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2018—2020

Report to COSPAR

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SRI NASU-SSAU
Space Research Institute
of National Academy of Sciences of Ukraine
and State Space Agency of Ukraine
Ukraine
03680, Kyiv 187
40, Glushkov Ave., bilding 4/1
http://www.ikd.kiev.ua

NASU
National Academy of Sciences of Ukraine
Ukraine
01601, Kyiv 30
54, Volodymyrska St.
http://www.nas.gov.ua

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Report to COSPAR summarizes the results of space research performed during the years 2018—2020. This edition presents the current state of Ukrainian space science in the following areas: Space Astronomy and Astrophysics, Earth observation and Near-Earth Space Research, Life Sciences, Space Technologies and Materials Sciences. A number of papers are dedicated to the creation of scientific instruments for perspective space missions. Considerable attention paid to applied research of space monitoring of the Earth. The collection can be useful for a wide range of readers, interested in space research.

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FOREWORD

The publication represents the results of space research and developments, performed by leading Ukrainian scientific teams in the years 2018–2020. Unfortunately, during this period, Ukrainian scientists were not supported by the National Space Programme, which was not developed and adopted by the Parliament. Therefore, this edition includes the works supported by the National Academy of Sciences and international grants in the following areas: Space Astronomy and Astrophysics, Near Earth Space Research, Space Biology, Earth Observation from Space, Space Technologies and Materials Science (according to the classification of COSPAR).

Section "Space Astronomy and Astrophysics" represents the review of the Institute of Radio Astronomy on synchronous coordinated ground-based support of space missions using Ukrainian radio telescopes UTR-2.

The second section includes the results of studying the processes in the Earth's atmosphere — ionosphere — magnetosphere system. The articles of Space Research Institute specialists are devoted to the mechanisms of seismic-ionospheric coupling and creation of operational service for local geomagnetic forecast. Researchers of the Institute of Technical Mechanics present the modeling of complicated interactions of a spacecraft with Earth ionosphere. The new concept of the particle microbursts satellite experiment advanced by the team of scientists including experts of the Institute of Radio Astronomy. Three articles reviews the different aspects of the interactions of Geospace environment with natural and man-made objects.

The next series of review articles represents the Ukrainian science centers activity in the Space Biology, Space Observation of the Earth and Space Technologies. Most of them dedicated to perspective space missions and utilization of space data for assessment the sustainable development goals.

In general, the presented review illustrates the current state and multidimensionality of the subjects of Ukrainian space science. Some of the results were obtained in the framework of international projects, programs and grants, including the European program Horizon 2020, and most of the results had been reported at the annual Ukrainian Conference on Space Research, international seminars and conferences.

The collection is intended for space scientists, post-graduate students and readers interested in space research.

ASSESSMENT OF SUSTAINABLE DEVELOPMENT GOALS WITHIN THE EUROPEAN NETWORK FOR OBSERVING OUR CHANGING PLANET (ERA-PLANET)

N. Kussul[1, 2], A. Shelestov[2, 1], M. Lavreniuk[1, 2], B. Yailymov[1], O. Fedorov[1], A. Kolotii[1, 2], H. Yailymova[1, 3], S. Skakun[4], L. Shumilo[1, 2], Y. Bilokonska[1], L. Kolos[1]

[1] Space Research Institute of NAS of Ukraine and SSA of Ukraine
[2] National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"
[3] Taras Shevchenko National University of Kyiv
[4] University of Maryland, College Park, MD, USA

Introduction

The ERA-PLANET Horizon 2020 project "The European Network for Observing our Changing Planet" is a contribution of the European Community for addressing the objectives of international agreements such as the Sustainable Development Goals (SDGs), the Paris Agreement on Climate and the Sendai Framework for Disaster Risk Reduction. One of the four strands, GEOEssential [1], of the project is focusing on Resource Efficiency and Environmental Management. Within this strand, Earth observation (EO) data are used for monitoring resource efficiency utilization, as well as for assessing the progress towards achieving SDGs. The main task of our research in this project is to contribute to SDG on agriculture aiming at: end hunger, achieve food security and improved nutrition, promote sustainable agriculture aimed at ensuring sustainable food production systems and implementing resilient agricultural practices. To reach these goals, specific targets have been set: ensuring the conservation, restoration and sustainable use of inland freshwater ecosystems and their services. In this paper, we focus on three particular indicators, namely:

- 2.4.1. Proportion of agricultural area under productive and sustainable agriculture;
- 15.1.1 Forest area as proportion of total land area; and
- 15.3.1 Proportion of land that is degraded over total land area.

