Kenya Journal of Science and Technology (A) (1982) 3: 43 — 54

Quasi-periodic patterns in the East African rainfall records

L.J. Ogallo,
Department of Meteorology, University of Nairobi, Nairobi, Kenya

SUMMARY

In this study East African rainfall records within the period 1922-80 were subjected to spectral analysis in order to examine whether the fluctuations in rainfall during 1922-80 exhibited any periodic or quasi-periodic patterns. The characteristics of the rainfall autocorrelations at the individual stations were also analysed. The data used here included monthly and annual rainfall records of about 100 stations distributed all over East Africa. Fluctuations in the regionally averaged rainfall records were also examined.

Results from spectral analysis indicated that a family of four spectral peaks were common in many rainfall records. The period of these peaks was centred generally around 2.2 to 2.8 years, 3.0 to 3.7 years, 4.8 to 6.0 years, and 10.0 to 12.5 years. Although all these spectral peaks appeared in many rainfall series, the proportion of the total rainfall variance explained by each varied significantly from region to region.

Results from autocorrelation analysis indicated that lag one autocorrelations were significantly different from zero at 16 stations for the annual records. The nature of persistence at these 16 stations was observed to be close to the linear markov type. ''Red noise'' hypothesis was used in testing the statistical significance of the spectral peaks observed at these stations while the ''white noise'' hypothesis was employed in the other cases.

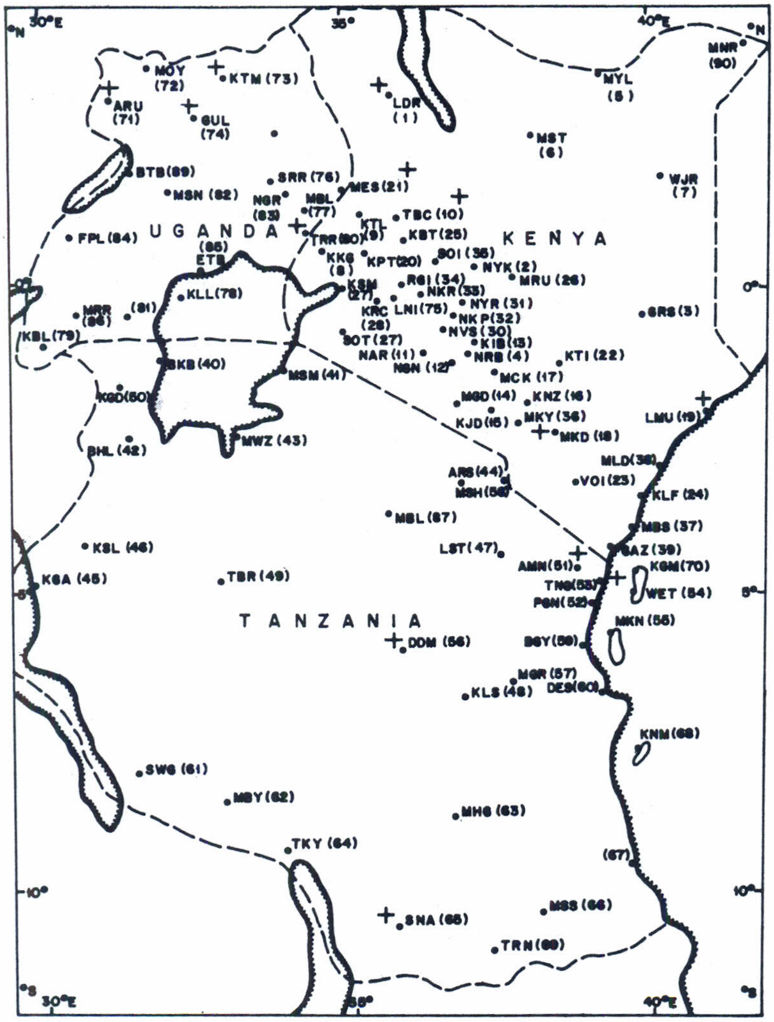
INTRODUCTION

Fluctuations have been observed in all climatic elements. The dynamic factor which causes these climatic elements to vary with time is the general circulation which is strongly influenced by the complex interactions between the surface, ocean and atmospheric systems. In this study an attempt is made to use the autocorrelation and spectral analysis techniques to examine whether the East African rainfall fluctuations during the period 1922-80 exhibited any periodic or quasi-periodic patterns.

