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National Severe Weather Warning Service
Evolution of forecasting for the offshore industry
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The Meteorological Office National Severe Weather Warning Service (NSWWS)

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Summary

The NSWWS provides Tier 1 warnings of severe weather to emergency organizations and to the public. Flash Messages are issued within six hours of the event, but Early Warnings, which are sent only to emergency organizations, may be issued up to five days ahead. Tier 2 warnings of hazardous conditions are mostly sent to Police and Fire services and to the BBC Travel Centre. The performance of the service is continually monitored and surveys of recipients are conducted annually. This enables the level of service provision to be improved to take account of developments in forecasting, communications and the views of recipients. This paper describes the service, summarizes the weather over the first two years of operation, and gives actual case-studies.

1. Introduction

After the Great Storm of October 1987 comments were commonplace in the Press criticizing the lack of warning given by the Meteorological Office. The emphasis had changed by October 1990 however, when, after the Meteorological Office forecast further gales, the *Daily Telegraph* reported 'since the storm of October 1987, which forecasters failed to predict, the Meteorological Office has been keen to give as much warning as possible of severe weather'. This shift of opinion by the Press reflects the efforts that the Meteorological Office has made in recent years to develop its severe weather warning service. A system now exists, established in its current form in 1990, which aims to provide the best possible advice to the emergency authorities and the public. It was developed through the Cabinet Office from the pre-existing severe weather Flash warning service to the media, and from the BBC Motoring Unit warning service. It is supplied as part of the government funded Public Meteorological Service.

As Fig. 1 shows, wind is frequently the most destructive type of severe weather since it causes immediate physical damage. The storm of 25 January 1990 resulted in 47 deaths and £2 billion damage to property across a large part of Britain. In the case of heavy and prolonged rain or snow, damage can result from flooding and from the collapse of roofs and electricity cables under the weight of snow. This is in addition to the disruption caused to transport. Foggy or icy conditions also pose a potential danger to life through their impact on travel.

Although damage can also result from the effects of severe thunderstorms, such as strong wind gusts, heavy rain or hail, these are usually localized and of short duration. Severe weather warnings are not routinely issued in

these circumstances. However, thunderstorms can be organized into mesoscale convective systems (MCS) which cover a large area and persist for several hours. Warnings will then be issued under the normal criteria.

2. Organization

There are two tiers of warnings within the NSWWS:

Tier 1 — warnings of severe or exceptionally severe weather

1a: Early Warnings of major severe weather events likely to result in widespread disruption and/or present a danger to life.

1b: Flash Messages of severe weather likely to result in considerable inconvenience to a large number of people and/or present a danger to life.

Tier 2 — warnings of hazardous conditions which might present the emergency authorities with potential operational problems.

Criteria for the issue of warnings are at Appendix A.

Recipients of Tier 1a Early Warnings include the county emergency services, local authorities, some government departments (e.g. Home Office, Cabinet Office, DOE, MOD, MAFF, DTp), and other large organizations, such as BT, which may need to take action to prevent or deal with emergencies arising out of severe weather. They also receive Tier 1b Flash Messages which are sent to radio and television stations for broadcast to the public. Tier 2 warnings are mostly sent to Police and Fire services and to the BBC Travel Centre for inclusion in their motoring bulletins.

Figure 1. The effect of severe weather. Friday 16 October 1987, Westcliff-on-Sea, Essex (top) Westbourne Grove, and (bottom) Prittlewell Chase. Photographs by courtesy of Lynn Tait Gallery, Leigh-on-Sea.

The warnings are issued by a cascade system to ensure effective and efficient distribution. They are sent first to focal points at the national and county levels who then cascade them down to other recipients. The focal points at the county level are mainly the Emergency Planning Units, but the county Fire Service may carry this responsibility instead, and so too, exceptionally, may the county Police. The Meteorological Office's responsibility is to these primary focal points, who subsequently distribute the warnings to other interested parties.

Early Warnings are issued by the Central Forecasting Office (CFO), Bracknell, when the forecasters have reasonably high confidence that severe conditions will occur. This may be for lead times of a few hours to several days. Once issued the warnings are updated each subsequent day until the event occurs or the warning is cancelled. Reference to the issue of an Early Warning will be made in the Synoptic Review issued as guidance to the regional Weather Centres, although on occasions the Chief Forecaster may decide that a Special Synoptic Review is necessary. A Press Release may be issued in conjunction with an Early Warning if the Chief Forecaster considers it appropriate.

Flash Messages are issued nearer the onset of the conditions, normally within six hours, by the regional Weather Centres, although CFO maintains a watching brief over the operation of the service, discussing the situation with Weather Centres whenever necessary. CFO also provides guidance on whether Flash criteria are likely to be exceeded in the short-period forecasts issued every six hours. The warnings will often be based upon actual reports of severe weather, providing greater detail than Early Warnings on location, duration and severity. When the severe weather is widespread, CFO may issue a composite Flash Message for national dissemination to avoid proliferation of warnings. Tier 2 warnings are also normally issued within six hours by the regional Weather Centres.

3. Weather summary — the first two years

3.1 1990/91 Season

The first full winter when the NSWWS was used operationally was noteworthy for two spells of snowy weather in the southern part of Britain. Warnings for both these events, on 8 December 1990 and between 6 and 13 February 1991, were passed to emergency authorities in good time, and the Meteorological Office received favourable Press coverage. This was despite the chaos and disruption to transport which occurred on both occasions and, after the snowstorms of 8 December 1990, the Home Secretary was quoted as saying 'what I think took people by surprise was that there was no lack of warning by the Meteorological Office'. Also during this winter there was a cold, stormy period at the end of the year which mainly affected northern Britain.

A breakdown of Early Warnings issued for severe weather events from April 1990 to March 1991 gives 11 nationwide, 2 of which were subsequently cancelled (see Table I).

Flash Messages issued via CFO for this period, which include composite messages, accounted for 57 occasions (see Table II).

Table I. Early Warnings issued for severe weather in 1990–91 and 1991–92 (April–March)

	Severe gales	heavy snow	heavy rain
1990–91	5	5	1
1991–92	5	1	2

Table II. Flash messages issued via CFO in 1990–91 and 1991–92 (April–March)

	Severe gales	heavy snow	heavy rain	icy roads	fog
1990–91	21	18	2	7	9
1991–92	34	2	17	0	30

3.2 1991/92 Season

Apart from one weekend around the middle of March, when for a short while blizzard conditions affected some parts of Scotland, the winter as a whole was not particularly noteworthy for extreme cold or snow. It was characterized by some very windy conditions however, especially over Scotland and northern districts of England. In the south of England freezing fog occurred widely in mid-December and late January.

A similar breakdown to that used for the previous season gives Early Warnings issued for 8 severe weather events nationwide (see Table I). Flash Messages issued via CFO accounted for 83 occasions (see Table II).

The difference between the above two seasons is readily seen from a more detailed breakdown of the number of Tier la warnings issued for heavy snow. In 1990/91 there were Early Warnings for four heavy snowfall events for Scotland and three for southern England. This contrasts with only one Early Warning for heavy snow in 1991/92, which was issued for Scotland. There were also 18 Tier 1b warnings for heavy snow issued in 1990/91, together with 7 warnings for icy roads, compared with only 2 heavy snow warnings during the following season. The higher incidence of fog during 1991/92 is also apparent with 30 Tier 1b warnings being issued compared with only 9 the previous season.

4. Analysis of warnings for 1991/92

In order to monitor the performance of the severe weather warning service each Tier 1 warning was assessed to determine whether the information was likely to have been beneficial or misleading to recipients. Warnings are likely to mislead under the following circumstances:

(a) expected severe weather does not occur,
(b) location of severe weather substantially different from that indicated, and
(c) incorrect timing.

4.1 Flash Messages

Flash Messages were issued on 83 occasions and gave specific advice on the location, duration and severity of the weather conditions. Flash Messages are often based upon actual reports of severe conditions to ensure accuracy and high confidence. Even so, around a quarter of the messages provided forecasts of the onset of the conditions up to about six hours ahead, with only 2 subsequently judged to have been false alarms.

4.2 Early Warnings

Early Warnings were issued for 8 widespread severe weather events, only one of which did not occur. This low false-alarm rate is a reflection of the confidence required before an Early Warning is sent. Subsequent analysis of Flash Messages issued during the season suggested that there had, in fact, been a further 13 occasions when severe conditions were sufficiently widespread that an Early Warning could have been issued had confidence been sufficiently high.

In the case of both Flash Messages and Early Warnings the aim is to issue as high a number of correct warnings as possible without this being at the expense of an unacceptable level of false alarms.

5. Case-studies

The operation of the NSWWS can best be illustrated by reviewing two events which occurred in February 1991 and October 1992.

5.1 4–7 February 1991

During this period very cold weather encroached from continental Europe with some heavy falls of snow occurring over many parts of England and Wales. The resulting disruption to transport was widely reported at the time, not least British Rail's problem with the 'wrong type of snow'.

A detailed account of the synoptic events of this particular cold spell is given by Brugge (1991). As early as 1200 UTC on Sunday 4 February reference was made in the medium-range forecast to a spell of very cold weather expected over the United Kingdom. A moderate probability of locally heavy falls of snow due to shower activity near some eastern and south-eastern coasts from Wednesday onwards was stated.

Sequence of warnings (issued by CFO)

(1) The first Early Warning of severe weather issued at 1115 UTC on Tuesday 5 February forecast snow showers over the east coast on Wednesday and the likelihood of prolonged and heavy snowfall over eastern and southern United Kingdom on Thursday and Friday. Disruption to transport was expected as a result. The forecast lead time of the warning was at least 24 hours. This was followed by a Press Release at 1215 UTC advising the public to keep in close touch with weather forecasts and warnings issued on radio and television. The forecast chart issued by CFO for 7 February is given at Fig. 2.

(2) A second Early Warning issued at 1100 UTC on Wednesday 6 February advised that other parts of England and Wales were also likely to be affected by snow. Second Press Release at 1130 UTC.

(3) A third Early Warning issued at 1000 UTC on Thursday 7 February updated the situation and advised of the continuation of snow showers into Friday. Third Press Release at 1115 UTC.

(4) A composite Flash Message was issued at 1515 UTC on Thursday 7 February. This was the first of a sequence advising of the continuation of very severe weather. The synoptic situation close to the time of issue of this first Flash Message is given at Fig. 3. Other Early Warnings were issued on 8 and 9 February forecasting the continuation of the very severe spell with a further 6 Flash Messages being issued between 8 and 12 February giving detailed advice on the extent and severity of the conditions. The Flash Messages were for areas south-east of a line from Derbyshire to Gloucestershire.

Fig. 4 shows the accumulation of snow cover over south-east England between 7 and 10 February. Despite the serious disruption to transport across much of England and Wales between 7 and 12 February because of the snow, it was reported in *The Times* on 13 February that 'local authorities across Britain praised weather forecasters for warning them about conditions'.

5.2 24/25 October 1992

The passage of a deep depression moving east across Wales and central England on 25 October brought severe gales to coastal and exposed parts of Wales and south-west England. The development of this depression was accurately forecast. In the Synoptic Review issued by CFO at 1010 UTC on 24 October it was predicted, for the following day, to become 'notably windy for a time around midday over west Wales and south-west England, these winds then moving quickly across southern England in the afternoon'. The Review stated 'very strong gradients to the rear of the depression will probably meet Flash criteria in exposed places tomorrow in the areas specified above'. A surface prognosis for midday 25 October together with verifying analysis are at Fig. 5

Sequence of warnings

(1) An Early Warning was issued by CFO at 1050 UTC on 24 October. The forecast lead time of this warning was approximately 24 hours.

Text of the warning: 'The passage of a deep depression across Wales and central England is expected to bring a period of very strong winds, initially to west

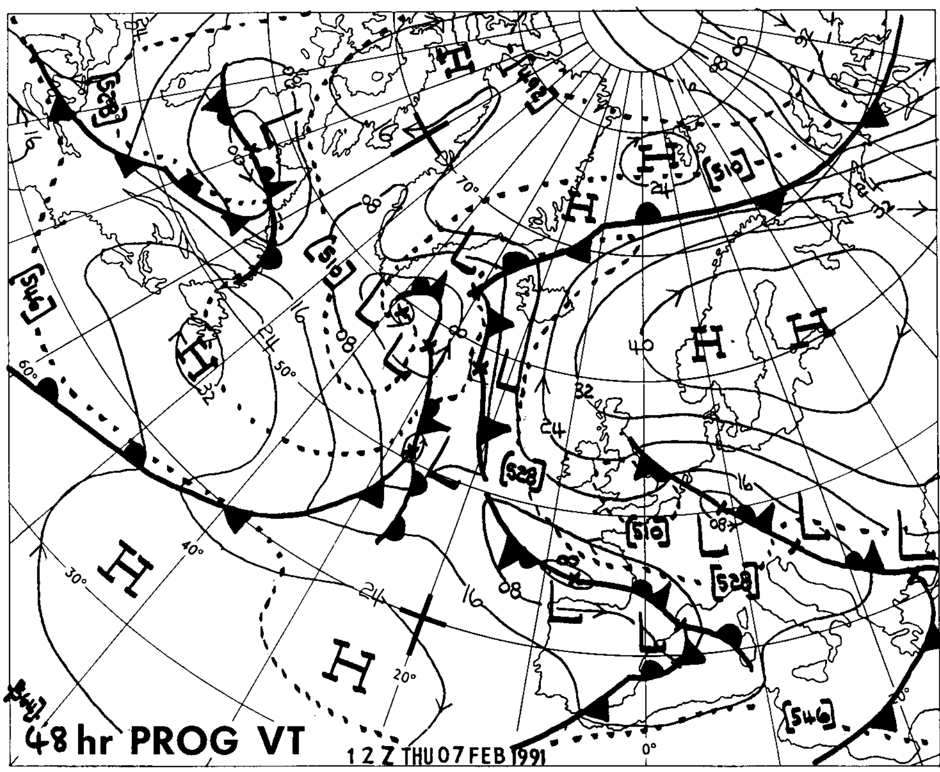


Figure 2. Forecast chart valid for 12 UTC on 7 February 1991 (issued 5 February) (1000–500 hPa thicknesses shown as broken lines).

