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Rainfall: Scarce Resource in 'Opportunity Country' [and Discussion]

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Rainfall: scarce resource in 'opportunity country'

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The rainfall of semi-arid lands represents a major resource in whose more effective utilization both contemporary and traditional technologies have increasing parts to play. Though infrequent, rains can be both heavy and widespread even in regions normally arid, as a result of major disturbances of global systems of winds and weather which are typically recognizable in real time in the course of routine synoptic weather analysis.

Introduction

Rainfall is a key resource which even in arid lands can rarely be regarded as totally negligible in amount, and can probably never be regarded as random in incidence. The spatial and temporal distribution of rainfall have implications for development in arid and semi-arid lands which are considered particularly appropriate for emphasis and discussion at this meeting. Attention is also drawn to the authoritative review of the very important topic of climatic change which is being presented elsewhere today (Mason 1976). The central point of the present paper is illustrated by table 1, which summarizes the records of the four driest fully documented rainfall stations in the World Meteorological Organization's current set of world-wide climatological normals – all four in the Sahara – together with corresponding figures from arid areas of Arabia and Indo-Pakistan. It will be noted that even Wadi Halfa, with its mean annual rainfall of 3 mm from a 24-year record, has still had a July with 29 mm of rain and an October with 14 mm; and the other five stations have all recorded individual totals of 25–330 mm of rain in a single month.

Table 1. Heavy rains in arid lands (millimetres)

		mean annual rainfall	wettest month on record	next wettest month
Sudan	Wadi Halfa 1937–60	3	29 (July)	14 (October)
	Abu Hamed 1931–60	17	110 (July)	48 (August)
Algeria	Aoulef 1931–60	11	25 (January)	20 (Aug. & Nov.)
Chad	Faya-Largeau 1941–60	16	48 (June)	31 (August)
South Yemen	Aden 1941–60	39	55 (November)	47 (September)
Pakistan	Jacobabad 1931–60	99	330 (July)	129 (August)

W.M.O. (1967) Climatological normals for 1931–60.

30-2

Rain in the southeastern Sahara: some general considerations

Evidence on the spatial extent of individual falls of rain is less readily available, but areas of the order of hundreds of thousands of square kilometres can be involved, indicating the scale of a resource usually exploited only by nomads and by migrant insects (the latter with a behaviour pattern which can enable them to reach the rain areas by using the wind-systems involved). Thus 28 of Wadi Halfa's peak month's total of 29 mm, in July 1950, fell during three consecutive days (19 on one of them); rain not only fell within this same period at both neighbouring stations (Station 6, 180 km to the SE, and Dongola, 320 km to the SSW) but must also have occurred at about this time over extensive uninhabited areas around Wadi Howar, some 700 km away to the SW, where widespread desert locust breeding (for which soil moisture equivalent to about 20 mm of rain is essential (Magor 1962)) was subsequently found to have taken place. Furthermore, at about this same time a French airline pilot, with considerable experience on trans-Saharan routes, commented, during debriefing in Nairobi, on having encountered rain in this same general area, further north into the Sahara than he had ever previously seen.

Making better use of such rains begins with recognizing, in real time, the situations which produce them. The low average rainfall of the great arid zones represents an inescapable effect of the global circulation of the atmosphere; this circulation is ultimately driven by the differential solar heating of tropical and polar latitudes; and these exceptional rains result from major disturbances of the normal circulation. Thus the major arid zones are normally dominated by air which has been dried out by a process of ascent in tropical latitudes, to about the level of the base of the stratosphere at around 15 km, during which its temperature will have fallen by some 100 °C with a consequent loss of nearly all its substantial initial water-vapour content (falling out as tropical rains) and a gain of the corresponding latent heat. Much of this air descends (and is further heated by compression) in the sub-tropical anticyclonic belts, with semi-permanent cells (characterized by low rainfall) like the familiar Azores anticyclone and the corresponding St Helena anticyclone in the South Atlantic in oceanic areas as well as others in continental regions. This upper-wind circulation was originally inferred by George Hadley (1735), an early Fellow of this Society, and reported in our *Philosophical Transactions* some 240 years ago, but it is only quite recently that convincing direct evidence of this circulation has been provided, by the extension of regular upper-air observations undertaken from the 1950s to meet the requirements of high-flying jet aircraft.

The aridity of these lands may therefore be somewhat crudely envisaged as being continuously replenished from above – in such a manner as to dispose unambiguously of the possibilities which have been suggested, for example in the Schwartz scheme of half a century ago for the northern Kalahari, for significantly increasing rainfall by increasing evaporating surfaces, such as by the construction of reservoirs or by afforestation. A recent demonstration of the insignificance of this effect has been provided by the Aswan high dam, where the evaporation from Lake Nasser has resulted simply in an increased local incidence of early-morning mist in the winter months – by overnight humidification of the lowest tens of metres of the atmosphere, effectively only skin-deep, and rapidly dispersed by convective mixing after sunrise. This point of course in no way weakens the case for afforestation on other grounds such as for combatting soil-erosion.

On the weather maps of the continental tropics the very low dew-points characteristic of air with a recent history of such desiccation and descent contrast conspicuously with the high dew-points of air recently off the tropical oceans and rain forests. A particularly impressive demonstration of this contrast is provided by some of the continental stretches of the intertropical front (i.t.f.); this is another feature of the global circulation, at which surface winds from the southern hemisphere can be envisaged as meeting winds from the northern hemisphere, and incidentally found to represent a dominating feature in the atmospheric environment of tropical migrant insects.

Figure 1 shows a set of observations made with a Pilatus Porter agricultural aircraft equipped with a Decca Doppler radar system for precision wind-finding; these were made during one of a series of research projects of the Ciba-Geigy Agricultural Aviation Research Unit at Cranfield, to whose Director, Vernon Joyce, we have been greatly indebted for opportunities of participation. Here can be seen northeasterlies which have previously been dried out as just described, still with dew-points of only 4–5 °C, meeting southerlies with relatively recent oceanic tracks which have given dew-points of 17–19 °C, at a frontal discontinuity with the main zone of transition as located by the wind-shift no more than a few kilometres thick. The effect of this humidity contrast could be seen in the sweat which appeared on the back of one's hand within a minute or two of flying southwards through the front – whose very existence, incidentally, is still said to be doubted by some tropical meteorologists in other regions.

These same observations conveniently introduce and illustrate the very important process of wind-convergence, most simply envisaged as giving a net inflow of wind across a closed perimeter, and more easily visualized from figure 2, which shows the size of the mean inflow or outflow component at right angles to each side of the rectangular flight-pattern. Convergence at low levels (where most of the atmosphere's water vapour is to be found) necessarily means ascent of air, and is a necessary though not sufficient condition for the production of rain.

The detailed three-dimensional structure of the intertropical front in tropical Africa is however not yet completely understood, with the rains commonly well to the south of the surface front – within a hundred kilometres on this particular morning, but often 200–500 km away (Osman & Hastenrath 1969). The exceptional rains of July 1950 at Wadi Halfa were associated with the i.t.f. being unusually far north, reaching 25° N at 12 h G.M.T. on 24 July, to the north of Aswan, some 900 km to the north of its average position at this time of year and 350 km north of Wadi Halfa. (A similarly exceptional northward surge of the i.t.f. appears to have been associated with exceptional desert rains at Kufra oasis at 23° N in Libya in August 1952 – Pedgley 1974.) I am indebted to the Sudan Meteorological Department for information and guidance on these points, as on many others in the course of the past quarter of a century.

