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Estimation of ground insolation using METEOSAT data over India

S. Kimothi[1], B. K. Bhattacharya[2], P. D. Semalty[1], V. K. Pandey[2] and V. K. Dadhwal[2,*]

[1]Department of Physics, S.R.T. Campus College, Badshahi Thaul, H.N. Bahuguna Garhwal University, Srinagar 249 199, India
[2]Crop Inventory and Modelling Division, Agricultural Resources Group, Space Applications Centre (ISRO), Ahmedabad 380 015, India

Ground insolation or short-wave incoming radiation (SWR) at the ground is an important input in models of vegetation productivity, hydrology, ecological functioning, crop growth, etc. but is measured over limited number of stations, which fail to capture its spatial variability. A physical retrieval scheme was used for mapping insolation using METEOSAT VISSR sensor data over the Indian landmass for the winter season. The analysis covered the months of November–December 1998 and January 1999, and used five daytime acquisitions of meteosat visible (0.3–1.1 μm), thermal (10.5–12.5 μm), water vapour (6.5–7.5 μm) channel data. A total of 450 images per band per month was processed to retrieve instantaneous, daily total and five-day average total SWR over India. The estimated SWR was compared with the ground-measured pyranometer data over 18 Indian land stations acquired from India Meteorological Department. This validation for instantaneous SWR at 10:00 and 14:00 h, and daily total SWR for six selected dates (1, 5, 10, 15, 20, 25) of each month indicated root mean squared error (RMSE) of 62.51–91.93 Wm^{-2}, i.e. 15–18% of observed mean and 1.14–1.74 MJm^{-2} respectively. When five-day averages for the three-month period were compared, METEOSAT-derived data had a RMSE of 1.93 MJm^{-2}, which is 12% of the mean over pooled data.

THE short-wave incoming radiation (SWR) or insolation received at the ground surface is one of the important inputs to energy–water models, ecological modelling, global climate-change studies, crop-simulation model and models for estimating net primary production (NPP). Ground-based measurements of insolation are generally made with pyranometers or with measurement of duration of sunshine at weather stations. These stations are too sparse to capture spatial variability of SWR. Because of the strong modulation of insolation by clouds, use of RS data is an ideal approach for routine regional mapping of SWR. While use of polar orbiting satellites with sensors such as ERBE[1] having broad visible band or NOAA AVHRR[2,3], Landsat TM[4] with multispectral bands has been made for insolation, it is the geostationary platform that provides multiple passes everyday, ideal for such an application. A

*For correspondence. (e-mail: vkdadhwal@sac.isro.org)

number of approaches such as regression-based[5], numerical[6,7] and physical[8] models have been developed and tested on sensors on-board geostationary satellites such as VISSR on Meteosat (EUMETSAT), VISSR on GMS (Japan), GOES, NOAA (USA). The present study reports retrieval using a simple physical model[9], validating with ground-measured radiation and spatial mapping of insolation in three winter months using METEOSAT geostationary satellite data over the Indian landmass.

The physical retrieval scheme adopted here for deriving instantaneous (Ss) and daily total SWR[9] (St) at ground is shown in Figure 1. The main steps for retrieval are: (i) computation of solar zenith angle (θ) from latitude, longitude, day and time of image acquisition; (ii) cloud detection and characterization, and (iii) atmospheric correction of radiation at top-of-atmosphere (SWR_{TOA}). The model computes instantaneous insolation (Ss, Wm^{-2}) as composed of direct (S_D) and diffuse (S_R: Rayleigh scattering and S_A: aerosol scattering and absorption). Cloudy pixels are detected using bi-spectral threshold technique[10] in VIS and thermal IR data from a given time series. In addition to scattering and absorption by different atmospheric components, the attenuation of insolation by different cloud types was characterized by cloud top albedo (A) and brightness temperature with clear skies, the direct (S_D) and diffuse (S_R and S_A)[11–13] components mainly depend on SWR_{TOA}, θ, correction for sun–earth distance (ε), atmospheric columnar water vapour or precipitable water, ozone content and Angstrom turbidity parameters[14].

$$Ss = (S_D + S_R + S_A)\,(1\text{-}aA), \tag{1}$$

$$A = R/\cos(\theta), \tag{2}$$

where R is the cloud top hemispherical reflectance computed from the ratio of reflected radiance detected by the METEOSAT VISSR and exo-atmospheric irradiance in the METEOSAT broad visible band and a is the cloud attenuation coefficient. Brightness temperature was computed from inverse Planck's function for equivalent blackbody using thermal IR data.