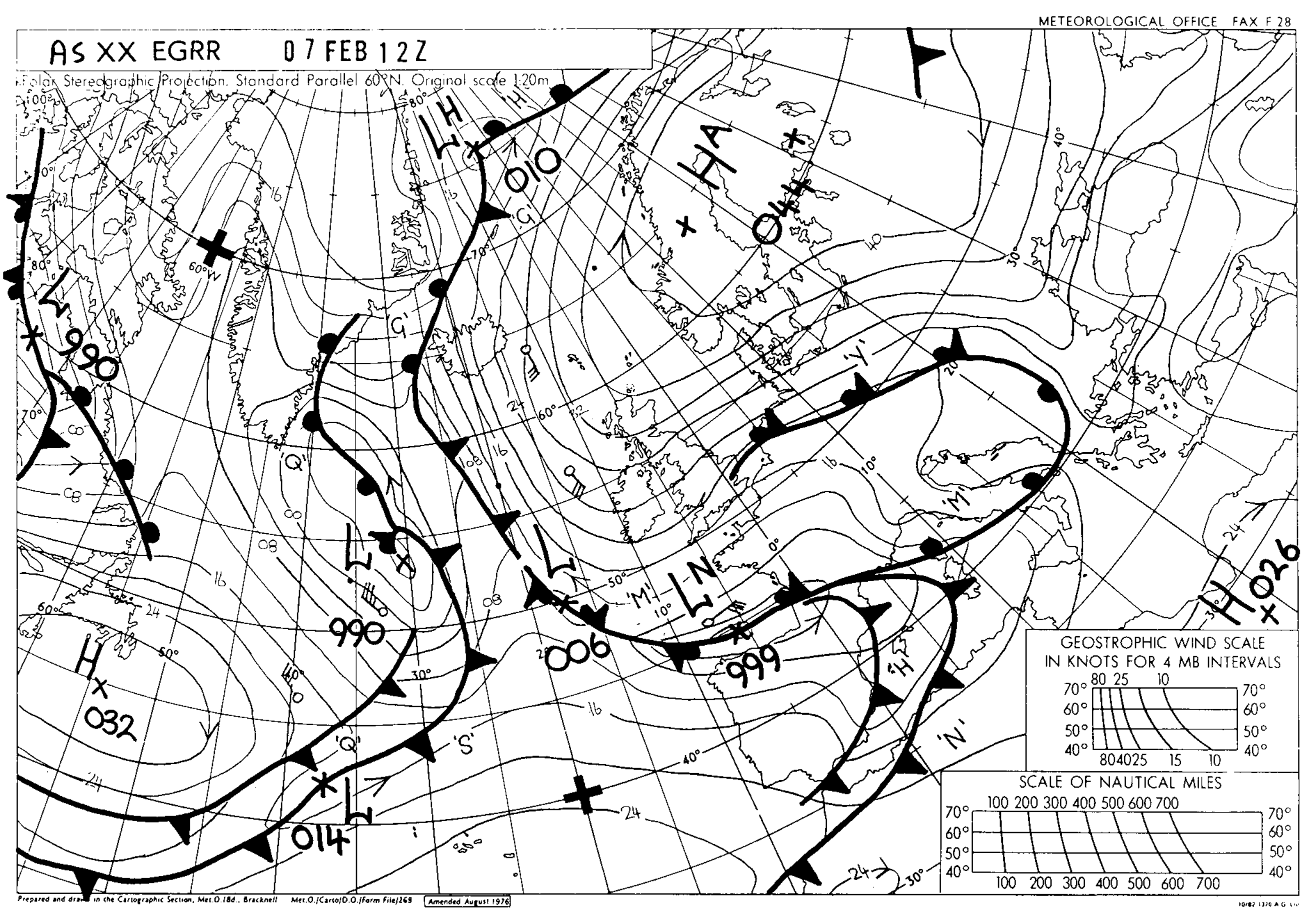


Figure 3. Surface analysis valid for 12 UTC on 7 February 1991.

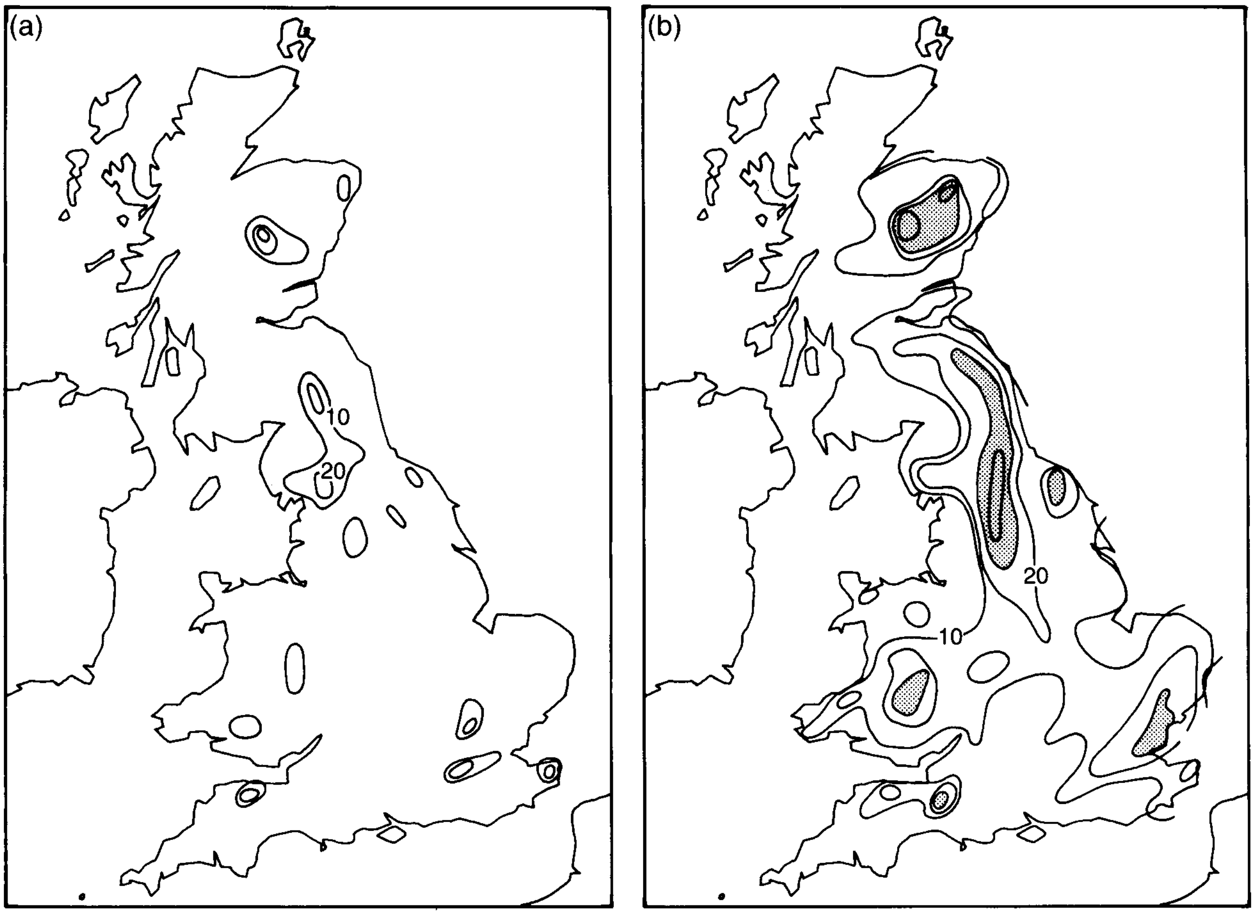


Figure 4. Accumulated snow depth (cm) on (a) 7 February and (b) 10 February 1991. Isopleths at 10 cm intervals with areas ≥30 cm stippled.

Wales and south-west England around midday tomorrow (Sunday). Winds will reach 45 m.p.h. mean speed and gust to 70 m.p.h. During the afternoon, these strong winds will also affect central southern England for a time. Heavy rain will accompany the strong winds. Damage to trees is likely, with minor damage to buildings. Driving conditions will become hazardous'.

(2) A composite Flash Message was issued early on 25 October. It was issued by CFO at 0635 UTC to cover the Cardiff, Bristol and Plymouth Weather Centre areas of responsibility.

Text of the warning: 'Very strong westerly winds associated with a vigorous depression moving quickly eastwards across central Britain will continue to affect much of Wales, south-west England, Avon, Gloucestershire, and Wiltshire today. Gusts of 70 m.p.h. or more may be expected'.

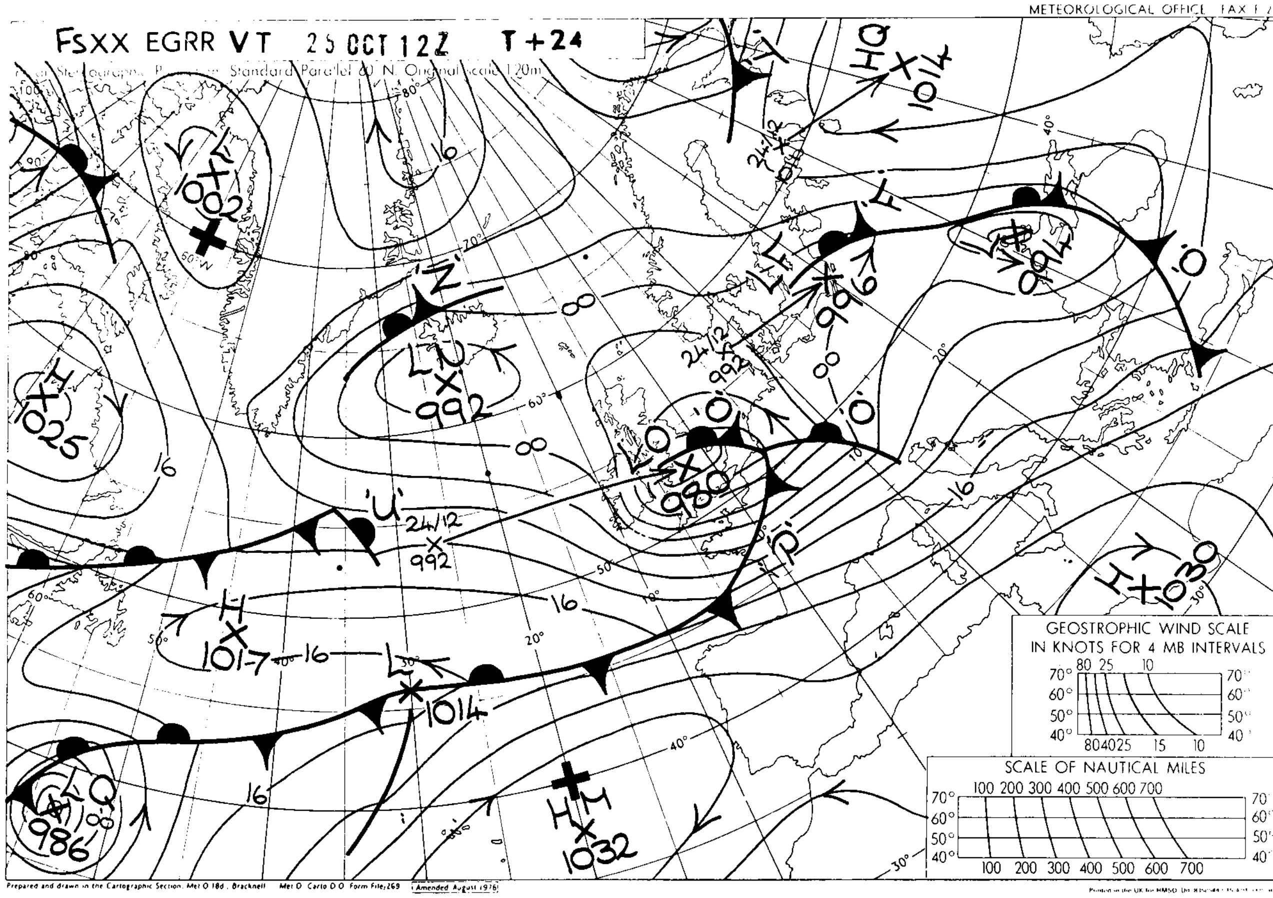
(3) The individual Weather Centres issued Flash Messages for their own areas to coincide with this composite from CFO. Fig 6 gives the maximum gust speeds reported on 25 October 1992 in knots (1 knot = 1.15 m.p.h.).

6. Customer satisfaction survey

The performance of the NSWWS is judged through the satisfaction of its customers. The results of a questionnaire distributed amongst selected emergency authorities in June of this year showed that satisfaction levels were very high with 93% either satisfied or very satisfied with the overall service, and 94% believing the detail of the information to be about right. The survey showed that 34% believed there was a tendency to over-forecast the severity of the conditions although 65% believed the warnings to be correctly forecast. This perception of over-forecasting may be partially related to the receipt of Tier 2 warnings. Of local authorities who receive these 71% identified over-forecasting as a problem. One view shared by recipients, which may also be a factor in the perceived tendency to over-forecast, is that the actual weather conditions experienced often seem to be less severe than those forecast in the warning. This is an understandable comment, the weather at one particular spot can often be different to that experienced at other localities in the area for which the warning is valid.

