The Role of Spatial Analysis in Seismic Explorations

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Abstract. Seismic exploration methods are commonly used in energy sector for discovering new oil and gas fields. They are a part of a larger branch of exploration geophysics. World's growing demand for energy results in an increased number of seismic exploration projects being conducted all over the globe. On-shore seismic projects usually require tremendous amount of equipment and workforce. In the same time, they depend heavily on the particular terrain, i.e. land use and land cover, relief and presence of man-made features such as build-up areas, roads, bridges etc. All this spatial information, when examined in details with proper tools, can significantly improve the overall seismic project performance.

Seismic operations consists of several different stages, such as planning, field scouting, survey design and project execution. The spatial aspect has significant influence at all stages of the whole seismic enterprise. First, the land cover and elevations have to be assessed in order to estimate project difficultness and terrain accessibility. Based on this analysis, areas of special interest may be chosen for the next phase: field scouting. All the information gathered during these initial stages can be taken into account when designing seismic survey. For example, each land cover type has different accessibility for vehicles and equipment. Similarly, abrupt elevation changes may cause certain areas to be excluded from the data acquisition. Finally, before the field works it is necessary to build up a camp near the project location for the whole crew. This place has to be carefully chosen, as a wrong location may significantly increase travel time, fuel consumption and decrease daily production. Therefore, the analysis of project's area accessibility is required to find a suitable camp location. These are just a few examples of spatial questions that need to be answered in virtually any on-shore seismic project.

Taking into account the two factors, the scale of seismic projects and their dependence on the terrain, it is clear that computer-based systems equipped with spatial data and analytical tools can significantly support decision-makers involved in the whole seismic enterprise. This is where the spatial decision support systems (SDSSs) can play an important role: to provide ready-to-use tools and algorithms for assessing spatial information, while taking into account users' requirements and their specific needs.

The main aim of this paper is to evaluate different aspects of implementing spatial analysis and spatial decision support systems within oil industry, specifically during seismic operations. This paper focuses on the following questions:

- What spatial problems most frequently occur at different stages of seismic projects?
- What spatial data shall be used to address these issues?
- What methods of spatial analyzes can be used in order to provide support for decision making process?

Keywords: spatial analysis, GIS, spatial decision support systems, SDSS, oil industry, seismic explorations.

1 Introduction

The world’s demand for energy is continually growing. There are many reasons for this phenomenon, such as economic development, increased population and consumption of resources. According to the American agency Energy Information Administration the world’s energy consumption in 2005 came to 462 quadrillion BTU (British Thermal Unit). According to one of the predictions this consumption may rise by 50 %, that is up to 695 BTU by the year 2030 [1].

The increased energy consumption stimulates explorations aimed at new discoveries of energy resources. Despite the fact that renewable resources, such as wind and solar power, are getting more and more popular, still nearly 60% of world's energy comes from oil and gas. Currently 37% of world's energy is generated from oil, 23% from natural gas, 6% is nuclear power and less than 8% comes from renewable resources [1].

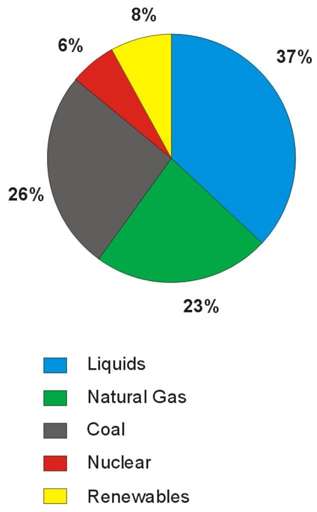

Fig. 1. World's energy use by fuel type [1]

This tremendous energy demand leads to the intensification of exploration works. They are within the domain of exploration geophysics, which uses seismic methods for discovering new oil and gas fields. The general idea behind seismic methods is to generate seismic waves (with help of explosives or vibrators) and record these waves reflected from underground layers. The information gathered, especially the time measurements of seismic waves' propagation within the ground, can be used to describe underground structures and may lead to locating possible oil and gas fields.

Within the exploration geophysics there are two major seismic methods used: 2D and 3D. The first assumes that source and receiver points are located along the same line. Therefore, the 2D seismic survey gathers data only along seismic profiles. The second method, 3D, requires a dense and regular grid of source and receiver points placed regularly along separate lines. This method allows to acquire data for the whole survey area.