Within the Global Support Program, a pilot project was setup by the UN Committee on Combating Desertification and the Security Assistance Program with the aim of reaching Land Degradation Neutrality (LDN). The goal of LDN is to maintain or enhance the natural capital of the land and associated land-based ecosystem services. Land cover change, land productivity dynamics (LPD) and organic carbon stock are selected as sub-indicators for the indicator 15.3.1. Land cover changes evaluated based on ESA’s Climate Change Initiative (CCI) Land Cover dataset and EC Joint Research Centre’s (JRC) LPD dataset are used as default sources for land productivity assessment [2]. The main problems associated with these datasets are coarse spatial resolution and lower accuracy compared to regional based products [3, 4].

Therefore, this study aims to fill the above-mentioned gap by improving the calculation of the SDG indicators through the use of moderate and high spatial resolution data [5, 6]. The main goal is to apply and improve the methodologies, which were used for generating global products with coarse spatial resolution data, to higher spatial resolution data, which will be better suited for regional products and applications. For calculating the selected SDG indicators, we use a food-water-energy nexus approach based on satellite data [7], in-situ data, vegetation indices (VIs) and meteorological data. Since global land cover products have lower accuracy for Ukraine compared to regional products [8], we use regional land cover maps with high spatial resolution based on Landsat 8, Sentinel-2 and Sentinel-1 data [9]. These regional land cover maps were produced using the state-of-the-art methodology based on deep learning approach [10–12]. We also propose a new improved methodology for calculating a land productivity map based on high spatial resolution satellite data.

Methodology

Workflows for calculating SDG indicators. From the list of 232 SDG indicators, we present a general workflow [13] for calculating three selected SDGs indicators as shown in Fig. 1.

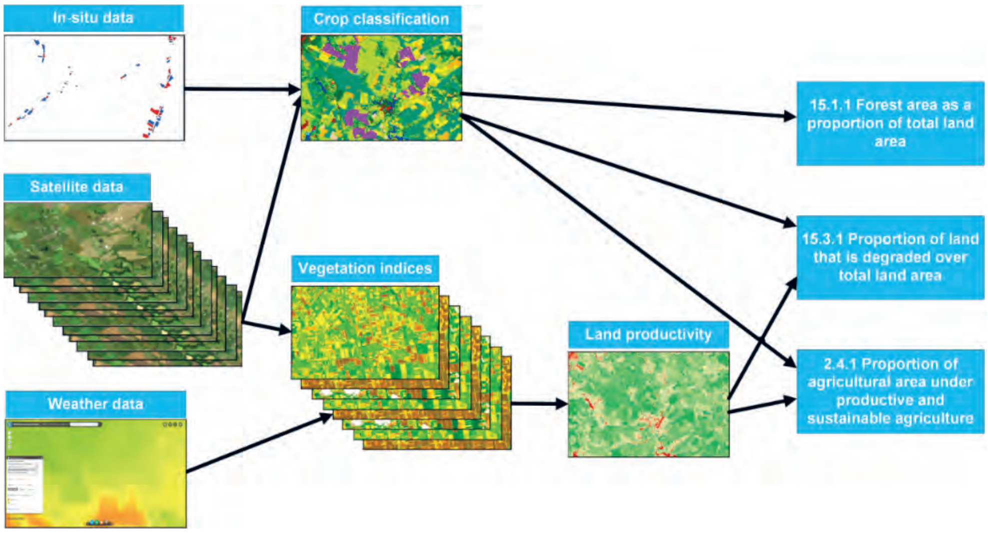


Fig. 1. Workflow for calculating Sustainable Development Goals indicators 15.1.1, 15.3.1 and 2.4.1

