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Large scale atmospheric circulation with respect to tropical droughts

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सार — दक्षिण एशिया में वर्षा के अपवादों को ज्ञात करने वाले तथा बड़े पैमाने पर होने वाले पर संचलन की चर्चा की गई है । जो वर्षा और तूफान की क्रियाओं में विचित्रता ग्रहीय परिसंचलन में होने वाले परिवर्तनों के साथ योगदान को दर्शाया गया है । तिब्बत से भूमंडलीय प्रवाहों की अन्योन्य क्रिया को दक्षिण एशिया की वर्षा के अपवादों के साथ साथ मध्यपूर्व और उत्तर अफ्रीका में शुष्कता के लिए प्रारंभिक स्रोत के रूप में माना गया है ।

ABSTRACT. The large scale circulation features which determine rainfall anomalies in South Asia are discussed. Singularities in rainfalls and typhoon activity supplemented changes in global circulation are shown. The interaction of planetary flows with Tibet is supposed to be a primary source for rainfall anomalies in South Asia as well as for aridity of the Middle East and North Africa.

1. Introduction

Considering the problem of droughts it is important to bear in mind that they should not be taken as a purely meteorological phenomenon. In general the droughts are referred to when the temporal lack of water in natural environment brings the damage to men's activities. But the dry season in tropics, for example is never called a drought, the vegetation, animals or people society being used to it. The meteorological mechanism of the two yet may be the same. We can see also that sometimes under the same meteorological conditions a drought (or lack of it) may be a result of changes in agricultural technology or a water storage in the soil etc. That is why intending to discuss here a background physical process associated with tropical droughts we are going to consider only the large scale atmospheric processes determining rainfall variations which droughts (or aridity) are embedded in.

It is quite clear that a drought (or aridity as well) is a consequence both of rainfall deficiency and low air humidity. The physical processes responsible for them are not so clear. Sometimes droughts (or aridity) are attributed to local processes which determine heat and moisture balances in a surface layer and to a feedback with the above atmosphere. The mechanism responsible for droughts formation supposed to be as follows: inhanced incident solar radiation and heating of the soil surface result in formation or strengthening of anticyclonic circulation which in its turn leads o stronger downward motion, more incident solar radiation and more heating of the soil surface and so on . . . till in spite of all those reasons it rains. Meteorologists who studied physical processes associated with droughts over the USSR have come to a conclusion, that the large scale processes are the primary source for them. The most important process for droughts formation is a large scale interlatitudinal air exchange occurring sometimes under special circumstances. In such circumstances the transformation of the air which moves from higher to lower latitudes is characterised by intensive heat flux and the lack of moisture flux. The dry warm air formed in that cases never bears rains and result in extraordinary evaporation. Being persistently involved into an anticyclonic circulation this air can bring a severe drought. Over European part of the USSR such air sometimes comes from the Middle Asia and consists of continental tropical air mass, originated from Arctic air. The air with the similar properties can be advected

