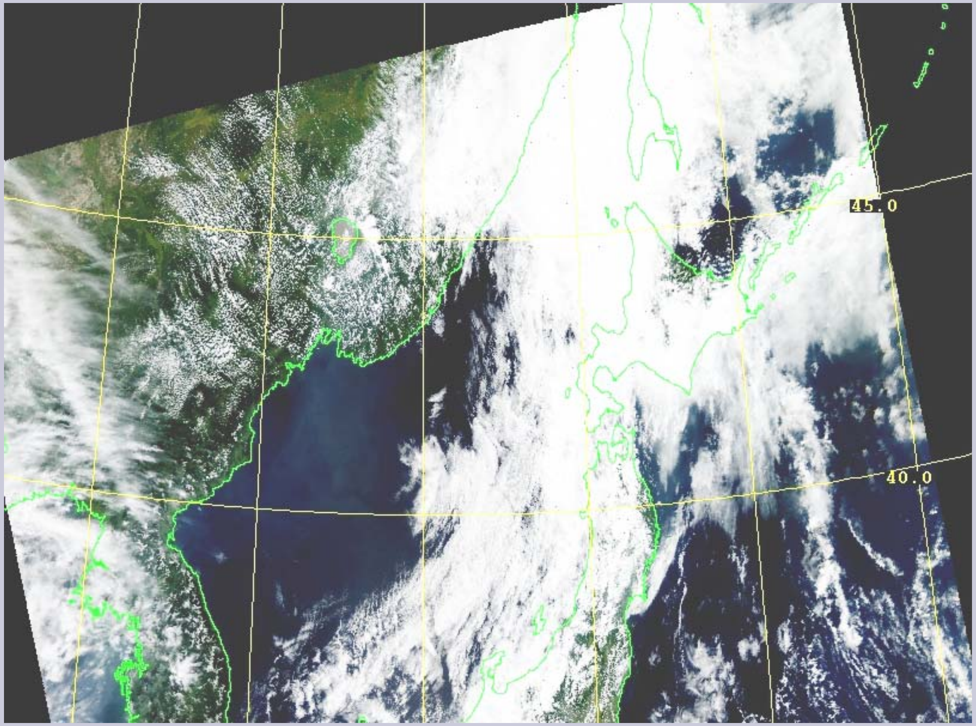
The application of empirical orthogonal functions in the ocean remote sensing



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Introduction

In the remote sensing of coastal waters there are problems with accurate estimations of bio-optical and physical parameters.

Standard algorithms and their modifications less accurate in the coastal areas and sometimes give data too mach duffer from *in situ* measurements.

Many investigators create their own algorithms using additional information and analytical models.

Most of applied algorithms use no more than 4 channels of the spectroradiometer MODIS. But there are 11 channels in the visible spectral range.

Can all 11 channels give us additional information?

The **objective** of this research is:

to investigate the availability of all visible channels of MODIS for remote sensing of marginal seas including the costal area.

Method:

application of empirical orthogonal functions for satellite data processing.

Used data

Spectroradiometer: MODIS

Channels: 412 nm, 443 nm, 469 nm, 488 nm, 531 nm , 551 nm, 555 nm, 645 nm, 667 nm, 678 nm, 748 nm

Data server: http://ladsweb.nascom.nasa.gov

Data level: L1B

SeaDAS data processing: L1B $\longrightarrow$ L2 $\longrightarrow$ ASCII

Output parameters: normalized water leaving radiances

Also data from IACP FEB RAS were used

The short mathematical background

$\mathbf{L}_k = \{ L_k(\lambda_1), \ldots, L_k(\lambda_r)\}$ - nLw spectrum,
k – the pixel´s number, *r* – the number of channels

P – data matrix, *n* rows, *r* columns

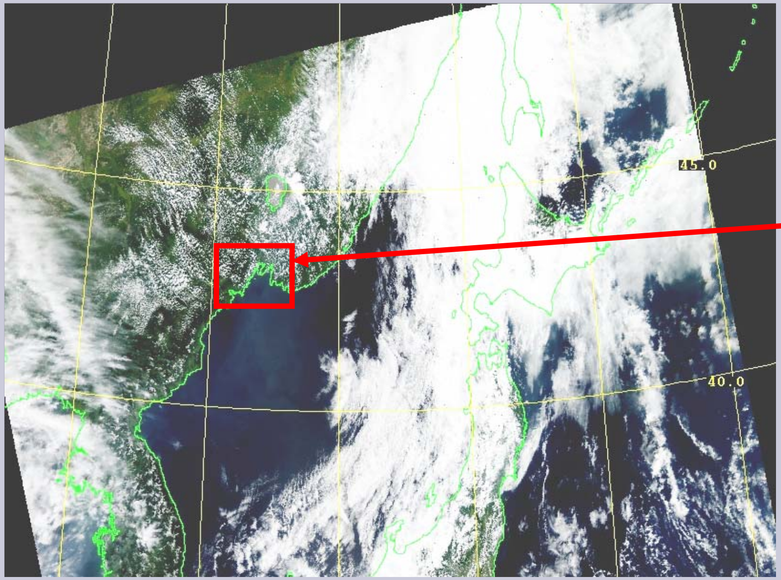
$\mathbf{K} = \mathbf{P}^T\mathbf{P}/(n-1)$ – covariance matrix

