CLIMATE VARIABILITY

Proceedings of International Workshop
on Climate Variabilities (IWCV)
13—17 July 1992, Beijing, China

Edited by

YE Duzheng Taroh MATSUNO
ZENG Qingcun HUANG Ronghui
ZHANG Renhe

China Meteorological Press

Statistical Analysis of Long–Term Monthly and Annual Ethiopian Precipitation Series and Their Relationship with ENSO Events*

Yilma Seleshi(1)(2)(3), *Gaston R. Demarée*(1)(2) and *Stephane Vannitsem*(1)

(1) Royal Meteorological Institute of Belgium, Brussels, Belgium
(2) Interuniversity Postgraduate Programme in Hydrology, Brussels, Belgium
(3) On leave from the Ethiopian Valleys Development Studies Authority, Addis Ababa, Ethiopia

Abstract

The purpose of the present paper is to identify temporal characteristics of Ethiopian meteorological droughts through the statistical analysis of long–term records of monthly and annual precipitation amounts. The rainfall series of the stations Addis Ababa and Asmara, which have uninterrupted records since the turn of the last century, are studied in detail.

Changes in the mean of the monthly and annual series are assessed by applying successively the following non–parametric statistical tests: the Mann–Kendall sequential trend test, the Lombard number of change–points test and the Pettitt change–points test.

It is suggested that changes in the mean of the seasonal precipitation depths are associated with ENSO activities. The relationship between Ethiopian highland rainfall patterns and the warm and cold ENSO events is investigated. A strong ENSO connection for Addis Ababa and a weak one for Asmara is detected.

I. Introduction

During the XX–th century, Ethiopia has experienced several periods of more or less prolonged dry conditions of varying magnitude, duration and spatial extent. As a result, highly populated areas in the drought prone regions of Ethiopia have been seriously affected, which resulted in some cases in wide–spread famine (Von Braun, 1991). The main factor which controls the productivity of all forms of agriculture in Ethiopia, on which 90% of all labour force is engaged in various forms and which constitutes the backbone of the national economy, is the availability of the necessary amount of rainfall in expected time and place.

In the present paper, the temporal characteristics of the succession of droughts and more humid periods are studied by the statistical analysis of the long–term rainfall series of the stations Addis Ababa (reference period 1898 / 1900— 1991) and Asmara (reference period 1890 / 1903—1990).

Changes in the overall mean of the series are assessed following the methodology recently proposed by Vannitsem and Demaree (1991). This technique detected the hydro–climatic jump in the west Sahelian rainfall series at the end of the sixties (Demaree and Nicolis, 1990). The latter jump has been embedded into a pattern of decadal changes during the summer season for a large region stretching from the Sahel to Japan (Yan, Ji and Ye, 1990). Although the Ethiopian

---

* Corresponding author address: Dr. Gaston R. Demaree, Hydrology Section, Royal Meteorological Institute of Belgium, Ringlaan 3, B–1 180 Brussels, Belgium.

series present a very different character than the West–Sahelian ones, the methodology still proved to be successful and reliable.

Section II describes the general Ethiopian rainfall characteristics and introduces the data used in the study. Section III reviews briefly the statistical tests and the methodology and brings the analysis on monthly and annual time basis. The relationship between the African precipitation patterns and the Southern Oscillation is discussed in Section IV. In the light of the analysis presented in Sections III and IV, the relationship with the seasonal Ethiopian rainfall data of this paper is searched for in Section V. The final Section is devoted to the conclusions.

II. The Ethiopian Precipitation Regime

1. General Considerations

Ethiopia is situated in the Horn of Africa and is therefore subject to the northeast, to the southeast and southwest (West African) monsoons bringing moisture from the Indian and Atlantic Oceans. In the boreal summer the moisture gradually penetrates into the country as the intertropical convergence zone (ITCZ) progresses northward. In general, the rainfall decreases from the south to the north but in Ethiopia the topography strongly influences as well the rainfall pattern.

Ethiopia has one of the largest highland areas in the tropics; 50% of the land above 2000 m in Africa, with half of the country above 1200 m. Besides the classical north– south gradient, a dominant east–west gradient ranging from Somalia, the Ogaden desert and Red Sea coast to inland is noticed (Griffiths, 1972; Downing, 1982; Degefu, 1987). Annual average Ethiopian precipitation (reference period 1969—1985) is represented in Fig. 1 (Eklundh, 1988).

Generally, the wet season in central Ethiopia is mainly from June to September but becomes gradually shorter with increasing latitude. The climate seasons are often referred to as Kermpt (long rainy season, end May / early June—end August / end September or early October), Tsedia (end of long rains, September—October), Bega (dry period, October—February) and Belgh (small rains, March — May). Makar, a wet spell between the long and small rains is often identified in the pattern.

The long–term mean average annual precipitation amounts at the stations Addis Ababa (09° 02'N, 38° 45'E, 2450 m elevation) and Asmara (15° 17'N, 38° 55'E, 2300 m elevation) are respectively 1203 mm and 531 mm. The June to September totals represent respectively 865 mm and 410 mm, e. g. 71.9% and 77.2% of the annual depths. The mean monthly precipitation expressed in per cent of the mean annual depths for the stations Addis Ababa and Asmara is represented in Fig. 2.

2. Data and Data Sources

Scientific literature directly concerned with drought in Ethiopia is scarcely available. A few papers approached the problem either by giving the chronology of Ethiopian droughts (Bahru, 1976; Wood, 1977; Degefu, 1987) or by attempting the problem in a broader view——as a part of African droughts (Nicholson, 1978).

