PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

A Meteosat Motion Picture of a Weather Situation Relevant to Locust Reports [and Discussion]

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A Meteosat motion picture of a weather situation relevant to locust reports

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[One plate]

The motion picture, of Meteosat VIS and IR half-hourly image sequences, covers the North African area with close-ups of northwest Africa from 28 to 31 March 1985. A cold front and horizontal vortex rolls, with their convergent upward atmospheric motions, visualized through dust being transported south from the Atlas mountains, may have transported locust swarms from the Algerian breeding area down to southeast Mauritania, where specimens were observed a few days after the event. This followed more than a year of no locust observations at all. Observation of dust in the atmosphere may give some insight into the transport and behaviour of locusts, both on the synoptic and mesoscale.

1. Introduction to Meteosat data

The use of satellites for monitoring sequences of weather favourable for reproduction and gregarization of Desert Locust *Schistocerca gregaria* (Fôrskal) has been discussed by Abdallahi *et al.* (1979), Müller (1976) and Hielkema & Howard (1976). Since 1978, the European satellite Meteosat has been used for the same purpose.

Meteosat transmits every half hour, that is, with a very high time resolution, pictures of the earth's disc, with Africa in the centre of view, in three different channels:

(i) VIS (0.4–1.1 μm) (the visible part of the electromagnetic spectrum). The intensity of the signal is proportional to the albedo of the objects (water, land, clouds, dust);

(ii) IR (10.5–12.5 μm) (the thermal infrared window of the electromagnetic spectrum). The intensity of the signal is proportional to the radiation temperature of the objects.

(iii) WV (5.7–7.1 μm) (the water vapour absorption band in the infrared spectrum). The intensity of the signal is inversely proportional to the upper tropospheric water vapour content.

The latter channel has little direct use for migrant pest research and operation. VIS and IR, however, are quite useful. The VIS data provide information on daytime cloud coverage with a spatial resolution of about 2.5 km. Processing the VIS data of cloud-free areas provides information about soil moisture, water content of lakes (ESA–EOQ 1989) and vegetation. The IR data, with a spatial resolution of about 5 km, provide information on cloud height and coverage 24 h per day, and information on convective precipitation (Turpeinen *et al.* 1987). IR data of cloud-free areas, after atmospheric correction, provide information on ground temperatures.

A further aspect of meteorological analysis with Meteosat imagery is the possibility of displaying time sequences of the half-hourly data in motion, which makes it possible to:

(i) calculate wind speeds and directions, through cloud motions;

(ii) make very short-term forecasts of weather, by using pictures showing cloud motion and change;

(iii) discriminate ground-fixed patterns from moving ones;

(iv) illustrate the nature of large-scale as well as mesoscale weather systems and their interactions, through their cloud motions and changes.

The possibility of obtaining wind data from cloud displacements observed in consecutive images is not discussed here in any detail. For a survey of such, the reader is referred to MOAG (1979). In the subtropics and tropics, the 'low level' cloud base (stratocumuli, cumuli and larger convective clouds) is generally around 1000 m or higher. Below this level the planetary boundary layer winds are the result of local small-scale atmospheric phenomena, which are usually not represented by the cloud winds. The 'low level' cloud winds represent the lowest level of the free atmosphere with their synoptic and mesoscale phenomena. They are useful for nowcasting (up to a few hours) and short-range (up to about 20 h) forecasting of subsynoptic to large-scale atmospheric motions. In the absence of other wind reports, such cloud winds can be useful for anti-locust operational measures and field research.

2. The Meteosat motion picture of 28–31 March 1985 as related to locust observations

On 29 March 1985, the Meteosat imagery shows large hazy patterns over North Africa, which are easily identified as dense dust clouds, both from their origin, their texture and their meteorological context (figure 1, plate 1 and figure 2). This strong dust event, which was certainly rich in details, was chosen as the subject of a Meteosat cloud motion film, produced by C.D.Z., in close cooperation with the European Space Agency (ESA) and the Free University of Berlin. The scene covers an area from the Mediterranean to 15 °N and from the Canary Islands to 25 °E. It shows the entire life cycle of a weak depression developing over north Algeria until its cloud patterns disintegrate over Libya. On its rear side, masses of dust are mobilized from the Atlas mountains (see mountain station report of 29 March 1985, 00h00 G.M.T., in figure 2), where copious fine soil weathering debris is available. This dust is transported south (10 °N) and east, and some is also westwards, over to the Canary Islands. This dust transport happens spatio-temporally in the same way in which mid-latitude cyclones mobilize cold air masses with their unstable lapse rates, stronger winds and convective clouds.

