Crustal Deformation Monitoring in Beijing Using Radarsat-2 InSAR Time Series Analysis

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Abstract. The main aim of this study is to investigate the current vertical crustal movement characteristics and evolution process in Beijing using InSAR technology. In this paper, the InSAR time series analysis method was used to monitor the crustal deformation in Beijing during the period from 2012 to 2015, and to quantitatively reveal the overall deformation characteristics of different areas within the study area. Based on 33 Radarsat-2 wide-mode SAR images covering Beijing, 68 interferograms were formed by optimizing the combination of baselines. Using the FRAM-INSAR technique, the cumulative deformation time series and images along the line-of-sight of the satellite in the 32-phase period were calculated, and the annual average deformation velocity field in Beijing and neighbouring areas during 2012-2015 was calculated. Based on the distribution of active structures in the study area and the distribution of ground subsidence, the relationship between the deformation characteristics of the entire crust and the tectonic activity and land subsidence in the study area was discussed, which provided an effective criterion for accurately carrying out seismic risk assessment in this area.

1. Introduction

As China's political center, cultural center, international exchange center and scientific and technological innovation center, Beijing has developed rapidly in recent years in economic, social development and urban construction. However, with the rapid development of economy and urban construction, land subsidence has gradually developed into one of the major geological hazards in Beijing and even in the entire North China Plain. This has caused certain negative impacts on Beijing's urban development. Its potential harm has been increasingly concerned by the society and the government [1,2]. Since 2002, the Beijing Municipal Government has increased its investment in enhancing the monitoring capabilities on the urban land subsidence. With the completion of Beijing's land subsidence early warning and forecasting system, a ground subsidence monitoring system consisting of ground subsidence monitoring stations, ground level monitoring networks, GPS monitoring networks and groundwater dynamic monitoring networks has been gradually formed [3].

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At the same time, Beijing is also a region where the tectonic movement is more active. Since the late Cenozoic era, there have been three active vertical tectonic zones (stripes) with strong differential faults. They are the NE-trending North China Plain fault zone, the Shanxi fault depression basin zone, and the Zhangjiakou-Bohai structural belt that is superimposed on the NW-wise extension of the northern part of these two zones and the southern margin of the Yanshan Mountains [4]. The seismic and geologic environment in the area is complex. The activities of the new structure are intense and the active faults are developed. It is one of the regions with the most severe earthquakes and the most serious earthquake disasters in the eastern part of China's mainland. Historically, there have been many major earthquakes in the area, such as the magnitude 8.0 earthquake in Sanhe-Pinggu and many over magnitude 5.0 earthquake [5]. Strengthening the monitoring and research on the features of crustal movement and fault activity in this area is of great significance for the prevention and relief of disasters in the region.

In recent years, more and more research teams have begun to pay attention to the phenomenon of land subsidence in Beijing. A variety of crustal deformation observation methods, such as leveling, GPS, and InSAR, are used for ground subsidence monitoring in the area. Among these observation technologies, InSAR technology as a kind of surface deformation monitoring of the rapid development of the technology, with its high monitoring precision, wide coverage, the application of low cost, short repeated cycle of advantages, is widely used in the ground deformation monitoring [6]. Land subsidence due to over-extraction of groundwater in the Beijing region was investigated using 41 Envisat ASAR and 14 TSX images and the results reveal that the Beijing region has experienced significant ground subsidence from 2003 to 2010 with a maximum accumulative displacement of 790 mm [7]. As the same method, Land subsidence from 2003 to 2014 due to groundwater extraction in Beijing plain was detected based on 39 ENVISAT ASAR images and 27 RadarSat-2 images using PS- InSAR, which showed that the land surface in Beijing plain area is settling at an accelerating rate, and the accumulative displacement is up to 1426 mm along the LOS by the end of 2014 [8]. Based on A multi-layer numerical groundwater flow model, an aquifer system of Beijing plain has been developed to accurately describe the characteristics of the groundwater flow field [9]. A Wavelet Based InSAR approach on two SAR image stacks was implemented to investigate the long-term displacement in eastern Beijing Plain and found that the Land subsidence in Beijing Plain has connection with hydraulic head level falling caused by over-exploitation of groundwater [10].