Recently, drought related topics, such as improvement of drought monitoring and forecasting and early drought warning receive high attention in Ethiopia (Drought Monitoring

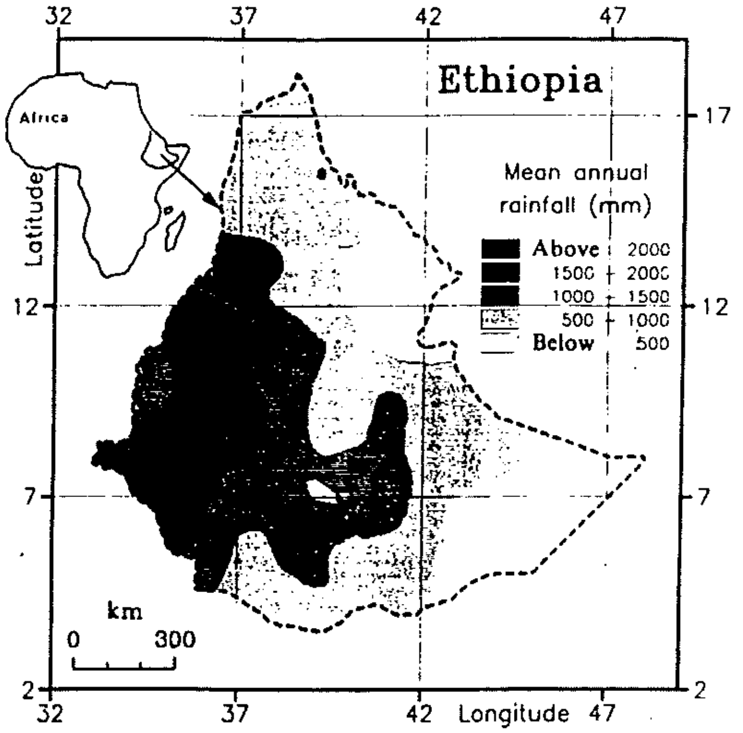

Fig. 1. Ethiopian mean annual rainfall interpolated from 63 rainfall stations over the reference period 1969—1985 (from Eklundh, 1988). The location of the stations Addis Ababa (*) and Asmara (o) is shown.

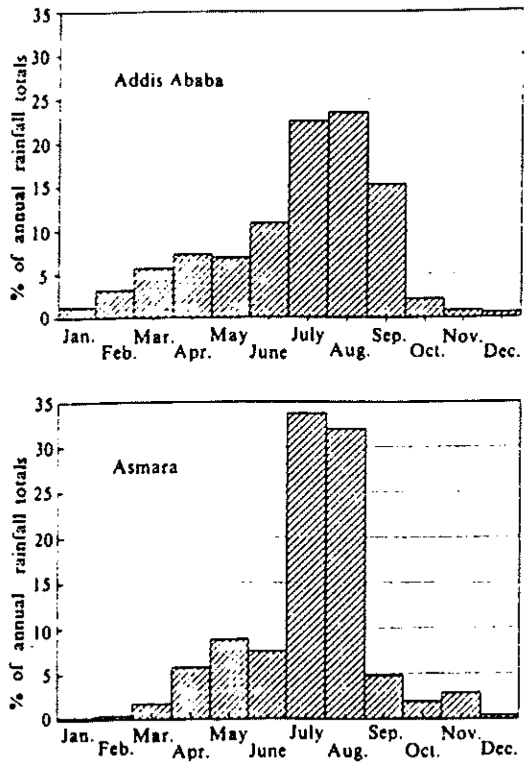

Fig. 2. Mean monthly precipitation distribution in per cent of the mean annual depths for the stations Addis Ababa and Asmara.

Bulletin, 1991). The National Meteorological Services Agency (NMSA) at Addis Ababa is investigating weather conditions leading to drought or non–drought years (Degefu, 1987; 1989a; 1989b; Tesfaye, 1987; 1990; Yeshanew and Apparao, 1989).

Based on the annual rainfall totals (reference period 1969—1988) Eklundh (1988) found the year 1984 as the year with the strongest below–average rainfall. This is in agreement with the fact that 1984 was the driest year on record for a large zone extending from northern Senegal to Ethiopia (Grove, 1986). Nicholson (1989) states that nearly the whole African rainfall was below–average in 1983. Degefu (1987) pointed out that, besides the absence of rain in the Bega season of 1983, the rain fell too late in 1984 further aggravating the situation.

Webb et al. (1990) indicated that the links between drought and food production are found to be relatively strong and food availability is largely determined by domestic production of cereals, which in turn is largely dependent on the timing and sufficiency of rainfall. Moreover, they showed the association of the most severe famines of the last three decades (1965—1966, 1973— 1974 and 1984— 1985), in the drought prone regions of Ethiopia, with the worst multiple–years droughts.

The basic data of the present study consists of the monthly and annual rainfall depths for the stations Addis Ababa (reference period 1898 / 1900— 1991) and Asmara (1890 / 1903— 1990). The original data, from 1947 and onwards, were kindly provided by the Ethiopian NMSA. Data covering the previous period were mainly extracted from the Fantoli ' s books (1964; 1965; 1966).

Hurst and Black (1943) give the monthly and annual rainfall depths at stations in and near the Nile basin for the period ending in 1937. Griffiths and Hemming (1963) list the annual rainfall totals for stations in eastern Africa. Both the stations Addis Ababa and Asmara are included in the latter lists. Captain Lyons (1906) reviews in detail the monthly rainfall totals at Addis Ababa differentiating between sources. He mentions the observations carried out by the Nicolas Central Observatory of St. Petersburg, the Italian Legation, Dr. Wakeman of the British Agency and Dr. De Convalette (Annales du Bureau Central Meteorologique de France, 1900). In the very early years, and due to the many interruptions in the observations, mean values derived from the above observations have been used.

