Daily Production in a Layer – Series Expansion of Analytic Solution

NAME

dwcpa – daily production for a layer in a vertically-uniform water-column

SYNOPSIS

`dwcpa [filename]`

The program has two operating modes, depending on whether a filename is provided on the command line. If no filename is provided, the program will provide an interactive data entry screen (Figure 1).

If the name of a suitable data file (extension "`.dat`") is provided, the program will run in "batch" mode and will create two new files (overwriting any existing files of the same name). The names of the new files are obtained by first removing any extension to obtain the "basename". The program will read data from "`basename.dat`", and will write the results on "`basename.out`". A processing log will be written on "`basename.log`".

PURPOSE

This program calculates estimates of daily production for layer in a vertically-uniform water-column using a truncated series expansion of the analytic solution[1] obtained by Platt *et al.* (1990).

DESCRIPTION

This program computes the total daily production for a layer as described below (see THEORY).

For each input data record, the program computes the day-length, D, the maximum (local noon) surface irradiance, I_0^m, the photoadaptation parameter, $I_k = P_m^B/\alpha^B$ and the dimensionless irradiance at local noon, $I_*^m = I_0^m/I_k$. The estimate for daily primary production in the layer from Z_1 to Z_2 is computed using a truncated series expansion of the analytic solution.

The requirement for a uniform water column need only hold for depths from the surface to the bottom of the layer (Z_2). Thus an important application is to compute production in the mixed-layer ($Z_1 = 0$, $Z_2 = Z_m$, where Z_m is the depth of the mixed layer).

[1] Note that the current program uses the new scaling introduced by Platt and Sathyendranath (1993). The result is that the values for $f(I_*^m)$ are lower by a factor of π than in the original paper, while values of the scale factor, A, are correspondingly higher.

```
Select variable, press [Enter] to edit:

** Exit (accept current values)
Latitude: 60.000  (decimal degrees, [-90 .. 90])
Longitude: -30.000 (decimal degrees, [-180 .. 180])
Day number: 165 [1=Jan 1st .. 365]
Initial slope of P-I curve, alphaB: 0.100 (mg C/(mg Chl)/h/(W/m^2))
Assimilation number, P_mB: 3.000 (mg C/(mg Chl)/h)
Biomass: 1.000 (mg Chl/m^3)
Diffuse vertical attenuation coefficient for irradiance: 0.100 (1/m)
Depth to top of layer: 0.000 (m)
Depth to bottom of layer: 200.000 (m)

            Results
Status code: 0 (0=OK, ...)
Day length: 18.400 (h)
Dimensionless irradiance at local noon: 11.477
Daily production for the layer: 1314.100 (mg C/m^2)
```

Figure 1. Interactive data entry screen for daily production in a layer.

THEORY

The absolute daily production for a layer is defined by the integral over depth and time:

$$P_{Z_1,Z_2,T} = \int_0^D \int_{Z_1}^{Z_2} B(z) P^B(z,t)\,\mathrm{d}z\mathrm{d}t, \tag{1}$$

where $B(z)$ is the biomass concentration (mg Chl m^{-3}), D is the day-length (h), Z_1 is the depth to the top of the layer (m), Z_2 is the depth to the bottom of the layer (m), and $P^B(z,t)$ is the primary production rate normalized to biomass (mg C (mg Chl)$^{-1}$ h^{-1}) as a function of depth, z (m) and time, t (h).

Platt *et al.* (1990) obtained an analytic expression for $P_{0,\infty,T}$ in the case of a uniform water-column (*i.e.*, B, K, α^B, and P_m^B are all constant) and assuming sinusoidal variation of irradiance through the day. This expression is a power series expansion of the canonical function:

$$f(I_*^m) = \frac{P_{0,\infty,T}}{A},$$

where $A = BDP_m^B/K$ is the scale factor with dimensions mg C m^{-2}. The series is truncated for numerical evaluation.

Given an expression for the canonical function f, an estimate for $P_{Z_1,Z_2,T}$ is obtained using the following equation (Eqn. 45 of Platt and Sathyendranath (1993) with $K_1 = K_2 = K$):

$$P_{Z_1,Z_2,T} = A \times [f(I_*^m e^{-Z_1 K}) - f(I_*^m e^{-Z_2 K})]. \tag{2}$$

It is important to note that (2) remains valid when the water-column properties are constant from the surface to the bottom of the layer.

