The forecasts produced by the Meteorological Office fine-mesh model during this period were of a high standard and enabled the timely issue of warnings of severe weather. In particular, the wind forecasts were sufficient to deter pleasure craft from venturing out to sea.

The synoptic situations for 24 and 25 August at 12 GMT are shown in Figs 1 and 2. During this 24-hour period the central pressure of the depression fell from 990 mb to 985 mb as it travelled towards south-west Ireland. The corresponding 24-hour fine-mesh forecast valid at 12 GMT 25 August is shown in Fig. 3 where it can be seen that the position and central pressure of the depression compare well with

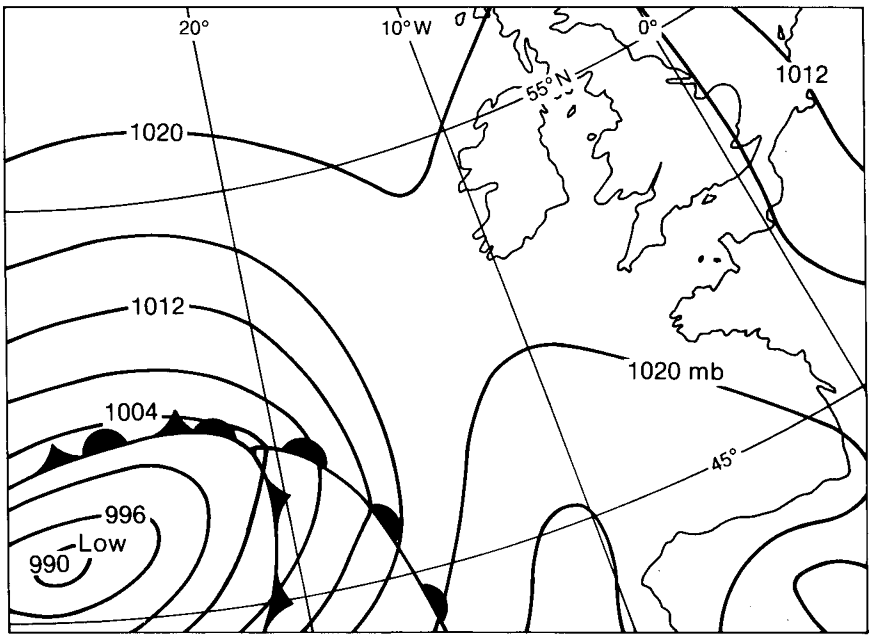

Figure 1. Surface analysis for 12 GMT 24 August 1986.

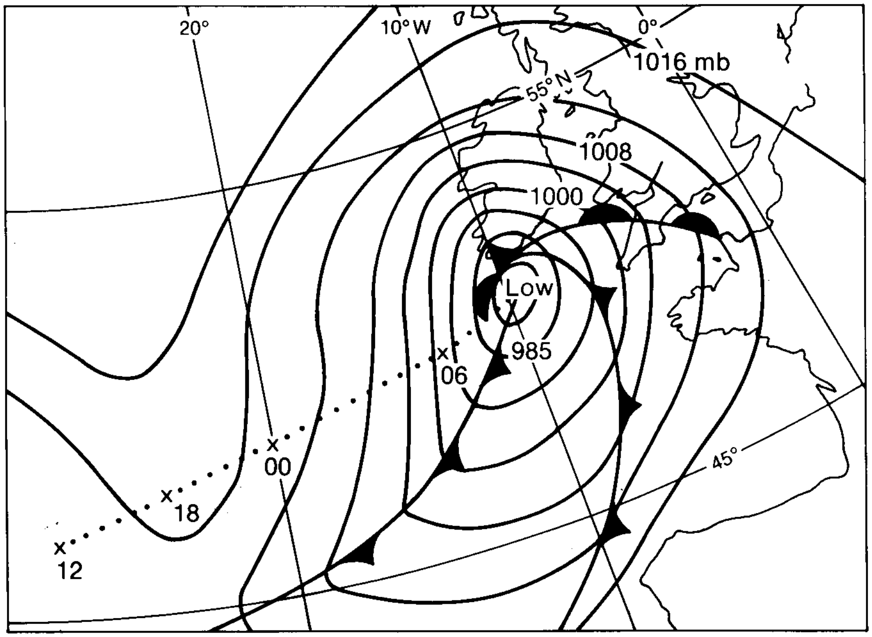

Figure 2. Surface analysis for 12 GMT 25 August 1986. The track of the depression over the previous 24 hours is shown.