Based on the above research progress, there are still some problems as following:

1) Most studies focused on the relationship between land subsidence and groundwater Overexploitation, without considering the context of the geological structure and the relationship between fault activities.

2) Most of the studies focused only on the subsidence areas in the plain area and did not cover the mountainous areas, which could not explain the overall movement characteristics of the whole area.

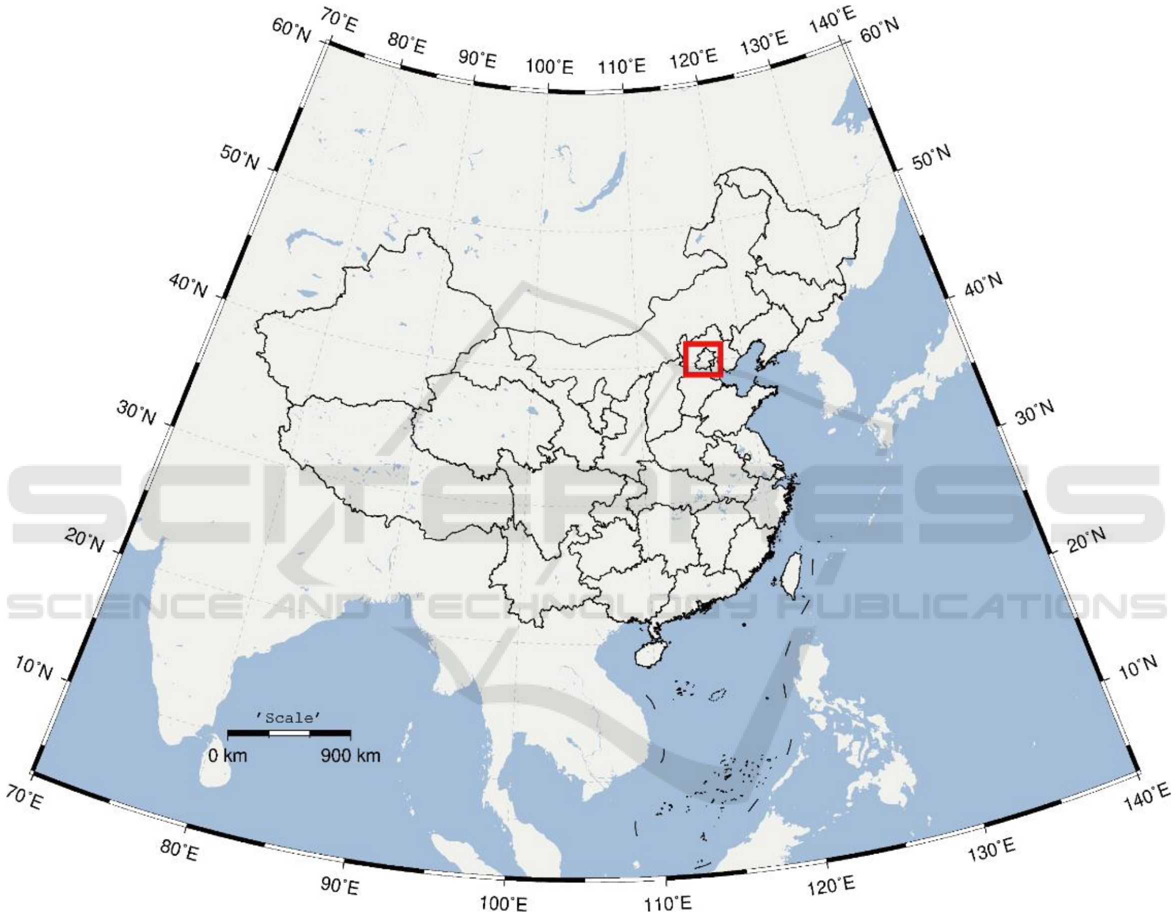
3) Due to the fact that there are few wide-range radar satellite data available during the period 2012-2015, most studies are based on high-resolution SAR images such as TerraSAR-X, which limits the ability to acquire large-scale deformation signal.

In this paper, INSAR time series analysis method based on 33 Radarsat-2 wide SAR imagery from 2012 to 2015 were used to obtain large-scale dynamic deformation time series and mean deformation velocity field in Beijing. Based on these results, the information of the overall vertical deformation in Beijing during this period was calculated, and the trend of land subsidence in the area and its relationship with fault activity were analyzed.

