International Forest Fire News (IFFN) No. 40 (July-December 2010), p. xx-xx ISSN 1029-0864 (web)

Importance of Aerospace Remote Sensing Approach to the Monitoring of Nature Fire in Russia

For the citizens of our country the summer of 2010 was marked by extreme heat, drought and disasters brought by nature fires (forest, steppe and peat fires) mostly in Central Russia (Fig. 1). During the summer months 62 persons died in the fires in the central regions of Russia. 2500 homes were damaged by fires in about 150 settlements. Over 3500 people lost their homes. During a few days many cities, including Russia's capital Moscow, had been covered by smoke. The fires disabled airports, roads, led to electricity black-outs, threatened strategic objects, such as the Russian Federal Nuclear Center in Sarov. The Forest Fund and agriculture were damaged seriously by the fires, and large amounts of gas emissions and aerosols emitted by the wildfires affected people's health and polluted the atmosphere.

After the fire season of 2010 we are able to make some conclusions.

According to the official data of the Federal Forest Agency (ROSLESKHOZ) between 10,000 and 40,000 wildfires are recorded on the territory of Russia, covering an area between 0.5 and up to 2.5 million ha of protected forests. Considering the fact that natural fires occur also on unprotected and occasionally protected territories (mainly in Siberia and on the Far East), the total surface covered by fires on the whole territory of the Russian Federation is ranging from 2 to 6 million ha annually.

Figure 1. Wildfires in summer 2010 burned numerous houses and entire villages in the European part of Russia.

The Ministry of Emergency of Russia (EMERCOM) also provides statistical data of the. EMERCOM data differs from data of ROSLESKHOZ. Example: According to data of ROSLESKHOZ the territory covered by fire in 2009 was 2.4 million ha and the number of fires was 22,540. According to the data of EMERCOM the surface covered by fire in 2009 was 1.14 million ha, and the number of fires was 21,900.

The discrepancy between the statistical data can be explained by different general approaches, and methods of data collection and assessments. It seems to be necessary, however, to provide objective information on the number of fires and the surface affected by fires using state-of-the-art technical means. Our analysis is based on space monitoring of fire by *Aerocosmos* (www.aerocosmos.info). An example of fire detection from space using *Aerocosmos* system is shown in the Figure 2.

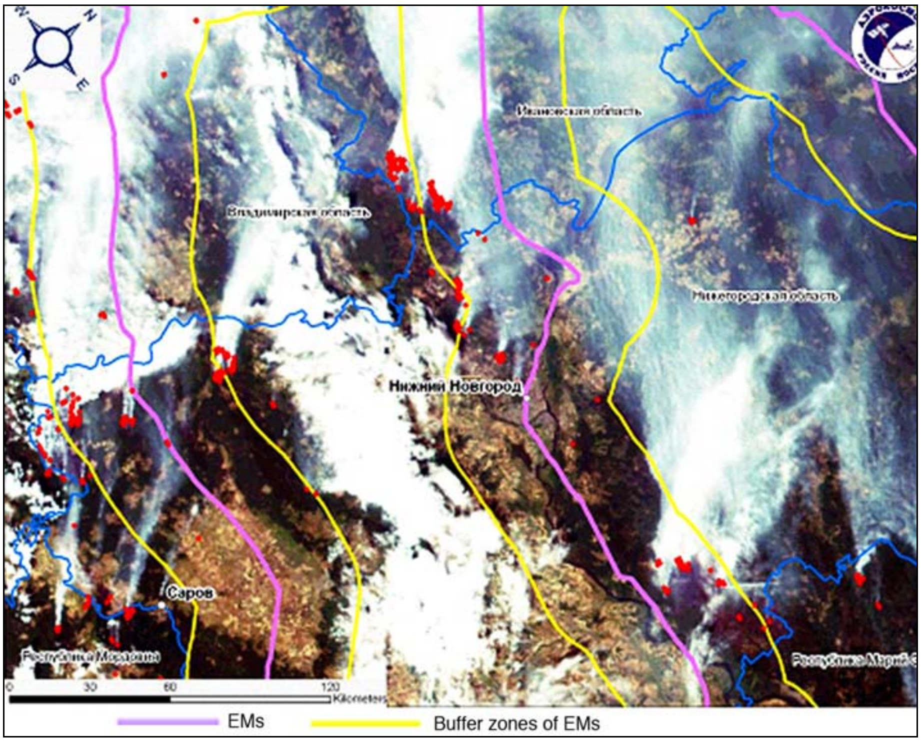


Figure 2. Detection of active fires in the center of the European part of Russia, 29 July 2010 (12h 09min) by the *Aerocosmos* space monitoring system.

The extreme weather conditions in the European part of Russia in 2010 reminded the years 1972 and 2002. Figure 3 provides a map generated the A*erocosmos* team based on AIRS data (AQUA satellite - http://mirador.gsfc.nasa.gov). The spatial distribution of the field of change of temperature in July 2010 is compared with the average temperatures for this month during the period 2002-2009. The red color on the graph shows the increase and the blue color shows the decrease of the it is shown that a thermal anomaly exceeding the average temperature for July in 2002-2009 by 7-10°C occurred in the European part of Russia in July 2010. The same thermal anomaly occurred in August 2010.

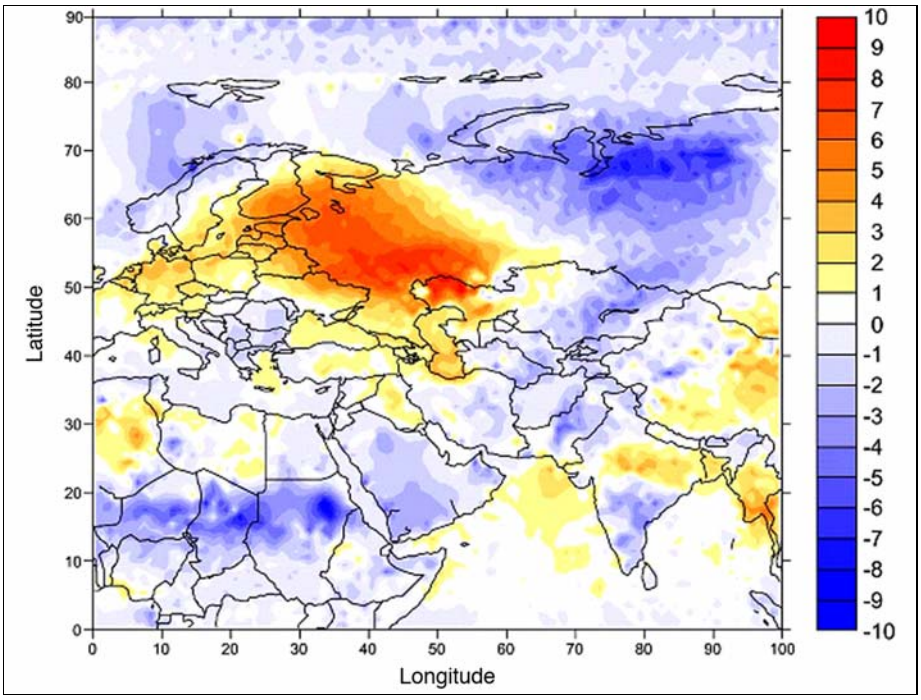


Figure 3. The thermal anomaly in July 2010 in the European part of Russia, based on AIRS data from satellite AQUA (http://mirador.gsfc.nasa.gov).

