Primary Productivity Model based on satellite observation

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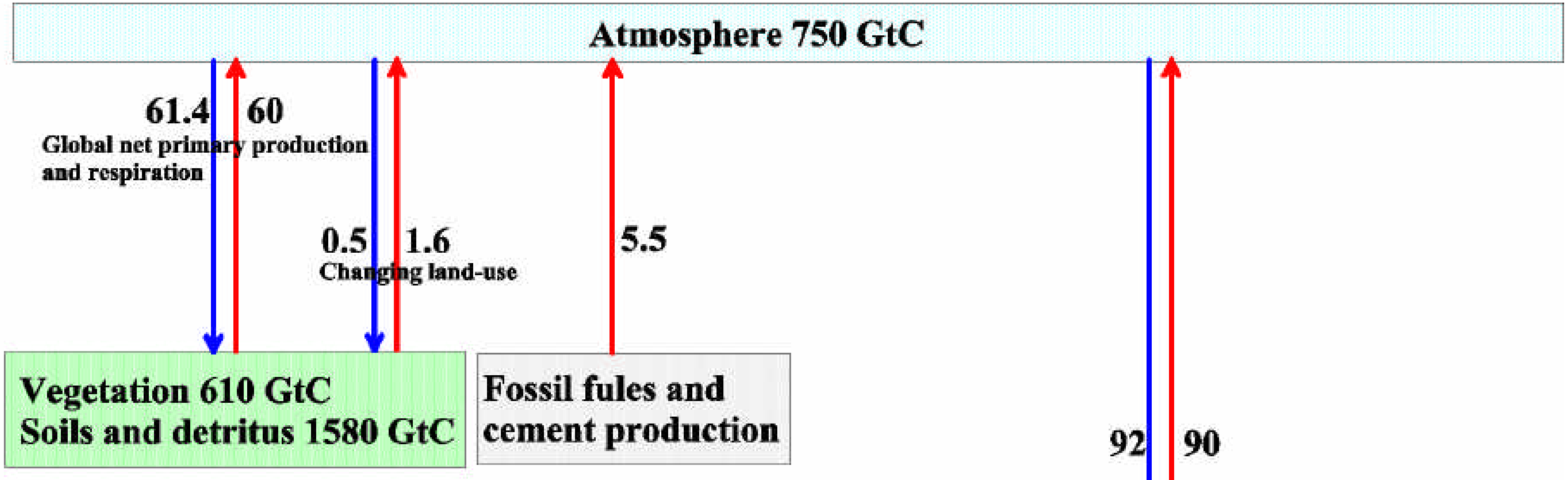
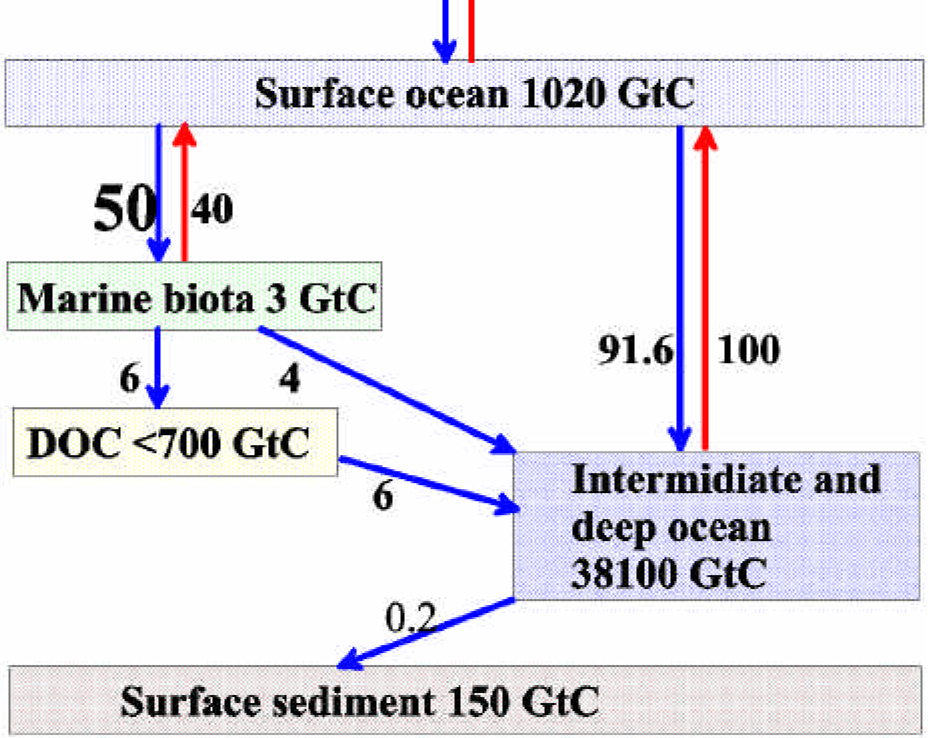
1. Introduction and simple primary productivity model

1. Carbon cycle
2. Definition of primary productivity
3. Simple primary productivity model
4. Monthly binned data
   a. Chlorophyll-a concentration
5. Practice
   a. How to play on SeaDAS
   b. How to implement simple primary productivity model





Why primary productivity?

- Phytoplankton is the base of food chain followed by zooplankton and fish.
- Phytoplankton has a role to transport carbons into a deep water (biological pump).
- It is necessary to evaluate a contribution of phytoplankton in a carbon cycle.

Approach:

- Modeling to estimate primary productivity from satellite observations.
- Regional to global model.

The global carbon cycle

"Wigley, T.M.L. and Schimel,D.S. (2000) The Carbon Cycle" shows the reservoirs and fluxes (GtC/yr) relevant to the anthropogenic perturbation as annual averages over 1980 to 1989.

CO_2 and O_2 cycle

$$CH_2 + 3/2O_2 \ ? \quad CO_2 + H_2O$$

Fossil-fuel burning
=destruction of organic matter
CH2 : fossil fuel

$$H_2O + CO_2 \rightleftarrows CH_2O + O_2$$

Photosynthesis and respiration
= formation of organic matter
CH2O : terrestrial organic matter

$$CO_2 + CO_3 + H_2O \rightleftarrows 2HCO_3^-$$

Reactions of the carbon system in seawater
CO_2 : carbon dioxide
CO3 : carbonate
HCO_3 : bicarbonate

The exchanges of carbon gasses across the air-sea interface are driven by disequilibrium between the air and sea, where a natural state seeks for a chemical equilibrium.

Uncertainty of photosynthesis processes

The approximate magnitude of net carbon fixation and biomass in the oceanic and terrestrial environments is known within approximately a 30 % uncertainty.

Table. Comparison of productivity and biomass in marine and terrestrial ecosystems.

Ecosystem Type	Total Net Primary Productivity (10^{15}g/yr)	Total Living Plant Biomass (10^{15}g)	Turnover Time (years)
Marine	25 – 50	1 - 2	0.02 – 0.08
Terrestrial	50 - 75	600 - 800	8 -16

From Falkowski et al. (1998)

Uncertainty of photosynthesis processes

The oceanic and terrestrial ecosystems exhibits different aspects:

1. The absolute magnitude of carbon fixation attributed to marine photosynthetic organisms accounts for approximately 40 % of the global total,

2. The Oceanic photosynthetic organisms turn over much more rapidly than their terrestrial counterparts, and

3. The Marine photosynthetic organisms, composed almost entirely of single-celled phytoplankton, account for less than 1 % of the total global plant biomass.

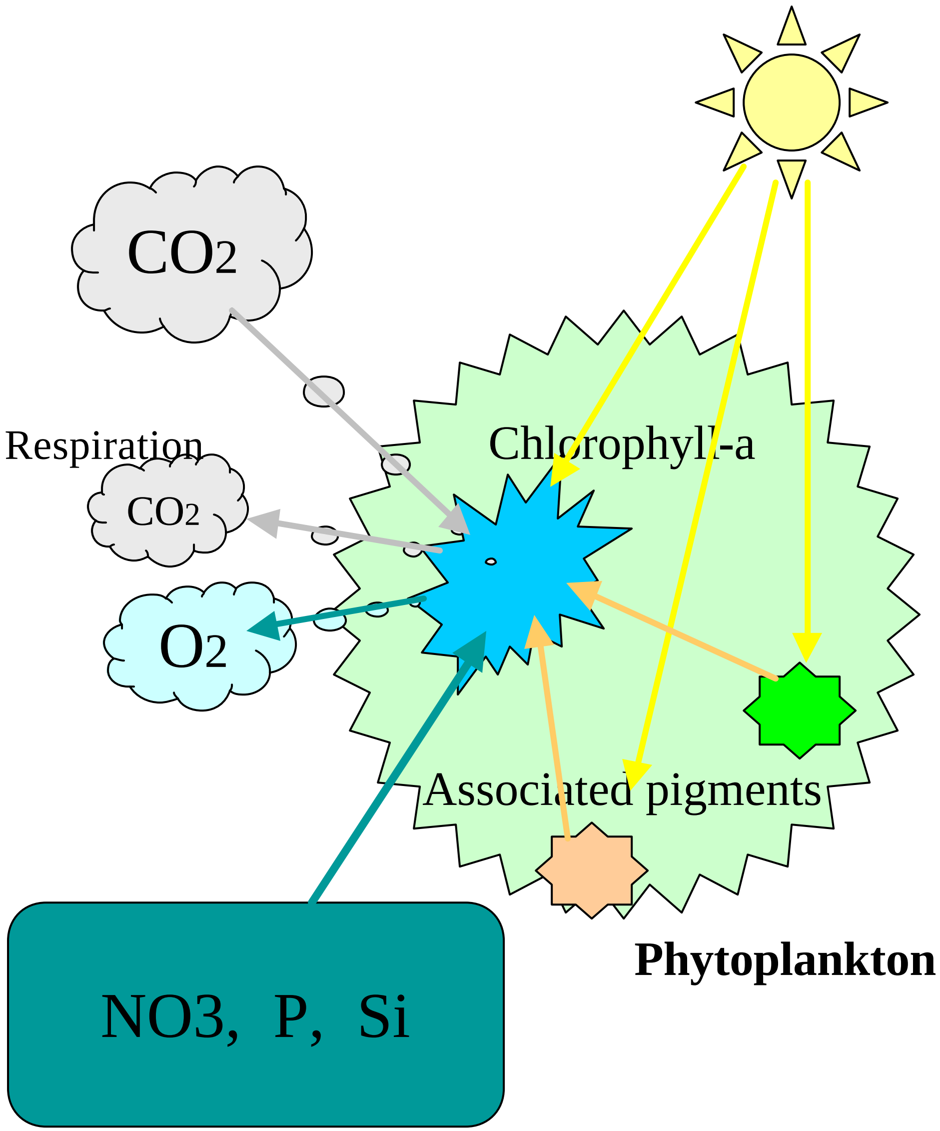
Biological pump

The biological pump is proposed by Volk and Hoffert (1985), which sustains a steady-state, air-sea gradient in inorganic carbon as a carbon flux.

Major questions on the oceanic biological pump in the global climate are:

1. Is the biological pump changing or is it in steady state?
2. If it is changing, what is the sign of the change, and how will the change affect atmospheric gas composition?
3. What could cause the biological pump to change and what is the capacity of the ocean to remove or add CO2 from, or to, the atmosphere via biological processes?

Why primary productivity?



– Phytoplankton in the water fixes inorganic carbons into organic carbons through phtosynthesis.

– In the photosynthesis, chlorophyll-a receives light and associated pigments transfer light energy to chlorophyll-a.

– Chlorophyll-a ingest inorganic carbon and nutrients (NO3, P, Si) with light energy.

Photosynthesis and respiration

$$2H_2O + CO_2 + light \rightleftarrows (CH_2O) + H_2O + O_2$$

CO_2: oxidized or inorganic form of carbon as;

CO_2 carbon dioxide

HCO_3^- bicarbonate

CO_3^{2-} carbonate

CH_2O: organic matters

$\longrightarrow$: photosynthesis

$\longleftarrow$: respiration

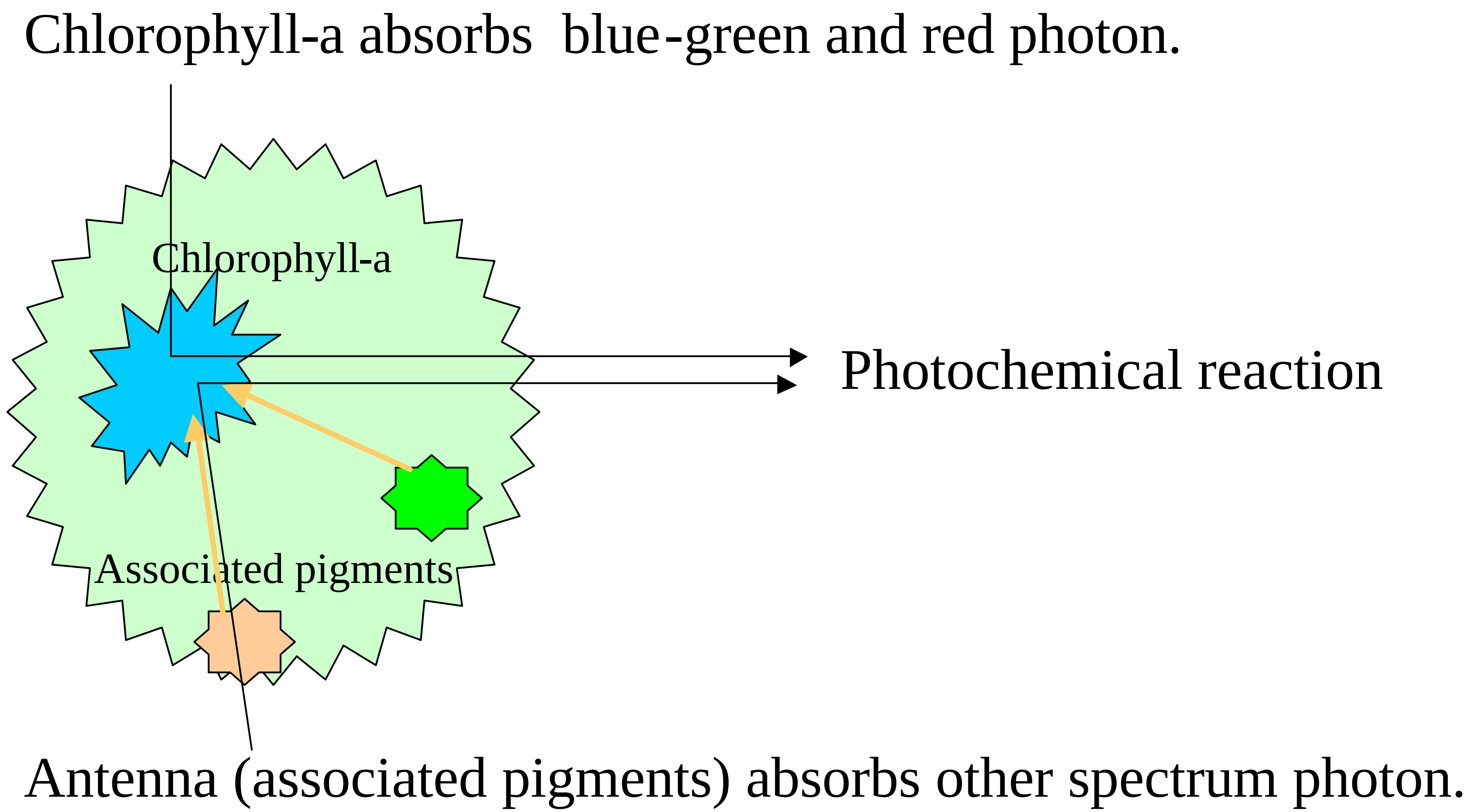
Photosynthesis and respiration

$$2H_2O + CO_2 + light \rightleftharpoons (CH_2O) + H_2O + O_2$$

$$\text{Quantum yield of photosynthesis} = \frac{CH_2O}{\text{light-absorbed}}$$

Photosynthesis and respiration

+ light



Photosynthesis and respiration

$$P_n = P_G - R_l$$

P_n : Net photosynthesis

P_G : Gross photosynthesis is defined as the number of electrons photochemically produced from the splitting of water

R_l : All the losses of fixed carbon due to respiratory processes of the photosynthetic organism ***in the light***.

