



Remote Sensing Technology Institute

**ATBD Primary
production
DRAFT**

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1. INTRODUCTION

1.1 Algorithm Identification

Net primary production is defined as the amount of photosynthetically fixed carbon available to the first heterotrophic level (Behrenfeld and Falkowski, 1997).

2. ALGORITHM OVERVIEW

Many primary productivity models have been developed which differ in the variables chosen for parameterization and in the levels of integration (i. e., integrated over wavelength, depth, or time). A comprehensive comparison and classification of the different models is given by Behrenfeld and Falkowski (1997). The most general models are spectrally, vertically and timely resolved. Figure 1 illustrates the scheme for calculating primary production by using such a model.

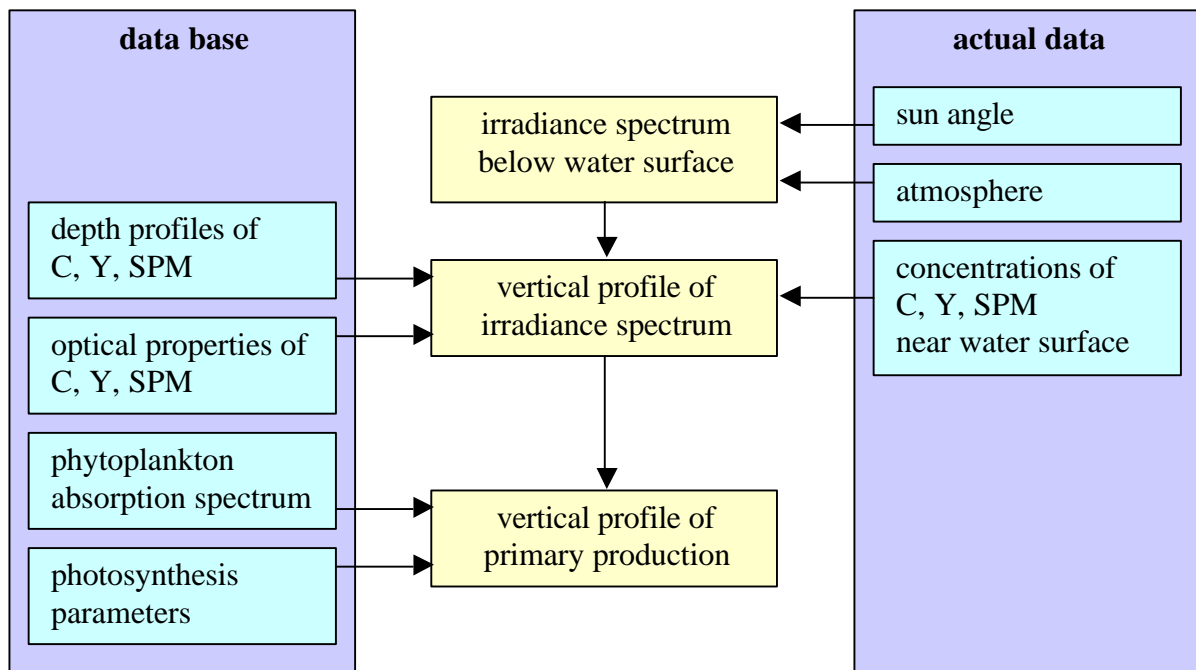


Fig. 1: Flow chart illustrating the calculation of the primary production by using a depth-, wavelength- and time-resolved model.

The downwelling irradiance at the water surface depends on the elevation of the sun and on atmospheric properties, e.g. clouds and aerosols. A large part of this radiation is transmitted through the air-water-interface. In the water column, the radiation is attenuated by the water molecules and by water constituents such as chlorophyll (C), yellow substance (Y) and suspended matter (SPM). In order to calculate the vertical profile of the light available for photosynthesis, information about the vertical distribution of the absorbing and scattering constituents and their optical properties is required. The vertical profile of primary production can then be calculated if the light absorbed by phytoplankton and some parameters describing the efficiency of photosynthesis are known.

