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THE DATA FUSION GRID INFRASTRUCTURE: PROJECT OBJECTIVES AND ACHIEVEMENTS

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Abstract. This paper describes the objectives and achievements of the project "Data Fusion Grid Infrastructure" jointly supported by INTAS, the Centre National d'Etudes Spatiales (CNES) and the National Space Agency of Ukraine (NSAU). Within the project, a Grid infrastructure has been developed that integrates the resources of several geographically distributed organizations. The use of Grid technologies is motivated by the need to make computations in the near real-time for fast response to natural disasters and to manage large volumes of satellite data. We show the use of developed Grid infrastructure for a number of applications that heavily rely on Earth observation (EO) data. These applications include: numerical weather prediction (NWP), flood monitoring, biodiversity assessment, and crop yield prediction.

Keywords: Environmental applications, Earth science, research infrastructure, grid computing, Earth observations

1 INTRODUCTION

At present, satellite data are used in many fields playing an important role in land, water and air applications. The use of satellite data in meteorology is of a key importance. The main advances, both in scientific and technological aspects of weather analysis and forecasting during past decades, are connected with an increase of available computational power and with an emerging of meteorological satellites as a new source of observations.

Modern meteorological satellites provide huge amount of data with different temporal, spatial and spectral resolution. These satellites include geostationary satellites such as MSG, GOES with visible and infrared sensors, and low orbiting satellites such as MODIS/Terra, MODIS/Aqua, ATOVS, AIRS/Aqua, SSM/I, QuikSCAT covering broad spectrum ranging from ultraviolet to microwaves. Geostationary satellites provide high temporal data for a fixed observed territory. Complementary, low orbiting satellites allow us to cover full Earth surface with observation with high spatial and spectral resolution sacrificing temporal resolution. The variety of observations with different physical characteristics emerges the need of data fusion techniques to produce a synergetic output. At present, the most sophisticated tools for fusion of meteorological data are numerical models, in particular Numerical Weather Prediction (NWP) models.

NWP models can be classified as general circulation models, among them are the Global Forecast System model (GFS) operated by the National Centre for Environmental Prediction (NCEP) [1], TL799L91 model operated by the European Centre for Medium-Range Weather Forecasts (ECMWF) [2], and regional models such as MM5 [3] and Weather Research and Forecasting (WRF) [4] models.

The models allow integration of different sources of satellite data indirectly in dynamically consistent way and conduct the state of the atmosphere. This process is referred as data assimilation [5]. There are numerous techniques for data assimilation. We can mention the optimum interpolation (OI) method that is historically available, 3-dimensional variation assimilation (3Dvar) that is still used in regional models; 4-dimensional variation assimilation (4Dvar), currently used by most weather agencies for global data assimilation and Kalman filter methods [6, 7, 8]. The meteorological data is important to many other applications including floods, droughts, vegetation state assessment, yield prediction, etc.

Numerical weather prediction is a very resource consuming task both in sense of computational resources and of data resources. For instance, a single 3-day weather forecast of WRF model for the territory of Ukraine on 10 km grid takes 10 hours and produces 5 Gb of output data. Moreover, the EO domain itself is characterized by the large volumes of data that should be processed, catalogued, and archived [9, 12]. The processing of satellite data for different applications is carried out not by the single application with monolithic code, but by the distributed applications. This process can be viewed as a complex workflow [13] that is composed of many tasks: geometric and radiometric calibration, filtration, reprojection, composites construction, classification, products development, post-processing, visualization, etc. For example, calibration and mosaic composition of 80 images generated by ASAR instrument onboard Envisat satellite takes 3 days on 10 workstations of Earth Science GRID on Demand that is being developed in ESA and ESRIN [9]. Dealing with EO data, we also have to consider security issues regarding satellite data policy, the need for processing in near-real time (NRT) for fast response within international programs and initiatives for disaster monitoring, in particular the International Charter "Space and Major Disasters" and the International Federation of Red Cross.

