MAUSAM, **52**, 4 (October 2001), 697-702

551.5 : 63

Ramdas layer and thermal wave during winter period

S. ABRAHAM THAMBI RAJA, G. RENUKA

and

K. RETNAKUMARI

Department of Physics, University of Kerala, Kariavattom,

Thiruvananthapuram - 695 581, Kerala, India

(Received 7 March 2000, Modified 9 April 2001)

सार - रामदास सतह के संबंध मे पहले किए गए कार्य उसकी निश्चितता, उसकी विद्यमानता, सतह पर ऊर्जा संतुलन और समरूपी गणितीय निदर्श के बारे में थे। हमें, सबसे पहले मृदा उष्मा फलस्क के पाक्षिक अध्ययन के दौरान, तिरूवनंतपुरम, केरल में इसका आठ दिन तक पता चला। तापमान में न्यूनतम वृद्धि कृषि और बागवानी को प्रभावित कर सकती है और इसलिए रामदास सतह के बनने की ऊँचाई के रेंज का पता लगाने के दृष्टि से रामदास अधिकतम और रामदास न्यूनतम का पता लगाया गया है। 24 जनवरी 1994 को रामदास सतह धरातल से 0.8 मीटर की अधिकतम ऊँचाई पर बनी और इस दिन को रामदास अधिकतम नाम दिया गया है। 1 फरवरी 1994 को यह सतह धरातल से 0.4 मीटर की निम्नतर ऊँचाई पर बनी और उस दिन को रामदास न्यूनतम का नाम दिया गया है।

धरातल पर और 0.05 मीटर की गहराई पर तापीय तरंग, तापीय तरंग का रेंज, रामदास सतह के साथ उसका संबंध, तापमान, प्रोफाइल तथा रामदास अधिकतम और रामदास न्यूनतम के दौरान उपमृदा सतह स्ट्रेटम (0.05 मीटर पर धरातल) पर धरातल और उपमृदा उष्मा फलक्स की दर सहित उस सतह में उष्मा में परिवर्तन की दर की तुलना और चर्चा इस शोध-पत्र में की गई है।

ABSTRACT. Earlier works on Ramdas Layer were about its certainty, its existence, energy balance on the layer and a matching mathematical model. We, first identified it in Thiruvananthapuram, Kerala, for eight days during a fortnight study on soil heat flux. A lifted minimum in temperature could have implications in agriculture and horticulture and so with a view to finding out a range of height through which Ramdas layer occurs, Ramdas-max, Ramdas-min are identified. On 24 January 1994, Ramdas layer occurred at a maximum height of 0.8m from the surface and the day is labeled as Ramdas-max. On 1 February 1994, it occurred at a lower height of 0.4m from the surface and the day is labeled as Ramdas-min.

The thermal wave at the ground and at 0.05m depth, the range of thermal wave, its relationship with Ramdas layer, the temperature profile, the rate of change of heat in that layer with that at the surface and the subsoil heat flux at the sub-soil surface stratum(surface-0.05m) during Ramdas-max and Ramdas-min are duly compared and discussed.

Key words – Ramdas layer, Thermal wave, Temperature profile, Subsoil heat flux.

1. Introduction

On calm clear nights, air at a height of a few decimeters above soil can be cooler than the surface by several degrees, which we shall call the Ramdas layer. Ramdas and his coworkers reported the existence of the lifted temperature minimum above bare soil. Later several authors supported its existence beyond doubt at various locations. A detailed mathematical model has been proposed and investigated by Narasimha and Vasudevamurthy (1995) and it shows very good agreement with observation. Earlier works on Ramdas layer by Ramdas (1953), Raschke (1957) and Geigar (1965) centered only on experimental work of its existence followed by theoretical work on evolving mathematical model and it lacks application point of view. Also the work was not delivered with the spirit of usefulness to the end users.

Ramdas layer has implications in agriculture and horticulture; for example in tomato plants frost first affects the fruits well above ground, if the soil is bare (Lake, 1956 & Narasimha, 1994). Present work on Ramdas layer is not only observed first in

Thiruvananthapuram (Kerala), but also helps in taking decisions whether bearing of fruits within the range of height of Ramdas layer, be allowed either to maximise the yield or to prevent from getting ruined, depending upon the situation favourable to farmers or agricultural experts.

