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Impact of total solar eclipse on spectral radiance characteristics of various objects and comparison of different vegetation indices

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सार – भारत मौसम विज्ञान विभाग के पुणे स्थित कृषि मौसम विज्ञान प्रभाग ने पश्चिमी बंगाल में केनिंग की प्रमुख वाष्पोत्सर्जन वेधशाला में अंतिम पूर्ण सूर्य ग्रहण के दौरान पर्यावरण में असामान्य विकिरण का अध्ययन किया है। 23 अक्तूबर 1995 से 25 अक्तूबर 1995 तक नग्न मृदा, जी.टी.आर., अंशशोधित पट्टी ($BaSO_4$) से समान रूप से ढकी हुई फसल के उगने के दौरान धान की फसल तथा उनमें फूल आने की अवस्था जैसी विभिन्न स्थितियों की स्पेक्ट्रल विकिरणित विशेषताओं को मल्टी बैंड ग्रांउड टूथ रेडियोमीटर के माध्यम से नीली (0.45–0.52μ) हरी (0.52–0.59μ), लाल (0.62–0.68μ) और लगभग अवरक्त (0.77–0.86μ) तरंग दैर्ध्य को मापा गया और विभिन्न फसल सूचकांकों को आकलित किया गया है। पूर्ण सूर्य ग्रहण के दिन 0830 बजे से 0930 बजे भारतीय मानक समय, के बीच चारों स्थितियों के स्पेक्ट्रल विकिरण के न्यूनतम मान प्रेक्षित किए गए है। ग्रहण की अवधि के दौरान धान की दोनों फसलों में अवरक्त बैंड के समीप वाले भाग में गिरावट की कमी का अनुपात अधिकतम पाया गया था। धान की फसल के पकने की अंतिम अवस्था के दौरान 0830 बजे से 0930 बजे भ.मा.स. के बीच (आर.वी.आई.) रेशों वेजिटेशन इंडैक्स और एन.डी.वी.आई. (नार्मलाइज डिफेंरस वेजिटेशन इंडैक्स) के मानों में तेजी से आई गिरावट का पता चला है जब कि 0830 बजे भ.मा.स. में धान की अन्य फसल में फूल आने की अवस्था में तेजी से आई गिरावट (दोनों मानों में) का पता चला है। ग्रहण के दिन 0730 बजे से 1000 बजे भा.मा.स. के बीच नग्नमृदा के आर.वी.आई. और एन.डी.वी.आई. दोनों के मानों में घटबढ़ का पता चला है। एम.जी.वी.आई. के मानों से पता चलता हे कि पूर्ण सूर्य ग्रहण की अवधि के दौरान ग्रहण वाले दिन चारों बैंडों में विभिन्न स्थितियों द्वारा परावर्तित विकिरण में गिरावट आई है।

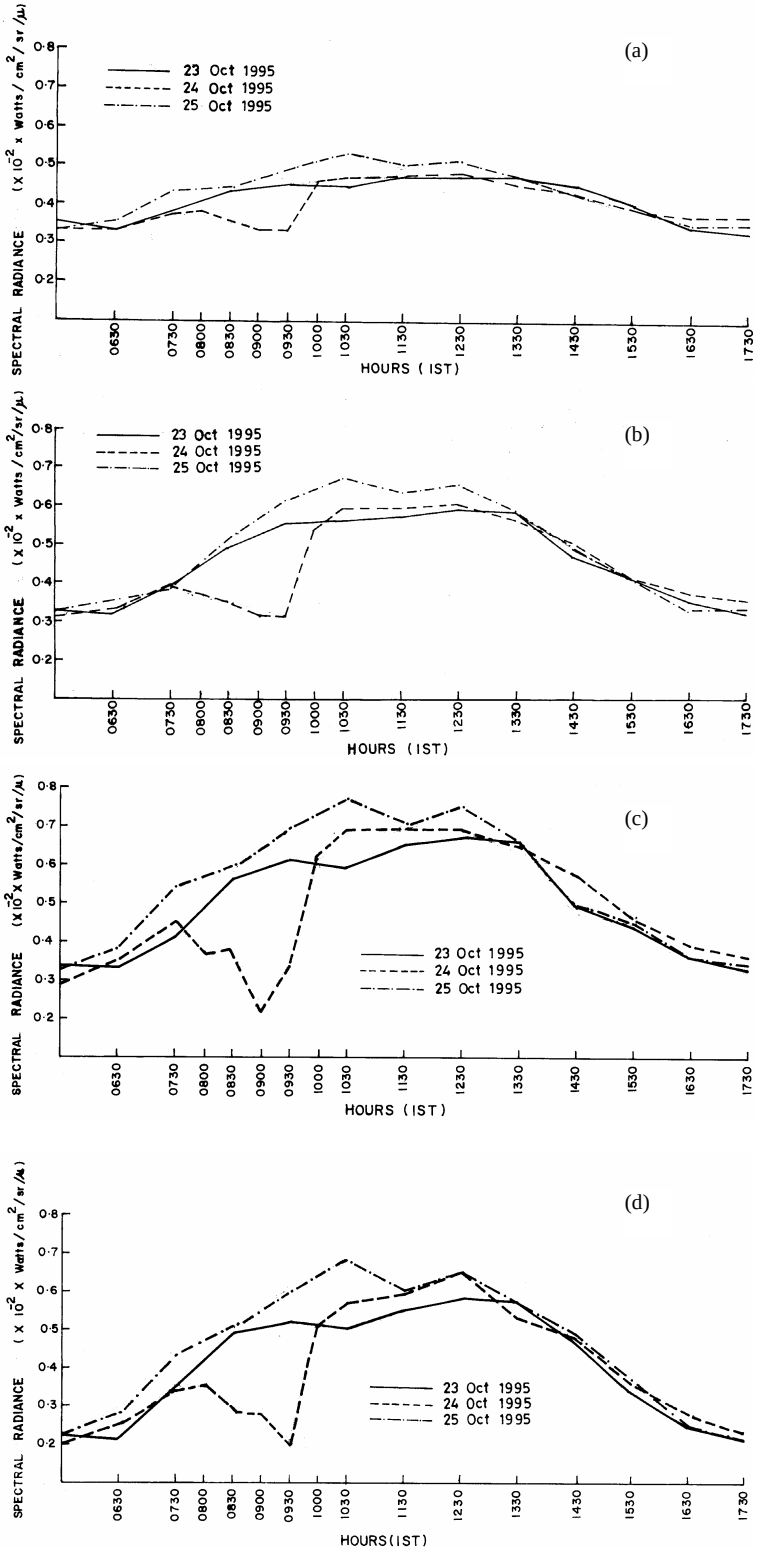
ABSTRACT. The division of Agricultural Meteorology, Pune of I.M.D. conducted a study of anomalous radiation environment during the last total solar eclipse period at Principal Evapotranspiration Observatory (PET) Canning, W.B. The spectral radiance characteristics from various objects *viz*. bare soil, G.T.R. calibration plate (coated uniformly with $BaSO_4$), rice crop at late vegetative stage and rice crop at panicle (flowering) stage were measured from 23-25 October 1995 to in blue (0.45–0.52μ), green (0.52–0.59μ), red (0.62–0.68μ) and in the portion of near infrared (0.77–0.86μ) wavelengths, by use of multi-band ground truth radiometer (G.T.R.) and different vegetation indices were computed. The minimum values of spectral radiance were observed from all the four objects between 0830 to 0930 hrs IST on the eclipse day. The proportion of drop was the maximum in the portion of near infrared (NIR) band during the eclipse period for both the rice crops. The rice crop at late vegetative stage showed sharp drop in both RVI (ratio vegetation index) and NDVI (normalized difference vegetation index) values between 0830 to 0930 hrs IST, while the other rice crop at panicle (flowering) stage showed sharp fall (in both the values) at 0830 hr IST. Both the RVI and NDVI values for the bare soil showed fluctuations on the eclipse day between 0730 to 1000 hrs IST. The MGVI (modified green vegetation index) values indicated that on the eclipse day during the period of total eclipse, quantity of radiation reflected by different objects dropped in all the four bands.

