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CHAPTER I

GENERAL INTRODUCTION.

The meteorology of India is determined by its geographical position in the south of the great Asiatic continent and to the north of the Indian Ocean, and the striking features of relief of the land masses outside and within the country. In *Fig. 1* is shown a contour map of India and its adjoining countries. As will be clear from it, India proper is separated from the rest of Asia by high mountain walls. The great Himalayan arc with its snow-covered peaks stretches for 1,500 miles between the gorges of the Indus on the west and the Brahmaputra on the east. The width of the Himalayas is between 150 to 300 miles and north of it is the extensive plateau block of Tibet with an average elevation of 15,000 ft. In the extreme northwest of India are the high mountains of the Hindu Kush and the Pamir plateau, and south of them are the Sulaimans and Kirthars separating India from the plateau-bowls of Iran and Baluchistan. In the northeast, the jungle-clad hills of the Patkais, the Chin hills, and the Yomas with an average height of 6,000 ft. and rising at places to 12,000 ft. separate India from Burma. Within India itself, there are important features of relief which exert a dominant influence on its meteorology. Broadly speaking, the country is made up of the great lowland plain of Hindustan formed by the valleys of the three rivers, the Indus, the Ganges and the Brahmaputra and the plateau of Peninsular India. The plateau is highest on the western edge bordering the Western Ghats and slopes down towards the east. A lower and more broken ridge, the Eastern Ghats, forms the eastern boundary of the plateau. The Western Ghats are highest in the south in the Nilgiris and the Travancore Hills. There are coastal plains between the Western and Eastern Ghats and the sea, the eastern plains being generally broader. Towards the north of the plateau and separating it from "northern India" are the west-to-east mountain ranges of the Satpuras and the Vindhyas, the Mahadeo Hills and the Maikal range. Two other hill ranges which exert important influence on the meteorology of the country are the Aravallis in the northwest and the Garo and Khasi Hills in the northeast. Owing to the great size and position of India, and the diversities of relief, there are many striking contrasts of meteorological conditions in different parts of the country. In the northwest lies the great Thar desert with an average annual rainfall of less than 5 inches; in the northeast are the Khasi Hills with an average annual fall of 425 inches at Cherrapunji. Dras in Kashmir has recorded a minimum temperature of —41°F, while Jacobabad in Sind has several times registered a temperature of over 126°F. Hill stations in the Himalayas such as Simla may be shrouded in cloud for days together in August with humidities of 100 per cent., while in December they may be overrun by air of nearly zero humidity. The mean maximum temperature at Cochin does not go above 91°F in any month nor the mean minimum below 71°F; while at Jacobabad in Sind, the mean maximum goes up to 111°F in June and the mean minimum to 43°F in January.

The Monsoons.—The most important feature in the meteorology of India is the alternation of seasons known as the monsoons. Strictly speaking, monsoons are seasonal winds whose direction more or less reverses twice during the year. Lying largely within the tropics and with the great Asiatic continent to the north and the wide expanse of the Indian Ocean to the south, India furnishes the best large scale example of a monsoon country. During the winter third of the year, the general flow of surface air over the country is from north to south, northwesterly in the plains of Hindustan, northerly in the central parts and northeasterly in the south of the Peninsula and the neighbouring seas. In this season, the air over the country is mainly of continental origin and hence of low humidity and the season is known as the northeast or winter monsoon. (*Fig. 2*). In the summer months June to September, the general flow of winds is from the opposite direction from sea to land and the season is one of much humidity, cloud and rain. The direction of winds in the major parts of the Arabian Sea and the Bay of Bengal being southwesterly, the season is named the southwest monsoon season. (*Fig. 3.*)

Between these two principal seasons are the transition seasons of the *hot weather* months April and May, and the *retreating monsoon* months, October and November. The causes determining the monsoon currents are many and complex, but the fundamental cause is undoubtedly the periodical excess of heating of the land masses of Asia in summer and of cooling in winter compared to the waters of the Indian Ocean and the China Seas.

BRIEF DESCRIPTION OF THE SEASONS.

1. The Northeast Monsoon season (December to February).—Clear weather sets in over northwest India in October and extends by the beginning of December over practically the whole country the only exception being the extreme southeast of the Peninsula, where the retreating monsoon continues to give cloud and some rain. The cold season may be said to begin over India as a whole early in December. In the season December to February very low temperatures prevail over the Asiatic continent and a belt of high pressure extends from Central Asia and northeast China to Persia and Arabia. Light westerly to northwesterly winds prevail in north India, while in the south, northeast winds hold sway. Clear skies, fine weather, low humidity and temperature, and a large diurnal variation of temperature are the usual features of the weather. From about the middle of December, the serenity of the weather in northern India is broken at intervals by a series of disturbances which travel eastwards across Persia, northern India and China. The number and character of these disturbances vary, but on the average four to six disturbances may be expected in each of the months of January and February. The precipitation associated with them is small in amount but very important for the winter crops of northwest India. Some of the disturbances give rain over the whole of northern India while others confine their activity to the extreme north or give moderate to heavy rain in the Punjab plains and Kashmir and snowfall in the higher Himalayas. The disturbances are attended with a clouding and a rise of temperature in front of them, while in their rear strongish westerly to northwesterly winds

bring in a spell of colder weather ; the fall of temperature may be considerable on some occasions. Taking the season as a whole, temperature is lowest in the northwest and increases eastwards and southwards. Rainfall is greatest in the northwest and decreases eastwards and southwards generally ; there is however an increase of rainfall in the extreme southeast.

