Remote sensing monitoring system of seasonal hydrological processes in the Caspian Sea river deltas

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Nowadays remote sensing data become one of the most significant sources of information on the environment. Remote Sensing Monitoring System was design in State oceanographic institute in 2002-2004 on the basis of medium resolution data, received by satellite platform TERRA-MODIS with equipment of Research and Development Center "ScanEx". The novelty of experiment lied in combined analysis in real time mode of daily remote sensing data and daily hydrometeorological data. Experiment covered seasonal hydrological processes in the Caspian river deltas. Experiment results showed possibility for creation of modern monitoring system for river deltas and coastal zones using data from standard observation network and remote sensing received from new satellite platforms.

Keywords: Remote sensing, river deltas, hydrological regime

1. INTRODUCTION

In the State Oceanographic Institute – SOI, a "Vernal Waters" experiment was carried out since 2002. It included monitoring of the seasonal natural processes in the Caspian Sea coastal zone and river deltas applying daily remote sensing data (RSD) of medium resolution, received by Terra-Modis satellite platform. Uniqueness of experiment concerned combined usage and analysis in real time mode of daily RSD and daily hydrometeorological data (HMD) collected over the standard observation network. The following items were monitored during the experiment (Fig.1):

- Process of spring flood wave propagation in the Lower Volga;
- Hydrological regime of the Volga delta and its shallow offshore zone during flood period;
- Catastrophic summer flush in the Terek delta;

2. EXPERIMENT "VERNAL WATERS"

On the first stage, the purposes of experiment were formulated:

- To assess potentialities of daily RSD from Terra-Modis satellite platform for usage in monitoring of seasonal natural processes in real time mode;
- To estimate spatial and temporal scales of natural processes in the river deltas and offshore zones for which usage of Terra-Modis operative information is possible;
- To develop the basis of information-technological infrastructure, necessary for remote sensing monitoring;
- To investigate process of spring flood wave propagation in the Lower Volga and inundation of the Volga delta;
- To conduct monitoring of the catastrophic summer flush in the Terek delta.

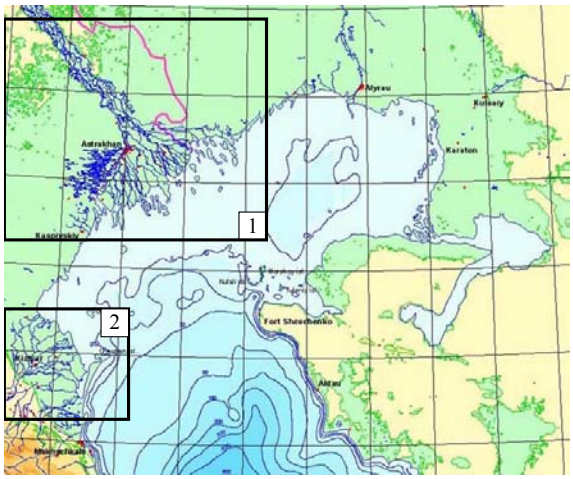

Figure 1. **Map of the Caspian Sea. The monitored regions.** 1 - Lower Volga region, 2 – Terek delta region.

Software-technological maintenance of experiment was based on the equipment, software and technological powers of the SOI Information Centre with use of the receiving equipment of Recearch and Development Center "ScanEx". The RSD with final resolution of 250 m/pixel were transmitted to the SOI via communication channels.

All used geoimages (satellite images, maps, schemes) were conformed to the unified geodetic basis (UTM projection, parameters of WGS-84 ellipsoid). It has ensured full compatibility of these geoimages and has increased accuracy of quantitative estimations.

The "Vernal Waters" experiment was conducted in a close contact with Regional Centers for Hydrometeorology and Environmental Monitoring (CHEM) of Roshydromet, which operatively provided the SOI with the daily data (mean diurnal) by the standard observation network in the Caspian river deltas and offshore zone. The scheme of communications is shown in Fig.2.

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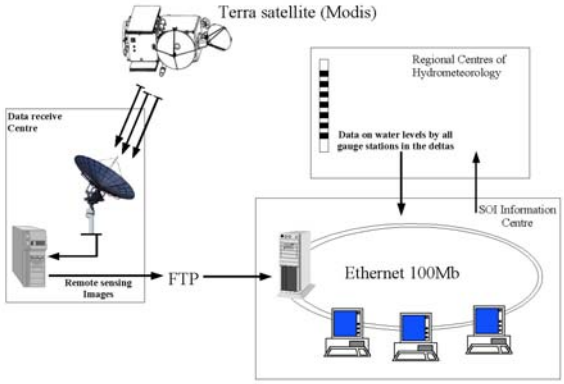

Figure 2. Scheme of communications during the "Vernal Waters" experiment.

