TIME-SPACE EARTH SURFACE GRADIENTS FOR SATELLITE MONITORING OF ECOSYSTEMS

Alexei V. Kartushinsky(1,2), Nikita A. Ogorodov(3,2), Alexander A. Larko(1)

(1) Institute of Biophysics SB RAS, Krasnoyarsk, Russia, kartushka@mail.ru
(2)Siberian Federal University, Krasnoyarsk, Russia, lantar@inbox.ru
(3) Federal Research Center KSC SB RAS, Krasnoyarsk Russia, Nogorodvv@yandex.ru

Abstract. The results of Earth surface gradients characteristics calculate based on satellite data are presents. Dynamics structural features of horizontal gradient fields in aquatic objects and land ecosystems by physical, biological parameters are considered. Problems of the parametrization for environment exchanges evaluations with using numerical modeling based on satellite data and software tools are submitted. Spatial-temporal scaling and averaging of gradient components are discussed. Develop improved estimates of Earth surface gradients fields in the different ecosystems is considered.

Keywords: satellite data, regional features, gradient fields, frontal zones, ecotone, spatial averaging, average seasonal variability, synergistic effect.

1 Introduction

Gradient indicators of measurable surface parameters of terrestrial and aquatic ecosystems show some spatial boundaries of various dynamic processes. Calculations of natural objects gradient characteristics are necessary to identify zones with different dynamic activity [1, 2]. The satellite measurements in visible and infrared ranges are images with spatial fields of various natural objects on the Earth's surface. The main parameters in our case are surface reflectivity and radiation temperature. A methodological concept is determined by a need to calculate spatial gradients of Earth's surface measurable characteristics. The calculated gradients with different spatial and temporal averaging are necessary to identify zones with different dynamic activity of physical and biological fields, land vegetation, geological indicators such as terrain or soil cover.

The gradient characteristics of parameters that are used to study surface dynamics of ecosystem spatial heterogeneities are differentiated indicators of values change rate. A gradient value in spatial coordinates provides an opportunity to obtain a vector of development or attenuation of a process. Gradient indicators of spatial variability of a studied object (field) are often not fully used, especially for quasistatic objects such as land ecosystems. In this case, calculations of studied fields dynamics are based on a combination or composition of source images (pictures) compared in absolute quantitative indicators, averaged and interpolated values [3, 4].

Determining development conditions and scale of hydrological processes is necessary for monitoring an ecological state of aquatic systems including oceans, seas, lakes and waterbodies. Calculation of spatial gradients from satellite data allows us to assess spatial and temporal scales of formation of zones with high gradient values. The possible conditions of acting factors and physical mechanisms of hydrobiological and hydrological components interaction can be studied using methods of numerical simulation based on calculation of partial derivatives of heat transfer, mass, and pollution diffusion equations with using satellite and contact data [5, 6, 7].

An analysis of Earth's surface state parameters time-space gradients variability is necessary to assess a dynamic process in aquatic systems and on the solid Earth's surface. Therefore, the main goal of this work is to implement a method of calculating Earth's surface gradient characteristics from satellite data using developed information technology and software with the application of mathematical statistics methods.

2 Materials and methods

Satellite data obtained by various scanners such as SeaWIFS, CZCS, AVHRR, MODIS, SPOT, LANDSAT, AQUARIUS were used to calculate gradient characteristics in various regions of the Global Ocean and Eurasia. The main attention is paid to identifying patterns of horizontal highly gradient zones formation according to physical and biological components of the Earth's surface. To do this, use a gradient method of processing satellite data using appropriate information technology and software [1]. A methodology to study variability of surface gradient fields of aquatic and terrestrial ecosystems as dynamic objects based on calculation of spatial gradients (latitudinal, meridional and absolute) with different averaging periods (week, month, season, year) is used. Source data in the work are satellite images and data of spectroradiometers obtained by high- and low-resolution hardware such as AVHRR MCSST, CZCS, SeaWIFS, MIRAS AQUARIUS, MODIS, MSS for various time periods from NOAA, TERRA, AQUA, SPOT-4, LANDSAT-8 satellites.

ENVI software product was used to calculate gradient fields of land vegetation, and IDL programming language was used to write calculation logic.

