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Synoptic Case-Study of Spring Rains in Eritrea

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With 6 Figures

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Summary

Synoptic analyses at sea-level, 850, 700, 500 and 250 mb have been used to examine the origin of a spell of rains in Eritrea during April 1970. A strong southward bend in the sub-tropical jet stream to 10^0 N seems to have provided a mechanism for the temporary development of deep convection clouds, fed by moisture from lower tropospheric south-easterly winds flowing across the southern Red Sea.

Zusammenfassung

Synoptische Untersuchung eines Frühjahrsregens in Eritrea

Auf Grund von synoptischen Analysen der Bodenwetterkarten und der 850-, 700-, 500- and 250mb-Karten wird die Ursache einer Regenperiode im April 1970 in Eritrea untersucht. Eine starke Ausbiegung des subtropischen Jetstreams nach Süden bis 10^0 N hat anscheinend die Vorbedingung für die Entwicklung mächtiger Konvektionswolken geschaffen, die von der Feuchtezufuhr durch südöstliche Winde, die das südliche Rote Meer in der unteren Troposphäre überstreichen, gespeist werden.

1. Introduction

The seasonal distribution of rainfall over Ethiopia has been well described (see, for example, [5, 7, 16, 17]). Over the plateau of Eritrea, in the north of Ethiopia (Fig. 1), there are essentially two rainy seasons — the "little rains", approximately from March to mid-May, and the "long rains", approximately from mid-June to mid-

September. In some years, however, there are significant falls in late October and November, but often the period mid-September to February is effectively rainless. By contrast, places along the eastward-facing escarpment of the plateau have substantial rains during this period. Whereas the spring rains on the plateau fall predominantly as thundery showers [1, 14] on 2—7 days per month [5] the

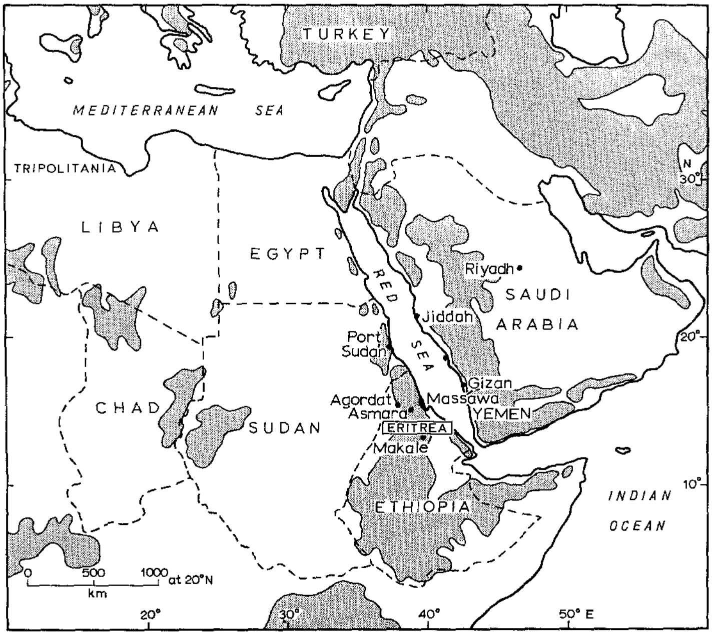

Fig. 1. Location map showing places mentioned in the text. Stippling shows land above 1000 m

winter rains along the escarpment are more frequent, they fall largely from stratiform clouds whose tops barely exceed the level of the plateau [6, 12] and they are of a drizzly nature. Occasionally this stratiform cloud spills on to the plateau to give short spells of light drizzle, mostly during the evening and night.

Spring rains in Eritrea have been ascribed to the presence of a trough in the upper tropospheric westerlies above moist south-easterly winds filling the Red Sea trench [6, 16, 17]. A similar association has been given for Yemen, on the opposite side of the Red Sea [18, 19], where spring rains on the plateau have for long been noted to accompany winds with a southerly component [9]. Winter rains at Port Sudan have been explained similarly [3, 4], and a case-study for north-western Saudi Arabia [13] showed the importance of both surface south-easterlies and a disturbance in the upper troposphere.

