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551.521.32 (547.1)

Net terrestrial radiant flux in the vertical over Pune

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सार—बैलून वाहित रेडियोमीटर सौंदे के उपयोग से पुणे में पार्थिव विकिरण अभिवाहों को नियमित रूप से मापा जा रहा है। इन मापों से एक दशक में प्राप्त कुलपार्थिव विकिरण अभिवाहों का अध्ययन किया गया है और इनके परिणाम प्रस्तुत किए गए हैं । कुलपार्थिव विकिरण अभिवाह ऊंचाई के साथ बढ़ता है और अधिकतम रूप से करीब 12 कि. मी. तक पहुंचता है और इसके बाद क्षोभ मंडलीय सीमा के पास इसकी वृद्धि दर कम हो जाती है। लगभग 25 कि. मी पर लगभग स्थिर मान के बहुत निकट पहुंचने से पहले निम्न समताप मंडल में अभिवाह फिर से बढ़ते हैं। विकिरण क्षेत्र को मेघ और वर्षा के वितरण गंभीर रूप से विकृत करते हैं।

ABSTRACT. The terrestrial radiant fluxes are being measured regularly at Pune using a balloon-borne radiometersonde. The net terrestrial radiant fluxes obtained from these measurements over a decade have been studied and results presented. The net terrestrial radiant flux increases with height and reaches a maximum around 12 km and then the rate of increase slows down near tropopause. In the lower stratosphere the fluxes again increase before reaching a nearly steady value at around 25 km. The clouds and rainfall distributions seriously distort the radiation field.

Key words — Terrestrial radiant flux, Radiometersondes, Mean annual distribution, Seasonal changes, Aerosols particles, Water vapour.

1. Introduction

The transformation of incident solar irradiation into scattered and thermal components and the consequent effects on the earth's gaseous envelope are very important. The thermal radiant energy, augmented by the solar irradiation, of the atmosphere provides the necessary driving force for the general atmospheric circulation. The re-distribution of this energy by dynamical and radiative processes and its ultimate return to space as low temperature terrestrial radiance is very vital for understanding the other related weather phenomena. This is mainly related to the conditions of the troposphere and the lower stratosphere. The trace gases, the suspended aerosol particles, water vapour and the clouds actively participate in these radiative processes and modify the field of terrestrial radiant energy. Thus the energy fluxes modified by each successive layer of the atmosphere results in a transfer problem of immense complexity. While a detailed study of the spectral variations in the thermal radiation field is highly desirable, it requires a very high order of specialised instrumentation involving huge expenditure. A simple radiometer attached to a radiosonde balloon provides an inexpensive device to obtain a vertical profile of the thermal radiation field.

The radiometer used in India for the purpose is a Soumi-Kuhn type economic radiometer. Regular measurements are being taken every fortnight in the evenings after the sunset. The conventional radiosonde ground equipment records the signals and data is then analysed using a computer. Mani *et al.* (1965, 1966 and 1981) have discussed the variations in the upper air radiation profile based on specific balloon measurements. Radiometer sounding of the upper atmosphere is being carried out regularly at Pune since 1963. IMD has published these data (Srivastava and Srinivasan 1969 and 1971) after carefully scrutinising the data. IMD (1988 and 1990) had brought out publications on the outgoing terrestrial radiant flux over India and its neighbourhood using satellite derived data. Arkin *et al.* (1989), Rao *et al.* (1989) also discussed the results of such estimations derived from the satellite. The salient features of only one parameter that of net terrestrial radiant flux collected at Pune over the decade 1978-87 are presented here.

2. Discussion

2.1. Mani *et al.* (1975) found that net terrestrial radiant (radiative) flux H_1^* increases with height till a maximum is reached at about 12 km, decreases till tropopause and then increases again in the stratosphere till steady values are reached at about 25 km. Kuhn proposed that for tropopause and higher levels $H_1^* = H_1\uparrow - H_1\downarrow$ may, to first approximation, be expressed as $H_1^* = H_1\uparrow$ where $H_1\uparrow$ is the upward terrestrial radiant energy and $H_1\downarrow$, the downward energy, *i. e.*, $H_1^* >> H_1\downarrow$.