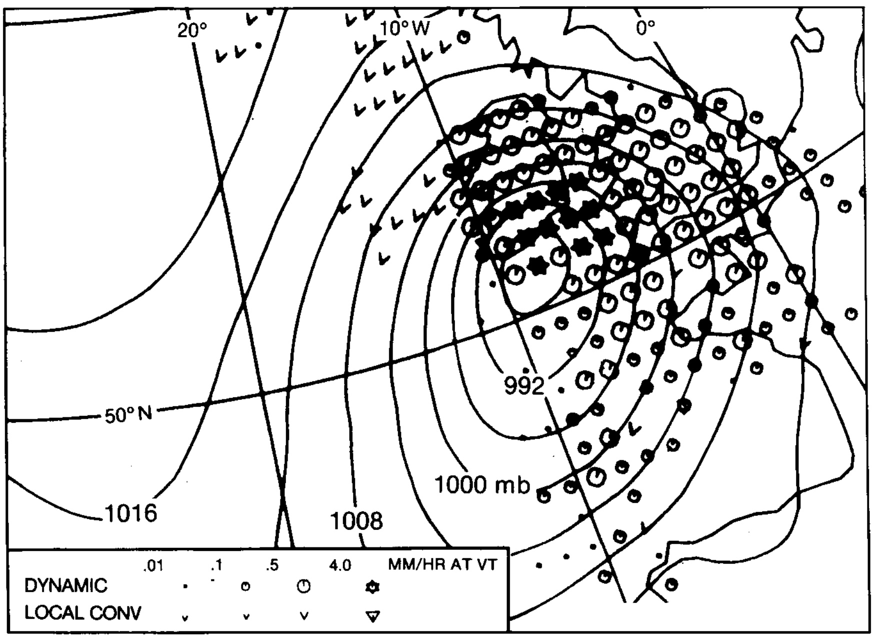

Figure 3. Fine-mesh 24-hour forecast valid for 12 GMT 25 August 1986 showing mean-sea-level pressure and intensity of precipitation.

the analysed values given in Fig. 2. The fine-mesh model had also forecast the heavy rainfall quite accurately. For example, the forecast 24-hour accumulations of rain over parts of the Republic of Ireland were in excess of 90 mm and in South Wales around 50 mm of rain was forecast. These values compare well with reported values considering that the fine-mesh grid points are 75 km apart. For example Dublin Airport reported 68 mm for the 24-hour period starting 06 GMT 25 August and there were reports of flooding in the Republic of Ireland. Flood damage also occurred in South Wales where there was one report of over 80 mm of rain in the 24-hour period starting 09 GMT 25 August.

The subsequent movement of the depression and the spread of the severe weather to northern England were also predicted accurately by the fine-mesh model.

This case clearly illustrates the ability of the fine-mesh model to handle situations which involve the development and spread of severe weather.

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Bringing the analysis of occluded fronts into the satellite age

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Summary

Attention is drawn to an inadequacy in the conventional representation of occluded fronts on surface charts. Mature depressions often have a spiral of frontal cloud which, it is suggested, should be represented in the analysis so as to convey more of the information gained from satellite images.

The way in which fronts are shown on surface pressure analyses has changed little since the Norwegian model of the development of a mid-latitude cyclone became well established earlier this century. There has been regular coverage of the earth by meteorological satellites since the 1960s, and the visible and infra-red images which they provide have considerably improved the reliability of surface analyses, especially over data-sparse regions such as the Atlantic Ocean. However, the classical model of the life cycle of an occluding depression appears to inhibit analysts from showing fronts as they really appear; certainly surface analyses could convey more useful information than is often the case. This is particularly true of mature occluded depressions which often have a spiral of cloud and precipitation wound around the depression centre. These cloud spirals are clearly of frontal origin and yet are rarely given such status. The occluded front is usually curtailed (in the classic way!) to the north-west of the low centre. This is best shown by an example — one chosen from many situations which illustrate the same point.

Fig. 1 shows the surface analysis, taken from the *London Weather Centre Daily Weather Summary** for 1200 GMT on 15 August 1985, and selected midday observations of wind and present weather. It shows a depression, with its centre over Northern Ireland, and an occluded front to the north and east. The satellite image, taken at visibile wavelengths by NOAA-9 at 1343 GMT, is shown in Fig. 2. South-west Scotland, north-west England, North Wales and much of the Republic of Ireland are covered by a spiral of dense cloud which gave heavy and continuous precipitation, particularly in western areas. Eskdalemuir, in the Southern Uplands of Scotland, recorded over 20 mm of rain in the

* Meteorological Office; *London Weather Centre Daily Weather Summary* 1200 GMT 15 August 1985.

