Modern Systems for Processing and Analyzing GEO-data Based On OLAP Technology

Pavel Lukashevich[a], Alexei Belotserkovsky[a] and Hrachya Astsatryan[b]

[a] *United Institute of Informatics Problems of the National Academy of Sciences of Belarus, 6 Surganova str. Minsk 220012, Republic of Belarus*
[b] *Institute for Informatics and Automation Problems of the National Academy of Sciences of the Republic of Armenia, 1 P. Sevak str. Yerevan 0014, Republic of Armenia*

Abstract

In Belarus, the demand for applications that are focused on geodata processing has been significantly increasing recently. Although Belarus has its satellite BKA, there is also access to satellites of the Kanopus-V constellation, and highly relevant open data from meteorological satellites, only a few specialists of the corresponding profile can use them. To meet the wide demand for geodata analysis and expand the scope of their application, it was decided to study the modern experience of market stakeholders based on On-Line Analytical Processing (OLAP) technologies. The paper describes the currently popular approach to processing satellite images based on OLAP and Data Cube technology. The existing approaches from major market players such as Google Earth engine and Copernicus DIAS are compared with the alternative to develop and host an own service based on the Open Data Cube. All pros and cons are considered, the cost is compared, the possibilities of their coding, and the flexibility of the tools provided are also described here.

Keywords 1

Satellite Image, Image Processing, On-Line Analytical Processing, GIS, Google Earth Engine, Copernicus Data and Information Access Services, Open Data Cube.

1. Introduction

Earth observations (EO), which include both in-situ and satellite data, provide robust monitoring to tackle environmental challenges, becoming critical because of the continuous pressure on natural resources. Remote sensing EO accurate and reliable data is a compulsory component of the environmental monitoring systems. Remote sensing open access data repositories offer precious, timely, and accurate remotely sensed EO information, such as American Landsat or European Sentinel satellites. The increasing complexities of practical tasks and applications, based on the operational analysis of remote sensing data, require new generations of remote sensing satellites providing more and more data of various types. Several new data services have emerged worldwide with broad potential to significantly impact on crucial environmental, economic and social issues at their local, regional, and global levels [1].

There is also a great demand in Belarus for operational geodata analytics applications. Since 2012 high-resolution remote sensing satellite BKA is operated in Belarus, providing high-precision capabilities to obtain remote sensing data focusing on the territory of Belarus [2] (operator GIS.by). Besides, it also supports receiving images from Russian Kanopus-V satellites [3]. There are other services for providing data that are relevant and unique for Belarus and its surroundings (see Table 1).

CMIS-2021: The Fourth International Workshop on Computer Modeling and Intelligent Systems, April 27, 2021, Zaporizhzhia, Ukraine
EMAIL: pavel.lukashevich@newman.bas-net.by (P.Lukashevich); alex.belot@gmail.com (A.Belotserkovsky); hrach@sci.am (H.Astsatryan)
ORCID: 0000-0001-9138-545X (P.Lukashevich); 0000-0002-8544-8554 (A.Belotserkovsky); 0000-0001-8872-6620 (H.Astsatryan)

At present, these data are widely used in various expert systems, which are developed mainly for large government customers, such as the Ministry of Natural Resources, Forestry, Cadastral Services, agro-technical enterprises, the Ministry of Emergency Situations, and other major stakeholders [4].

Table 1
List of services

Name	Description	URL
A Geoportal "MeteoEye"	Provides highly relevant meteorological data received from various meteorological satellites to predict the weather and prevent emergencies and forest fires.	https://meteoeye.gis.by
Geoportal BelPSKHAGI	Provides ultra-high-resolution data received by manned and unmanned aircraft. This data is mainly used to update digital maps and cadastral needs.	https://www.dzz.by
Geoportal of the Land Information System of the Republic of Belarus	Maintains its own set of high-resolution images for cadastral needs.	http://gismap.by

The applications extract and process valuable information from remote sensing data to address societal and scientific challenges in the country and beyond. However, the high threshold for data processing specialists and infrastructure complexities to process the data limited the widespread usage to dive into the applied analysis of remote sensing data. Remote sensing data are highly heterogeneous in terms of the acquisition, digital representation formats, spatial resolution, etc. Besides, even today, many archived data from foreign and domestic satellites are used insufficiently, despite their wide availability.

The solution to this problem is complicated for countries with developed economies and even more difficult for developing countries interested in using EO. It is technically or financially unmanageable for many researchers to use their means to obtain and process data locally to solve applied problems taking into account the data size, data pre-processing and processing difficulties, and data storage and sharing.

