AN ANNOTATED BIBLIOGRAPHY OF THE CLIMATE OF SUDAN

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compiled by M. Hulme

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Cover picture: A diagrammatic representation of January mean surface winds in the Sudan.

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CONTENTS

INTRODUCTION

This annotated Bibliography contains upwards of 240 works on the climate of Sudan, published between 1829 and 1987. The purpose of the Bibliography is to facilitate access to the surprisingly large literature on this particular aspect of the Sudanese environment, one that has become increasingly important in the last decade. The works cited here provide a far more comprehensive list than the climatology/meteorology sections of contemporary Sudan bibliographies, eg. World Bibliographical Series, Vol. 40, Sudan (ed. Daly) and An Agricultural Bibliography of Sudan, 1974-83 (ed. Zahlan), and updates the older, specialist meteorological bibliographies of 1951 (see entry 3) and 1962 (see entry 2), which in any case have different geographical domains.

This compilation cannot claim to be comprehensive, but it has included several of the earliest works dating from the 19th and early 20th centuries and all the important works of more recent decades. A small number of non-English works have been included (eg. Arabic, French, German and Italian), but again no claim to completeness here is made. Some of the earliest or less accessible references cannot be fully authenticated by this author since these works have not been examined. In such cases, or where accuracy is in doubt, this is indicated by a double asterisk (**). Unpublished theses and dissertations are included, following an exhaustive search of Sudanese, British and American (although not European) unpublished material.

The Bibliography includes works which are exclusively concerned with the climate of Sudan (defined as the 20th century nation, not the vegetational zone), or with a majoring emphasis on Sudanese climate where the work concerns wider climatic and atmospheric processes. Excluded are works which discuss the climate of Sudan within the context of investigations into

regional-scale events, for example, Sahelian climate or north-east African climate (unless, of course, Sudan is taken as the major illustrative example). Abstracts are only selective, but have been included for the majority of works. These have been compiled either by the present author or, where possible, extracted from the original work.

Works have been classified according to seven categories. Although some works inevitably fall into more than one category, no work is included twice and judgement was employed to identify the primary emphasis of the work. The seven categories are listed below. The first of these, general climatology, is used as the 'dustbin' category. There is also a listing of Monthly or Annual Reports or Publications of relevance (mostly by the Sudan Meteorological Service) although the present status of some of these is uncertain. The Bibliography is completed with an index by year and author.

a. General climatology
b. Meteorology and synoptic climatology
c. Precipitation climatology
d. Applied climatology
e. Evaporation
f. Climatic change
g. Atmospheric dust
h. Monthly/Annual reports and publications

a. GENERAL CLIMATOLOGY

1 **On the components of the radiation balance at the Gezira, Sudan**
Adam,E.H.S. (1971) Unpublished PhD Thesis, University of Reading, 38pp.

The components of the radiation balance were measured over cotton, groundnuts and bare ground at Wad Medani from September 1970 to January 1971. All the measurements were made under clear sky conditions. Incoming shortwave radiation, reflection coefficients, and outgoing longwave radiation were measured. Canopy temperatures were obtained from longwave radiation measurements and compared to screen temperatures. The latter were consistently 2 degrees centigrade higher than canopy temperatures. Net radiation was determined both from regression estimation and from direct measurement. These two values agreed to within 10%.

2 **An annotated bibliography on climatic maps of Sudan [**]**
Allen,W.J.Jr. (1962) U.S. Weather Bureau

3 **Bibliography: climatology of north-east Africa**
American Meteorological Society (1951) Meteorological Abstracts and Bibliography 2(10), 831-65

Over 250 items are listed, dated between 1862 and 1951, covering aspects of climatology from Egypt, Sudan, Ethiopia, Somaliland and northeast Africa in general. Brief abstracts are included. All the relevant items are incorporated in this current bibliography, which has additional items in the period 1862 to 1951 to the 1951 bibliography.

4 **On a climatic classification for the Sudan and short-term soil moisture conditions in the central region**
Awadulla,S.A. (1981) Unpublished PhD Thesis, University of Sheffield,

This thesis classifies the climate of the Sudan on the basis of Penman estimates of potential evapotranspiration (P.E.). To derive all the components of Penman's formula, the required parameters were made available at 286 points each of which had at least 20 years of rainfall records. A Distance-Weighted Least Squares Approximation Method was used to extrapolate parameters from measured sites. From the resulting P.E. estimates, soil mositure indices were derived and climatic boundaries drawn. After modifying pentadly evapotranspiration according to the soil moisture depletion curve of Thornthwaite, the pentadly march of water balance was investigated using Fourier Time Series Analysis. This enabled investigations of the temporal variability of the peak of soil moisture content. Wet and dry pentads were identified and a Markov chain probability model was applied to determine the likelihood of runs of dry pentads.

5 Climatological diagrams: Egyptian and Sudanese stations
Ball,J. (1910) Cairo Scientific Journal 4, 278-79

Two diagrams are constructed, one plotting temperature and relative humidity for Egyptian stations and the other for Sudanese stations.

6 The diversity of Sudanese climate
Barbour,K.M. (1961) pp.38-51 in, 'The Republic of the Sudan: a regional geography' Barbour,K.M., University of London Press, London, 292pp.

This chapter presents a comprehensive overview of the climate of Sudan with sections on the range of climate, a brief synoptic climatology, the seasons of the year (shita, sief, kharif and darat) and the main climatic regions. Nine maps of different climatic parameters are included. The data is mainly based on the 1921-50 reference period.

7 Autumn temperatures in the Red Sea Hills
Berry,L. and Cloudsley-Thompson,J.L. (1960) Nature 188, 843

Some very high sand surface tempertures were recorded in the autumn of 1960 from the Red Sea Hills area to the north of Port Sudan. For example, on September 24th at 1300 hours a sand temperature of 83.5°C (air temperature 40 to 44°C) was recorded. Enormous diurnal temperature fluctuations exist in such desert habitats.

8 Weather at Port Sudan [**]
Bhalotra,Y.P.R. (1960) Memoir No.3, Sudan Meteorological Service, Khartoum

9 Correlation of wind direction and temperature
Bliss,E.W. (1913) Cairo Scientific Journal 7, 177-79

This study is undertaken to determine if hot weather at Khartoum was connected with easterly winds. The same method is then applied to Helwan and Alexandria in Egypt. Methods are discussed and representative data for 1908-12 are given.

10 Notes on Sudan weather
Bliss,E.W. (1914) Cairo Scientific Journal 8, 161-62

One table gives the number of days with thunder or lightning at various places in the Sudan by month; another shows diurnal variation of rainfall for various places, averaged for 1909-1913.

11 The climate of Sennar [**]
Brocchi,G.B. (1829) National Philosophical Journal, 7

12 **The climate of the Egyptian Sudan**
Bruckner,E. (1899) Quart. Jl. of the Royal Met. Soc. 25, 175

A brief summary of the temperature and rainfall regime of the Egyptian Sudan as understood at the time of Kitchener's campaign to reclaim the Sudan. Rains only become regular south of Dongola, at Khartoum the rainy season is July to September with some May showers and up the Blue Nile at Gedaref and Sennar the rainy season is from the end of June to the end of December. Comment is also made on Kordofan and the Upper Nile areas, the former experiencing rainfall every `3rd or 4th day' during the rainy season. No specific rainfall totals are given, but mean temperatures are quoted and it is claimed that around Makraka and Sueli in southern Sudan the `climate is suited even for European habitation'.

13 **Khartoum weather**
Davies,H.R.J. (1959) Journal of Geography 58, 286-93

14 **Annual Meteorological Report**
Egyptian Government (1900-49) (40 volumes), Meteorological Department, Cairo

This annual report includes yearly climatic data from Sudanese as well as Egyptian stations. For example, in 1907, fifteen 2nd order climatic stations and 62 rainfall stations were recording from Sudan. For Sudanese data this Report was superceded by the Annual Meteorological Report published by the Sudan Meteorological Service from 1950 onwards (see **40**).

15 **Climatic normals for Egypt, Sudan, Candia, Cyprus and Abyssinia**
Egyptian Government (1922) Ministry of Public Works, Physical Department, 100pp. Cairo

Monthly and annual averages of various climatic parameters are included for varying periods up to 1920. Up to 30 Sudanese stations are included.

16 **Climatic normals for Egypt, Sudan, Candia, Cyprus and Abyssinia**
Egyptian Government (1938) Ministry of Public Works, Physical Department, 148pp. Cairo

Monthly and annual averages of various climatic parameters are included for varying periods up to 1934. Over 50 Sudanese stations are included.

17 **The climate of the Sudan** (in Arabic) [**]
El Tom,M.A. (1974) The Institute of Arab Research and Studies, Cairo, Egypt, 132pp. (plus 52 maps)

18 **The diurnal variation of wind over tropical Africa**
Farquharson,J.S. (1939) Qtly. Jl. of the Royal Met. Soc. 65, 165-83

In central Sudan wind speed decreases from morning to midday. Upper wind observations made twice daily at Khartoum during 1935 and 1936 provided data for the investigation of this unusual type of variation. It is shown that this diurnal variation is typical of a wide belt of tropical Africa and, based on upper air temperature observations at Khartoum, the suggestion is made that it is due to the midday rise in temperature within the region of the thermal equator at the height of the geostrophic wind level, being less than that in regions north and south of it.

19 **Sunshine in the southern Sudan**
Flower,W.D. (1939) Qtly. Jl. of the Royal Met. Soc. 65, 448-50

The founder of the independent Sudan Meteorological Service presents mean monthly sunshine hours for two southern stations, Meridi and Yei. These are briefly discussed. Data are based on several years in the 1930s. A correction to the estimated cloud amounts is published in Qtly. Jl. of the Royal Met. Soc. 80, 102 (Pepper, 1954; not separately listed), in which the cloud amounts are substantially reduced.

20 **Climatic statistics for selected stations in Anglo-Egyptian Sudan**
Frankel,M.H. (1942) U.S. Weather Bureau, Special Report No.107, 5pp.

Climatological data for varying numbers of years are tabulated for stations in the Sudan: Hillet Doleib, Khartoum, Lerua, Port Sudan, Mongalla and Kodok.

21 **Climates of Africa**
Griffiths,J.F. (ed.) (1972) World Survey of Climatology, Vol.10, (series ed.) Landsberg,H.H., Elseiner, Amsterdam, 604pp.

Several sections in this volume relate to Sudanese climate, especially: pp.75-131 (the northern desert, Sahara), pp.193-219 (semi-arid zones) and pp.221-57 (wet and dry tropics). The following Sudanese stations have full climate statistics tabulated, based on 1931-60 means: Dongola, Er Roseires, Juba, Kassala, Khartoum, Malakal, Wadi Halfa and Wau.

22 **Cloud distribution and development around Khartoum**
Hammer,R.M. (1970) Weather 25, 411-14

Although authors have been unable to define the exact nature of rain-producing conditions in the Khartoum region, in general they conclude that there is a dominance of local storm development to the east and southeast of Khartoum. This study shows more precisely the meso-scale distribution of cumuliform clouds and evaluates cloud distribution in terms of surface features. A study of cumulus development and distribution was made by visual observation during the rainy seasons, July to September, of 1964 and 1965. Hourly observations were made on 102 days to determine the area or areas of the first cumulus development of the day. Orographic and vegetative inducements of cloud are rejected and the distribution of water and irrigated surfaces presents the closest ralationship to the cloud patterns, with cloud developing on the windward side of water surfaces.

23 Results of meteorological observations in Upper Egypt and Sudan (in German)
Hann,J. (1908) Meteorologische Zeitschrift (Berlin), 25, 559-62

A tabulated summary is made of climatological observations kept between 1901-05 at Khartoum, Aswan, Berber, Ed Dueim and Mongalla.

24 Summer weather over the Anglo-Egyptian Sudan
Harry,T. (1947) Weather 2, 281-84

This is a general description of summer weather, reproduced from the Navigation Bulletin of the RAF. Comment is mostly made on the August synoptic situation and thunderstorm and haboob frequencies are of major importance. Widespread summer sandstorms are distinguished from intense, downdraught haboobs which predominantly occur in the afternoon and night. The description is written from the perspective of air pilots. A photograph of a haboob is included.

25 The climate of the Sudan
Ireland,A.W. (1952) pp.62-83 in Agriculture in the Sudan (ed.) Tothill,J., Oxford University Press, London

A brief summary of the atmospheric circulation and resulting climate of Sudan is presented with the aid of half-a-dozen maps. Of greater value perhaps, are the eight tables of monthly mean statistics for 35 stations throughout Sudan. These are for: Piche evaporation, rainfall, relative humidity, mean maximum and minimum temperature, mean temperature range and absolute maximum and minimum temperatures. The data are based on varying periods up to 1940.

26 Solar radiation over Sudan - comparison of measured and predicted data
Khogali,A. (1983) Solar Energy 31(1), 45-53

Measurements of global solar irradiance on a horizontal surface at 14 meteorological stations in Sudan are compared with predictions made by two independent methods. The first method is based on Angstrom formula which correlates relative global solar irradiance H/H_o to corresponding relative duration of bright sunshine n/N. Regional regression coefficients are obtained and used for prediction of global solar irradiance. The agreement with measurements is better than 7.5%. In the second method an empirical relation due to Barbaro et al. which uses sunshine duration and minimum air mass inputs is employed. An appropriate regional parameter is determined and used to predict solar irradiance at all stations with an accuracy better than 8%. A comparison of the two methods is presented. Eight stations have measurement records of more than 15 years to 1980 (Port Sudan, Shambat, Wad Medani, El Fasher, Abu Na'ama, Ghazala Gawazat, Malakal and Juba) and six stations of less than 15 years (Dongola, Hudeiba, Aroma, El Showak, Zalingei and Kadugli).