Hence, all these factors, such as the need for processing data in NRT, the need for managing large volumes of satellite data and derived products and providing a uniform access to them, lead to the use of Grid technologies [9, 12, 14]. In this case, a Grid environment is considered not only for providing high-performance computations, but, in fact, can facilitate interactions between different actors by providing a standard infrastructure and a collaborative framework to share data, algorithms, storage resources, and processing capabilities [9].

This paper describes the objectives and achievements of the INTAS-CNES-NSAU project "Data Fusion Grid Infrastructure" that is being carried out by the Institute of Informatics, Slovak Academy of Sciences (II-SAS), CNES, Space Research Institute of the National Academy of Sciences of Ukraine and the National Space Agency of Ukraine (SRI NASU-NSAU), and the Space Research Institute of Russian Academy of Sciences (IKI RAN). We describe the Grid environment that has been developed within the project. We will show several real-world applications that are addressed within developed Grid infrastructure, in particular numerical weather prediction (NWP), flood monitoring, biodiversity assessment, and crop yield prediction.

2 PROJECT OBJECTIVES AND TASKS

The aim of the project was to develop new methods of data fusion and to provide Grid-based solutions for image processing and geospatial modelling, targeting to improve applied agricultural problems solving and other applications. To achieve this goal several concrete objectives were followed:

- to develop robust method of environmental model adaptation, and to verify this approach for Numerical Weather Prediction (NWP) model for the region of Ukraine;
- to determine optimal set of variables for data assimilation for NWP model for the region of Ukraine;
- to improve existing methods of yield prediction to assimilate data of NWP;
- to adopt improved methods of yield prediction for different regions (in particular Ukraine);
- to develop problem-oriented environment targeting NWP model. The particular problems that will be addressed are adaptation and data assimilation for Weather Research and Forecasting (WRF) model;
- to harmonize existing Grid resources of Ukraine with CEOS (Committee on Earth Observing Satellites) Working Group on Information Systems and Services (WGISS) initiative Wide Area Grid (WAG);
- to fill the gap in existing Grid infrastructure such as geospatial data archives and visualization.

Real-life applications for solving domain-specific problems are often highly resource (CPU, data, network) consuming and require large amounts of computational power to be involved. Utilizing Grid technology helps distribute the problem on multiple weakly coupled computational resources from different administrative domains.

The project research programme consisted of four work packages (WPs). Activities within WP1, "Image processing", were directed to the development of intelligent methods for adaptation of complex models (in particular, NWP) and data assimilation in order to provide new-quality solutions for applied problems. These included: the development of robust method for environmental model adaptation; verification of this approach for NWP WRF model for the region of Ukraine; establishing data, software and hardware capabilities to create initial conditions for regional NWP WRF model; selection of the most appropriative set of satellite data with regards to objective criteria; to improve existing methods of yield prediction by assimilating data from NWP.

Adaptation of environmental models and data assimilation could be represented as complex optimization problem in which functional is defined on hybrid discrete-continuous space with non-convex surface. This limits the use of classical optimization techniques. That is why in this project we used intelligent methods, in particular genetic algorithms [10], in order to find near-optimal solution for this non-classical optimization problem. The advantages of genetic algorithms lie in the little use of a priori knowledge of optimization surface. However, the methodology allows to increase the quality of solution by including information given by experts. Expert's knowledge can be used to adjust statistical distribution for initial population, to specify mechanisms of mutation and crossover. Genetic algorithms already proved to be useful for agriculture model transfer [11]. In the project genetic algorithms were applied to solve optimization problems arising in adaptation of NWP models and assimilation process.

WP2, "Infrastructure", aimed at providing essential services for the implementation and exploitation of methods developed in WP1. These included: the development of software for implementation a Grid-enabled archive of geospatial data and deployment of this software on Satellite Data Storage System of IKI-RAN; development of Grid-enabled visualization service for geospatial data; harmonization of developed services and existing Grid infrastructure within WAG (Wide Area Grid) activities initiated by CNES.