Heating and cooling of surface, transmitted into soil in depth is exhibited as thermal wave at various depths. In all soils, the amplitude of the diurnal wave of temperature decreases rapidly with depth and the times of occurrence of maximum and minimum temperature are progressively later as the depth increases (Oke, 1978). Thermal waves at different depths in a particular location have information about the energy exchange between surface and atmosphere.

2. Data & method

For a fortnight from 21 January 1994, we recorded the three hourly data of soil temperature at 0.05 m depth below the surface, surface temperature and air temperature above the surface at 0.04 m, 0.08 m, 1.22 m (screen height) and 1.6 m in a site adjacent to the observatory of India Meteorological Department (IMD), Thiruvananthapuram (Kerala). We also collected wind speed and cloud cover from them. The experimental site comes under soil series of laterite landscape developed under tropical climate with alternate wet and dry seasons having a mean annual rainfall of 183 cm and temperature of 27° C. The soil is dark brown to dark reddish brown with gravelly sandy loam.

It is necessary to ascertain whether the observed lifted temperature minimum is due to the existence of Ramdas layer. For that, the observed values of temperature are analysed and are found to agree with the boundary condition of one-dimensional energy equation given by Narasimha *et al.*(1995) in their mathematical model representing the process involved in the Ramdas layer.

The one dimentional energy equation is given by

$$\rho_a Cp\, \delta T / \delta t = \delta Q / \delta z \qquad (1)$$

where ρ_a - density of air, Cp - specific heat capacity at constant pressure, Q- total energy flux at height z, and $\delta T / \delta t$ - rate of change of temperature T with time t.

Eqn. (1) is supplemented with initial boundary condition at $t = 0$ corresponding to a constant lapse rate τz (Narasimha *et al.*, 1995) as

$$T(z,0) = T_{go} - \tau z \qquad (2)$$

where $T(z,0)$ and T_{go} are the temperature at a height z from the ground and at the ground respectively. The boundary condition at the surface ($z = 0$) uses the work of Brunt (1941) who showed that to a good approximation the problem of determining ground temperature can be reduced to that of heat conduction in the soil subject to a constant flux boundary condition at the surface. Thus the ground temperature can be expressed as

$$Tg\,(t) = T_{go} - \beta t^{1/2} \qquad (3)$$

where β - specific cooling rate (unit: $\mathrm{Kh}^{-1/2}$), $Tg\,(t)$ - temperature at ground ($z = 0$) at any time t.

The initial time corresponds approximately to the time of sunset (6 pm) and is best determined alongwith β by fitting Eqn. (3) to observed ground temperature distributions (Vasudevamurthy *et al.*,1993). In this work Ramdas-min and Ramdas-max refer to the day of occurrence of the Ramdas layer whereas Ramdas-min layer and Ramdas-max layer refers to the height of occurrence. The work was carried out with observed ground temperatures on Ramdas-min (1 February 1994, when Ramdas layer occurred at a minimum height of 0.4 m from the surface) and Ramdas-max (24 January 1994, when Ramdas layer occurred at a maximum height of 0.8 m from the surface). The results are discussed under section 3.5.

Solutions of the energy Eqn. (1) also demand a top boundary condition which following Vasudevamurthy *et al.* (1993) can be given as

$$\delta T(\alpha,t) / \delta z = -\Gamma z \qquad (4)$$

corresponding to a uniform lapse rate of the temperature at a height above the Ramdas layer and it is different from τz given in Eqn. (2) a constant lapse rate found below the Ramdas layer. Observed data with reference to top boundary condition are also discussed in section 3.5.

3. Results and discussion

3.1. *Thermal wave*

Diurnal variation of temperature, near the ground gives the key characteristics of the boundary layer. Estimation of diurnal and annual variations of temperature in the root zone of a crop during its growth is necessary for understanding plant responses to various cultural practices (Chaudhary and Sandhu, 1982).