$\mathbf{Kx} = \boldsymbol{\mu}\mathbf{x}$ equation for eigenvectors and eigenvalues

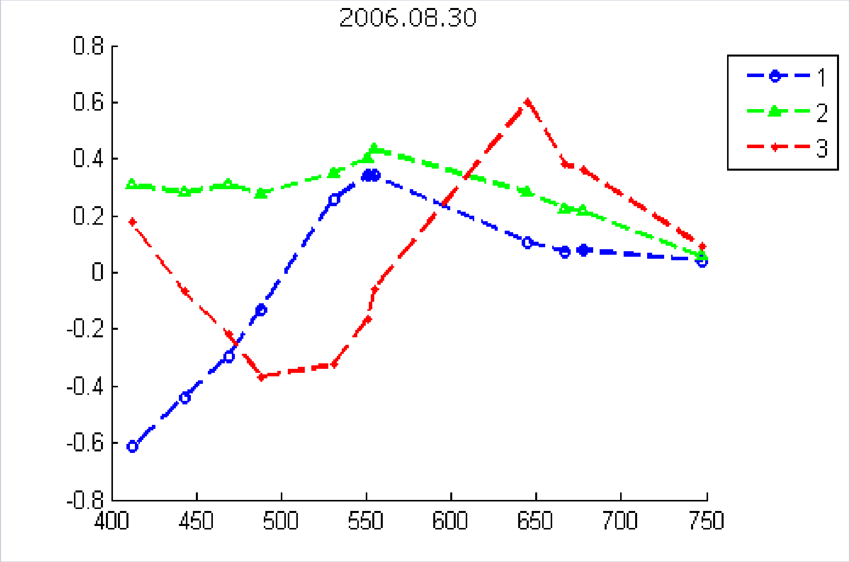
$\mathbf{x}_i\ \mathbf{x}_i = \boldsymbol{\mu}_i^2$ normalized eigenvectors – empirical orthogonal functions

$\mathbf{L}_i = \sum^r_{k=1} c_{ik}\mathbf{x}_k$ - expansion spectra in series using empirical orthogonal functions as a basis

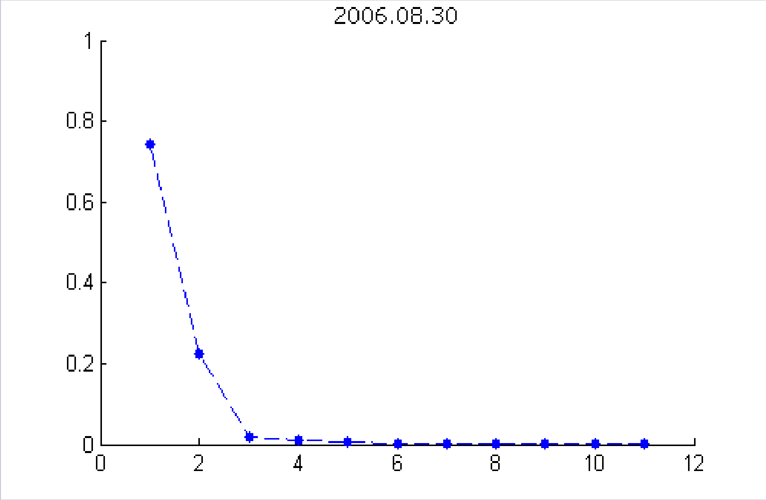
Peter the Great Bay, 30 Aug 2006, MODIS Terra



