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Parametric Characterization of Natural Variability Factors In Assessment of Solar Radiation Intensity

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Abstract:

The advancement in human needs, what we call the development, is deeply suffering from the basic concept of existence and identity in form of "sustainability. The natural solar radiation, natural solar energy forms and the artificial green energy is the only solution for sustainable development. The fundamental source of this ultimate type of energy required is the Sun. In this communication, an attempt has been made to parameterize the natural variability factors in solar radiation due to changes in earth-sun relative positions and orientations even for the same place and the given surface. The solar radiation assessment challenges are classified as: regular annual cycle variation factors, regular daily cycle variation factors, place variation factors, surface variation factors and the natural atmospheric attenuation factor.

Key Words: Solar Intensity, Annual Cycle, Daily Cycle, Atmospheric Attenuation.

1. Introduction:

It is the ***Motion*** which signifies life: breathing, heart-beat, growth and death of flora and fauna, flow of rivers, changes in topography of hills, mountains and changes in man-made structures of any kind. As per my hypothesis everything is live irrespective of being biological or inanimate, because they have their own vibrational frequencies and are always in state of working for their existence and identity after their creation/construction as a unit. Every entity and their various aspects of all the activities are always in motion at least the ***spin motion*** which is the basic law of nature. Hence, every entity of this universe has its own life, life-style and purpose of being. This is similar to being at some temperature, every entity emits the thermal radiation. Being as an entity, they emit their own *"**vibes**"* having a broad-band of *"**reasons and visions**"*. Under the natural order and development, all the entities of this universe are always in *"**quasi- static equilibrium**"* with their environment under the dynamism of various phenomena and processes and so is the case with sun, earth and life on earth as animal life, plant life and eco-system life. Man is the ultimate creation of nature to demonstrate the ability to: coexist with individuals' identity, sustain with development, develop with togetherness and together with synergistic gain provided there is no lust. This is possible only when man will understand the basic law of nature as: change is the permanent event hence to follow the pace and phase and sustainability with co-existence of diversity in altogether because the whole universe is integrated but with gradients. This is not only possible but definitely possible with the follow-up of use of ***clean energy*** and **green energy** with clean mind, of which the basic source is the sun in form of providing us the solar radiation round the clock unconditionally. The basic ***challenges!!*** are: how to estimate the available solar radiation at a place, at a time and designing the technology accordingly to use it with the optimum efficacy within the limitations of its intermittences!!

2. Solar Radiation Spectrum:

The sun is a sphere of hot gaseous and plasma state of matter with the average diameter of $1.39\text{x}10^9$m and the average distance from earth of $1.50\text{x}10^{11}$m. As observed from the earth with respect to earth, the sun rotates about its own axis once in every month where equatorial plane takes about 27 days and polar region takes about 30 days. For the radiation received on earth's surface sun acts as an effective black body of temperature of about 6000K.

2.1 Extra-terrestrial Solar Spectrum: The outer space beyond the earth's atmosphere is termed as extra-terrestrial region of earth's surface. In this region, the spectral distribution of solar radiation corresponds to the energy output of a black body at a temperature of about 6000K. The spectral distribution observed is significant in three basic regions: ***U.V. region (0.25 μm - 0.38 μm which is around 9% of the total energy), visible region (0.38 μm - 0.78 μm and around 40% of the total energy) and I.R. region (0.78 μm - 3.5 mm and around 51% of the total energy).*** In this spectral distribution the peak intensity is about 2074 Wm^{-2} which corresponds to 0.48μm wavelength falling in the green portion of the visible region. Since the peak falls in the green region that's why we can say that the incoming solar energy itself is optimally green and gives hint to go green as the ultimate path [1,2,3].

2.2. Terrestrial solar spectrum: Extending from earth's surface to the outer limit of earth's atmosphere is termed as terrestrial region. From the device in use point of view, it is further classified as: ***sky- region*** and ***ambiance*** of the device. In the terrestrial region, it is the earth's atmosphere, in form of its compositions and variable constituents as impurities, obstructs the extra-terrestrial region radiation to reach completely on the earth's surface. The three basic processes are responsible for this attenuation named: atmospheric reflection, atmospheric scattering and atmospheric absorption. Out of these, the reflection and absorption reduce the intensity while the scattering spreads the scattered radiation in the atmospheric dome. The scattering is primarily due to aerosols, dust particles, water droplets, greenhouse gases and natural air- molecules. The absorption in various spectral regions is primarily due to: Ozone, Oxygen, Nitrogen, Carbon monoxide, Carbon dioxide, Methane and Water vapour. The x-rays and the extreme U.V radiations are absorbed highly in the ionosphere mainly by Nitrogen and Oxygen and other atmospheric gases. The water vaper absorbs the extreme I.R. radiations while U.V. radiations are absorbed by ozone. There is almost complete absorption of short-wave radiations ($\lambda < 0.28$ μm) in the atmosphere and long wavelength radiations ($\lambda > 2.3$ μm). So, ***the***

solar radiation received on the earth's surface consists of the spectral-band as 0.128 μm - 2.34 m in which the U.V. region contains the energy fraction of nearly 6.4%, visible region. Contains nearly 48·0%, and the I.R. region contains the remaining 45.6%. [1,2,3]. The question is: is earth only receives from the sun? The answer is no. It radiates also. Since the average earth's surface temperature is about 288K hence it radiates in long wavelength region only while from the sun it receives the short- wave radiations. This is shown in Figure-1[2, 6].

