TECTONIC SHIFT MEASUREMENT WITH GEODETIC SAR PROCESSING

Hartmut Runge, Ulrich Balss, Steffen Suchandt, Michael Eineder

DLR, German Aerospace Center, Institute of Remote Sensing Technology, 82234 Wessling, Germany

ABSTRACT

We describe a new method for precise, geometrically high-resolution and large-scale measurement of plate tectonics with the aid of radar remote sensing and show first results. For the derivation of the 3D vectors of tectonic displacements two measurement intervals, separated by at least one year are necessary. At each interval several satellite images from different radar viewing angles are obtained, and the 3D-coordinates of ground control points (GCPs) are calculated. By correcting the influence of the ionosphere, atmosphere and earth tides, it is possible to measure the absolute coordinates of ground control points with high accuracy. By comparing the absolute positions of the GCPs of the two acquisition periods, the displacements that have occurred in the meantime can be determined in X, Y and Z.

The applications are in the measurement of continental drift, of elevations and subsidence by the melting of very large glacier areas, as well as of tectonic shifts after earthquakes. Furthermore, the continuity of continental drift in earthquake-prone areas can be checked with the help of long-term recording series.

Index Terms— SAR geodesy, plate tectonics, earthquake

1. INTRODUCTION

The technique described here makes it possible, with the aid of Radar remote sensing, to measure an entire network objects with an accuracy that would otherwise be feasible only with the aid of GNSS and a measurement on site. The detected objects are radar point scatterers, retro reflectors on a dark Radar background. These are usually corners at building which that are aligned with the sensor orbit inclination and lamp posts that form a right angle with the ground. For this reason, the method works best in urban or populated areas and fails with scenes that do not have such features.

2. METHODOLOY

Accurate measurement of 3D positions of objects in SAR data was only possible with the introduction of elaborate geodetic corrections, described in [1-6]. To determine the 3D shift vector, the 3D positions of these objects with those of a second series of photographs, obtained e. g. one year later, are compared. Overall, only relatively few satellite images, e. g. 2x6 acquisitions are necessary.

For the finally achieved accuracy four factors are decisive:

a) The number of point targets present in the scene. This is the largest in urban areas.

b) The geometric resolution of the SAR mode. We have therefore achieved the best results with the Staring Spotlight Mode from TerraSAR-X.

c) The time lag between the two recording series. The time must be long enough to get out of the measuring noise. Ideal is the use of data archives, which may go back far enough into the past, eg. that of TerraSAR-X goes back until 2007.

d) The number of satellite images used. The achieved accuracy can be increased by averaging the measurements.

3. FIRST RESULTS

In order to measure the tectonic shift of Honshu island of Japan after the Tōhoku earthquake in March 2011 we have analyzed 5 scenes using the TerraSAR-X SpotLight mode and the obtained the following results:

Sendai (2008/18)
Used GCPs: 117 better 20 cm
South: 121 +/- 8 cm
East: 443 +/- 9 cm
Elevation: 6 +/- 7 cm

Naka (2008/18)
Used GCPs: 66 better 30 cm
South: 47 +/- 10 cm
East: 163 +/- 18 cm
Lowering: 21 +/- 17 cm

Sambongi (2010/11)
Used GSPs: 277 better 10 cm
South: 55 +/- 4 cm
East: 45 +/- 6 cm
Elevation: 4 +/- 4 cm

Osaki (2009/18)
Used GCPs: 49 better 20 cm
South: 149 +/- 9 cm
East: 415 +/- 17 cm
Elevation: 3 +/- 17 cm

Narita (2009/11)
Used GCPs: 66 better 30 cm
South: 6 +/- 12 cm
East: 83 +/- 15 cm
Elevation: 24 +/- 19 cm

These remote measurements from Space correspond very well with in-situ GPS-measurements processed by the Caltech-JPL ARIA group [7]. Figure 1 illustrates the results.

