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APPLICATION OF SATELLITE TECHNOLOGIES FOR MONITORING THE RADIATION STATE OF THE ATMOSPHERIC AIR DURING THE WAR AND POST-WAR RECONSTRUCTION OF UKRAINE

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The potential of satellite technologies as an effective tool for monitoring the radiation and chemical composition of atmospheric air under martial law in Ukraine is determined. The article analyses modern methods of collecting and processing data obtained from satellite platforms, as well as the possibilities of their application for identifying sources of pollution, assessing and forecasting the state of atmospheric air. The article provides an overview of the latest research tools that demonstrate the effectiveness of satellite observations in the early detection of environmental threats, forecasting changes in the composition of the atmosphere and optimising response measures in times of emergencies and the consequences of military impact. The article emphasises the importance of integrating innovative technologies into the state monitoring system to ensure sustainable development and operational control of the state of atmospheric air. It is proposed to carry out radiation monitoring using remote methods as an effective approach to identify environmental threats caused by radionuclide emissions and to predict changes in the composition of atmospheric air in the conditions of the wartime period in Ukraine.

INTRODUCTION

In Ukraine, after the Chornobyl disaster and in the context of the war period, attention should be paid to the development of a modern state monitoring system that will include continuous collection, analysis, assessment and forecasting of reliable and high-quality environmental data, especially in areas that are difficult to access for air sampling and where military operations are underway, especially with a focus on radiation monitoring using innovative observation methods. The importance of organising and conducting atmospheric air monitoring and assessing its condition is a strategic direction of the state environmental policy to achieve Ukraine's sustainable development goals on the way to implementing and harmonising national legislation with the requirements of the European Union (EU) and the International Atomic Energy Agency (IAEA) [1] in order to warn the population against possible health risks.

To obtain high-quality, highly accurate, continuous environmental data for monitoring the state of atmospheric air in Ukraine with subsequent prompt response and preventive measures in case of possible threats to the environment and public health in the context of man-made impacts, emergencies and military consequences, it is advisable to use satellite technologies and remote sensing. Environmental data obtained through satellite technology and remote air monitoring provide data on a large scale, from local areas to entire countries. The availability of these data facilitates timely assessment of radiation and chemical pollution of the atmospheric air composition with the possibility of building complex models to predict changes in the state of the atmospheric air, determine the directions of substance distribution and assess potential risks, with the subsequent development and implementation of measures at the state level to reduce pollution and improve air quality.

It is important to note that there is a problem with the use of satellite technologies and remote sensing for radiation monitoring, the experience of which is not sufficiently covered, and information is available in single studies, unlike studies of environmental data obtained by means and methods of remote sensing of chemical pollutants with their subsequent forecast and impact on the atmosphere using various platforms and resources.

The purpose of this paper is to focus on the use of satellite technologies and remote sensing methods as an approach to obtaining comprehensive data on air pollution monitoring, including radioactive substances, which should complement the data of state environmental monitoring, especially in the context of martial law and post-war reconstruction of Ukraine. This approach to the monitoring system will allow for timely response and consequences of pollution, modeling of the spread and assessment of the impact of radioactive substances on humans and the environment for further mapping and display in real time in order to implement operational measures to ensure environmental safety and prevent public health.

EXPERIENCE OF USING SATELLITE TECHNOLOGIES FOR ATMOSPHERIC AIR MONITORING IN THE WORLD AND IN UKRAINE

The organisation and conduct of state air monitoring is regulated by international legal documents, including the recommendations of the IAEA [1] and the Euroatom Council Directive on Radiation Safety [2], Directive 2008/50/EC on air quality and cleaner air for Europe [3], WMO global guidelines on air quality [4], and national legislation of Ukraine in the field of radiation control [5].

The national legislation in the field of atmospheric air monitoring is regulated by the Laws of Ukraine and regulations, which state that monitoring of radiation and chemical state of atmospheric air is carried out, including the use of satellite technologies and innovative technologies to obtain environmental and geophysical data for the purpose of assessing the impact and forecasting of atmospheric air pollution. The Laws of Ukraine "On Air Protection" [6] and "On Environmental Protection" [7] provide for the control of radiation and chemical pollution levels in the atmosphere, the Resolution of the Cabinet of Ministers of Ukraine of 13 June 2024 No. 684 "Some Issues of the Functioning of the State Environmental Monitoring System and its Subsystems" [8] and the Resolution of the Cabinet of Ministers of Ukraine of 14 August 2019 No. 827 "Procedure for State Monitoring in the Field of Atmospheric Air Protection" [9] provide for the possibility of applying

At the state level, radiation monitoring in Ukraine is carried out in accordance with the Law of Ukraine "On Nuclear Energy Use and Radiation Safety" [10] and [5], which provide for the use of automated radiation monitoring systems and establish the priority of human and environmental safety, define the legal basis for the use of ionising radiation sources, guarantee safety and radiation situation, and establish the legal basis for Ukraine's international obligations on the use of nuclear energy [1].

