FUSION OF DATA SOURCES IN AN EFFORT TO STUDY GLOBAL CLIMATE CHANGE FOR THE GREAT LAKES OF NORTH EURASIA

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ABSTRACT

Within the framework of project of Russia's Ministry of Science and Technologies and grants of Russian Foundation of Basic Research, at the Space Research Institute RAS, the Institute of Solar-Terrestrial Physics SB RAS and the Limnological Institute SB RAS a start has been made on the creation of a system of satellite data banks on the state of major lakes of North Europe and Asia. The prime objective of the projected information system is to study variations in the hydrophysical and hydrobiological regime of the lakes in connection with global climate change and anthropogenic influences. The base study objects are: Lake Baikal, The Caspian Sea, Ladoga Lake and The Aral Sea. Satellite images from AVHRR of NOAA satellites provide the basis for the development of the information system. High resolution satellite data of Russian «Resurs» satellite is used for calibration and validation. Baikal ERS SAR images given in our disposition in the framework of European Space Agency Announcement of Opportunity serve for detailed studies of physical and biological processes on the lake surface. The following examples of data fusion are presented: studies of coastline position changes, verification of ice and snow classes classification using high-resolution data, studies of physical factors forming green-blue algae bloom using SAR and IR imagery.

1 INTRODUCTION

Within the framework of project of Russia's Ministry of Science and Technologies and several grants of Russian Foundation of Basic Research, at the Space Research Institute RAS, the Institute of Solar-Terrestrial Physics SB RAS and the Limnological Institute SB RAS a start has been made on the creation of a system of satellite data banks on the state of major lakes of North Europe and Asia. The prime objective of the projected information system is to study variations in the hydrophysical and hydrobiological regime of the lakes in connection with global climate change and anthropogenic influences. The base study objects are:

Lake Baikal, the largest of the world's reserves of fresh surface-water, is chosen is the base water body for developing analysis algorithms for satellite information. Lake Baikal, a UNESCO World Heritage site now, is a water basin that contains about 20% of fresh water available on the globe. High drinking water qualities, a highly endemic ecosystem, and the recreational qualities
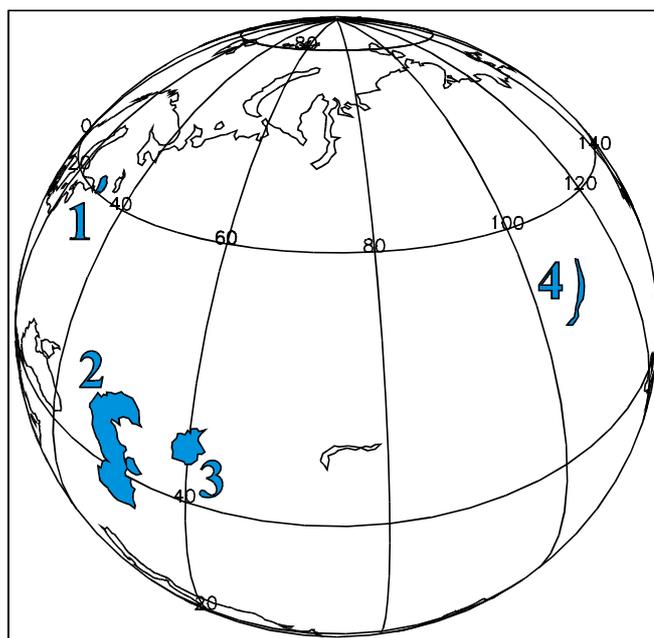

Figure 1. Great Lakes of North Eurasia.
1—Ladoga Lake, 2—Caspian Sea, 3—Aral Sea,
4—Lake Baikal

of the region that is not yet dramatically affected by the technogenic influence — all these factors betoken the importance of research into Baikal's ecosystem dynamics and its possible changes in connection with climate change and anthropogenic influences.

The Caspian Sea, the Earth's largest inland water body; economic activity has drastically affected the Caspian region. This lake's level undergoes changes probably caused by natural cyclic processes. Of critical importance for the hydrophysical regime and ecosystem of the Caspian Sea are the influent rivers.

Ladoga is the largest lake in Europe affected by intensive industrial pressure and changing in its ecosystem.

