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FUNDAMENTALS OF REMOTE SENSING: HISTORY AND PRACTICE

Translation from Ukrainian:
O. Savychenko, O. Oleshko

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O-75 **Fundamentals** of Remote Sensing: History and Practice: Guidance Manual / S. O. Dovgyi, V. I. Lialko, S. M. Babiichuk, T. L. Kuchma, O. V. Tomchenko, L. Ya. Iurkiv; translation from Ukrainian O. Savychenko, O. Oleshko — K.: Institute of Gifted Child of the NAPS of Ukraine, 2019. — 316 pages.

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This Guidance Manual introduces readers to the history of development, physical basics and areas of application of the remote sensing data. In addition, the Manual also contains information on the nature of electromagnetic radiation and its role in the decoding and interpreting satellite imagery. The Guidance Manual presents examples of the remote sensing data application in the field of natural sciences.

The Manual may be used by methodologists and heads of sections of the Junior Academy of Sciences of Ukraine, and teachers and students of schools, lyceums, gymnasia within the frame of educational and research activities, as well as by anybody who has the desire to master the fundamentals of remote sensing.

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List of Abbreviations and Explanation of Symbols

GIS	—	geographic information system
RS	—	remote sensing of the Earth
SSAU/ NSAU	—	State Space Agency of Ukraine (after 2010) / National Space Agency of Ukraine (before 2010)
EGP	—	exogenous geological process
ECM	—	electronic computing machine
ESA	—	European Space Agency
SV	—	space vehicle
JAS	—	Junior Academy of Sciences
ISS	—	International Space Station
MES	—	Ministry of Education and Science
NAASU	—	National Academy of Agrarian Sciences of Ukraine
NASU	—	National Academy of Sciences of Ukraine
NASA	—	National Aeronautics and Space Administration (USA)
AES	—	artificial earth satellite

INTRODUCTION

What the Earth looks like from a bird's-eye view? This has been a matter of particular interest to humanity for a long time. With the advent of the first aircrafts, aerial photography provided an opportunity to increase significantly the accuracy of maps, and the work of cartographers obtained new, more progressive features.

Truly revolutionary breakthrough in the aerial observation took place with the launch of an artificial Earth satellite. Remote sensing has brought the study of the Earth's surface to a higher level. Remote sensing data are applied in the field of natural sciences for making precise land surveys.

There is seen a year-by-year increase in the accuracy and information content of satellite imagery. The techniques of satellite observations are constantly improving: the resolution of satellite imagery increases, the range of imaging may provide detailed information about the level of plants vegetation in the certain area and the level of humidity/aridity of the territory, movements of atmospheric fronts, etc.

The combination of remote sensing and geoinformation systems allowed us to study our planet in a new way: now we may see the areas hidden for human eye, explore in detail the areas still undiscovered by scientists.

Advantages of satellite-based monitoring:

- integrity and validity (satellite imagery represents real-world information);
- visibility and detailed presentation (possibility to observe any territory on the Earth with the feature level of detail — up to 30 cm);
- relevancy, high frequency, efficiency (imaging from space with minimal time for data acquisition by the user);
- multispectral observations (set of spectral bands in one image);

- potential for multisectoral use (environmental monitoring; agricultural industry, forestry and water industry; forecasting and control of emergency situations; territorial management and development planning; land inventory and control over land use; cartography, construction, transport, communications and etc.).

This Guidance Manual will be useful for methodologists and heads of sections within the system of the Junior Academy of Sciences of Ukraine, as well as teachers and students of general secondary education institutions, who have the desire to master the fundamentals of remote sensing. The course of study may be held in general secondary education institutions specialized in any area, following the fundamentals of Computer Science and Geography course.

Section 1

HISTORY OF REMOTE SENSING

Section 1.
HISTORY OF REMOTE SENSING

Remote sensing (hereinafter referred to as the RS) — is the acquisition of information about an object or phenomenon without any physical contact. In current usage, the RS term generally refers to the thematic analysis of both terrestrial and man-made radiation within the range from ultraviolet to radio waves. At the same time, the extension of geodetic and cartographic knowledge made it possible to refer satellite imagery to a specific place on the Earth's surface, which it represents. Without terrestrial geodetic observations, geographical projections and coordinates, the use of satellite imagery as a source of geodata would be impossible.

Introduction of the RS into the practice is associated with the invention of photography in the first half of the 19th century, which allowed to capture images, including their time and space variations. That very century was also marked with the development of theoretical foundations for the electromagnetic radiation beyond the visible spectrum: infrared radiation — by Herschel, ultraviolet light — by Ritter, radio wave — by Hertz; and in 1863, the electromagnetic theory was developed that allows for the quantitative interpretation of multi-wave spectral information delivered from various objects *(Annex 1).*

1.1. Aerial Surface Observation

The use of aerial Earth survey has started immediately with the invention of the photographic method. The first aerial photograph was taken by Gaspard-Félix Tournachon (known by the pseudonym Nadar) — it was a picture of a village near Paris captured from a balloon at an altitude of 80 m.

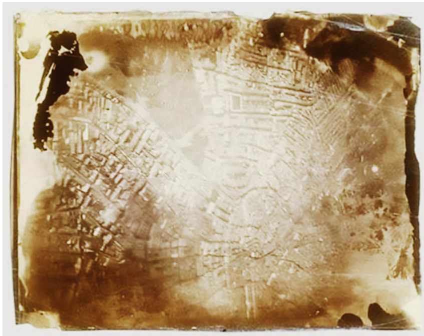

Fig. 1.1. The first aerial photograph taken by Gaspard-Félix Tournachon (1858) [1]

Starting from the end of the XIX century, due to the improvement of photographic methods, many experimenters began to use cameras in unmanned aerial vehicles.

In 1907, Julius Neubronner, a pharmacist, invented the **pigeon photographer method** for aerial photography. Initially, he used carrier pigeons to deliver medicines, and then he decided to make an experiment designing an aluminium chest harness with minicamera for pigeons, which took automatic photos at regular intervals [2]. Subsequently, in 1909, Neubronner sold some of such pigeon photography images turned into postcards.

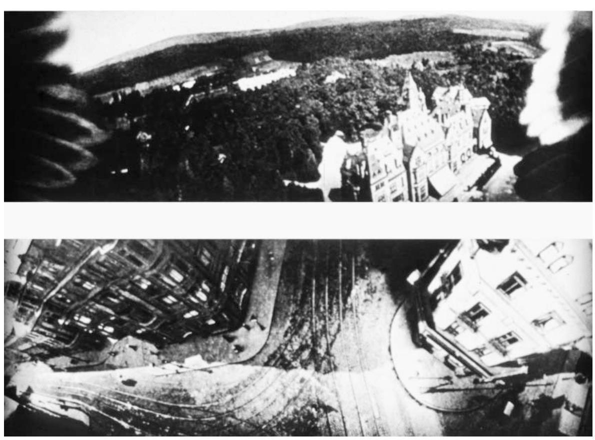

Fig. 1.2. Photographs taken by Neubronner's pigeons [3]

Aerial photographs started to be taken from planes in 1909. Aerial photography was used during the World War I in military intelligence. The period between the two world wars was marked with the development of methods for civil application of aerial photography, first of all in cartography, geology, agriculture and forestry. Cameras, films and aircrafts improved along with significant development of stereographic mapping method. The first satellite image was taken from V-224 missile in October 1946 [1].

Exploration of the outer space was the revolutionary step in the development of remote sensing techniques. Manned spacecrafts, artificial Earth satellites and orbital stations started to deliver extensively satellite images. The first photographs of ground surface have been captured by TIROS weather satellite and Mercury 1–4 spacecrafts in 1960–1962.

Fig. 1.3. First space photograph taken in 1946.
The picture captures Mexico [1]

According to the delivered colored imprints of the images of the Caribbean Region and Northwest Africa, many new tectonic disturbances have been deciphered and encoded, and previously unknown outcrops of parent materials of different age have been identified, along with determination of their occurrence mode. First satellite images of the territory of the USSR in the visible range of electromagnetic spectrum were made by astronaut G. S. Titov in 1962 from Vostok satellite.

1.2. Space Age: Stages of Development

The Second World War has made significant contribution in the development of remote sensing. The aerial photographic intelligence has reached a high technology level: German invasion of England, originally scheduled for September 1940, was canceled as a result of observations data on the concentration of ships along La Manche. This was a period of development of tools sensitive to infrared radiation, as well as radar systems.

The color infrared film was initially developed for military use, and in the 1950s, it started to be applied in the plotting of vegetation maps. At the same time, high-resolution visual radars have been designed.

These developments continued with the installation of sensors at space vehicles (SV) in the 1960s. Initially, it was a part of the Moon observation program, and later on the benefits of the use of the same methods for the Earth observation have been recognized. First multispectral Earth images from the space have been made from the board of *Apollo-6* manned spacecraft. Although unmanned satellites for remote sending have already been operating at that time, it is believed that the modern era of the remote sensing from space started in June 1972 with the successful launch of *ERTS* — Earth Resources Technology Satellite of the National Aeronautics and Space Administration (NASA). Later on *ERTS* received a new name — *Landsat-1*; Landsat program is still running.

The period from 1960 to 2010 was marked with significant changes in the field of remote sensing. Some of these changes are listed below.

- Firstly, the term "remote sensing" was initially introduced in 1960. Before 1960, the term "aerial photography" has been predominantly used. However new methods and technologies for the exploration of the Earth's surface went beyond the scope of black-and-white aerial photography and required the introduction of new, more comprehensive term.
- Secondly, 1960s and 1970s have been marked with the transfer of remote-sensitive devices from airplanes to satellites. Satellites can provide much bigger coverage of ground surface compared to airplanes, and may ensure regular monitoring of survey area.
- Thirdly, digital images have replaced analogous one. Digital format allowed the reflection and analysis of imagery using computers — the technology that undergone rapid changes over the same period. Computer technologies progressed from large electronic computing machines (ECM) to small microcomputers, and provided information more in graphic, rather than numerical form.
- Fourthly, it was the time of emergence of sensors recording the Earth's surface simultaneously in several different parts of electromagnetic spectrum, which allowed studying the area in more detail, reviewing several different images, including beyond the visible spectrum. This technology makes it possible to see the processes, events, phenomena, etc. occurring on the Earth's surface, invisible to the human eye.
- Finally, active social and ecology movements in 1960s and 1970s brought out new and sustained concerns about the changes in the physical environment of the Earth. Remote data delivered by satellites following their processing and improvement by computers, made it possible to identify and monitor such changes. Thus, there has been and remains strong social support of this technology; however the public awareness of the meaning of term "remote sensing" is still limited.

Currently, many satellites equipped with various remote sensing tools monitor the Earth's surface. For instance, the CORONA mission, which was originally a classified program of military reconnaissance, now operates using advanced Keyhole satellites, and Landsat, open

Earth resources program, is running through the use of improved satellite monitoring programs.

The main modern tendencies of RS development **worldwide** are as follows (according to *Lialko V. I., Popov M. O.*, 2017) [4]:

- Currently, the global RS-services amount to nearly USD 2 billion annually. The total number of operating SV-missions used to obtain thematic data is gradually increasing. Modern technologies ensuring the possibility to design SVs and on-board sensors with longer operational life in space (10 years and more) have also contributed to the increase in the total number of SVs on orbit. In parallel, the range of countries launching their own satellites to obtain thematic space data with high spatial resolution is also expanding.
- The level of detail afield provided by satellite optical imagery currently is very close to the limit defined by the physical laws. For example, GeoEye company (USA) started in 2008 the construction of GeoEye-2, third generation SV, equipped with on-board electro optical sensor having spatial resolution of 30 cm. There should also be noted a significant breakthrough achieved over the last years in increasing the spatial resolution of space radar images (up to 1 m).
- One of the requirements to RS is the possibility to perform continuous monitoring of objects within all studied territories, sometimes located in different geographic regions. It is impossible to satisfy this requirement using imagery delivered by airplanes or single orbital vehicle. Therefore, the leading countries of the world work towards the creation of the space groups, which allow capturing images of any part of the globe with the required regularity, up to several times a day.
- Multispectral, hyperspectral sensors are successfully developed and applied for the fulfilment of industry-specific tasks (natural-resource, environmental, agricultural and etc.). It should be noted, however, that multispectral images are widely and efficiently used in the RS now, while the application of hyperspectral images is not that extensive. This is due to the fact that the spatial resolution of hyperspectral sensors lags far behind that of multispectral ones.

- To realize the potential of space methods, the satellite imagery information should comply with certain requirements, in particular:
  - spatial resolution;
  - rapid delivery of information;
  - completeness (comprehensiveness) of imagery information;
  - possibility of observation of specified geographic territories;
  - periodicity of remote sensing.

Requirements set for the parameters of space information in various fields of science, industry and agriculture, indicate that in order to solve substantial part of thematic RS-related tasks there is need for space survey materials with a spatial resolution of up to 5.0 m, and most (65%) tasks require the use of remote sensing data with a resolution of less than 15 m. The resolution of satellite imagery significantly affects the economic efficiency of their use.

1.3. Establishment of RS in Ukraine

Remote sensing has been and continues to be one of the three priority lines of scientific and practical research (along with telecommunications and navigation) pursued by the space industry of Ukraine. Ukraine has always paid attention to the development of remote sensing, and consequently RS became an important scientific and technical component of the nationwide complex, comprising its research institutions, centers for reception, processing and distribution of space information, integrated into one infrastructure.

The history of research in the field of RS dates back more than half a century in Ukraine. With the establishment of the State Space Agency of Ukraine in February 1992, these researches received a fresh impetus.

In August 1995, Ukrainian carrier rocket Tsyklon-3 launched into orbit the first locally produced SV — Sich-1 designed for the RS. The successful launch of Ukrainian satellite demonstrated high capacity, which allowed encompassing the complete manufacturing cycle of the space system at the national level — from the development and production, to operation and distribution of information delivered by satellites. To expand the range of scientific and applied exploration of the Earth, a set of arrangements has been undertaken in line with the decisions of the leaders of Ukraine's State Space Agency and National Academy of Sciences (NASU); in particular, several departmental agencies for applied scientific research in the field of RS have been established, namely: Scientific Centre for Aerospace Research of the Earth of the NASU and "Pryroda" Scientific and Production Center (Kyiv city), Center for Radiophysical Sensing (Kharkiv city), and Dniprokosmos company (Dnipro City, formerly known as Dnipropetrovsk).

Recently adopted by Verkhovna Rada, the concept of 2018–2022 Target Scientific and Technical Space Program of Ukraine includes the implementation of priority projects aimed at further development of research, and the creation of new remote sensing technologies in order to solve the urgent problems of industry, agriculture, science, national security and defense.

A new concept of space program includes the formation within 10 years of own group of RS-vehicles on the basis of 6–8 satellites with different spatial resolution that will fly over the territory at various time during a day and provide immediate, high-quality and unbiased information. By 2022, it is planned to launch first 4 SVs with subsequent addition of one satellite each year.

Numerous national institutions and organizations are involved in the fulfilment of RS-tasks. The activities of these institutions and organizations are outlined in detail in the following subsection 1.4.

Several higher educational institutions of Ukraine provide training courses for RS-specialists: Taras Shevchenko National University of Kyiv, Kyiv National University of Construction and Architecture, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", National Aerospace University named after N. E. Zhukovsky "Kharkiv Aviation Institute", National University of "Kyiv-Mohyla Academy", National Aviation University, National University of Life and Environmental Sciences of Ukraine, State Academy of Housing and Communal Services, Lviv Polytechnic National University, etc.

In recent years, attention has been paid to the development of the regulatory, research and methodological basis for the RS, and scientific researches in the field.

In 2002–2003, the first Ukrainian national standard for RS was developed by joint efforts of Yuzhnoye Design Office, Scientific Centre for Aerospace Research of the Earth and Dniprokosmos company — "Remote Sensing of Earth from Space. Terms and Definitions", which was approved and put into effect by the Order No.155 of the State Committee for Technical Regulation and Consumer Policy dated 15.09.2003. There has also been established the National standard for the RS — "Remote Sensing of Earth from Space. Data Processing and Interpreting." The Institute of Agroecology and Natural Management of the NASU has developed the standard "Remote Sensing of Earth from Space. Surface Data on Crops and Agricultural Plants Productivity Control", approved by the Ministry of Economic Development and Trade of Ukraine on 01.01.2014.

In 2004, the "Glossary of RS terms" was published, which includes the system of terms and definitions used in the RS field, and their explanations.

During 2004–2010, a large volume of scientific and practical research has been carried out in Ukraine in different areas of RS, including ecological monitoring of environment; operational monitoring of floods, waterlogging, forest fires and other natural disasters; assessment of pipelines' condition; minerals exploration; assessment of agricultural lands and crop forecasting; prediction of changes in terrestrial systems and climate with the use of space information, etc. Some developments of Ukrainian RS specialists have been patented at the State Department of Intellectual Property of Ukraine. Some of these materials has been published in the *Space Science and Technology* journal and *Ukrainian Journal of Remote Sensing* — an industry-specific online source [4].

1.4. Enterprises and Institutions Operating in the field of Remote Sensing in Ukraine

Fig. 1.4. Structure of enterprises, institutions and organizations operating in the field of RS in Ukraine

National Space Agency of Ukraine (since 2011 — **State Space Agency of Ukraine** — SSAU) was established in 1992 for the purpose of implementation of the government policy in space activities. The management sphere of the SSAU includes over thirty industrial enterprises, research institutes and design bureaus, due to which Ukraine is known in the global market for its space products: "Zenit-2", "Tsyklon-3", "Dnipro" carrier rockets, "Kurs" docking unit for International Space Station, unique objects of ground infrastructure, etc.

"Pryroda" State Scientific and Production Center for Aerospace Information, Remote Sensing and Environmental Monitoring (SSPC "Pryroda")

SSPC "Pryroda" is a governmental institution, which deals for over 25 years with archiving, processing and transfer of satellite imagery data to concerned ministries, departments, institutions (including the National Security and Defence Council of Ukraine, the Ministry of Defence of Ukraine, the Ministry of Ecology and Natural Resources of Ukraine, the Ministry of Agrarian Policy and Food of Ukraine, regional state administrations) and is a part of ground information complex of the State Space Agency of Ukraine. At the users' requests, the Center carries out works and provides services related to processing of RS materials, development and maintenance of databases, creation of thematic GISs, profile geoportals and specialized information services, etc.

The history of the Center's establishment dates back to 1992, when the Science and Research Center for Space Information "Pryroda" was formed at the Ukrainian State Institute of Engineering Geodetic Surveying (UkrDIIGVIZ).

Main areas of activity of SSPC "Pryroda":

- Operation of RS data archives (archiving, cataloging and disseminating of RS data; processing of RS data upon user request).
- Operation and development of departmental geoportal of the State Space Agency of Ukraine (SSAU) for distribution of satellite and geospatial data.
- Creation of pilot projects of sectoral geoinformation services for advertising and marketing purposes for the benefit of public and commercial customers.
- Implementation of remote sensing techniques and geoinformation systems for environmental monitoring.

The existing archive of remote sensing data of the SSPC "Pryroda" is the largest in Ukraine. It contains aerospace, space data and consists of two parts: a photographic data archive and digital data archive.

Information obtained from "Sich-1", "Sich-2", "Ocean-O", "Meteor-3 M", "Resurs-F", TERRA/MODIS, IKONOS, SPOT-4, 5, NOAA, ERS-1, Landsat-4, Landsat-5, Landsat-7, IRS, Quick Bird, ALOS, EROS, Sentinel-1, Sentinel-2, Landsat 8, Dove (Planet) satellites is stored in digitalized form.

The archive of photo carriers includes satellite images obtained with КАТЕ-200, МК-4, КФА-1000, КФА-3000 cameras and data of aerial photographs.

Official website: *www.pryroda.gov.ua*

Centre for Aerospace Research of the Earth

Development of RS in the Institute of Geological Sciences of the NASU.

The Department of Heat and Mass Transfer in the Earth's Crust of the Institute of Geological Sciences (IGN), the Academy of Sciences of the UkrSSR, in 1974, started application of physical and mathematical methods in aerospace exploration of the Earth when solving theoretical and applied geological and geophysical tasks [5]. The Centre was established in 1992 on the basis of the said Department and Kyiv Research Institute of space and aerial methods

of the former Ministry of Oil and Gas Industry of the USSR and Academy of Sciences of the USSR. The Center for the Collective Use of Spectrometric Equipment operates at the Centre for Aerospace Research of the Earth. In addition, in 2014, Ukrainian Journal of Remote Sensing — an industry-specific online source was established.

The Centre deals with the development of the scientific school "Energy and Mass Exchange in Geosystems". The processes of energy-mass transfer in geosystems and their effects on the physicochemical and biological mechanisms responsible for the formation of the spectral response of natural objects are studied. Researches are fundamental and applied.

The main task of the Centre — fundamental and applied research of the Earth using remote methods in order to obtain new scientific knowledge and implement such knowledge in practice with a view to pursue the innovative development of Ukraine and meet economic, social and defense needs.

The Centre develops and distributes effective methods and technologies for:

- remote exploration of oil and gas deposits on land and shelf;
- agro audit, assessment of condition and yield of agricultural crops on the basis of a comprehensive analysis of aerospace and field data;
- remote evaluation of ecological status of territories and water areas;
- aerospace monitoring of heat losses in urban territories;
- space monitoring and auditing of the greenhouse gas balance, etc.

The aerospace methods and technologies to address natural resources problems, which have been developed at the Centre, are protected by more than 70 patents of Ukraine.

Official website: *www.casre.kiev.ua*

Junior Academy of Sciences of Ukraine

The Junior Academy of Sciences of Ukraine (JASU) — is an educational system that ensures the organization and coordination of research, design, innovative and exploratory activities of Ukrainian students, creates conditions for their intellectual, spiritual, creative development and vocational orientation, and promotes the formation of scientific potential of the country.

In its activities, the Junior Academy of Sciences of Ukraine integrates the best achievements of the pedagogical practice of institutions of general, secondary and higher education and fundamental scientific research of Ukraine's National Academy of Sciences and National Academy of Pedagogical Sciences. Recognized scholars and specialists work on a voluntary basis with young researchers, provide the JASU student members with the opportunity to use specialized libraries, funds, archives and laboratories.

Currently, improvement of the quality of extracurricular education is a topical issue in the educational system of our country. In particular, one of the innovative vectors of the municipal extracurricular educational institution "Kyiv Junior Academy of Sciences" — the territorial branch of the JASU — is the implementation of IT, namely the use of the GIS and RS by the student members in their research activities. Since this trend develops only at the level of higher education in our country, the achievements of the Kyiv Junior Academy of Sciences can be considered a platform for the practical implementation of the GIS and RS in the system of both formal and extracurricular education.

In 2013, a new section — GIS in Geography — was opened within the Department of Earth Sciences at the Kyiv Junior Academy of Sciences. Over the period of its operation, nearly 200 Kyiv city students attended the classes of GIS in Geography section, and more than 30 of them participated in the district and citywide stages of Ukrainian Nationwide Research Paper Defense Competition for the student-members of the Junior Academy of Sciences of Ukraine.

The basic methodological resources for the use of GIS in research activities by the students of Kyiv Junior Academy of Sciences include the curriculum for non-formal education in the field of GIS in Geography, textbooks "Fundamentals of electronic map compilation using ArcGIS 10.1 application", "Reflection of Ukraine's cultural heritage using electronic maps in the GIS environment of the JASU".

Official website: *www.man.gov.ua*

Taras Shevchenko National University of Kyiv

GIS and RS are among the main priorities for university education in Earth sciences of the majority of developed countries worldwide. There is an indispensable link between real-time monitoring and mastering of modern IT techniques in the field of Earth sciences. In Ukraine, there are many institutions of higher education training specialists in this field, which include Taras Shevchenko National University of Kyiv, National Aviation University, Kyiv National University of Construction and Architecture, etc.

Below is given a detailed discussion of GIS and RS study courses held by one of the leading Ukrainian universities — Taras Shevchenko National University of Kyiv (KNU) [6]. The students have an opportunity to master here the specialty of GIS and RS at the Faculty of Geography and at the Educational and Scientific Institute "Institute of Geology". Following completion of the studies, the graduates become specialists familiar with the methods of modern geoinformation technologies and RS data application, required for land management and in municipal information systems, and can implement GIS in the management of territories [7].

Official website: *www.geol.univ.kiev.ua/depts/geoinf*

Educational and Research OSGeo Lab at KNU

The first in Ukraine educational and research open source geospatial laboratory — OSGeo — was established in 2014 at the Department of Physical Geography and Geoecology of the Faculty of Geography of KNU [8]. The primary mission was the development of cooperation between academic, industrial, government and public organizations in the field of free GIS and open geodata.

The laboratory runs many projects using RS-materials and develops training courses. Apart from practical implementation of the projects, the Lab also deals with translation of documents and creates examples for QGIS, SAGA application. For instance, the User Manual of the Semi-Automatic Classification Module, which is used for decoding satellite images, has been translated at the Lab.

Official website: *www.lab.osgeo.org*

"TVIS" LLC

"TVIS" Limited Liability Company — is a private enterprise, which entered the market of the RS-services at the beginning of 2010s and presents itself as the first Ukrainian supermarket of satellite imagery. Owing to direct contacts with operator companies, "TVIS" sells commercial radar and optical data with high spatial resolution (30 cm-3 m), for instance Pleiades 1 A/B, WorldView-1–4. GeoEYE, Spot 6/7, Kompsat 3/3 A, Deimos-2, Planet, and terrain models of Airbus Defence and Space line of products. The company also offers services of aerial photographs decoding, creating and updating topographic maps and orthophotomaps, as well as photography with unmanned aerial vehicles.

Starting from 2010, "TVIS" LLC organizes GISTECH.UA, annual international conference and business forum, usually held in May in Kyiv. This event brings together specialists and interested users of the RS/GIS technology working in Ukraine. In particular, the forum was attended by the representatives of 160 Ukrainian organizations in 2018.

Official website: *www.tvis.com.ua*

1.5. Current State and Development Potential of Remote Sensing Techniques in Ukraine

Introduction of the RS-data into the global information space provides numerous **advantages**: it gives the possibility to improve significantly meteorological forecasts; ensure the monitoring of environment with unique characteristics in terms of scale, repeatability and efficiency; generates additional opportunities when solving the issues of nature management, pollution control, prevention of catastrophic processes, etc. According to achieved success, the conclusion was made at the World Summit on Sustainable Development (Johannesburg, 2002) on the impossibility of sustainable development of world economy without the use of aerospace Earth observation systems.

The most dynamic and consistent development demonstrate the services that address the tasks of the Earth observation. Over the past five years, the total income in this field has been increasing by 4–5% annually, and revenues in Earth observation services demonstrate annual growth of 8–10%. Comparing to 2010, when the budget revenues of Earth observation services amounted to USD 1.0 billion, they increased in 2016 to USD 2.0 billion and, according to the analysts of the

European Commission, by 2020, this market will reach USD 5.3 billion. Such rapid growth results, inter alia, from the wide range of potential users of information products of RS systems, expanded lines of services, which are easy to scale and can be provided in the near real-time and up to online mode. It is important to note that the users of RS-products include government (real sector of economy, the geocadastre service, security, defense and law enforcement agencies, scientific institutions, etc.) and private sector institutions (agro holdings, farmers, resource-extracting companies, and etc.). All mentioned above components make the RS-market very economically attractive.

The stated above shows that the level of the RS development in Ukraine remains quite high and domestic scientists and specialists successfully solve the most complex scientific and applied problems.

It should be noted, however, that there is still a potential for much faster development of RS research, and quicker implementation of obtained results in the real sector of economy and more efficient their use for the benefit of the country's defense. For this purpose, a number of existing negative factors and circumstances should be conquered. In particular, the State Space Agency of Ukraine plans to develop and launch space systems of "Sich" series for remote environmental monitoring. The successful entry of "Sich" products into the international space information market is near-impossible without their validation at land-based test sites in accordance with the standard rules set by the International Committee on Earth Observation Satellites (CEOS). Therefore, one of the most urgent tasks is the harmonization of Ukrainian norms and definitions with the international standards.

In general, the priority tasks in the area of RS development in Ukraine are as follows:

1. Development and establishment of the state RS system, and adjustment of its interaction with national and international systems of environmental monitoring.

2. Performance of scientific and applied tasks on the processing and use of aerospace data with the aim of addressing issues in the field

of natural resources and environment (environmental monitoring of the country and individual regions; forecasting of crop yields and forest fire risks; identification of oil and gas deposits; assessment of the state of urban agglomerations (landslides, flooding, etc.) and quality of land, study of modern geodynamic processes in the restructuring of coal mines, and etc.).

3. Development of methodological guides and software applications for the support of state and sectoral programs of natural environmental monitoring.

4. Terrestrial and ground-truth (aero) calibration and test works at Ukrainian land and sea ranges, which outcomes may useful also in the calibration of imagery delivered by foreign and international SVs.

5. Establishing mutually beneficial cooperation with international organizations and programs.

6. Improvement of scientific and methodological, informational and scientific and publishing activities: holding conferences, seminars and exhibitions, publishing of scientific and technical, educational, methodological, reference and information materials, facilitating the commercialization of data and training of specialists in RS.

1.6. International Organizations

International Society for Photogrammetry (at present — International Society for Photogrammetry and Remote Sensing (ISPRS)) was established on July 4, 1910 by Eduard Dolezal, professor of Technical University in Vienna. It is the oldest international

organization in the field [10]. ISPRS — non-governmental organization devoted to the development of international cooperation in the area of photogrammetry and RS, promotion of their application through encouragement and facilitation of research and creation of scientific networks and holding interdisciplinary events.

Scientific interests of the Society include photogrammetry, remote sensing, geospatial information and cover such related disciplines as cartography, geodesy, Earth exploration and environmental protection.

Official website: *www.isprs.org*

European Space Agency (ESA) — international organization that deals with the fulfilment of joint space exploration programs and practical application of artificial satellites. It was established in 1975 in Paris by the member states of the European Space Conference (Belgium, Great Britain, Denmark, Spain, Italy, the Netherlands, France, German Federal Republic, Switzerland, Sweden). The head office of ESA is in Paris (France).

The organization's activities aim at promoting and developing cooperation between countries in the field of space research, creation and practical application of space systems and technologies for peaceful purposes [11]. Recently, in spring 2018, Ukraine signed agreement on cooperation with the European Space Agency.

Scientific researches play a key role in the activities of the ESA. These researches are mainly focused on:

- technologies for space exploitation in the area of navigation (Galileo project), global environmental and security monitoring (the Copernicus system, formerly known as GMES — Global Monitoring for Environment and Security) and satellite telecommunications;
- space transport technologies that are vital for independent access to space for European countries;
- development of scientific areas of activity in space, for example, within the framework of International Space Station use or related to exploration of space.

With the establishment of the ESA, the EU became as early as in the 1970s the third, after the USSR and the USA, space state, with a powerful infrastructure capable of creating all types of own VSs (except manned ones), and bringing them into orbits by their own carriers from their own spaceports (rocket carriers of Arian series) [12].

Official website: *www.esa.int/ESA*

National Aeronautics and Space Administration (NASA) — is an agency of the United States Federal Government established in 1958 for aeronautics and space research. The head office is in Washington. The first space program of NASA started with the launch of Pioneer SV in 1958 that collected information for further manned space activities, the most famous of which was the Apollo-11 Moon landing mission, which took place on July 16–24, 1969 [13].

Since its establishment, NASA has conducted the majority of its space exploration programs in the USA, including Apollo-11 mission, Skylab space station and a space shuttle later on. NASA supports International space station and supervises the development of multipurpose Orion crew, space launch system etc.

NASA's scientific research aim at studying the Earth through the use of the Earth observation system, and heliophysical research as part of the "Heliophysics" research program. The Agency also explores cosmic bodies throughout the Solar system, using advanced technologies and explores astrophysical issues, such as Big Bang, via related programs.

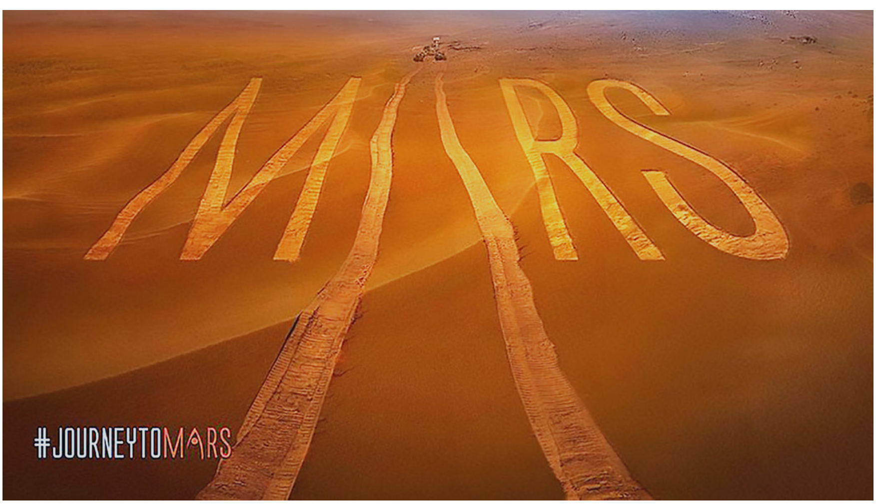

Fig. 1.5. NASA's graphics "Trip to Mars" [13]

NASA's ongoing investigations include in-depth surveys of Moon, Mercury, Mars and Saturn and studies of the Sun. Other active spacecraft missions are *Juno* for Jupiter and *Dawn* for the asteroid belt [13].

In 2017, NASA officially declared that it has been working on sending humans on Mars by the year 2033.

> AAmerica's space agency, NASA, issues a book of satellite images, which presents satellite imagery as unique pieces of art. The book is called **"Earth Art"** and contains the collection of the best images from various parts of the Earth. To find out more, visit www.nasa.gov/connect/ebooks/earth_art_detail.html..

Official website: *www.nasa.gov*

Global Earth Observation System of Systems (GEOSS)

Since the First Earth Observation Summit in 2003, there has been continued work over the creation of harmonized Earth observation system using the existing ones [14]. The Third Summit held in Brussels in 2005 adopted the GEOSS 10-year implementation plan.

Earth observation systems comprise instruments designed for measuring, controlling and forecasting physical, chemical and biological data. Meteorological stations register the state of air masses, temperature and tendencies of climate change; ocean buoys monitor water temperature and salinity; underwater sound ranging and radar systems estimate populations of fish and birds; seismic and global positioning systems (GPS) record crustal movements and changes in the terrain of the planet; high-tech satellites scan the planet out of space; powerful computerized models generate simulations and forecasts; and early warning systems alert on potentially hazardous situations.

Generally, all these systems operate independently. Over the last years, however, there have been put into operation complex technologies with the aim to collect large volumes of high-resolution Earth observation data in a real-time mode. At the same time, improved forecasting models and decision support tools offer increasing opportunities for the extensive use of this flow of information.

Since the costs of technical, financial and administrative support of further expansion of Earth observation are very high and beyond the power of individual states, the combination of different observation systems through international cooperation provides significant cost saving and makes it possible to get a complete picture of the state of the Earth.

GEOSS supports data sharing principle, which aim is to ensure full and open exchange of data, metadata, and products. GEOSS delivers information and analysis directly to users. GEOPortal is the only internet gateway to the data produced by GEOSS.

There are nine main areas of GEOSS data use: disasters, healthcare, power industry, climate, water, weather, ecosystems, agriculture and biodiversity.

Official website: *www.earthobservations.org*

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Section 2

PHYSICAL PRINCIPLES OF REMOTE SENSING

Section 2.

PHYSICAL PRINCIPLES OF REMOTE SENSING

2.1. Electromagnetic Radiation

Light is an electromagnetic radiation (EMR) within the certain range of electromagnetic spectrum. When represented schematically, light is a diagram of electric and magnetic fields oscillating perpendicular to each other. **Electromagnetic spectrum** is a system, which “classifies all energy by wavelengths (from short wavelength cosmic energy to long wavelength radio waves) that travel harmonically with constant speed of light” (NASA, 2013).

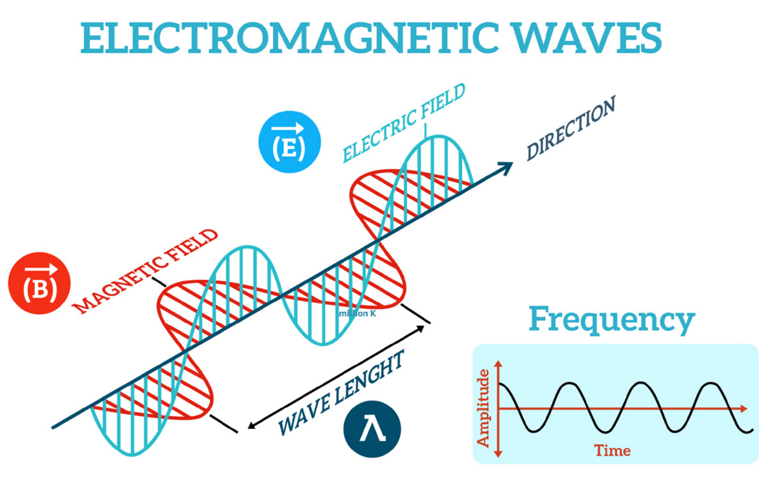


Fig. 2.1. Electromagnetic waves

The phenomenon of white light division into its component colors is well known (as early as in 1629, Descartes determined how the beams pass through prisms and glasses of various forms), but it was Newton who provided the explanation for this phenomenon in 1666, after his successful experiment with splitting of the beam of light by the prism [1]. White color is composed of the sum of simple colored beams, of which violet beams have the highest angle of refraction and red — the lowest one. Each color of the spectrum is monochromatic, i.e. single-color, and has its own wavelength and frequency, which form the electromagnetic spectrum.

Wavelength — distance between two consecutive points, or crests, of the waves. In fact, it is the distance the wave passes over the period equal to one oscillation. The wavelengths are very diverse (from nano microns to tens of kilometers).

Wave's frequency — number of repetitive oscillations made by the wave in 1 second. In other words, the shorter the wave is, the higher frequency it has.

It is the change of wavelength and frequency that gives special properties to the waves, according to which the waves are divided into gamma-, beta-, alpha-waves, X-rays, ultraviolet radiation, visible rays, infrared rays and radio waves.

The range of electromagnetic waves with different frequencies is called a *spectrum*.

Electromagnetic waves have the same properties as the waves of other nature, namely they:

1) exhibit even and rectilinear propagation in a homogeneous environment;
2) are reflected by dielectrics and conductors according to the law of reflection;
3) exhibit refraction;
4) focus;
5) cause diffraction and interference; and
6) polarize.

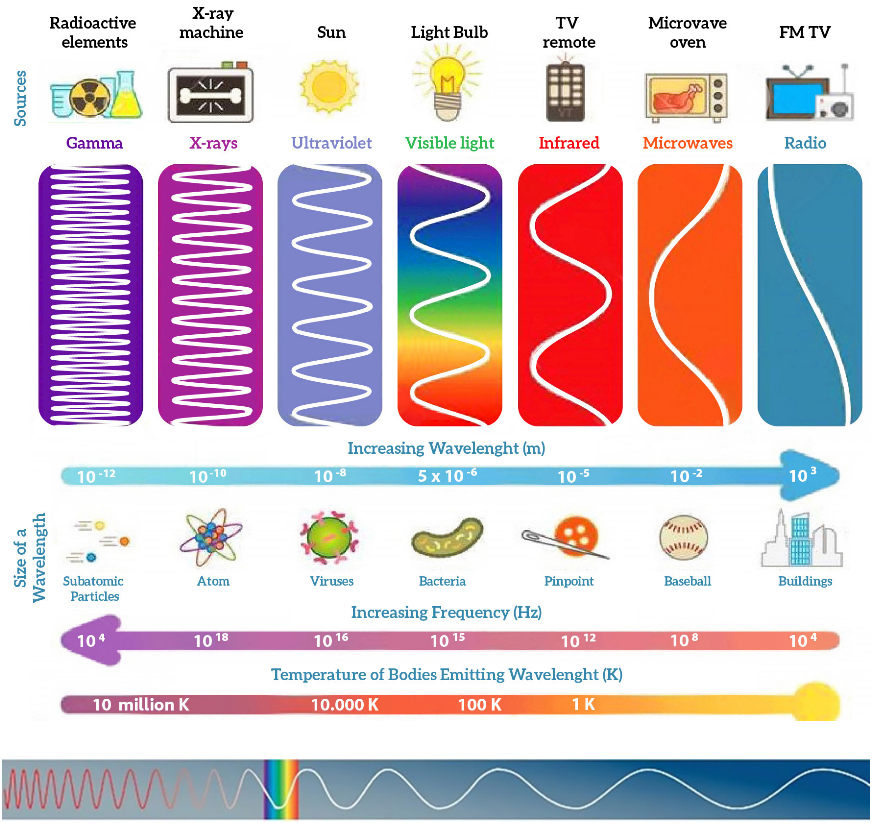


Fig. 2.2. Electromagnetic spectrum

The following ranges of electromagnetic radiation such as ultraviolet, visible, infrared, microwave, and radio are used to obtain remote sensing data.

Ultraviolet range (0.1–0.38 µm) is used to assess the state of plants and water reservoirs, and determine the expansion of trace gases and ozone in atmosphere.

Visible (0.38–0.74 µm) range and **infrared** (0.75–1000 µm), which is divided into three types due to its wide range: near-infrared (0.75–1.5 µm), intermediate (1.5–3 µm) and far-infrared (3–1000 µm) radiation *(see Fig. 2.3)*.

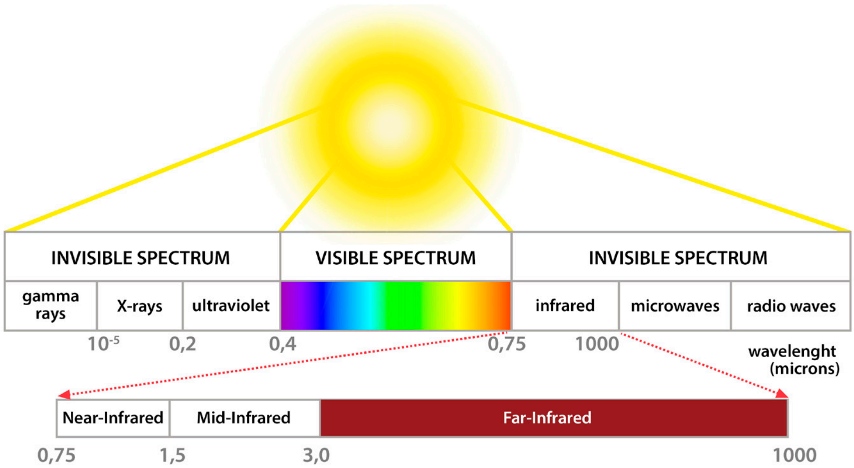


Fig. 2.3. Pattern of infrared spectrum distribution

Near-infrared and visible ranges are widely used to obtain images of forest areas. The following principle is applied to get information — spectral characteristics of objects on the Earth's surface change under different conditions.

For example, the chlorophyll contained in the leaves absorbs red and blue rays, and mostly reflects green ones. Within the blue and red zones of the visible spectrum the plants' ability to reflect rays is very poor. But within the near-infrared range maximum values of reflection coefficients have been registered. Therefore, when studying the condition of forests, the images made in the "far red" (wavelength 0.7–0.75 μm) of the visible spectrum and near-infrared ranges (0.78–0.88 and 0.9–1.05 μm, respectively) are used.

Color – subjective characteristic of light that represents the ability of the human vision to distinguish frequencies of electromagnetic oscillations within the visible light. The spectrum consists of 7 colors: red, orange, yellow, green, blue, dark blue, and violet, which produce other colors when overlay. Red, green, and dark blue colors are the most important for our sight. And it is because different bodies reflect, refract and absorb light in different ways, we see everything around us in color.

It is known that electromagnetic waves emitted by the objects have different lengths. Long waves are perceived as red-orange, short – as green and blue.

Eye retina consists of several layers, including the layer of photo- and color sensitive cells. There are two types of cells in the retina: rods, sensitive to light intensity, and cones, sensitive to color. Cones can perceive colors only in good light and that is why everything seems gray at night.

Every living creature on the planet perceives and interprets the world in its own way. What a human eye sees is the minimum part of what can be seen. The world is completely different from what we see. The limitations of human eye prevent us from seeing what is really surrounding us. Instead, the methods of remote sensing make it possible to see more; they reveal to us a real world that we cannot see due to the limited possibilities of our vision.

Thermal range (2.5 μm — 1 mm) provides information on the heat field. It has been shown that the temperature difference can reach several degrees in different types of vegetation, plantations of different densities, composition and age, in the surface layer, at the level of the surface and in the soil. Therefore, the application of thermal imaging technique provides additional information about forests, conditions of their locations, etc.

Thermal imaging survey can be used to detect ill, damaged and dead wood, because they sharply differ from healthy vegetation in the temperature intensity. In addition, thermal surveys are one of the best methods for detecting forest and peat fires.

As you know, 65-70% of the human body consists of water, and the active resonating frequency of water is about 8 to 10 μm and belongs to long-wave radiation.

The waves with long-wavelengths of 4 to 14 μm have the most beneficial effect on the human body. Waves with a length of 10 μm can penetrate up to 2-3 cm deep in the body, warming up tissues, organs, muscles, bones and joints. The effect of thermal treatment is based on this property of infrared radiation. The same principle is utilized in infrared heaters, which heating source transmits energy with 3-10 μm wave frequency.

This part of the radiation corresponds to the radiation of the human body, so any external emission with the same length of waves has beneficial influence on the human body.

Microwave radiation (1 mm — 1 m) range provides information about topographic characteristics of territories and water zones, deposits of moisture in soil and plant leaves, effects of industrial emission on plants.

Radiofrequency range (1 m — > 10 km) provides information about the underlying terrain. Radar surveying is characterized by deep shadows, used to identify objects with significant level differences. Radiofrequency range allows for analysis of the relief of the territory, identification of hazardous natural processes, such as mudflows, landslides etc. Radar photography is possible under any weather conditions and at any time of the day.

Processes of Scattering, Absorption and Atmospheric Dispersion

Solar radiation travels from the Sun to the Earth and is captured by the sensor. On its way, the solar energy can be (NASA, 2013) [2]:

- Penetrating — energy penetrates atmosphere and its speed changes depending on the refraction indexes of various media.
- Absorbed — energy that is transmitted to an object via electron or molecular reactions.
- Reflected — energy that returns unchanged with the same angle of reflection as the angle of incidence. Reflectance is the ratio of the reflected energy to incident energy. The wavelength of reflected energy (not absorbed one) determines the color of an object.
- Dissipated — the direction of energy propagation changes at random. Rayleigh or Mie scattering are the two most important types of atmospheric dispersion.
- Emitted — in fact, energy is first absorbed and then emitted again, usually with longer wavelengths. The object heats up.

Dispersion of light — the phenomenon, in which the velocity of light beam propagation in a given medium depends on the beam color (dependence of absolute refractive index on the length of light wave). It is a common phenomenon in our life, which, however, often remains unnoticed.

A rainbow is an excellent illustration of light dispersion. A rainbow is a very complex optic phenomenon involving numerous physical processes. It forms as a result of splitting of sun beams by raindrops into seven colors, i. e. dispersion in the raindrops.

R. Descartes was the first to provide scientific explanation of the rainbow in 1637, and in 30 years, I. Newton supplemented his theory with clarification of the refraction of colored beams in raindrops.

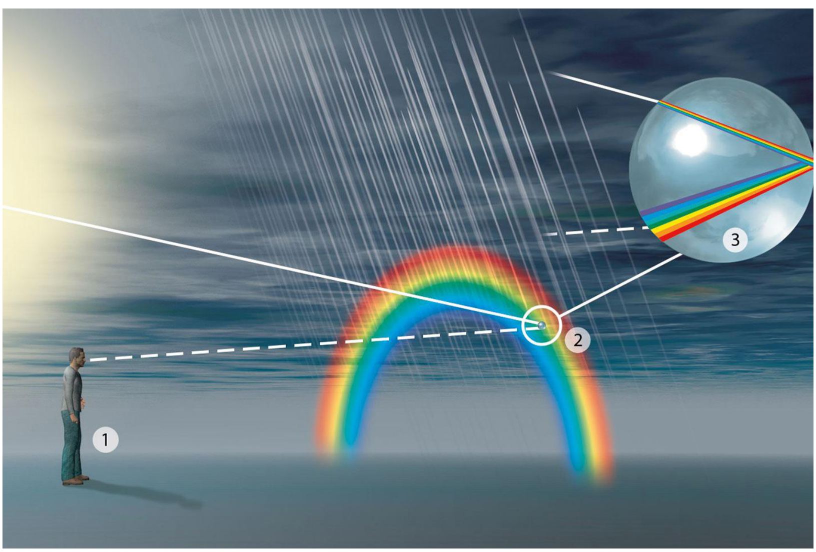


Fig. 2.4. Conditions for rainbow formation [3]

Conditions for rainbow formation:

1. It appears only when the sun comes out from behind the clouds and only on the opposite to the sun side.
2. It appears when the sun throws light on the blanket of rain.
3. It is essential that the sun's elevation angle does not exceed 42^{o}.

When passing through the fuzzy barrier between vacuum and atmosphere, solar radiation is partially scattered by atmospheric gases and aerosol impurities, partially absorbed and converted to heat that warms up the atmosphere. Unscattered and non-absorbed in the atmosphere, direct solar radiation reaches the Earth's surface, where it is partially reflected by the surface and the majority of it is absorbed and causes heating of the surface.

Solar radiation with the highest speed possible travels millions of kilometers to reach the Earth. However, when it enters the Earth's layer of gases, atmosphere, a great amount of radiation, including a good deal of harmful one, is absorbed. Water vapor, oxygen and ozone, carbon dioxide reduce the transmission at certain wavelengths, creating absorption bands in the atmosphere. Portions of electromagnetic spectrum to which Earth's atmosphere is transparent are called ***atmospheric windows***. For example, one of them lies in the range of 300–750 nm and lets ultraviolet and visible light to pass through [4].

Absorption

The atmosphere absorbs the majority of harmful ionizing radiation, creating for the human comfortable living conditions on the planet. Water accounts for nearly 70% of the total absorption of solar radiation in the atmosphere.

For example, *ultraviolet* is absorbed in the upper atmosphere. The energy of ultraviolet photon is used to split a single O_2 molecule into two atoms. Free atoms are then combined with the oxygen molecule to form a molecule of ozone [4]. The latter is not entirely stable and under ultraviolet light splits into atom of oxygen and oxygen molecule.

Absorption occurs as a result of interaction of photons with molecules in the atmosphere. Molecules absorb photons with a certain quantum of energy only. It must coincide with the amount of energy required by the electron to move to another energy state or to raise the entire molecule to another level of vibration [4].

Scattering

Scattering of light — the process of solar energy redirection through interaction with molecules and particles present in the atmosphere. There are several types of scattering depending on the relative size of particles participating in the process compared to the length of solar radiation wavelength.

Rayleigh scattering is caused by molecules of oxygen, nitrogen and fine dust particles.

The scattering increases with the lower wavelengths, i.e. it is wavelength-dependent. This means that violet and blue spectral bands are subject to greater scattering than, for instance, red one (4-fold increase). This is the reason for the blue color of daytime sky. At sunset, the rays have to pass longer distance in the atmosphere than normal and scatter more. Much of the blue light has been scattered out, leaving the red light in a sunset.

Mie scattering is caused by smoke, dust, pollen and droplets of water. This type of scattering also depends on the wavelength, however to a lesser degree than Rayleigh scattering. Pure Mie scattering causes the sky to look off-white.

Non-selective scattering is caused by bigger droplets of water and dust. By contrast to the previously described types, this scattering is not dependent on the wavelength of incident radiation. It occurs when the particles are much larger than the wavelength. This type of scattering is partially responsible for the white color of clouds [4].

Visible light is a kind of electromagnetic radiation, it is a narrow part of the electromagnetic spectrum that is visible to the human eye (400–700 nm). In laboratory tests, human eye can perceive objects in the infrared range of up to 1050 nm, and young people and children perceive wavelengths in the ultraviolet to about 310–313 nm.

However, some birds and mammals see the world "wider" than the humans do — in the portion of the ultraviolet spectrum, and snakes can even perceive objects in the infrared spectrum (see Table 2.1).

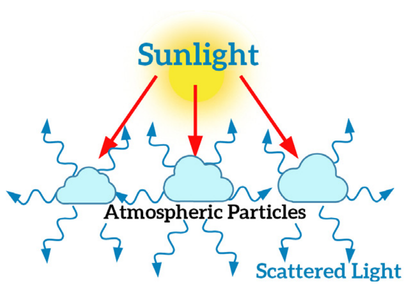


Fig. 2.5. Scattering of light [5]

Section 2. PHYSICAL PRINCIPLES OF REMOTE SENSING OF ENVIRONMENT

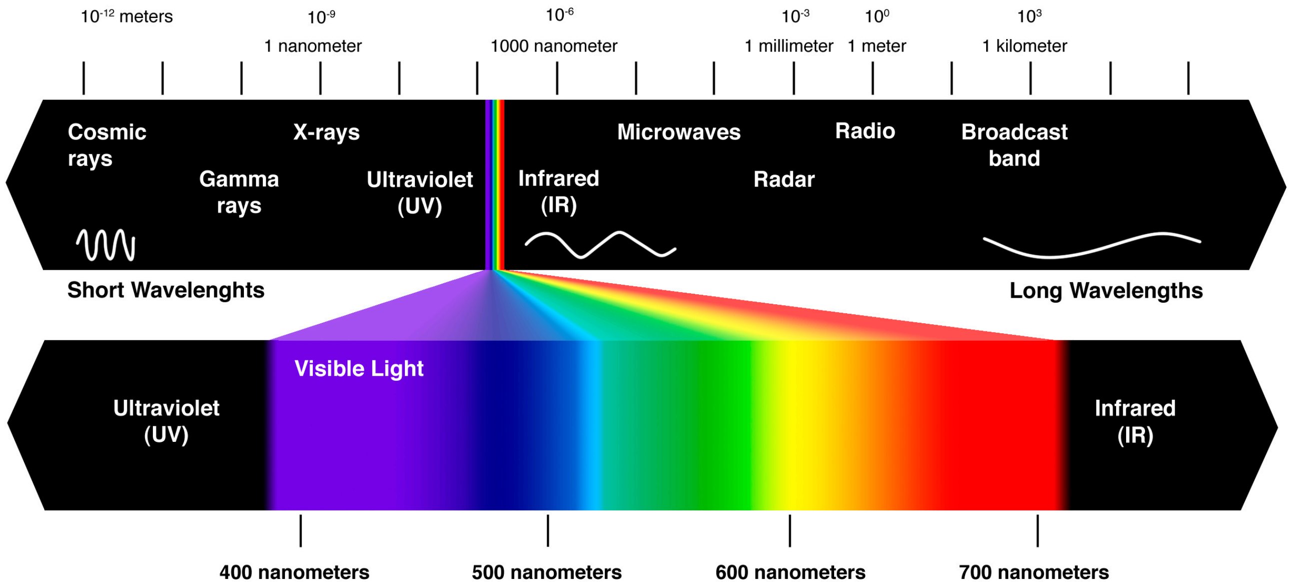


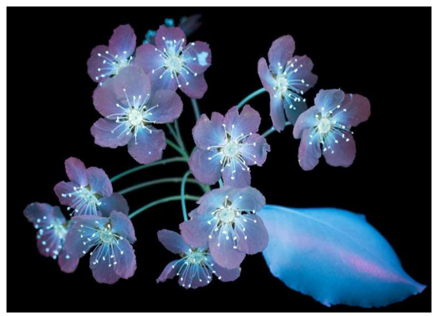
Fig. 2.6. Portion of visible light in the spectrum

Table 2.1. *The way animals see the world (according to [6], supplemented)*

A flower in visible *(a)* and ultraviolet light *(b)*

a *b*

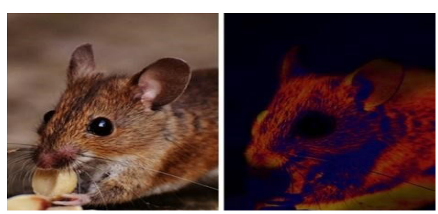
A flower in infrared light; image taken by photographer Craig Burovs [7]



Pigeons can distinguish more color gradations than advanced computer applications. Pigeons are thought to have the most powerful vision. They can see in five spectral bands. Picture *a* demonstrates how the human eye can see, and picture *b* shows the abilities of pigeon's vision.

a *b*

Snakes can see in two modes. In one mode, snakes see objects the same way as human eyes do, and distinguish all colors quite well *(a)*. The other mode is similar to infrared *(b)* and allows them to distinguish warmth emitted by living creatures.



a *b*

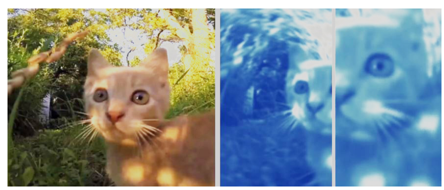
Parrots *(b)* may perceive the whole color spectrum that the human eye can see *(a)* plus ultraviolet, which is of key importance for their lives.

a *b*

Fish have a strong color perception; they distinguish the whole spectrum visible to human eyes *(a)* plus ultraviolet (some fish species can also see in the infrared spectrum) *(b)*.

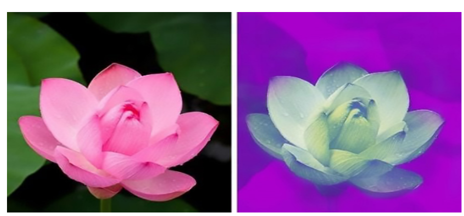
a *b*

Mice have dichromatic color vision. They distinguish blue and partially ultraviolet spectra. They poorly identify color shades, but are good in distinguishing the color intensity.



a *b left right eye*

Bees see wider color spectrum, including ultraviolet light *(b)*. It makes possible for the bees to find pollen on the flowers. They see sort of "runways" on the flowers, invisible for the human eye *(a)*. Generally, concentric colored circles or points, specifying the location of nectar, represent such runways. Interestingly, red roses remain nearly invisible for the insects since in ultraviolet light these flowers do not have sharp change of color.



a *b*

Dogs do not differentiate red and greed colors, and do not see the difference between these two colors and yellow and orange *(b)*. Many people *(a)* cannot even imagine that dogs don't distinguish the colors.

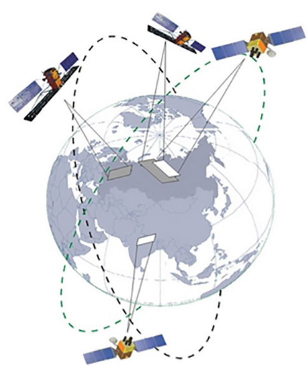
a *b*

Cones of **cat's** eyes (like in the majority of other mammals, except for primates *(a)*) lack a pigment sensitive to red color *(b)*. Some mammals (primarily primates) have three types of cones: sensitive to blue color, sensitive to green color and sensitive to yellow-green and red colors.

a *b*

2.2. General Pattern of Remote Sensing

Our world experiences massive digital transformations. We make everything automatic, measure everything that moves and changes, from satellites and unmanned aerial vehicles. The development of technical facilities, high regularity, promptness and availability of remote sensing materials now allow for the implementation of the tasks, which previously could only be performed using expensive professional equipment.



Combination of surface information with remote sensing data regarding the territory, use of modern computer technologies and various mathematical models makes it possible to perform a comprehensive study of the problem using remote survey.

Depending on the information flows used (obtained from various survey systems in terms of physical content), the RS systems can be classified as follows:

- airbased imaging systems (digital photogrammetry);
- spacebased imaging systems (space photogrammetry);
- LiDAR and laser airbased systems (LiDARgrammetry);
- spacebased radar systems (radargrammetry).

Passive and Active RS

RS system measuring natural emission operates with **passive remote sensing**. Accordingly, this system can sense only when there is natural emission available:

- during the day — in the visible range;
- during the day and at night — in thermal infrared and microwave range.

Another type of RS is **active remote sensing**. It operates under the following principle: the device installed at the satellite has a source of emission, which is directed to a studied object and the satellite registers subsequently the reflected emission.

Advantages:

- imaging is possible at any time of the day;
- it is possible to control the emission generated by the device installed at the satellite;
- it is possible to use the wavelengths rarely available in natural emission sources.

One of the examples of active RS is LiDAR (Light Identification Detection and Ranging). This technique is used to obtain and process information about remote objects and operates on the basis of light absorption and scattering in optically transparent media, already discussed in subsection 2.1.

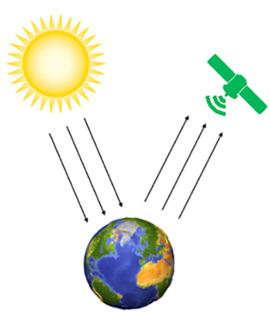


Fig. 2.7. Passive RS

This imaging technique allows for measuring distances to the target (a studied object) by illuminating the target using pulsed laser light and measuring reflected impulses with the sensor. The difference in the time of laser signal return and wavelengths can be used to create digital 3D-models of the target [48].

LiDAR is generally used in the compilation of high-resolution maps. This technology is applied in various sectors, in particular, geodesy and cartography, archeology, geography, geology, forestry, meteorology, etc., as well as for the management and navigation of some autonomous vehicles [48].

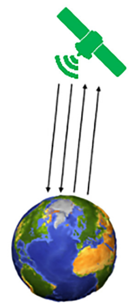


Fig. 2.8. Active RS

Systems of Remote Sensing: Aeropace- and Ground-based

There are two types of RS — ground-based and aerospace (according to the location of the carrier, which transmits data). **Aerospace RS** mainly refers to the cases when the carrier is located in outer space.

Efficacy of RS system depends significantly on the effectiveness of the ground-based infrastructure of satellite control, and receipt, processing and distribution of data (**ground-based RS**). For the purposes of the users, satellite information is delivered to the branched network of reading sites [8]. In Ukraine they are, namely:

- Center of the Special Information Receiving and Processing and the Navigating Field Control (Dunayivtsi town);
- Center for Radio Physical Sensing of the Earth under NAS and SSA of Ukraine (Kharkiv city) and other organisations.

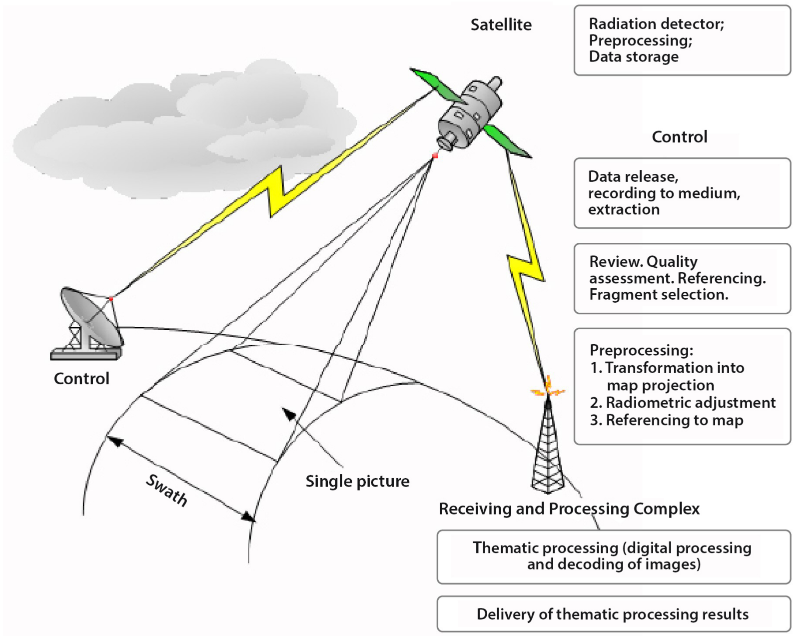


Fig. 2.9. Systems of remote sensing — aerospace- and ground-based [9]

2.3. Aircraft Carriers

To make imaging possible in RS, the surveying equipment is installed on a carrier, which raises it to the desired height, moves relative to the earth's surface and provides a certain orientation in space.

