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

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1. Introduction

Satellite monitoring of harmful algal blooms (HABs) is one of the important tasks of the environment control. The task is not solved yet in spite of significant achievements for last years in the field of satellite facilities and appropriate algorithms of water bio-parameter calculation. Good indicators for red-tide events such as chlorophyll-a concentration, turbidity, fluorescence parameter and others are not specific to HABs. Red-tide is not HAB often and during the HAB the phytoplankton concentration does not reach red-tide one. By this reason it is the only one way to solve the task - to detect plankton species concentrations.

Most of the existing algorithms for HAB detection are empirical, they operates in appropriate regions only with certain bio-optical conditions and do not operate in the coastal zones. There are two ways the task solution on the base of satellite information. First is the use of "satndard" ocean colour products and a knowledge about the regional peculiarities of plankton species bloom for interpretation of satellite images. The approach fails often because of unstable pattern of a plankton community evolution. Another approach is phytoplankton species detection on the based of the plankton species peculiarity of sun light diffusion and absorption in the sea water. This approach is the most promising but and the most heavy. The sense of the approach is in the use of radiance characteristics of each plankton species in different spectral bands (or appropriate absorption and scattering characteristics) together with traditional level-2 products to classify the colour satellite information, detect the main plankton species and it's concentrations. There are follow main difficulties and unsolved tasks of the approach in according to its decreasing significance.

- 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 contaminations.
- 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.

The task of the bottom influence estimation is not solved yet, but a good progress has been achieved last years. A solution of the direct task of radiance propagation in a water was presented in a set of works of Dr. Kopelevich and oth. According to which 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, $e(\lambda,z)=\exp(-2K_d(H-z))$, K_d -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.

Atmosphere correction.

Atmosphere correction presented in SeaDAS package try to estimate some terms of an equation for water leaving radiance. Errors of aerosol radiance estimation have greatest consequence on bio-parameter values calculated with satellite information usually (as the results, we have chlorophyll-a concentration exceeded in times the real one and negative water leaving radiance in violet and red spectral bands). The algorithm of aerosol radiance estimation is based on aerosol model selection by atmosphere humidity field in according to a scheme selected. Predicted humidity field is used for the final result reception. It is possible to control and delete rough errors of atmosphere correction and increase the product quality on the base satellite estimation of the humidity field. But the problem will not be solved problem as a whole soon. It is necessary an additional procedure for recalibration of water leaving radiance using as a standard a pure water radiance parameters.

Estimation the alga species concentrations.

There 2-3 dominant algae in sea water often during the intense algal bloom. It allows to form and solve a task for alga species detection and its concentration estimation. Some experiments were made in the Amursky bay near Vladivostok on the base of satellite and *in situ* measurements in August 2006. Two algal species (Coscinodiscus oculus-iridis и Ditylum brightwellii) have 70-90% of bio-mass measured. The approach used was based on a simple states. Satellite radiance value of any spectral band (charnel) is depend on pure water radiance, alga concentration and its spectral properties. Thus, we can write the normalise water leaving 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 – biomass concentration of an alga *i*; $R_{i,k}$ –radiance variability due to the algae *i* for the channel *k*.

It was used 17 parameters produced with SeaDAS program (both level 1 and level 2). 10 of them were sensitive to the alga concentration. Square root method allowed to get stable and good accuracy results. Each alga can be characterised by unique spectral properties of bio-mass unit (alga passport) which may be use to detect the alga species with satellite information.

Conclusion.

The experiments allowed to make follow conclusion. The approach tested is rather promising for a satellite HAB monitoring. 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. 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 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.