From these studies, one may suppose that the usual mechanism leading to spring rains around the Red Sea is the development of upper tropospheric divergence, for example ahead of a trough in the westerlies, which, by inducing upward motion in the middle and lower troposphere, modifies the static stability in favour of deep, cloudy convection. This can be envisaged as being brought about in two ways: by removal of the stable layer usually present near 700 mb above the moist south-easterlies in the lower troposphere; and by mid-tropospheric cooling and moistening which itself can form sheets of altocumulus and altostratus clouds, with embedded castellanus, capable of giving outbreaks of light rain. Such cloud sheets show clearly on satellite pictures; on rare occasions they can give spells of winter and spring rains in Upper Egypt [2] and northern Sudan [10], but it is only where low-level moisture is available that deep convective clouds can develop, particularly over the Red Sea and nearby plateaux of Ethiopia and Arabia.

This mechanism leading to convective spring rains is well known in other sub-tropical regions. Although synoptic examples have been given for northern India [15] and Australia [8], among other places, there do not seem to be any published case-studies for Eritrea. This paper describes the synoptic events leading to a spell of spring rains in 1970.

2. The Weather of April 1970

Fig. 2 shows a time sequence of 12 GMT synoptic observations from Asmara (15° 17′ N, 38° 55′ E, altitude 2325 m) for April 1970. Particularly obvious are the persistent east winds that usually blow in spring on the southern sides of the sub-tropical anticyclones in mid-troposphere. These easterlies are reinforced by diurnal wind circulations between the plateau of Eritrea and the free air over the Red Sea. (Asmara lies only a few kilometres from the top of the eastward-facing escarpment of the plateau.)

Temperatures were mostly 20—25° C and dew points 5—10° C, but there were oscillations during the month. Relatively high temperatures and low dew points occurred on the three days with west winds — reflecting the absence of cool, moist air from a source to the east. However, low dew points below 5° C did occur on four days with east winds. Temperatures showed a decline from 25° C at the start of the month to about 19° C between the 7th and 13th, then a rise to 24° C on the 17th, followed by a second fall to about 20° C between the 19th and 21st, and finally a sudden rise to about 25° C for the remainder of the month.

Convective clouds developed every day, but with variable amount and vertical extent. Cumulonimbus clouds with anvils were present at 12 GMT each day from the 7th to 11th (with thunderstorms on the first four days) and also on the 20th (again with thunder). The thunder coincided with the two cool spells whereas, by contrast, the warm spells were characterised by weak development of convective clouds. This coincidence of low temperatures with thundery weather is unlikely to have been due to cooling by the evaporation of rain. Thus, on the 8th, rain had not fallen by 12 GMT yet the temperature was only 18° C, the lowest of the month for that time of day. Moreover, both thundery spells were preceded and followed by rainless days with temperatures little above the lowest. Note that there was very little middle and upper cloud.

Sequences of 12 GMT synoptic observations at Agordat (15° 33′ N, 37° 53′ E, altitude 626 m) to the west of Asmara, and at Makale (13° 30′ N, 39° 29′ E, altitude 2212 m) to the south, showed similar

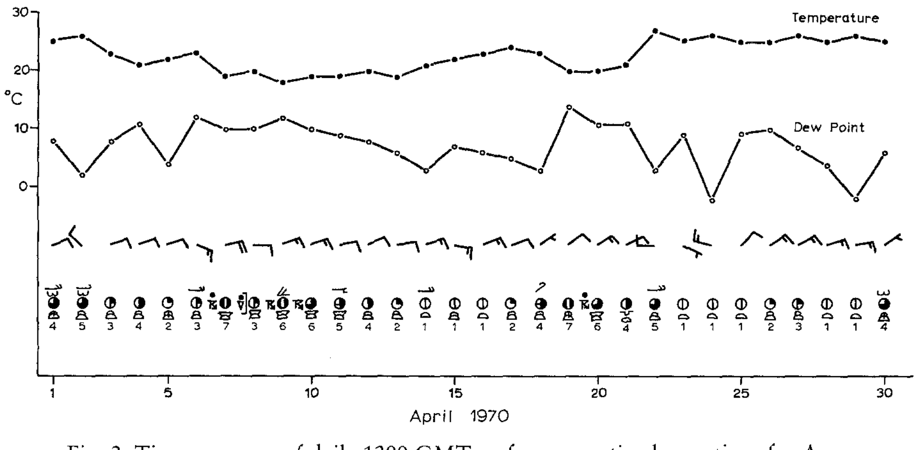

Fig. 2. Time sequence of daily 1200 GMT surface synoptic observations for Asmara, Eritrea, Ethiopia during April 1970, showing temperatures and dew points; also winds, clouds and weather using conventional symbols

spells of deep convection. Cumulonimbus clouds with anvils were seen at Agordat on the 8th and at Makale on the 9th, the latter with thunder.

