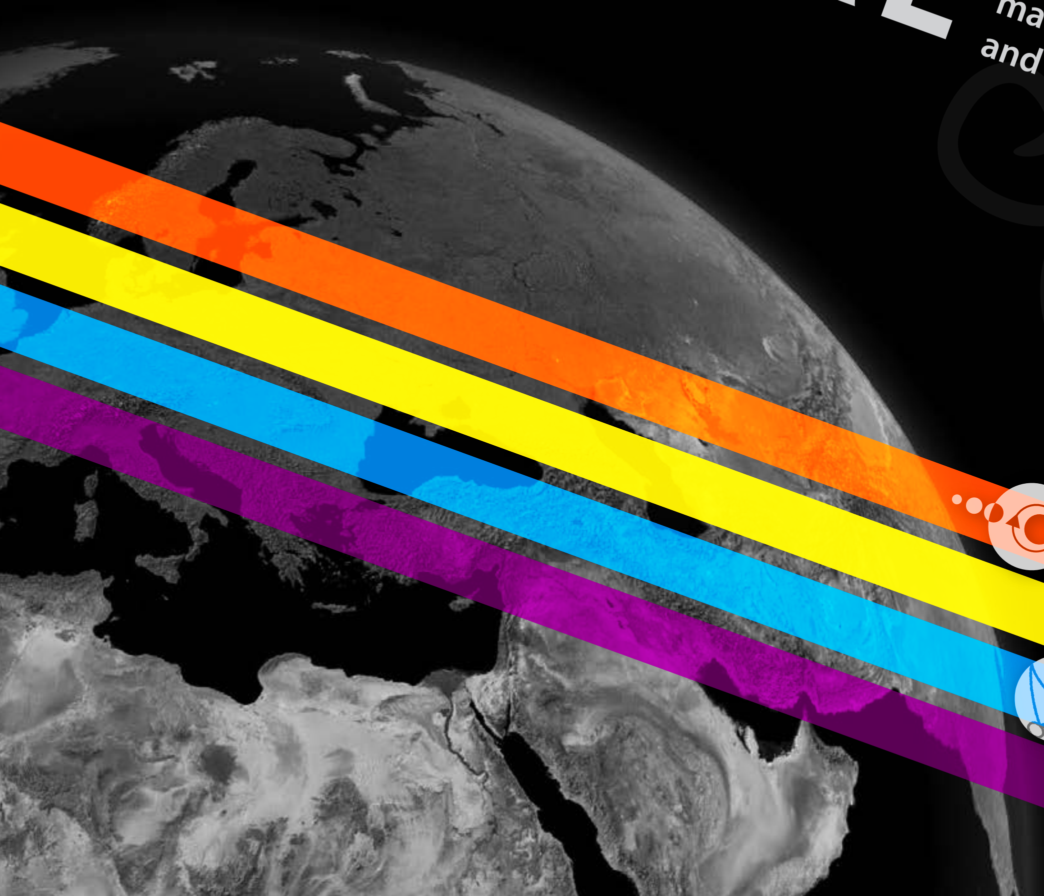
REMOTE SENSING CENTRE

Providing fast, accurate and reliable thematic spatial data for efficient management of natural and built environments



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Observing Earth since 1995

Remote Sensing Centre is the leading Earth observation group in Slovenia. It currently involves nine highly experienced and motivated members – four of us have PhDs and another two are doctoral students. Half of the group is female and the average age is 35 years. We actively participate in basic and applied national and international projects, funded by national and foreign research agencies, European Commission, European Space Agency, Inter-American Development Bank, several national and local administrative institutions, and private companies.

We deal with problems of automatic satellite imagery registration and orthorectification, radiometric pre-processing, lidar data processing and visualization, advanced classification and change detection, paying particular attention to the development of new techniques of artificial intelligence and object-based modelling. In addition, we are generating variables important in environmental modelling and statistically analyse their significance, explore cognitive cartography techniques, and validate modelling of present and historical natural and cultural landscapes. We have developed STORM – a complete and fully automatic processing chain from raw satellite data to web-delivered map-ready images and products.

In more than 20 years, we have used Earth observation in several applications, ranging from rapid disaster mapping and monitoring, land cover mapping in various landscape settings, land and air temperature modelling, and detection of water bodies, to analysis of biophysical parameters for agriculture and forestry. Selected applications are briefly described in the following pages.

Krištof Oštir and Žiga Kokalj

Ljubljana, November 2015

Automatic satellite data processing

Applications

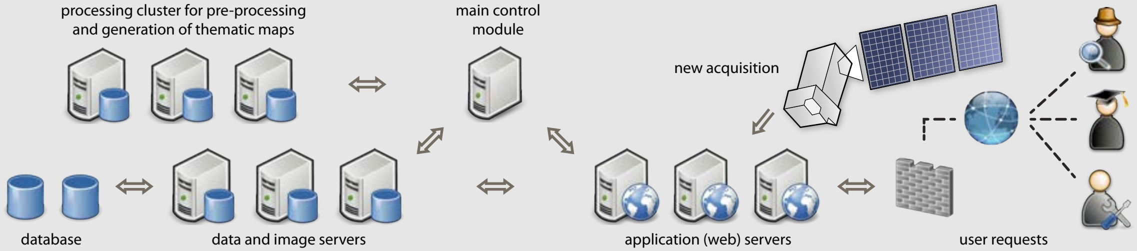
- automatic generation of orthoimages (which present an alternative to the aerial orthophotos) from optical satellite images of medium, high and very-high resolution
- automatic generation of thematic maps
- monitoring seasonal activities and sudden changes

