Journal of Agrometeorology

ISSN : 0972-1665 (print), 2583-2980 (online)
Vol. No. 25 (1) : 51 - 60 (March- 2023)
DOI: https://doi.org/10.54386/jam.v25i1.1971
https://journal.agrimetassociation.org/index.php/jam

Invited Articles (Silver Jublee Publication)

Importance of solar radiation and the need for improved respect to Sun by Agrometeorologists

MANNAVA SIVAKUMAR

Founding Editor-in-Chief, Weather and Climate Extremes (Elsevier)Geneva, Switzerland
e mail: mannavas@gmail.com

ABSTRACT

Solar radiation refers to energy produced by the Sun, some of which reaches the Earth. This is the primary energy source for most processes in the atmosphere, hydrosphere, and biosphere. Solar radiation is of crucial importance in providing the energy source for photosynthesis. During 1973 to 1977, when I did my Ph.D. in Agroclimatology in the Iowa State University, USA, I conducted the field experiments during 1975 and 1976 on soil-plant-water relations, growth and nutrient uptake patterns of field grown soybeans under water stress at the Western Iowa Experimental Farm, Castana. During these experiments, the solar radiation was measured with a pyranometer sensor mounted on an anodized aluminimum base. Daily solar radiation values were obtained from an LI-500 integrator attached to the pyranometer sensor. The attenuation of photosynthetically active radiation (PAR) and net radiation (NRAD) in the soybean canopy was determined during the growing season by using vertical profiles of radiation and leaf-area-index values. Once I received my Ph.D., I worked at the Headquarters of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Hyderabad from 1977 to 1983 and at the ICRISAT Sahelian Center, Niamey, Niger from 1984 to 1996. In several field experiments in ICRISAT, the hourly values of net radiation were obtained through net radiometers mounted above the crop canopies. The growth and interception of PAR in a maize/pigeonpea intercrop and sole maize and sole pigeonpea crops grown in large plots were compared. The productivity of maize, sorghum, pigeonpea and a maize/pigeonpea intercrop in the operational research watersheds was measured in relation to the interception of PAR. In another study, it was shown that different shading ability of the crop canopies was one of the factors which determined the crop/weed competition balance and thus contributed to differential crop productivity observed in different cropping systems. Afterwards, when I worked at the World Meteorological Organization from 1996 to 2016 as the Chief of the Agricultural Meteorology Department, as the Director of the Climate Prediction and Adaptation Branch and as the Acting Secretary of the Intergovernmental Panel on Climate Change, a lot of work was done on Solar Radiation. Given all the above work on Solar Radiation, I emphasized the need for improved respect to Sun Bhagawan by Agrometeorologists at the end of this article.

Key words – Solar radiation, Photosynthetically Active Radiation, Net Radiation, Photosynthetic photon flux density, Improved respect to Sun

The sun is way bigger than the Earth. In fact, its radius is 109 times bigger than the radius of the Earth. For those of you who are curious, the sun's Radius is 696,000 km and the Earth's radius is 6,376 km (NASA, 2022). The sun's average surface temperature is 5,700 °C. Compare that to the Earth's average temperature, which is 20 °C. The sun is 150 million km (93 million miles) away from the Earth.

Fig. 1 shows white Sun in the blue sky, which is very normal. When we use our eyes to see the white Sun in the sky, we can see that around the Sun, there is a bright red color (Fig. 2). Sometimes, instead of the red color, even a bright yellow color appears. Nothing is more important to us on Earth than the Sun. Sun is the primary source of energy on earth. May be, you know the importance of oxygen and air on the earth. Oxygen is impossible without sun, as oxygen generates at the time of photosynthesis and photosynthesis doesn't take place without sun light. Solar radiation is the energy emitted by the Sun in interplanetary space. Some of the energy produced by the Sun reaches the Earth. Without the Sun's intense energy and heat, there would be no life on Earth. While the Earth's climate is influenced by many factors – among them greenhouse gases, ocean temperatures and volcanic eruptions – the sun plays a particularly central role. Scientists therefore rely on solar radiation measurements in order to

***Article info - DOI**: https://doi.org/10.54386/jam.v25i1.1971*
Received: 24 November 2022; Accepted: 07 December 2022; Published online : 17 February 2023

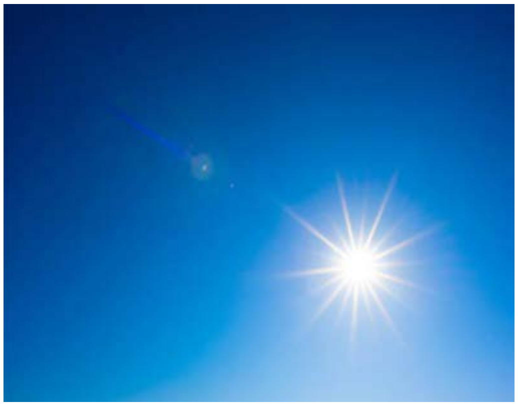

Fig. 1: White Sun in the blue sky, which is very normal.

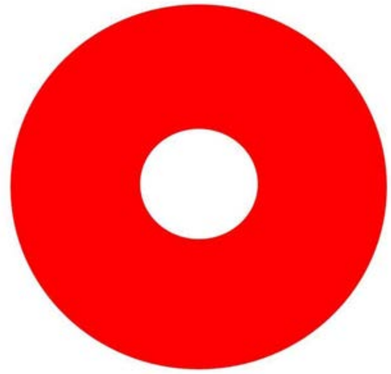

Fig. 2: Bright red color around the Sun, when we use our eyes to see the white Sun in the sky.

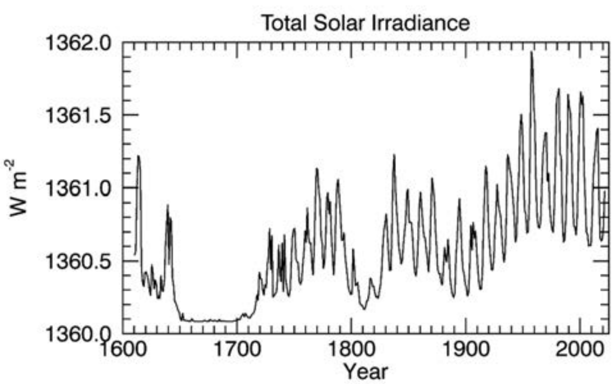

Fig. 3: Reconstruction of total solar irradiance based on sunspot observations since the 1600s (NOAA Climate.gov image, based on the Climate Data Record by Coddington, et al., 2016)

study climate variability and change and to forecast the weather.

