Automated Systems of Ecological Monitoring as an Effective Factor of Sustainable Development

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Abstract. Scientific basis for development and implementation of automated control systems (ACS) in the USSR of 1960s provided the 10 principles proposed by V.M. Glushkov. They summarized the experience of first industrial control systems "Lviv" and "Galvanic" introduced in the production processes. During that period, many industrial ACS were created in Soviet Union. Among them the ACS of the Ministry of Radio Industry was of particular importance. Its chief designer was A.I. Kitov with V.M. Glushkov as scientific supervisor. The ACS has been selected by Government as a model for all 9 military-related ministries. The hierarchical multi-level problem-oriented systems for solving environmental problems in accordance with the UN Concept of the Earth Sustainable Development became an important direction of further ACS development at V.M. Glushkov Institute of Cybernetics. The Institute achievements in methods of mathematical modeling and simulation of processes in complex systems began from solving the problems of modeling the water objects posed to scientists immediately after the Chernobyl accident. The developed models have created the basis for the first in Ukraine automated simulation system for water objects SIMVO. The next stage of the direction progress has begun from the first in Ukraine standard regional automated environmental monitoring system EMS implemented in Kiev in early 2000s. Both of the systems have had no analogues. Now, an ecology ACS is developed within the Ukrainian part of the Horizon-2020 project ERA-PLANET which combines national and international goals to achieve the sustainable development and increases the contribution of Europe to the Global Earth Observation System of Systems (GEOSS).

Keywords: automated systems, automated control systems, ACS, ecological monitoring, sustainable development, smart city.

1 Introduction

V.M. Glushkov Institute of Cybernetics (GIC) of National Academy of Sciences of Ukraine (NASU) under supervision of Academician V.M. Glushkov since early 1960s held works on automation of scientific research and complex object testing, on automated problem-oriented laboratories (APOL), on automated design of computers. The first Soviet general-purpose computer for technological processes control "Dnepr-2"

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(1961) equipped with Object Communication Device (USO) began development of automated control systems (ACS) in the national economy of USSR [1 – 4].

The USO of the "Dnepr-2" computers made it possible for the first time to implement remote communication between Ukrainian academic institutes (a prototype of regional network). It was used also for implementation at Dnieper Metallurgical Plant of the first in Europe remote automated control on the Bessemer technological process. For many years, “Dnepr-2" computers were used to automate the technological process control in hundreds of enterprises and operated as the onboard computers of various military vehicles, ships and equipment. During the Soyuz-Apollo space flight, two “Dnepr-2” computers controlled the large-screen information display of the Soviet Flight Control Center.

The success of the above projects was facilitated also by choosing GIC as the leading organization in the All-Union Target Programme for Automation of Scientific Research, Complex Object Tests, and Design Work.

Those works were preceded by two important achievements. First, Small Electronic Calculating Machine (MESM) developed by a team of scientists from the Kiev Institute of Electrotechnology under the direction of S.A. Lebedev (1951) was the first universally programmable electronic computer in the Soviet Union [5]. Second, research publications of A.I. Kitov, A.A. Lyapunov, S.I. Sobolev and others [6 – 9] had explained the meaning and importance of cybernetics and computer technology to Soviet Union leaders and society. Among the publications, the country's first book on this subject [9] played an important role in overcoming the negative interpretation of cybernetics as a “bourgeois science” which was official in 1950s. The achievements led to computer technology recognition and development in Soviet Union. The written appeal of A.I. Kitov, then head of Computing Center of the USSR Ministry of Defense, to the Central Committee of Communist Party of Soviet Union (CC CPSU) in which he declared the need to develop computer technology affected the Decree of CC CPSU and Council of Ministers of the USSR on accelerating and increasing the production of computers and their implementation in the national economy (1959). At the same time, A.I. Kitov prepared a report (“Red Book”) for CC CPSU substantiating the feasibility of creating a unified ACS for the armed forces and the national economy on the base of a common network of computer centers (Economic Automated Management System, EAMS) for improvement of central planning. The idea of EAMS had not received recognition from the country's leadership because of concerns in the military that they would be required to share information with civilian planners. But, along with the publications [10 – 13], “Red Book” highly contributed to the idea future development [5].