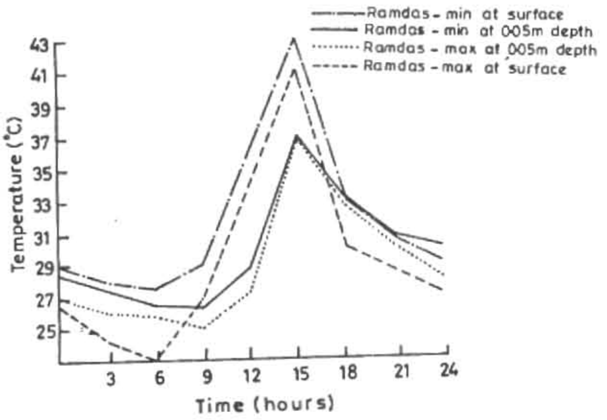

Fig. 1. Thermal wave at the ground and at 0.05m depth during Ramdas- min & Ramdas- max

Diurnal variations of temperature in a layer is known as thermal wave. The thermal wave at the surface and at 0.05m depth during Ramdas-max and Ramdas-min are given in Fig. 1. From the figure, a time lag is discernible in the thermal wave minimum between the surface and that at the 0.05m depth.

3.1.1. *Thermal conductivity*

The temperature rise within the top layers of the soil depends on the thermal conductivity of the soil. Lower is the thermal conductivity of the soil, shallower is the depth through which heat penetration occurs. In order to find out the actual thermal conductivity of the soil, observations were taken every 15 minutes during the study period by recording the temperature at these levels (Padmanabhamurthy *et al.*,1998). It was worked out using Eqn. 2.4 of Oke (1978) as 2.5 W m^{-1} K^{-1}. This value is as high as 2.2 W $m^{-1}K^{-1}$ quoted by him against sandy soil (40% pore space-saturated). The heat capacity required for the calculation is also taken from Oke (1978).

3.1.2. *Range of the thermal wave*

It is the difference between the maximum and minimum occurrence of temperature in a layer. The range of thermal wave during Ramdas-max and Ramdas-min are given in Table 1.

From the Table 1, it is clear that there is a close relationship between the height of the Ramdas layer from the ground and the range of thermal wave at the ground as well as that at 0.05 m depth. The charging and discharging of the heat store in a layer in a day is actually the graphical representation as thermal wave and so it infers us that the amount of heat given out by the layer to its surroundings depends on the range of the thermal wave. Therefore, higher the range of the thermal wave, larger the heat given out by the layer to its surroundings and hence makes the Ramdas layer realised as Ramdas-max layer.

TABLE 1

Range of thermal wave (°C) at the surface and at 0.05 m depth during Ramdas- min & Ramdas-max

Day	Height of Ramdas layer (m)	Range of thermal wave (°C)	
		surface	0.05m depth
Ramdas-max	0.8	17.25	11.25
Ramdas-min	0.4	16.0	10.75

3.2. *Temperature profile*

The temperature distribution near ground is very important in agriculture and horticulture. It also affects the formation of fog and dew (Monteith,1957). Of the temperature profile involving Ramdas layer, observed on all the eight days during the study period, only Ramdas-min and Ramdas-max were identified because of the existence of the Ramdas layer at night for a duration of nine hours unlike other days and are given in Fig. 2.

It is evident from Fig. 2, that the lifted temperature minimum occurs at 0.4 m above the surface for about nine hours continuously starting from sunset (6pm) on 1 February 1994 whereas on 24 January 1994, the occurrence of the lifted temperature minimum is at 0.8 m above the surface for about nine hours but not continuously during the night. The range of the lifted temperature minimum between Ramdas-min and Ramdas-max is 0.4 m. This range finds significance in agriculture and horticulture as bearing of fruits within this range may be advantageous to certain crops and disadvantageous to certain other crops. This range may vary with respect to a period of study or season. The fruit bearing season of the crop may be taken into consideration as a study period in order to deliver the full use of the work to the end user.

On Ramdas-min layer (0.4m), the temperature is less through 4.5° C to 3.5° C during night from the ground temperature and on Ramdas-max layer (0.8m), the difference ranges from 2.8° C to 1.5° C during night. The lifted temperature minimum reported by Vasudevamurthy *et al.* (1993) in their paper, the difference between surface temperature and the lifted minimum temperature is around 3° C.

