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Severe thunderstorms over western Germany — a case-study of the weather situation on 20 August 1992

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1. Introduction

In the relatively warm summer of 1992 there were several occasions of heavy convective overturnings with hazardous weather in central Europe. On one of these occasions — the 20th of August — gusts of 90 and 70 kn were recorded in Saarbrücken and Frankfurt/M. respectively during the passage of a squall line accompanied by hail and heavy rain. The course and development of this weather situation will be described in the following. The description is partly based on an internal report by Liebetruth (1992) from the Regional Forecasting Centre Frankfurt.

2. Large-scale weather development

The surface charts for 19–21 August 1992 (Fig. 1) show, typically for late summer, an initially slack pressure gradient over central Europe with an area of high pressure extending from the North Sea towards Poland, and a shallow depression over Biscay moving slowly north-eastwards.

A poorly defined surface front, separating moist and hot tropical air in the south from cooler and drier air in the north, runs along 50° N before curving south, behind the Biscay low, towards Iberia. The position of this front is well reflected in the distribution of the equivalent-potential temperature (θ_e) at 850 hPa (Fig. 2). Analyses of that temperature are generally used in the DWD for fixing surface fronts. However, the temperature distribution in the tropical air is not uniform. In the θ_e field as well as in the pure temperature at 850 hPa (Fig. 2) a zone of high values exists which extends from Spain over the Alps up to the Balkans.

During the 20th the originally shallow depression experienced some intensification and arrived over the German Bight at 0000 UTC on the 21st with a central pressure near 1000 hPa. As a consequence of the increase of the pressure gradient, together with the deepening, the cold front pushed eastwards more quickly and reached the western parts of Germany on the night of the 20th/21st. Meanwhile widespread thunderstorms were released ahead of the front, which strongly influenced the temperature distribution near the ground through their cold air production, and the front became barely recognizable at the surface. Instead, a new convergence line with cold front characteristics developed at the fore part of the area with thunderstorms on the evening of the 20th and cleared most of Germany by the end of the day. This process is also reflected in the θ_e field which shows a cold inlet just over Germany ahead of the original front.

Corresponding to the above air-mass distribution, there was a west to south-west current in the middle and upper troposphere over western and central Europe starting in a trough west of the Iberia (Fig. 2). Stronger, wavy winds blew north of 50° N and it is interesting to note that the baroclinicity in the middle troposphere was smaller than in the lower levels.

The upper trough swung slowly north-eastwards, to a position over Biscay at 0000 UTC on 20th, and subsequently crossed France to reach the southern parts of the North Sea and western Germany during the following

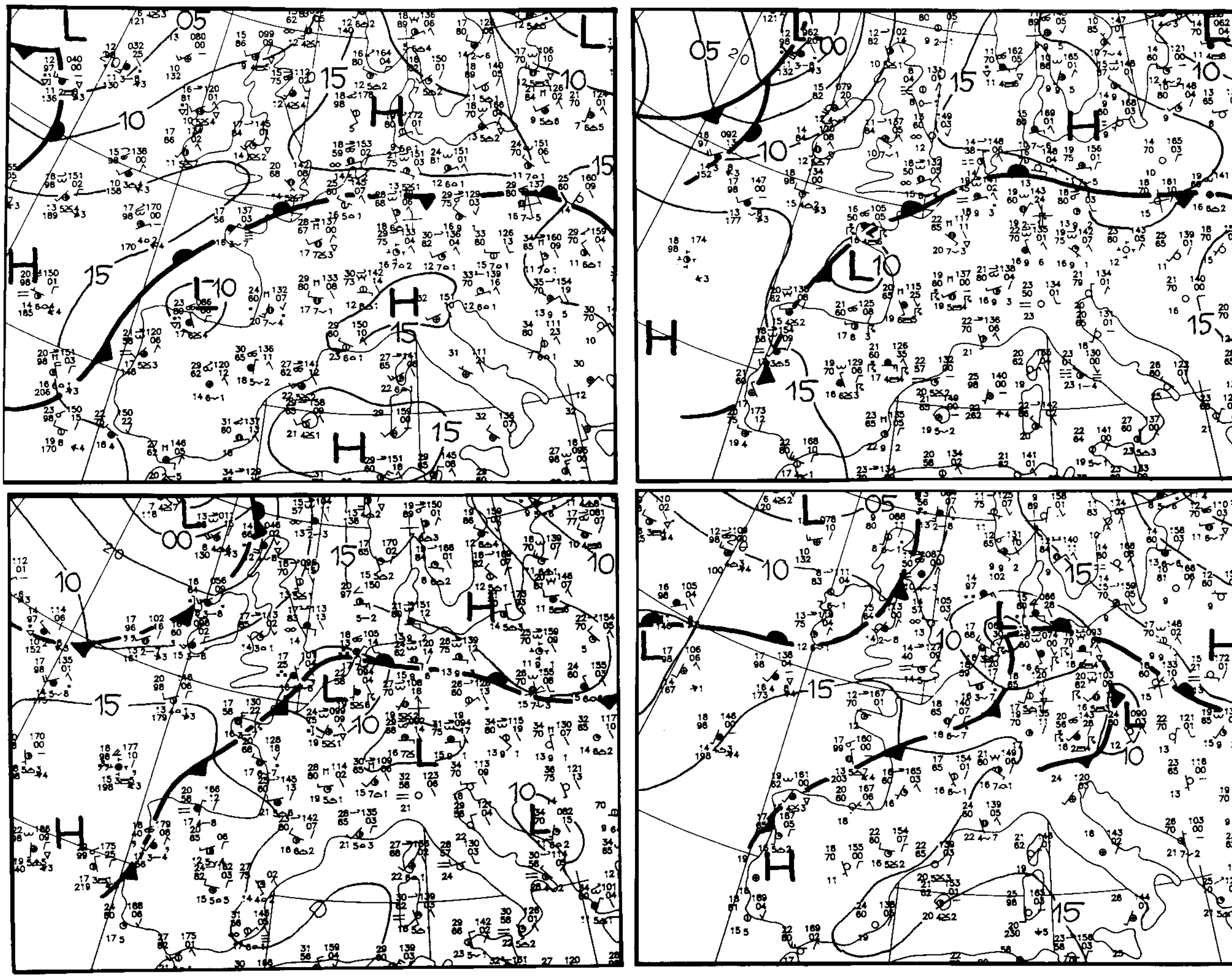


Figure 1. Surface isobars and fronts at 1200 UTC on 19 August (top left), 0000 UTC on 20 August (top right), 1200 UTC on 21 August (bottom left) and 0000 UTC on 21 August (bottom right).

night. The surface low deepened ahead of it. Another important aspect is that the trough had already overtaken the surface front towards the warm air early on and remained there relative to the front. That was decisive for the release of the convective overturnings, since the ascending motion ahead of the trough could fully catch the tropical air south of the front (see section 4).

3. Weather events

3.1 First convective overturnings

Light rain or drizzle was often observed near the front in western and central Europe during this time. As regards convective activity, the first thunderstorms had already developed over eastern France in the afternoon hours of the 18th moving quickly north-eastwards and crossing southern Germany. Their intensity was rather low judging from the measurements in the synoptic network of the DWD.

A small circular convective cell formed north-west of Frankfurt about 0000 UTC on the 19th and intensified while moving eastwards. Gusts of up to 31 kn with 8 mm precipitation were recorded during its passage of the eastern part of the Erzgebirge (Saxony). This cell subsequently crossed Poland and the Ukraine and was north of the Black Sea at noon on 20th.

Likewise in the second half of the 18th many thunderstorms developed over the Iberia and encroached on the Pyrenees and south-western France during the following night as the cloud slowly spread out north-eastwards. A nearly circular convective cell formed at its leading edge, and again over eastern France at noon on the 19th. It broke loose from the main cloud and crossed the centre of Germany by the next morning. Its activity was significantly stronger than its forerunners. Frankfurt/M. (10637) had a gust of 45 kn and 26 mm of precipitation; 53 kn was registered at Tholey (10706). That cell moved further eastwards while weakening, and disappeared over the Ukraine during the afternoon of the 20th.

3.2. The main event

Meanwhile the main cloud area had been displaced north-eastwards and covered western Germany, the Low Countries, northern France, England and the southern

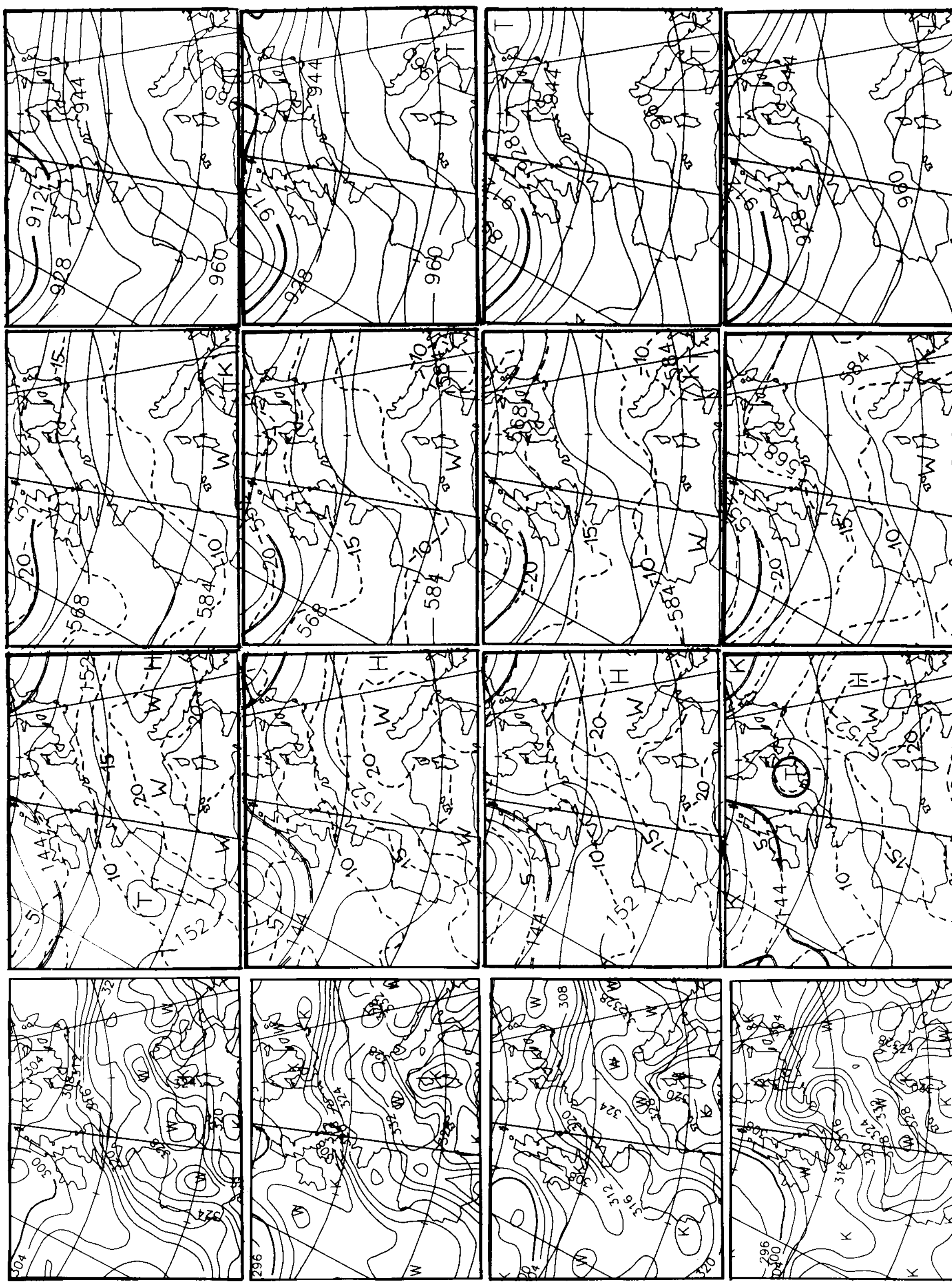


Figure 2. (Columns, left to right) analyses of θ_e equivalent potential temperature at 850 hPa, and geopotential (solid lines, in gpdam) at 850, 500 and 300 hPa at 12 UTC on 19 August (row 1), 00 UTC on 20 August (row 2), 12 UTC on 20 August (row 3) and 00 UTC on 21 August (row 4).

North Sea at noon on the 20th. Rainfall was observed at many places in its domain, partly accompanied by thundery outbreaks in Belgium and northern France. However, very intense thunderstorms developed at the southern edge of this cloud area after it reached eastern France at noon. The satellite images (Figs 3(a) and 3(b)) show very impressively, how a shield formed out of some thunderstorm cells in a very short time. The shield, with a diameter of nearly 500 km, covered the whole of central Germany at 1800 UTC (Fig. 3(c)). The temperature at the top was −68 °C corresponding to a height of nearly 45 000 ft. The shield soon merged with the clouds from powerful cells that developed further south. A broad, deep comma-like cloud zone had formed by 0000 UTC on the 21st, stretching from the North Sea over Denmark, eastern Germany, Poland and the CSFR to the eastern Alps.

Contrary to the impression conveyed by the explosive spread of cirrus shields, the radar measurements (Fig. 4) demonstrate, together with the surface observations, that the main thunderstorm activity was organized first of all in the form of a typical squall-line and later on in the form of a line-like elongated zone. The line came into the range of the Frankfurt radar after 1330 UTC and had a length of about 150 km and a width of 30 km at that time. It moved north-eastwards at roughly 40 kn and passed Saarbrücken Airport between 1432 and 1455 UTC with heavy hail and a gust of up to 90 kn from the north-west. This was the highest wind speed ever recorded at this site. The observed hail fall tallied with the strength of the radar reflectivity exceeding 55 dBZ in the core of the line.

During the next hour the line merged with cells developing ahead of it and at its eastern flank. It therefore lost its original character and became more of an elongated zone of convective activity moving further north-eastwards with a speed of 45–50 kn. The zone reached the Frankfurt area at around 1600 UTC causing gusts to 70 kn, torrential rain (60 mm within 2 hours) and hail with a diameter of up to 5 cm.

Fig. 5 allows a comparison between the NOAA-12 IR image for 1814 UTC, the radar measurements of the DWD network and of the COST network to the west. The precipitation detected by the radar is confined to the western half of the big cloud shield, and the zone of strongest echoes running along the River Weser is 350 km long by 50 km wide.

3.3 Effect of the convective overturnings

As demonstrated by Fig. 6(a), most of the stations in the climatological network of the DWD reported thunderstorms in the course of the 20th. Only in north-western and northern Germany and in some parts of the south-west was no thundery activity recorded. The main activity was concentrated in the middle parts of Germany where precipitation totals generally exceeded 10 mm: the highest total was 59.6 mm at Gross-Auheim east of Frankfurt. The structure of the precipitation field (Fig. 6(b)) shows a large and some smaller strips of large amounts orientated from south-west to north-east.