The remainder of this paper is concerned with the period 4—13 April 1970.

3. Synoptic Developments

Surface: Throughout the period 4—13 April 1970, south-east winds entered the southern end of the Red Sea, but the Red Sea Convergence Zone (RSCZ, separating these south-easterlies from north-westerlies usually present over the northern Red Sea; see [12]) was

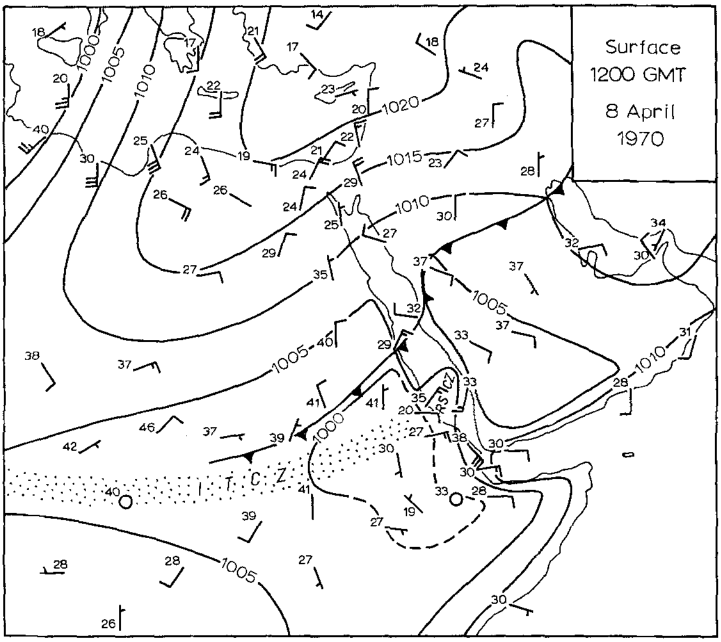

Fig. 3. Surface synoptic chart for 1200 GMT, 8 April 1970, showing winds and temperatures. Isobars are at 5 mb intervals. ITCZ shows the position of the Inter-tropical Convergence Zone over the Sudan; RSCZ shows the estimated position of the Red Sea Convergence Zone

diffuse up to the 6th, and it probably lay near Port Sudan and Jiddah. A vigorous cold front spread from the north-west between the 6th and 11th, merging with the Inter-Tropical Convergence Zone (ITCZ) over Sudan at about 10°N on the 8th (Fig. 3) and becoming indeterminate over the Arabian peninsula by the 10th. The cold front was followed by a strong anticyclone moving from Tripolitania on the 5th to central Turkey on the 8th, when it became stationary until at least the 13th. North to northwest winds behind the cold front had passed south of Port Sudan and Jiddah by the 8th and Riyadh by the 9th, when the RSCZ sharpened and moved south to persist near Massawa and Gizan until the 12th. By then, flow over the northern Red Sea had become light and variable ahead of another vigorous cold front that had entered north-western Egypt.

850 mb: South-east winds persisted over the southern Red Sea throughout the period. There was an anticyclone over the Arabian peninsula until the 8th, but another anticyclone, moving from western Libya on the 6th to the eastern Mediterranean on the 8th, became dominant and quasi-stationary over the Middle East from the 9th to at least the 13th, after absorbing the Arabian anticyclone. Winds from the southern Red Sea fed south-easterlies over Egypt on the 4th and 5th, but by the 7th north winds had spread across Egypt ahead of the Libyan anticyclone. With the establishment of this anticyclone over the Middle East, south-east winds