The second term in eq. (1) on the right-hand-side equals 1, when the sky is clear ($a = 0$). A multiple of acquisi-

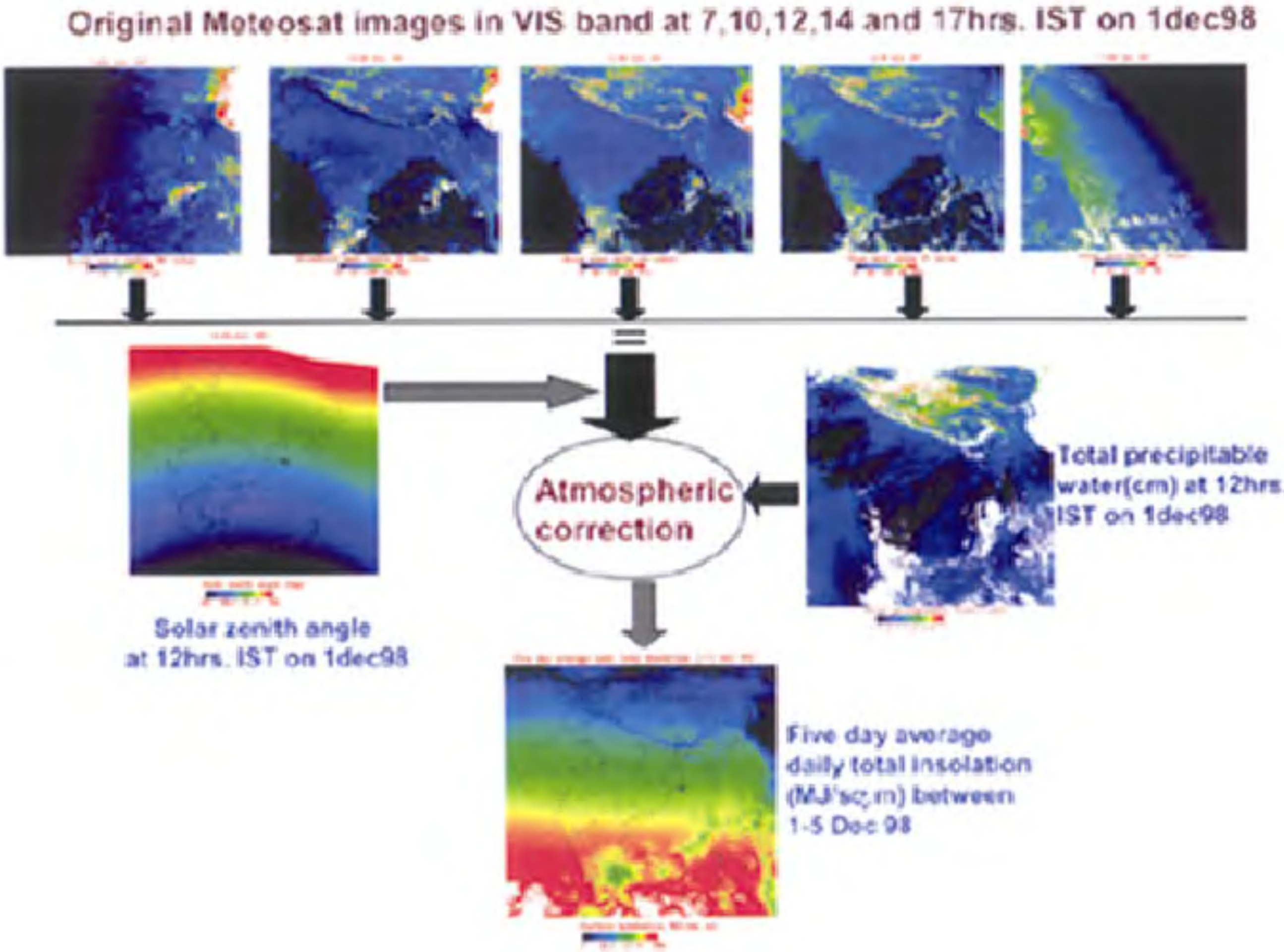

Figure 1. Flow of retrieval of insolation at the ground with geostationary satellite data using a physical model.

tions in a day are used to compute the daily total insolation (St, MJm^{-2}).

$$St = (36 \times 10^{-4})\, L_d (1/N) \sum_{i=1}^{N} Ss\ , \quad (3)$$

where L_d is the daylength (h) which depends on latitude, day of the year and is computed using standard astronomical formulae.

