THE RECENT CLIMATIC FLUCTUATION IN LOWER LATITUDES AND THE GENERAL CIRCULATION OF THE PLEISTOCENE

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1. Recent Changes of the General Circulation in the Lower Latitudes of the Old World

In order to compensate for the somewhat secondary interest commonly devoted to the problems related to general circulation anomalies of the Pleistocene in lower latitudes, the present writer (K. W. BUTZER 1957 b) has already discussed the meteorological significance of the pluvials in subtropical latitudes. In this essay it shall be attempted to analyze the character of the recent climatic fluctuation in the subtropics and tropics in order to assess its applicability to some further problems connected with the atmospheric circulation of the Quaternary, namely with interpluvial and interglacial epochs. A general warming up of the northern Atlantic region has been of great interest in the past decades, but the trends of precipitation in different geographical areas have not been given a deserving attention. These precipitation anomalies are of an equally striking nature and equal palaeoclimatological implication as the recent temperature changes. Consequently the emphasis here shall be upon the circulation changes related to precipitation in lower latitudes. The large number of well-qualified and important articles considering our present climatic fluctuation have also only paid passing attention to the mediterranean climatic province and the trade wind deserts of the Old World; and largescale maps of barometric pressure and precipitation anomalies have been based on too few stations in this area, with often misleading results.

To help bridge this deficiency, pressure and rainfall changes in lower latitudes between 20° E and 75° W have been computed from the *World Weather Records* and presented in the form of three maps. Firstly January and July barometric pressure changes are summarized in Fig. 1 and 2. The differences are based on the records of 37 stations for the period before 1920 and 1921—1940. This apparently inhomogeneous comparison is necessitated by the scarcity of stations, but largely eliminated by the fairly uniform trends between 1881 (earlier limit of records applied) and 1920. This procedure has already been employed by K. KRAMES (1951, 1952) for temperature fluctuations. Almost all of the stations used begin recording between 1881 and 1900. Based on 72 stations, Fig. 3 illustrates the rainfall anomalies for the 30-year means before and after 1910 for the greater

Fig. 1. Barometric Pressure Changes 1881/1901—1920 to 1921—1940 (in millibars). January.

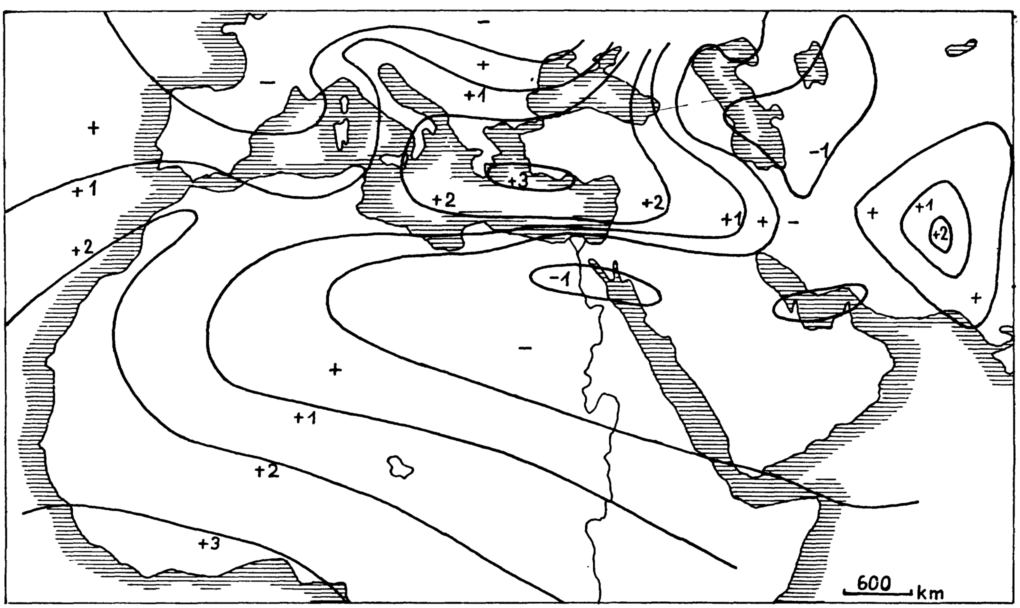

Fig. 2. Barometric Pressure Changes 1881/1901—1920 to 1921—1940 (in millibars). July.