It is interesting to note that hail was only reported in the southern half of Germany and sometimes in areas with relatively small amounts of precipitation. Hail and heavy rain was only observed at the squall-line in the Federal States of Saarland, Rhineland-Palatinate and Hesse.

The most striking effect of the convective overturnings were the extremely strong gusts registered in Saarbrücken, Frankfurt and other places. As shown by Fig. 7, the gust of 90 kn in Saarbrücken had to be estimated since the registration form only went up to 80 kn! There were no marked wind shifts connected with the gust but a more or less steady veering from south-west to north-west. After the gust the wind rapidly decreased and turned to an easterly direction clearly indicating the backward direction of the cold air outflow of the squall-line.

Simultaneously with the gust, the surface pressure made a jump of nearly 7 hPa upwards immediately followed by a fall of around 4 hPa. A few minutes later heavy hail set in lasting more than a quarter of an hour. The diameter of the hail was between 2 and 4 cm. The temperature dropped from 28 °C to 14 °C whereas the relative humidity rose from 50 to 95%. The observer at the Saarbrücken Airport characterized the event with the words "minutes of horror and stress, but possibly unique in an observer's life!"

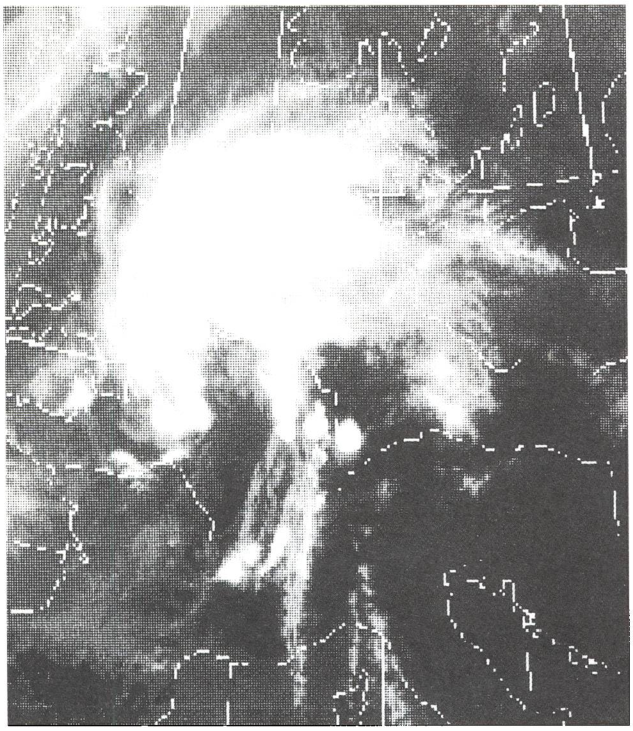
Many trees were overturned by the gusty winds, causing great damage and dangerous obstacles for traffic. At places with heavy rain, as, for example, in the Frankfurt area, many streets were flooded and the fire brigades were very busy pumping out flooded cellars. In Frankfurt it was the second night of uninterrupted operation for the police and fire brigades.

4. Physical aspects of the release of the convective overturnings

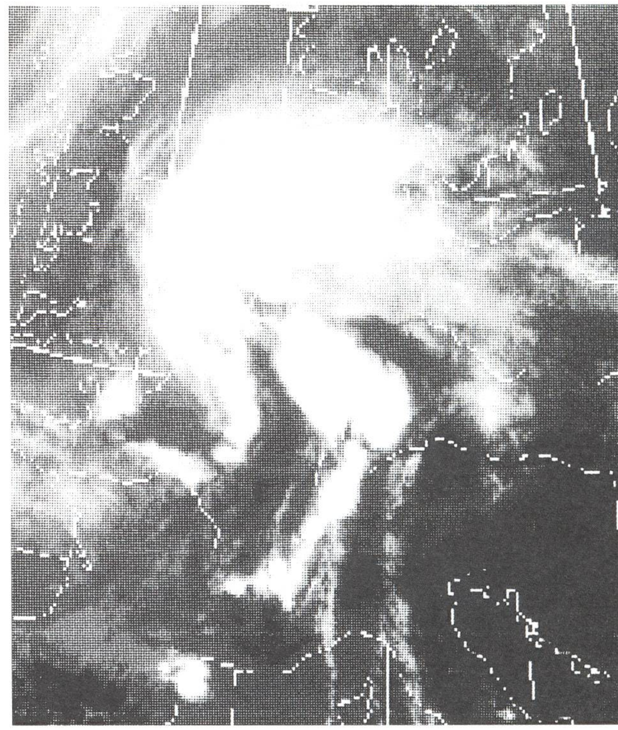
4.1 Vertical stability

As is typical for air masses of tropical origin, the lapse rate in the warm, moist air south of the surface front was conditionally as well as potentially unstable. However, as demonstrated by the ascents from Nancy (07180) at noon on 19th and 20th in Fig. 8, the release of the conditional instability was hindered by stable layers at 850 and 800 hPa, respectively, and surface heating to 32–34 °C was needed to cause deep convection. (Nancy is the upper-air station nearest to the origin of the thunderstorms during those afternoons.)

On the 19th the required temperatures had been partly reached in the area concerned, so that the development of the thunderstorms which formed on the leading edge of the main cloud area that day, and moved towards Germany, could be traced back to the heating from the ground in course of the day. This explanation is, however, not valid for the next day and the formation of



(a)



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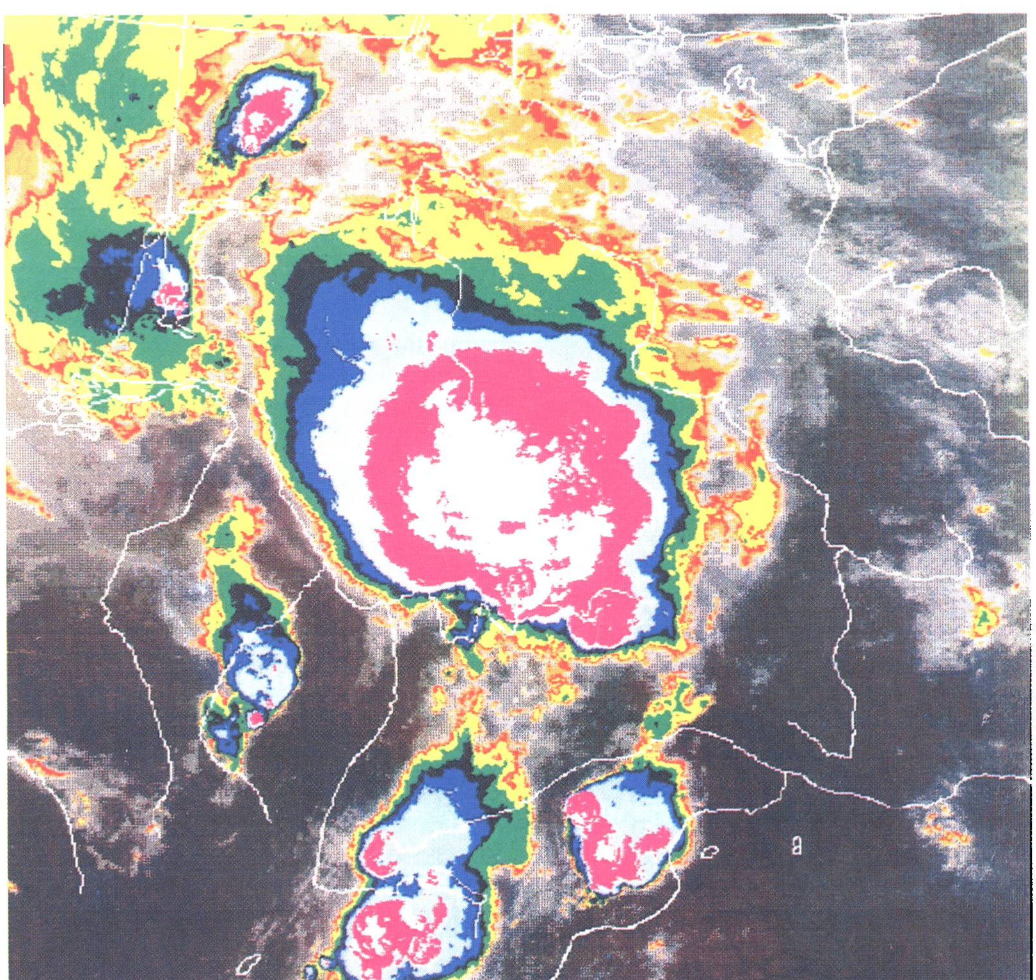

(c)

Figure 3. Meteosat images at (a) 1400 UTC and (b) 1600 UTC on 20 August, and (c) NOAA-12 image at 1814 UTC on 20 August.

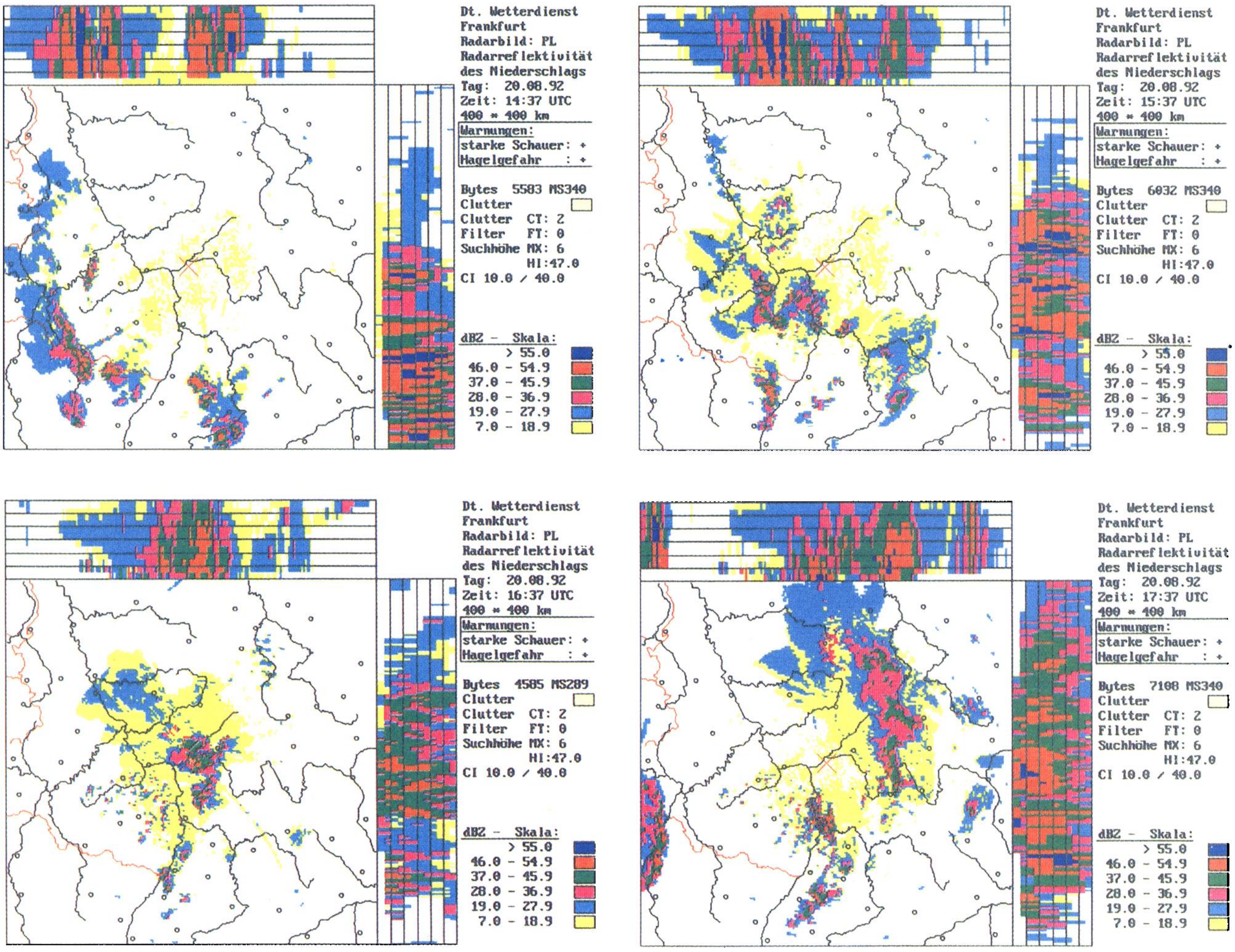

Figure 4. DWD weather radar images from Frankfurt at 1437 UTC (top left), 1537 UTC (top right), 1637 UTC (bottom left) and 1737 UTC (bottom right). The cross-sections show the vertical distribution of the strongest echoes in east–west and south–north directions.

the squall line. The temperature had only risen to about 28 °C in the area of origin by noon and the new threshold of 30 °C was only reached later in smaller areas further east and south. That means that another process must have been effective in releasing the convective overturnings in addition to warming from the ground. A characteristic of the formation of mesoscale convective systems is widespread ascent as an additional trigger.

The vertical stretching below the level of the strongest ascent leads to an increase of the vertical temperature gradient. If enough latent heat is released through condensation in the lower levels, the threshold to moist or even absolute instability can eventually be crossed. The prerequiste for this is a potentially unstable lapse rate of the ascending air mass. It is indicated by a decrease of the equivalent potential temperature in the vertical.

Such conditions could be found between the surface layers and the middle troposphere in the soundings at Nancy on both days. The equivalent potential temperature decreased from values between 60–70 °C near the surface, down to 50 °C or less between 500 and 600 hPa. However, very low values of θ_e were reached as low as 850 hPa on the 19th.

For the presentation of the horizontal distribution of the potential instability the so-called KO-Index (developed in the DWD) can be used: it is defined as

$$KO = \tfrac{1}{2}(\theta_{e500} + \theta_{e700}) - \tfrac{1}{2}(\theta_{e850} + \theta_{e950}).$$

The index reflects approximately the vertical gradient of the equivalent potential temperature. The distribution of KO, derived from the numerical analyses and given in Fig. 9, shows negative values (corresponding to a decrease of θ_e between the lower and the middle troposphere) in the area covered by tropical air, and values below −10 K.