Rainfall is the climatic element of maximum significance. In East Africa it influences the economies of the three countries which greatly depend on the agricultural and pastoral products. Knowledge of the rainfall patterns is very essential in solving problems related to agriculture and pasture, and in the general planning of water for domestic and industrial use.

In East Africa, Rodhe and Virji (1976) examined the trends and periodicities of the annual rainfall records at 35 stations which were concentrated mainly in Kenya and northern Tanzania. They observed no significant trends except in the northeastern part of Kenya. Results from spectral analysis indicated cycles of about 2.5 years, 3.3 years and 5 to 5.5 years. Ogallo (1981, 1982) observed no significant trends in the East African monthly, seasonal, annual and regionally averaged rainfall records for the period 1922-75. Out of about 100 stations used, both statistical and graphical methods indicated significant trends only in the annual records of three stations namely; Lodwar, Wajir and Magadi.

In this study periodic fluctuations have been examined using the monthly and annual rainfall records of about 100 stations distributed all over East Africa within the period 1922-80. The distribution of these rainfall stations is given in figure 1 and table 1.



+ Indicate stations with significant r_1 value.
(CODE NAME AND NUMBER ARE GIVEN FOR EACH STATION)

Figure 1. The Spatial distribution of rainfall stations

Table 1. List of the stations and their code names

Country and station	Station's code name	Country and station	Station's code name
KENYA		TANZANIA	
Garissa	GRS	Amani	AMN
Gazi	GAZ	Arusha	ARS
Kabarnet	KBT	Bagamoyo	BGY
Kabete	NRB	Biharamulo	BHL
Kakamega	KKG	Bukoba	BKB
Kapsabet	KPT	Dar es Salaam	DES
Kericho	KRC	Dodoma	DDM
Kiambu	KIB	Kagondo	KGD
Kilifi	KLF	Kasulu	KSL
Kisii	KIS	Kigoma	KGA
Kisumu	KSM	Kigomasha	KGM
Kitale	KTL	Kilindoni	KNM
Kitui	KTI	Kilosa	KLS
Konza	KNZ	Kilwa	KLW
Lamu	LMU	Lindi	LND
Lodwar	LDR	Lushoto	LST
Londiani	LNR	Mahenge	MHG
Machakos	MCK	Masasi	MSS
Magadi	MGD	Mbeya	MBY
Makindu	MKD	Morogoro	MGR
Makuyu	MKY	Moshi	MSH
Malindi	MLD	Musoma	MSM
Marsabit	MST	Mwanza	MWZ
Meru	MRU	Mkokotoni	MKN
Mombasa	MBS	Pangani	PGN
Mt. Elgon	MES	Singida	SGD
Moyale	MYL	Songea	SNA
Naivasha	NVS	Sumbawanga	SWG
Nakuru	NKR	Tabora	TBR
Nanyuki	NYK	Tanga	TNG
Narok	NAR	Tukuyu	TKY
Ngong	NGN	Tunduru	TRN
N. Kinangop	NKP	Wete	WET
Nyeri	NYR		
Rongai	RGI	UGANDA	
Rumuruti	RRT	Arua	ARU
Simba	SBA	Butiaba	BUT
Solai	SOI	Fort Portal	FPL
Sotik	SOT	Gulu	GUL
Tambach	TBC	Hoima	HOM
Voi	VOI	Kabale	KBL
Wajir	WJR	Kalangala	KLL
		Kitgum	KTM
		Masaka	MSK
		Masindi	MSN
		Mbale	MBL
		Mbarara	MRR
		Moyo	MOY
		Moroto	MRT
		Ngeta	NGT
		Ngora	NGR
		Serere	SRR
		Tororo	TRR

The autocorrelation method

Estimates of the autocorrelations may be used to conjecture about the nature of the non-randomness in any time series. The autocorrelation function r_k may be expressed as:

$$r_k = \left[\frac{1}{N} \sum_{t=1}^{N} x_t \quad X_{t+k} \right] / S^2 \quad (1)$$

where $X_t = X_t - \overline{X}_t, X_{t+k} = X_{t+k} - \overline{X}_t$

$\overline{X}_t$ is arithmetic mean of the series X_t, S^2 the variance, k the time lag, and N the number of observations.

