PART 2.1.: DEFINITIONS AND PARAMETERIZATIONS

By definition below we mean a word definition if you wish but primarily the formula with which it is derived. Please ensure you also define the symbols used for environmental parameters such as sea surface temperature or latitude.

1. How do you define the euphotic depth?

- Z_{eu} = depth where PAR (photosynthetically available radiation) is reduced to 1% of its "just-below-the-surface" value (antoine, heidi, nick, scardi, tim).
- Morel's Case I model, Morel and Berthon, 1989, 1% light level (Behrenfeld, ishizaka, modis_bf) :
  Chl = satellite chlorophyll A (mg m^{-3})
  Chl_{eu} = total Chl in the water column defined by Morel

  $$Chl_{eu} = 38.0 * Chl^{0.425} \quad \text{if } (Chl < 1.0)$$
  $$Chl_{eu} = 40.2 * Chl^{0.507} \quad \text{else}$$

  $$Z_{eu} = 68.89 * Chl^{-0.125} \quad \text{if } Chl < 0.0435$$
  $$Z_{eu} = 37.67 * Chl^{-0.317} \quad \text{if } 0.0435 \leq Chl < 1$$
  $$Z_{eu} = 36.12 * Chl^{-0.378} \quad \text{if } Chl \geq 1$$
- Not used (modis_hyr which uses the mixed-layer as a bounding limit)
- Not defined in the model (tasha, waters).

For MODIS product generation, a shallow water mask is used to filter out the worst cases where Z_{eu} goes below the ocean bottom. The mask indicates regions where the ocean depth is < 30m, for which the integration depth is capped at 30m.

2. If you estimate a vertical profile of biomass, how do you do this?

- asanuma :
  $Chl(z) = [0.1 - 0.7 * Chl_0 * \mathrm{e}^{-0.8*PAR\%(z,Chl_0)}] * \mathrm{e}^{-0.8*PAR\%(z,C_0)} + C_0$
- antoine :
  This is done following Morel and Berthon (1989), i.e., the shape of the profile is determined from the surface chlorophyll value, with a chlorophyll maximum that decreases in amplitude and comes closer to the surface as the concentration increases.

This formulation is used as long as the euphotic depth is greater than the mixed-layer depth. In the opposite case, a homogeneous profile is considered, with a constant value equal to the surface value.

- modis_bf :
  An integrated chlorophyll calculation is imbedded in Morel and Berthons' model (see question 1). The actual code includes the following calculation, which was folded into the relationship given in the answer to question 1. The relationships described in question 1 are actually calculated in the model code as follows :

  $$\begin{array}{ll} Chl_{eu} = 38.0 * Chl^{-0.425} & \text{if } Chl < 1 \text{ mg m}^{-3} \\ Chl_{eu} = 40.2 * Chl^{-0.507} & \text{if } Chl \geq 1 \text{ mg m}^{-3} \end{array}$$

  $$\begin{array}{ll} Z_{eu} = 200.0 * (Chl_{eu})^{-0.293} & \text{for } Z_{eu} > 102.0 \text{ m} \\ Z_{eu} = 568.2 * (Chl_{eu})^{-0.746} & \text{otherwise} \end{array}$$

  where the order of steps is important. The integrated chlorophyll quantity, Chl_{eu}, is related to the biomass, but is actually an auxiliary calculation for the P1 (VGPM) model.

- nick :
  The vertical profile of biomass is a gaussian defined by the triplet $[z_m, \sigma, \rho]$ according to Longhurst's provinces and season.
  The maps of profiles' parameter have been subsequently smoothed spatially. Therefore, the resulting maps of production don't show discontinuities at the provinces' boundaries. This is done for aesthetic reasons and because there is no reason that those fields be discontinuous. Four seasons are considered, and there is a weighting according to the month number (for instance, the calculation for January uses the parameters for winter with the weight 1; the calculation for February uses the parameters for winter with the weight 2/3, and the one for spring for 1/3).
  The satellite chlorophyll is considered as surface value and is used to scale the gaussian.

- The vertical profile of biomass is taken constant (tim, waters).

- Not applicable for behrenfeld, heidi, ishizaka, modis_hyr, scardi and tasha.

3a. How do you define the diffuse attenuation coefficient for PAR? If applicable, how is it defined for each wavelength or range of wavelengths?

- anasuma :

$$\begin{aligned} K_d &= \ln(PAR(z)/PAR(0))/Z_{eu} \\ &= -0.0018 * Chl_0^3 + 0.022 * Chl_0^2 - 0.11 * Chl_0 - 0.024 \end{aligned}$$

- antoine :
  Definition : $K_d(z,\lambda) = -d\ln(E_d(z,\lambda))/dz$
  Practical way to compute it : $K_d(z,\lambda) = k_w(z,\lambda) + \chi(\lambda)\, Chl^{e(\lambda)}$,
  where $k_w(\lambda)$ is for sea water itself ($k_w(\lambda) = a_w(\lambda) + b_w(\lambda)/2$), and where the coefficient $\chi(\lambda)$ and the exponent $e(\lambda)$ have been derived from a large set of in situ determination of K_d and Chl (Morel and Maritorena, 2001; see their Table 2 in particular).
  Spectral step is 5 nm.

- behrenfeld :
  The diffuse attenuation coefficient is calculated as the average value for the euphotic depth and taken as $-\ln(0.01)/Z_{eu}$, where Z_{eu} is calculated as described in question 1, i.e. :
  $K_d = 4.6/Z_{eu}$ (inverse of penetration depth).

- modis_hyr :
  The calculation of K_d(PAR) follows Nelson and Smith (1991) and has the following form:

$$K_d(\mathrm{PAR}) = 0.04 + 0.0088 * Chl + 0.054 * Chl^{0.66}$$

  PAR is assumed to be over the range 400-700nm.