The seasonal movements of the intertropical convergence zone (i.t.c.z., within which the i.t.f. is one particular manifestation), following the Sun, are associated in general terms with the seasonal rains of the tropics, and in turn with regular seasonal migrations of pastoral human populations such as the Rizeiqat of the western Sudan. The Rizeiqat are a Baggara tribe estimated to include some 180 000 nomads, with about $1\frac{1}{2}$ million cattle, migrating regularly between winter grazing areas to the south of the Bahr el Arab and summer grazing areas some hundreds of kilometres away to the north, in central and northern Darfur. A recent consultant's report (for which I am greatly indebted to Hunting Technical Services) on an F.A.O./U.N.D.P. savanna development project, referring to these grazing practices of the Rizeiqat, described their 'nomadic system (as) a great asset to the nation...the nomadic producers of southern

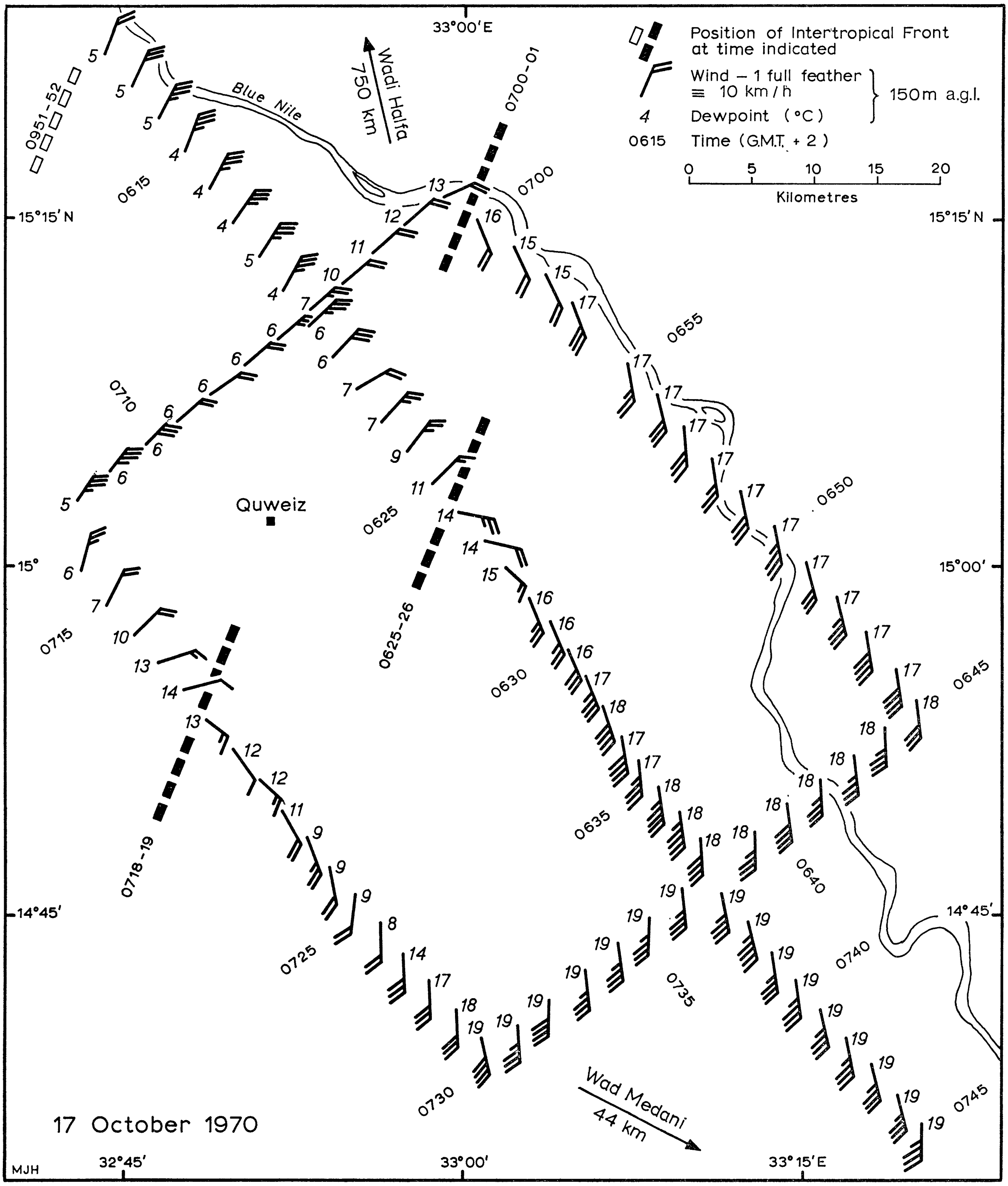

FIGURE 1. Air-mass contrast and wind-convergence at the intertropical front. Dry northeasterly winds with a history of subsidence in the subtropical anti-cyclone belt meet humid southerly monsoon air at the sharply defined intertropical front with marked convergence, associated with rain at the time around Wad Medani.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