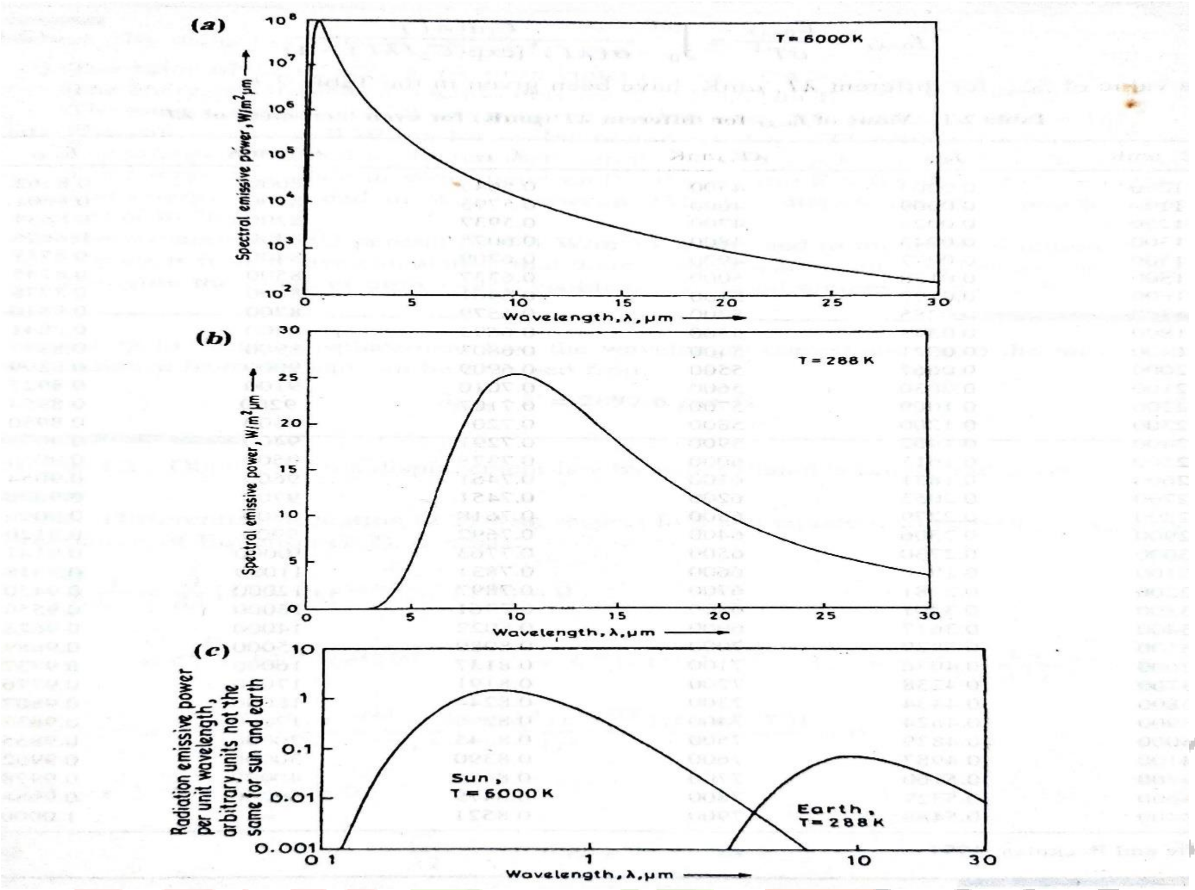

Figure 1: Effect of temperature of a blackbody on its emissive power **(a)** T = 6000K (Sun), **(b)** T = 288K (Earth) and **(c)** comparison [2, 6]

3. Importance of Solar Radiation Assessment as a Basic Resource:

The basic resource of all the solar energy systems is the sun: directly or indirectly. Because of this, a thorough knowledge of the quantity of solar energy available at the ground level is of prime importance. Although, the available total insolation just outside the earth's atmosphere is relatively constant [(1367 ± 3.4%) Wm^{-2}], the local climatological influences and changes in it, causes a wide range of variations in available insolation on the earth's surface from site to site. In addition, the relative motion of the sun with respect to a place on the earth's surface governs the variability to intercept different quantities of solar insolation depending on the orientation of the receiving surface and its tracking ability to the sun's direction. So, at a site the rigorous assessment of available solar insolation at the ground level is important due to the following reasons:

[1]. In real terms, all the energy forms consumed by humans have come from the sun. Coal, oil and natural gas are the residues of plants and animals which originally derived all its energy for their growth and progress from the solar insolation received by the earth.