Input

The input data file consists of a two-line header followed by one or more data records. Each data record consists of values for location (latitude and longitude), the day number, photosynthesis–light parameters (α^B and P_m^B), biomass B, attenuation coefficient, K, and the depths Z_1 and Z_2. The data file corresponding to Figure 1 is:

```
Latitude Longitude Day  alphaB     P_mB     B        K      Z_1     Z_2
(f6.2,x,f11.2,x,i3,x,f8.3,x,f8.3,x,f8.3,x,f8.3,x,f7.2,x,f7.2)
 60.00      -30.00 165    0.100    3.000    1.000    0.100    0.00  200.00
```

The fields in each input data record are as follows:

1) latitude (decimal degrees, $-90°$ at the South pole to $+90°$ at the North pole);
2) longitude (decimal degrees), although not required for the production calculations, is often useful in subsequent processing;
3) day number, an integer running from 1 to 365;
4) α^B, the initial slope of the photosynthesis–light curve (mg C (mg Chl)$^{-1}$ h^{-1} (W m^{-2})$^{-1}$);
5) P_m^B, the assimilation number (mg C (mg Chl)$^{-1}$ h^{-1});
6) biomass, B, (mg Chl m^{-3});
7) diffuse vertical attenuation coefficient for irradiance, K, (m^{-1});
8) depth, $Z_1 \geq 0$, to top of layer (m);
9) depth, $Z_2 > Z_1$, to bottom of layer (m);

Output

The output file also consists of a two-line header followed by one output data record for each input record. The output file corresponding to Figure 1 is:

```
Latitude Longitude Day status daylength I_*M  P_Z1Z2T
(f6.2,4x,f7.2,2x,i3,4x,i2,4x,f5.2,2x,f6.3,x,f7.1)
 60.00     -30.00  165     0    18.40  11.477  1314.1
```

The corresponding log file is:

```
Daily water-column production -- truncated power series solution

Program: BIN\DWCPA.EXE:
 Output file: dwcpa.out
 Log file:    dwcpa.log
 Input file:  dwcpa.dat

Limits:
 Value of epsilon in test (Daylength > epsilon):    .10000E-05
 Number of terms, N, in truncated series expansion:  50
```

```
Summary:
     3 records processed (including two header records)
No processing errors.
```

The first two output records form the output data header, and are followed by one or more output data records. By convention, the first output record lists the output variables. The second output record provides the FORTRAN format statement required to read the remaining output (data) records.

The fields in each output data record are as follows:

1) latitude (decimal degrees, $-90°$ at the South pole to $+90°$ at the North pole);
2) longitude (decimal degrees), although not required for the production calculations, is often useful in subsequent processing;
3) day number, an integer running from 1 to 365;
4) status code (a status of 0 indicates no error, see DIAGNOSTICS for other codes);
5) day length, D (h);
6) dimensionless irradiance at local noon, I_*^m; and
7) daily production for the layer (mg C m^{-2})

PROCESSING

The input data records are processed in a loop that reads one input data record, processes the data, and writes the corresponding output record. The longitude is not used in the calculations, but is stored as a double precision value and reproduced unchanged in the output data record.

SPECIAL CASES

Two cases require special handling: a) the case where the noon zenith angle exceeds $80°$, and b) the case of twenty-four hour darkness (*i.e.*, day length is zero). In the latter case, total daily production, $P_{Z_1,Z_2,T}$, for the layer and noon irradiance, I_*^m, are set to zero. In the case where day length is not zero but the noon zenith angle exceeds $80°$, the values of $P_{Z_1,Z_2,T}$ and I_*^m are set to missing value codes. In both cases, the status code is set to a positive value (see DIAGNOSTICS).

FILES

In addition to the binary executable program, one input data file is required. Two new files will be created, an output data file and a log file containing a record of the processing (previously existing files having the same names will be destroyed without warning). Each file is identified by its extension (the three letters following the "`.`" character):

1) the program (executable) itself (`.exe` extension);
2) input data (ASCII text, `.dat` extension);
3) processing log (ASCII text, `.log` extension); and
4) output data (ASCII text, `.out` extension).

All the names are determined from the command line at run time (*i.e.*, the program does not rely on any "hard-coded" file names). When no file name is given on the command line, the program creates the file "`dwcpa.dat`" using values entered interactively by the user. In this case, the output files will be "`dwcpa.log`" and "`dwcpa.out`".

Requirements

The numerical calculations are not demanding. An effort has been made to ensure that the results will remain consistent across a range of hardware platforms. It is assumed that double precision variables conform to the IEEE floating point arithmetic standard. This is the most efficient data type for floating point computations on modern microprocessors with hardware floating point support.

To run the program under MS-DOS, approximately 400k bytes of free memory are required. The `ansi.sys` device driver must be loaded in `config.sys`.

Bugs

The analytic solution used here assumes a sinusoidal pattern for irradiance over the day. This assumption breaks down for high latitudes in the summer.

Limits

The number of terms, N, in the truncated series expansion, is shown in the log file.

Diagnostics

The following messages may occur:

`warning: could not determine noon irradiance`

This warning will be issued when the value for I_0^m cannot be determined. The output status will be set to 1 and the remaining output variables will be given negative values.