2. Study area and data

2.1. Study area

The research area of this study is in Beijing and its adjacent areas (115°E~118.2°E, 38.8°N~41°N), which is located at the junction of the North China Plain and the Taihang Mountains and the Yanshan Mountains. The southeastern part of this area is plain and belongs to the northwestern fringe of the North China Plain; The western mountainous region is the northeastern part of the Taihang Mountains; The northern and northeastern mountainous region is the western branch of the Yanshan Mountains (Figure 1).



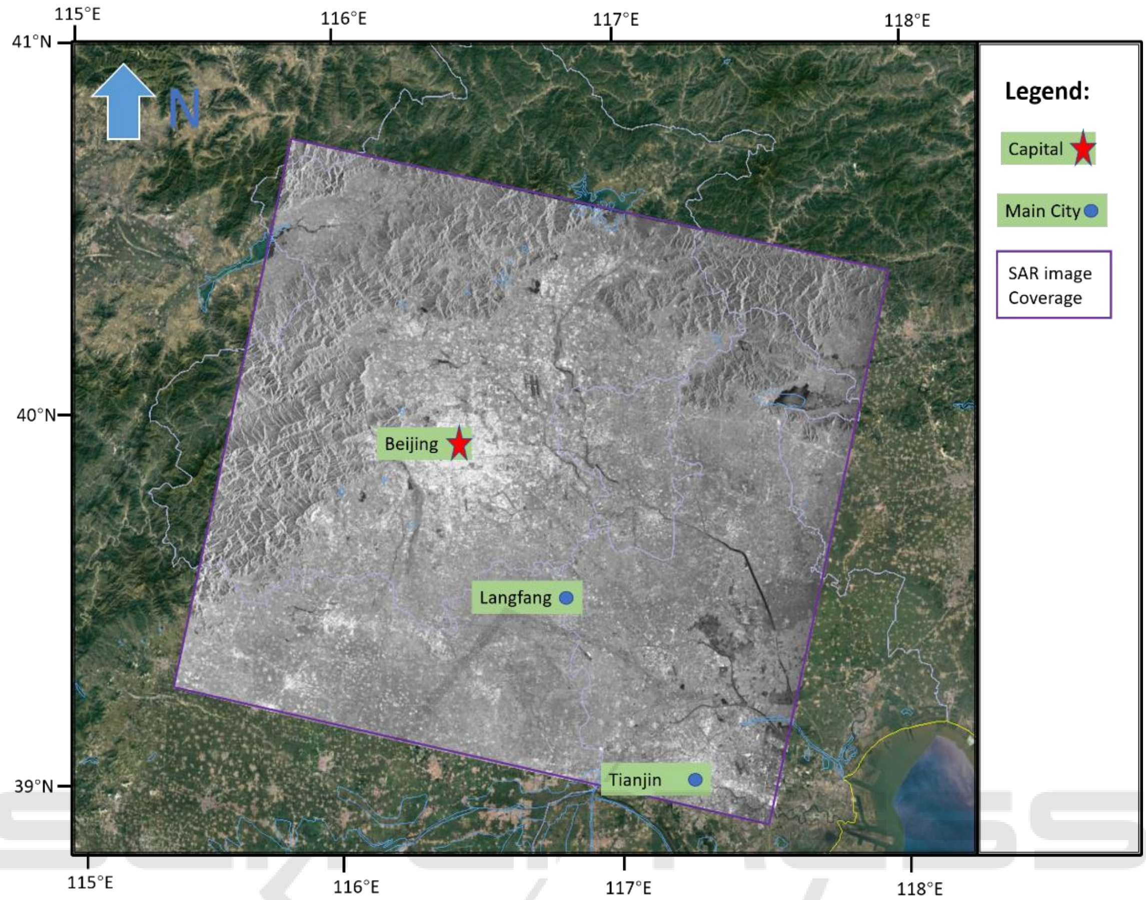


Figure 1. Location of the study area and the coverage of SAR images.

