Ocean Primary Production
- observations and modelling

Nimit Kumar

INCOIS

Training programme on

“Remote Sensing of Marine Phytoplankton - optics, pigment and taxonomy”

ITCOOcean (INCOIS), Hyderabad

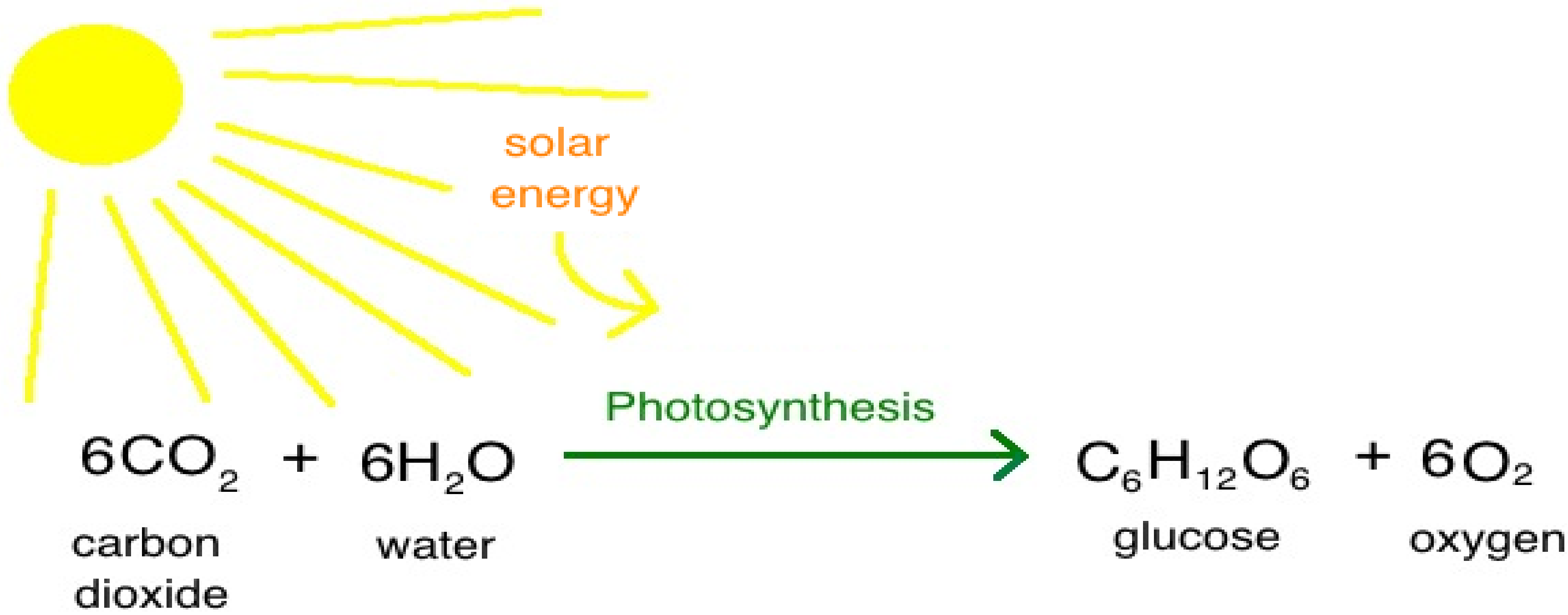
March 23, 2018

Special Thanks: Aneesh L., Satya P.

Gist

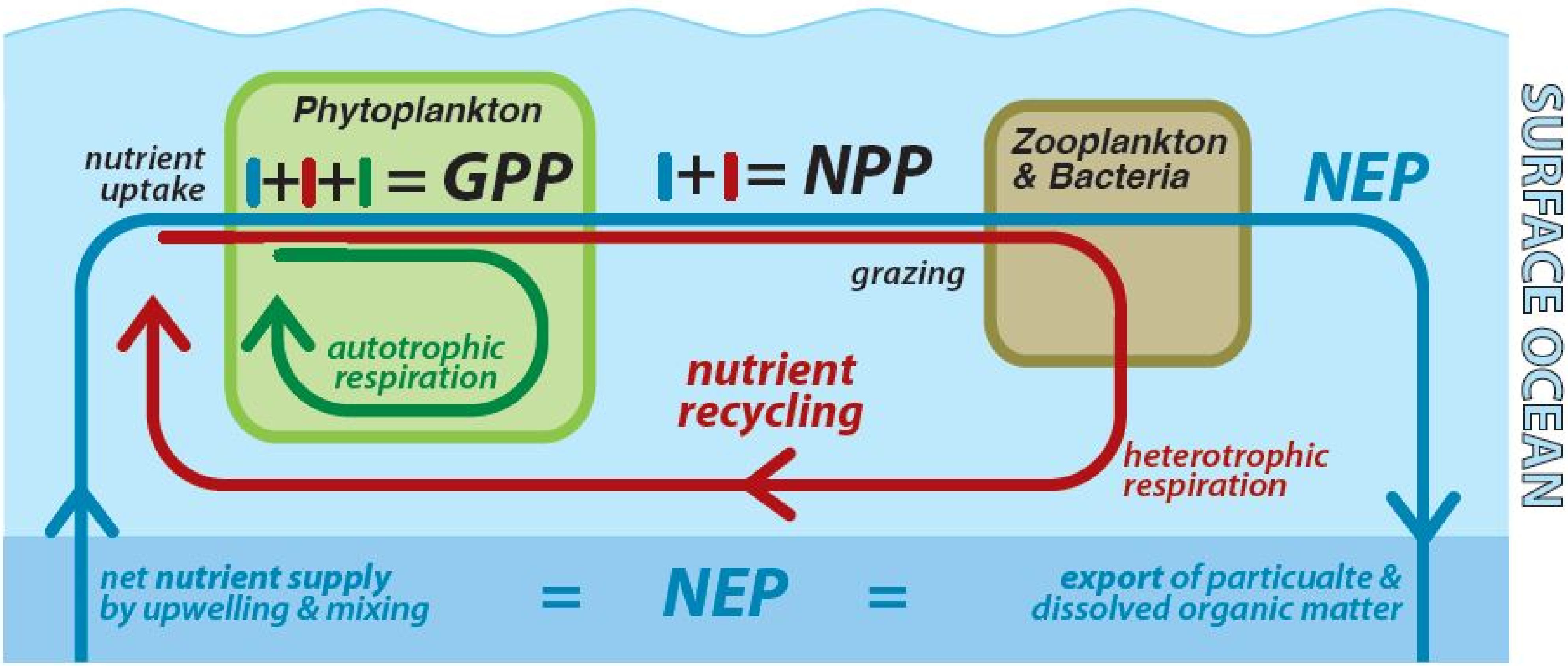
- **Carbon cycle**
- **Ocean Primary Productivity**
- **PFT**
- **Remote Sensing**
- **Applications**

Photosynthesis



- ✓ Primary Productivity is the rate at which light energy or inorganic chemical energy is converted to the chemical energy of organic compounds by autotrophs in an ecosystem.
- ✓ In the ocean, photosynthesis is performed by phytoplankton in the sunlit or euphotic zone.
- ✓ This process takes carbon dioxide and water and combines them with the help of the energy contained in sunlight creates a monosaccharide and oxygen