WP3, "Project Management", and WP4, "Dissemination and Exploitation", were to enable and foster intra- and inter-project communications and collaboration, and transfer of knowledge and software within and outside the consortium. A particular attention was brought to the communication with other projects and initiatives, in particular with WAG, WGISS and GEOSS, dissemination of results on international conferences and workshops, distribution of developed software.

The following sections will highlight the results that were achieved within the project.

3 DESCRIPTION OF THE GRID INFRASTRUCTURE

The Grid infrastructure that has been developed within the INTAS-CNES-NSAU project "Data Fusion Grid Infrastructure" integrates the resources of geographically distributed organisations, in particular:

- SRI NASU-NSAU (Ukraine) with deployed computational and storage nodes based on Globus Toolkit 4 [15] and gLite 3 [16] middleware, access to geospatial data and Grid portal;
- Institute of Cybernetics of NASU (IC NASU, Ukraine) with deployed computational and storage nodes based on Globus Toolkit 4 middleware and access to computational resources (approximately 500 processors);
- Center of Earth Observation and Digital Earth (CEODE, China) with deployed computational nodes based on gLite 3 middleware and access to geospatial data (approximately 16 processors).

Satellite data are distributed through the Grid environment. For example, ENVISAT WSM data (that are used within the flood application) are stored on the ESA's rolling archive and routinely downloaded for the Ukrainian territory. Then, they are stored in the SRI's archive that is accessible via the Grid. MODIS data from

Terra and Aqua satellites that are used in flood, crop yield prediction and biodiversity assessment applications are routinely downloaded from the USGS's archives and stored in the SRI NASU-NSAU, IC NASU and IKI RAN resources.

Access to the resources of the Grid environment is organised via a high-level Grid portal that has been deployed using GridSphere framework [17]. Through the portal, users can access the required satellite data and submit jobs to the computing resources of the Grid in order to process satellite imagery. The workflow of the data processing steps in the Grid (such as transformation, calibration, orthorectification, classification etc.) is controlled by a Karajan engine [18].

The existing architecture of the Grid is shown in Figure 1.

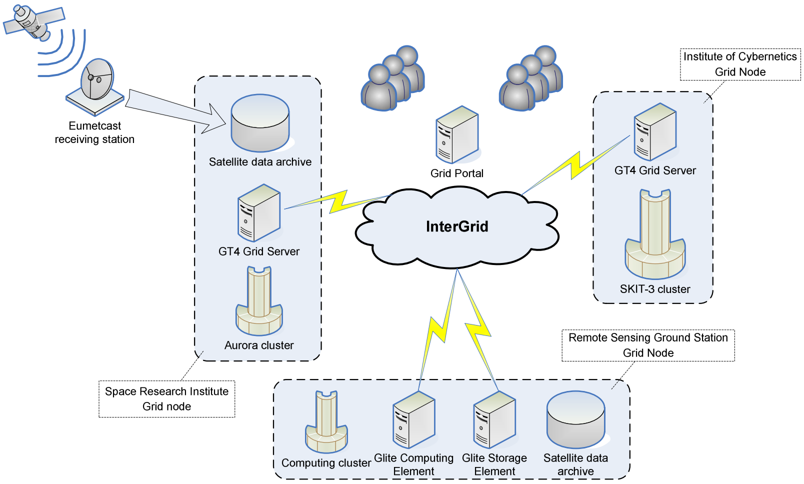


Fig. 1. Architecture of the grid infrastructure

4 VISUALIZATION OF DATA IN GRID INFRASTRUCTURE

In order to visualize the results of data processing in the Grid environment, we use an open-source OpenLayers framework [19] and UNM Mapserver v5. OpenLayers is a JavaScript library for building rich web-based geographic applications, with no server-side dependencies. OpenLayers implements industry-standard methods for geographic data access, such as the Open Geospatial Consortium's Web Mapping Service (WMS) and Web Feature Service (WFS) protocols.