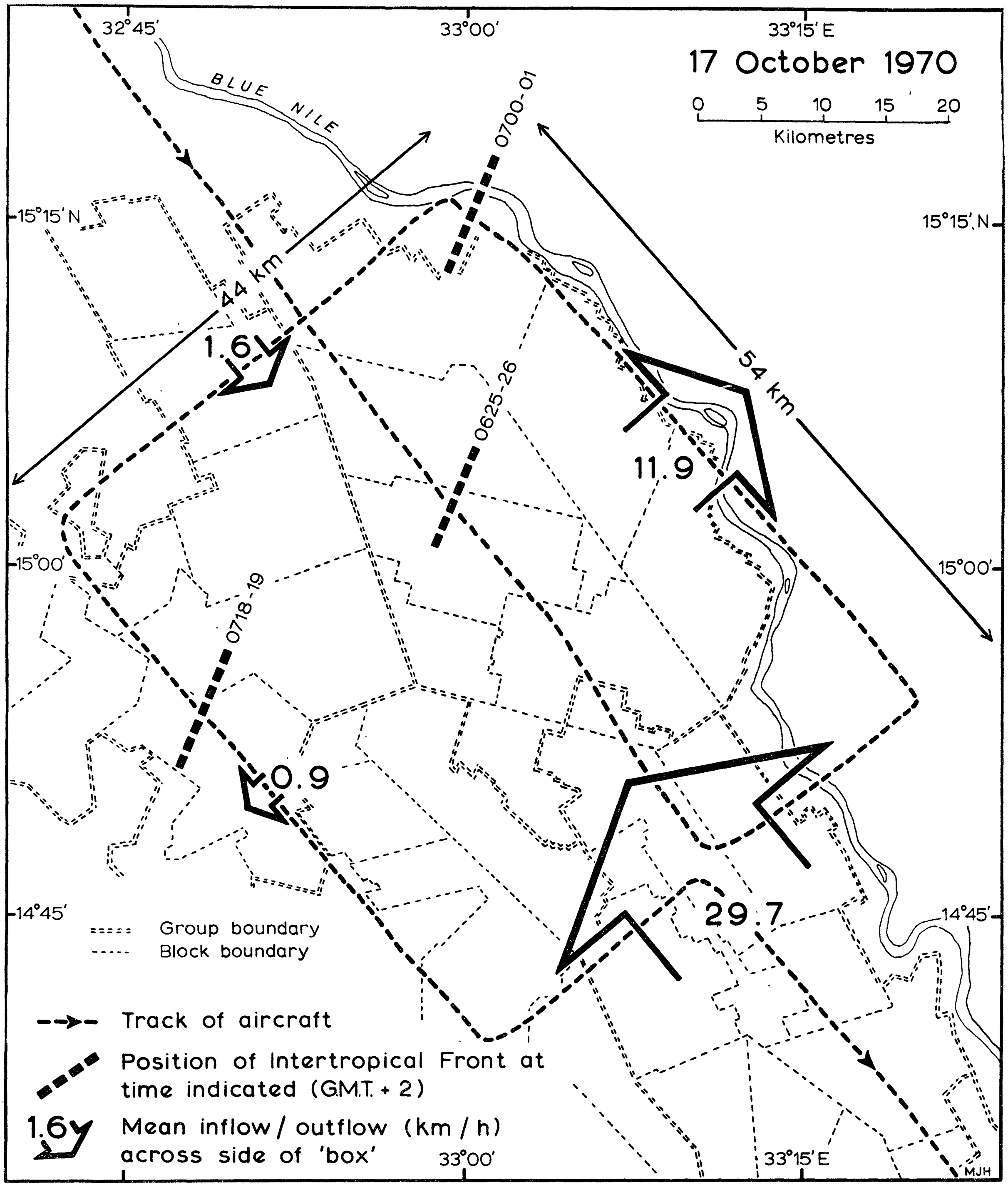

FIGURE 2. Estimation of wind-convergence. Low-level wind-convergence inevitably involves ascent of air and is essential for the production of rain; it can also concentrate flying insects. If around a closed horizontal pattern of area A the wind experienced over one small element, of length δl has an inward component of velocity V in a direction at right angles to the element, the average convergence over the area of the pattern is $\Sigma V\delta l/A$. For the observations of figure 1, treated as effectively instantaneous, this expression becomes $[44(29.7+1.6)-54(11.9+0.9)]/44\times 54$, giving convergence at an estimated rate of 0.29 per hour. On the simplest of assumptions, airborne insects would be concentrated by such convergence at an initial rate of 29% increase in area-density per hour. The figure also shows the boundaries of some of the 12 Groups and 103 Blocks which are the operational units of the Sudan Gezira Board, whose 800000 ha of intensive co-operative irrigated agriculture represent one of the largest agricultural enterprises under one management anywhere in the world.

Darfur are so far unsurpassed in terms of all recognized criteria (herd performance, cost effectiveness, net foreign exchange product)' (Adams 1975).

The seasonal migrations of locusts have also been found to be dominated by the i.t.c.z. and other zones of convergence (Rainey 1951), by reason of the down-wind displacements shown by the flying swarms of these insects. Low-level wind convergence moreover will concentrate any airborne insects constrained, e.g. by air temperature, against unlimited ascent and otherwise without systematic movement of their own relative to the air, and this process can have important effects on the population-density of insect pests (Rainey 1976). Sharply defined zones of convergence like the i.t.f. in the Sudan at this season have been found to provide radar line-echoes attributable to the insects concentrated within them (Schaefer 1976).

Rain in the Empty Quarter of Arabia

A further example of widespread and heavy rains in the desert relates to the Rub al Khali, the Empty Quarter of southeastern Arabia, and was investigated in the course of a study (Rainey 1965) of the upsurge of the desert locust plague which took place in the winter of 1948–9. What had been regarded as the last records of the preceding plague had been of swarming locusts which had disappeared both from northeastern Africa and from Indo–Pakistan during the summer of 1948. The first locust reports of what was regarded at the time as a new plague came from the Mudafin and Wadi al Ain areas of the interior of Oman in February 1949, and were provided by the explorer Wilfred Thesiger in the course of a series of famous camel journeys (Thesiger 1950–51) during which he had also encountered exceptional widespread and heavy rains which extended across the eastern sands of the Rub al Khali almost to the Hadhramaut. At Abu Dhabi in late October 1948 (long before the oil finds) Thesiger was 'delayed by a torrential thunderstorm, which flooded a large part of the island and rendered the salt flats impassable to camels', and, en route to Buraimi on 1–4 November, noted that 'the rains had formed extensive lakes on the flats among the dunes, and promised bountiful grazing in the months to come'; the rains had been experienced over an area extending from Buraimi to Sabkhat Mutti, 400 km away to the west.

Across the southern Rub al Khali the information collected by Thesiger shows that these rains also extended eastwards from Wadi Qinab for some 700 km to beyond Mughshin, where flood damage occurred. This was before the time of the use of current weather maps in locust control; and, so far as the Desert Locust Survey of those days was concerned, our first enlightenment as to the reason for these rains was provided by a Pakistani forecaster who chanced to be on night duty at Karachi Airport a year or so later when I called in at the meteorological office there for a casual look at their synoptic charts while awaiting a connecting flight. He immediately recalled an exceptional tropical cyclone with an unusual track which had taken it into southeastern Arabia. Figure 3 shows the successive positions of the centre of this cyclone, as deduced at the time in the Aden meteorological office from the normal routine meteorological observations made in the region. This track had been presented in a report (Bradbury 1949) prepared entirely without knowledge of the information collected by Thesiger on the extent of the rains of late October in the interior, which is clearly consistent (figure 3) with the inland track of the cyclone as inferred from the synoptic evidence.

The weather experienced along the track of the cyclone is illustrated by observations made at the aerodrome at Salala, beginning on the 23rd, two days and some 750 km ahead of the passage of the centre, with an unusual wind of 45 km/h from the north at 16 h (local time), a time of day at which a southeasterly sea-breeze may usually be expected. Distant lightning was noted at 22 h that evening, and the following morning (24th) the northerly wind, still blowing at 35–55 km/h, brought rising sand and reduced visibility to 2 km. At 11 h intermittent drizzle began, developing by later afternoon into intermittent moderate rain, falling through a persistent thick haze which obscured the sky, and becoming heavy though still intermittent in the late evening. The following morning (25th), the persistent northerly wind, of near gale force

