ISOBARS IN THE TROPICS—SOME BASIC IDEAS OF TROPICAL METEOROLOGY

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THE weather forecaster depends entirely on the observations that he is able to obtain at the time of forecasting. The meteorological observations that were ordinarily available to a forecaster in India before 1939 were confined to the Indian area comprising of India, Burma, Ceylon and the sporadic observations from the ships in the north Indian Ocean. Some of the forecasting centres got a few observations from Indo-China, Siam, Malaya Iran, Iraq, Aden and Egypt. The attention of the forecaster was therefore focussed to the use of data from regions in and immediately surrounding India and the more distant observations were used only to supplement the usual charts. When the war broke out in East Asia, the observations from the more eastern regions and Burma were cut off. The radio silence had been imposed on ships. It was therefore necessary to improve the network of observatories and communications from the regions belonging to the allies. Observations from Russian Turkestan were received at Poona from May 1942. Those from the islands in the Indian Ocean, East Africa, Arabia, Iraq and Egypt and sometimes Turkey and portions of China began to be received in time for daily forecasting by 1943. The receipt of so many unfamiliar observations necessitated their proper appreciation and improved technique.*

There are available monthly charts for the Indian Ocean area prepared by the various Hydrographic and Naval Services, daily charts for the northern hemisphere for the Polar Year (1932–33) and the daily charts prepared by the India Meteorological Department between 1893 and 1904 with the help of observations, received by post, from distant observatories and ships. While all these charts are instructive and useful to verify any new results that may be deduced with the present data, the daily weather forecaster who gets the data in time for forecasting is likely to observe more closely, check immediately and modify rapidly the technique that can be of greatest use even when some of the data are missing due to failure of communications.

* Substance of a colloquium on the subject in Poona Meteorological Office in Jan. 1943.

Unfortunately the failure of communication in one region or another is a common experience. A more intimate knowledge of Indian conditions applied daily to these data can furnish useful information, which an after-study may not always show up. The daily weather forecasting is interesting like the news, when it is actually fresh, and as each day brings its own weather problems, the past weather fails often to attract the same detailed interest in a worker. While it is difficult to self-analyse one's own deductions, an attempt has been made here and elsewhere to place on record the experience gained and the new results obtained.

Choice of Charts of Observations

The problem that is posed to the weather forecaster increases daily. Agriculture, aviation and operations all need that forecasts over large areas be given for as much time ahead as possible. The type and number of observations have also increased. The weather forecaster's observations include: the surface observations (like barometric pressure, temperature, humidity, present weather, wind speed and its direction at lower levels, visibility, clouds and their movement, past weather and precipitation) taken at definite hours of the day, the pilot balloon observations giving the speed and direction of wind at higher levels, Radio-sondé or aeroplane soundings giving temperature and humidity at higher levels, the atmospherics, the radar observations and special observations from ships and aeroplanes. If all observations are plotted over any big area, the task of absorbing the data and suitably interpreting them in the small amount of time that is available to a forecaster before he puts out his forecast is beyond a human being. By sheer necessity, a forecaster concentrates his attention to a set of observations with which he feels the greatest confidence. To prevent strain, he might choose a chart which has less number of observations for a given area and attempt to forecast mainly with its help, supplemented occasionally by reference to other available charts. The chart containing surface observations, and the charts from the derived quantities (like pressure change, pressure departure, etc.) and the upper wind charts for an area like India and the immediate neighbourhood are sufficient to occupy one completely. The isentropic, constant level, constant pressure charts are all attempts to decrease the total intake of the mind at the time of forecasting. But it must be made clear at the outset, that the surface and its derived charts, the upper wind charts, observations of cloud cells, radar observations and the thermodynamic charts are all cross-sections of the weather-pattern and *cannot* be mutually exclusive. The degree of specialisation that one has had determines one's choice as far as general weather forecasting is concerned;

and when specific requirements are to be complied with, the corresponding charts are referred to.

The surface and its derived charts have an initial advantage that the observations have been taken at definite points of space at related times (comparable) and that the observations are available for a fairly long period so that a reference to past surface data is always possible in case of a new idea or theory. The speed and direction of upper wind have also been available for a few decades at many places though the distribution has become satisfactory only comparatively recently.

When surface charts are drawn, the problem that interests one most in the tropical regions is the relation of the isobars to the winds. It is therefore necessary to look into the question closely.