Agriculture is an exploitation of solar energy, made possible by an adequate supply of water and nutrients to maintain plant growth (Monteith, 1958). Although 99% of the solar radiation falls between limits of 0.2 and 4 microns, different wavelength bands show various biochemical effects. The wavelength band from 0.4 to 0.7 microns is photosynthetically active radiation (PAR). The photon flux density of PAR is defined as photosynthetic photon flux density or PPFD (Shibles, 1976).

Solar radiation is becoming increasingly appreciated because of it's influence on living matter and the feasibility. Solar radiation is the primary energy source for most processes in the atmosphere, hydrosphere, and biosphere.

Solar radiation is the primary source of warmth for land, and the driver of plant photosynthesis. It is well documented that stomatal closure is the main cause for transpiration decline as water stress develops. The total resistance of the leaf follows a diurnal pattern of behaviour, with higher resistance during periods of darkness and lower resistances during periods of light. Stomatal resistance has been shown to be a definitive function of light intensity. In well-watered crops, light is a primary determinant of stomatal resistance (Turner, 1969). Dale (1961) showed that stomatal opening of cotton leaves was highly correlated with solar radiation within a day. Stomatal resistances of crop canopies have been found to increase in the lower portion of the canopy (Hatfield, 1975), which is attributed to diffuse light extinction in the canopy.

Designs of homes take advantage of this by siting their walls, windows, and landscaping to capture the levels of light needed for optimum growth of indoor and outdoor plants, to reduce the solar heating at times of year and day when outside temperatures exceed human comfort levels, and to maximize solar heating when outside temperatures are uncomfortably cold (Dickinson, 2003).

Reconstruction of total solar irradiance based on sunspot observations since the 1600s is shown in Fig.3. During strong solar cycles, the Sun's total average brightness varies by up to 1 Watt per square meter. Changes in the Sun's overall brightness since the pre-industrial period have been minimal, making a very small contribution to global-scale warming. NOAA Climate.gov image, based on the Climate Data Record by Coddington, et al., 2016.

Changes in the Sun's overall brightness since the pre-industrial period have been minimal, likely contributing no more than 0.01 degrees Celsius to the roughly 1 degree of warming that occurred over the Industrial period.

In the context of current global change, over the last 40 years scientists have measured slight fluctuations in the amount of energy released by the Sun and have found that global warming today is not caused by changes in the amount of energy coming from the Sun.

The Sun emits many forms of electromagnetic radiation in varying quantities. About 43 percent of the total radiant energy emitted from the Sun is in the visible parts of the spectrum. The bulk of the remainder lies in the near-infrared (49 percent) and ultraviolet section (7 percent). Less than 1 percent of solar radiation is emitted as x-rays, gamma waves, and radio waves.

We make use of this solar energy in a number of different ways. It helps to support life, can generate electricity and can even heat our water.

Our sun gives us light, heat and energy. It may seem that energy comes from other sources such as gasoline and electricity but the ultimate source of energy for the Earth is nothing else but the sun. Without the sun, life on Earth would not exist. It would be so cold that no living thing would be able to survive and our planet would be completely frozen.

From the simulation models, the Intergovernmental Panel on Climate Change (IPCC) concluded that climate forcing from changes in solar radiation and volcanism is likely to have caused fluctuations in global and hemispheric mean temperatures in the first part of the 20^{th} century. Well-mixed greenhouse gases (carbon dioxide, methane, chloroflurocarbons etc.) must have made the largest contribution in radiative forcing to warm the climate in the late 20^{th} century (IPCC, 2001).

A comprehensive review of published scientific research by the IPCC concluded that, averaged over the solar cycle, the best estimate of the Sun's brightness change between the pre-industrial period and the present (2019) is 0.06 Watts per square meter. That increase could be responsible for about 0.01 degrees Celsius—around 1 percent—of the warming the planet has experienced over the industrial era (0.95–1.2 degrees Celsius in 2011–2020 versus 1850–1900).

REVIEW OF WORK ON THE IMPORTANCE OF SOLAR RADIATION

Review of work at the Iowa State University, USA (1975 -1976)

During 1973 to 1977, when I did my Ph.D. in Agroclimatology in the Iowa State University, USA, I conducted the field experiments during 1975 and 1976 at the Western Iowa Experimental Farm, Castana to evaluate the effects of moisture stress on the growth, nutrient accumulation and stomatal resistance of soybeans. During these experiments, the solar radiation was measured with a pyranometer sensor mounted on an anodized aluminimum base. Daily solar radiation values were obtained from an LI-500 integrator attached to the pyranometer sensor. Net Radiation (NRAD) is correlated strongly with solar radiation, as reported by Shaw, (1956); Fritschen, (1967); and Davies and Buttimor, (1969). In the research work afterwards on photosynthesis-radiation relationships, more preference is given to measuring photosynthetically active radiation (PAR) than the total short wave radiation. Because solar radiation and PAR are highly related, it was expected that PAR and NRAD at the top of the canopy would also be highly related.

In the field experiment, conducted at the Western Iowa Experimental Farm, NRAD was measured with a precalibrated portable net radiometer and PAR was measured by using a quantum sensor equipped with a quantum meter. The attenuation of PAR and NRAD in the soybean canopy was determined during the growing season by using vertical profiles of radiation and leaf-area-index values.

In the article on "Leaf response to water deficits in Soybeans", Sivakumar and Shaw (1978) quoted that the apparent differences in the leaf area distributions in the canopy seemed to be mediated by moisture stress effects associated with leaf senescence and light penetration in the lower depths of the canopy.