3. SPRING FLOOD IN THE LOWER VOLGA REGION

The Lower Volga region (Fig.3) covers the Volga-Akhtuba flood-plain (1), Volga Delta (2) and the northern part of the Caspian Sea – Volga Shallow Offshore Zone (3). The Lower Volga water flow is regulated by the reservoir of the Hydroelectric Power Station, situated at the top of the Volga-Akhtuba flood-plain.

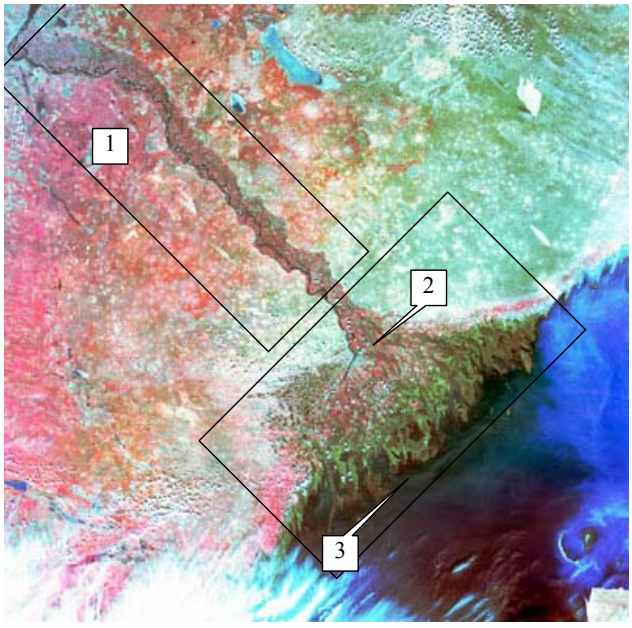

Figure 3. **Experimental Volga Region, covered with the RSD.**

The spring flood at the Lower Volga in 2002 was close to climatic mean in terms of amplitude and duration. It began in the top of the Volga-Akhtuba flood-plain on 16.04. Onset of the level rise in the Volga delta top was recorded on 23.04. The SOI Information Centre began to receive daily RSD on the Lower Volga from the TERRA-MODIS satellite platform in an operative mode since 17.04. The whole flood period in the Volga delta lasted from 23.04 through 21.07. The analysis of the coverage of flood period with the RSD implies that 37% of days yielded satellite images useful for the scientific work (without clouds).

Analysis of daily RSD and observational data of hydrological network during the flood has allowed to compare character of propagation of a flood wave in the Volga-Akhtuba flood-plain and in the Volga delta and to reveal the basic distinctions.

Rise of a water level in the upper part of the Volga-Akhtuba flood-plain began from the second decade of April, and the total inundation of this area was recorded by RSD on 28.04-02.05. In the first decade of May the southern border of the inundated areas moved downwards across the Volga-Akhtuba flood-plain, and 10.05 whole territory of the flood-plain was covered with water. Generally, the process of inundation steadily propagated from the Volga-Akhtuba flood-plain top downward to the Volga delta. The maximal inundation was recorded on 18-20.05. On 22-24.05, in the upper part of the flood-plain the gradual drainage of the inundated areas began. It was accompanied by fast vegetation in these areas. Process of the Volga-Akhtuba flood-plain drainage was distributed from the top downward similarly to the process of its inundation. Analysis of the RSD has shown, that in the Lower Volga region, the beginning of the active vegetation indirectly pointed to the stabilization of the water levels or to the beginning of a water runoff from inundated territories to the channel network.

The mechanism of inundation of the Volga delta substantially differs from the mechanism of inundation of the Volga-Akhtuba flood-plain. Analysis of the RSD revealed two phases during the flood rise period, particularly 22.04-10.05 and 11.05-20-22.05.

According to the medium resolution RSD, during the first phase of flood rise period by 10.05, the contours of the areas, which would be inundated during the flood were precisely designated across the whole area of the upper delta zone. Meanwhile in the lower delta zone an active inundation occurred, and by 10.05 this zone was completely flooded already.

During the second phase of the flood rise period, the border of active inundation gradually moved from the lower delta zone upwards to the Volga delta top, in contrast to movement this border from the top downward in the Volga-Akhtuba flood-plain. The area of inundation, designated during the first phase of flood rise period, practically did not extend, but depth inside these borders was gradually increasing.

Joint analysis of the RSD and hydrometeorological data revealed the timing and boundaries of the Volga delta inundation during the peak of the flood on 18–22.05 (Fig. 4, Table 1). Maximal areas of inundation were recorded by the RSD until mid-June.