[2]. The solar insolation, provided by the sum, also drives the earth's hydrological-cycle of rain which is used to operate the modern hydroelectric generators. The differential heating of earth's atmosphere causes a large- scale atmospheric circulations appearing in form of winds that have powered the wind mills from many decades.

[3]. The most significant ingredient of all the renewable energy sources is the solar radiation. The accurate measurement of Direct Normal Irradiance (called the Beam Radiation) is essential in many disciplines such as atmospheric-sciences, climate change studies, meteorology, air-quality predictions, solar cell technology development. The radiation data obtained can be used directly, for instance, to evaluate the solar resource at a specific site and indirectly, for instance, to monitor trends in atmospheric turbidity and pollution in it over a long period of time.

[4]. The majority of solar applications belongs to indirect solar energy use as: conversion in heat and its storage. With the increased interest in solar energy conversion, the need for quantitative data has assumed prime importance. Besides, because of the variability behaviour of solar radiation, both on diurnal and seasonal scale, the accurate estimation of the solar radiation as a resource becomes very essential for its effective utilization which is unlike the systems based on use of other energy forms where the input energy is available at constant rate.

[5]. Under clear skies, the ***precipitable-water*** and ***aerosol-turbidity*** in many *forms (Linke Turbidity coefficient, Angstrom Turbidity coefficient, Schürff Turbidity coefficient, Rayleigh turbidity coefficient and Monteith Turbidity coefficient)* are the two most important atmospheric variables affecting the direct solar irradiance available at a site on the earth's surface. The measured data with great accuracy empowers to have better models of either kind: ***correlations-based*** or ***classical equation-based*** or both to regenerate the solar radiation data during missing period to complete the unbroken series, needed to design and access the performance of a: green building, solar distilla- -tion and greenhouse technology, solar crop drying, solar pond, solar water heating system, solar cooker, etc.

3.1 Response of Solar Enthusiasts: The earth and its atmosphere receive continuously around 10^{17} W of solar insolation from the sun. Say, the world population of about 20 billion with a total pawer needed per person of 10 kW would require about $2\text{x}10^{11}$ kW energy. It is thus apparent that if the irradiance available on the earth's surface, say, has only 2% of collection possibility with only 10% of conversion-efficiency of the device in use, the available energy per person will be given by:

$$\mathbf{E = [10^{17} \bullet (2/100)] \bullet [10/100] \div [1/ (20 \bullet 10^{9})]\ Wm^{-2} = 10\ kW\ per\ person.}$$

That is, the solar energy alone could provide the energy needs of all the people on earth with the population up to 20 billion (which is nearly only 8 billion in 2023) [4]. So, this looks enthusiastically that every problem of energy sector is addressed much before the peak demand occurs. But reality is not free from limitations. It has many inherent challenges.

3.2 Limitations of the Available solar Energy on Earth's surface:

Unlike above calculation, unfortunately the nature of this solar insolation has two-fold problems**:** ***technological problems*** and ***economic limitations*** which are not apparent from the above macroscopic view of the total energy budget. The principal limitations of the available solar energy budget and its utilization are as follows:

[1]. First of all, it is of ***small flux density***: which requires the large surface area to collect the sufficient energy for large scale applications. Further, the need of larger surface area which to be acquired, will be more expensive and this will make the delivered energy cost ineffective.

[2]. Secondly, even it is available in plenty in remote areas due to their topography, due to lack of basic infrastructure: first of all, it is very tough to reach with the solar energy devices which requires some available means of transportation to supply and secondly, the available trained manpower to maintain the devices and provide the necessary services at the need of the hour.

[3]. Thirdly, as input energy, it is not steady as desired. It is intermittent due to natural motions and local climatological variations categorised under:

- Annual cycle variation
- Daily cycle variation.
- Place variation.
- Surface variation.
- Variable atmospheric attenuation

