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Analysis of Short and Long Wave Radiation over Bengaluru

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Abstract

The surface radiative energy remains the primary component of the energy balance of the earth atmosphere system and is a central determinant of the earth's climate. Energy is exchanged between the surface and the air radiatively at visible and infrared wavelengths through conduction, convection or latently. This energy at the surface of earth is important to many inter-related research disciplines such as atmospheric sciences, hydrology, agrometeorology and climatology. The incoming short wave radiation is a primary source for photosynthetic activity and the hydrological cycle. The availability of surface radiation is also important for architects and solar engineers. It gives an accurate estimate of the available solar energy resource. Energy exchange between land and atmosphere are important in climatic processes. In this paper, the diurnal and seasonal dynamics and variations of surface radiation components are investigated. One year data is used to emphasize the separate contribution of each radiation balance component. The analysis shows important results such as

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the relevance of the short wave radiation in the net radiation budget especially in the wet season and the variations of the long wave radiation.

1. Introduction

The Sun is the ultimate source of energy that drives the weather on Earth. From everyday experience, it is known that the Sun emits light, heat and other radiations. All types of radiation, whether gamma, x-rays, UV, visible, radio waves and heat waves, travel through the vacuum of space at 3×10^5 km/s. Radio waves have the longest wavelengths, up to tens of kilo meters in length. Gamma rays are the shortest, being less than a billionth of a centimeter long. Visible light is roughly in the middle of this range. It is important to note that the Sun emits all forms of radiation, but in varying quantities. The short waves ($\lambda<4$ μm) carry most of the energy associated with solar radiation and long waves ($\lambda>4$ μm) encompass most of the terrestrial (Earth-emitted) radiation. The relatively narrow visible region, which extends from wavelengths of 0.39 to 0.76 μ mis the wavelength that human eye is capable of sensing. The near infrared region extends from the boundary of the visible up to 4 μm, is dominated by solar radiation, whereas the remaining part of infrared region is dominated by terrestrial radiation. Hence, near infrared region is included in short wave radiation. Microwave radiation is not important in the Earth's energy balance but it is widely used in remote sensing because it is capable of penetrating through clouds (Kounouhewaet al. 2013).

The Earth's surface reflects part of the solar energy. The most obvious aspect is the brightness of the Earth's cloud cover. A significant part of the Earth's reflectivity can be attributed to clouds. The albedo of Earth depends on the geographical location, surface properties and the weather. On average, Earth's albedo is about 0.3. This fraction of incoming radiation is reflected back into space. The other 0.7 part of the incoming solar radiation is absorbed by our planet. By absorbing the incoming solar radiation, the Earth warms up, like a black body and its temperature rises (Gautier, 1984). If the Earth would have had no atmosphere or ocean, as is the case for example on the moon, it would get very warm on the sunlit face of the planet and much colder than we experience presently, on the dark side. The exchange of energy between land and atmosphere are important in climatic processes. In view of this, in the present work we have investigated the diurnal and seasonal dynamics and variations of surface radiation components using one year data to emphasize the separate contribution of each radiation balance component. The analysis shows the relevance of the short wave radiation in the net radiation budget especially in the wet season and the variations of the long wave radiation.

2. Experimental Methodology

Continuous atmospheric observations were made by making use of a Mini Boundary Layer Mast (MBLM) deployed at Bangalore University (12.945 N, 77.507 E and 920 m above mean sea level) under the network of Indian Space Research Organization (ISRO) Government of India. MBLM uses advanced high resolution sensors such as pyranometer and pyrgeometer to measure the incoming short wave radiation and outgoing long wave radiation, respectively. The pyranometer is high-performance smart sensors for the measurement of general purpose solar radiation in automatic weather station environments. The sensor is based on a multi-element thermopile, with a two-stage filter system that determines the spectral band of energy measured. A quartz dome and a planar filter isolate the radiation thermopile from the environmental effects. The structure of the sensor is conducive to easy thermal equilibrium. The sensor has a precision temperature sensor for accurate measurement of the second junction temperature of the thermopile. Signal processing is built-in the sensor device with a 24 bit sigma-delta precision quantized and a co-housed microprocessor making the main and auxiliary measurements and converting the results to Wm^{-2}. The sensor also offers the measured values of the microvolt outputs of the thermopile and of the temperature measurements. However, pyrgeometer is used for measuring long wave radiation originating from the atmosphere and earth surface. The long wave radiation can be measured either directly by subtracting the global radiation from the total radiation or directly using pyrgeometer. The thermocouple receiving surface radiations is covered with a hemisphere dome. This dome has a silicon coating inside which acts as an interference filter. Pyrgeometer gives a full view. The measured output signal is the difference between the irradiance emitted from the source and the black body radiative temperature of the instrument, while using these pyrgeometers it is necessary to know the temperature of the detector. Knowing detector temperature, a correction can be applied. The missing data is vey less and about 15% on an average for the entire year. Hence, statistically the values obtained are also of significance.