Since 1950, a large area of land subsidence has continued to occur as a severe geological disaster. By the end of 2005, the area of ground settlement greater than 50 mm reached 4114.12 km2, and the area greater than 100 mm reached 2815.29 km2. Settlement amount reaches 1086mm, and the most serious area is still sinking at a speed of 30~60mm/year. The maximum average settlement speed reaches 66.3mm/year [11]. By the end of 2009, the maximum annual settling speed reached 137.51mm [12,13]. Land subsidence has brought major losses to Beijing's social economy. The results of the study show that 34% of broken water supply pipelines in urban areas in Beijing were caused by land subsidence [14].

2.2. Data

In this paper, we used 33 Radarsat-2 wide SAR images range from the year 2012 to 2015 covering most of Beijing area to acquire the crustal deformation along the line of sight (LOS) direction. All the SAR images were imaged in wide mode with the VV polarization mode. The coverage of the Radarsat-2 SAR images is shown in figure 1.

In the process of data processing, in order to maintain good interference coherence and to ensure the reliability of the interference results, the Small Baseline Subset (SBAS) algorithm must be used to select the time baseline and space baseline when combining the interference pairs. In this study, the spatial baseline threshold was chosen to be ±200m and the time baseline threshold was ±300 days. To ensure the stability of the mesh, some interference pairs with the baseline of the time was slightly longer than the baseline threshold and the vertical baseline was small. Finally, 47 interferograms with high interference quality are obtained. The combined network diagram is shown in Figure 2.

