The Theory of the South-West Monsoon.

By L. C. W. BONACINA.

IN the widest sense the term "monsoon" in climatology is applicable to those seasonal modifications, or subversions, of the planetary circulation which are established by the differences of temperature due to the irregular distribution of land and water, especially as seen in such regions as Eastern and Southern Asia, where a definite continental outflow of air in winter, and inflow in summer, characterise the surface circulation.

In relation to India the expression "south-west monsoon" is nowadays quite a commonplace, but it cannot be said that the theory of the phenomenon has hitherto been properly elaborated. The text-books commonly describe the monsoon as a kind of magnified sea-breeze action, an explanation of a complex phenomenon which can stand only as a first approximation. It must be emphasised, indeed, that the south-west monsoon of India is not in the main a special local effect of the heated condition of India at all, but is part of a general circulation of air with respect to a system of low barometric pressure originating primarily in the heated condition of the vast Asiatic continent as a whole. It is when one abandons a merely qualitative conception of the monsoonal circulation and considers the latter in the form which it actually takes as a wind-system of particular direction, speed, and structure that the mechanism is realised to be much more complex than is suggested by the above simple statement. For, just as one cannot understand the many puzzling peculiarities of the small-scale diurnal sea-breeze effect familiar round the English coast in summer-time without referring to the general barometric-gradient wind of which it is often nothing more important than a coastal modification in direction and speed, so one cannot properly deal with the large-scale seasonal sea-breeze effect in monsoon countries otherwise than as an item in a wider system of circulation. This outlook is the key to the problem, and has enabled Dr. G. C. Simpson[1] to present meteorologists with the most effective analysis that has yet appeared. He shows the futility of trying to explain the monsoon in terms of a single cause, and the necessity of seeing in the phenomenon the final result of a number of interacting factors.

Before stating Dr. Simpson's theory, it may be well to review the main seasonal divisions of the Indian year. These are: (1) a cool, dry season, November to February, definitely dominated by the north-east monsoon, which really belongs to the north-east trade system as regulated at this season by high barometric pressure in Central Asia; (2) a hot, dry season, March to May, characterised by light air-currents gradually changing round from north-east to south-west,