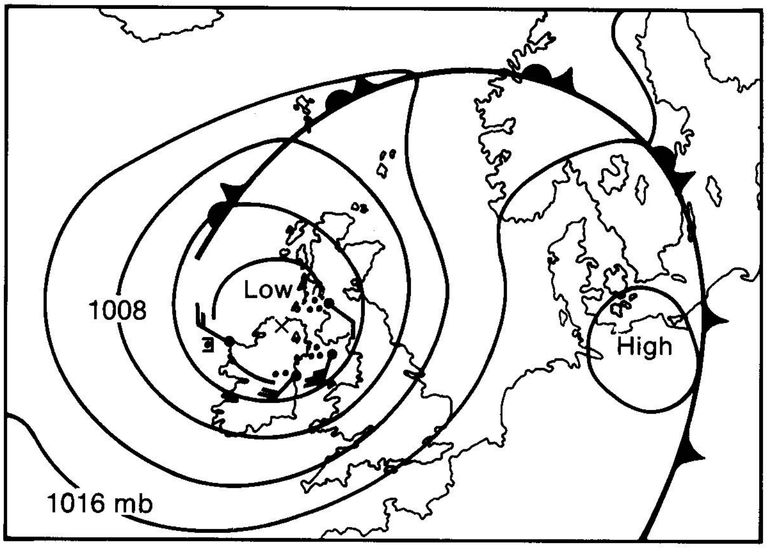
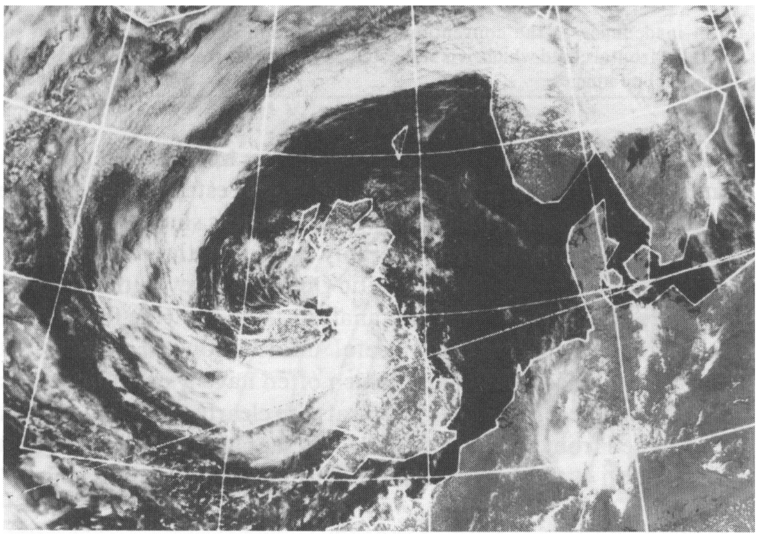


Figure 1. Surface analysis in the vicinity of the British Isles for 1200 GMT on 15 August 1985 taken from the *London Weather Centre Daily Weather Summary*. Also shown are observations of wind and present weather at four stations near the depression centre.



Photograph by courtesy of University of Dundee

Figure 2. Visible (Channel 2) Advanced Very High Resolution Radiometer image from NOAA-9, at 1343 GMT on 15 August 1985.

4 hours following the time of the satellite image. The cloud spiral was prominent in earlier satellite images and yet the cloud and precipitation would be unsuspected from the surface analysis shown in Fig. 1, though one would, of course, expect extensive showery rain. Because this cloud is so clearly of frontal origin, the analysis should convey this information by an extension of the occluded front into the low centre, as shown in Fig. 3. This adaptation is not a large one but is vitally important for those living

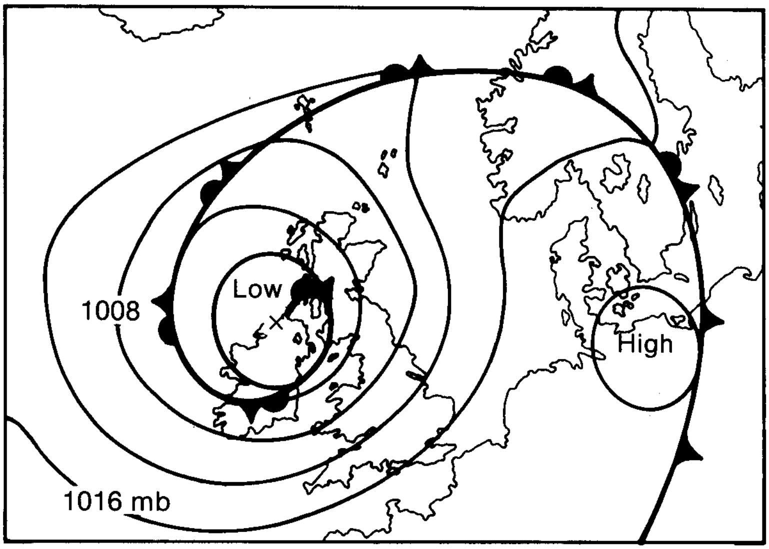


Figure 3. Modified surface analysis for 1200 GMT on 15 August 1985.

in the west of the British Isles and trying to reconcile the surface analysis with the observed weather. This lack of inhibition in drawing occluded fronts should be extended to textbooks showing the life cycle of a depression and, indeed, to the preparation of forecast charts.