Upper Ocean Productivity

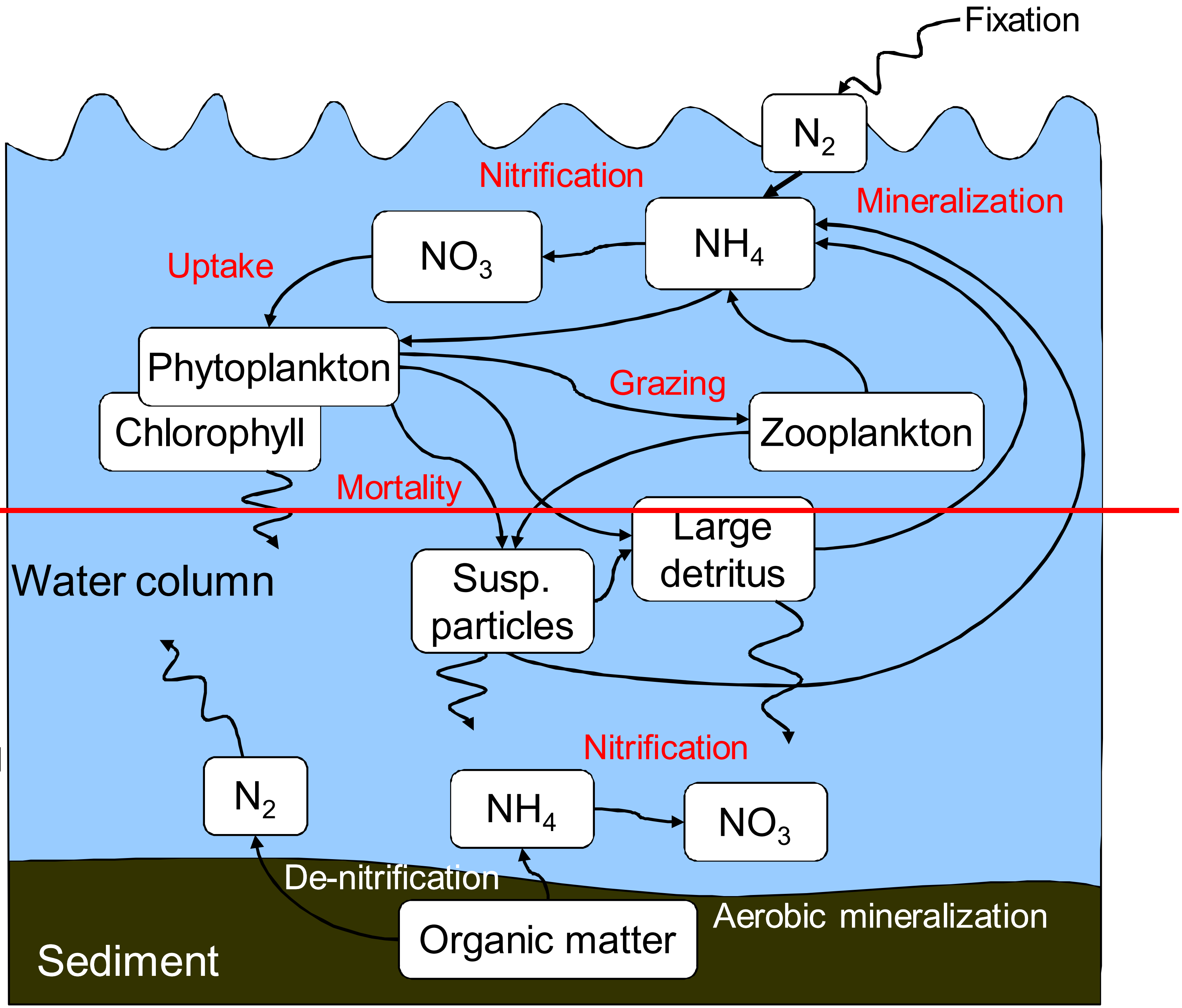


✓"Gross primary production" (GPP) refers to the total rate of organic carbon production by autotrophs

✓ "respiration" refers to the energy-yielding oxidation of organic carbon back to carbon dioxide.

✓ "Net primary production" (NPP) is GPP minus the autotrophs' own rate of respiration; it is thus the rate at which the full metabo-lism of phytoplankton produces biomass.

Mix Layer depth



Continental shelf sediments are responsible for up to 67% of marine N denitrification estimates

De-nitrification – the removal of fixed N, mostly $NO3^-$, resulting in the formation of nonbiologically available N, primarily N_2 gas

Partition of Anthropogenic Carbon Emissions into Sinks [2000-2006]

45% of all CO_2 emissions accumulated in the atmosphere

55% were removed by natural sinks

Ocean removes ~ 24%

Land removes ~ 30%

Primary Productivity (conti.)

1) Light/Dark Bottle Method

- Calculate DO in both bottles at $t=t_0$, $t=t_1$
- $GPP = (DO^{light}_{t1} - DO^{dark}_{t1})/(t_1-t_0)$
- $NPP = (DO^{light}_{t1} - DO^{light}_{t0})/(t_1-t_0)$
- Quick but only an estimation (based on O_2 consumption)

2) Nitrogen/Cabron istotop method

- Inoculate C^{13}/C^{14} (DIC), various light-levels, temp. regulation
- Filter samples, flush excess isotops, POC retained on filter paper
- Measure ratio to C^{12} with IRMS/Mw-IRMS, highly precise

C-13 method

Similar to N-15 in principle

$NaH^{13}CO_3$ is used as a salt to prepare tracer

13C atom% is 99

Carbon has three isotopes: 12, 13 and 14

12 and 13 are stable, 14 is radio-active

Abundance: 13C = 1.2%; 12C = 98.8%

C14 is not found naturally due to its small half life; whatever available is produced artificially

Tracer addition is again 10% of the ambient; average concentration dissolved carbon in sea water is 2μM, so 0.2μmole/l should be added

Should be incubated for 12 hours,

Preservation analysis and calculation are similar to that of N-15

Can be used to generated P-I curve efficiently

C-14 method

14C Method

- Inoculate samples with 14C sodium bicarbonate
- Incubate 2-3 hours
- Filter samples on GF/F filters,
- Acidify filters to get rid of the inorganic carbon
- Count 14C using scintillation counter
- Normalise to Initial available 14C

1-Sampling Preparation

- Rinse culture bottles with milli-Q water
- Can be washed using acid bath but should be copiously rinsed, acid would degrade chlorophyll-a

2-laboratory analyses, before starting the incubation

- Fill culture bottles with sample
- Install bottles in the incubator + 2 dark bottles
- Inoculate each bottle with 5ml of 14C
- Put caps on bottles
- Close the incubator
- wrap dark bottles in aluminum foil and place in water bath
- Turn on lamp from slide projector
- note start time

2-laboratory analyses, before starting the incubation (con't)

- prepare the standards:
  - Mix 5ml of 14C to 100ml of sample
  - Put 1ml of this mix in 3 scintillation vial
  - Fix with 1ml of hyamine hydroxyde,
  - Add 10ml of scintillation cocktail
  - Count as soon as possible

3-Laboratory analyses, after incubation

- turn off lamp and note end time
- Filter each bottle on a GF/F glass fiber filter (0.7mm)
- Put each filter on a tray
- Go outside and acidify the filter with 1 drop of HCl acid
- Put the filters in scintillation vial
- Add 10 ml of scintillation cocktail
- Let sit in the scintillation counter over night
- Count after 24 hours or more (very stable)

