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Solar Irradiance Short Wave Radiation Users Guide

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Solar irradiance for short wave radiation (400–700 nm) at the sea surface can be calculated using inputs obtained from satellite systems and model estimates. The short wave solar irradiance is important for 1) estimating the surface heating that occurs in the near surface and 2) estimating the available irradiance for biological growth in the upper ocean. The variability of the solar irradiance is believed to have significant influence on the global carbon cycle. This users guide provides an understanding of the models and operational procedures for using the software and understanding the results.

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Contents:

Solar Irradiance - Short Wave Radiation
Users Guide

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Introduction

The solar irradiance (SI) for short wave radiation (400 - 700 nm) at the sea surface can be calculated using inputs obtained from satellite systems and model estimates. The short wave solar irradiance is important for (1) estimating the surface heating that occurs in the near surface and (2) estimating the available irradiance for biological growth in the upper ocean. The variability of the solar irradiance is believed to have significant influence on the global carbon cycle (Arnone, 1994; Arnone et al, 1993; Terrie et al, 1991). This Users Guide provides an understanding of the models and operational procedures for using the software and understanding the results.

A detailed synopsis of the irradiance model itself is beyond the scope of this quide. The user is referred to the papers in the reference section and the "irradiance" page in the appendix.

This Users Guide describes the solar irradiance program "**ird**" which has been developed to create solar irradiance image products in the same format as the monthly 20 km NRL Ocean Color Optics Database. The program can generate mean solar irradiance at a specified wavelength between 350 and 700 nm or the photosynthetic available radiation (PAR) over this range for a given month. The program attenuates the irradiance at the top of the atmosphere for the effects of Rayleigh scattering, aerosol extinction, water vapor absorption, ozone absorption, absorption due to gases (oxygen), and the effects of clouds to obtain the solar irradiance or PAR at the surface. Additionally, the irradiance can be extended through the air-sea interface. The program will also produce mean cloud cover percentages and mean ozone amounts for the same month.

The C program is run at the command prompt and has a simple question and answer interface. This document will describe the questions and their appropriate answers. The guide will also discuss the basic methodology of the program, diagnostic output, and files required.

This program is based on models from Bird et al, 1984, Gregg and Carder, 1990 and Arnone et al, 1993. The program computes the solar irradiance for large regions which are described as images regions. Presently the areas are regions described by the Coastal Zone Color Scanner satellite which have been assembled into a global data base (Arnone et al, 1992, and Feldman et al, 1989).

Methodology

When **ird** is executed, it begins by reading in a table of coefficients for water vapor absorption, gas absorption, ozone abortion and extraterrestrial irradiance at 1 nm wavelengths in the range of 350 to 700 nm (See Table 1 in Gregg and Carder, 1990). This table is the ASCII data file 'lidata.dat' and must reside in the directory from which ird is executed.

After the table is read, the program prompts the user for some needed information (locations of data files, names of output files, etc.). These questions will be discussed below. If the solar irradiance at a specified wavelength was requested, ird extracts the absorption coefficients and the extraterrestrial irradiance from the Gregg and Carder table.

The program will produce three output files based on the user selected aerosol input image. For each pixel in the Mercator projected aerosol image, the output product (monthly mean solar irradiance, monthly mean ozone, or monthly mean percent cloud cover) is calculated by averaging the extracted or determined product at each hour of each day for a given year. For the average ozone amount or average cloud percent, this is simply the average of the ozone or cloud percent extracted from the TOMS ozone database or the Air Force Real-Time Nephanalysis (RTNEPHN) databases for the given time frame. For the average solar irradiance it is calculated using a simple spectral model.

For each pixel, the location is determined using the fact that the aerosol file is a Mercator projected image. For this pixel, several nested loops are entered and the required parameters to the irradiance model (aerosol value, ozone value, cloud percentage, solar zenith and azimuth angles, etc) are determined. Each parameter is determined based on its temporal nature. For example, the cloud percentage is a monthly average for eight 3-hour time zones, and so these values are extracted every third hour. As another example, the solar zenith angle can only determined once the location, year, day and hour are set.