According to the type, there are two main groups of carriers used in RS systems *(Fig. 2.10):*

- aircraft — airplanes, helicopters, sail-planes, trikes, unmanned aerial vehicles, aerostats (airships and air balloons);
- space — artificial satellites of the Earth and other planets, space stations, interplanetary space vehicles.

Aerial photography is performed with the use of specially equipped airplanes or helicopters. Depending on the aerial camera axis, there are two types of aerial survey — vertical and oblique.

In **Vertical (planimetric)** air photography the camera axis is perpendicular to the ground that allows for horizontal imaging. However, as the plane sways during the flight, the camera bends.

Compared to vertical, **oblique images** capture big areas and the resulting images have more usual for human eye perspective.

Aircraft-base imaging systems are equipped with GPS receiver (registration of linear element of external orientation) and inertial navigation system INS (registration of inclination angles of a camera). This equipment is being constantly improved, especially with regard to the accuracy of determining the angles of camera's inclination.

Drones — mobile instruments with a high level of detail. Since the flying height of the drone is usually from 100 to 300 meters above the Earth's surface, it is possible to obtain images with a resolution of centimeters per pixel.

Drones make it possible to collect huge amounts of data within the shortest time. One of the special features is that drones allow for the use of spectral cameras, which obtain images in the near infrared spectrum. Based on such images, the NDVI-indexes are calculated [11].

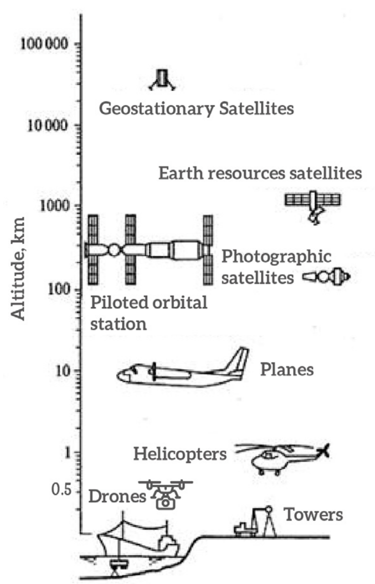


Fig. 2.10. Carriers of RS photography systems (according to [10], supplemented)

Fig. 2.11. Layout of ground surface imaging from drone [12]

The use of drones has both advantages and disadvantages. The **advantages** include immediacy of imaging, mobility, high accuracy (from 2 cm), and possibility of imaging in cloud cover. The **disadvantages** are mainly the following: effect of weather conditions on the quality of images, zones inappropriate for photography (territories near airports, military and restricted premises), high cost of drone.

Dronestagram – the first social media platform for drone photography. Currently, the most advanced culture of photography using unmanned aerial vehicles is in the USA, France, UK, Brazil and Italy.

Annually, National Geographic publishes at Dronestagram, the platform for sharing drone photography, photos made by the winners of Drone Aerial Photography Contest. All drone pictures are unique, since they provide a view of the world, which is not possible for a man. It is a new look at the world. In 2015, among the photos selected for the Contest, was a picture of light fire at the petroleum storage depot in Vasilkivskyi district of Kyiv region.

Fig. 2.12. Fire at petroleum storage depot near Kyiv city, in Kriachky village of Vasylkivskyi district (picture made from drone, 2015) [12]

Currently, the drones represent the one of the best technologies, which opens up new horizons.

2.4. Space Carriers

Space monitoring became ingrained in our everyday lives. Scientists estimate that as of 2018, there are over 18 000 manmade objects on the Earth orbit [13]. They all capture images of the Earth's surface and provide information for further processing and addressing specific issues.

Technical progress in the field of space imaging is associated with:

- increased spatial resolution of imaging systems;
- extended spectral range of registered images and possibility to obtain multispectral pictures.

Classification of SVs is rather time-consuming task, since each vehicle is unique and the range of tasks performed by SVs is constantly expanding. Currently, the most required are telecommunication, navigation, remote sensing and scientific satellites. Military and reconnaissance satellites constitute a separate group however they perform the same tasks as their "civil" peers.

Every year, 20–25 new systems are put into operation. The pioneer in the creation of ultra-high resolution systems is the United States, primarily GeoEye and DigitalGlobe companies. Nearly all countries of the world participate in the joint international space projects. Overall, the USA, Russia, France, Ukraine, India, China, Israel, Japan, Germany and Italy have their own space-based systems.

In January 2018, British company Earth-i launched VividX2 satellite. It was the first of 15 satellites, which make it possible to record the objects up to 60 cm in size with the speed of up to 50 pictures per second. It is quite sufficient to see the cars on the highway and even people. Besides, it is not a military project.

VividX2 can create real-time video for landing strips of airports; track the traffic of ships in harbors and cargoes in ports. The images can be used to control the exact number of cars on highways, calculate the people crossing state borders, and determine the capacity of wind power plant in real-time mode and even to track the migration of birds [14].

Information from space is obtained using surveying instruments installed on space aircrafts, which can be classified into artificial earth satellites (AESs), manned spacecrafts (MSs), manned orbital space stations (MOSSs), and automatic interplanetary stations (AISs) [15].

2.4.1. Artificial Earth Satellites (AESs)

First off, if there are natural satellites (for the Earth it is the Moon, which we sometimes simply call "satellite"), there are also artificial ones. These are objects that are launched into the orbit of the Earth or other celestial bodies with manpower. We would not have satellite TV or the Internet without AESs; they are used for both practical and scientific purposes.

As early as in 1957, it became obvious that the space studies in the USA are not far off and soon a satellite would be launched. The Soviet Union, instead, kept intrigues and organized a network of optical observation stations. In autumn 1957, there have already been established 66 stations at universities, pedagogical institutes, and observatories.

The Lviv station was organized at the Faculty of Physics of Lviv University and had a number 1031. The staff of the first Lviv observers of the AESs consisted of the employees of the Astronomical Observatory and the students of the Faculty of Physics of Lviv University [16].

Over the period of the station's operation, 1957-1968, more than 5000 visual images reflecting the positions of 120 different artificial space objects were received.

At the end of the 1960s, first visual, and then photographic observations of AESs in Lviv were closed. The station 1031 was transformed into the Department of the Astronomical Observatory.

The German V-2 rocket was the world's first man-made object to travel into space, which was successfully launched in early 1944. All USA and USSR space programs started with the launch of these rockets.

In 1953, the USSR initiated a successful testing of R-5 rocket, which became a major step forward, compared to V-2. With the range of flight 1,200 km, the R-5 became the first Soviet missile with nuclear warhead. In 1956, it was adopted for armament.

In 1954, the development of R-7 rocket — the world's first intercontinental ballistic missile started. With the help of this rocket, the first satellite was put into orbit, which transmitted to the Earth radio signals of sufficient power to be registered by amateur radio stations. In January 1958, the satellite deviated from the orbit and, apparently entering the earth's atmosphere, totally burnt up.

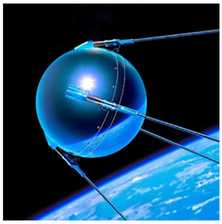


Fig. 2.13.
The first artificial satellite of the Earth [17]]

The First Satellite

The beginning of the flight — October 4, 1957 at 19:28:34 Greenwich Mean Time.
End of flight — January 4, 1958.
On-orbit life — 92 days.
Revolutions made — 1440.
Weight — 83.6 kg.
Maximum diameter — 0.58 m.
Inclination of the orbit — 65.1°.

In November 1957, the USSR launched the second satellite into outer space carrying a living animal — dog named Laika, and in May 1958 — the third one. This was the beginning of a regular launch of new satellites, Moon and interplanetary space probes.

There are following main types of satellites:

- astronomical satellites — used to explore planets, galaxies and other space objects;
- biosatellites — designed for the scientific research and experiments on living organisms in space;
- weather satellites — used to make weather forecasts and monitor the Earth's climate;
- orbital stations — SVs, intended for the long-term stay of people in the near-Earth orbit for the purpose of conducting scientific researches in the outer space.

2.4.2. Manned Spaceships

Manned spaceships are SVs intended for the flight of people into space. Vostok-1 was the first manned spaceflight in the history. It was launched on April 12, 1961, with cosmonaut Yuri Gagarin aboard, making him the first human to cross into outer space. And on June 16, 1963, Vostok-6 was launched, which became the first human spaceflight to carry a woman, cosmonaut Valentina Tereshkova, into space. During the flight of Voshod-3, the next series of manned spaceships with up to 3 crew members, Alexei Leonov became the first person to leave the spacecraft to conduct a "spacewalk" on March 18, 1965.

The series of American manned spaceships includes Mercury (1961–1963), Germini (1965–1975), Apollo (1968–1975), and reusable spacecraft Space Shuttle (1981–2011). Apollo-8 was the first manned spacecraft to reach the Moon, orbit it, and return; and during the Apollo-11 mission, American astronaut Neil Armstrong was the first man to land on the Moon. The latest series of Soviet and now Russian multimanned spacecarfts include SVs of Soyuz series, which has been operating since 1967 and up to now. Another example of a series of modern manned ships is Shenzhou, Chinese multimanned vehicles developed in 2003. Manned spacecraft today are mainly used for the delivery of crews and cargoes to orbital stations.

2.4.3. Orbital Stations

Orbital stations are space vehicles intended for the long-term stay of man in the near-Earth orbit for conducting scientific research in outer space, exploration and monitoring of space objects, as well as the surface and atmosphere of the Earth. The orbital stations include SVs of Salyut program, Kosmos-557, SkyLab, Mir, International Space Station (ISS), Genesis and Tiangong.

Modern orbital stations have modular architecture. Separate blocks or modules of the station are delivered to orbit gradually by cargo spacecraft, depending on the needs and technical tasks and the purpose of the research to be conducted on it. Some Soviet Salyut stations have been joined to constitute the Almaz space program, which was designed to perform the tasks of the Ministry of Defense of the Soviet Union. In particular, on July 18, 1987, there was successfully launched an automated version of Almaz orbital station, named Kosmos-1870. High-quality radar images delivered by it have been widely used both in defense field and for the monitoring of natural resources *(Fig. 2.14).*

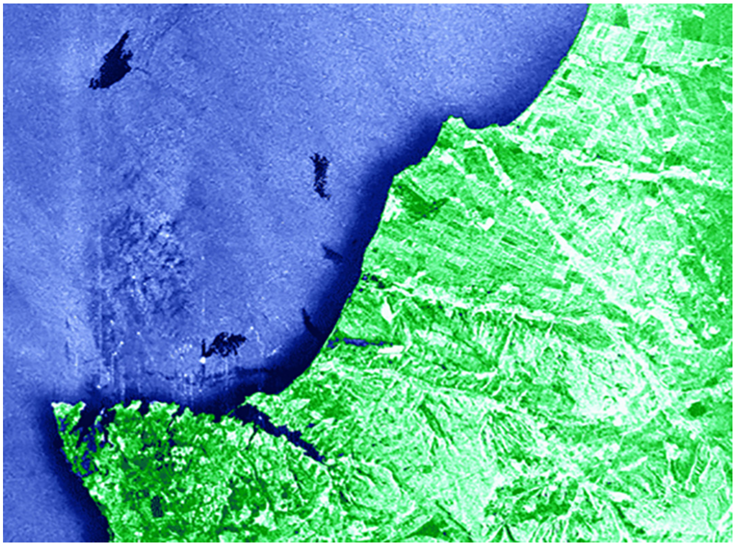


Fig. 2.14. Radar imaging by Almaz-1 (in pseudo color), the Black Sea water area near the northern coast of Crimea, there are clearly visible vessels (white dots), some of which dump ballast water contaminated with oil (black spots). Source: Archives of SSPC "Pryroda"

International Space Station

The International Space Station is a manned artificial satellite travelling on the Earth's orbit at an altitude of 330 to 435 km (205 and 270 miles). Currently, ISS is the largest AES on the orbit. ISS has a modular structure: its various segments have been created by the efforts of participating countries for the special purposes: experimental, residential or storage. The ISS program is a joint project of five space agencies: NASA, Roscosmos, Japan Aerospace Exploration Agency, European Space Agency and Canadian Space Agency. It is 18 years to the day since the first crew arrived at the station (November 1–2, 2000). It is the longest in the history uninterrupted human stay in the Earth orbit, which exceeds the previous record of 9 years and 357 days, spent on Mir station. ISS has been visited by astronauts, spacemen and space tourists from 17 countries.

History of Development and Perspectives

The first module of the ISS, (Russian "Zarya"), was launched in 1998 and used at an early stage of the station assembly, as the source of electrical power and for attitude control and maintenance of temperature mode. Currently, Zarya is used as a warehouse. The last module was installed in 2011. It was initially planned that ISS station would be kept running through 2010. Now, another date was announced — 2028. According to experts, after decommissioning ISS will not be plunged into the ocean and will be used as the base for interplanetary space ships.

The ISS is the largest human-made body in low Earth orbit and can often be seen with the naked eye from the Earth. The ISS serves as a microgravity and space environment research laboratory in which crewmembers conduct experiments in biology, human biology, physics, astronomy, meteorology, and other fields.

The station is divided into two sections, the Russian Orbital Segment (ROS) and the United States Orbital Segment (USOS), which is shared by many nations. According to the original Memorandum of Understanding between NASA and Roscosmos, the International Space Station was intended to be a laboratory, observatory and factory in low Earth orbit. It was also planned to provide transportation, maintenance, and act as a staging base for possible future missions to the Moon, Mars and asteroids. In the 2010 United States National Space Policy, the ISS was given additional roles of serving commercial, diplomatic and educational purposes. The ISS crew provides opportunities for students on Earth by running student-developed experiments, making educational demonstrations, allowing for student participation in classroom versions of ISS experiments. With the support of ISS, ESA offers a wide range of free teaching materials that can be downloaded for use in classrooms. In one lesson, students can navigate a 3-D model of the interior and exterior of the ISS.

ISS also provides a wide range of training materials for non-formal education. They include, in particular:

■ International Observe the Moon Night [18] is a global celebration of "lunar" science and research, held annually starting from 2010. It is one day each year to look at and learn about the Moon together. The event is held in September or October, when the Moon is in its first quarter. During this period, the Moon is visible at noon and in the evening.

The next dates for the International Observe the Moon Night:

October 5, 2019;
September 26, 2020.

■ HubbleSite is the development of Space Telescope Science Institute (official website — http://hubblesite.org/), which aims at the distribution of information about the space for educational purposes.

HubbleSite makes it possible:

- using video clips, investigate constellations, planets, deep space objects that can be seen every month in the sky;
- to see the photos of planets and other space objects that are made from the space telescope and read more information about them.

■ For the purposes of education, NASA experts have also prepared a series of information and educational video records "Not a small step" for the students that assist in getting more information about the functions and features of the ISS.

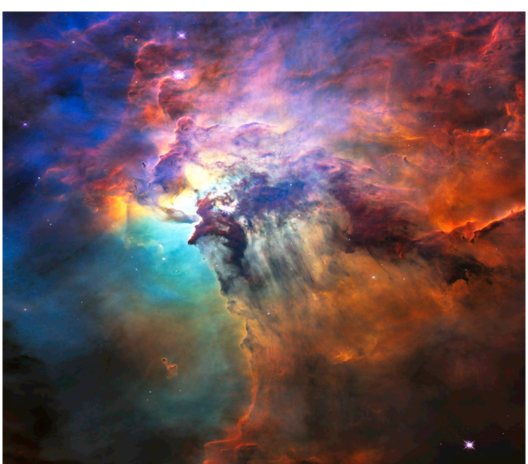


Fig. 2.15. Lagoon Nebula (visible view). This colorful image has been made by NASA Hubble space telescope [19]

In general, there are many educational materials based on the operation of the ISS and they are divided into categories [20], depending on the age of participants: for teachers, students, NASA kids club etc.

2.5. Examples of the Most Popular Remote Sensing Systems (Landsat, Sentinel, Terra (Modis, Aster), RapidEye, Planet Labs)

The specified Earth observations are becoming the main driving force in the so called Forth Industrial Revolution — the era of Big Data analytics.

The amount of data received using satellites, unmanned vehicles and sensors is increasing faster than the machines for their processing and application are developed. Currently, we can receive real-time data in many various formats. This flow of data and easy access to databases creates a beneficial environment for innovations.

Geospatial real-time data can be tracked online at www.liveearth.com.

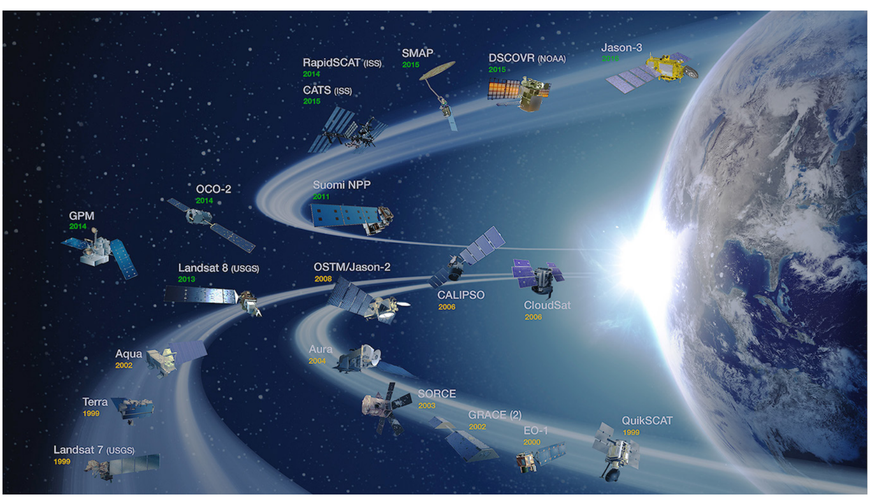


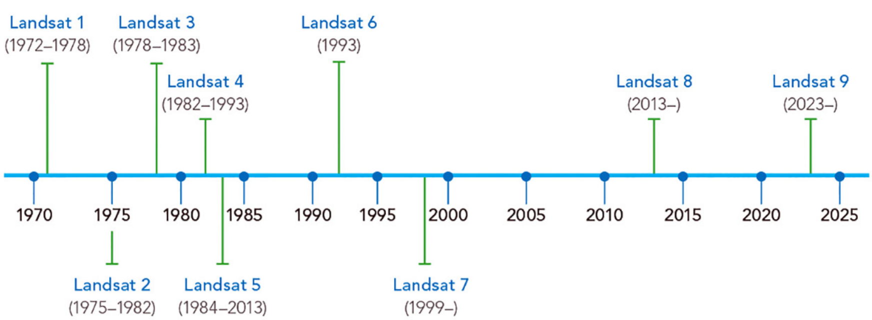
Fig. 2.16. Examples of satellites used for observation from space [21]

The distinguishing characteristic of geospatial data is that they are the tools for integration and analysis of time and space. Geospatial data are used to develop new models and find new solutions. It is the geospatial data revolution that allows us to have a comprehensive view of the world, and solve problems more efficiently; it also facilitates better decision-making process.

Landsat

The Landsat program is the longest-running enterprise for the acquisition of satellite imagery of the Earth. The first satellite within the program was launched in 1972, the most recent one, Landsat 8, on February 11, 2013. The tools installed on the Landsat satellites have produced millions of images. The images, archived in the United States and at receiving stations around the world, constitute a unique resource for a number of researches in agriculture, cartography, geology, forestry, regional planning, surveillance and education. In particular, Landsat 7 data have eight spectral bands with spatial resolutions ranging from 15 to 60 meters; the global temporal resolution is 16–18 days.

Satellite chronology [22]:



Landsat 1 (originally named ERTS-1, Earth Resources Technology Satellite 1) was launched on July 23, 1972, and decommissioned on January 6, 1978.

Landsat 2 (ERTS-B) was launched on January 22, 1975 and decommissioned on January 22, 1981.

Landsat 3 was launched on March 5, 1978 and stopped its operation on March 31, 1983.

Landsat 4 was launched on July 16, 1982 and decommissioned in 1993.

Landsat 5 was launched on March 1, 1984 and stopped its operation on December 21, 2012.

Landsat 6 was launched on October 5, 1993 but it failed to reach the orbit.

Landsat 7 was launched on April 15, 1999 and is still running. In May 2003, there was registered a malfunctioning of the Scan Line Corrector (SLC) module. Since September 2003, it has been used without correction of scanning lines, which reduces the amount of information to 75% of originally received data [23]. Landsat 7 has the same 7 bands, similar to Landsat 4 and 5, plus one additional band with wide spectral range and resolution of 15 m per 15 m. In addition, the spatial resolution in band 6 (thermal infrared range) has been increased from 120 to 60 m. These modifications along with the high level of accuracy make it possible to better study the global changes and perform major mapping [24].

The Landsat program is running within the Landsat Data Continuity Mission. Currently (2018), there is Landsat 8 satellite in orbit, which was launched on February 11, 2013.

The launch of Landsat 9 is scheduled for 2023 [26].

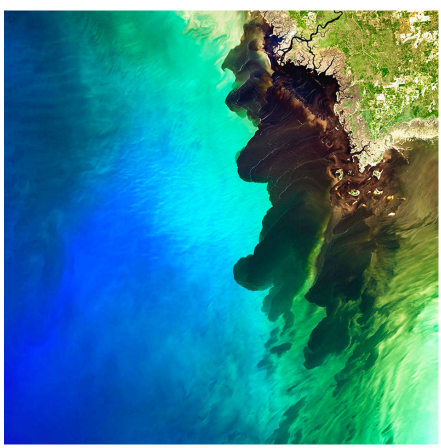


Fig. 2.17. Landsat 8 satellite image — OLI of river with black water that meets with the sea in the Gulf of Mexico (February 20, 2015) [25]

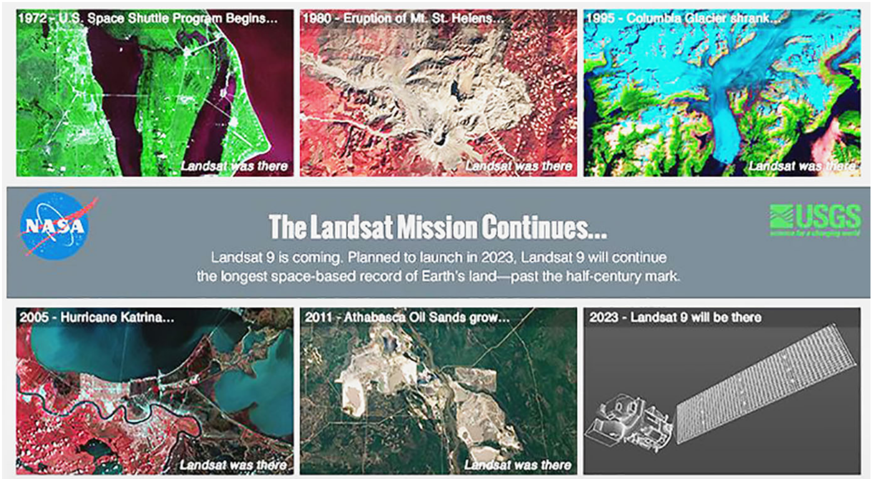


Fig. 2.18. Continued Landsat mission [26]

Today, the remote sensing data obtained by the Landsat spacecrafts have been used in more than 100 countries. Of these, 17 countries, including the United States, have their own data acquisition stations. Information delivered by the satellites of Landsat system is widely used in addressing numerous economic, scientific, political and military issues. In particular, RS data found application in the following fields: geography, oceanography, hydrology, geology, study of natural resources of individual regions, countries and the Earth in general, mapping of the Earth's surface, environmental control.

Sentinel

Copernicus is the European professional programme managed by the European Union with its space component coordinated by the European Space Agency (ESA). The programme provides data required for timely monitoring of the environment and civil security. All the data are made available on a full, open and free-of-charge basis.

Sentinel Missions

ESA is currently developing seven missions under the Sentinel programme. The Sentinel missions include radar and super-spectral imaging for land, ocean and atmospheric monitoring. Each Sentinel mission is based on a constellation of two satellites, providing robust datasets for all Copernicus services.

Fig. 2.19. Constellation of Sentinel satellites [27]

The Sentinel missions have the following objectives [28]:

Sentinel-1 provides all-weather, day and night radar imaging. The first Sentinel-1A satellite was successfully launched in 2014, and the second, Sentinel-1B, in two years — on 25 April 2016.

Sentinel-2 provides high-resolution optical imaging for land services (e. g. imagery of vegetation, soil and water cover, inland waterways and coastal areas). Sentinel-2 also provides real-time information for emergency services. The first Sentinel-2 satellite was successfully launched on 23 June 2015.

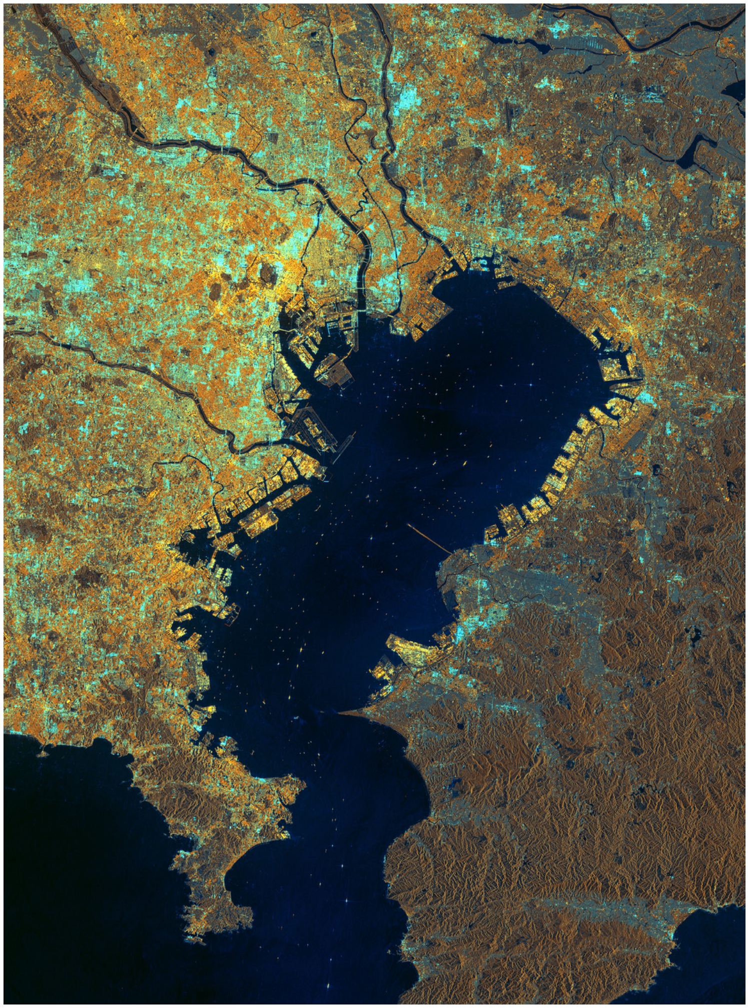


Fig. 2.20. Radar image from Sentinel-1A,
July 11, 2014, Tokyo Bay in Japan [29]

Sentinel-3 provides ocean and global land monitoring services. The first Sentinel-3A satellite was launched on 16 January 2016.

Sentinel-4 will be launched in 2023. It is intended to provide data for monitoring of atmospheric composition and operate jointly with a Meteosat Third Generation Satellite.

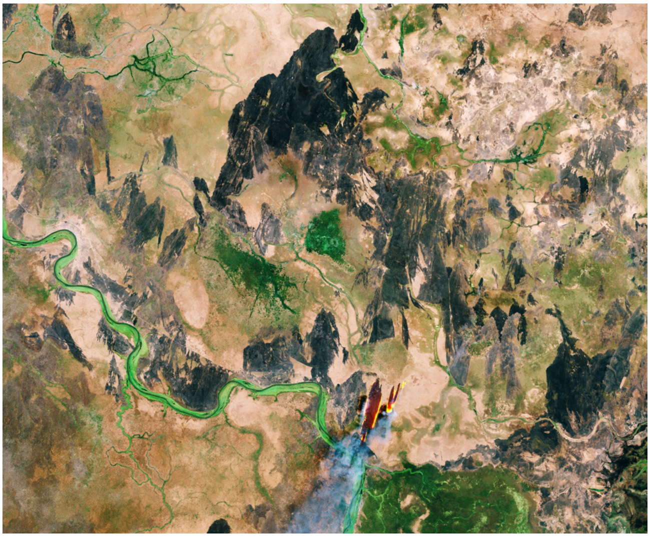


Fig. 2.21. Image of the Southern Sudan made from Sentinel-2B satellite [30]

Sentinel-5 Precursor is a subset of the Sentinel 5 sensor set. It was launched on 13 October 2017. The primary purpose of this was to reduce the data gap (especially SCIAMACHY atmospheric observations) between the loss of ENVISAT in 2012 and the launch of Sentinel-5 in 2021.

Sentinel-5 will also provide data for atmospheric composition monitoring. It will be embarked on a post-EUMETSAT Polar System (EPS) spacecraft and launched in 2021.

Sentinel-6 is intended to provide continuity in high precision altimetry sea level measurements following the Jason-3 satellite. Sentinel-6A, also known as the Jason Continuity of Service (Jason-CS), is scheduled for launch in November 2020.

Sentinel-7 is Carbonsat mission (measuring of carbon dioxide content).

Sentinel-8 is thermal infrared mission.

Sentinel-9 is infrared mission for measuring ice and snow.

Sentinel-10 is hyperspectral mission.

In addition, within the framework of Copernicus programme, special services are being created in EU using Sentinel satellites [31]:

1) Land Monitoring Service provides geographical information on land cover and its changes, and vegetation state, which can be used for spatial planning, forestry management, water management, agriculture, etc.

2) Marine Environment Monitoring Service provides regular and systematically updated information on the state of oceans and sees, and, as a priority, data on currents, winds and sea and ocean ice movements. This information will help to improve ship routing services, offshore operations or search and rescue operations, thus contributing to marine safety. The service also contributes to the protection and the sustainable management of living marine resources, in particular for fishery, research etc.

3) Atmosphere Monitoring Service provides continuous data and information on atmospheric composition. It provides daily information on the global atmospheric composition, develops maps of distribution of greenhouse gases (carbon dioxide and methane), reactive gases (e.g. carbon monoxide, oxidized nitrogen compounds, sulphur dioxide), ozone and aerosols.

4) Emergency Management Service provides timely and accurate geospatial information required for emergency management in case of natural disasters, man-made emergencies, as well as humanitarian crises.

5) Climate Change Monitoring Service is designed to address environmental and social issues associated with climate changes caused by human activities. The service provides access to information for monitoring and forecasting of climate changes and, therefore, contributes to supporting adaptation and mitigation of potential consequences.

6) Security Service deals with border surveillance, maritime surveillance; in particular, in terms of border surveillance, the main objective is to reduce the death toll of illegal immigrants. In terms of maritime surveillance, the overall objective of the European Union is to support Europe's maritime security objectives and related activities in the maritime domain.

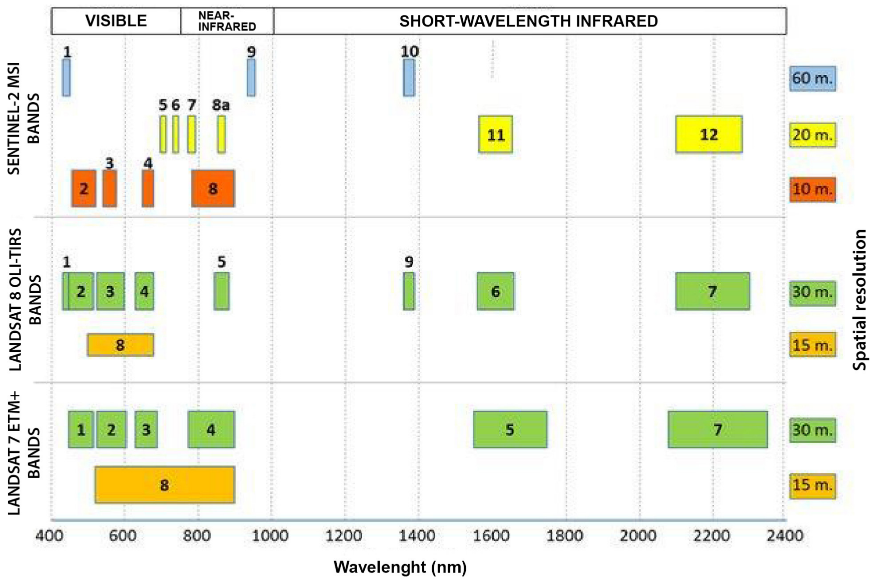


Fig. 2.22. Comparison of Sentinel-2 and Landsat 7 and 8 bands [32]

The location of Sentinel-2A bands compared to Landsat 8 and Landsat 7 bands is illustrated in Fig. 2.22. Sentinel-2A satellite features spectral bands similar to those of Landsat 8 (except for the thermal band of thermal IR-sensor of Landsat 8). Of the 11 Landsat 8 bands, only shortwave (1–4 and 8) correspond to the visible spectrum; others are sensitive to the areas of the spectrum not visible by the human eye. Sentinel-2 satellite produces images within 12 spectral bands, where RGB and NIR bands have spatial resolution of 10 m.

Terra

In December 1999, NASA launched Terra satellite designed for systematic observations of the Earth. Terra carries a payload of five tools designed to monitor the state of Earth's atmosphere, ocean, land, snow and ice, and energy budget *(Fig. 2.23)*. In general, these observations provide unique information on how the Earth system functions and changes. They also show the influence of humanity on the planet and provide important data on natural hazards such as fires and volcanoes [33].

The Earth's energy budget, or terrestrial radiation balance, is the difference between total (direct and diffuse) solar radiation absorbed by the earth's surface and the effective irradiation of the same surface; it can be positive (during the day, in summer) and negative (at night, in winter) [34].

Terra carries a payload of five remote sensors designed to monitor the state of the Earth's environment and ongoing changes in its climate system:

- ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) is used to produce temperature maps of the Earth surface, emissivity, reflectance and altitude maps;
- CERES (Clouds and Earth's Radiant Energy System) measures the total background radiation of the Earth and provides assessment of the cloud properties, which allows scientists to determine the role of clouds in the radiation flux from surface to the top layers of the atmosphere;
- MISR (Multi-angle Imaging Spectroradiometer) is designed to measure the intensity of solar radiation reflected by the Earth system (planetary surface and atmosphere) in various directions and spectral bands;
- MODIS (Moderate-resolution Imaging Spectroradiometer) is designed to provide measurements in large-scale global dynamics including changes in the Earth's cloud cover, radiation budget and processes occurring in the oceans, on land, and in the lower atmosphere;
- MOPITT (Measurements of Pollution in the Troposphere) is designed to monitor changes in pollution patterns of the atmosphere [35].

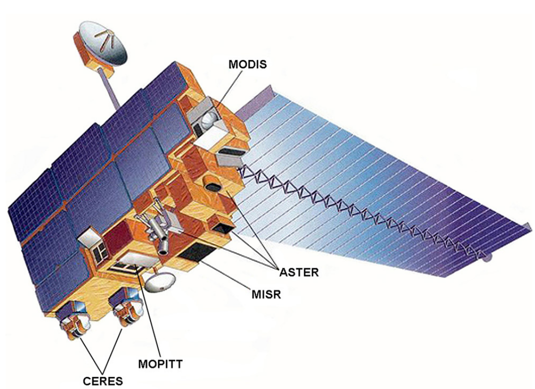
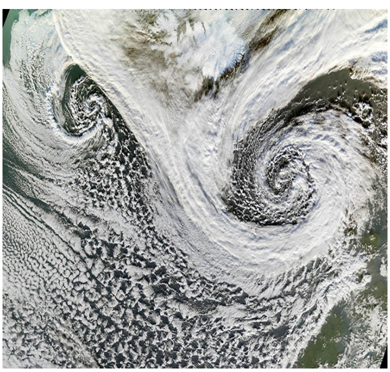


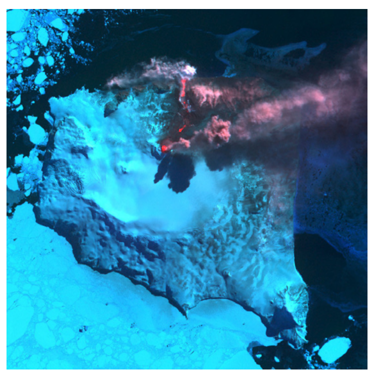
Fig. 2.23. NASA sketch of SV Terra with specification of the tools [33]

***MODIS* scanner** *(Moderate Resolution Imaging Spectroradiometer)* is one of the key payload scientific instruments of American Terra and Aqua satellites of EOS series, which captures images of the Earth surface along the path with a swath width of 2300 km and nearly daily global repetition; it collects data in 36 spectral bands (hydro spectral imaging technique) ranging in wavelength from 0.4 to 14.4 μm. The instruments produce images in two bands of visible and near infrared ranges of spectrum at spatial resolution of 250 m, and in five bands of visible, near and middle IR ranges — at spatial resolution of 500 m, and in the rest of bands — at 1000 m). The entire set of MODIS bands allows replacing the data of SeaWIFS, AVHRR/NOAA imaging systems with the addition of new bands in the thermal range. The scanner is designed to observe large-scale global dynamics, including changes in Earth's cloud cover, heat balance and processes occurring in the oceans, on land, and in the lower atmosphere *(Fig. 2.24).*

Earth heat balance is the balance of energy of heat transfer and emission processes occurring in the Earth's atmosphere and on its surface [36].



a



b

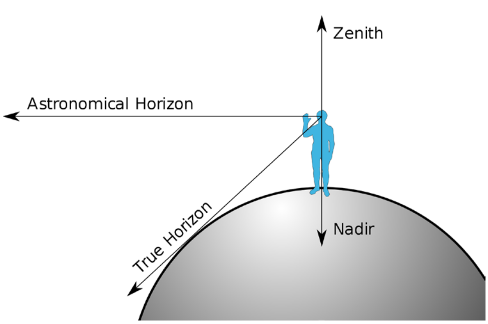
Fig. 2.24. Examples of satellite images made by MODIS spectroradiometer on board of Terra satellite:
a — the image of two cyclones that were formed in tandem (on November 20, 2006);
b — the image of volcanic eruption of mount Belinda on Montagu Island, identified by MODIS thermal alert system based on heat abnormalities or "hotspots" in October 2001 [38]

Terra-MODIS datasets can be accessed free-of-charge. The global catalogue of materials is available at: *https://modis.gsfc.nasa.gov/data/*. In Ukraine, the MODIS data is received in Dunayivtsi town (Khmelnytsk region).

MODIS remote data is useful in addressing various tasks related to regular monitoring of natural phenomena over large regions (e. g. monitoring of ice conditions, global snow cover trends, wildland fires, floods, vegetation etc.) [37].

Ice conditions – the state of ice cover of seas, rivers, lakes, water storage basins at a particular time point, or ice distribution according to various characteristics in the area of its floating.

There is one more multispectral (hyperspectral) scanner on board of Terra satellite — ***ASTER*** *(Advanced Spaceborne Thermal Emission and Reflection Radiometer)*. The scanner provides images in 14 different bands: three in visible and near infrared range with the spatial resolution of 15 m (for stereo photography), six bands in short-wave infrared range with resolution of 30 m and five bands in thermal range with resolution of 90 m. The swath of ASTER is 60 x 60 km. Off-nadir angle of +/– 106 km for thermal and short-wave infrared bands and up to +/- 314 km for visible and near IR bands does not allow making images of any territory more frequently than every 16 days in all 14 bands and every five days in the three bands of visible and near IR light. Production of images using ASTER scanner is relatively inexpensive.



The nadir (from Arabic, meaning "counterpart") – the apparent point of intersection of a vertical line to the surface of the earth ellipsoid with the celestial sphere; the point of celestial sphere opposite the zenith. In other words, nadir is facing downward from the observer to the center of the Earth [39]..

The images can also be received using the Internet via FTP (typically, data is ready to be downloaded in a few hours, sometimes in 1–2 days). Large amounts of images (about 120 MB for full picture) and limited access time (three days from the time of order, 24 hours from the time of the first access) require high-speed connection; it is preferable to have the software allowing data downloading under the conditions of communication interruption [37].

RapidEye

The RapidEye satellite constellation, consisting of five mini-satellites, was launched from Baikonur Cosmodrome on Dnepr carrier rocket on August 29, 2008. The space vehicle is owned by BlackBridge AG company (formerly known as RapidEye AG) (Germany). Every satellite manufactured by MDA Company (Canada) jointly with SSTL (UK) is equipped with multi-spectral imager of Jena Optronics GmbH (Germany), capable of capturing images with the spatial resolution of 6.5 m. Each RapidEye satellite weighs 150 kg *(Fig. 2.25)*.

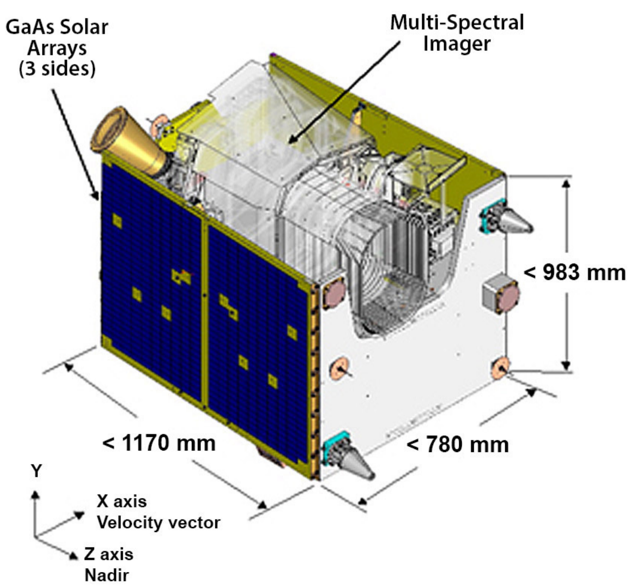


Fig. 2.25. Layout of RapidEye satellite [40]
(image credit: SSTL, MDA, BlackBridge)

The collection of high-resolution surface image data is made in five bands. The unique is the "red-edge" band that perfectly matches for the observation of changes in the vegetative cover. The designed on-orbit lifetime of these satellites is 7 years.

Each satellite was given a Greek name — Tachys, Mati, Choma, Choros, Trochia (which means "Fast", "Eye", "Earth", "Space" and "Orbit", respectively) *(Fig. 2.26)*. The satellites travel on the same orbital plane — at an altitude of about 630 km. Circling the Earth from North to South, the satellites cross equator at 11:00 am local time with a distance of about 660 km and interval of 20 min. The images are produced in sessions with the maximum swath width of 3000 km. During one session, a satellite can capture images of 77 km wide and 1500 km long Earth surface area *(Fig. 2.27)*.

Fig. 2.26. Five RapidEye space vehicles before their launch [41]

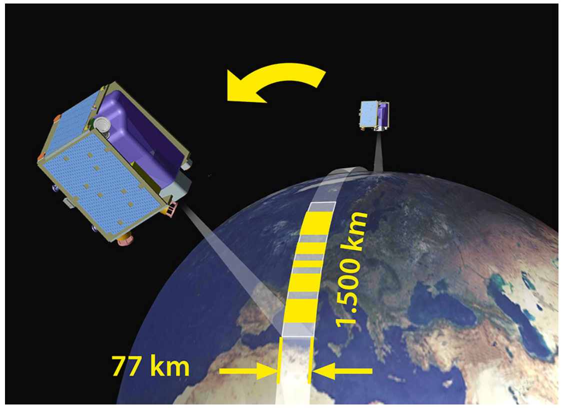


Fig. 2.27. RapidEye imaging session [40]]

Thus, RapidEye satellites are capable of providing a daily coverage of 4 million square kilometers. The parameters of RapidEye satellite constellation have been optimized to provide data that can be applied in various industries, primarily in agriculture and forestry; oil and gas industry, energy and infrastructure, telecommunications; in thematic and special mapping; ecology and environmental safety; and crisis management [40] *(Fig. 2.28).*

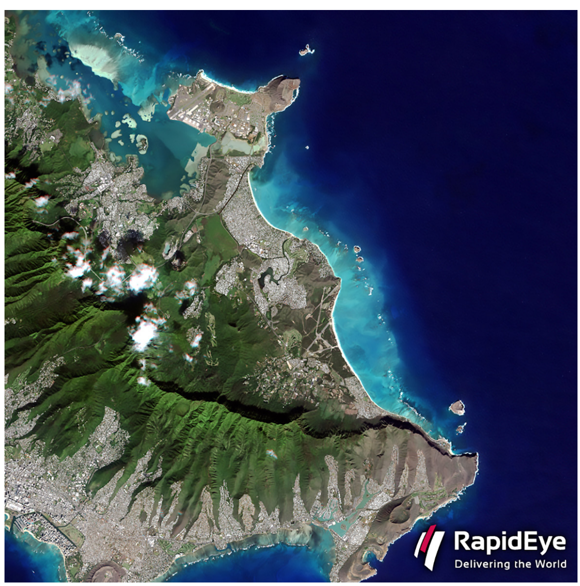


Fig. 2.28. Example of satellite image made by RapidEye, Oahu island, Hawaii [42]]

Planet Labs

Planet Labs is a startup of former NASA scientists, who initially met at one of the conferences for young researchers interested in the exploration of space. The main goal of the company was to develop a service that provides an opportunity to access real-time imagery of any area on the Earth's surface for a subscription fee. Unlike Google maps, the data will be updated every day and allow for near real-time monitoring of changes in the areas of interest.

The Planet company designs and manufactures miniature satellites for remote sensing, called Doves. The constellation of dove-satellites, Flock, provides the global coverage of the Earth and produces images with a resolution of 3–5 m, the portion of which is freely available. The Planet company states, that in contrast to many Earth-imaging companies, it continuously designs and improves the satellites (at the moment, the development of the 14^{th} generation doves is in progress) [43].

Doves are small cylindrical satellites equipped with cameras and solar batteries, which can be launched into orbit by the dozens at once. One satellite does not exceed in size the shoebox (10x10x30 cm), weighs about 5 kg, and belongs to CubeSat type. It is easier and cheaper to deliver into orbit small-sized and lightweight objects. Additionally, in case of launch failures, the loss of inexpensive satellites is not a big deal. The estimated lifecycle of one satellite is 3 years, after which the satellite reenters the atmosphere and must burn up completely, leaving no debris in the orbit.

The satellites are equipped with sensors providing imagery in four spectral bands (blue, green, red and near infrared) and with a spatial resolution of 3–5 m, depending on the flight altitude. They are orbiting at an altitude of about 400 and 475 km. The satellites travel on two orbits: of the International Space Station and sun-synchronous. On sun-synchronous orbit, the satellite makes complete revolution in about 90 minutes, which is 16 revolutions around the Earth per day.

In addition, each "dove" has Forest Stearns' artwork on it *(Fig. 2.29)*.

Flocks

The goal of Planet Labs is to image the entirety of the planet daily, so it plans to develop a set of satellites that produce images of the Earth's surface one-by-one, like a scanner; this goal can be achieved with lots of satellites in orbit *(Fig. 2.30)*.

Over the last years, the company has launched 233 satellites aboard various American, Indian, Japanese and Russian rockets. The satellites are often delivered into orbit as secondary payloads on other rocket launch missions [43].

Planet Labs started to create a "flock" in 2014 with the launch of Flock-1 constellation. Then, in 2015–2017, there were launched units of Flock-2 constellation, and in 2017, the company launched the largest constellation ever put on orbit — Flock-3, which consists of 88 CubeSats.

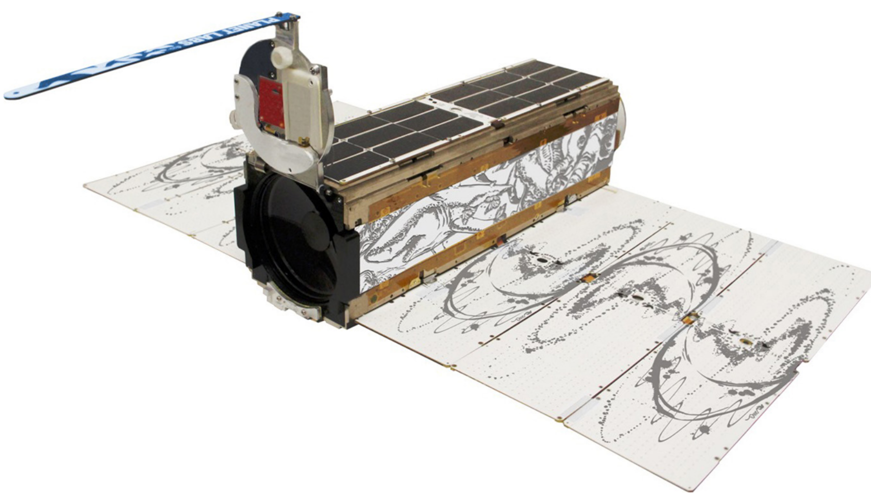


Fig. 2.29. Dove satellite,
photo by Planet Labs [43]

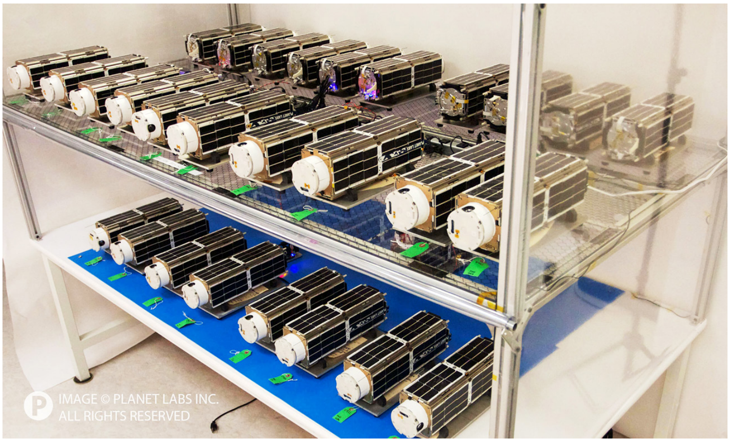


Fig. 2.30. Photo of the satellite batch of Planet Labs [43]

Besides, the company launched six more SkySat sub-meter resolution observation satellites in October, in addition to seven units already present in orbit.

To manage all satellites, the company develops its own software for automation. This software allows a small number of people to plan imaging, update programs on the devices and download data [43].

The images gathered by the satellites can be accessed online and provide information relevant for weather monitoring, prevention of natural disasters and crop yield forecasting *(Fig. 2.31)*. With acquisition of BlackBridge in July 2015, Planet Labs had 87 Dove and 5 RapidEye satellites. In 2017, Planet launched an additional 88 Dove satellites. The combined batches of Doves form the largest constellation ever put into orbit.

Most of traditional satellite images show the surface of the Earth with great detail, but from one perspective — exactly perpendicular. In this case, dimensional objects are lost on the background of everything else, so the Planet team decided to reconfigure some satellites, including 13 SkySats, located at an altitude of 450 km above the Earth, and provide images at a scale of 80 cm per pixel. After that, satellites began to capture images from a certain angle. The difference was significant *(Fig. 2.31, b)*.

2.6. Space Debris

Humanity is no longer able to stop using space technologies. Therefore, it is obvious that the number of satellites and space debris will increase.

The term "space debris" literally means the pollution of space. This term was introduced as early as in the 1980s. This problem has been recognized officially on the international level following the report by Secretary General of the UN: "Environmental Effects of Space Activities" (1993).

According to official data, there are 7500 tons of space debris in space now (BBC News, 2018). In total, there are about 70–150 thousand objects of 1 to 10 cm in size, and millions of bits of debris smaller than 1 cm in diameter in orbit around the Earth. In low Earth orbits, within 400 km of the ground surface, the pieces of space debris slow down their speed by the upper atmosphere and fall back towards Earth; however, objects located in geostationary orbits can orbit for an unlimited time.

The situation with space debris makes worse every year. First off, any pieces of space debris (small or large) affect the objects placed in the orbit. There is also a potential danger of pieces of space debris falling on the Earth. As of 2018, there is also Elon Musk's Tesla Roadster travelling in the outer space, which was launched in February.

a *b*

Fig. 2.31. Examples of satellite images by Planet Labs:
a — Northern part of Crimea — intense and differing colors of lakes are due to the vital activity of microorganisms [44]; *b* — tridimensional satellite image of Doha city, Qatar [44]

The greatest concentrations of space debris are found in two areas. The first one — low Earth orbit, within 850–1200 km of the ground surface. It is also the orbit for many meteorological, military and scientific satellites. The second area of pollution is geosynchronous orbit (beyond 30000 km), where over 800 objects of various countries are travelling. Every year this number increases by 20–30 new stations.

Large parts of rockets and blocks used for launching a satellite into orbit as well as defunct satellites account for nearly 85% of the space debris. And about 12% result from processes of disintegration during launching and commissioning of satellites.

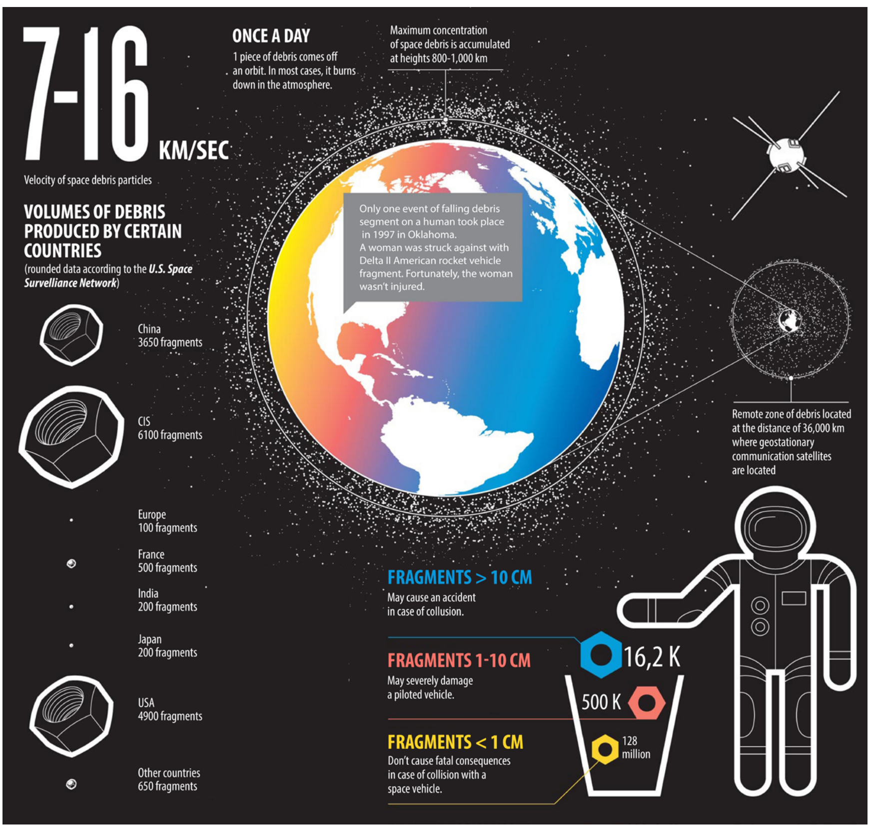


Fig. 2.32. Space debris (according to [45], supplemented)

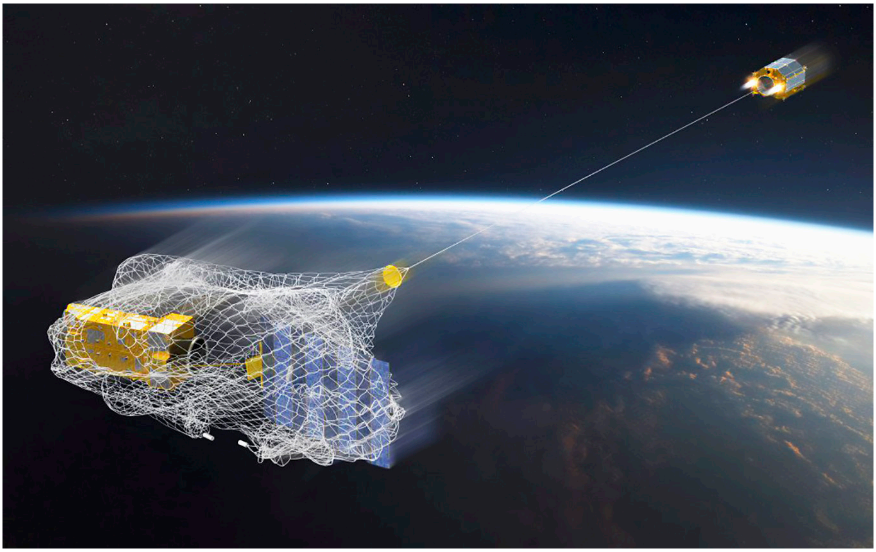


Fig. 2.33. Illustration of scenario, according to which RemoveDEBRIS captures metal piece of space debris [47]

Currently, the scientists experiment over the technology for space debris removal. In 2018, the British RemoveDEBRIS satellite successfully demonstrated its ability to use a net to capture pieces of debris. And on September 16, the harpoon fired by RemoveDEBRIS for the first time captured a simulated target — metal piece [46]. Currently, further tests of this technology are being carried out, but there is a real chance for the humanity to get rid of at least some of the defunct objects that pollute the outer space.

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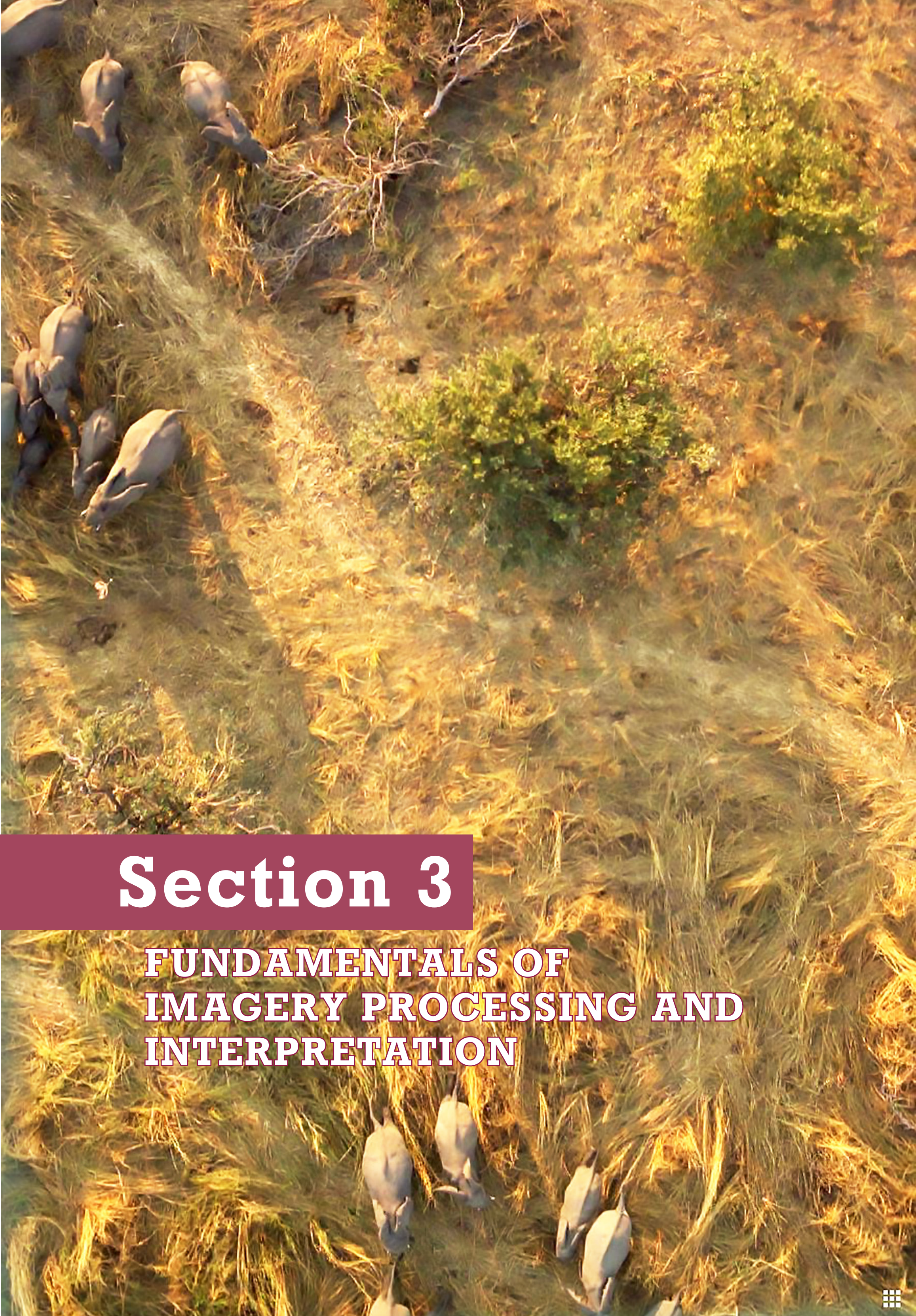

Section 3

FUNDAMENTALS OF IMAGERY PROCESSING AND INTERPRETATION

Section 3.

FUNDAMENTALS OF IMAGERY PROCESSING AND INTERPRETATION

3.1. The Essence and Features of Processing

Processing of remote sensing data refers to decoding and extraction of information from the images. In other words, ***decoding*** means detection, identification and interpretation of various information from the Earth surface images. Specifically, geographical objects are first detected and then identified along with the determination of their qualitative and quantitative characteristics, and subsequent reflection of such study on the image or map using special symbols. Decoding results depend on optic and geometric properties of the images, methods used and the level of knowledge and experience of the user performing decoding [1].

When decoding images, the photographic images of an object with a number of ***distinctive (decoding) features***, i. e., the characteristic features, according to which the objects can be distinguished from one another, are analyzed. These features may be direct or indirect (mediated).

Direct decoding features — properties of objects and their images, which make it possible to directly determine the specifics and characteristics of objects on the ground surface. These features include:

- *Size* is one of the main direct features, which allows for distinguishing an object from the set of similar ones according to its length, width and height, and compare its size with that of the other objects. This depends on the scale of the image.

- *Shape* is characterized by the general outline of the object captured in the image. There are geometric, linear, compact and tridimensional shapes of objects. Manmade objects (constructions) often have a one-dimensional shape and are easy recognizable according to this feature, for example, a field with agricultural crops from grassy meadows. The field will have a rectangular shape, and the meadows are mostly located in the draws or along the river beds and have complex shapes.
- *Tone* — a feature that allows the identification of the displayed object from the overall image background; this feature is the most important for black and white imagery. It is characterized by variability and changeability, since the image of one and the same object can have various tone depending on the light pattern, type of aerial photography, season, weather conditions and etc.
- *Color* is an important decoding feature for color and multiband aerial photographs. Presentation of objects in color significantly expands opportunities for their interpretation, compared to the black-and-white images. In particular, the color images made during summer allow for identification of more terrain elements and their details than winter images, since in summer terrain objects present in a wide color range.
- *Shadows* play an important role in the identification of small in size and low-contrast dimensional objects (skyscrapers, branches of trees, chimneys of factories and etc.). The shadows may be of the object itself, present on the object (i. e. matching the object's contour), or falling, i. e. thrown by objects on the other ones or on the ground surface. The shadows are represented very poorly in satellite imagery; there are seen clear shadows produced mainly by clouds and objects elevated above the ground. Some objects, such as power transmission and communication line poles, aerial masts, positioned rockets, observation towers, and wire fences are most often recognized only by their shadows.