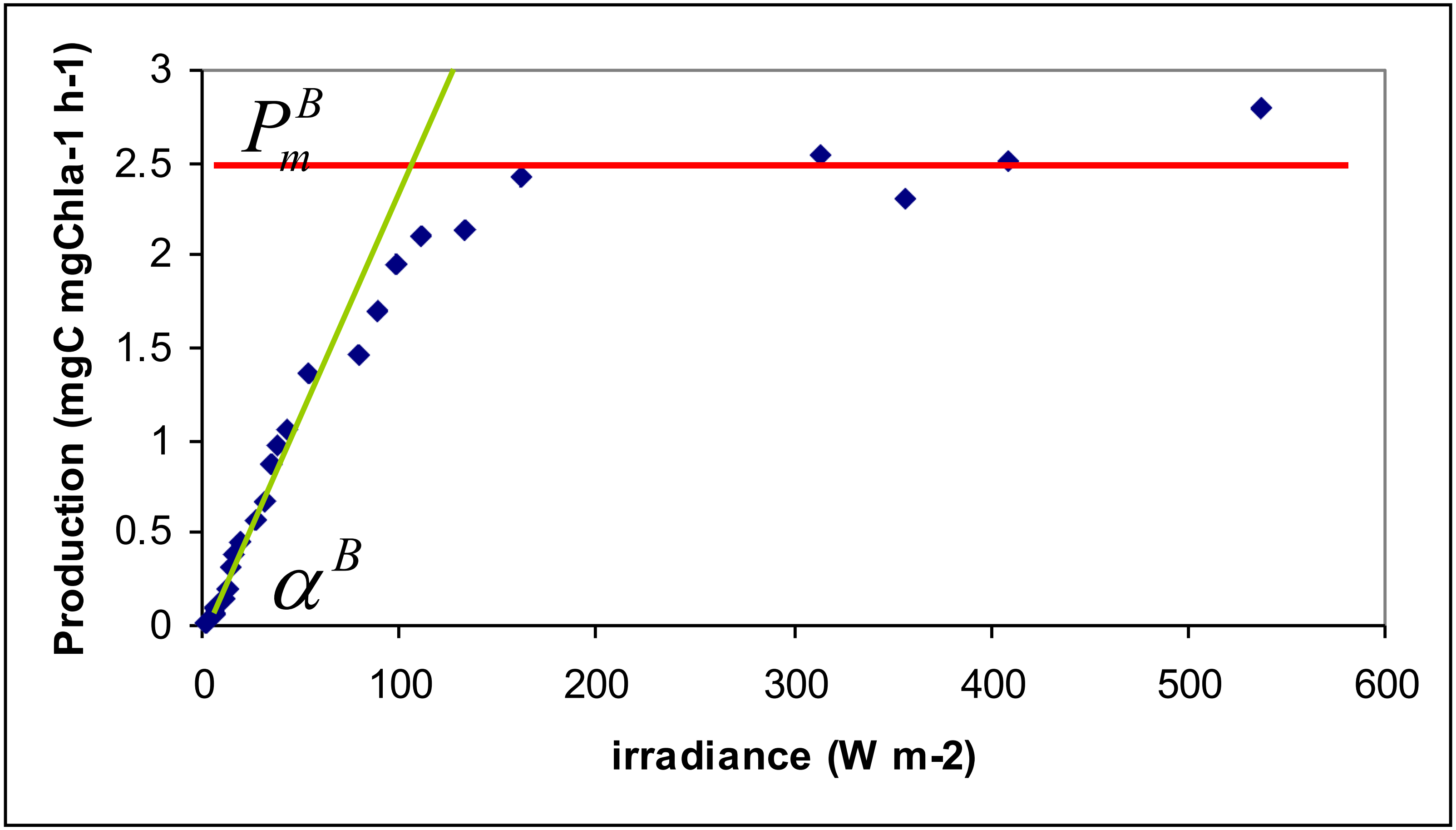
4-data processing

- Production is calculated from:

$$P = \frac{\left(DPM_S - DPM_D\right) * 12000 * \text{alkalinity} * 1.05}{DPM_{ST} * 100 * T}$$

- where
  - DPM_S is the count for sample
  - DPM_D is the count for dark
  - DPM_{ST} is the count for standard
  - *alkalinity* equals 2 in salt water
  - T is time of incubation

Production-light relationship



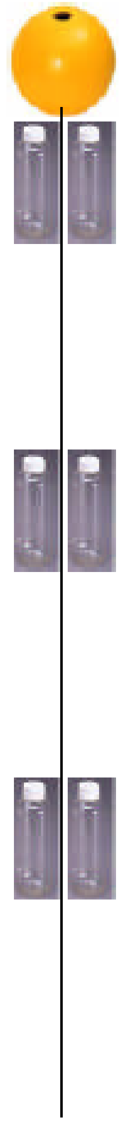
PI experiment

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

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

b. Tracer spiking

Polycarbonate bottle

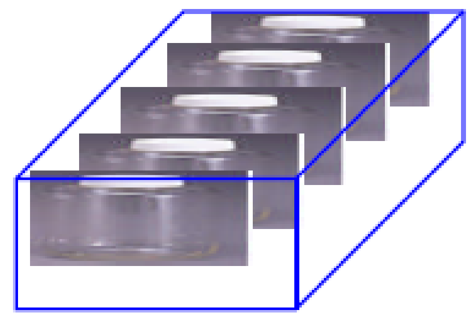


c-1. In-situ incubation

c-2. Simulated in-situ incubation

on deck (light source=the sun)

in lab (light source=artificial light)



