Satellite monitoring of forests in Russia

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We present the main results of joint activity of scientific, educational, state, and commercial organizations in establishing and development of satellite systems that are now being employed in research and monitoring of forests in Russia.

Introduction

Forest fires are still one of the powerful natural factors affecting the global changes of the environment. Traces of this large scale disastrous phenomenon can be found in every continent. However, very often situations occur when all the known fire control technologies cannot stop the disaster and only nature itself can stop such disastrous fires. Fires of last years in Russia, USA, Mexico, and Australia are known for their disastrous consequences.

The main reasons of such events are in delayed fire control measures or late detection, when there are no adequate technologies and resources for their liquidation.

From the point of view of operational fire detection at early stage of ignition, the systems of satellite monitoring are widely used in practice equally with the known systems of ground (visual, television, etc.) and aerial observation.

In Russia, such systems can be divided into two levels: regional and federal. The first versions of these systems are based on the five-channel scanning radiometers AVHRR, installed onboard NOAA satellites (USA). Characteristics of this satellite group and optoelectronics devices, intended for solution of meteorological problems can be used in systems of satellite monitoring of forest fires.

At present, there is a transition to using images formed with the MODIS optoelectronics systems (Terra and Aqua satellites, NASA, USA). Characteristics of this device allow solving a wider scope of research and monitoring problems. This has been achieved because of better spatial resolution in the visible spectral region and larger number of spectral channels (36).

Note some peculiarities of origin and development of these systems. The stations of satellite data reception established by the independent commercial company "ScanEx" (formed in 1989) served as material resources. Nowadays more than 30 stations of this company have been arranged and put into operation in Russia. Regional and departmental centers of satellite forest monitoring were formed on the basis of these stations.

Moreover, this process was initiated under support of the International Forest Institute, mainly, by institutions of RAS. First of all, it is the Institute of Space Researches (ISR RAS), Institute of Solar-Terrestrial Physics (ISTP SB RAS), Center for Ecological Problems and Forest Productivity (CEPFP RAS), V.N. Sukachev Forest Institute (FI SB RAS), Institute of Cosmophysical Researches and Aeronomy (ICPRA SB RAS). Later, the Institute of Atmospheric Optics (IAO SB RAS) and other institutes joined this process. The practical implementation of satellite forest monitoring in Russia is carried out due to the support from regional and federal forest services. Modern centers of operational forestland monitoring have appeared at a regional level to solve the problems of fire detection (including the early one), estimation of consequences (for instance, forest area damaged by fire), and other problems.

Information system of remote monitoring of forest fires of the Federal forestry agency

Information system of remote monitoring (ISRM) of forest fires was established by cooperation of Institutes of RAS (first of all, ISR RAS, CEPFP RAS, and ISTP SB RAS) with International Forest Institute, branch Institutes of Federal Forestry Commission, and Federal Hydrometeorology and Environment Commission. They cover a wide range

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of forestry problems. To solve them, the results of instrumented Earth observations from space can be used. The works on establishment and improvement of ISRM have been carried out since 1995 [Refs. 1–6].

The system provides integration of information obtained due to the satellite data processing NOAA (then Terra, Aqua), with other data sources on current burning of forests to making decisions by forest protection services.

The system solves the following problems: satellite data reception, operational processing, integration of processing results with information obtained from other sources, and operational data representation for users.

The main requirements to the system, have determined its architecture and basic technologies:

– entering of main operational data flow into the system from satellites, which allow observing the whole territory of Russia several times a day, efficient data reception (i.e., information should be collected from several centers for reception and processing satellite data);

– control of the required collection efficiency, processing, and disseminate information among end users;

– match the input data and results of their processing with the results of aerial and ground observations;

– possibility for efficiently receiving results obtained by processing satellite information both for the Central Base of Aircraft Fire Control and for regional bases and other services and departments;

– stability and independence of processing procedures and data analysis realized in the system of conditions and regions of observation;

– flexibility and possibility of its modification and expansion;

– low operation cost.

Figure 1 presents the scheme of reception, processing, and dissemination of data in ISRM.

Development and operation testing of the basic elements of the system were carried out mainly in fire seasons of 2004 and 2005. Conventionally, one can determine three basic areas in the development and revision of ISRM:

"organizational" means making rules and organizational grounds for system operation;

"technological" means formation of technical and technological elements providing the efficient representation of information necessary for making administrative decisions and estimation of forest fire consequences;

"methodical" means formation and development of techniques connected with processing, analysis, and use of various data.