The Hot Weather season (March to May).—This is a period of continuous and rapid rise of temperature and decrease of barometric pressure in India. Simultaneously there is a continuous decrease of temperature in the South Indian Ocean and adjacent land areas of Africa and Australia and an intensification of the southern anti-cyclone. With the steady northward movement of the area of greatest heat in India, the equitorial winter belt of low pressure also moves northward. In March the highest day temperatures, about 100°F, occur in the Deccan. In April the highest temperatures, 100°F to 110°F. occur in the south Central Provinces and Gujarat. In May the highest temperatures are found in northern India ; in the northwest desert day temperatures of 120°F or over are not infrequent. The area of lowest pressure also lies then over northwest India, with a trough of low pressure stretching thence to Chota Nagpur.

During this period of rising temperature and diminishing barometric pressure, important changes take place in the surface air movements over India. The northerly winds of the winter monsoon get modified and the air circulation over India and the adjacent seas becomes a local circulation, characterised by increasing land and sea winds in the coastal regions. In northern India the winds are strong westerly during day and weak with variable direction during night. Violent local storms often form in regions where deep humid winds from the sea meet the hot dry land winds. These storms are often accompanied by violent winds hail and torrential rain, and are on that account very destructive. In Bengal they are known as " Nor'westers " on account of the accompanying squall being usually from the northwest. Dust-storms and dust-raising winds are common in this season in the drier tracts of northern and northwestern India.

The Southwest Monsoon season (June to September).—Towards the end of May the air circulation over India becomes more and more vigorous, until the southeast trade winds from the south of the equator are induced northwards first into the Bay of Bengal and later into the Arabian Sea and get caught up in the Indian circulation. In most years, this relatively cool and humid current, known as the southwest monsoon, bursts on the Malabar coast during the first five days of June. It gradually extends northwards and is usually established over most of the Indian area by the end of June. It is the great rain-bearing current for most of India. The orographical features of India are of great importance in modifying the flow of the monsoon currents and the distribution of monsoon rainfall. The mountain ranges to the east and north of India are equivalent to two sides of a box, through the other two sides of which the monsoon currents stream. The Bay of Bengal current is deflected first northwards through northeast Bay of Bengal and Burma, and then westwards up the Gangetic Plain. The Arabian Sea current surmounts the Ghats on the west coast, causing copious rain there and advances over the Deccan and the Central Provinces. When the monsoon is fully established, the Arabian Sea current meets the Bay of Bengal current

along the line of the trough of low pressure, which normally extends from Orissa to northwest India. Depressions form in succession in the north of the Bay and move along this trough. The depressions intensify the monsoon and sometimes concentrate rainfall in their vicinity. The trough does not remain stationary but moves north or south of the normal position and affects the rainfall distribution as it moves. Consequently the monsoon period is not one of continuous rain in any part of India. Bursts of general rain alternate with breaks, partial or general. The pulsatory character of air movements and of rainfall is one of the most important features of the monsoon period. On the average, the strength of the currents and the accompanying rainfall increase from June to July and remain steady till about the end of August. The monsoon begins to retreat from northwest India in the third week of September. The total rainfall of the monsoon season (June to September) is 100″ over parts of the west coast; the amount diminishes east of the Ghats becoming 20″ to 30″ over a large part of the centre and east of the Peninsula. It is over 100″ on the Tenasserim and south Burma coasts, and decreases again to 20″ in Upper Burma. It is over 100″ in the north Assam valley and diminishes steadily westward and is less than 5″ in Sind and Baluchistan.

There are four important variations from the normal in the monsoon rain over the country: firstly, the commencement of the rains may be considerably delayed over the whole or a large part of India; secondly, there may be a prolonged break or breaks in July or August; thirdly, the rains may terminate considerably earlier than usual; and lastly the rains may be deflected more largely than usual towards one part of the country than another. The last one constitutes the most common abnormality.

The retreating Southwest Monsoon season (October and November).—The southwest monsoon retreats from the Punjab and adjacent regions usually in the third week of September, after which clear cool weather sets in over that area. The fine weather conditions extend slowly eastwards and southwards, as the Bay of Bengal current retreats down the Gangetic Plain and the Arabian Sea current retreats from Rajputana, Gujarat and the Deccan by a series of intermittent actions. By the end of October the low pressure over north India becomes obliterated and is transferred to the centre of the Bay. The rainy area is then to be found on the east coast of Madras and the south of the Peninsula where the rainiest periods of the year are the latter half of October and November. By the beginning of December the low pressure belt has moved to the south of the Bay, and by the end of the month it passes out of the Bay limits into the equatorial belt. Similar conditions obtain in the Arabian Sea also.