Many terrain objects are not directly displayed on the images, or different objects may have the same direct decoding attributes and therefore cannot be identified directly. In such cases, indirect signs of decoding are used [1].

Indirect signs of decoding base on different interrelations between objects and elements of ground surface. Often, indirect signs indicate individual properties of objects that were not obtained during production of images as a result of geographical, photographic and geometric characteristics. Indirect signs that help to establish natural laws and relationships are called indirect landscape signs. The second group of indirect signs includes indirect social and geographical features, which are based on the interrelation of anthropogenic and natural phenomena and objects. For example, the pattern of a steppe road makes it possible to conclude about the soils of the locality: in wet areas the road is very blurred and has many detours; in sandy soil the boundaries of the road are blurred; on the clay soil the contours of the road are sharp, as if they were cut [1].

Examples of decoding of some elements

When identifying the terrain in satellite images, most often the following objects are decoded: settlements, routes, water objects, ground relief, and vegetation.

Settlements are clearly distinguished from other elements of the terrain by the structure of the image, the presence of a large number of regular-shaped figures. The type of settlement (city, urban-type settlement, rural area) is determined based on the housing density, size, nature of planning (regular, irregular, compact, etc.). Cities have compact development density, regular planning, multistory buildings, industrial enterprises and high-quality roads (Fig. 3.1). Rural settlements are often located near rivers, streams, beams. They are characterized by the presence of residential and outbuildings, private plots with yards and gardens. They are usually surrounded by agricultural lands [1].

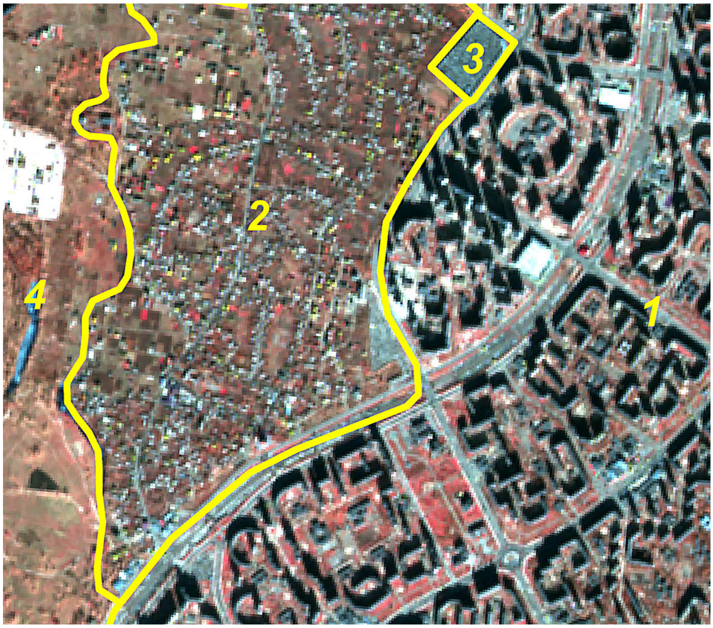

Fig. 3.1. Example of building system interpretation (1 — town area with blocks of flats; 2 — single- and two-storey buildings in the suburbs; 3 — garages, industrial areas; 4 — undeveloped meadowland)

The *transport network* can be distinguished by its form and location, as well as the light tones of images. Railways are typically characterized by straight lines, smooth rounded transitions from one segment to another, snow-retaining plantations along them, embankments and cuttings, stations and crossing loops. Motor roads present in the images as light lines of different thickness and different curves, depending on their type. Paved roads are characterized by straight-lines, smooth rounded turns, embankments and earth cuts, forest belts, bridges. Natural field roads are displayed as light, moderately curving lines with roundabouts [1].

Nature-made objects are typically characterized by irregular shape, diversity of forms and colors, wide range of sizes.

Elements of surface relief can be defined with highest precision by stereoscopic examination of aerial photographs. In this case, the decoding features include dimensional form, planned configuration, shadow, structure of the image, as well as the composition of the plant cover. Aerial photography makes it possible to outline the forms and elements of the mesorelief — the benches and flood plains of the rivers, gullies, ravines, valleys, hollows, slopes, cliffs, etc.

Water surfaces in the near and middle IR bands absorb energy very actively, which reduces their reflectivity and as a result they appear in satellite images like dark fragments and can be well-defined during interpreting. The direction of river flow is determined by the shape of the islands, the direction to river outlet and other features [1].

Swampy areas are displayed in totally gray tone, which varies greatly depending on the presence of grass, moss or other vegetation and the degree of humidity of the marsh. The moss (upland) moors have irregular, vague contours. Low (grass) moors are typically located along rivers with low banks and in low grounds in forests. Due to the high moisture content, they have a dark gray tone on the images.

Vegetation cover is interpreted by the tone and structure of photo image, form of falling shadows and the specifics of spatial placement of the greenery, and the relation to relief and hydrographic network. Forest vegetation can be differentiated by the structure and tone of image, and its confinement to certain location. Forests have relatively dark tones and grain pattern in the images, which depend on the form, size and brightness of tree crowns, and composition of forest trees. The composition of species can be determined according to differing spectral half-shadows of the leaves surface. Sometimes the composition of plantations can be identified by falling shadows at the borders, if the length of the shadow is equal to or greater than the height of the trees. Rounded crown of birch, oak, aspen, pine differs from the cone-shaped crown of the fir-tree. In the images, cultivated plantations of trees and shrubs are characterized by a regular structure and confinement to settlements *(Fig. 3.2)*

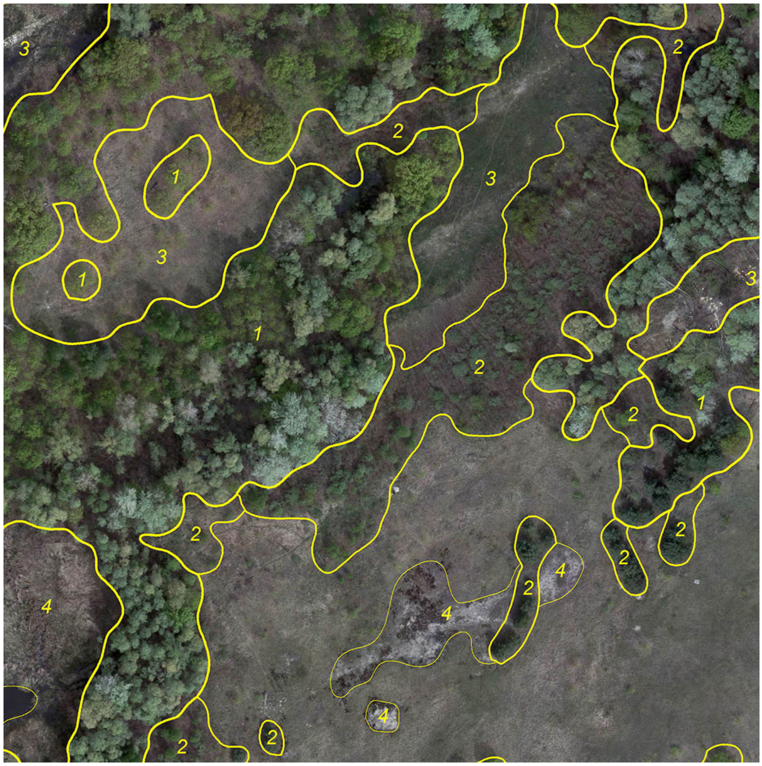

Fig. 3.2. Example of vegetation interpretation
(1-forest; 2-woodlands and shrubs;
3-meadows; 4 — swampy areas)

Areas of grass and shrubs are represented in satellite images as unstructured regions in gray tone. However, in isolated cases it is possible to recognize some herbal ecosystems of cold deserts, swamps on large-scale images. The meadows are typically located near river- and creek-valleys, and forest glades. Dry meadows have monotonous uniform light gray tone. Wet meadows located in lowlands are colored dark in the images and sometimes have elongated contours. The meadow vegetation in forests is often located near beams and hollows, and therefore such meadow sections have characteristic configuration.

The *images of farm fields and other agricultural lands* have sharply expressed geometric contours, many tones and often a specific striped-line pattern that reflects the effects of soil cultivation or planting [1].

The procedure of satellite imagery interpretation (processing):

1. Determination of information-bearing spectral bands of satellite images.
2. Image adjustment (spectral, geometric, radiometric).
3. Masking of clouds and lost data in defined bands of images; atmospheric correction.
4. Determination of local spectral features of the surface; visual decoding.
5. Semi-automatic or automatic decoding.
6. Clarification of decoding results taking into account local features, as well as application of integrated decoding rules.
7. Assessment of decoding accuracy.
8. Generation of analysis results.

The mentioned above stages of RS data processing can be subdivided into two main groups:

- *preprocessing of satellite imagery* — a complex of image processing operations, aimed at elimination of various distortions. Distortions can be caused by the drawbacks of recording equipment, atmospheric effects, interference during image transmission via communication lines, geometric distortions characteristic of satellite survey method, lighting environment of underlying surface, photochemical processing and analog-digital image conversion (when working with photographic materials) and other factors. Preliminary RS data processing includes geometric, radiometric, atmospheric image adjustment, geographic bridging of images [1];
- *thematic processing of satellite imagery* — identification of objects and phenomena in satellite images based on their attributes.

3.2. Preprocessing of Satellite Imagery

When describing the first group of image processing techniques, it can be noted that they are mainly problem-oriented. In particular, the improvement technique beneficial for a certain image may be found not effective for the other one [2]. Therefore, there is no general rule of image improvement. The selection of methods depends, first of all, on the nature of the data, the purpose of processing, familiarization with the territory captured in the image and previous experience in image improvement. However, there are three main ways of image adjustment, including geometric, radiometric and brightness transformations, which form the basis of the RS data improvement process *(Fig. 3.3.)*.

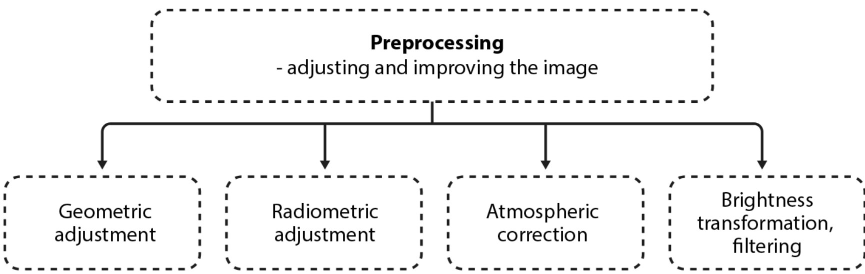

Fig.3.3. Chart representing procedure of satellite images preprocessing

Geometric adjustment is the elimination of geometric distortions (orthorectification) in the image and its geo-referencing. In the first stages, this type of adjustment can be performed automatically, according to satellite's orbital parameters. More precise transformation and referencing of the image to a certain coordinate system are usually performed using interactive reference points. With transformation, the pixel values are transferred to a new raster grid, which results in a more or less changed shapes of captured objects, and conversion of the image frame from the common rectangular into a parallelepiped or a more complex figure with curved edges. Geometric adjustment of high-resolution images makes it possible to eliminate distortions caused by ground relief [3].

Radiometric adjustment or image calibration is the calibration of output signal values of the camera device and their transformation into the absolute albedo and radiation temperature values. Images received from satellites are first recorded in the form of the so called "raw values" of DN brightness (Digital Number). Data in this format cannot be adequately compared with the data of other surveys.

Radiometric calibration aims at bringing these values to physical units. Calibration is performed using telemetry reports delivered by the satellite along with the images, and the calibration coefficients, calculated for each camera device based on the results of ground and flight tests. Calibration means transformation of nondimensional data obtained from sensors in certain spectral zones into the true normalized values of the reflected or emitted energy [3].

Filtering is transformation, which makes it possible to enhance the representation of certain objects, reduce undesirable masking, and remove other accidental disturbances (noise).

One of the easiest filtering techniques is transformation in the sliding window. With such transformation, the brightness values for all image pixels are recalculated. Recalculation for each pixel is performed in the following way. When the given pixel occupies a central position in the window sliding along the image, it is assigned a new value, which is the function of the values of surrounding pixels [3].

3.3. Image Interpretation Techniques

The second group of RS data processing methods includes the procedures of information retrieval from the processed materials. This is carried out with the use of logical and arithmetic operations, classifications and other methodical techniques, including visual decoding of images.

The primary thematic processing techniques are as follows:

- combination of bands;
- index images;
- principal component analysis;
- spectral division technique;
- classification.

Technique of band combination of satellite imagery refers to the determination of spectral ranges essential for the representation of certain objects and synthesis of respective spectral bands of satellite images to obtain color imagery. In particular, the synthesis of the bands in the visible spectrum produces an image similar to the normal photograph, or what can be seen by the human eye. The objects of decoding will have a familiar and understandable color and, accordingly, appearance that can significantly simplify the process of objects identification in the images. This combination of bands is called *natural colors*. However, much of the information will remain hidden with such combination of bands; thus, to identify such objects or their properties, it is necessary to use a combination of bands in the near, middle or far infrared ranges of spectrum. Usually, they are combined with one or more bands of the visible range. The result is a *pseudo color image*. For example, healthy vegetation with active photosynthesis is characterized by a high value of reflection in green spectral range, in contrast to weak or diseased vegetation, which has minimum reflection values in the green and infra-red portions of the spectrum. Therefore, it is reasonable to use a combination of bands — middle infrared, near infrared and green spectral ranges, in order to distinguish healthy and diseased vegetation.

Technique for creation of index images — one of the simplest and most popular methods of satellite imagery decoding, which also bases on spectral features of studied objects and literally is a mathematical operation using several spectral bands. However, in contrast to bands combination technique, this method results in the index image with the pixel that may acquire values within a certain given range. This allows for comparing index images of different territories or made at different time. One of the most common indexes are the *Normalized Difference Vegetation Index, NDVI,* and *Normalized Difference Water Index*, *NDWI*. The examples of these indexes application are given in Sections 4.1 and 4.2.

The use of **visual decoding method** provides that the decoding is done by an expert well acquainted with the specifics of the territory and properties of the objects captured in the image. This method is labor- and time-consuming, thus it is relevant to use automatic imagery interpretation techniques (automatic classification).

The issue of **classification**, as the satellite imagery decoding technique, i. e. the method allowing for recognition and identification of any objects captured in satellite images, shall be considered in more detail [3]. The classification belongs to the automatic decoding techniques. Their use does not require manual outlining of object's boundaries since it is done by a computer program.

Automatic classification is the process of breaking pixels of continuous raster image into the categories according to their spectral values with resulting new value assigned to each pixel. In terms of the degree of user participation in the automatic decoding, there are two groups of classification algorithms: unguided classification (autonomous classification, unsupervised classification, clusterization) and guided classification (supervised classification) [3] *(Fig.3.4).*

If prior to classification it is not known how many and what objects are captured in the image, the *unguided classification* (unsupervised classification) is used. This means that the image pixels will be distributed automatically based on the analysis of statistical distribution of their brightness. The disadvantage of this classification is the need to perform the decoding of the resulting classes in order to determine which objects in the images they correspond to. Unsupervised classification is often used as a preliminary step of guided classification.

The most common methods of unguided classification are as follows:

1. ISODATA — Iterative Self-Organizing Data Analysis Technique, which is based on cluster analysis. The main parameter given before calculation is the number of resulting clusters;

2. K-means method differs from ISODATA in that it requires a certain number of mean values to be given for the formation of original classes; thus this method is used when the objects can be well distinguished in the images [3].

Guided classification (supervised classification) is used when the number of object classes and their typology is known in advance. With this classification, the distribution of pixels into classes is performed based on the comparison of the values of each pixel with the samples (testing sets), established for each class by the selection of pixels with certain range of properties in line with real terrain objects in the image.

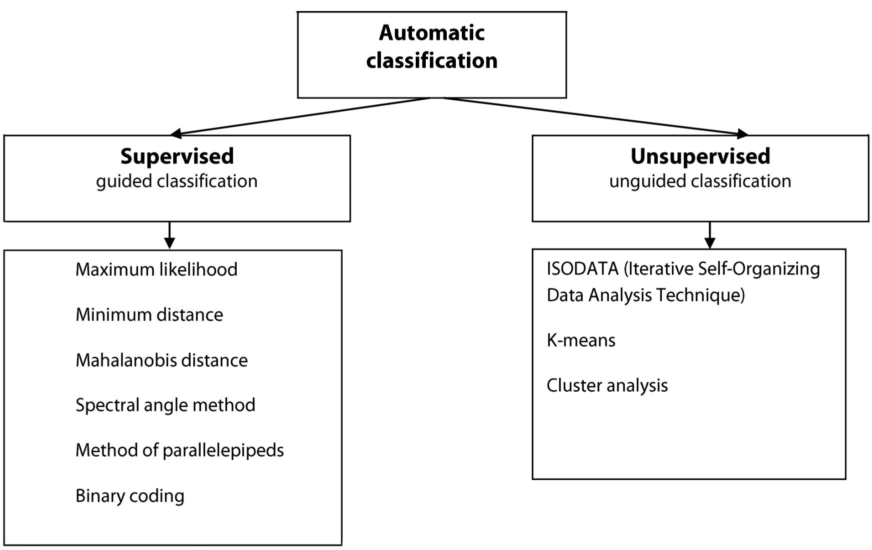

Fig.3.4. Basic automatic classification techniques

There are several stages of guided classification:

- determination of the number of classes and their content;
- development of testing sets (user samples);
- verification of testing sets quality;
- selection of algorithm (method) of guided classification;
- running of classification;
- post-classification processing of classification map;
- assessment of classification results accuracy.

Maximum likelihood technique evaluates the probability that the given pixel belongs to a certain class. The user specifies the number and parameters of classes by providing testing sets. Each pixel is assigned to the class it represents with the highest likelihood. The calculation of probability often takes into account the brightness of the pixel and the brightness of surrounding pixels [3].

Minimum distance method is used when different classes have similar spectral features and the ranges of their brightness overlap.

Mahalanobis distance technique is similar to minimum distance method with the only difference: it uses for classification not Euclidean distance (minimum distance method), but Mahalanobis one. This means that the technique takes account of the distribution (dispersion) of pixel brightness values in the standard regions. Therefore, if the Euclidean distance from the vector of brightness of this pixel to two reference vectors is the same, this pixel will be assigned to the class with the higher dispersion of the reference sample.

Spectral angle method works well when it is necessary to run classification for the objects having similar brightness values in all spectral bands. Besides, since pixel brightness values are not taken into account with this method, the results are not influenced by the effects of images' light-shorting.

Method of parallelepipeds is used when the ranges of objects brightness values do not overlap.

Binary coding is used when all the pixels present in the image should be divided into two classes, for instance: land and sea. With binary coding, all pixels are assigned one of two values based on comparing to the values of reference samples. For the purposes of classification, the value of each pixel is compared to the average of reference sample. The result is a binary image [3].

The following principles underlie all image interpretation techniques:

1. analysis of signal distribution within defined spectral bands;
2. rule of assigning image segment or pixel to a corresponding class;
3. statistical analysis of spectral characteristics distribution for individual image segments or pixels;
4. reliability assessment of assigning registered signal to corresponding class.

3.4. Software for Satellite Imagery Processing

Geographic Information System (GIS) is a set of electronic maps with symbols marked on them, databases with information about these objects and software for the convenient use of maps and databases as a whole. GIS enables integration of all data with their subsequent visualization and analysis of relationships, development of models, predictive analytics and planning based on this array of data. But the most important thing is the possibility to make decisions on the basis of data, which increases the chances for the right decision to be made taking into account various scenarios (see Fig. 3.5).

Geo-Information Technologies (GIS-technologies) — the technological basis for the creation of geographic information systems that enable the implementation of GIS functionality. The application of GIS-technology is possible subject to availability of four components: people, mapping, information support (data, satellite imagery) and software (GIS packages) [4].

Fig. 3.5. Data-to-action model used in GIS software

Currently, there are dozens of commercial GIS packages worldwide. However, only ten-fifteen of them are well-known and widely used commercial GIS packages. The global leaders in software are packages by ESRI (ArcGIS Desktop product line), MapInfo Professional package and Idrisi package (developed by Clark University, USA), AutoCad and ERDAS IMAGINE, ENVI and Digitals [5].

Software solutions of ERSI Company (UAS), the world's oldest supplier of software for GIS (the company was founded in 1969), are currently represented by the set of specialized software packages having common name ArcGIS.

ArcGIS includes many integrated software solutions designed both for the development and operation of geoinformation systems of various complexity, and for geoinformation support in addressing the tasks related to the use of spatial information, including field

ArcGIS

Fig.3.6.
ESRI logo

observations, and activities in computer networks, including the Internet. It should be noted that ERSI company over the last years puts special emphasis on the development of network software solutions for GIS, and respective enhancement of functionality of the traditional GIS packages to enable them to function in computer networks [5].

The main components of ArcGIS are:

- *desktop GIS tools (ArcGIS Desktop),* including the following GIS packages: ArcInfo, ArcEditor and Arc View with a set of supplementary modules,
- *server software solutions for GIS (Server GIS),* which includes the following packages: ArcIMS, ArcSDE and ArcGIS Server,
- *mobile GIS tools (Mobile GIS),* represented by ArcPad package,
- *viewers, Web-viewers,* in particular ArcReader and ArcExplorer *(Fig. 3.7).*

Server GIS is used to create and manage server GIS-applications, which disseminate GIS functions and spatially-distributed information internally and between organizations via computer networks, including Internet.

ArcGIS Desktop has a wide array of mapping, geostatistics and spatial modeling tools developed as individual modules, such as Spatial Analyst (for spatial modeling, including interpolation), 3d Analyst (for operations with relief), Geostatistical Analyst (for spatial statistics), Network Analyst (for operations with road networks). These modules are optional and can be bought by the user separately, as needed.

Instruments designed for the work with raster data are used for the processing of RS data. These tools can be found in ArcToolbox menu, Data Management Tools/Raster tab (see Fig. 3.8)

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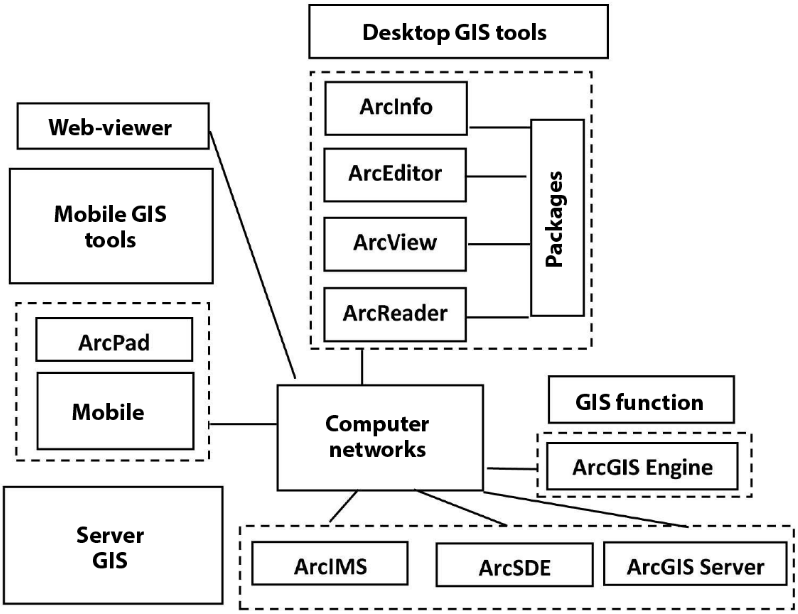


Fig. 3.7. ArcGIS family of software GIS packages [5]

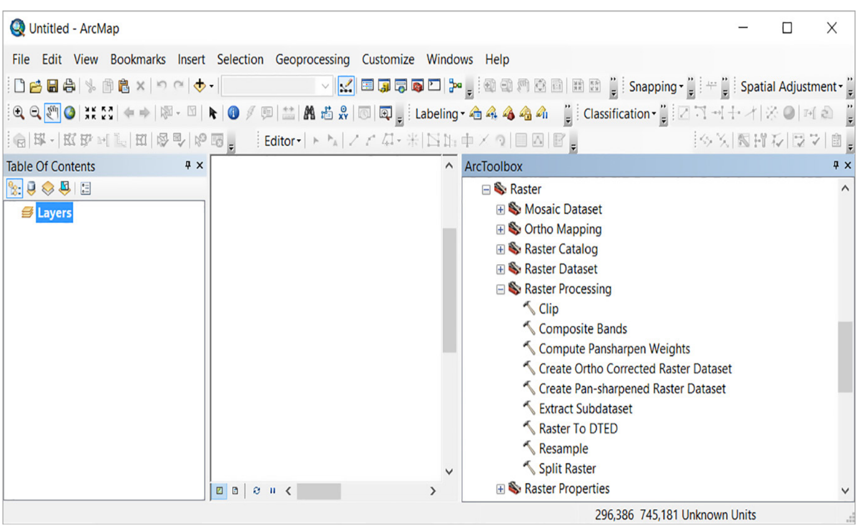


Fig. 3.8. Interface of ArcToolbox tools for operation with raster data

The most commonly used tools for processing of satellite imagery are Clip (cropping), Composite Bands (combination of bands), and Mosaic (creating a mosaic from different images). These tools belong to the basic set of ArcGIS desktop tools, however a number of instruments, in particular, for image processing, are part of the Spatial Analyst module; therefore, to work effectively with satellite data in ArcGIS, it is necessary to buy Spatial Analyst module in addition to the basic version of ArcGIS. These tools also can be found in the ArcGIS toolbox/Spatial Analyst Tools menu. The most useful among them is a set of tools designed for automated classification (Segmentation and Classification tab), and a raster calculator (Map Algebra tab), which allows the application of mathematical operations along with the overlay of different layers of satellite images *(Fig. 3.9)*.

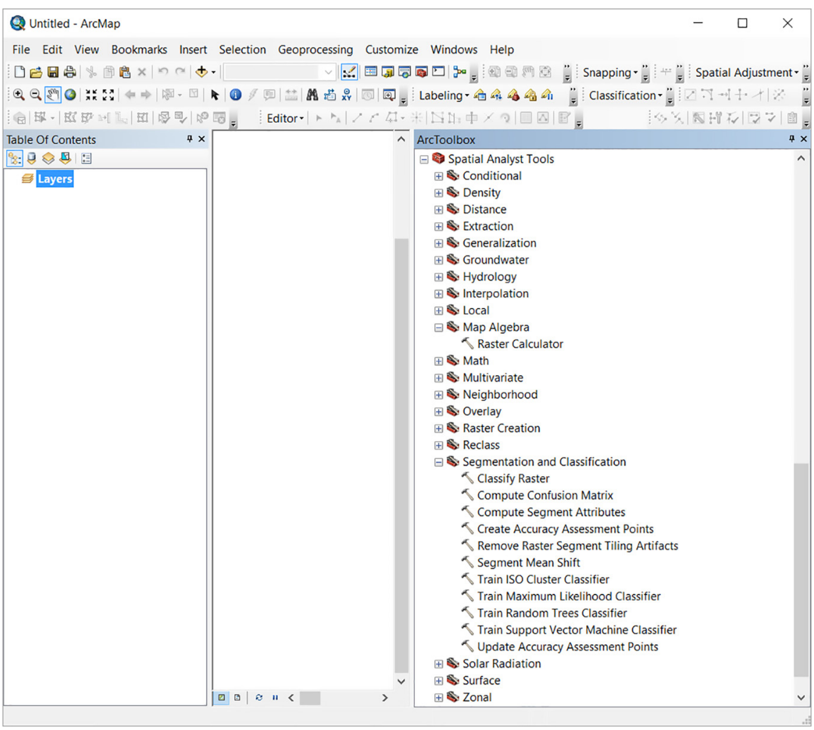


Fig. 3.9. Tools used for the automated classification of images

Another useful set of tools for fast processing and adjustment of satellite imagery can be found in the Windows/Image Analyst menu. These tools open in a separate window *(Fig. 3.10)* and contain instruments for filtering of images, adjustment of brightness, contrast and improvement of picture sharpness, image cropping in the cartographic window, and calculation of NDVI vegetation index or other mathematical operations with imagery.

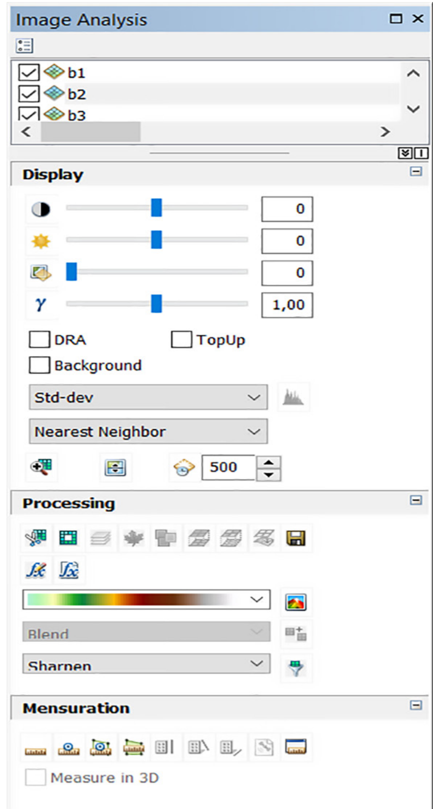


Fig. 3.10. Raster data processing window in ArcGIS

In addition to commercial software solutions, there has been seen rapid growth in the industry of development of free and open software applications for processing and analysis of spatial data, such as QGIS, GRASS GIS, R, etc. over the last years.

QGIS (Quantum GIS) is a free and open-source cross-platform desktop geographic information system application. QGIS has the highest functionality and is the most easy-to-use among other free GIS applications; it also integrates with other open-source GIS-packages, including PostGIS, GRASS and MapServer. Plugins written in C++ or Python extend QGIS's capabilities

Fig. 3.11. Quantum GIS (QGIS) logo

The search and selection of instruments and plugins in QGIS, in particular for processing of raster data (the most widely used format of satellite images), can be done in Plugins\Manage and Install Plugins menu *(Fig. 3.12)*.

Following installation using the respective window, the plugins become available in Raster menu. Many integrated tools of SAGA and GRASS GIS applications are made available via Processing\Toolbox menu. The set of all available integrated tools opens in a separate toolbar when this menu is selected (see Fig. 3.13). GRASS GIS\Imagery tab contains instruments for preprocessing and adjustment of images.

Among other useful functions for RS data processing in QGIS, worthy of separate attention is the semi-automatic classification module *(Fig. 3.14)*. It allows the creation of reference objects (signatures) and application of automatic image classification methods according to the set of signatures in order to select the desired objects on the image (see section 3.3 for more detailed description of classification methods).

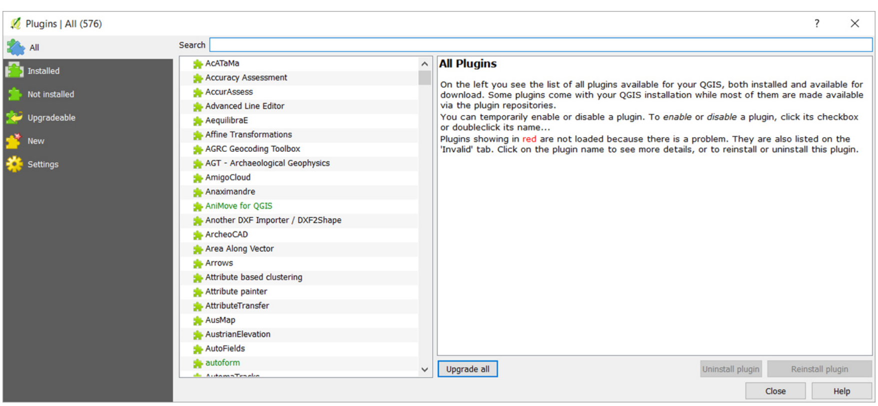


Fig. 3.12. Window for search and installation of plugins and tools for data processing in QGIS.

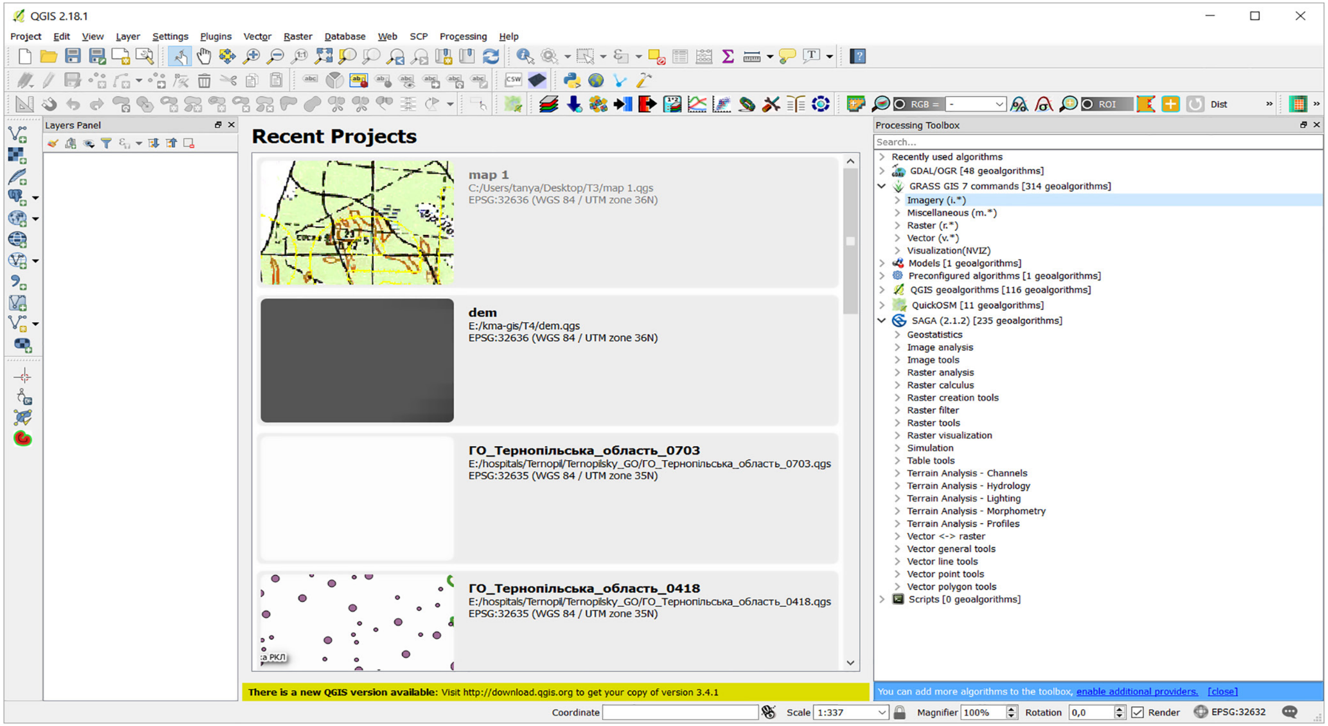


Fig. 3.13. QGIS toolbar of instruments integrated in SAGA and GRASS GIS

Section 3. FUNDAMENTALS OF IMAGERY PROCESSING AND INTERPRETATION

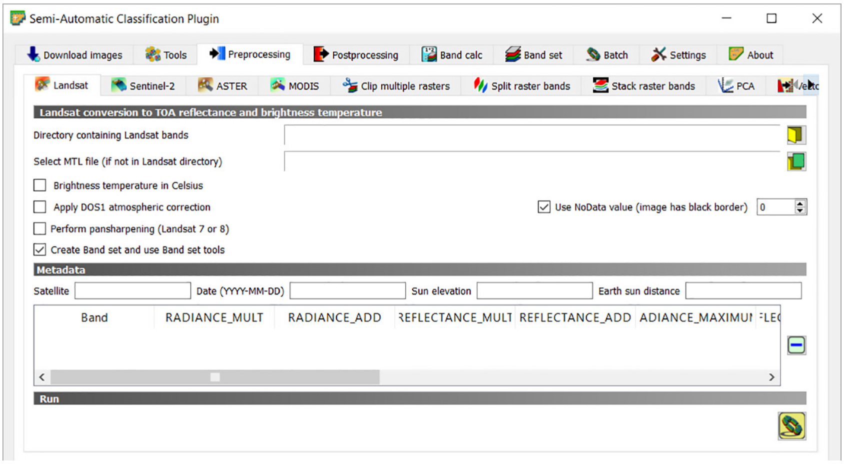
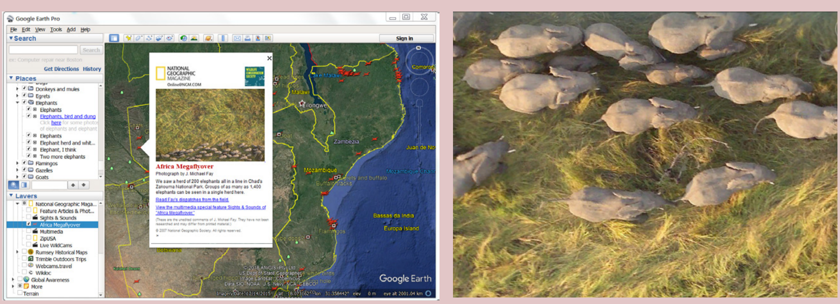


Fig. 3.14. Window of semi-automatic satellite imagery classification module in QGIS.

Google Earth program

Google Earth is a free program developed by Google company, which represents virtual globe. Under this project, satellite imagery of the greater part of the Earth has been posted on the Internet. For some regions, these



a *b*

Fig. 3.15. Examples of imagery from the thematic layer "Africa Megaflyover" in Google Earth program (*a* – work window in Google Earth program; *b* – aerial photograph of a population of several hundred elephants.

images have very high resolution (up to 15 centimeters). Using the program, a certain location can be found by entering the geographic coordinates or simply using map navigation. As an example, we can use the image of detailed ground surveying from the layer "National Geographic" magazine, subsection "Africa Megaflyover" (see Fig. 3.15).

In addition to the Earth, there are also images of other celestial bodies such as Mars and the Moon. With Google Sky feature users can access precise celestial charts.

Official website: www.google.com/intl/uk/earth/index.html

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Section 4

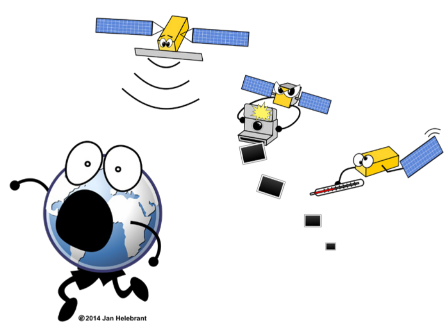
SCOPE OF RS APPLICATION

Section 4.
SCOPE OF RS APPLICATION

4.1. Earth Sciences

The term "Earth Sciences" encompasses all natural sciences, the subject of study of which is the Earth, in particular, the physical characteristics of our planet. The main areas of research of the Earth Sciences are: the lithosphere, the hydrosphere, the atmosphere, and the biosphere.

As a rule, scientists that explore our Earth, use instruments and geographical, historical, physical, chemical, biological and mathematical methods to obtain a quantitative understanding of how the Earth «lives» and develops. The Earth Sciences study our daily lives. For example, meteorologists study the weather conditions and observe dangerous climatic phenomena (storms, tornadoes, droughts, etc.). Hydrologists study bodies of water and warn of floods and freshets. Seismologists investigate earthquakes and try to forecast epicenters thereof. Geologists study earth formations and help in the exploration of minerals.



In this Section, "Scope of RS Application", we will consider such disciplines of the Earth Sciences cycle as hydrology, climatology and meteorology, geology, landscape science and urban planning.

4.1.1. Climatology and Meteorology

"Global Warming of 1.5 Degrees" is the title of a special report prepared by the Intergovernmental Panel on Climate Change (IPCC) and published on October 7, 2018. The experts point out that increased anthropogenic emissions of greenhouse gases has already led to warming of climate by 0.8–1.2 °C. It is still possible to achieve the purpose of the Paris Agreement on the maintenance of warming at the level of 1.5 °C, however this requires significant emission reductions and rapid, far-reaching and unprecedented changes in all spheres of human activity [1].

Remote sensing from the space together with mathematical modeling is crucial for the understanding of modern climatic processes, as well as for the accumulation of data and evidence base to predict global climate change in the future and develop an effective policy for security and sustainable human development.

Depending on the wavelength and the nature of the electromagnetic radiation detected by the satellite sensor, remote sensing systems accumulate the data on processes occurring in the atmosphere, ocean, on Earth's surface, as well as on rocks formations, soil, vegetation, water bodies, glaciers, snow cover etc. Interpretation of remote sensing data in combination with mathematical equations, algorithms and models makes it possible to transform data into information essential for decision-making at different levels of management.

One of the important indicators in the climate studies is the albedo – the ratio of radiation reflected (scattered) by the Earth's surface to the solar radiation received by it. According to certain calculations, if the Earth was completely covered with ice, its albedo would be about 0.84, i.e. it would reflect 84% of solar radiation. On the other hand, if the Earth was completely covered with dark green forest cover, its albedo would be about 0.14 (the major part of the sunlight would be absorbed). According to the satellite measurements accumulated since the late 1970s, the average albedo of the Earth is estimated at 0.30. If the flux of solar energy entering the surface and reflected therefrom is unchanged, the Earth's thermal balance remains in equilibrium and the global temperature stays relatively stable.

Since the ascending radiation from the Earth's surface, passing through the atmosphere, is reflected in all directions, a certain portion of the radiation can return to the Earth's surface, so any changes in the energy balance may lead to an increase or decrease in the global temperature, and also affect evaporation, precipitation, winds, sea currents associated with the Earth's thermal balance. Changes in ice cover, cloudiness, atmospheric pollution, greenhouse gases level, as well as changes in soil cover (for instance, deforestation for farmlands or construction purposes) have an impact on the global significance of albedo. Thus, for the purpose of assessing climate change, mapping is important at the planetary level for tracking of changes in radiation fluxes and global albedo dynamics, as well as at the local level — for the monitoring of land cover changes, vegetation and water bodies, increase in the urban areas, etc., which also influence the climatic and energy processes of the Earth.

In 2010, the Global Climate Observing System (GCOS) developed fifty parameters of the Earth's biosphere, which are considered important for the detection and quantification of climate-related changes, known as *Essential Climate Variables* (ECVs) [2]. Nearly half of them may only be determined by remote sensing methods *(Table 4.1)*.

Currently, around thirty satellite Earth observation systems with low and medium spatial resolution (30 meters or more) operate in near-Earth space, providing space-based surveys in various spectral bands for global and regional research. The list of such systems, types of sensors and their main targeted uses are specified in Appendix 2. Almost all of these data are distributed free of charge for scientific research.

Significantly fewer data with high spatial resolution (from 1 to 30 meters) are freely available for research (Appendix 3). From the list of satellite spatial resolution systems in Annex 3, the SPOT data are commercially available and RS and ENVISAT satellite systems have already completed their missions, but their data is available for retrospective studies.

Table 4.1. List of Essential Climate Variables (ECVs), detected by remote sensing methods ([2]).

Scope of Monitoring	Essential Climate Variables (ECVs)
Atmospheric processes	*At the close proximity to the surface:* air temperature, wind speed and direction, water vapor, pressure, precipitation, surface radiation. *In the upper airspace (up to the stratopause):* temperature, wind velocity and direction, water vapor, cloud properties, radiation balance of the Earth (including solar radiation). *In general:* carbon dioxide, methane and other long-lived greenhouse gases, including N_2O, SF_6, chlorofluorocarbons, hydrochlorofluorocarbons, as well as ozone and aerosols, in particular NO_2, SO_2, CO and formaldehyde.
Oceanic processes	Sea surface temperature, salinity, sea level, ice, surface currents, ocean color, oxygen, partial pressure of carbon dioxide, acidity, phytoplankton.
Land surface processes	River runoff, use of water, groundwater, lakes, snow cover, glaciers and ice caps, ice shields, permafrost, albedo, vegetation cover (including vegetation type), fraction of absorbed photosynthetically active radiation (FAPAR), leaf area index (LAI), terrestrial biomass, soil carbon, fires, soil moisture.

In November 2014, the European Commission signed an agreement with the European Center for Medium-Term Weather Forecasts (ECMWF) on the implementation of the Climate Change Monitoring Service within the Copernicus Programme. This Service is based on satellite observations and ground measurements, and provides free access to climatic indicators and indices such as temperature rise, ocean water level rise, melting of glaciers, heating of ocean waters, etc.

Thus, a large amount of data from various satellite systems allows obtaining information on biosphere and climatic processes almost continuously. This amount of data, on the one hand, is an advantage, however, on the other hand, it is a drawback or a challenge for the reliable interpretation of remote sensing data. Data processing algorithms, especially new satellite systems, need to be improved and tested on explored sites in different climatic zones and selected specific natural objects using ground-based observations and high-precision measurements in the field. In addition, it may be difficult to use data from different sensors simultaneously, since even the small difference in the spectral range captured by the sensor may significantly affect the signal quality and therefore raise the need for preliminary verification of data. Another significant disadvantage of the use of remote sensing data is the need for efficient algorithms for atmospheric correction of data, taking into account the research subject, since even minor changes in the concentration of gases, aerosols and dust in the air affect the level of reflection of electromagnetic radiation by the object of observation, causing false values. It is also worth noting that satellite imagery data is usually of large volume and its processing and interpretation requires the use of specialized software and advanced hardware.

Modern meteorological and synoptic services apply data sources, the major part of which obtained using the remote sensing methods: data from meteorological stations, radar sensing network, aviation stations network, data of aerodrome meteorological stations, information from the network of meteorological radars, information of the world's forecasting centers, volcanic ash advisory centers (VAACs) and tropical cyclone advisory centers (TCACs), data of airborne sensing (AMDAR system), and data delivered by meteorological satellites [3].

Air Monitoring

In October 2017, the ESA successfully launched Sentinel-5P satellite designed to monitor the atmosphere, air pollutants and greenhouse gas concentrations. The satellite was equipped with Tropomi spectrometer detecting electromagnetic radiation in ultraviolet, visible, near and medium infrared ranges, which allowed to determine the content of ozone, methane, formaldehyde, aerosols, carbon monoxide, nitrogen dioxide and sulfur dioxide in the atmosphere. Tropomi sensor is an upgraded version of the OMI sensor installed on the operating Aura satellite, as well as the SCIAMACHY sensor operating on the Envisat satellite in 2003–2012. The main enhancement of Tropomi is an improved spatial resolution that allows capturing images with a pixel size of 7 x 3.5 km, analyzing contamination in large cities, and identifying sources of pollution.

Sentinel-5P data is available for download from the EO Browser (https://apps.sentinel-hub.com/eo-browser). Figure 4.1 presents a map of average NO_2 concentrations over the sixteen-day period, from July 10 to July 25, 2018, on the territory of Ukraine and Central Europe. Such analysis of the values averaged over a certain time period allows identifying permanent sources of pollutants' emissions. Among the largest cities in Ukraine, the most NO_2 polluted are Zaporizhia, Kyiv and Dnipro. The most polluted regions include some parts of Donetsk and Luhansk Regions.

Within Kyiv city, the highest air concentrations of NO_2 have been registered over the same period in Holosiivskyi and Solomianskyi Districts, where possible sources of atmospheric emissions may include means of transport, especially in the area of *the ring road,* and CHPs, in particular, Darnytsia CHP *(Fig. 4.2).*

In Kryvyi Rih, the concentration of NO_2 in the air, as expected, is higher in the industrial zone and nearby tailing facilities *(Fig. 4.3).*

According to "Global Warming of 1.5 Degrees" report, to achieve the objective of maintaining warming at 1.5 °C, CO_2 emissions should be decreased by 45% by 2030 (compared to 2010 levels). Emissions of other greenhouse gases (such as nitrogen oxide and methane) should also be limited to achieve the purpose. But even under such conditions, warming is still expected at 3.1–3.7 °C by 2100.

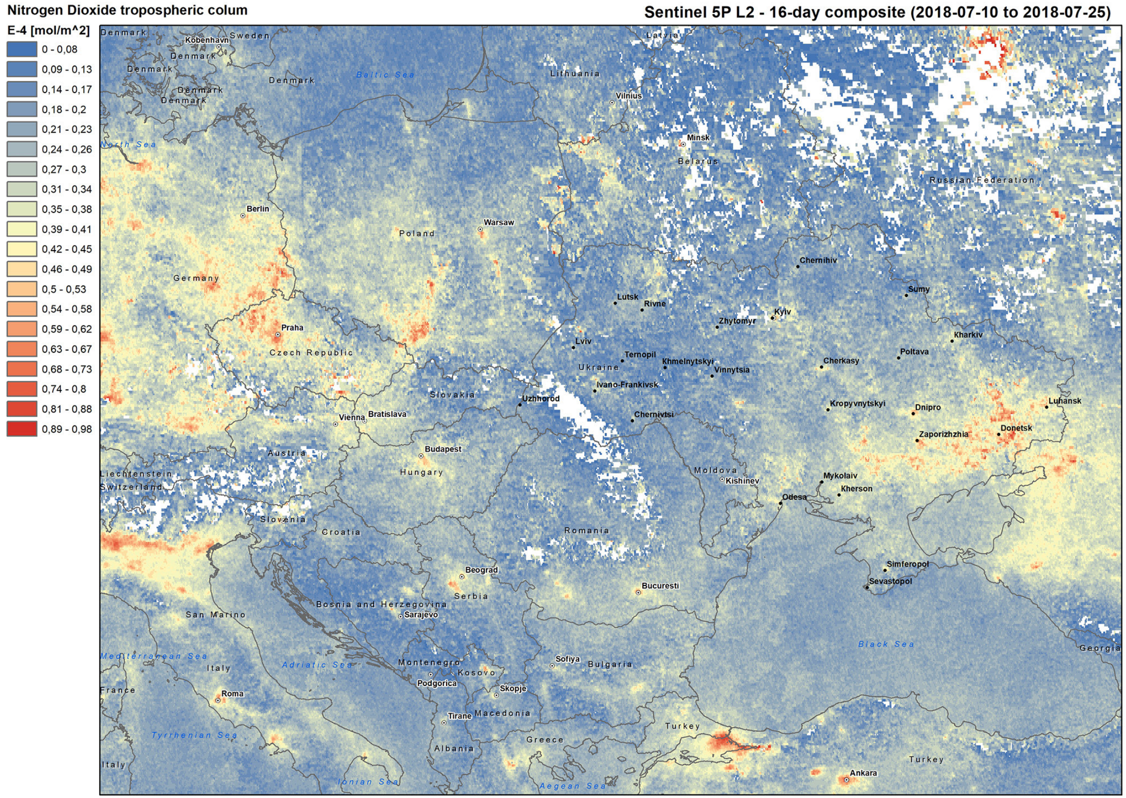


Fig. 4.1. Map of NO_2 air pollution in Ukraine and Central Europe.

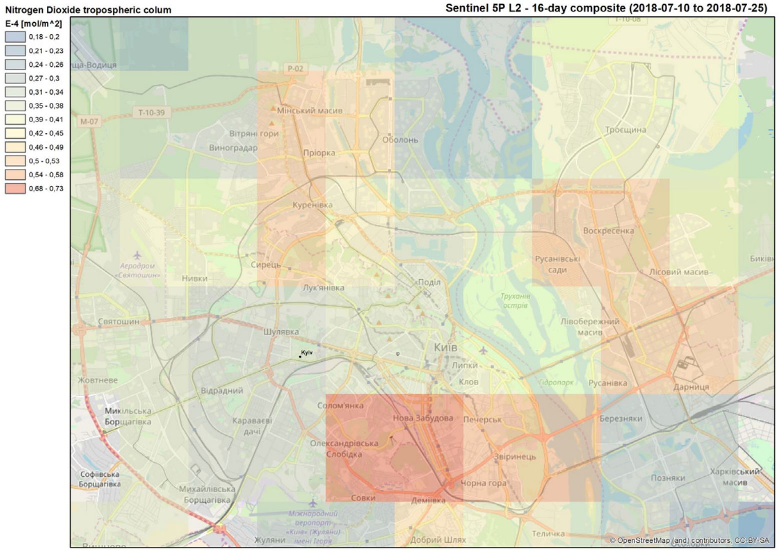


Fig. 4.2. Map of NO_2 air pollution in Kyiv city.

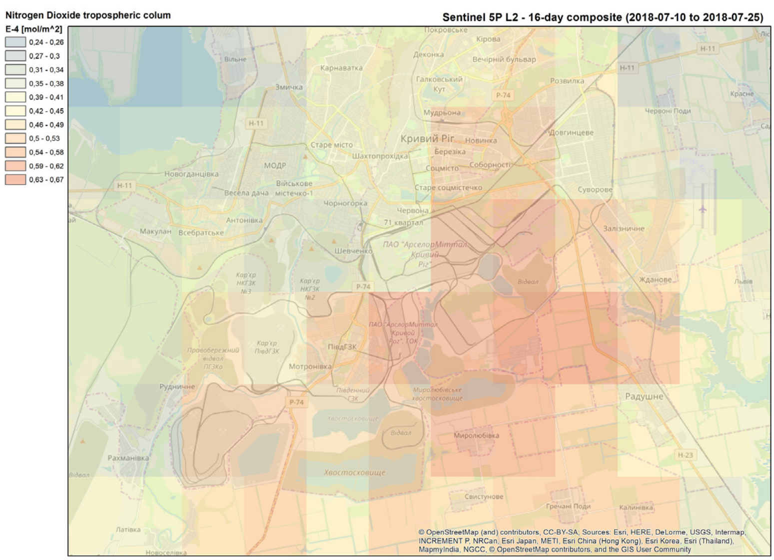


Fig. 4.3. Map of distribution of NO_2 concentration in the air in Kryvyi Rih.

According to AIRS/Aqua satellite data (obtained from the NASA portal https://giovanni.gsfc.nasa.gov/giovanni), the CO2 atmospheric concentration on the territory of Ukraine is growing at rather high pace — for the period from 2002 to 2017 it increased by 35 ppm *(Fig. 4.4)*, which coincides with the global trends on the Earth.

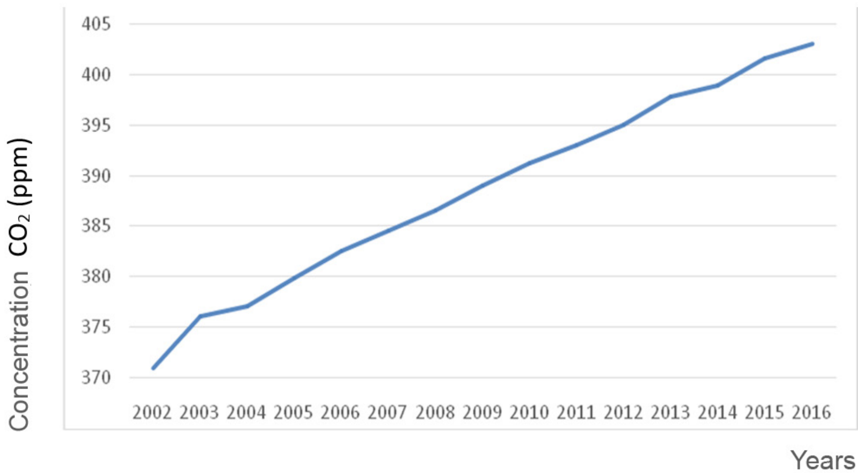


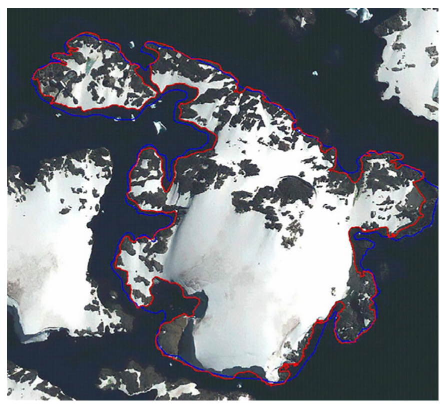
Fig. 4.4. Dynamics of CO_2 content in the atmosphere of Ukraine according to AIRS/Aqua satellite data.

Analysis of Ice Cover Dynamics

Galindez Island is one of the Antarctic islands, a part of the Argentine Islands group of the Wilhelm Archipelago. Academician Vernadsky Ukrainian Antarctic Station is located on Marina, the northwestern cape of Galindez Island. The Station was founded by Faraday, the English Antarctic Society, and was sold to Ukraine at a symbolic price of one pound sterling in 1996. Research and observation at the Station during the year are extremely important for understanding of planetary climatic processes, since they enable us to assess the impact and consequences of extreme changes and conditions [4].

The National Antarctic Science Center together with ECOMM Co and “Pryroda” Scientific and Production Center, in the process of developing geographic information system “Antarctic Vernadskyi”, have created a topographic map of Galindez Island, and based on the QuickBird satellite images vectorized the coastline and the boundaries of the ice cover. According to meteorological observations collected during operation of Faraday/Vernadsky Station, the average annual temperature in this area increased by 2.5 °C [5]. Obviously, this should have had an effect on the structure of the island ice cover. To determine the intensity of such changes, researchers compared the data received from QuickBird satellite in 2003 and aerial images of the island, made by the British scientists in 1956 *(Fig. 4.5)*.

a



b

Fig. 4.5. Images of Galindez Island:
a) aerial image made in 1956; *b*) image delivered by QuickBird satellite in 2003 (the coastline of 1956 is marked with blue color and the coastline of 2003 is marked with red color).

“Having lived in Antarctica for almost 2.5 years, I saw the real climatic changes and their effects during different times of the year and seasons,” writes Ihor Dykyi, a member of the three Antarctic expeditions, “the melting of glaciers and snow cover in Antarctica is highly dynamic, and this is an indisputable fact. Antarctica is a unique continent, located on the South Pole of the planet. It is totally covered with snow and ice and, like a litmus test, is an indicator of the state of the Earth" [6].

Monitoring of the changes of glaciers clearly confirms the general trend of global warming on the planet. The study of ice cover is illustrated by the example of Columbia glacier (Alaska, USA), a coastal type glacier located in the Prince William Strait on the southern coast of the state of Alaska (USA). It is one of the fastest moving glaciers in the world, which began to melt and retreat in the early 1980s. By that time, Columbia glacier had a length of 64 km and a thickness of 600 m. It was an interesting tourist attraction on the way between the cities of Valdis and Whittier. Usually, ferries stopped to hoot between groups of icebergs in expectation that high volume of their hoots would cause split-off of boulders from the glacier. But after a while, this glacier began to melt and retreat. Icebergs became quickly split-off into the Gulf of Prince William, and the snow compaction was not so fast enough to cover these losses. As a result of a quick spin-off, the glacier has lost 400 m in thickness and retreated by 16.9 km since the observations start [8].

The glacier retreating speed reached its maximum of almost 30 meters per day in 2001. The average speed was about 0.6 km (0.37 miles) per year since 1982. It is expected that the glacier will retreat by another 15 kilometers in the next few decades, to the point where the bed of the glacier rises above the sea level.

Thanks to National Geographic images made in this zone, one can clearly define the degree of the processes in progress *(Fig. 4.6).*

Different methods are used to determine the boundaries of the glacier. One of them is manual digitizing — this method requires an experience of visual decoding of glaciers. Another method is based on the determination of the NDSI snow index using an automated threshold classification; this method bases on the difference between the spectral characteristics of snow and ice, and those of indigenous rocks [8].

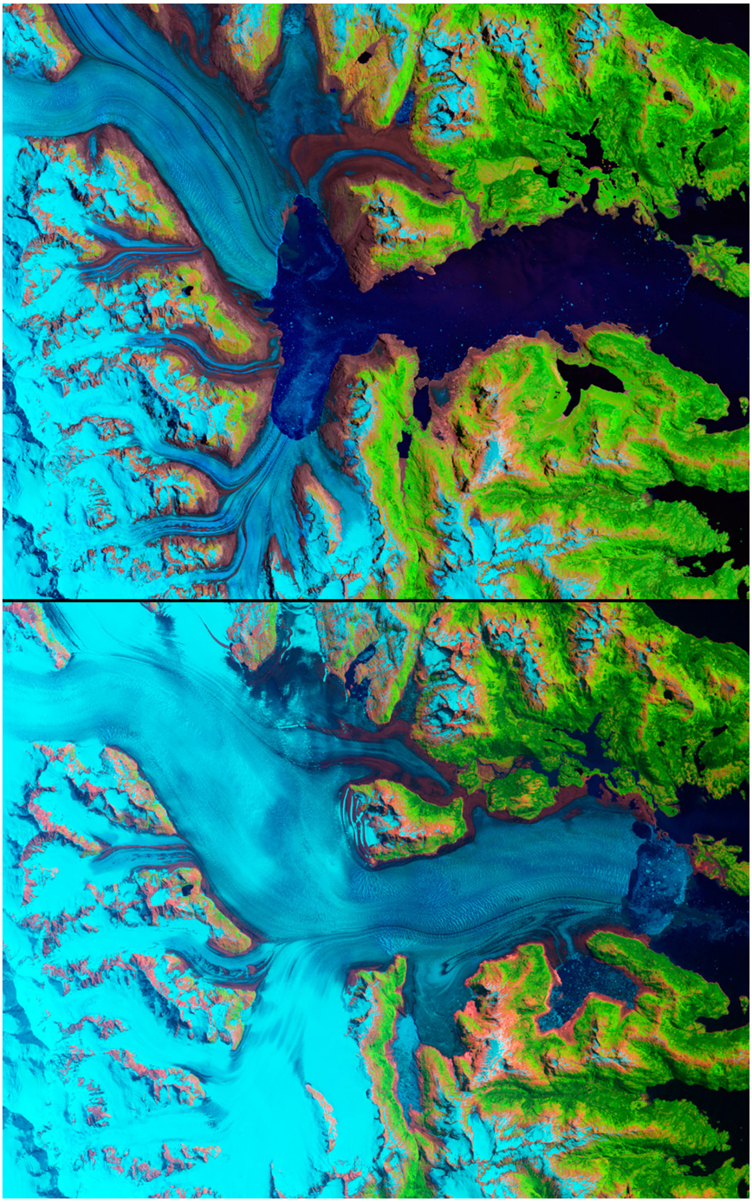
a *b*

Fig. 4.6. Images of Columbia glacier:
a — 2006 (James Balog);
b — 2012 (Mathew Kennedi)

Normalized-Difference Snow Index (NDSI) — the normalized difference between two spectral bands (one in the visible spectral range and another — in the near infrared range or the short-wave infrared range of the spectrum) is used to represent the snow and ice cover. With this technique it is possible to generate a diagram map of Alaska glacier ice cover for the period of forty years, and monitor the dynamics of glacier's regression and changes in its dimensions.

Monitoring of El Niño and La Niña Phenomena

The phenomenon of El Niño was known long ago. Initially it was described only on the shores of Ecuador and Peru. Thus, in the 15th century, fishermen from the South America noticed unusually warm stream appearing at times during Christmas along the shore, and bringing a lot of sardines. This stream was called El Nino (in Spanish "boy, child") as a gift of nature in honor of Christ. However, it should be noted that this phenomenon exists over at least 100 thousand years (as evidenced by geological and paleoclimatic studies). Regular fluctuations from warm to neutral or cold conditions occur every 3-5 years. So, El Niño phenomenon was registered globally 23 times and La Niño phenomenon – 15 times over the last 100 years [9].



a *b*

Fig. 4.7. Dynamics of Colombia glacier melting; according to images delivered by Landsat satellite (*a* — 1980; *b* — 2015) [7].