Benefits

- rapid processing of satellite data
- prompt automatic interpretation, which makes satellite data a valuable source for forestry, agriculture, natural disasters prevention, hydrology, biology, insurance business
- autonomy of processing and an increasing volume of available satellite data enable continuous monitoring of many processes on the Earth's surface

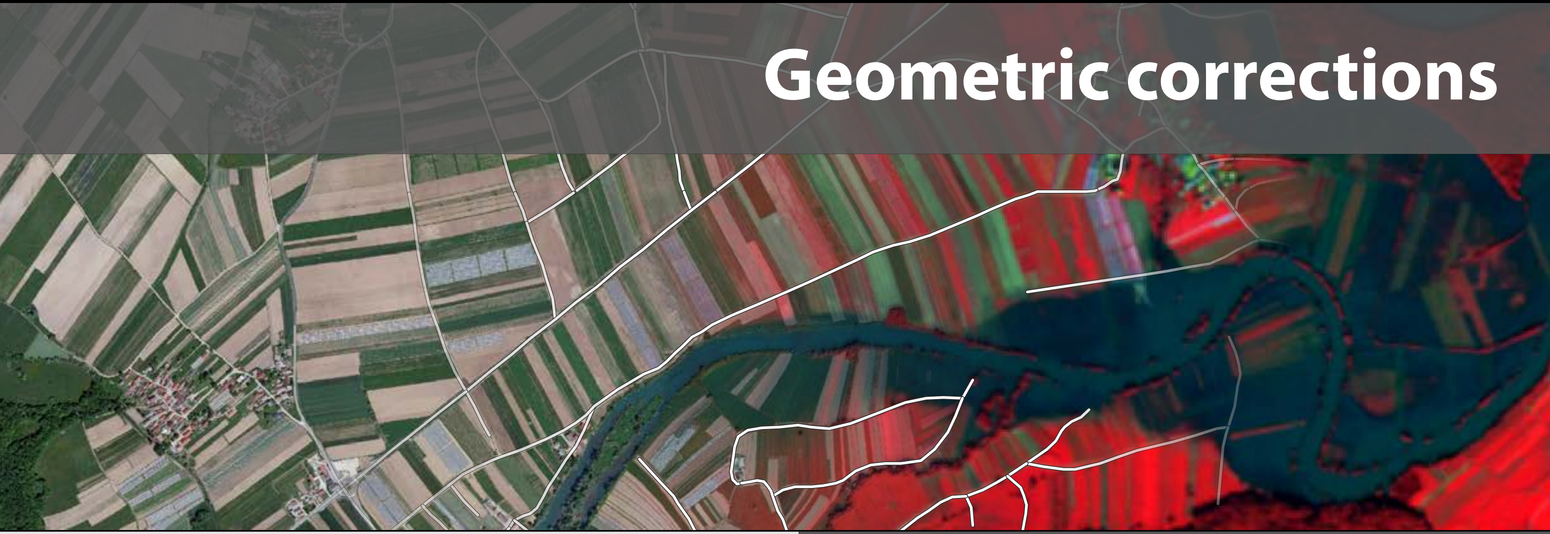
Automatic satellite data processing is a dream of every remote sensing professional. Our *STORM processing chain* is a first step towards fulfilling this dream. The processing chain automatically executes all the necessary processing steps from raw optical satellite data to end-user-oriented web-delivered thematic maps.

A satellite image is positioned into the chosen coordinate system, and atmospheric and topographic corrections are applied to ensure comparability of multitemporal images. Finally, the image is interpreted into a thematic product which is easily understood by experts from different fields.



Automatic processing of optical satellite data (the STORM processing chain) enables fast availability of accurate and exact spatial information. It is therefore one of the key elements of advanced processing systems, such as rapid mapping of natural disasters.

Geometric corrections



Applications

- automatic generation of orthoimages (which are an alternative to aerial orthophotos)
- processing optical satellite images from multiple sensors of medium, high, and very-high resolution

Benefits

- geometric corrections position a satellite image into a chosen coordinate system
- orthorectification enables spatial comparability with other spatial data
- automatic processing (in the frame of the STORM processing chain)

Geometric distortions of a raw satellite image are a result of height, speed, position and orientation of the satellite, sensor optics, rotation and curvature of Earth and terrain. Geometric corrections remove all these effects.

If the image is not geometrically corrected it is practically useless for mapping, interpretation or analysis. On the other hand, each pixel of the corrected image, *i.e.* an orthorectified image, possesses geometric fidelity. This means we can make direct and accurate measurements of distances, angles, positions, and areas directly from the image. The measurements are essentially the same as if they were taken on Earth's surface.

An important part of the automatic geometric correction process is automatic extraction of ground control points. It is performed with image matching based on reference road data (left).

River Drava (NE Slovenia) on a raw (middle) and an orthorectified image (right). Rotation and displacement of the relief can be clearly seen.

