THE EFFECT OF LATITUDE, SEASON, TIME OF DAY AND ASPECT ON DIRECT SOLAR RADIATION

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ABSTRAK

Dalam mempelajari faktor yang menentukan besarnya radiasi gelombang pendek langsung yang menimpa permukaan bumi, sebuah eksperimen sederhana dilakukan dengan menggunakan alat "solarscope". Paramater yang diukur adalah altitude matahari (h), azimut (A), panjang hari dan waktu di mana radiasi langsung mencapai suatu sisi dari bukit. Pengukuran diambil pada musim panas dan musim dingin di Equator, Brisbane, Cairns dan Melbourne (Australia). Data yang didapat dari pengukuran kemudian dibandingkan dengan nilai yang didapat dari perhitungan. Walaupun nilai-nilai azimut dan altitude yang didapat dari perhitungan sedikit lebih tinggi dari nilai pengukuran, namun perbedaan itu tidak nyata. Ini menggambarkan kemampuan alat "solarscope" dalam mengukur parameter-parameter tersebut. Hasil pengukuran untuk panjang hari tidak berbeda jauh dengan hasil yang tercatat di "Smithsonian Table". Pengaruh musim dingin dan musim panas terhadap parameter-parameter yang diukur dan pengaruh arah dan kemiringan permukaan tanah terhadap intensitas dan panjang hari dibahas dalam hubungannya dengan energi yang dapat ditangkap suatu daerah untuk kepentingan pertanian.

ABSTRACT

In order to gain an understanding of the importance of factors determining direct shortwave radiation reaching the earth's surface, a simple experiment was done using a solarscope. Measurement was taken for Equator, Brisbane, Cairns and Melbourne (Australia). Parameters measured are solar altitude (h), azimuth (A), length of day and time of day when direct solar radiation falling on the slope of a hill for summer and winter soltice. All measured data were then compared to the value obtained from calculation. Although the calculated values for azimuth and solar altitude are slightly higher than the measured values, they were not significantly different, which indicated the validity of the solarscope in measuring these parameters. The measured values for length of day were no much different from the values in the Smithsonian Tables. The effect of summer and winter on the parameters measured and the effect of direction and slope of the land surface on intensity and daily duration of insolation are discussed in relation to their importance on determining the load of energy for agricultural purposes.

INTRODUCTION

Virtually all the energy received by the earth is supplied by the sun. This energy is used for the processes of photosynthesis, heating of the soil (conduction), heating of the air (convection) and evaporation. The amount of solar radiation reaching the earth's surface depends upon a number of factors. These include the intensity of radiation emitted by the sun, latitude of the horizontal and the azimuth of the normal to the surface and the transparency of the atmosphere. These have important consequances on the growth of plant corresponding to the heat load upon them and the amount of plant corresponding to the heat load upon them and the amount of water they need.

By using a solarscope a simple experiment was done in order to gain some quantitative and qualitative appreciation of the importance of the various factor determining the direct shortwave radiation reaching the earth's surface.

METHODS

A solarscope was used in this experiment. Time of year, time of day and latitude can be altered by controlling three different knob on the equipment. By altering these parameters, solar altitude, azimuth and daylenght can be measured.

There were three diffferent works being done in this experimental wowrk, which will be described briefly below:

1. Measuring the solar altitude (h) and azimuth (A) for Brisbane (Latitude 27.5°S) at 9 am, 10 am, 11 am and 12 noon, for the dates of Feb 22, Oct 21 and Dec 22 by using a spike of known height on the solarscopoe. The length and directions of shadow of the spike is recorded with the equation below, A and h can be calculated.

$$\text{tg } h = \frac{\text{height of spike}}{\text{length of shadow}}$$

A was measured from the directions of the shadow, eastward from north. Also, by using equations below, calculation was done to find azimuth and latitude and the two values (calculated and measured) were compared.

$$\sin h = \cos L \cos \delta \cos t + \sin L \sin \delta$$
$$\sin A = - \sin t \cos \delta / \cos h$$

where:

h = solar altitude
A = solar azimutH
L = latitude
δ = declination of suN
t = hour angle, calculated from midday (N), positive toward the afternoon, and 1 hour corresponds to 15°.

2. Determining the length of day (in hours) at Cairns (Latitude 16°55'S) and Melbourne (Latitude 37°49'S) for summer and winter soltice, and compare the result to the value recorded in The Smithsonian Table.

3. Determining hours of direct solar radiation falling on the slope of a cone (inclination 60° to the horizontal) for Brisbane, equator and Melbourne for the summer and winter soltice. And by using the equation :

$$Is = Io (\cos h \sin c \cos (A-b) + \sin h \cos c)$$

Where:

Is = direct beam solar irradiance falling a slope
Io = direct beam solar irradiance falling on a surface normal to the solar beam.
h = altitude of the sun
c = inclination of slope to the horizontal (negative if underside of slope).
A = azimuth of sun
b = azimuth of the normal to the slope; the value for north = 0, S = 180, SE = ± 135, NE = ± 45, SW = ± 135, NW = ± 45, E = ± 90 and W = ± 90. Before noon NE, E and SE have positive sign, while NW, SW and SW have negative sign. In the after noon the sign reversed.