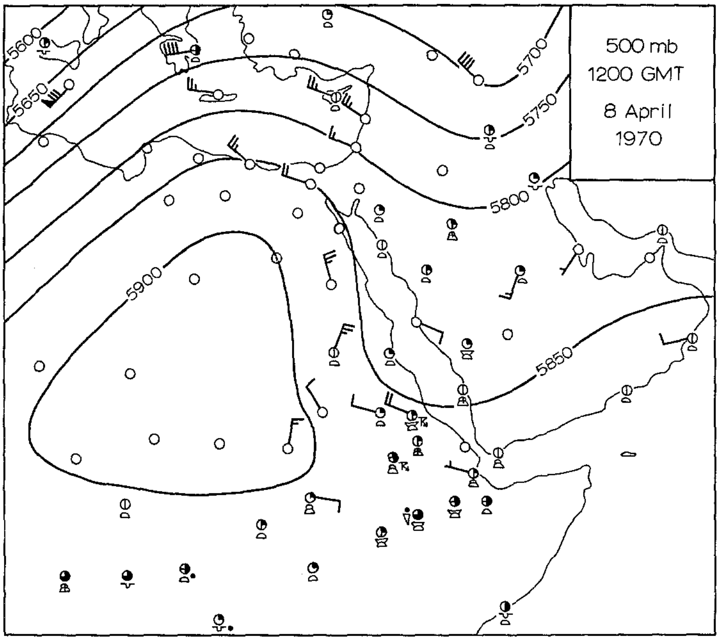

Fig. 4. 500 mb synoptic chart for 1200 GMT, 8 April 1970, showing winds and contours (in geopotential metres). Also shown are the amounts and types of *low cloud* and weather at surface synoptic stations. Open circles indicate no low cloud

returned to Egypt and persisted to the end of the period. Over the Sudan, the ITCZ lay generally near 10^0N, but moved temporarily to 15^0 N on the 12th.

700 mb: As might be expected from Fig. 2, winds over the southern Red Sea persisted from between north-east and south-east. A weak anticyclone lay over Arabia until the 8th, but another developed over the Middle East on the 9th and was quasi-stationary until the end of the period. A weak cyclonic circulation moved east across northern Sudan between the 4th and 9th.

500 mb: An anticyclone to the west of the Sudan gave north or north-east winds over Eritrea between the 4th and 7th. During this period a weak trough in the westerlies moved eastwards across the eastern Mediterranean at a speed of about 6^0 longitude per day, but on the 8th (Fig. 4) it started extending southwards from eastern Turkey towards Ethiopia. Its northern part then moved slowly eastwards to Afghanistan by the 13th, but its southern part became slow-moving over the southern Red Sea, giving north-west winds that veered to north-east by the 12th, when an elongated cyclonic centre temporarily developed over the southern end of the Red Sea. From the 10th to 13th, an anticyclone persisted over north-western Arabia, whilst another was centred over northern Chad or north-western Sudan.

250 mb: For the first three days, the flow was essentially westerly, but a trough developed over central Arabia on the 7th and 8th (Fig. 5), intensifying to become very well marked on the 11th, when north winds were blowing over the southern Red-Sea. The trough moved slowly to eastern Arabia by the 13th, when winds backed to north-west over the southern Red Sea. Between the 10th and 13th a strong ridge was slow-moving between western Sudan and the Middle East. The position of the sub-tropical jet stream at this level cannot be located precisely because there are insufficient data, but the broad-scale trends are clear. From the 4th to 6th, the axis lay near 20^0 N, but then a distortion developed in association with the trough over Arabia, taking the axis further south, probably as far as 10^0 N on the 9th and 10th. Winds decelerated downstream only slowly from the 4th to 6th, but then more rapidly as the axis veered to a position from Egypt to Ethiopia. As the trough moved east, the weakening jet, now lying north-south, moved to western Arabia by the 13th, crossing the central and southern Red Sea on the previous day.

4. Discussion

Developments in the wind fields can be summarized conveniently in two periods.