For centuries, more heat is accumulated in the tropical zones of the planet, and smaller amounts — near the poles; ocean and atmosphere ensure the redistribution of heat across the planet, establishing a balanced climate system with seasonal fluctuations in temperature and precipitation. However, heat redistribution in the tropics occurs every five to ten years and has a powerful impact on the entire planet. These phenomena called El Niño and La Niña represent the opposed extreme values of water temperature and atmospheric pressure in the equatorial zone of the Pacific Ocean. During El Niño, the surface temperature of the Pacific Ocean in the tropical and central parts increases by 5–10 degrees, and La Niña, in contrast, manifests itself as a decrease of water surface temperature in the east of the tropical zone of the Pacific Ocean. This phenomenon lasts from six months to a year.

Daily global satellite-based surveys since 1992 have produced a large amount of data for understanding climatic processes, such as ocean and atmosphere surface temperatures, sea level rise and ocean currents, which now allows to track the signs of approaching El Niño and La Niña and forecast this phenomena *(Fig. 4.8).*

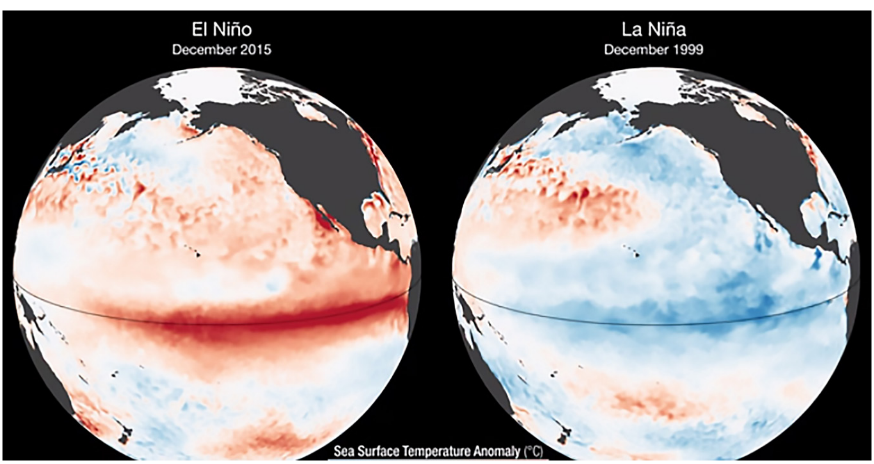


Fig. 4.8. El Niño and La Niña phenomena according to the data obtained from satellite-based survey of ocean surface temperature [10].

Due to more intensive warming of water during El Niño, an abnormal zone of convection is formed, which leads to increase in the number of hurricanes, showers and other extreme weather conditions, the impact of which is also observed in Ukraine. That is why it is important to timely detect and forecast the approximation, intensity and duration of El Niño in the Pacific Ocean by the ocean surveys from the space.

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4.1.2. Hydrology

Space hydrology is a branch of hydrology and one of the Earth sciences, which deals with the space observations of the Earth's hydrosphere. The primary objective of the space hydrology is continuous monitoring and study of certain elements or complexes of hydrological objects.

Water bodies are very distinct on satellite images, which allows for their efficient remote mapping and monitoring. With satellite imagery, it is possible to monitor the development of various processes in rivers, lakes, reservoirs, determine their consequences, caused both by natural and anthropogenic factors.

The main advantages of satellite images are as follows: simultaneous coverage of large water areas, continuity of information content of the image for each captured point, high frequency of recording of the state of water masses and coastal areas.

Using RS data and software packages for their processing one can address numerous important *hydrological tasks*. Namely, it is possible [1, 2]:

- to receive multiscale site maps of water intake structures and assess the extent of their anthropogenic disturbance;
- to control the hydrographic network and structures located in the bottomland and nearby areas, especially in large cities and in the areas of major hydrotechnical construction;
- to do inventory of waterbodies and water passages;
- to monitor and forecast the processes of vegetal invasion of estuaries and bogging of near-by territories and landscape transformation (including historic reconstruction);
- to determine the biological productivity of waterbodies, assess biological resources (stocks of phytomasses of upper aquatic vegetation, degree of development of groups of zoo- and phytoplankton, size of

spawning grounds, nursery grounds and places for feeding water-fowl, etc.);

- to detect changes in water bodies caused by anthropogenic and natural factors (natural and anthropogenic eutrophication, changes in the water transparency, general mineralization, presence of suspensions, etc.);
- to identify the sources of water contamination (isolated and diffuse) and the components of such contamination, including organic and mineral particles, surface oil slicks, dissolved organic matter; identify areas of algal bloom, thermal pollution and determine pollutants migration pathways;
- to carry out environmental monitoring on the basis of GIS-technologies;
- to determine the intensity and extent of erosion and abrasion of shores, landslides, mudflows and sinkholes (suffosion), as well as boundaries of karst regions and to register the transformation of river beds and mouth bars;
- to monitor the harmful effects of water (flooding, salinization, disastrous floods);
- to perform monitoring and simulation of territories waterlogging during floods on the basis of a series of satellite images and 3D relief models;
- to determine the impact of anthropogenic load (caused by urban agglomerations, industry and agriculture) on the land plots adjacent to water bodies (including recreation ones);
- to monitor the hydro- and ice regimes of waterbodies, observe the processes of snow melting for flow forecasting, monitor ice conditions during river floods;
- to identify areas of violation of sanitary protection zones in the areas of water intake;
- to assess the state of water and environmental protection sites and monitor the compliance with the provisions of the current legislation regulating the relationship between man and nature.

In practice, there are following *types of research* [3]:

- study of rivers;
- study of water storage reservoirs, lakes;
- study of marshes;
- study of glaciers;
- study of sea waters and waters of World ocean;
- hydro- and aerial observations (space meteorology);
- specific hydrological studies;
- study of groundwater.

Monitoring of overgrowing processes in river estuaries, upper reaches of water storage reservoirs and waterlogging of adjacent territories

The studies of any changes occurring in the ecosystems are performed on the basis of comparative analysis of data collected at different times. Among modern methods of retrospective comparisons, the most effective ones base on the use of remote sensing data. The use of remote monitoring is particularly important for the studies of changes in landscape structures of large nature-made objects, when regular field research is difficult and rather expensive.

Vegetation is the most accessible feature of landscape, including aquatic one. By tracking the restructuring of species and coenotic composition of vegetation cover, redistribution of dominants or areas occupied by different associations of plant species, it is possible to estimate and predict the transformation of landscape complexes. In any landscape structure one may identify spatial areas, which are characterized by the homogeneity of abiotic factors and the formation of a specific set of phyto-and zoocenosis. They are called biotopes. They can be classified, ranked, may occupy large areas, and their boundaries are clearly seen in satellite images. Some of them are used as indicators, since the comparing of the changes in their structure or occupied area allows for the identification of the main trends in the development of aquatic ecosystems.

Aquatic landscape – aquatic complex within the Earth's landscape. Depending on the origin, it can be natural or man-made. Natural landscapes comprise inland (seas, lakes, rivers) and oceanic units (inland seas, marginal seas and the oceanic landscapes). The man-made landscapes include artificial water reservoirs – water storage basins, canals, ponds.

Phytocoenosis or plant community is a collection of plant species within a designated homogeneous area, which have a relatively uniform pattern of interaction with environment and with each other.

Biotope is an area of uniform environmental conditions in terms of abiotic factors, providing a living place for a specific biocenosis (i.e., the habitat of species, organisms). A biocenosis is a specific assemblage of living organisms living together at a certain place of land or water area, called a biotope.

Here is given an example of the study of wetlands transformation in the upper reaches of a large plain water reservoir (the Kyiv Reservoir) based on the analysis of changes occurring in their biotopical structure according to the results of retrospective interpretation of the series of satellite images *(Fig. 4.9)* [4].

As seen from the interpretation of satellite images of the upper reaches of the Kiev Reservoir for the 30-year period (1985–2015), wetlands have undergone significant transformations. These changes have been caused by the redistribution of areas of the main types of terrestrial and aquatic landscapes. On the one hand, there is an increase in the area of waterlogged settlements (hygrotopes), and on the other hand — a constant decrease in hydrotopes. In addition, there is observed a constant increase in the areas of macrophyte thickets growth and degradation of meadow vegetation. This substantiates the earlier hypothesis on the secondary deltafication processes in the upper reaches of large plain reservoirs, aimed at restoring the natural structure of the passage, flood plain and the system of bottomland waters [6].

Monitoring of algal bloom

Algal bloom is the rapid increase in the population of microscopic algal (usually blue-green) accompanied by significant worsening of the quality of water. A number of factors contribute to this phenomenon, including climate change, abundance of different minerals and organic substances in water and intensification of human economic activity. In particular, the runoff of municipal or agricultural wastes contaminated with biogenic matter, mineral fertilizers, synthetic detergents and etc.

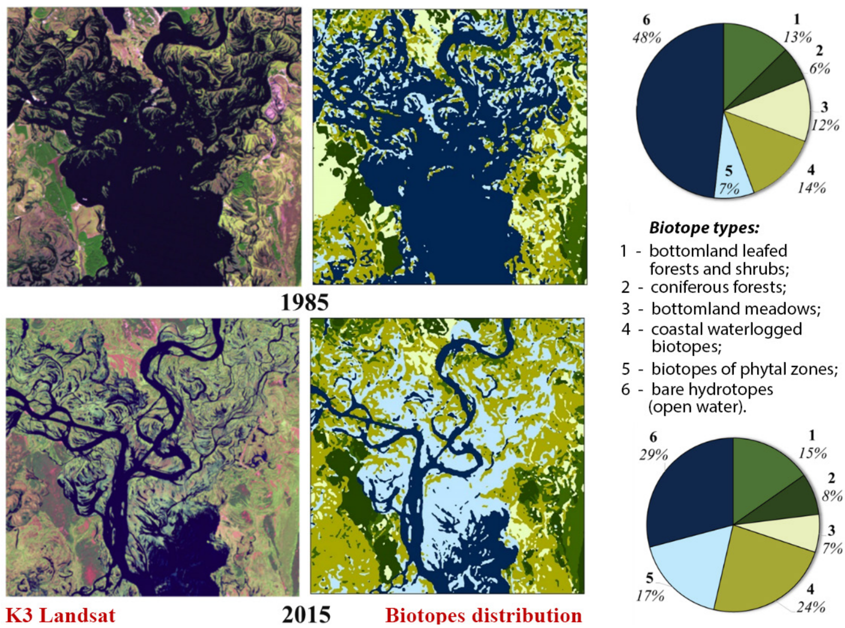


Fig. 4.9. Study of dynamics of overgrowing in the upper reaches of the Kyiv Reservoir according to K3 Landsat data interpretation [5] Notes: *1* — bottomland leafed forests and shrubs; *2* — coniferous forests; *3* — bottomland meadows; 4 — coastal waterlogged biotopes (of helophyte assemblages); *5* — biotopes of phytal zones; *6* — bare hydrotopes (open water)

Algal bloom is the indicator of imbalance in the processes of production and degradation in the ecosystem and increased trophic state index towards eutrophication, which is usually accompanied by the deterioration of water quality, up to hypertrophication, when the abundance of biogenes in water causes increased oxygen consumption, mass death of biota and a sharp change in the ecosystem characteristics.

Trophic state index — a feature of the habitat (ground, water reservoir) of living organisms in terms of biological productivity, which depends on the content of biogenic elements.

Eutrophication is when a body of water becomes enriched with biogenes, which is accompanied by the destruction of water reservoir productivity. Eutrophication may be a result of natural ageing of waterbody, fertilizers' use or contamination with wastewater.

Hypertrophication is characterized by excessive enrichment of water-body with biogenic elements.

Biogenic substances (elements), or biogenes (from Greek bios – life and genos – birth) are the substances taking the most active part in the life of aquatic organisms. They include mineral compounds of nitrogen (NH_{4+}, NO_{2-}, NO_{3-}), phosphorus (H_2PO_{4-}, HPO_{2-4}, PO_{3-4}), silicon ($HSiO_{3-}$, SiO_{2-3}), iron (Fe_{2+}, Fe_{3+}) and compounds of some microelements.

Diffuse or scattered reflection of light is the reflection of light from a surface such that a ray incident on a surface is scattered at many angles. Diffuse reflection is explained by the reflection of light from irregular surfaces and is opposite to specular reflection.

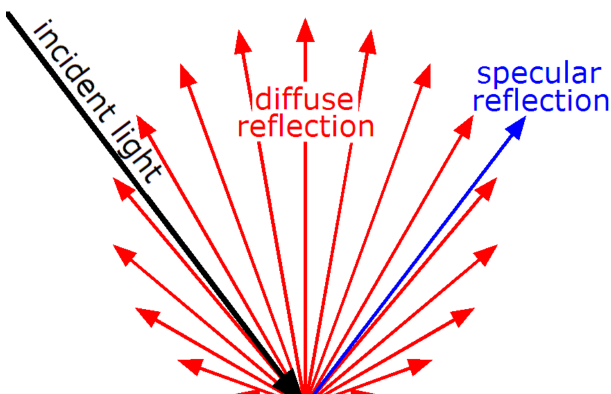
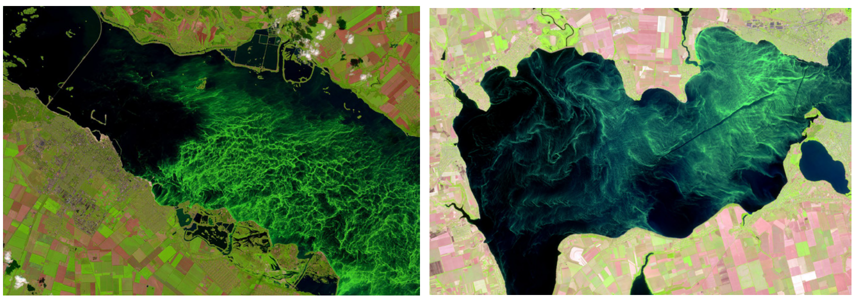


Fig.4.10. Diffuse and specular reflection

Algal bloom is recognized by the discoloration of the water as a result of rapid increase in the population of microscopic algal. For this reason, the methods of satellite imagery processing aimed at the identification of algal bloom areas usually base on the analysis of variations of the factor of diffuse reflection of light from surface and subsurface water layers with increased concentration of phytoplankton. Red visible light from 600 to 700 nm and near IR range are the most suitable for the observations. Vegetation index NDVI is useful for the identification of the areas of algal bloom. The texture of the image can also be used as an additional interpretation feature for the identification of algal bloom zones. Usually, the areas of intense algal bloom are characterized by specific filamentary image texture *(Fig. 4.11.)*.



a *b*

Fig.4.11. Algal bloom acquired by Sentinel-2 satellite; illustrated by the images of: *a* — the Kremenchuk Reservoir (image of August 22, 2015); *b* — the Kakhovka Reservoir (image of August 10, 2016) [7]

The satellite image demonstrates that the areas of intense algal bloom lay along the currents and are involved in vortex-type flows; in addition, the most significant influence on the transfer of algal has the wind. During prolonged periods of warm, sunny and windless weather, cyanobacteria combine into aggregates that come to the top and form surface or subsurface clusters. On satellite imagery, cyanobacteria appear as bright filamentary stripes or even aggregates. The color of these spots depends on the stage of algal development and ranges from bright green to chestnut brown [2].

Intense algal bloom is typical for the reservoirs with weak currents, as in the case of the cascade of water reservoirs on Dnipro River. Here is an example of the study of the areas of algal bloom in the Kyiv Reservoir, where the vegetation index has been used to identify the centers of blue-green algal blooming *(Fig. 4.12.)*.

The results allowed to map and confirm the results of ground surveillance obtained by Hydrometeorological Service of the Central Geophysical Observatory of the Ministry of Emergencies of Ukraine in 2013, which prove that the qualitative and quantitative indicators of phytoplankton development in the Kyiv Reservoir reached in 2013 the maximum values in the middle (Strakholisya village) and the lower (Novy Petrivtsy village) parts of the reservoir.

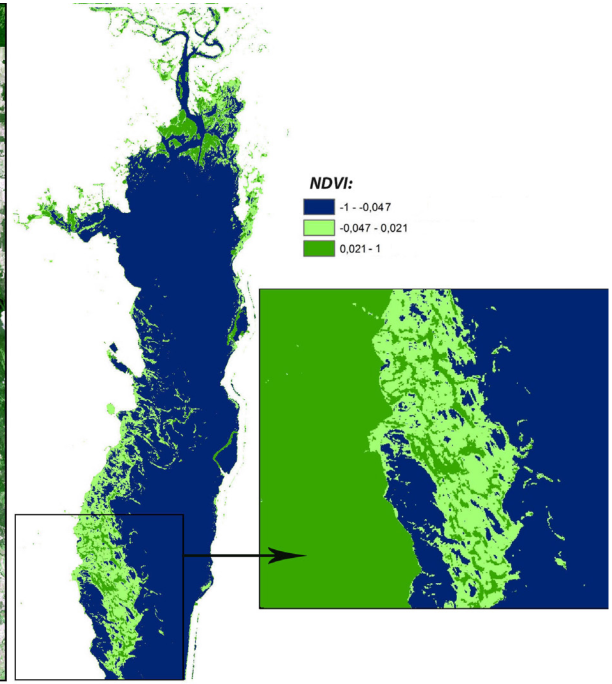
Monitoring of thermal pollution of waters

Thermal pollution occurs when warm water used by CHP plants, NPPs and other power engineering facilities is returned to the natural environment. The largest amount of warm water is discharged into the reservoirs by nuclear power plants. The pollution is manifested in the increased water temperature. It is accompanied by the changed chemical and gas composition of water, reduced concentration of oxygen, algal bloom, and increased content of microorganisms. Warm water changes the thermal and biological regimes of water bodies and negatively affects their inhabitants. According to the studies conducted by hydrobiologists, water heated to a temperature of 20–30°C inhibits the activity of fish and other aquatic organisms; and water heated to the temperature of 36°C results in the death of fish.

The data of remote sensing obtained within the wavelength range of 8–14 μm (far-infrared radiation) provides information on the thermophysical properties of the objects on the Earth surface and landscapes of various kinds.

Open source raster data of thermal radiation with a medium spatial resolution (100 m or more) is represented by the data collected by TIRS sensor installed on Landsat-8 satellite. These data present in two spectral bands (10.3–11.3 μm and 11.5–12.5 μm); for their conversion to temperature distribution, there was used the inverse Planck function for the thermal emission of the "gray body", which is the transformation of the spectral density of the energy brightness of thermal radiation provided by the TIRS sensor, with due regard to the coefficient of thermal emission, which reflects the ability of different surfaces to emit heat.

a



b

Fig. 4.12. Study of the spatial distribution of the areas of blue-green algal bloom within the territory of the Kyiv Reservoir (*a* — the fragment of satellite image made by Landsat 8 as of 13.08.2013; *b* — distribution of vegetation indexes in the area of the most intense algal bloom — between Kozarovychi and Liutizh villages) [2]

A cooling pond (cooling reservoir) is a man-made body of water, designed to cool the turbine condensers, which allows producing electric energy. Cooling water in the pond is made due to evaporation and convection heat transfer

The results of heterogeneity study of the Netishyn Reservoir temperature fields (cooling reservoir of Khmelnytsk NPP) are presented below. The cooling pond (cooling reservoir) is an artificial open body of water formed for the purpose of cooling turbine condensers and producing electric energy. The water cools in the pond mainly due to the evaporation and convective heat transfer.

The imagery as of 18.09.2015 *(Fig. 4.13b)* acquired by Landsat 8 spacecraft demonstrates that the pattern of temperature distribution under varying conditions (with 1 and 2 units operating and with different directions of wind) is rather irregular. Although the differences in the temperature are not significant, there can be distinguished several thermal zones: the zone of elevated temperature in the eastern and central parts of the cooling pond and low temperature zones in the southern and western parts *(Fig. 4.13)* [8]. The thermal maps allow assessing the pattern of discharged hot water circulation in the cooling pond and providing specific recommendations on the improvement of the pond's operating efficiency.

Study of ocean surface temperature distribution

Imaging with the aid of thermal infrared radiometers installed at all operating meteorological satellites opened up the possibility for simultaneous global recording of ocean surface temperatures, which could not be done before using ships or aircrafts. The global satellite photomaps of Sea Surface Temperature (SST) include AVHRR/NOAA images, which have been produced in real time on the basis of multiband temperature determination algorithm since 2001 and are used for the operational purposes (see Fig. 4.14) [9]. The distribution of water temperature represents the main diagnostic feature for the forecasting of the areas with the most probable fish aggregations.

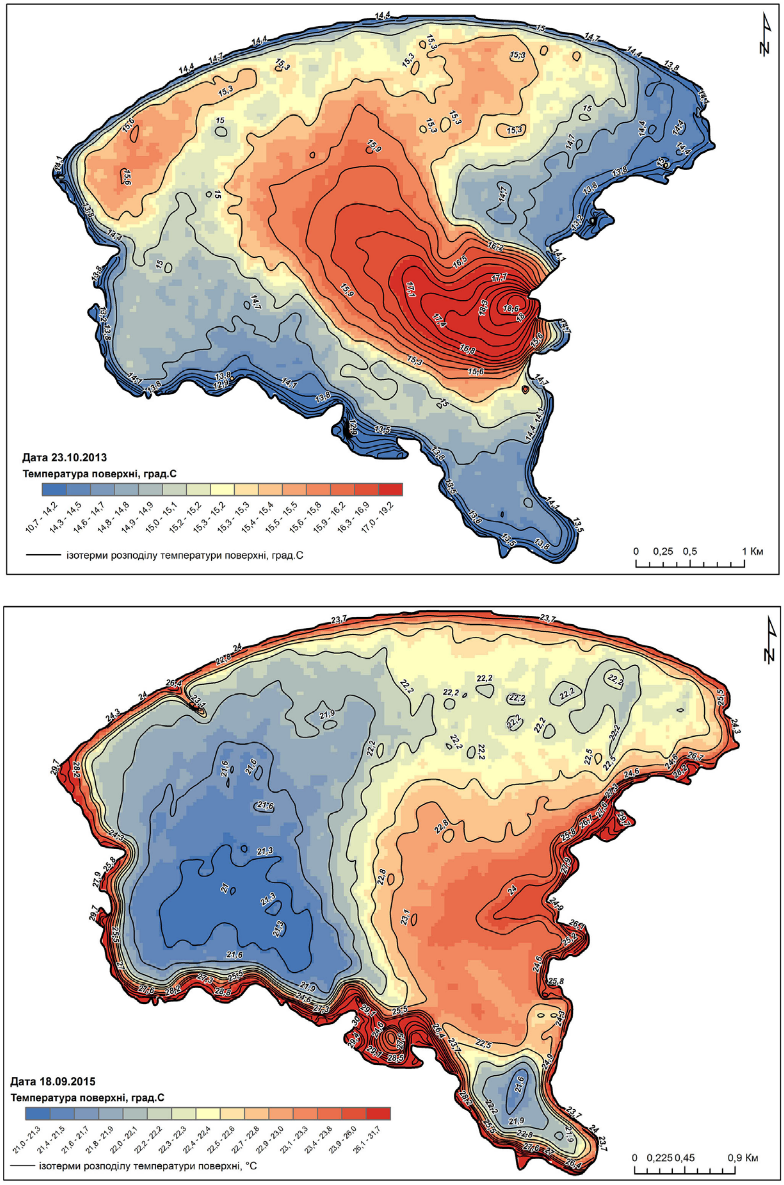


Fig. 4.13. Distribution of surface temperature
in the Netishyn Reservoir, Iziaslav District, Khmelnytsk Region
(*a* — as of 23.10.2013; *b* — as of 18.09.2015) [8]

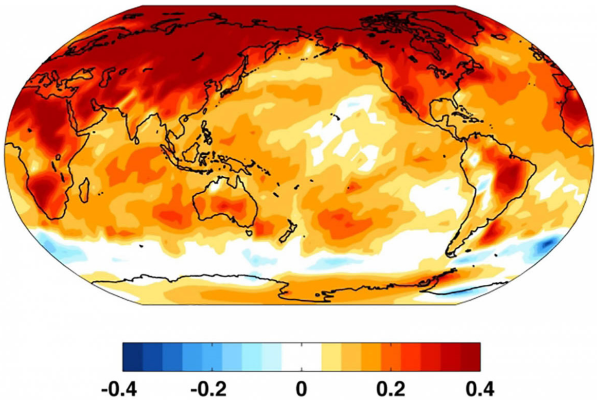


Fig. 4.14. Temperature changes over the last 50 years (centigrade temperature for decades), according to thermal survey by NOAA satellite [9]

The pattern of ocean water temperature distribution, as shown in satellite imagery, significantly differs from the earlier concepts. Contrary to the gradual temperature changes at ocean surface, as specified in the published collections of maps, there is seen a very complex and contrasting pattern caused by jet currents and vortexes. In the coastal regions of subtropical and tropical latitudes, there are registered fronts between warm oceanic waters and cooler coastal ones. In addition to studying water temperatures, thermal infrared imagery provides data for the examination of dynamic processes in the ocean, currents, oceanic vortices and fronts, upwellings and other phenomena, which study also involves the use of ocean surface level data.

In particular, in the image of the Atlantic Ocean *(Fig. 4.15)* there can be clearly seen the Gulf Stream with the water temperature substantially higher than the temperature of surrounding ocean waters, and vortex structures — the **rings** — appearing at the boundaries of warm and cold waters [9].

The Gulf Stream is a warm current located in the northern part of Atlantic Ocean - a very powerful ocean current carrying warm water northwards from the Equator. The Gulf Stream causes significant water circulation: warm – northwards and cold – southwards. These processes are clearly illustrated by the thermal maps produced using RS data.

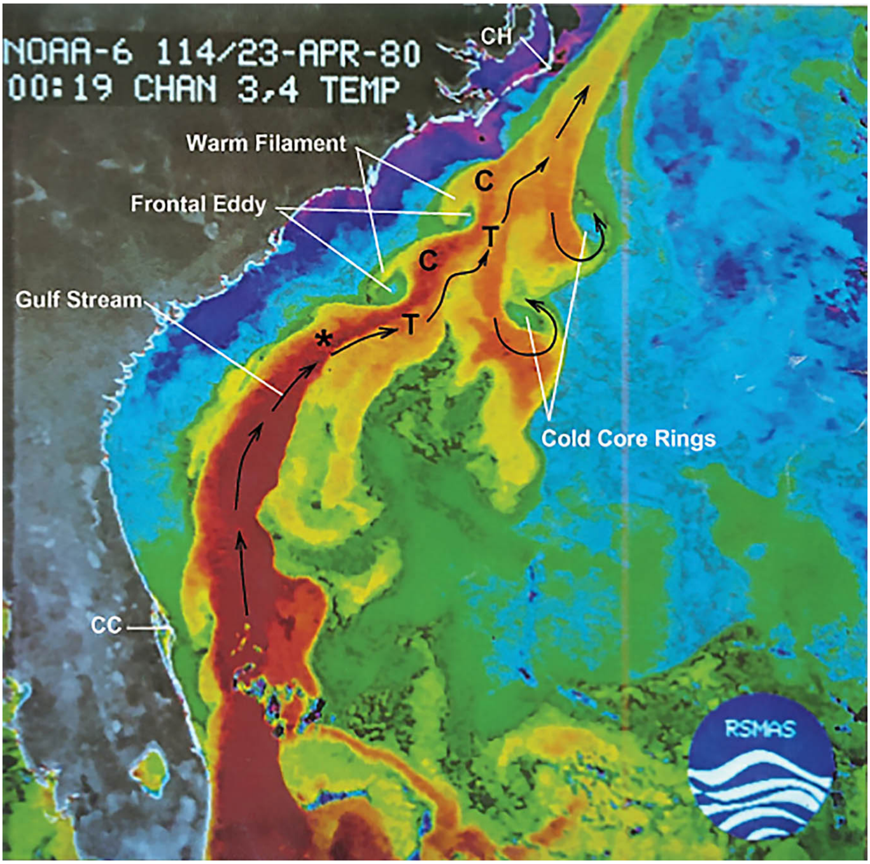


Fig. 4.15. The Gulf Stream within the temperature pattern of the ocean surface, according to thermal infrared imagery by AVHRR radiometer from NOAA satellite (http://oceanexplorer.noaa.gov) [9]

Study of river bed evolution

It is commonly known that riverbeds change their horizontal position and elevation in the course of time. Over some 30–50 years the river can shift for a distance equal to the width of its channel; there can appear new branches or island formations. Currently, integrated observations of riverbeds dynamics using RS data are becoming more and more popular.

When studying river bed evolution, the combined use of remote aerospace methods and ground geomorphological and geology and geophysics data may provide more precise information of higher quality regarding the changes. Large-scale topographic materials produced in the 1980s with the rivers specified on them often do not correspond to the actual state of hydrographic objects [10].

The dynamics of river bed evolution is usually associated with natural factors, primarily the neotectonic movements.

The comparative interpretation of the images of Tysa river made at different times demonstrated that over the period starting in 1984 the river bed to the west of Solotvyno urban settlement migrated towards the settlement and split into two channels in the western part of the studied area with formation of an ait. South westward of the settlement, where the source of Iza tributary is, Tysa makes a characteristic curve again towards Solotvyno urban settlement. Southwards and south eastwards of the settlement, the river becomes straighter and less twisty *(Fig. 4.16)* [11].

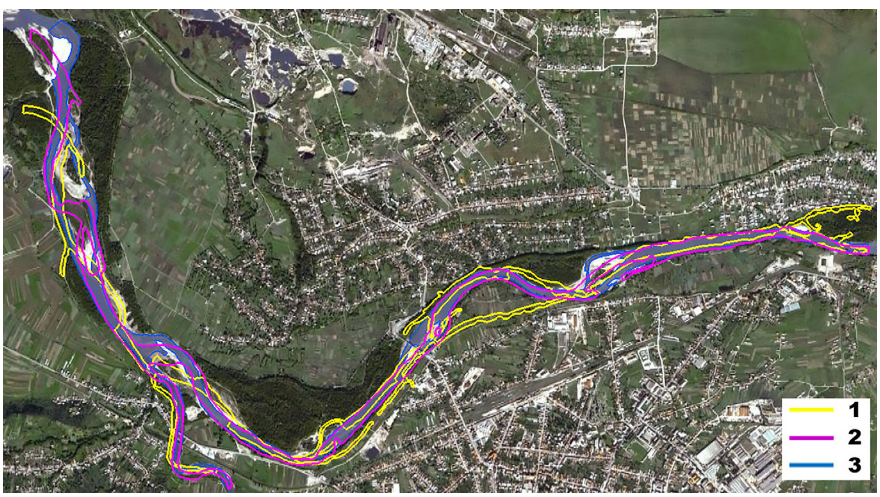


Fig. 4.16. Study of Tysa river bed changes [11]
(*Notes: shoreline of Tysa river is marked according to: 1 — satellite image by KFA-1000 camera as of 1984; 2 — satellite image by Landsat-7 camera as of 2000; 3 — satellite image by Spot-5 camera as of 2007)*

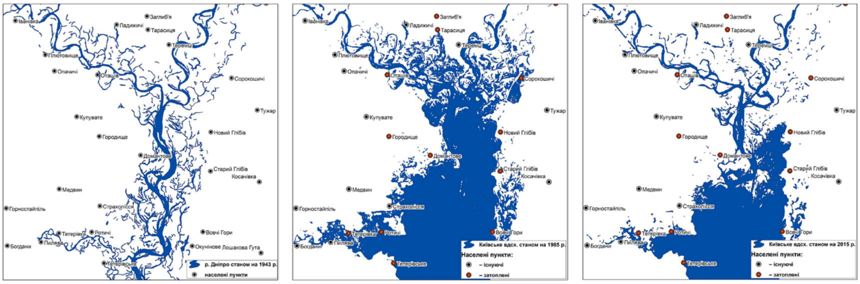
Historical reconstruction of hydrographic network and assessment of landscapes transformation

The comparison of historic maps and modern RS data makes it possible to reconstruct the hydrographic network of any territory or landscape maps of both separate reservoirs and water basins. Comparing appearance of water bodies before and after anthropogenic transformations also provides interesting results. The assessment of Dnipro river bed and its floodplain transformation in the upper reaches of the Kyiv Reservoir may be used as an example.

The primary vegetation of Polissia floodplains of the Dnipro River and the lower reaches of Prypiat' and Teteriv rivers prior to the formation of the Kyiv Reservoir was represented by hardy-shrub species, meadow, marshy and semi-aquatic (amphibian) phytocoenoses. The Kyiv Reservoir, put into operation in 1964, changed the natural environment of the territory considerably, including hydrological, subsoil and soil and ecological and biological regimes of the meadows that were subject to shallow flooding and subsoil and ground impoundment.

The obtained maps that represent the reconstructed old channel of Dnipro River allowed restoring the historic appearance of the river prior to the formation of the reservoir. When comparing these materials with the current real-time satellite images (following their interpretation) it is possible to determine the degree of impoundment and transformation of Dnipro river floodplain resulting from the river regulation by Kyiv Hydroelectric Station. The natural channel of Dnipro River and the basin of the Kyiv Reservoir are displayed, under condition of complete filling, in Fig. 4.18.

Fig. 4.17. provides detailed examples of the gradual transformation of the most dynamic part of the water reservoir — its upper reaches. The images clearly demonstrate a significant overgrowth of higher aquatic vegetation in the reservoir's basin over a period of study, and even though it is currently represented by the species differing from historical meadow vegetation, it is noticeable that the floodplain gradually restores its original form [12].



a *b* *c*

Fig. 4.17. Restoration of natural river bed and bottomland biotopes of Dnipro River in the upper reaches of the Kyiv Reservoir. Changes of the area under investigation over time: in 1943 — according to German topographic map (*a*), in 1985 — according to satellite imagery acquired by Landsat — 5 (*b*), in 2015 — according to satellite imagery acquired by Landsat-8 (*c*) [12]

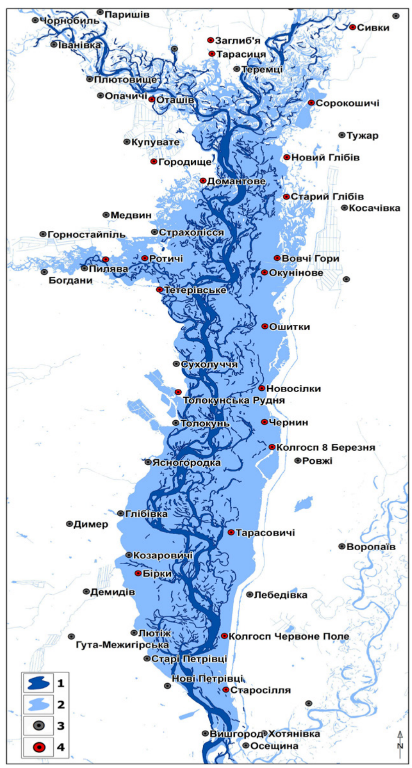


Fig. 4.18. Transformation of river bed and bottomland complexes of Dnipro River as a result of creation of the Kyiv Reservoir [12]

1 — Dnipro River as of 1943;
2 — Kyivske Reservoir as of 1985;
3 — existing settlements;
4 — settlements flooded while creating a reservoir in 1964–1966.

Monitoring of water bodies drying up

The Aral Sea was formerly a large, but currently nearly totally dried up salt lake, which looks like a large salt desert. Its drying up is considered one of the biggest ecological catastrophes of our time, because some 50 years ago the Aral Sea was the fourth largest lake in the world with an area of 50 000 km^2 and the maximum depth of 68 m. However, the process of its disastrous shrinking has already started, which was directly caused by human economic activity, namely the construction of large-scale irrigation systems in the Kazakhstan and Uzbekistan steppes due to the fact that the Aral is a salty lake and its water was unsuitable for irrigation [13].

The Aral Sea was fed by the two main rivers, Amu Darya and Syr Darya; and it has been decided to take water from these very rivers for the irrigation of collective farm lands. In 1960, the irrigating draft amounted to 60 km^3 annually, and by 1990 it reached 120 km^3. The absence of streamflow disrupted the water balance of the Aral Sea — the amount of water evaporated from its surface was not replenished. The lake started to shrink very intensely in 1961: during the day the water level subsided several tens of meters from the shore. The annual rate of shrinking increased from 20 cm in the 1960s to 90 cm in the 1980s. By 1989, the Aral Sea lost nearly 1000 km^3 of its water and split into two separate bodies of water, the North Aral Sea (or Small Aral Sea) and the South Aral Sea (or Large Aral Sea). The water level of the Aral Sea fell

Fig. 4.19. The Aral Sea [13]

by 22 m by the 2000s, compared to original level, and was only 31 m. In 2009, the southern part of the sea completely dried up and the western one split into several small isolated lakes [13].

The sharp drop in the water level of the Aral Sea is a huge ecological disaster of the present time (probably even bigger than the Chornobyl), which induced a number of negative changes. Drying up has altered dramatically the local climate and natural ecosystems. Large body of water moderated the continental climate of the region, and loss of water in Aral Sea resulted in hotter and drier summers and cooler, more prolonged winters with less snow in its original territory. However, the biggest problem was the emergence of dust storms in the dry valley over the sea area. They spread the toxic mixture of dust and salt, enriched with mineral fertilizers and pesticides that accumulated over the years in the bottom sediments of sea ooze, arriving there from nearby fields [14].

In an effort to save at least some parts of the Aral Sea from complete drying up, the Kok-Aral Dam dividing the North (Small) Aral Sea and the South (Large) Aral Sea was constructed in 2005. The project also included the reconstruction of hydro-technical utilities on the Syr Darya river. The 45 m high dam allowed raising the water level in the Small Aral Sea to 42 m and reduced its salinity *(Fig. 4.21)*. This resulted in the restoration of fish population and had a positive impact on the regions' climate, which became softer, in particular, the level of dust contamination reduced and rain clouds, not observed in the region for a long time, started to form [16]

Dynamics of ice conditions of inland waters

Melting of ice on water bodies occurs at different times and depends on the climate conditions, supply sources, structure of river beds, dynamics of currents, etc. The most intense processes are seen near river banks, which can be explained by both, the effect of the water flowing from the basin and the quicker warming of the ground. As a result, the ice along river banks breaks with formation of strips of free of ice water — ***flange ice***. The water level grows rapidly, the ice cover collapses, and the ice may partly move down and stop again — it is an ice motion.

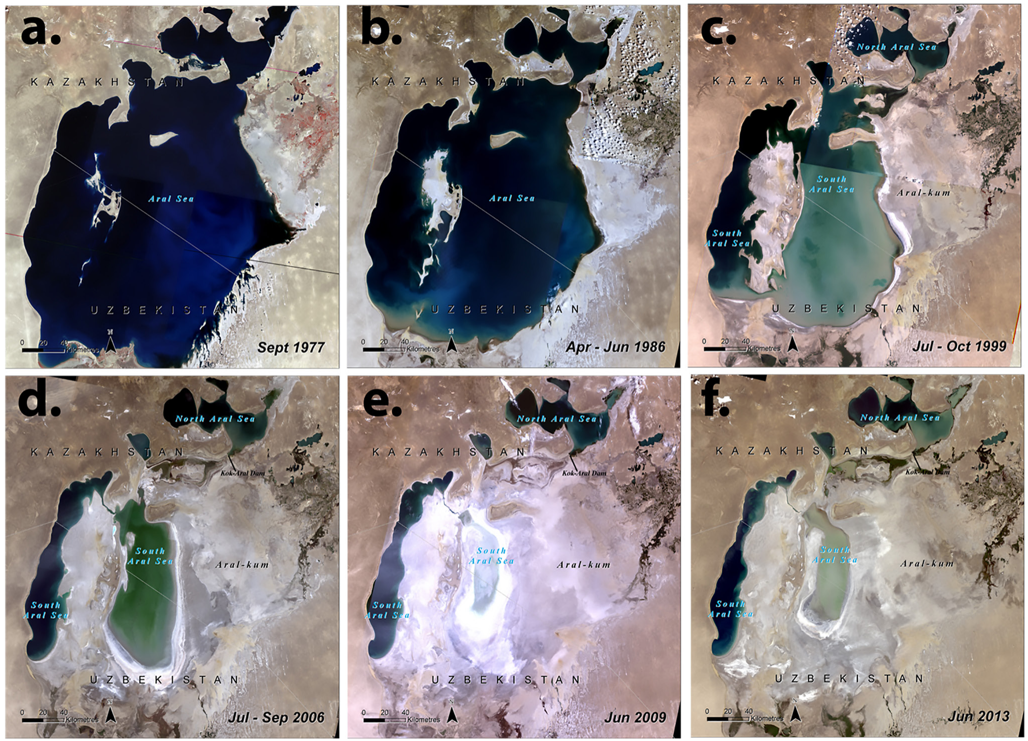


Fig. 4.20. Dynamics of Aral Sea drying up according to Landsat satellite imagery taken in 1977 through 2013 [15]
Source: USGS/NASA; imaging by UNEP/GRID-Sioux Falls.

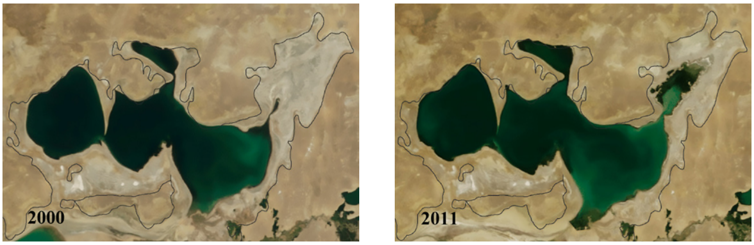
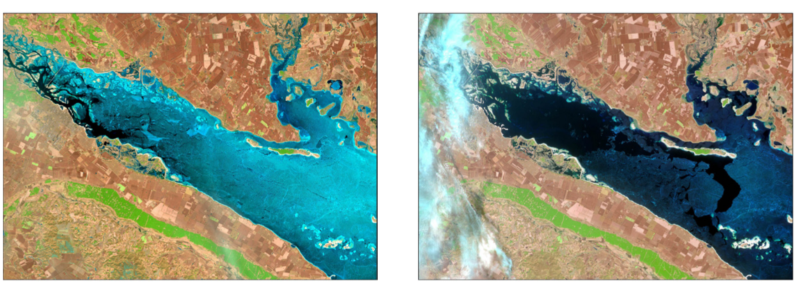


Fig. 4.21. Illustration of restoration processes in the Small Aral Sea, according to Landsat satellite imagery produced in 2000–2011.

In addition, the movement of ice and ice fields on rivers and water reservoirs is induced by the currents; this phenomenon is called ice drift. The areas of clean water in the ice cover formed as a result of ice motion are called ice lead [17].

The satellite image represents the process of ice melting — the phase of ice regime, which is characterized by the destruction of ice cover. Figure 13 shows examples of ice conditions monitoring over the territory of the Kremenchuk Reservoir in 2017. The images have been synthesized in "artificial colors", where the colors of the image match the following spectral bands of the satellite image representing different parts of the electromagnetic spectrum: 1 — SWIR Band (1610 nm), 2 — NIR Band (842 nm), 3 — Red Band (665 nm).



a *b*

Fig. 4.22. Ice phenomena on the Kremenchuk Reservoir; images produced by Sentinel-2 satellite (*a* — as of March 4, 2017; *b* — as of March 11, 2017 [18]

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4.1.3. Geology

In Ukraine, professional aerial photography was introduced in 1922 in the vicinity of Kharkiv by Ukrpovitriashliakh, Joint Stock Company. It was initially carried out as research works for obtaining high-quality aerial images of various scales in the visible range. Since 1924, aerial photography has become systematic and scheduled. The first customers and active users of the imagery were surveyors who, in the process of creating and updating detailed scale topographic maps of eastern and southern territories of Ukraine, started to use topographic decoding of aerial imagery. Geologists began to use it a bit later to study the territory of Ukraine. In general, the introduction of remote sensing data into the domestic geological industry was closely linked with similar works carried out in Russia (formerly — the USSR).

Academician O. E. Fersman who organized and headed in 1929 the Aerospace Research Institute in Leningrad (now — St. Petersburg), initiated the use of remote methods in geology. Just thanks to his support in 1929–1935, large-scale studies of natural resources by aerial photography were performed in hardly accessible territories of Siberia and Asia. One of the lines of these studies was focused on addressing certain geological problems. The experience of introducing aerial photography into the geological survey was first summarized by A. V. Haveman in 1937.

During the Second World War, aerial photography was expanding significantly along with updating of its technological processes which was dictated by the need for a quick and objective tackling of military intelligence tasks. There was qualitative development of surveys in the visible range of electromagnetic spectrum, and at the same time, emerged aerial imagery in the radar and thermal zones of the electromagnetic spectrum.

In Ukraine, aerial photography was first applied in geological cartography by A. O. Zviahelskyi and V. M. Fedirchenko in 1962, who studied the northern part of the Ukrainian Shield. Thanks to the work by these researchers, new geological and tectonic information was obtained, which convincingly indicated the feasibility of using aerial methods in geologically closed regions of Ukraine.

In general, the period of the early 70s — late 80s of the XX century is characterized by extremely active and fruitful use of aerospace methods in geology. At the beginning of this period, remote sensing materials on the continental and regional levels of generalization have been used, later on, more detailed materials have been applied, which allowed many researchers to analyze the deep-seated structure of Ukraine's regions and, based on generated results, create corresponding cosmological maps of different levels of generalization.

An important stage in the use of satellite information was the creation of the "Cosmotectonic Map of the Ukrainian Shield" with a scale of 1:1 000 000, which represented the main tectonic elements of the Precambrian age of the Ukrainian Shield according to aerial survey data. The metallogenic analysis of the main cosmological structural elements of the shield has been performed and new ore-prospective structures and structural units have been identified.

Since the second half of the 80s, remote methods have been increasingly used in ecological and geological research. A set of specialized works — aerospace monitoring of the geological environment — has been performed. Within the framework of these studies, new methods have been developed for the generation of forecast maps for groundwater exploration, assessment of probability of exogenous geological processes manifestation (silver medal of the USSR VDNG (National Economy Achievements Exhibition), and protection of underground waters.

The emergence of spacecrafts designed for the purposes of natural resources exploration (Landsat, Space Shuttle (USA), Meteor, Cosmos, Soiuz, Resource, Myr (USSR), Spot (France)) and equipped with on-board spectroscopy and radiometric tools providing the survey of terrestrial formations in ultraviolet, visible infrared ranges and the radio range, made it possible for scientists of the leading institutions of the National Academy of Sciences of Ukraine to substantiate the theory and methodology of the use of remote sensing, integrated geological interpretation of surveying materials for the exploration of oil, gas, sulfide ore, areas of feeding and unloading the groundwaters of the regions of Ukraine.

Materials of new technologies made it possible to perform geological studies with specification of previously discovered structural elements and mapping new ones.

Since the late 80s through late 90s of the last century, the detailed satellite data have been intensely used in addressing the issues of geological exploration. In addition, there was initiated a transition from a qualitative approach to a quantitative analysis of data sets aimed at the assessment of the prospects of forecasted aerospace and geological objects.

Over the last decades, upon the request by Pivnichheolohiia, State Regional Geological Enterprise, methodological techniques for the exploration of non-ferrous metal deposits at the level of individual ore nodes based on spectrometric analysis of RS materials and vegetation data have been developed (V.Ye. Filipovych, V. L. Prykhodko et al [1)], along with creation of the factographic and interpretation portion of the Remote Basics of the State Geomap-200 (V.Ye. Filipovych, A. H. Mychak, N. V. Pazynych, O. I. Kudriashov, L.P Lischenko); similar works have been carried out directly on the initiative of the State Geological Service of Ukraine (O. O. Yantsevych, O. T. Azymov et al.) [2].

Space geology studies the material composition, depth and surface structure of the earth's crust, patterns of mineral deposits, using information from satellites

Space research methods supply new information useful for many branches of geology: geotectonics, geomorphology, seismology, engineering geology, hydrogeology, mineral exploration etc. As the scope of information about the Earth increases, the knowledge of the general planetary features thereof becomes essential, and spacecrafts help to accomplish these tasks. We may detect the areas with different tectonic structures on satellite images, and see all information obtained during ground-based surveys in one image. Depending on the scale of the image, we can study the continents as a whole, platforms and geosynclinal areas (large areas that differ from adjacent territories by the age of folding and peculiarities of development history), individual folds and faults.

A view from space allows us to draw conclusions about the combination of individual structures and the general tectonic structure of the region. Herewith in many cases it is possible to objectively demonstrate the situation and clarify the composition of the surface and deep structure buried under the cover of younger sediments. This means that with analysis of satellite images, we obtain new information on the structural features of the region, which will significantly clarify existing or help in generation of new geological and tectonic maps, and thus improve and make more purposeful the exploration of minerals, give grounded forecasts of seismicity, engineering geological conditions etc. Satellite images allow us to establish the nature and direction of tectonic movements, and the nature and intensity of modern geological processes. The images provide an opportunity to trace the interrelations between the relief and hydrographic network and the geological features of the studied object. Information from outer space allows us to assess the impact of human economic activity on the state of the environment [3].

With the use of spacecrafts, we may study the relief, material composition, tectonic structures of upper shells of other planets. This is important for geology, since it allows comparing the structure of the planets, and identifying their common and distinctive features.

We may highlight the following ***main areas*** of RS methods use in geology:

- structural and meta-structural analysis of the Earth's surface;
- analysis of local and global anomalies;
- geological study of the area and generation of geological maps;
- geoecological monitoring of exogenous geological processes [4]:
    - gravitational (sloping);
    - karst-suffosion processes and their man-made analogues;
    - erosion-abrasive;
    - cryogenic
    - forecasting of minerals locations:

- regional stage — estimation of forecasted mineral resources of oil, gas and ore provinces, ore-bearing zones and areas;
- detailed (exploration) stage — zonal forecast for the detection of oil, gas and ore zones, ore areas and nodes;
- local (survey) forecasting stage — exploration of deposits, inventory estimation [5].

Remote geological methods refer to the study of the Earth's geological structure when the equipment for recording of information is located at a distance from the studied object, and research is carried out without direct contact therewith. Information about the studied objects is transmitted to the receiver using light emission, infrared, ultraviolet, radio and other types of radiation. In this case, the intrinsic radiation and radiation reflected from the studied objects is used. In addition, gamma surveys and remote gravimetry are applied. But the imaging materials in the visible and near-infrared portions of the spectrum have been and remain the major sources of aerospace information.

The tasks addressed through the use of aerospace information in geology are as follows:

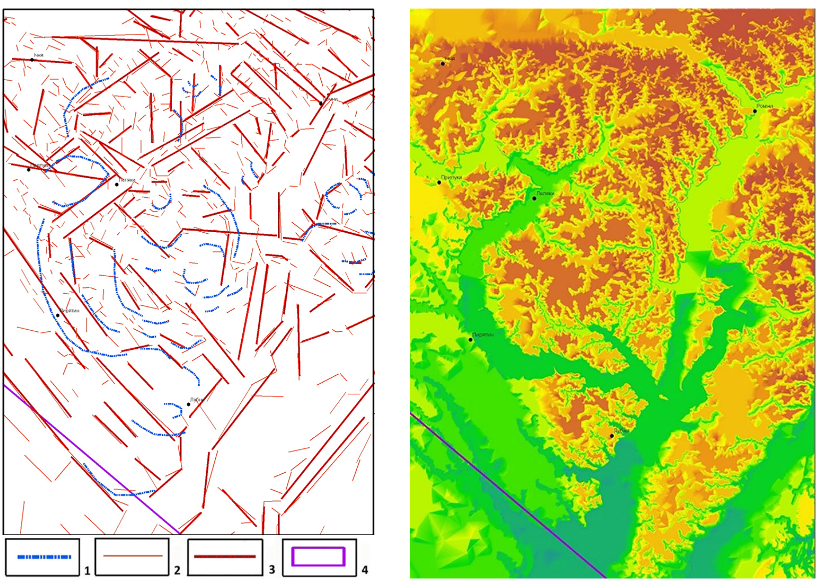
- study of the crust structure;
- forecast and search for raw energy resources;
- forecast of natural geological phenomena;
- geoecology and sustainable use of natural resources.

Methods of Remote Exploration of Mineral Deposits

1. Regional level

The purpose of regional geological study is to identify the most important features of the geological (tectonic) structure, their elements and their interrelations: linear structures of different extension (meridional, transverse, diagonal), which can be superimposed, through, as well as structural zones, basins, regional blocks, large-scale ring structures, large volcanic vehicles (volcanites), etc. It provides an opportunity to assess the overall structural position of the metallogenic province (region) on subregional (in some cases continental) levels, identify general structural patterns, address some of the existing geological and tectonic issues in the region. And finally, at the regional stage, it is possible to analyze the distribution of endogenous mineralization (significant amounts of ore minerals) across the studied area, determine the basic patterns of minerals' deposits [6, 7].

Conducting structural-geomorphological studies (SGS) at the regional stage allows more rational planning of detailed exploration works. The main objectives of the SGS at the regional level are the study or specification of the tectonic structure of oil and gas prospective regions and large local structures. Let's consider examples of the study of the Dnipro-Donets Basin (DDB) with the aim of forecasting structures which are perspective on oil and gas *(Fig. 4.23)* [7].



a *b*

Symbols: 1 — arcuate elements of relief; 2 — lineaments; 3 — zones of lineaments; 4 — the explored territory.

Fig. 4.23. Identification of morphological elements of relief (*a*) according to SRTM (fragment of radar topographic image) (b) on the territory of Dnipro-Donets Basin [7].

2. Local level

For the purposes of decoding remote sensing materials, three main techniques have been applied:

- comparing with satellite imagery made in the territory of reference areas — oil and gas reservoirs;
- comparing and matching identified anomalies in the relief structure with anomalies over the hydrocarbon deposits in order to justify the geo-indicative features of deep structures manifestation in the landscape;
- geological interpretation of decoding results on the basis of a comprehensive analysis of geological and geophysical, structural-geomorphological, geochemical, neotectonic materials and data on oil and gas content in area under exploration [8, 9].

According to previous aerospace and geological studies carried out within the DDB, it was proved that due to neotectonic activity, a significant part of structural elements (local structures, faulted zones) is represented in the relief structure and landscape features.

Based on the analysis of geological and geophysical materials, satellite image decoding materials, and topographic maps, the lineaments and their locations have been proven to correspond to the key structural elements of the DDB — zones of boundary faults, faults that limit the structural shafts, northeast faults, along which the changes in the configurations of salt stocks are observed.

Let's consider the examples of the study of the Bohatoiske Deposit located on the right bank of Orel River, on the slopes of the Neogene age Novokhrakivska Terrace. Taking into account the geomorphology of the studied area and peculiarities of its structure, a structural decoding of Bohatoiske Deposit site has been performed using images delivered by Landsat-7, Sich-2 satellites, radar topographic survey (SRTM) and TERRA (Aster) data *(Fig. 4.24)* [10].

The study resulted in the development of a fault block model of the Bohatoiske Deposit *(Fig. 4.25.)*.

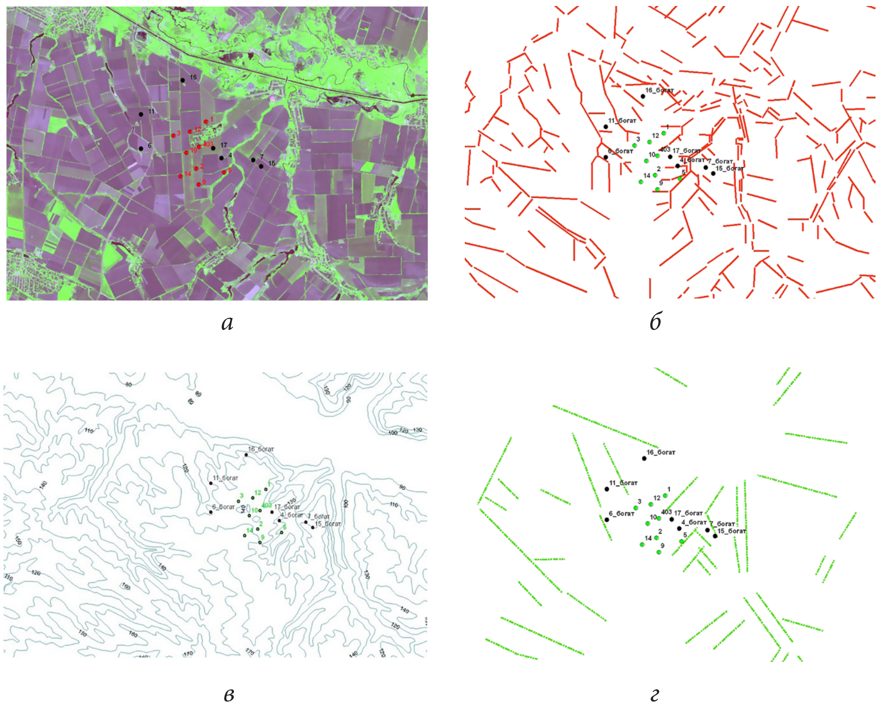


Fig. 4.24. Structural decoding of Bohatoiske Deposit (South adjacent rock area of the DDB): *a* — image made by Sich-2 satellite; *b* — structural decoding of the satellite image; *c* — hypsographic curves of relief based on radar topographic survey (SRTM); *d* — structural decoding results [10].

The exploration activities focus primarily on the clarification and supplementing information on the objects discovered at the previous stage. Structural framework of individual lineaments, their zones, ring formations, geological boundaries of the identified geological bodies are also specified. Additional information is obtained for the study and clarification of the consistent patterns of minerals distribution, potential ore-bearing areas, nodes, separate objects for further exploration, and exploration and appraisal works.

The classification of remote data, with due consideration of geological and geophysical component, provides an opportunity to determine the degree of similarity between the forecasted areas and the standard benchmarks for a certain region and to distinguish areas of various potential, without establishment of special libraries for geological objects [11].

Geo-Ecological Monitoring of Exogenous Geological Processes

Development of the economic complex of Ukraine takes place in the context of increasing man-made destabilization of the environment, causing a further increase in the number of crisis phenomena in ecological systems, and activation of exogenous geological processes (EGP).

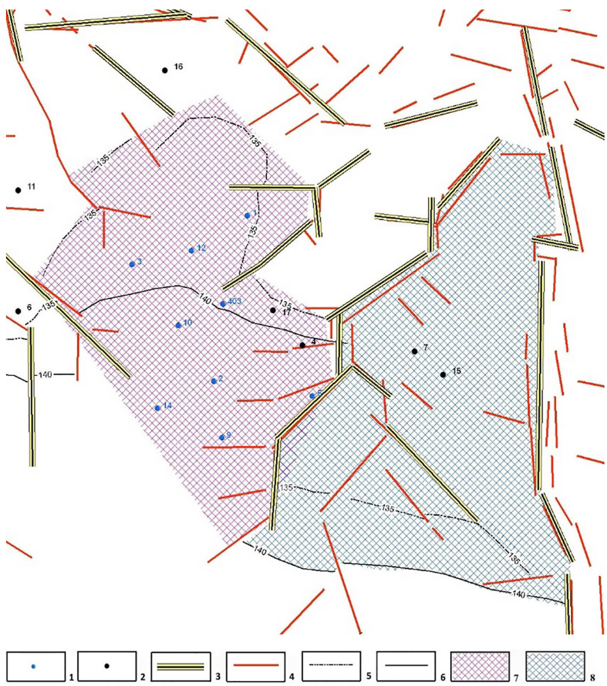


Fig.4.25. Fault block model of Bohatoiske Deposit [10].

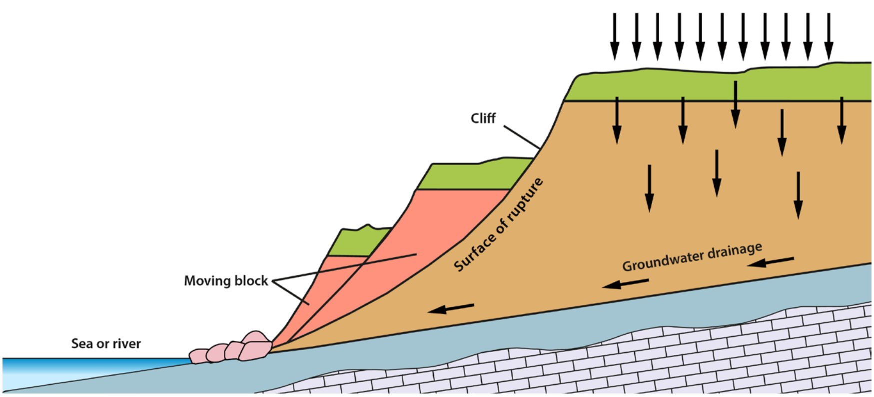
Symbols: *1* — productive wells; *2* — nonproductive wells; *3* — boundaries of neotectonic blocks; *4* — lineaments; morphotecto-hypsographic curves: *5* — 135 m; *6* — 140 m; neotectonic elevations: *7* — first priority for the production of detailed geophysical studies, *8* — second priority.

Exogenous processes are geological processes occurring on the surface of the Earth and in its near-surface layers (weathering, denudation, abrasion, erosion, glaciers and groundwater activity) and caused mainly by the energy of solar radiation, gravity force and vital activity of organisms.

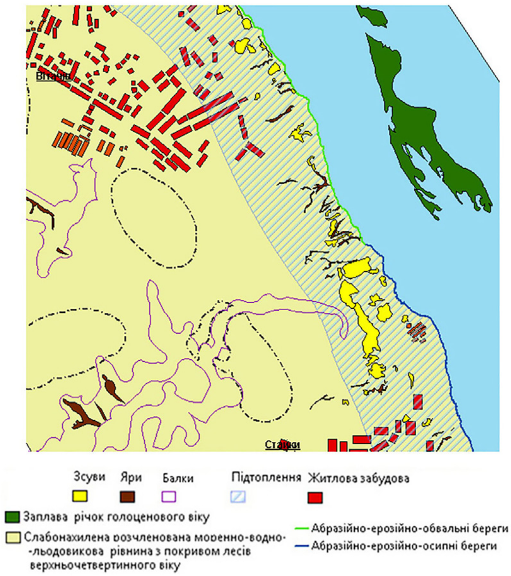
According to the materials of the Public Service of Geology and Subsoil of Ukraine, the following EGP are widespread on the territory of Ukraine:

- landslides;
- flooding;
- karst;
- abrasion;
- processing of the banks of reservoirs;
- subsidence;
- erosion;
- subsidence of the earth's surface above the mining works.

A landslide refers to ecological disturbance of masses of earth materials with loss of their integrity and movement in the horizontal or close to horizontal direction. Landslides occur during mountain forming, due to soil watering or human activities (man-made landslides occur as a result of mining and construction works, etc.).



Landslides dominate among the exogenous geological processes due to their prevalence in nearly all administrative areas, but, first of all, in the regions with active economic development. They emerge



b

a *c*

Fig. 4.26. Study of landslide processes on the right bank of the Kaniv Reservoir within the boundaries of Kyiv Region, as exemplified by the area of Vytachiv-Stayky: a — fragment of the map; b — appearance in the satellite image caused by quarrying operations, Stayky Village, Kaharlytskyi District; c — appearance of the same area in the image — landslides in brown and colorful clay within the upper landslide terrace, Stayky Village [13].

in a relatively small area, but their activation has significant negative consequences due to the rapid development and significant deformation and destruction of engineering and economic facilities. The main natural factors of landslides formation include meteorological, hydrological, hydrogeological, seismic, and similar processes. Activation of landslides depends on the intensity of soil supply with underground and surface waters. The amount of soil displaced during a landslide may range from several hundred to thousands of millions of cubic meters, and the speed may range from several meters per year to several meters per second.