V.M. Glushkov’s publications [14, 15] on the role of computers and cybernetics in the production process automation, and especially his 10 basic principles of ACS development and implementation [16] created then a scientific basis for implementation of computer technology, economic and mathematical methods in the national economy of Soviet Union. The active implementation of early ACS in Soviet Union was facilitated by the Academician V.M. Glushkov appointment in 1963 as Chairman of the Interdepartmental Scientific Council in Computer Technology under the State Committee for Science and Technology.

In 1963-1965, active work began on the development of ACS for production processes (ACSPP) at enterprises of various sectors of the national economy and the military-industrial complex (MIC). The earliest ACSPP were implemented at the big enterprises “Lviv” and “Galvanic” on the basis of the Lviv television plant “Electron” and the Kiev plant “Arsenal”.

In the early 1960s, V.M. Glushkov proposed a project to create a nationwide automated system for managing the economy of the country (OGAS) [17]. It aimed both electronic document management (“paperless economy”) and electronic payments (“moneyless economy”), and its distributed multilayer network of computer centers resembled future American ARPANET [18]. After the OGAS project was not accepted for national scale implementation (the request for funding was turned down in 1970), the development of enterprise scale ACS has intensified in various sectors and departments of the national economy and the military-industrial complex (MIC). The developments were understood as the first steps toward OGAS.

During 1960s and 1970s, a big number of industrial automated control systems were implemented. Among them the ACS of the USSR Ministry of Radio Industry was selected by the Government as the model for automated control systems of all 9 military related Ministries of USSR. The ACS chief designer was A.I. Kitov, and its scientific supervisor was V.M. Glushkov. Another typical ACS “Healthcare” also developed under A.I. Kitov leadership became widely distributed in heath care centers of USSR. Huge work on the automated control system development and implementation was carried out by many leading scientists of the former Soviet Union, leaders and representatives of various industries and Government departments.

The fundamental results of V.M. Glushkov in theory and practice of planning and controlling complex processes [19 – 22] together with the IC achievements in optimization methods [23 – 28] and in technology of hierarchical multi-level problem-oriented systems [29], and in efficient parallel solving of ordinary differential equation systems [30] started the next stage of ACS development and became the basis for early ACS applications to environmental problems.

It is a well known fact that for many years the human society development priority was economy. Insufficient accounting the important environmental factors caused a significant increase in anthropogenic impact on the environment and has led to threatening negative consequences. Global understanding the consequences initiated the adoption by United Nations of the sustainable development concept. In 1992, the UN Conference on Environment and Development published the Earth Charter, which outlines the building of a just, sustainable, and peaceful global society in the 21st century and included the action plan “Agenda 21” aimed changing business approaches to involve cross-sectoral coordination, broad public participation and integration of the environmental and social concerns into all development processes. With this in mind, there is a need to create, in addition to ACS in the economy, automated environmental monitoring systems.

GIC traditionally elaborates a wide range of research and development projects of assessing the risks of environmental and technological disasters and predicting measures to eliminate their consequences on the base of a systematic approach to monitoring, mathematical modeling and simulation of processes in complex systems.

The work on modeling the hydrodynamic states of water objects began in GIC immediately after the accident at the Chernobyl nuclear power plant. They resulted in development of the first in Ukraine automated System for Water Objects Simulation SIMVO [31, 32]. It aimed obtaining comprehensive assessments of the ecological conditions of specific water bodies and watercourses on the basis of a systematic approach to the development of mathematical methods, models and simulation using hardware-software complexes for automating the studies. Then, in 2003, GIC developed the standard regional automated environmental monitoring system EMS. It was implemented in Kiev city also first in Ukraine. The systems was developed taking into account the basic Glushkov's principles of ACS construction as automated hierarchical problem-oriented systems and in accordance with the concept of sustainable development. At present, IC is participating in the ERA-PLANET/UA Academic Research Programme of NASU. ERA-PLANET/UA aimed at the implementation of the Ukrainian part of the EU Horizon 2020 project ERA-PLANET [33]. ERAPLANET/UA joins efforts of 6 NASU institutes and several non-academic organizations under general supervision of Space Research Institute of NASU and State Space Agency of Ukraine in the development of a new integrated open data solution for environment monitoring, simulation and decision support as a part of European Research Area (ERA). Planned studies are Europe's contribution to the emerging Global Earth Observation System of Systems (GEOSS). They help achieving national and international goals of sustainable development.