Analysis of the RSD yielded that during the flood fall period from 25.05 the area of inundation began to decrease firstly in the upper delta zone. This process was propagated from the top downward, contrary to process of inundation. Identified by the RSD borders of inundated area have begun to gradually reduce only by mid-June, but active vegetation has essentially complicated this analysis, in particular, in the lower delta zone.

The spatial scales of the RSD from TERRA-MODIS satellite platform within the framework of the "Vernal Waters" experiment, made it possible for the first time to carry out the

combined monitoring of the Volga delta and shallow offshore zone.

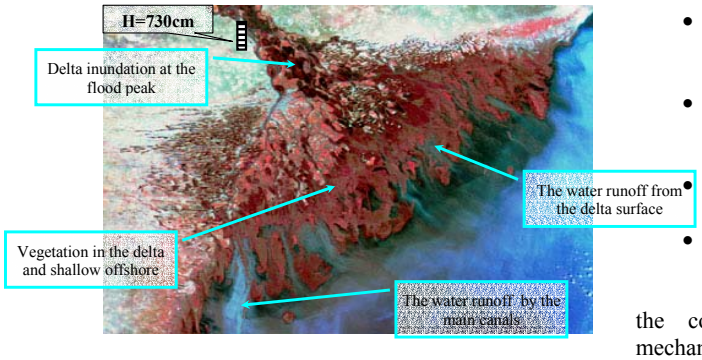

Figure 4. Inundation during the flood peak in 2002 according to RSD

Periods	Water Surface Area (km^2)
Low water period	910
The flood peak – 22.05.	6695

Table 1. The area of the water surface in the Volga delta in 2002 by the RSD.

Analysis of the RSD has shown that during flood rise period in 2002 the Volga delta accumulated water in the flood-plain, whereas the runoff to the shallow offshore zone occurred only in the main canals likely to the low water period. Turbidity river water of main canals stand out against a background of transparent filtered water of shallow offshore zone (Fig. 4).

The maximal volume of water was accumulated in the Volga delta by the flood peak on 18-22.05. Occurrence of wide turbidity water streams from the delta surface between main canal tracks to the shallow offshore zone was recorded in the RSD on 22-25.05, the maximal surface runoff was recorded on 04-05.06. Then the water level in the shallow offshore zone stabilized at -26,8 ÷ -26,7 m BS till mid-July. The termination of the water level rise in the shallow offshore zone at the first decade of June is indirectly supported by the fast vegetation in this area since the second decade of June, recorded in RSD of medium resolution. By the end of the first decade of July, significant decrease of surface runoff from the Volga delta, particularly in its eastern part was recorded by the RSD.

Combined analysis of the RSD and hydrometeorological observational data allowed to record termination of steady fall of water levels in the delta channel network and in the flood-plains at the end of the second decade of July.

The further complex study is necessary to obtain a quantitative estimation of variations of the inundated areas in the Volga delta during the flood period. Such studies should include the combined analysis of the RSD of medium resolution time series, the separate images of high resolution, the data from the standard network of the hydrometeorological observations, as well as special site surveys of the migration of the inundated area boundaries and of the level regime in the flood-plains in various zones of delta.

Generally, combined analysis of the RSD and data from the standard network of the hydrometeorological observations in the Volga delta allowed:

- to carry out monitoring of a flood wave propagation in the Volga-Akhtuba flood-plain and in the Volga delta;
- to determine the timing of onset of the basic phases of a flood period on various zones in the Volga delta and to link these phases to daily water levels;
- to contour the maximum inundation areas for various zones of the Volga delta;
- to evaluate a role of the Volga delta and its shallow offshore zone in accumulation and the subsequent passing of flood waters to the Caspian Sea;

the conducted experiment has allowed to determine mechanism of the Volga delta inundation during the flood period.

4. CATASTROPHIC SUMMER FLUSH IN THE TEREK DELTA

The catastrophic flush in the Terek delta occurred in June – July, 2002. By 24-25.06, the maximal water discharges in the Terek delta top reached 1530m^3/s with the mean annual water discharge being 270 m^3/s. For more than 30 days, the daily average water discharge exceeded 1000 m^3/s, the sediment load during this flush period estimated as 53.4 mil. tons. The flush of such volume and duration is absolutely unique for the Terek delta. During the flush, tens of kilometers of protective levees and dams in the Terek delta were destroyed, thousands of hectares of agricultural areas were inundated, both environment and economy of the region suffered from serious loss.

