Earth Observation in Sustainable Urban Planning and Management: the GEOURBAN Project

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ABSTRACT

Cities require enormous quantities of resources and concurrently generate large amounts of waste and pollutants. Accordingly, urban planning increasingly demands alternative concepts and techniques to implement and assure effective and sustainable urban development. In this context, up-to-date and area-wide information on the characteristics and development of the urban system is a key requirement. Nowadays, most of this information is collected by means of statistics, surveys and mapping or digitizing from imagery; however, in consideration of statistical information these approaches often show a comparably coarse spatial and temporal resolution while surveying and mapping is time consuming and cost-intensive - properties which significantly restrict periodic updates and regional, national or even global analyses. Earth Observation (EO) has become a promising tool to provide the required geo-data. Furthermore, an important step towards the improvement of the generated information products and their acceptance by decision makers consists of the adoption of holistic approaches on complex urban systems. GEOURBAN (ExploitinG Earth Observation in sUstainable uRBan plAnning & management) was a two-year project and its main achievements are presented in this study. In particular, these include: the organization of consultation meetings in the selected cities to capture users requirements and to take into account the potential users' perspective; the EO data analysis to derive key products capable of evaluating indicators; the selection and development of a list of indicators with emphasis to the common priorities of each city, as well as to the priorities of each city separately; and the development of a Web-based Information System.

Introduction

Grimmond et al. (2010) identified the needs for improvements in observations, data, understanding, modelling, tools and education to ensure that in the next 10 years we actively move towards developing more sustainable cities. Among others, the authors identified the need to explore the use of new measurement techniques including the application of Earth Observation (EO) data and the need to meet observation requirements to allow translation of research findings into urban planning tools and guidelines for different climate zones and classes of urban land use. Although urban planning and management need to describe and monitor the processes of urbanization, they also need to better predict local and regional environmental effects and feedbacks associated with possible urban trajectories. Despite the promise of new and

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fast-developing EO, a gap exists between the research-focused results offered by the urban EO community and the application of these data and products by the governments of urban regions. The urban EO community often notes the lack of communication of new knowledge and its implications to users, such as urban planners, architects and engineers. Nevertheless, increasing attention has been recently focused on bridging this critical gap and the GEOURBAN (ExploitinG Earth Observation in sUstainable uRBan plAnning & management) project contributes to this effort. In particular, the project aims at: analyzing the urban planning and management requirements relative to EO; reviewing the EO data sources and the respective analysis techniques and implement the most promising ones at selected case studies; analyzing the potential of future EO missions to support urban planning and management; developing a set of EO-based indicators capable of supporting sustainable urban planning and management; developing a Web-based Information System (WIS) to online evaluate these indicators; and demonstrating the developed WIS in specific case studies.

Past R&D activities focused on urban monitoring and modelling using visible and near infrared EO data as for instance in the European projects MURBANDY-MOLAND (Lavalle et al. 2001), Geoland – Land Information Service (GMES 2010), Urban Atlas (EEA 2010), as well as in US projects, such as the Urban Dynamics Research project (USGS 2010) and the Urban Environmental Project (ASU 2010). Concerning thermal infrared EO data, the majority of previous research has focused on surface temperature patterns and their relationships with urban surface biophysical characteristics, especially with vegetation indices and land use/cover types. Less attention has been devoted to the derivation of urban heat island parameters from land surface temperature (LST) data and to the use of remote sensing techniques to estimate surface energy fluxes (Weng 2009). Furthermore, EO data have been exploited together with in-situ observations and numerical models in GIS-based studies in a variety of R&D projects, e.g., the FP7 project BRIDGE (Chrysoulakis et al. 2013) focusing on urban metabolism. Several EO-based tools have been developed in the framework of these projects and some of them are web-based, (e.g., NASA's Giovanni). However, the innovation of the GEOURBAN project lies in the development of a WIS which reflects the multidimensional nature of urban planning and management, as operationalized in intelligible and transferable indicators, which are easily understood and applicable even by non-experts.

The allocation of space to the different human activities in a city and the regulations on their physical design are the principal means of development plans and control. To accomplish this task, the environmental, social and economic implications of the spatial pattern of human activities in the city must be understood to integrate sustainability principles into urban development practice. Furthermore, the feasibility to reduce environmental impacts by more efficient infrastructures and technical systems strongly depends on the type of settlement. There is an expanding market for EO data for a wide range of applications including land use/cover mapping, architectural applications, disaster and emergency assessment, facility mapping, real estate business, environmental studies and simulations, and utility provision. However, datasets including urban physical features as surface sealing or percentage of vegetation cover (intended either as overall or specifically including trees and shrubs, lawns etc.) were generally unavailable at a high spatial resolution for an effective urban planning at city level . Therefore, the potential of EO to support urban planning and management is high and GEOURBAN will contribute to the exploitation of this potential.