Fortunately, data management and data analysis challenges are possible overcome with the support of relatively new infrastructural approaches to organizing data storage and processing. The article aims to present the modern systems for processing and analyzing GEO-data based on OLAP (Online Analytical Processing) technology, and the capabilities and experience of Belarussian and Armenian communities actively developing new paradigms and services for representing and processing remote sensing data. The remaining content of the paper is organized as follows. The local unique data in Belarus is given in Section 2. The overview of OLAP technology can be found in Section 3 and coding OLAP systems in Section 4. Finally, the Belarusian Data Cube system in Section 5 and the conclusions in Section 6.

2. Local unique data in Belarus

Since July 22, 2012, Belarus has its own high-resolution remote sensing satellite BKA operated by "Geoinformation Systems".

BKA, equipped with a panchromatic imaging system (PAN), was developed by order of the National Academy of Sciences of Belarus. PAN allows obtaining black-and-white images with a resolution of 2.1 m, and a multispectral imaging system (MUL) for acquiring images with a resolution of 10.5 m in four spectral ranges). The satellite has a mass of 400 kg, an orbit with an altitude of about 500 - 520 km. Also, "Geoinformation Systems" has access to Russian EO satellites Kanopus-V. Currently, these satellites form one constellation.

At present, GIS provides the most relevant high-resolution data on the territory of Belarus. These data are unique for Belarus and have a higher resolution and relevance than competitive platforms, where high-resolution data is limited at all for our region at all, or is updated extremely rarely (once a year or worse).

In addition to space imagery in Belarus, remote sensing data are having been collecting by drones or manned aircrafts (such data are represented in geoportal BelPSKHAGI [5]). The resolution of such images is up to 0.05 meters per pixel. Unfortunately, the update frequency is not enough.

Currently, there are plans to launch a new generation satellite with a higher resolution - 0.35 m in pan chrome and 1.4 m in multispectral range. In addition to high-resolution data, the GIS operator has developed and maintains a new service called "MeteoEye" [6], which allows users to obtain operational data from a variety of available meteorological satellites: AQUA (AIRS, MODIS), MetOp-A (AVHRR, AMSU, HIRS, IASI, MHS), MetOp-B (AVHRR, AMSU, HIRS, IASI, MHS), MetOp-C (AVHRR, AMSU, IASI, MHS), NOAA18 (AVHRR, AMSU), NOAA19 (AVHRR, AMSU, HIRS, MHS), NOAA20 (ATMS, CRIS, VIIRS), Suomi NPP (ATMS, CRIS, VIIRS), TERRA (MODIS), Feng-Yun 3D (MERSI, HIRAS, MWHS, MWTS, MWRI).

MeteoEye data are received on Belarus and neighboring territory close to real-time mode (as the satellites fly over the receiving stations).

All these collected data may be used to: create and update topographic and navigation maps, control over land use and agricultural production, monitor land reclamation facilities, monitor changes in the forest fund, control forest inventory and manage reforestation, control constructions, control mining, control environment and manage hydrometeorology.

As already mentioned, there is a demand in the scientific community for the widespread use of these data, and it is also supported by the state's strategic plans for the informatization of society. The suggested solution is to apply of already proven approaches based on OLAP technologies.

3. Overview of OLAP technology

The growth of the number of EO data sources and the improvement of their qualitative characteristics have been stimulating the research and development of science and technology specialists to simplify access to multidimensional data, their interactive online processing and analysis. Approaches to remote sensing data processing based on the OLAP methodology mean online preparation and delivery of aggregated information based on extensive data arrays structured according to the multidimensional principle. Currently, it has become widespread.

OLAP approaches led to developing a specialized high-performance database for storing, processing, and issuing large volumes of raster information RasDaMan (raster data manager), funded by the European Union.

In May 2018, an international team of specialists formulated a list of additions to the ISO SQL standard to provide the ability to operate with multi-dimensional raster data (datacube functionality). In June 2019, the ISO / IEC 9075-15: 2019 SQL multi-dimensional arrays (SQL / MDA) standard, expands the storage, processing, and delivery of multi-dimensional raster data through SQL database queries, was officially approved.

Based on OLAP approaches and SQL / MDA standards, nowadays, new services for storing, processing, and providing remote sensing data are widely developed worldwide. For example, the European Commission has launched an initiative to facilitate access to Copernicus data and information services. In addition to the classical approaches to data distribution services, a new conception of access was proposed. It is based on the DIAS (Data and Information Access Services) approach, which is designed to improve the methods of obtaining and processing Copernicus EO data. Based on this methodology, five large cloud platforms were created: CREODIAS, MUNDI, ONDA, SOBLOO, and WEKEO.

