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Growth of thunderstorm and latent instability over eastern India

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सार — कलकत्ता और दमदम से ऊपरी वायु परिज्ञप्ति के साथ पार्सल विधि द्वारा कलकत्ता में चंडवात सहित तड़ित्-झंझा दिनों के लिए गुप्त अस्थिरता की विद्यमानता का विश्लेषण किया गया है। इसमें देखा गया कि 250 मि. बार तक कुल ऊर्जा धनात्मक थी जो इस बात को सूचित करती थी कि तड़ित्-झंझा के लिए अस्थिरता एक आवश्यक अवस्था थी। पर्यावरण में संरोहण, वायुमंडलीय कर्षण और प्रतिकारी अधोमुखी गति पर विचार नहीं किया गया। पवन अपरूपण के वेगालेख संवहन के कारण पाये गये। पार्सल के उत्थापक संघनित स्तर, मुक्त संवहन के स्तर और तापमान प्रोफाइलस का आकलन किया गया। इस शोधपत्र में उन पर विचार विमर्श किया गया है।

ABSTRACT. The existence of latent instability has been analysed for thunderstorm days accompanied by squall in Calcutta by the parcel method with upper air soundings from Calcutta and Dum Dum. It was found that the total energy up to 250 mb was positive, implying that instability was a necessary condition for thunderstorms. In this analysis entrainment, atmospheric drag and the compensating downward motion in the environment were not considered. The hodographs of wind shear were found to be due to advection. The lifting condensation level, level of free convection and the temperature profiles of the parcel were calculated. They have been discussed in the paper.

1. Introduction

In earlier years latent instability could be inferred from a thermodynamic diagram, such as, a tephigram. This can be now done much faster on a computer.

Prosser & Foster (1966) devised a method, which is much faster, by using a computer. The principles are similar to the Showalter (1953) index. Showalter's stability index is obtained by lifting a parcel of air from some specified base level (850 mb for stations with elevation less than 1.0 km) dry adiabatically to its lifting condensation level (LCL). Subsequently the rising parcel of air is assumed to ascend along a saturated adiabat to 500 mb. The temperature, thus, derived at 500 mb is then subtracted from the observed temperature at 500 mb. The temperature difference is referred to as Showalter's stability index. Large negative values of the index (—3 or less) favour severe thunderstorms.

In the present paper we have used the parcel method but we did not calculate the stability index or the lifting index. We preferred to calculate the total energy of the parcel up to 300 mb (or up to 250 mb level when data were absent), the height of the level of free convection (LFC) and the lifting condensation level (LCL). The temperature and pressure at these levels were computed by numerical integration. An expression for the static energy was used to determine the parcel temperature and specific humidity at all intermediate levels from the surface to 300 mb. We used the temperature and the dew-point at standard pressures, and interpolated the values at intermediate levels. The parcel was lifted from the surface, first dry adiabatically and then moist adiabatically from the LCL. The specific humidity and saturation specific humidity were calculated by Tetens (1930) formula. We used both the 00 GMT & 12 GMT data from Calcutta and Dum Dum.

2. Governing equations

The static energy of an unsaturated parcel of air :

$$E = c_p\, T + gZ + Lq_p \tag{2.1}$$

where, c_p stands for the specific heat at constant pressure, T is the temperature of the rising air, g stands for the acceleration due to gravity, Z is the altitude, q_p refers to the specific humidity and L is the latent heat of condensation.

The specific humidity is expressed by :

$$q_p = 0.622\ e_p/(p - 0.378\, e_p) \tag{2.2}$$

The saturation vapour pressure e_p at the dew-point temprature T_d is obtained by using Tetens (1930) formula :

$$e_p = 6.11 \exp \{a\ (T_d - 273.16)/(T_d - b)\},$$

$a = 17.26$ for water and 21.87 for ice and

$b = 35.86$ for water and 7.66 for ice.