RELATION OF ISOBARS TO WINDS IN THE TROPICS.*

The dynamical equation of wind is given by the following vectorial equation:

$$d\underset{\cdot}{V}/dt = 2\,\underset{\cdot}{\Omega}\,X\underset{\cdot}{V} = -\nabla p - \underset{\cdot}{F} - (0, 0, g)$$

Where

$\underset{\cdot}{V}$ is the wind velocity, g is the value of gravity,

$\underset{\cdot}{\Omega}$ earth's angular velocity,

$\underset{\cdot}{F}$ frictional force and

p barometric pressure.

Of the terms, the rotational term (second term) involves the component of earth's rotation in a direction at right angles to the direction of the wind and so involves the latitude of the place ϕ $(2\,|\,\Omega\,|\sin\phi)$. The term $\sin\phi$ decreases when the latitude of the place approaches the equator. It is usual to treat that, as the equator is approached, the rotational term is negligible and to discuss the equation of the wind without it near the equator. This involves the assumption that the other terms retain the same order of magnitude in the tropics as in the temperate latitudes. Actually this is not always true. In the Indian Ocean area round South India, the assumption is definitely not correct. The pressure gradients found in higher latitudes (say 35° or 40° N.) are of the order of 2 mbs. per 70 miles (or across a degree of latitude) and gradients of 4 to 5 mbs. per 70 miles are not uncommon. But in the lower latitudes (both north and south of the equator) south of India the gradient hardly exceeds 0·4 mbs. per 70 miles (across a degree of

* Part of Colloquia at the Poona Met. Office in June-July, 1945.

latitude) and is generally much less near the equator in the neighbourhood of the Comorin. The gradients are so weak that some workers cease to attach any importance to the pressure values of these places. It is therefore not correct to assume that only the rotational term should be ignored near the tropics and that the pressure gradients term retained when both the terms are decreasing in about the same proportion.

If the rotational term be neglected, it is of course valid to say that the wind direction is guided by the pressure gradient term (which is at right angles to the isobars) when the winds are steady. But if the pressure gradient and the rotational terms are both retained as being equally small the vectorial nature of the equation shows that when the winds are steady, the isobars follow the winds even in the tropics as in the temperate latitudes. Due to friction term whose value is undetermined, even in the steady state, a small deviation may be possible. But the general conclusions that are drawn in the temperate latitudes apply to a great extent near the tropics where the pressure gradients are small.

In the Indian Ocean, during the S. W. monsoon, strong pressure gradients associated with steady winds are encountered on the East African coast (from 2° to 10° N.) and to a lesser extent on the east coast of India. In most other places, either the winds are not steady or the pressure gradients are not steep. In the region of steady winds, it is advantageous to draw isobars to follow the winds and deduce the maximum possible information from the isobaric pattern.

As the pressure gradients are small near the equator or the tropics, the pressure values have to be given correct to a tenth of a millibar at individual stations if they are to be of any use at all. Over the tropical region of N.E. Africa where pressure gradients are steep, some forecasters might be satisfied with pressure readings correct to a millibar.

Isobaric Patterns

This is really an application of methods used in many branches of Science. In Hydro-dynamics, given the velocity at discrete points, sources and sinks are constructed easily. In similar branches like Electricity and Magnetism isopleths are drawn to determine most of the fundamental ideas. Naturally many workers assume the methods to be almost axiomatic.

The drawing of isobars requires experience and judgement. When relatively flat pressure areas or regions of few observations are encountered, considerable latitude exists in the method of drawing isobaric patterns. It is often mentioned by older officers that in the Indian area, Hemraj used the geometry of isobars very effectively. Unfortunately, little has been left on record of his method. It has been found that a careful drawing of isobars can indicate movements of disturbances which are not obvious from mere observations and a cursory study. They also indicate approximately the regions of partitions of air masses.

In higher latitudes, the earth's rotational term would be predominant. If further, one considers a few kilometres above ground in those latitudes even the frictional force can be considered negligible. In those latitudes and at those higher levels, the isobars and the streamlines are practically the same. That is the ideal condition. In practice, an approximation to the ideal condition would be suggestive. Even at the surface in other latitudes, the isobaric pattern, that tends to approximate to the streamlines, gives more information. In drawing the isobars, when one takes account of both pressure and wind direction, this approximation is inevitably carried out.

With the risk of repeating rules which might have been used by many, a few of them are given here. All isopleths have to be similarly considered though isobars being the most important are dealt with here.

The isobars should appear to belong to a family of curves, so that the closed (low or high) pressure areas become the nodal curves; and the wedges, ridges, or troughs become the natural cusps of the family.

