The Nature of Rainfall over the Sudan and the Potentialities for its Artificial Modification

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FOREWORD

The research paper before us deals with the question of rainfall over the Sudan. The paper falls into two parts. The first is a general treatment in which the author considers the basic factors which influence the amount, distribution and effectiveness of rainfall. In order to do this the writer had to analyse the pressure system, which governs the circulation of major air masses that blow over the Sudan. In short, the author has presented the reader in this section with a candid picture of the main features of the Sudanese climate. The second part of the paper deals with the problem of artificial stimulation of rainfall. In this section the writer presents a survey of the attempts made by scientists to influence world climates and concludes by pointing out the risks as well as the problems and practical difficulties which face the implementation of the proposed techniques. After surveying the international situation, the author goes on to focus on the Sudanese experiment in this connection by presenting a critique of the Hunderson Inc. report on "Rainfall Modification in the Sudan".

On the whole, it may be said that research into the nature of rainfall, and the possibility of its stimulation artificially, is of paramount importance in a country like the Sudan where the question of rainfall, and of water in general, forms the keynote to economic advance.

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(With 10 Maps).

THE NATURE OF THE SUDAN'S RAINS

The occurence of rainfall in the Sudan, or any other part of the world, is governed by a number of factors whose relative significance may vary considerably with time and place. However, in all the cases, the actual process of precipitation must be preceded by extensive evaporation and condensation and so the conditions must be favourable for these two processes to take place.

The Sudan with its present topographical features lacks any suitable evaporation fields due to the complete absence of any major water bodies inside the country except perhaps for the Nile system and the swampy area of the Sudd region (Fig. 1). This also applies to the immediate surroundings of the Sudan except for the Red Sea whose narrowness and location reduce greatly its evaporation potentialities.

These facts imply that the necessary moisture must be drawn from distant sources such as the Atlantic and the Indian oceans which are physically capable of yielding enormous amounts of water vapour (Fig. 2). However, the distant location of these sources requires the existence of an efficient transportation system in the form of prevailing or seasonal winds, or a combination of the two. The winds affecting the Sudan show a marked seasonal variation as a consequence of the seasonal changes and displacements of the pressure cells over and in the immediate vicinity of the African continent, (Figs. 3-6).

During the winter season, the northern part of Africa is dominated by the Saharan anticyclone which is an extension of the permanent Azores anticyclonic cell. The low temperatures attained over the Sahara during this time of the year are responsible for the establishment of the observed high pressure conditions over this part of Africa. The winds associated with this anticyclonic system blow outward and in a clock-wise direction and so they reach the Sudan as north Easterly winds since the Sudan lies to the East of the centre of this particular pressure system. These are the North Easterly trade winds.

During the same time of the year, an anticyclonic system will develop over Arabia as a consequence of thermal changes that are very similar to those responsible for the creation of the Saharan anticyclone. The winds associated with the Arabian cell also blow in a clock-wise direction and they reach the Sudan as Southerly or South-Easterly currents. This is a consequence of the location of the Sudan relative to the centre of the Arabian cell.

So during the winter season the Sudan will be dominated by the North-Eastern trades except for the narrow coastal belt where an additional Southerly or South-Easterly current may blow from over the Red Sea in association with the Arabian cell. The latter winds are likely to transport some moisture from over the Red Sea to the coastal belt. This is also true for the section of the north Easterly trades that blow from over the Red Sea. But in both cases the amounts of water vapour involved are very limited indeed due to the narrowness of the sea and the consequent short water expanses over which these winds can travel before reaching the coast. As a result of this, the amount of moisture reaching the coastal belt should be very small and its effects should be confined to a small area beyond the coastal line.

For the largest part of the country, however, the N.E. Trades are continental off-shore winds and so they tend to blow in the wrong direction as far as the required moisture transportation is concerned.

Radical changes occur during the summer season. These changes follow the seasonal migration of the overhead sun towards the Tropic of Cancer and the gradual increase of temperature over the Sahara which eventually becomes one of the hottest areas in the world. This will lead to the creation of a thermal low pressure belt that will gradually attract the South Easterly Trades of the southern hemisphere.

As these winds cross the Equator they will gradually obtain a westerly component and become South Westerly winds. This change of direction is a consequence of the coriolis force of the Earth. The original South-Easterly Currents blow in association with the permanent sub tropical Indian and South Atlantic anticyclones which tend to spread laterally during this time of the year in response to the establishment of high pressure conditions over the Southern half of Africa which during this time of the year will be experiencing its winter season.

Due to these drastic changes in the nature and areal extents of the atmospheric pressure systems, the South Westerly winds will gradually replace the North-Easterly Trades over the Sudan to produce a radical change in the winds direction. However, these South-Westerly currents originate over oceanic waters and start their journey towards the Sudan from over the Guinean Gulf. It is in these South-Westerly on-shore winds that we find the necessary Transportation System between the extensive oceanic evaporation fields and the country under consideration. Consequently, all the precipitation potentia-ities should be confined to the summer season when these humid S.W. winds reach the Sudan and dominate the lower layers of the atmosphere.

During their long journey over west Africa and the Sudan, only a few obstacles interrupt the smooth flow of these South-Westerly winds. The possible interruption inside the Sudan, takes place in the vicinity of Jebel Marra, the Nuba Mountains and the Red Sea hills (Fig. 1). The latter are the most effective in this respect due to their general trend and areal extent. They are followed in significance by Jebel Marra, since the isolated nature of the Nuba Mountains makes them the least effective.

Outside the Sudan, topography also offers very little resistence except perhaps along the Eastern and the South-Eastern frontiers of the country where the Ethiopian plateau stands as an effective barrier in the face of the surface winds. However, the winds approaching from this latter direction are not significant as far as the rains over the Sudan are concerned.

The arrival of these humid winds over the Sudan should be associated with extensive condensation before any rains may occur. This process normally takes place as a consequence of vertical motion or uplifting. Such vertical motion may take place in the form of Orographical uplifting, Frontal uplifting or thermal uplifting.

In the case of the Sudan, Orographical uplifting may take place in the vicinity of the Jebel Marra, the Nuba Mountains and the Red Sea hills. However, the fact that these high regions cover less than 3% of the total area of the country, indicates the insignificant role that the relief may play in the over all picture.

On the other hand, the possibility of large scale Frontal uplifting in the tropical regions in the form of an extensive Equatorial or Inter Tropical Front, is not accepted today but it had dominated thinking on Tropical meteorology for quite a time. However, the possibility of localized frontal activities is still advocated by some tropical meteorologists (e.g Grimes 1951). They believe that some localized frontal uplifting may take place between tropical air masses from two distinct antieyclonic cells in the same hemisphere. The Red Sea region may witness such a development if the air masses associated with the Saharan and the Arabian anticyclones possess the necessary horizontal contrasts.

It is also advocated that air masses moving in the same direction in the Tropical regions may some times converge at angles which again with sufficient horizontal differences may lead to a localized form of frontal uplifting. However, the possibility that such a development may lead to a simple confluence can hardly be excluded.

The third possible form of vertical motion is that associated with thermal convection which itself is a consequence of excessive ground heating. This seems to be the most important uplifting process in the Tropical continental areas like the Sudan where the summer temperatures normally attain very high levels. During the winter season of the Sudan the highest temperatures are experienced in the extreme southern part of the country where thedaily maximum temperatures may rise above 36°C (96.8°F). However, as the summer approaches, the zone of maximum temperature tends to migrate northward gradually following the overhead sun. It reaches the central part of the country in April and by July it establishes itself over the northern part where it remains almost stationary up to September after which it starts retreating Southward to occupy its winter position over the Southern Sudan (Fig. 7). It is worth mentioning that in the period July-September inclusive, the daily maximum temperature over the Northern Sudan averages 42°C (107.6°F) while over the Southern Sudan it hardly rises above the 30°C (86°F) level. During this same period a confined thermal low establishes itself in the North Eastern part of the Sudan, but occasionally it merges into the broad thermal belt of the Sahara desert.