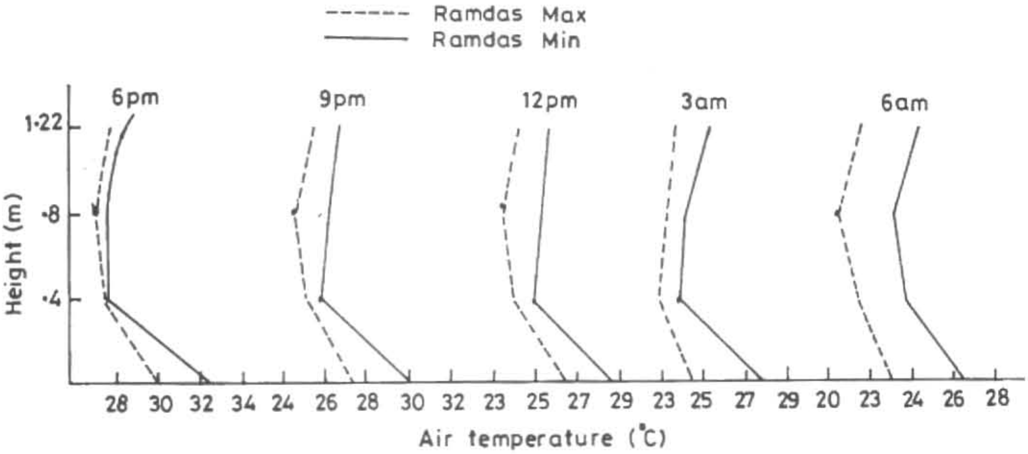

Fig. 2. Plots of air temperature (°C) *versus* height at various night hours during Ramdas- min & Ramdas-max

3.3. *Rate of change of heat*

The heating or cooling of a layer or stratum is given by Chowdhury *et al.*(1991) as

$$H = (T1 - T2) \ / \ (t1 - t2) \qquad (5)$$

where $T1$ and $T2$ are the temperature observed at times of $t1$ and $t2$ respectivily. Computation of rate of change of heat at a layer is done with the help of Eqn. (5). Such computations at four layers *viz.* 0-surface, 0.4, 0.8 and 1.22m above surface on Ramdas-min and Ramdas-max are given in Table 2.

From Table 2, it is clear that on comparision of the rate of change of heat at the surface with Ramdas-max layer (0.8m) during Ramdas-max (24 January 1994), the rate of cooling is the same (-0.83 & -0.33) on both the layers for about six hours from around sunset (6 pm) and during Ramdas-min (1 February 1994), the rate of change of heat at the Ramdas-min layer (0.4m) is almost that at the surface (-0.75/-0.58, -0.5/-0.33,-0.42/-0.33) for about nine hours during night. It indicates that the thermal conductivity of the soil plays an important role in the process by keeping 0 to 0.05m sub-soil surface stratum warm.

TABLE 2

Rate of change of heat (°C/hr) (upper and lower rows shows respectivily Ramdas-max & Ramdas-min values)

Layer	Time (IST)			
(m)	1730 – 2030	2030 – 2330	2330 – 0230	0230 – 0530
At surface	-0.83	-0.33	-0.66	-0.5
	-0.75	-0.5	-0.42	-0.25
0.4	-0.75	-0.42	-0.33	-0.5
	-0.58	-0.33	-0.33	-0.08
0.8	-0.83	-0.33	-0.17	-0.83
	-0.5	-0.33	-0.33	-0.03
1.22	-0.75	-0.42	-0.25	-0.66
	-0.58	-0.33	-0.08	-0.33

The mathematical model given by Narasimha and Vasudevamurthy (1995) demands that the surface emissivity should not be too close to unity and the soil conductivity should be sufficiently high to keep ground cooling slow for the occurrence of the lifted temperature minimum. Evaluation of thermal conductivity of the soil in sec. 3.1.1. also supports the existence of higher value of thermal conductivity but the comparision of rate of change of heat of Ramdas layer with that of the surface reveals that the role of the thermal conductivity of the soil is not to keep the ground cooling slow but, to supplement the heat store of the ground with heat from layers beneath, resulting the ground to maintain at higher temperature and the heat loses equally from the heat store of both the Ramdas layer and the ground.