The main achievements of the GEOURBAN project are presented in this study. In particular, these include: the organization of consultation meetings in the selected case-study cities to capture the users requirements and to take into account the potential users' perspective from the beginning of the project; the EO data analysis to derive key EO-products capable of evaluating the GEOURBAN indicators; the selection and development of a list of environmental indicators with emphasis given to the common priorities of each case-study city, as well as to the priorities of each city separately; the design, development and demonstration of the GEOURBAN WIS. The GEOURBAN approach is presented in Section 2, the main achievements of the project are discussed in Section 3, whereas Section 4 includes the conclusions.

The GEOURBAN approach

Population growth, regional in-migration, and increasing ecological problems require advanced methods for city planners, economists, ecologists, and resource managers to support sustainable development in these rapidly changing regions. Despite the heterogeneity of the urban environment, EO is able to provide data with high temporal and spatial resolution for land-use characterization and analysis. However, urban environmental quality is a complex and spatially variable parameter which is a function of interrelated factors including the urban heat island phenomenon, the distribution of greenery, building density and geometry, air quality and urban metabolism. GEOURBAN focuses on both urban structure and urban environmental quality at micro, local and regional scales. Especially at regional scale where detailed information from other sources is not available to planners, EO is a particularly valuable tool.

The GEOURBAN consortium consists of six (public and private) organizations from as many countries: Greece, Germany, Switzerland, Turkey, Israel and Russia. The project is funded by ERA.Net-RUS focusing on the scientific cooperation of Russia with European Union and FP7 Associated Countries. Three cities have been selected as GEOURBAN application areas (case studies) with three different city typologies: a high-latitude continental city with a dynamic planning process reflecting the economical, social, and political changes that occurred within last two decades (Tyumen, Russia); a low-latitude Mediterranean city with high vulnerability in climate change, which also requires a substantial amount of energy for cooling (Tel-Aviv, Israel) and a representative central European city (Basel, Switzerland), where the cooperation between EO scientists and urban planners has been built on the basis of the past R&D projects investigating the urban microclimate.

The innovation of GEOURBAN lies in the development of a WIS which reflects the multidimensional nature of urban planning and management, which will be operationalized in intelligible and transferable indicators that can be easily understood by non-experts. The overall GEOURBAN approach is shown in Figure 1. It explores the potential of EO to support urban planning and management by providing guidelines towards sustainability objectives at micro, local and regional scales, as well as towards climate-change adaptation. These guidelines are the result of the combination of several EO-based indicators using the WIS. The web-based character of this tool makes it easily transferable from city to city and the indicators can be evaluated if EO data are available. Auxiliary vector data that may be needed to describe the urban surface topology and to spatially constrain the indicator calculations are available from public sources (i.e. Urban Atlas, CORINE Land Cover, GMES Service Elements, etc.). However, the user will have the option to use own spatial data to support the indicators evaluation, especially in cities where no other spatial information is available.