According to the latest data of the Public Service of Geology and Subsoil, about 23 thousand landsides have been registered on the territory of Ukraine. The most significant activation of landslide processes has been observed on the Black Sea coast in Odesa and Mykolayiv Regions and the Crimea, on the Azov Sea coast and in the Siverskyi Donets river basin (Donetsk Region), the Dnipro river's right bank and right tributaries thereof, in the basins of Uzh, Tysa, Latorytssa, Rika, Tereblia, Teresva (Transcarpathia Region) rivers and basins of Dniester, Prut, Cheremosh, Syrets, Stryi, Vyshnia rivers (Lviv, Ivano-Frankivsk, Chernivtsi Regions) [12].

The landslide relief forms are decoded on satellite images by lighter tone and typical oval shape, while water-erosion forms — by wavy oblong shape.

a *b*

Fig.4.27. Activation of landslides in Rzhyschiv Urban-Type Settlement, Kaharlytskyi District (*a* — 2010; *b* — 2016).

a *b*

Fig. 4.28. Landscape protection vegetation in Vytachiv Village, Obukhivskyi District (*a* — archival aerial image as of 1945; *b* — modern satellite image from Google Earth) [13].

Flooding is a complex natural and man-made process characterized by the rise of groundwater level and increased humidity of earth materials across the aeration zone. The main factors contributing to the development of flooding include human economic activity and changes of hydroclimate conditions in the territory. The development of flooding is influenced by irrigation of the land, banking-up of ground water by water reservoirs, deterioration of drainage of the territory as a result of small rivers silting, filling of beams and ravines, water losses from technical networks, violation of groundwater evaporation regime, etc.

The **flooding** process is the most widespread among modern EGP, which manifests both under natural conditions and as influenced by man-made factors. According to the data of the Public Service of Geology and Subsoil, the area of flooding on the territory of Ukraine reaches 89,062 thousand km^2 (14,7% of the territory); 4747 settlements face flooding processes of different intensity [12]. Under natural conditions, the most prone to flooding are the low-lying territories in terms of geomorphology. These include the territory of Ukrainian Polissia (Volyn, Zhytomyr, Rivne Regions and the northern part of Kyiv). Here, under the influence of natural factors, an area of regional high-level groundwater has been formed. Waterplanes lie at depths of 0 to 2.0 m, more often — 0.2–0.5 m. Nearly 70% of the wetlands of Ukraine are concentrated in Polissia, due to constant excess moisture.

Natural and man-made flooding occurs in the central and southern regions of Ukraine: in Dnipropetrovsk, Zaporizhia, Kharkiv, Luhansk, Donetsk and in the north of Odesa, Mykolaiv and Kherson Regions. The groundwater balance in such territories is slightly interfered or disrupted as a result of increased nutrition due to a decrease in natural drainage in the territory. The areas adjacent to floodplains of rivers, areas in the zones affected by reservoirs and channels, forged by mining work, etc. experience most intense flooding

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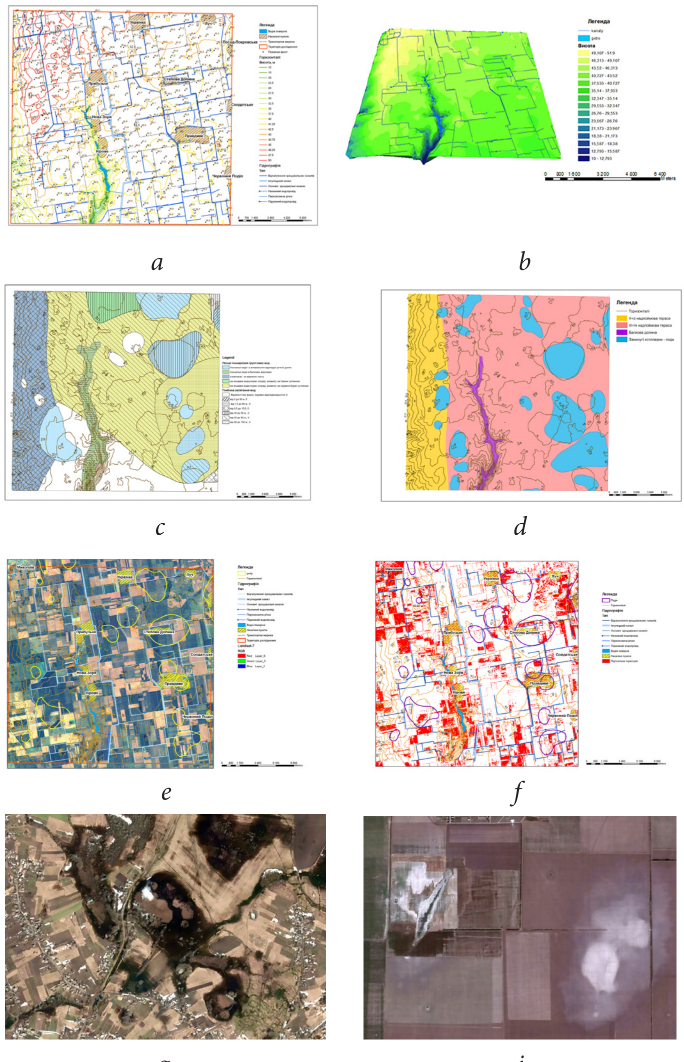
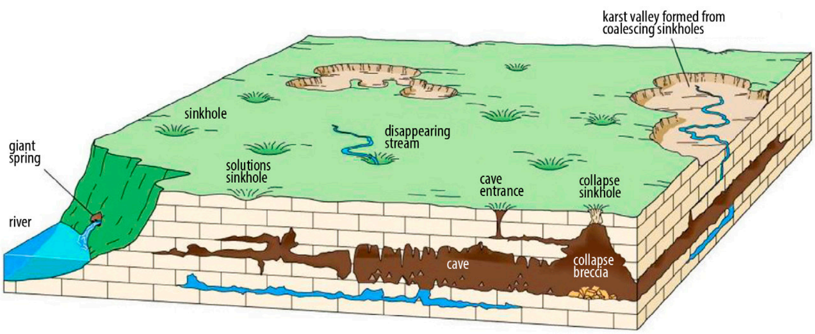


Fig. 4.29. Study of flooding processes in Zhovtnevyi District of Mykolaiv Region (*a* — topographical base; *b* — three-dimensional (3D) model of relief; *c* — map of groundwater conditions; *d* — geomorphological map; *e* — comparison of LANDSAT-7 image and digital mapping basis; *f* — map of permanent and periodic flooding in Kherson Region, and *g* — area of flooding in the QuickBird image; *i* — examples of soil salinization on QuickBird image [14]).

Karst is a geological formation generated as a result of dissolution or desalination of rocks by surface or ground waters and the formation of a specific (surface and underground) terrain. This term comes from the name of the limestone plateau Karst (or Kras) near Trieste, Slovenia. The most prone to karstification are salt, gypsum, limestone, dolomite, chalk, marl. As a result of karst processes, the following forms of relief are generated: curries, karst cavities (funnels), basins, ponors, mines, caves, underground rivers and springs. [15].



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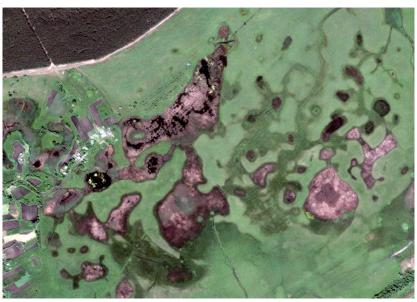
Karst is a particularly dangerous exogenous process that develops under the interaction of water with soluble rocks, and leads to deterioration of stability of the territory, i.e. its ability to maintain functional load-bearing properties under the influence of engineering structures. Sudden activation of the karst may lead to instantaneous sinkholes or subsidence of ground surface.

According to the data by the Public Service of Geology and Subsoil, 74.2% of the territory of Ukraine contains earth materials that may undergo karstification under certain conditions (sufficient rainfall and availability of certain materials). Expansion of underground and surface karsting is seen almost everywhere. The most common surface forms include karst funnels, depressions, and niches. A large number of karst funnels is observed in the areas of open-type karsts, which occupy 1.9% of the entire territory of Ukraine, and covered-type, occupying 14.5% of the territory [12]. According to updated information, there are nearly 22 thousand registered karsts; however there are far more karsts in the nature.

Many karst forms may be identified on satellite images. They include curries, depressions, funnels (including those occupied by lakes), valleys of specific morphology, etc. Besides, if we look at the layout of watercourse and watersheds on a satellite image, we can see the significant distinction from the areas free of karst. Here we may distinguish the closed hollows. Erosive forms sometimes end up in ponors, and not connect with rivers. We may observe a characteristic plan picture of the erosion network [16].



a

b

Fig. 4.30. Example of karst formation process, according to QuickBird imagery from Google Earth. The most characteristic are the saucer-shaped funnels, the dark color on photo of which is symbolic of water immolation (*a* — the formation of karst within Druhyi Lyman Village, Dvorichanskyi District, Kharkiv Region, *b* — karst funnels to the west of Novoselivka Village, Horodenkivskyi District, Ternopil Region). [17].

Abrasion is a process of shores (of oceans, seas, lakes or large reservoirs) destruction and drifting of rocks in the coastal zone of reservoirs by waves and surf. As a result of abrasion, specific forms of relief are formed; abrasive ledges (clips), wave niches, underwater abrasive terraces or platforms (benches) etc. Abrasion of the shores of artificial reservoirs is called **processing of banks**, i.e. the processes of their formation and destruction immediately after the reservoirs' filling [18].

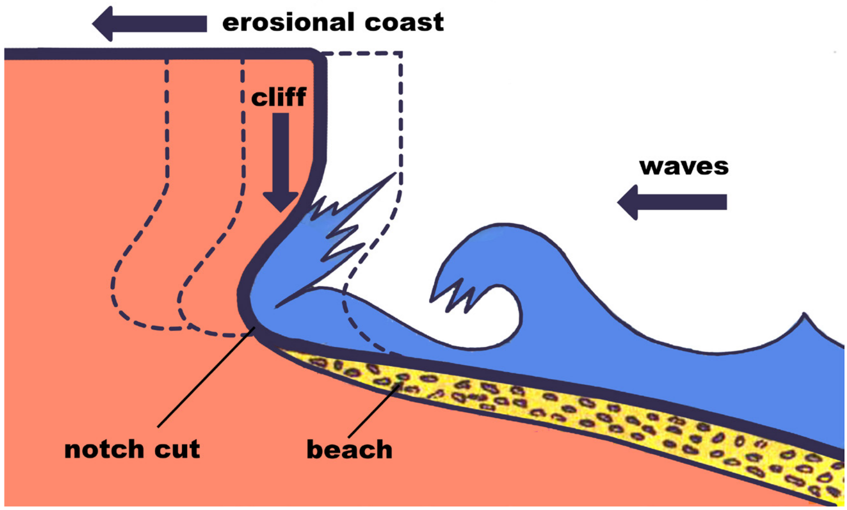
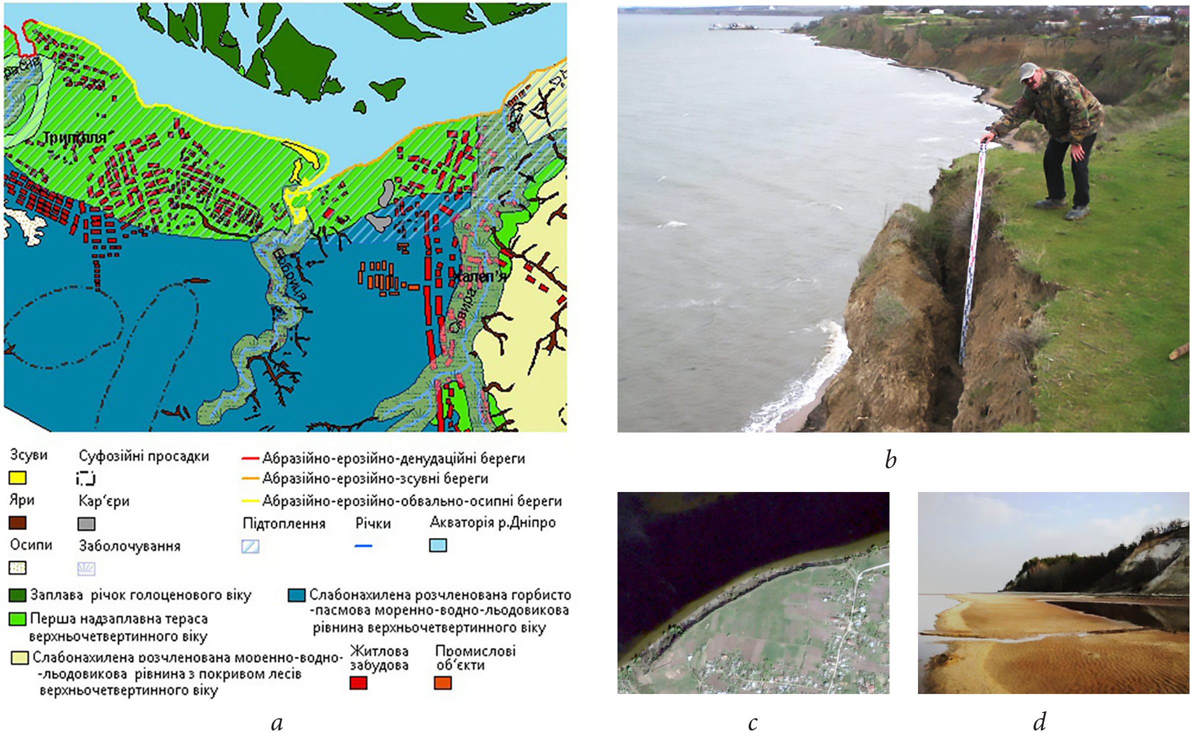


Fig. 4.31. The scheme of coastal destruction as a result of the waveguide

According to the data by the Public Service of Geology and Subsoil, the development of **abrasion** continues in the coastal zone of the Azov and Black Seas (within Donetsk, Zaporizhia, Mykolaiv, Odesa Regions and the Crimea), as well as in inland reservoirs — lakes and estuaries. Activation of the process is caused by intensive economic activity (river flow control, inefficient beach strip development, excessive extraction of sand from coastal areas, disturbance of natural regime of sediment migration). Abrasion is a factor that intensifies the landslides occurrence due to the blurring and soaking of unstable rocks of the coast.

The main factors that determine the development of abrasion are geological and geomorphological (lithology of rocks, neotectonics, seismic, coastal and beach morphology), hydrometeorological (wave, wind and sea flow level) conditions and human activities. The length of the coastline with abrasion is 1,415 km, including the area with recorded activation of abrasion — 973.7 km, and coastline area of 253 km complicated by landslides. The total length of the coast in the built-up area is 730.5 km, and area with abrasion — 501 km [12].



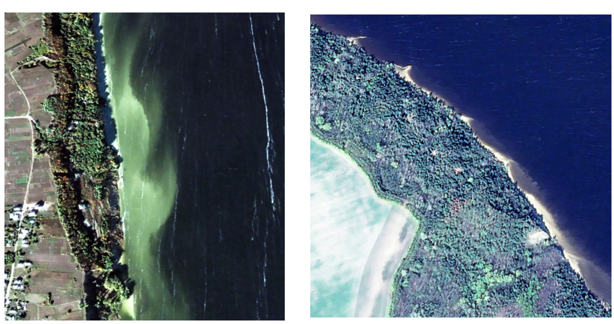
a *b* *c* *d*

Fig. 4.32. Study of abrasive processes on the right bank of the Kaniv Reservoir within the boundaries of Kyiv Region, as exemplified by Trypillia-Khalepie: *a* — fragment of the map; example of accumulative bank in the area of Khalepie Village of Obukhiv District in the photo (b, d) and in the satellite image (c) [13].

The **bank processing of reservoirs** depends on the same factors and conditions of development, as abrasion. Creation of reservoirs disturbs the natural formation of slopes of river valleys — the river erosion turns into the wave abrasion. The intensity of the bank processing depends on its geological structure and the size of the reservoir, which determines the parameters of the waves.

The Dnipro cascade forms the largest in Ukraine system of reservoirs with the coastline of 3529 km. Here, coastline of 1329 km continuously experiences bank processing, and the banks require engineering protection. The other 611 km of the coastline are protected with engineering structures, and 1589 km are "neutral", where the process development is minimal due to the flatness of the banks. The maximum speeds of banks processing of the Dnipro reservoirs cascade were observed in the first 5–10 years of their existence, when the banks composed of loose rocks, retreated to 50–100 m per year. Subsequently, the average speed did not exceed 5.0 m per year; the maximum speed (at separate sites) was 20.0–30.0 m per year [12].

Soil subsidence is referred to the lowering of soil masses under the influence of sufficient moisture, which greatly reduces the ground strength. Soil subsidence occurs within the areas of loess soils, characterized by the ability to subside when watered.



a *b*

Fig. 4.33. Examples of abrasive banks in Kyiv Region on satellite images of the Google Earth (*a* — in the north of Rzhyshchiv Urban-Type Settlement (Kaharlytskyi District); *b* — in the west of Vytachiv Village (Obukhivskyi District)).

The main sources of RS data that provide information on exogenous processes are modern, archival and historical materials of aerial and aerospace imagery. On images, exogenous processes may be detected according to a number of direct (form, color, structure, texture of the image) and indirect (features of the vegetation cover) information signs. Loess and loess-type soils occupy 363.77 thousand km^2, i. e. 60.3% of the territory of Ukraine; of which, 44.25% of the total area are covered by the soils prone to **subsidence**. These are the sediments of special type, characterized by porosity greater than 45%, low humidity, filtration anisotropy (water permeability increased in the vertical direction against the horizontal one), large content of readily soluble salt, predominance of dust particles over the clay components in the granulometric composition. When treated with water, these sediments may provide additional compacting both due to their own weight, and with additional load with simultaneous changes of the soil structure. This property is called subsidence [12].

Erosion is the process of soil destruction by water flow (water erosion), wind (wind erosion, or deflation) or ice. As a result of water erosion, gullies, beams, river valleys, etc. are formed [19].

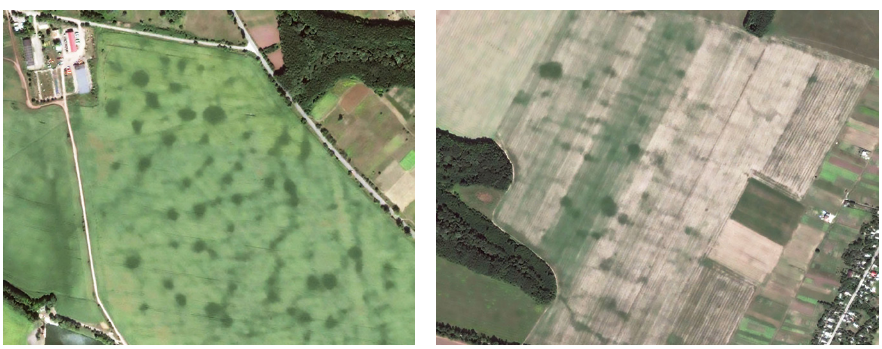


Fig. 4.34. Examples of suffosion subsidences in Kyiv Region; according to satellite images of Stayky Village, Kaharlytskyi District (a) and Vytachiv Village, Obukhivskyi District (b).

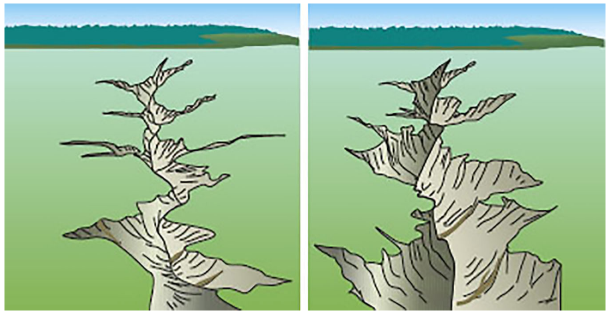


Fig. 4.35. Stages of erosion and growth of a gully due to water erosion.

Erosion is one of the main external (exogenous) factors of terrain surface formation. It is the process of destruction of the upper and most fertile layers of soil. The territory of Ukraine is characterized by widespread processes of stream erosion of permanent watercourses (rivers) — lateral and deep; erosion of temporary watercourses — linear and gully; slope erosion — slope wash (removal of humus from the soil) [12]. In Fig. 4.35, lighter areas represent washed soils, where the upper humus layer was washed by water, and substituted by pale and brown slightly humic soil layers coming to the surface; thus, the lighter the soil, less humus it contains.

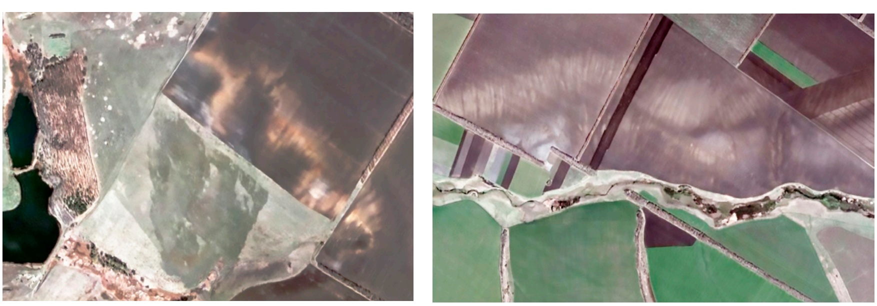
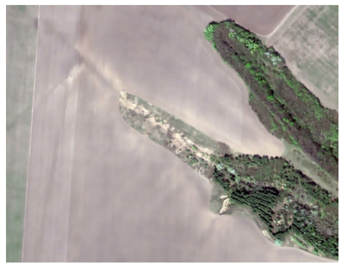


Fig. 4.36. Examples of slope erosion in Blyzniukivskyi District of Kharkiv Region; according to QuickBird satellite image. Lighter color on photo represents areas of slope wash of soil (*a* — the area of slope erosion in Vodolazke Village, and *b* — the gully near Mykilske Village) [17].

a *b*



c *d*

Fig.4.37. Examples of linear and gully erosion:
a — manifestations of linear erosion on the photo; *b* — appearance of linear erosion on satelliteimage from Google Earth (Kalacheve Village, Bereznehuvatskyi District, Mykolayiv Region); *c* — appearance of gully erosion on the photo; *d* — manifestations of gully erosion on satellite image (Rzhyschiv Urban-Type Settlement, Kaharlytskyi District of Kyiv Region). [20]

a *b*

Fig. 4.38. Examples of conservation vegetation near Rzhyschiv Urban-Type Settlement, Kaharlytskyi District of Kyiv Region) (*a* — 1945; *b* — 2016).

Subsidence of the earth's surface above mining works is one of the most significant man-made influences of mining on the geological environment. Negative changes in the geological environment largely depend on both the method of development, and liquidation of mines, and on the geological and hydrogeological and structural and tectonic natural conditions, which have their own specific features in each individual case [12].

The development of this process is associated with a decrease in engineering and geological integrity of rocks, decompaction of massifs that lie above underground mines, redistribution of load near mined-out area. The excavation of coal beds and other deposits of minerals causes the formation of large subterranean cavities. The rocks that lie in the upper layers of mining operations start to move under the influence of gravity and rock pressure, causing shifting of the whole rock mass, including the earth's surface, and resulting in disturbance of integrity thereof along with formation of new zones of rock fracturing. The thickness of this zone, as a rule, is 40–60 m. The mass of the rocks, which lies above (300–400 m), smoothly subsides without disturbing the massif's integrity. The mass located below, deflects, forming subsidence troughs. This gives rise or intensifies dangerous geological processes (land flooding and waterlogging, intensification of karst and suffosion processes, etc. causing deterioration of underground and surface waters quality). The total area of such territories exceeds 5.5 thousand $km^{2.}$

The most negative consequences of earth's surface subsidence are observed within industrial and urban agglomerations, mainly where places of mining works locate under the developed sites. These areas include Donetsk, Makiivka, Horlivka, Yenakiieve, Bilozerske, Kalush, Sokal, Chervonohrad, Kryvyi Rih, Pavlohrad, and etc. [12].

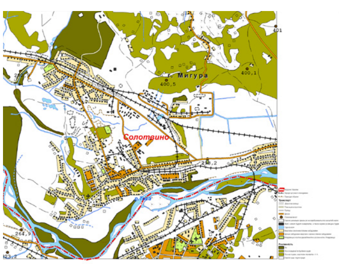
In particular, desalination cavities emerged near Solotvyno settlement, causing disturbance of oversalt mass, sinkholes and karst funnels and subsidence troughs on the earth surface at different depth levels. More specifically, intensive karst processes caused by the salt mining, took place in the eastern part of the salt stock in Solotvyno over the area of 43 hectares. The total amount of NaCl in brines, annually pumped out there, is 28 thousand m^{3}.

Karst funnel (also known as karst sink-hole) is a karst cavity formed as a result of the breakdown of the underground cavity roof due to desalination of earth materials.

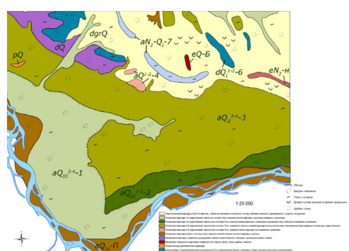
Subsidence (shift) trough of the earth surface is a part of the earth's surface, characterized by the shifting of earth materials under the influence of mining works. Due to disturbed natural equilibrium in the rock masses, caused by excavation, the rocks move in the interior towards mined-out area. The zone of shift is formed, the upper part of which is a subsidence trough.

Salt stock is a vertical cylindrical formation made up of salt and penetrating the above-mentioned deposits.

Comprehensive analysis of remote sensing data, digital relief model, various geological maps and results of previous studies, made it possible to identify specific features of karst processes and differentiate within the territory of deposits the areas of potential further development of new karst sinkholes [21].



a



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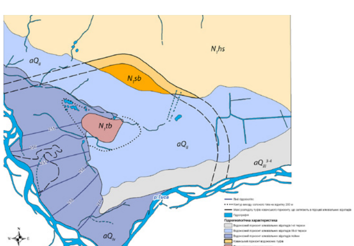

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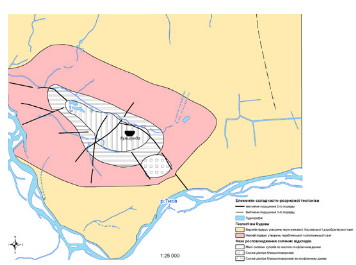

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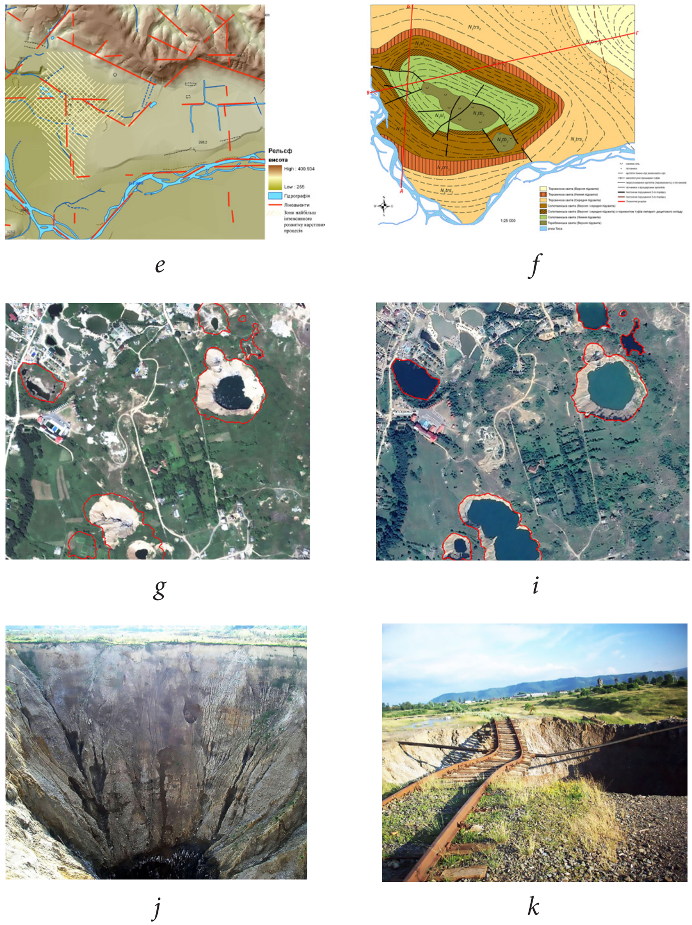

Fig. 4.39. Study of the earth's surface subsidence above mining works in the area of Solotvyno settlement, Tiachivskyi District of Transcarpathian Region [21] (*a* — topographic basis; *b* — map of minerals of the quaternary complex with elements of geomorphology; *c* — hydrogeological map; *d* — map of the boundaries of the salt body with elements of folded — break tectonics; *e* — scheme of lineaments with the zones of the most intense karstification processes; *f* — geological map; *g* — karst holes/lakes on satellite images from Google Earth (2012); *i* — sawcut/lake on satellite image from Google Earth Resource (2017); *j* — abandoned mine on the territory of Solotvyno salt deposits [22], *k* — karst funnel formed under the railroad track) [23].

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4.1.4. Landscape Science and Urban Planning

Throughout the whole history, humankind has been constantly increasing its detrimental effects on the geographic envelope of the Earth. Human activities change the appearance of the earth surface, decrease the share of natural while increasing the share of manmade landscapes.

RS is one of the most advanced surveying methods, which is continuously developing along with the growth of technologies. These methods are applied in various fields, among which the cartographic research is the most popular area of the earth sciences. The processing of multispectral satellite imagery of certain landscapes allows for different-scale environmental surveys. Small-scale images with low resolution (hundreds of meters) are used to study the dynamics of urban complexes growth, the features of landscape and functional zones distribution, types of manmade impact on the natural environment. Large-scale images with high resolution (up to several centimeters) are employed in the studies of the selected elements of urban structure, the nature of environmental effects of potentially hazardous man-made objects [1].

Hyperspectral survey systems are used in the applied spheres of remote sensing, which record almost the whole spectrum of reflected electromagnetic radiation at a certain point. This helps in the automatic recognition of types of land use and their varieties.

Spatial development is one of the priority lines for the strategic planning of the development of cities and states in general. Remote sensing methods open up great opportunities in the area of social and geographical research, in particular, for the investigation of spatial development features. The satellite images illustrate the status of site development, transport infrastructure, vegetation cover, land use, etc.

Such a wide use of remote sensing methods in the studies can be explained by the easy access to data, since there are many websites, where satellite images of the interested territory are readily available for downloading.

In the urban studies, RS data is used for the following purposes:

- updating of the cartographic base for the mapping of urban territories;
- design and planning of territories' development;
- inventory of planting, estimation of its total area, determination of prospects for planting greenery or cleaning territories contaminated by various pollutants;
- monitoring of road transport infrastructure, in particular the construction of new, reconstruction or modernization of existing highways, based on the traffic data;
- monitoring of construction, determination of precise construction site boundaries;
- composition of ecological maps of the cities, including maps of thermal anomalies, etc.

The most urgent and essential is the use of RS in rapidly developing regions. Firstly, it concerns the region of the national capital and the suburbs of the major regional centers, for example, Lviv, Dnipro, Odesa, Kharkiv and also towns attractive for tourism, in Ukraine they are Morshyn, Bukovel, Truskavets, the Black and Azov sea coasts, and etc.

When studying urban complexes using satellite imagery, it is possible to identify the processes and phenomena that are difficult to localize in land surveys.

Transformation of island landscapes of Dnipro river floodplain

In the last 100 years, the shoreline of Kyiv has started to change very intensively due to the rapid expansion of the city and its redevelopment. The mapping of the historical channel of the old Dnipro River was made according to the German topographic maps (http://www.wwii-photos-maps.com) and aerial photography dating back to the Second World War (http://warfly.ru), which allowed to obtain the historical appearance of Dnipro riverbed prior to the formation of the Kyiv Reservoir. Comparing of these materials with modern data collected on the basis of interpretation of the actual satellite imagery of Google Earth resource *(Fig. 4.40.),* provided an overview of the transformations of the Dnipro floodplain resulting from river regulation by Kiev Hydroelectric Station dam [2].

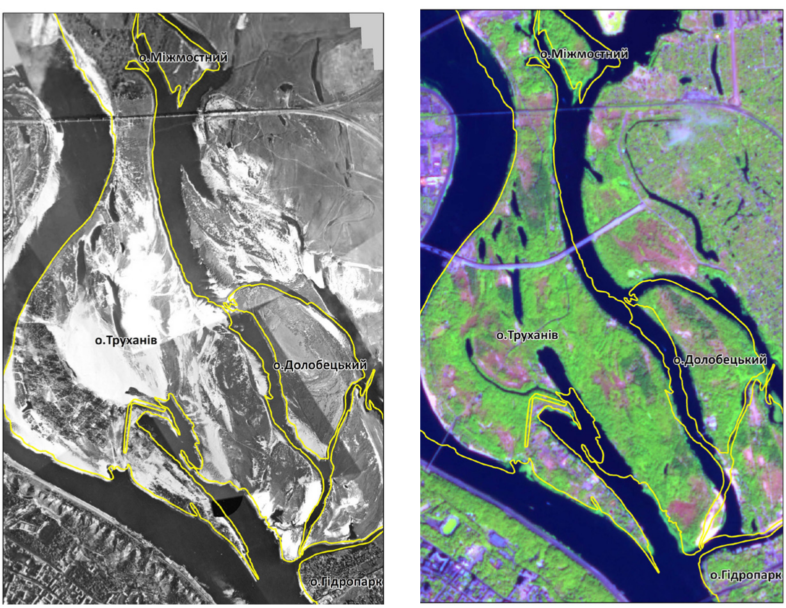


Fig.4.40. Dynamics of changes in the area of Kyiv islands over 75 years: *a* — aerial photography dating back to 1942; *b* — modern satellite image delivered by Sentinel-2 2017 [2]

Thus, the vector layers — the contours of the shoreline of Kyiv islands as of 1942 and 2017 have been produced, and the areas of the islands have been determined using GIS/RS techniques *(Fig. 4.40, 4.41)*. Comparative analysis of historical maps and current RS data allowed assessing the changes in the areas occupied by Kyiv islands, which have occurred over 75 years.

Use of GIS/RS techniques made it possible to identify significant changes in the areas of Kyiv archipelago islands. It has been established that the islands started to shrink due to man-made changes (sand sluicing), which had a negative effect on their biotopes.

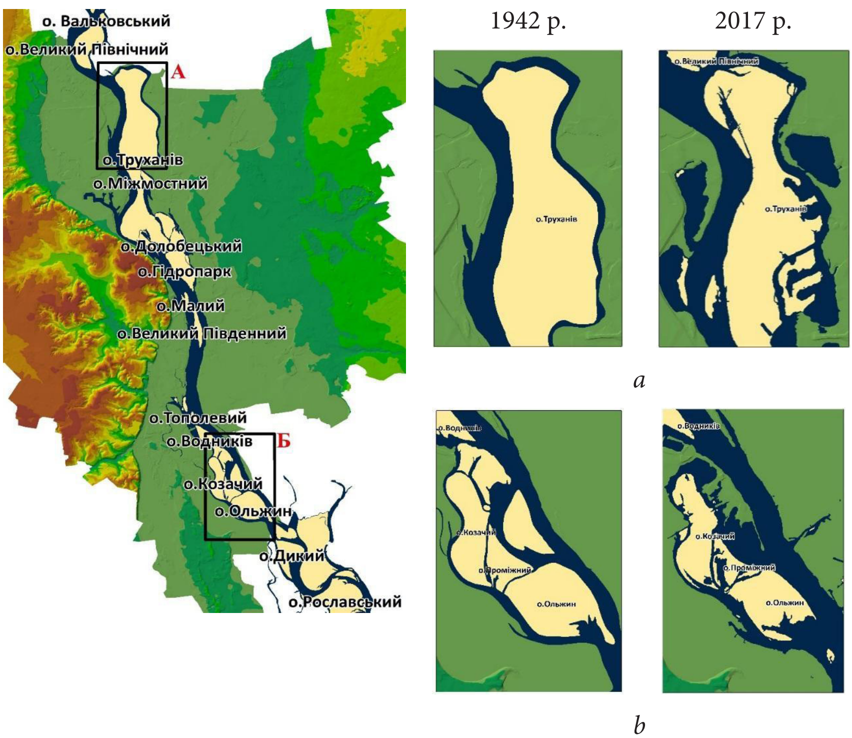


Fig. 4.41. Visual representation: historical reconstruction of the Dnipro floodplain transformation within Kyiv region. The vector of the group of Kyiv islands was overlapped with the relief in the ArcGis application: *a* — example of Trukhaniv Island transformation; *b* — example of the changes of the southern islands [3].

Monitoring of illegal amber mining

Over the last years, the illegal amber mining has grown dramatically in Ukraine. The highest activity is observed in Olevsk and Ovruch Districts of Zhytomyr Region, Rokytne, Dubrovytsia, Volodymyrets, Zarichne and Sarny Districts of Rivne Region, and Ratne and Lyubeshiv Districts of Volyn Region [4]. Thus, the north-western part of Ukraine, occupying some 14.6 thousand km^2, is nearly completely overtaken by the amber rush.

Amber is a natural organic compound – dense and viscous (fossilized) resin of coniferous trees. It is used in jewelry, perfumery, folk medicine and electricity.

Fig. 4.42. Consequences of illegal amber mining in the wooded area

The main method of illegal amber extraction is the hydraulic method which involves pumping of water into forest soils with high pressure pumps some 6–10 m deep. The technique used for the identification of illegal amber mining sites bases on the spectral and texture differences of these sites from the surrounding, intact forest and swampy-forest landscapes. By comparing the data obtained with the calculation of the time series of temperature images and images filtering according to their spectral characteristics, it is possible to identify with high probability the processes of formation of waste dumps, indicative of the amber extraction. Data gathered by Landsat satellites update every 16 days and, in the absence of clouds in the images, this allows for quick identification of the territories with signs of illegal amber extraction *(Fig. 4.43.)*. At a detailed level, it is recommended to use high-resolution images representing the area of 0.5–2 m, such as shown in Fig. 4.44. The spread of the "white spots" clearly indicates intense illegal amber mining, which causes huge environmental damage for the flora and fauna of the region *(Fig. 4.45.)*.

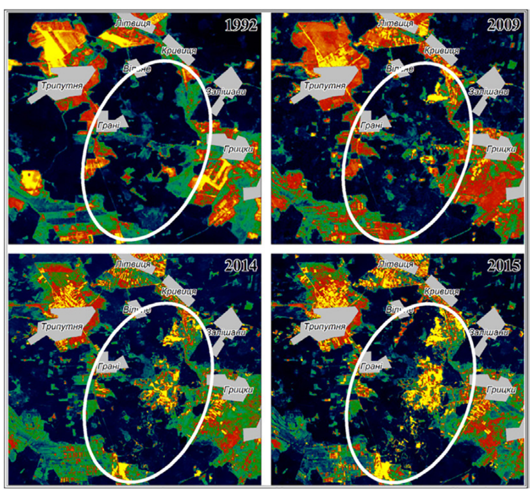
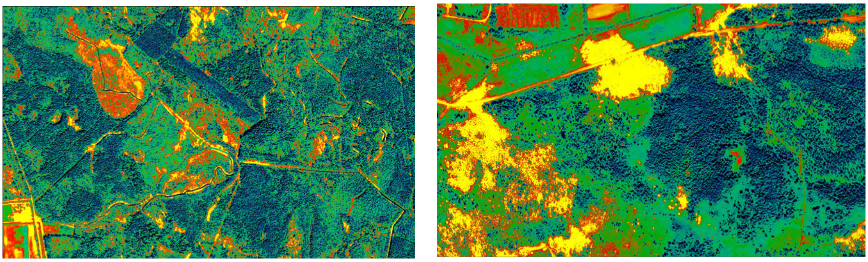


Fig. 4.43. Monitoring of the territories of illegal amber mining at the regional level. Rivne Region. White color indicates the areas of illegal amber extraction during 1992–2015. [5]



a *b*

Fig. 4.44. Identification of the sites of illegal amber mining at the local level (*a* — registered sites of illegal amber extraction in forest areas near Zhovkyni — Dubivka settlements (Volodymyrets District, Rivne Region; *b* — near Volodymyrets urban settlement — Dubivka village (Dubrovytsya District, Rivne Region)

The proposed detailed GIS (with the scales of 1 : 2 500– 1 : 10 000) allows to perform not only semi-automatic mapping of affected areas but also the amount of damage caused to the state [6].

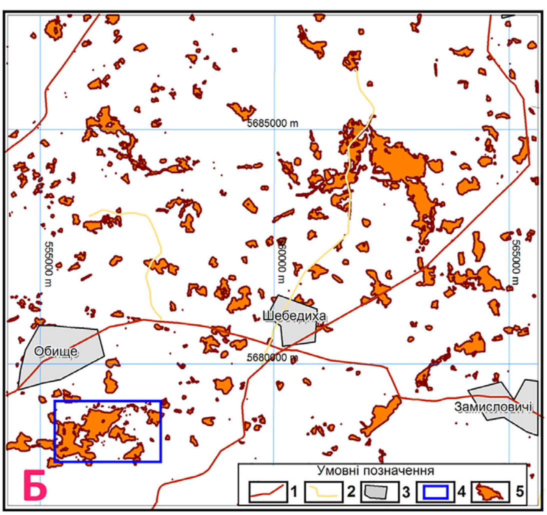


Fig.4.45. Map of degraded soils and vegetation cover of Olevsk District, Zhytomyr Region, near Obysche — Shebedykha villages. Compilation is made on the basis of digitally processes Spot 6, 7 satellite data (France). Original scale M 1 : 10 000. Areas of illegal amber mining and soil degradation as of March 28, 2016.

Symbols: Roads: *1* — hard surface, *2* — natural, *3* — settlements, *4* — test area for assessment of the damage, *5* — degraded soils

Man-made changes of shorelines of water bodies

Fig. 4.46. Soil jetting for the formation of a new island [7]

Dubai is famous for many things made for the first time in the world. One of the wonderful examples is the series of artificial archipelagos constructed in emerald waters of the Persian Gulf. Man-made archipelagos became a visiting card of United Arab Emirates. The construction of islands cost a lot for the city municipality, but huge investments have been repaid a hundredfold. Dubai's coastline has increased by as much as 520 kilometers.

Burj Al Arab hotel in Dubai was built on the first artificial island in the Persian Gulf. Among the most famous artificial islands are the tree of the Palm Islands series located on the coastal area of the emirate of Dubai: Palm Jumeirah, Palm Jebel Ali and Palm Deira.

The construction of The World archipelago was one of the biggest projects in Dubai; it includes nearly 300 islands that form a map of the Earth continents. It is planned to further expand the archipelago, supplementing it with new islands under The Universe project.

With this project of creating a man-made archipelago, humanity threw down the challenge to the nature. The continental sand, abundant in United Arab Emirates, was not suitable for construction due to the lack of required viscosity. Therefore, special dredges — floating technological plants with installed extraction and processing equipment — have been used to extract sea sand from the bottom of the bay and pile it up in the form of a palm tree. Later on, the sand was tamped with vibrating machine to reach solid ground so that the island could resist storms and caving of banks.

a *b*

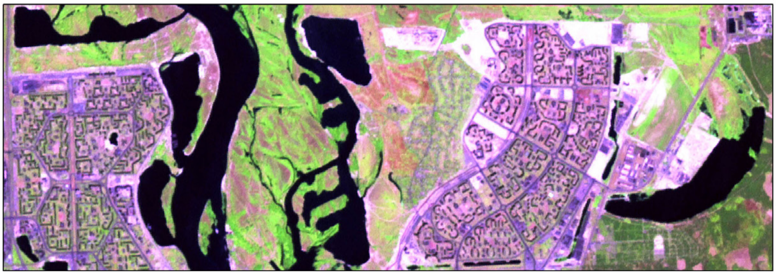
c

Fig.4.47. Artificial islands located on the coastal area of United Arab Emirates, according to Landsat satellite images (*a* — as of 2001, *b* — as of 2012) [8], and planned construction sites — draft, scenic view (*c*) [9]

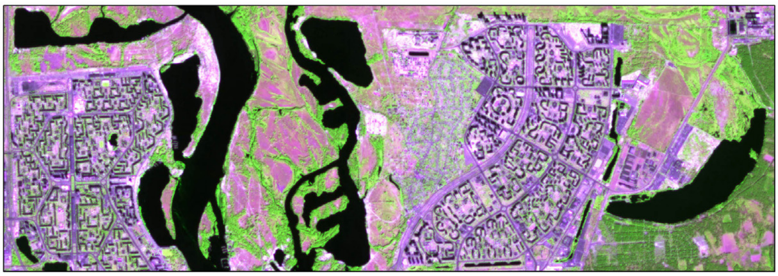
Influence of Man's Activities on Suburban Landscapes

The sand extracted from Dnipro River islands is usually used in the hydraulic fill for the construction of new residential districts. This technique came into common use at the end of the 1970s, when the building of Obolon and Troyeschyna residential areas started. In the 1970s, the hydraulic deposition of soil for Obolon residential area was initiated with resulting elevation of the ground level. The land development, hydraulic fill and building of the phase 1 construction of Troyeschyna residential area started in 1981. This process can be illustrated by archival Landsat satellite images (Fig. 4.48). The sand from the northern group of islands (Velykyi Pivnichnyi, Trukhaniv, etc.) was used for the building of Obolon and Troyeschyna residential areas. The archival satellite images demonstrate the areas of hydraulic fill prior to the construction start, represented as white spots (Fig. 4.48a). The satellite imagery also provides an outlook of the dynamics of formation of an artificial waterbody — Almazne lake, one of the most polluted lakes in Kyiv city. It is located northward of Lisovyi neighborhood and eastward of Vygurivschyna-Troyeschyna residential area in Desnyanskyi District of Kyiv city. It is one of the biggest and deepest lakes in Kyiv: its depth reaches 35 m. The lake appeared in the first half of the 1980s at the site of former small peaty moor and was a result of hydraulic sand fill for the construction of Vygurivschyna-Troyeschyna residential area. The current size of the lake remains stable since 1993. In other words, the lake is a former quarry filled with water.

a



б



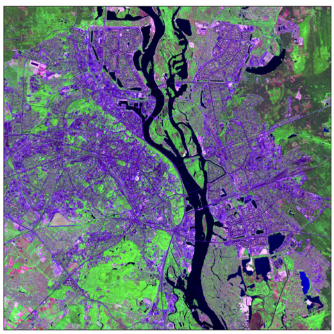
в

Fig. 4.48. Construction of Troyeschyna residential area according to Landsat satellite imagery (*a* — 1985; *b* — 2000; *c* — 2017) [3]

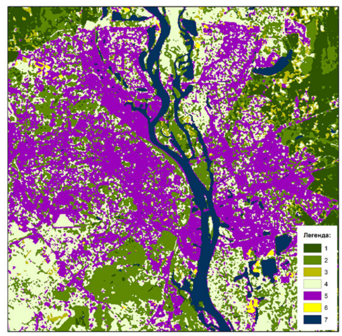
Visual Representation of Anthropogenic Impact of Metropolis

GIS-modelling is a modern term that refers to a model representation of a certain territory in the form of maps, charts, satellite and aerial photographs along with the provision of any tabulated information using cartographic research method — the study of interrelationships (analysis of phenomena as a system). It is easier to perform such analysis when at least one of the characteristics subject to spatial changes is considered evenly distributed. Then all other characteristics connected with it can be analyzed against this background. For this purpose the image transformation may be used. The transformation refers to the transition from the cartographic representation, which is usually based on the topographic metric of the ground surface, to other expression on the basis of a metric of mapped phenomenon. These transformed images are called **anamorphoses**. In other words, anamorphosis is an image transformed according to a certain feature or coefficient [10].

The use of GIS-modelling of anthropogenic influence on urban complexes may be illustrated by the environmental changes that have occurred in Kyiv city over 30 years, using remote sensing (RS) and Earth observations data. Below is given the example of cartographic representation of combination of terrestrial statistical analysis data of the state of Kyiv city environment and results of satellite imagery interpretation in order to assess the areas occupied by the townscape components *(Fig.4.49).*



a



b

Fig.4.49. Use of RS data for the identification of urban landscape components of Kyiv city (*a* — satellite imagery by Landsat 8 (as of 24.05.2015); *b* — map of urban landscape (*1* — coniferous plantings; *2* — broadleafs; *3* — tree and shrubbery plantings; *4* — grassland vegetation and agricultural lands; *5* — residential area (buildings and roads); *6* — sand massifs and quarries; *7* — water bodies)) [10].

Fig.4.50 shows one of the variants for representation of thematic data regarding the population density and air quality of Kyiv city. Such representation together with diagrams provides an overview of the structural composition of urban landscapes with breakdown by districts. Fig. 4.50 also demonstrates the correlation between the green areas in the districts and amount of NO_2 (nitrogen dioxide) emission in the air (mean values as of August 2015); the coefficient of correlation is 0.73, which proves the inverse relationship. Thus, it becomes clear that Holosiyivskyi District of Kyiv city is the greenest one with the lowest level of air pollution.

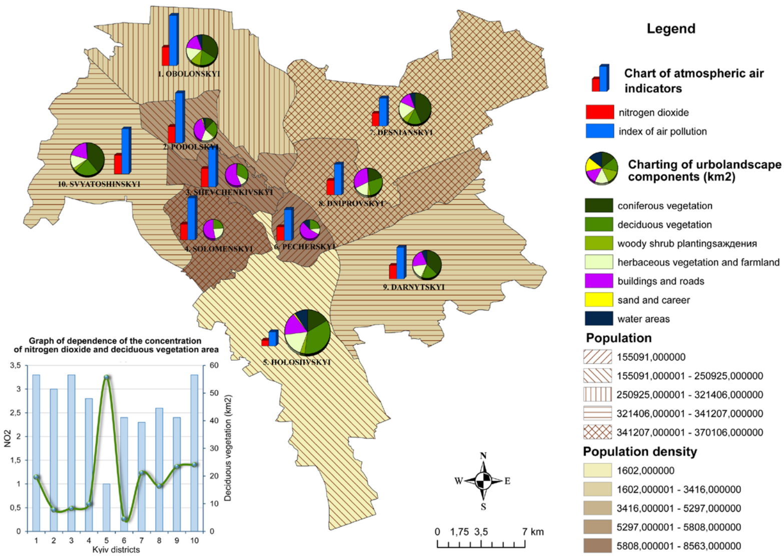


Fig.4.50. Map of man-made load in Kyiv city [11].

For the purpose of comparative analysis of anthropogenic impact of metropolis, traditional maps *(Fig. 4.51 a) and b))* have been initially created on the basis of RS data, which represent the built-up territories and the green areas of Kyiv city (% of the total area of the district).

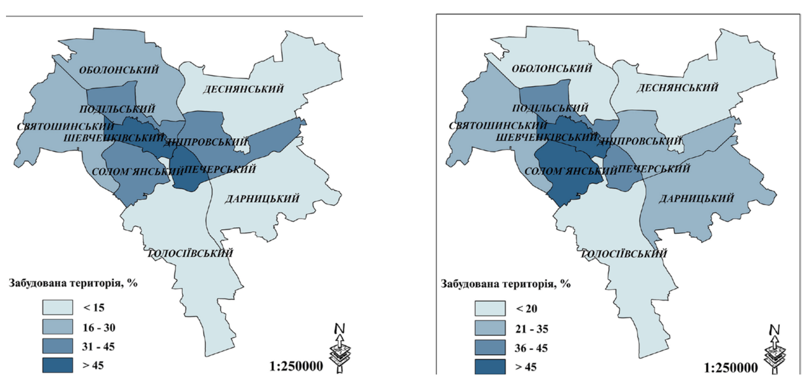


Fig. 4.51. Anamorphic maps of buildings distribution in Kyiv city with breakdown by districts as of: *a*) 11.07.1989, *b*) 06.08.2013

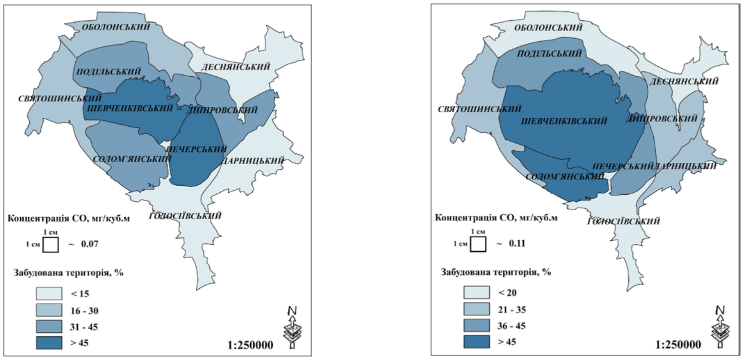


Fig. 4.52. Anamorphic maps of buildings distribution in Kyiv city, with breakdown by districts as of: *a*) 11.07.1989, *b*) 06.08.2013

Later on, two types of anamorphic maps have been created (see Fig.4.52 and Fig. 4.54). In particular, Fig.4.52 represents anamorphic images, where anamorphic projection is performed on the basis of CO concentration in the air, mg/m^3 (value — size of object), and share of the building development of Kyiv city (value — color gradient). Fig. 4.54 demonstrates anamorphic images produced on the basis of the built-up territories, in per cent (value — building size), and green areas (value — color gradient).

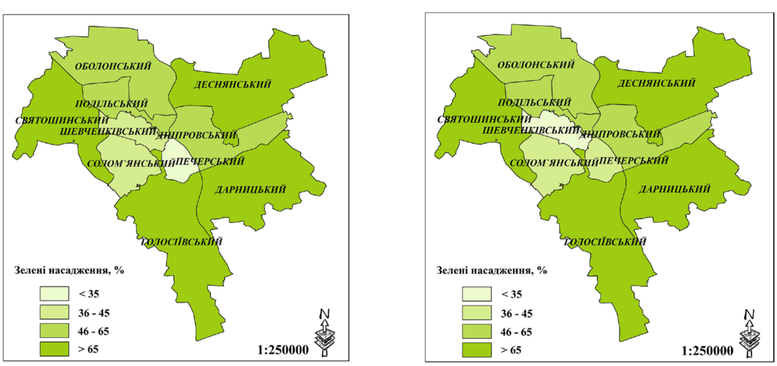


Fig. 4.53. Maps of green areas distribution in Kyiv city, with breakdown by districts as of: a) 11.07.1989, b) 06.08.2013

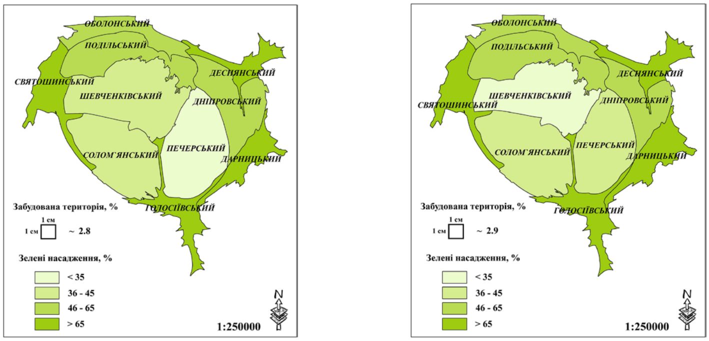


Fig. 4.54. Anamorphic maps of green areas distribution across the districts of Kyiv city, as of: *a*) 11.07.1989, *b*) 06.08.2013

Thermal Anomalies in Kyiv City

According to satellite imagery, the air temperature in Kyiv city has increased over the last 80 years. Fig. 4.55 shows the temperature map of Kyiv made on the basis of Landsat-8 data as of July 31, 2014 (Stankevich et al., 2015). As seen from the map, the major territory of the city has air temperature above 30 °C. According to the Centre for Aerospace Research of the Earth, the images made during summer, in particular in July and August, demonstrate that in 1985 through 2014 the air temperature in the central parts of Kyiv has increased by 0.08 °C annually [12].

Using the imagery acquired by Landsat satellite in 2013–2015, non-governmental organization Ukrainian Ecological Club "Green Wave" and scientists of National University of "Kyiv-Mohyla Academy" and Scientific Centre for Aerospace Research of the Earth have studied the thermal pollution of Kyiv's landscape. The correlation between the results of this study and green areas has been established. National building regulations require that the green areas occupy at least 25% in the residential districts [12].

The results demonstrated that the "hottest" are the residential and industrial areas. The highest temperatures have been registered in Troyeschyna (10–15% occupied by green areas) and Poznyaky (0.10% occupied by green areas) neighborhoods, while the lowest — in the districts with many green areas and water bodies, such as Holosiyivskyi, Borschagivka, Syrets and etc. (20–40% occupied by green areas).

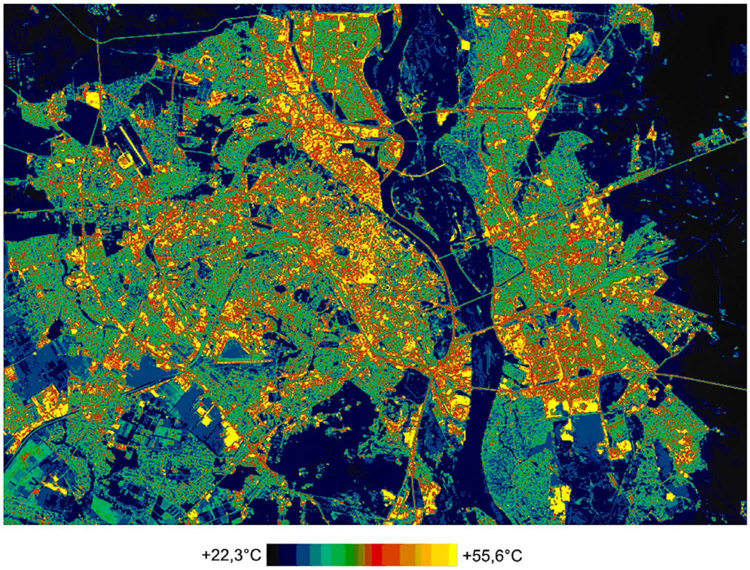
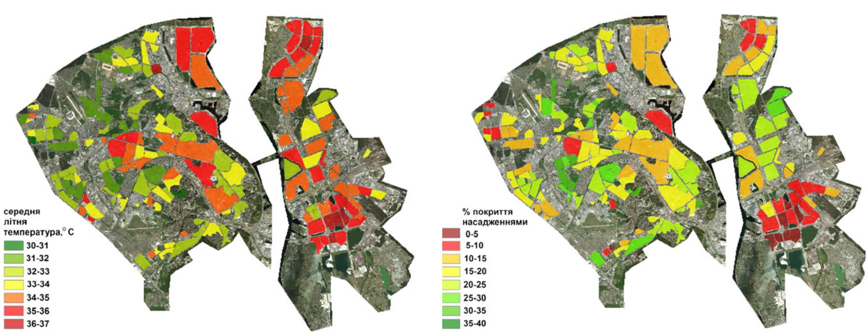


Fig. 4.55. Air temperature in Kyiv districts, according to Landsat-8 data as of July 31, 2014 (Stankevych et al., 2015).

Photographic survey of Kyiv from drones demonstrated that the best cooling effect provide the trees, as they cool the air better than flower beds and grasses (see Fig.4.56). Their surface heats up to 25 °C maximum [12]. This should be taken into account in urban planning.



a *b*

Fig. 4.56. Connection between mean summer temperatures (*a*) and green areas (in%) (*b*) [12]

Since the cities have a dominant role in atmosphere contamination, they should be primarily held accountable for the climate change. There are many ogranisations and foundations dealing with climate issues, which help the cities to adapt to climate changes; however Kyiv fails to use this opportunity.

The Effect of Urban Plantations on the Climate in the Cities of Ukraine

Any locality can be compared to a living organism that grows and develops. Especially high rates of development are observed in the cities due to the continuous influx of people from the region, and in the case of Kiev city — from all over Ukraine. The constant population growth drives the need for changes in the infrastructure. Maintenance of a balance of green areas' effect on the environmental status of the city is a challenge.

In 2018, a team of Ukrainian scientists from National University of "Kyiv-Mohyla Academy", Centre for Aerospace Research, Institute of Botany and Institute of Biochemistry of the National Academy of Sciences of Ukraine together with the specialists of DroneUA company received a research grant of the *National Geographic*. According to this grant, the scientists had to study the effects of urban plantations on the climate in Ukraine's cities (see Fig. 4.57) [13]. *National Geographic* has supported the Ukrainian project in order to develop a scientific basis for the strategic planning of urban green areas adaptation to climate changes in the cities of Ukraine, as well as other countries of Eastern Europe. This is an extension of the previous, already described in this Section, project on the study of thermal anomalies of Kyiv city using satellite data. The previous project allowed performing a series of terrestrial observations and collecting information using drones and satellite maps. However, project results covered only a small territory — central and park areas. The present project, implemented jointly with *National Geographic,* is an extension study of the bigger territory — the whole Kyiv city.

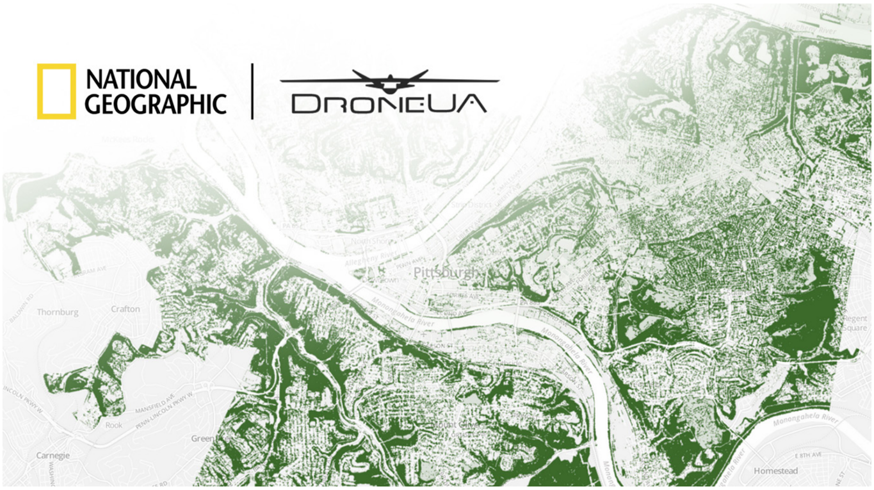


Fig. 4.57. Logo of the *National Geographic's* project
on the study of the effect of urban plantations on the climate
in the cities of Ukraine

People in Ukrainian cities give little attention to the negative consequences of climate changes observed in the residential areas. In general, there is no systematic data available in Ukraine on CO_2 concentrations in large cities and suburbs that may be used in estimating the emissions. The Smart City concept, successfully applied in various cities worldwide, includes the use of innovative technologies for prompt optimum decision-making based on large data sets. There is no database in Ukraine that could be used by local authorities in the decision-making process.

The purpose of the project is to accurately determine the influence that the vegetation (its size and density) exerts on the reduction of the "heat waves" in different urban settlements and cities. Project participants will study the systematic effect of urban green areas on the formation of microclimate, namely the changes in temperature, humidity, and CO_2 concentration in residential areas of Kyiv using RS methods: thermal mapping from drones, processing and classification of optical and thermal images received by satellites, etc. [13].

The expected outcomes of the study include the determination of the most effective tree species for the use in urban greening and development of recommendations regarding the plantations planting, density, types of landscaping, etc. In future, obtained results may also be applied in other cities of Eastern Europe.

