STUDY OF AIR MASS CHARACTERISTICS OVER INDIA AND USE OF UPPER AIR DATA.

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Weather, to the present day meteorologists, depends largely on the character of the air mass present, and in a locality where two air masses are in juxtaposition, on the nature of the interaction between the two. An air mass is commonly defined as an extensive body of the earth's atmosphere whose physical properties approximate horizontal homogeneity at each level. What degree of approximation is allowable, up to what height in the atmosphere we have to look for such a homogeneity, and how extensive the body of the air is to be are points the answer to which will obviously depend upon the extent of detail to which one wishes to pursue the study of weather. For a broad geographical classification of air masses in connection with a general consideration of world climatology, the basis will naturally be very different from what has to be adopted if a detailed study of weather over restricted area is to be undertaken. With regard to the physical properties which one should consider in connection with the air mass study, it is found convenient to take into account such amongst them as are more truly characteristics of an air mass and are not affected materially by factors, such as, adiabatic changes, diurnal variation, etc. Potential temperature, wet bulb or saturation potential temperature, equivalent potential temperature, humidity mixing ratio at heights not too close to the ground are the more important amongst the conservative or quasi-conservative properties of an air mass.

In India, although the air mass method of analysis of synoptic charts, has been in use for a number of years, the cataloguing of the air masses in a form, generally acceptable to meteorologists in this country, has not yet been finalised. A tentative scheme of classification has been suggested by the writer of this note in a recent departmental publication [1] in which a list of the main air masses in various seasons, and also the regions where they usually occur have been given in Appendix I, while their associated climatological characteristics are described briefly in Appendix 2.

Broadly speaking, India's air masses are two in number, (1) the north-east or dry monsoon of the winter period, bringing air of continental origin with its source region in the vast anticyclonic system covering central and south-west Asia, and (2) the south-west or wet monsoon of the summer months, when maritime air originating in the sub-tropical high of the southern hemisphere dominates over the greater part of the Indian sub-continent. When subjected to a closer scrutiny, the characteristic properties of the air in the different parts of these two monsoon fields, however, show significant differences, and from the point of view of a detailed study of weather, a more elaborate classification of the air masses becomes necessary. In fact, there is no limit to the number of classes into which air masses of a country can be subdivided. For practical purposes a limit has however to be set, and the tentative classification proposed in the publication referred to may be considered

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[1] Ind. Met. Dept., Tech. Note No. 16, Air-Masses in India by A. K. Roy (1946).

to be sufficient for a general understanding of the weather features over different parts of India in the various seasons.

The main distinguishing characteristics of air masses are (1) thermal property of the air, i.e. its temperature or its derivative, viz., potential temperature, (2) water vapour content, i.e. the relative humidity or mixing ratio, and (3) the vertical distribution of these two elements on which depends the relative stability or otherwise of the atmosphere, a factor which is of very great significance in determining the character of weather which is to develop in an air mass. The consideration of the characteristic properties of the air at one particular level is not sufficient in connection with the study of air masses in relation to the weather associated with them, and what is needed is a full knowledge of the upper air data which alone can provide us with a complete picture of the air mass structure. For example, there may be two days in the month of February on which the air over South Bengal on the ground or, say, at 1,000 ft. may have identical properties with regard to temperature and humidity, as observed in the morning. Depending on the vertical distribution of temperature and humidity up to a height of some 4 or 5 km. (and also on other factors which we may not consider for the present), weather on one of these days may be characterized by the development of towering Cu and Cb clouds in afternoon, to be followed by heavy thundershowers in the late afternoon or evening, while on the other day the sky may remain clear or practically so during the whole day and all that may happen is fairly widespread fog or mist early in the following morning. Again, on a third occasion, with an air mass structure in its broad features similar to that on the second day, very little fog or mist may develop—the divergence in weather in the two instances having been due to differences in the lapse rates of temperature and in the rate of hydro-lapse in the layer up to some 500 or 1,000 ft. above ground. For a systematic study of air masses in relation to weather the collection of upper air data by regular soundings is, therefore, essential. Once such a classification has been completed, and the characteristic curves for each of the air masses have been drawn and the weather features associated with each have been suitably catalogued, one simple method of predicting in a general way the weather over a particular locality on one day would be to identify the air mass which happens to be present there on that day, by collecting necessary temperature and humidity data at heights up to some 5 or 6 km. The thermodynamical diagrams usually drawn in the India Meteorological Department are the D.B. and W.B. curves on a T-ϕ paper, with temperature and entropy (or logarithim of potential temperature) as the two coordinates. For purposes of air mass identification, it is more helpful to plot some of the derived quantities, such as, potential temperature and equivalent potential temperature, as on the (θ, θ_E) diagram of Rossby, or to draw Normand curves on the T-ϕ paper by joining the points corresponding to the level of condensation of the air at each height. In connection with the air mass classification by the writer, curves joining (θ_s, w), i.e. 'saturation potential temperature-humidity mixing ratio' points of the air at different heights have been found most useful, as these bring out the distinguishing features of the different air samples more prominently than the curves plotted on a T-ϕ diagram.