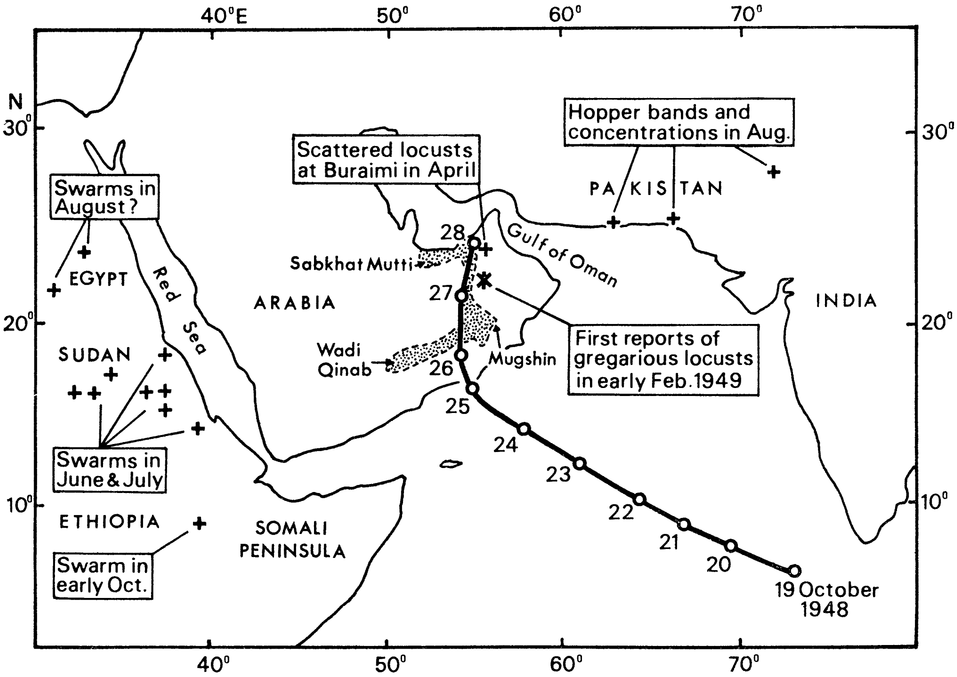

FIGURE 3. The 1948 Oman cyclone: rains, track and locusts. Extent of rain in Arabia as established by information from bedouin (Thesiger 1950–51); track of cyclone established independently by synoptic analysis at Aden meteorological office (Bradbury 1949); and reports of desert locust populations in 1948 which may have been subsequently affected by the cyclone.

(55 km/h at 10 h), which had already caused damage to local shipping and airfield buildings, abruptly died down at 11h15, though drizzle continued: at 11h20 the wind veered to the south, suddenly freshened again, 'began to blow corrugated iron sheets about the camp as if they were autumn leaves', and was recorded as southwesterly 45 km/h at 13 h, 55 km/h at 16 h and 80 km/h (strong gale) at 19 h. On the morning of the 26th the wind had abated, and there were breaks in the cloud cover after 10 h, but further rain and drizzle fell during the day and until 05 h on the morning of the 27th, making a total of 157 mm recorded over the four days, comprising successive daily totals of 48, 41, 43 and 24 mm: the normal total *annual* rainfall at Salala, averaged over a 20 year period (1946–65), is 112 mm. In the hinterland the information collected by Thesiger shows that the rains extended over a WSW/ENE distance of some 700 km. At Masira, 640 km to the northeast away from Salala and from the track of the centre of the cyclone, there was heavy rain all night on the 24/25th, totalling 19 mm and accompanied by strong easterly winds, still 45 km/h from ENE at 07 h on the 25th, but recorded as veering to SSE at 08 h as the rain stopped. At midday on the 26th, rain was reported by an

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

aircraft over the Gulf of Oman, extending for 400 km along 25° N, while at Sharjah, on the Trucial coast of the Persian Gulf, 19 mm were recorded on the 25/26th, and rain was again reported on the 28th.

Figure 4 shows that the area over which surface winds were affected by the cyclone extended from the Gulf of Oman to beyond the southern Red Sea, where both at Assab in Eritrea and at Perim the normally persistent southeasterly winds characteristic of this season of the year were

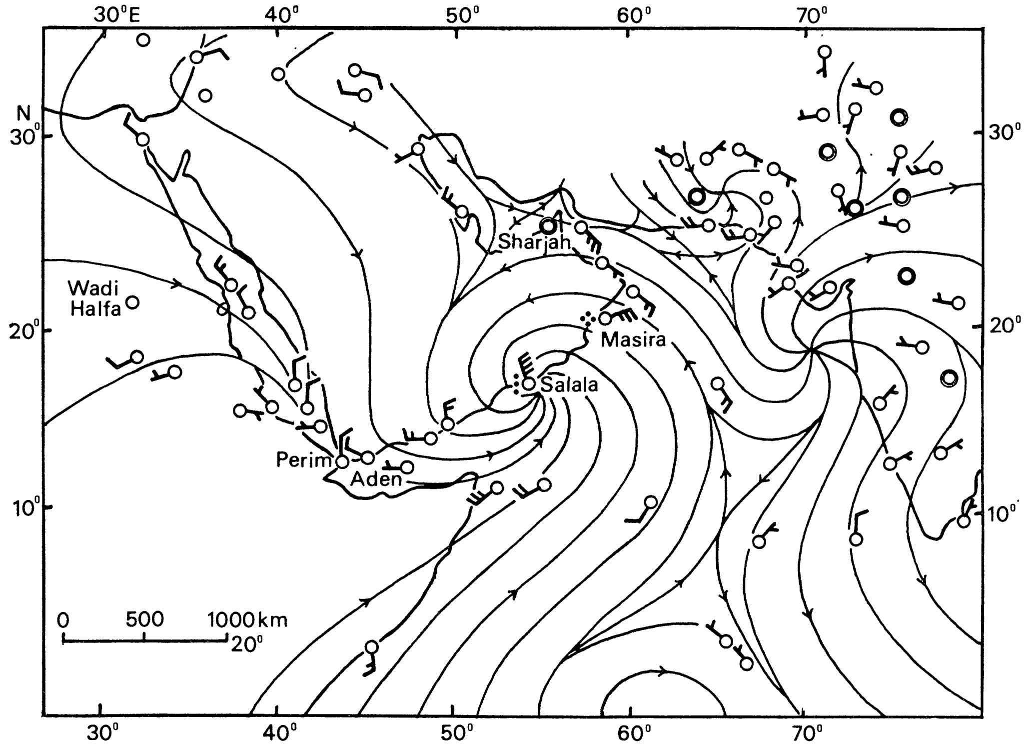

FIGURE 4. The Oman cyclone: surface winds and streamlines at 03 h G.M.T. 25 October 1948.

interrupted by an exceptional two-day spell of northerlies and northeasterlies on 25 and 26 October. In view of the down-wind direction of displacement which has been found so consistently in airborne locust populations, this meteorological evidence thus supported a suggestion that locusts derived from swarming populations in the Red Sea and/or in Baluchistan might well have participated in breeding in the eastern Rub al Khali in November 1948, in addition to any remaining local solitary-living locust populations, and that the widespread rain would have provided extensive conditions suitable for the multiplication of all locusts involved, with a probable rate of development appropriate for the following generation to reach the stages reported by Thesiger in the following February.