Key words – Solar eclipse, Total eclipse, Spectral radiance, G.T.R., RVI, NDVI, MGVI, NIR.

1. Introduction

The total solar eclipse is a rare natural phenomenon, which occurred on 24 October 1995. The moon's shadow stretched along a 14000 km path from central Iran to south China sea including the Indian subcontinent, covering a 46 km strip from Bikaner in Rajasthan to Diamond Harbour in West Bengal. The eclipse started in India at around 0723 hr IST and ended at around 1019 hr IST with the duration of totality varied between 48 seconds in Rajasthan to 82 seconds in West Bengal.

The division of Agricultural Meteorology of IMD, Pune had planned to undertake a study of crop behaviour



Figs. 1(a-d). Spectral radiance obtained from bare soil in (a) 0.45 to 0.52 µ, (b) 0.52 to 0.59 µ, (c) 0.62 to 0.68 µ and (d) 0.77 to 0.86 µ band of G.T. radiometer, on the eclipse day and in the preceding and succeeding days

under anomalous radiation environment during the total solar eclipse period. Within the path of totality, the most suitable site available was at Principal Evapotranspiration Observatory (PET), Canning in W.B., where the observational set up was already existing. Crop facility (mainly rice crop at various growth phases) in Central Soil Salinity Research Institute of I.C.A.R., just adjacent to PET Canning was available. It was proposed to study spectral radiance characteristics from various objects viz. bare soil, G.T.R. calibration plate (coated uniformly with $BaSO_4$), rice crop at late vegetative stage and rice crop at panicle (flowering) stage by use of multi-band ground truth radiometer. Intensive observations were carried out for the 3 days (from 23-25 October 1995) which were analyzed critically to find out the impact of total solar eclipse on spectral radiance behaviour of various objects. Different vegetation indices (*viz*. ratio vegetation index, normalized difference vegetation index and modified green vegetation index) were compared to judge the reduction in reflected radiation energy in different wavelengths with time.

2. Methodology

PET Canning (Lat. 22° 15' and Long. 88° 40') is located in 24 Parganas (W.B.). The agroclimatic normals for the 43 standard weeks (*i.e*. 22-28 October) in the station are: rainfall −19.3 mm, maximum temperature −31.0° C, minimum temperature −23.1° C, R.H. −90 % (at 0700 hrs LMT) and 63 % (at 1400 hr LMT), wind speed −3 km/hr, bright sunshine −9.5 hr.

The multi-band ground truth radiometer model 041, weighing 3.4 kg, designed and developed by the Space Application Centre, Ahmedabad was used for measuring spectral radiance characteristics obtained from different objects by holding it 1.0 m height above the object. The eight bands of the radiometer operate in the visible to near infrared region (*i.e*. from 0.45 to 0.90μ). The first four bands are identical with the four bands of IRS satellites and next four are identical to four bands of TM. The forward and reverse reading (*i.e*. slot I to VIII and back to I) were taken and averaged for respective bands. Band I and V represented blue (0.45 to 0.52μ), II (0.52 to 0.59μ) and VI (0.52 to 0.60μ) represented green, III (0.62 to 0.68μ), and VII (0.63 to 0.69μ) represented red and IV (0.77 to 0.86μ) and VIII (0.76 to 0.90μ) represented a portion of near infrared (0.77 to 0.86μ). The ground surface covered by the 15°$\pm$ 2° field of view of the sensor is approximately of 13 cm radius. The radiance from G.T.R. calibration plate (provided with uniform $BaSO_4$ coating to give 100% reflected radiation), bare soil (the 1.0 m × 1.0 m plot from which all vegetations were removed), rice crop at late vegetative stage and rice crop at panicle (flowering) stage were measured at each of the eight bands. The mean radiance of band I, II, III and IV only were presented (though the respective group spectral ranges *i.e*. I and V, II and VI, III and VII and IV and VIII were almost same for ground truth radiometer, to simplify the study only four bands readings were considered).