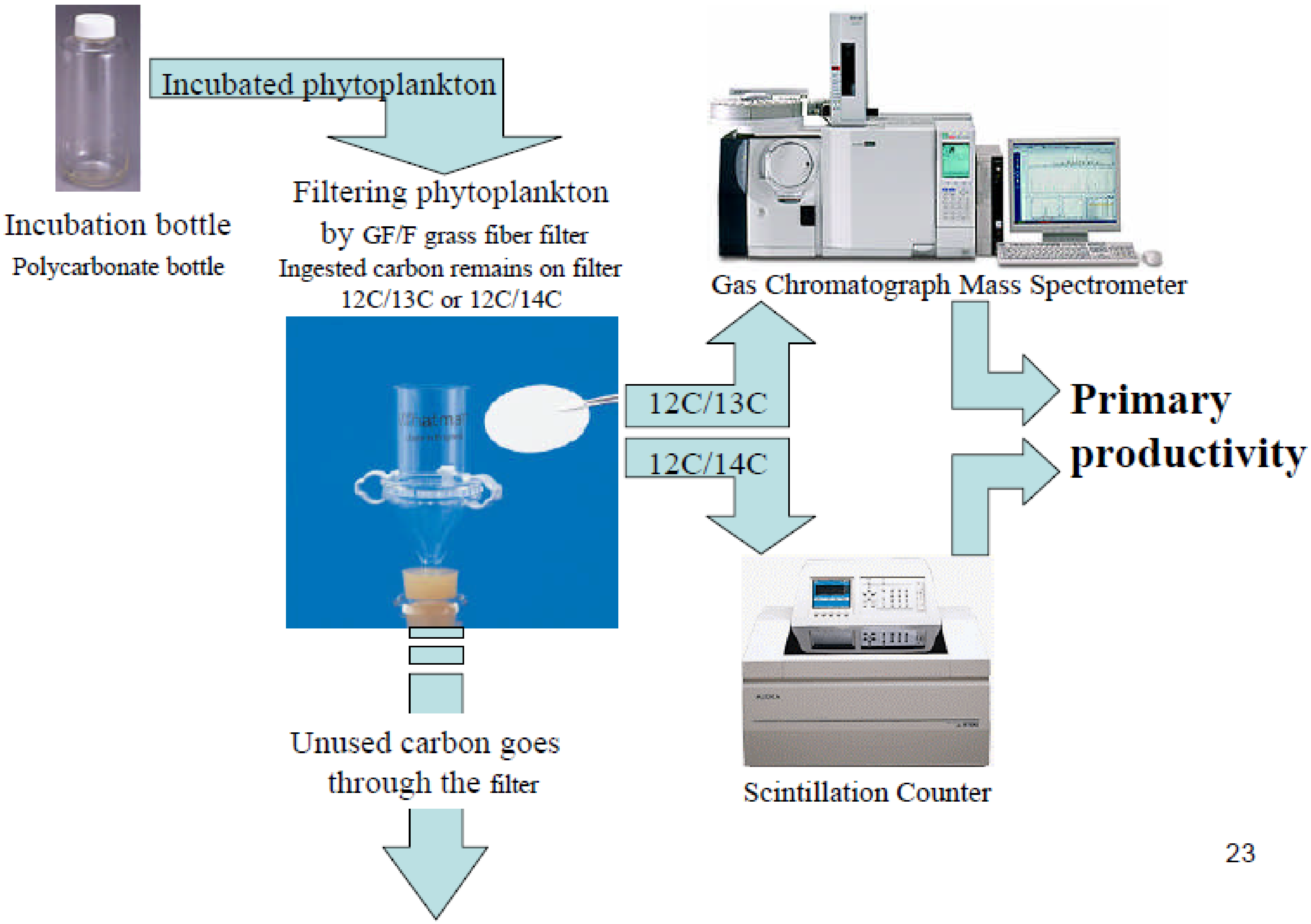
a. Water sampling

before sunrise, or

shortly before local apparent noon

e.g. Niskin water sampling bottle

PI experiment



modeling P-E relationship

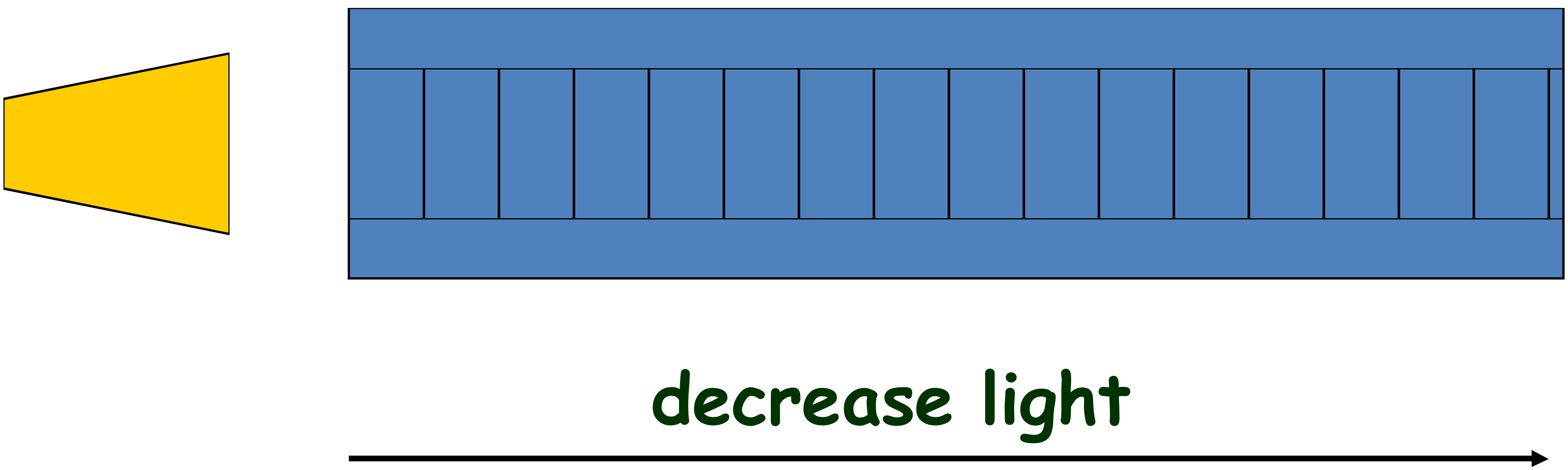
$$\boxed{P^{B} = P_m^{B}[1 - \exp(-\alpha^{B} E / P_m^{B})]}$$

Platt et al. 1980

measurements

- P-E curve
  - Light gradient incubator
  - 14C method
  - 2-3h incubation

light gradient Incubator



Primary Productivity Models

I. Wavelength-resolved models (WRMs)

$$\sum PP = \int_{\lambda=400}^{700} \int_{t=\text{sunrise}}^{\text{sunset}} \int_{z=0}^{Z_{eu}} \Phi(\lambda, t, z) \times \text{PAR}(\lambda, t, z) \times \times \text{Chl}(z)\, d\lambda\, dt\, dz - R$$

- ✓ WRM convert absorbed radiation i.e. Photosynthetically Utilizable Radiation (PUR) into net photosynthesis using a suit of empirical quantum efficiency models based on photosynthesis-irradiance variables

II. Wavelength-integrated models (WIMs)

$$\sum PP = \int_{t=\text{sunrise}}^{\text{sunset}} \int_{z=0}^{Z_{eu}} \varphi(t, z) \times \text{PAR}(t, z) \times \text{Chl}(z)\, dt\, dz - R$$

- ✓ WIM eliminated wavelength dependencies and NPP is described as a function of PAR rather than PUR and calculated by integrating PAR dependent photosynthesis-irradiance function over depth and time

Primary Productivity Models

II. Time-integrated models (TIMs)

$$\sum PP = \int_{z=0}^{Z_{eu}} P^b(z) \times \mathrm{PAR}(z) \times DL \times \mathrm{Chl}(z)\,\mathrm{d}z$$

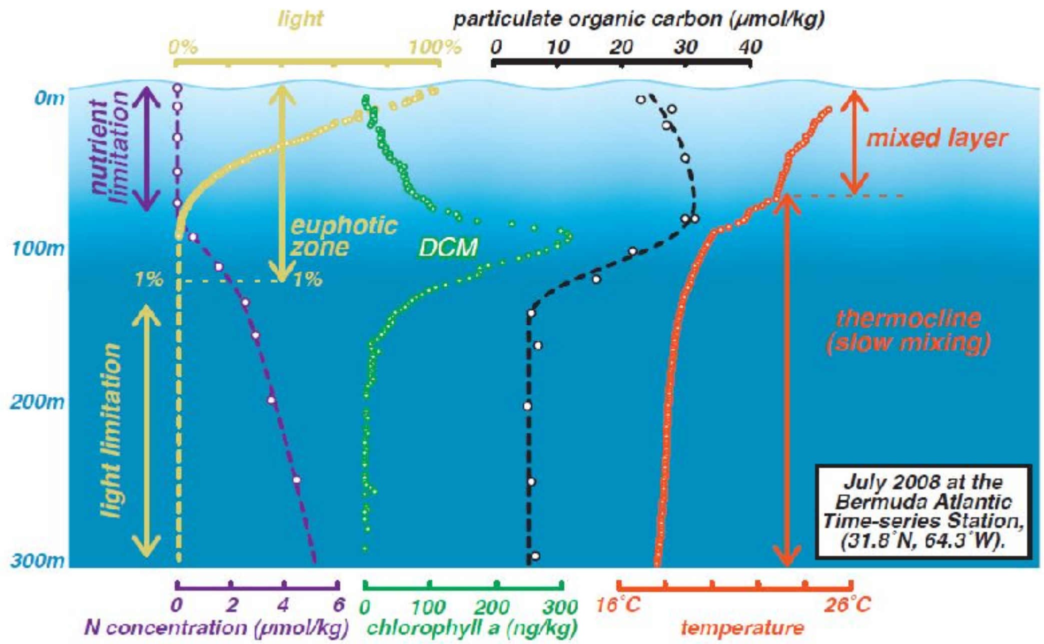
- ✓ TIM eliminates time-dependent resolution in solar irradiance. TIM intrinsically integrate a range of photosynthetic rates into a single productivity value.