Other global market players have similar services [7], such as Google Earth Engine (GEE) [8], Earth on Amazon Web Services (EAWS) [9], PDGS-DataCube [10], Earth System Data Lab (ESDL) [11], and others [12].

Australian Geoscience DC (AGDC), renamed Digital Earth Australia (DEA) [13], was the first successful attempt, making the entire continent's geographical datasets available to researchers and policy-makers [14]. Now several other countries have a national-scale DC, including Switzerland [15], Colombia [16], or China [17].

The Armenian DC [18] contains US Landsat and European Sentinel analysis ready data over the territory of Armenia. The full coverage of Armenia includes 11 Sentinel (38TLL, 38TML, 38TNL, 38TLK, 38TMK, 38TNK, 38SMJ, 38SNJ, 38SPJ, 38SNH, 38SPH) and 9 Landsat (171031, 170031,169031, 171032, 170032, 169032, 168032, 169033, 168033) scenes. The Armenian DC is used to address diverse challenges and scientific questions in Armenia. For instance, to improve the hourly air temperature prediction for up to 24 hours in the Ararat valley based on machine learning methods and approaches by utilizing the EO data received from several meteorological stations and the large satellite analysis-ready datasets at different frequencies and resolutions [19].

Lessons [20] learned from design and implementation of AGDC underpin Chinese DC (CDC) based on the new Open Geospatial Consortium (OGC) Discrete Global Grids System (DGGS) standard and cloud computing technologies and Colombian DC. The Committee of EO Systems (CEOS) has a vision, that more over 20 countries will develop and realize their Data-Cube infrastructure by 2022 [21].

In addition to data processing convenience, DC is almost the only way to process Big Data. After all, for example, the European Union's Copernicus program generates up to 12 terabytes of data every day. Such large scale data offers various opportunities for climate change analysis, land monitoring, marine and coastal monitoring, atmospheric monitoring, human safety, and emergency and disaster management. However, self-loading and storing this data brings some sophisticated logistical challenges. DC answers these questions as users no longer need to download bulky files from multiple sources and process them locally. Instead, DC platforms provide massive cloud storage of satellite data, acting as a single point of access to data, allowing users to independently develop and deploy new topical applications in the cloud, including very complex ones that require large volumes and deficiency of good processing capacities for Big Data processing.

Big Data and cloud computing enable Earth scientists and developers to create web-accessible frameworks and platforms to store, retrieve and analyze Big Earth Data efficiently [22]. In the Earth science domain, scientists rely on a series of data models, frameworks, and initiatives to ensure heterogeneous data sharing and analysis.

DC is now considered a promising technology to perform time-series analyses of significant satellite Analysis Ready data-sets like Landsat and Sentinel [23]. There are several operational DC initiatives, covering various spatial scales and storing different data, using a wide range of infrastructures and software implementations – such as GEE, EAWS, PDGS, ESDL, and others – is a new paradigm aiming to meet the Big Earth Data challenge as a new approach to store, organize, manage and analyze EO data [24].

However, it is essential to distinguish Data Cubes for S&E (science and education) and commercial cloud-based processing facilities, such as DIAS, GEE, or EAWS. Cloud-based EO platforms commonly provide free and open access to global EO datasets (available datasets are growing daily) together with powerful space and time analysis tools supporting different programming languages (e.g., JavaScript, Python, and R). Recently, these online platforms were transformed into an environment where the user community works with satellite EO data. They remove most of the burden for data preparation, yield rapid results and foster a community of contributors, which is growing fast. However, it brings a hard dependency for users to work with a commercial platform, so with well-known challenges [25].

4. Coding OLAP systems

The main focus of this section is to present best practices for displaying and analyzing programs based on the well-known Google Earth Engine. The other services, which are Mundi (https://jupyterhub.mundiwebservices.com), PDGS Data Cube (https://jupyter.pdgs.eo.esa.int), Terrascope (https://notebooks.terrascope.be) and so on, will have a very similar IPython-based interface and Jupyter Notebook. One of the Google Earth Engine differences is that it provides standard interfaces for Python analogs and a JavaScript API, which is much more convenient when embedding programs directly into a web application. The OLAP is widely used by the Armenian and Belarussian communities, such as the web-based interactive visualization and analytical platform for weather data in Armenia by integrating the three existing infrastructures for observational data, numerical weather prediction, and satellite image processing [26]. Another example is to apply OLAP system to develop a data quality alerting model for Big Data analytics [27].