The Aral Sea, the study of which is of great interest in connection with a substantial alteration of the regime of this water body due to the anthropogenic influence.

Satellite images from AVHRR (Advanced Very High Resolution Radiometer) sensors on NOAA satellites provide the basis for the development of the information system. It is common knowledge that NOAA satellites are weather satellites which are traveling in nearly circular Sun-synchronous orbits, with the orbital altitude of 850 km and the inclination of about 90 degrees. At least two satellites are orbiting simultaneously. The AVHRR sensors measure the incident radiation and the Earth-reflected radiation in five spectral channels, of which channel 4 and channel 5 are designed for measuring the radiation near a maximum energy flux from the Earth in the ranges 10.3-11.3 nm, and 11.5-12.5 nm, respectively.

Images from the five spectral channels in digital form that are received by the satellite receiving station SCANOR in the high resolution HRPT mode with the pixel size 1.1x1.1 km at nadir, are used in the processing and analysis. Multispectral images are processed with the purpose of deriving the brightness temperature and albedo; after that, they are converted to geographic coordinates using the XV-HRPT software package developed by the XV-group (Moscow, Zakharov et al., 1995) by referencing the image in channel 2 to the shoreline of the lakes and/or to characteristic landscape features. Resulting images have the pixel size 1x1 km.

Multispectral cameras MSU-E and MSU-SK are installed on the Russian Resurs satellites. Their working ranges include the following spectral regions: 0.5-0.6, 0.6-0.7, and 0.7-0.8 mm. The spatial resolution of images for MSU-E and MSU-SK is 40 m and 150 m, respectively. The receiving stations ensure stable reception of images for the entire territory of Russia. ERS SAR images given in our disposal in the framework of European Space Agency announcement of opportunity. Fusion of low-resolution AVHRR data with high resolution «Resurs» data is used for calibration and validation of ice classification, coastline changes detection. Images of ERS SAR serve for detailed studies of physical and biological processes on the lake surface. Fusion with AVHRR data gives the possibility to give large scale presentation on the processes and improve the description of surface features using IR-derived temperature.
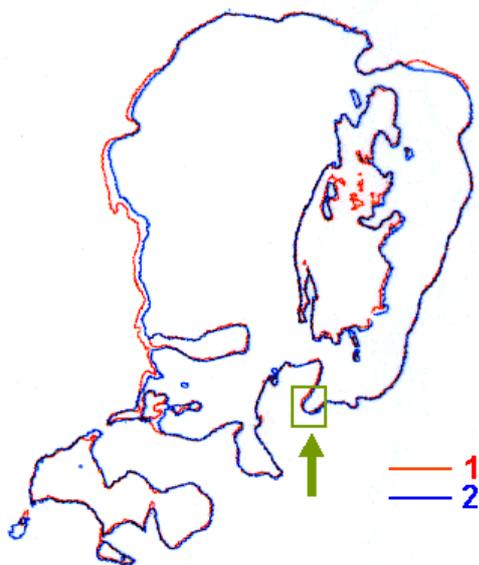

Figure 2. Changes in position of Aral Sea coastline derived using channel 2 of AVHRR. 1 is for May 1997, 2 is for May 1996.

Figure 4. MSU-E true color composite image of Aral Sea coastline position for the area pointed in Fig.2

2 COASTLINE CHANGES

For such water objects as Caspian Sea and Aral Sea changes in coastline position play am important role for surrounding human population, exploitation and ecology of the whole region. Climate-induced variation of Caspian Sea level have been noted in historic chronic. For the Aral Sea using of river water for irrigation effects in the dramatic increasing

of water level and catastrophic consequences for local population. Near infrared Channel 3 of AVHRR can be used effectively for coastline position detection on regular basis. Fig 2 presents changes in Aral Sea level during one year period, detailed structure of formed sea bottom position is studied using high-resolution multispectral Resurs data (Fig.3).