Monitoring of artificial Earth illumination from space

A group of scientists has studied in detail a set of images of the Earth at night, made in 2012–2016. These images have been acquired by NASA satellite, equipped with a special instrument — a radiometer. It measures the brightness of night illumination. According to the study results, illumination has increased by 2% annually and continues to grow. Decreased illumination has been registered in two countries only — war-troubled Yemen and Syria.

Fig. 4.58. Satellite image of artificial illumination of North Korea and South Korea, illustrating the correlation between night lights and economic activity of the country (NASA/The Washington Post) [14]

In 2017, *Nature* journal published an article, which stated that artificial illumination poses threat to pollination of crops by nocturnal insects [15]. A study conducted in the UK showed that trees bud a week earlier on the territories with artificial lighting than in other sites. Artificial lighting also significantly changes the behavior of birds traditionally migrating at night [16].

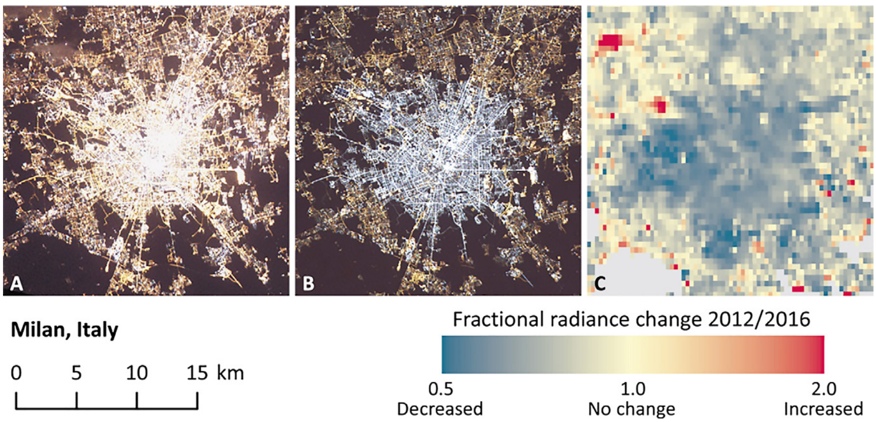


Fig.4.59. Changes in the street lighting in Milan (Italy) in 2012 (A) and 2015 (B), according to satellite imagery [17]

Dr. Kyba states that the quality of illumination depends not on its amount, but on the contrast. It is possible to improve the visibility with lower lighting by decreasing the contrast of street lamps and avoiding the use of blinding lamps. In addition, this approach may increase energy efficiency. According to scientists, there are no such changes observed on a global scale.

It is possible to watch video at NASA's YouTube channel www.youtube.com/watch?v=8dc58ZrOuck - Lights of Human Activity Shine in Image of Earth at Night.

By studying Earth at night, researchers can investigate how cities expand, monitor light intensity to estimate energy use and economic activity, and etc.

Assessment of Urbanization Using Night Images

Below is given an example of satellite imagery use in the evaluation of development of Ukrainian cities. The study objects were the territories of the towns of regional subordination. The total intensity of illumination at night was used as a measure of the urban growth rate.

The intensity of urban growth and its differentiation was carried out as follows. A quantitative indicator of the total lighting intensity (TLI) was proposed as a quantitative criterion characterizing the spatial concentration of the population, and, accordingly, the economic activity of the territory [18–20]. TLI is the sum of the illumination values of all pixels on the territory of each city. The use of TLI allowed analyzing the distribution of night lighting in urban areas and comparing it with the population density and economic development of the area.

DMSP/OLS satellite delivers night images of the ground surface in the visible spectral range with the spatial resolution of 900 m [21]. The archival data collected in 1992–2012 have been used in the study. The study allowed identifying the “dominating” cities in Ukraine, which contribute significantly to the total night illumination of the region *(Fig. 4.60., Table 4.2.)*.

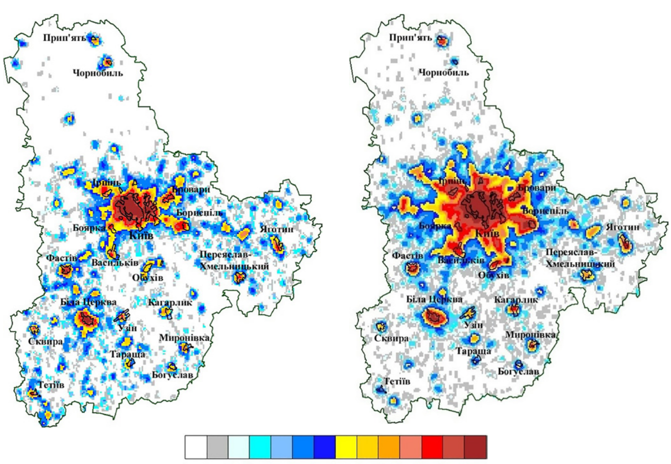


Fig. 4.60. Changes in the nighttime TLI in 2012 compared to 1992 in Kyiv Region (*a* — 1992; *b* — 2012)

Table 4.2. *Assessment of the cities according to the total lighting intensity at night*

Rating of regional centers according to the rate of their development during 1992–2012

Group	Mean TLI	Cities
I	>20*10 3	Kyiv, Dnipro, Kharkiv, Odesa, Donetsk, Zaporizhia, Mykolaiv, Lviv
II	10*10 3 to 20*10 3	Luhansk, Simferopol, Poltava, Chernivtsi, Vinnytsia, Sumy, Rivne, Kropyvnytskyi, Zhytomyr, Kherson
III	<10*10 3	Cherkasy, Ivano-Frankivsk, Lutsk, Khmelnytskyi, Chernihiv, Ternopil, Uzhhorod

There have been identified "dominant" cities, based on the rating of the city's contribution to the total illumination of the region, according to 2012 illumination data. The results showed that in Ukraine not all "dominant" cities are urban agglomerations; often they represent sole productive site within the region, which is indicative of a negative economic tendency. "Dominant" cities of Ukrainian are, namely: Kyiv (53.46%), Odesa (47.06%), Mykolaiv (42.30%), Rivne (42.14%), Chernivtsi (39.14%), Kharkiv (38, 02%), Lutsk (37.46%), Kherson (36.75%), and Lviv (36.27%).

Thus, satellite imagery presenting nighttime illumination may be used as an independent source of information on the degree of socioeconomic development of various cities. It also makes it possible to trace the changes in the night lighting of the territories and rank the cities according to the level of their development.

Based on the analysis of 2014–2016 infrared night surveys performed using Visible Infrared Imaging Radiometer Suite (VIIRS) sensor installed at Suomi NPP satellite, the changes in the economic status of temporarily uncontrolled territories of Ukraine in Donetsk and Luhansk Regions (as a result of the armed conflict) have been assessed. These assessments stem from the well-known fact that one of the indicators of the economic activity on the territory is the level of electric energy consumption, which can be evaluated on the basis of night illumination data [22].

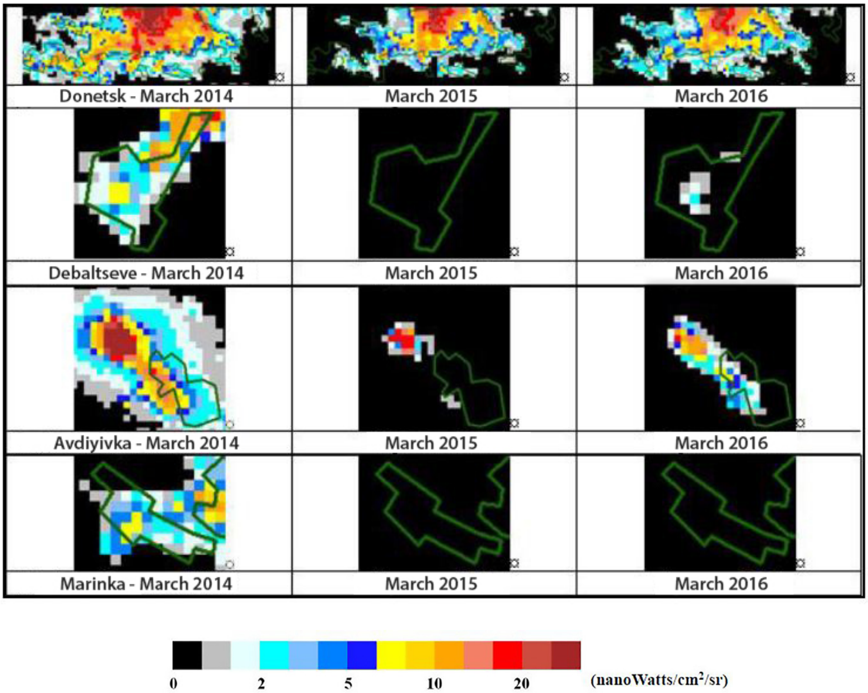


Fig.4.61. Night images of the settlements in Donetsk Region as of March 2014, 2015 and 2016, delivered by NPP/VIIRS satellite [23]

According to the given data, it has been determined that the economic activity in the occupied portions of Donetsk and Luhansk regions in the spring of 2016 was 54% of that observed in March 2014. On the basis of these results, a clear view of the losses incurred by the region's economy due to a military conflict may be formed. These results may also serve as guiding points in the planning of future actions aimed at the recovery of the region.

Given that the military factor greatly limits the possibilities for ground-based monitoring of the state of the environment, there is a need to use the capacities of RS techniques and mathematical modeling in addressing anticipated tasks and justifying priority protective actions.

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4.2. Ecology and Agricultural Sciences

Ecology is the science that studies the patterns of relationships between organisms and the environment, as well as the organization and functioning of the systems of supraorganisms (populations, species, biocenose, biosphere). The main spheres of scientific interest of ecology are as follows: biodiversity, dissemination of organisms, biomass and populations of organisms, as well as intra- and interspecies cooperation, symbiosis and competition. Ecology studies ecosystems, i. e.

dynamically interacting systems of organisms and nonliving components of their environment. Agricultural sciences are of special importance because of a society's special interest therein. It is hard to imagine life of a modern person without such an important industry as agro-industrial complex (including all components thereof). However, the development of this industry in the XXI century should be discussed with due consideration of environmental aspects, since the influence of humanity on the ecosystem in some cases has irreversible and devastating consequences.

4.2.1. Лісознавство

Forestry refers to a body of knowledge on the species composition of forests, forest vegetation groups and the environment, in which forest plants grow [1].

In summer of 2017, the number of **trees withering core areas** destroyed by **the bark beetle (*Ips acuminatus* Gyll.)** increased dramatically on the territory of Drevlianskyi wildlife sanctuary in the north of Zhytomyr Region, as well as in the whole Polissia. The sanctuary's name comes from the name of the eastern Slavic tribe, *drevlians, derevlians,* who lived in this territory and later became known as *polischuks*. The etymology of both names is associated with "tree" and "forest". This sanctuary was established to preserve the unique forests and wetlands of Ukrainian Polissia region, and study the changes in the ecosystems due to natural and anthropogenic factors. The major part of sanctuary forests was heavily contaminated by radionuclides as a result of Chornobyl disaster and recognized as the compulsory evacuation zone; so the human impact was minimal after the disaster [2]. In general, the number of pine trees destroyed by the bark beetle in the sanctuary reached thousands.

This beetle was named so because it invades bushy top of trees and ruins it in 6–8 weeks killing the trees. The ground survey methods are not effective for investigation of these processes, since it is difficult to examine the tree crown from the bottom, and also because regular ground surveys are associated with significant costs. In such cases, satellite or aerial photography has many advantages, since it provides coverage of large areas, including all difficult to access marshy places, and makes it possible to analyze the state of trees at certain intervals.

The first researchers to use aerial photography in the studies of forests in the 1930s were S. H. Spurr, S. T. B. Losee, H. E. Seely, who worked in the USA and Canada. In particular, H. E. Seely published an article on the method of determining the height of trees by their shadows on aerial images in 1942 [3]. "None of the natural resources (including the soil, forest, minerals and water) may be covered by the aerial photography better than forest … the survey of forestlands should never be performed without the use of aerial photography," wrote Seely [4]. Thus, remote sensing data started to be widely used for the forest resources management, which is, however, mostly based on estimating timber logging, i.e, areas and volumes of timber, taking into account the species composition of trees [5].

With the development of satellite **multispectral surveying** (imagery in various spectral ranges), new forest inventory methods emerged that provided information on vegetation health, biodiversity, tree damages and the impact of climate change. The availability of images with a very high spatial resolution (less than 1 m) allowed accurate mapping of the areas with the homogeneous structure of the timber stand (age, size, share of forest plantations of one type, etc.). New **laser scanning** techniques changed substantially the approaches to the analysis of the structure and functions of forest ecosystems due to more accurate and more detailed three-dimensional, automated evaluation of forest composition. The terrestrial laser scanners are currently widely used for the analysis of **microhabitats** on trees *(Fig. 4.62)*. It is believed that the more diverse the structure of the tree, the more microhabitats it will have, which means higher biodiversity and productivity of the forestlands in general.

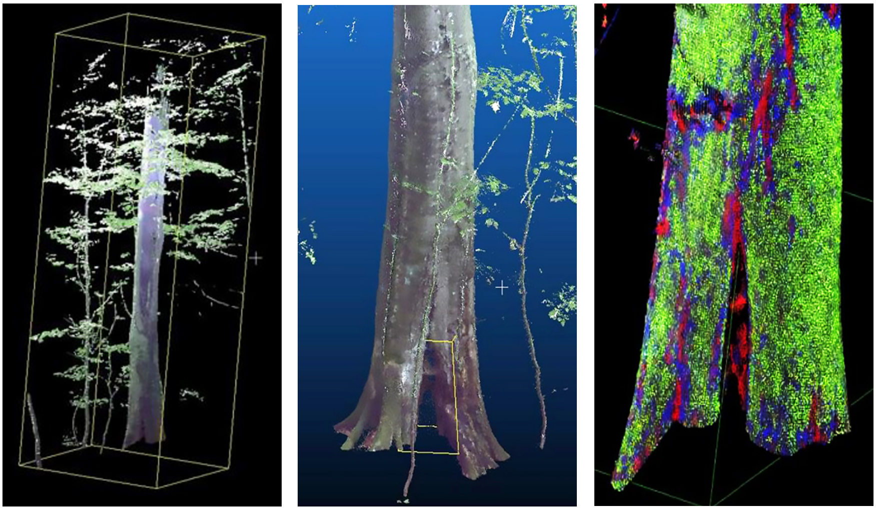


Fig. 4.62. 3D models of a tree (the European beech), generated with the use of a terrestrial laser scanner by the students of a summer school studying beech primeval forests, held by the Swiss Federal Institute for Forest, Snow, and Landscape Research (WSL) on September 2–8, 2018, on the basis of the Carpathian Biosphere Sanctuary, the Uholka-Shyrokyi Lug.

In general, there are three the most important areas of the use of RS data in the forestry [6]:

- **Large-scale monitoring of forests and tree plantations**
- Identification of forest areas suppressed as a result of diseases or pest contamination — special attention is paid here to the early detection of core areas affected in order to take timely actions;
- Identification of trees damaged by natural or anthropogenic adverse effects, for example, fires, storms, emissions from industrial production adjoining forestlands;
- Monitoring of meteorological and climatic conditions affecting the forests, such as humidity and temperature.

- **Detailed forest inventory (tree stand condition) for the estimation of timber volume and stock**
- age of forest plantations, height, diameter of the stem;
- tree plantations density, crowns thickness or projective coverage;
- boundaries of quarterly views with homogeneous plantings.

- **Analysis of forest structure for sustainable use of forest resources**
- retrospective analysis of the territory — time and volume of the logging area, irregularities (if any) associated with timber logging caused by the adverse factors — all this is important, in particular, for the identification of ancient sites and valuable ecosystems;
- Simulation of CO_2, one of the greenhouse gases, discharge in different scenarios of forest management;
- Assessment of ecosystem services — benefits (direct and indirect) provided by the forestlands, such as wood, mushrooms, berries, climate regulation, water regime, etc.

Detection of Trees Damaged by Fire

On August 19, 2007, the forest cover in the Kherson Region caught fire, which spread rapidly in the dry steppe and forests of Tsiuriupynskyi and Holoprystanskyi districts. Firefighting activities, which lasted for 10 days, were carried out with the participation of the Ministry of Emergencies of Ukraine, the State Forestry Committee and other departments (totally 1341 people) [7]. This fire was one of the largest in the region. After its elimination, huge areas were covered with ash and it was hard to differentiate, which trees were destroyed by fire and which were not.

The State Forestry Committee made a decision to use multispectral satellite imagery for these purposes. The **method of bands combination** in Landsat 5 image captured in late August has been applied for the identification of dead trees. The combination of bands 3, 2, 1, which was an image in a visible range, was close to what could be seen on the site with unaided eyes. However it was difficult to recognize the living and dead trees using such image *(Fig. 4.63a)*.

The trees with ongoing process of photosynthesis have high reflection values in the green spectral range, in contrast to dead trees having minimum reflection values in the green and infrared portions of the spectrum. Besides, damaged trees have a higher reflection value in the middle infrared band, which is associated with a decrease in the leaf moisture content. Therefore, in order to distinguish damaged and undamaged trees, one should use the combination of bands — middle infrared, near infrared and green. For Landsat 5 satellite image this means a **combination of bands 7, 4, 2** *(Fig. 4.63b)*. In this way, it was possible to determine the forestlands with withered trees and estimate the damage caused by the fire.

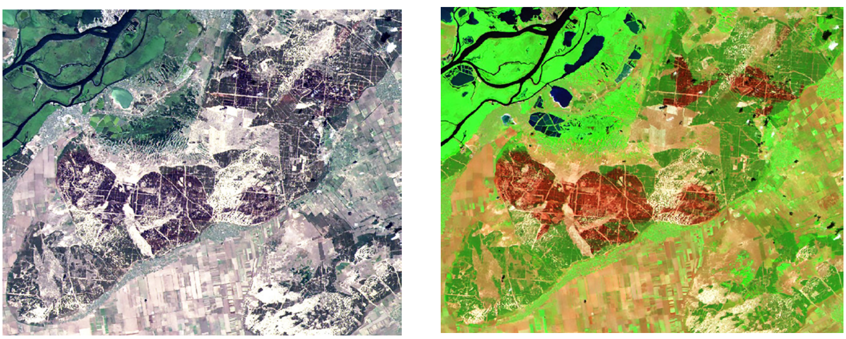
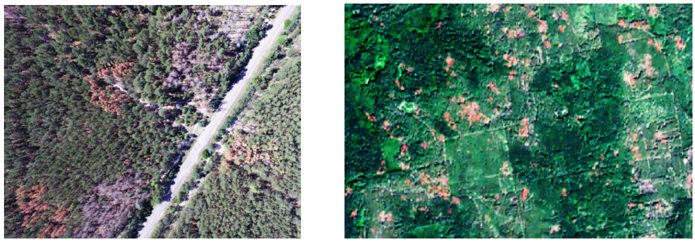


Fig. 4.63. Landsat 5 image with a different combination of bands for assessing the effects of August 2007 fire: a) combination of bands 3.2.1 in the visible range — the forestland is depicted in dark green, the river bed — in black, the algal blooms on the water surface and the fields — in green, open soil — in gray, sand dunes — in white; b) combination of bands 7,4,2 — medium infrared, near infrared and green ranges — live forest vegetation is displayed in dark green color, and dead trees among them — in bright brown color.

Monitoring of Core Areas of Forestlands Attacked by Pests

Remote sensing methods may be successfully applied to identify forestlands damaged by pests and core areas of withered pines, in particular, due to the attacks of bark beetle. These methods may include aerial and satellite imagery, aerial survey, LIDAR survey *(Fig. 4.64)*.



a *b*

Fig. 4.64. The manifestation of the damaged pine plantations in aerospace images: a) imagery by a quadcopter; b) satellite surveying by Sentinel-2 (withered pines are marked as red spots — the newer core area, the brighter the color).

The aerial survey is the most popular instrument for forest resources management. The advantage of the visual method is the relatively low cost and the ability to detect even individual affected trees [8, 9]. The disadvantages include high labor input and the probability of missing the damaged sites in case of large areas examination.

The use of unmanned aerial vehicles survey *(Fig. 4.65)* may significantly reduce the labor costs, cover large areas and reduce the possibility of missing certain forestlands. However, it is often difficult to determine the exact affected forest areas due to the complexity of geographic references and geometric correction of survey materials if the study area is large.

Fig. 4.65. Results of aerial imagery by unmanned aerial vehicle, July 2018

Interpretation of aerial photography materials, including LIDAR one, provides high precision and detail. However, because of the high costs of this method, it is applied not so often and not always in a due time, which does not allow effective monitoring of the emergence of new pest core areas during the vegetation season.

The use of ultra-high spatial resolution (less than one meter) also allows obtaining results with high decryption accuracy. For example, White (2005) using the Ikonos satellite images, estimated the withered coniferous area with the level of precision of 71% for low degree of forestland pest infestation, and 92% for high degree of forestland pest infestation [10]. However, RS data of ultra-high spatial resolution may not also provide the required survey timelines and frequency due to the technical requirements and high costs. Another significant drawback of these data is low spectral resolution, which complicates automated images processing.

Therefore, the most optimal method for monitoring of pest infestations of forestlands during the vegetation season is the **use of satellite data of medium and high spatial resolution** (10–30 meters). These types of surveys include Landsat-8 (15–30 m) and Sentinel-2 (10 m) satellite imagery. These satellite systems provide a large amount of multispectral imaging throughout the year, and multiple coverage of the area under study. The effectiveness of these images use for identification of pest-attacked coniferous forests has been proved in numerous scientific studies [11].

When using multispectral satellite data of high and medium spatial resolution, in particular for monitoring of forest areas affected by pests, it should be taken into account that the crown of an individual tree takes less than one pixel in an image, thus significantly complicating the identification of individual dead trees. The value of spectral radiation in the pixel of the image is a complex combination of reflected radiation from crowns of trees, crowns of the 2nd tier, new growth, understory trees, living aboveground cover, soil, as well as the shadow of neighboring trees [8]. When the trees are damaged, especially in the case of attack by bark beetle, the reflection ability of pine crowns changes due to the alteration of biophysical processes in the trees, causing the color change in the satellite image.

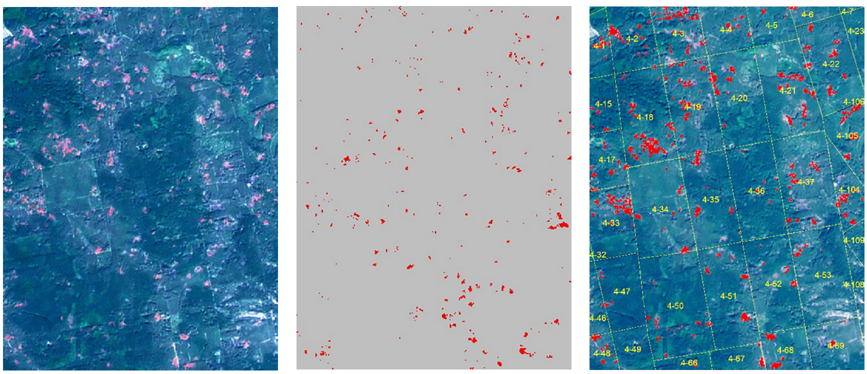
However, it should be noted that, in addition to the trees dieback, changes in the spectral reflectivity of forest areas during the vegetation season cause changes in phenological phases, soil and plants moisture content, etc. Following the analysis of a series of satellite data collected over one year, scientists discovered that damaged trees within the studied area are better identified from July to August and manifest in the images before the beginning of December. In the images taken from January tthrough July, it is almost impossible to detect damaged trees.

To detect core areas of coniferous tree pests according to satellite images, both visual and automated **image classification**, i.e. extraction of necessary information from satellite images, are used. In some cases, **visual decoding** provides quick results and requires fewer terrestrial surveys to form a set of standards. However, a significant drawback of this method is the high likelihood of errors due to the missed sites, especially small one, covering one or several pixels only. In addition, the decoding of information by several experts may provide unstable results. Therefore, for the monitoring of Drevlianskyi wildlife sanctuary territory researchers applied the method of **automated image classification**.

For the purpose of automated decoding of satellite images, various algorithms of computer classification are used, in particular, the maximum likelihood classification. This method involves the initial etalon objects selection, i.e. highlighting the exact locations of trees affected by pests, and further automated identification of the forest areas with similar characteristics on satellite images using this set of standards.

In order to create a database of reference core areas of withered pines, researchers used the imagery taken by unmanned aerial vehicle in July 2018. Aerial photography by unmanned aerial vehicle was carried out under favorable weather conditions: almost cloudless sky, good visibility. A series of flights along the compartment at a height of 20 m with intervals of 30 m was performed to determine the boundaries of affected areas *(Fig. 4.65)*.

For the classification, the Semi-Automatic Classification Plugin for QGIS has been used. As a result, experts received a raster image with selected withered trees that was automatically converted into vector format in order to easily determine the affected areas within forest districts and plan forest sanitation measures *(Fig. 4.66)*.



a *b* *c*

Fig. 4.66. Classification of Sentinel-2 satellite image for identification of core areas of withered pines damaged by the bark beetle: *a*) Sentinel-2 original image as of July 30, 2017; *b*) raster file with result of classification by greatest similarity; *c*) Sentinel-2 satellite image with a vector layer of isolated core areas of withered pines (red color) and a net of rides (yellow color).

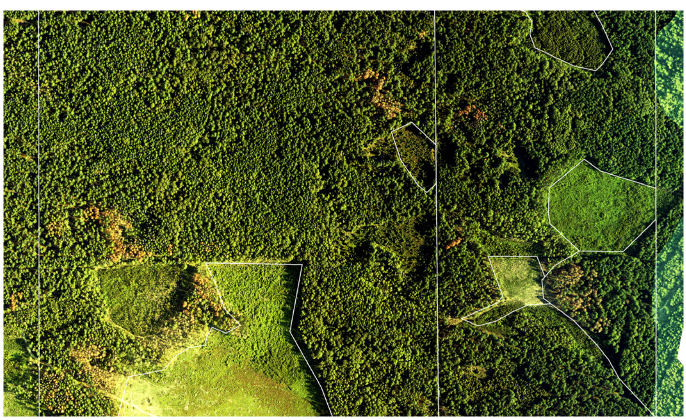
Specification of boundaries of compartment sections with homogeneous forest plantations

To take inventory of the structure of forestlands and specify the boundaries of compartment sections, one should use satellite or aerial imagery with high spatial resolution — less than one meter. The relevance of the survey and spectral differentiation are not extremely important for this analysis. Since trees planting and felling is carried out simultaneously within one forest section in industrial forestlands, the structure, age, height and diameter of the tree stem and, accordingly, the trees crown should be more or less similar within the same section.

Therefore, the diameter of a tree crown may be used as an indicator for the assessment of whether one section contains one or several tree classes *(Fig. 4.67)*.

Forest section is a part of forest compartment and the smallest unit to which, as a rule, all statistical data is linked; so it is important for such areas to be homogeneous.

a



b

Fig. 4.67. Editing the boundaries of compartment sections based on: *a*) satellite image with high spatial resolution; *b*) aerial image.

Remote monitoring of deforestation

The dynamics of deforestation of the Boiarska Forest Research Station (FRS) is monitored by means of retrospective analysis of Landsat 4, 5, 8 satellite images. Landsat program is the longest mission of remote sensing from outer space that delivers multispectral images of the Earth's surface with a spatial resolution of 15 meters. For the purpose of the study, experts downloaded from the open catalogue of satellite imagery 20 Landsat [12] images taken during the growing season (May — September) [13] in 1985–2015.

Color images close to natural colors, were formed by a combination of spectral bands: infrared, near infrared and green. On images, healthy vegetation is colored in bright green, herbal groups in green, open ground (deforestation area) in bright pink color; brown and orange tones are characteristic of sparse vegetation, dry vegetation is colored in orange, water in blue *(Fig 4.68)* [13].

As a result of decryption of satellite images of deforestation areas, the researchers vectorized and estimated the areas thereof on annual basis. The dynamics of the deforestation in the territory of the Boiarska Forest Research Station in 1985–2015 is shown in Fig. 4.69 [13].

The study demonstrated a sharp increase in the deforestation area, starting from 2000s (from 1–2% to 5% of the total area of the forestlands). In addition, some individual deforestation sites occupy area of 10 to 25 hectares, in particular near Plesetske Village. Obtained data prove that due to such anthropogenic activity as construction and deforestation within the Boiarska FST, natural areas forming the ecosystem, the habitats of rare plant species of animals breeds, as well as the most rare plant species and animal breeds are in danger of extinction [13].

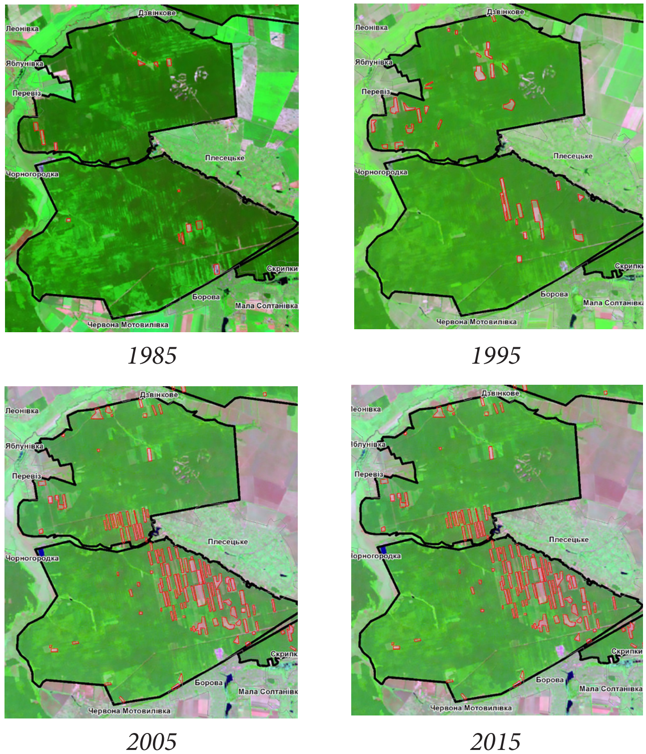
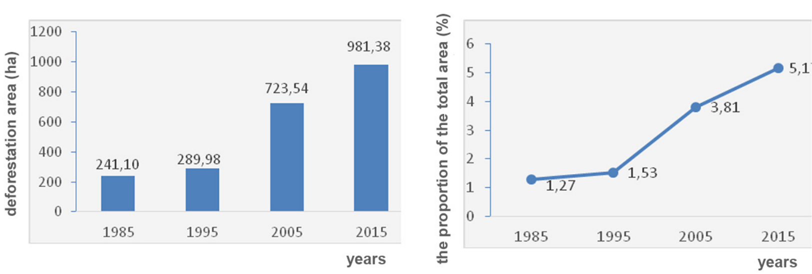


Fig. 4.68. The dynamics of deforestation nearby Plesetske Village (deforestation sites are colored in red) [13].



a *b*

Fig. 4.69. The dynamics of deforestation within the boundaries of the Boiarska Forest Research Station in 1985–2015: *a*) the area of deforestation (ha); *b*) share of the total area (%) [13].

Global Forest Monitoring using Forest Watch Online Platform

For the global monitoring of forestation and deforestation, the World Resources Institute in collaboration with many scientific and non-governmental organizations, including Google, USAID, University of Maryland and ESRI, have created an online Global Forest Watch Platform [14] based on Modis and Landsat satellite images, which allows to track changes in the forest cover in a real-time mode.

Using the cartographic interface of the system *(Fig 4.70)*, it is possible to select the territory, time interval and get information on the area of the lost forest cover and forestation area. According to the system data, 2917 hectares of forest cover have been lost within the forestland of the Boiarska FST over the period from 2001 through 2017, and 1007 hectares of forest were restored. Following the selection of the area of interest on the map, the each user may subscribe to data update of this area, if amended. Thus, the system allows assessing the level of deforestation on a global scale, and on the other hand, provides the public with an instrument for the monitoring of illegal deforestation [15].

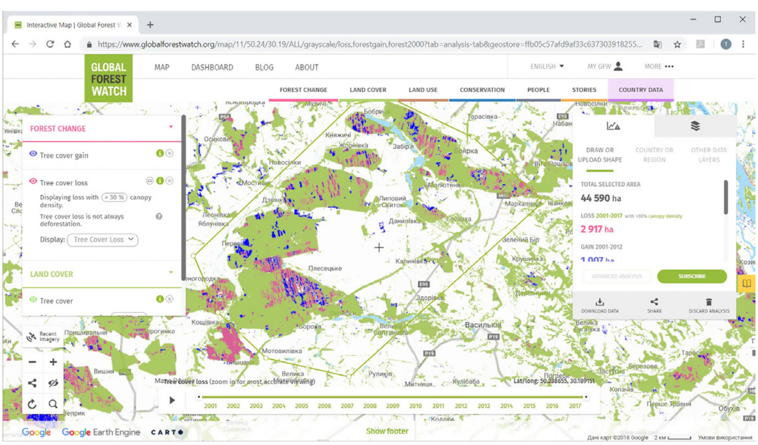


Fig. 4.70. Interface of Global Forest Watch online forest monitoring platform; the forestation areas are colored in the map in blue, and deforestation areas are colored in red (due to felling, fires, etc.).

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4.2.2. Agronomy

Imagine that an apple represents the Earth. If we slice the apple into three equal slices, 1/3 of the apple will represent the area covered by land. Moreover, only 37% of the total land area can be used in agriculture, and the share of arable lands on which crops are grown amounts to some 11%. In other words, if we divide an apple into thirty parts, only one of them will represent the portion of land that should provide the entire population of the planet with foods of plant origin. This portion has changed negligibly over the last 15 years (in 2003 it was 10.8%), contrary to the population of the planet, which has increased by 1 billion 250 million people over the same period [1]. Consequently, the development of agricultural production technologies should aim at increasing the yield while using the same land areas.

Aerial and satellite systems that provide continuous monitoring of biophysical processes can contribute to increasing the productivity of agrarian lands. Implementation of these systems is beneficial for both farmers, who can gain more profits, and national governments that can strengthen food security.

Section 4. SCOPE OF RS APPLICATION

How exactly remote sensing data can help farmers, landowners or agricultural holdings? In general, RS data may facilitate decision-making process during the cultivation of crops by providing up-to-date information on:

- **soil condition** required for the development of the cropping plan. In particular, it is better to use depleted and degraded soils for the growing of perennial grasses or medicinal herbs, instead of arable crops, as the latter will result in poor yield and heavy expenses concerned with fuel consumption and fertilization;
- **crop condition**, i. e. on the status of germination, winter crops vegetation, biomass accumulation and ripening; on any signs of inhibition of the plants potentially caused by the spread of diseases or plant pests, or nutrient defficiency; on the need to use irrigation systems or plant protection agents, and etc.;
- **agroecological characteristics of fields** — monitoring of meteorological, climatic and agrochemical conditions, for example, moisture content in the soil or estimation of harvest losses due to extreme or adverse weather conditions such as showers, hail, etc.;
- **efficacy of technological processes** — when and where it is better to apply fertilizers; what quantities should be applied; was the soil properly prepared for the seeding; how the effect of poor weather conditions may be mitigated;
- **field history** — collection of data on the crops being grown in the field in the past and respective yield;
- **identification of sampling sites** — identification of homogeneous and heterogeneous areas of the field in terms of soil and crop condition with a view to reduce the number of sampling sites for a detailed analysis of the situation in the field.

At the national level, the following lines of aerial and satellite surveys are important for the state administration bodies:

- **inventory of crops** — information about the structure and areas occupied by the crops, for the purposes of the government statistics;

- **yield forecasting**, which is essential in the planning of export and import, forecasting of market prices of food products, etc.;
- **status of agricultural lands** — identification of illegal land use or abandoned agricultural lands, overgrowing of arable lands with trees and shrubs, impaired crop rotation;
- **agroclimatic conditions within districts and regions —** forecasting of stressful events on cultivated lands; forecasting of climate change impact; planning of measures aimed at adaptation to climate change.

The studies related to the use of satellite data in agriculture started with the launch of Landsat-1 satellite in 1972. In 1974, the US Department of Agriculture jointly with NASA and NOAA initiated a project called *«LACIE» (Large Area Crop Inventory Experiment)*, which purpose was to demonstrate the economic benefits of satellite imagery application. Wheat was used as a test agricultural crop. Data on wheat productivity was assessed on the basis of satellite information acquired by Landsat, compared with results of sampling on fields and integrated with meteorological data collected by NOAA satellites and ground weather stations. This allowed making forecasts of wheat yields under various weather conditions [2].

In 1975, the Food and Agriculture Organization, FAO, created a program called *GIEWS (Global Information and Early Warning System)* for the monitoring of food security situation in the world. For the purpose of providing rapid response to regional food crises, the maps of soil cover and land use are developed, combined with ground-based agrarian statistics and information on agricultural market situation and weather conditions on the basis of satellite data.

In the 1980s, there was gradually launched a series of NOAA satellites equipped with AVHRR (Advanced very-high-resolution radiometer), which allowed receiving daily images of the Earth. Despite rather low spatial resolution (1.1–4 km), global operating systems of satellite agromonitoring have been developed on their base.

These systems primarily focus on food security and combatting hunger in developing countries and yield and global agricultural market prospects.

The systems of global satellite agromonitoring include, in particular:

- FAS (USDA Foreign Agricultural Service)
- GLAM (Global Agriculture Monitoring program)
- FEWS (USAID Famine Early Warning System)
- MARS (EU DG-JRC Monitoring Agriculture with Remote Sensing)
- GMFS (EU Global Monitoring of Food Security)
- Copernicus (EU Earth Observation Programme).

Ukraine's part is represented in the MARS project by L. Pohorilyi Ukrainian Research Institute of Forecasting and Testing of Equipment and Technologies. According to the order by the Ministry of Agrarian Policy and Food of Ukraine, this Institute has access to project results, on which base it develops information notes on the agroecological state and yield prospects of various agricultural crops.

Other scientific institutions of Ukraine involved in the development of methods for aerial and space agricultural monitoring are namely:

- within the National Academy of Agrarian Sciences: Sokolovsky Institute for Soil Science and Agrochemistry Research, Laboratory of Water Resources and Monitoring of the Institute of Hydrotechnics and Melioration and Laboratory of Aerospace Sensing of Agri-sphere of the Institute of Agroecology and Natural Management;
- within the State Space Agency: Center for Special Information Reception and Processing and Navigation Field Control and "Pryroda" State Scientific and Production Centre;

- within the National Academy of Sciences of Ukraine — Scientific Centre for Aerospace Research of the Earth Institute of Geological Science and Space Research Institute.
- and agro-industrial enterprises: Druzhba-Nova, UKRPROMINVEST-AGRO, etc.

Monitoring of crop condition

FAS and GLAM programs led to the creation of **Crop Explorer** [3] — a popular online platform, which provides a mapping view of crop condition at any date since 2002 (Fig. 4.71), makes it possible to select a certain region on the map and analyze crop condition dynamics over the whole growing season and compare it with the past data or multiannual mean value *(Fig. 4.72).*

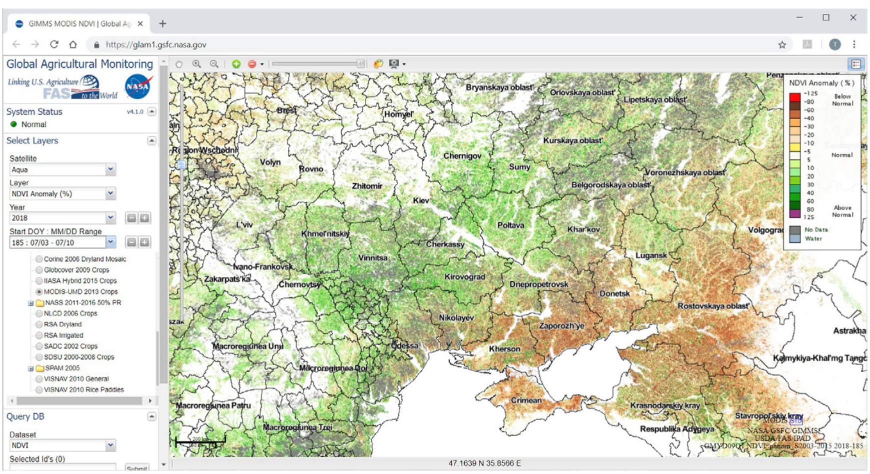


Fig. 4.71. Interface of Crop Explorer platform: map of vegetation condition in agricultural lands over the period of July 3–10, 2018 — shades of green represent normal condition of vegetation (Chernihiv, Poltava, Kyiv, Cherkasy Regions), shades of yellow and red indicate suppressed vegetation (Donetsk, Zaporizhia, Kherson Regions and Crimea).

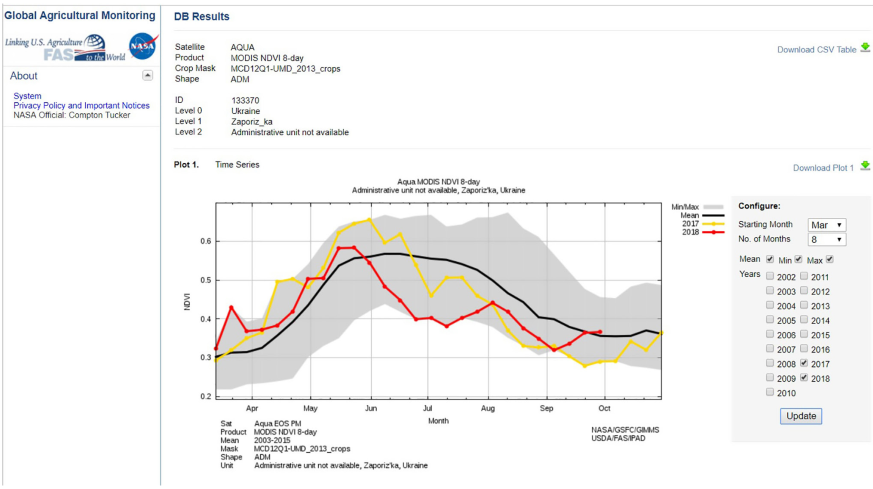


Fig. 4.72. Interface of Crop Explorer platform: chart representing the dynamics of crop condition indicator within certain region for the growing season (red curve), previous year (yellow curve) and multiannual mean value (black curve). The chart demonstrates significantly reduced productivity in June-July (time of grain crops ripening), 2018 compared to 2017 and multiannual mean value. Such a reduction may be caused by drought conditions in the region.

Why are leaves green? The use of multispectral satellite images for the study of vegetation is based on the analysis of solar radiation reflected by plants in various ranges of electromagnetic spectrum. Vegetation in good condition (with a lot of chlorophyll in the leaves and active photosynthesis) has high reflection value in the green portion of the spectrum (that is why the leaves appear to us green), high absorption in the red portion of the spectrum and very high reflectivity in the near infrared range *(Fig. 4.73)*. With the deterioration of condition, the reflectivity of vegetation in the green and near infrared ranges reduces, which is displayed on the spectral curve. .

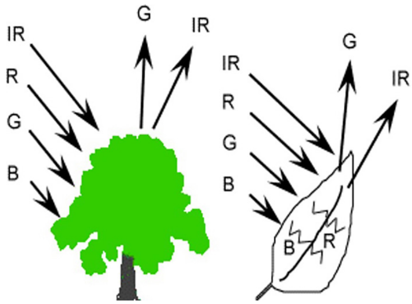


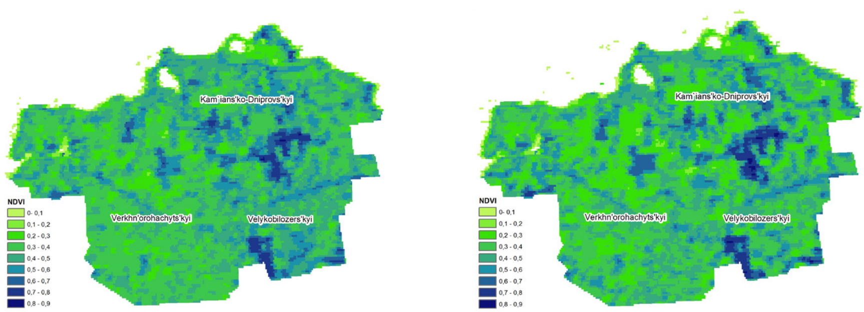
Fig. 4.73. Interaction of light energy in various ranges of the spectrum with plants (B — electromagnetic radiation in the blue range of the spectrum, G — in the green range, R — in the red range, IR — in the infrared range) [4].

Thus, the ratio of the light energy that is absorbed, reflected and transmitted by the plants in various spectral bands depends on the content of chlorophyll, humidity, cell structure, i. e. the condition of the plant. These ratios, being in fact the combinations of different spectral bands of satellite imagery, are called indexes and when applied for vegetation analysis — **vegetation indexes**. Obtained in such a way numeric values are used for the analysis of biophysical characteristics of vegetation. There are about 200 versions of vegetation indexes, which suit certain types of vegetation and soil.

One of the most famous vegetation indexes is the **normalized difference vegetation index, NDVI** — normalized difference of reflected energy in red and near-infrared bands of electromagnetic spectrum, which combines information about the chlorophyll content (red band) and cell structure of the leaves (near-infrared band). By using the normalized difference instead of just ratio it is possible to diminish the influence of the atmosphere, level of illumination and time of imagery on the index value, which allows to trace the vegetation changes over time more accurately.

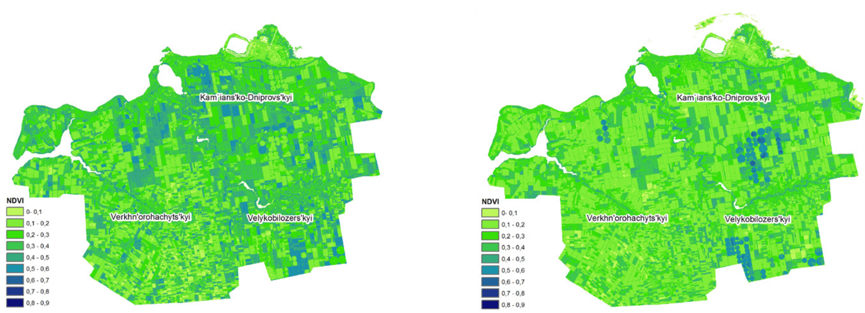
Crop Explorer platform uses **TERRA/AQUA MODIS satellite data** of daily images with spatial resolution of 500 m. With this precision, it is possible to identify regional signs of deterioration in the crop condition or, for instance, monitor renewal of spring vegetation in winter crops. However, to study in detail certain field or territory of agricultural enterprise, the images with better spatial resolution should be used, for example acquired by **Landsat** or **Sentinel**. Figures 4.74–75 compare the images of three districts in Zaporizhia Region acquired by MODIS and Landsat. According to Crop Explorer, these districts demonstrated decrease in the crop productivity in the summer of 2018 compared to the previous years.

Figures 4.74b and 7.75b represent the images made by various sensor systems on the same date. It is apparent that MODIS sensor provided higher NDVI values, however the spatial configuration looks similar. MODIS data clearly specify the zones with high NDVI values in the central and southern parts of the studied area. Landsat data show that this is a territory of irrigation fields that have round shape, which represents the operation of irrigation systems.



a *b*

Fig. 4.74. MODIS imagery:
a) image as of June 18, 2018; *b*) image as of June 28, 2018



a *b*

Fig. 4.75. Landsat-8 imagery:
a) image as of May 27, 2018; *b*) image as of June 28, 2018

The timing difference between images is ten days for imagery delivered by MODIS and one month for imagery delivered by Landsat. There was little change over ten days, but within one month the situation changed significantly. At the end of June, only the fields with irrigation systems present in very good condition (that are the fields with high NDVI values). To determine the factors that led to the deterioration of crop condition, and when such deterioration occurred, it is essential to receive images of the territory made at short intervals. Therefore, the **frequency of imagery**, or even the possibility of receiving a new image every day, is sometimes more important than the spatial resolution of the image. Thus, it is important to combine data with different resolution, spatial and temporal (indicating the frequency of photography), in order to analyze the dynamics of biophysical processes.

One of the simplest and most popular methods for identification of the site of **temporal changes** is the arithmetic difference between the images made at different time. In other words, the value of the raster NDVI layer as of 27.05.2018 should be subtracted from the value of the raster NDVI layer as of 28.06.2018. The negative values of the resulting layer will represent the fields with deteriorated crops condition, and positive values — the fields with increase in the biomass *(Fig. 4.76).*

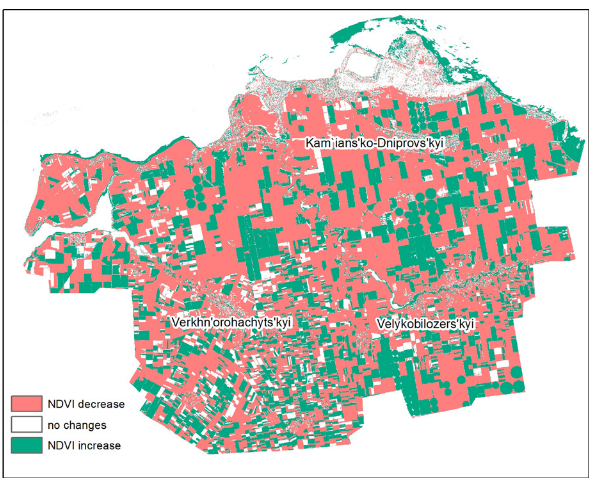


Fig. 4.76. Analysis of NDVI change over the period from May 27 through June 28, 2018

In a similar manner other mathematical operations may be performed using a set of raster data for a certain time in order to determine the average, minimum, maximum or total values of a particular biophysical indicator.

The harvesting results in Zaporizhia Region showed that in 2018 the yield of winter wheat was 25.2 hundred kilograms per hectare, which means 27% decrease compared to 2017 [5]. Such a result could be predicted by analyzing the dynamics of crop productivity *(Fig. 4.72)*.

Monitoring of agroclimatic conditions — evaluation of soil moisture content

Was the loss in the crop productivity in the summer of 2018 really caused by the drought in Zaporizhia Region? The soil moisture content is so important for the agricultural industry that there are several satellites on orbit, which have been specially designed to monitor moister in soil. These satellites are namely SMOS, SMAP and METOP. Of these, **SMAP satellite** (Soil Moisture Active Passive) delivers data with the highest spatial resolution (10 km). It was launched by NASA on 31 January 2015. The wide swath (1000 km) makes it possible to update the soil moisture maps every 2–3 days.

The SMAP measurement system consists of a **radiometer** (passive sensor) and a **synthetic aperture radar** (active sensor) transmitting radiowave impulses to the target and registering reflected waves. This survey method allows analyzing the surface structure and, combined with the hydrologic modelling data, determining the moisture content not only at surface, but also in the top layer of soil (up to 5 cm), which is important for the assessment of moisture intake by the root system of plants.

The map of moisture content in the upper layer of soil as of May 26, 2018, according to the SMAP data representing the territory of Ukraine *(Fig. 4.77)*, shows the soil moisture deficit (<5 mm) in the greater part of Zaporizhia Region. The same is observed on the entire territory of Vinnytsia and in some parts of Dnipropetrovsk, Khmelnytskyi, Kirovograd, Zhytomyr and Odesa regions.

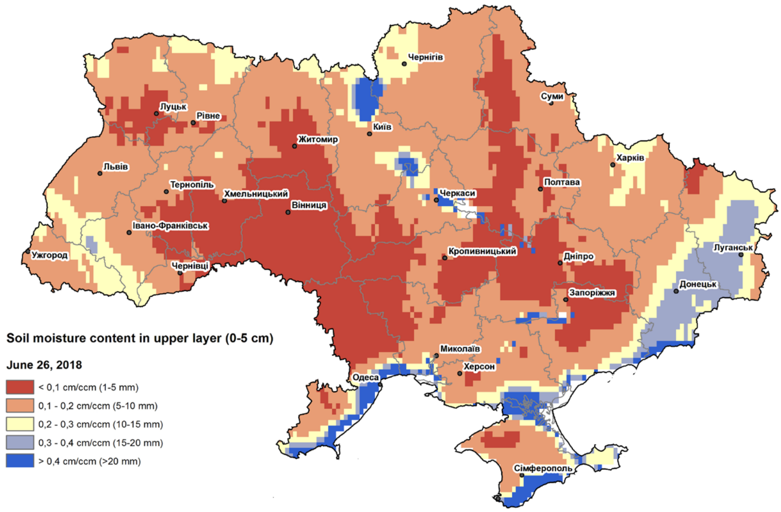


Fig. 4.77. Moisture content in the top layers of soil — the territory of Ukraine as of June 24–26, 2018

Consequently, low productivity of crops in the summer of 2018 may be due to the drought in the region. In general, information on soil moisture content is important for early warning of drought conditions and timely planning of actions for mitigating drought impact. For example, in case of low soil moisture content at the beginning of the seedage, direct seeding is recommended, i. e. without pre-sowing treatment, since tillage will lead to loss and evaporation of already deficit moisture from the soil.

Evaluation of soil cover condition — identification of water erosion

Water erosion is a process of flushing away or detachment of soil particles by melt- and rainwater. Surface runoff, especially on mild slopes, causes evenly displacement of the upper layer of soil, which is rich in humus. The danger of this erosion is that initially it remains unnoticed and manifests only in the minor changes of soil color.

The assessment of relationship between reflection indices in different spectral bands and concentration of substances at certain sampling points is one of the methods used in the studies of agrochemical elements distribution in the soil. Humus (or organic matter) content is the indicator of the level of erosive degradation of soil and its fertility. It is important to perform such studies when the soil is free from vegetation or snow cover.

When studying the use of RS for humus content evaluation, the scientists have drawn samples and measured humus concentrations (in laboratory) in six fields across Hoshovskyi District of Rivne Region *(Fig. 4.78)* [6]. The image delivered by **Sentinel-2** as of April 4, 2018 has been downloaded from the archive of the European Space Agency. The spectral reflectance has been determined for each sampling point in the following bands: 2, 4, 5, 6, 8, 8 a, 11, 12 (i. e. the bands with spatial resolution of 10–30 m).

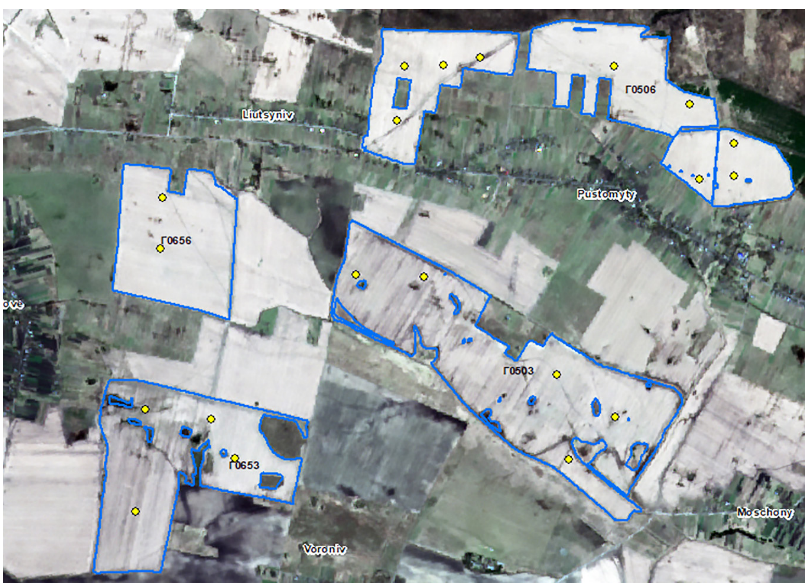


Fig. 4.78. Sentinel-2 satellite image
as of April 4, 2018 with field boundaries (marked in blue)
and sampling sites (marked in yellow).

Thus, a table was formed, where each value of the humus content matched to the respective value of spectral band in the sampling point.

The correlation between humus content and spectral values of the bands was determined with multiple linear regression technique using SPSS software package; the resulting multiple regression equation is the sum of spectral bands with respective coefficient established for each band. A new raster layer, where each image pixel contains information on humus content, can be calculated according to multiple regression equation using all given bands of satellite image, each used as a separate raster layer (b2, b3, b4 and etc.) *(Fig. 4.79)*. The image shows heterogeneous pattern of humus content and sites with the signs of erosive degradation (light color), in particular in the fields 656 and 653.

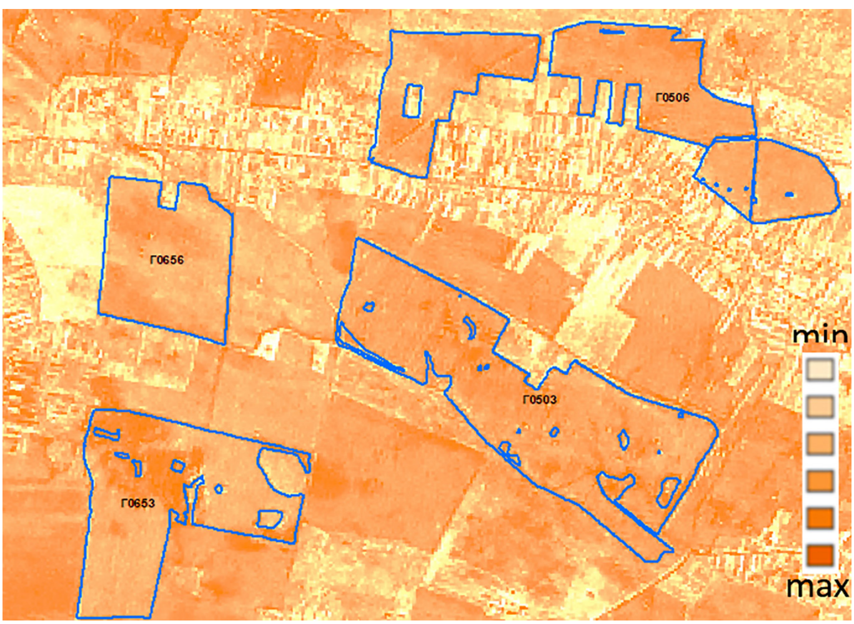


Fig. 4.79. Map of humus content in fields (marked in blue), according to Sentinel-2 data [6].

Consequently, we have studied the examples of remote sensing data application in agriculture based on the analysis of time series of satellite images and vegetation indices, as well as assessment of relationship between the concentration of agrochemical elements and the multispectral satellite imagery data.

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4.2.3. Environmental Protection and Sustainable Management

Remote sensing data open new ways for establishment of sustainable land use methods. In general, both at regional and country level, there is a need for economic land use planning, combined with the balanced use of natural resources, and the conservation of territories important for the maintenance of the ecological balance, primarily the environmental protection.

The use of satellite images to monitor and assess the condition of environmentally protected areas of different levels of protection (national or local) is an effective and objective method that allows obtaining results in the shortest possible time. Due to the poor transport accessibility of sanctuaries, national parks and wildlife reserves, remote methods allow to address a set of problems that are difficult to tackle using traditional ground-based observation techniques.

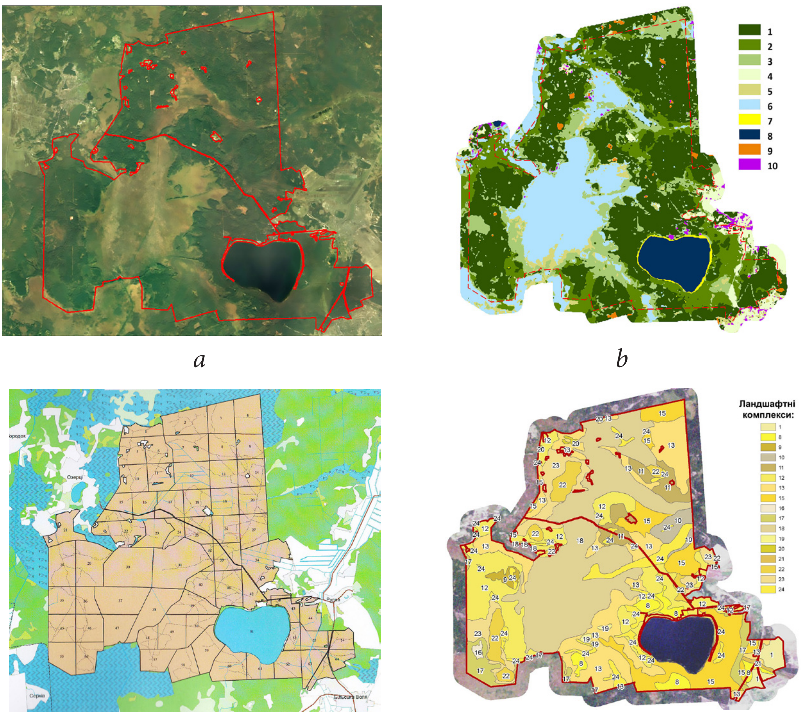
Using remote sensing techniques, we may:

- monitor the condition of existing protected areas, namely, detect violations of the protection regime (logging, pollution, illegal construction, landscape transformation, etc.);
- map different types of habitats and natural complexes within protected areas; — monitor the dynamics of environmental and man-made changes occurring within the protected areas (natural changes of vegetation, for example colonization by shrubs, degradation of certain types of natural habitats due to indirect influence of adjacent technogenic territories, etc.);
- formation and specification of the boundaries of existing and projected protected areas.

Mapping of Landscapes within Protected Areas

Satellite images are used for background monitoring — inventory and operative mapping of natural resources, phenological and dynamic monitoring, i. e. observation of seasonal and long-time changes in the natural environment, as well as for the assessment of the impact of human activities on the natural environment, control of size, form, strength and effects of the economic activity *(Fig. 4.80)* [1].

Current thematic maps compiled on the basis of remote data, help to assess the sites of the largest recreational load, control the influence of anthropogenic factors on forest resources (in particular, the deforestation shown in Fig. 4.81). Despite the formally high conservation status of this territory, recreational activities are allowed in some parts thereof, which often take a spontaneous character, in particular as within 150 m of eastern and northern coastline of Bile Lake, and 50 m water area thereof.



a *b* *c* *d*

Fig. 4.80. Mapping of the landscapes and remote monitoring of biotopes of the Bile Lake area of Rivne Sanctuary (*a* — boundaries of the sanctuary in satellite image; *b* –map of biotopes based on the classification of Landsat 8 satellite imagery (biotope types: 1 — coniferous forest, 2 — deciduous forest, 3 — sparse forests and second growth, 4 — meadow vegetation, 5 — shrub vegetation, 6 — hydrophilic and waterlogged vegetation, 7 — shallow waters, 8 — waters, 9 — deforestation, 10 — open ground, construction), *c* — scheme of stows locations with breakdown by categories, *d* — map of landscape complexes) [1].

a *b*

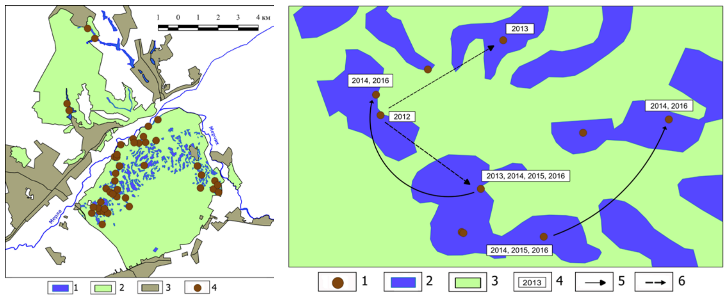
Fig. 4.81. An example of deforestation of the Bile Lake area of Rivne Natural Sanctuary (*a* — 2007, *b* — 2011).

Obtained results can be applied in practice for the development of ecological networks, the main purpose of which is to ensure the preservation of biological and landscape diversity, background monitoring of environment, stabilization of ecological balance, increase landscape productivity, improve the environment and ensure the ecological safety of the territories of the natural sanctuary fund [2].

