How can Remote Sensing and GIS help in the verification of International Treaties?

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This research is designed to investigate how remote sensing and GIS can be used in the verification regime of International Treaties..It focuses on the semantic difference and transformation from the goals of a treaty to the observable and verifiable elements.

A case study for the Comprehensive Nuclear Test Ban Treaty (CTBT) is presented, demonstrating the potential capabilities for the use of Satellite Imagery and Remote Sensing as a verification technology for the use on an On-Site Inspection (OSI) to narrow down the search area for an unknown underground event or a possible underground nuclear explosion.

GIS, by spatially linking different layers of information, acts as a logical analytical tool to overview all the inputs for the verification. In simpler words, it adds up all the clues automatically in order to view the whole situation. For example, in the case of a CTBT verification regime, one has multiple data layers in the GIS database representing various technologies. One layer for the Seismic network and findings, another layer for the radionuclide measurements, and another for the visual observation findings. By overlaying all those layers together and by performing spatial querying in the GIS database, suspicious areas are denoted and identified, and hence an On-Site Inspection can be called to concentrate on those areas at first instead of the whole Inspection Area thus saving time and resources.

It is clearly demonstrated that Satellite Imagery and GIS are useful tools and technologies in the verification regime for CTB treaty. However, it has to be understood that satellite imagery and GIS alone are insufficient, they have to be used together with all the other technologies stated in the treaty (e.g. seismic, radionuclide, etc.) and that they can not be the only technology used for the verification. Even though they are a powerful tool, they are strongly dependant on human operators and if the analyst makes a mistake in one of his approaches, the whole azimuth of the results shifts towards a wrong solution. Therefore, Satellite Imagery and GIS when integrated with other technologies acts as a strengthening tool to strengthen or weaken the assumptions but not as a litmus test giving a yes or no answer.

Keywords: Remote Sensing, Verification, GIS, Satellite, Monitoring

I. INTRODUCTION

At its simplest level, the Comprehensive Nuclear-Test-Ban Treaty (CTBT) is intented to prohibit nuclear explosions from being conducted by anyone, anywhere and for any reason. The treaty was opened for signature in New York on 24 September 1996 and is currently signed by 174 member states [1].

In order to further enhance the verification capability of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) a field experiment was copnducted in the year 2002 (FE02) in the republic of Kazakhstan at the former Soviet nuclear test site of Semipalatinsk in order to further develop the readiness of the On-Site Inspection (OSI) division of the CTBTO in a case representing a type of non compliance with the treaty.

The FE02 scenario was to conduct a chemical explosion (12.5 tons granulated TNT) in one of the old boreholes, 250 meters deep, at the Semipalatinsk area and then to follow the procedure of calling an OSI. A team of 27 surrogate inspectors was sent to the area with a mandate to verify whether a nuclear explosion has occured and if so where. The team was allowed to use only the approved technologies described in the treaty, mainly seismic aftershock monitoring systems, radionuclide monitoring and visual observations.

This paper describes a scoping study undertaken after the return of the team to investigate the potential capability for the use of Satellite Imagery and GIS as a verification technology for the use on an OSI to narrow doen the search area for an unknown event or a possible underground nuclear explosion.

II. FE02 SCENARİO

On Saturday 14 September 2002, the International Monitoring System (IMS) of the CTBTO recorded a seismic event in the Semipalatinsk area at 06:30 GMT. 50 seconds later, another relatively stronger seismic event in an area very close to the first event was also detected. The magnitudes of both events were estimated at 2.1 and 3.5 Richter respectively. Following the request of one of the member states, the International Data Center of the CTBTO (IDC) conducted a special study on the two events. The study indicated that both events were also recorded by stations in Russia and Norway, and by using seismic triangulation methods, while the first event was located in an area around an open pit coal mine, the second event was located approximately 20 km south of the coal mine.

The executive council convened and by a majority of votes gave the green light to go ahead with the request for inspection. Later the Director General gave the mandate to call upon and to form the inspection team. On Thursday 20 September 2002 the inspection team leader arrived to Vienna together with core members of the team and at noon the Director General handed the Inspection Team Leader (ITL) the inspection mandate with its annexes and the map showing the approved Inspection Area.