Regular rainfall observations at Asmara started in 1903 (Fantoli, 1966). Earlier monthly totals are reported by Lyons (1906) and Eredia (1932). Knox (1911) lists mean rainfall at Asmara covering 25 months during the period May 1894 to September 1905, but unfortunately not mentioning the original sources.

No descriptions of the raingauges, their exposures or station history elements are readily available so that it remains difficult to assess the problem of homogeneity of the time–series of monthly and annual precipitation depths. It is tacitly assumed that the conclusions of this paper will not be influenced too much by any such heterogeneities, if present.

III. Statistical Tests, Methodology and Hypothesis Testing

The methodology proposed by Vannitsem and Demaree (1991) has been used here. This methodology consists of the consecutive use of three non–parametric tests;

(a) the sequential form of the Mann–Kendall trend test (Sneyers, 1975);

(b) the Lombard number of change–point test (Lombard, 1988; Vannitsem and Nicolis, 1991);

(c) the Pettitt change–point test (Pettitt, 1979).

In general, Mann–Kendall's test will assess the overall trend, Lombard's test the number of change–points and Pettitt's test allows to position them within the given time–series.

Annual precipitation depths at the stations Addis Ababa and Asmara are shown in Fig. 3; the values are represented as normalized departures expressed in standard deviations from their long–term mean. Positive (negative) values are indicating exceeding (deficient) precipitation amounts. It can easily be seen that both stations do not belong to the drought stricken area of the 1983 / 84 natural disaster; Degefu (1987) quantifies the stations Addis Ababa and Asmara as having then merely a 20% below "normal" precipitation.

From Fig. 3, it can be seen that no apparent monotonously decreasing or increasing trend seems to be present in the annual rainfall amounts. This will be further confirmed by application of the Mann–Kendall test. This result contrasts strongly to the well–known findings indicative of the recent Sahelian drought and which show deficit rainfall amounts over the whole Sahelian area since the end of the 1960s (Nicholson, 1983; 1989; Lamb, 1985; Demaree and Nicolis, 1990; Hulme, 1990; Yan, Ji and Ye, 1990; Vannitsem and Demaree, 1991; Lamb and Peppler, 1991).

The most salient feature of Fig. 3 is the presence of groupings of 4 to 10 years periods with successive above or below average rainfall; e. g. Addis Ababa annual totals are below average over the period 1931—1945, while for Asmara below average rainfall was observed for the period 1963—1974. The Mann–Kendall sequential trend test (see Fig. 4) demonstrates that the time series can be seen as stationary since indeed the graph of the forward and backward

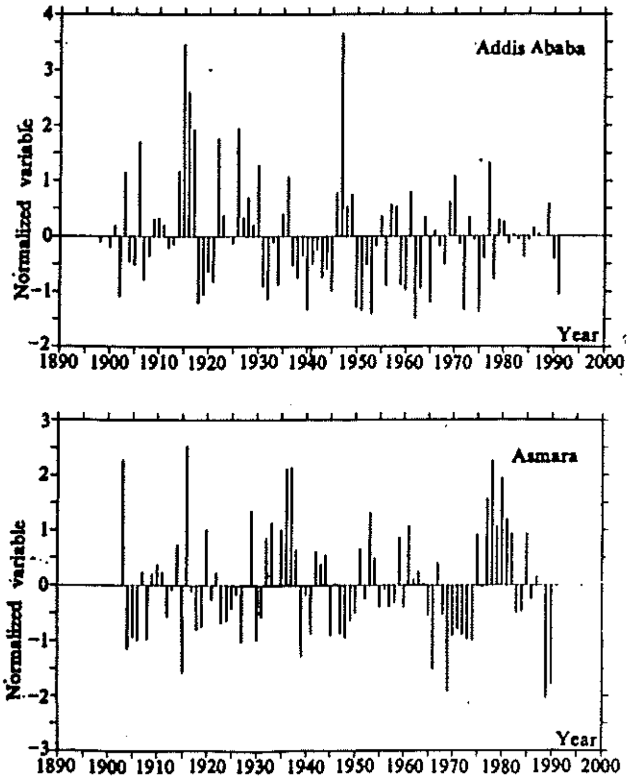

Fig. 3. Normalized annual precipitation departures from the long–term mean at the stations Addis Ababa and Asmara.

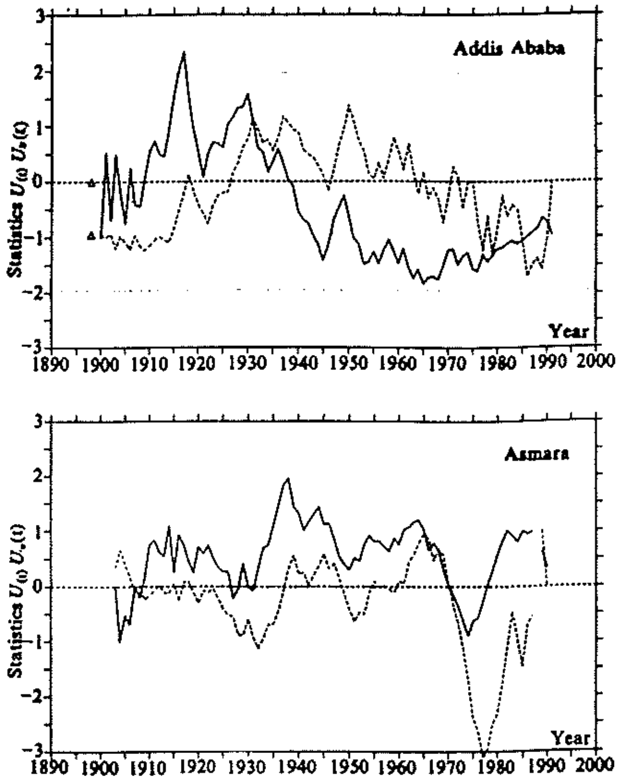

Fig. 4. Application of the sequential Mann–Kendall trend test to the annual precipitation depths at the stations Addis Ababa and Asmara.

test statistic remains well within the region delimited by the two–sided 5% significance level.

