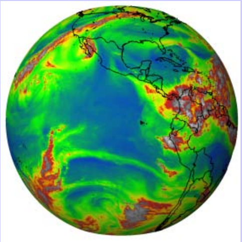
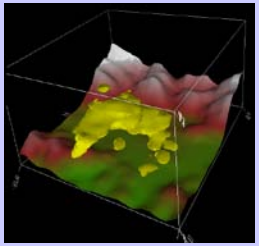
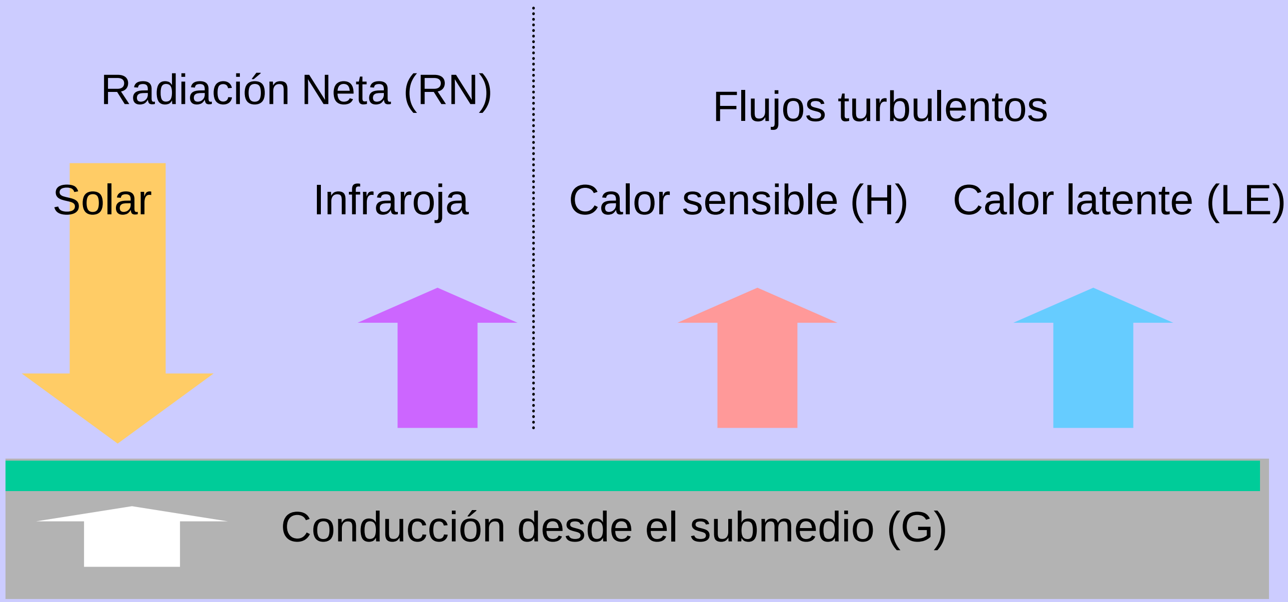
    

Universidad de Chile
Departamento de Geofísica

Balance de Energía Superficial: Radiación Solar

Prof. René Garreaud
www.dgf.uchile.cl/rene

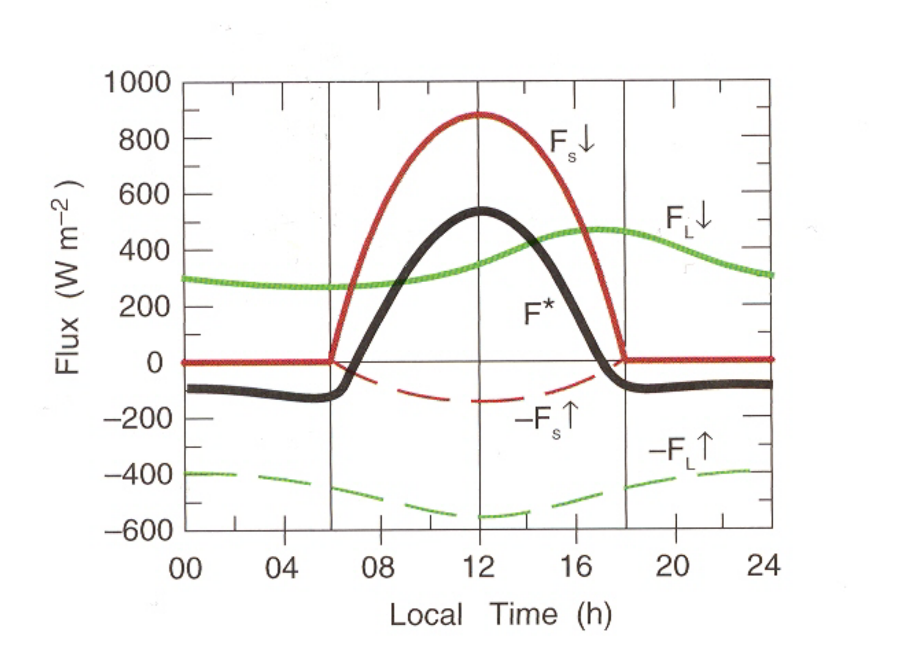
Balance de Energía Superficial

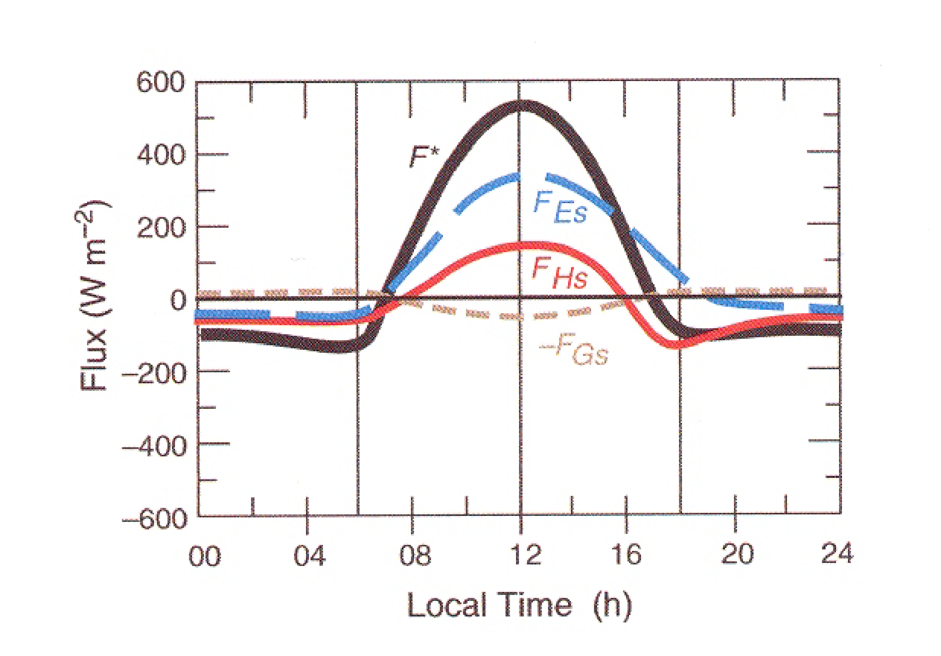


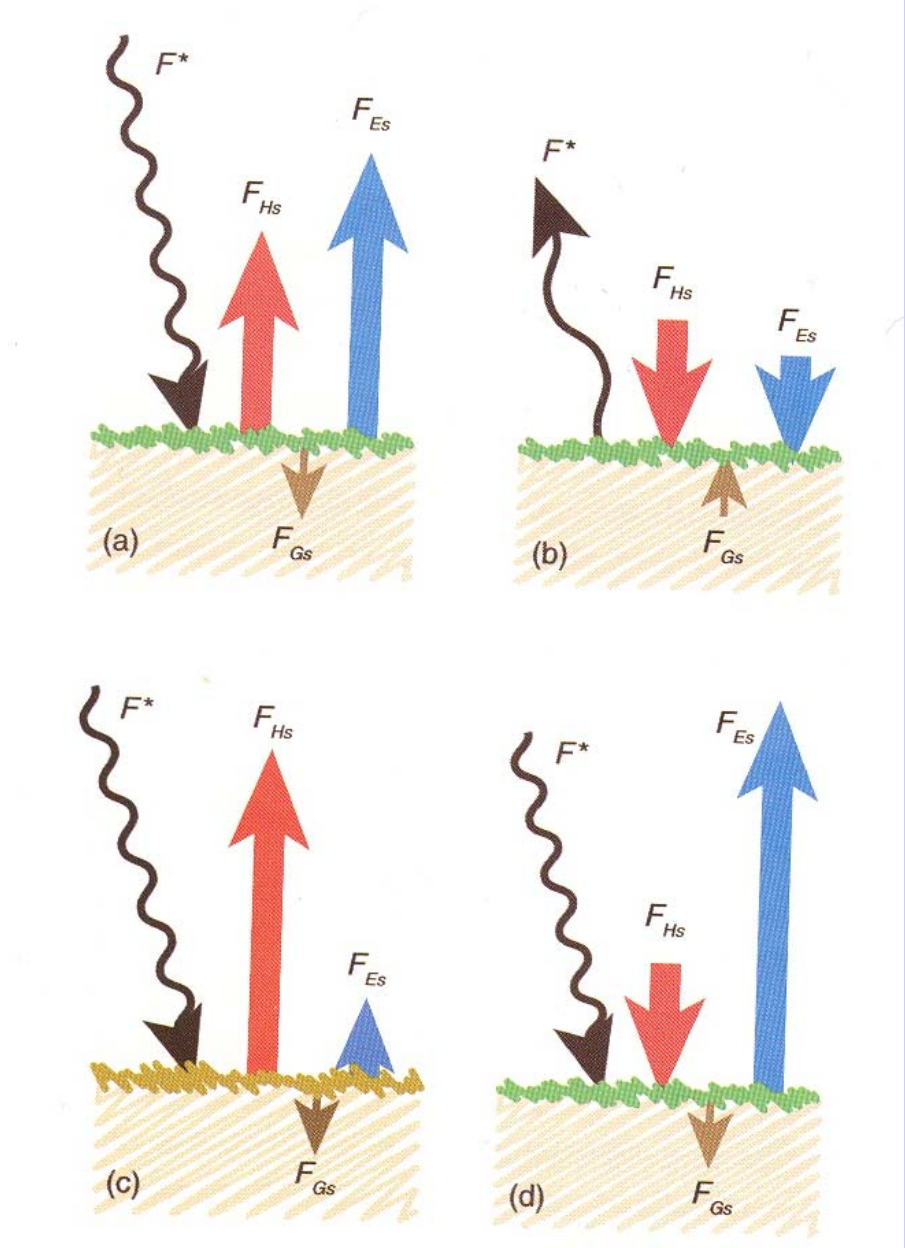
$$\rho c_p H \frac{\partial T}{\partial t} = RN + H + LE + G$$