At first, this event was not connected with research on migrant pests. Later on, however, it was realized that in April 1985, i.e. only a few days after the period covered by the film, four isolated, but gregaricolour, Desert Locusts were observed in S.E. Mauritania, after a whole year (1984) with no reports of Desert Locust swarms anywhere (Rainey 1989). In the following September and October, observations from Mauritania and the tropical Atlantic west of Africa seem to support the idea that these April 1985 observations indicated the beginning of an upsurge (Rainey 1989). Thus it was of interest to investigate whether there was any relation between the upsurge and the satellite observation of huge dust clouds; not that the dust is important in itself, but rather the larger scale atmospheric environment and context. There are also meso-scale details observable in the motion picture which may contribute to the understanding of how swarms are mobilized and maintained in the air for considerable lengths of time.

3. Large-scale features

On the large scale there are two distinct types of weather systems relevant to successful breeding of locusts. On the one hand the tropical weather systems of the Inter-Tropical

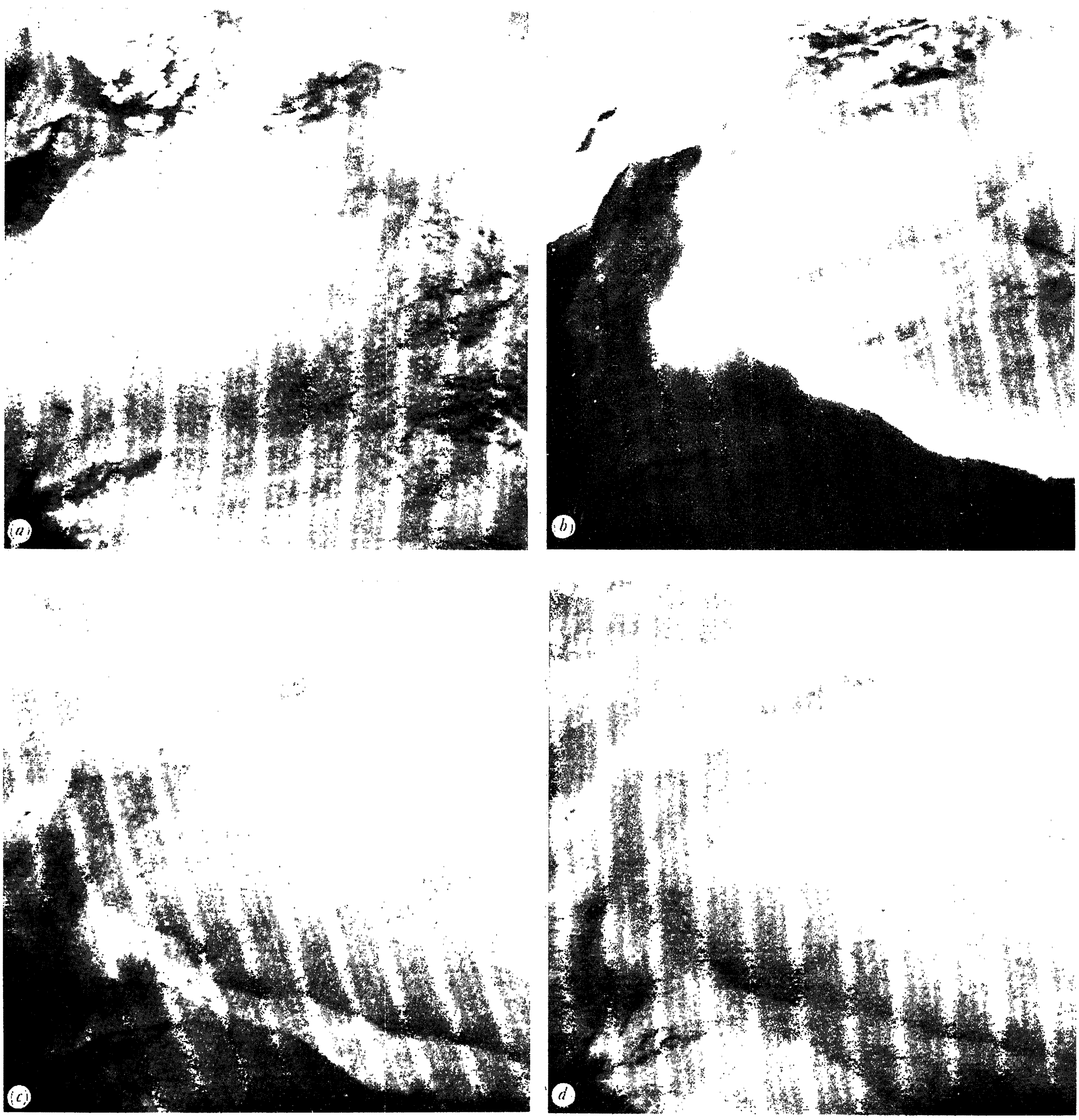

FIGURE 1. Meteosat IR pictures during 29 March 1985 ((*a*) 02h30 G.M.T. (*b*) 13h00 G.M.T. (*c*) 19h00 G.M.T. (*d*) 21h00 G.M.T.). Dust is transported southward from the Atlas mountains, the leading edge of it is the 'dust cold front'. Different contrast enhancements have been applied in these pictures to display the ground (with its highly varying temperatures) against the dust features. During the night (d), the 'dust-free' ground has a lower temperature than the dust concentrated aloft in the 'dust front'.