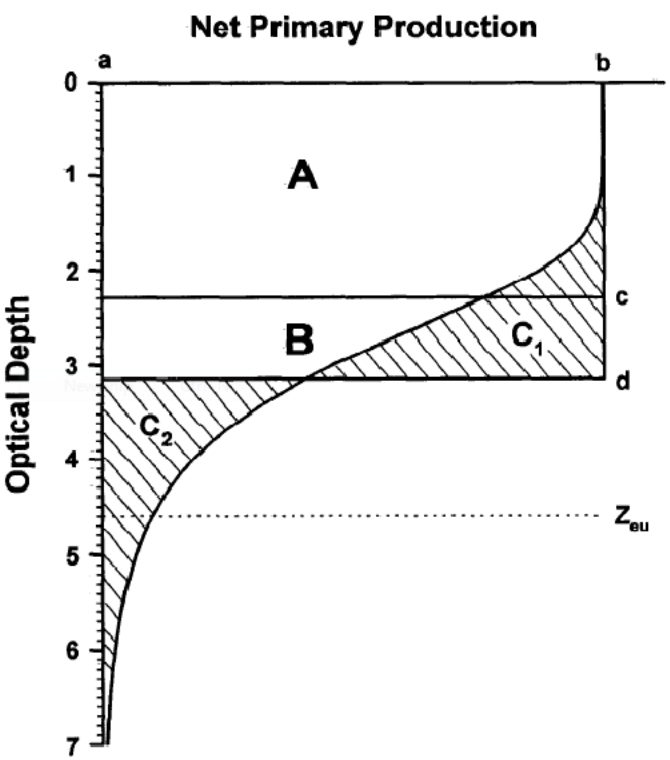
IV. Depth-integrated models (DIMs)

$$\sum PP = P^b_{opt} \times f[\mathrm{PAR}(0)] \times DL \times \mathrm{Chl} \times Z_{eu}$$

- ✓ DIM includes all models lacking any explicit description of the vertically resolved component found in TIM, WRM and WIM.

PP model: Behrenfeld and Falkowski (1997)





$$\int_{z=0}^{\infty} P_z = \frac{P^b{}_{opt} \times C_{surf} \times DL}{k_d} \times [\ln(E_0/E_k^*) + 0.82].$$

$$P^B{}_{opt} = -3.27\times10^{-8}T^7 + 3.4132\times10^{-6}T^6 - 1.348\times10^{-4}T^5 + 2.462\times10^{-3}T^4 - 0.0205T^3 + 0.0617T^2 + 0.2749T + 1.2956.$$

PP models using PI parameters

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$$P^B(I) = p^B(I; \alpha^B, P_m^B),$$

Table 1. Some commonly-used, two-parameter representations of the P^B vs I curve, with references to their first appearence in the phytoplankton literature. The function p^B is defined by the equation $P^B = p^B(I; \alpha^B, P^B)$. Also given, in the third column, is the equivalent function expressed in terms of the dimensionless irradiance, $I_* = I/I_k$, where $I_k = P_m^B/\alpha^B$.

Reference	$p^B(I)$	$p^B(I_*)$
Blackman 1905	$\alpha^B I$ for $I \leq I_k$; P_m^B otherwise	$P_m^B I_*$ for $I_* \leq 1$; P_m^B otherwise
Smith 1936	$\dfrac{\alpha^B I}{\sqrt{1+(\alpha^B I/P_m^B)^2}}$	$\dfrac{P_m^B I_*}{\sqrt{1+I_*^2}}$
Tamiya 1951 †	$\dfrac{P_m^B \alpha^B I}{P_m^B + \alpha^B I}$	$\dfrac{P_m^B I_*}{1+I_*}$
Jassby & Platt 1976	$P_m^B \tanh(\alpha^B I/P_m^B)$	$P_m^B \tanh(I_*)$
Platt *et al.* 1980 ¶	$P_m^B (1 - \exp(-\alpha^B I/P_m^B))$	$P_m^B (1 - \exp(-I_*))$

Non-spectral and Spectral equivalent

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Table 1. Some commonly-used, two-parameter representations of the P^B vs I curve, with references to their first appearance in the phytoplankton literature. The function p^B is defined by the equation $P^B = p^B(I; \alpha^B, P^B)$. The equations are given in their non-spectral form, $p^B(I)$, and their spectral equivalents $p^B(I(\lambda))$.

Reference	$p^B(I)$	$p^B(I(\lambda))$
Blackman 1905	$\begin{cases} \alpha^B I, & \text{for } I \le I_k; \\ P^B_m, & \text{for } I > I_k. \end{cases}$	$\begin{cases} \int \alpha^B(\lambda) I(\lambda) \mathrm{d}\lambda, & \text{for } I \le I_{k,\lambda}; \\ P^B_m, & \text{for } I > I_{k,\lambda}. \end{cases}$
Smith 1936	$\dfrac{\alpha^B I}{\sqrt{1 + (\alpha^B I / P^B_m)^2}}$	$\dfrac{\int \alpha^B(\lambda) I(\lambda) \mathrm{d}\lambda}{\sqrt{1 + [(1/P^B_m)(\int \alpha^B(\lambda) I(\lambda) \mathrm{d}\lambda)]^2}}$
Tamiya 1951 †	$\dfrac{P^B_m \alpha^B I}{P^B_m + \alpha^B I}$	$\dfrac{P^B_m \int \alpha^B(\lambda) I(\lambda) \mathrm{d}\lambda}{P^B_m + \int \alpha^B(\lambda) I(\lambda) \mathrm{d}\lambda}$
Jassby & Platt 1976	$P^B_m \tanh(\alpha^B I / P^B_m)$	$P^B_m \tanh\left((1/P^B_m) \int \alpha^B(\lambda) I(\lambda) \mathrm{d}\lambda\right)$
Platt *et al.* 1980 ¶	$P^B_m (1 - \exp(-\alpha^B I / P^B_m))$	$P^B_m \left(1 - \exp\left(-(1/P^B_m) \int \alpha^B(\lambda) I(\lambda) \mathrm{d}\lambda\right)\right)$