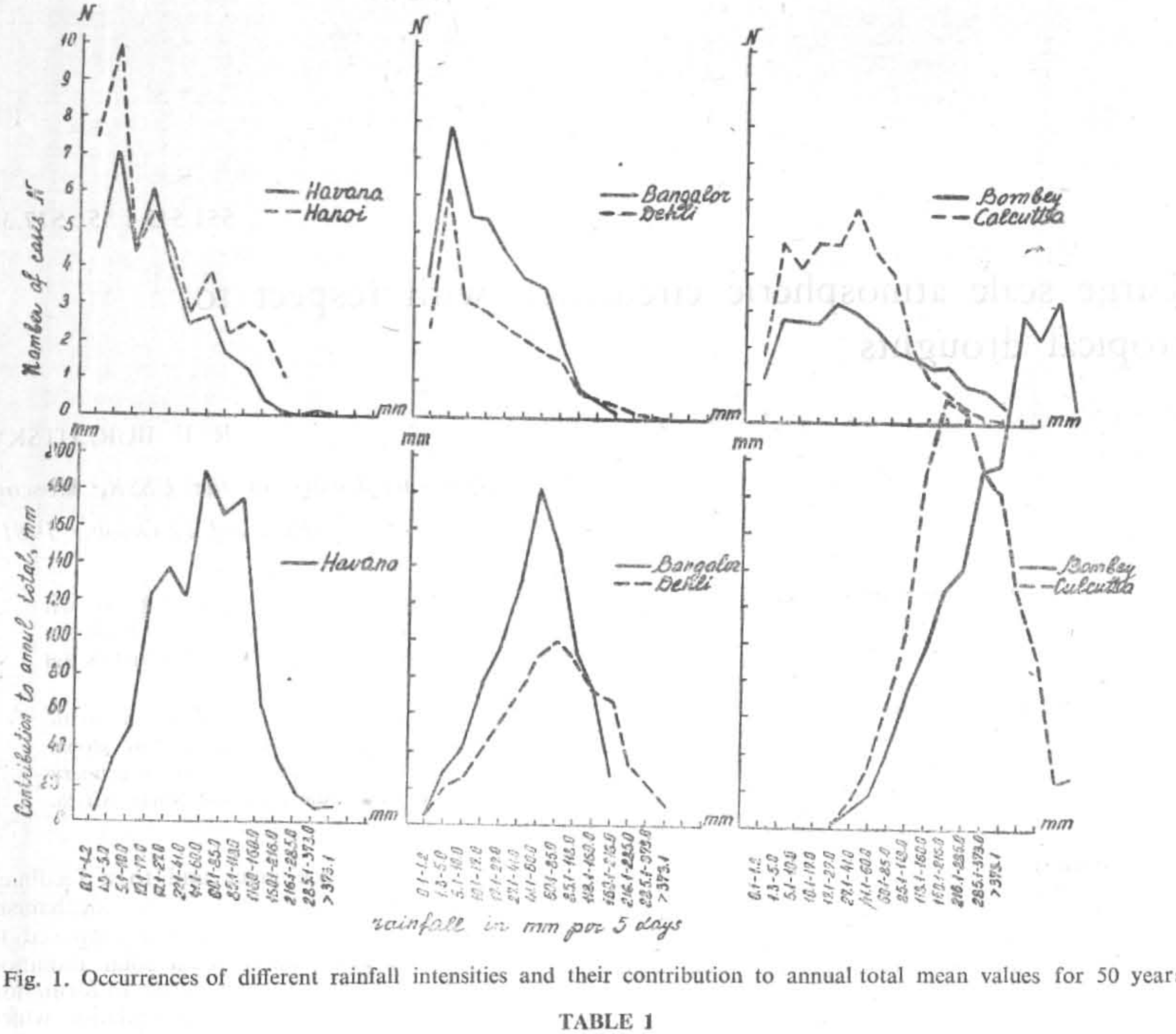

Fig. 1. Occurrences of different rainfall intensities and their contribution to annual total mean values for 50 years

TABLE 1

Contribution of 5-day rainfall totals into annual totals

5-day rainfall totals (mm)	Mean 50 years contribution (mm)	Annual Total (mm) <700	700-800	800-900	900-1000	1000-1100	1100-1200	1200-1300	1300-1400	1400-1500	1500-1600	1600-1700	1700-1800
0.1 - 40	469	460	401	452	479	468	484	478	460	478	800	437	418
40.1 - 400	664	126	362	415	483	610	694	752	864	902	921	1063	1440

TABLE 2

Frequency of synoptic patterns, associated with more than 40 mm/5 days rainfalls for 10 arid and 10 humid years in Havana

Synoptic patterns	Humid years (1300 mm)	Arid years (900 mm)	Difference
Southern or south-western fringe of subtropical anticyclone	53	36	17
Tropical cyclones	23	6	17
Frontal disturbances	31	18	13
Southern fringe of extratropical anticyclone	19	12	7

from Africa or Mediterranean. But its origin as we show later remains principally the same. Proceeding to discuss physical processes determining rainfall anomalies we would like to stress that above conclusions are fully justified for tropical regions also.