In many respects, it was just the solution of *organizational* problems that allowed the basic elements of ISRM to be reduced to *commercial operation*. Among these elements there are the following: development and approval of the regulations of ISRM operation, correction of the lists of areas with different protection level (unprotected areas were determined as zones of "space monitoring of the first level", and protected areas are divided into a zone of

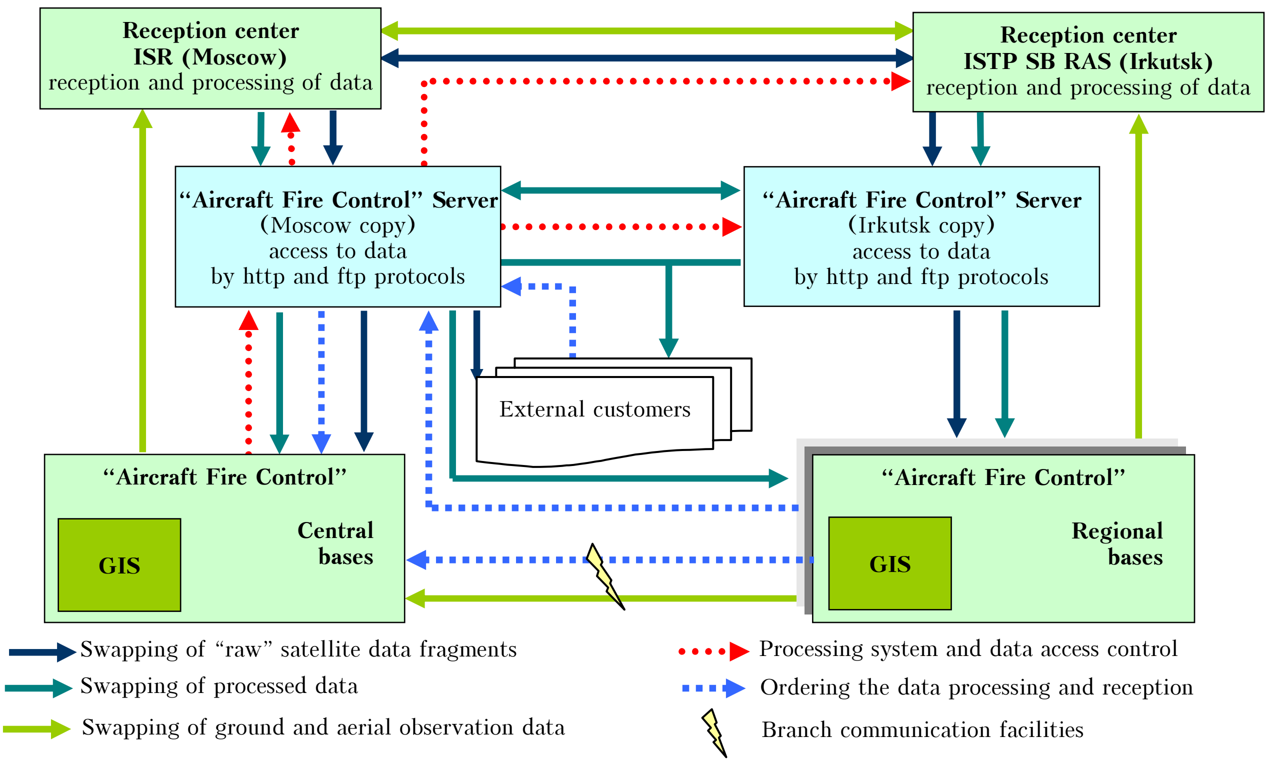

Fig. 1. General scheme of ISRM system (reception, processing, and data dissemination).

space monitoring of the second level and zones of ground and aircraft fire control), and development of the rules for making reports based on data of satellite monitoring.

The work in *technological sector* was oriented to the improvement of some elements of the ISRM. The information sources used in the system are extended due to the technical and technological developments. Therefore, an additional center of reception and processing of satellite data in Khanty-Mansiysk was included into the list of reception centers operating for the ISRM. This center is a part of the Yugorsk Research and Development Institute for Information Technologies [Ref. 7]. Additional stations recording the lightning discharge were put into operation that provided for extending the control or its effect on the forest fires.