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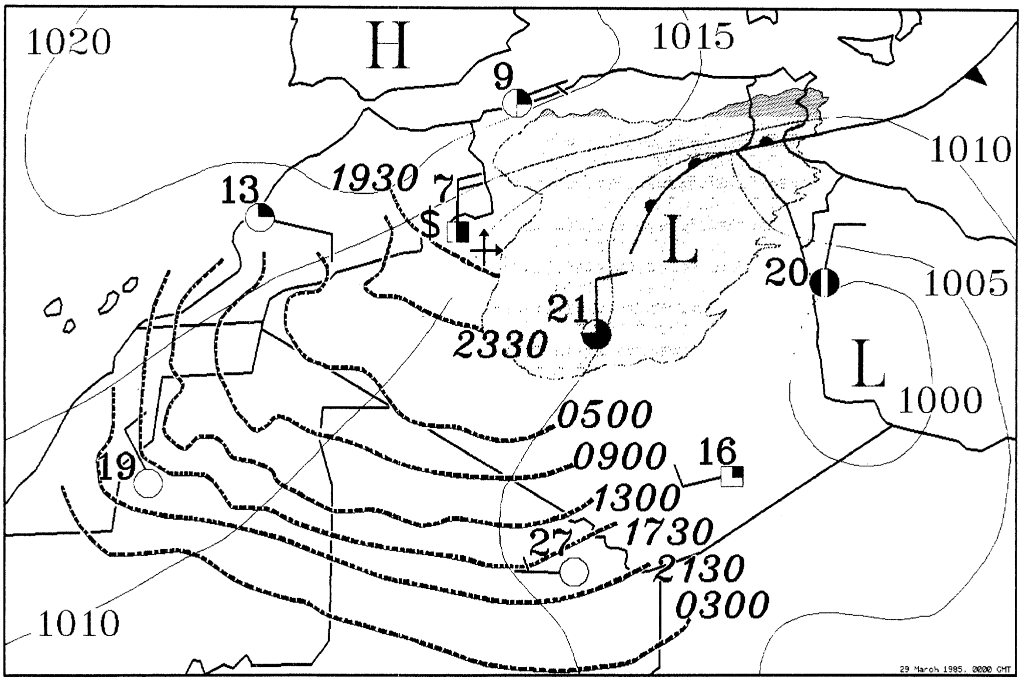

Figure 2. Surface weather map 29 March 1985, 00h00 g.m.t. (after German Weather Service, DWD). The central cloud deck of the developing lee depression is shown in a grey tone. The positions of the 'dust cold front' between 28 March, 19h30 g.m.t., and 30 March, 03h00 g.m.t. (times shown in italics) are dashed. Note the strong surface pressure gradient in the lee of the Atlas mountains; the mountain station Colomb-Béchar reports a north wind of 20 knots and dust storms continuing for at least 6 h.

Convergence Zone (ITCZ); on the other, troughs, with disturbances penetrating south but originating from the west. The main geographical distribution of the Desert Locust over Africa reflects this differentiation (Rainey 1963). The case presented here relates to the latter type of large-scale weather system.

To see any large-scale relation between the weather at the end of March 1985 and the 1985 locust upsurge after this date, one may study the analyses published monthly by the German Weather Service (DWD 1984, 1985), each containing a sequence of 500 hPa maps showing several characteristic weather periods ('Witterungsabschnitte') over Europe during that month. Each map is an average of the 500 hPa maps of a varying number of days (2–6 generally), showing the characteristic 500 hPa patterns during that period of weather. A simplified presentation of the significant features of these maps of relevant periods in 1984 and 1985 is shown in figure 3. Clearly, these maps do not extend far into North Africa. The author hopes, however, that the reader will accept that these available analyses for the edge of the area of interest are sufficient for the requirements of this work.

