Monitoring of Surface Deformation In Dangxiong Using Time Series Analysis Techniques

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ABSTRACT:

The geographical scope of the experiment in this paper is Dangxiong in Tibet. The rift basin of Yangbajing-Dangxiong-Gulu locates at the east side of the Nyainqentanglha. The crustal activities in Dangxiong basin are frequent and a great deal of geothermal energy converged under the surface. Two geothermal power plants were built. The power generated through the exploitation of underground thermal. The excessive underground thermal extraction caused the surface deformation in surrounding areas of the power plants. In this paper, we investigated the surface deformation caused by the thermal extraction in Dangxiong with 23 ENVISAT ASAR images from 2006 to 2010 based on the time series analysis. The results showed that the centre of the basin was relatively stable. The deformation rate was between -1mm/yr – 2mm/yr. The surface subsidence rate of the region with the power plant was about 8mm/yr.

1. INTRODUCTION

The purpose of this paper is to apply the PSInSAR technique to monitor the surface deformation. The geographical scope of the experiment in this paper is Dangxiong in Tibet. The crustal activities in Dangxiong basin are frequent and a vast amount of geothermal energy converged under the surface. For the development and utilization of geothermy resources, two geothermal power plants were built. The power was generated through the exploitation of underground thermal. The excessive underground thermal extraction caused the surface deformation in nearby areas of the power plants.

We investigated the surface deformation caused by the thermal extraction in Dangxiong by using 25 ENVISAT ASAR images from 2006 to 2010 based on the time series analysis. The time series analysis was a technique that exploited several characteristics of radar scattering and atmospheric decorrelation to measure surface deformation in the non-optimum conditions [4] .The results demonstrated that the centre of the basin was relatively stable while it was obvious that the land subsidence was caused by the excessive exploitation of groundwater and the subsidence sites were mainly concentrated at the region of geothermal exploration wells.

2. BACKGROUND

Dangxiong basin and adjacent areas are located at the central Tibetan Plateau orogenic belt. The average elevation is about 5,000 meters. The geographical scope of the Dangxiong basin in this paper was among 90 degrees to 90.5 degrees east and 29.5 degrees to 30.5 degrees north。The total area was about 150 km^2.

The eastern side of the Nyainqentanglha is Yadong-Yangbajing-Gulu-Naqu rift system. The Dangxiong-Yangbajing basin is one part of the rift system. The basin had a complex geological evolution history. The zone experienced serious tectonic movement with strong magmatic, gathered a large amount of geothermal. The fracture became a good channel for geothermal accumulating and upward moving.

Figure 1 shows the Dangxiong-Yangbajing basin and the Mount Nyainqentanglha from ALOS PRISM data with 10m resolution. Figure 2 describes an SLC image produced from a July 29, 2007 scene. Yangbajing is a town that located approximately 90 km north-west to Lhasa. The town lies just south of the Nyainqentanglha Mountains. The Yangbajing was about 4,300 meters above sea level. It was a warm, green grassland valley encircled by snow-capped mountains of over 5,500 meters. The geothermal area has many hot water wells and hot springs. By using its rich natural resources, the geothermal has been used for many years. Yangpachen has the largest geothermal energy power station in China, whose yearly output supplies 45% of electricity required by Lhasa City. The geothermal power plants are located at the northern part of the study area. Yangbajing was undergoing rapid subsidence due to withdrawal of ground water, especially the area around the geothermal power plants. This paper used PSInSAR approach to investigate the subsidence which was usually steady over periods of months and sometimes years [4]. The PSInSAR results would show the spatial and temporal patterns of the subsidence. Those may give clues to the reasons for subsidence and help mitigate subsidence hazard caused by nature or human.