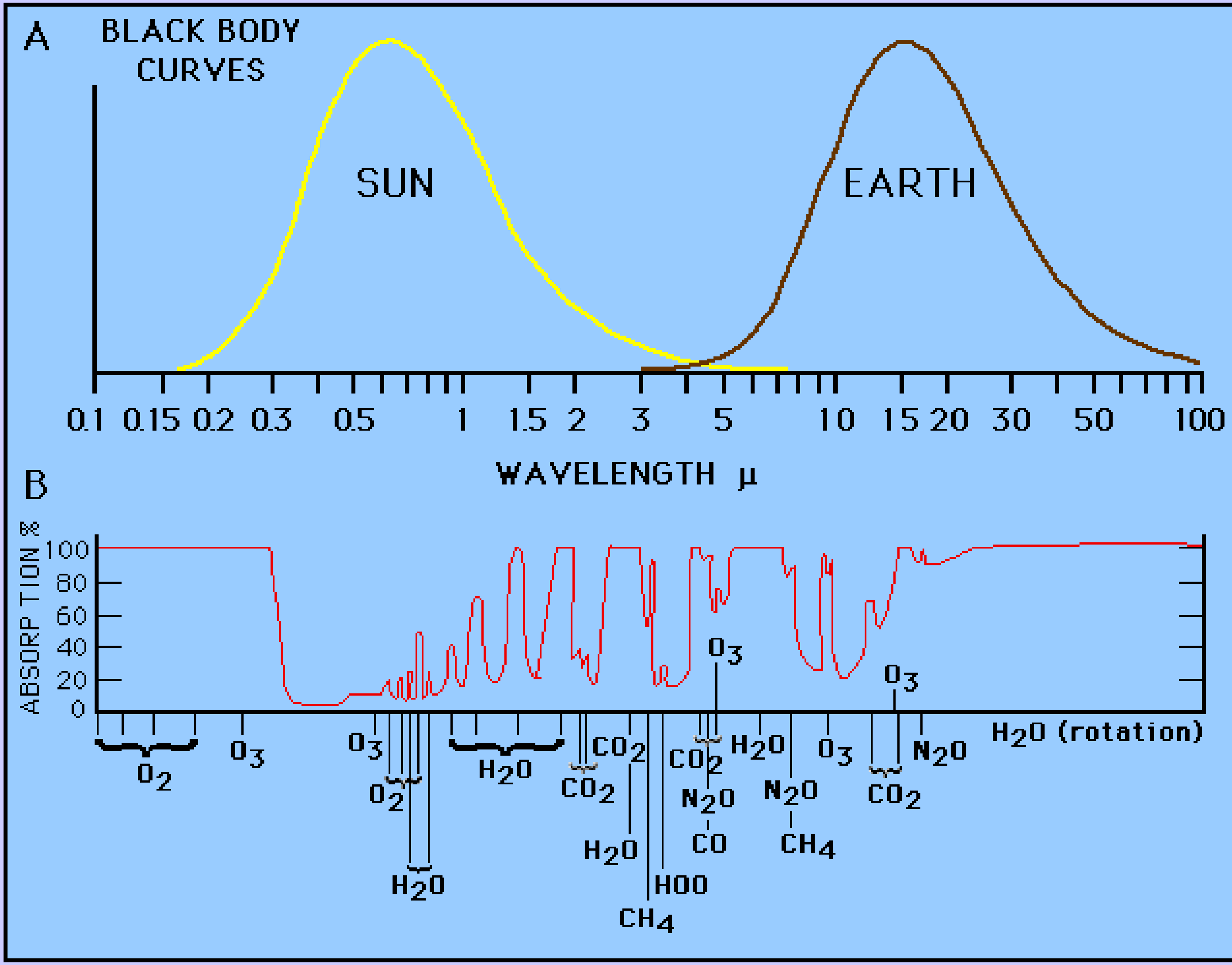
$$RN + H + LE + G = 0 \quad para\ h \rightarrow 0$$

Balance de energía superficial






F*
F_Es
F_Hs
F_Gs
(a)
F*
F_Hs
F_Es
F_Gs
(b)
F*
F_Hs
F_Es
F_Gs
(c)
F*
F_Es
F_Hs
F_Gs
(d)



En su paso por la atmósfera, la radiación solar sufre absorción y dispersión debido a las moléculas de aire y aerosoles. En promedio, la absorción de la RS es solo de un 20%, pero muy efectiva en el rango de los rayos gama y UV.

Constante Solar: Cuanta energía recibimos del sol

La energía emitida por el sol por unidad de área

$$E = \sigma T_s^4$$

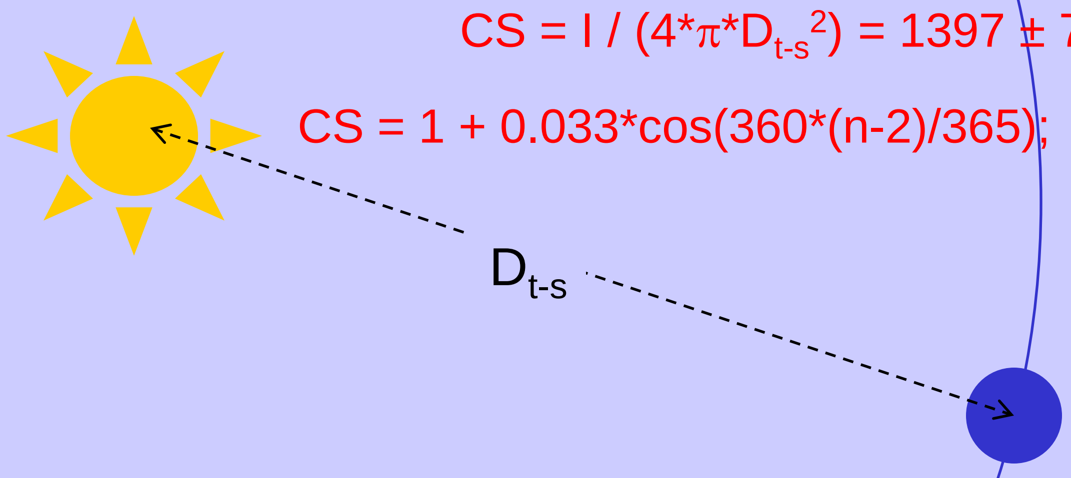
Energía total que emite el sol

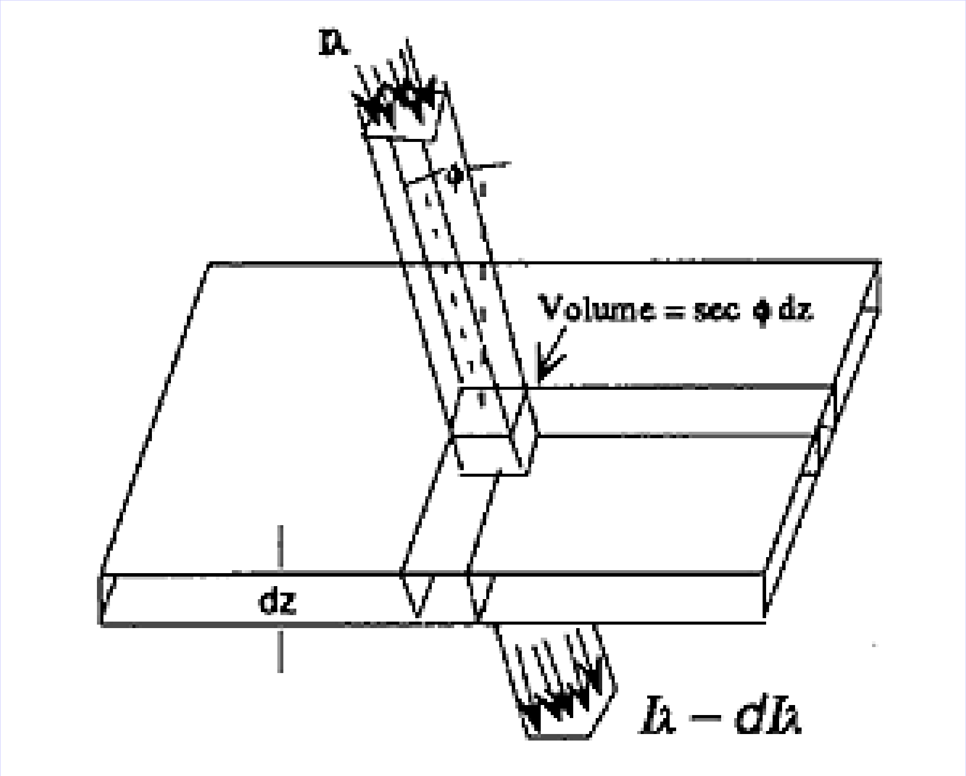
$$I=4*\pi*R_s^2*E$$

Energía por unidad de area a la distancia de la tierra:

$$CS = I / (4*\pi*D_{t-s}^2) = 1397 \pm 7 \text{ W/m}^2$$

$$CS = 1 + 0.033*\cos(360*(n-2)/365); \quad n = \text{día juliano}$$

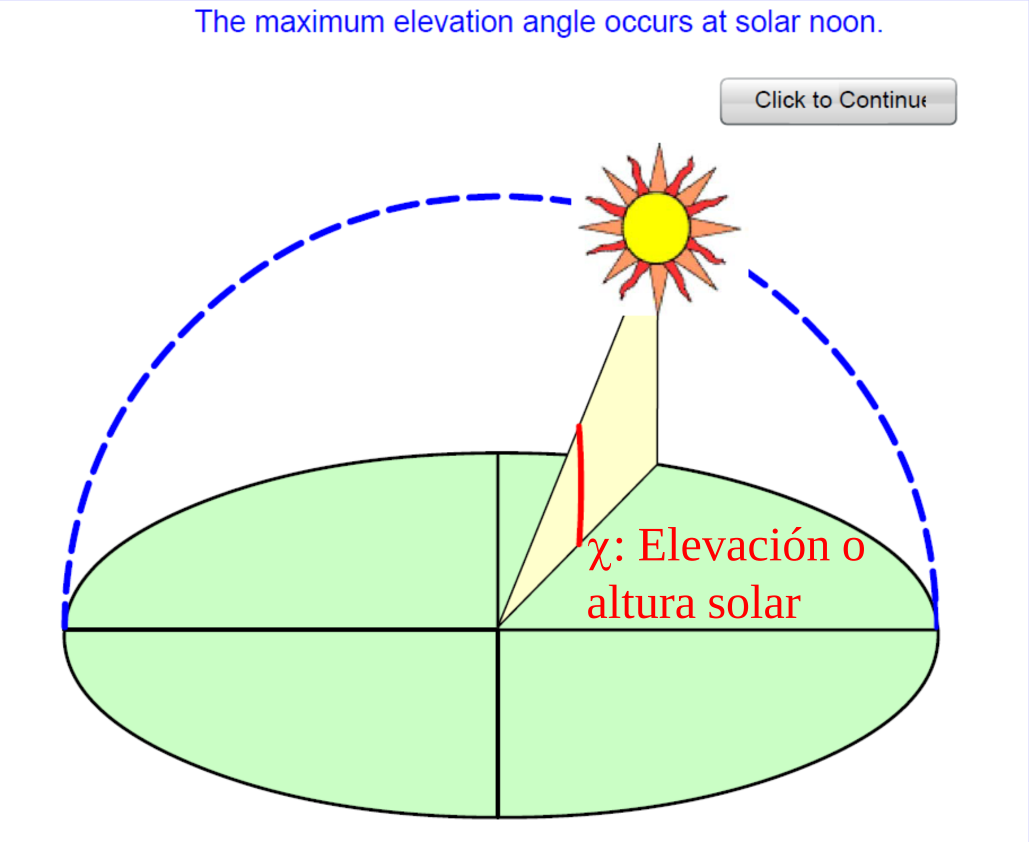




$$dI_\lambda = -I_\lambda \rho k_\lambda ds$$

$$I_\lambda(z) = -I_\lambda(\infty)\exp(-\tau_\lambda \sec\phi)$$

$$\tau_\lambda = \int_z^\infty k_\lambda \rho dz$$



$$K\downarrow = -CS'\sin(\chi)T_N$$ Radiación incidente en plano horizontal

$$sen\psi = sen\phi sen\delta_s - cos\phi cos\delta_s cos[\frac{180t_{UTC}}{12} - \lambda_e]$$

$$T = T(\chi, nubes, altura, etc.....)$$

Chile continental:
t_{UTC} = HL + 4,3

Declinación solar

La inclinación de la tierra, combinado con el movimiento de traslación de la tierra produce la alternancia de las estaciones: máxima energía solar en HS o HN. Factor de segundo orden: excentricidad de la orbita terrestre (4% menos que el promedio en Enero, actualmente)

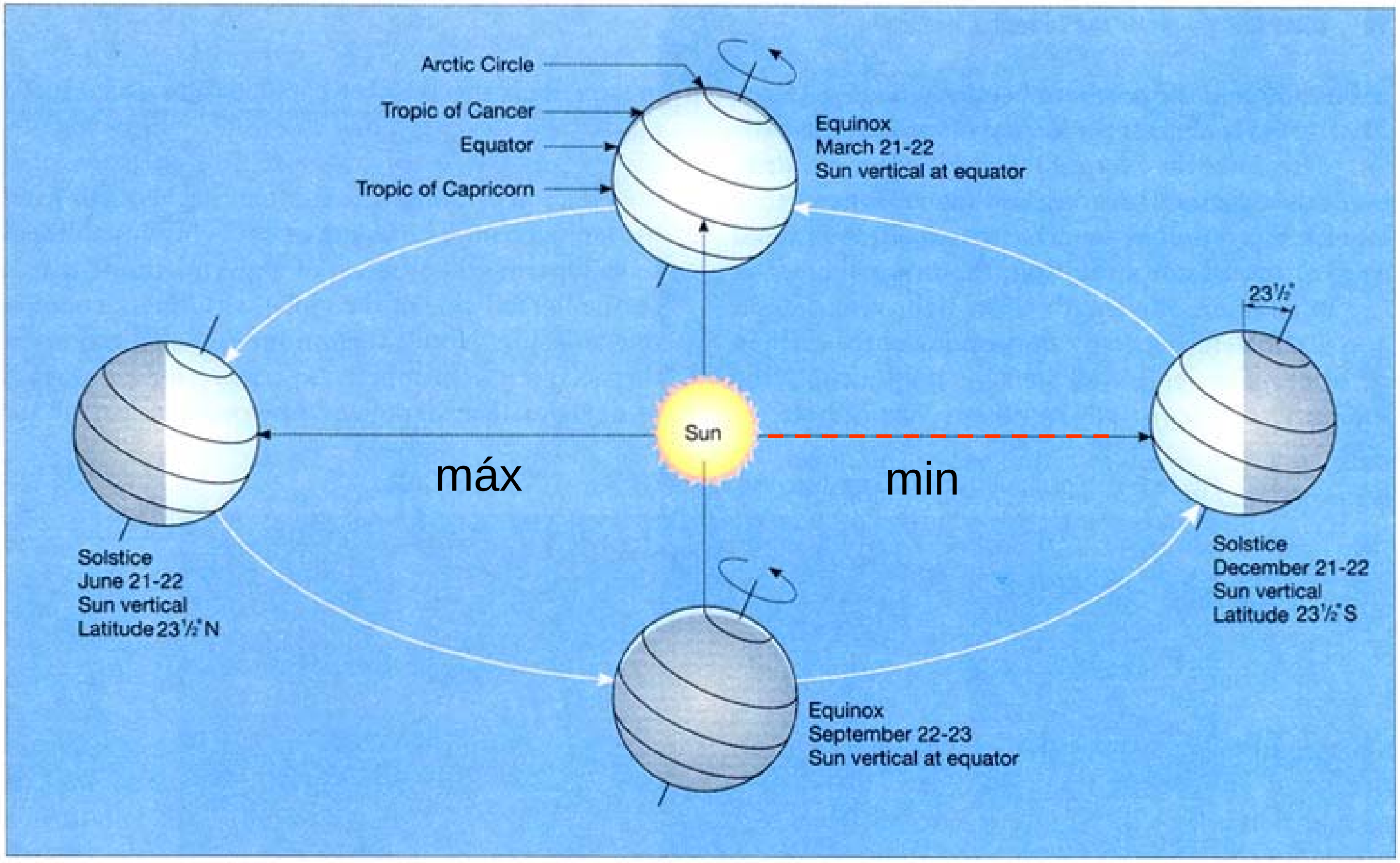


Figure 2•3 Earth–sun relationships.

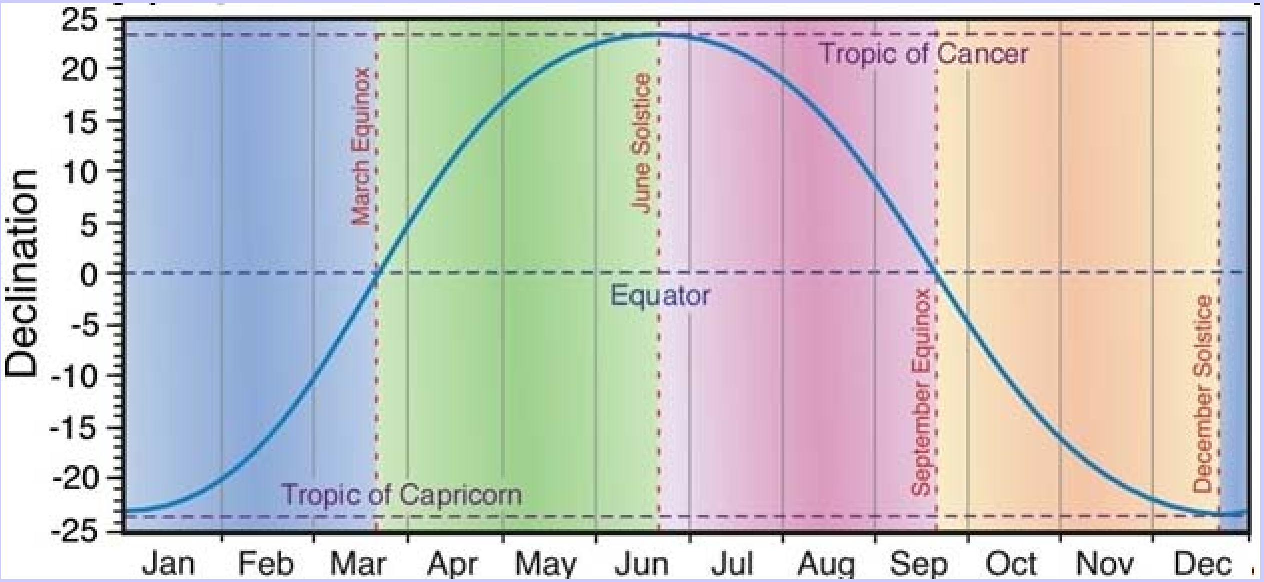
δ: declinación solar : Latitud a la cual los rayos solares llegan normales