4—7 April: Patterns did not differ substantially from those often found in April. In the lower troposphere, south-east winds persisted over the southern Red Sea, extending at first to the northern part, where they were replaced by north winds behind an advancing cold front which sharpened the previously weak RSCZ near Port Sudan and Jiddah. In mid-troposphere, a cell in the belt of sub-tropical anticyclones gave north winds over the southern Red Sea, whilst

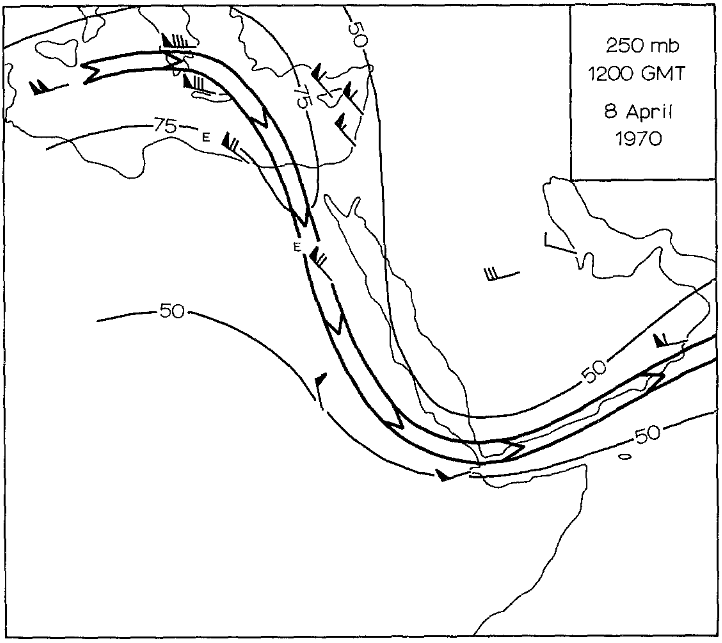

Fig. 5. 250 mb synoptic chart for 1200 GMT, 8 April 1970, showing winds and isotachs at 25 kt intervals, and the approximate axis of the sub-tropical jet stream. *E* indicates winds that have been estimated from vertical time sections. The analysis is tentative and depends heavily on continuity with analyses on previous and following days

a weak trough in the westerlies moved east at a speed of about 6^0 longitude per day across the eastern Mediterranean. There was a similar trough in the upper troposphere, whilst the axis of the sub-tropical jet lay west-north-west to east-south-east near 20^0N from southern Libya to the south coast of the Arabian peninsula.

8—13 April: The westerlies of the middle and upper troposphere became progressively distorted as:

(a) a trough deepened over Arabia, and tilted to lie from north-east to south-west, with its southern end temporarily forming a cyclonic circulation in mid-troposphere over the southern Red Sea;

(b) a ridge built north-eastwards from western Sudan to the Middle East.

The sub-tropical jet dipped southwards, reaching about 10^0 N on 9—10 April and, on its eastern side, winds became northerly over much of the Red Sea. The north-south axis moved east, crossing the Red Sea on the 12th. Below the upper ridge, an anticyclone became slow-moving in the middle and lower troposphere over the Middle East. Lower tropospheric south-east winds persisted over the southern Red Sea, but the surface RSCZ first moved south to about Massawa—Gizan before weakening ahead of another cold front approaching the northern Red Sea.

The most significant development of the period was the southward penetration of a trough in the sub-tropical jet stream. Little is known about the synoptics of this jet over the Red Sea, but a similar event occurred in April 1968 [13], also associated with an outbreak of thunderstorms but on that occasion over north-east Sudan and north-west Saudi Arabia. On both occasion the storms developed beneath the left exit of a jet speed maximum, where positive vorticity advection can be expected to induce divergence in the upper troposphere, leading to vertical stretching of the middle and lower troposphere. Such stretching would have two important effects on the thermodynamic structure.

(a) Dynamic cooling in mid-troposphere, accompanied by the generation of cyclonic vorticity (in both instances, 500 mb troughs intensified, eventually leading to the temporary formation of a closed cyclonic centre), thereby modifying the lapse rate and humidity in favour of deep, cloudy convection.

(b) Weakening of the inversion that usually caps the lower tropospheric south-easterly winds flowing through the Red Sea trench from the Indian Ocean, and deepening the moist layer beneath the inversion, thereby allowing convective clouds to grow out of the moist layer, especially where daytime heating over the adjacent mountains enhances convection.

