LAND SUBSIDENCE MONITORING BY USING PSI WITH ASCENDING- AND DESCENDING- ORBIT SATELLITE IMAGES

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ABSTRACT: The land subsidence has been a global serious problem due to climate change and ground water extraction, and the inexpensive land subsidence monitoring technique is highly required. Persistent Scatterers Interferometry (PSI) is the land subsidence measurement method by using multi-temporal synthetic aperture radar (SAR) images, and it can accurately measure wide range of land subsidence. However, the estimated displacement is obtained only along the radar line-of-sight (LOS) direction. Therefore, it is expected to develop a method for measuring three dimensional (3D) displacements by combining multi-directional observation. In this work, we examine the fusion of the displacement results from SAR images observed on ascending- and descending-orbits. First, we estimate the displacement from the ascending- and descending-orbit SAR images, individually. Then, the vertical and horizontal land subsidence components are estimated from the two results. In experiments, we selected Kansai International Airport, located in the western Japan, as a study area because it is reported to show both vertical and horizontal displacements. We used 24 ALOS-PALSAR ascending images from 2006 to 2010 and 14 ALOS-PALSAR descending images from 2006 to 2010. We compared with the annual leveling data the vertical displacement estimated from the ascending-descending combination. The root mean squared error (RMSE) of the velocities by ascending-descending combination analysis was 0.015 m/year. Further investigation is necessary to match pixels that represent the identical location among ascending- and descending- orbit SAR images, and to validate the estimated horizontal displacement.

1. INTRODUCTION

The land subsidence has been a global serious problem due to climate change and ground water extraction, and the inexpensive land subsidence monitoring technique is highly required. Persistent Scatterers Interferometry (PSI) (Ferretti et al., 2000) is the land subsidence measurement method by using multi-temporal synthetic aperture radar (SAR) images, and it can accurately measure wide range of land subsidence. However, the estimated displacement is obtained only along the radar line-of-sight (LOS) direction. Therefore, it is expected to develop a method for measuring three dimensional (3D) displacements by combining multi-directional observation.

In this work, we examine the fusion of the displacement results from SAR images observed on ascending- and descending-orbits. First, we estimate the displacement from the ascending- and descending-orbit SAR images, individually. Then, the vertical and horizontal land subsidence components are estimated from the two results.

This paper is organized as follows. In Section 2 is the study area and data used. The method to estimate land subsidence in Kansai International Airport are described in Section 3. The used method is mainly composed of two parts, PSI processing part and combination part of the both estimated deformation results. The results are shown in Section 4. In Section 5, the validity of the estimated results is discussed. Finally, this paper is concluded in Section 6.

2. STUDY AREA AND DATA USED

We selected Kansai International Airport (KIX), located in the western Japan, as a study area. It is reported that KIX has been suffering from land subsidence. KIX has two islands. In 2015, the subsidence velocities of Islands I and II were 6 cm and 34 cm, respectively.

In this research, we used 24 Advanced Land Observing Satellite (ALOS)/Phased Array type L-band SAR (PALSAR) level 1.1 (L1.1) images from November 2007 to December 2010 on the ascending orbit and 14 ALOS/PALSAR images from November 2007 to December 2010 on the descending orbit. We also used the Digital Map 5m Grid (Elevation) published by Geospatial Information Authority of Japan to remove the effect of topography. We analyzed only Island I, and the area of the scene is shown in Figure 1. For the validation of the land subsidence results, we used 17 leveling stations, shown by filled circles in Figure 1, measured by Kansai Airports in annual leveling survey.

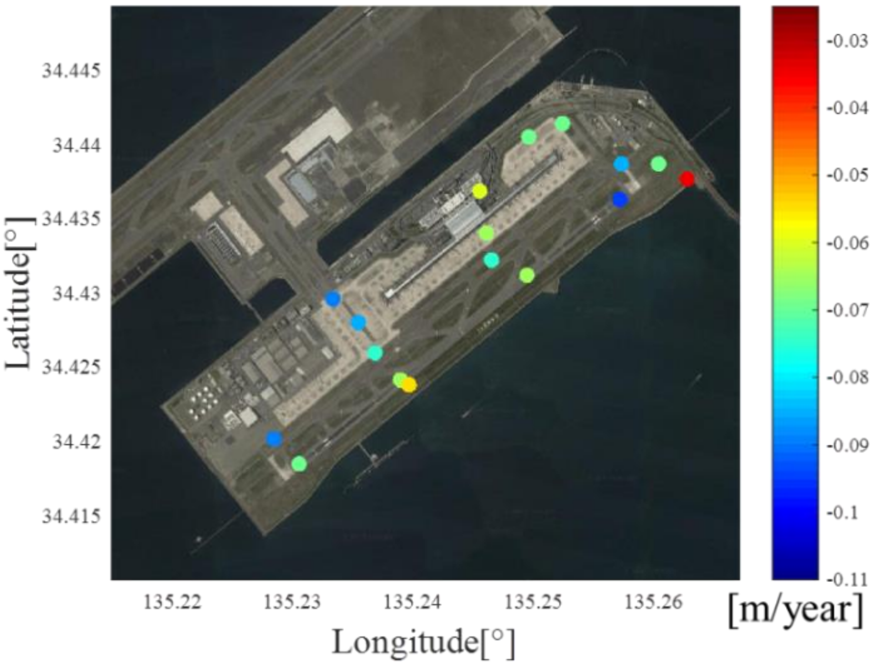


Figure 1. Study area, Kansai International Airport from Google Earth image. The points represent leveling point, and the colors of the points correspond to leveling values.