Mapserver is an Open Source development environment for building spatially-enabled internet applications. It supports the OGC's WMS standard that enables the creation and display of registered and superimposed map-like views of information that come simultaneously from multiple remote and heterogeneous sources [20].

Having created WMS services for the EO derived products, we use them in the OpenLayers framework and in Google Earth by generating corresponding KML (Keyhole Markup Language) files.

The examples of results of data processing are given in the following section.

5 APPLICATIONS WITHIN THE GRID

In this section we review applications that are solved using the resources of the Grid system. In particular, we focus on the weather modelling application, flood monitoring, and biodiversity assessment. The motivation for the selection of these applications comes from the following:

(i) numerical weather prediction belongs to computationally intensive applications;
(ii) flood applications need fast response to the emergencies, and thus require a reliable infrastructure for data management and processing;
(iii) biodiversity assessment belongs to data intensive application where different data and products are analysed in order to produce the final product.

5.1 Weather prediction

Weather forecast data is used in the core models of flood monitoring and crop state prediction applications in the Grid environment. The numeric weather prediction model WRF was configured and adapted to the territory of Ukraine [21]. Currently, we routinely produce 72-hours forecasts every 6 hours with a spatial resolution of 10 km. The horizontal grid dimensions are 200 × 200 points with 31 vertical levels. We use NCEP GFS forecasts as boundary conditions. This data is available via the Internet though the NOMADS system (National Operational Model Archive & Distribution System). The workflow of the model run is composed of the following steps:

(i) data acquisition;
(ii) data pre-processing, computation of forecasts using WRF model and data post-processing;
(iii) visualization of the predicted parameters.

With such configuration, the model runs approximately 6 hours on the Grid's SCIT-3 supercomputer of the IC NASU (total 300 Intel Xeon 3.0 GHz cores) and produces approximately 5 Gb of output data. The visualization interface for the model is shown in Figure 2.

We have also tested the performance of the WRF model in dependence of the number of computational nodes. For test purposes, we used the WRF model version 2.2 with a model domain identical to those used in operational NWP service (200 × 200 × 31 gridpoints with horizontal spatial resolution 10 km). We observed almost linear productivity growth within increasing number of computation nodes. For instance, 8 nodes of the SCIT-3 cluster of the Grid infrastructure gave the performance increase in 7.09 times (of 8.0 theoretically possible) when compared to the single node. The use of 64 nodes increases the performance in 43.6 times.