Radiation monitoring is carried out by the State Emergency Service of Ukraine (SESU), which monitors radiation safety throughout the country in accordance with the requirements and norms of the current legislation of Ukraine. The Ukrainian Hydrometeorological Service monitors the radiation situation. The State Agency of Ukraine on Exclusion Zone Management controls the Chornobyl zone. In accordance with the reform of Ukraine's national environmental policy on the path to EU integration and in accordance with the requirements of the Law of Ukraine "On the Basic Principles (Strategy) of the State Environmental Policy of Ukraine for the Period up to 2030" [11], it is envisaged to improve radiation and chemical monitoring systems in Ukraine due to the unsatisfactory state of the state environmental monitoring system, which requires methodological, technical and legislative changes in accordance with international norms and standards.

According to the national legislation of Ukraine, which is the legal basis for state monitoring, and international requirements, in particular Directive 2008/50/EC [3], monitoring of pollutants included in List A and List B of the Resolution of the Cabinet of Ministers of Ukraine [9] is mandatory. The main focus of Directive 2008/50/EC [3] is on chemical pollutants that may pose a risk and have a serious impact on health. In accordance with the WMO recommendations on air quality, in addition to the list of chemicals specified in Directive 2008/50/EC [3], the measurement of radon concentration in the air is subject to mandatory control. In addition, according to the first version of the requirements of the Resolution of the Cabinet of Ministers of Ukraine [9], when conducting air monitoring, it is mandatory to measure ionising radiation in order to protect the population from its negative impact.

Based on the WMO recommendations [4], stricter standards for air pollutants have been revised and set for the pollutants that cause millions of deaths and loss of healthy years of life.

International EU requirements in the field of air monitoring are implemented within the framework of EU initiatives, namely the European satellite air monitoring programme – Copernicus Atmospheric Monitoring Service (CAMS) [13], and the transmission of monitoring data with reporting to the European Environment Agency (EEA) [12].

Ukraine has experience in using international satellite technology platforms to obtain environmental monitoring data, including the European CAMS programme [13]. CAMS allows obtaining environmental monitoring data on the chemical composition of atmospheric air directly by direct measurements and satellite images, as opposed to radiation composition. It should be noted that one of the most important processes in the atmosphere is the transfer of radioactive substances, so it is proposed to use data obtained by modern high-performance computing platforms, such as the Global Modeling and Assimilation Office, NASA Goddard Space Flight Centre, for its further study [14].

In accordance with the harmonisation of national legislation with EU requirements, Ukraine is a voluntary participant and transmits radiological data to the European Radiological Data Exchange System (EURDEP) [15], which is developed and maintained by the European Commission's Joint Research Centre. According to Article 2(b) of the Euratom Treaty [16] and Council Directive 2013/59/Euratom [2], common safety standards are established to protect the health of workers and the public, and Article 30 of the Euratom Treaty defines 'basic standards' to protect the health of workers and the public from threats caused by exposure to ionising radiation.

Ukraine's experience in the field of remote radiation monitoring is represented by the State Space Agency of Ukraine and the National Space Facilities Management and Testing Centre, which analyses satellite images to assess environmental changes, including tracking the

radiation background based on the results of atmospheric aerosol analysis using domestic and international space-based remote sensing systems, as well as products and services based on them.

The SESU and the State Ecological Inspectorate of Ukraine also use satellite data from NASA [14] and ESA [17] to control the radiation situation and monitor forest fires in the Chornobyl zone. The public platform SaveEcoBot [18] uses international satellite technology platforms using NASA Terra satellites to display the results of radiation monitoring and displays the results of real-time monitoring data displayed on the publicly available website [14].

Previous experience in the application and use of various remote sensing methods that allow obtaining spatially detailed information and time series of data for monitoring changes in the radiation situation in Ukraine is given in Table.