3 LAKE ICE STUDIES USING FUSION OF NOAA, RESURS AND ERS DATA

The freeze-up period of Ladoga, Baikal and Aral lasts several months. Interannual variability of the freeze-up and breakup periods is statistically associated with the temperature regime for several preceding months and is therefore frequently well correlated with global variability. We used the procedure of multivariate statistical analysis to obtain a classification of the types of Lake Baikal's snow-ice cover. Variations in the space-time distribution of the main types of underlying surface are representative of the effect of local and global factors during the winter period (Maslanik, 1987).

To identify the main possible states of the underlying surface on the Lake Baikal's surface during the winter period on the basis of a sequence of multispectral images we make use of a popular method of Empirical Orthogonal Functions (EOF). In the analysis, we used a seven-dimensional space of signatures involving, in addition to the normalized albedo for channels 1 and 2 and the brightness temperature for channels 3, 4 and 5, the brightness temperature difference for channels 4 and 5 *(p4-p5)*, and the normalized vegetation index NDVI calculated by the formula *NDVI=(p2-p1)/(p2+p1)* , where p2 and p1 are the normalized albedo for AVHRR channels 3 and 1, respectively. Upon calculating the eigennumbers and eigenvectors of the correlation matrix configured for 56 pictures in accordance with the concepts embodied in the EOF method, it was found that the first two eigenvectors describe 85% of total dispersion.

A next step involved calculating the frequency histogram of distribution of the first two main components for the entire sequence of pictures. Peaks of two-dimensional distribution were interpreted as different classes of the state of the underlying surface. Classes were singled out manually by delineating the histogram peaks using a specially developed program. This was followed by a mapping of the derived classes for each picture, and by a visual determination of the correspondence of each class and of the type of underlying surface depending on a particular month. In doing the analysis, we discarded classes corresponding to clouds and fog above the water which are a common occurrence on Baikal in January. Note that a classification using the entire set of images covering both the freeze-up and breakup periods can lead to the inclusion in a single group of some types of ice typical of these periods only. Conceivably as soon as a more representative data set has been accumulated, it would be appropriate to carry out a classification for the periods of freeze-up (January), stable ice cover (February-April) and breakup (April-June) (Semovski, 1998a).
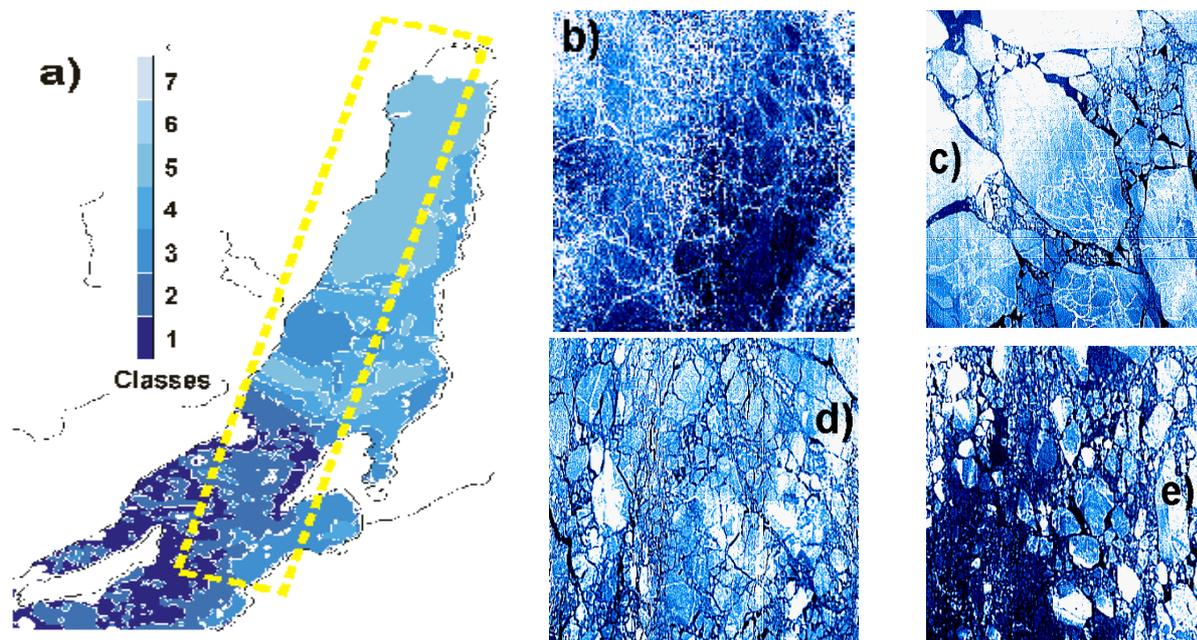

Figure 4. May 18, 1999, (a) the distribution of classes of underlying surface for a multispectral picture from AVHRR, and the correspondence of some of the classes and types of ice identified in the image in MSU-E channel 2: (b) class 2, (c) class 3, (d) class 4, (e) class 5.