4.2 Release of the instability through superimposed ascent

The widespread ascent necessary for the release of the potential instability can come as large-scale forcing in baroclinic waves or as a mesoscale process — with its typical form of transverse circulations — at well defined fronts. Since the front in the situation under consideration was only poorly defined and not subjected to

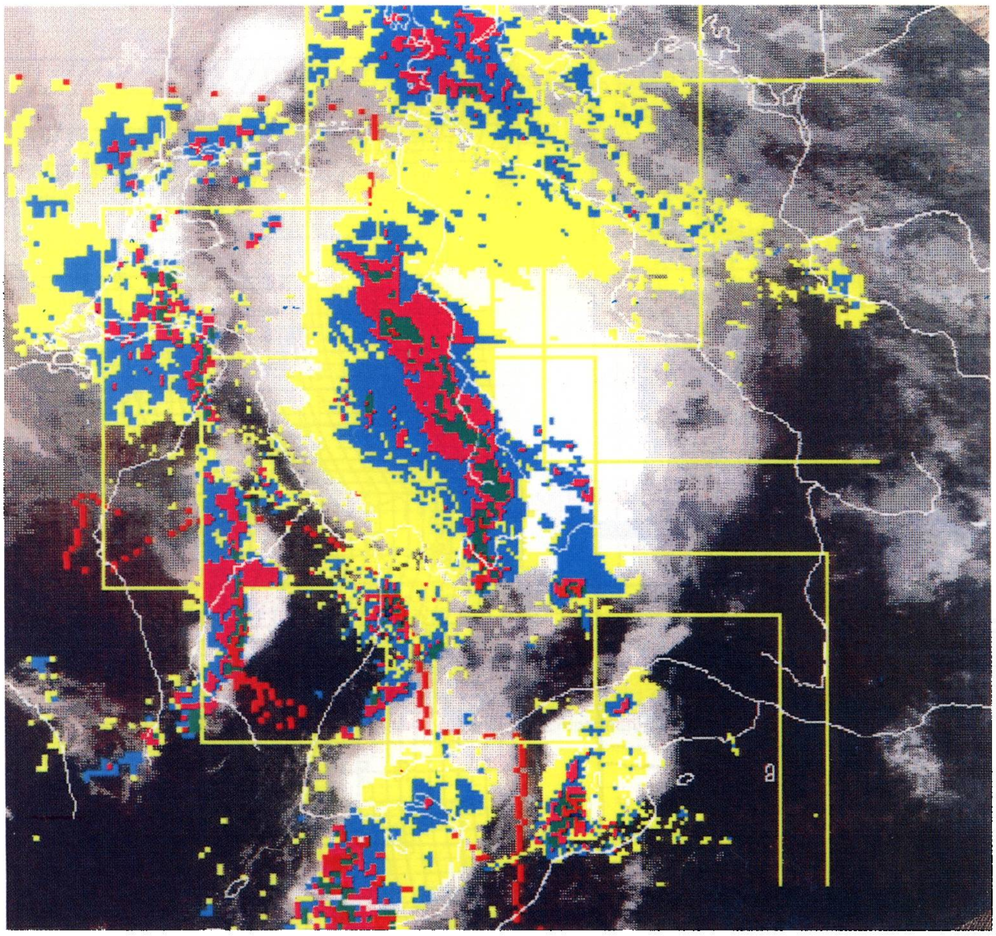

Figure 5. NOAA-12 infrared image at 1814 UTC on 20 August with radar data for 1800 UTC (green 37–45.9, violet 28–36.9, blue 19–27.9 and yellow 7–18.9 dBZ radar reflectivity).

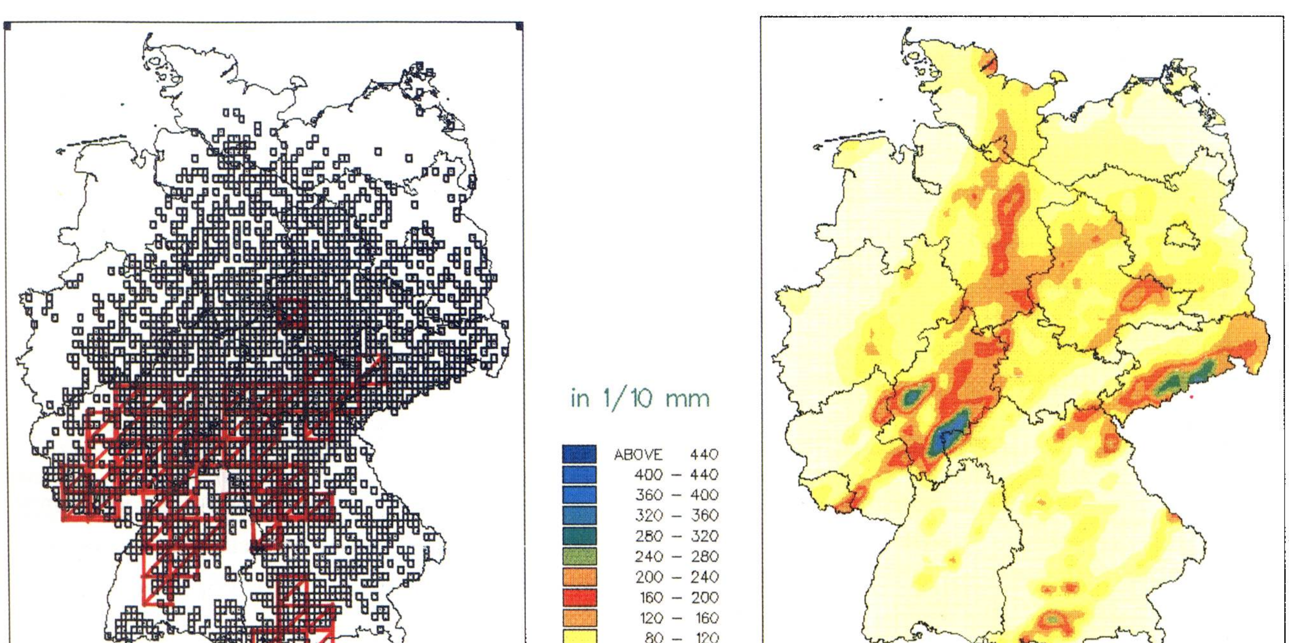

Figure 6. (a) Stations of the DWD reporting thunderstorms (black squares) and areas reporting hail (red squares) on 20 August, and (b) total precipitation from 0500 UTC on 20 August to 0500 UTC on 21 August.

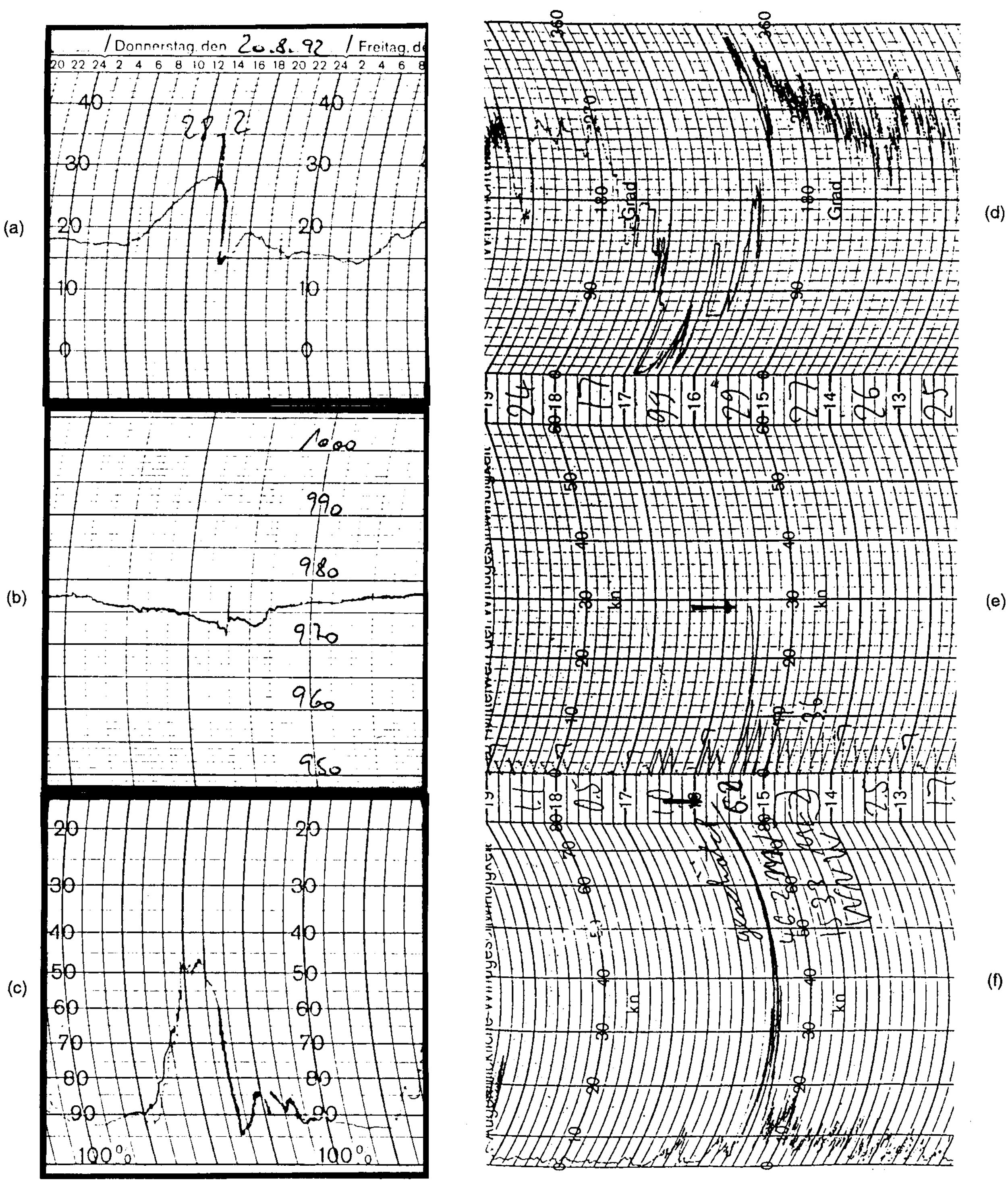

Figure 7. Autographic records from Saarbrücken Airport on 20 August 1992 showing (a) temperature, (b) pressure (hPa), and (c) relative humidity. Note the reversed time-scale of the anemogram in which (d) is direction, (e) is the 10-minute mean and (f) is the instantaneous speed. Arrows mark the peak speeds in (e) and (f).

frontogenetic effects, at least in the beginning, we have to look for large-scale ascending motions.

The distribution of large-scale vertical motions is described by the well known omega equation which contains in its simplest, quasi-geostrophic form, two forcing functions — the vertical gradient of vorticity advection and the horizontal distribution of temperature advection. Ascent is to be expected in areas with vertically increasing positive vorticity advection and/or maximized warm air advection. For example, the former works ahead of mobile short-wave upper troughs, the latter ahead of warm fronts. When ascent causes condensation the vertical motion can be boosted by the release of latent heat.

In terms of looking at the forcing at a particular level, it is advantageous to use an alternative form of the omega equation containing only one forcing function.

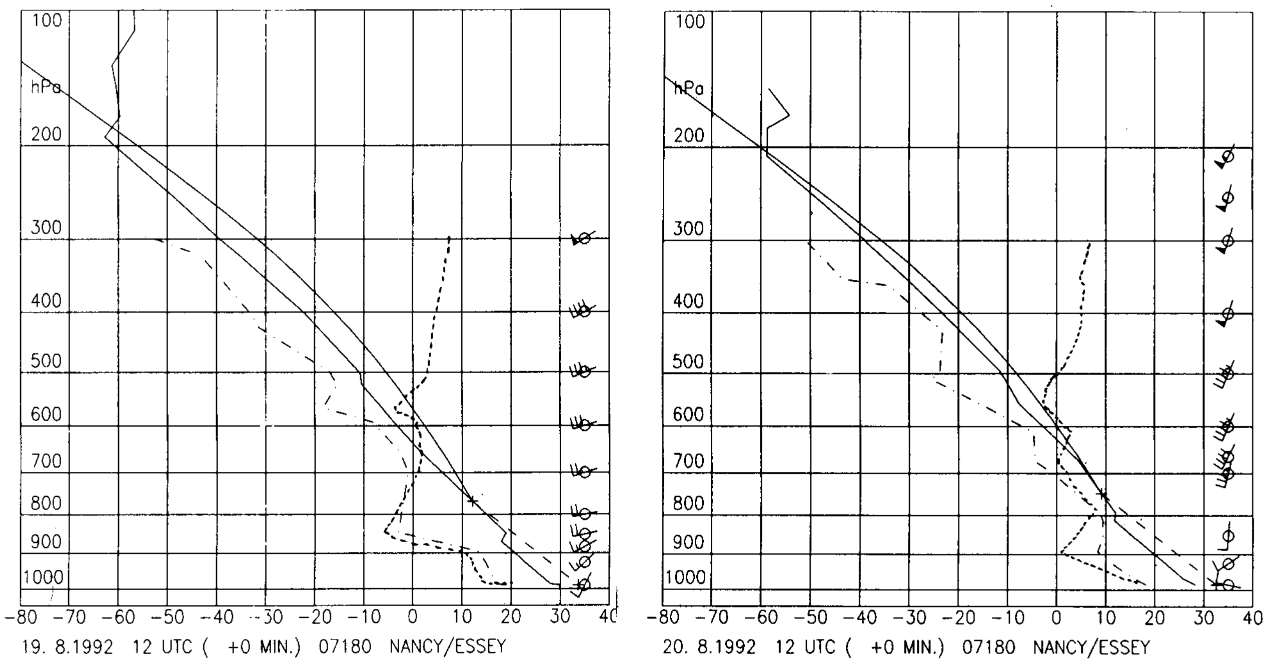

Figure 8. Radiosonde ascents from Nancy at (left) 12 UTC on 19 August and (right) 12 UTC on 20 August, showing temperature and dew-point, adiabatic through cumulus condensation level and, dotted, equivalent potential temperature (50 subtracted).

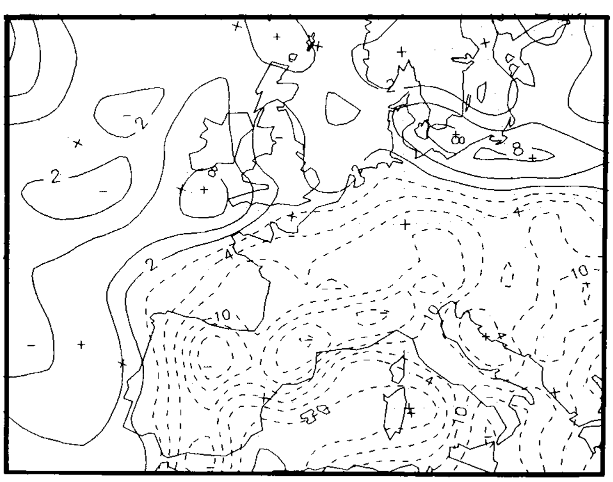

Figure 9. Analysis of the KO-index for 0000 UTC on 20 August.