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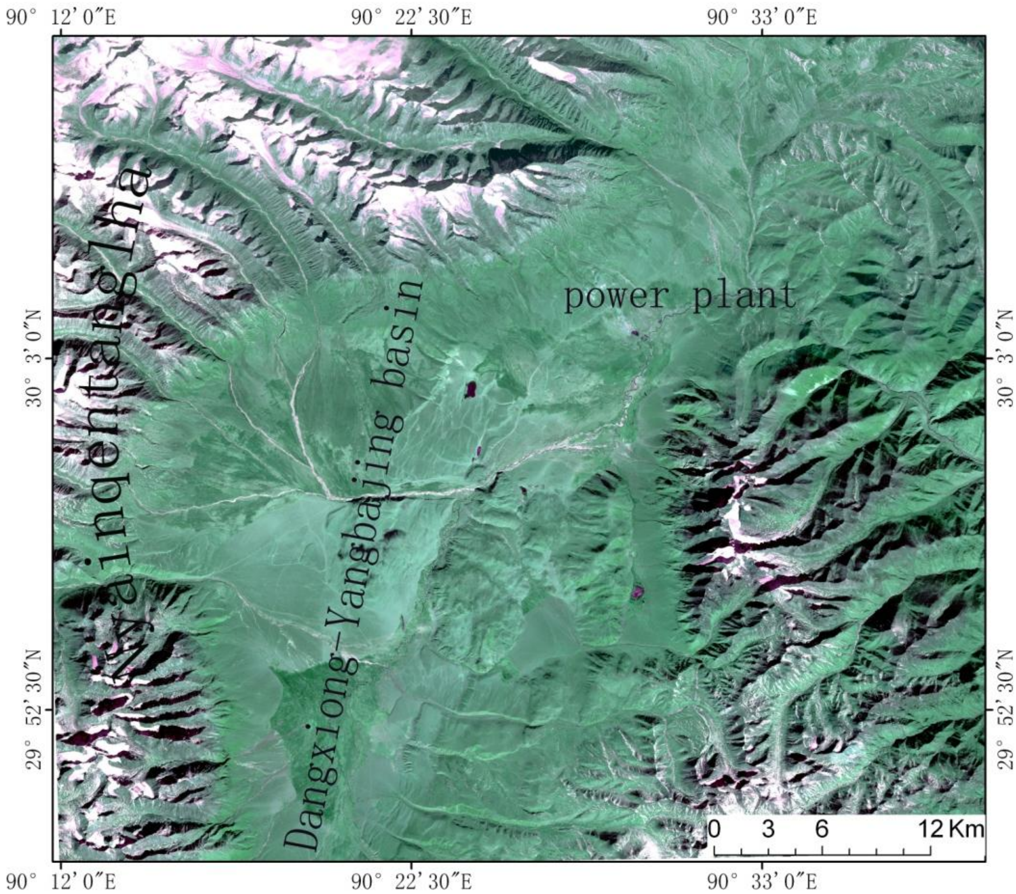

Figure 1. Morphology of the Dangxiong-Yangbajing basin from ALOS PRISM data with 10m resolution.

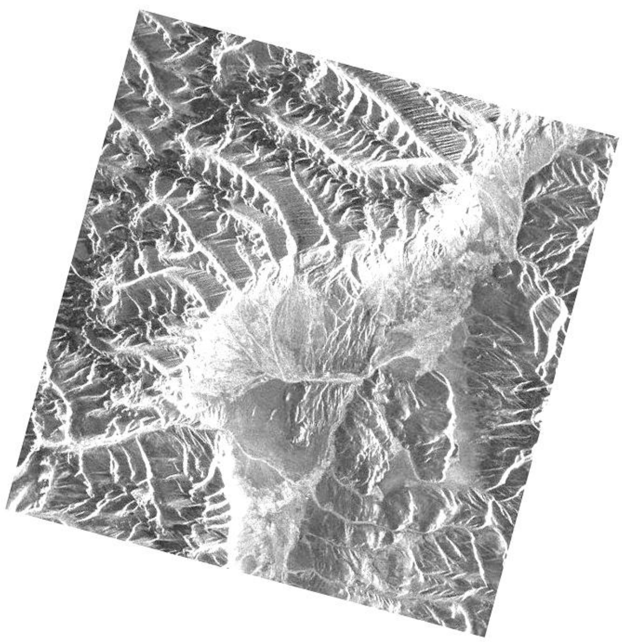

Figure 2. SAR image of the experiment site, Dangxiong-Yangbajing basin.