Photosynthesis can occur only in the light.

Photosynthesis and respiration

$$PP = ? \ (P_n - R_d)dt$$

PP : Primary productivity

Primary productivity has dimensions of carbon fixed, or oxygen evolved, per unit area and per unit of time (Rate of primary production).

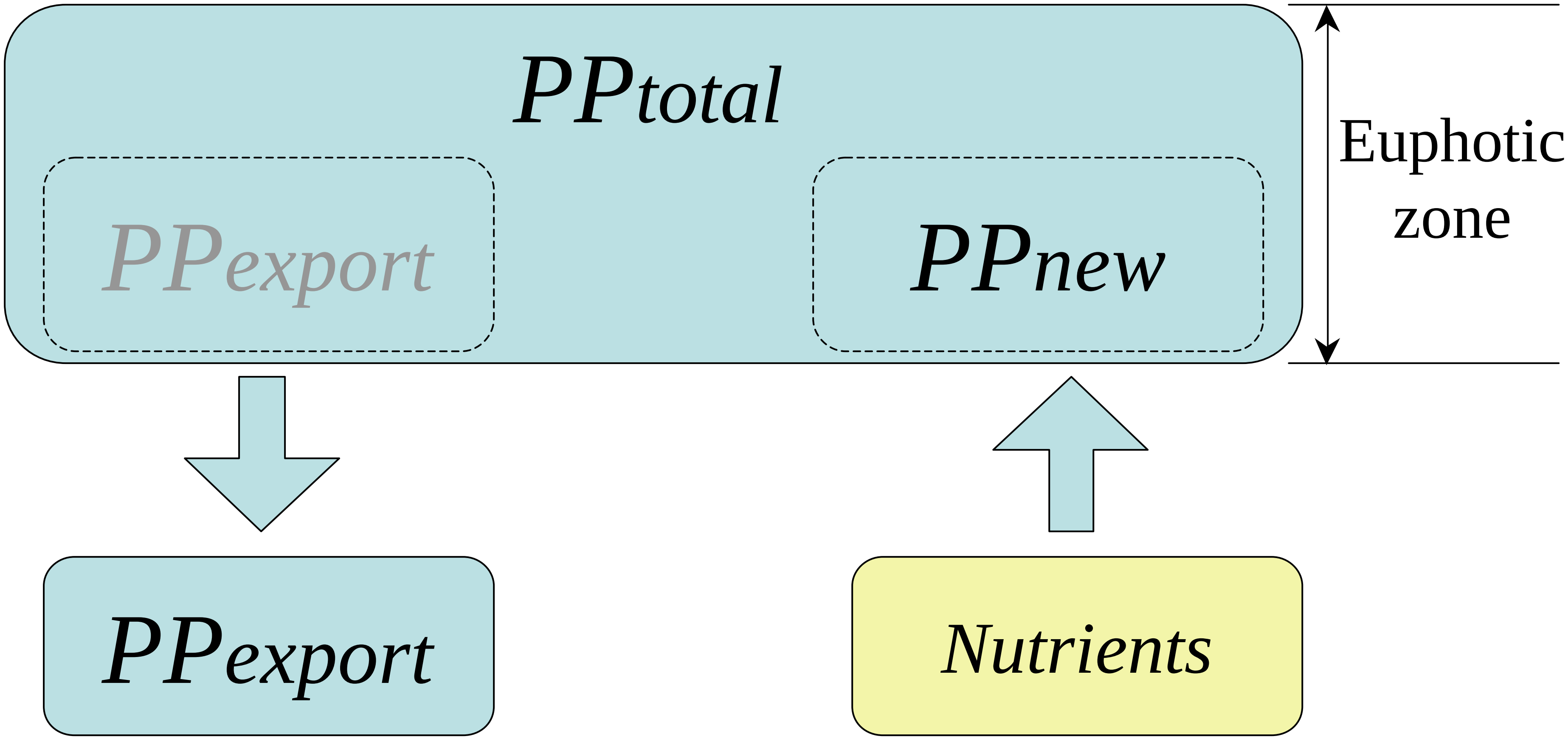
P_n : Net photosynthesis

R_d : ***Dark*** respiration by the photosynthetic organism. (Respiratory losses in the dark.)

$$PP_{total} = ? \ PP\ dd$$

PPtotal : Integrated water column primary productivity.

Export and new primary production



PPexport = PPnew in a steady state.

$$f\text{ ratio} = \frac{\text{New primary production}}{\text{Total primary primary production}}$$

Export and new primary production

Nutrients

- vertical fluxes from the ocean interior
- biological nitrogen fixation
- atmospheric deposition
- lateral fluxes from terrestrial runoff

Primary productivity models

Wavelength resolved models (WRMs)

$$S\ \ PP = ?_{?=400}^{700} ?_{sunrise}^{sunset} ?_{z=0}^{Zeu} f\ (?,t,z) PAR(?,t,z) a^*(?,z) Chl(z)\ d?dtdz - R$$

Wavelength integrated models (WIMs)

$$S\ \ PP = ?_{sunrise}^{sunset} ?_{z=0}^{Zeu}\ F\ (t,z)\ PAR(t,z)\ a^*(z)\ Chl(z)\ dtdz - R$$

Time integrated models (TIMs)

$$S\ \ PP = ?_{z=0}^{Zeu}\ P^b(z)\ PAR(z)\ DL\ Chl(z)\ dz$$

Depth integrated models (DIMs)

$$S\ \ PP = P^b{}_{opt}\ PAR(0)\ DL\ Chl\ Zeu$$

Primary productivity models

Wavelength resolved models (WRMs)

$$S\ \ PP = ?_{?=400}^{700} ?_{sunrise}^{sunset} ?_{z=0}^{Zeu} f\ (?,t,z) PAR(?,t,z) a^{*}(?,z) Chl(z)\ d?dtdz - R$$

$f\ (?\ ,t,z)$	: chlorophyll specific quantum yields for ***available*** photosynthetically active radiation (PAR),
$PAR(?\ ,t,z)$	: photosynthetically active radiation,
$a\ ^{*}(?\ ,z)$	: chlorophyll specific spectral ***absorption*** coefficient for phytoplankton, which is normalized for chl-a conc.
$Chl(z)$	: chlorophyll *a* concentration at depth z,
R	: daily phytoplankton respiration,
Zeu	: depth of the euphotic zone,
$?$	: wavelength,
t	: time,
z	: depth.

Primary productivity models

Wavelength integrated models (WIMs)

$$S\ \ PP = ?_{sunrise}^{sunset} ?_{z=0}^{Zeu} F\,(t,z) PAR(t,z) Chl(z)\ dtdz - R$$

F (t,z) : chlorophyll specific quantum yields for ***absorbed*** photosynthetically active radiation (PAR),

PAR(t,z) : photosynthetically active radiation,

Chl(z) : chlorophyll *a* concentration at depth z,

R : daily phytoplankton respiration.

Primary productivity models

Time integrated models (TIMs)

$$S\ PP = ?_{z=0}^{Zeu}\ P^b(z)\ PAR(z)\ DL\ Chl(z)\ dz$$

$P^b(z)$	: chlorophyll specific photosynthetic rate,
$PAR(z)$	: photosynthetically active radiation,
DL	: day length,
$Chl(z)$	: chlorophyll a concentration at depth z.

Primary productivity models

Depth integrated models (DIMs)

$$S\ PP = P^b_{opt}\ PAR(0)\ DL\ Chl\ Zeu$$

P^b_{opt}	: optimum chlorophyll specific carbon fixation rate within a water column,
PAR(0)	: photosynthetically active radiation,
DL	: day length,
Chl	: chlorophyll a concentration,
Zeu	: depth of euphotic zone.

Measurement of primary productivity

13C enriched Sodium Hydrogen Carbonate ([13C]-$NaHCO_3$), or

14C enriched Sodium Hydrogen Carbonate ([14C]-$NaHCO_3$)

b. Tracer spiking

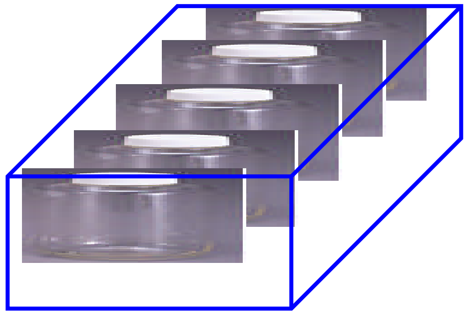
Polycarbonate bottle

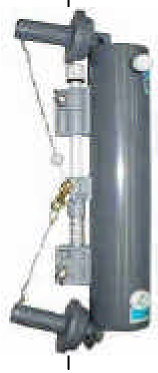
c-1. In-situ incubation

c-2. Simulated in-situ incubation

on deck (light source=the sun)

in lab (light source=artificial light)





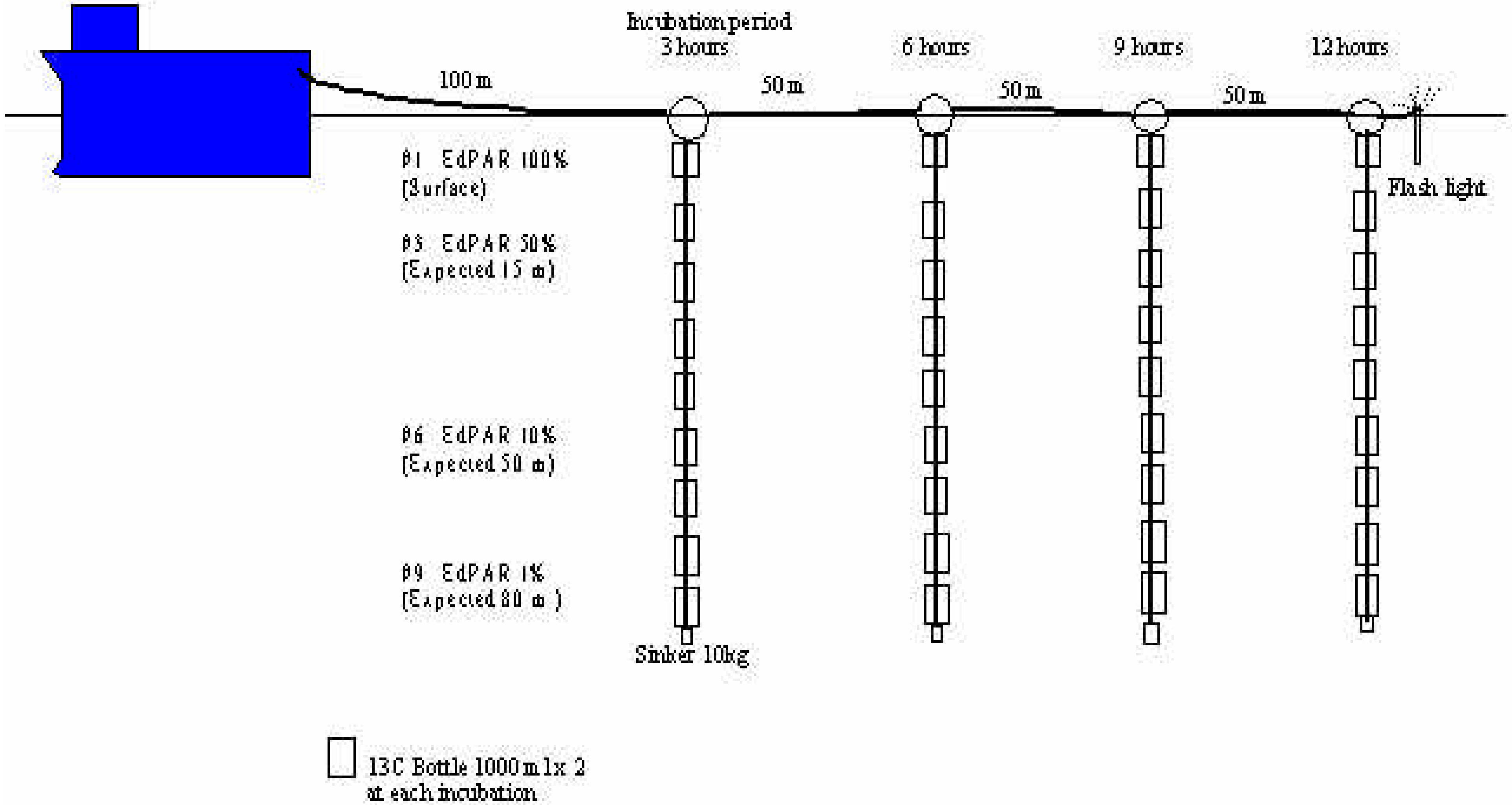
a. Water sampling

before sunrise, or

shortly before local apparent noon

e.g. Niskin water sampling bottle

In-Situ Incubation Plan for K95-06 (Jan, 1996)   JAMSTEC



Measurement of primary productivity

Incubation bottle

Polycarbonate bottle

Incubated phytoplankton

Filtering phytoplankton
by GF/F grass fiber filter
Ingested carbon remains on filter
12C/13C or 12C/14C

Unused carbon goes
through the filter

12C/13C

12C/14C

Gas Chromatograph Mass Spectrometer

Scintillation Counter

Primary productivity

3. Simple primary productivity model

Implementation of empirical model

- Epply et al. (1985)

$$log_{10}(dpc) = 3.0 + 0.5log_{10}(C_K)$$

- Berger (1989)

$$log_{10}(dpc) = 2.793 + 0.559log_{10}(C_K)$$

where

dpc : daily productivity, $mgCm^{-2}d^{-1}$

C_K : average chlorophyll *a* concentration, $mgChl\ m^{-3}$

3. Simple primary productivity model

Implementation of empirical model

- One approach to expand the seasonal and spatial range

- Annual primary production algorithm
- Annual mean chlorophyll a concentration within the top optical depth
- Daily phytoplankton particulate organic carbon production, averaged monthly and annually.

$$Ppc = 135.3 + 47.8\ C_K$$

Ppc : annual primary productivity, gCm-2yr-1

C_K : annual mean chlorophyll a concentration, mgChlm-3

SeaDAS practice 1

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1. Estimate daily primary productivity for one month of the globe with the empirical model proposed by Berger (1989).