2.2. *Mean annual distribution*

Fig. 1 gives the mean annual vertical distribution of the net terrestrial radiant flux for the period 1978-1987. Close to the earth's surface, the temperature of

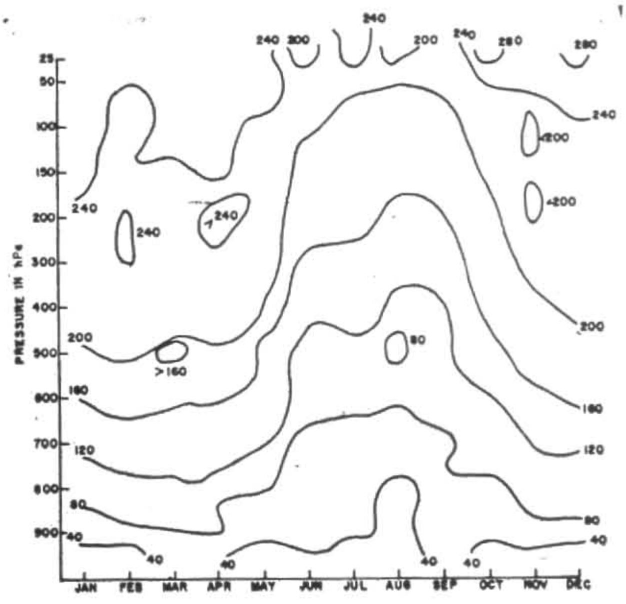

Fig. 1. Mean variations in net terrestrial radiant flux (Wm^{-2})

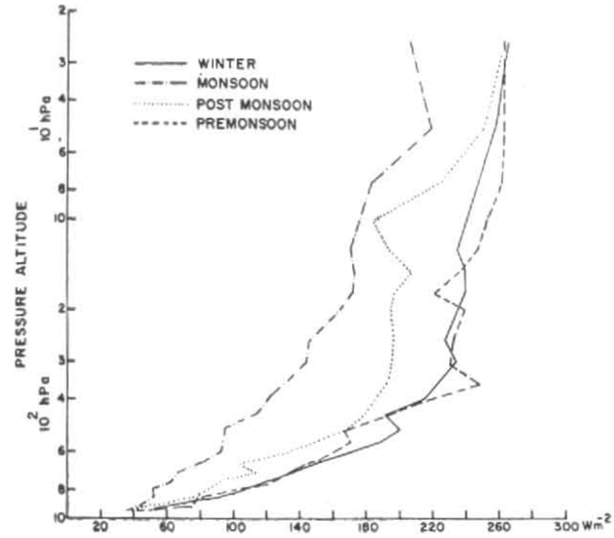

Fig. 2. Seasonal vertical profile of net terrestrial radiant flux (Wm^{-2})

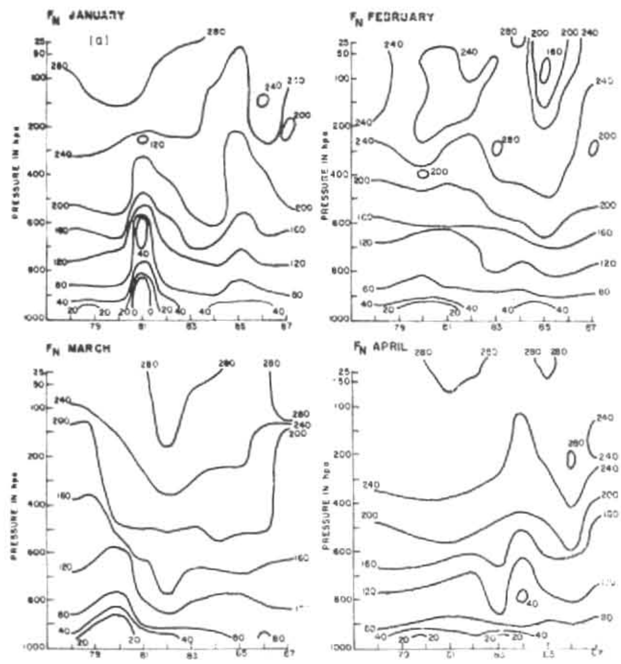

Fig. 3 (a). Variation in net terrestrial radiant flux (Wm^{-2}) over a decade

the earth's surface, the atmospheric humidity and the cloudy conditions determine the actual net terrestrial radiant loss. The presence of clouds, particularly the low clouds suppress the heat loss by reradiation to the earth's surface. The cloudless skies and nearly dry air of February increases the net terrestrial flux to about 39 Wm^{-2} as compared to that in January. It remains nearly steady till May when it registers only 25 Wm^{-2} affected by the large sized tall clouds and higher humidity conditions. The lowest value recorded is 21 Wm^{-2} in August. With the passing off of the monsoon season, the net terrestrial radiation increases to 51 Wm^{-2} in September.