Sivakumar and Shaw (1979) informed that irradiance is not uniformly distributed over the surface of all leaves in crop canopies under field conditions. Available energy decreases progressively from the top of the canopy downward. The radiation values of great interest in plant communities are NRAD and PAR because of their close association with evapotranspiration and photosynthesis, respectively.

Review of work at ICRISAT, Hyderabad, India (1977-1983)

Sivakumar (1979) mentioned that the ultimate source of all energy exchanged in the biosphere is the sun. Extraterrestrial sunlight has a value of 2.0 cal/cm^2/min. Due to attenuation by the atmospheric constituents and pollutants, the intensity of direct solar radiation gets reduced. Average global solar radiation during the rainy season varies from 16.7 to 18.8 MJ/m^2/day while in the postrainy season solar radiation on an average is reduced by 0.4 to 1.7 MJ/m^2/day.

In several field experiments in ICRISAT, the hourly values of net radiation were obtained through net radiometers mounted above the crop canopies.

In their publication on plant and atmospheric parameters in water stress studies, Sivakumar and Virmani (1978) showed that net radiation is of basic importance in describing the physical environment of the crop since it represents, among other things, the energy available for growth. In the absence of advected energy, potential evapotranspiration is determined by net radiation.

Sorghum is one of the important crops grown under residual soil moisture situation during the post-rainy (*rabi*) season in India. Sivakumar et al. (1979) conducted a field study in ICRISAT center on deep vertisol during the post-rainy season of 1977 (October 1977 to February 1978) on the effects of water stress on the growth and dry matter accumulation of sorghum. Incoming solar radiation was measured at hourly intervals with a pyranometer sensor attached to an LI-500 integrator. Hourly values of net radiation were obtained from two SWISSTECO net radiometers mounted 1 m above the sorghum canopy in the irrigated and non-irrigated plots. Irrigated sorghum canopy showed higher net radiation than the non-irrigated sorghum because of lower albedo and surface temperature. The higher transpiration rates observed in the case of the irrigated sorghum could be explained by the increased net radiation measured over the irrigated canopy.

Intercropping, i.e., growing two or more crops simultaneously on the same land, has been practiced for centuries by farmers in tropical and subtropical countries, and the aim of intercropping research is to optimize the use of natural resources including light, water and nutrients (Donald, 1963). In their study during 1978-79, Sivakumar and Virmani (1980) compared the growth and interception of PAR in a maize/pigeonpea intercrop and sole maize and sole pigeonpea crops grown in large plots in an operational research watershed at ICRISAT research center. Slow growing legume crop such as pigeonpea, with a low leaf area index (LAI) for the first 80 days after planting, seem to show a photosynthetic response to increasing incident light flux much like that of a single leaf, and reach light saturation fairly early. But when grown along with maize, the total LAI for intercrop is high and shaded leaves at the bottom of the canopy can continue to respond to an increase in incident light flux with canopy growth up to progressively higher levels, which might explain the higher efficiency of PAR-utilization in intercrop compared with sole pigeonpea. The efficiency of dry matter production, calculated from the relations between dry matter production and cumulated intercepted PAR, was highest for the maize/pigeonpea intercrop, followed by sole maize and sole pigeonpea, proving the utility of such intercrops in making better use of resources in the Semi-Arid Tropics.

Sivakumar and Virmani (1984) assessed the crop productivity in relation to interception of PAR. The attenuation of photosynthetic photon flux density (PPFD) in maize, sorghum, pigeonpea, and a maize/pigeonpea intercrop in the operational research watersheds at ICRISAT Center in India was measured on a weekly basis throughout the growing season. A 2-m high frame covering an area of 3 m^2 was designed to accommodate four manually-operated quantum sensors for the measurement of PPFD. The interception of PPFD by the crop canopies was found to be closely related to the leaf area index. The plots of the regression relationship between drymatter for different crops and cumulative intercepted PPFD (grams of drymatter/einstein intercepted) was used to define the efficiency of light interception by crops. The maize/pigeonpea intercrop proved to be most efficient, followed by maize, sorghum and pigeonpea.

Light is one of the major factors influencing crop-weed balance. Shetty et al. (1982) investigated the influence of shading on the growth, leaf area, dry matter production, and seed production of some common weeds of the semi-arid tropics in a field study at the ICRISAT Research Center in Hyderabad during the 1978 and 1979 rainy seasons. Dry matter production of weeds was reduced up to 80% at higher shading levels. PPFD measurements showed a negative correlation between levels of shading and the seed production in these weeds.

Review of work at the ICRISAT Sahelian Center in Niamey, Niger (1984 -1996)

The largest geographical area of the semi-arid tropics (SAT) on a regional basis lies in West Africa – about 24% -- with 13% of the total population of SAT. Sorghum and millet, the two mandate cereal crops of ICRISAT, rank first in calorie intake in Africa. According to the World Bank in 1984, at least 80% of the population in the SAT of West Africa are engaged in agriculture, most of it in subsistence production. Increasing population and economic pressures in recent times forced rapid changes in the above system through continuous cropping which coupled with lack of suitable soil and crop management practices to conserve fragile resource base has resulted in accelerated deforestation, soil erosion and soil degradation.

At the ICRISAT Sahelian Center, a climatological data bank of long term daily rainfall data for many locations in West Africa was set up. In collaboration with the National Meteorological Services in West Africa, rainfall climatology studies were carried out to provide information on rainfall probabilities, water balance and preparation of maps showing the relative potentialities for cropping in different regions. Sivakumar et al. (1993); Sivakumar and Faustin (1987) produced the publications on the Agroclimatology of Niger and Burkina Faso in West Africa.

Several factors are responsible for the low agricultural productivity in West Africa. The most important however are climatic: the low and highly variable rainfall coupled with the high demand for water imposed by the constantly high temperatures and radiation throughout the year causes large variability in crop yields from year to year (Sivakumar, 1985). Microclimatic factors such as soil temperature, net radiation and surface albedo influencing the soil evaporation were monitored continuously. Automatic weather stations proved to be cost effective and easy to operate. We operated three such stations in Niger since 1986 at Sadore, Bengou and Maradi. The Executive Director of the ICRISAT Sahelian Center authorized the purchase of similar stations for the WASIP programs in Mali and Nigeria. In the Sahelian zone, the variability in rainfall at the beginning and the end of season is high and the water demands are high due to the high radiation load in this zone.