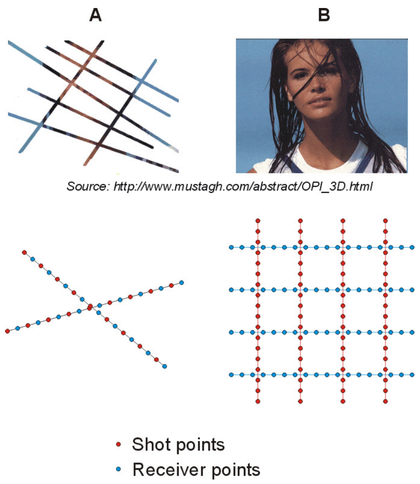

Fig. 2. Comparison of 2D (A) and 3D (B) seismic survey methods.

Seismic exploration work consists of several different stages, such as planning, scouting, designing and execution. The use of spatial analysis and multicriteria decision making is getting more and more popular and can have an important role to play at each of the stages of seismic project.

According to Malczewski [3] “GIS-based (or spatial) multicriteria decision analysis can be defined as a collection of techniques for analyzing geographic events”. Spatial decision support system can be, therefore, regarded as a specialized GIS system designed for analyzing spatial data and producing results, which can support decision makers in solving spatial problems. In other words, GIS can be regarded as a tool for spatial data manipulation and processing, that integrates different types of data (e.g. satellite imagery, digital terrain models). It can provide data for SDSS, which focuses on data analysis aimed at providing answers to spatial questions. It has to be underlined, however, that there is no clear and sharp distinction between pure GIS and SDSS. They are rather two different approaches to spatial data and some tools and applications may have a functionality of both approaches.

The main aim of this paper is to evaluate different aspects of implementing spatial analysis and spatial decision support systems within oil industry, specifically during seismic operations. This paper focuses on the following questions:

- What spatial problems most frequently occur at different stages of seismic projects?
- What spatial data shall be used to address these issues?
- What methods of spatial analyzes can be used in order to provide support for decision making process?

2 Spatial component in seismic explorations

Space and location are key components of all kinds of geophysical explorations and seismic explorations in particular. This type of survey is conducted on a given area with its own land cover, elevation etc., within a given country and is based on precisely defined source and receiver points. Finally, the aim of the survey is to describe underground structures and locate possible oil and gas fields. It is assumed that more than 80% of data in the Exploration and Production (E & P) upstream business has direct spatial component and can be mapped using GIS [4]. Moreover, nearly all other data in the industry can be indirectly linked to these spatial objects.

There is a wide range of advanced geophysical software packages, which can be used for analyzing and processing spatial data. They are, however, focused on the raw geophysical data analysis and interpretation, rather than on managing the whole seismic enterprise. Therefore, spatial decision support systems does not bring a revolution to the industry in terms of “spatially-enabling” data and analyses. Together with GIS they can help to integrate non-geophysical data and data coming from different sources, which have not been widely used before. This includes remotely sensed data, such as satellite imagery and digital terrain models and all kinds of general spatial datasets such as road networks, land use / land cover, water bodies etc. Using this kind of information it is possible to manage the whole project in terms of logistic operations and monitor the progress of seismic data acquisition. This is the universality of GIS systems that can be the main advantage over the other types of spatial software used earlier (such as geophysical software or CAD packages).

3 Using satellite imagery for spatial analysis

3.1 Applications in seismic explorations

Satellite images can be utilized at the initial stage of the seismic project. The areas of interest are very often remote, distant and loosely populated regions such as deserts, jungles or even seas and oceans. This kind of location results in a very limited information about the particular terrain. Coordinators of seismic projects do not have enough access to detailed maps and cannot assess the level of difficultness of the terrain, which has significant influence on the project. Satellite imagery can be used before scouting to define certain areas, which should be examined in details e.g. due to the abrupt elevation changes, presence of populated places or military areas. All this information acquired from satellite imagery can significantly improve field scouting. It involves assessing different types of land cover, evaluating the elevation, checking road network and finding suitable location for the camp. It is hardly possible to check the whole area of the seismic project (e.g. all seismic profiles) during the initial field reconnaissance. Therefore, using satellite imagery it is possible to limit the scouting to the areas of special interest and possible problems.