27 An exceptionally cool season in north-eastern Africa
Lebon,J.H.G. (1958) Weather 13, 153-57

The weather of January to March 1957 was remarkable for persistently sub-normal temperatures, because polar continental air from the Eurasian land mass predominated over air currents from other sources. The synoptic charts for northern Africa and southwest Asia revealed that outflow of air from the Russian winter anticyclone was exceptionally strong. The coldest outburst occurred at the end of January when temperatures fell to 7-10 °C below the average. Recorded temperatures were only very slightly above absolute minima at Khartoum. An intensifying cold front passing NW-SE over the Mediterranean and Egypt was responsible.

28 Iceberg in the Sudan
Lee,B.W. (1950) Weather 5, 108

A likely hail storm in Northern Darfur near Kereinik is reported, although local reports describe the event as an `iceberg falling from the sky´.

29 Climatic influences in Egypt and the eastern Sudan
Lyons,H.G. (1910) Qtly. Jl. of the Royal Met. Soc. 36, 211-35

The author reviews climatic knowledge of Sudan and the advance in understanding and detail from Bruckner´s comments of 1899 (see 12) is marked. The review incorporates data on Nile discharge in Sudan, mean monthly temperatures, pressures, relative humidity and rainfall, January and July pressure charts and a discussion on the monsoonal regime over Sudan. Connections are made between winter pressure in Egypt and rainfall in Ethiopia in the following summer (a primitive teleconnection). Some specific rainfall data for Khartoum, Kassala, Ed Dueim and Wad Medani are presented, Khartoum´s mean rainfall being 140mm. This is excellent reading for an appreciation of the state of knowledge of northeast African climate in the first decade of the 20th century.

30 Low dew point at Khartoum
Matthews,L.S. (1950) Weather 5, 263

A very low dew point temperature of -8.3°C recorded at 0300hrs. on May 7th 1950 at Khartoum is discussed. Meteorological data are presented for the 24 hour period surrounding the event.

31 Climate of the Sudan [**]
Mustafa,G. (1965) Unpublished report, Sudan Meteorological Service, Khartoum

32 The diurnal regime of rainfall at Khartoum [**]
Oliver,J.E. (1963) Geogl. Mag. (Univ. of Khartoum), 1, 20-22

33 **The climate of Khartoum Province**
Oliver,J.E. (1965) Sudan Notes and Records 46, 90-129

A detailed summary of the climatic charactersitics of Khartoum Province, although most of the data are for Khartoum itself. 1921-50 and 1931-60 reference periods are used. The paper consists of a commentary on each of the main climatic parameters in turn, air temperature, soil temperature, sunshine and cloudiness, rainfall, relative humidity, evaporation, wind and haboobs. This discussion is prefaced by a comment on the annual synoptic regime and concluded by a comment on the applied dimension of the previous statistics. 21 tables of statistics and 8 diagrams are also included making it a valuable published data source from the mid-1960s. There is no discussion of any real concept of climatic change or variability.

34 **Soil temperatures in the arid tropics, with reference to Khartoum**
Oliver,J.E. (1966) Jl. of Trop. Geog. 23, 47-54

The author discusses the factors influencing soil temperatures in the tropics. Data from Khartoum are used for examples. The intensity of insolation in the arid tropical regions is the dominant control of soil temperatures. Moisture from rain plays a highly significant part at certain times of the year, but its effect in dry soils in causing abrupt changes in soil temperatures is different from that normally experienced in permanently moist soils. The annual pattern and diurnal regime of soil temperatures must therefore be considered in relation to the climatic region.

35 **A rainfall map of the Sudan Gezira**
Randall,J.R. (1961) Sudan Notes and Records 62, 29-36

Up to 123 station rainfall records are used to compare annual isohyetal maps over the Gezira based on different densities of stations. Generalised maps at 100mm intervals using 30-year mean rainfalls from only 16 stations are suggested to be inadequate for agro-climatological purposes. A much higher density of gauges should be used to compile maps. Some attempt is then made to account for the micro-variations in annual and monthly isohyets over the irrigated Gezira which leads into discussions of precipitation mechanisms. Some comparisons are drawn with other irrigated terrain rainfalls in the U.S.S.R. and the U.S.A.

36 **The climate of the Sudan** [**]
Rath,U.C.W. (1955) pp.105-12 in Proceedings of the Sudan Philosophy Society Conference in food and society in the Sudan Khartoum

37 **The development of cumulonimbus cloud over the Sudan** [**]
Rath,U.C.W. (1955) Technical Note No.1 (Old series), Sudan Meteorological Service, Khartoum

38 **The climate of the Egyptian Sudan** [**]
Stone,C.P. (1885) Science 5

39 The climate of the study area
Sudan Government (1983) pp.14-30 in, Development studies in the Jonglei Canal area Final Report, Vol. 2 'Background', Ministry of Finance and Economic Planning, Khartoum

This presents detailed information on the climatic statistics of the Jonglei area in southern Sudan: temperature, humidity, sunshine, solar radiation, wind, evaporation and rainfall. It is information rather than analysis, prepared under the auspicies of the Jonglei Development Council.

40 Annual Meteorological Report
Sudan Meteorolgical Service (1950-85) Volumes 1-36, Khartoum

Full monthly meteorological summaries are incorporated for between 50 and 90 Sudanese meteorological stations. Mean monthly pressure, air temperature, vapour pressure, relative humidity, rainfall, surface wind, cloud amount, Piche evaporation and visibility are among the parameters included. Additionally, until 1980 when the Annual Rainfall Report (see 128) was instigated, monthly and annual rainfall totals were included for varying numbers of raingauge stations (between 200 and 700).

41 Wind speed statistics [**]
Sudan Meteorological Service (1954) Pamphlet No.3, Khartoum

42 Khartoum temperatures [**]
Sudan Meteorological Service (1955) Pamphlet No.5, Khartoum

43 The climate of Khartoum
Sutton,L.J. (1923) Ministry of Public Works, Egypt, Physical Department, Paper No.9, Cairo, 65pp.

A thorough survey of the climate of Khartoum is made including numerous illustrations, charts and tables. The climatological elements examined in detail are atmospheric pressure, temperature, humidity, clouds, sunshine, haze, surface and upper air winds, rainfall and evaporation.

44 Climatological normals for Egypt and the Sudan
Wright,J.W. (1938) Geog. Jl. 92, 563-64

The author comments on the 'normals' recently published for over 100 Egyptian and Sudanese meteorological stations and an equal number of raingauges (see 16). There is no standard period, however, for these normals. A relationship between Egyptian winter rainfall and Sudanese summer rainfall is remarked upon, as is the diurnal surface wind regime at Khartoum, which reaches a maxima at 0900 hours.

45 The climate of the Sudan according to three climatic classifications [**]
Youssef,A.M.F. (1966) Bulletine de la Societe de Geographie d'Egypte 39, 61-82

b. METEOROLOGY AND SYNOPTIC CLIMATOLOGY

46 **Thunderstorms in the Sudan**
Abdalla,M.K. (1969) Unpublished MSc Thesis (No.12), University of Birmingham, 59pp.

47 **The study of the circulation regime in N.E.Africa conformably (sic) to the problems of weather forecasts [**]**
Ahmed,M. El B.M. (1982) Unpublished PhD Thesis, Leningrad Hydrometeorology Institute, 239pp.

Examples of synoptic circulation data are included from Egypt, Sudan, Ethiopia and Somali.

48 **The meteorology of Sudan**
Bhalotra,Y.P.R. (1963) Memoir No.6, Sudan Meteorological Service, Khartoum, 136pp.

A comprehensive guide to the mechanics and characteristics of climate in Sudan representing the contemporary understanding of the early 1960s. This account remains perhaps the best detailed introduction to the meteorology of Sudan.

49 **Upper air research at Roseires: preliminary notice of the results obtained at Roseires during May and July, 1909**
Curry,P.A. (1909) Cairo Scientific Journal 3, 254-56

The author studies the circulation of the atmosphere above the Blue Nile area during the rainy season and attempts to confirm that rains probably come from the South Atlantic. Wind direction and predominance and velocity at different altitudes are summarised in diagrammatic form.

50 **Objective method for forecasting rain and thunderstorms at Khartoum and east central Sudan [**]**
Delsi,M. (1965) Unpublished report, Sudan Meteorological Service, Khartoum

51 **Synoptic circulation in relation to seasonal rainfall and Nile flood in the Sudan**
Delsi,M. (1973) Unpublished M.Phil. Thesis, University of Reading

It is shown that rainfall in the Sudan is closely related to the behaviour of the ridge of the contours of the 700mb surface which separates the southwesterly low level flow from the upper easterlies. Synoptic scale circulation systems are identified at this level and their behaviour appears to be closely related to mid-latitude disturbances. Similarly, monthly rainfall has been related to the monthly mean circultaion at the 700mb level. It is also shown that once the changeover of the circulation pattern from the winter to the summer regime (which is completed by June) has occurred, the circulation tends to persist throughout the summer, thus exhibiting a mode of circulation of a time-scale of a season. This

phenomenon was employed in the forecasting of seasonal rainfall and the Nile flood in the Sudan.

52 **Upper winds at Wadi Halfa (Sudan)** [**]
Durward,J. (1936) Professional Notes, Met. Office, London, No.72, 11pp.

A year's observations of upper air winds at Wadi Halfa are summarised in discussion and tables.

53 **Handbook of instruments for meteorological observers in Egypt, the Sudan and Palestine**
Egyptian Government (1923) Ministry of Public Works, Physical Department, 56pp. Cairo

One part of this publication contains instructions for taking and recording observations and notes on care of instruments. The second part gives fuller descriptions of the various instruments in use at meteorological stations of the Egyptian-Sudanese Service and instructions as to how they should be exposed.

54 **The formation of depressions of the Khamsin type**
El Fandy,M.G. (1940) Qtly. Jl. of the Royal Met. Soc. 66, 323-35

A further study has been made of the conditions in spring which produce khamsin conditions in Egypt. Depressions are then formed which travel from west to east roughly parallel to the North African coast. Such depressions are regarded as produced by unstable conditions prevailing between intensely heated air to the south and cool air to the north. The cold air is due to an anticyclonic distribution in the Mediterranean, while the hot air is drawn northward from the Sudanese low when it suffers large oscillations towards the north. These oscillations are in the main brought about by the travelling depressions, the current bringing the hot air being especially strong when the depressions reach the Red Sea. [Several pressure maps are included of spring conditions over Sudan].

55 **The effect of the Sudan Monsoon low on the development of thundery conditions in Egypt, Palestine and Syria**
El Fandy,M.G. (1948) Qtly. Jl. of the Royal Met. Soc. 74, 31-38

The thundery conditions which often develop in Egypt, Palestine and Syria, during the autumn, have been further investigated. They have been found to occur when the Sudan monsoon low intensifies towards the north and supplies the eastern Mediterranean with a warm south-easterly current. In a great many cases, shallow depressions form over the south-eastern Mediterranean, or the adjacent land areas, as a result of the meeting of the above current with the relatively cold north-easterly air of anti-cyclonic distribution in Asia Minor.

56 Forecasting the summer weather of the Sudan and the rains that lead to the Nile floods
El Fandy,M.G. (1949) Qtly. Jl. of the Royal Met. Soc. 75, 375-98

In the Sudan, pressure-distribution shows a characteristic seasonal variation. In summer, an oscillatory barometric minimum is located over the NE Sudan and is normally an area of almost cloudless skies and intense insolation; while over the greater part of Ethiopia and SE Sudan extends a barometric maximum which also suffers fluctuations in its strength and northward extent. `Haboobs´ and local convectional rain over the Sudan usually accompany the northward oscillations of this barometric maximum. The paper studies the disturbances in the average pressure distribution and the variations in the generl wind circulation. Four different types of summer disturbance have been distinguished as follows: i) sandstorms with a modification of the general circulation by the onset of strong southerly winds; ii) duststorms (or `haboobs´) with induced cold fronts or line squalls set up by thunderstorms; iii) low-level thunderstorms which form by direct convection within the S to SW monsoon; iv) high-level thunderstorms followed by fairly widespread outbreaks of rain. [See correspondence with Soliman (78) re. ICZ terminology].

57 Effects of topography and other features on the movement of lows in the Mid-East and the Sudan
El Fandy,M.G. (1950) Bulletin of the American Met. Soc. 31, 375-84

58 Troughs in the Upper Westerlies and cyclonic developments in the Nile Valley
El Fandy,M.G. (1950) Qtly. Jl. of the Royal Met. Soc. 76, 166-72

In the Middle East area troughs in the upper westerlies are found, generally, at levels over 2km intruding into low latitudes as far south as the northern Sudan (20°N). These troughs usually travel eastwards, but tend to trail over the NW of the Ethiopian Plateau. Analysis of these troughs has some value in forecasting upper winds on the Cairo-Khartoum air route and the local weather associated with these cyclones and also in studying the general circulation in these latitudes.

59 The tropical easterly jet stream over Africa [**]
El Tantawy,A.H.I. (1963) Egyptian Meteorological Department, Cairo, 19pp.

60 Investigations on the Tropical Easterly Jet
Flohn,H. (1964) Bonner Meteorologische Abhandlungen No.4, 83pp.

During the northern summer, the Tropical Easterly Jet (TEJ) extends in the layer 200-100mb in the latitutde belt 5-20°N from the Philippines across southern Asia and northern Africa to the western Atlantic. Its persistency in position, direction and intensity is remarkable. Based on all available actual wind observations during the period July-August 1956-62, the cross-circulations in the entrance and exit region of the TEJ are quantitatively estimated. In the exit region (above Africa) the high-tropospheric component perpendicular to the TEJ-axis is directed towards the north and

produces large-scale subsidence on the northern side of the jet. The unique summer aridity of the desert belt from the western Sahara to Pakistan - which extends futher equatorward than in all other continents - is strongly correlated with this forced descending motion on the northern side of the TEJ exit region.