Atmospheric and topographic corrections


Photo: Žiga Kokalj

Applications

- generation of atmospherically and/or topographically corrected optical satellite data of medium, high, and very-high resolution
- enables direct comparison between satellite data of the same or different sensors

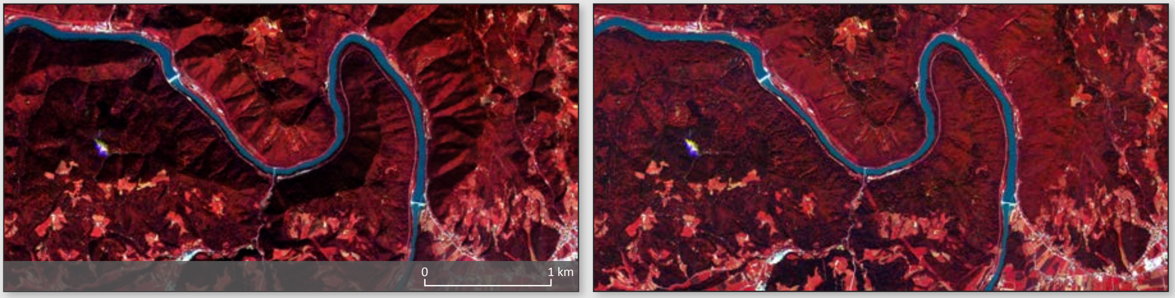
Benefits

- enhanced temporal comparability of satellite imagery
- improved interpretation
- image pixel values represent reflectivity
- adequate monitoring of landscape changes are possible only on atmospherically and topographically corrected images
- automatic processing (in the frame of the STORM processing chain)

Due to several reasons, pixel values of a raw satellite image are not entirely precise; effects of atmosphere and relief have the biggest impact. These effects are minimised with the atmospheric and topographic corrections.

Atmospheric corrections minimize the effect of atmosphere, such as haze and scattering, and determine the positions of clouds and their shadows.

Topographic corrections minimize the differences between illumination of surfaces exposed to Sun and surfaces in shadows. They are dependent on the Sun incidence angle and relief.



Appearance of an image is more homogeneous and two-dimensional after corrections. An area along the river Drava (NE Slovenia) is shown on a RapidEye image with 6.5 m resolution. An uncorrected image is shown on the left and corrected image on the right.

Monitoring invasive plants

Applications

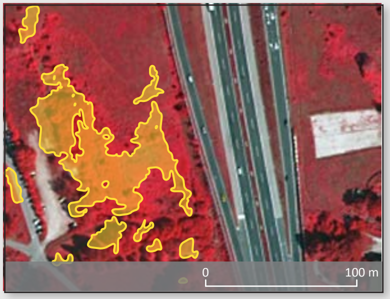
- detection of invasive species growing sites
- monitoring the level of spread and environmental damage
- monitoring the effectiveness of eradication

Benefits

- high accuracy of detection of sites
- planning assistance of eradication activities
- simultaneous inspection of the entire area of a municipality or region

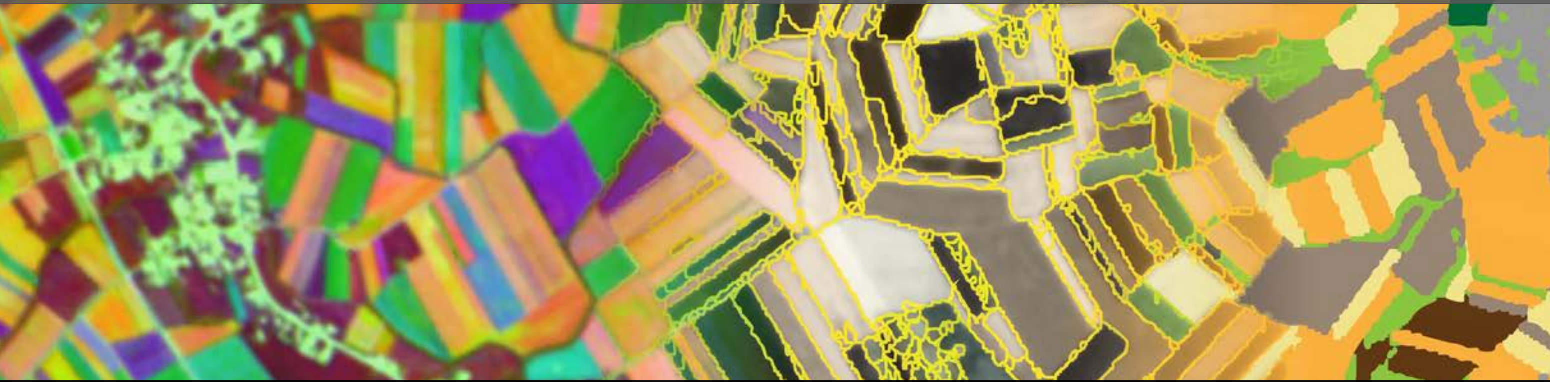
We often hear that Slovenia is a European crossroad. This also brings a rapid spread of non-native invasive plant species. One of the worlds' most intrusive plants is Japanese knotweed that thrives well along streams, roads, and construction sites, but is also spreading increasingly on meadows and fields.

We designed a mapping method of its occurrence sites in all stages of growth. We can also monitor its sprawl and the effectiveness of the (mostly unsuccessful) eradication. The accuracy of detection of Japanese knotweed sites is almost 90 %, which is much better than previously known methods. Most of the undetected sites are either too small to be detected or are located under tree canopies.



Japanese knotweed growing sites along the eastern Ljubljana bypass and the Ljubljanica river. The plant is rapidly spreading across Slovenia due to insufficient eradication and restriction measures. The same applies to other non-native invasive plant species (Canadian goldenrod, Himalayan balsam *etc.*).

