Satellite monitoring of algal bloom in coastal zone: problems and achievements

Anatoly Alexanin
Institute of Automation and Control Processes, Far-Eastern Branch of Russian Academy of Sciences

The main task is satellite monitoring of harmful algal blooms (HABs).

Good indicators for red-tide events such as chlorophyll-a concentration, turbidity, fluorescence parameter and others are not specific to HABs.

Two ways the task solution:

- Use of "standard" ocean colour products and a knowledge about the regional peculiarities of plankton species bloom for interpretation of the satellite images.
- Phytoplankton species detection on the based of the plankton species peculiarities of its sun light diffusion and absorption in the sea water.

Phytoplankton species detection

Main difficulties:

- Bio-optical algorithms do not work in coastal area usually. Bottom influence in the shallow waters is the main problem. Another problem is an influence of different impurities such as suspended sediments and other contamination.
- Atmosphere correction errors are significant, especially in the coastal zone (no good aerosol models for atmosphere formed over the land). As the sequence the normalise water leaving radiance in violet and red spectral bands is wrong or negative.
- No dominant algae in the water. Plankton community consists of 10 and more species and each alga concentration is less 20% of total bio-mass usually. It is difficult to solve the identification task correctly.
- Water leaving radiance has significant dependence on the alga stage of life. Radiance characteristics in the end of bloom have low coincidence with ones in the beginning stage.
- Alga species detection is invert mathematical task. Such tasks have no single solution usually and rather sensitive to data errors. Heterogeneity of alga distribution in depth and plankton migration makes difficult the solution verification.
- Low spatial and radiance resolution of satellite information.

Shallow water problem

Grounds.

The ratio $R(z,\lambda)$ of upwelling and downwelling irradiance in the water at the depth z can be described as:

$$R(z,\lambda)=E_u(z,\lambda)/E_d(z,\lambda)=R_\infty(\lambda)+(R_b(\lambda)-R_\infty(\lambda))\cdot e(\lambda,z),$$

where λ - wave length, $R_\infty(\lambda)$,$R_b(\lambda)$- spectral diffuse reflection for a deep ocean and the bottom albedo, $e(\lambda,z)=\exp(-2K_d(\lambda,H-z))$, $K_d(\lambda)= K_u(\lambda)$- -spectral diffuse attenuation coefficient, H - the bottom depth. This model has a good accordance with in situ measurements. There are two parameters account for the bottom influence only - $R_b(\lambda)$ and H. The first results have been received to use the propagation model for Chlorophyll-a and suspended matter estimation.

It can be used follow approximation:

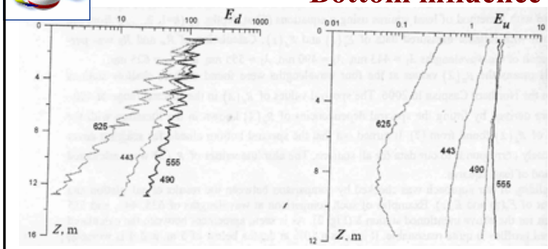
$K_d(\lambda_i)= K_d(\lambda_i)+\Sigma c_j\psi_j(\lambda_i)$, j=1,2

ψ_j-eigenvectors of K_d covariance matrix calculated from NASA bio-Optical Marine Algorithm Data set.

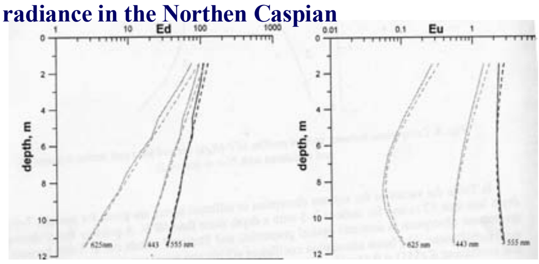
Set	approximation error (%)
Clear	0.3
Intermediate	2
Turbid	6

O. Kopelevich and oth., Institute of Oceanology RAS, E-mail: Oleg@sio.rssi.ru

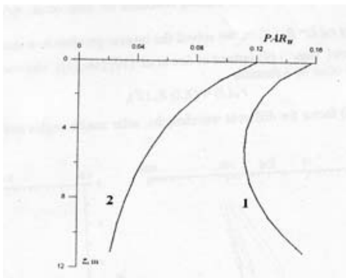
Bottom influence



Profiles of downwelling (left) and upwelling (right) radiance in the Northen Caspian



Results of measurements and calculations (direct task). Approximation accuracy is less 10%.