We shall now consider some of the main air masses in India during winter. An examination of the prevailing circulation shows that the usual air in the lower levels in this season is what originates from the cold anticyclonic source over Central Asia, and after flowing in more or less parallel streams across India, terminates in the cyclonic system south of the equator. At higher levels, the westerlies or northwesterlies of the temperate zone after circulating round the anticyclonic cells over and near India merge gradually with the prevailing equatorial easterlies. Considering the ultimate source, winter air mass over India is to be treated as the continental air of polar or subpolar origin, and according to the broad geographical classification should have the designation 'Polar Continental' (Pc). In course of its entry into India across the massive Himalayan barrier and as a result of its

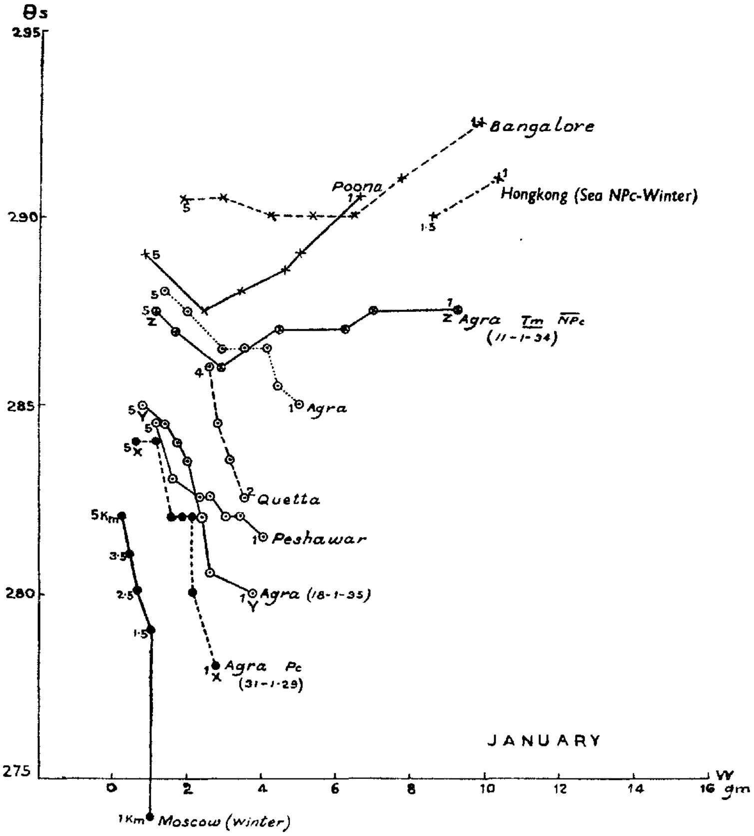

FIG. 1. Monthly mean (θ_S, w) curves for January for selected stations. XX represents Pc air, at Agra on 31-1-1929, while ZZ represents Tm NPc air over the same station on 11-1-34.

travel over increasingly heated surface further and further towards the south, the original polar air mass however undergoes important modifications and loses much of its source characteristics and, as such, the more appropriate designation for the air mass normally found over northern India in the winter is NPc, meaning 'Transitional Polar Continental' or PcTc, meaning Polar Continental air in the process of transition to Tropical Continental (Tc). The climatological features associated with this usual air mass over northern India are as below:—

'Cool days and cold nights. Low absolute humidity, but relative humidity at surface fairly high in the morning. Large diurnal range of temperature, about 30°F. in north-west India. Sky clear generally—occasional high clouds. Marked ground inversion during night and early morning, and morning mist or fog prevalent. Lapse rate during day 6° to 8°C./km. in the first 1 or 2 km. with a shallow isothermal or inversion layer above. Winds light to moderate. Visibility generally good.'

While flowing further southward into the Deccan, the South Peninsula and the neighbouring seas, this PcTc air undergoes yet further modifications in regard to its temperature, humidity and stability conditions, and has then to be given different designations. For example, the northern Indian air by the time it reaches the North Deccan acquires much of the characteristics of 'Tropical' air and is to be termed Tc. Also, when the PcTc air over a certain area in northern India stagnates for some time and then returns northwards under the influence of an approaching western disturbance it becomes Tc $\overline{\text{NPc}}$ air relating to the latter area. Similarly, the usual air over South Madras which is normally the land air across the central parts of the country, modified later by travel over the west Bay, may be termed Tc Tm. Occasionally, the air from these low latitudes, after acquiring a certain degree of maritime characteristics in the lower layers invades northern India under the influence of an active western disturbance, and we may have, for example, over the west U.P. on some occasions an air mass of the type $\underline{\text{Tm}}\ \overline{\text{Tc}}$ or $\underline{\text{Tm}}\ \overline{\text{NPc}}$, instead of the Pc Tc type which is normally present there. The weather features which would prevail over the area, when dominated by such an air mass would be substantially different from those associated with the Pc Tc, and be somewhat as follows:—