3. PSINSAR

DInSAR is used to detect ground deformation with accuracy up to millimetres. DInSAR can be used to monitor various sites like volcanic activities, earthquake deformation, landslides and underground subsidence due to water extraction. The greatest benefit of DInSAR is the potential to collect data with high spatial resolution and continuous coverage of the measurement area without using ground-based instruments and a prior knowledge of a site [1][2][3] [4].

DInSAR technique is powerful to measure changes in the earth's surface, it also has several limitations. These include temporal decorrelation, geometrical decorrelation and variable tropospheric water vapor. The water vapor can generate variable phase delay owing to the influence of water vapor the propagation speed of microwave signals. The variable phase could be misinterpreted as surface change [4][7].

PSInSAR technique was first presented by Italian scholar A. Ferretti. The PSInSAR technique was developed to detect and track pixels with consistently high amplitude to tackle the problem of atmospheric delay error at the expense of many images and sparse, pixel-by-pixel based evaluation. The point targets (PS point) could be detected and recognized by using statistical method, because they were not affected by temporal changes [4][5][6].

The interferometric phase of each target j in each interferogram i contains the following phase components: a topographic component, a displacement component, and noise components, all of which are different in each image of series of images, see (1).

$$\phi_{\Delta tij} = \phi_{topo} + \phi_{def} + \phi_{atm} + \phi_{noise} \qquad (1)$$

Where ϕ_{def} is the phase change due to the movement of the pixel in the LOS direction, It contains the deformation velocity of the radar target. ϕ_{atm} is the phase equivalent of the difference in atmospheric retardation between passes, It contains Atmospheric Phase Screen (APS). ϕ_{topo} contains the correction for the actual target height in relation to the used DEM, ϕ_{noise} contains the effect of other components, noise due to temporal and spatial decorrelation and non linear target movement[1][2][3].

The PSInSAR technique was very suitable for investigating surface deformation while minimizes errors which come from uncertainties and inaccuracy of topography and atmospheric conditions. The contribution of topography and atmosphere may be estimated and removed by carefully exploiting their different time-space behaviours. This increased the measurement precision from centimetre to millimetre level[3]. The atmospheric phase contributions were correlated within a single SAR scene. Atmospheric effects can be estimated and removed by combining data from long time series of SAR images, averaging out the temporal fluctuations. Conversely, surface motion is usually strongly correlated in time. [1][2][3] [4]

This experiment was based on one of the permanent scatterer techniques called StaMPS(Stanford Method for Persistent Scatterers), the method was introduced by Hooper .

The PS candidates were chose by using the amplitude dispersion index and the phase stability of the PS candidates were estimated based on the phase analysis. Then the PS pixels were selected from the candidates and the contribution of the spatially uncorrelated part was removed from the original phase. The phase unwrapping was based on the selected points. The phase difference between adjacent pixels was unwrapped in time dimension firstly. A cost function for each unwrapped differenced phase value was built. The Snaphu method was used to solve the 2-D unwrapping problem. The Last step, the deformation phase was obtained by estimating the spatially correlated and uncorrelated terms based on the unwrapped results[1][2][3][7].

4. DATA AND RESULTS

4.1 Data used

We analyzed the data from ENVISAT ASAR data. The ASAR data spanning from 2006 to 2010 provided a dense coverage of surface observations in the LOS direction. The sense acquired on 2007-07-29 was chose as the master image and the spatial perpendicular baselines are shown in Tab.1. The SAR

data archive comprised 23 images and tracks were 176 with descending orbit. The experiment site covered an area of 40 Km by 40 Km.