An important element of the ISRM was the *subsystem of automatic generation of reporting forms.* A detailed description of its possibilities and structure can be found in Ref. 8. At present, it provides introduction of specialized databases that allows one to compare satellite and cartographic information. Besides, it automates generation of different reporting forms by users' inquiry. Access to the information is provided through the system of information servers of ISRM and specialized GIS of the federal and regional level.[1,2] It should be noted that nowadays, the system operates in a fully automated mode.

The main task of developing the *information server* is to provide remote operational access to the ISRM data (http://www.nffc. aviales.ru/rus/main.sht). The description of the functional capabilities of this system can be found in Ref. 9.

Formation of system of the operational estimate of the areas damaged by fire using SPOT VGT data. Until 2005, the estimate system of forest fire consequences, based on the SPOT VGT data, was intended for operation with data available at the end of a fire season.[10] The system of operational SPOT VGT data reception from archives of the VITO company, their processing and integration into the information blocks was established and experimentally tested in 2005.[11] It provided the ISRM users with information about areas damaged by fire, during the fire season.

Among the studies in the *methodical area* actively conducted at the ISRM in 2005 and 2006 we should like to note the *development of methods for estimation of damages to the forest based on satellite data*. Solution of this problem is necessary for estimating the variations in the forest resources as well as of the carbon emissions that in, the future, for preparing reports required by the Kyoto Protocol. The estimation of damage to forests caused by fires mainly assumes using the SPOT VGT data. The capabilities of such estimation and prospects for its further development have been discussed in Ref. 12.

In addition to the techniques enumerated in ISRM, the development is being done *of a procedure for joint analysis of data of satellite, ground-based, and aerial observations* (that is important for validation of the competitive algorithms of forest fire detection from space[13]).

Regional systems of operational space monitoring

Regional operational systems of spaceborne monitoring of forests are intended not only for making control over limited areas, but for improving and development of new information and algorithmic means for thematic processing of images taken from satellites, validation, comparison of competitive algorithms of the satellite data analysis, formation of new methods of forecasting fire threats and models of fire propagation, etc. That means that these centers in Russia can be considered as test fields for development of the traditional and realization of new approaches, methods, and ideas of efficient use of satellite observations in the interests of rational nature management.

This has become a reality because some of them have been established on the basis of Institutes of RAS, in which one or another aspects of the studies connected with the environment or with its remote sensing, are among their the research activities. Among these research facilities there the FI, IAO, ICPRA, and ISTP, SB RAS. Each of these centers carries out research into some concrete problems, close to the research activity of the host Institute. The centers in Irkutsk and Yakutsk are mainly involved in the development of GIS and are seeking effective algorithms of thematic processing of satellite data with the account of climatic and geographical features of these particular regions. The main results of their activity have been described in Ref. 4. As an addition to this study, we would like to present the results obtained in 2006 and 2007 at the V.N. Sukachev Forest Institute and at IAO.

The Krasnoyarsk system of space monitoring of boreal Siberian forests has been developed since 1994, when a station for reception and processing information from the polar-orbiting satellites of NOAA series has been mounted at FI, SB RAS, in conformity with the agreement between NASA and RAS on the joint studies. The GIS developed at this station differs from other systems of monitoring forest fires in Russia by its functionalities and by the fact that it includes the subsystem of estimate and forecast of fire threats.

The fire risk index characterizes the readiness of forest combustible materials (FCM) to inflame and maintain burning. The determining factor is the moisture content of FCM. In Russia we use the fire risk index developed by V.G. Nesterov.[14] The technique of operational estimate of this index with the use of satellite data has been formed at FI, SB RAS (TOVS instrumental group, NOAA satellites).[15]

It is important to compare the Russian index with the competitive one that uses the same initial data, to estimate its efficiency with regard for other technically proved approaches to the fire risk estimation.[16] Figure 2 presents an example of such a comparison, where the values of Canadian (DMC/CFFDRS) and Russian (PV-1) fire risk indices are calculated by measurements at two meteostations in Krasnoyarsk Region.

On the whole, the results calculated using data of five meteostations have shown high correlation between these indices. In some cases, the correlation coefficients are close to 1. Note that the Canadian system index DMC (Duff Moisture Code), which shows the degree inflammability and ability to maintain burning of the litter, most closely corresponds to the Russian PV-1 index.