61 **Contributions to a synoptic climatology of the Red Sea trench and adjacent territories**
Flohn,H. (1965) Bonner Meteorologische Abhandlungen No.5, 34pp.

The occurrence of cool-season rains in the Red Sea Trench between latitude 13-20 °N is derived from an interaction between a regular meso-scale convergence zone, diurnal circulations along the coasts and escarpments and synoptic-scale processes. The Red Sea Convergence Zone is produced by the semi-permanent Cyprus Low in the eastern Mediterranean together with the orographically forced convergence of the NE-trades into the Gulf of Aden. Data from Sudan, especially the Red Sea Hills area, are included in the analysis and the synoptic patterns and processes discussed have a major bearing on the climatology of NE Sudan.

62 **A note on the influx of cold air into Egypt and northern Sudan from 18th to 23rd April, 1930**
Flower,W.D. (1930) Qtly. Jl. of the Royal Met. Soc. 66, 216-22

A synoptic analysis is made of conditions during this period when two depressions of khamsin type passed over lower Egypt and Palestine; pressure in the centre of the first was abnormally low for the time of year in the region and the movement of cold air into Egypt and Sudan is considered.

63 **Spatial distribution of rainfall in the Sudan**
Hammer,R.M. (1967) Unpublished PhD Thesis, University of California, 315pp.

This thesis studies the spatial distribution of rainfall south of the ITC during the rainy season in Sudan (May-October). The basis of the analysis is a series of daily maps showing the distribution of rainfall stations reporting rainfall. On each of these maps areas were delimited according to the percentage of stations reporting rainfall within the area. This analysis was completed for two years, 1953 and 1961. The grosser aspects of rainfall for these two years showed striking differences. 1953 was a year of rainfall deficiency in southern Sudan and an above average rainfall year in most of central Sudan. In contrast, 1961 was a well above average year for the southern Sudan and about average in central Sudan. The investigation of daily rainfall distribution patterns showed that there was a definite sequence of development. Over a period of four to five days, rainfall tended to increase to a peak and then to decline to the level of the first day. The most common pattern of rainfall observed is one of scattered patches with areas of no rainfall in between. The areas of rainfall appear to develop in situ and rarely show movement from one day to the next.

64 **Spatial characteristics of thunderstorm development in the central Sudan**
Hammer,R.M. (1971) Proceedings of the American Association of Geogs. 3, 67-70

65 **Air currents at different heights during the rainy season in the Egyptian Sudan** (in German)
Hann,J. (1909) Meteorologische Zeitschrift (Berlin), 26, 565-66

The author reports on balloon experiments carried out by B.F.E.Keeling and L.Clower into air currents up to an altitude of 14km at Mongalla in southern Sudan. These were carried out in July and August of 1907 and followed similar experiments at Cairo and Khartoum. Wind velocity and direction were detemined for 1km intervals up to 14km and the discontinuity between lower westerlies and upper easterlies was found to be between 4 and 6kms [this experiment is reported more fully in the Cairo Scientific Journal of 1908, which is not listed in this bibliography]. See also 85.

66 **Takoradi-Khartoum air route**
Hare,F.K. (1943) Aviation Meteorological Report No.17, 42pp., Meteorological Office, London

Original version of the report later published in Climatic Change (see 67). Climatic tables for El Geneina, El Fasher, El Obeid, Jebel Aulia and Khartoum are included. Written under wartime conditions and had restricted circulation.

67 **Takoradi-Khartoum air route: general synoptic climate**
Hare,F.K. (1977) Climatic change 1, 157-72

The Takoradi-Khartoum air route runs from the Gold Coast across the interior of Africa to the Nile valley at Khartoum. It covers 35 degrees of longitude; at one point the route lies 1200 miles from the nearest sea. This paper originally written in 1942 (see 66), describes the synoptic climatology of this traverse across the African Sahel in terms of general controls on weather and daily changes in monsoon air. Four photographs are included.

68 **Forecasting divergence as a tool to forecast thunderstorms in the Sudan [**]**
Kruger,E. (1960) pp.155-67 in Tropical meteorology in Africa (ed.) Berganon,D.F., Munitalp Foundation, Nairobi

69 **On the relation between variations of atmospheric pressure in northeast Africa**
Lyons,H.G. (1905) Proc. of the Royal Soc. of London (A) 76, 66-86

The author attempts to show that pressure anomalies are closely related to the excess or deficit of the monsoon rainfall of Abyssinia and consequently to the Nile flood. Available data concerning Abyssinian rainfall are summarised and other data for flood and pressure conditions from various places in Sudan and Egypt are examined and compared.

70 Some unsolved problems of the Nile Basin
Lyons,H.G. (1908) Cairo Scientific Journal 2, 79-94

This contains discussion of some meteorological problems of the region considering the questions of the monsoon rains of Abyssinia and Sudan, of climatic changes in the whole Nile region and of underground water and Nile levels.

71 The variations of the Sudan monsoon low
Mahmoud,H. (1940) Qtly. Jl. of the Royal Met. Soc. 66, 335-36

This paper briefly comments on the correlation between surface temperature and pressure using data from five Sudanese stations for the months of January and April. The association is a very strong positive relationship confirming that the Sudan monsoon low develops in response to rising temperatures.

72 Upper air data for stations maintained by the Meteorological Office, Part 4, Khartoum [**]
Meteorological Office (1955) H.M.S.O., London

Radiosonde observations of temperature and humidity and radar wind measurements at standard pressure levels, 1953-55.

73 Electronics and meteorology in the Sudan
Millward,W.D. (1957) Sudan Eng. Soc. Jl. 1956-57, 47-50

74 On the synoptic climatology of summer rainfall over central Sudan
Osman,O.El T. (1969) Unpublished MSc Thesis, University of Wisconsin, 64pp.

75 On the synoptic climatology of summer rainfall over central Sudan
Osman,O. El T. and Hastenrath,S.L. (1969) Archiv für Meteorologie, Geophysik und Bioklimatologie (Series B), 17, 297-324

The development and decay of the summer circulation over the Sudan are studied on the basis of mean monthly pressure, relative humidity, surface streamline charts, 300mb contour maps and meridional-vertical cross-sections. The Intertropical Front (ITF) is identified as a discontinuity in the surface moisture and wind field. Synoptic case studies for selected periods (e.g. a wet July 1958 and a dry July 1966) hint at the role of the upper-tropospheric circulation in hampering the rainfall activity, but hypotheses await testing on the basis of ampler observational data.

76 Thunderstorms over Sudan [**]
Rath,U.C.W. (1955) Technical Note No.2 (Old series), Sudan Meteorological Service, Khartoum

77 Sferics in the Sudan
Rogers,P. (1956) WMO Bulletin 5, 159-60

A report on the establishment of a sferics system to locate thunderstorm activity in Sudan. Three sets were in operation in June 1956, at Khartoum, El Obeid and Port Sudan, with the latter to be moved to Er Roseires. A fourth is recommended to obtain more accurate fixes. Radio transmission of information is used, with hourly observations during daylight.

78 Summer weather of the Sudan
Soliman,H.K. (1950) Qtly. Jl. of the Royal Met. Soc. 76, 487-89

This consists of correspondence with El Fandy following his 1949 paper (see **56**). It raises a dispute concerned with the location and terminology of the Inter-tropical Convergence Zone (ICZ).

79 The meteorology of central Africa
Solot,S.B. (1943) U.S. Air Weather Service, Research Report 105-50, 59pp. Accra, West Africa

A comprehensive and detailed survey made principally of the weather of the Anglo-Egyptian Sudan. The chapters consider the general circulation in the lower circulation, air mass properties, the intertropical front, haze, dust and sandstorms, harmattan haze, rainfall in the Sudan and lastly dynamic climatology and classification. A number of synoptic and adiabatic charts and diagrams are appended.

80 General circulation over the Anglo-Egyptian Sudan and adjacent regions
Solot,S.B. (1950) Bulletin of the American Met. Soc. 31, 85-94

A study is made of air flow patterns over northeast Africa during four seasons: the dry season, the season of approaching rains, the rainy season and the season of retreating rains. Detailed one-day and five-day trajectories of the air flow in the layer from the surface to 10,000 feet, typical synoptic charts for the various seasons, seasonal upper air temperatures, air mass properties and location of upper air observation stations are presented in graphs, charts and tables. The ITC (Intertropical Convergence Zone) is shown to be the major climatic control [see **84** for comments].

81 The upper currents of the atmosphere in Egypt and the Sudan
Sutton,L.J. (1925) Ministry of Public Works, Physical Department, Paper No.17, 136pp. Cairo

Detailed and extensive work presents a summary of most available observations of motion in the upper strata of the atmosphere over Egypt and Sudan. For Egypt the objective is to find mean values of the wind velocity and direction at various heights and to associate these values, where possible, with recognised types of pressure distribution at the surface. This method is considered inapplicable to the Sudan due to paucity of observations at that time. Charts illustrate velocities, directions and frequencies of upper air winds. Some rainfall maps are included.

82 **The upper winds at Cairo and Khartoum**
Sutton,L.J. (1930) Ministry of Public Works, Physical Department, Paper No.27, 52pp. Cairo

The results of 2600 pilot balloon observations between 1920-28 at Cairo and Khartoum are presented as monthly frequency tables of direction and speed, for altitude intervals of 500 meters; observations are included for 5,000 and 10,000 meters. Direction of resultant wind at each altitude is tabulated.

83 **Synoptic disturbances over the Nile valley north of the intertropical convergence zone**
Tucker,M.R. and Pedgley,D.E. (1977) Tellus 29, 17-24

The synoptic climatology of disturbances crossing the Nile Valley of Egypt and Sudan during 1967 was studied using 1200 GMT horizontal time sections at the surface and upper levels for 13 stations roughly along a north-south line from Nicosia (35°N) to Juba (5°N). Disturbances were defined as prescribed depressions from dominant surface wind direction or speed at two or more stations. During the year 43 disturbances were identified, most frequently in winter and spring. Almost all were windshift lines associated either with cyclonic centres over the north of the Mediterranean, or with decaying depressions. The lines were accompanied by changes in temperature tendency and were therefore advective discontinuities. Because they were followed by falling temperatures, they were also cold fronts. In winter, cool air at the rear of disturbances penetrated deep into Sudan, while in late spring, khamsin weather with southerly winds and interdiurnal temperature increases of up to 13°C preceded fronts over north Egypt. Most disturbances were associated with troughs in the upper tropospheric westerlies.

84 **General circulation in the Anglo-Egyptian Sudan**
Van Burkalow,A. (1951) Geogl. Rev. 41, 503

This note is a comment on the content of the paper by Solot (see **80**). The role of intertropical convergence in the regional circulation is discussed, utilising radiosonde data collected during the war years.

85 **An examination into the air currents during the rainy season in the Egyptian Sudan (in German)**
Wagner,A. (1910) Meteorologische Zeitschrift (Berlin), 27, 227-28

Similar experiments to those listed by Hann (see **65**) were carried out at Er Roseires in May-July of 1909. A total of 79 balloon ascents were monitored by theodolite and wind velocity and direction measurements obtained. A detailed table of results in presented which indicates a switch in the resultant air flow from westerly to easterly at between 2 and 2.5km.

86 **Sudan rainfall variability and tropospheric circulation**
Zahran,A.M.B. (1979) Unpublished MA Thesis, University of Khartoum, 343pp.

The thesis is concerned with the relationship between rainfall variability, including drought years, and the behaviour of the lower tropospheric circulation. Lower tropospheric wind data is available for 20 stations in Sudan from balloon ascents to about 6km. Rainfall variability is investigated through the use of deciles to define extreme rainfall anomalies. Data are for selected years in the 1960s and 1970s. The thesis only marginally touches on upper tropospheric circulation, using radiosonde ascents up to 12km for Khartoum for 1959-61.

c. PRECIPITATION CLIMATOLOGY

87 **Rainfall distribution: a simple assessment as seen for El Geneina area**
Abdalla,H.A.B. (1982) Unpublished report, Sudan Meteorological Service, Khartoum

88 **Spatial variability of rainfall in Jebel Marra Region of Sudan, 1950**
Bhalotra,Y.P.R. (1960) Scientific Note No.1, Sudan Meteorological Service, Khartoum

89 **Rain at Port Sudan [**]**
Delsi,M. (1967) Unpublished report, Sudan Meteorological Service, Khartoum

90 **The distribution of catchment coverage by stationary rainstorms**
Eagleson,P.S. (1984) Water Resources Research 20, 581-90

The occurrence of wetted rainstorm area within a catchment is modeled as a Poisson arrival process in which each storm is composed of stationary, non-overlapping, independent random cell clusters whose centres are Poisson-distributed in space and whose areas are fractals. The two Poisson parameters and hence the first two moments of the wetted fraction are derived in terms of catchment average characteristics of the (observable) station precipitation. The model is used to estimate spatial properties of tropical air mass thunderstorms on six tropical catchments in the Sudan.

91 **A regional study of seasonal rainfall conditions in the Sudan**
El Seed,A.M.G. (1983) Unpublished PhD Thesis, University of Sheffield

92 **Some aspects of the annual and monthly rainfall over the Sudan**
El Tom,M.A. (1966) Unpublished MA Thesis, University of Durham

Special attention is given to the variability of both the annual and monthly rainfall over Sudan. The percentage probability of receiving below or above certain amounts of rainfall is of great significance to the farmer and is hence determined here. The study is concluded by a statistical analysis (multiple regression) of the relationships between the mean rainfall and four climatic factors which appear to be important contributors to rainfall over Sudan. Sixty-six stations are used in the study, mean values being those for the 1931-60 reference period.