Satellite imagery is often used for land use / land cover analysis. It can also be used to assess (directly or indirectly) the terrain relief. With high-resolution imagery it is possible to recognize and locate natural and man-made features, which can be important during the seismic survey. For example, roads will be used to transport all the equipment and staff to the camp and during the project execution for daily travels to the field. It is also important to locate all objects, which can enforce redesigning seismic profiles (such as inaccessible water bodies, inhabited places or military areas). All these areas can be located on high-resolution imagery.

When preparing for the transition-zone seismic projects or other projects located on the floodplains, satellite imagery can be used to determine water extent at different seasons, or even at different hours of a day. Images for the same area taken at high and low tide or at dry and wet season can provide information about water level changes, which may be hardly to obtain from different sources. It is, therefore, important to have imagery taken at proper time, taking into account local variation of water level.

As it was mentioned before, land cover significantly affects different aspects of the seismic explorations. Generally, it is much more difficult to conduct seismic survey in the jungle or wetlands than on the sand deserts. Similarly, it is more probable that dense forest will cause more problems than flat agriculture fields. Therefore, the land cover not only influences the time needed for the project, but also implies what type and what quantity of the equipment will be necessary. All this can be directly translated into real costs of the project.

One of the main advantages of the satellite imagery is that it provides an objective description of the whole area of the project. The average area of the 3D seismic survey can range from a few hundreds square kilometers up to thousands square kilometers. Such large areas cannot be visited and properly assessed during the reconnaissance.

Therefore, there is an important role of the automatic image classification which can be used to create land cover maps. Initial, unsupervised classification can lead to defining test / training fields, which can be checked during scouting. These fields can later be used for the more detailed supervised classification. In this way it is possible to create land cover maps without significant additional costs.

3.2 Technical aspects of utilizing satellite imagery

There are, however, some disadvantages and limitations in using satellite imagery for seismic operations. As it was mentioned before, seismic surveys can be very large. At the same time they require a precise location of source and receiver points. This location can be affected even by relatively small objects, such as single houses or wells. As a result, the satellite imagery should cover the whole area of the project in resolution as high as possible. This, of course, generates huge costs. In case of 300 square kilometers 3D survey, the average price for 1-meter imagery would be around 6000 US dollars. Even bigger problem arises when taking about 2D surveys. These projects consists of several or even hundreds of seismic profiles, which may cover the area of tens of thousands of square kilometers. The location of source and receiver points is still precise, can also be affected by even small objects, therefore satellite imagery should be also of high-resolution. It is possible to acquire imagery for buffers created around each profile and reduce the whole area of imagery needed. Unfortunately, 2D profiles can often be redesigned, which makes it hardly possible to properly estimate the extent of required imagery. Additionally, positive results of 2D surveys lead to 3D works, which would require ordering new images for the areas not covered with 2D lines during previous works.

Despite the financial aspect, there is also a matter of quality of satellite imagery, especially in terms of its resolution and time of acquisition. As it was already mentioned, the resolution is strictly connected with spatial character of the seismic explorations. On the one hand, these works are conducted on the large areas, on the other hand they require precise location of hundreds of thousands of points. The optimal resolution depends on the aims. Low resolution images can be used for general assessment of land cover or for creating maps with satellite background. In this case the resolution of few or even ten meters should be enough. The exact boundaries of objects and land features is not required, and all the estimations of land cover should be within a reasonable errors. But if the imagery is to be used for designing seismic profiles and offsets or for digitizing buildings, wells, canals and roads, in this case the resolution should be high, or even – as high as possible.

There are also some organizational aspects of utilizing satellite imagery within the seismic industry. Geophysical companies, when bidding for seismic projects, have limited time for making an offer. Acquiring satellite imagery, however, can be time consuming, especially when images are not available in the archives and need to be acquired by the satellite. A new task need to be placed in the "ordering cue" for each satellite, it is also necessary to define time window for image to be taken and parameters of the image acceptable for the client. Time required for this task can be extended due to bad weather conditions (e.g. cloud cover) which makes taking images almost impossible. There is also a great risk involved in buying images for the contract, which has not yet been won. The solution may be to buy cheaper imagery from the archives. It is also possible to use freely available imagery databases for initial analysis. However, there is always a question of data quality, reliability and suitability.