The observations on spectral radiance were recorded at hourly interval between 0530 to 1730 hr IST from 23 October 1995 to 25 October 1995, except on 24 October 1995 (*i.e*. the eclipse day) between 0730 to 1030 hr IST, observations were recorded at half hourly interval. The values for bare soil, rice crop at late vegetative stage and rice crop at panicle (flowering) stage are presented in the form of diagrams for all the first four bands separately Figs. 1. (a-d) to Figs. 3. (a-d).

With the advent of the space applications, research and development work has been carried out towards establishment of different indices for identification and quantification of resource phenomena such as crop growth and development, its identification, soil moisture changes, effect of background soil radiance on vegetation, reflectance etc. Rouse *et al.* (1974), Kauth and Thomas (1976), Richardson and Wiegand (1977), Hielkema (1978) and Tucker (1979) summarized indices developed recently which have theoretical and practical importance.

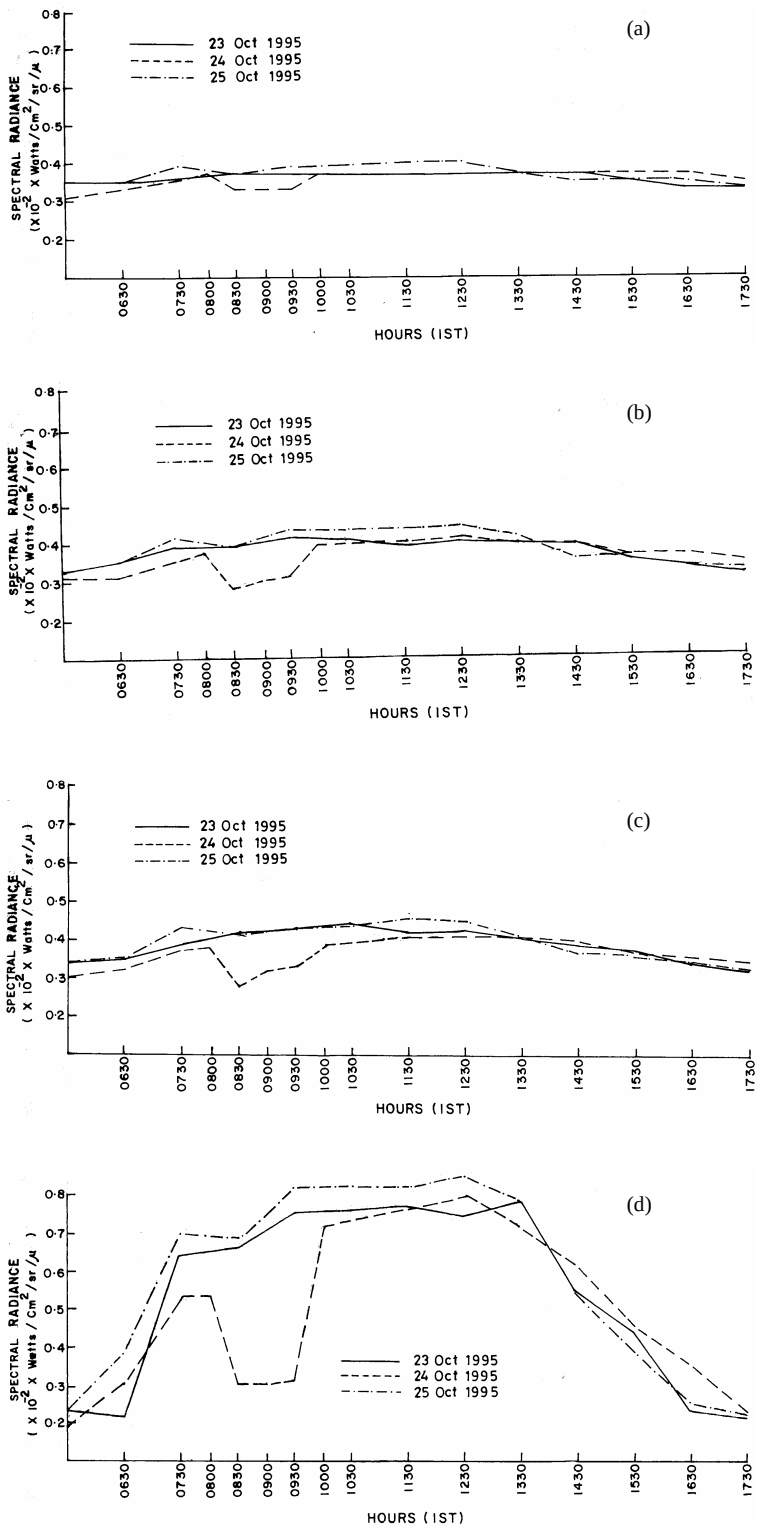
The ratio vegetation index (RVI) which uses transformation of near infrared (NIR) to red (R), is computed by the formula (Jordan 1969):

$$\text{RVI} = \frac{\text{NIR}}{\text{R}} = \frac{\text{Mean of band IV}}{\text{Mean of band III}} \qquad (1)$$

The computed RVI values for bare soil, rice crop at late vegetative stage and rice crop at panicle (flowering stage) are presented in Figs. 4 (a-c).