Zoogeographical Mapping of European Beaver Habitats

In many countries worldwide, the researchers focus their attention on beavers in the context of the climate change, degradation of transformed aquatic ecosystems, and reduction of biodiversity. The beavers and reservoirs created by them increase the number of birds, amphibians, fish, and ensures preservation and cleaning of fresh waters, and contributes to raising the ground waters levels. The species able actively modify the natural systems are called ecosystem engineers. Modern technologies enable us to look at the beaver activity from the outer space, assess the degree of their impact and forecast changes. Let's consider this matter on the example of the Slobozhanskyi National Natural Park [3].

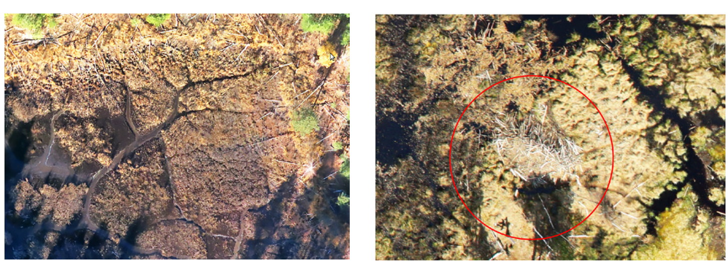
Field censuring data are collected to form the database of family sites, along with updating of the vector layer of spatial location of beaver structures and their use *(Fig. 4.82.a)*. For the purpose of land navigation and recording the measurement results, the record keepers use mobile devices and applications (NextGIS mobile, ArcGIS Mobile) with a set of special terrain maps and field diaries. Reflection in the GIS of beaver families breeding data and emergence of new wintering areas provides interesting information on the settlement of animals and successful rate of territory use *(Fig. 4.82.b)*.



a *b*

Fig. 4.82. GIS-project for studying beavers at Slobozhanskyi NPP (*a* — location of wintering areas of European Beaver in 2016; *b* — the dynamics of several settlements of beavers). *a*) 1 — reservoirs; 2 — territory of Slobozhanskyi NPP; 3 settlements; 4 — wintering areas of the European Beaver. *b*) 1 — beaver holes; c) 2-swamps and lakes; 3 — forest; 4 — the year of living beavers in wholes in winter; 5 — the possible way of resettlement in 2014 and 2016; 6 — the possible way of resettlement in 2013

With drying of forest lakes, beavers should also make efforts aimed at the restoration of water regime. They dig canals that are clearly visible during surveying from unmanned aerial vehicles (UAVs) and in high-resolution satellite images *(Fig. 4.83.)*. Intensive digging activity allows retaining rainwater and raising groundwater levels [4].



a *б*

Fig. 4.83. Study of beaver activities using UAVs (*a* — beaver canals; *b* — beaver hole).

Assessment of Protected Areas Vulnerability to Recreational Load

Fig. 4.84. Holiday-makers on Svitiaz Lake

Each ecosystem can recover from the negative impacts. This capacity is called the potential for natural cleaning, or resilience. However, it has also certain limit of resistance to human influence — these are the changes, whereupon the natural conditions may not be recovered. Such changes do not necessarily include direct mechanical perturbation or disturbance with immediate consequences. There is a wide range of indirect human-induced impacts, which reveal over time only. These impacts include a recreational load. The effect of excessive number of holiday-makers on the natural ecosystem can be as significant as the work of an excavator, however we will not see it immediately. Only in the course of time, we may see how many tracks were trampled down by people, how much garbage they left and now many rare species settlements they destroyed.

Excessive recreational activity has a special negative influence on aquatic ecosystems. They are usually seen in water areas that are difficult to trace from the coast. However, such changes may be easily observed using RS, which may be illustrated by the results of Svitiaz Lake satellite imagery decoding.

Svitiaz Lake is the largest and deepest natural lake in Ukraine. Thanks to the unique herbal and animal complexes preserved here, its ecosystem is protected as part of the Shatskyi National Natural Park. The international significance of the Shatskyi NPP is demonstrated by the fact that in 1995, under the Ramsar Convention its area was classified as the territory having the international importance, mainly as an habitat of waterfowls; and in 2002, by the decision of the 17th session of the Bureau of the Coordinating Committee of UNESCO MAB, the park was granted the status of the Shatskyi Biosphere Reserve. In 2012, Zakhidne Polissia international biosphere reserve was established under the UNESCO program, which included biosphere reserves Shatskyi (Ukraine), Zakhidne Polissia (Poland) and Prybuzke Polissia (Belarus).

Due to the advantageous geographical location and rich natural and resource potential, the lake has high capacities for the development of tourism and recreation.

Svitiaz Lake is an endorheic reservoir, which ecosystem was relatively unchanged for a long time, thanks to the preservation of surrounding natural landscapes and traditional management techniques at the water intake facility. The major asset of the lake is its transparent water of very high quality, which is maintained by abundant aquatic plants — macrophytes [5]. They collect, process, accumulate and store both nutrients and pollutants that enter the lake from the water intake facility, blocking its further way into the ecosystem over the supply chains. This results in the low growth of microscopic algae and animals, and high water transparency.

However, recently, due to its attractiveness for tourists, the lake suffers from the recreational load *(Fig. 4.84.)*, which leads to a decrease in the resilience of the lake's ecosystem. It has been found out, that people entering the water and swimming, intensively trample down the aquatic plants in shallow waters [6]. The direct mechanical effects caused by holiday-makers, leads to degradation (thinning out) or destruction of groups of aquatic plants, primarily in shallow waters near the shore *(Fig. 4.85)*. Namely, they act as a natural barrier and filter against sewage waters coming from the dry land, and determine the self-cleaning potential of the lake.

Ecosystem is a complex of living organisms adapted to a common habitat in a certain environment, being the integral part thereof.

Habitat is an area inhabited by a certain specie or a group of species.

The main purpose of the study was to identify and analyze the transformations of these vulnerable shallow settlements of Svitiaz Lake and study the effectiveness of satellite imagery use to assess the impact of holiday-makers on the coastal vegetation of the lake [7] and forecast the consequences thereof.

Analysis of archives of Landsat TM and ETM+ satellite images (July-August) over the 30-year period (1985–2015) and seasonal series of Sentinel-2 satellite imagery over 2016–2017, provided possibility to assess the impact of recreation on the coastal shallow water settlements near the Svitiaz Lake. It has been determined that the increase in the number of holidaymakers led to the degradation and destruction of thickets of aquatic plants in shallow waters. The greatest transformations occured in the shallow waters in the midst of the summer season, however, the structure of shallow water restored during the next autumn and spring. Natural cleaning mechanisms of the lake still cope with the existing load. However, predictive estimates based on the results of RS-data analysis have also suggested that, if the number of holidaymakers continues to grow, the area of the destroyed macrophyte thickets will increase by more than 50%, and the ecosystem of the reservoir may lose its resilience *(Fig. 4.85)*.

Macrophytes are large aquatic plants (algae and higher aquatic plants) visible to the unaided eye. Macrophytes are producers of organic matter, habitats and spawning grounds for many species of aquatic animals.

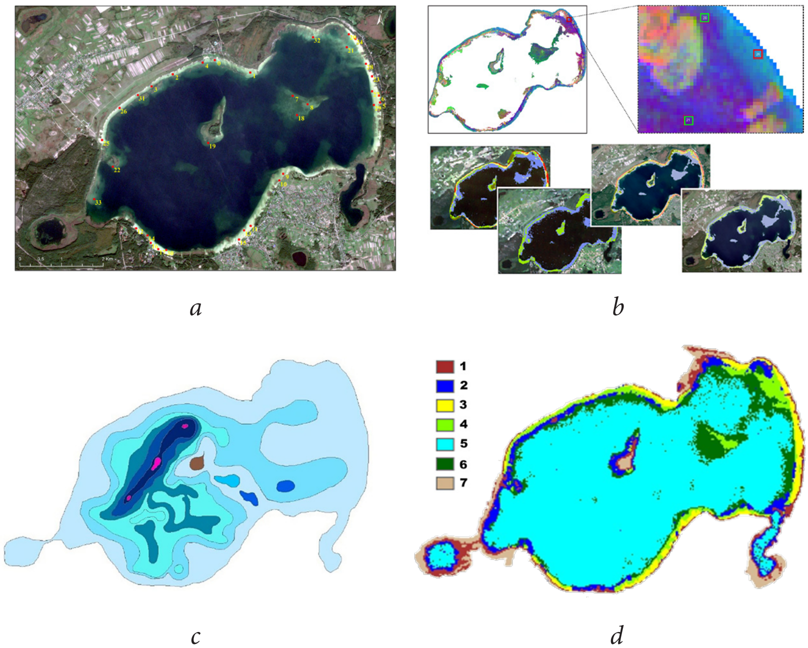


Fig. 4.85. Estimation of the degradation of the shallow settlements of the Svitiaz Lake due to the recreational load using satellite imagery (*a* — satellite image depicting the templates of macrophyte groups, *b* — seasonal changes of vegetation index taken into account for clarification of classification; *c* — map of lake bed; *d* — map of the types of habitats obtained as a result of the classification of Landsat satellite images) (legend: 1 — wetlands, 2 — bulrush, 3 — degraded shallow waters, 4 — undisturbed shallow waters, 5 — lake stretch, 6 pondweed groups, 7 — shrubbery bogs).

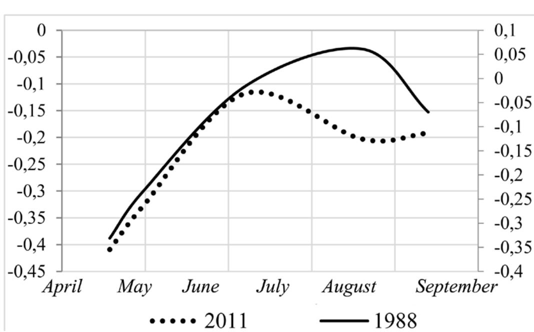


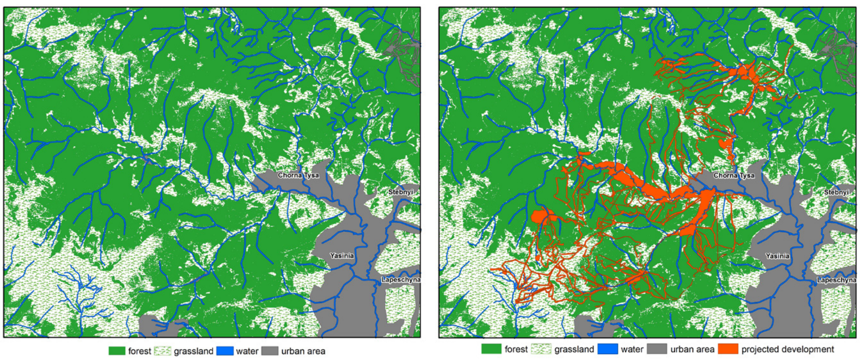
Fig. 4.86. Seasonal vegetation index progress in the shallow water plants trampled down by holidaymakers

Estimation of Ecosystem Services of Forestlands

According to the Convention on Biological Diversity, **the ecosystem** is a dynamic set of groups of plants, animals and microorganisms, as well as non-living environment thereof, interacting as a single functional entity [8]. Thus, ecosystems are multifunctional systems that may provide a number of direct and indirect services to the mankind. Ecosystem services act as direct and indirect contribution of ecosystems in the well-being of humanity. The concept of ecosystem services has evolved in the early 2000s, thanks to the Millennium Ecosystem Assessment international program, which has published a number of reports on the assessment of the effects of changes in ecosystems and natural resources on life and health, and the welfare of current and future generations [9].

In early 2017, the local authorities of Tiachivskyi and Rakhivskyi Districts organized public hearings and presented a plan for the construction of a ski resort on the territory of the village councils of Yasynia, Chorna Tysa and Lopukhovo. According to the proposed plan, it was scheduled to build 60 hotels, 120 restaurants, 33 ski lifts and 230 km of ski slopes, as well as a number of shopping malls, medical and fitness centers, banks, multistory parking lots and even a takeoff runway [10]. Ecosystem services concept application may be exemplified by the analysis and comparison of different scenarios of territorial organization. Thus, on the example of Svydovetsski resort construction project, a group of ecologists analyzed two scenarios of the territorial organization: the first scenario was the provision of ecosystem services by the forest ecosystems in the current situation; the second scenario was the provision of ecosystem services in the territory following deforestation for the ski resort construction. Thus, they gain an opportunity to consider which ecosystem services and in what degree will reduce upon the loss of forestlands in the planned construction sites [11].

Figure 4.87a presents a map of the land cover of the studied area, wherein the boundaries of the forestlands are marked in green. These boundaries were determined based on the forest maps of forestry enterprises and supplemented based upon Sentinel-2a satellite images as of July 2017. According to the map design of the resort construction project, the boundaries of the planned resort infrastructure were also digitized and superimposed with the land cover map of the studied area *(Fig. 4.87b)*. As a result, it was determined that 830 hectares of forest will need to be clear-cut for the construction of tourist facilities [10].



a *b*

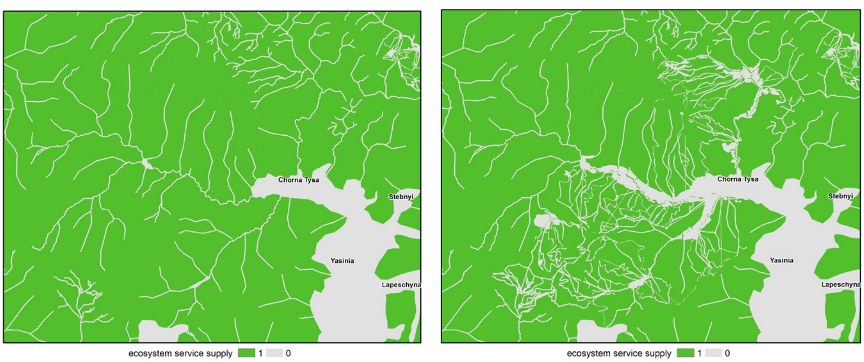
Fig. 4.87. Land use maps:
a) current situation (scenario 1); *b*) deforestation due to the planned construction (scenario 2) [11].

In order to determine the list of important ecosystem services of forest ecosystems in the region, at first the risks from the loss of forest areas have been analyzed. These risks for the mountainous region include, in particular [11]:

- increased risk of natural hazards, in particular floods and snow slides;
- disturbance of water supply due to the impairment of water-retaining function of forests, and substantial increase in water intake for the needs of hotels and tourist complexes;
- local influence on microclimate, change of temperature regime;
- loss of additional income by the local population from picking of berries and mushrooms.

Based upon the identified risks of forest cover loss, experts made a clear list of basic ecosystem services provided by forest ecosystems in this region, namely: additional income from mushrooms and berries picking and cattle grazing, water supply, climate regulation and mitigation of natural disasters.

For the mapping the ecosystem service related to the generation of additional profit from berries and mushrooms picking, and cattle grazing on mountain meadows, the map of the land cover of the current situation (scenario 1) and map of the planned construction (scenario 2) have been re-classified, in such a way that forestlands and mountain meadows were assigned value 1 (i. e. the ecosystem service was provided within this territory), and all other classes of terrestrial cover were assigned value 0, i. e. the service was not provided. In this way, two maps have been created for the additional income generation service according to scenarios 1 and 2 *(Fig. 4.88)* [11].

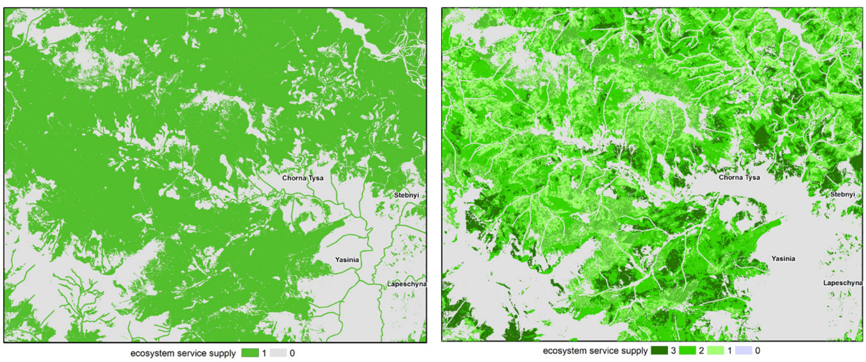


a *b*

Fig. 4.88. Providing services for the generation of additional profits — harvesting berries, mushrooms, cattle grazing: *a*) current situation (scenario 1); *b*) deforestation due to the planned construction (scenario 2) [11].

Similarly, maps for water supply services provision were created because only the forestlands support the water-retention function, the class of forestlands and the class of water bodies were assigned a value of 1, and all other classes of ground cover were assigned a value of 0 *(Fig. 4.89a)*.

To assess the climate regulation, we have taken into account the fact, that trees with higher biomass and larger crowns will be more important for climate regulation, CO_2 accumulation and cooling. As a result, based on Sentinel-2a satellite image, taken in the summer of 2017, the NDVI vegetation index has been calculated, which represented the biomass and the intensity of photosynthesis in plant groups. Thus, forestlands with a high NDVI were assigned a value of 3, reflecting the level of maintenance of climate management services, forestlands with mid NDVI — a value of 2, and forestlands with low NDVI — a value of 1 *(Fig. 4.89b)* [11].

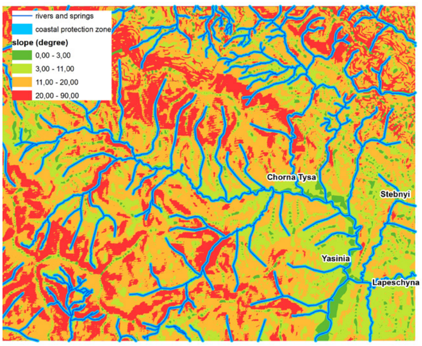


a *b*

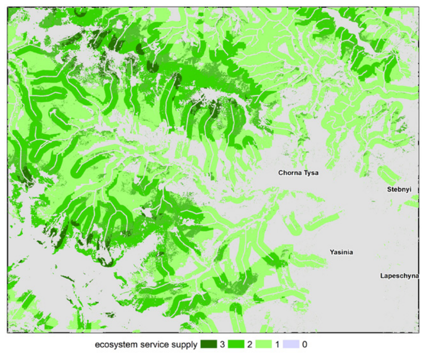
Fig. 4.89 Provision of regulatory services (scenario 1):
a) water supply: *b*) climate regulation

In order to assess the service related to the mitigation of the effects of natural disasters, such as floods and snow slides common for mountain regions such as the studied area, the experts considered the fact that forestlands at an altitude above 1000 m above sea level are the most important for disaster management, as well as forests on the slopes and within the water protection areas. Thus, for the given analysis, a digital model of studied area relief has been first created based on the horizontals of 1:50 000 topographic maps, as well as map of steep slopes. On the basis of the steep slopes map, water protection zones have been identified — from 50m to 100m from the river border *(Fig 4.90a)*.

Accordingly, forests located within the water protection zone and at an altitude above 1000 m have been assigned a value of 3, representing the highest level of natural disasters mitigation service; forests located at an altitude above 1000 m or within the water protection zone were assigned a value of 2, and all other forestlands — a value of 1. All other classes of land cover have been assigned a value of 0 *(Fig. 4.90b)* [11].



a



b

Fig. 4.90 Provision of natural disasters (floods, snow slides) mitigating service: *a*) a map of slopes angles and water protection areas; *b*) a map of natural disasters management service provision (scenario 1).

At the last stage, the experts compiled a comprehensive integrated map of ecosystem services by overlapping all the maps representing the provision of various ecosystem services. Such a map took into account the location of land cover classes and biophysical status thereof, in particular, relief and biomass. This allowed identifying the natural locations within the studied area, providing the largest number of ecosystem services of the highest quality, which are important for the region *(Fig. 4.91a)*. On the map, these areas were marked with shades of blue and dark blue. When the scheme of ski resort development was superimposed on this map, it was found out that more than 50% of the planned deforestation area intended for construction site represents essential forestlands in terms of ecosystem services support. Such areas are marked in black on Fig. 4.91b [11].

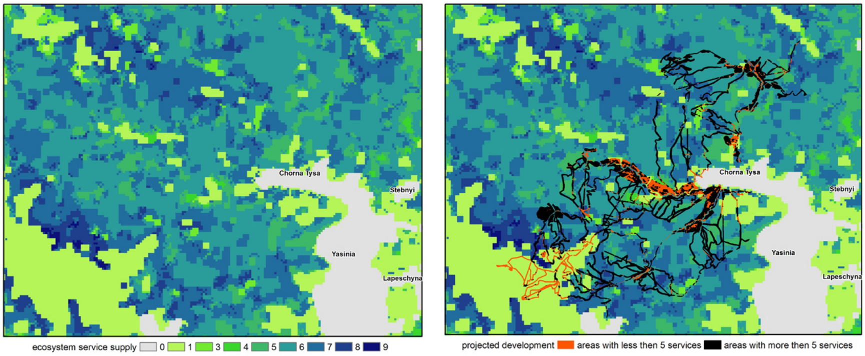


Fig. 4.91. Identification of especially valuable areas requiring protection: *a*) current situation; *b*) location of planned deforestation areas requiring protection.

Thus, the application of an integrated methodology for the assessment of ecosystem services based on the biophysical mapping method allows analyzing and comparing different scenarios of territorial development, as well as more effectively assessing the environmental impact (EIA) of various infrastructure projects.

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4.2.4. Monitoring of Emergency Situations and Environmental Assessment

Iceland is an island country that formed as a result of volcanic eruptions. Iceland has hundreds of volcanoes with about 30 active volcanic systems. Iceland's flag is a red cross inserted into a white cross on a deep blue background. It represents melted volcanic lava covered by glaciers and surrounded by the ocean. There is a constant threat of natural disasters

in Iceland: eruptions of volcanoes, hurricanes, glaciations, earthquakes. However, this fact does not stop hundreds of thousands of tourists that visit Iceland every year, and 300,000 Icelanders that live there permanently. If a natural disaster can not be prevented, it is possible to adapt to its consequences and minimize its effects with effective emergency monitoring system. The United Nations General Assembly initiated the celebration of the International Day for Disaster Reduction every 13 October to promote a global culture of risk-awareness and disaster reduction.

Effective monitoring system should include forecasting, timely identification, and control of progression and assessment of consequences of emergencies. Remote sensing data represent one of the fastest way of retrieval of information on the state of the territory prior to and following the emergency situation in order to ensure preparedness and effective planning of actions aimed at the recovery of the territory [1]. Remote sensing data may be useful at each stage of the monitoring process, namely for:

- Identification and monitoring of **natural disasters' development**, in particular the calamities affecting large territories, such as tropical cyclones, tsunami, volcanoes, droughts, etc.
- Monitoring of the **spread of pollution resulting from accidents** or man-made disasters, e. g., tracking the movement of smoke clouds from fire at oil station.
- Emergencies mapping and **impact assessment**, e. g., evaluation of forest area (in hectares) destroyed by fire.
- **Updating of cartographic data on the area** affected by emergency.
- Analysis of **digital relief model** created based on the data delivered by ASTERGDEM, SRTM or LIDAR satellites, in particular for 3D-modelling of potentially hazardous objects or distribution of sewage waters and pollutants in rivers or forecasting of floods.
- Use of data on the condition of natural objects as a component for **forecasting models** and spread of emergencies.
- Creation of **risk maps** and schematic layouts for the planning of disaster relief and site remediation operations.

- Identification of **local emergencies**, such as floods, fires, mud flows, landslides, sites of land subsidence, erosion and local accidents.
- Identification of signs of **imminent natural disasters**, monitoring of weather conditions, such as ice situation, or signs of volcanic craters deformation preceding eruption.

Despite wide possibilities, RS data have many inherent limitations associated with the fact that often data with sufficient spatial resolution have unsatisfactory imaging frequency or vice versa.

Detection of Active Fires

Identification of fires using RS data is based on the search for **thermal anomalies** in satellite imagery. The algorithm applied for the selection of "hot pixels" takes into account the values of the bands in the visible, near, mid, and thermal infrared ranges and detects places that significantly differ from the surroundings. This allows to register not only open fires with visible flame *(Fig 4.92),* but also, for example surface or subsurface forest fires with litter or peat on fire [2,3].

Fig. 4.92. Large fire on Borneo Island registered by MISR/Terra on 14 October 2015 [4]

It is obvious that efficient fire monitoring requires the use of imagery made **with high frequency (high temporal resolution)**, at least daily. These images include data of MODIS sensor, which is a payload of Terra and Aqua satellites, and VIIRS sensor of Suomi-NPP satellite. The images of thermal anomalies according to MODIS data are stored in the form of MOD14/MYD14 products with spatial resolution of 1 km, and VIIRS — with spatial resolution of 375 m. Maryland University jointly with NASA and the Food and Agriculture Organization of the United Nations have developed FIRMS system (the Fire Information for Resource Management System) for the distribution of near real-time global fire data. FIRMS is a website where one can visualize and download data on thermal anomalies in vector format for free (Fig. 4.93) over the last 24, 48 and 78 hours and 7 days [5].

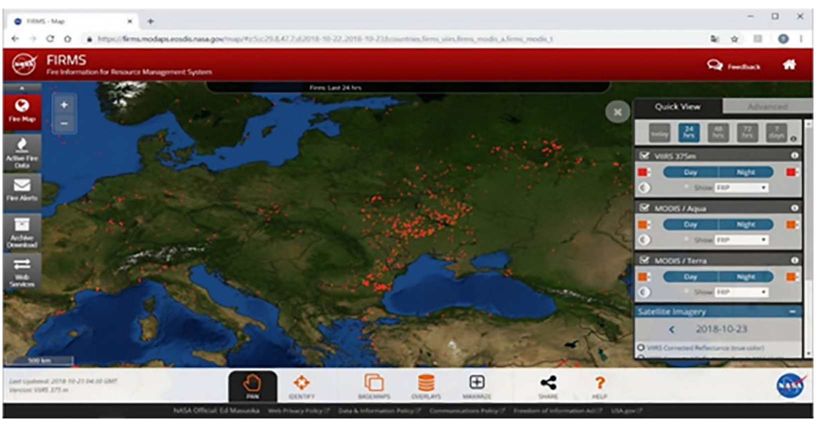


Fig. 4.93. Interface of FIRMS
online system representing thermal anomalies
over the last 24 hours [5]

However, due to the low **spatial resolution** of MODIS and VIIRS imagery, the maps of thermal anomalies generated based on such data may be used only for the preliminary assessment of fire situation, identification of potential hot spots or general assessment of emissions of CO_2 or other combustible substances globally *(Fig. 4.95).*

Small bodies of fire, often hidden by clouds or smoke, may remain unidentified, while some man-made objects may be mistakenly taken for fires. On the other hand, data with high spatial resolution, e. g. acquired by Sentinel-2, have lower imaging frequency, and thus may not be used for the efficient analysis of situation but only for the assessment of fire effects: determination of burned up areas *(more detailed information is provided in Section 4.2.1 Agroforestry).* Fig. 4.93 shows the fire situation in the central part of Ukraine as of 23 October 2018, which looks disastrous when compared to Europe in general. When zoomed-in, it is noticeable that nearly all bodies of fire are located on the fields; that means they are the outcomes of the popular in Ukraine practice of autumn stubble burning. This is proven by Sentinel-2 image of one of such territories; two puffs of smoke are clearly seen on the field near Ivanivka village of Kobeliaky District in Poltava Region *(Fig. 4.94).*

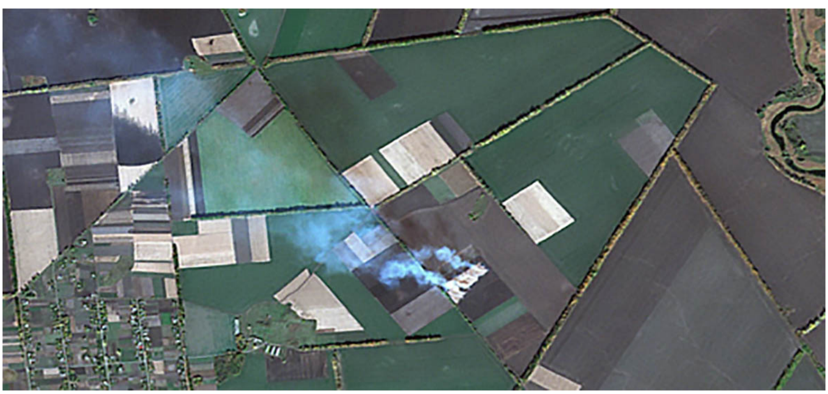


Fig. 4.94. Epicenters of stubble burning on the field, according to Sentinel-2 satellite image of October 19, 2018

The stubble is burned in order to quickly clear the field and supposedly enrich the soil with nutrient trace elements contained in ash. However, this leads to the destruction of useful soil microorganisms, precisely responsible for the absorption of micronutrients by plants, loss of soil moisture and fall of the soil fertility.

In addition, GWIS (Global Wildfire Information System) service of Copernicus programme of the European Space Agency and the European Commission makes it possible to analyze the effect of fires in terms of sulphur dioxide (SO_2), nitrogen oxide (NO), methane and other greenhouse gases emissions *(Fig. 4.95)*. This allows an integrated assessment of the negative impact of this widespread and prohibited practice of burning crop waste on the fields.

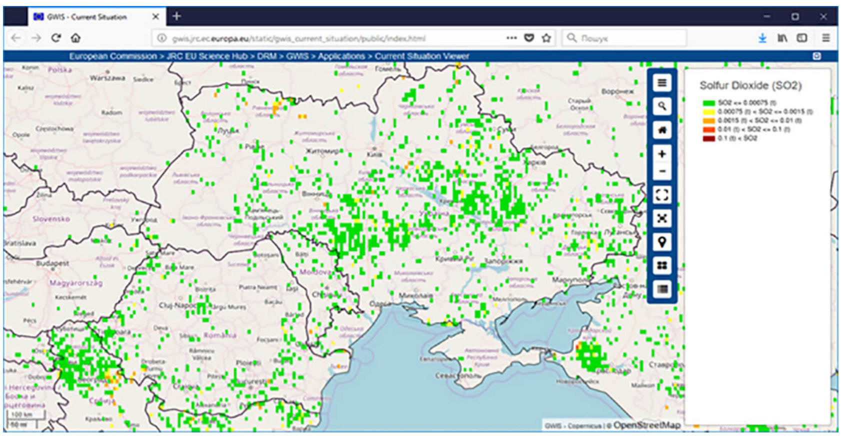


Fig. 4.95. Map of SO_2 emissions caused by fires over the period of 16–23 October 2018; according to GWIS (Global Wildfire Information System) data [6]

Monitoring of Volcanic Eruptions

The powerful eruption of Eyjafjallajökull (Eyjafjöll) volcano occurred in southern Iceland in April 2010. The eruption lasted for one and a half months and released large amounts of ash in the air. This led to the prolonged shut down of airspace over Europe. To respond to such natural disasters as volcanoes, it is extremely important to ensure the continuous monitoring of emergencies' progress on a global scale, which, in fact, may be provided by satellite monitoring.

For the monitoring of **volcanic dust cloud movements**, like in the case of fire smoke (Figures 4.96–97), there may be used data in the visible range, imaging in ultraviolet range provided by OMI, GOME-2A, GOME-2B, OMPS satellites, and in infrared range provided by AIRS, IASI-A, IASI-B, S-NPP/VIIRS and other satellites.

Fig. 4.96. Image of eruption of Eyjafjöll volcano made on 17 April 2010 by Árni Friðriksson [7]

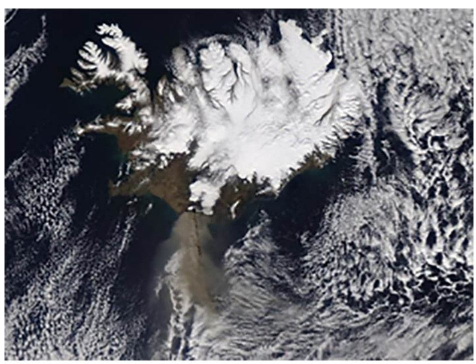


Fig. 4.97. Eruption of Eyjafjöll volcano in MODIS image as of 17 April 2010 [8]

Falconieri et al. (2018), when working over the improvement of volcanic dust movements monitoring system, compared two established algorithms of images classification using as example Eyjafjöll eruption: DDA AIRS — detection of dust according to AIRS sensor data and according to SEVIRI sensor data of Meteosat Second Generation satellite. The study showed that at some stages of eruptive activity those two algorithms give similar results (2010/05/07), while in some cases the results differ significantly because various algorithms detect various specific atmospheric conditions. Thus, it is important to combine different available satellite imaging techniques to obtain more accurate results *(Fig. 4.98)* [9].

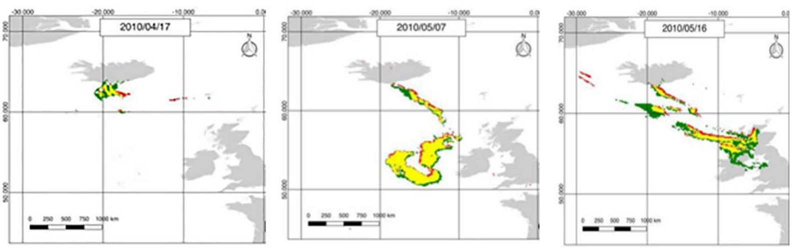


Fig. 4.98. Comparative analysis of various monitoring techniques of volcanic dust distribution as a result of Eyjafjöll eruption: dust cloud detected using two methods (yellow color), data delivered by SEVIRI sensor (red color) and DDA AIRS data (green color) [9]

TROPOMI sensor of Sentinel-5P satellite measures the density of aerosols and sulphur dioxide and also allows to monitor the duration of volcanic eruption and spreading of volcanic cloud *(Fig. 4.99)*.

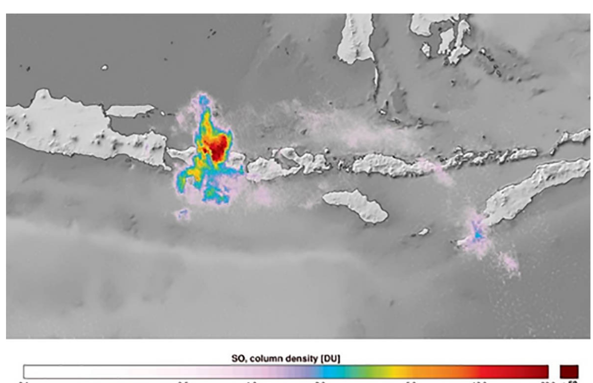


Fig. 4.99. Spreading of volcanic dust as a result of eruption on Bali Island; according to data acquired by Sentinel-5P satellite on 1 December 2017 [10]

The European Support to Aviation Control Service (SACS) uses volcanic alert system that operates in near real-time mode based on RS data *(Fig. 4.100)* [11]. There is also NOAA/NESDIS volcanic alert system developed by NASA/NOAA and International Civil Aviation Organization [12].

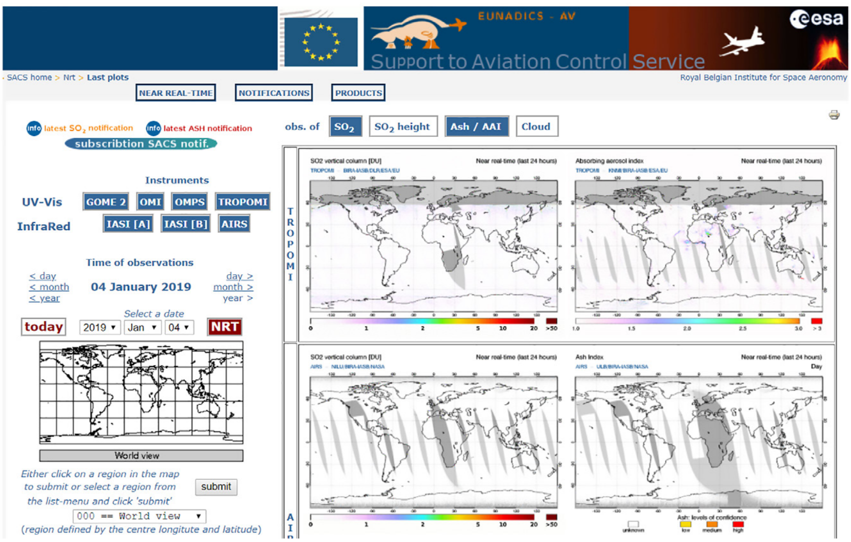


Fig. 4.100. Interface of Volcanic Alert System [11]

The database of Global Volcanism Program provides information on 1434 volcanoes that have erupted during Holocene period (over the past 10,000 years). Generally, there are around 50 eruptions registered annually, therefore, in addition to monitoring of volcanic ejecta spread, it is important to monitor the signs of eruptive activity [13]. These signs may include mild earthquakes or crustal movements caused by the changes in the pressure of magma. Usually such signs may be observed several days or weeks before the eruption. The **crustal deformations** may be detected using **InSAR (Interferometric Synthetic Aperture Radar)** technology. This geodetic method uses two or more synthetic aperture radar images to detect differences in the phase of the waves. The technique can potentially measure millimeter-scale changes in deformation over spans of days to years, depending on the interval between images. It has applications for geophysical monitoring of natural hazards, for example earthquakes, volcanoes and landslides, and in structural engineering, in particular monitoring of subsidence and structural stability.

Using InSAR technology, Sang-Ho Yun et al. (2007) have studied the volcanic deformations 12 days prior to eruption of Sierra Negra volcano in Ecuador in 2005 *(Fig. 4.101)*. There was registered an earthquake three hours before the eruption start, which caused migration of magma. Thus, it is an example of how eruptive activity of volcano can be detected at an early stage; in this case, the first signs of volcanic activity were seen 8 days before the eruption start [14].

Monitoring of Oil Spills at Sea

Oil spills at sea often occur during transportation or oil production. Despite the fact that large amounts of oil release straightway into the sea due to accidents on oil tankers, drilling platforms or underwater pipelines, they account for only 25% of the total marine oil pollution, while remaining 75% fall on the ordinary transportation — unauthorized discharge of ballast water by vessels, oil leaks from engine rooms, etc. [15,16]. When oil enters the sea, it forms slicks of different thickness. In the absence of wind, waves and currents, 1 m^3 of crude oil spreads in 1.5 hours across the water surface to form oil slick with a radius of 50 m [17]. Cleanup and recovery from such an oil spill may take from several months to several years.

When studying environmental parameters, the services monitoring coastal zones and water reservoirs generally use marine or aircraft surveillance, which are not always able to cover the whole territory, even within the territorial waters, and can operate only during daylight hours and under appropriate weather conditions. Radar sensing is an effective tool for the monitoring of sea-based oil pollution. It registers variations

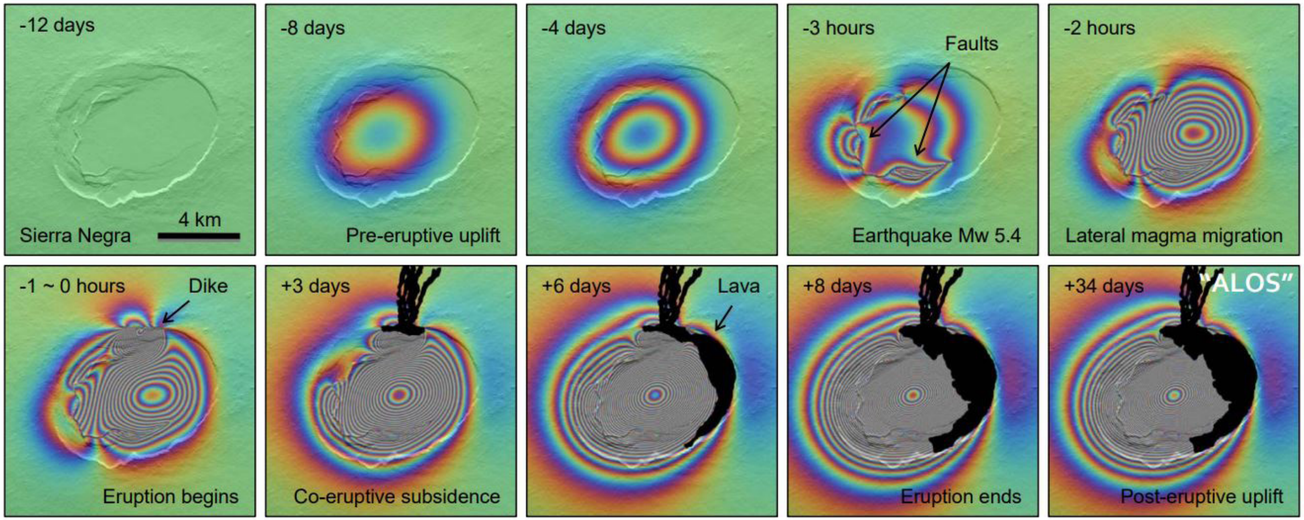
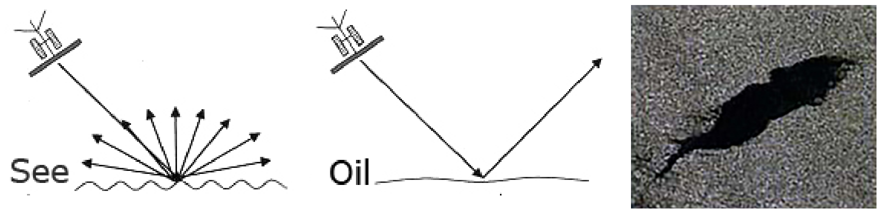


Fig. 4.101. Interferograms of volcanic deformations over 46 days of Sierra Negra volcano activity in Ecuador in 2005 [14]

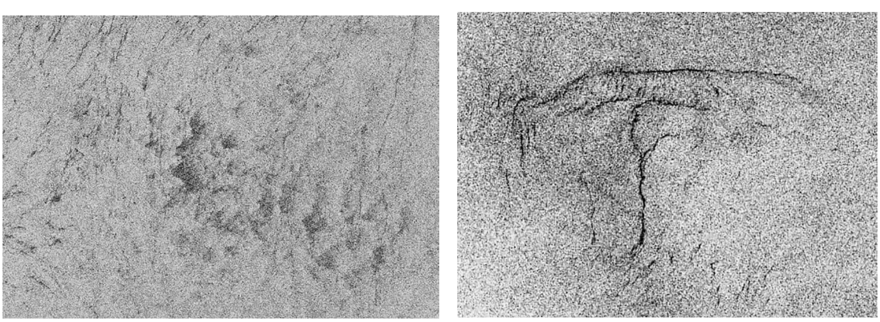
of surface waves at the sea *(Fig. 4.102)*. An oil slick decreases the backscattering of the sea surface and results in a dark formation that contrasts with the brightness of the surrounding spill-free sea [16].



a *b*

Fig. 4.102. Identification of oil slicks by radar satellites

However, the same "dark-zones" may be caused on radar imagery by a number of ocean and sea phenomena: atmospheric front, wind shadow, current, rain, underwater topography, sewage runoff, ice, internal waves, etc. *(Fig. 4.103)*.



a *b*

Fig. 4.103. Examples of spots of natural origin on ERS-2 imagery: structures resulting from heterogeneous windfields, currents and temperature of sea surface [16]

Therefore, the following information should be considered when analyzing dark zones on the image [16]:

- season (probability of ice formation);
- wind speed (at wind speed below 2–3 m/s there is no sea disturbance, while at wind speed exceeding 10–15 m/s the oil slick is washed off the sea surface);
- shape of potential oil spill (as a rule, oil spills have sharp edges; Fig. 4.104 a-b)
- size of potential oil spill (large areas represent zones of low-level wind or natural oil);
- geographical location (if there is a coast or ship nearby *(Fig.3c)*, depth and etc.)

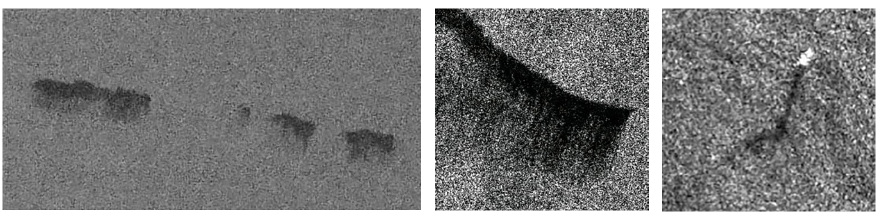


Fig. 4.104. Examples of oil spills represented on radar images acquired by ERS-2 [16].

In the course of joint studies of Black Sea pollution with oil, the Joint Research Center of the European Commission, SSPC "Pryroda" and Odessa National University analyzed ERS-2 and ENVISAT radar satellite images made in 2000–2004 and generated a map of oil spills detected in the Black Sea *(Fig. 4.105)*. Based on this map and using spatial modelling in GIS, a map of oil pollution density in the Black Sea has been created *(Fig. 4.106)*.

The study also showed that the majority of oil spills locate within transport and oil-transport routes. The map of oil spills density illustrates the risk zones of oil pollution in the Black Sea. Such studies may currently use radar data of Sentinel-1 with 10–20 m resolution provided for free by the European Space Agency and commercial data with ≤ 3m resolution, e. g. provided by Radarsat and TerraSAR satellites.

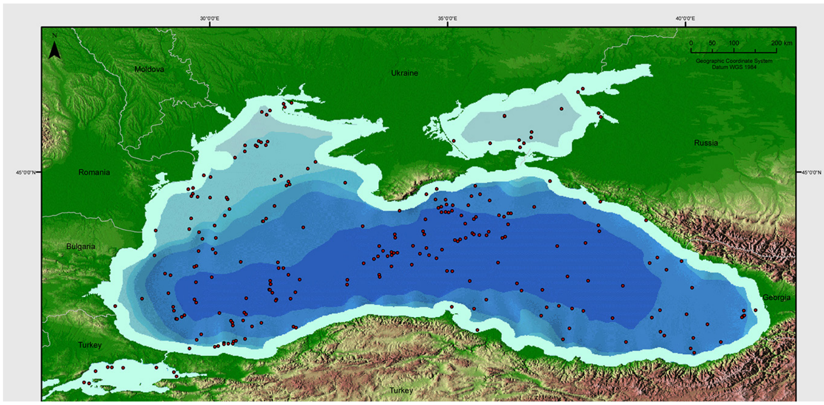


Fig. 4.105. Map of oil spills identified
on radar satellite images acquired by ERS-2 and ENVISAT
during 2000–2004 [18]

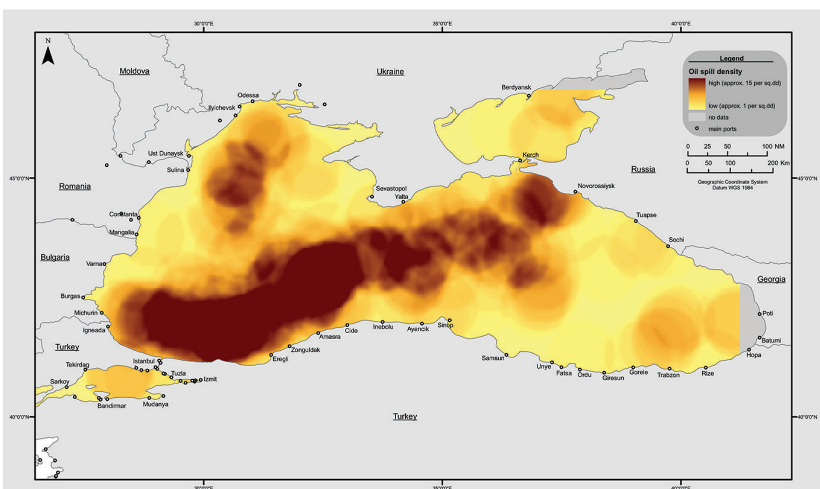


Fig. 4.106. Map of oil spills density generated based
on radar satellite images delivered by ERS-2 and ENVISAT
during 2000–2004 [18]

Monitoring of Freshets

Flood (high water) – a relatively long and significant increase in river water content that raises its level and is accompanied by the flowage and flooding of bottom-lands. Usually, it is a regular process, which occurs every year in the same season (from March to June).

Low water is referred to the lowest level of river over a certain period (summer or winter time), when the river is fed mostly by groundwater.

Freshet is overflowing of a river caused by heavy rain or melting snow. As contrasted with floods, the freshets occur irregularly and are characterized by vigorous short-time increases in the water levels.

In Ukraine, these processes are most commonly observed on the rivers in Polissia area and on Dnipro River. The peak period for high water in Ukraine: from March through beginning of April.

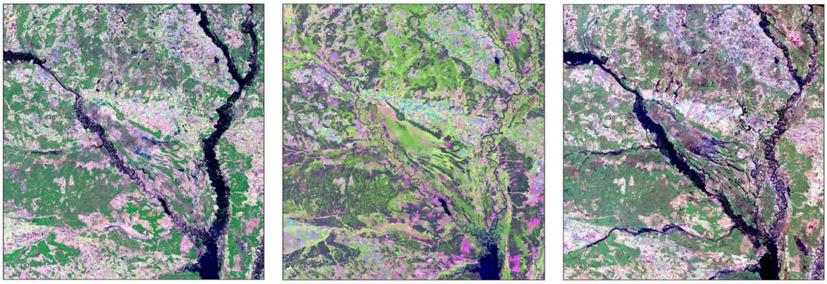
When monitoring freshets, it is important to follow the process of their evolution in order to effectively assess the threat and determine the required number of evacuation or countermeasures equipment (for example, how many buses are needed to evacuate people from a part of the city at risk). Therefore, it is important to use all available high- or medium-resolution imagery, both radar and optical, such as Sentinel-1 (radar) and Sentinel-2 (optical, multispectral). However, freshets are often accompanied by prolonged rains, so it is nearly impossible to obtain optical images during the freshet; in this case, radar data may be effective, which allow to "see" through the clouds. When radar and optical imagery was taken on the same day, it is recommended to **fuse the images** prior to decoding start. Since radar imagery reflects the variations in surface structure, such combination of data gives more clear picture of the boundaries between water and ground surface, and allows to identify flooded areas, not entirely covered by water, which is rather difficult to detect only by optical images.

The example of RapidEye satellite imagery use for the monitoring of freshet on Prut River near Chernivtsi city in July 2008 is given on Fig. 4.107.

Fig. 4.107. RapidEye image as of July 27, 2008 — end-stage freshet on Prut River (blue contour — maximum overflow of the river; white contour — river bed prior to freshet start, at the beginning of July). Source: archival data of "GIS Analyst Center", LLC

The following measures must be taken as part of freshet monitoring:

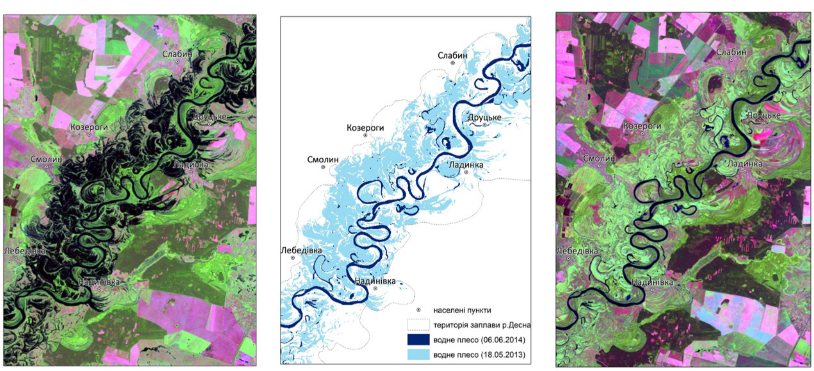
- preparing a digital map or geotagged mosaic of satellite images for the region affected by flood in order to provide prompt referencing of new images, and interpretation and identification of objects captured on them;
- preparing a vector map of the river bed state in the low-water period, updated according to the actual satellite imagery; river bed map is required for prompt assessment of territories and areas affected by flood.



a *b* *c*

Fig.4.108. Monitoring of floods on Prypiat River (on the left) and Dnipro River (on the right): *a*) image as of 14.04.2005; *b*) image as of low-water period; *c*) image as of 23.04.2013

The satellite images given in Fig. 4.108 illustrate water afflux in Dnipro and Prypiat rivers during spring freshets (the water is identified by intense blue color). To represent the consequences of the flood and quickly assess the flooded areas on the satellite imagery, a normalized water index (NWI) should be calculated. Below is given the example of such calculation for Desna River *(Fig. 4.109).*



a *b* *c*

Fig.4.109. Area of Desna River floodplain covered with water during flood (*a* — fragment of Landsat satellite image as of 18.05.2013; *b* — schematic map of flood distribution generated on the basis of satellite imagery; *c* — fragment of Landsat satellite image as of 06.06.2014)

Identification and Monitoring of Landfills

According to the Ministry of Ecology and Natural Resources of Ukraine, the amount of residential waste increases by 50 million cub. m or 14 million tons annually (300–400 kg/year per 1 person), and industrial waste — by 175 million cub. m annually, of which only some 2–3% undergo recycling or proper disposal. The greater part of such wastes is transported to local dumping grounds and landfills of industrial solid wastes (ISW). Currently, there are about 4,500 ISW landfills in Ukraine, most of which are unauthorized [19].

"Interactive Map of Landfills" Project

Today, the problem of illegal dumping monitoring and handling takes on particular importance in Ukraine. None of responsible authorities however has performed systematic search of unauthorized landfill sites and study of wastes' state and composition until the launch of "Interactive map of landfills" web resource in by the Ministry of Ecology and Natural Resources of Ukraine September 2016 [20]. The citizens may appeal there on the identified unauthorized landfill sites, providing geotagging and photographic evidences. These appeals are subject to prompt submittal by Ukraine's Ministry of Ecology and Natural Resources to local authorities, responsible for the timely removal of identified illegal dumping sites [20]. Information on the status of appeal processing and relevant activities by local authorities is displayed in the user's personal cabinet. The map comprises several layers, representing the data from the register of waste disposal sites and spontaneous landfills, points of recyclate collection, etc. *(Fig. 4.110).*

RS data may be effectively used for the monitoring of landfills. These data are characterized by operational efficiency, regularity, accuracy, eligibility for retrospective analysis. Application of RS with the use of geographic information system tools will allow not only the monitoring landfill sites, but also the rates of domestic waste accumulation and establish respective database *(Fig.4.111).*

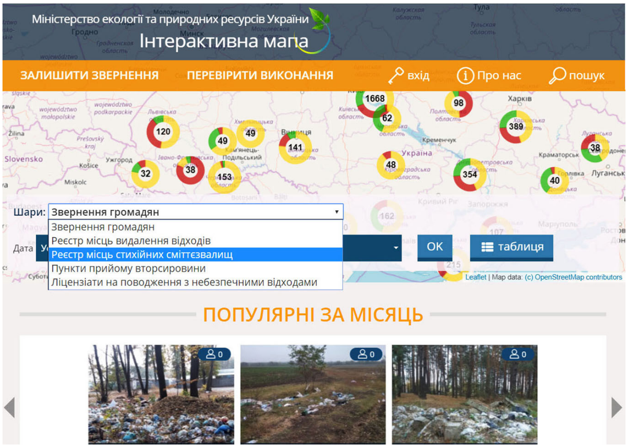


Fig. 4.110. "Interactive map" web resource of the Ministry of Ecology and Natural Resources [20]

The establishment and provisioning of unauthorized landfills database have been effected using three main sources of information: processing of mass media data on illegal landfills and their removal, appeals represented on the map of Ukraine's Ministry of Ecology and Natural Resources and analysis of Google Earth images.

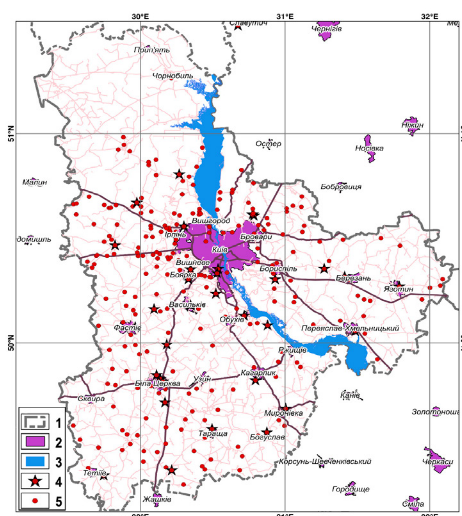


Fig.4.111. Map of landfills in Kyiv Region, identified according to RS data.
(1 —administrative boundaries,
2 — cities,
3 — water objects,
4 — official landfills (33 objects),
5 — unofficial dumps (231 objects))

The database of unauthorized landfills has following sections: source of information on the landfill, dominating wastes' type, status (removed or active), image and comment on the specific features of the landfill, e. g. presence of hazardous wastes, etc. With generated maps, every citizen of Kyiv as well as respective authorities may identify the locations of spontaneous and formal landfills within Kyiv city and monitor them in the future [21].

RS and GIS make it possible to conduct more specific and detailed studies, in particular:

- study the state of certain landfill sections (series), map such landfills and adjoining territories. Satellite images represent quite clearly the internal "structure" of landfills: exhausted sites covered with a layer of soil; current sites of waste discharge; product water storage reservoirs or isolated areas for precipitation of contaminated water; access roads, ditches, etc. [22];
- identification of smoke and spontaneous combustion of wastes;
- study of landfill territory dynamic pattern *(Fig. 4.112).*

a *b*

Fig.4.112. Examples of expansion of spontaneous landfill identified according to satellite imagery near Gorenka village in Kyiv-Sviatoshynskyi District (*a*- landfill boundaries as of 2007; *b* — as of 2011)

Dumping grounds and landfill sites are environmental facilities used for the disposal and biodegradation of solid household wastes (SHW). At the same time, they are the sources of negative environmental impact. The negative effects include withdrawal of significant land areas from economic use for the long term, contamination of soil and disturbance of its structure, pollution of atmosphere, underground and surface waters, fire hazard, etc. The most serious problem is the pollution of ground waters. Seeping through the layers of landfilled waste, rain water "enriches" with various chemicals that are formed during the decomposition of garbage, and transforms into dangerous filtrate water *(Fig.4.113).*

a *b* *c*

Fig.4.113. TPV No.5 dumping ground ("Kyivspetstrans" OJSC), according to Quick Bird satellite image (general appearance and dynamics of product water reservoir filling) (*a* — as of 2007; *b* — as of 2011; *c* — as of 2018)

Analysis of satellite images from Google Earth resource showed that unauthorized landfills in Kiev Region are mainly located on agricultural lands and outskirts of the settlements. It is safe to suggest the presence of unauthorized landfill nearby every second settlement. In addition, based on the specifics of the region's relief, landfills are most often located on the slopes of ravines [23].

Emergency Mitigation — Hot OSM Volunteer Project

Currently, everyone can contribute to reducing the negative effects of natural disasters via Hot OSM humanitarian project. It is important to have detailed mapping information about the affected area in order for humanitarian missions and emergency services to quickly and effectively plan rescue operations. The most important here is information on how many houses, and, accordingly, people, can be in the area affected by natural disaster and may need help, and also, what are the potential intact access routes to settlements. In many countries worldwide, especially in remote places, in mountains with common earthquakes, or on small islands where typhoons can occur, there are still many white spots on maps. Hundreds of people around the world (with and without mapping experience) help to fill such white spots by digitizing houses and roads according to satellite images in the OSM project [24].

OSM project (https://www.openstreetmap.org), which means “open street map”, is an online map, which data can be easily downloaded by anyone in the form of digital layers and edited or supplemented. Created by Steve Coast in 2004, it was inspired by the success of Wikipedia. Since then, it has grown to over 2 million registered users, who can generate cartographic data. The most active members of the OSM community, which know the territory well and are in charge of it, verify all changes; so any improper changes are immediately deleted from the maps.

To respond quickly to natural disasters, the humanitarian team of OSM has created a web page, https://tasks.hotosm.org, which illustrates open tasks for joining at the Start Mapping tab *(Fig. 4.114)*.

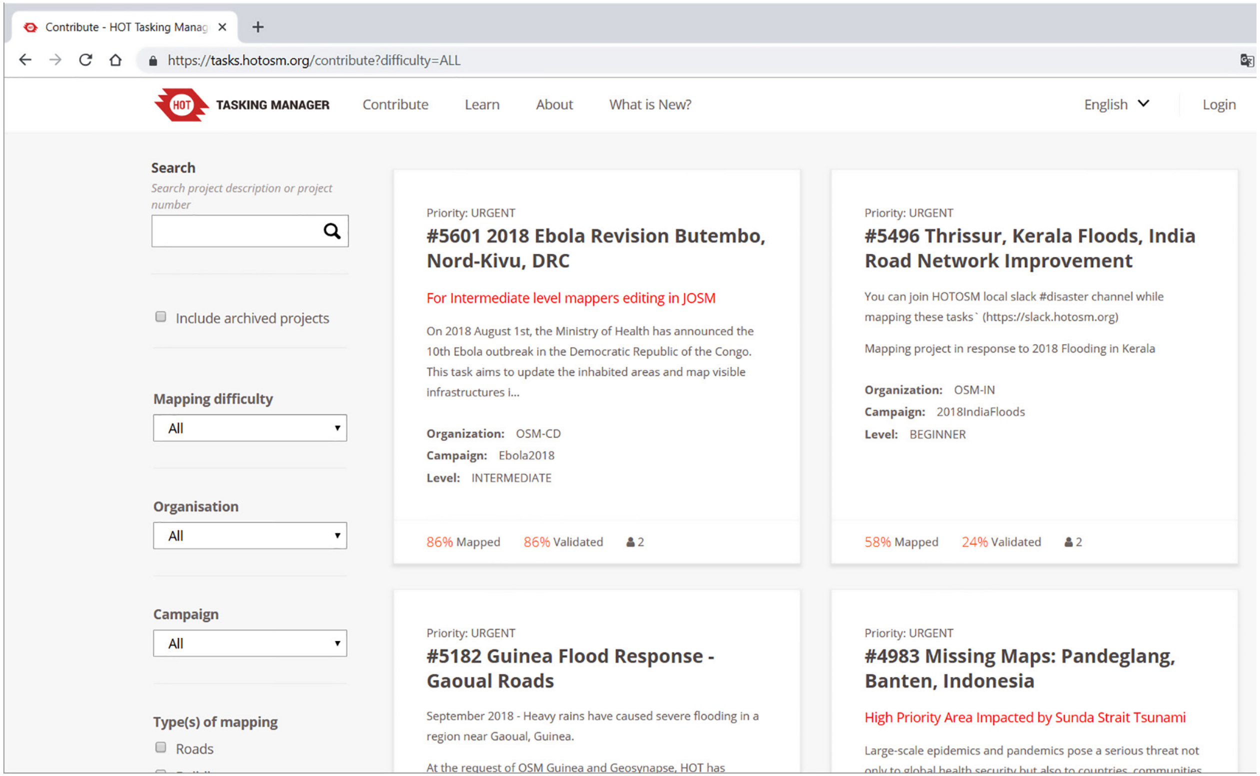


Fig. 4.114. Interface for selection
of tasks for mapping of the zone affected by emergency

The tasking manager page displays open tasks for block editing, with specified priority (how urgent the task is), title, short description and region, and the level of experience required for mapping (beginner or experienced user). For convenience, the whole area is divided into small blocks, usually of the size suitable for vectoring in 10 minutes. To participate in the project, one should register with OSM, select the project, find out what object should be digitized (usually — houses or roads), select the block and map required objects. The page https://tasks.hotosm.org/learn provides 2-minute movie tutorials on the mapping of roads and houses and general activities under the project. In order to respond to global emergencies or just effectively spend time together, students and school children organize cartographic marathons to map given territory *(Fig. 4.115).*

Fig. 4.115. University of Zambia students participating in cartographic marathon [25]

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CONCLUSION

Informatization has penetrated into all spheres of modern human life. Information technologies (IT) break new ground for the development of scientific knowledge, providing access to real-time spatial information. Increased amounts of data and information exchange rate give rise to the reinforcement of requirements for the information processing, quality, storage and structuring. There is a certain tendency towards increase in the dependence on the ability to quickly find proper information and represent it in a convenient format.

