DIURNAL VARIATION OF OPTICAL DEPTH AT THE PHOTOSYNTHETIC ACTIVE RANGE OF SOLAR IRRADIANCE AT FOUR SOLAR WAVELENGTH CHANNELS

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Abstract: Solar measurements were made at Wukari (Latitude 7.9303ºN, Longitude 9.8125ºE) using an EKOMS 120 sun photometer with half band width of 5nm and nominal wavelength of ±2.0nm at four semi-monochromatic wavelength of 430nm, 453nm, 640nm and 669nm. These wavelengths are the peak of the photosynthetic absorbance of green plants and algae. The filters were interference filters which allow direct solar radiation only. These wavelengths are variously referred to as channels 1, 2, 3 and 4. The mean optical depths measured in the months of October, November and December of 2020 are 0.8, 1.0, 0.4 and 0.7 respectively. This is a result that shows improvement over values deduced from literature. The peak absorptions occur at channels 1, 2 and 4 with a minor peak at channel 3.
Keywords: Diurnal Variation, Solar Irradiance, semi-monochromatic, Wavelength channel

Introduction

Solar radiation, essentially powers all Earth systems as it affects weather events and photosynthetic activities of green plants. The radiation is in form of electromagnetic waves whose energies in increasing order ranges from microwaves (wavelength ~2400nm) to cosmic rays (wavelength ~200nm). While the extremely powerful radiation of γ-rays X-rays and UVC rays are shielded from the earth's surface by various atmospheric gases (Kuo-Nan, 2000) UVB, UVA, visible light, microwave and radio waves substantially arrive at the earth's surface. The visible range and UVB, UVA ranges substantially acts as the atmospheric window where there is weak attenuation of solar radiation (Coulson, 2002). The peak of solar radiation lies in the visible. Plants make use of radiation in the UVA and visible ranges. However, production of vitamin D in the skin of man is an interaction between UVB (wavelength ~280nm – 315nm) and 7-dehydrocholesterol in the skin that is converted to previtamin D3 and Isomerized into vitamin D3(Mathias and Michael, 2018). In plants, glucose is generated as a result of the interaction between water and carbon dioxide, at photosynthetic active wavelengths, producing glucose and oxygen (chlorophyll, 2018). This work is a research into the direct diurnal variation of these activity wavelengths at this sub-Saharan site (Wukari).

The world is slowly and steadily divorcing herself from fossil fuel usage as a result of carbon dioxide emission and harmful radiation from radioactive Nuclear-Plants. While greenhouse gases create unacceptable climate variation as a result of global warming, nuclear energy is creating its own hazards as a result of emission of harmful heavy metals and radioactive wastes resulting from fission processes (Dittrich et al, 2011). Researchers are increasingly turning to the plants to learn how energy from the sun is utilized in various biological processes. The well-known silica solar cells have undergone tremendous improvement in that efficiencies of up to ~40% particularly in space programs are mind boggling (Sze, 1981). However, materials utilized and the processes required to fabricate these cells are hazardous and create toxicity. Theses have adverse effects on man and the environment. This is why it is vital to develop a non-toxic and renewable photosynthetic solar cell that can efficiently produce electrical energy. The first step being to investigate the radiation that assists the photosynthetic process (Rittman, 2008).

Literature Review

Absorption spectra of chlorophyll include solar wavelengths of blue and orange to red light as indicated by their peaks around 425-475nm and 625 – 675nm (Hoppe and Sariciftc, 2014). Chlorophyll α absorbs violet and orange light the most while chlorophyll β absorbs mostly blue and yellow light though they absorb radiation at other wavelengths but with less intensity. Chlorophyll absorbs best at ~ 430nm which is blue though absorption takes place in the entire visible range with less intensity except green (Box and Deepak, 1981).

Visible absorption spectra of chlorophyll α and β studied in monolayers have to be compared with those taken in several organic solvents (Griffin and Quach, 2019) and the results show that red and blue absorption peaks of chlorophyll in monolayers at water-air and water-oil interfaces were found to shift towards lower frequencies when compared to their solution peaks (Glenn and Shaw, 2009).