One may practice coding JavaScript API at https://code.earthengine.google.com. Google Earth Engine JavaScript API code sample, development environment interface and results are presented in Figures 1 and 2.

```
var dem = ee.Image('USGS/SRTMGL1_003');
var xy = ee.Geometry.Point([86.9250, 27.9881])
var elev = dem.sample(xy, 30).first().get('elevation').getInfo()
print('Mount Everest elevation (m): ' + elev) //OUTPUT: 8729

// Set visualization parameters.
Map.setCenter(86.9250, 27.9881, 4);
var vis_params = { min: 0, max: 8729,
  palette: ['006633', 'E5FFCC', '662A00', 'D8D8D8', 'F5F5F5']}

Map.addLayer(dem, vis_params, 'Mount Everest DEM');
```

Figure 1: Google Earth Engine: JavaScript API – Code Sample

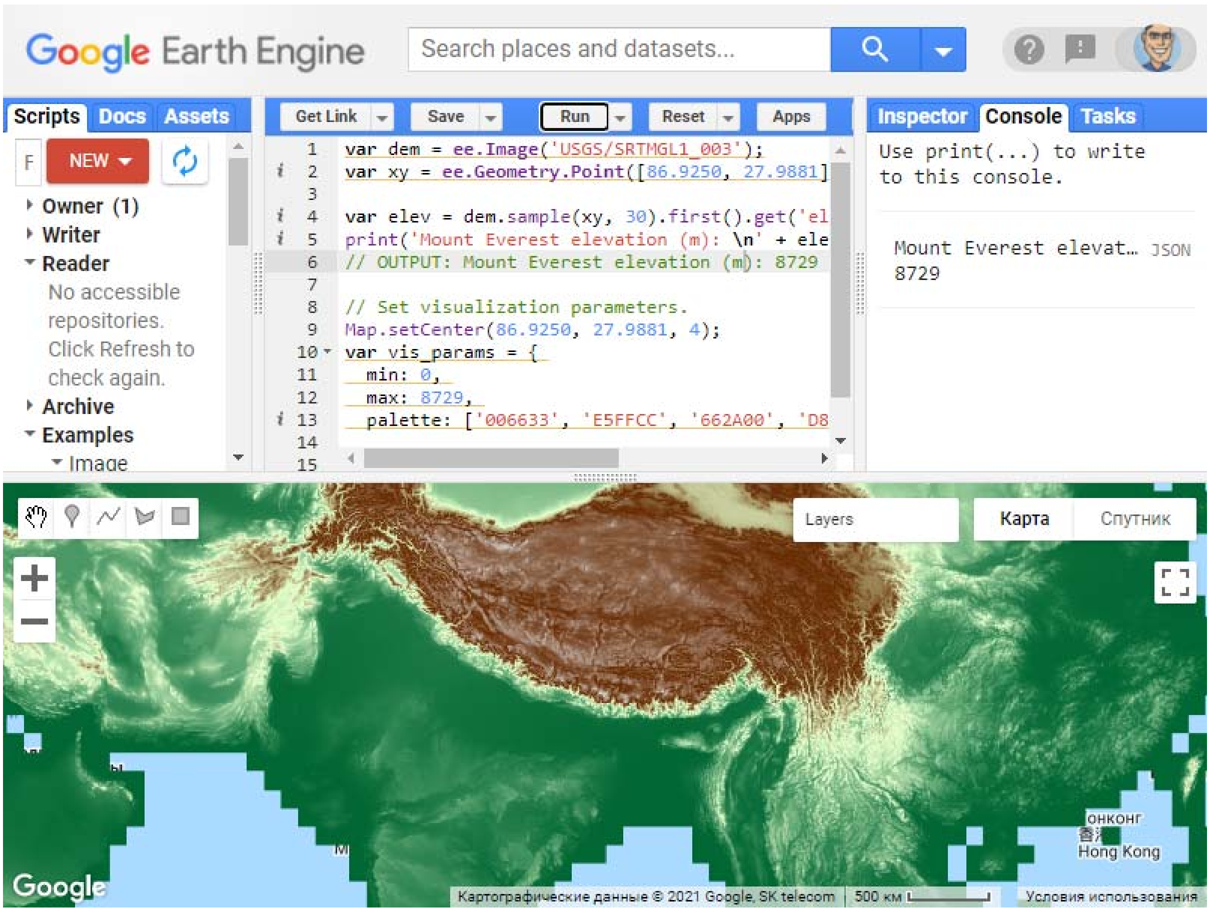

Figure 2: Google Earth Engine: JavaScript API – Development Environment Interface and Results

Also, Google Earth Engine provides access to its tools through the Python API. One may use the Python API from the Google Cloud Platform resources and through the Google Colab Platform (https://colab.research.google.com can be used for free).