The declination angle can be calculated by the equation [1]:

$$\delta = 23.45^\circ \sin\left[\frac{360}{365}(d-81)\right]$$

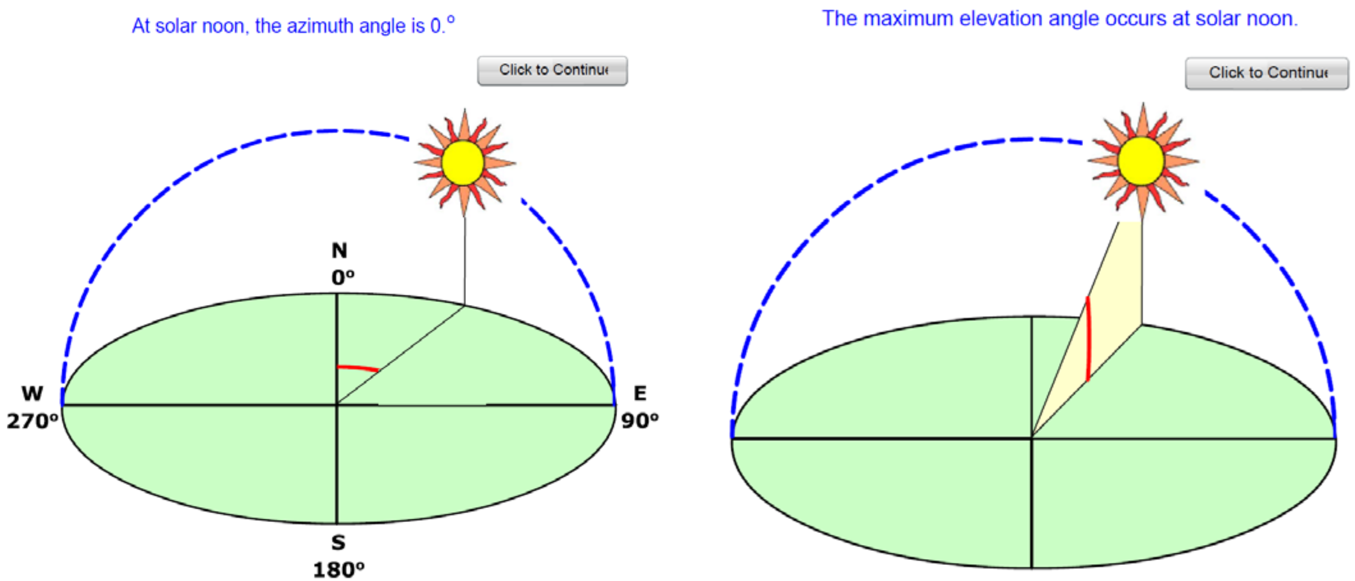
where d is the day of the year with Jan 1 as d = 1. A more accurate expression is:

$$\delta = \sin^{-1}\left\{\sin(23.45^\circ)\sin\left[\frac{360}{365}(d-81)\right]\right\}$$



En algunas aplicaciones también se necesita el azimuth

http://pvcdrom.pveducation.org/index.html



$$Elevation = \sin^{-1}[\sin\delta \sin\varphi + \cos\delta \cos\varphi \cos(HRA)].$$

$$Azimuth = \cos^{-1}\left[\frac{\sin\delta\cos\phi - \cos\delta\sin\phi\cos(HRA)}{\cos\alpha}\right]$$

Hora local (LT), hora solar (LST) y angulo solar (*h*)

LSTM = 15 (diff. HL – GMT)
TC = 4 (Longitude – LSTM)
LST = LT + TC
H = 15 (LST– 12)

Ejemplo: Chile contiental (lon=-70 W), hora de verano (diff = -3hr)
LSTM = -45
TC = -100 min = -1 hr 40 min

Si LT = 13:40 entonces LST = 12:00 (mediodia solar) y *h* = 0

2.18. Sun Position Calculator

Using the equations on the previous page, the position of the sun in the sky can be determined from the observer's location and the time of day. In the top blue squares, enter the observer's location and time of day.

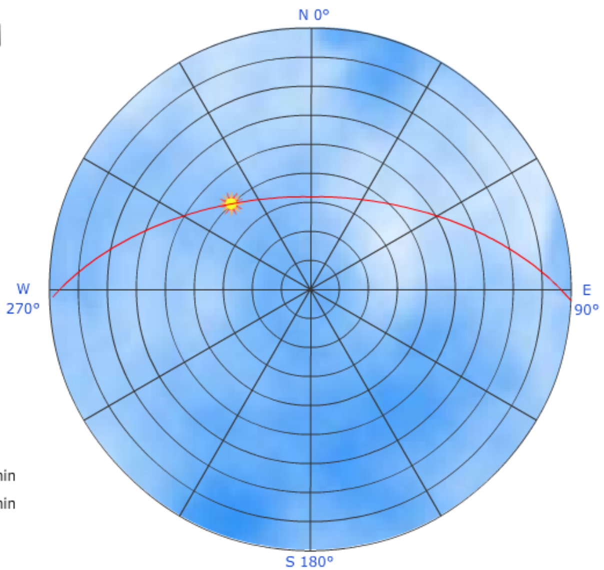
Time and Date

The time is given as 24 hour time and the minutes are entered separately. Thus for 5:15 pm, enter 17 in the hour box and 15 in the minute box.

Longitude, Latitude and Time Zone (GMT)

Longitude, latitude and time zone of locations throughout the world are available at www.timeanddate.com. Minutes of longitude and latitude are entered as fractions, so 17° 30' becomes 17.5. Enter locations with an east longitude as negative. For daylight saving (summer time), subtract 1 hour from the given values. Generally speaking, locations east of Greenwich (UK) are positive and locations west of Greenwich are negative. There are other services that will determine your approximate latitude and longitude from your IP address. For example ip2location.com.

Month	March	
Day	17	
Hour	15	
Minute	33	
Latitude	-34	
Longitude	140	
GMT Offset	11	
day number	76	days
EoT	-9.06	min
Time Corr.	-109.06	min
declination	-2.02	deg.
hour angle	25.98	deg.
altitude	49.86	deg.
azimuth	317.22	deg.
sunrise	7:44	hour:min
sunset	19:55	hour:min



latitude -90 0 90
time 0 12 24
day Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

The graph on the right shows the position of the sun's azimuth and elevation angles projected onto a two-dimensional plane. An elevation angle of 90° corresponds to the stage when the sun is directly overhead and appears in the centre of the graph. An elevation angle of 0° corresponds to the point when the sun is on the horizon, and appears on the outer edge of the graph. The azimuth angles are marked around the graph's edge, so an azimuth angle of 0° is at the top of the graph. The graph is best understood by trying a number of times and locations and seeing where the azimuth and elevations are plotted.

Using the equations on the previous page, the position of the sun in the sky can be determined from the observer's location and the time of day. In the top blue squares, enter the observer's location and time of day.

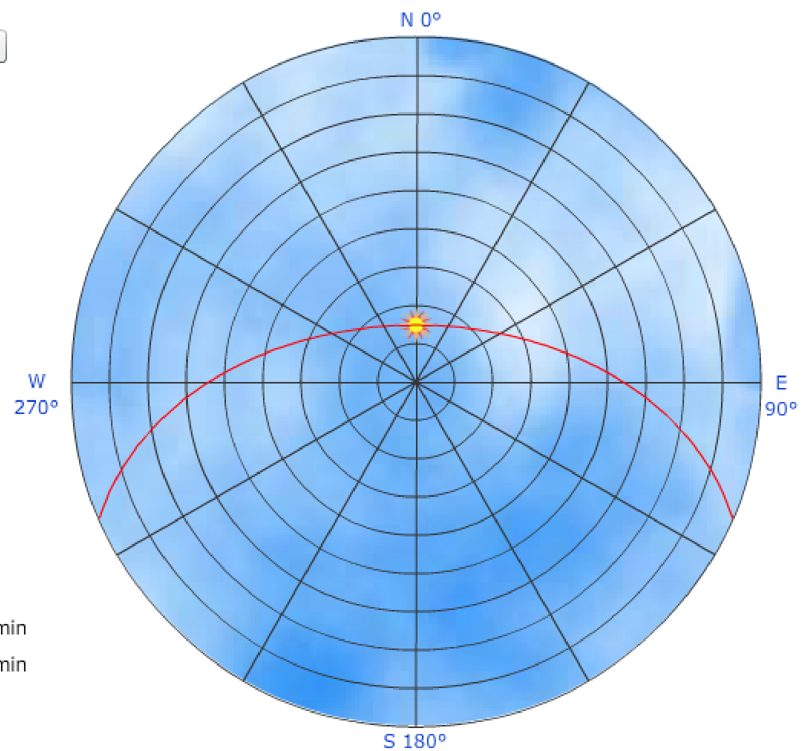
TIME AND DATE

The time is given as 24 hour time and the minutes are entered separately. Thus for 5:15 pm, enter 17 in the hour box and 15 in the minute box.

LONGITUDE, LATITUDE AND TIME ZONE (GMT)

Longitude, latitude and time zone of locations throughout the world are available at www.timeanddate.com. Minutes of longitude and latitude are entered as fractions, so 17° 30' becomes 17.5. Enter locations with an west longitude as negative. For daylight saving (summer time), subtract 1 hour from the given values. Generally speaking, locations east of Greenwich (UK) are positive and locations west of Greenwich are negative.
There are other services that will determine your approximate latitude and longitude from your IP address. For example ip2location.com.