It is important to have available such a general model for simulation purposes, but there are several reasons for using a less general model for deriving the depth-integrated primary production from MERIS data:

- The vertical profiles of the water constituents are known only roughly;
- The accuracy of the irradiance vertical profile depends on the accuracy of the estimate of absorption and scattering by water constituents and thus decreases with depth;

- The light available for photosynthesis decreases exponentially with depth, thus phytoplankton at large depths contributes only minor to the depth-integrated production;
- Calculating the vertical profile of the irradiance spectrum with high spectral resolution and integrating the primary production over depth is time consuming;
- It was shown by modeling that errors introduced by using a depth-integrated model instead of a depth-resolved model are small compared to uncertainties of the photosynthetic parameters (Behrenfeld and Falkowski 1997).
- It was shown experimentally for Lake Constance that a depth-integrated model achieves a similar accuracy as a depth-resolved model (Häse 1996).

For these reasons it is advisable to use either a depth-integrated model or a model with some simplifications at spectral or vertical aspects.

In general, the way to the MERIS Primary Productivity Processor can be described as shown in Fig. 2:

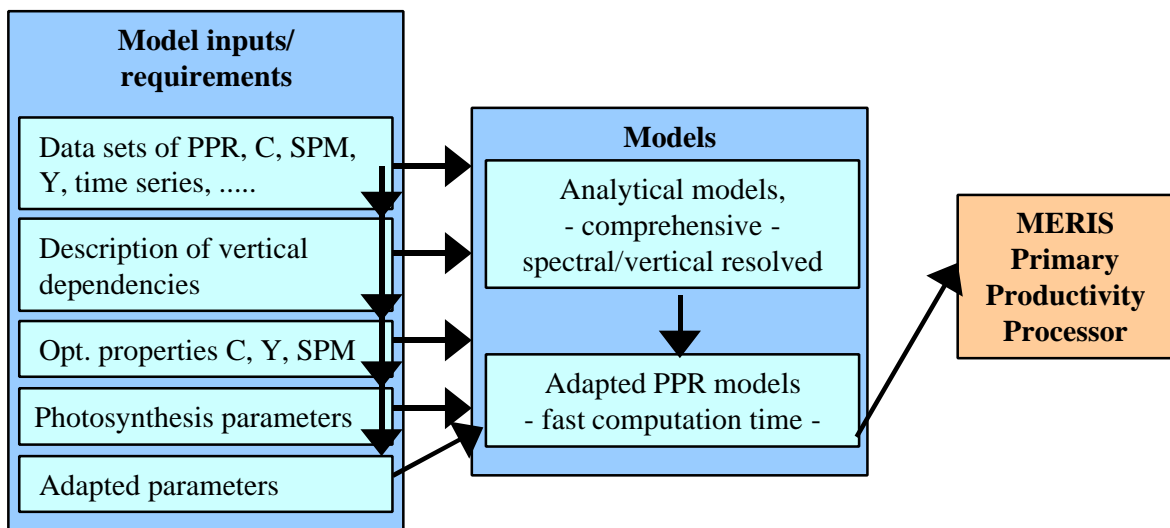
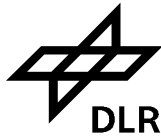


Fig. 2: Flow chart illustrating the working process to develop the MERIS Primary Productivity Processor for Lake Constance

At first, the input parameters and a characterisation of vertical properties for the primary productivity models have to be worked out. Knowledge and verification of sufficient light models, which are used for the PPR-model, also belongs to these basic investigations.

The next step consists of the validation of an analytical model using data sets of *in situ* measurements of PPR and the test of adapted simple models, which can be used as the MERIS Primary Productivity Processor for Lake Constance.

For the present an extensive analytical model, the *Ocean Primary Productivity Processor* OPPP from ESA/ESRIN was tested to derive the primary productivity at Lake Constance (van der Piepen et al., 2000). Modifications were implemented in order to adapt the Lake Constance conditions to the OPPP. As the OPPP was originally constructed for use with case 1-waters, some limitations arised for some adaptations. For example the vertical profiles of Chlorophyll



found in Lake Constance show usually much stronger gradients as they can be described by the Gaussian form of Sathyendranath et al., which is implemented with fixed profile width in the OPPP. A second example for the currently limitation of the OPPP is given for the underwater light field: In the OPPP scatterers cannot taken into consideration independent of phytoplankton or Chlorophyll. As in Lake Constance the light scattering can be dominated by phytoplankton independent materials as resuspended or river imported suspended anorganic matter, this simplifications lead to large errors for the calculated vertical light profile.