- nick :
  mean$K(PAR) = 4.6/Z_{eu}$.
  K_d for downwelling irradiance is computed separately for direct and diffuse downwelling irradiance Ed_d and Ed_s, as $K_d = (a + b_b)/\mu$ where μ is the mean cosine for downwelling light, direct or diffuse.
  a and b_b are total absorption and back-scattering coefficients (in m^{-1}). All variables are spectral.

- scardi :
  The (downwelling) diffuse attenuation coefficient K_d is defined as follows :
  $K_d(z) = -1/E_d(z) * dE_d(z)/dz$ (same as antoine),

where z is the depth, $K_d(z)$ is the (downwelling) diffuse attenuation coefficient at depth z and $E_d(z)$ is the downwelling irradiance at depth z.
The formulation I used for PPARR3 doesn't use K_d as a predictive variable. If I use K_d too, the model provides better estimates, but I excluded this variable because it is only useful if its measurements are independent of those for chlorophyll. If K_d is estimated as a function of Chl, then it doesn't provide new info for the neural network model.

- tasha :

$$K_d = [a_w + b_w + a_{det} + a_{dissolved} + chl_a * (a_{chl} + b_{chl})]/\mu$$

a_w = absorption coefficient for water (m^{-1})
b_w = backscatter coefficient for water (m^{-1})
a_{det} = absorption coefficient for detritus (m^{-1})
$a_{dissolved}$ = absorption coefficient for dissolved matter (m^{-1})
chl_a = chlorophyll a concentration (mg m^{-3})
a_{chl} = absorption coefficient for phytoplankton (m^2 mg^{-1})
b_{chl} = backscatter coefficient for phytoplankton (m^2 mg^{-1})
$\mu = 0.75$
The coefficients are wavelength dependent.

- tim :
The value of spectral K is a sum of k_w (pure water) and k_c (chlorophyll) using the lookup tables of Morel 1991.

- waters :
K_d is calculated using the simple approximation in Kirk (1983):
$K_d = a/u_d + b_b/u_d - R_{b_b}/u_u$
where a is the absorption coefficient,
b_b is the backscattering coefficient,
u_d is the average cosine of the downwelling light field (= μ for nick and tasha),
R is the reflectance (= 0.33 b_b/a),
u_u is the average cosine of the upwelling light field (assumed = 0.5).
The values of u_d are parameterized based on Bannister (1993).
Absorption and scattering coeffs are obtained by splitting into parts as
$a = a_w + a_{ph} + a_{CDM}$
$b_b = b_w + b_{ph}$
The backscattering coefficients (b_b) are calculated by assuming pure water has a Rayleigh type phase function and the other scatterers have a phase function similar to that found by Petzold (1972) in San Diego Harbor.
a_w is based on Pope's measurements
a_{ph} is based on Bricaud's (1995) measurements
a_{CDM} can be set in a variety of ways, including as a function of a_{ph} as given in

Prieur and Sathyendranath (1981). I should have run the model with that set, but I forgot to do so.

- Not applicable for heidi, ishizaka and modis_bf (not calculated directly in this case).

4a. We provide you with a daily integrated PAR above the sea surface (E0+). Do you change this value at all?

- No change in the value for antoine, behrenfeld, heidi, ishizaka, modis_bf, scardi.
- modis_hyr :
  Yes. The model assumes units of Watts m^{-2}. To convert from moles of photons per day, we divide by

$$\begin{aligned} 0.397423 &= (6.022 * 10^{23} photons/mole) \\ &*(2.77 * 10^{-18} ergs/photon) \\ &*(8.64 * 10^{-4} sec/day) \end{aligned}$$

- nick :
  We converted the input PAR as a spectral value over the course of the day, but the resulting integrated value equals the input provided.
- tasha :
  We convert it to spectral irradiance and account for surface reflection of 10%.
- tim :
  Yes, it is assumed that 96.7% of the incident (spectral) light is transmitted through the air-sea interface.
- waters :
  Yes and no. The total value is not changed, but it is split both temporally and spectrally. The Tanre 5S code is used to generate clear sky spectral irradiance throughout the day. This is then normalized so that it integrates to the PAR value given. The model can take light input as a time dependent variable and will normalize through the course of the day.

4b. What does your model expect to get, PAR just under or just above the sea surface?

- antoine :
  It does not matter since the conversion between both is straightforward.

- Just above the sea surface for behrenfeld, heidi, modis_bf, modis_hyr, scardi, tasha, tim and waters.

- nick :
  We used the input PAR as PAR(0+), and transformed it to PAR(0-) with Fresnel's reflectanc for diffuse and direct components.

4c. If relevant, what time course of PAR through the day do you use?

- asanuma :
  Carbon fixation rate is given for PAR at noon.
  PAR(day)=Integrated PAR for a given day.

- antoine :
  The PAR time course is computed from latitude, date and hour of the day. This is done through astronomical equations determining the position of the sun in the sky and through the use of an atmosphere model (5S in this case), fed with mean atmospheric parameters.

- behrenfeld :
  This model is time integrated so we use daily PAR.

- heidi :
  Daily integrated PAR.

- Daily average PAR for modis_bf and modis_hyr.

- nick :
  Computed PAR scaled so that integrated PAR is equal to the provided value. PAR is computed daily (6 time intervals between dawn and noon) with the Gregg and Carder model for clear sky, together with ancillary data for ozone, aerosol, water vapor, relative humidity, wind. The influence of the clouds is calculated with the TOMS daily reflectivity , and approximate radiative transfer equations and cloud microphysics. Monthly maps are eventually computed for the SeaWiFS period. For the calculations looking at separate stations (and not necessarily in the SeaWiFS years), a global climatology of PAR provides the spectral shape and direct/diffuse ratio.