METEOSAT are placed over Africa and Europe, but METEOSAT-5 (EUMETSAT) was shifted to 63°E long from July 1998 to provide Indian Ocean coverage. The Indian Ocean coverage data from a three-channel Imager, MVISSR (Meteosat Visible and Infrared Spin Scan Radiometer) on-board METEOSAT-5 geostationary satellite in visible (0.3–1.1 μm; 2.5 km × 2.5 km resolution), water vapour (WV; 6.5–7.5 μm) and thermal IR (10.5–12.5 μm; 5 km × 5 km resolution) bands were acquired from EUMETSAT. A study region covering 7–38°N to 68–100°E (1338 scan lines and 1442 pixels/scan line) for five acquisitions at 7, 10, 12, 14, 17 h IST for the period 1–30 November, 1–30 December 1998 and 1–30 January 1999 was extracted. The ground measurements of hourly and daily total insolation using pyranometers at 18 land stations for the corresponding period were obtained from India Meteorological Department (IMD) for validation. The hourly measurements at 10:00 and 14:00 h, and daily total were used for validation. Application of the model requires the following parameters in addition to time and sensor geometry, Angstrom turbidity parameters (α and β), ozone content and total precipitable water (TPW). TPW can be estimated by a number of techniques using RS data. It is generally estimated using two split-thermal channels, 10.5–11.5 and 11.5–12.5 μm bands in NOAA AVHRR. However, this cannot be applied to VISSR sensors, which have only one thermal channel. TPW is also available as an operational product (1° × 1°) from NOAA TOVS (TIROS operational vertical sounder) only at satellite overpass (14:00 h equator local time); but due to poor resolution, its direct use in the model created artifacts in the retrieval of insolation in a preliminary investigation. Since the METEOSAT sensor has a single thermal channel (10.5–12.5 μm), it was not possible to estimate TPW using split thermal windows in the current study. Studies with INSAT 2E VHRR WV channel[15] data demonstrated the technique for estimating atmospheric middle level (300–500 mb pressure) layer precipitable water over the Indian Ocean by developing exponential model between brightness temperature of WV band and coincident TOVS middle level layer precipitable water. Thus an approach was developed for computation of TPW METEOSAT 2.5 km resolution using single thermal (IR) and single water vapour channel (WV). An exponential model (TPW = 7.1667*EXP (– 0.041*DBT)) (r = 82.6, N = 150) was developed between NOAA TOVS TPW at 14:00 h. IST and difference of brightness temperatures (DBT) in thermal IR and WV channels of METEOSAT for corresponding acquisition. About 150 datasets from 15 selected clear days in December pooled over ten stations located at different parts of India, were used to develop the model. This relationship was then applied to estimate TPW for all the five acquisitions. Average values of ozone over India (U_{O3} = 0.3 atm-cm) and Angstrom turbidity[14] (α = 1.3 and β = 0.1) for winter visibilities were used in the model.

With cloudy skies, apart from atmospheric inputs, cloud attenuation coefficients for different combinations of cloud top albedo and brightness temperatures obtained from the look-up table[9] were used. TPW with cloudy sky conditions[9] was assumed to be 3.0 cm. Observed hourly and daily total data were subjected to a quality check and before validation, the hourly observed data were converted to instantaneous SWR corresponding to 10:00 h and 14:00 h image acquisitions. The 3 × 3 pixels average of retrieved instantaneous SWR at 10:00 and 14:00 h, daily total and five-day average daily total over 18 land stations were computed. The retrieved instantaneous and daily total SWR on six selected days (1, 5, 10, 15, 20 and 25) during each month was compared with ground observations, whereas all the retrieved five-day average daily total datasets pertaining to different stations were used for validating five-day average insolation.

The observed daily total and corresponding retrieved insolation varied from 5.03 to 20.04 MJm^{-2} and 3.90 to 20.58 MJm^{-2} respectively, during the season.

