LATENT INSTABILITY IN THE ATMOSPHERE AND ITS CONSEQUE CES.

By N. K. Sur, *Meteorological Office, Poona.*

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In the absence of Dr. Sur, the President called upon Dr. R. Ananthakrishnan to read the paper on "Latent Instability in the Atmosphere and its Consequences".

Dr. Ananthakrishnan.—I am glad that the absence of Dr. Sur has given me an opportunity of partaking in the Symposium. Before proceeding to give an account of the consequences of latent instability described in the present paper, I shall briefly explain what the term latent instability means. This term was introduced in meteorology by Dr. Normand about seven years ago and it implies a state of the atmosphere in which the distribution of pressure, temperature and humidity is such that energy is latent in the atmosphere and can be released by certain simple natural processes which cause the adiabatic ascent of air from lower to higher levels of the atmosphere. The idea of latent instability can be best brought out with the aid of the tephigram.

Dr. Ananthakrishnan then explained the idea of latent instability with the aid of diagrams, after which he read the paper by Dr. Sur.

1.

In the daily weather charts prepared at the Meteorological Office at Poona, lines of flow of air currents in the upper levels above ground are drawn from day to day in conformity with the direction of upper winds measured at different pilot balloon stations in India and its neighbourhood, the velocities being made use of only when trajectories are drawn for more detailed study. These lines of flow at different levels serve to show the place of origin of the winds, i.e. they help to identify different air-masses. This is of use to the forecaster, as it gives him some idea about the nature of the phenomena which can possibly occur by the interaction of the different air-masses or stream lines. We have not yet been able to collect climatological data of the upper air all over India, but a few properties of some currents of air over India in different seasons are known from available data, and in other cases are inferred from their geographical origin. For example during winter in north India cold air from regions to the north of India sweeps over Sind, Rajputana, the central parts of India, the Gangetic valley and partly over the Deccan, and we know that it is a relatively dry air-mass giving fine clear weather. But when during winter a western disturbance affects north-west India, warm humid air from the Arabian sea is drawn towards that part of India, and comes in juxtaposition with the comparatively dry colder current. Low clouds gather over some parts of the affected region due to the flow of the humid air-mass, and rainfall may be forecasted either due to the ascent of the warmer humid air over the colder one along a warm front, or from thunderstorms along a cold front. The different currents in such extra-tropical depressions are generally identified by stream lines drawn on the charts, but data for temperature and humidity of the upper air may also be available for the north-west of India from aeroplane ascents. Similarly, when a forecast is issued for the rainfall and direction of movement of storms or depressions in the Bay of Bengal or the Arabian Sea, either in the pre- or post-monsoon seasons, or in the Bay during the monsoon season, it is based on the properties of air currents coming together to form such storms or depressions. Further, the possibility of the occurrence of thunderstorms and duststorms during summer in North India is also similarly inferred. In this note it is proposed to discuss briefly latent instability, which in India is found to be associated with all these phenomena.

2.

When a dry atmosphere is in convective equilibrium, the lapse rate of temperature is 9·8°C per kilometre, and entropy is constant throughout such an atmosphere. Usually however the lapse rate is about 6°C per km. and entropy increases with height, i.e. the layer of air having the greatest entropy is uppermost, with the layers of gradually decreasing entropy lying below in a sequence. But at any place such a condition is not constant throughout the year. Entropy may increase upwards from the ground in some seasons but decrease in others. For example, in Bengal, if we compare the wet bulb potential temperature, which is a measure of the entropy of moist air, at Darjiling (height=2·265 km.) with that at Jalpaiguri (height=·84 km.), on different dates chosen at random throughout a year, we find that during November–March the W.B.P.T. at Darjiling is greater than that at Jalpaiguri, while during April–October the reverse is the relation between the values of W.B.P.T. at the two places. This changed condition of the atmosphere is associated with instability during the summer and monsoon seasons.