Google Earth Engine Python API code samples are presented in Figures 3 and 5. The result of image generating from geodata, Google Colab development environment interface and result of map overlay are presented in Figures 4 and 6.

```python
import ee
ee.Authenticate() # Trigger the authentication flow.
ee.Initialize()   # Initialize the library.

# Print the elevation of Mount Everest.
dem = ee.Image('USGS/SRTMGL1_003')
xy = ee.Geometry.Point([86.9250, 27.9881])

elev = dem.sample(xy, 30).first().get('elevation').getInfo()
print('Mount Everest elevation (m):', elev) # OUTPUT: 8729

# Import the Image function from the IPython.display module.
from IPython.display import Image
ROI = ee.Geometry.Rectangle([85.9250, 26.9881, 87.9250, 28.9881])
# Display a thumbnail of global elevation.
Image(url = dem.updateMask(dem.gt(0))
  .getThumbURL({'min': 0, 'max': 8729, 'dimensions': 512,
                'palette': ['0000FF', '00FF00', 'FF0000'],
                'region': ROI}))
```

Figure 3: Google Earth Engine: Python API Code Sample – Data Analysis and Image Composing

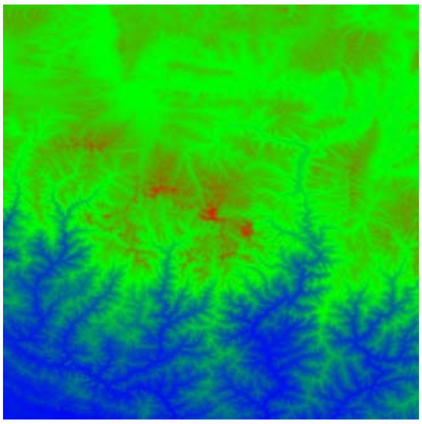

Figure 4: Google Earth Engine: Python API – Result of Generating of Image from raw Geodata

```python
import ee
ee.Authenticate() # Trigger the authentication flow.
ee.Initialize()   # Initialize the library.

# Import the Folium library.
import folium

# Define a method for displaying Earth Engine image tiles to folium map.
def add_ee_layer(self, ee_image_object, vis_params, name):
  map_id_dict = ee.Image(ee_image_object).getMapId(vis_params)
  folium.raster_layers.TileLayer(
    tiles = map_id_dict['tile_fetcher'].url_format,
    name = name,
    overlay = True,
    control = True
  ).add_to(self)

# Add EE drawing method to folium.
folium.Map.add_ee_layer = add_ee_layer

# Set visualization parameters.
vis_params = {'min': 0, 'max': 4000,
             'palette': ['0000FF', '00FF00', 'FF0000']}

# Create a folium map object.
my_map = folium.Map(location=[27.9881, 86.9250], zoom_start=4)
my_map.add_ee_layer(dem.updateMask(dem.gt(0)), vis_params, 'Everest DEM')
my_map.add_child(folium.LayerControl())

# Display the map.
display(my_map)
```