A comparison between vertical profile of photosynthetically active radiation derived from a real station (1) and calculated for the deep sea (2).

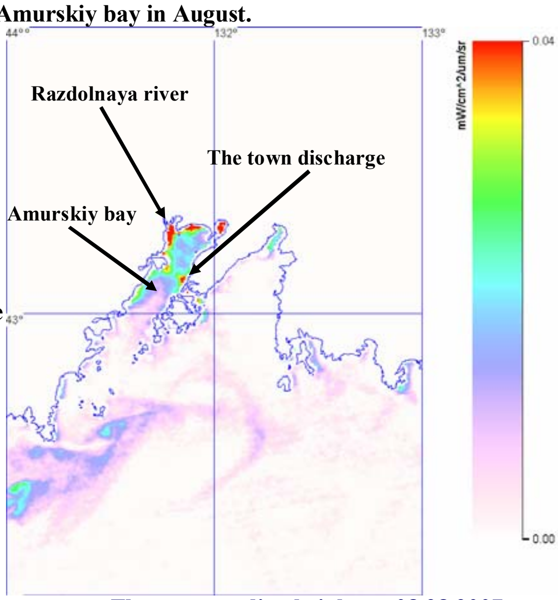
The first results have been received to use the propagation model for Chlorophyll-a and suspended matter estimation.

Alga species detection, observation conditions

The research purpose - **alga species detection and its spectral properties estimation on MODIS imagery in Amurskiy bay in August.**

Amurskiy bay characteristics:

- **Razdolnaya river is a slimy river. Significant amount of solid suspended matter comes in the bay.**
- **The town discharge has both solid suspend matter and coloured dissolved organic matter.**
- **Shallow waters are near the shore line.**
- **The wind in August is from the land. Mineral dust in atmosphere.**



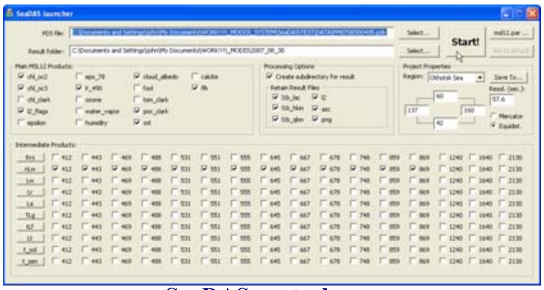
Fluorescence line height on 08.28.2007

Atmosphere correction

Data procession (SeaDAS)

<u>Input data</u> - MODIS/AQUA raw data.

<u>Ancillary data</u> - vapour, wind and ozone information



SeaDAS control program.

<u>The problem of negative values of water leaving radiance</u>.

Water leaving radiance for wave length nnn :

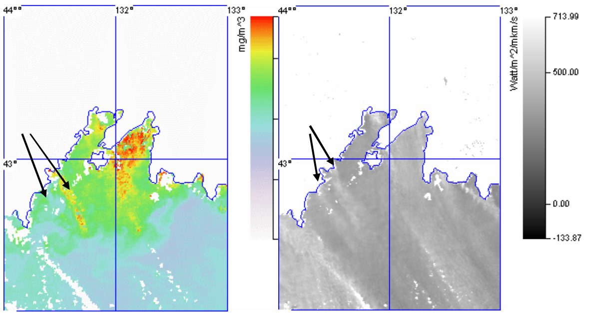
Lw_nnn = [(Lt_nnn - tLf_nnn) /t_oz_sen_nnn /t_oz_sol_nnn /polcor_nnn - TLg_nnn - Lr_nnn - La_nnn] /t_sen_nnn * t_oz_sol_nnn,

where Lt_nnn - TOA (top of atmosphere radiance), tLf_nnn - foam (white-cap) radiance, TLg_nnn - sun glint, Lr_nnn - Rayleigh radiance , La_nnn - aerosol radiance. Other parameters are slow variable values.

Experiments have shown the main reason of Lw negative values is high value of La_nnn. La_nnn value depends on aerosol model used. Last one selection is based on atmosphere vapour data. There are 12 aerosol models and 4 algoritms for model selection. The most reliable algorithm is MUMM (Management Unit of the North Sea Mathematical Models, Belgium) - parameter aer_opt=-10 of the utility msl12 (SeaDAS).