The aerosol value for a given pixel is determined on a monthly basis. The aerosol amount can either be extracted from the aerosol file or set to a constant. If the aerosol is extracted from the aerosol file but is zero, the program will either set the output pixel to zero and advance to the next pixel or set the aerosol value to a constant. The user has three options for the aerosol value: (1) set it to a constant throughout the image; (2)

extract it from the aerosol file, replacing it with a constant value if it is zero; or (3) extract it from the aerosol file, skipping the pixel if it is zero.

The ozone amount for a given pixel is determined every third day from the TOMS database. If the ozone value is missing, then the Van Heulen ozone climatological equation is used to estimate ozone.

The percent cloud cover is determined every third hour and is extracted from the Air Force NRTEPH database which has been reformatted by NRL. If the percent cloud cover is invalid or missing, the cloud cover percentage is set to zero, that is, a cloudless day is assumed.

The solar zenith angle for the given hour and day is computed. If the user selected below the surface, then the surface reflectance attenuation is next computed. Here, the direct component is determined based on Gregg and Carder's algorithm.

If the user had selected SI for a specified wavelength, the routine irradiance is called to compute the total irradiance or a loop which calls irradiance for several wavelengths between 350 and 700 nm is entered to determine the integrated total irradiance or PAR.

The cloud percentage, ozone amount, and total irradiance are then summed over the day of the year and hour loop. The result for each product is then divided by the number of values summed to obtain the monthly mean, which is stored in the appropriate output array. After the image is completely processed, the program writes the products to individual disk files. A report file is also generated. The ASCII report file contains the user's input parameters and statictical information (e.g., minimum/maximum irradiances, start/stop times of program). The program is now complete.

Running ird

The solar irradiance program ird is begun by typing **ird** at the command prompt. The program begins by displaying a banner describing its function and version. This manual discusses version 7.1.

The first five questions provide ird with the time frame for determining the average solar irradiance. For a given pixel, the model will output the average solar irradiance by calculating the irradiance for each hour of each day for a given year. The user is asked for the year, starting and stopping day of the year, and the starting and stopping hours of the day. Note: the user should restrict the days to a desired month.

As with many questions asked by ird, the users responses are not checked. For example, if the starting Julian day is larger than the ending Julian day the program will not produce any output. As another example, if the user enters an incorrect aerosol file the program will simply terminate.

Once the time frame has been entered, the program asks for the aerosol input file. For this revision (7.1), the aerosol file *must* be from the 20 km NRL Ocean Optic Database and should represent the monthly mean radiance at 670 nm in uW/cm2/nm (Aerosols is characterized by the 670 radiance channels on CZCS which is valid for open ocean waters). If the file is non-existent or unreadable, the program will terminate. The aerosols can be used in three different methods. In the **first method**, the file will be used for navigation and the aerosol radiance at 670 nm data will be used unless zero. In the 20 km NRL Ocean Optic Database, a zero represents either land or no data, and so this method skips those pixels and solar irradiance is not computed. In the **second method**, all pixels in the input image are processed. However, those representing land or no data (ie. set to zero), can be set to a default 670 nm radiance value. Finally, in a **third method**, a constant 670 nm radiance aerosol value can be used throughout the entire image. Here, the CZCS radiance aerosol file is used only for navigation. Note that the last two methods will greatly slow down the processing time of **ird**, as many more pixels will be processed including all land and water pixels containing no aerosol data. If the second or third method is requested, the program will prompt the user for the default 670 nm radiance value to use. This value should be in uW/cm2/nm and range from 0 255.

This program can determine solar irradiance (SI) at a specified wavelength or photosynthetic available radiation (PAR) over the 350 to 700 nm wavelengths. The user is prompted for the product to generate. If the user enters "PAR", the photosynthetic available radiation will be generated. Note, that the calculation of PAR is an integration and is, therefore, very time consuming. If the user selects SI, the program prompts the user for the desired wavelength. The wavelength must be between 350 and 700 nm.

The output product, either SI or PAR, can also be extended below the surface of the water. If the user selects below the surface, the program will prompt for the wind stress in m/s. The wind stress determines the roughness of the water and its effect on the attenuation through the air-sea interface.

Next several atmospheric parameters will be requested each with an appropriate default. These include: atmospheric pressure in millibars, precipitable water vapor amount in 1/cm, and the aerosol Angstrom exponent. Presently, these are considered constants applied to the entire image. The pressure is used in the Rayleigh computation. The precipitable water is used in the atmospheric attenuation in the near infrared wavelengths. The angstrom exponent is used to characterize the aerosol optical depth in other wavelength besides the 670 nm from the database.