For our case, the relevant map (figure 3) comprises the days of 25–29 March 1985. It shows a large-scale westerly current over North Africa, with a short trough over Algeria. Set into its temporal context, we see that it marks the end of a rather quiet homogeneous 'cold' period beginning on 6 March with a deep trough over the same area. It is comparable to almost the same period (11–28 March) of the previous year. It is followed by a rapid build-up of a ridge and consequently warmer and drier weather in the area.

With regard to the observation soon afterwards of four isolated gregaricolor locusts in S.E.

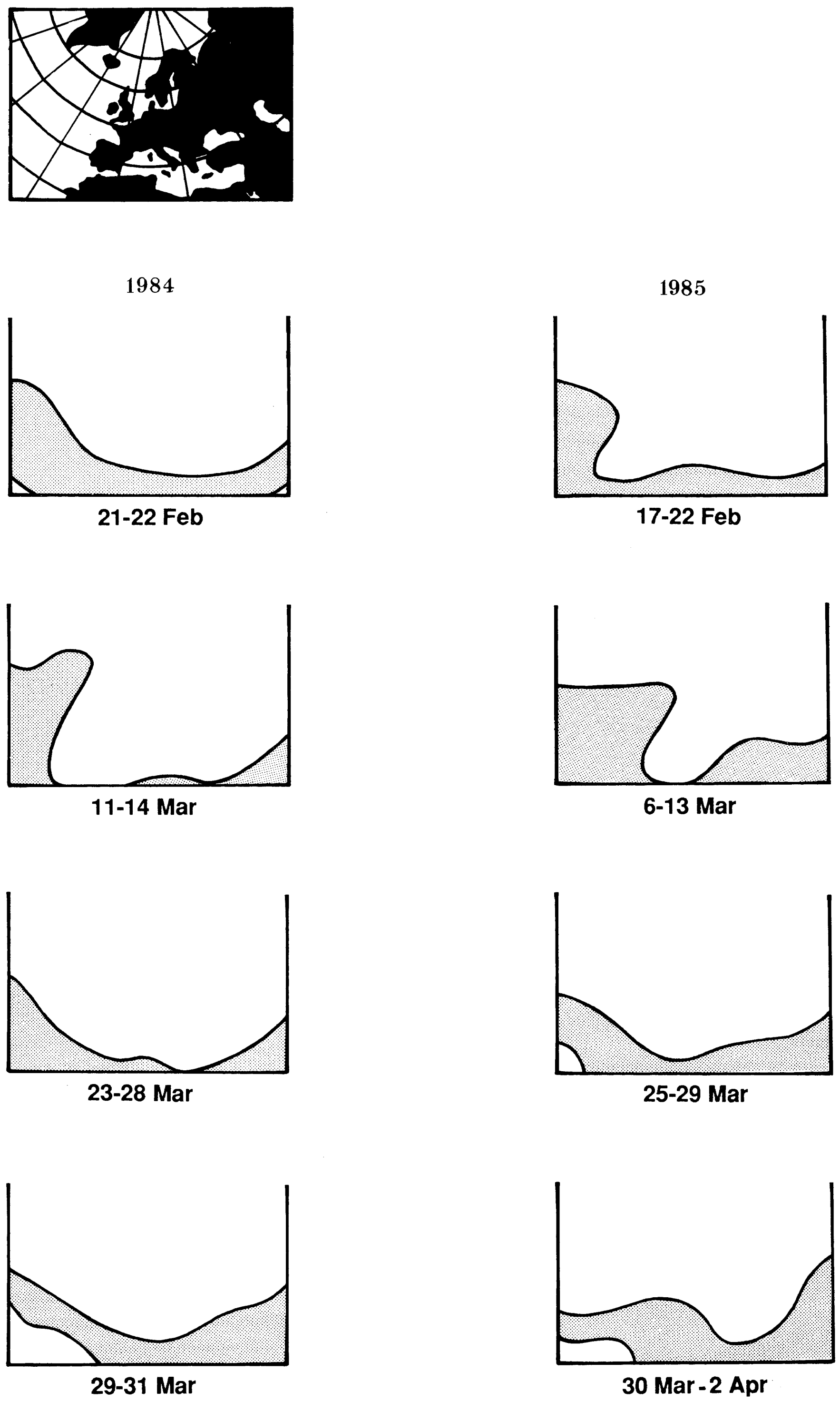

FIGURE 3. The change of characteristic periods of 500 hPa patterns over southern Europe, for periods in 1984 and 1985. The diagrams were generated from the German Weather Service 500 hPa maps showing characteristic weather periods ('Witterungsabschnitte') over Europe, by isolating maps, the 564 gpdm and the 580 gpdm lines to emphasize the southernmost 500 hPa patterns. The geographical background is shown once (top left-hand corner of diagram).