3.4. *Sub-soil heat flux Qg*

Actual heat store of a stratum is given as soil heat flux, which on surface to 0.05 m depth soil stratum is named as sub soil heat flux. At night when the surface is cooling, the sign of the temperature gradient is reversed

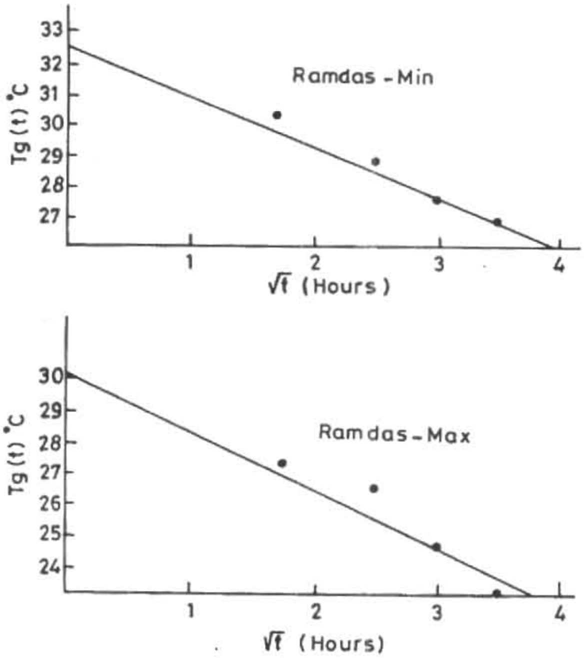

Fig. 3. Comparision of observed ground temperature variation with Eqn. 7 during Ramdas-min & Ramdas-max

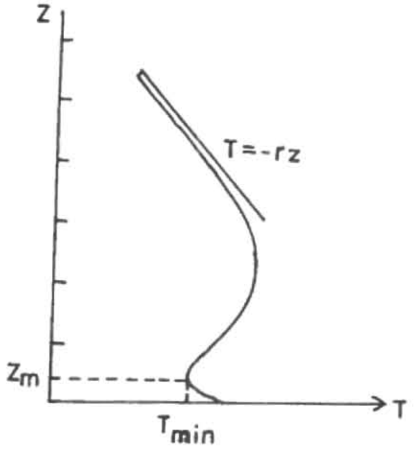

Fig. 4. A schematic diagram showing the nature of the temperature distribution under conditions of lifted minimum

and the heat may be expected to flow upwards. The rate of these heat flows depends on the strength of the mean temperature gradient $\Delta T / \Delta z$, and the ability of the particular soil to transmit heat is given by Oke (1978) as

$$Qg = - K_s (\Delta T / \Delta z) \qquad (6)$$

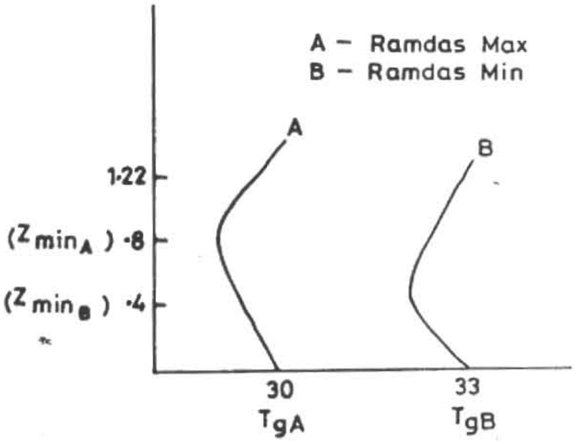

Fig. 5. Temperature distribution describing the range of lifted temperature minimum

TABLE 3

Comparison of observed ground temperature variation with Eqn.(2)

Day	Ground Temperature(°C) T_g		Ground Cooling Rate($Kh^{-1/2}$) β	
	Observed	Fitted	Observed	Fitted
Ramdas Min.	32.5	32.5	1.70	2.00
Ramdas Max.	30.00	30.25	1.90	2.20

where K_s is the thermal conductivity of the soil. The negative sign indicates the direction of flow of heat in accordance with the convention, *i.e*, $\Delta T / \Delta z$, -ve gives a +ve value of Qg, indicating a flux away from the surface or surface energy loss.

Sub-soil heat flux is estimated using the Eqn. (6) at the sub soil surface stratum for both the days Ramdas-min and Ramdas-max. The time lag required for the thermal wave to travel across the stratum in order to extract the genuine charging of the heat store of the stratum was taken into account for the accurate estimation of sub-soil heat flux. It is found that the sub-soil heat flux is maximum at Ramdas-max (*i.e.* -20.8 W/m^2) and it is minimum at Ramdas-min (*i.e.* -45.8 W/m^2) around sunset (6 pm). As it is the new work of sub-soil heat flux on Ramdas layer, we have no other data available for comparision.