Such high temperatures are experienced at a time when the Sudan is largely dominated by the humid South-Westerly winds. Beside the possibilities of local heating and thermal convection, these S.W. winds are themselves generally unstable and have a general tendency towards upward movement in contrast to the N.E. Trades which are both stable and have strong subsident tendencies.

So with the excesive ground heating, the great thermal instability and the general ascending tendencies, large scale convection is likely to take place in all the areas dominated by the humid South-Westerly winds. This implies that the extent of the effective thermal activity is determined by the extent of the area covered by the S.W. winds, (i.e effective as far as the precipitation or, the condensation are concerned.) So the area of the effective convection should increase gradually with the northward advance of the humid South Westerlies.

The northward advance of these Southerly winds is made at the expence of the North-Easterly Trades. These two air currents meet along the Inter Tropical Convergence Zone, (I.T.C.Z.) which may be described as a broad meeting zone that slopes gradually upward in the direction of the Geographical Equator. The S.W. winds are relatively denser due to their moisture content and so they occupy the lower layers of the atmosphere forcing the relatively lighter N.E. Trades to ride above the I.T.C.Z. (Fig. 8). The depth of the humid winds tends to increase southward from the surface position of the I.T.C.Z. This may suggest that the condensation potentialities should increase in the same direction since more moisture and greater depths will be available for the condensation processes as we move southward from the surface postion of the I.T.C.Z. On these basis, it may be expected, at least theoretically, that the frequency of condensation and precipitation increase southward as the I.T.C.Z. advances towards the northern frontier of the Sudan. This implies that the amounts of precipitation should increas steadily south of the surface position of the I.T.C.Z.

However, the relation between the surface position of the I.T.C.Z. and the frequency of condensation and precipitation is not so simple. In reality, the frequency of condensation and the resultant precipitation follow a patternt very different from the theoretical one. In fact, up to 300 Kms south of the surface position of the I.T.C.Z. there is hardly any significant condensation or precipitation. The maximum convectional activity and the maximum precipitation tend to occur in an area between 300 and 600 Kms south of the surface position of the I.T.C.Z. Beyond the 600 Kms limit, there is a noticeable drop in the frequency of condensation and in the amounts of precipitation.

No full explanation can be provided for the observed distribution of condensation and precipitation behind the I.T.C.Z. However, part of the explanation may be provided by the Tropical Easterly Jet Stream which develops within the upper Easterly winds that dominate the upper layers of the atmosphere over the Sudan and the similar Tropical regions during the summer season (Fig 9). The presence of this jet stream was suggested by Koteswaram in 1958. It is believed that this particular jet stream originates over the Tibetan plateau and disintegrates over the Sudan. So the Sudan forms part of the exit' zone of the Tropical Easterly Jet Stream.

The core of this jet stream lies around latitude 15°N. during the peak of the rainy season. Its centre always coincides with the belt of maximum precipiation since it is characterized by a very strong vertical motion. This contrasts very sharply with an observed general subsidence at the northern edge of the jet stream, somewhere around latitude 18°North. So the position of the area of maximum convection and precipitation largely coincides with the centre of the Tropical Easterly Jet Stream and thus the latter may at least be partly responsible for the concentration of the maximum rains within a confined central belt.

At the same time, the downward movement near the northern edge of the jet stream seems to combine with the shallowness of the moist layer as well as with the subsident nature of the upper trades, to explain the general dryness of the areas that lie in the immediate vicinity of the surface position of the I.T.C.Z. This can also explain why the summer rains in the Sudan hardly extend beyond latitude 18°North.

Beside this, the observed decrease in the frequency of condensation south of the 600 Kms limit may partly be attributed to the relatively low temperatures over the Southern Sudan during the peak of the rainy season. Also the occasional domination of anticyclonic conditions from the Southern hemisphere may be regarded as an additional contributing factor. The temporary invasions of these anticyclonic conditions will be accompanied with horizontal divergence and general subisdence which are both capable of checking all possible upward motion and condensation.

It is believed that in areas like the Sudan, rainfall is unlikly to occur unless horizontal convergence occurs simultaneously on the ground as well as at two or more lower atmospheric pressure levels. Above these there must be a divergent pattern to allow the ascending air to reach sufficient heights and thus to allow condensation to reach maturity without any effective suppression. Thompson (1965) believes that during the summer season the conditions are generally favourable for such a vertical distributional pattern (Fig. 10). He states that the highest rains seem to coincide with a trough at a level midway between 850 mbs and 700 mbs. However, the most prolonged falls occur when the 700 mbs trough coincides with the 850 mbs trough. He draws the attention that this latter case may develop without any great change in the position of the surface trough. So the latter may be very midleading as far as the position of the rainy belt is concerned.

Over most of the Sudan, the rains are largely received as showers of short durations produced by confined cumulus and cumulonimbus cloud formations. They normally develop as single storms, a group of storms or line storms (i.e line squalls). All these types are composed of cumulus or cumulonimbus formations that may develop vertically to very great heights. They tend to develop vertically rather than horizontally and so they are generally very confined in their distribution and effect. All these storms should originate within the humid South-Westerly sector and consequently are carried North-Eastward as long as their development is confined to the belt of the South-Westerly winds. In certain cases, however, some of the violent storms may develop to great heights and may penetrate into the zone of the upper Easterlies. As soon as these storms reach such a stage, they will be carried westward or south westward with the upper Easterlies and so they appear to be moving in a direction opposite to that of the surface winds. These produce the well known North-Easterly (or Abbadi) lightning which normally preceds extremely heavy showers.

The single storms and the group of storms tend to develop haphazardly within the rainy belts. The line squalls, however, are very organized formations that develop in lines that may extend to more than 200 miles. They are composed of extremely violent thunder storms. They normally reach the level of the upper easterlies and so they nearly always move in a westward direction.

Topography seems to play a very important role in the development of these line squalls. Most of the line squalls moving across the Sudan seem to develp over the western foothills of the Ethippian plateau. However, minor formations may develop in the vicinity of the western slopes of the Red Sea hills and Jebel Marra. Beside these, Bhalotra (1963) observed that some linesqualls may develop quite suddenly over the central Sudan plains. Such linesqualls seem to develop as secondary formations infront of linesqualls approaching from the direction of the Ethiopian plateau. Bhalotra attributed these secondary formations to the down drafts associated with the original linesquall. These down drafts seem to undercut the relatively warm and moist air in front of the storms causing the warm air to rise rapidly along the entire length of the linesquall formation. Such a development should lead to rapid condensation and to longitudinal storms formation.

The relation between the linesqualls and the upper atmospheric conditions over the Sudan, is not clear at the moment. However, somewhat similar, but unrelated developments over west Africa have been attributed to temporary changes in the Usual stability of the upper Easterlies (Gregory 1965). The suggested temporary instability takes place in the lower layers of the upper Easterlies at a time when the lower layers of the atmosphere are dominated by the unstable South-Westerly winds. It is believed that such conditions will lead to very rapid development of thunder storms that will eventually be carried westward with the upper Easterlies.

However, despite the extensive and violent nature of these linesqualls, they normally disintegrate very quickly and within very short distances from their sources.

So over the largest part of the Sudan the rains are confined to the summer season in association with the I.T.C.Z. The rainfall distribution behind the I.T.C.Z. seems to be greatly influenced by the Tropical Easterly Jet Stream as well as by the vertical distribution of pressure. Uplifting is largely governed by the possibility of thermal convection.

