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Potential convective instability analysis on squall days at Calcutta

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सार — कलकत्ता में, चंडवात के साथ आए तड़ित् झंझा के दिनों की विभव संवहनी अस्थिरता का विश्लेषण किया गया है। यह विश्लेषण कलकत्ता में चंडवात के दिनों में विभव संवहनी अस्थिरता की उपस्थिति को दर्शाता है। प्रेक्षित चंडवात गतियों और सतह दाब परिवर्तनों के मध्य कुछ सहसंबंध भी पाए गए हैं। अधोप्रवाह की परिकलित ऊर्ध्वाधर गतियों और प्रेक्षित चंडवात गतियों के मध्य भी कुछ समाश्रयण पाए गए हैं। इस अध्ययन में कलकत्ता में, चंडवात सहित 13 दिनों में 00 ग्री. मा. स. और 12 ग्री. मा. स. दोनों समय के उपरि पवन सांउडिग का प्रयोग किया गया है। यहां पर इन्ट्रेनमेंट, वायुमंडलीय पश्चकर्षण, पर्यावरण में प्रेरित क्षतिपूरक निम्नमुखी गति जैसे कारकों पर विचार नहीं किया गया है।

ABSTRACT. The potential convective instability has been analysed for thunderstorm days accompanied by squalls at Calcutta. The analysis shows the existence of potential convective instability at Calcutta on squall days. Some correlation is also found between observed squall speeds and the surface pressure changes. There is also some regression between the calculated vertical speeds of the downdrafts and the observed squall speeds. The upper air soundings both at 00 GMT and 12 GMT on 13 days with squalls at Calcutta have been used in this study. Here the factors like entrainment, atmospheric drag, compensating downward motion induced in the environment have not been taken into account.

1. Introduction

In thermodynamic analysis of the atmopshere, the widely used thermodynamic parameters are the equivalent potential temperature (θ_e) and the moist static energy (E_s). The mean vertical distribution of E_s for the equatorial trough was presented by Riehl and Malkus (1958). With the aid of this profile, the buoyancy in the core of cumulonimbus, at selected levels can be calculated, permitting a parcel ascent under the condition of conservation of E_s from subcloud layer to the upper troposphere. This process is an estimation of the limit of penetrative convection in the equatorial trough. Similar estimation, using the total specific energy profile of the environment was carried out by Darkow (1968). The tornado proximity sounding was checked. It shows higher total energy values in the lower troposphere and lower values in the middle troposphere. The severe storm forecasting is given in term of a "Total Energy Index". It indicates not only the energy release associated with the ascending potentially warm air but also the possible contribution to the penetrative downdraft. The vertical profiles of θ_e (Rossby 1932), would yield similar results.

A comparison of the equivalent potential temperature and static energy was made by Madden and Robitailie (1970), Betts (1974). From their work it is clear that θ_e is exactly conserved during thermodynamic process but E_s is only approximately conserved. In using E_s the implicit assumption is made that the kinetic energy term is very small as compared to the other terms.

In the present paper, the wet bulb potential temperature of the environment have been calculated at different mandatory pressure levels. These have been used directly for analysing the potential convective instability of the atmosphere. The maximum available kinetic energy of the penetrative downdraft has been calculated by using parcel method, which has been cooled by evaporation of liquid water to its wet bulb temperature.

2. Basic formulation for calculation of thermodynamic variables

If T_w, θ_w and θ_{sw} are the wet-bulb, wet-bulb potential temperature and Pseudo-wet-bulb potential temperatures respectively of a layer of atmosphere, then there will be potential convective instability if

$$\frac{\partial \theta_{sw}}{\partial z} < 0 \quad \text{or} \quad \frac{\partial \theta_w}{\partial z} < 0$$

with sufficient accuracy.

The static energy of a parcel of air is given by :

$$E_s = c_p T + gZ + Lq_p$$

where the symbols have their usual meaning and

q_p = Specific humidity of a parcel of air

$$= f(T_d, p) \tag{1}$$

where T_d is the dew-point temperature and p is the pressure. Similarly,

q_{sp}=Saturation specific humidity at temperature T

$$= f(T, p) \tag{2}$$

The function :

$$f(T, p) = \frac{0.622\, e_s}{(p - 0.37\, e_s)} \tag{3}$$

where,

$$e_s = 6.11 \exp\left[\frac{a(T - 273.16)}{T - b}\right]$$

the values of $a = 17.26$ and $b = 35.86$ for water phase.

