THEORETICAL & EXPERIMENTAL ANALYSIS OF THE DIRECT & GLOBAL SOLAR RADIATION OF ADDIS ABABA REGION

B Y

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A B S T R A C T

The thesis submitted is divided into three parts; theoretical, computational, and experimental.

In the first part, general theory of attenuation of solar radiation in the atmosphere due to molecular scattering, water vapour and aerosol absorption is presented. The theoretical consideration includes integral turbidity factor and its relation to different absorption mechanisms. The calculated value due to the above absorption mechanisms and the integral turbidity factors for Addis Ababa region, are shown in Chapter Two.

In the second part of the thesis different empirical formulas relating global solar radiation, geographical and meteorological parameters of a given locality are collected. The most general formula by Saiyigh et.al. |29| has been chosen and applied to Addis Ababa region. With constants given by Sayigh et. al. which are claimed to be universal, considerable discrepancies were obtained. Because of this reason, an effort was made to determine a new set of nine constants of the Sayigh's equation which are applicable to Addis Ababa region.

In this process the Gauss - Newton method of least squares for non-linear regression modified by H.O.Hartly |30| was used. The regression was made using one year data of the global solar radiation supplied in Chapter 3.

In the third experimental part, a Pyranometer based on the thermoelectric principle was constructed. The instrument is simple and in-expensive. The description and comparision measurements between the experimental and local meteorological station Pyranometers were taken, the results obtained are reported in Chapter 4.

CHAPTER 1

INTRODUCTION

1.1 The Solar Energy

The Earth and its atmosphere receives continuously 1.7×10^{17} W of radiation from the sun. A world population of 10 milliard with a total power need per person of 10 KW would require about 10^{11} KW. Taking only the irradiance on only 1% of the Earth's surface could be converted into useful energy with 10 percent efficiency, solar energy could provide the energy needs of all the people on the Earth.

Solar energy is the world's most abundant permanent source of energy. The amount of solar energy intercepted by the planet Earth is 5000 times greater than the sum of all other inputs (terrestrial, nuclear, geothermal and gravitational energies,) of this 30% is reflected to space, 41% is converted to low temperature heat and radiation to space and 23% powers the evaporation.

Total terrestrial radiation is only about one-third of the extraterrestrial during a year and 70% of that falls on the oceans. However, the remaining 5.4×10^{19} J that falls on land is a prodigious amount of energy about 5000 times the total energy usage of the world in 1978. However, only a small fraction of this total can be used because of physical and socio-economic constraints.

1.2 Solar Radiation

When we speak about radiation, reference is made to the electromagnatic emission directly from the sun's disc. This radiation reaches the earth about eight minutes after the emission process.

The sun's electromagnetic radiation covers an extremely wide range of wavelengths; from ($10^{-4}\mu$ - $10^{10}\mu$). Of the whole spectrum, we can sense only those that have approximately 0.1 to 100 microns. Within this limit, cause our body to heat up. Hence these waves are called "thermal radiation". Visible light ray occupy a very narrow band of the thermal radiation spectrum.

1.3 Solar Radiaton at the Earth's Surface

From the point of view of utilization of solar energy we are more interested in the energy received at the Earth's surface than in the extraterrestrial energy. Solar energy received at the surface of the Earth is entirely different due to various reasons. Before studying this, it is important to know the following terms.

The Solar Radiation reaches the ground in two forms,

a) Direct Solar Radiation

Solar Radiation intercepted by the surface of the

Earth with neglegible direction change and scattering in the atmosphere. Direct radiation is also reffered to as beam radiation.

b) Diffuse Radiation

- Solar radiation scattered by aerosols, dust, and by Rayleigh mechanism, and doesnot have unique direction.

c) Global Radiation

- Global radiation is the total of direct and diffuse radiation, global radiation is sometimes refered to as total radiation.

1.4 The Solar Constant

Referring to Figure 1.1, the geometry of sun-Earth relationships, eccentricity of the Earth's orbit is such that the distance between the Earth and the sun varies ±3%. The characterestics of the sun and its spatial relationship to the Earth result in a nearly fixed intensity of solar radiation outside of the Earth's atmosphere. The "Solar Constant", I_o is the energy from the sun, per unit time, received on a unit area of surface perpendicular to the radiation, in space, at the Earth's mean distance from the sun.

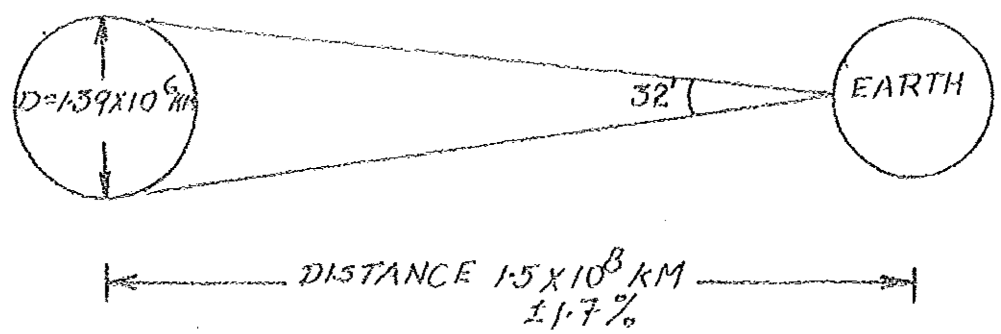


Fig. 1.1 Schematic of sun-Earth relationships (not to scale.)

Until recently, estimates of solar constant had to be made from ground based measurments of solar radiation after it had been transmitted through the atmosphere, and thus in part absorbed and scattered by components of the atmosphere. Extrapolations from terrestrial measurments, which were made from high mountains, had to be based on estimates of atmospheric transmission in various portion of solar spectrum. Pioneering studies were done by C.G. Abbot and his colleagues at Smithonian institute.

However recently, the availablity of very high altitude aircrafts, balloon and space crafts has permitted direct measurment of solar intensity on most or all of the Earth's atmosphere. These measurments have been reviewed and summarized and a new standard value of solar constant is given by Thekaekara |1|. And more recently rocket and satellite measurements make it possible to estimate the value of I_o to an accuracy of ±0.5 percent or better. Following the adoption of the World Radiometric reference (WRR) |2|, the present and the most reliable value of I_o is 1370±6W-M^{-2}, (about 1.95 cal $CM^{-2}min^{-1}$) in SI units ±6W - M^{-2}.

For any mean distance between sun-Earth, the Extra terrestrial radiation can be calculated by considering the Earth's orbital eccentricty factor e(n) that is,

$$I_o' = I_o e(n) \qquad (1.1)$$

Where approximately $e(n) = 1 + 0.0\,34 \text{ Cos } [\frac{2\pi n}{365}]$ (1.2) in which 'n' is the day number counted from January 1^{st}. These values are available on a table, FRANK KREITH |3|. In its annual revolution round the sun, the Earth moves not in a circle but in an ellipse. At different times it moves nearer or farther from the sun. Early in January, the Earth passes through the point in its orbit when it is nearest to the sun, known as perhelion, and at the begining of July, it passes through the farthest point, called the aphelion.

1.5 Spectral Distribution of Solar Radiation

The extra atmospheric distribution of energy in the solar radiation spectrum can be found either by direct measurments, or by extrapol ation beyond the surface of the atmosphere, of surface spectrometric measurement data. So far direct measurements are taken by means of rockets.

In 1977, the WMO working groups on radiation measurement system of the commission for instruments and methods of observation (CIMO) recommended the use of spectral distribution, summerized by Smith and Gottlieb |4| and the accuracy of the data is about ±2%.

The spectral irradiance reaching the Earth's surface, according to the above convention, is in the range of (0.29 - 4.00) μm in which it constitutes 99.125% of the total solar radiation.

The spectral radiation, according to their constituent is described as follows:-

Wave length App. range (μm)	Name	%
(0.29 - 0.40)	Ultra Violet	07.672
(0.40 - 0.75)	Visible	43.806
(0.75 - 4.0)	Infrared	37.697

Table 1.1 - Main Spectral Distribution of Solar Radiation

From the point of view of utilization of solar energy, we are interested in the energy recived at the Earth's surface than in the extrateresterial energy. Due to the following reasons, the solar radiation received by the Earth's surface is entirely different.

1.6 Attenuation of Solar Radiation

The variation in solar radiation reaching the Earth than received at the outside of the atmosphere is due to absorption and scattering in the atmosphere. All atmospheric components contribute to a greater or lesser degree to the attenuation of the direct solar radiation on its path to the Earth's surface. The attenuation of the direct flux of radiation takes place as the result of the mechanisms of absorption and scattering which affects simultaneously all parts of solar spectrum. In the upper layer of the atmosphere, the main process are absorption of the X-ray and ultravioret regions of the solar spectrum and scattering in the violet and blue ranges.

As the radiation penetrates to lower layer of the atmosphere, the attenuation affects the longer wavelength portion of the solar radiation.

The basic atmospheric gases-nitrogen and oxygen mainly attenuate radiation in the ultraviolet visible regions of the spectrum through molecular scattering. Solar radiation is scattered not only by gas molecules and water vapour, but also by solid drop particles, fog and ice crystals. Diffuse radiation constitutes a significant part of the radiation flux, while part of which goes back to space.

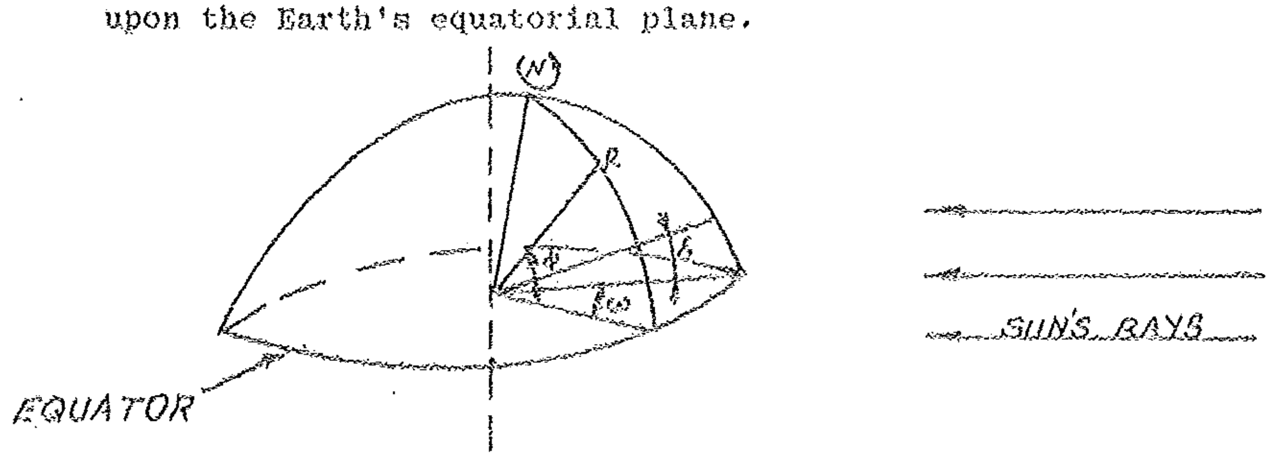
1.7 The geometry of Sun-Earth - Time System

Inorder to understand, calculation of solar radiation, some basic terms in solar radiation geometry are given.

Basic Sun Earth Angles. The lattitude ϕ of a point on the surface of the Earth is its angular distance north or south of the equatormeasured from the center of the Earth.

The hour angle (ω) is the angle through which the Earth must turn to bring the meridian of a point directly in line with the sun's ray. At solar noon, the hour angle is zero and it expresses the time of the day with respect to solar noon. One hour angle equivalent to $\frac{2\pi}{24}$ = 0.262 rad or $\frac{360°}{24}$ = 15° (1.3).

The Sun's Declination (δ) is the angular distance of the sun's rays north (or south) of the equator. It is the angle between a line extending from the center of the sun to the center of the Earth, and the projection of this line upon the Earth's equatorial plane.



The variation of the sun's declination angle δ (the maximum value of δ is at summer solstice* (+23.5°) and winter solstice(-23.5°)) roughly can be found using the equation;

$$\delta = 23.5 \sin \left(\frac{2\Pi K}{365}\right) \quad (1.4)$$

Where k = 0, at March 21^{st}

For solving practical problems in actinometry, the position of the sun is determined most conveniently by system of horizontal coordinates, using the sun's elevation and azimuth. The sun's altitude angle is determined by the direction towards the sun and the plane of the horizon. The azimuth of the sun Ψ, is the angle between the local meridian and the vertical plane of the sun.

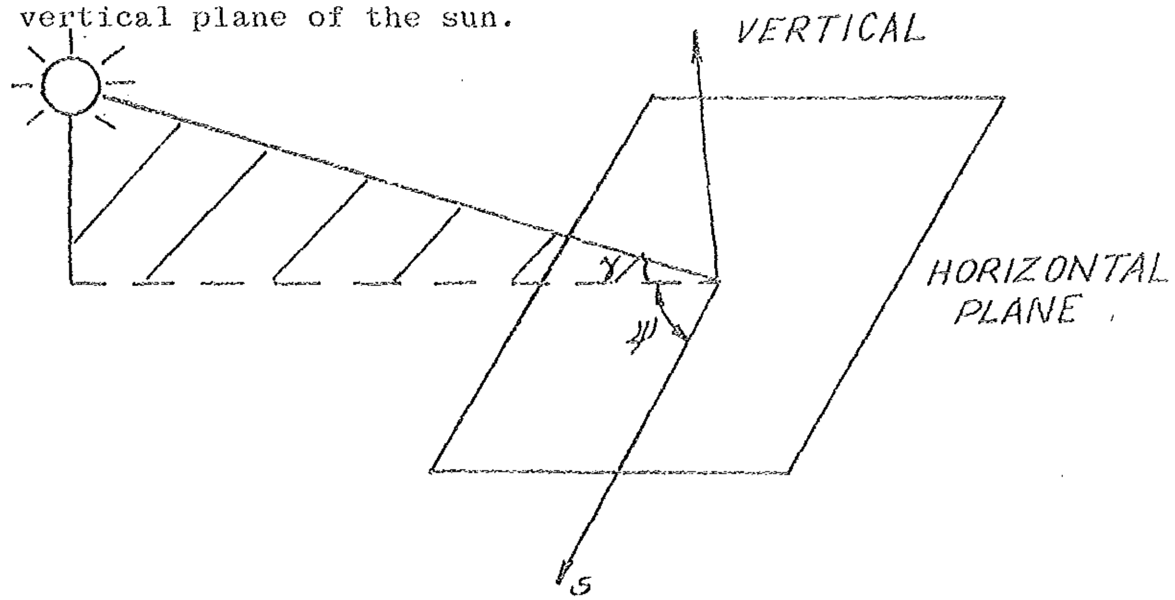


Fig. 1.3 Diagram showing solar altitude angle γ and solar-azimuth angle Ψ.

*Solstice means "sun standing still" of min. or max. diclination.

Solar attitude and azimuth are not fundamental angles, however they must be related to the fundamental angular quantities, hour angle, latitude and solar declination.

Considering the spherical triangle of the above diagram will have sides, (90 - δ), (90 - L) and z = (90 - γ)

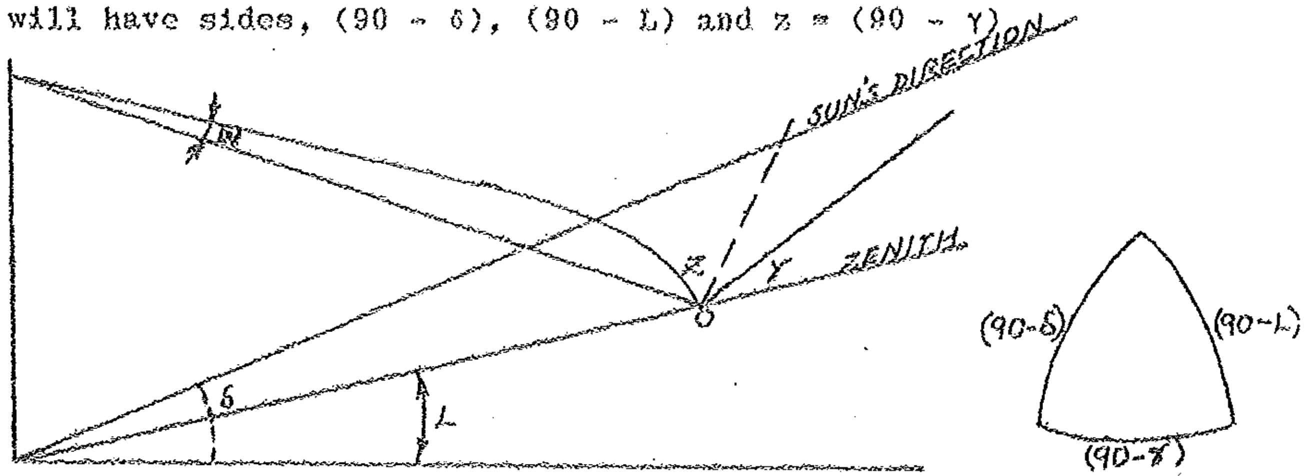


Figure 1.4 - Shows δ, L, ω of the Solar Geometry Z = (90 - γ)

Using spherical trignometrics according to KELLS KERN and BLAND |5| and using Napier's rule for spherical triangles, "The cosine of any side of a spherical triangle is equal to the product of the cosines of the two other sides increased by the product of the sides of the two other sides and the cosine of the angle included between them."

Symbolically considering the spherical triangle of figure (1.4)

$$Cos(90-\gamma) = Cos(90-L)\ Cos(90-\delta) + Sin(90-\delta)\ Sin\ (90-L) \times Cos(\omega) \quad (1.5)$$

Simillarly the azimuthal angle Ψ can be computed as,

$$\text{Sin } (\Psi) = \frac{\text{Cos } (\delta) \times \text{Sin } (\omega)}{\text{Cos } (\gamma)} \quad (1.7)$$

Length of the day; Another important factor for solar radiation is the length of the day. This can be calculated as follows; at the time of sun rise or sun set, the zenth angle z = 90°, and hence substituting into (1.5) and solving for (ω)

$$\omega = \cos^{-1} (-\tan\phi \tan\delta) \quad (1.8)$$

The length of the day 15 (Td) = 2ω

$$2\omega = 15 \text{ Td} = 2 \cos^{-1} (-\tan\phi \tan\delta)$$

and hence $\text{Td} = \frac{2}{15} \cos^{-1} (-\tan\phi \tan\delta)$ (1.9)

the length of the day Td is a function of latitude and solar declination.

1.8 The Equation of Time

It is noted that the time specified in all of the sun angle relationships is solar time, which does not coincide with local time.

It is necessary to convert standard time to solar time by applying two corrections. First, there is a constant correction for any difference in longitude between the location and the meridian on which the local standared time is based. The second correction is from equation of time which takes into accoun the various perturbations in the Earth's orbit and rate of rotation which affect the time the sun appears to cross the observers meridian. This correction is obtained from published charts. Thus, solar time can be obtained from standard time by this

$$\text{Solar Time} = \text{Standard time} + E + 4\,(LST - LOC) \quad (1.10)$$

Where E → the equation of time, tables in minutes. (6)

LST → the standard meridian of the local time zone.

LOC → the longitude of the location in question, in degrees west.

Values of the equation of time for any day in the year can be estimated from a graph known as the Anelmma and this can be found on solar energy books.

CHAPTER 2

ATTENUATION OF DIRECT SOLAR RADIATION MOLECULAR SCATTERING AND TURBIDITY FACTOR

2.1 Introduction

In recent years requests have come from physicists, engineers and from biologists for more information concerning the quantity and quality of solar radiation reaching the Earth's surface. Increasing awarness of the depletion of the non-renwable energy sources has stimulated investigations into new methods of converting solar energy into useful power.

Among the major factors governing the "heat balance" at the Earth's surface are:

a) direct solar radiation reaching the Earth's surface after penetration of the atmosphere,

b) diffuse radiation reaching the Earth's surface,

c) radiation leaving the Earth's surface (albedo α).

The sky radiation (diffuse) includes:

i) radiation from the extraterrestrial source including stars, moon, planets and the dust particles causing zodiacal light,

ii) radiation due electric excitation of the atoms and molecules in the atmosphere,

iii) scattered radiation passing through the atmosphere,

iv) "thermal" radiation from the atmosphere.

The contribution of (i) and (ii) to heat balance are negligible as compared to the contribution of (iii) and (iv).

Solar radiation reaches the Earth's surface either directly or after being scattered by atmospheric particles. This paper reports the analysis of the measurements in Addis Ababa, of the molecular scattering of the direct beam radiation, the integral turbidity factor calculation and the contribution of attenuation due to water vapour and aerosol concentrations.

The spectral distribution of solar radiation was first investigated qualitatively by Langley (1881), but there have been few systematic investigations of direct beam spectral irradiance in spite of reports of changes in atmospheric transmission.

Various authors have reported examples of calculated spectral distribution based on various model atmospheres, Unsworth and McCartney (7); measured narrow band spectra has also been published, both in energy units, Dunkel man and Scolnic (8).

In the calculation of the attenuation of the direct solar radiation factors and relations, in the atmosphere, were found by considering the theoretical transfer of heat in the atmosphere.

2.2 Solar Radiation Transfer in the Atmosphere

All the atmospheric components contribute to a greater or lesser degree to the attenuation of the direct solar radiation on its path to the Earth's surface. The attenuation of the direct flux of radiation takes place as a result of the mechanisms of absorption which affect simultaneously all parts of the solar spectrum.

In the upper layers of the atmosphere, the absorption of solar radiation is caused by oxygen, oz-one and nitrogen oxides and, in the lower stratosphere and troposphere, by water vapour, carbondioxide, aerosols and other minor components. The variations in the concentration of water vapour and oz-one and optical characterstics of aerosols under the influence of various processes of interaction between solar radiation field, the atmosphere and the underlying surface result in constant fluctuations in spectral transmissions in the atmosphere.

2.3 Attenuation of Direct Radiation

Radiation at normal incidence received at the surface of the Earth from the sun is subject to variation due to ,

1. variations in distance from Earth to sun,
2. variations in atmospheric scattering by air molecules, water vapour, and dust, and
3. variations in atmospheric absorption by O_2,O_3,H_2O and CO_2.

Scattering, which results in attentuation of direct radiation by air molecules, water vapour, and dust, has been the subject of a number of studies and an approximate methods have been developed to estimate the magnitude of the effect.

2.4 The Equation of Radiative Transfer

Due to great complexity of the processes that determine the radiative transfer, the transfer equation is complex. In the atmospheric radiative transfer we usually confine the problem to consideration of radiative transfer for a stationary field of unpolarized radiation, without taking account of refraction.Kondrayatev |9| .

The thermal emissions were considered unpolarized and the refraction in the atmosphere is neglected in the general consideration of the problem.

In the derivation of the general transfer equation for a stationary field of unpolarized radiation, we take an arbitrarly directed ray r-direction and consider an environmental element in the form of a cylinder of unit section, the axis of which coincides with the direction of the ray. Let the ray cut the basis, perpendicularly as shown in the Figure 2.1 E.M. Feigel'son |10| .

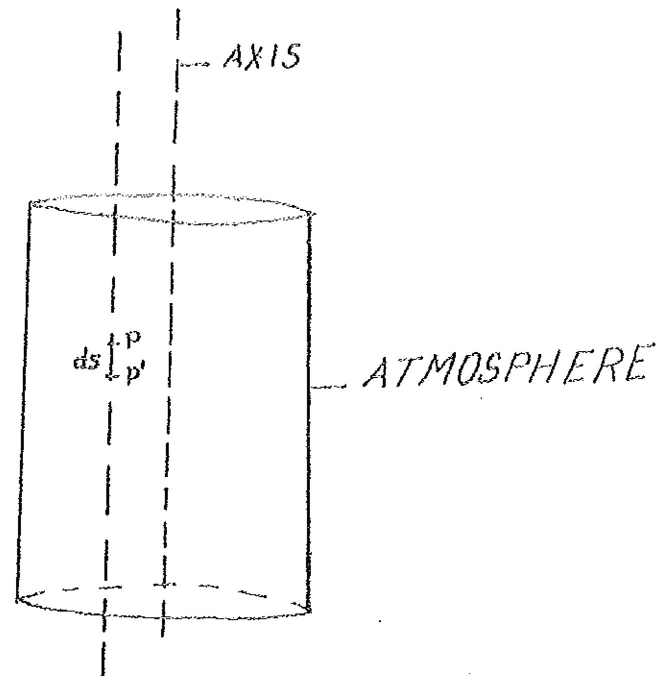


Fig.2.1: Cylinderical Cross Section of Environmental Atmosphere

Then, the intensity of radiation at point p and p' be

$$I_\lambda(p',r) = I_\lambda(p,r) + \frac{\partial I_\lambda}{\partial s} ds \qquad (2.1)$$

The variation of intensity from point p and p' is caused by

a) attenuation due to absorption of radient energy, which can be expressed as

$$-k_\lambda(p)\ I_\lambda(p,r)\ \rho(p)\ ds \qquad (2.2)$$

Where ρ, is the density and k_λ is the mass absorption coefficient at point p.

b) Attenuation due to scattering radient energy by considered environmental element, which can be presented in the form

$$-\delta_\lambda(p)\ I_\lambda(p,r)\ \rho(p)ds \qquad (2.3)$$

where δ_λ is scattering coeffcient.

c) Increase of the intensity of radiation owing to the considered element of the medium emitting in the direction r, which can be written as,

$$\eta_\lambda \ \rho(p)ds \tag{2.4}$$

d) Increase of the intensity of radiation resulting from scattering process due to which the rays of various direction passing through elmentary cylinder add a part of their energy to the ray of the direction r.

If we consider the ray of the direction 'r'' through an element of medium, if the part of this energy equal to

$$\delta_\lambda(p) \ I_\lambda(p,r')\rho ds \tag{2.5}$$

will be scattered by this element and a part

$$\delta_\lambda(p) \ I_\lambda(p,r') \ \frac{\gamma_\lambda(p,r',r)}{4\pi} \ \rho ds \tag{2.6}$$

will go in the direction r.

Here the expression $(\frac{1}{4\pi})\gamma_\lambda(p,r,r')$ characterizes the scattering function, and this means the total quantity of the scattered radiation, the portion of $(\delta_\lambda \ I_\lambda\rho)$ equal to $(\frac{1}{4\pi} \ \gamma\delta_\lambda I_\lambda\rho \ ds)$ departs in the direction r. Integrating the whole expression overall possible directions, we have,

$$\frac{\delta_\lambda(p)}{4\pi} \int I_\lambda(p,r') \ \ \gamma_\lambda \ (p,r',r)d\omega'\rho ds \tag{2.7}$$

Then summing over all (a,b,c,d), and

taking into consideration all obtained results and reducing by ds we get

$$\frac{1}{\rho}\,\frac{dI_\lambda}{ds} = \eta_\lambda + \frac{\delta_\lambda}{4\pi}\int I_\lambda(p,r')\,\gamma_\lambda(p,r',r)\,d\omega' - (k_\lambda+\sigma_\lambda)I_\lambda \qquad (2.8)$$

As mentioned by the relation, substituting a change of variable as shown in the diagram,

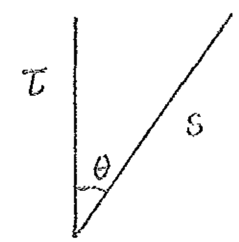


Fig. 2.2 Atmospheric Thickness and Sun's Ray

$$\cos\theta\, ds = d\tau$$

$$\frac{1}{\rho}\,\frac{dI_\lambda}{ds} = \frac{1}{\rho}\,\frac{dI_\lambda}{dz}\,\frac{d\tau}{ds} = \frac{1}{\rho}\cos\theta\,\frac{dI_\lambda}{d\tau} \qquad (2.9)$$

where τ is the atmospheric thickness.

$$\text{Cos}\,\frac{1}{\rho}\,\frac{dI_\lambda}{d\tau} = \eta_\lambda + \frac{\delta_\lambda}{4\pi}\int I_\lambda(p,r')\gamma_\lambda\,(p,r',r)\,d\omega' - (k_\lambda+\sigma_\lambda)I_\lambda \qquad (2.10)$$

and the relation $I_\lambda(p,r) \rightarrow I_\lambda(\tau,r)$

$$\rightarrow \quad \text{Cos}\,\theta\,\frac{1}{\rho}\,\frac{dI_\lambda}{d\tau} = \eta_\lambda + \frac{\delta_\lambda}{4\pi}\int I_\lambda\,(\tau,r')\gamma_\lambda(\tau,r',r)\,d\omega'$$

$$- (k_\lambda+\sigma_\lambda)I_\lambda \qquad (2.11)$$

If the medium is in thermodynamic equilibrium, the emisitivity and the absorptivity of the medium are related by Kirchoff's law,

$$\eta_\lambda = K_\lambda\, B_\lambda\,(T) \qquad (2.12)$$

where $B_\lambda(T) = \dfrac{2hc^2}{\lambda 5} \dfrac{1}{(\mathrm{Exp}(hc/K_\lambda T)-1)}$ 2,13

The lower atmosphere (troposphere) generally statisfies the condition of the local equilibrium. Then the eqn. becomes,

$$\mathrm{Cos}\,\theta \frac{dI_\lambda}{d\tau_\lambda} = -I_\lambda(\tau, \xi) + \frac{\beta_\lambda a_\lambda}{4\pi} \int I_\lambda(\tau, r')\gamma(\tau, r, r')d\omega' \qquad (2,14)$$

Where, $a_\lambda = \rho\delta_\lambda + \rho\kappa_\lambda$ and $\rho\delta_\lambda = (a_\lambda - \rho\kappa_\lambda) = \beta_\lambda a_\lambda$, $a_\lambda I_\lambda = I_\lambda(\tau, r)$

In a cloudless atmosphere the absorption by atmospheric gases is neglected and the equation becomes,

$$\mathrm{Cos}\,\theta \frac{dI}{d\tau} = \frac{1}{4\pi} \int I(\tau, r')\gamma(\tau, r, r')d\omega' - I(\tau, r) \qquad (2,15)$$

Seperating the unknown $I(\tau, r)$ between the diffuse and the direct radiation, we get,

$$I(\tau, r) = I_s(\tau, r) + I_r(\tau, r) \qquad (2,16)$$

Where $I_s(\tau, r)$ is the intensity of the parallel beam of the sun rays determined from the above equation, for the direct beam we have $\frac{d\omega}{4\pi} = 0$, this implies,

$$\mathrm{Cos}\,\theta \frac{dI}{d\tau} = -I(\tau, r) = -I_s(\tau, r) \qquad (2,17)$$

Solving the equation using the boundary condition

$$I_s(\tau^*, r) = \pi s\delta(r, r_0) \qquad (2,18)$$

$$\Rightarrow \frac{dI}{d\tau} = -I_s \,\mathrm{Sec}\,\theta$$

$\therefore \quad I_s(\tau,r) = c\, e^{-\sec\theta\tau}$ using the boundary condition

$$I_s(\tau,r) = \pi s\delta\,(r-r_\theta)\; e^{-\sec\theta(\tau^*-\tau)} \qquad (2.19)$$

Where $\sec\theta = m$; m, the atmospheric mass and θ is the zenth angle determined by the relation of equations (1.5)

and $(\pi s\delta(r-r_\theta))$ where $r=r_\theta$ is the extrateresterial solar radiation.