The lapse rate of temperature in the atmosphere lies very often between those of dry and saturated adiabats. In such a case the stability or instability of the atmosphere is dependent upon relative humidity or on wet bulb temperatures. If humidity is sufficiently high in a layer or layers of air near the ground, it or these may become warmer than the environment, if raised to a suitable height, and therefore can release energy (vide fig. 1 T-ϕ gram.). A layer near A when raised up gradually, attains condensation point at H, and releases energy along JK. DF is the wet-bulb curve. Along JK the instability is manifested. To realise the energy given by the area JCK an amount of work equal to the area AHJ has to be spent on the layer at A. This type of instability has been called latent instability by Dr. Normand.[1]

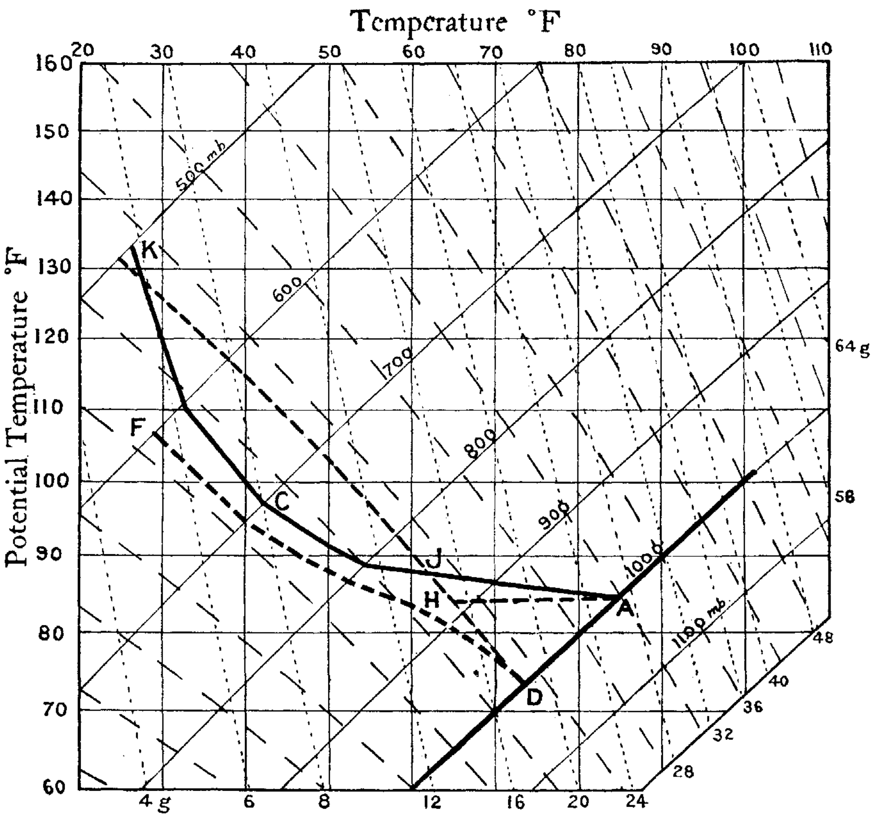

FIG. 1.

Prof. Rossby has defined a state of convective instability, in which the lapse rate of wet bulb temperature exceeds the wet adiabatic rate. For the atmosphere to have latent instability, the wet bulb potential temperature θ' at any level should exceed θ' at any higher level, and therefore it is always associated with convective instability as shown by Dr. Normand.[2] When a layer is pushed upwards adiabatically without vertical distortion, convective instability first produces latent instability, which in turn leads to instability.

With a given distribution of dry bulb temperatures in the layers of air above the ground as well as in the free atmosphere, and with a lapse rate of temperature between dry and wet adiabatics, the atmosphere may not have latent instability if the humidity is not sufficiently high.

As both the wet bulb potential and equivalent potential temperatures are measures of entropy, theoretically speaking, a decrease of E.P.T. with height is associated with convective instability; but it may or may not lead to latent instability. In India, it has been found that though E.P.T.s may decrease upwards from the ground within the first 2 or 3 km., there may be no latent instability in the atmosphere. On the other hand an increase of E.P.T. upwards within the same layers may be followed by a subsequent decrease of E.P.T. with latent instability in the atmosphere.

3.

The conditions under which latent instability is found to exist in the atmosphere in India will now be described.