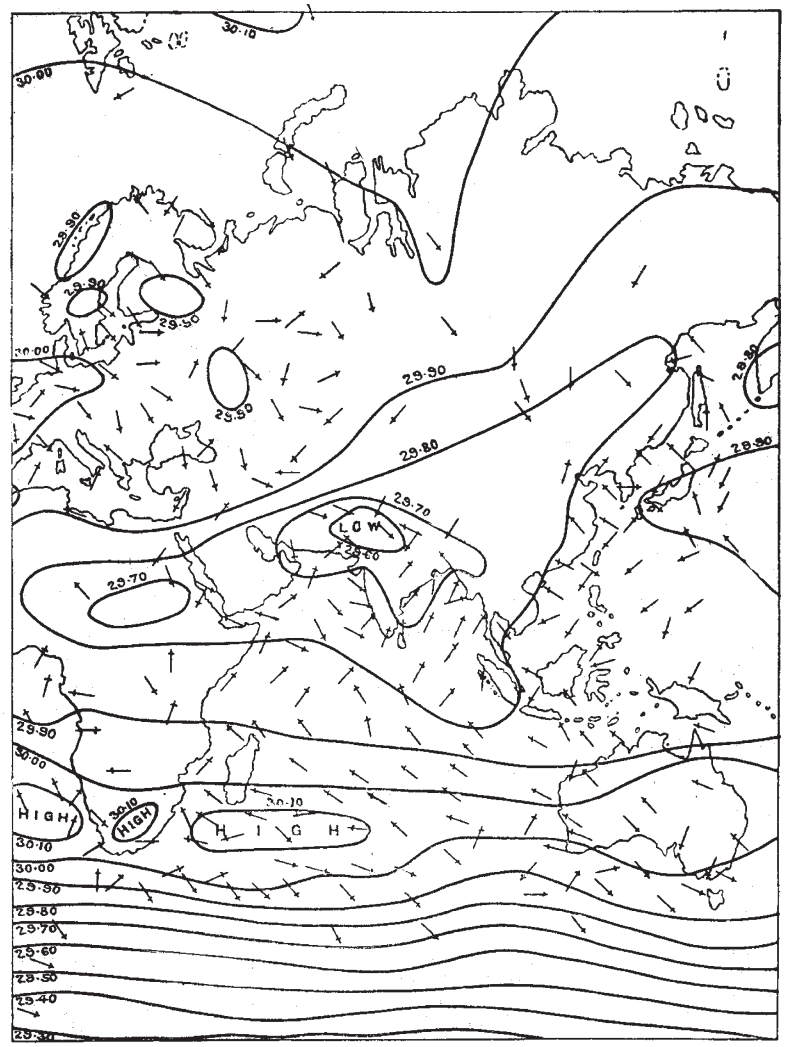

FIG. 1.—Average wind and pressure distribution around India in May. Pressure in inches.

[1] "The South-West Monsoon. Lecture delivered to the Royal Meteorological Society, March 16, 1921, and published in the Society's Journal for July, 1921.

culminating in unstable conditions productive of violent thunderstorms; (3) a wet season, June to September, dominated by the south-west monsoon, a powerful current bringing heavy rainfall everywhere in India except the north-west corner and those parts situated on the lee side of the mountain ranges; (4) a short transition period embracing the month of October, during which the south-west monsoon is retreating with belated rains on the Madras coast.

Now, in order to strike at the root of the prevalent misconception that the south-west monsoon current is due essentially to the heated surface of India itself, Dr. Simpson points to the outstanding seasonal anomaly in the climate of India. The anomaly in question is the fact that the hottest month of the year in India as a whole is not July, but May, coming, that is to say, just before the high solstice, instead of just after, as in England and most countries. The mean day and night temperature for the whole of India in May is 88·7° F., with a large part of the northern central region more than 90°, whereas in July the mean is only 83·5°, with the area more than 90° relegated to the Thar Desert in the north-west.

Clearly, in all the more northern portions of India which lie away from the nearly non-seasonal equatorial regimen controlling the climate of Ceylon and the extreme south of the peninsula, the temperature ought to continue rising until July, and the fact that after May it appreciably declines is evidently the result of the cutting off of sunshine by the dense canopy of cloud and rain rolled in by the south-west monsoon. Why, then, does not the south-west monsoon burst in May? Because in that month the summer low-pressure system to the north-west of India is not in a sufficiently advanced stage of development. It is not until June that this low-pressure area and, contemporaneously, the high-pressure area in the South Indian Ocean become pronounced enough to induce the south-east trade wind to cross the equator, thereby to become deflected by the rotation of the earth into the current which feeds the south-west monsoon. The difference is illustrated in Figs. 1 and 2, which show the average distribution of wind and pressure over a large area surrounding India in May and July. The difference between the two maps will be brought out more fully in relation to the monsoon rainfall. Meanwhile, let there be noted what is exhibited with much greater distinctness in maps[2] of wind and pressure for India alone, that in both months, but more conspicuously in May, the isobars, with corresponding deflection of the wind arrows, bend southward in crossing the Indian land-mass—away, that is to say, from the centre of low pressure in the north—signifying that there actually is some indraught due to India itself, though it is only a superposed secondary feature, giving the isobars their precise trend—a local modification of the general Asiatic circulation.