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Rainfall pattern associated with a split cold front as seen on FRONTIERS*

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Summary

The radar rainfall pattern associated with a split cold front is used to illustrate the way in which the FRONTIERS display can be used to understand subsynoptic weather systems.

On 5 November 1986, whilst looking over the shoulder of the FRONTIERS operator in the Central Forecasting Office of the Meteorological Office, I saw the interesting radar rainfall pattern shown in Fig. 1 (see Browning (1986) for a description of the FRONTIERS programme); the corresponding surface analysis is shown in Fig. 2. The main feature was a split cold front of the type commonly encountered in the British Isles and described by Browning (1985).

An upper cold front lay from the Humber to the Bristol Channel with the surface cold front in the Irish Sea some 200 km to the north-west. Along the upper cold front there was a band of precipitation extending to medium levels. A combination of visible and infra-red imagery from Meteosat indicated

* FRONTIERS: Forecasting Rain Optimized using New Techniques of Interactively Enhanced Radar and Satellite.

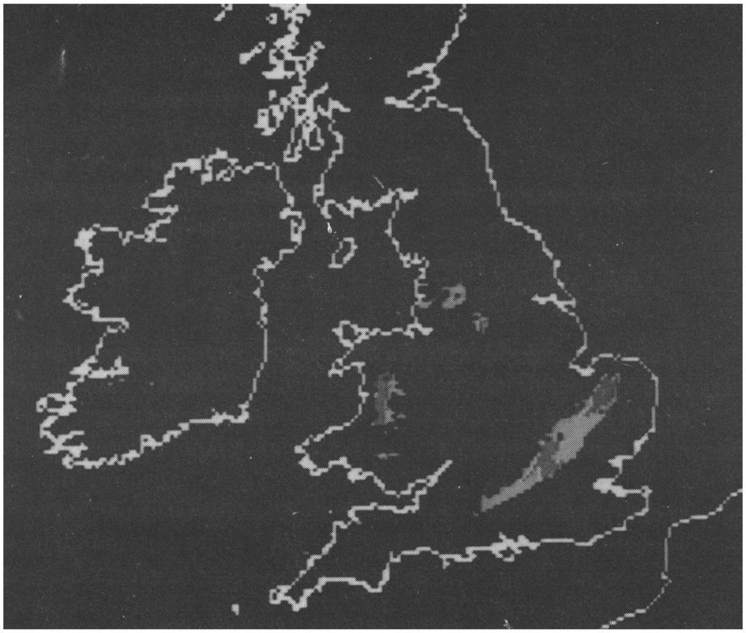

Figure 1. Radar rainfall pattern at 1430 GMT on 5 November 1986 taken from the FRONTIERS display. Light shading < 1 mm h^{-1} and dark shading $\geqslant 1$ mm h^{-1}.

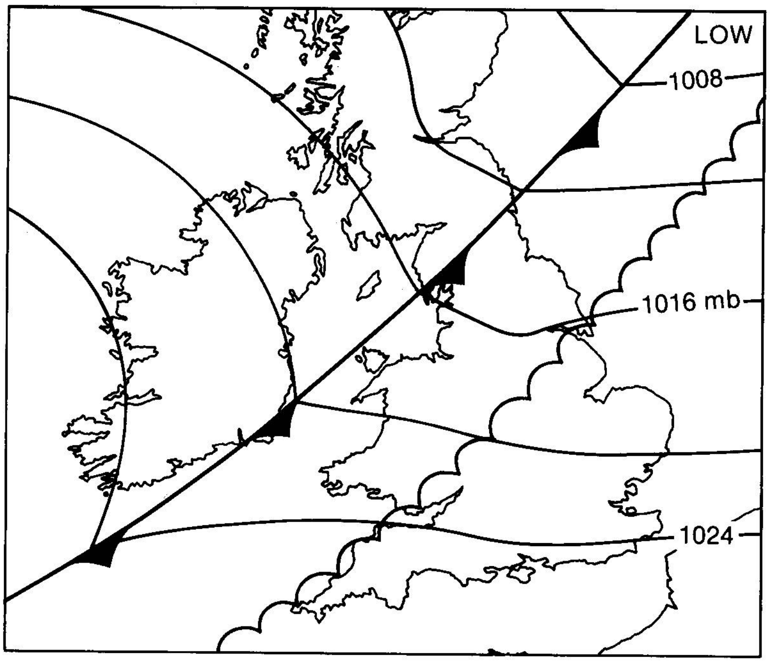

Figure 2. Surface analysis at 1400 GMT on 5 November 1986. The position of the upper cold front as inferred from satellite imagery is shown by a cusped line.

that this precipitation band extended north-eastwards into the North Sea. Between the upper cold front and the surface front there was a shallow moist zone. Satellite infra-red imagery showed the cloud tops in this zone to be no higher than 700 mb. The strong moist west-south-westerly flow at low levels in this zone was generating areas of orographic rain especially over the Welsh hills and the Pennines as shown in Fig. 1. Although patches of drizzle too light to be detected by the radars occurred in some low-lying areas, action replay sequences showed that the main areas of rain in the shallow moist zone remained stationary over the hills — unlike the rain band associated with the upper cold front which travelled rapidly eastwards. An advantage of the FRONTIERS display system is that it enables the operator to compare, replay and otherwise manipulate radar and satellite imagery so that a detailed understanding of subsynoptic weather systems can be built up quickly.