3. Results and Discussion

The data stored in the data logger of the MBLM is in a non-readable format. This data is converted in text files by running a suitable code and the output is given in hourly averages. The quality control of data made by checking the validity of data and omitted erroneous values beyond 3σ values. There are a few studies available on radiation energy budget (Liet al. 2015).The total flux of solar radiation, S~1360 Wm^{-2}, of this 30% is reflected back fromEarth by bright surfaces including clouds and ice. The remaining component is absorbed, warming the surface and the atmosphere. Much of the heat radiation emitted by the surface is trapped within the atmosphere by greenhouse gases, mainly water vapour, but in the absence of other changes, enough heat is emitted to space to balance the incoming solar radiation and establish climate equilibrium. While this balance is achieved globally, not every location on the Earth's surface is in energy balance and it is the distribution of the net radiation imbalances that drives the global circulations of the atmosphere and oceans.

Near the Earth's surface, many variables have a characteristic diurnal or daily cycle, driven by the diurnal cycle of the incoming solar radiation, which is zero at night and peaks at local noon. The atmosphere is relatively transparent to the shortwave radiation from the Sun and relatively opaque to the thermal radiation from the Earth. As a result, the surface is warmed by a positive net radiation balance in the daytime, and cooled by a negative radiation balance at night. The surface temperature oscillates almost sinusoidal between a minimum at sunrise and a maximum in the afternoon hours. This is referred to as the diurnal cycle. The variation of incoming shortwave and outgoing long wave radiation for a typical day are shown in Fig. 1. Also shown is the variation of incoming, outgoing and net wave radiations with in-situ measurement of temperature near to the surface of Earth. In warm seasons, the daily net radiation balance is positive, and the daily mean temperature is determined by the daily mean surface energy balance, which involves not only the short and long wave radiation components, but also heat transfers to the atmosphere. The magnitude of this diurnal range of temperature is determined by many factors. The most important are the nature of the underlying surface, whether land or water, and the coupling to the atmosphere above. The phase change of water, particularly evaporation and condensation, plays an important role in moderating the diurnal range of temperature, because of the large latent heat of vaporization. In cold climates the freezing and thawing of the soil is also important on the seasonal time scale. Over the ocean (and large lakes), the diurnal temperature range is small, because the incoming solar energy is mixed downward into an ocean 'mixed layer', which is usually tens of meters deep.