RESULT AND DISCUSSION

The soltice occurs twice annualy, that is when the sun's path is displaced farthest north or south from the earth's equator. In the southern hemisphere the summer soltice occurs about December 22 and the winter soltice occurs about June 22.

The solar declination (δ) is its angular distance north (+) or south (-) of the plane of the earth's equator. The total range, -23.5° to 23.5°, is relatively large and its effects on solar radiation are profound, especially at higher latitudes.

The azimuthal angle is the angle between true north and the projection of the sun's rays onto the horizontal. The maximum solar altitude occurs only at solar noon when the azimuthal angle is 180° (true south). These maximum solar altitude occurs only when the solar declination is in perfect correspondence with the latitude of the side, that is, when = -23.5°, the solar altitude is 90° at latitude 23.5°S (Tropic of cancer). This can never occur north of the Tropic of cançer or south of the Tropic of capricorn. That is the reason why the solar altitude for Brisbane never reach 90°, because it's latitude is 27.5°S. Hence solar declination is not in perfect correspondence with the latitude. Places which have solar altitude 90° are places within the band 23.5°N and 23.5°S.

Table 1 shows the solar altitude and azimuth for Brisbane. Calculated and measured values do not significantly differ, but the calculated values are slightly higher. It proves the validity of the solarscope in measuring the azimuth and the altitute of the sun. Azimuthal angle decreses as the solar altitude increases and it is zero at 12 am. Solar altitude increases toward the noon. Azimuthal angle before 12 am and solar altitude on December 22 is relatively higher than it is on Feb 22 and Oct 21. These values are calculated as follows:

Table 1. Calculated and measured values of solar altitude and azimuth for different time of the year and different time of day for Brisbane (Latitude 27.5o).

Date	Time of Day	Azimuth		Solar Attitude	
		Calculated Value	Measured Value	Calculated Value	Measured Value
February 22	9	77	76	44.47	42.84
	10	64.72	62	57.06	53.31
	11	42.5	42	67.87	64.8
	12	0	0	72.96	71.57
October 21	9	77	75	44.47	45.57
	10	64.72	60	57.06	56.31
	11	42.5	38	67.86	65.73
	12	0	0	72.96	71.57
December 22	9	85.14	94	49.38	48.58
	10	87.58	86.5	62.67	61.23
	11	76.4	73	75.86	74.65
	12	0	0	85.89	78.91

Brisbane: Feb 22, 9 am

a. Measured value

$tg\ h = 51/55$
$h = 42.84$

b. Calculated value

$\sin h = \cos L \cos \delta \cos t + \sin L \sin \delta$
$= \cos(-27.5) \cos(-10o27') \cos(-45) + \sin(-27.5) \sin (-10o27')$
$= (0.887)(0.9834)(0.7071) + (-0.4617)(-0.1814)$
$h = 44.47$

$\sin A = - \sin t \cos \delta / \cos h = - \sin(-45) \cos(-10o27') / \cos (44.47$
$= (0.7071)(0.9834) / 0.7136$
$= 77$

Solar altitude is higher on Dec 22 (summer soltice) than on Feb 22 or Oct 21, because at summer soltice the sun declination is closer to the latitude of Brisbane.

Table 2. Time of sunrise and sunset and length of day for different time of the year for Cairns (Latitude 16o55'S) and Melbourne (Latitude 37o49'S).

Place	Time of Year	The Time of Sunrise am	The Time of Sunset pm	Day Length	
				Measured	Smithsonian
Cairns	Winter	6.3	5.24	10 h 54 m	11 h 14 m
	Summer	5.2	6.30	13 h 10 m	13 h 01 m
Melbourne	Winter	4.45	4.45	9 h 30 m	9 h 25 m
	Summer	7.20	7.20	14 h 45 m	15 h 01 m

Table 2 shows the time of day for sunrise and sunset, hence daylength can be measured, for Cairns and Melbourne for the summer and winter soltice. Sunrise in winter is later than in the summer and the difference is more obvious at higher latitude such as Melbourne compared to Cairns. Cairns, which lies at a lower latitude than Melbourne, does not differ much in daylength between winter and summer compared to Melbourne (Table 2). The measured values are not much different from the values in "The Smithsonian Tables" (List, 1971).

According to Rosenberg (1974) the maximum monthly radiation reception is experienced at the higher latitudes, although total annual receipts is lower, due to the result of cosine law" and daylength factors. So, in a poleward direction the progressively shorter growing season and weaker light are more than compensated by the increasing length of day in summer.