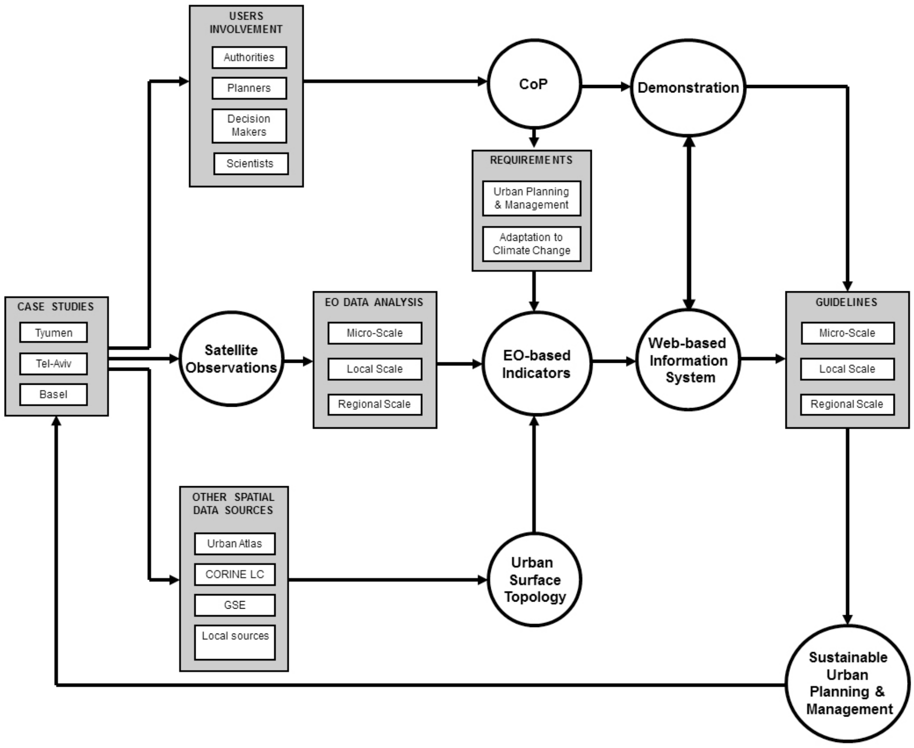


Figure 1. Flowchart of the GEOURBAN methodology.

In order to develop a method that will be welcomed by local governments, it was considered important to involve them in the project from the beginning. The project uses a Community of Practice (CoP) approach (Chrysoulakis et al. 2013), which means that in the case studies, local stakeholders and scientists of the GEOURBAN project meet on a regular basis in order to learn from each other. The CoP identified and provided insight into aspects which were important for the future users of the GEOURBAN products. It also provided network contacts for collecting auxiliary datasets for each case study. One of the main purposes of the CoP was to acknowledge the different stakeholders' perceptions into the indicator development. The end users were strongly involved in urban planning, as most of them work in city planning organizations in GEOURBAN case studies. Urban planners in these organizations, who are aware of human reactions and behaviors in reply to urban planning policies, provided their experience to define EO-related requirements for the WIS development and they will evaluate it during a demonstration event to be organized in the second phase of the project. It should be noted that the GEOURBAN consortium had the appropriate urban planning expertise, since several scientists involved in the project had considerable urban planning experience. Moreover, external experts from urban planning community were contacted and were involved in the CoP in each case study.

EO data was the main input for GEOURBAN indicators. Well-known EO analysis methods were used to calculate products from raw data. It should be noted that the development of new EO data processing tools was not among the objectives of GEOURBAN, but rather state-of-the-art methods were implemented. However, the users were provided with guidelines on the implementation of a minimum set of these methods, capable of extracting the products that are needed for indicator estimation, provided that suitable EO data are available. These methods were implemented off-line, therefore they aren't part of the WIS; only their products were used as inputs. Two protocols summarizing the EO analysis techniques used in GEOURBAN were developed: the first is related to Very High spatial Resolution (VHR) data analysis, whereas the second is related to High spatial Resolution (HR) and to Low spatial Resolution (LR) data analysis. Both protocols are available to the user community and describe in detail the particular EO analysis techniques, which are out of scope of the present overview article. Some of the GEOURBAN indicators, especially at regional scale, can be evaluated by EO higher level products that are available online, such as MODIS Level-2 products. In this case, the indicator evaluation is automatic. However, at micro-scale, where VHR EO data are needed, the respective analysis was implemented off-line for the GEOURBAN case studies. This can lead to a new service, since the indicators can be easily transferable from city to city.

As mentioned above, the users at GEOURBAN case studies were involved in the project from the beginning via a CoP approach. They provided the consortium with requirements related to urban planning and management, as well as to adaptation to climate change. User requirements led to EO-based indicators, as well as to specifications for the WIS design. A subset of these requirements that can be supported by EO methods and data was selected after a first round of CoP meetings in all case studies. A second round of CoP meetings, as an umbrella CoP, was organized during the demonstration of the GEOURBAN WIS. In this demonstration event, hands-on applications were organized giving the users the opportunity to get used to the final version of the WIS. However, the WIS was being developed in an iterative procedure and the users had access to each version of the system as it was released. The consortium released the first WIS prototype at the end of the first phase of the project and several versions of the WIS were released during its development exercise in the second phase. Since it is a web-based tool, the users were able to evaluate it online and provide their feedback to the consortium. The consortium was taken into account the user suggestions in developing next versions of the WIS. The final version was available during the above mentioned demonstration event.

Several R&D projects addressed the EO capabilities to support urban planning, but few of them integrated all different planning scales and developed EO-based indicators capable of supporting urban planning and management. A web-based tool, capable of evaluating such indicators, was available to the urban planning and management community in the beginning of GEOURBAN. It is true that a fully operational automatic online WIS cannot be developed, due to the physical and technical constraints related to the spatial resolution and revisit time of satellite sensors. However, the adaptation of the developed WIS to future missions will be addressed as a follow-up of GEOURBAN. It is therefore expected that a fully operational tool can be developed in the future.