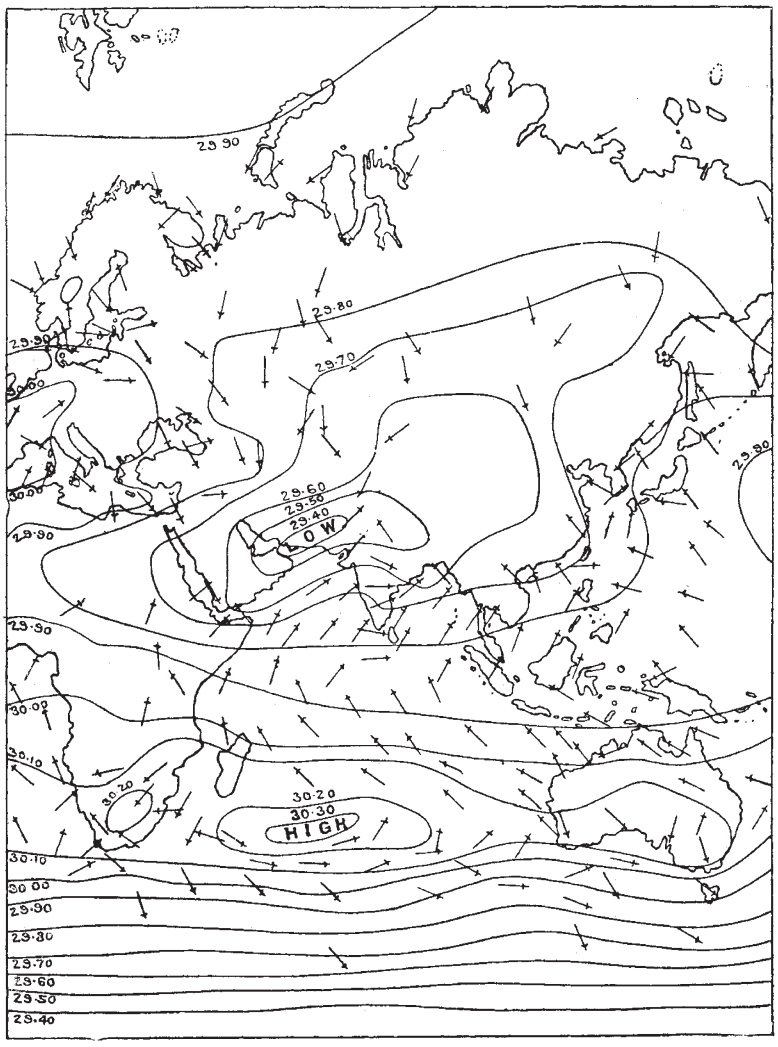

FIG. 2.—Average wind and pressure distribution around India in July. Pressure in inches.

Now to explain the great meteorological characteristic of the south-west monsoon, viz. the heavy rainfall. The diagram Fig. 3 was devised by Dr. Simpson to represent the chief alignments of mountains in and around India (thick-lettered lines), and the chief air-stream lines of the south-

[2] See Dr. Simpson's original paper, and Sir John Eliot's "Climatological Atlas of India."

west monsoon current (numbered arrows). It should be studied in relation to Fig. 4, showing the mean rainfall over the same area in July, the typical monsoon month. The disposition of the mountain ranges is such as very effectively to entrap in a kind of box the humid air brought into the Indian area by the south-west monsoon, with the consequence that the air is mechanically forced to ascend with copious condensation of moisture as a result of cooling by adiabatic expansion. Where the ranges obstruct the air-currents at right angles, as in the case of the Western Ghats, KL, or the Khasi Hills, HI, enormous falls of rain occur during the four or five months of the wet season. The Khasi Hills, moreover, contain a spot, Cherrapunji, so peculiarly favourable to orographic precipitation that the average annual rainfall is as high as 424 in., nearly all of which falls during the monsoon period. In the Gangetic Plains the heavy rainfall is largely due to the convergence of air-streams III., IV., V., and VII., assisted by the Himalayan wall, CD, at the base of which the forced ascent of air causes another specially wet submontane strip of country.