That form results by using the Q-vector defined by Hoskins *et al.* as

$$\mathbf{Q} \equiv \mathrm{d}g/\mathrm{d}t.\nabla_{\mathbf{p}}.\theta = (-\partial \mathbf{v}_g/\partial x.\nabla_{\mathbf{p}}.\theta - \partial \mathbf{v}_g/\partial y.\nabla_{\mathbf{p}}.\theta),$$

where subscript g denotes geostrophic.

It describes the total time rate of change of the gradient of the potential temperature θ within a geostrophic current at a pressure surface. The forcing of vertical motion is given by

$$2h.\nabla_{\mathbf{p}}.\mathbf{Q} \qquad (h = R/p_o(p_o/p)^{c_v/c_p}.$$

This can reasonably be assumed to be directly proportional to omega. Ascent is therefore to be expected in regions with a convergence of the Q-vector whereas descent occurs in areas with a divergence of **Q**.

To use these correlations for synoptic diagnosis, maps, containing the vorticity advection 500 hPa, the thickness advection for 500–1000 hPa and the Q-vector divergence at 700 hPa derived from numerical analyses, are distributed in the fax programme of the DWD (DCF 54). These maps, supplemented by some other fields are reproduced in Fig. 10.

By comparing the position of the individual thunderstorm areas with these analyses, an amazing correspondence can be found in most cases. This is already the case for the first thunderstorms moving from Germany towards Poland on the 19th which correlated with an area of forced ascent at 700 hPa mainly caused by maximized warm-air advection in the area concerned. The convective overturnings taking place over the Iberian Peninsula at the same time, and encroaching on western France, were released, or at least supported in their development, by large-scale lifting ahead of the upper trough approaching from the west.

The correlation was weaker for the formation of the thunderstorm cell over eastern France during the afternoon of the 19th. Forced ascent was only indicated there by the Q-vector-convergence analysed at 850 hPa.

The ascending motion over western France during the night of the 19th/20th had its origin partly in warm air advection, and partly in the positive vorticity advection ahead of the upper trough. It produced the large cloudfield with embedded thunderstorms in that area. It also led to convergence in lower levels and therefore to the production of cyclonic vorticity which became visible in the formation of the surface low pressure centre. The

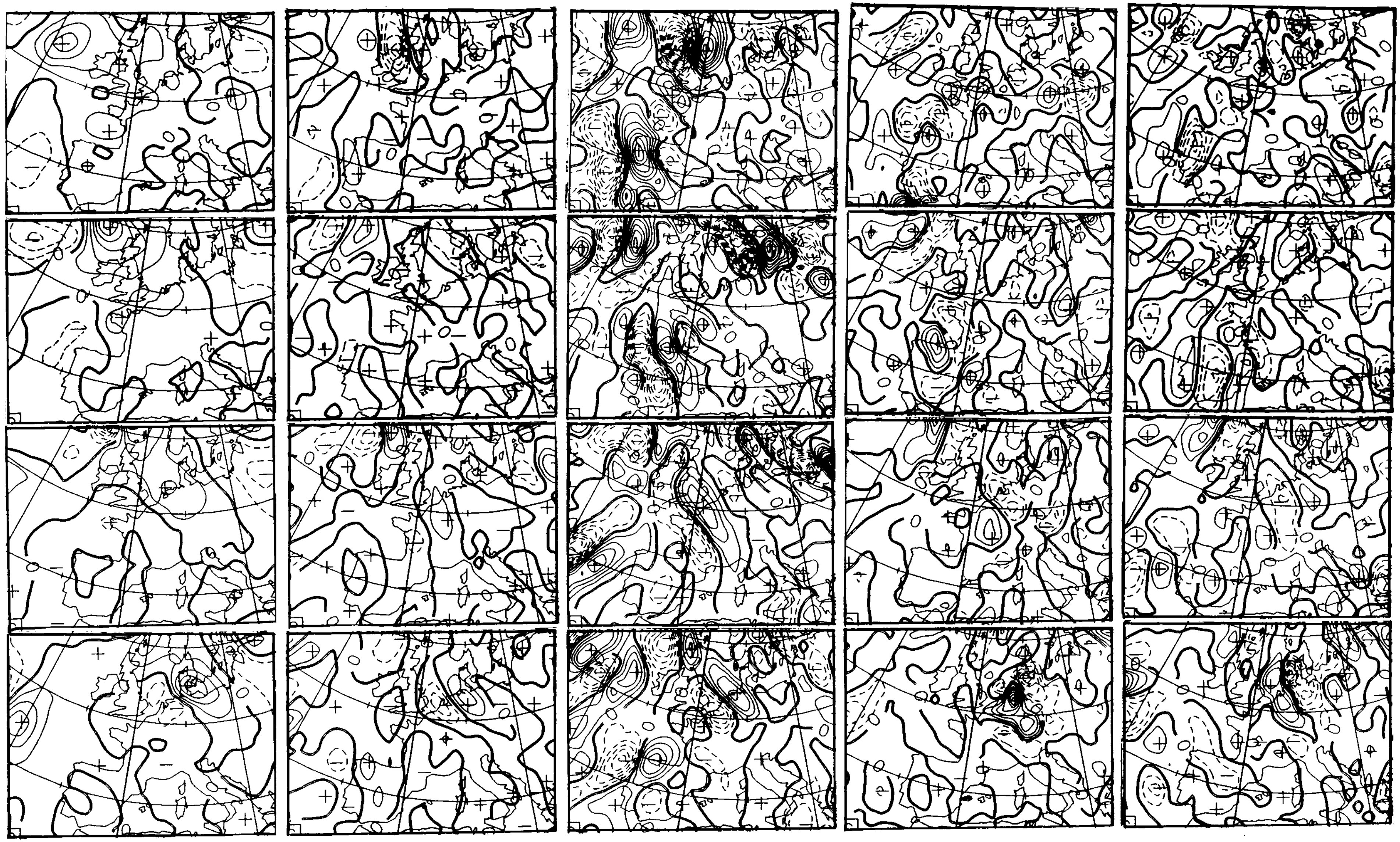

Figure 10. (a) Thickness advection 1000–500 hPa (2×10^{-7} m^3 kg^{-1} s^{-1}), (b) vorticity advection at 500 hPa (2×10^{-9} s^{-2}), (c) vorticity advection at 300 hPa (2×10^{-9} s^{-2}), (d) Q-vector divergence at 850 hPa (5×10^{-18} m kg^{-1} s^{-1}), and (e) Q-vector divergence at 700 hPa (5×10^{-18} m kg^{-1} s^{-1}), at 12 UTC on 19 August (row 1), 00 UTC on 20 August (row 2), 12 UTC on 20 August (row 3) and 00 UTC on 21 August (row 4).

somewhat noisy structure of the distribution of vorticity advection on that date (Fig. 11) was possibly not fully realistic since the numerical analysis did not exactly catch the position of the upper trough.

The correspondence between thunderstorm development and large-scale forced ascent is striking at noon on the 20th. Precisely there where the line of thunderstorms formed over eastern France forced ascent is indicated at 700 hPa which can be again traced back partly to warm air advection and partly to positive vorticity advection ahead of the upper trough. Therefore deep convection was possible without the need for high temperatures near the ground, rather the release was due to a superimposed large-scale ascending motion typical for most strong convective overturnings.

Besides containing the zone of ascent over the North Sea and eastern central Europe (which corresponds well with the cloud configuration) the distribution of the Q-vector divergences for the 21st at 0000 UTC has an area with strong forced descent due to the combined effect of cold air advection and negative vorticity advection behind the trough. The cold air advection works in the lower levels not only at the rear of the original cold front but also ahead of it too, namely behind the newly formed front at the forward edge of the thunderstorm area.

It is of great interest to compare these results with the vertical motions produced by a numerical model. They contain not only the large-scale forcing, but also the convection simulated within the model physics. Fig. 12 shows analyses of the vertical motion at 500 hPa from the DWD operational T+106 model. The comparison shows a qualitative correspondence with the quasi-geostrophic estimated forcing in many areas on the one hand, and on the other a good correlation with the development of cloud and hydrometeors in most cases. That is especially true for the Iberian Peninsula and Biscay on the 19th and the night of the 20th, as well as for the release of the thunderstorms at noon and in the afternoon of the 20th over eastern France.

In order to have a chance of forecasting the release of potential instability by superimposed lifting, 12-hourly forecasts of KO-Index and omega at 500 hPa are distributed twice a day in the DWD facsimile broadcast. The relevant forecast maps from 19–20 August 1992 are reproduced in Fig. 11. They clearly indicate the highly potentially unstable conditions south of the air mass boundary throughout the whole period. The forecast ascent at 500 hPa was generally in agreement with the analyses just described and the quasi-geostrophic reasoning with aid of the Q-vector divergences. In particular, the strong upward motion predicted for noon on the 20th over eastern France, was a significant hint that

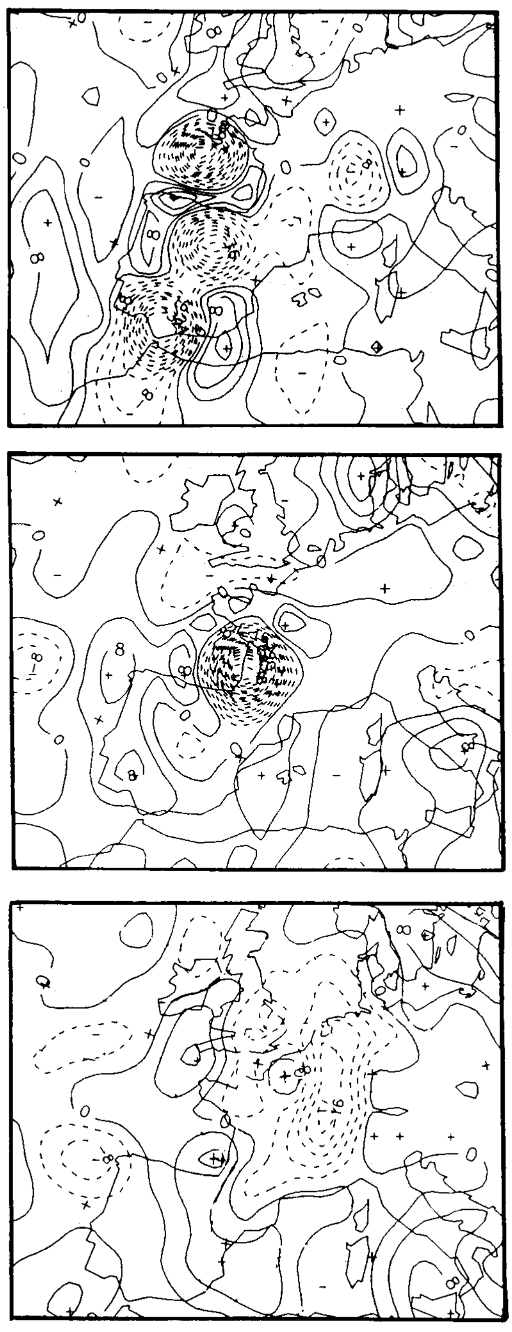

Figure 11. DWD analyses of omega at 500 hPa (hPa h^{-1}) at 1200 UTC on 19 August (top), 0000 UTC on 20 August (centre) and 1200 UTC on 20 August (bottom).

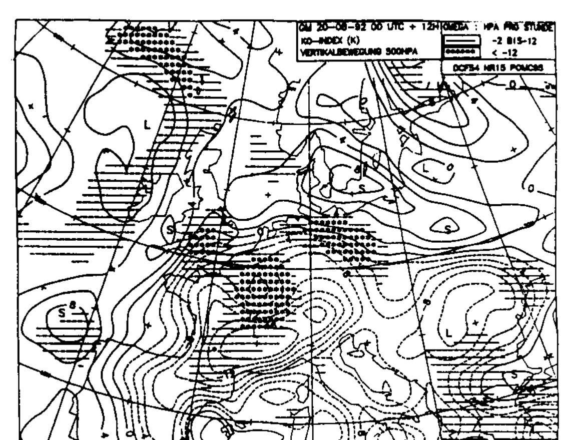

Figure 12. KO-index at 0000 UTC on 20 August with areas of ascent ($\omega \leq -2$ hPa h^{-1}).

corresponding intense convective overturnings could be expected in that area. The use of these maps tailored for very-short-range forecasting can therefore be strongly recommended.

5. Conclusions

The described weather situation was characterized by a sequence of convective systems developing over eastern France and crossing Germany eastwards or north-eastwards. The size and intensity of the convective overturnings increased from day to day and culminated in the passage of the line-like thunderstorm zone with hail, severe squalls and torrential rain in the afternoon and evening of the 20th.

The convective overturnings were released in conditionally and potentially unstable tropical air masses south of a poorly defined surface front which did not play any role in the release of the deep convection. Nor was the daily heating due to insolation enough to explain the convective development on all days. That is especially true for the main event on the 20th. The release of the instability on that day can be definitely traced back to large-scale ascent ahead of an upper trough swinging north-eastwards.

That reasoning is corroborated by diagnoses of the quasi-geostrophic forcing of vertical motions using vorticity and temperature advection functions on the one hand and Q-vector divergences as direct indicators of the forcing on the other. A comparison with the vertical motion simulated by a numerical model shows a qualitative correspondence with the quasi-geostrophic forcing in many areas.

In order to forecast the release of potential instability by superimposed ascent, 12-hourly prognoses of a stability index and the model omega at 500 hPa are produced and distributed twice a day in the DWD facsimile broadcast. For the main event this map gave a clear indication for the release of strong convective overturnings over eastern France exactly in the area where the development of the line-like thunderstorm zone started.

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A message from the Editor

I am very aware that, with only a few issues of *The Meteorological Magazine* left, I shall not be able to publish all the papers that have been submitted to me in the past year or so. When the November issue has been made-up I will write to authors whose work has not been used, offering to return it or to pass it on to another publication. I am also aware that many of the unused papers will be from overseas, and that these papers are important to remind UK readers that there are meteorological services elsewhere that do research work. I therefore hope to use some of these papers in the *Meteorological Office Science & Technology Review* (*MOST*): being of restricted circulation, publication in *MOST* should not preclude publication of the same work in a 'learned' journal where more kudos may be earned.

Meanwhile, I am anxious to build up a network of correspondents outside the UK, who will let me know of interesting developments in meteorological methods and instrumentation in their part of the world. Although I get to read about many of the more exciting weather events in the British press, accounts are often incomplete and inaccurate. So accounts, or local newspaper cuttings will be welcome. Because space will be limited (and reproduction will be by photocopier) lengthy items with colour illustrations will be inappropriate during 1994. Items for *MOST* should be more like Hisscott (February 1993) and Moir (July 1993) than Forbes (July 1993) and Kurz (this issue). Articles of a more general nature (such as the history of weather forecasting at London Airport) may be longer, but subject to serialization.