In northern India the clear Autumn weather which sets in with the retreat of the monsoon persists till the third or fourth week of December when the cold weather disturbances from the west begin to appear.

The above procession of the seasons with numerous variations and modifications which are inseparable from the drama of weather repeats itself year after year.

The distribution of mean pressure and wind at 8 a.m. and of the mean temperature of the day for the typical months of the four seasons, viz. January, April, July and October are given in *Figs. 4 to 7*.

CHAPTER II

RAINFALL.

From the point of view of rainfall, the year in India may be divided into two main periods, (1) from June to November, when the great oceanic rain bearing southwest monsoon current advances into India, holds sway and retreats from the country and (2) from December to May when dry air from the northwest covers most of the country. The dry period consists of the two seasons, the cold weather season from December to February and the hot weather season from March to May. The wet period may be similarly sub-divided into the southwest monsoon proper from June to September and the retreating monsoon season comprising October and November. The annual distribution of rainfall is shown in *Fig. 8*. The distribution of rainfall and of the number of rainy days in the four seasons are shown in *Figs. 9 to 16*. It should be mentioned that a rainy day is one in which at least a tenth of an inch of rain has fallen. *Fig. 17* gives an idea of the distribution of heavy rainfall exceeding 3″ over the country.

The Cold Weather season.—There are two exceptions to the generally dry weather which prevails over the greater part of India in this season, namely the retreating monsoon rains of December in the southeast of the Peninsula, and the rainfall of northwest India associated with western disturbances. The latter occurs at intervals throughout the season.

The equatorial doldrum belt lies in the extreme south of the Bay in December and the humid winds curving round it continue to give rain in the southeast of the Peninsula, especially on the south Coromandel coast. Storms occur occasionally in December. A storm may be expected once in three years and usually strikes the coast to the south of Madras and gives heavy rain in the coastal districts. The total rainfall of the month on the coast from Cuddalore to Point Calimere is about ten inches, occurring on the average on nearly ten days in the month. Both the amount and the frequency of rainfall decrease rapidly inland. The rainfall is less than an inch in the Mysore plateau and occurs on one or two days. A few showers may occur in this region in January; during the rest of the season the weather is dry.

In northwest India, the precipitation associated with the western disturbances, which advance from the west and pass across the country, occurs chiefly in the mountain regions forming the northwest and northern border of India and in the adjoining plains. On the average about five disturbances may be expected in each month, and all of them are not equally active so far as their rain giving capacity is concerned; precipitation therefore occurs at intervals throughout the season. The snowfall is very heavy on the inner Himalayas, and extends occasionally to the outer hills and rarely to the foothills and the adjacent plains. It is in this period and the early spring that the chief additions to the snows on the inner Himalayas are made.

The precipitation is chiefly in the form of rain in the outer hills and the plains of the Punjab, and is sometimes heavy. It extends, also though less frequently to the Gangetic plain, and on rare occasions to the whole of northern India including Bengal. Occasionally rainfall occurs in the central parts of the country and the northern parts of the Peninsula. Hence the precipitation of the season, which is equivalent to about 10″ of rain in the western Himalayas diminishes southwards from the Himalayas across the submontane tracts to only a small amount in the plains. It is only on approaching southeast Madras that the rainfall again increases, the amount exceeding 10″ on the south Coromandel coast.

The Hot Weather season.—The second half of the dry period is the hot weather season from March to May and even to June in parts of northwest India. In the early part of the season, western disturbances continue to give rain in parts of northwest India, and in their progress eastwards across northern India give rise to thunderstorms which are occasionally severe in the Gangetic plain and northeast India. Local sea winds blow inland from the head of the Bay of Bengal ; they are very steady and sometimes strong. They not only increase in strength as the season advances, but are drawn from farther out in the sea and extend much farther inland. In Bengal and Assam thunderstorms known locally as Nor'westers are not infrequent, and sometimes the showers are heavy and prolonged. This is chiefly the case in the damp regions of eastern Bengal and Assam. The showers become more frequent as the season advances and the May rainfall of Assam is two-thirds of that of June, the first month of the monsoon season.

The sea winds are fairly strong in the east and south of the Peninsula also ; in the south of the Peninsula irregularly distributed thundershowers occur chiefly in the months of April and May, and amount to a total of three to four inches. In Malabar, rainfall is moderate to large in the month of May when temporary advances of the monsoon cause widespread thunder showers on the western sea board. In the northwest of the Peninsula, this is the season of dry northwesterly winds, and rainfall is almost entirely withheld till near the end of the season when temporary incursions of monsoon winds give rise to the pre-monsoon thunderstorms.