Classification of agricultural land



Applications

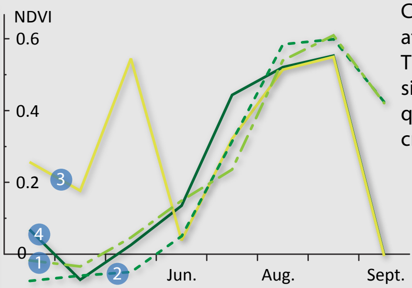
- monitoring crop type, location, area, and stress
- transparent and timely information on agricultural land
- consistent and product-oriented infrastructure for observation of crop dynamics

Benefits

- automatic farmland detection processes
- less manual vectorisation and visual interpretation
- fast processing of larger areas (country scale)
- all-seasonal data display
- additional temporal dimension of data
- multilevel operation, simultaneous learning, iterative verification
- advanced and robust procedure

Remote sensing is a well-established source for monitoring agricultural land, as it provides transparent, timely, and clear information on some of the key indicators.

In Slovenia, the location of agricultural land and its classification are determined by visual interpretation of aerial photographs. Such a procedure is time consuming and uncertain for most crops. We have therefore designed a method for producing high-quality land cover maps from raw images without the intervention of the operator. Important additional information is data of phenological phases of vegetation obtained from time-series of satellite images.



Change of growth properties at four different fields. Time-series of satellite images significantly improve the quality of determination of crops characteristics.

Determination of ineligible land use

Photo: Žiga Kokalj

Applications

- eligibility control of agricultural subsidies
- increase of effectiveness of risk analysis
- support for visual control and field verification

Benefits

- fast verification of large areas
- fewer and better targeted field checks
- survey of an entire region not just trial areas
- determination of ineligible land use categories which cannot be checked visually

Agricultural subsidies in Slovenia are paid per area of agricultural land. Farmers have a right to obtain a subsidy if their farmland is used *e.g.* as field, grassland or orchard (eligible land use). Land use categories that are not eligible for subsidies are *e.g.* overgrowing fields, built-up areas, or forest. The control is currently done by visual image interpretation and field verification, where trial areas are selected randomly and with infringement risk analysis. It is thus time consuming and partial.

We are therefore developing a process for automatic identification of particular types of ineligible land use. The results will serve as an aid to visual inspection and as an additional parameter in the risk analysis.

Areas of ineligible land use have to be correctly identified and mapped on aerial or satellite images to properly distribute the agricultural subsidies

farmland registered for subsidy

farmland ineligibly registered for subsidy

Mapping the effects of major disasters

Applications

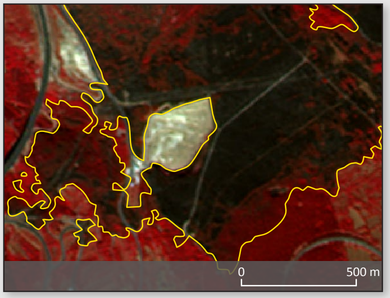
- situational maps of large areas
- study of the dynamics of a disastrous event in a wider area
- damage assessment
- preparation of mitigation and prevention management plans for extreme natural processes

Benefits

- rapid mapping
- time series maps (monitoring the development of a disaster in time)
- radar data are weather independent
- optical data give better spatial distribution of the phenomena

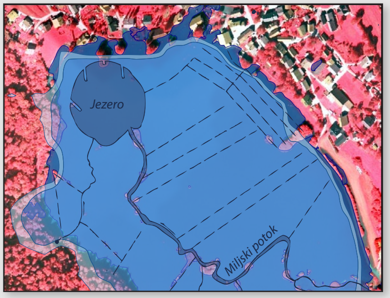
The largest space agencies and other satellite data providers have committed their resources to the International Charter Space and Major Disasters for providing space data acquisition and delivery in the case of major natural or man-made disasters.

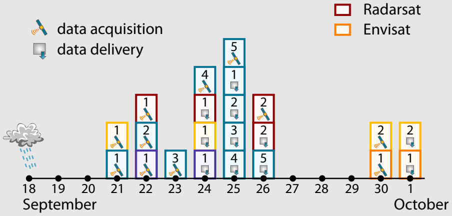
The Charter is activated by authorised users – in Slovenia this is the Administration for Civil Protection and Disaster Relief. Remote Sensing Centre participated as a local data processing partner, performing mapping and analysis in all past Slovenian activations, including the first ever activation of the Charter, immediately after its establishment in autumn 2000 .



Fire extent estimation at Črni Kal (SW Slovenia) from a 6.5 m RapidEye image (left).

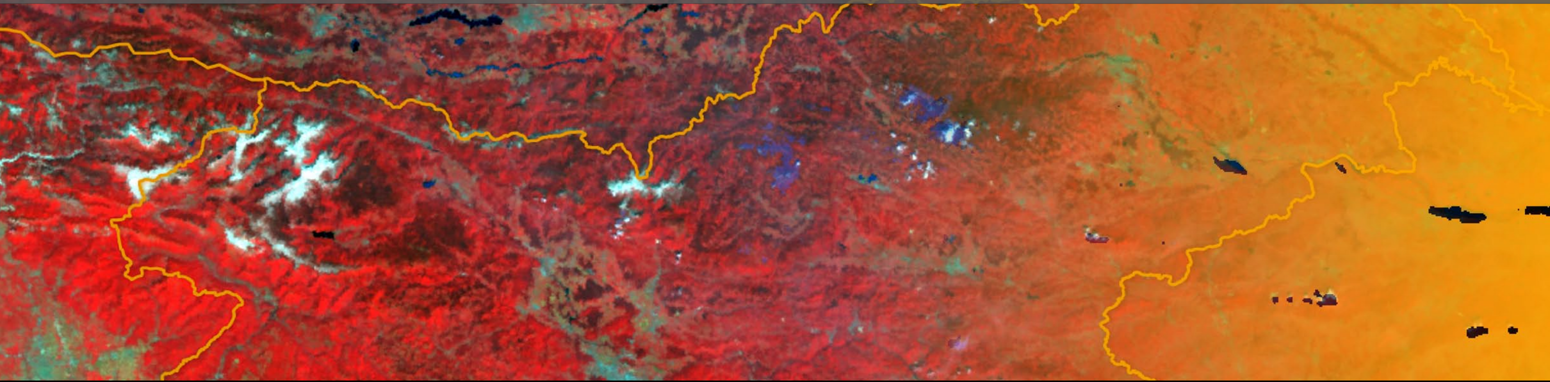
A usual water level and flood conditions of Podpeško jezero, as detected by different systems in September 2010.