Denoting $\pi s\,\delta(r-r_\theta) = I_o$ extraterestrial radiation and $m = \sec\theta$, the equation becomes,

$$I(\tau,r) = I_o(e^{-m\tau}) \qquad (2,20)$$

And this equation is known as Lambert-Beer equation.

2.5 Spectral Distribution of Direct Solar Radiation

The attenuation of monochromatic radiation in the direct beam by the atmosphere may be described by Lambert-Beer's equation, thus, the total energy integrated over all wave-length in the direct solar beam at normal incidence on the Earth's surface,

$$I_{N,R} = \int_{0.29um}^{4.0um} I(\lambda)d\lambda \qquad (2.21)$$

$$\rightarrow I_{N,R} = \int_{0.29um}^{4.0um} I_o(\lambda)Exp\{-m(\theta)\tau(\lambda)\}d\lambda \qquad (2.22)$$

Where $I_o(\lambda)$ extraterrestrial radiation and $m(\theta)$ is atmospheric air mass in the direction of the sun. The radiation in the interval (0.29 - 4.0) um constitutes 99.195% of the solar radiation according to WMO(4)bulletin.

The integrad of eqn. 2.22 can be written as

$$I(\lambda) = I_o(\lambda)e^{-\tau(\lambda)m(\theta)} \qquad (2.23)$$

Where the atmospheric thickness

$$\tau(\lambda) = \tau_R(\lambda)+\tau_g(\lambda)+\tau(\lambda) \qquad (2.24)$$

and denoting $p(\lambda) = e^{-\tau(\lambda)}$ (2.25) where $p(\lambda)$ is the transparency coefficient.

$$I_{N,R} = \int_{0.29um}^{4.0um} I_o(\lambda)Exp(-m_h(\theta)(\tau_R(\lambda)+\tau_g(\lambda)+\tau(\lambda))d\lambda \qquad (2.26)$$

Where, $\tau_R(\lambda)$ $\tau_g(\lambda)$, and $\tau(\lambda)$ are respectively the vertical attenuation coefficients for molecular scattering, absorption by atmospheric gases (water vapour, carbondioxide, ozone, oxygen) and aerosol extinction.

Using eqn.(2.25) we get,

$$I(\lambda) = I_o(\lambda)\ P_\lambda^{m(\theta)} \qquad (2.27)$$

Then integrating over all possible wavelengths we get,

$$I_m = \int_{0.29um}^{4.0um\ d\lambda} I(\lambda)d\lambda = \int_{0.29um}^{4.0um} I_o(\lambda)\ P_\lambda^m d\lambda \qquad (2.28)$$

Then the transparency coefficient, averaged over the whole spectrum

$$I_m = P_m^m \int_{0.29um}^{4.0um} I_O(\lambda)d\lambda = I_o P_m^m \qquad (2.29)$$

$$P_m^m = \frac{\int_{0.29um}^{4.0um} I_O(\lambda)P_\lambda^m d\lambda}{\int_{0.29um}^{4.0um} I_O(\lambda)d\lambda} \qquad (2.30)$$

By taking into account of the radiation due, to, molecular scattering and absorption of radiation by water vapour and aerosol as,

$$\tau(\lambda) = \int K_\lambda \rho dh + \int a_{\omega,\lambda} \rho\omega dh + \int a_d \rho_d dh. \qquad (2.31)$$

Where ρ, ρω and ρd are molecular, water vapour and aerosol concentration respectively. From (2.31) it can be written a ,

$$\tau(\lambda) = T_\lambda \int K\lambda \rho dh \qquad (2.32)$$

where $$T_\lambda = 1 + \frac{\int a_{\omega,\lambda} \rho\omega dh}{\int K_\lambda \rho dh} + \frac{\int_{0.29um} a_{d,\lambda} \rho d \, dh}{\int K_\lambda \rho dh} \qquad (2.33)$$

Therefore, the monocromatic direct solar radiation flux at a given solar zenith distance (given atmospheric mass) can be presented in the form,

$$I_m(\lambda) = I_o(\lambda)\, Exp\, \{-T_\lambda m \int K_\lambda \rho\, dh\} \qquad (2.34)$$

Setting $q(\lambda) = Exp\, \{-\int K_\lambda \rho\, dh\}$ (2.35)

Then for full flux of direct solar radiation I_m, becomes,

$$I_m = \int_{0.29um}^{4.0um} I_o(\lambda)\; q(\lambda)^{mT\lambda} d\lambda \qquad (2.36)$$

If q_m and T_m are the averaged values over the whole spectrum we get,

$$I_m = q_m^{mT_m} \int_0^\infty I_o(\lambda)\, d\lambda = I_o\; q_m^{mT_m} \qquad (2.37)$$

Where, T_m is the integral turbidity factor.

And hence, $\frac{I_m}{I_o} = q_m^{mT_m}$ (2.38)

Comparing with the expression of the transparency coefficient, we get,

$$P_m^m = \frac{I_m}{I_o} = q_m^{mT_m} \qquad (2.39)$$

Solving for the integral turbidity factor T_m from (2.39)

$$T_m = \frac{1}{m \ell_n q_m}\; \ell_n\; \left(\frac{I_m}{I_o}\right) \qquad (2.40)$$

denoting $I_{ideal} = I_o \, q_m^m$, where I_{ideal} is only molecular scattering where q_m is as defined in (2.35) .

It can be shown that the following relation holds namely,

$$\frac{1}{m \ell_n \, q_m} = \frac{1}{\ell_n \left(\frac{I_{ideal}}{I_o} \right)} \qquad (2.41)$$

Substituting (2.41) into (2.40) and simplifying we get

$$I_m = \frac{\ell_n (I_m) - \ell_n (I_o)}{\ell_n (I_{ideal}) - \ell_n (I_o)} \qquad (2.42)$$

Where I_{ideal} , is the radiation received by the Earth depleted due to molecular scattering. (Rayleigh scattering mechanism).

Inorder to calculate the integral turbidity factor (2.42) , it is important to calculate I_{ideal} , the solar radiation due to molecular attenuation.

2.6 Molecular Scattering of Solar Radiation (Rayleigh Scattering)

The most important contribution to this field was made by Lord Rayleigh in early 1870, who contended that air molecules were the causes of light scattering. The molecular scattering of Rayleigh is the scattering of light caused by density fluctuations.

The following fundamental assumptions were taken into consideration.

a) The dimensions of the scattering particles (Rayleigh particles) which scatter the radient energy in this case are roughly less or equal to 0.1λ, as compared to the wavelength (λ) of the solar spectrum.

b) The scattering particles and the medium are not conductors and do not contain free electric charges.

c) The particles scatter light independently to each other.

The Rayleigh volume scattering coefficient of standard air, at a particular wavelength λ may be written as

$$\beta(\lambda) = \frac{32\pi^3 (n_\lambda - 1)^2}{3_\lambda^4 N} \left| \frac{6 + 3\rho_{n\lambda}}{6 - 7\rho_{n\lambda}} \right| \qquad (2.43)$$

Where N_s is the number density (mole/cm), ρ_n is the depolarization factor and n_s is the refractive index of standard air.

The spectral solar radiation intensity reaching the Earth's surface after depletion due to scattering by air molecules may be written as,

$$I_\lambda(\theta,h) = I_{o\lambda} \, \mathrm{Exp}\{-\beta(\lambda)\, m_h(\theta) H\} \qquad (2.44)$$

Where (H = 7996m) is the vertical height of the imaginary homogenous atmosphere at NTP.

Denoting the optical thickness of the atmosphere as

$$\tau(s,s') = \int_{s'}^{s} \beta\, ds \qquad (2.45)$$

where s' is at the surface of the Earth and s at the top of the atmosphere, then we can write,

$$I_{Ideal}(\theta,h) = \int_{0.29um}^{4.0um} I_o(\lambda) \mathrm{Exp}\{-\tau(\lambda)m(\theta)\}d\lambda \qquad (2.46)$$

Where, $\tau(\lambda)$ is Rayleigh molecular attenuation coefficient and $I_{ideal}(\theta,h)$&$I_o(\lambda)$, are spectral energy at the wavelength λ, on the Earth's surface and outside the Earth's surface respectively.

And the airmass $m(\theta)$ is the absolute airmass which takes account, the stations altitude h, by means of the formula Kodrayatev |11| .

$$M_h(\theta) = \frac{P_h}{P_o}(m(\theta)) \qquad (2.47)$$

Where P_h is the pressure at the station and P_o pressure at sea level.

Molecular attenuation coefficients $\tau(\lambda)$, calculated from Rayleigh's theory via (2.44) and (2.45), were tabulated by Pendorf |12| and the evidence supporting the accuracy of theory was reported by Chandra M.|13| .

The integrated effect of gaseous absorption on the attenuation of solar radiation has been investigated by several authors, MacDonald |14| ; Roach |15| ; and Yamamoto |16| .

Thus, the total energy integrated over all wavelengths in the direct solar beam at normal incidence on the Earth's surface, after having traversed the Rayleigh atmosphere is calculated via (2.46) .

2.7 Atmospheric Turbidty

Several atmospheric turbidty coefficients have been introduced during the past decades inorder to quantify the influence of atmospheric aerosol content on a direct radiation received at the Earth's surface. The most currently used are Linke factor T. and Angstrom Coeffcient β. Turbidity usually occurs in conditions of high humidity, and in the presence of hygroscopic aerosol particles. Variations in atmospheric turbidity are also possible in conditions of low relative humidity if air contains dry aerosol particles, natural or man made-origin.

In practical calculations of the attenuation of solar radiation in the atmosphere due to aerosol scattering, extensive use is made of the method proposed by Angstrom, expressed as,

$$a_p(\lambda) = \beta_o \lambda^{-\alpha} \qquad (2.48)$$

Where , β is the Angstrom turbidty coefficient, can be determined by measuring direct solar radiation in the band (0-0,630) μm , and α is an index related to dimensions of the scattered particles and the nature of their size distribution. This is an emperical relationship obtained from the observational data.

Wide band direct beam solar irradiance can be similarly analysed interms of aerosol attenuation (turbidty). H.A. McCARTNEY and M. HUNSWORTH |17| used an integral turbidty coefficient, $\tau(\Delta\lambda)$, to describe aerosol attenuation in a finite wave band, $\Delta\lambda$, by analogy to Lambert-Beer's law (2.20).

$$\tau(\lambda) = |\ell n(I_*(\Delta\lambda)) - \ell n\{I(\Delta\lambda)\}|/m_h\ (\theta) \qquad (2.49)$$

Where $I(\Delta\lambda)$ is the direct irradiance in the wave band $\Delta\lambda$ and $I_*(\Delta\lambda)$ is irradiance emerging from an aerosol free atmosphere.

<u>Linke Turbidity Factor</u>

In practice, the characterstic of atmospheric transparency is widely used; turbidity factor (Trubungs Faktor) denoted by T was proposed by Linke (Sutton) |18|.

The turbidity factor is defined as the ratio of the coeffcient of total extinction of solar radiation in a real atmosphere to the coeffcient of extinction by the component of ideal atmosphere, i.e., by molecular scattering and selective absorption by ozone, oxygen and carbondioxide.

The turbidity factor gives a clear idea of radiation extinction, since it characterizes variable extinction in the real atmosphere relative to constant extinction in ideal atmosphere.

Recalling (2.33) and denoting,

$$W = \frac{\int a_{w,\lambda} \ \rho_w \ dh}{\int k_\lambda \ \rho \ dh} \ , \ R = \frac{\int a_{d,\lambda} \rho_d \ dh}{\int k_\lambda \ \rho \ dh} \qquad (2.50)$$

We get, $T = (1 + W + R)$ (2.51)

Corresponding to selective (water vapour) and aerosol extinction of solar radiation, the turbidity factor, as might be expected, shows marked variations with time and place. The greatest changes in variation of atmospheric turbidity are those which arise from atmospheric pollution.

From the definition factor it follows that $T = 1$ if the attenuation of solar radiation is caused by molecular scattering only. The second term on the right-hand side of (2.51), the value of W, is called humid turbidity factor, and characterizes the influence of absorption and scattering by water vapour on the attenuation of solar radiation.

The third term R, is known as the residual turbidity factor, determining the effect of radiation attentuation due to absorption and scattering by dust and aerosol particles. It is possible to calculate the aerosol and water vapour attenuation as,

$$R = T - 1 - W \qquad (2.52)$$

Where $W = 0.5\ e_o^{0.43}$, and e_o absolute humidity Sivkov |19|.

2.8 Results

The calculations for radiation depleted due to Rayleigh scattering mechanism and the integral turbidity factor were calculated using (2.46) and (2,42).

a) Molecular Scattering of Solar Radiation

The attentuation of solar radiation due to molecular scattering can be theoretically calculated for any locality. And this value can have a slight difference from place to place, considering the atmosphere to be ideal or the constitution of the gases in the atmosphere has the ideal percentage.

The variation only comes due to the airmass variation calculation from place to place. As it has been seen in (2.47) the airmass is dependent on the pressure value at a given place, which in turn takes into consideration the altitude of a given locality.

In our calculation for the A.A. region of the year 1983, the atmospheric pressure was in the interval (76,660.36 - 77,060.32) Pa. according to NMA* compared to the (101,325) Pa. at sea level. This has introduced a difference in calculation of the airmass at sea level and in Addis Ababa of altitude 2,408 m above sea level.

* NMA, National Meteorological Agency.

The attenuation of the direct solar radiation due to Rayleigh atmosphere was calculated using (2.46). For the range 0.29 to 4.0μ, in steps of 0.01μ between 0.2 and 0.8μ, in steps of 0.1μ from there on upto 2μ, in steps of 0.5μ between 2 and 4μ.

And the values $I_o(\lambda)$, extraterrestrial and $\tau(\lambda)$, attenuation coeffcient for the respective wavelength was considered in the calculations.

The integrations for the mentioned equation was carried on by Simpson's integration rule with the above steps. The input data used in the calculations-direct solar radiation, pressure of each day, (source NMA) and declination angle (δ) and Earth's elliptic orbit escentricity $E(I)$ are shown on appendix A. The direct solar radiation was measured by Eppley pyrheliometer. The wavelength interval (λ), the Rayleigh molecular attenuation coeffcient $\tau(\lambda)$, extraterrestrial radiation $I_o(\lambda)$ for the spectrum in the interval (0.29 - 4.0) μ are shown on appendix A.

Three different airmass at 13:00, 14:00 and 15:00 hrs LST were considered in the calculation and three airmass using (2.19) and (2.47) are tabulated on Appendix B.

The calculation of solar radiation received by the Earth's surface due to Rayleigh scattering mechanism, using (2.46) was carried on by a computer for the days of the year 1983 of A.A. region, and calculated values are reported on Appendix C.

The values are in the interval (931.71 - 1,012.98) $W\text{-}M^{-2}$, comparing this with the extraterrestrial radiation $I_o = 1{,}370 \pm 6\ W\text{-}M^{-2}$ shows that (26.05 - 31.95) % of the extraterrestrial radiation was depleted due to molecular scattering. The annual evolution of the monthly mean values of this scatttering is shown in Figure (2.3).

b) <u>The Turbidity Factor 'T'</u>

The turbidity factor was also calculated using (2.42) . The values for 335 days of the year 1983 of A.A. region were calculated by having the corresponding values of I_m measured, and these are on appendix A, I_{ideal} calculated for each day. In calculating the turbidity factor the value of I_o (extraterrestrial radiation - the recent value $I_o = 1{,}370 \pm 6\ W\text{-}M^{-2}$) according to W M O Technical Note was adopted.

The values of the turbidity factor for each day of the whole year are reported on Appendix C and the annual evolution of 'T' monthly mean values are shown in Figure (2.4) . The integral turbidity factor as might be expected, shows marked variations with time and place. There are usual variations in summer and winter, but the greatest changes are those which arise from the atmospheric pollutions.

FIG.2.4 THE ANNUAL EVOLUTION OF TURBIDITY MONTHLY MEAN VALUES.

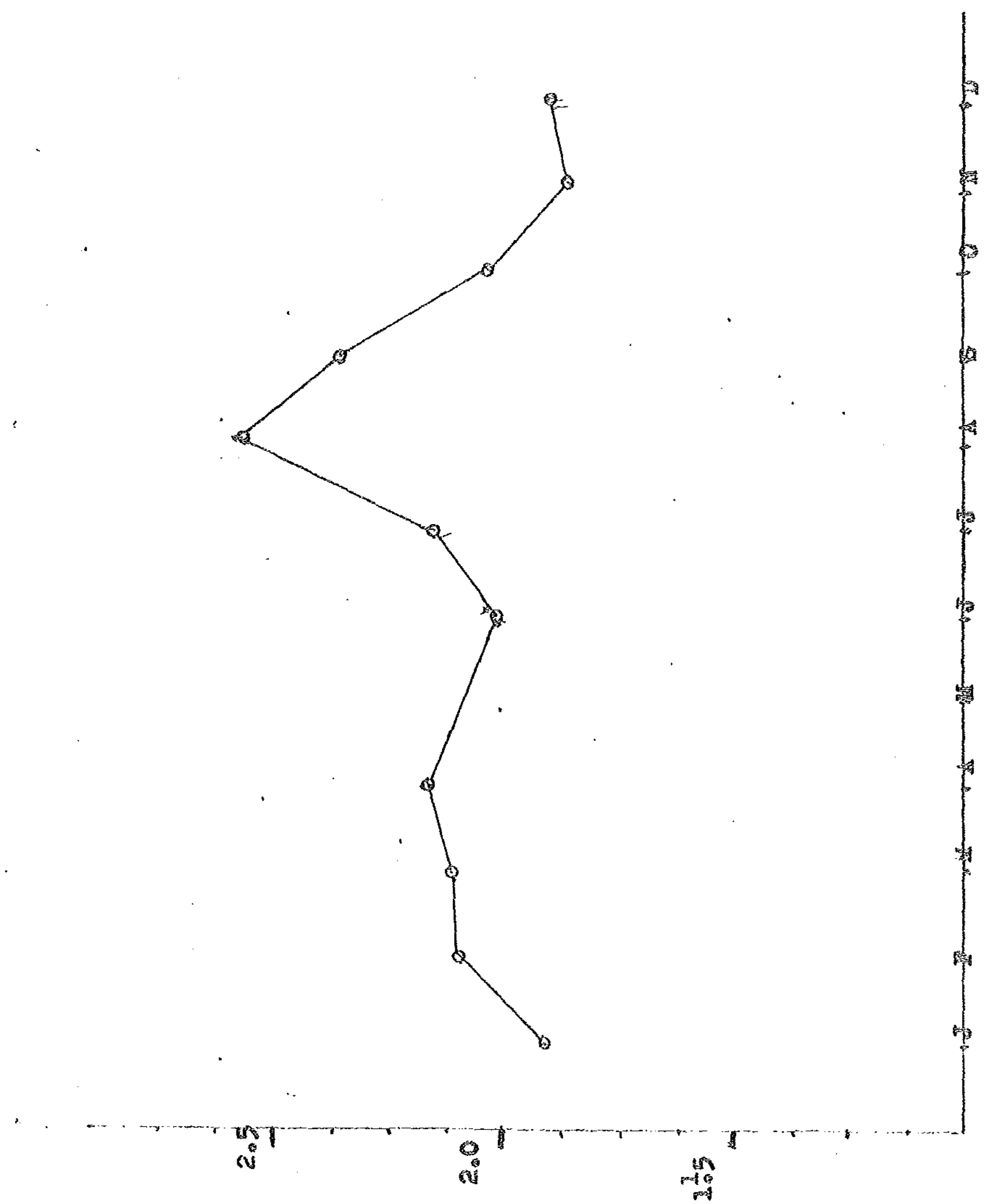
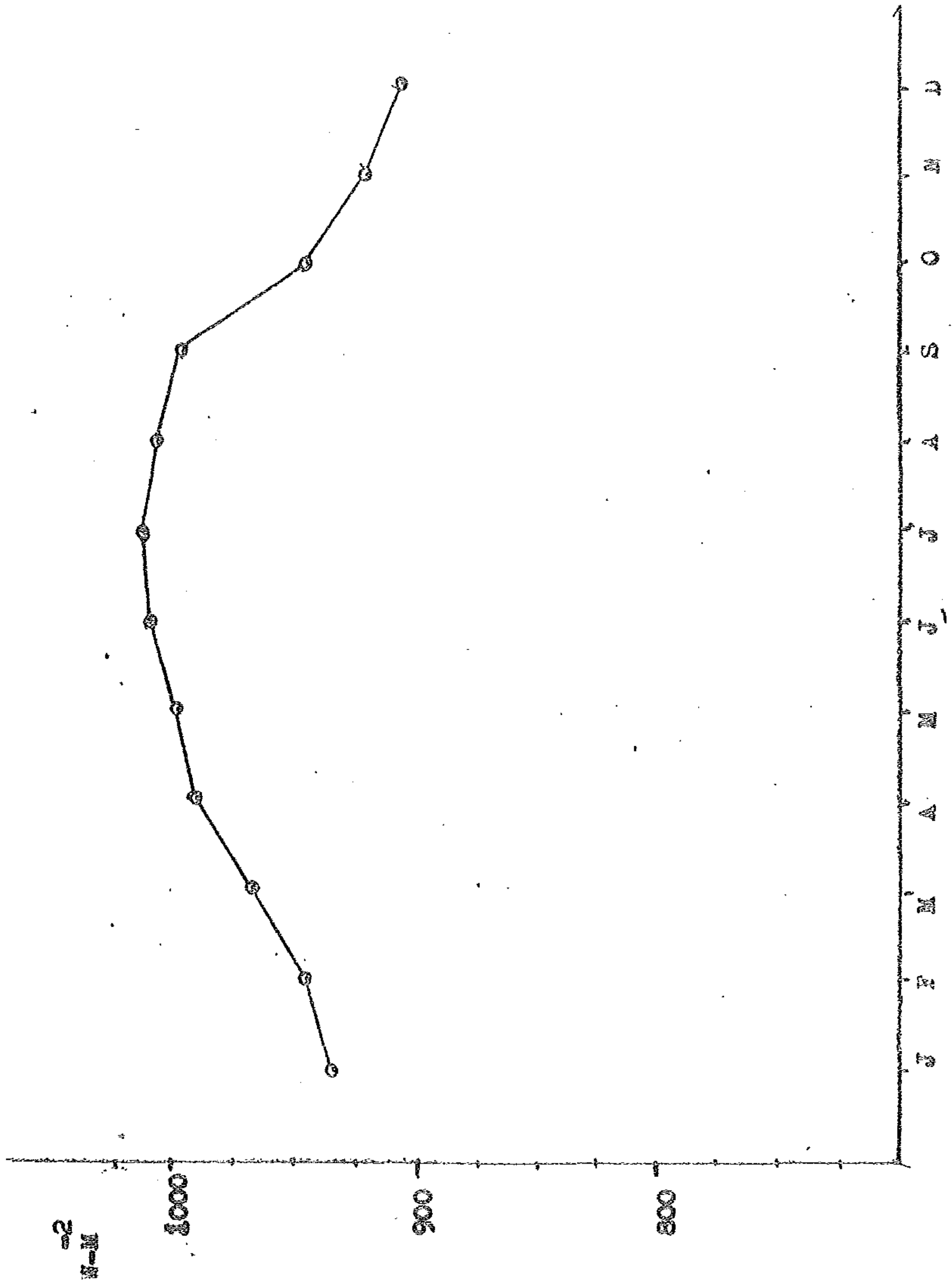


FIG.2.3 THE ANNUAL EVOLUTION OF THE MONTHLY MEAN VALUES OF RAYLEIGH SCATTERING.



As it has been done for the molecular scattering, the direct radiation measured was considered only for the time (13:00 - 15:00) MST. This has been chosen due to airmass variation is negligible, however, the molecularly scattered radiation received by the Earth was calculated at three different hour angles and averaged values are tabulated on Appendix C for the whole year. This work could have been continued to evaluate aerosol concentration using (2.52) , however, lack of data of absolute humidity has hindered the process. Correlation of turbidity factors could have also been done by a linear regression $\beta = a + bT$ M. Katz |20|, but lack of measured values of I_m in a different wave bands, has also hindered the process.

CHAPTER 3

Estimation of Global Solar Radiation
From Sunshine Hours,
Geographical & Meteorological Parameters

3.1 Estimation of Global Solar Radiation With Various Empirical Formulas

For the proper planning of the utilization of solar energy, it is necessary to know the total radiation falling in a particular region.

There are various methods for estimating the global solar radiation but it seems no single form of equation is applicable to all atmospheric enviroments and their applicablities should be tested for a particular region.

The possible approches, in estimating the global solar radiation can be made employing one of the following:

i) Using equations relating global solar radiation to number of bright sunshine hours.

ii) Using equation relating global values to other mete orological parameters.

Many authors have proposed various equations by using the first, the second approches. The latter considers a large number of metorological parameters, and is more dependent on the considered area.

These formulas were tested at various places, most of the equations are, conversion from daily sunshine duration to daily global radiation by Angstrom and schuepp formula.

$$G = Go\ (a + b\ (^{S}/So)\ )\quad \text{Angstrom}\quad (3.1)$$

$$G = a + b\ (\tfrac{1}{2}\ (^{S}/So)\quad (1 + {}^{S}/So))^{\frac{1}{2}}\quad \text{Schuepp}\ (3.2)$$

Where S and So are daily hours of bright sunshine, maximum possible daily hours of bright sunshine hours and Go, clear sky global radiation, respectively.

Using (3.1) R.H.B. Excel |21| A.J.Biga |22|, A.I.Kundish |23| and make use of 3.1 and 3.2 by Cesen |24| working group, P.Kulisk |25|, T.D.M.A. Samuel |26| and F. Kasten |27| had used these equations for various regions in the world and reported the regression constants ('a' and 'b') determined for their localities. However, more recently using (3.1) determination of regression constants 'a' and 'b', based on 11 year solar radiation data at Trieste, found substantial temporal and spatial scattering. P. C. Jain |28|.

However, estimation of solar radiation from meteorological data, such as humidity, temprature and geographical factor lattitude and attitude are more related to solar radiation. One has to consider all the parameters, and deleting some of these may bound to an error. using these parameters, A. M. Sayigh et.a. |29| in 1975 deduced a formula, that can predict solar radiation on a horizontal plane.

$$G = 1.53\ K\ Exp\ \{\phi\ (D - \frac{R^{1/3}}{100} - \frac{1}{T_{max}}))\quad (3.3)$$

Where, ϕ is the lattitude of the place in radians, R is relative humidity, D, relative sunshine hours to 12 hrs., T_{max}, maximum temprature of the day in °C.

and $K = (\lambda z + Cos\phi\ \Psi ij\ ) \times 10^2\ (cal + cm^{-2} - day^{-1})$

$\lambda = 0.2/(1+0.1\phi)$

z, the length of the day, Ψij seasonal factor.

The seasonal factor has i = 1,2,3 stands for inland station, coastal station and hilly station respectively. J = 1,2,3 ---- 12, number of months starting from January. The monthly value is given on table (3.1)

	1	2	3	4	5	6	7	8	9	10	11	12
Ψ_1	1.28	1.38	1.54	1.77	2.05	2.30	2.48	2.41	2.36	1.73	1.38	1.17
Ψ_2	1.46	1.77	2.05	2.15	2.05	2.05	2.10	2.17	2.14	1.96	1.60	1.43
Ψ_3	1.60	1.81	2.00	2.17	2.25	2.26	2.24	2.20	2.10	1.92	1.74	1.60

Table 3.1 Monthly seasonal factor values

The selection of the seasonal factor values using the above criteria and humidity (annual) of the given locality should be taken.

The equation (3.3) by Sayigh et. al has been used to obtain daily global solar radiation, by considering the corresponding data of metereorological parameters for the Addis Abeba region. The results were compared with the daily measured value of gobal solar radiation.

However, decripancies ranging (20 - 300)% were obtained between the calculated and measured global solar radiation.

Therefore, the following general form of the Sayigh et. al. equation was considered.

$$G'(X_i, \theta_k) = \alpha K \, Exp \; A1\phi^{A} \, (B1D^{B} + C1R^{C} + E1\, T_{max}^{E}) \quad (3.4)$$

$$X_i = (K, \phi, D, R, T_{max}) \quad (3.5)$$

and $\theta_k = (\alpha, A1, A, B1, B, C1, C, E1, E)$ (3.6) are general constants.

Due to the above reasons an effort was done to determine the general constants using the global solar radiation, and meteorological parameters of the year 1983 for the Addis Ababa region.

