Landslide movement monitoring with ALOS-2 SAR data

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Abstract. Landslide is a hazard that threaten the people who lives in the mountain area, it comes active especially rainy seasons and causes a large number of casualties every year. The movement of the slope is an indicator of activity of the landslide, it is helpful to capture the precursor of the activity, the monitoring of the movement of the slope is very important. However it is a difficult problem due to complex topography, cloudy and rainy weather for optical sensors, In this paper we will show the capability of up-to-date Advanced Land Observing Satellite-2 (ALOS-2) Synthetic Aperture Radar (SAR) data in monitoring the movement of the landslide which located in south China, which can capture the fast and slow movement with different spatial and temporal baseline combination, the results shows that the L-band SAR data has its advantage in monitoring the movement of the landslides especially in the low latitude, cloudy and rainy area.

1. Introduction
Landslides are natural hazard with fatal impact to people who lives in mountain area, and they are sometimes caused by deep slope under heavy rains [1-4]. The understanding of the characteristics of the landslides are important to prevent the hazardous accidents. The movement characteristic of the slope is one of the most important indicator factor of the landslide, and it is always a precursor of happening of the landslide. The traditional technique like leveling and GPS network have been applied to the land surface movement monitoring but it is labor, financial consuming and not efficient [5,6], especially in mountain area, it is difficult to reach and apply leveling or GPS measurements. Satellite remote sensing data can be more effective in monitoring the movement of the landslides area, with their textual and magnitude information. We do not need to arrive at the site where displacement happens. Compared with optical remote sensing, Interferometric Synthetic Aperture Radar (InSAR) is an effective remote sensing technique for surface movement monitoring, and it has been recognized as the only technique that could provide area monitoring capability by now especially in cloudy and rainy area [7-10]. Although many advantages, due to the de-correlation effect of the plant on the slope, the X and C band SAR data will not performance well in low latitude area. In this paper we will exploit
the capability of the L-band SAR data in the surface movement information extraction and the real data from Advanced Land Observing Satellite-2 (ALOS-2) will be used as demonstration.

2. Techniques and methodologies

SAR interferometry is a promising technique and has been used in many areas such as large area subsidence due to underground water extraction, glacier velocity estimation, surface movement due to the earthquake, coal mining caused earth surface change and many others, due to its valuable for estimation of ground displacement. Differential InSAR exploits the phase difference of two SAR images acquired within certain period of the same target. Figure 1 gives the schema of the InSAR method, when the first trip of the satellite pass the target P, the slant range between the satellite and the target is \( r_1 \), then after sometime the second trip of the satellite pass the target, the slant range is \( r_2 \), during this period the target P has a displacement of \( \Delta r \), then with some derivation the displacement of the target could be written as [11]:

\[
\Delta r = -\frac{4\pi}{\lambda} \Delta \phi
\]  

(1)

where \( \Delta \phi \) is the difference phase of the interferogram.

Figure 1. Illustration of InSAR method.

The measurement accuracy could to be millimeter theoretically, however due to the errors from different sources the precision will be contaminated. The error sources could be atmospheric screen, thermal noise, spatial de-correlation, temporal de-correlation, volume de-correlation and other sources. And wavelength is a critical factor for InSAR processing. In common situation the longer the wavelength, the smaller effect from the landscape change. The C and X band InSAR have serious de-correlation effect especially in plant area due to volume-decorrelation, while the L band InSAR will get much better result for its longer wavelength.

Commonly, there are several steps for InSAR data processing, first the single looking complex data of two acquisitions are cropped to the same area which cover the target, due to the acquisition geometry is different of the two image, they are not co-registered perfectly, one image will be selected as master image, and with orbit ephemeris the coarse coregistration parameters are obtained, then with magnitude correlation method the slave image will be co-registered to the master image with sub-pixel precision in order to keep the phase information correct, and with the coregistration parameters the slave image is resample to the same coordination system of the master image, the interferogram is generated using complex conjugate multiple and the reference and the topography phase will be removed with external digital elevation data, after that the deformation phase is obtained and be transfer into displacement and geocoded. The final result will be overlay on the maps then the movement area could be identified.
3. Study area and dataset

3.1. Study area

The study area located in the west mountain part of Sichuan province, P. R. China (Figure 2), the altitude is from 3000~4500m. The study area is within the subhumid climate zone. The temperature in the area was relatively high, the annual average temperature was 12~20 degrees, the annual difference was small, the diurnal range was large, the early and cold afternoon was warm, the seasons are not obvious, but the dry wet season was distinct. Precipitation is relatively small. There are less clouds and more sunny days. Most of the area are covered with short plant and the geological structure is complex. Most of the area belong to the Barkam geological division, and the narrow part of the southeast belongs to the Longmen mountain geological division. Rock formations are mainly composed of sand, black shale, sandstone, and igneous rock. The soil is dominated by dark brown soil, brown soil and brown soil.

The area located on the Longmen mountain seismic belt, it is one of the seismically active areas in China, and the body of most mountains are relative stable before 2008. However the Mw 8.3 Wenchuan earthquake occurred on May 12, 2008 strike this area, there are more than 100 thousand km² severely damaged areas, and a total of more than 10 counties located in the extremely heavy disaster areas. The big earthquake result in the loose of the mountain, and have brought abundance of source materials and will probably cause the landslide disaster once the rainfall. There are more than 10000 potential hazardous sites and hundreds of new unstable slope in this area. There happened a tragically landslide in MaoXian County 2017 and more than 100 people were buried and dead. Early warning and slope movement monitoring becomes a core issue in the field of landslide disaster prevention especially in rainy season.