4. Parameterization of Natural Challenges in Estimation of Solar Radiation reaching on Earth's surface:

4.1 Challenges of Regular Annual Cycle:

❖ **Elliptical Orbit Parameter:** This parameter corresponds to the variation of earth-sun mean distance(1AU) of about ±1.7% due to elliptical orbit of the earth around the sun. This parameter is characterised in terms of the ***"n^th^ day of the year"*** starting n = 1 on January 1^{st} and n = 365 on December 31^{st}. From various measurements it was estimated that just outside the earth's atmosphere, at the earth-sun mean distance, the received solar insolation intensity, normal to a surface directly from the sun, is $1367 Wm^{-2}$. This is a constant and known as Solar Constant $\mathbf{I_{sc}}$**.** But, due to the orbit being elliptical rather than circular, the variation in solar insolation is about ±3.4% which is due to the variation of ±1.7% in earth-sun mean distance ($1AU = 1.496 \times 10^{11}$ m). Thus, the regular annual cycle challenge in form of elliptical orbit is characterised by finding the limits of variation in solar insolation intensity $\mathbf{I_{on}}$ just outside the earth's atmosphere normal to a surface comes out to be:

$$\mathbf{I_{on}} \text{ (max.)} = 1413 Wm^{-2}$$

$$\mathbf{I_{on}} \text{ (min.)} = 1220\ Wm^{-2}$$

Taking these limiting values in to account the elliptical orbit parameter is characterised in terms of the ***"day of the year"***. In general, for any **n^{th} day** of a year, starting from n = 1 on January 1^{st}, the solar insolation normal to a surface just outside earth's atmosphere is given by,

$$\mathbf{I_{on}} = \mathbf{I_{sc}} \bullet [1 + 0.033 \bullet \cos(360 \bullet n / 365], \text{ where, } \mathbf{I_{sc}} = 1367 Wm^{-2}$$

- **Equatorial Plane Inclination Parameter:** The axis about which the earth is spinning is not exactly perpendicular to its orbital plane. It is inclined by 23.45^0 but it is fixed during the formation of our solar system itself. Because of this inclination, the equatorial plane of earth and the orbital plane around the sun are also inclined. Irrespectively, in this challenge the advantage is that, this inclination is always constant round the annual cycle of earth's motion about the sun. Because of this inclination, for a given place the angle made by the direct sun-rays incident (they are always in the equatorial plane) on earth surface with respect to the equatorial plane of earth changes with the nth day of the year. This equatorial plane inclination parameter which varies only with the day of the year is characterised in terms of **"declination angle δ"** and it is given by:

$$\boldsymbol{\delta} = \pm [23.45^0 \bullet \sin [\ 360 \bullet (n + 284) \bullet 365] \text{ Degree}$$

where +ve sign for places being in Northern Hemisphere and -ve sign for Southern Hemisphere. Further,

δmin = 0°, [Mar. 21, Sept. 24] and **δmax** = ± 23.45^0 , [June 22, Dec.22]

This is shown in Figure-2 **[3],** where it is clearly understood in terms of the angle between the line joining the centres of earth and sun and the earth's equatorial plane.