The paper describes SIMVO, EMS and ERA-PLANET to show how general principles of ACS for complex environment monitoring, simulation and evaluation were transformed in time.

2 Automated Systems of Ecology and Environment Protection

2.1 Automated System for Water Objects Simulation SIMVO

With the aim of the Chernobyl disaster mitigation, GIC has developed models and implemented the layer-by-layer calculations of the Dnieper river Kiev reservoir current states under various hydrometeorological conditions. The modeling results were immediately transferred to the Governments of Ukraine and Soviet Union and have played a paramount role in making the operational decisions. Similar calculations were then carried out for the entire cascade of Dnieper reservoirs. In addition, the data preparation and calculations provided input information for water flow simulation models. The modeling results which presented the integrated water circulation model in the form of information arrays, maps and diagrams were transferred to the disaster mitigation management for making operational decisions on eliminating the consequences of the Chernobyl disaster. The same data were transferred to Institute of Hydrobiology of NASU, to relevant ministries and Government departments for use in assessing water quality and bio-productivity of water objects, for predicting hydro biological indicators and parameter evolution.

Similar modeling was implemented for Sasyk reservoir, reservoir-cooler of Krivorozhska power plant, and all lemans of the North-Western Black Sea region.

The developed models of layer-by-layer current states were also used to model the desalination processes of the estuaries of Dniester, Tiligul, Berezan, and Dnieper-Bug lemans. For them, simulations and evaluation of current states at various depths were carried out for more than 1000 variants of hydro-meteorological conditions (for different wind directions and speeds). This allows us to predict the values of the integral water circulation, the direction of the currents and water exchange depending on the wind and to obtain the dynamic characteristics of the estuaries (Fig. 1, 2).

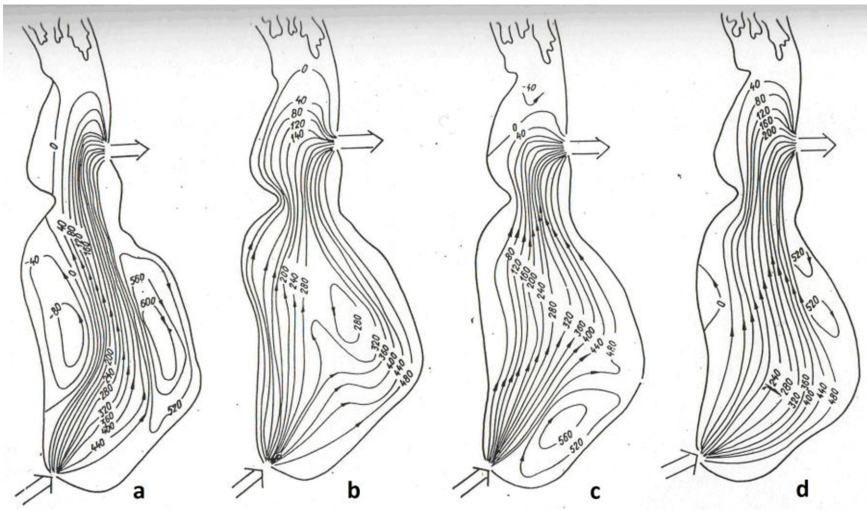

Fig. 1. Water circulation patterns in the Sasyk reservoir during the transit of Danube water of flow rate 500 m^3/sec and the average wind from north (a), south (b), east (c) and west (d)

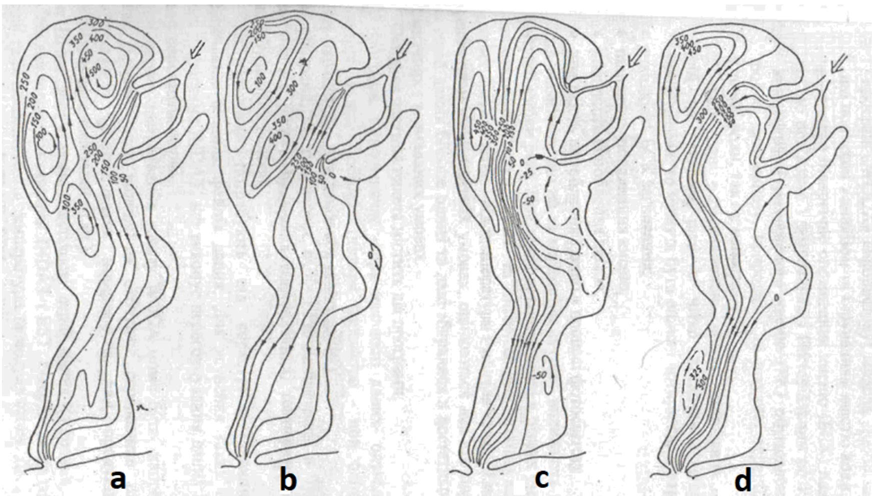

Fig. 2. Water circulation patterns in the Dniester leman with northern (a), eastern (b), southern (c), and western (d) wind of velocity 5 m/sec. The flow rate of Dniester is 300 m^3/sec