93 **Statistical analysis of rainfall over the Sudan**
El Tom,M.A. (1969) Geographical Journal 135, 378-87

The paper analyses statistically the relationships between annual and monthly rainfall and four likely determining factors: the location of the ITCZ, relief, monsoonal dominance and line-squalls. These are selected because it is believed that the rainfall over Sudan is associated with the movements of the ITCZ and the monsoonal winds, the effects of which are influenced by relief. Line-squalls also seem to play an important part in

the distribution of rainfall especially in the central parts of the country. Multiple regression is applied to data from 15 representative stations to establish the degree of importance of these four factors. Latitude (i.e. ITCZ) is found to be the most important single factor, with the August regression model presenting the highest degree of explanation. An additional factor of possible importance not investigated is surface temperature, especially where convectional rainfall predominates.

94 **A contribution to the precipitation climatology of the Sudan**
El Tom,M.A. (1971) Unpublished PhD Thesis, University of Sheffield, 335pp.

The thesis investigates the annual, monthly and pentadly rainfall distribution over Sudan, using 65 stations and statistics from the period 1931-60. The resulting distributions are described and anomalies, such as the apparent dryness of the Sudd, explained. There is some extensive discussion on measures of rainfall variability most appropriate for such a climatic regime. The thesis forms the basis of the author's later book [see 101].

95 **The reliability of rainfall over the Sudan**
El Tom,M.A. (1972) Geografiska Annaler (A) 54, 28-31

The paper attempts to throw some light on the variability and reliability of rainfall over the Sudan. Twenty stations are used to calculate the standard deviations and the coefficients of variation. The latter index gives a more realistic impression of the rainfall variability. Also, an attempt is made to measure the reliability of rainfall as a means for determining the extent and reliability of rain-cultivation in the country. The magnitude of the risk involved in the transitional areas is indicated by the percentage probability of receiving critical rainfall values.

96 **Towards a rational estimation of the average rainfall in the Sudan**
El Tom,M.A. (1972) Sudan Notes and Records 53, 125-53

Regression analysis is employed to define a model determining mean pentad rainfall over Sudan. The model is constructed using 1931-60 pentad means for 19 stations throughout Sudan. Three explanatory variables are incorporated (latitude, distance from the southwest border and distance from the eastern border) with a fourth later being added (mean daily maximum temperature) to represent convective processes. Residuals are improved by sub-dividing the country into three zones (8.5 and 17 degrees N being the boundaries) and constructing three separate regression models. The results of these models are presented in the paper through the 16 maps which accompany it. Mean pentad rainfall can be estimated for any location in Sudan within small, known error margins.

97 **A harmonic analysis of the rainfall over the Sudan**
El Tom,M.A. (1973) Jl. of Trop. Geography 37, 9-15

Harmonic analysis is employed to investigate the temporal pattern of precipitation over the Sudan. Analysis uses 19 stations from throughout Sudan based on mean pentad rainfalls for the period 1931-60. The analysis was carried to the 6th harmonic, with the first three accounting for between 75% and 98% of the variation in precipitation over Sudan. The

predominance of the 1st harmonic (80% over southeastern Sudan) reflects the marked bi-seasonal nature of Sudan rainfall. The results of the harmonic analysis may be used to assist in the regionalisation of precipitation regimes over Sudan.

98 **The variability of the pentad rainfall over the Sudan [**]**
El Tom,M.A. (1973) The East African Geogl. Review 2

99 **Some remarks on the seasonality of rainfall over the Sudan [**]**
El Tom,M.A. (1974) Bulletin de la Societe de Geographie D'Egypte 43/44

100 **The relative dryness of the White Nile**
El Tom,M.A. (1974) Sudan Notes and Records 55, 161-66

101 **The rains of the Sudan: mechanism and distribution**
El Tom,M.A. (1975) University of Khartoum Press, Khartoum, 89pp.

The book is organised in three main sections; i) the process of precipitation which is general in nature and not related directly to Sudan; ii) the mechanisms of precipitation in Sudan; iii) the distribution of precipitation in Sudan. This latter section looks at annual, monthly and seasonal distributions with the aid of 40 pages of rainfall distribution maps. It it assumed the data are from 1921-50, although this is nowhere specified. No indication either is given of the station density used to construct the diagrams.

102 **Times of daily rainfall occurrence in the Sudan and their hydrological significance [**]**
El Tom,M.A. (1977) Bulletin of Arab Research and Studies 8

103 **Rain from altocumulus clouds, central Sudan**
Flower,W.D. (1937) Meteorological Magazine 72, 163-64

Light showers around Khartoum and elsewhere in central Sudan were recorded between February 18th and 20th, 1937. These were associated with the passing of a cold front oriented NNE and SSW with a cloud base of 12,000 feet. Unusually, rain was falling from alto-cumulus cloud.

104 **Rainfall variability in the Sudan**
Hammer,R.M. (1967) Sudan Notes and Records 48, 167-70

The author uses an index of variability (standard deviation divided by mean) to study annual rainfall variability over Sudan. This observed distribution of the parameter is then compared with an expected distribution based on a standard exponential equation relating annual rainfall mean to the variability index. A map of the difference between observed and expected is presented and the outstanding anomalies discussed. The most noticeable of these is the unexpectedly high variability of the Sudd. The variability here, in a regime of 800-1000mm per year, is more akin with that expected under a regime of 400-500mm. No reason is put forward, but the issue highlighted for further investigation.

105 A note on rainfall in the Sudan
Hammer,R.M. (1968) Weather 23, 211

To study the contribution of various daily rainfall amounts to the total annual rainfall in Sudan, 24 stations were randomly selected from those available in 1961. The results produce a negative exponential curve of cumulative % of raindays against cumulative contribution to annual rainfall total. 15% of raindays produced 46% of total rainfall and 32% of days produced 72% of total rain. These results accord well with those from other tropical regions. A slight regional difference was detected indicating that a smaller number of dynamically induced rainfalls and a greater number of orographically-developed random convectional rainfalls may occur in southern Sudan.

106 Satellite evaluation of rainfall patterns and amounts in the Sudan
Hammer,R.M. (1970) Proceedings of a WMO-AMS symposium on tropical meteorology, Hawaii (June), 4A,1-4

Daily precipitation maps were prepared for central Sudan for the year 1968 from ground data from 182 stations for the months June to September. ESSA 3 and 5 imagery was overlayed for two sample fortnightly periods to compare cloud interpretation with ground-based rainfall measurement. In situ storm development was investigated and was favoured as a general pattern of rainfall behaviour over the westward propagation of specific storms over successive days. Previous storm cloud debris did not appear to provide a likely source for storm growth on the following day, which was as likely to occur in cloud-free regions.

107 Rainfall patterns in the Sudan
Hammer,R.M. (1972) Jl. of Trop. Geography 34, 40-50

This paper presents a kinematic study of the spatial and temporal characteristics of daily rainfall in the Sudan. From these characteristics a pattern of surface and cloud features is developed which can be used as a base for evaluating atmospheric dynamics in the Sudan. Four years are chosen, 1953, 1961, 1968 and 1969. The spatial evidence from the wet season of these years indicates the restricted effect of random storm rainfall. Extensive and heavy rainfall with limited interdaily movement is associated with quasi-periodic in situ development in the same general geographic locations. These rainfall characteristics appear to indicate the functions of surface features and low, middle and upper level air flow in storm development.

108 Spectral signatures of rainfall in the Sudan
Hammer,R.M. (1972) Trans. Am. Geophys. Un. 53, 388

This is an abstract of a paper presented at the annual conference of the American Geophysical Union. In recent years the presence of a 4-5 day cycle in tropical atmospheric conditions has been indicated by power spectrum analysis of wind and cloud data. The paper shows the spectral characteristics of rainfall in the Sudan during the 90-day period June 10th to September 7th. Daily rainfall totals for approximately 200 stations in the Sudan, from 4-17°N were analysed for this period during the years 1953, 61, 68, 69, 70. The spectral analysis indicates major power is contained in the 3 to 6 day period. During the average to above average rainfall years, 1953, 61 and 69, major deviance was centred at 4.3 days. In contrast, the

below average rainfall years, 1968 and 70, displayed pronounced bimodal characteristics which peaked at about 3 and 6 days, with the drier year, 1970, closer to the extremes. The spectral signatures combined with recorded rainfall data would seem to indicate significant changes occur in the frequency and intensity of the precipitation mechanism or a possible change of mechanism.

109 **Rainfall characteristics in eastern Sahel**
Hammer,R.M. (1976) Nature 263, 48-50

The recent drought conditions in the Sahel region of Africa have generated studies of long term trends in rainfall and monthly or seasonal atmospheric conditions related to the area. The results of these studies, in general, indicate no specific trends in precpitation and some evidence of direct and/or long distance relationships between monthly or seasonal atmospheric state and Sahelian rainfall. Presented here are the results of a study which suggest the major factor affecting rainfall during the drought was a change in easterly wave activity over northern tropical Africa. Daily rainfall from over 200 Sudanese stations for 6 years were analysed using power spectrum techniques. The three dry years (1969, 1970 and 1971) experienced a breakdown in the regular pulse of easterly wave activity.

110 **Rainfall at Khartoum** (in German)
Hann,J. (1909) Meteorologische Zeitschrift (Berlin), 26, 569-70

The author comments on the paper by Turstig in the Cairo Scientific Journal (see 130) and list the 1900-07 rainfalls at Khartoum. Work by J.I.Craig is also mentioned (see 116).

111 **Unusual rains in the 1982-83 `dry' season at Khartoum**
Hulme,M. (1983) Weather 38, 275-76

An unprecedented January rainfall of 1mm was recorded at Khartoum in 1983. This was associated with an incursion of cold air in a decaying low pressure system from the North African coast.

112 **The Nile Basin: Volume 6 `Monthly and annual rainfall totals and number of rainy days at stations in and near the Nile Basin for the period ending 1937'**
Hurst,H.E. and Black,R.P. (1938) Ministry of Public Works, Physical Department, 613pp. Cairo

Isohyetal maps of annual rainfall in the Nile Basin at 100mm intervals and tabulated rainfall data are included. Northeast Africa and east central Africa is covered. [Supplements 1 and 2 provide additional data for up to 1943 and 1950 respectively; Papers Nos. 43 and 49]

113 The Nile Basin
Hurst,H.E. and Phillips,P. (1931) Ministry of Public Works, Physical Department, Papers No.26, 114pp., Cairo

This paper is one of a series published by the same authors (Nos. 28-38, 1931-1943) which deal with the physiology of the Nile Basin. In addition to rainfall data from stations within the Nile Basin and discussion of a range of climatic parameters, Paper No.26 has an extensive bibliography on meteorological and climatological subjects in the Nile Basin.

114 Spatial variability of convective rainfall: a tripartite analysis from Africa
Lightwood,D.S. (1987) Unpublished BSc Dissertation, Department of Geography, University of Salford, 103pp.

The issue of spatial patterning of semi-arid convective rainfall is addressed, using data from Sudan, Kenya and Zimbabwe, although the major emphasis is on Sudan. The daily rainfalls of between 34 and 45 stations in central Sudan are analysed for 8 years between 1948 and 1979. Distinct spacing of storms is identified at between 35-50km, although this pattern varies between months and years. It is strongest in the 4 years before the recent drought and weakest in the 4 years during the post-1960s drought.

115 The physiography of the River Nile and its basin
Lyons,H.G. (1906) Cairo, 411pp.

This volume is concerned primarily with the hydrology of the Nile basin, but various monthly rainfall data from Sudan are included from 1899 to 1904. El Obeid, Ed Dueim and Khartoum are the main stations discussed [see pp. 161-79 especially].

116 The rains of the Nile Basin and the Nile flood
Lyons,H.G. and Craig,J.I.C. (1905-1913) Egyptian Survey Department, Paper Nos. 2, 9, 14, 17, 26, 27 and 32, Cairo

In the context of rainfall input to the hydrology of the Nile, this series of reports includes substantial comment on the meteorology of the central Nile basin in Sudan. Monthly rainfall data for the preceding year for up to 20 stations are tabulated and monthly isohyet maps constructed for central Sudan (these are based on only a handful of years, however, and require extensive extrapolation. The relationship between the level of the Nile floods, rainfall and atmospheric pressure is investigated.

117 The frequency of daily rainfalls of specified amounts in the Sudan
Matthews,L.S. (1969) Pamphlet No.6, Sudan Meteorological Service, Khartoum

This is an updated version of the pamphlet first published in 1955 by the Sudan Meteorological Service (see 123).

118 Estimating daily rainfall from satellite data in central Sudan
Mustafa,E.M. (1975) Unpublished MSc Thesis (No.40), University of Birmingham, 49pp.

This thesis uses ESSA-5 infrared imagery from the 1967 wet season to investigate the possibilities of estimating rainfall in central Sudan from satellite data. The area studied in detail was to the east of Khartoum, 14 to 16°N and 32 to 37°E. The methodology adopted for estimation followed the Barrett/Bristol method quite closely. Moderate success with an estimation index is achieved, with a low skill score of 0.13, but better than chance. Improvements, such as incorporating a `memory' factor in the index, are suggested. The study is prefaced with a fairly thorough synoptic analysis of precipitation in semi-arid Sudan including the easterly waves and diurnal patterns of rainfall.

119 Diurnal variations in the incidence of monsoon rainfall over the Sudan
Pedgley,D.E. (1969) Meteorological Magazine 98, 97-107 (Part I) and 129-34 (Part II)

Using 15 years of data from 17 autographic raingauges in Sudan, the diurnal incidence of monsoon rainfall has been tabulated by months. The considerable differences in space and time are systematic and reveal clearly defined patterns. These paterns are discussed in terms of the likely mechanisms for rainfall growth and suppression. Daytime convection, leading to a maximum incidence during the afternoon and early evening, is dominant only in places distant from the Ethiopian Highlands. Elsewhere, rainfalls are more evenly distributed throughout the day, with weak maxima possible at any time depending on location and month. However, an early morning maxima occurs widely. The Ethiopian Highlands appear to influence the diurnal pattern in several ways and over distances of 100kms.