Month	November	
Day	15	
Hour	13	
Minute	25	
Latitude	-34	
Longitude	-70	
GMT Offset	-3	
day number	319	days
EoT	14.88	min
Time Corr.	-85.12	min
declination	-19.15	deg.
hour angle	-0.03	deg.
altitude	75.15	deg.
azimuth	0.11	deg.
sunrise	6:31	hour:min
sunset	20:19	hour:min



latitude -90 0 90

time 0 12 24

day Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

A partir de la radiación solar incidente, $RS \downarrow$, se puede calcular la insolación diaria, definida como:

$$Insolacion = \int_{h_s}^{h_p} RS \downarrow dh \quad (10)$$

donde h_s y h_p son las horas de salida y puesta del sol, respectivamente, que se obtienen a partir de la Ecuación 7 como:

$$h_s = h_p = acos(-tg\phi tag\delta_s) \quad (11)$$

y para h_s en *grados*, la duración del día, t_d, en *horas*, es:

$$t_d = 2\frac{h_s}{15}$$

A veces, solo interesa la insolación {integral de la radiación}

Una aproximación a la insolación diaria, I (MJ/m^2), esta dada por la siguiente expresión:

$$I \cong 7{,}2 \cdot 10^{-3}\frac{S_{max}t_d}{\pi} \quad (13)$$

donde, t_d se ingresa en horas y S_{max} (W/m^2) es la máxima radiación solar incidente dada por (Figura 2):

$$S_{max} = S(h=0) = S(0{,}8)(1-0{,}4\sigma_{C_H})(1-0{,}7\sigma_{C_M})(1-0{,}4\sigma_{C_L})(sen\phi sen\delta_s + cos\phi cos\delta_s) \quad (14)$$

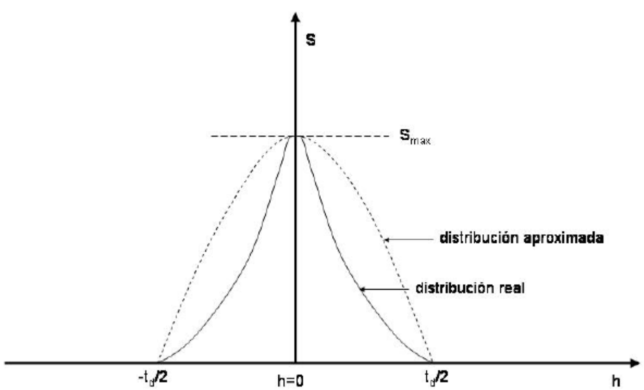


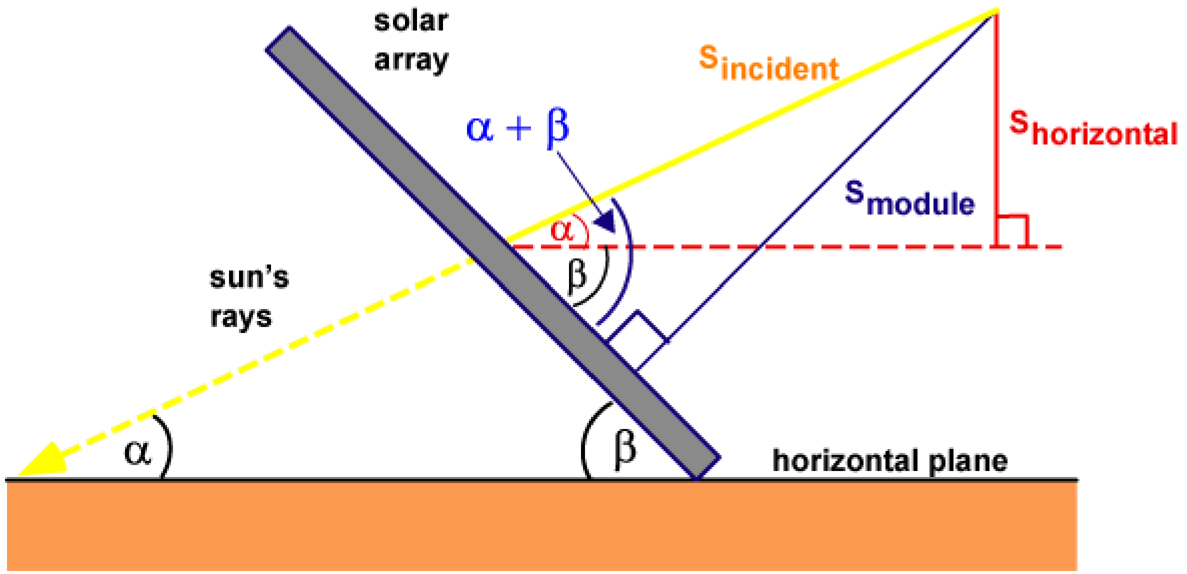
Figura 2: Aproximación para calcular la insolación diaria.

Aplicación importante: energía solar - Conceptos claves:

* Radiación solar global (directa + difusa)
* Insolación diaria
* Mediciones versus simulaciones

Todo lo que necesita saber sobre calculo de RSOL:

http://pvcdrom.pveducation.org/index.html



$$Elevation = \sin^{-1}[\sin\delta \sin\varphi + \cos\delta \cos\varphi \cos(HRA)]$$

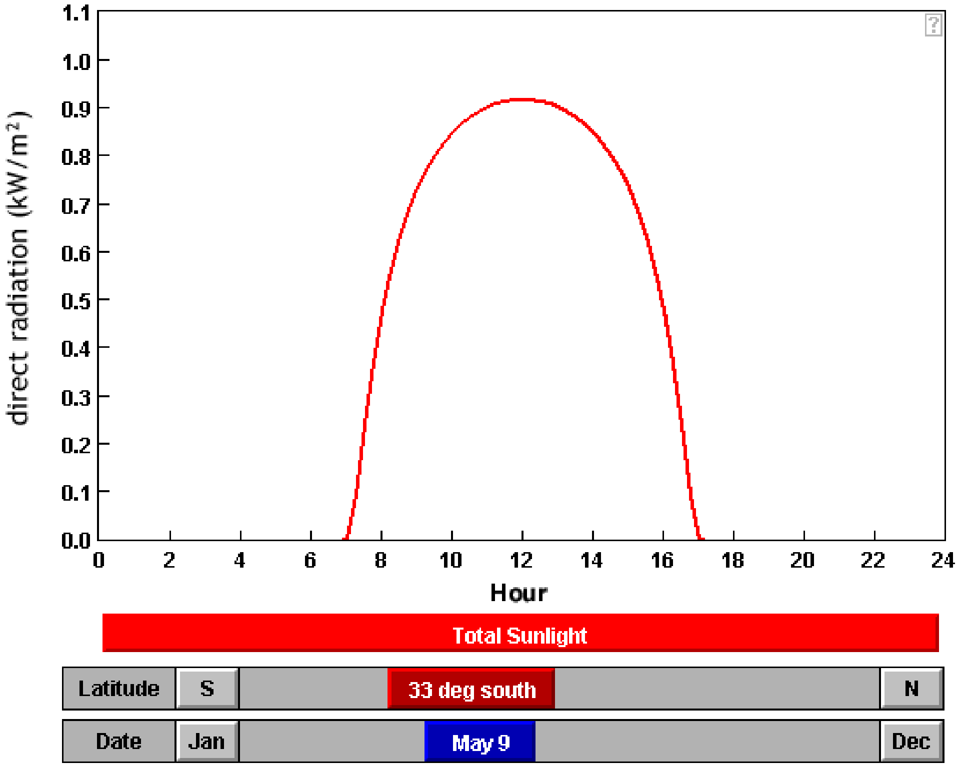
$$Azimuth = \cos^{-1}\left[\frac{\sin\delta \cos\phi - \cos\delta \sin\phi \cos(HRA)}{\cos\alpha}\right]$$