As the sea winds increase in strength and extend farther inland, thundershowers also occur in the central parts of the country and the Gangetic plain. In the dry tracts of northwest India, however, duststorms take the place of thunderstorms.

The thunderstorms are sometimes accompanied by hail. Hailstorms are comparatively more common in the Punjab and the west United Provinces and in Assam and its neighbourhood ; they also occur in the central parts of the country and the Deccan. In all these regions the number of storms associated with hailstones decreases as the season advances. In the Mysore plateau in the south of the Peninsula hailstorms occur chiefly in April and May. The hailstorms in north India are occasionally very destructive, the stones varying from the size of marbles to ice concretions two to three inches across.

The total rainfall of the period March to May is less than one inch in Sind, Rajputana, Gujarat, Khandesh and Central India and varies between 2 and 6 inches in the provinces of Bihar and Orissa, in the submontane districts of the United Provinces and of the Punjab, in the North-West Frontier Province and over the greater part of the Peninsula. It exceeds 10 inches in Malabar, the eastern half of Bengal, Assam and the coast of Burma, being greatest in Assam and Tenasserim, where it is over 20″ in amount.

The Southwest Monsoon season.—As stated earlier, towards the end of May when the weather is at its hottest in India, the southeast trades in the Indian Ocean extend rapidly northwards across the equator into the Arabian Sea and the south of the Bay of Bengal and in the course of about two weeks become established over both seas as far north as their northern coasts. This humid current, or the southwest monsoon as it is called, is frequently ushered in by a cyclonic storm either in the Bay or the Arabian Sea with the associated heavy rainfall. Ordinarily monsoon rainfall extends into Gujarat and the central parts of the country in the second week of June, into the United Provinces by the middle of the month and is established over nearly the whole of India excluding the western regions of northwest India by the end of June. The monsoon enters India in two main branches, the Arabian Sea current and the Bay of Bengal current. The former strikes the west coast and begins to give heavy rain in the coastal districts and on the neighbouring ghats. After surmounting the Ghats the southern part of the current blows across the Peninsula as a west or in places as a northwesterly wind ; occasionally rainfall associated with thundery weather occurs in the interior of the Peninsula. The northern portion of the current which crosses the Sind and Kathiawar coasts blows across Rajputana as a southwest wind and gives rain mostly in the coastal districts, near the Aravalli hills and the Punjab-Kumaon hills, but very little in the plains of Rajputana. The Bay of Bengal current, which is mainly from the southwest, gives plenty of rain on the Tenasserim and Arakan coasts. A part of the current extends as a southerly stream up the Irrawaddy valley and also across the Arakan Yomas ; but the rainfall rapidly decreases to a minimum in the central districts of Burma. The remainder which crosses the Bengal coast is deflected westwards up the Gangetic plain by the mountains to the east and north of Bengal.

The rainfall of June exceeds 30″ along the west coast of the Peninsula and along the Tenasserim and Arakan coasts and is 20″ to 30″ near the Khasi Hills and parts of north Bengal. The rainfall decreases to less than 10″ on the western border of Bihar and Orissa and lies between 5″ and 10″ over most of the United Provinces, the central parts of the country and Gujarat. The greater rainfall in northeast India is due, apart from the earlier setting in of the monsoon, to the periodic indraft of moist currents caused by depressions which form in the northen half of the Bay and move towards northwest or north.

During July and August the damp sea winds of the southwest monsoon blow more or less steadily over the country and carry rainfall to its farthest limits. The two factors which determine the strength of the monsoon and

play an important role in determining the distribution of rainfall are the position and strength of the trough of low pressure over the Gangetic plain and the depressions from the Bay of Bengal which travel across the country. The trough of low pressure which exists throughout the monsoon season between the westerly winds of the Arabian Sea current and the easterly winds of the deflected Bay of Bengal current stretches from southwest Bengal upto Rajputana and Sind. The eastern end of the trough usually extends into the head of the Bay of Bengal prior to the formation of a depression there ; there is a weakening of the monsoon at this time and a decrease of rainfall in Bengal and Assam.