The revolution in access to satellite imagery was definitely made by Google, when Google Earth viewer was introduced. This application gives users free access to a tremendous amount of high-resolution satellite imagery. The great popularity of Google Earth enforced most of GIS vendors to equip their software with KML import / export options. This enables to overlay vectors layers, such as seismic profiles, on top of high-resolution imagery. The easiness and accessibility to this enormous amount of spatial datasets leads to some misunderstanding of remote sensing techniques among non-expert users. Some users are surprised by the high costs of satellite images, as they can view it for free. Users can be also surprised by the fact, that they may be required to wait weeks for the image to be taken (e.g due to the cloud cover). This extremely easy access to high-resolution data increases the demands that users have towards satellite images. The resolution worse then few meters is often regarded as low-quality or even useless. From time to time users even complain that images in Google Earth are static and ask when Google will provide real-time animated images! [2].

4 Terrain analysis

Both elevation and relief of the terrain have a significant impact on the seismic explorations. The relief and relative elevation differences determines the source of seismic waves. For example relatively flat areas enables vibrators to be used. On the other hand, steep slope or mountainous regions requires using dynamite, as big vehicles such as vibroseises cannot access these areas. The terrain, similarly to the land cover, determines the accessibility of each part of the survey area for different types of vehicles, equipment, and also people. In the case of abrupt elevation changes and very steep slopes it may be even required to use helicopters to transport people and the equipment. In the sand deserts with high sand dunes it may be necessary to use bulldozers that clear the roads for vibrators and cut the dunes for other vehicles. The amount of sand dunes, as well as their height and direction (especially in relation to the direction of seismic profiles), determines the amount of equipment (e.g. bulldozers) required for the project. This, as a result, determines the time needed for the project and generates important share of total costs.

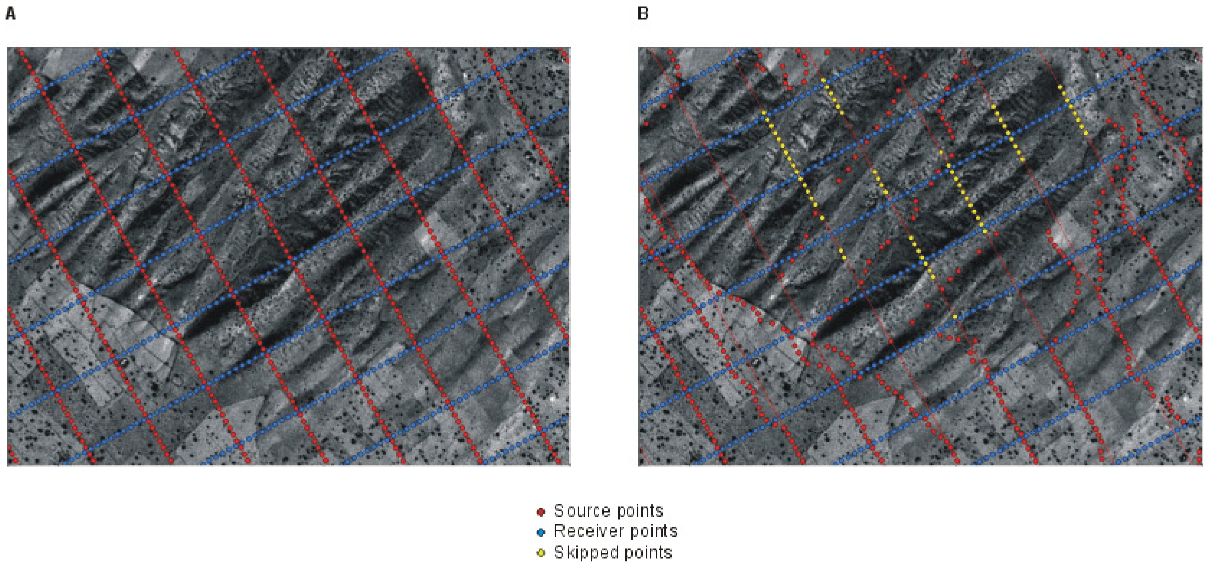

Fig. 3. Influence of the terrain relief on seismic lines design.
A) theoretical (pre-plot) design, B) real (modified) design according to elevation and sand dunes.