The area of research:
Japan/East Sea
42°N – 43°30´N
131°E - 133°E



Empirical orthogonal functions



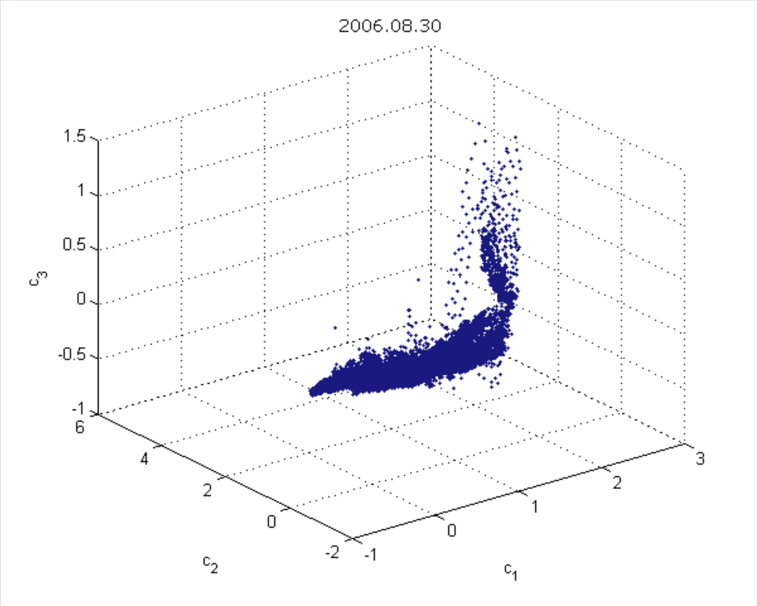
Only few EOF are responsible for a major part of spectra variability

Peter the Great Bay, 30 Aug 2006, MODIS Terra

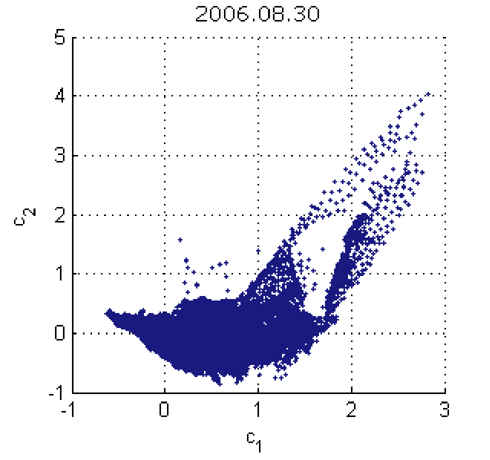
In the space of coefficients C_i each spectrum is represented by a point.

In a general case the dimension of this space is equal 11.
But the nature is more rational and in most cases restricts it to 3 or 4.

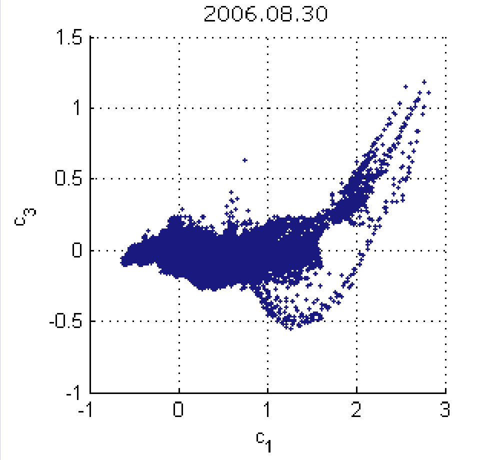
A cloud and protuberances of these points contain a lot of Information about an upper layer of sea waters.



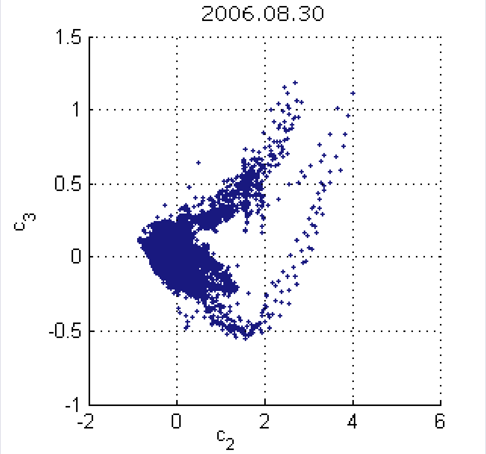
In projections on 2D:



(c1, c2)



(c1, c3)



(c2, c3)