However, one should note the lower sensitivity of the Canadian index to the amount of precipitations, especially, at low values of this quantity in the range of 0.5–5 mm. In some cases, (especially under conditions of the long-term preliminary drying period) such approach is justified, since it does not lead to sharp reduction of the fire risk index at increasing amount of precipitations over this range. In contrast to the Canadian index, one can see more sharp minima in the curves presenting the Russian system of fire risk estimate PV-1, in the corresponding observation periods.

In recent time, new approaches, methods, and concrete algorithmic facilities for remote qualitative estimate of forest fire consequences have been sought at FI SB RAS. Some results of these investigations can be found in Ref. 17.

The main research tasks being tackled at IAO SB RAS connected with the development of satellite monitoring systems are the development of technologies of operational correction for the atmospheric effects of data of passive sounding of the earth's surface in the optical wavelength range. At the first stage, these studies have been carried out in addition to the early detection of small size fire centers.[13,18] At present, within the limits of Governmental contract No. MG-02.06/23K, an operational atmospheric correction technology is being developed for ISRM for six spectral channels of the MODIS device.

One of the physical phenomena reducing the efficiency of passive satellite methods in solving the problems of sounding the earth's surface are the sun glints from water surfaces (that can be explained from the physical point of view), from aerosol formations in the atmosphere,[13] and from cloud boundaries. The studies of the conditions and physical causes of their origin in cloud systems are among the tasks of IAO SB RAS to be achieved in the nearest future.

Figures 3 and 4 present the data obtained in analyzing satellite images of Tomsk Region, taken from NOAA-14 satellite by means of the AVHRR device. To study the sun glints appearing at the boundary regions of clouds, we have chosen a field with geographical coordinates of 59–61°N and 80–86°E, where a considerable number of temperature anomalies can be revealed. Besides, one can distinguish both the fields of the underlying surface with no clouds, and the cloud cover of different types.

As follows from data presented in Fig. 3, the highest values of radiation temperature $T3$ (> 305 K) are realized, mainly, over the range of *albedo* values $A1$ = 15–35%, that, in this case, corresponds to the cloud cover with relatively low optical density.

Analysis of data presented in Fig. 4, allows one to easily outline the cloud boundaries with the values of $A1$ within the range of 10 to 30%. In comparing the spatial structures of $A1$ and $T3$, the high values of $T3$ (higher than 300–305 K) are really found at the boundaries of clouds of the lower layer. The values of $T3$ of the higher cloud cover do not exceed 270 K, and temperature of $T3$ at cloud boundary is within the range of 275 to 280 K. Note that $T3$ of cloudless regions is approximately (293 ± 3) K.