Time series of image acquisitions during floods in 2010.

Drought monitoring



Applications

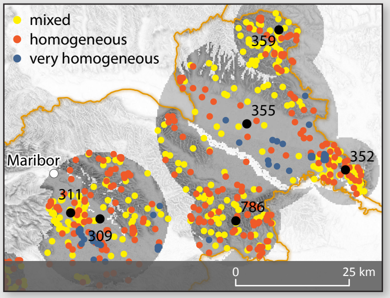
- rapidly available drought maps
- occurrence maps of droughts in the past
- analysis of the drought incidence depending on the type of vegetation
- planning of irrigation systems

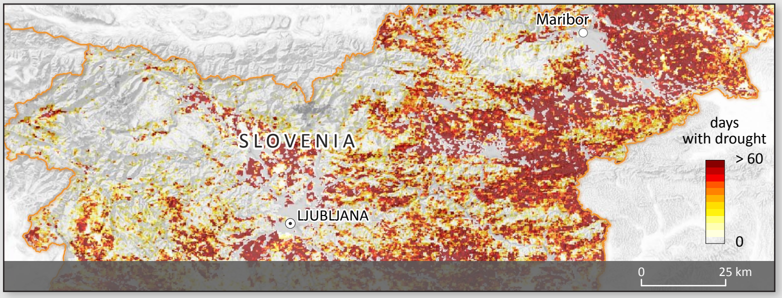
Benefits

- the system is calibrated on local data
- multiyear satellite and meteorological observations are used together with best available ancillary data
- drought recognition accuracy is 92 % overall
- the system can be relatively easily upgraded to new sensors that will have higher spatial, temporal, and/or spectral resolution

We are establishing a system for automatic detection of the vegetation state, which is the basis of an integrated system for identifying drought conditions. The system is based on machine learning methods, satellite data, meteorological measurements, and other spatial data.

In the preparation for new European satellites Sentinel-2 and Sentinel-3 we currently support MODIS and MERIS satellite data. The obtained results are relevant to the area of Slovenia and its surroundings, but the method is designed so that the model can be easy recalibrated to other regions and is particularly suitable for variable landscapes.

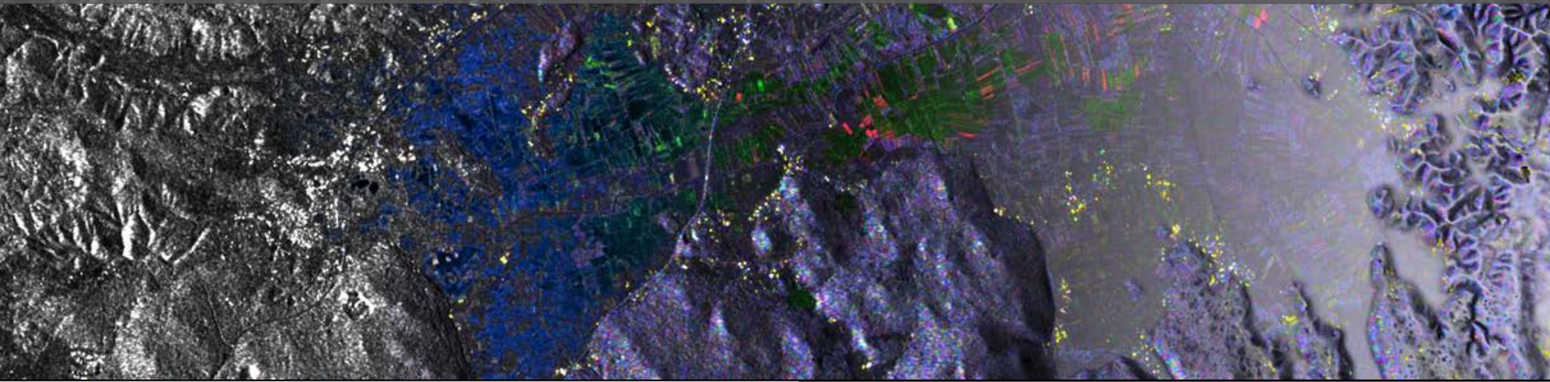




Training points for calibration of the system for automatic detection of drought condition (far left). Cumulative i

mage of detected drought conditions for year 2013, when Slovenia was hit by a catastrophic drought (left).

Mapping water bodies



Applications

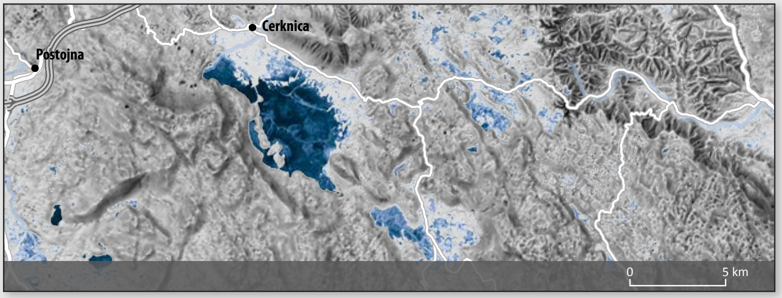
- continuous monitoring of water levels and water volume
- verification of hydrological models
- flood monitoring
- flood risk assessment

Benefits

- daytime and nighttime observations
- independent of weather conditions
- fully automatic operation
- short processing time

We developed a system for detection of water bodies from Sentinel-1 radar data. The system is triggered as new data becomes available. The algorithm automatically detects water bodies and prepares the results for distribution. The best available terrain model is used in the process of detection and filtering where neighbouring operations are applied to determine the presence of water at each pixel.