The use of r_k in searching for periodicities is quite old (Craig 1916; Yule 1927; Walker 1931). The graphical plot of r_k against the time lag k is shown as the correlogram. The nature of the correlogram can give some idea about the generating process of the time series. For a periodic process, the correlogram is periodic. It decays exponentially for the first order markov process, while it is in form of damped harmonics for mixed processes. In this study the autocorrelations were calculated and the correlograms plotted for each case. The statistical significance of the observed autocorrelations were also examined. Methods of calculating confidence limits for the autocorrelations have been discussed by many authors including Anderson (1942) and Kendall (1976).

The spectral analysis

In order to examine whether the rainfall series exhibited any periodic or quasi-periodic fluctuations during the period of study, the rainfall time series were also subjected to spectral analysis. Spectral analysis has a long history during which many methods have been developed for computing spectral estimates. The most common methods of computations include autocorrelation transform, fast fourier transform, and maximum entropy method (Jenkins and Watts 1968; Cooley, Lewis and Welch 1967; Burg 1972).

In this study the autocorrelation transform technique was employed. The smoothed spectral estimates for a unit time interval $F(\lambda)$ may be expressed as:

$$F(\lambda) = 2 \left[1 + 2 \sum_{k=1}^{m} r_k W_k \; Cos(2\pi\lambda k) \right] \quad (2)$$

were m is the maximum time lag, W_k is the lag window, and λ the wavelength. Both Parzen and Tukey windows were used independently in the computation of the spectral estimates. At least three different time lags were applied in each computation. In order to ensure stationary conditions in all time series, the rainfall time series were passed through a first difference filter before they were subjected to spectral analysis. The gain $[G(\lambda)]$ and the response $[R(\lambda)]$ functions for this filter are given by:

$$G(\lambda) = 2 \left| Sin(\pi\lambda) \right| \quad (3)$$

$$R(\lambda) = 2i \; exp(-i\pi\lambda) \; Sin(\pi\lambda) \quad (4)$$

Periodic fluctuations appear as peaks in the graph of the smoothed spectral estimates $F(\lambda)$ versus the wavelengths λ. The statistical significance of the spectral peaks observed in the rainfall records were tested using the "white noise" or "red noise" hypothesis depending on the generating process of the time series as indicated by the characteristics of r_k. The "red noise" hypothesis was assumed when the neighbouring points of the time series were noted to be correlated, while that of the "white noise" was used when the generating process of the time series was taken to be purely random.