According to the space monitoring data of *Aerocosmos* (www.aerocosmos.info), the total number of fires in the period from March to October 2010 on the whole territory of Russia was about 33,000, and in the European part of Russia ca. 13,600. For example, in the year of 2009 these numbers were ~25,000 and ~8,500 respectively. A histogram in Figure 4 shows the monthly distribution of the relative number of fires on the European part of Russia for the period from March to October 2010, based on the space data by *Aerocosmos*. The analysis of this histogram shows that the maximum number of fires in the European part of Russia was recorded in the hottest months – July and August 2010.

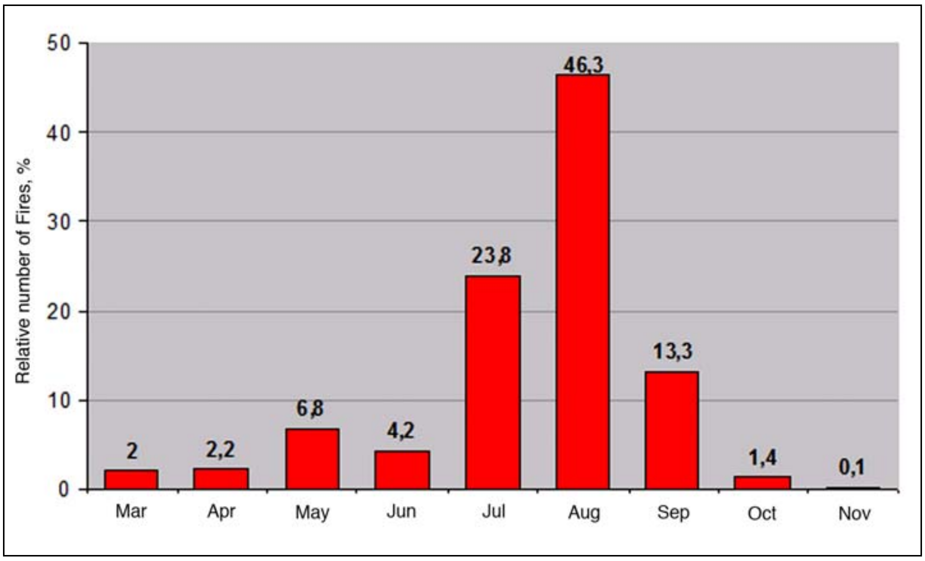


Figure 4. Relative number of fires per months (in percents) in the period from March to November 2010 in the European part of RF (data by *Aerocosmos*)

Figure 5 shows the surfaces, covered by fire during the summer months of 2010 (a) in the European part of Russia and (b) in the region of Moscow, the data is obtained by "Aerocosmos" from MODIS sensors on the satellites TERRA and AQUA, the validation by the Landsat Thematic Mapper (resolution 30m) and by Rapid Eye (resolution: 6.5m). The general surface covered by fire for the European part of Russia from March to October 2010 was 2.2 million ha and for the whole territory of Russia ~10.9 million ha. That data coincides with the data of the Global Fire Monitoring Center (GFMC), Germany, and with the data of the V.N. Sukachev Institute of Forest, Russian Academy of Sciences, Siberian Branch (~10.8 million ha) (http://www.fire.uni-freiburg.de/current/globalfire.htm), and with the data of SCANEX (~10 million ha) (www.scanex.ru).

The highest number of active fire registered from space occurred on 29 July 2010 (see for example Fig. 2 and Fig. 9). The largest surfaces, covered by fire in the European part of Russia were registered on 1 and 2 August 2010, and in the region of Moscow – on 2 August 2010 (Fig. 5).

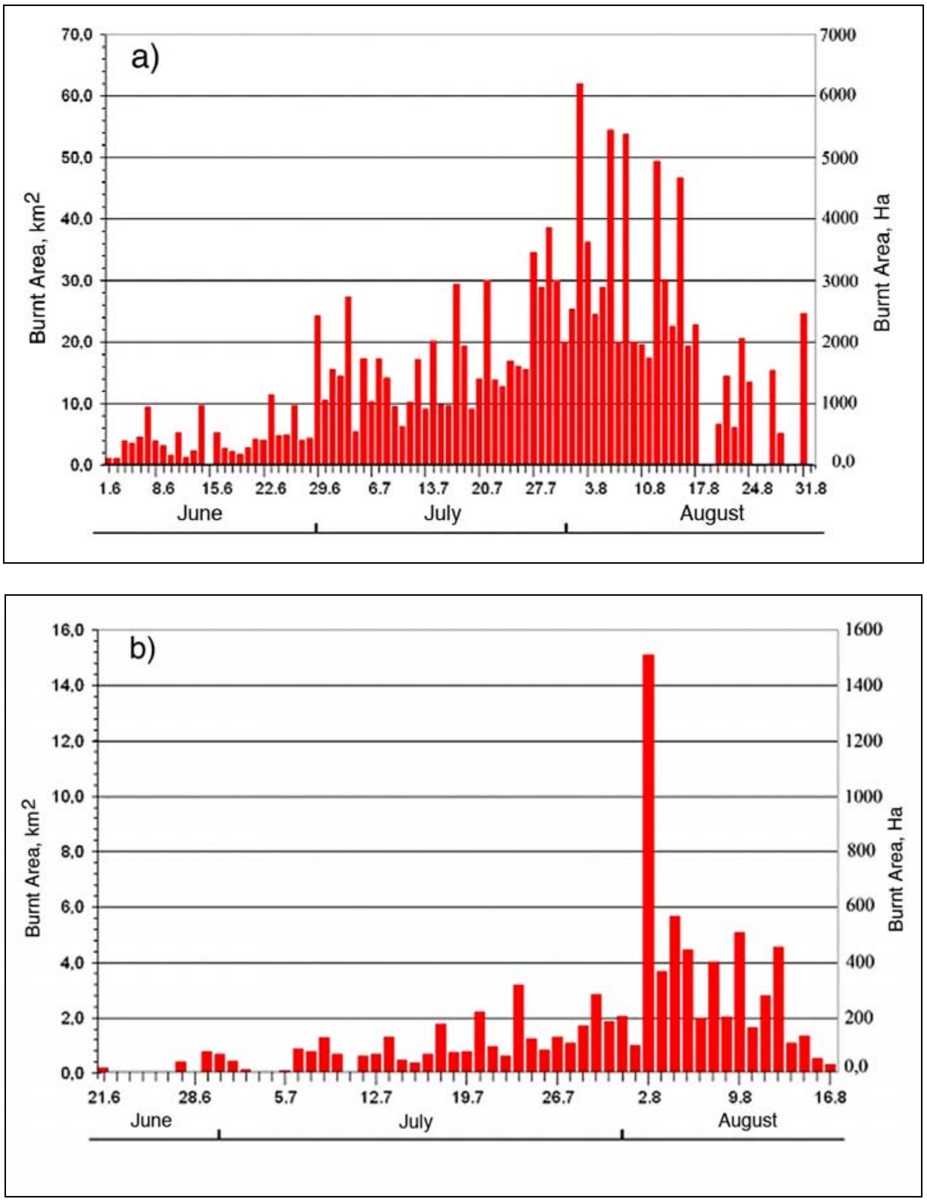


Figure 5. Surfaces, covered by fire in the period from June to August 2010, (a) on the territory of the European part of the Russian Federation and (b) on the territory of the region of Moscow (data by *Aerocosmos)*.