The height above the surface of a parcel descending downward is :

$$Z_1 = Z_2 - \frac{R}{g} T_m \log_e \left(\frac{p_1}{p_2}\right) \;;\; Z_1 < Z_2 \tag{4}$$

where T_m is the mean temperature between Z_1 and Z_2. The downward acceleration for a non-entraining parcel is :

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

where T_{wv}, T_{ve} are virtual temperatures of a parcel, cooled to its wet bulb temperature and that of the environment respectively. The total kinetic energy of the parcel upto the surface is given by :

$$\tfrac{1}{2}w_1^2 = \tfrac{1}{2}w_2^2 + g\int_{z_1}^{z_2} B(z)\, dz$$

Initially $w_2 = 0$, therefore,

$$\tfrac{1}{2}w_1^2 = g\int_{0}^{z_2} B(z)\, dz \tag{5}$$

This integral is discretized and evaluated by summation for each layer.

The virtual temperature :

$$T_v = T(1 + 0.61\, q) \tag{6}$$

For the environment the virtual temperature is T_{ve} and specific humidity q_e, and for the parcel the virtual temperature is T_{wv} and specific humidity q_p.

3. Computational scheme

The following steps are followed for the evaluation of the potential convective instability :

(*i*) The temperature, dew-point temperature profiles for the environment, at the mandatory pressure levels and at the surface are given.

(*ii*) Find the wet bulb temperature T_u at every pressure level.

(*iii*) Find the wet bulb temperature T_w at every pressure level for the entire environmental profile.

(*iv*) Find the wet bulb potential temperature θ_w corresponding to each pressure level of the environment.

(*v*) Find the minimum $\theta_{w\min}$ of all θ_w except that at the surface which is θ_{w1} .

(*vi*) If $\theta_{w\min} < \theta_{w1}$ there is potential convective instability.

(*vii*) We take T_w and pressure corresponding to the level of $\theta_{w\min}$ and bring a parcel evaporatively cooled to its saturation T_w moist adiabatically up to the surface. Then using the Eqns. (5) and (6) calculate the energy of the downdraft. We take the $\theta_{w\min}$ level because the downdraft developing from that level will have the maximum kinetic energy, hence the maximum vertical speed. In these calculations no viscous forces dissipating the energy and reducing the velocity of downdraft have not been taken into account. A much bigger factor of entrainment of the surrounding air with near zero vertical velocity has also not been taken into account. The values of energy and the vertical velocity are, therefore, unrealistically large.

The computational procedure followed for evaluation of the thermodynamic variables mentioned above are detailed below :

(a) *Numerical computation of T_w*

Let us consider any pressure level p where temperature T and dew point temperature T_d are known. Specific humidity, (q_p) and saturation specific humidity (q_{sp}) are calculated using Eqns. (1) and (2). If the parcel is saturated T is same as T_w. Otherwise, increase q_p by a small amount δq_p to be suitably choosen, *i.e.*, evaporation of δq_p liquid water and consequent cooling. Then the new temperature T' :

$$T' = T - (\delta q_p L)/c_p$$

is obtained after evaporative cooling. Changed specific humidity :

$$q' = q_p - \delta q_p$$

if

$$q' < q_{sp}(T')$$

TABLE 1

Maximum wind speed reached and the associated pressure changes in squalls

Date (1970)	Time (IST)	Pressure change (mb)	Max. wind speed (kmph)
2 Apr	2158-2201	+2.7	58
10 Apr	1539-1542	+1.0	50
18 May	2300-2315	+1.9	71
22 May	1648-1650	+1.0	50
3 Jun	1359-1408	0.0	54
19 Jun	1825-1836	+0.5	52
20 Jun	1943-1950	+1.5	74
21 Jun	0005-0020	+1.2	60
28 Jun	1610-1630	+1.7	53
22 Jul	1735-1745	+0.1	46
24 Jul	1938-2003	+1.0	68
29 Jul	1345-1356	0.0	54

the process is continued until,

$$q' = q_{sp}(T')$$

Then $T_w' = T_w$, the required wet bulb temperature.