It is easy to bring evidence for a close relationship between large scale processes and rainfall anomalies. The Fig. 1 presents mean frequencies of different five day rainfall totals (upper curve) and mean contribution of each gradation into the annual total (lower curve) for Havana.

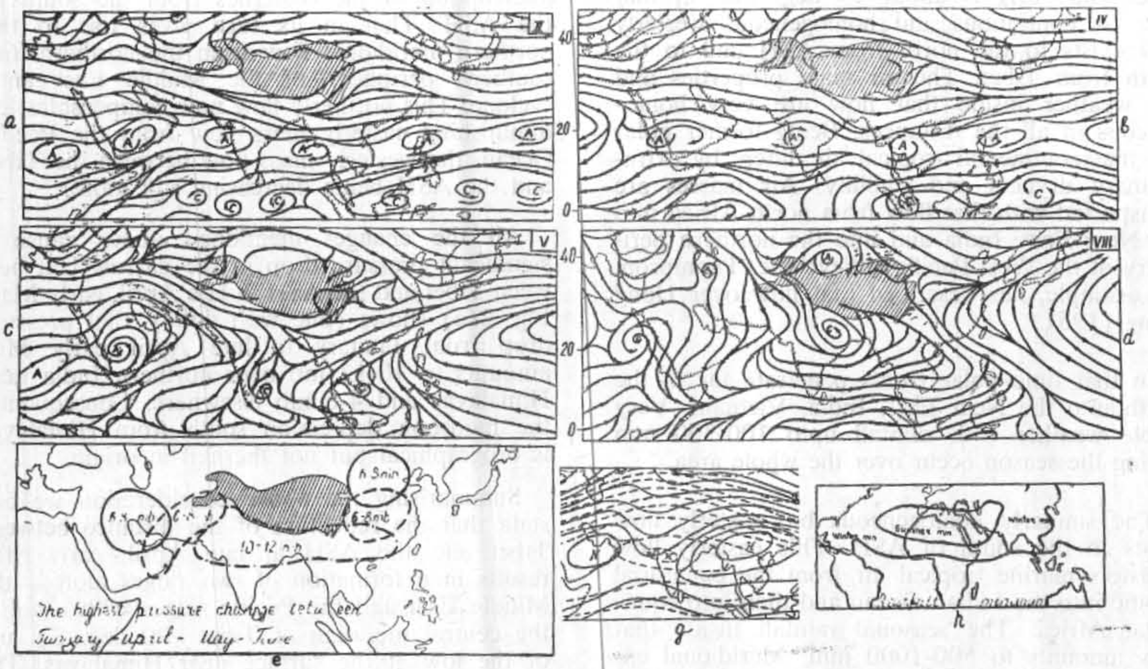

Fig. 2. Streamlines at 700 mb/4/(a,b,c,d); the highest pressure change between January-April-May-June (e), 200 mb patterns before and after monsoon onset in 1973 (g); geographical distribution of rainfall minimum in annual course

The sum of ordinates for the upper curve presents the number of pentads with rainfall for a year (50), and that for lower curve presents mean annual total (1133 mm). Different amounts of five day rainfalls result from different rain bearing processes. Rainfall amounts upto 40 mm are the result of thermal convection. Rainfall amounts over 40 mm are produced by synoptic scale disturbances. The former presents 82 per cent of all pentads with rainfall and gives 40 per cent (471 mm) of the annual rainfall. The latter presents only 18 per cent of all pentads with rainfalls, but gives 60 per cent (662 mm) of the annual rainfall.