A mathematical method modified by H. O. Hartley |30|, "The modified Gauss - Newton method for fitting of non-linear regression functions by least squares" was used in determining the above nine constants for Addis Ababa region.

3.2 The Formulation of the Regression

The formulation of the non-linear regression problem was, given for n sets of "observed" (k + 1) tuples, Y_h; X1h, X2h, ---- XKh.

$$h = (1,2,3 \text{ --- } n)$$

$$G(X,\theta) = G(X_1, \text{ ---- } X_k, \theta_1, \text{ --- } \theta m) \quad (3.7)$$

It is required to determine, a set of θ_i for which the sum of the squares:

$$Q(\theta) = \sum_{h=1}^{n} (y_h - G(xh,\theta))^2 = \text{Min.} \quad (3.8)$$

Where, Y_h is the measured global solar radiation.

i) Introducing the first dirivative of $G(X_h, \theta_k)$ with regard to θ_i as.

$\frac{\partial G}{\partial \theta_i} = G_i (X,\theta)$, we get, nine sets of equations.

$$G1 (X, \theta) = \frac{G(X,\theta)}{\partial \alpha} = K \exp \ A11^A (BID^B + C1R^C + E1 \ T^E) \quad (3.9)$$

$$G2\ (X,\ \theta) = \frac{\partial G\ (x,\theta)}{\partial A1} = (\alpha K\ (L^A\ (B1D^B\ ;\ C1R^C + E1T^E))\ X$$
$$Exp\{\ (A1L^A\ (B1D^B + C1R^C) + D1T^D)\ \}\ (3.10)$$

$$G3\ (X,\ \theta) = \frac{\partial G\ (X,\theta)}{\partial B1} = (\alpha K\ (A1L^A\ D^B)\ Exp\ \{\ (A1L^A\ (B1D^B + C1R^C$$
$$(1R^C + E1T^E)\ \}\quad (3.11)$$

$$G4(X,\theta) = \frac{\partial G\ (X,\theta)}{\partial C1} = (\alpha K\ (A1L^A\ R^C)\ Exp\{\ (A1L^A\ (B1D^B +$$
$$C1R^C + E1T^E)\ \}\ )\quad (3.12)$$

$$G5\ (X,\ \theta) = \frac{\partial G\ (X,\ \theta)}{\partial E1} = (\alpha K\ Exp\ \{(A1L^A)\ (B1D^B + C1R^C + E1T^E\}\ x$$
$$(A1L^A\ T^E))\quad (3.13)$$

$$G6\ (X,\ \theta) = \frac{\partial G(x,\theta)}{\partial A} = (\alpha K\ Exp\ \{(A1L^A)\ (B1D^B + C1R^C + E1T^E)\}\ x$$
$$A1\ (B1D^B + C1R^C + E1T^E)\ (L^A\ LN(L)))\ (3.14)$$

$$G7\ (X,\ \theta) = \frac{\partial G\ (x,\ \theta)}{\partial B} = (\alpha K\ Exp\ \{A1L^A\ (B1D^B + C1R^C + E1T^E)\}\ x$$
$$(A1L^A\ B1)\ \ \ell n\ (D)\ D^B))\quad (3.15)$$

$$G8\ (X,\ \theta) = \frac{\partial G(x,\theta)}{\partial C} = (\alpha K\ Exp\ \{A1L^A\ (B1D^B + C1R^C + E1T^E)\}\ x$$
$$(A1L^A\ C1)\ x\ \ell n\ (R)\ R^C)\quad (3.16)$$

$$G9\ (X,\ \theta) = \frac{\partial G\ (x,\theta)}{\partial E} = (\alpha K\ Exp\ \{(A1L^A\ (B1D^B + C1R^C + E1T^E)\}$$
$$(A1.\ L^A.\ E1)\ x\ \ell n\ (T)\ T^E))\quad (3.17)$$

Then using the above definitions of (3.8) it is possible to write,

$$\frac{\partial Q}{\partial \theta i} = Q\theta i \ (x;\ \theta) = -2 \sum_{h=1}^{n} (Y_h - G(X_h;\ \theta))\ G_i\ (X_h,\ \theta) \quad (3.18)$$

3.3 <u>The modified Gauss - Newton Iteration</u>:- We start with initial values of the constants $o\theta i = (\alpha o,\ A1_o,\ A_o,\ B1_o,\ C_o,\ E1_o,\ E_o)$

The first step is compute "Corrections" to the elements $o\theta i$ of the starting vector $_o\theta$. These correction will be proportional to the solutions Pi of the Gauss - Newton equation corresponding to (3.8)

Expanding G (X, θ) by Taylor's series at $\theta = {_o\theta}$ and considering upto the linear term and substituting into (3.8) we get:

$$2 \sum_{j=1}^{m} \{ \sum_{h} G_i\ (X_h,\ o\theta)\ G_j\ (X_h,\ o\theta)\}\ P_j = -\ Q_i\ (X : o\ \theta) \quad (3.19)$$

Where $P_j = ({_1\theta_i} - o\theta i)$ for our case $i = 1,2 -- 9$ (3.20)

and,

$$\begin{aligned} -\tfrac{1}{2} Q_1\ (X,\ o\theta) = & ((G1\ (X1, o\theta)\ G1\ (X1,\ o\theta) + \text{-------} + \\ & G1\ (X365, o\theta)\ G1\ (X365,\ o\theta))\ P1 + \\ & ((G1\ (X1,\ o\theta)\ G2\ (X1, o\theta)) + \text{---} + \\ & (G1\ (X365, \theta o\ )\ G_2\ (X365, \theta o\ ))\ P2 + \text{---} + \\ & (G1\ (X1,\ o\theta)\ G9\ (X1, o\theta) + \text{----} + \\ & G1\ (X_{365},\ o\theta)\ G9\ (X_{365},\ o\theta))\ P9 \end{aligned} \quad (3.21)$$

$-\frac{1}{2}\, Q_9$ (X, o0) = (G9 (X1, o0) G1 (X1, o0) + ------ + G9
(X365,o0) x G1 (^{X}365, o0)) P1 + ------
+ (G9 (X1, o0) G9 (X1, o0) + ---- +
G9 (X 365, o0) G9(X365, o0)) P9 (3.22)

and where Q_i are determined as:

$-\frac{1}{2}$ Q1 (X,θ) = (((Y (1) - G(X1, oθ) G1 (X1, oθ)) + (Y(2) - G
(X2, oθ) x G1 (X2, oθ) + ------- +
(Y (365) - G (X365, oθ)) (G1 (X365, oθ))

$-\frac{1}{2}\, Q_2$ (x,θ) = ((Y1 - G(X1, oθ)) G2 (X1,oθ) +
(Y2 - G(X2, oθ)) G2 (X2, oθ) + ---- +
(Y365 - G(X365, oθ) G2 (X365, oθ))

$-\frac{1}{2}$ Q9 (X, θ) = ((Y1 - G (X1,0θ)) (G9 (X1,oθ) +
(Y2 - G (X2, oθ)) (G9 (X2, oθ) + ---- +
(Y365 - G(X365, oθ) G9 (X365, oθ)) (3.23)

By this we get systems of linear equations of nine variables namely (P1, P2 ---- P9). The determinant of linear equation (3.18) thus can always be solved yeilding the elements Pi of the vector P as solutions. Considering the function:

Q (V) = Q(X, oθ + Vp), for O≤ V≤ 1 (3.24) and denoting V the value for which Q (v) is minimum on the interval $0 \leq V \leq 1$. Defining the vector

$$_1\theta_o = {}_o\theta + V'P \quad (3.26)$$

with elements $_1\theta i = {}_o\theta i + V'Pi$ (3.26)

After getting Pi, the next stage is to determine, the minimum value of Q we proceed by an approximate method:- we evaluate Q for V = O, V = ½ and V = 1 and determine the level of V for which the parabola through Q (o), Q (½), Q (1) attains its minimum from

$$V_{min} = \tfrac{1}{2} + \tfrac{1}{4} \ (Q(o) - Q(1))/(Q(1) - 2Q(\tfrac{1}{2}) + Q(o)) \quad (3.27)$$

In this formula: $Q(o) = \sum_{h=1}^{365} (Yh - G(X_h, {}_o\theta))^2$, and (328)

$$Q(\tfrac{1}{2}) = \sum_{h=1}^{365} (Yh - G(X_h, \tfrac{1}{2}\theta_i))^2 \quad (3.29)$$

Where $\tfrac{1}{2}\theta i = {}_o\theta i + \tfrac{1}{2} Pi$, $V = \tfrac{1}{2}$

and $Q(1) = \sum_{h=1}^{365} (Yh - G(Xh, {}_1\theta i))^2$ (3.30)

Where $_1\theta i = {}_o\theta i + Pi$, V = 1 (3.31)

By doing So Vmin is calculated, then the next set of constants

$$_1\theta i = {}_o\theta + V_{min} Pi$$

$$\text{i.e.,} \quad {}_1\alpha = \alpha_o + V_{min}\,P1 \qquad (3.32)$$
$$_1A1 = A1_0 + V_{min}\,P2$$
$$\vdots \qquad \vdots$$
$$_1E = E_o + V_{min}\,P9$$

The whole process is repeated with ($_1\alpha$, $_1A1$, $_1A$, $_1B1$, $_1B$, $_1C1$, $_1C$, $_1E1$, $_1E$) taking the starting trial place of o θ i. Carrying in this manner, several cycles can be done until the new set of constants has no appreciable difference with the preceeding cycle set of constants. In other words having Vmin and (P1, P2 --- P9) to be small.

3.4 Data Analysis and Computation

The determination of new general constants of Sayigh's equation was carried on by writing a computer program based on the above method. The program is attached in appendix (D).

The global solar radiation for the year 1983, of Addis Ababa region, measured by Eppley integrator was used. The corresponding day meteorological parameters, sunshine hours (measured by campbell stokes sunshine recorder), relative humidity R, and maximum temprature of the day Tmax, all measured by NMA,* were taken in the calculation.

Due to power interuption and malfunction of the recording instruments, in the regression the data available were only for three hundred fifteen (315) days of the year. These values with the corresponding day meteorlogical parameters are in appendix (E). In the determination of new sets of constants the cycle in which the whole iteration to be repeated was seven times. The set of constants determined by each cycle and solutions of the linear equations (3.21) are shown in table (3.2). The regression was started by arbitrary sets of constants which were close to Sayigh's constants.

The final set of constants which were determined by the last (seventh) cycle are also given in table (3.2). It follows from this, the solar radiation in Addis Ababa is given by the empirical expression:

$$G(X,\ \theta) = 2.65 \times 10^{-4}\ K\ (4.184 \times 10^{6})\ \text{Exp}\ \{1.46\ \phi^{0.52}$$

$$(0.52\ (D)^{0.23} - 0.17R^{0.38} + 0.38\ Tmax^{\ 0.43}) \qquad (3.33)$$

*NMA - National Meteorological Agency

1.5300	1.0000	0.5000	0.5000	0.3000	0.5x10	0.4000	0.6000	0.4000
-1.5405	0.0334	0.0034	-0.0001	0.0061	-0.0184	0.0001	0.0001	0.0081
-0.5244	1.0446	0.5045	0.4993	0.3082	-0.0196	0.4001	0.6108	0.3992
0.5196	0.0648	-0.0597	0.0025	-0.0759	0.0263	-0.0002	0.0030	0.3993
-0.0679	1.1015	0.4521	0.5021	0.2415	0.0035	0.3999	0.6135	0.3993
0.0579	0.0182	0.1332	0.0041	0.1160	-0.1238	-0.0033	-0.2778	0.0124
-0.0197	1.1167	0.5630	0.5055	0.3381	-0.0995	0.3971	0.3821	0.4103
0.0012	0.2959	-0.0697	0.0244	-0.1849	-0.0251	-0.0258	-0.0060	0.1024
-0.0194	11.1840	0.5455	0.5117	0.2665	-0.1029	0.3907	0.3806	0.4360
0.0146	0.2609	0.2008	-0.0318	0.0584	-0.2551	-0.0159	0.0044	0.0382
-0.0157	1.2489	0.5955	0.5038	0.28100	-0.1664	0.3867	0.3817	0.4456
0.0196	0.2589	0.5955	0.5038	0.0533	-0.0078	-0.0065	-0.0000	-0.0077
2.65×10^{4}	1.4606	0.5260	0.5294	0.2374	-0.1728	0.3813	0.3817	0.4392
α	A1	A	B1	B	C1	C	E1	E
2.65×10^{-4}	1.46	0.52	0.52	0.23	-0.17	0.38	0.38	0.43

Table(3.2): Shows set of constants and solution of (3.18) for each cycle.

Where G (X, θ), is in $J-M^{-2}$ - day^{-1}, ϕ, lattitude of the place in degrees, D relative sunshine hours to 12 hrs, R relative humidity, Tmax maximum temprature of the day and K as it was defined in (3.3).

The daily solar radiation calculated by (3.3), (3,34) and measured values are plotted on figures (3.1) - (3.11). A converting factor for the radiation value from cal - cm^{-2} - day^{-1} to J - m^{-2} - day^{-1} was considered since the measured values are in J - m^{-2} - day^{-1}.

Global solar radiation calculated via (3.3) and (3.33) were compared with the measured value and the percentage deviation calculated by,

$$\left(\frac{Gcal - Gm}{Gm}\right) \times 100 \qquad (3.34)$$

are shown in appendix (F).

The new set of constants has made the maximum temprature of the day to play a dominant role in the calculation of the global solar radiation. A change of 1°C in the temprature while the other parameters being constant can result a considerable change in the radiation. The relative sunshine hour (D) is the second important variable in the determination of the radiation. The least important is

Fig.3.1 DAILY MEASURED AND ESTIMATED GLOBAL SOLAR RADIATION OF ADDIS ABEBA REGION FOR THE MONTH JANUARY 1983.

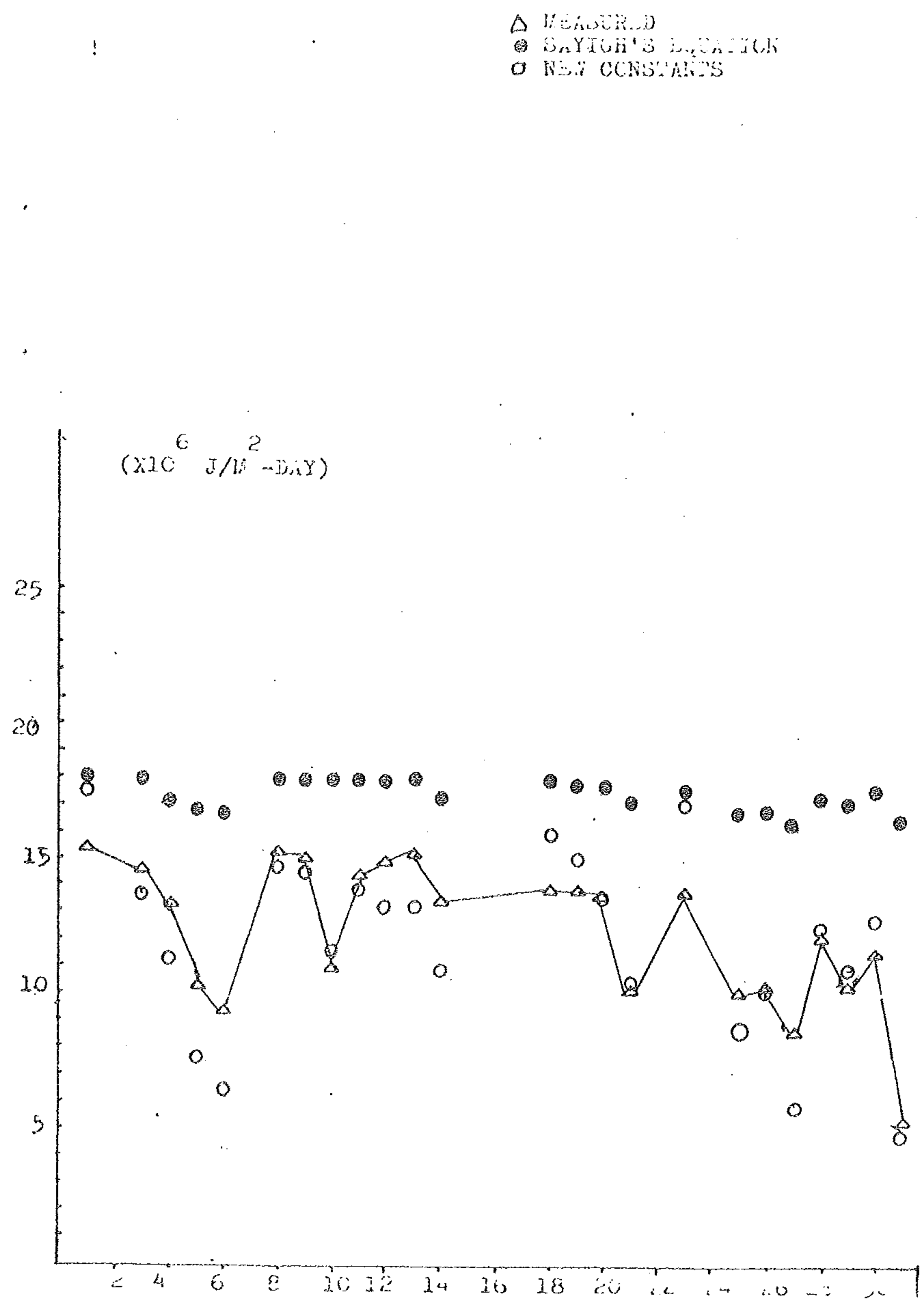


Fig.3.2 DAILY MEASURED [illegible] FOR TOTAL SOLAR RADIATION OF ADDIS ABEBA [illegible] FEBRUARY 1983.

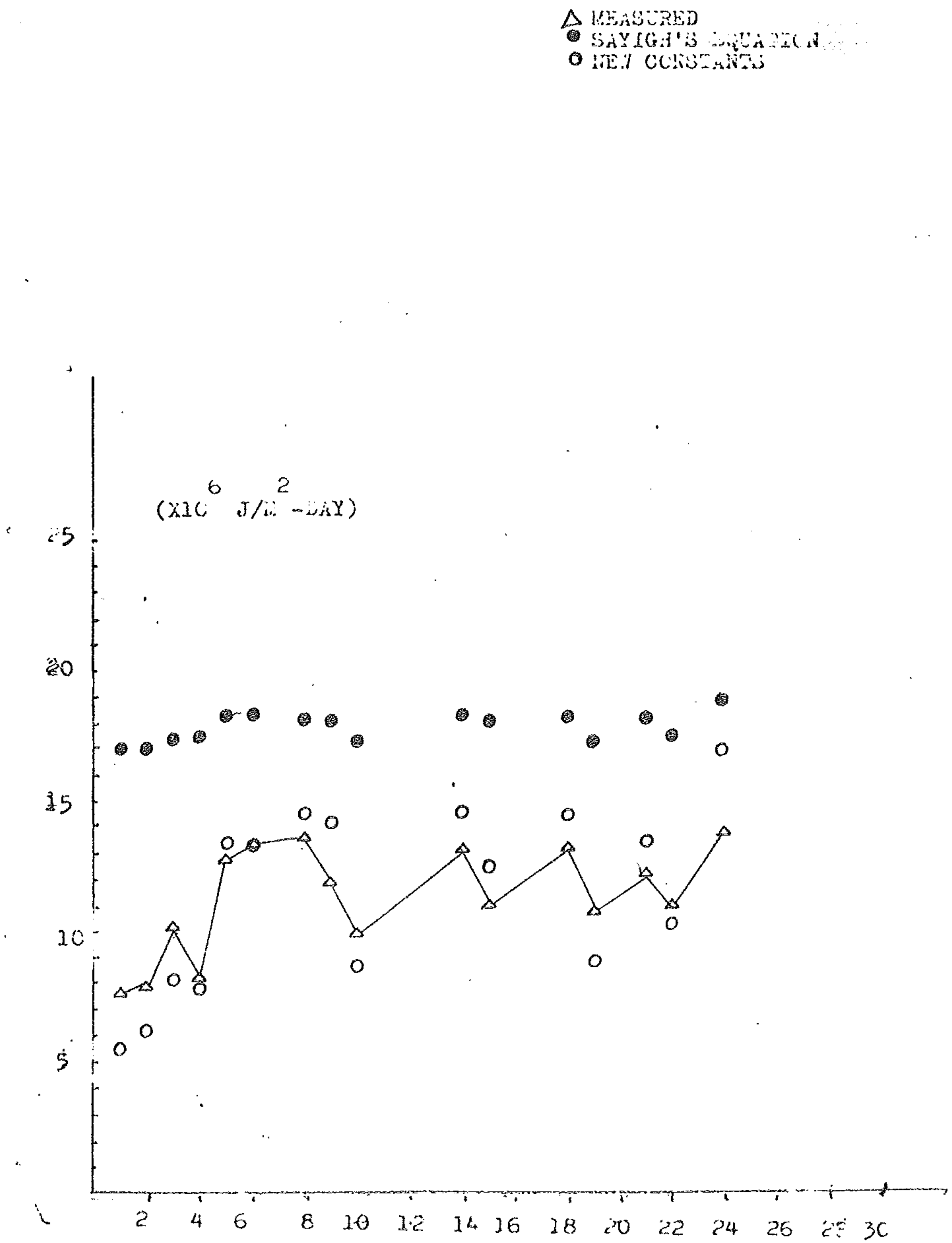


Fig.3.3 [illegible] MARCH 1983.

△ [illegible]
⊕ [illegible]
○ [illegible]

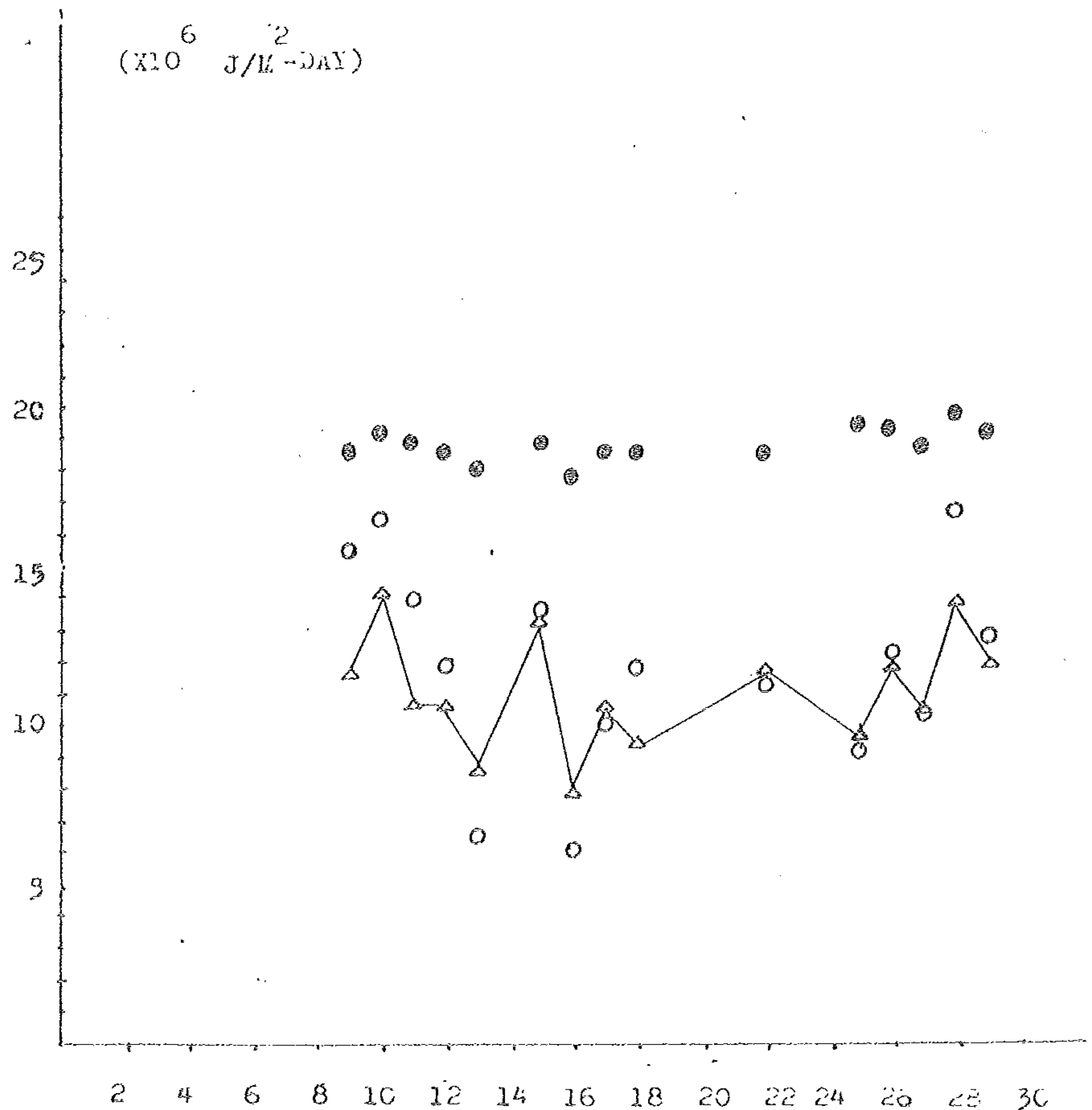


Fig.3.4 DAILY MEASURED AND ESTIMATED GLOBAL SOLAR RADIATION OF ADDIS ABEBA REGION FOR THE MONTH APRIL 1983.

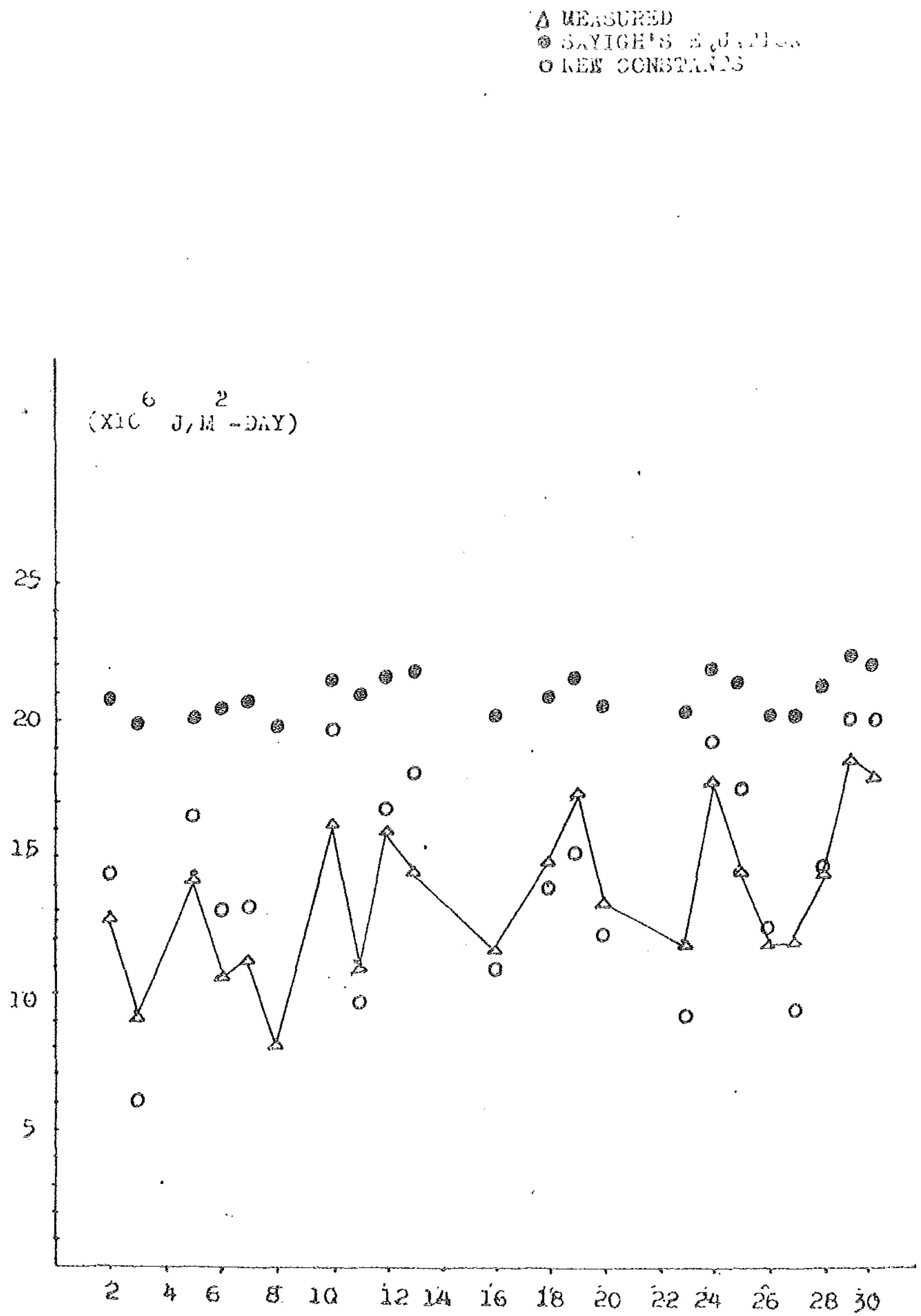


Fig.5.9 DAILY MEASURED AND [illegible] GLOBAL SOLAR RADIATION OF ADDIS ABEBA REGION FOR THE MONTH JUNE 1983.