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Reviews

The Bunker climate atlas of the North Atlantic Ocean, Volume 1: Observations, by H.-J. Isemer and L. Hasse. 240 mm × 315 mm, pp. vii + 218, *illus.* Springer-Verlag, Berlin, Heidelberg, New York, Tokyo, 1986. Price DM 275.

The data on which this atlas is based were originally assembled and validated by the late Andrew F. Bunker of the Woods Hole Oceanographic Institution. Bunker, with his co-workers, published several important papers during the mid-1970s on the surface heat budget of the North Atlantic Ocean. However, on his death in 1979 much of his data and results were left in an unpublished state. Isemer and Hasse have obtained Bunker's original computer print-outs, transferred these data to magnetic tape, and used objective analysis techniques, first to reduce the data to a regular grid, and then to draw the charts and graphs contained in this atlas.

This first volume summarizes the basic observations, and these are presented in three formats: firstly as time–latitude diagrams giving the zonally averaged annual variation; secondly as graphs of the mean annual cycle of each variable at 11 characteristic area locations and for the whole North Atlantic; and thirdly, as charts of the monthly and annual means, annual range, and standard deviations. These charts form the major part of the atlas. The variables considered include most of those reported by ships (excluding wave observations): sea surface and air temperature, mixing ratio, relative humidity, air pressure, both total and low cloud cover amounts, and percentage frequency of precipitation reports. The wind field is represented by the mean scalar wind speed, the mean resultant wind velocity vector, the directional steadiness, and the divergence.

A number of the plots tempt one to anticipate the flux data which are to be presented in Volume 2. Charts of the differences in air temperature and in mixing ratio between the air and sea allow one to imagine, for example, the sequence of air-mass transformation as cold, winter-time air from the eastern USA flows out over the Gulf Stream. Although estimating the fluxes from the mean values can be misleading, there are charts of the standard deviations of the thermodynamic variables and the eastward and northward wind components, and it might be possible to estimate, where necessary, a suitable correction factor. That approach, however, would seem a singularly inappropriate use of this atlas since a major feature of Bunker's own work was that he derived the fluxes separately for each individual ship report before performing any averaging. In this respect the atlas will not be complete until Volume 2 is available.

Before the presentation of the graphs and charts, the data set and the analysis techniques are described in a short introductory section. The brief discussion of the accuracy of the data source, the routine reports from the Voluntary Observing Ships, is little more than a warning that errors may exist. Since the authors' stated policy is to leave Bunker's work unchanged as far as possible, they have not applied any corrections to the observations. However, Bunker did apply bias corrections, by adjusting the bulk aerodynamic formulae transfer coefficients, before calculating the fluxes. It will be interesting to see what the authors have chosen for transfer coefficients in calculating the fluxes for presentation in Volume 2. Also briefly summarized in this section is the actual subject of the charts, the climate over the North Atlantic Ocean. Unfortunately, I found that the value of this discussion was diminished by the authors' decision not to quote particular chart numbers. For example, the May sea surface temperature distribution is referred to on page 11 but we are not told that this is chart 10, to be found on page 47. Indeed, a shortcoming of the atlas is that there is no single overall contents list or index. Instead, the contents of each section are hidden away separately (pages 17, 23, and 37), and one is left leafing through the atlas to find a particular chart.

Given that various climatic atlases of the North Atlantic already exist, what then is the value of this particular publication? The authors argue that this atlas is 'unprecedented in the size of the data base and in spatial resolution' and that 'it is based on objective analysis and the most recent understanding of the parameterization of derived quantities such as fluxes of heat and momentum'. The latter argument may apply to Volume 2, but it is not clear that these are the main advantages of Volume 1. Bunker's data set covers the period 1941 to 1972 and was based on the 'TDF-11' data set which has also been used by other authors. The spatial resolution of the data presented is based on a 1-degree grid. However, since these have been derived by interpolating Bunker's results, which were calculated for irregular areas of typical dimensions 2 degrees latitude by 5 degrees longitude, the 1-degree scale data are not, and are not claimed to be, independent. The overall result is that, despite the apparent differences in calculation, comparison of the charts with those in, to take an example, the US Navy *Marine climatic atlas of the world Volume I North Atlantic* (1974 revision), uncovered practically no signficant difference in the isopleths, at least for the random sample which I examined.