These peaks were postulated to be possible due to a physical condensed state of the molecules in monomolecular layers stressing the possibility that the chlorophylls in vivo are in films absorbed at liquid interfaces (Kerkes, 2001). The three major pigments of the lamellar structure were found to account for radiation absorbance. However, incorporation of β carotene in thin films of chlorophyll extract also enhanced absorption of radiation in the 698.50nm spectrum. Chlorophyll α and β constitutes total chlorophyll content in plant leaves (Guidi et al, 2017). According to Guoterman's model, the absorption bands of cyclic tetrapyrroles are due to transition dipoles oriented in two perpendicular directions in the macrocyclic ring maintained essential by the 430nm and 453nm solar bands (Diarra et al, 2011). These frequencies create electronic transition leading to vibronic counterpart formation in the Q – bands referred in this work as channels 1 and 2. However, when two hydrogen atoms [H_2] substitute the magnesium ion [mg^{2+}] during the formation of pheophytins, the degeneracy of the electronic transition is broken and the Q-bands display transitions in two distinct directions of the marocyclic ring (Diarra et al, 2011). The electronic bands (channels 3 and 4) present their vibronic bands around 640nm and 669nm wavelengths (Clauds et al, 2012). The role of chlorophyll α and β in the absorption response of aliquot containing natural pigments extracted from green tea (Camellia Sinensis) from the mambila Plateau of Taraba State is part of this project.

Materials and Methods

The instrument used in this project is an Eko Sun photometer [MS120] with four filters referred to as channels 1 to channels 4 donated by the NASA, Goddard Space flight Centre, University of Maryland, Maryland, USA.

Specifications

(Gleen and Shaw, 2009) (Chandrasekhan, 1950)

Table 1: Specification and comparison with WMO standards

Specification	Eko 120	WMO
Full View Angle (o)	2.4	2.4
Linearity [% of full scale]	±0.2	0.1
Precision [% of full scale]	0.2	0.01
Stability [% of full scale]	0.2	0.1
Half-bandwidth (nm)	5.0	5.0
Normal Wavelengths	430nm	430nm
	453nm	460nm
	640nm	620nm
	670nm	669nm

Potential Absorption Errors for Ozone

Table 2: Errors arising from various channels

λ_o(nm)	$\Delta\tau$	Species
430	0.004	O_3
453	0.005	O_3
640	0.000	-
669	0.000	-

Principle of Measurement

The expression used to determine the optical depth is Beer-Bouguer-Lambert Law expressed as;

$$I(\lambda) = I_o(\lambda)\left(\frac{(r_m)}{r}\right)^2 \exp(-m\tau) \text{------------------------------ } 1$$

(Coulson, 2010) where

$$m\tau = m_m\tau_m + m_R\tau_R + m_o\tau_o \text{ --------------------- } 2$$

(Oluwafemi, 2019)

Here $I(\lambda)$ is irradiance at observatory , $I_o(\lambda)$ is exoterrestial irradiance or calibration value, r_m is mean Sun- Earth distance, r is distance at time of measurement (equation 1) τ_m, τ_r, τ_o are optical depths of aerosol, Rayleigh and Ozone.

Fig.1 shows the calibration curve for all the 4 channels of the sunphotometer. Overtime the filter calibration begins to degenerate as a result of weather effect and they need to be changed regularly for accuracy of results. The calibration is the value of I_o (λ), i.e. the exoterrestrail value of measurement in equation 1.

Values of m can be deduced from the solar zenith angle as sec θ_o, where θ_o is the solar zenith angle. m_R, τ_R, m_o, τ_o values are available in WMO tables.

From fig. 2, optical depth across all channels dipped towards the end of October 2020. A result which can be attributed to the cumulus cloud cover and high humidity. This drop was sustained in November of 2020 (fig. 3). Stability was attained form the middle of the month.

Fig. 3 shows high jump in optical depth as a result of the Harmattan haze and low humidity.