Rain around the Kalahari

The strongly convergent winds of the Arabian cyclone are also likely to have concentrated any locusts in flight in them, though the observations in this case were inadequate for any quantitative estimate of possible rates of concentration. Because of the importance attached

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

to possible changes in the population density of the locusts in the development of gregarious behaviour, however, attention had been directed to the corresponding findings of a series of studies made at about this same time on the dynamics of a better-documented and somewhat, analogous cyclone from the southern Indian Ocean (Black 1950; Kreft 1953; Sellick 1958). This cyclone (figure 5) now has relevance for the present meeting by reason of having brought widespread rains to the semi-arid regions bordering on the Kalahari desert and discussed by

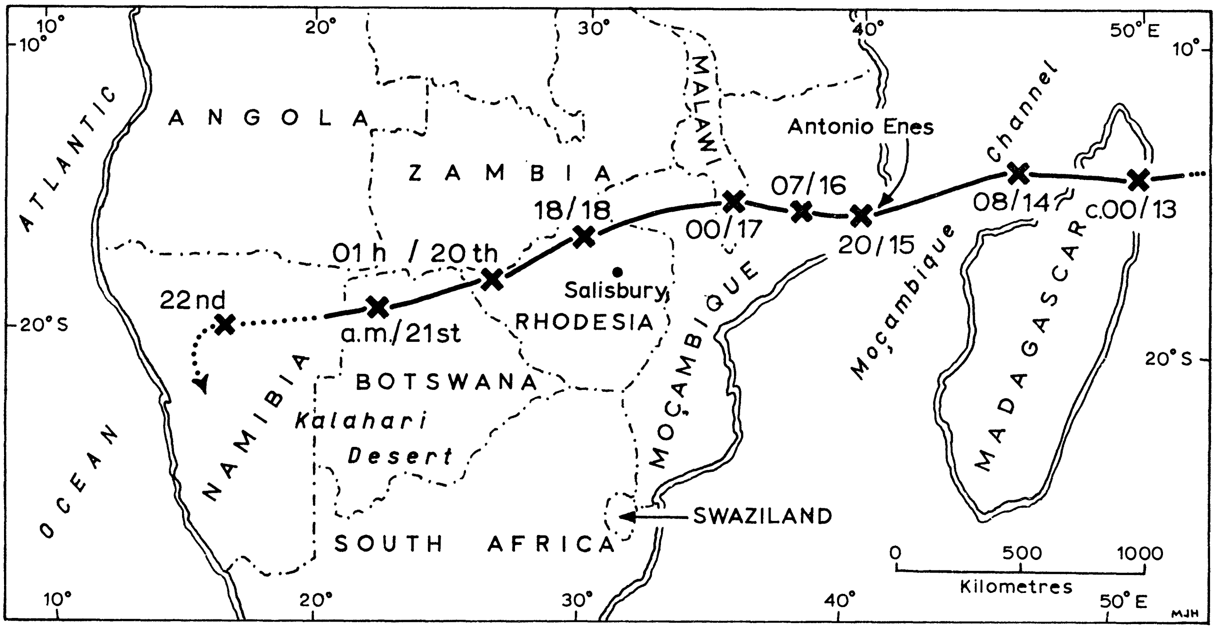

FIGURE 5. Track of an unusual cyclone from the southern Indian Ocean: February 1950. (Data of Black 1950, Kreft 1953 and Sellick 1958.)

Pereira (pp. 555–562). It crossed Madagascar and the Mozambique Channel and then moved inland across Mozambique, Malawi, Rhodesia and Zambia between 16 and 20 February 1950, at a latitude (15°–18° S – instead of N) and a speed (13–14 km/h) closely comparable with the Arabian cyclone just described, and also giving a roughly comparable rainfall: a total of 145 mm fell in three days (13–16th) at Antonio Enes on the Mozambique coast over the period of the passage of the cyclone, followed by a well-documented average daily fall of 52 mm over an inland area of 155000 km² on the 18th and 19th, with indications that precipitation of this order had persisted for four or more days. The 1950 cyclone moved on across Botswana on 21 February and was still giving good rains over northern Namibia on the 22nd. There was considerable similarity between the wet-bulb temperatures which had been recorded at Salala, which remained between 22 and 23 °C for at least 12 h during the passage of the Arabian cyclone, and the wet-bulb potential temperatures, between 21 and 22 °C from the ground up to at least 7500 m above sea level, recorded at Salisbury in Rhodesia during the radiosonde ascent on 18 February 1950, which was regarded as representative of the inland rain-area.

It was shown that the total water-vapour content of the atmosphere at the time, as indicated by this radiosonde ascent, was equivalent to only 36 mm of liquid water; and that evaporation and transpiration were not likely to have returned more than about 5 mm of the rainfall per day to the atmosphere. In order to maintain the observed rate of precipitation, the wind-system must therefore have been such as completely to replace, once in every 20 h or so, the whole of the air over the rain area, up to a great height; and this was shown to require a net inflow component of the wind, near the ground, of the order of 7 km/h around the perimeter of an area 440 km in diameter, representing the central part of this wind-system. Hypothetical airborne insects experiencing such convergence would be concentrated at a rate which on the simplest of assumptions would increase their area-density by an average factor of five over an area of more than 10^5 km^2 within a period of four days.

Rain in the outback

The Oman cyclone of October 1948 provided months of bountiful grazing to the bedouin of the Empty Quarter of Arabia. A somewhat similar meteorological system which benefited the cattlemen of the Australian outback in the same way was cyclone 'Audrey' of 1964 (figures 6 and 7), of which we heard a great deal in the course of field work around Nockatunga in this area the following year, under the auspices of the C.S.I.R.O. Division of Entomology (Clark, Ashall, Waloff & Chinnick 1969). I am greatly indebted to Derek Reid, of the C.S.I.R.O. Division of Meteorological Physics, for these analyses, and to the Director of the Commonwealth Bureau of Meteorology for the basic data and routine charts.

Rainfall amounts of more than 200 mm were recorded in the vicinity of the track of 'Audrey', with the fall over a period of a week in a number of places approaching the median annual rainfall (Gibbs 1969) for the area. Local systems for the exploitation of such rains, epitomized in the term 'opportunity country' (Ricketts 1969), were illustrated by an extensive cattle station on which we worked, in an area with a median annual rainfall of about 200 mm and carrying relatively few cattle in drier years. This station was owned and operated, in the way indicated by Tribe (p. 565), by a syndicate which also owned a second station in the higher-rainfall Mitchell River area some 1300 km away to the north with a median annual rainfall of more than 1000 mm. From this second station, after rains like those of 'Audrey', store cattle were brought in for fattening on the resulting extensive but temporary grazing, using 'beef-trains' of heavy road trucks with multiple trailers for the rapid transport of stock without loss of condition.

Cyclone 'Audrey' had incidentally been followed by an upsurge of the Australian plague locust (*Chortoicetes terminifera* Walk.), though the evidence available was insufficient to substantiate transport and concentration of flying locusts by the convergent wind-system of the cyclone in a manner suggested by analogy with the Oman cyclone of 1948. However, the late Dr D. P. Clark, of the C.S.I.R.O. Division of Entomology, subsequently directed attention to the fuller and acceptable evidence on this same point which was secured by his field staff (particularly R. A. H. Davies) on the locust developments in 1971–72 which were associated with the passage of another cyclone across the same general area.