- scardi :
  I use integrated from other sources, or I integrate the hourly counts from my instruments.

- tasha :
  We revised our model to take this single PAR value, although we usually use a PAR that varies throughout the day.

- tim :
  Re-arranging the equations found in Kirk (Light and Photosynthesis in Aquatic Ecosystems; 2nd edition p.38), PAR is resolved into hourly time-steps:

$$\begin{aligned} \mathrm{PAR}_H &= 10^6 * (\sin(secs_after_sunrise * PI/daylen_secs)) \\ &\quad *PI * \mathrm{PAR_image}[x][y]/(2 * daylen_secs) \end{aligned}$$

  where PAR_H is hourly PAR, and the secs_after_sunrise and daylen_secs are derived from the daylength lookup table provided for PPARR3. The PAR value given is extracted from the PAR_image pixels (PAR_image[y][x]). The units are uE m^{-2} s^{-1}

- waters :
  See answer to 4a. The day is split into 16 time slices from 0400 to 2000 local time.

4d. If applicable, how do you convert from PAR to spectral values?

- antoine :
  We perform all steps of the PP calculations spectrally (step is 5 nm), and the spectral integration is only performed at the end.

- behrenfeld :
  This model is wavelength integrated.

- nick :
  PAR is computed daily (6 time intervals between dawn and noon) with the Gregg and Carder model for clear sky, together with ancillary data for ozone, aerosol, water vapor, relative humidity, wind. The influence of the clouds is calculated with the TOMS daily reflectivity , and approximate radiative transfer equations and cloud microphysics. Monthly maps are eventually computed for the SeaWiFS period. For the calculations looking at separate stations (and not necessarily in the SeaWiFS years), a global climatology of PAR provides the spectral shape and direct/diffuse ratio.

- tasha :
  We convert to spectral values using the file spectrum.asc (which weve sent to you by email), scaled so the integral equals one. A value of PAR is computed for wavelengths 400-700 at intervals of 10 nm.

- tim :
  PAR is converted to spectral values by using a lookup table of irradiance * wavelength values below :

400	407.836	500	645.6565	600	737.7024	700	688.6334
405	408.38742	505	671.24196	605	758.5006		
410	409.01231	510	685.31454	610	749.38134		
415	452.409345	515	665.92899	615	743.83143		
420	460.5489	520	662.34688	620	769.513		
425	470.1724	525	685.64265	625	750.65		
430	361.40124	530	724.34358	630	742.7133		
435	478.656165	535	728.753995	635	763.000125		
440	508.48688	540	695.37474	640	758.1856		
445	555.46502	545	729.76808	645	758.182665		
450	621.28125	550	724.2873	650	718.58865		
455	607.798555	555	738.732195	655	681.3441		
460	623.16844	560	716.8532	660	728.11332		
465	628.869255	565	730.80942	665	767.656715		
470	615.45983	570	712.72173	670	758.35357		
475	656.599625	575	745.70025	675	750.349575		
480	672.49632	580	756.1547	680	743.3624		
485	645.770225	585	767.49309	685	742.395465		
490	651.76468	590	680.71722	690	671.14299		
495	682.73073	595	718.225095	695	692.18664		

These were generated by running the Gregg and Carder (1990) spectral solar irradiance model at 50 N on serial day 181 assuming a clear sky. The PAR was calculated from this lookup table (LUT) and found to be 1695.175049 uE m^{-2} s^{-1}. The ratio was then taken of the PAR_H calculated from the provided image and this ratio used to weight the spectral values in the LUT. e.g., if the ratio was found to be 0.5 then the irradiance * wavelength at 700 nm would be reduced to 344.3167 at that pixel. This approach is spectrally flat.

- waters :
  See answer to 4a. Tanre 5S code is used.

- Not applicable for heidi, modis_bf, modis_hyr and scardi.

5. If you use an irradiance-dependent function that describes the depth of light saturation of photosynthesis (for example, functions such as F, the relative fraction of photosynthesis lost within the euphotic zone due to light limitation or R the change in integral photosynthesis as a function of light), how is it defined and what is its form?

- antoine :
- behrenfeld :
  F=PAR/(PAR+4.1)
- heidi :
  F=PAR/(PAR+11.77)
- modis_bf :
  F=P^b_{opt} * PAR/(PAR + 4.1), P^b_{opt} = chlorophyll-normalized production at the optimal optical depth.
- modis_hyr :
  Instead, this model calculates the average energy level over the water column to the bottom of the mixed-layer, or $\bar{E}$. Using the light attenuation down to the mixed-layer, the model calculates $\bar{E}$ as follows:

  $$\bar{E} = \mathrm{PAR} * (1 - \exp(-K_d(\mathrm{PAR}) * Z)/(K_d(\mathrm{PAR}) * Z)$$

  where Z is the depth of the bottom of the mixed-layer.
- tim :
  Yes - the irradiance function of Morel 1991 equation 22a is used. See answer to question 6c. In our derivation of the model, f is assigned as a function of $\varphi_{\mu max}$ (the maximum quantum yield of growth) and represents the increase in $\varphi_{\mu max}$ at decreasing irradiance and the decrease in $\varphi_{\mu max}$ as the irradiance increases.
- Not applicable for ishizaka, nick, scardi, tasha and waters.

6a. If you use a variable such as psi (the photosynthetic cross-section of light within the water column), how is it defined?