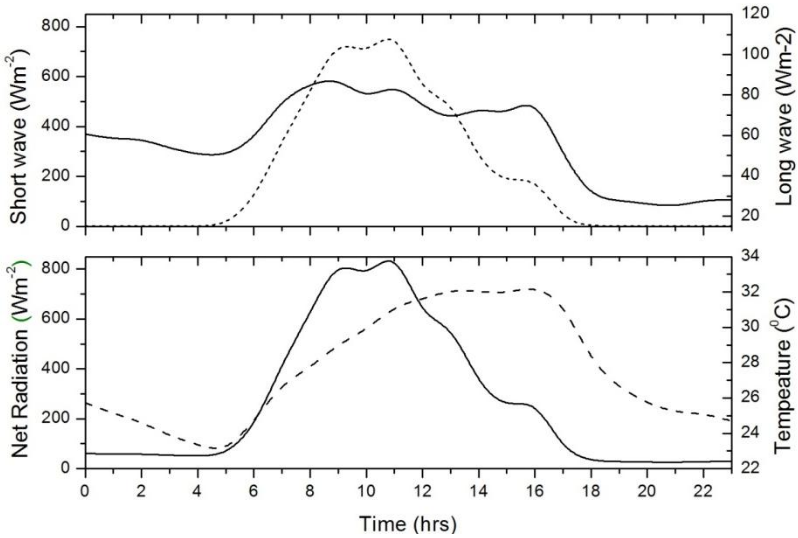

Fig. 1: Diurnal variation of incoming shortwave (dotted line) and outgoing long wave (solid line) radiation on top panel, and of Net radiation (solid line) and temperature (dashed line) in bottom panel for a typical day

On time scales longer than the diurnal, evaporation of water primarily balances the surface net radiation budget. Over land, only a small fraction (20%) of the net radiation at the surface is conducted downward in daytime, or stored by warming trees on the surface for example. As a result, the surface temperature rises rapidly after sunrise until near balance is achieved between the net radiation and the direct transport of heat to the atmosphere (referred to as the sensible heat flux) and evaporation of water (or transpiration from plants), referred to as the latent heat flux. If the surface is a desert then the daytime temperature rise is large, but if water is readily available for transpiration then the daytime rise of temperature is greatly reduced, because most of the net radiation goes into the latent heat of vaporization. The surface sensible and latent heat fluxes have a large diurnal cycle, with a peak near local noon, as they are driven primarily by the incoming solar radiation. The surface temperature peaks a little later in the afternoon, when the surface sensible heat flux goes negative as the surface cools. The temperature is minimum during night time and increase after sunrise and reaches peak value during afternoon hours. The temperature and relative humidity are anti-correlated. The temperature structure is mainly because of incoming solar radiation and outgoing long wave radiation during day and only due to long wave radiation during night time. The long wave radiation profile is in similar trend with the temperature observed. However, the net radiation is mainly by the short wave radiation.

Daily variation of incoming and outgoing energy

The amount of solar radiation absorbed by any surface is simply the product of how much solar energy is incident on that surface, and the fraction of that incident radiation that is absorbed. The flux of solar radiation at any location is a vector and has a magnitude, which is the energy it carries, and a direction, which is the direction from the Sun to that location.

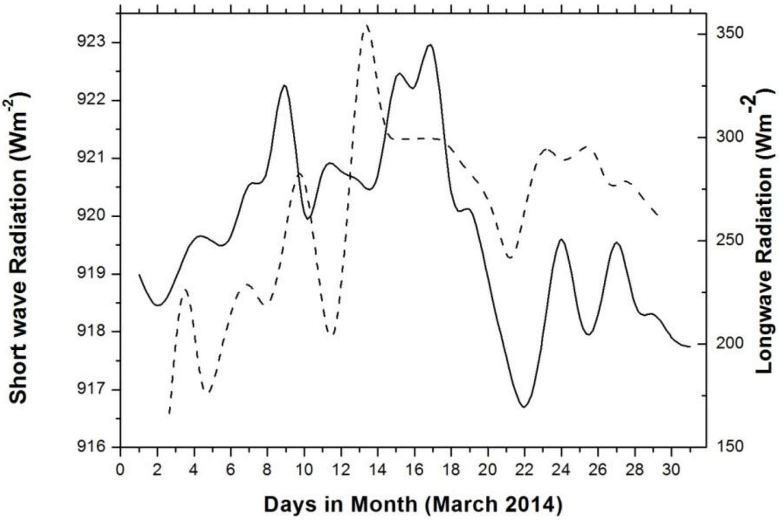

Fig. 2: Daily variation of incoming shortwave (solid line) and outgoing long wave (dashed line) radiation

The key parameter determining how much energy is incident on a given surface is the angle between the direction of the Sun and that surface (Garrat and Prata, 1996). If the surface is turned to face the Sun, i.e., directly overhead for a flat surface on the ground, it receives its maximum solar energy, the same as the magnitude of solar flux at that level. Otherwise, the surface receives an amount reduced by the cosine of the angle between the direction of the Sun and the line that the Sun would take for maximum receipt of solar energy. This geometrical reasoning for the determination of the amount of incident solar radiation enters in many ways of descriptions of climate over land and climate in general. The daily variation of incoming and outgoing radiation from Sun and Earth are shown in Fig. 2. There is a correlation between the two and the difference between them shows the energy required for different atmospheric processes.