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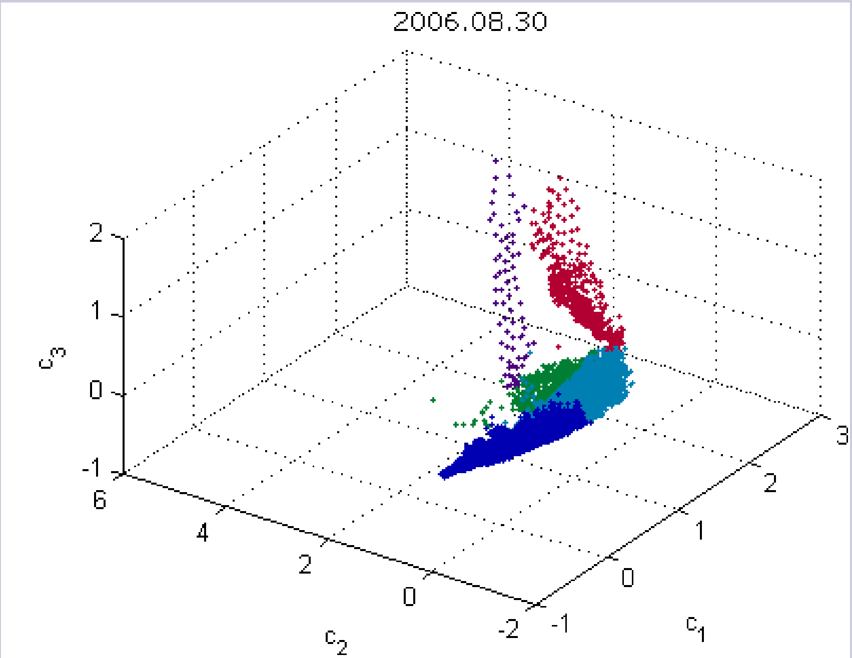
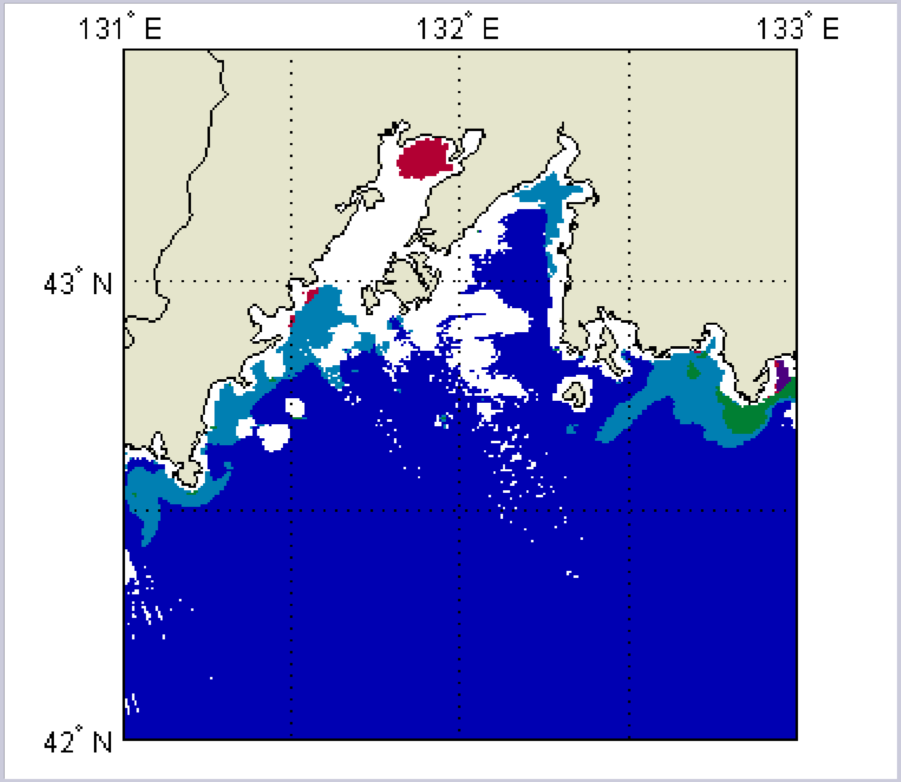


Classification in the 3D space (c1, c2, c3)

Even a simple classification gives us an information about a structure of upper layer of sea waters.