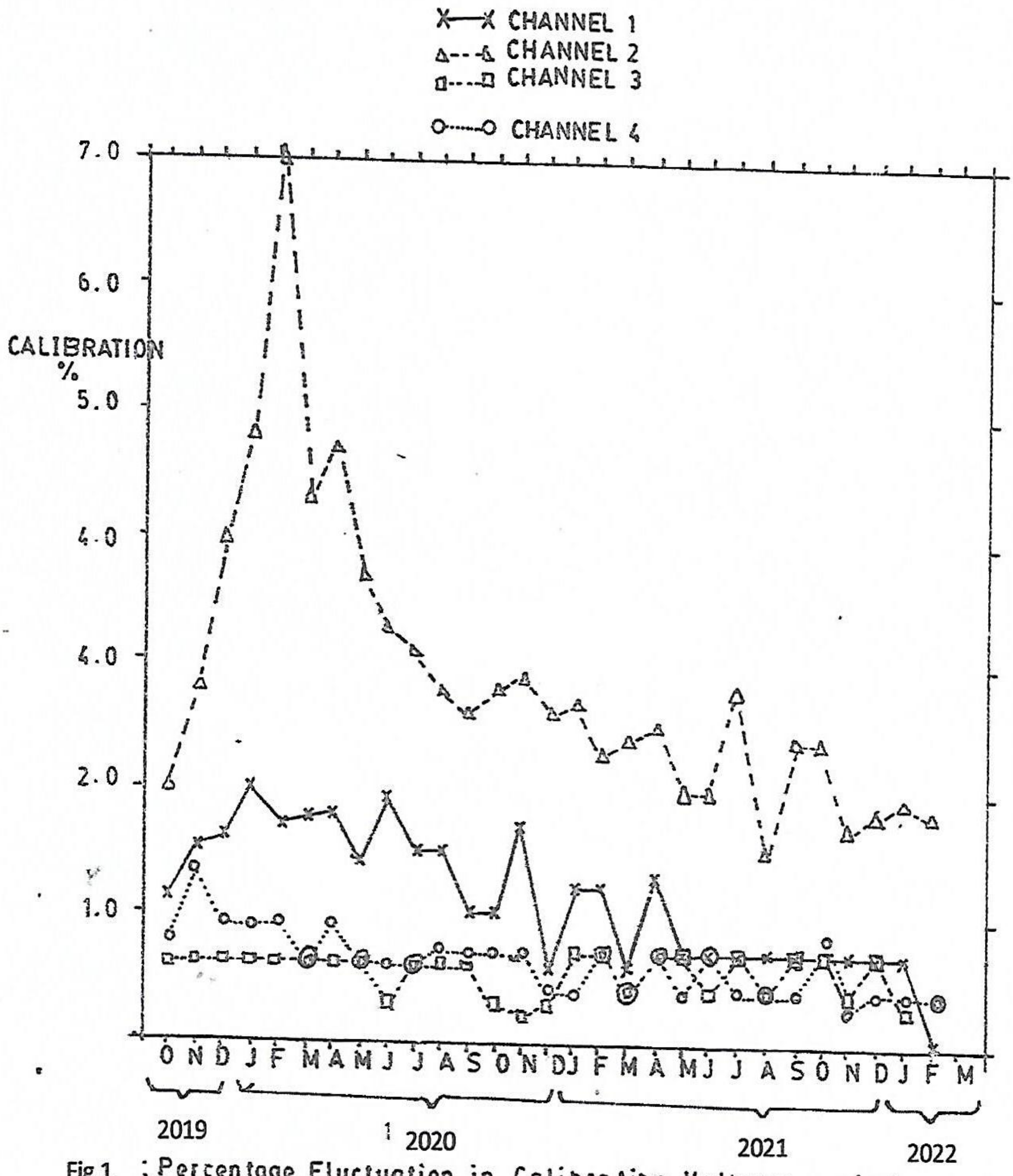

Fig 1 : Percentage Fluctuation in Calibration Voltages against The Months of Year.