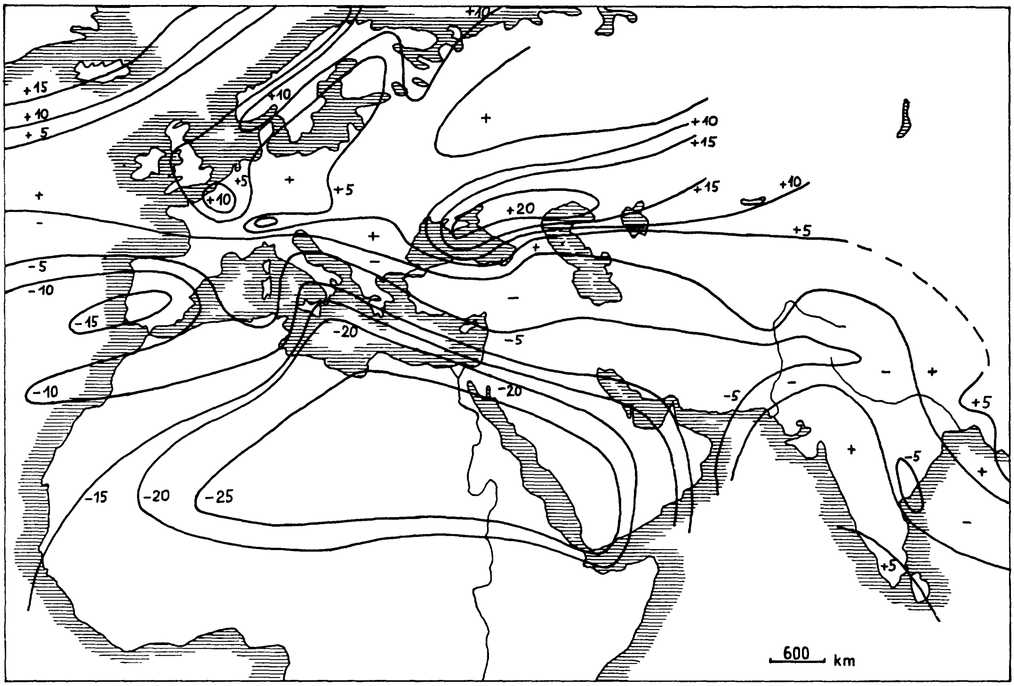

Fig. 3. Precipitation Anomalies 1881—1910 to 1911—1940 (expressed in percentage deviations from the mean 1881—1910). Annual.

part of the Old World (from H. H. CLAYTON 1927, 1934 and 1947; L. LYSGAARD 1949). Differences between 30-year means have been defined as climatic fluctuations by the International Meteorological Conference, Warsaw 1935. This is preferable to the comparison of decennial means often employed in recent investigations. The units refer to the change between the means for 1881—1910 and 1911—1940, expressed in per cent of the 1881—1910 mean. A regional geographical account of these changes in the Mediterranean have already been given by K. W. BUTZER (1958), but the lengthy tables upon which Figs. 1—3 are based have been omitted for lack of space.