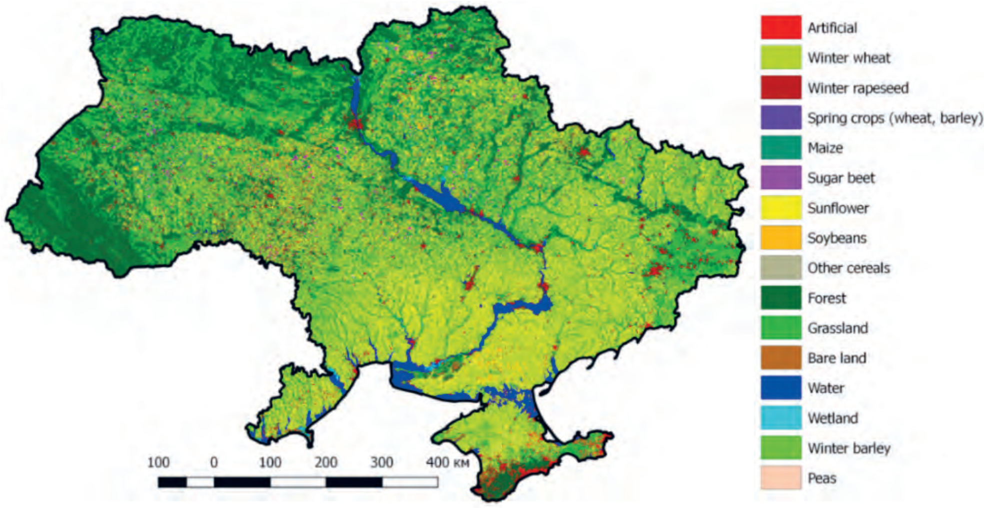
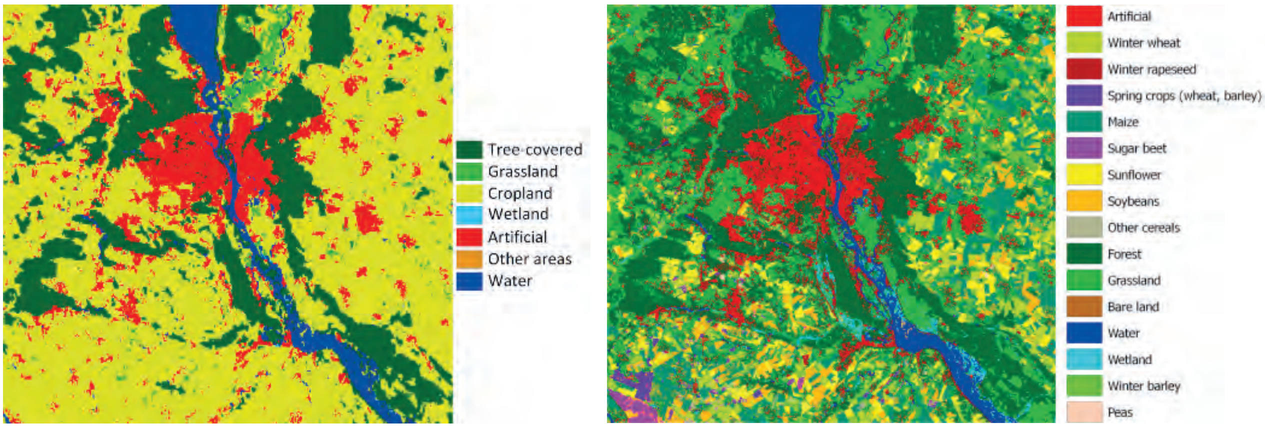


Fig. 2. Crop classification map at 10 m spatial resolution for Ukraine for 2017

GEOEssential ERA-Planet project is focused on development of workflows for Essential Variables (EVs) monitoring and SDG estimation using remote sensing (RS) data within nexus approach. This nexus approach is considering environmental system as model constructed from food, water and energy components and relationships between them. Thus, EVs can often belong to more than one nexus approach component. Within the project the list of EVs for food-water-energy nexus approach was created and described in deliverable 6.1 "Description of Food Water Energy EVs" [14]. Workflows for indicators 15.1.1, 15.3.1 and 2.4.1 based on EVs related to food, water, energy nexus approach was developed.

EVs from the food security domain include crop area and crop type represented by crop classification map, crop condition assessment and crop phenology characterized by vegetation indices (VIs) as such as NDVI, DVI, EVI [15], and biophysical parameters [16] such as leaf area index (LAI) [17]. For better estimation of crop condition and crop phenology with the use of VI, weather data that relate to Water and Energy Essential Variables are valuable. Water and Energy Essential Variables include precipitation, evaporation, surface air temperature, solar surface irradiation, humidity, and wind speed. These agrometeorological parameters are essential for VI modelling and enhancement of satellite-based estimation of crop productivity [18].

