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Lag coefficient of Bimetal Thermometer of Chronometric type Radiosonde (Model 2)

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ABSTRACT. The lag coefficient of the bimetal thermometer element as used in chronometric radiosonde of the India Meteorological Department has been calculated with the help of the difference in temperatures obtained from a radiosonde during its ascent and descent. The average lag in the recorded temperature has also been calculated.

1. Introduction

The temperature-element of the chronometric radiosonde (Mathur 1948) consists of a steel-invar bimetal strip in the form of a spiral. One end of the spiral is attached to a metallic frame and the other carries a pointer. This instrument is exposed to the air-current during its ascent and the magnitude of opening or closing of the spiral with changes in temperature gives the value of the air temperature itself.

The temperature measurements obtained from the instrument are subject to a few errors enumerated below.

(*i*) There is a lag between the recorded temperature and the true temperature of the surrounding air. This slackness on the part of the instrument in registering the temperature of the environment is dependent on two factors—

(*a*) The effective heat-capacity of the bimetal—As the bimetal is in thermal contact with the metallic frame of a different metal possessing different heat-capacity, its effective heat-capacity is different depending upon the heat-capacity and the conductivity of the frame. The smaller the effective heat-capacity of the bimetal the smaller will be its lag factor.

(*b*) The ventilation of the temperature element—It influences the exposure of the temperature element as it depends upon the surface effectively exposed to the air-current through which it passes and the roughness of the surface itself. The effective exposure of the element is largely dependent upon its orientation to the air-current, the air-density and the speed with which it passes through the air, *i.e.*, its rate of ascent. The better the ventilation the nearer the recorded temperature would be to the true temperature of the surroundings.

(*ii*) Error due to solar and atmospheric radiation—The chief process of heat exchange between the element and the environment is thermal conduction, especially in the lower and middle troposphere where the air-density is high. But in the high troposphere and stratosphere where the air-density is low, the main process of heat-exchange is no longer conduction but radiation. It has been found (Mani, Venkataraman and Huddar 1959) that the radiation effect is negligible up to 400-mb level. Above this level it becomes significant and goes on increasing with height.

In this study the difference in temperatures recorded by a radiosonde instrument during its ascent and the subsequent descent

TABLE 1

Serial No.	Date of ascent	Time of ascent (IST)	Mean difference in temperature (°C) between ascent and descent (ascent-descent)	Rate of ascent m/sec	Rate of ascent n	Rate of descent m/sec	Rate of descent n	λ_1 in seconds	Temperature lag in °C	λ_1 in seconds	Temperature lag in °C
1	9-11-56	0815	1·45	6·7	—0·65	8·4	—1·0	12·0	0·80		
2	13-12-56	0807	1·40	6·7	—0·65	7·5	—0·73	11·0	0·74		
3	26-2-57	2000	0·98	5·0	—0·55	7·7	—0·76	11·0	0·55		
4	2-3-57	0800	1·22	6·0	—0·60	8·6	—1·0	13·6	0·82		
5	2-3-57	2000	0·95	5·6	—0·58	7·7	—0·76	9·5	0·53		
6	3-3-57	2000	1·35	5·3	—0·56	7·1	—0·68	13·4	0·71		
7	12-3-57	0800	1·50	6·5	—0·64	10·4	—1·0	15·3	0·99		
8	14-3-57	0800	1·34	6·6	—0·64	8·0	—0·80	11·5	0·76		
9	15-3-57	2000	1·10	6·3	—0·62	7·7	—0·76	9·7	0·61		
10	16-3-57	0800	0·72	6·7	—0·64	11·3	—1·0	7·2	0·48		
Average			1·2	6·14 (21·8 km/hr)		8·44 (30·4 km/hr)		11·4	0·7	17·6	1·1

has been utilised to calculate the lag coefficient of the temperature element. It can easily be seen that in this case the radiation error which is the same during ascent and descent gets eliminated and does not affect the calculation of the lag coefficient.