Severe weather warnings are also valued by the public. Their importance was affirmed by nearly 98% of those surveyed in a recent market research exercise regarding the content of weather forecasts on radio and television.

The first annual report was produced for the year 1991/92 and was distributed to users of the NSWWS, with the objective of providing information and feedback to recipients on principal aspects of the service.



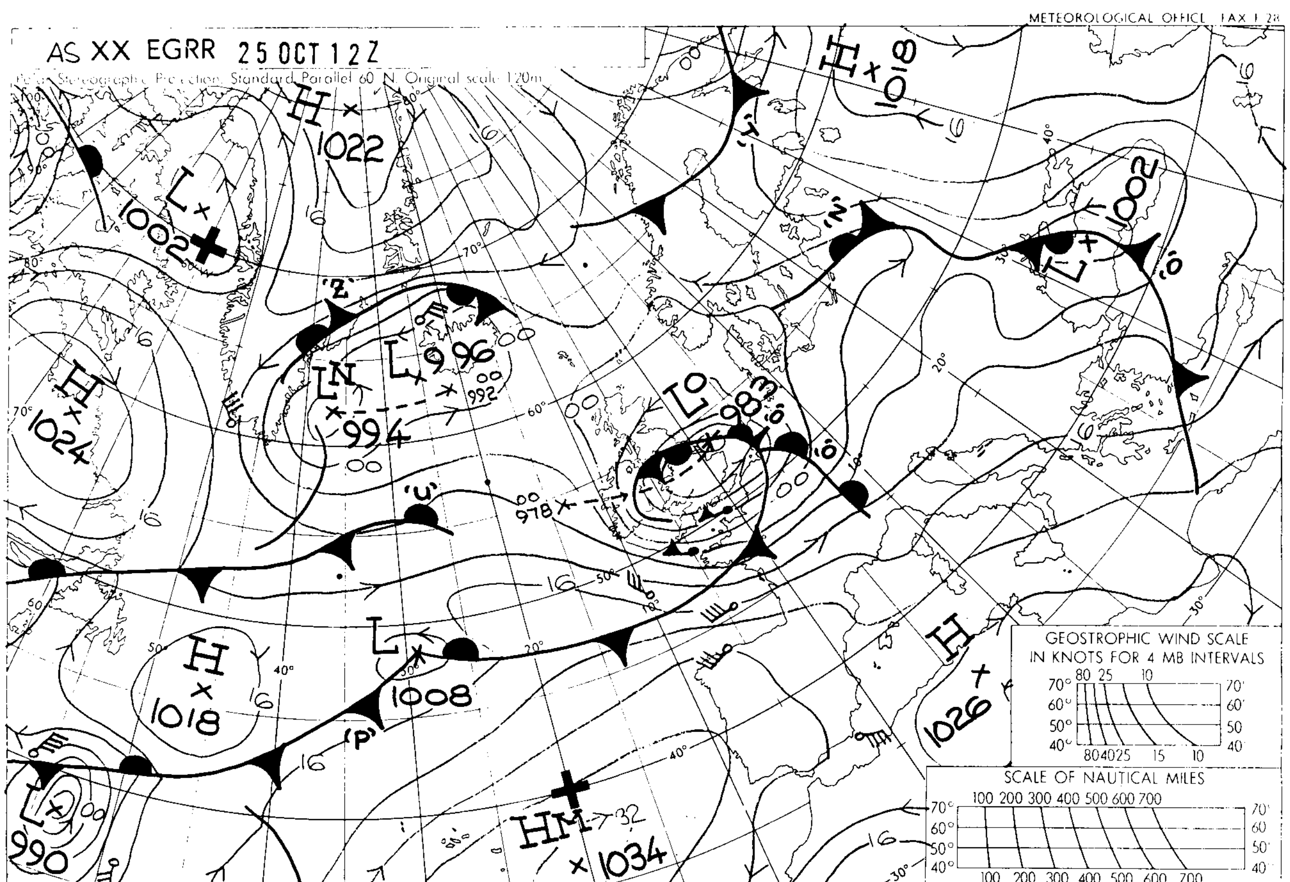


Figure 5. (top) Forecast chart valid for 12 UTC on 25 October 1992 (issued 24 October), and (bottom) surface analysis valid for 12 UTC on 25 October 1992.

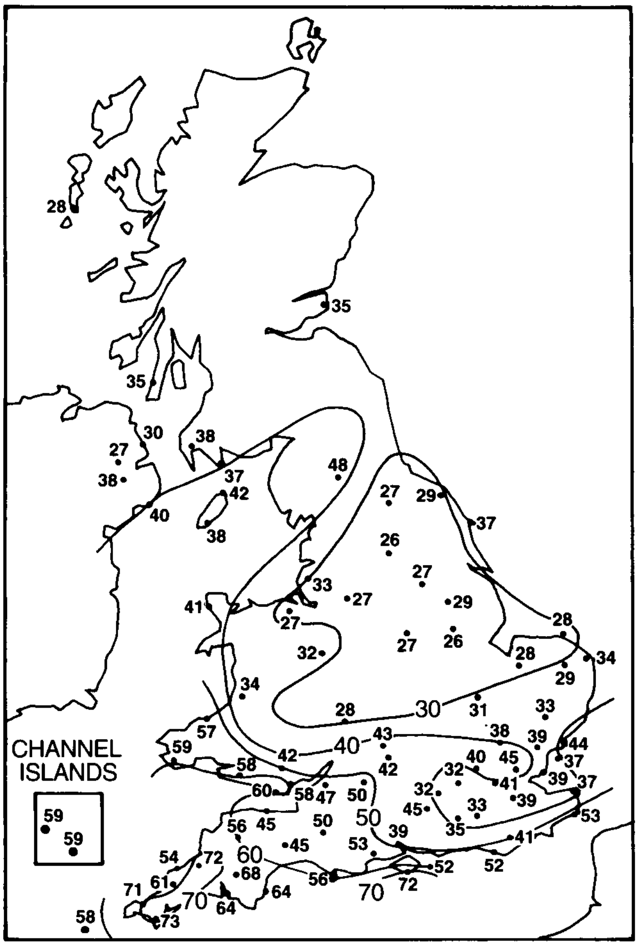


Figure 6. Maximum gusts reported on 25 October 1992.

7. Recent developments

The most recent development of the service was the introduction of Emergency Flash Messages from April 1992. These warnings are issued by CFO only when exceptionally severe conditions are expected to occur over a wide area, i.e. gusts of 80 m.p.h. or more or very heavy snow giving depths of 30 cm or more. The messages are intended to receive a greater degree of prominence from the national media.

A table of damage and advice for severe weather warnings has been constructed to assist in the phrasing of such advice and is attached at Appendix B. This was done with advice from the Forestry Commission and Building Research Establishment. The intention is to give the best possible advice to the public on the damage which can be expected, particularly those aspects likely to pose a danger to life.

Reference

Brugge, R., 1991: The cold snap of February 1991. *Weather*, **46**, 222–231.

Appendix A

Criteria

Tier 1 Warnings (Severe Weather Warnings)

The overriding criterion for the issue of warnings is the **strong likelihood** of severe weather which may cause **considerable inconvenience** to a large number of people and/or present a danger to life. Early warnings are only issued when such conditions are expected to cause disruption over a wide area.

The conditions set out below give guidance concerning the severity of the weather likely to meet this criterion.

(a) Gales
  (i) Severe gales — gusts of 70 m.p.h. or more.
  (ii) Severe gales/storms — gusts of 80 m.p.h. or more
(b) Snow
  (i) Heavy snow — snow falling at a rate of approximately 2 cm per hour or more expected for at least two hours.
  (ii) Blizzards/drifting — moderate or heavy snow accompanied by winds of 30 m.p.h. or more with visibility reduced to 200 m or less, or lying snow with strong winds giving rise to similar conditions.
  (iii) Very heavy snowfall, blizzards or drifting — expected to give depths of 30 cm or more potentially resulting in widespread dislocation of communications.
(c) Heavy rain — rain expected to persist for at least two hours giving a fall of 10 mm or more.
(d) Dense fog — visibility generally less than 50 m.
(e) Glazed frost/widespread icy roads — generally occurs when rain freezes on contact with road surfaces.

Notes
Early Warnings and Flash Messages of severe weather are issued for:
(a) Gales.
(b) Snow.
(c) Heavy rain.

Flash Messages only are issued for:
(d) Dense fog.
(e) Glazed frost/widespread icy roads.

Early Warnings and Emergency Flash Messages of exceptionally severe weather are issued for:
(a) Severe gales/storms.
(b) Very heavy snowfall, blizzards or drifting

Tier 2 Warnings (Hazard Messages)

These less stringent warnings are intended to advise of hazardous conditions which might present the emergency authorities with potential operational problems. The prime concern is of adverse weather conditions affecting road traffic. The conditions for the issue of the warnings are:

(a) Strong winds with mean speeds and/or gusts of 35 m.p.h. or more.
(b) Snow.
(c) Heavy rain persisting for at least one hour or a period of moderate rain expected to give more than 15 mm in ten hours or less.
(d) Fog with visibility less than 200 m.
(e) Icy roads.

Appendix B

Tables of damage and advice for severe weather warnings

Table I. Wind warnings.

50 m.p.h. gusts — Tier 2
- Difficult driving conditions for high-sided vehicles, especially on exposed roads or bridges.

60 m.p.h. gusts — Tier 2
- Difficult driving conditions: unladen high-sided vehicles at risk of being overturned
- Some damage to trees, e.g. falling branches.

70 m.p.h. gusts — Tier 1
- Hazardous driving conditions: unladen high-sided vehicles at risk of being overturned and motorists advised to drive with particular care.
- Damage to trees, e.g. falling branches, with some being uprooted.
- Minor damage to some buildings, particularly to tiles, slates and chimneys.

80 m.p.h. gusts — Tier 1
- Dangerous driving conditions: high-sided vehicles at risk of being overturned and motorists advised to avoid driving if possible.
- Considerable damage to trees with significant tree uprooting.
- Extensive minor damage, particularly to tiles, slates and chimneys, and structural damage to some buildings.

90 m.p.h. gusts — Tier 1
- Driving extremely dangerous.
- Widespread uprooting of trees.
- Widespread damage to buildings with potential for severe structural damage.
- Public advised not to venture out of doors unless really necessary.

Table II. Snow warnings

Snow — Tier 2
- Difficult driving conditions.

Heavy snow — Tier 1
- Dangerous driving conditions.
- Motorists advised to avoid driving if possible.

Blizzards or severe drifting — Tier 1
- Driving extremely dangerous.
- Some roads likely to become impassable.
- Public advised not to venture out of doors unless really necessary.

Table III. Other warnings

Heavy rain, fog or icy roads — Tier 2
- Difficult driving conditions.

Heavy rain, dense fog or widespread icy roads/glazed frost — Tier 1
- Dangerous driving conditions.
- Motorists advised to use extra care.
- Localized flooding (in association with heavy rain).

Editor's note: the following article is a transcript of a talk given by the author to the Royal Meteorological Society at its meeting on 18 November 1992 at Imperial College, London. The opinions expressed are not necessarily shared by The Meteorological Office and may, in part, have been designed to provoke discussion!

551.509.58:622.24

The evolution of weather forecasting services for the offshore industry in developing countries — from the stone age to the space age.

N. Lynagh
Managing Director, Noble Denton Weather Services Limited

(The author would like to acknowledge the great help received in preparation of this talk from Mr. David Hibbert, former owner and Managing Director of IMCOS Marine Ltd.)

Good afternoon ladies and gentlemen. When I started preparing this talk it very quickly became apparent that I had enough material for a talk lasting 2–3 hours. I have therefore had to be very selective, with the aim of giving something of a flavour of how weather forecasting services for the offshore industry evolved in developing countries. I'll also give my views on where I think we are today and how I think weather services to the offshore industry can be improved.

The offshore oil and gas industry is less than 50 years old. It was only after the Second World War that the first serious attempts began in the search for oil and gas under the sea. These earliest moves offshore were in the Gulf of Mexico and immediately created a demand for a new type of weather forecast service — that is, site-specific forecasts of wind and sea state for as far ahead as possible. That is still the requirement today. In the USA there was, of course, even at that time a relatively well-established meteorological infrastructure. Nevertheless, there was no forecast service which met the needs of this new offshore industry. A few entrepreneurial consultants soon set themselves up to fill this gap and there is no doubt that the leader was Al Glenn. Al, with a few associates, began providing a specialist forecast service for the embryonic offshore industry in 1946, and in 1948 they pioneered the concept of on-site forecasters working offshore. As far as I know Al Glenn is still active in the industry today.

Following fairly closely behind the developments in the Gulf of Mexico, the oil and gas industry soon began to 'get its feet wet' in other parts of the world, notably in the Arabian Gulf. For the meteorologist at that time such areas of the world might almost have been on another planet. There was no well-established meteorological infrastructure and the distribution of synoptic reporting stations was very sparse indeed.

One of the first offshore operators in the Arabian Gulf was Shell, based in Doha and using the jack-up rig MU-2. Shell were certainly conscious that there was a potential threat to the safety of this rig from the weather during location moves. As there was no worthwhile weather service available to them they established weather reporting stations themselves at Ras Rakan and Halul Island and also stationed a workboat between Qatar and Bahrain to report the weather during rig-moves. All these reports were limited to wind only and the assumption was that if all 3 had light winds it was safe to carry out the move. This was a meteorological version of Russian Roulette!

On only its third location move, during 27–28 December 1956, the rig was struck by a sudden storm whilst under tow. The rig sank with some loss of life and was a total loss. Clearly there was a need for a better forecasting service for such weather-sensitive marine operations. This loss was the trigger for that.