2. Estimate annual primary productivity with the annual algorithm by Behrenfeld et al. (1997).

2. Depth integrated primary productivity model

2-1. Depth integrated primary productivity model

2-2. Monthly binned data

a. Chlorophyll-a concentration
b. Sea surface temperature
c. PAR
d. K490

2-3. Practice 2

a. How to play on SeaDAS
b. How to implement temperature and PAR dependent primary productivity model

2-1. Depth integrated primary productivity models

Depth integrated primary productivity models (DIMs)

$$S\ PP = P^b_{opt}\ PAR(0)\ DL\ Chl\ Zeu$$

P^b_{opt}	: optimum chlorophyll specific carbon fixation rate within a water column,
$PAR(0)$	: photosynthetically active radiation,
DL	: day length,
Chl	: chlorophyll a concentration,
Zeu	: depth of euphotic zone.

2-1. Depth integrated primary productivity models

Depth integrated primary productivity models (DIMs)

Simplest one: Chlorophyll a concentration only

(Smith and Baker 1978, Eppley et al. 1985)

Second level: Depth-integrated chlorophyll-a concentration
Daily integrated surface PAR

(Falkowski 1981, Platt 1986)

Third level: Depth of euphotic zone
(Light penetration depth of 1 % surface irradiance)
Depth-integrated chlorophyll-a concentration
Daily integrated surface PAR with day length

(Wright 1959, Platt and Sathyendranath 1993, Behrenfeld and Falkowski 1997)

2-1. Depth integrated primary productivity models

Depth integrated primary productivity models (DIMs)

$$S \; PP = P^b_{opt} \, PAR(0) \, DL \, Chl \, Zeu$$

will be;

$$S \; PP = P^b_{opt} \; f(PAR_0) \; DL \; Chl_{surf} \; Z_{eu} \, ,$$

where

$f(PAR_0)$ is the irradiance dependent function,
Chl_{surf} is the surface chlorophyll a concentration,
Z_{eu} is the depth of the euphotic zone.

2-1. Depth integrated primary productivity models

Behrenfeld and Falkowski (1997) proposed the depth integrated model.

$$S\ PP = C_{surf}\ Z_{eu}\ P^{b}_{opt}\ DL\ \ 0.66125 PAR_{0}/(PAR_{0}+4.1),$$

where

$S\ PP$ is the daily carbon fixation (mgC.m^{-2}.d^{-1}),
C_{surf} is the chlorophyll concentration (mg.Chl.m-3),
Z_{eu} is physical depth receiving 1 % of surface irradiance (m),
P^{b}_{opt} is the optimum chlorophyll-specific carbon fixation rate (mg C (mg Chl)-1 h-1),
DL is the day length (h),
PAR_0 is the photosynthetically available radiation (Ein.m-2.d-1).

2-1. Depth integrated primary productivity models

S PP is the daily carbon fixation from the surface to Z_{eu} ($mgC.m^{-2}.d^{-1}$),

C_{surf} is the chlorophyll concentration measured at the depth nearest the surface or as derived by satellite (mg.Chl.m-3),

Z_{eu} is physical depth receiving 1 % of surface irradiance, which is equivalent to 4.6. divided by the mean attenuation coefficient for PAR (i.e. k_d) (m),

P^b_{opt} is the optimum chlorophyll-specific carbon fixation rate observed within a water column measured under conditions of variable irradiance during incubations typically spanning several hours (mg C (mg Chl)-1 h-1),

DL is the day length (h),

PAR_0 is the photosynthetically available radiation (Ein.m-2.d-1).

2-1. Depth integrated primary productivity models

S PP is the daily carbon fixation from the surface to Z_{eu} ($mgC.m^{-2}.d^{-1}$),

C_{surf} is the chlorophyll concentration measured at the depth nearest the surface or as derived by satellite (mg.Chl.m-3).

From the equation, the integrated chlorophyll concentration along the water column is given as;

$S\ C = C_{surf} \times Zeu$ (mg Chl m-2).

2-1. Depth integrated primary productivity models

Z_{eu} is physical depth receiving 1 % of surface irradiance, which is equivalent to 4.6. divided by the mean attenuation coefficient for PAR (i.e. k_d) (m).

$Csat = 0.28$ mg Chl m-3 >>> an average Zeu of 56 m (Morel and Berthon, 1989)

$Zeu = 4.6/k_d$,

where *Zeu* is the euphotic depth,

k_d is the attenuation coefficient for PAR ˜ k_{d490}.

For reference, the integration depth, which ocean color sensor observes, is proposed by the next equation.

$Zint = 1.0/k_d$

2-1. Depth integrated primary productivity models

Ryther and Yentsch (1957)

$P^b_{opt} = 3.7$ mg C (mg Chl)$^{-1}$ h^{-1}) · · · · · B

Falkowski (1981)

$P^b_{opt} = 2.5$ mg C (mg Chl)$^{-1}$ h^{-1}) · · · · · A

Cullen (1990)

$P^b_{opt} = 4.8$ mg C (mg Chl)$^{-1}$ h^{-1}) · · · · · C

Megard (1972)

$P^b_{opt} = 0.118\,T + 1.25$ mg C (mg Chl)$^{-1}$ h^{-1}) · · · · · D

Antoine et al. (1996) following to Eppley (1972)

$P^b_{opt} = 10^{(0.0275T-0.07)}$ normalized to 4.6 mg C (mg Chl)$^{-1}$ h^{-1}) at 20d-C · · · · ·

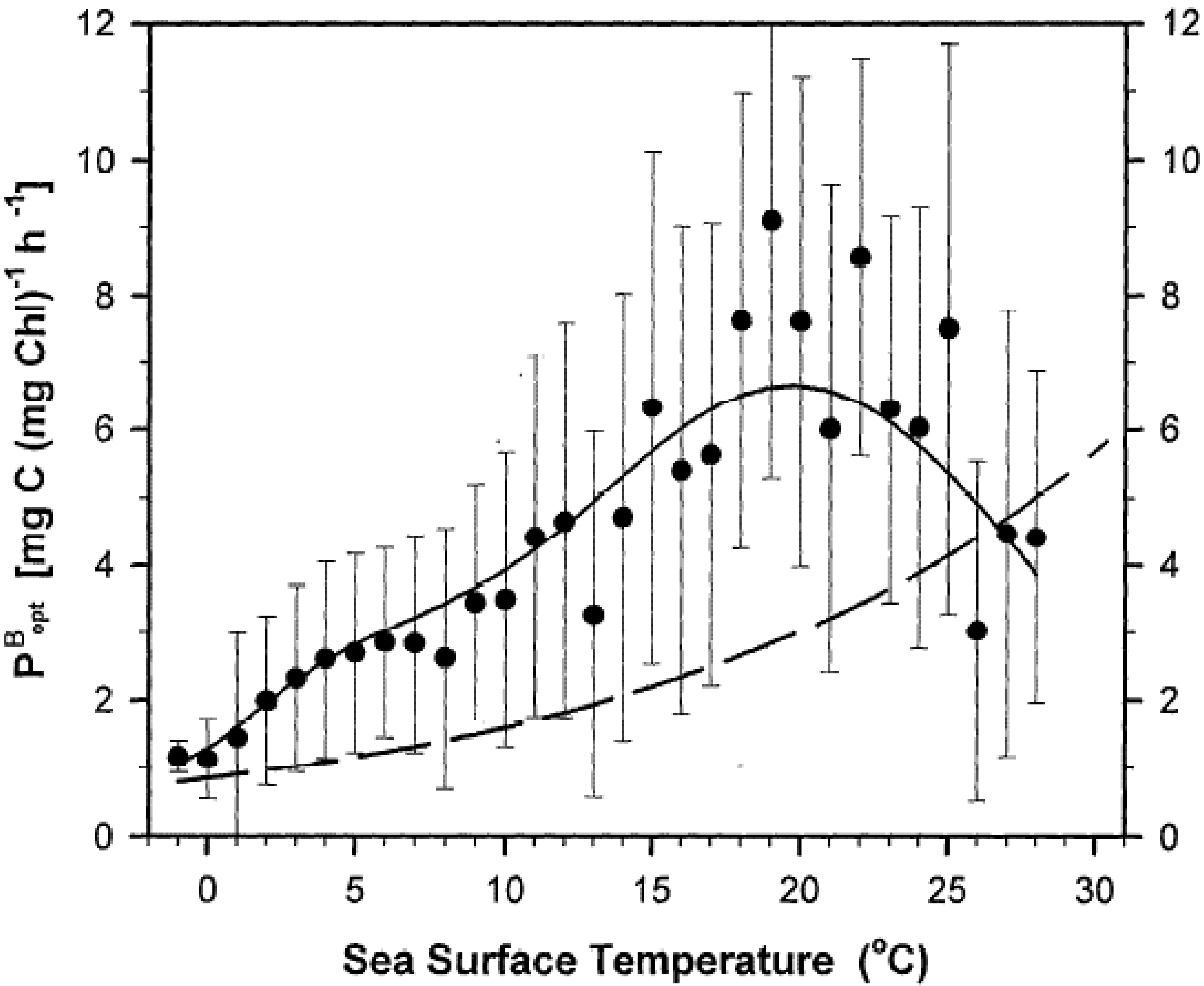
Behrenfeld and Falkowski (1997)

$$P^b_{opt} = -3.27x10^{-8}T^7+3.4132x10^{-6}T^6-1.348x10^{-4}T^5 +2.462x10^{-3}T^4-0.0205T^3+0.0617T^2+0.2749T+1.2956$$

· · · · · F

Balch et al. (1992)

$P^b_{opt}\,DL = 10^{(-0.054T+2.21)}$ · · · · · G



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January 1997 Volume 42 Number 1
Photosynthetic rates derived from satellite-based chlorophyll concentration
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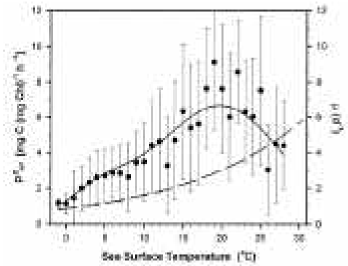
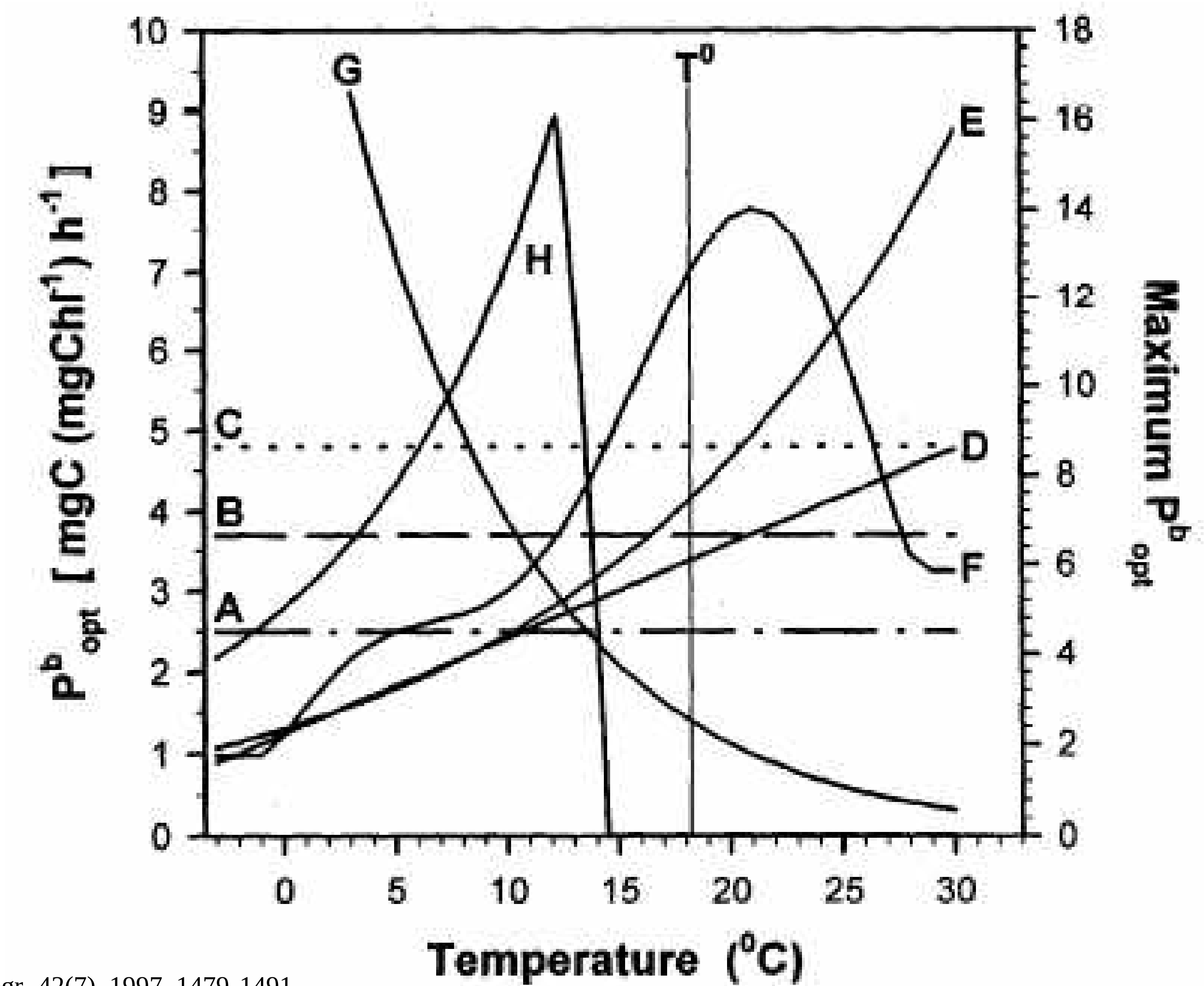


Fig. 7. Measured (? ; +SD) and modeled (—— ; Eq. 11) median value of the photoadaptive parameter, Pbopt, as a function of sea surface temperature. Dashed curve indicates the theoretical

maximum specific growth rate (µ ; d-l) of photoautotrophic unicellular algae described by Eppley (1972), which is used in a variety of productivity models (e.g. Balch and Byrne 1994; Antoine et al. 1996).