As result from unsufficiently adapted vertical chlorophyll and light profiles the comparison of productivity calculated from OPPP with *in situ* measurements showed deviations of up to 700% (?), which were assumed not to originate only from insufficiently given photosynthesis parameters.

These experiences showed, that an analytical model will work satisfactory only with well adapted input parameters.

Therefore in the following a description of the basic investigations for primary production input parameters and models is given.

A. Vertical profiles of water constituents

More than 800 vertical profiles of chlorophyll and suspended matter (data collected by the Limnological Institute, Univ. Konstanz / SFB 248) were investigated. A description by the Gaussian form of Sathyendranath et al. lead to large differences between the fitted Gauss curves and the measured profiles. With a variable Exponent n in

$$Chl_a(z) = Chl_{a,0} + Chl_{a,max} \exp[-\{|z - z_m|/(2s)\}^n]$$

always a good agreement between fit curve and measurement in Lake Constance is possible. All measured profiles were characterized by the curve parameters ($Chl_{a,0}$, $Chl_{a,max}$, s , z_m , n). The calculated average chlorophyll profile for Lake Constance, the average curve parameters and the standard deviations are given in Fig. 3. The large standard deviations represent the extreme high vertical variability of profile forms, which are possible in Lake Constance. Subsequent sensitivity analyses will show the error for PPR-calculations introduced by differences between an actual natural and the average model profile. Temporal classifications of curve parameters were investigated, but lead to no significant results. Only during spring bloom a distinct decrease of the variability of s , z_m , and n could be observed, which probably is originated by the specific temporal stratification of the Lake in this phase.

In case of suspended matter similar results occurred. Anyway, the vertical gradients are lower ($\bar{n} = 2.3$). Therefore, subsequent sensitivity analyses could show that the error for light field calculations introduced by differences between an actual natural and the average model profile is less important for errors to the PPR.

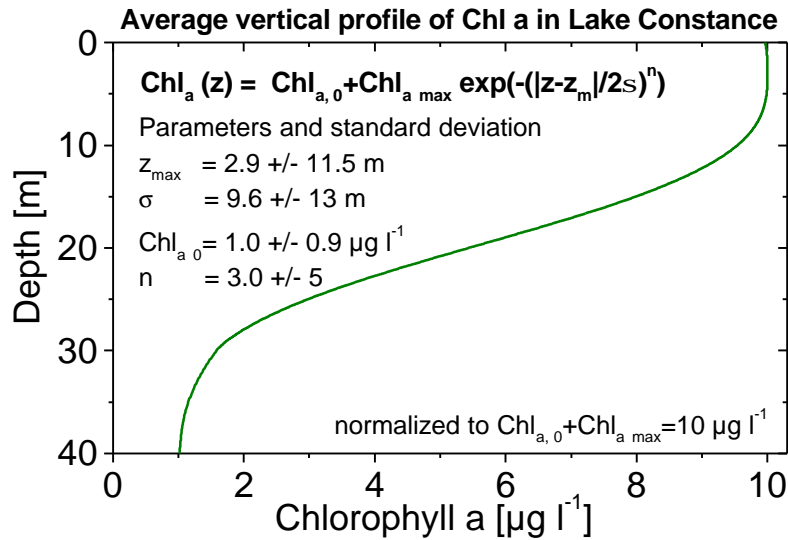


Fig. 3: Average vertical profile of Chl a and standard deviations of profile curve parameters in Lake Constance.

Horizontal and vertical gradients of yellow substances are neglectable (Heege, 2000)

To quantify the role of vertical gradients for the calculation of water constituent concentrations from space, the average deviation of concentrations in depth z to the surface layer (0-1 m depth) was calculated from these profiles (see. Fig. 4). It is shown, that – dependent on the signal depth (see below) – here in general no substantial errors can occur.