Rouse *et al.* (1973, 1974) developed a modified transformation called the normalized difference vegetation index (NDVI) which is given by the formula:

$$\text{NDVI} = \frac{\text{NIR} - \text{R}}{\text{NIR} + \text{R}} = \frac{\text{Mean of band IV} - \text{Mean of bandIII}}{\text{Mean of band IV} + \text{Mean of band III}} \qquad (2)$$



Figs. 2(a-d). Spectral radiance obtained from rice crop at late vegetative stage in (a) 0.45 to 0.52 μ, (b) 0.52 to 0.59 μ, (c) 0.62 to 0.68 μ and (d) 0.77 to 0.86 μ band of G.T. radiometer, on the eclipse day and in the preceding and succeeding days

The NDVI values computed for bare soil, rice crop at late vegetative stage and rice crop at panicle (flowering) stage are presented in Figs. 5 (a-c).

Kauth and Thomas (1976) proposed green vegetation index (GVI) for landsat TM as has been modified by Tassled cap transformation (Jensen 1986) for using the mean radiance of all the first four bands of the radiometer which is expressed as:

$$MGVI = -0.247\,B_1 - 0.163\,B_2 - 0.406\,B_3 + 0.855B_4 \quad (3)$$

where B_1 ,B_2 ,B_3 and B_4 represented the mean of band I, II, III and IV, respectively. The MGVI (modified green vegetation index) values computed for bare soil, rice at late vegetative stage and rice crop at panicle (flowering) stage are presented in Figs. 6 (a-c). As the band widths of IRS is comparable to landsat TM first four bands, the first four coefficients of landsat TM Tassled cap transformation are used for MGVI computation.

3. Results and discussion

During the period of solar eclipse, radiation coming from the sun was reduced which simultaneously curtailed the spectral radiance coming from different objects, as observed through the multi-band ground truth radiometer. The observations recorded from bare soil, $BaSO_4$ coated G.T.R. calibration plate, rice crop at late vegetative stage and rice crop at panicle (flowering) stage showed differential spectral characteristics in various wavelengths. Indices like RVI, NDVI, MGVI were computed to judge the reduction in reflected radiation energy in different wavelengths with time during the study period. Whatever mean radiance values were obtained in the four bands of the radiometer and various vegetation indices computed, are mentioned in different sub-sub heads.

3.1. *Spectral radiance from bare soil*

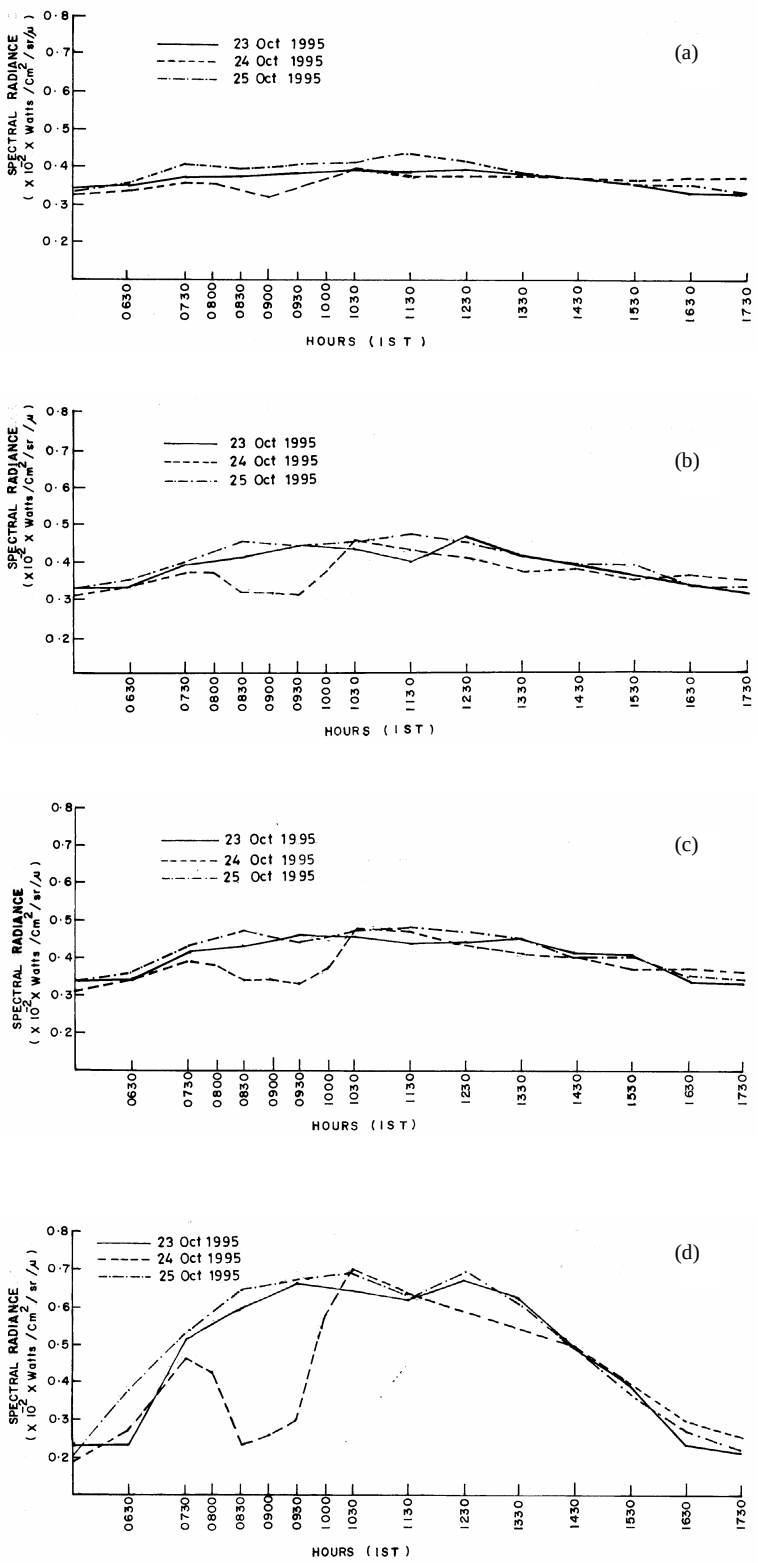
The spectral radiance (in $10^{-2} \times$ Watts /cm^2 /Sr /μ) from bare soil during 23 October 1995 to 25 October 1995 in all the first four mean wavelengths (bands) are presented in Figs. 1 (a-d), which showed sharp drop in radiance on the eclipse day during the period of solar eclipse in all the bands. The spectral radiance obtained from bare soil at various bands showed higher radiance in 0.62 to 0.68μ. On the eclipse day, in all the four bands between 0730 to 1000 hr IST, the radiance values were low as compared to the usual trend as observed in the preceding and succeeding days. The minimum values were recorded between 0900 to 0930 hr IST for all the four mean bands of the radiometer, which were almost similar to that observed at early morning (0530 hr IST) and at evening (1730 hr IST). The spectral radiance values observed at 0930 hr IST in band I, II and IV on the eclipse day were 0.33, 0.31 and 0.20, while that observed at 0900 hr IST in band III was 0.21.