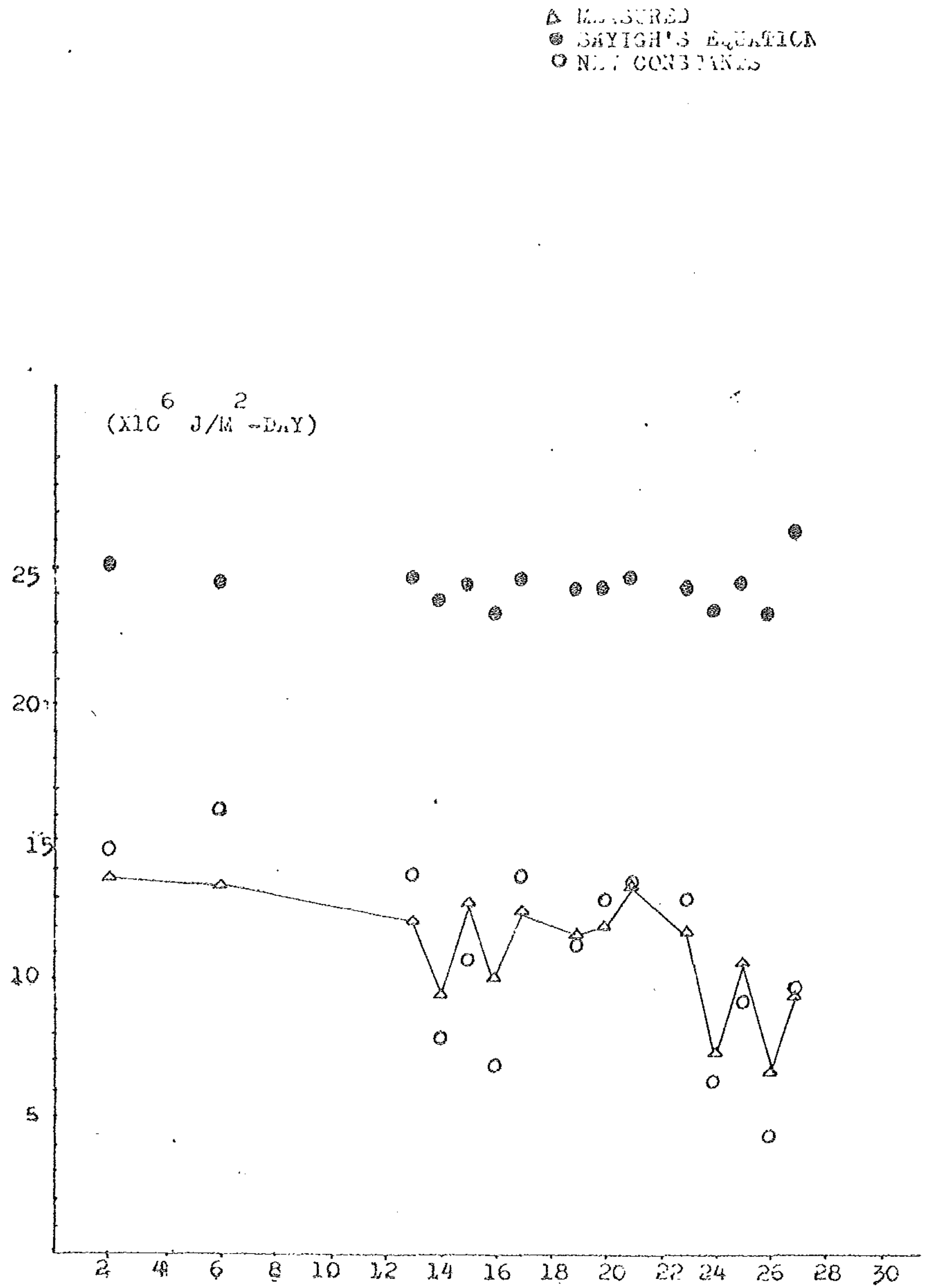


Fig.3.6 DAILY MEASURED AND ESTIMATED TOTAL SOLAR RADIATION OF ADDIS ABABA REGION FOR THE MONTH JULY 1983.

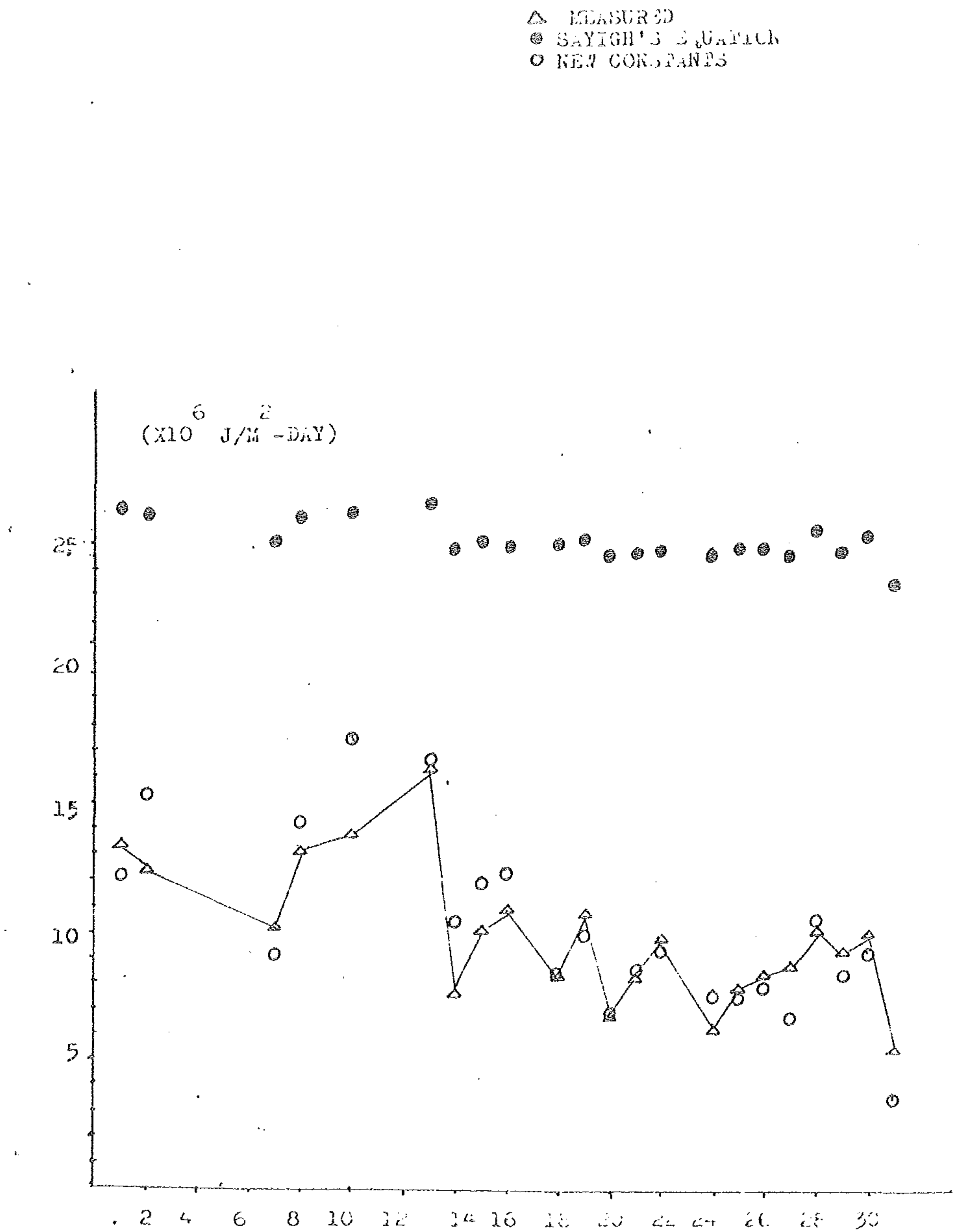


Fig.5.7 DAILY MEASURED AND ESTIMATED GLOBAL SOLAR RADIATION OF ADDIS ABABA REGION FOR THE MONTH AUGUST 1983.

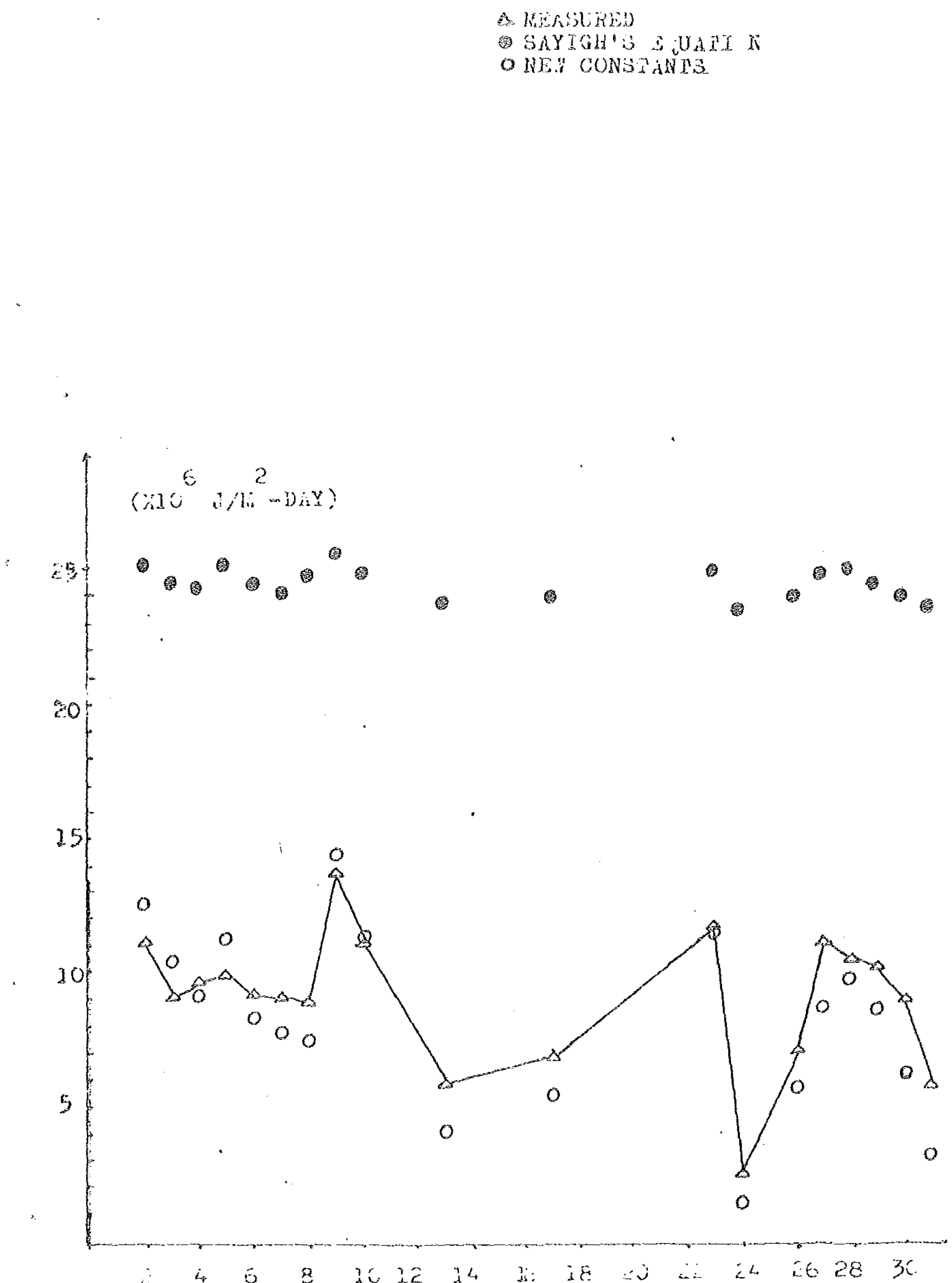


Fig.2.8 DAILY MEASURED AND ESTIMATED GLOBAL SOLAR RADIATION OF ADDIS ABEBA REGION FOR THE MONTH SEPTEMBER 1983.

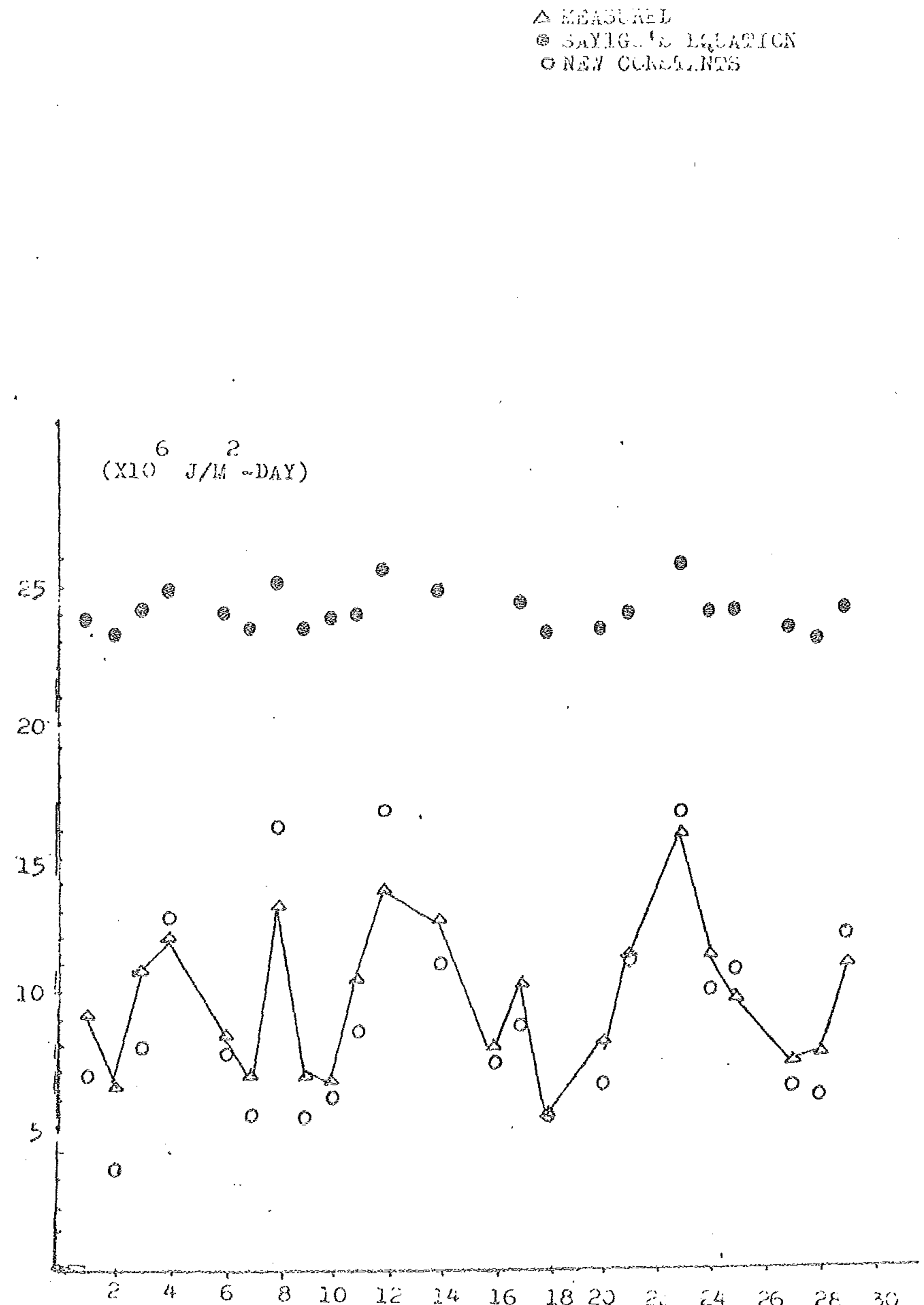


Fig. 3.9 DAILY MEASURED AND ESTIMATED GLOBAL SOLAR RADIATION OF ADDIS ABEBA REGION FOR THE MONTH OCTOBER 1983.

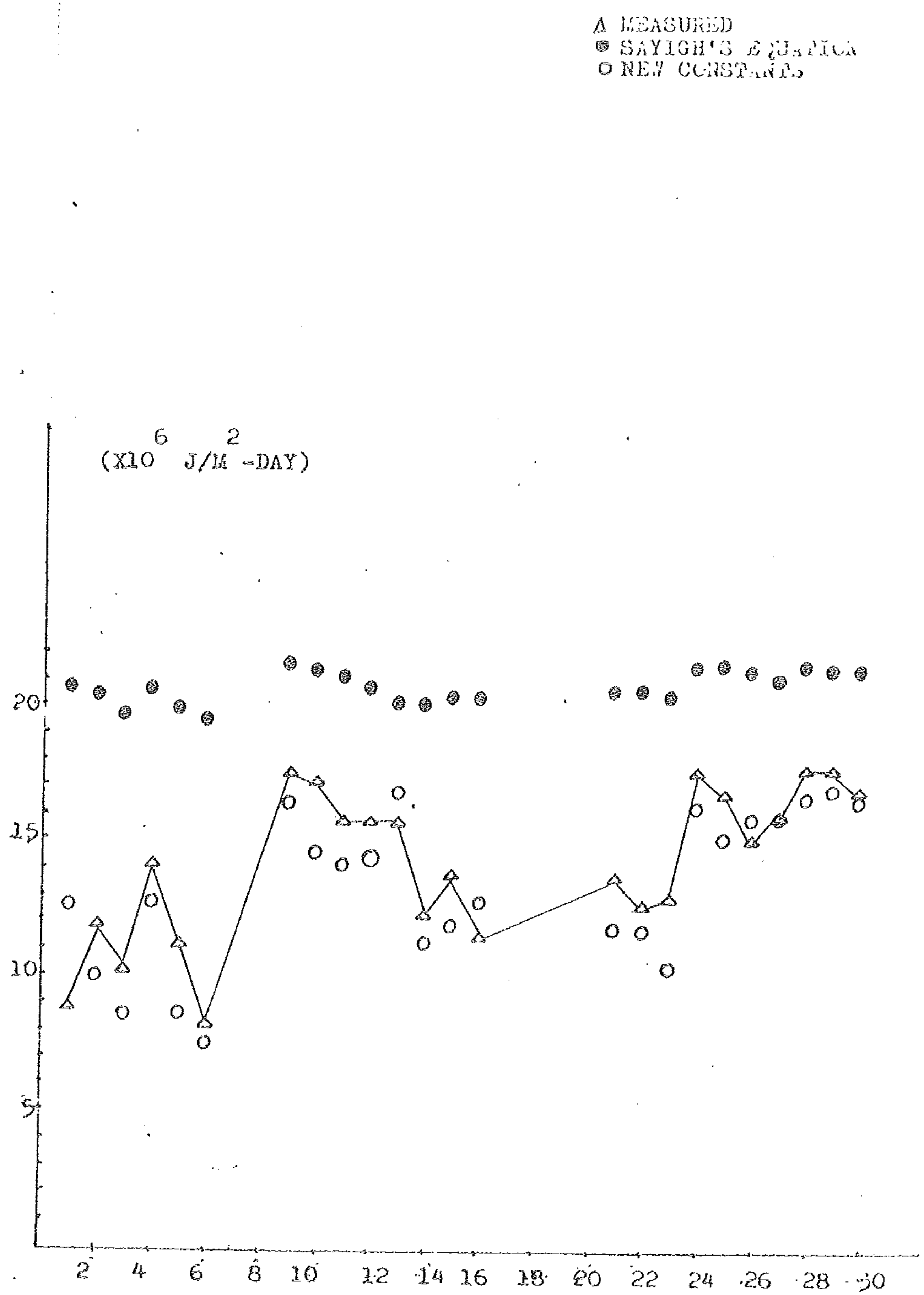


Fig.10 DAILY MEASURED AND ESTIMATED GLOBAL SOLAR RADIATION OF ADDIS ABEBA REGION FOR THE MONTH NOVEMBER 1983.

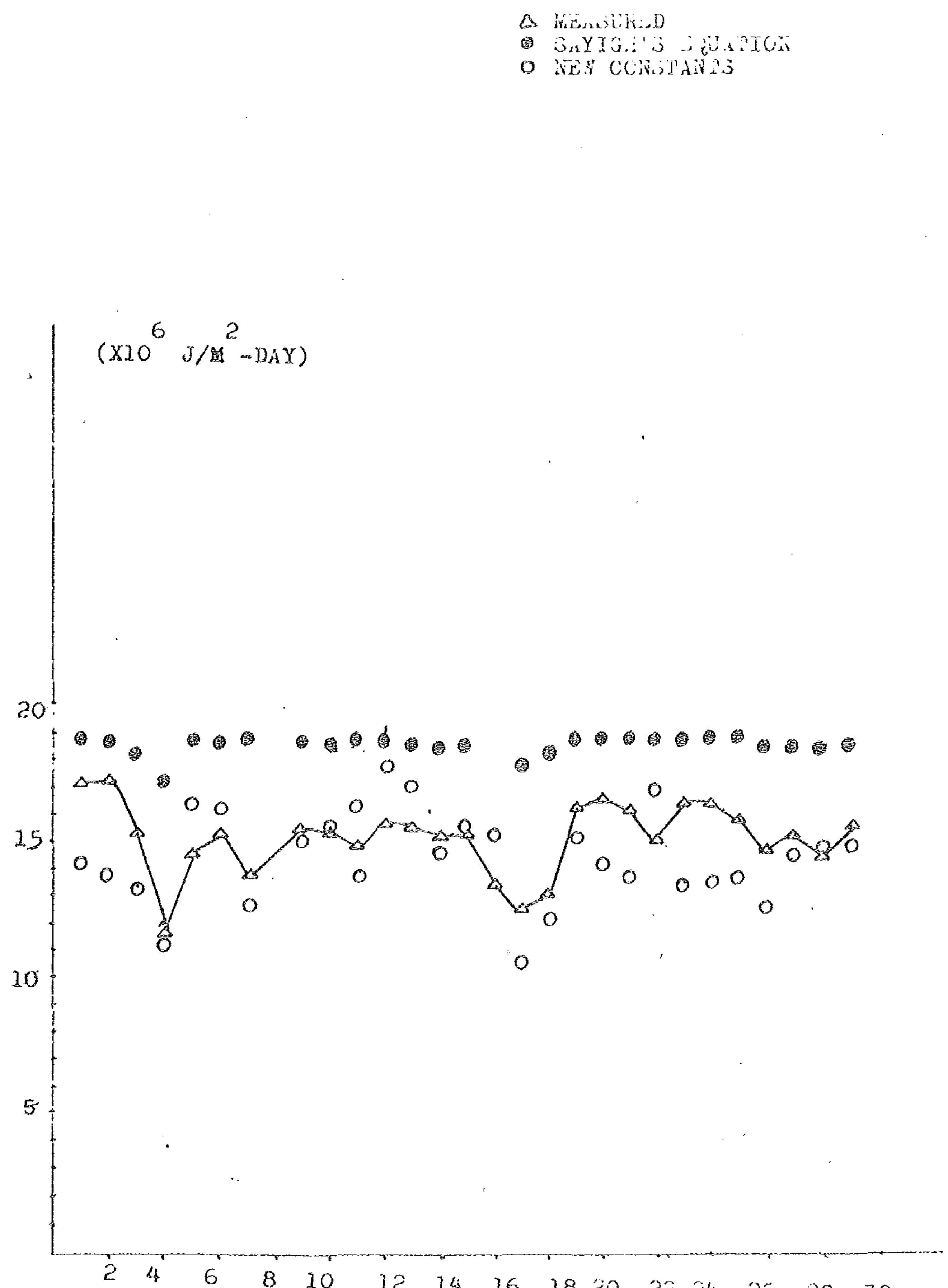
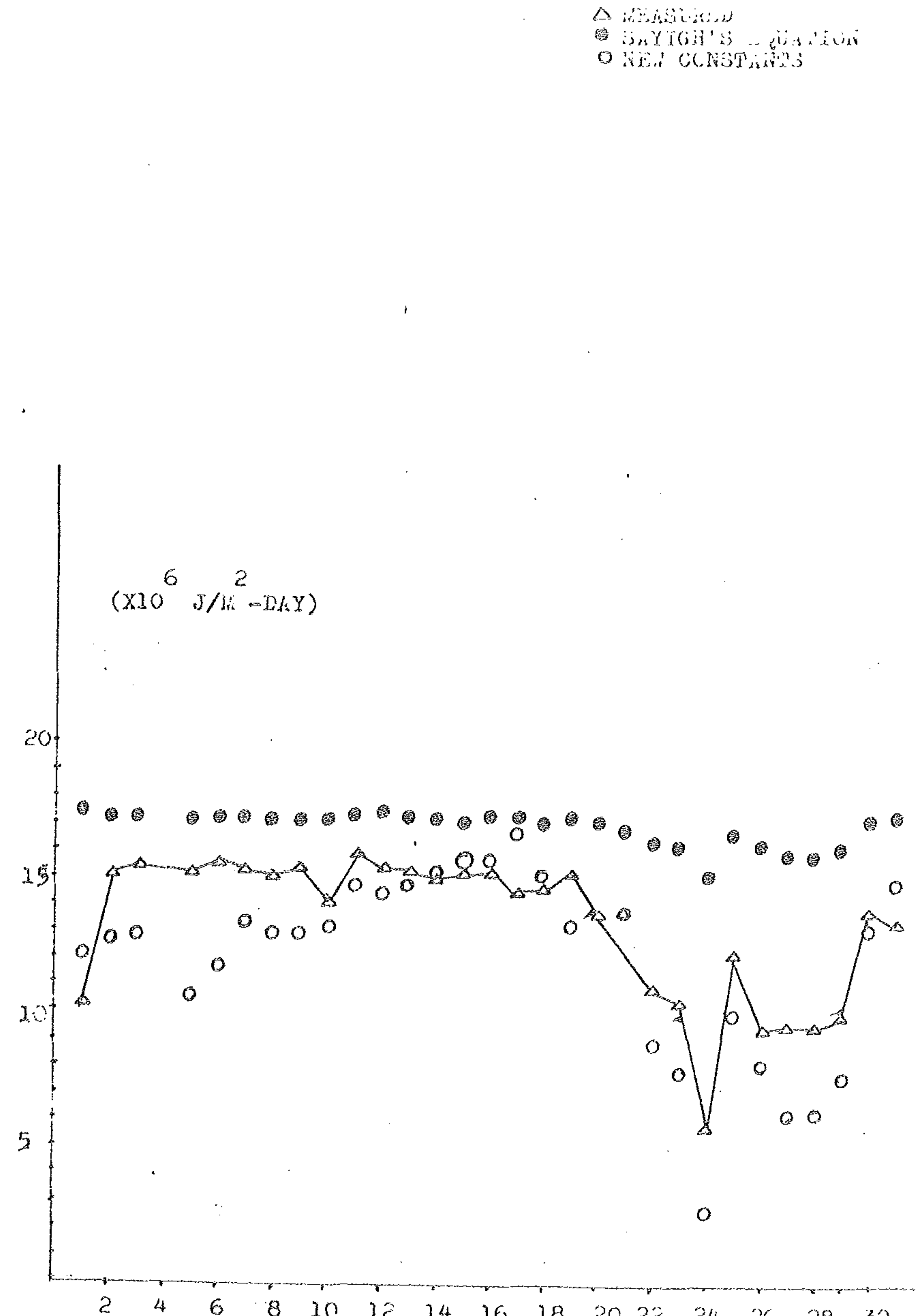


Fig. 11 DAILY MEASURED AND ESTIMATED GLOBAL [illegible] RADIATION OF [illegible] FOR THE MONTH DECEMBER 1983.



the relative humidity. Since the constants were determined for one locality, it was not possible to see radiation dependence with lattitude.

As it has been done by various authors in calculating, the global solar radiation via (3.1) and (3.2), needs determination of regression coeffcients which have spatial variations.

Eventhough, the constants of (3.3) were said to be universal by the authors, the inadequency for estimating the radiation was shown by figures (3.1 - 3.11) and parangotopo et. al. [31] have also reported recently the inadequency of (3.3). And hence it is essential to determine a new set of constants for every region, however it could be possible to use the constants for extrapolating for other regions with the same geography and climate.

CHAPTER 4

4. CONSTRUCTION OF SIMPLE SOLAR RADIATION MEASURING DEVICE

4.1 Introduction

Solar radiation measurements were originally made in early ninteenth century for the purpose of basic research in radiation physics. This research centered largely on measurements of sunlight intensity and later on the spectral intensity of sunlight. The Smithonian Institute of Washington D.C. was active with such research.

Radiometers are finding extensive application in the masurement of total and net exchange radiation and for evaluating the thermal efficiency of solar collecting devices. In-general, the instruments for measuring solar radiation can be divided into three types,namely thermoelectric,photovoltaic and calometric type. In comparison with the thermoelectric and calometric type, the photovoltaic has disadvantage in that the spectral response is not linear, even though its response rate is very rapid.

4.2 Solar Radiation Instruments

The most commonly used instruments for determining the available solar energy are 1) Pyrheliometers - for measuring the intensity at normal incidence of the direct radiation from the solar disk. The sensor of this instrument has a clock driven motor for tracking the sun's direction.

2) Pyranometers - are used for measuring the global radiation (direct plus diffuse) which falls on a horizontal surface. If the sensor is shielded from the direct sunlight it measures the difuse solar radiation.

4.3 The Duration of Sunshine Instruments:

- Are instruments used for measuring the fraction of time during the day the solar disk is not hidden by clouds. Sunshine duration is important in characterizing the climate of a given location, its value is also used in roughly deducing the flux of solar radiation on a horizontal surface at locations for which no Pyranometric data are available.

These instruments Pyreheliometers, Pyranometers and duration of sunshine instruments, come in many forms by different manufacturing companies and are classfied by the commission for instruments and methods of observation of the world meteorological organization (Geneva) as standard, first, second and third class according to a certain criteria. And these were summarized by Kinsell L. Culson |32|.

A radiometer was constructed by making use of semi conductor type thermojunctions, but this type of radiometer has less sensitivity. Soldered Constantan Manganin strip was also used. Monteith |32|. But this has a disadvantage of high cost in production.

Simple and in-expensive sensitive radiometers can be obtained in two ways. One way is to use a thermopile material with high thermoelectric power, and another way is to place a thermocouple.