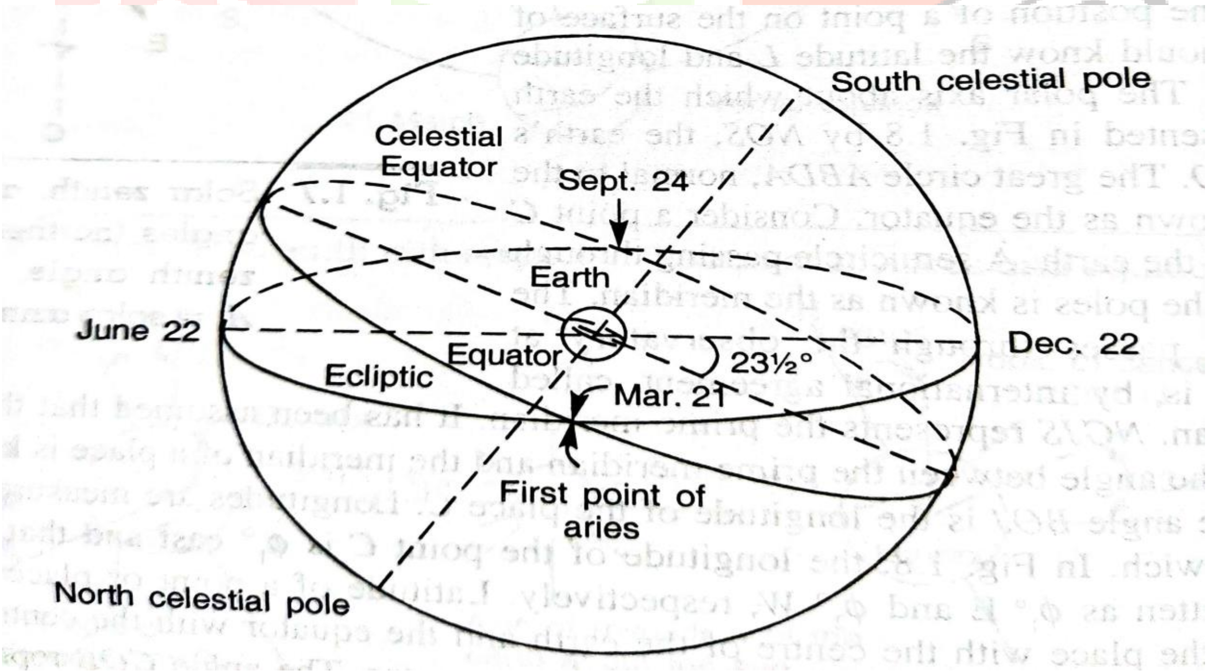

Figure-2: The variation of declination angle **[3]**

- **Eccentricity variation Parameter:** The local time defined for a place, due to the elliptical orbit of the earth, does not perfectly match in terms of position of the sun in the sky every day. For example, if an observer on earth facing the equator sets a clock (running at a uniform rate) at 12.00 Noon when the sun is directly overhead to the local meridian, then after a month or so at 12:00 Noon clock time, the sun does not appear exactly overhead to that the local meridian. This discrepancy is overcome by formulating the term ***"Eccentricity correction "***, which implies reducing the real elliptical path and nonuniform orbital angular speed of earth into an effective circular path and uniform orbital angular speed, and this eccentricity variation parameter is characterised in terms of **"Equation of Time EOT".** This correction makes the terrestrial motion of the earth at a uniform rate, following Spencer, J.M. 17 (1971) [5]. It is given by the expression,

$$\textbf{EOT}\text{ (minute)} = 229.2 \cdot [0.00075 + 0.001868 \cdot \cos B - 0.032077 \cdot \sin B - 0.014615 \cos 2B - 0.040890 \sin 2B]$$

where, $B = [360^0 \cdot [n - 1] / 365]$, known as ***"day angle".***

The physical significance of **EOT** is that regarding time its consideration makes the earth's effective orbit circular and its motion in it at unform rate. If **EOT** comes out to be +ve implies that the sun's motion is fast and -ve implies that it is slow with respect to the local standard clock-time of a place.

4.2 Challenges of Regular Daily Cycle:

- **Longitude Correction Parameter:** Along with the day of the year, declination angle and EOT in terms of day angle, the solar insolation intensity further depends on the longitude and latitude of the place. For a given latitude (ϕ), the longitudes are spreaded up to 360^0. For every longitude, the sun rises in east and sets in west. The 1^0 longitude corresponds to 4 minutes. The local clocks are synchronised with the Standard Longitude identified with respect to the Greenwich Mean Time. This is known as Standard Meridian **(L_{std})** and in general any considered place is known as Local Meridian **(L_{loc})**. The **L_{std}** signifies that the sun is exactly overhead at this meridian at clock time of 12.00 Noon (neglecting the EOT correction). This is the **Solar Noon** and maximum solar insolation intensity available to be received by the place. But at this time some **L_{loc}** lies either east of **L_{std}** or west of **L_{std}.** Since the solar insolation intensity has meaning only with the sun's position i.e. **Solar Time** not the clock time hence longitude correction comes into picture. At 12.00 Noon in a clock is defined as the time when sum is exactly overhead (is due south in northern hemisphere or due north in southern hemisphere) i.e. equator facing at the standard meridian of the time zone / country. But a place of observing solar insolation may be east or west of standard meridian, so the clock-time does not serve the purpose to identify the position of sun in the sky. To overcome this challenge the concept of **"Solar Time"** is defined which says that ***"Solar Time is a 24-hour clock with 12.00 solar noon as that exact time at which the sun is exactly overhead at the local meridian"***. This becomes capable to predict exactly the direction of sun's rays relative to a place on earth's surface. The expression of solar time is obtained by using the longitude correction and the eccentricity correction in terms of EOT. It is expressed as, Solar Time = [Standard clock-time] + [Longitude Correction]

+ [Eccentricity correction]

where,

Longitude Correction = 4 • [$L_{std} – L_{loc}$] (in minutes) in case of West of GMT.

= 4 • [$L_{loc} – L_{std}$] (in minutes) in case of East of GMT.

Eccentricity correction = EOT

Since the earth spins from west to east, the sun seems to be moving east to west relative to a place on earth. Depending on the n^{th} day of the year EOT attains its +ve and -ve values decided by the day angle but longitude correction sign is decided by the relative longitudes of local and standard meridians being in East of GMT or West of GMT.

- **Hour Angle Parameter:** Due to the rotation of the sun with respect to the earth, for a local meridian the sun has its angular position being at a time either solar forenoon, solar noon or solar afternoon. This parameter gives the angle in degree by which the local meridian should be rotated, east or west, to bring it to the sun being at overhead where rotation takes place at 15^0 per hour. Since the rotation rate is 15° for hour so to account the angular displacement of the sun at a time east or west of the local meridian, the concept of hour angle ω is formulated as,

$$\text{Hour Angle } (\omega) = [\text{Solar Time (in hours)} – 12] \cdot 15^0$$

where w = 0 at solar noon hour, -ve in the forenoon hours and +ve in afternoon hours. This angle lies in the horizontal plane and by knowing this one can estimate that after how many hours the solar noon will occur or it has already occurred.

