

"Western Disturbances" and Indian Weather

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(Received 10 October 1955)

1. Introduction

The virtual global character of weather phenomena has been one of the recent realisations of the synoptic meteorologist. So far he has been accustomed to treat the weather at any one place as a consequence of phenomena occurring in that area and the antecedent phenomena that have occurred in its immediate neighbourhood. In other words, weather systems were supposed to move from one place to another with reasonable speeds and their modifications were taken to be determined by synoptic situations in the immediate neighbourhood. Consequently the synoptic meteorologist used to treat the tropical weather as something different from the weather of the extratropics, and the northern hemispheric weather as independent of the weather situation in the southern hemisphere. Meteorologists are now gradually realising, that the tropical weather and extra-tropical weather are mutually dependent. The influence of "Western Disturbances", which are only developments of eastward moving troughs in the extratropical zonal westerlies, on Indian weather is an aspect of this interaction between the tropics and the extratropics, with which we in India are vitally concerned.

This survey attempts to present only some of the salient features of this interaction, as could be gathered from the synoptic experience of the Indian meteorologists who have been engaged in the field of synoptic meteorology of India and its neighbourhood. We shall also touch upon some of the features which are at present indefinite and which need further study and investigation with

global synoptic charts extending well into the stratosphere even over the tropical regions. It is hoped that the observations proposed to be taken during the International Geophysical Year will help to solve some of the weather riddles of the tropics.

2. Winter period

Eastward moving upper air troughs in the sub-tropical westerlies, often extending down to the lower troposphere of the north Indian latitudes, during the winter months, are known as "Western Disturbances" in the meteorological literature of India. These moving troughs often give rise to closed cyclonic circulations on the sea-level charts of Iran, Western Pakistan and North India, during the winter period. They are responsible for the winter precipitation of these areas and are of considerable economic importance to Pakistan and North India.

The behaviour of western disturbances during the winter months has been the subject of numerous studies by meteorologists in India. It is now generally believed that the westerly troughs and the associated low level cyclonic systems originate in the Mediterranean or the West Atlantic region, with secondaries developing over the Persian Gulf, either directly or as a result of the arrival of low pressure systems from S.W. Arabia. They appear to have a life-history similar to that of the Bjerknes cyclones of the Pacific and Atlantic, and to arrive over the Indian longitudes more or less in an occluded state, and therefore without marked frontal structure at the lower levels. The rather rugged orography of Iran, Afghanistan and Western Pakistan also seems practically

to obliterate the frontal structure of these systems at the lower levels.

Although it has been the subject of a few investigations, the mechanism of formation of the secondaries over the Indo-Pakistan region is not yet well understood. The separation of the secondaries from the primaries even when the primaries are well defined, is often very small, suggesting that the mechanism of formation of the secondaries over this area is different from that over the northeast Atlantic. There are also occasions, when the existence of primaries is more an assumption under the cover of absence of data. On other occasions, the barometric falls and precipitation amounts associated with the secondaries are much larger than those associated with the primaries. Some western disturbances are unusually active, while others, although equally deep as far as the sea-level pressure deficiencies are concerned, cause little or no precipitation. These features are probably due to differences in the general circulation patterns prevailing at the moment either upstream or downstream from the Indo-Pakistan region, or to the differences in the circulation patterns prevailing near the equatorial latitudes of the two hemispheres, or due to the differences in the vertical structures of the disturbances at the stratospheric or substratospheric levels.