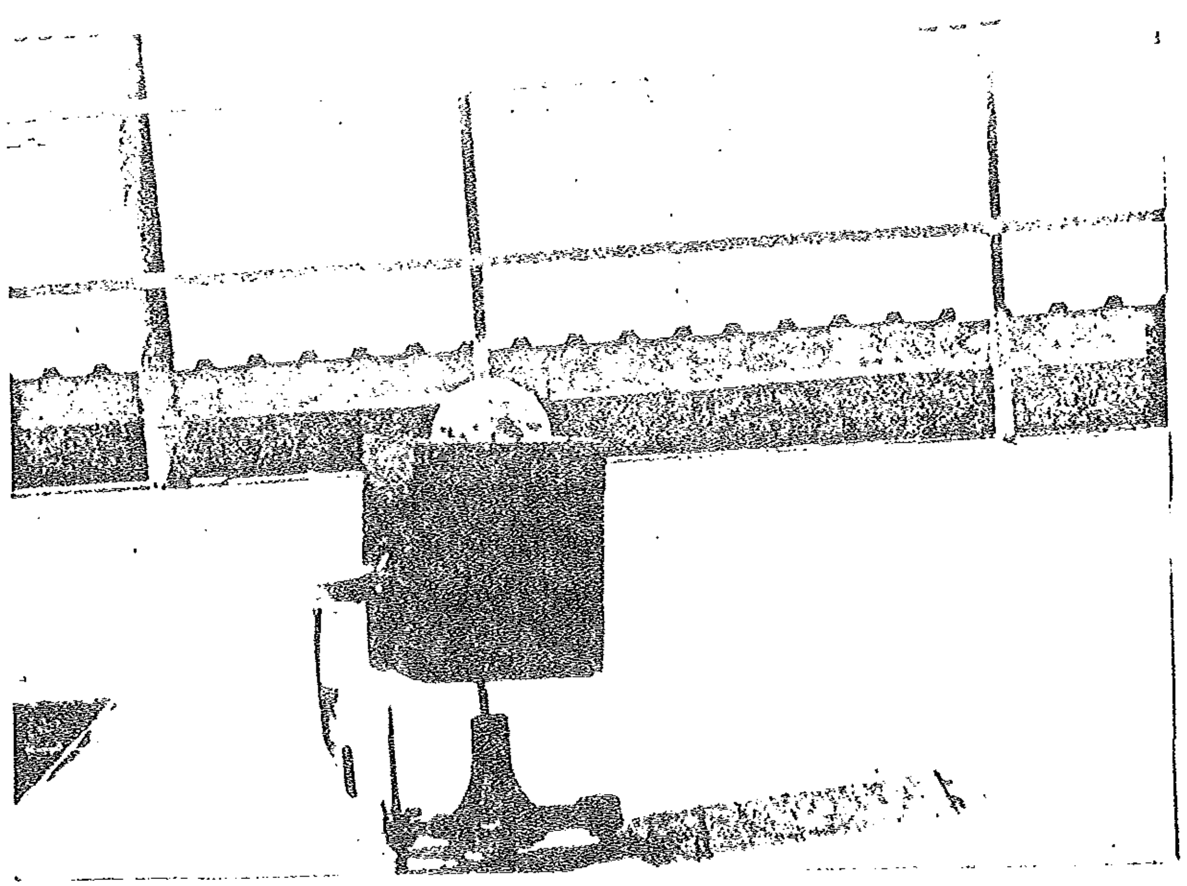
Using thermopile by plating Copper on Constantan has also being used and its design feature and its comparison with standard radiometers developed at central building research, Roorke, was also reported by K.N. Agaraval |35|.

However, a simpler radiometer that operates on thermoelectric principle by measuring, heating and cooling rate of the sensor, constructed by S. X. CHENG |36| was adopted in our work. The experimental and theoretical analysis is as follows:

4.4 The Experimental Pyranometer

The Photo of the Experimental Pyranometer is shown in figure (4.1a). A Schematic diagram showing the construction of this Pyranometer is given in figure (4.1b).

FIG 4a. PHOTO OF THE EXPERIMENTAL PYRANOMETER.



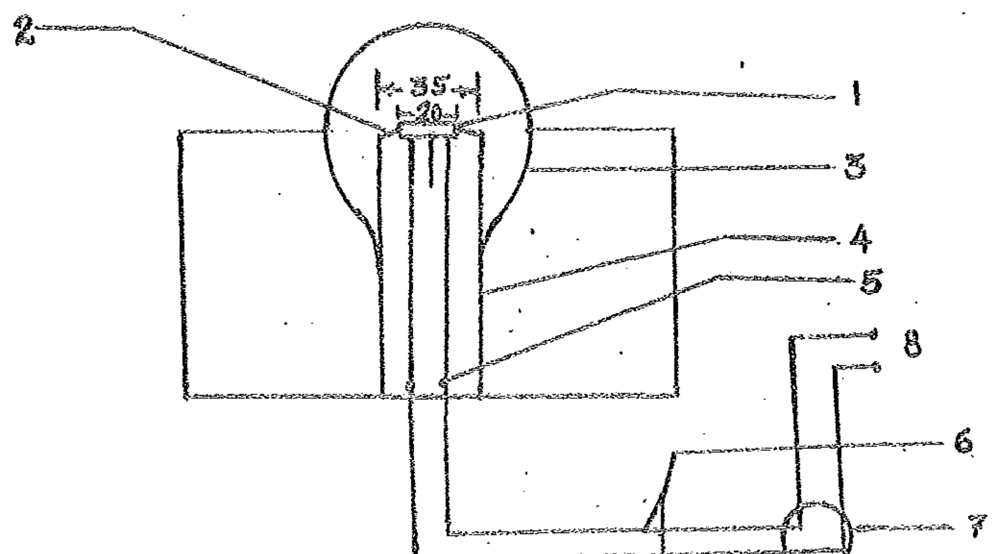


FIG.4b. SKETCH OF THE CONSTRUCTION OF THE EXPERIMENTAL PYRANOMETER. 1 SENSOR 2 THREAD, 3 GLASS COVER 4 SUPPORT TUBE 5 HOLES FOR THE WIRES 6 THERMO COUPLE, 7 ICE POINT ,8 TO CHART RECORDER

The sensor of the Pyranometer is a blackened red copper disk, 0.1 mm thick and 20 mm in diameter. A 0.1 mm constantan and 0.07 mm copper, thermocouple is soldered to the back of the disk for temprature measurments. The sensor is suspended by four threads inside a glass tubing to minimize conduction loss. The sensor is placed at the center of spherical glass cover 140 mm in diameter.

4.5 Theory of the Measuring Technique

The measuring technique presented in this work has made number of assumptions as follows:

1) Considering the heat capacity of the sensor is small and that of the spherical glass cover is large, in a cycle of heating and cooling processes the temprature of the glass cover can be considered to be constant.

2) In heating and cooling process, the temprature of the sensor is uniform at any given time.

Let G be the total solar radiation absorbed per unit time by the sensor when it is exposed to the sun, and hence G be formulated as,

$$G = A \int_0^{\infty} \int_0^{2\pi} \int_0^{\pi/2} \alpha_\lambda(\theta,\phi) T_\lambda(\theta,\phi)\, I_\lambda(\theta,\phi)\, \mathrm{Sin}\theta\, \mathrm{Cos}\theta\, d\theta d\phi\, dA \quad (4.1)$$

Where I_λ is the spectral intensity of total solar radiation, T_λ is the spectral transmittance of the glass cover to total solar radiation, α_λ is the spectral absorptance of the sensor to total solar radiation, λ is the wavelength, A is area of the sensor, θ and ϕ are the angles of incidence in polar and azimuthal directions respectively.

Knowing that the global radiation is composed of beam and diffuse parts which have different spectral distributions, it is necessary to consider the contributions refined as follows:

$$G = \alpha_d T_d G_d A + \alpha_b (\theta_o, \phi_o) \tau_o (\theta_o, \phi_o) G_b \cos\theta_o A. \quad (4.2)$$

Where the first term on the right of the equation denotes, the difuse energy absorbed by the sensor, the second term is the beam radiation absorbed at θ_o, ϕ_o directions, G_d is diffuse irradiance. When the radiation is incident on the blackend sensor, the energy balance of the sensor can be written as:

$$G = C_p M \left(\frac{dT}{d\tau}\right)_h + Q_{rad} + Q_{conv} + Q_{cond} \quad (4.3)$$

Where M and C_p are specific heat and mass of the sensor respectively. $\left(\frac{dT}{d\tau}\right)_h$ is the temprature slope at any given time during the heating process and Q_{rad}, Q_{conv}, and Q_{cond} represent the heat loss by radiation, convection, and conduction respectively.

When the sensor is shielded from the radiation the sensor undergoes a cooling process. The following energy balance equation can be written for this process.

$$- C_p M \left(\frac{dT}{d\tau}\right)_c = C_p M \left(\left|\frac{dT}{d\tau}\right|\right)_c = Q'_{rad} + Q'_{conv} + Q'_{cond} \quad (4.4)$$

Where $(\frac{dT}{d\tau})_c$ is the temprature slope at any given time during cooling process, Q'_{rad}, Q'_{conv} and Q'_{cond} represent the heat loss for the cooling process.

The temprature-time history of the sensor can be plotted as shown in figure (4.2). Regardless of the heating and cooling process, the heat loss of the sensor at points A and B is identical, because the sensor is at the same temprature.

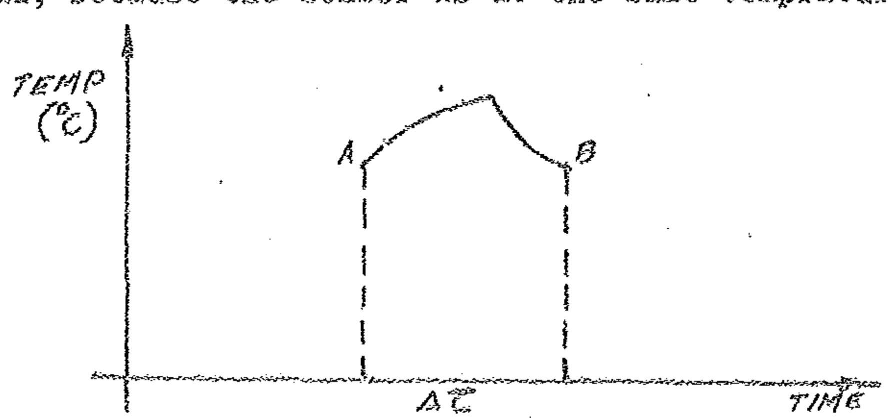


Fig. (4.2) Temprature - time history of the sensor in the heating and cooling process.

This permits writing: $Q_{rad} = Q'_{rad}$

$$Q_{conv} = Q'_{conv} \qquad (4.5)$$

$$Q_{cond} = Q'_{cond}$$

These equations enable the heat loss terms in (4.3) and (4.4) to be cancelled out there by resulting:

$$\alpha_d \tau_d G_d A + \alpha_b (\theta_o, \alpha_o) \tau_b (\tau_o, \phi_o) G_b C_o S\theta_o A =$$
$$C_p M((\frac{dT}{d\tau})_b + (|\frac{dT}{d\tau}|)_c) \qquad (4.6)$$

Using the following relationships to account for the difference in materials spectral response to beam and diffuse radiation

$$\alpha_d - \alpha_b = \pm\Delta\alpha \text{ and } \tau_d - \tau_b = \pm\Delta\tau \qquad (4.7)$$

Then (4.6) can be written as:

$$G_d + G_b \text{ Cos }_o = (\frac{C_p M}{A\alpha_d \tau_d}) ((\frac{dT}{d\tau})_b + (|\frac{dT}{d\tau}|)_c) \pm$$
$$(\frac{\Delta\alpha}{\alpha d} + \frac{\Delta\tau}{\tau d}) G_b \text{ COS }_o \qquad (4.8)$$

$$\text{or, } G_d + G_b \text{ COS }_o = (\frac{C_p M}{A\alpha_b \tau_b}) ((\frac{dT}{d\tau})_b + (|\frac{dT}{d\tau}|_c)) \pm$$
$$(\frac{\Delta\alpha}{\alpha_b} + \frac{\Delta\tau}{\tau_b}) G_d \qquad (4.9)$$

The physical meaning of (4.8) and (4.9) can be explained as, if there is only diffuse radiation that is $G_b = 0$, it follows from (4.8) that:

$$G_d = \left(\frac{C_p M}{A \alpha_d \tau_d}\right) \left(\left(\frac{dT}{d\tau}\right)_h + \left(\left|\frac{dT}{d\tau}\right|_c\right)\right) \quad (4.10)$$

(4.10) Can be used to determine the diffuse radiation, if the sensor is shielded from the direct radiation.

If there is direct solar radiation, that is $G_d = 0$, (4.9) is simplified to be:

$$G_b = \left(\frac{C_p M}{A \; C.S\theta.\alpha_b \; \tau_b}\right) \left(\left(\frac{dT}{d\tau}\right)_h + \left(\left|\frac{dT}{d\tau}\right|\right)_c\right)$$

$$G_b = \left(\frac{C_p M}{A_s \alpha_b \; \tau_b}\right) \left(\left(\frac{dT}{d\tau}\right)_h + \left(\left|\frac{dT}{d\tau}\right|\right)_c\right) \quad (4.11)$$

Where A_s is the projection area of the sensor in the direct radiation direction. If the assumptions are further made; $\Delta\tau << \tau_d$ and τ_b, and $\Delta\alpha << \alpha_d$ and α_b, the second terms of (4.8) and (4.9) are neglected. And hence,

$$G = \left(\frac{C_p M}{\tau_b \; \alpha_b A}\right) \left(\left(\frac{dT}{d\tau}\right)_h + \left(\left|\frac{dT}{d\tau}\right|_c\right)\right) \quad (4.12)$$

Letting $K = \dfrac{C_p M}{\tau_b \alpha_b \; A}$ (4.13)

For a given sensor and a glass cover, k is a constant. The calibration of k can be carried out by either of the following methods:

a) C_p, M, α_b and τ_b are accurately measured in advance. In this case the pyranometer becomes an absolute radiometer.

b) By means of standard pyranometer, the constant k can be calibrated.

Measured Result

After relatively calibrating the instrument by means of method b, several comparision measurments had been taken. The global solar radiation data measured by the newly constructed instrument and local meteorological station are shown on table (4.1)

1. LOC. P.	285	360	333	355	325	302	396
2. EXP. P.	329	420	330	364	270	245	318
% deviation	15	17	-0.003	-2	-16	-18	-19

Table (4.1) 1 Local station, 2 Experimental Pyranometer
Measured Radiation in $W - M^{-2}$

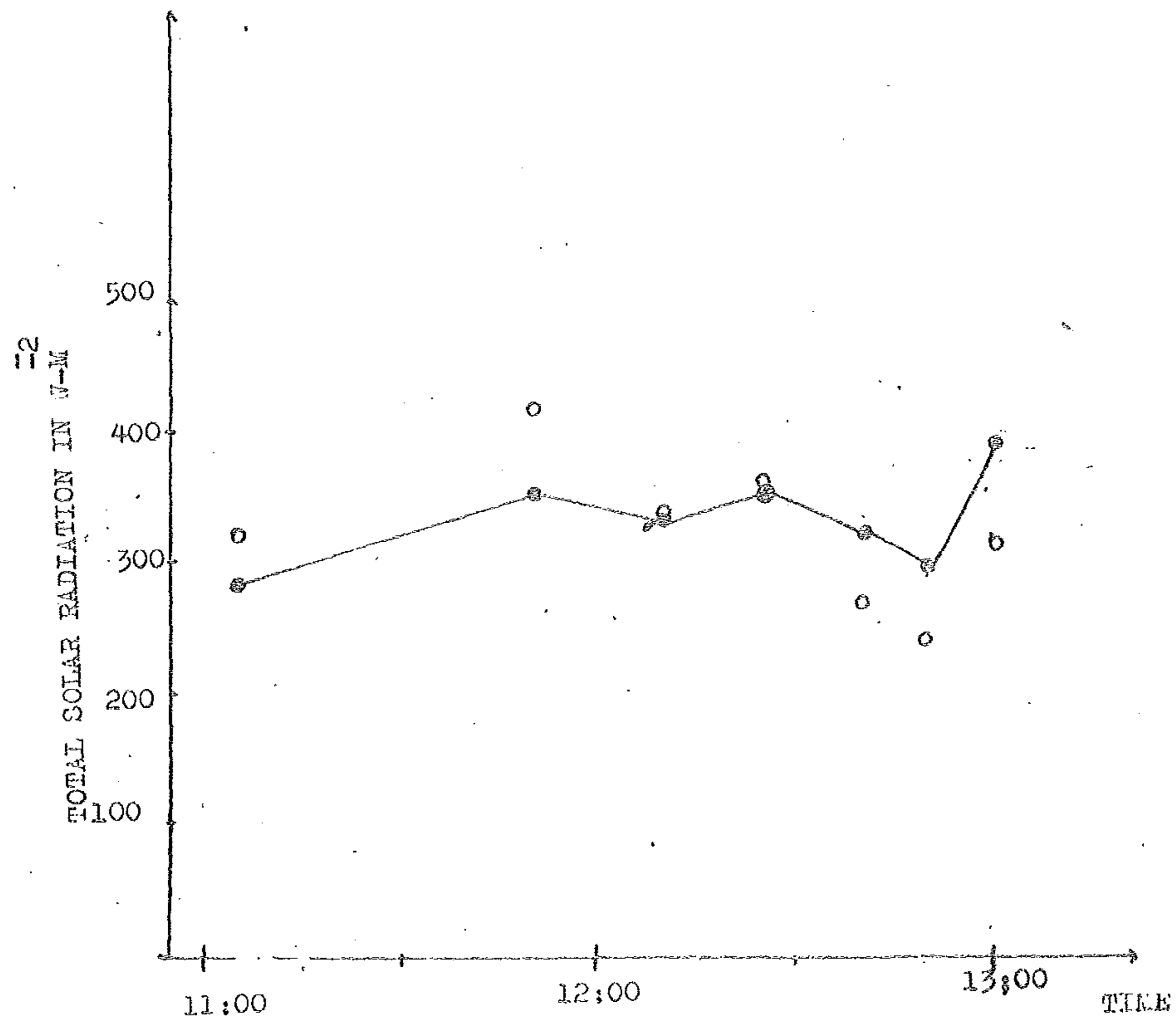


FIG.4.3 MEASURED RESULTS (MAY 23,1985) BY THE EXPERIMENTAL PAYRANOMETER 8; o MEASURED BY LOCAL METEOROLOGICAL STATION. (MAY23,1985)

The measurement was taken during (12.00 am. - 14.00 pm.) on may 23, 1985. These values are plotted on figure (4.3). The maximum relative deviation of the measured data from that of a local meteorological station is about 19 percent.

Conclusion

It is important to know the attenuation of solar radiation, for a particular place, and which attenuation mechanism affects the radiation more. Specially the integral turbidity factor, which predicts the solar radiation attenuation via (2.51) is very important. As it has been seen in Figure (2.4) the maximum monthly mean value is in August, which is by 50% less than that of great Britain; where we do have man made aerosol pollution. In addition, these molecularly attenuated radiation and integral turbidity factors are important in meteorological predictions.

In the estimation of global solar radiation, the newly determined set of constants would have betterly estimated the radiation for Addis Ababa, had we used several consecutive years of data. However the discrepancies between the measured and estimated, have reduced considerably, and these constants can be used for estimating the future years global solar radiation of Addis Ababa region.

For routine measurement of global solar radiation, the instrument in discussion of Chapter Four, can be produced cheaply and easily.

These types of instruments can be used to replace the expensive ones and can also be installed, in places where standard Pyranometers are not availaible. These instruments can also be made as Pyrheliometer, by mounting the sensor on clocak driven motor for tracking the Sun's disc. The experimental instrument's out put can also be directly connected to a micro-computer, having inner built solar radiation analysis program, to process the solar radiation measurement.

A P P E N D I X - A

INPUT DATA OF DIRECT SOLAR RADIATION, D(I), PRESSURE, P(I) AND DECLINATION ANGLE, ~~DEL(I)~~ OF A.A. REGION

FOR THE YEAR 1983.

DAY	D(I)	E(I)	P(I)	DEL(I)	DA	(I)	(I)	(I	(	DAY	D(I)	(I)	P(I)
1	5373	0.9667	575.0	-23.0607	3	5107	0.9667	578.0	-22.[illegible]913	[illegible]	4371	0.9667	576.3
5	2380	0.9669	576.5	-22.6949	6	857	0.9669	577.3	-22.5365	[illegible]	5330	0.9669	578.0
8	5571	0.9669	577.1	-22.3498	9	5407	0.9669	57[illegible].8	-22.2215	[illegible]	3[illegible]	0.9671	57[illegible]
11	3686	0.9671	577.5	-21.9451	12	4326	0.9671	576.9	-21.7772	13	4932	0.9681	575.0
14	886	0.9670	575.0	-21.4820	19	304	0.9677	574.5	-20.5834	[illegible]	3869	0.9682	575.0
21	1481	0.9682	577.0	-20.1809	23	3192	0.9682	5[illegible]5.0	-19.7545	24	141	0.96[illegible]2	572.0
25	466	0.969[illegible]	578.0	-19.3046	26	1056	0.9693	577.0	-19.0711	27	708	0.9693	578.0
28	1394	0.9693	577.	-18.5872	29	2381	0.9693	578.0	-18.3369	30	2546	0.9693	577.0
31	90	0.9693	577.0	-17.82[illegible]1	1	505	0.9708	577.0	-17.5538	2	[illegible]21	0.9708	578.0
3	8	0.970	578.0	-17.0056	4	4100	0.9708	579.0	-16.7239	5	4392	0.9723	578.0
6	4952	0.9723	579.0	-16.1457	7	3937	0.9723	578.0	-15.8494	8	2883	0.9723	57[illegible]
9	1711	0.9723	575.0	-15.24[illegible]7	10	4004	0.9738	574.0	-14.9326	11	1978	0.9738	576.0
12	2469	0.9738	577.1	-14.2991	13	1685	0.9738	576.0	-13.9760	14	570	0.9738	577.0
15	633	0.9757	576.0	-13.3174	16	500	9.7575	577.0	-12.9821	17	3208	0.9757	575.0
18	1389	0.9757	5[illegible]6.0	-12.3002	20	2342	0.9777	577.0	-11.6036	21	1830	0.9777	578.0
22	2450	0.9777	579.	-10.8933	23	5499	0.9777	579.0	-10.5333	24	3338	0.9777	578.0
25	5481	0.9798	578.0	-9.8019	27	301	0.9798	578.0	-9.0630	1	4696	0.9819	578.0
3	3060	0.9819	579.0	-7.5497	4	4210	0.9819	578.0	-7.1655	5	2925	0.9842	578.0
6	2827	0.9842	577.0	-6.3909	7	3033	0.9842	577.0	-6.0007	8	2753	0.9842	578.0
9	2050	0.9842	578.0	-5.2150	10	3441	0.9864	578.0	-4.8199	11	1864	0.9864	577.0
12	1234	0.9864	577.0	-4.0253	13	544	0.9564	578.0	-3.6262	14	[illegible]7	0.9864	577.0
15	773	0.9892	576.0	-2.8248	16	174	0.9892	577.0	-2.4228	17	1323	0.9892	577.0
18	327	0.9892	578.0	-1.6167	19	375	0.9892	577.0	-1.2129	20	196	0.9920	578.0
21	4106	0.9920	577.0	-0.4044	22	1894	0.9920	576.0	0.0000	23	3431	0.9920	577.0
24	6090	0.9920	578.0	0.8089	25	1081	0.9950	578.0	1.2131	26	2023	0.9950	576.0
27	1144	0.9950	577.0	2.0202	28	1120	0.9950	577.0	2.4229	29	476	0.9950	576.0
30	2985	0.9950	575.0	3.2261	31	1780	0.9950	576.0	3.6263	1	2858	0.9986	576.[illegible]
2	3394	0.9986	577.0	4.4233	3	1076	0.9986	577.[illegible]	4.8200	4	838	0.9986	576.0
5	2438	1.0013	575.0	5.6088	6	655	1.0013	577.0	6.0008	7	496	1.0013	576.0
8	126	1.0013	577.0	6.7793	9	35	1.0013	576.0	7.1657	11	36	1.0040	576.0
12	3566	1.0040	578.0	8.3114	13	3390	1.0040	577.0	8.6885	14	1611	1.0040	578.0
15	2898	1.0067	577.0	9.4350	16	1612	1.0067	578.0	9.8041	17	23	1.0067	578.0
18	3955	1.0067	578.0	10.5334	19	4623	1.0067	578.0	10.8934	20	2184	1.0096	576.0
21	1075	1.0096	578.0	11.2503	22	23	1.0096	577.0	11.6037	23	424	1.0096	575.0
24	4895	1.0096	577.0	12.3003	25	3387	1.0125	578.0	12.6431	26	576	1.0125	577.

INPUT DATA OF DIRECT SOLAR RADIATION, D(I), PRESSURE, P(I), AND DECLINATION ANGLE, ~~DEL(I) OF A.A. REGI~~

FOR THE YEAR 1983.

DAY	D(I)	E(I)	P(I)	DEL(I)	DAY	D(I)	E(I)	P(I)	DEL(I)	DAY	D(I)	E(I)	P(I)
27	1655	1.0125	578.0	13.3175	28	3156	1.0125	578.0	13.6488	29	6437	1.0125	577.0
30	5034	1.0125	577.0	14.2992	1	3522	1.0155	577.0	14.6181	2	3796	1.0155	576.0
3	1353	1.0155	575.0	15.2428	4	915	1.0155	578.0	15.5484	5	305	1.0177	577.0
6	4934	1.0177	577.0	16.1457	7	4604	1.0177	577.0	16.4373	8	2283	1.0177	578.0
9	1754	1.0177	577.0	17.0056	10	4646	1.0199	578.0	17.2823	11	4016	1.0199	576.0
12	3908	1.0199	576.0	17.8202	13	3482	1.0199	575.0	18.0813	14	2070	1.0199	576.0
15	2168	1.0220	575.0	18.5872	16	2599	1.0220	576.0	18.8320	17	1037	1.0220	576.0
1	1641	1.0284	576.0	21.9452	2	674	1.0284	577.0	22.0866	3	4626	1.0284	575.0
4	4710	1.0284	576.0	22.3499	5	3154	1.0296	575.0	22.4715	6	1471	1.0296	576.0
7	3875	1.0296	576.0	22.6949	8	4407	1.0296	578.0	22.7965	9	2765	1.0296	577.0
10	1424	1.0308	576.0	22.9794	11	3996	1.0308	577.0	23.0607	12	4000	1.0308	576.0
13	1465	1.0308	578.0	23.2027	14	5337	1.0308	578.0	23.2634	15	2946	1.0317	577.0
16	1601	1.0317	577.0	23.3641	17	1319	1.0317	579.0	23.4041	18	2370	1.0317	572.0
19	1351	1.0317	578.0	23.4632	20	1781	1.0327	578.0	23.4324	21	2188	1.0327	578.0
22	1748	1.0327	577.0	23.4998	23	1798	1.0327	577.0	23.4981	24	2746	1.0327	578.0
25	2721	1.0332	577.0	23.4737	26	1782	1.0332	578.0	23.4510	27	1165	1.0332	577.0
28	2120	1.0332	576.0	23.3850	29	305	1.0332	576.0	23.3416	30	360	1.0332	578.0
1	2578	1.0337	578.0	23.2339	2	2119	1.0337	578.0	23.1698	3	3366	1.0337	576.0
4	1797	1.0337	578.0	23.0209	5	3810	1.0337	577.0	22.9362	6	2602	1.0337	577.0
7	903	1.0337	577.0	22.7465	8	2059	1.0537	577.0	22.6416	9	3002	1.0337	578.0
10	2708	1.0337	577.0	22.4115	11	2709	1.0337	577.0	22.2865	12	1699	1.0337	578.0
13	2271	1.0337	577.0	22.0167	14	989	1.0337	576.0	21.8720	15	1250	1.0331	575.0
16	1137	1.0331	575.0	21.5632	17	1157	1.0331	577.0	21.3992	18	917	1.0331	576.0
19	1585	1.0331	577.0	21.0522	20	537	1.0324	577.0	20.8693	21	[illegible]	1.0324	578.0
22	8	1.0324	576.0	20.4851	23	343	1.0324	577.0	20.2838	24	478	1.0324	578.0
25	1032	1.0316	576.0	19.8633	26	608	1.0316	577.0	19.6442	27	477	1.0316	577.0
28	1411	1.0316	576.0	19.1886	29	1131	1.0316	577.0	18.9523	30	977	1.0316	578.0
31	69	1.0316	578.0	18.4620	1	294	1.0300	577.0	18.2098	2	1781	1.0300	576.0
3	347	1.0300	577.0	17.6870	4	3	1.0300	578.0	17.4187	5	681	1.0288	577.0
6	1381	1.0288	5780.0	17.1446	7	742	1.0288	578.0	16.8654	8	4	1.0288	576.0
9	2603	1.0288	578.0	16.2921	10	2614	1.0272	576.0	15.9982	11	57	1.0272	577.0
12	190	1.0272	577.0	15.3961	13	13	1.0212	577.0	15.0883	14	50	1.0272	577.0
15	1	1.0257	577.0	14.4592	16	87	1.0257	576.0	14.1381	17	1064	1.0257	[illegible]

WAVELENGTH(LAM), RAYLEIGH MOLECULAR ATTENUATION COEFFICIENT THOU(LAM), EXTRATERRESTRIAL SOLAR RADIATION I(L)FOR THE SPECTRUM IN THE INTERVAL (290 - 4000)NM