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Mauritania, the large-scale weather situation of our case should be considered as the end of a prolonged period of depressions passing over northwest Africa and providing, through their cold fronts and convective clouds, the intermittent rainfall necessary for successful breeding. Indeed, several weak depressions brushed the Atlas mountain range during that time, as can be seen from the daily Meteosat images (European Space Agency 1985). In March 1985 there was over 200% (90–279 mm) of the average monthly precipitation on the north side of the Atlas, but it was slightly colder than the monthly average. The preceding month, however, was 2–3 degrees warmer than average, in the same area.

A possible explanation for the unsuccessful breeding during the similar 1984 period (11–28 March) in the North African area is suggested by the climatological data for 1984. Both February and March 1984 were colder than the monthly average, and only February 1984 had a local Tunisian maximum of precipitation (200–400% of the climatological average). The following month of March remained very dry (25–50%).

The period 22 December 1984 to 18 January 1985, although otherwise similar to the March 1985 period, was colder. Also, during the period 1–20 February 1984, there was a comparable large-scale trough over Egypt and Libya, but both periods were probably not favourable to successful breeding because of the winter season: northwest African locusts need the warmer spring temperatures and the precipitation of spring depressions for successful breeding.

4. Synoptic and mesoscale features

Rainey (1963) has emphasized the importance of depressions for the transport of locusts from southern Morocco to Tunisia, and this may indeed have happened during February–March 1985: the periods 17–22 February and 6–13 March (see figure 3) with their large-scale southwesterly flow in that area would have been favourable. The depression in question here, however, is an Atlas lee depression travelling east. On its rear side, huge masses of dust were raised by strong winds over the Atlas mountains during the night of 28–29 March (figures 1*a* and 2). During daytime (figure 1*b*) the leading edge of the cool, i.e. bright, dust cloud becomes a clear-cut feature against the diurnally heated 'dust-free' ground. Relative to the cloud-covered vortex centre this 'dust front' is positioned and shaped like a typical cold front of a depression in the westerlies. And in our case it is quite reasonable to speak of a cold front, as it is dynamically defined rather than appearing only as a belt of clouds. The cold front is the leading edge of the cooler, drier air mass being transported equatorwards on the rear side of the depression. Along the front, dynamic mass convergence forces lifting of the air.

The dust, in particular the dust concentrated along the cold front, shows clearly the southwestward trade wind flow on this day (29 March, see figure 2). The dust is transported in an atmospheric layer between about 500 m and 1000 m. In the motion picture one can see that by night (figure 1*c*, *d*) the surface has undergone strong nocturnal radiative cooling, while the dust, in particular in the 'dust front', remains at its level of transport and consequently keeps a constant temperature, resulting in a temperature slightly higher than that of the adjacent ground (figure 1*d*). Thus this rapidly moving frontal system remains clearly identifiable as a thermal pattern and, as we know, a dynamic synoptic scale convergence pattern, for about two days. Within this atmospheric system, locusts of Algerian origin may well have been carried across the Sahara to their place of detection in Mauritania the following April.

During 29 March 1985 the Meteosat picture (figure 1*b*) shows long streamers of dust aligned with the mountain ranges of the Atlas as well as on each side of the Mcherrah/Aftout massif with its huge Ergs on either side. These streamers of dust result from mesoscale convergent patterns at the level of the dust, about 500 m to 1000 m. This effect, when observed with small cumulus clouds, is called cloud streets. It is due to the formation of longitudinal vortex rolls with a horizontal axis in the atmospheric boundary layer (Brown 1980); they are aligned more or less with the direction of the mean wind in that layer, and they usually develop through thermal (convective) instability of the boundary layer due to surface heating and/or cold air advection. The destabilization of the lowest 1000 m of the atmosphere during daytime because of heating of the ground, well observable in the IR motion picture, and the consequent upward motion of air provide the energy necessary to mobilize swarms of locusts. Also the mesoscale 'dust street' convergences within the air mass may well keep the swarms together and in the air during daytime.

5. Conclusions

The Sahara and the Ergs have been an area of dust deposition for many thousands of years, with the dust being raised and transported in a manner similar to the case described here. This case, with its cloud and dust patterns in motion, is a clear example of a regularly occurring interaction between the atmosphere and ground, which raises and transports dust from the Atlas mountains southwards, southeastwards and southwestwards. The existence of the long-term regular repetition of this process is shown by the huge sand dunes within the Ergs, having the same orientation and shape as our 'dust street' convergences. On this large scale the regular transport mechanisms of dust across northwest Africa, by physical mechanisms, which are also favourable to the mobilization and transport to locusts, may provide a clue to the link between the otherwise widely separated northwestern Africa areas of locusts (Rainey 1963) and the tropical belt of West Africa. Similar to conclusions drawn by Rainey about the systematic swarm displacements from northwestern Africa to Mauritania, the specimens observed in April 1985 may have been carried there from breeding areas in Morocco and Algeria, by the synoptic scale features observed in the cloud motion picture. Subsequently, the ITCZ over Mauritania has been claimed, with good reason, to be the appropriate feature governing their movement.