From a recent study of the tephigrams of sounding balloon ascents at Agra, Poona and Hyderabad, Mr. Sohoni and Miss Paranjpe [3] have come to the conclusion that such a type of instability is frequently developed at these places with the incursion of oceanic air of tropical or equatorial origin. At Agra latent instability is found to occur frequently during the monsoon, pre- and post-monsoon seasons, whereas at Poona and Hyderabad mostly during July–September. It is much less common during winter, when continental air generally holds sway over India. Data from soundings are not available for north-east India except during April and May. In Bengal during these two months, when Nor'westers or thunderstorms are common, latent instability is produced by the incursion of humid air from the Bay of Bengal in the first 1 or 2 km. above ground, below the dry continental air from the north-west of India and occasionally from north-east of India also. Further, from a study of duststorms at Agra [4] it has been found that these occur frequently during March–June. The frequency is maximum in May and is only slightly smaller in June. These duststorms with the associated thunderstorms are invariably preceded by the development of latent instability in the atmosphere, which is therefore believed to be a necessary condition for these to occur, though it may not be a sufficient one. Here again there is an incursion of tropical oceanic air into the region of the continental air in the north-west of India. The injection of humid air in March, April and May mostly produces duststorms and dry thunderstorms, and in June when the proportion of moisture increases, due to the gradual penetration of the S.-W. monsoon current over north India, we get more thunderstorms than duststorms at Agra, accompanied with rainfall and preceded by a high degree of latent instability.

Similarly, from a study of squalls at Karachi [5] with the aid of aeroplane data, it has been found that the occurrence of squalls is on most occasions preceded by the development of latent instability.

4.

In the storms which form in the Indian Seas during the pre-monsoon and post-monsoon seasons, it has been found that two deep air-masses from different sources and hence with different properties come together before these storms can develop. One of these is of continental origin, the other oceanic, and the storms form on the diffuse boundary of these two. These storms, which do not have a symmetrical structure, have *sometimes* sharp fronts like those of an extra-tropical depression, and their direction of movement is believed to be the same as that of the warmer of the two air-masses between 4–8 km. These decay when the rich supply of water vapour is cut off. No sounding directly over the place of origin of such a storm is available, but it can be inferred that in such cases also latent instability is developed. For when two air-masses of different temperature and humidity flow past each other, horizontal instability is produced, as is known from the famous work of Margules. But the region of partition between two such air-masses, when one flows over the other, may also be an environment of a high degree of latent instability. This can be at once seen by plotting on a tephigram the average values of dry and wet bulb temperatures in July over Poona up to 3 km., representing the moist oceanic air, with the average Agra values above it, say up to 6 km., representing the continental air.

That such storms in the post-monsoon season may be associated with latent instability is supported by some evidence obtained in the field of a tropical cyclone.[6] On the 14th November 1933, a depression formed in the south-east of the Bay of Bengal, intensified into a storm on the 16th, and crossed the north Madras coast very near Nellore on the evening of the 17th. Some ascents were made at Madras and Poona during 15–20th November 1933. Unfortunately meteorographs let off at Madras on the evening of the 17th and on the morning of the 18th, when the centre of the storm was nearer than on any other day, were not recovered, but some information regarding latent instability in the free atmosphere over the neighbourhood of Madras has been obtained from those recovered. If the dry bulb and saturation temperatures at different heights, obtained from ascents at Madras during 15–19th November are plotted on tephigrams, the following interesting results are obtained:—

I. Denotes environment of latent instability, and
II. Layers of latent instability—

	I.	II.
15th (1716 hrs.)	Nil.	Nil.
16th (1800 hrs.)	From 460 to 310 mb. (very slight degree of latent instability).	Between 1000–720 mb.
17th (0404 hrs.)	From 800 to 170 mb.	Between 930–400 mb.
18th (1755 hrs.)	From 860 to 130 mb. (degree greater than on 17th).	Between 1000–920 mb.
19th (0400 hrs.)	No latent instability.	

It is quite clear that before the storm had affected Madras, and after it had moved away, there was no vertical instability of the latent type in the atmosphere over Madras. As it approached nearer to the place, latent instability increased gradually.