Despite the above comments, I believe that this atlas will prove a very important publication. The charts are based on a validated data set for which good documentation is available. Perhaps the most significant factor is that magnetic tapes both of Bunker's results and of the interpolated data are available from the authors. Thus the data set can be used directly as boundary conditions for numerical models. For such usage the wind field is particularly important and it has received especially detailed treatment within the atlas. As a concise summary of the Bunker data set the atlas will receive wide distribution. If, with the increasing emphasis on climate research, this results in an increased use of Bunker's data set it will be no more than a fitting tribute to his efforts. It will also reward the considerable work performed by Isemer and Hasse in making Bunker's results so readily available.

P.K. Taylor

Floodshock: the drowning of planet earth, by A. Milne. 172 mm × 246 mm, pp. 224, *illus*. Alan Sutton Publishing Ltd, Gloucester, 1986. Price £12.95.

The history of the human race contains many unhappy events. Some are undoubtedly of our own making; others represent natural catastrophes in which the efforts of mankind are overwhelmed and belittled by the forces of Nature. Perhaps the most potent threat is that posed by flooding, a view that is put forward in *Floodshock: the drowning of planet earth*. This somewhat disorganized book by Antony Milne, an environmental scientist whose credentials include an involvement with NATO's Committee on the Challenges of Modern Society, would have had more impact had the contents been arranged either chronologically or strictly thematically. Instead, legends concerning a great flood give way to discredited theories about the legends, which in turn precede an account of more acceptable ideas before returning to the legends again. The sea, storms, rivers and dams are the subjects for much of the remainder of the book. The author's aim of alerting the public to the immense destruction that can be accompanied by flooding, a fact that is not generally appreciated in this country, is only partially successful.

Descriptions of some of the world's most devastating water-related incidents commence with the most famous of all floods. The western civilizations are familiar with this through the account in Genesis, but other cultures (such as the Sumerians, Indians and Chinese) recount similar legends. Did it really occur or is it an abstruse piece of theology? Spurred on by the well publicized findings of an archaeological expedition half a century ago at Ur, in Iraq, the book proceeds as if it did and we are led into various theories, some more plausible than others, that might explain the Great Flood. The Biblical explanation of forty days and nights of rain is dismissed as being insufficient; it is also probable that it is an allegory. From the time of Plato to the present day, there seems to have been no shortage of alternative ideas, some of the more recent being the effect of a celestial object passing too close to the earth — the pole shift theory and the melting ice caps theory.

Our attention is then turned from a legendary flood to more recent and better-documented catastrophes in which the sea has played a major part. Nature has extracted a high price for man's desire to create communities in close proximity to the sea, not only altering its average depth but also producing hazards such as surges, tides and tsunami. The tragic consequences are highlighted in selected examples from around the world.

Storms are the subject matter of the next chapter and we learn that it is usually the poorest countries that are most at risk from cyclones and hurricanes. In spite of the Bay of Bengal's history of being a favoured location for devastating cyclones, the loss of life that they cause in that region is still very high. Even when accurate forecasts of impending conditions are broadcast, there is usually nowhere to which the population can flee.

The most ruthless and effective destroyer of life and property is the subject considered next. Rivers have the ability to change quickly from slow, meandering waterways into fast-moving, uncontrollable mixtures of water, rock and debris that can destroy most structures in their path. This devasting power cannot be illustrated more clearly than by considering the reputation of the Hwang Ho (Yellow River) in China to have claimed the lives of more people than any other agent of natural disaster anywhere in the world. Indeed, in just one year, it was responsible for the deaths of seven million people. By comparison, perhaps the best known of Britain's river disasters, that at Lynmouth, Devon in 1952, resulted in 24 deaths. It is entirely probable that the lack of a recent major flooding tragedy in Britain is the reason why the public consider a flood to be 'the least of their worries', even when living in notoriously flood-prone areas. Or could it be because they have faith in our ability to forecast flood-producing conditions sufficiently far in advance for preventive measures to be taken?

In attempting to control rivers or harness their energy, large numbers of dams have been built. Ironically this has led, in several cases, to an increased risk of flooding due to the 'dangerous state of disrepair' of many of them. Recent disasters include the failure of the split-elevation dam at Stava, northern Italy in 1985 which killed 230 people.

Our desire to improve upon the environment in which we find ourselves goes far beyond dam building. In *Floodshock*, the massive Soviet project whereby Siberian rivers will be diverted to irrigate the arid lands of central Asia is described. What are the consequences on global climate of such 'earth-shaping' plans? Of more immediate interest are the climatic implications of deforestation, and Milne argues that this will lead to more floods.