Results and discussion

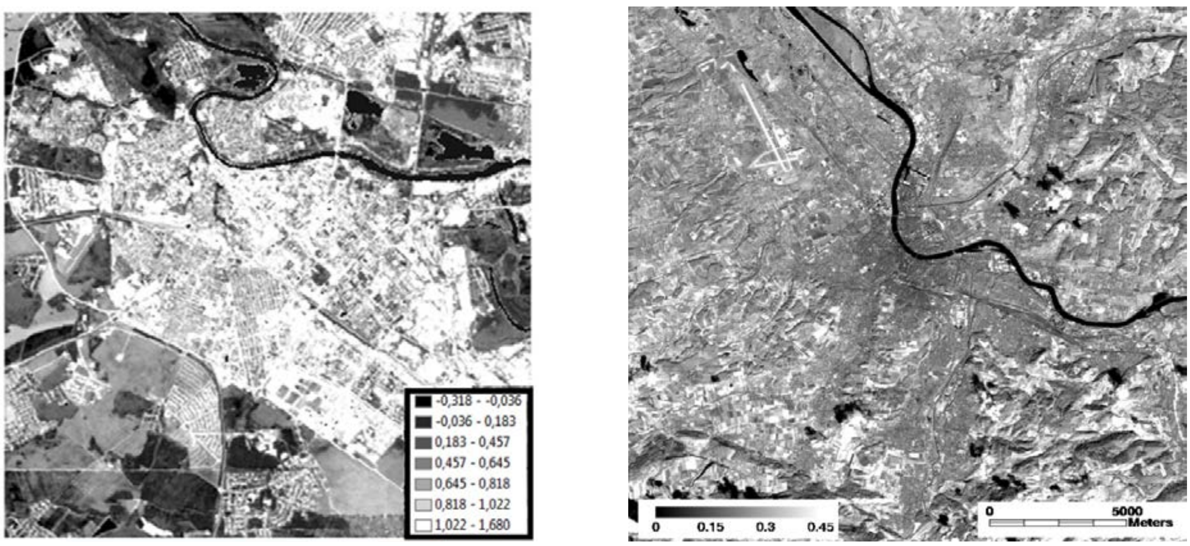
The main achievements of the project were the capture of user requirements in the CoP meeting; the selection and development of an urban environmental indicators list, taking into account the potential users' perspective; the generation of satellite-derived products capable of being used in the evaluation of the above indicators at both local and regional scales; and the design, development and demonstration of the GEOURBAN WIS.

The CoP Meetings in the GEOURBAN Case Studies

Urban planning and management can enhance planning initiatives in order to design the appropriate framework of sustainable activities. The contribution of EO data in the implementation of these activities is of high importance, because of the increasing availability and the reduced time-consuming processing and analysis. This issue was discussed in the CoP meetings for different GEOURBAN case studies. These meetings focused on the needs for urban planning and management in terms of routine requirements (including requirements for natural disaster risk mitigation and urban security) and requirements for adaptation to climate change for the three specific case studies. The experience in CoP meetings organization acquired during past projects (Chrysoulakis et al. 2013) was exploited in GEOURBAN. For handling these requirements, appropriate urban indicators, that can be evaluated using EO-products, were selected. After describing the urban development management goals, the results showed that in three study areas common approaches in handling urban environment can be established in order to achieve sustainable living conditions. These approaches refer to the application of the appropriate methodologies in EO data so as to retrieve urban indicators, suitable to characterize air pollution and public health, energy efficiency, transportation accessibility, thermal comfort, urban green and vulnerability to natural hazards. Moreover, the impact of these urban environment characteristics on climate change can be also assessed. A detailed description of the CoP outcomes is given by Chrysoulakis et al. (2014)

The GEOURBAN indicators set

The GEOURBAN indicators selection was based on the CoP outcomes with the constraint that their estimation is defined as a synthesis of EO products. These indicators are able to assess urban quality of life and provide useful information to urban planners and decision makers towards sustainability in cities. The EO-based urban environmental indicators can therefore support urban planning, saving time and reducing costs.



a) b)

Figure 2. Examples of GEOURBAN indicators: a) the percentage of impervious surfaces for the Tyumen case study, as derived by synergistic analysis of RapidEye observations; b) broadband shortwave albedo for the Basel case study, as derived from Landsat multispectral observations.

In a first step, a preliminary set of indicators was defined by the consortium, which was then revised by local stakeholders during the CoP meetings. This resulted in a final indicators set including core and secondary indicators related to: urban surface structure; urban surface type;

urban sprawl; urban environmental quality; vulnerability to natural hazards; and socioeconomics. These indicators are generated as a synthesis of key EO-products which are derived by applying state-of-the-art algorithms to EO raw datasets. The GEOURBAN indicators list is reported in Table 1. The last column shows the importance of each indicator based on the users' perspective in each case study, which is reflected in the previous three columns. Examples of the indicator's spatial distribution are shown in Figures 2a and 2b.