Workflow for calculating indicator 15.3.1. The indicator "15.3.1 Proportion of land that is degraded over total land area" is a binary, degraded/not degraded, quantification based on the analysis of available data for sub-indicators to be validated and reported by national authorities (namely, Trends in Land Cover, Land Productivity and Carbon Stocks) [13, 19]. This indicator is based on



a *b*

Fig. 3. Visual comparison of the (*a*) 300m landcover ESA CCI-LC and with the (*b*) 10m crop classification map for Kyiv

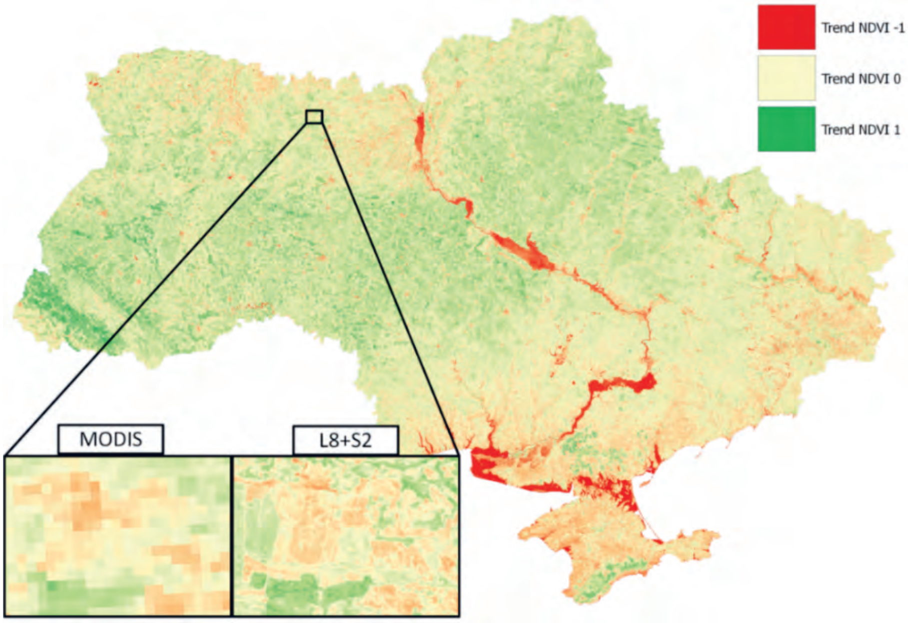


Fig. 4. Comparison coarse resolution productivity map based on MODIS data and our high-resolution productivity map for Ukraine territory for the year 2017

statistical principal "One Out, All Out" on evaluation of changes in the sub-indicator. This principle means that we have three types of changes in the sub-indicators, which are depicted as positive or improving, negative or declining and sustainable or unchanging. If one of the sub-indicators has negative changes for some area, then this area has negative productivity.

Our proposed methodology is based on a deep learning approach, in particular an ensemble of neural networks [12]. At the core of the architecture are multilayer perceptrons (MLP), which are trained using different parameters and architectures (number of hidden layers), and form an ensemble, which outperforms any of the individual MLPs. The rectified linear unit (ReLU) function is used as the activation function for neurons in the hidden layers,

Table 1

Forest area as a proportion of total land area by statistics and our classification maps in 2000, 2010 and 2016 years

	2000	2010	2016
Statistics	0.172	0.172	0.176
Classification maps	0.176	0.179	0.189

Table 2

Indicators 15.3.1 and 2.4.1 for territory of Ukraine for 2016 and 2017 years

	2016	2017
Indicator 15.3.1	46.19%	48.24%
Indicator 2.4.1	37.6%	42.8%

and training of the MLPs is performed using a stochastic gradient-based optimizer. In order to avoid overfitting, an L2 regularization was used with regularization coefficient set to 0.1, and learning rate was set to 10^{-3}. A committee of neural networks is used for providing crop classification and land cover maps for Ukraine using high spatial resolution Landsat 8, Sentinel-1 and Sentinel-2 imagery [20–23] and appropriate in-situ data for 2000, 2010, 2016 and 2017 [24–26]. The spatial resolution of the resulting maps is 30m for 2000 and 2010, and 10m for 2016 and 2017 (Fig. 2).

The overall accuracy is improved by more than 10 % compared to ESA's Climate Change Initiative Land Cover dataset; the kappa coefficient for ESA's Climate Change Initiative Land Cover dataset is 0.75, while the kappa coefficient for our map is 0.9 [8]. Fig. 3 shows the difference between coarse-resolution ESA's Climate Change Initiative Land Cover for 2015 and our high-resolution classification map for 2016 year in Kyiv region.