At that time a British company, International Meteorological Consultancy Services (better known as IMCOS) was well established in London. Its Director and owner, David Hibbert, happened to know Tom Gaskell of BP who were about to commence offshore operations off Abu Dhabi. They were cooperating with Shell in Qatar and the upshot of this contact was that IMCOS was invited to initiate a marine weather forecast service for Shell and BP in the Gulf, in 1957. The first temporary forecast office was set up on Das Island.

One problem which had to be solved very quickly was the sparsity of weather observations from within the Gulf. IMCOS encouraged co-operation amongst the growing number of operators in the area and set up an organization which eventually became known as the Oil Companies Weather Co-ordination Scheme. By 1959 this scheme had 8 members and it grew to a maximum of around 20 by the early 1980s covering all countries with a Gulf coastline. Under the scheme, the members took regular weather observations from their operating sites and fed them into a communications network which

IMCOS developed. Most of these communications were by voice and the aim was to get all the observations to the collecting centre in Doha.

IMCOS forecast offices proliferated and were set up at a number of locations in the Gulf. Some which come to mind were at Kuwait, Abadan, Kharg Island, Bushehr, Ras al Khafji, Ras Tanura, Bahrain, Doha, Lavan Island, Das Island, Abu Dhabi and Dubai (Fig. 1). The forecast offices were almost all one-man-band offices, totally dependent on radio-teletype for their information.

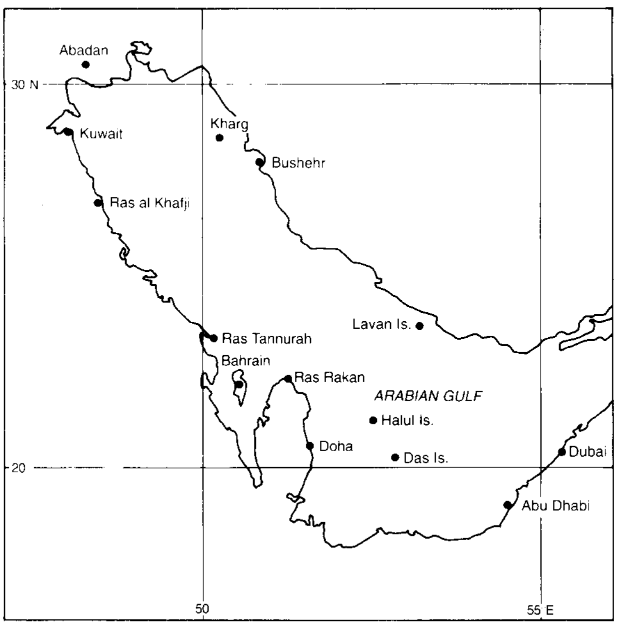


Figure 1. Map showing IMCOS offices in the Arabian Gulf.

To provide these forecast offices with the collection of observations from the Gulf and also with the growing amount of information coming from the rest of the Middle East region, IMCOS set up its own radio-teletype transmitting station in Doha. Much later this moved to Bahrain. It was known as IMCORTT (Fig. 2).

The 1960s and 1970s were the heyday of the single-operation forecast office. Although by no means the only player in the field IMCOS Marine Ltd. was perhaps the leader and over a period expanded all over the world and had forecast offices established in more than 20 countries. Each one of these was a totally independent office, usually staffed by only one man and either looking after a single operation or a group of operations for one client. In most cases the forecaster was collocated with the main operational decision maker or, at worst, he had very good telephone or radio contact with him.

To obtain the necessary data and products the forecasters were totally reliant on radio-teletype and radio-fax. They had to be extremely self-sufficient and were expected to arrive in some godforsaken part of the world with a dozen or so boxes of equipment, unpack them, install the equipment and be up and running as an operational forecast office all within 24 hours of arrival. This contrasts with the 18 days* it took for the Meteorological Office Mobile Meteorological Unit to become operational in Bahrain during the Gulf War a couple of years ago. The operational requirements were, of course, very different and the technology has become much more complex. The fact is, you do not need all that much to become operational. The bells and whistles are nice to have but they are not essential.

The supply of forecasters with the right sort of attitude and the right sort of training and experience was, and still is, limited. To help satisfy its growth requirements during the 1970s IMCOS established its own Forecaster Training School in Aberdeen where meteorological graduates were given specialist training in marine forecasting. Following training they were employed as assistant forecasters until they were ready to take a full role in the company's worldwide business which was, by then, very extensive.

A little earlier I made the point that a forecast office can be established with minimal facilities. I'll illustrate this now with a few examples. I worked regularly on the drill ship *Sedco 445* for 3 years in the early 1970s while it drilled in various locations all over the world. It was a prototype ship for drilling in deep water, a test bed for all the new equipment and in the early 1970s it pushed the water depth record beyond 4000 ft.

The weather forecast office on the rig was located in a corner of the chartroom (Fig. 3). There were two radio-teletype sets and one radio-fax. That was it. That was all that was needed to provide an efficient weather forecast service. To be located at the operational site was the key. That was invaluable and greatly outweighed any disadvantage resulting from the limited data supply. Two forecasters were assigned to the rig and the general system was to work one month on, one month off. During his month on the rig the forecaster was on call 24 hours a day and during periods of threatening weather sleep was often in short supply. Living with the weather like this resulted in a very high level of job satisfaction and this was reflected in the high quality of service provided.

Going back to earlier times, in the 1960s IMCOS established on-site forecast offices in some very primitive conditions in Brazil. The concept was the same — very basic, simple radio-teletype and radio-facsimile equipment enabling each office to become operational very quickly.

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* *W.R. McQueen MBE, MMU writes*
The comparison is wrong. Under normal circumstances the MMU can be 'up and running' almost immediately. We have very good communications equipment which allows us to connect very rapidly to our own dedicated radio-teleprinter and facsimile broadcasts. During periods of military conflict of course the security of meteorological information and output becomes especially important (for both sides), therefore the establishment of secure lines of communication was essential. One of the guiding principles during the build-up to the Gulf conflict was to ensure that everything was in position and ready to go before the expiry of the deadlines. Haste was not required.

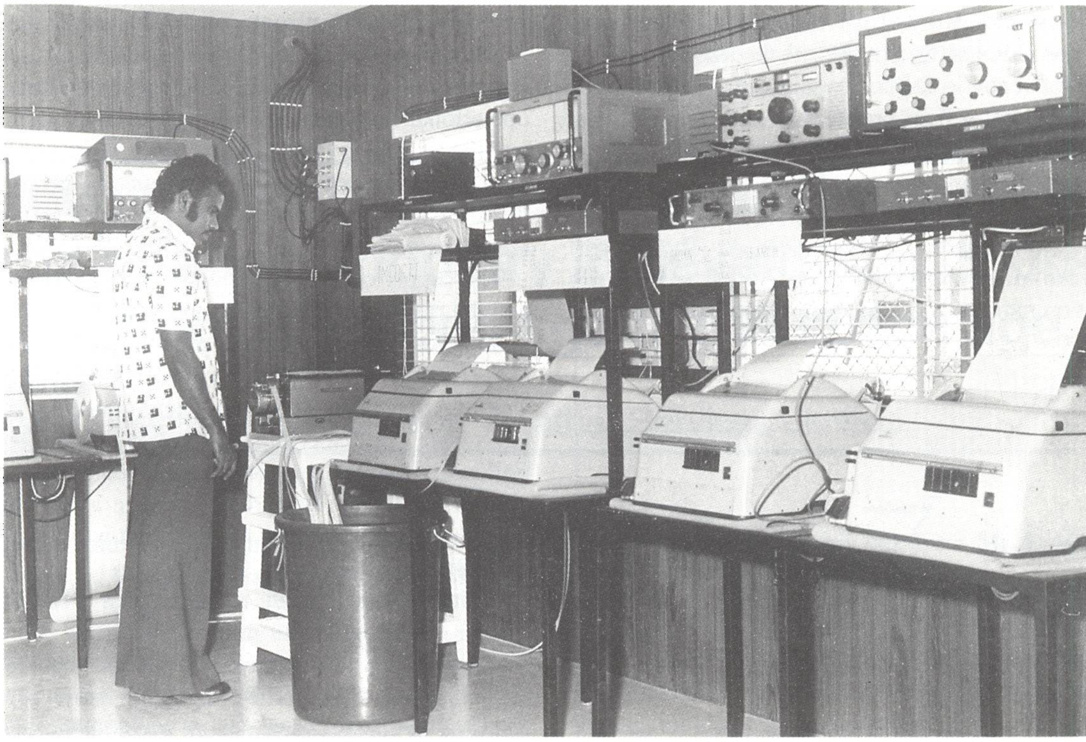

Figure 2. IMCOS radio station on Bahrein.

Figure 3. Weather forecast office aboard *Sedco 445*.

In 1970, the Italian oil company, AGIP, began an exploration campaign in the South China Sea, north of Natuna Island using the drill ship *WODECO VII* (Fig. 4).

Because of distance, the only possible location for helicopter support was Natuna Island itself so the main shore facilities were set up there. The operation was certainly exposed to a significant threat from the weather, being at the southern edge of the typhoon belt and also being totally exposed to the NE monsoon. AGIP therefore decided they needed to have a dedicated weather forecast office at the shorebase on the island. Again, the

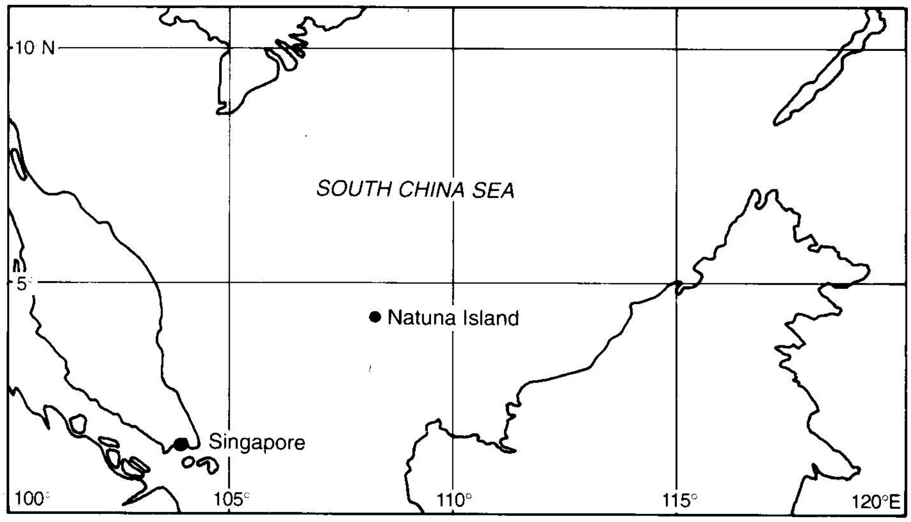

Figure 4. Map showing location of Natuna Island.

equipment in the office consisted of 2 radio-teletype terminals and one radio-fax, each forecaster did 2–3 months on the island at a stretch and was on call 24 hours a day. He had the great advantage of being in constant radio contact with the rig. His office adjoined the radio room and his accommodation was only about 20 paces away (Fig. 5). He could talk to the rig at any time and the personnel on the rig could talk to the forecaster whenever they wanted to. This was taking the meteorology to the client.

During the latter part of the 1970s and, more particu larly, in the 1980s, meteorological communications improved greatly making it much easier to obtain data covering a wider area. Also, the advent of satellite communications suddenly made it possible to transmit forecasts from any point to suitably equipped offshore installations anywhere in the world. As a result there has been a gradual process of centralization with further expansion of meteorological services coming mainly through a relatively small number of large forecast offices while the number of small offices dedicated to single operations has probably decreased.

It would be very difficult to check in detail but I suspect that today throughout the world there are fewer

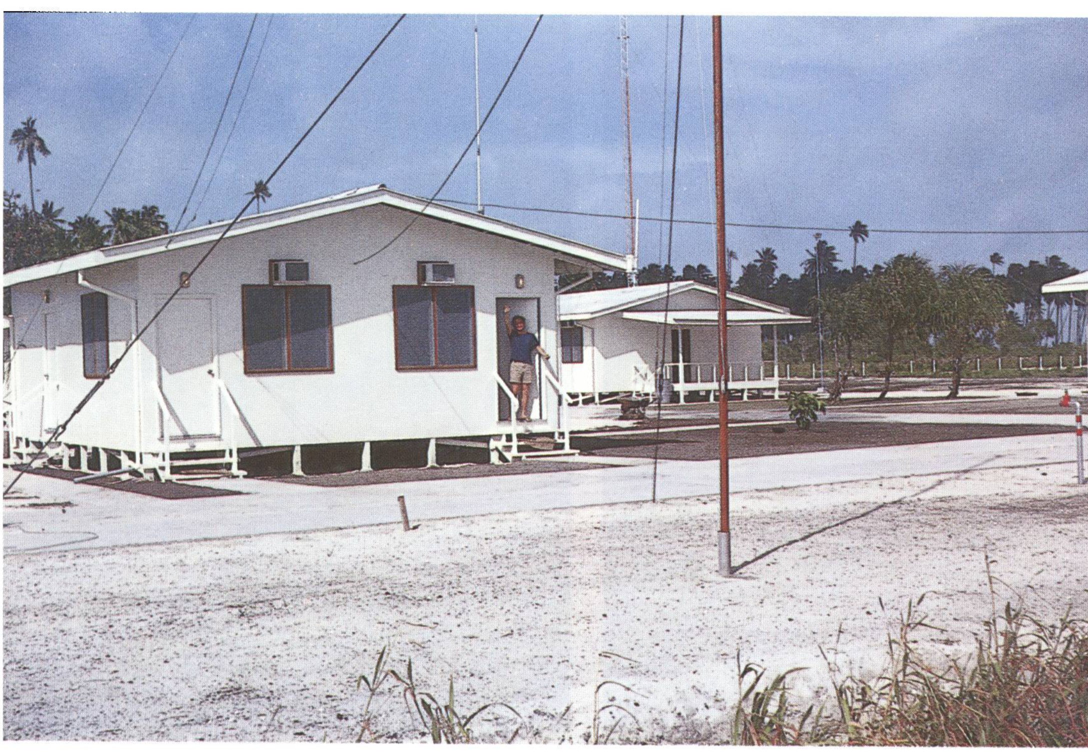

Figure 5. Weather forecast office on Natuna Island in 1972.

weather forecast offices dedicated to the offshore industry that there were 20 years ago even though the industry has grown enormously in that period. Taking a very narrow accountants' view this may seem to be a movement in the right direction with increased efficiency resulting in a reduced unit cost. I don't think it's as simple as that because the quality of service suffers. Forecasters are being required to handle an ever-increasing number of operations per shift. More and more reliance has to be placed on automation and on computer products which are often of doubtful accuracy in the context of site-specific forecasts of wind and sea state. There's not enough thinking time today and less of the one-to-one contact which used to be the hallmark of weather services in the offshore industry.