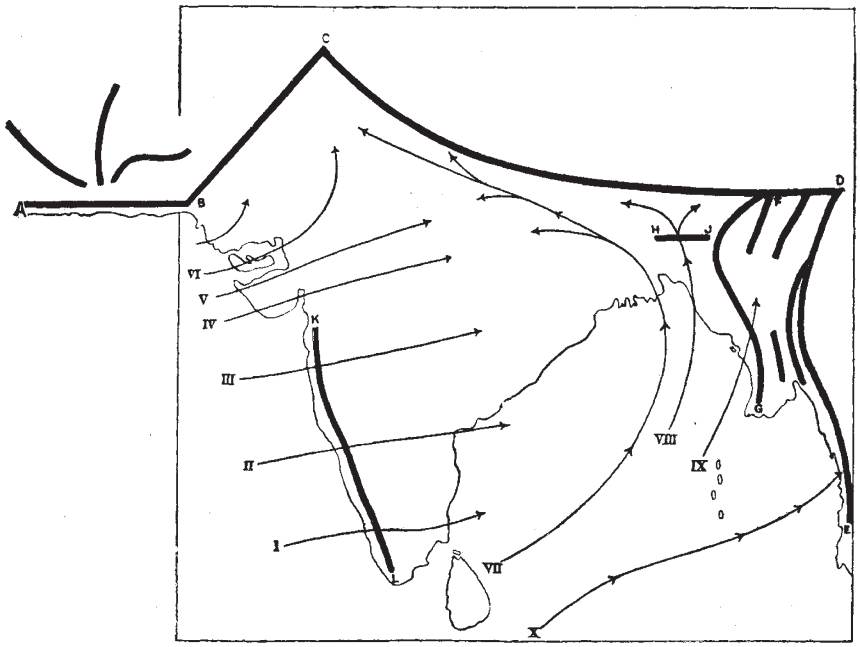

FIG. 3.—Chief alignments of mountains, and air-stream lines of south-west monsoon, in and around India. (After G. C. Simpson.)

The dry areas in July are mostly in the "rain-shadow" of the mountains, but the desert region in the north-west of India is nearly rainless for a complexity of reasons—partly because the trend of the neighbouring mountains is not such as to force upward the comparatively small amount of air which flows into this corner of the country; partly because, with the initial conditions thus unfavourable to cloud production, what little air does arrive there from the sea is heated up so that its relative humidity is lowered and the tendency to drought consequently increased; and partly because over this part of India the upper-air current from the north-west, as revealed by direct kite observations, is warm and dry, a condition most unfavourable to condensation of moisture in any surface air that may be caused to rise. In the burning-hot Thar Desert a number of interacting factors thus conspire to maintain intense drought during what in India generally is the rainy season.

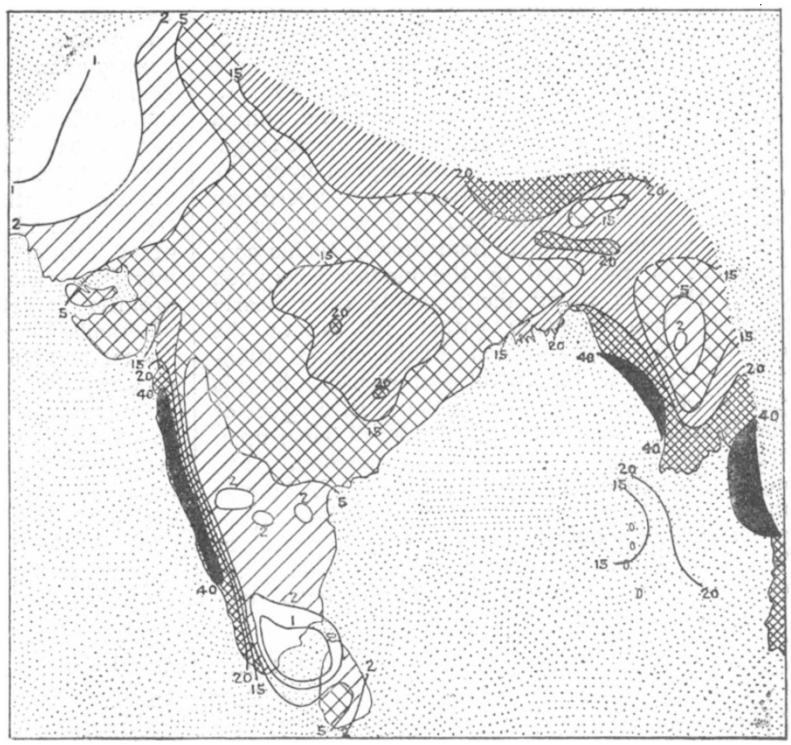

FIG. 4.—Average rainfall (in inches) of India in July.