‹ Arbitrary Orientation and Tilt

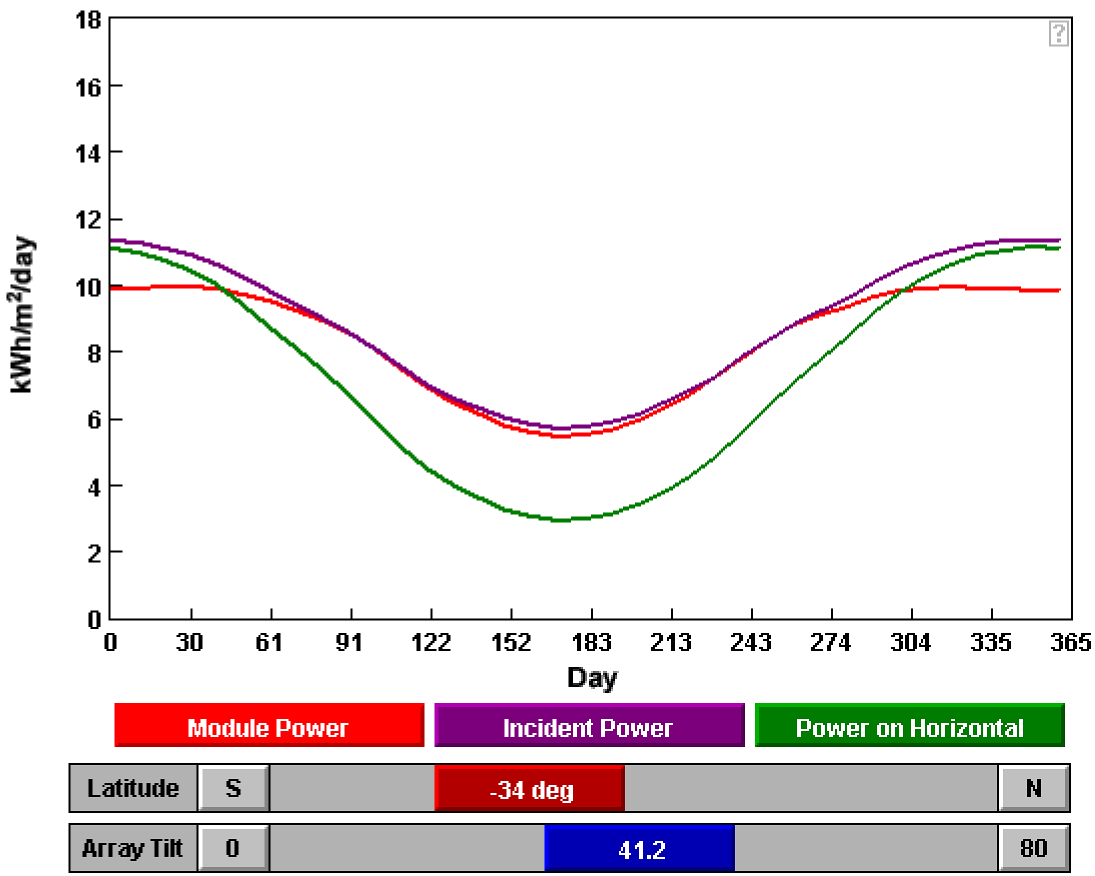
Calculation of Solar Insolation

Measurement of Solar Radiation ›

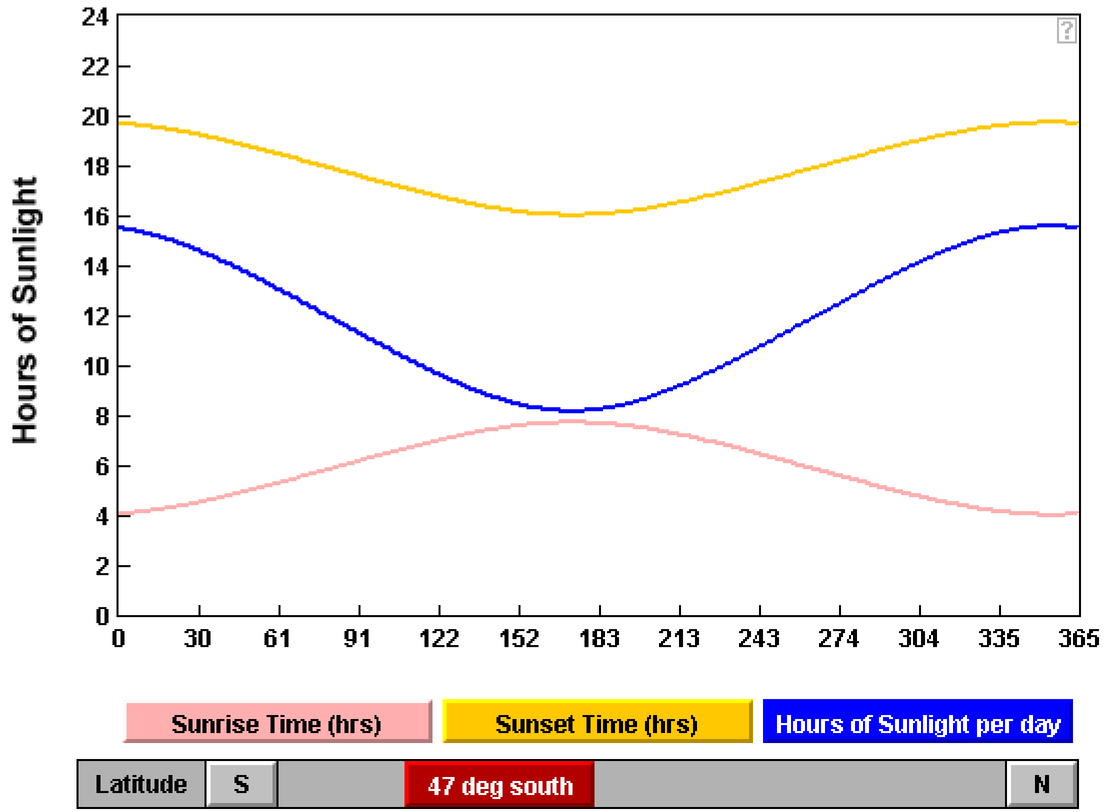
Based on the equation of the sun's position in the sky throughout the year, the maximum amount of solar insolation on a surface at a particular tilt angle can be calculated as a function of latitude and day of the year. These calculations are also essential in using experimental data from sunshine hour recorders. The following animations calculate the daily solar irradiance, the solar insolation and the number of hours during the day which the sun is shining. They do not include local weather effects and so these theoretical graphs are not used in system sizing or prediction of operation. A description of each graph is given in the caption underneath.



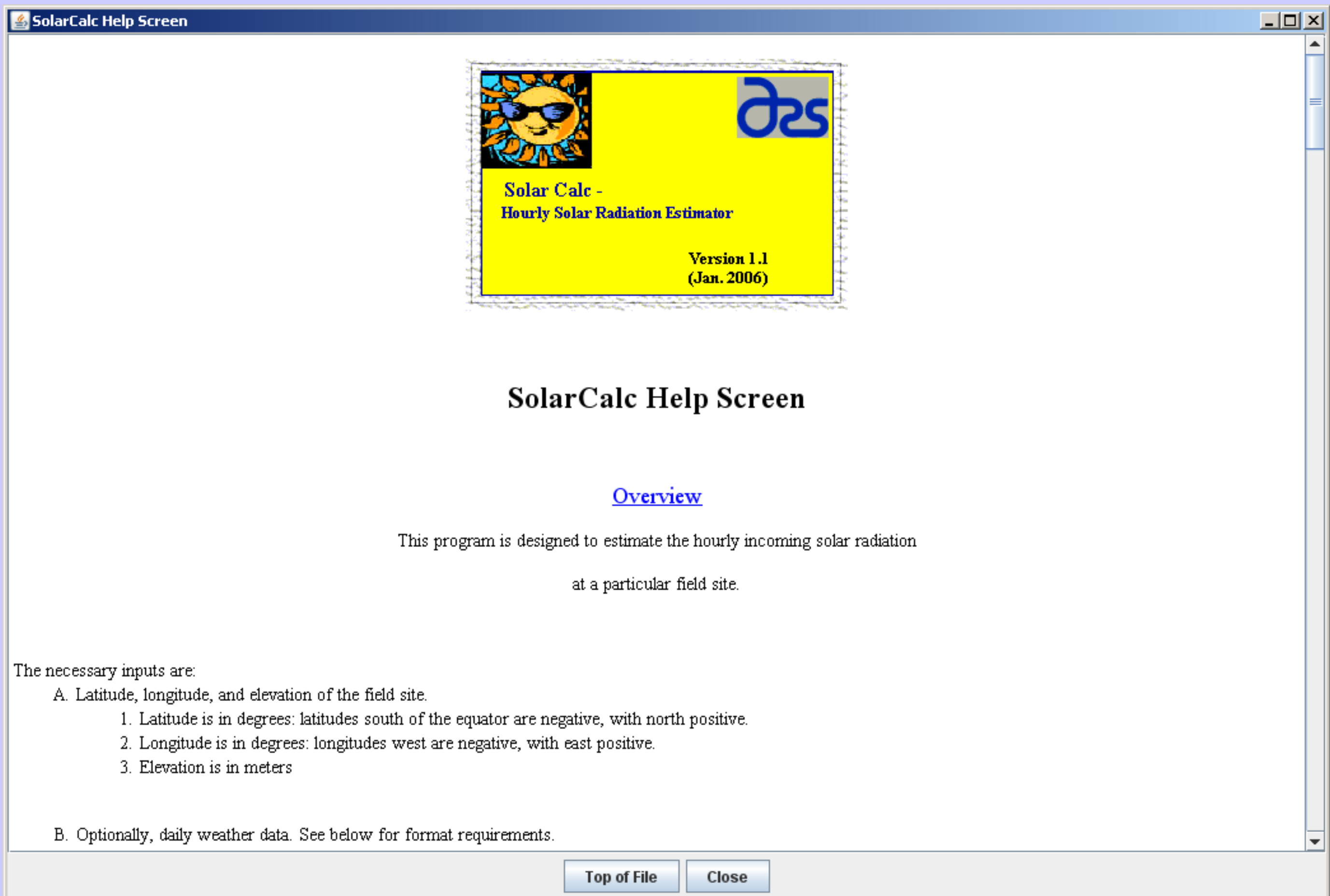
The graph shows the intensity of direct radiation in W/m² through out the day. It is the amount of power that would be received by a tracking concentrator in the absence of cloud. The time is the local solar time. Set the latitude to your location and then adjust the day slider to see how much radiation there is for each day of the year. Show Data pveducation.org/pvcdrom/properties-of-sunlight/calculation-fo-solar-insolation