A sample of the atmosphere influence

Simplest visual control of the results of satellite image processing:
1. Different algorithms of chlorophyll-a concentration estimation should give similar results.
2. Aerosol with cloudy albedo value more 1% may be the source of errors.



Errors due to wrong atmosphere correction (Piter the Great bay): "wild" Chlorophyll-a concentration (left) and cloudy brightness used for albedo estimation (right) on 11.19.2005).

Arrows indicate two aerosol clouds with the same albedo values

Peter the Greate bay
MODIS/AQUA 30.08.2006

Algae species detection and its bio-mass estimation

The task:
Radiance variability of a channel *k*:
R_k-R_w=$\Sigma C_i \cdot R_{i,k}$, where
R_w – pure water radiance; C_i – concentration of an alga *i*; $R_{i,k}$ –radiance of an algae *i* for channel *k* per biomass unit.
MSR-method is used.

Alga species:
From 50 up to 90% of biomass was 2 alga biomass:
Coscinodiscus oculus-iridis
и Ditylum brightwellii.
4 species have more 90% of the total biomass.

Measurements in the Amurskiy bay on 08.30.2006						
Nn	T	Time	Dencity	Biomass	Dominant spicies	% of biom
			N, кл/Л	B, мг/м3		
1	21°C	10 00	125357,14	2842,96	Coscinodiscus ocul	55
					Ditylum brightwellii	40
2	21°C	10 15	231200,00	2455,12	Coscinodiscus ocul	35
					Ditylum brightwellii	48
3	21°C	10 30	131142,86	733,82	Ditylum brightwellii	75
4	21°C	10 45	173828,57	3482,62	Ditylum brightwellii	80
5	21°C	11 00	24857,14	991,15	Coscinodiscus ocul	41
					Ditylum brightwellii	37
6	21°C	10 25	98971,43	1426,08	Ditylum brightwellii	61
7	22°C	12 00	24100,00	1003,18	Coscinodiscus ocul	38
					Ditylum brightwellii	40
8	22°C	12 30	11228,57	646,72	Coscinodiscus ocul	37
					Ditylum brightwellii	30
9	21°C	12 55	8571,43	405,78	Coscinodiscus ocul	60
10	22°C	13 15	12942,86	391,52	Ditylum brightwellii	56
11	22°C	13 35	12000,00	617,92	Coscinodiscus ocul	76
12	21°C	16 30	33942,86	284,84	Coscinodiscus ocul	38
13	22°C	17 00	12900,00	285,90	Coscinodiscus ocul	66
14	22°C	17 30	6857,14	299,11	Coscinodiscus ocul	54

Co-authors: T. Orlova, O. Shevchenko, Marine Biology Institute FEB RAS
Project of FEB RAS " Biological security of Far-Eastern seas of Russian Federation"

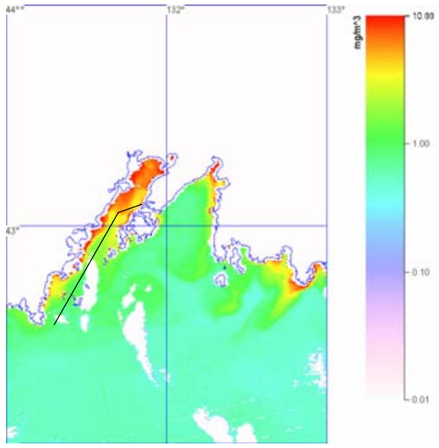
Task versions - 3,4 и 5 alga species. Final version - 3 alga species. Third alga is "universal" alga - the same spectral parameters for all measurement points.

Parameter set - 4 level-2 and 13 - normalised water leaving radiation of 13 spectral bands per biomass unit.

Decision acceptance - on the base of the analysis of linear equation discrepancies and parameter verification.

Only 11 parameters were sensitive to alga concentrations - appropriate linear equation discrepancies were in the range 5-30% of original values.

Chlorophyll-a concentration on 08.31.2006 and the vessel track.