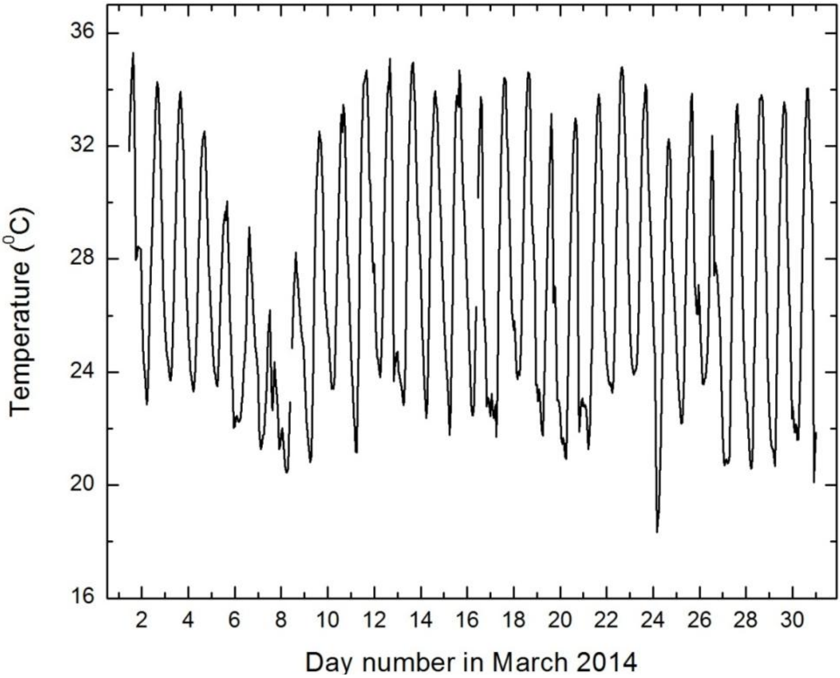

Fig. 3: Continuous variation of temperature during March 2014

Fig. 3 shows the continuous variation of hourly values of temperature for entire month i.e., in March 2014. The temperature in 2013 (not shown in graph) shows a consistency for different days with minimal deviations from day-to-day due to wind and turbulence. However, in March 2014, the temperature has decreased from the beginning to 10th March and exhibited a behavior similar to that of 2013 in the later part. This is clearly influenced by the change in long wave radiation during 2014, i.e. the long wave also shows similar trend. Further, long-term study is required to see this behaviour.

Monthly mean of incoming and outgoing radiation near earth's surface

The monthly variation of short and long wave radiation are shown in Fig. 4. The seasonal and latitudinal distribution of insolation is an important determinant of climate. The instantaneous insolation per unit of surface area is given by the total solar irradiance times the cosine of the solar zenith angle, the angle between local vertical and the Sun. The daily average insolation available at the top of the atmosphere is given as a function of latitude and season.