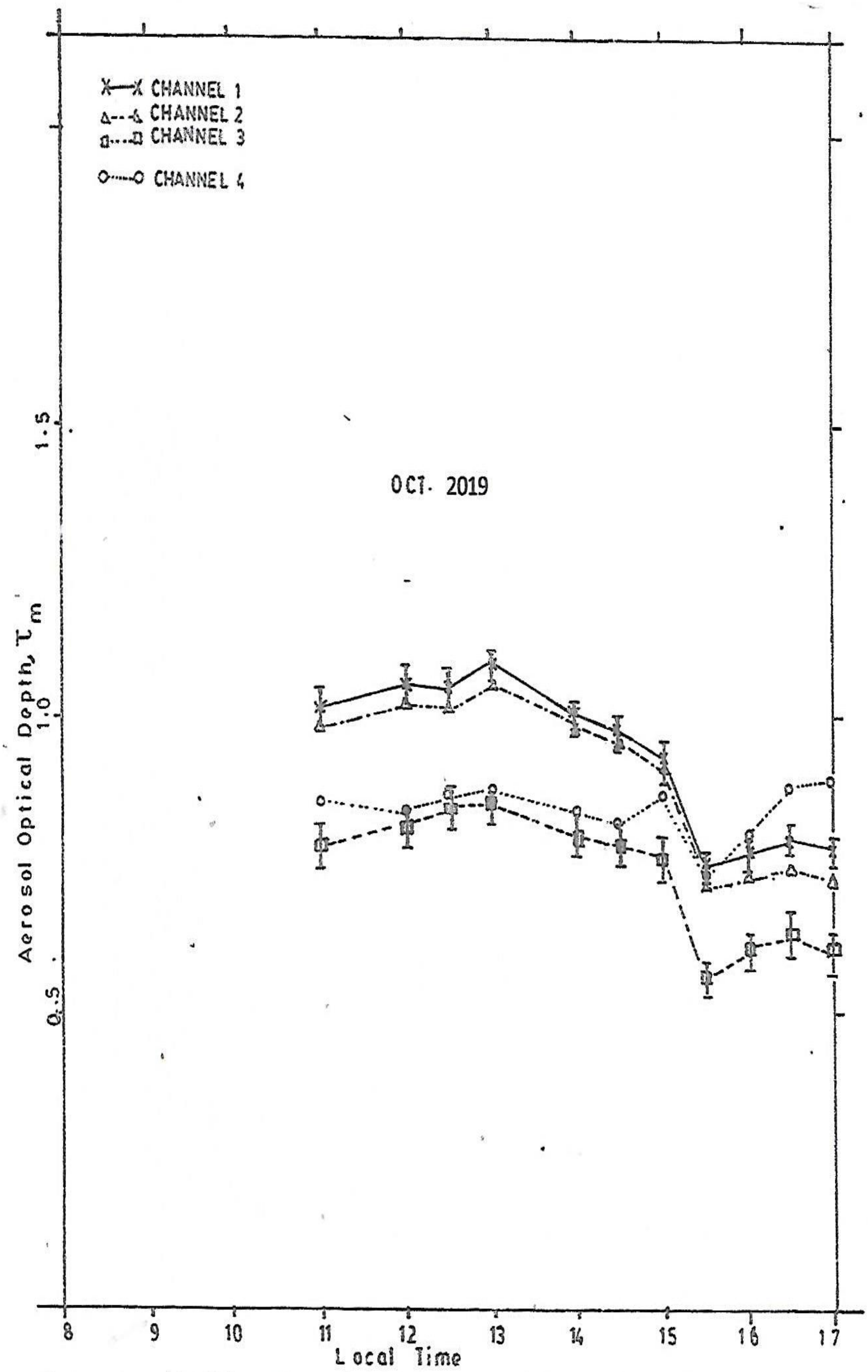

Fig 2 . Monthly Mean Diurnal Variation of Optical Depth With Local Time for October 2019

