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Nocturnal radiation at Calcutta Airport on clear winter nights

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सार – शीत ऋतु की मेघरहित रात्रि में किसी भी समय वास्तविक स्थलीय अभिवाह (टैरेस्ट्रियल फ्लक्स) F_N ज्ञात करने के लिए अंगस्ट्राम पायरजियोमीटर प्रेक्षणों का प्रयोग एक अनुभाविक सूत्र के स्थिरांकों का मान ज्ञात करने के लिए किया गया है। अनुमानित मानों की तुलना वास्तविक प्रेक्षणों के साथ करने पर इस विधि की क्षमता बहुत अच्छी पाई गई।

यहां F_N को केवल सतही ताप (T) तथा वाष्पदाब (e) का फलन माना गया है। F_N तथा अधोमुखी अभिवाह F_d पर इन कारकों के प्रभाव और इन कारकों के साथ F_N एवं F_d के रात्रि के दौरान विचरण की संक्षिप्त विवेचना की गई है।

ABSTRACT. In order to find out the net terrestrial flux F_N at any time on a cloudless winter night. Angstorm pyrgeometer observations are used to find the values of constants of an empirical formula. On comparing estimated values with the actual observations efficacy of the method was found to be very good.

F_N has been assumed here to be a function of surface temperature (T) and vapour pressure (e) only. Effect of these elements on F_N and the downward flux F_d as well as variation of F_N, F_d with the above elements during night is briefly discussed.

1. Introduction

Knowledge of net terrestrial flux F_N is required to obtain the radiative cooling at any time in the night. This cooling rate is helpful in the prediction of radiation fog and minimum temperature. Hence, there is a need to empirically obtain the net flux during night in the absence of actual measurements.

Terrestrial radiation fluxes were being recorded by Angstorm pyrgeometer instantaneously at certain stations in India at fixed hours, *viz.*, 2030, 2330, 0230 and 0530 IST (at 0430 IST at Calcutta upto 1979). These observations of terristrial fluxes at Calcutta have been utilised in the study. It may be mentioned that the observations are taken only in the absence of precipitation, duststorm and when winds are not very strong to ensure reliability of data obtained.

Based on a number of observations at European stations Brunt (1932) had given an empirical formula for finding the net terrestrial flux on clear nights. The earliest study in this direction was by Ramanathan and Desai (1932). Subsequently, many other workers attempted to investigate the nature of the terrestrial flux based on observational data for selected Indian stations (Chacko 1951; Mani and Chacko 1963; De and Gupta 1964; Mani *et al.* 1965; Swaminathan and Desikan 1967 etc).

The geographical position of the station which is neither very much inland nor exactly coastal and which has a humid climate has prompted the present author to undertake this radiation study. In this study, net fluxes obtained from the night pyrgeometer observations only have been utilised to fit the well known Brunt's formula with a view to finding the nocturnal radiation. It has also been examined how the radiation fluxes vary throughout the winter night in relation to surface conditions (temperature and humidity) only.

2. Data

All Angstorm pyrgeometer observations in respect of Calcutta upto 1986 at 2030, 2330, 0230, 0430 IST were scrutinised and all those days when sky was clear and winds were light and calm in the nights from November to March were chosen for the studies. The mean monthly values of F_N, F_d at these hours were utilised to obtain an empirical relation.

3. Empirical formula for F_N

Based on shelter temperature and humidity observations, Brunt (1932) obtained the formula for downward flux F_d as

$$F_d = \sigma T^4 (a + b\sqrt{e})$$

where, e = Surface water vapour pressure (mb)

T = Surface temperature in °K and a, b are numerical constants.