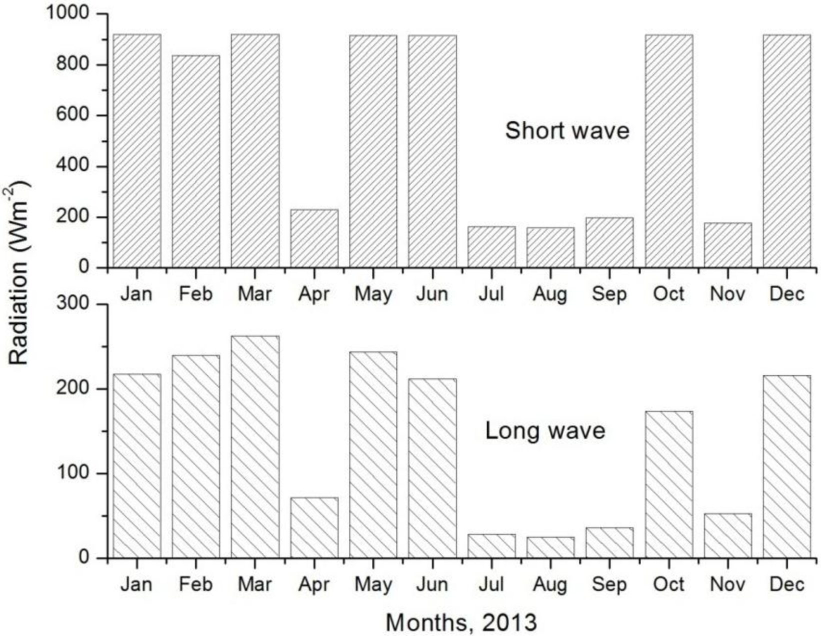

Fig. 4: Relative variation of short/long wave radiation for different months in 2013

The insolation decreases with increasing latitude, except in summer, and the annual variation of insolation is greatest near the poles, where six months of darkness alternate with six months of daylight. In Polar regions during summer, the available insolation is greater than that at the Equator, because, although the Sun is near the horizon, it shines 24 hours a day at the poles during the summer half-year. The insolation available during Southern Hemisphere summer is about 7% greater than that available during Northern Hemisphere summer, because the Earth's orbit is not perfectly circular and at the present time the Earth is closer to the Sun during Southern Hemisphere summer.

The monthly statistical variation of temperature for 3-heights i.e., 4m, 8m and 15m and short/long-wave radiation for the year 2013 is shown in Fig. 5. The temperature is more or less constant throughout the year except during March, April and May. It shows that the year shown does not have any extreme weather conditions. Similar behaviour is observed with incoming short wave radiation and is due to the geometry of earth and sun. However, the outgoing long wave radiation is considerably more during June to September and it is evident of monsoon over the region.

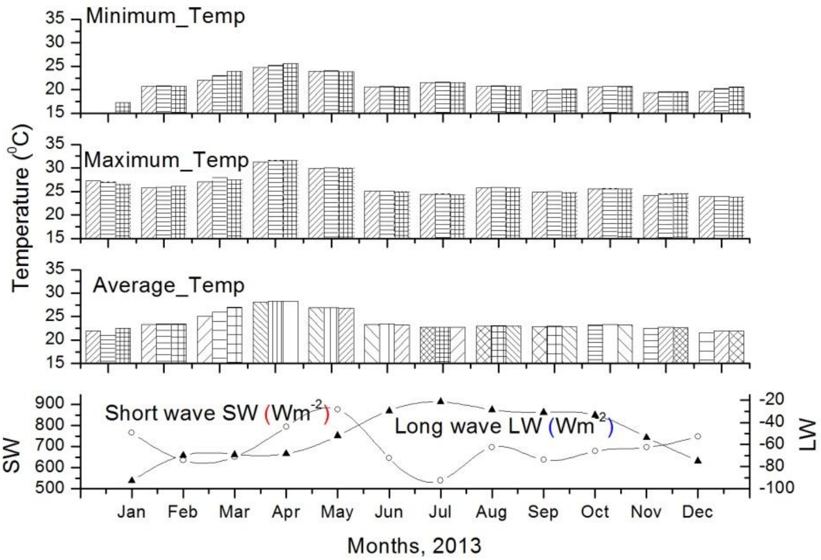

Fig. 5: Statistical variation of monthly values of temperature for different height and short and long wave radiation for 2013

Continuous observations were made by making use of pyranometer and pyrgeometer for incoming solar radiation and the radiation emitted by the Earth's surface for two years. The link between the Earth's atmospheric temperature with short and/or long wave radiation and their correlations were studied in detail. The temperature at the surface shows correlation of 20%, 29% and 36% with shortwave, long wave and net radiation, respectively. It suggests that the temperature is mainly by the radiation energy budget of the Earth and its atmosphere.