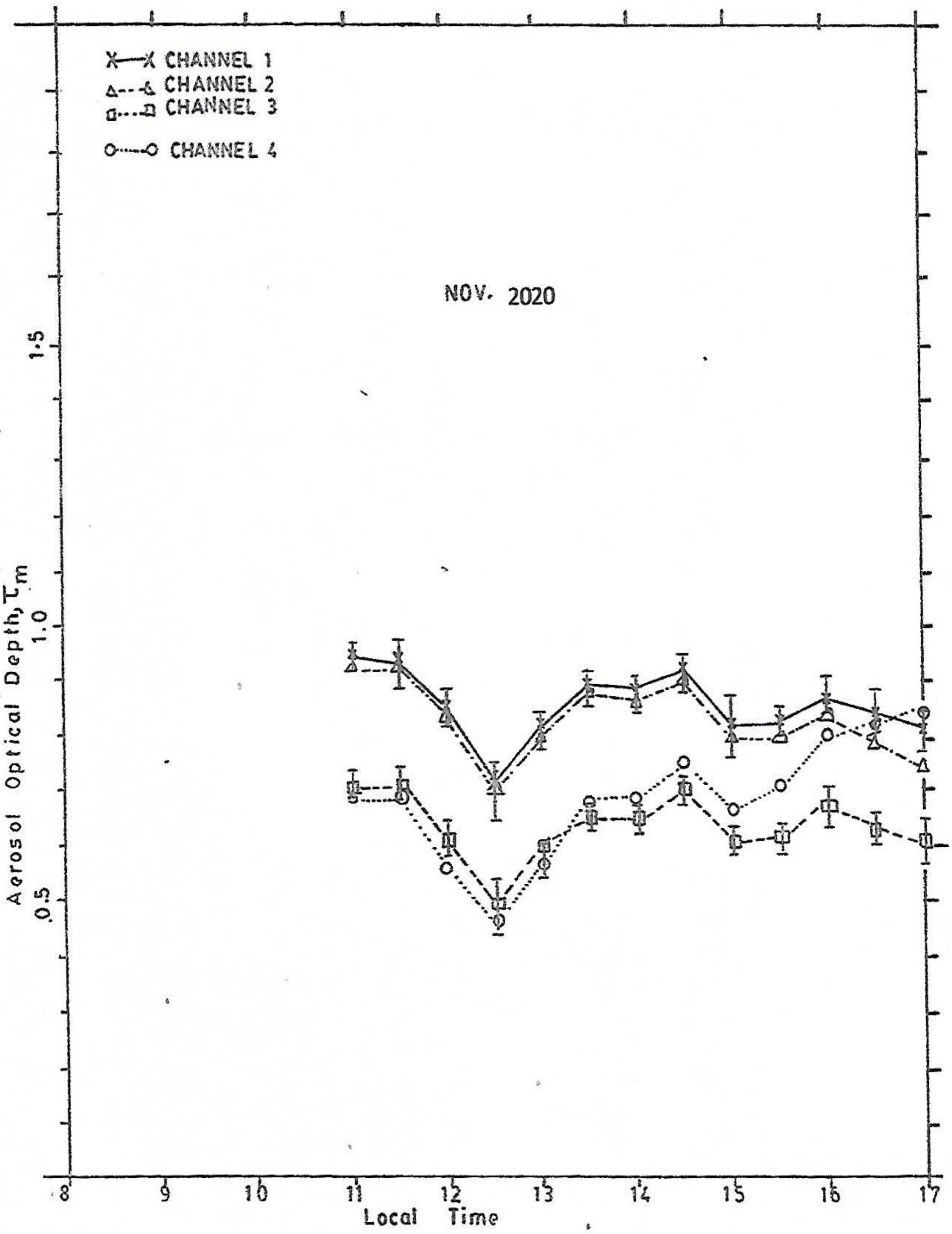

Fig 3 Monthly Mean Diurnal Variation of Optical Depth With Local Time for November 2020