If there be two closed (low or high) pressure areas, the next isobar drawn to enclose both of them must necessarily dip between the closed curves from both sides. In successive isobars, the dip becomes less and less marked. In the wedge also, the successive isobars which turn back on themelves become less and less acute. The curve joining the turning points of successive isobars in a wedge should be smooth and not erratic.

As observations are taken at discrete points, the attempt to make isobars tend to streamlines would necessitate drawing isobars approximately as envelopes of the wind directions . In fact, if the wind directions were known at places recording the same pressure at a given epoch of time, the envelope is got by producing the wind directions (or tangent curves of the envelope) at various places and smoothing the resulting curves. As the wind directions and pressures are taken at fixed points one has to judge points of equal pressure and estimate the probable wind direction and speed there and draw the isobar. The isobar so drawn should not be at variance with the existing observations or the observations that may come in later. The isobar that can be drawn with greatest certainty is drawn first and the pattern is completed round about it or making it a part of a bigger system. The distance between successive isobars (drawn at equal pressure intervals)

FIG. 1.

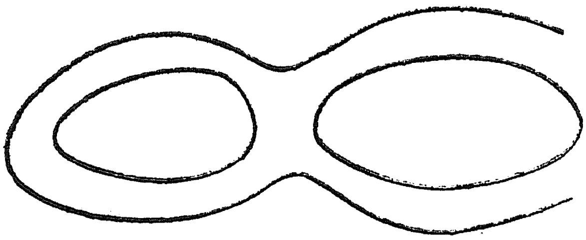


FIG. 2

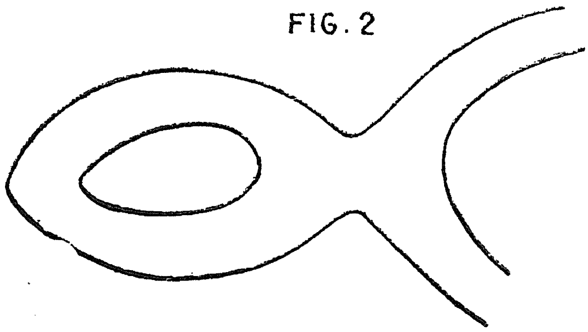
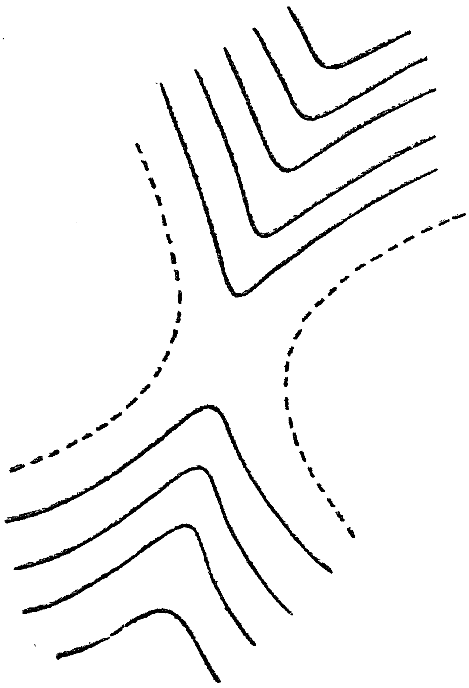


FIG. 3.



is adjusted with the help of the wind speed in that area. When an isobar bends on itself at a point, the wind speed at the point is nil (calm). Over a chart covering a wide area, each small area is completed and extended to the next area to form a logical picture. To take the extreme case, examples

FIG. 4.

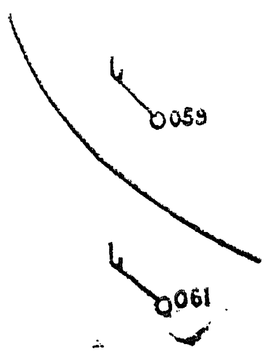


FIG. 5.

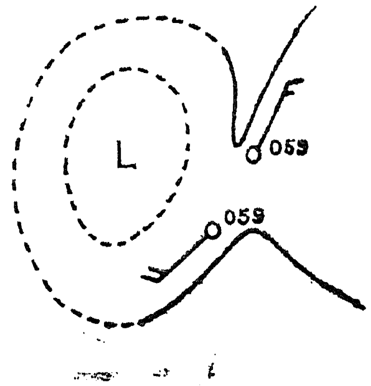


FIG. 6.