Retrieval accuracy was assessed by computing mean absolute bias (MABS) and root mean squared error (RMSE). The results from the validation analysis are given in Table 1. MABS and RMSE for instantaneous SWR were 92.0–117.8, 88.35–91.93 Wm^{-2} i.e. 15.2–16.3% of ground observed mean at 14:00 h and 81.25–103.9, 62.51–86.85 Wm^{-2}, i.e. 15.5–17.8% of ground observed mean at 10:00 h respectively and correlation (r) between

Table 1. Statistical analysis for validation of retrieved instantaneous, daily total, five-day average daily total insolation

Acquisition (IST)	Month	Number of cases	r	Mean absolute bias (Wm^{-2})	RMSE (Wm^{-2})
Instantaneous SWR (Wm^{-2})					
10:00 h	November	50	0.752	103.9	62.51
	December	49	0.819	81.25	74.97
	January	58	0.773	92.0	86.85
14:00 h	November	49	0.659	117.8	91.93
	December	51	0.637	77.0	73.72
	January	49	0.715	92.0	88.35
Daily total SWR (MJm^{-2})					
	November	51	0.728	2.23	1.61
	December	48	0.736	1.23	1.14
	January	64	0.845	1.47	1.74
Five-day average (MJm^{-2})					
	November	84	0.726	2.53	1.66
	December	91	0.752	1.79	1.78
	January	96	0.843	1.66	2.02

them was from 0.637 to 0.819. A study on comparison of GOES-derived instantaneous surface insolation[16] with pyranometer observations in USA showed overestimates having 75% correlation with higher RMSE of 135 Wm^{-2} or 28.3% of mean daily values.

The bias and errors for daily total on six days of each month were 1.14–1.61 and 1.23–2.23 MJm^{-2} respectively, and the correlation coefficient between them was 0.728–0.845. This suggests that mean accuracy of retrieval for daily total SWR was 86.5%.

For five-day average daily total these bias, RMSE, r were 1.66–2.02, 1.66–2.53 and 0.726–0.845 MJm^{-2} respectively. A scatter-plot of observed and retrieved five-day average, and SWR for pooled datasets is given in Figure 2. It indicates RMSE of 1.93 MJm^{-2}, i.e. 12% of the mean for winter months. Correlation between retrieved and observed, and retrieval accuracy were substantially improved in daily total and five-day average daily total data than instantaneous data.

Extensive studies with another retrieval approach, the Heliosat model, using METEOSAT data over Europe and Africa gives RMSE of about 40–50 Wm^{-2} for instantaneous SWR and 0.5 MJm^{-2} for daily total[6,9]. The higher observed errors in the present retrieval study over the Indian landmass could be due to the following:

(i) Only five acquisitions were used for the present study, whereas hourly data are generally used. In Japan, with GMS-5 data, RMS error of 0.25 MJm^{-2} for 0.01°grid spatial average of daily total insolation was reported[7] with hourly acquisitions.

(ii) Constant Angstrom turbidity coefficient was assigned instead of using spatially and temporally variable values.

(iii) A simple approach of TPW estimation based on exponential relation as mentioned above was used for the present study as the split-thermal technique is not applicable to METEOSAT. With two split-thermal channels, improved retrieval of TPW is possible, as demonstrated with GMS-5 and GOES. Angular corrections in TPW estimation from single thermal IR and WV channels are, however, needed to account for its diurnal and seasonal variation.

(iv) Cloud attenuation coefficients can vary regionally and seasonally. Revised cloud attenuation coefficients based on ground observations need to be developed.

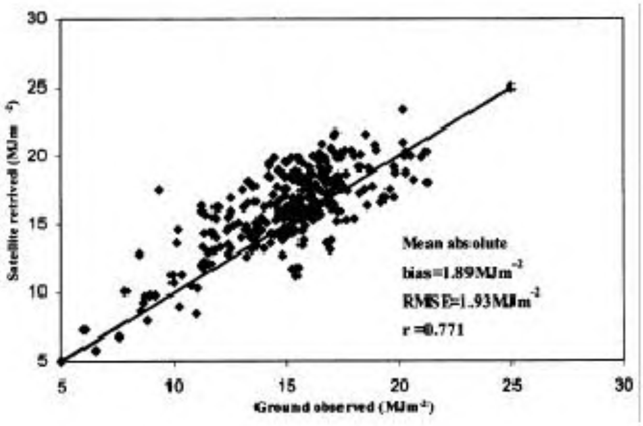

Figure 2. Comparison of retrieved five-day average daily total SWR and observations with pooled datasets over Indian land stations.