Figure 5: Google Earth Engine: Python API Code Sample – Map Overlay

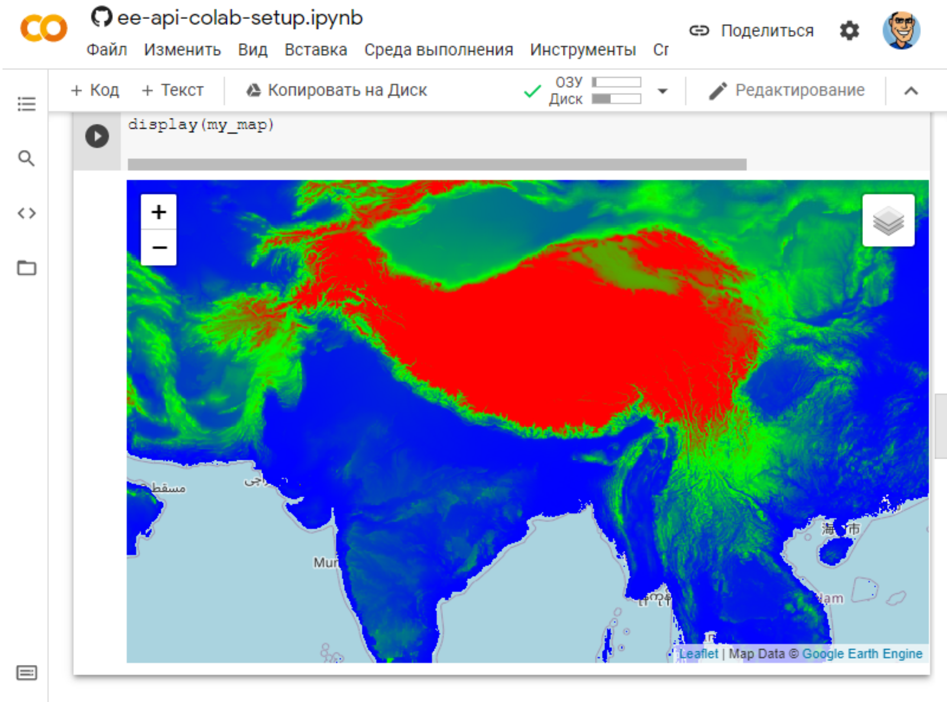

Figure 6: Google Earth Engine: Python API – Development Environment and Resulting Map Overlay

5. Belarusian Data Cube system

As seen from the previous section, modern EO information systems based on DC technology, such as Google Earth Engine, systems similar to Copernicus DIAS, and others, look quite attractive. Many of them even provide limited free access and a convenient development environment.

Unfortunately, the full functionality of such platforms for third countries (non-EU and not associated countries) is possible only under a commercial license or eligible at all. We provide a price assessment of using such systems.

As a basis we have taken the maximum configuration (LARGE) of the Mundi service from Copernicus DIAS (https://mundiwebservices.com/offer) – vCPU: 32, RAM: 256 GB, Storage: 80 TB. Such a configuration should be sufficient for the simultaneous work of several specialists and the background calculation of a very limited number of tasks.

The exact configuration for the Mundi service (https://mundiwebservices.com/offer) will be around 3000 EUR / month, similar to other Copernicus DIAS services. Google Cloud resources (https://cloud.google.com/products/calculator) look a bit costly – approx. 4000 USD / month, but AWS services (https://calculator.aws) are even higher – the minimum price for such a configuration is 4837 USD per month. The actual cost of servicing such a system on cloud platforms will be increased since the intensive use of the system presupposes the active transfer of large geodata, which is also charged.

But the cost issue is not the last one. Only data optimized to provide the best coverage for the European and North American regions are available for processing and analysis on the platforms listed. In most cases, there is no up-to-date high-resolution data for our region, and low-resolution weather data comes with a significant delay from 1 to 9 days. So such a set of data does not always provide the necessary accuracy and relevance to solve domestic scientific and practical problems in Belarus.

To order and receive additional high-resolution datasets for our region is not always possible through the platform. It may be available under require extra agreements and financial costs. Besides, Belarus already has its datasets optimized for current scientific needs (see section 2). The use of these data on platform resources will require downloading them to a remote resource (which is tens of gigabytes per day), payment for their storage (tens of terabytes), and their manual preprocessing and combining with geodata presented on that platforms. It negates all the advantages of the cloud platform and the DC approach.

Therefore, the only option is to develop our DC system to build a reliable national system, which will increase the availability of our geodata, value and usability. When creating our own regional "BYCube" system, the main emphasis will be on receiving and downloading highly relevant data from various meteorological satellites (receiving delay up to 3 hours), and high-resolution EO data from the national satellite BKA and other satellites of the constellation.

Figure 7 shows a conceptual infrastructural scheme of the regional system "BYCube". We are deliberately tied to the Belarusian Earth Remote Sensing System (elements enclosed in the first rectangle, excluding meteorological satellites), which is hosted by the Unitary Enterprise "Geographic Information Systems". For us, as a parent organization, this means the fastest possible automatic retrieving, preprocessing, and uploading of highly relevant data from a variety of meteorological satellites, as well as high-resolution remote sensing data from the national satellite BKA at the organizational level. On the other hand, the BASNET academic network is a provider of computing services and connectivity for state science and education, and primarily for scientists of the National Academy of Sciences of Belarus. BASNET is the national research and educational network of the GÉANT Association and has the necessary capacity to host and further support the "BYCube".

It is assumed a lot of work on the study and testing of the technologies available at the present stage to implement a DC that allow on-demand scaling of the computing infrastructure and expanding its functionality using a deep learning algorithm for analyzing EO data.