TABLE 1

Mean monthly values of $\partial F_N/\partial T$ and $\partial F_N/\partial e$ at different hours of winter night

Time (IST)	(T °C)	F_N (cal/cm²/min)	$\frac{\partial F_N}{\partial T} = \frac{4F_N}{T}$ (cal/cm²/min/°K)	e (mb)	F_d (cal/cm²/min)	$\frac{\partial F_N}{\partial e} = \frac{-bF_u}{2\sqrt{e}}$ (cal/cm²/min/mb)
			November			
1630	26.25	—	—	21.76	—	—
2030	23.44	.093	1.2549×10^{-3}	21.53	.545	-2.0625×10^{-3}
2330	19.84	.109	1.4889×10^{-3}	20.61	.498	-2.0568×10^{-3}
0230	19.55	.108	1.4767×10^{-3}	20.69	.498	-2.0056×10^{-3}
0430	22.79	.091	1.4740×10^{-3}	23.65	.542	-1.9951×10^{-3}
			December			
1630	22.75	—	—	14.80	—	—
2030	19.40	.099	1.3543×10^{-3}	16.61	.505	-2.2230×10^{-3}
2330	16.48	.118	1.6305×10^{-3}	16.46	.462	-2.1444×10^{-3}
0230	15.22	.116	1.6099×10^{-3}	15.70	.454	-2.1578×10^{-3}
0430	17.22	.106	1.4610×10^{-3}	15.82	.484	-2.2138×10^{-3}
			January			
1630	23.75	—	—	14.99	—	—
2030	19.64	.096	1.3122×10^{-3}	16.57	.511	-2.2367×10^{-3}
2330	14.66	.113	1.5713×10^{-3}	15.05	.457	-2.2039×10^{-3}
0230	13.15	.111	1.5516×10^{-3}	13.90	.443	-2.2289×10^{-3}
0430	17.02	.102	1.4068×10^{-3}	15.84	.482	-2.2011×10^{-3}
			February			
1630	25.25	—	—	12.30	—	—
2030	22.07	.099	1.3421×10^{-3}	18.02	.528	-2.2155×10^{-3}
2330	18.97	.106	1.7125×10^{-3}	19.10	.496	-2.0677×10^{-3}
0230	16.74	.107	1.4772×10^{-3}	17.20	.476	-2.1086×10^{-3}
0430	19.33	.108	1.4778×10^{-3}	17.44	.498	-2.1623×10^{-3}
			March			
1630	32.90	—	—	20.77	—	—
2030	26.68	.100	1.3348×10^{-3}	24.39	.567	-2.0258×10^{-3}
2330	22.97	.101	1.3650×10^{-3}	24.17	.533	-1.9313×10^{-3}
0230	21.75	.104	1.4114×10^{-3}	23.46	.523	-1.9324×10^{-3}
0430	23.90	.113	1.5224×10^{-3}	24.28	.540	-1.9543×10^{-3}

The upward terrestrial flux is $F_u = \sigma T^4$ assuming earth to be a near black body.

So, $F_N = F_u - F_d$

$$F_N = \sigma T^4(1 - a - b\sqrt{e}) \tag{1}$$

3.1. F_N *in the night*

Here, we shall fit the Eqn. (1) for the winter-night using mean values of radiation fluxes at 2030, 2330, 0230 and 0430 IST by the method of least squares. Thus we obtain a regression line of F_d/F_u on $\sqrt{e}$ with $a=0.69$ and $b=0.03$. The coefficient of correlation between F_d/F_u and $\sqrt{e}$ is 0.71 and these values are correlated even at 0.1% level of significance.

4. Discussions

4.1. *Variation of F_N with respect to T, e*

The rate of variation of F_N with temperature can from Eqn. (1) be given as

$$\frac{\partial F_N}{\partial T} = \frac{4F_N}{T} \tag{2}$$

and the same with humidity from Eqns. (1) and (2) be shown as

$$\frac{\partial F_N}{\partial e} = -\frac{b}{2\sqrt{e}}\, F_u \tag{3}$$

$$\therefore\ dF_N = \frac{4F_N}{T}\, dT - \frac{b}{2\sqrt{e}}\, de \tag{4}$$

Eqn. (4) shows clearly that contributions to dF_N due to changes in T and e are in opposite directions.

Mean monthly values of $\partial F_N/\partial T$, $-\partial F_N/\partial e$ for different hours are given in Table 1. These values were obtained from monthly values of F_N, F_u, T, e by use of Eqns. (2) and (3).