The autocorrelation function presents a significant correlation at the 5% significance level at lag 4 (Addis Ababa) and 12 (Asmara). Furthermore, application of Lombard's test suggests the presence of 17 change–points at Addis Ababa and of 8 at Asmara, i. e. on the average respectively every 5.5 and 10.5 years. These values are compatible with those obtained from the autocorrelation analysis. It is however not possible to locate exactly the positions of all change–points in the monthly and annual series and therefore only a simplified picture will be given. From all this, it can be inferred that these series cannot be seen as pure random noise but rather as multi–year random successions of dry or wet periods.

The evolution of the monthly rainfall depths during the Addis Ababa main rainy season (from May to September) can be globally characterized by a higher level from the turn of the century to the 30s or the 40s (July, September). From that moment on, a relatively dry state was set in. This dry state ended in the 60s or the 70s leaving the place to a mildly more humid period but continued well into the 80s for the months July and September. This monthly analysis corroborates well with the seasonal drought analysis by Seleshi and Demaree (1992) who concluded at a higher frequency of droughts in the second half of the XX–th century than in the first one.

The most significant features in the Addis Ababa monthly or annual rainfall amounts are:

(a) an abrupt transition from a more humid to a dry state in 1929—1930 for August, the rainiest month, (reference period 1903—1968) with an associated probability of no–change of 0.3%. The levels of this transition are respectively 318 mm before and 256 mm after, giving a drop of 62 mm or 20%.

(b) this change in the rainiest month still results into a similar abrupt change in the annual depths in 1930—1931 with an associated probability of 9%. The "a posteriori" Student's difference test is, with at value of 2.61, significant at the 5% significance level.

Application of Pettitt's test to the August rainfall amounts at Addis Ababa over the reference period 1903—1968 present a sharp maximum for the test statistic in 1929; this is indicative of an abrupt change in the mean. The horizontal dashed-dotted lines represent the approximate critical values corresponding to the 10%, 5%, and 1% significance levels.

In the same way, the Asmara monthly rainfall depths of the rainy season (June to September) are characterized by intermediate (July and August) or high (June and September) levels from the turn of the century to the 40s (August), 50s (June and September) or 60s (July). Afterwards, a low level is sustained until the 70s (June, July and August), with a recovery from the "dry" state in the mid 70s. The September rainfall depths continue to be very low until the end of the record.

For the station Asmara, several abrupt changes in the mean of the monthly rainfall amounts are detected. Therefore, the annual amounts obey to a relatively complex pattern. Several subperiods of varying duration with low or with high rainfall amounts can be recognized. Their succession approaches the number of change points which was assessed by Lombard's test.

It can be concluded from this analysis that this century rainfall record of the stations Addis Ababa and Asmara presents the following characteristics:

(a) on the decadal level: a jumpwise decrease around the mid of the century;

(b) on the interannual level: back and forth switching between low and high levels.

IV. The Relation between East African Precipitation Patterns and the El Nino / Southern Oscillation

Teleconnections between ENSO (El Nino / Southern Oscillation) events and global precipitation patterns have been well documented in recent studies (Ropelewski and Halpert, 1987; 1989; WMO, s. d.). The term ENSO refers to the planetary scale phenomenon involving a see-saw fluctuation in the surface pressure between Indonesia and the tropical Southeast Pacific which consequently links together oceanic and atmospheric changes in the Pacific Ocean region.

The term El Nino refers to the more localized phenomenon of persistent anomalous warm sea surface temperatures in the central and / or eastern equatorial Pacific Ocean. El Nino is well known for its climatic anomalies and their societal and environmental impacts in Peru. The term "La Nina" is generally accepted for the event with colder than normal tropical Pacific sea surface temperatures. The ENSO related teleconnections and their impacts which are now widely recognized, have been studied recently in many papers (e.g. Lau and Sheu, 1991) edited by Glantz, Katz and Nicholls (1991).

In Africa, the Southern Oscillation (SO) has been generally associated with droughts / floods which frequently occurred over the last decades in Ethiopia, Sudan and East Africa. ENSO events, and particularly strong ENSO events, tend to be accompanied by droughts in Ethiopia, such as the tragical sequence of the 1888 drought and the resulting famine (Pankhurst, 1966; Nicholls, 1991; Whetton et al., 1990) and the disastrous August—September flooding in Sudan (Sutcliffe et al., 1989; Hulme and Trilsbach, 1989) during the anti-ENSO or cold episode of 1988.

Janowiak (1988) reports as the salient feature of African precipitation the existence of areas with strong coherence like in West Africa during the boreal summer and in southern and equatorial Africa during the austral summer. However, several weak and unequal dipoles, indicating paired areas where anomalies of opposite sign are observed are also present.

For instance, a 10% to 20% above normal precipitation is observed east of 20°E and between 5°N and 10°S in the Southern Hemisphere (SH) rainy season (DJFM) for warm (W) episodes ENSO years, i.e. low index of the Tahiti–Darwin Southern Oscillation Index (SOI). Years of high values of the SOI or cold (C) events, are associated with a 10% to 20% below normal precipitation east of 30°E and between 5°N and 10°S in the austral summer.

Janowiak further concludes to the existence of a N–S and a E–W dipole during the Northern Hemisphere (NH) rainy season (JJAS). The latter dipole induces a 10% reduction in precipitation over northern Kenya during warm ENSO events and up to 30% increase in northern Kenya and southern Ethiopia during cold ENSO events. Let us note that opposite patterns in the SOI vs. precipitation relationship are recognized respectively for warm or cold ENSO events and for the NH or SH rainy seasons.