TABLE 1

Results with 00 GMT data

Date (1970)	IST of the squall (hr)	K.E. up to 300/250 mb ($m^2/s^2/g$)	LCL T (°K)	LCL Z (gpm)	LCL p (mb)	LFC T (°K)	LFC Z gpm)
2 Apr	2158-2201	736.582	292.084	527.073	943	283.814	2376.29
10 Apr	1539-1542	1252.91	296.834	137.723	992	289.482	1926.18
18 May	2300-2315	1893.26	300.880	132.500	984	300.880	132.500
22 May	1648-1650	784.135	296.834	138.137	989	291.146	1532.42
3 Jun	1359-1408	469.274	296.832	138.694	985	287.550	2383.48
19 Jun	1825-1830	1526.16	299.586	267.143	966	297.714	762.013
20 Jun	1943-1950	1338.86	299.590	266.871	967	299.144	1689.87
21 Jun	0003-0020	293.589	295.589	271.124	968	286.900	2327.72
28 Jun	1610-1630	1511.92	299.596	266.330	969	—	—
22 Jul	1735-1745	1161.00	297.818	139.439	983	296.158	561.849
24 Jul	1938-2003	1365.44	298.604	265.179	970	296.406	836.351
29 Jul	1345-1356 1454-1505	918.828	298.160	0.0	1000	294.100	1012.99
12 Nov	1032-1045	213.341	294.160	0.0	1006	293.642	112.209

TABLE 2

Results with 1200 GMT data

Date (1970)	IST of the squall (hr)	K.E. up to 300/250 mb ($m^2/s^2/g$)	LCL T (°K)	LCL Z (gpm)	LCL p (mb)	LFC T (°K)	LFC Z (gpm)
2 Apr	2158-2201	399.493	289.102	1043.87	884	281.188	2746.96
10 Apr	1539-1542	432.586	282.218	2585.42	726	280.216	2997.33
18 May	2300-2315	1472.77	296.472	797.802	908	—	—
22 May	1648-1650	855.722	292.542	1309.24	854	290.728	1749.18
3 Jun	1359-1408	1317.55	298.016	534.000	935	297.574	647.598
19 Jun	1825-1830	1722.46	298.476	797.393	905	298.442	806.383
20 Jun	1943-1950	2230.45	300.750	664.903	921	299.870	908.353
21 Jun	0005-0020	1233.51	296.76	664.347	921	—	—
28 Jun	1610-1630	1209.91	298.808	139.903	983	294.462	1257.95
22 Jul	1735-1745	1736.95	299.88	132.999	977	—	—
24 Jul	1938-2003	1313.02	296.22	928.027	892	—	—
29 Jul	1345-1366 1454-1505	1687.40	299.684	267.415	965	—	—
12 Nov	1032-1045	444.993	293.834	137.433	984	293.494	219.159

We also have q_{sp}, the saturation specific humidity, which is expressed by :

$$q_{sp} = 0.622\, e_{sp} / (p - 0.378\, e_{sp}) \tag{2.3}$$

where e_{sp}, the saturation vapour pressure for temperature T is given by :

$$e_{sp} = 6.11 \exp \{ a (T - 273.16) / (T - b) \}$$

If T, T_d and p are known q_p and q_{sp} can be calculated.

The height Z_2, ascended by the parcel from Z_1 is given by :

$$Z_2 = Z_1 + R/g\, T_m \,.\, \ln \frac{p_1}{p_2} \tag{2.4}$$

where, T_m is the mean temperature of the parcel between the levels Z_1 and Z_2, and p_1, p_2 are pressures at Z_1 & Z_2 respectively $(p_1 > p_2)$.

The vertical acceleration for a non-entraining parcel is :

$$\frac{dw}{dt} = g \left(\frac{T_v - T_{ve}}{T_{ve}} \right) = gB,$$

where, T_v, T_{ve} are virtual temperatures of the parcel and environment respectively at any level and B is the buoyancy factor.

The kinetic energy of the parcel up to Z_2 is given by :

$$\tfrac{1}{2} w_2^2 = \tfrac{1}{2} w_1^2 + g \int_{Z_1}^{Z_2} B(Z)\, dZ \tag{2.5a}$$

Initially we put $w_1 = 0$ at the surface, whence

$$\tfrac{1}{2} w_2^2 = g \int_{Z_1}^{Z_2} B(Z)\, dZ \tag{2.5b}$$

This was evaluated numerically.

