Primary productivity time series (biological organic carbon by phytoplankton) as gridded data sets for the time of available high quality remotely sensed data for the Arctic Ocean

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List of abbreviations

PP – primary production.
chl – chlorophyll concentration.
MLD – mixed layer depth.
Bhr 97 – PP algorithm suggested by *Behrenfeld et al*., 1997
Bhr 05 - PP algorithm suggested by *Behrenfeld et al*., 2005
Marra - PP algorithm suggested by Marra *et al*., 2003
"Behrenfeld" data – Oregon State University data set (http://www.science.oregonstate.edu/ocean.productivity/)
GSM-Bhr ("Behrenfeld")– *chl*obtained by Oregon State University: GSM algorithm + procedure of cloudiness partial removal).
OC3/4 – *chl*obtained by the standard NASA algorithms (SeaWiFS/MODIS sensors).
GSM/NASA – *chl* obtained by the NASA GSM retrieval algorithm.

Key words phytoplankton, primary production, Arctic Ocean, SeaWiFS, HYCOM, in situ measurements, multi-year trends in primary production

1 Spaceborne data

The following SeaWiFS and MODIS ocean colour data sources were used in the present research:

- OceanColour SeaDAS: standard OC3/4 retrieval algorithm: Level 3 monthly averaged data (spatial resolution - 4km - MODIS and 9km - SeaWiFS)
- OceanColour SeaDAS/NASA GSM retrieval algorithm: Level 3 monthly averaged data (spatial resolution - 4km - MODIS and 9km - SeaWiFS)
- Oregon State University data set (http://www.science.oregonstate.edu/ocean.productivity/) (Ocean Colour MEASURES Project data (http://adsabs.harvard.edu/abs/2008AGUFMIN51B1156M): GSM + procedure of cloudiness partial removal): Level 3 monthly averaged data (spatial resolution - 9km). Hereafter labeled "Behrenfeld"

We have chosen these three options of ocean colour data sources in order to eventually choose the one, which provides most reliable information.

In addition to ocean colour data, we employed space data on sea surface temperature (Pathfinder-AVHRR (http://www.nodc.noaa.gov/SatelliteData/pathfinder4km/userguide.html), MODIS (http://oceancolor.gsfc.nasa.gov/)), cloudiness (ERA-INTERIM (http://www.ecmwf.int/research/era/do/get/era-interim), GLOBCOLOR project(http://www.globcolour.info)), wind (Blended Sea Winds (http://www.ncdc.noaa.gov/oa/rsad/seawinds/html)). Figure 4 illustrates the time series of satellite data downloaded and used in the present study.

In June 2008, August 2009 and 2010 SeaWiFS had performance failures, and these months have been replaced by MODIS data (justification of this replacement see in Figure 3). And Oregon State University data set have same problem, however, a gap in the *chl* data is bigger than in Ocean color data(June, July and August 2008, all 2009 and 2010). Data 2008 and 2009 years were replaced by MODIS data.

Table 1. General characterization of the downloaded and employed satellite data.

Total number of parameters/products	Annual observation period	Data size	Amount of pixels
13 (see Table 3 for specification)	June-September	185 Gb	$14*10^8$

Table 2. List of spaceborne - and simulation – derived parameters encompassed by our database.

Parameter
Cloudiness
Wind (speed & direction)
Mix layer depth, MLD
Sea Surface Temperature, SST
Remote Sensing Reflectance, R_{rs} ()
Coefficient of downwelling irradiance, K_d(490)
Depth of euphotic zone, Z_{eu}
Photosynthetic available radiation, PAR
Dissolved organic matter, DOM
L_u (upwelling radiance)
Phytoplankton chlorophyll concentration, *chl*
Backscattering coefficient, b_{bp}(440) (by GSM)
Phytoplankton absorption coefficient, a_{chl}
Ice extent (by SSMI)