A storm in the post-monsoon season in the Arabian sea [7] may also be associated with latent instability. On the morning of 12th November 1927 a storm lay over the sea near Bombay in the south-west direction from it. Due to the storm there was a marked frontal discontinuity along a line from the centre of the storm right up to Allahabad. The discontinuity was strongly evident both in the direction and the force of the wind on the two sides of it, as well as in the type of rainfall, which extended over a belt of country 800 miles in length. The rain was caused by the ascent of warm south-easterly air from the Bay of Bengal over a north-easterly current of air. On the morning of the 13th November, the storm had crossed the Konkan Coast, and lay as a deep depression over the Bombay Deccan. Agra was far away from the centre of the depression, but an ascent on the 13th November at 1630 hrs. at Agra when it was drizzling there, shows an environment with a slight degree of latent instability between about 940–680 mb. levels, and layers of latent instability from the ground up to about 730 mb. The latent instability at Agra was in this case associated with a warm front with humid south-easterly air ascending over cold north-easterly air. The height of the warm front over Agra was about 2·8 km., and its intersection with the ground was at a distance of about 500 km. from Agra, so that its slope was about $\frac{1}{180}$.

5.

We now consider the depressions forming in the Bay of Bengal during the south-west monsoon season. A depression [8] formed on the 2nd September 1932 off the Orissa-Ganjam coast. It crossed the coast near Puri, and lay as a shallow low pressure area on the ground with its centre near Sambalpur on the morning of the 4th September. It intensified later and moved in a north-westerly direction. Its centre was near Guna in Central India both on the 6th and 7th September. It commenced to weaken on the 8th and moved past Nowgong through the southern divisions of the U.P. It disappeared by the morning of the 13th September, after persisting for a couple of days over Mainpuri near Agra in west U.P. Results of sounding balloon ascents at Agra on the 3rd, 5th, 6th, and 7th September are available. The following features regarding latent instability are noticeable:—

	I.	II.
3rd (1724 hrs.)	Nil.	Nil.
5th (1715 hrs.)	From 870–100 mb. (about).	Between 976–300 mb. (about).
6th (1720 hrs.)	From 900–100 mb. (about).	Between 978–350 mb. (about).
7th (1725 hrs.)	Practically nil, though relative humidity was 80% from ground to 6 gkm.	

It is clear that as the depression moved towards Agra, latent instability developed in the free atmosphere round about Agra, and it was wiped out when the depression weakened.

Another example of a depression during the S.-W. monsoon season developing latent instability in the region through which it passed is that of one with its centre near Puri [9] on the morning of 11th July 1937. The next morning it lay with its centre near Raipur in the Central Provinces, and on the morning of the 13th July it was over the west Central Provinces. It passed through Sambalpur in Orissa between the mornings of 11th and 12th July, and out of a number of meteorographs let off there during the passage of the depression, 4 have been recovered. These show the following features as regards latent instability:—

	I.	II.
12th (0200 hrs.)	From 840 to 400 mb. (about).	Between 980–430 mb. (about).
12th (1200 hrs.)	From 940 to above 350 mb.	Between 980–690 mb. (about) with the exception of layers between 900–835 mb.
12th (1413 hrs.)	From 920 to 810 mb. and from 750–above 350 mb.	Between 980–390 mb.
13th (0200 hrs.)	Above 500 mb.	Between 985–960 mb.

No record giving the condition of the atmosphere just before the depression approached Sambalpur is available. But it is clear from the data that there was latent instability to a marked degree in the atmosphere even just after the depression had passed away from Sambalpur; it diminished considerably on the 13th, when the depression moved further away. The reason of the increase in depth of layers with latent instability extending from 980 to 390 mb. at 1423 hrs. on the 12th as compared with those at 1200 hrs. on the same day is not clear.

6.

From the preceding discussion it would appear that latent instability should be a practically useful criterion not only for the forecasting of instability phenomena like thunderstorm and duststorm, but also of the region of rainfall along the path of depressions during all seasons in India. But this criterion can be usefully applied only if the means for its measurement from day to day be available. Aeroplane ascents and radio-sondes are the means to achieve this end. But quite a useful purpose can also be served by collecting climatological data of the upper air by the aid of soundings with Dines meteorographs. The results from these in conjunction with a knowledge of the trajectories of air currents on the daily weather charts will enable us to know the properties of different air currents in India in different seasons. This will greatly help in inferring the existence of latent instability or otherwise when two or more different streams of air are present in the upper levels over any place and therefore in forecasting the consequences of the existence of latent instability.