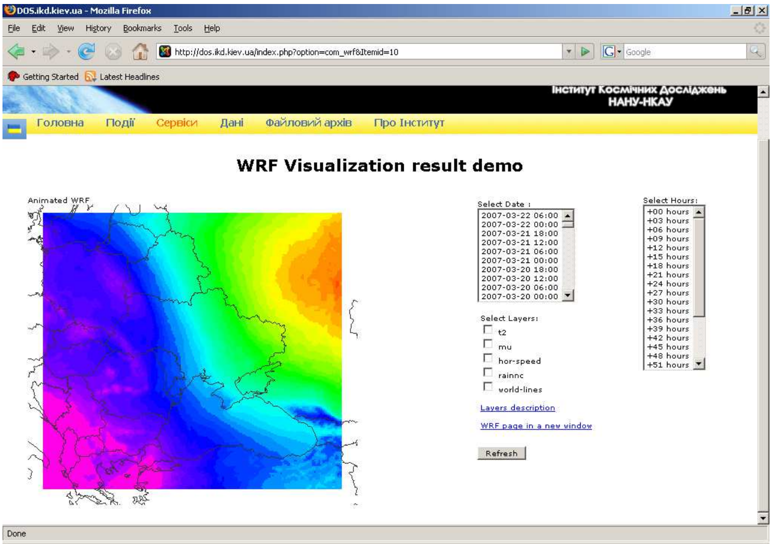


Fig. 2. Forecasts of the pressure using WRF model

5.2 Flood monitoring

We developed a neural network approach to flood extent extraction from satellite synthetic-aperture radar (SAR) imagery [22, 23]. We developed a parallel version of our method that can be run on several computational nodes. The use of the Grids allowed us to considerably reduce the time required for image processing. In particular, it took approximately 10 minutes to process a single SAR image on a single workstation. The use of Grid computing resources allowed us to reduce the time to less than 1 min. The developed Web service is accessible via the Internet through the address `http://floods.ikd.kiev.ua` (Figure 3). The resulting flood maps can be also visualised using KML files through Google Earth (Figure 4).

5.3 Biodiversity Assessment

In collaboration with scientists from the Centre for Aerospace Research of the Earth (Ukraine), we developed an approach for land biodiversity assessment and mapping using EO data [24]. The proposed approach was developed for the Pre-Black Sea region, but, in general, can be extended to any other region.

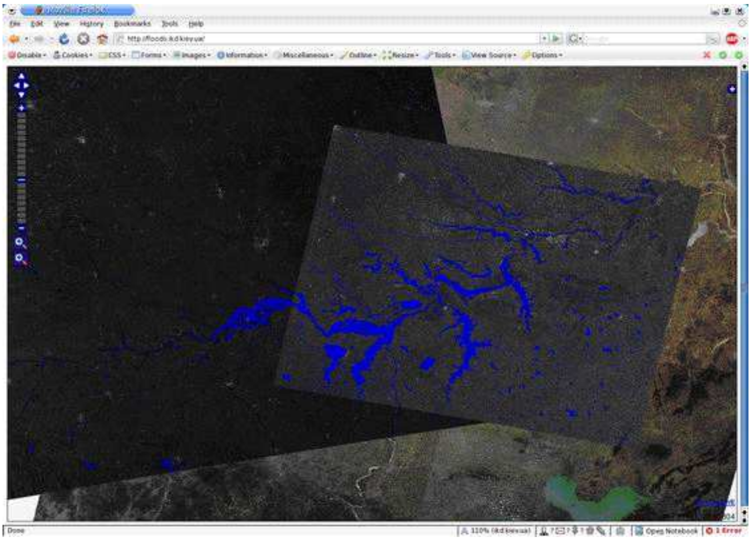


Fig. 3. Flood application within the Grid infrastructure. Flood event: River Huaihe, China, July, 2007. Data sources: Envisat/ASAR (© ESA, 2007) and RADARSAT-1 (© CSA, 2007)

Biodiversity is associated with a number of abiotic and biological factors that can be identified using remote sensing data. These factors include: landscape types, geographical latitude/altitude, climate conditions (such as mean daily temperatures, humidity, etc.), structure and primary productivity of a vegetation mantle. These factors can be estimated using EO data from space [24]. The workflow for biodiversity estimation consists of the following steps: data acquisition, data processing, and visualization.

Special system was developed in order to acquire satellite data on regular basis. This system operationally monitors for the new products and provides automatic data acquisition from different sources: Level 1 and Atmosphere Archive and Distribution System (LAADS), Land Processes Distributed Active Archive Center (LP DAAC) and National Snow and Ice Data Center (NSIDC). The acquired data is stored in the data archive of SRI.