The case of the Red Sea region is somewhat different. Here orographic uplifting is very effective. Rains may be experienced throughout the year in association with the onshore N.E. and S.E. winds. But there is a marked winter maximum which is a consequence of the seasonal intensification of the Saharan and the Arabian anticyclones. However, the amounts of precipitation are normally rather small due to the limited vapour that can be transported from over the Red Sea. In addition to this, some of the moist South Westerly winds may succeed to reach some parts of the coastal region through the existing gaps especially in the area of the Tokar delta. Such invasions normally lead to a noticeable increase in the amounts of the summer rains.

II

CHANGING THE NATURE OF RAINFALL

Man has always dreamt of modifying the weather and climate of the Earth so as to create more suitable climatic environments for his various activities. It is quite true that the heat balance of the Earth as a whole is well maintained by a natural mechanism, but on the local scale almost all parts of the world are suffering from either general defcits or general surpluses in their individual heat balances. This is also true for another vital element i.e rainfall or precipitation which is deficient in some parts of the world and excessive in other parts.

So attempts were made to influence the climate of the earth in order to reduce the observed climatic differences.

Thinking on these lines went into three directions. The first of these has been directed towards influencing the distribution of pressure and winds as well as influencing the distribution of the solar energy. Other attempts have been made to influence or rather to control the amount of water vapour in the atmosphere. The greatest efforts, however, have been directed towards affecting the microphysics of the clouds.

Very ambitious projects were suggested for influencing the distribution of the solar energy received on the earth. The main objective was to produce drastic changes in the distribution of the atmospheric pressure and winds since the latter two are directly controlled by the distribution of insolation.

Some of the projects put foreword suggest the creation of:

1- A high altitude dust ring composed of particles of metallic pottasium that either passes over the two poles or at a certain angle to the earth's axis.

These rings are intended to increase the overall intake of solar energy through effectively dispersing the sun light . They should channel an additional amount of diffused radiation in the direction of the earth. It is also believed that such rings will capture most of the energy that is now being lost through reflection from the earth. In fact about 40% of the incoming solar engrgy is now lost through the process of reflection. Some scientists suggest that the creation of such rings in the outer space is likely to increase the amount of solar energy over the earth by up to 12%. It is expected that the greatest increase will be over the high latitudes between latitudes 55^{o} and 90^{o} where the total possible increase is likely to be twice the increase over the Equator.

Such changes in the distribution and in the amounts of solar energy will largely eliminate the latitudinal as well as the seasonal thermal differences. This will lead to a new distribution of solar energy which will greatly affect the nature of the wind systems and the associated weather conditions.

2- Another project of somewhat similar objectives, suggests the erection of a reflecting ring composed of tiny reflecting particles. The designer of this project even visualizes the possibility of directing the angles of these reflecting particles so as to increase the solar energy intake over selected areas i.e over areas where additional energy is realy needed. The net results of this project should be somewhat similar to those of the previously mentioned projects.

3- A third project visualizes the erection of a shade-ring over the equator in order to reduce the amount of solar energy received within the low latitudes. This is bound to reduce the energy surplus in these parts of the world and thus to reduce the gap between them and the high latitude which are characterized by general energy deficits.

The ultimate end of this project will also be a direct intervention with the natural distribution of solar energy and the natural distribution of the associated pressure and wind systems.

4- Another group of scientists believe that somewhat similar results may be obtained by removing the polar ice caps. The main assumption here is that the polar ice cap is not a permanent feature and if it is removed, it will not be able to reestablish itself under the present weather conditions.

The removal of the ice caps can be achieved by various methods such as by spreading coal dust over the ice during the summer seasons. This will reduce the very high albedo that characterize the polar regions and so more energy will be available for melting the ice. It is believed that a 10-20% reduction in the ice's albedo (which normally rises to more than 80%) will lead to the melting and the complete disappearance of the polar ice within a few years.

It has also been suggested that the melting of the ice caps can be achieved by channelling some of the warm ocean currents towards the Arctic Seas. Other projects visualize the use of advanced technology or electricity to remove these ice caps.

It is believed that the removal of the ice cap will lead to summer temperature rises of up to 5°C (41°F) in the high latitudes. In the winter, however, the rise in temperature is estimated to be 30°C (86°F) and over most of the high latitudes the winter temperature will hardly fall below the freezing level. These changes should also produce a new distribution of temperature on the Earth, and consequently a new distribution of pressure and winds.

One of the expected results is the displacement of the subtropical high pressure cells by up to 6° of latitude poleward of their mean positions. At the same time the Thermal Equator will move 200-300 Kms poleward of its present day maximum poleward position. These changes should lead to a very marked northward extension of the belt of the humid south westerlies over the Sudan and the similar areas. So eventually, an extensive part of the present day desert will lie under the influence of these humid winds and so they will be capable of receiving some rains.

Another group of scientists have adopted a radically different approach. They have realized that the main problems in areas like the Sudan are connected with the general deficiency of moisture. They believe that the nature of rains over such areas may be modified favourably by increasing the amount of water vapour in the atmosphere. Several projects were suggested for this purpose.

The first project visualizes the transference of the Sudan belt, that extends from the west African coast to the Red Sea coast, into an extensive agricultural region. To do this, it is suggested that the Nile and the Niger rivers must be used exclusively for irrigation. At the same time the Congo river must be blocked near its mouth and diverted northward to lake Chad to fill the surrounding depression and thus to form an extensive inland sea. After the Chadian depression takes its full capacity, the excess water may be led through the desert to the Mediterranean Sea.

These measures are intended to raise the water vapour content of the atmosphere over the entire Sudan belt. These ends can be achieved through the expected increase in the rate of evaporation which itself is largely determined by the humidity differences between the ground surface and the air; differences that will definitely increase with irrigation and agriculture. This will also be helped by the fact that the visualized agricultural activities will reduce the albedo over the Sudan belt by up to 30% and this is bound to increase the amount of energy needed for the evaporation process.

The advocators of this scheme believe that the cultivation of the Sudan belt will lead to very marked increases in precipitation. This will particularly favour the northern part of the belt. So in this way the amount of precipitation can be increased and the area affected by the summer rains can be extended beyond its present day northern limits.

An alternative scheme to increase the water vapour content of the atmosphere over the Sudan and the nearby regions, suggests the use of atomic energy for warming or even boiling the waters of the Guinean Gulf. This is intended to increase the rate of evaporation from the Gulf and thus to increase the amount of vapour that can be absorped by the atmosphere. Such a process, even when it becomes economically feasible, can be effective only if the wind systems are capable of transporting that water vapour inland. So, as far as the Sudan is concerned this can only be a seasonal activity connected with the summer south-westerly on-shore winds.

However, all the previously mentioned projects are too ambitious, general and risky since they involve a wide range of unknowns as well as a wide range of foreseeable complications and practical difficulties. The relatively more reasonable projects in this connection are directed towards influencing or controlling the microphysical processes in the clouds. The main objective here has always been to stimulate rains. No body can make or create rains. The required stimulation can be done through attempting to increase the rate of condensation inside the clouds so as to enhance the process of precipitation.

Under natural conditions, condensation should start as soon as the saturated air reaches its dew point. It normally starts around condensation or freezing nuclei which are available in varying amounts in the atmosphere. The actual precipitation commences when the minute cloud droplets join together to form large rain drops that will continue growing in size until they become too heavy to be held in suspension inside the cloud and so they start falling towards the ground surface. This is the normal precipitation process in the so-called warm clouds. Somewhat similar developments take place inside the so-called super-cooled clouds which are composed of ice crystals as well as super cooled water droplets, i.e water droplets that are capable of retaining their liquid nature at temperatures as low as -40°C below the freezing level. Within the latter type, the ice crystals grow in size until they become too heavy to be held in suspension and so they start falling towards the ground surface. They either melt in the way or retain their solid nature depending on whether the temperature between the cloud base and the ground surface is above or below the freezing level.