3.2. *Spectral radiance from G.T.R. calibration plate*

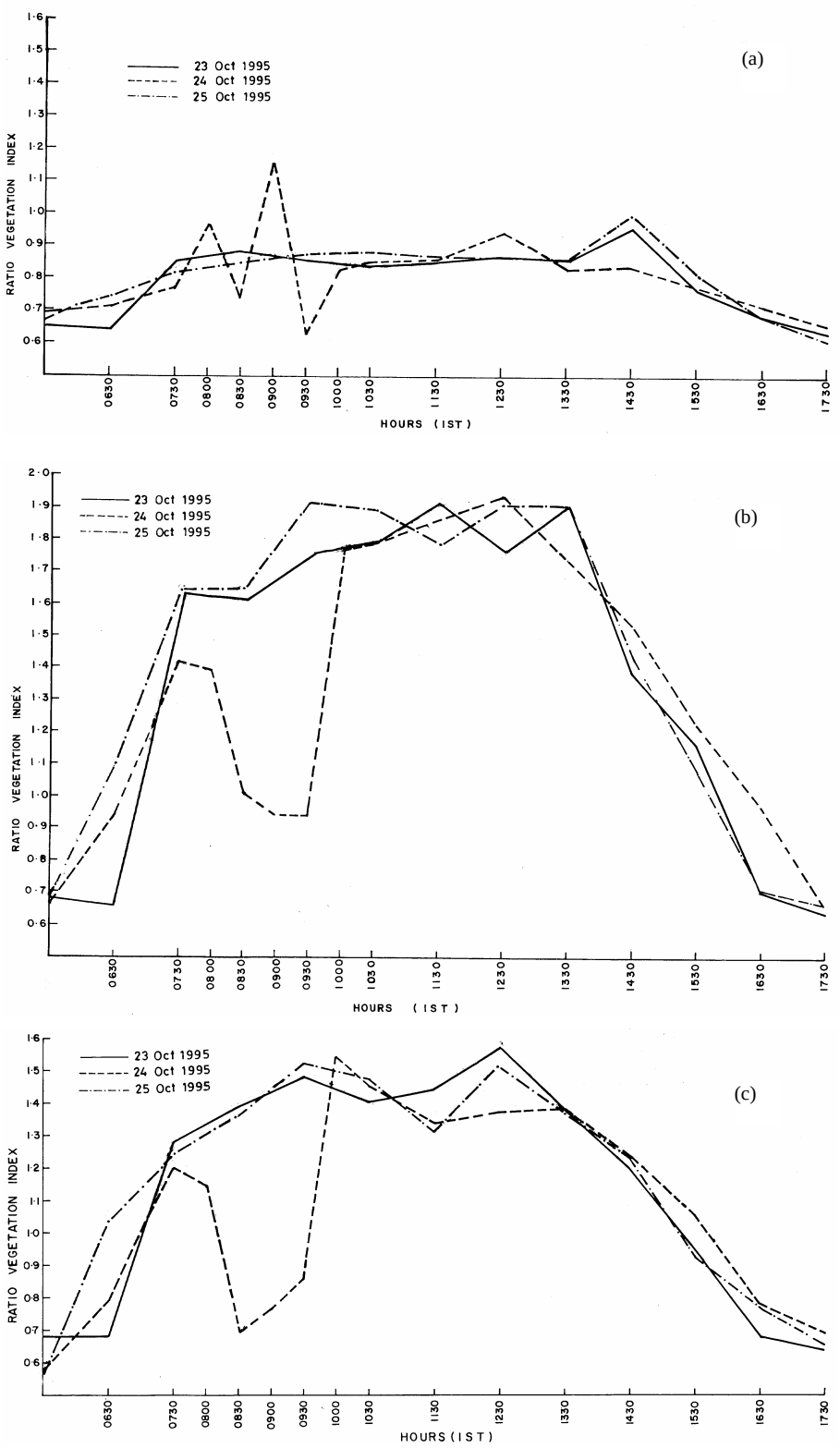
The spectral radiance characteristics obtained from G.T.R. calibration plate during 23 October 1995 to 25 October 1995 in all the first four mean bands showed that on the eclipse day the usual trend was maintained for all the four mean bands. During the eclipse period the minimum values were recorded at 0900 hr IST in all the four bands which were almost comparable to that observed in the early morning (0530 hr IST) or evening (1730 hr IST) hours of observations. Among the four mean bands, the drop was more conspicuous in green (*i.e*. 0.52 to 0.59μ) and red (*i.e*. 0.62 to 0.68μ) wavelengths. The spectral radiance pattern obtained from G.T.R. calibration plate, because of the uniform white $BaSO_4$ coating, is reflecting almost all its radiation incident on it. Thus, its spectral radiance is almost representing the incoming solar radiation in four different bands.