The length of the growing season is used as the primary criterion for the delineation of the Sudano-Sahelian zone (SSZ). On this basis, the SSZ extends over several countries from Senegal and Gambia in the west to Chad in the east. With a growing season length varying from 60 to 150 days, it offers a range of growing conditions, but a large part of the region has a growing season of less than 120 days (Sivakumar, 1989).

Air temperatures in the SSZ are usually higher because of the high radiation load. For the SSZ as a whole, the range in minimum temperatures on an annual as well as the rainy season basis, is small in comparison to the maximum temperatures. In comparison to the low rainfall, the potential evapotranspiration (PET) is very high in the SSZ since the radiation and temperature are consistently high for locations situated in the north (Sivakumar, 1989). The reduction in evaporation (and the change in surface energy balance) associated with the removal of vegetation in the Sahel has been shown to result in reduced rainfall. Our studies on energy balance over a fallow bushland and a bare soil at the ICRISAT Sahelian Center (Wallace et al. 1990) showed significant differences in net radiation over the two contrasting surfaces. Albedo is an important factor controlling the surface energy balance via its effect on net radiation and potential evaporation.

Review of work at the World Meteorological Organization (WMO) (1996-2016)

In the World Meteorological Organization (WMO), I worked as the Chief of the Agricultural Meteorology Department, as the Director of the Climate Prediction and Adaptation Branch and as the Acting Secretary of the Intergovernmental Panel on Climate Change (IPCC).

From WMO, we organized the "International Workshop on Agrometeorology in the 21st Century: Needs and Prospectives" from 15 to 17 February 1999 in Accra, Ghana. The workshop was organized in conjunction with the 12th Session of the Commission for Agricultural Meteorology (CAgM) of WMO, which took place in the same venue from 18 to 26 February 1999. The Proceedings of this International Workshop were edited by Sivakumar et al. (2000), which was brought out as a Special Issue of Agricultural and Forest Meteorology Journal.

In this International Workshop, Sivakumar et al. (2000) dealt with the important issue of Agrometeorology and Sustainable Agriculture. It was pointed out that the new concern with sustainability has drawn the attention of the agrometeorologists towards the need for a greater understanding of the various aspects of natural resources including the nature of inherent variability, methods of efficient use while ensuring proper conservation, and the development of suitable practices to ensure resource amelioration in the long term. For example, while solar energy sets the maximum value of energy available for plant growth, water determines to what extent the energy can be used.

In this International Conference, Rijks and Baradas (2000) pointed out that one of the products used for application of the results of research is the agro-meteorological characterization of the regions. One of the examples is the quantitative values (maximum, optimum, minimum) of relevant parameters such as solar radiation and temperature that define maximum production for different crops.

In their article on the Agrometeorology in the 21st century: workshop summary and recommendations on the needs and perspectives, Stigter et al. (2000) pointed out that the strengthening of agrometeorological observation and information networks is critical. A reevaluation of existing networks, including the use of automatic weather stations, is essential to respond adequately to the needs of the vulnerable priority regions, often in remote areas.

An "International Workshop on Automated Weather Stations for Applications in Agriculture and Water Resources Management: Current Use and Future Perspectives" was held at the University of Nebraska from 6 to 10 March 2000. This workshop was co-sponsored by the National Weather Service (USA); the United States Department of Agriculture (USDA); the High Plains Climate Center, University of Nebraska, Lincoln (USA) and WMO. Hubbard and Sivakumar (2001) organized the Proceedings of this workshop with different articles which addressed a number of important topics related to automatic weather stations such as communication, site selection and network density, sensor performance and calibration, maintenance, quality assurance and network management, data management and data access, applications of software and regional networks.

Following the International Workshop on Climate Prediction and Agriculture (CLIMAG) held in WMO, Geneva in September 1999 (Sivakumar 2000), the CLIMAG project was initiated based on the premise that advantage should be taken of current data bases, increasing climate knowledge and improved prediction capabilities to facilitate the development of relevant climate information and prediction products for applications in agriculture to reduce the negative impacts due to climate variations and to enhance planning activities based on the developing capacity of climate science. The key weather variables for crop prediction are rainfall, temperature and solar radiation, with humidity and wind speed playing also a role.

The Commission for Agricultural Meteorology (CAgM) of WMO established the Expert Team on the Contribution of Agriculture to the State of Climate at its thirteenth session. WMO, Agriculture and Agri-Food Canada (AAFC) and Environment Canada (EC) organized the "International Workshop on the Contribution of Agriculture to the State of Cimate" from 27 to 30 September 2004 in Ottawa, Canada. Desjardins et al. (2007) organized the Proceedings of this International Workshop, which was published as a Special Issue by the Agriculture and Forest Meteorology Journal. In this Special Issue, Salinger (2007) provided information from IPCC which concluded that climate forcing from changes in solar radiation and volcanism is likely to have caused fluctuations in global and hemispheric mean temperatures in the first part of the 20th century. Sivakumar (2007) pointed out that human activities – primarily burning of fossil fuels and changes in land cover – are modifying the concentration of atmospheric constituents of properties of earth's surface that absorb or scatter radiant energy.

The "International Workshop on Climate Prediction and Agriculture: Advances and Challenges" was held in WMO from 11 to 13 May 2005. Hansen et al. (2006) edited the Proceedings of this workshop, which were published as Special Issue of Climate Research Journal in 2006. The articles in this Climate Research Special represent a synthesis of key advances and remaining challenges in bringing climate prediction to bear on the needs of agriculture. Sivakumar (2006) gave an overview of climate risks to agriculture and of approaches to seasonal forecasting, and provided examples of efforts to foster the use of advance information to manage climate risk.

The Commission for Agricultural Meteorology (CAgM) of WMO, at its thirteenth session formed an Expert Team on "Reduction of the Impact of Natural Disasters and Mitigation of Extreme Events in Agriculture, Forestry and Fisheries". The China Meteorological Administration (CMA) hosted a meeting of this Expert Team in Beijing, China from 16 to 20 February 2003. Sivakumar et al. (2005) prepared the proceedings of this meeting, which was published by Springer.