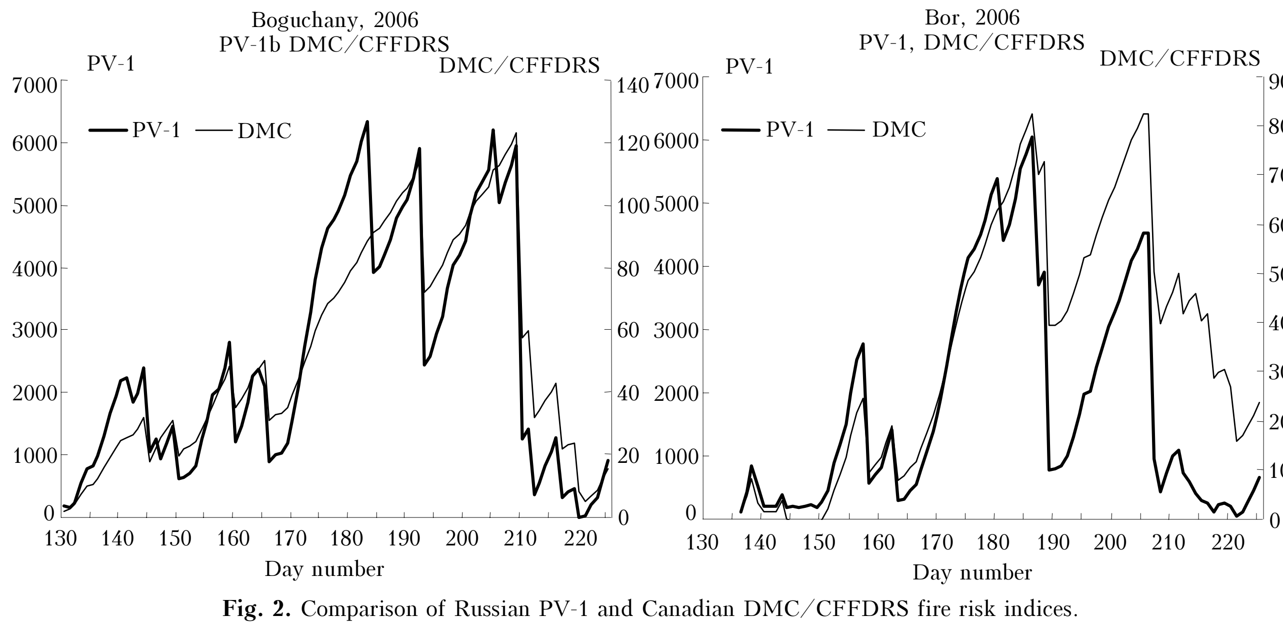

Fig. 2. Comparison of Russian PV-1 and Canadian DMC/CFFDRS fire risk indices.

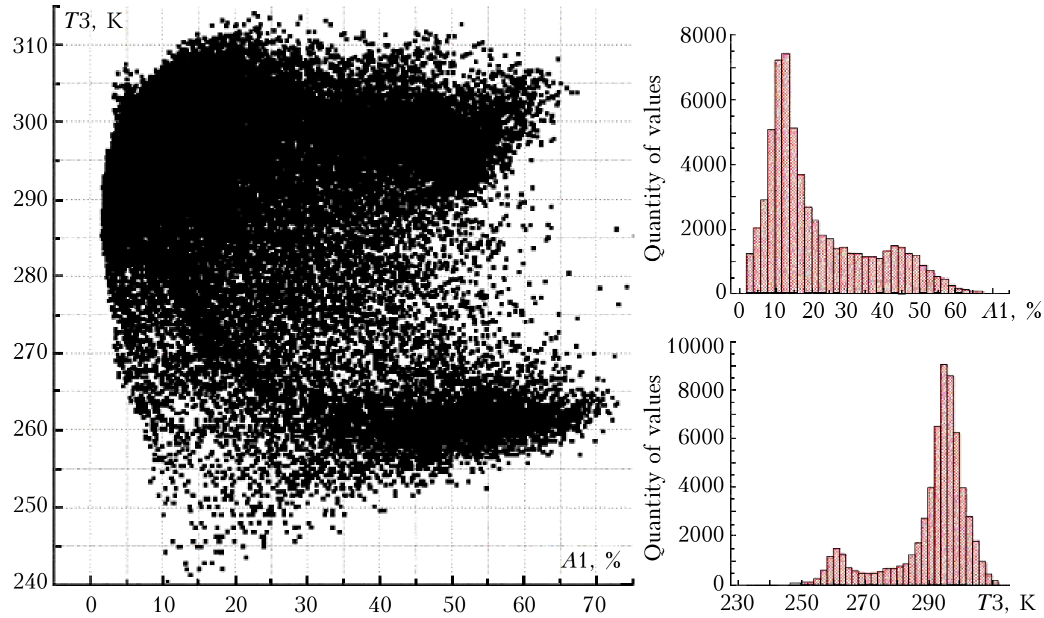

Fig. 3. Data on *albedo* values $A1$ (channel No. 1, $\lambda = 0.63$ μm), radiation temperature $T3$ (channel No. 3, $\lambda = 3.74$ μm) and histograms of their values.