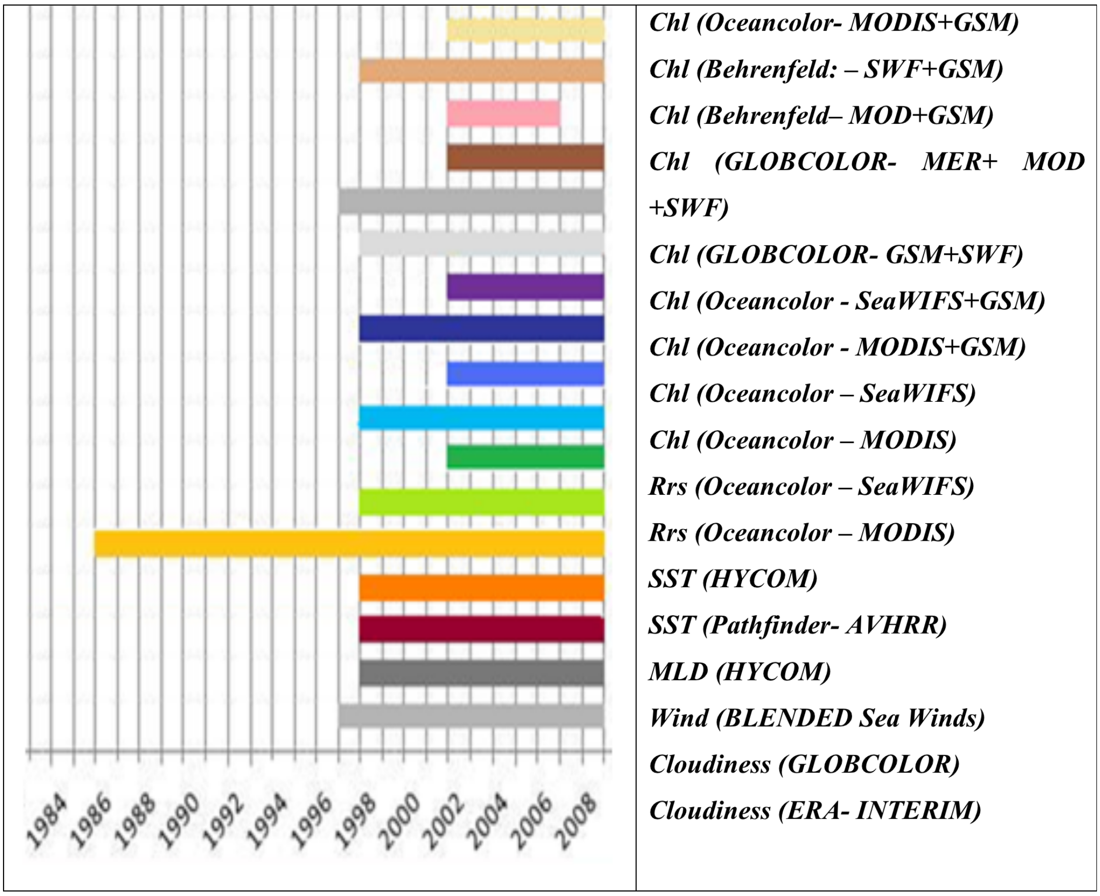

Figure 1. Illustration of temporal distribution of the data collected in this study

2 Model data

Sea surface temperature and mixed layer depth data were equally employed from the HYCOM model, which is a data-assimilative hybrid isopycnal-sigma-pressure (generalized) coordinate ocean model (http://hycom.org/hycom/overview).

All data are presented in one Lambert azimuthal equal-area projection at a 4km spatial resolution. Figure 2 exemplifies the raw image transformations performed before its further processing.