A similar coincidence of dust and locust reports occurred on 23 September 1985. Over the ship 'Ile Maurice' in the tropical Atlantic numerous groups of 'criquets' in flight were reported, and four days later isolated locusts over a distance of some hundred kilometers, some 600 km further out to sea (Rainey 1989). These reports also coincided with a huge dust cloud over that area in the Meteosat VIS pictures of the same dates (European Space Agency 1985).

It is not claimed that dust may serve as a tracer for locusts in the atmosphere; such a correlation would have been well-known since biblical times. But by observing the mechanisms for transporting dust, and its 'behaviour' in the atmosphere we may gain some insight into the similar mechanisms and behaviour of locusts, both on the mesoscale and on the very large synoptic scale.

I thank Dr K. A. Browning for stimulating this work, and Dr R. C. Rainey for providing literature and data about migrant pests and insect flight.

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Discussion

R. S. Scorer (*Imperial College, London, U.K.*). The phenomenon of 'rope clouds' shows how well the dividing front between two air masses can remain preserved long after cloud and rain systems have ceased to function, and may sometimes never have existed.

Rope clouds can be seen in satellite pictures in many parts of the world: a good example is the N.W. Pacific where cold fronts crossing Japan remain marked by rope clouds for hundreds of miles into the ocean (Scorer 1990). The same can be seen in the north Atlantic, but it is a less common feature there, possibly because the large dry inland area of Asia is not replicated west of the Atlantic (Scorer 1986; 1990; Scorer & Verkaik 1989). The boundary of an area of dust collected over the Gobi Desert is a classic example in the Japanese literature (Scorer 1986).

Rope clouds frequently occur in the Mediterranean, where it is quite usual for a stable layer of air to be enclosed by the surrounding mountains, with occasional invasions from the N.W. the boundary being marked by rope. But these are usually too shallow to cross the Atlas mountains, as in Zick's case.

Sea breezes do not show rope clouds normally, because they would be evaporated by surface heating. But the fronts where convergence occurs can sometimes be seen in IR satellite pictures by the temperature contrast on, or in moisture in air just above, the ground (Scorer 1990). A very spectacular case of rope at the front of the reverse flow at the inversion out to sea was recorded by the Gemini crew orbiting in September 1966, although the phenomenon is more common in the quieter weather of March and April (Scorer & Verkaik 1989).

The very sharp boundary of the upper level outflow is not usually included in discussions of sea breezes, but it might be important over the Arabian Sea, which is sometimes crossed by locust swarms that experience convergence and arrive in Pakistan as dense swarms (for example, as in January 1962).

There should be no surprise when convergence lines are found around the Red Sea and the Gulf of Aden, and inland in Africa near mountain ridges or plateaux.

In the remarkable case shown by Dr Zick it is worth noting that at the front fresh dust is being picked up all the time so that individual particles do not travel the whole distance traversed by the dust front.

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J. R. Milford (*Department of Meteorology, University of Reading, U.K.*). The film of well-defined fronts marked by dust, and also the illustrations of rope cloud over Europe provided by Professor Scorer are of considerable general interest, but are essentially anecdotal. The question is how such ideas can be put to use in dealing with migrant pests in practice.

The first method is through training operational personnel so that they are aware of the importance of mesoscale convergence regions and are therefore looking out for them. Such training may need to be extensive, as few cases are as clear as those chosen as illustrative material, and many are hard to detect on satellite pictures available in real time.

Before providing training in recognition of these particular features, we should also be able to quantify their importance: are they the prime mechanism for concentrating swarms? Such a question asks for an answer based on statistics: it does not appear that anyone has devised a viable means of gathering such data since no such results have been published, or referred to in this meeting.

I would welcome comments, particular from those involved in the field, which would tell us whether we need to quantify the effects of mesoscale convergences on insect populations. Some 15 years ago Dr J. E. Simpson, Dr D. A. Mansfield and I used a numerical model to calculate the concentration of aphids over southern England resulting from the passage of a sea-breeze front. This was not published because there seemed no way to verify the results, and also because no-one placed much reliance on the few figures we found for flight characteristics. I observe that models of this type do not seem to have developed and ask whether this is again because of the absence of reliable flight data on migrant pests. Such models, with stochastic features built in, appear to be necessary if the effects of the features shown here in films and slides are to be fully understood.