Observations of each part of Europe are available every 6 days (3 days with both satellites), which enables continuous monitoring of the extent of water bodies, and fast response in the case of a natural disaster.



Heavy rains in autumn 2014 caused catastrophic floods in much of central and western Slovenia. Broken tree crowns caused by a record ice storm in spring of the same year can also be seen on the far left image.

Cumulative image of detected water bodies in central Slovenia during floods in autumn 2014 (left).

Monitoring forests

Photo: Žiga Kokalj

Applications

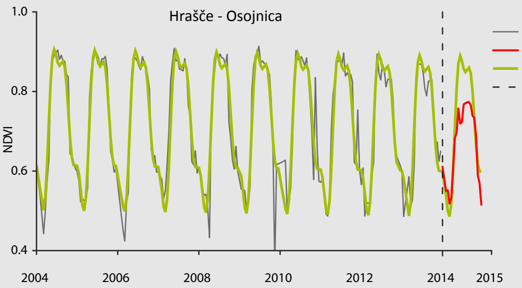
- large area forest observation
- dynamics of processes in forest through vegetation parameters
- analysis of the forest state, monitoring natural vegetation processes, and timely detection of harmful processes
- monitoring adverse events and hazards, and assessment of consequences

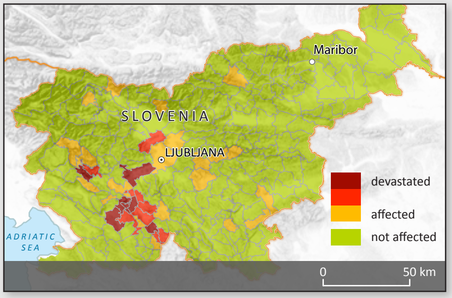
Benefits

- quick access of forests state maps
- time-series observations (monitoring development)
- timely detection of deviations and adverse processes
- establishment of an early warning system

Satellite observations provide continuous quantitative measurements of forest parameters and enable real-time mapping, change detection, and early detection of developing trends. We can obtain information on photosynthetic activity, stress, moisture content, and other biophysical properties of plants, and estimate structural characteristics of forest stands.

Satellite observations complement field surveys in large-scale forest monitoring and in remote areas. They contribute to understanding the complex relationships and recognition of processes in forest ecosystems, as well as to planning and monitoring forest management measures.





Vegetation index (NDVI) dynamics for the forest management unit (FMU) Hrašče - Osojnica (central Slovenia) that was distressed by sleet. Vegetation index is calculated from MODIS satellite data for a ten-year period and an average in the area of forest within a FMU (far left).

FMUs most heavily affected by 2014 ice storm (left).

Urban heat island

Applications

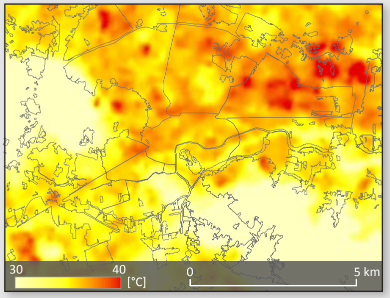
- production of hot-spot maps, that enable identification of the most heat-polluted areas
- annual and seasonal comparisons (including daily and hourly comparisons in lower spatial resolution)
- creation of detailed heat maps of individual buildings from aerial observations, allowing a creation of energy efficient reconstruction plans

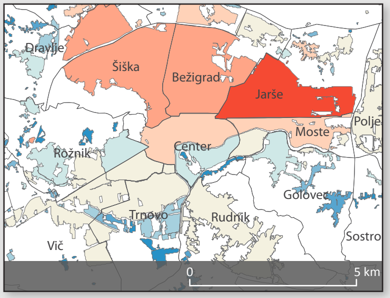
Benefits

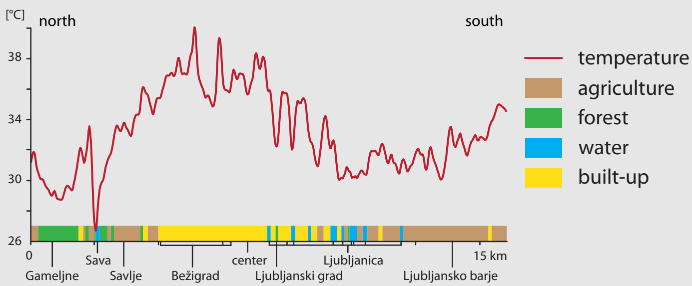
- relatively high spatial resolution
- continuous temperature measurements across the observed area
- various detailed spatial analysis are possible
- flexibility according to the purpose of observation

Increase of the average temperature in urban areas has a strong impact on people who live there. To maintain the same quality of life, an urban heat island and its characteristics must be taken into account for efficient planning of urban activities and infrastructure.

