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A DESTRUCTIVE TROPICAL CYCLONE SEASON IN THE SW INDIAN OCEAN: JANUARY–FEBRUARY 1984

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ABSTRACT

The characteristics of a destructive tropical cyclone season in the SW Indian Ocean are analysed. Circulation anomalies contributing to active cyclone seasons in the SW Indian Ocean include enhanced upper easterlies north of 20°S, upper cyclonic and anticyclonic rotors to the west and south of Madagascar, respectively, and a low level cyclonic circulation anomaly centered over Madagascar involving increased NW monsoon flow to the north and increased easterly trade winds to the south. In the first two months of 1984, eight tropical disturbances tracked westward across the SW Indian Ocean. SSTs were 2-3°C above normal and exceeded 28°C around Madagascar. OLR anomalies were 15-20 W m^{-2} below normal in the ITCZ cyclogenesis region and a convective axis extended NW-SE across Madagascar. Low level wind anomalies were cyclonic and NW monsoon outflow was at a historical peak, penetrating toward northern Madagascar. Trade wind flow to the south of Madagascar was enhanced by a mid-latitude ridge and a strengthened SW Indian Ocean anticyclone. Upper easterly flow was above normal over the 0-20° tropical belt across much of the Indian Ocean. Climatic conditions were thus set for a destructive tropical cyclone season. The case of cyclone Domoina, which served as a conduit for the NW monsoon, is analysed using satellite imagery and OLR data, ECMWF winds and radiosonde sections. Following dissipation of the cyclone, a convective spell brought relief to the drought stricken plateau of SE Africa. The mechanisms sustaining this event are studied.

Introduction

Recent trends in climate suggest that tropical cyclones may increasingly affect SE Africa (Brundrit *et al.*, 1990). The global warming scenario suggests that the critical 27°C sea surface temperature (SST) isotherm will move southward in the Mozambique Channel, bringing with it meteorological conditions within which tropical cyclones may intensify and propagate. In this context, the summer of 1983/84 will be remembered by many residents and meteorologists of the SW Indian Ocean region as particularly destructive. Eleven named tropical disturbances transited the region (Mauritius Meteorological Services Annual Report for 1984; hereafter MMS 1984), only slightly above the normal nine. However, four attained intense tropical cyclone status (Saffir-Simpson category >3), compared with a mean of two. All of the disturbances occurred between December and April, with over 80 per cent concentrated in January and February 1984. The first and last cyclones of the season followed almost identical tracks and brought great destruction to northern Madagascar. Domoina was the first tropical cyclone in recent history to have caused flooding and extensive damage (approaching $10 billion) along the Natal coast of South Africa (South African Weather Bureau (SAWB) Newsletter, 1984, 1990; Dunn, 1985).

The islands of Mauritius and Madagascar lie within the basin-wide maximum in tropical cyclone frequency near 20°S, 55°E in the SW Indian Ocean (Neumann and Randrianarison 1976; Padya, 1989). In the oceanic area bounded by 12,5–20°S, 40–70°E over 75 cyclones have passed through each 2,5° box since the mid-1800s. These numbers are probably an underestimate for the pre-satellite years (Solow and Nicholls, 1990). Most tropical cyclones form just to the north of the 28°C SST isotherm which runs diagonally from 18°S, 40°E to 10°S, 70°E. The peak area for tropical cyclogenesis is near 12°S, 58°E (Jury *et al.*, 1991). The topography of Madagascar (rising over 1000 m in a North-South axis along 48°E spanning 13–25°S) retards tropical cyclogenesis and appears to promote an eastward movement of cyclones forming within the Mozambique Channel. Relatively few tropical cyclones cross the Mozambique coast (Dunn, 1985; Jury *et al.*, 1991), and those that do typically impinge onto the southeastern escarpment of Africa near the Limpopo river valley (22°S).

The forecasting of cyclone intensity and movement is of particular concern, and statistical models have been formulated for such purposes (Neumann and Randrianarison, 1976; McBride and Holland, 1987; De Coning, 1990). Conventional data in the SW Indian Ocean are sparse, given the geographical layout and limited meteorological resources of the area. Commercial aircraft ply the region between Johannesburg, Mauritius and Singapore and provide upper wind reports. In recent years the advent of satellite remote sensing and sophisticated numerical weather models have increased the detail with which the tropical cyclones and their surrounding environment can be analysed and forecasted.

It is the purpose of this paper to determine how the background climate contributed to the formation and movement of tropical disturbances in the January–February 1984 period. The roles of low level monsoon and trade wind flows, upper easterly wind anomalies and above normal SST are assessed. The regional circulation and structure of cyclone Domoina is analysed to provide insight to one of the most destructive events to occur on the northern coast of Natal, South Africa.

Data and Methods

Detailed information on tropical cyclone movement and intensity comes from the operational weather analyses of the Mauritius Meteorological Service as reported in annual reports of the cyclone season (MMS, 1984). Use is made of numerous shipping and aircraft reports, NOAA and INSAT satellite imagery, island-based surface weather stations, radiosonde and pilot balloon profiles, and European Centre for Medium-range Weather Forecasting (ECMWF) model products in the MMS analyses. The background circulation is studied using Climate Analysis Centre (CAC) 5° gridded winds over the January–February period for summers with active ITCZ systems, as defined by an area rainfall index derived from four stations in Madagascar. For specification of the SST field, data gridded at 5° resolution were available from the British Meterological Office using a blend of infrared satellite and ships data.

Convective structure is analysed using gridded outgoing longwave radiation (OLR) data as in Gruber *et al.* (1986). Jury *et al.* (1991) have shown that OLR is negatively correlated (r = -0,93) with co-located rainfall departures in the SE Africa region during the summer season. Five-day smoothed OLR anomaly maps were analysed, following the methods of Wang and Rui (1990), to study convective events in the 1984 cyclone season. Regional circulation anomalies are interpreted from the CAC Climate Diagnostics Bulletin (1984) and from FSU surface wind analyses (Jury *et al.*, 1992). The case study of cyclone Domoina is presented using NOAA visible images and

ECMWF 850 and 200 hPa wind fields at two day intervals from 15 January to 4 February 1984. A radiosonde time-height section is constructed from profiles of wind and thermodynamic data collected at Antananarivo, Madagascar (19°S, 47°E, elevation 1262 m) over the period 18–26 January 1984 when cyclone Domoina passed through. Standarised departures of the geopotential height, temperature and dewpoint are calculated, and winds are analysed from 850 to 300 hPa. The influence of the Madagascar highlands limits extrapolation of the system's structure to the surrounding oceanic areas.

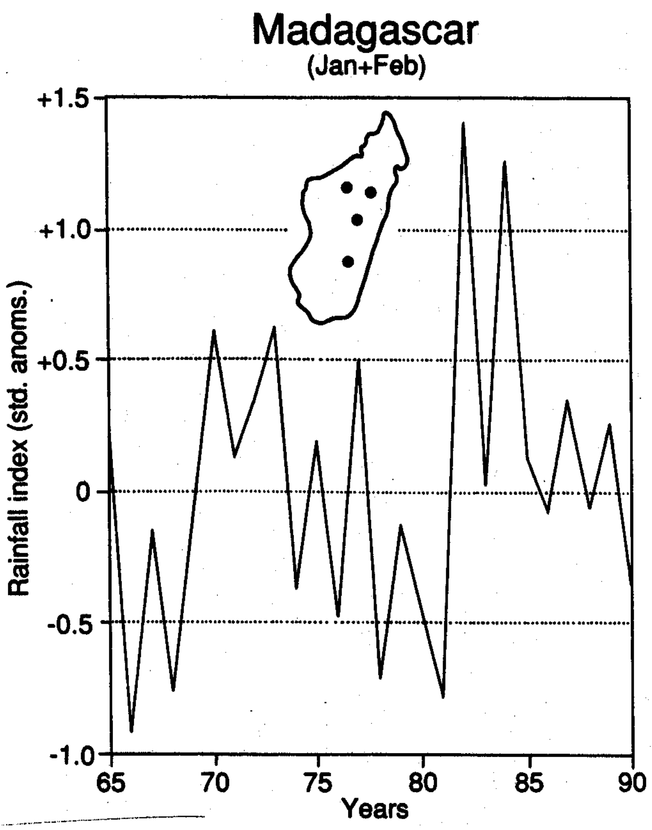

FIGURE 1: Standardised January–February rainfall departures for four highland stations in Madagascar (inset), 1965–1990. Wet (1982, 1984) and dry summers (1978, 1981) are used for construction of composites (Fig. 2).

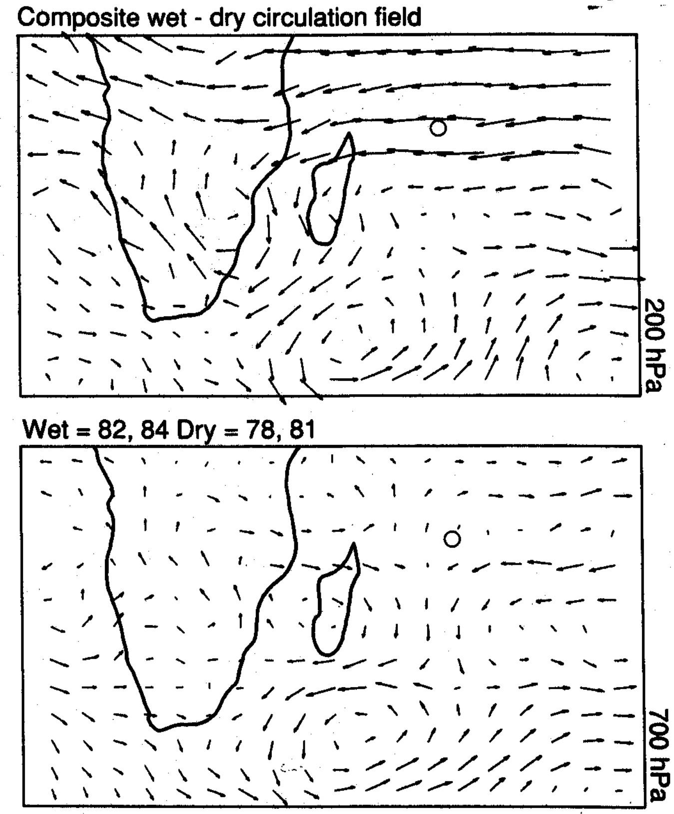

FIGURE 2: Composite wind vector differences between wet and dry summers at the 200 hPa (top) and 700 hPa level. Circle represents area of 1984 cyclogenesis.

Results

Climatological factors in the SW Indian Ocean

Figure 1 illustrates summer season, standardised rainfall departures over Madagascar which are correlated with the frequency and intensity of passing cyclones. Madagascar rainfall is known to be enhanced by easterly wind shear and increased NW monsoon flow, and is anti-correlated with rainfall departures over SE Africa (Jury *et al.*, 1991). From the index time series, two dry summers (1978 and 1981), and two wet summers (1982 and 1984) were chosen to form composites of CAC winds at 200 hPa and-700 hPa levels. The resultant difference vectors are shown in Figure 2.

At the upper level increased easterly anomalies are found across the region to the north of 20°S. Cyclonic and anticyclonic rotors are noted to the west and south of Madagascar, respectively. The upper easterly anomalies may be linked to the Quasi-Biennal Oscillation (QBO) of stratospheric (30–50 hPa) zonal winds which during 1982 and 1984 averaged -30 m s^{-1} at Singapore (CAC, 1984). Enhanced easterly vertical shear and horizontal shear would assist in barotropic instability processes in the region of repeated cyclogenesis. At the lower level poleward flow and zonal convergence are evident to the east of Madagascar. The low level anticyclonic anomaly south of Madagascar is coincident with its upper tropospheric counterpart. SST correlations and composites (not shown) favouring tropical cyclogenesis and above normal rainfall exhibit a pattern of cooler seas to the south and warmer seas to the northeast of Madagascar.

1984 seasonal climatology

Cyclogenesis points and tracks for the 1983/84 season are shown for the eleven named disturbances (A–K) in Figure 3. Surface wind speeds in excess of 32 m s^{-1} were reported on 23 days during the summer. The area near 11°S, 63°E was most favourable for cyclogenesis (five systems). Two disturbances formed in the Mozambique Channel. On many occasions two or more systems existed simultaneously. Some details of these disturbances (from MMS 1984) are listed in Table 1.

TABLE 1: Summary of SW Indian Ocean Tropical Disturbances 1983-1984

Name	Category	Dates	Max wind (m s^{-1})	Lowest pressure (hPa)	SS Category
ANDRY	Intense Cyclone	6–15 Dec	51	957	4
BAKOLY	Cyclone	21–29 Dec	45	967	3
CABOTO	Moderate Depression	5–7 Jan	18	1 002	0
DOMOINA	Severe Depression	18–30 Jan	33	983	1
EDOARA	Severe Depression	22–25 Jan	45	986	3
FANJA	Severe Depression	24–30 Jan	28	991	0
GALY	Moderate Depression	29–30 Jan	18	1 001	0
HAJA	Severe Depression	7–22 Feb	33	985	1
IMBOA	Severe Depression	11–21 Feb	33	984	1
JAMIMY	Intense Cyclone	5–22 Feb	51	957	4
KAMISY	Intense Cyclone	6–16 April	51	956	4

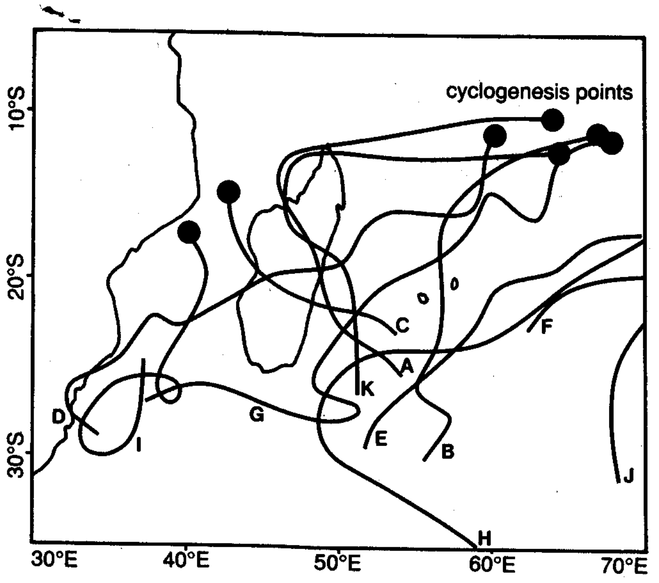

FIGURE 3: Genesis points and tracks for all tropical disturbances in the 1984 season (A–K refer to disturbance names, adapted from MMS 1984).

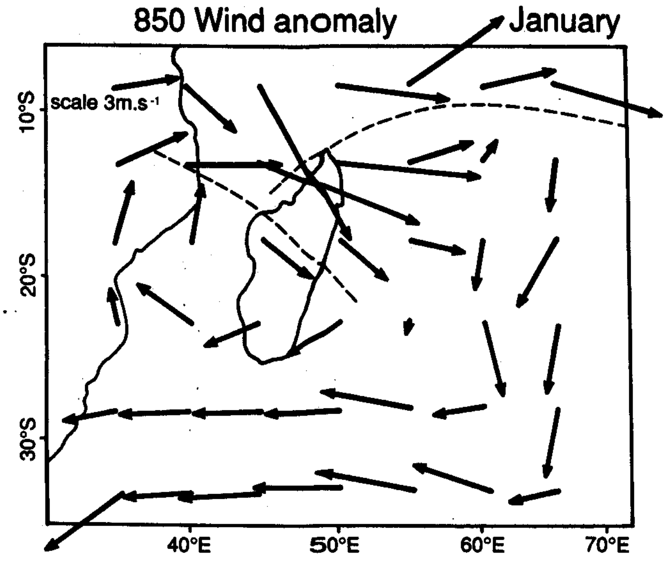

FIGURE 5: 850 hPa wind anomaly vectors for January 1984 (adapted from CAC 1984). Dashed line represents OLR minimum (ITCZ).

The SST anomaly field for January–February 1984 (Figure 4) displays two large areas of positive anomalies to the NE and SE of Madagascar. SSTs were in the 27–29°C range across the region as far south as 25°S. In the area dominated by Indian winter monsoon outflow off the east coast of equatorial Africa, SST were depressed 2°C below normal. Monsoon air flowing from cool to warm seas to the north of the ITCZ provided substantial latent heat flux inputs. Computations of ECMWF water vapour advection in the 850–200 hPa layer reveal a flux maximum of 200 g $(cm/s)^{-1}$ associated with the January 1984 low level equatorial westerlies near 7,5°S, 60°E, just to the north of the region of repeated cyclogenesis. The ITCZ structure (OLR minimum, dashed line in Fig. 5) in January–Feburary 1984, reveals a NW–SE trough axis lying across Madagascar, similar to that referred to by Sadler (1975) and Lyons (1991). Convective minima (OLR maxima) were located over the oceanic areas SE and SW of Madagascar, and off equatorial east Africa. A region of repeated convection (OLR anomalies <-30 W m^{-2}) was situated over the central Indian Ocean during January–February 1984 (Gruber *et al.*, 1986; Jury *et al.*, 1991), coincident with upper (200 hPa) easterly wind anomalies of over 10 m s^{-1} and a strong QBO signal (CAC bulletin, January 1984).

The circulation structure at the lower levels was dominated by above normal Indian winter monsoon outflow (Briedenbach, 1990; Jury *et al.*, 1992). The cross-equatorial flow was most notable at 45°E where 850 hPa wind anomalies from the NW reached 9 m s^{-1} as shown in Figure 5. Equatorial westerlies were 3–5 m s^{-1} above

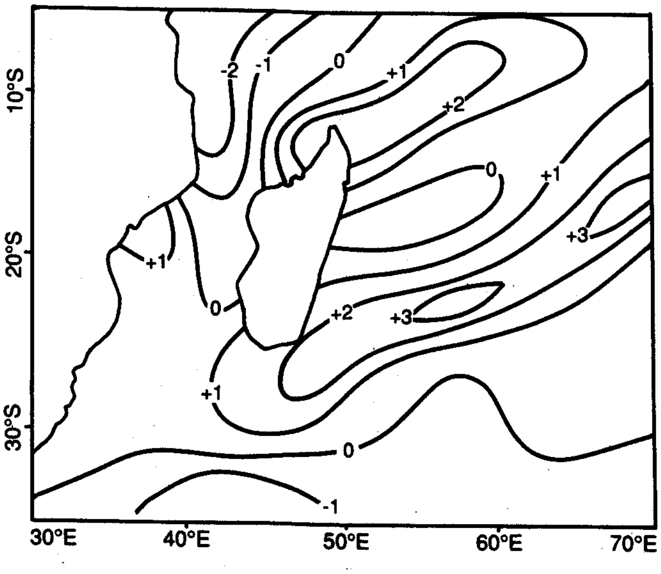

FIGURE 4: Sea surface temperature anomalies for January–February 1984.

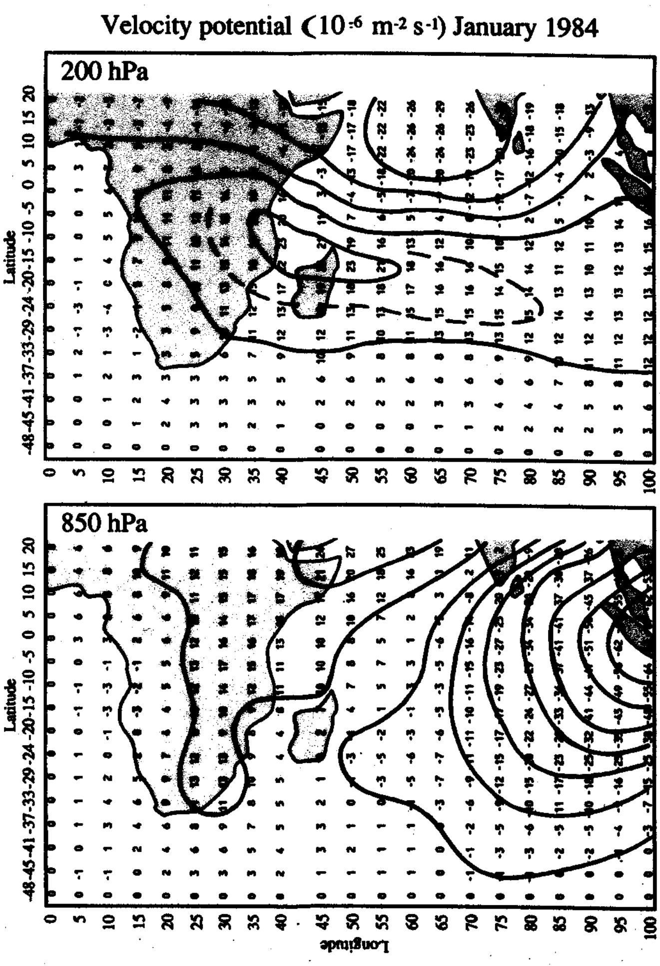

FIGURE 6: 200 hPa (top) and 850 hPa velocity potential analyses for January 1984. The flow diverges from negative to positive values.

normal in the 5–10°S band, while easterly trade winds were similarly strengthened to the south of Madagascar near 30°S. The result was a cyclonic circulation anomaly centered on Madagascar and coincident with the tropical trough (OLR minimum). The westward movement of tropical systems was promoted by a 500 hPa ridge located near 50°S, 30°E which induced a retreat of mid-latitude westerlies. A deep layer of easterly wind shear was evident in the cyclogenesis region; possibly connected to a Walker-type circulation cell with upper easterlies overlying surface westerlies, ascent to the northeast of Madagascar and descent to the west over drought-stricken southern Africa. Aspects of the divergent flow field are contained in the velocity potential analyses shown in Figure 6.

Significant divergent anomalies in the upper troposphere were located over the eastern Indian Ocean. Upper convergence was noted over eastern Africa extending toward the south along 25°E. Low level velocity potentials were positive (convergent) over the eastern Indian Ocean, with a convergent band extending across the area of repeated cyclogenesis. Lower divergent flow was notable in the northern Indian Ocean, perhaps acting as a source region (Fig. 6). Background conditions were thus ripe for excessive tropical cyclogenesis during January–February 1984.

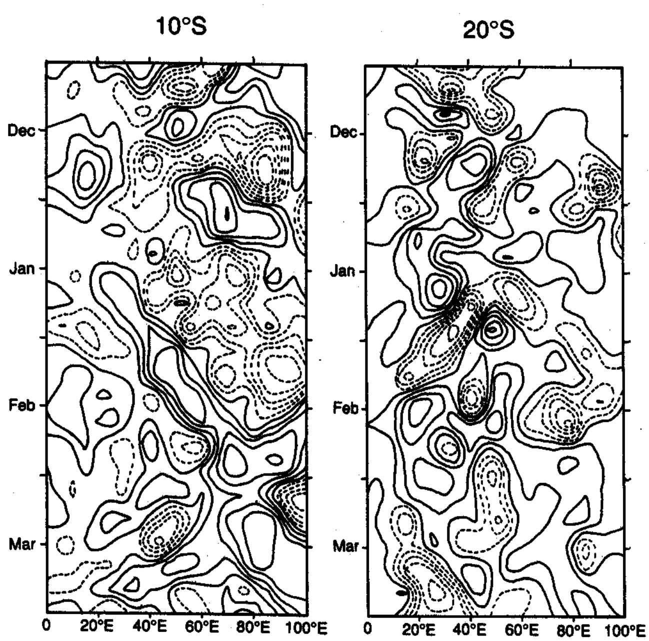

FIGURE 7: Hovmoller (time-longitude) analyses of OLR anomalies over the 10°S (left) and 20°S latitude band for the period 1 December 1983–31 March 1984. Contour interval 10 W m^{-2}, first solid line is 0. Negative OLR departures (active convection) are dashed.

1984 event scale climatology

Hovmoller plots of precipitable water (PW, for 15°S, not shown) and OLR (for 10 and 20°S, Fig. 7) were analysed to gain insight to the event scale structure. The PW hovmoller displayed a diagonally banded pattern, reflecting the presence of easterly wave systems (possibly an artifact of the ECMWF model) with phase speeds of order 6 m s^{-1}. The systems dissipated or moved out of the 15°S band on passing Madagascar. The OLR anomaly hovmoller plots (Fig. 7) highlight eastward moving intra-seasonal convective waves in the monsoon region and patchy westward moving systems at 20°S. The peak of summer convective activity (OLR minimum) in the SW Indian Ocean was reached as cyclone Domoina crossed the Mozambique Channel. Subsident outflows associated with Domoina were evident.

OLR anomaly maps for five day sequences in the period 1 January to 29 February 1984 are displayed in Figure 8. In the period 6–10 January convection over the central Indian Ocean was minimal. Then a dramatic increase in convection was seen over the equator south of India. This convective area surged southward and spawned cyclone Domoina, lying northeast of Madagascar by 16–20 January. The convective area split, with a part remaining in the central Indian Ocean and another over southern Africa by early February. A second convective outbreak to the south of India was evident, while subsident motions developed over southern Africa after 10 February. According to ECMWF winds (not shown) the second outbreak was formed from a strengthening of the equatorial

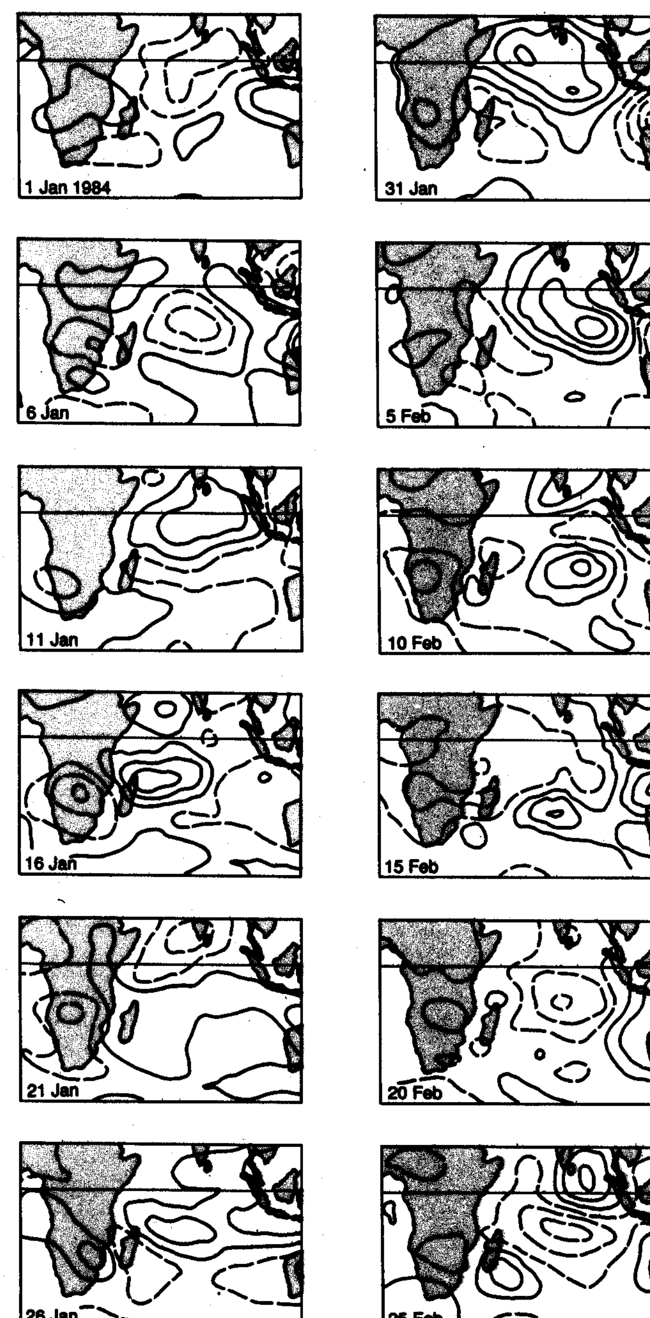

FIGURE 8: Pentad (5-day mean) OLR anomaly maps for the Indian Ocean region for the period 1 January–29 February 1984. Contour interval is 10 W m^{-2}, first solid line is -5 W m^{-2}. Dotted lines represent subsident areas.

FIGURE 9: Daily NOAA satellite visible images for 15 January–4 February 1984. The domain shown is 0–40°S, 10–110°E.

trough, with cyclonic circulations on either side of the equator leading to a burst of monsoon westerlies and the development of intense cyclone Jamimy (Table 1). This cyclone remained in the central south Indian Ocean where mid-latitude westerlies had encroached.

In the following section cyclone Domoina and the convective outbreak following dissipation over southern Africa are analysed.

Case study: Cyclone Domoina

A strong cyclonic perturbation developed within the ITCZ region near 13°S, 59°E on 17 January 1984 as shown by the satellite imagery sequence in Figure 9. The 850 hPa circulation was dominated by Indian winter monsoon outflow being entrained into the eastern limb of the cyclone (Fig. 10). The monsoon input was maintained through the lifespan of the cyclone, according to the ECMWF wind field analyses, and impacted moisture availability and subsequent rainfall. The cyclone tracked along the 19°S latitude across Madagascar from 21 to 25 January and regained strength in the Mozambique Channel. During this phase, 200 hPa flow (Fig. 11) was easterly and exceeded 20 m s^{-1} over the northern Mozambique Channel.

Madagascar radiosonde sections of wind and standardised thermodynamic departures are shown for the period 18–29 January 1984 in Figures 12 and 13. In the pre-cyclone phase weak SE winds were evident, geopotentials were uniformly 1,0 to 0,5 above normal, and subsidence caused dewpoint temperatures to drop 2,0 below normal in the 850–500 hPa layer. Temperature departures were weakly positive in the lower layer and weakly negative aloft. During the passage of cyclone Domoina winds rapidly veered from 15 m s^{-1} SE to 25 m s^{-1} NW in the 700–500 hPa layer. Positive temperature and dewpoint departures of over 1,0 (100 per cent > mean, standardised by level) occurred through most of the troposphere. In the lower levels, negative temperature departures

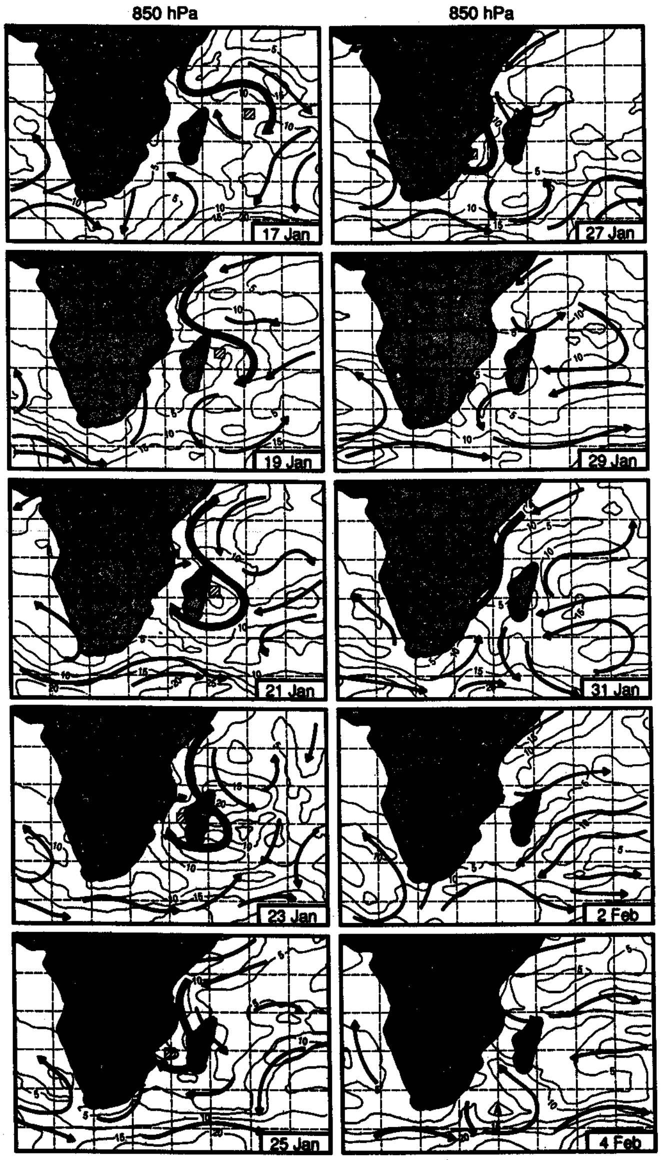

FIGURE 10: 850 hPa winds from ECMWF analysis for alternate days in the period 17 January–4 February 1984. The domain is 10°N–45°S, 0–80°E. The bold arrow highlights the monsoon conduit, the square denotes cyclone Domoina. The "A" at lower right highlights an anticyclone supporting convection.

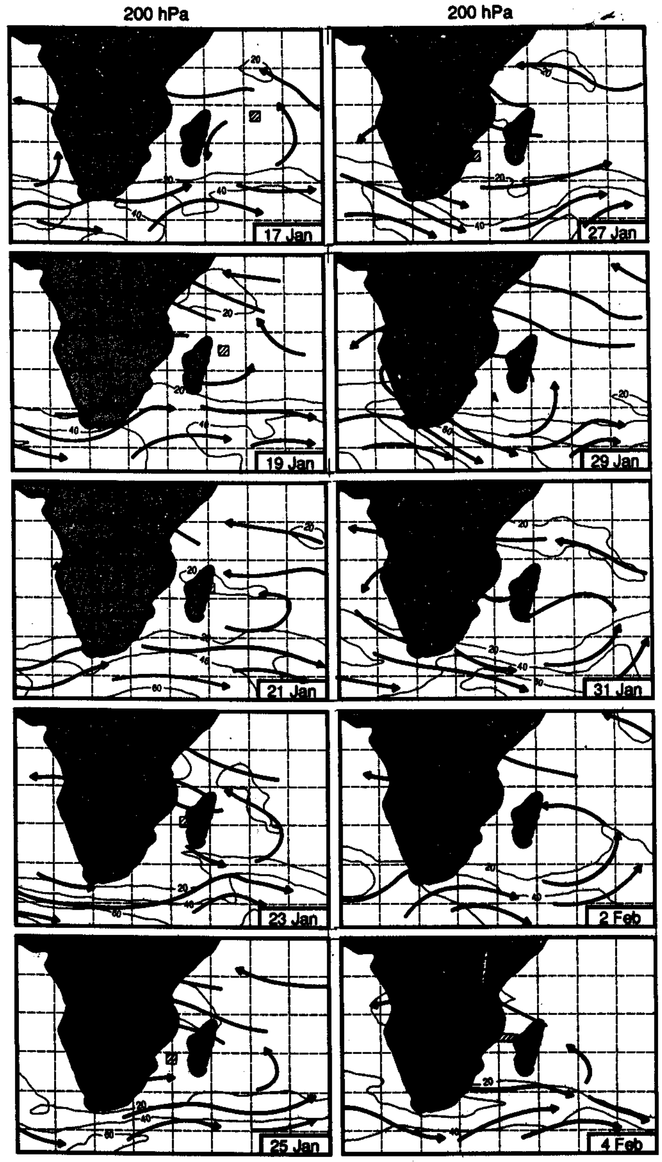

FIGURE 11: 200 hPa winds from ECMWF analyses as in Figure 10. The bold lines represent convective axes.

coincided with heavy rainfall. Moisture departures reached a positive peak of 1,8 near the surface while temperature departures exceeded 1,4 near the 300 hPa level at the time of cyclone passage on the afternoon of 22 January 1984. Geopotential departures reached -1,7 in the 700 hPa layer at passage. Conditions reverted to normal a day or so later, with the exception of continued moist NW wind flow below 500 hPa. The radiosonde sections highlight the asymmetry of the circulation field surrounding the cyclone: NW monsoon flow clearly dominated over the SE trade wind input, even though the cyclone appeared to pass directly over the station.

The cyclone tracked directly below (and partially induced) the upper ridge line and crossed the southern Mozambique coast on 27 January. Convection flared over the eastern escarpment as the upper anticyclone associated with the cyclone outflow strengthened over the southern Mozambique Channel. Simultaneously a mid-latitude trough with winds exceeding 60 m s^{-1} passed to the south of Africa, advecting cyclonic vorticity onto the plateau. The plentiful moisture introduced by the cyclone, coupled with heating and orographic forcing, enhanced instability and led to 800 mm of rain at some locations on the SE–facing mountains of northern Natal, South Africa, over the period 28–31 January 1984 (SAWB Newsletter, 1984). OLR anomalies over Zimbabwe subsequently dropped to the lowest values of the summer season (Lyons, 1991) as zonally banded convection (Fig. 9) was sustained by an 850 hPa ridging anticyclone on 4 February 1984 (lower right, Fig. 10).

Summary

The climatic environment of the summer of 1984 was well suited to tropical cyclogenesis and westward propagation. Low level cyclonic and convergent circulation anomalies, high water vapour fluxes in the equatorial westerlies, a deep layer of moisture along a NW–SE axis over Madagascar resulting from the monsoon – cyclone interaction, above normal SST (reaching a Jan-Feb average of 29,6°C off northern Madagascar), and upper level easterly anomalies (with QBO) all contributed to a high number of destructive tropical cyclones in the SW Indian Ocean. Cyclone Domoina served as a conduit for cross equatorial flow and caused extensive flooding along the SE coast of Africa. As the cyclone dissipated, moisture was advected over the plateau and convectively triggered.

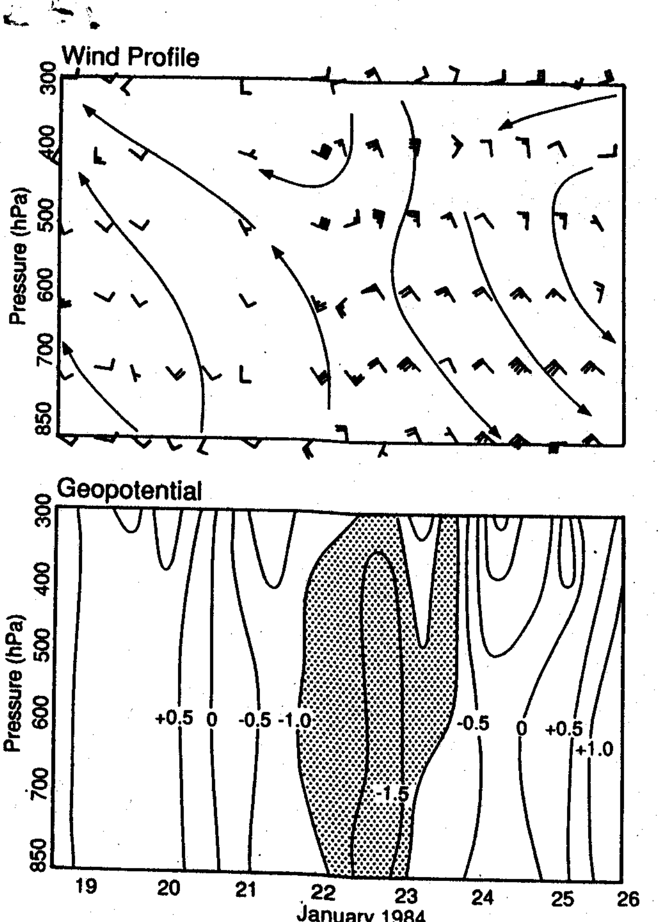

FIGURE 12: Radiosonde time-height sections at Antananarivo, Madagascar showing the passage of the tropical cyclone in the wind field and standardised geopotential departures (bottom).

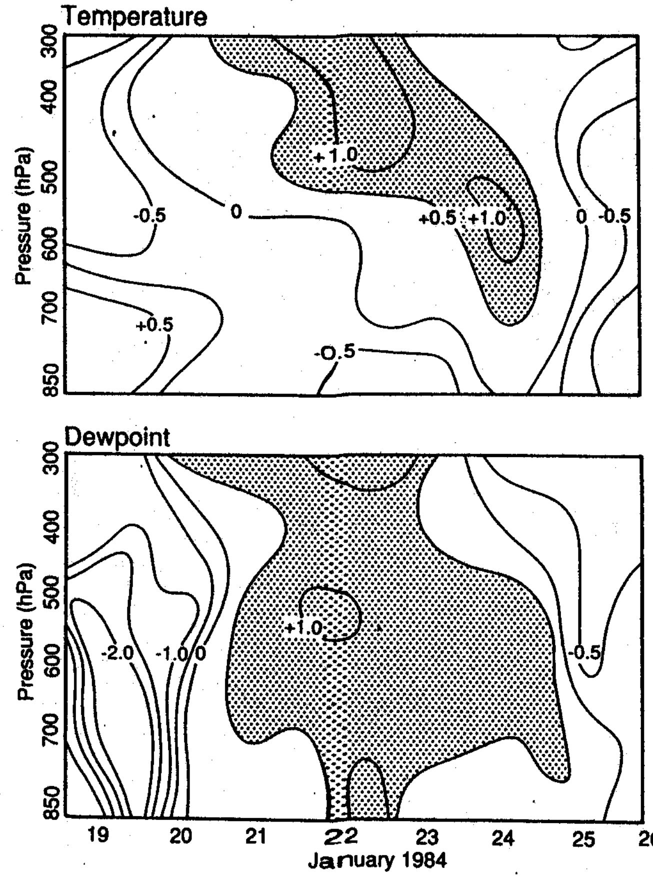

FIGURE 13: Radiosonde time-height sections as in Figure 12 but for standardised departures of temperature and dewpoint (bottom).

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