There are a few synoptically verified ideas regarding the interaction between these westerly troughs and the easterly waves moving westwards along the equatorial latitudes during the winter. When there is an in-phase superposition of the two waves, whereby the trough line of a westerly wave and the trough line of an easterly wave arrive at the same longitude, the "highs" to the east of the two trough lines reinforce each other and there is the possibility of the moist air of the easterly wave system feeding to the eastern side of the westerly wave, and thereby increasing the precipitation capacity of the western disturbance. When such a superposition takes place over the Arabian Sea,

Gujarat and Madhya Bharat experience the effects of the reinforcement of the westerly wave; when the superposition takes place along the central meridian of India, the effects are felt over Madhya Pradesh and Orissa; when it takes place over the Bay of Bengal, the effects are felt over East Bengal and Assam. On such occasions of superposition, there is a possibility of asymptotic confluence of relatively dry northerly air arriving from the rear of the westerly wave, with the tropical maritime air of the easterly wave, on the western side of the easterly wave also. Such a confluence of contrasting air masses serves to increase the rainfall on the western side of the easterly trough. Some of the instances in which the northeast monsoon becomes active over Tamilnad and Travancore-Cochin, appear to be associated with the superposition of the trough lines over the Bay of Bengal.

It is well known that western disturbances occasionally deepen when they come over the Indo-Pakistan area, particularly over Rajasthan and the Punjabs. The usual explanation offered is the feed of relatively moist air from the Arabian Sea or from the Bay of Bengal and the central parts of India, the deepening being attributed to the warmth and humidity of the oceanic air. Dynamic meteorologists are generally of the opinion that pressure changes at any locality are predominantly caused by dynamic effects and not by the advection of air masses of different temperature and density. Hence the occasional deepening of the sea-level 'low' of the western disturbances, is probably connected with marked diffluence in the upper air flow patterns at the 300-mb level and aloft prevailing vertically over the sea-level 'lows'. Counter patterns with strong observed upper winds to the left of the troughs and relatively weak winds to the east of the troughs are not uncommon over N.W. India during the winter period (Fig. 1). Such a flow pattern pours in a considerable amount of cyclonic vorticity to the trough line, all of which

is not removed by the relatively weaker and less cyclonic winds to the right. The observed higher temperature of the upper air behind the trough line is probably associated with marked subsidence in this air. Such a subsidence would serve to transport the excess cyclonic vorticity downward and thereby increase the low-level cyclonic circulation.

A probable cause of the formation of the so-called "secondaries", without corresponding well marked primaries, appears to be associated with the cross-isobaric flows which have to develop round anticyclonic ridges, when they are of sufficiently sharp curvature. For a given pressure gradient (or contour spacing), there is a minimum radius of curvature which an anticyclonic current of air can follow. The value of this radius of curvature is given by $4v_g/l$ where v_g is the geostrophic wind and l is the Coriolis parameter $2\Omega \sin \phi$. For a geostrophic wind of 40 knots, the value of this radius of curvature, at 25°N , is nearly 12 degrees of latitude (geostrophic winds of this magnitude are frequent at 300-mb levels). If the anti-cyclonic contours with such a gradient have a radius of curvature smaller than 12 degrees of latitude at 25°N , the air stream will not follow the contours but will shoot across the contours into regions of lower contour heights and will rapidly speed up in the process. Such situations do occasionally arise over N.W. India. Whenever air is fed into a trough with a sufficiently high velocity, mass divergence is bound to occur as the coriolis and centrifugal forces cannot be balanced by the pressure gradient forces. There is some evidence that some of the secondaries develop over the Indo-Pakistan area under such circumstances.

3. Hot weather period

Even during the hot months of April and May, these western disturbances move across North India as closed cyclonic system on the sea-level chart. The atmosphere being relatively dry, hot and unstable, the