120 Precipitation and climatic change in central Sudan
Perry,A.H. (1986) pp.33-42 in, Rural development in White Nile province, Sudan (ed.) Davies,H.R.J., United Nations University, Tokyo

A brief examination of the precipitation record of three stations along the northern White Nile is made in the context of a geographical research programme into land degradation. The paper is largely a review of other recent climatic work, although some detailed rainfall data is provided for Khartoum, Ed Dueim and El Geteina.

121 Rainfall averages, 1921-50
Sudan Meteorological Service (1954) Pamphlet No.1, Khartoum

Tables of monthly and annual rainfall averages to the nearest mm for the period 1921-50 for just over 200 stations are included. Not all stations are based on the full 30-year records.

122 Annual rainfall parameters, 1921-50
Sudan Meteorological Service (1954) Pamphlet No.2, Khartoum

123 The frequency of daily rainfalls of specified amounts in the Sudan
Sudan Meteorological Service (1955) Pamphlet No.6, Khartoum

124 **Rain-day averages, 1921-50**
Sudan Meteorological Service (1955) Pamphlet No.4, Khartoum

125 **Rain-day averages, 1931-60**
Sudan Meteorological Service (1963) Pamphlet No.4, Khartoum

This is an update of the 1955 pamphlet No.4 (see 125), using 1931-60 'normal' period rather than 1921-50.

126 **Average pentad rainfall**
Sudan Meteorological Service (1963) Pamphlet No.7, Khartoum

127 **Rainfall averages, 1941-70**
Sudan Meteorological Service (1973) Pamphlet No.1 (New series), Khartoum

Monthly and annual rainfall averages for the standard 30-year period 1941-70 are included. The number of stations is not known. This updates the 1921-50 pamphlet (see 122).

128 **Annual Rainfall Report**
Sudan Meteorological Service (1980-86) Vols. 1-7, Khartoum

An on-going annual publication which lists annual and monthly rainfall totals, 1mm and 10mm rainday frequencies and maximum rainfall in each month. The number of stations inlcuded varies between 50 and 100, although several of these may have no returns incorporated. Data should be very carefully checked for errors and omissions.

129 **Diurnal frequency and direction of approach of rainstorms in Sudan**
Turstig,R. (1908) Cairo Scientific Journal 2, 358-63

This study, primarily of rainfall data from Omdurman between 1900-05, investigated the diurnal pattern of rainfall and the direction from which storm events approached Khartoum. A clear nocturnal rainfall regime was identified and the majority of storms approached from the southeast. Although based on a sample of only 6 years, some differences between wet and dry years in both parameters were identified.

130 **Rainfall in Sudan**
Turstig,R. (1908) Cairo Scientific Journal 2, 391-98

An analysis of the short record of rainfall data available from Sudan up to 1907. The author suggests that it is not the heaviest falls that determine the magnitude of the annual total, but the frequency of falls between 20 and 40mm [see 110].

d. APPLIED CLIMATOLOGY

131 **Recent approaches to rainfall analysis and its relation to agriculture**
Abdalla,H.A.B. (1980) Unpublished MSc Thesis, University of Reading, 103pp.

This study deals with the problems of rainfall analysis in relation to agriculture in arid and semi-arid regions of the tropics. Work has been concentrated on advanced methods of rainfall analysis. A brief description of the statistical theory is first given, followed by a detailed study of Francistown in Botswana. The statistical methods are then used for a comparative study between rainfall series in Sudan and Botswana. Particular emphasis is given to the distribution of dry spells within the rainy season and the distribution of rain spells in relation to the water requirements of major crops.

132 **An agrometeorological study of the agricultural prospects at El Fasher**
Abdalla,H.A.B. (1981) Sudan Meteorological Service, Khartoum

133 **Dunes and their environment in northern Sudan**
Abdu,A.S.El D. (1975) Agricultural Research Council, Technical Bulletin No. 2, Khartoum, 68pp.

This bulletin investigates the characteristics of dunes and their relationship with wind fields in northern Sudan. A brief analysis of the wind field is provided with wind roses and wind resultants over the northern part of the country [see pp.45-53 especially].

134 **Monitoring the impact of climate and man on land transformation: a study in an arid and semi-arid environment in central Sudan**
Ahlcrona,E. (1986) Lund Publications No.66, Sweden, 88pp.

This study analyses the impact of climate variation and human influence on land transformation. Changes in rainfall parameters, i.e. the amount of rainfall and the number of days with a certain amount of rainfall, during 1950-84, and the relationship with crop yield (1961-83) have been analysed. Land transformation studies based on air photos (1961) and satellite imagery (1972, 1975, 1978 and 1983) have been performed to detect changes in major land cover borders, cultivation patterns and intensity, sand dunes and desertified village perimeters. The most common vegetation species and changes in the vegetation composition obtained through interviews in 57 villages have been analysed.

135 **A study of the climate of the Sudan with special reference to agriculture**
Ahmed,B.Y.M. (1982) Unpublished PhD Thesis, University of Durham, 487pp.

This study gives special consideration to the relationships between climate and agriculture. The importance of agriculture to the economy of Sudan and the key role played by climate, necessitates the investigation of such relationships. The first part of the thesis provides a general survey of the climate of Sudan, including a climatic classification and potential

estimation of rainfall from satellite imagery. The second half explores the climate-agriculture relationship in the Sudan and presents a detailed study of the relationships between climatic variables and cotton, sorghum, sesame and groundnut yields as examined using a variety of statistical methods.

136 **Adverse weather conditions at Khartoum, El Obeid and Wadi Halfa, 1959**
Bhalotra,Y.P.R. (1959) Memoir No.2, Sudan Meteorological Service, Khartoum

137 **Aviation hazards at Malakal and Juba**
Bhalotra,Y.P.R. (1962) Memoir No.4, Sudan Meteorological Service, Khartoum

A statistical analysis has been made in this memoir of the frequency, diurnal variation and duration of meteorological conditions adverse to aviation, which occur at the Malakal and Juba airfields. The analysis is based on the study of available meteorological data for the years 1955-57, except for data on squalls. Climatological reference period values are provided on parameters such as thunderstorm frequency, squall duration and intensity, cloud cover, visibility and wind velocities.

138 **Adverse weather conditions at Khartoum, El Obeid and Wadi Halfa** [**]
Bhalotra,Y.P.R. (1963) Memoir No.7, Sudan Meteorological Service, Khartoum

139 **Wind energy for windmills in Sudan** [**]
Bhalotra,Y.P.R. (1964) Memoir No.8, Sudan Meteorological Service, Khartoum

140 **Simultaneity of adverse conditions at Khartoum and Port Sudan** [**]
Bhalotra,Y.P.R. (1966) Technical Note No.2 (New Series), Sudan Meteorological Service, Khartoum

141 **Bioclimatic observations in the Red Sea Hills and coastal plain, a major habitat of the desert locust**
Cloudsley-Thompson,J.L. (1962) Proc. Royal Ent. Soc. London (A), 37, 27-34

Sand surface temperatures depend upon insolation, wind-speed and the consistency of sand itself. The highest temperatures recorded in the Red Sea Hills during the fieldwork performed in September and December 1960 (83.5 °C) were at 13.00 hours on fine, wind-blown sand, which has high insulating qualities. The colour of sand or rock is of less importance in affecting its temperature. Low humidities were recorded, even among grass roots and it is concluded that the primary biological advantage of vegetation lies in the reduction in temperature afforded. In general, higher humidities and lower temperatures were recorded near the sea, but the salt-encrusted soil in many places was practically sterile. The distribution of terrestrial anthropods on the Erkowit plateau near Sinkat is outlined and an explanation of it is given in terms of rainfall and vegetation. Finally, the effects of extreme climatic conditions on the composition of the fauna are discussed and comments made on its sparseness.

142 **Climate and fauna in the central and southern Sudan**
Cloudsley-Thompson,J.L. (1966) Sudan Notes and Records 67, 127-36

A very descriptive study of an expedition up the White Nile into southern Sudan in December 1961 to collect a variety of species, mostly insects. A series of bioclimatic readings were taken, mainly relative humidity and air and ground temperature over the one month period. Some attempt is made to relate insect prevalence to these readings. A list of species collected is appended.

143 **Rainfall and cotton yields in the Sudan Gezira**
Crowther,E.M. and Crowther,F. (1935) Proceedings of the Royal Soc. (B) 118, 343-70

The relationship between seasonal yield and weather fluctuations for cotton grown under irrigation in the Sudan Gezira were analysed for periods up to 28 years. Nine rainfall stations in the Gezira for the period 1906-33 were analysed. The analysis confirmed the generally recognised bad effects of high rainfall about the period of sowing cotton, but showed that this effect was not universal. An unsuspected but apparently general effect was discovered. Cotton yields were negatively correlated with the amount of early - May and June - rainfall. In some areas yields were negatively correlated with late rinafll and with the total rainfall in the preceding year. The differences between areas in their responses to weather could be partially interpreted in terms of their situations and agricultural histories. The total annual rainfall in the Sudan Gezira exhibited a significant seven-year periodicity, which was reflected in cotton yields, dura exports and recorded famines. It happened that the first trial of irrigated cotton and the first use of the Sennar Dam coincided with minimal rainfalls on this periodicity. The early promise and rapidly increasing difficulties may well have been due in part to the recurrence of unfavourable weather conditions and not necessarily to soil deterioration and pests.

144 **The rains that lead to the Nile floods [**]**
El Fandy,M.G. (1953) Bulletine de la Society de Geographie d'Egypte 25, 93-102

145 **Some remarks on the climate of the area affected by desertification in western Sudan**
El Tom,M.A. (1983) Sudan Environment 3, 3-7

A very brief comment on some of the key rainfall characteristics of North Darfur and North Kordofan Provinces. This is drawn exclusively from the author's previous work, although it is not clear to which period the data refer.

146 Climate, environment and development in the Sudan
El Tom,M.A. (1986) Geo Journal 12(4), 399-402

A general discussion on the impact of human activities on climate, indicators of climatic change in Sudan (e.g. dust storm frequencies, line squall intensities and ITCZ behaviour) and the response of a changing environment. Development cannot be extended or planned without proper consideration of the changing nature of the physical environment in general and the nature of climate in particular.

147 Toward a drought-oriented climatic prediction system in western Sudan
El Tom,M.A. (1986) Proceedings of ISLSCP Conference, 1985 ESA Publication No.SP248, pp.439-42

The large-scale suffering which resulted from drought in western Sudan calls for a better understanding of the climatic controls in the area. It also calls for the establishment of a drought-oriented climatic prediction system which is likely to give an early warning of the possible occurrence of a below-normal rainy seasn. For this system to succeed there is a need to identify the climatic indicators of drought and to establish a network for observing and monitoring these indicators.

148 Some factors in thermal sanitation in the tropics
Grabham,G.W. (1921) Jl. of Hygiene 19, 245-76

Measured temperatures of different coloured objects exposed to the sun in Sudan are presented. Measurements are conducted under one thickness of thin cloth and by thermometers inserted in small cylindrical tin flasks.

149 The relationship of rainfall to cotton yields in the Sudan Gezira: a review
Hamid,O.B. (1965) Sudan Agricultural Journal 1(2), 62-70

150 Application and consequences of precipitation observations in the Republic of Sudan in view of the nomadic life and economy
Hammer,R.M. (1973) Geoforum 14, 11-18

Within the Sudan the rain season is controlled by the annual movement of the Intertropical Convergence. Studies of daily rainfall conditions show that most rainfall develops in situ, reoccurs in the same geographic areas, has little inter-daily continuity and occurs with an approximate 4-5 day cycle. Using satellite visible and infrared imagery the above conditions were confirmed. In addition, using cloud shape, organisation, spacing and occurrence of wave forms, the amounts and spatial coverage of daily rainfall was predicted from satellite imagery with 60% success. Nomadism is an important factor in the life of the Sudan and because of the high degree of dependence on rainfall, methods are discussed by which satellite technology can aid in the decisions made concerning short and long-term nomadic activity.

151 **Desertification in the Sudan: satellite data for landscape productivity monitoring** (in Swedish)
Hellden,U. (1985) Svensk Geografisk Arsbok (Lund Univ.) 61, 166-79

A study of the relationship between a vegetaion index based on NOAA AVHRR GAC data and precipitation data in the Sudan was carried out. A very strong relationship was found between the index and precipitation characteristics at the end of the rainy season. It was concluded that the satellite-based index probably indicates the distribution of green biomass at the end of the rainy season.

152 **Rainfall and cotton yields in the Sudan** [**]
Hewison,R. (1931) Empire Cotton Growing Review 8, 290a-n

153 **Rainfall and vegetation monitoring in the savanna zone of the Democratic Republic of Sudan using the NOAA Advanced Very High Resolution Radiometer**
Hielkema,J.U., Prince,S.D. and Astle,W.L. (1986) Int. Jl. of Remote Sensing 7, 1499-1513

Daily rainfall data for 12 meteorological stations spanning the Savanna Zone in Sudan were analysed. Rainfall in Sudan during 1980 was below normal, but in 1983 and 1984 there were moderate and severe droughts. The satellite data for these three years were used to calculate normalised difference vegetation index (NDVI) values which were processed into 10-day composite sets. For each of the three growing seasons, these composites were found to be closely correlated with rainfall. It is suggested that NOAA NDVI values can be used to monitor effective rainfall in central Sudan.

154 **Climatic change and economic development**
Hildore,J.J. and El Tom,M.A. (1975) pp.25-30 of African environment, problems and perspectives African Environment Special Report, International African Institute, London No.1 (ed. Richards,P.)