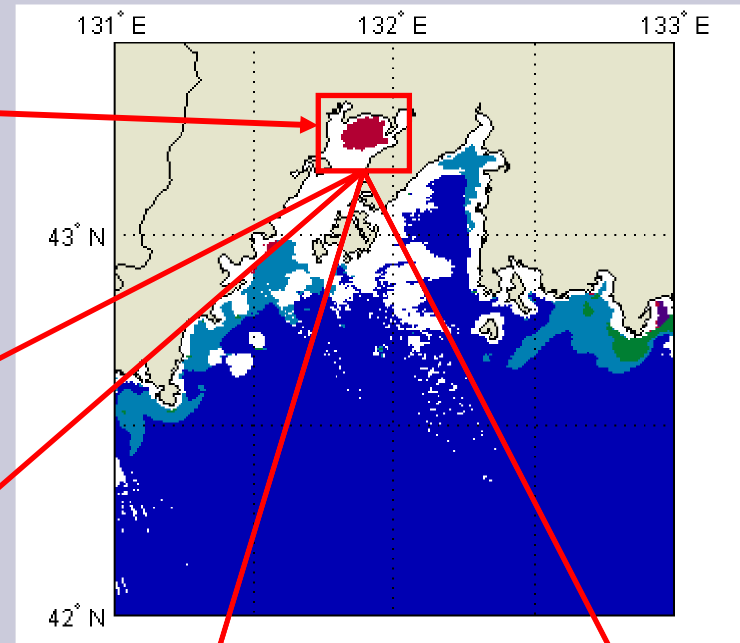
The map of clusters

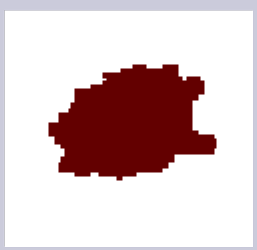


Peter the Great Bay, 30 Aug 2006, MODIS Terra

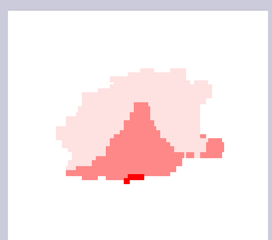
Each cluster of points has more complex structure.

Having *in situ* data it is possible to derive the regression equation for the measured parameter estimation.