It is worrying that the number of major losses in the industry directly attributable to the weather appears to be on the increase. Even more worrying is the fact that when these losses are examined in detail a common thread running through many of them is that they occurred when weather sensitive operations were being carried out in weather patterns unsuitable for such operations, that is in weather patterns in which there was a threat that severe weather might occur, even though it was by no means certain and was perhaps not even the most probable development. The fault appears to lie in lack of adequate communication between the weather forecasters and the decision makers. Following these losses the decision makers often claim they were unaware of the threat. The quality of the meteorological advice available is, potentially at least, much better than 20 years ago but we seem to be failing to get the story across to the user properly in some cases. If we were to get back to the situation where each weather sensitive operation had its own dedicated forecaster I am convinced that most of the losses could be eliminated. Ideally, the forecaster and the decision maker should be collocated as was often the case in the past but, if not, the forecaster can be anywhere provided there is good communication between him and the decision maker.

Unfortunately we live in an age where accountants tend to call the tune. In the award of contracts cheapest price is often considered more important today than level of service. This has encouraged competitive pricing amongst the various weather forecast suppliers resulting in centralization to achieve economies of scale. In terms of meteorological capability we are far ahead of where we were 20 years ago and can provide much more accurate information to operators in developing countries. Nevertheless in my opinion, we do not have sufficient forecasters living in the pockets of marine superintendents around the world. That's where we should be — at the scene of the action.

For any given level of meteorological capability an individual client gets the best possible service if the forecaster has only his single operation to consider. As soon as the forecaster has two or more operations to consider the quality of service to each one begins to suffer — the bigger the number of operations the poorer the service to each one.

To ensure the highest level of safety in operations the offshore industry needs a meteorological consultancy service, not merely a weather forecasting service. There is a great difference.

The concept of weather forecast offices dedicated to single operations is by no means dead and there are quite a number of these still operating around the world. Nevertheless, they represent a decreasing percentage of the total weather services provided to the offshore industry. I consider this to be a backward step which is having a negative impact on safety. The onus is on us, the meteorologists, to convince the operators of that and get them to ease their purse strings just a little. The price of increasing safety margins is small but the potential cost of not doing so is very high. We must convince them of that.

From the Editor

Big storm on Eastern Seaboard

Over the weekend of 13/14 March 1993 'the worst storm of the century' moved from the Gulf of Mexico to the Denmark Strait leaving a trail of broken records. If any reader was caught up in this storm and can let me have their experience in writing, or local newspaper stories, before the end of May, I would consider incorporating them in the weather notes for March. Photographs (with copyright release) will be especially welcome.

A New Moon

In the January 1993 issue I reported that a large reflector was to be launched into space in February. I have since read that it was successfully unfurled and the bright flash was widely seen during the next few hours. Other tasks on board the spacecraft were advanced and the reflector was allowed to start tumbling out of control after a few orbits. The experiment was regarded as a success.

Rime and hoar-frost depositions

W.S. Pike
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The recent cold spell of Christmas weather over southern United Kingdom (which lasted from 21 December 1992 to 3 January 1993 in west Berkshire) produced some interesting opportunities for the photographic study of rime and hoar-frost deposition.

Fig. 1 was taken in an open field where puddles in farm tractor 'ruts' had desiccated or drained away from beneath the frozen, solidified surface. Ice begins to form from the edges of a puddle of water inwards, and this thickens into ridges where these 'frost feathers' have first crystallized; the puddle is not, therefore, a completely flat surface. This photograph shows that these ice ridges have been of sufficient amplitude to have captured some rime at 1135 UTC on 24 December 1992, after an 18-hour period of freezing fog, during which the local minimum air temperature fell to −6 °C the previous night.

Fig. 2 shows east-facing 2 cm accretions of translucent rime on a twig (in the author's garden) at 1338 UTC on 2 January 1993. An overnight minimum temperature of −5 °C had occurred in freezing fog, which was slowly lifting into low stratus by 1230 UTC. Visibility had improved to 1500 m temporarily by 1338 UTC when, although the dry-bulb was still reading near −1.5 °C, a little thawing was occurring on most surfaces, probably due to radiation beneath the lifting low-cloud layer. Hence, this rime did not have the same sharp, 'fresh-frozen', crystalline appearance (as in Fig. 4 of Pike (1992)).

Although freezing fog returned during the late afternoon and evening, this fog and all low cloud dispersed again overnight, allowing a steady fall of air temperature to reach a minimum of −7 °C by soon after dawn. During these clear, near-calm conditions, a heavy hoar-

Figure 1. Rime-covered ice ridges on a puddle in a harvested maize field at Woodlands St Mary, 1135 UTC on 24 December 1992.

Figure 2. Two centimetres of translucent rime on a twig at 1338 UTC on 2 January 1993.

frost deposition occurred onto the pre-existing rime, resulting in trees being coated with an opaque frosting (see Fig. 3) which produced a natural 'Christmas card effect'. Close inspection (see Fig. 4, taken at 0953 UTC on 3 January 1993) revealed the 'icing sugar' to have sharp, hoar-frost needles which had grown out horizontally (or near-horizontally) into the prevailing easterly 'drift' of air.

Further to the concluding remark expressed in Pike (1992), these frost needles can be interpreted as further evidence of accretion (rather than condensation) of microscopic water vapour droplets into hoar-frost depositions.

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Figure 3. Trees covered by 'icing sugar' effect of hoar-frost on pre-existing rime at Woodlands St Mary (view to north along Inholmes Road) at 0948 UTC on 3 January 1993.

Figure 4. Close-up view of hoar-frost deposition showing ice needles. Woodlands St Mary at 0953 UTC on 3 January 1993.

Richardson's Forecast factory: the $64 000 question

P. Lynch
Meteorological Service, Dublin

Lewis Fry Richardson served as a driver for the Friends' Ambulance Unit in the Champagne district of France from September 1916 until the Unit was dissolved in January 1919 following the cessation of hostilities. For much of this time he worked near the front line, and during the Battle of Champagne in April 1917 he came under heavy shelling (Ashford 1985). It is a source of wonder that in such appalling inhuman conditions he had the buoyancy of spirit to carry out one of the most remarkable and prodigious calculational feats ever accomplished. During the intervals between transporting wounded soldiers back from the front he worked out by manual computation the changes in the pressure and wind at two points, starting from an analysis of the condition of the atmosphere at 0700 UTC on 20 May 1910. Richardson described his method of solving the equations of atmospheric motion and his sample forecast in what has become the most famous book in meteorology, his *Weather Prediction by Numerical Process* (Richardson 1922). The unrealistic values which he obtained are a result of inadequacies and imbalances in the initial data, and do not reflect any flaw in his method, which is essentially the way numerical forecasts are produced today.

How long did it take Richardson to make his forecast? And how many people would be required to put the method to practical use? The answers to these two questions are contained in section 11/2 of his book, but are expressed in a manner which has led to some confusion. On page 219 under the heading 'The speed and organization of computing' Richardson wrote:

'It took me the best part of six weeks to draw up the computing forms and to work out the new distribution in two vertical columns for the first time. My office was a heap of hay in a cold rest billet. With practice the work of an average computer might go perhaps ten times faster. If the time-step were 3 hours, then 32 individuals could just compute two points so as to keep pace with the weather ...'.

Could Richardson really have completed his task in six weeks? Given that 32 computers working at ten times his speed would require 3 hours for the job, he himself must have taken some 960 hours — that is 40 days or 'the best part of six weeks' working flat-out at 24 hours a day! At a civilized 40-hour week the forecast would have extended over six months. It is more likely that Richardson spent perhaps ten hours per week at his chore and that it occupied him for about two years, the greater part of his stay in France.

Now to the question of the resources required to realize Richardson's dream of practical forecasting. Quoting again from page 219 of the book:

'If the coordinate chequer were 200 km square in plan, there would be 3200 columns on the complete map of the globe. In the tropics the weather is often foreknown, so that we may say 2000 active columns. So that $32 \times 2000 = 64\ 000$ computers would be needed to race the weather for the whole globe. That is a staggering figure'.

It is indeed staggering, when we recall that these 'computers' were living, feeling beings, not senseless silicon chips. Richardson proposed taking 128 chequers or grid-boxes around each parallel and 100 between the poles. This gives a grid cell which is roughly a square of side 200 km at 50° north and south. He outlined a scheme for reducing the number of chequers towards the poles but made no allowance for that in the above reckoning. His claim that 3200 columns or chequers would cover the globe has been questioned by Sydney Chapman in his Introduction to the Dover Edition of *Weather prediction by numerical process:*

'As to Richardson's estimates of the time and cost of full application of his methods, he made an uncharacteristic error in giving 3200 as the number of squares ... to cover the globe. His number is only a quarter of the true value, so that his required staff and his cost estimate must be quadrupled'.

So, Chapman's estimate of the staff required is $4 \times 64\ 000 = 256\ 000$. However, this is not entirely correct. The envisaged computational grid would indeed have required $128 \times 100 = 12\ 800$ chequers for global coverage — four times the value stated by Richardson. But Richardson considered the grid-boxes in pairs, one for mass and one for momentum, and it was such a pair for which he made his sample forecast and upon which he based his estimates. Thus, 6400 pairs of chequers would cover the globe and, with 32 people working on each pair, a total horde of 204 800 would be involved in a bid to race the weather for the whole globe. That is a stupendous figure!

So where did Richardson come by the figure of 3200 chequers to cover the globe? The error is inescapable but is not, I believe, a numerical slip. Richardson intimated that the weather in the tropics was sufficiently steady for variations to be neglected. But in such a case the global forecasting problem falls neatly into two parts and it is natural to consider each hemisphere separately. The northern hemisphere can be covered by 3200 *pairs* of columns. Assuming with Richardson that the values at 1200 pairs may be prescribed and assigning 32 individuals to each of the remaining pairs, one finds that 32 × 2000 = 64 000 souls are needed to race the weather *for the extratropical northern hemisphere.*

If this is what Richardson intended, his 'uncharacteristic error' was not an arithmetical howler but a lapse of expositional precision. For his staggering figure of 64 000 is clearly stated to refer to *the whole globe.* Later in the paragraph he speaks of a forecast-factory for the whole globe (in fact, the word 'globe' occurs five times on page 219). In his wonderful fantasy of a theatre full of computers, the tropics 'in the upper circle' are treated on an equal footing with the temperate and frigid zones. Given that Richardson's assumption of constancy of tropical weather was over-optimistic, a full complement of 32 computers for each pair of columns in his *forecast-factory for the whole globe* would have provided work for 204 800 people.

Even this vast multitude could compute the weather only as fast as it was evolving. To obtain useful and timely predictions, the calculations would need to go several times faster than the atmosphere. Allowing for a speed-up factor of five, the establishment of a 'practical' forecast-factory would have reduced the ranks of the unemployed by over a million.

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Some analogous synoptic features associated with the ozone minima over the north-west Pacific and south-east Asia

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Summary

Global minima in total ozone occur over the north-west Pacific during the active winter monsoon period and over south-east Asia during the active summer monsoon period. The earth's highest tropopause level appears during the occurrence of ozone minimum over these regions. Further, the earth's coldest monthly mean temperature at around the 100 hPa level during the corresponding months of ozone minimum is also seen there. The data for outgoing long-wave radiation for the earth show minimum values over the north-west Pacific during January and over south-east Asia during July indicating deep convection over these areas. The monthly mean of rainfall takes the highest global value during this period. An interpretation is offered that the thickness of the ozone-rich layer in the lower stratosphere is reduced by the overshooting of tropospheric ozone-poor air by intense convective activities.

1. Introduction

The influence of meteorological processes on the normal distribution of total ozone has been pointed out by many workers (e.g. Dobson *et al.* 1946, Reed 1950; Ramanathan 1963; Schoeberl 1983; Tung 1986; Chimonas 1987; McKenna *et al.* 1989; Gary 1989, etc.). Their studies reveal that chemically produced ozone can be redistributed due to dynamical transport in the atmosphere. In my earlier work (Hingane 1990), it has been seen that, during the middle part of monsoon season (i.e. July and August), the values of ozone at subtropical stations such as Delhi (29° N, 75° E) and Varanasi (25° N, 83° E) are lower than those at tropical stations such as Kodaikanal (10° N, 78° E) and stations lying outside the monsoon trough area. This anomaly is then defined as an 'ozone-valley' in the subtropics. The qualitative analyses of corresponding meteorological processes showed that the occurrence of an ozone-valley may be a manifestation of dynamical processes.