Table 1. GEOURBAN indicators list and importance for each case study as an outcome of the CoP meetings.

Category	Indicator	Importance for			GEOURBAN Priority
		Basel	Tel Aviv	Tyumen	
Urban Surface Structure	Open Spaces	++		++	High
	Green Spaces	++		++	High
	Built-up Density	++		++	High
	Building Density	++		++	High
	Building Volume	++		++	High
Urban Surface Type	Imperviousness	+	++	++	Very High
	Vegetation Fraction	++		++	High
	Surface Albedo		++	++	High
	Surface Emissivity		++	++	High
	Urban Form	++			Moderate
	Surface Materials		++		Moderate
	Land cover Type	++			Moderate
Urban Sprawl	Land Cover Change	++		++	High
	Built-up Density Change	++			Moderate
	Building Volume Change	++			Moderate
	Contagion Index Change				Low
Urban Environmental Quality	Heat Island Intensity	+	++	++	Very High
	Aerosols Concentration	++	++		High
	Landscape Fragmentation		++		Moderate
	Greenhouse Gases		++	++	High
	Vegetation Fraction	+	++	++	Very High
Vulnerability to Hazards	Surface Topography				Low
	Built-up Density				Low
	Population Distribution				Low
	Accessibility	++		++	High
	Ground Subsidence		++		Moderate
	Critical Infrastructure				Low
Socio-economics	Land Use	+			Moderate
	Population Distribution			++	Moderate
	Access to Green Areas	+		++	High
	Traffic	+		++	High
	Exposure to PM		++	++	Low

The EO data analysis and the derived products

State-of-the-art EO analysis techniques are used in GEOURBAN to derive the key EO-products using raw satellite observations. The indicators shown in Table 1 can be evaluated provided that a reduced number of such EO-products are available. In particular, key necessary products are: DEM/DSM; land cover; fractional land cover; material-based land cover; vegetation indices; albedo; emissivity; LST; aerosol optical thickness. VHR EO (Quickbird, RapidEye and aerial images) data were used for micro-scale applications. A land cover classification for the city of Tel Aviv is shown in Figure 4a. Based on an extensive literature review about existing algorithms which are used for feature extraction from VHR images, a protocol on VHR data analysis in the framework of GEROURBAN was developed containing information required for the selection of VHR images for micro-scale applications. HR EO data was used for local and regional scale applications. This data included both optical (Landsat, ALOS, ASTER) and radar (TerraSAR-X) observations. Results for the urban footprints, as derived from TerraSAR-X analysis for all case studies, are shown in Figure 3, whereas the spatial distribution of LST for Basel, derived from Landsat thermal infrared imagery analysis, is shown in Figure 4b. It is noted that MODIS products are directly used for regional scale applications. A protocol on HR-LR data analysis in the framework of GEOURBAN was developed containing information required for the use of high resolution (HR) and low resolution (LR) images to drive EO-based indicators to guide users.

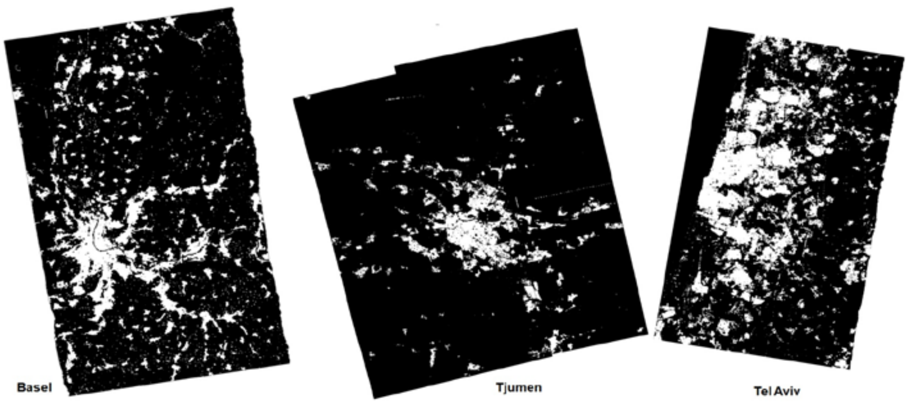
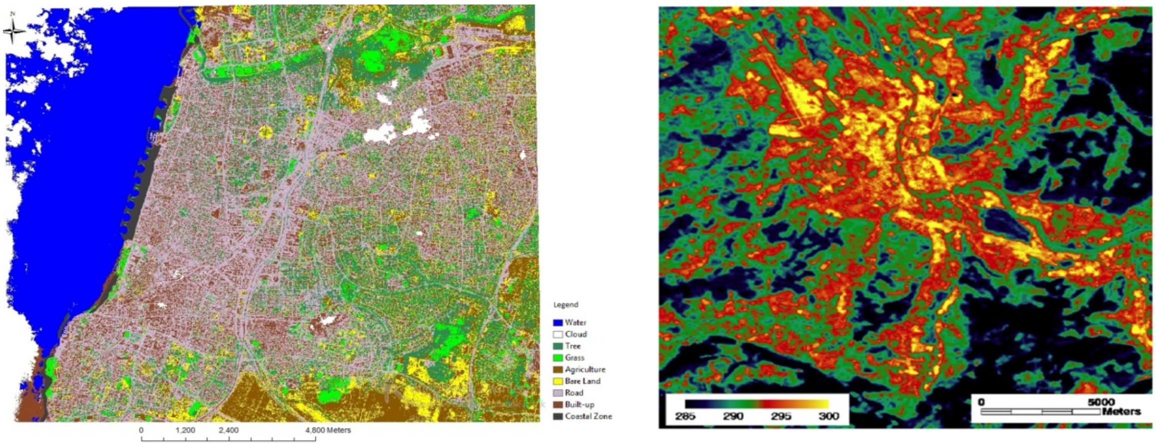