Characteristic for the January pressure anomalies of the lower atmosphere (Fig. 1) is a pressure rise of 2 mb in Northwest Africa, 3 mb in the eastern Mediterranean and over 7 mb in the Aralo-Caspian area. The general positive trend in the Mediterranean Basin indicates a distinct weakening of the westerly circulation in the lower atmosphere and a considerable northward shift of the jet stream. A slight pressure increase in the Gulf of Lions indicates the number of cold fronts entering the western Mediterranean could not have decreased too strongly, but that the associated disturbances must have filled up more quickly or taken more northerly routes, the van Bebber storm tracks 5c and 5b instead of 5d and 5e. The number and intensity of minima penetrating the central and eastern Mediterranean must have decreased appreciably, a fact substantiated by an glance at the precipitation anomalies (Fig. 3). The strong positive anomaly over Cyprus can only be fully explained by a decrease in local cyclogenesis and of the 'Cyprus lows' which are of great significance for Near Eastern precipitation. The greatest positive anomaly over Central Asia is due to the westward shift of the Siberian anticyclone during the 20's and 30's. The overall picture is one of a filling-in of the secondary minima of the Meditarranean, and judging by small, localized negative anomalies in the eastern Sahara, a northward shift and intensification of the subtropical high pressure cells.[1] The positive anomalies in West Africa further indicate a southward extension of the trade wind belt and of the Harmattan winds. The picture of July pressure anomalies (Fig. 2) is fairly well identical in the etesian zone although not as pronounced in character. The center of the Asiatic low in North Baluchistan is filled in somewhat, but its domain extended further northwards. L. LYSGAARD'S (1949) large-scale map of world pressure changes suggests a predominance of negative anomalies for higher middle latitudes, from which we may conclude a slightly intensified pressure gradient between northern and southern Europe, that would necessitate an intensified zonal circulation in the lower atmosphere. R. SCHERHAG (1950) has shown that this zonal circulation increased from 1911 to 1930 but decelerated appreciably during the 30's.

The annual precipitation trend expressed in Fig. 3 show a $\pm$ 0 isoline running from southern France to northwestern India across the Alps, Balkans, Pontic Mountains and Caucasus. North of this line rainfall has generally increased (to over 20 % +), south of it, decreased (to over 25 % —). The whole mediterranean climatic province and particularly its eastern half has become very much drier. However the greatest decrease occurred on the northern and southern margins of the Saharan-Arabian deserts. The latter values are no local trends; they are valid for the whole Abyssinian drainage basin of the Nile (to account for a 16 % decrease in Nile volume during this period (c. f. BUTZER 1958)), and shorter records at other West African stations tend to confirm an identical anomaly. The aerological work of H. FLOHN (1953) would suggest this explanation for this phenomenon: the number of upper air cold fronts from higher latitudes and the number of disturbances in the equatorial easterlies have decreased. The pronounced increase in summer precipitation in South Russia and Central Asia, noticeably along the storm tracks 5 b, 5 c and particularly 3 a, again confirm the shift to more northerly cyclone routes and of a general northward recession of the polar front. The precipitation increase illustrated for the North Atlantic and West Europe compares with no relative change in the lee of Scandinavia. Trends between these two areas vary conversely according to KRAMES (1951, 1952) who has studied the dynamical processes of such precipitation swings more closely. The winter rains in the Punjab likewise diminished according to the northward shift of the local jet stream already discussed further west. The Indian Southwest Monsoon did not penetrate quite so far up the Ganges Valley as usual, possibly due to the weakening of the Asiatic low. Elsewhere there was apparently an intensification of the monsoon on the coasts with westerly exposure. This complicated picture of rainfall trends on the Indian subcontinent expressed in Fig. 3 is likewise reflected in the much-disputed Pleistocene stratigraphy of this area.

[1] K. KRAMES (1951, 1952) and other authors have already expressed a similar opinion.

The above considerations of Fig. 1—3 can be summarized in the following:

a) An intensification and northward shift of the subtropical high pressure cells and an intensification of the trades, accompanied by an expansion of the Saharan-Arabian arid zone in both latitudinal directions.

b) Decreased cyclogenesis in the equatorial convergence zone due to fewer upper air cold fronts from higher latitudes (meridional exchange of the upper atmosphere decreased) with a shrinkage of the humid tropics in Africa north of the equator.

c) A pronounced weakening of the lower westerlies in latitudes 30—40° N with northward shifts of the jet stream and polar front. The cyclones have tended to prefer more northerly routes and a decrease in pressure has slightly intensified the pressure gradient between northern and southern Europe. This implies a stronger zonal flow over central Europe and Central Asia.