However, the most important factor in the process of condensation, is the availability of the condensation nuclei, in the case of warm clouds, and the availability of freezing nuclei in the case of super cooled clouds. In both cases, the existence of Giant nuclei produce very rapid developments inside the clouds.

All the human efforts in this respect have been directed towards increasing the rate of condensation so as to enhance the process of precipitation. To achieve this, several techniques were employed. One of the earliest methods used was the production of loud sounds and explosions near already existing clouds. There was once a general belief that such explosions cause rains to fall. There is no scientific foundation for this belief. However, a possible consequence of such explosion may be the shattering of the existing ice crystals and this is bound to increase the number of the freezing nuclei. Such a development may lead to an increase in the rate of condensation.

Also some workers in this field advocate the use of extensive fires in order to produce convectional currents. Such currents are likely to encourage the vertical uplifting of the saturated air as well as of the cloud formations and this is likely to increase the rate of condensation in the atmosphere. However, beside being largely ineffective, this technique is rather risky since it involves great fire dangers.

The third and more scientific method for encouraging, or increasing the rate of condensation, involves the introduction of nucleating particles into the clouds. The materials used for this purpose include common salt, silver iodide, water drops and dry ice (CO_2). It seems that for super cooled clouds, the silver iodide and the dry ice are much more effective than the common salt or the water droplets. The opposite seems to be true for the warm clouds.

In all cases, these materials must be carried to the level of the clouds and spread either inside the existing clouds or alternatively into ascending air currents under the cumulus cloud formations. In the latter case one has to go hunting for the suitable clouds and has to find the most suitable ascending currents. In the particular case of silver iodide ground generators may be used to raise the silver iodide in smoke form. This method is cheaper than the previous ones but there is no guarantee that the generated smoke will reach the required cloud. The smoke may even sweep horizontally rather than vertically if there is a temperature inversion. Another major disadvantage is that the silver iodide tends to lose its nucleating power through long exposure to the sun rays. So even when it succeeds to reach the required levels it may not produce the required effects.

Although the introduction of the previously mentioned materials into clouds with the idea of stimulating rains has been practised extensively in the last few decades, no conclusive results have yet been reached. The relative success achieved in this connexion has always been over mountainous regions and in particular over coastal ranges that are characterized by on-shore humid winds. Even here, the results are not very satisfactory. Attempts to stimulate rains over plain lands have not produced significant results.

It is evident, however, that rains can never be stimulated where there are no rain-producing clouds. It has also been observed that the best results are always obtained when the rains have already started falling before the commencement of the treatment. Obviously, under such circumstances, there is always the possibility that the rains which fall during or after the cloud seeding may do so in any case, irrespective of any artificial stimulation or any human intervention.

Another major difficulty is the problem of controlling the treated clouds. These clouds are carried in suspension by the air currents and so they are always on the move. Consequently no body can guarantee that the seeded clouds will stay where needed or will precipitate where required.

A third serious aspect is that the total amount of precipitation on the Earth is CONSTANT, so any increase over a certain area will be at the expense of another area. This is a natural consequence of the limited amount of water vapour in the atmosphere. Unless the amount of water vapour is increased, such as by boiling oceanic waters, many areas are likely to be deprived of their precipitation if the artificial stimulation of rains become successful. This can be so even on a local scale. It has been observed that when a single cumulus cloud is treated, it tends to increase in size very rapidly and that will be at the expense of the nearby untreated clouds. Consequently the resultant rains will be confined to a very limited area.

III

RAINFALL MODIFICATION IN THE SUDAN

(A consideration of the Hunderson Inc. Report)

In 1969, the Hunderson Inc. of the U.S.A. was asked to carry out an investigation on the potentialities for rainfall stimulation in the Sudan. Eventually the company submitted a report on the experiments it carried out as well as a programme of weather modification for the entire country.

All the report and the conclusions were based on an experiment that was conducted during a single afternoon of a single day in a single year (1969). The company carried out five cloud seedings or rather five tests. In the first and the third tests, the rains started before the commencement of the treatment. In the fourth and fifth tests, the plane that was used for spreading the silver iodide did not stop to see the results. Beside these, the plane had to cover long distances in search for the suitable clouds.

With all these serious limitations, the authors of the report believe that from these tests "one has an understandable tendency to be extremely optimistic". One wanders how the company can be so optimistic from the results of these unreliable experiments. In addition to this, the statement that "the company had seldom observed so many cloud developments on a single day that responded so positively to treatment with silver iodide", may indicate quite correctly that the success, if accepted as being so, is rather rare or rather unusual.

Surprisingly enough, not a single measuring device was carried in the plane used for the clouds seeding. Although the authors of the report admit that "the lack of measuring devices made it extremely difficult to precisely establish the results from these tests", yet they give an estimate of 6 m.m. (0.24 inches) of rainfall and allege that "this estimate is extremely modest and minimal". They even go further and use this figure to calculate the economics of the whole operation.

However, if we accept the 6 m.m. figure, there is not any guarantee that the rains actually fell where required. The idea that wherever the rains fall they will be of use, is difinitely unacceptable.

One of the most serious aspects of the report is that dealing with the length of the rainy season. The company suggests that "the normal precipitation season in the Sudan can be expanded by approximately 60 days through well designed weather modification programme". The idea of increasing the duration of the rainy season by two months is definitely unwarranted if we take the nature of the Sudan rains and the dynamics of the atmosphere into consideration. The duration of the rainy season is directly controlled or determined by the movements of the I.T.C.Z. which itself is controlled by the pressure conditions over and in the vicinity of the African continent. However, even if the above statement is intended to mean an increase in the number of rain occurences within the limited rainy season, it should also be rejected. It seems that no consideration was given to the fact that any increase in the rainfall amounts over a certain area will be at the expense of other areas that may be of greater need. On these grounds, one finds it very difficult to accept all the conclusions based on this statement such as the one suggesting that "through a properly designed weather modification programme, the precipitation of the Sudan can be increased by 20%". That will be at the expense of the marginal areas.

In addition to this, the statement that "cloud seeding in areas like the Sudan usually spreads the rains out over large areas and decreases the wind velocity at the surface around the total storm system", may be regarded as very misleading especially when used to suggest a marked reduction in the intensity of the dust storms i.e haboobs. The argument that can be used in this respect is that the purpose of the whole exercise is to enhance cloud development so that clouds can reach maturity within a very much shorter period than can be achieved under natural conditions. This is bound to increase the rate of the associated winds including the downdrafts which normally produce the dust storms. Beside this, the seeding of a cumulus cloud formation may lead to the very rapid growth of that particular cloud formation and that will be at the expense of the untreated clouds in the vicinity. Consequently, the resultant rains should be very confined in their distribution. This is just the opposite of what is suggested in the above statement.

Finally, it is quite evident that the Hunderson Inc. report is commercial rather than a scientific report.

IV

CONCLUSION

In conclusion it may be stated that rains can never be made or produced out of the thin air. They can, however, be stimulated artificially under very special conditions but even here the results cannot be guaranteed and the area of precipitation can hardly be contvolled or determined in advance.

The possibility of a direct interference with the global distribution of solar energy, atmospheric pressure and the wind circulation is very remote and involves a wide range of unknowns. The attempts to increase the vapour content of the atmosphere may be more feasible. The visualized inland seas can be more effective if they are extensive enough and if they are located in areas where vertical diffusion of the water vapour is physically possible. The use of atomic energy to increase the rate of evaporation may be possible in the future, i.e from an economic point of view, but here also some risks are ir olved since no one can predict all the likely consequences. Until uch processes come into operation one can predict that any increase in the rainfall amounts over a certain area as a result of successful artificial stimulation will be at the expense of other areas that may be in vital need for their present day slight rains.