4.3 Challenges of Surface Characterisation:

- **Zenith and Altitude Angle Parameters:** The ultimate is the surface which receives the solar insolation intensity. At any place a given surface is characterised in terms of tilt with respect to horizontal and orientation east or west with respect to equator facing (i.e. with respect to south in northern hemisphere and north in southern hemisphere). At any place the vertical line is fixed and it always passes through the centre of the earth. At the same time horizontal is parallel to the tangential plane of the earth's surface. The **Zenith Angle (θ_z)** is defined as the angle made by sun's incident ray and normal to the horizontal surface. It varies as $0^0 \leq \theta_z \leq 90^0$. This angle lies in the vertical plane. On the same line in other words the **Altitude Angle (α)** is defined as the angle made by the direct incident sun's ray with respect to the horizontal. This is also in the vertical plane. They are always related as: $\boldsymbol{\theta_z + \alpha = 90^0}$ as shown in Figure- 3 **[6].**

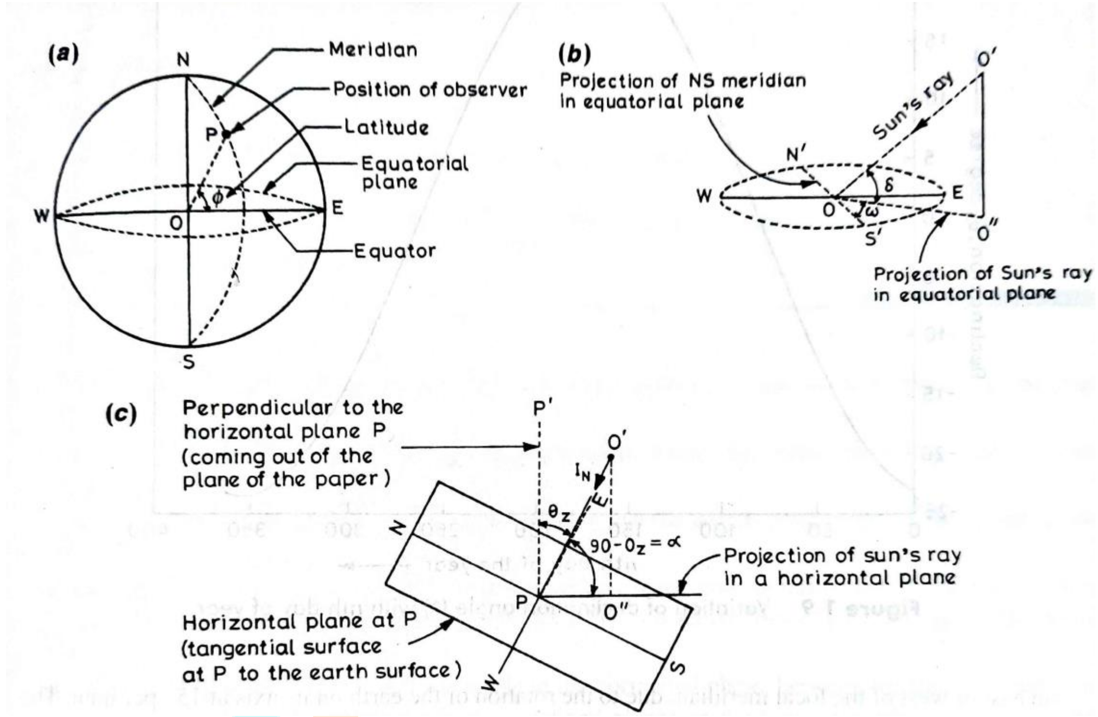

Figure-3: View of various characterised angles. **[6]**

- **Surface Azimuth Angle Parameter:** In northern-hemisphere the reference is due south while in southern-hemisphere it is due north. In general, it is termed as equator facing. This angle is in the horizontal plane. At a place, the **Surface Azimuth Angle (γ)** is defined as the angle in horizontal plane between line due equator (south or north as the case may be depending on the hemisphere) and the projection of the normal of the considered surface in the horizontal plane. This has meaning only for a tilted surface. It gives the orientation of the normal of the tilted surface in horizontal plane to adjust the surface to collect the maximum solar insolation intensity in case of sun tracking surfaces. It varies as: $-180^0 \leq \gamma \leq +180^0$ taken as equator facing as the reference line used in definition. For equator facing $\gamma = 0^0$ i.e. south facing in northern-hemisphere and north facing in southern hemisphere, while $\pm 180^0$ means opposite to the equator facing i.e. north facing in northern-hemisphere and south facing in southern hemisphere.
- **Solar Azimuth angle Parameter:** In northern-hemisphere the reference is due south while in southern-hemisphere it is due north. In general, it is termed as equator facing. This angle is also in the horizontal plane. At a place, the **Solar Azimuth Angle (γ_s)** is defined as the angle in horizontal plane between line due equator (south or north as the case may be depending on the hemisphere) and the projection of direct sun's rays.
- **Surface Tilt Angle Parameter:** The reference surface is the horizontal plane surface having no tilt and no orientation. The **Surface Tilt Angle (β)** is in the vertical plane and has meaning only for sun facing side of the surface. It is defined as the angle made in vertical plane by the sun facing surface with respect to horizontal at the place. For horizontal sun facing surface $\beta = 0^0$ and for vertical surface i.e. a wall $\beta = 90^0$. It is given as: $0^0 \leq \beta \leq 90^0$. At a given tilt angle to track the sum, the surface is rotated east to west through south in northern hemisphere and through north in the southern