Lmnol Oceanogr, 42(7), 1997, 1479-1491

A consumer's guide to phytoplankton primary productivity models
Michael J. Behrenfeld and Paul G. Falkowski
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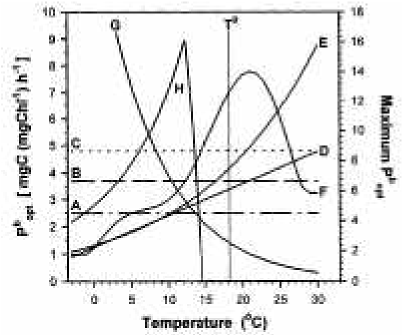

Summary of published models for estimating the optimum chlorophyll-specific carbon fixation rate within a water column (Pbopt).

A = calculated value implicit in the 9 model of Falkowski (1981).

B = Ryther and Yentsch's (1957) estimate of 3.7 mg C (mg Chl)-' h -I.

C = Cullen's (1990) revised value for B of 4.8 mg C (mg Chl--l h-l.

D = Megard's (1972) model converted to hourly rates by dividing by 13.7 h (Eq. 32).

E = Eppley's (1972) equation for the optimum specific growth rates (Eq. 33) converted to carbon fixation by normalizing to 4.6 mg C (mg Chl)-' h-l at 20 ° C following Antoine et al. (1996).

F = Behrenfeld and Falkowski's (1997) seventh-order polynomial model.

G = Balch et al. (1992) (Eq. 34). H = Biphasic model of Balch and Byrne (1994) for the maximum achievable Pbopt (c alculated for 20-30" latitude using a carbon : chlorophyll ratio of 150 and expressed in units of mg C (mg Chl)-' h-l (see their Fig. 6). The left axis applies to models A-G and the right axis to model H. T' = Levitus climatological median upper ocean temperature (18.1"C) as computed by Antoine et al. (1996).

2-1. Depth integrated primary productivity models

Practice for P^b_{opt}

P^b_{opt} is the optimum chlorophyll-specific carbon fixation rate observed within a water column measured under conditions of variable irradiance during incubations typically spanning several hours (mg C (mg Chl)-1 h-1).

Calculate P^b_{opt} models from A to G on the Excel and plot its graphs.

2-2. Monthly binned data (Ca)

The chlorophyll-a concentration is the product of SeaWiFS, called OC4V4.

$$Ca = 10^{0.366-3.067R+1.930R^2+0.649R^3-1.532R^4},$$

where

$$R = \log_{10}\left(\frac{R_{rs}443 > R_{rs}490 > R_{rs}510}{R_{rs}555}\right),$$

R_{rs} **is the remote sensing reflectance at the wavelength.**

2-2. Monthly binned data (SST)

The sea surface temperature is the product of MODIS.

The standard MODIS 11µm NLSST algorithm (non-linear sea surface temperature)

$$NLSST = c1 + c2(T31) + c3(T32 - T31) + c3(T32 - T31)(SST_{guess}) + c4(\sec ? \ -1)(T32 - T31),$$

where

T31 and *T32* are the brightness temperature (deg-C) at bands 31 and 32,

SST_{guess} is the first guess SST from Reynolds OISST products,

? is the satellite zenith angle,

c1 to *c4* are coefficients derived by RSMAS.

2-2. Monthly binned data (PAR)

The photosynthetically active radiation (PAR) is the product of SeaWiFS, which is the integrated energy of the downwelling irradiance between 400 and 700 nm, (Einstein.m-2.day-1).

$$PAR = ?_{sunrise}^{sunset} \; ?_{400}^{700} \; Ed(?,t)d?dt,$$

where *Ed(? ,t)* is the downwelling spectrum irradiance at

? nm at *t*.

2-2. Monthly binned data (K490)

The diffused attenuation coefficient at 490 nm (K490) is the product of SeaWiFS. K490 indicates the turbidity of the water column – how visible light in the blue – green region of the spectrum penetrates within the water column.

$$K(490) = K_w(490) + A[L_w(?_1)/L_w(?_2)]^B,$$

where $K_w(490)$ **is the diffuse attenuation coefficient for pure water, 0.016** m^{-1}**,**

$A = 0.15645$

$B = -1.5401$

$?_1 = 490$ nm

$?_2 = 555$ nm

SeaDAS practice 2

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1. Estimate a primary productivity with SST and PAR dependent model for P^b_{opt} of A to G.

3. Time and Depth resolved primary productivity model

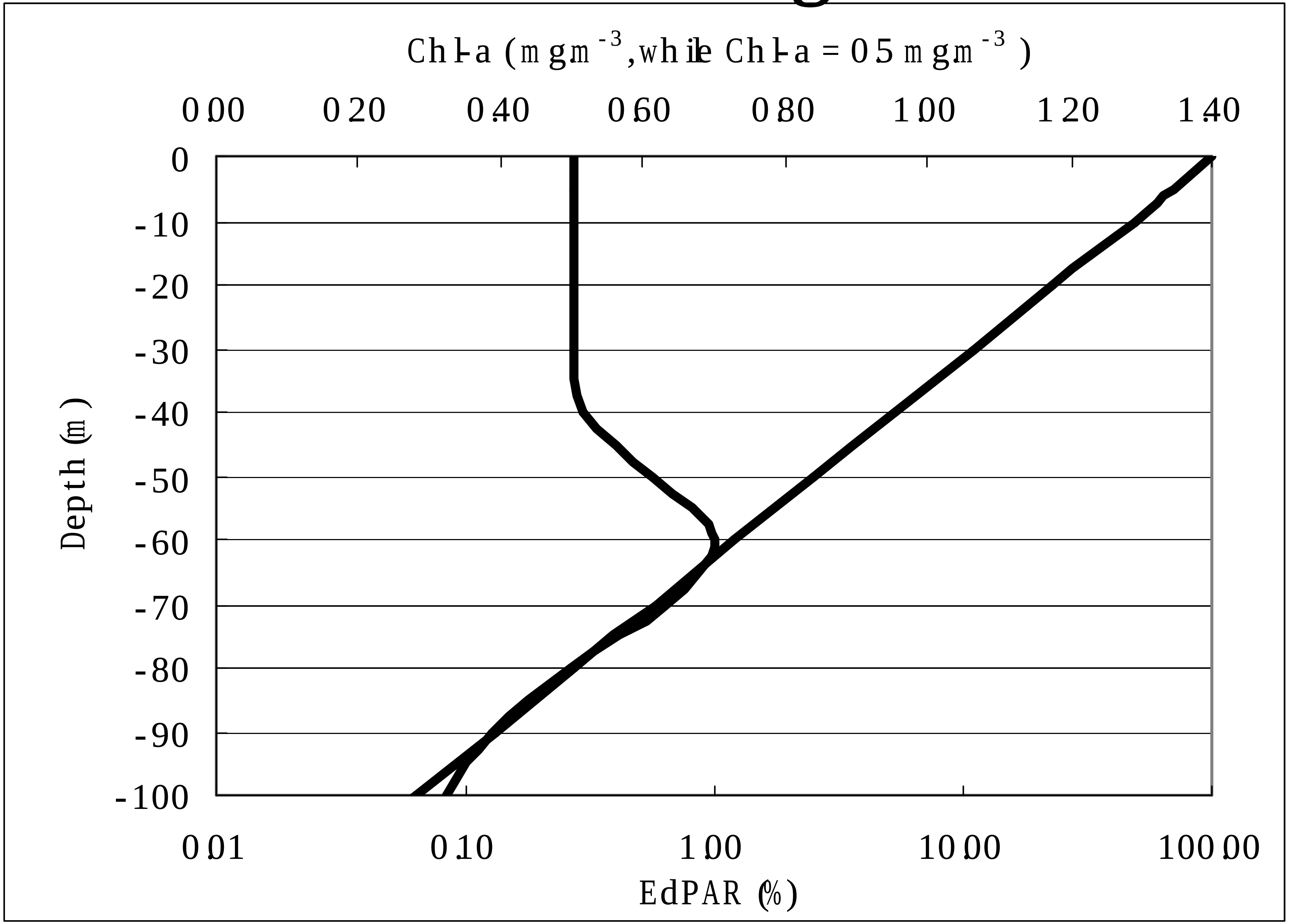
1. **Depth resolved primary productivity model**
   a. **Vertical distribution of PAR**
   b. **Vertical distribution of chlorophyll-a**
2. **Monthly binned data**
   a. **Chlorophyll-a concentration**
   b. **Sea surface temperature**
   c. **PAR and MODTRAN estimated PAR**
3. **Practice**
   a. **How to implement the depth resolved primary productivity model**

Time & depth resolved primary productivity model

$$PP_{eu} = ?_t ?_z\, P^b(z,PAR(z,noon),T)\, C(z)\, PAR_M(0,t)/PAR_M(0,noon)\,dz\,dt$$

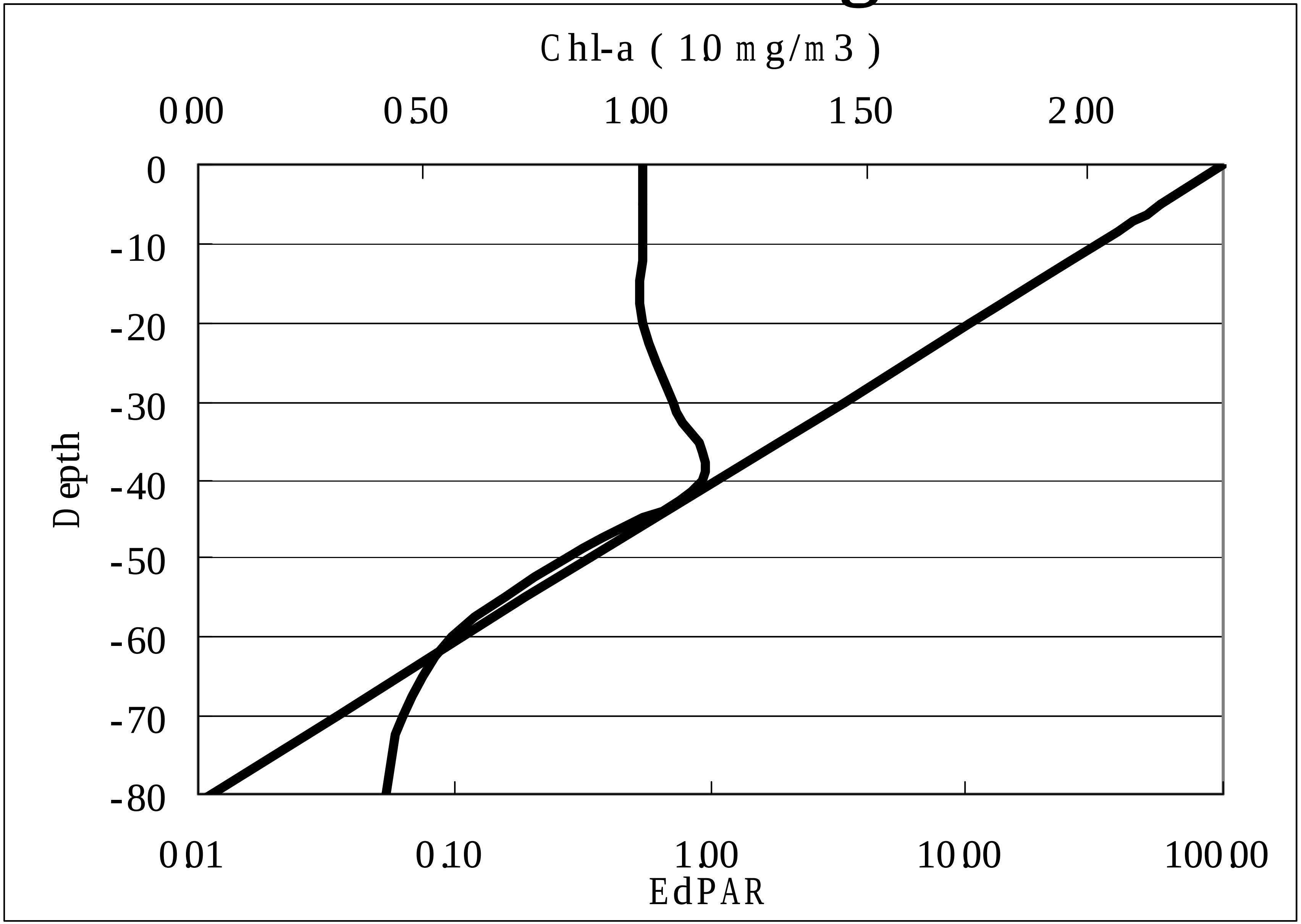
PP_{eu}; primary productivity ($mgC.m^{-2}.day^{-1}$)
P^b ; carbon fixation rate ($mgC.mgChl\text{-}a^{-1}.hour^{-1}$)
PAR; photosynthetically available radiation observed ($Ein.m^{-2}.day^{-1}$)
PAR_M; photosynthetically available radiation MODTRAN estimated ($Ein.m^{-2}.day^{-1}$)
C ; chlorophyll-a concentration ($mg.m^{-3}$)
T ; temperature (deg-C)