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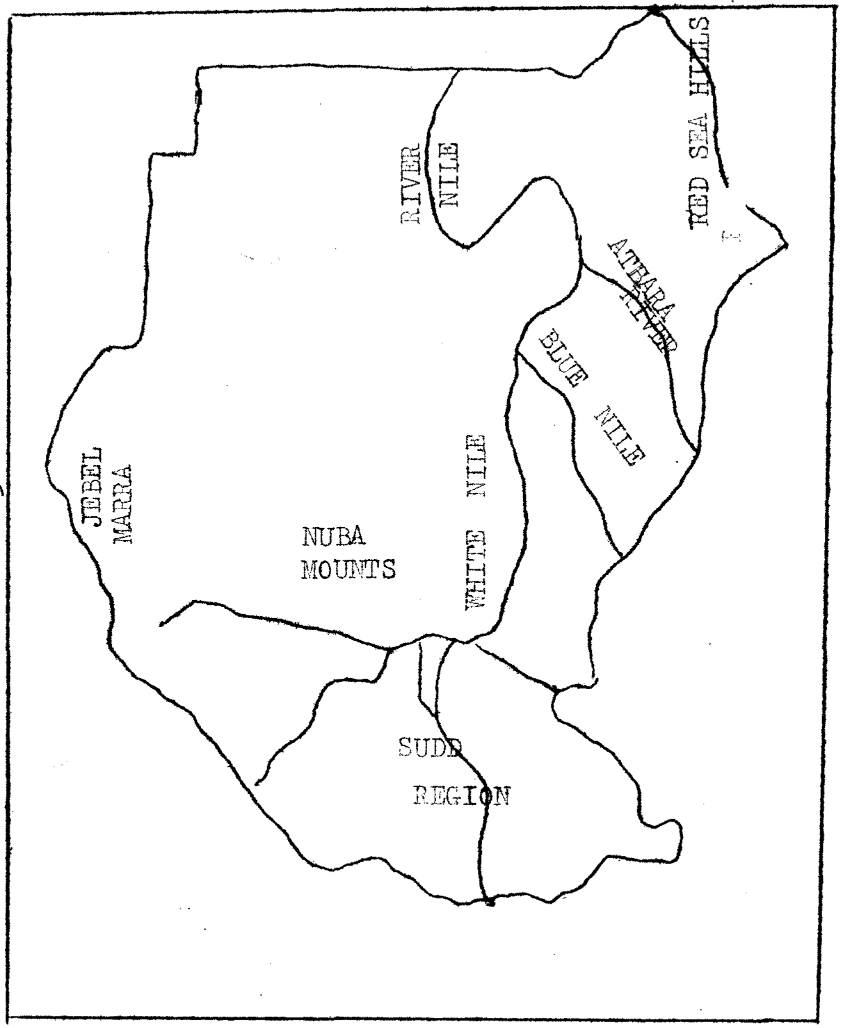
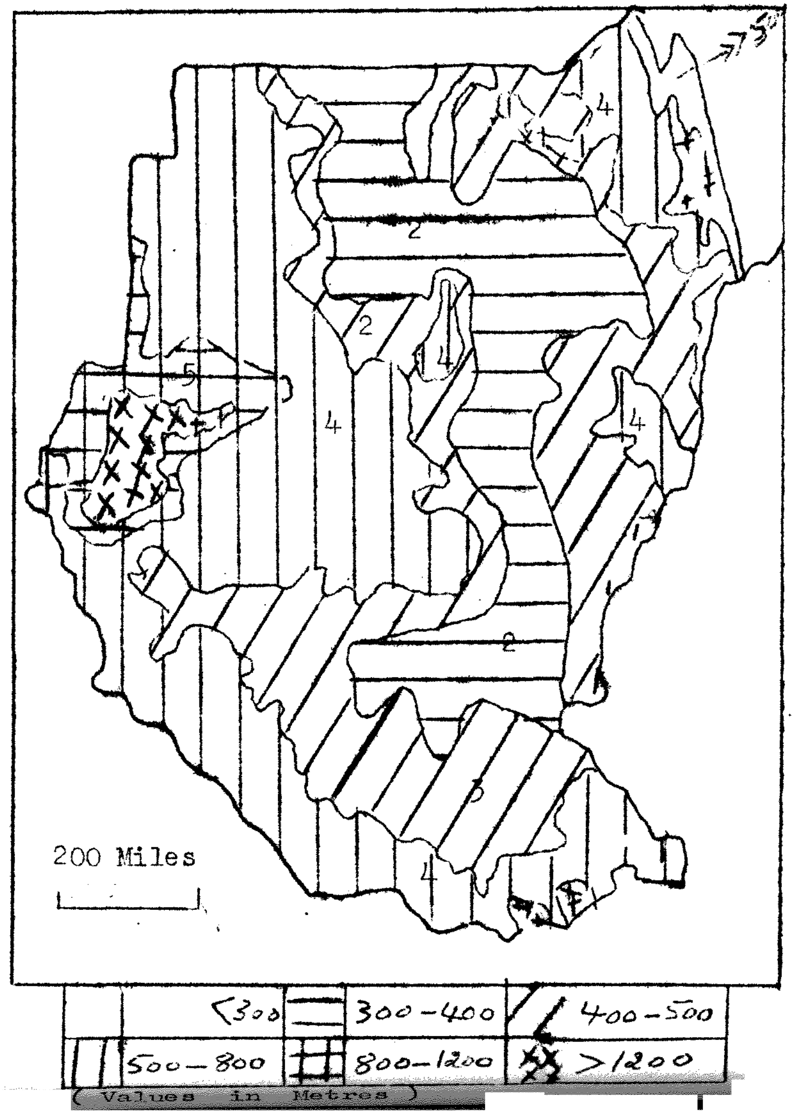