Tab.1 List of SAR image used for time series analysis

Pair	Satellite	Dates	Track	Orbit	Bprep
1	ENVISAT	20061022	176	24278	-324.2
2	ENVISAT	20061126	176	24779	-85.9
3	ENVISAT	20070311	176	26282	450.7
4	ENVISAT	20070415	176	26783	-81.2
5	ENVISAT	20070520	176	27284	-16.4
6	ENVISAT	20070624	176	27785	71.8
M	ENVISAT	20070729	176	28286	0
8	ENVISAT	20070902	176	28787	256.5
9	ENVISAT	20071007	176	29288	-94.1
10	ENVISAT	20071111	176	29789	235
11	ENVISAT	20080504	176	32294	12.4
12	ENVISAT	20080713	176	33296	274.9
13	ENVISAT	20080921	176	34298	-97.6
14	ENVISAT	20090315	176	36803	557.6
15	ENVISAT	20090419	176	37304	-77.5
16	ENVISAT	20090524	176	37805	125.6
17	ENVISAT	20090906	176	39308	310.3
18	ENVISAT	20091115	176	40310	248.2
19	ENVISAT	20091220	176	40811	-87.2
20	ENVISAT	20100124	176	41312	317.6
21	ENVISAT	20100228	176	41813	-169.8
22	ENVISAT	20100509	176	42815	270.4
23	ENVISAT	20091220	176	44318	-70.5

5. DATA AND RESULTS

5.1 Results and Discussion

The Figure 3 shows the estimated average velocity field for the basin. The coloured dots superimposed on an ALOS PRISM background image. The deformation generally ranged from between +8 mm/yr (blue) and -10 mm/yr (red). The deformation values were range changes in the direction of radar illumination. Negative values indicated motion away from satellite, consistent with subsidence. Some PS may have rates of movement that exceed these limits.