Therefore, there is a need for incorporating elevation and the relief in the overall project assessment and time / cost predictions. Digital terrain models provide detailed information about the terrain and can be used for automatic extraction of such parameters as height, slope and aspect, which have direct impact on the project. DTMs can be used to generate elevation profiles for each seismic line and to calculate slopes and relative elevation differences. In this way DTMs enables to assess the general elevation patterns and locate areas of possible problems (e.g. areas with limited accessibility). In this way it is possible to determines areas, which should be carefully examined during the scouting. Elevation and slopes have also an impact on the fuel consumption. During an average 3D seismic survey there may be as much as hundreds of vehicles in use every day. Taking into account the third dimension can lead to a better estimation of travel times and fuel consumption, which are one of the major part of the costs of the whole seismic crew. What is more, digital terrain models can be used to optimize the location of radio rooms and GPS base stations and improve their coverage. This type of analysis is commonly used by the GSM service providers.

Acquiring digital terrain models poses similar problems as acquiring satellite imagery. Terrain models, in order to be used efficiently in planning, need to represents the terrain in details. Therefore, the high-resolution DTMs, that covers the whole area of seismic survey, are required. Such models can be hard to obtain, especially for the remote and loosely populated areas. Moreover, such models require a lot of memory on hard disks and powerful computers to process them. Finally, costs of acquiring these models are very high. If topographic maps are available for the particular area, it is possible to digitize contour lines and generate DTM. This, however, is very time-consuming and the accuracy depends on the contour line intervals.

Alternatively, it is possible to use freely available SRTM (Shuttle Radar Topography Mission) model. Its resolution is approximately 90m and it covers all land areas between 60º N and 57º S [5], which is around 80% of landmass in the world. Its limitation is poor ground resolution, which generalize the elevation and neglects smaller terrain features that can be important from the seismic survey perspective. Therefore, there is a need for further research on the SRTM model and its suitability for terrain analysis at different stages of geophysical explorations.

It is worth mentioning that digital terrain model can be generated at the end of the seismic project, based on the field measurements. An average 3D seismic project consists of several hundreds thousands of measured locations. Measurements are frequently made using GPS RTK techniques, which provides reliable coordinates and centimeter precision of the location, including elevation.

5 The role of GIS and Spatial Decision Support Systems

As it was previously mentioned, there is a wide range of geophysical software packages explicitly designed to analyze and interpret seismic data, which is spatial in nature. These programs are equipped with some mapping functionality typical for GIS systems (e.g. working in the coordinate system, measuring tools and creating simple maps).

GIS systems are much more universal. They integrate different types of spatial data. Moreover, most of them have built-in spatial analysis tools, such as distance analysis, buffering, topological relations analysis, measuring areas and lengths. They also provide powerful and efficient tools for data management (e.g. georeferencing rasters, digitizing and editing vector datasets), and some basic data analysis (e.g. 3D analysis: slope, aspect, profiles). GIS systems integrate seismic data (e.g. location and characteristics of source and receiver points and up-holes) with general topographic data (e.g. roads, rivers, water bodies, buildings). GIS-based systems focused on spatial analysis This integration of spatial analysis tools combined with both seismic and topographic datasets results in a powerful solutions. For example, at each of the seismic project so called “safe distances” are used, which are the minimum distances from source points to other objects such as houses or wells. The idea is to ensure minimum impact on these objects when generating seismic waves. A typical GIS system provides standard tools that make it possible to check whether all source points fulfill the required safe distances from houses or other objects.

GIS systems are designed to handle effectively raster data such as satellite imagery and digital terrain models. Most of GIS systems provide integration with GPS receivers, such as direct import / export functions. One of the main features of GIS software is advanced cartography and mapping, which allows for creating professional maps. Additionally, GIS systems are used for extended visualization (including 3D environments), labeling, symbolization etc. They provide a wide range of cartographic methods for representing certain phenomena (such as cartograms, cartodiagrams). Often it is this advanced mapping functionality that encourages companies to implement GIS. Unfortunately, it can also be a case that GIS will be limited to a mapping software, neglecting its analytical potential.