Workflow for calculating indicator 2.4.1. The indicator "2.4.1: Proportion of agricultural area under productive and sustainable agriculture" can be calculated using the same methodology as proposed for indicator 15.3.1 calculation. This indicator is a ratio of agricultural area that has a positive productivity value to the total agricultural area by the rule "One Out, All Out". For this indicator, we use the same sub-indicators as for indicator 15.3.1, but the area of interest is not the whole land area, but rather the agricultural (cultivated) land. For this indicator, the use of high spatial resolution satellite images is particularly important, since mixed pixels greatly affect the value of sub-indicator changes.

Workflow for calculating indicator 15.1.1. The indicator "15.1.1 Forest area as proportion of total land area" is a ratio of all land area to forest area. We estimate total land area, removing water and wetland areas, using classification map, and then calculate this indicator as proportion of forest area to total land area.

Implementation of the SDG Indicator's workflows in the Virtual Laboratory. In the ECOPotential project (http://www.ecopotential-project.eu), several partners are responsible for generating heterogeneous resources such as satellite data, in-situ data, services, analysis and modelling tools, processing algorithms, models/workflows and models results. To address these requirements, an interoperability framework, that was developed as a Virtual Laboratory (VLab: https://vlab.geodab.eu/), provides a web service-based access to the resources. Using cloud computing resources [27], with direct access to data of the GEOSS Portal, VLab has the ability to introduce workflows to calculate and monitor essential variables of water, food and energy and, accordingly, to calculate SDGs indicators for different countries around the world. We use the VLab tool to calculate the indicators 2.4.1 and 15.3.1. The benefits of using VLab are an opportunity to implement complex workflows in a cloud platform [28] with an easy access to data from GEOSS and other major data providers and the possibility of knowledge generation for ECOPotential storylines. The workflow for indicator 2.4.1 calculation in VLab takes as an input a classification map with agricultural classes of land cover and a time series of satellite images [29] for several years. For indicator 15.3.1 VLab takes land cover change map and land productivity map as inputs, calculates area of productive land and total area of land, and outputs their ratio.

Results

Using the proposed workflow shown in Fig. 1, we calculated indicators 15.1.1, 15.3.1 and 2.4.1 for the territory of Ukraine. Forest and total land area values were derived from land cover maps for 2000, 2010 and 2016. Thus, indicator 15.1.1 was calculated as a proportion of forest and total land area for these years (Table 1). We could see the positive trend when using statistics data as well as with satellite data. It means that in Ukraine, forest plantations dominate deforestation.

A land productivity map has been obtained using NDVI based on high resolution Sentinel-2 and Landsat-8 satellite images for 2013–2017 years. In Fig. 4, a comparison of coarse resolution productivity map based on MODIS data and our high-resolution productivity map is shown for Ukraine territory for 2017. Using our high-resolution productivity map and crop classification map we calculated indicators 15.3.1 and 2.4.1 for territory of Ukraine for 2016 and 2017. Combined values of indicators 15.3.1 and 2.4.1 for 2016 and 2017 are shown in Table 2.

We can observe a positive dynamic in productivity growth for all land from 46.19 % to 48.24 % and for agricultural land from 37.6 % to 42.8 %, but the area with negative trend of vegetation index is still more than 29.046 thousand ha. The growth can be explained by the introduction of effective agricultural practices, the establishment of harvesting systems, but usually these actions are carried out in large agricultural lands or in fields belonging to large agricultural enterprises, so this large part of the land with a negative trend still exists. Particularly highlighted with the negative value of productivity, we find: Eastern Ukraine [30] and Crimea due to the deterioration of the situation and problems with access to water; and Western Ukraine through deforestation. If we consider general growth, then, in addition to improving the conditions of agricultural land in Ukraine, there is a restoration of cut down forests, which provide improvement each year with a significant trend of vegetation. According to the State Agency for Forest Resources of Ukraine, 52.6 thousand hectares of forest was restored in 2016, and 53.2 thousand ha in 2017.