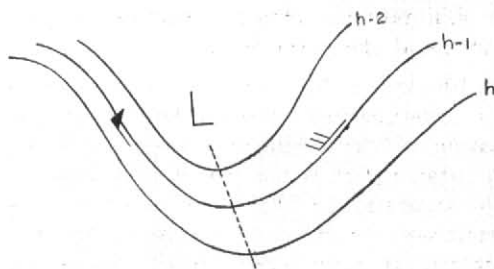


Fig. 1. An asymmetric upper air trough with closer packing in the rear

passage of these disturbances is associated with violent duststorm activity over Western Pakistan and Northwest India, and with violent nor'westers often of tornadic violence over Northeast India and Eastern Pakistan. Usually these phenomena occur ahead of the trough in the upper troposphere, where high level divergence favours convergence and convective activity in the lower troposphere. On some rare occasions, the troughlines of the westerly troughs extend to considerably low latitudes— 15° to 20°N —even during the month of April and May. If on these occasions there is an easterly wave or a temporary advance of a fresh monsoon current from the south Indian Ocean, conditions become very favourable for the formation and intensification of deep depressions or cyclonic storms of comparatively small extent. The distinct feature of such storms or depressions is their lack of any westward component of motion. They move in some northeasterly direction and often with speeds much higher than those common to tropical cyclonic systems. Such storms usually develop in the Andaman Sea and in the southeast and east central Bay of Bengal. There appears to have been a few instances when such developments took place in the southeast Arabian Sea.

4. Monsoon period

It has been suggested that the burst of the monsoon over the India-Burma area occurs only when the semi-permanent upper air trough lying roughly along the longitude 90°E , shifts to the Kashmir area. This means that the monsoon bursts

over the India-Burma area, only when the western disturbances cease to travel along the southern periphery of the Himalayas. This is not supported by subsequent observations. The burst of the monsoon over South India and Burma, is largely determined by the general circulation in the south Indian Ocean and in the lower latitudes of the northern hemisphere. However, during the early part of June, the eastward movement of the westerly troughs along the Gangetic valley, prevents the extension of the monsoon current into Bihar and Uttar Pradesh. It is also well known that the advance of the monsoon along the Konkan coast is sometimes delayed, even after its appearance along the Malabar coast. While it is true that the synoptic situation over the south Indian Ocean may be the chief factor in the advance of monsoon up the Konkan coast, the effect of the westerly troughs affecting the wind flow as far south as the Bombay latitude, in preventing the advance of the monsoon, cannot be precluded. There are also definite instances, when an active western disturbance serves to extend the Arabian Sea branch of the monsoon into the Punjab *via* East Rajasthan, without the Bay current having a chance of extending even into Uttar Pradesh. It is only when the Western Disturbances cease to skirt the southern periphery of the Himalayas and begin to move northeastwards across Kashmir, that the easterly moisture bearing winds of the monsoon extend up the Gangetic valley into the Punjab and Kashmir.

The upper level divergence and the compensating low level convergence ahead of the westerly troughs, moving across the extreme north India during the height of the monsoon, are apparently responsible for the pulsatory extension of the monsoon rainfall into the Punjab and Kashmir during this period and associated heavy rainfall there.

During the months of July, August and September, the westerly troughs have on the average a more northerly trajectory

and are rarely associated with closed isobars on the sea-level charts. Hence it has not been customary in the India Meteorological Department to designate them as Western Disturbances during these months. However there are a few occasions when these troughs move in a somewhat lower latitudes than usual, so that one can follow them moving eastward across the Tibetan plateau and the adjoining Himalayas by the eastward travel of day-to-day pressure changes, the Cirrus movements, and the changes in the 6 km winds, when available. It has also been noticed that a passage of these westerly waves in quick succession during the monsoon season leads to the so-called "Break Monsoon" conditions over India. The westerly waves serve to divert the usual southeasterly monsoon current of the Gangetic valley into a southwesterly or westerly current, which, impinging on the Eastern Himalayas gives copious rainfall there. The importance of these waves in the forecasting of devastating floods in the rivers having their catchment areas in the Eastern Himalayas cannot be over-emphasised. Perhaps the year 1954 is unique, in that even the mean monthly upper air contours for July for the 500-mb level show a "low" towards the north of the Eastern Himalayan range, instead of the "high" shown by the normal monthly charts. It is definite that the unprecedented floods of 1954 in Assam, north Bengal and Bihar are closely associated with this feature.