3.3. *Spectral radiance from rice crop, at late vegetative stage*

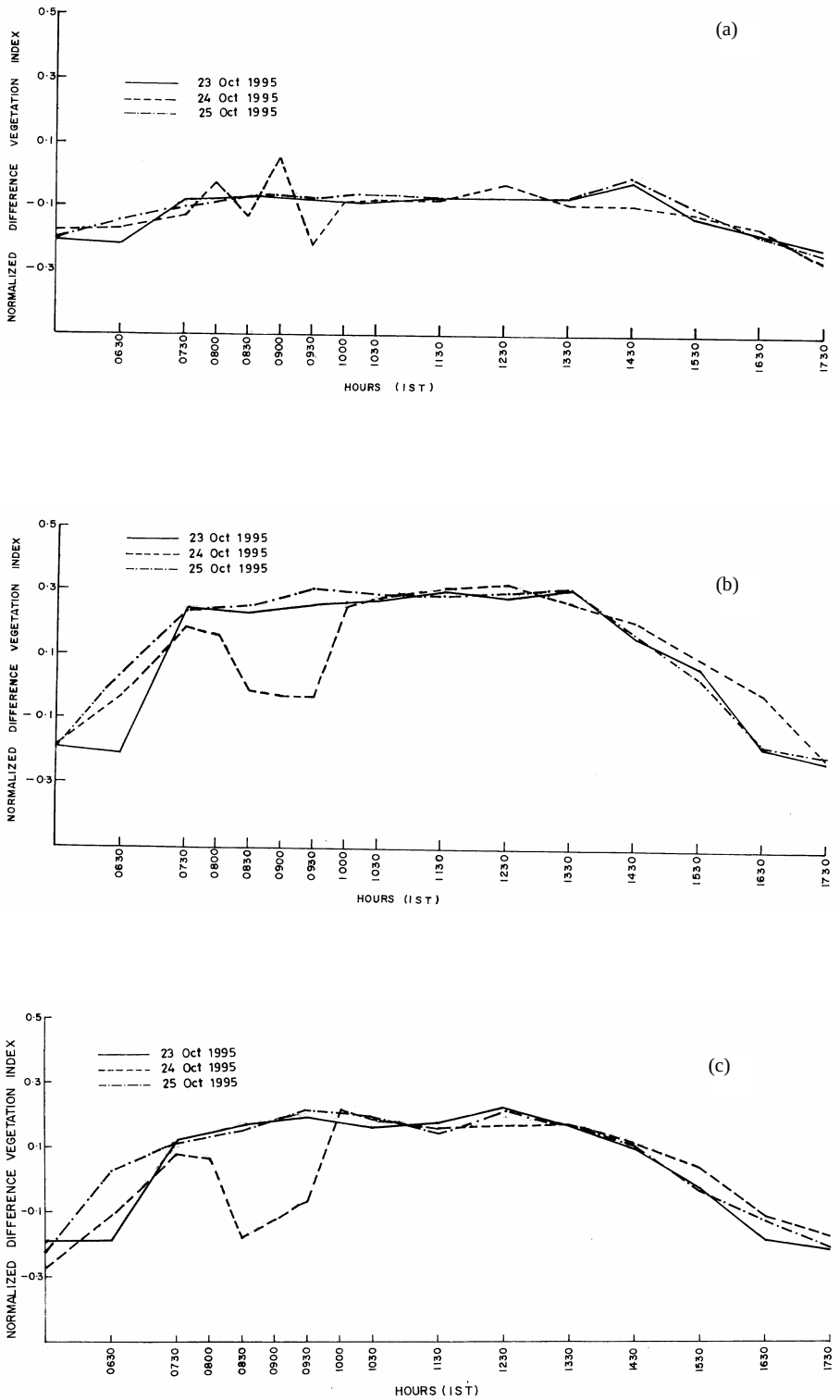
The spectral radiance obtained from rice crop, at late vegetative stage in all the first four mean bands during 23 October 1995 to 25 October 1995 are presented in Figs. 2 (a-d). The usual trends were maintained for all the four mean bands during the days studied. But, on the eclipse day during eclipse period the spectral radiance values were dropped between 0800 to 1000 hr IST. In band I, the values showed sharp fall at 0830, 0900 and 0930 hr IST (each were 0.33) and in band II, III and IV, sharp fall were observed at 0830 hr IST (the values were 0.28, 0.28 and 0.30 in band II, III and IV, respectively). The spectral characteristics obtained from rice crop, at late vegetative stage showed the maximum radiance in the portion of near infrared wavelength (*i.e*. 0.77 to 0.86μ) because this band is sensitive to green or photosynthetically active vegetation (as supported by Colwell 1974, Tucker 1977). During the eclipse period, proportion of drop was the maximum in band IV (*i.e*. in the portion of near infrared) as compared to the other bands. On the eclipse day because of totality, the dropped values were almost comparable to that observed at the early morning or in the evening in all the four bands.