Ropelewski and Halpert (1987; 1989) associate greater than normal precipitation in East Equatorial Africa (EEA) in October (0) to April (+) of an idealized ENSO cycle for warm events or low SOI years and lower than normal precipitation in November (0) to April (+) for cold events or high SOI years. The monthly time series are referred to an idealized 24–month ENSO cycle around June (0). In the case of warm ENSO episodes, the earlier subseason October (0)—December (0) shows a stronger ENSO relationship than the later January (+)— April (+) subseason. Their EEA core region which encompasses parts of Kenya, Uganda, Rwanda, Burundi and Tanzania, demonstrates that 11 out of 13 warm ENSO events are wet years for the October (0)—April (+) rainfall. Similarly, of the 11 cold ENSO events 8 were dry for the November (0)—March (+) rainfall; the latter relationship drops to the 90% level.

However, data coverage in the region of interest (Ethiopia) in the above–mentioned papers which concentrate, among others, on the EEA region, is poor. Furthermore, the gradual shift of the rainy seasons with the north–south movement of the ITCZ together with a corresponding decrease in seasonal rainfall amounts, underlines the necessity of more regional studies.

In particular, the relationship between SOI and seasonal or annual precipitation amounts have been studied for the following regions: East Africa, e. g. Kenya, Uganda and Tanzania, (Ogallo, 1988; Ogallo et al., 1988), Kenya (Njau, 1987; Farmer, 1988), Somalia (Hutchinson, 1990) and also Ethiopia (Tesfaye Haile, 1987; 1990; Ininda et al., 1987; Amare Babu, 1991). Tesfaye Haile, Ininda et al., and Amare Babu conclude on a qualitative basis that warm ENSO events are generally characterized in Ethiopia by drought. This conclusion will be investigated in some more detail in the next section on the basis of the available long–term rainfall series of Addis Ahaba and Asmara.

V. The Relation between Ethiopian Highland Precipitation and ENSO

The period for which annual precipitation depths at Addis Ababa and Asmara are available spans about 20 warm or cold ENSO episodes. The list of warm ENSO episodes included in this paper is taken from Rasmusson and Carpenter (1983) plus the years 1982 and 1986; the list of cold events is taken from Van Loon and Shea (1985) plus the years 1975 and 1988. The warm episodes are in agreement with the analysis of Quinn et al. (1987) who attributed to these events the following scale: M, moderate; W / M, near moderate; S, strong and VS, very strong. A slightly different chronology has been constructed by Wang (1992) based on the number of landing typhoons in South China for the period 1884—1989 and on Shi and Wang (1989). Differences in the chronologies found in the literature are mainly due to the fact that weak or near to moderate events are listed or not and that ENSO might be spread over two consecutive years. It must be remembered that Quinn 's list refers to El Nino occurrences and that no one to one relationship with the SO exists.

List of the warm ENSO episodes

1899 / 00 S	1902 M+	1905 W / M	1907 M	1911 / 12 S
1914 M+	1918 / 19 W / M	1923 M	1925 / 26 VS	1930 / 31 W / M
1932 S	1939 M+	1940 / 41 S	1943 M+	1951 W / M
1953 M	1957 / 58 S	1965 M+	1969	1972 / 73 S
1976 M	1982 / 83 VS	1986 / 87 M		

List of the cold ENSO episodes

1989	1903	1906	1908	1916
1920	1924	1931	1938	1942
1949	1954	1964	1966	1970
1973	1975	1978	1988 / 89	

From the previous section, it is clear that possible relationship of rainfall patterns in Ethiopia with ENSO should be looked for at the level of seasonal precipitation amounts. Therefore the annual rainfall amounts are subdivided into two parts according to precipitation seasons: the June (0)—September (0) depths corresponding to the main rainy season and the October (0)—May (+) depths merging the Bega dry period and the Belgh small rains.

Fig. 7 shows the relationship between the seasonal rainfall depths and the SO for the station Addis Ababa. The hatched bars represent the warm ENSO years and the solid the cold ones. For the June—September precipitation 18 out of 22 seasons in warm ENSO years are associated with below the long–term average precipitation and 14 out of 19 seasons in cold ENSO years are associated with above average precipitation. For the October (0)—May (+) rainfall depths only 12 out of 22 seasons in warm ENSO years are associated with above average precipitation, while 13 out of 18 in cold ENSO years are associated with below average precipitation. In this last case, for the El Nino events which are labelled strong (S) or very strong (VS) by Quinn et al. (1987), 6 upon 7 are events below the average. The Asmara precipitation depths follow over the whole a less pronounced relationship with ENSO; however 12 out of 19 warm ENSO years have a below average June—September rainfall depth and 12 out of 18 October—May rainfall depths in cold ENSO years are also below average.

The conclusions of Janowiak (1988) and Ropolewski and Halpert (1987; 1988) relative to the EEA area and those of Farmer (1988) for the Kenya Coastal Zone have been extended over

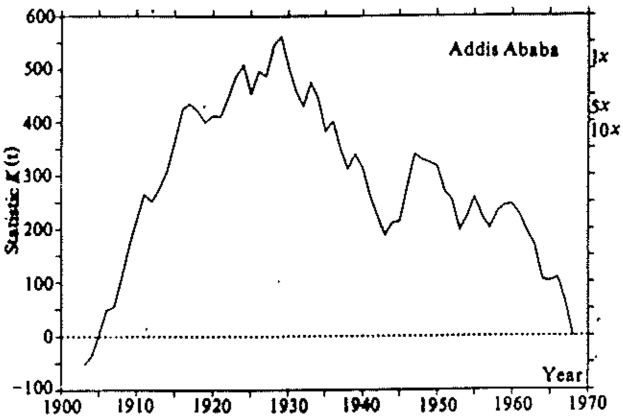

Fig. 5. Application of Pettitt's test for detecting a shift in the mean in the time series of the August precipitation depths at Addis Ababa over the reference period 1909—1968.