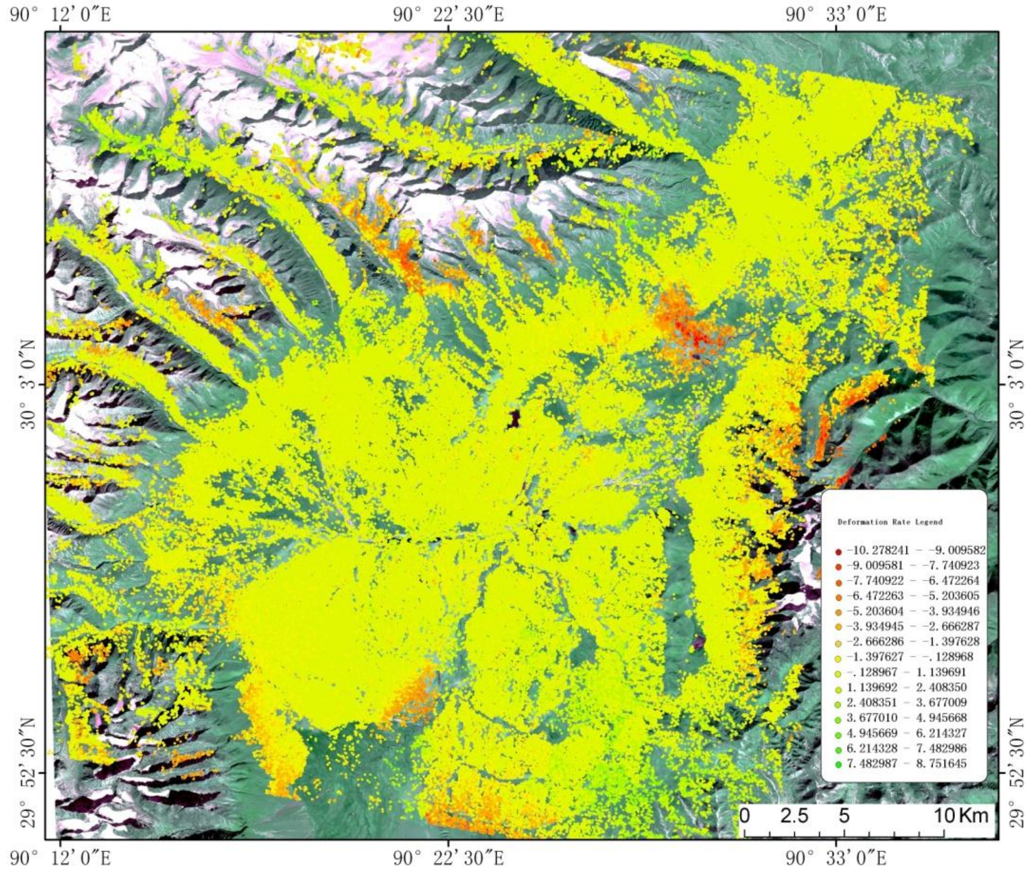

Figure 3. The estimated average velocity field for the basin by time series analysis

The basin surface was relatively stable in most parts. The deformation velocity was about -1mm/yr – 2mm/yr. The deformation occurred mainly at the middle and two sides of the basin. Both sides of basin were mountainous terrain. The subsidence occurred mainly due to the landslide. The deformation in the middle of the basin was located at the Yangbajing power plants. It was the centre of the drastic subsidence. The subsidence was caused by the over extraction of the ground-water. The velocity was up to 8mm/yr.

A total of 263454 PS points were extracted. From the velocity histogram, the deformation rate was mainly distributed ranging from -5mm/yr to 4 mm/yr, see Figure 4.

In the following section, we focus on the yangbajing area and explain subsidence patterns and possible explanations. Figure 5 was an enlarged map of the power plants. The deformation occurred mainly in the vicinity of geothermal exploration wells and the power plants. It was possible that groundwater extraction could induce surface subsidence in the region of extraction wells and houses. The point A was selected for the time series analysis. The deformation rate of point A was -5.7 mm/yr. One PS point near the extraction well was selected for

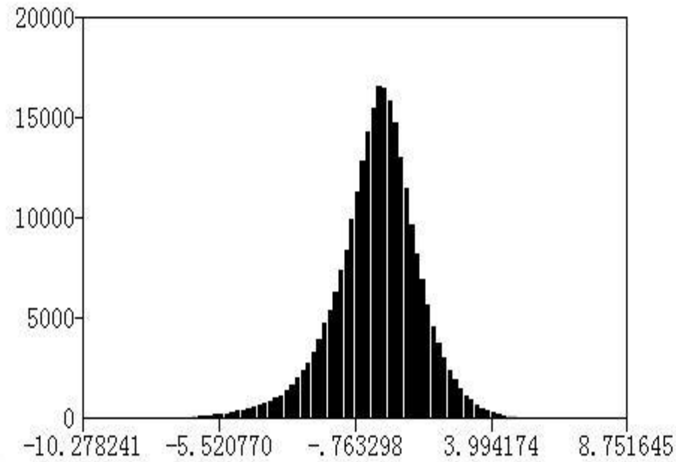

Figure4. The Histogram shows the distribution of the deformation velocity

the multi-temporal analysis, see Figure 5. From the Figure 6, the deformation rate was arrayed in a linear deformation characteristic.