Conclusions

In this paper, we proposed an improved workflow based on satellite data, in-situ data, Essential Variables, vegetation indexes and meteorological data for calculating three SDG indicators "2.4.1 Proportion of agricultural area under productive and sustainable agriculture", "15.1.1 Forest area as proportion of total land area" and "15.3.1 Proportion of land that is degraded over total land area and indicator". Within a pilot project of the UN Committee on Combating Desertification and the Security Assistance Program, a methodology for calculating index 15.3.1 was developed. It is based on ESA's Climate Change Initiative Land Cover dataset and JRC LPD dataset. These datasets are global and therefore have course spatial resolution and not perfectly accurate. Thus, we used land covers provided by our deep learning methodology based on high spatial resolution imagery from Landsat, Sentinel-2 and Sentinel-1 for Ukraine territory. Quality and accuracy of such land covers are much higher than global ones (gain is approximately 10%). Also, in this study, we proposed a new methodology for generating a land productivity map using high spatial resolution Sentinel-2 and Landsat-8 data that allow us to calculate indicator 15.3.1 and other derivatives indicators 15.1.1 and 2.4.1 more precisely. We conclude that newly available high-resolution RS products can significantly improve our capacity to assess several SDGs indicators through dedicated workflows from data to indicators and through essential variables.

REFERENCES

1. Kussul N., Lavreniuk M., Shumilo L., Kolotii A., Rakoid O., Yailymov B., Shelestov A., Vasiliev V. Assessment of Sustainable Development Goals Achieving with Use of NEXUS Approach in the Framework of GEOEssential ERA-PLANET Project. *Recent Developments in Data Science and Intelligent Analysis of Information*. 2018.

2. Gallego J., Kussul N., Skakun S., Kravchenko O., Shelestov A., Kussul O. Efficiency assessment of using satellite data for crop area estimation in Ukraine. *International Journal of Applied Earth Observation and Geoinformation*. 2014. Vol. 29. P. 22–30.

3. Kussul N., Shelestov A., Basarab R., Skakun S., Kussul O., Lavreniuk M. Geospatial intelligence and data fusion techniques for sustainable development problems. *11th International Conference on ICT in Education, Research and Industrial Applications: Integration, Harmonization and Knowledge Transfer*, ICTERI 2015 (14–16 May 2015, Lviv, Ukraine). 2015. Vol. 1356. P. 196–203.

4. Lavreniuk M., Kussul N., Skakun S., Shelestov A., Yailymov B. Regional Retrospective High Resolution Land Cover For Ukraine: Methodology And Results. *International Geoscience and Remote Sensing Symposium 2015* (IGARSS 2015), № 15599383, P. 3965–3968.

5. Kussul N., Skakun S., Shelestov A., Lavreniuk M., Yailymov B., Kussul O. Regional scale crop mapping using multi-temporal satellite imagery. *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences*. 2015. P. 45–52.

6. Lavreniuk M., Skakun S., Shelestov A., Yalimov B., Yanchevskii S., Yaschuk D., Kosteckiy A. Large-Scale Classification of Land Cover Using Retrospective Satellite Data. *Cybernetics and Systems Analysis*. 2016. Vol. 52, No. 1. P. 127–138.

7. Kussul N., Lavreniuk M., Shumilo L., Kolotii, A. Nexus Approach for Calculating SDG Indicator 2.4.1 Using Remote Sensing and Biophysical Modeling. *IGARSS 2019-2019 IEEE International Geoscience and Remote Sensing Symposium*. 2019. P. 6425–6428.

8. Kussul N., Kolotii A., Shelestov A., Yailymov B., Lavreniuk M. Land degradation estimation from global and national satellite based datasets within UN program. *Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications (IDAACS), 9th IEEE International Conference*. 2017. Vol. 1. P. 383–386.

9. Kussul N., Shelestov A., Skakun S. Flood Monitoring from SAR Data. *NATO Science for Peace and Security Series C: Environmental Security*. 2011. P. 19–29.

10. Kussul, N, Skakun S., Shelestov A., Kussul O. The Use of Satellite SAR Imagery to Crop Classification in Ukraine within JECAM Project. *IEEE Geoscience and Remote Sensing Symposium*. 2014. P. 1497–1500.

11. Kussul N., Skakun S., Shelestov A., Kravchenko O., Gallego F., Kussul O. Crop Area Estimation in Ukraine Using Satellite Data within the MARS Project. *IEEE International Geoscience and Remote Sensing Symposium*. 2012. P. 3756–3759.

12. Kussul N., Lavreniuk M., Skakun S., Shelestov A. Deep learning classification of land cover and crop types using remote sensing data. *IEEE Geoscience and Remote Sensing Letters*. 2017. Vol. 14(5). P. 778–782.

13. Kussul N., Lavreniuk M., Kolotii A., Skakun S., Rakoid O., Shumilo L. A workflow for sustainable development goals indicators assessment based on high-resolution satellite data. *International Journal of Digital Earth*. 2019.