- antoine :
  PSI formulation from GBC 1996 paper : At a given moment, the water column

primary production can be mechanically described in a compact and diagnostic form through [Morel, 1978, 1991]

$$PSR =< Chl >_{eu} *\text{PAR} * \psi^*$$

where the algal biomass is quantified as being the column-integrated chlorophyll content, $< Chl >_{eu}$ in g Chl m^{-2}, where PAR (J m^{-2}) is the photosynthetically available radiant energy (within the spectral range delta=400 to 700 nm) incident at the sea level per unit area and during a given lapse of time (e.g. one day), and where PSR (J m^{-2}) is the energy photosynthetically stored (during the same duration as chemical energy within the plant biomass throughout the water column of unit section. The height of this column corresponds to the productive layer, in which the net photosynthesis is positive for the time scale considered. According to the structure of the Eq above, the factor ψ^* has the dimension of a cross section of algae for photosynthesis and per unit of areal chlorophyll biomass; it is expressed as m^2 (g Chl)$^{-1}$. The single quantity ψ^* actually merges the two basic processes involved in the photosynthetic carbon fixation, namely the capture of radiant energy and then the transformation of this harvest energy into chemical energy stored in the algal biomass. The carbon fixation, P (expressed as mass of C fixed per area and time units) and PSR are related through $P = PSR/Jc$ where Jc represents the energetic equivalent of photosynthetic assimilate (expressed as kJ (gC)$^{-1}$). The same quantity relates ψ^* to the "light utilization index", ψ, introduced by Falkowski (1981) according to $\psi = \psi^*/Jc$ where ψ is expressed as gC (g Chl)$^{-1}$ (J m^{-2})$^{-1}$.

- Not applicable for behrenfeld, heidi, ishizaka, modis_bf, modis_hyr, nick, scardi, tim and waters.

6b. If you use a variable such as Pbopt (the maximum chlorophyll -normalized rate of carbon fixation within the water column), how is it defined?

- behrenfeld :
  P^b_{opt} is defined as the maximum daily carbon fixation rate in the water column and is calculated as a function of sea surface temperature (sst) using either the polynomial

$$\begin{aligned} P^b_{opt} &= 1.2956 + 2.749 * 10^{-1} * sst + 6.17 * 10^{-2} * sst^2 \\ &\quad -2.05 * 10^{-2} * sst^3 + 2.462 * 10^{-3} * sst^4 \\ &\quad -1.348 * 10^{-4} * sst^5 + 3.4132 * 10^{-6} * sst^6 \\ &\quad -3.27 * 10^{-8} * sst^7; \end{aligned}$$

or the exponential function

$$P^b_{opt} = 1.54 * 10^{0.0275*sst-0.07}$$

we have provided separate model results for these two different expressions.

- heidi :
  The variability in P^b_{opt} could not be explained by any combination of parameters measured at the study site. We used the mean measured over time and space.

- ishizaka : We defined P^b_{opt} as a function of sea surface temperature (T) and sea surface chlorophyll concentration (Chl). The function is expressed as following equation,

$$\begin{aligned} P^b_{opt} &= (0.071 * T - 3.2 * 10^{-3} * T^2 + 3.0 * 10^{-5} * T^3)/Chl \\ &\quad +1.0 + 0.17 * T - 2.5 * 10^{-3} * T^2 - 8.0 * 10^{-5} * T^3 \end{aligned}$$

- modis_bf :
  P^b_{opt} is computed as a 7th order polynomial in SST (C), with coefficients $a(i) * 10^{-i}$, $i = 0...7$, where $a =$ [1.2956, 2.75, 6.17, -20.5, 24.62, -13.48, 3.4132, -0.327] (same as behrenfeld polynomial).

- scardi :
  As in Behrenfeld and Falkowski (1997). I use their function to get P^b_{opt} estimates and I use those estimates as predictive variables in my model (of course, using real values would provide much better results).

- Not applicable for antoine, modis_hyr, nick, tasha, tim and waters.

6c. If you use a variable such as Pbmax (the maximum chlorophyll-normalized rate of carbon fixation measured under constant irradiance), how is it defined?

- antoine :
  See Morel et al. 1996.

$$P^b_{max} = \alpha^b * E_k$$

  E_k is a paramter used to characterize the onset of light-saturated regime.
  α^b is the initial slope of the curve, within the light-limited regime (see 7a).

$$P^b_{max} = 12\, a^*_{max}\, \varphi_{\mu max}\, [x.f(x)]_{max}\, KPUR$$

- modis_hyr :
  P^b_{max} is calculated as an exponential function of SST (Eppley, 1972):

$$P^b_{max} = 24 * \exp(0.09 * SST)$$

- nick :
  Based on incubations experiments, a data base of 1862 P-I curves is distributed in 4 biomes, polar, westerlies, tradewinds, coastal, (Sathyendranath et al., Deep-Sea Res., I, 1773-1802, 1995).
  There has been a subsequent smoothing of the P-I parameters in space, just as for the chlorophyll profile parameters. Same weighting as for the chlorophyll profile parameters according to the month of the year (see question 2).

- tim :
  This is defined following Morel 1991:

$$P^b_{max} = 12.0 * \varphi_{\mu max} * A_chl_{max} * KPUR_T * f_{max}$$

  where :
  $f_{max} = \beta^\beta * (1+\beta)^{-(1+\beta)}$
  $\beta = 0.01$ giving $f_{max} = 0.945$
  $KPUR_T = KPUR * 1.065^{SST-20.0}$
  $A_chl_{max} = 40.3 * Chl_value^{-0.33}/1000.0$
  $\varphi_{\mu max} = 0.06$.
  The units given in the output table of P^b_{max} are gC (g Chl)$^{-1}$ h^{-1}.

- Not applicable for behrenfeld, heidi, ishizaka, modis_bf, scardi, tasha and waters.

7a. If you use a variable such as alpha (maximum rate of light utilization), how is it defined?