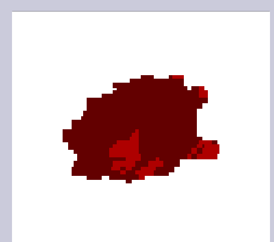




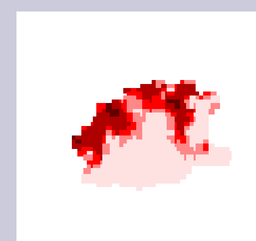
c1



c2

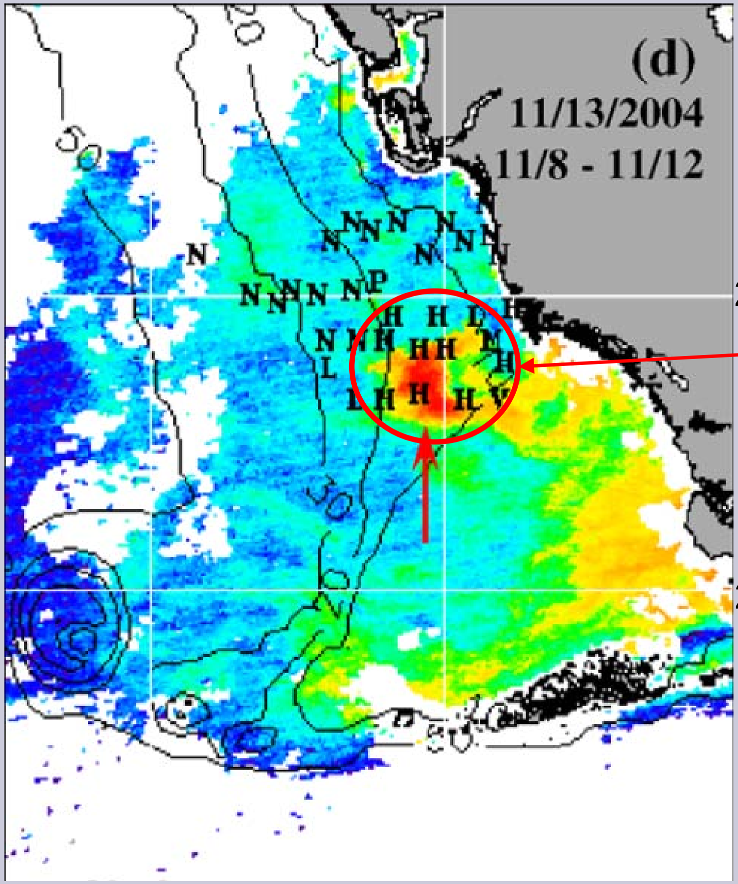


c3



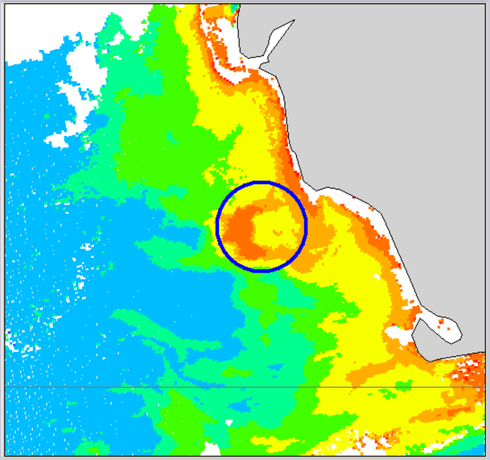
c4

Florida, 13 Nov 2004, MODIS Aqua

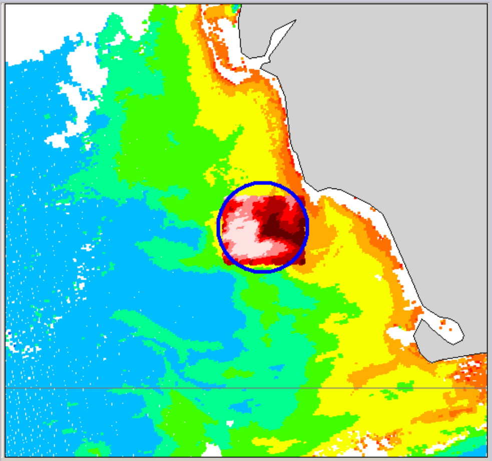


C.Hu et al /Remote Sensing of Environment, **97**, (2005) 311-321/ :
In situ data showed that the bloom contained high concentrations ($>10^5$ cell/l) of *K.Brevis*

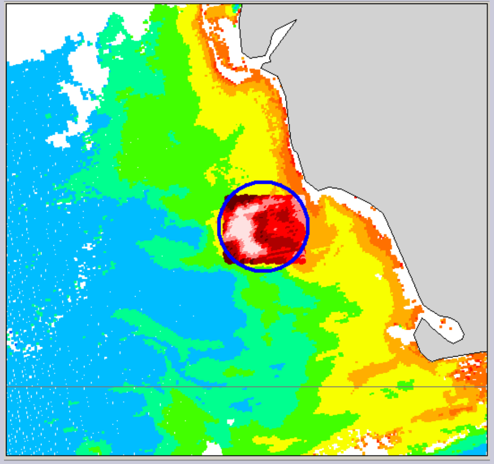
Florida, 13 Nov 2004, MODIS Aqua



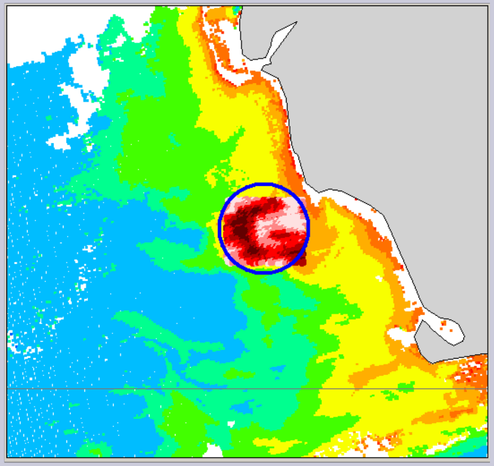
The chlorophyll a concentration



The superposition with c1.

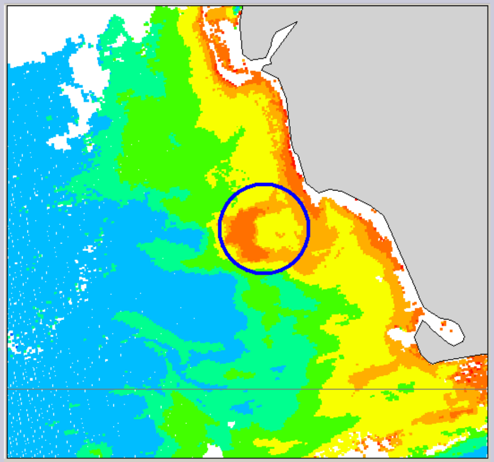


The superposition with c2.

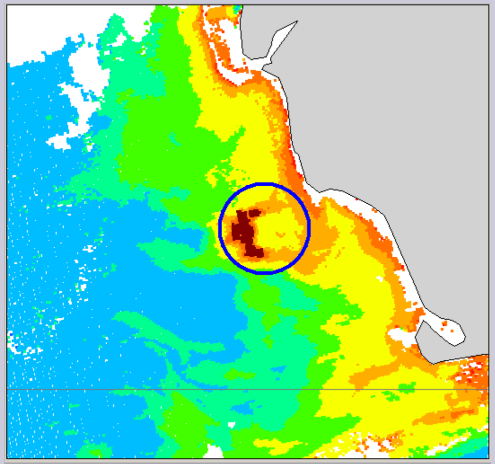


The superposition with c3.