Figure 3. Urban footprints of the three GEOURBAN case studies as derived from TerraSAR-X analysis.

Besides the detailed information contained in the above mentioned protocols, available at the GEOURBAN Web-site (http://geourban-fp7-eranet.com/), a short description of the EO data analysis procedure in the framework of GEOURBAN is given by Esch et al. (2013). The VHR classification was based on supervised support vector machine (SVM) method, whereas standard methods for classification (i.e. maximum likelihood), post classification and quality assurance/control were used in HR analysis. Spectral unmixing techniques (Mitraka et al. 2012) were used for fractional cover estimation and the approach of Liang (2000) was used to derive the broadband shortwave albedo from Landsat narrowband albedos. The latter, as well as the brightness temperatures, were estimated as per Chander et al. (2009), after atmospheric correction. LST was calculated from brightness temperature taking into account the surface emissivity as per Sobrino et al. (2004). ASTER elevation product (Abrams et al. 2010) was also used in GEOURBAN as key EO-product. Finally, the aerosol optical thickness was directly derived from MODIS Level-2 aerosol product (Remer et al. 2005).



a) b)

Figure 4. a) Land use/cover classification for the Tel Aviv case study using Quickbird observations. b) Surface temperature distribution for the Basel case study, based on Landsat thermal infrared observations.

The GEOURBAN WIS

The WIS prototype can be accessed via http://geourban-fp7-eranet.com/. It is a fully dynamic system exploiting all internet capabilities and the “open layers” availability, containing an analytic and a visualization mode, as shown in Figure 5. It was developed using in-house developed software and algorithms for spatial analysis and web visualization. It is a fully dynamic system exploiting all internet capabilities and the “open layers” availability. The user solely needs a web-browser and internet connection to access the WIS. It provides analysis and visualization capabilities of GEOURBAN indicators, such as Built-Up Density, Open Space Density, Green Space Density, Building Density and Imperviousness which are evaluated for Basel, Tel Aviv and Tyumen case studies. The indicators evaluation algorithms implemented as a fixed set of base mathematical operation with raster input data such as Land Cover. OpenStreetMap was used as basic layer. Major WIS Functionality Includes:

- Objects searching
- View object’s attributes
- Manage map’s (layer) scale and displayed area
- Hide/Show layers
- Distance Measure
- Area size evaluation
- Create objects like point, line or polygon
- Layers Management (Admin. Only)
- Raster / Vector downloading and uploading (Admin. Only)
- Online Indicators evaluation

All WIS data is based on Mercator map projection. Interactive web maps are using "Spherical Mercator" system based on Mercator projection over a sphere. The WIS vector-based indicators are evaluated using administrative political community boundaries. The value of each indicator is estimated using an appropriate formula within each polygon of political community boundaries. The WIS provides two methods of generating Indicators:

- Using fixed layer with boundaries.
- User-defined Areas of Interest using polygons.

The GEOURBAN WIS can be easily transferable to any city and thus, the WIS Administrator is equipped with a set of tools to define new layers, boundaries and add raw EO data maps.