The distribution of total ozone (monthly average) over the earth, has been presented by WMO (1985), Bowman and Krueger (1985) and Ghazi (1980). The existence of a climatological ozone minimum in the tropics is well known. It is, however, seen from the above studies that during the winter monsoon season, a distinct low in the distribution of total ozone appears over the maritime regions of Taiwan and the Philippines (north-west Pacific), and another over south-east Asia during the active summer monsoon season.

The interannual variability in various meteorological parameters would be produced by non-linear interaction among the various kind of forcing functions and transient disturbances. The influence of climate anomalies like El-Niño on monsoon circulation is well documented. Similarly, periodic meteorological phenomena such as quasi-biennial oscillation (QBO) show significant roles in monsoon circulation. The work of Ramanathan (1963), Angell and Korshover (1964), Oltmans and London (1982), Hesebe (1984), etc. have reported the existence of an equatorial QBO in temperature, total ozone, and tropopause height which is well related to QBO in equatorial zonal winds. In our study of year-to-year variability in the seasonal average of total ozone, tropopause height, and rainfall, it can be seen that during the wet monsoon period, most of the stations over India show negative anomalies in total ozone and positive anomalies in the tropopause height. For example, during the monsoon season (June–September) of the years 1975 and 1988, India received respectively 27% and 18% higher rainfall than normal. July and August of the same years showed an 8–10% decrease in the monthly mean of total ozone, and a 1.5–2.5 km increase in tropopause height. Therefore to obtain the ideal value of the normal for the above parameters, a long-term homogeneous data set (about 30 years) is necessary, but it is not available so far. However, this constraint should not inhibit efforts to identify and interpret the periodic occurrence of extreme minima in total ozone.

In this paper the importance of meteorological systems is examined in the hope of throwing some light on the mechanism of occurrence of ozone minima over the region mentioned above.

2. Deep upward motion, the earth's coldest 100 hPa temperature and earth's highest tropopause level

2.1 Western Pacific

As mentioned in the previous section, the global ozone minimum appears over the western Pacific during January which is a representative month of winter monsoon (December–February) influencing the region (Fig. l(a)). The comprehensive work of Ramage (1975), Lau and Chan (1983a, 1983b) has shown that deep convective zones of monsoon of the northern hemisphere (NH) migrate from the summer-time positions over north-east India to the north-west Pacific near Kalimartar, Indonesia. Krishnamurti (1971) and Chang and Krishnamurti (1987) have mentioned that when fully developed, the winter monsoon convection drives a gigantic planetary-scale overturning motion both in the east–west and north–south directions. During the active winter monsoon conditions, this region experiences very deep tropical convection (the frontal activities of cold air masses travelling from the Siberian high and overriding moist warm air masses from low latitudes of the Pacific also leads to the chains of overshooting cumulonimbus clouds over a large area). These features can be seen in the satellite-measured outgoing long-wave radiation (OLR) field. During the active phase of the winter monsoon over this region, the value of OLR is always less than 225 W m^{-2} indicating deep convection (see Lau and Chan (1983a)). The deep moist convection obviously leads to the enormous amount of rainfall. The global chart of mean monthly rainfall (Fig. 2(a)) shows that the earth's highest rainfall during the month of January occurs over the western Pacific. The deep convection would lead to the overshooting of tropospheric air into the stratosphere. In the course of upward air movement and adiabatic expansion, the tropopause height would necessarily go up and the temperature of uppermost parts of the troposphere and lower stratosphere go down. The above-mentioned facts (discussed in more detail in the next section) are clearly reflected in the global chart of mean monthly 100 hPa temperature and monthly march of the tropopause height (Fig. l(a)). In these figures the earth's extreme 100 hPa temperature minimum and highest tropopause level during January is seen over the western Pacific.

2.2 South-east Asia

The normal position of the intertropical convergence zone (ITCZ) shows extraordinary deep intrusion over south-east Asia during July. Over India, it migrates almost up to 30° N (see Riehl (1979)). This unique feature of the ITCZ is undoubtedly due to the differences in topography and land–sea contrast in this region. The east–west extension of the great Himalayan mountain wall (2500 km long with an area of over 10^6 km^2 having 14 peaks above 8000 m and 100 over 7000 m) causes orographic lifting (forced convection) of moist monsoon air brought by strong south-westerly winds. The developed heat source of the high and broad Tibetan Plateau (average height of 4.5 km) induces a reversal of the thermal gradient in the upper troposphere. The combined effect of both should lead to thermal and dynamical lifting of moist monsoon air to greater heights. Ramage (1975) as well as Lau and Chan (1983a, 1983b) have identified the deep convective zones during summer-time position as lying over north-east India. The global precipitation pattern for the month of July (see Fig. 2(b)) clearly shows that the area of maximum rainfall in July lies in south-east Asia. The deep convection should raise

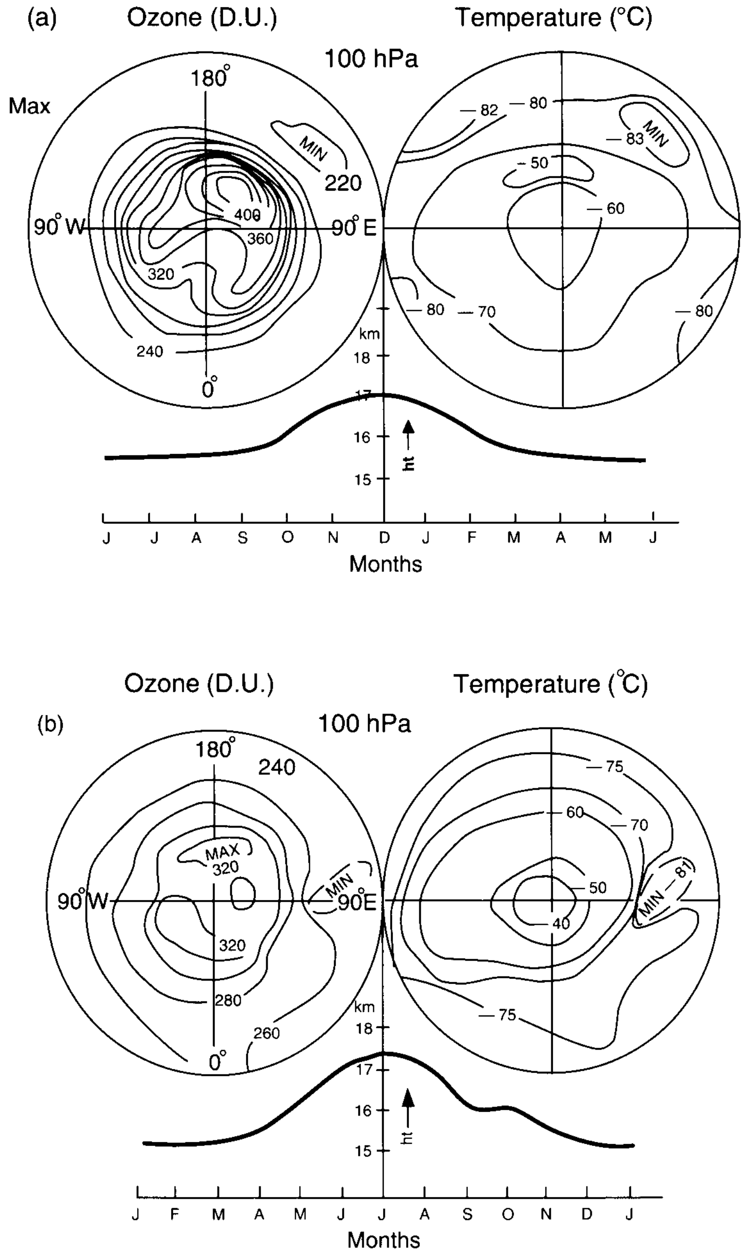

Figure 1. (a) Distributions of monthly mean total ozone (Dobson units) and temperature (°C) at the 100 hPa level for January over the northern hemisphere, and tropopause height over the western Pacific. (b) As (a) but for July and tropopause height over south-east Asia. (Sources: total ozone — WMO (1985) and Ghazi (1980): 100 hPa temperature — WMO 1980–89: tropopause height — Reid and Gage 1981, India Meteorology Department).

the tropopause height and reduce the temperature around the tropopause due to the adiabatic expansion of air coming from below (detailed discussion of this hypothesis is given in next section). Fig. 1(b) shows the global 100 hPa mean temperature chart for July and indicates the extreme minimum temperature over south-east Asia. This diagram also shows the monthly march of tropopause height indicating the highest tropopause level over this region during the month of July.

3. Discussion and conclusion

As seen in the earlier sections, there undoubtedly exists a strong upward motion during the period of occurrence of total ozone minimum over the north-west Pacific and south-east Asia. This upward motion should, in principle, cool down the upper troposphere and lower stratosphere due to the adiabatic expansion of air parcels coming from below. This mechanism could be a major cause of the occurrence of minimum temperature at 100 hPa over both the regions.

Manabe and Strickler (1964) suggested that the equatorial distribution of ozone tends to make the isothermal part of the stratosphere thinner than does the distribution of ozone in the higher latitudes, but this tendency, however, does not explain completely the sharpness of the equatorial tropopause. Their study also demonstrate

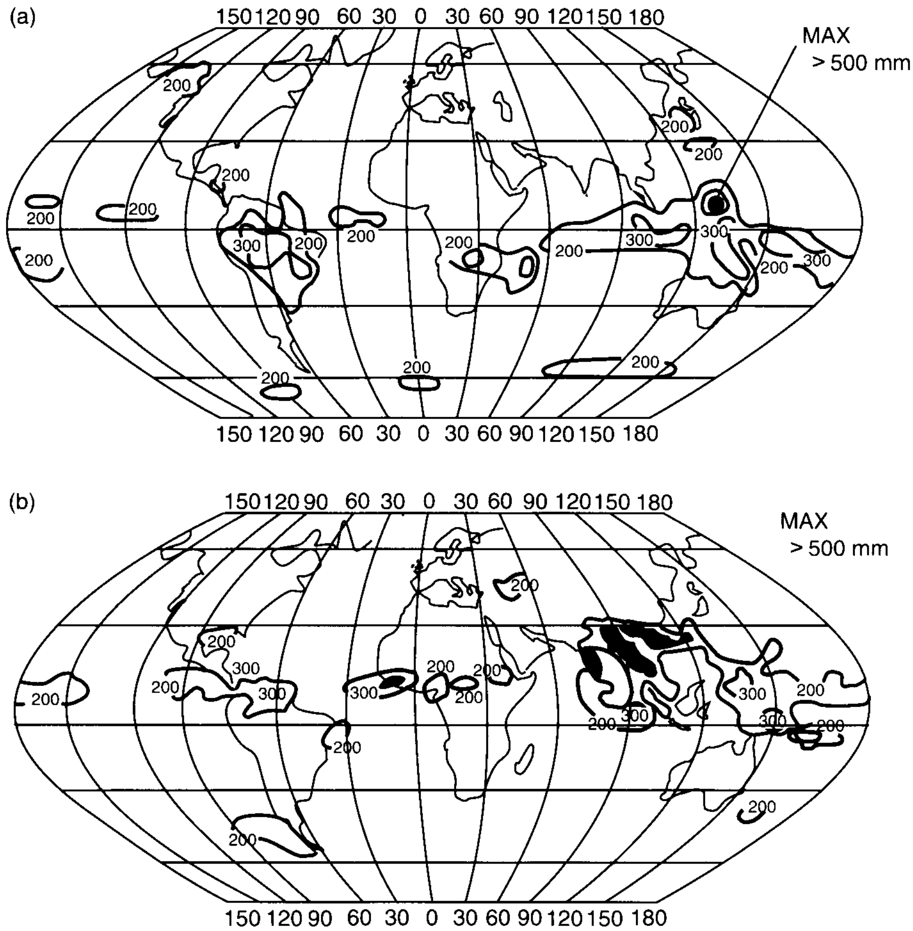

Figure 2. Global precipitation pattern (mm) for (a) January and (b) July. (Source WMO (1979)).

the importance of ozone in maintaining the existing structure of temperature in the stratosphere. The calculation of the thermal equilibrium at the tropopause and the temperature in the lower stratosphere by Goody (1949) confirm the hypothesis suggested by Dobson *et al.* (1946), that the anomalous seasonal variations in the stratospheric temperature are due to seasonal variations of ozone concentration. From these studies it can be inferred that the coldest temperatures in the lower stratosphere as seen over the north-west Pacific and south-east Asia during the time of intense convection, need not only be due to the adiabatic expansion of the air but can also be due to the decrease in partial pressure of ozone (through its optical property) in the lower stratosphere (see Held (1982)).

In Japan, an increase in tropopause height and a decrease in tropopause temperature indicates the advection of tropical air and replacement of cold air by warm fronts associated with deep upward motion. In Europe, the variation in tropopause height is associated with the intensity of events like cut-off lows, warm and cold fronts. Dobson *et al.* (1946) were the first to point out that the increase/decrease in the level of tropopause would decrease/increase the total amount of ozone. The one-dimensional model result of Chimonas (1987) show the conspicuous decreases in total ozone by a height increase of the tropical tropopause. The minimum in the mean annual distribution of total ozone is well associated with the higher level of tropopause there (Newell and Gould-Steward (1981) and Reid and Gage (1981)). As seen in the earlier section, the earth's highest tropopause appearing over the north-west Pacific during January, and over south-east Asia during July is associated with minimum in total ozone. Therefore, the possible mechanism of occurrence of ozone minimum in these regions is expected to be written in the meteorological processes prevailing during the time of occurrence of ozone minimum. It is clearly seen that there exists very deep moist convection over a large area of NW Pacific during January and over south-east Asia during July. Very deep convection or upward motion would naturally carry air masses from below and expand it quasi adiabatically with increase in altitude. The monthly mean data of tropopause height show the highest value (the temperature at 100 hPa show the lowest values) during the time of occurrence of the ozone minimum over both the regions mentioned above. The elevated level of the tropopause, and the reduced temperature around it indicate the removal or dilution of lower stratospheric ozone-rich air by tropospheric ozone-poor air. This phenomena should obviously reduce the partial pressure of ozone.