A striking feature seen is the low level of the flux density during the cloudy monsoon season. It looks as if the radiant field gets expanded in vertical extent. The flux level of 160 Wm^{-2} which occurs at around 600 hPa level during the winter is reached only at and beyond 300 hPa during the monsoon period. The 40 Wm^{-2} flux level is reached only at 800 hPa in August as compared against the features of other periods. Another striking feature is the decreasing tendency of the net terrestrial radiant flux at heights lower than 700 hPa, as the season advances from January to April. During this period the skies are mostly cloudless and the air is relatively dry. Beyond 700 hPa, the values under cloudless conditions show 12-16 per cent increase up to 300 hPa. The rate of increase drops to 3 per cent above the 300 hPa level till stratosphere is reached.

2.3. *Seasonal changes*

The net terrestrial radiant flux at the surface on an average remains around 36 Wm^{-2} in all the seasons. In winter (December-February) the net terrestrial radiant flux H_1^* shows a sharp increase of 86 per cent from the surface (about 950 hPa) to 65 Wm^{-2} at 900 hPa (Fig. 2). The rate of change in H_1^* decreases progressively for every 50 hPa variation till 450 hPa, where it becomes as low as 5 per cent (191 Wm^{-2}). A sharp increase of 13 per cent is seen beyond 450 hPa. A similar reversal of rate of change in H_1^* is seen between 300 and 200 hPa levels. The decrease in cooling in the 500-450 hPa layer and again in the 300-250 hPa layer must be due to dust particles possibly denser at the lower levels.

The pre-monsoon season (March-May) is characterised by a drier atmospheric condition in March and then slow build up of the moisture in the atmosphere. The increase in the surface — 900 hPa layer is too sharp, more than 100 per cent from 37 Wm^{-2} to 75 Wm^{-2} at 900 hPa. The fair weather low clouds, shallow in depth, causes a sharp drop in the rate of increase in H_1^* to 5 per cent followed by a 29 per cent increase above them in the 850-800 hPa, and

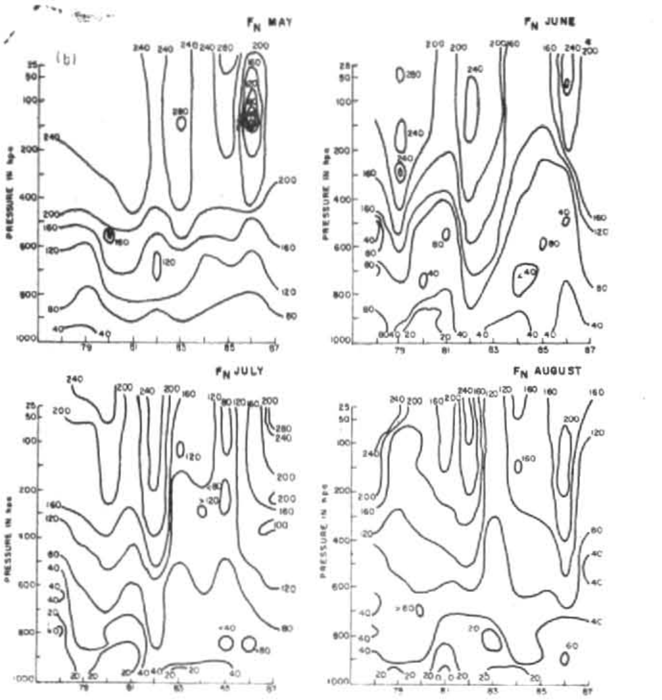

Fig. 3 (b). Variation in net terrestrial radiant flux (Wm^{-2}) over a decade

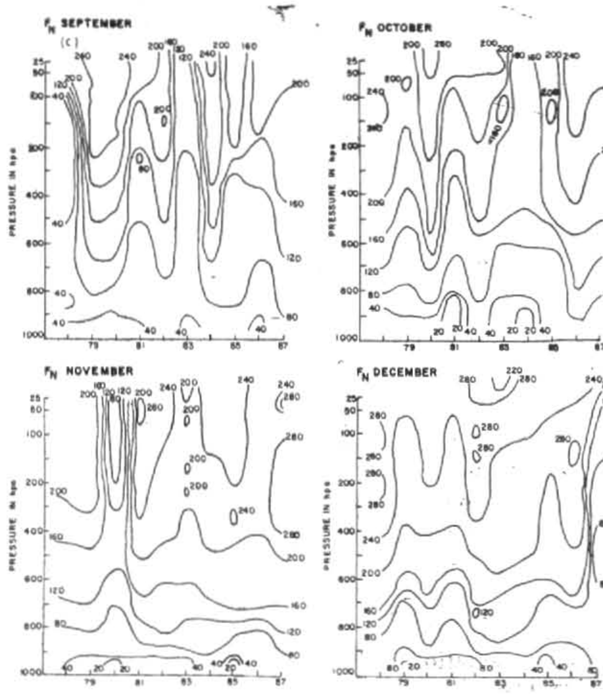

Fig. 3 (c). Variation in net terrestrial radiant flux (Wm^{-2}) over a decade

further by another 21 per cent increase at 750 hPa level. The possible medium clouds (*Ac* and *As*) around 500 hPa reduce the rate of increase in H_1* to just 2 per cent below this level and then causes a sharp 16 per cent increase beyond. As the tropopause approaches, beyond 175 hPa, H_1* drops from 239 Wm^{-2} at 200 hPa to 221 Wm^{-2} at 175 hPa.