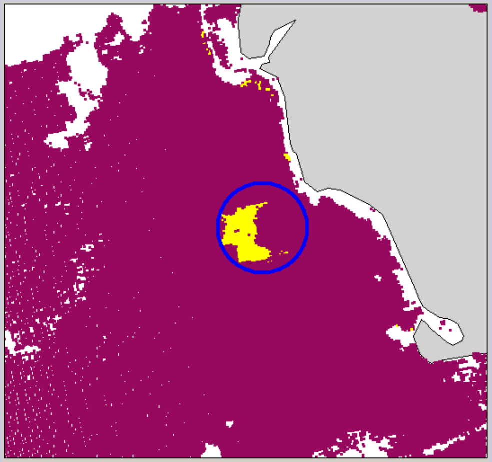
Florida, 13 Nov 2004, MODIS Aqua



The map of the chlorophyll a concentration



The cluster of pixels with near values of (c1, c2, c3)

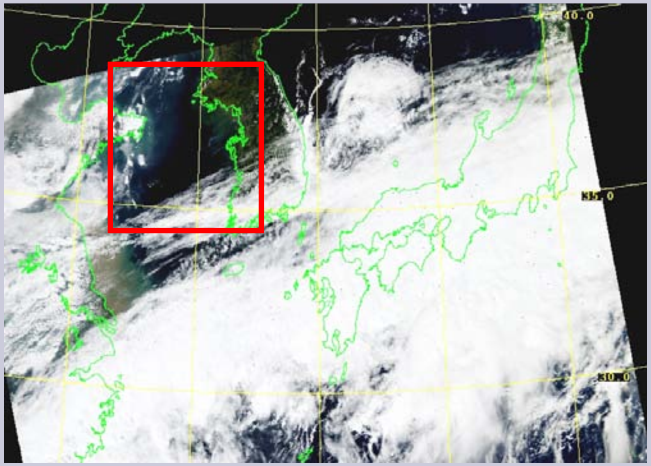


The result of a spatial request shows a unique cluster of points in the investigated area.

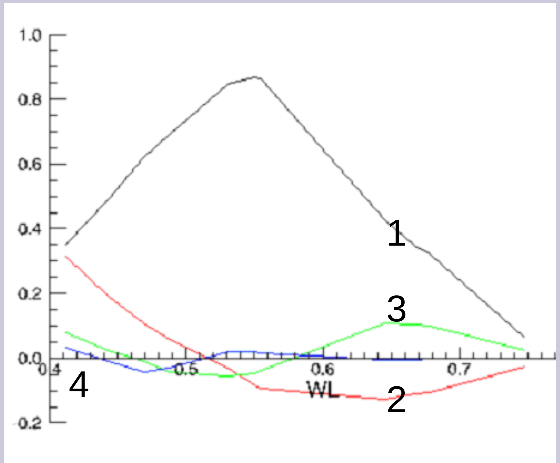
It coincides with a result of C.Hu et al. They used fluorescent line height calculation for HAB detection.