The analysis of the data shows that in 2010 the general number of fires and the general surface covered by fires in the European part of Russia were much higher than in 2009. The share of “large” fires (with a surface burned >500 ha) has increased in 2010 in this region of the country compared to 2009, and it increased especially (more than ten times) in the regions of Ryazan and Vladimir. A higher number of the most dangerous large fires were also a peculiarity of the summer 2010.

Causes of nature fires

The main cause of nature fires is human activity (~79%), and people are the main originators (~70%). About 9.1% of wildfires are caused by agricultural and forestry activities, expeditions and transport systems. About 13% of the fires are caused by natural factors (lightning). The causes of the remaining part of fires are unknown.

The main factors that determine the efficiency in fighting wildfires are the elapse of time of detection and rapid suppression response in the early stage of the fire. This was a common practice in our country. For some organizational reasons it was not done in 2010 (see contribution by Goldammer, this volume).

The fire danger of territories is defined by the moisture content of vegetation and soil. When the moisture of dead vegetation, mosses, lichens and other phytomass is lower than 25% the conditions for the occurrence and spread of surface fires are favorable. At the same time, a serious danger of transfer of surface fires into the high (crown) fires is arising if the moisture contents of tree crowns is lower than 80%. Crown fires are most dangerous because of the speed of fire spread (3 to 100 m/min and more) and also because of danger of destruction of the forest flora and fauna.

For this reason the frequency of fire occurrence is increasing in hot and dry periods. This is confirmed by both historical facts and contemporary data. As it can be seen from preserved historic annals, extreme wildfires in the past occurred mainly during droughts. For example, the annals of Suzdal inform us that the years 1223 and 1298 were hot and dry in Russia and many strong forest and peat fires occurred. The annals of Nikon and Novgorod mention about droughts and forest fires between the 14^{th} and 17^{th} centuries, which were accompanied by hunger among the population, and death of many wild animals. The information about droughts and extreme forest fires in 18^{th} and 19^{th} centuries can be found in many historical documents, in the preserved correspondence of celebrities, and in contemporary magazines and journals. The number of droughts and forest fires that are mentioned in Russian annals is not exceeding 50 cases. In the last century and at the beginning of this current century the statistics of nature fires have become regular, and the progress of scientific development has contributed to this. The relation between abnormal heat and droughts and big number of nature fires is confirmed by the events of 1972, 2002 and 2010 that are known among the contemporary generation of people.

Features of the aerospace fire monitoring system developed by *Aerocosmos*

The satellite systems are used with success to control and prevent natural fires. The detection of fire seats is usually done using IR-radiometers that are part of on-board complexes of a range of satellite systems. The algorithms of detection are based on the registration of the radiating temperature in the spectral range 3.5-3.7 µm and differences of radiating temperatures in this channel and in the spectral channel ~11.0 µm.

Several countries of the European Union and North America are using satellite data for fire monitoring. For the Russian Federation, with its huge area of ~17.1 million square kilometers with extended territories that are difficult to access, the use of space information for early detection and estimation of consequences of nature fires is important. Fire information systems based on satellite remote sensing are provided by ROSLESKHOZ, with participation of *Avialesookhrana* (the Aerial Forest Protection Organization), the Space Research Institute (IKI), the Scientific Research Center *Planeta* and other organizations. Satellite data is also used by EMERCOM for fire control. The Engineering and technology center SCANEX is carrying out space monitoring of fires. An advanced, real-time system of space monitoring of nature fires is provided *Aerocosmos* Scientific Center for Aerospace Monitoring (www.aerocosmos.info). The *Aerocosmos* system architecture provides information on early detection, monitoring and prognosis of the development of nature fires, and assessment of consequences of nature fires, as well as creation and transmission of information to clients in emergency situations (Fig. 6 and Fig. 7). The territories covered by space information, which is received by ground stations of this system, are illustrated in Figure 8.

Compared to the existing means of remote detection of nature fires, the System of Emergency Space Monitoring (SESM) of *Aerocosmos* has a range of special features:

- Fast (real-time 7 near-real time) monitoring of the whole territory of Russian Federation and bordering countries
- High frequency of survey of the same region – 25 times a day

- High speed of data processing and transmission of informational products to the customers (10 minutes after receiving initial data)
- Fully automated work of the system in the mode of rapid fire detection
- High precision and reliability / confidence of obtained data
- Combination of monitoring and detailed space information in detection and in estimation of consequences of fires
- Prognosis of fire development
- Formation of a wide range of informational products in GIS format
- Swift transmission of information to the authorities responsible for the safety pf complex technical systems (energy units, electricity mains, oil and gas pipelines, strategically important units, etc.)
- Decision support in fire management