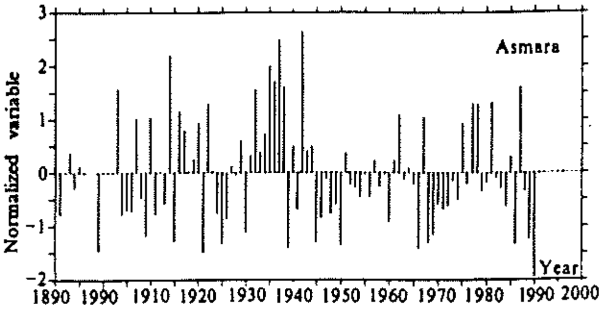

Fig. 6. Normalized August precipitation departures from the long-term mean at the station Asmara.

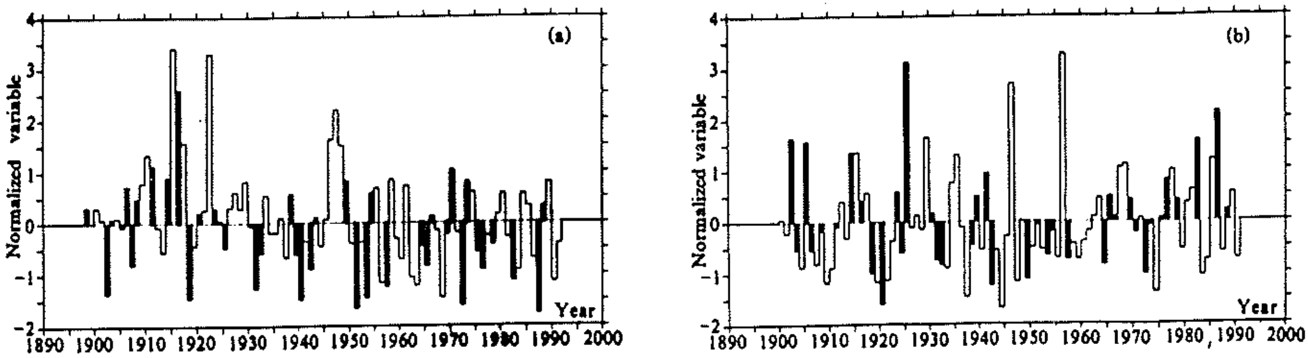

Fig. 7. Relationship between seasonal rainfall depths and SO for Addis Ababa. The hatched bars indicate warm ENSO years, the soild bars indicate cold ENSO years. (a) June—September rainfall and (b) October (0)—May (+) rainfall.

a longer time basis for the Ethiopian highland region. The Addis Ababa rainfall has a strong ENSO component while for Asmara, which is situated 720 km northwards, it is weak. This shows that to a greater extent than at Addis Ababa, other factors such as topography, ITCZ, rainfall seasons and others, are intervening in the Asmara rainfall patterns.

VI. Conclusions

The rainfall series of Addis Ababa and Asmara do not present long–term decreasing or increasing trends. This is in contrast with the precipitation climate of the Sahelian region where evidence of a long lasting drought since the end of the 60s and stretching over a large area from the western Sahel to Sudan is well known. This fact implies that other precipitation mechanisms are operating in Ethiopia. The second part of the present paper is identifying such a mechanism.

The Ethiopian series can rather be viewed as a multi–year succession of wet or dry periods. Moreover, significant abrupt changes in the mean at the interdecadal level are identified. In general, the second part of this century has been more subject to drought than its first part.

Application of the Lombard test revealed a relatively high number of change points in the mean at Addis Ababa and a lesser number at Asmara. It is suggested to link these changes to ENSO activities. For the seasonal precipitation depths at Addis Ababa it can be seen that

ENSO events have a sizeable influence on the precipitation patterns. On the basis of the long–term time–series the conclusions of Janowiak, Ropelewski and Halpert, and Farmer of opposite patterns in SOI vs. precipitation relationship for warm and cold ENSO events, and for long and short rainy seasons can be extended to the Ethiopian highlands. However, a different timing of the rainy seasons in Ethiopia than in EEA or the Kenya coastal zone is met. The above–mentioned relationship becomes much weaker for the Asmara rainfall. At the same time, it is clear that ENSO is not the only factor intervening in Ethiopian precipitation.

In order to assess the relationship between Ethiopian rainfall patterns and the worldwide ENSO phenomena, a more detailed quantitative study on monthly or seasonal time step involving all available long–term records is required.

The authors are grateful to the National Meteorological Services Agency at Addis Ababa, Ethiopia, for making the data available. This work has been supported, in part, by the Global Change Programme of the Belgian Government under contract GC / 34 / 019.

References

Amare Babu (1991), The influence of El Nino / Southern Oscillation (ENSO) on the Ethiopian seasonal rainfall, *Long–Range Forecasting Research Report Series* No. 14, WMO / TD No. 395. Trieste, Italy, 8—12 April 1991, pp. 13.

Annales du Bureau Central Meteorologique de France (1900), II Observations Année 1898, Paris pp. C. 77.

Bahru, Z. (1976), A historical outline of famine in ethiopia, *Drought and Famine in Ethiopia*, A. M. Hussein (Ed.) International African Institute, London, pp. 52—58.

Degefu, W. (1987), Some aspects of meteorological drought in ethiopia, *Drought and Hunger in Africa: Denying Famine a Future*, M. H. Glantz (Ed.), Cambridge University Press, Cambridge, pp. 23—36.