Spatial and spectral resolution of pictures taken with the AVHRR instrument, however, gives no way of investigating the detailed structure of the ice edge and of the ice cover. A significant dependence of remote sensing in the visible range on atmospheric conditions pose also major problems for the study of a detailed picture of rapid changes in ice cover during freeze-up and breakup. To investigate a more detailed structure of ice cover, especially during breakup of the lake, as well as to verify the classification procedure that was performed for AVHRR images, we utilised high-resolution pictures taken with cameras MSU-E and MSU-SK (Resurs satellites, Russia), and images taken by the synthetic aperture radar (ERS-1 and ERS-2 satellites, EuropeanCommunity).

It is especially advantageous to use information from the Resurs satellites during ice cover disintegration. A detailed description of the ice structure during this period is of important significance for navigation. Fig. 4 shows for May 18, 1999 the distribution of classes of underlying surface for a multispectral picture from AVHRR, and the correspondence of some of the classes and types of ice identified in the image in Resurs MSU-E channel 2. Note that the types of ice taken from the MSU-E image are brought to maximum sharpness to illustrate them more emphatically; therefore, their brightness are not consistent. The size of each area is 14x14 km.

During 1997-1998, the mobile station of the European Space Agency (ESA), located in Ulan Bator, Mongolia, was receiving images taken by the synthetic aperture radar (SAR) from the ERS-1 and ERS-2 satellites. Under an agreement with the ESA, about 80 images of Lake Baikal for September-October and May-August 1998 were made available to us. The pictures for May 1998 furnish a unique opportunity to investigate in detail the ice cover degradation on North Baikal. There are well-known advantages of the microwave range such as the independence from atmospheric conditions, high spatial resolution (12.5 m for ERS), and high sensitivity to changes in underlying surface roughness. The possibility of utilising SAR images in investigating the ice cover mechanics was described in a variety of publications; for an analysis of the ice conditions of lakes see, e.g., (Jeffries et al., 1994). Fig. 5b,c present the degradation of ice cover on North Baikal for 24 hours (May 27-28, 1998). In all likelihood, a transformation of the ice cover occurs in the absence of a high wind at the expense of warming only, because only the formation and growth of cracks is observed, with the form of the ice field unchanging. Fig. 5a illustrates the distribution of classes of ice snow cover obtained on the basis of a multispectral AVHRR image taken on May 27, 1998. The region corresponding to the portion of the SAR image in Fig. 5b,c is marked off. There is a clear-cut position of the left-hand field, to which a separate class of underlying surface corresponds.
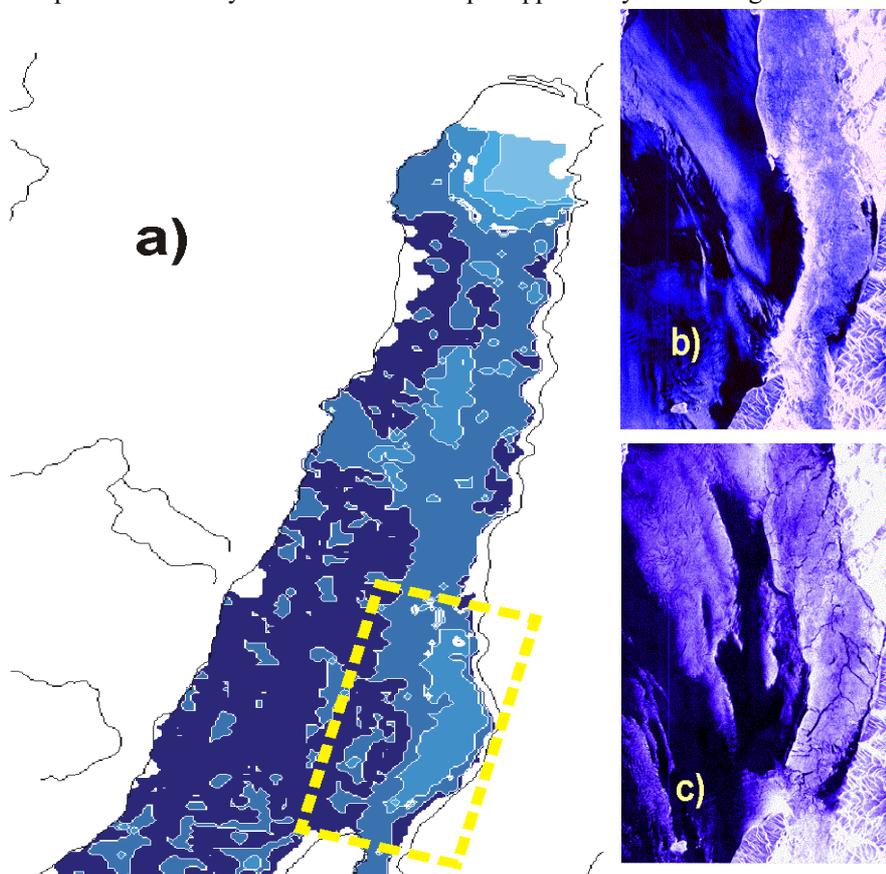
Figure 5.(a) Distribution of classes of ice snow cover obtained on the basis of a multispectral AVHRR image taken on May 27, 1998. The region corresponding to the portion of the SAR image in Fig. 5b,c is marked off. ERS SAR images presenting the degradation of ice cover on North Baikal for 24 hours from May 27 (b) to May 28 (c), 1998.