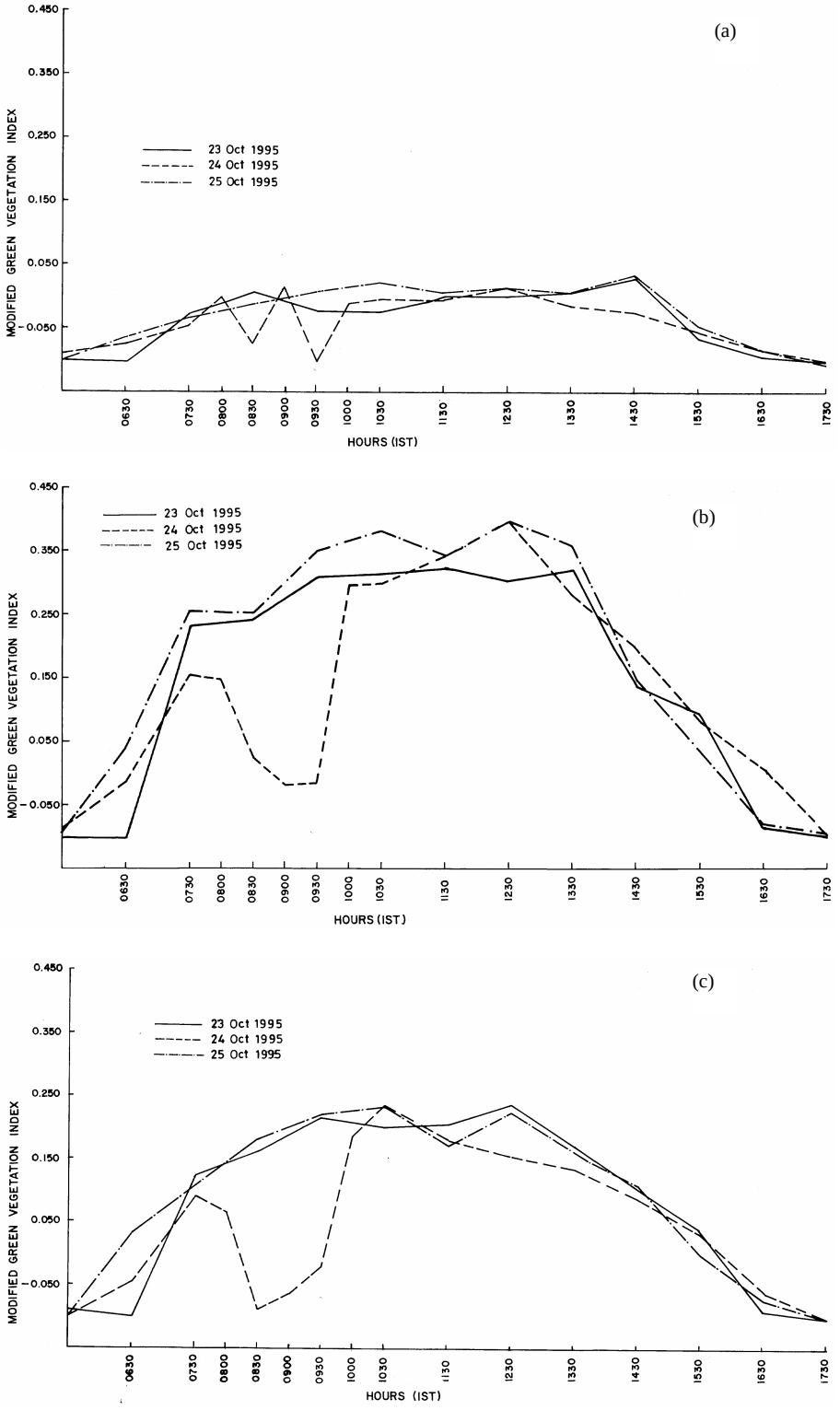
Figs. 3(a-d). Spectral radiance obtained from rice crop at panicle (flowering) stage bare soil in (a) 0.45 to 0.52 μ, (b) 0.52 to 0.59 μ, (c) 0.62 to 0.68 μ and (d) 0.77 to 0.86 μ band of G.T. radiometer, on the eclipse day and in the preceding and succeeding days



Figs. 4(a-c). Computed ratio vegetation index for (a) bare soil, (b) rice crop at late vegetative index and (c) rice crop at panicle (flowering) stage on the eclipse day and in the preceding and succeeding days



Figs. 5(a-c). Computed normalized difference vegetation index for (a) bare soil, (b) rice crop at late vegetative index and (c) rice crop at panicle (flowering) stage on the eclipse day and in the preceding and succeeding days



Figs. 6(a-c). Computed modified green index for (a) bare soil, (b) rice crop at late vegetative index and (c) rice crop at panicle (flowering) stage on the eclipse day and in the preceding and succeeding days

3.4. *Spectral radiance from rice crop, at panicle (flowering) stage*

The spectral radiance characteristics from rice crop, at panicle (flowering) stage was studied to have a comparison with the values obtained from rice crop, at late vegetative stage and are presented in Figs. 3 (a-d). The observations were taken in all the first four mean bands during the study period (*i.e*. from 23 October 1995 to 25 October 1995). The usual trend obtained were almost the same for both the rice crops at different growth stages. On the eclipse day, sharp drop was observed at 0900 hr IST in band I (0.32), at 0930 hr IST in band II and III (the values were 0.31 and 0.33, respectively) and at 0830 hr IST in band IV (0.23). The minimum values recorded during totality phase were almost comparable with the early morning or evening hours of observations. Because of slight reduction in greenness (due to advancement in growth stage of the crop), the spectral radiance in the portion of near infrared (*i.e*. band IV in the wavelength 0.77 to 0.86 μ) was slightly lesser for the rice crop, at panicle (flowering) stage as compared to the values obtained from rice crop, at late vegetative stage.