Chl-a = 0.5 mg/m^{-3}



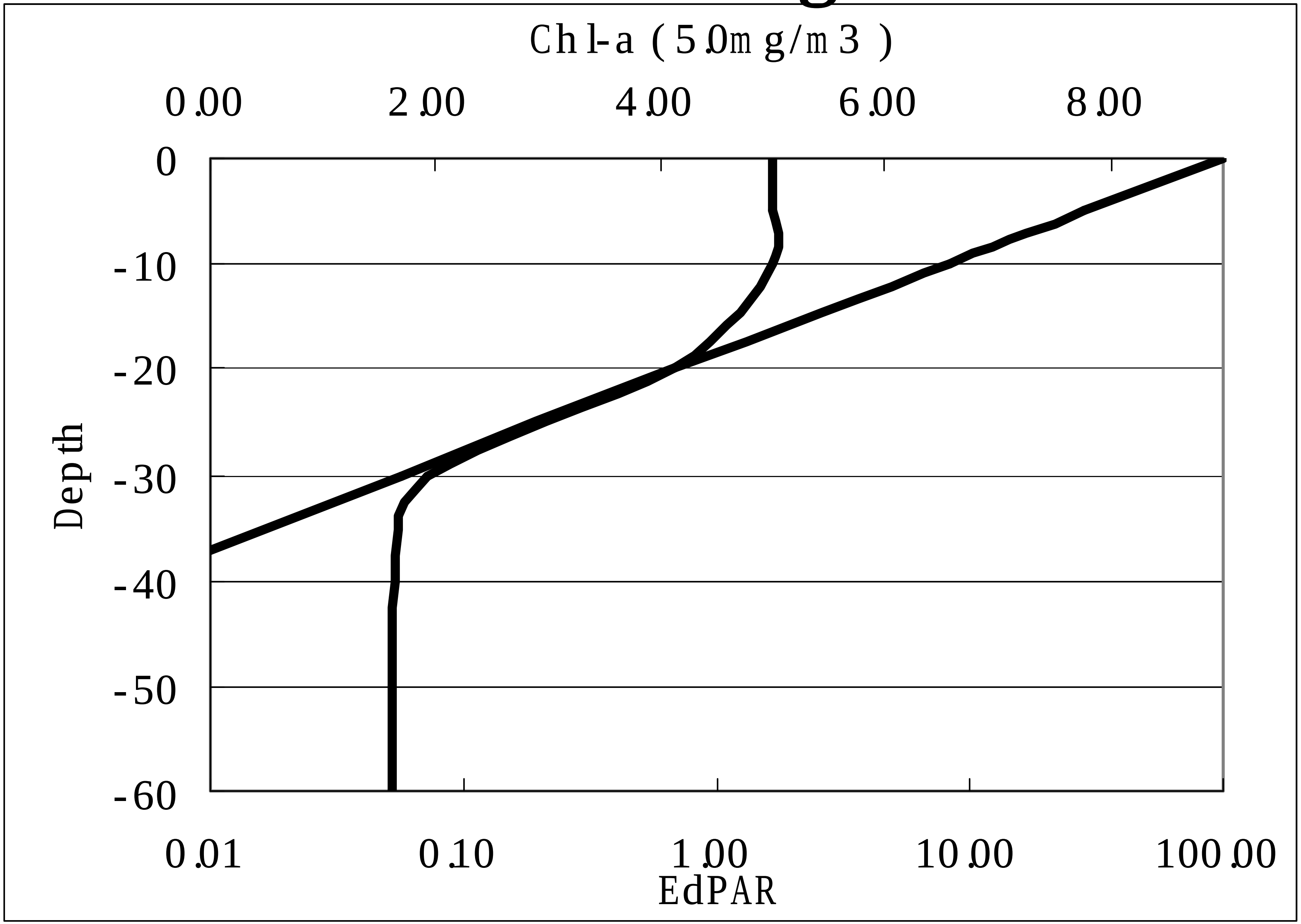
Chl-a (mg m-3, while Chl-a = 0.5 mg m-3)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
Depth (m)
0.01
0.10
1.00
10.00
100.00
EdPAR (%)

Chl-a = 1 .0 mg/m^{-3}



Chl-a (1.0 mg/m3)
0.00
0.50
1.00
1.50
2.00
0
-10
-20
-30
-40
-50
-60
-70
-80
Depth
0.01
0.10
1.00
10.00
100.00
EdPAR

Chl-a = 5.0 mg/m^{-3}



Chl-a (5.0mg/m3)
0.00
2.00
4.00
6.00
8.00
0
-10
-20
-30
-40
-50
-60
Depth
0.01
0.10
1.00
10.00
100.00
EdPAR

Asanuma 2001

(1) Vertical distribution of PAR%

$$\log(PAR\%)=(-0.025\ C_0\ -0.017)Z+2$$

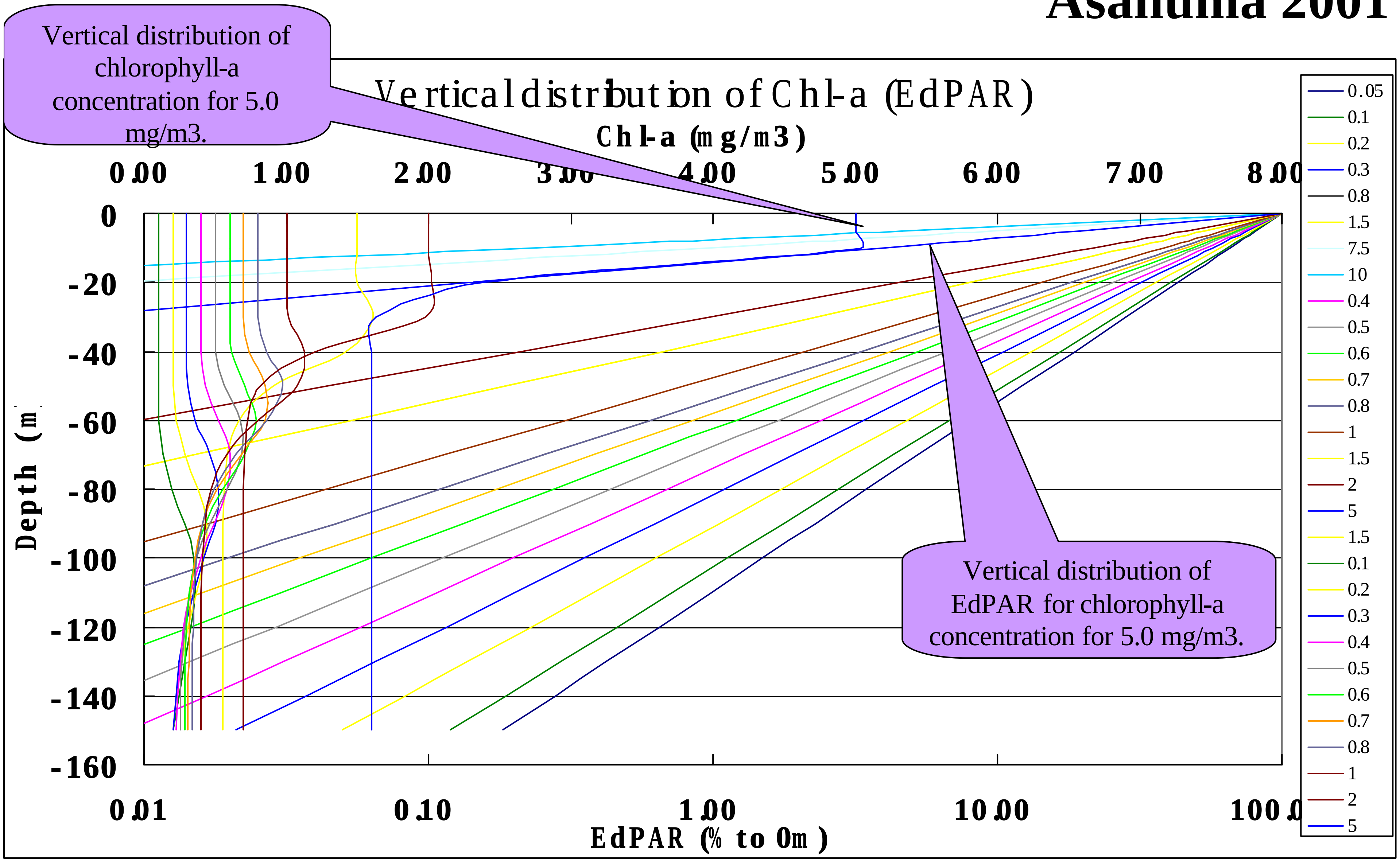
Asanuma 2001

(2) Vertical distribution of chlorophyll-a concentration

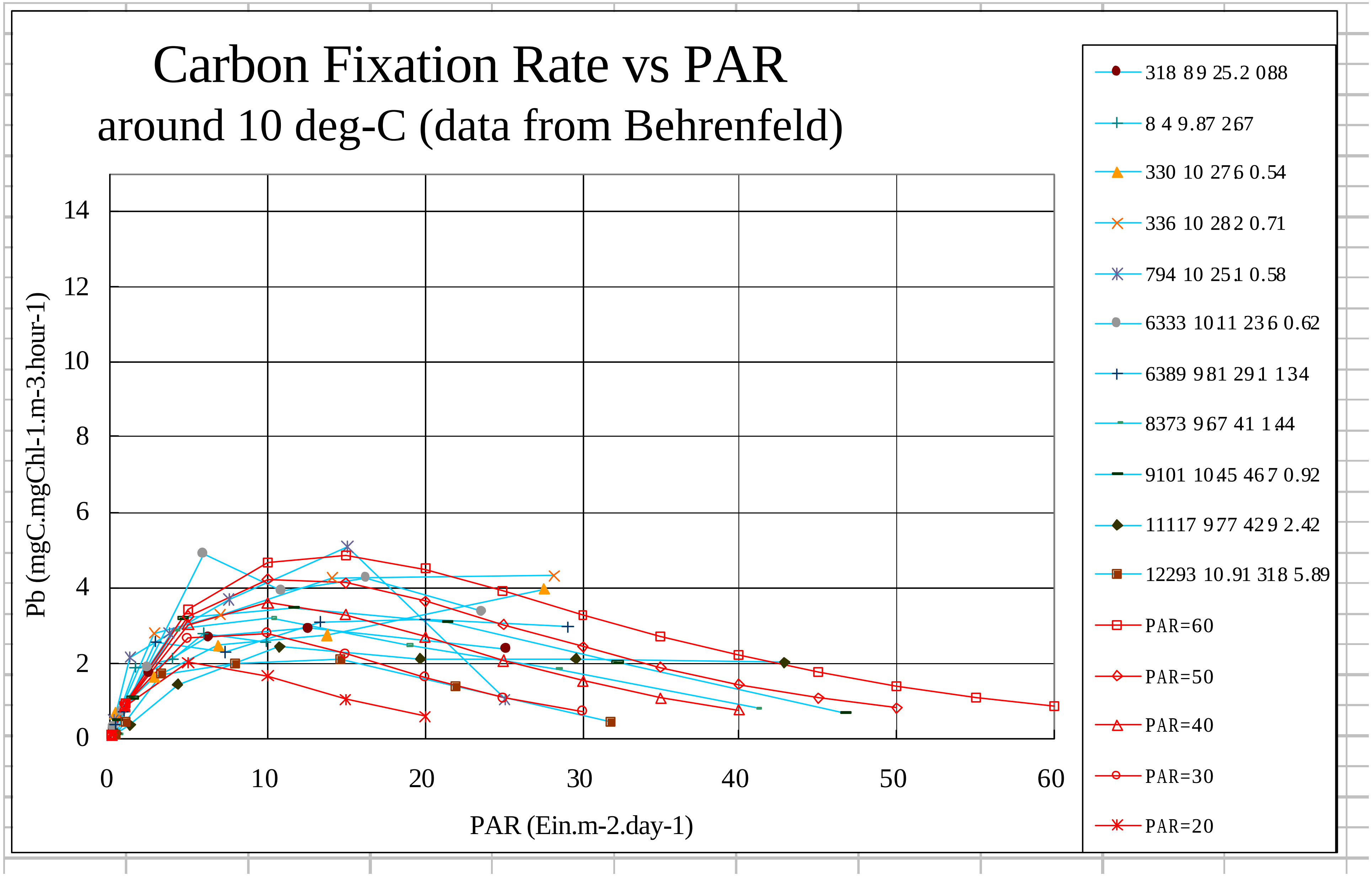
$$C(z)=[0.1-0.7C_0)exp\{-0.8PAR\%(z,C_0)\}]$$
$$?exp\{-0.8PAR\%(z, C_0)\} + C_0 \quad (mg.m^{-3})$$