The virtual temperature is :

$$T_v = T\,(1 + 0.61\, Q) \tag{2.6}$$

where, Q is the specific humidity.

When, $T_v = T_{ve}$, Q=specific humidity for environment$=q_e$

$T_v = T_v$, Q=specific humidity of the parcel $= q_p$,

At the surface $q_e = q_p$.

2.1. *List of symbols used*

E Static energy.

c_p Specific heat at constant pressure.

T Dry-bulb temperature.

T_d Dew-point temperature.

g Acceleration due to gravity.

Z Altitude.

L Latent heat of condensation.

q_p Specific humidity.

q_{sp} Saturation specific humidity.

q_e Specific humidity of the environment.

e_p Saturation vapour pressure at dew-point.

e_{sp} Saturation vapour pressure at dry-bulb temperature.

T_v Virtual temperature of the parcel of air.

T_{ve} Virtual temperature of the environment.

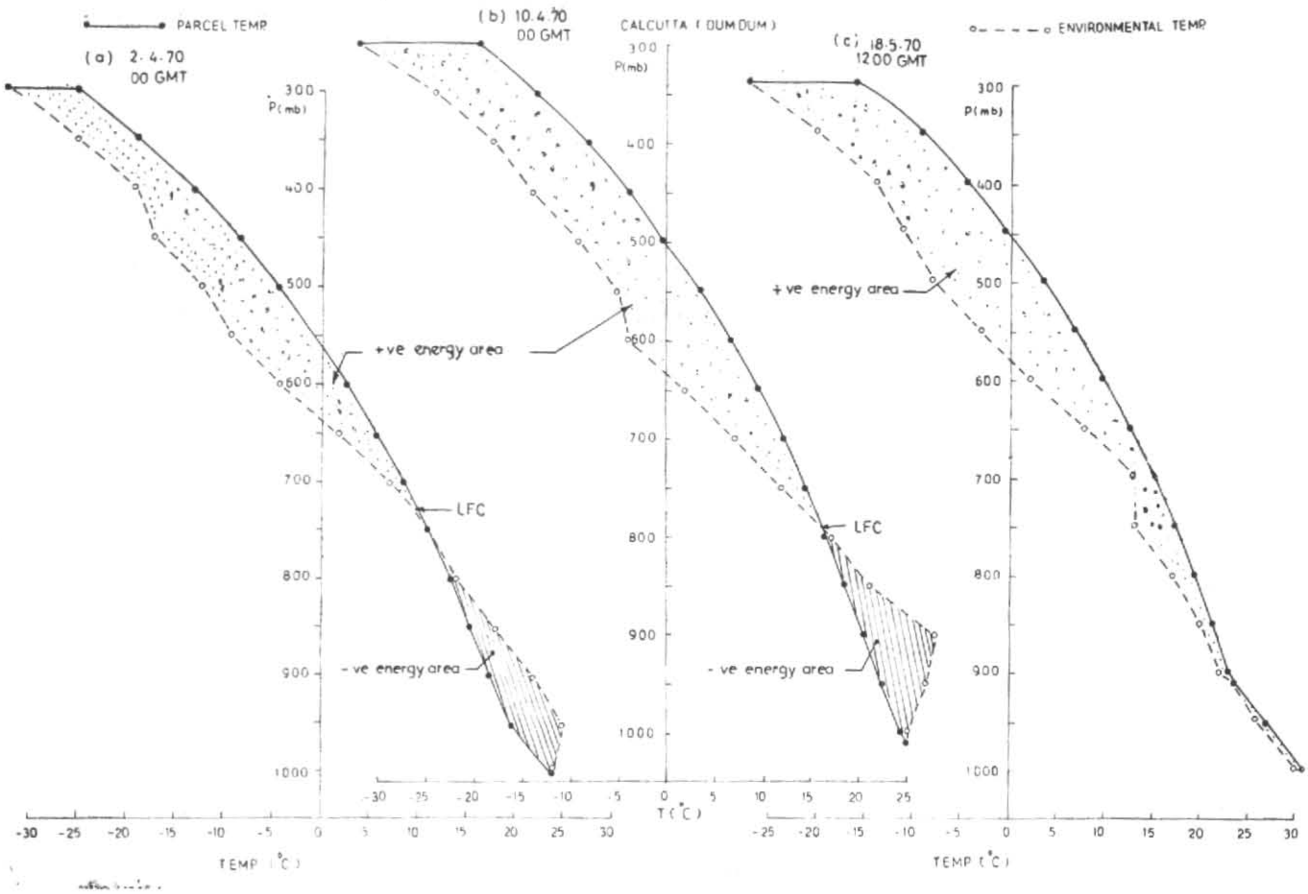
B Buoyancy factor.