Attention may here be drawn to rather an important gap in our information regarding the development of latent instability in different seasons in

India. Though it is easy to see how latent instability can be produced by the injection of moist air in a mass of continental air, *e.g.* by the flow of air with properties of the S.-W. monsoon air during July at Poona extending, say, up to 2 or 3 km. above the ground below a mass of continental air, like the air over Agra in April above 2 or 3 km., it is not at all clear how in July or August the ascent of south-easterly monsoon air in the Gangetic valley represented by the air over Agra in August, above the south-westerly monsoon air from the Arabian sea represented by the air over Poona in July, can give rise to latent instability. For if the appropriate mean values of dry and wet bulb temperatures at different levels are plotted on a tephigram in the two cases respectively, latent instability is found to exist in the first case, but not in the second. It needs therefore further work to explain its development in the Gangetic valley or in Central India during the S.-W. monsoon season. Also, investigation is necessary to find the connection, if any, between the wet bulb temperatures prevailing in a given column of air having latent instability with the amount of rainfall from the column.

From an examination of about 250 sounding balloon records over Agra, Poona and Hyderabad (Deccan) and an analysis of the air-masses relating to each individual record by means of wind trajectories, Mr. Sohoni and Miss Paranjpe [3] have come to the conclusion that absence of latent instability is associated with dry fine weather with occasional high clouds of the non-convectional type, and latent instability with convective types of clouds like cumulus and cumulo-nimbus, or rain or thunder or thunderstorms. But it has been noticed that occasionally the existence of latent instability has not necessarily led to disturbed weather. Of course it is known that a suitable trigger is necessary to liberate the energy from the atmosphere having latent instability to produce a disturbance in weather, and the absence of a trigger may account for its non-occurrence. But it is not known whether in such cases, though few, the records of the upper air data are not open to doubt. If such occasions exist, a further examination of the data is necessary to find, if possible, the precise conditions under which the existence of latent instability may not result in disturbed weather.

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DISCUSSION.

The President: This paper is now open for discussion.

Dr. Ramanathan: During the approach of a storm, have the levels up to which latent instability extends and their variation in different phases of the storm been studied?

Dr. Ananthakrishnan: A complete quantitative study has not been made.

Dr. Roy: The temperature and the moisture content of an air-mass may be such that, although dynamically stable, it is thermodynamically unstable. The expression 'Latent Instability' is probably used by Dr. Normand in relation to such a thermodynamically unstable air-mass. Perhaps Dr. Normand will enlighten us on this point.

Mr. Basu: Latent instability, I suppose, means certain conditions in the air column irrespective of the structure. In this sense, latent instability is different from conditional instability of Rossby which is something associated with a single air-mass.

Dr. Ananthakrishnan: The term 'latent instability' merely denotes a certain vertical distribution of pressure, temperature and humidity such that the atmosphere under these conditions acts as a reservoir of latent energy, which is capable of being released by suitable means. It is not necessary to bring in the concept of air-masses to explain 'latent instability'.

Dr. Normand: It is preferable to consider each of the terms, latent, convective and conditional instability, as describing a vertical distribution of energy or entropy, irrespective of the air-masses that compose the vertical structure. If the energy of latent instability is due to one air-mass lying over another, its release tends to mix up or rearrange the masses, as in a Nor'wester.

Mr. P. R. K. Rao: In Mr. Sohoni's Memoir, latent instability was subdivided into real and pseudo-types. This division is necessary.

Dr. Ananthakrishnan: I do realise that it is; but it has not been attempted in the present paper.

Mr. Ramakrishnan: As regards quantitative study, it may be mentioned that, even at a glance, a rough idea of how significant the latent instability is can be had by seeing the thickness of the layer of latent instability and how close the environment of latent instability is to the layer. The larger the thickness of the layer, the greater the amount of energy and the nearer the environment to the layer, the easier it is to realise the energy.