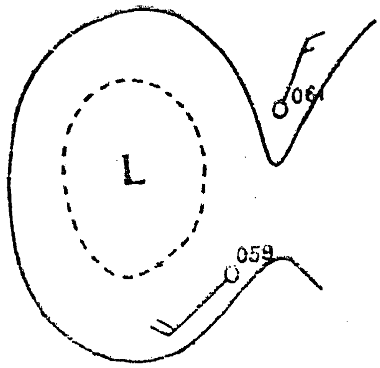


FIG. 7

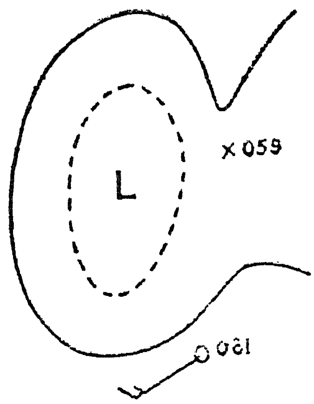
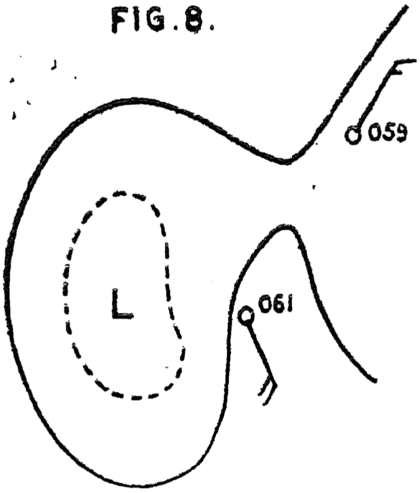


FIG. 8.



PRESSURES PLOTTED IN TENTHS OF MILLIBARS.

(Hundreds & Thousands Figures omitted)

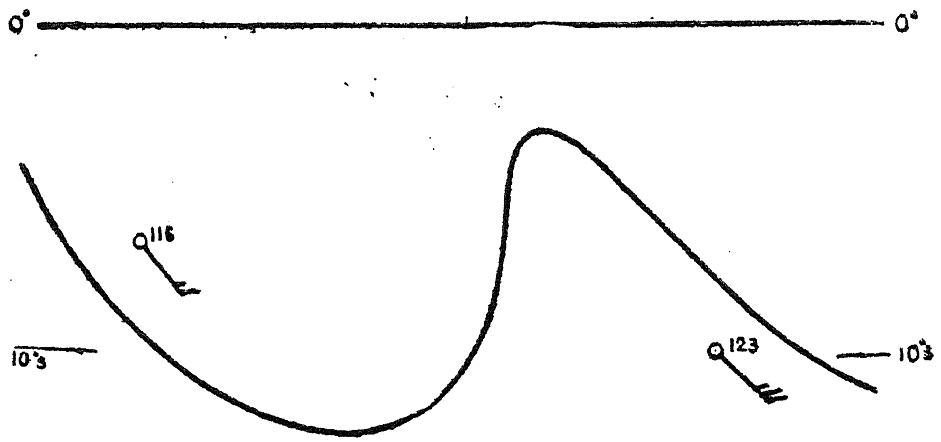
WINDS PLOTTED IN TERMS ½ FEATHERS

FIGS. 4-8 REFER TO NORTHERN HEMISPHERE

of isobar drawing at the boundary of one's observations are given with two observations:

The concepts inherent in the exmples are necessary in storm warning work and must have been used by many workers. But they can be used daily in drawing weather charts at the boundaries of one's observations, particularly in the Persian Gulf, Arabia and the South Indian Ocean from where the number of observations received are very small. How sharp the various kinks or dips should be depends on the individual forecaster and the relative importance he attaches to the kink. When he expects that the

FIG. 9.



air mass is to be indicated and partitions marked, he may make the kink prominent and carry the kink over in successive isobars. If by chance more observations from the same area are recieved, it will be found that the pattern of the isobar will not be materially changed though particular lines may have to be displaced to a certain extent.

A logical sequence in the isobaric pattern should be maintained in successive synoptic charts.

As far as possible, the observations from stations of poorly represented areas should be given full weight so that no essential weather feature is missed.

Methods used in Drawing Conclusions

The meteorological observation received from the wide region were used almost immediately for daily forecasting and little time was spent to collect a number of instances before a particular criterion was "verified and statistics collected". As the observations poured in they were used and any flaws in judgement corrected in the next synoptic hour. The general principles were: (1) a "confusion" of cause and effect, and the (2) the "principle of superposition."*

* The methods were outlined in a draft of Forecasting in and near India prepared in Feb.-March 1943 extracts from which were printed in Tech. Note. No. 1, 1943 of India Met. Dept.