- antoine :
  $\alpha^b = 12\,\bar{a}^*\,\varphi_{\mu max}$
  $\bar{a}^*$ is a mean absorption coefficient normalized with respect to Chl and in relevance to the spectral composition of the available radiation, PAR(λ). It is defined as :

$$\bar{a}^* = \int_{\lambda 1}^{\lambda 2} a^*(\lambda)\,\mathrm{PAR}(\lambda)\,d\lambda \;/\; \int_{\lambda 1}^{\lambda 2} \mathrm{PAR}(\lambda)\,d\lambda$$

  The limits of the integral are in general 400 and 700 nm.
  $a^*(\lambda)$ represents the spectrally varying chlorophyll-specific absorption coefficient of algae.

- modis_hyr :
  α is this initial slope of the photosynthesis vs. irradiance curve, which is set to 0.11*24 in units of (mg Chl) (Watts m^{-2}) (mg C)$^{-1}$ day^{-1}, an average from table 4 in Platt et al. (1991).

- nick :
  Based on incubations experiments, a data base of 1862 P-I curves is distributed in 4 biomes, polar, westerlies, tradewinds, coastal, (Sathyendranath et al., Deep-Sea Res., I, 1773-1802, 1995). There has been a subsequent smoothing of the P-I parameters in space, just as for the chlorophyll profile parameters. Same weighting as for the chlorophyll profile parameters according to the month of the year (see question 2).

- tim :
  $\alpha = P^b/PUR_{total}$
  The units being gC (g Chl)$^{-1}$ (uE m^{-2})$^{-1}$.

- Not applicable for behrenfeld, heidi, ishizaka, modis_bf, scardi, tasha and waters.

7b. If you use a variable such as E_k (onset of light saturation, scaling irradiance), how is it defined?

- antoine :
  $E_k = \alpha^b / P^b_{max}$

- nick :
  Same as antoine but not used per se.

- tasha :
  $E_k = E_{k_max} / [1 + 2 * e - PUR * \exp(1.089 - 2.12 \log E_{k_max})]$
  E_{k_max} = maximum value of E_k,
  PUR = Photosynthetically Usable Radiation

- tim :
  E_k can be indirectly calculated by taking the ratio of α and P^b.

- waters :
  Not used directly. A function of (quantum PAR)/E_k is parameterized.

- Not applicable for behrenfeld, heidi, ishizaka, modis_bf, modis_hyr, and scardi.

8. If applicable, how do you parameterize the expression between Pb and E, Pmax and E?

- asanuma :

  $P^b(z) = 13*[1-\exp(-0.1a*PAR\%(z)*0.01)]*\exp(-0.4b*PAR\%(z)*0.01)+1$

  $a = 0.1 * s * PAR(0, noon) + i$
  $s = -0.0001 * T^3 + 0.0036 * T^2 - 0.0007 * T + 0.2557$
  $i = 0.00021 * T^3 - 0.0106 * T^2 + 0.0868 * T - 0.1042$

  $b = 0.0005 * T^3 - 0.0202 * T^2 + 0.1134 * T + 3.1214$

- antoine :
  $P^b_{max} = \alpha^b * E_k$

- modis_hyr :
  The average production over the water column is calculated according to Platt and Jassby as
  $$Pz = Chl * (P^b_{max} * \bar{E})/(P^b_{max}/\alpha + \bar{E})$$
  Chl is the satellite estimated chlorophyll concentrations (mg m^{-3}),
  P^b_{max} is the maximum photosynthetic yield (normalized to chlorophyll),
  α is the average maximum rate of light utilization,
  $\bar{E}$ is the average light level over the mixed-layer.

- nick :
  $$P^b = xx/\sqrt{(1 + xx^2/P^2_{max})}$$
  (production normalized by chlor. concentration).
  xx is a spectral integral:
  $$xx = \int_\lambda [\alpha * a_p(\lambda)/\bar{a_p} * (Ed_d(\lambda)/\mu_d + Ed_s(\lambda)/\mu_s)]\, d\lambda$$
  with $\mu_s = 0.831$ and μ_d =cosine of solar zenith angle below surface.

- tim :
  P^b and E :
  $$P^b = 12.0 * \varphi_{\mu max} * A_chl_{max} * KPUR * f(x)$$
  The irradiance term E is included in $KPUR$.

  P^b_{max} and E, as defined in 6c :
  $$P^b_{max} = 12.0 * \varphi_{\mu max} * A_chl_{max} * KPUR_T * f_{max}$$
  The Irradiance term E is included in $KPUR_T$.

- Not applicable for behrenfeld, heidi, ishizaka, modis_bf, scardi, tasha and waters.

9. If you use a variable such as a_p (chlorophyll specific absorption coefficient), how is it derived? If applicable, what are the spectral values of this variable?

- antoine :
  We use a mean spectrum for the shape of the chlorophyll-specific absorption coefficient (i.e., values normalized by their maximum). References are in Morel (1991). Values are (from 400 to 700 nm, each 5 nm) :

  data astar :

400	.68700	500	.66800	600	.25800	700	.21500
405	.78100	505	.64500	605	.26000		
410	.82800	510	.61800	610	.26200		
415	.88300	515	.58200	615	.26700		
420	.91300	520	.52800	620	.27600		
425	.93900	525	.50400	625	.29900		
430	.97300	530	.47400	630	.31700		
435	1.00000	535	.44400	635	.33300		
440	1.00000	540	.41600	640	.33400		
445	.97100	545	.38400	645	.33200		
450	.94400	550	.35700	650	.35600		
455	.92800	555	.32100	655	.38900		
460	.91700	560	.29400	660	.44100		
465	.90200	565	.27300	665	.53400		
470	.87000	570	.27000	670	.58000		
475	.83900	575	.26800	675	.54400		
480	.79800	580	.26500	680	.50200		
485	.77300	585	.26000	685	.42000		
490	.75000	590	.25800	690	.32900		
495	.71700	595	.25500	695	.26200		

  The dimension is given by the value of the $a^*_{max} = 45$ m^2/g(Chl).