Rainfall in such areas does not have to be on this scale to be associated with recognizable synoptic systems. Thus for example during our own period of field work in and around south-western Queensland, in January–March 1965, rains were less than 50 % of normal; but each of the four occasions during this period on which our party noted rain was subsequently found to have been associated with the passage of a trough of low pressure, shown at the time on the routine synoptic charts of the Commonwealth Bureau of Meteorology. These features were marked locally by extensive cirrus and alto-cumulus cloud and by freshening winds shifting

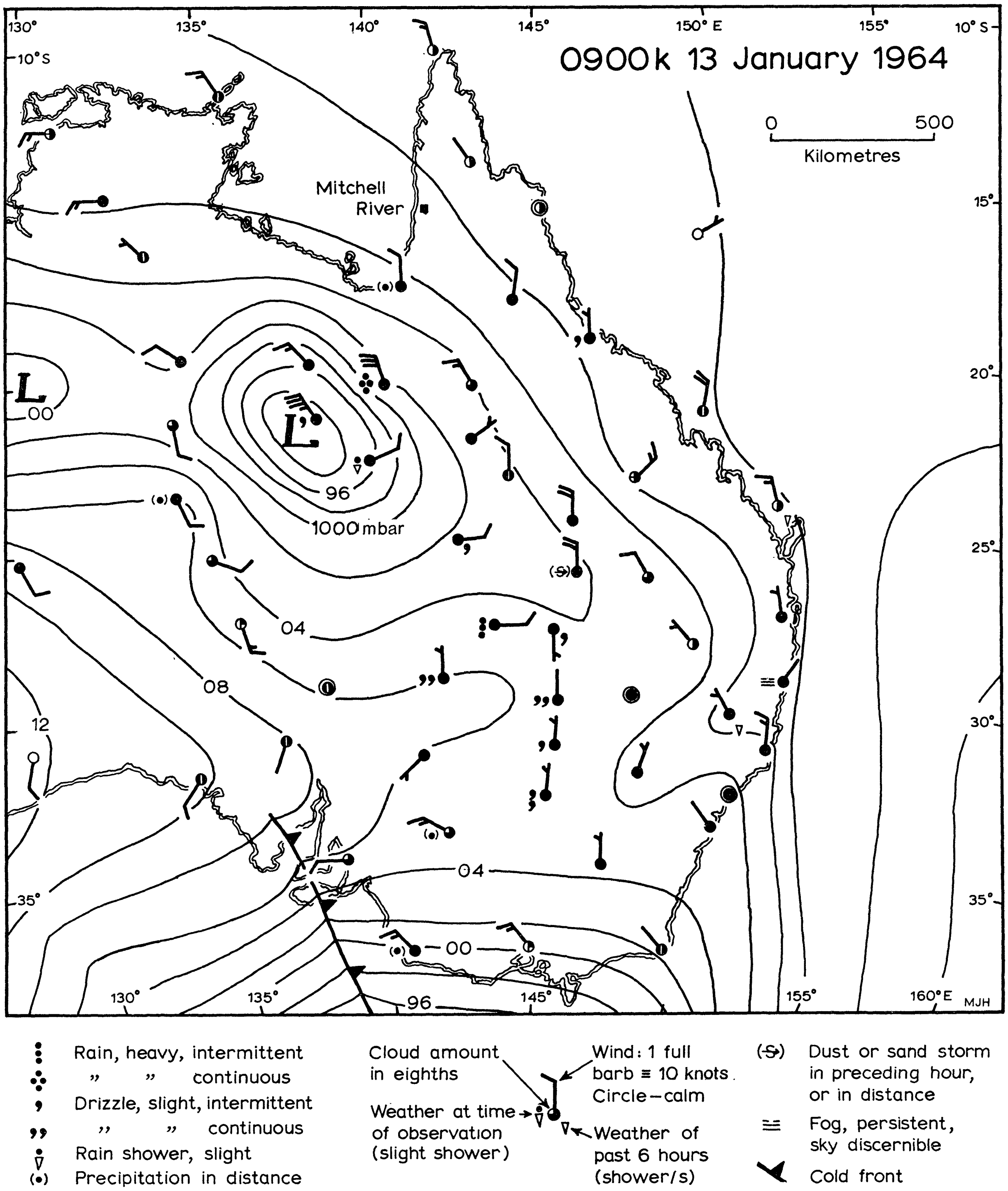

Figure 6. Cyclone Audrey: surface synoptic analysis.
(Data and analysis of Commonwealth Bureau of Meteorology.)

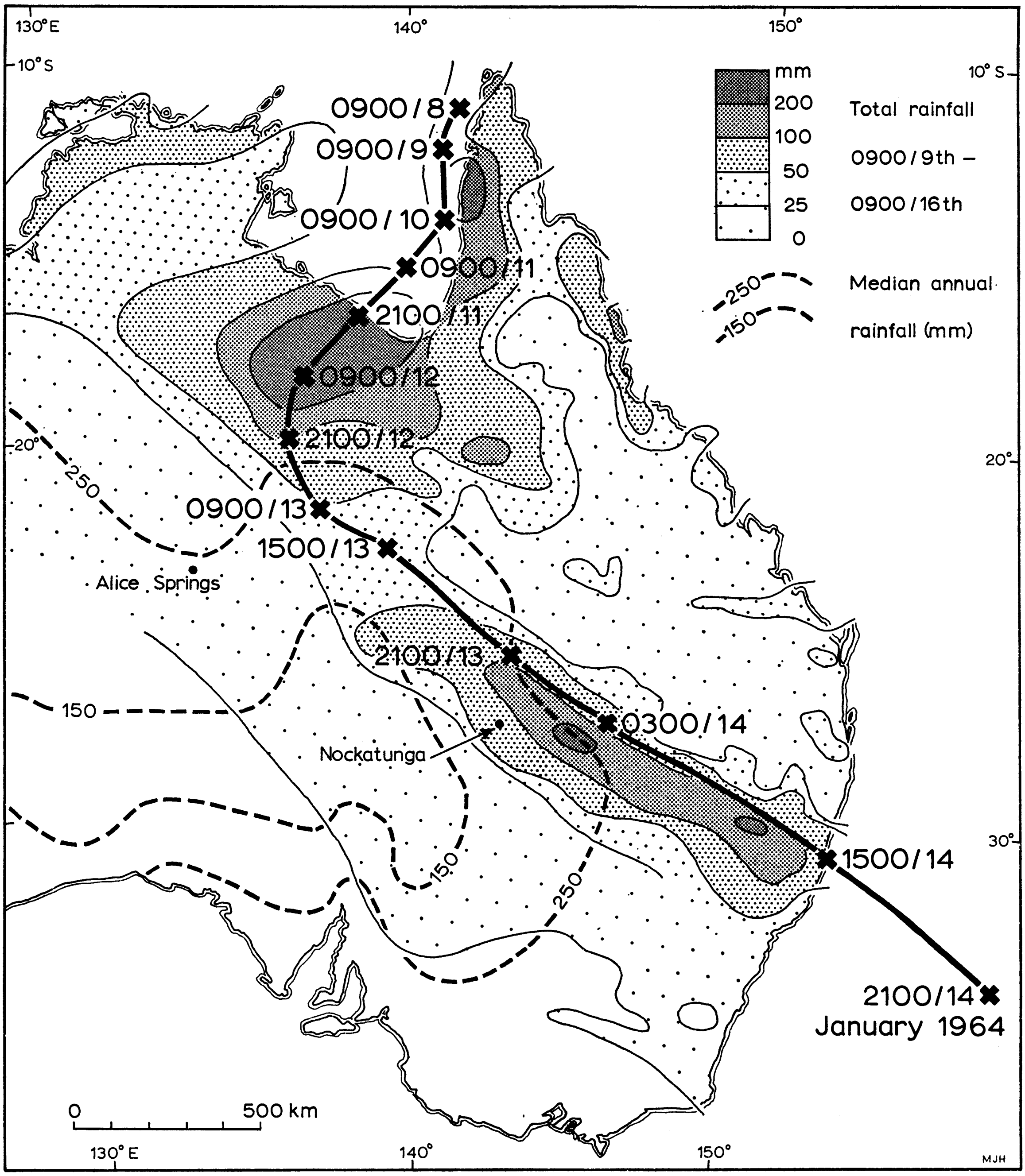

FIGURE 7. Cyclone Audrey: track and rainfall.
Isohyets of median annual rainfall from Gibbs (1969).