2. Observations

Regular radiosonde ascents at New Delhi Office of the India Meteorological Department used to be made with a paper-parachute attached to the balloon. It was being attached with the object of bringing the instrument down (after the balloon has burst) slowly so that it may not get damaged completely on falling to the ground. With a parachute attached to the balloon it was possible to obtain the record of descent of the radiosonde instrument provided it continued to function properly. A thorough search of the old flight yielded ten good records for the present detailed study.

For the computation of the data from the records of the descent, the same calibration curve and zero errors were used as for ascent. As expected, the rate of descent in all the cases was higher than that of the ascent. The range of the rate of ascent was from 5·0 to 6·7 m. sec^{-1} whereas that of descent, from 7·1 to 8·6 m. sec^{-1} except in two cases (Table 1).

3. Nature of Records

From a study of Figs. 1 and 2 it can be seen that

(*a*) In general, the descent shows a temperature lower than that of the ascent when the lapse-rate

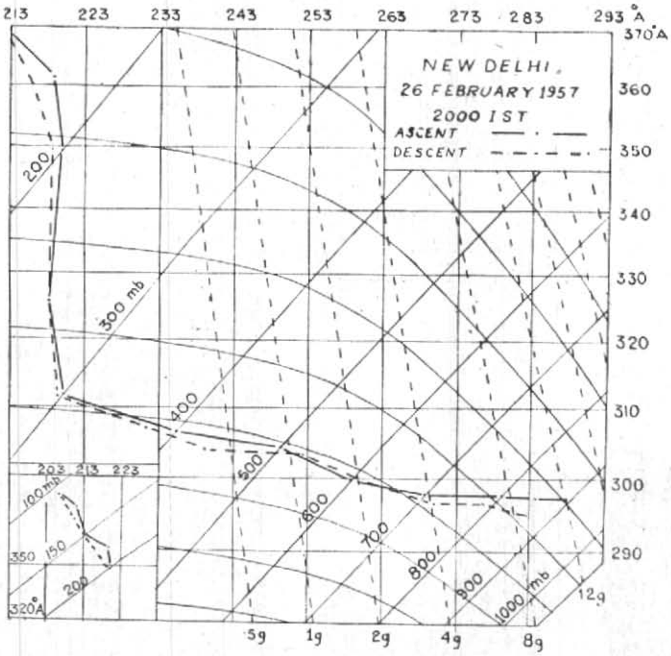

Fig. 1

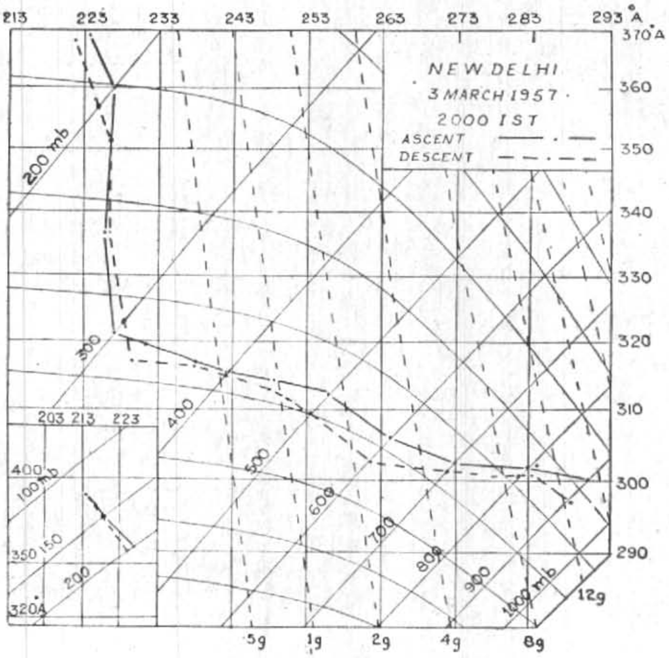

Fig. 2
Tiphigrams showing ascent and decent records

is normal. It will be observed, however, that the descent temperature has a tendency to shoot beyond the ascent temperature in case the lapse-rate is approaching dry adiabatic. Actually, the descent temperature is invariably lower than that of the ascent at the top of such a layer. But at the bottom it is, in quite a few cases, higher than the latter. The value of this positive difference, however, is very small.

(*b*) In the case of isothermal layers the descent shows almost the same temperature. Difference is very small and it is both positive as well as negative.