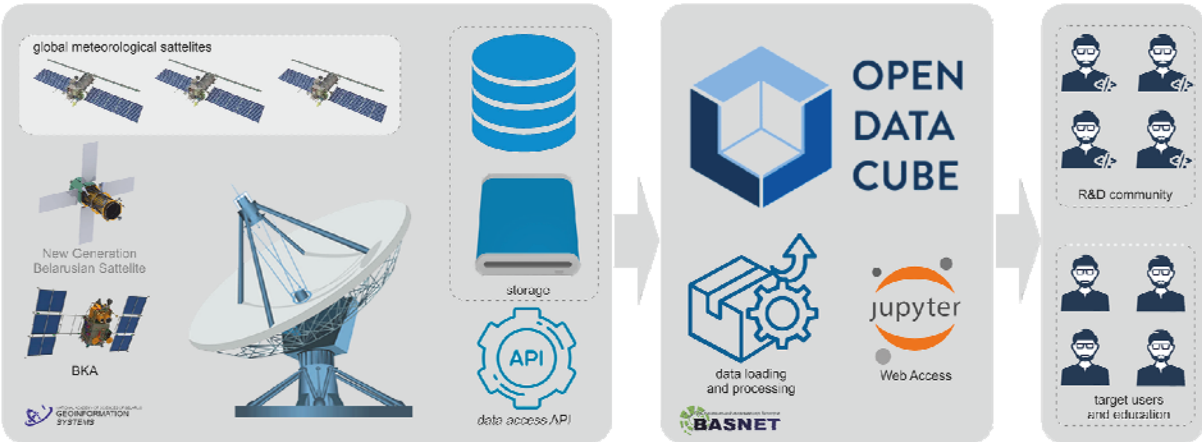

Figure 7: Conceptual infrastructural scheme of the regional system "BYCube"

6. Conclusions

The implementation of an online computing infrastructure based on the DC technology for the needs of Belarusian researchers and institutions of higher education will significantly increase the value of the received EO data in Belarus due to:

- the minimization of time and special knowledge required for access and preparation of satellite data;
- accumulation of free and open satellite data in Belarus;
- providing easy access to open-source software solutions for remote sensing data processing, which are promoted thanks to the contribution of the community;
- using consistent data structures that allow code, tools, and algorithms to be shared;
- joint use of several heterogeneous sets of remote sensing data in complex analysis algorithms.

The first demonstration applications on the developed platform are planned utilities for the operational determination of heat anomaly maps, temperature distribution maps, cloud masks, and snow masks based on data from meteorological satellites. These data can be used both independently and together with high-resolution EO data. In the future, it is planned to scale BYCube by increasing the applied algorithmic repository by active users from S&T community, which in turn will contribute to the formation of scientific potential and new specialized personnel in the academic environment capable of quickly solving applied problems of EO.

7. Acknowledgements

The work is supported by the EaPConnect project funded by European Union within the EU4Digital initiative under Grant Agreement number ENI / 2019 / 407-452. Provide scheme will be elaborated in the frame of state activity "To create a software package for collecting, storing and processing remote sensing data based on technology "Data Cube", providing remote access to up-to-date multi-satellite remote sensing data for the Republic of Belarus, their operational centralized processing and analysis for solving scientific, technical and educational problems" subprogramme 6 "Exploration and use of outer space in peaceful purposes" of the State programme "Science-intensive technologies and equipment" for 2021 - 2025.