In his presentation on the Impacts of Sand Storms/Dust Storms in Agriculture, Sivakumar (2005) explained that the very fine fraction of soil-derived dust has significant forcing effects on the radiative budget. Dust particles were thought to exert a radiative influence on climate directly through reflection and absorption of solar radiation and indirectly through modifying the optical properties and longevity of clouds. Depending on their properties and in what part of atmosphere they are found, dust particles can reflect sunlight back into space, thus reducing the amount of energy reaching the surface.

According to Sivakumar et al. (2005), in the monsoon season, radiation was the dominant variable for regulating the potential evapotranspiration (PE) variation at nearly all stations. Changes in both radiation and relative humidity are associated with decreases in PE in the post-monsoon season.

According to Maracchi et al. (2005), temperature, incoming solar radiation, water and nutrient availability are the main factors that generally determine agricultural production in Europe.

Biological systems are based primarily on photosynthesis, and thus dependent on incoming radiation.

In their article, Salinger et al. (2005) pointed out that research on the regionalization of climate changes must be carried out, with focus on improving techniques themselves, but also the evaluation of the impact of climate change on agriculture and environment. In relation to the forecasts currently available, there is a need to enlarge the range of variables considered, e.g., global solar radiation, as well as air humidity and wind speed, variables which affect agriculture and forestry production.

To review advances in application of seasonal climate prediction in agriculture over 5 years, and identify challenges to be addressed in the following 5-10 years to further enhance operational use of climate prediction in agriculture in developing countries, the Global Change System for Analysis, Research and Training (START), the WMO and the International Research Institute for Climate Society, organized the "International Workshop on Climate Prediction and Agriculture – Advances and Challenges" from 11 to 13 May 2005 at WMO in Geneva (Sivakumar and Hansen, 2007). Calculations of crop water requirements use precipitation and variables that determine evaporative such as relative humidity, wind speed and incoming solar radiation (Wheeler et al. 2007).

WMO and the COST Action of the European Science Foundation jointly organized the "Symposium on Climate Change and Variability – Agrometeorological Monitoring and Coping Strategies for Agriculture" from 3 to 6 June 2008 in Oscarsborg, Norway. Orlandini et al. (2009) organized the Proceedings of this Symposium which was published in a Special Issue of Idojaras, a quarterly journal of the Hungarian Meteorological Services. In this issue, Sivakumar and Stefanski (2009) pointed out that there is a need for better assessment of risks associated with variable and uncertain environmental conditions. This likely would involve documentation of climatic variation (temporal and spatial) so that probabilities of climatic conditions can be better estimated.

Agrometeorology is facing a lot of challenges as well as opportunities for achieving the path of sustainability. In his Lead Talk during the First International Symposium on Agrometeorology and Food Security (INSAFS) organized by the Association of Agrometeorologists Anand and Central Research Institute for Dryland Agriculture held at Hyderabad during 18-21 February 2008, Sivakumar (2008) has emphasized that since the diversity of climate, soil and moisture regimes makes the research challenging but it also provides opportunity to agrometeorologists to make a substantial contribution in the identification of the solution, wherein ten such area of contribution were advocated.

Indian Meteorological Society, in association with WMO, India Meteorological Department (IMD), Ministry of Earth Sciences, Department of Science and Technology and Department of Space, Government of India organized the "International Conference on Challenges and Opportunities in Agrometeorology" during 23-25 February 2009 in New Delhi, India. Several papers presented in this Conference were edited by Attri et al. (2011) and the book on "Challenges and Opportunities in Agrometeorology" was published by Springer in 2011. In the above Conference, Ramesh et al. (2011) pointed out that the understanding of crop-weather relationship is an important aspect to maximize productivity from cultivated plants. They showed that *Valeriana jatamansi* is an understorey plant, which when brought under cultivation, needs to be studied for their stomatal behaviour. In *V. jatamansi*, the adaxial surface is exposed to solar radiation. The number of stomata, epidermal cells, stomatal density and stomatal index were observed to be significantly higher under full light conditions.

WMO organized the Technical Conference on "Changing Climate and Demands for Climate Services for Sustainable Development", which was held in Antalya, Turkey, in February 2010, with the co-sponsorship of the World Climate Research Programme (WCRP), the Turkish State Meteorological Service (TSMS) and Meteo-France. Sivakumar et al. (2011) edited the Proceedings of this Technical Conference, which was published by the Climate Research Journal. The Conference focused on the role of partnerships and the climate research community in advancing the WMO response to societal needs in the face of escalating impacts from climate variability and change, and their effects on sustainable development.

In the "International Conference on Challenges and Opportunities in Agrometeorology", Sivakumar (2011) showed that to account for the impact of weather and climate variability on disease and pest incidence, information on agrometeorological variables such as total solar radiation, relative humidity, maximum and minimum temperature, total rainfall and wind direction and wind speed are vital. Agrometeorological information is needed to model the incidence of pests and diseases and for developing effective control strategies.

In the above Conference, Stefanski (2011) showed the importance of the World Agrometeorological Information Service (WAMIS) website which has been operational since December 2003. WAMIS is a dedicated web server that countries and organizations can place their agrometeorological bulletins and advisories.

The countries of West Asia and North Africa (WANA) have long had the challenge of providing sustainable livelihoods for their populations in the fragile ecosystems of semi-arid and arid areas. WMO, in collaboration with the Association of Agricultural Research Institutions in the Near East and North Africa (AARINENA), FAO, the International Center for Agricultural Research in the Dry Areas (ICARDA), the Ohio State University (OSU), the Kuwait Institute for Scientifc Research (KISR), the Meteorological Department of the State of Kuwait, the Global Forum of Agricultural Research (GFAR),and the European Union (EU), organized an International Conference entitled "Adaptation to Climate Change and Food Security in West Asia and North Africa" in Kuwait City, Kuwait, from 13 to 16 November 2011. The Proceedings of this international conference, edited by Sivakumar et al. (2013), was published by Springer.