I would also wish to voice my disappointment at the absence of quantitative modelling from the topics of this meeting in general, and ask whether this is related to the absence of any section in the programme, which could be headed ‘progress’, with regard to the Desert Locust, and similar pests.

P. Wickham (*Meteorological Office, Bracknell, U.K.*). As a meteorologist, I was excited to see on Mr Zick’s pictures of March 1985, that the structure of the event showed up so clearly on both the visible and infrared (IR), particularly when highly enlarged. Of course the IR shows temperature contrast, and I wonder what that was on these pictures. Was it entirely dust that we were looking at, coming down behind the main frontal zone and in those streaks in the airflow? What was the temperature contrast that showed so clearly there? Could water vapour have been involved?

C. Zick. I did not see clear structures such as showed on the film, in the water vapour images; the Meteosat photographs don’t show any streaks behind the leading edge. You can conclude from the visible images that the streaks were not clouds. If they had been, they would have shown as white spots, at least around midday. Dust behaves, in terms of radiation theory, very

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much as semi-transparent cirrus does: the visible short wave radiation simply goes through it, without being absorbed. It's only the longer wave thermal radiation that is absorbed, by dust in the atmosphere for example, and emitted again at the relevant wave length. That is why you can see it only in the IR and not in the visible.

M. S. Boulahya (*National Meteorological Office*, *Algiers*). I would like to confirm that it was dust in March 1985. I was travelling in western Algeria at the time and all the southwestern airports were closed for three days, so I had to go by road. Even then, going around the mountains from Algiers to Bechar, the car's engine became completely filled with sand.

R. M. Morris (*Meteorological Office*, *Bracknell*, *U.K.*). Satellite imagery needs to be exploited much more thoroughly to improve the conventional weather analysis in the region. For example, the movement of the dust cloud needs to be related to the boundary layer wind speed and direction for consistency; conceptual models of frontal structures can be invoked to improve the analysis of temperature, in the horizontal and in the vertical.

R. J. V. Joyce (*Cranfield Institute of Technology*, *Bedfordshire*, *U.K.*). Mr Zick has shown a most illuminating and impressive film of two Meteosat case studies of two periods important in relation to the recent upsurge of the Desert Locust.

The dates enabled Dr Rainey to secure further information on locust reports, which he regarded as critical for the understanding of the initiating events. Dr Rainey has drawn attention to the fact that, after a whole year (1984) with no reports of Desert Locust swarms anywhere, the only slender evidence that the species might be somewhere in West Africa was a report of four locusts showing the pinkish colouration that is manifest only by locusts from swarming populations, which were seen in April 1985 near Aioun-el-Atrouss in southeastern Mauritania. Further reports were lacking and, by June, it was suggested that Desert Locust numbers might be at their lowest ebb since sytematic collection of data started some 60 years earlier. In late September, however, reports from three ships recorded scattered flying locusts seen at sea off the coast of Mauritania and Senegal, extending N.N.E.–S.S.W. over a distance of some 500 km. In early October many hundreds of square kilometres of advanced-instar hoppers and pink adults were discovered in southwestern Mauritania, necessitating control on a substantial scale. By the end of the month, there was the first report of a young swarm of the next generation. It was clear that there had been undiscovered breeding on a large scale on the heavy rains which had been recorded in the area in July and early August, and that the locusts seen at sea would have represented some of the last parent population.

Mr Zick's Meteosat image sequences show that the weather system, which developed over Mauritania during the last days of March 1985, may well have brought together locusts from a wide area for breeding on the rains associated with this disturbance. His subsequent sequences also fit the inferred later movements of the locusts of the new generation.

D. E. Pedgley (*ODNRI*, *Chatham*, *U.K.*). Mr Zick has shown us a fascinating use of satellite imagery to reveal remarkable detail in a synoptic-scale disturbance over northwest Africa. He must compare his results with the hourly observations available from all the synoptic observing stations over which the disturbance passed. Perhaps Mr Boulahya would be able to provide observations from Algeria, and also help to get others from neighbouring countries. Such a comparison would go towards answering the query on temperature contrasts raised by Mr Wickham. Should it be thought that the use of weather maps and satellite imagery is something new in the forecasting of locust movements, let me say that both have been employed routinely for nearly 30 years. Strong winds behind cold fronts, sometimes accompanied by dust storms but usually less dramatic than the one shown by Mr Zick, are well known to be involved in the long-distance displacements of locust swarms. The cold front associated with Mr Zick's storm would appear very clearly in a synoptic analysis of all the available records. The analysis presented from the daily European Meteorological Bulletin was deficient, no doubt through the sparsity of observations, as often happens when there are widespread dust storms, owing to poor radio communications.