III. THE INSPECTİON AREA (IA)

The inspection area is about $560km^2$ and is located in the former Semipalatinsk Nuclear Testing Site (SNTS), also known as "the Polygon". It is a zone of 18,500 km^2 located in a relatively flat steppe area near the town of Kurchatov. This town was built to service the test site and was the main settlement with about 60,000 inhabitants during the 40-year test period. Starting from 1949 until 1989, in the Polygon area, three types of nuclear tests were conducted by the former Soviet Union:

1. Surface and atmospheric testing; In the Opytnoye Pole Area "Technical Area" 50 km west of Kurchatov, until 1962, 26 surface and 87 atmospheric tests have been conducted.
2. Tunnel testing; in the Degelen Area, from 1961 until 1989, 213 nuclear tests have been conducted in tunnels, with horizontal depths ranging from 500 to 2000 meters.
3. Underground testing; in the Balapan Area, from 1968 until 1989, 136 underground nuclear tests have been conducted, with vertical depths of 500 – 1.5 km.

The FE02 Inspection Area is situated around the Shagan river, very close to "Lake Balapan" or "Atomic Lake" which is the result of the excavation explosion "Chagan", which produced this lake which is about 500 meters in diameter and 100 meters deep with cliffs up to 100m high [2].

IV. FE02 IMAGE ANALYSİS

This investigation of the OSI FE02 is done to test the utility of commercial satellite imagery and GIS for resolving CTB compliance issues. Taking the FE02 scenario as an example of a future CTB compliance dispute, commercial satellite images from a variety of sensors are used along with other data. This case study attempts to answer a few key technical questions: Can satellite imagery and GIS confirm reports of nuclear tests and dispel those that are inaccurate? If so, with the approval of state signatories, in accordance with the treaty, can satellite imagery and GIS be a verification tool together with the other "post-test" verification technologies? Moreover, in the case of an on-site inspection, how can satellite imagery and GIS help in narrowing down the search area and search time in order to confirm a violation or conversely, can this information be used to vindicate a state that has been falsely accused due to malintent or misinterpretation of available evidence?

V. ANALYSİS PROCEDURES

The following explains how commercial satellite imagery was obtained, processed, and analyzed; it also provides the interpretation of the images and describes the discoveries that were made.

Since the allegation in FE02 is a CTB compliance dispute, analysts would seek to resolve the issue by completing three principle objectives:

1. Obtain archived data of the inspection area, this will form a historical background for the area in which changes will be calculated from that time onwards.
2. Request a recently acquired image by commercial imaging satellites. This pre-test image is used to assess amd identify the preparatory work for the alleged nuclear test explosion.
3. Request for a post image for change detection analysis. Change detection will be applied from those images to both previous images thus making a comparison for changes that have occured a year ago with those that occured ten or more years ago. This part in the analysis reduces dramatically the effect of natural change detection caused by atmospheric and environmental effects.

Imaged portions of the inspection area were obtained from the archives and from the recently acquired commercial imaging satellites. The following table lists all of the satellite images that were used and explains why each specific image was selected for detailed analysis

Satellite and sensor	Ground Sampling Distance (GSD)	Acquisition date	Relevance to the case study
QuickBird	70cm	16th August 2002	Hi-Resolution Site Preparation Image
QuickBird	2.8m	16th August 2002	Hi-Resolution Site Preparation Image
IKONOS	1m	01 May 2001	Hi-Resolution Site Preparation Image
ASTER	15m	30 April 2002	Pre-Explosion Image
ASTER	15m	01 October 2002	Post-explosion Image
LANDSAT	30m	26 July 1989	Historic base reference Image

Table I Satellite images available for the study

The Landsat archive image was selected as a reference image for the whole area, since it provides a clear view of the area very close to the time it was officially announced closed for testing on August 29 1991 by Kazakh president, Nursultan A. Nazarbayev's decree 409 after the independence from the Soviet Union [3]. The image was acquired on 26 July 1989 by the Landsat TM sensor with an optical resolution of 30 meters and a ground sampling resolution of 28.5 meters.