In the above conference, Sivakumar et al. (2013) pointed out that a warmer climate in WANA is expected to impact the distribution of extreme events, with an increased frequency of heat waves and dry spells likely even in areas with slight rainfall increases.

Fig. 4: Image of Sun God riding a chariot that is harnessed by seven horses which represent the seven *chakras* in the body or the seven colors of the rainbow (*Rigveda*, 1.50.8)

Satellite observations of climate and environmental change have become an increasingly important tool in recent years for helping to shape the response of international communities to this critical global change. Hence Qu et al. (2013) invited several authors to contribute their chapters to the book entitled "Satellite-based Applications on Climate Change", which was published by Springer. The support from the Center for Satellite Applications and Research (STAR) of the National Oceanic and Atmospheric Administration (NOAA) and the Environmental Science and Technology Center (ESTC) of George Mason University (GMU) was gratefully acknowledged by Qu et al. (2013).

In their article in the above book, Qu et al. (2013) mentioned that extreme weather and climate events have over the years impacted human society and have currently become a more complex challenge with the changing climate. One way to assess the impacts of observed climate change is by viewing the earth from space. Satellite observations make a significant contribution to the Essential Climate Variables (ECVs) and their associated data sets and products of the Global Climate Observing System (GCOS) which was established to ensure that all users have access to the climate observations, data records, and information which they require to address pressing climate-related concerns. Qu et al. (2013) summarized the applications of satellite data for climate change based on the 20 chapters in this book, and discussed the recent advances of climate change monitoring from space.

I served as the Acting Secretary of the Intergovernmental Panel on Climate Change (IPCC), which is based in WMO, in 2016. As the Acting Secretary of IPCC, I was invited to contribute an article on "IPCC at the Science-Policy Interface" for the Special Issue on "The G7 Summit, Ise-Shima, Japan" which was published by Climate Change - The New Economy Limited. My article is on pages 40 to 43 of this Special Issue (Sivakumar, 2016).

In the front pages of this Special Issue, there are articles by HE Shinzo Abe, Prime Minister of Japan; HE François Hollande, President, The French Republic; HE Justin Trudeau, Prime Minister, Canada; and HE Barrack Obama, President, USA.

NEED FOR IMPROVED RESPECT TO SUN BHAGAWAN BY AGROMETEOROLOGISTS

Even ancient people have recognized what the Sun can bring to life on Earth. Most of them even considered the Sun as God. The Figure 4 below shows that the Sun God rides a chariot that is harnessed by seven horses which represent the seven chakras in the body or the seven colors of the rainbow. Sun God is depicted with four hands in which He carries a wheel, a conch-shell, and a lotus. His fourth hand is held in the *Abhaya Mudra*.

Agrometeorologists must be offering their prayers to Gods, whose statues must be in the different temples in the country. We need to realize that the only God whom we can view throughout the day is the Sun God. As scientists covering solar radiation in our studies, we should offer our daily prayer to Sun God.

The following Mantras show the importance of Sun God.

Navagraha Dhyana Shlokam on Surya

Navagraha stotram is composed by Sage Vyasa to praise the Navagrahas or the nine celestial planets. The following is the Shlokam on Sun God.

Hima kumda mrunalabham daityaanam paramam Gurum
Sarva-sastra pravaktaram Bharghavam pranamamyaham

Meaning of this mantra: The one who is compared to the attributes like snow, jasmine, and the stem of the lotus (Mrunala), who is the best or superior Guru to the Daitya's. An expert in all the sastras, O the Bhargava I prostrate before you.

Importance of Surya Mantras

Agrometeorologists can invoke the blessings of Lord Surya (The Sun) by chanting Surya Mantras. Surya Mantras are salutations to Lord Surya (The Sun) who is the giver of energy to the world.

A Surya Mantra helps to bridge the gap between the agrometeorologist and the Sun God when the agrometeorologist chants regularly (with full devotion and faith).

When the agrometeorologist regularly chants Surya Mantra, he or she can obtain any desired boon with the blessings of Sun

God. The Sun God grants us a high status in society and success in your work field. He also grants skills, fame and good speech as He is the very part of our soul. He represents our soul *(Atma*).

Chanting of Surya Mantra can help the agrometeorologists to attain a high position in any organization. The agrometeorologist can gain intelligence, courage, confidence, good health, leadership qualities, power, fame, success, and many other boons while chanting Surya mantra regularly.

Surya Mantra - 1

Om Bhaskaraya Vidhmahe

Mahatejeya Dhimahi

Tanno Surya Prachodayat

Meaning of this mantra: Om, let me meditate on the Sun God, Oh, maker of the day, give me higher intellect, And let Sun God illuminate my mind.

Surya Mantra – 2

"Om Adityaya Vidmahe

Sahasra Kiranaya Dhimahi

Tanno Surya Prachodayaat"

Meaning of this mantra**:** I meditate on the Sun God, the one with thousands of rays. Let the Sun God (Surya Deva) illuminate my intellect.

Conflict of Interest Statement: The author(s) declare(s) that there is no conflict of interest.

Disclaimer: The contents, opinions, and views expressed in the research article published in the Journal of Agrometeorology are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

Publisher's Note: The periodical remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

REFERENCES

Attri, S.D., Rathore, L.S., Sivakumar, M.V.K. and Dash, S.K., (2011). "Challenges and Opportunities in Agrometeorology", Springer, Berlin, Germany.

Coddington, O., Lean, J. L., Pilewskie, P., Snow, M., and Lindholm, D., (2016). A Solar Irradiance Climate Data Record, *Bull. Amer. Meteorol. Soc.,* 97: 1265–1282. https://doi.org/10.1175/BAMS-D-14-00265.1

Combes, D., Sinoquet, H. and Varlet-Grancher, C. (2000). Preliminary measurement and simulation of the spatial distribution of the morphogenetically active radiation (MAR) within an isolated tree canopy. *Ann. For. Sci*. 57:497-511.

Dale, J.E., (1961). Investigations into the stomatal physiology of upland cotton. 1. Effects of hour of day, solar radiation and leaf water content on stomatal behaviour, *Ann. Bot*., 25:39-51.