Next, the program needs to know the locations of several databases. It begins by requesting the Total Ozone Mapping Spectrometer (TOMS) database. These files represent a three day composite of ozone for the world. Each file represents one year of ozone values. Once given the TOMS database filename, the program will read the complete database into memory. If an error occurs, the program will stop.

The next required database is the Air Force's RTNEPH (Real-Time Nephanalysis) data base of percent cloud cover. This file is slightly different than what might be received from the Air Force. Due to differences in the way the data was received from the Air Force, a reformatter, **create_dbase.pro**, has been developed under PV-WAVE. Percent cloud cover databases in the NRL format for the years covering the NRL Ocean Optic Database have previously been generated. The databases contain mean monthly cloud cover percentages at three-hour intervals.

The program will generate three output files. A monthly mean solar irradiance image, a monthly mean percent cloud cover image, and a monthly mean ozone image. The program will prompt for the name of each output image. The images will be in PC-SEAPAK format. The header from the input aerosol file will be written to each of these outputs.

Finally, the program will ask whether the user wants a report to be generated. In either case, the program will begin to generate the solar irradiance image.

Conclusions

An example of the output is shown in figure 1. This four panel figure shows in panel 1 the input CZCS 670 nm radiance (aerosols) for June 1979 for region 4 in the Arabian Sea. Each pixel represents an area approximately 18 km. In this example, the first method was used to compute aerosols, in which the 670 nm CZCS data which were non-zero were used to compute solar irradiance. Panel 2 shows the percentage of monthly mean cloud cover. Panel 3 shoes the Total ozone distribution during this time period. Panel 4 shows the June 1979 mean solar irradiance at a single wavelength (490 nm) that occurs just above the sea surface.

Presently this software is operating on a Silicon Graphic Crimson (128 mb, 80 mhz). The model requires about 1 hour to run for a 512 x 512 square area for a single wavelength. It requires approximately 7 hours to complete a 512 square area for a monthly PAR below the surface on this SGI configuration. We are presently porting it to a faster SGI computer.

A summary of the module that comprise the solar irradiance model are listed in the following Appendixes.