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World weather news — December 1992

This is a monthly round-up of some of the more outstanding weather events the month, three preceding the cover month. If any of you, our readers, has first hand experience of any of the events mentioned below or its like (and survived!), I am sure all the other readers would be interested in the background to the event, how it was forecast and the local population warned.

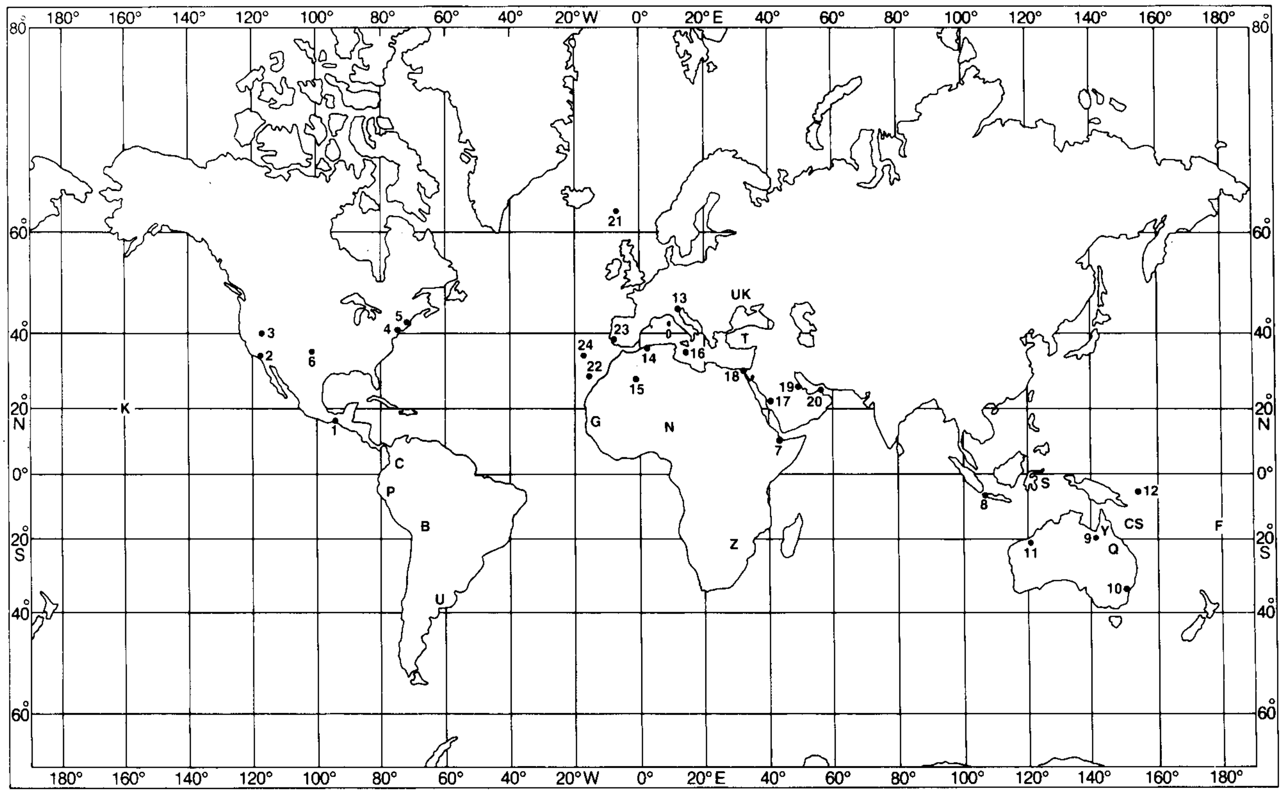
These notes are based on information provided by the International Forecast Unit in the Central Forecasting Office of the Meteorological Office, Bracknell and press reports. Naturally they are heavily biased towards areas with a good cover of reliable surface observations. Places followed by bracketed numbers or letters in the text are identified on the accompanying map. Spellings are those used in The Times Atlas.

South America

There were few reports of notable weather from this continent but on the 6th/7th heavy rain was reported in Peru (P) with Puerto Maldorado on the border with Bolivia (B) getting 108 mm and 101 mm. On the 9th, Tipuani in Bolivia had a heavy storm and at least 150 gold miners were reported to have died in rock and mudslides. More heavy rain was noted mid-month; on the 14th Camiri on the eastern side of the Andes in Bolivia got 161 mm: next day Apertado (Colombia (C)) had a temperature of 39 °C then 100 mm of rain in the next 24 hours. On the 17th heavy rain in Uruguay (U) gave Salto 160 mm and Paso de los Toros 132 mm. In the far north it had been very hot around the Gulf of Mexico; Salina Cruz (1) on the Pacific coast of Mexico broke its December record by 1 °C with 35.0 °C.

North America

The 7th brought catastrophe to California as a low moved south-east across the state. The heavy rain gave nearly the whole month's average rain in a day in some places; Los Angeles (2) International Airport had 55 mm and flooding 'down town' was nearly a metre deep. Flooding in Malibu affected the home of some film stars. Woodland, Sacramento (3) had 130 mm and there were some 70 cm of snow in the Sierra Nevada. Total damage was estimated at about $100m and two dead.



Locations of places mentioned in text

On the 8th the island of St Paul had another stroke of lightning (see November notes).

The BIG storm afflicted the Eastern Seaboard on the 11th and 12th. The worst storm in 30 years, it gave onshore gales, heavy rain and snow, did about $650m worth of damage and led to the deaths of thirteen people. With tides as much as 2 m above normal, sea defences were severely tested: cars were submerged in Manhattan, and La Guardia airport was closed by flooding when the sea wall collapsed (the wind was 45 kn gusting 70 kn with a total of 80 mm of rain). By the 12th most of the rain had turned to snow with 10 cm in New York City (4) and 30–60 cm inland and higher up; with the gale, drifting was severe. Boston (5) collected 144 mm during the two days and of this 82 mm fell in 12 hours as snow; Boston's Logan International Airport was closed for a time! The cold front was still active when it reached Bermuda, of its 90 mm, 75 mm fell in 6 hours (the December average is 90 mm). While this was happening, the Mid West was having one its worst snowstorms since 1978 with 15–30 cm.

On the 14th many places from north Texas to west Missouri had more than 50 mm of rain from heavy thunderstorms, Amarillo (6) in Texas for example had 76 mm. Near the end of the month southern California had heavy rains with more than 70 mm and the highest noticed was at the appropriately named Running Springs with 130 mm.

Kauai (K) in the Hawaiian islands has a December average rainfall of 132 mm; this year they had 552 mm which included a fall of 127 mm in one day on the 5th!

Tropical and southern Africa

There a few reports of unusual heat; on the 9th several parts of South Africa had temperatures in excess of 39 °C followed on the 23rd by a report of the harmattan raising the temperature to 39.5 °C at Birni N'Konni in Niger (N) and 37.8 °C in The Gambia (G), both near their December records. There were some reports of heavy rains on the 10th and 11th with 50 mm in Botswana and Zimbabwe (Z) (where similar amounts were reported on the 19th and 24th). Reports of heavy rain in Djibouti (7) on the 27th are possibly related to cyclone '12A' which was earlier heading that way while dissipating.

Australasia

The month started with reports from Indonesia of Djakarta (8) having 200 mm of rain in the first three days, equivalent to the December average. Kuantan had 177 mm over the period 5th to 6th but Toli Toli on Sulawesi (S) trumped these with 255 mm in 6 hours on the 5th.

Tropical air from the Coral Sea (CS) met cooler air from south Australia over Queensland (Q) on the 4th and some severe thunderstorms broke out; several places had more than 40 mm of rain but Croydon (9) had 410 mm as the temperature fell from 39 °C to 24 °C: a similar storm gave Moranbah 350 mm. Over the next two days eighteen synoptic stations in New South Wales reported more than 50 mm, the top total was Morunga's 188 mm but almost 100 mm fell near Canberra and Sydney (11). Staying on the mainland, the next items deemed newsworthy were hot spots. Marble Bar (11) on the edge of the Great Sandy Desert, had six days with maxima >40 °C out of the seven preceding the 13th — the lowest maximum of the preceding three weeks was 37.5 °C. Not far away Broome managed 44.2 °C on the 15th.

On the 11th cyclone 'Joni' passed through the islands of Fiji (F) with winds of 80 kn gusting to 120 and over 100 mm of rain. There was coastal flooding and transport disrupted. Ten people were reported missing afterwards, most of them fishermen. There was then a two-day wet spell in Queensland with Lockhart River on the Cape York Peninsula (Y) getting 228 mm in 48 hours and Bowen 130 mm. Some places had more than 70 mm on the 19th. Then cyclone 'Nina' brought floods of rain as she crossed the Cape York Peninsular on the 26th with winds of 65 kn gusting to 80 kn; damage was minor and only ten people were temporarily stranded; Willis Island's 117 mm (in the Coral Sea) and Lockhart River's 174 mm were examples of the rainfall. By the 31st, Coen on the Cape York Peninsula had had 396 mm since the 26th. Papua New Guinea was also affected by 'Joni', in a two day spell Rabaul (New Britain (12)) had 106 mm.

Hailstorms in November and December have damaged the wheat harvest in many southern Provinces of Australia, at A$21m this is the worst since 1985. About 44% was unharvested when rain halted work and by 18 December it was being affected by fungus and sprouting.

Europe and Arabia

The month started with a strong westerly flow that brought very changeable weather to western Europe (varying from rain to heavy rain!): many areas had more than 20 mm. Over Wales a prolonged SSW gale lead to much orographic rain (about 75 mm a day) for the first three to four days of the month with consequent flooding. By the 5th cold air reached the Mediterranean, a 'Genoa low' developed and heavy rain and snow fell over northern Italy; Chioggia (13) was flooded and Venice's (13) 107 mm overnight on the 5th/6th (December average is 61 mm) helped create a depth of 145 cm of water in St Marks's Square. A fresh burst of polar air reached the western Mediterranean on the 7th to give a new low; Bejaia (14) on the NE coast of Algeria got 98 mm, snow fell on the Atlas Mountains and the minimum at Timimoun (15) in the Sahara was only +1 °C. More than 60 mm was widespread over Italy (snowfall over the Alps was heavy, e.g. 285 cm at Säntis). It was probably this low that generated a hailstorm that damaged many light aircraft parked in the open at Luqa in Malta (16).

On the 10th both Jiddah (17) and Makkah exceeded their December records with 35.0 °C and 36.2 °C respectively. Then on the 13th a new burst of cold air entered the eastern Mediterranean to generate a vigorous low over Turkey (T). Thundery rain was particularly notable over Israel with many falls of more than 100 mm — 295 mm in 42 hours at Tel Aviv was twice the December average. In Cairo (18) winds reached 30 kn and heavy rain was reported from the Western Desert. At Alexandria (18), 3 m waves closed the harbour from 14th to 16th. The storms penetrated to the Persian Gulf causing floods in southern Iran. Bahrain (19) accumulated 31 mm by the 22nd (three times the December average) and even Khasab (20) managed 61 mm in the 36 hours to midday on the 23rd.

Meanwhile 'back at the ranch' the 18th brought widespread heavy rain to the west of England and Wales: flood warnings were again issued for many rivers in these areas. The surface wind reached violent storm force off the west coast of England and the 10 000-ton *Demetros*, en route to the breakers' yard, broke its tow and broke up on the rocks at Prawle Point in Devon. In Scotland the week of the 12th to 19th had brought much snow, 45 cm at Aviemore, with light winds, creating ideal skiing conditions. Now the southerly gale with gusts to 100 kn caused severe drifting to block access roads and then a rapid thaw that brought floods. This was all brought about by several Atlantic lows combining all their energy into one centre. Pressure south-east of Iceland fell 40 hPa in 24 hours and the wind speed at Akraberg (21) in the Faeroes reached 75 kn at 0600 UTC on the 18th. The burst of cold air southwards behind these lows led to the formation of a 'cold cut-off' near the Canary Islands where Tenerife (22) had 73 mm in the week to the 20th. The low brought thundery weather to the south of Portugal where one of its early consequences was the crash of a DC-10 airliner at Faro (23) as it was caught in crosswinds or downdraughts as it landed (54 of the 327 passengers and 13 crew were killed). Not unusually the low persisted for many days with little movement but the consequences were more drastic than usual; by the 23rd there had been 186 mm in 72 hours at Faro (December average 67 mm) and Madeira (24) 83 mm (December average 77 mm) in 36 hours. A few days later the low transferred across North Africa to rejoin this story in the next paragraph.