WL(LAM)	THOU(LAM)	IO(LAM)	WL(LAM)	THOU(LAM)	IO(LAM)
0.290	0.141100E 01	5.240	0.300	0.122000E 01	6.180
0.310	0.106000E 01	6.350	0.320	0.962000E 00	7.810
0.330	0.812700E 00	9.000	0.340	0.716400E 00	8.940
0.350	0.634100E 00	9.490	0.360	0.563400E 00	10.510
0.370	0.502300E 00	10.400	0.380	0.449400E 00	9.450
0.390	0.403300E 00	11.340	0.400	0.363000E 00	16.310
0.410	0.327700E 00	17.000	0.420	0.296600E 00	16.590
0.430	0.269100E 00	16.720	0.440	0.244700E 00	19.280
0.450	0.223100E 00	20.060	0.460	0.203800E 00	19.860
0.470	0.186500E 00	19.890	0.480	0.171100E 00	18.880
0.490	0.157200E 00	19.560	0.500	0.144700E 00	19.020
0.510	0.133500E 00	18.310	0.520	0.123300E 00	18.590
0.530	0.114000E 00	19.170	0.540	0.105700E 00	18.560
0.550	0.980500E-01	18.410	0.560	0.911000E-01	18.280
0.570	0.847700E-01	18.340	0.580	0.789700E-01	18.080
0.590	0.736700E-01	17.630	0.600	0.688000E-01	17.410
0.610	0.643300E-01	17.050	0.620	0.602200E-01	16.580
0.630	0.564300E-01	16.330	0.640	0.529400E-01	15.990
0.650	0.497100E-01	15.200	0.660	0.467300E-01	15.550
0.670	0.439700E-01	15.160	0.680	0.414100E-01	14.890
0.690	0.390300E-01	14.500	0.700	0.368200E-01	14.160
0.710	0.347700E-01	13.850	0.720	0.328600E-01	13.560
0.730	0.310700E-01	13.160	0.740	0.294100E-01	12.840
0.750	0.278600E-01	12.650	0.760	0.264100E-01	12.360
0.770	0.250500E-01	12.070	0.780	0.237800E-01	11.830
0.790	0.225800E-01	11.610	0.800	0.214700E-01	101.170
0.900	0.133500E-01	81.560	1.000	0.873600E-02	6.820
1.100	0.595500E-02	5.560	1.200	0.419800E-02	4.640
1.300	0.304400E-02	3.850	1.400	0.226100E-02	2.670
1.500	0.171500E-02	3.230	1.600	0.132400E-02	2.140
1.700	0.103800E-02	1.750	1.800	0.825700E-03	1.440
1.900	0.664900E-03	1.200	2.000	0.541400E-03	0.550
2.500	0.221500E-03	0.150	3.000	0.106700E-03	0.030
3.500	0.576100E-04	0.530	4.000	0.000000	0.000

APPENDIX - B

AIRMASS AT THREE DIFFERENT HOUR ANGLES. MH(H,THETAI) = P(I)/P1(SIN(THETAI)) FOR THE YEAR 1983 OF
A.A. REGION. (Po=760MM)

DAY	MH(TITA1)	MH(TITA2)	MH(TITA3)	DAY	MH(TITA1)	MH(TITA2)	MH(TITA3)
20	0.79930E 00	0.89170E 00	0.10928E 01	21	0.79693E 00	0.88893E 00	0.10891E 01
22	0.79461E 00	0.88622E 00	0.10855E 01	23	0.79508E 00	0.88663E 00	0.10857E 01
24	0.79560E 00	0.88709E 00	0.10859E 01	25	0.79477E 00	0.88605E 00	0.10843E 01
26	0.79125E 00	0.88200E 00	0.10791E 01	27	0.79188E 00	0.88259E 00	0.10795E 01
28	0.791119E 00	0.88170E 00	0.10781E 01	29	0.78916E 00	0.87933E 00	0.10749E 01
30	0.78718E 00	0.87701E 00	0.10717E 01	31	0.78798E 00	0.87773E 00	0.10724 01
1	0.78745E 00	0.87708E 00	0.10712E 01	2	0.78832E 00	0.87794E 00	0.10720E 01
3	0.78787E 00	0.87733E 00	0.10709E 01	4	0.78610E 00	0.87524E 00	0.10661E 01
5	0.78436E 00	0.87319E 00	0.10653E 01	6	0.78676E 00	0.87575E 00	0.10681E 01
7	0.78510E 00	0.87379E 00	0.10655E 01	8	0.78621E 00	0.87491E 00	0.10665E 01
9	0.78462E 00	0.87305E 00	0.10640E 01	11	0.78429E 00	0.87246E 00	0.10627E 01
12	0.78691E 00	0.87526E 00	0.10658E 01	13	0.78547E 00	0.87356E 00	0.10635E 01
14	0.78679E 00	0.87492E 00	0.10648E 01	15	0.78542E 00	0.87329E 00	0.10626E 01
16	0.78680E 00	0.87473E 00	0.10641E 01	17	0.78686E 00	0.87469E 00	0.10637E 01
18	0.78695E 00	0.87468E 00	0.10635E 01	19	0.78706E 00	0.87471E 00	0.10632E 01
20	0.78434E 00	0.87168E 00	0.10596E 01	21	0.78721E 00	0.87477E 00	0.10631E 01
22	0.78603E 00	0.87336E 00	0.10611E 01	23	0.78350E 00	0.87046E 00	0.10573E 01
24	0.78646E 00	0.87364E 00	0.10609E 01	25	0.78808E 00	0.87535E 00	0.10627E 01
26	0.78700E 00	0.87405E 00	0.10609E 01	27	0.78867E 00	0.87581E 00	0.10628E 01
28	0.78900E 00	0.87608E 00	0.10629E 01	29	0.78799E 00	0.87487E 00	0.10612E 01
30	0.78836E 00	0.87519E 00	0.10613E 01	1	0.78875E 00	0.87553E 00	0.10615E 01
2	0.78779E 00	0.87438E 00	0.10599E 01	3	0.78685E 00	0.87325E 00	0.10583E 01
4	0.79141E 00	0.87822E 00	0.10641E 01	5	0.79050E 00	0.87713E 00	0.10625E 01
6	0.79098E 00	0.87757E 00	0.10628E 01	7	0.79147E 00	0.87803E 00	0.10632E 01
8	0.79334E 00	0.88003E 00	0.10654E 01	9	0.79248E 00	0.87900E 00	0.10639E 01
10	0.79438E 00	0.88102E 00	0.10662E 01	11	0.79217E 00	0.87849E 00	0.10629E 01
12	0.79271E 00	0.87901E 00	0.10633E 01	13	0.79188E 00	0.87801E 00	0.10619E 01
14	0.79380E 00	0.88008E 00	0.10642E 01	15	0.79298E 00	0.87909E 00	0.10629E 01
16	0.79492E 00	0.88117E 00	0.10652E 01	17	0.79548E 00	0.88172E 00	0.10657E 01
1	0.80340E 00	0.88964E 00	0.10731E 01	2	0.80524E 00	0.89164E 00	0.10754E 01
3	0.80288E 00	0.88899E 00	0.10721E 01	4	0.80469E 00	0.89095E 00	0.10743E 01
5	0.80368E 00	0.88981E 00	0.10729E 01	6	0.80546E 00	0.89174E 00	0.10751E 01
7	0.80582E 00	0.89210E 00	0.10755E 01	8	0.80896E 00	0.89555E 00	0.10795 01

AIR*ASS AT THREE DIFFERENT HOUR ANGLES. MH(H,THETAI) = P(I)/P0(SIN(THETAI)) FOR THE YEAR 1983 OF A.A. REGION. (Po=760MM)

DAY	MH(TITA1)	MH(TITA2)	MH(TITA3)	DAY	MH(TITA1)	MH(TITA2)	MH(TITA3)
9	0.80788E 00	0.89433E 00	0.10780E 01	10	0.80673E 00	[illegible]	[illegible]
11	0.80846E 00	0.89492E 00	0.10786E 01	12	0.80732E 00	0.89363E 00	[illegible]
13	0.81036E 00	0.89697E 00	0.10809E 01	14	0.81057E 00	0.89719E 00	[illegible]
15	0.80935E 00	0.89583E 00	0.10795E 01	16	0.80952E 00	0.89599E 00	[illegible]
17	0.81247E 00	0.89924E 00	0.10835E 01	18	0.80276E 00	0.88849E 00	[illegible]
19	0.81127. 00	0.89791E 00	0.10819E 01	20	0.81134E 00	0.89798E 00	[illegible]
21	0.81139E 00	0.89802E 00	0.10820E 01	22	0.81000E 00	0.89649 00	[illegible]
23	0.80999E 00	0.89648E 00	0.10801E 01	24	0.81137E 00	[illegible]	[illegible]
25	0.80991 00	0.89639E 00	0.10800E 01	26	0.81123E 00	[illegible]	[illegible]
27	0.80972E 00	0.89620E 00	0.10798E 01	28	0.80819E 00	0.89452 00	[illegible]
29	0.80804E 00	0.89436E 00	0.10777E 01	30	0.81067E 00	0.89729 00	[illegible]
1	0.81046E 00	0.89708E 00	0.10810E 01	2	0.81024E 00	[illegible]	[illegible]
3	0.80719E 00	0.89350E 00	0.10768E 01	4	0.80973E 00	0.89833E 00	[illegible]
5	0.80804E 00	0.89448E 00	0.10781E 01	6	0.80772E 00	0.89417E 00	[illegible]
7	0.80739E 00	0.89383E 00	0.10775E 01	8	0.80704E 00	0.89347 00	[illegible]
9	0.80807E 00	0.89464E 00	0.10787E 01	10	0.80628E 00	0.89270E 00	[illegible]
11	0.80588E 00	0.89229E 00	0.10760E 01	12	0.80685E 00	0.89341E 00	[illegible]
13	0.80502E 00	0.89142E 00	0.10752E 01	14	0.80317E 00	0.88941E 00	[illegible]
15	0.80131E 00	0.88740E 00	0.10705E 01	16	0.80083E 00	0.88691E 00	[illegible]
17	0.80312E 00	0.88950E 00	0.10733E 01	18	0.80122E 00	0.88745E 00	[illegible]
19	0.80209E 00	0.88847E 00	0.10723E 01	20	0.80157E 00	0.88794 00	[illegible]
21	0.80242 00	0.88894E 00	0.10737E 01	22	0.79910E 00	0.88532 00	[illegible]
23	.79994E 00	0.88631E 00	0.10703E 01	24	0.80076E 00	0.88730 00	[illegible]
25	0.79745E 0	0.88367E 00	0.10674E 01	26	0.79827E 00	0.88465E 00	[illegible]
27	0.79771 00	0.884[illegible]9E 00	0.10683E 01	28	0.79576E 00	[illegible]	[illegible]
29	0.79658E 00	0.88298 0[illegible]	0.10673E 01	30	0.79740E 00	0.88395E 00	[illegible]
31	0.79684E 00	0.88340E 00	0.10682E 01	1	0.79491E 00	0.88133E 00	[illegible]
2	0.79298E 0	.87927E 00	0.10636E 01	3	0.79381E 00	0.88027E 00	[illegible]
4	0.79465E 00	0.88128E 0[illegible]	0.10664E 01	5	0.79327E 00	0.87975E 00	[illegible]
[illegible]	0.79412E 01	0.88077E 01	0.10660E 02	7	0.79360E 00	0.88027E 00	[illegible]
8	0.79309E 00	0.87979E 00	0.10652E 01	9	0.79259E 00	0.87932E 00	[illegible]
10	0.78937E 00	0.87583E 00	0.10608E 01	11	0.79027E 00	0.87691E 00	[illegible]
12	0.78981E 00	0.87649E 00	0.10621E 01	13	0.78938E 00	0.87669E 00	[illegible]
14	0.78895E 00	0.87572E 00	0.10616E 01	15	0.78855E 00	0.87536E 00	[illegible]
16	0.78680E 00	0.87351E 00	0.10594E 01	12	0.78644E 00	0.87320E 00	[illegible]

AIRMASS AT THREE DIFFERENT HOUR ANGLES. MH(H,THETAI) = P(I)/PJ(SIN(THETAI)) FOR THE YEAR [illegible]

A.A. REGION. (P_0 = 760 MM).

DAY	MH(TITA1)	MH(TITA2)	MH(TITA3)	DAY	MH(TITA1)	MH(TITA2)	MH(TITA3)
18	0.78747E 00	0.87443E 00	0.10610E 01	23	0.78340E 00	0.870[illegible] 00	0.10[illegible]
24	0.78730E 00	0.87482E 00	0.10630E 01	25	0.78441E 00	0.87171E 00	0.10[illegible] 01
26	0.78428E 00	0.87167E 00	0.10597E 01	27	0.78418E 00	0.87165E 00	0.105[illegible] 01
28	0.78410E 00	0.87168E 00	0.10602E 01	29	0.78542E 00	0.87325E 00	0.10624E [illegible]
30	0.78542E 00	0.87334E 00	0.10628E 01	31	0.78680E 00	0.87497E 00	0.10651[illegible] 01
1	0.78414E 00	0.87213E 00	0.10619E 01	2	0.78560E 00	0.87386E 00	0.10[illegible]4[illegible] 01
4	0.78725E 00	0.87591E 00	0.10673E 01	5	0.78609E 00	0.87473 00	0.10662E 01
6	0.78360E 00	0.87207E 00	0.10632E 01	7	0.78524E 00	0.87401E 00	0.10659[illegible] 01
8	0.78419E 00	0.87295E 00	0.10649E 01	9	0.78591E 00	0.87497E 00	0.10678E 01
10	0.78766E 00	0.87704E 00	0.10704E 01	11	0.78946E 00	0.87915E 00	0.107[illegible] 01
12	0.78857E 00	0.87827E 00	0.10725E 01	13	0.78908E 00	0.87895E 00	0.10737[illegible] 01
14	0.79100E 00	0.88120E 00	0.10767E 01	15	0.79022E 00	0.88045E 00	0.1075[illegible] 01
16	0.78948E 00	0.87975E 00	0.10756E 01	17	0.78879E 00	0.87909E 00	0.1075[illegible] 01
18	0.79087E 00	0.88153E 00	0.10783E 01	19	0.79300E 00	0.88402E 00	0.10817[illegible] 01
20	0.79380E 00	0.88503E 00	0.10833E 01	21	0.79189E 00	0.88301E 00	0.108[illegible] 01
22	0.79553E 00	0.88719E 00	0.10865E 01	23	0.79507E 00	0.88680E 00	0.108[illegible] 01
24	0.79742E 00	0.88954E 00	0.10900E 01	25	0.79704E 00	0.88924E 00	0.10[illegible] 01
26	0.79809E 00	0.89053E 00	0.10919E 01	27	0.80057E 00	0.89341E 00	0.10[illegible]3E 01
28	0.80031E 00	0.89325E 00	0.10959E 01	29	0.80288E 00	0.89623E 00	0.10999E 01
30	0.80688E 00	0.90082E 00	0.11058E 01	1	0.80674E 00	0.90079E 00	0.110[illegible] 01
2	0.80944E 00	0.90392E 00	0.11103E 01	3	0.80798E 00	0.90241[illegible] 00	0.1108[illegible] 01
4	0.80795[illegible] 00	0.90250E 00	0.11092E 01	5	0.81217E 00	0.90734E 00	0.11129[illegible] 01
6	0.81362E 00	0.90909E 00	0.11180E 01	7	0.81229E 00	0.90773E 00	0.11166E 01
8	0.81523E 00	0.91113E 00	0.11211E 01	9	0.81821E 00	0.91459[illegible] 00	0.112[illegible] 01
10	0.81697E 00	0.91333E 00	0.11245E 01	11	0.81718E 00	0.91369E 00	0.112[illegible] 01
12	0.81884E 00	0.91567E 00	0.11281E 01	13	0.82197E 00	0.91928E 00	0.1132[illegible] 01
14	0.82226E 00	0.91974E 00	0.11338E 01	15	0.82402E 00	0.92183E 00	0.113[illegible] 01
16	0.82581E 00	0.92396E 00	0.11396E 01	17	0.82907E 00	0.92773E 00	0.114[illegible] 01
18	0.83092E 00	0.92992E 00	0.11476E 01	19	0.83424E 00	0.93370E 00	0.115[illegible] 01
20	0.83470[illegible] 00	0.93440E 00	0.11538E 01	21	0.83808E 00	0.93831E 00	0.115[illegible] 01
22	0.84003E 00	0.94062E 00	0.11622E 01	23	0.84201E 00	0.94295[illegible] 00	0.116[illegible] 01
24	0.844[illegible] 00	0.94531E 00	0.11687E 01	25	0.84749E 00	0.94934E 00	0.1174[illegible] 01
26	0.85100[illegible] 00	0.95339E 00	0.11793E 01	27	0.85159E 00	0.95417E 00	0.118[illegible]
[illegible]	0.[illegible]53[illegible] 00	0.95661E 00	0.11840E 01	29	0.85574E 00	0.95907E 00	0.11[illegible]

30	0.85784E 00	0.96154E 00	0.11907E 01	31	0.85995E 00	0.96402E 00	0.11941E 01
1	0.86206E 00	0.96651E 00	0.11975E 01	2	0.86568E 00	0.97069E 00	0.12030E 01
3	0.86631E 00	0.97151E 00	0.12044E 01	4	0.86844E 00	0.97402E 00	0.1207[illegible] 01
5	0.87058 00	0.97653E 00	0.12112E 01	6	0.87271E 00	0.97903E 00	0.12147E [illegible]
7	0.87484E 00	0.98154E 00	0.12181E 01	8	0.87545E 00	0.98233E 00	0.12174E [illegible]
9	0.87908E 00	0.98652E 00	0.12249E 01	10	0.87967E 00	0.98729E 00	0.1226[illegible]
11	0.88330 00	0.99147E 00	0.12316E 01	12	0.88385E 00	0.99220E 00	0.1232[illegible]
13	0.88746E 00	0.99635E 00	0.12383E 01	14	0.88952E 00	0.99877E 00	0.1241[illegible]
15	0.89157E 00	0.10012E 01	0.12449E 01	16	0.89358E 00	0.10035E 01	0.12481E 01
17	0.89557E 00	0.10059E 01	0.12513E 01	18	0.89755E 00	0.10082E 01	0.12544E 01
19	0.90105E 00	0.10122E 01	0.12597E 01	20	0.90141E 00	0.10127E 01	0.1260[illegible]
21	0.90017 00	0.10114E 01	0.12592E 01	22	0.90201E 00	0.10135E 01	0.1262[illegible]
23	0.90539E 00	0.10175E 01	0.12672E 01	24	0.90874E 00	0.10213 01	0.12723E 01
25	0.90734E 00	0.10198E 01	0.12706E 01	26	0.909[illegible]3E 00	0.10218E 01	0.12733E 01
27	0.91063E 00	0.10237E 01	0.12760E 01	28	0.91387E 00	0.10274E 01	0.12806E [illegible]
29	0.91702E 00	0.10310E 01	0.12855E 01	30	0.91695E 00	0.10310E 01	0.128[illegible]7E [illegible]
1	0.92000E 00	0.10345E 01	0.12902E 01	2	0.92142E 00	0.10362E 01	0.12925[illegible]
3	0.92278E 00	0.10378E 01	0.12946E 01	4	0.92568E 00	0.10411E 01	0.1299[illegible]E 01
5	0.92372E 00	0.10389E 01	0.12964E 01	6	0.92651E 00	0.10421E 01	0.1300[illegible]E 01
7	0.92603E 00	0.10417E 01	0.13001E 01	8	0.92870E 00	0.10447E 01	0.13041E 01
9	0.92810E 00	0.10441E 01	0.13034E 01	10	0.92903E 00	0.10452E 01	0.1304[illegible]E 01
12	0.93151E 00	0.10480E 01	0.13085E 01	13	0.93232E 00	0.10489E 01	0.1307[illegible]E 01
14	0.93305E 00	0.10498E 01	0.13110E 01	15	0.93372E 00	0.10506E 01	0.13121E 01
16	0.93432E 00	0.10513E 01	0.13130E 01	17	0.93322E 00	0.10501E 01	0.13116E 01
18	0.93530E 00	0.10524E 01	0.13146E 01	19	0.93730E 00	0.10547E 01	0.13175E 01
20	0.93599E 00	0.10532E 01	0.13157E 01	21	0.93784E 00	0.10553E 01	0.13183E 01
22	0.93634E 00	0.10536E 01	0.13162E 01	23	0.93487E 00	0.10520E 01	0.1314[illegible]E 01
24	0.93488E 00	0.10520E 01	0.13142E 01	26	0.93632E 00	0.10536E 01	0.131[illegible]E 01
27	0.93612E 00	0.10534E 01	0.13159E 01	28	0.93584E 00	0.10531E 01	0.13154E 01
29	0.93550E 00	0.10527E 01	0.13149E 01	30	0.93346E 00	0.10504E 01	0.13119E 01
31	0.93269 00	0.10494E 01	0.13104E 01		0.00000	0.00000	0.000[illegible]

APPENDIX - C

CALCULATED VALUES OF DIRECT SOLAR RAD. DUE TO RAYLEIGH SCATT[ERING ME]CHANISM IN(TETHA,H) - TURBIDITY FACTORS FOR THE YEAR 1983 OF A.A. REGION

DAY	IN(TITA,H)	T(I)	DAY	IN(TITA,H)
1	0.9317124E 03	0.1775227E 01	3	0.9313916E 03
5	0.9320720E 03	0.1958809E 01	6	0.9319731E 03
8	0.9323645E 03	0.1767316E 01	9	0.9325623E 03
11	0.9329453E 03	0.1860602E 01	12	0.9332134E 03
14	0.9337903E 03	0.2182322E 01	19	0.9355142E 03
21	0.9359907E 03	0.2067322E 01	23	0.9365967E 03
25	0.9377734E 03	0.2328668E 01	26	0.9381736E 03
28	0.9386431E 03	0.2082022E 01	29	0.9387146E 03
31	0.9393667E 03	0.2700492E 01	1	0.9410659E 03
3	0.9413953E 03	0.3247268E 01	4	0.9414780E 03
6	0.9434365E 03	0.1797636E 01	7	0.9438552E 03
9	0.9448572E 03	0.2038118E 01	10	0.9467329E 03
12	0.9467231E 03	0.1955879E 01	13	0.9471560E 03
15	0.9495032E 03	0.2264073E 01	16	0.9496352E 04
18	0.9502417E 03	0.2087000E 01	20	0.9525105E 03
22	0.9526606E 03	0.1959522E 01	23	0.9528955E 03
25	0.9555667E 03	0.1778511E 01	27	0.9560166E 03
3	0.9587661E 03	0.1911184E 01	4	0.9591335E 03
6	0.9619438E 03	0.1930032E 01	7	0.9621384E 03
9	0.9623557E 03	0.2002860E 01	10	0.9646899E 03
12	0.9652021E 03	0.2118439E 01	13	0.9358564E 03
15	0.9685981E 03	0.2225161E 01	16	0.9685947E 03
18	0.9687327E 03	0.2419759E 01	19	0.9690339E 03
21	0.9720471E 03	0.1848529E 01	22	0.9723337E 03
24	0.9722563E 03	0.1759470E 01	25	0.9753101E 03
27	0.9756819E 03	0.2138545E 01	28	0.9757805E 03
30	0.9762815E 03	0.1921893E 01	31	0.9762065E 03
2	0.9797341E 03	0.1893628E 01	3	0.9798040E 03
5	0.9828989E 03	0.1969308E 01	6	0.9826360E 03
8	0.9827349E 03	0.2639453E 01	9	0.9829368E 03
12	0.9853708E 03	0.1883811E 01	13	0.9855559E 03
15	0.9882446E 03	0.1931442E 01	16	0.9880986E 03
18	0.9881143E 03	0.1861037E 01	19	0.9881160E 03
21	0.9909614E 03	0.2156385E 01	22	0.9911157E 03
24	0.9910957E 03	0.1813504E 01	25	0.9937668E 03
27	0.9937275E 03	0.2059383E 01	28	0.9937036E 03
30	0.9938083E 03	0.1807763E 01	1	0.9967197E 03
3	0.9969717E 03	0.2105775E 01	4	0.9964485E 03
6	0.9986846E 03	0.1813368E 01	7	0.9986404E 03
9	0.9985459E 03	0.2047268E 01	10	0.1000493E 04
12	0.1000715E 04	0.1866539E 01	13	0.1000825E 04
15	0.1002778E 04	0.2000292E 01	16	0.1002559E 04
1	0.1007976E 04	0.2064202E 01	2	0.1007765E 04
4	0.1007843E 04	0.1825695E 01	5	0.1009143E 04
7	0.1008900E 04	0.1870040E 01	8	0.1008533E 04
10	0.1009977E 04	0.2096642E 01	11	0.1009781E 04
13	0.1009564E 04	0.2090029E 01	14	0.1009541E 04
16	0.1010552E 04	0.2070203E 01	17	0.1010204E 04
19	0.1010348E 04	0.2108499E 01	20	0.1011321E 04
22	0.1011480E 04	0.2050535E 01	23	0.1011481E 04
25	0.1011980E 04	0.1950585E 01	26	0.1011822E 04

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0.20?7?13E	[illegible]	3	0.1?77??	[illegible]	[illegible]	[illegible]
5	0.1?7??	01	6	0.1??2?97E	04	0.1???7	01
8	0.201?201E	01	9	0.1?12644E	04	0.192?947E	01
11	0.1951879E	01	12	0.101277?E	04	0.2?57???E	01
14	0.2179893E	01	15	0.101??21E	04	0.212?69?E	01
17	0.2144273E	01	18	0.101?6??E	04	0.219?9??E	01
20	0.2317795E	01	21	0.1011?93E	04	0.3209379E	01
23	0.2419267E	01	24	0.1012121?E	04	0.2344146E	01
26	0.2259707E	01	27	0.1011672E	04	0.2544022E	01
29	0.2342404E	01	30	0.101?167?E	04	0.21?249?E	01
1	0.2453362E	01	2	0.1010599E	04	0.2045922E	01
4	0.3490979E	01	5	0.1009362E	04	0.226?697?E	01
7	0.2244259E	01	8	0.1009345E	04	0.342575?E	01
10	0.1959259E	01	11	0.1008072E	04	0.2524024E	01
13	0.3157726E	01	14	0.1008187E	04	0.2654336E	01
16	0.2723645E	01	17	0.100697?E	04	0.216239?E	01
23	0.2017715E	01	24	0.1004799E	04	0.3736593E	01
26	0.2270573E	01	27	0.1002564E	04	0.2157264E	01
29	0.2163316E	01	30	0.1002567E	04	0.2354082E	01
1	0.2534623E	01	2	0.9994543E	03	0.2331022E	01
5	0.2011445E	01	6	0.9975605E	03	0.3174922E	01
8	0.1959220E	01	9	0.9972544E	03	0.234???E	01
11	0.2054313E	01	12	0.9946091E	03	0.1911615E	01
14	0.2974091E	01	15	0.9917109E	03	0.276?77?E	01
17	0.2033331E	01	18	0.9915786E	03	0.2543574E	01
20	0.3121680E	01	21	0.9887559E	03	0.2927512E	01
23	0.1870265E	01	24	0.9880500E	03	0.2047665E	01
26	0.1935922E	01	27	0.984??74E	03	0.214??07E	01
29	0.2263136E	01	30	0.9837935E	03	0.2033550E	01
2	0.2026622E	01	3	0.98?574?E	03	0.2216321E	01
5	0.1963918E	01	6	0.977710?E	03	0.2400347E	01
8	0.2247850E	01	9	0.9771221E	03	0.15?400?E	01
11	0.2107466E	01	12	0.9691743E	03	0.1911976E	01
14	0.1943817E	01	15	0.970?719E	03	0.24327??E	01
17	0.2136915E	01	18	0.9698245E	03	0.1754017E	01
20	0.1893017E	01	21	0.9662202E	03	0.1?524??E	01
23	0.2266761E	01	24	0.9654895E	03	0.2755421E	01
26	0.1852437E	01	27	0.9616543E	03	0.1535532E	01
29	0.1827284E	01	30	0.9608943E	03	0.1900122E	01
1	0.1766009E	01	2	0.9565538E	03	0.1834710E	01
4	0.1926484E	01	5	0.9538230E	03	0.1?57?4?E	01
7	0.1900732E	01	8	0.9532292E	03	0.1?04???E	01
10	0.1827708E	01	11	0.9?017??	03	0.1?54?	01
13	0.1893821E	01	14	0.9494?97	03	0.1??57??	01
16	0.185??35E	01	17	0.9465???	03	0.1?54???	[illegible]
19	0.177436?E	01	[illegible]	0.94?7???	[illegible]	[illegible]	[illegible]
22	0.1784537E	01	[illegible]	0.9433???	[illegible]	0.1?7???	[illegible]
25	0.1774655E	01	[illegible]	0.945????	[illegible]	0.17????	[illegible]
28	0.1895700E	01	[illegible]	0.94?1???	[illegible]	0.1?774??	[illegible]
1	0.1792945E	01	[illegible]	0.?370???	03	0.1?034??	[illegible]