Vertical distribution of Chl-a and PAR

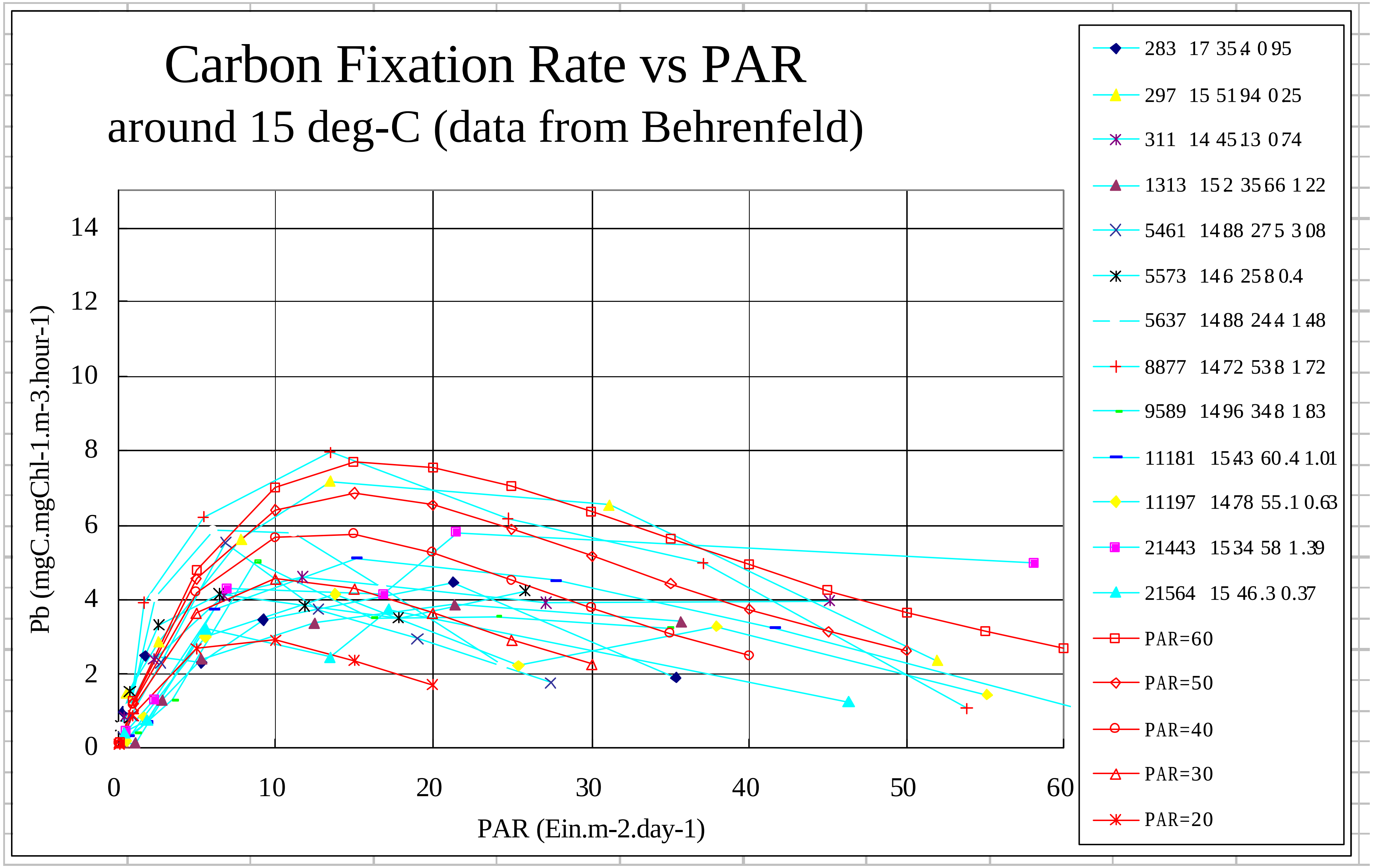
Asanuma 2001



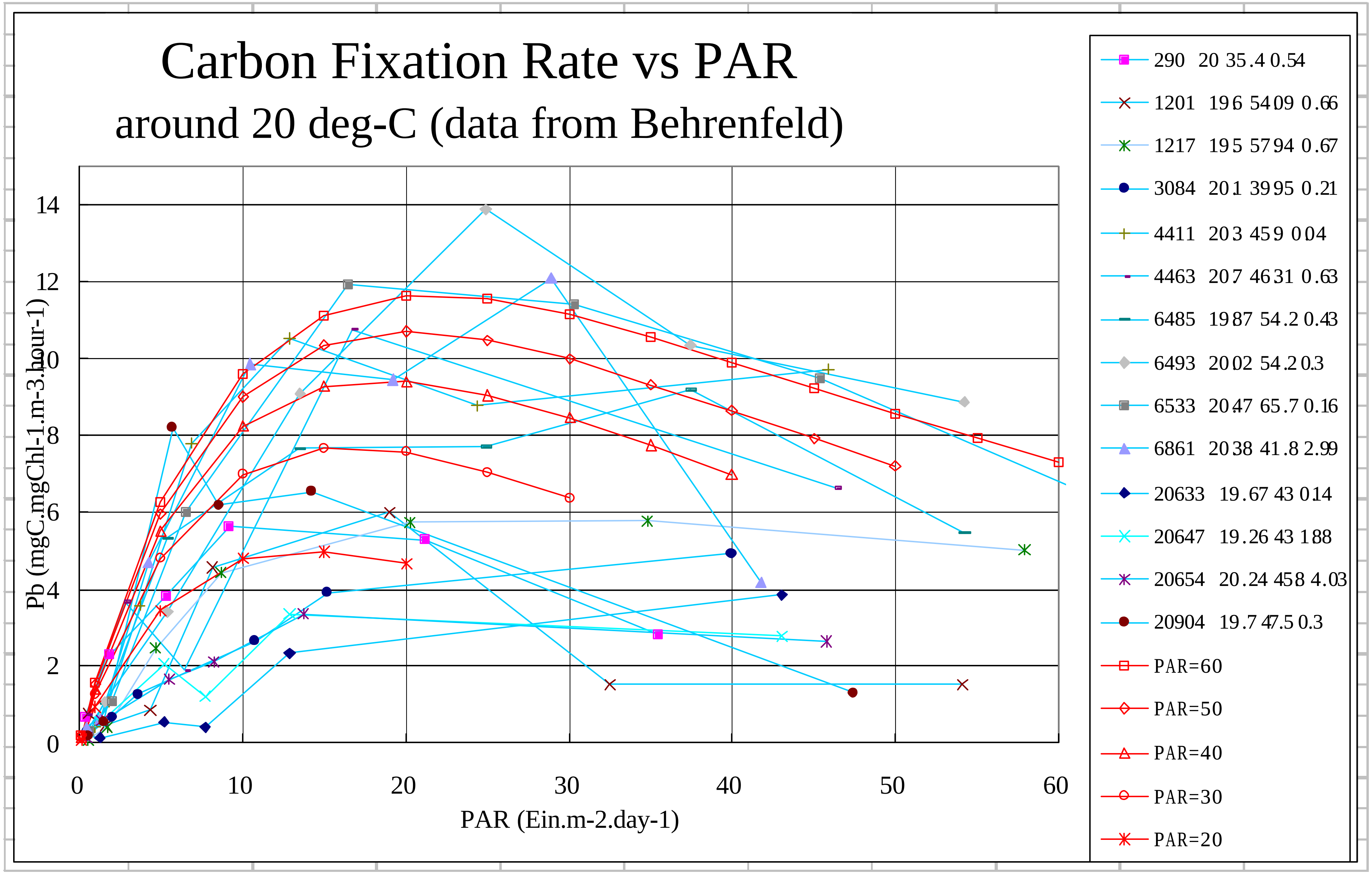
Pb function (red) fitted forobserved Pb (blue)
as a function of PAR at temperature range



Pb function (red) fitted forobserved Pb (blue) as a function of PAR at temperature range



Pb function (red) fitted forobserved Pb (blue) as a function of PAR at temperature range



(8) Carbon Fixation Rate $Pb_{(Z,PAR_0,T)}$

$$P^b(z) = 17\,[1-\exp\{-0.04\,a\,PAR\%(z)\,0.01\}]$$
$$\exp\{-0.3\,b\,PAR\%(z)\,0.01\}$$

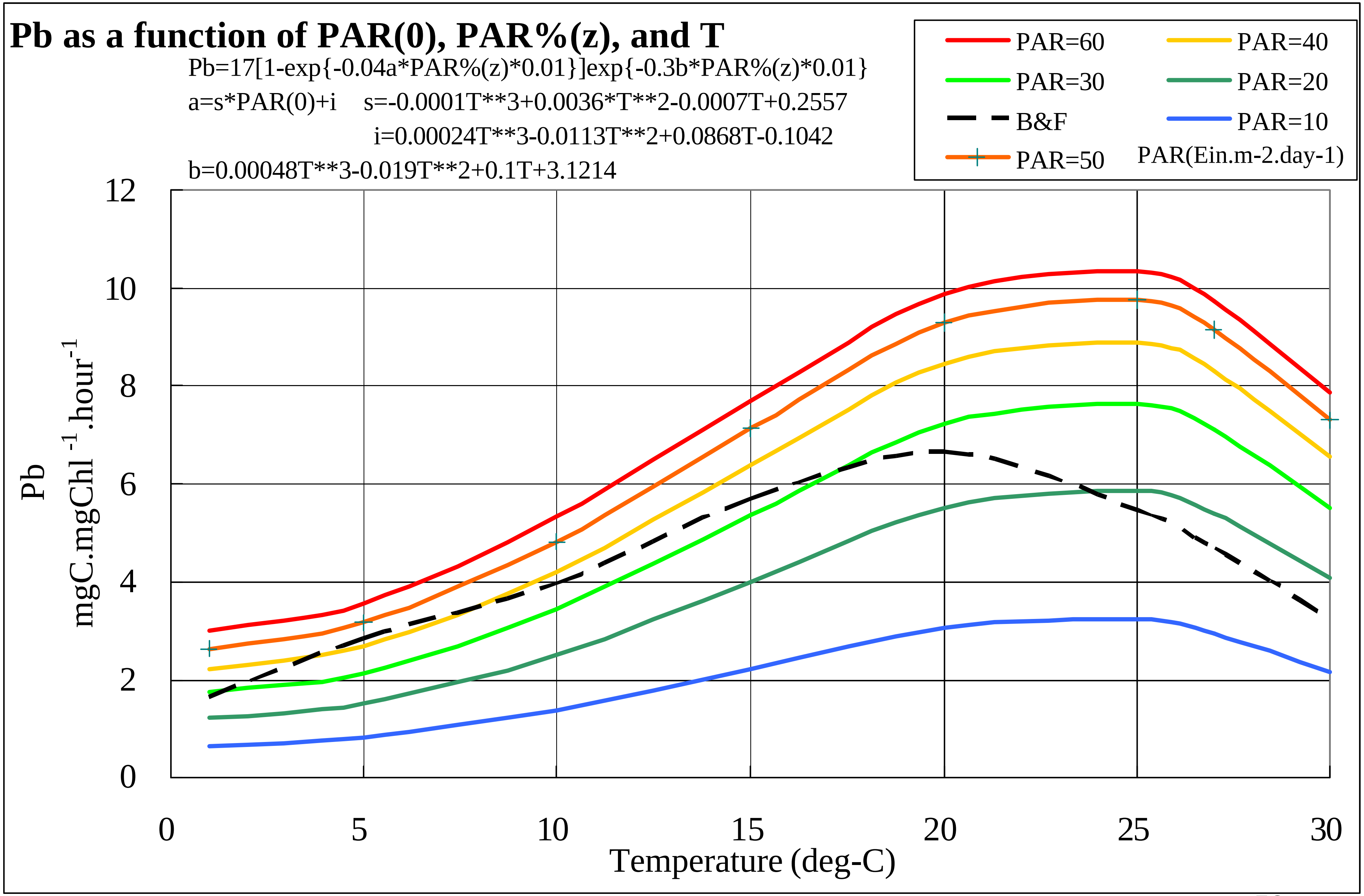
$$a = 0.1\,s\,PAR(0,day) + i$$

$$s = -0.0001T^3 + 0.0036T^2 - 0.0007T + 0.2557$$
$$i = 0.00024T^3 - 0.0113T^2 + 0.0868T - 0.1042$$

$$b = 0.00048T^3 - 0.019T^2 + 0.1T + 3.1214$$

Asanuma 2001

Carbon Fixation Rate as a function of SST & PAR



Asanuma 2001

(4c) Carbon fixation rate is given for PAR at noon.

$$PAR(noon) = PAR(day)\ PAR_M(noon)/PAR_M(day)$$

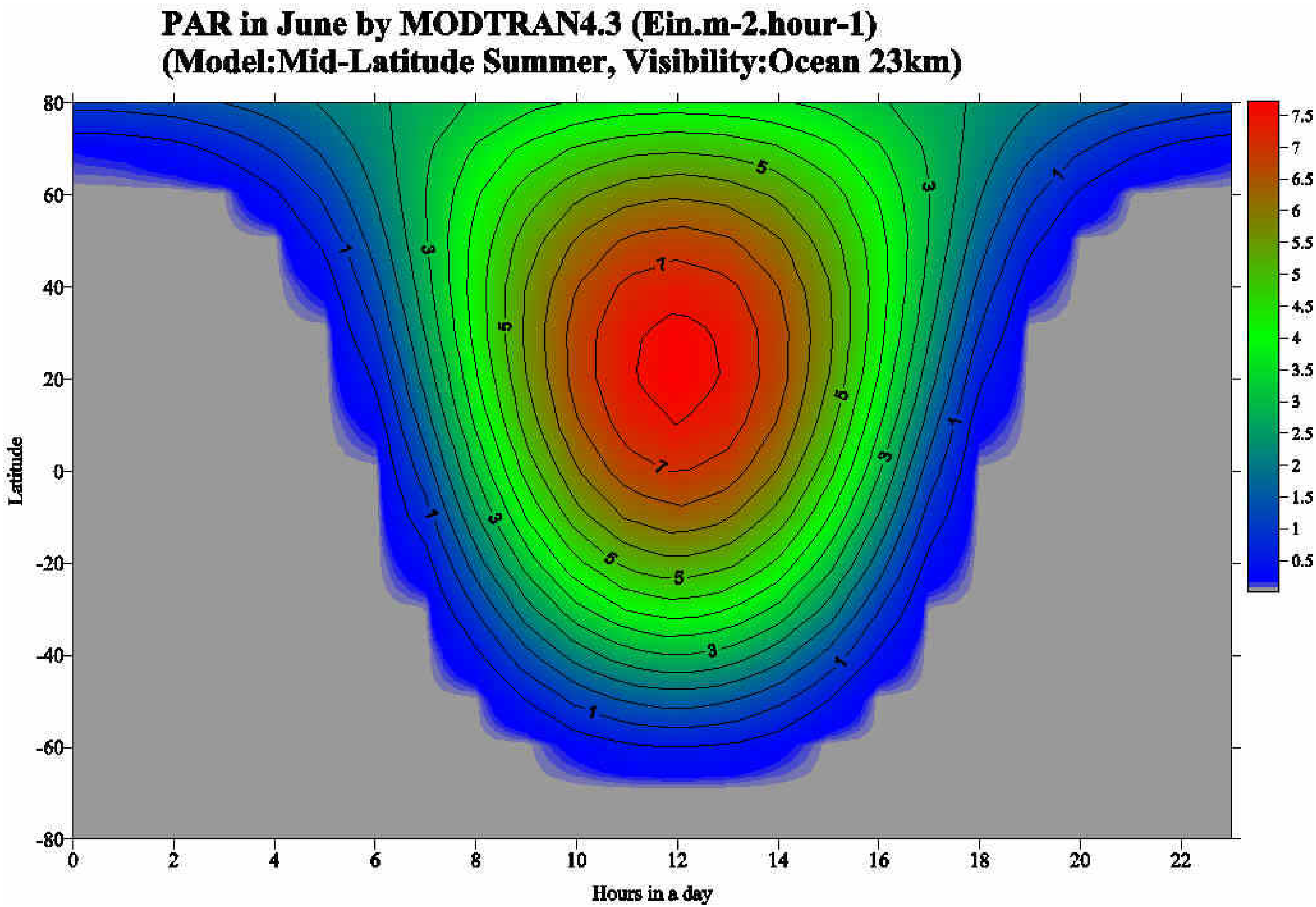
PAR(noon) : *PAR on the surface at noon estimated*

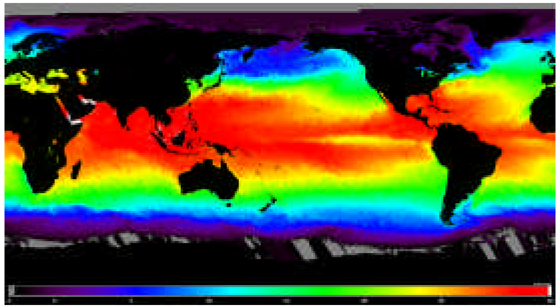
PAR(day) : *Integrated PAR for a day observed.*