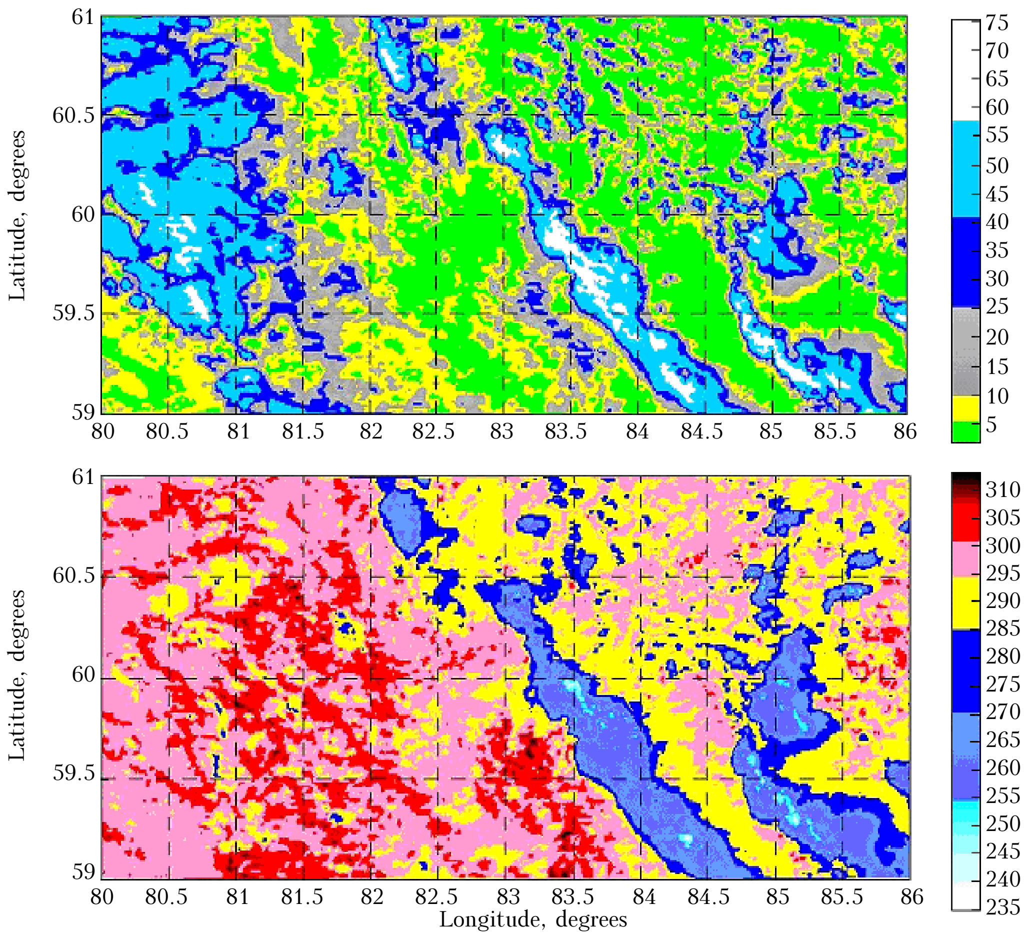

Fig. 4. Spatial distributions of *albedo* $A1$ and radiation temperature $T3$.

The threshold methods of sun glint filtration at boundary cloud region are widely used in practice.[19] Analysis of the efficiency of these algorithms performed at IAO enables one to suppose that application of the physical approach (i.e., revealing the nature and conditions for this phenomenon origin) to solving the problem on sun glints identification could make their detection more reliable as compared to the methods of their suppression used at present.

Conclusion

Thus, for rather a short period, under unfavorable economic conditions in Russia, joint efforts the Institutes of RAS together with International Forest Institute, affiliated Institutes of Federal Forestry Commission ISRM of forest fires and regional space monitoring systems of forestlands have been developed and operated. Since 2006, the satellite data on forest fires are included into formal reports of forest protection services along with data of ground and aerial observations.

In completing the review of structure and state of space monitoring systems, note that in order to make their efficiency higher, the main efforts of basic and applied researches, from our point of view, should be directed to solution of the following problems:

– development of fire detection algorithms for reduction a number of missed fires and elimination of false alarms;

– improvement of algorithms for estimation of areas damaged by fire and fire consequences;

– formation of information and algorithmic means of efficient estimation of the fire risk with use of satellite data;

– development of a system of comparing data obtained by means of the ground-based, aerial, and satellite observations;

– development of the blocks forecasting the fire development.