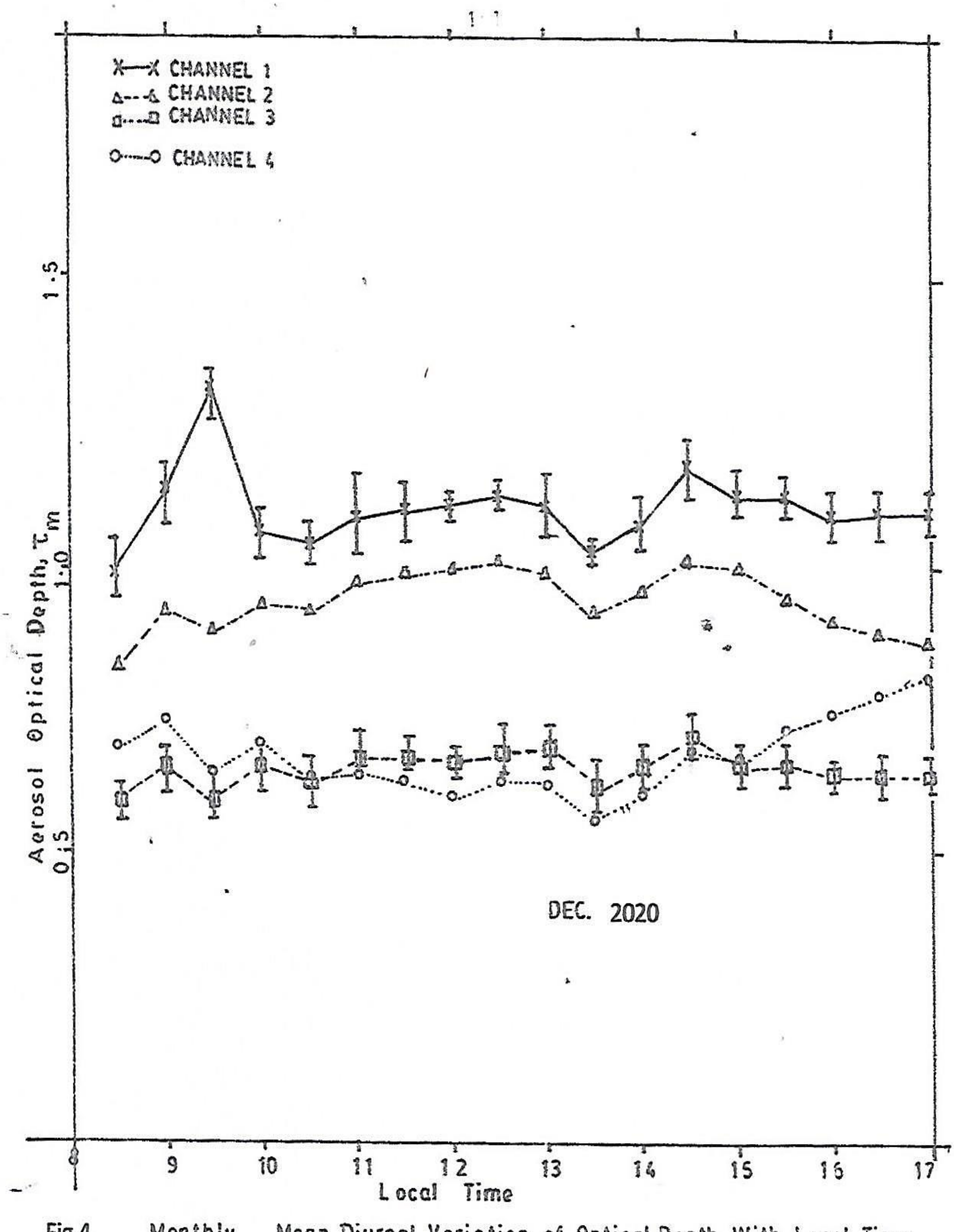

Fig 4 Monthly Mean Diurnal Variation of Optical Depth With Local Time For December 2020

Plot of values of diurnal variation for optical depth for October – December 2020 are shown in figs 2, 3, 4.
Channel 2 show consistent highest values indicating the most possible frequency of solar irradiance. The least being channel 3
These represent the results of 3 months analysis of diurnal radiation in the photosynthetic active range of chlorophyll (α and β) i.e. for the months of October, November and December of 2020.

Discussion.

Passive remote sensing of radiation in the most active chlorophyll absorption solar bands has been measured with a view to creating chlorophyll assisted solar cell for energy generation. It is observed that the most active frequency is 453nm followed by 430nm solar irradiance. Other peaks are 669nm which is followed by 640nm. The total energy in these wavelengths at the ground surface is on average (1395 + 1400 + 1200 + 600) x 10^3 $Wm^{-2}/nm_{)}$ i.e. 4595$Wm^{-2}nm^{-1}$

Therefore depending on the efficiency and durability of our chlorophyll extract, enough energy can be abstracted from solar radiation using chlorophyll for electricity generation.

The current challenge is the storage process of the chlorophyll extract that presently does not exceed 2 days before degenerating. While in vivo chlorophyll can be in leaves for a minimum of 3 months the extracted hardly stay for 2 days; a major challenge.

Conclusion

Passive solar measurements of solar irradiance at photosynthetic wavelengths were carried out in the months October, November and December 2020 at the Federal University Wukari, using an Eko sun photometer model MS120. The result has improved our knowledge of the diurnal variation at those frequencies of measurement. The peak of most probable radiation in the solar spectrum also coincided with the peak of photosynthetic abstraction which is a major finding in this work.

It shows clearly that a further research on the stability of chlorophyll extract needs to be continued to meet the goal of fabrication of a stable solar cell for general use.

Nomenclature

WMO: World Metrological Organization
NASA: National Aeronautic and Space Agency
SOLAR: Sun

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