(*c*) In inversions it has a tendency to be higher than that of the ascent.

4. Data

The differences in temperatures of ascent and descent (ascent—descent) of every flight were tabulated for levels 900, 850, 800, 700, 600, 500, 400, 300, 250, 200, 175, 150, 125, 100, 80, 60 and 50 mb as were available. Those values which were positive at levels not relating to any isothermal or inversion layer were rejected. Average of these differences (absolute) were calculated for each flight.

5. Theory

If a radiosonde instrument at a temperature θ_0 is placed in a surrounding of temperature θ_e (assumed to be a linear function of time) it has been shown (Middleton 1947) that it will record a temperature θ after a time t given by the equation—

$$\theta - \theta_e = -\beta\lambda(1 - e^{-t/\lambda}) \qquad (1)$$

where β is the change of temperature of the environment per unit time and λ the lag coefficient of the temperature element.

For a time period $t >> \lambda$ this equation can be written as

$$\theta - \theta_e = -\beta\lambda \qquad (2)$$

It follows, therefore, that in a surrounding where the temperature changes at a rate β, the thermometer at any instant would record a temperature which differs from temperature of the environment by an amount equal to the product of its lag coefficient and the rate of change of temperature with time.

As discussed earlier, the lag coefficient of the temperature element depends on its effective heat-capacity and ventilation. The heat-capacity of the element being the same during ascent and descent, the error introduced by it appears twice in the difference of temperature calculated. The effect of ventilation, however, varies because of the difference in the rate of ascent and descent. Middleton, Edwards and Johnson (1938) have investigated the relation between the lag coefficient and the ventilation and have expressed it by an equation of the type

$$\lambda = k v^n \qquad (3)$$

where k=a constant for the particular thermometer (Suomi and Barrett 1952), and

v=effective ventilation which is the product of the rate of ascent or descent and the air-density.

Since the air-density at any level during descent is the same as during ascent it is only the rate of ascent or descent which is the variable factor in v.

n has been found to have a value in the neighbourhood of $-0{\cdot}5$. But it is not constant. It tends to increase with the rate of ventilation. According to Petterson and Womack (1937) it approaches -1 when the ventilation rate is high. Mitra and Datta (1954) have found out the value of n for different values of v for the bimetal thermometer under consideration. The values obtained by them are given below—

v (m/sec)	3·7	4·4	4·8	5·2	6·0	6·9	7·7
n	-0·5	-0.52	-0·54	-0·57	-0·60	-0·66	-0·70

Let us denote the ascent parameters by suffix 1 and those of the descent by 2, then equation (3) can be written

for ascent $\lambda_1 = kv_1^{n_1}$

for descent $\lambda_2 = kv_2^{n_2}$

Hence, $\frac{\lambda_2}{\lambda_1} = \frac{v_2^{n_2}}{v_1^{n_1}}$

Or $$\frac{v_2\lambda_2}{v_1\lambda_1} = \frac{v_2^{n_2+1}}{v_1^{n_1+1}} \quad (4)$$

The difference between the temperatures of ascent and descent at any level is the sum of the lags during ascent and descent.

Expressing mathematically

$$\left.\begin{array}{l}\theta_1 - \theta_e = \beta_1\lambda_1 \\ \theta_2 - \theta_e = -\beta_2\lambda_2\end{array}\right\} \quad (5)$$

and $\beta = \frac{\text{Change of temperature}}{\text{time}}$

$$= \frac{\text{Change of temperature}}{\text{distance}} \times \frac{\text{distance}}{\text{time}}$$

$$= \nu \times v \quad (6)$$

where ν = lapse-rate of temperature and
v = velocity (rate of ascent or descent)

$$\therefore\ \theta_1 - \theta_e = -\nu v_1 \lambda_1$$

$$\because\ \theta_2 - \theta_e = -\nu v_2 \lambda_2$$

$$\therefore\ \theta_1 - \theta_2 = \nu\,(v_1\lambda_1 + v_2\lambda_2)$$

as the total difference is additive (absolute value of ν is taken).