Degefu, W. (1989a), Ethiopia. Recommendations from the workshop on drought early warning, *Drought Network News*, **1** (2): 10—11.

Degefu, W. (1989b), Proceedings on drought assessment in ethiopia, *Drought Network News*, **1** (3): pp. 18—19.

Demaree, G. R. and Nicolis, C. (1990), Onset of Sahelian drought viewed as a fluctuation–induced transition, *Q. J. R. Meteor. Soc.*, **116**: 221—238.

Downing, T. E. (1982), Climate change, variability and drought in Eastern Africa, *East Africa Regional Studies*, RP 9. The Program for International Development, Clark University, Worcester, 69 pp.

Drought Monitoring Bulletin (1991), Drought Monitoring Centres Nairobi / Harare, UNDP Regional Project, RAF / 88 / 044.

Eklundh, L. (1988), The rainfall climate of Ethiopia. An analysis of rainfall data 1969—1985, The Royal Swedish Academy of Sciences, Stockholm, Sweden. Conference on "*Environmental Stress and Political Conflicts in Africa*", December 13—15, 1988, 12 pp.

Eredia, F. (1932), Sulla temperatura dell' aria e sulle precipitazioni acquee di Asmara. Ministero delle Colonie, Ufficio Studi e Propaganda. Istituto Poligrafico dello Stato, Roma, 14 pp.

Fantoli, A. (1964), Contributo alla Climatologia dell' Etiopia (Edizione in bozze). Ufficio Elaborazione Pubblicazione Dati Meteorologici Ex Colonie Italiano, 572 pp.

Fantoli, A. (1965), Contributo alla Climatologia dell' Etiopia. Riassunto dei Risultati e Tabelle Meteorologiche e Pluviometriche, Ministero degli Affari Esteri, Roma, 558 pp.

Fantoli, A. (1966), Contributo alla Climatologia dell' Altiplano–Etiopico Regione Eritrea, Riassunto dei Risultati e Tabelle Meteorologiche e Pluviometriche, Ministero degli Affari Esteri, Roma, 230 pp.

Farmer, G. (1988), Seasonal forecasting of the Kenya coast short rains, *Journal of Climatology*, **8:** 489—497.

Glantz, M. H., Katz, R. W. and Nicholls, N. (Eds.) (1991), *Teleconnections Linking Worldwide Climate Anomalies–Scientific Basis and Societal Impact*, Cambridge University Press, Cambridge, 535 pp.

Griffiths, J. F. (1972), Climates of Africa, Chapter 4, The Horn of Africa; Chapter 11, Ethiopian Highlands, *World Survey of Climatology*, **10.**

Griffiths, J. F. and Hemming, C. F. (1963), A rainfall map of Eastern Africa and Southern Arabia. East African Meteorological Department, *Memoirs* **3:** No. 10, 42 pp. + Map.

Grove, A. T. (1986), The state of Africa in the 1980s, *The Geographical Journal*, **152:** 193—203.

Hellden, U. and Eklundh, L. (1988), National drought impact monitoring–A NOAA NDVI and precipitation study of Ethiopia, *Lund Studies in Geography*(Ser. C), No. 15, 55 pp.

Hulme, M. and Trilsbach, A. (1989), The August 1988 storm over Khartoum; its climatology and impact, *Weather*, **44:**, 82—90.

Hulme, M. (1990), The changing rainfall resources of Sudan, *Trans. Inst. Br. Geogr. N. S.*, **15:** 21—34.

Hulme, M. (1990), Global Climate Change and the Nile Basin, Paper presented at the conference on the Nile convened at the Royal Geographical Society and at the University of London (SOAS) on 2—3 May 1990, pp. 59—75 + 8 Fig. s.

Hurst, H. E. and Black, R. P. (1943), The Nile Basin, Volume VI. Monthly and Annual Rainfall Totals and Number of Rainy Days at Stations in and near the Nile Basin for the period ending 1937. Ministry of Public Works, Egypt. Physical Department Paper No. 43, Schindler's Press, Cairo.

Ininda, J., Desalegne, B. and Befekadu, A. (1987), The characteristics of rainfall in Ethiopia and its relationship to El–Nino Southern Oscillation. *Proceedings of the First Technical Conference on Meteorological Research in Eastern and Southern Africa*, Nairobi, Kenya, 6—9 January 1987, pp. 133—135.

Janowiak, J. E. (1988), An investigation of interannual rainfall variability in Africa, *Journal of Climate*, **1:** 240—255.

Knox, A. (1911), *The Climate of the Continent of Africa*, Cambridge Univ. Press, 552 pp.

Lau, K. –M. and Sheu, P. J. (1991), Teleconnections in Global Rainfall Anomalies; Seasonal to Interdecadal Time Scales, *Teleconnections Linking Worldwide Climate Anomalies–Scientific Basis and Societal Impact*, M. H. Glantz, R. W. Katz and N. Nicholls (Eds.), Cambridge University Press, Cambridge, pp. 227—256.

Lombard, F. (1988), Detecting change points by Fourier analysis, *Technometrics*, **30:** 305—310.

Lyons, Captain, H. G. (1906), The Physiography of the River Nile and its Basin, Survey Department, Egypt. Cairo, National Printing Department, 411 pp.

Nicholls, N. (1991), Teleconnections and health, *Teleconnections Linking Worldwide Climate Anomalies–Scientific Basis and Societal Impact*, M. H. Glantz, R. W. Katz and N. Nicholls (Eds.), Cambridge University Press, Cambridge, 493—510.

Nicholson, S. E. (1978), Climatic variations in the Sahel and other African regions during the past five centuries, *Journal of Arid Environment*, **1:** 3—24.