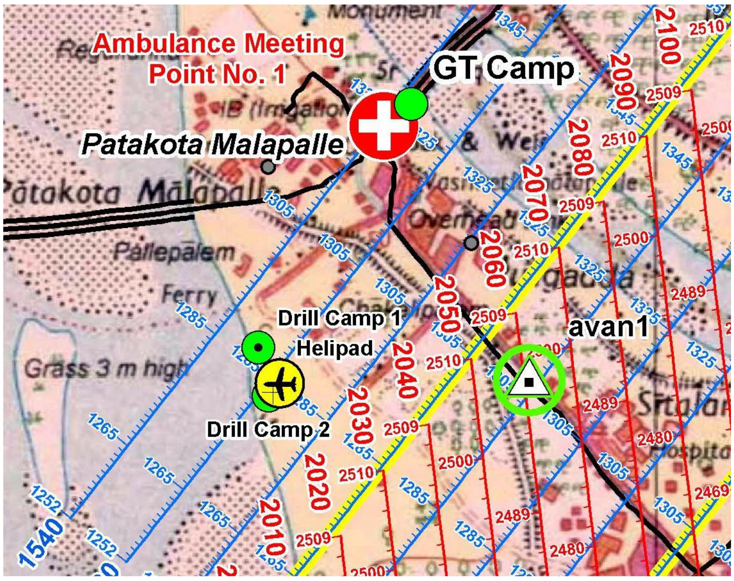

Fig. 4. Sample map of 3D project.

Another advantage of GIS systems is their ability to be customized in order to fit some standard needs of different clients. There is a wide range of off-the-shelf advanced desktop GIS packages. These are ready-to-use solutions providing the user with a set of standard tools for handling spatial data. However, GIS market is getting more and more specific and GIS systems are being designed and created for certain tasks and needs. These may include server and network GIS solutions (so called webGIS), mobile applications (designed to acquire and update data directly in the field) or desktop applications, which functionality and interface are fitted to particular client needs.

6 Conclusions

Geophysical explorations, and seismic explorations in particular, are spatial in nature. They depend heavily on the terrain and its components, such as land cover and elevation. These factors have a significant impact on the overall performance of seismic projects, including such key components as time and costs. However, these factors are difficult to handle by the project managers. Since they are spatial in nature, they need to be analyzed and parameterized by spatially enabled software, that is Spatial Decision Support Systems. According to Malczewski [3] "SDSS can be defined as an interactive, computer-based system designed to support a user or group of users in achieving a higher effectiveness of decision making while solving a semistructured spatial decision problems" [3].

Therefore, there is a great need for applying SDSSs and GIS within the oil industry and specifically in seismic explorations. These types of systems provide tools for acquiring and managing spatial data, enable analyzing these data and transforming them into useful information that can support decision makers at different stages of seismic projects.

Geophysical industry, especially those branches that are oriented to oil and gas exploration and exploitation are million dollar businesses. This applies to field operations in particular. Even an average seismic project costs millions of dollars. In the same time these huge enterprises depends heavily on the terrain, which is very often one of the least known and estimated factor, which determines time needed for the project and costs involved. Therefore, every single information, that can lead to a higher speed of data acquisition or that can optimize works or overcome some problems that hinders recording, can result in significant savings of time and money.

There is, however, a great need for further research on the methodology for analyzing spatial data focused on solving real-life problems and answering spatial questions, that are being asked during seismic operations. The methodology should be then implemented into ready-to-use tools, spatial decision support systems, that can facilitate spatial analyzes and provide users with easy interface and advanced modeling functionality.

The research should also be focused on evaluating different types of spatial data with respect to its suitability within oil and seismic industry. Such parameters as data accuracy and resolution should be examined in details.

Reference

1. EIA, *International Energy Outlook 2008*, Energy Information Administration, DOE/EIA-0484(2008), http://www.eia.doe.gov/oiaf/ieo/index.html.
2. Google Sightseeing, *Live Satellite Images in Google Earth!*, http://googlesightseeing.com/2007/04/01/live-satellite-images-in-google-earth.
3. Malczewski J., *GIS and Multicriteria Decision Analysis*. John Wiley and Sons, 1999, ISBN 0471329444, 9780471329442.
4. Smith G., Jepps C., *The Role of GIS in E&P Information Management*, http://www.exprodat.com/papers/default.asp?pid=10.
5. Rabus B., Eineder M., Roth A., Bamler R., The shuttle radar topography mission – a new class of digital elevation models acquired by spaceborne radar. *ISPRS Journal of Photogrammetry & Remote Sensing*, 57, Elsevier, 2003, ISSN: 0924-2716