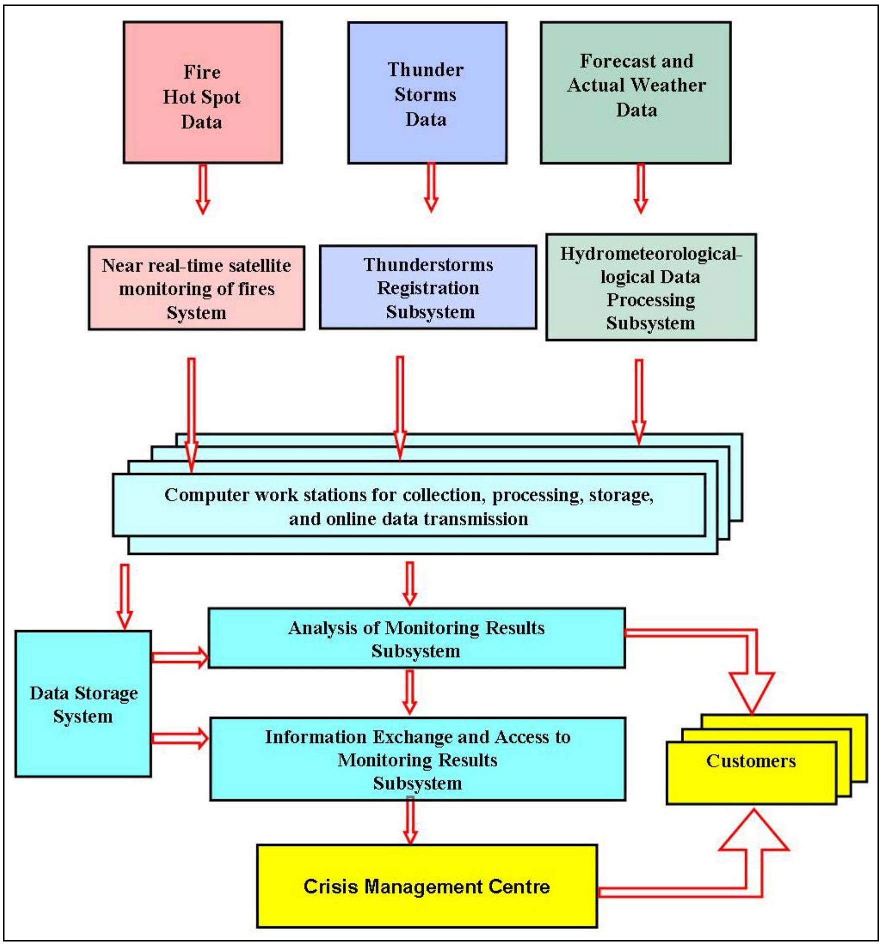


Figure 6. Structure of monitoring of nature fires

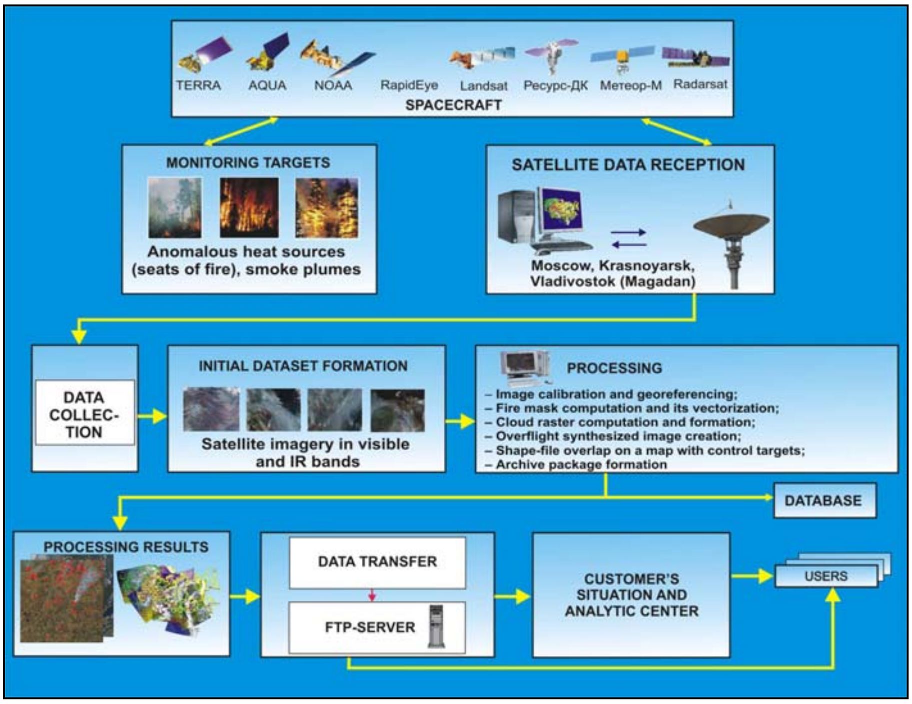


Figure 7. Data and information flow in the space monitoring system of nature fires by SE *Aerocosmos*.

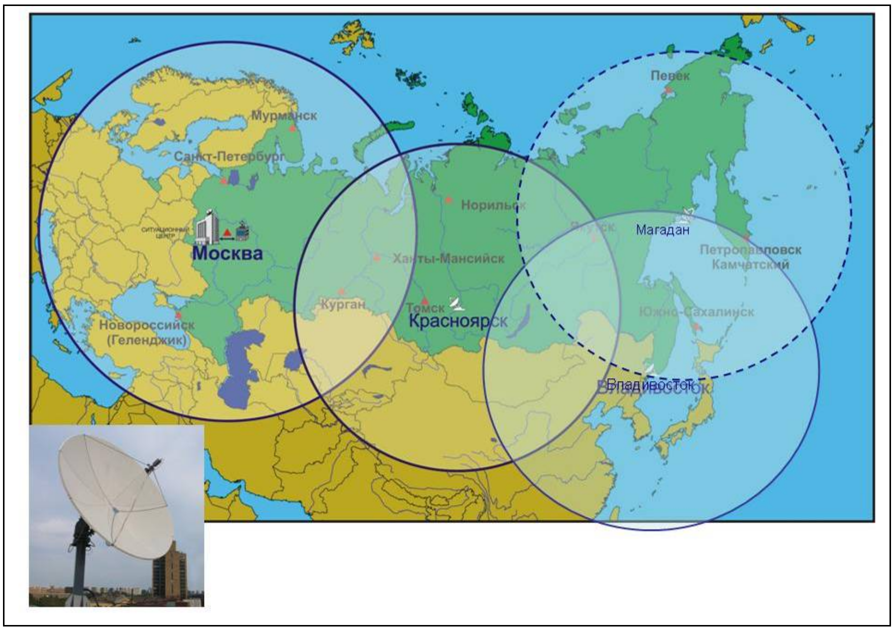


Figure 8. The zones of continuous reception of space information by the ground stations of *Aerocosmos.*

The SESM of *Aerocosmos* consists of the following infrastructure:

- A headquarters (in Moscow) and two regional centers (in Siberia and in the Far East) for receiving space information from satellites are equipped with infrared and multispectral optical remote sensing tools.
- Specific software for automated collection, processing and storage of data, as well as for forming of informational packages and data transmission.
- Geo-informational maintenance.

- Communication means that guarantee fast data transmission from regional reception centers to headquarters, as well as transmission of monitoring results to the situation-analytical centers of the customers and to local users.

The system complies with the fundamental principles of open systems: it is functionally extendable, updateable; the information sources can be integrated. It is built on the basis of the principle of extendable territories to be covered, using identical hard- and software in the three ground centers for providing monitoring data for the whole territory of the country.

On each ground station the raw space data is received, followed by radiometric correction, calibration, geo-referencing. After preliminary processing, data is passed on to the operative data server. Infra-red space images are processed by SESM using algorithms and software developed by *Aerocosmos*. Thermal anomalies caused by active fires are allocated, and fire masks are vectorized. Attributive tables of shape-files of fires are based on fire seats (locations of active fires). False thermal anomalies (e.g., thermal sources not representing nature fires) are filtered. The generation of synthetic images allows the mapping of cloud cover and smoke from nature fires. SESM forms mosaics of space data, obtained from all three ground reception centers that are reflected with help of *Google Earth* (Fig. 9).