According to the definition originally given by H.C. WILLETT in 1944 and more detailed analyses by WILLETT (1949) and H. FLOHN (1953), such circulation anomalies indicate an overall tendency towards *a dominance of zonal components* on the Old World continents south of about latitude 50° N. WALLÉN (1953) has shown that the typical zonal flow pattern described by WILLETT and FLOHN cannot have dominated in the summer in northernmost Atlantic and Scandinavia during the present fluctuation, rather a southmeridional circulation form[2]. The picture there is more complicated, largely due to the different forms of blocking highs tending to have reverse effects upon glacier ablation in Scandinavia. For example the blocking highs of type E (already described by D. F. REX), centered over Fennoscandia, favour increased warm air supply to Norway while the type A, centered between Iceland and Scotland, results in abnormal cold and rainfall in northern Europe (H. FLOHN 1953). Flohn believes these two opposed types of blocking highs are equally plentiful at present. The present increased northeastward flow of air over the North Atlantic is probably compensated by southeastward flow in eastern Siberia according to PETTERSSEN (1949), but the northward shift of the polar front and the decreased meridional exchange between lower and higher latitudes in both the lower and upper atmosphere can only mean that *the recent circulation changes over the area considered* (by Figs. 1 and 2) *have been towards an intensified zonal pattern* in the sense of Willett and Flohn.

Despite certain similarities between long-term rainfall fluctuations in northern Europe and in the Mediterranean Basin during the climatic phases of the geological past (BUTZER 1957 a, b), the presentday (short-term!) fluctuation expressed in Fig. 3 shows diametrically opposed tendencies. The overall circulation trend of the last 75 years, termed an intensified 'zonal' anomaly and defined in statements a), b) and c) above, provides an actualistic model for the reconstruction of an interpluvial circulation pattern in lower latitudes. Let us proceed to review the geological evidence.

[2] The negative pressure anomalies of S. PETTERSSEN (1949) for the Mediterranean Basin are not compatible with Figs. 1 and 2. The isobaric anomalies here described would indicate *an overall decrease in meridional exchange over the European mainland.*

2. Arid Pleistocene Climates in the Saharan-Arabian Area

Pleistocene geologists, meteorologists and prehistorians have in the past been disturbed by the occurrence of fossil dunes far equatorwards of the southern boundaries of the Sahara, which indicate a climate once very much drier than that of the present day. Without adequate reason a number of authors considered these fixed dunes as contemporary to the glaciations and postulated a southward shift of the Sahara during the glacials, a northward shift during the interglacials. This opinion is still widely held today, see for example a recent article by L. BALOUT (1952).

Basing himself on earlier work by J. DUBIEF, BALOUT assumes that glacial periods were characterized by an equatorward shift and acceleration of the jet stream while stronger 'étesiens' (trade winds) blocked the tropical monsoons, forcing the desert axis southwards. During interglacials the jet stream would be weakened along with the trades, permitting monsoonal rains to penetrate to the southern rim of the Atlas, as for example during the Neolithic period. Before considering the geological evidence, the meteorological concepts upholding this theory must be referred to. Our investigation of the recent climatic fluctuation has shown a northward shift and deceleration of the jet stream in subtropical latitudes, accompanied by an intensification of the subtropical high pressure cells and of the etesian and harmattan winds. The monsoons at the same time did not penetrate so far inland and their rains diminished. Similarly, shorter periods of low index or meridional circulation in recent decades (H. FLOHN 1953) were accompanied by a local intensification of the westerlies, disintegration and weakening of the high pressure belt and the associated trade winds, and increased cyclogenesis in the tropics. A stronger jet stream and stronger trade winds do not occur simultaneously but alternatively, so that the meteorological basis of the BALOUT-DUBIEF hypothesis is certainly not tenable. Neither does the Neolithic Subpluvial support it in any way. In the Near East (BUTZER 1957 a, c) there is evidence of increased moisture at this time all along the northern margins of the Saharan—Arabian arid zone, not of increased aridity as Balout implies. The pluvial characteristics of the Neolithic moist phase become increasingly weaker going south from latitude 30 to 23° N., so that a southerly source of moisture from a northward extension of the summer monsoonal rains is most unlikely.