Photosynthesis – Irradiance parameters

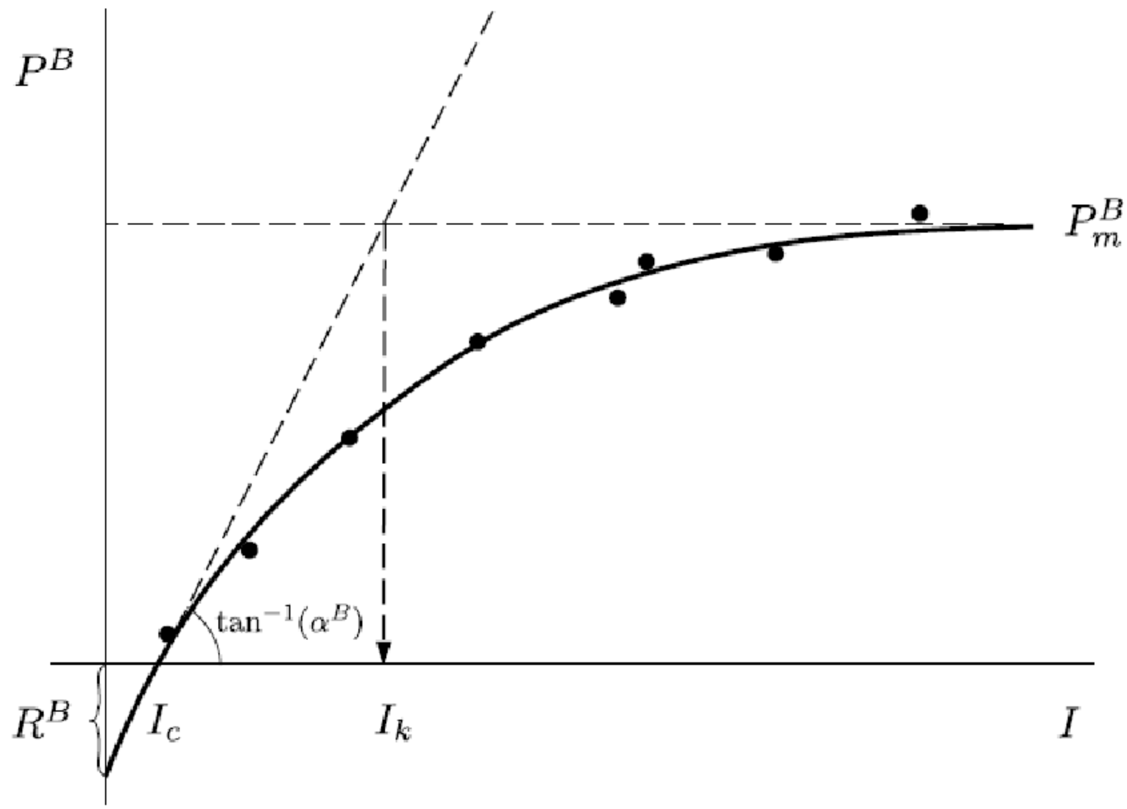


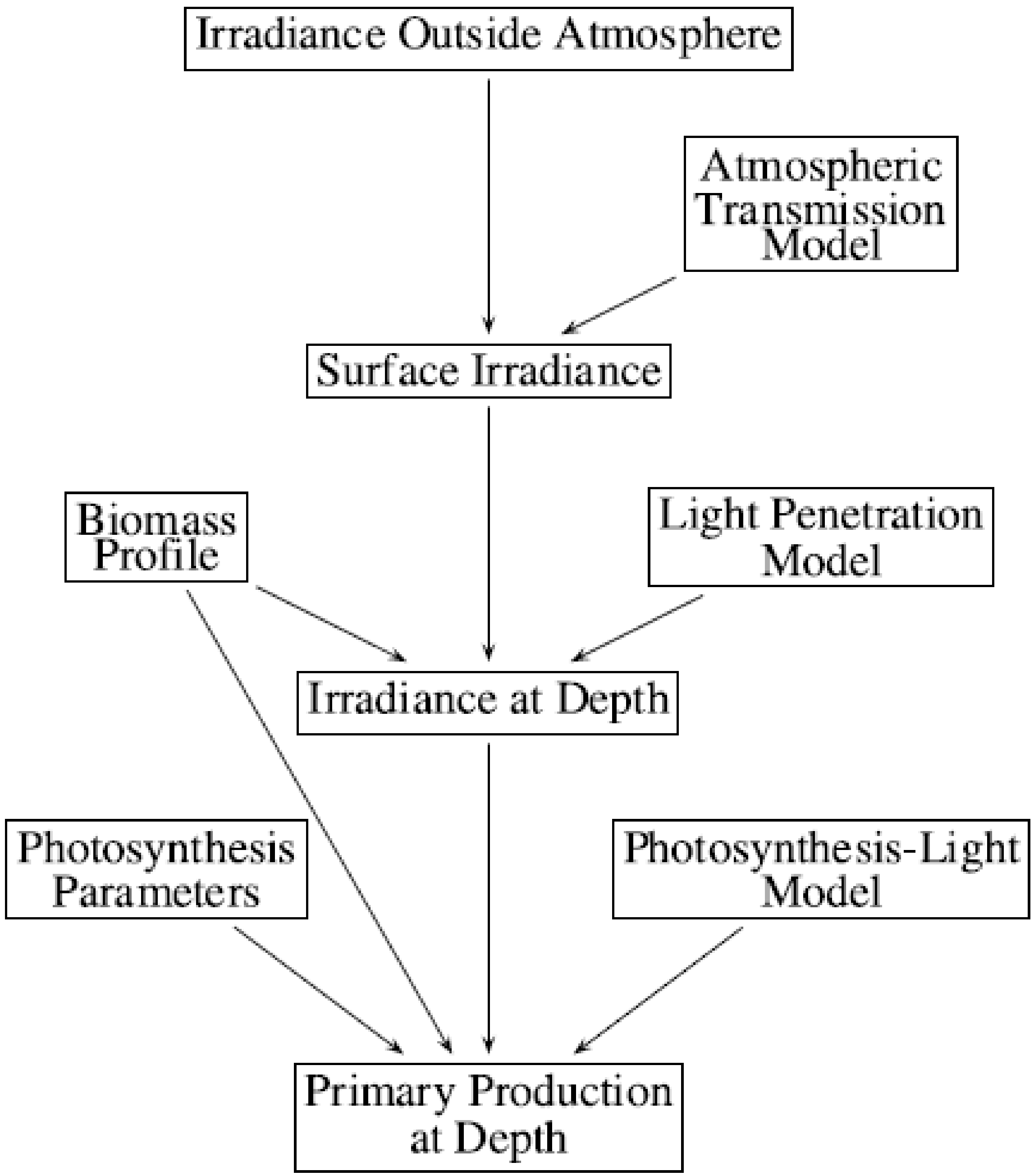
Figure 1. The photosynthesis – light curve (solid line) as fitted to imaginary experimental data (solid circles). The broken lines are construction lines to show the meaning of the parameters.

$R^B = 0$, we have $P_m^B / I_k = \alpha^B$

$$I_k = P_m^B / \alpha^B$$

$$I_* = I / I_k = \alpha^B I / P_m^B$$

PP computation flowchart



PP modeling

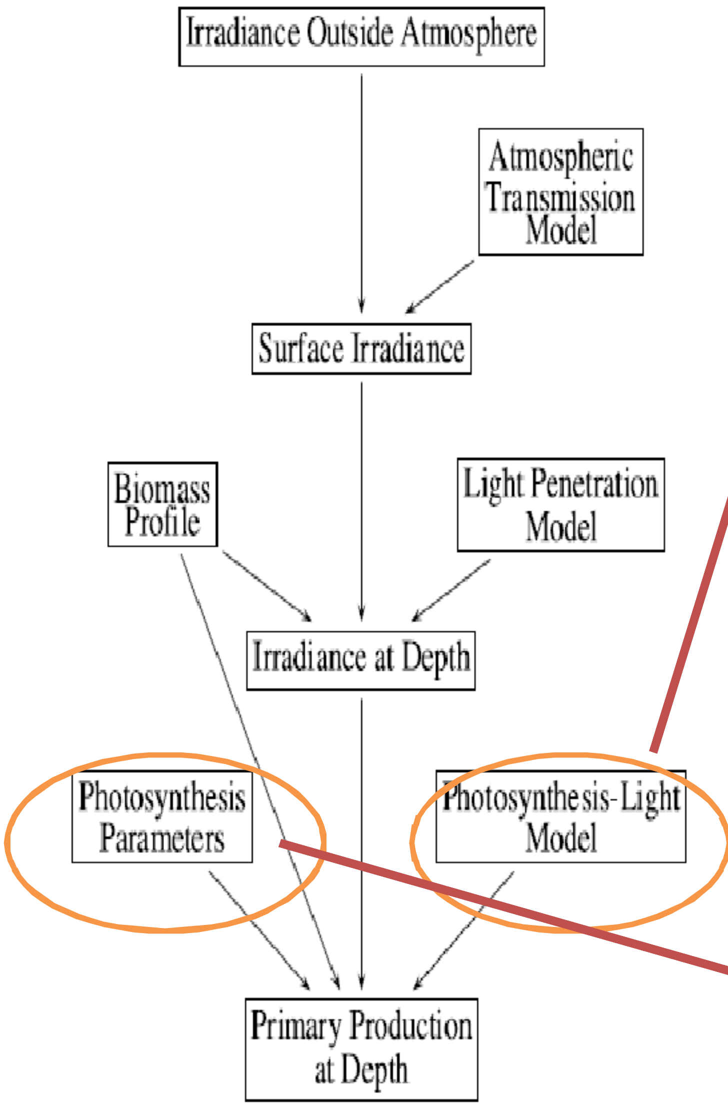


Figure 1. A flow chart describing the steps involved in computation of primary production at depth in the water column, using a light-dependent model of primary production. A number of possibilities exist for the execution of each of the steps involved in the calculation, and the success of the venture will depend on careful selection of suitable protocols for each of the steps.