Although aimed at the 'popular' market, the scope of the book is quite large, and various aspects of meteorology, climatology, hydrology, history, geology and astronomy are mentioned. It is well endowed with black-and-white illustrations, and an up-to-date bibliography and comprehensive index complete the book. The diversity of topics has led to some serious errors, for example, a front is described as 'a belt of air of a consistent temperature'. Also, 'ridges of low pressure' are mentioned as are 'jet streams —sometimes known as circumpolar vortexes'. We learn that 'the total mass of humanity now weighs about 180 million tonnes, more than half the total mass of the earth'. And if 'the reason the Sahara receives hardly any rain at all from one year to the next is because the sun burns so fiercely it can actually vaporize any tiny clouds that do appear', why is it that 'the areas of highest rainfall are at the equator'? Additionally, the author's tendency to hyperbolize has apparently gone unchecked and this further detracts from the book from a professional viewpoint. By its very nature, much of the content has appeared elsewhere; nevertheless, the publication of a book solely on the flood hazard is to be welcomed. Time will tell whether the threat of flooding is 'the least of our worries'.

M.S. Shawyer

Cloud investigation by satellite, by R.S. Scorer. 165 mm × 235 mm, *illus.* Ellis Horwood Ltd, Chichester, 1986. Price £39.50.

Professor Scorer is renowned for his classical work on the interpretation of clouds as viewed from the surface of the earth. In his latest book, although the source of the images changes to space-based systems, the philosophy of using them to analyse the dynamics of the atmosphere remains the same. In this approach lies the deep rift between the ubiquitous coffee-table books with their stunning colour pictures and vacuous texts, and this one, in which modest monochromatic images are used to illustrate a tutorial on the mechanics of the atmosphere.

However, the success of even a book such as this, depends upon the quality of its images. Poor visual material could easily obscure a point rather than clarify it. The economic balance between the price of the book and the sumptuosity of its production, and hence the clarity of its images, must have been difficult to achieve. I feel that the publishers have been largely successful. It is true that the images presented do not have the remarkable quality of the originals created at the University of Dundee. However, for the most part, they are clear enough to do the job of illustrating each point made by the author. They are certainly much better than the grubby bits of facsimile paper seen on the benches of our forecasting offices!

Professor Scorer selects most of his material from the images produced by the Advanced Very High Resolution Radiometer situated aboard the TIROS-N series of polar-orbiting satellites. Occasional images from the Ocean Colour Monitor on NIMBUS-7 are also used. The images produced by these instruments have spatial resolutions of about one kilometre, thereby allowing details of even mesoscale weather systems to be studied. One chapter is devoted to the Japanese geostationary satellite Himawari (which means sunflower).

The book is not a systematic treatment of all cloud imagery. Instead, the author has selected a pot-pourri of topics ranging from the traditional meteorology of 'cloud streets and cells' to the more exotic of 'condensation trails'. The satellite images used profusely to illustrate each topic are accompanied by thought-provoking and informative text.

Many of the pictures presented are visually stunning. I enjoyed an image showing cloud streets that were one thousand kilometres long and a few kilometres wide, and go on to merge with extensive cellular cloud. I suspect that this might make salutary viewing for the atmospheric modellers.

My adverse comments are few. Occasionally, more assistance is required to locate within the picture the geographical references of the text. One or two of the images are rather featureless. More importantly, while it is clear that much patient work has gone into a dynamical reconciliation of imagery and observational data, the reader is denied any access to the latter. Figures showing relevant facets of the behaviour of the atmosphere would have been useful.

Professor Scorer does not appreciate the serious uses of colour to enhance satellite images, finding them 'great fun and...popular with the media', a somewhat damning indictment. However, it was John Ruskin (*Stones of Venice* (1851–53)) who noted that 'The purest and most thoughtful minds are those which love colour the most.'

R.J. Allam

Books received

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

Climate of Antarctica, edited by I.M. Dolgin, translated from Russian by M. Nataraja Pillai (Rotterdam, A.A. Balkema, 1986. Hfl 95.00, US $38.00, £27.50) presents papers read at the All-Union Symposium on the study of the climate of Antarctica during the last 20 years, at which the contributors highlighted the different stages of development of the aerometeorological studies taking place in that region. These papers describe certain new aspects in climatic study, such as the problem of the heat and moisture exchange, the mechanism of atmospheric circulation and the assessment of the relative severity of the climate of different regions of Antarctica, which is examined here for the first time. Other articles include the inflow and outflow of radiational heat energy, new information on the total content of ozone, carbon monoxide and methane in the atmosphere of Antarctica, and the application of statistical methods and computer techniques to the study of the structure of the atmosphere.