The reason why the mountains provoke so enor-

mous a rainfall out of the monsoon current of July, and scarcely any out of the indefinite sea-winds of May, is shown by Dr. Simpson to be twofold—the July winds are both markedly stronger and damper. At Bombay, for example, the mean wind velocity is 7·4 miles per hour in May and 14·2 in July, and the relative humidity 74 and 86 per cent. respectively. Consequently, when a wind from the Arabian Sea mounts the Western Ghats, condensation will for two reasons proceed more actively in July than in May. Referring to Figs. 1 and 2, it will be seen that the pressure-gradient over India is steeper in July than in May, which means stronger winds, and that the powerful monsoon current of the former month is supplied from the south-east trade wind, with the result that the air which reaches India, after traversing some 2000 miles of sea, is necessarily very humid. In May, on the contrary, the light winds on the west coast blow somewhat north of west and conflict with the south-east trade wind over the equatorial part of the Indian Ocean, where rain falls instead of in India.

Realising how illusory charts of mean monthly meteorological conditions may be as representing actual conditions on any particular day, Dr. Simpson is able to show that the circulation in the Indian area rarely differs essentially from the mean, and that breaks in the monsoon are associated with temporary reversions to the conditions typical of May, when clear skies and fierce sunshine are broken only by violent local thunderstorms.

One cannot but support his conclusion that without the mountains the general rainfall of India would be lighter, if more evenly distributed. Those who argue that in any case the southern portion of the peninsula, below about 18° N., would experience the full effect of the annual northward swing of the equatorial rain-belt forget that the steady equatorial rains depend upon the convergence of air-streams from the northern and southern trade systems, and that where, as on the Benadir coast (Italian Somaliland), such a convergence is prevented by the monsoon regimen itself, there is found the anomaly of a nearly rainless strip of coast within 10° N. of the equator. A problem which should engage attention as facilities for travel and research in this part of the world increase is the precise effect of the Himalayas and the high plateau of Tibet upon the strength of the south-west monsoon. The effect of a broad, cold tableland 10,000 ft. high is more likely to be negative than positive—that is, to weaken rather than to strengthen the monsoon. The late Prof. Herbertson, whose insight into climatological questions was not perhaps adequately appreciated by meteorologists, used repeatedly to discountenance exaggerated notions concerning the "flue-like" action of Central Asia often entertained by those who rely too much on isothermal maps reduced to sea-level. In any case, there would be a general inflow of air towards Asia in summer, as is so well exemplified in China; but the real controlling centre of the powerful south-west monsoon of India is situated near the mouth of the Persian Gulf, and it is this "cyclonic" centre which guides the air-currents across India to the base of the Himalayas, which they must perforce mount, and thence on to the highlands of Tibet.

To summarise, the primary condition of the south-west monsoon is a centre of low barometric pressure situated to the north-west of India, due to the heated state of this region in summer, and to a certain extent of the Asiatic land-mass as a whole. The special local effect of India itself is quite subsidiary, merely serving to give the isobars and air-currents across the peninsula their final trend. In May the local heating of India, then at its maximum, does not suffice to bring about monsoonal conditions, but the general Asiatic heating in July does, for reasons discussed. A heavy rainfall accompanies the monsoon because it is both a humid and a powerful current, and is met more or less at right angles by various high mountain ranges.

Finally, it is advisable to refer to certain general principles in connection with the theory of the monsoonal circulation, the importance of which is duly emphasised by Dr. Simpson. Whilst it is a conspicuous fact that, broadly speaking, the continents command high pressure in winter and low in summer, and the oceans *vice versa*, the more detailed relationship between pressure and temperature is exceedingly complex, and the precise location of a centre of high or low pressure depends upon many other factors, such as the rotation of the earth and the configuration of the land. In other words, the atmosphere being a unity of interdependent parts, it is largely a matter of compromise, as between region and region, what type of circulation shall prevail here and what there. To take but an instance. Nothing is more perplexing than the drought-producing wind and pressure regimen of the Mediterranean basin in summer with intense insolation and active evaporation to a meteorologist who conceives of this region as isolated from other regions, and forgets that the Mediterranean circulation has to adapt itself to the great monsoon system of Asia, as well as to the conditions in other parts of the world.

Helium in Natural Gas.

By H. B. MILNER.

THE researches of H. P. Cady and D. F. McFarland in 1905 on some natural gas from Kansas led to the interesting discovery of the presence of helium in that gas, a fact of which advantage was taken afterwards by the United States military authorities during the later stages of the war. In 1915 the natural gas resources of this country were investigated for a similar purpose