Nicholson, S. E. (1983), Sub–Saharan rainfall in the years 1976—1980; Evidence of continued drought, *Monthly Weather Review*, **111:** 1646—1654.

Nicholson, S. E. (1989), Long–term changes in African rainfall, *Weather*, **44: 2**, 46—56.

Njau, L. N. (1987), Seasonal variability of Kenya rainfall and its teleconnections. *Proceedings of the First Technical Conference on Meteorological Research in Eastern and Southern Africa*, Nairobi, Kenya, 6—9 January 1987, 160—165.

Ogallo, L. J. (1988), Relationships between seasonal rainfall in East Africa and the Southern Oscillation, *Journal of Climatology*, **8:** 31—43.

Ogallo, L. B., Janowiak, J. E. and Halpert, M. S. (1988), Teleconnection between seasonal rainfall over East Africa and global sea surface temperature anomalies, *Journal of the Meteorological Society of Japan*, **66:** 807—821.

Pankhurst, R. (1966), The great Ethiopian famine of 1888—1892, *Journal of the History of Medicine and Allied Sciences*, **21:** 95—124 and 271—294.

Pettitt, A. N. (1979), A non-parametric approach to the change-point problem, *Appl. Statist.*, **28: 2**, 126—135.

Quinn, W. H., Neal, V. T. and Antunez de Mayolo, S. E. (1987), El Nino occurrences over the past four and a half centuries, *Journal of Geophysical Research*, **92:** C13, 14, 449—14, 461.

Rasmusson, E. M. and Carpenter, T. H. (1983), The relationship between eastern equatorial Pacific Sea surface temperatures and rainfall over India and Sri Lanka, *Mon. Wea. Rev.*, **111:** 517—528.

Ropelewski, C. F. and Halpert, M. S. (1987), Global and regional scale precipitation patterns associated with the El Nino / Southern Oscillation, *Mon. Wea. Rev.*, **115:**, 1606—1626.

Ropelewski, C. F. and Halpert, M. S. (1989), Precipitation patterns associated with the high index phase of the southern oscillation, *Journal of Climate*, **2:** 268—284.

Seleshi Yilma and Demarée, G. R. (1992), The temporal distribution of Ethiopian meteorological droughts in the XX-th century, Paper presented at the International Symposium "*Biological Indicators of Global Change*", 7—9 May 1992, Brussels, 14 pp.

Shi Wei and Wang Shaowu (1989), Southern oscillation index, 1857—1987, *Meteor. Mon.*, **15 (5)**:29—33 (in Chinese).

Sneyers, R. (1975), Sur I' analyse statistique des series d' observations Note Technique n° 143, OMM-N°415, Geneve, 192 pp.

Sutcliffe, J. V., Dugdale, G. and Milford, J. R. (1989), The sudan floods of 1988, *Hydrological Sciences Journal*, **34:** 355—364.

Tesfaye Haile (1990), Drought in ethiopia, *Extended abstracts of papers presented at the Third WMO Symposium on Meteorological Aspects of Tropical Droughts with Emphasis on Long-Range Forecasting*, Niamey, Niger, 30 April - 4 May, 1990. WMO / TD - No. 353, pp. 273—278.

Tesfaye Haile (1987), Climatic Variability and Droughts in Ethiopia, *Proceedings of the First Technical Conference on Meteorological Research in Eeastern and Southern Africa*, Nairobi, Kenya, 6—9 January 1987, pp. 117—120.

Van Loon, H. and Shea, D. J. (1985), The southern oscillation, Part IV: the precursors south of 15°S to the extremes of the oscillation, *Mon. Wea. Rev.*, **113:** 2063—2074.

Vannitsem, S. et Demaree, G. R. (1991), Detection et modelisation des secheresses au Sahel - Proposition d' une nouvelle methodologie, *Hydrologie Continentale*, **6:** 155—171.

Vannitsem, S. and Nicolis, C. (1991), Detecting climatic transitions: statistical and dynamical aspects, *Contributions to Atmospheric Physics*, **64:** 245—254.

Von Braun, J. (1991), A Policy Agenda for Famine Prevention in Africa, *Food Policy Report*, The International Food Policy Research Institute, Washington, D.C., 24 pp.

Yan Zhongwei, Ji Jinjun and Ye Duzheng (1990), Northern Hemisphere summer climatic jump in the 1960s, I and II, *Science in China* (Series B), **33:**, 1092—1101 and **34:**, 469—478.

Yeshanew, A. and Apparao, G. (1989), Annual Rainwater Potential and its Variability in Drought Years over Ethiopia, *Conference on Climate and Water*, Helsinki, Finland, 11—15 September 1989, **1:** 219—235.

Wang Shaowu (1992) Reconstruction of El Nino event chronology for the last 600 years period, *Acta Meteorologica Sinica*, **6:** 47—57.

Webb, P., Von Braun, J. and Teklu, T. (1990), Drought and famine in ethiopia and Sudan, An ongoing tragede, *Drought Network News*, **2: (3):**, 3—4.

Whetton, P., Adamson, D. and Williams, M. (1990) Rainfall and river flow variability in Africa, Australia and East Asia linked to El Nino-Southern Oscillation events, *Geological Society of Australia Symposium Proceedings*, **1:** 71—82.

WMO (s. d.) The Global Climate System-Climate System Monitoring June 1986 November 1988, World Meteorological Organization World Climate Data Programme, United Nations Environment Programme, CSM R 84 / 86, 70

p. + Corrigenda.

Wood, C. (1977), A Preliminary Chronology of Ethiopian Droughts, *Drought in Africa*, 2. Dalby, D., Harrison Church, R.J.and Bezzaz, F. (Eds.) International African Institute, London, pp. 68—73.