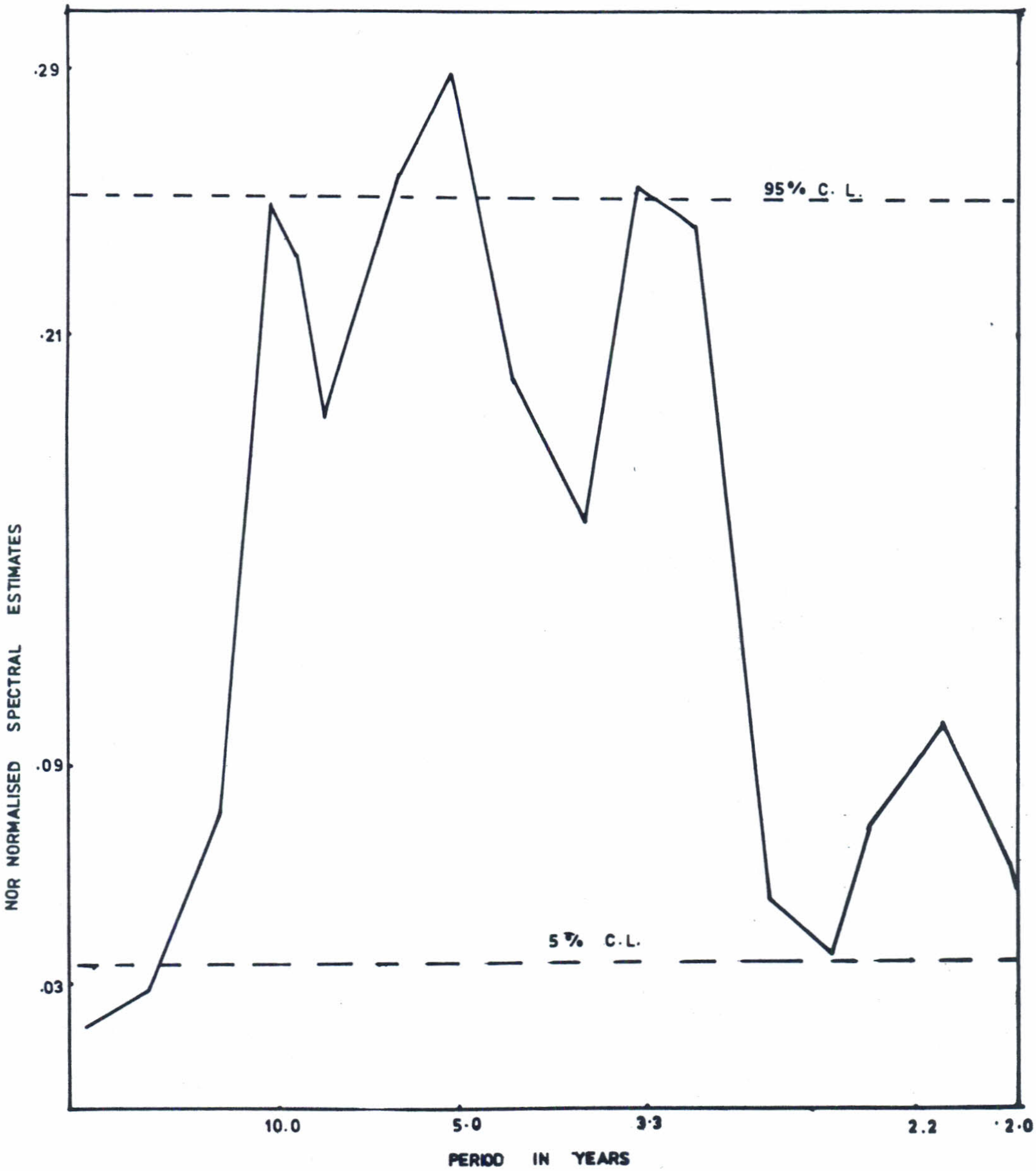


Figure 6. Observed spectral peaks in the annual rainfall at Nairobi

The 2.2 to 2.8 years spectral peak was common in all rainfall series, but was generally dominant in the coastal regions, especially in Tanzania where it explained as high as 25% of the total annual rainfall variance.

The 3.0 to 3.7 years peak appeared generally in all rainfall series with the exception of the rainfall series from the southern highlands of Tanzania. This spectral peak was dominant in the inland stations.

The most common spectral peak in the East African annual rainfall was that centred around 4.8 to 6.0 years. This peak was observed in all stations, but the proportion of the total variance it explained varied significantly from one region to another.

The 10 to 12.5 year cycle also appeared in many rainfall series, but it was generally weak at most of the stations. The few stations where this cycle indicated some significance were concentrated mainly in Uganda. The results from the monthly and the regionally averaged rainfall records indicated that the records of the wet months and wet seasons had characteristics close to those of the corresponding annual rainfall records. This may be due to the strong seasonality of rainfall in East Africa. The results from the regionally averaged rainfall records indicated that the spectral patterns which were observed at the individual stations were discernible in the respective regionally averaged series. The regionally averaged rainfall records were obtained using the empirical orthogonal functions (Ogallo 1980).

These cycles which are appearing in the East African rainfall records have also been observed in the fluctuations of many weather elements (Craddock 1968; Wagner 1971; Holton and Lindzen 1972; Rodhe 1974; Rodhe and Virji 1976; Madden 1977; Vincent, Davis and Bereford 1979). Such fluctuations have also been indicated in the rainfall records from other parts of Africa (Winstanley 1973; Tyson, Dyer and Mametse 1975; Landsberg 1975; Ogallo 1979).

It is generally important to discuss, attach or relate the observed fluctuations in the climatic elements to some known physical processes in the atmosphere or to some major functions which may influence climate. Since the variations in the weather elements are the general expressions of certain characteristics in the general circulation of the atmosphere, variations of rainfall at any location will be controlled largely by the structure of the large scale atmospheric circulation systems. If this holds in any region then adjacent rainfall stations in that region should have similar responses to rainfall. Such stations should, therefore, indicate similarity in the spectral patterns. If the spectral patterns differ significantly then other forcing functions are operating, which may result in more complex spatial or temporal relationships.