Computer graphic presentation of the results in the form of drawings, diagrams, vectors of wind directions with an indication of the scale of the grid was implemented using an interactive program Environment developed in Leningrad at the Institute of Social and Economic Problems (ISEP).

The research results were put in the base of implementation of the Complex Republican Research Program "Economic and Environmental Problems of the Creation of the Danube-Dnieper Water Management Complex for 1986-1990," which was however subsequently canceled.

The complex of models developed in the GIC during the above works has become the basis for development of problem-oriented subsystems of the system SIMVO for modeling the flow states of water objects. Now, SIMVO consists of 4 subsystems:

- WODA for modeling changes in the oxygen regime in watercourses;
- FEFLOW for modeling the underground aquifer processes;
- STREAM for modeling the pollution transfer in watercourses;
- and POTOK for modeling the stationary stock-wind currents in shallow water reservoirs at specific deep horizons.

Besides, SIMVO includes the program library APPROXIMATION for processing, compression and recovery of numerical data arrays with guaranteed accuracy. The library is based on the set of best Chebyshev approximation algorithms that are optimal in accuracy. It is an invariant component included in all the subsystems [34].

The relevance and novelty of SIMVO is based on use of the ready to use verified models of all its subsystems for water objects of Ukraine. It uses the models first developed at GIC within the described works. But from the structure viewpoint, SIMVO is an open system able to incorporate more models. It is planned to replenish it with new models and port to the SCIT cluster complex [35] as a part of its basic application software toolkit. More detailed description of SIMVO was published in [36].

SIMVO is important because of collected archives of the water current states at specific winds which help predicting water exchange rates in Ukrainian water bodies and evaluating their dynamic characteristics.

The development and use of SIMVO models played a decisive role in assessing the real consequences of the Chernobyl disaster and for taking water protection measurements as a part of the complex work of its mitigation.

2.2 Automated Environmental Monitoring System EMS for Kiev City

The automated EMS of Kiev was developed according to all the 10 Glushkov’s basic principles of ACS design [16] and general recommendations for the functioning of multi-level hierarchical problem-oriented systems [28], as well as the sustainable development concept based environmental factor priority.

The system development started from approval of the first in Ukraine technical specification for a Typical Regional Automated Hierarchical (two-level) Environmental Monitoring System (2003). Its hierarchical architecture corresponds to the recommendations of [28], and its regional (cross-sectoral) nature fits to the “Agenda 21” approach. The structural basis of the EMS according to [16] is an open geographically distributed radial computer network of problem-oriented control complexes (POCC), the Center of Operational Monitoring (COM) and the customer organizations of the system with their local computer networks protected as well as the communication channels between POCC and COM or between PTO and the customers. The EMS basic principles of modularity and openness simplify adding new POCCs. Using systematic approach the technical specification proposed interfaces for the data structure compatibility of information from different monitoring objects and the possibility for the information integration within the predictive assessments of the environment integrated state. The EMS software also includes the set of data processing and compression libraries based on the best Chebyshev approximation algorithms.

EMS was planned as a typical regional system. Its first phase implementation in Kiev was explained by several factors including increased environmental hazard in the city (industrial pollution of air, soil-water-vegetation ecosystems, dangerous geological processes, etc.), the Kiev capital status, good communication and ecology control networks, and high concentration of research and budget resources. Kiev city seems to be the most prepared region of Ukraine for transition to the path of sustainable development.

The relevance of creating EMS in the city of Kiev is due to the facts that the global problems of sustainable development are manifested and solved at the regional level, and the negative technological impacts of megacities is among the most critical (both strong and raising) ecological risk sources. High environmental hazards in the city include industrial pollution of air along highways and near residential areas, soil-water-vegetation ecosystem exhaustion, and dangerous geological processes (erosion, flooding, landslides, etc.).

