Daily Water-Column Production – Numerical Integration of Spectral Model

NAME

dwcpn – daily, water-column production by numerical integration of a spectral model

SYNOPSIS

`dwcpn [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, water-column production by numerical integration of a spectral model.

DESCRIPTION

This program computes the total daily, water-column production as described below (see THEORY). The chlorophyll profile is modelled by a shifted-Gaussian curve (Figure 2), as described in Platt *et al.* (1994). Direct and diffuse components of the surface irradiance are computed using the clear sky, spectral irradiance model of Bird (1984), as adapted by Sathyendranath and Platt (1988), to give the spectral downwelling irradiance $I_0(\lambda, t)$ (Watts·m^{-2}) at the surface for a given location and zenith angle.

For each input data record, the program computes day length, D, surface irradiance, $I_0(\lambda, t)$, for 13 equally-spaced time steps from dawn to noon and 61 wavebands. An estimate for primary production is computed at each time step by integrating from the surface to the photic depth, and over wavelength. Total daily production is obtained by integrating from dawn to noon and doubling the result.

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

** Exit (accept current values)
Latitude: 30.00  (decimal degrees, [-90 .. 90])
Longitude: -60.000 (decimal degrees, [-180 .. 180])
Day number: 15 [1=Jan 1st .. 365]
Initial slope of P-I curve, alphaB: 0.106 (mg C/(mg Chl)/h/(W/m^2))
Assimilation number, P_mB: 3.670 (mg C/(mg Chl)/h)
Depth of chlorophyll maximum: 74.700 (m)
Background component of chlorophyll-depth profile: 0.086 (mg Chl/m^3)
Gaussian height parameter: 43.000 (mg Chl/m^2)
Gaussian scale parameter, sigma: 56.300 (m)