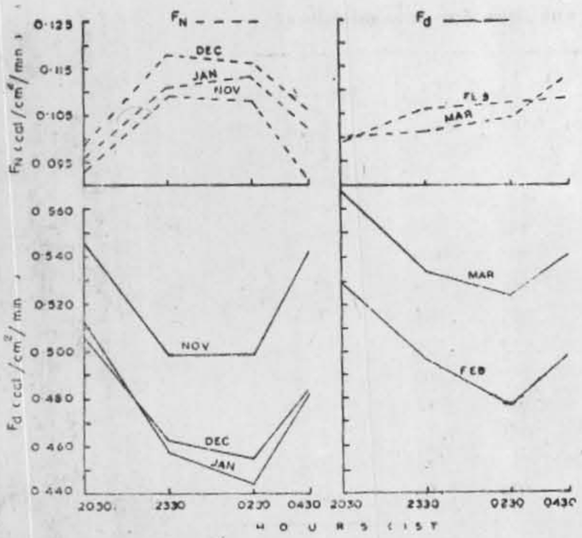

Fig. 1. Variation of downward flux (F_d) and net upward radiation flux (F_N) during calm & clear winter night

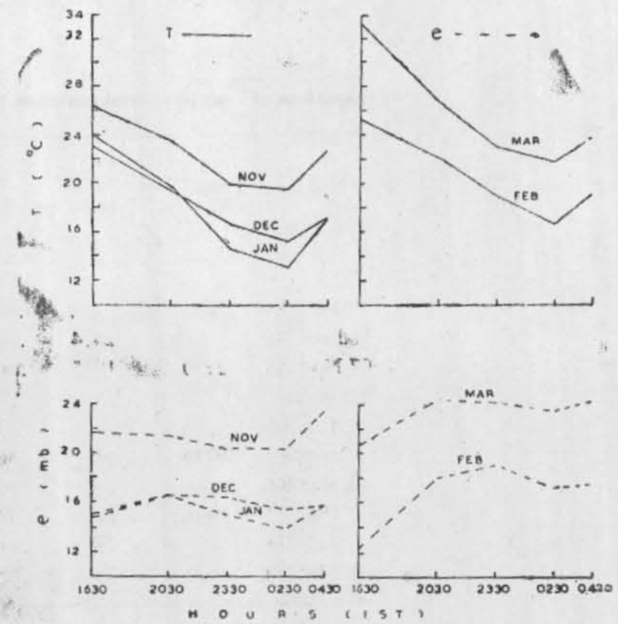

Fig. 2. Variation of temperature (T) and vapour pressure (e) during calm & clear winter night

$\partial F_N/\partial T$ increases from 2030 to 2330 IST and thereafter it generally decreases till 0430 IST in the months November-January. The variation due to e is in contrast just opposite and is seen to be having a increasing trend after 2030 IST. This variation between 2330 and 0430 IST is little in all months. Only November shows decreasing tendency in this period. The relative effect on F_N will then depend upon the relative dominant variations in T and e. Many times the variations take place in opposite directions in such a way that F_N remains fairly constant particularly from 2030 IST onward.

4.2. *Variation of F_d, F_N*

Average monthly values of F_d and F_N during winter nights have been shown in Fig. 1.

4.2.1. The values of F_N shown slight increase in winter months between 2030 and 2330 IST. They remain almost constant in March. F_N remains almost steady thereafter upto 2030 IST and if any variations are found they are only marginal. November-January show fall in F_N between 0230 and 0430 IST while F_N remains almost steady from 2330 to 0430 IST in February. March shows an increase between 0230 and 0430 IST. The differences in the trends of variation in F_N are to be attributed to the relative effect of vriation in T and e.

4.2.2. F_d

The variation of the downward flux F_d is almost diametrically opposite to F_N. All the months register a very sharp fall from 2030 to 2330 IST in F_d, the least sharp fall being in February and March. Excepting November the decreasing tendency continues upto 0230 IST but at a very much reduced *rate. In November F_d remains constant.* After 0230 IST, F_d again increases rather sharply, the steepest increase being in November from 0.498 cal/cm^2/min to 0.542 cal/cm^2/min.

4.2.3. *Effect of T, e on F_N and F_d*

Mean monthly values of T, e during winter nights are shown in Fig. 2.