Image 1 Landsat TM 28.5 meter resolution taken on26 July 1989

The Landsat image is of zero cloud coverage consisting of 7 bands. It shows relatively flat terrain at the north of the area with slight elevation towards the south. There is no sign of the open coal mine, since it was not yet constructed. Many features and signatures of previous underground activity and fresh boreholes are to be seen on the image.

Two ASTER images were selected for use in the search for triggering event for the Field Experiment. ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) is an imaging instrument that is flying on Terra, a satellite launched in December 1999 as part of NASA's Earth Observing System (EOS) [4]. ASTER is used to obtain detailed maps of land surface temperature, emissivity, reflectance and elevation.

The first ASTER image was acquired on 30 April 2002, the image contains all 15 spectral bands. This image will serve as the "before" image in the change detection analysis. The image is of 10 percent cloud coverage and a ground sampling resolution of 16.47 meters.

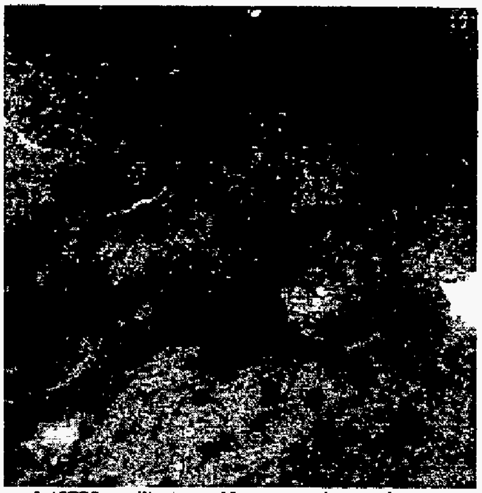

Image 2 ASTER satellite image15 meter resolution taken on 30 April 2002

The second ASTER image was acquired on 1 October 2002; the image also contains all 15 spectral bands. This image will serve as the "after" image where all the techniques for the change detection will be applied in order to denote anomaly areas where something has considerably changed. The scene does not cover the whole Inspection Area, there are some parts south east of the area that are not shown. This could clearly affect the total analysis of the area, but this is a true example of what might an image analyst face in real situation where some parts of his area of interest will have no data or is covered by clouds.

Image 3 ASTER satellite image15 meter resolution taken on 01 October 2002

The space imaging IKONOS high resolution image was acquired on 1 May 2001, the image does not cover the whole inspection area but covers only the northern part of the area with a ground sampling resolution of 1 meters. This image will be used for anomaly detection where pixels which have a spectral signature that deviates markedly from most other pixel spectra in the image would be identified.

Image 4, Space Imaging Ikonos satellite image 1 meter resolution taken on 01 May 2001

The last scene is acquired from Digital Globe's quickbird satellite; the scene was acquired on 16 August 2002 in 4 bands at 2.8 meters resolution and at 70 centimeter panchromatic ground sampling resolution. The reason those images were acquired is that they would serve for searching of recent changes between May 2001 and until August 2002.

Image 5 Digital Globe Quickbird satellite image2.8 meter resolution taken on 16 August 2002

VI. ANALYSİS WORKFLOW

Following registration of the images and unification of the coordinate system a vector layer representing the Inspection area is developed and respectively all the different layers are cut to fit the Inspection Area.

As a first step in the analysis, the Inspection Area is divided into tiles, and respectively all the satellite image data is divided into those corresponding tiles. By doing so it will be much easier to look into the tiles and analyze each of them separately, for the analyst's eye it is much easier to pick up changes over a smaller area than a larger area, also it would take a lot less time to process those tiles and to do change detection rather than process the whole image at once. For example, when using the Orthogonal Subspace Projection (OSP) algorithm [5], i.e., simultaneously reducing data dimensionality, suppressing the background clutter signal, and maximizing the target spectrum Signal to Noise ratio (S/N), to do an Anomaly Detection, the background materials are estimated from the entire scene. If the scene consists of several different areas, it may be desirable to process these different areas separately. Here it should be mentioned that those satellite images have a very large size and even on a powerful workstation it is not easy to work around with such large files, for example the QuickBird Pan image has a size of 4 Gigabytes and by making a resolution merge to produce a Pan Sharpened product of this image would produce a file which is 16 Gigabytes in size!