Population pressure on the environment is often relieved by out-migration or by artificially increasing the carrying capacity of the environment. In many instances, however, neither of these happen. Population increases at the expenses of the environment and eventually causes its deterioration. Climate can complicate this process, itself casing changes in the carrying capacity. Population tends to increase as favourable climate increases carrying capacity, but if climatic trends worsen, population pressure on the environment becomes too great. Vast arid and semi-arid areas of Africa are particularly hard-hit by such changes and the Sahel drought is one example of this.

155 **Four reasons why annual rainfall totals are an inadequate guide to the environmental impact of rainfall in semi-arid Sudan**
Hulme,M. (1985) Sudan Environment 5, 1-5

Rather than analysing annual rainfalls in semi-arid Sudan, four alternative rainfall parameters are suggested as being more useful in environmental impact studies: storm intensity, diurnal occurrence, wet season structure, rainfall localisation.

156 **The adaptability of a rural water supply system to extreme rainfall anomalies in central Sudan**
Hulme,M. (1986) Applied Geography 6, 89-105

Rural water supply in semi-arid Sudan is closely dependent upon annual rainfall. Yet in discussions on the consequences of rainfall anomalies in this climatically marginal zone, the impact on rural water availability is rarely examined in detail. A case study is presented from the White Nile Province of the impact of two anomalously wet seasons on the rural water system: 1978, the second wettest year this century in north-central Sudan and 1983, one of the six driest.

157 **A monthly rainfall assessment model for central Sudan**
Hulme,M. (1986) Discussion paper No.31, Department of Geography, University of Salford, 25pp.

This paper presents an operational system for the real-time assessment of monthly rainfall totals for 12 central Sudanese stations in relation to shortfalls in likely subsequent rainfed crop production. This system enables two levels of warning to be issued at monthly stages during the wet season: a `severe' warning or a `moderate' warning. Where no warning is issued, the cumulative rainfall would not appear to be sufficiently abnormal to think that serious difficulties with rainfed harvests would occur for climatic reasons. The critical rainfall thresholds for the 12 stations are listed and this list, together with rapidly obtained successive monthly totals from recording stations, is all that is necessary for the system to be used.

158 **Rainfall in central Sudan: an asset or a liability?**
Hulme,M. (1987) Geoforum 18

Sudan has been at the centre of the debate of drought and famine issues over the last three or four years. While the idea of a simplistic causal link between these two phenomena has been partially slain, there still remains the desire in some circles to find a scapegoat for famine. Drought remains one of the readiest to hand. Rather than being seen as a basic characteristic of the rainfall resource which requires management, drought is seen as such an abnormality that it provides too convenient an excuse for the failure of agriculture, inadequacy of water supplies, exhaustion of soils and other environmental phenomena that have afflicted Sudan within the last three to four years (and longer). This paper examines rainfall in Sudan as a resource and hence a potential asset. Drought is recognised as an inherent characteristic of that resource and its management discussed. Some broad options for future perspectives on the effective management of rainfall are outlined.

159 **Rainfall trends and rural changes in Sudan since Nimeiri: some thoughts on the relationship between environmental changes and political control**
Hulme,M. and Trilsbach,A. (1986) pp.3-18 in, Sudan since Nimeiri (ed. P.Woodward), SOAS, London

The 17 years since Nimeiri first came to power have seen great changes in the Sudanese environment. A continuing series of dry years in central Sudan commenced in the late 1960s, with 1984 experiencing the driest conditions this century. Attitudes toward the Sudanese environment have also changed

from a predominantly `developmental management' strategy to a `crisis management' approach of recent years. This paper comments on selected aspects of these two changes drawing heavily upon examples from the rural areas of semi-arid central Sudan and from the period of the Nimeiri regime. It is suggested that changes in rainfall characteristics, although genuine and severe, are alone inadequate to account for the crisis in environmental management. External and internal influences of international, national and individual origin are of equal, or ultimately greater, importance upon the environment.

160 **Frequency of low temperatures in the Sudan and its effect on the cotton crop**
Hurst,H.E. (1913) Cairo Scientific Journal 7, 265-68

Statistics for 1902-12 and the relations between temperatures and cotton yields are sought. Risky regions for growing cotton in Sudan are noted.

161 **The rains of the Nile Basin and the Nile flood of 1913**
Hurst,H.E. (1923) Ministry of Public Works, Physical Department, Paper No.12, 98pp. Cairo

The contents include chpaters on: the normal distribution of rainfall and the rainfall of 1913; the low stage preceding the Nile flood and the flood of 1913, along with a resume of the 1912 flood and the low stage of 1913; and finally, tables of rainfall and river gauge readings which comprise most of the report.

162 **The problem of desertification in the Republic of the Sudan with special reference to Northern Darfur Province**
Ibrahim,F.N. (1978) Science Research Council Monograph, Khartoum University press

An assortment of climate data primarily from western Sudan is presented in this monograph, in particular an analysis of 20th century rainfall variability at El Fasher and data on the increasing frequency of poor visibility events due to dust at El Fasher. Drought is viewed as a typical part of the climatic pattern in this semi-arid region [NB. the visibility data are of dubious accuracy].

163 **The climatic preconditions of desertification in Darfur**
Ibrahim,F.N. (1984) pp.50-70 in Ecological imbalance in the Republic of the Sudan with special reference to desertification in Darfur Ibrahim,F.N., Bayreuth Press, 215pp.

The author presents a variety of climatic data from Northern Darfur addressing the issues of water balance, the distribution of precipitation within the rainy season and the spatial and temporal variability of rainfall. Thornthwaite's water balance approach is used to compile deficit maps. The within-season distribution of rainfall is discussed in relation to the indigenous climatic calendar of western Sudan which divides the wet season into 14 thirteen-day periods. Indigenous cultivators attach particular importance to the success or failure of the rains within certain of these periods. Longer-term rainfall variability is analysed primarily for El Fasher and El Geneina stations which have the longest records in

Northern Darfur. This section of the book provides an essential precipitation background for later discussions on desertification and degradation.

164 **Climate and building design in the Northern Sudan**
Ireland,A.W. (1949) Sudan Notes and Records 30 (supplement), 46-49

The author discusses the relationship between building design and climatic parameters, these latter being diurnal temperature range, relative humidity, cloud cover and insolation, prevalent wind direction and intense rainfall events. He concludes that the following features be incorporated into Sudanese buildings: double rooves, insulated outside surface, light surface colouring, a vertical dimension approximately three times the horizontal, a verandah and free ventilation. Many traditional eastern designs include several of these features.

165 **Health and comfort in hot climates**
Ireland,A.W. (1955) Sudan Notes and Records 36, 105-11

A climatic comfort classification for five Sudanese locations is constructed based on the comfort indices devised by Professor Sir D Brunt. Air temperature and relative humidity form the two basic climatic parameters used and the comfort graphs are designed for an outdoors situation with light clothing. Graphs for Wadi Halfa, Port Sudam, Khartoum, Malakal and Juba for 8am and 2pm are included. An Arabic summary is attached.

166 **Desertification or climate? An investigation regarding the relationship between land degradation and climate in the central Sudan**
Olsson,L. (1983) Lund Publications No.60, Sweden, 36pp.

This report forms part of the research project between the University of Lund and the Institute for Environmental Studies, Khartoum into, `Regional Studies of Desertification and its Control: approaches to rehabilitation of degraded ecosystems in Africa'. This report investigates the relationship between climate and desertification using data from Kordofan Province. A basic analysis of rainfall data is performed and then relationships between land use, crop yields and duststorms with rainfall are investigated. About a dozen rainfall stations are used in the analysis for the period 1950-80.

167 **Report on pollution problems in the Sudan [**]**
Parramena,J.A. (1976) Memoir No.9, Sudan Meteorological Service, Khartoum

168 **Rainfall and agriculture in the Sudan [**]**
Rath,U.C.W. (1956) Technical Note No.3 (Old series), Sudan Meteorological Service, Khartoum

169 **The demand for soft drinks in the Sudan: a case study**
Sherbini, A.A.El (1961) Sudan Notes and Records 62, 102-17

The demand for soft drinks in the Sudan is a function of several important variables. Temperatures, sales promotion, Muslim festivities, income, competition and price are all important determinants of soft-drink sales. However, they vary in their relative importance. The temperature factor was investigated for the period January 1956 to August 1958 using mean monthly temperatures (it is assumed these are for Khartoum although no indication is given). Regressions with sales figures of soft drinks showed consistant relationships with anomalous months being accounted for by price changes or advertising. Temperatures are therefore shown to be a useful planning parameter for soft drinks sales managers in Khartoum.

170 **The distribution of tree species in Sudan in relation to rainfall and soil texture**
Smith,J. (1949) Ministry of Agriculture, Bulletin No.4, Khartoum, 83pp.

This work is primarily a commentary on the vegetation geography of Sudan, but relates the distribution of species to the prevailing annual rainfall patterns in the country. The memoir commences by discussing the role of climate (rainfall) in determining species distribution, although a very static view of climate is adopted. There is also discussion of the effectiveness of rainfall under different soil conditions in creating soil moisture availability for plant growth. A generally optimistic view of vegetation regeneration is taken, arguing that there is no climatic obstacle to such restoration.

171 **Desertification and rural change in the central Sudan**
Trilsbach,A. (1983) Unpublished PhD Thesis, University of Wales, 517pp.

Chapter 4 of this thesis examines rainfall variability in the context of rural change in central Sudan. Twenty-four rainfall stations in central Sudan are analysed to look at parameters of annual rainfall variations since the first quarter of the century. This is followed by a more detailed study of the Gezira/northern White Nile area, utilising an extra 14 stations. Analyses are conducted for various time periods ranging from 20 years to single wet seasons. A number of rainfall inconsistencies are identified.

172 **Desert steppes and fog oases in the southern Nubian coastal region; study of vegetation and agriculture of the tropics** (in German)
Troll,C. (1935) Gesellschaft fur Erdkunde zu Berlin, Zeitschrift 7/8, 241-81

Vegetation and agricultural zones are correlated with climatic conditions in the region of Sudan near the coast. Meteorological tables for towns in the region are appended.

173 The climate of the southern Sudan in relation to cotton growing
Wardle,R.A. (1926) Manchester Memoirs 70(6), 59-69

The author summarises the climatic regimes of central and southern Sudan in view of the attempts being made to establish the cultivation of American Upland varieties of cotton as a rain crop in the region. On the whole, climatic conditions in the central Sudan rainfall area, although favourable for short-staple cotton growing, are not suitable for the cultivation of cotton with fibre-length of greater than 25mm. The moister areas of southern Sudan (Bahr-el-Ghazal and Mongalla Provinces) are likely to be more suitable.

174 Cotton growing in relation to climate in Egypt and the Sudan
Williams,C.B. (1924) Ministry of Agriculture, Bulletin No.47, Cairo, 31pp.

A method is devised by the author to show how the relation of the cotton plant to temperature and rainfall in the different cotton-growing parts of the world can be studied by means of a diagram representing, vertically, the temperature or rainfall and, horizontally, the stages in the growth of the plant. The method is applied to a study of the variety of climatic conditions under which cotton is grown in Egypt and the Sudan. Meteorological tables are given for different places including Khartoum, Kassala and Wad Medani.

e. EVAPORATION

175 **Current processes on measurement and estimation of evaporation from lake surfaces [**]**
Abdalla,H.A.B. (1981) Unpublished report, Sudan Meteorological Service, Khartoum

176 **A note on estimating evaporation using the Penman formula**
Adam,E.H.S. (1973) Pamphlet No.8, Sudan Meteorological Service, Khartoum

177 **Water balance in the Sudan**
Awadulla,S.A. (1977) Unpublished MSc Thesis, University of Sheffield, 178pp.

This thesis provides the detailed groundwork which led to the author's publication (see **178**) tabulating monthly P.E. values for 300 stations in Sudan. The details of the application and modification of Penman's equation are presented and also the details of the statistical interpolation technique which was used to establish the necessary parameters for the network of stations (see **4**).

178 **Potential evapotranspiration over the Sudan: an application of Penman's model over a dense spatial pattern**
Awadulla,S.A. (1983) Scientific Note No.3, Sudan Meteorological Service Khartoum

Estimates of monthly average potential evapotranspiration for Sudanese stations have been determined through an application of Penman's formula. In Sudan, first-order stations measuring sunshine and radiation for a period long enough for averaged values number only about 20. The spatial pattern created by these first-order stations leave very big gaps over the different parts of the country, particularly north of Khartoum. To overcome this problem a statistical interpolation routine was used to establish mean monthly P.E. values for the standard period 1950-80 for over 300 stations in Sudan. These data are tabulated in the memoir. The details of the techniques used are found in the author's previous MSc thesis (see 177).

179 **Evaporation in Egypt and the Sudan**
Craig,J.I.C. (1912) Cairo Scientific Journal 6, 103-07

The author derives comparable and reasonable means of evaporation for different regions in Egypt and the Sudan. Tables are given for six districts along the Nile, using data 1907-1911.

180 **Some aspects of measured and estimated evaporation in the Sudan**
El Seed,A.M.G. (1968) Unpublished MA Thesis, University of Durham, 150pp.

The thesis analyses, for the Sudan, the methods of evaporation measurement by Piche evaporimeter and Class `A' pan, together with the estimation of

open-water evaporation (EO) from Penman's formula and potential evapotranspiration (PE) by Thornthwaite's method. Regression analysis shows a close correlation between measured and computed evaporation at some stations in northern Sudan where the correlation coefficients are large (over 0.70). At some stations in central and southern Sudan the correlation coefficients are low (under 0.50). Also discussed is the distribution of average annual, seasonal and monthly Piche evaporation over the Sudan. Annual values reveal a steady decrease from north to south and evaporation isolines seem to run roughly along latitudes from east to west, interrupted only by upland areas.