Previous experience of using remote sensing methods to obtain radiation monitoring data in Ukraine

Approach	Method characteristics	Experience
Satellite sensing	Analysis of surface spectral characteristics, use of multispectral data. Data from Sentinel-2 and Landsat satellites can interpret parameters that indirectly indicate radioactive contamination.	Although satellite platforms are designed to monitor land cover and environmental changes, their data are integrated with radiometric measurements to build complex models.
Airborne radiometric sensing	Conducting aerial surveys using specialised radiometric systems that measure gamma radiation. These systems install sensors on aircraft or helicopters, which allows for the creation of detailed maps of the radiation background.	The method is widely used, in particular, in the areas around the Chernobyl nuclear power plant, where large-scale mapping of radioactive contamination was carried out after the accident.
Drone (unmanned aerial vehicles (UAVs)) sensing	The use of UAVs equipped with compact radiometric sensors allows for measurements at low altitudes and in hard-to-reach areas and territories where military operations are underway.	The use of UAVs has become increasingly popular in recent years, as they provide high spatial resolution and speed of data collection.
Ground-based measurement systems	Construction of networks of stationary observation points that continuously monitor the radiation background, the data from which are used to verify and calibrate data obtained from airborne and satellite systems.	Such networks are used by government agencies and scientific research institutions to ensure a high level of measurement reliability.

RESEARCH METHODOLOGY

This paper analyses and proposes the use of the experience of international platforms, among which the most widespread and accessible is the European Union's Earth monitoring programme in the Copernicus services [13], and the European Space Agency (ESA) [17] provides access to Sentinel satellite data and databases of this programme, covering various aspects of remote sensing for environmental data collection and providing comprehensive data, forecasts and analysis of atmospheric composition data, and some of the satellites in the programme are equipped with instruments capable of detecting and measuring ionising radiation.

The mechanism of radiation background measurement by the Copernicus EU programme [13] is based on the use of specialised satellite sensors, the Sentinel-2 programme and the use of Landsat systems [14], which, using spectrometric analysis to record gamma radiation. Their data, combined with radiometry and other analytical methods of analysis, are indirect indicators of changes in the radiation background. The data undergoes a calibration and correction process and correction, and then integrated with information from ground-based systems to create accurate maps of the distribution of radiation contamination distribution.

The EU Copernicus Sentinel-5P series satellites are equipped with the TROPOMI (TROPOspheric Monitoring Instrument) [19], which measures the concentrations of various gases and aerosols in the atmosphere that affect air quality and climate. It is not directly designed to measure radiation background, but its data can also be used to assess atmospheric conditions that affect the spread of radioactive substances. In addition, the Copernicus programme cooperates with other international missions and organisations that directly provide radiation data.

MODIS (Moderate Distributed Spectroradiometer) [20] was created on NASA Terra satellites [14], and, playing an important role in the remote monitoring system, you can study it in the atmosphere, hydrosphere and on the ground surfaces. When MODIS is introduced into the analysis of an object, it is necessary to use MODIS to analyse the current effects of the theory, global economic analysis of climate change, etc. It has a wide coverage area of about 2.330 km, which allows it to obtain global images every 1-2 days. The advantages of using

MODIS in satellite systems for monitoring atmospheric air are represented by measuring aerosol optical characteristics, which allows assessing the level of air pollution and the distribution of fine particles; detecting clouds, their structure, as well as monitoring concentrations of greenhouse gases and other atmospheric impurities; and implementing global environmental monitoring.

Various available tools and image processing software, including GIS technologies, are used to process remote sensing data.

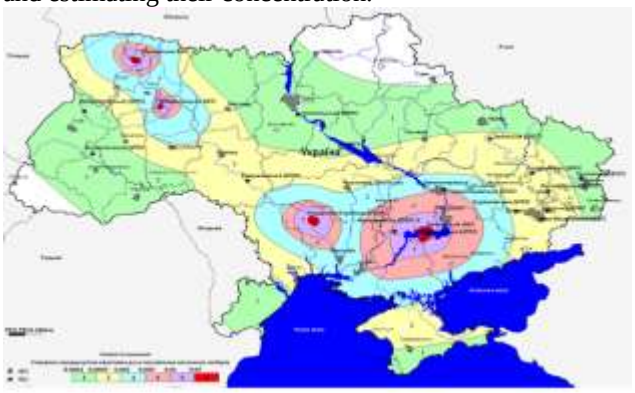
Therefore, the use of an integrated approach that allows both to respond promptly to radiation impacts and to conduct long-term environmental monitoring will ensure a high level of safety and reliability when obtaining radiation data from satellite monitoring.

The approach proposed by the authors will include the use of integrated monitoring data obtained using the latest satellite technologies as an additional component to the state environmental monitoring system, as one of the powerful tools for government bodies to develop strategies and plan measures to reduce air pollution and control compliance with environmental standards for making management decisions to prevent emergencies and respond promptly to them, especially in conditions of martial law in Ukraine.