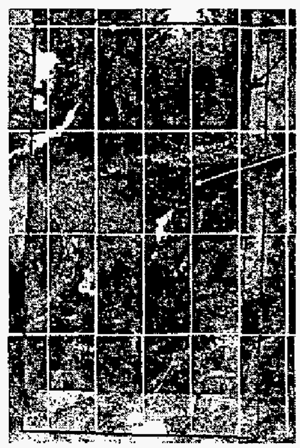

Image 6. Satellite imagery splitting and working blocks

VII. ANOMALY AND CHANGE DETECTİON

The simplest scenario from the analyst's point-of-view is one where the signatures of either the material-of-interest or the surrounding environment are known. The question could be framed, "Is there anything unusual in this scene?" Examples would be vehicles in an uninhabited area or vegetation in desert terrain.

Therefore to make things easier for the analyst, anomaly detection was applied to all the images. This task searches the input image to identify those pixels which have a spectral signature that deviates markedly from the background spectra [6]. The output is continuous gray-scale anomaly mask. In our case the boreholes are the main anomalies and they are shown much clearer.

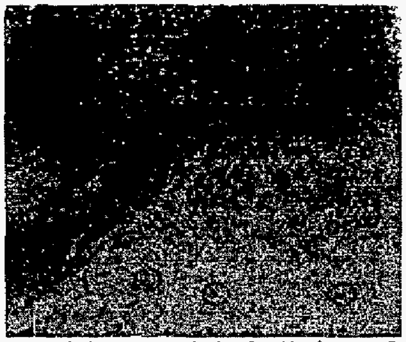

Image 7, Anomaly Detection applied to Quickbird 70 cm PSM image, red circles indicate the location of Boreholes

By applying change detection algorithm, the history of those boreholes is deduced and it will show if there are any new ones that have been dug during the last 13 years between 1989 until 2002.

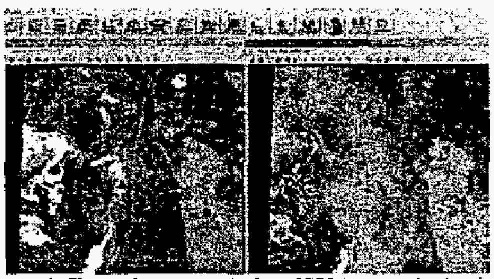

Image 8, Change detection applied to ASTER image and to Landsat image,red areas indicate the changes between the two images

Image analysis shows, with a probability of confidence of about 80 percent, taking into consideration climatic and environmental factors, that there does not seem to be any new boreholes created since 1989 but there seem to be some visible anomalies in one of the boreholes. It seems that one of the boreholes has undergone some major changes.

Image 9, Anomaly detection applied to ASTER image and to Landsat image, yellow dots represent boreholes, by comparing both images, no new borehole has been dug between 1989 and 2002

Later on it was mentioned that the Inspected State Party (ISP) started to mask the borehole after September 14th 2002 and they have started creating the other distracting signatures in the area after that day.

Having those findings we had to concentrate on this area and look for more signs of anomalies. By examining the High Resolution image of IKONOS taken on May 2001 and that of QuickBird taken in August 2002, those show that there has been new fresh tracks and there has been some recent activities in the area. The post image taken in October 2002 shows that there is a Plum around that borehole and by using the infrared band of the ASTER satellite we denote that there is thermal activity in this area .

VIII. FURTHER ANALYTICAL RESULTS

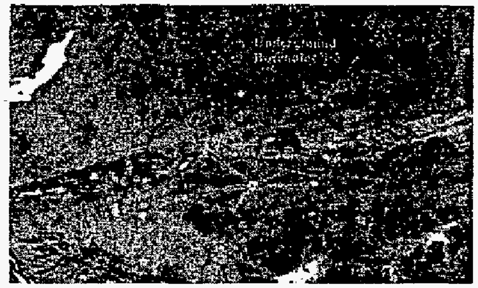

Image 10, LANDSAT Image taken on 26th July 1989. The boreholes could be seen clearly on this 28.5 meters image.