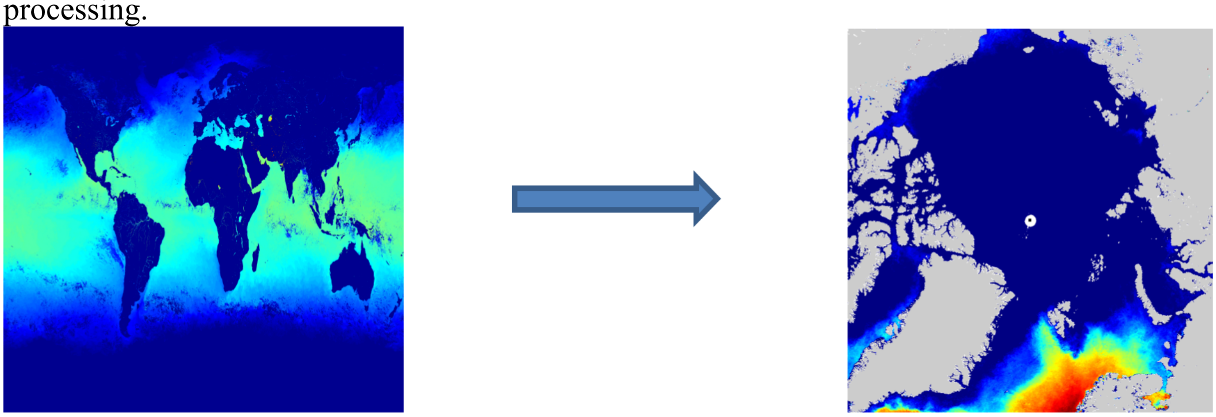

Figure 2. Illustration of the image the projection transformations performed in the present study

3 Methodology

As indicated above, the following primary productivity, PP retrieval algorithms were tested for the pelagic and shelf regions of the Arctic Ocean: Marra *et al.*, 2003; Behrenfeld *et al.*, 1997; Behrenfeld and Falkovski, 2005, Pabi *et al.*, 2008.The basic information about these algorithms is given below.

3.1 The Marra et al., 2003 algorithm

$P(z)\ [mgC/m^{2}\cdot day] = \varphi\cdot a^*_{ph}\cdot chl_a\cdot E_{par}(z)$

where φ is the quantum yield [molC mol photons $^{-1}$];

a^*_{ph} is the chlorophyll-specific phytoplankton absorption coefficient [$m^2(mg\,chl_a)^{-1}$];

E_{par} is the photosynthetically active radiation [mol photons $m^{-2}d^{-1}$]

Z in [0 – 100] m

3.2 The Behrenfeld et al. 1997 algorithm

PP in the entire euphotic zone:

$P_{eu}\ [mgC/m^2\cdot day]=0.66125\cdot P^B_{opt}\cdot[E_{par}/(E_{par}+4.1)\cdot Z_{eu}\cdot C_{opt}\cdot DL],$

where $P^B_{opt}[mgC/mgChl\cdot hr]=-3.2710^{-8}\cdot T^7+3.4132\cdot 10^{-6}\cdot T^6+1.348\cdot 10^{-4}\cdot T^5+2.462\cdot 10^{-3}\cdot T^4-0.0205\cdot T+0.0617\cdot T^2+0.2749\cdot T+1.2956$

C_{opt} [$mg\cdot m^{-3}$] - concentration of *chl* at P^B_{opt}

E_{par}=PAR[$Einstein\cdot m^{-2}\cdot day^{-1}$]

$Z_{eu}\ [m] = \ln(0.01)/K_d(490)$

3.3 The Behrenfeld and Falkowski, 2005 algorithm

Net primary production:

$NPP\ [mgC/m\cdot day]=C_{sat}(2\text{ cell divisions }day^{-1}\{chl{:}C_{sat}/0.22+(0.045-0.022)e^{-3Ig}\})\ \square(-\ln(0.01)/K_d(490))(0.66125\cdot E_{par}/E_{par}+4.1)$

where C_{sat} and I_g defined as $C_{sat}\ [mgC\cdot m^{-3}]=\{(b_{b,p}(443)-0.00035)\square 13{,}000\}$

$I_g = E_{par}\cdot e^{(-K_d(490)\cdot MLD/2)}$; E_{par}= photosyntheticall available irradiation

3.4 The Pabi et al.,2008 algorithm

$PP\ [mgC/m_2\cdot day]=$

$G(z,t)$ – is the net biomass-specific phytoplankton grow rate [day^{-1}]

$G(z,t)\ [hr^{-1}]=G_o\cdot exp(r\cdot T(t))\cdot L(z,t)$

G_o is the maximum microalgal net growth rate at 0 C = 0.59 day $^{-1}$

r = 0.0633 □C

$L(z,t)=1-exp(-E_{PUR}(z,t)/E'_k(z,t))$

$E_{PUR}(z,t)$ [] is photosynthetically usable radiation and

$E`k(z,t)$ [] is the spectral photoacclimation parameter.

The application of the above algorithms required input data, which are specified in Table 4.