The basis for applying an integrated approach to radiation monitoring is data from international satellite platforms for monitoring the composition of atmospheric air, which allows obtaining information about the distribution of concentrations of atmospheric air pollutants. It is worth noting that the radiation component in obtaining data from satellite technologies and remote sensing by direct measurements is underdeveloped, compared to obtaining monitoring data on the chemical component for assessing the state of atmospheric air in order to track its changes. In the approach proposed by the authors, attention is paid to the most important process of monitoring the radiation state of atmospheric air in terms of forecasting and early warning of changes in atmospheric air quality and modelling the distribution of radiation emissions with subsequent mapping. The result of such monitoring can be presented in the form of an interactive map with the distribution areas of radioactive substances, as proposed, for example, in the work [21] of one of the authors of this publication, which is shown in Figure. Such an interactive map will provide a detailed picture of the distribution of radioactive substances in real time.

It is important to note the aspects of using satellite technologies to monitor atmospheric air pollution by radioactive substances.

Satellite monitoring of atmospheric air pollution by radionuclides involves the use of specialized orbital platforms and sensor systems to detect and map radioactive contamination over large areas. Satellites can be equipped with specialized detectors, such as gamma spectrometers, which are capable of recording highly sensitive signals from radionuclides. In addition to direct measurements, optical and infrared sensors are used to determine the changed parameters of atmospheric aerosols that can accompany radioactive contamination. The data received from the detectors undergo pre-processing directly on board the satellite to reduce the amount of information transmitted to Earth. Using special algorithms, the spectral characteristics of the radiation are analyzed, which allows identifying specific radionuclides and estimating their concentration.



Distribution of individual effective doses of ionising radiation to the population from emissions from Ukrainian nuclear power plants [21] (the figure is in the original language)

Satellite data is transmitted to ground processing centers, where detailed interpretation of the information is carried out. Integration of satellite measurements with data from ground stations allows for a more complete picture of the spread of pollution, as well as data verification.

Based on satellite monitoring data sources, models of the distribution of radioactive substances in the atmospheric air are being developed, which allow predicting their contamination and timely informing authorities and the population in order to respond promptly to them.

Thus, satellite technologies for monitoring atmospheric air pollution by radioactive substances are an important tool for timely detection and assessment of threats, contributing to increasing the effectiveness of warning and public protection systems.

CONCLUSIONS

Ukraine does not have its own satellite observation systems, and monitoring data is provided by European and American environmental monitoring platforms. Integration of monitoring data from various sources using satellite, aviation, UAV and ground systems will allow obtaining a more complete picture of the distribution of radioactive contamination and timely response to possible threats to the environment and the population.

It is important to carry out reforms at the legislative, organizational, and methodological levels in order to improve the current state environmental monitoring system, especially during martial law in Ukraine.

The use of satellite technologies for radiation monitoring of atmospheric air has a number of advantages that can significantly supplement the state environmental monitoring system with environmental data, which is especially relevant in the conditions of martial law and post-war reconstruction of Ukraine. The use of the integrated approach proposed in the article with obtaining satellite data will contribute to increasing the efficiency of monitoring and comprehensive assessment of the state of atmospheric air with the further development of the latest technologies at the state level in the direction of the state's environmental policy in accordance with the framework of European legislation. The use of satellite technologies, in particular the CAMS [13] and NASA [14] platforms, for research and monitoring of the radiation state of the atmospheric air during martial law in Ukraine and post-war recovery will increase the efficiency of comparative quality analysis, providing daily forecasts of air quality, global atmospheric transport of pollutants, including radioactive ones over long distances, as well as background air quality, including the entire territory of Ukraine. Integration of satellite monitoring data into the state monitoring system is advisable when obtaining additional, more accurate data and conducting a comprehensive study of the composition of atmospheric air and making operational management decisions.

Further prospects for the development of the state monitoring system in Ukraine are the development of satellite technologies in Ukraine with the involvement of international funds and partners with experience in the field of satellite monitoring.

Ambitious goals include creating our own platforms and observation networks that will meet European requirements, integrating into the international satellite observation network, taking into account the best global practices and involving international experts to train Ukrainian specialists in working with the latest technologies and analyzing data from satellite observation systems.

Investing in environmental monitoring with the development of national satellite technologies can ensure independence and efficiency in data collection, and the creation of a single platform for collecting and analyzing data from ground stations and satellites will contribute to more accurate and comprehensive environmental monitoring during martial law and post-war reconstruction in Ukraine.