'Day temperature moderate, lower than that in Tc air but higher than that in Pc Tc. Night temperature distinctly higher, and diurnal range much less than normal, being of the order of 20°F. instead of the usual 30° to 35°F. Very shallow or no ground inversion during night and early morning. Stratification of air much less stable than in Pc Tc or Tc, and the lower layer up to 2 km. definitely unstable convectively. Sky expected to be partly covered with Sc, Cu clouds in morning. Large Cu and Cb clouds with scattered thundershowers in afternoon/evening.'

Fairly widespread thundershowers and/or squall type duststorms occur when such an air mass reaches northern India during late winter period.

A similar consideration of the air masses in India during the south-west monsoon months shows that, while the air which is normally found over India to the south of latitude 22°N. and over the Indian seas and Burma is the Equatorial Maritime (Em), the easterly branch of the monsoon which has its sway to the north and north-east of the seasonal trough of low is a much modified air, and has to be distinguished from the fresh Equatorial Maritime air mass. The designation EmT, meaning Equatorial Maritime in the process of transition to Tropical, has been suggested for this air mass. The usual air over the extreme north-western part of India to the west of the Indus is again of an altogether different origin and is to be treated as Tropical Continental (Tc). Besides these three, we also get at times in certain areas air masses of superposed types, consisting of one kind of air up to the first 1 or 2 km. and air of a different type at higher levels, e.g. $\underline{\text{Em}}\ \overline{\text{Tc}}$, which is frequently found over Lower Sind and South Rajputana, and $\underline{\text{Em}}\ \overline{\text{EmT}}$—a type of superposition which occurs in a marked manner over the central parts of the country during periods of activity of the seasonal trough under influence of depressions travelling from the Bay of Bengal. The weather features which prevail over an area when one or the other of these air masses are present show distinct differences in character, as has been illustrated by two examples in the case of two air masses of the winter season.

As has been mentioned above, identification of an air mass is greatly facilitated by the use of (θ_s, w) curves which can be prepared on the basis of data collected by upper air sounding at a station. Fig. 1 is added to illustrate the principle. In this are shown, monthly mean (θ_s, w) curves for January for a few selected stations, and also the characteristic curves of air over Agra on a few individual days in January. The character of the curve for 11-1-1934 is distinctly different from that of the curves for the other two dates, viz., 31-1-1929 and 18-1-1935; and these differences are well reflected on the types of weather which prevailed on the different occasions. For example, on 11-1-1934 the sky at Agra was overcast with St, Sc and Cb clouds, and there was general rain in the Punjab hills and local rain in the West U.P. On 18-1-1935, sky was clear at Agra and was so generally over north-west India. A comparison of the characteristic curves on the two dates shows that on 11-1-1934 the curve was more or less of the Bangalore type, while on 18-1-1935 it resembled the mean curve for Peshawar air, with somewhat lower θ_s and w values up to 2 km.

than what occurs normally at Peshawar, suggesting that the air over Agra on the day was probably of the Pc type for that station. For identification of air mass at a station by the use of characteristic curves of this type, a systematic sounding of the upper air by radiosonde or other methods is essential. Until recently daily upper air soundings were not available except at one or two stations in north-west India, and the identification of air masses had to be made from other considerations. The question whether any of the surface meteorological conditions could provide a clue to the nature of the air masses was looked into carefully. The conclusion of the writer is that if the identification is to be based on any single factor, the minimum temperature is the most representative element, except during the south-west monsoon and particularly in South India. Vapour pressure or dew point at the surface which is closely related the minimum temperature can also be used, but on the whole minimum temperature is more dependable. A careful study of the hydrometeors which provide indirect aerological information relating to a station is also useful, but none of these methods can be as satisfactory as the one based on actual sounding through the air mass under consideration. The radiosonde method of exploring the upper atmosphere has been brought into use in India during the last four years, and about fifteen stations are at present in regular operation. The upper air data so collected are of considerable value in air mass method of analysis of synoptic charts, and provide the necessary materials for the more recent methods of weather analysis, such as, isentropic and constant pressure analysis.

To be of maximum use, the accuracy of the data at present collected by radiosonde instruments has to be improved further. In a country like India, where the contrasts between air masses are usually much less marked than in Europe or America, we need a greater degree of accuracy than in extra-tropical latitudes. Accurate measurements of humidity is of utmost importance for a correct assessment of the stability or otherwise of the atmosphere, and an improvement in the present technique of humidity measurement in the upper air is essential. This point is engaging careful attention of the India Meteorological Department at present.