THE PHYSICAL FEATURES OF THE SUDAN



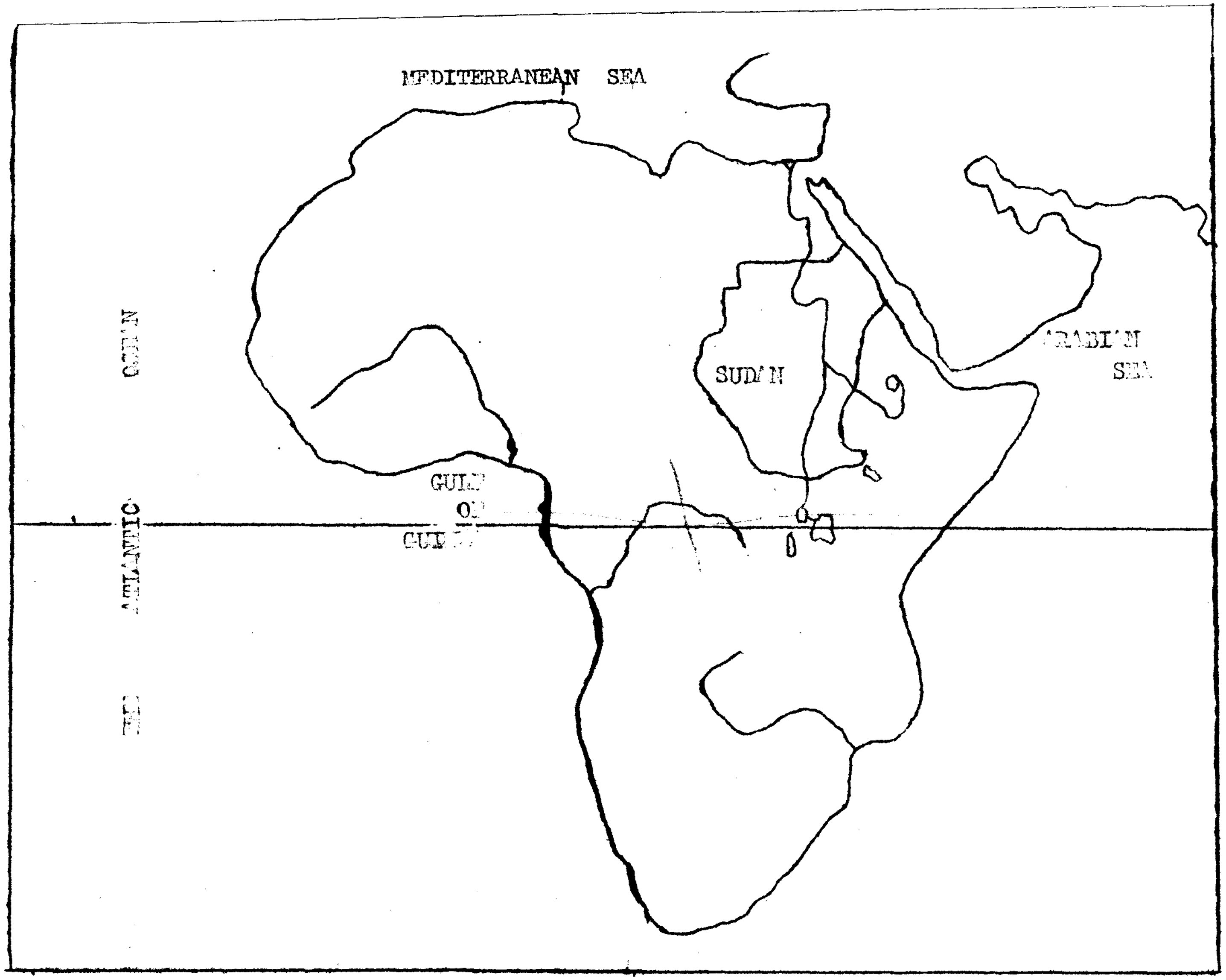


FIG. 2 WATER BODIES AROUND SUDAN

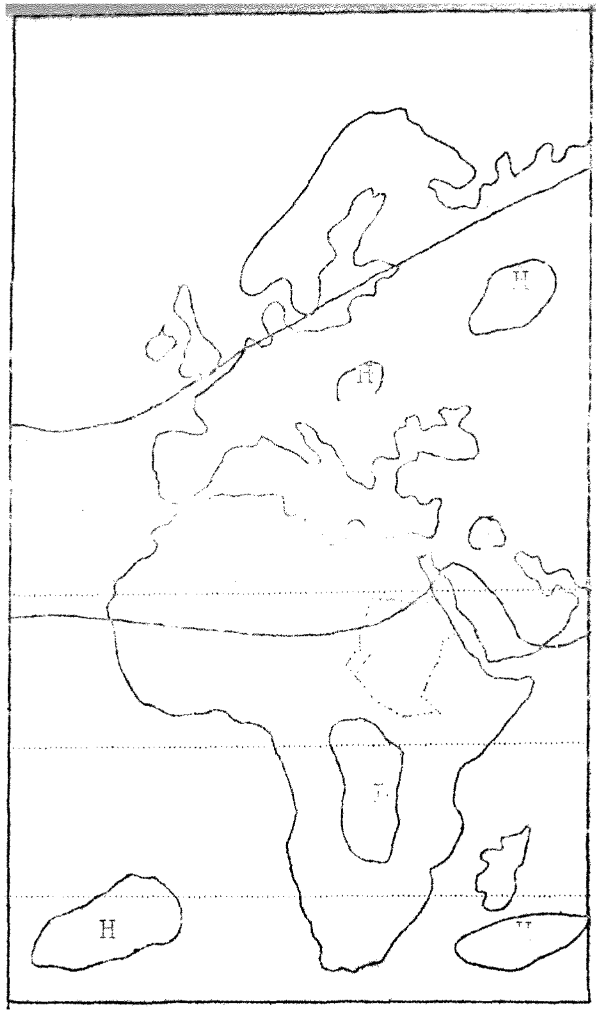


FIG 3 JANUARY PRESSURE

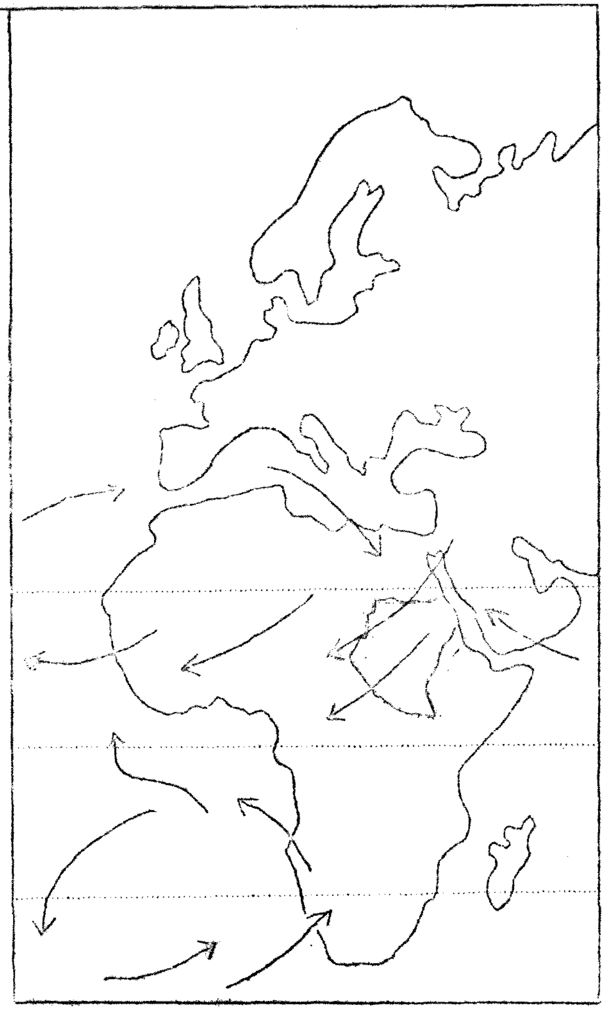