3 Summary and discussion

Calculation of spatial gradients of Earth's surface characteristics in latitudinal and meridional directions allows us to identify areas with significant differences which can be interpreted as boundary or anomalous.

3.1 Gradient fields in the surface Ocean

Gradient fields of hydrological parameters in aquatic systems allow us to estimate intensity of dynamic processes variability. An interaction of different water masses with different properties forms hydrological fronts that are determined exactly by calculations of relevant gradients (Figure 1). In this case, the Global Ocean is a dynamic system in which there are hydrophysical and hydrobiological structures formed by processes of various spatial and temporal scales.

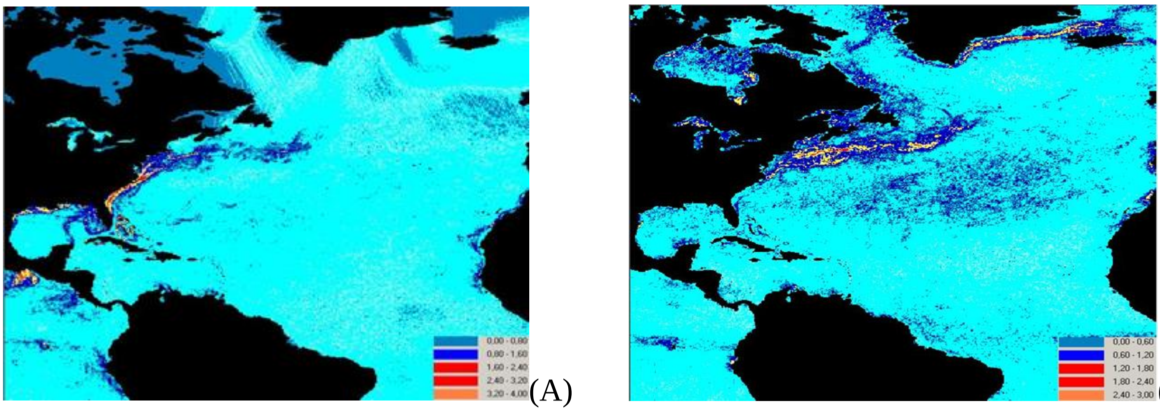

Figure 1. A structure of temperature frontal zone of interaction system between the cold Labrador Current and the warm current Gulf Stream according to calculation of surface ocean temperature absolute (modulo) gradients for 2000; A - winter; B - summer.

Currently, considerable attention is paid to processing of observational data and their re-analysis using general ocean circulation models to improve global models of interaction in an atmosphere-ocean-land system [9, 10, 11]. It is important to understand a trigger for formation of such phenomena as North Atlantic Oscillations (NAO), El Niño-South Oscillations (ENSO). An analysis of ocean high-gradient zones dynamic activity, determination of ocean's temperature field local interaction effects and formation of atmospheric circulations (cyclones, anticyclones) relevant response based on gradient indicators will make it possible to understand time-space scales of local processes that determine synergism of global (planetary) phenomena.

The use of spatial gradient indicators calculated from satellite data in mathematical models gives a magnitude of change rate in a surface layer structure. An analysis of dimensions of heat transfer, mass, and impurity diffusion equations terms, based on theory of similarity, makes it possible to introduce initial, boundary conditions and a grid calculation scale in mathematical models when conducting numerical simulations. Numerical modeling based on a 2D model of heat transfer allows us to study variability of an ocean temperature frontal zones structure, depending on dynamic conditions of heat transfer, mass and impurity concentration.

3.2 Gradient fields in the surface Land

As for land surface and terrestrial ecosystems, it is important to determine spatial scales of ecotones (transitional boundaries between ecosystems) and time scales of variability of such zones. Processes with a low rate of dynamic activity in space such as soil erosion, vegetation cover, and Earth's surface morphology are practically not evaluated by gradient fields [1]. However, these processes turn out to be significantly related in long-term series of observations.