Towards the end of the monsoon these westerly waves recommence their regular travel across more southerly latitudes. Sometimes their trough lines extend to even south Rajasthan. Even now, closed cyclonic pressure systems at the sea-level chart do not develop in association with these troughs, so that it has not been customary to speak of western disturbances during this period also. Occasionally the eastern depressions moving westnorthwestwards across the Gangetic valley or the central parts of the country, come under the field of the eastern side of these westerly troughs. Then the depression

loses its westward component of motion, moves northward or northnortheastward and finally breaks up against the Punjab-Kumaon hills. Subsequent eastern depressions are usually deflected at more and more eastern longitudes, until the monsoon gradually withdraws from north India. The appearance of the westerly troughs over the north Indian latitudes is probably not the sole cause of the final withdrawal of the monsoon. The appearance of these troughs is, however, certainly associated with changes in the pattern of the general circulation in the northern hemisphere and probably in the southern hemisphere also.

5. Post-monsoon period

During the post-monsoon period also the westerly troughs are not quite frequent, although their trough lines extend to more and more southerly latitudes and a cell of the semi-permanent sub-tropical high forms over central Burma and sometimes over the central Bay of Bengal and Hyderabad. The trough lines of the westerly troughs, usually find a chance of extending to more southerly latitudes through the col areas between the semi-permanent highs. When such an extended trough line coincides with the trough line of an easterly trough of the low latitudes, a temporary interlocking of the two occurs leading to an intensification of both the troughs. On other occasions, the westward moving tropical low pressure areas of the easterly waves arrive vertically under the upper tropospheric anticyclonic flow in the rear of the eastward moving westerly troughs. A few such situations are found to be favourable for the intensification of the tropical low pressure systems into tropical cyclones. Some of the post-monsoon cyclonic storms in the Bay of Bengal apparently form in this manner.

Well developed westerly troughs extending to sufficiently low latitudes also appear to be responsible in effecting the recurvature of tropical cyclonic storms both in the Bay of Bengal and in the Arabian Sea, particularly when the recurvature takes place rather

abruptly, and the recurved storm continues to be active. It is true that the directive field, associated with a semi-permanent high, may also effect a recurvature of a tropical storm, when it arrives at the western end of this "high". But in this case, the "storm" should fill up the moment it recurves, as it will be coming under the influence of upper air convergence, prevailing in the northwest sector of a pure subtropical high.

6. Concluding remarks

We have mentioned in the foregoing a few aspects of the westerly waves appearing over the Indo-Pakistan region and their apparent interaction with the southwest monsoon in its advancing and retreating phases. The lack of surface and upper air data over Iran, Russian Turkistan, Tibet and China is keenly felt. Some of the ideas presented here require adequate data from these areas for their full justification. It is possible that complete upper air data from these areas, may call for modifications of some of the ideas presented in this paper, particularly those concerning the formation of "secondaries" and the advance, breaks, and withdrawal of the monsoon. Data from these areas may also enable us to know whether the formation of monsoon depressions in the north Bay of Bengal is associated with any fracture in the high over the Tibetan area, and the extension of trough lines of westerly troughs through the col area of the fracture into the north Bay of Bengal.

The interactions between the westerly troughs and the monsoon field outlined here are helpful only in the issue of short range forecasts of 24-28 hrs ahead; they are not of much value in the issue of medium range forecasts of five to seven days ahead. For this purpose, we should be in a position to anticipate the track and intensification of these westerly troughs in the Indian area. These we believe are intimately connected with the "general circulation" and its associated meandering jet streams in the northern hemisphere, which gets modified from time to time, most probably as a result of variations

in the energy supply occurring over areas distant from the Indian area. Whether we can get a clue about the trends in the tracks and intensities of these Western Disturbances by adopting methods similar to those adopted by U. S. Weather Bureau, in issuing their 5-day forecasts, can be found only by

actual application of those procedures over our area. It is also possible that the tracks and intensities of these Western Disturbances are influenced to an appreciable extent by the general circulation of the Southern Hemisphere, at least that part of it close to the equatorial latitudes.

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