Editors of other journals will be encouraged to reprint items from *MOST* in their own language.

Because it seems likely that 1994 will arrive before the next issue of the Magazine, I would like to take this chance to wish all our loyal readers greetings appropriate to their celebrations of Christmas and the New Year.

Rodney Blackall
17 November 1993

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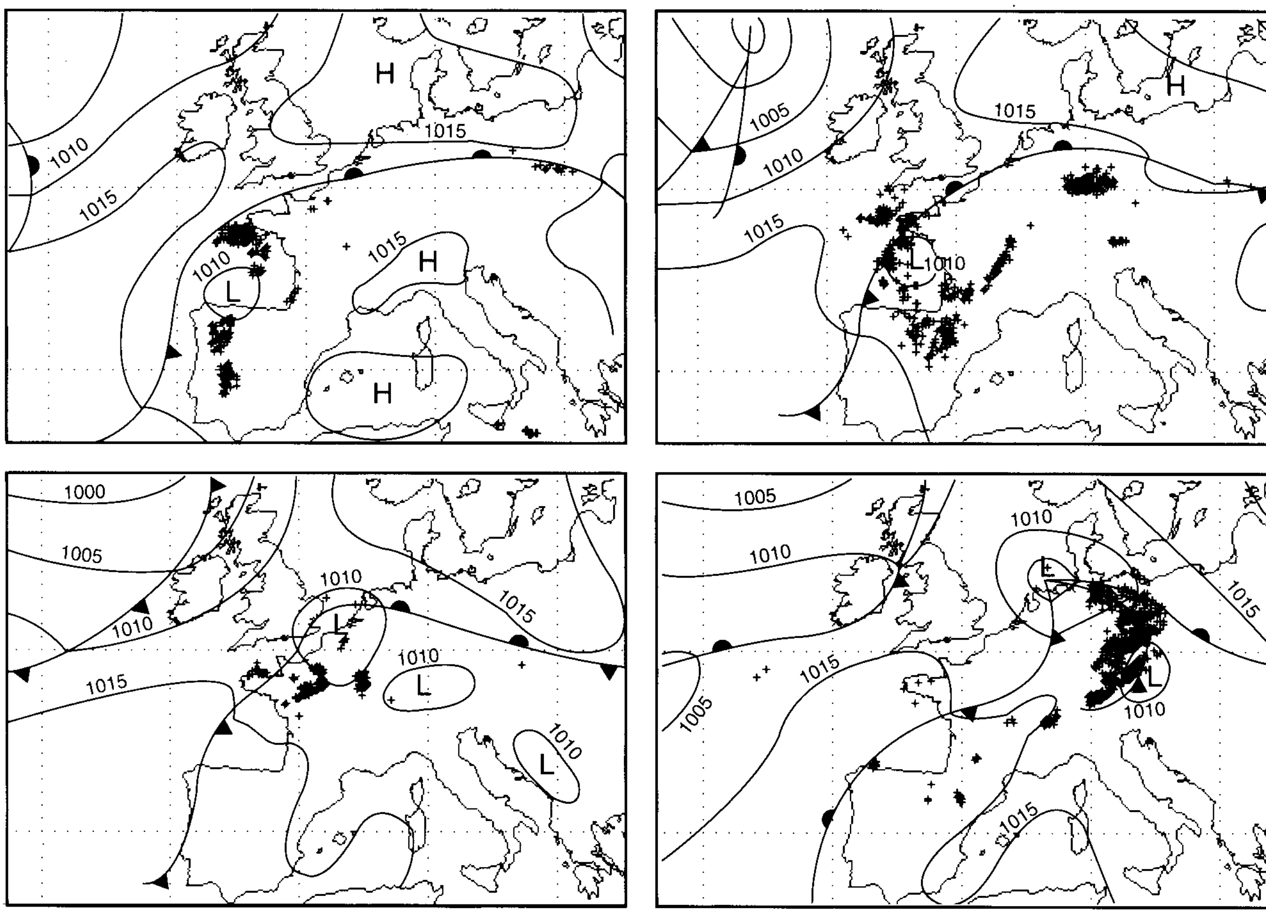
The thunderstorms of 19/20 August 1992 — a view from the United Kingdom

R.M. Blackall and P.L. Taylor
Meteorological Office, Bracknell

The article by Dr Kurz gives a very good description of the main event. However, I thought readers would be interested to see what the UK Meteorological Office ATD system detected. The four charts are for the same time as Kurz's Fig. 1. The surface analysis has been redrawn on the projection of the ATD charts. Taylor asked his system to print a '+' for each report in the four hours preceding the surface analysis time. Naturally there is a lot of overlap, but this makes the main clusters show up more clearly than any written description.



UK Meteorological Office ATD reports combined with DWD surface analyses for 1200 UTC on 19 August (top left), 0000 UTC (top right) and 1200 UTC (bottom left) on 20 August, and 0000 UTC on 21 August (bottom right).

Editor's note — what follows has been extracted from the transcript of a talk given at a Meteorological Office colloquium in September 1992. With the rise of climate modelling as a science, it behoves us all to be more knowledgeable about the behaviour of the large ice fields. This also is the second in our series on marine subjects (the North Sea was described last month).

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Sea Ice — a view from the Ice Bench

A.P. Maytham

Meteorological Office Sea Ice Office with Metroute

1. Introduction

The essential requirement of any ice service is the dissemination of sea ice data, and those from the Meteorological Office are largely collated from external sources. A watch is maintained on the seasonal variations in the mass balance of the cryosphere as these variations are an essential part of the seasonal global pattern.

2. The formation of ice

When cold air passes over water it removes heat from the surface, the cooled water is denser than the warmer water underneath, and so it sinks — being replaced by that warmer water from below. This process would continue until the whole column of water had cooled to zero; then a change of state, from liquid to solid, would talk place. The Arctic, being between 1000 m and 2000 m deep, with a maximum of 3800 m, would never have any sea ice at all. Firstly the winter season would not be long enough to freeze it all. Secondly the North Atlantic Drift, passing vast volumes of temperate water into the Arctic basin via the Fram Strait, would ensure that the Arctic column always remained well above freezing, and therefore liquid. Most substances contract when cooled, one of the facts of physics. However, fresh water behaves anomalously and expands when cooled below +4 °C. This expansion gives the coldest water more volume and less density, so instead of sinking, it creates a stable layer at the surface, which can now be cooled to freezing if the air is cold enough. This stable surface layer is usually about five centimetres deep, but is dependent upon the severity of the frost. The mixing will carry on as normal below this level until the next 5 cm layer is at 4 °C, and becomes stable and ice can form. The ice will grow further as the layers underneath cool and become stable.

Sea water usually has a salt concentration of about 35 parts per 1000 and has to be cooled to about −1.8 °C before ice forms. Sea ice has a large temperature gradient from top to bottom and consists of pure water ice with pockets of more concentrated brine within. The brine has a still lower freezing point and gravity pulls it downwards towards the higher temperature. This process continues until the salts are eventually expelled back into the sea, and within two years the sea ice is pure. This process creates areas of very cold dense saline water which sink. The maximum growth of sea ice is about 2 m in a winter. We do not normally get more than this, because the degree-days of frost for further downward growth would require air temperatures to fall much below −60 °C, and this is rare.

3. Some characteristics of the North polar region

(a) The Arctic ice sheet is free-floating but surrounded by land which naturally inhibits seasonal spread.

(b) The ice sheet is one seventh the size of the Antarctic and contains one eighth of the ice.

(c) The ice is mainly 2 m thick, with one eighth above and seven eighths floating below sea level. (The Greenland ice sheets are separate from Polar as far as the Ice Bench is concerned.)

(d) The average winter extent of sea ice is 15 million km^2 (msk). The average summer extent of sea ice is 8 msk giving an annual range for the Arctic of only 7 msk

(e) The ice grows in the Arctic for four months of the year, from November to February. The Arctic has a four-month decay period from March to May. The seasonal change is called the ice pulse. Because snow has a very high albedo, most of the sun's heat is reflected and the surrounding snow-covered land encourages ice formation in Winter. The land assists in warming the sea in Summer, but when the spring thaw starts, fresh water coming from the land flows under the ice, protecting it from the warmer, saltier water below.

From the Ice Bench point of view, we divide the cryosphere into five parts. Each is a distinct system, differing not only by seasonal fluctuations, but in the forces and ice dynamics which control the systems. There are four systems in the northern hemisphere, and one in the southern hemisphere. All are so different that they have to be independently discussed.

In the north, three of the four systems are shown in Fig. 1.

1 — The North Atlantic with access to the Pole; and major outflow of ice from the polar region.

2 — The North Atlantic without access to the Pole (Baffin Bay, Hudson Bay and Davis Strait, etc.).

3 — The north Pacific area, with access to Pole, but no forced outflow, only seasonal ice growth, and unaffected by the polar gyre.

4 — Freshwater sea ice areas of the Baltic and enclosed Black Sea.

For the fifth, The Antarctic, there is not enough space here. The reader is advised to read the fuller version published in *The Marine Observer* (Maytham 1993, 1994).

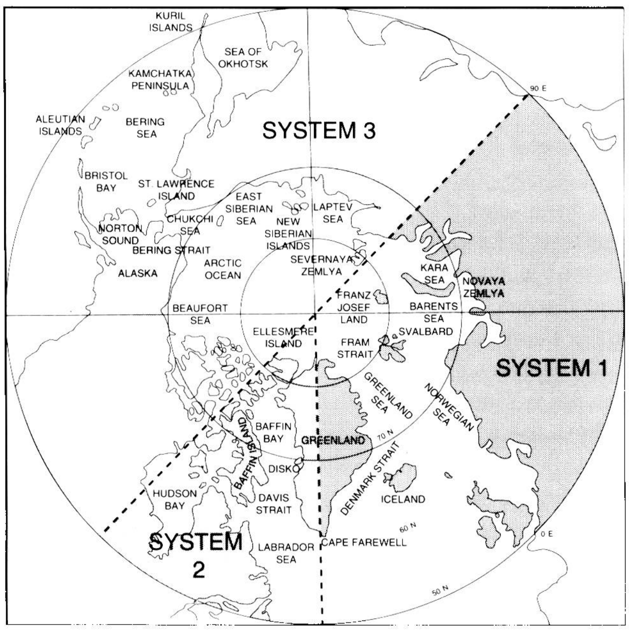

Figure 1. The Arctic, showing Systems 1 to 3.

4. Systems

System 1

The main factors here are the Polar Gyre and the Trans-Polar Drift. Although the weather patterns over the pole are varied, the polar region as a whole enjoys a degree of stability: a cold high tends to dominate the area. However, one special feature of the north is the Beaufort Sea low. This is formed by the upwelling from currents in the Beaufort Sea area clearing the ice; the exposed warm water generates a low. The winds, blowing anticlockwise around the low, move the ice, which is nearer the pole, in a clockwise gyre. The low is not always present, and the gyre may be maintained, even started — by the dominant polar high. It is however, known as the Beaufort Gyre even if it is not started by the Beaufort Low. We will refer to it hence forward as the Polar Gyre to avoid confusion.

The Polar Gyre, is the main influence moving the ice around and this has been shown in the main drift patterns of ships that have gone into and through the ice. Their tracks around the Arctic Ocean are well documented, and they all tend, in the long term, to the Fram Strait. However, the currents also influence the Polar region, but not until the gyre is stopped; and then the ice cap can be literally pulled apart by them. The sub-surface currents, which cause upwelling and 'downwelling' bear no resemblance at all to the surface currents (Fig. 2), or the actual gyration of the ice cap, but they do play a part in

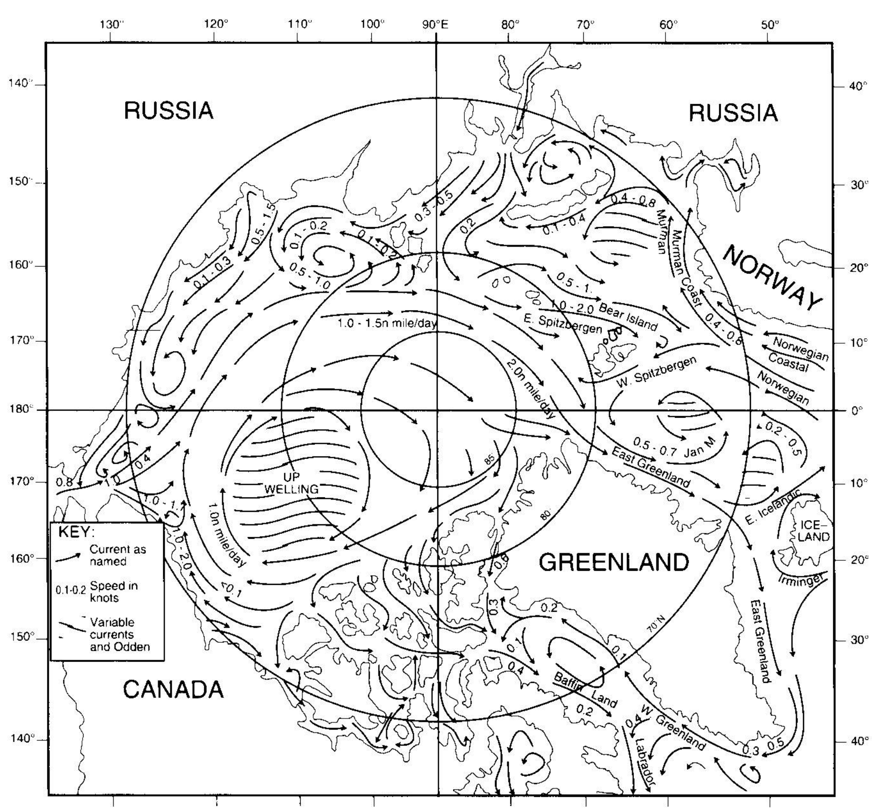

Figure 2. The Arctic. General surface currents (speed in knots, except where shown).

the starting off of the Beaufort Low. The sub-surface current at depths of up to 150 m brings warm water to the Beaufort Sea area. *Note that the ice is mainly driven by the winds.*

There have been occasions when explorers walking to the pole have encountered vast areas of open water, entirely unexpectedly. (See the section on Odden below.)