Table 1. Some commonly-used, two-parameter representations of the P^B vs I curve, with references to their first appearence in the phytoplankton literature. The function p^B is defined by the equation $P^B = p^B(I;\alpha^B,P^B)$. Also given, in the third column, is the equivalent function expressed in terms of the dimensionless irradiance, $I_* = I/I_k$, where $I_k = P_m^B/\alpha^B$.

Reference	$p^B(I)$	$p^B(I_*)$
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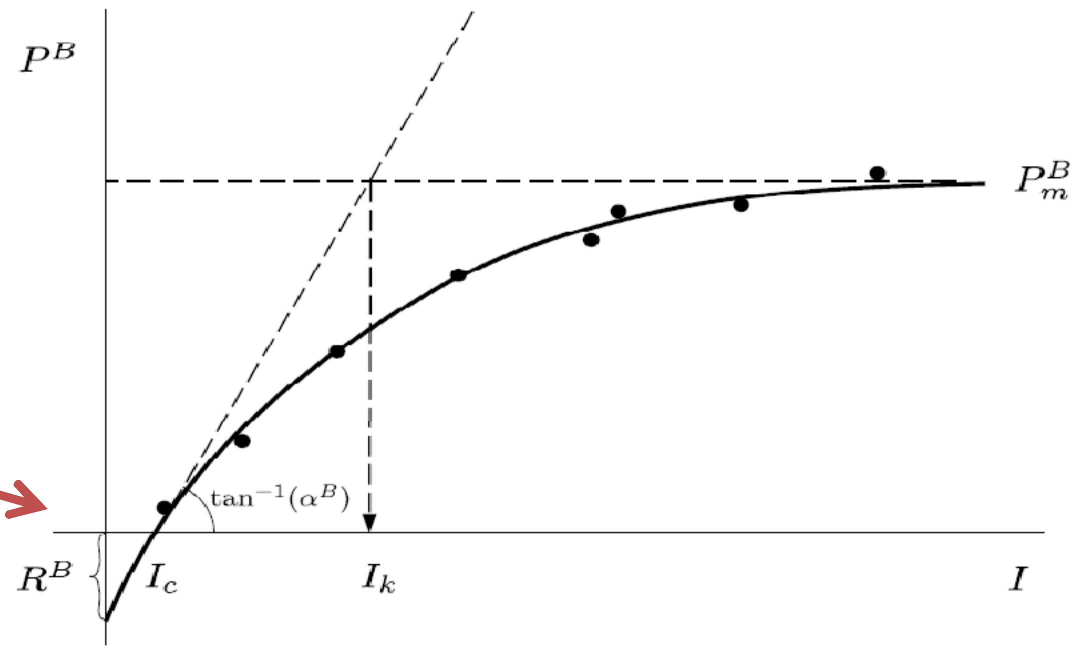
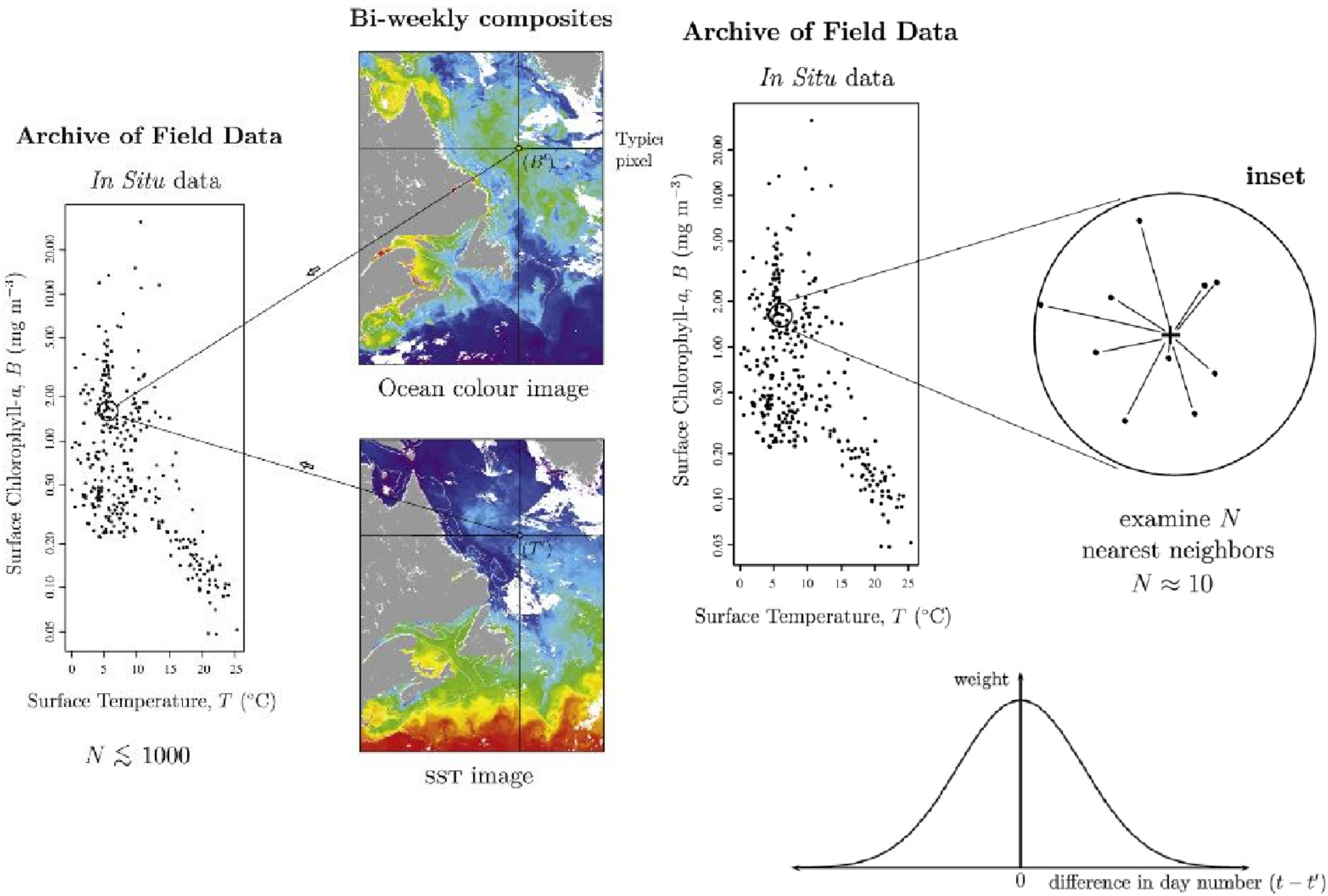
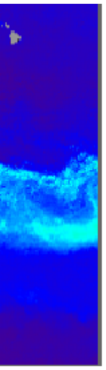


Figure 1. The photosynthesis – light curve (solid line) as fitted to imaginary experimental (solid circles). The broken lines are construction lines to show the meaning of the parameters.

Satellite application – Platt et al. (1980)



Lookout



OCEAN PRODUCTIVITY

https://www.science.oregonstate.edu/ocean.productivity/

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Welcome to the *Ocean Productivity* Home Page

The diversity of life on Earth is astonishing, yet most of the ecosystems you and I are familiar with share a common dependence on a miraculous process called ***photosynthesis***. Photosynthesis uses the energy in sunlight to fix carbon dioxide (CO2) into organic material. Aquatic and terrestrial photosynthetic plants use some of their newly formed carbon products immediately for energy and maintenance. The remaining photosynthetic products are available for plant growth or consumption by the heterotrophic community. We refer to this "available" carbon as ***net primary production***, and it is equal to gross photosynthetic carbon fixation minus the carbon respired to support maintenance requirements of the whole plant.