PAR_M : *PAR computed by MODTRAN-4 for day and hour by the oceanic atmosphere.*

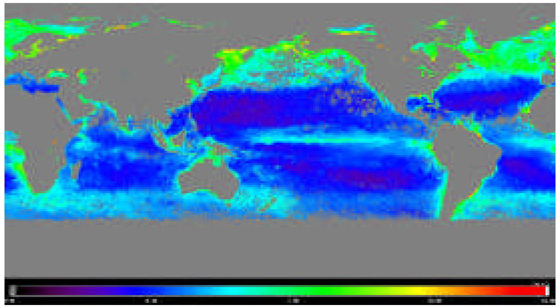
Asanuma 2001

PAR on the surface in June by MODTRAN

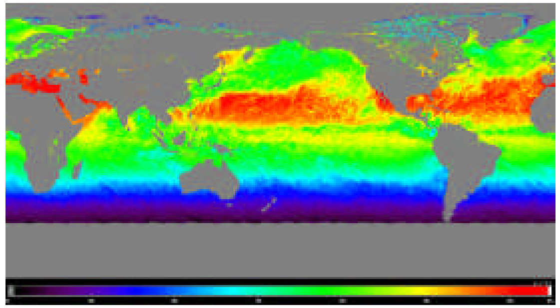




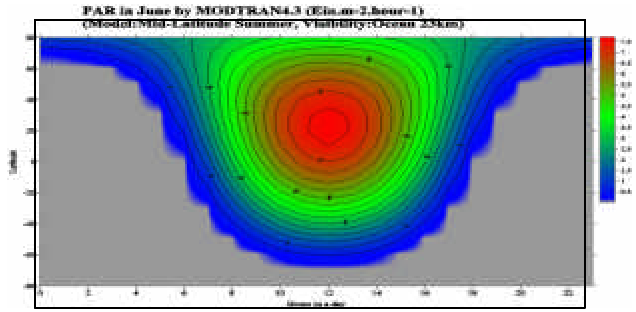
MCSST



Chl-a



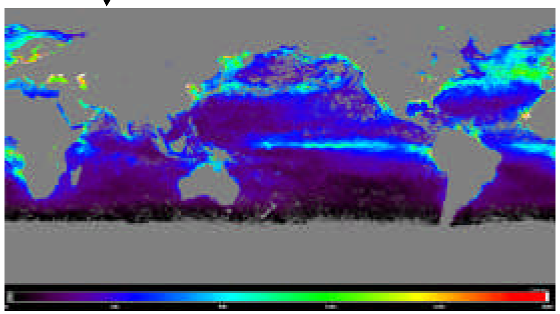
PAR



MODTRAN PAR (June)

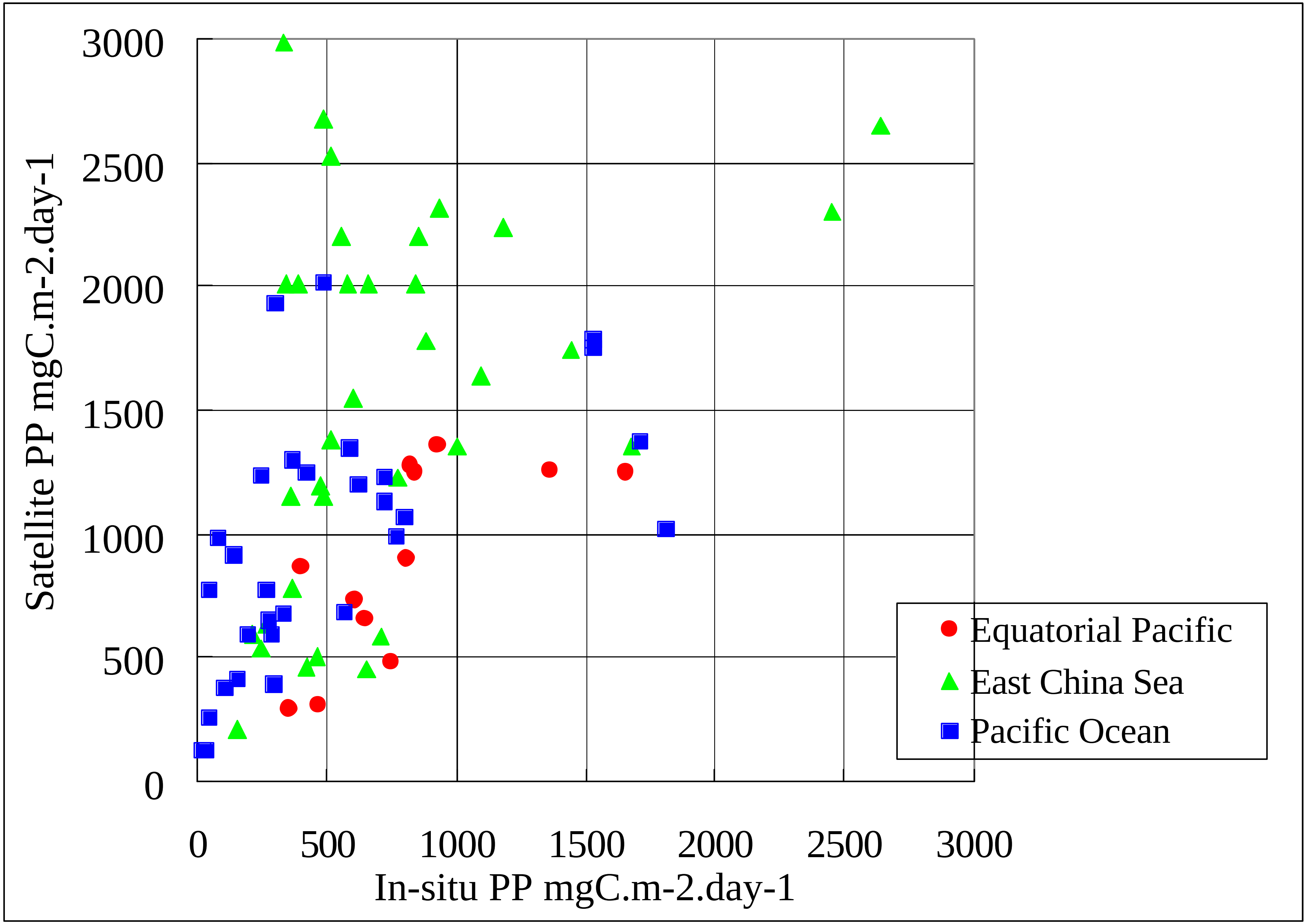
$$PP_{eu} = ?_t ?_z \, P^b(z, PAR(z, noon), T) \; C(z)$$