Sea ice in the Arctic can only ever develop to about two metres thick. But by the time it has spent up to five years in circling the Arctic, pressure from the polar gyre and polar drift, rafting, ridging, hummocking and various impacts, its thickness could be four, or in extreme cases, five metres. By this time it is heading through the Fram Strait and comes into what is known as the marginal ice zone (MIZ), The Fram Strait is the only feeder of ice that influences this system. The ice tracks down the east Greenland coast with the East Greenland Current to Cape Farewell — the southernmost point of Greenland (Fig. 3).

The rate that ice, as heavy, medium and light floes, moves out through Fram Strait follows a similar pattern every year. However, the gyre does vary in strength, and the volume of ice passing out can be predicted from it. The stronger the Polar Gyre, the more ice flows out. The Fram Strait monthly flow does have a consistency worth monitoring. Torna Vinje, who is the head of the Norwegian Polar Research Institute, has done a vast amount of research on the Fram Strait. Vinje has shown, by flow meters across the Strait, that in fact the inflow equals the outflow, which is not shown from the charts of surface currents. The currents play a large part in the flow of the ice along this coast. The charts show the main current down the coast of Greenland, and the main strength. This main strength follows the continental shelf, and this is fairly consistent with the maximum flow of ice. This main flow of ice is along the marginal ice zone, and this is where the main mixing and the melting take place. After the Fram Strait, there are various features in the topography that divert the current, and the ice. The eddies in the Gulf Stream drift also affect the mixing areas.

From the Ice Bench point of view, the mixing areas are quite interesting as they do have various features. Where there is mixing, there are little vortices. These show fairly clearly on satellite pictures taken by NOAA Advanced Very High Resolution Radiometers (AVHRR).

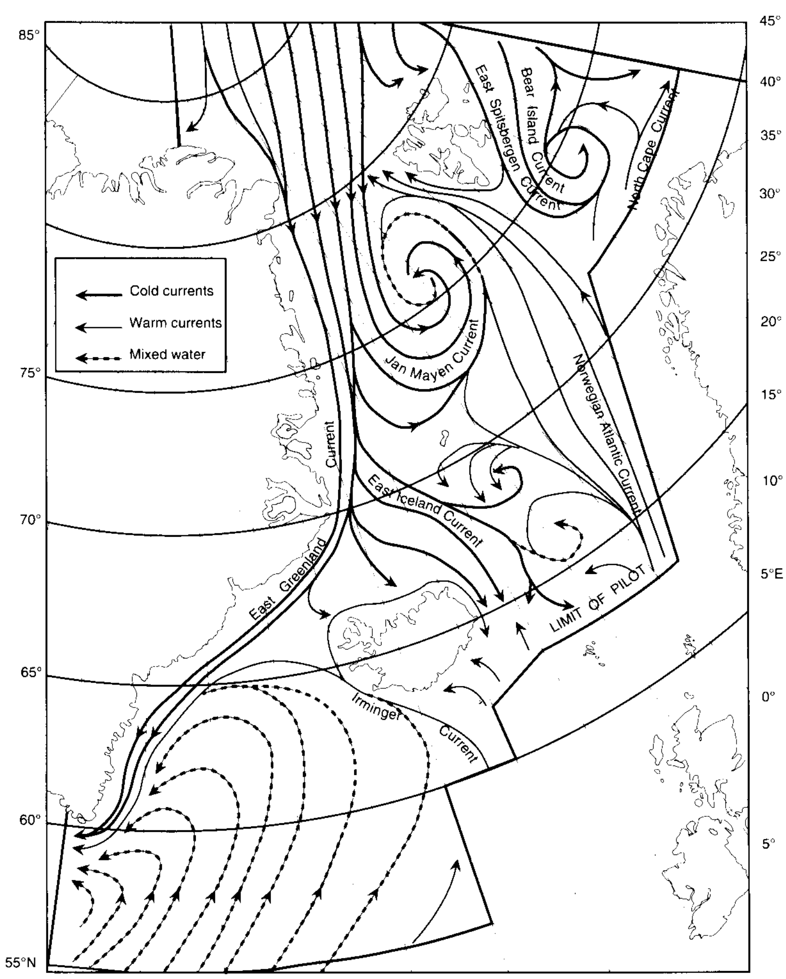

Figure 3. Norwegian Sea and Fram Strait; general surface circulation (extracted from Admiralty Pilot NP11, *The Arctic*, published by the Hydrographer of the Navy).å

These give a good overall picture, but on some channels the footprint is small. The Synthetic Aperture Radar (SAR) microwave scanner of ERS-1 is best for showing actual ice concentrations because it has the right size footprint and shows the mixing and the vortices along the MIZ.

The large melt in this area generates vertical frontal systems in the water. The main currents do not mix, as the cold melt water flowing south is stable and as dense as the warmer water flowing north. The resulting front can be seen on a bathygram of the various areas. There are some areas that are virtually stable fresh water, and there are others of mixed water both stable and unstable. It is the areas of mixed water that create the fog problems in this particular region; but cold, stable water will refreeze as soon as there is cold air above.

The topography of the area shows why we get certain currents. The East Icelandic Current, The Irminger Current, the Jan Mayen Current, and all the eddies associated with these, follow the main ridges and shelves. These divert the ice away from the continental shelf flow and it then melts rapidly.

One notable feature of System 1, is the scarcity of icebergs of land origin. Most are calved from the Siberian glaciers and are mainly trapped in the New Siberian Islands by the pressure of the Trans-Polar drift, so they do not actually pass into the gyratory system. They do not become a major feature; in fact the reverse, the lack of bergs is the interesting feature.

System 2 (Baffin Bay, Hudson Bay and the area to the St Lawrence Seaway and the Grand Banks)

The main feature of our System 2 is bergs. There is no access to the polar gyre, and the region is not influenced by the trans-polar drift. Surrounded by land and islands, it is an entirely independent system. The predominant feature which governs the berg flow, is a warm current passing up the west coast of Greenland. This plays an important part in the ecology of the area, and controls the ice melt/growth in the seasonal pulse. The importance of the current, which begins at Cape Farewell, can be seen from the actions of the bergs. They are all taken by the current northwards to Baffin Bay, to circulate for up to three years, before drifting southwards to the Grand Banks — which area they have made famous.

Ice coming down from the Arctic Ocean will, in Winter and extreme conditions, reach Cape Farewell. And although this is not normal, some ice may round the Cape and travel into our System 2. (To all intents and purposes, System 1 ends at Cape Farewell, where System 2 starts.)

The warm current going up the west Greenland coast collects the bergs as it tracks northwards. There are small bergs calved south of Disko Island, but the main calving grounds for the larger bergs are further north where there are about 100 main tidal fjords which maintain a heavy flow of bergs. The sea ice is never more than about four metres thick — from rafting and ridging. However, the bergs are land ice, and are up to the depth of the glacier, usually soon breaking up into smaller pieces. As a norm, sea ice is usually present for most of the year, very light and coastal only — caused by land cooling. Even in mid-Summer there are still bits of sea ice about. They are never of great depth or in heavy concentrations. Most is light sea ice which has drifted out of the fjords, with bits of land ice from small glaciers. The current, although it plays a large part in keeping this little system moving, keeps the Davis Strait and Baffin Bay mainly free of sea ice in Summer. This is because the current brings water with temperatures of up to 8 °C. In water this warm, a normal berg of flawed land ice will melt in about 5 or 6 days. They do not survive long south of Disko Island.

The bergs are brought south with the vast amounts of soil, rocks and debris that glaciers gouge out of the land under normal circumstances. Normally sea ice, in salt water is 1/7th above the water line: freshwater ice, in fresh water is 1/8th above. But with ice of land origin there is no way of estimating the keel depths, because it has the rocks and various other debris within, and the mass balance is entirely changed. Gravity will pull much from the berg as they come down east of Baffin Island and into the Labrador Current: then down to the Grand Banks, where they greatly influence commerce. The Ice Bench is always particularly interested in the icebergs in this region.

The Labrador Current divides over the Grand Banks, and carries smaller bergs along the coast, or grounds them on the banks. A display of the topography over the banks, which is mostly mud, shows great grooves covering almost the entire surface. As the bergs melt, they change shape and may capsize, changing their draught. A berg may initially clear the banks on a high tide only to ground later. Drift will continue with the next high tide, or after some melt has taken place. The debris that is retained on arrival at the banks, will be released, and will help the bergs to split into smaller pieces. It also reduces the depth of water. Much of the silt settles between the boulders, and gives a flat appearance, scared by bergs grounding.

The main flow of the bergs is with the currents around the Grand Banks, and with the tides. There are little vortices and eddies which bring the bergs south of Newfoundland. Although the main southbound current flow stops at about 43 °N, there have been bergs much further south; and bergs have been reported as far south as Bermuda and as far east as the Azores: these must be considered.

In Winter the sea ice along the Labrador current is mixed with bergs. There are some bergs on the outer limits, but not many. The current, being cold, ensures that bergs within survive, but those outside the main flow soon encounter eddies and warm water mixing which destroys them.

As a result of the sinking of *Titanic* on 15 April 1912 the International Ice Patrol (IIP) (based in Groton, Connecticut) was set up in 1914. This body reports on the extent of the icebergs while the main bergs are drifting southwards. This occurs as the sea ice recedes and releases the bergs to the currents during June and July. Of all bergs, 94% appear between March and June, but 64% between April and May.

The lesser Bays, Basins, Gulfs and Inlets are all usually sea ice free in Summer, and follow the seasonally adjustable patterns. The Hudson Bay area does not have glaciers, so there are no icebergs. The seasonal pulse is greatly influenced by the heat budgets of a particular season. The heat budget for Hudson Bay is huge, and can prevent the early growth of sea ice, even though the land mass may be forming coastal ice. (It has been reported that sufficient heat is absorbed in one season to light the entire country of Canada.) The heat that is absorbed, and retained, is quite sufficient to prevent the ice from growing to any great depth and sometimes from forming at all.

System 3

There are three main features of System 3, peculiar to this area. First, although it is exposed to the pole, it is not influenced in any way by either the polar gyre or the Trans-Polar drift. The sea ice follows a fairly constant seasonal pattern of growth and decay. The current in the Bering Strait is in a northerly direction, and therefore has no effect on outflow of ice. The second feature is that all the ice is new ice, there is never any second or multi-year ice in the Pacific area, although some may be wind driven out of the Bering Strait. The third feature, peculiar to this area, is lack of icebergs. There are no glaciers which feed the Pacific area, and none flow out from the Arctic basin into the Pacific.

The air temperatures in Japan give severe winters: they get a lot of snow, but sea ice only grows as far south as Hokkaido Island in north Japan. The ice never grows further south because the currents moving north inhibit the growth. Currents along the west coast of Canada keeps that coast ice-free also. Due to the northbound currents, the mean concentrations of sea ice are fairly high.

System 3 has no pressure, no main outflow, and no current driven pattern. The sea ice will seasonally grow and recede through the Bering Straits, and will have a maximum keel depth of one or two metres depending on its history.

System 4

Our other ice systems in the north are the Baltic and the Black Sea. The Crimean ice grows because it is in very shallow water, and it cools and freezes rapidly. Never growing to any great depth because of time (or lack of it); it decays rapidly as the air temperature rises. The ice season is very dependent upon air temperatures, and, when ice does form, it is usually between February and March.

The Baltic ice is a major influence on shipping concerns in our area. On average it will grow to cover the Gulf of Bothnia. The northern part is known as the Bay, and the southern part the Sea; the whole being the Gulf. On average it will always freeze. The Gulf of Leningrad usually freezes, but not always the Baltic Sea, either North or South. Because it is fresh water, between 1.002 and 1.006 density, it starts to freeze as soon as the air temperature cools it to 0 °C. The sea ice does not often reach the North Sea, and when it does, is usually Baltic ice tide-drifted out.

The ice in the Arctic Ocean has only ever been measured to about 5 or 6 metres, and that from heavy ridging and rafting. However, in the Baltic, hummocking, rafting and pressure ridging, can generate keel depths down to 28 metres, which — from a sea ice point of view — is phenomenal.

5. Features

5.1 Polynya

These are areas of open water in a ice field. There are three types of polynya. The 'shore polynya', the 'flaw polynya', and the 'reoccurring polynya'. A shore polynya occurs between the shore and the ice, a flaw polynya is a crack opened up by current, tide or upwelling. A reoccurring polynya is largely self explanatory, and an example is the Beaufort Sea Polynya. A land/shore polynya is not always opened up by tides or current — wind may create an opening. There is also upwelling which can start a shore polynya to be maintained by the wind.

The polynya are not unusual, they can occur anywhere and everywhere; and frequently do. The only recurring one is the Beaufort Sea Polynya. The others are usually wind generated on the southern part of the east Greenland coast, and current generated on the northern part of the east Greenland coast. Polynya are very easily seen from satellites. In the north there are many small currents which all play a part in packing the ice/bringing warm surface water/bringing warm sub-surface water for upwelling melt/clearing ice/packing ice — and many other small influences like eddies and small vortices. Some are peculiar to Summer only. The main currents are the Jan Mayen Current, The Irminger Current, the East Iceland Current and the Norwegian Current (remnants of the Gulf Stream Drift).

5.2 Odden

'Odden' is Norwegian for tongue; they occur when cold air passes over cold stable water. Ice forms, probably 9 or 10 tenths coverage, but only a few centimetres thick. The ice will last only as long as the cold air is above it, as sub-surface currents and warm air soon cause its decay. The only odden are the Jan Mayen Odden, the Bear Island Odden and the North-East Odden. All are associated with currents in the area. Some mixing with sub-surface currents in the area may keep the odden ice very thin and even inhibit development. The North-East Odden and the Bear Island Odden are not actually discernible, because the current brings ice anyway. The Jan

Mayen current does not carry ice far from the continental shelf barrier, so this odden is the most conspicuous.

5.3 Whalers' Bay

Warm water from the North Atlantic Drift, becomes the West Spitzbergen Current, and flows into the Arctic basin. This warm water causes the ice to decay, and a vast area of open water develops north of Spitzbergen. This has a bay-like shape, and can last for some considerable time. The warm water can be seen passing Iceland, and takes about two weeks to arrive at 80 °N and start the Bay forming.

5.4 Fronts

The fronts are persistent interfaces between cold and warm water. The south-flowing cold water has much the same density as the warm northerly flow because it is mainly fresh melt, less saline, and colder. The volumes of water have a vertical contrast of salinities and temperature, rather than the normal horizontal divisions. Along the fronts there is upwelling of warm saline water and the cold denser water sinking. these movements are known as funnels, and the effect known as the 'chimney effect'. These chimneys don't only occur in this part of the world, they do occur throughout the globe where there is, for whatever reason, mixing taking place. By and large, in the open oceans, the layers are fairly well defined in a horizontal pattern. But along the east coast of Greenland they are not.