- nick :
  a_p computed as a function of λ and Chl_a according to Bricaud et al., 1995.

$$a_p(\lambda, Chl_a) = A(\lambda) * Chl^{1-B(\lambda)}$$

  The spectral values are variable with chlorophyll concentrations. One output file of PART2_2 provides spectral values for the 26 chlorophyll surface concentrations.

- tasha :
  Derived from Riegger and Robinson, 1997. Spectral values :

400	0.0135	500	0.0107	600	0.0027	700	0.0005
410	0.0142	510	0.0097	610	0.0031		
420	0.0150	520	0.0086	620	0.0035		
430	0.0158	530	0.0075	630	0.0039		
440	0.0160	540	0.0065	640	0.0036		
450	0.0149	550	0.0054	650	0.0034		
460	0.0139	560	0.0045	660	0.0062		
470	0.0131	570	0.0036	670	0.0097		
480	0.0124	580	0.0030	680	0.0097		
490	0.0116	590	0.0028	690	0.0061		

- tim :
  a_p is derived using the following equation (in the C programming language):

$$0.06 * Achl(l) * mean_Chl_value^{0.65}$$

  where the $mean_Chl_value$ is the mean chlorophyll value of a depth interval (which for the purposes of PPARR3 is set to the surface value of chlorophyll detected using SeaWiFS) and $Achl(l)$ is a spectrally dependent LUT.

  Spectral values $Achl(l)$:

400	0.687	500	0.668	600	0.236	700	0.215
405	0.781	505	0.645	605	0.279		
410	0.828	510	0.618	610	0.252		
415	0.883	515	0.582	615	0.268		
420	0.913	520	0.528	620	0.276		
425	0.939	525	0.504	625	0.299		
430	0.973	530	0.474	630	0.317		
435	1.001	535	0.444	635	0.333		
440	1	540	0.416	640	0.334		
445	0.971	545	0.384	645	0.326		
450	0.944	550	0.357	650	0.356		
455	0.928	555	0.321	655	0.389		
460	0.917	560	0.294	660	0.441		
465	0.902	565	0.273	665	0.534		
470	0.87	570	0.276	670	0.595		
475	0.839	575	0.268	675	0.544		
480	0.798	580	0.291	680	0.502		
485	0.773	585	0.274	685	0.42		
490	0.75	590	0.282	690	0.329		
495	0.717	595	0.249	695	0.262		

- waters :
  From Bricaud 1995 :
  $$a_p(\lambda) = A(\lambda) * Chl^{1-B(\lambda)}$$

- Not applicable for behrenfeld, heidi, ishizaka, modis_bf, modis_hyr and scardi.

10. If you use a variable such as a quantum yield, how is the maximum quantum yield defined?

- antoine :
  See 6c.

- tim :
  The maximum quantum yield is set following Morel 1991:
  $\varphi_{\mu max} = 0.06$

  The realized quantum yield is defined as:
  $\varphi_\mu = \varphi_{\mu max} * f(x)$
  where $f(x) = (1.0/x) * (1.0 - \exp(-x)) * \exp(-\beta * x)$
  and $x = PUR_{total}/KPUR_T$ where $KPUR_T = KPUR * 1.065^{SST-20.0}$
  and $\beta = 0.01$.

- waters :
  Somewhat arbitrarily set to 0.03 globally. This is a value that was found in-situ at the HOTS site. Lazily applied it everywhere.

- Not applicable for behrenfeld, heidi, ishizaka, modis_bf, modis_hyr, nick, scardi and tasha.

11. If any of the above variables (alpha, E, Pbmax, ap, etc) vary with depth, what form does the depth dependence take?

- No change in depth for antoine and ishizaka

- nick :
  No dependence for the P-I parameters. PAR is changing according to light propagation down the water column. *ap* is changing through the changes with chlorophyll concentration (see question 9) along the water column (see question 2).

- tasha :
  E varies with depth, and since E_k is a function of light history, it varies with

depth as well. E decreases exponentially according to Beers Law using the K_d described in question 3a.
These variables are calculated independently at each depth and averaged over the mixed layer. Below the mixed layer E_k can vary with depth.

- tim :
  Spectral E varies logarithmically with depth using the diffuse attenuation coefficients (k) for both the pure water and chlorophyll components. α is calculated at each depth step individually - the calculations of P^b_{max} showed it to be invariant with depth.
  The realized quantum yield is recalculated at each depth step.

- waters :
  Variables only vary with depth if they vary with light. The light drives them, not the depth.

- Not applicable for behrenfeld, heidi, modis_bf, modis_hyr and scardi.

12. List the variables or parameters in your model which are temperature dependent. What is the form? (Repeat if already answered above).

- antoine :
  Temperature dependence applies to P^b_{max} only. The temperature effect is accounted for by allowing P^b_{max} to be dependent on temperature with a Q10 (increase in growth rate per $10^\circ C$ rise) equal to 1.88 as suggested by Eppley [1972], thus
  $$P^b_{max}(T) = P_{max}(20^\circ C) * 1.065^{T-20}$$

- behrenfeld :
  P^b_{opt} is the only temperature-dependent function used. The equation for the polynomial model is :
  $$\begin{aligned} P^b_{opt} &= 1.2956 + 2.749 * 10^{-1} * sst + 6.17 * 10^{-2} * sst^2 \\ &\quad -2.05 * 10^{-2} * sst^3 + 2.462 * 10^{-3} * sst^4 \\ &\quad -1.348 * 10^{-4} * sst^5 + 3.4132 * 10^{-6} * sst^6 \\ &\quad -3.27 * 10^{-8} * sst^7 \end{aligned}$$
  and the exponential function :
  $$P^b_{opt} = 1.54 * 10^{0.0275 * sst - 0.07}$$

- None for heidi, nick and waters (but quantum yield should vary with T).