The annual totals in Havana range from 600 mm to 1800 mm. The Table 1 shows the contributions of rainfalls upto 40 mm and rainfalls over 40 mm into annual totals separately. It seems striking that the contribution of rainfalls upto 40 mm remains practically constant, about 460 mm, no matter a drought or wet year it is. It implies that convective processes remain more or less on the same level through years. The contribution of rainfalls over 40 mm changes drastically through drought and wet years. It varies from 126 to 1440 mm. So we can see that the rainfall anomalies for a year are completely determined by the large scale atmospheric processes.

Table 2 shows the frequencies of different synoptic patterns bearing over 40 mm rainfall through 10 drought and 10 wet years. The number of rain bearing patterns in wet years exceeds that of dry years on 54. That means 5, 4 more processes a year. So we may state that the dryness or wetness of a particular year depends on occurrence of only a few large scale synoptic patterns. It is also interesting to note a large contribution of rainfalls connected with anticyclones into annual anomalies. Their contribution to variance of annual totals is even larger than that of tropical cyclones (compare the first and fourth lines with the second line). It proves once more that only an anticyclonic circulation is not yet sufficient for a drought formation.

The frequency of rainfall intensities at different points in Asia being very similar to that in Havana (Fig. 1), the above conclusions seem to be valid for the whole tropical belt.

2. Summer monsoon development

Now let us go into details of the large scale circulation over south Asia and its impact on rainfalls. A set of experiments fulfilled with the help of the soviet scientific ships, particularly "Monsoon" and "Monex" let the author present a new interpretation of the monsoon development in south Asia (1, 2, 3.). In contrast with a common point of view on primacy of the trade winds of the southern hemisphere, the results of the experiments imply the primacy of the interaction of planetary flow with Tibet in monsoon development.

The axis of the subtropical high pressure belt (ASH) occur near 10-15 deg. N over the West Pacific and the Indian Ocean in winter (Fig. 2a, b). The distance between the southern fringe of

Tibet and ASH is about 15 deg. Lat. in that time. A continuous and homogeneous westerly flow exists to the north from ASH and to the south from Tibet. The air mass properties and the weather inside that flow are very homogeneous in all the distances. Being former polar air, that continental tropical air differs by extraordinary dryness and stability. Air masses are transported with that flow from north Africa into the Near East, India and into the northern periphery of the West Pacific anticyclone. Thompson, for example, has described that flow over Hong Kong (1951).

In that time polar fronts penetrate far to the south into the Near East, India, Vietnam. Very stable weather with rainfall upto 100-300 mm during the season occur over the whole area.

The similarly homogeneous but easterly flow exists to the south of ASH. This easterly flow transfers marine tropical air from the equatorial Pacific into the Indian Ocean and then into equatorial Africa. The seasonal rainfall inside that flow amounts to 500-1000 mm. Meridional exchange of air mass between the easterly and westerly flows across ASH is practically absented.

Such conditions conserve themselves practically unchangeable through the whole season till April. In early spring a number of considerable changes takes place in all the tropical and subtropical belt. In March the southern end of a polar front removes from the Middle East into the Middle Asia; the easterly monsoon appears over eastern Java. In April the east monsoon appears over western Java. Following the polar front in Asia and eastern monsoon in the southern hemisphere ASH moves rapidly to the north at the late April-early May. The distance between ASH and Tibet reduces upto 4 deg. Lat. The vast westerly flow, which earlier existed to the north of ASH appears to be interrupted in lower troposphere by Tibet (*see* Fig. 2 c, d). That interruption result in a set of mutually connected changes of the atmospheric circulation.

The mass flow from Asia into northern periphery of the Pacific anticyclone diminishes substantially. This decrease of the mass flow causes the pressure drop to the north of ASH from the side of the Pacific anticyclone (Fig. 2e). The pressure drop gives rise to a meridional flow from the southern into northern periphery of the Pacific anticyclone (Fig. 2c, d). This southerly flow now compensates the diminishing westerly mass flow from Asia.