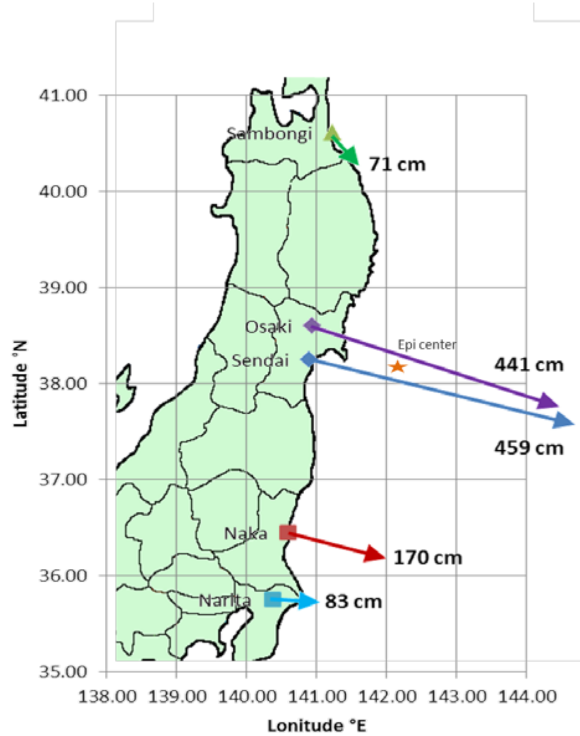

Figure 1: Tectonic Shift of Honshu island after the Tōhoku earthquake in March 2011 obtained with TerraSAR-X SpotLight Mode

4. COMPARISION WITH OTHER METHODS

The advantages compared to conventional methods, e.g. the application of measuring networks based on GNSS receivers and laser geodimeters, are:

- The process is more cost-effective, as remote sensing eliminates the need for on-site installation and deployment. In addition, in a scene (up to 30 km x 60 km in TerraSAR-X) we measure a very large number of highly accurate control points (typically several hundred to a thousand), which would be extremely expensive with GNSS or laser geodimeters. There are only relatively few satellite images necessary.

- Satellite remote sensing also enables measurements in regions and countries where no personnel can be deployed for safety reasons, such as: In Afghanistan.

- The procedure is simpler in terms of organization, since in many countries geodetic surveys first have to obtain permits from authorities that are often denied foreigners.

- Results can be achieved much faster, since large archives with remote sensing data can be used. For areas where data is available from a longer period of time to the present, statements can be made within hours. If only older recordings are available, new recordings must be made, but this is possible within a few weeks.

The above-described control point method can only be used in terrain with corresponding structural structures. For the measurement of tectonic shifts after earthquakes so far the so-called "speckle tracking method" was used. It is already being used very successfully in the movement measurement of glaciers and was also tested for deformation measurements after the Nepal earthquake in 2015 with Sentinel-1. A measurement of the displacement vectors using the speckle tracking technique was carried out shortly after the Tohoku-Oki earthquake in 2011. At that time, however, no geodetic corrections were used [8].

With SAR interferometry and PSI techniques, only shifts in the line-of-sight (LOS) of the radar can be measured. On the other hand, we can also measure subtle shifts that occur in the satellite's direction of flight. The resolution in the third dimension is obtained by measurements using different aspect and radar angles of incidence. Furthermore, the interferometric techniques have the disadvantage that they do not provide absolute measurements, but can only measure changes within a scene. Larger shifts cannot be detected and the scene decorrelation often causes great problems. By contrast, our measurements are based on the measurement of geodetic 3D coordinates of concrete objects, such as B. the footsteps of lamp masts.

5. OUTLOOK

A new method of measuring geodesic displacements using radar remote sensing was presented. It delivers very promising results over urban areas. The existence of archives of satellite data reaching as far back as possible is very beneficial. The applied geodetic correction methods and algorithms are very complex and the amounts of data to be processed very large. Therefore, efficient software implementation and automation is required to achieve acceptable processing cycle throughput. The geodetic corrections applied in our SAR Geodesy Processor SGP are operationally available for the German satellites TerraSAR-X and Tandem-X, and all satellite modes are geodetically calibrated. The recently launched Spanish radar satellite PAZ, which is almost identical in construction, supplies compatible input products, but these still need to be calibrated. Until the final version of the paper even more areas are to be measured.

11. REFERENCES

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