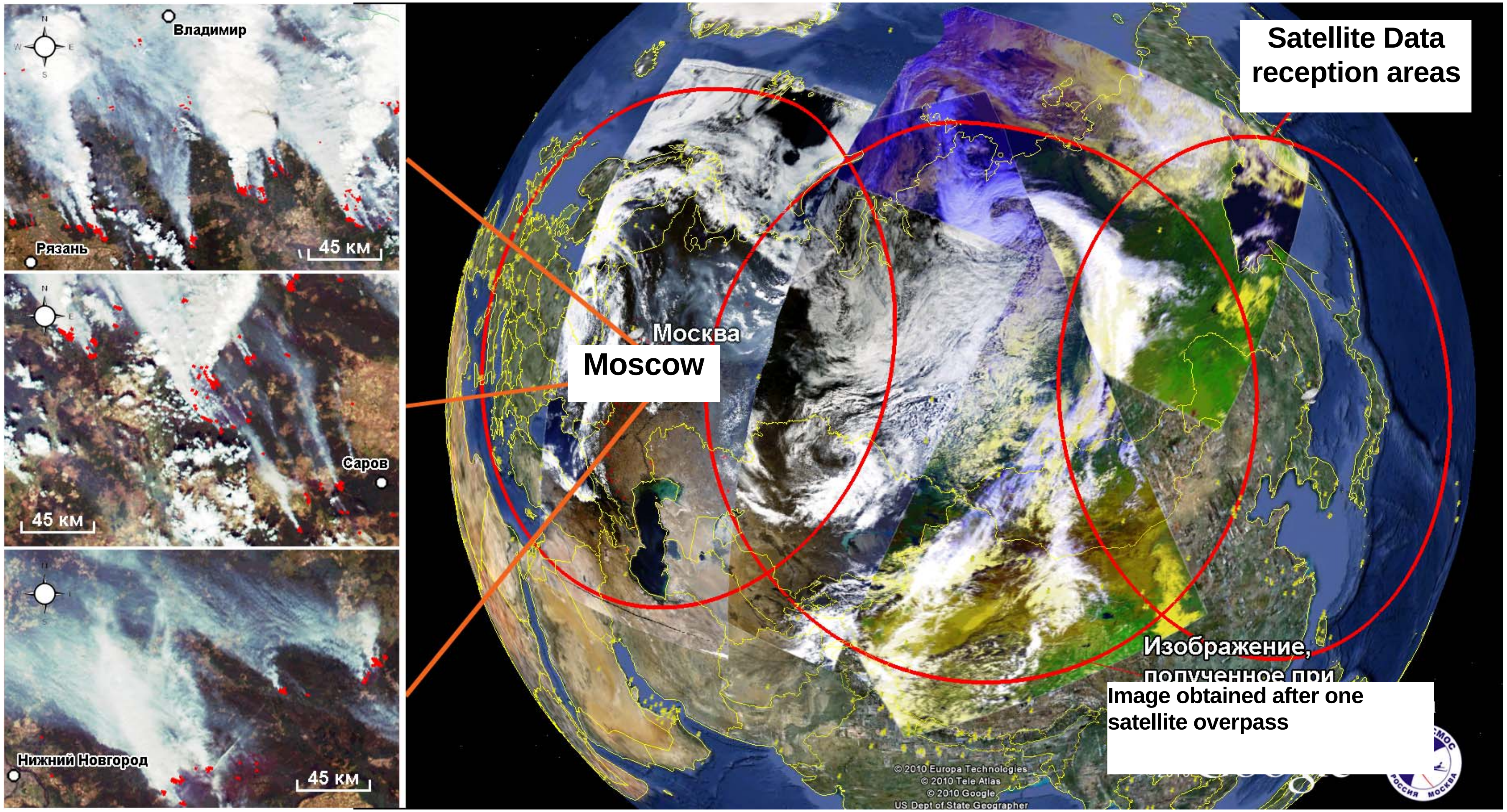
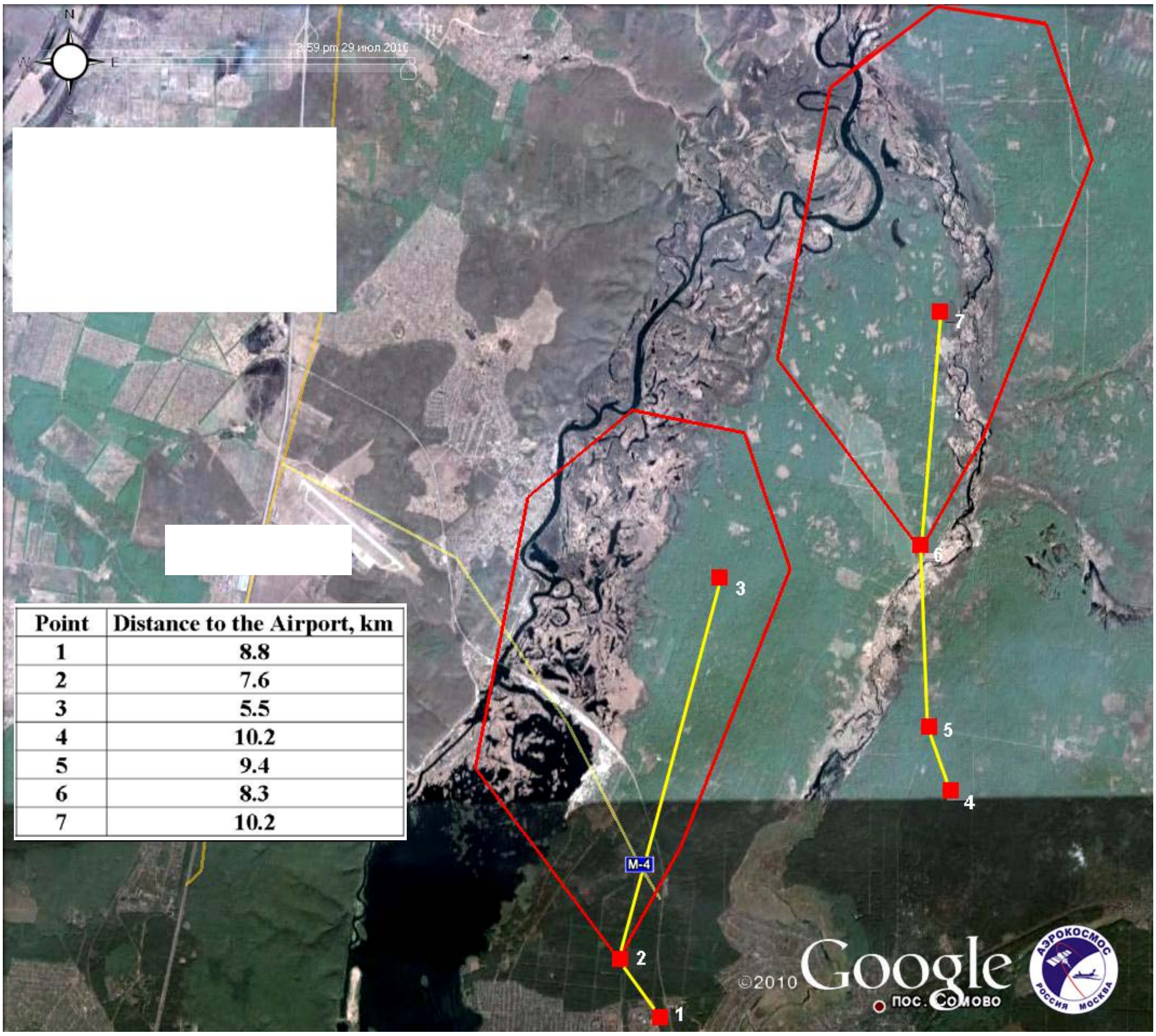


Figure 9. Composite of space images of 29 July 2010 showing active fires and smoke plumes in the Central Federal District of Russia

SESM tasks include:

- Data of detected thermal anomalies (coordinates, probability of correct detection, intensity, estimated burned area, etc.)
- Synthesized images of earth surface in the format of graphic files JPG with file binding (file of binding JGW for JPG and in format ESRI world file JGW) in Albers equal-area conic projection;
- Cloud cover information (overcast mask)
- Weather parameters
- Prognosis information about the direction of active fires spread depending on meteorological conditions (Fig. 10)
- Maps with overlapped shape files of active fire locations
- Files for display of monitoring results in a geo-browser (KML format)
- Recommendations for decision making.



Point	Distance to the Airport, km
1	8.8
2	7.6
3	5.5
4	10.2
5	9.4
6	8.3
7	10.2

Figure 10. Prediction of fire spread determined by weather conditions and with calculated distances to an airport.