Remote sensing monitoring of the catastrophic flush was performed on the basis of the complex analysis of the daily RSD, information on the conditions of water objects in the Terek delta, scales of the inundation, newly formed cut-offs in the protective levees and dams along the delta channels. In July, 2002, on the basis of the RSD of medium resolution, it was performed the express-analysis of the flush progress in the Terek delta, resulting from the main cut-off through protective dam at the 24-th km mark downstream from the delta top. The boundaries of the maximal inundation were marked for the different regions of the Terek delta. The areas of inundation and their fluctuations during the flush were estimated (Table 2, Fig. 5). Inundated area was measured each day under cloudless conditions. On the basis of the analysis of the RSD, the boundaries of the maximal inundation in the Terek delta were marked on 22.07, in comparison with low water conditions marked on 11.04 (Fig. 5).

Periods	Water Surface Area (km^2)
Low water period– 11.04.	437
Flush period – 22.07.	801

Table 2. The area of the water surface in the Terek delta in 2002 by the RSD.

For specification of the results from the medium resolution RSD, a series of the high resolution images (15-30 m/pixel, satellite LANDSAT-7) was collected. That series of images covered in detail conditions in the Terek delta prior to the beginning of the flush, during the flush peak, before and after the main cut-off through the protective dam, and also under conditions of the autumn low water during site survey. The qualitative analysis has allowed to confirm the general conclusions, made on the basis of the medium resolution RSD analysis. On the basis of the analysis of the high resolution images the analysis of the protective levees and dams along the Terek channel was carried out and the basic directions of prime hydraulic engineering works in the Terek delta were defined.

The results obtained on the basis of remote sensing monitoring were checked up and supplemented with site survey data of the Terek delta which was carried out in October, 2002 by the SOI expedition team together with Regional Dagestan CHEM. The site survey was based on a cartographical basis of topographical maps of 1:100000 scale and the high resolution satellite images (15 m/pixel).

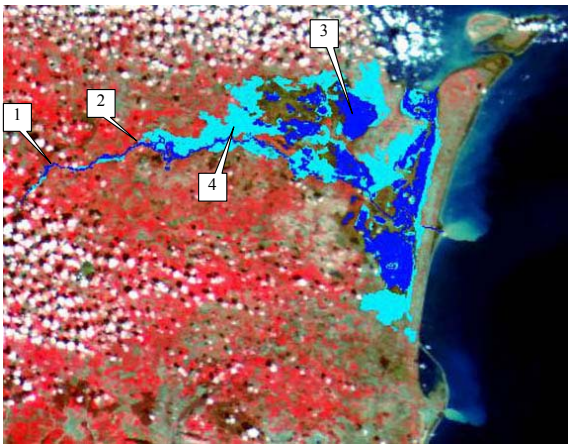

Figure. 5. Inundation of the Terek delta during catastrophic flush on the basis of RSD.
1 - the top of the Terek delta; 2 – the main cut-off through protective dam; 3 – water surface before the flush, 4 - maximal water surface during the flush.

The works executed within the framework of complex monitoring in 2002, have allowed:

- To estimate scales of inundation in the Terek delta during the catastrophic flush peak and fluctuations of the inundated areas;
- To obtain morphometric characteristics along the Terek channel during the low water period;
- To evaluate conditions of protective levees and dams along the Terek channel after the catastrophic flush.
- The conducted experiment has allowed to determine optimum directions for water drainage from the flooded regions and to mitigate possible economic damage at the Terek delta.

5. CONCLUSIONS

Nowadays, the data of remote sensing of the Earth from space get the increasing value. The results obtained within the framework of experiment on remote sensing monitoring of seasonal processes in river delta areas of the Caspian Sea coastal zone, have once again confirmed necessity of work with the information received from satellite platforms of new generation.

The applied in the experiment scheme of reception and analysis of RSD by the satellite platform TERRA-MODIS provides achievement of the purposes to the full extend. RSD, received from this platform, allow to conduct monitoring not only of seasonal processes, but also to operatively trace short term processes, covering the part of a delta.

The carried out experiment is especially important methodically as its results have shown necessity and urgency of creation of modern system of monitoring of delta areas of the rivers and a coastal zone of the seas with use of daily hydrometeorological observational network data and the daily RSD, received from the modern satellite platforms. The experience acquired during the experiment, enables to design the main principles of construction and structure of such monitoring systems.

Experiment has shown wide opportunities of the used approach from the point of view of reception of new scientific results in researches of natural processes in the river deltas and a coastal zone of the seas.

Nowadays available in SOI scientific, technological and software capabilities to the full extend provide the solution of the tasks of monitoring of natural processes with application of RSD from satellite platform TERRA-MODIS under condition of regularly receiving of the RSD.

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