$$\text{or } \theta_1 - \theta_2 = \nu v_1 \lambda_1 \left(1 + \frac{v_2\lambda_2}{v_1\lambda_1}\right)$$

Substituting (4) in the equation

$$\theta_1 - \theta_2 = \nu v_1 \lambda_1 \left(1 + \frac{v_2^{n_2} + 1}{v_1^{n_1} + 1}\right) \quad (7)$$

$$\text{or } \lambda_1 = \frac{\theta_1 - \theta_2}{\nu v_1 \left(1 + \frac{v_2^{n_2}+1}{v_1^{n_1}+1}\right)} \text{ seconds} \quad (8)$$

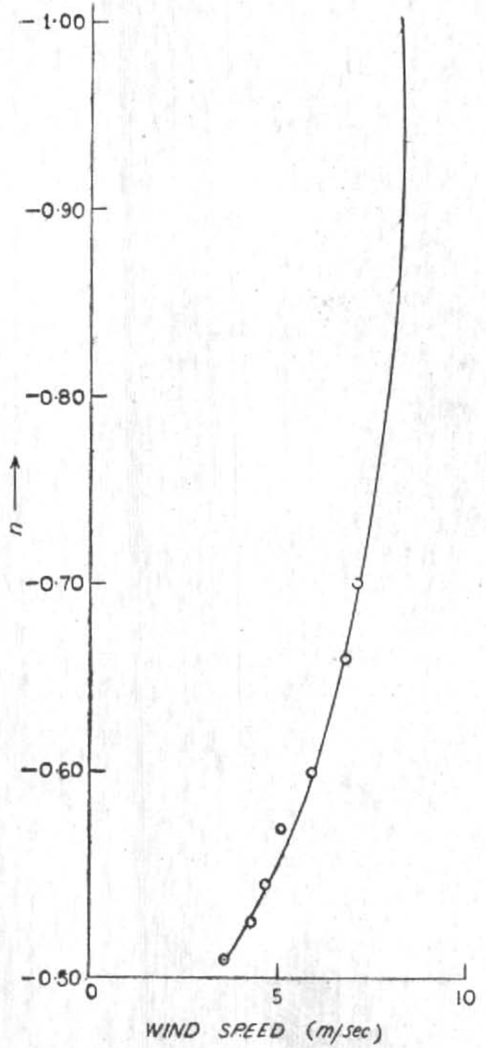

Fig. 3. Graph showing the value of n against wind speed

Using this equation, λ_1 has been calculated for two values of ν, *i.e.*, —10°C/km and —6·5°C/km (Table 1). Values of n have been taken from a smooth curve (Fig. 3) based on the values obtained by Mitra and Datta. The values of n available in their study is only up to a rate of ascent of 7 m/sec. Above this value the curve has been extrapolated and where the curve could not give any value n was assumed to be —1.

The actual lag (in °C) of the recorded temperature has been calculated (Table 1) with the help of equation (5) using the value of λ_1 obtained in the above calculation. For calculating β for the two values of ν, *i.e.*, —10°C/km and—6·5°C/km, equation (6) has been utilised.

6. Result

(*i*) It can be seen from Table 1 that the mean temperature-differences between ascents and descents are quite consistent though rates of ascent and descent, especially of descent, vary considerably.

(*ii*) The lag coefficients obtained are also fairly consistent though there are a few high values. These high values are in cases where the rate of descent is high.

(*iii*) According to this study the average lag coefficient of the bimetal and the average lag in the recorded temperature for the normal lapse-rate (—6·5°C/km) of the atmosphere are 17·6 seconds and —1·1°C respectively. The average rate of ascent in this case is 21·8 km/hr and the average rate of descent, 30·4 km/hr. It means, these values of the lag coefficient and the temperature-lag are for an average rate of ascent of 26 km/hr (average of 21·8 km/hr and 30·4 km/hr). The corresponding values obtained by Mitra and Datta are 8 seconds and —0·4°C respectively for a rate of ascent of 18-20 km/hr. The values obtained in this study are, therefore, comparatively higher than those of the above quoted authors. It appears that the rate of increase of the lag coefficient with the rate of ascent is not constant. It increases much faster for the high values of rate of ascent than for the low values.

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