Does the geological evidence support a shifting Sahara during the Pleistocene, or a simultaneous shrinkage or expansion during glacials and interglacials respectively? By analogy, our investigation of the recent climatic fluctuation supports the latter case for the Saharan interpluvials: an expansion of the arid zone in both latitudinal directions. Just as the earlier interglacials of higher latitudes were invariably warmer than the postglacial period, there is no reason why the interpluvials of lower latitudes could not have been drier than the postpluvial period. In this sense it is meteorologically feasible and in accordance with the present circulation anomalies that the interpluvials corresponded to greater aridity on the Sudanese margins of the Sahara. Although our present knowledge of Quaternary stratigraphy in the Sahara still leaves much to be desired, we believe it possible to show, although on somewhat indirect evidence, that the Sudanese and Mediterranean interpluvials were contemporary.

The fossil dunes or Qoz, as they are known in Kordofan, Darfur and Chad, are stabilized by a thin surface crust of iron oxide or clay and fixed by vegetation. Due to their perviousness, rainwater is largely absorbed and little surface drainage has developed on their undulating surface. The Qoz forms a belt averaging 300 km in width, reaching across the African continent from Dakar to the Nile. In Senegal it attains 350 km breadth at places and in Kordofan almost 500 km, reaching to 10° N latitude between the Jebel Marra and the Nuba Hills. The direction of the 'sef' lines of the dunes is generally north-south, and as northerly winds are invariably dry, the associated climate must also have been so. It is of no little surprise that the Sahara once reached over 300 km farther south. The Qoz does not, however, belong to one single period. It represents a number of stages, the greatest and oldest of which belongs to the Middle Pleistocene, the youngest dating from the early Holocene.

In the southwest Sahara at Cap Vert (Dakar), CORBEIL, MAUNY & CHARBONNIER (1948) have established the only existing direct association with the glacial chronology. The maximum extension of the Qoz was shown to be interdigited with the marine deposits of the 30m Tyrrhenian Transgression, and is most probably of Mindel/Riss Interglacial age. These fossil dunes lie directly upon a thick, hard iron crust of fossil red soil. In view of the present steppe soils this is an indication of pluvial conditions (laterization). Overlying the dune sands are two thinner, intermittant fossil red soil horizons, the upper of which contains a Mousteroid industry and is designated as the last, Würm Pluvial.[3]

Mlle. ALIMEN's admirable study of the Wadi Saoura gives a good indication of the Pleistocene succession in the northwestern Sahara. The reddish dunes of the Grand Erg Occidental have been blown up during a major arid phase following the major pluvial associated with a Chelleo-Acheulian pebble culture (H. ALIMEN 1955, p. 162 ff.). The areally quite insignificant light-yellow dune sands ('petits ergs') overlying the fluviatile deposits of the subsequent pluvial are associated with a Micoquian hand-axe industry. These are fixed by a tufaceous crust indicating a subsequent return to moister conditions during the Aterian and Upper Palaeolithic. From a comparison on sound stratigraphical and typological grounds Mlle. ALIMEN has been able to point out the equivalence of the pluvials of the Magrib and of the Sahara, and by means of the marine chronology, the contemporaneity of the Saharan Acheulian and Micoquian with those of Europe (*ibid.* p. 180—82). This likewise seems to place the great aeolian phase of the northwestern Sahara into the Mindel/Riss Interpluvial, the minor aeolian phase of the 'petits ergs' into the Riss/Würm Interpluvial.

In the Near East (K. W. BUTZER 1957 c) it was possible to show the interglacial age of the two last interpluvials, both of which apparently exceeded the present climate in aridity. However conditions are not quite so suitable in the Central and Eastern Sudan. The depo-

[3] At the INQUA Congress in Madrid, September 1957, Dr. WERNER BRÜCKNER has informed the writer of similar correlations in Ghana where periods of peneplanation (arid) corresponded to marine transgressions, periods of 'laterite'-formation (humid) to marine regressions. A note by P. MICHEL, J. TRICART and J. VOGT at the same congress presented evidence that the Qoz in the Senegal Valley at one place was deposited below modern sea-level. It is perfectly well possible that this could occur during the generally arid Late Glacial phases.