w Vertical acceleration of the parcel of air.

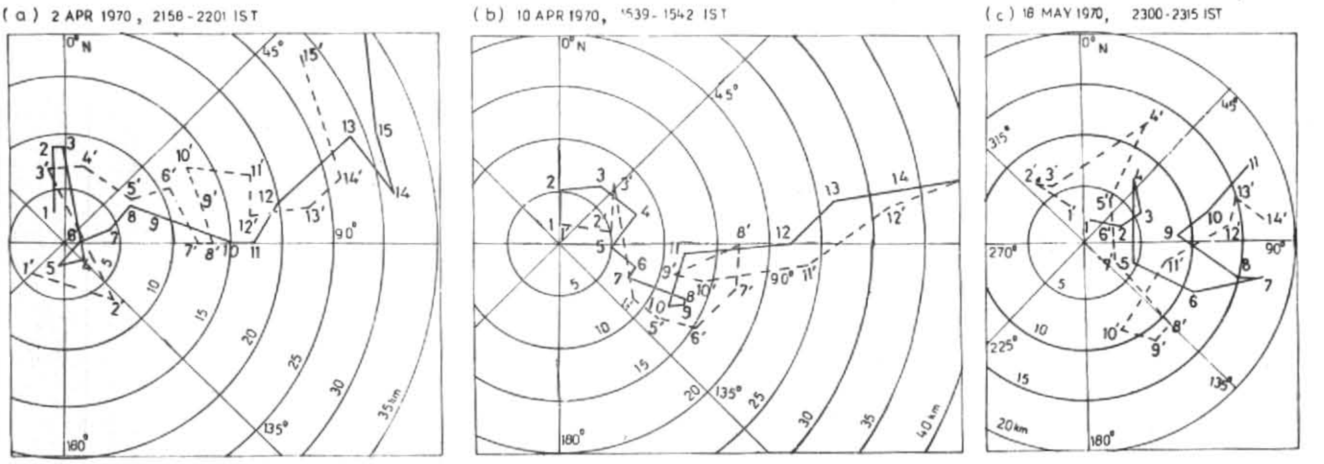
T_m Mean temperature of the parcel of air between any two levels.

3. Numerical simulation

We are provided the dry-bulb and dew-point temperature at different pressures. Consider a parcel of air having the same temperature as that of the environment at the surface. We can calculate the specific humidity and saturation specific humidity from (2.2) and (2.3). They are the same for the parcel and the environment at the surface. If the parcel is not saturated, *i.e.*, if, $q_p < q_{sp}$, it is raised dry adiabatically by assuming the conservation of static energy. In calculating the temperature of the parcel at the higher level, we first choose a hypothetical lapse rate which is much greater than the observed environmental lapse rate, and then adjust the temperature so that the static energies of the parcel at these levels (lower and higher) become equal. Thus the temperature of the rising parcel at the higher level is obtained. Subsequently, the saturation specific humidity q_{sp} of the parcel is computed again with (2.3). During the dry adiabatic phase the moisture content of the rising parcel remains unchanged so q_p does not change, but q_{sp} decreases with fall of dry-bulb temperature of the parcel. Now, the virtual temperature of the parcel T_v as well as that for the environment T_{ve} are calculated by (2.6) which require the values of q_p and q_e. q_p is calculated at the beginning, q_e is calculated by Lagrange interpolation from the given data. After calculating T_v and T_{ve}, B is calculated. Thus the kinetic energy of the parcel at the higher level is obtained. If $q_p < q_{sp}$ at this level, the parcel is still unsaturated. The parcel is again raised and its kinetic energy and q_{sp} are calculated and so on. As soon as $q_p = q_{sp}$, the parcel becomes saturated and it is raised moist adiabatically, that is, we calculate q_{sp} in place of q_p in (2.1) which is a function of temperature. The process is continued up to 300 mb or 250 mb as the case may be, and thus the total energy of the parcel is obtained. Initially, the energy is negative since work is being done by the parcel on environment (*i.e.*, the parcel is colder than environment). But, after crossing the LFC level (if it does exist) the energy is positive, that is, work is being done on the parcel to increase its kinetic energy. This means that the parcel is rarer (warmer) than the environment. We have also calculated the levels LCL where, $q_p = q_{sp}$, LFC where $q_p = q_e$ and the temperature profile of the parcel.