(b) *Numerical computation of θ_w.*

We bring the saturated parcel of air from that level p up to to 1000 mb moist adiabatically and the temperature attained will be θ_w. For doing this, moist static energy is conserved for the descending parcel. The parcel is brought down and its pressure increased by a small amount. It will warm up slightly. This temperature is assumed initially and it is iteratively improved to keep the moist static energy constant, meanwhile keeping the parcel continuously saturated. Once the temperature is numerically obtained, the parcel is again brought down by a small distance and the process is repeated until we reach 1000 mb level. The temperature obtained on reaching 1000 mb in this manner is the θ_w.

For doing the above mentioned computations a computer program in FORTRAN was written debugged and used for all the computations of T_w, θ_w, heights, energy and vertical velocity etc.

4. Results of the study and discussions

The upper air data for 13 days in 1970, when squall was experienced, were collected. The intensity of the squall and the associated changes in surface pressure are given in Table 1.

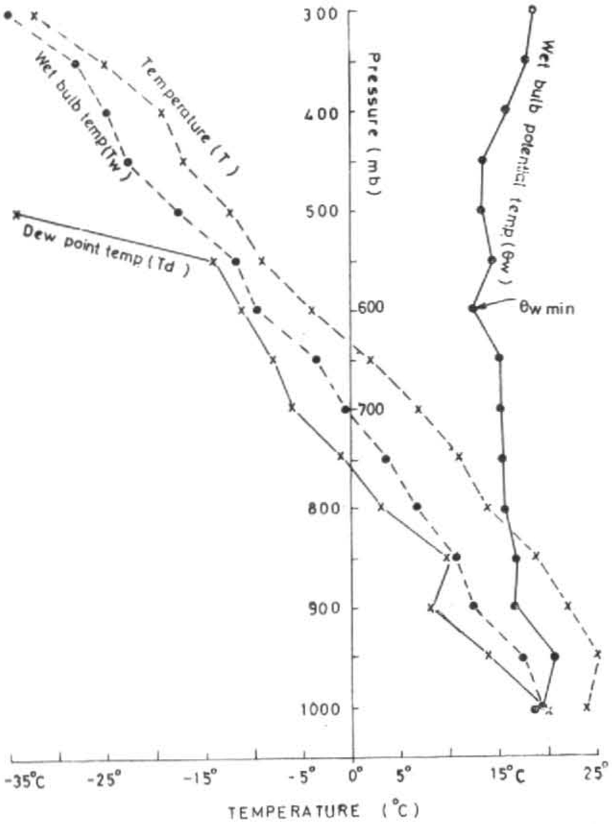

Fig. 1. The profiles of T, T_d, θ_w and T_w for 00 GMT of 2 Apr 1970 at Calcutta

On the days of squalls the upper air data for 00 GMT and 12 GMT were analysed and computations were made for the potential convective instability. The values of the parameters calculated are given in Table 2.

The profiles of T, T_d, θ_w and T_w for 00 GMT of 2 April 1970 at Calcutta are given as a sample in Fig. 1.

In case of potential convective instability the environment if cooled by evaporation of falling rain causes downdrafts. This cooling should basically increase the surface pressure. A scatter diagram between the pressure rise at the squall time and the squall speed is given in Fig. 2. Although the scatter of the points is large, but nevertheless it shows that pressure rise and the speed of the squall have some correlation.

As mentioned earlier viscous forces and the entrainment are not considered in computations, therefore, the vertical velocities are unrealistically large. The downdrafts normally get diluted by entraining environmental air. Therefore, the speed of downdrafts will be inversely proportional to the entrainment. The amount of entrainment will be proportional to the vertical descent, therefore, downdraft will be inversely proportional to the vertical descent. To obtain an approximate measure of the estimated downdrafts the computed vertical velocities have been divided by the amount of vertical descent. This will be a rough measure of downdraft