14. McCallum I., Montzka C., Bayat B., Kollet S., Kolotii A., Kussul N., Mosnier A. Developing food, water and energy nexus workflows. *International Journal of Digital Earth*. 2020. Vol. 13(2). P. 299–308.

15. Kogan F., Kussul N., Adamenko T., Skakun S., Kravchenko O., Kryvobok O., Shelestov A., Kolotii A., Kussul O., Lavrenyuk M. Winter wheat yield forecasting in Ukraine based on Earth observation, meteorological data and biophysical models. *International Journal of Applied Earth Observation and Geoinformation*. 2013. Vol. 23. P. 192–203.

16. Kogan F., Kussul N., Adamenko T., Skakun S., Kravchenko O., Kryvobok O., Shelestov A., Kolotii A., Kussul O., Lavrenyuk A. Winter wheat yield forecasting: A comparative analysis of results of regression and biophysical models. *Journal of Automation and Information Sciences*. 2013. Vol. 45, No. 6. P. 68–81.

17. Shelestov A., Kolotii A., Skakun S., Baruth B., R. Lopez Lozano, Yailymov B. Biophysical parameters mapping within the SPOT-5 Take 5 initiative. *European Journal of Remote Sensing*. 2017. Vol. 50(1). P. 300–309.

18. Kussul N., Kolotii A., Shelestov A., Lavreniuk M., Bellemans N., Bontemps S., Defourny P., Koetz B. Sentinel-2

for agriculture national demonstration in Ukraine: Results and further steps. *IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*. 2017. P. 5842–5845.

19. Yailymov B., Lavreniuk M., Shelestov A., Kolotii A., Yailymova H., Fedorov O. Methods for determining significant variables to assess the land cover state. *Space Science and Technology*. 2018. Vol. 24, No. 4. P. 24– 37 (*in Ukrainian*).

20. Skakun S., Kussul N., Shelestov A., Kussul O. The Use of Satellite Data for Agriculture Drought Risk Quantification in Ukraine. *Geomatics, Natural Hazards and Risk*. 2015. Vol. 7(3). P. 901–917.

21. Kussul N, Lemoine G., Gallego F., Skakun S., Lavreniuk M., Shelestov A. Parcel-Based Crop Classification in Ukraine Using Landsat-8 Data and Sentinel-1A Data. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*. 2016. Vol. 9(6). P. 2500–2508.

22. Kussul N., Lavreniuk M., Shelestov A., Skakun S. Crop inventory at regional scale in Ukraine: developing in season and end of season crop maps with multi-temporal optical and SAR satellite imagery. *European Journal of Remote Sensing*. 2018. Vol. 51(1). P. 527–636.

23. Ghazaryan G., Dubovyk O., Löw F., Lavreniuk M., Kolotii A., Schellberg J., Kussul N. A rule-based approach for crop identification using multi-temporal and multi-sensor phenological metrics. *European Journal of Remote Sensing*. 2018. Vol. 51(1). P. 511–524.

24. Shelestov A., Lavreniuk M., Kussul N., Novikov A., Skakun S. Exploring Google Earth Engine Platform for Big Data Processing: Classification of Multi-Temporal Satellite Imagery for Crop Mapping. *Frontiers in Earth Science*. 2017. Vol. 5. P. 17.

25. Skakun S., Kussul N., Shelestov A., Lavreniuk M., Kussul O. Efficiency Assessment of Multitemporal C-Band Radarsat-2 Intensity and Landsat-8 Surface Reflectance Satellite Imagery for Crop Classification in Ukraine. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*. 2016. Vol. 9(8). P. 3712–719.

26. Waldner F., Abelleyra D., Verón S., Zhang M., Wu B., Plotnikov D., Bartalev S., Lavreniuk M., Skakun S., Kussul N., Maire G., Dupuy S., Jarvis I., Defourny P. Towards a Set of Agrosystem-specific Cropland Mapping Methods to Address the Global Cropland Diversity. *International Journal of Remote Sensing*. 2016. Vol. 37(14). P. 3196–231.

27. Kravchenko A., Kussul N., Lupian E., Savorsky V., Hluchy L., Shelestov A. Water resource quality monitoring using heterogeneous data and high-performance computations. *Cybernetics and Systems Analysis*. 2008. Vol. 44, No. 4. P. 616–624.