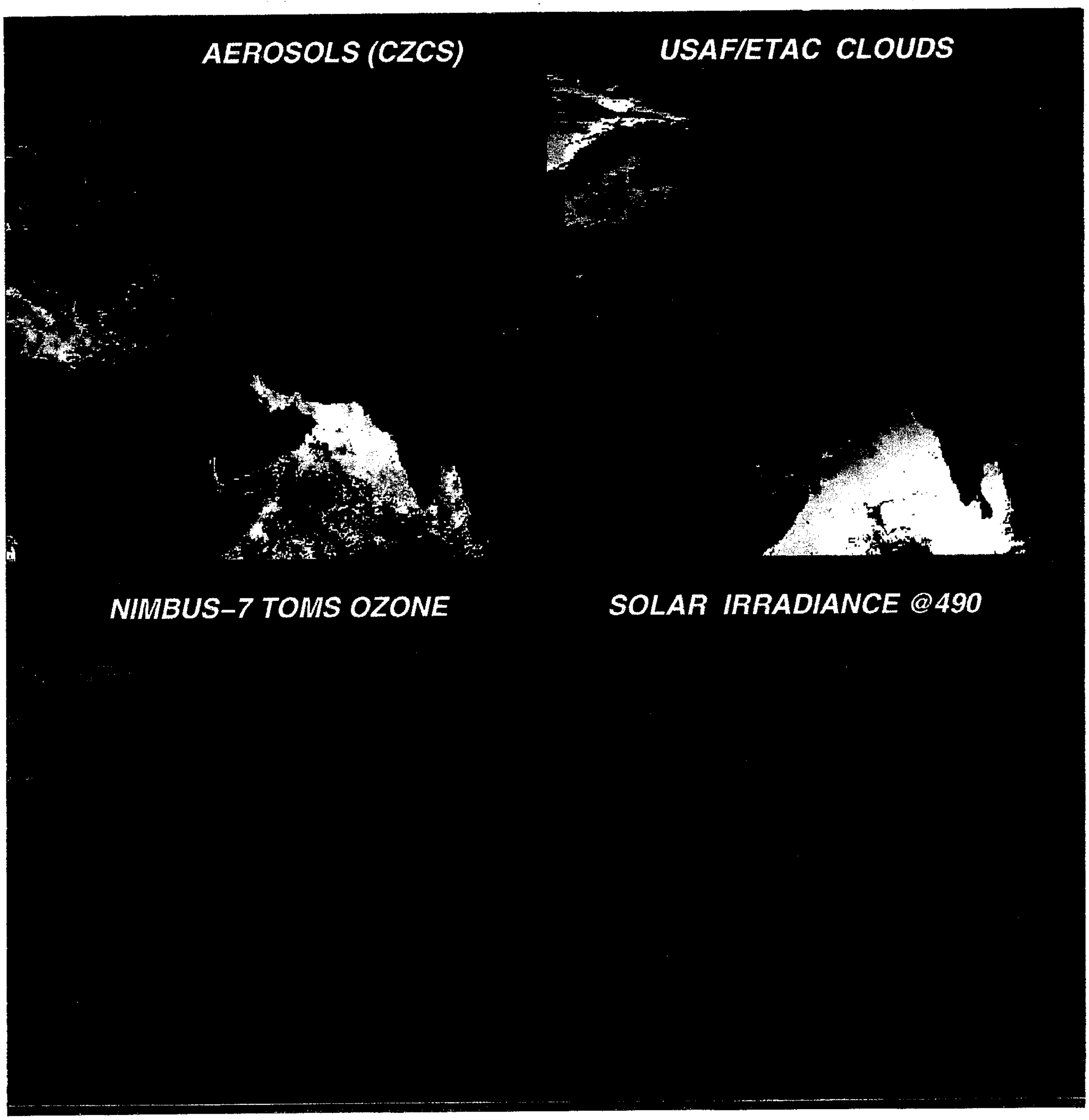
AEROSOLS (CZCS)
USAF/ETAC CLOUDS
NIMBUS-7 TOMS OZONE
SOLAR IRRADIANCE @490

Figure 1

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Arnone, R. A and Oriol, R.A., Terrie, G. and Estep, L. 1992 " Ocean Optical Database" NOARL Technical Note 254, May 1992

Bird, R. E., "A Simple Solar Spectral Model for Direct-Normal and Diffuse Horizontal Irradiance." Solar Energy 32:461-471 1984

Feldman, G., Esaias, W.G, Mc Clain, R.C., Evans, R., Brown, O. and Elrod, J "Ocean Color: Availability of the global data set", EOS Tran. AGU 70(23),643, 1989

Gregg and Carder, "A simple spectral solar irradiance model for cloudless maritime atmospheres", Limon. Oceanograph. 35(8), 1990, pp 1657-1675.

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Appendix

NAME

irradiance - calculate direct sunlight irradiance on a surface

SYNOPSIS

void irradiance (double solar_zenith, double wv_coef, double oz_coef, double gas_coef, double extra_ird, double pressure, double wavelength, double precip, double ozone, double cloud, double la670, double angstrom_exponent, double earth_sun_corr, double rod, double ros, double *total_solarird, double *direct_ird, double *diffuse_ird);

DESCRIPTION

This subroutine calculates the total irradiance at the surface or below the surface of the water based on Gregg and Carder's direct irradiance equation, Haggerty's calculation for Aerosol transmittance, and Lestrade's determination of cloud effects on direct and diffuse irradiance.

METHOD

Step 1. The routine uses Gregg and Carder's direct irradiance equations, which states:

Irr = H*D*cos(zth)*Tr*Toz*Tw*Tug*Ta*(1-rod)

where,

Irr - Direct Solar irradiance
H - Extraterrestrial irradiance in W/m2/um.
D - Earth-Sun distance correction
Tr - Rayleigh scattering transmittance
Toz - Ozone transmittance
Tw - Water vapor transmittance
Tug - Uniform gas transmittance
Ta - Aerosols transmittance
rod - Water surface reflectance

Step 1a. Determine relative, pressure corrected, and ozone air masses.

M = [cos(Z) + 0.15(93.885 - Z)**(-1.253)]**(-1)

where, M is relative air mass and
Z is the apparent solar zenith angle in degrees.

M' = MP/P0

where, M' is pressure corrected airmass,
P is measured surface pressure in millibars, and

P0 is the standard surface pressure (1013.0).