hemisphere. If β is > 90^0 then considered sun facing surface starts facing the ground and the solar insolation intensity calculated will be nothing but the only reflected insolation by the ground and its conditionings. It may or may not come out to be zero.

- **Solar Beam Direction Parameter:** The crux of the solar insolation intensity estimation problem is that at a given time, for a given meridian, on a considered surface: at what angle the direct beam radiation falls on the surface? This is characterised in terms of solar beam direction parameter and termed as **"Angle of Incidence (θ_i)"**. It is defined as the angle between the normal of the surface and the incident direct beam radiation. For a horizontal surface $\boldsymbol{\theta_i} = \boldsymbol{\theta_z}$. In terms of the parameters characterising the various variability factors defined in terms of the angles **δ, ω, ϕ, γ,** and **β,** the θi is formulated as:

$$\cos\theta_i = [\cos\phi\cos\beta + \sin\phi\sin\beta\cos\gamma]\bullet[\cos\delta.\cos\omega] + [\cos\delta\sin\omega\sin\beta\sin\gamma] + \{\sin\delta\bullet[\sin\phi\cos\beta - \cos\phi\sin\beta\cos\gamma]\}.$$

where, **ω** and **γ**: are +ve for west and -ve for east with respect of south in northern-hemisphere and with respect of north in southern-hemisphere.

In general, we can express **θ_i, δ** and **ω** as:

$$\theta_i = f(\delta, \omega, \phi, \gamma, \beta)$$

$$\delta = f(n^{th}\text{ day of the year})$$

$$\omega = f(\textbf{Solar Time})$$

- **Daylight Hours Parameter:** The daylight hours parameter is used to characterise the total number of sunshine-hours on a particular day. It is defined as the number of hours **(N)** between the sunrise and the sunset on a particular day. Consider a horizontal surface at a place **(L_{loc}, ϕ),** then we have: $\boldsymbol{\theta_i} = \boldsymbol{\theta_z}$, $\boldsymbol{\beta} = 0^0$ and $\boldsymbol{\gamma} = 0^0$.

Now, since sunrise will be at $\boldsymbol{\theta_z} = -90°$ and sunset will be at $\boldsymbol{\theta_z} = +90°$, therefore, the total sunshine-hour angle is given by,

$$\Delta\omega = 2 \bullet \cos[-\tan\phi\tan\delta]\text{ degrees}$$

Since, 15° ≡ 1 hour duration, therefore the total number of sunshine-hours or daylight **(N)** is given by,

$$N = [2/15]\bullet\cos^{-1}[-\tan\phi\tan\delta]\text{ hours}$$

4.4 Challenges of Atmospheric Attenuation:

Around the earth, the earth's natural atmosphere can be assumed symmetrical in terms of its effective physical existence because of the uniform spinning of the earth about is axis of rotation. This natural atmosphere attenuates the incident solar radiation in terms of path-length traversed by the direct solar beam in the atmosphere before reaching to the surface considered to receive it at a given time of the day.

Ideally, the maximum path-length is traversed is at sunrise and sunset hours i.e. $\boldsymbol{\theta_z} = 90^0$ and minimum at the solar zenith hour i.e. $\boldsymbol{\theta_z} = 0^0$. This attenuation due to path-length in the natural atmosphere is characterised in terms of **"air-mass (m)"** which is a numerical value. But the ultimate challenge is the characterisation of attenuation due to various natural constituents and the dynamically variable contents of the actual atmosphere in which the solar device has to be installed to perform.

- **Homogeneous spherical Atmospheric attenuation Parameter:** This attenuation is characterised in terms of the parameter **"air-mass (m)"** of the atmosphere and it is a number. It is defined as:

*air-mass (**m**) = [The actual path-length traversed by the direct solar beam] ÷*

[The vertical path-length of the atmosphere at the soar zenith

By many scientists and profound researchers, it is observed that for R= 6370 km, the radius of the earth and h = 7991km, the extent of the spherical earth's atmosphere for the range of zenith angle: -70° < $\boldsymbol{\theta_z}$ < +70° around the solar zenith, the air-mass is expressed as:

$$\mathbf{m} = [\ 1 / \cos \boldsymbol{\theta_z}\ ]$$

The value of m = 0.00 for surface being outside the earth's atmosphere. The m = 1.00 when the sun is at its zenith. Similarly, m = 2.92 for $\boldsymbol{\theta_z} = 70^0$. Hence, on the earth's surface air-mass varies as: $1.00 \leq m \leq 2.91$.