Table 3 shows the daylength when direct solar radiation fall on eight sides of a cone with inclination 60° to horizontal for Brisbane, Melbourne and Equator for winter and summer soltice. The direction of the cone sides (slopes) caused marked variations in daily duration of insolation, especially at higher latitude. For Brisbane and Melbourne, in winter, the slope facing south will not received any direct radiation, since they have zero daylength. While in summer all slope will received direct radiation (Table 3). Slope facing north has the longest daylength for both Melbourne and Brisbane in the winter (Table 4). At the equator, all slopes will received direct radiation all the year Around. At the southern hemisphere's, summer soltice, slope facing south will get the longest daylength and slope facing north the shortest. At the winter soltice, a slope facing north has a longer daylength than a slope facing south.

Table 3. Daylength when direct solar radiation fall on eight major compass directions of the sides of a cone (inclination of side 60° to horizontal) at Brisbane, Melbourne and Equator for summer (Dec 22) and winter (June 22) soltice.

Place	Time of Year	Sides of Cone							
		N	NE	E	SE	S	SW	W	NW
Brisbane	Summer	9	8	7	9	11	8	8	8
	Winter	9	7	5	3	0	4	5	7
Melbourne	Summer	9	7	7	9	14	8	8	9
	Winter	8	6	4	4	0	4	5	7
Equator	Summer	3	6	6	8	11	8	7	6
	Winter	8	7	5	5	7	6	7	8

Table 4. The intensity of solar radiation falling on eight different slopes for Brisbane on October 21 (Wm-2).

Time	Slope							
	N	NE	E	SE	S	SW	W	NW
6 am	86.3	353.5	425.3	259.6	0	0	0	0
7	140.97	558.7	715.5	519.6	85.65	0	0	0
8	296.12	697.7	846.9	629.2	172.32	0	0	0
10	527.60	733.6	718.6	491.7	185.70	0	0	221.6
12	704.10	632.6	403.7	287.3	218.80	287.3	459.9	632.6
2 pm	571.70	240.1	0	0	201.20	532.8	778.6	794.7
4	237.10	0	0	0	151.80	554.4	746.1	614.7
5	99.0	0	0	0	60.12	364.8	502.4	392.3
Daily Average	332.90	402	388.7	273.4	134.10	217.4	310.9	332.0

Table 4 shows the intensity of solar radiation falling on eight different slopes at Brisbane on October 21. All the values are calculated from the equation below.

Data for Io (direct solar radiation measured on a surface normal to the sun's rays) for Brisbane are calculated from Spenser (1971) and given in Table 5.

Table 5. Irradiance measured on a surface normal to the sun's ray (Io), solar altitude and azimuth for Brisbane for Oct 21.

Time of Day	Io (Wm-2)	A	H
6 am	476	80.70	4.8
7	732	87.37	18.03
8	849	85.58	31.33
10	850	64.72	57.06
12	962	0	72.96
2 pm	921	64.72	57.06
4	748	85.58	31.33
5	514	87.37	18.03

Example of the calculation is given below:
For 6 am, N slope

$$\begin{aligned} Is &= Io (\cos h \sin c \cos (A-b) + \sin h \cos c) \\ &= 476 (\cos 4.8 \sin 60 \cos (80.7-0) + \sin 4.8 \cos 60 \\ &= 86.3 \end{aligned}$$

It is found that on Oct 21, the slope facing south and southwest received the lowest intensity of light and slopes facing N and NE get the highest.

In winter when the sun declination is ± 23.5°, direct sunlight on steep south-facing slope may be completely unavailable at noon, as indicated by Table 4 and 8 where the daylength of south slope is zero. Even in summer, the slope facing south (in high latitude) will get smaller intensity of radiation compared to north facing slope (Table 4). On such slope, plants must rely heavily on sky light or diffuse sky radiation. In high latitudes the diffuse radiation is a very important source of solar radiation and contribute 30-40% of total radiation. The diffuse contribution is greatest during the winter months and when the solar angle is low. Due to lower intensity of light received by it, the south facing slope may have lower temperature, hence lower rate of evaporation and as a result the plant community will be different from that on the north facing slope. By knowing the amount of light intensity and duration of insolation at a site, the potensial of that site for agriculture can be evaluated, because the load of light energy on crop determines the growth and development of the crop, hence its yield (assuming other factors are not limited).

CONCLUSION

The calculated values for azimuth and solar altitude are slightly higher than the measured values, but they were not significantly different. Indicating the validity of the solarscope to measure these parameters.

A site at a lower latitude does not have much different daylength between winter and summer.

The direction of the cone sides (slopes) caused marked variation in daily duration of insolation, which increases with latitude.

REFERENCES

List, R.J. (1971). Smithsonian meteorological Tables. Smithsonian Institution Press. Washington.

Spencer, J.W. (1971). Solar position and radiation tables for Brisbane (Latitude 27.5oS). C.S.I.R.O. Div. Bldg. Res. Rech. Pap. No. 28.

Rosenberg, N.J. (1974). Microclimate: The biological environmental. John Wiley and Sons. New York.