Acknowledgements

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References

1. D.V. Ershov, G.N. Korovin, E.A. Lupyan, A.A. Mazurov, and S.A. Tashchilin, in: *Scientific Reports Russian System of Satellite Monitoring of Forest Fires* (Poligrafservice, Moscow, 2004), pp. 47–57.
2. A.I. Belyaev, G.N. Korovin, and E.A. Lupyan, in: *Scientific Reports* (GRANP-Poligraph, Moscow, 2005), Vol. 1, pp. 20–29.
3. A.I. Belyaev, V.V. Ershov, E.A. Lupyan, B.V. Romanuk, A.I. Sukhinin, and S.A. Tashchilin, in: *Material of International Scientific-Practical Seminar*, Khabarovsk, 2003 (Alex, Moscow, 2004), pp. 156–166.
4. E.A. Lupyan, A.A. Mazurov, E.V. Flitman, D.V. Ershov, G.N. Korovin, V.P. Novik, N.A. Abushenko, D.A. Altyntsev, V.V. Koshelev, S.A. Tashchilin, A.V. Tatarnikov, A.I. Sukhinin, E.I. Ponomarev, A.M. Grishin, S.V. Afonin, V.V. Belov, Yu.V. Gridnev, G.G. Matvienko, V.S. Solov'ev, V.N. Antonov, and V.A. Tkachenko, *Satellite Monitoring of Forests in Russia* (IAO SB RAS, Novosibirsk, 2003), 135 pp.
5. N.A. Abushenko, S.A. Bartalev, A.I. Belyaev, V.V. Ershov, G.N. Korovin, V.V. Koshelev, E.A. Lupyan, Yu.S. Krasheninnikova, A.A. Mazurov, N.P. Min'ko, R.R. Nazirov, A.A. Proshin, and E.V. Flitman, Naukoemkie Tekhnolog. **1**, No. 2, 4–18 (2000).
6. N.A. Abushenko, S.A. Bartalev, A.I. Belyaev, D.V. Ershov, M.Yu. Zakharov, E.A. Lupyan, G.N. Korovin, V.V. Koshelev, Yu.S. Krasheninnikova, A.A. Mazurov, N.P. Min'ko, R.R. Nazirov, S.M. Semenov, S.A. Tashchilin, E.V. Flitman, and V.E. Shchetinskii, Issled. Zemli iz Kosmosa, No. 3, 89–95 (1998).
7. V.N. Kopylov, in: *Collected Articles* (GRANP-Poligraph, Moscow 2005), Vol. 1, pp. 140–148.
8. A.A. Galeev, D.V. Ershov, R.V. Kotel'nikov, E.A. Lupyan, A.A. Mazurov, A.A. Proshin, and E.V. Flitman, in: *Collected articles* (Open Company "Azbuka-2000", Moscow, 2006), Vol. 1, Is. 3, pp. 359–365.
9. A.A. Galeev, D.V. Ershov, V.Yu. Efremov, Yu.S. Krasheninnikova, R.V. Kotel'nikov, E.A. Lupyan, A.A. Mazurov, A.A. Proshin, and E.V. Flitman, in: *Collected Articles*, Is. 3, (Open Company "Azbuka-2000", Moscow, 2006), Vol. 1, pp. 351–358.
10. S.A. Bartalev, A.I. Belyaev, and V.A. Egorov, in: *Collected Articles* (GRANP-Poligraph, Moscow, 2005), Vol. 1, pp. 380–387.
11. *The Vegetation User Guide* (VEGETATION, 2002), http://www.spotimage.fr/data/images/vege/VEGETAT/home.htm
12. A.I. Belyaev G.N. Korovin, and E.A. Lupyan, in: *Collected Articles,* Is. 3 (Open Company "Azbuka-2000", Moscow, 2006), Vol. 1, pp. 341–350.
13. S.V. Afonin and V.V. Belov, Atmos. Oceanic Opt. **18**, No. 12, 927–935 (2005).
14. S.M. Vonsky, V.A. Zhdanko, V.I. Korbut, M.M. Semenov, L.V. Tetyusheva, and L.S. Zavgorodnyaya, *Formation and Application of Local Scales of Fire Safety in Forest* (LenNauch. Issled. Institut Lesn. Khoz., Leningrad, 1975), 57 pp.
15. A.I. Sukhinin and E.I. Ponomarev, Sib. Ekol. Zh. **10**, No. 6, 667–669 (2003).
16. A.M. Grishin, *Modeling and Forecast of Disasters* (Publishing House of Tomsk State University, Tomsk, 2003), 520 pp.
17. A.J. Soja, H.H. Shugart, A. Sukhinin, S. Conard, P.W. Stackhouse Jr., in: *Mitigation and Adaptation Strategies for Global Change* (Publisher: Springer Netherlands), ISSN: 1381–2386 (Paper) 1573–1596 (Online) DOI: 10.1007/s11027-006-1009-3, Issue 11, No. 1, 75–96 (2006).
18. S.V. Afonin and V.V. Belov, Issled. Zemli iz Kosmosa, No. 6, 1–9 (2001).
19. L. Giglio, J. Descloitres, C.O. Justice, and Y.J. Kaufman, Remote Sens. Environ. **83**, Nos. 2–3, 273–282 (2003).