After the required data has been acquired, the data is re-projected to a conical Albert projection and scaled to the spatial resolution of 250 m. Since we use data from multiple sources different tools were applied for the re-projection and scaling purposes. In particular, we used MODIS Swath Reprojection Tool, MODIS Reprojection Tool, and GDAL library (Geospatial Data Abstraction Layer, `http://www.gdal.org`). Since biodiversity index represents a parameter that is estimated for the time range, it is required to calculate average values for the parameters influencing biodiversity. For this purpose, average composites of images were created. Using these composites and solar irradiation acquired from SRTM

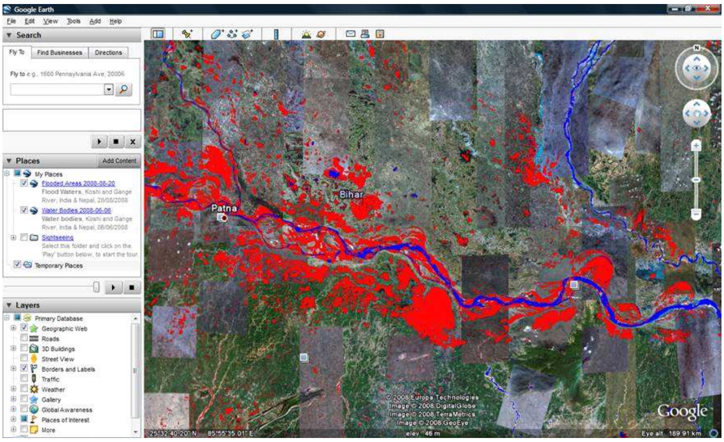


Fig. 4. Flood application within the Grid infrastructure visualised using Google Earth. Flood event: River CityKoshi, India and Nepal, August, 2008. Data sources: Envisat/ASAR (© ESA, 2008)

DEM v2, we estimated the biodiversity index using the fuzzy model [24]. The resulting product is a georeferenced file in GeoTIFF format showing biodiversity index over the given region.

We developed a Web service for biodiversity monitoring that enables regular and operational acquisition of biodiversity estimates for the Pre-Black Sea region and allows to track changes in its values. This, in turn, reveals negative changes in the environment of the given region and provides adequate information on biodiversity hotspots. This Web service is implemented on the basis of OGC standards, Web Map Service 1.1.1 (`http://www.opengeospatial.org/standards/wms`) and Web Coverage Service 1.0 (`http://www.opengeospatial.org/standards/wcs`). The developed Web service is accessible via Internet through the address `http://biodiv.ikd.kiev.ua` (Figure 5).

5.4 Crop Yield Prediction

We implemented a time series analysis of vegetation index approach for yield prediction and vegetation state assessment [25]. As a basis, we used the enhanced vegetation index (EVI). Crop state estimation requires analysis of 217 Mb of data per run, and yield prediction requires approximately 4 Gb per run, which takes approximately 30 minutes in the Grid infrastructure. Estimation is started routinely for the next 16 days. Reanalysis and model real-time calibration requires nearly 20 Gb of historical data processing, and is started at least once per harvest. The WOFOST model is used with the assimilation of Leaf Area Index (LAI) derived from satellite observations. The visualization interface for the developed services is shown in Figure 6.