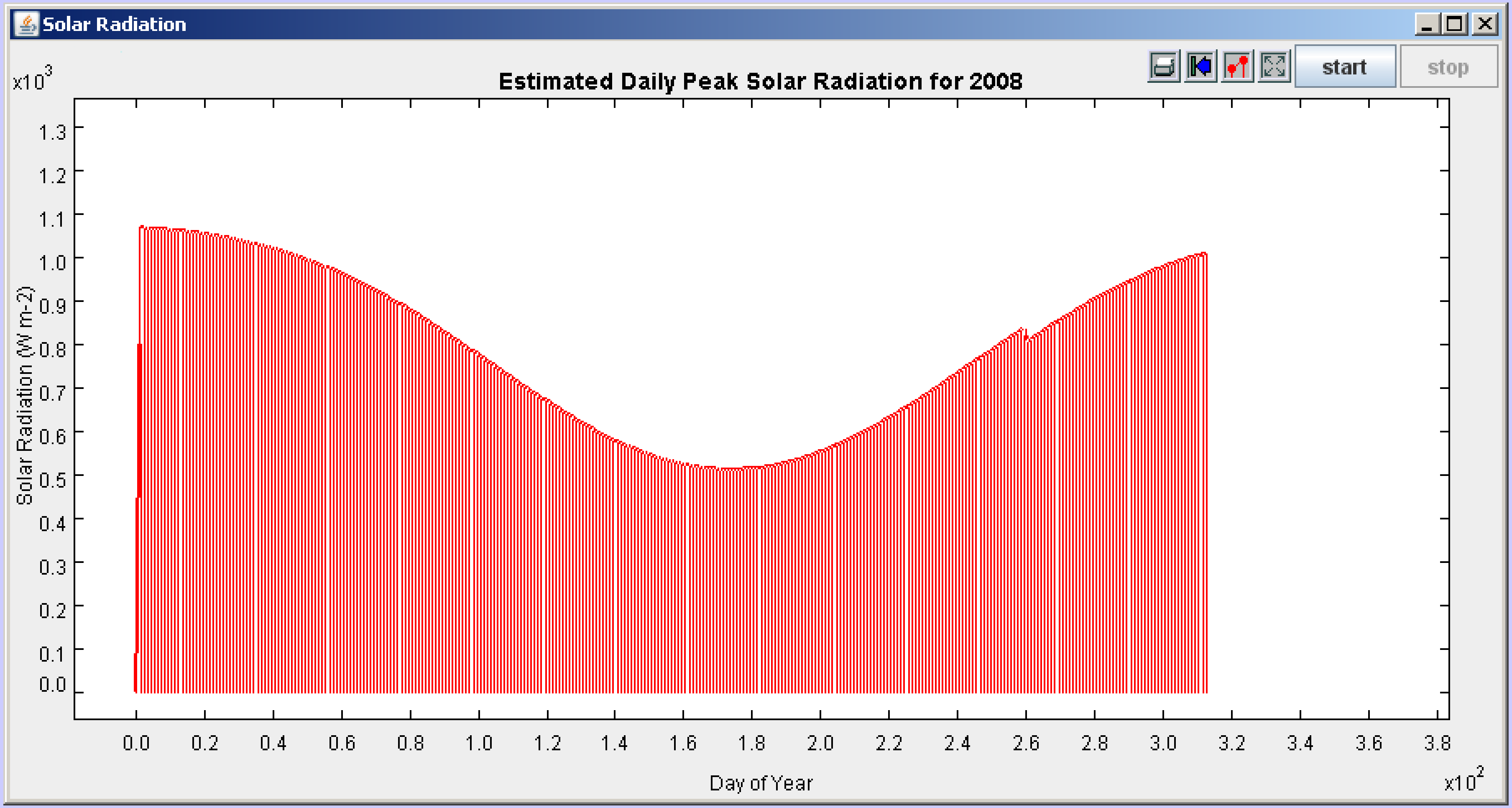


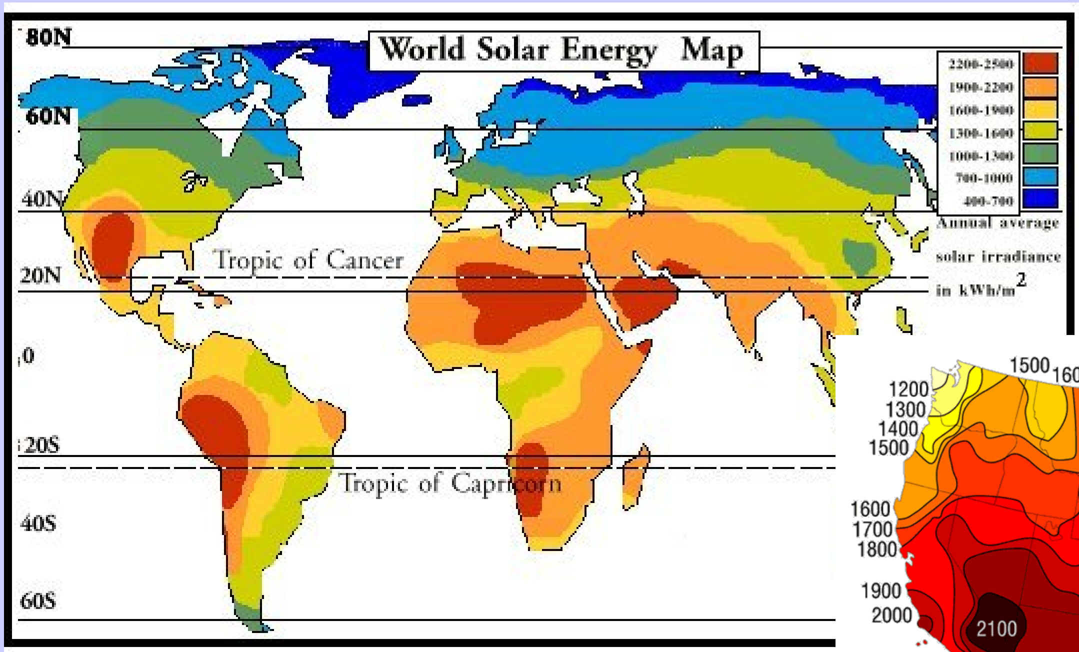
The average daily solar insolation as a function of latitude. The three curves are the incident solar insolation, the horizontal solar insolation and the solar insolation on a titled surface as defined in the page Module Tilt. The daily insolation is numerically equal to the number of sunhours in a day. The module is assumed to face the equator so that it faces South in the northern hemisphere in North in the southern hemisphere. As the latitude is adjusted through zero going across the equator, the module faces in the opposite direction. the graph changes suddenly at the equator since the module is now facing in the opposite direction. Show Data pveducation.org/pvcdrom/properties-of-sunlight/calculation-fo-solar-insolation

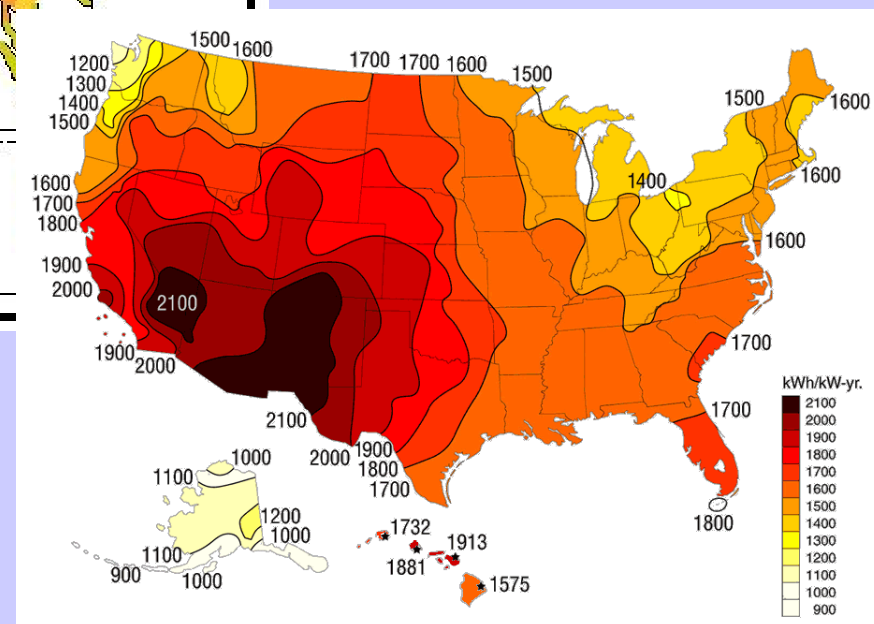


The number of hours the sun is shining each day, that is the number of hours between sunrise and sunset each day. In latitudes above 67° the sun shines for 24 hours during part of the year. Surprisingly, when averaged over the year, the sun shines an average of 12 hours per day everywhere in the world. In the northern latitudes the average *intensity* is lower than at the southern latitudes. Show Data http://www.ars.usda.gov/services/software/



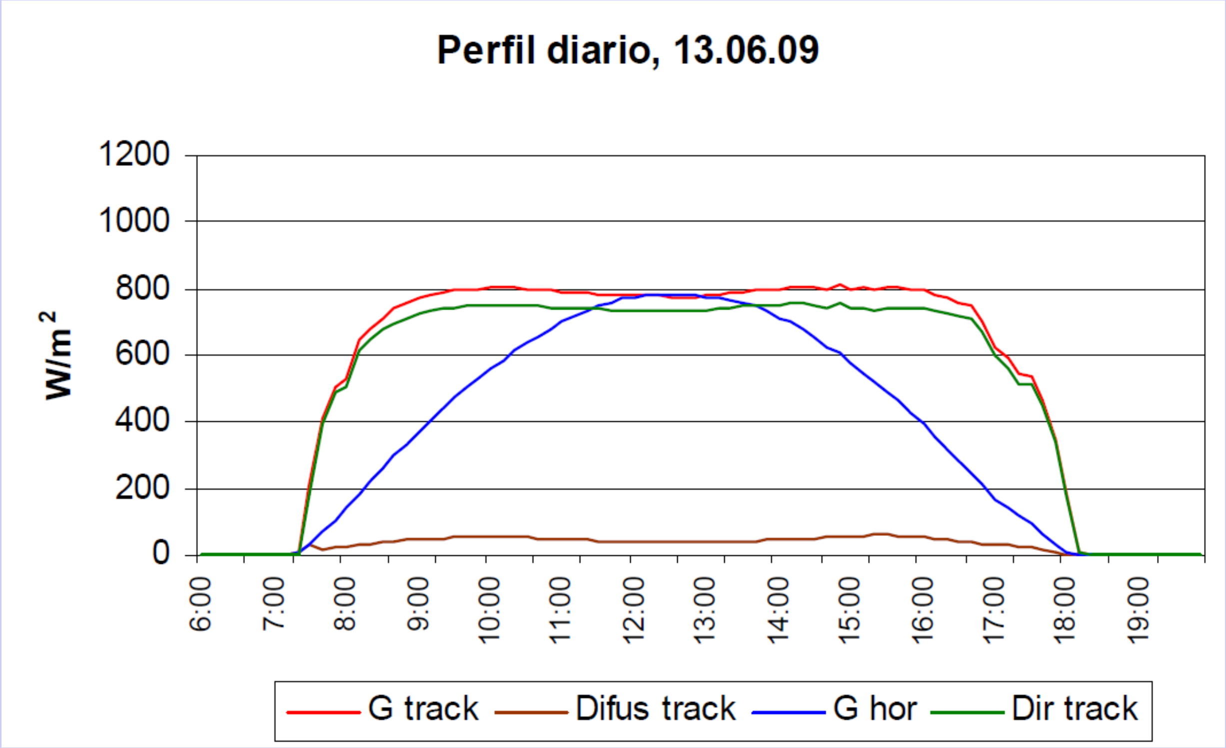

Solar Radiation
start
stop
Estimated Daily Peak Solar Radiation for 2008
x10^3
Solar Radiation (W m-2)
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
Day of Year
x10^2