FIG 4 JANUARY WINDS

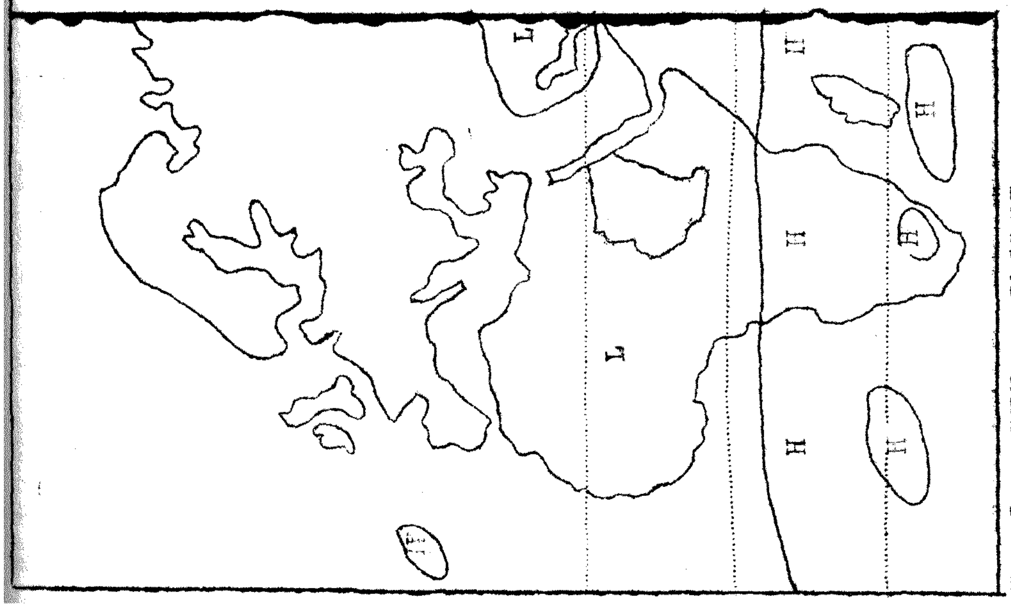


FIG. 5 JULY PRESSURE

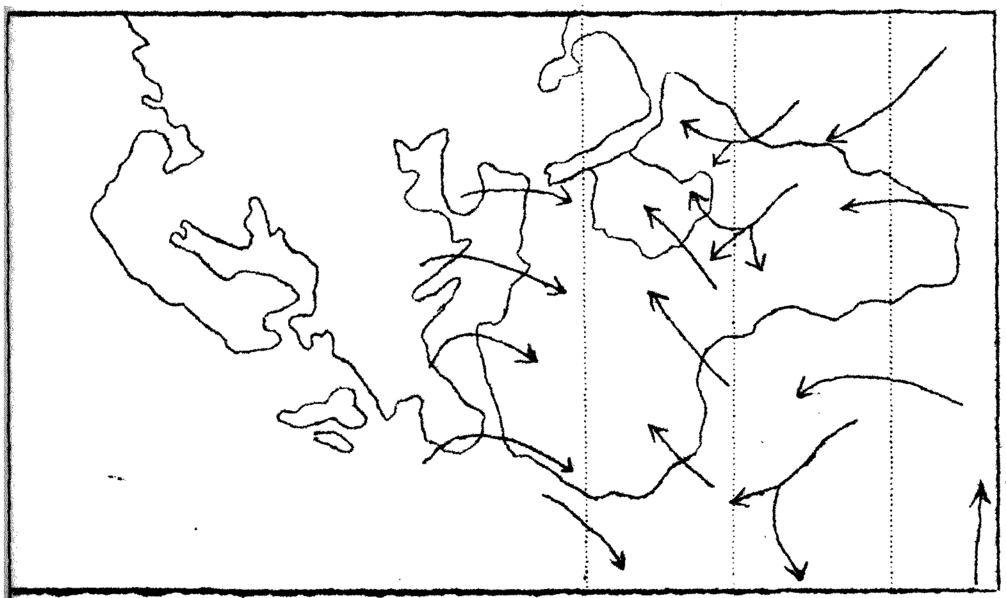
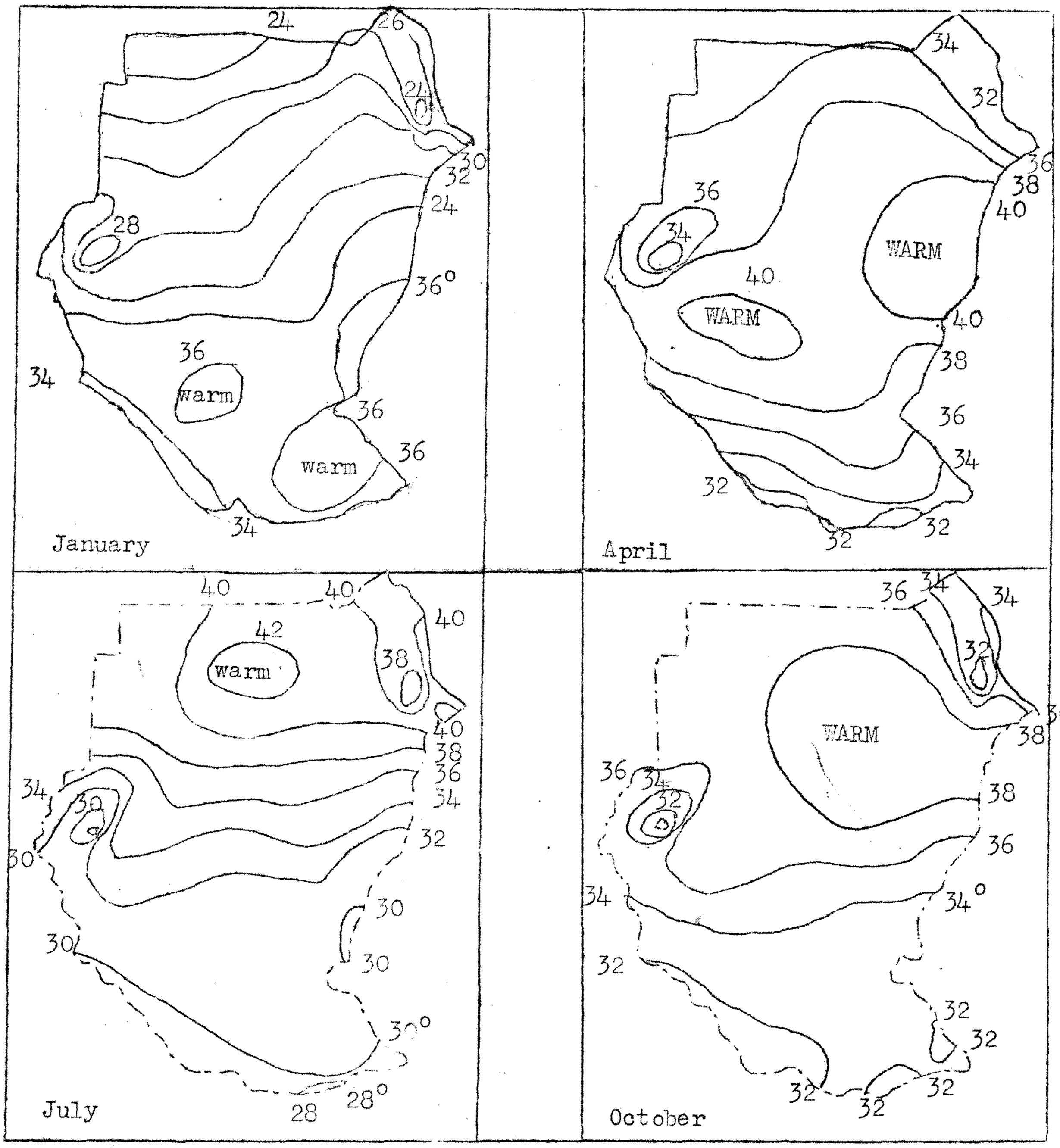
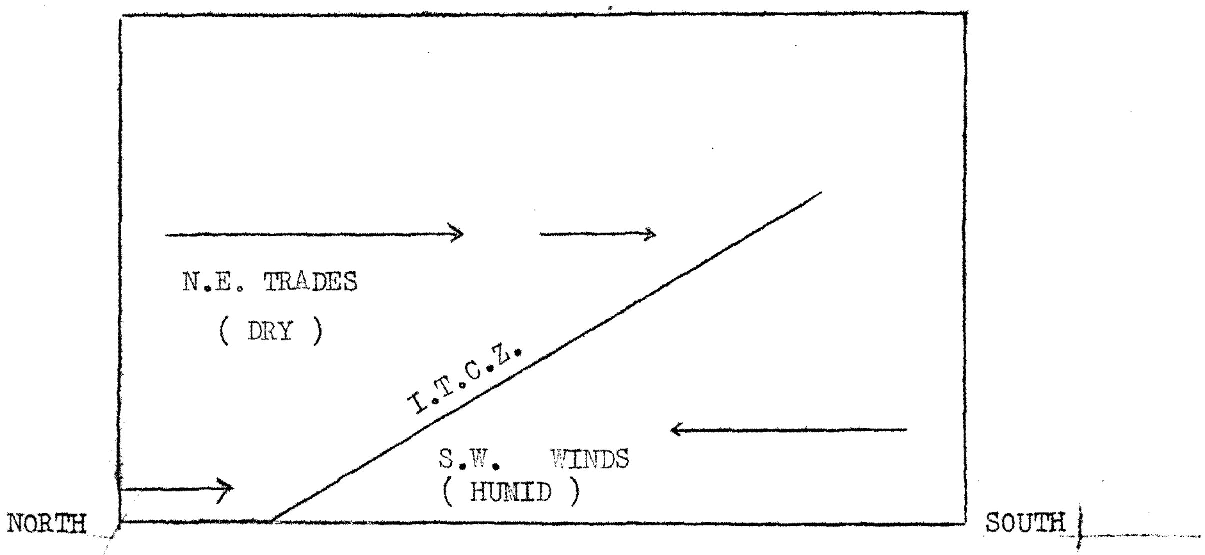