Y	[illegible]		[illegible]	[illegible]		[illegible]	
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	0.2?14[illegible]	01	[illegible]	[illegible]	03	[illegible]	01
9	0.1774134E	01	[illegible]	0.9330452E	03	0.1777154E	01
12	0.1824643E	01	13	0.9287124E	03	0.1651305E	01
19	0.1826690E	01	[illegible]	0.9360342E	03	0.1550844E	01
23	0.1394407E	01	24	0.9374966E	03	0.2595463E	01
26	0.2144409E	01	27	0.9382365E	03	0.2216259E	01
29	0.1951315E	01	[illegible]	0.93[illegible]235	03	0.1745395E	01
1	0.2311913E	01	[illegible]	0.9411456E	03	0.3024356E	01
4	0.2239[illegible]57	01	5	0.9433511E	03	0.1624677E	01
7	0.1647977E	[illegible]	[illegible]	[illegible]7[illegible]	03	0.1[illegible]245E	01
10	0.1846744E	01	13	0.9460653E	03	0.2[illegible]05595E	01
13	0.2042333E	01	14	0.9472412E	03	0.2257679E	01
16	0.2837294E	01	17	0.9501614E	03	0.1597931E	01
20	0.1969634E	01	21	0.9529862E	03	0.2025365E	01
23	0.1777023E	01	24	0.9532898E	03	0.1589952E	01
27	0.2434215E	01	1	0.9585039E	03	0.1314294E	01
4	0.1939252E	01	5	0.9615837E	03	0.1922167E	01
7	0.1914223E	01	8	0.9621639E	03	0.1936129E	01
10	0.1896378E	01	11	0.9650263E	03	0.2025111E	01
13	0.2296628E	01	14	0.9655366E	03	0.3267947E	01
16	0.2562330E	01	17	0.9674956E	03	0.2103736E	01
19	0.2384957E	01	2[illegible]	0.9717546E	03	0.2[illegible]E	01
22	0.2523642E	01	23	0.9729695E	03	0.1659255E	01
25	0.2151172E	01	26	0.9757373E	03	0.2009639E	01
28	0.2143397E	01	29	0.9760350E	03	0.2337063E	01
31	0.2034809E	01	1	0.9796164E	03	0.1932547E	01
3	0.2153517E	01	4	0.9800286E	03	0.2210181E	01
6	0.2265506E	01	7	0.9826472E	03	0.2327521E	01
9	0.2929363E	01	11	0.9856597E	03	0.2923649E	01
13	0.1395343E	01	14	0.9854179E	03	0.2065587E	01
16	0.2064070E	01	17	0.9881682E	03	0.3025477E	01
19	0.1625732E	01	20	0.9912634E	03	0.1990173E	01
22	0.3026238E	01	23	0.9914260E	03	0.2367105E	01
25	0.1897392E	01	26	0.9939097E	03	0.2297462E	01
28	0.1913345E	01	29	0.9938376E	03	0.1752157E	01
1	0.1839224E	01	2	0.9965467E	03	0.1[illegible]72529E	01
4	0.2194009E	01	5	0.998726[illegible]E	03	0.2443634E	01
7	0.1329009E	01	8	0.9964316E	03	0.1987589E	01
10	0.1827317E	01	11	0.1000757E	04	0.1560394E	01
13	0.1892694E	01	14	0.1000[illegible]	04	0.201024[illegible]	01
16	0.1959179E	01	17	0.1002504E	04	0.2169901E	01
2	0.2265334E	01	[illegible]	0.1006052E	04	0.1[illegible]	01
5	0.1915701E	01	[illegible]	0.1006935E	04	0.20[illegible]	01
8	0.1540796E	01	9	0.1[illegible]	04	0.194[illegible]	01
11	0.1[illegible]227[illegible]	01	12	0.10092[illegible]	[illegible]	[illegible]	[illegible]
14	[illegible]	[illegible]	15	[illegible]	[illegible]	[illegible]	[illegible]
17	0.2115351E	01	18	0.1011357E	04	[illegible]	[illegible]
20	0.2045233E	01	21	0.1011316E	04	0.19[illegible]	01
23	0.2044156E	01	24	0.1011513E	04	[illegible]	01
26	0.2046222E	01	27	0.10115[illegible]	04	0.2142[illegible]	01

CALCULATED VALUES OF DIRECT SOLAR [illegible] DUE TO [illegible]
[illegible] YEAR 19 [illegible]

DAY	IN(TITA,H)	T(I)	DAY	[illegible]
28	0.1012180E 04	0.2007111E 01	29	0.101219[illegible] [illegible]
1	0.1012392E 04	0.1962868E 01	2	0.101241[illegible] [illegible]4
4	0.1012470E 04	0.2044507E 01	5	0.1012667E 04
7	0.1012734E 04	0.2206241E 01	8	0.103236[illegible] 04
10	0.1012850E 04	0.1951943E 01	11	0.1012[illegible]E 04
13	0.1012982E 04	0.1991800E 01	14	0.1013196E 04
16	0.1012871E 04	0.2148352E 01	17	0.101259[illegible]E 04
19	0.1012696E 04	0.2073138E 01	20	0.1012063E [illegible]4
22	0.1012339E 04	0.3269361E 01	23	0.101223[illegible] 04
25	0.1011724E 04	0.2170094E 01	26	0.1011615E 04
28	0.1011894E 04	0.2099422E 01	29	0.101173[illegible] 04
31	0.1011732E 04	0.2781960E 01	1	0.10103[illegible] 04
3	0.1010488E 04	0.2416448E 01	4	0.1010375E 04
6	0.1001660E 04	0.1896223E 01	7	0.1009297E 04
9	0.1009391E 04	0.1960402E 01	10	0.1008193E 04
12	0.1008113E 04	0.2552288E 01	13	0.1002262E 04
15	0.1006746E 04	0.3739030E 01	16	0.1006942E 04
18	0.1006834E 04	0.2794729E 01	23	0.1005280E 04
25	0.1002869E 04	0.2797448E 01	26	0.1002868E 04
28	0.1002856E 04	0.2272294E 01	29	0.1002683E 04
31	0.1002485E 04	0.2992448E 01	1	0.9996440E 03
4	0.9992231E 03	0.1985176E 01	5	0.9972832E 03
7	0.9973486E 03	0.1940306E 01	8	0.9974556E 03
10	0.9947517E 03	0.2089625E 01	11	0.9945205E 03
13	0.9945310E 03	0.3082137E 01	14	0.9942854E 03
16	0.9917798E 03	0.2108763E 01	17	0.9918435E 03
19	0.9913091E 03	0.3172833E 01	20	0.9885496E 03
22	0.9883096E 03	0.2378400E 01	23	0.9883447E 03
25	0.9850371E 03	0.1963362E 01	26	0.9848960E 03
28	0.9845981E 03	0.3327519E 01	29	0.9842800E 03
1	0.9807559E 03	0.2004913E 01	2	0.9804233E 03
4	0.9805583E 03	0.2003734E 01	5	0.9778982E 03
7	0.9778452E 03	0.2063915E 01	8	0.9774856E 03
10	0.9743142E 03	0.1841813E 01	11	0.9742708E 03
13	0.[illegible]73680[illegible] [illegible]	0.2140621E 01	14	0.9736274E 03
16	0.970[illegible]468[illegible] 03	0.1810069E 01	17	0.9700554E 03
19	0.969425[illegible] [illegible]	[illegible].2554647E 01	20	0.9666238E 03
22	0.965976[illegible]E 03	0.[illegible]992898E 01	23	0.9657354E 03
25	0.9[illegible]21548E 03	0.1786043E 01	26	[illegible].[illegible]617395E 03
28	0.9614[illegible]23E 03	0.179764[illegible] 0[illegible]	29	0.9[illegible]1494E 03
31	0.9606389E 03	0.1779[illegible]	1	[illegible].95[illegible]8173 [illegible]
3	0.9564702E 03	0.18[illegible]2536[illegible] [illegible]	4	[illegible].956214[illegible]E [illegible]3
6	0.[illegible]535684[illegible] 03	[illegible].205[illegible]928[illegible] [illegible]	7	[illegible].[illegible]33137E 03
9	0.95280[illegible]3E 03	0.[illegible]795846 [illegible]	[illegible]	0.95[illegible]5935E [illegible]3
12	0.9500974E 03	0.1[illegible]3[illegible]13 01	[illegible]	[illegible].9496524E [illegible]3
15	0.9470671E 03	0.182561 [illegible]	[illegible]6	[illegible].9468313 [illegible]3
1[illegible]	0.9463655E 03	0.1886249 [illegible]	[illegible]	[illegible]4596[illegible] [illegible]
[illegible]1	0.9439[illegible]80E 03	0.1762004 01	[illegible]	[illegible].9[illegible]369[illegible] [illegible]
[illegible]4	0.9429299E 03	0.1803[illegible]1 0	5	[illegible]412361E [illegible]
[illegible]	0.9408474E 03	0.18450[illegible]8 0	[illegible]	[illegible]4[illegible]488[illegible] [illegible]
[illegible]	0.[illegible]401331E 03	0.1849857[illegible] 0[illegible]	[illegible]	.[illegible]37[illegible]61[illegible]

A P P E N D I X - D

```
      DOUBLE PRECISION SS(400,10),APOW(400),APOW1(400),QS(3),QPOW1(400),
     F1(10),FM(10),YMIN(10),VMIN,QPOW2(400),QPOW3(400),VMN1,VMN2,VMN3,B
     (10),C(400),D(400),R(400,8),X,Z(400),SSS(400),F(10),T,G(400),FY(10
     ),A,BB,CC,DD,E(400),Y(400)
      REAL W(10),U(400,8),Q(400),V,H
      INTEGER NN,JT,IT,MTO
      COMMON L(10),K(10),A(10,10),BB(10,10),T(10),CC(10),DD(10)
      DATA H/9.033/
    1 FORMAT(F5.0,F10.1,F6.2,F5.1,F8.2)
      M10=0
      MTO=313
      X=0.D0
      DO 1115 I=1,MTO
      D(I)=0.D0
      F(I)=0.D0
      C(I)=0.D0
      Z(I)=0.D0
      G(I)=0.D0
 1115 CONTINUE
      DO 1116 I=1,8
      DO 1117 J=1,MTO
      R(J,I)=0.D0
 1117 CONTINUE
 1116 CONTINUE
      JT=10
      IT=JT-1
      READ(2,2020)(W(I),I=1,9)
      DO 919 I=1,IT
      F(I)=(DBLE(W(I)))
  919 CONTINUE
 2020 FORMAT(1X,9F7.4)
      DO 3 J=1,MTO
      READ(2,1)Q(J),(U(J,I),I=1,4)
    3 CONTINUE
      DO 4 I=1,MTO
      R(I,2)=(DBLE(U(I,2)/(100.0)))
      R(I,1)=(DBLE(U(I,1)))
      R(I,3)=(DBLE(U(I,3)))
      R(I,4)=(DBLE(U(I,4)))
    4 CONTINUE
      DO 5 I=1,MTO
      E(I)=DBLE(U(I,4))
      C(I)=DBLE(Q(I))
      Z(I)=R(I,1)/12.D0
      D(I)=0.D0
    5 CONTINUE
      CALL KROSE(MTO,D,E,Y)
```

```
=1
DO 9  LLL=1,15
DO 1112 I=1,MTO
APOW(I)=0.DO
APOW1(I)=0.DO
QPOW1(I)=0.DO
QPOW2(I)=0.DO
QPOW3(I)=0.DO
SSS(I)=0.DO
CONTINUE
DO 1113 I=1,IT
DO 1114 J=1,MTO
SS(J,I)=0.DO
CONTINUE
CONTINUE
DO 8 N=1,MTO
APOW(N)=((F(2)*(X**F(3)))*((F(4)*(Z(N)**F(5)))+F(6)*(R(N,2)**F(7))+
F(8)*(R(N,3)**F(9)))))
CONTINUE
DO 9 N=1,MTO
APOW1(N)=((X**F(3))*((F(4)*(Z(N)**F(5))+F(6)*(R(N,2)**F(7))+F(8)*(
R(N,3)**F(9)))))
CONTINUE
DO 10 N=1,MTO
SSS(N)=((F(1)*D(N))*(DEXP(APOW(N))))
CONTINUE
DO 11 N=1,MTO
SS(N,1)=(D(N)*(DEXP(APOW(N))))
CONTINUE
DO 12 N=1,MTO
SS(N,2)=(((F(1)*D(N))*(APOW1(N)))*(DEXP(APOW(N))))
CONTINUE
DO 13 N=1,MTO
SS(N,3)=((((F(1)*D(N))*((F(2)*(X**F(3)))*(Z(N)**F(5))))*(DEXP(APOW
(N)))))
CONTINUE
DO 14 N=1,MTO
SS(N,4)=((F(1)*D(N))*(((F(2)*(X**F(3)))*(R(N,2)**F(7))))*(DEXP(APO
W(N))))
CONTINUE
DO 15 N=1,MTO
SS(N,5)=((F(1)*D(N))*((F(2)*(X**F(3)))*(R(N,3)**F(9))))*(DEXP(APOW(
N))))
CONTINUE
DO 16 N=1,MTO
SS(N,6)=(((F(1)*D(N))*(DEXP(APOW(N))))*(((X**F(3))*(DLOG(X))))*(F(
2)*(((F(4)*(Z(N)**F(5))))+(F(6)*(R(N,2)**F(7)))+(F(8)*(R(N,3)**F(9
))))))
CONTINUE
DO 17 N=1,MTO
SS(N,7)=(((F(1)*D(N))*(DEXP(APOW(N))))*(F(2)*(X**F(3))*F(4))*((DLO
G(Z(N)))*(Z(N)**F(5))))
CONTINUE
DO 18 N=1,MTO
```

```
      K=1
      DO 99 LLL=1,5
      DO 1112 I=1,MTO
      APOW(I)=0.D0
      APOW1(I)=0.D0
      OPOW1(I)=0.D0
      OPOW2(I)=0.D0
      OPOW3(I)=0.D0
      SSS(I)=0.D0
 1112 CONTINUE
      DO 1113 I=1,IT
      DO 1114 J=1,MTO
      SS(J,I)=0.D0
 1114 CONTINUE
 1113 CONTINUE
      DO 8 N=1,MTO
      APOW(N)=((F(2)*(X**F(3)))*((F(4)*(Z(N)**F(5)))+F(6)*(R(N,2)**F(7))+
     4F(8)*(R(N,3)**F(9)))))
    8 CONTINUE
      DO 9 N=1,MTO
      APOW1(N)=((X**F(3))*((F(4)*(Z(N)**F(5)))+F(6)*(R(N,2)**F(7))+F(8)*(
     5R(N,3)**F(9)))))
    9 CONTINUE
      DO 10 N=1,MTO
      SSS(N)=((F(1)*D(N))*(DEXP(APOW(N))))
   10 CONTINUE
      DO 11 N=1,MTO
      SS(N,1)=(D(N)*(DEXP(APOW(N))))
   11 CONTINUE
      DO 12 N=1,MTO
      SS(N,2)=(((F(1)*D(N))*(APOW1(N)))*(DEXP(APOW(N))))
   12 CONTINUE
      DO 13 N=1,MTO
      SS(N,3)=((((F(1)*D(N))*((F(2)*(X**F(3)))*(Z(N)**F(5)))))*(DEXP(APOW
     6(N)))))
   13 CONTINUE
      DO 14 N=1,MTO
      SS(N,4)=((F(1)*D(N))*(((F(2)*(X**F(3)))*(R(N,2)**F(7)))))*(DEXP(APO
     7W(N))))
      CONTINUE
      DO 15 N=1,MTO
      SS(N,5)=((F(1)*D(N))*(((F(2)*(X**F(3)))*(R(N,3)**F(9)))))*(DEXP(APOW(
     8N))))
   15 CONTINUE
      DO 16 N=1,MTO
      SS(N,6)=(((F(1)*D(N))*(DEXP(APOW(N))))*(((X**F(3))*(DLOG(X))))*(F(
     92)*(((F(4)*(Z(N)**F(5))))+(F(6)*(R(N,2)**F(7)))+(F(8)*(R(N,3)**F(9
     $))))))
   16 CONTINUE
      DO 17 N=1,MTO
      SS(N,7)=(((F(1)*D(N))*(DEXP(APOW(N))))*(F(2)*(X**F(3))*F(4))*((DLO
     $G(Z(N)))*(Z(N)**F(5))))
   17 CONTINUE
      DO 18 N=1,MTO
```

```
      SS([illegible],[illegible])=(((F(1)*D(N))*(DEXP(APOW(N))))*(F(2)*(X**F(3))*F([illegible]))*([illegible]
     6(R(N,2)))*(R(N,2)**F(7))))
   18 CONTINUE
      DO 19 N=1,MTO
      SS(N,9)=(((F(1)*D(N))*(DEXP(APOW(N))))*(F(2)*(X**F(3)))*(F(6)*(DEXP
     1(R(N,3)))))*(R(N,3)**F(9))))
   19 CONTINUE
      DO 2222 I=1,IT
      B(I)=0.D0
      T(I)=0.D0
      CC(I)=0.D0
      DD(I)=0.D0
      DO 2221 J=1,JT
      A(I,J)=0.D0
      BB(I,J)=0.D0
 2221 CONTINUE
 2222 CONTINUE
      DO 29 I=1,IT
      DO 30 N=1,MTO
      B(I)=B(I)+(C(N)-SSS(N))*SS(N,I)
   30 CONTINUE
   29 CONTINUE
      DO 36 J=1,IT
      DO 37 KK=1,IT
      DO 35 N=1,MTO
      A(J,KK)=A(J,KK)+(SS(N,J)*SS(N,KK))
      BB(J,KK)=BB(J,KK)+(SS(N,J)*SS(N,KK))
   35 CONTINUE
   37 CONTINUE
   36 CONTINUE
      DO 38 I=1,IT
      A(I,10)=B(I)
      BB(I,10)=B(I)
   38 CONTINUE
      CALL GAUSS(JT,IT,M10)
   95 FORMAT(1X,/T4,'Y (',I2,' ) = ',D12.5)
      DO 41 I=1,IT
      F1(I)=F(I)+T(I)*0.5D0
      FM(I)=F(I)+T(I)
      FY(I)=F(I)
   41 CONTINUE
      WRITE(3,97)
   97 FORMAT(1X,/T5,15HY(I)+(0.5*X(I)),4X,9HY(I)+X(I),8X,4HY(I)/)
   96 FORMAT(1X,/I3,2X,D12.5,2X,D12.5,2X,D12.5)
      DO 42 I=1,IT
      WRITE(3,96)I,F1(I),FM(I),FY(I)
   42 CONTINUE
      DS(1)=0.D0
      DS(2)=0.D0
      DS(3)=0.D0
      DO 44 N=1,MTO
      QPOW1(N)=((F(1)*D(N))*(DEXP((F(2)*(X**F(3)))*((F(4)*(Z(N)**F(5))+F
     .(6)*(R(N,2)**F(7))+F(8)*(R(N,3)**F(9)))))))
   44 CONTINUE
```

```
      DO 46 N=1,MTO
      QS(1)=QS(1)+(C(N)-QPOW1(N))**(2)
   46 CONTINUE
      DO 1118 I=1,IT
      F(I)=0.D0
 1118 CONTINUE
      DO 47 I=1,IT
      F(I)=F1(I)
   47 CONTINUE
      DO 48 N=1,MTO
      QPOW2(N)=((F(1)*D(N))*(DEXP((F(2)*(X**F(3))))*((F(4)*(Z(N)**F(5))+F
     (6)*(R(N,2)**F(7))+F(8)*(R(N,3)**F(9)))))))
   48 CONTINUE
      DO 50 N=1,MTO
      QS(2)=QS(2)+(C(N)-QPOW2(N))**(2)
   50 CONTINUE
      DO 1119 I=1,IT
      F(I)=0.D0
 1119 CONTINUE
      DO 51 I=1,IT
      F(I)=FM(I)
   51 CONTINUE
      DO 52 N=1,MTO
      QPOW3(N)=((F(1)*D(N))*(DEXP((F(2)*(X**F(3))))*((F(4)*(Z(N)**F(5))+F
     (6)*(R(N,2)**F(7))+F(8)*(R(N,3)**F(9)))))))
   52 CONTINUE
      DO 53 N=1,MTO
      QS(3)=QS(3)+(C(N)-QPOW3(N))**(2)
   53 CONTINUE
      VMIN=0.D0
      VMIN=((QS(1)-QS(3))/((QS(3)+QS(1)-QS(2)*2.D0)*4.D0)+0.5D0)
      WRITE(3,978)
  978 FORMAT(1X,/T8,4HQ(0),T21,6HQ(1/2),T36,4HQ(1)/)
      WRITE(3,210)(QS(I),I=1,3)
  210 FORMAT(1X,3D12.5)
      WRITE(3,235)VMIN
  235 FORMAT(1X,/T4,'VMINIMUM = ',D12.5)
      DO 1120 I=1,IT
      F(I)=0.D0
 1120 CONTINUE
      DO 54 I=1,IT
      F(I)=FY(I)+T(I)*VMIN
   54 CONTINUE
      DO 55 I=1,IT
      WRITE(3,95)I,F(I)
   55 CONTINUE
   99 CONTINUE
  100 STOP
      END
```

```
      SUBROUTINE KRDS (MTO,AK,EE,ZZ)
      DOUBLE PRECISION AK(400), SIG(400),A2,ZZ(400),Z1,EE(400)
      INTEGER G,MTO
      DATA G/0/
      DO 18 I=1,MTO
      SIG(I)=0.D0
      ZZ(I)=(2.D0/15.D0)*EE(I)
   18 CONTINUE
      A2=0.D0
      M=0
      DO 4 I=1,MTO
      M=M+1
      IF((I.LE.27))A2=1.28D
      IF((I.GE.28).AND.(I.LE.53))A2=1.38D0
      IF((I.GE.54).AND.(I.LE.82))A2=1.54D0
      IF((I.GE.83).AND.(I.LE.109))A2=1.77D0
      IF((I.GE.110).AND.(I.LE.135))A2=2.30D0
      IF((I.GE.136).AND.(I.LE.166))A2=2.48D0
      IF((I.GE.167).AND.(I.LE.195))A2=2.41D0
      IF((I.GE.196).AND.(I.LE.225))A2=2.36D0
      IF((I.GE.226).AND.(I.LE.254))A2=1.73D
      IF((I.GE.255).AND.(I.LE.283))A2=1.38D0
      IF((I.GE.284).AND.(I.LE.313))A2=1.17D
      SIG(M)=A2
    4 CONTINUE
      M=0
      LL=0
      KK=0
      DO 110 I=1,MTO
      KK=KK+1
      M=M+1
      LL=LL+1
      AK(KK)=((0.105D0)*ZZ(LL)+((0.9875D0)*SIG(M)))*(4184.D0)
  110 CONTINUE
      RETURN
      END
```

```
          SUBROUTINE GAUSS(JT,IT,M10)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C THE PURPOSE OF THIS PROGRAM IS TO SOLVE UP TO 10 SIMULTANEOUS
C   EQUATIONS BY GAUSS-JORDAN METHOD.
C
C     N = THE NUMBER OF DECIMAL PLACES DESIRED.
C     JT = THE NUMBER OF COLUMNS , NO MORE THAN 10 ENTRIES PER CARD.
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
          DOUBLE PRECISION RR,T,A,BB,CC,DD
          REAL ZZ
          INTEGER M,JI,O,JT,IT
          COMMON L(10),K(10),A(10,10),BB(10,10),T(10),CC(10),DD(10
          DATA ZZ,O,RR/0.0,0,1.D-10/
          DO 111 I=1,JT
          K(I)=0
111       CONTINUE
C IT(I TOTAL) IS THE NUMBER OF ROWS.
C READ IN THE MATRIX BY COLUMNS, NO MORE THAN 10 ENTRIES PER CARD.
          M=0
          JI=0
C SET ROW INDEXES, L(I).
          DO 5 I=1,IT
 5        L(I)=I
          DO 66 J=1,IT
C THE SUBROUTINE FINDS THE PIVOT ROW FOR EACH COLUMN.
          CALL MAX(J,IT,M)
          K(J)=M
C THE PIVOT IS ZERO OR NEAR TO ZERO, THE METHOD IS INAPPLICABLE.
          IF(DABS(A(M,J)).LE.RR) GO TO 60
C REDUCE ROW M, THE PIVOT ROW, STARTING AT COLUMN J+1.
 7        JI=J+1
          DO 8 JP=JI,JT
 8        A(M,JP)=A(M,JP)/A(M,J)
C REDUCE OTHER ROWS, STARTING IN COLUMN JI.
          DO 66 IP=1,IT
C THE NEXT STEP SKIPS THE PIVOT ROW.
          IF(IP.EQ.M)GO TO 66
          DO 6 JP=JI,JT
          A(IP,JP)=A(IP,JP)-A(M,JP)*A(IP,J)
 6        CONTINUE
 66       CONTINUE
C STORAGE OF THE ANSWERS.
          DO 10 I=1,IT
          M=K(I)
 10       T(I)=A(M,JT)
C DISPLAY THE ANSWERS.
          M10=M10+1
          WRITE(3,103)M10
103       FORMAT(1X,///T4,'CYCLE ',I3)
          DO 51 I=1,IT
 51       WRITE(3,104)I,T(I)
104       FORMAT(1X,/T4,'X(',I2,' ) = ',D12.5)
```

APPENDIX - E

..........1.........2.........3.........4.........5.........6........

15341	10.1	26.50	25.1	86.12
7053	10.2	23.00	23.2	86.13
14620	10.3	30.25	23.0	86.15
13216	06.9	47.75	24.0	86.17
10312	05.6	55.50	22.1	86.18
9363	04.7	61.25	21.5	86.21
14744	09.9	59.00	22.7	86.23
15235	10.3	30.50	23.6	86.25
15004	10.1	27.00	23.5	86.27
11456	10.0	53.00	23.0	86.30
14433	10.1	47.00	24.0	86.32
14991	09.5	40.25	23.5	86.35
15280	10.0	47.00	23.5	86.38
13468	07.3	36.50	23.5	86.41
13810	09.8	41.00	25.0	86.54
13867	09.1	54.75	25.4	86.57
13526	09.2	56.75	24.5	86.62
10082	06.5	57.75	24.0	86.65
13840	08.5	53.75	26.3	86.72
9829	02.6	62.25	23.0	86.76
10098	04.5	60.75	24.0	86.80
11411	05.6	60.00	25.1	86.85
8712	02.9	60.60	22.5	86.89
12368	06.8	57.25	25.2	86.93
10956	05.8	57.75	25.5	86.98
11486	07.3	51.25	25.0	87.02
5216	02.7	74.00	21.2	87.07
7637	02.8	73.00	22.0	87.11
7989	03.0	74.00	22.6	87.16
10205	04.7	65.50	23.2	87.21
8379	05.0	64.25	22.6	87.26
12870	08.5	51.25	24.3	87.31
13485	08.5	45.70	24.0	87.35
13951	09.5	46.50	26.0	87.41
13638	07.5	50.00	25.5	87.46
11912	07.0	55.50	25.3	87.51
10087	04.6	58.25	23.6	87.57
13590	09.2	31.50	27.0	87.62
10938	07.5	46.50	26.5	87.67
10390	09.6	48.50	25.5	87.73
13285	08.4	51.00	25.0	87.78
11136	07.2	53.25	24.5	87.84
13733	09.8	49.25	26.3	87.90
13139	08.5	42.00	27.4	87.95
13350	08.3	50.50	25.0	88.04
10831	04.0	65.00	24.5	88.07
12445	08.0	49.50	24.5	88.18
11008	05.2	59.75	24.5	88.24
9674	09.4	50.75	25.0	88.30
13991	10.3	43.50	25.0	88.36
17339	10.5	24.75	27.0	88.42
11722	10.6	30.75	27.5	88.48
13717	09.0	48.75	26.5	88.60
16975	10.2	37.50	26.0	88.66
14710	08.4	[illegible]1.00	27.5	88.79

L COPRNT RELEASE   EXTENDED A SET   ARDPRNT

..........1..........2..........3...... ..4..........5..........6........

16358	09.2	[illegible]5.00	28.5	88.85
12005	08.4	34.00	28.7	88.91
14324	08.7	37.50	27.0	88.98
13816	07.1	43.75	27.2	89.04
13314	07.5	38.75	27.0	89.10
11664	04.5	48.00	27.5	89.16
14007	06.5	62.00	27.6	89.23
11637	05.4	47.00	25.8	89.29
10638	04.1	48.25	25.6	89.35
08637	01.8	67.00	24.0	89.42
06250	00.3	65.00	21.5	89.48
13204	05.2	52.25	26.0	89.55
07922	01.1	63.00	24.7	89.61
10638	04.0	54.00	24.5	89.67
09490	04.0	49.50	25.7	89.74
13096	09.5	58.50	26.4	89.80
16843	10.2	45.00	27.7	89.87
15352	09.0	36.00	28.5	89.93
11784	03.2	52.00	26.2	90.00
14612	03.2	58.00	22.4	90.06
09708	03.3	59.25	24.5	90.19
11801	06.8	63.00	24.3	90.25
10690	04.6	63.50	24.5	90.33
13798	06.2	49.25	25.6	90.38
11859	06.4	54.00	24.6	90.44
13245	08.8	46.50	26.5	90.51
13510	08.2	50.75	26.5	90.57
12651	06.9	51.25	27.0	90.64
12699	06.0	80.25	26.0	90.70
09104	02.6	55.75	21.3	90.76
14114	07.5	53.75	25.4	90.89
10554	04.8	49.25	25.1	90.95
11095	05.4	71.50	25.5	91.01
08131	02.4	50.50	21.6	91.08
16232	08.4	40.50	25.8	91.20
10867	03.4	65.00	24.5	91.26
15896	08.8	72.25	25.4	91.33
14472	09.8	51.00	24.8	91.39
16087	10.1	59.50	26.2	91.45
14818	09.3	60.25	27.0	91.51
11516	03.6	43.25	24.5	91.57
14984	06.2	65.75	25.1	91.69
17267	09.0	75.25	24.5	91.75
13250	04.6	45.25	24.5	91.81
10788	01.5	49.00	21.2	91.86
3563	00.1	53.25	18.5	91.92
11707	03.8	67.25	23.5	91.98
17764	09.9	53.50	25.3	92.04
14470	07.4	60.50	26.1	92.09
09085	01.7	65.50	22.8	92.15
11827	03.4	61.00	24.0	92.21
14250	06.1	54.00	25.2	92.26
18587	11.0	47.00	24.9	92.32
17817	10.0	66.25	26.1	92.37
16908	09.9	56.25	25.0	93.75

..........1.........2.........3.........4.........5.........6.........