It has been observed from the results of spectral analysis that although a family of four spectral peaks appeared in most of the rainfall series, the proportion of the total variance accounted for by each peak varied significantly from one region to another. These spectral patterns may suggest that although rainfall in East Africa may be influenced by some common large scale forcing mechanisms, the influence of the local functions play some significant role in the spatial distribution of the rainfall variance. The local functions include altitude, nearness to water sources, and other local circulations (meso-scale circulations of thermal or terrain origin).

The question of the reality of the cycles observed from meteorological records have been discussed by many authors since such cycles may be statistically significant but have no physical reality. The fluctuations displayed by the climatic elements are known to be the general expressions of certain characteristics within the general circulation systems, which are controlled by complex interactions between the surface, ocean and atmospheric systems. Many attempts have, therefore, been made to examine the relationships between the fluctuations patterns of some general circulation parameters and the various cycles which are commonly observed in the climatic elements (Sansom 1955; Namias 1959; Willet 1965; Deshpande 1968; Kreuger and Gray 1969; Lawrence 1971; King 1973; Edbon 1975; Favorite and McLain 1973; Trenbert 1976; Brier 1977 and many others). The parameters which have been used in such relationships include the sunspot cycle, sea surface temperature, Walker's southern oscillation and the quasi-biennial oscillation.

In this study no attempt was made to examine the relationships between the cycles observed in East African rainfall and the fluctuations in various general circulation parameters. A joint statistical test was, however, included to investigate any evidence for the low period cycles (2.2 to 2.8 years, 3.0 to 3.7 years and 4.8 to 6.0 years) to represent the harmonics of the more commonly appearing 10 to 12.5 year cycle. The results from this test indicated that the existence of the 10 to 12.5 years cycle cannot be accepted statistically as a convincing cause for the appearance of the smaller period fluctuations. This indicated that the lower period oscillations did not appear due to the presence of the 10 to 12.5 years cycle, and vice versa.

The relationship between the 10 to 12.5 years cycle and the 11.1 years solar cycle have not been examined here.

CONCLUSION

The results from this study indicated that although a family of four spectral peaks were common in most of the East African rainfall records, the proportion of the total rainfall variance accounted for by each spectral peak varied significantly from one region to another. The period ranges of the four spectral peaks were centred around 2.2 to 2.8 years, 3.0 to 3.7 years, 4.8 to 6.0 years and 10.0 to 12.5 years. The four spectral peaks together explained less than 60% of the total variance in the annual rainfall records of all regions of East Africa.

The results from the correlograms, and the large ranges observed in the periods of the above spectral peaks indicate some variability in the periods of the "cycles" exhibited by East African rainfall during the period 1922-80. Such variability in the periods, together with the relatively low variance that they explain make it difficult to use the knowledge of the observed quasi-periodic fluctuations in any long range statistical forecasting of seasonal rainfall in East Africa.

REFERENCES

(1) Anderson, R.L. (1942). Distribution of the serial correlation coefficients. *Annal. Math. Stat.*, 13: 1—13.

(2) Brier, G.W. (1977). Quasi-biennial oscillation and feedback processes in the atmoshere-ocean-earth system. *5th Conf. on Probability and Statistics in Atmospheric Sc., Amer. Met.:* 228-232.

(3) Burg, J.P. (1972). The relationship between maximum entropy and maximum likelihood spectra. *Geophy.* 37: 375-376.

(4) Cooley, J.W., Lewis, P.A.W. and Welch, P.D. (1967). Historical notes on the Fast Fourier Transform. *IEEE,* 79-84.

(5) Craddock, J.W. (1968). Atmospheric oscillations with periods of about two years. *Brit. Met. Office, Met.* 013, No. 22.

(6) Craig, J.I. (1916). The periodogram and method of correlation. *Brit. Assoc. Adv. Sc. Rep.* No. 86.

(7) Deshpande, D.V. (1967). Sunspot cycle and regional rainfall. *Weather,* 23: 78-79.