          Results
Status code: 0 (0=OK, ...)
Day length: 10.270 (h)
Total surface irradiance: 1643.400 (Watts/m^2/d)
Daily water-column production: 255.000 (mg C/m^2)
```

Figure 1. Interactive data entry screen for daily water-column production .

THEORY

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

$$P_{Z,T} = \int_0^D \int_0^\infty B(z) \int_{PAR} \Pi(z, \lambda, t)\, \mathrm{d}\lambda \mathrm{d}z \mathrm{d}t, \tag{1}$$

where $\Pi = P_m^B(1 - \exp(-\alpha^B(\lambda)I(z,\lambda,t)/P_m^B)$ is the rate of photosynthesis (mg C (mg Chl)$^{-1}$ h^{-1}(nm)$^{-1}$) as a function of depth, z (m), wavelength, λ (nm), and time, t (h); D is the day length (h); $B(z)$ is the biomass (mg Chl m^{-3}); $\alpha^B(\lambda)$ is the photosynthetic action spectrum (mg C (mg Chl)$^{-1}$(W m^{-2})$^{-1}$ nm^{-1}); $I(z,\lambda,t)$ is the available light (W m^{-2}); and P_m^B is the assimilation number (mg C (mg Chl)$^{-1}$ h^{-1}).

A Gaussian profile was used by Lewis *et al.* (1983) to describe the vertical distribution of chlorophyll biomass in the ocean. Later, Platt *et al.* (1988) introduced a shifted-Gaussian, that is a Gaussian superimposed on a constant background, to provide a more versatile profile (Figure 1 of Platt *et al.* (1994). It allows one to match the surface values without compromising the structure of the rest of the profile. This is the standardised profile that has been adopted by subsequent authors (Morel and Berthon 1989, Sathyendranath and Platt 1989, Sathyendranath *et al.* 1989, André 1992, Gordon 1992). It has been found that a shifted-Gaussian provides a suitable description of the vertical distribution of chlorophyll at a wide range of locations in the ocean. Explicitly,

$$B(z) = B_0 + \frac{h}{\sigma\sqrt{2\pi}} \exp\left[-\frac{(z - z_m)^2}{2\sigma^2}\right] \tag{2}$$
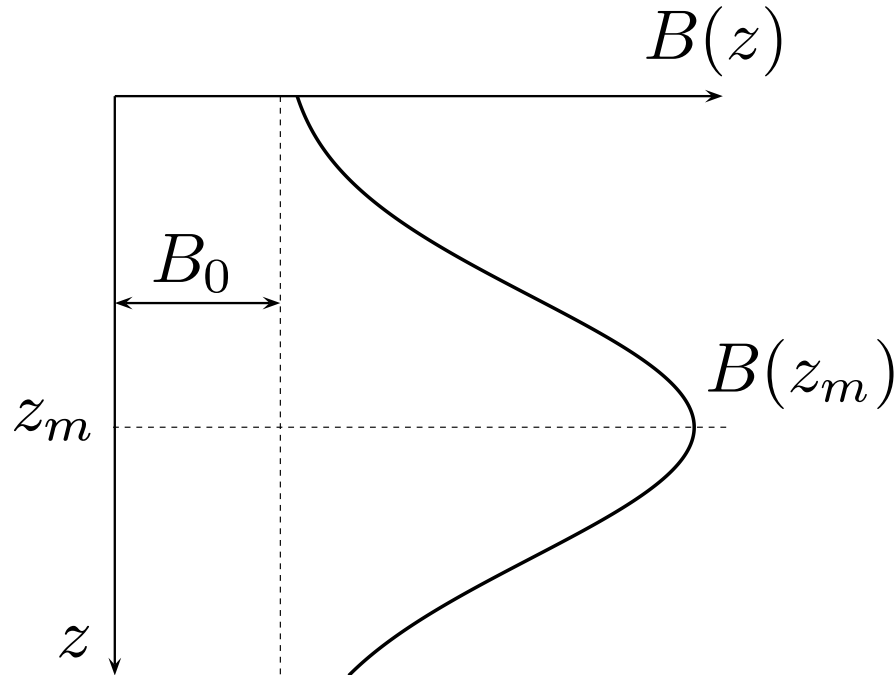
Figure 2. Shifted-Gaussian model for biomass–depth profile.

where a background biomass B_0 has superimposed on it a Gaussian curve (Figure 2) with parameters z_m, the depth of the chlorophyll maximum; σ, a measure of the thickness or vertical scale of the peak; and h, the total biomass in the peak such that $h/(\sigma\sqrt{2\pi})$ is a measure of the height of the peak above background.

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), and biomass parameters (z_m, B_0, h, and σ). The data file corresponding to Figure 1 is:

```
Latitude Longitude Day alphaB  P_mB   z_m   B_0        h    sigma
(f6.2,x,f11.2,x,i3,x,f6.4,x,f6.2,x,f6.2,x,f7.5,x,f6.2,x,f6.2)
 30.00      -60.00  15 0.1060   3.67  74.70 0.08600  43.00  56.30
```

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), format $f w.p$;
2) longitude (decimal degrees), format $f w.p$, although not required for the production calculations, is often useful in subsequent processing;
3) day number, an integer running from 1 to 365, format $i w$;

4) α^B, the initial slope of the photosynthesis–light curve (mg C (mg Chl)$^{-1}$ h^{-1} (W m^{-2})$^{-1}$), format $\mathtt{f}w.p$;

5) P_m^B, the assimilation number (mg C (mg Chl)$^{-1}$ h^{-1}), format $\mathtt{f}w.p$;

6) "depth[1]" of the chlorophyll maximum, $-999.999 \leq z_m \leq 9999.999$ (m), format $\mathtt{f}w.p$;

7) the background component, $0 \leq B_0 \leq 9999.999$ (mg Chl m^{-3}), format $\mathtt{f}w.p$;

8) height parameter for the Gaussian component, $0 \leq h \leq 9999.999$ (mg Chl m^{-2}), format $\mathtt{f}w.p$; and

9) Gaussian scale parameter, $0.001 \leq \sigma \leq 9999.999$ (m), format $\mathtt{f}w.p$.

OUTPUT

This program takes much longer to execute than any of the other programs in this package. To provide an indication of progress, a short message is printed for each time step. The number of time steps for which the calculation is performed will vary depending on the input data because no calculation is done for times at which the zenith angle exceeds $80°$.

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   D     I_T   P_ZT
(f6.2,4x,f7.2,2x,i3,5x,i2,x,f5.2,x,f6.1,x,f7.1)
 30.00     -60.00   15      0 10.27 1643.4   255.0
```