3.5. *Ratio vegetation index (RVI)*

The computed RVI for bare soil, rice crop at late vegetative stage and rice crop at panicle (flowering) stage are presented in Figs. 4 (a-c). The computed RVI for the bare soil acted as control for comparison. On the eclipse day between 0730 to 1000 hr IST the paths differed from the usual trend. The RVI values for the bare soil showed wide fluctuations between 0730 to 1000 hr IST on the eclipse day. The value of the index showed its peak (1.21) at 0900 hr IST indicating, thereby, that the proportion of NIR was sufficiently high as compared to R in the reflected portion of radiation. In case of both the rice crops, at late vegetative stage and at panicle stage, almost similar trend was observed on the eclipse day during the eclipse period, but the ratio values were very high as compared to that computed for the bare soil. The rice crop at late vegetative stage recorded sharp drop in RVI values at 0900 and 0930 hr IST (both the values were 0.94) on the eclipse day. Similarly, the other rice crop (at panicle/flowering stage) recorded sharp fall at 0830 hr IST (the value was 0.70) on the eclipse day. The results indicated that because of solar eclipse, reduction in reflected radiation occurred in both NIR and R, but the reduction in NIR part was more, as compared to the R part in the wavelength pattern, when the radiation was reflected from rice crop canopy.

3.6. *Normalized difference vegetation index (NDVI)*

The computed NDVI values for the bare soil, rice crop at late vegetative stage and rice crop at panicle stage are presented in Figs. 5 (a - c). On the eclipse day between 0730 to 1000 hr IST, the paths differed from the usual trend. The NDVI values for the bare soil showed fluctuations on the eclipse day between 0730 to 1000 hr IST with the peak (0.05) obtained at 0900 hr IST. The computed NDVI values were slightly higher for the rice crop at late vegetative stage as compared to the crop at panicle (flowering) stage, because of more greenness at the earlier crop growth stage. The NDVI value for the rice crop at late vegetative stage showed sharp drop between 0830 to 0930 hr IST (the values were from −0.01 to −0.03) on the eclipse day. The other rice crop at panicle (flowering) stage showed sharp negative drop at 0830 hrs IST (−0.18) on the day. The rice crop at late vegetative stage recorded positive values between 0730 to 1530 hr IST for all the three days, but, on the eclipse day between 0830 to 0930 hr IST, the values were negative, while the other rice crop observed positive values between 0730 to 1430 hr IST for all the three days studied except on 24 October 1995 between 0830 to 0930 hr IST (when it was negative). So, it may be stated that on the eclipse day during the specified period as mentioned earlier, reflected radiation coming from rice crop canopy showed that proportion of Red was more as compared to NIR, which indicated conformity with the RVI values during the totality phase of the solar eclipse.

3.7. *Modified green vegetation index (MGVI)*

The computed MGVI for bare soil, rice crop at late vegetative stage and rice crop at panicle (flowering) stage are presented in Figs. 6 (a-c). On the eclipse day between 0730 to 1000 hr IST, the paths differed from the usual trend. The MGVI values were slightly higher for rice crop at late vegetative stage as compared to the other two objects. The MGVI values for the bare soil recorded fluctuations on the eclipse day between 0800 & 1000 hr IST with the lowest value (0.1) at 0930 hr IST. The values for the rice crop, at late vegetative stage recorded the lowest between 0900 & 0930 hr IST (all the values were −0.02) on the eclipse day. The other rice crop, at panicle (flowering) stage observed the lowest value at 0830 hrs IST (−0.09) on 24 October 1995. The results thus indicated sharp fall in reflected radiation in all the four bands for all the objects during the totality phase on the eclipse day.

4. Conclusions

The present study revealed the following conclusions :

(*i*) The spectral radiance obtained from bare soil on the eclipse day between 0730 & 1000 hr IST were low as compared to that observed during the preceding and succeeding days. The minimum values were recorded between 0900 & 0930 hr IST for all the bands, which were almost similar to that observed at early morning or at evening.

(*ii*) The spectral radiance obtained from G.T.R. calibration plate recorded the minimum values at 0900 hr IST on the eclipse day in all the four bands, which were almost comparable with the early morning or evening hours of observation. The drop was more conspicuous in green and red bands.

(*iii*) The spectral radiance as obtained on the eclipse day from the rice crop at late vegetative stage showed sharp drop between 0830 & 0930 hr IST in band I and at 0830 hr IST in the rest of the bands. During the eclipse period proportion of drop was the maximum in the portion of NIR band.

(*iv*) The spectral radiance obtained from the rice crop, at panicle (flowering) stage showed sharp drop, at 0900 hr IST in band I, at 0930 hr IST in band II and III and at 0830 hr IST in band IV. Because of slight reduction in greenness of the crop, the reflection in the portion of NIR was a bit lower at this growth stage as compared to the earlier rice crop at late vegetative stage.

(*v*) The RVI values showed wide fluctuations for bare soil between 0730 to 1000 hr IST on the eclipse day. The rice crop at late vegetative stage recorded sharp drop at 0900 and 0930 hr IST on the eclipse day, while the other rice crop (at panicle/flowering stage) observed sharp fall at 0830 hr IST. The RVI values indicated that the reduction in spectral radiance from rice crop canopy was more conspicuous in the portion of NIR band as compared to the R band.

(*vi*) The NDVI values for the bare soil showed fluctuations on the eclipse day between 0730 & 1000 hr IST. The NDVI values for the rice crop at late vegetative stage showed sharp drop between 0830 & 0930 hr IST (both the values were negative) on the eclipse day, while sharp drop was observed at 0830 hr IST (the values were negative between 0830 & 0930 hr IST) for the other rice crop at panicle (flowering) stage. Hence, the NDVI values for the rice crop canopy indicated that the proportion of Red was more as compared to NIR during the specified totality phase.

(*vii*) The MGVI values for the bare soil recorded, fluctuations on the eclipse day between 0800 & 1000 hr IST. The values for the rice crop, at late vegetative stage recorded the lowest between 0900 & 0930 hr IST on 24 October 1995, while the other rice crop, at panicle (flowering) stage observed the lowest value at 0830 hr IST. Thus, the GVI values indicated that on the eclipse day during the totality phase, reflected radiation dropped in all the four mean bands for all the objects studied.

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