- **Atmospheric Constituents and Contents Attenuation Parameters:** It is this challenge which is not only dynamic but spread all over the globe in varieties of ways with different capacity. This is so because it involves the varieties of physical processes due to the pure constituents of the natural atmosphere as atmospherical gases and the additional contents in it in form of: *water vapour, water droplets of variable size and density, clouds, aerosols, dust particles, green-house gases and other industrial pollutants* in the atmosphere. Their concentration and extent both are dependent on natural as well as human industrial and local activities. These challenges are attempted to study under the phenomena of: *reflection, scattering and absorption*. These are complex to formulate because of being spectral in nature on one hand and daily variability due to natural and human activities and various internal known and unknown chemical and physical processes. The multiple-reflections within the atmosphere gives rise to the concept of **"Diffuse Radiation"** which is received by the surface along with the beam radiation directly reaching to the surface termed as **"Direct Beam Radiation".** Taking care of reflection. scattering and absorption due to the real atmosphere, for India climatic conditions; for clear days the standard atmosphere is considered under the conditions of 15 mm of precipitable water, 2.5mm of ozone and 300 dust particles per cubic at 760mm of Hg pressure. For the considered surface, the solar radiation can reach through the reflection from the surrounding surfaces also. Hence, in general, the total solar radiation received by a given surface consists of direct beam radiation from the sun, diffuse radiation from the atmospheric dome and the reflected radiations from the surrounding structures and the ground, ie

***Total Solar Radiation** on a surface = [**Direct Beam Radiation** from the sun] + **Diffuse Radiation** from the hemi-spherical atmospheric dome of the sky] + [**Reflected Radiations** from the surrounding structures and the ground]*

5. Symbols:

m:	air-mass
n:	n^{th} day of the year starting from n=1 on January 1^{st}
B:	Day angle
E:	Energy required
N:	Daylight hours
I_{sc}:	Solar Constant
I_{on}:	Solar Beam Radiation Intensity just outside atmosphere normal to the surface
δ:	Declination angle
ω:	Hour angle
α:	Solar altitude angle
β:	Surface tilt angle
ϕ:	Latitude of the place
γ:	Surface azimuth angle
γ_s:	Solar azimuth angle
θ_z:	Solar zenith angle
θ_i:	Solar beam radiation incident angle on the surface
L_{std}:	Standard meridian (longitude angle) of the zone/country
L_{loc}:	Local meridian (longitude angle) of the place
IR:	Infra-Red
UV:	Ultra-Violet
EOT:	Equation Of Time

6. Conclusions:

❖ The tilt of earth's equatorial plane with respect to its orbital plane around the sun causes the daily variation in solar radiation received and it is parameterized in terms of an angle known as **"Declination Angle (δ)".**

❖ The continuous spinning of earth about its own tilted axis changes the position of sun at every moment with respect to the place of receiving the solar radiation and it is parameterized in terms of an angle known as **"Hour Angle (ω)".**

❖ The local meridians of the place and its angular position with respect to the equatorial plane, receiving the solar radiation, are parameterized in terms of **"Longitude Angle (L_{loc}) and Latitude Angle (Φ)".** This is fixed for a place.

- The variability of sun's position even for the same place with the clock-time is due to the elliptic nature of the earth's path. This is parameterized in terms of **"Solar Time"** which includes the longitude-correction and eccentricity- correction in local clock time.
- The **longitude-correction** is due to the differences in the local meridian of the place and the standard meridian prescribed for that place.
- The **Eccentricity-correction** is due to the non-uniform angular speed of the earth in its elliptical path. Its incorporation in the solar time expression makes the effective path circular in which the effective speed becomes uniform and **Solar Time Clock** becomes a 24-hour uniform clock.
- The surface designed to receive the solar radiation is parameterized in terms of the angles known as **"Surface Tilt Angle (β)** and the **"Surface Azimuth Angle (γ).** These angles are fixed for a given surface.
- The path traversed by the solar beam radiation at a time of the day, in earth's atmosphere is parameterized in terms of **"Air-mass (m)".** It is required to estimate of the attenuation in the solar beam radiation due to the thickness of the atmosphere at a time. The variation comes out to be exponential in nature.
- The reflection, scattering and absorption of incident solar radiation by the real atmosphere are parameterized in terms of **Reflection Coefficients, Scattering Coefficients, Turbidity Coefficients and Absorption Coefficients** by many researchers and based on their findings different models are proposed to estimate the hourly average, the daily average, the monthly average and the annual average of solar radiation intensity available on a given surface at a given place under different classified climate conditions of the globe.

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