So, when evaluating biomass of gross primary production (GPP) and net primary production (NPP) of terrestrial ecosystems using satellite data, it is sometimes difficult to determine the area of individual ecosystems and their spatial boundaries (ecotones). In addition, in many works, spatial distribution of dynamics of NPP or another indicator is not considered, but trends averaged over area are estimated [8]. The obtained average results during further verification by their terrestrial data are often very ambiguous. Therefore, we can talk about inapplicability of linear models for analysis of time series in complex, spatially distributed systems. Therefore, there is a question of verifying and analyzing applicability of various methods for obtaining time trends, a detailed examination of their features, strengths and weaknesses, as applied to Earth remote sensing data included in an NPP assessment model [12].

Calculation of gradient fields of land vegetation indicators, in particular, the NDVI gradients, can help determine spatial boundaries of ecosystems that in many respects correspond to terrain. The speed and direction of changes in soil and vegetation cover may have different coherence, which is a response to climate change.

An example of a gradient field of a vegetation index calculated based on a use of space data GIMMS (Global Inventory Modeling and Mapping Studies) NDVI from 1982 to 2006, half-month composite images, 8-km resolution (on the equator line), global scale, NOAA satellite AVHRR scanner, presented for the Baikal region in Figure 2.

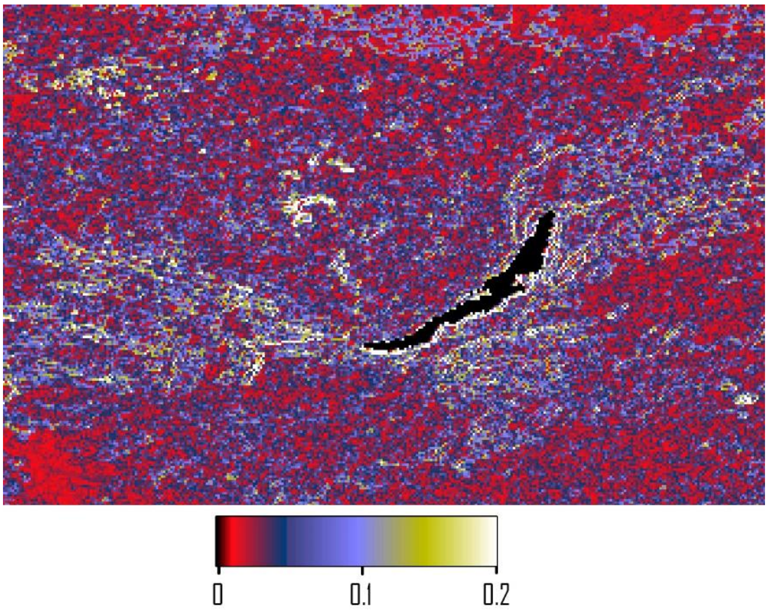

Figure 2. NDVI gradient field calculated modulo (absolute gradients).

Thus, as a result of applying the gradient approach, it became possible to isolate large changes in boundary transition between biomes and ecosystems such as taiga – tundra transition or zones of high mountain regions and lowlands with corresponding types of vegetation.

3 Conclusion

Calculations of gradient characteristics of ecosystems surface based on satellite data make it possible to identify zones with different dynamic activity. An analysis of gradient fields value distribution makes it possible to identify heterogeneous and homogeneous zones of ecological systems and, with an appropriate averaging period, to obtain degree of dynamism of such zones. This allows us to study natural systems structural organization processes and time-space scales of variability that can be used in development of statistical and deterministic mathematical forecast models.

For aquatic systems, studying a structure of gradient fields of water temperature, salinity, chlorophyll concentration, turbidity makes it possible to identify a scale of zones of non-uniform characteristics distribution, to determine lifetime of boundary (transition) zones by magnitude of gradient in meridional, latitudinal direction and modulo. Such a methodology, combined with a use of appropriate information and software tools, makes it possible to evaluate effect of factors of a physical and biological nature on ecosystem formation as a whole or to assess cyclical nature of these factors action in individual parts of a system. For land ecosystems, degree of surface heterogeneities variability is much lower than in aquatic systems, however, the gradient approach can provide a differentiated picture of ecosystem boundaries based on satellite data. Therefore, it is possible to evaluate a synergetic component in self-organization of a systemic level of interaction between ecosystems and elements of the Biosphere system at an Atmosphere-Ocean-Land level with relevant scales of time-space averaging.

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