Neither of these effects can be demonstrated directly from temperature soundings because none were available for Eritrea. However, day-to-day changes in the vigour and depth of convection were well illustrated by the sequence of 12 GMT observations at Asmara (Fig. 2). Moreover, similar convection developed widely over the mountains of northern Ethiopia and south-western Saudi Arabia (Fig. 4). Over Saudi Arabia, the rainy spell was from 7th to 11th north of 22^0 N. Further south, more days were rainy, although the period 5th to 9th was the wettest, except near 17—18° N, where the period 10th to 12th was wettest. Total falls were generally less than 20 mm (comparing with 7 mm at Asmara), but a few places had more than 50 mm [11]. There were even some falls of a few millimetres in parts of northern Saudi Arabia on the 8th, when the upper trough was deepening and the first cold front was approaching the area. At most places in Saudi Arabia, those were the only rains in April.

Thus, the thundery showers often found in spring along the seaward-facing scarps of the plateaux of Ethiopia and Arabia, and which are fed by moist, lower tropospheric south-easterly winds from the Indian Ocean, became heavier and more widespread, probably as a dynamical consequence of developments in the upper

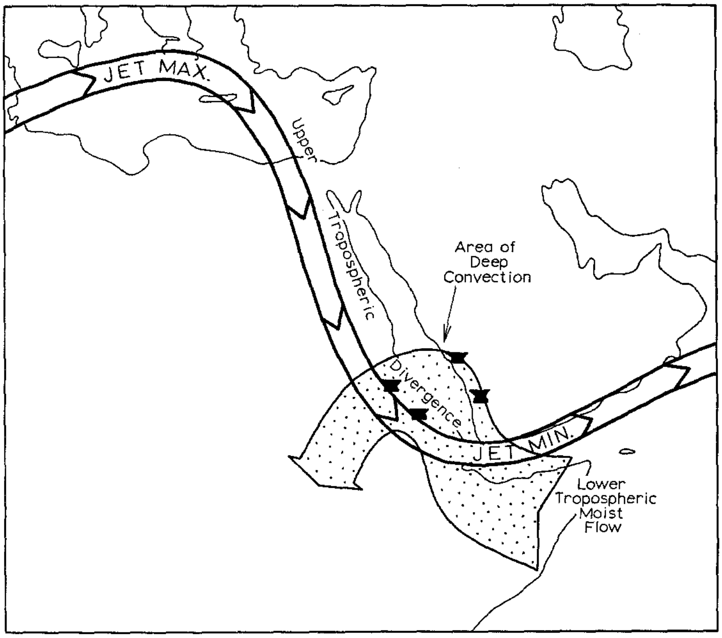

Fig. 6. Schematic synoptic pattern of the mechanism leading to a spell of rains over Eritrea in April 1970

troposphere that favoured a temporary increase in convective activity. This synoptic pattern is shown schematically in Fig. 6. The origin of the upper tropospheric developments must be sought in hemispheric charts. The 200mb charts in the Täglicher Wetterbericht of the Federal Republic of Germany showed a deep trough appearing at about 90^0 W over the U.S.A. on the 6th, and another downstream near 10^0 W on the 8th. By that day, the longitudinal separation was about 60^0, the same as that between the 10^0 W trough and the one over Arabia. Thus, there was a progressive downstream development of upper troughs, with another developing by the 12th near 100^0 E.

5. Conclusions

The spell of thundery rains over Eritrea between 7 and 11 April 1970 (and more widely over south-western Saudi Arabia between 5th and 13th) was associated with a strong southward bend of the sub-tropical jet stream, reaching about 10^0 N on the 9th and contrasting with its usual April position near 30^0 N. It is likely that divergence in the left exit of the jet speed maximum favoured deep convection, thereby intensifying and making more widespread the showers that often occur in spring near the seaward-facing scarps of the plateaux of Ethiopia and Arabia. The moisture for these rains was provided by persistent south-east winds in the lower troposphere blowing from the Indian Ocean through the trench of the southern Red Sea.

This study provides further detailed evidence of the significance of events in the upper troposphere in controlling the development of widespread and heavy rains around the Red Sea. It also adds to our knowledge of the behaviour of the sub-tropical jet stream.

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