Regional effects

29 Sept 2008

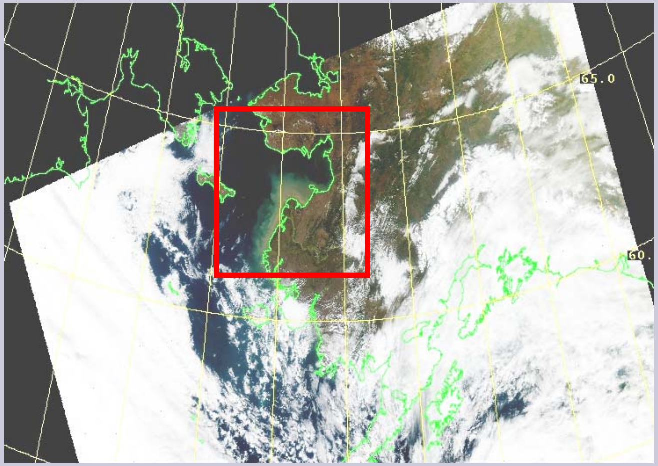


Yellow sea near the coast of Korea

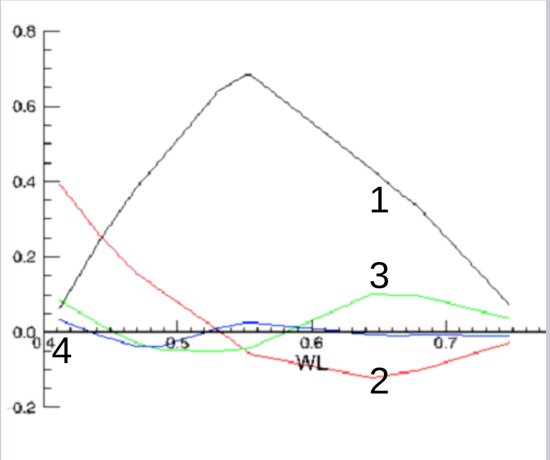


Empirical orthogonal functions

25 Sept 2008



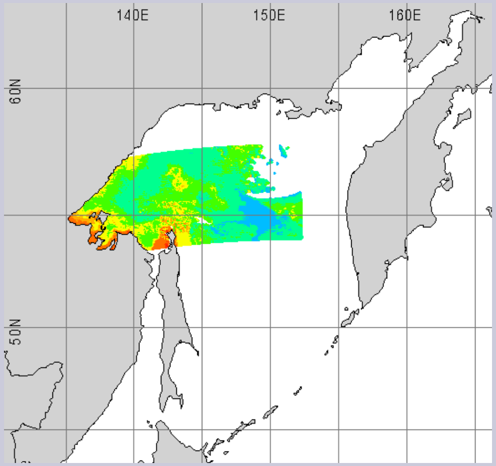
Bering sea near the coast of Alaska



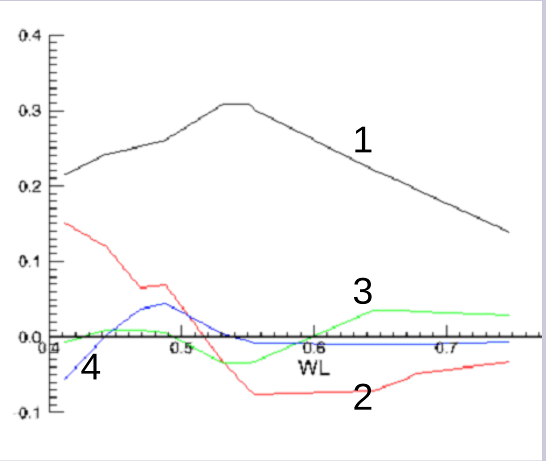
Empirical orthogonal functions

Different days, different seas and near identical functions.

Regional effects

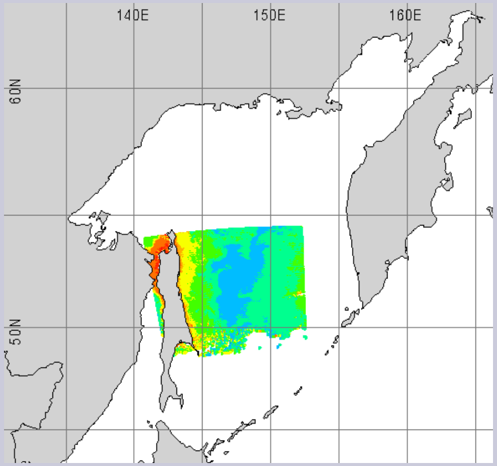


5 Sept 2008

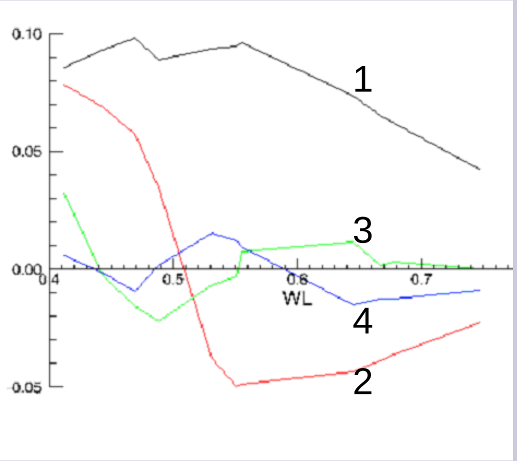


OC3 Chl-a in the Okhotsk sea

First empirical orthogonal functions



5 Sept 2008



One day, one sea and different functions

Conclusions:

-empirical orthogonal functions can be used as a tool for upper layer monitoring of sea waters

-for effective use there is needed an adjustment for known phenomena

-regression equations can be derived for physical parameters estimations in the presence of enough *in situ* measurements

-method mainly can be used for regional monitoring