Other than that, thematic layers of GIS, containing information about fire locations in the region of protected objects, for example electric mains, electric units, oil pipelines (Fig. 2, Fig.11), strategic units (Fig. 12, 13), nuclear stations (Fig. 14), territories covered by fire, etc. are generated. In addition, non-operative information that include high-resolution images, fire emissions data, statistics and other data are generated.

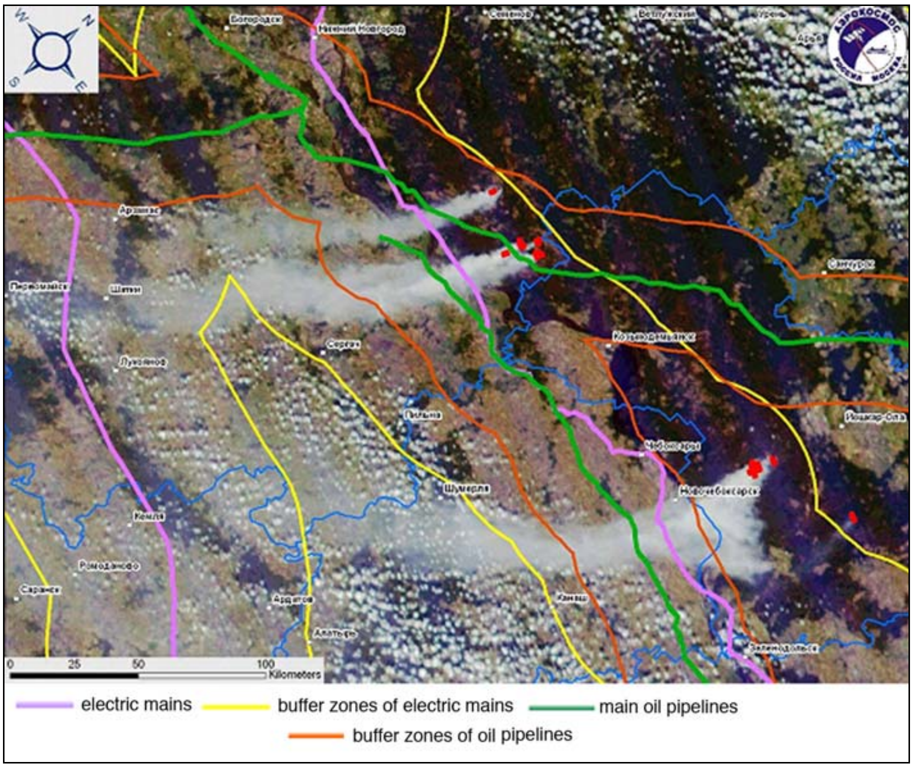


Figure 11. Fires detected from space in Nizhniy Novgorod region and in the Republic of Mari El on 30 June 2010 (at 12h:39min) in the vicinity of electric mains and main oil pipelines.

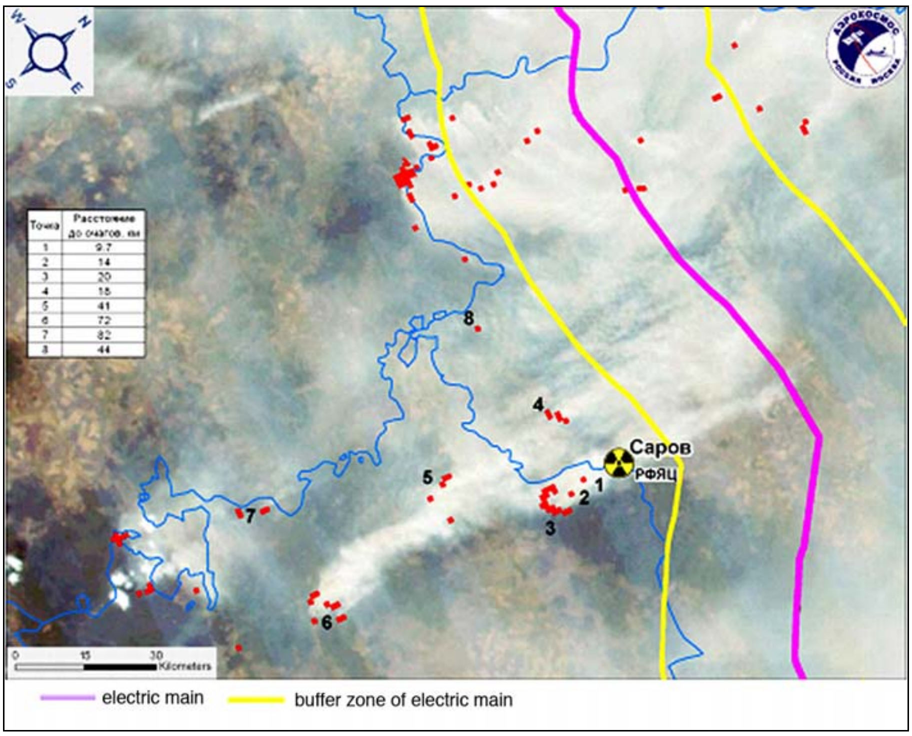


Figure 12. Fires, detected from space, in the vicinity of the Russian Federal Nuclear Center Sarov on 3 August 2010 (12h 27min).

Some examples from the application of the space monitoring system for fires developed by *Aerocosmos*

Figure 9 shows an example of a composite of space images of the observations on 29 July 2010 projected on the *Google Earth* imageries. On the left side of this Figure 9 enhanced maps show intensive fires burning at mid-day in Vladimir, Ryazan, Moscow and Nizhniy Novgorod regions. Figure 10 illustrates an example of prognosis of fire development near an airport based on weather conditions, notably on wind speed and direction. The red-colored zones show the possible direction of fire spread. The distances from the existing and the modeled fire seats to the airport are provided.

Figure 11 shows results of fire detection Nizhniy Novgorod region and in Republic Mariy El on 30 July 2010 (12h 39min). This figure shows the oil pipelines and electric mains, and also their buffer zones. It is visible that intense fires are threatening these areas. The same picture can be seen on Figure 2, where intense fires threatened the electric mains in the European part of Russia on 29 July 2011.

Figures 12 and 13 show the results of fire detection from space in the region of the Sarov city. Figure 12 shows a space image received on 3 August 2010 (12h 27min) where the seats of fire in the regions of Vladimir, Nizhniy Novgorod and the Republic of Mordovia are shown. Numbers indicate the seats of fire near to the Russian Federal Nuclear Center (RFNC). The table shows the distances from the active fires to the Center. Figure 13 illustrates active fires burning on 11 August 2010 near Sarov, based on MODIS-AQUA and RapidEye data, as well as the smoke plumes depicted by MODIS. The enlarged scenes of RapidEye show the zone affected by fire during the previous days, and also the distance from the three active fires from the city of Sarov and the experimental polygon of the RFNC.