Mo = 1.0035/sqrt[cos(zth)**2+0.007]

where, Mo is the ozone airmass and
zth the solar zenith angle.

Step 1b. Determine the Rayleigh transmittance.

Tr = exp{ -M'/[w**4(115.6406-1.335/w**2)]}

where, Tr is the Rayleigh scattering transmittance,
M' is the pressure corrected air mass, and
w is wavelength (um) .

Step 1c. Determine the water vapor absorption.

Twv = exp{-0.2385*awk*w*0.5]*M
/(1.0+20.07*awk*w*M)**0.45}

where, Twv is the Water vapor transmittance,
awk is the water vapor absorption coefficient at wavelength,
w is the precipitable water in cm in a vertical path, and
M is relative air mass.

Step 1d. Determine ozone transmittance

Toz = exp [- aow*oz*Mo]

where, Toz is the Ozone transmittance,
aow is the ozone absorption coefficient at wavelength w,
oz is the ozone amount in a vertical column in cm, and
Mo is the ozone airmass.

Step 1e. Determine uniformly mixed gases transmittance (oxygen)

Tug = exp[-1.41*auk*M'/(1+118.93*auk*M')**.45]

where, Tug is the uniform gas (oxygen) transmittance,
auk is the absorption coefficient at wavelength w, and
M' is the pressure corrected air mass.

Step 1f. Determine the aerosol transmittance
Step 2. Determine effects of clouds.

Step 3. Add diffuse and direct irradiance to obtain the total irradiance.

REFERENCES

Gregg and Carder, "A simple spectral solar irradiance model for cloudless maritime atmospheres", Limnol. Oceanogr., 35(8), 1990, pp 1657-1675.

Haggerty, et. al, "A Comparison of Surface and Satellite Derived Aerosol Measurements in the Western Mediterranean", J. of Geo-physical Research, Vol. 95, No. C2, pp 1547-1557, 1990.

Lestrade, et al, "The Effect of Cloud Layer Plane Albedo on Global and Diffuse Insolation",Solar Energy Vol.44,No.2, pp.115-121,1990.

NAME

ird - the solar irradiance program

SYNOPSIS

%ird

DESCRIPTION

This program calculates the total solar irradiance for a given wavelength or for PAR (350-700nm) at or below the surface of the water.

SEE ALSO

solar_ird, irradiance

NAME

solar_ird - calculate the surface solar irradiance

SYNOPSIS

void solar_ird (unsigned char *labuf, short *tomsbuf, unsigned char *irdbuf, unsigned char *ozbuf, unsigned char *cldbuf, SEAPAK_HEADER *hd, FILE *fpcldin, FILE *fpird, FILE *fpoz, FILE *fpcldout, char *tmpdir, int str_jday, int end_jday, int str_hour, int end_hour, int n_wvl, int below_surface, double wavelength, double *extra_irds, double *wv_coeffs, double *oz_coeffs, double *gas_coeffs, int verbose, int a_type, double def_aerosol, double angstrom_exponent, double pressure, double precipitation, double wind_speed);

DESCRIPTION

This subroutine loops through an aerosol image and for each pixel determines PAR or irradiance at a specific wavelength at or below the surface of the water for a given day of the year range and hour of day range. Input parameters to the irradiance routine are processed by this subroutine. These include extraction of aerosol value, ozone value, and clouds cover percentage. It also determines the earth-sun distance correction and solar zenith angle. It sums up all the irradiances for a specific pixel and places them into the output image array.

NAME

getlidata - read in the coefficients table

SYNOPSIS

void getlidata(char *file, double extra_irds[], double wv_coeffs[], double gas_coeffs[], double oz_coeffs[]);

where,

file	- name of table.
extra_irds	- extraterrestrial irradiances
wv_coeffs	- water vapor coefficients
gas_coeffs	- gas coefficients
oz_coeffs	- ozone coefficients

DESCRIPTION

This C routine reads an ASCII table of coefficients for the solar irradiance program.

FORMAT

The ASCII table contains four lines at the start which are ignored by this routine. The remaining lines contain 10 fields, where:

Fields 1 and 6	- Wavelength in nm
Fields 2 and 7	- Extraterrestrial Irradiance in 0.1*W/m2/nm
Fields 3 and 8	- Ozone absorption coefficients in 1/cm
Fields 4 and 9	- Gas absorption coefficients in 1/cm
Fields 5 and 10	- Water vapor absorption coefficients in 1/cm

NOTES

Upon return the extraterrestrial irradiance is returned in W/m2/nm.