13760	07.3	64.75	23.5	93.76
14111	08.6	46.00	25.0	93.79
16480	11.3	63.50	24.3	93.81
17841	11.2	50.00	25.6	93.82
13453	05.7	44.25	24.5	93.84
14341	08.3	46.00	26.2	93.86
16490	09.9	45.00	25.7	93.87
16015	09.2	39.00	27.0	93.89
13172	05.3	42.25	26.3	93.90
17614	10.9	35.75	27.2	93.91
13593	06.7	81.00	26.5	93.92
12119	06.4	64.00	23.5	93.93
09490	03.7	75.50	21.5	93.94
12819	05.5	72.22	22.3	93.94
10071	03.2	77.25	21.0	93.95
12432	06.0	57.50	23.5	93.95
10441	06.1	55.75	25.0	93.96
11666	04.7	62.50	23.0	93.96
11955	04.6	64.25	24.2	93.96
13393	06.1	55.25	23.3	93.95
12486	06.1	51.00	25.3	93.95
11730	04.7	63.25	24.2	93.94
07312	02.3	68.50	21.0	93.93
10611	05.3	69.50	21.1	93.94
06637	01.7	77.75	19.5	93.91
09307	07.5	72.00	20.0	93.92
13312	07.5	66.00	21.5	93.91
12302	06.8	68.00	23.8	93.89
14432	08.4	68.25	25.0	93.88
12624	07.1	61.75	23.8	93.87
15044	09.3	57.75	25.1	93.85
15003	09.1	60.00	25.2	93.83
10036	04.0	63.00	21.5	93.81
13081	06.9	62.75	23.0	93.80
13763	07.1	61.50	24.0	93.77
14486	09.3	49.00	25.2	93.75
14026	07.4	53.75	24.5	93.73
11031	06.1	63.00	24.0	93.70
16384	08.4	58.75	23.3	93.69
07556	03.2	64.00	23.5	93.65
09985	04.1	68.25	23.0	93.62
10881	03.5	65.50	23.8	93.60
08610	02.6	79.00	19.2	93.57
08091	03.6	75.66	21.6	93.53
10752	04.4	75.50	22.2	93.50
06844	02.7	71.50	21.0	93.47
08291	03.1	70.75	22.2	93.43
09736	03.4	68.25	22.5	93.40
09471	02.3	71.25	20.6	93.36
06033	02.5	74.00	21.9	93.32
07759	03.2	79.50	21.2	93.29
08347	03.5	70.00	21.2	93.[illegible]5
08696	02.5	71.25	21.0	93.[illegible]1
10046	05.5	7[illegible].50	21.8	93.17
09210	03.3	75.75	22.0	93.12

..........1.........2.........3.........4.........5.........6..........

09931	05.1	73.75	21.0	93.[illegible]8
05466	00.6	77.50	20.0	93.[illegible]4
08298	02.3	74.00	20.4	92.99
11060	05.6	71.00	23.3	92.95
09008	03.7	62.25	23.1	92.90
09629	02.8	58.75	22.9	92.85
09902	05.6	63.75	22.2	92.80
09224	03.4	73.50	22.0	92.76
09070	02.3	69.25	22.5	92.71
08946	04.4	73.75	20.2	92.66
13720	06.9	69.25	23.5	92.61
11095	04.8	67.75	23.0	92.55
05906	00.6	60.75	17.6	92.50
07638	00.6	82.75	18.6	92.45
05980	01.4	79.00	19.2	92.40
04049	00.1	89.25	17.5	92.34
01441	00.1	97.50	13.5	92.29
07282	00.7	74.75	19.0	92.23
06940	02.2	86.00	20.4	92.18
13269	01.1	80.50	19.6	92.12
08145	01.3	68.00	20.7	92.07
11760	05.1	69.25	22.9	91.84
02537	00.1	[illegible]4.00	16.8	91.78
06262	00.5	80.25	19.3	91.72
07163	02.3	74.75	19.5	91.66
11183	04.7	71.50	21.1	91.60
10326	05.4	76.25	21.5	91.54
10165	03.7	65.00	21.6	91.48
08985	02.3	76.75	21.0	91.42
05796	00.7	81.25	18.9	91.36
09248	03.5	74.00	20.5	91.29
06546	00.5	75.50	20.2	91.23
10857	04.4	71.50	20.7	91.17
12110	06.4	63.50	22.8	91.11
11098	08.8	57.75	23.8	91.05
08415	03.9	68.75	20.9	90.98
15414	08.9	61.50	23.9	90.92
13249	07.7	62.75	23.9	90.86
06995	02.2	78.75	20.4	90.79
06790	03.2	73.00	19.9	90.73
10520	03.8	77.25	22.0	90.67
13858	09.0	59.50	23.5	90.60
08292	02.8	70.50	20.5	90.54
12731	06.6	71.50	21.8	90.48
07705	01.4	71.75	19.7	90.41
08009	03.8	70.50	20.7	90.35
10420	05.2	76.50	21.1	90.28
05443	01.7	75.00	21.0	90.22
06604	01.5	75.75	19.5	90.16
08232	02.6	63.75	21.0	90.09
11640	04.5	48.50	22.7	90.03
14505	08.6	44.25	23.8	89.96
15954	10.0	61.00	23.6	89.90
11438	04.4	69.75	22.7	89.83
09888	04.8	54.50	22.4	89.77

L CDPRNT RELEASE   EXTENDED A SET   CARDPRNT 1

..........1..........2..........3..........4..........5..........6........

12494	05.1	71.00	20.5	89.71
07507	03.1	74.75	20.8	89.64
07949	01.3	62.25	22.3	89.58
11171	04.8	64.25	23.7	89.51
13388	05.8	74.50	19.6	89.54
08889	07.3	52.25	23.5	89.39
11978	05.9	57.00	22.5	89.32
10184	03.3	58.75	23.5	89.26
14134	07.2	46.75	23.3	89.20
11018	04.7	67.75	22.5	89.13
08194	03.9	75.25	22.5	89.07
12563	04.5	59.75	22.5	89.01
17570	10.6	30.75	22.9	88.88
17248	10.4	29.50	22.1	88.82
15710	08.6	40.00	23.0	88.76
15732	07.9	39.75	23.6	88.70
15746	09.3	41.00	24.3	88.63
12306	05.7	43.50	23.0	88.57
13945	06.2	50.50	23.5	88.51
11350	06.3	49.00	24.1	88.45
09036	03.5	74.75	20.7	88.39
07941	01.4	76.00	20.6	88.33
08447	01.8	75.50	20.2	88.27
13779	07.1	50.50	22.8	88.15
12852	07.8	47.75	22.3	88.10
12903	07.0	46.50	21.8	88.04
17375	10.8	41.50	23.3	87.98
16828	10.8	36.75	22.5	87.92
15130	10.3	43.00	23.4	87.87
15881	09.0	48.00	24.2	87.81
17598	10.8	41.50	23.5	87.76
17637	10.8	36.00	23.4	87.70
16882	10.8	40.00	23.4	87.65
17576	10.8	19.25	23.0	87.59
17070	10.8	34.00	22.9	87.54
17122	10.4	31.25	22.8	87.49
15264	10.1	42.25	23.0	87.44
11780	06.5	42.25	23.6	87.38
14475	10.2	41.00	24.7	87.33
15299	10.6	38.00	24.2	87.28
13722	07.9	47.75	24.0	87.23
11234	04.1	49.00	23.0	87.19
15572	10.6	44.50	24.0	87.14
15226	09.6	40.00	24.5	87.09
14865	10.6	44.25	24.6	87.04
15630	10.1	41.25	25.5	87.00
15579	10.1	41.75	25.1	86.95
14216	10.0	47.75	24.2	86.91
15167	08.9	45.50	25.1	86.87
13425	09.8	43.00	24.3	86.82
12562	07.0	50.00	23.2	86.78
13042	09.3	47.75	23.0	86.74
16203	10.8	38.25	23.2	86.70
16498	10.7	48.50	23.6	86.67
16018	10.9	40.00	23.0	86.63

L COPRNT RELEASE EXTENDED A SET CARDPRNT01

..........1.........2.........3.........4.........5.........6........

15051	10.6	31.00	24.4	86.59
16400	10.8	40.75	22.9	86.52
15949	10.6	32.50	22.8	86.49
15996	10.8	36.75	23.0	86.46
14777	08.9	37.00	23.0	86.42
15159	10.6	36.25	23.4	86.39
14294	10.3	41.25	23.8	86.37
15448	10.6	32.25	23.4	86.34
10304	10.9	38.25	22.6	86.31
15155	10.6	45.00	23.3	86.29
15556	10.3	46.25	23.5	86.26
15191	09.4	49.25	22.1	86.24
15188	10.1	47.75	22.0	86.22
15461	10.7	48.50	22.8	86.19
15237	10.5	41.75	23.6	86.18
15039	10.6	40.75	23.3	86.16
15364	10.6	33.25	22.9	86.14
14108	10.5	42.00	23.5	86.12
15900	10.8	30.25	23.7	86.11
15366	10.5	26.75	23.5	86.10
15128	10.7	24.25	23.5	86.08
14952	10.6	24.50	23.8	86.07
15150	10.0	22.25	22.7	86.06
15111	10.7	25.00	24.2	86.05
14453	10.7	22.50	24.5	86.05
14686	09.9	28.75	24.3	86.04
15099	10.6	36.00	23.3	86.04
13636	10.3	37.00	23.8	86.04
13598	08.8	37.75	24.5	86.03
10847	06.4	42.75	22.5	86.03
10302	05.4	57.75	22.6	86.03
05688	01.1	71.00	19.7	86.04
12282	08.0	53.00	22.9	86.05
09308	06.0	57.25	22.6	86.05
09457	04.5	63.75	21.9	86.06
09985	05.6	58.50	22.5	86.07
13952	09.9	42.25	23.8	86.08
13251	10.3	38.75	24.5	86.10

APPENDIX - F

MEASURED	SAYIGH S	NEW CONST
15341.000E 03	17921.070E 03	17623.120E 03
70530.000E 02	17937.260E 03	14570.700E 03
14620.000E 03	17960.140E 03	13609.400E 03
13216.000E 03	17179.660E 03	11272.260E 03
10312.000E 03	16679.200E 03	77223.870E 02
93630.000E 02	16679.660E 03	64138.470E 02
14744.000E 03	17867.810E 03	11109.790E 03
15235.000E 03	17973.390E 03	14650.580E 03
15004.000E 03	17928.080E 03	14446.070E 03
11456.000E 03	17900.830E 03	11907.730E 03
14433.000E 03	17932.400E 03	13932.270E 03
14991.000E 03	17793.280E 03	13066.450E 03
15280.000E 03	17912.450E 03	13030.600E 03
13468.000E 03	17296.540E 03	10874.610E 03
13810.000E 03	17889.820E 03	15941.020E 03
13867.000E 03	17728.770E 03	15037.700E 03
13526.000E 03	17752.770E 03	13472.420E 03
10082.000E 03	17134.770E 03	10487.610E 03
13840.000E 03	17610.380E 03	17142.000E 03
98290.000E 02	16284.150E 03	59886.100E 02
10098.000E 03	16704.330E 03	86633.140E 02
11411.000E 03	16957.150E 03	11025.480E 03
87120.000E 02	16358.160E 03	59245.320E 02
12368.000E 03	17235.090E 03	12452.610E 03
10956.000E 03	17016.210E 03	11882.670E 03
11486.000E 03	17357.390E 03	12956.170E 03
52160.000E 02	16323.300E 03	46264.280E 02
76370.000E 02	17003.180E 03	54390.050E 02
79880.000E 02	17055.660E 03	60237.440E 02
10205.000E 03	17449.600E 03	81921.220E 02
83790.000E 02	17520.240E 03	78635.710E 02
12870.000E 03	18360.110E 03	13455.800E 03
13485.000E 03	18364.450E 03	13314.440E 03
13951.000E 03	18622.580E 03	18468.110E 03
13638.000E 03	18140.990E 03	14619.440E 03
11912.000E 03	18027.630E 03	14260.620E 03
10087.000E 03	17463.620E 03	87900.360E 02
13590.000E 03	18576.340E 03	21440.190E 03
10938.000E 03	18166.800E 03	16916.940E 03
10390.000E 03	18675.780E 03	16872.000E 03
13285.000E 03	18386.060E 03	14599.950E 03
11136.000E 03	18101.780E 03	12537.940E 03
13733.000E 03	18745.650E 03	18787.200E 03
13139.000E 03	18438.770E 03	20305.630E 03
13350.000E 03	18387.790E 03	14558.190E 03
10831.000E 03	17376.820E 03	89795.930E 02
12445.000E 03	18327.100E 03	13509.440E 03
11008.000E 03	17669.700E 03	10376.260E 03
96740.000E 02	18681.490E 03	15597.990E 03
13991.000E 03	18910.910E 03	17006.500E 03
17338.990E 03	18979.520E 03	24252.910E 03
11722.000E 03	19011.200E 03	24824.990E 03
13717.000E 03	18620.580E 03	18358.140E 03
16974.990E 03	20070.420E 03	20862.610E 03
14710.000E 03	19618.500E 03	20826.910E 03
16358.000E 03	19838.670E 03	26556.820E 03
12005.000E 03	19638.260E 03	25979.710E 03
14324.000E 03	19715.230E 03	21456.510E 03
13816.000E 03	19310.800E 03	19064.110E 03
13314.000E 03	19418.500E 03	19683.280E 03

Cont'd

MEASURED	SAYIGH'S	NEW CONSTANTS
1[illegible]19.00[illegible] 02	[illegible]7.[illegible]	[illegible]
94[illegible]0.0[illegible]	23[illegible]1.2[illegible] 03	7[illegible].31[illegible]
12519.00[illegible] 02	[illegible]4[illegible].73[illegible]	[illegible]7[illegible]
1[illegible]071.[illegible] 03	23731.42[illegible]	[illegible]
12432.[illegible] 03	24[illegible]4[illegible].[illegible]	137[illegible]
1[illegible]441.000E 03	24[illegible].[illegible]E 03	1[illegible]7[illegible].[illegible] 03
11666.000E 03	24222.70[illegible]E 03	1122[illegible].03[illegible] 03
11955.000E 03	24193.33[illegible]E 03	1[illegible]7[illegible]7.0[illegible] 03
13393.000E 03	24674.75[illegible]E 03	13[illegible]2[illegible].02[illegible] 03
~~12486.00[illegible]E 03~~	~~24[illegible].30[illegible] 03~~	~~177[illegible].6[illegible] 03~~
11730.000E 03	24[illegible]25.[illegible]E 03	1[illegible]7[illegible] 03
73120.000E 02	23[illegible]5[illegible].[illegible] 03	[illegible].1[illegible] 02
10611.000E 03	24[illegible].1[illegible]E 03	9[illegible]37.44[illegible] 02
65370.000E 02	23[illegible]51.3[illegible]E 03	43[illegible]47.4[illegible] 02
93070.000E 02	2[illegible]42.7[illegible] 03	97[illegible]37.[illegible] 02
~~13312.000E 03~~	~~2[illegible]57.2[illegible]~~	~~[illegible]14.[illegible] 03~~
12302.000E 03	26132.290E 03	15230.490E 03
14432.000E 03	26694.560E 03	19754.140E 03
12624.000E 03	26234.620E 03	16009.24[illegible] 03
15044.000E 03	27011.760E 03	22040.11[illegible] 03
15003.000E 03	26939.100E 03	2183[illegible].91[illegible] 03
~~10036.000E 03~~	~~25164.320E 03~~	~~9[illegible].50[illegible] 02~~
13081.000E 03	26152.300E 03	14220.49[illegible] 03
13763.000E 03	26226.360E 03	16417.30[illegible] 03
14456.000E 03	27[illegible]04.270E 03	23166.50[illegible] 03
14026.000E 03	26331.040E 03	18414.68[illegible] 03
11031.000E 03	25877.130E 03	15093.24[illegible] 03
~~15384.000E 03~~	~~26664.320E 03~~	~~16651.77[illegible] 03~~
75560.000E 02	24901.340E 03	10471.95[illegible] 03
99850.000E 02	25190.690E 03	10799.49[illegible] 03
10881.000E 03	24997.33[illegible]E 03	11229.5[illegible] 03
86100.000E 02	24659.500E 03	51724.12[illegible] 02
80910.000E 02	25005.100E 03	82909.3[illegible] 02
~~10752.000E 03~~	~~25271.350E 03~~	~~93132.45[illegible]~~
68440.000E 02	24701.260E 03	6831[illegible].49[illegible] 02
82910.000E 02	24837.370E 03	5542[illegible].33[illegible] 02
97360.000E 02	24935.900E 03	95[illegible]4.29[illegible] 02
94710.000E 02	24558.240E 03	61203.420E 02
60330.000E 02	24629.900E 03	74288.890E 02
~~77590.000E 02~~	~~24847.340E 03~~	~~73704.66[illegible] 02~~
83470.000E 02	24943.730E 03	79[illegible]38.25[illegible]E 02
86960.000E 02	24612.660E 03	66586.790E 02
10046.000E 03	25605.100E 03	10543.840E 03
92100.000E 02	24872.030E 03	83993.720E 02
99310.000E 02	25494.330E 03	90446.610E 02
~~54660.000E 02~~	~~23539.040E 03~~	~~34559.690E 02~~
82980.000E 02	24[illegible]70.150E 03	57329.62[illegible]E 02
11060.000E 03	25157.14[illegible]E 03	125[illegible].82[illegible] 03
90030.000E 02	24532.54[illegible]E 03	1[illegible]461.[illegible] 03
95290.000E 02	24[illegible]3.[illegible]5[illegible] 03	917[illegible].7[illegible] 02
99020.000E 02	25[illegible]35.[illegible] 03	11[illegible]2.44[illegible] 03
~~92240.000E 02~~	~~24412.3[illegible] 03~~	~~[illegible].47[illegible] 03~~
90700.000E 02	24[illegible]62.52[illegible]E 03	7731[illegible] 02
89450.000E 02	24710.35[illegible]E 03	742[illegible].31[illegible] 02
13720.000E 03	25559.040E 03	14425.9[illegible] 03
11095.000E 03	24654.7[illegible]E 03	1[illegible]1.7[illegible] 03
59060.000E 02	23465.[illegible]1[illegible]E 03	242[illegible]1.[illegible]
~~7[illegible]380.000E 02~~	~~23471.[illegible] 03~~	~~27[illegible].57[illegible]~~
53800.000E 02	25721.79[illegible]E [illegible]	4[illegible]32.[illegible]
40490.000E 02	23294.3[illegible] [illegible]2	1[illegible].6[illegible]
14410.000E 02	23227.31[illegible]E [illegible]	[illegible]3[illegible].44[illegible]

Measured Cont'd	SAYIGH's	NEW CONSTANTS
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
11557.[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
35370.000E 02	[illegible]	[illegible]
57500.000E 02	[illegible]	27742.37[illegible]
13204.000E 03	16677.070E 03	13673.9[illegible] 03
77220.000E 02	17?55.730E 03	60139.23[illegible] 02
10638.000E 03	[illegible]	[illegible] 03
94900.000E 02	[illegible]	11831.[illegible] 03
13096.000E 03	[illegible]	10127.38[illegible] 03
15842.990E 03	[illegible]	24?52.24[illegible] 03
15352.000E 03	[illegible]	[illegible] 03
11784.000E 03	16430.35[illegible] 03	[illegible] 03
14612.000E 03	[illegible]	69120.61[illegible] 02
~~97080.000E 02~~	~~[illegible]~~	~~[illegible]~~
11801.000E 03	19536.250E 03	12251.100E 03
10690.000E 03	18794.050E 03	10336.970E 03
13798.000E 03	19716.530E 03	16768.170E 03
11859.000E 03	19256.140E 03	12794.360E 03
13245.000E 03	19890.130E 03	19524.130E 03
~~13510.000E 03~~	~~19739.230E 03~~	~~18514.43[illegible]~~
12651.000E 03	20994.560E 03	19319.65[illegible] 03
12699.000E 03	20744.750E 03	14326.16[illegible] 03
91040.000E 02	19821.140E 03	60237.96[illegible] 02
14114.000E 03	21176.980E 03	16597.03[illegible] 03
10554.000E 03	20444.110E 03	13059.60[illegible] 03
~~11095.000E 03~~	~~20610.22[illegible] 03~~	~~13241.[illegible]~~
31310.000E 02	19601.340E 03	62151.[illegible] 02
16232.000E 03	21464.130E 03	19706.620E 03
10867.000E 03	20094.960E 03	97380.180E 02
15896.000E 03	21582.720E 03	16841.55[illegible] 03
14472.000E 03	21874.210E 03	18139.63[illegible] 03
~~16087.000E 03~~	~~21972.560E 03~~	~~21004.[illegible] 03~~
14818.000E 03	21752.300E 03	21925.97[illegible] 03
11516.000E 03	20180.240E 03	10794.6[illegible] 03
14984.000E 03	20892.270E 03	13661.68[illegible] 03
17266.990E 03	21676.180E 03	15175.950E 03
13250.000E 03	20469.330E 03	12185.100E 03
~~19788.000E 03~~	~~19430.380E 03~~	~~49958.[illegible] 02~~
35630.000E 02	19262.900E 03	16835.870E 02
11707.000E 03	20262.240E 03	90013.480E 02
17764.000E 03	21971.120E 03	19211.740E 03
14470.000E 03	21269.280E 03	17480.5[illegible] 03
90850.000E 02	19722.690E 03	59987.470E 02
~~11827.000E 03~~	~~20181.200E 03~~	~~93497.[illegible] 02~~
14250.000E 03	20922.110E 03	14634.53[illegible] 03
18586.990E 03	22316.5[illegible] 03	20074.43[illegible] 03
17816.990E 03	22?35.5[illegible] 03	[illegible] 03
16904.000E 03	[illegible]	21621.1[illegible] 03
13700.000E 03	25047.7[illegible]	147[illegible] 03
~~14111.000E 03~~	~~[illegible]~~	~~[illegible]~~
16480.000E 03	[illegible]	[illegible]
17840.990E 03	26567.510E 03	[illegible] 03
13453.000E 03	24545.33[illegible] 03	[illegible] 03
14341.000E 03	25410.11[illegible] 03	25561.73[illegible] 03
15490.000E 03	25947.[illegible]	14752.[illegible] 03
~~15015.000E 03~~	~~[illegible]~~	~~21454.4[illegible]~~
13172.000E 03	24433.55[illegible] 03	19364.7[illegible] 03
17614.000E 03	[illegible]	[illegible]
13593.000E 03	[illegible]	[illegible]

Cont'd

MEASURED	SAYIGH'S	NEW CONSTANTS
77820.000E 02	[illegible] 03	[illegible] 02
63400.000E 02	[illegible] 03	[illegible] 02
13269.000E 03	[illegible] 03	[illegible] 02
31450.000E 02	[illegible] 03	[illegible] 02
11760.000E 03	[illegible] 03	11474.[illegible] 03
25370.000E 02	23255.7[illegible]E 03	13724.59[illegible] 02
62620.000E 02	[illegible] 03	29385.08[illegible] 02
71630.000E 02	23939.78[illegible] 03	51771.300E 02
11183.000E 03	24716.37[illegible]E 03	[illegible]741.470E 02
10326.000E 03	24941.[illegible] 03	96039.510E 02
10155.000E 03	[illegible]7.3[illegible] 03	95013.48[illegible] 02
89850.000E 02	23931.34[illegible]E 03	[illegible].730E 02
57960.000E 02	23403.14[illegible]E 03	20401.150E 02
92480.000E 02	23967.42[illegible]E 03	68415.93[illegible] 02
65460.000E 02	23033.25[illegible]E 03	33267.620E 02
10557.000E 03	24243.23[illegible]E 03	78559.4[illegible] 02
12110.000E 03	24901.540E 03	12749.650E 03
11098.000E 03	25701.520E 03	17494.180E 03
84150.000E 02	24069.[illegible]60E 03	77070.230E 02
15414.000E 03	25722.270E 03	17541.630E 03
13249.000E 03	25313.240E 03	16130.160E 03
59950.000E 02	23514.[illegible]00E 03	54575.[illegible] 02
67900.000E 02	23815.950E 03	60762.870E 02
10520.000E 03	24016.260E 03	25135.830E 02
13858.000E 03	25721.570E 03	16916.660E 03
82920.000E 02	23679.540E 03	62310.870E 02
12731.000E 03	24896.740E 03	11032.78[illegible] 03
77050.000E 02	23228.930E 03	43079.35[illegible] 02
80090.000E 02	23976.520E 03	73520.340E 02
10420.000E 03	24417.470E 03	87764.360E 02
54430.000E 02	23314.740E 03	54704.900E 02
66040.000E 02	23234.300E 03	42288.490E 02
82320.000E 02	23581.470E 03	66691.470E 02
11640.000E 03	24188.100E 03	11254.690E 03
14505.000E 03	25528.420E 03	16281.040E 03
15954.000E 03	25986.560E 03	16716.190E 03
11438.000E 03	24133.680E 03	10194.950E 03
98880.000E 02	24255.540E 03	10861.560E 03
12494.000E 03	24326.830E 03	81699.180E 02
75070.000E 02	23691.730E 03	66952.510E 02
79490.000E 02	23146.560E 03	61190.800E 02
11171.000E 03	24238.560E 03	12269.980E 03
13388.000E 03	24526.000E 03	75937.790E 02
88890.000E 02	20668.220E 03	12813.440E 03
11978.000E 03	20297.760E 03	99253.140E 02
10184.000E 03	19616.330E 03	85254.770E 02
14134.000E 03	20642.260E 03	12714.010E 03
11018.000E 03	19960.380E 03	85091.300E 02
81940.000E 02	19745.550E 03	75953.120E 02
12563.000E 03	19[illegible].320E 03	85979.640E 02
17576.000E 03	21553.[illegible]90E 03	16262.620E 03
17248.000E 03	21455.39[illegible]E 03	14558.320E 03
15710.000E 03	21[illegible]36.14[illegible]E 03	14075.99[illegible] 03
15732.000E 03	20785.72[illegible]E 03	143[illegible].55[illegible] 03
15746.000E 03	21169.23[illegible] 03	16[illegible]4[illegible].77[illegible] 03
12306.000E 03	20178.02[illegible]E 03	11[illegible].77[illegible] 03
13945.000E 03	20[illegible]5.91[illegible] 03	11021.430E 03
11350.000E 03	2[illegible].42[illegible] 03	12[illegible].97[illegible] 03
99360.000E 02	19[illegible]7.[illegible]9[illegible]E 03	57199.970E 02
79410.000E 02	19[illegible]23.51[illegible]E 03	39744.270E 02
34470.000E 02	19121.43[illegible] 03	40758.590E 02

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MEASURED	SAYIGH'S	NEW CONSTANTS
13779.000E 03	20569.310E 03	11592.840 03
12352.000E 03	20699.770E 03	1157[illegible] 02
12903.000E 03	20465.570E 03	10312.500E 03
17374.990E 03	21517.700E 03	16225.920E 03
16828.000E 03	21507.360E 03	15[illegible]42.95[illegible] 03
15130.000E 03	21365.970E 03	15556.650E 03
15881.000E 03	21002.020E 03	15822.620E 03
17598.000E 03	21490.380E 03	16616.750E 03
17636.990E 03	21490.780E 03	16895.710E 03
16382.000E 03	21434.300E 03	16530.800E 03
17576.000E 03	21481.540E 03	17966.960E 03
17070.000E 03	18942.270E 03	14151.660E 03
17122.000E 03	18837.950E 03	13394.330E 03
15264.000E 03	18757.790E 03	13180.750E 03
11780.000E 03	17868.860E 03	11188.420E 03
14475.000E 03	18780.350E 03	16429.350E 03
15299.000E 03	18872.210E 03	16057.290E 03
13722.000E 03	18207.170E 03	12663.800E 03
11234.000E 03	17311.920E 03	80367.960E 02
15572.000E 03	18855.710E 03	15144.040E 03
15226.000E 03	18607.940E 03	15554.910E 03
14865.000E 03	18848.560E 03	16301.100E 03
15630.000E 03	18725.870E 03	17918.510E 03
15579.000E 03	18718.860E 03	17038.800E 03
14216.000E 03	18684.860E 03	14758.190E 03
15167.000E 03	18417.550E 03	15570.760E 03
13425.000E 03	18628.050E 03	15104.350E 03
12562.000E 03	17944.940E 03	10623.510E 03
13042.000E 03	18490.510E 03	12201.870E 03
16203.000E 03	18857.060E 03	14284.680E 03
16498.000E 03	18829.650E 03	14185.640E 03
16018.000E 03	18873.220E 03	13871.910E 03
15051.000E 03	18804.100E 03	17062.930E 03
16400.000E 03	18836.480E 03	13554.400E 03
15949.000E 03	18785.020E 03	13866.990E 03
15996.000E 03	18831.650E 03	14027.480E 03
14777.000E 03	18363.500E 03	12550.590E 03
15159.000E 03	18777.010E 03	14462.720E 03
14294.000E 03	18702.700E 03	14711.480E 03
15448.000E 03	18773.090E 03	14958.250E 03
10304.000E 03	17318.980E 03	12217.610E 03
15155.000E 03	17251.340E 03	12679.900E 03
15556.000E 03	17181.260E 03	12706.790E 03
15191.000E 03	16969.710E 03	99701.710E 02
15188.000E 03	17124.080E 03	10321.500E 03
15461.000E 03	17260.700E 03	11770.630E 03
15237.000E 03	17219.470E 03	13293.530E 03
15039.000E 03	17238.750E 03	12942.800E 03
15364.000E 03	17235.980E 03	12827.560E 03
14108.000E 03	17212.320E 03	13108.740E 03
15900.000E 03	17282.350E 03	14594.500E 03
15366.000E 03	17213.520E 03	14317.330E 03
15128.000E 03	17257.420E 03	14724.920E 03
14952.000E 03	17235.140E 03	15159.810E 03
15150.000E 03	17093.890E 03	13001.920E 03
15111.000E 03	17257.520E 03	15959.720E 03
14453.000E 03	17259.490E 03	16853.420E 03
14686.000E 03	17075.790E 03	15066.930E 03
15099.000E 03	17227.310E 03	13267.530E 03
13636.000E 03	17161.320E 03	13306.460E 03
13598.000E 03	16629.100E 03	13706.040E 03

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