181 **Changes in evaporation rates along a 17km strip of the Sudan Gezira**
Davenport,D.C. and Hudson,J.P. (1967) Agricultural Meteorology 4, 339-52

Differences in evaporation from water dishes and in temperature and vapour pressure of the air were observed in the Sudan Gezira where large cotton fields are interspersed amongst uncropped dry fallows. Lateral movement of energy resulted in high evaporation rates near the leading edges of irrigated fields and in a progressive decrease of about 30% in evaporative demand within the leading 60m of a cotton field. Evaporation rates increased as the wind blew across dry, uncropped fields lying downwind of cotton. Water losses from evaporimeters with equivalent exposures, decreased at the rate of nearly 2% per kilometre over a transect of 17km. The lateral changes in evaporation rates were due to changes in temperature, vapour pressure deficit and wind speed along the transect. Advection was found to be less apparent in the temperate conditions in England than in the hot, arid climate of Sudan.

182 **Meteorological observations and Penman estimates of evaporation along a 17km transect in the Sudan Gezira**
Davenport,D.C. and Hudson,J.P. (1967) Agricultural Meteorology 4, 405-14

Daily measurements of maximum and minimum temperature, wind velocity and vapour pressure were made at windward and leeward edges of selected cotton fields, interspersed amongst cropped fields in the Sudan Gezira. Mean temperature, vapour pressure deficit and wind run were lower at the leeward than windward edges of the cotton fields. At comparable windward sites, wind run per day and mean daily temperature decreased as the downwind distance from the most windward edge of the 17km transect increased. Values of evaporation, calculated by the Penman formula from meteorological data at various sites, were reduced by the presence of upwind stretches of cotton. Negative Bowen ratios indicated that advection conditions existed.

183 **Climatonomical study of irrigation effects on soil moisture in Sudan's Gezira region**
Debailo,S.M. (1976) Unpublished MSc Thesis, University of Wisconsin-Madison, 39pp.

184 **The determination of potential evapotranspiration by the use of drainage lysimeters**
El Nadi,A.M.H. (1963) Unpublished MSc Thesis, University of Khartoum, 87pp.

This is a critical assessment of Penman's estimation technique for P.E. by using empirical measurements of P.E. in semi-arid Sudan. The author concludes that Penman is not applicable in northern Sudan because of the dominance of the advection process in this region.

185 **Evaporation and waterloss in the Nile basin** (in German)
Haude,W. (1959) Geogr. Annaler 41, 49-66

186 **Evaporation under hot, dry conditions: changes across 10 miles of cotton and fallow in Sudan** [**]
Hudson,J.P. (1964) Empire Cotton Growing Review 41, 241-54

187 **Evaporation in Egypt and Sudan**
Keeling,B.F.E. (1909) Egyptian Survey Department, Paper No.15, 29pp. Cairo

This report summarises the current knowledge of the rate of evaporation from water surfaces in Egypt and Sudan. A comparison of evaporimeters is made. A summary is given of rates of evaporation observed at second-order meteorological stations in the Nile Valley. The relation between evaporation and other meteorological factors in the region is pointed out and the diurnal variation of evaporation is described. Some representative tables of data are included.

188 **Evaporation and soil moisture depletion in the Gedaref region of east-central Sudan**
Musa,S.B. (1986) Unpublished Ph D Thesis, University of Wales

This thesis studies evaporation, the depletion of soil moisture during the rainy season and tests the applicability of various evaporation estimation methods in the hot, semi-arid conditions of the Gedaref region of the Sudan (annual rainfall between 300mm and 700mm). The evaporation measurement methods employed included a Class `A' pan, a Piche atmometer and 20 weighable lysimeters for the assessment of actual and potential rates of bare soil evaporation and evapotranspiration. Established evaporation estimation methods tested for applicability proved to be inadequate in the Gedaref region. The original Penman method, for example, greatly underestimates measured potential evapotranspiration (PE) with mean monthly deviations as high as 5.4lmm/day. New regression models were therefore developed and the Penman formula revised. The former approximated measured PE very closely with highest mean monthly deviations only 0.38mm/day and the revised Penman formula produced deviations of 0.89mm/day.

189 **Rainfall and evaporation loss in the Sudan**
Oliver,J.E. (1965) Weather 20, 58-64

Rainfall effectiveness in Sudan is influenced by the diurnal rainfall pattern. To obtain a full picture of rainfall effectiveness one must consider soil texture and structure, vegetation cover and slope and evaporation losses. The timing of rainfall during the rainy season affects its availability to plants. The timing during the day modifies evaporation. These issues of rainfall effectiveness and seasonal and diurnal distributions are examined using rainfall data from 9 stations in semi-arid Sudan, together with data on windspeed and soil temperatures.

190 Problems of determining evapotranspiration in the semi-arid tropics illustrated with reference to the Sudan
Oliver,J.E. (1969) Jl. of Trop. Geography 28, 64-74

A discussion of evapotranspiration calculations in the tropics after Penman and Thornthwaite is followed by a comment on the maps of Satakopan (see 192). Anomalies from theoretical determinations in Sudan are mentioned. There are two situations in the Sudan in which actual evapotranspiration will depart from potential evapotranspiration. In unirrigated, sparsely vegetated areas actual losses will fall short of the estimates, whilst from irrigated lands, especially in cases of small pump irrigated schemes, calculated values based on the site climatic data can be considerably exceeded by actual evapotranspiration. Examples of both are given.

191 Water saving through reduction of evaporation [**]
Saeed,A.A.S. (1957) Technical Note No.1 (New series), Sudan Meteorological Service, Khartoum

192 Water balance in the Sudan
Satakopan,V. (1961) Memoir No.5, Sudan Meteorological Service, Khartoum, 33pp.

The concept of water balance of an area as derived from its precipitation, potential evapotranspiration, soil moisture retention and runoff introduced by Thornthwaite in 1948 has found useful application in different parts of the world. In the Sudan, with its extensive semi-arid and arid regions, harnessing available water resources and their conservation for consumptive use constitute the basic problems in many development projects in the country. It was therefore, considered desirable to study the water balance of the country according to methods evolved by Thornthwaite. This memoir presents a report on such a study. 1921-50 is the reference period used in data selection and the water balance is calculated for 69 stations throughout Sudan. Monthly P.E. and water deficit maps are constructed in colour and included in the memoir. A climatic regionalisation of Sudan according to Thornthwaite's method is also attached.

193 Evaporation from the Nile at Khartoum (in German)
Turstig,R. (1912) Meteorologische Zeitschrift 29, 454-62

Measurement procedures are described. Temperature differences between air and water are noted and wind conditions charted. Evaporation is related to these climatological conditions. Tables are brief and cover only a two month period, March and April.

f. CLIMATIC CHANGE

194 **Notes on Quaternary climates in Sudan**
Andrews,G. (1944) Appendix 25 in Soil conservation committee report Sudan Government, Khartoum

An assortment of evidence is presented from Sudan of the likely climatic regime of the Quaternary era. This is collated in view of the brief of the Committee to `report and recommend on the soil erosion and desiccation argument' in Sudan. The main body of the report concludes, "There is therefore, very strong evidence in the Sudan that the climate of today with its normal variation has undergone no basic change for better or worse since the close of the final major wet phase of Pleistocne times ... the soil deterioration that has occurred and which is still occurring may therefore safely be attributed to the work of mankind and his domesticated animals ..."

195 **Changing rainfall patterns in western Sudan**
Eldredge,E., El Sayeed Khalil,S., Slater,C., Nicholds,N., Abdalla,A.A. and Rydjeski,D. (1987) Unpublished paper, UNEOS, Khartoum

Rainfall series for North Darfur and North Kordofan through 1986 have been examined. Annual and monthly series are presented and analysed. Relatively dry conditions have persisted in this region since 1966 due mainly to declines in rainfall during July, August and September, the critical months for the annual agricultural cycle. Changes in daily rainfall magnitude and frequency are examined for the four rainy season months. It is recommended that agricultural planning and government policies be based on recent meteorological patterns.

196 **The nature of rainfall over the Sudan and the potentialities for its artificial modification [**]**
El Tom,M.A. (1972) Sudan Research Unit, Pub. No.15, Khartoum, 44pp.

197 **The low rainfall of 1913**
Grove,A.T. (1973) Savanna 2, 133-38

Evidence is presented for the exceptional nature of the 1913 rainy season in the Sahel and Nile Basin. The 1913 Nile flood was the lowest for which authentic data exist. Rainfall conditions in the Nile Basin represented by 118 stations (including 42 from Sudan) supports the contention of an extremely dry year.

198 **Pluvial lakes of north-western Sudan**
Haynes,C.V., Mehringer Jr.,P.J. and Zaghloul, El S. (1979) Geogl. Jl. 145, 437-445

The extreme desert of south-western Egypt and north-western Sudan has revealed traces of numerous small, shallow, rain-fed lakes, relics from earlier periods of less arid climate. In 1976, sites of such lakes at the oases of Selima, Laqiya Arba'in and Merga in north-western Sudan were studied. Samples of lacustrine deposits yielded sufficient carbonate material for radiocarbon dating and values obtained indicate that the lakes dried up some 6000 years ago, occasioning the withdrawal of the Neolithic

inhabitants. Sediment cores taken at Merga for pollen and radiocarbon analysis suggest a later hyperarid phase ending about 600 years ago.

199 **1983: an exceptionally dry year in central Sudan**
Hulme,M. (1984) Weather 39, 281-85

Annual and monthly rainfalls for 1983 are presented and placed in the context of the 20th century rainfall record. Between 14 and 16 degrees north 1983 was the driest year this century resulting in widespread crop failure. Famine was already being reported in January 1984 in Darfur Province.

200 **Secular climatic and hydrological change in central Sudan**
Hulme,M. (1985) Unpublished Ph D Thesis, University of Wales, 282pp.

Changes in 20th century rainfall characteristics in the 12 to 16°N zone of Sudan are investigated at two levels. First, up to 55 annual rainfall series are analysed with respect to climatic change. Secondly, 12 long-term series of daily rainfalls are analysed with respect to changes in daily rainfall magnitude-frequencies and wet season structures. The hydrological response to such rainfall changes is explored in the context of a local study area in the White Nile Province. Experimental, interview and limited archival material is used to examine several hydrological variables, including infiltration capacities, wadi flow magnitude-frequencies, groundwater aquifers and water quality.

201 **The 1986 wet season in central Sudan**
Hulme,M. (1987) Weather 42, 193-95

Preliminary data from the 1986 wet season in central Sudan is presented and the rainfall performance of that year placed in the context of recent dry years. A standardised regional rainfall series (see **199** and **203**) is updated and 1986 is shown to be the wettest year since 1981 in central Sudan. Using a water balance model, the 1986 wet season onset and termination is compared to the previous 6 years and found to be quite favourable for crop performance.

202 **Secular changes in wet season structure in central Sudan**
Hulme,M. (1987) Jl. of Arid Envrionments 13, 31-46

This paper investigates climatic change in central Sudan through analysing changes in wet season structures over 80 years for 12 stations. A wet season model is defined, based on daily rainfalls, potential evapotranspiration and an assumed field capacity. Analysis centres on the timing of wet season onset and termination and the frequencies of breaks within the wet season and wet season failures (`null starts').

203 **Generation of drought that triggered disaster**
Hulme,M. and Walsh,R.P.D. (1985) New Scientist 4th April, p.11

A standardised regional rainfall series for central Sudan (1900-84) using 26 stations is presented and briefly commented upon.

204 **Changes in the climate and vegetation of the Sudan**
Jackson,H.C. (1957) Sudan Notes and Records 38, 47-66

The climatic history of Sudan from the Palaeolithic (600,000BP) to the present is summarised, with major emphasis on the last few thousand years. There is a predominance of archaeological and literary evidence over environmental evidence. For example, records from the Egyptian dynastic period, the geographers of Classical times and the accounts of Medieval Arab and modern European geographers are discussed. The history ends in the last 200 years with the contention that there have been only minor fluctuations in climate since the end of the Neolithic pluvial. There is a recognised sparsity of detail from southern Sudan. A reference list of over 50 items on archaeological and environmental change is included.

205 **A wetter climate in eastern Sudan, 2,000 years ago?**
Mawson,R. and Williams,M.A.J. (1984) Nature 309, 49-51

Within the past 15 years accurate radiocarbon dating and plant microfossil analysis of tropical lake sediments in Africa and elsewhere have revealed that the early Holocene (11-7kyr) was generally wetter than today throughout the tropics, in contrast to the last glacial maximum (18 ± 2kyr), which was cool, dry and windy. Desiccation beginning ca. 4.5kyr ago forced Neolithic herders to abandon previously habitable Old World deserts. Less well known is the climate of proto-historic times (ca. 2kyr ago), when iron-smelting became important in Africa. Here we present the first evidence that the Red Sea Hills were somewhat wetter at this time and suggest that this was also true of much of northern Africa. Freshwater molluscs from the alluvial clays which line the main valley near the original site at Erkowit in the Red Sea Hills were collected, identified and dated. Additional archaeological and archival evidence is also used to support the argument.

206 **Desiccation or destruction; notes on the increase of desert areas in the Nile Valley**
Robinson,A.E. (1935) Sudan Notes and Records 18, 119-30

It is pointed out that increases in desert areas in the Nile Valley are in many cases due to human neglect or destruction and not entirely caused by climatic changes. References to numerous studies of changes in civilisation, agriculture, river level and climate are made in footnotes.