REFERENCES

1. IAEA Safety Standards. Series No. GSR Part 3. Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards. IAEA Vienna, 2014. URL: https://www-pub.iaea.org/MTCD/publications/PDF/Pub1578_web-57265295.pdf.
2. Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom.
RL: https://eur-lex.europa.eu/eli/dir/2013/59/oj/eng.
3. Directive 2008/50/EC on ambient air quality and cleaner air for Europe. URL: https://zakon.rada.gov.ua/go/994_950
4. WMO Air Quality and Climate Bulletin URL: https://wmo.int/publication-series/wmo-air-quality-and-climate-bulletin-no-4-september-2024.
5. Resolution of the Cabinet of Ministers of Ukraine dated April 29, 2022 No. 323-r. “On approval of the Strategy of the Integrated Automated Radiation Monitoring System for the period until 2024”. URL: https://zakon.rada.gov.ua/go/323-2022-%D1%80.
6. Law of Ukraine “On Air Protection”. URL: https://zakon.rada.gov.ua/go/2707-12.
7. Law of Ukraine “On Environmental Protection” URL: https://zakon.rada.gov.ua/go/1264-12.
8. Resolution of the Cabinet of Ministers of Ukraine dated June 13, 2024, No. 684 “Some issues of the functioning of the state environmental monitoring system and its subsystems”. https://zakon.rada.gov.ua/laws/show/684-2024-%D0%BF#Text.
9. Resolution of the Cabinet of Ministers of August 14, 2019 No. 827 “Some issues of state monitoring in the field of atmospheric air protection” as amended by Resolution of the Cabinet of Ministers of May 7, 2023, No. 513. URL: https://zakon.rada.gov.ua/laws/show/827-2019-%D0%BF#Text.
10. Law of Ukraine “On the use of nuclear energy and radiation safety”. URL: https://zakon.rada.gov.ua/laws/show/39/95-%D0%B2%D1%80#Text.
11. Law of Ukraine “On the Basic Principles (Strategy) of the State Environmental Policy of Ukraine for the Period Until 2030”. URL: https://zakon.rada.gov.ua/laws/show/2697-19#Text
12. European Environmental Agency. URL: https://www.eea.europa.eu/en
13. Copernicus (CAMS) EU. URL: http://atmosphere.copernicus.eu/.
14. Global Modeling and Assimilation Office, NASA Goddard Space Flight Center URL: https://gmao.gsfc.nasa.gov/
15. The EUropean Radiological Data Exchange Platform (EURDEP) URL: https://remon.jrc.ec.europa.eu/About/Rad-Data-Exchange.
16. Treaty establishing the European Atomic Energy Community URL: https://zakononline.com.ua/documents/show/342775___342840##document_code__994_027__##
17. European Space Agency URL: https://www.esa.int/
18. SaveEcoBot URL: https://www.saveecobot.com/widgets/air-quality-informer/

19. The TROPOspheric Monitoring Instrument. URL: https://www.tropomi.eu/
20. MODIS. URL: https://modis.gsfc.nasa.gov/
21. G.D. Kovalenko. Radioecology of Ukraine: Monograph / 3rd ed. Kharkiv, 2013, 344 p.

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ЗАСТОСУВАННЯ СУПУТНИКОВИХ ТЕХНОЛОГІЙ ДЛЯ МОНІТОРИНГУ РАДІАЦІЙНОГО СТАНУ АТМОСФЕРНОГО ПОВІТРЯ В УМОВАХ ВІЙНИ ТА ПІСЛЯВОЄННОГО ВІДНОВЛЕННЯ УКРАЇНИ

Г.В. Хабарова, Г.Д. Коваленко, С.В. Барбашев

Визначено потенціал супутникових технологій як ефективного інструменту для моніторингу радіаційного та хімічного складів атмосферного повітря в умовах воєнного стану в Україні. Проаналізовано сучасні методи збору та обробки даних, отриманих із супутникових платформ, а також можливості їх застосування для виявлення джерел забруднення, оцінки та прогнозу стану атмосферного повітря. Представлено огляд новітніх засобів дослідження, що демонструють ефективність супутникових спостережень у ранньому виявленні екологічних загроз, прогнозуванні змін у складі атмосфери та оптимізації заходів щодо реагування в період виникнення надзвичайних ситуацій та наслідків впливу воєнного характеру. Підкреслено важливість інтеграції інноваційних технологій у систему державного моніторингу для забезпечення стійкого розвитку та оперативного контролю стану атмосферного повітря. Запропоновано проведення радіаційного моніторингу з використанням дистанційних методів як ефективного підходу для виявлення екологічних загроз, спричинених викидами радіонуклідів та прогнозування змін складу атмосферного повітря в умовах воєнного періоду в Україні.