"Confusion" of cause and effect is essentially a process of looking out for similar causes when the effects are very similar. For example, when conditions are unsettled or depression is formed in the Arabian Sea during the month of October, the hot desert winds from Rajputana give very hot days over lower Sind. It would therefore be natural to look out for unsettled conditions or even a depression in the month of October if the temperatures are abnormally high over lower Sind. This method is one of probability and not necessarily one of certainty. It is necessary to stress this point, as it may be argued that there are several instances in October, when temperatures were high over Sind and there was no trace of a depression in the Arabian Sea. Taking another example, when the upper winds at 2 and 3 kms. at Lahore are southerly in winter, rain falls subsequently in Kashmir. The fact that there are occasions when winds were favourable for rain in Kashmir without any subsequent precipitation does not take away the utility of the criterion evolved from experience. It is possible to magnify the differences between the weather charts and argue that no two charts are alike. It is more profitable to confine oneself to those aspects of the problem which can be solved and systematised and leave the finer details for later study. The broad common features will then be evident.

"Principle of superposition", the weather at a place is due to the combined effect of the prevalent circulation and any perturbing factor. The method of obtaining the resultant depends on the particular problem and on the relative magnitudes of the prevailing circulation and the perturbing factor. The land and sea breezes are minor perturbations on the general circulation, while the S.W. monsoon is a major perturbation on the circulation of the atmosphere in the tropics. The monsoon depressions are perturbations imposed on the S.W. monsoon.

The method of cause and effect comes in even in drawing isopleths or fronts or partitions. The lines representing these are drawn with a view to account for the weather actually experienced. For a novice, it is puzzling that, after having drawn a front or partition or even a wedge by taking account of the actual weather, the same front or partition or even a wedge is given as a reason for the weather. The process employed has a good logical background. It corresponds to the successive approximations of an equation or to the self-consistent models in atomic physics. Just as the case of an atom, after final evaluation, the density of electrons and the field strength should be consistent with each other, and as in the case of an equation the final root should satisfy the original equation for which successive approximations were sought, the weather and the picture of isobars, partitions, fronts or wedges must all be self-consistent.

In the method of drawing isobars outlined above, it is often noticed that a number of small low pressure areas will have been drawn. Every one of them will not be a depression or even give rise to one. But at the same time they are not altogether to be ignored. Some of the low pressure areas are quasi-permanent with only a small shift in their locality and intensity from day to day.* Others move in a more or less regular fashion. The motion of monsoon "pulses" have been shown to be associated with the movement of shallow low pressure areas from south of the equator to the north (*ibid.*). The movement of far-eastern transitional air is also often associated with the motion of shallow low pressure areas. It is likely that even at other places, the motion of shallow low pressure areas should exist when maritime air is involved but is masked due to steeper pressure gradients there. The motion of dry continental air is however shown by the steeper pressure gradients, which one would associate with the rear of extra-tropical depressions. The significance of the quasi-permanent and moving low pressure areas have been given in the book. Usually the low pressure areas arrange themselves in a systematic fashion in the Indian area. When there are more closed isobars or steeper pressure gradient (in the afternoon) than usual more instability weather can be expected. A natural inference of the existence of the shallow lows and absence of weather on many occasions would be that, these shallow low pressure areas indicate a certain amount of vorticity in the isobaric system and if energy is fed into them by incursion of maritime air (or more southerly air in the northern hemisphere) weather often results. In other words, two distinct features; vorticity and injection of a maritime air (a northward flow of air in the northern hemisphere) are both required to produce weather. These points are being looked into further.

Summary

The subject of Tropical Meteorology is of late assuming importance to be dealt with theoretically. Meteorological network is also being developed. It is shown that even in the tropics, in the region of steady winds and small pressure gradients, the isobars follow the wind directions. Taking the idea of streamlines and isobars at upper levels in higher latitudes, methods of drawing isobars are given. This is particularly important, as due to small pressure gradients in the tropics, there is great latitude in drawing isobars and some almost ignore the pressure values. Methods of drawing conclusions from meteorological facts are given.

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* Tech. Note. No. 20, India Met. Dept. 1945 and also p. 13 of "Forecasting Weather and near India" released Nov. 1945 to be re-printed later with diagrams, tables and addend .