3 CYANOBACTERIA BLOOM AND FACTORS OF ITS FORMATION ON SAR AND AVHRR IMAGES

Although the AVHRR spectral resolution gives no way of obtaining a consistent estimate of the concentrations of chlorophyll and dissolved organic matter on the surface of water bodies, during spring bloom, as well as in the area of estuaries and river mouths it is possible to use these data to estimate total suspension and, on occasion, also the phytoplankton concentration (Stumpf R.P., 1987). The transport of dissolved elements is also affected dramatically by hydrological fronts in outfall areas, as well as by upwelling fronts and various vertical formations. Dynamics of thermal fields control development and transport of phytoplankton and fish larvae in coastal areas.

SAR images in their turn are two dimens-ional maps of the radar backscattering, here from the water surface. This backscattering is caused by small-scale surface waves, which have wavelength comparable to the radar wavelength (Bragg waves). These waves are often damped by the surface films produced by the (blooming) algae, so that the natural slicks apart from other water and atmospheric phenomena, are visible in SAR images as dark irregular patches and «strips». IIn low wind speed conditions, film material accumulates at the surface, and forms a distribution which is inherently patchy, probably as a result of a combination of local variations in biological productivity, structure in the atmospheric boundary layer and of vertical transport mechanisms in the upper ocean boundary layer. Even slow oceanic flows are able to distort these patchiness patterns in a way which indicates the regions of compression, expansion and shear associated with the flows. It is possible to use films deliberately added to the surface to provide a more controlled indication of shear. Mesoscale patterns may be observed in sunglint and also in SAR images (e.g. Espedal et al., 1996). The mechanisms by which these patterns are maintained on the surface are not yet clear, although the assumption that they are passive tracers of water motions appears to be a reasonable one.