The system of education, which aims at the training of youth for living in the second half of XXI century, cannot stand apart. Key condition to successful implementation of IT in the education is the training of specialists able not only to be well-versed in the world around us but also receive, analyze and generate new information.

Currently, there is a dramatic increase in the demand for remote sensing specialist on the labor market. Modern working conditions require a young generation to carry out careful and thoughtful resources management, master new tools and methods of spatial information processing and analysis, promptly address management tasks, and evaluate and control various dynamic processes. Rapid improvement of hardware and software tools for remote sensing, hyperspectral photography and etc. necessitates the training of specialists, mastering available technologies and algorithms and able to quickly and qualitatively learn new information.

Schools, colleges and universities in many countries worldwide have remote sensing courses. Considering the growing demand for competitive manpower typical for XXI century economy, the number of RS specialists constantly increases on the global labor market. In addition, RS allows the continuous monitoring of the current state of the ground surface using both manned and unmanned aerial vehicles. High-resolution images allow for quick and effective decision-making in various areas of life, including climatology, hydrology, geology, agroforestry, agronomy, urban planning, etc.

Thus, RS use in the educational sector strengthens the activity-related approach to learning. Students acquire new knowledge, get basic training and gain practical experience using modern IT — RS, without assistance.

ANNEXES

Annex 1

Stages of Remote Sensing Formation (from Campbell 1996, as supplemented by the Scientific Centre for Aerospace Research of the Earth, Institute of Geological Science, National Academy of Sciences of Ukraine) [1-3].

1800	Discovery of infrared radiation by W. Herschell.
1839	Beginning of photography practice.
1847	Infrared spectrum illustrated by Armand Hippolyte Louis Fizeau and Jean Bernard Léon Foucault for the separation of the properties of visible light.
1850–1860	Photography from air-balloons.
1873	Formulation of the theory of electromagnetic radiation by James Clerk Maxwell.
1909	Photography from airplanes.
1910–1920	First World War: air intelligence.
1920–1930	Development of aerial photography and photogrammetry and start of their use.
1930–1940	Development of radars in Germany, USA and UK.
1940–1950	World War II: use of invisible portions of electromagnetic spectrum; education during receipt and interpretation of aerial photos.
1950–1960	Military research and development.
1956	Disease diagnosis by infrared imaging: study by Colwell.
1960–1970	First ever use of the term “remote sensing”.
1965	Almaz-1B (Russia) — a series of orbital stations developed to fulfill the tasks of the Soviet Ministry of Defence. The development of stations started in the mid-1960s — the time of hard confrontation between the URRS and USA.
1970–2000	FSW satellites (China).
1972	Launch of Landsat-1 satellite (USA).
1970–1980	Rapid progress of digital images processing.

1979–1993	Resurs- F1 satellites (Russia), also known as Kosmos-1127.
1982–1993	Resurs-O1 satellites (Russia) have been developed on the basis of upgraded SP-P space platform (Resurs-UKP). SP-II platform has been developed and commissioned as part of Meteor-3 meteorological system.
1980-тi	Development of hyperspectral sensors.
1984	Landsat-5 satellite (USA).
1987	Almaz-T (Russia), also known as Kosmos-1870.
1988	IRS-1D satellite (India).
1991	Launch into orbit of upgraded automated variant with significantly improved on-board equipment — Almaz-1A.
1993	Landsat-6 satellite (USA).
1995	Radarsat-2 satellite (Canada).
1995	ERS-2 satellite (ESA).
1998	SPOT-4 satellite (France).
1999	Landsat-7 satellite (USA).
1999	Ikonos-2 satellite (USA).
1999	CBERS-1 satellite (China, Brazil).
1999	InSat-2E satellite (India).
1999	Okean-O satellite (Russia, Ukraine).
2000	NOAA-16 satellite (USA).
2000	EO-1 satellite (USA).
2000	Eros-A satellite (Israel).
2001	QuickBird-2 satellite (USA).
2001	Meteor-3 M satellite (Russia, Ukraine).
2002	SPOT-5 satellite (France).
2002	MeteoSat-8 satellite (ESA).
2003	IceSat satellite (USA).
2003	UK-DMC satellite (UK).
2004	RocSat-2 satellite (Taiwan).
2004	Sich-1 M satellite (Ukraine).
2005	TopSat satellite (UK).
2005	Monitor-E satellite (Russia).

2006	Radarsat-1 satellite (Canada).
2006	Eros-B satellite (Israel).
2006	KompSat-2 satellite (Korea).
2006	MetOp-1 satellite (ESA).
2006	Resurs-DK satellite (Russia).
2007	ALOS satellite (Japan).
2007	EgyptSat-1 satellite (Egypt).
2007	Cosmo-SkyMed satellite (ESA) funded by the Italian Ministry of Research and Ministry of Defence.
2011	Electro-L satellite (Russia).
2011	Sich-2 satellite (Ukraine).
2012	SPOT-6 satellite (France).
2012	RISAT-1 satellite (India).
2013	Landsat-8 satellite (USA).
2013	InSat-3D satellite (India).
2014	SPOT-7 satellite (France) was sold to the Space Agency of Azerbaijan, Azercosmos.
2015	Sentinel- 2A satellite (ESA).
2016	CartoSat-2 satellite (India).
2016	Sentinel-3A satellite (ESA).
2016	Sentinel-1B satellite (ESA).
2016	WorldView-4 satellite (USA).
2016	TanSat satellite (China).
2017	Sentinel-2B satellite (ESA).
2017	Venta-1 satellite (Latvia).
2017	Kanopus-V-IK satellite (Russia).
2017	FORMOSAT-5 satellite (Taiwan).
2017	Sentinel-5p satellite (ESA).
2017	JPSS-1 satellite (USA).
2017	GCOM–C satellite (Shikisai) (Japan).
2017	SLATS satellite (Tsubame) (Japan).
2018	GaoJing-1 03 (SuperView-3) and GaoJing-1 04 (SuperView-4) satellites (China).

2018	Launch of Elon Musk's Tesla Roadster. Currently, it is the first standard roadworthy vehicle sent into space.
2018	PAZ satellite (Spain).
2018	TESS satellite (USA).
2018	Sentinel-3B satellite (ESA).
2018	InSight satellite (USA).
2018	GRACE-FO 1 and GRACE-FO 2 satellites (USA).
2018	ADM-Aeolus satellite (ESA).
2018	MetOp-C satellite (ESA).

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Annex 2

Modern Satellite Systems with Low and Medium Spatial Resolution

No.	Satellite Name	Agency (Institution)	Sensor	Application
1	Aqua	NASA/ JAXA/INPE	AIRS, AMSR-E, AMSU-A, CERES, HiRDLS, HSB, MODIS	Biological and physical processes, surface temperature of land and ocean
2	Aquarius	CONAE/ NASA	Aquarius L-Band Scatterometer, Aquarius L-Band Radiometer	Ocean surface salinity, parameters of environment and atmosphere
3	Aura	NASA/ NSOFMI/ NIVR/ UKSA	HiRDLS, MLS (EOS-Aura), OMI, TES	Chemistry and dynamics of Earth's atmosphere from the Earth through the stratosphere
4	Biomass	ESA	P-Band SAR	Forest biomass monitoring
5	CBERS 4	INPE/ CRESDA	DCS, IRS, MUX, PAN (CBERS), WFI-2	Natural resources, monitoring of the environment, ground surface surveillance
6	CryoSat-2	ESA	DORIS-NG, Laser Reflectors (ESA), SIRAL	Ice thickness
7	UK- DMC2	UKSA	SLIM-6	Cartography, monitoring of crops, ecological resources, disaster management

8	Envisat	ESA	AATSR, DORIS-NG, MERIS, MIPAS, MWR, RA-2, SCIAMACHY	Physical oceanography, surface of the earth, snow and ice, atmospheric chemistry, atmospheric dynamics
9	ERS-1	ESA	AMI/SAR/ Wave, AMI/ Scatterometer, ATSR	Natural resources, physical oceanography, geodesy, ground and atmospheric research
10	ERS-2	ESA	AMI/SAR/ Wave, AMI/ Scatterometer, ATSR/M	Natural resources, physical oceanography, geodesy, ground and atmospheric research
11	GEDI (on board ISS)	NASA	LIDAR	Forest cover, carbon cycle
12	GOCE	ESA	EGG, GPS (ESA), Laser Reflectors (ESA), LRR, SSTI	Ocean circulation, geodesy, solid-earth physics
13	GOSAT	JAXA/ MOE/NIES	TANSO-CAI, TANSO-FTS	Observations of greenhouse gases
14	Jason-1	NASA/ CNES	DORIS-NG, JMR, LRA, POSEIDON-2 (SSALT-2), TRSR	Physical oceanography, geodesy, gravity, climate monitoring, marine meteorology
15	Landsat-8	USGS/ NASA	TIRS	Natural resources, surveillance of land coverage, environmental monitoring, agriculture and forestry
16	MetOp-A	EUMET-SAT/ NOAA/ CNES/ESA	IASI	Meteorology, climatology

17	MetOp-B	EUMET-SAT/ NOAA/ CNES/ESA	IASI	Meteorology, climatology
18	Meteosat-10	EUMET-SAT/ ESA	GERB, MSG Comms, SEVIRI	Meteorology, climatology
19	OCO-2	NASA	Spectrometer	Measuring of carbon dioxide
20	OrbView-2	GeoEye	SeaWiFS (Sea-Viewing Wide Field-of-View Sensor)	Global ocean bio-optical properties
21	OSTM/ Jason-2	NASA/ NOAA/ CNES/ EUMETSAT	AMR, DORIS-NG, GPSP, JMR, LRA, POSEIDON-3	Physical oceanography, geodesy, gravity, climate, marine meteorology
22	Proba-V	ESA	Vegetation Imaging multi-spectral radiometers	Mapping of ground cover and vegetation development
23	SMOS	ESA	Microwave Imaging Radiometer using Aperture Synthesis (MIRAS)	Mapping soil moisture and ocean salinity
24	Swarm	ESA	ACC, ASM, EFI, GPS Receiver (Swarm), Laser Reflectors (ESA), STR, VFM	Earth's geomagnetic field
25	Sentinel-3	ESA	OLCI, SLSTR, SRAL	Oceanic processes

26	SPOT-4	CNES	DORIS (SPOT), VEGETATION	Ground cover, agriculture and forestry, environmental monitoring
27	SPOT-5	CNES	DORIS-NG (SPOT), VEGETATION	Ground cover, agriculture and forestry, environmental monitoring
28	Terra	NASA/ METI/CSA	MODIS, MOPITT, MISR, ASTER, CERES	Biological and physical processes, surface temperature of land and ocean, CO measurement in the troposphere
29	Topex/ Poseidon	NASA/ CNES	DORIS, LRA, POSEIDON-1 (SSALT-1), TMR, TOPEX	Physical oceanography, geodesy, gravity
30	Sentinel-5P	ESA	Tropomi	Atmospheric composition and air quality control services

Annex 3

Satellite Systems with High Spatial Resolution

No.	Satellite Name	Agency (Institution)	Sensor	Application
1	Sentinel-1	ESA	C-Band SAR	C-band (radar) data for prompt use, including digital relief models, ground cover
2	Sentinel-2	ESA	MSI (Sentinel-2)	Assistance in monitoring of lands and related services
3	SPOT-4	CNES	HRVIR	Ground cover, agriculture and forestry, digital relief models, environmental monitoring
4	SPOT-5	CNES	HRG, HRS	Ground cover, agriculture and forestry, digital relief models, environmental monitoring
5	Envisat	ESA	ASAR	Physical oceanography, surface of the earth, snow and ice, atmospheric chemistry, atmospheric dynamics

6	ERS-1	ESA	AMI/SAR/Image	Natural resources, physical oceanography, geodesy, ground and atmospheric research
7	ERS-2	ESA	AMI/SAR/Image	Natural resources, physical oceanography, geodesy, ground and atmospheric research
8	Landsat-7	USGS/NASA	Enhanced Thematic Mapper +	Natural resources, ground cover, agriculture and forestry, environmental monitoring
9	Landsat-8	USGS/NASA	OLI	Natural resources, ground cover, agriculture and forestry, environmental monitoring
10	Terra	NASA/METI/ CSA	ASTER	Ground cover, agriculture and forestry, environmental monitoring

GLOSSARY OF TERMS

(compiled on the basis of Remote Sensing Dictionary / edited by V. I. Lialko, M.O. Popov — Kyiv: AVERS JSM, 2004. — 170 p.)

ABSORPTION refers to the transformation of radiation energy into another form of energy as a result of interaction with a substance.

ABSORPTION BAND — Interval of wavelengths or frequencies of the electromagnetic spectrum wherein electromagnetic radiation is absorbed by the given substance.

ACQUISITION is a process or result of objects' search and perception at the initial stage of image (photo) decoding. This includes identification of the most probable areas of objects' positioning on the image. The essence of objects remains unclear when perceived: the visual analyzer of decoder determines the signal-to-noise ratio at each section of the image and compares its value with some threshold values. Formally, each image section is assigned to one of the two categories: "signal" or "noise". The probability of acquisition increases with enhanced contrast, angular size of the object, and time of image viewing.

ACROSS-TRACK SCANNER — An iconic device that generates images by means of scanning of objects' space. The scanning is performed with the help of optical parts (mirrors, glass prisms, drums, pyramids), some of which are moving (by special mechanical drive). Conversion of optical signals of a scene to electric ones is effected using single- or multicomponent photoconverter.

AERIAL PHOTO refers to the image of remote sensing object obtained with the use of RS tools (photography system) installed on the air-based platform (aerial vehicle).

ALBEDO is a value that characterizes the surface's ability to reflect (scatter) the incident radiation. Albedo may be *true* (Lambert albedo), which coincides with the diffuse (scattered) reflection coefficient, and *visible*. True albedo refers to the ratio of the flow scattered by the surface in all directions to the incident flow. Visible albedo means the ratio of brightness of the surface, which is illuminated by a parallel beam of rays, to the brightness of an absolutely white surface normally positioned to the rays and having a true albedo equal to one. In remote sensing, the concept of true albedo is more commonly used.

APPARENCY means the possibility of convenient visual perception of spatial forms, dimensions, locations and interconnections between objects on the map. It is achieved by the reasonable choice of map content elements, feasible generalization, and careful selection of imaging tools.

AREA means the inner area of a flat two-dimensional object generated by a closed sequence of arcs in a vector-topological representation or segments of a non- topological model of "spaghetti", which is identified by the inner point and associated attribute values.

ATMOSPHERIC CORRECTION means the radiometric correction of satellite photo aimed at compensating the effects of scattered light selectivity associated with radiation environment, namely the atmosphere.

ATTRIBUTE means the characteristic feature of a surveyed object represented in RS data, which allows to recognize, distinguish and identify such object.

AZIMUTH means the angle showing the northward direction. Azimuth may be *astronomical*, i. e. clockwise angle in the horizontal plane from the northward direction of the astronomical meridian to the given direction; *geodetic,* i. e. clockwise angle in the plane tangent to the ellipsoid from the northern direction of the geodesic meridian of the given point to a given direction; *magnetic,* i. e. clockwise angle in the horizontal plane from the northward direction of the magnetic needle to the given direction. The magnetic needle deflects from the astronomical meridian by a degree of magnetic declination. Magnetic declination to the east is designated with the mark " + ", and to the west with the mark "–". Azimuth may vary from 0 to 3600. Azimuth in the direction from a given point to another one is called forward azimuth, and azimuth from another point to the given one is called back azimuth.

CARTOGRAPHIC INFORMATION —

1. Information on cartographic works. Specialized services and automated cartographic information retrieval systems provide systematic collection, processing, storage and prompt delivery to users of information about maps (published and handwritten), atlases, aerospace materials and other cartographic sources;

2. Information provided in the form of cartographic works;

3. Information used to create or update the cartographic works;

4. The result of human (or automatic recognition device) perception of information on the objects, phenomena and processes represented on maps. Cartographic information is delivered using the cartographic and graphic image tools.

CARTOGRAPHIC PROJECTION, MAP PROJECTION, PROJECTION means mathematically determined tool for displaying the surface of terrestrial sphere or ellipsoid (or other planet) on a plane. The general equation of the cartographic projection links the geodetic latitudes (B) and longitudes (L) to rectangular x and y coordinates on the plane as x = f1 (B, L); y = f2 (B, L), where f1 and f2 are independent, single-valued and finite functions. All cartographic projections are characterized by certain distortions that emerge with the transition from a spherical surface to a plane. According to the nature of distortions, cartographic projections may be conformal (equal-angle projection) free from any distortions in angles and directions;

equal-area free from any distortions of the area; equidistant, which prevent distortions in certain directions (meridians or parallels), and conventional, which contain some distortion of angles and areas.

CELL, GRID CELL, TILE means a two-dimensional spatial object, an element of earth surface break-up by the lines of the uniform grid, i. e. uniform cell representation of spatial objects, in contrast to the pixel (as an element of cell representation) generated by line-wise break-up of a raster image (not the earth's surface). Cell usually has regular geometric shape (triangle, tetragon, hexagon, trapezoid, etc.) and is characterized by absolute dimensions in the linear or degree measures, which determine the spatial discrepancy of the generated uniform grid.

CHANGE DETECTION means a detection of changes in the brightness and location of decoded objects, based upon multi-temporal imagery, for example, during the monitoring of environmental pollution.

CHROMATICITY means characteristic of a color quality, which is determined by its chromaticity coordinates or the dominant wavelength and color purity.

CLASSIFICATION, CATEGORIZATION means division of a given set into subsets according to accepted rules, sorting objects by category.

CLUSTER — A group of elements with the same common property. In automatic image recognition, cluster refers to a group of objects that form a compact domain (in some way) in the studied area.

COLOR means

1. An aspect of visual perception, which allows the observer to distinguish between color stimuli differing in the spectral composition of radiation, i. e. distinguish one object from another, if the difference between them is caused by the discrepancy in the spectral composition of emitted light only;

2. A three-dimensional vector value characterizing a set of spectral radiations that are not visually distinguished under available colorimetric conditions, i. e. under the conditions of visual comparison where any radiation of the same spectral composition is not visible to naked eye.

COLOR TEMPERATURE — Spectrophotometric or colorimetric temperature, a physical parameter that determines the changes in the radiation intensity of a source with a change in the wavelength in the optical range of continuous spectrum. The color temperature is the temperature of an ideal black-body radiator that radiates light of a color comparable to that of the light source.

CONTOR means a closed curve or sequence of restricting arches (polylines) of a spatial object.

COORDINATES, POSITION DATA means linear and/or angular values which determine the position of a point along a direction either on a plane or in space. To determine the location of a point object in space we use geographic coordinates, i. e. angular values, which are referred to as latitudes and longitudes. They determine the location of the earth's point relative to the equator and the initial meridian. Geographic coordinates may be astronomical and geodetic. Latitudes and longitudes of the points determined on the basis of geodetic measurements and subsequent calculations on the reference ellipsoid surface are referred to as geodesic and are usually designated by letters B and L. Astronomical latitudes and longitudes are determined by observations of celestial bodies in these points. They are usually designated by the letters j and l. Geodetic geographical coordinates are connected with a normal passing through a given point to the reference ellipsoid surface, while astronomical geographic coordinates — with the direction of a straight line at this point.

COVERAGE — ArcInfo vector data format, built on the file principle and designed to store information on the spatial position, form and attribute characteristics of spatial objects; the geometric information on the spatial objects is stored as a set of primary spatial objects (such as arcs, nodes, polygons and spot marks) and secondary spatial objects (such as extents, links between objects, annotations), and semantic information thereof is accumulated in the attribute tables.

DATA CALIBRATION is the estimation (determination) of radiometric and geometric distortions in the image, which arise during the surveying process, and correction thereof.

DATA PRODUCT LEVEL, PROCESSING LEVEL — A specific status of RS data. It is formally determined by the corresponding indicator of the degree and content of data processing. For example, it can be measured in whole numbers from 0 to 4, where level 0 corresponds to pre-processed image, 1 — to normalized and geographically referenced image, 2 — to fully normalized image that has been transformed into a given cartographic projection, 3 — to decoded image with specified general information and level 4 — to the image with selected thematic information resulting from the processing of data at the previous levels using auxiliary information. Sequential performance of level 0–2 operations results in the preprocessed image. Performance of all operations with the image, including those of level 4, results in thematically processed image. There may be other variants of level-by-level RS data distribution.

DATASET means

1. Any class of spatial objects, a table or a set of classes in the geodatabase;

2. Named set of logically interconnected data elements, arranged in a certain way.

DATA VISUALIZATION —

1. In GIS — design and generalization of images, other graphics on display devices (mainly on display screen) based on output digital data, as well as rules and algorithms for conversion thereof;

2. In RS — the reproduction of a digital image or results of its processing on the display using special data structures enabling to

significantly increase the speed of visualization, for example, the so-called pyramidal layers, which allow to write the set of pixels of the output image in a limited number of pixels of the display window with the output of one of the previously built-in images with consistent 2-, 4-or 8-fold reduction of resolution.

DIFFUSION — Change in the spatial distribution of a bundle of rays deviating in different directions by a surface or medium without changing the frequencies of its monochromatic radiation.

DIGITAL ELEVATION MODEL refers to digital representation of three-dimensional spatial objects (surface, relief) in the form of three-dimensional data as a set of heights or depth markers and other applicate values (Z coordinate) in the nodes of uniform grid with the formation of heights matrix, triangulated irregular network (TIN), or as a set of records of contours (isohyps, isobath) or other isolines. The most common tools for digital relief representation include raster imaging and a special spatial data model that is based on the TIN structure and approximates the relief by a multifaceted surface with altitudes (depth marks) in the nodes of triangulated network. The process of digital relief modeling involves the creation of digital elevation models, their processing and application. The source data for the creation of digital elevation model include topographic maps, aerospace images and other RS data, altimetric survey data, data of GPS satellite-based navigation systems, marine charts, echo sounder measurements, etc.

DIGITAL IMAGE EDITING refers to operations which are not related to direct processing of digital image content, but essential for improving processing quality and speed, namely: visualization, mosaic, fragmentation, synthesis, discretization, etc.

DIGITAL MAP refers to a digital model of a map, created by digitizing source maps, photogrammetric RS data processing, digital or another recording of the field data. In other words, it is a digital model of the earth's surface generated with due regard to cartographic generalization rules with conventional projection, sheet division, coordinates system and system of heights applicable in maps. Digital map is used as the basis for the production of paper and electronic maps, constitutes a part of the mapping database, is an essential element of GIS information support and may be a product of geoinformation technology.

DIGITIZING refers to a process of analog-to-digital data conversion, i. e. conversion of data to digital format.

DIRECT ATTRIBUTE means a decryption character that characterizes the decryption object.

DISTRIBUTION TEMPERATURE — The temperature of a black body, at which ordinates of spectral distribution curve of the radiance thereof in the visible spectrum are proportional to the corresponding ordinates of the spectral distribution curve of radiation under study. Units: Kelvin (K). Both types of radiation have the same (within permissible range) color value.

EMISSIVITY — A measure applied for heat emitters. Emissivity refers to the ratio of the thermal radiance of the body Me, th to the radiance of a black body, Me (e = 1) at the same temperature.

FILTERING — Procedure for processing (conversion) of image signals using appropriate filter. The overall purpose of this conversion is to improve the image quality. When the procedure is performed with the video signal in real or quasi-real time, it is called filtering in time domain; when the procedure is performed with points (pixels) of generated image, it is called filtering in spatial domain, or spatial filtering. If the chosen procedure (algorithm) of spatial filtering is the same for all points (pixels) of the image, it is called space-invariant filtering; if the parameters or type of signal processing procedure change for image points depending on their coordinates, then it is called a space-dependent or adaptive filtering.

FLIGHT ALTITUDE means a distance between satellite and the Earth's surface, which is measured along the line of satellite connection with the center of the Earth.

FULL RADIATOR, PLANCKIAN RADIATOR, BLACK BODY, BLACKBODY refers to a thermal radiator that exhibits maximum spectral radiance at a given temperature for all wavelengths. It completely absorbs all incident radiation irrespective of the wavelength, incident direction and degree of radiation polarization.

FULL RADIATOR TEMPERATURE — The temperature, at which a black body has the same thermal radiant exitance as the studied body. Units: Kelvin (K).

GEOGRAPHIC (AL) INFORMATION SYSTEM is a system for processing spatially coordinated (spatial) data, which provides for their collection, pre-processing, data management, modeling, analysis, accumulation and representation of information results. Depending on the geographical coverage, GIS may be global (planetary), subcontinental, national (county-wide), regional, and local (district). Depending on the subject area of information modeling, GIS may be municipal, environmental, land, etc.

GEOINDICATIONAL SIMULATION is the study of links between geological objects and natural formations with subsequent formation of the corresponding model of natural indication system. Such a model involves establishment of basic geo-indicators, description of their genetic and causal links with the corresponding geological objects and, thereupon, estimating (predicting) the existence of various geological objects based on a set of indicators reproduced in the images.

GEO-INFORMATION SCIENCE is a component of computer science, which studies natural and artificial (anthropogenic) geosystems, their structure, spatial and information interrelations, functioning in space and time. The main instrument of geo-information science is the GIS.

GEOMETRIC CORRECTION means removing geometric distortions in an image.

GEOMETRICAL ERROR — A measure of inaccuracy between the actual coordinates and forms of remote sensing targets in the image and the ideal coordinates and forms that would have been theoretically obtained with ideal RS tools under ideal conditions. Geometrical errors emerge in aerospace images due to the curvature and motion of the Earth, aberrations of optical systems, etc.

GEOMETRIC DISTORTION; SPATIAL DISTORTION — Reproduction of a three-dimensional representation of a scene based on stereopair; i. e. two overlapping images obtained at different angles with respect to nadir when imaging the overlapping part.

GEO-STATIONARY ORBIT means a satellite orbit following the direction of the Earth rotation, wherein a satellite remains in a fixed position over one point on the Earth's surface.

GEO-SYNCRONOUS SATELLITE ORBIT means an orbit, wherein the speed of a satellite equals the rate of the Earth's rotation.

GIS ANALYSIS — Analysis of location, structure and interrelation of objects and phenomena using methods of spatial analysis and geomodeling.

GROUND SWATH; SWATH WIDTH refers to a part of the Earth's surface of which imagery is collected from aircraft or space. The swath width is measured perpendicularly to the motion of the vehicle and is determined by the field of view of the survey (iconic) RS tool. The longitudinal extent of the swath is measured along the motion of the vehicle and is determined by the field of view of the survey tool and the time of continuous imaging. The longitudinal extent of the swath is sometimes called a track (not to be confused with the route).

HYPERSPECTRAL PHOTO, HYPERSPECTRAL IMAGE is the set of images of the same scene on the Earth's surface obtained simultaneously in many narrow zones of the electromagnetic spectrum. The number of spectral zones used for hyperspectral image may range from several dozens to several hundred**.**

HUE means the characteristic of a color when described in words: blue, green, yellow, red, etc.

IMAGE means spatial representation of an object or scene (two-dimensional or three-dimensional). Image may be actual (then it can be registered on some medium, for example, on a photographic film) and imaginary.

IMAGE COMPOSITION refers to the procedure of superimposition by pixel of two or more monospectral images of the same scene obtained in various bands of iconic RS device, which results in obtaining a new synthetic image.

IMAGE (SCENE) DECODING, PHOTO INTERPRETATION, IMAGE INTERPRETATION is the process of obtaining information about locations (or, in a broader sense, objects and phenomena of the geographical environment) according to their images. Image decoding is based on the knowledge of the patterns of objects properties reproduction in images, features of their spectral characteristics (signatures), geometric forms, and location. Image decoding procedure involves the identification, recognition and interpretation of objects and terrain. There are two types of image decoding: geographic and industry-specific (thematic). Geographic image decoding aims at obtaining generalized information about the Earth's surface: regional or typological zoning, detection of hydrography system, road network, settlements, vegetation, other elements of the area, and establishing their interrelations. The geographic includes topographic and landscape decryption. Industry-specific (thematic) image decoding addresses tasks of certain industry related to characterization of individual sets of objects located on the earth's surface and in the atmosphere.

Types of industry-specific (thematic) decryption: geological, forest, soil, hydrological, geomorphological, etc.

IMAGE PROCESSING means a set of operations with RS data and necessary supporting information to achieve a certain level of RS data processing. Such operations may include primary processing of image signals, data compression, recovery, adjusting, filtering, archiving, visualization, etc. The goals of image processing may include improvement of the image quality, its storage efficiency and environment for interpretation, etc.

INFRARED SCANNER — a scanner that acquires data and generates images of objects in the infrared range of wavelength.

INTERNATIONAL REMOTE SENSING SYSTEM — RS system owned and managed by legal entities or individuals from several countries.

INTERPRETATION is the final stage of decryption, which involves the analysis and generalization of quantitative and qualitative characteristics (attributes) of an object in order to establish the status and significance, and opportunities thereof in a given environment. Quantitative and qualitative characteristics of the objects within an area are determined by evaluation of image parameters: geometric dimensions, optical densities, halftones, parallaxes, etc. This allows to define the state of vegetation, the composition of forest rocks, nature of the soil, etc.

INFORMATIVITY is information content of the data with regard to the problem addressed. In cartography informativity means the evaluation of amount of information that may be retrieved by a user from the map. Information may be evident (directly perceived when reading maps), and hidden (associative) (may not be obtained without appropriate measurements, comparisons, transformations, logical considerations). In remote sensing, the informativity is measured by the amount of information that is contained in the image with respect to the objects which are the subject of search, analysis and interpretation.

INFRARED RADIATION means radiation, wavelengths of monochromatic components whereof are larger than wavelengths of visible radiation and smaller than about 1 mm. The boundaries of the spectral range of infrared radiation are rather conditional and may vary depending on the applications. The CIE (International Commission for Illumination) defines in the spectral range between 780 nm and 1 mm the following: IR-A from 780 to 1400 nm, IR-B from 1.4 to 3 μm, and IR-C from 3 μm to 1 mm.

INDEX means

1. Parameter, numeric characteristic;

2. In RS: a conventional indicator, which is calculated by the empirical formula; as a result of arithmetic operations with the brightness of the satellite image (picture) pixels, a certain index (value) is calculated, providing a numerical probabilistic estimate of the presence of certain substances, materials (vegetation, minerals, etc.) on the Earth's surface.

INDIRECT ATTRIBUTE means a decryption value that characterizes the decryption object by any natural or artificial component, which is not the property of the image of the studied object.

LANDSCAPE INTERPRETATION means interpretation aimed at identifying the morphological structure of the landscape based upon the complex features (such as pattern, texture, contour size, spectral brightness, etc.), analysis of natural and territorial complexes of the rank "facies — tract — terrain".

LATITUDE — is a geographic coordinate that specifies the north–south position of a point on the Earth's surface. The latitudes may be *astronomical*, meaning the angle between a vertical line at a given point and a plane perpendicular to the axis of the Earth's rotation, *geodetic* — the angle between the normal line to the surface of earth ellipsoid at a given point and the equatorial plane; *geocentric* — the angle between the radius from geocenter and a plane perpendicular to the axis of the Earth's rotation. Latitudes may vary from 0 at the equator to 90 degrees at the poles, and in the northern hemisphere they are called "northern" and positive, and in the southern hemisphere — "southern" and negative. On the globes and maps, latitudes are represented using parallels.

LEGEND means

1. In RS: narrative description of image interpretation results;

2. In cartography: a system of symbols used on a map, and text explanations that interprets the content. Legend includes explanations, interpretations of symbols, and reflects the logical basis of the mapped object. There are special tables of symbols developed for topographic maps, which application is mandatory for all the maps of respective scale. A legend on thematic maps is often written (printed) on a map itself.

LIDAR means an active RS tool which involves the use of laser or other source of high-intensity monochromatic optical radiation. The main function is measurement of distances (ranges, altitudes). The principle of measuring distance is based on registration of optical pulse passage time to the object and backwards. The measurement error of the distance does not exceed 10 cm. The term is the abbreviation of Light Intensity Detection And Ranging. One type of lidar was designed specifically for monitoring atmosphere. It is equipped with two lasers; the wavelength of the first laser is equivalent to the maximum absorption of radiation by atmospheric pollutants, and the wavelength of the second laser coincides with the minimum absorption.

LIGHT SENSITIVITY refers to the capability of a material (photographic films, semiconductors, etc.) to respond to light emission. Light sensitivity may be total and effective. Total light sensitivity refers to the sensitivity of a material to the continuous emission of a given spectral composition in the visible range. Effective light sensitivity is the sensitivity of black-and-white photographic materials to the light that has passed through the given light filter.

LONGITUDE is a coordinate, which determines the point's position on the Earth from west to east in relation to the initial meridian. Longitude may be: astronomical, determined as a dihedral angle between the planes of the astronomical meridians of given point and the initial one; geodetic, determined as a dihedral angle between the geodetic meridian planes of the determined point and the initial meridian; geocentric, as a dihedral angle between the planes of the geocentric meridian of the determined point and the initial meridian. The longitude is defined from 0 to 3600 from west to east, or both ways — from 0 to 1800, with specification "East" or "plus", and "West" or "minus", respectively.

LUMINOUS FLUX is a measure of emitted light in terms of its effect on the selective receiver, which spectral response is determined by the normalized relative spectral luminous efficiency function. Symbol — Φv; Φ. Units: lumen (lm).

MAP means mathematically defined, scaled-down, generalized image of the Earth's surface, or surface of another celestial or space body, which reflects objects located or projected thereon using the agreed system of symbols. Map refers to a model of characters and symbols that is highly informative, exhibits space-temporal similarity to the original, and also metricity, visibility and prominence. Maps differ according to spatial reach, scale, content, and purpose. In terms of spatial reach, maps may represent a globe, hemispheres, continents and groups thereof, oceans, seas and groups thereof, states and groups thereof, and other political and administrative subdivisions. In terms of scale, maps may be large-scale (1:5000 and larger), medium-scale (from 1:100 000 to 1:500 000) and small-scale (from 1:1 000 000 and smaller). There are also other classifications. In terms of content, maps may be geographic and thematic. Geographic maps represent the set of main terrain elements, i. e. hydrography, relief, settlements, roads and other elements. Their content depends mainly on the scale of the map. The content of thematic maps is determined by a specific theme. These maps represent certain element (elements) or phenomenon (phenomena), for example, settlements, soils, vegetation, hydrography, climate, location of deposits of natural minerals, etc. Sometimes thematic maps, depending on the thematic coverage, are divided into general and industry-specific.

MAPPING, MAP (ATLAS) COMPILATION means a set of processes, methods and technologies applied for compiling maps, atlases and other cartographic works. In terms of scale, mapping may be large-scale, medium-scale, and small-scale; according to geographic locations, mapping may be astronomical, planetary and global; according to method, mapping may be ground, aerospace, and underwater.

MEASUREMENT ACCURACY refers to proximity of a measured value to a true value that is measured. Error is a characteristic of measurement accuracy — deviation of measurement result from the true measured value. In fact, a true value is unknown, and errors are assessed through repeated measurements of the same value. The errors may be gross, which significantly exceed the expected error under given conditions; systematic — a component of measurement error, which remains consistent or undergoes regular changes with repeated measurements; random — a component of measurement error, which undergoes random changes with repeated measurements. Gross and systematic errors must be excluded from calculations. Random errors cannot be avoided. It is only possible to diminish their influence by improving the measurements quality and using proper methods of mathematical processing of measured results. The probability of random errors is subject to statistical random values distribution law, the main parameters of which are: averaged value — average result of repeated measurements of the same value; root-mean-square deviation (RMS), which is calculated based on the deviations of repeated measurements results from their mean value, and is the main criterion of measurements accuracy. The accuracy of calculation of these parameters increases with increased number of repeated measurements. Errors are often subject to normal distribution law, according to which small error values occur more frequently than larger, errors that result from addition or subtraction are equally probable and in case of large numbers their mean values approach zero; according to absolute value the errors do not exceed the RMS, 2 RMS, 2.5 RMS and 3 RMS, respectively, in 68.3; 95.4; 98.6% and 99.7% of cases. During mathematical processing of measurements with different accuracy, the quality of a separate measurement is taken into account through introduction of "weight" notion, which refers to a value equal to the squared ratio, where RMS is the numerator, which weight is taken as 1 (it is called root-mean-square error of the unit of weight), and denominator is RMS of the current measurement. The weight of equal measurements is one.

MERIDIAN means a line on the Earth's surface, all points of which have the same longitude. Meridian indicates the south-north direction. Meridian may be astronomical, i. e. formed by crosscutting the Earth's surface with a plane passing through a sloping line at a given point and parallel to the axis of the Earth's rotation; geodetic, i. e. defined by a plane passing through the normal to the surface of the Earth ellipsoid at a given point and its small axis; geocentric, i. e. defined by a plane passing through this point and axis of the Erath's rotation; initial (Greenwich) meridian, i. e. the starting point of the reference period of longitudes; axial, i. e. referred to as axis of the coordinate system on a plane (surface).

METADATA means information on the following: catalogs, directories, registries, inventories, metadata bases and other forms of description of sets of digital and analog data containing information about the composition, content, status (relevance and updating), origin (methods and terms of collection), location, quality (completeness, non-contradiction, authenticity), formats and forms of submission, terms of access, acquisition and use thereof, copyright, property and related rights thereto and additional characteristics. Moreover, spatial metadata may be characterized by additional mandatory or optional features, including methods of digitization, coordinate systems, spatial representation accuracy, spatial discreteness and level of generalization, scale, cartographic projections, map legends and other specific features of representation, processing and reproduction of spatial data.

MONITORING means periodic observation of objects and phenomena in order to identify their quantitative or qualitative changes.

MONOCHROMATIC IMAGE means an image of a scene obtained with the use of RS tools in one spectral range (band).

MULTISPECTRAL CLASSIFICATION means classification of an image based on the splitting of the spectrum properties domain into the areas that correspond to individual classes.

MULTISPECTRAL IMAGE, MULTI-BAND IMAGE is the set of images representing the same scene and made simultaneously (synchronously in time), but in different ranges (zones) of electromagnetic spectrum.

MULTISPECTRAL RADIOMETER — Radiometer for separate measurement of electromagnetic radiation energy in several spectral bands simultaneously.

MULTISPECTRAL SCANNER — A scanner that simultaneously acquires images of the ground surface in various spectral bands at the same time. It enables generation of data (including images formatting) according to the number of spectral bands.

MULTISPECTRAL SURVEY, MULTI-BAND SURVEY means the surveying process with the use of iconic remote sensing tools, which results in obtaining a multispectral image.

NADIR means a point at the object of remote sensing, located on the line connecting RS tool and the center of the Earth.

NATIONAL REMOTE SENSING SYSTEM — RS system owned and managed by legal entities or individuals from the same country.

NORMALIZED DIFFERENCE VEGETATION INDEX is a normalized index (coefficient), which is the ratio of the difference and sum of values of spectral brightness in the near infrared and red ranges of electromagnetic spectrum. Output values of spectral brightness for calculations are defined based on data obtained from two spectral bands of AVHRR radiometer installed on NOAA space platform (USA). Normalized difference vegetation index is successfully used for assessing the vegetation development and forecasting yields based on space surveys. However, this index is sensitive to atmospheric variations, which impairs the accuracy of estimates. Thus, the use of the normalized difference vegetation index requires atmospheric correction of satellite images. Sometimes, depending on the degree of atmospheric correction, appropriate changes are made to the expression for the calculation of the normalized difference vegetation index and in such a case it is referred to as modified.

OBJECT OF INTERPRETATION (DECODING) means an object (phenomenon) of natural or artificial origin, obtaining information whereof is the purpose of decoding.

OBJECT GLASS, LENS, OBJECTIVE means an optical system, which generates a projective image of flat or dimensional objects on a flat surface of the receiver (photographic film, photocathode of an electron-beam tube, matrix photo-converter, etc.). Objectives may be: high-power, wide-angle, long-focus, normal. High-power objectives have a relative aperture greater than 1:2.8. Field of view of wide-angle objectives exceeds 600. Long-focus objectives are characterized by a focal length, equal to three or more linear fields of the image. Normal objectives are objectives with the abovementioned characteristics, which do not reach the indicated values.

OPERATIVE FORECAST means a forecast with up to 1 month warning period for scientific, technical, social, economic and other objects.

OPTICAL DENSITY means a measure of substance opacity. In terms of quantity, it is expressed as a decimal logarithm of the value, reciprocal to the transmission coefficient. It is referred to as D.

OPTICAL-ELECTRONIC SYSTEM means the image generation system, wherein the optical radiation of a scene (object) is converted into electrical signals.

OPTICAL PHOTOGRAPHIC SYSTEM means the image generation system, which ensures the registration of a scene (object) directly on a film and further generation of the so called "hidden image".

OPTIC (AL) RADIATION means electromagnetic radiation with wavelengths located between the transition area near X-rays (about 1 nm) and the transition area of radio waves (about 1 mm).

ORBIT means a satellite trajectory around a celestial body (for example, the Earth) under the influence of gravity. The orbit of the Earth's artificial satellite has a spiral shape approaching the Earth.

ORTHOTRANSFORMATION, ***ORTHORECTIFICATION*** means the transformation of an aerial or satellite image, aimed at elimination of distortions resulting from relief patterns. Orthotransformation is used in the generation of photographic maps (orthophotographic maps) of relief pattern. The image is brought to one scale, element by element, through continued changes of design height depending on the geodetic heights of points in an area, reflected in each current element. An image obtained in this way is referred to as an orthophotographic image. A more general option: redesigning an image from initial projection (for example, the central one) to the orthogonal projection. The essence of orthotransformation is the correction of an image according to the slope of image plane and relief of captured surface.

ORTHOPHOTOGRAPHY means an aerial or satellite image, generated by orthorectification.

OVERLAY —

1. Superposition of one or more layers. This results in a graphic composition or graphic overlay of initial layers, or one derivative layer with the composition of spatial objects of initial layers, topology of this composition and attributes, which are arithmetically or logically derived from the values of the attributes of original objects in the topological overlay of vector representations of spatial objects;

2. The group of analytical operations serving overlay operation;

3. In English terminology: a layer.

PANCHROMATIC IMAGE means a black and white image obtained with the use of specific (iconic) tool in the visible range of wavelengths.

PHOTO, IMAGE means the image of an object obtained by surveying system (an iconic RS tool) in the form of two-dimensional or other record on a photographic film, magnetic or optical disk, etc., and allowing to reproduce two-dimensional image of an object**.**

PIXEL means the smallest spatial element of a digital image (derived from Picture Element). Splitting of image field into pixels is achieved by image discretization (splitting into indivisible elements — discretes or raster dots). Brightness and color (the latter concerns color images) remain unchanged within this element.

POLAR ORBIT means an orbit that passes over both geographic poles of the Earth.

POLYGON means a polygon, polygonal object, contour, contour object, area i. e. two-dimensional (plane) object, one of the four main types of spatial objects (along with dot lines and surfaces). Polygons may be simple, i. e. without internal polygons, and complex i. e. containing internal polygons, which are referred to as "islands" and enclaves. One type of polygon is linked by its topology to adjacent and restricting arcs; a similar links in case of polygonal and other spatial objects is typical for the SDTS standard.

POSITIVE PHOTOIMAGE means a photographic image (imprint of a photographic negative), wherein relative distribution of brightness or color match the distribution thereof in the surveyed object. Positive photographic image is obtained according to a schedule similar to a photographic negative obtaining, namely: photographic paper exposure, development, intermediate rinse, fixation, final wash and drying.

POST-PROCESSING means a procedure for conversion and computing the GPS data, which is performed upon the completion of collection thereof. Post-processing is usually carried out in laboratories using the appropriate software, resulting in more precise coordinate determination than those obtained directly from the measurement data.

PRECISE POSITIONING SERVICE is a highly accurate navigation by GPS-technique, which may be performed using the standard GPS system use. It is fulfilled through the processing of signals at L1 and L2 frequencies having P-coding.

PREPROCESSING means an initial stage of RS data processing, wherein the initial data are decoded and further calibrated and transformed into a raster structure.

PRIMARY DATA PROCESSING means processing of image data with regard to reference thereof according to orbital data, normalization, geographic references and transformation into a given cartographic projection. At this stage, some elementary operations of image transformation may also be performed as required by the user.

PROJECTION — Representation of a spatial object on a plane according to a certain rules.

PSEUDOCOLOR means

1. A method of representing a digital image (usually a thematic layer) that provides appropriate coloring of different classes of objects;

2. A method of representing a halftone image with appropriate coloring of different grading levels. The image thus formed is referred to as pseudo-colored.

PUSH BROOM SCANNER is a device that generates images by scanning the picture plane and ensures minimum geometric aberrations. The use of solid-state semiconductor photoconverter and absence of moving parts make these scanners highly reliable and efficient. The most widely used in the RS are the scanners based on charge-coupled device (CCD) line or matrix. In these scanners, the traverse scanning is ensured by the electronics and the longitudinal scanning — by straightforward movement of the platform (aircraft or space vehicle) equipped with such scanner.

QUANTITY of LIGHT — luminous energy that is the product of luminous flux by time. Units: lumen second (lm·s).

RADAR — Active RS tool, which principle of action is based on the use of radio frequency waves. Radars make it possible to identify fixed and moving objects, trace their motion paths, measure distances (remoteness, altitude), and obtain images of the site and objects located thereon. RADAR is the abbreviation for Radio Detection And Ranging.

RADAR IMAGE means image obtained with the use of a radar unit, including side-view radar.

RADAR SYSTEM refers to an active remote sensing system that surveys the landscape using radio waves.

RADIATION, EMISSION OF RADIATION —

1. Electromagnetic radiation is the emission or distribution of electromagnetic waves (according to the classical theory of radiation) or the process of transition of a quantum system from one energy state to another one with the emission or absorption of photons (according to the quantum theory of radiation);

2. Radioactive emission is the emission of alpha particles, beta particles and gamma rays by atomic nuclei upon the radioactive transformation thereof.

RADIOMETER — A device for measuring electromagnetic radiation energy in a certain wavelength range of any portion of electromagnetic spectrum. Radiometers may be *infrared* (for measuring electromagnetic radiation energy in infrared range), *microwave* (for measuring electromagnetic radiation energy in the microwave range), *optical* (for measuring the electromagnetic radiation energy within the optical spectrum).

RADIOMETRICAL RESOLUTION — The smallest difference in the intensity of two signals (radiation) from the object of sensing, which can be determined using the remote sensing tools.

RADIOMETRIC CORRECTION means the correction of image brightness distortion. Notes: 1. Distortion of brightness due to the RS tools failure, atmospheric distortion, solar illumination, etc. 2. Radiometric correction provides radiometric comparability of panchromatic, multi-spectral and asynchronical digital aerial and satellite images.

RADIOMETRIC CORRECTION refers to the correction of image pixel brightness in order to eliminate deviations in data caused not by the studied object but by other sources, for example, atmospheric effects, uncontrolled changes of RS-instrument parameters, etc.

RASTER DATA STRUCTURE, GRID DATA STRUCTURE, TESSELATION DATA STRUCTURE — Raster data model, digital representation of spatial objects as a set of raster cells (pixels) with assigned to them object class values, in contrast to the formally identical regular-cell representation as a set of cells of a regular network (elements of ground surface break up). Raster data structure includes positioning of objects to indicate their location in the rectangular matrix corresponding to the raster, using the same procedure for all types of spatial objects (points, lines, traverses and surfaces).

RASTER TO VECTOR CONVERSION, VECTORIZATION refers to automatic or semi-automatic transformation (conversion) of raster data structure of spatial objects to a vector representation using a set of operations, usually including "thinning operation" with raster lines (its thinning); generalization with the use of discharging operators (operators eliminating excessive points in the digital line recording), their smoothing, simplification of the picture, removal of gaps, "pending lines". Raster to vector conversion is supported by specialized software — vectorizers.

RECOGNITION —

1. The second stage of decoding, which involves separate recognition and analysis of the object's attributes (elements, details) and determination of the essence of identified object (type, class and etc.). The recognition probability increases with increased image spatial resolution, contrast, tone gradations represented in the image, analysis term. If performed by a person, this process is often called identification;

2. The process of computer-aided analysis of objects (patterns) and their features in images in order to determine the class an object belongs to;

3. Identification of contours, various geometric forms or configurations, implemented with the use of automated information processing tools.

RECTIFICATION, ALIGNMENT, COREGISTRATION, GEOCODING, GEOCORRECTION, GEOREFERENCING — Geometric transformation of a raster image, which eliminates the distortion caused by optical system and includes projection of three-dimensional spatial surfaces onto 2D media, and referencing of resulting image to any coordinate system on the Earth's surface. When it is also necessary to eliminate to the maximum extent the distortions caused by the terrain, such rectification is referred to as orthorectification.

REFERENCE DATA, GEO-REFERENCE DATA refers to the tables representing the data on the geographic locations which contain spatially referenced information (addresses, geographic coordinates, etc.) used to perform geocoding operations.

REFLECTANCE; REFLECTION FACTOR means the ratio of the reflected light flux (radiation flux) to the incident light flux (radiation flux). In general, the reflection factor value depends on the method of illumination, the spectral composition and the state of radiation polarization. Reflection factor is referred to as re, rv, r.

REFLECTION is the returned emission by the object without changing the frequencies of its monochromatic radiation components.

REMOTE SENSING METHODS (TECHNIQUES) means non-contact methods for studying the Earth's surface, hydrosphere, lithosphere, atmosphere and cosmic bodies.

REMOTE SENSING OF THE EARTH (FROM SPACE), EARTH SATELLITE OBSERVATION means the acquisition of the data about the Earth using the properties of the electromagnetic waves emitted, reflected, absorbed or scattered by the remote sensing objects.

REMOTE SENSING SYSTEM — combination of space and ground-based functionally and structurally interconnected technological and information tools that ensure the remote sensing.

RESOLUTION POWER — A parameter characterizing the capability of an optical device or a photographic system to resolve two closely-spaced points. The smallest linear (or angular) distance between two points, at which these points merge and cease to differ, is called linear (or angular) boundary of dispersion. The resolution power of aerial photo camera (optical system and aerial photographic materials) is determined as the maximum spatial frequency of a periodic grid, which ticks are visually recognized on a photographic image created by such system when applying a standard measure of the given contrast. In the context of remote sensing tasks, the resolution power characterizes the capability of the system to reproduce small details of aerial landscape. Resolution power is marked as R and is measured in mm-1 (in words "lines per millimeter").

SATELLITE IMAGE GEOCODING means establishing the correspondence between the coordinate system of an image and the geographical coordinate system based on the characteristics of the RS tools, orbital data, contour maps of the terrain, ground reference points, etc.

SCANNER —

1. A device for analog-to-digital conversion of images for their further input to ECM in raster format with high spatial resolution (usually minimum 600 dots per inch) by means of sequential dot-to-dot scanning of image field (in reflected or transmitted light). According to the functionality, the scanners may be color (for input of color images) and monochrome (for input of black-and-white images); and according to the structure, the scanners may be flatbed, drum, roller-type and hand-held;

2. In RS: on-board optical-electronic or radar technical device for generation of terrain images by scanning according to the given rules and registration of own or reflected radiation.

SCANNING refers to the procedure of sequential review of elements of the scene (terrestrial surface, object). The dimensions of scene elements are determined by the immediate angle of view of the system. Scanning can be performed in objects' space or in the imaging plane. With the scanning in objects' space, the review of the scene elements is carried out through the sequential movements of observation line within the scene. A curve made by the observation line in the objects' space is called a scanning path. Modern RS tools use scanning paths of the ground surface represented in the form of lines or parts of circle with cyclic scanning procedure. Scanning in the imaging plane is performed as follows: using an optical system, the scene is first projected onto a sensitive area of photoconverter, which is a matrix or line of photodetectors, where one photodetector corresponds to one element of the scene. Here, optical signals of the scene are converted to corresponding output electric signals of photodetectors. In this case, the scanning operation involves the survey of the state of photodetectors' the outputs. The accepted calling sequence determines the scanning path in the imaging plane.

SCALE means the ratio of the length of an infinitely small segment on the geographic image to the length of the corresponding infinitely small segment on the surface of the ellipsoid or the globe. Map scale may be numerical (numerical scale) as a fraction where a numerator is equal to one, and a denominator is equal to the degree of decreasing the lengths on a map; denominated — refers to inscription indicating the length of the line in the area, which corresponds to 1 cm on the map; graphic (or linear scale), which refers to a scale with graduating marks (usually 1 or 2 cm) with assigned corresponding lengths in the area (in meters or kilometers). On small-scale maps, there are distortions of scale lengths due to the cartographic projections, with distinguishing the main and the partial scale. There are practically no scale differences in plans, topographic map sheets, large-scale maps and maps of small territories (up to 1000 km). There are also surveying scale (for shooting), compiling scale (for compiling maps) and issuing scale (for issuing maps), which are often finer than compiling scale.

SCENE —

1. In RS: portion of the Earth's territory captured by remote sensing tool during imaging session and recorded as an integral image;
2. In computer graphics: visualized three-dimensional space with objects being displayed in it.

SENSITIVITY refers to the capability of the technical device to respond to weak output signals (optical, electrical, etc.). In terms of quantity, it is defined as the ratio of output signal increment value to the increment of the input value, which determines it. The sensitivity may be absolute and relative.

SHAPEFILE is a geospatial vector data format of software applications of ESRI Company (USA), which is used for storing the location, shape and attributes of spatial objects.

SIGNATURE refers to any characteristic or the group thereof, according to which the object may be identified in the picture, image or data package. The signature may be represented by the spectral characteristics of the object or class of objects on the Earth's surface; it is called a spectral signature in this case.

SKETCH MAP means a simplified map without a map grid. Sketch map provides a general idea of the phenomena reproduced thereon.

SPACE PHOTO, SATELLITE IMAGE means an image of a surveyed object, obtained from the space with the use of RS tools.

SPACE PHOTO, SATELLITE IMAGE means an image of a surveyed object, obtained with the use of RS tools (surveying system) installed on the space-based platform (SV).

SPACE SEGMENT OF GPS means GPS segment, which contains up to 26 artificial satellites (it is expected that the number of satellites will increase in future) located in 6 orbits. Orbit planes are inclined at an angle of about 55° to the equator plane and shifted longitudinally by 60°. The radius of an orbit is about 26 thousand km, and the revolution period is half a star day (about 11 hours 58 minutes). Such satellite position allows to observe simultaneously at least 5 of them at any point of time and at any point on the Earth's surface. Transmitters that are installed on board of each satellite continuously radiate electromagnetic signals in the direction of the Earth's surface.

SPATIAL DATA REPRESENTATION, (GEO)SPATIAL DATA MODEL means a method of digital description of spatial objects, type of spatial data structure. The following methods are the most commonly and widely used: vector representation (vector-topological and vector-non-topological, or "spaghetti" model), raster, quadtree. Hypergraph model, the TIN model and multidimensional extensions thereof are less common or used to represent spatial objects of a certain type. Hybrid models of spatial data are also known. Machine forms of spatial data models is referred to as spatial data formats. There are methods and technologies for transition from one (geo) spatial data model to another one (for example, raster-vector, vector-raster transformation).

SPATIAL FREQUENCY IMAGE STRUCTURE — Space frequency representation of an image, which is made by Fourier representation or a function describing the image (in case of determined signals) or by autocorrelation function of the image (in case of random distribution of brightness). Spatial frequency image structure provides information about the availability of certain space harmonics in the image.

SPATIAL RESOLUTION — Characteristic of an image produced by image-forming (iconic) RS device, which is determined as the diameter of a circle with the smallest compact object on the earth's surface of the given contrast inserted in it that can be detected in the image with a given probability. Spatial resolution is expressed in units of length, usually in meters.

SPECTRAL BAND — The interval of the electromagnetic spectrum determined by two wavelengths.

SPECTRAL BAND; SPECTRAL INTERVAL is the interval of an electromagnetic spectrum determined by two wavelengths, two frequencies or by wave numbers. Spectral bands may be as follows: 1) optical: a) ultraviolet (UV) 1 nm — 0.38 μm; b) visible 0,38–0,76 μm; c) infrared (IR): — near 0.76–1.3 μm; — short 1.3–3.0 μm; — medium 3,— 8.0 μm; — distant 8.0 μm — 0.1 mm; 2) radio range: a) submillimeter 0.1–1.0 mm; b) microwave: — millimeter 1.0–10.0 mm; — centimeter 1.0–10.0 cm; — decimeter 0.1–1.0 m; c) ultrashort waves 1.0–10.0 m; d) short waves 10.0–100.0 m; e), medium waves 0.1–1.0 km; e) long waves 1.0–10.0 km; g) super-waves from 10.0 to 100.0 km. Sometimes the range of wavelengths of 8.0–14.0 μm is called thermal.

SPECTRAL SENSITIVITY — The ratio of the value characterizing the level of receiver's response (e. g., photo stream) to the radiation flux or energy of monochromatic radiation that produces such response. There is absolute spectral sensitivity, which is expressed in A/W, and dimensionless relative spectral sensitivity, which is the ratio of the spectral sensitivity at a given wavelength n to the maximum spectral sensitivity.

SPECTROMETER — an instrument used to receive and register spectral components of electromagnetic radiation. Measurement results are expressed in standard units.

SPECTRORADIOMETER — an instrument used to measure the spectral distribution (spectral density) of radiation energy. The measurement results are expressed in absolute units. The device combines the functions of spectrometer and radiometer.

SPECTROPHOTOMETER — is an instrument applied for photometric measurements. It compares the measured radiation flux with the reference one. It is intended for measuring transmission or reflection coefficients of materials depending on the wavelength.

SPECTRUM refers to the dispersion of (complex) radiation into monochromatic components. In terms of distribution (form), the spectrum may be continuous (constant), line and combined. Continuous is a spectrum the form whereof is described by a continuous function of continuous argument (radiation frequency or its wavelength). Continuous spectrum light is generated, for example, by a tungsten incandescent lamp; it is possible to see all of the spectral components of the visible and infrared wavelength ranges (although of varying intensity). In the line spectrum, the radiation energy is concentrated in the narrow frequency or wavelength bands. This spectrum is typical for gas-discharge lamps, coherent sources of optical radiation, in particular, semiconductor lasers. Combined (continuous linear) spectrum is produced, for example, by fluorescent lamps.

SPHEROID — The figure that the Earth could take in a state of hydrostatic equilibrium and under the influence of only the forces of interaction attraction between its particles and the centrifugal force of its rotation about permanent axis.

STEREOMODEL refers to the spatial model of remote sensing target obtained according to serial images. Stereomodel is used as the basis for the creation of digital elevation models.

SUN-SYNCHRONOUS ORBIT means an orbit of the Earth's satellite, a plane whereof is close to the polar one, and amplitude whereof is such, that a satellite passes over all points of the Earth, having the same latitude, twice a day at the same local solar time.

SUPERVISED CLASSIFICATION means the classification with training on reference image fragments, where the characteristics of the spectral reflection properties are determined for each pixel in all bands, and are comparable with the given classes of spectral features or with such on the reference objects.

SURFACE, RELIEF means a three-dimensional object belonging to four main types of spatial objects (along with points, lines, and polygons as planimetric objects), which is determined not only by plan coordinates, but also by Z applicate, that is triplet coordinates; body shell or a part thereof.

SURVEYING SYSTEM is a set of technical means used for acquisition and recording the electromagnetic radiation of the studied objects in the form of analogue or digital records.

THEMATIC EARTH SURFACE MAP — When information is analyzed in the form of a thematic map, the basis whereof is an aerial image with the required amendments, symbols and inscriptions.

TEMPERATURE — Physical value characterizing the system's thermodynamic equilibrium. If the system is not in equilibrium, it is subject to heat transfer. According to kinetic gas theory, texture is proportional to the average kinetic energy of microparticles.

TEXTURE — The notion that is used with relation to images having pronounced statistical properties. The characteristics of texture include homogeneity, density (tone), presence of long formations and their orientation, regularity of image structure, etc.

THERMAL RADIATION refers to electromagnetic radiation emitted (released) by the substance and generated by its inner energy (e. g. contrary to luminescence generated by external energy sources). Thermal radiation has a continuous spectrum, which maximum depends on the substance temperature. With its elevation, the total emitted energy increases while the maximum shifts towards small wavelengths.

THERMAL SURVEY is the formation of an image (photo) by registering the thermal radiation of the Earth's surface with millimeter and centimeter ranges of wavelengths. The characteristic of the radio-thermal image is that the distribution of the pixel amplitudes (half-tones) thereon reflects the nature of the distribution of the radiating surface temperatures. The temperature depends on the humidity, salinity, soil composition; therefore, dry and moistened soils, waters and dry lands etc. are well distinguished on radio-thermal images.

TOPOGRAPHICAL INTERPRETATION refers to the decoding of the elements of topographic maps content (coast, lakes, year, reservoirs, hydrography, relief, settlements, road networks and other natural and anthropogenic objects).

TRAINING SAMPLE is a set of object images with indication of the class of each object that is used for the training of the images recognition (interpretation) system. As a rule, training samples include images of objects of two or more classes.

TRANSMISSION — Propagation of radiation through a media without changes in the frequencies of its component monochromatic emissions.

TRANSPARENCY refers to the physical property of allowing light to pass through the material without being scattered. It is determined by the ratio of the luminous flux (radiation flux) propagating through a media for distance equal to the unit of length without changing its direction to the incident luminous flux (radiation flux) as parallel light.

TURBIDITY INDEX means the index of spectral brightness, which is determined when calculating the satellite image index to detect the concentration of suspended matter in water.

ULTRAVIOLET RADIATION — is a type of radiation with wavelengths of its monochromatic components shorter than the wavelengths of visible radiation and longer than approximately 1 nm. The boundaries of the spectral region of ultraviolet radiation are conventional and may vary depending on the purpose of their use. According to CIE, the spectral range from 100 and 400 nm can be subdivided into UVA (315–400 nm), UVB (280–315 nm), UVC (100–280 nm).

UNDERLYING SURFACE means a surface whereon sensing objects are located or on which background they are observed.

UNSUPERVISED CLASSIFICATION means the division of a given set into subsets in accordance with accepted rules for sorting objects by categories without the use of training samples.

VECTORIZATION is raster-to-vector transformation of spatial data. Since spatial information in raster form is represented in images, the transformation process includes recognizing images and has two main parts: image vectorization and topological or non-topological structuring of spatial information. In a more general case, the transformation process means the creation of a vector data model or vector representation.

VISIBLE RADIATION means radiation, which may directly cause visual sensation. The boundaries of the spectral range of visible radiation are conditional and may vary depending on the application. The lower boundary is usually found between 380 and 400 nm, the upper — between 760 and 780 nm.

WAVELENGTH is a distance in the direction of periodic wave distribution between two successive points with the same phase of oscillation. The wavelength in the medium is equal to the ratio of the wavelength in the void to the refractive index of the medium. Typically, the wavelengths are defined for air. In all other cases, the environment is displayed. The refractive index of normal air (15°C, 101 325 $N \cdot m^{-2}$) for visible radiation lies in the range from 1.00027 to 1.00029.

ZENITH is the point of intersection of a straight line or normal to the surface of the Earth ellipsoid with the celestial sphere.

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Methodological Guideline

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