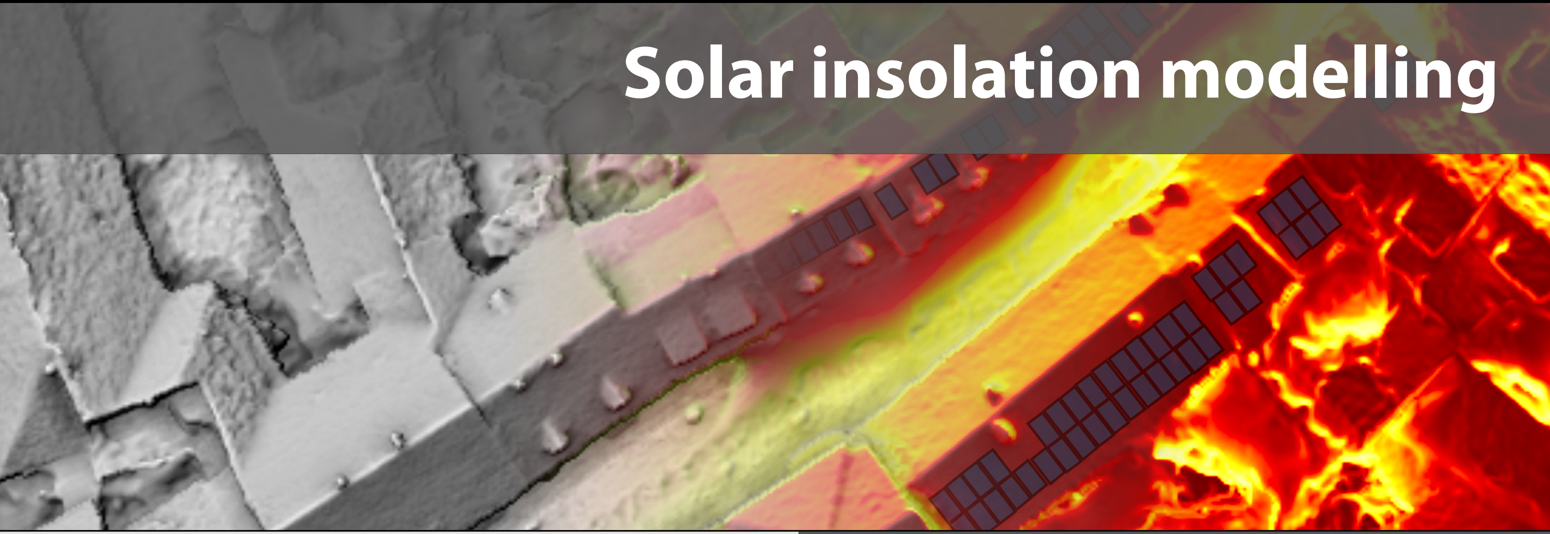
Temperature differences can be observed with a series of satellite images. Observations of the Slovene capital Ljubljana showed a presence of the urban heat island; temperatures of the ground in the city are much higher than in rural areas. On a hot summer day the difference may exceed 10 °C. The most heat-polluted areas are major industrial facilities and shopping centres.







Solar insolation modelling



Applications

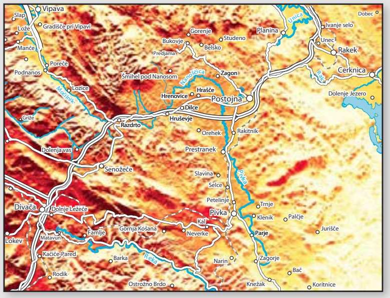
- evaluation of locations for solar power plants
- assessment of solar power plant profitability
- viability of placement of the solar domestic water heating panels
- estimation of optimal orientation of solar panels

Benefits

- very high temporal and spatial accuracy of the results
- calculations are tailored for a particular building
- models incorporate effects of nearby vegetation and other factors, which influence insolation

The measurements of solar energy in Slovenia are only available for a few meteorological stations. We therefore calculated the amount of received solar energy for the whole Slovenia with our own algorithms that are based on physical laws and incorporate detailed information about the terrain and ground albedo. This way we obtained solar insolation maps for every month and for the whole year. We also calculated the optimal orientation of solar panels at individual location. The maps are freely available on the internet (gis.zrc-sazu.si/zrcgis).

For high-precision insolation mapping we use advanced algorithms based on detailed models of buildings.



We modelled the insolation received by a ground surface for the entire country. We also produce highly detailed city models so that we can accurately determine the optimal position and orientation of solar panels on roofs of individual buildings, taking into account vegetation, chimneys, roof windows, and other obstacles.

Advanced maritime surveillance


Photo: Urša Kanjir

Applications

- detection and identification of vessels
- classification of vessels
- monitoring coastal areas and deep waters

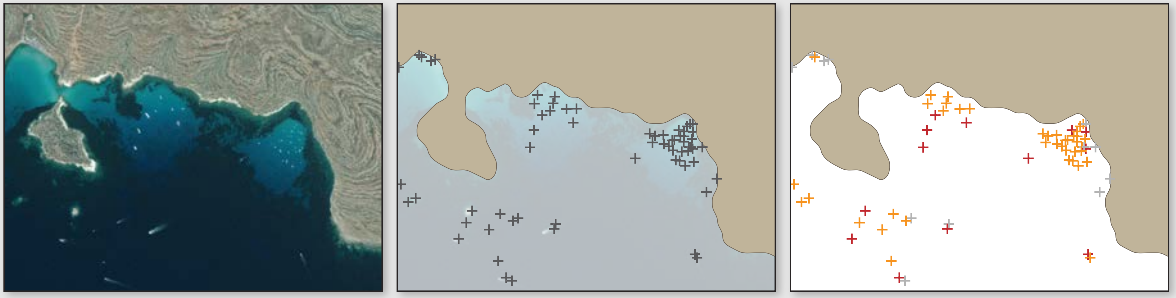
Benefits

- effective and universal method – it works with different very high resolution optical systems
- employment of spectral and spatial characteristics of vessels
- successful operation also on rough seas
- fast performance
- substantial reduction of time effort for manual certification

Ship detection with remote sensing is an important segment in ensuring maritime safety, fisheries control, observation and prevention of oil spills, oversight on unauthorized migration on the sea, and similar.