The wavelength column is ignored by this routine. The solar irradiance program **assumes** a starting wavelength of 350 and an ending wavelength of 700.

NAME

interp - interpolate table values

SYNOPSIS

```
double interp(double *table, int *size, double wavelength)
```

where,

table	- 1-D array containing coefficients
size	- size of table (ignored by this routine)
wavelength	- wavelength in nm (between 350 and 700)

returns,

value	- interpolated coefficient

DESCRIPTION

This routine convert wavelength into an index into the table of coefficients and then interpolates the value.

SEE ALSO

getlidata

NAME

findll1 - determine index of TOMS data via lat/lon position

SYNOPSIS

void findll1(double lat, double lon, int *index)

where,
lat - latitude of requested point
lon - longitude of requested point
index - index of requested data

DESCRIPTION

This function uses calculations to convert the lat/lon position to index into TOMS data.

NAME

getbox

SYNOPSIS

```
void getbox( double lat, double lon, int *in, int *jn, int *box );
```

where,

lat	- latitude of interest
lon	- longitude of interest
in	- column number within box (1-64)
jn	- row number within box (1-64)
box	- box number within hemisphere (1-64, excluding 1, 8, 57, 64)

DESCRIPTION

Uses equations obtained by the US Air Force for converting latitude and longitude into box, i, j locations for their RTNEPNH (Real-Time Nephanalysis) Climatic database.

NAME

getclouds - get cloud percentage at lat/lon point

SYNOPSIS

```
double getclouds( double lat, double lon, int month,
     int hour, FILE *fpcld );
```

where,

lat	- latitude in degrees
lon	- longitude in degrees
month	- month of year (1-12)
hour	- hour of day (GMT, 0-23)
fpcld	- FILE pointer to clouds database

returns

cloud	- cloud percentage

DESCRIPTION

Subroutine getclouds retrieves the percent cloud value from the RTNEPH cloud database for the specified latitude / longitude position. The year, month and hour are also inputs. Note that the database contains a monthly average of the cloud amount at eight (8) three (3) hour intervals (i.e. 0-2, 3-5, ..., 21-23).

NOTES

The cloud file must be opened prior to calling this routine.

NAME

solar_angs - compute sun azimuth and zenith angles

SYNOPSIS

void solar_angs(int iday, int hr, double rad, double lon, double lat, double *suna, double *sunz);

DESCRIPTION

Computes sun azimuth and zenith angles for a given time, date, latitude and longitude. This program is from the NMFS ELAS computer code. Modified for standard coordinates (W long. negative), to correct for dateline problem, and to correct coefficients (taken from Iqbal, 1983, An Introduction to Solar Radiation). Watson Gregg, Research and Data Systems, Corp.

NAME

surface_reflectance - computes surface reflectance

SYNOPSIS

void surface_reflectance(double rad, double theta, double ws, double *rod,double *ros);

DESCRIPTION

Computes surface reflectance for direct (rod) and diffuse (ros) components separately, as a function of theta, wind speed or stress.

REFERENCE

Gregg and Carder, "A simple spectral solar irradiance mode for cloudless maritime atmospheres", Limon. Oceangr. 35(8), 1990, pp 1657-1675.

NAME

julday_month.c

SYNOPSIS

int julday_month(int year, int julday);

DESCRIPTION

This C subroutine converts a julian day to month.

NAME

julian_to_month - return month given year and julian day.

SYNOPSIS

int julian_to_month(int year, int julday);

DESCRIPTION

This C subroutine converts a julian day to month.

NAME

solar_angs - compute sun azimuth and zenith angles

SYNOPSIS

void solar_angs(int iday, int hr, double rad, double lon, double lat, double *suna, double *sunz);

DESCRIPTION

Computes sun azimuth and zenith angles for a given time, date, latitude and longitude. This program is from the NMFS ELAS computer code. Modified for standard coordinates (W long. negative), to correct for dateline problem, and to correct coefficients (taken from Iqbal, 1983, An Introduction to Solar Radiation). Watson Gregg, Research and Data Systems, Corp.