- ishizaka :
  P^b_{opt} is only temperature dependent parameter in our model. This form is as follows :

$$\begin{aligned} P^b_{opt} &= (0.071 * T - 3.2 * 10^{-3} * T^2 + 3.0 * 10^{-5} * T^3)/Chl \\ &\quad +1.0 + 0.17 * T - 2.5 * 10^{-3} * T^2 - 8.0 * 10^{-5} * T^3 \end{aligned}$$

- modis_bf :
  P^b_{opt} is computed as a 7th order polynomial in SST (C), with coefficients $a(i) * 10^{-i}$, i=0...7, where a = [1.2956, 2.75, 6.17, -20.5, 24.62, -13.48, 3.4132, -0.327] (see 6b).

- modis_hyr :
  P^b_{max} is calculated as an exponential function of SST (Eppley, 1972):

$$P^b_{max} = 24 * \exp(0.09 * SST)$$

  It is worth noting that P2 uses mixed-layer depth, which is also temperature dependent. For instance, the FNMOC MLD data used in MODIS operations is defined to be the depth where temperature change exceeds .5C.

- scardi :
  Only P^b_{opt} depends on SST.
  As for the form, see Behrenfeld and Falkowski (1997).

- tasha :
  Maximum growth rate is temperature dependent.

- tim :
  $KPUR$ as a function of temperature $KPUR_T$:

$$KPUR_T = KPUR * 1.065^{SST-20.0}$$

  where $KPUR = 80$ (the value of KPUR at 20°C)

13. These questions apply to model developers or modifiers only (if you are using a model off-the-shelf, just give us a reference):

13a. In developing (or modifying) your model did you use oceanic data, lab data or both?

- antoine : both
  Oceanic data have been used

- in the K_d modeling, which determine the PAR availability at any depth in the water column (Morel and Maritorena, 2001),
- for deriving the parameterization of the vertical Chl profile (Morel and Berthon, 1989),
- for the adjustment of some of the model parameters (Morel et al., 1996), such as the maximum of the phytoplankton chlorophyll-specific absorption coefficient and the "KPUR" (see answers to questions 6 to 8).

Lab data have been used for the mean shape adopted for the phytoplankton absorption spectra.

- behrenfeld :
  The simple expressions used in our model were developed using ocean data.

- heidi :
  Oceanic data and lab data

- ishizaka :
  We used only oceanic data.

- modis_bf :
  BEHRENFELD, M.J. AND FALKOWSKI, P.G., 1997a, Photosynthetic rates derived from satellite-based chlorophyll concentration. Limnology and Oceanography., 42(7): 1-20.

- modis_hyr :
  HOWARD, K.L., 1995, Estimating global ocean primary productivity using satellite-derived data. M.S. Thesis (University of Rhode Island, Kingston), 98pp.

- nick :
  BIO-type of model. The original model developer used oceanic data.

  Description in
  Longhurst A.R., S. Sathyendranath, T. Platt, C. Caverhill: An estimate of global primary production in the ocean from satellite radiometer data. J. Plank. Res., 17(6), 1245-1271, 1995.
  Sathyendranath, S., A. Longhurst, C.M. Caverhill, T. Platt: Regionally and seasonally differentiated primary production in the North Atlantic. Deep Sea Res., 42(10), 1773-1802, 1995.

- scardi :
  Only oceanic data : OPPWG data base (filtered), NODC F049 and F029 data sets, other sources for the Mediterranean Sea (i.e. Stazione Zoologica "A. Dohrn" of Naples)

- tasha :
  Oceanic data.

- tim :
  We are using the model of Morel 1991 :
  Morel A. (1991), LIGHT AND MARINE PHOTOSYNTHESIS - A SPECTRAL MODEL WITH GEOCHEMICAL AND CLIMATOLOGICAL IMPLICATIONS, PROGRESS IN OCEANOGRAPHY 26 (3): 263-306

- waters : Both.

13b. From what oceanic regions and years did the field data come from?

- antoine :
  K_d : see Table 1 in Morel and Maritorena (2001),
  $Chl(z)$: see in Morel and Berthon (1989),
  Parameter assignment : see in Morel et al., 1996.

- behrenfeld :
  The basic expressions were developed using the MARMAP data set and then tested using data from around the globe

- heidi :
  Antarctic Peninsula Summers 1991-1999

- ishizaka : We used OPPWG dataset assembled by Behrenfeld and Kolber, and the data measured by 13C method by Japanese. The data included in OPPWG dataset were measured from all oceans and the data in 13C dataset were measured in western North Pacific.

- nick :
  All data used to build the data base are prior to 1995. The chlorophyll profiles are distributed worldwide with great disparity. The P-I curves data are all from North Atlantic regions.

- scardi :
  N Pacific, E tropical Pacific, NW Atlantic, tropical Atlantic, Arctic, Southern Ocean, Western Mediterranean (see dataset.gif).
  Sampling years range from 1958 to 1994.

- tasha :
  The Southern Ocean during the austral summers of 1997-98 and 1998-1999.

- waters :
  Tropical Pacific 1990's, Sargasso Sea late 1980's.

13c. What percentage of these data were acquired in the southern hemisphere?

- antoine : 0%
- behrenfeld :
  In the development data set, 0%
  in the test data set, 20%
- heidi : 100%
- ishizaka : 3%
- nick :
  None for the P-I curves. few for the chlorophyll profiles (distribution plotte in Longhurst A.R., S. Sathyendranath, T. Platt, C. Caverhill: An estimate of global primary production in the ocean from satellite radiometer data. J. Plank. Res., 17(6), 1245-1271, 1995.)
- scardi : 11.42% (288 out of 2522 records)
- tasha : 100%
- waters : 0%

13d. What percentage from latitudes north of 45degN?