8. References

[1] L. Friedl, Benefits Assessment of Applied Earth Science, in: M. Onoda, O. R. Young (Eds.), Satellite Earth Observations and Their Impact on Society and Policy, Springer, Singapore Singapore, 2017, pp. 73–79, ISBN 978-981-10-3713-9.
[2] Belarusian spacecraft (BKA), Research Center for Earth Operative Monitoring. URL: http://gis.by/en/tech/bka.
[3] Kanopus-V, ESA Earth Observation. URL: https://earth.esa.int/web/eoportal/satellite-missions/k/kanopus-v-1.
[4] S. A. Zolotoy, A. V. Kosilo, A. A. Stavrov, I. B. Strashko, Software solutions in the field of geoinformatics, in: Proceedings of the National Academy of Sciences of Belarus, physical-technical series 4 (2016) 113–120. URL: https://vestift.belnauka.by/jour/article/download/281/279.
[5] BelPSKHAGI Geoportal. URL: https://www.dzz.by.
[6] MeteoEye Geoportal. URL: https://meteoeye.gis.by.
[7] K. Anderson, B. Ryan, W. Sonntag, A. Kavvada, L. Friedl, Earth observation in service of the 2030 Agenda for Sustainable Development, Geo-Spat. Inf. Sci. 20 (2017) 77–96.
[8] Google Earth Engine, A planetary-scale platform for Earth science data & analysis. URL: https://earthengine.google.com.
[9] Earth on AWS, Build planetary-scale applications in the cloud with open geospatial data. URL: https://aws.amazon.com/earth.
[10] PDGS-DataCube. URL: http://eodatacube.eu.
[11] The Earth System Data Lab (ESDL), Earth in a Box. URL: https://www.earthsystemdatalab.net.
[12] A. Lewis, L. Lymburner, M. B. J. Purss, B. Brooke, B. Evans, A. Ip, A. G. Dekker, J. R. Irons, S. Minchin, N. Mueller, Rapid, high-resolution detection of environmental change over continental scales from satellite data – The Earth Observation Data Cube, Int. J. Digit. Earth 9 (2016) 106–111.
[13] Digital Earth Australia (DEA). URL: https://www.ga.gov.au/dea.
[14] A. Gore, The Digital Earth, Australian Surveyor, 43 (1998) 89–91.
[15] EO for monitoring the environment of Switzerland in space and time, Swiss Data Cube (SDC). URL: https://www.swissdatacube.org.
[16] C. Ariza-Porras, G. Bravo, M. Villamizar, A. Moreno, H. Castro, G. Galindo, E. Cabera, S. Valbuena, P. Lozano, CDCol: A Geoscience Data Cube that Meets Colombian Needs, in: A. Solano, H. Ordoñez (Eds.), Proceedings of the Advances in Computing, Springer International Publishing, Cham Switzerland, 2017, pp. 87–99.
[17] X. Yao, Y. Liu, Q. Cao, J. Li, R. Huang, R. Woodcock, M. Paget, J. Wang, G. Li, China Data Cube (CDC) for Big Earth Observation Data: Lessons Learned from the Design and Implementation, in: Proceedings of the 2018 International Workshop on Big Geospatial Data and Data Science (BGDDS), Wuhan China, 22–23 September 2018, pp. 1–3.

[18] S. Asmaryan, et al. Paving the Way towards an Armenian Data Cube, Earth Observation Data Cubes, 4 (2019) 117. URL: https://www.mdpi.com/2306-5729/4/3/117.
[19] H. Astsatryan, H. Grigoryan, A. Poghosyan, et al. Air temperature forecasting using artificial neural network for Ararat valley, Earth Sci. Inform., 2021. URL: https://doi.org/10.1007/s12145-021-00583-9. doi:10.1007/s12145-021-00583-9.
[20] Open Data Cube Manual, Open Data Cube Documentation. URL: https://datacube-core.readthedocs.io/en/latest.
[21] S. R. Rizvi, B. Killough, A. Cherry, S. Gowda, The Ceos Data Cube Portal: A User-Friendly, Open Source Software Solution for the Distribution, Exploration, Analysis, and Visualization of Analysis Ready Data, in: Proceedings of the IGARSS 2018–2018 IEEE International Geoscience and Remote Sensing Symposium, Valencia Spain, 22–27 July 2018, pp. 8639–8642.
[22] H. Guo (Ed.), Manual of Digital Earth, Springer Nature, 2020. URL: https://doi.org/10.1007/978-981-32-9915-3. doi: 10.1007/978-981-32-9915-3.
[23] Earth Observation: Copernicus Sentinel Satellite Data-Open Access, ESA Earth Observation. URL: http://open.esa.int/copernicus-sentinel-satellite-data.
[24] An Open Source Geospatial Data Management & Analysis Platform, Open Data Cube. URL: https://www.opendatacube.org.
[25] G. Giuliani, J. Masò, P. Mazzetti, S. Nativi, A. Zabala, Paving the way to increased interoperability of Earth Observations Data Cubes, Earth Observations Data Cubes, 4 (2019) 113, JRC117467, ISSN 2306-5729.
[26] H. Astsatryan, H. Grigoryan, E. Gyulgyulyan, A. Hakobyan, A. Kocharyan, W. Narsisian, V. Sahakyan, Y. Shoukouryan, R. Abrahamyan, Z. Petrosyan, J. Aligon, Weather Data Visualization and Analytical Platform. Scalable Computing: Practice and Experience (2018).
[27] E. Gyulgyulyan, and J. Aligon, F. Ravat, H. Astsatryan, Data Quality Alerting Model for Big Data Analytics, International Workshop on Qualitative Aspects of User-Centered Analytics - European Conference on Advances in Databases and Information Systems (QAUCA@ADBIS 2019), Bled, Slovenia.