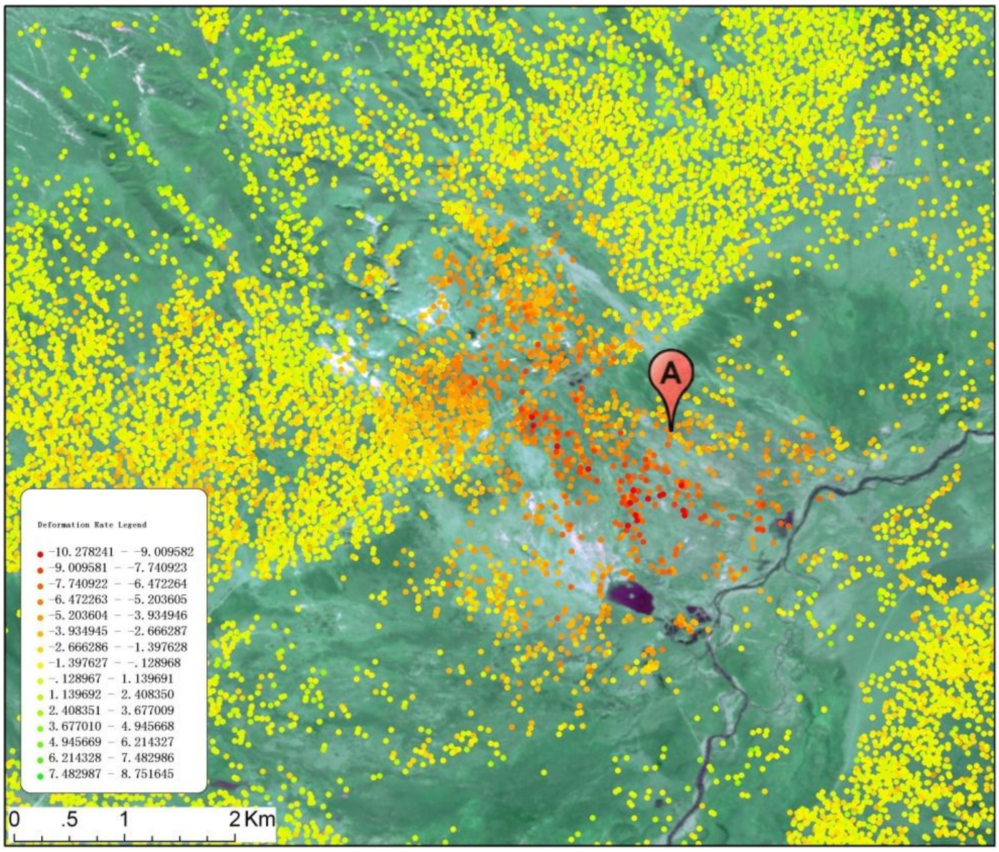

Figure 5. Enlarged map of estimated average velocity field at the power plants.

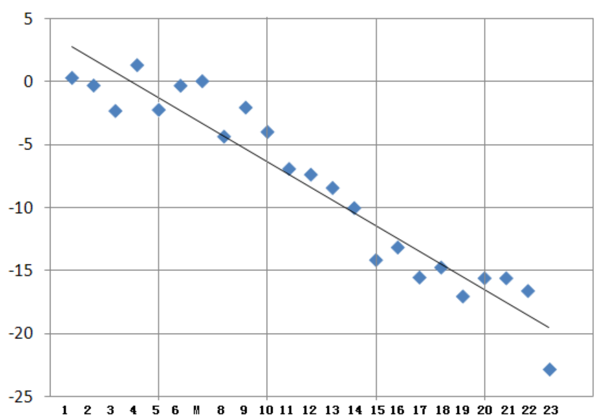

Figure 6. The time series deformation at the point A in Figure 5.

It's hard to validate the results because of lacking of GPS or levelling data in this region. The overall deformation trend of this region was studied by the Wu Zhonghai[8]. He used the geological method to measure the different height of the fault scarp in different times. The study showed that the vertical activity rate was between 0.4 and 2mm/yr. The result in this paper was consistent with Wu's result.

6. CONCLUSIONS

The paper investigated the surface deformation based on the time series analysis using 23 ENVISAT ASAR images from 2006 to 2010. The results illustrated that a very significant subsidence central was located at the thermal power plants. The subsidence was mainly caused by the over extraction of groundwater. The subsidence rate at the power plants was up to 8 mm/yr. The deformation rate at the other parts of basin ranged from -1mm/yr to 2 mm/yr.

More details about subsidence area need to be studied in order to completely understand the subsidence mechanism. The introduction of the high resolution SAR data is a good solution.

7. REFERENCES

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