Seasonal variation of incoming and outgoing energy

For given amount of solar absorption and net radiation, the land surface can still reach a wide range of states and interact with the atmosphere over a wide range of possibilities. Over the course of a day, some of the daytime heating can conduct downward into the soil and be released again at night. Averaged over day and night, the net absorption of radiation is largely balanced by fluxes of energy that the land surface delivers to the atmosphere. The turbulent motion of air near the land surface determines these fluxes. Convection and mechanical mixing in turn determine the intensity of the turbulence. The intensity of mechanical mixing is determined by the strength of surface winds and by the roughness of the surface. Positive net land surface heating normally occurs only during the day, and it usually has small negative values at night. The energy carried from the surface by water vapour is simply the energy that was required to evaporate the water from its liquid state at the land surface or equivalently the energy that will be released when this water vapour is converted back to liquid form through formation of clouds and precipitation. The transport of dry atmospheric energy is the energy carried upward by relatively warm air rising and cold air sinking.

This transport of dry atmospheric energy provides the intense daytime convection that generates the boundary layer turbulence needed to remove the energy supplied to the surface by daytime radiation. The flux of dry energy is proportional to the difference between land surface temperatures (i.e., that of leaves and soil surface) and that of the overlying air (Li et al. 2015). The flux of water vapour is proportional to the difference between water vapour concentrations at the surface and that of the overlying air. Where materials at the surface are supplied with water, such as inside leaves and in moist soil, the consequent water vapour concentration depends only on temperature. How the land surface responds to a given amount of net radiation depends on how it divides the removal of this energy between evaporation and dry atmospheric energy flux. The seasonal variations of short and long wave are shown in Fig. 6. Both show seasonality and are more during monsoon season compared to other seasons. However, long wave radiation shows predominant changes.

4. Summary

This research analyses the continuous observations of incoming shortwave and outgoing long wave radiation over a tropical station Bengaluru. In this paper, the diurnal, daily, monthly and seasonal dynamics

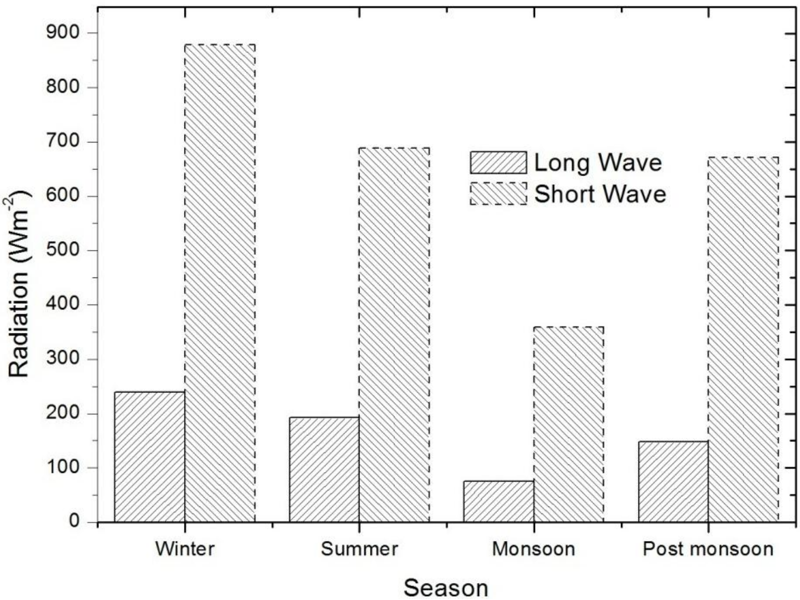

Fig. 6: Seasonal variations of short and long wave radiation

and variations of surface radiation components are studied and reported. The data is used to emphasize the separate contribution of each radiation balance component. The analysis show important results such as the relevance of the short wave radiation in the net radiation budget especially in the wet season and the variations of the long wave radiation.

Even though, the incoming solar radiation from Sun drives the atmosphere, the land surface energy fluxes such as latent heat, soil evaporation, sensible heat, and the ground heat flux play an important role. Therefore the main aim of this work is to achieve energy flux to show that indeed the relationship between incoming radiation and outgoing long wave fluxes will be additional information for refining the models. The continuous observations were made to measure the incoming solar radiation and the radiation emitted by the Earth's surface. The temperature at the surface shows correlation of 20%, 29% and 36% with shortwave, long wave and net radiation, respectively. It emphasizes that the atmospheric temperature is the result of radiation energy budget of the Earth and its atmosphere.

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