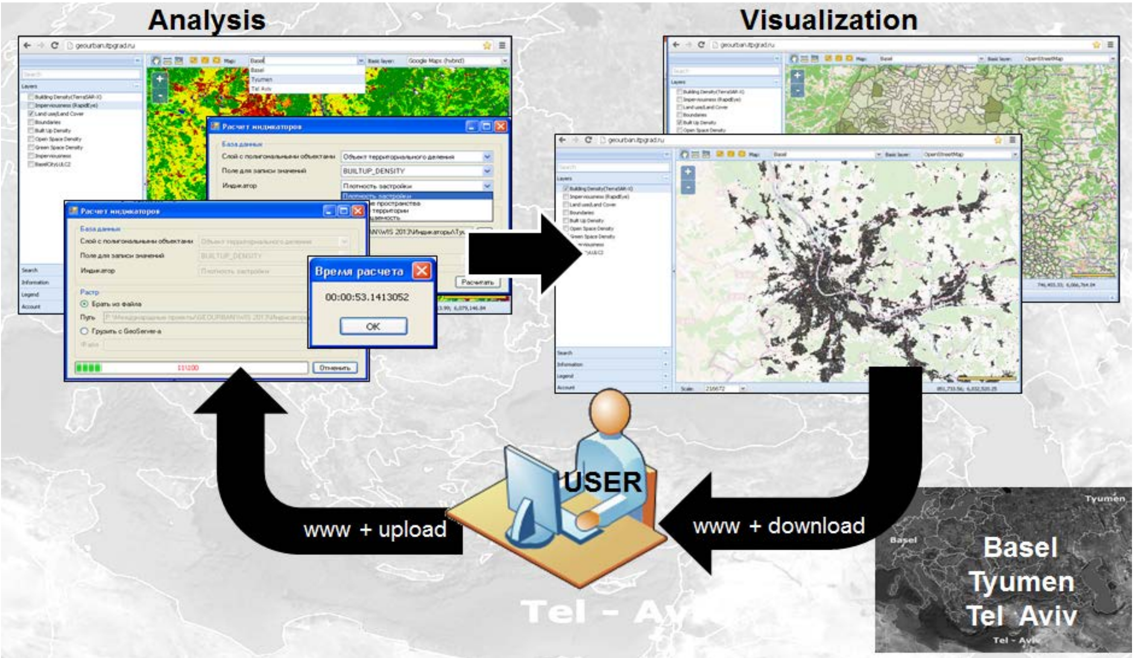


Figure 5. The GEOURBAN WIS operational scema.

A demonstration event was organized by the end of the project providing the means to disseminate the GEOURBAN achievements to urban planners and local/regional Authorities. The application of the WIS prototype for different case study cities demonstrated during this event. Users' feedback was important to address the requirements for adapting the system in future missions. Thus, the goal was to get feedback from the users regarding the applicability, usefulness and potential impact of WIS. As a result, a demonstration proceedings report included urban planning guidelines, based on the application of the WIS was produced.

Conclusions

GEOURBAN aimed at bridging the gap between EO scientists and urban planners by addressing issues of needs and the potential of EO methods and data for diverse stakeholders dealing with urban and regional planning and management. In the framework of the GEOURBAN project, key phenomena and challenges were identified that can be addressed by means of EO data. State-of-the-art EO-analysis methods were used to derived key EO-products from satellite observations. These products were utilized to evaluate the environmental indicators that were selected and implemented in the developed WIS prototype. The set of GEOURBAN indicators was the means to exploit EO potential in addressing several issues related to urban planning and management.

The developed WIS has both automatic and semi-automatic functionality, depending on the application and scale, since it will cover micro, local and regional scales. It has also the potential to support activities of local government, business and urban communities related to urban planning documentation and registration of approved urban planning documentation, monitoring the current status of the territory and controlling its development on the basis of urban planning documentation, monitoring the implementation of legislation in the sphere of urban development, operating with information about the subjects of urban development activities, and managing the land and improving the investment climate in the city.

The GEOURBAN WIS is easily transferable to any city, but since every city is unique, the development of additional algorithms and software will be based on specific solutions defined by the actual end users and will support new services. The GEOURBAN consortium plans to exploit this tool by updating it with new processing methods and by adapting it to future missions such as the Sentinels (ESA 2013), EnMAP (DLR 2013) and HyspIRI (NASA 2013). It is therefore expected the WIS to become a fully operational tool, provided that EO data at the requested spatial and temporal scales are available.

Acknowledgments

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References

Abrams, M., B. Bailey, H. Tsu, and M. Hato. 2010. "The ASTER Global DEM." *Photogrammetric Engineering and Remote Sensing* 76: 344 - 348.