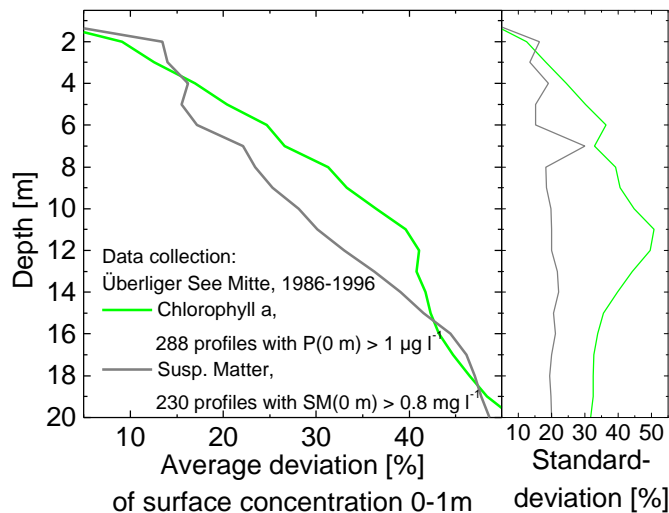


Fig. 4: Average deviation of surface concentration to concentrations in depth z

B. Calculation and validation of the vertical irradiance model

The scalar irradiance $E_0(z)$ is needed as input for the calculation of PPR. If the vertical diffuse extinction coefficient $k_0(z)$ is known, $E_0(z)$ can simply be calculated by

$$E_0(z) = E_0(z = 0m) \exp[-z \cdot k_0(z)].$$

In order to calculate $k_0(z) \approx k_E(z) = a(z)/\mu \{a(z), b(z), \mu_{in}, z\}$, a model of Bannister (1992) was adapted and validated for use at Lake Constance. Coefficients a, b are calculated as a function of the water constituents concentration using the water constituents specific optical properties. Figure 5 shows results of this validation, where profiles of $k_{dw}(z, I)$ were measured with an underwater radiometer MER and calculations of $k_E(z, I)$ based on at the same time measured *in situ* profiles of water constituents.

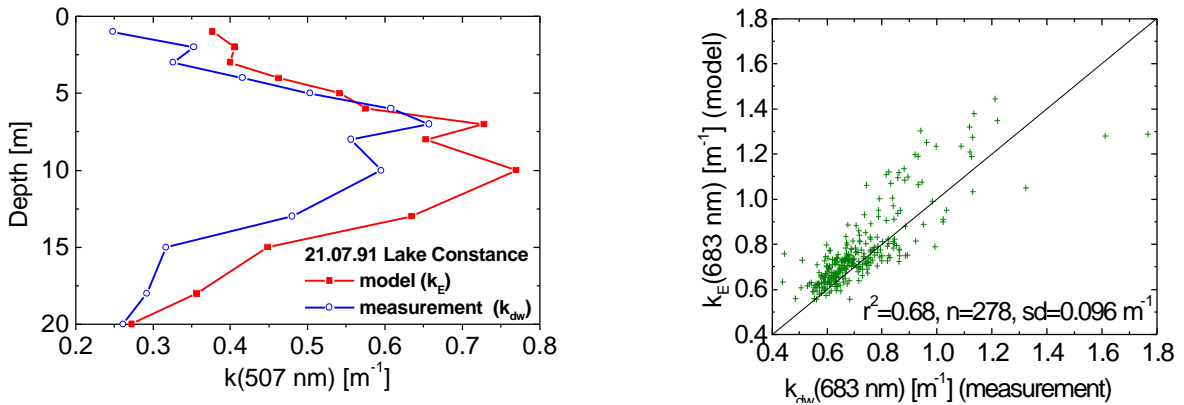


Fig. 5: Validation examples of the calculated vertical diffuse extinction coefficient

As output from light field modeling the Remote Sensing Signal Depth (z_{90}) is calculated for different typical water bodies. z_{90} is directly related to the water layer depth containing the water constituent concentrations calculated from space. Therefore, the information about z_{90} are essential for the connection between the vertical profile and the from space measured concentrations. Fig. 6 shows, that the concentrations calculated with MERIS data mostly are average values of the first two or three meters.