Table 4. Input parameters required for the PP-retrieval algorithms that have been tested in the present research; for simplicity reasons, the algorithms are named by the first author(where, as above, PAR= photosynthetically available radiation; SST= sea surface temperature, $K_d(490)$= downwelling diffuse irradiance attenuation at the wavelength of 490 nm; DL= day length; $b_{b,p}$= backscattering coefficient of suspended particulate matter; MLD = mixed layer depth)

Algorithm	Input parameter						
	chl$_a$	PAR	SST	K_d(490)	DL	$b_{b,p}$	MLD
Marra, 2003	+	+	+				
Behrenfeld, 1997	+	+	+	+			
Behrenfeld, 2005	+	+	+	+	+	+	+

Pabi, 2008	+	+	+				

4. The employed phytoplankton chl retrieval algorithms

For the ice-free pelagic (beyond the 200m isobaths) and shelf regions(inside the area bordered by the 200m isobaths) of the Arctic Ocean we tested three available sources of data on *chl*, which generally are yielded by NASA ocean colour observations, but processed differently (Figure 3). In addition, we also retrieved *chl* concentrations (simultaneously along with the retrieval of concentrations of suspended minerals and dissolved organic matter) from level 3 of the NASA SeaWiFS and MODIS-Aqua data making use of the BOREALI algorithm (Korosov et al., 2009). Based on a combination of the Levenberg-Marquardt multivariate optimization procedure and neural network emulation technique, the BOREALI algorithm has been developed specifically for coastal/optically complex waters experiencing a significant impact of land and river run-off (Korosov *et al.*, 2009).

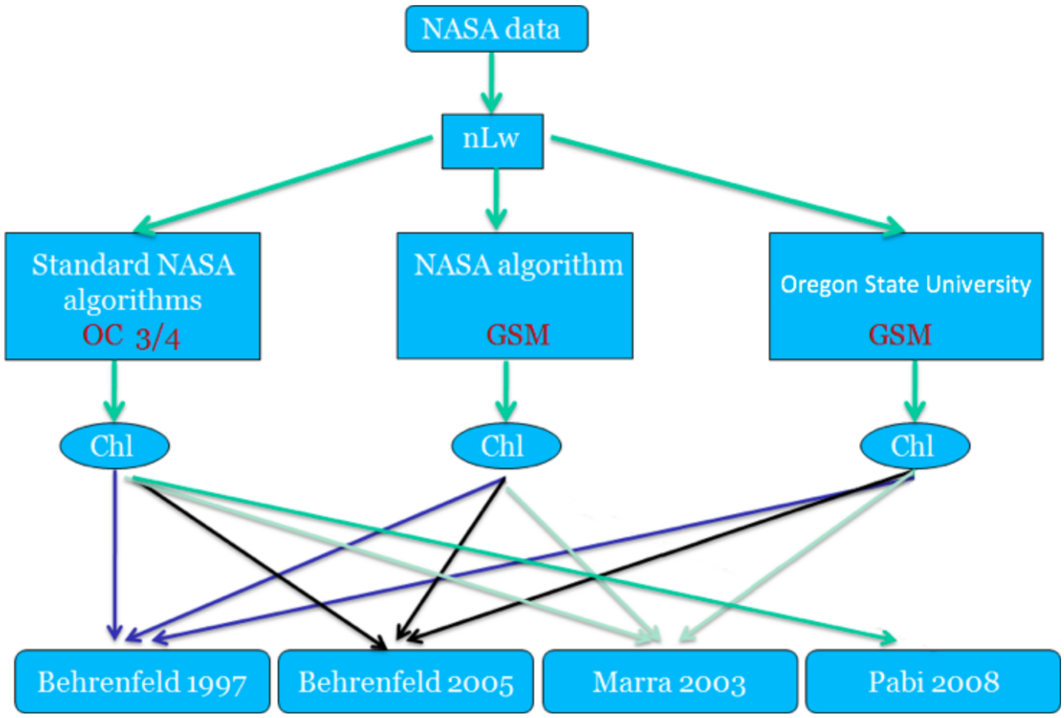

Figure 3. A flow-through diagram illustrating the fluxes of *chl* data used as inputs for the models discussed hereafter.

5. Acknowledgements

The work on retrieval of NPP from remote sensing data has been performed under the project MONitoring and Assessing Regional Climate change in High latitudes and the Arctic (MONARCH-A), funded by Seventh Framework Programme, Theme 9Space FP7-SPA.2009.1.1.02, Grant agreement no. 242446

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