The physics of atmospheres, (second edition) by J.T. Houghton, (Cambridge University Press, 1986. £27.00, US $54.50 (hardback), £9.95, US $16.95 (paperback)) is a revision of the first edition of this textbook in order to bring it completely up to date. Several factors have led to vigorous growth in the atmospheric sciences, particularly the availability of powerful computers for detailed modelling, the investigation of the atmospheres of other planets, and techniques of remote sensing. The physical processes governing the structure and circulation of the atmosphere are described. Simple physical models are constructed by applying the principles of classical thermodynamics, radiative transfer and fluid mechanics, together with analytic and numerical techniques. These models are applied to real planetary atmospheres.

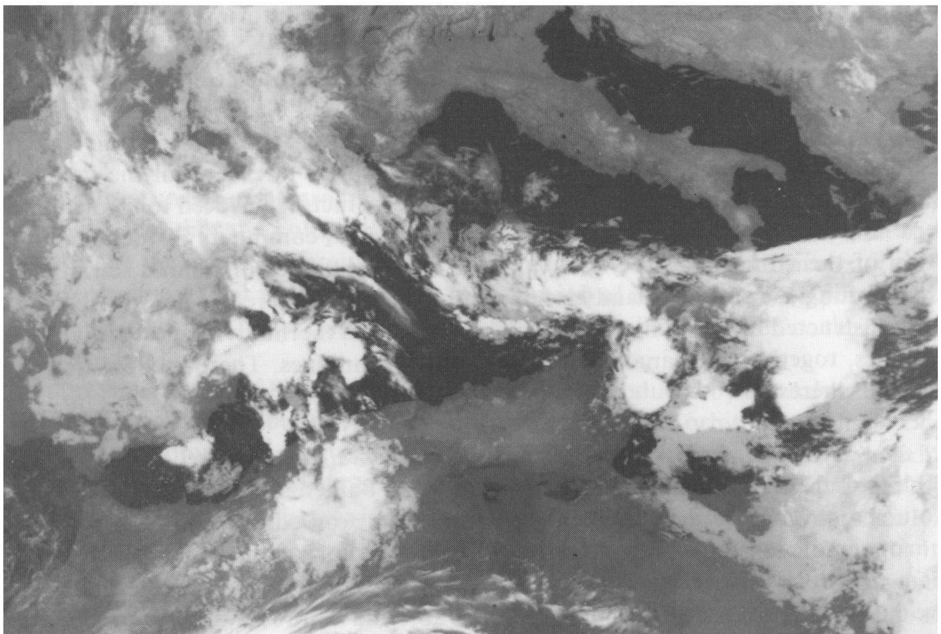
Remote sensing for resource development and environmental management, edited by M.C.J. Damèn, G. Sicco Smith and H.Th. Verstappen, (Rotterdam, A.A. Balkema, 1986. Hfl 265.00, £82.00) consists of two volumes (with a third promised) containing the proceedings of the seventh international symposium on remote sensing for resources development and environment management, held in August 1986. There are many papers presented under the general headings: visible and infra-red data, microwave data, spectral signatures of objects, renewable and non-renewable resources, hydrology, and human settlement. Many of the latest techniques in different disciplines are discussed in contributions from world-wide authors.

Satellite photograph — 17 October 1986 at 0300 GMT

This picture was taken from the infra-red channel on the NOAA-9 satellite and shows thunderstorms affecting coastal areas of the western Mediterranean, in particular the holiday areas from the Costa Brava to the Costa Blanca, and the Balearic Islands. Highest reported 6-hour rainfall totals in the period from midnight included 51.0 mm at Cap Bear, France (a few kilometres north of the border with Spain). Nearby Perpignan only managed 14.6 mm in the same period. Further south, Alicante recorded 45.0 mm during the previous 6-hour period from 1800 GMT, followed by another 11.0 mm after midnight.

Images such as this can be analysed in detail in the Satellite Meteorology Branch of the Meteorological Office. The infra-red channel indicates the temperature of the surface being viewed and images can be calibrated so that the temperature in °C of a particular spot (or pixel) can be read directly. As an example, the two most northerly large cloud masses, situated over the Costa Brava, were examined. The more northerly one shows a storm at its maximum development with cloud-top temperatures around −60 °C, indicating a height in excess of 40 000 ft (12 000 m). The other cloud mass shows a decaying storm with cirrus streaming away to the north-west with cloud-top temperatures around −54 °C.

The synoptic pattern was not particularly menacing, with relatively low pressure over north Africa and a mainly light easterly flow over the western Mediterranean. The 1000–500 mb thickness pattern showed a weak warm ridge over the area. However, the air within the lower part of this layer was very moist and relatively warm, a recognized precursor to thunderstorm activity. By contrast, the air over Italy was very dry (less than 35% relative humidity at 700 mb compared with over 85% in the thundery area) and the resulting clear conditions allow rivers, lakes and snow-covered mountains to stand out clearly.



Photograph by courtesy of University of Dundee

Meteorological Magazine

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