Then as a fresh pulse of the monsoon advances up the Bay, the depression begins to develop and rainfall increases on the Arakan and Chittagong coasts. A low pressure wave from the east across Burma often helps the development of these depressions. As the depression moves towards the coast, rainfall extends to southeast or south Bengal and lower Assam. And with its further movement westward the belt of moderate to heavy rain extends to Chota Nagpur and Bihar to its north, and also makes its appearance in Orissa. When the depression crosses the Orissa coast and enters the Central Provinces the Arabian Sea current strengthens and moderate to heavy rainfall commences on the southern sector of the depression. Widespread and locally heavy rain then falls over the north of the Peninsula, the Central parts of the country and the southern districts of the United Provinces. The rainfall is then carried by the depression into Gujarat and Rajputana before it merges into the seasonal low in northwest India. When the Arabian Sea current is strong and the depression takes a westerly course across south Rajputana, rainfall extends to Kathiawar and Sind. On such occasions the heavy rainfall in lower Sind may sometimes approach or exceed the annual normal at some of the stations. After the death of a depression there is generally a weakening of the monsoon. With a revival in the strength of the monsoon another depression forms at the head of the Bay and a similar general progression of rainfall occurs across the country. Thus the monsoon in an average year is by no means steady, and periods of general rain alternate with intervals of comparatively dry weather. In some seasons the depressions may follow each other in quick succession along practically the same track, and by concentrating rainfall in the narrow belt of country traversed by them, cause floods there and lead to drought in regions farther to the north and south. The local heavy falls in 24 hours caused by depressions usually vary from 3 to 8 inches and often extend over several districts. Falls amounting to 10 to 15 inches in a day have been recorded especially in the neighbourhood of the hills and on the coasts near the central regions of the storms. The greatest falls recorded in the plains are 39″ at Dharampur in the Surat District of Gujarat, and 35″ at Purnea in Bihar.

In the absence of depressions, rainfall is chiefly influenced by orography, the trough of low pressure in the Gangetic plain, and the ill marked and short lived low pressure areas which make their appearance erratically over the country. The influence of the trough of low pressure depends mainly on its position. A more southerly position of the trough is favourable for the general activity of the monsoon and widespread rain then falls over most

of the country. A more northerly position is associated with a northward shift of the area of rainfall, with consequent decrease of rainfall in the field of the Arabian Sea current, while the rainfall due to the Bay current occurs chiefly in the eastern parts of northeast India. When such conditions persist and the trough lies close to the Himalayas for a longish period, there is a complete cessation of rainfall over most of northern India and the activity of the Bay current is confined to the eastern Himalayas and the adjacent hills and plains. These are termed " breaks " in the rains and they may be partial or complete depending upon the amount and period of the northerly shift of the trough of low pressure. When a break in the rains is prolonged and extends over several weeks, dry westerly winds similar in character to the winds of the hot season prevail over northern India.

The rainfall of July is about 30″ over most of the west coast and increases towards the Western Ghats, being 40″ to 50″ over the greater part of its length. It falls off rapidly to the east of the Ghats and is less than 5″ over the east of the Peninsula south of Lat. 16°N. North of this latitude rainfall increases and is 15″ to 20″ in the Central Provinces. Over northern India there is the usual decrease from 15″ to 20″ in east Bengal and Assam to less than 5″ in west Rajputana, the west Punjab and Sind. The rainfall is high, 40″ to 50″ on the Tenasserim coast and most of the Arakan coast, and steadily decreases eastwards to about 5″ or less in central Burma.

The distribution of rainfall in August is similar to that in July, but the amounts are smaller, 20″ to 30″ on the west coast, and 30″ to 40″ in north Tenasserim and on the Arakan coast. The region receiving 15″ to 20″ is much smaller in the central parts of the country. Over northern India, however, the amounts are similar, decreasing from 15″ to 20″ in east Bengal and Assam to less than 5″ in the west Punjab, west Rajputana and Sind.

The month of September witnesses the gradual weakening of the monsoon and its withdrawal from northwest India. In the earlier part of the month the distribution of rainfall is similar to that in August. But as the season advances, the trough of low pressure broadens and extends farther south in the Bay. The depressions also form in more southerly latitudes and after advancing some distance inland, take a northwesterly or northerly course towards the Himalayas. Consequently rainfall increases in the eastern half of the Peninsula, although it decreases over most of northern and central India. Occasional bursts of heavy rain occur on and near the Punjab-Kumaon hills and the adjoining plains when depressions break up against these hills. Heavy falls also occur sometimes on and near the Sikkim Himalayas under the influence of depressions. In the Deccan plateau the intervals between spells of rain increase and rainfall is mostly associated with thunderstorms. By the third week of September, the monsoon withdraws from northwest India, and at the close of the month monsoon rainfall is coming to an end in the west United Provinces, Central India West and Gujarat.

The distribution of the total rainfall of the month is similar to that in August, but the amounts are smaller except in Tenasserim; the contrast between the windward coasts and the interior on the leeward side of the hills is less marked both in the Peninsula and Burma. The total rainfall exceeds 30″ in parts of Tenasserim and is over 20″ in a narrow strip of the

Arakan coast, near the Sikkim Himalayas and on the Western Ghats in the north Konkan. 10″ to 15″ of rain are received in Assam and east and north Bengal, but the amounts decrease to less than 10″ even in parts of south-west Bengal and are between 5″ and 10″ over most of the country from the Deccan to the United Provinces. Over northwest India, rainfall is generally less than 5″ and is less than 2″ to the west of the Aravallis.