207 **Long-term variation in precipitation in the Sahel and Sudan**
Sherematova,L.M. (1977) Leningrad Glav. Geof. Obs. 386, 122-29

Data from the Sahel are analysed (including four Sudanese stations) from the beginning of the century to 1974. Secular trends and fluctuations are examined as well as inherent rainfall variabilities. Some subjective comment and judgements are passed on the impact of the drought. [This paper originally appeared in Russian, but has been translated by S.G.Crawford at the Meteorological Office, Bracknell]

208 Temperature trends in Egypt and Sudan
Sutton,L.J. (1936) Qtly. Jl. of the Royal Met. Soc. 62, 120-22

Temperature data from 1900-34 for seven Sudanese stations are examined by the current Director of the Sudan Meteorological Service (he retired in 1936). A warming in mean temperature of between 0.5 and 1°C is found between 1906-19 and 1920-34 for the Sudanese stations. Data from several Egyptian stations display a similar tendency and some comments are made about the relationship of this temperature trend with rainfall levels.

209 Recent rainfall changes in central Sudan and their physical and human implications
Trilsbach,A. and Hulme,M. (1984) Trans. Inst. Brit. Geogs. 9, 280-98

The paper examines rainfall changes in the critical desertification zone between 12 and 16°N in Sudan. Three aspects of rainfall change are examined: changes in annual rainfall, changes in daily rainfall magnitude-frequency, and rainfall localisation. Some physical and human implications of these rainfall changes are discussed, quoting examples from the White Nile Province.

210 Recent rainfall changes and their impact on hydrology and water supply in the semi-arid zone of the Sudan
Walsh,R.P.D. and Hulme,M. (1987) Geogl. Jl. 153(3)

Rainfall decline in semi-arid Sudan since 1965 has continued and intensified in the 1980s, with 1984 the driest year on record. In White Nile Province annual rainfall in 1965-84 was 40% below 1920-39 levels: wet season length has contracted by 39-51%; and the frequency of both large and minor daily falls has declined by up to 51%. Hydrological consequences of these changes have been varied. Models of the hydrological impact of rainfall decline must take into account local physical and human conditions, changes in a variety of rainfall parameters and different types of human response to drought in order to be useful.

211 Changes in the climate and vegetation of the Sudan since 20,000BP
Wickens,G.E. (1975) Boisseira 24, 43-75

Presents evidence for concluding that the evidence that the isohyets moved by as much as 450km southwards and 400km northwards of their present position during the period and that parallel shifts in the vegetation explain the presence today, in isolated localities, of such species as Anogeissus leiocarpus and Terminalia brownii.

212 Quaternary environments in Northern Africa
Williams,M.A.J. (1982) pp.13-22 in, A land between two Niles (eds.)
Williams,M.A.J. and Adamson,D.A. Balkema, Rotterdam, 246pp.

A brief overview of the salient changes in the environment of the Sahara with a specific section on Quaternary changes in climate in Sudan. An extensive bibliography on all aspects of Quaternary environments in northeast Africa is supplied.

g. ATMOSPHERIC DUST

213 **Duststorms at Khartoum**
Bhalotra,Y.P.R. (1958) Memoir No.1, Sudan Meteorological Service, Khartoum

214 **The relationship of dust to cold fronts over the Sudan during the dry season**
Delsi,M. (1967) Meteorological Magazine 96, 50-57

The traditional theory relating dust to cold fronts during the dry season (winter) over north and northern central Sudan limits the occurrence of dust to the rear of the front and therefore has the effect that fronts are placed to mark the southern limit of dust. This theory works satisfactorily during the early part of the season. However, if the leading edge of dust is taken to represent the front in the later part of the season (April-May), then the front appears to progress unevenly with sudden jumps and with temperature apparently rising behind the front on some occasions. An example is given of the type of analysis under consideration. It is shown that late in the season a dust belt 60 to 200 miles wide develops ahead of cold fronts and that the edge of the pre-frontal dust belt need not be taken as the real cold front position. The causes of the pre-frontal dust belt are discussed.

215 **Downdraft haboob in Khartoum**
Delsi,M. (1968) Unpublished report, Sudan Meteorological Service, Khartoum, 17pp.

The synoptic conditions most favourable for the development of haboobs are described: light, moist, surface southwesterlies which enable vigorous surface convection currents to be transmitted to the upper easterlies, thereby initiating strong downdrafts.

216 **A few characteristics of fronts of winds during sandstorms in Egypt** (in Italian)
El Fandy,M.G. (1948) Annali di Geofisica 1, 610-615

Wind velocities during various sandstorms in North Africa are studied from anemometer records for Khartoum, Cairo, Heliopolis and Almaza.

217 **Haboobs and instability in the Sudan**
Farquharson,J.S. (1937) Qtly. Jl. of the Royal Met. Soc. 63, 393-414

The duststorms of the Sudan, called haboobs, are shown to be associated with thunder squalls. Several haboobs are discussed with particular reference to upper winds and upper air temperatures, an indication of the speeds of the vertical currents associated with a haboob. Conditions associated with instability in the Sudan are investigated and it is suggested that they may be related to a discontinuity between SW monsoon and NE trade with specified slope. The author favours the thunder squall association over the cold front phenomena, although elsewhere (see 228 and 229) Sutton suggests both causes as possible. [Photographs included]

218 **Sandstorms in the Sudan**
Fleming,J. (1953) Meteorological Magazine 82, 26-27

A brief note on the characteristics of haboobs from observations made at Khartoum. There is the claim that the haboobs of recent years (1940s and 50s) were less dust-laden than earlier years because of increased vegetation cover in the Gezira. Two black and white photographs are included.

219 **Sand devils in the Sudan**
Flower,W.D. (1938) Meteorological Magazine 73, 146-50

A brief report of sand devil occurrences in April and May 1937 and again April 1938. These were observed near Wad Medani, Khartoum and Musmir in Northern Province and were up to several 100 feet in vertical extent, anti-clockwise in rotation and possessing a maximum lifespan of about 15 minutes.

220 **Duststorms of the Anglo-Egyptian Sudan**
Freeman,M.H. (1952) Meteorological Office Reports No.11 (Vol. 2), H.M.S.O., London, 22p.

In a survey of 82 summer haboobs at Khartoum, the author found a maximum duration of 6.5 hours with a peak between 30 minutes and one hour. However, 33 of these haboobs were ended prematurely by rain.

221 **Haboob structure at Khartoum**
Lawson,T.J. (1971) Weather 26, 105-11

An expedition to Khartoum during June 1969 was designed to obtain time-lapse film of downdraught haboobs so that motions at the front could be compared with results from tank experiments in the laboratory. A secondary aim was to find whether the dust-content contributed significantly to the density gradients. The frontal structure of a haboob is described, along with the surface temperature record during the passage of the haboob front. A two degree centigrade reduction in temperature occurred over a 30 second period. Particle-size analysis showed a range of 10 to 50 microns which corresponds to a fall-out time from 1000m of between one and seven hours. Two photographs of haboobs over Khartoum are included.

222 **A review of weather systems connected with dust storms in the Sudan and surrounding areas**
Morales,H. C. (1979) Lund Publications No.41, Sweden, 28pp.

Ground conditions in the arid northern and central parts of Sudan are particularly favourable to the formation of dust. The occurrence of strong turbulent winds in conjunction with these ground conditions make dust storms frequent. There can be several types of dust storms and the various air masses, wind systems and weather conditions which cause these storms ae detailed.

223 The use of meteorologial observations for studies of the mobilistaion, transport and deposition of Saharan soil dust
Morales,H.C. (1979) pp.119-31 in Saharan Dust (ed.) Morales, H.C., SCOPE 14, Wiley,

SYNOP reports (weather reports from the meteorological network of so-called SYNOP stations) contain much valuable information in relation to studies of the mobilisation, air-borne transport and deposition of desert soil dust. Details of this information are presented in the paper. A further two examples are given on how to make use of the SYNOP reports, one showing the migration of a duststorm over the Sudan area on a series of weather maps, the other for a study on the threshold wind velocity for raising desert soil dust. Sudan case study data are from 1974.

224 Case study of a dust storm weather situation in the Sudan, April, 1973
Morales,H.C. (1980) Pure and Applied Geophysics 119, 658-76

225 Effect of drought on dust production in the Sahel
Middleton,N.J. (1985) Nature 316, 431-34

The severe drought currently afflicting the Sudano-Sahelian zone to the south of the Sahara Desert has been suggested to be instrumental in producing an increased output of soil-derived aerosols into the atmosphere from the region. Data are presented here from selected meteorological stations which show that dust-storm activity in the west and east of the Sudano-Sahelian belt has dramatically increased during the drought years; by a factor of 6 in Mauritania and up to a factor of 5 in Sudan. [Sudan data consists of 5 stations in central Sudan for the period 1950-78 and is frequency of occasions with visibility <1000m].

226 On haboobs in the Egyptian Sudan
Schempf,W.H. (1943) Bulletin of the American Met. Soc. 24, 371-77

A thorough, descriptive account of haboobs referring to source material rather than using original data.

227 Meteorological note on the Sudan haboob
Sudan Government (1951) Met. Mag. 80, 298-99

This note consists of the text of `Notices to Airman, No.8/51' circulated in March 1951 by the Sudan Government. In contains meteorological information on haboobs likely to be encountered by aviators in Sudan. Haboobs are claimed to be encountered between May and September, may rise to a height of 6,000 to 9,000 feet and may last 2-4 hours in the early season, but of much shorter duration (15 minutes) in late season, when they are more likely to be accompanied by rain.

228 Haboobs
Sutton,L.J. (1925) Qtly. Jl. of the Royal Met. Soc. 51, 25-30

The author presents a general description of atmospheric dust events in northern Sudan, haboobs being the most dramatic and frequently identified. Monthly frequency data are tabulated for observed haboobs in Khartoum for 1916-23. Direction of haboob approach is also indicated. Of the 196 in the

8-year period, 159 occurred in the rainy season and 37 at other times. The rainy season haboobs approached from the south or southeast. Some comment is also made on the relationship of haboob passage to surface temperature. A general lowering of temperature seems to occur for up to three days before a haboob event. H G Lyons, in discussion after the reading of the paper, emphasised the difficulty of terminology of atmospheric dust events and argued for a clear distinction between small, circular storms of short duration and prolonged dust events of lesser intensity.

229 Haboobs

Sutton,L.J. (1931) Qtly. Jl. of the Royal Met. Soc. 57, 143-61

The author extends his previous study on haboobs (see **228**) by providing more detailed statistical and synoptic analyses of their occurrence in northern Sudan. Records for 1916-29 at Khartoum and 1921-29 at Kassala are presented. Khartoum data indicate an average of 20 haboobs per year, of 3 hours duration and typically occurring in early evening. The author then investigates the synoptic history of several haboobs including autographic charts of pressure, temperature, humidity and wind velocity during haboob events. He concludes that the majority are likely to be linked to convective processes. No data are presented on visibility during haboobs, which is now the main way the Sudan Meteorological Service records dust events. In two pages of discussion following the paper, a variety of contributors draw comparisons with dust events in other parts of the world.

h. MONTHLY AND ANNUAL REPORTS

Egyptian Government, Meteorological Department, Cairo:

230 **Annual Meteorological Report** (1900-1949)

Forty volumes are included within this time period, usually being published two to three years after data collection. A wide range of stations from Egypt, Sudan, Abyssinia are included with monthly summaries of standard meteorological parameters. Since 1950, Sudanese stations have been published separately be the Sudan Meteorological Service [Entry 14].

231 **Report on the weather and state of the river Nile for the month** (1934-1944) [**]

Monthly descriptive comments are made and brief summary tables of pressure, temperature and rainfall for various sections of Egypt and the Sudan. Discharges of the Nile are included for 1934 to 1938.

Sudan Meteorological Service:

232 **Monthly rainfall statistics** (1944-1986; ongoing)

Detailed monthly data for the period are included for numerous stations in Sudan, along with some Eritrean rainfall statistics.

233 **Pentad Rainfall Summary** (1949 and various following years)

Five-day rainfall totals are included for selected Sudanese stations for the period April to October.

234 **Annual Meteorological Report** (1950-1985; ongoing)

Full monthly meteorological summaries are incorporated for between 50 and 90 Sudanese meteorological stations. Mean monthly pressure, air temperature, vapour pressure, relative humidity, rainfall, surface wind, cloud amount, Piche evaporation and visibility are among the parameters included. Additionally, until 1980 when the Annual Rainfall Report (see 128) was instigated, monthly and annual rainfall totals were included for varying numbers of raingauge stations (between 200 and 700) [Entry 40].

235 **Agrometeorology Bulletin** (1958-1985; ongoing)

A monthly bulletin providing listings of mean monthly parameters, including: wind direction and speed, daily rainfall, solar radiation and sunshine duration, soil temperatures at 10 depths, Piche evaporation and wind speed, temperature and humidity at 5 different heights above ground. Number of stations ranges from four in earlier years to seven or eight in later years.

236 **Annual Agrometeorology Report** (1962 and various following years)

Annual report for the agrometerological year from April to March. Based on the returns published in the monthly Agrometeorological Bulletin (see 235) with the same stations included.

237 **Synoptic Bulletin** (1965 and various following years) [**]

238 **Annual Rainfall Report** (1980-1986; ongoing)

An on-going annual publication which lists annual and monthly rainfall totals, 1mm and 10mm rainday frequencies and maximum rainfall in each month. The number of stations included varies between 50 and 100, although several of these may have no returns incorporated. Data should be very carefully checked for errors and omissions. [Entry 128]

Sudan Government:

239 **Sudan Almanac** (various years from 1900)

Miscellaneous climatic information and data on Sudan usually included. Compiled by Intelligence Unit, Cairo and published by HMSO, London.

United Nations Emergency Office, Sudan (UNEOS)

240 **Early Warning System Bulletin** (January 1986; ongoing)

A monthly bulletin prepared with the intention of providing environmental and economic information relevant to identifying areas prone to food shortage and famine. Amongst other items, rainfall data (aggregates, distribution and rainday totals) are included during the wet season for a handful of key stations throughout the country. Probably represents the most rapid published dissemination of Sudanese rainfall data.

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