`warning: 24 hour darkness`

This warning will be issued when the day-length is zero. The output status will be set to 2 and the remaining output variables will be given values of zero.

`warning: negative zenith angle`

This warning will be issued when the computed zenith angle at noon is less than zero. The output status will be set to 5 and the remaining output variables will be given negative values.

`warning: zenith angle exceeds 80 degrees`

This warning will be issued when the computed zenith angle at noon exceeds 80°. The output status will be set to 6 and the remaining output variables will be given negative values.

`warning: latitude lies outside domain of the approximation`

This warning will be issued when the latitude lies outside the range for which the assumption of sinusoidal variation in surface irradiance is valid. The output status will be set to 7 and the remaining output variables will be given negative values.

`warning: depth Z1 .gt. Z2`

This warning will be issued when the depth to the top of the layer exceeds that of the depth for the bottom of the layer. The output status will be set to 8 and a negative value assigned to the production.

`warning: dimensionless irradiance lies outside domain of the approximation`

This warning will be issued when the computed dimensionless irradiance at local noon exceeds 20. The output status will be set to 9 and the remaining output variables will be given negative values.

`** error in get_files **`

An error occurred in the `get_files` subroutine. This message will be preceeded by a message indicating the type of error that occurred.

`** error ** file I/O`

An error occurred while reading or writing a file. This could indicate a missing or corrupted file, a disk problem such as lack of space, or a program which uses more files than the operating system configuration allows (many systems limit the number of files a program can use; in some cases the user may be able to increase this number via a configuration option).

`** error ** getarg`

The system function used to obtain the command line parameters returned an error. This may indicate lack of memory, an incompatible command processor, or a command line that is too long.

`** error ** name too long: ...`

A program or file name was too long.

`** error ** limit exceeded: too many files to read`

This is an internal program error which should not occur. The list of input file extensions passed to the subroutine has more entries than the number of files requested.

`** error ** limit exceeded: too many files to write`

This is an internal program error which should not occur. The list of output file extensions passed to the subroutine has more entries than the number of files requested.

`** error ** opening file ...`

The indicated file could not be opened. The file name may have been entered incorrectly or the file may have a hidden, read-only, or system attribute.

`** I/O error **`

An error occurred while reading from or writing to a file or the console. This could indicate a missing or corrupted file, a disk problem such as lack of space, a buffer overflow, or a control character inadvertently entered from the keyboard.

`-- End of file --`

This is not always an error, but may indicate a file that has been truncated or damaged.

`** error:  input file(s) **`

A problem occurred with an input file. The file name passed to the program may be incorrect, or the file may have a hidden or system attribute.

`** error:  output file(s) **`

A problem occurred with an output file. The file name passed to the program may be incorrect or the file may have a hidden, system, or read-only attribute.

`** error:  input record format **`

The input record format (obtained from the second line of the input file) did not have the required number and types of fields.

References

Platt, T. and S. Sathyendranath (1993), 'Estimators of primary production for interpretation of remotely sensed data on ocean color', *J. Geophys. Res.* **98**, 14561–14576.

Platt, T., S. Sathyendranath, and P. Ravindran (1990), 'Primary production by phytoplankton: Analytic solutions for daily rates per unit area of water surface', *Proc. Roy. Soc. London, Ser. B* **241**, 101–111.

NOTATION

α^B	initial slope of the relationship between production and irradiance, defined as $\partial P^B/\partial I\|_{I\to 0}$, mg C (mg Chl)$^{-1}$ h^{-1} (W m^{-2})$^{-1}$.
B	biomass, as concentration of chlorophyll *a*, mg Chl m^{-3}.
D	day length, hours.
f	function of I_*^m arising in dimensional analysis and in canonical form, of solution for daily primary production, dimensionless.
I_0^m	maximum surface irradiance at local noon, W m^{-2}.
I_*^m	dimensionless irradiance at local noon, $I_*^m \equiv I_0^m/I_k$.
I_k	photoadaptation parameter of the photosynthesis–light curve, $I_k \equiv P_m^B/\alpha^B \equiv P_m/\alpha$, W m^{-2}.
K	diffuse vertical attenuation coefficient for irradiance, $K = -I^{-1}(dI/dz)$, m^{-1}.
P^B	primary production rate normalized to biomass, $P^B \equiv P/B$, mg C (mg Chl)$^{-1}$ h^{-1}.
$P_{Z_1,Z_2,T}$	daily primary production for the layer $Z_1 \le z \le Z_2$, mg C m^{-2}.
P_m^B	assimilation number, specific production at saturating light, in the absence of photoinhibition, $P_m^B = P^B\|_{I\to\infty}$, mg C (mg Chl)$^{-1}$ h^{-1}.
z	depth (origin at surface, positive downwards), m.
Z_1	depth (m) to top of layer.
Z_2	depth (m) to bottom of layer.