The corresponding log file is:

```
Daily water-column production -- numerical integration of spectral model

Program: \PROJECTS\SOFTWARE\TEST\BIN\DWCPN.EXE
 Output file: dwcpn.out
 Log file:    dwcpn.log
 Input file:  dwcpn.dat

Limits:
  Value of epsilon in test (Daylength > epsilon):    .10000E-05
  Maximum depth (m):    250.50
  Depth increment (m):    .50000

Messages:

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

---

[1] In rare cases the fitting procedure will yield a negative estimate for z_m, *e.g.*, for two of the 28 cases shown in Table 3 of Platt *et al.* (1991), representing only three profiles in a data set of more than 600 profiles.

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) total daily surface irradiance, I_T (Watts m^{-2}d^{-1}); and
7) daily, water-column production (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, $P_{Z,T}$, and total irradiance, I_T, are set to zero. In the case where day-length is not zero but the noon zenith angle exceeds $80°$, the values of $P_{Z,T}$ and I_T 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 "`dwcpn.dat`" using values entered interactively by the user. In this case, the output files will be "`dwcpn.log`" and "`dwcpn.out`".

REQUIREMENTS

The numerical calculations are time consuming but not otherwise 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 software cannot easily be revised to allow computation of production in an arbitrary layer.

LIMITS

The maximum depth, depth increment used in the numerical integration, and the value of *epsilon* are 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 $I_0(t)$ cannot be determined at noon. 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 output variables which cannot be computed will be given negative values. The value for day-length, D, will, however, be provided.

```
warning:  zenith angle exceeds 80 degrees
```

This warning will be issued when the 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.

```
** 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

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NOTATION

α^B	initial slope of relationship between photosynthesis and irradiance, $\alpha^B \equiv \partial P^B / \partial I \vert_{I \to 0}$, mg C (mg Chl)$^{-1}$ h^{-1}(W m^{-2})$^{-1}$.
$\alpha^B(\lambda)$	photosynthetic action spectrum, mg C (mg Chl)$^{-1}$(W m^{-2})$^{-1}$ nm^{-1}.
B	biomass, as concentration of chlorophyll a, mg Chl m^{-3}.
$B(z)$	chlorophyll concentration as a function of depth, mg Chl m^{-3}.
B_0	background concentration in the shifted-Gaussian model, mg Chl m^{-3}.
D	day-length, hours.
h	parameter for the amplitude of the chlorophyll maximum in the shifted-Gaussian model, mg Chl m^{-2}.
$I_0(\lambda, t)$	downwelling irradiance at the surface, Watts·m^{-2}·nm^{-1}.
$I(z, \lambda, t)$	available light at depth z.
I_T	total irradiance at the surface, Watts· m^{-2}d^{-1}.
$\Pi(z, \lambda, t)$	rate of photosynthesis, mg C (mg Chl)$^{-1}$ h^{-1}(nm)$^{-1}$.
$P_{Z,T}$	daily water-column primary production, mg C m^{-2}.
P_m^B	assimilation number, specific production at saturating light, in the absence of photoinhibition, $P_m^B = P^B \vert_{I \to \infty}$, mg C (mg Chl)$^{-1}$ h^{-1}.
σ	scale parameter for the width of the peak in the shifted-Gaussian model, m.
z	depth (origin at surface, positive downwards), m.
z_m	"depth" (in rare cases, the value of z_m may be negative) of chlorophyll maximum, in the shifted-Gaussian model, m.