The basic information and technical resource of Kiev EMS included hardware and software tools for automated data collection, processing, saving, display and transmission. Its hardware was organized in local workstation networks. Its basic software consisted of intelligent application software for processing and compressing information arrays, system software of central database (EMS DB) and problem-oriented databases of individual POCCs with ensuring compatibility of their data structures.

The results of the Kiev EMS work have been repeatedly demonstrated at exhibitions of various levels, in particular, at the annual Dovkillia 2004 and Dovkillia 2012 exhibition forums, at the Pan-European Ecology Summit, were awarded with diplomas and received positive feedback from experts.

In 2013, Kiev EMS was put in the base of a NASU Programme for development of Automated Integrated Environmental Monitoring System (ASKEM). The Programme was developed under the leadership of GIC together with scientists from other academic institutes of NASU and specialists from many other organizations. ASKEM was proposed as a typical regional component the Unified National Monitoring System. Unfortunately, the Programme funding was not started.

2.3 Smart City Interoperable System of ERA-PLANET/UA Infrastructure

The ERA-PLANET project of the European Horizon 2020 Programme is dedicated to the implementation of the European Research Area (ERA) principles in the field of Earth research in order to strengthen Europe's role in Group on Earth Observatory

(GEO) and Copernicus. Participants of the project are 35 research centers from 15 European countries. The project combines work packages into 4 strands:

- the work package SMURBS (SMart URBan Solutions for air quality, disasters and city growth) for the strand 1 “Smart Cities and Resilient Societies”,
- the work package GEO-Essential (Essential Variables workflows for resource efficiency and environmental management) for the strand 2 “Resource Efficiency and Environmental Management”,
- the work package iGOSP (Integrated Global Observing Systems for Persistent Pollutants) for the strand 3 “Global change and Environmental treaties”,
- the work package iCUPE (Integrative and Comprehensive Understanding on Polar Environments) for the strand 4 “Polar areas and natural resources”.

Ukraine participates in the first 3 strands [37, 38], and GIC participates in works on SMURBS. The SMURBS purpose is to integrate data from local monitoring stations, smart sensors, satellites, simulation systems, open data sources and individual observers to inform target working groups, decision makers and ordinary citizens, as well as to coordinate through the data the national and regional environmental protection programs for cities in 3 main areas: urban growth, air quality, environmental disaster management (including peat fires, landfill fires, man-caused disasters).

In the direction of urban growth, SMURBS task is to develop machine learning and gridding technology to calculate and annually update Urban Atlas maps [39] for all major cities based on open multi-channel data from satellites (such as Landsat-8 [40], Radarsat-2 [41], Terra and Aqua MODIS [42], Copernicus Sentinel-1A and other satellites [43], MetOp series satellites A/B/C [44], Suomi NPP [45], Aura [46]), open maps of the road network with adjacent buildings (such as Open Street Map [47]), population levels (GHSL [48]), atmosphere monitoring systems (CAMS [49]), etc. Now, Urban Atlas presents data only for EU cities with a population of over 100,000.

In the direction of air quality, SMURBS should calculate similar pollution maps based on satellite data, in-situ monitoring of air pollution by "big particles" of dust (PM_{10} – up to 10 microns) from roads and industrial plants and "small particles" of smoke ($PM_{2.5}$ - up to 2.5 microns), analysis of the air chemical composition in stationary and mobile control points, the Real-time Air Quality Index data (WAQI [50]) and indirect data of the analysis of plants and water reservoirs, as well as the population medical surveys.

In the direction of disaster protection, SMURBS tasks are detection of fire sources on the base of temperature data from satellites, generalized estimation of air composition and density of impurities, simulation based pollution forecasting by meteorological reports and satellite data on temperature, cloudiness, force and direction of winds.

An information system for solving such complex problems meets the difficult task of integrating data of different origins and nature, of different formats, scales and coordinate systems with the requirement of bidirectional interoperability (i.e. openness for easy integration with existing and future data sources and information systems) [51]. Similar problems were solved by GIC within the automated control system development for SIMVO and SEM, but, in a much smaller scale. A novel feature of the new system is implementation of the European open data principles for the research results. To date, GIC has implemented a final version of the working prototype of the system for mapping information and two prototype variants for general information (semantic directories, dashboards). The choice of the two remains to be made. General architecture of ERA-PLANET/UA subsystem of SMURBS is presented on Fig. 3. The work continues.