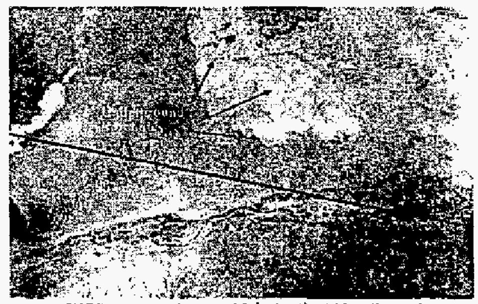

Image 11, ASTER image taken on 30th April 2002. There doesn't seem to be any activity near the borehole. No recent signatures or earth disturbances.

Image 12, Space Imaging IKONOS 4 meters Multispectral image taken on 1st of May 2001.

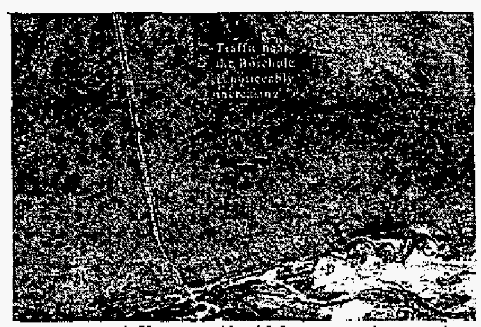

Image 13, Digital Globe Quickbird 2.8 meters Multispectral image taken on 16th August 2002. New features at the top right hand corner near the borehole can be noticed.

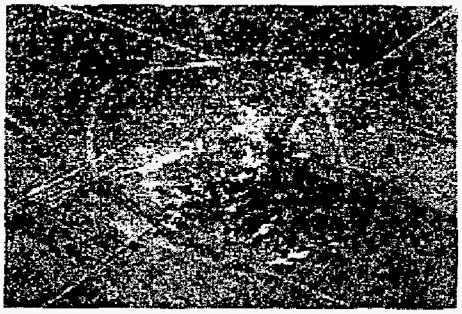

Image 14, A close up of the IKONOS image taken on 1 May 2001

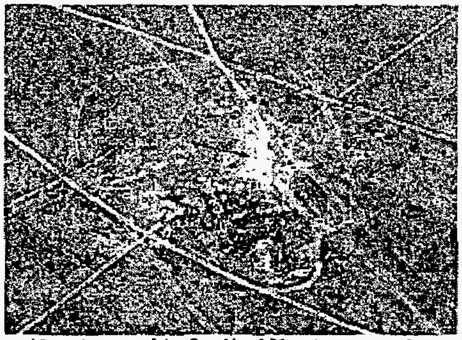

Image 15, A close up of the Quickbird 70cm image, new features are shown in the image, tracks have been accessed more frequently and a new track has been created. Land excavation can be seen.

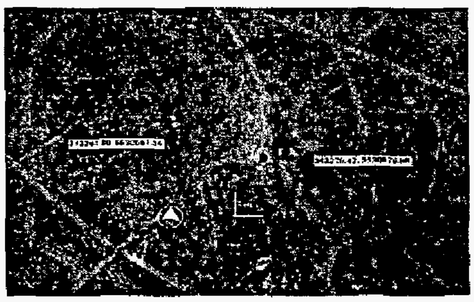

Image 16, Gamma Processed Quick-Bird 70 cm Pan Sharpened Image Showing the exact locations of the Main Borehole that was used and the satellite Borehole and their coordinates

Image 17, LANDSAT Image taken on 01 October 2002. A Plum can be clearly seen around the suspected borehole.

IX. CONCLUSION

It is clearly demonstrated that Satellite Imagery and GIS are useful tools and technologies in the verification regime for CTB treaty. However, it has to be clearly understood that satellite imagery and GIS alone are insufficient, they have to be used together with all the other technologies stated in the treaty (e.g. seismic, radionuclide, etc.) and they can not be the only technologies used for the verification. Even though they are powerful tools, they are strongly dependant on human operators and if the analyst makes a mistake in one of his approaches, the whole azimuth of the results might be shifting towards a wrong solution. Therefore, Satellite Imagery and GIS when integrated with other technologies will act as a strengthening tool to strengthen or weaken the assumptions.

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