Davies, J.A., and Buttimor, P.M., (1969). Reflection coefficients, heating coefficients and net radiation at Simoce, Southern Ontario, *Agric. Meteorol*., 6:373-386.

Desjardins, R.L., Sivakumar, M.V.K., and de Kimpe, C., (Eds.). (2007). "The Contribution of Agriculture to the State of Climate", *Special Issue of Agric. For. Meteorol*, 142**:**324 pp.

Dickinson, R.E., (2003). "Land-Atmosphere Interactions: Overview", In: *Encyclopedia of Atmospheric Interactions (Ed. James R. Holton), Elsevier Science*, 1116-1120.

Donald, C.M., (1963). Competition among crop and pasture plants, *Adv. Agron*., 15: 1-118.

Fritschen, L.J., (1967). "Net and solar radiation relations over irrigated field crops", *Ibid*. 2:165-172.

Hansen, J.W., Sivakumar, M.V.K. and Bates, B.C. (Eds.). (2006). Advances in the Application of Climate Prediction to Agriculture, *Clim. Res. Spec., 16*, **33**: No. 1.

Hatfield, J.L., (1975). "Relationships of photosynthetically active radiation to apparent photosynthetic distributions within soybean canopies". Ph.D. Dissertation. Iowa State University, Ames, Iowa. University Microfilms Order No. 76-1842.

Hubbard, K.G., and Sivakumar, M.V.K., (Eds.). (2001). "Automated Weather Stations for Applications in Agriculture and Water Resources Management: Current Use and Future Perspectives", Proceedings of an International Workshop held in Lincoln, Nebraska, USA, 6-10 March 2000. Lincoln, Nebraska: High Plains Climate Center and Geneva, Switzerland: World Meteorological Organization, WMO/TD No. 1074.

IPCC., (2001). "Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change" In: Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Dai, X., Maskell, K. and Johnson, C.A. (eds.) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Maracchi, G., Sirotenko, O., and Bindi, M., (2005). Impacts of present and future climate variability on agriculture and forestry in the temperate regions: Europe". *Clim. Change,* 70:117-135.

Monteith, J.L., (1958). "The heat balance of soil beneath crops" In: Climatology and Microclimatology, UNESCO, Paris.

NASA., (2022). "Overview – Sun NASA Solar System Exploration", Communication Office of The National Aeronautics and Space Administration (NASA) Headquarters

300 E. Street SW, Suite 5R30, Washington, DC 20546, USA.

Orlandini, S., Sivakumar, M.V.K., Sivertsen, T.H., and Skelvåg, A.O., (Eds.). (2009). "Symposium on Climate Change and Variability – Agro Meteorological Monitoring and Coping Strategies for Agriculture", *Special Issue, Időjárás*, 113(1-2): 156 pp.

Qu, J., Powell, A.M., and Sivakumar M.V.K. (Eds). (2013). "Satellite-based Applications and Research for Understanding Climate Change", Springer, Berlin, Germany.

Qu, J.J., Powell, A.M., and Sivakumar, M.V.K., (2013). Recent advances and challenges of monitoring climate change from space, Pages 359-366 In: Qu, J., Powell, A.M. and Sivakumar M.V.K. (Eds). 2013. Satellite-based Applications and Research for Understanding Climate Change. Springer, Berlin, Germany.

Ramesh, K., Raj Kumar, S., and Singh, V., (2011). Stomatal adaptation and leaf marker accumulation pattern from altered light availability regimes: A field study, Pages 505-510. In: Attri, S.D., Rathore, L.S., Sivakumar, M.V.K. and Dash, S.K. (eds.). Challenges and Opportunities in Agrometeorology. Springer, Berlin, Germany.

Rijks, D., and Baradas, M.W., (2000). The clients for agrometeorological information, *Agric. For. Meteorol.,* 103: 27-42.

Rout G.R., Samantary, S. and Das, P. (2000). In vitro manipulation and propagation of medicinal plants. *Biotechnol. Adv.,* 18: 91-120.

Salinger, M.J., (2007). Agriculture's influence on climate during the Holocene, *Agric. For. Meteorol.,* 142: 96-102.

Salinger, M.J., Sivakumar, M.V.K., and Motha, R., (2005). Reducing vulnerability of agriculture and forestry to climate variability and change: Workshop summary and recommendations, *Clim. Change,* 70: 341-362.

Shaw, R.H., (1956). A comparison of solar radiation and net radiation, *Bull. Amer. Met. Soc*. 37: 205-206.

Shetty, S.V.R., Sivakumar, M.V.K., and Ram, S.A., (1979). Effect of shading on the growth of some common weeds of the semi-arid tropics". *Agron. J.*, 74: 1023-1029.

Shibles, R., (1976). Terminology pertaining to photosynthesis, *Crop Sci.,* 16: 437-439.

Sivakumar, M.V.K., (1979). Environmental factors affecting plant productivity, Pages 183-203. In: Saleed Ahmed, H.P.M. Gunasena and Y.H. Yang (eds.). Proceedings of the Final Inputs Review Meeting of Adaptive Production Systems. East-West Center, Honolulu, Hawaii, USA.

Sivakumar, M.V.K., (1985). "Climate and crop production in West Africa", Presentation made at the Donor's meeting, 4-6 September 1985, ICRISAT Sahelian Center, Niamey, Niger.

Sivakumar, M.V.K., (1989). Agroclimatic aspects of rainfed agriculture in the Sudano-Sahelian zone, Pages 17-38, In: *Soil, Crop and Water Management Systems for Rainfed Agriculture in the Sudano-Sahelian Zone*. Proceedings of International Workshop, January 1987, ICRISAT Sahelian Center, Niamey, Niger.

Sivakumar, M.V.K. (ed.)., (2000). Climate prediction and agriculture, Proceedings of the START/WMO International Workshop held in Geneva, Switzerland, 27-29 September 1999. International START Secretariat, Washington DC, USA

Sivakumar, M.V.K., (2005). Impacts of Sand Storms/Dust Storms on Agriculture, Pages 159-178 *In:* Sivakumar, M.V.K., Motha, R.P., and Das, H.P., (eds.) Natural disasters and extreme events in agriculture. Springer, Berlin, Germany.