(8) Edbon, R.A., (1975). The quasi-biennial oscillation and its association with stratospheric circulation patterns. *Meteorol. Mag.,* 104: 282-297.
(9) Favorite, F. and McLain, D.R. (1973). Coherence in transpacific movements of positive and negative anomalies of the sea surface temperature. *Nature,* 244: 139-143.
(10) Holton, J.R. and Lindzen R.S. (1972). An updated theory for quasi-biennial oscillation. *J. Atmos. Sci.,* 20: 1070-1080.
(11) Jenkins, G.M. and Watts, D.G. (1968). *Spectral Analysis and Its Applications.* Holden-Day, California, USA.
(12) Kendall, M.G. (1976). *Time Series.* London: Charles Griffin.
(13) King, J.M. (1973). Solar radiation changes and the weather. *Nature,* 245: 443-445.
(14) Kreuger, A.F. and Gray Jr., T.I. (1969). Long-term fluctuations in the equatorial circulation and rainfall. *Mon. Weather Rev.,* 97: 700-711.
(15) Landsberg, H.E. (1975). Sahel drought, change or part of climate. *Arch. Meteorol. Geophy. Bioklimatol. Ser. B 23.* 193-200.
(16) Lawrence, E.N. (1971). Recent weather extremes and sunspot cycles. *Weather,* 26: 129-131.
(17) Madden, R.A. (1977). Estimates of the autocorrelations and spectra of seasonal mean temperatures over N. America. *Mon. Weather Rev.,* 105: 9-18.
(18) Namias, J. (1959). Recent interactions between north pacific waters and the overlying atmospheric circulation. *J. Geophy.,* 64: 631-646.
(19) Ogallo, L.J. (1979). Rainfall variability in Africa. *Mon. Weather Rev.,* 107: 1133-1139.
(20) ——— (1980). Regional classification of East African rainfall stations into homogeneous groups using the method of principal component analysis. *Statist. Climatology, Developments in Atmos. Sci.,* 13: 255-261. Amsterdam: Elsevior.
(21) ——— (1981). Rainfall characteristics in the arid and semi-arid regions of Kenya. *International Workshop for Developing Resources for the Arid and Semi-Arid Areas of Kenya, August 4-8,* Nairobi, Kenya.
(22) ——— (1982). Trend of rainfall in East Africa. *Kenya Journal of Science and Technology Series A Physical and Chemical Sciences* 2: 83-90.
(23) Rodhe, H. (1974). Year to year variations in some hydrological parameters in Kenya, Secretariat Inter. *Ecology Sweden* (SIES) 4: 1-7.
(24) Rodhe, H. and Virji, H. (1976). Trends and periodicities of East African rainfall data. *Mon Weather Rev.,* 104: 307-315.
(25) Sansom, H.W. (1955). Prediction of seasonal rains of Kenya by means of correlation. *Weather* 10: 81-86.
(26) Trenberth, K.E. (1976). Spatial and temporal variations of the southern oscillation. *Q.J.R. Meteorol. Soc.,* 102: 639-653.
(27) Tyson, P.D., Dyer, T.G.J. and Mametse M.N. (1975). Secular changes in South African rainfall. *Q.J.R. Meteorol. Soc.,* 101: 817-833.
(28) Vincent, C.E., Davis, T.D. and Bereford, A.K.C. (1979). Recent changes in the level of Lake Naivasha, Kenya, as an indicator of equatorial westerlies over East Africa. *Climatic Change,* 2: 175-189.
(29) Wagner, A.J. (1971). Long period variations in seasonal sea level pressure over northern hemisphere. *Mon. Weather Rev.* 99: 49-66.
(30) Walker, C.J. (1931). Periodicities in the series of related terms. *Proc. R. Soc.,* A131: 518.
(31) Willet, H.C. (1965). Solar-climatic relationship in the light of standardized data. *J. Atmos. Sci.* 22: 120-136.
(32(Winstanley, D. (1973). Recent rainfall trend in Africa, Middle East, and India. *Nature,* 243: 464-465.
(33) Yule, G.V. (1927). On the method of investigating periodicities in disturbed series with special reference to the Wolfer's sunspot numbers. *Trans. R. Soc., A:* 226-267.

L.J. Ogallo,
Department of Meteorology, University of Nairobi, P.O. Box 30197, Nairobi, Kenya

Acceptance date: 9 December 1982.