The presence of extensive low level clouds during the monsoon inhibits the cooling rates during this season; the increase in H_1* is 28 per cent in the lowest 50 hPa thick layer as compared to the 86 per cent of the winter. The thick blanket of clouds causes little changes in H_1* in the 850-800 hPa layer, beyond which the intense cooling causing a sharp increase of 21 per cent in H_1* is noticed. That multi-layer clouding present is evidenced by the sharp decline in rate of increase in H_1* in 600-500 hPa layer and again around 300 hPa layer. Another 20 per cent sharp increase is noticed in the 75-50 hPa layer, in which H_1* increases from 183 Wm^{-2} at 75 hPa. This is most probably due to dust particles suspended at these levels.

The post-monsoon season appears as a transition stage to winter. The loss in the radiant energy level is about 59 per cent from 37 Wm^{-2} at the surface to 59 Wm^{-2} at 900 hPa. There is a decrease in H_1* from 113 Wm^{-2} at 700 hPa to 104 Wm^{-2} at 650 hPa due to the prevailing medium clouds, followed by a sharp increase of 28 per cent to 133 Wm^{-2} in the 600 hPa level.

2.4. *Variation in H_1* from year to year*

The year to year values of the net terrestrial radiant fluxes show drastic changes due to the prevailing atmospheric conditions. Fig. 3 depicts the variations in H_1* in the vertical for each month and for each year.

In January 1981 [Fig. 3 (a)] H_1* shows large deviation from the normal pattern. The downward fluxes received up to 900 hPa were more by 9 Wm^{-2}

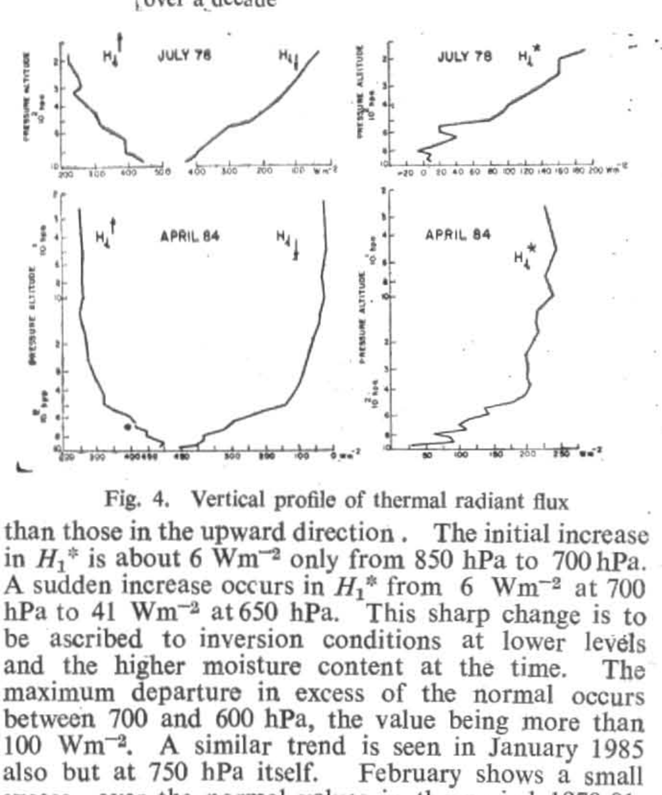

Fig. 4. Vertical profile of thermal radiant flux

than those in the upward direction. The initial increase in H_1* is about 6 Wm^{-2} only from 850 hPa to 700 hPa. A sudden increase occurs in H_1* from 6 Wm^{-2} at 700 hPa to 41 Wm^{-2} at 650 hPa. This sharp change is to be ascribed to inversion conditions at lower levels and the higher moisture content at the time. The maximum departure in excess of the normal occurs between 700 and 600 hPa, the value being more than 100 Wm^{-2}. A similar trend is seen in January 1985 also but at 750 hPa itself. February shows a small excess over the normal values in the period 1978-81. The lowest values recorded in February are in 1980 (3 Wm^{-2}) and 1981 (11 Wm^{-2}). In most of the cases the increase from 950 hPa to 900 hPa is of the order of 100 Wm^{-2} or more. Similar warmer conditions prevail in March during 1978-80 period.