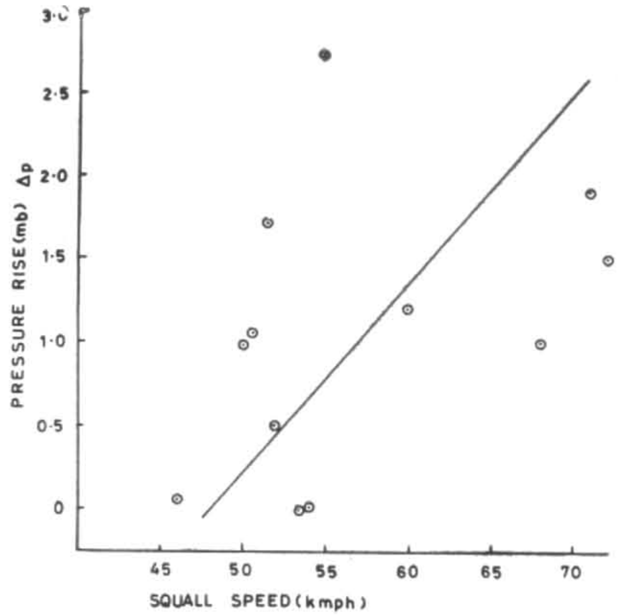

Fig. 2. Scatter diagram between the pressure rise at squall time and the squall speed

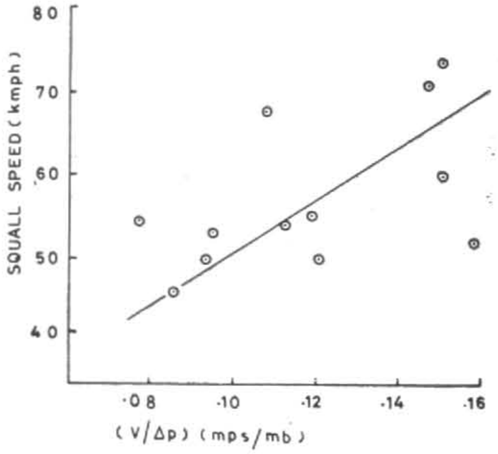

Fig. 3. Scatter diagram between calculated approximate downdraft and the squall strength

TABLE 2

Total energy and computed downdraft and the level of maximum potential convective energy

Date (1970)	00 GMT			12 GMT		
	Pressure level (mb)	Energy available ($m^2/s^2/g$)	Vertical velocity (m/s)	Pressure level (mb)	Energy available ($m^2/s^2/g$)	Vertical velocity (m/s)
2 Apr	600	1209.67	49.2	650	868.67	41.7
10 Apr	550	1470.92	54.2	600	1467.77	54.2
18 May	550	1579.98	56.2	700	972.35	44.1
22 May	550	1210.80	49.2	500	1071.58	46.3
3 Jun	650	635.65	35.7	450	1138.74	47.7
19 Jun	500	1058.66	46.0	700	1117.52	47.7
20 Jun	650	1013.79	45.0	650	1382.03	52.6
21 Jun	650	953.31	43.7	600	653.76	36.2
28 Jun	500	1122.15	47.4	500	963.68	43.9
22 Jul	650	439.42	29.6	600	544.74	33.0
24 Jul	700	604.48	34.8	650	717.87	37.9
29 Jul	400	1054.60	45.9	550	665.42	36.5
12 Nov	650	368.71	27.2	600	799.05	40.0

taking into account entrainment in a very crude way. A scatter diagram between these values and the actual squall strength values are given in Fig. 3. The visual inspection suggests a regression as given in the figure. This suggests that potential convective instability is an important component of the total instability present on the days on which squalls are experiened at Calcutta.

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References

Betts, A.K., 1974, Further comments on "A comparison of the equivalent potential temperature & static energy", *J. atmos. Sci.*, **31**, 1713-1715.

Darkow, G. L., 1968, "The total energy environment of severe storms", *J. appl. Met.*, **7**, 199-205.

Kessler, E., 1985, *Thunderstorm Morphology & Dynamics*, Second Edition, University of Oklahoma Press, Norman & London.

Madden, R.A. and Robitailie, F.E., 1970, "A comparison of the equivalent potential temperature & the static energy", *J. atmos. Sci.*, **27**, 327-329.

Riehl, H. and Malkus, J.S., 1958, "On the heat balance in the equatorial trough zone", *Geophysica*, **6**, 505-535.

Rossby, C.G., 1932, *Thermodynamics applied to air mass analysis*, MIT Meteor. Papers, **1**, No. 3, 48 pp.