The front that is most noteworthy is the 'Norwegian Coastal Front' as it changes character twice a year. In the summer the land heats coastal waters, these become much warmer than the Gulf Stream drift, so a front forms with warm water landward and cold to sea. In the winter the land cools the coastal waters, while the warm water of the Gulf Stream drift is largely unchanged; this puts cool water to landward, reversing the front.

Graphs of salinity and temperature comparison show the fronts well. The very concentrated cold salt water excluded from the sea ice naturally sinks, and is replaced by warmer water which gives a fairly clear-cut level under the ice. As this is continually mixing at the MIZ the expectation is for a continuous front. It does not follow these lines. The 35 parts per 1000 average salt water does not vary much in any of this area. Graphs show 35 or 34.9. But where the salts are being pulled through the ice it can go up to 40 parts, but this usually sinks so rapidly that it is not seen for long. There are places that have recorded 50 parts per 1000 but this is unusual.

5.5 Icing

One of the worst features of sea ice areas is the icing of ships. The main problem with it is that it can be seen happening, but the extent of the danger is not known. The ice seals the doors and the windows and all exits, so it can become impossible to get out. Radio aerials become iced over, and can break, leaving no means of communicating the distress or the problem in the area.

5.6 Satellites

Guidance in using meteorological satellite data to distinguish between clouds, ice and snow will be found in Chapters 1 and 8 of *Images in weather forecasting* to be published by Cambridge University Press early in 1994.

The Farnborough research centre produces a seven-day mean isotherm chart. We also get satellite data. We receive very useful data in real time from the Norwegians, who can do no wrong in our eyes.

We generate our own SXNT ice chart on Tuesdays from the Norwegian and Canadian data, on Thursday we use data from NOAA and the Joint Ice Centre. We also produce our AXXX sea isotherm chart. The ice bench charts are distributed mainly to CFO, and to the search and rescue centre at Chivenor, Devon, who disseminate to various authorities that require this information.

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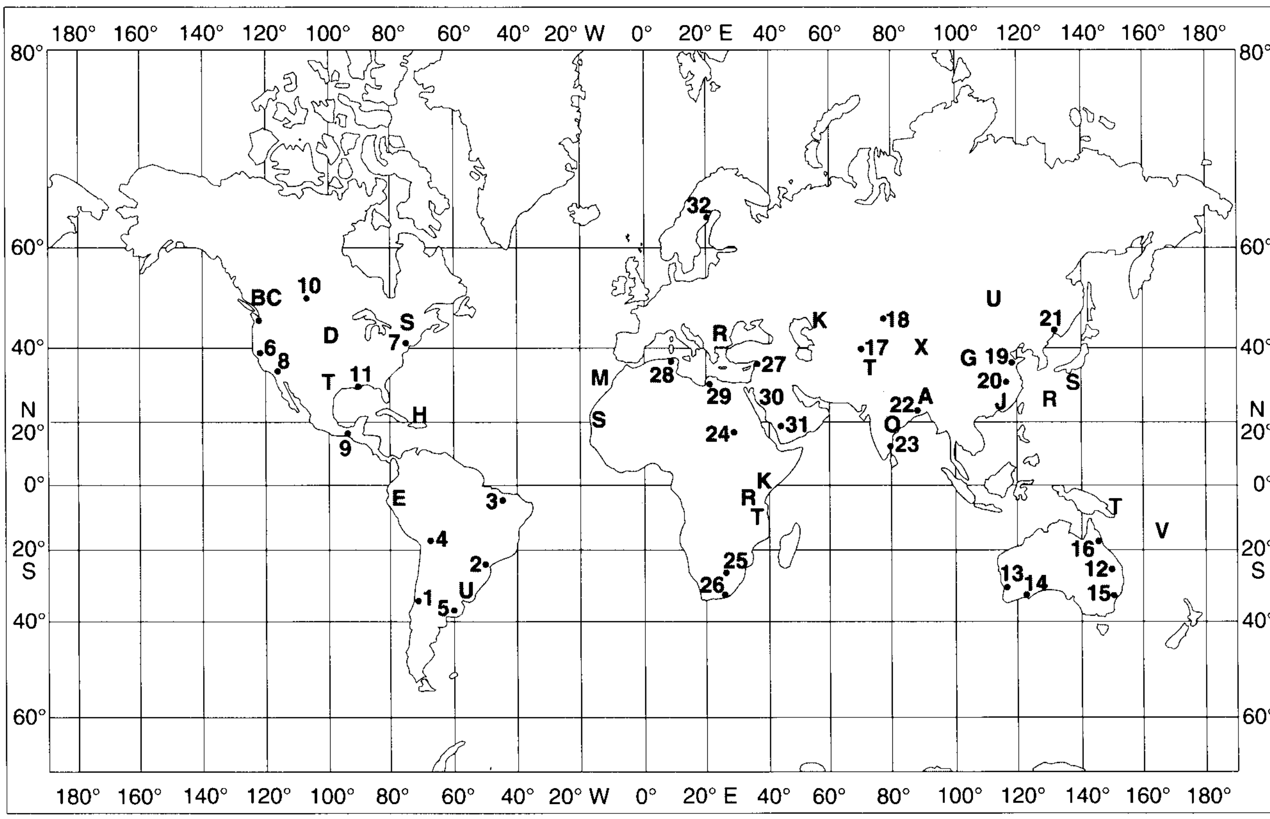
—, 1994: The Cryosphere — a view from the Ice Bench. *Mar Obs*, **64**, 19–27.

World weather news — May 1993

This is a monthly round-up of some of the more outstanding weather events of 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 areas followed by letters, in the text are identified on the accompanying map. Spellings are those used in The Times Atlas.



Location of places mentioned in text

South America

Heavy rain at the beginning of the month led to landslides and much flooding around Santiago (1), Chile, on the 4th with a death toll of 11. Ecuador (E) suffered a calamity on the 9th when an earth tremor coincided with heavy rain near the Peruvian border, a cliff honeycombed with gold miners' tunnels collapsed with a heavy toll of life as 64 bodies were recovered and more than 200 were reported missing. Earlier in the month, heavy rain had caused the river Paute to flood in rural Ecuador with the loss of 20 lives. On the 8th, Artigas in Uruguay (U) found there had been 158 mm of rain in the previous 24 hours; this is about 50 mm more than the average for the whole month: to prove this was not a fluke, Salto next day beat its average by a similar amount when they measured 137 mm. Not to be outdone the Argentinian town of Concordia managed 155 mm in the week to the 10th, which is double the average for the month. The result of these remarkable rainfalls which had been occurring on and off since April was $400m of flood damage to Argentina's farm belt but no deaths. The Salado river was at its highest ever and flooded four million hectares.

Irati, near Curitiba (2) in southern Brazil had falls of 58 mm and 118 mm on the 13th and 14th respectively — their monthly average is 115 mm. On a different note, the eastern Brazilian town of Teresina (3), where the record temperature for May used to be 35 °C, had a hot spell starting on the 14th; maxima reported were 36.0, 35.6 and 36.0 °C. This is winter down south and La Paz, Bolivia (4), had a night minimum of −5 °C on the 18th, 2 °C lower than the previous record. In Patagonia −10 °C was quite common on the 26th breaking some records. Returning to the rainy theme, Tandil (5), 200 miles south of Buenos Aires, had 86 mm of rain on the 24th, their monthly average is 63 mm.

North America (and Gulf of Mexico)

A cold front crossing Texas (T) early in the month brought warm, wet air up from the Gulf and converted it to heavy rain; on the 6th San Antonio had 159 mm, nearly double the normal for the whole month; not far away Victoria had 194 mm while around Houston there were reports of tornados and baseball-sized hail. On the 9th there was a tornado near Dallas which killed one and injured 30: the same day brought news of high temperatures with the news with 33 °C in San Francisco (6) and 31 °C in New York (7) though the hottest was Monrovia (8), California, with 38 °C. The heatwave extended as far south as Salina Cruz (9) on the Pacific coast of Mexico where the 40.0 °C on the 10th was just above the old record. At the other end of the continent Edmonton (10) in north-west Canada managed 32.6 °C on the 12th which is 2.6 °C above the previous record: records were still being broken in British Columbia (BC) on the 18th.

In mid-month news came of a week of heavy rain over Hispaniola (H) and eastern Jamaica causing damage to crops, flooding and landslides. Twelve were killed in the Dominican Republic and traffic was severely disrupted in Santo Domingo. The period 18th/19th was probably the worst in Jamaica when 96 mm (the average for the whole month) fell, but no one was killed.

Rather imprecise information on the 22nd spoke of violent storms in South Dakota (D) and Texas with high winds, hail up to an inch in diameter and 150 mm of rain in two hours. The 26th brought heavy thunderstorms to the Mississippi delta flooding New Orleans (11) with 75 mm (May normal of 112 mm). On a general note, after analysing VHRR scans at the end of April, NOAA announced that 'In the USA the area with well developed vegetation is much smaller than in any of the last five years. Development is three to five weeks behind schedule except in south Florida, California and Texas.' On a more sinister note: after a record wet April Lake Ontario was 20 cm above flood level. The St. Lawrence Seaway (S) was being used to relieve the situation. It was closed to shipping two days a week so that locks could be left open. Watch this section next month.

Australasia

This information is largely based on that kindly given by the Australian Bureau of Meteorology. The month seems to have been uneventful over much of Australia with only Surat (12) in Queensland being picked out for mention — its mean maximum temperature of 26.8 °C was the highest in the 44 years of record. All the news seems to be reserved for Western Australia where wind and rain were the dominant features. The 1st brought heavy thunderstorms around Perth (13). In the country there were losses of newly shorn sheep and damage to roads and property: in the city electrical failures upset traffic lights and computers and one strike ignited a petrol pump. One man escaped unhurt when his umbrella was destroyed by lightning! Several places had their lowest May maxima for more than 30 years because of rain. The rapid deepening of a low near Esperance (14) on the evening of the 28th lead to them recording a new record gust of 82 kn (mean speed 59 kn) just before a power failure cut off the anemometer. At least six widely spaced gauges collected new May monthly record rainfalls of around 130 mm: Perth got half the month's normal rainfall in 48 hours from the 27th to 29th as 67 mm fell.

There were some notable storms elsewhere, Ulladulla (15), about 100 mile south of Sydney, had 101 mm on the rain day ending the 9th, and 91 mm of that fell in six hours. Innisfail, near Cairns (16) had 77 mm on the 22nd at the end of a week that brought 231 mm (the month's average is 305 mm).

Further afield the short-lived cyclone Adele developed near the island of Bougainville on the 14th and caused havoc in the Trobriand Islands (T) before crossing the extreme south-east of Papua New Guinea. No deaths were reported but a high proportion of the buildings on the Trobriands were destroyed. Sola in the Vanuatu (V) group attracted attention on the 22nd when 275 mm fell in 12 hours.

Asia

The southern Japanese island of Shikoku (S) started by getting half the usual month's rainfall almost at once with 117 mm in 24 hours to midday on the 2nd. However, the dominant feature seems to have been an especially potent cold front. The news from China on the 5th was dramatic! A 'cataclysmic' sandstorm in the north-west Chinese province of Gansu (G) lasting about two hours and laden with sand and pebbles killed 47, most of these were children swept into watercourses where they drowned: power lines and trees were blown down of course. Crops were buried or blown away and at the time the story emerged, 25 were still missing and 153 were injured. Further west, in Xinjiang Province (X), hurricane force winds created a violent sandstorm that blocked the main railway line in seven places stranding 48 trains, 10 000 people and damaging seven locomotives. These stories are probably related to the events further north in Mongolia. A depression moved east, and in Ulaanbaatar (U) the balmy 19 °C of the 5th (well above normal) was replaced by −6 °C, snow and sandstorms killing at least 16 people. A comparable change occurred in Tashkent (17) soon after when their maxima fell sharply: 7th, 26 °C (average); 8th, 21 °C; 9th, 7 °C. Alma Ata (18) reached 22 °C on the 7th, 8 °C on the 8th and 3 °C with heavy snow showers on the 9th. Tajikistan (T) was pounded by torrential rain on the 8th which brought flooding and destroyed 3000 homes, a dam and half the power supply system of the capital Dushanbe. The capital of China's Shandong Province, Jinan (19), had torrential rain at the end of this period when 84 mm fell in the second half of the 11th, this is 48 mm more than their daily record and monthly average. A little later Wuhan (20) on the Yangtze river just set a new record with a fall of 96 mm. In Jiangxi Province (J) the heavy rain and hail killed eleven and caused the river Gan to flood. The big change reached Japan on the 13th when Tokyo's maximum of 30.7 °C (near the May record) was rapidly followed by 21 mm of rain and a maximum of only 13.9 °C next day.

Severe contrasts were noticed again in Mongolia on the 19th with daytime maxima ranging from near 20 °C to continuous snow and night minima between −5 °C and −10 °C. Reports emerged of severe flooding in Khazakhstan (K) in mid-month as a result of torrential rain and heavy snowfalls. The worst effects were said to have been along the banks of the River Ural which rose more than 8 m. Our customary report of heavy rain in the islands comes from Cilacap on the south side of Jawa, here on the 19th, they managed 189 mm, 167 of which fell between 1200 and 1800 UTC. Daily totals well in excess of 100 mm were then reported from China on the 25th and 26th on the Ryuku Islands (R) on the 27th: out of all these 90 mm at Wutai-Shan, 200 miles south-west of Beijing, was perhaps the most impressive; their monthly normal is only 11 mm!

Sometime on the 24th or 25th one of the worst hailstorms for eight years hit eastern Iran; violent thunderstorms accompanied by hailstones weighing 150 g caused extensive damage to crops. To finish as we began, Vladivostok (21) had a maximum of 27 °C on the 27th, a new record by more than 3 °C, after the passage of a cold front the best next day was a mere 10 °C.

Indian subcontinent

'It was winter. We were of Kipling's 'hosts of tourists who travel up and down India in the cold weather showing how things ought to be managed'. It is a common expression there 'the cold weather,' and the people think there is such a thing. It is because they have lived there half a lifetime, and their perceptions have become blunted. When a person is accustomed to 138 °F in the shade, his ideas about cold weather are not valuable. I had read, in the histories, that the June marches made between Lucknow and Cawnpore by the British forces in the time of the Mutiny were made in that kind of weather — 138 °F in the shade — and had taken it for historical embroidery. I had read it again in Sergeant-major Forbes-Mitchell's account of his military experiences in the Mutiny — at least I thought I had — and in Calcutta I asked him if it was true, and he said it was. An officer of high rank who had been in the thick of the Mutiny said the same. As long as these men were talking about what they knew, they were trustworthy, and I believed them; but when they said it was now 'cold weather,' I saw that they had travelled outside their sphere of knowledge and were floundering. I believe that in India 'cold weather' is merely a conventional phrase and has come into use through the necessity of having some way to distinguish between weather which will melt a brass door-knob and weather which will only make it mushy. It was observable that the brass ones were still in use while I was in Calcutta, showing that it was not yet time to change to porcelain. I was told that the change to porcelain was not usually made until May.' From Mark Twain in chapter LVII of *More Tramps Abroad*. 138 °F = 59 °C.