The appearance of the strong meridional flow from the southern into northern periphery of the Pacific High means also a decrease of the mass flow from the Pacific into the Indian Ocean and interruption of the easterlies from the south of the ASH. That in its turn gives rise to the northern meridional flow from the northern into southern periphery of the Middle East anticyclone. This northerly flow now compensates the diminishing easterly mass flow from the Pacific Ocean, the westerly mass flow between the Tibet and the ASH being decreasing still more.

All the changes mentioned above cause a significant pressure drop in the narrow belt between Tibet and the ASH in late April, early May. Fig. 2(e) shows (line with dotts), that pressure drop from January to late April - early May amounts to 10-12 mb over northern India near Himalayas and 4-6 mb elsewhere. Consequently the monsoon depression south from Himalayas is orographical but not thermal in origin.

Summarising the above consideration we can state that the reduction of the distance between Tibet and the ASH at late April - early May results in a formation of two ridges aloft — the Middle East and the Pacific ridges with a col at the central meridian of Tibet (90 deg. E) and of the low at the surface near Himalayas. The majority of India and the Arabian Sea appears to be under the Middle East ridge, but the Bengal Bay and Indonesia — under the Pacific ridge. This lead to a fundamental changes in air mass displacements and in weather.

The surface low causes appearance of surface westerlies over all the north Indian Ocean and south Asia in late April. In the troposphere the maritime tropical air, which flew from the Pacific into the Indian Ocean and equatorial Africa in winter, is now deflected to the north and northeast over the Bengal Bay and spread over southeast Asia instead of former polar dry air. The southwest monsoon starts over the eastern shore of the Bengal Bay, and the plum rains start over southeast China.

The dry air of the northern periphery of the Middle-East ridge, consistent from tropical continental mass (polar in origin), which flew south from Tibet into the Pacific Ocean in winter is now deflected to the south over the Indostan peninsular becoming even more warmer and dryer. The highest temperatures at the surface (upto 40-45 deg. C) and highest lapse rates in the troposphere (7 deg. C per km and more) occur over India at that time. The dry and hot northern flow is changed by the wet southern flow in the col over the West Bengal Bay almost without any transition. The cloudless Indostan peninsula contrasted with the overcast of the Bengal Bay.

Following the southern periphery of the Middle East ridge the air masses displace from India into the Arabian Sea and north Africa. So it appears that the former polar air entered the north Africa with the westerlies at the southern ends of polar fronts in winter; and the same, polar in origin, air but deflected to the south and much more heated and dried continue to enter north Africa with easterlies in spring and summer. Therefore, Tibet is the cause of aridity of both the Middle East and Sachara.

At early June the polar front removes from the Middle Asia to the north and the westerly jetstream in the upper troposphere jumps from the northern to southern fringe of Tibet (Fig. 2g). The westerlies are almost completely interrupted by Tibet in the lower troposphere. At that time the largest pressure drop occurs over Arabia and south China (Fig. 2e), where the distances between the ASH and the mountain fringe contract more significantly. The jump like pressure drop over Arabia strengthens immediately pressure gradients over the Arabian Sea and the so called monsoon burst follows over the Arabian Sea and the western shore of India. The plum rains remove into the middle China.

With the shift of the ASH to the north the Middle East ridge appears over north Pakistan and the Pacific ridge — the north Indo-China. The eastern tip of one and the western tip of another ridge following Tibet fringe at height of 700 mb remove to the west and to the east from the previous col respectively. The col region is occupied by Tibet and the col looks to be broken — one part being a trough at 70 deg. E in the place, where the Middle East ridge thrust into Tibet. So the well known shift of the tropospheric monsoonal trough from 90 deg. E to 70 deg. E is also caused by Tibet. In the upper troposphere at the place of the previous col an anticyclone appears and the easterly jet develops to the south of it (Fig. 2g).