4.2.3.1. Normally higher values of T under cloudless sky condition would give rise to high values of F_N but this is highly modified and controlled by high values of e which results in more absorption of radiation and causes an increase in the downward radiation F_d.

In November higher values of T are counter balanced by very high values of vapour pressure resulting in sharp decrease in F_N and sharp increase in F_d. The sharp increase in November in F_d after 0230 IST is directly the result of high values of e and T. In contrast, F_N, the net (upward) terrestrial radiation registers a steep fall after midnight in November.

4.2.3.2. The temperatures are of lower order in December and January and the vapour pressure values are also quite low. This naturally leads to very low values of F_d and comparatively higher values of F_N. In fact, F_N is highest in December and F_d lowest in January after 2030 IST.

4.2.3.3. February presents a higher temperature regime in the nights than in December and January and e is only little higher in February than in December and January. The decrease in both T and e case fall in F_d between 2330 and 0230 IST. The almost steady value of F_N and the sharp increase in F_d after 0230 IST are apparently caused by the continued high values of e and increase in T during the period.

4.2.3.4. Variations in F_N and F_d are mainly caused by the variations in T but kept under check by the high or low values of e. In fact, the counter sky radiation F_d is maximum at all hours in March and e is maximum during 2330-0430 IST in March. This accounts for the least values of F_N during the above period in March,

TABLE 2

Comparison of net terrestrial radiation fluxes (F_N) with those derived empirically (F_{Nf})

Date	Time (IST)	T (°C)	F_u (cal/cm²/min)	e (mb)	F_N (cal/cm²/min)	F_{Nf}	Error (% $\frac{(F_N - F_{Nf}) \times 100}{F_N}$
25 Feb '73	2030	25.8	.659	20.4	.122	.112	8
21 Nov '73	,,	24.4	.647	25.1	.096	.100	−4
07 Nov '66	2330	19.5	.605	20.0	.116	.104	10
21 Jan '67	,,	13.0	.553	14.0	.100	.107	−7
07 Feb '68	,,	17.8	.591	16.3	.118	.109	8
23 Jan '67	0230	14.2	.562	14.1	.110	.105	5
15 Mar '66	,,	20.0	.509	15.9	.109	.112	−3
18 Dec '72	0430	17.0	.584	14.3	.103	.112	−9
12 Feb '73	,,	18.0	.617	17.1	.093	.112	−20
10 Mar '74	,,	22.2	.627	21.7	.100	.103	−3

4.2.3.5. Summing up, T decreases in November-March upto 2330 IST while e remains almost constant in November upto 0230 IST but increases in December-March upto 0230 IST. Effect of T is predominant on F_d while that of e is on F_N in February and March. Both T and e decrease during the period 2330-0230 IST in winter months except in November and decrease of T is minimum. This explains the decrease and constancy of F_d in November. In the period 2330-0430 IST decreasing and increasing effect of T and e respectively on F_N is such that F_N remains almost constant during 2330-0230 IST in January and 2330-0430 IST in February.

5. Comparison

The formula which is used here from a number of observations by a statistical method is empirical and approximate in nature. The empirically derived values of net flux were required to be compared with those of actual values and errors found out. Table 2 give minimum necessary examples of comparison and errors. It is observed that the error exceeded 20% in only 1 case and it was 12-20% in 2 cases out of 20 cases chosen at random. In most of the cases, the error was less than 12%. Thus Eqns. (1) and (2) can be applied to find F_N in night with a reasonable degree of accuracy.

6. Conclusions

(*i*) The empirical formula used here provides a method for finding nocturnal radiation at any time of clear winter nights based on surface conditions only.

(*ii*) The dependence of the above radiation on surface temperature and humidity shows that contributions to variations in the flux due to change in T and e are in opposite directions.

(*iii*) Downward and net fluxes do not remain constant during the night. The effect of one of the two parameters, temperatures and humidity may dominate the other and their relative values determine the variations in the fluxes.

(*iv*) After 2330 IST the joint effect of parameters T and e on F_N is found such that F_N has a tendency to remain steady under cloudless sky conditions till 0230 IST.

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