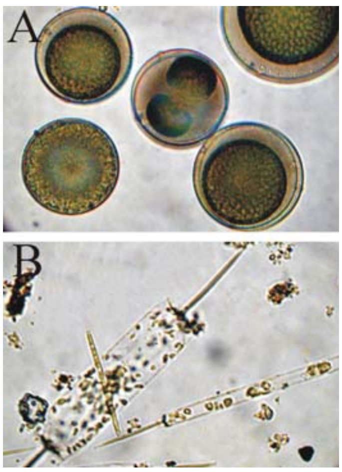


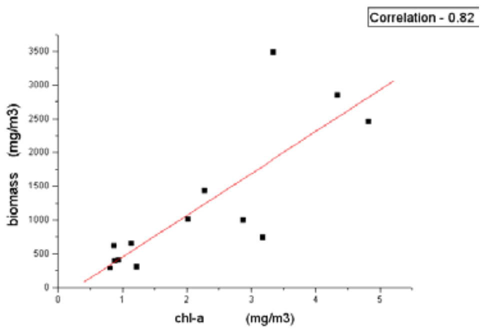
Algae and their biomass

Alga photos

A – ***Coscinodiscus oculus-iridis*** **;**

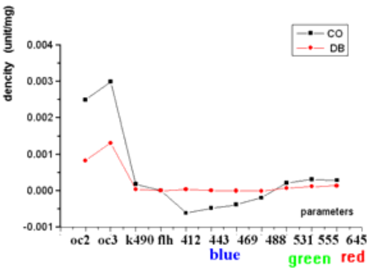
B - ***Ditylum brightwellii***





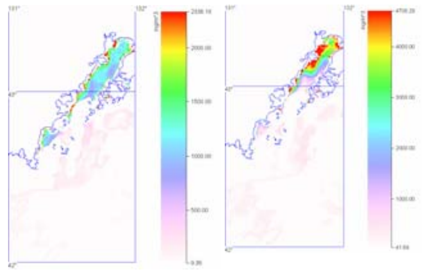
Chlorophyll-a (satellite estimations) and biomass relationship.

Spectral parameters of the alga biomass



Radiance parameters of the algae:
CO -Coscinodiscus oculus-iridis ;
DB - Ditylum brightwellii

Biomass concentration estimation on 08.31.2006
CO and DB



Parameter ratios and estimation errors

Para-meter	chl-OC2	Chl-OC3	K490	flh	nLw-412	nLw-443	NLw-469	NLw-488	NLw-531	NLw-551	NLw-555
Ratio CO/DB	3.0	2.3	4.3	2.9	-17.4	-63.3	-397.	40	3.0	1.95	2.0
Errors	7%	3%	21%	250%	24%	22%	18%	36%	2%	10%	8%

Some words about main difficulties

Pseudo-nitzchia monitoring is failed. Alga biomass concentration was less 50%

Main difficulties:

•Water leaving radiance has significant dependence on the alga stage of life. Radiance characteristics in the end of bloom have low coincidence with ones in the beginning stage.

•Bio-optical algorithms do not work in coastal area usually. Bottom influence in the shallow waters is the main problem. Another problem is an influence of different impurities such as suspended sediments and other contamination.

•Atmosphere correction errors are significant, especially in the coastal zone (no good aerosol models for atmosphere formed over the land). As the sequence the normalise water leaving radiance in violet and red spectral bands is wrong or negative.

•No dominant algae in the water. Plankton community consists of 10 and more species and each alga concentration is less 20% of total bio-mass usually. It is difficult to solve the identification task correctly.

•Alga species detection is invert mathematical task. Such tasks have no single solution usually and rather sensitive to data errors. Heterogeneity of alga distribution in depth and plankton migration makes difficult the solution verification.

•Low spatial and radiance resolution of satellite information.

There are 30-50 alga species in Far-Eastern seas of Russia, which can have significant intense bloom. And less 20 species of them can produce toxins.

Conclusions

•To make efficient HAB monitoring it is necessary to measure spectral properties of each species in a laboratory for each alga life stage.

•An easy way and inexpensive realisation of monitoring technology creation is to organise the regular measurements on any test sea area near a shore of the Amursky bay. It should be lidar and/or spectroradiometer remote measurements from the shore and in situ measurement of alga composite and water radiation properties both in deep and shallow waters.

•Lidar sounding of the atmosphere together with AMSU atmosphere profiles should allow to control the key atmosphere parameters: aerosol particle size, its height, humidity, ozone and others.