The continental tropical air (polar in origin) retreats from India into Pakistan following the eastern periphery of the Middle East ridge. But transition between that air and wet southwesterlies remains very sharp as it was over the Bengal Bay before. That is why wet regions in India are changed by deserts in the west practically without any transition. At the second half of July the polar front over Asia takes the northern most position, and the ASH in the troposphere shifts on central latitude of Tibet. The plum rains stop over China and Japan but a new rain period connected with ITCZ starts over the west Pacific, Philippines, south China, the Bengal Bay. The former polar air deflected by Tibet and perhaps by European mountains spreads continuously into the Middle East and north Africa. In all that region a continental tropical air is formed — surface temperatures upto 40-45 deg. C and lapse rates over 7 deg. C per km (as it was in early summer in India). In the whole Mediterranean and the Middle East summer minimum of rainfalls occur (Fig. 2h).

3. Teleconnections in rainfall over South and East Asia

The relation between rainfalls and the circulation considered above can be illustrated by the annual course of rainfall in south and east Asia (Fig. 3). The rainfall regime in Asia reveals some drastic changes through the annual course and these changes are opposite in different regions.

The rise of rainfall in Bombay and over the Arabian Sea in June is caused by the southwest monsoon. Simultaneously the rainfalls enhance over south China (Hong Kong), which means the start of the plum rain period. The Fig. 3 shows that these processes develop quite suddenly, at full strength and show extraordinary ties on calendar.

The plum rains reflect themselves in annual course of rainfall also in middle and northern China. But corresponding rainfall enhancement takes place later in northern latitudes — over *Yangtze* river in June, at Peking in July (Fig. 3). The end of the plum rain period in south China corresponds to the secondary minimum of rainfalls in Hong Kong at the end of June-start of July. The shift of the plum rains to the north results from corresponding shift of the polar front.

The next change in the rainfall regime takes place in the second half of July and corresponds to the equatorial monsoon and the movement of the ITCZ to the north. We can note that change in the rainfall regime over the Bengal Bay, in Hong Kong (secondary maximum), Manila and also in the abrupt increment of typhoons in the West Pacific (Fig. 3). So the mean regime of rainfalls agrees very well with the large scale circulation. It is interesting to note that the annual course of rainfalls in the Middle Asia (and in the whole zone of summer rainfall minimum) is reversed that over monsoonal Asia. That fact implies that rain-bearing large scale processes in the two areas follows one by another. The same conclusion comes from comparison of rainfalls in Manila and the plum rains over China. These features implies also that breaks in annual courses of rainfall in different areas should be mutually related.

To judge the question we consider the cumulative curves for deviations of moving 10-year totals of rainfall over Middle Asia (mean for 10