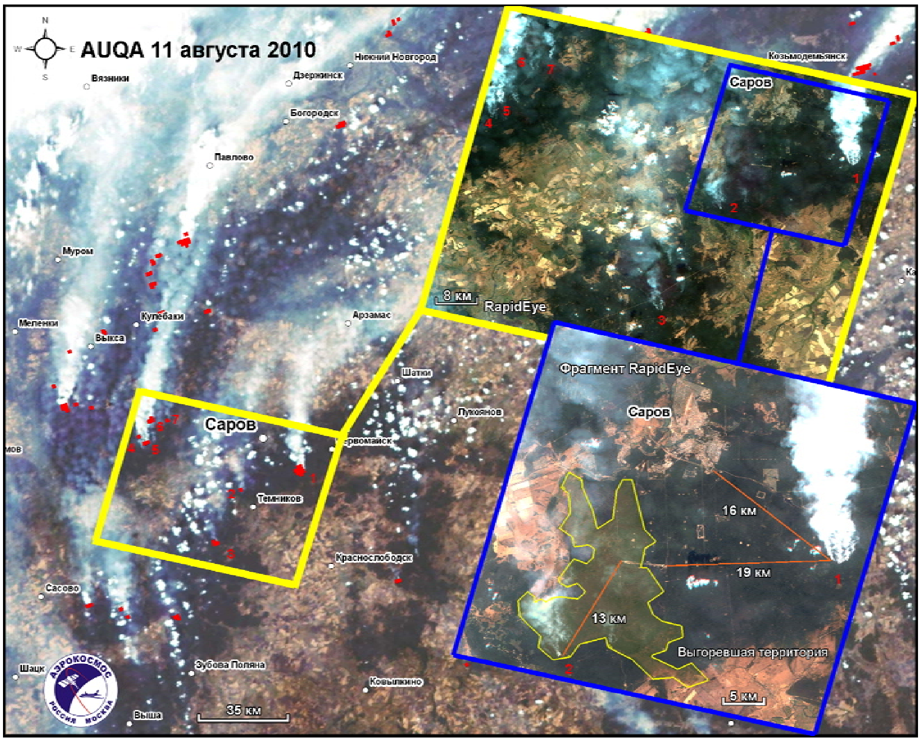
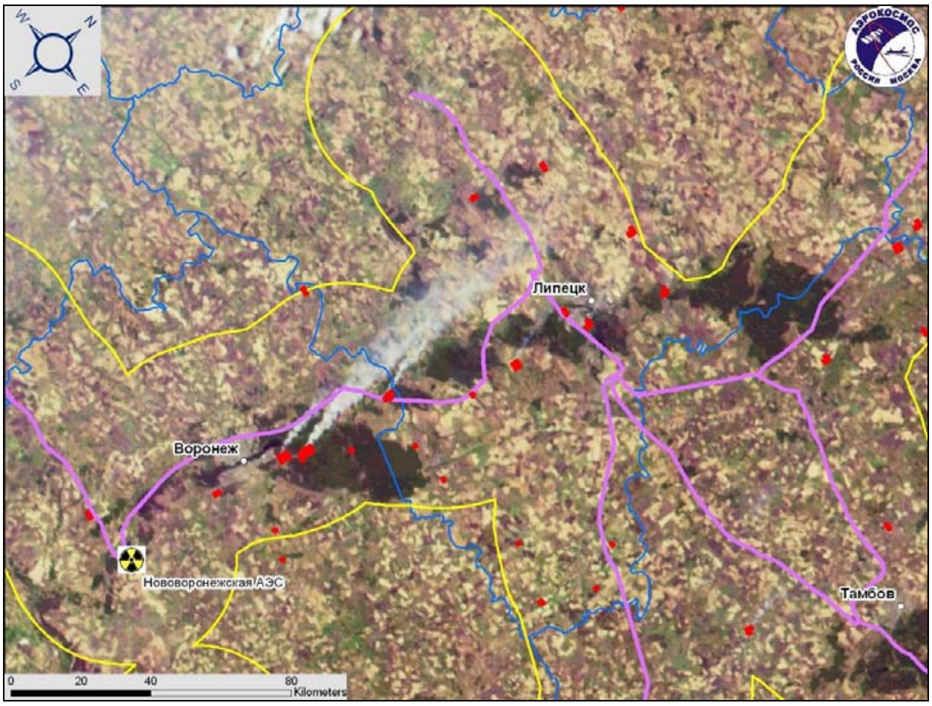


Figure 13. Monitoring of fire seats and detection of burnt-out areas near Sarov (11 August 2010) based on space images, obtained from the MODIS in instrument on AQUA and on RapidEye.

Figure 14 demonstrates the development of fires near the Novovoronezhskaya Nuclear station on 29 July 2010, detected from space. Figure 14a shows that there were three intensive fires near Voronezh at 12h09min. At 13h58min the fires became stronger and their number has increased due to the influence of the southern gale-force winds. These wildfires were developing in the buffer zones of the electric mains, close to the Novovoronezhskaya Nuclear Station, and also close to the cities of Voronezh and Lipetsk, and caused damage to many settlements in this region.

An estimation of carbon monoxide (CO) emissions during the summer months of 2010 on the territory of the European part of Russia and on the territory of Moscow region is shown in Figure 15a-b based on methods of SE *Aerocosmos*.

Figure 16 shows the distribution of CO concentration for the 15 August 2010 on the heights from 2 to 10 km over the territory of Eastern and Central Europe, built upon data from the infra-red sensor AIRS on the satellite AQUA (http://airs.jpl.nasa.gov/maps/satellite_feed/). It can be seen from this image that the strongest CO emissions took place over the European part of Russia, where strong natural fires occurred at that time, and the cloud has spread over a large part of the Eastern Europe because of the transport of air masses.



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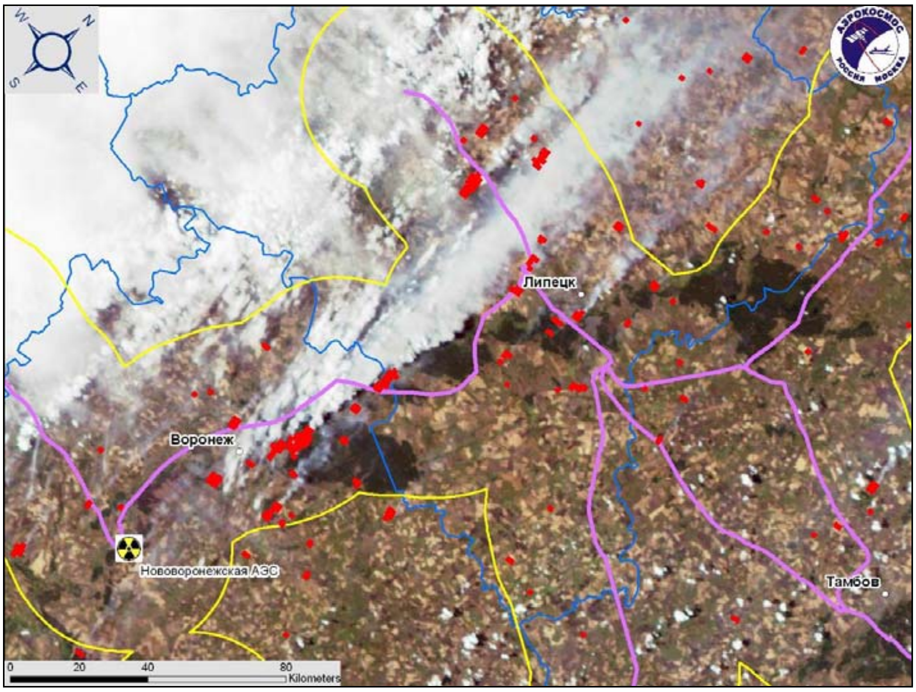

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Figure 14. Dynamics of development of natural fires on 29 July 2010 near Novovoronezhskaya Nuclear Station, detected upon space data, obtained (a) at 12h09min, and (b) at 13h58min.