The retreating Southwest Monsoon season.—Monsoon rainfall ceases in the east United Provinces early in October, and the Bay current which continues to give rain in northeast India withdraws from this region and Upper Burma by about the tenth of the month. By this time the Arabian Sea current has also withdrawn from the central parts of the country and the northwest of the Peninsula and dry weather begins there. The belt of low pressure is transferred by the middle of October to the centre of the Bay and by the end of the month to the south of the Bay. The Bay monsoon which continues to give rain in lower Burma, curves round this low pressure area and strikes the Coromandel coast, as the so called "northeast monsoon", in the third week of October. The rainfall caused by it decreases from the coast towards the interior. October is the month of dangerous storms in the Bay of Bengal; and they frequently travel towards the northeast of the Bay. During their curved course they carry heavy rainfall to the north Madras coast, deltaic Bengal and the Arakan and Chittagong coasts. Those which strike the Coromandel coast cause heavy rainfall there. Disturbed conditions in the southeast Arabian Sea cause occasional heavy rain in Malabar. Similar conditions persist in November but most of the storms strike the south Coromandel coast and rainfall there is greater than in October.

The total rainfall of October exceeds 10″ in south Tenasserim, the south Coromandel coast and south Malabar, and is below 5″ roughly to the west of a line joining Mangalore and Dibrugarh, and less than an inch in northwest India. The total rainfall of November is 10 to 15 inches on the south Coromandel coast, but rapidly decreases towards the interior of the Peninsula and is less than an inch to the west of a line joining Mangalore and Dibrugarh.

Rainfall variations.—From the foregoing description it will be understood that the distribution of rainfall over India depends largely on its orographical features. If the hills and mountains of India were effaced the country will receive much less rainfall. The rainiest season in most provinces is the monsoon period, June to September and the important rains in southeast Madras occur in the months October to December. Rainfall during the cold weather is scanty. Stress has also been laid on the great variability of monsoon rainfall in time and space in any one year. Long breaks in the monsoon, or an early abrupt termination of the rains is disastrous to the crops, and produce droughts and famines. On the other hand tracts of country are sometimes deluged with rain and suffer distress through excessive flooding. The variations in the amount of precipitation received from year to year are also surprisingly large. The annual rainfall of India is 42″ and variations from this normal as great as + 12 inches and — 8 inches occurred in 1917 and 1899 respectively. As a rule rainfall is most precarious in the driest parts of the country and most regular in the wettest provinces.

CHAPTER III

TEMPERATURE, HUMIDITY AND AIR DENSITY.

As already mentioned India exhibits great diversities of climate. In northern India alone, Assam in the east and Sind in the west present us with a contrast of dampness and dryness greater than that shown by the British Isles and Egypt. Again in the Punjab, we find a continental climate of the most pronounced character with extreme summer heat and almost freezing winter cold while in Travancore in the south an almost unvarying heat with great humidity prevails throughout the year. A further variety is introduced by the hills. At high level stations the atmosphere is cooler and on the average damper than in the neighbouring plains; but while hill stations in northwest India are subject to great variations of heat and dampness during the course of the year, those in south India and Ceylon are comparatively uniform in these respects; their fine clear season is also shorter in duration.

Temperature.—The most important factors which determine the temperature of a place are the altitude of the sun, latitude, elevation, distance from the sea and the character of the prevailing winds (hence also amount of cloud and rainfall). From January to May or June the heating by solar action is greater than the loss of heat by radiation and other actions, and hence the temperature rises more or less steadily with the increasing elevation of the sun. During the remainder of the year the balance is the other way and the general tendency is for the temperature to decrease from June or July to December. In the regions to the west of the Indus where the monsoon does not penetrate, viz., in parts of Baluchistan, Afghanistan and Persia, the hottest month of the year is July. This is, however, modified over the greater part of India by the clouds and rainfall of the southwest monsoon, which cause a rapid fall of temperature with the setting in of the monsoon. With the cessation of the rains and before the commencement of the winter there is in many parts of India a period of a secondary maximum of temperature in September or October.

In the winter months, November to February, continental winds prevail over most of India, temperature increases from the north to the south and the isotherms run across India nearly parallel to the parallels of latitude. December and January are the coolest months, the mean maximum ranging from about 85°F. in parts of the Peninsula to about 65°F. in the northwest, while the mean minimum decreases from about 75°F. in the extreme south to below 40°F. in the northwest. Over northern India as a whole February is definitely colder than November and at many stations in northeast India and the United Provinces the lowest temperature of the year is often recorded in the early days of February. In the Peninsula and lower Burma on the other hand days are hotter in February than in November, a mean maximum temperature of over 90°F. being recorded in February over fairly large areas.

In the rear of some of the western disturbances of the cold season are cold winds from the Caspian and Turkistan region invade India and carry

a cold wave over most of northern India and occasionally the north of the Peninsula also. During these cold waves, temperatures fall occasionally 15° to 20° below normal, and several degrees of frost have occurred on rare occasions in the plains of northwest India.