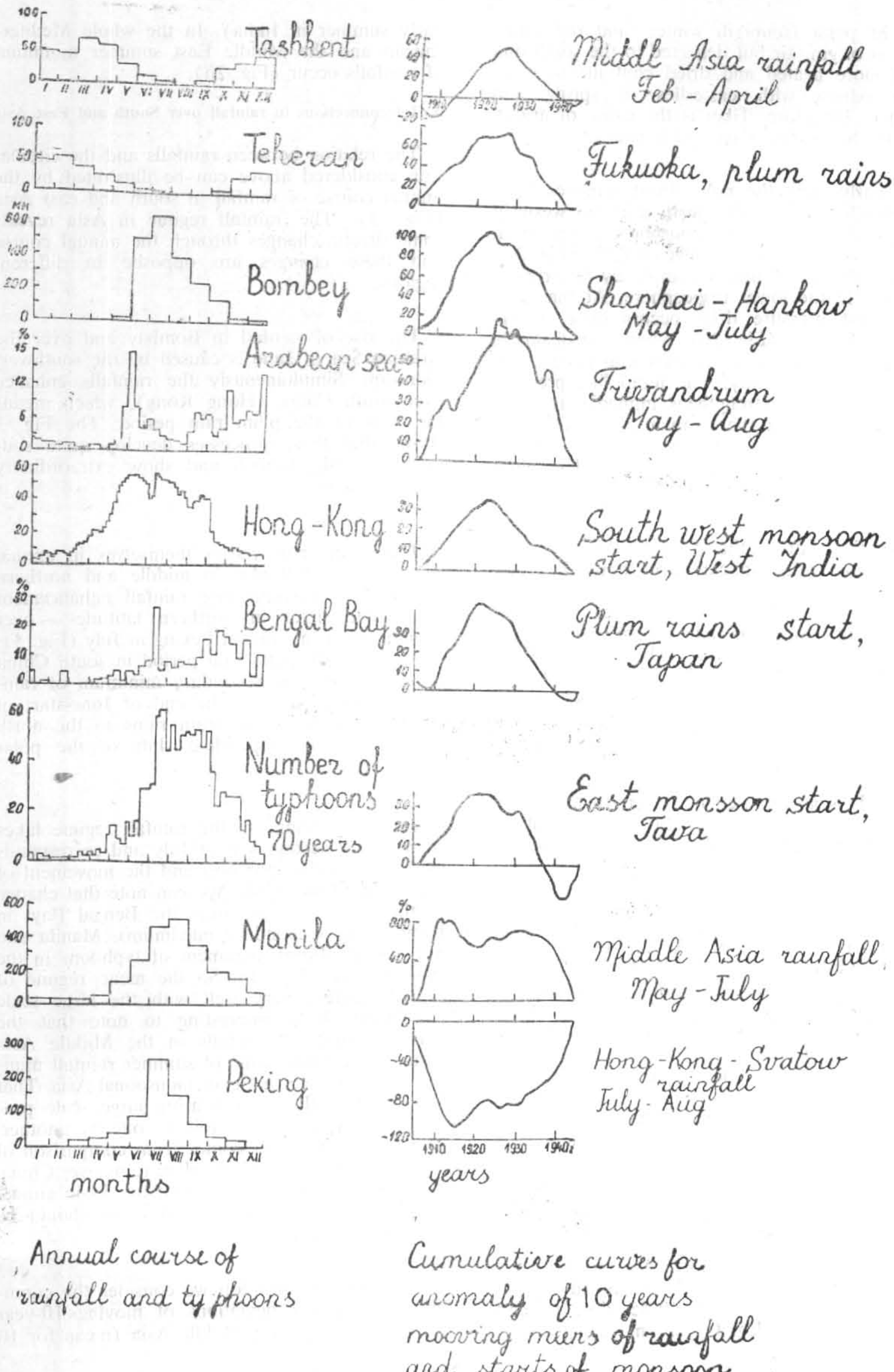
Tashkent
Teheran
Bombey
Arabean sea
Hong-Kong
Bengal Bay
Number of typhoons 70 years
Manila
Peking
months
Middl Asia rainfall Feb - April
Fukuoka, plum rains
Shanhai - Hankow May - July
Trivandrum May - Aug
South west monsoon start, West India
Plum rains start, Japan
East monsson start, Java
Middle Asia rainfall May - July
Hong-Kong - Svatow rainfall July - Aug
years
Annual course of rainfall and typhoons
Cumulative curves for anomaly of 10 years mooving mens of rainfall and starts of monsoon

Fig. 3

stations), Japan, China, India and also the onset of southwest monsoon in India, plum rain in Japan and east monsoon in Java. All the data refer to 1880-1950. The results are shown in Fig. 3.

Precipitations over the Middle Asia in early spring correlates positively with rainfalls in early summer almost over all monsoonal Asia. This relation concerns asynchronous phenomena. As we see in Fig. 3 in the Middle Asia in spring and in south and east Asia in summer, the mean 10-year rainfalls were above normal from 1905 to 1925 and below normal after 1925.

The positive correlation between spring rainfalls in the Middle Asia, and plum rains in the Middle China and Japan is especially well pronounced. The relation is much worth with rainfalls in south China and absent completely with the north China rainfalls.