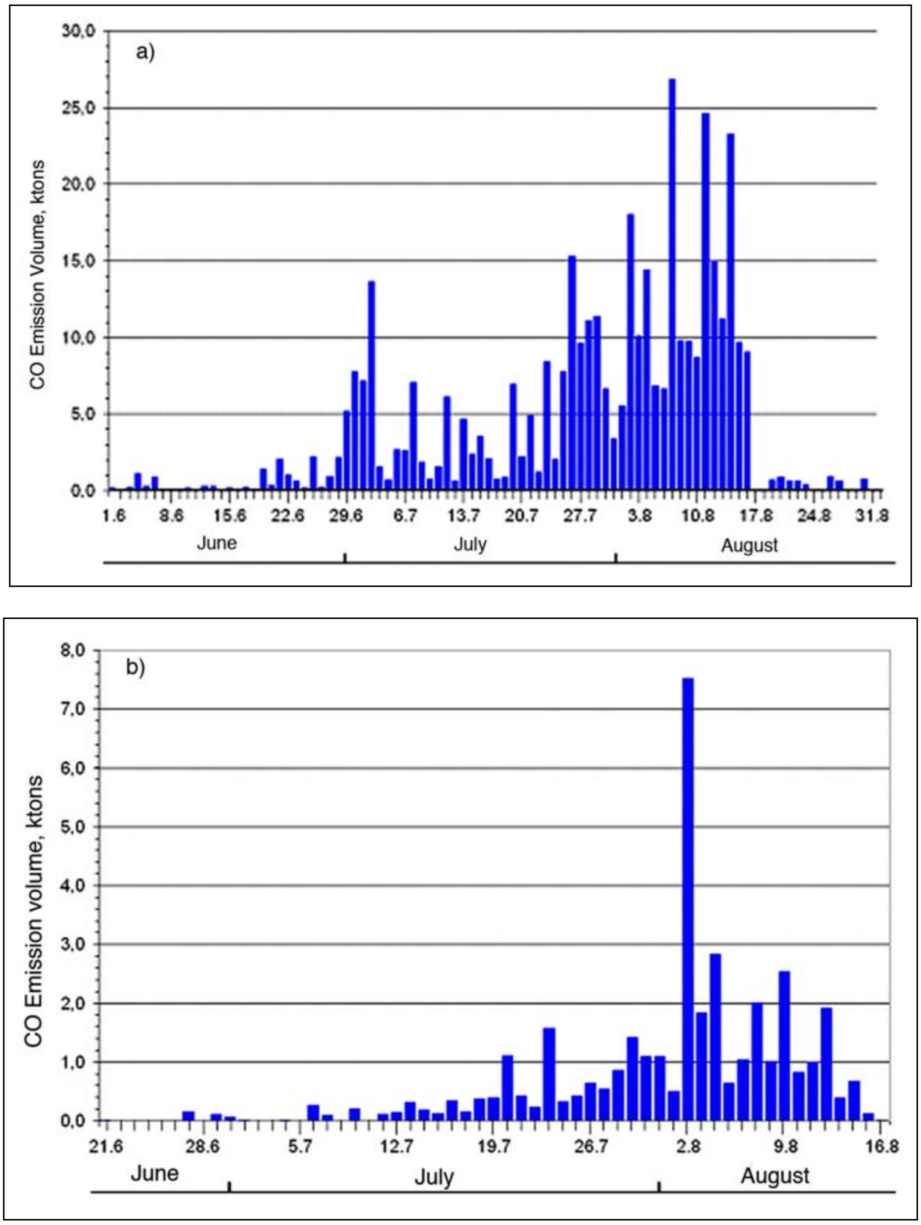

Figure 15. Results of space data-based estimation of carbon monoxide (CO) emission from 1 June to 31 August 2010 on the territory of the European part of (a) Russia and (b) Moscow region.

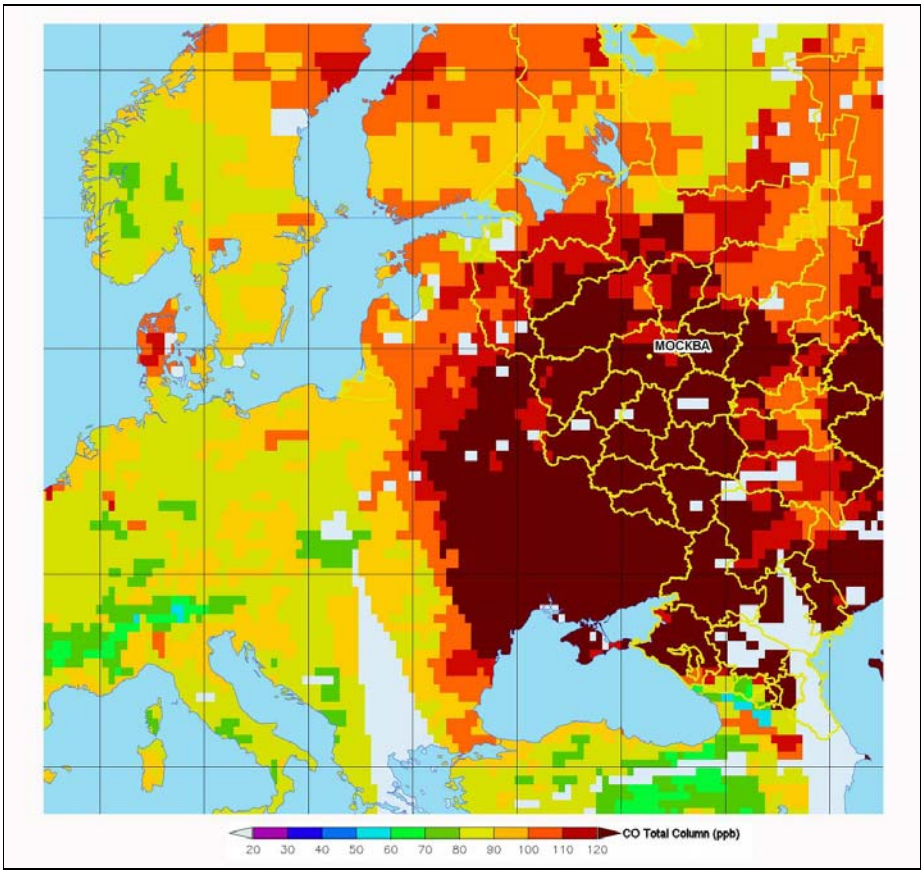

Figure 16. Distribution of CO concentration on 15 August 2010 over Eastern and Central Europe depicted by the AIRS instrument on AQUA (http://airs.jpl.nasa.gov/maps/satellite_feed/).

Conclusions

The preliminary analysis of nature fires, which occurred during the extremely hot and droughty summer of 2010 on the territory of the Russian Federation, as well as the demonstrated examples of detection of active fires from space, and the analysis of fire consequences, has proven the utility of space monitoring to manage wildfires in the situation of 2010. Space-based fire monitoring systems provide the capability of fast detection, detailed information on ongoing fires and an overall reliability and fidelity.

Future perspectives of further development of these systems will require the full use of the existing sensor systems and intensified research and development for enhancing future sensor systems to provide accurate and timely information on early detection and monitoring of active fires and fire impacts.

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