ASU (Arizona State University). "The 100 Cities Project – Urban Systems”, Center for Environmental Science Applications." Accessed June 12, 2010. http://cesa.asu.edu/urban-systems

Chander, G., B. L. Markham, and D. L. Helder. 2009. "Summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM+ and EO-1 ALI sensors." *Remote Sensing of Environment* 113: 893 - 903.

Chrysoulakis, N., C. Feigenwinter, D. Triantakonstantis, I. Penyevskiy, A. Tal, E. Parlow, G. Fleishman, S. Düzgün, and T. Esch. 2014. "A conceptual list of Indicators for Urban Planning and Management based on Earth Observation." *ISPRS International Journal of Geo-Information*: submitted.

Chrysoulakis, N., M. Lopes, R. San José, C.S.B. Grimmond, M. B. Jones, V. Magliulo, J. E. M. Klostermann, A. Synnefa, Z. Mitraka, E. Castro, A. González, R. Vogt, T. Vesala, D. Spano, G. Pigeon, P. Freer-Smith, T. Staszewski, N. Hodges, G. Mills, and C. Cartalis. 2013. "Sustainable urban metabolism as a link between bio-physical sciences and urban planning: the BRIDGE project." *Landscape and Urban Planning* 112: 100 - 117.

DLR (German Aerospace Center). "EnMAP - Mission statement." Accessed March 22, 2013. http://www.enmap.org

EEA (European Environemnt Agency). "The GMES Urban Atlas.” Accessed June 15, 2010. http://www.eea.europa.eu/data-and-maps/data/urban-atlas

ESA (European Space Agency). "GMES Sentinels overview." Accessed March 22, 2013. http://www.esa.int/esaLP/SEM097EH1TF_LPgmes_0.html

Esch, T., H. Taubenböck, N. Chrysoulakis, H. S. Düzgün, A. Tal, C. Feigenwinter, and E. Parlow. 2013. "Exploiting Earth Observation in Sustainable Urban Planning and Management - the GEOURBAN Project." In *Proceedings of the Joint Urban Remote Sensing*, Sao Paulo, Brazil, April 21 - 23: JURSE.

GMES (Global Monitoring for Environment and Security). "Operational Monitoring Services for our Changing Environement - Geoland 2." Accessed June 12, 2010. http://www.gmes-geoland.info

Grimmond, C.S.B., M. Roth, T. R. Oke, , Y. C. Au, M. Best, R. Bettse, G. Carmichael, H. Cleugh, W. Dabberdt, R. Emmanuel, E. Freitas, K. Fortuniak, S. Hannal, P. Kleinm, L. S. Kalkstein, C. H. Liu, A. Nickson, D. Pearlmutter, D. Sailor, and J. Voogt. 2010. "Climate and More Sustainable Cities: Climate Information for Improved Planning and Management of Cities (Producers/Capabilities Perspective)." *Procedia Environmental Sciences* 1: 247 - 274 (2010).

Lavalle, C., L. Demicheli, M. Turchini, P. Casals-Carrasco, and M. Niederhuber. 2001. "Monitoring megacities: the MURBANDY/MOLAND approach." *Development in Practice* 11: 350 - 357.

Liang, S. 2000. "Narrowband to broadband conversions of land surface albedo: I. Algorithms." *Remote Sensing of Environment* 76: 213 - 238.

Mitraka, Z., N. Chrysoulakis, Y. Kamarianakis, P. Partsinevelos, and A. Tsouchlaraki. 2012. "Improving the estimation of urban surface emissivity based on sub-pixel classification of high resolution satellite imagery. " *Remote Sensing of Environment* 117, 125 - 134.

NASA (National Aeronautics and Space Administration). "HyspIRI : Hyperspectral Infrared Imager." http://decadal.gsfc.nasa.gov/hyspiri.html

Remer, L.A., Y. J. Kaufman, D. Tanré, S. Mattoo, D. A. Chu, J. V. Martins, R. R. Li, C. Ichoku, R. C. Levy, R. G. Kleidman, T. F. Eck, and E. Vermote, E. 205. "The MODIS Aerosol Algorithm, Products, and Validation." *Journal of the Atmospheric Sciences* 62: 947 - 973.

Sobrino, J.A., J. C. Jiménez-Muñoz, and L. Paolini. 2004. "Land surface temperature retrieval from LANDSAT TM 5." Remote Sensing of Environment 89: 467 - 483.

USGS (United States Geophysical Survey). "Urban Dynamics Research Program." Accessed June 15, 2010. http://landcover.usgs.gov/urban/intro.php

Weng, Q. 2009. "Thermal infrared remote sensing for urban climate and environmental studies: Methods, applications, and trends. "*ISPRS Journal of Photogrammetry and Remote Sensing* 64: 335 - 344.