The synchronous correlation between summer rainfalls in monsoonal Asia and summer rainfalls in the Middle Asia exists also (Fig. 3). But if the correlation with the spring rainfalls reveals itself in the same manner over all monsoonal Asia the correlation with summer rainfalls is different for different latitudes.

The summer rainfalls over Middle China and south Japan appear to be correlated positively with summer rainfalls over the Middle Asia. But that correlation is less pronounced. The synchronous correlation of summer rainfalls in the Middle Asia with rainfalls in South China in July-August is much more pronounced. But that correlation is negative. We have already told about two maximums of rainfalls in Hong-Kong — one at the late May early June and another at the end of July-August. The first one is caused by plum rains (polar front), the second — by the equatorial monsoon (the ITCZ). So the first maximum correlates positively but asynchronously with spring rainfalls and the second one correlates synchronously but negatively with summer rainfalls in the Middle Asia.

4. Discussion

The fact that the Middle Asia rainfalls caused by polar front correlate with rainfalls in south and east Asia, that fact implies the correlation between position of polar front over the middle Asia and the development of monsoon over south and east Asia. The rainfalls of the whole area of the summer rainfall minimum (Fig. 2h) being associated with the polar front, the wider interrelationships are possible between position of polar front in all that area and the monsoon circulation in Asia and Africa including Sachel.

Taking into account the circulation considered above the mechanism of rainfall variation may be described as follows. Through the years when cold air surge enter frequently the Middle Asia in winter and early spring the polar front moves far to the south, into the Near East and than stays over the Middle Asia in spring for a long time. These events forces the ASH to move to the south abnormally, and the western monsoon of the southern hemisphere develops intensively. The cold weather with a low rainfalls predominates over the Middle Asia in winter and spring. The western monsoon on Java appears to be prolonged and the dry east monsoon is late (Fig. 3). Conditions favourable for winter droughts appear over the Middle Asia and for wet weather — in the southern hemisphere.

The polar front displacement is late over the Middle Asia during such years. That results in late displacement of the west jet stream from southern to northern fringe of Tibet, late onset of the monsoon and frequent breaks of it, late start of the plum rains. The weakening of the easterly jet stream in that cases seems to cause rainfall deficiency in Sachel. Thus, the drought favourable conditions rises in spring over the Middle Asia and in early summer in south Asia.

Through the years with moderate surges of cold air and stronger surges of warm air in winter and early spring — intensive cyclonic activity develops over the Middle Asia bringing enhanced rainfalls. Under that circumstances the ASH moves to the north earlier. The east monsoon in Java comes earlier. The western jet stream shifts over Tibet earlier. The west monsoon and plum rains develops more intensively. The rainfalls of the early summer become above normal. 1954 can be pointed out as an example of such conditions — when the enhanced cyclonic activity develops in the Middle Asia and the plum rains result in an extraordinary floods in the Yangtze valley.

At the end of July the polar front shifts in the northernmost position over Asia. Simultaneously the ITCZ enters south Asia, the typhoon season develops fully, rainfalls start in Manila, Hong-Kong, the Bengal Bay. But through the years with frequent cold surges in summer the polar front returns to the Middle Asia. Rainfalls occur above normal there. When the polar trough intrudes into the Middle Asia the westerly jet stream re-establishes south from Tibet, monsoons breaks, but the plum rains appear over Middle China (the first decade of August 1957 is an example). The ITCZ removes itself out from south Asia, rainfalls disappear, typhoon activity diminishes. Conditions favourable for droughts establish in the late summer in south Asia. So the negative correlation between rainfalls in the Middle Asia and south Asia and positive correlation with rainfalls in middle China appear. The discussed features of the circulation and rainfalls prove close teleconnections between rainfall anomalies and interlatitudinal air mass exchange. The main physical process which lead both to the aridity of climate or to temporal lack of rainfalls and droughts consist in penetration of air from northern to southern latitudes under considerable heat flux and under deficit of moisture flux.

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