3.2. Dataset

The Advanced Land Observing Satellite-2 (ALOS-2) is the successor of the ALOS, it was launched in May 2014 by Japan Aerospace Exploration Agency (JAXA) [12], with an orbit attitude about 628 km, the revisit time is 14 days, and the resolution of ALOS-2 has been improved to 1~3 m. The ALOS-2 SAR sensor has the same band with ALOS but with more powerful capabilities, it has several different modes such as “Strip Map mode”, “Spotlight mode” and can be used in different applications regardless of the time of day and whether conditions. The primary mission of ALOS-2 including monitoring disaster for safe life, tackling global-scale environment problems and supporting economic and food contribution. Especially compared with C and X band, the L band SAR data is more suitable in monitoring displacement in mountain and low correlation area.

To study the landslide area of the test site, we obtained three scenes which acquired in 2016 and 2017 (Table 1), the data format is Single Looking Complex (SLC), and the orbit direction is descending. the InSAR pair A has two images acquired in 2016/03/06 and 2016/03/20, with a short temporal baseline of 14 days and spatial baseline 140 m, while the InSAR pair B has two images acquired in 2016/03/20 and 2017/07/09, with a long temporal baseline of 476 days and spatial baseline 384 m.
Table 1. Dataset information.

| No. | Master image | Slave image | Spatial Baseline(m) | Temporal Baseline(d) |
|-----|--------------|-------------|---------------------|----------------------|
| A   | 2016/03/06   | 2016/03/20  | 140                 | 14                   |
| B   | 2016/03/20   | 2017/07/09  | -384                | 476                  |

4. Results analysis and discussion

The SAR SLC dataset are processed with InSAR processing flow. The SAR sensor take images of the targets in slant and azimuth direction, for the altitude varies largely in the study site there are obvious layover and foreshorten phenomena in the SAR magnitude image (Figure 3). It also shows that the ridges of the mountain is inclined to the sensor in SAR image coordination system, and has large backscatter than other area, anyhow these areas are difficult to obtain the real phase information since phase information from many different targets are mixed.

![Figure 4. Interferogram of InSAR pair A. Colorbar range in (-\(\pi\), \(\pi\)).](image1)

![Figure 5. Interferogram of InSAR pair B. Colorbar range in (-\(\pi\), \(\pi\)).](image2)

Figure 4 and Figure 5 are the interferograms of two InSAR pairs. The figures show that the InSAR pair A has much higher coherence than InSAR pair B, especially on the high altitude area, this corresponding to the criteria that the longer temporal and spatial baseline, the lower coherence. And due to the topography change in a large extent, the coregistration errors are not uniform, this phenomena has been found in many other area.

![Figure 3. Layover and foreshorten phenomena in SAR magnitude image.](image3)

After remove the flat earth phase and topography phase with SRTM data, the deformation maps are obtained and then geocoded. Figure 6 and figure 7 show the geocoded displace map of these two InSAR pairs, obviously the layover and foreshorten part on the SLC image in SAR coordination system is extended on geocoded image but we obtain no information as we mentioned before.

Although both Figure 6 and Figure 7 are deformation maps. There are obviously differences between them. Firstly the phase noise is lower of the InSAR pair A since it has short temporal baseline and small spatial baseline. For the InSAR pair A has a temporal baseline about 14 days, and one cycle of the colormap corresponding with 1.1 cm, and the equivalent displacement velocity is about 28.6 cm per year.

![Figure 6. Deformation map of InSAR pair A.](image4)

![Figure 7. Deformation map of InSAR pair B.](image5)

There are three evident displacement phase centre on the figure 6, the largest displacement of the slopes is larger than 50 cm per year, the displacement phase centres 1 and 2 on Figure 6 are zoomed and displayed in Figure 8, clear phase fringes could be seem in Figure 8 from blue to yellow. Anyhow, these displacement centre could not be identified on the figure 7 which has longer spatial baseline and large temporal baseline, since the displacement will be quite large with a period of one year and the phase is wrapped seriously, then the fringe of the phase will be destroyed, but we could see that there has other kind of displacement phenomena on Figure 7, the equivalent displacement velocity is within...
10 cm per year, these displace phase centre could be identified on Figure 7 quite well. Figure 9 show the zoomed area of the displacement phase centres 1 and 2 on Figure 7, we could only see small velocity signal on it.

Table 2 gives the longitude, latitude, the area and the equivalent velocity of six clearly identified moving slope, we could see that both group A and B has slopes with different size and velocity, whereas the slope B0, B1 and B2 has small moving velocity, and the summation displacement of these three sites will be very small during 14 days, that’s why we could not see them from figure 6.
5. Conclusions
Landslide movement is precursor of landslide hazard, and it is important to map the distribution of the movement for local government. Anyhow the movement of the landslides have different behaviour, some of them move slowly while others move quickly, these demand a combination monitoring with InSAR pairs. In this paper we used two pairs of ALOS-2 SAR data to monitoring the landslide area in south China, the results show that with difference baseline the detection capability and advantages are different, the longer temporal baseline the small velocity moving slope could be identified, while with small temporal baseline the quick moving slope could be clear identified, with the combination both slow and quick movement of the landslides can be identified. In the future more data will be acquired and the time series SAR interferometry will be used to compare with the InSAR results. Meanwhile we could see that there is only small area could be monitoring with satellite SAR sensors, we wish the future Moon-based InSAR could provide large coverage and large area monitoring capability.

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