from the usual easterlies and southeasterlies into the northerly and westerly quarters, as well as by records of rain at one to nine of the 21 regular rainfall stations within 300 km of Nockatunga. The distinction shown by these data, between extended spells of completely dry weather and shorter unsettled spells with rain recorded simultaneously at several points, was demonstrated even more strikingly by the records of six stations within 100 km of Alice Springs in central Australia during the drought year of 1961: the 69 occasions during this complete year

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

on which rain was recorded at one of these six stations were confined to 36 of 365 possible days, occurring in 23 sequences of up to four successive days with rain, and separated by completely dry spells of up to four months (Newsome 1965).

Rain in the southwestern Sahara

A final example comes from West Africa: on 9–10 February 1968 widespread rains fell in the western Sahara, over an area whose extent is directly illustrated by the range of the stock movements undertaken by the nomads of the region in exploiting the resulting grazing. For details of this particular occasion, and for much other information on this subject ('le Sahara n'est pas du tout une région abiotique'), I have been very greatly indebted to M. Abdallahi Ould Mohamed Sidia, Director-General of O.C.L.A.L.A.V. (Organisation Commune de Lutte Antiacridienne et de Lutte Antaviare), the international organization responsible for the control of desert locusts and other migrant pests in nine countries of western Africa, from Mauritania and Senegal to Chad and Cameroun. M. Abdallahi comes himself from Mauritania, from a community of nomads who still make regular seasonal migrations; his own recollections go back to the rains in northern Mauritania in February 1935, flooding the clay plain of Rhallamane and recalled as the 'year of the truffles', from the truffle *Terfezia* which grows on the desert rock-rose *Helianthemum*. These 1935 rains were experienced and recorded by Monod; the scope and value of the collection and critical analysis of such information from the nomads on the rainfall régime and ecology of the Sahara has been recognized in many studies, such as those of Dubief on rainfall and run-off.

The rains recorded during 9–10 February 1968 reached 41 mm, at Akjoujt; and figure 8 shows two noteworthy stock movements which were made possible by the resulting grazing; a fall of 20 mm has been found sufficient to initiate the growth of useful grazing (Toupet 1975). In one of these movements, cattle were brought from the Moudjeria area, the northern limit of their usual distribution, over a distance of some 500 km to within 60 km of Bir Moghrein – a feat providing evidence of the degree of continuity of the vegetal cover and in turn of the rains which had evoked it. The second was a movement of other stock between the Bir Moghrein area and In Nabnane, 1000 km away on the Mali/Algeria border – a movement which is understood to have exploited not only the grazing but also certain gaps in the customs coverage of these frontiers. Clearly these rains must have covered a total area of hundreds of thousands of square kilometres, at a time of year when losses by evaporation are much less than they would be in summer (cf. Perry, p. 493 – on differences between summer and winter rainfall cropping limits around the Sahara); and the value of the resulting grazing is not merely that of its extent. The high nutritive value of such temporary winter grazing in the Sahara has helped to make it the traditional complement to the summer grazing of the Sahel to the south; and the very great value of such stock movements between complementary seasonal grazing areas, in resting land at present heavily overgrazed, is now well recognized (Monod 1975, etc.).

In the exploitation of the grazing following such desert rains the Sahara nomads use not only a very extensive information network of their own but also an impressive series of traditional techniques, ranging for example from the estimation of the distance of a rainstorm from observations of the associated lightning, to the use of the desert crucifer *Schouwia* for promoting fertility in livestock; and their vocabularies include for example different words for the characteristically convective showers of afternoon and evening and for the more general and less stormy rains of night and morning.

Contemporary technology provided information on these rains of February 1968 illustrated both by satellite photography on cloud coverage (shown in figure 8 as the coded nephanalysis which was received in Kensington a few hours later, as part of the desert locust forecasting system of those days), and by the evidence on the mechanism of these particular rains which was

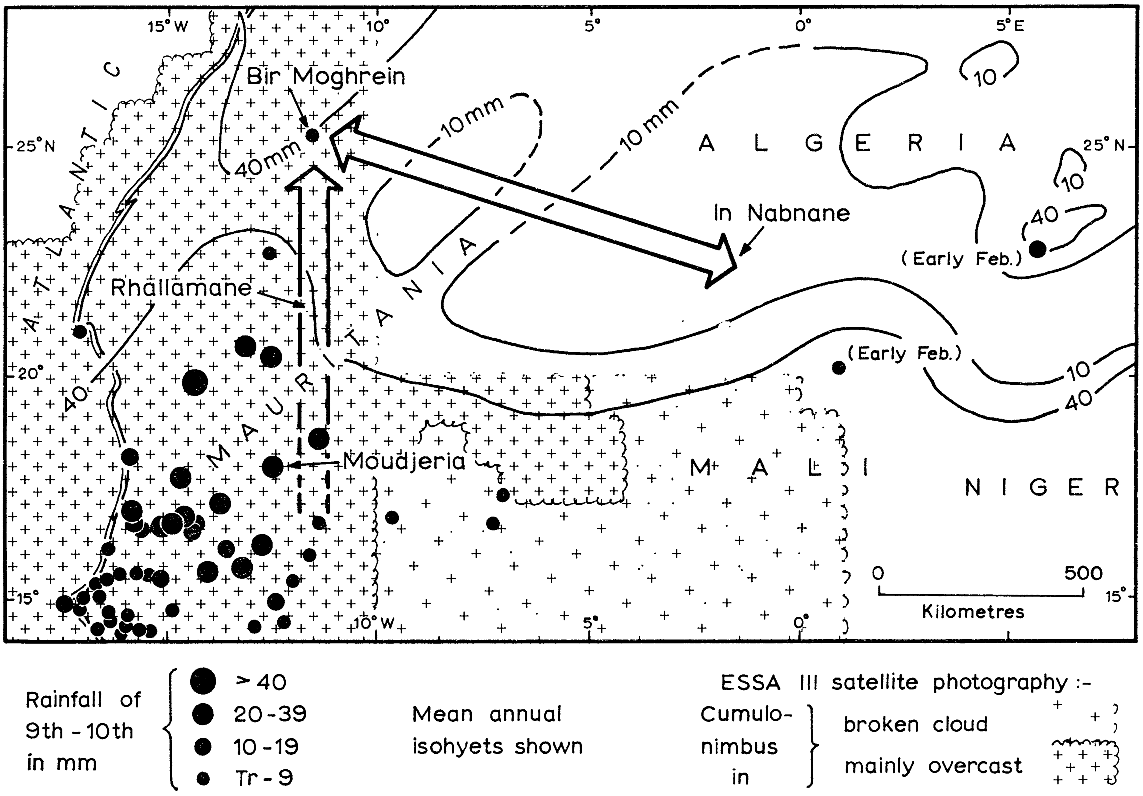

Figure 8. Rains in western Sahara, February 1968: exceptional stock movements on subsequent grazing. (Rainfall observations from A.S.E.C.N.A. Dakar; annual isohyets from Dubief (1959–63).)