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A consumer's guide to phytoplankton primary productivity models

Michael J. Behrenfeld and Paul G. Falkowski
Department of Applied Science, Oceanographic and Atmospheric Sciences Division, Brookhaven National Laboratory, Upton, New York 11973-5000

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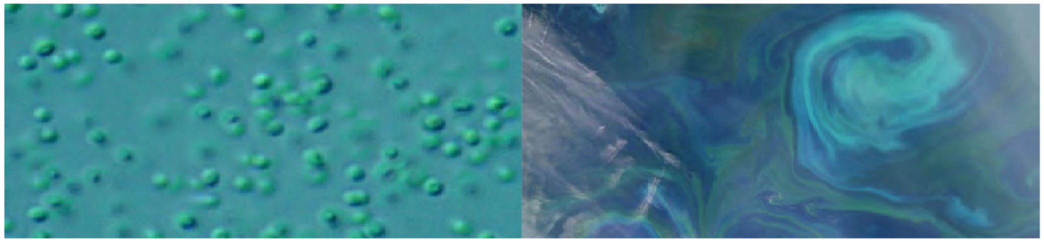
The Biological Productivity of the Ocean

Daniel M. Sigman[1] & Mathis P. Hain[1,2] © 2012 Nature Education

Productivity fuels life in the ocean, drives its chemical cycles, and lowers atmospheric carbon dioxide. Nutrient uptake and export interact with circulation to yield distinct ocean regimes.



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journal homepage: www.elsevier.com/locate/rse

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Operational estimation of primary production at large geographical scales

Trevor Platt [a], Shubha Sathyendranath [b], Marie-Hélène Forget [c,*], George N. White III [a], Carla Caverhill [a], Heather Bouman [d], Emmanuel Devred [e], SeungHyun Son [e,f]

[a] Bedford Institute of Oceanography, Box 1006, Dartmouth, Nova Scotia, Canada B2Y 4A2
[b] Plymouth Marine Laboratory, Prospect Place, The Hoe, Plymouth PL1 3DH UK
[c] Department of Biology, Dalhousie University, Halifax, Nova Scotia, Canada B3H 4J1
[d] Department of Earth Sciences Oxford University Parks Road, Oxford, OX1 3PR UK
[e] Department of Oceanography, Dalhousie University, Halifax, Nova Scotia, Canada B3H 4J1
[f] STAR/NESDIS/NOAA, Camp Spring, MD 20746, USA

IEEE JOURNAL OF SELECTED TOPICS IN APPLIED EARTH OBSERVATIONS AND REMOTE SENSING

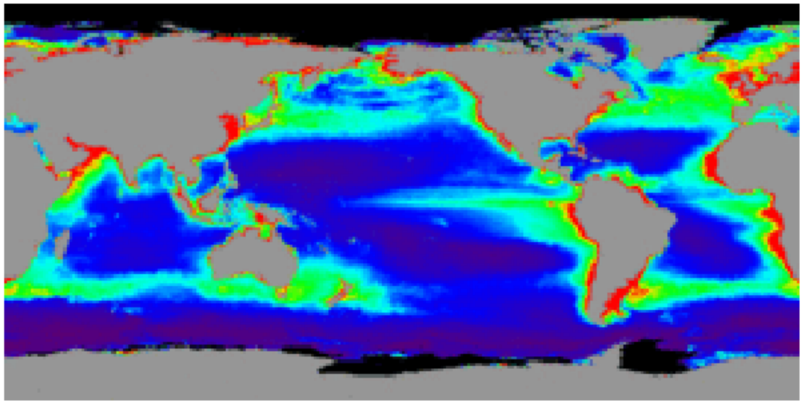
Estimation of Marine Primary Productivity From Satellite-Derived Phytoplankton Absorption Data

Sheng Ma, Zui Tao, Xiaofeng Yang, *Member, IEEE*, Yang Yu, Xuan Zhou, Wentao Ma, and Ziwei Li

Satellite application - VGPM

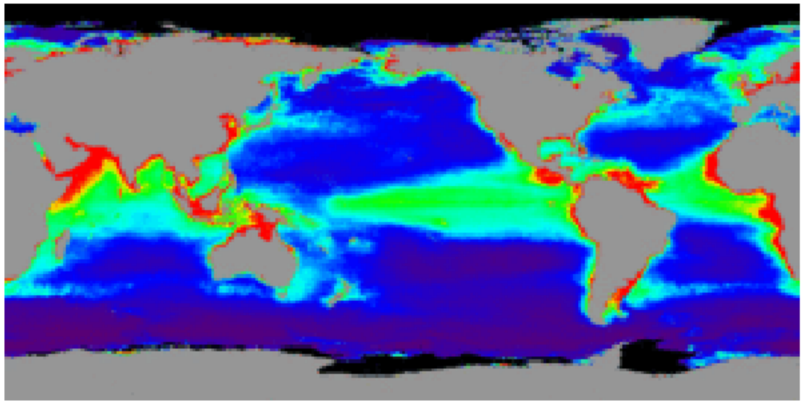
Annual Net Primary Production for 2003

VGPM (chlorophyll based)



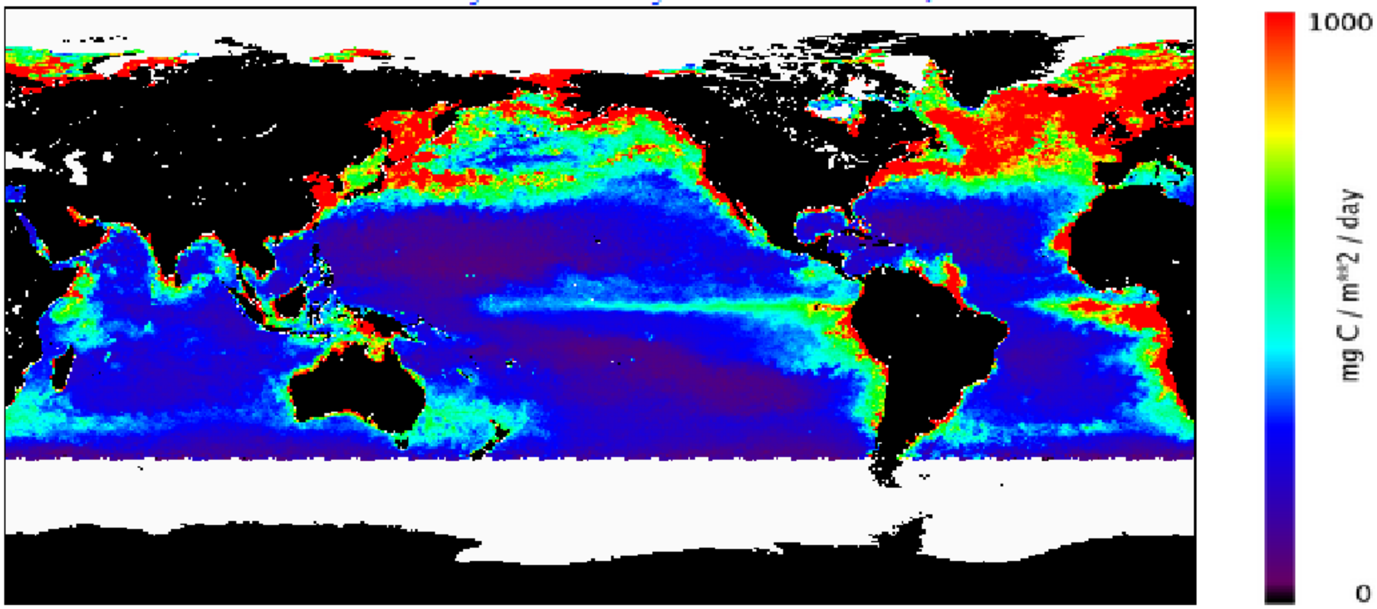
pb_opt = *polynomial* function of SST

Eppley (VGPM variant)



pb_opt = *exponential* function of SST

Monthly Net Primary Production: June , 2005



Standard Product: Net Primary Production using MODIS CHL and SST, SeaWiFS PAR, and z_eu = f(CHL) as inputs to the VGPM