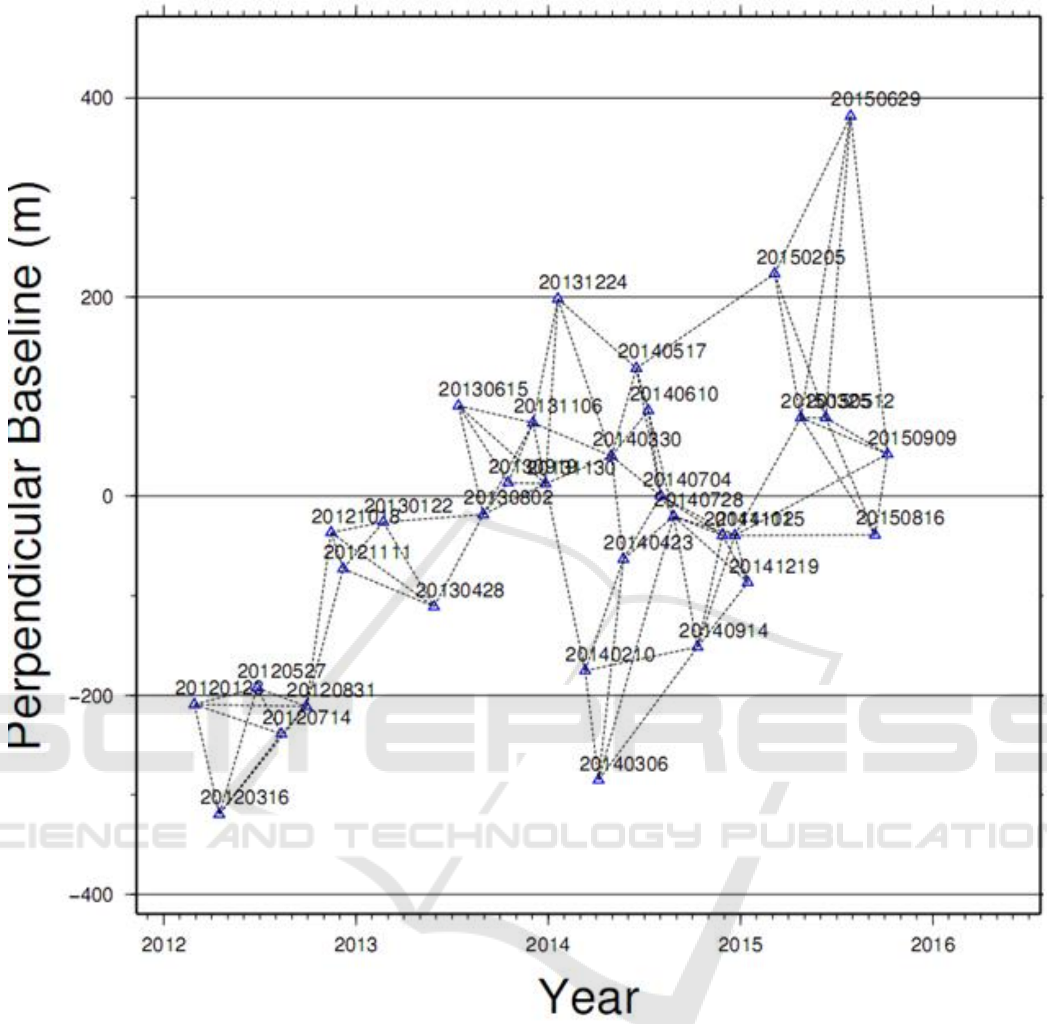


Figure 2. Spatial and temporal baselines of Radarsat-2 SAR images used in this study.

In the data processing process, in order to remove the topographic phase in the interferometric phase, the SRTM-DEM data SRTM3 (3 arc-seconds) jointly measured by the NASA and the National Mapping Agency of the Ministry of National Defence (NIMA) was selected as the external DEM data, which is at the version of V4.1 and was publicly released in 2003. The data range is 38°-40° north latitude and 109°-111° east longitude. Figure 3 shows the image of the DEM we used in this study.

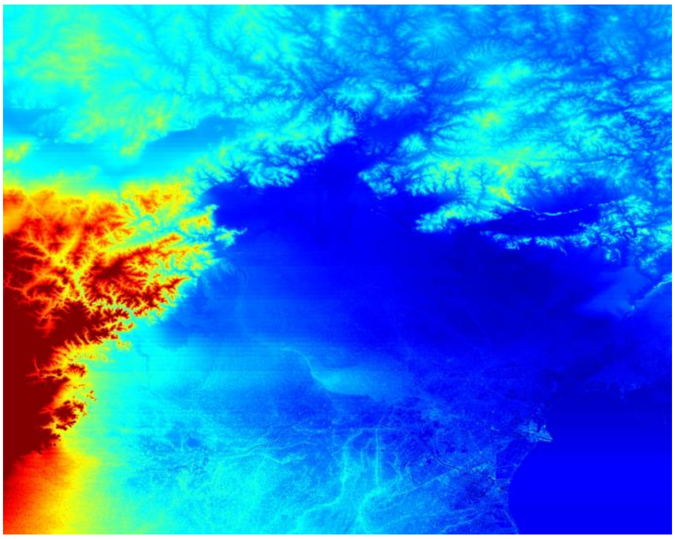


Figure 3. The DEM image we used in this study.