The low level inversion and the clouding combine to give negative values in April at the surface. When this inversion is broken, the increase in H_1* is quite large. The increase was as high as 130-170 per cent during April in 1978, 1981 and 1983. In 1984, however, H_1* increased from 28 Wm^{-2} at 950 hPa to 94 Wm^{-2} at 900 hPa, an increase of more than 230 per cent. A reference to raw data indicates that this is most probably due to the effect of clouds (Fig. 4). The value shoots up to 112 Wm^{-2} at 750 hPa and falls once more to 97 Wm^{-2} at 700 hPa due to medium clouds. The upward terrestrial radiant flux H_1* remains constant in the shallow layer 700-650 hPa indicating that the instrument was passing through a cloud layer. Beyond 650 hPa H_1* again increases to 144 Wm^{-2}. After a slight fall H_1* increases sharply from 136 Wm^{-2} at 550 hPa to 181 Wm^{-2} at 500 hPa, possibly due to the intense cooling above the clouds of ice crystals. The variations in the energy levels are more for 1984 from 800 hPa upwards. A similar variation is also seen in April 1987.

From Fig. 3 (b) for May, a cloud layer from 900 to 850 hPa, again from 750 to 700 hPa and possibly around 550 hPa can be inferred. Particularly the sharp increase in H_1* from 153 Wm^{-2} at 550 hPa to 227 Wm^{-2} at 450 hPa is most likly due to high level *As* clouds.

The monsoon in June ushers in a heavy moisture regime (20 mm and more of water vapour) over Pune affecting the radiation field in the vertical because of the extensive low clouds. The surface value of H_1* is quite low (18 Wm^{-2} in 1980) [Fig. 3 (b)] and generally it decreases with height at lower levels. This is most striking in 1978, with a mere 10 Wm^{-2} at 700 hPa. The cloud ceiling at 500 hPa (H_1* is hardly 29 Wm^{-2}) causes a sudden jump in H_1* to 134 Wm^{-2} at 450 hPa, the increase being of the order of 360 per cent. Similar effects are seen in 1981, 1984 and 1985. In 1986, the energy content at each level even up to 250 hPa is very high, *i.e.*, H_1* recorded is quite low. Beyond 250 hPa the increase in H_1* was more than 122 per cent. That year Pune had a good rainfall activity and evenly spread during the month.

July 1982 experienced poor rainfall with less extensive clouding resulting in large values of H_1*. July 1978 shows an interesting feature (Fig. 4) of net terrestrial radiant flux directed downward in the 850-750 hPa layer due to a stable cloud cover overlaying a passing cloud layer. September 1978 again indicates very low values for H_1* at each level, the deviation from the normal remaining more than 100 Wm^{-2} for 350 hPa and above. This is repeated in 1983 as well, the maximum value of 100 Wm^{-2} occurring only at 75 hPa level. This is obviously due to the clouding at the lower levels at the time of measurement.

With a relatively drier atmospheric condition in October [Fig. 3 (c)], the stage is set for the H_1* regime to reflect the winter pattern. Any deviation is seen to be ascribed only to clouding and the occasional rainfall that occur at Pune during these periods. Only November 1980 stands out with sharp changes. H_1* gradually increases from a mere 150 Wm^{-2} at 400 hPa, then decreases to 77 Wm^{-2} at 150 hPa and again gently increases to 89 Wm^{-2} at 125 hPa.

3. Concluding remarks

3.1. The net terrestrial radiant flux H_1* generally increases with height but the rate of increase reduces just below the tropopause. The maximum is reached at about 12 km; the net terrestrial radiant flux then decreases till tropopause and again increases in the lower stratosphere till steady values are reached at around 25 km.

3.2. The net terrestrial radiant flux at the surface at Pune is, on an average, around 36 Wm^{-2}. The clouds, water vapour present and the aerosol layers affect this field seriously.

3.3. The radiant field undergoes wide fluctuations in the presence of clouds. The net flux decreases with height up to the cloud base, particularly below the low level warm clouds. There is a rapid cooling above the clouds giving rise to steep cooling rates. This is more pronounced in the case of clouds with super cooled water deposits or ice crystals.

3.4. Inversion layers drastically reduce the cooling rate with height. Just above the inversion layer, a sudden increase in H_1* is seen, just as it is over the cloud tops.

3.5. A sharp fall in H_1* at every level occurs during the years with good rainfall.

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