During the hot weather months March to May local sea winds prevail in the coastal districts and dry land winds in the interior. Hence temperature is highest in the interior and there is a large contrast of temperature between the interior and the coastal districts. As the season advances, the hottest area is slowly transferred from the south and central Deccan to northwest India. The isotherms during this period are hence closed curves with a central area of highest temperature. The temperature steadily increases with the advance of the season over most of the country, the increase being more marked in the maximum temperature than in the minimum. In March the mean maximum temperature generally exceeds 95°F to the south of the Vindhyas and is over 100°F locally in parts of the Deccan ; in April the mean maximum temperature exceeds 100°F in the tract of country stretching from Sind and the southwest Punjab to Chota Nagpur, Orissa and the Circars and rises above 105°F locally in the Central Provinces ; the mean maximum temperature in May is over 105°F over most of northwest and central India and exceeds 110°F in upper Sind.

On individual days in May maximum temperatures exceeding 120° F have been recorded in west Rajputana, the southwest Punjab and upper Sind, the highest temperature recorded being 126°F at Jacobabad. The mean minimum temperature exceeds 70°F over the whole country in May and is over 80°F in the eastern half of the Peninsula.

With the advent of the southwest monsoon rains, there is a rapid fall in the maximum temperature in the north of the Peninsula and the central parts of the country ; as the monsoon rainfall penetrates farther inland in the latter half of June and early July, there is a progressive fall in maximum temperature in northwest India. Taking the season as a whole, temperature is almost uniform and varies only slightly throughout the period in the area of frequent rain, which includes about two-thirds of India. Although temperature, rises temporarily whenever the rains are interrupted as during a break, it never attains the same intensity as during the hot weather, when the land surface lay parched under the torrid sun. In the area which is only occasionally invaded by the monsoon winds, comprising upper Sind, the southwest Punjab and northwest Rajputana, temperature is highest throughout the period, but steadily declines from June to August. In June maximum temperature continues to be as high as in May (over 105°F) in northwest India ; and at many stations in the United Provinces, the west Punjab and Sind the highest temperature of the year is recorded in early June. In July maximum temperatures exceeding 100°F are met with only in the Thar desert and the regions to the west of it. In August there is a further decrease in temperature, but with the cessation of the rains in northwest India about the middle of September temperature rises again in this region ; maximum temperatures of about 105°F are again recorded in the region to the west of the Aravallis and of 110°F. or more in Upper Sind.

The clear autumn weather following the cessation of the rains in north India is accompanied by a rapid fall of temperature in the latter part of October over this region, the fall being more marked in the minimum than in the maximum temperature. The mean maximum temperature is below 100°F even in northwest India in October, while in November temperatures of over 100°F are rare even on individual days in this region. The mean minimum temperature of November is below 50°F in the Punjab, and on individual days temperatures below the freezing point may be recorded in the extreme north.

The distribution of the mean pressure in the four typical months, January, April, July and October are shown in *Figs. 4 to 7*. The distribution of the mean maximum temperature in May and of the mean minimum temperature in January are shown in *Figs. 18 and 19*. The distribution of the highest maximum temperature and the lowest minimum temperatures recorded during the year can be seen from *Figs. 20 and 21*.

Diurnal range of temperature.—In fine cloudless weather changes of temperature during the day, are remarkably regular in India. The air is coolest shortly before sunrise ; as soon as the sun appears above the horizon, temperature begins to rise rapidly and, although the rate of rise decreases after about 9 a.m., it continues to rise until the highest point is reached at about 2 p.m. Temperature then begins to fall, at first slowly and afterwards more rapidly till about sunset, the fall being as rapid as the rise in the forenoon. Later on the fall slackens, and after midnight continues slowly and steadily till the minimum is reached a little before sunrise. In the coastal districts the rise of temperature is usually brought to an end with the setting in of the sea breeze shortly after noon.

The range of temperature during the day depends chiefly on the dryness of the air and the clearness of the skies. It is much greater in the interior of the country and especially in northwest India than on the coasts and in the neighbourhood of the seas ; and as a general rule is greatest in the driest spring months and least in the rainy season. On the mean of the year the diurnal range is 25°F to 30°F in northwest India and decreases towards the east and south. The range is 15° to 20° in northeast India and the coastal districts from Kathiawar to Lower Burma ; it is above 20° in the inland districts of central and upper Burma. In Sind and Baluchistan and throughout the dry tract to the west of the Jumna and the Aravallis, the daily range of temperature is greatest in October and November, when the diurnal range is not less than 30° and rises to 40° in places. In the northwest of the Peninsula and adjoining regions the greatest range of 30° to 35° occurs in February and March.