supplied by current synoptic analyses. The rains were associated with the passage of a higher-latitude disturbance which was dominating the weather as far north as Britain, and on which I am greatly indebted to M. Robert Garnier, of the Dakar Bureau d'Etudes of A.S.E.C.N.A. (Agence pour la Securité de la Navigation Aerienne en Afrique et à Madagascar) for the benefit of his synoptic experience and for the following comments:

'Typical interaction between meteorological phenomena of temperate and tropical latitudes: surge of polar front brought substantial invasion of cold air to low latitudes over Atlantic. At 1200 GMT 9 February this deepened a trough of low pressure which extended at all altitudes from a depression over the British Isles to Cape Verde, and the gradient between this trough and high pressures over the Sahara produced a strong SW current (exceeding 220 km/h at heights from 7500 up to 16000 m between Dakar and Nouadhibou) which brought up equatorial air giving the cloud, thunderstorms and rains over Senegal and Mauritania. This situation began on the evening of the 8th and lasted until the night of 10/11th.'

Conclusion

It is suggested that the full exploitation of the considerable resources represented by rains such as those described – as well as the timely and economic control of upsurges of migrant pests themselves exploiting such rains – requires the integration of the information networks of international meteorology with those of the desert nomads; and attention is directed to this opportunity and challenge of bringing to bear the modern observational resources and the synoptic expertise of contemporary meteorology on the basic human needs not only of the desert nomads, but also of their neighbours in a future of increasing pressure on global food supplies. More specifically, there already is an internationally supported organization, with terms of reference very reasonably appropriate for the provision of such an integrated information service on current rainfall and grazing conditions, and very recently established in a highly appropriate area, in the shape of Dr Rijks' U.N.D.P./F.A.O. Sahel Centre for Agrometeorology and Applied Hydrometeorology at Niamey in the Niger Republic.

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Discussion

E. G. Davy (*World Meteorological Organization, Case Postale No.* 5, *CH*–1211–*Geneva*). It is not very uncommon in the Northern Sahel, or even in the Sahara, for the occasional period of very heavy rain in an arid area to be followed by abnormally good growth of animal grazing to which the nomadic herds are attracted from great distances as in the case cited for northern Mauritania.

I would sound a note of warning on the attractive suggestion that the existing communications systems of the nomads should be perfected by modern technologies, including monitoring by earth satellites, to make greatest use of such grazing opportunities.

Such localities provide the seed banks which are replenished perhaps once in five or ten years in arid regions. From these, much wider areas are seeded for future years by wind dispersion. Larger numbers of animals directed to those areas would not only seriously diminish seed production but also remove the vegetation cover of the soil to expose to increased desertification those areas which are already at greatest risk.

R. C. Rainey. I fully accept Mr Davy's note of warning, which is, however, particularly relevant to the overgrazed areas of the northern Sahel in and around which stock are almost continuously present. The important point about the kind of rains which I have been describing in the Sahara, further to the north, is their extent, which may amount to hundreds of thousands of square kilometres on a single occasion, and over which the effects of additional stock movements, like those recorded on p. 451, might be expected to be small, while at the same time helping to relieve grazing pressure in the Sahel.

G. Stanhill (*Volcani Center of Agricultural Research, Israel; for correspondence, Botany Dept, Cambridge University*). A key to the successful exploitation of scarce rainfall is the recognition of its large interannual variability. Once this is acknowledged, settled agriculture appears possible in surprisingly low rainfall areas. For example, in southern Israel, attempts to crop annually with winter cereals an area with an average annual rainfall of 200 mm and a coefficient of variation of 35 % had to be abandoned when a run of wetter-than-average years came to an end. Experiments to replace cereal cropping with a flexible system of sheep farming on perennial pastures appear to be successful and show promise of long term stability.

Further south, Professor Evanari's reconstruction of Nabatean farms at Avdat has shown that it is possible to crop perennially deciduous fruit orchards with a mean annual rainfall of less than 100 mm by exploiting the special runoff and infiltration properties of the loess soil.

E. B. Worthington (*I.B.P., c/o The Linnean Society, Burlington House, Piccadilly, London W*1*V* 0*LQ*). The question of the distribution of pests and vectors of disease through climatological disturbance such as thermals lifting small organisms from the water or land for subsequent movement by prevalent winds: were there examples of this other than the well established movements of locusts? Climatological disturbance might for example account for the recent somewhat unexpected reappearance of adult *Simulium damnosum*, infected with onchocerciasis, in parts of the zone in West Africa from which this vector had already been eliminated in the great experiment being undertaken by W.H.O. which is designed to eradicate river blindness from a huge area in West Africa.

R. C. Rainey. Other pest organisms subject to important redistribution by air movements include the spores of rust-fungi. Thus 'an annual double transcontinental migration through the atmosphere is an essential condition for the development of the rust epidemics [of *Puccinia graminis* and *P. triticina*] which regularly attack cereal crops in North America' (Gregory 1961). Again, the progress of the 5-year spread of American maize rust (*P. polysora*) across Africa following its first arrival, in Sierra Leone in 1949, showed a remarkable analogy with the 5-year spread of the swarms of the last major outbreak of the migratory locust (*Locusta migratoria migratorioides*) across Africa following their first appearance, in Mali in 1928 (Rainey 1973).

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D. E. Pedgley (*Centre for Overseas Pest Research, College House, Wrights Lane, London W*8 5*SJ*). At the request of the World Health Organization, the Centre for Overseas Pest Research had a first look in 1975 at the evidence for downwind movement of *Simulium damnosum*, the vector of river blindness in West Africa. Both the few published accounts and some current season's records from the W.H.O. control programme were used, with the tentative conclusion that first appearances of biting flies after the dry season were associated with convergence zones in the wind-field – both the intertropical convergence zone and the smaller-scale zones in squall lines. Much work needs to be done, not only on tracking flies in changing wind fields but also on the flight behaviour of individual flies, including their height, endurance and timing of flight.

R. C. Rainey. A brief spell of field work for the W.H.O. Onchocerciasis Control Programme, undertaken in Upper Volta and Ivory Coast during August 1976 which used the same Doppler-equipped aircraft mentioned on p. 441, is already helping to throw light on the wind-systems which appear to be involved in the crucial problem of re-invasion to which Dr Worthington has referred.

W. B. Broughton (*Animal Acoustics Unit, City of London Polytechnic, Calcutta House, Old Castle St, London E*1 7*NT*). Dr Rainey spoke of the air drying out as it rises in the tropical zone. What happens to the water it loses, and, when a disturbance of the usual atmospheric circulation brings the infrequent rain to an area of convergence, where does it pick up this water?

R. C. Rainey. The water lost by the air rising in the tropical zone provides the rains of this zone (p. 440), and the water which provides the rain associated with convergence in an atmospheric disturbance in a normally arid region will, likewise, have been picked up from the tropical oceans.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES