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Intraseasonal Wind Anomalies Related to Wet and Dry Spells During the "long" and "short" Rainy Seasons in Kenya

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With 12 Figures

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Summary

The largest part of Kenya exhibits two major rainy seasons, the March-May « long rains » and the October-December « short rains », both related to the passage of the ITCZ, but differing in the amount of rainfall recorded and its interannual variability. In order to investigate whether these differences also apply at intraseasonal time-scales, daily rainfall data for the peak month of each rainy season (April and November) were collected for 7 consecutive years (1982–1988). The network comprises 68 stations, from which a classification of the spatial patterns of daily rainfall anomalies has been performed. Wind anomalies corresponding to the various rainfall types and to specific regional rainfall departures were determined using four pilot balloon stations and one radiosonde station. They revealed that there exist significant differences between upper-air circulation anomalies exhibited in the « long» and « short » rainy seasons, especially as far as rain spells in the Eastern Highlands are concerned. In that region, easterly anomalies in the « short rains » period are associated with an increase in rainfall. During the « long rains », enhanced easterlies more generally coincide with an overall drop of convection in the country. In Western Kenya, wet conditions are more systematically associated to westerly wind anomalies.

1. Introduction

Owing to its location across the equator and along the quasi-meridional western edge of the Indian Ocean, most of East Africa experiences bimodal rainfall regimes. In Kenya, the two main rainy seasons are generally referred to as the "long rains" from March to May, and the "short rains", from October to December. They are associated with the north-south and south-north movement of the ITCZ over East Africa (Anyamba, 1983; Ogallo, 1988). At the time of the rainy seasons, the meridional flow corresponding to the monsoons switches to a quasi-easterly flow (Fig. 1, 700 hPa), advecting moisture from the Indian Ocean, with little difference between the first and second rainy season. However, regional peculiarities occur as a result of the influence of large water bodies (Indian Ocean, Lake Victoria) and orography. This is particularly so in the northern summer: while most of East Africa remains dry due to the much more northerly position of the ITCZ, the Western Highlands and the Coast still receive substantial precipitation (Davies et al., 1985; Camberlin, 1996).

Yet, the two main rainy seasons are not the mirror image of each other:

(1) Rainfall amounts significantly differ in most stations (Fig. 2). The "long rains" are generally more abundant, particularly in the Western, South-Western and Coastal regions of Kenya (Tomsett, 1969). However, several stations located on the Eastern slopes of the Kenya Highlands receive more rain from October to December (up to twice the

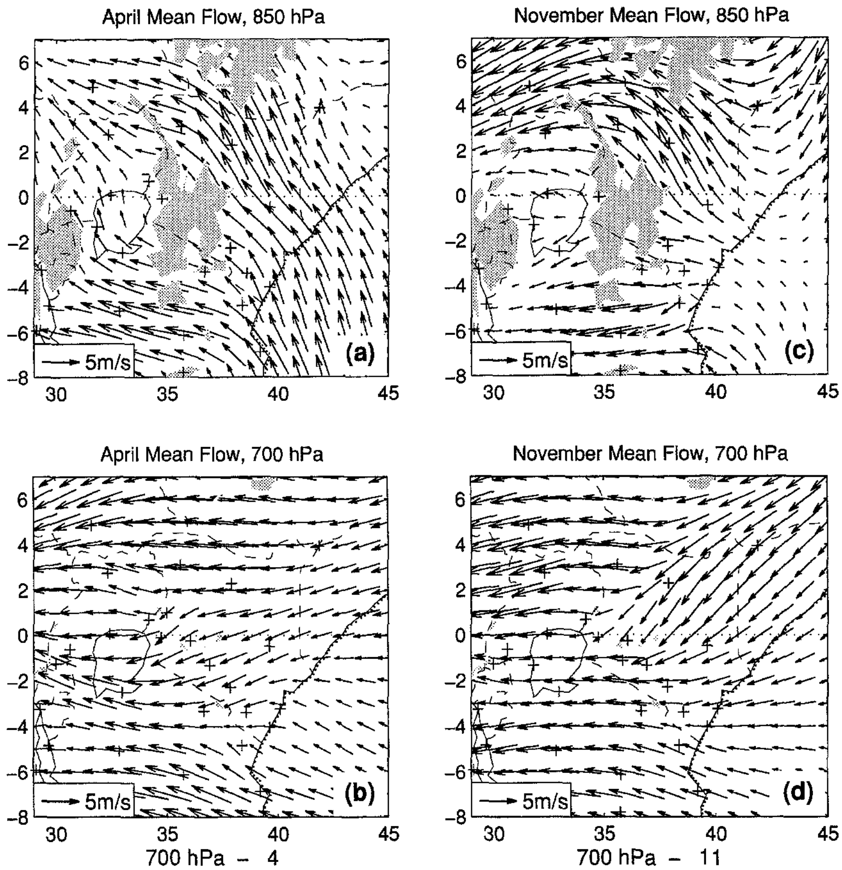


Fig. 1. Mean wind flow over East Africa (a) April, 850 hPa; (b) April, 700 hPa; (c) November, 850 hPa; (d) November, 700 hPa. *Interpolated from pilot balloon and radiosonde ascents for the stations shown by '+' Areas above 1500 m and 3000 m are shaded, for the 850 and 700 hPa maps respectively*

March-May total at Mutomo and Endau, in Kitui District).

(2) Interannual variability is distinctly greater for the second rainy season, as shown in Table 1 by the standard-deviations for selected stations (Odingo, 1971; Jaetzold and Schmidt, 1983; Camberlin, 1994). The variability of these "short rains" is also spatially very coherent (Table 1). In addition, it shows strong connections with large-scale circulation over the Pacific and Indian oceans (Ogallo et al., 1988; Beltrando, 1990; Rowell et al., 1994). This is not so clear for the "long rains".

In this study, we examine whether these differences between the two rainy seasons are also apparent at intraseasonal time-scale. Many investigations about wind-rainfall relationships have already been carried out at an interannual time-scale (Anyamba, 1983; Agumba, 1985; Minja, 1987; Nyenzi, 1988a; Beltrando, 1990). However, as stated by Hills (1979), "*the interpretation of short period rainfall patterns in relation to the mean monthly flows and divergence patterns is difficult, largely because it has to be shown whether such patterns are related to the mean monthly conditions or result from perturbations within them*". Therefore, there is a need to investigate these relationships at intraseasonal time-scales. To this end, after a look at the methods and data used (Sections 2 and 3), we present a classification of days according to the associated spatial rainfall distribution over Kenya (Section 4.1). For each type of rainfall distribution, as well as for more specific regional rainfall anomalies, the corresponding deviations in upper-level winds (850, 700 and 500 hPa) were determined for various stations over the country (Sections 4.2 and 4.3). A discussion of the results is presented in Section 5.

2. Methodology

The study has focused on the two months which constitute the peak of each of the East African rainy seasons: April, for the "long rains", and November, for the "short rains". These months represent respectively 49% and 46% of the total rainfall amount for each three-month season, as

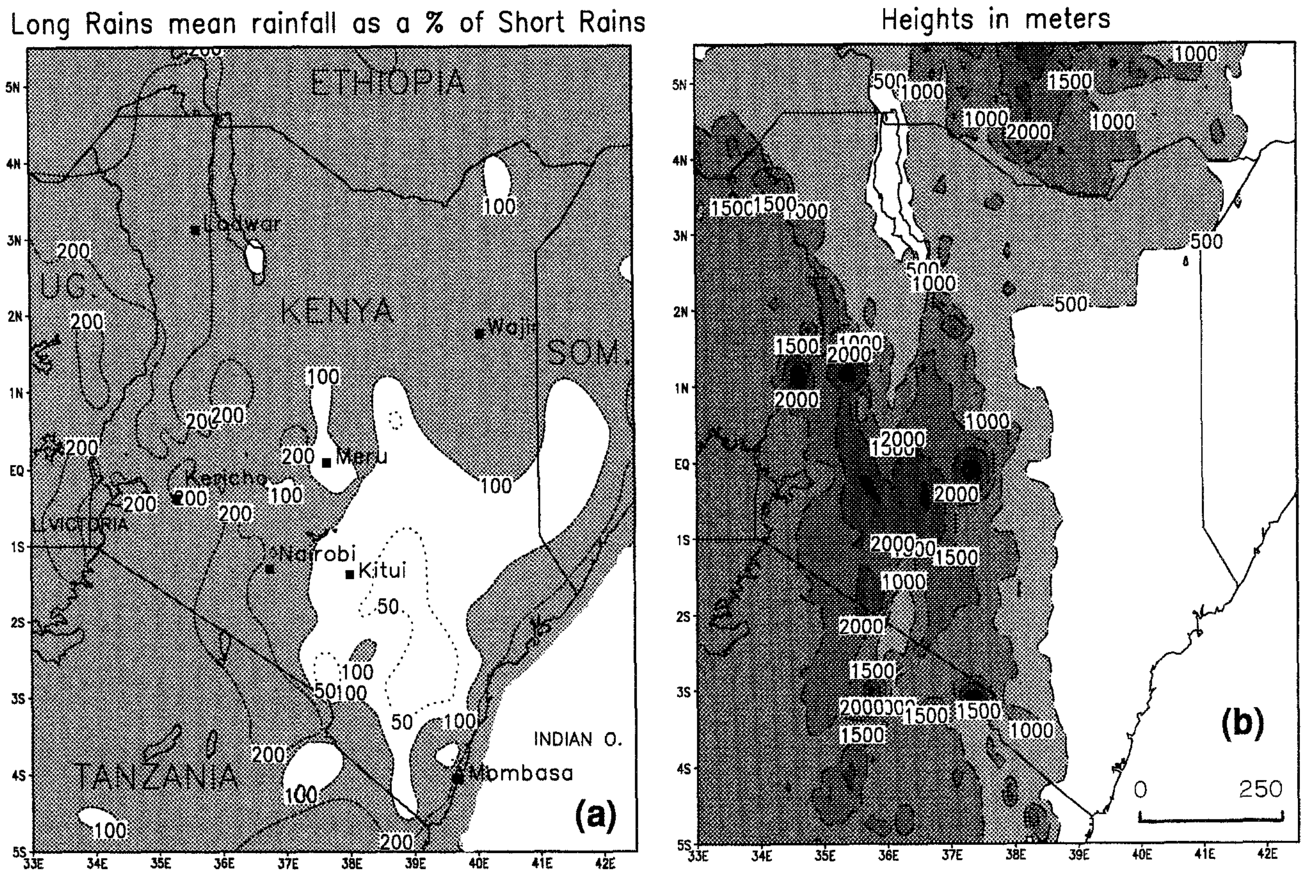


Fig. 2. (a) Relative importance of the « long rains » (March–May mean rainfall) expressed as a percentage of the « short rains » (October–December mean rainfall) in Kenya. Shaded areas receive greater rainfall amounts during the « long rains ». (b) Relief map of Kenya. Heights in meters

an average over Kenya. In each case, a classification of days was performed on the basis of the spatial patterns of rainfall distribution. The procedure followed is an agglomerative hierarchical clustering, which groups days showing similar rainfall anomaly patterns over Kenya, using Ward's minimum-variance method (Ward, 1963). In order to reduce the large spatial variations and the skewness of the daily data (great number of observations with nil rainfall, few observations with very large amounts), and following previous studies (Richman and Lamb, 1985; Bärring, 1988), square-root transformed data were used. Since we are aware that inter-

Table 1. *Comparative Statistics Showing the Greater Spatial Coherence, but Large Interannual Variability of the Kenya « Short Rains » as Compared to the « Long Rains »*

		« Long Rains » (March-May total rainfall)	«Short Rains » (October-December total rainfall)
Spatial coherence			
Average Correlation between all Kenya stations (26 stations, 1951–1988)		0,36	0,67
Interannual variability			
Average for all Kenya stations	Mean rainfall	376 mm	240 mm
	Standard-deviation	154 mm	131 mm
Kericho (W. Kenya)	Mean rainfall	652 mm	367 mm
	Standard-devaition	153 mm	176 mm
Wajir (N.E. Kenya)	Mean rainfall	144 mm	113 mm
	Standard-deviation	103 mm	111 mm

annual variability can significantly affect the rainbearing mechanisms, we have chosen to analyse several consecutive years (1982 to 1988) rather than a single year which might have been highly exceptional. This should offer for each of the months studied a more representative sample of daily patterns (210 days), including dry years (e.g., April 1984) wet years (e.g., November 1982), or average years.

The second step was to compare the daily wind anomalies over Kenya during dry and wet spells, for both April and November. Some indications about wind-rainfall mechanisms in Eastern Africa have already been given in previous publications (Johnson and Mörth, 1960; Sissons, 1966; Nyenzi, 1988b), but from case studies or very limited samples of data (in time and space). The systematic approach adopted here will allow a better understanding of rainfall mechanisms during very crucial months of the agricultural calendar. For each of the rainfall types obtained from the clustering, composites of zonal and meridional components of the wind, over all the days included in the type, were computed as the average of the anomalies from the monthly means. This enabled to show the typical wind conditions associated to recurrent spatial modes of rainfall distribution.

3. Data

3.1 Rainfall Data

Daily rainfall data for April and November 1982–1988 was obtained from Kenya Meteorological Department (KMD) for a selection of 68 stations (Fig. 3). The stations selected were those which had sufficient data, but the selection was also made in such a way that we get a regular stations network. The available rain gauge network in the Highlands is much denser than in the Northern and Eastern Lowlands, and several stations had to be excluded in the former region in order to prevent too large discrepancies in station densities. As mentioned above, the series were first square-root transformed in order to reduce the skewness of the distributions. From this, two kinds of data have been prepared:

(1) A 1° longitude × 1° latitude grid was superimposed on the network of rainfall stations.

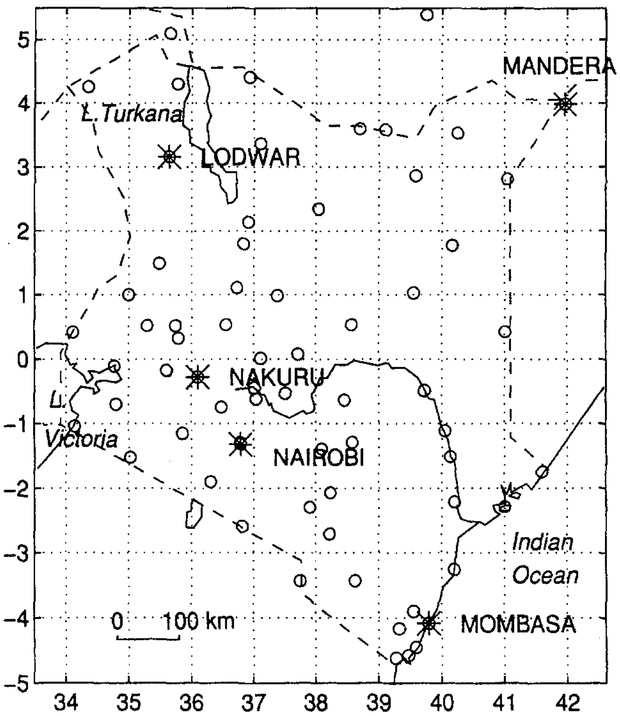


Fig. 3. Location of the rainfall stations (circles) and upper-air stations (stars) used in the study

The simple arithmetic average of the daily rainfall for all stations falling within a given box-square was computed. Values for some box-squares were reported missing, and these were interpolated on a spatial basis only, that is by replacing them by the average of the falls from the eight contiguous boxes. More complex methods of interpolation gave very similar results, and were therefore not retained. Although any interpolation of daily rainfall is highly questionable, this has no serious implications in this study because no more than 6% of the data are missing. This gridded data set served as input data for the classification of daily rainfall patterns.

(2) Regional indices were calculated as the average daily rainfall over 4 to 6 representative and well-correlated stations. The first index covers the central Rift Valley, around Nakuru, and the second one the South-Eastern Highlands, east of Nairobi.

3.2 Wind Data

The upper-level wind data (see also Fig. 3), also obtained from KMD, are of two types: pilot balloon data for 4 stations at the periphery of

Kenya (Lodwar, Mandera, Mombasa, Nakuru); radiosonde data for Nairobi.

Daily observations of wind directions and wind speeds were transformed into zonal and meridional components. Four standard levels were considered (850, 700, 500 and 300 hPa). For the pilot balloon data, and in an attempt to reduce measuring errors, data were averaged over three successive levels (e.g., for the 850 hPa level, over 1200, 1500 and 1800 meters). Only the results for the morning observations (9 AM local time, 3 AM for Nairobi) are shown. In fact, afternoon observations are strongly disturbed by local and/or thermal effects, and indeed they gave less consistent results than the morning ones. The period retained is the same as for the rainfall data (1982–1988), but the series are often disrupted, and a large number of data are missing, especially pilot balloon data in the upper levels. From these daily zonal and meridional components, monthly means were computed, and daily wind anomalies were obtained as the deviations from these means. Such an upper-air network is barely enough to accurately depict all the small-scale circulation features over Kenya, but it gives a first account of large-scale anomalies, and more stations will be used in further studies.

4. Analysis

4.1 Types of Daily Rainfall Patterns

The most common types of daily rainfall patterns have been defined separately for the months of April and November. Figure 4 shows a sample of their succession for November 1982–1984.

In April, 7 major types of spatial rainfall distribution are distinguished, each of them representing more than 7% of the 210 days examined (Fig. 5). The most common type (31% of all cases) shows dryness or little rainfall throughout Kenya. This indicates that even in the middle of the "long rains", isolated days or even spells of fairly dry weather are not an uncommon feature, like in 1983. Type 2 (10%) opposes a wet Coast to dry conditions or light rains in the rest of the country. It emphasises the role of coastal circulations such as sea and land breezes to differentiate this region from continental ones. Types 3 (14%) and 5 (8%) exhibit an east-west

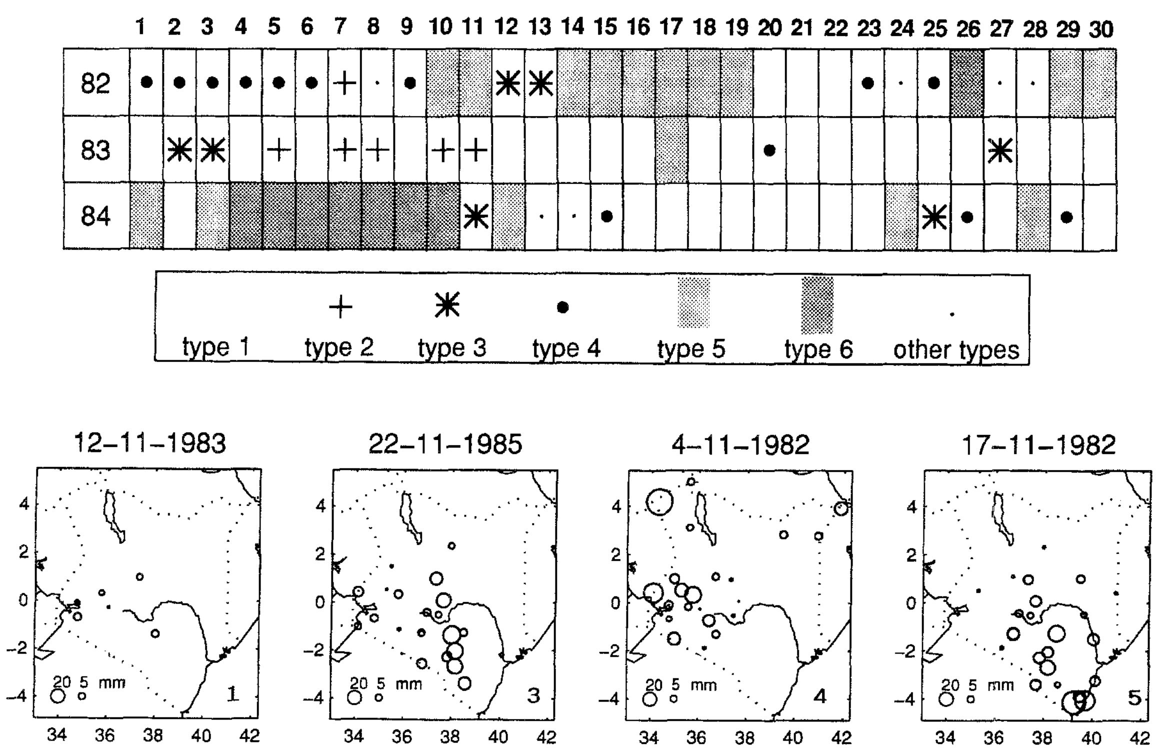
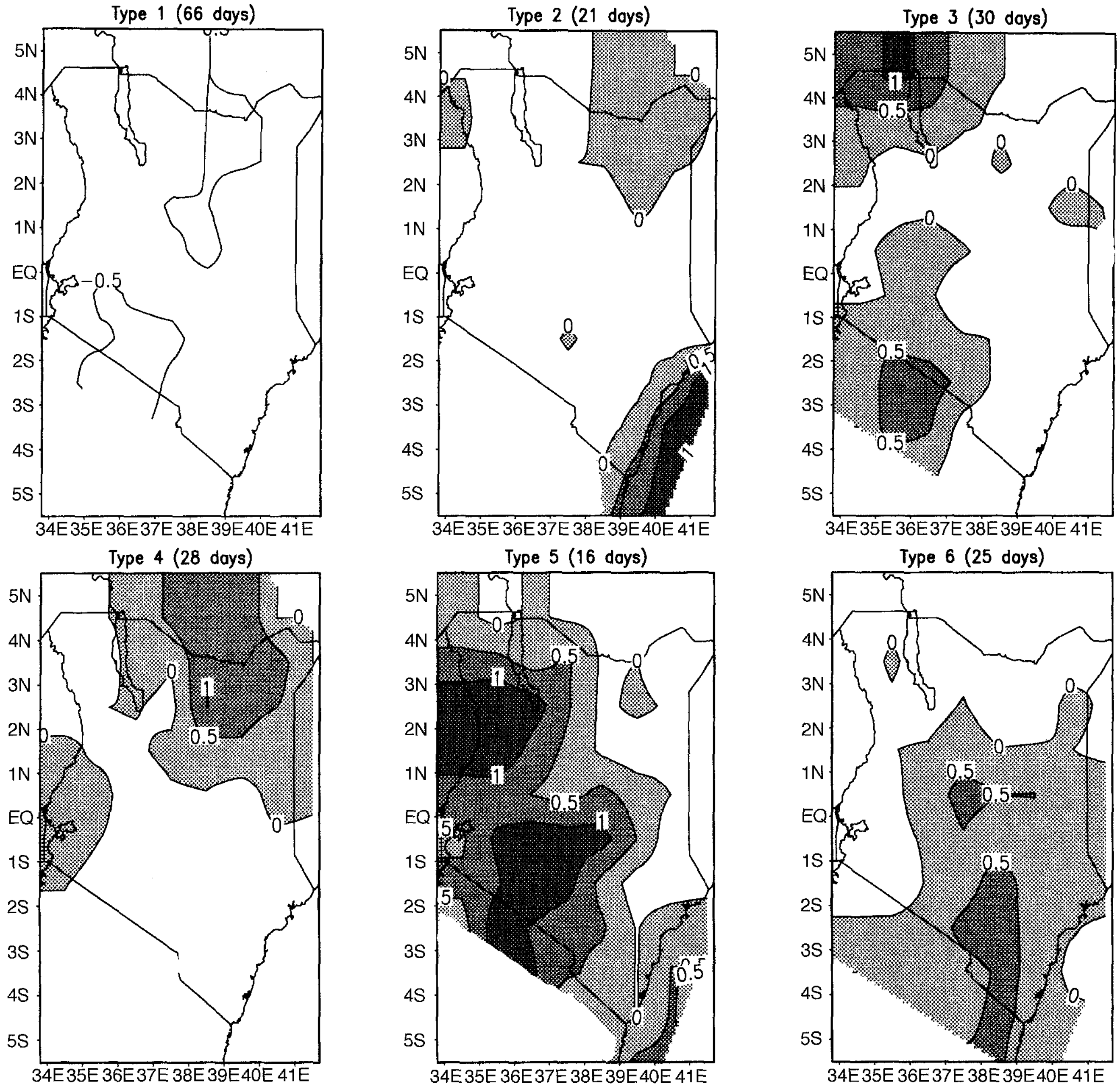


Fig. 4. Rainfall types for each day of November 1982–1984, and samples of rainfall distribution for type 1(12/11/1983), type 3(22/11/85), type 4 (04/11/82) and type 5(17/11/82)



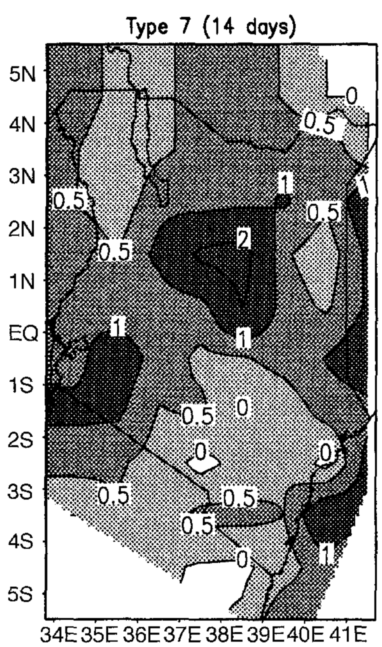


Fig. 5. Types of daily rainfall anomalies for the month of April. From a hierarchical clustering method (see text). 7 most common types. Values represent standardised anomalies of precipitation. Wetter than average areas are shaded

opposition between dry and wet areas, respectively, although type 5 is better defined than type 3, and also associates wet conditions along the coast. Another opposition, in the south-north direction, is described by types 4 (13%) and 6 (12%). The latter shows heavy showers along the eastern slopes and below-average rainfall in the north-west, while the former depicts dry conditions in the south and abnormally rainy conditions in the northernmost part of Kenya. In type 7, above-average rainfall is recorded over virtually the whole country, but such conditions are not very common (less than 10% of all observations).

The *November* patterns are sensibly different (Fig. 6). A first change is the increase of the number of dry or below-average days over the whole country (type 1, 40% of all days). Reciprocally, the number of days which are wet in the whole country drops. The other types often materialise in an east-west opposition. For example, type 4 (16% of all days) is dry to the

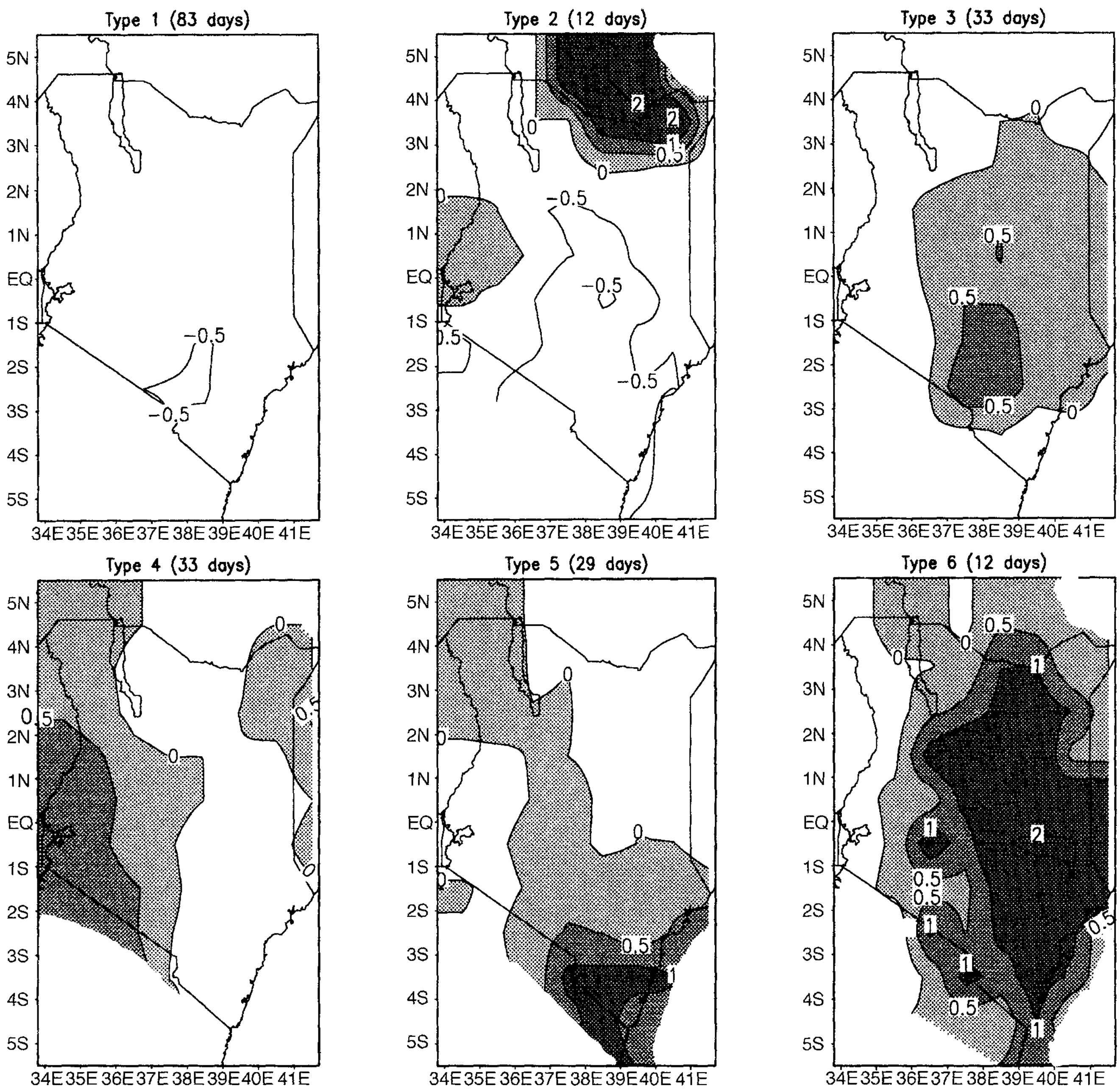


Fig. 6. Same as Fig. 5, for the month of November

east of the Eastern Highlands, and wet in the Western Highlands (see the case of 4/11/1982 in Fig. 4). On the contrary, type 6, and to a lesser extent type 3, show positive rainfall departures to the east of the Rift Valley, that is mainly over the plains and gently sloping ground facing the Indian Ocean (22/11/1985 in Fig. 4). As opposed to April, the coastal strip does not appear as a distinct entity in November, since it generally exhibits rainfall patterns similar to the rest of South-Eastern Kenya (though amounts are smaller). The occurrence of each type undergoes large interannual variations. Type 1 (nearly dry throughout Kenya) occurred on 20 days in November 1983, but only 3 in November 1982 (Fig. 4).

4.2 Wind Anomalies During dry Days

The upper wind anomalies from the monthly means, associated with the two « dry types » of April and November, have been computed in each of the five stations available, at the surface, 850, 700 and 500 hPa levels. In order to more closely identify dry days, only « type 1 » days with less than 20% of the stations reporting rainfall above 1 mm (threshold value for a rainy day as adopted by KMD) have been used in the composite analysis. It is interesting to note that the wind anomalies in the two rainy seasons are not similar.

In April, dry days are mostly associated with strong easterly anomalies at the 700 and 500 hPa levels (Fig. 7). The Student t-test reveals that these anomalies are significant at the 5% level over most stations, indicating a strengthened and broad easterly flow, especially over the highlands. The prevailing 700 hPa easterlies and north-easterlies appear to be about 2 ms^{-1} stronger than normal over Mandera, Lodwar and Nairobi (to be compared with the mean patterns in Fig. 1). Wind anomalies are weaker along the coast, and this may underline the importance of meso-scale (breeze) circulation in this area.

In November, wind anomalies are quite dissimilar, and less significant. At lower levels, there exists a marked diffluence anomaly (850 hPa; Fig 8): while anomalous easterlies occur near Lake Turkana, south-westerly anomalies are found over Mandera close to the Somalia boundary, and northerly anomalies (though not significant) over Mombasa. At 700 hPa, the composite wind anomalies are weak. It must be noted that the strong easterly anomalies observed in April are virtually absent in November, except at 500 hPa. This absence of coherent anomalies could be due to the fact that dry days in November are the result of different types of daily wind anomalies, or that larger scales mechanisms are prominent.

4.3 Wind Anomalies During wet Spells over Selected Regions

4.3.1 Central Rift Valley

In April, wet days (defined as receiving more than 5 mm in a majority of stations) are clearly associated with westerly wind anomalies over

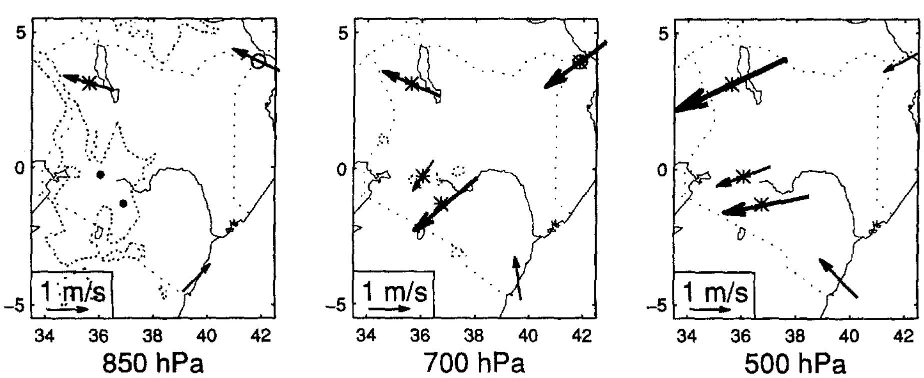


Fig. 7. Wind anomalies from the April monthly means, corresponding to "dry days" in April (see text). Levels: 850, 700 and 500 hPa. Significant values at the 1% level (Student t-test) are denoted by stars, at the 5% level by circles. Black dots indicate unavailability of data. Dotted lines represent surface contours of 1500 m and 3000 m

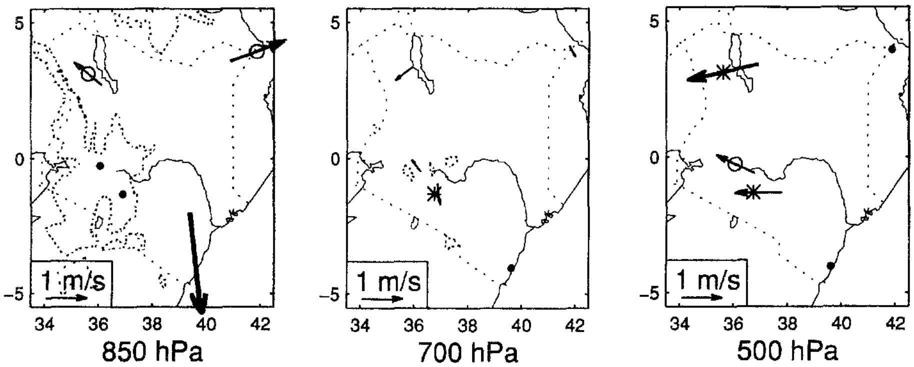


Fig. 8. Same as Fig. 7 for "dry days" in November

virtually the whole country (Fig. 9). These extend from 850 to 500 hPa levels, and are very significant (1%) over Western Kenya. This is also an indication of an anomalous convergence over this region, since the westerly anomalies are strong over Western Kenya, but weaker or absent in the east (850 and 700 hPa). The pattern is somewhat similar for the "short rains" (Fig. 10). This indicates that in both seasons, wet spells in the Rift Valley are related to a slow-down of the easterlies, or even, in extreme cases, its reversal over Western Kenya. Similar results were obtained when considering the types showing abundant rainfall over most of Western Kenya (types 3 and 5 for April, type 4 for November, not shown). One can note that these wind

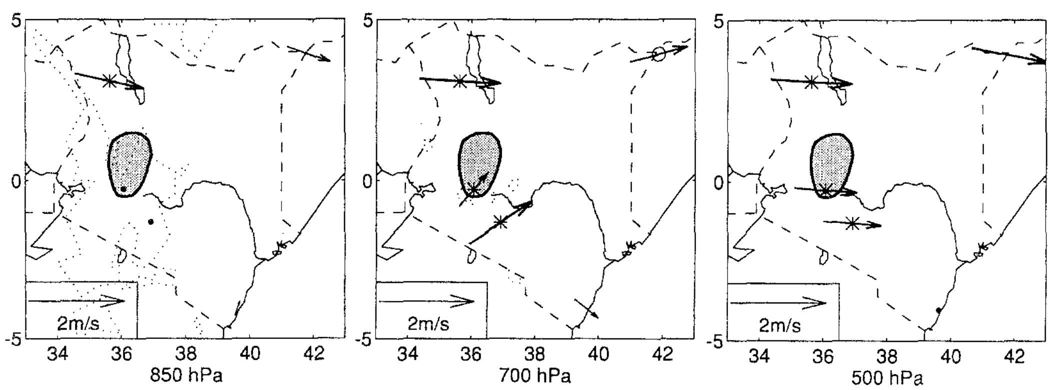


Fig. 9. Wind anomalies from the April means, corresponding to wet days in the Central Rift Valley (area enclosed by a black line). Levels: 850, 700 and 500 hPa. Legend as in Fig. 7

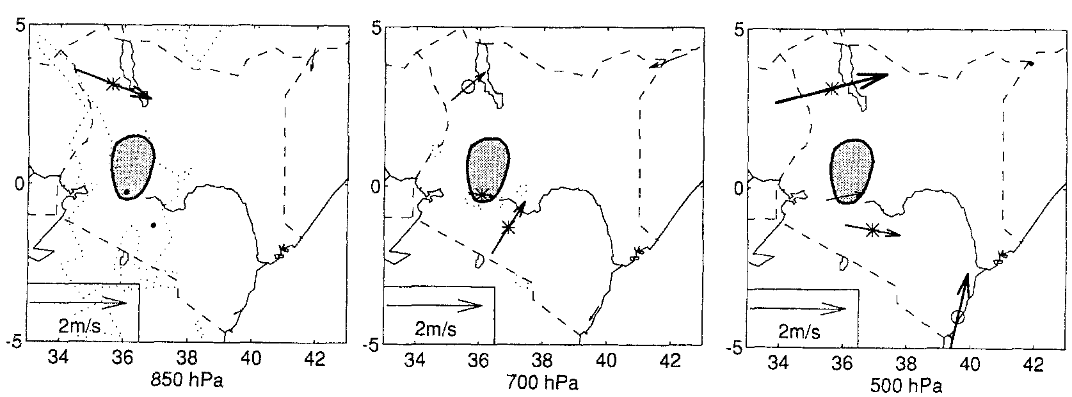


Fig. 10. Same as Fig. 9. for October-November

anomalies are generally persistent over a few days, allowing for some forecasting skill. For example, the strongest westerly anomalies over Mandera, at 850 hPa, are recorded the day before the rain spell in the Rift Valley.

4.3.2 South-Eastern Highlands

For this region, including the stations of Meru, Embu, Nyeri, Nairobi and Kitui, wet days in April are also associated with westerly anomalies (700 and 500 hPa, Fig. 11), though they are slightly weaker than for the Rift Valley area. Anomalous convergence is also shown by the weakness, or even the absence, of the westerly anomalies in the east (700 hPa). Significant differences from the Rift Valley pattern are only noticed on the coast, where a north-east anomaly prevails.

However, for the "short rains", wind anomalies completely differ from those observed for the Rift Valley. Although a speed convergence is still noticeable at 850 and 700 hPa, Fig. 12 reveals that anomalies are now mostly from an easterly direction. Similar analyses, carried out for the composite types showing above-average rainfall in Eastern Kenya (types 3 and 5 of Fig. 6), all indicate easterly anomalies over most of Kenya. This confirms that rain spells restricted to the East of the Rift Valley during the "short rains" preferably occur at times of speed increase of the north-east monsoon and/or its early occurrence. This is in complete opposition with the April pattern, which depicts an increase in precipitation over the South-Eastern Highlands when north-easterlies weaken.

4.4 Discussion

In the heart of the "long rains", in April, the probability of dry spells lasting more than 5 days is the lowest of the year (Alusa and Gwage, 1978). However, the present study reveals that dry days, or those with only a few scattered showers, remain very common. Such almost dry days over the whole country correspond to a general reinforcement of the equatorial easterlies in the low and middle troposphere. Similarly, rainy events for most of the regions tend to be associated with an anomalous westerly component of the wind, and anomalous convergence. This is very consistent with earlier observations made by Johnson and Mörth (1960) for the Nairobi area alone, where the likelihood of rain is greater (at all seasons, but particularly during the "long rains") if the winds in the lower troposphere are from the west. Nyenzi (1988b) indicated that a strong ridging from the south in the lower levels, implying easterly anomalies, was associated with a significant reduction of rainfall in East Africa. An example of a disruption of the equatorial easterlies, replaced by north-westerlies leading to enhanced rainfall in the Kenya Highlands during the 1965 "long rains", has been given by Sissons (1966). These results make a lot of sense to Hills' remark (Hills, 1979) regarding the relation between circulation

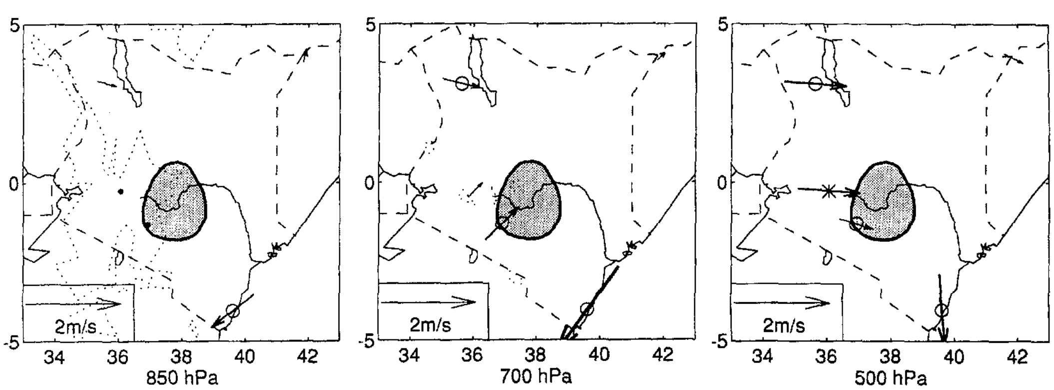


Fig. 11. Wind anomalies from the April means, corresponding to wet days in the Eastern Highlands (area enclosed by a black line). Levels: 850, 700 and 500 hPa. Significant values at the 1% level (Student t-test) are denoted by stars, at the 5% level by circles. Large dots indicate unavailability of data. Dotted lines represent surface contours of 1500 m and 3000 m

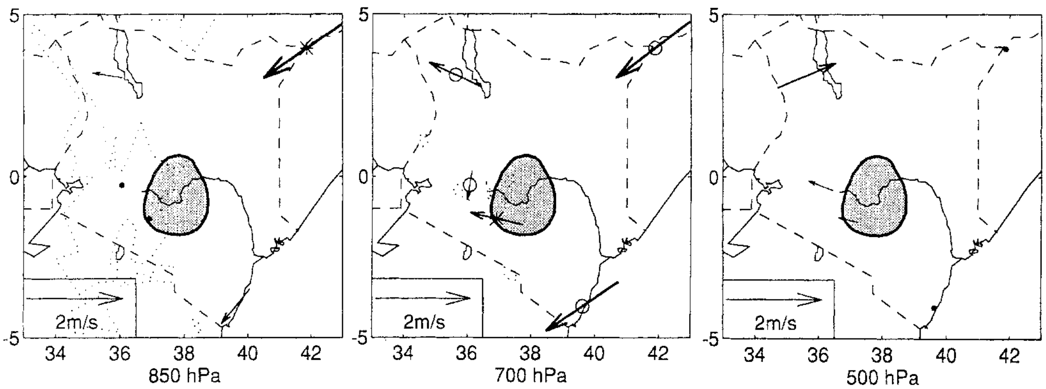


Fig. 12. Same as Fig. 11, for October-November

anomalies and short period rainfall patterns. Although the "long rains" period coincides with a marked easterly component of the wind over East Africa, most of the rainy days occur with a significant reduction of this component, or even its inversion.

However, some cases of generalised heavy convection could be associated with a speed convergence in the easterlies. This kind of circulation anomaly may correspond to a "duct" pattern, characterised by a pair of anticyclones on each side of the equator, leading to convergence and increased convection at its entrance (Johnson and Mörth, 1960). From our composites, such patterns seem to remain rare.

In November, the rainfall-wind relationship is not as coherent as in April. Dry days are mainly associated with a divergent pattern in the lower levels. For the wet events, one must distinguish between the Eastern and Western parts of the country. In Western Kenya (including the Rift Valley), rainy days correspond to anomalous westerlies between 850 and 500 hPa, that is to say close to the April pattern. This does not apply to Eastern Kenya, where wet spells often coincide with easterly anomalies. For the Nairobi area, Johnson and Mörth (1960) indicated that easterlies are generally wetter in the November rains than in the "long rains", although for the former period the occurrence of a northerly component seems more distinctive. Our results also confirm those of the same authors, stipulating that the "*November rains over Eastern Kenya are believed to result almost entirely from ducts*", i.e. converging easterlies between two cells of high pressure in each hemisphere. Strong moist converging easterlies were also found to contribute to the unseasonal heavy rainfall of January 1979 (Wairoto and Nyenzi, 1987; Wairoto and Bundi, 1993). It ought to be recalled that the stations where the contribution of the "short rains" in the annual total is greatest are also the most directly exposed to easterly/northeasterly winds. Together with this, the present results suggest that orographic lifting is a key mechanism in explaining rain occurrences in Eastern Kenya and the windward side of the mountains during this season.

5. Conclusions

From a composite analysis of daily wind anomalies associated with dry and wet spells in Kenya, significant relationships have been found for the two main rainy seasons. Stronger than usual easterlies, between the 850 and 500 hPa levels, generally correspond to days with no or little rainfall over the country, although this is much better shown during the « long rains ». During the « short rains », there is stronger evidence of divergent wind anomalies in the lower troposphere. Reciprocally, wet events in most parts of the country occur when the wind flow exhibits an anomalous westerly component, especially over Western Kenya, as well as anomalous convergence. Again, the « short rains » demarcate from the « long rains » in that for the Eastern part of the country during the « short rains », wet days are not associated with westerly, but easterly anomalies.

Are these observations consistent with those made at the interannual time-scale? For the "long rains", a study made by Agumba (1985), of seasonal upper wind anomalies, has shown that wet years were associated with deep anomalous westerlies over equatorial and eastern Africa, and an anticyclonic structure over North Africa. Reciprocally, equatorial easterlies tend to be dynamically stable and subsiding, thus giving lesser rainfall (Sissons, 1966; Hills, 1979). Anomalous easterly component of the seasonal mean wind was shown to be associated to the poor "long rains" of 1983 and 1984 (Ogallo and Anyamba, 1985). Similar results were obtained by Nyenzi (1988a), with some year-to-year variability. However, the above results show that at an intraseasonal time-scale, no generalisation should be made, since cases of rain spells with anomalous easterlies can be recorded, especially in the "short rains" in Eastern Kenya where they are dominant. In this respect, it is interesting to note that, although in-phase variations over the whole East Africa tend to occur at interannual time-scale during the "short rains", shorter period variations show distinct wind associations for the various regions, i.e. no unique circulation anomalies prevail over the country.

The absence of symmetry between the rainfall mechanisms in the two rainy seasons can partly be ascribed to several differences in the mean circulation patterns:

(i) A stronger southerly (northerly) component is shown in the lower levels during the "long rains" ("short rains") (Hills, 1979). This results in part from very different pressure conditions in the Arabian Sea, where a weak anticyclonic cell in April is replaced by a strong pressure gradient in November, directing strengthened north-easterlies towards East Africa (Hastenrath and Lamb, 1979). This could lead to more persistent "duct" situations.

(ii) The upper levels (around 300 to 200 hPa) show divergence in the "short rains", but convergence in the "long rains" (Hills, 1979). This pattern, accompanied by the diffluent anomalies observed at low levels for dry occurrences in November, is indicative of the barotropic nature of rain-bearing mechanisms during the "short rains". The performance of the « short rains » has been shown to be strongly dependant on barotropic east-west atmospheric circulation along the Indian and Pacific Oceans (Ogallo et al., 1988; Beltrando, 1990; Hastenrath et al., 1993). An evidence for this is the marked sensitivity of the « short rains » to ENSO events (above-normal rainfall when El-Niño events develop in the Pacific).

(iii) The transition between the summer and winter conditions, characterised by the meridional displacement of the ITCZ, is faster in October-November than in March-April (Sumner, 1982).

More work remains to be done in order to fully understand the circulation patterns associated to wet and dry spells in East Africa, and their different behaviour between the "long rains" and the "short rains". The present study, which is based on systematic rainfall and wind observations for a 7-year period, however enables to confirm, and better understand, several observations gained from case studies or field experience in forecasting. They show that the circulation anomalies associated to intraseasonal rainfall variations over Kenya can be very different from those obtained at the interannual time-scale. Some patterns also appear to be persistent enough to enable their use as additional forecasting indicators. For instance, the easterly to north-easterly anomalies observed in April during dry spells are already present 1–2 days before the beginning of the spell. Preliminary composite analyses reveal that fairly dry weather over the whole country is heralded by significant 700 hPa northerly anomalies of about 2 ms^{-1} over Nakuru and Nairobi, and 850 hPa easterly anomalies over Lodwar (3 ms^{-1}) and Mandera (6 ms^{-1}). Further work is underway to assess the forecasting skill of these wind anomalies.

References

Agumba, F. O., 1985: Fluctuations of long rains in Kenya in relation to large scale circulations. KMD Research Report n° 1/85, 27 pp.

Alusa, A. L., Gwage, P. M., 1978 : The occurrence of dry spells during the East African long rains. KMD Research Report n° 2/78.

Anyamba, E. K., 1983: On the monthly mean lower tropospheric circulation, and the anomalous circulation during the 1961/62 floods in East Africa. M.Sc. thesis, University of Nairobi. 240 pp.

Bärring, L., 1988 : Regionalization of daily rainfall in Kenya by means of common factor analysis. *J. Climatol.,* **8**, 371–389.

Beltrando, G., 1990: Space-time variability of rainfall in April and October-November over East Africa during the period 1932–1983. *Int. J. Climatol.,* **10**, 691–702.

Camberlin, P., 1994: Les précipitations dans la Corne orientale de l'Afrique : climatologie, variabilité et connexions avec quelques indicateurs océano-atmosphériques. Ph.D. thesis, Université de Dijon, France. 379 pp.

Camberlin, P., 1996: Intraseasonal variations of June-September rainfall and upper-air circulation over Kenya. *Theor. Appl. Climatol.,* **54**, 107–116.

Davis, T. D., Vincent, C. E., Beresford, A. K. C., 1985: July-August rainfall in West-Central Kenya. *J. Climatol.,* **5**, 17–33.

Hastenrath, S., Lamb, P. J., 1979: *Climatic Atlas of the Indian Ocean Part 1: Surface Climate and Atmospheric Circulation.* Madison: The University of Wisconsin Press, 116 pp.

Hastenrath, S., Nicklis, A., Greischar, L., 1993: Atmospheric-hydrospheric mechanisms of climate anomalies in the Western Equatorial Indian Ocean. *J. Geophys. Res.,* **98** (C11), 20219–20235.

Hills, R. C., 1979: The structure of the Inter-Tropical Convergence Zone in Equatorial Africa and its relationship to East African rainfall. *J. Inst. Brit. Geogr.,* **4–3**, 329–352.

Jaetzold, R., Schmidt, H., 1983: *Farm Management Handbook of Kenya.* Nairobi: Ministry of Agriculture, 3 Volumes.

Johnson, D. H., Mörth, H.T, 1960: Forecasting research in East Africa. Proc. of the symposium on Tropical Meteorology in Africa. Nairobi, Kenya: WMO/Munitalp Foundation. 56–132.

Minja, W. S. M., 1987: The weather anomalies over Africa during the drought year 1972 and the floods of April 1977 over parts of Eastern Africa. Proceed. 1st Tech. Conf. Meteo. Research in Eastern and Southern Africa. KMD, Nairobi, 6–9 Jan. 1987, 99–101.

Nyenzi, B. S., 1988a: Mechanisms of East African rainfall variability. Ph.D. thesis, Florida State University, Tallahassee, U.S.A 184 pp.

Nyenzi, B. S., 1988b: Equatorial zonally moving disturbances which contributed to the East African long rains of March to May 1979., In *WAMEX related research and tropical meteorology in Africa.* WMO, TMRP, n° 28, 270–271.

Odingo, R. S., 1971: *The Kenya Highlands.* Nairobi: East African Publishing House, 229 pp.

Ogallo, L. J., 1988: Climatology of rainfall in East Africa. In *WAMEX related research and tropical meteorology in Africa.* WMO, TMRP, n° 28, 136–142.

Ogallo, L. J., Jonawiak, J. E., Halpert, M. S., 1988: Teleconnection between seasonal rainfall over East Africa and global sea-surface temperature anomalies. *J. Meteor. Soc. Japan.* Ser. **11, 66–6**. 807–822.

Ogallo, L. J., Anyamba, E. K.,1985: Drought of tropical central and eastern Africa. Proc. WMO Symposium on Medium and Long Range Forecasting. Maryland, USA WMO/TD n° 87, 67–72.

Richman, M. B., Lamb, P. J., 1985: Climate pattern analysis of three and seven-day summer rainfall in central United States: some methodological considerations and a regionalization. *J. Climate Appl. Meteor.,* **24**, 1325–1343.

Rowell, D. P., Ininda, J. M., Ward, M. N., 1994: The impact of sea surface temperature patterns on seasonal rainfall in East Africa. Proc. Int. Conf. on Monsoon Variability. Trieste, Italie. WMO/TD n°619. 666–672.

Sissons, J., 1966: Some examples of synoptic situations which affect East Africa. *Weather,* **21**, 228–231; 260–262; 298–300.

Sumner, G. N., 1982: Rainfall and wind circulation in Coastal Tanzania. *Arch. Met. Geoph. Biokl., Ser. B,* **30**, 107–125.

Tomsett, J. E., 1969: Average monthly and annual rainfall maps of East Africa. EAMD Tech. Memo., n° 14.

Wairoto, J. G., Nyenzi, B. S., 1987: The unseasonal heavy rains in Kenya during January 1979. Proceed. 1st Tech. Conf. Meteor. Research in Eastern and Southern Africa. KMD. Nairobi, 6–9 Jan. 1987, 173–178.

Wairoto, J. G., Bundi, P. M., 1993: Temporal and spatial characteristics of rainfall during October 1978 to January 1979 in Kenya. Proceedings of the First Intern. Conf. of African Meteor. Society, Nairobi, 8–12 Febr. 1993. 553–564.

Ward, J. H., 1963: Hierarchical grouping to optimize an objective function. *J. American Statist. Association,* **58**, 236–244.

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