sition of Qoz sands east of the White Nile at Kosti indicates the major aeolian period was older than the White Nile at this locality (G. EDMONDS cited by G. ANDREW 1948). However the necessity of subdividing the Qoz phase is again apparent in the Chad area. H. FREYDENBERG (1908, p. 8, 61—69) has published stratigraphical profiles from a number of wells in Kanem and also west of Lake Chad. These all show a major horizon of white silicified dune sand below —6 m, which forms the main aquifer. Above this are clayey horizons indicating lagoonal conditions and one or two further dune intercalations. The last major depositional stage was followed by a lacustrine phase during which shelly, freshwater limestones and diatomaceous beds were deposited all along the Sahel from Mauretania to Kordofan. These deposits indicate lakes some 5—10 m deep in the hollows of the undulating Qoz surface. In Borku these final lacustrine sediments were associated with a Mousterian industry (M. DALLONI 1934, p. 137—41). In the Gezira Plain south of Khartum, J. D. TOTHILL (1946) believes the Qoz preceded the deposition of the Gezira clay plain under pluvial conditions in Upper Levalloisian and early Upper Palaeolithic times. These prehistoric associations would at least indirectly suggest a pre-Würm age for the last important Qoz phase. The industries associated with depositional and erosional cycles in British Somaliland, let alone Ethiopia, are quite insufficient to permit any parallelizations. Similarly the great aeolian phase of the Hadramaut, during which at least 4m of red windborne silt were deposited over wide areas was contemporary with a very crude and scarce flake industry representing the entire local Palaeolithic (G. CATON-THOMPSON 1953). Miss CATON-THOMPSON'S suggested relation to an intensification of the monsoons, based on a questionable Indian parallel, does not carry too much conviction. Despite occasional traces of water-action, this appears to be an interpluvial deposit.

During the arid postpluvial period in the Near East, with interruptions from 16,000—5,000 B. C. (BUTZER 1957 c), precipitation was less with greater aerial deflation and transport than at present. Examples are provided by the deposition of the Libyan loess upon pluvial gravels, the severe wind-scour of the Upper Palaeolithic lake sediments in the Fayum, and the deflation of the younger Würm-age sediments to well below present kavir level in the Lut Desert of Iran. Similar conditions dominated elsewhere in the Sahara as well. Minor dunes were deposited between the last Upper Palaeolithic moist phase and the Neolithic Subpluvial in the Saoura Valley, and aeolian erosion was particularly active during the same interval at Asselar in the southern Sahara (H. ALIMEN 1955, p. 162—74). An identical case has been illustrated by TOTHILL (1946) in the Gezira Plain.

This brief survey of particularly dry periods in the Sahara places the major phase of sustained aridity with large-scale aeolian deflation and deposition in the long Mindel/Riss Interpluvial of the early Middle Pleistocene. A greater expansion of the Sahara is further evidenced during the Riss/Würm Interpluvial and during the early postpluvial period (Postpluvial I and II stages of the Near East). The latter two were of decreasing significance and intensity, although still appreciably drier than the present. The meteorological implications are of considerable importance. *The circulation pattern of the last two interpluvials was very closely related to the circulation anomalies of the recent climatic fluctuation, specifically, to an intensified zonal or high index type.* A similar circulation must have dominated during the late glacial period, from the retreat from the Pommeranian moraines to the onset of the Atlantic, with exception of the Upper Dryas glacial relapse (the short Subpluvial I of the Near East). *The circulation pattern associated with the retreat of the continental glaciers was apparently of a zonal or high index type as well.* The problem of the moist Neolithic Subpluvial II during the Atlantic (c.f. BUTZER 1957 a, b, c) still remains to be solved. The evidence for very moist periods of exceptionally long duration in the Saharan area in pre-pleistocene times when there was no question of glaciations and when temperatures were well above those of the present, suggests that *another form of non-glacial circulation favouring greater precipitation in the trade wind belts may possibly exist.* In an earlier article (BUTZER 1957 b) we advocated the essential independence of the circulation changes from planetary temperatures at the beginnings of the Pleistocene glaciations. The meridional—low index type circulation responsible for lower latitude pluvials may also possibly have functioned in a modified form during certain intervals of higher world temperatures. In any case it is well to maintain a distinction between the terms pluvial and glacial, interpluvial and interglacial. *The present zonal circulation anomalies provide valuable actualistic experience for the reconstruction of an interpluvial circulation, but not necessarily for every form of interglacial circulation.*

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