- antoine : 0%
- behrenfeld :
  In the development data set, 0%
  in the test data set, 5%
- heidi : 0%
- ishizaka : 3%
- scardi : 6.94% (175 out of 2522 records)
- tasha : 0%
- waters : 0%

13e. What percentage from latitudes south of 45degS?

- antoine : 0%
- behrenfeld :
  In the development data set, 0%
  in the test data set, 4%
- heidi : 100%
- ishizaka : 1.3%
- scardi : 0.91% (23 out of 2522 records)
- tasha : 100%
- waters : 0%

	Did you use oceanic data or lab data ?	From what oceanic regions and years did the field data come from ?	What % of these data were acquired in the southern hemisphere ?	What % from latitudes north of 45N ?	What % from latitudes south of 45S ?
antoine	Oceanic data : K_d modelling, parameterization of the vertical Chl profile, adjustment of some model parameters. Lab data : mean shape of the phytoplankton absorbtion spectra	Morel & Maritonera (2001) Morel & Berthon (1989) Morel et al. (1996)	0%	0%	0%
behrenfeld	Oceanic data	MARMAP data set and data from around the globe	0% in devpt data set and 20% in test data set	0% in dev data set and 5% in test data set	0% in dev data set and 4% in test data set
heidi	Both	Antarctic Peninsula Summers 1991-1999	100%	0%	100%
ishizaka	Oceanic data	OPPWG data set (from all oceans) 13C data set (Western North Pacific)	3%	3%	1.3%
scardi	Oceanic data	N Pacific, E tropical Pacific, NW Atlantic, tropical Atlantic, Arctic, Southern Ocean, Western Mediterranean Sampling years range from 1958 to 1994	11.42% (288 out of 2522 records)	6.94% (175 out of 2522)	0.91% (23 out of 2522)
tasha	Oceanic data	Southern Ocean, austral summers of 1997-1998 and 1998-1999	100%	0%	100%
waters	Both	Tropical Pacific 1990's Sargasso Sea late 1980's	0%	0%	0%

14. If you want to improve the model you use, what type of data would you need? Field measurements of primary production? Photosynthetic parameters? Optical measurements? Other? Please be specific.

- behrenfeld :
  Profiles of density, beam attenuation, k490, and nitracline depth

- heidi :
  Model improvement could be attained by a better parameterization of P^b_{opt}. I tried to develop a relationship to predict P^b_{opt} by looking at many different variables (e.g., Light, Light averaged over 3 days prior, cloud factor, SST, species composition from HPLC diatoms vs. cryptophytes, etc.) and nothing seemed to correlate.
  I don't know what else we would need to better estimate this parameter.

- ishizaka :
  We need field measurement size-fractionated primary production data for P^b_{opt} model development. In addition, it is required to gather more data from polar region, because there are limited profiles in low temperature.

- nick :
  Photosynthetic parameters, quantum yield.
  Field measurements of primary production are always welcome if accompanied by chlorophyll data, PAR value with cloud cover.

- scardi :
  From my very particular (neural network oriented) point of view, I could use whatever is related to PP. In fact, my PPARR3 model only uses latitude, longitude, date and the variables you provided, deriving from them a P^b_{opt} estimate (a la B&F) and some other predictive variables (e.g. the day of the year is mapped onto a "yearly clock" using 2 new variables - sin and cos functions). These predictive variables are actually a subset of those that a previous neural network model was using. For instance, I'm not using in PPARR3 the bathymetrical information - namely variance of depth in the area around the point where PP is to be predicted - because you said that we should only use the predictive info you provided to everybody. However, in case Santa is going to bring new data to good modelers, I think that I'd like to have more climatological data. In fact, I was planning (since a few years, but I had no time) to use this kind of info for improving my "full" neural network model. However, in my opinion a global model is only useful if it uses predictive info that can be easily retrieved from remote sensing or from existing data sets. If direct measurements are involved

for predictive variables, then it can be much more accurate (just think about the case of real P^b_{opt} data: they can obviously boost the performance of any model), but certainly much less useful for practical applications. So, I guess that global climatological data (e.g. monthly - or weekly - average rainfall, wind stress, evaporation, etc.) could be very useful as new predictive variables, The same applies to info about salinity or nutrients, even though it is clearly less reliable because it is based on interpolation of quite sparse data sets.
Finally, new PP field data would be welcome, especially as far as (1) Southern Ocean, (2) Indian Ocean and (3) central and western parts of Pacific Ocean are concerned.

- tasha :
  More field measurements of primary production coupled with ancillary data such as temperature, irradiance, chlorophyll.

- tim :
  The handling of the light field data could be improved. This could be done in the following ways :

  1) The LUT used to resolve the given PAR image into the spectral components should take account of cloudiness. A separate LUT could be used for varying degrees of cloudiness (run using a modified version of the Gregg and Carder model - see above). If, say the ISSCP data was made available for the time periods of interest then this could possibly be done.

  2) No account has been taken of the sun angle (particularly important at high latitudes) which affects the transmission of light accross the air-sea interface. An improvement to the model could be achieved by having a lookup table of noon-sun angle for the month in question.

  Field data could help in the implementation of this model if profiles of chlorophyll were prescribed for each image pixel - this could be a massive undertaking however and may mean that the computational time will increase substantially.

  3) Assuming a vertical homogenous biomass, fm etc.. is only correct for well mixed waters. When generating output for global map possibly large errors incurred in stratified oligotrophic regions, where surface Chla is low, and PmB and α or fm can be high and are not representative of corresponding values at the DCMU - where the majority of production is occurring.

- waters :
  The place I suspect I need the most improvement is the estimation of the quantum yield. Currently this is driven by light, but should be driven by light and temperature. I would need P vs E data derived from in-situ incubations such that E_k is derivable as a function of depth/light level and temperature. This could, of course, be totally fruitless and they may be no relation where I'm hoping there is one.