28. Shelestov A., Lavreniuk M., Vasiliev V., Shumilo L., Kolotii A., Yailymov B., Yailymova H. Cloud approach to automated crop classification using Sentinel-1 imagery. *IEEE Transactions on Big Data*. 2019.

29. Kussul N., Shelestov A., Yailymov B., Yailymova H., Lavreniuk M., Shumilo L., Bilokonska Y. Crop monitoring technology based on time series of satellite imagery. *IEEE 11th International Conference on Dependable Systems, Services and Technologies (DESSERT)*. 2020. P. 346–350.

30. Skakun S., Justice C., Kussul N., Shelestov A., Lavreniuk M. Satellite data reveal cropland losses in South-Eastern Ukraine under military conflict. *Frontiers in Earth Science*. 2019. Vol. 7. P. 305.

LIST OF IMPLEMENTING ORGANIZATIONS

No.	Organization	E-mail
1	Educational and Scientific Center "Institute of Biology and Medicine" of Taras Shevchenko National University of Kyiv	decanat_bf@univ.kiev.ua
2	Institute for Scintillation Materials of NAS of Ukraine	info@isma.kharkov.ua
3	Institute for Safety Problems of Nuclear Power Plants of NAS of Ukraine	ispnpp@ispnpp.kiev.ua
4	Institute of Ecology of the Carpathians of NAS of Ukraine	ecoinst@mail.lviv.ua
5	Institute of Food Biotechnology and Genomics of NAS of Ukraine	office.ifbg@nas.gov.ua
6	Institute of Ionosphere of NAS and MES of Ukraine	iion@kpi.kharkov.ua
7	Institute of Radio Astronomy of NAS of Ukraine	rai@ri.kharkov.ua
8	Institute of Technical Mechanics of NAS of Ukraine and SSA of Ukraine	office.itm@nas.gov.ua
9	Karpenko Physico-Mechanical Institute of NAS of Ukraine	pminasu@ipm.lviv.ua
10	Lviv Center of Space Research Institute of NAS and SSA of Ukraine	vakor@isr.lviv.ua
11	M.G. Kholodny Institute of Botany of NAS of Ukraine	inst@botany.kiev.ua
12	M.M. Gryshko National Botanical Garden of NAS of Ukraine	nbg@nbg.kiev.ua
13	Main Astronomical Observatory of NAS of Ukraine	office.mao.kiev.ua
14	Main Center of Special Monitoring, National Space Facilities Control And Test Center	ncuvkz@spacecenter.gov.ua
15	National Aerospace University "Kharkiv Aviation Institute"	khai@khai.edu
16	National Aviation University	post@nau.edu.ua
17	National Space Facilities Control and Test Center	ncuvkz@spacecenter.gov.ua
18	National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"	mail@kpi.ua
19	Oleksandr Dovzhenko Hlukhiv National pedagogical university	gnpuoffice@gmail.com
20	Palladin Institute of Biochemistry of NAS of Ukraine	secretar@biochem.kiev.ua
21	Poltava Gravimetric Observatory of Institute of Geophysics of NAS of Ukraine	pgo@poltava.ukrtel.net
22	Private Joint Stock Company "Research and Production Complex "KURS"	npk_kurs@ukr.net
23	Private Joint Stock Company "ELMIZ"	info@elmiz.com
24	Scientific Production Company "Alex Detector" LLC	konstructor_a@ukr.net
25	Space Research Institute of NAS of Ukraine and SSA of Ukraine	ikd@ikd.kiev.ua
26	State Institution "Scientific Centre for Aerospace Research of the Earth of Institute of Geological Sciences of NAS of Ukraine"	casre@casre.kiev.ua
27	Taras Shevchenko National University of Kyiv	rector@univ.net.ua
28	V.N. Karazin Kharkiv National University	univer@karazin.ua
29	V.N. Karazin Kharkiv National University, Institute of Astronomy	sky@astron.kharkov.ua

Звіт для COSPAR узагальнює результати космічних досліджень, проведених протягом 2018—2020 років. У цьому виданні представлено сучасний стан української космічної науки за такими напрямами: космічна астрономія та астрофізика, спостереження Землі та навколоземні космічні дослідження, науки про життя, космічні технології та науки про матеріали. Низку робіт присвячено створенню наукового обладнання для перспективних космічних місій. Значну увагу приділено прикладним дослідженням космічного моніторингу Землі. Видання може бути корисним для широкого кола читачів, які цікавляться космічними дослідженнями.

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Науковий редактор
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