3.5. *Boundary conditions*

The result of Eqn. (3) on Ramdas-min and Ramdas-max are given in Fig. 3. The observed values of ground temperatures and ground cooling rates with that obtained from graph are given in Table 3.

To support Eqn. (4), lapse rate is considered on Ramdas-max beyond the screen height as the temperature 28° C at 1.22 m changes to 27.75° C at 1.6 m. On Ramdas-min the lapse rate is not confined within the height of 1.6 m. Limiting of our observation within 1.6 m height from the surface is a handicap for proving top boundary condition satisfactorily. However, the schematic diagram of top boundary condition of the solution of the Eqn. (1) corresponding to a uniform lapse rate is given in Fig. 4. (Vasudevamurthy *et al.*, 1993).

3.6. *Range of lifted temperature minimum*

The range of lifted temperature minimum near the ground by identifying Ramdas-min and Ramdas-max assumes significance in determining the environment in which crops grow and so could have implications in agriculture and horticulture. The curves shown in Fig. 5 gives the range of the lifted temperature minimum (0.4 m) during the study period between Ramdas-min and Ramdas-max. The range helps the farmers or agricultural experts to take a decision whether bearing of fruits within the range of height of Ramdas layer, be allowed either to increase productivity or to decrease the loss due to decay of fruits depending upon the situation.

The existence of Ramdas layer may be destroyed by the wind speed. However, as the wind speed increases, the Ramdas layer vanishes and so the threshold value of wind speed at which the layer begins to emerge as lifted minimum is of scientific interest to us. Also, thermal conductivity plays an important role in the creation of Ramdas layer; hence it is important to parameterise the thermal conductivity of the soil from the ground temperature in order to realise its effect on the lifted minimum.

4. Conclusions

(*i*) The range of the lifted temperature minimum during the study period between Ramdas-min and Ramdas-max is 0.4 m.

(*ii*) Almost identical rate of cooling in both the Ramdas layer and the surface indicates that the thermal conductivity of the soil plays an important role in making the lifted temperature minimum by keeping sub-soil stratum warm.

(*iii*) Sub-soil heat flux is maximum at Ramdas-max and minimum at Ramdas-min during sunset.

(*iv*) Evaluation of actual thermal conductivity from the accurate time lag of thermal wave supports the mathematical model given by Narasimha and Vasudevamurthy (1995).

(*v*) Higher range of thermal wave has the Ramdas layer realised at higher heights.

References

Brunt, D., 1941, " Physical and dynamical meteorology", Cambridge University press, Cambridge.

Chowdhury, A., Das, H. P. and Pujari, A. D., 1991, " Sub-soil temperature variation and estimation of soil heat flux at Pune", *Mausam*, **42**, 4, 357-360.

Chaudhary, T. N. and Sandhu, B. S., 1982, "Review of soil research in India", Part. 1, 50 (Private Communication).

Geigar, R., 1965, "The climate near the ground", Harvard University Press, Boston.

Lake, J. V., 1956, "Discussion on the paper of Lake", *Quart. J. R. Met. Soc.*, **82**, 187-197.

Monteith, J. L., 1957, " Dew", *Quart. J. R. Met. Soc.*, **83**, 322-341.

Narasimha, R., 1994, " The Dynamics of Ramdas Layer", *Current Sci.*, **66**.1, 16-23.

Narasimha, R. and Vasudevamurthy, A. S., 1995, " Energy Balance in the Ramdas Layer", *Boundary-Layer Meteorol.*, **76**, 307-321.

Oke, T. R., 1978, " Boundary layer Climates", John Wiley and sons, Methuen Co. Ltd., New York.

Padmanabhamurthy, B., Amaralingeswara Rao, K. and Mukherjee, R., 1998, " A Preliminary Analysis of soil temperature at five different sites under land surface Process", *Indian J. Radio & Space Phys.*, **27**, 5, 199-206.

Ramdas, L. A., 1953, "Proc. Indian Acad. Sci.", A37, 304-316.

Raschke, K., 1957, "Meteorol. Rundsch.", **10**, 1-11.

Vasudevamurthy, A. S., Srinivasan, J. and Narasimha, R., 1993, "A theory of the Lifted minimum on calm clear nights," Phil. Trans. Roy. Soc.(London), A**344**, 183-206.