We have developed a simple, universal, and efficient method for detection and classification of vessels from optical data. The method is useful in particular when there is a need to provide results in real-time, which is of major importance in maritime domain.

The accuracy of detection on images of different sensors and in varied regions exceeds 80 %.



Detection and identification of vessels on the coast of Lampedusa island (S Italy). The image with a spatial resolution of 0.5 m was acquired by GeoEye satellite on July 14th 2013.

- not a vessel
- small vessel
- medium sized vessel
- large vessel

Mapping informal settlements

Photo: Primož Kovačič

Applications

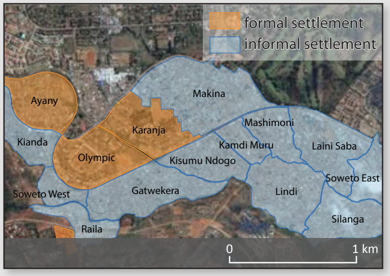
- map production without a long-term field survey
- monitoring expansion and density increase of informal settlements
- support to the improvement of the quality of life of the population living in the area

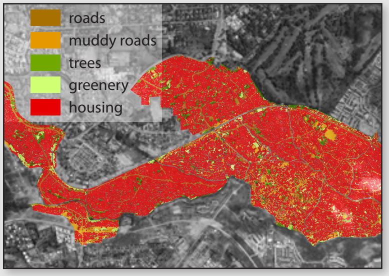
Benefits

- mapping of large and complex areas
- monitoring, planning, and management of informal settlements
- estimation of population without a census
- observation of the growth and/or emergence of new informal settlements

Cartographic information about informal settlements (shanty town, slums) is usually rare, if it exist at all, and poorly accessible due to intensive and hard to follow immigration. We can improve or acquire it with the analysis of very high resolution satellite images.
With satellite images taken at different dates we can observe and monitor changes in the structure of the settlement and its expansion, and give an assessment of the number of inhabitants. Such remotely collected spatial information may assist in the improvement of infrastructure and social welfare services in informal settlements worldwide.

Photo: Anuša Pisanec





Kibera (Nairobi, Kenya) is one of the largest informal settlements in Africa. We observed spatial development of the settlement between 2006 and 2009, based on very high resolution GeoEye and Quickbird images. Together with the MapKibera team we also provided an estimated number of inhabitants.

Observation of archaeological sites

Applications

- effective interpretation of lidar data
- identification, mapping, and monitoring archaeological sites
- lidar data is usable also in many other fields, e.g. detailed hydrological modelling, observation of forests, 3D modelling of cities, and production of topographical maps

Benefits

- very detailed information about the shape of terrain and natural and man-made objects lying on it
- surveying challenging terrain, for example densely overgrown and steep ground
- extensive areas can be covered rapidly
- field examination can be more targeted and better planned

Aerial laser scanning (lidar) has a great potential in archaeology because it provides not only deeper understanding of already known sites, but also gives a unique way of searching for new ones. With data processing we can virtually remove the vegetation cover and get a product that exposes natural and anthropogenic objects, both modern and ancient, also under a dense forest canopy.

We focus on development and testing of techniques for lidar data processing, visualization, and preparation of suitable products that help with assist archaeological interpretation. Our tools (iaps.zrc-sazu.si/en/rvt) are used in everyday operational work in many countries, from Europe to China and USA.

Roman settlement traces have been found on a levelled hilltop with a church of St. Helena (W Slovenia). The images show a helicopter orthophoto, the area of the archaeological site with visible outlines of ancient houses and a slope endangered due to erosion, and heights of trees around the site.

Analysis of historical landscapes

Applications

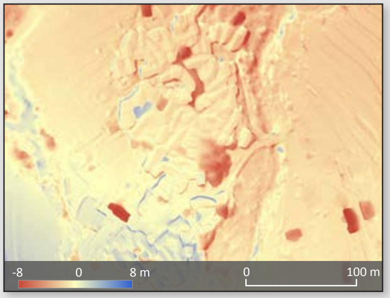
- perception and characterization of landscape changes
- historical analysis of locations and events
- identification of hidden archaeological traces
- support for decision making in spatial development
- monitoring changes in high spatial resolution
- topographic mapping

Benefits

- accessible and high quality source of historical spatial data
- archives keep aerial photographs of the past 100 years
- with images acquired in stereo mode we can produce detailed terrain models, even for decades ago
- historical view of the landscape that also enables spatial assessment of phenomena (extent, location, change)

Aerial photographs were first captured for military-intelligence reasons, but their applicable value has soon exceeded this strategic frame.

Historical aerial photographs are an original document of time, events, and often bygone appearance of landscape. They are becoming increasingly important in areas where the subject of interest is to understand the development of landscape with archaeological and historical remains in it. The photographs are an important data source in a growing number of studies and provide answers to numerous questions in archaeology, history, urban planning, and nature conservation.



A series of aerial images of Breginj (W Slovenia) after the first earthquake in 1976 (source: GURS). Special methods of image data processing enable production of a highly accurate model of a past landscape, which allows a metric comparison of a historical situation with the current state.

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