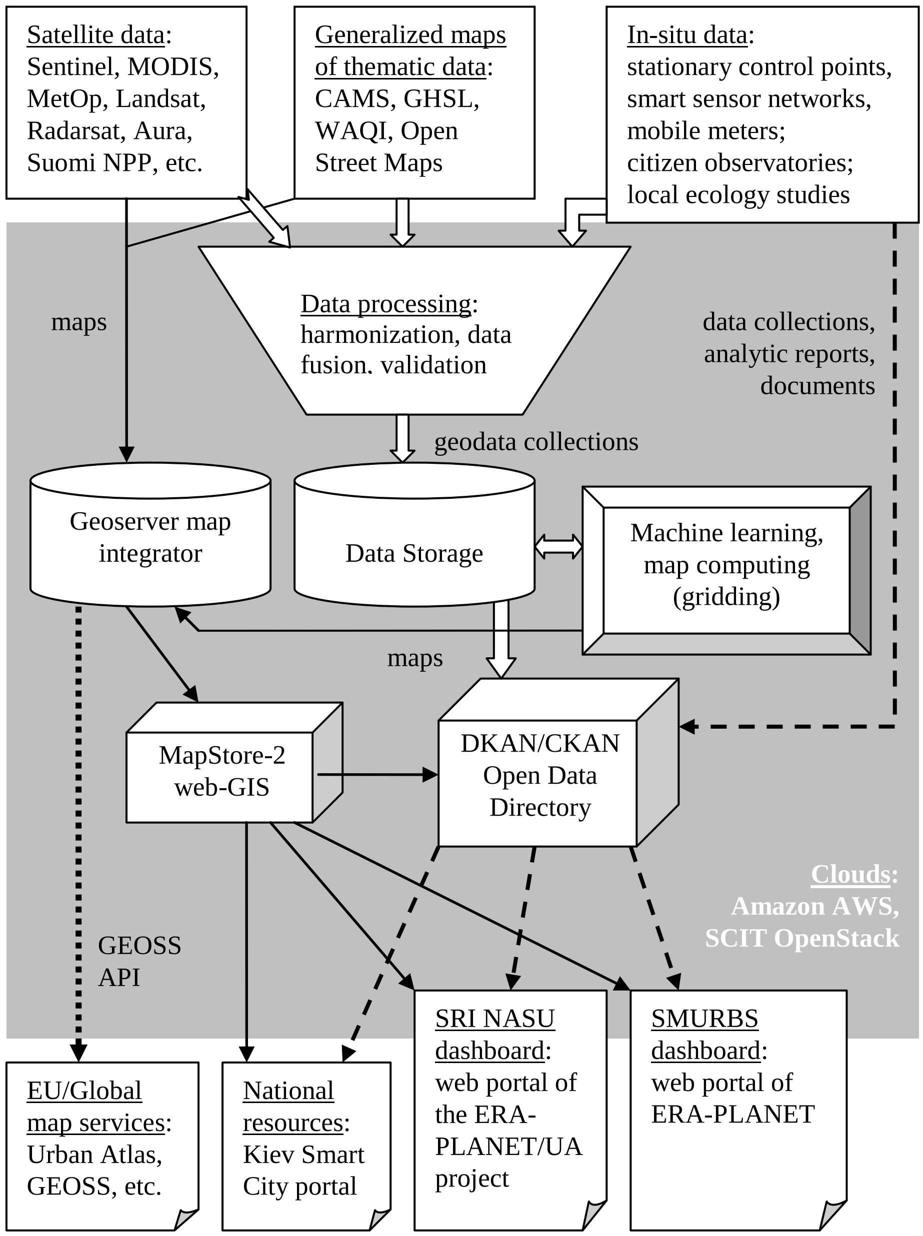

Fig. 3. Architecture of ERA-PLANET/UA SMURBS subsystem

3 Conclusion

The extensive experience of V.M. Glushkov Institute of Cybernetics in the development and implementation of ACS, power of its parallel computer complex SCIT of cluster architecture provide the Institute with the status of a basic organization for the further development of automated regional control systems of ecological monitoring and modeling based decision making in accordance with the Concept of Sustainable Development of Planet Earth.

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