For the September 1997and August 1998 ERS SAR images show slicks formed by films of biological origin on the North Baikal (Fig.6b). Probably, intensive bloom of nitrogen-fixing filamentous cyanobacteria (blue-green algae)*Anabaena lemmermanii* was detected (see Lake Baikal, 1998). *In situ* observations made in the same time in research cruise of r/v «Vereshchagin» show high concentration of this algae in surface layer. This species are capable to form patterns of high concentration (5-10 g/m^3) in the thin surface layer during low wind conditions. AVHRR-derived surface temperature demonstrate similar structures of circulation field, that determines transport of cyanobacteria from warm coastal area into pelagic waters (see Fig.6a).
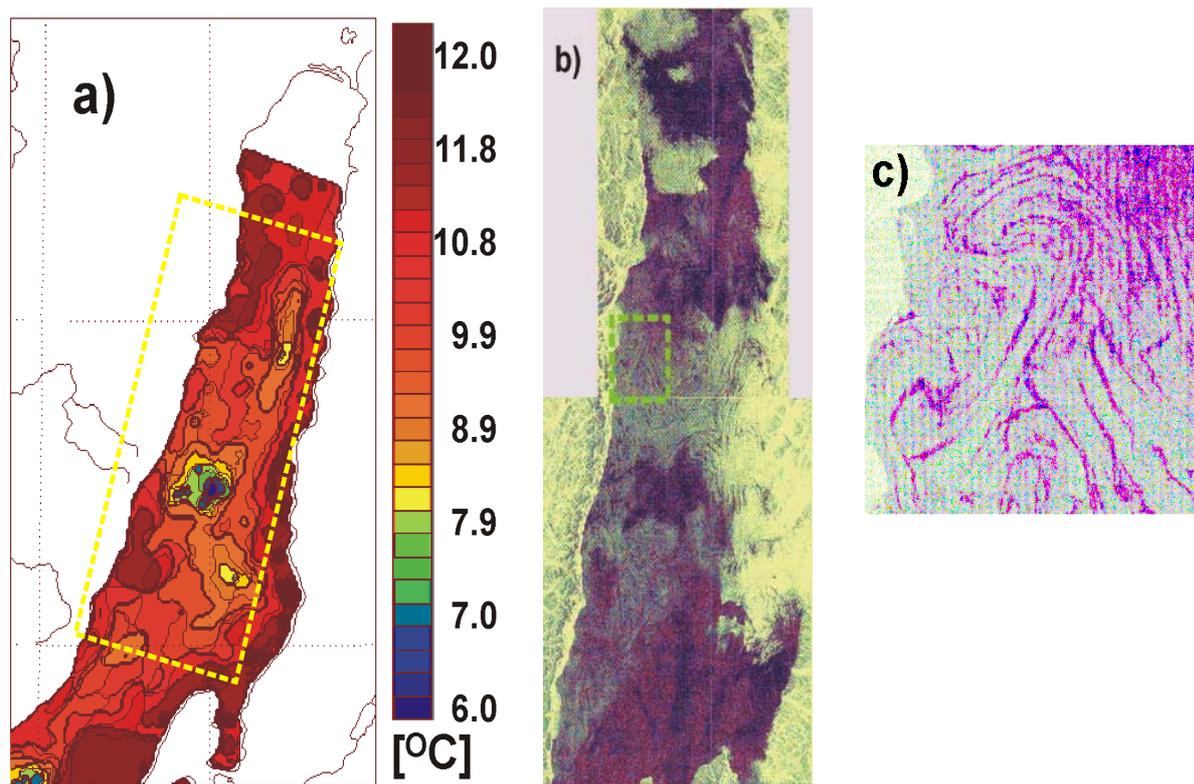

Figure 6. North Baikal September 27, 1997. (a) AVHRR-derived surface temperature and position of ERS SAR image (b), slicks tracing coastal current of hammer-head (dipole) structure (c).

Slicks, that are correspond to streamlines of surface currents, are traced by segmentation method (Fig.6c) and are used for calculation of advection field. Method of currents estimation is based on the analysis of sequential AVHRR-derived surface temperature maps (see, for instance, Semovski, 1998b).

During low wind conditions the structure of roughness field is formed by local winds — breese circulation. Simulation of North Baikal local atmosperic circualtion by Argutchintsev (1976) demonstrates presence of calm areas practically without wind in the center of the lake. Such area can be seen on SAR image (Fig.6b) and it coincides with cold region on the map of surface temperature. Correspondence of low roughness and low temperature regions for some situation in Ladoga lake was shown by Ivanov (1999). This feature in North Baikal is correlated as well with local hydrodynamics, because cold area is situated in the center of climatic cyclonic gire.

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