3. Data processing and results

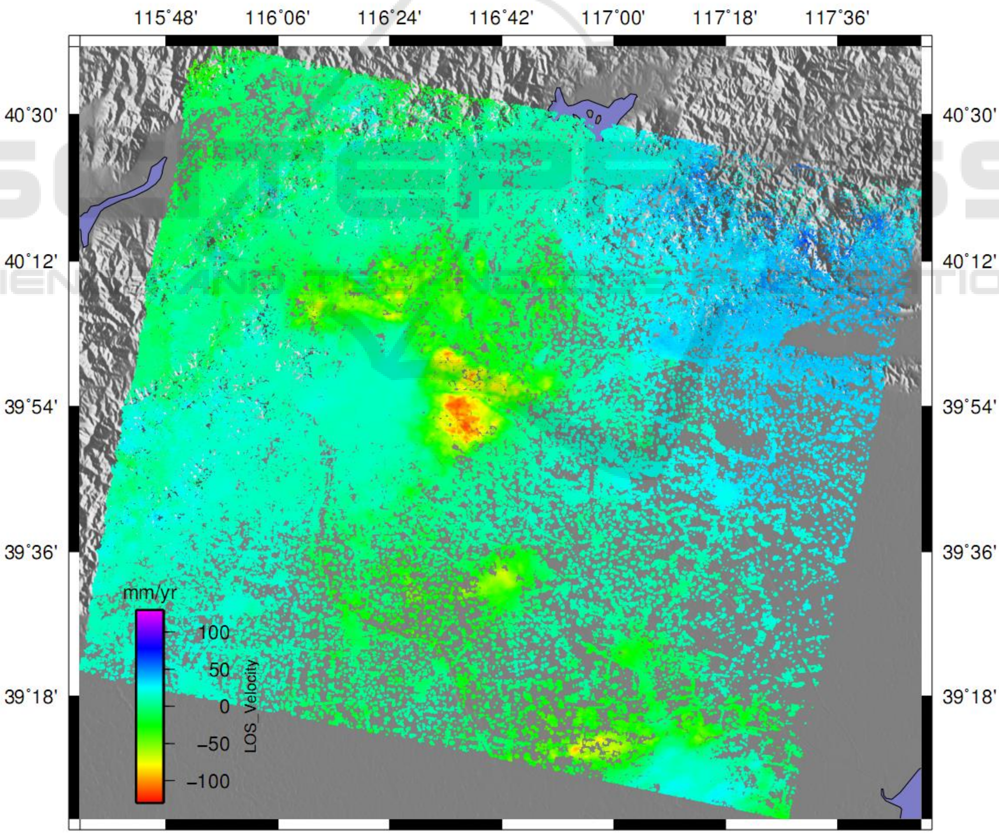


Figure 4. The mean velocity field of crustal deformation along the line of sight (LOS) direction from 2012-2015 derived from RADARSAT-2 WIDE mode SAR images.

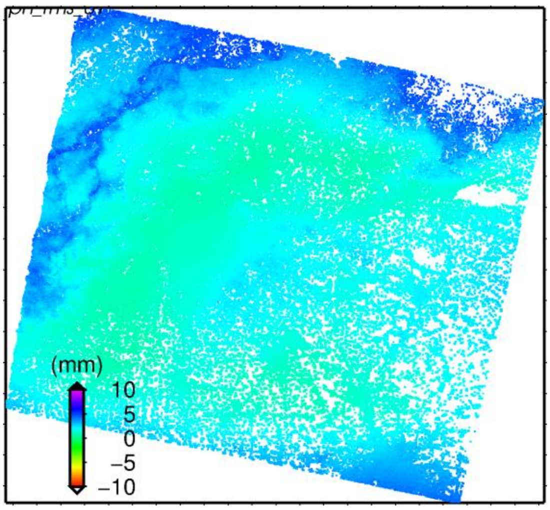


Figure 5. The error distribution of the mean velocity field.

The InSAR time series analysis was carried out by using the software named Full RAnk Matrix – Small BAseline Subset (FRAM-SBAS) which was developed by Yongsheng Li in Institute of Crustal Dynamics, CEA, China and Newcastle University, UK.

FRAM-SBAS is a multi-function processing platform based on Linux that includes radar interferometric processing, time series analysis, and geometric correction. Currently supports all global commercial SAR satellite platform data. The software is simple and easy to use, supports process processing, and can be applied to the domain of urban land subsidence, co-seismic and post-earthquake deformation analysis, volcano monitoring, landslide debris flow monitoring. The FRAM-SBAS software is one of the most effective processing tools to solve the small deformation monitoring of the crustal plate. The continuous improvement and innovation of new methods and innovations have continuously improved and supplemented the SBAS theoretical model in different aspects [15].

Based on the FRAM-SBAS software, we got the mean velocity field of crustal deformation along the line of sight (LOS) direction from 2012-2015 in Beijing area. Figure 4 shows the final result of the mean velocity field and figure 5 shows the error distribution of the mean velocity, which show a good result with reasonable accurate.

4. Conclusions

Based on 33 Radarsat-2 wide SAR images, in this paper, we obtained the crustal deformation field information covering the entire Beijing area, including the annual mean deformation velocity field and 32 periods of accumulated deformation sequence images from 2012 to 2015. From the calculation results, the following conclusions can be drawn:

1) The overall performance of the Beijing area showed a trend of slow mountain uplift and rapid settlement in the plain area, among which the mountain uplift speed is relatively slow, averaging around 1 mm/year; the main urban area (within the third ring) is relatively stable; the eastern part has more serious settlement, and the largest velocity reaches 130mm/year.
2) The subsidence areas in Beijing are mainly distributed in the plain area. There are three more serious areas, namely The Haidian-Changping-Shunyi area, the Chaoyang-Tongzhou border area, and the Langfang area bordering Beijing.
3) Judging from the cumulative deformation evolution image, During the period of 2012-2015 in Beijing where the three settlements are more serious, the trend of settlement has continued to increase.

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