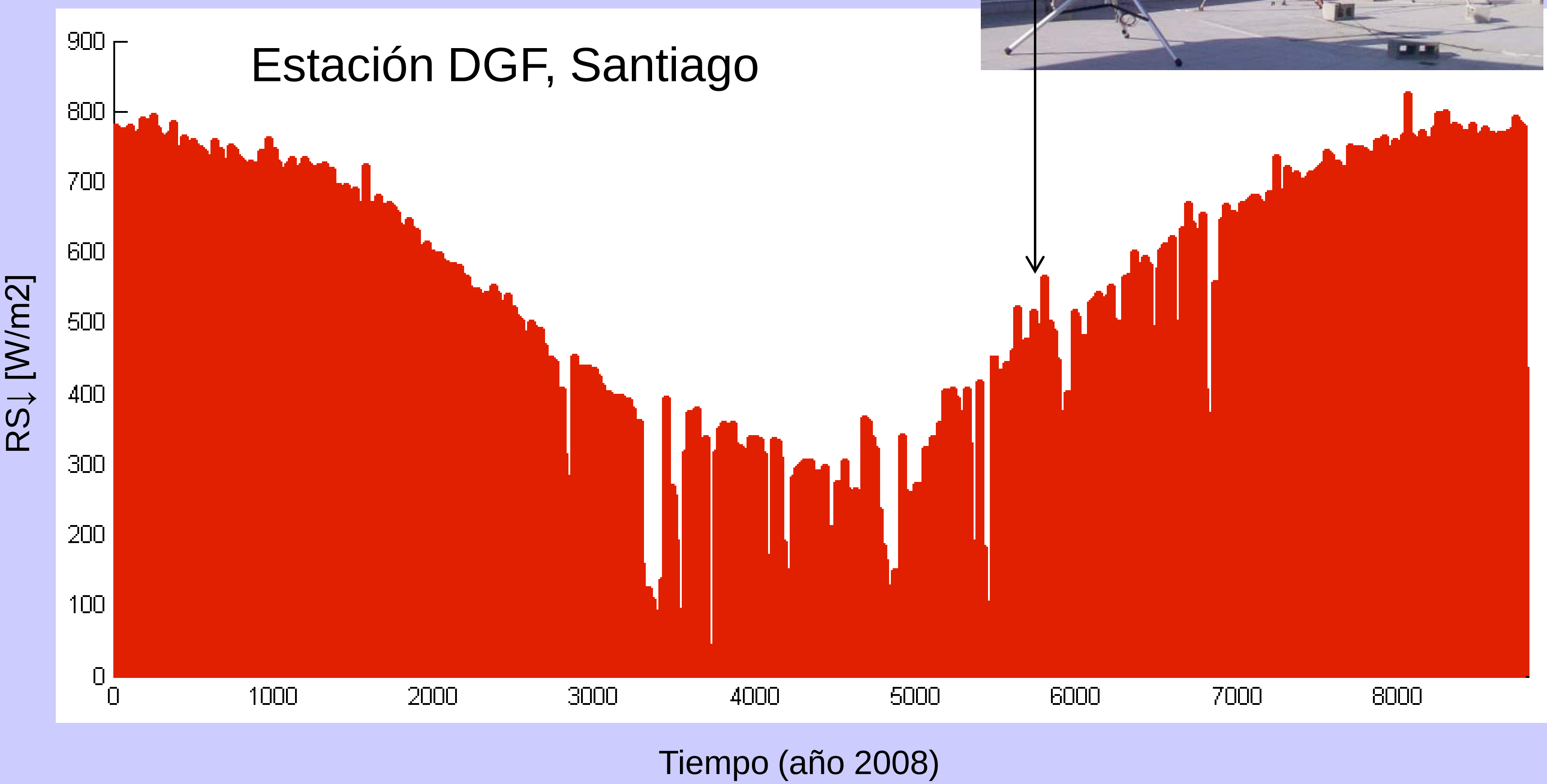


Para Chile, ver el explorador de Energía solar y eolica en: http://quique.dgf.uchile.cl/EnergiaRenovable/Explorer2/

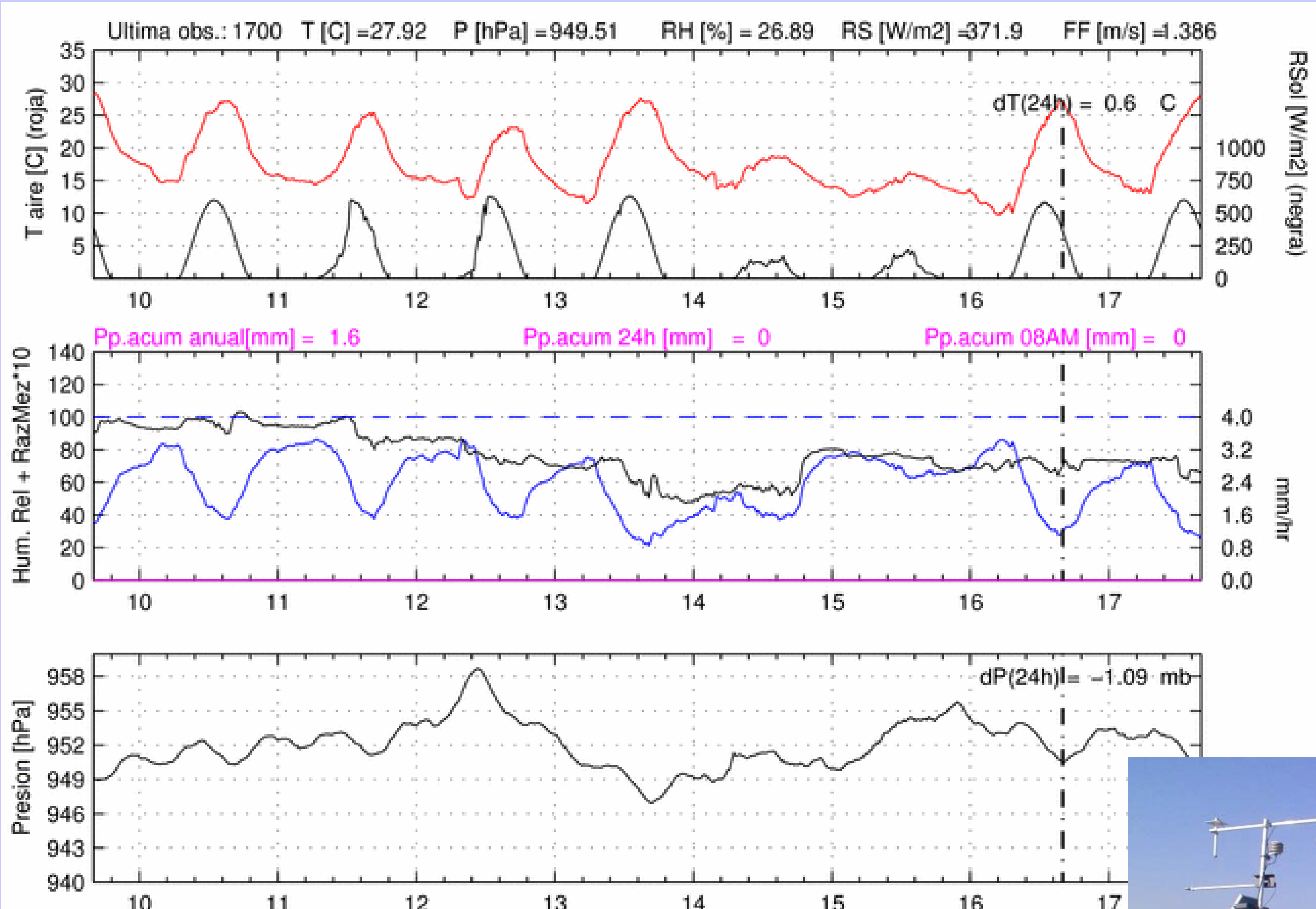
Figura 1: Vista completa de la estación



Radiación global horizontal:	5.17	kWh/m^{2}día
Radiación global en seguimiento:	7.72	kWh/m^{2}día
Radiación difusa en seguimiento:	0.44	kWh/m^{2}día
Radiación directa en seguimiento:	7.27	kWh/m^{2}día


Estación DGF, Santiago
RS↓ [W/m2]
0
100
200
300
400
500
600
700
800
900
0
1000
2000
3000
4000
5000
6000
7000
8000
Tiempo (año 2008)

Introducción a la Meteorología – Rad. Solar
UCH/FCFM/DGF – R. Garreaud



Regresemos al Bal. Energía Sfc…otros terminos

$$RS\downarrow = \begin{cases} ST_K sen\psi & \text{durante el día } (sen\psi \text{ es positivo}) \\ 0 & \text{durante la noche } (sen\psi \text{ es negativo}) \end{cases}$$

$$RS\uparrow = -aRS\downarrow$$

Tabla 2: Albedo superficial y emisividad superficial para distintas superficies.

Tipo de suelo	Albedo (a)	Emisividad (ϵ_{IR})
Tierra/cemento	0,05-0,40	0,90-0,98
Desierto	0,20-0,45	0,84-0,91
Cesped	0,16-0,26	0,90-0,95
Suelo agrícola	0,15-0,25	0,90-0,99
Bosque	0,15-0,20	0,97-0,98
Agua	0,03-0,10	0,92-0,97
Nieve	0,40-0,95	0,82-0,99
Hielo	0,20-0,45	0,92-0,97