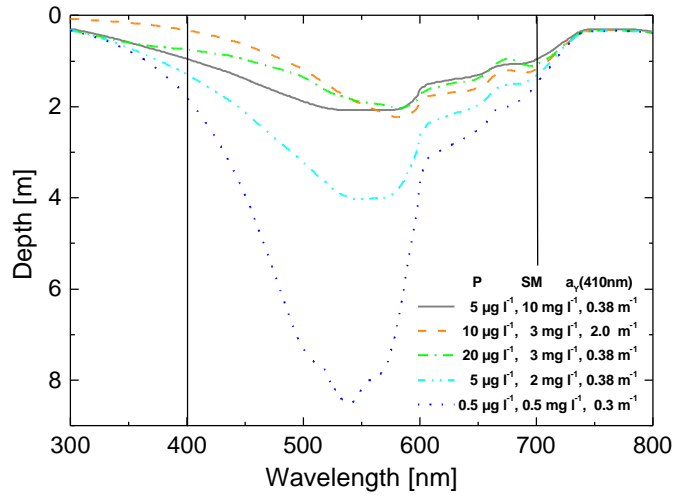


Fig. 6: Signal depth at different typical water bodies in Lake Constance



3. ALGORITHM DESCRIPTION

This section has two parts. The first part is a theoretical discussion of the algorithm including a description of the physics of the problem, a mathematical discussion of the algorithm, and an error analysis. The second part of this section covers practical considerations of implementing the algorithm, including a discussion of validation plans, methods of quality control, a discussion of data dependencies, and a description of the output product.

3.1 Theoretical Description

3.1.1 Physics of the Problem

The physical basis of the problem is given.

Assumptions on the pre-processing of the input data shall be given. The anticipated sources and accuracy of auxiliary information are given, as well as information regarding the processing required to present them in a convenient format for processing in the algorithm. Actions on the non-availability of these sources of information shall be given.

3.1.2 Mathematical Description of the Algorithm

A detailed mathematical description is given together with a schematic description.

3.2 Practical Considerations

This section describes anticipated techniques for algorithm implementation. This section focusses on scientific issues involved in algorithm implementation.

3.2.1 Numerical computation considerations

3.2.2 Calibration and Validation

Validation methodologies shall be outlined.

3.2.3 Quality Control and Diagnostics

Quality control and diagnostics will be developed to inform the users of the uncertainties expected in the final results, for example, the effects of sub-pixel clouds and adjacent clouds.

3.2.4 Exception Handling

Actions on saturation or data dropouts shall be given.

Action on non-availability of ancillary and auxiliary data shall be given. The product(s) format will be described with their likely precision. Accompanying each product will be a summary of the input parameters used and an error budget. A data product summary sheet shall be produced (Chapter 7).

3.2.5 Output Product

4. ERROR BUDGET ESTIMATES

An error budget on the uncertainties/errors described in the above section is given. The extend of validity is discussed, for example it's regional and seasonal applicability.



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5. ASSUMPTIONS AND LIMITATIONS

Assumptions and limitations shall be summarized including assumptions on the quality of input data (L1b, L2 data, ancillary data, flags) required to achieve certain accuracy.

6. REFERENCES

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H. van der Piepen,: OPPP, Interner Bericht DLR

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MAPP DATA PRODUCT SUMMARY SHEET

Product name:	
Product code:	
Product Level:	
Description of the Product:	
Product Parameters:	
Coverage	
Packaging:	
Units:	
Range:	
Sampling:	
Resolution:	
Accuracy:	
Geo-location:	
Format:	
Appended data:	
Frequency of generation:	
Size of product:	
Additional information:	
Identification of bands used in algorithm	
Assumption on MERIS input data	
Identification of ancillary and auxiliary data	
Assumptions on ancillary and auxiliary data	