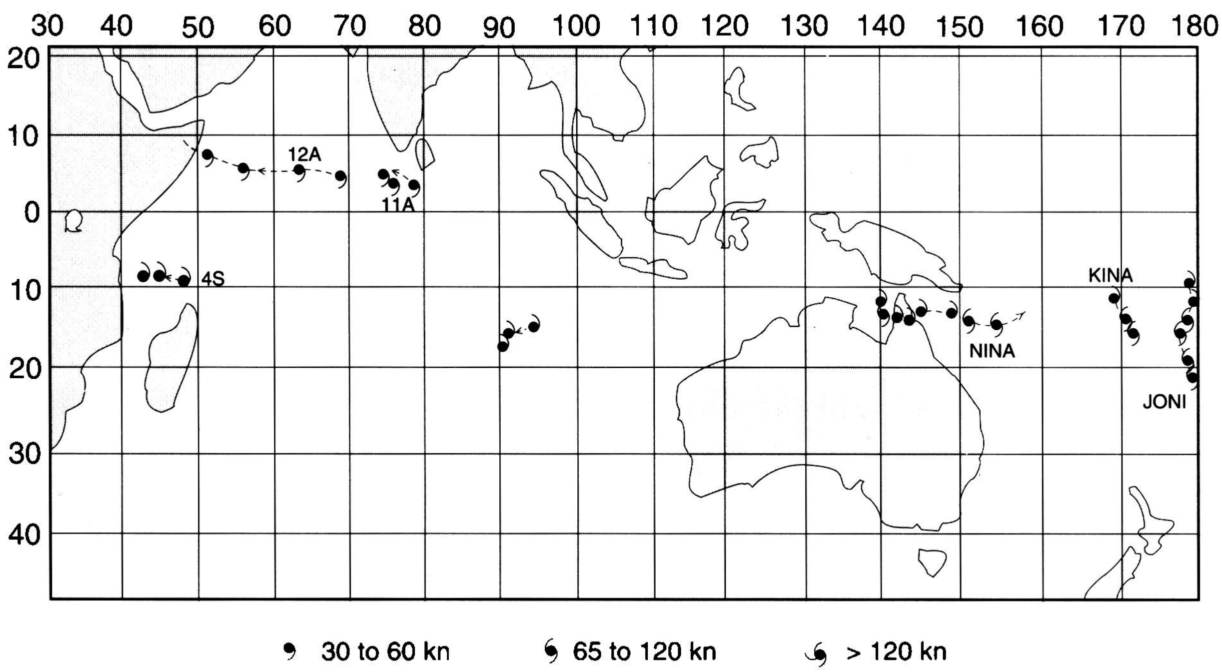
A large anticyclone over Central Europe helped drive a fresh blast of cold air south and west from the Ukraine (UK), this reached Cyprus on the 23rd. On Christmas Eve Akrotiri's maximum of +10 °C was the lowest on record and was followed by a frost next morning, −1 °C being another December record. The cold spread to Egypt and the Sudan with near freezing overnight temperatures breaking records. Further north, Venice's −4 °C was another near record. The relatively very warm sea triggered heavy showers producing more than 100 mm over many coastal areas of Italy. As a low moved east across North Africa and the European high intensified, the pressure gradient gradually strengthened and the wind reached 55 kn in parts of the Alps. By the 29th rain, snow and high winds were disrupting land, sea and air transport across Greece. As the year drew to a close near record low temperatures were being reported from Spain to Syria with snow over the Atlas Mountains (Constantine's maximum of +0.9 °C being 12 °C below the December average).

The World

The 1992 globally-averaged surface air temperature, based on measurements over land and sea, was 0.17 °C higher than the 1951–80 average. 1992 was the 10th warmest year in the near 140-year long record. Eight of the ten warmest years have occurred since 1980, and 1992 continues the general pattern of warmth which has prevailed since the late 1970s. However, 1992 was about 0.2 °C colder than 1991. There is good reason to believe that the eruption of Mount Pinatubo in June 1991 will have had a noticeable cooling effect in 1992. The end of the 1991 El Niño warm phase will also have had a cooling influence.

December tropical storms

This is a list of tropical storms, cyclones, typhoons and hurricanes active during December 1992. The dates are those of first detection and date of falling out of the category through dissipation or becoming extratropical. The last column gives the maximum sustained wind in the storm during its lifetime. The map shows 0000 UTC positions.



No.	Name	Basin	Start	End	Max.
1	11A	NI	30 Nov.	3 Dec.	50
2	12A	NI	20 Dec.	24 Dec.	50
3	4S	SWI	7 Dec.	10 Dec.	35
4	Ken	SWI	19 Dec.	23 Dec.	45
5	Joni	AUS	6 Dec.	12 Dec.	110
6	Nina	AUS	23 Dec.	3 Jan.	75
7	Kina	AUS	27 Dec.	3 Jan.	125

Basin code: N — northern hemisphere; S — southern hemisphere; A — Atlantic; EP — east Pacific; WP — west Pacific: I — Indian Ocean; WI — west Indian Ocean; AUS — Australasia.

Hong Kong rainstorm — addendum

Our January 1993 issue carried an article by Dr Lam on the record-breaking rainstorm in Hong Kong on 8 May 1992. An unfortunate oversight, caused by writing the *World weather news*, resulted in the omission of the photographs that add considerable colour to the story. They are printed here with my apology to Dr Lam.

(Right) A slope failed in the heavy rain and two persons in this high-rise building were killed by the downhill rush of water-laden mud. The force of the mudslide can be gauged from the height of the stains on the wall. (Photograph courtesy of *Ming Pao Daily News*, Hong Kong.)

(Below) Roads on the steep slopes of Hong Kong Island turned into torrents. Traffic in the business districts virtually came to a stop. (Photograph courtesy of Wah Kiu Po, Hong Kong.)

Reviews

Seasonal snowpacks: Processes of compositional change.

edited by T.D. Davies, M. Tranter and H.F. Jones. 168 mm × 247 mm, pp. ix+471, *illus*. Berlin, Heidelberg, New York, Springer Verlag, 1991. Price DM288. ISBN 3 540 51760 X.

This book is the result of a NATO Advanced Study Workshop, held in 1990, on the chemical changes in seasonal snow cover. The format is a series of fourteen peer reviewed papers, mostly single authored, with shorter discussion papers following many of the main contributions. These are in fact not discussions in the sense of a recorded interchange of ideas between participants, rather they are short pieces on the same subject. The discussion papers are perhaps a weakness of the volume as they have not undergone a review process as have the main papers, thus allowing some disagreement with points raised in the main texts without reply from their authors. Some discussants used the opportunity to add additional material, often quite specific, while others stuck to actually discussing the previous paper, summing up salient points.

The majority of the main papers are reviews of different aspects of the incorporation, diagenesis and loss of chemical species from seasonal snow cover. The volume has been laid out logically: the first paper starts off naturally enough in the atmosphere with a review of the processes leading to snow formation and the effect this has on snow composition. By the second paper, the snow is on the ground, and there is a review of how dry deposition and gaseous exchange can add to the chemistry of the original snowfall. The next paper looks at the effects of the redistribution of chemistry and alteration of physical properties by wind-induced transport. Following this are two papers that consider snowpack physics and the effect of snow metamorphism on the location of chemical species and one includes an attempt at modelling these processes.

The sixth paper takes us away from the physical approach to consider how biology can affect the snowpack composition. For me, this was the strongest review in the volume, with a magnificent effort to bring together the available data. There appears to be very little good quantitative data available, and some of the argument is necessarily qualitative, but the author has gone to great lengths to put together a complete picture. The alteration of the snowpack composition by vegetation, animal life, insects and bacteria can be enormous, though often localized.

Returning to physical processes, the next paper expands on the factors affecting the snow-melt itself, and discusses the phenomenon of preferential elution of species from the snowpack. Then, two papers move away from the review format with two specific studies: one with detailed experimental data from the Alps, and one rather weak paper on urban snow. Then it is back to reviews for a paper on organic compounds in snow.

There is a temporary departure from the seasonal snowpack with two papers that consider permanent snow cover. One article sits somewhat uncomfortably within the subject matter of this volume with a discussion of records in polar snow, though the author has attempted to steer his article towards processes in compositional change during burial rather than reviewing the data obtained from deep ice-cores. The other paper considers high-altitude, non-polar ice sheets and points out the palaeoenvironmental information available from these areas is valuable for its regional bias rather than the global picture painted by those involved in polar ice cores.

The last paper makes an attempt at modelling the effect of climatic change on future snow cover, in particular the change in melt and acid run-off from seasonal snows. While there is clearly still a long way to go to produce a realistic model, the results are thought provoking. Finally, the book is rounded off with a short discussion of what has been achieved in this field and what questions remain to be answered, with some broad areas noted for further study.

The book makes a good attempt at presenting the current state of knowledge of snowpack composition. The volume works at its best when presenting comprehensive reviews of the processes involved together with substantial bibliographies, and less well when describing results from particular experiments in detail, since those included are but a small part of the wide range of studies taking place. It is a good book, though expensive, and one senses it is the result of a successful workshop. As an introduction to the subject it can hardly be bettered, with plenty of information for those entering the field or planning experiments. On this last point, one remark that will remain with me comes from the close of the review on biological processes: when choosing a site for chemical analysis, first take a good look at the biological aspects of the area.

R. Mulvaney

International weather radar networking,

edited by C.G. Collier. 160 mm × 235 mm, pp. xiii + 332, *illus*. Dordrecht, Kluwer Academic Publishers, 1992. Price £66, $110.00, Dfl 190.00, ISBN 0 7923 1706 8.

In the October 1992 issue of *Meteorological Magazine* we carried a transcript of a talk given by Mr C.G. Collier on this topic. This is 'the book of the talk', the collected papers presented at the final seminar of the COST Project 73 held in Ljubljana, Slovenia in June 1991. This is a book of remarkable contrasts and a mine of miscellaneous information. Not least of the contrasts is that between progress reported then and the subsequent political disaster there.

The first 10%, the opening ceremonial speeches, would normally be expected to be a boring space-filler, but here it shows that no budget need not mean no progress, given the good will. The rest of the book consists of papers covering almost every aspect of radar meteorology — if you can find it. I deliberately describe it as a mine; the information is the valued ore which must be won from the overburden or spoil. The lack of a subject index means that you have to rely on the titles of the papers given in the front list of contents: the list at the rear is almost the same but gives times rather than page numbers! The mathematical complexity of 'On the importance of the noise figure in reflectivity radars' is followed immediately by the short descriptive 'Operational radar measurements of rainfall: the accuracy of point measurements of rainfall rate'. 'Report by the COST Project 73 telecommunications working party' gives a full description of the BUFR code with 14 pages of tables; it is followed by a nicely illustrated 'Weather radar data distribution and presentation in Austria'.

The contrast in contents is perhaps less disconcerting than the publisher's policy of photo-reproduction of the text as received. The result is sometimes violent changes of font, a change from high-quality type to draft-mode nine-pin dot-matrix, proportional to fixed-character spacing, and most irritating of all, a density range from seven lines and twelve characters per inch to an incredible eight-and-a-half lines and twenty characters. The illustrations are generally well done with good colours.

Finally, if purchasing a copy, check through all the pages. I know that at least one batch had some pages that had been through the press twice, making them almost illegible. I think that this book is rather too costly.

R.M. Blackall

Diffraction effects in semi-classical scattering, by H.M. Nussenveig. 155 mm × 234 mm, pp. xiii + 238. Cambridge University Press, 1992. Price £35.00, $59.95. ISBN 0 521 38318 8.

The Montroll Memorial Lecture Series in Mathematical Physics, given at the University of Rochester, USA aims to provide a forum for the presentation of new developments and coherent overviews in mathematical physics. This book is the first in a new series which will make the lectures available in book form, and contains the 1988 lectures.

The central theme of the text is an analysis of the scattering of electromagnetic waves from dielectric spheres at optical frequencies, in particular critical effects such as coronae, rainbows, glories, orbiting, and resonances. The first four chapters are introductory, intended to introduce the various effects. They are largely descriptive, though they introduce the reader to the significant mathematical analysis in the later chapters. Chapter five gives a too-brief outline of the Mie theory exact solution of the problem, and describes the rapid variations which can occur in backscatter cross-section with increasing scatterer size.

The next nine chapters describe and apply complex angular momentum (CAM) theory to the various phenomena. As a prelude to the main problem, scattering by an impenetrable sphere is first considered, and leads to the concept (by analogy with quantum mechanics) of diffraction as a tunnelling phenomenon. When applied to the Mie theory, the effective potential for a transparent sphere is seen to be similar to that giving rise to quasi-bound states in atomic theory. Different types of resonances are seen to correspond to different Regge poles. Amongst its successes, the CAM theory has given an accurate quantitative theory of the rainbow and a detailed physical explanation of the meteorological glory. The final two chapters discuss applications in other areas as diverse as determination of particle size and refractive index, radiative transfer, seismology, and atomic nuclear and particle physics.

This book is born out of the author's research in the area over more than thirty years. The insight it provides into the detailed scattering mechanisms underlying observations is a valuable contribution to the literature. Another aspect of value is the application of methods from another area (high energy physics) to the understanding of the light scattering problem. The figures are clear, but I fear that the text is really too brief in places to be self-standing. In too many places the reader is referred to the literature for explanations that should have been incorporated in the text. Another disappointment is that there is only scant reference to the scattering problem at microwave frequencies, of interest to those interested in the radar remote sensing of rain.

This text is for those with a background in theoretical physics, but they will read it with considerable profit.

A.R. Holt

Books received

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

Phenomena in atmospheric and environmental electricity, by R. Reiter (Amsterdam, Elsevier, 1992. $165.00, Dfl.290.00) attempts to present, define and explain the phenomena, emphasizing on levels up to 70 km. It is the twentieth in the *Developments in atmospheric science* series. ISBN 0 444 89286 9.

GUIDE TO AUTHORS

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

Preparation and submission of articles

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

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

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

Mathematical notation should be written with extreme care. Particular care should be taken to differentiate between Greek letters and Roman letters for which they could be mistaken. Double subscripts and superscripts should be avoided, as they are difficult to typeset and read. Notation should be kept as simple as possible. Guidance is given in BS1991: Part 1:1976 and *Quantities, Units and Symbols* published by the Royal Society. SI units, or units approved by the World Meteorological Organization, should be used.

Articles for publication and all other communications for the Editor should be addressed to: The Editor, Meteorological Magazine, Meteorological Office Room 709, London Road, Bracknell, Berkshire RG12 2SZ.

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