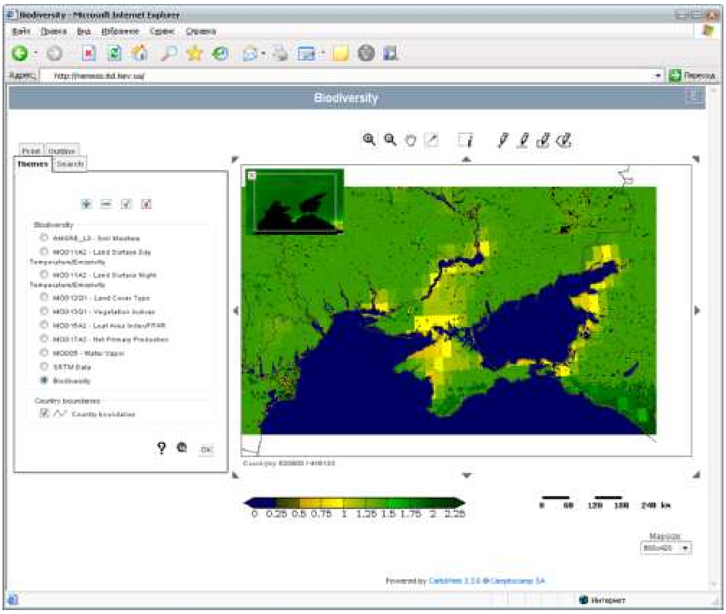
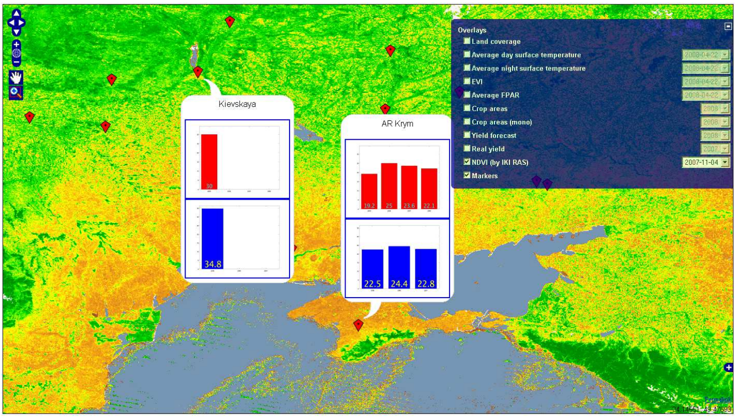


Fig. 5. Demonstration of Web service for biodiversity assessment using EO data products for the Pre-Black Sea region of Ukraine

6 CONCLUSIONS

In this paper, we presented the objectives and the achievements of the project "Data Fusion Grid Infrastructure" jointly supported by INTAS, CNES and NSAU. Within the project Grid infrastructure has been developed that integrates resources of several geographically distributed organizations: SRI NASU-NSAU, IC NASU and CEODE. The specific results that were achieved within the project are:

- new intelligent methods for complex environmental models adaptation were developed, and verified for NWP model for the region of Ukraine;
- data, software and hardware capabilities were established in order to create initial conditions for regional NWP WRF model; the optimal set of satellite data for NWP data assimilation was identified;
- existing methods of yield prediction were improved by assimilating data from NWP models and adaptation of models to particular region;
- archive for geospatial data was developed and deployed on resources of SRI NASU-NSAU, IC NASU and IKI-RAN;
- visualization services for geospatial data were developed;
- developed services and existing Grid infrastructure were harmonized with WAG project initiated by CNES.



Overlays
☐ Land coverage
☐ Average day surface temperature 2008-04-22
☐ Average night surface temperature 2008-04-22
☐ EVI 2008-04-22
☐ Average FPAR 2008-04-22
☐ Crop areas 2008
☐ Crop areas (mono) 2008
☐ Yield forecast 2008
☐ Real yield 2007
☑ NDVI (by IKI RAS) 2007-11-04
☑ Markers

Fig. 6. Wheat yield forecast (Ukraine, 2008)

Currently, we are using a Grid portal solution based on GridSphere framework to integrate Grid systems with different middleware, such as GT4 and gLite 3. In the future, we plan to implement a metascheduler approach based on a GridWay-like system.

We showed the use of the Grid infrastructure for a number of applications that heavily rely on EO data. These applications included: numerical weather prediction, flood monitoring, biodiversity assessment, and crop yield prediction.

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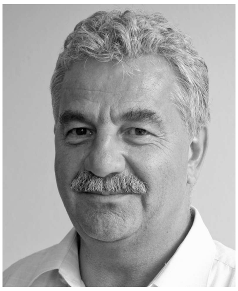

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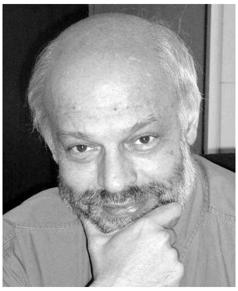

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