FIG. 6 JULY WINDS



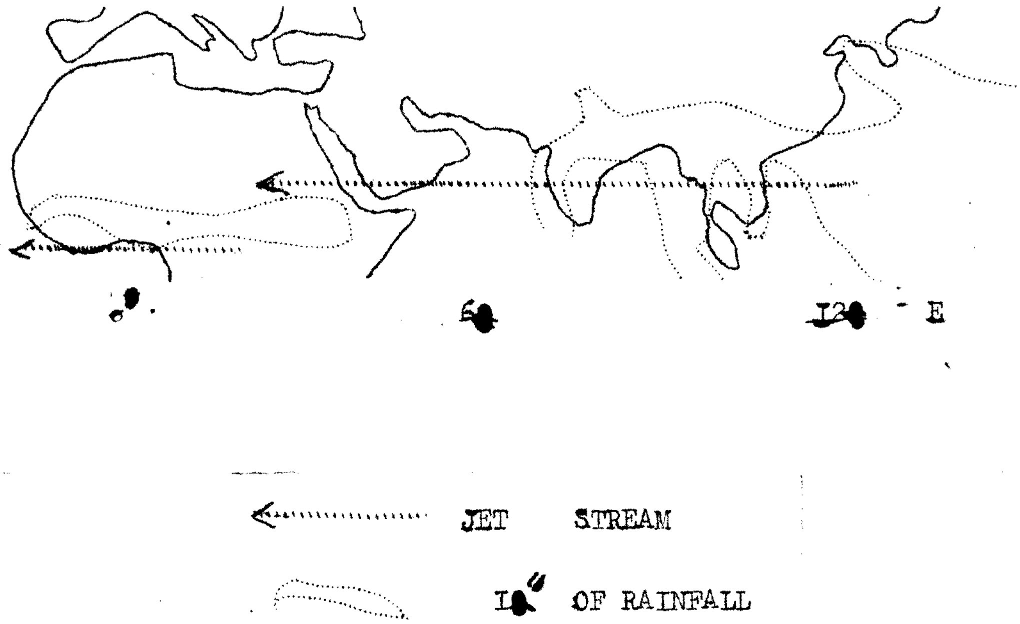
MEAN DAILY MAXIMUM TEMPERATURE IN °C (AFTER BHALOTRA 1963)

FIG. 7



STRUCTURE OF I.T.C.Z.

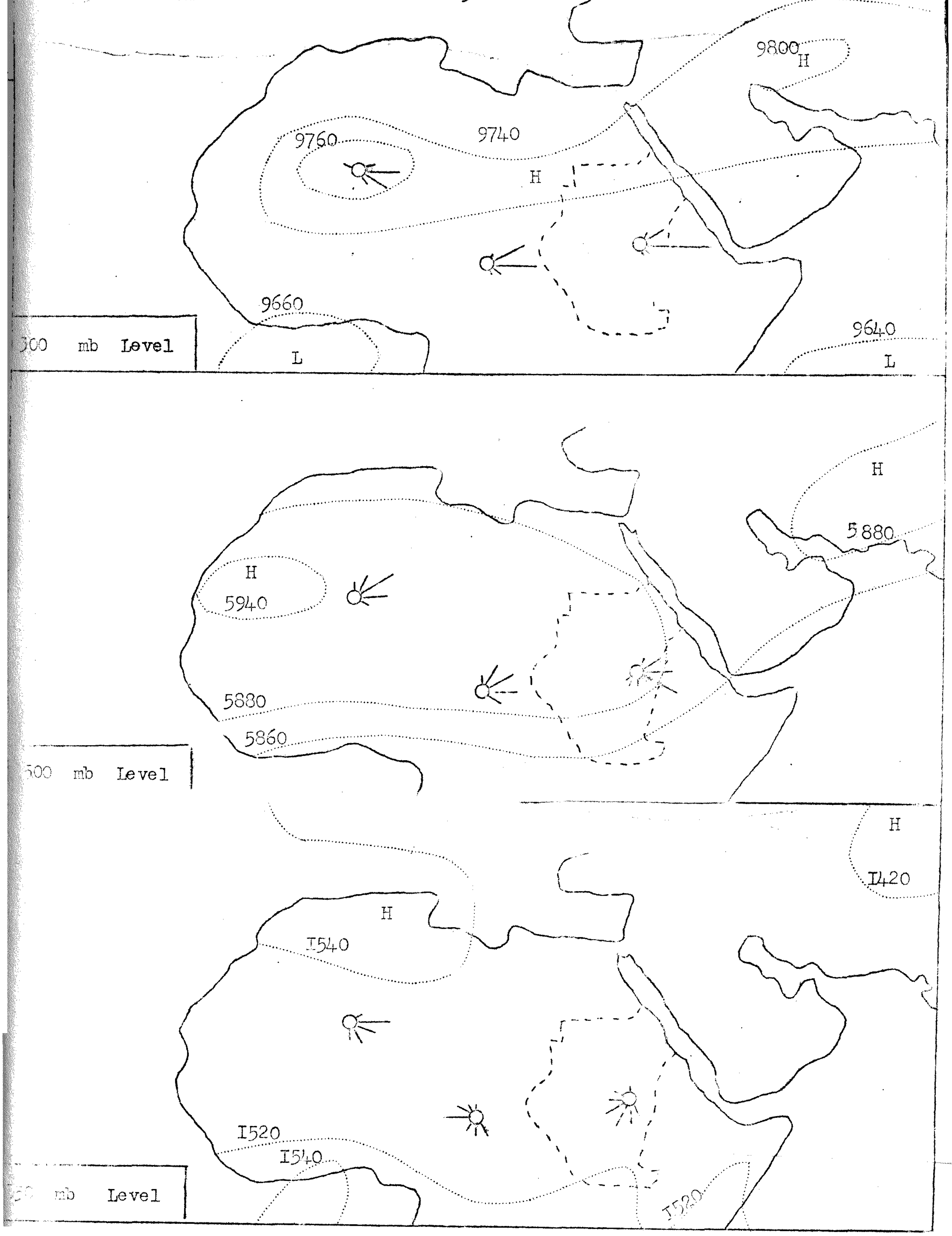
FIG. 8



TROPICAL EASTERLY JET STREAM AND RAINFALL DISTRIBUTION

(AFTER KOTESWARAM)

(1958)



IO JULY UPPER - Air PRESSURE AND WIND FREQUENCEY OVER NORTH AFRICA (AFTER THOMPSON [illegible]65)