To prove the above is not totally unfounded, the 2nd brought maxima in excess of 46 °C in east Pakistan and Orissa (O). The month opened with heavy rain in Assam (A) and Tripura which caused flash-flooding and made tens of thousands homeless. About the same time Dhaka (22), Bangladesh, was struck by a 45-minute storm of great violence. Nine were killed and 250 injured as gale force winds flung debris around. Shortly afterwards there were heavy hailstorms in surrounding areas. Three major rivers then broke their banks under the weight of water flowing from the Himalayan foothills. The Ganges delta had a 'tornado' on the 14th with wind speeds of about 100 kn that killed 25, injured 2000 and razed 15 000 bamboo huts. Madras (23) was rudely awakened on the 15th when a thunderstorm deposited 72 mm in three hours before local noon (this about three times the monthly average).

Storms in the north of Afghanistan between the 14th and 16th were said to have killed at least ten humans and 200 animals. Far away to the south-east, Comilla near Dhaka, suffered a period of 'seasonal storms' on the 16th and 17th: the heavy rain and tornados killed 8 and made 5000 homeless and in surrounding areas 100 000 were marooned by flooding. The last week of the month brought heavy rain and widespread flooding to much of Sri Lanka, killing five and making 150 000 homeless.

Africa (except the north coast)

Northern parts of Tanzania (T) were hit by a five-hour rainstorm on the 2nd which brought flooding and extensive damage to crops. Nearby on the shore of Lake Malawi, Nkhata Bay measured 145 mm on the morning of the 1st and a further 114 mm on the morning of the 2nd. Early on the 3rd Nyere, Kenya (K) followed suit with 108 mm (average for the month is 120 mm). Mwanza on the south shore of Lake Victoria had just over half its usual monthly fall on the 4th with 58 mm. It was not all rain in this part of the world, Nairobi's 28.6 °C on the 9th was a near record and followed eight days of above average warmth. Further north the heat triggered thunderstorms and Mandera's 125 mm was about five times the average for the whole month and Meru's 114 mm was nearly four times the average.

Over on the west coast Senegal (S) fairly sizzled on the 11th when Matam broke its May record by nearly a degree in reaching 48.0 °C. Back in the wetter east, Rwanda's (R) capital Kigali just managed a new May 24 hr rainfall record on the 16th when 69 mm fell: Dzaoudzi in the Comoros (north-west of Madagascar) normally only has 36 mm of rain in May; they had 99 mm in 30 hours to 1200 UTC on the 17th. The rains spread further north into the Sudan than usual when on the 23rd El Obeid (24) got 23 mm compared with the monthly average of about 18 mm. In contrast to the frost in South Africa (e.g. −4 °C in Bloemfontein (25) and −3 °C at Tsabong, Botswana) Zimbabwe and Kenya had near record maxima of 28 °C on the 28th and 29th respectively.

The following notes are kindly supplied but the South African Weather Bureau. While the south-west coast was wet most other areas were having about 25% of normal rain and Port Shepstone's 0.1 mm was a new record. At the other extreme Vredendal's 80.8 mm was also a record. The 1st brought heavy rain and flooding to the Cape Peninsula, 55 mm at Goodwood, and on the 16th a deep low to the south brought gales. Out at sea, off Port Elizabeth (26), storm force winds and an 11 m swell brought about the loss of the *Nagos* when a hatch cover blew off: half the crew was rescued but the weather was too bad to pick up the remaining 17.

Europe, North Africa and Arabia

A low developed over Syria on the 5th producing heavy rain and thunderstorms on its western side. Hama's (27) 32 mm on the 4th/5th was the wettest and 11 mm above the average for the whole month. Meanwhile at the other end of the Mediterranean a low had drifted from Madeira into the Alboran Channel, so on the 5th Gibraltar got 26 mm of rain in 12 hours instead of taking a month over it. Across the Strait, Tangiers (May average 39 mm) had 27 mm on the 3rd and 51 mm on the 4th. The heavy rains spread along the north African coast and Annaba (28) in north-east Algeria had 46 mm in the 24 hours to 0600 on the 6th (the 38 mm that fell in one 6-hour spell equalled the usual total for the whole month) and Ajdabiya (29) in eastern Libya got 13 mm in a thunderstorm on the 6th (their May average is about 6 mm). By the 7th the low was just south-east of Sicily, and although Malta's 15 mm exceeded the monthly normal of 11 mm they got off lightly — 67 mm fell on the south coast of Sicily and 55 mm on Tunis. Two days later it was the turn of Souda, Crete to get three times its month's rainfall in one day when 43 mm fell. By the 10th this low had lost its identity over Turkey but still gave Antalya, on the south coast, their average month's rain, 33 mm, in one day. The moist air hung around a bit till the 12th when at Iskenderum (27), near the Syrian border, 132 mm thundered down in twelve hours.While all this had been going on another low had given Madeira (M) heavy thunderstorms on the 9th; Funchal had a record 56 mm in six hours (the previous record was 41 mm in 24 hours, the average for the whole month is 18 mm).

Violent thunderstorms struck many parts of France on the 11th leading to some soil erosion and hail damage as well as flooding; although there were no human casualties there were fears that champagne grapes might have been affected. Your editor had avoided the steamy heat of Bracknell (the maximum of 25.1 °C on the 12th was above that in Madrid, Malaga or Rome) and fled to the Lake District and on the 13th and 14th saw a cold front stalled over north-west England and south-west Scotland; prolonged rain through the cold air behind it lowered temperatures further to give significant snow to quite low levels — the Kirkstone Pass in the Lake District was blocked for a while. There was more snow the next day (22 cm on Lowther Hill, midway between Carlisle and Glasgow, and the large rainfall totals on the windward slopes leading to flooding in Northumberland with 52 mm in 18 hours at Newcastle upon Tyne and 75 mm in 30 hours at Ballypatrick Forest in Northern Ireland. (On the 14th May 1992 Edinburgh's maximum temperature was 29 °C; this year it was 4 °C.) The cold air and warm sun led to some strong convection: there was heavy hail and violent rain in Bracknell on the 15th. In south-west England on the 17th a soldier was killed on Dartmoor when the aerial of his radio was struck by lightning. In Wales, five miles north of Rhyader, a tornado is reported to have carried a flock of sheep over five stone-walled fields and a river, killing at least six but with twenty survivors: some farm outbuildings were flattened and ten vehicles and caravans badly damaged.

At the far corner of this region all had not been quiet as sharp troughs moved east. Riyadh (30), Saudi Arabia had a burst of heavy rain on the 12th when 25 mm fell to break their previous daily record fall of 18 mm: Libya had a ghibli on the 12th with 35 kn southeast winds bringing temperatures of 36 °C and 500 m visibilities in desert dust: Corfu had thundery rain on the 13th and 14th totalling 72 mm. More heavy rain was reported from Saudi Arabia on the 15th when 44 mm fell at Khamis Mushait (31): Hail, on the edge of the Nafud Desert, found 24 mm in the gauge at the end of the 18th.

By the 20th a cold front was slow moving from Algeria to Iceland and ripples running northwards along it gave more than 30 mm of rain to much of the south of France. In the south-easterly flow ahead of it Trondheim, being in the lee of the Norwegian mountains for a change, had a maximum of 28 °C on the 19th which was 3 °C above the previous record. The 20th saw a similar pattern, this time the 30 mm of rain was over central southern England and the warmth continuing over Scandinavia (an interesting point here was that Lulea (32) at the north end of the Gulf of Bothnia had temperatures of around 20 °C inland with ice floes at sea).

The 23rd brought news of a well documented lucky escape. A parachutist jumping from 4000 feet near Toulouse had fallen to 1000 feet when he entered the updraught of a Cb and was lifted to at least 25 000 feet (the limit of his altimeter) and held there for nearly two hours at −30 °C before the canopy suddenly collapsed. On the way down he retained consciousness long enough to open his reserve parachute and land senseless in a farm yard 30 miles from his target.

Violent thunderstorms and torrential rain struck Romania (R) on the 24th and 25th, in the resultant floods six were killed and four missed, hundreds of head of livestock lost and hundreds of homes destroyed. On the 25th a complex area of low pressure covered Biscay and Iberia and this triggered some big thunderstorms: Guadalajara came top with 68 mm, Soria had 60 mm, there was 39 mm in Madrid and Toledo. England's turn came on the 26th when the village of Faringdon, Oxfordshire, had a violent storm. Local flooding temporarily isolated it and left the market square with a thick layer of mud. The nearest synoptic gauge was at Wootton Bassett, Wiltshire, where 50 mm fell in three hours. The storms also affected Ireland where 30 mm seems to have been common in the south-east quarter of the country. When the storms got to Switzerland, Comprovasco, on a windward slope in Ticino canton, collected 127 mm in the 24 hours to 0600 UTC on the 28th.

The Antarctic

Vostok started the month with near normal temperatures, i.e. about −64 °C; after that it got colder and by the 7th it was down to −79.4 °C. After a mini heatwave mid-month when temperatures soared to −61 °C they fell back to −81 °C by the 22nd.

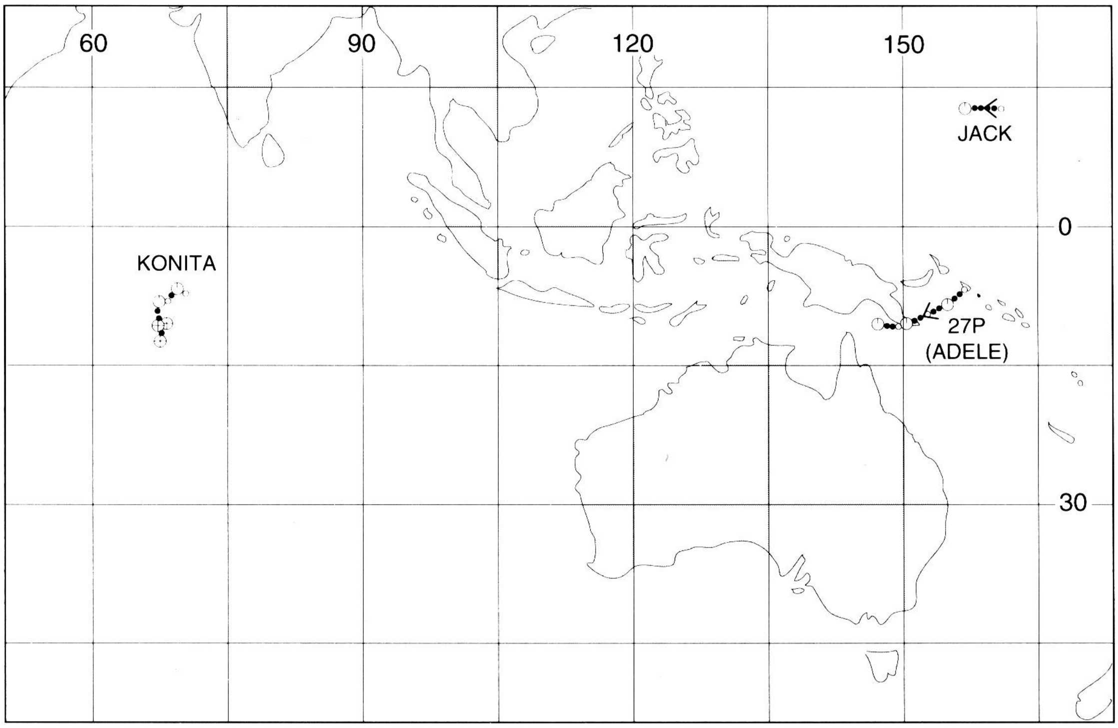
May tropical storms

This is a list of tropical storms, cyclones, typhoons and hurricanes active during May 1993. The date 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 this month. The maps show 0000 UTC positions: for these I must thank Julian Heming and Susan Coulter of the Data Monitoring group of the Central Forecasting Office.

No	Name	Basin	Start	End	Max. (kn)
1	Konita	SWI	02/05	07/05	85
2	27P (also called Adele)	AUS	13/05	16/05	45
3	Jack	NWP	17/05	22/05	35

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.

Cyclone Konita followed a hook-shaped course to SW, S and finally NNE. Adele did a lot of damage on the Trobriand Islands off New Guinea.



Your Editorial Board announces that the Meteorological Office Board has decided that the publication of the *Meteorological Magazine* will cease with the issue for December 1993.

As one of the leading European establishments for research into meteorology our publications should be subject to external peer review: this is already the case for much Meteorological Office work. The publication of a new international and European quarterly journal by the Royal Meteorological Society (to be called *Meteorological Applications*) is expected to provide a suitable vehicle for the kind of articles that now appear in *Met Mag*, namely on research, practice, measurements, reviews, applications of meteorology, book reviews, etc.

The first edition of the *Meteorological Magazine* was published in 1920 by HMSO. It took over from *Symons's Meteorological Magazine* which started in 1866. This decision therefore brings to an end a continuous publishing record of 129 years (except for the duration of World War II). It is understood that legal obligations accepted when *Symons's Meteorological Magazine* was adopted are fulfilled by the continuing production of the *Monthly Weather Report* and *Rainfall 19XX* and our internal journal mentioned below.

The December 1993 issue of *The Meteorological Magazine* will be a bumper one of about 40 pages celebrating the Magazine's contribution to the development and dissemination of meteorological knowledge. It will contain a selection of highlights from 1866 up to around 1986.

The United Kingdom Meteorological Office (UKMO) Annual Scientific and Technical Review

This Review describes the major developments in science and technology within the UKMO over the year and is produced as part of the Meteorological Office Annual Report and becomes available in July each year. If you wish to be put on the mailing list please write to:

The News Desk,
Publications (room 709),
Meteorological Office,
London Road,
Bracknell,
Berks
RG12 2SZ.

Informal communications

The UKMO has instituted an in-house periodical for informal and rapid dissemination of the latest relevant science and technology news to its staff and outside collaborators. Most contributions come from UKMO staff, but offers of material from outside will be welcome — though there is no guarantee of publication.

Back numbers: Full-size reprints of Vols 1–75 (1866–1940) are available from Johnson Reprint Co. Ltd., 24–28 Oval Road, London NW1 7DX. Complete volumes of *Meteorological Magazine* commencing with volume 54 are available on microfilm from University Microfilms International, 18 Bedford Row, London WC1R 4EJ. Information on microfiche issues is available from Kraus Microfiche, Rte 100, Milwood, NY 10546, USA.

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