$$PAR_M(0,t)/PAR_M(0,noon) dz \; dt$$

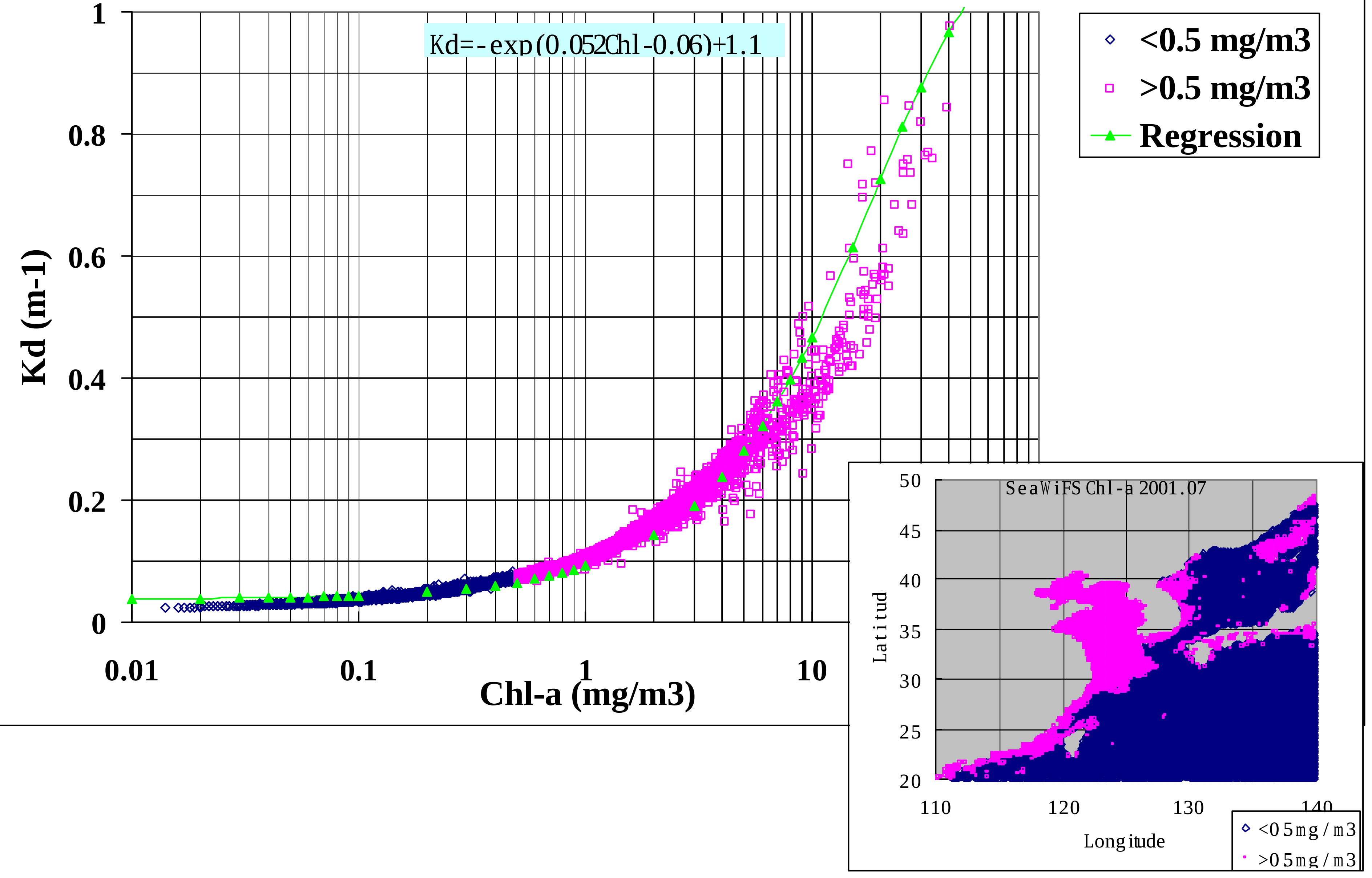


Validation of the model

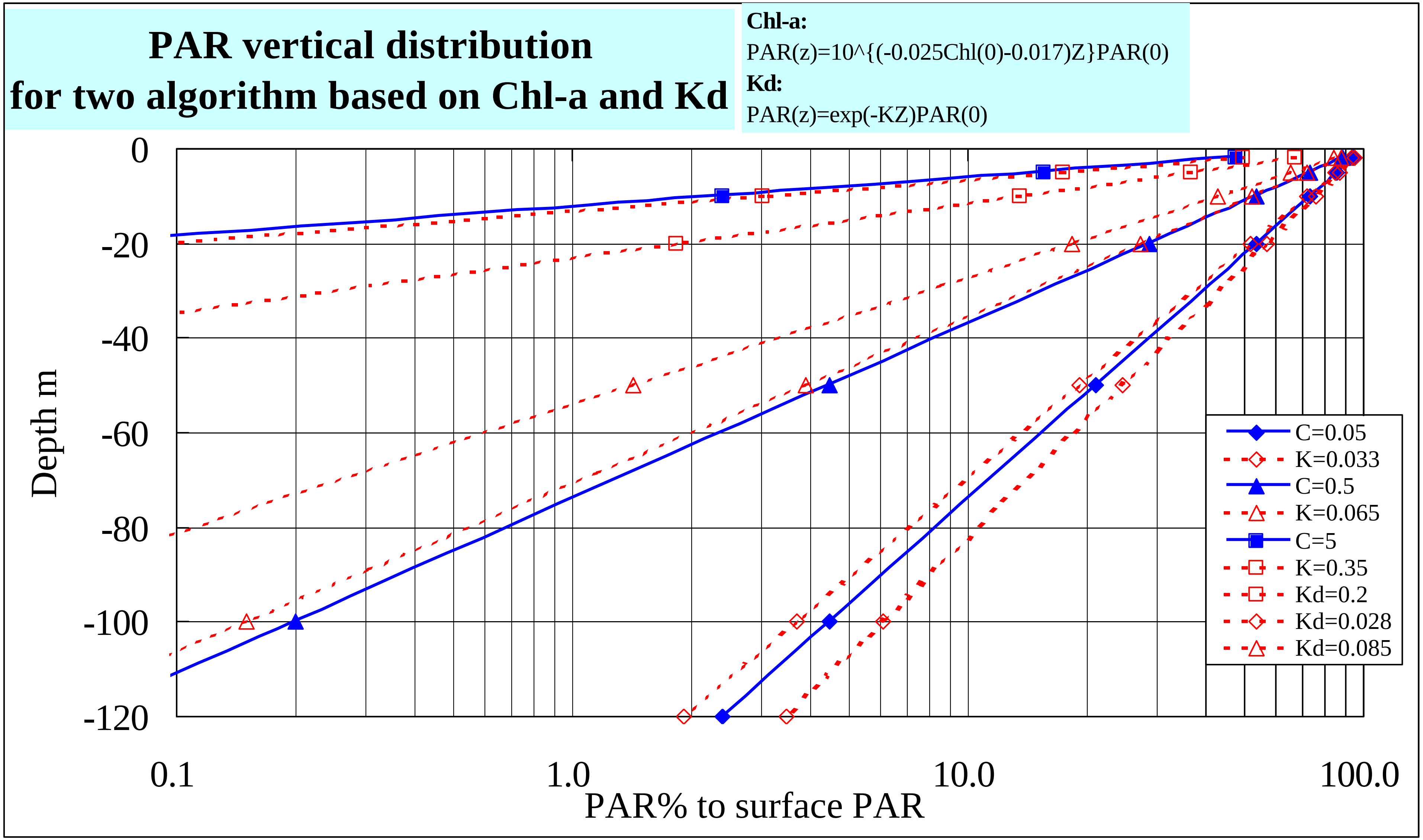
Asanuma 2001



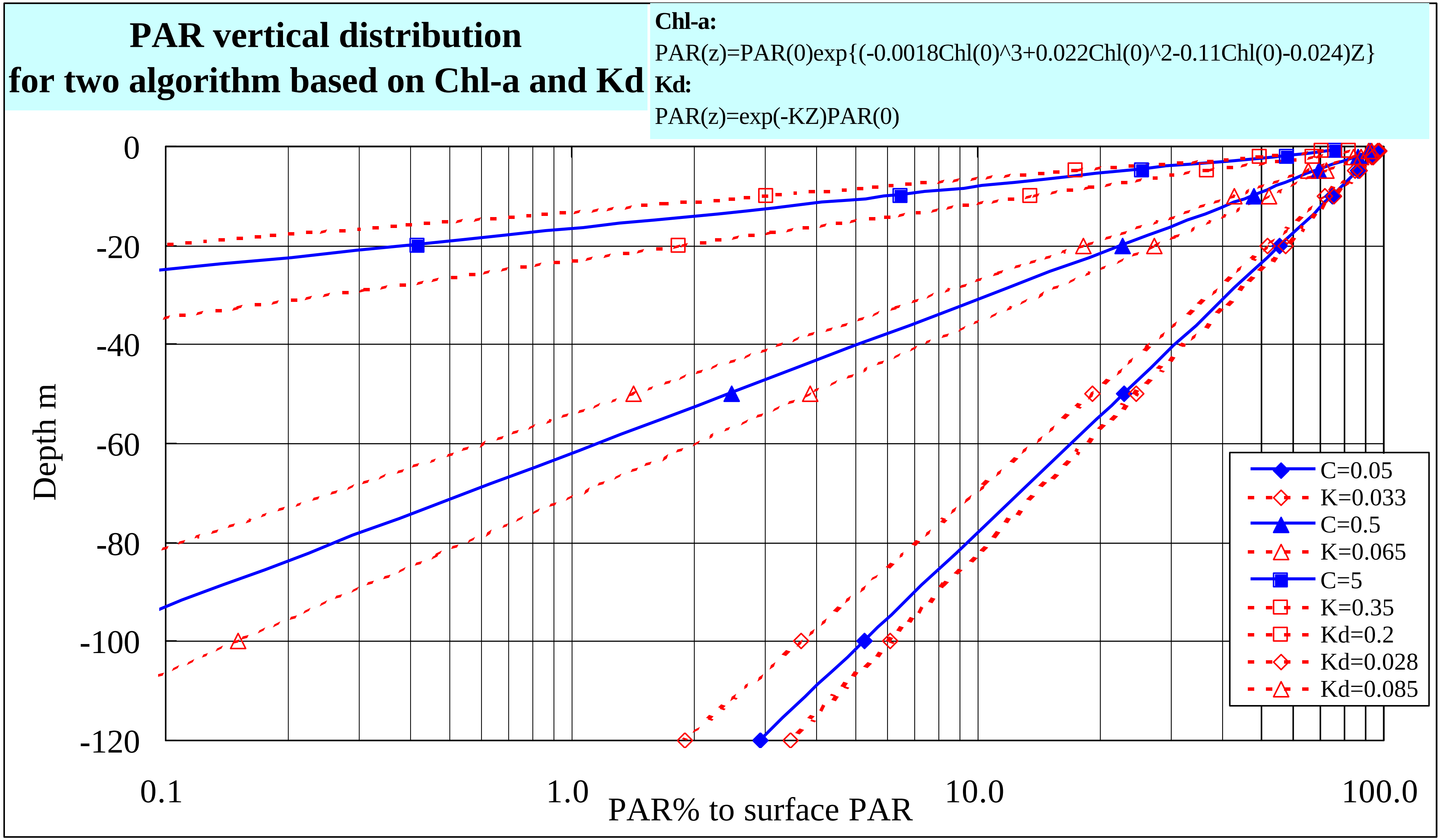
Chl-a vs Kd from SeaWiFS 2001.07 grouped by Chl-a



Asanuma 2001



Asanuma 2002



Asanuma 2002

(1) Vertical distribution of PAR%

$$ln(PAR\%)=(-.0018\ C_0^3+.022\ C_0^2-.11\ C_0-.024)Z$$

Asanuma 2002

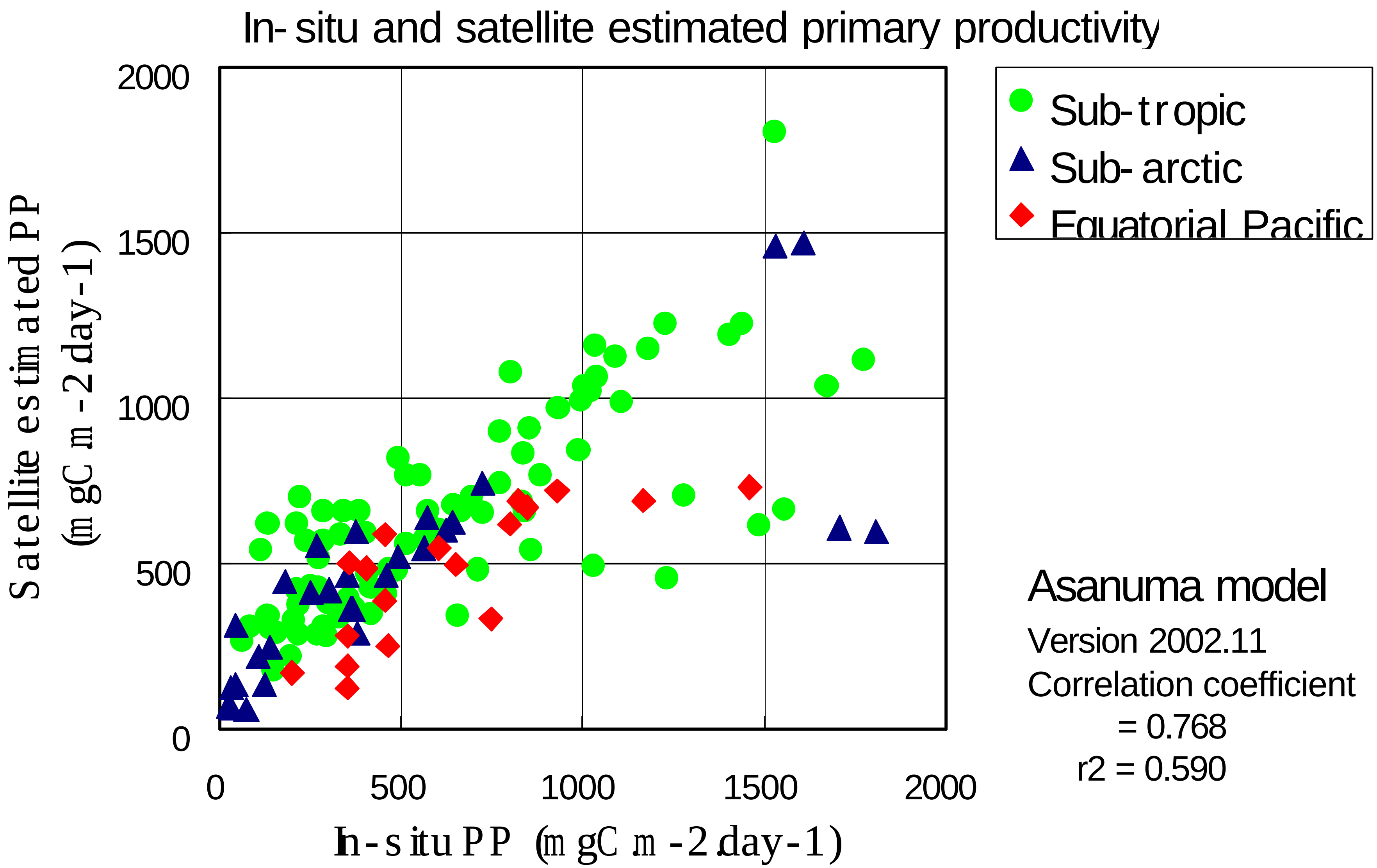
(3) Kd for PAR

$$Ln(PAR(z)/PAR(0))$$
$$=(-.0018\, C_0^3+.022\, C_0^2-.11\, C_0-.024)Z$$

$$Kd = -.0018\, C_0^3+.022\, C_0^2-.11\, C_0-.024$$

Validation of the model

Asanuma 2002



Asanuma model

Version 2002.11

Correlation coefficient

= 0.768

r2 = 0.590

SeaDAS practice 3

Ichio Asanuma
The Tokyo University of Information Sciences

1. Estimate a primary productivity by the time and depth resolved primary productivity model on the glove.

2. Estimate a primary productivity for the region of interest off Brazil.

SeaDAS practice 4

Ichio Asanuma

The Tokyo University of Information Sciences

1. Compare estimate primary productivity among models.

    1) Statistics of the region of interest.
        a. on oligotrophic water
        b. on eutrophic water
    2) Line profile along the meridian line.

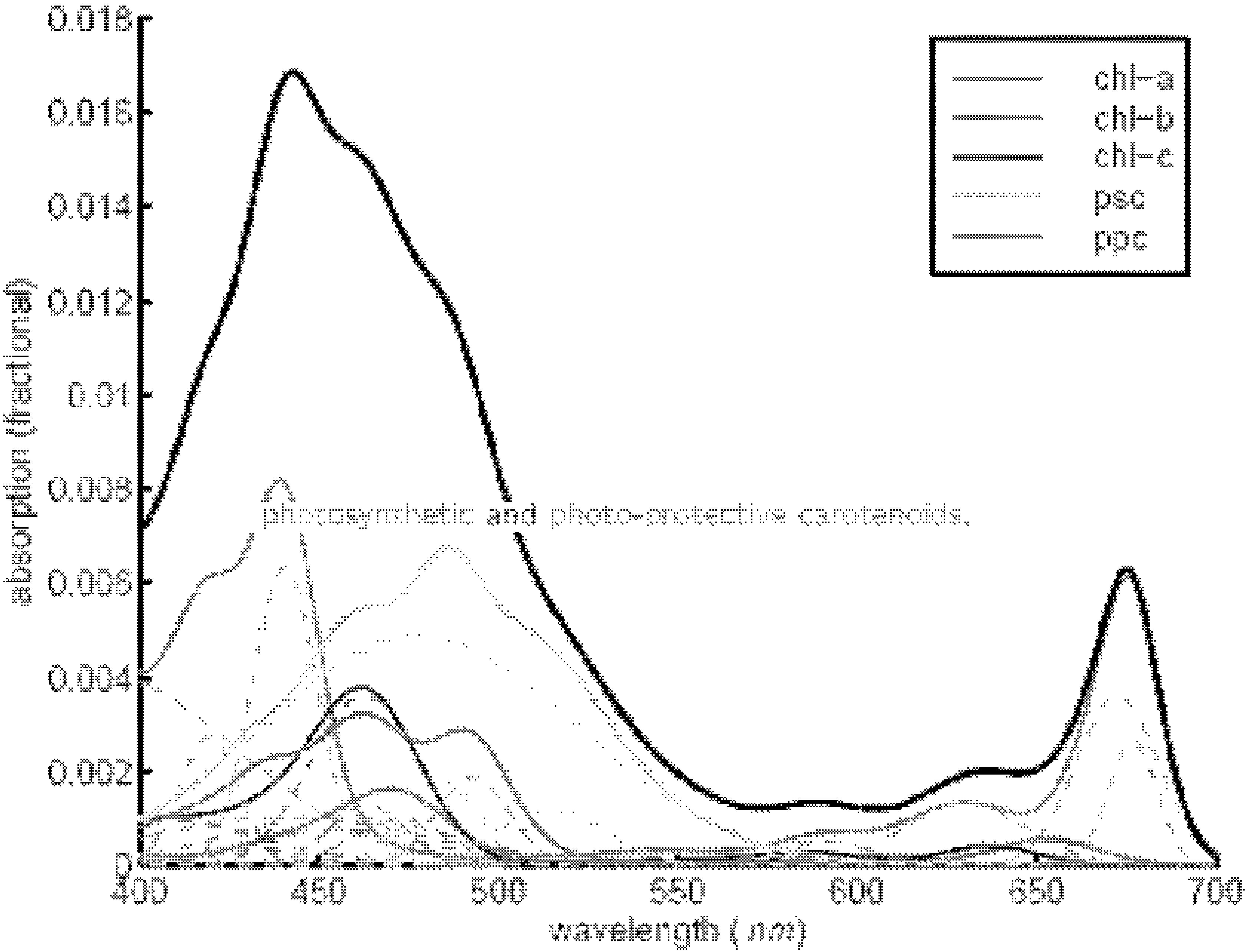
2. Discuss the difference of estimated primary productivity.
3. Estimate a time series of primary productivity and discuss the temporal change.

References

- Falkouski, P. G., M. J. Behrenfeld, W. E. Esaias, W. Balch, J. W. Campbell, R. L. Iverson, D. A. Kiefer, A. Morel, and J. A. Yoder (1998) Satellite Primary Productivity Data and Algorithm Development: A Science Plan for Mission to Planet Earth, SeaWiFS Technical Report Series, S. B. Hooker and E. R. Firestone, Editors, TM-104566, 42, 36pp.
- Behrenfeld, M. J. and P. G. Falkowski (1997a) Photosynthetic rates derived from satellite-based chlorophyll concentration. Limnol. Oceanogr., 42(1), 1-20.
- Behrenfeld, M. J. and P. G. Falkowski (1997b) A consumer's guide to phytoplankton primary productivity models. Limnol. Oceanogr., 42(7), 1479-1491.
- Balch, W. M. and C. F. Byrne (1994) Factors affecting the estimate of primary production from space. J. Geophys. Res., 99, C4, 7555-7570.
- Carr, M. E., et al. (2006) A comparison of global estimates of marine primary production from ocean color. Deep-Sea Research II, 53, 741-770.
- Asanuma, I., J. Nieke, K. Mastumoto, T. Kawano (2003) Optical properties contraol primary productivity model on the East China Sea. in Frouin, J. R. (Ed.), Ocean Remote Sensing and Applications, 4892, SPIE, 312-319.
- Ryther, J. H. and C. S. Yentsch (1957) The estimation of phytoplankton production in the ocean from chlorophyll and light data. Limnol. Oceanogr., 2, 281-286.
- Falkowski, P. G. (1981) Light-shade adaptation and assimilation numbers. J. Plankton Res., 3, 203-216.
- Cullen, J. J. (1990) On models of growth and photosynthesis in phytoplankton. Deep-Sea Res., 37, 667-683.

References

- Megard, R. O. (1972) Phytoplankton, photosynthesis, and phosphorus in Lake Minnetonka, Minnesota. Limnol. Oceanogr., 17, 68-87.
- Antoine, D., J. –M. Andre, and A. Morel (1996) Oceanic primary production 2. Estimation at global scale from satellite (coastal zone color scanner) chlorophyll. Global Biogeochem. Cycles, 10, 57-69.
- Eppley, R. W. (1972) Temperature and phytoplankton growth in the sea. Fish. Bull., 70, 1063-1085.
- Balch, W. M., R. Evans, J. Brown, G. Feldman, C. McClain, and W. Esaias (1992) The remote sensing of ocean primary productivity: Use of new data compilation to test satellite models. J. Geophys. Res., 97, C2, 2279-2293.



Photosynthetic carotenoid (PSC) or Photo-protective carotenoids (PPC)