Figs. 1 (a-c). Observed temperature profiles of the environment and calculated temperature profiles of the parcel on (a) 2 Apr 1970 (00 GMT), (b) 10 Apr 1970 (00 GMT) and (c) 18 May 1970 (12 GMT)



Figs. 2(a-c). Hodographs on 2 & 10 Apr and 18 May 1970 with upper air soundings from Calcutta (Dum Dum). The solid lines are those at 00 GMT & dashed lines are those at 12 GMT. Wind speed (m/s) is along the vertical, Nos. 1, 2, ..., & 1′, 2′ ....,etc denote the subsequent pressure levels (from surface) at 00 GMT and 12 GMT

4. Numerical results

The numerical results are given in Table 1 and Table 2. We have calculated the temperature profiles of the parcel at each pressure level using both the 00 GMT and 12 GMT soundings.

In Figs. 1(a-c) the calculated temperature profiles of the parcel are plotted only at different pressures with the observed temperature profiles of the environment on 2 & 10 April and 18 May 1970. In every case, the positive area is greater than that of negative area, that is, the total energy is positive which indicates instability. We have found similar results for other days. This is also indicated by the computed values of kinetic energy in Tables 1 and 2.

5. Hodograph analyses

We observed the following from the hodographs of thunderstorm days :

(*i*) Warm air advection in the lower part of the atmosphere, a few hours before the storm (*i.e.,* veering of wind with height below 4 km).

(*ii*) Cold air advection (backing of wind) in the upper part (above 5 km) of the atmosphere a few hours before the storm.

(*iii*) The intensity of the storm increases with an increase of veering with height.

(*iv*) The wind speed is less than 15 m/s in the lower troposphere (less than 4 km), but could increase up to 45 m/s in the upper troposphere.

In Figs. 2(a-c) the hodographs on 2 April & 10 April and 18 May 1970 are shown for 00 GMT & 12 GMT. The hodographs of the wind speed before the onset of the storm [2 April (12 GMT), 10 April (00 GMT), 18 May 1970 (12 GMT)] agree with our observations stated in (*i*), (*ii*) and (*iii*).

6. Conclusions

The main conclusions of our study may be summarised as follows :

(*i*) On thunderstorm days accompanied by squall, the energy is always positive, *i.e.,* there is always latent instability.

(*ii*) The degree of instability depends upon :

(*a*) The surface temperature,

(*b*) Surface dew-point and

(*c*) The temperature and dew-point profile of the environment.

If the difference between the surface temperature and dew-point is small, and the dew-point is large (*i.e.,* the environment is humid), the LCL is low (little water vapour is necessary to saturate the ascending parcel), the LFC is low and positive energy is large and *vice versa.*

If the difference between surface temperature and dew-point temperature is small, the temperature at the surface is high. The temperature as well as the dew-point of the environment falls rapidly with height T_v-T_{ve} is always large, $q_{sp}>q_e$ and the positive energy area is large.

(*iii*) The intensity is minimized when the storm is over.

(*iv*) The LCL depends on the environmental humidity profile.

(*v*) The LFC is always below 3 km in the troposphere.

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