Humidity.—The term humidity refers to the invisible water vapour which may be mixed in varying proportion with dry air. There is a maximum limit to the amount of water vapour which air at a certain temperature can hold, and the air is said to be saturated when it holds the maximum amount. The amount of water vapour in the air when it is saturated increases with temperature. In the India Meteorological Department humidity is usually expressed either as vapour pressure or as relative humidity. The atmospheric

pressure due to water vapour present in the air is known as vapour pressure ; this is naturally greatest when the air is saturated, and is then known as saturation vapour pressure. Relative humidity is the ratio of the actual vapour pressure present in the air to the saturation vapour pressure at the temperature of the air, expressed as a percentage.

The moisture in the atmosphere is obtained by evaporation from the earth's surface, from the sea, from moist land, from vegetation etc. Hence humidity is greatest in areas where winds of oceanic origin, especially from warmer seas predominate, and least where land winds from a colder region prevail.

The chief factors which determine the distribution of aqueous vapour pressure present in the air over India are the distance from the sea and the character of the prevailing winds. It is generally lowest in northwest India and increases towards the sea in all directions ; in the hot weather, however, the seat of the lowest vapour pressure is found in the central parts of the country while in the monsoon months a stretch of country in the Peninsula immediately to the east of the Western Ghats has the lowest vapour pressure. Vapour pressure is lowest over the whole of India in December and January when winds of land origin prevail. It begins to increase with the commencement of the sea winds on the coast. The sea winds increase in intensity and extend into the interior from March to May. Hence the amount of aqueous vapour increases steadily and rapidly in the coastal districts. In the interior, the large increase occurs later in the season. For example, it is only in May that there is a marked increase in the Punjab. The change from local sea winds to the humid winds of the oceanic southwest monsoon causes a large and rapid increase of absolute humidity over the whole of the interior, with the result that the spatial variation of vapour pressure is less in July and August than in any other month. The diurnal variation of vapour pressure is generally small.

The distribution of relative humidity over India is determined mainly by the character of the prevailing winds. Both because of greater moisture content and of lower temperature in the coastal districts than in the interior relative humidity diminishes from the coast towards the interior in all the months. The mean annual humidity is a little below 50 per cent. in the driest part of India, the Thar desert and the adjoining regions, and is about 80 per cent. in the dampest regions, in Assam and along most of the coastline.

In the cold weather, temperature as well as vapour pressure decrease on passing from the coast into the interior ; hence the variations of relative humidity over India are smaller than in the hot weather period. The air is driest, with relative humidity 40 per cent. to 50 per cent. in the west Deccan, Gujarat and southwest Rajputana.

In the hot weather months, the decrease of relative humidity in passing from the coast into the interior districts is specially rapid. During this period the air is very dry over the whole of the interior, but more especially in the central parts of the country and the adjacent Deccan plateau, where the mean relative humidity is about 30 per cent. or less.

During the hot afternoons of the summer, humidity as low as 5 per cent. has occasionally been recorded at stations in Upper India from the Punjab to Bihar, and more rarely in the central parts of the country and the north Deccan. Such low values do not seem to be due merely to the heating up of the air near the ground. The turbulent motion in the atmosphere, which is common in all countries in dry warm weather, is developed to a high degree in the north Indian summer ; consequently the air near the ground is replaced by originally colder and drier air at a higher level, which is heated partly on account of its descent and partly by contact with the hot ground. This explains the extreme dryness of the hot weather afternoons in northern India.

In the southwest monsoon season or the rainy season, temperature and the amount of aqueous vapour vary but slightly over the greater part of India. Hence in this period the air is very damp and the relative humidity ranges between 80 per cent. and 90 per cent. over the greater part of India. It falls below 80 per cent. only in northwest India.

Thus a characteristic feature of the climate in most parts of India is the great variability of relative humidity. In the rains during a spell of very wet weather, the air is sometimes saturated or has a relative humidity of 95 per cent. to 100 per cent. but when a hot wind is blowing, such as is common in April and May in upper India, it is frequently less than 10 per cent. The relative humidity varies during the day also, but almost exactly in the opposite manner to the temperature. The atmosphere is most damp in the early morning before sunrise, and humidity begins to decrease shortly after sunrise. The driest time of the day is the same as that of the highest temperature, and humidity increases in the later hours of the afternoon and evening as the temperature falls.

The distribution of relative humidity in January and July are shown in *Figs. 22 and 23.*

Air Density—normal air density at M.S.L.—*Fig. 24* shows the distribution of normal air density in India at mean sea level in January, April, June and October. The lines of equal density or isopycnics, as they are called, have been drawn at intervals of 10 grammes per cubic metre (10 gm/m^3). The lie of the isopycnics in each season is in general similar to that of the lines of equal pressure and temperature. In winter the air density is greater over the north than over the south. The gradient of density is largest in this season, the maximum occurring in January. During the hot weather the seat of low density lies in the centre of the country, while in the monsoon it shifts to northwest India, the lowest density in the year occurring in the month of June over Sind and Baluchistan. In October with the advent of the winter conditions the reversal takes place again, the values over northern India becoming greater than those over southern India.

Mean monthly densities in grammes per cubic metre at various heights over northern and southern India are shown in *Table I.*