The present study has generated instantaneous, daily total and five-day average maps of insolation over India for three winter months (November 1998 through January 1999). This could form the input in a number of applications, such as use of crop-simulation models for yield forecasting, primary productivity models, hydrology-balances, etc. The achieved accuracy is better than alternative approaches like interpolation of sparse network of sunshine hours, which could give estimated accuracy up to 60–70% at spatial distance[17] of 10 km or more, or use of NCEP (National Centre for Environmental Protection) reanalysis insolation data which had overestimates[18] of up to 40%. However, compared to other RS-based retrieval methods, it could be improved by introducing region-specific tuning parameters as discussed above. This procedure can be adapted to INSAT VHRR as future INSAT 3D will carry improved VHRR having broadband VIS, SWIR at 1 km spatial resolution, split thermal channels at 4 km resolution, WV bands at 8 km resolution. Apart from VHRR, it will also carry a sounder which will provide atmospheric temperature and humidity profiles at 10 km spatial resolution. There is a need to develop procedures and software for regular generation of insolation product using INSAT 3D data for a range of applications.

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Kolleru lake is vanishing – a revelation through digital processing of IRS-1D LISS-III sensor data

K. Nageswara Rao[1,*], G. Murali Krishna[1] and B. Hema Malini[2]

[1]Department of Geo-Engineering, and
[2]Department of Geography, Andhra University, Visakhapatnam 530 003, India

Digital processing of the IRS-1D LISS-III image revealed a highly degraded state of the Kolleru lake. Among the several techniques tried, image enhancement through automatic log residuals method clearly indicated that about 42% of the 245 km² lake area was encroached for aquaculture and 8.5% more area was occupied for agriculture, while the rest of the lake is either being dried out by reclamation or is infested with weed. The study provides unambiguous visual information on the alarming levels of human-induced environmental degradation of Kolleru lake, which is one of the important coastal wetland ecosystems in the country.

THE Kolleru lake, situated between the Krishna and Godavari deltas along the east coast of India is the largest (245 km² as in topographic maps of 1930s) freshwater body in the country. Although the lake is about 35 km inland from the present coast, it was a coastal lagoon in the geological past, believed to have been formed around 6000 years BP, when the shoreline was far inland along the southern (seaward) margin of the lake, as evident from the presence of a series of relict sandy beach-dune ridges right up to the southern margin of the lake near Kaikalur and Akividu towns[1]. Kolleru still maintains its connection with the Bay of Bengal through a 60 km long, intricately meandering tidal channel called Upputeru – a typical characteristic of coastal lagoons (Figure 1). Apparently, this lagoon has progressively fallen inland with the advancement of the Krishna and Godavari deltas on both sides of it. As a number of rivulets such as Tammileru, Budimeru and several other smaller ones draining a total catchment of about 5400 km² are decanting their waters into it[2], the Kolleru has turned into a freshwater body, except in its southeastern part where brackish conditions prevail, especially during dry summer months due to incursion of tidal water through Upputeru. The lake continued to exist through thousands of years after its formation, in spite of sedimentation through inland streams and reduction in the flushing capacity of Upputeru due to the overextension of its course by progressive advancement of the coastline far away into the sea. Perhaps its topographical location over a deep-seated tectonic depression, which is geophysically known as Gudivada sub-basin or graben between the Bapatla and Tanuku subsurface ridges or highs[3,4], might be responsible for the persistence of the lake, although other lagoons much younger to Kolleru in the area toward the coast seem to have been emerged and dried out subsequently[5].

Kolleru has been designated as a Ramsar site[6], considering that the lake functions as a flood-balancing reservoir between the Krishna and Godavari deltas and that it supports vulnerable species like grey pelican as well as water fowl, including a variety of resident and migratory birds. However, the reality appears different. Due to lack

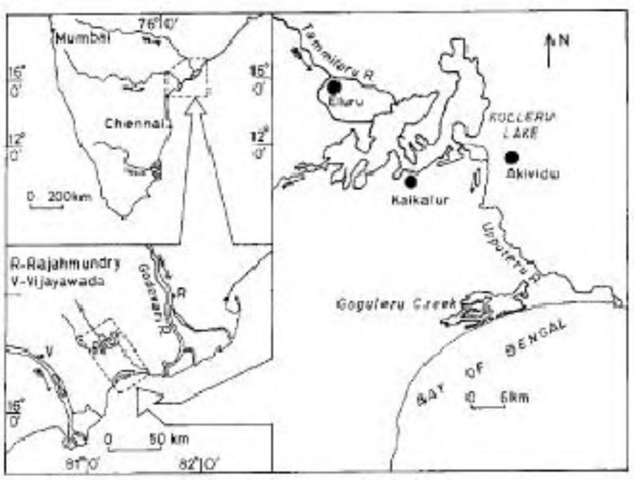

Figure 1. Map showing the location of Kolleru lake.

*For correspondence. (e-mail: nrkakani@yahoo.com)