Sivakumar, M.V.K., (2006). Climate prediction and agriculture: current status and future challenges, *Clim. Res. Special*, 33: 3-17.

Sivakumar, M.V.K., (2007). Interactions between climate and desertification, *Agric. For. Meteorol*., 142: 143-155.

Sivakumar, M. V. K. (2008). Agrometeorology and Food Security, *J. Agrometeorol.,* 10 (Special Issue part-1): 1-8.

Sivakumar, M.V.K., (2011). Operational Agrometeorological Strategies in Different Regions of the World. Pages 545-564. In: Attri, S.D., Rathore, L.S., Sivakumar, M.V.K., and Dash, S.K. (eds.). Challenges and Opportunities in Agrometeorology. Springer, Berlin, Germany.

Sivakumar, M.V.K., (2016). IPCC at the science-policy interface, Pages 40-43 In: G7 Climate Change, The New Economy. The G7 Summit, Ise-Shima, Japan, 26-27 May 2016. http://touchline.s3-website-eu-west-1.amazonaws.com/g7/climatechange2016/1-1.

Sivakumar, M.V.K., and Faustin, G., (1987). "Agroclimatology of Burkina Faso", Information Bulletin No. 28, International Crops Research Institute for the SemiArid Tropics, Patancheru, India. 192 pp.

Sivakumar, M.V.K., and Shaw, R.H., (1978). Leaf response to water deficit in soybeans, *Phy. Plant*, 42: 134-138.

Sivakumar, M.V.K. and Shaw, R.H., (1979). Attenuation of radiation in moisture stressed and unstressed soybeans", *Iowa State J. Res*., 53: 251-257.

Sivakumar, M.V.K., and Stefanski, R., (2009). Climate change mitigation, adaptation, and sustainability in agriculture, *Időjárás*, 113: 89-102.

Sivakumar, M.V.K., and Virmani, S.M., (1978). Plant and atmospheric parameters in water stress studies, Pages 181-184, *In*: Proceedings of the International Workshop on the Agroclimatological Research Needs of the Semi-Arid Tropics, 22-24 Nov. 1978, ICRISAT, Hyderabad, India.

Sivakumar, M.V.K., and Virmani, S.M., (1980). Growth and resource use of maize, pigeonpea and maize/pigeonpea intercrop in an operational research watershed, *Expl. Agric.*, 16*: 377*-386.

Sivakumar, M.V.K., and Virmani, S.M., (1984). Crop productivity in relation to interception of photosynthetically active radiation, *Agric. For. Meteorol*., 31:1-11.

Sivakumar, M.V.K., Seetharama, N., Sardar Singh, and Bidinger, F.R., (1979). Water relations, growth, and dry matter accumulation of sorghum under post-rainy season conditions, *Agron. J*., 71: 843-847.

Sivakumar, M.V.K., Maidoukia, A., and Stern, R.D., (1993). "Agroclimatology of West Africa: Niger (Second Edition)", Information Bulletin No. **5**, ICRISAT, Patancheru, India. 108 pp.

Sivakumar, M.V.K., Gommes, R., and Baier, W, (2000). Agrometeorology and Sustainable Agriculture, *Agric. For. Meteorol*., 103: 11-26.

Sivakumar, M.V.K., Stigter, C.J., and Rijks, D, (Guest Editors). (2000). Agrometeorology in the 21st Century: Needs and Perspectives, *Agric. For. Meteorol.,* 103: Nos. 1-2.

Sivakumar, M.V.K., Das, H.P., and Brunini, O., (2005). Impacts of present and future climate variability and change on agriculture and forestry in the arid and semi-arid tropics, *Clim. Change,* 70: 31-72.

Sivakumar, M.V.K., Motha, R.P., and Das, H.P., (Eds.). (2005). "Natural Disasters and Extreme Events in Agriculture: Impacts and Mitigation", Springer, Berlin, Germany. 420 pp.

Sivakumar, M.V.K., and Hansen, J. (Eds.). (2007). "Climate prediction and agriculture: advances and challenges", Springer, Berlin, Germany. 306 pp.

Sivakumar, M.V.K., Bessemoulin, P., Peterson, T., and Asrar, G. (Eds.), 2011, "Climate services for sustainable development", *Climate Research Special 25*, 47: 150 pp.

Sivakumar, M.V.K., Lal, R., Selvaraju, R., and Hamdan, I., (Eds.). (2013). "Climate Change and Food Security in West Asia and North Africa", Springer, Berlin, Germany, 423 pp.

Sivakumar, M.V.K., Ruane, A.C., and Camacho, J., (2013). Climate change in the West Asia and North Africa region, Pages 3-26 *In* Sivakumar, M.V.K., Lal, R, Selvaraju, R, and Hamdan, I. (Eds.). Climate Change and Food Security in West Asia and North Africa. Springer, Berlin, Germany.

Stefanski, R., (2011). Overview of the World Agrometeorological Information Service (WAMIS), Pages 573-578. In: Attri, S.D., Rathore, L.S., Sivakumar, M.V.K., and Dash, S.K. (eds.). Challenges and Opportunities in Agrometeorology. Springer, Berlin, Germany.

Stigter, C.J., Sivakumar, M.V.K., and Rijks, D.A., (2000). Agrometeorology in the 21st Century: Workshop summary and recommendations on needs and perspectives, *Agric. For. Meteorol.*, 103: 209-227.

Turner, N.C., (1969). Stomatal resistance to transpiration in three contrasting canopies, *Crop Sci.,* 9**:** 303-307.

Wallace, J.S., Gash, J.H.C., and Sivakumar, M.V.K.,(1990). Preliminary measurements of net radiation and evaporation over bare soil and fallow bushland in the Sahel, *Int. J. Climatol.,* 10: 203-210.

Wheeler, T., Challinor, A., Osborne, T., and Slingo, J., (2007). Development of a combined crop and climate forecasting system for seasonal to decadal predictions, Pages 31-40. In: Sivakumar, M.V.K. and J. Hansen (eds.) Climate prediction and agriculture: advances and challenges. Springer, Berlin, Germany.