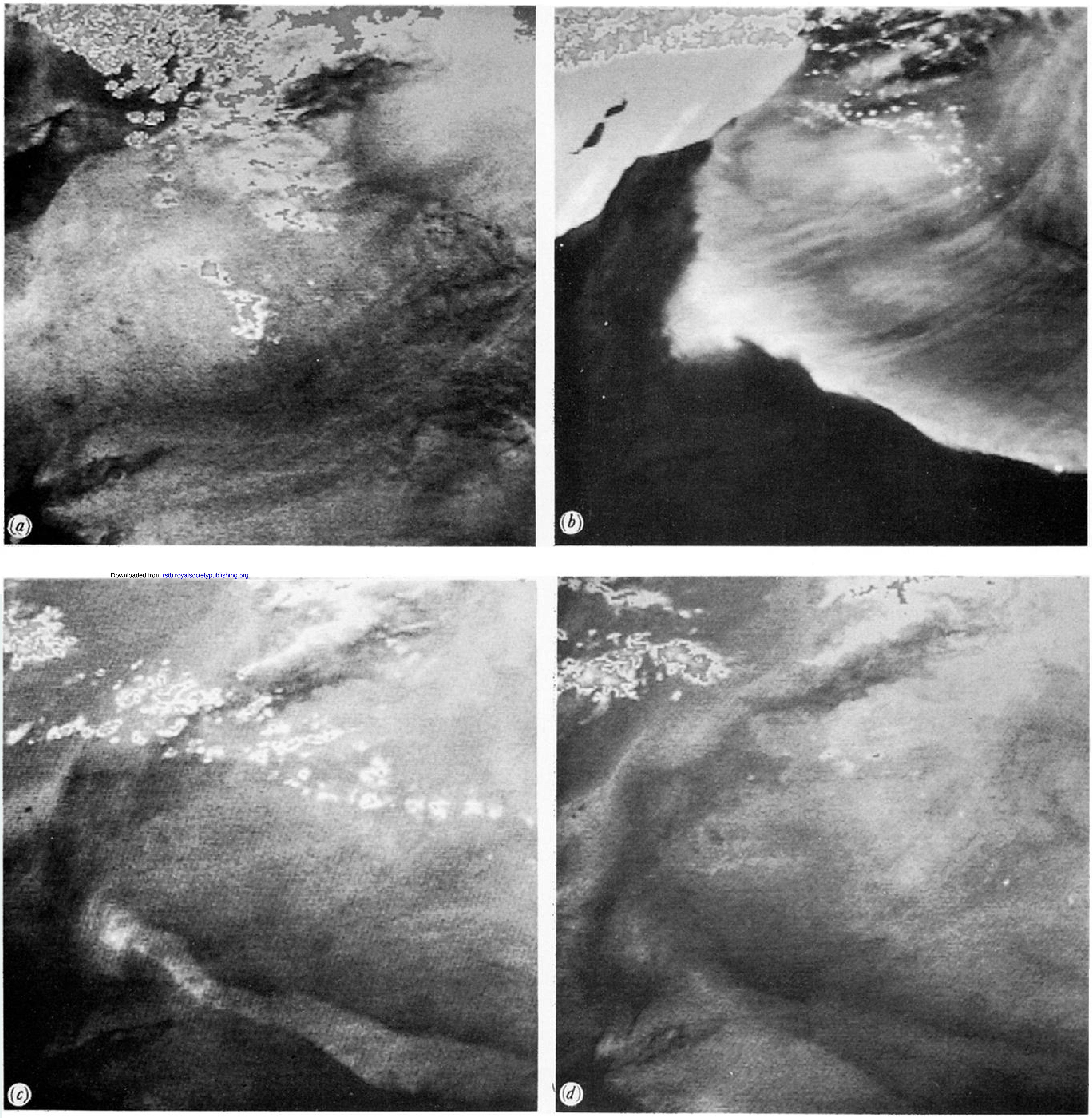

FIGURE 1. Meteosat IR pictures during 29 March 1985 ((*a*) 02h30 G.M.T. (*b*) 13h00 G.M.T. (*c*) 19h00 G.M.T. (*d*) 21h00 G.M.T.). Dust is transported southward from the Atlas mountains, the leading edge of it is the 'dust cold front'. Different contrast enhancements have been applied in these pictures to display the ground (with its highly varying temperatures) against the dust features. During the night (d), the 'dust-free' ground has a lower temperature than the dust concentrated aloft in the 'dust front'.

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