3. Method

In this section, we describe the used method to estimate the vertical and horizontal land subsidence in Kansai International Airport. Figure 2 shows the flowchart of the used algorithm. We estimate the displacement from the 24 ascending-orbit SAR images and 14 descending-orbit SAR images by PSI, individually. Then, the vertical and horizontal land subsidence components are estimated from the two results.

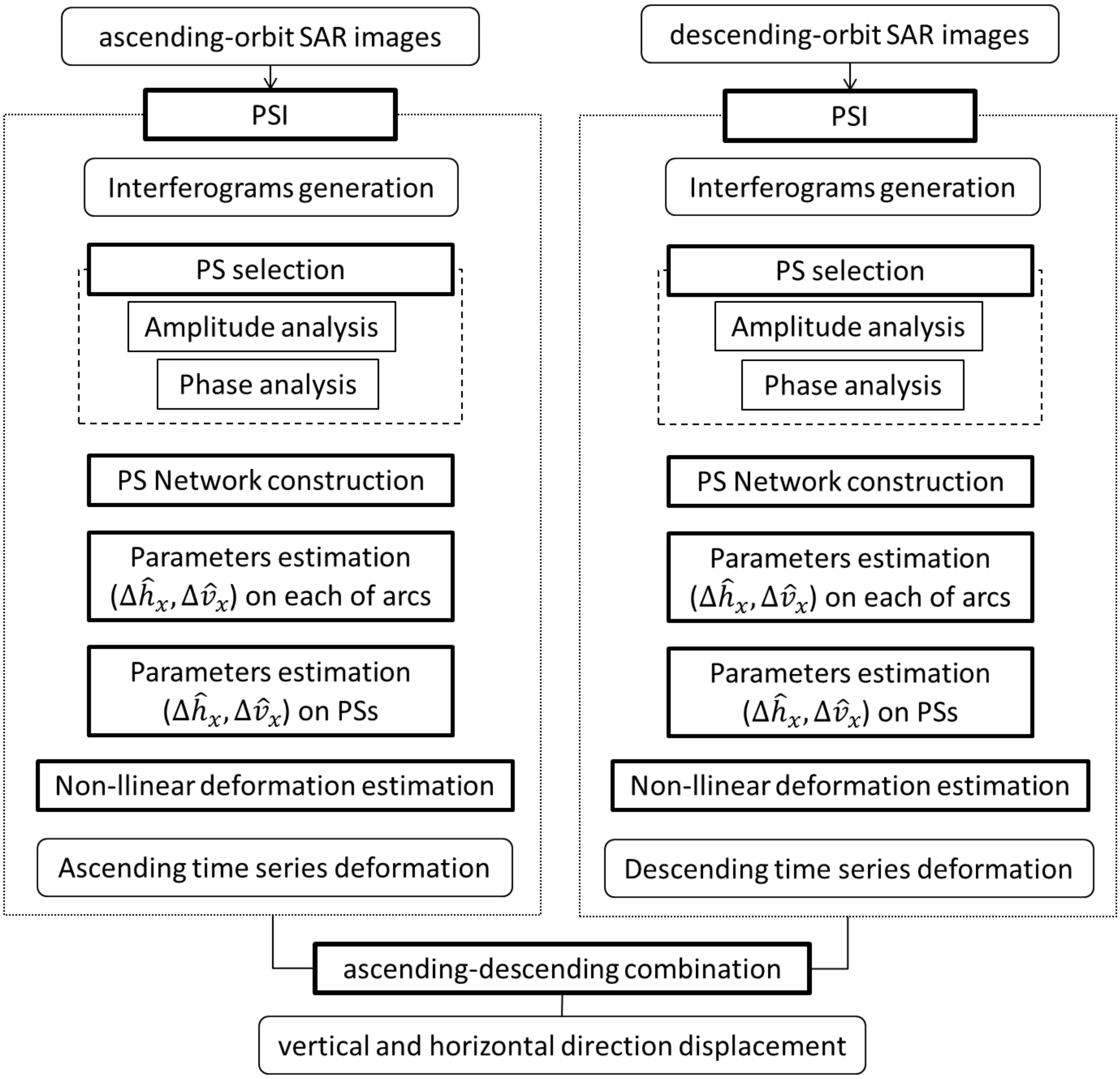


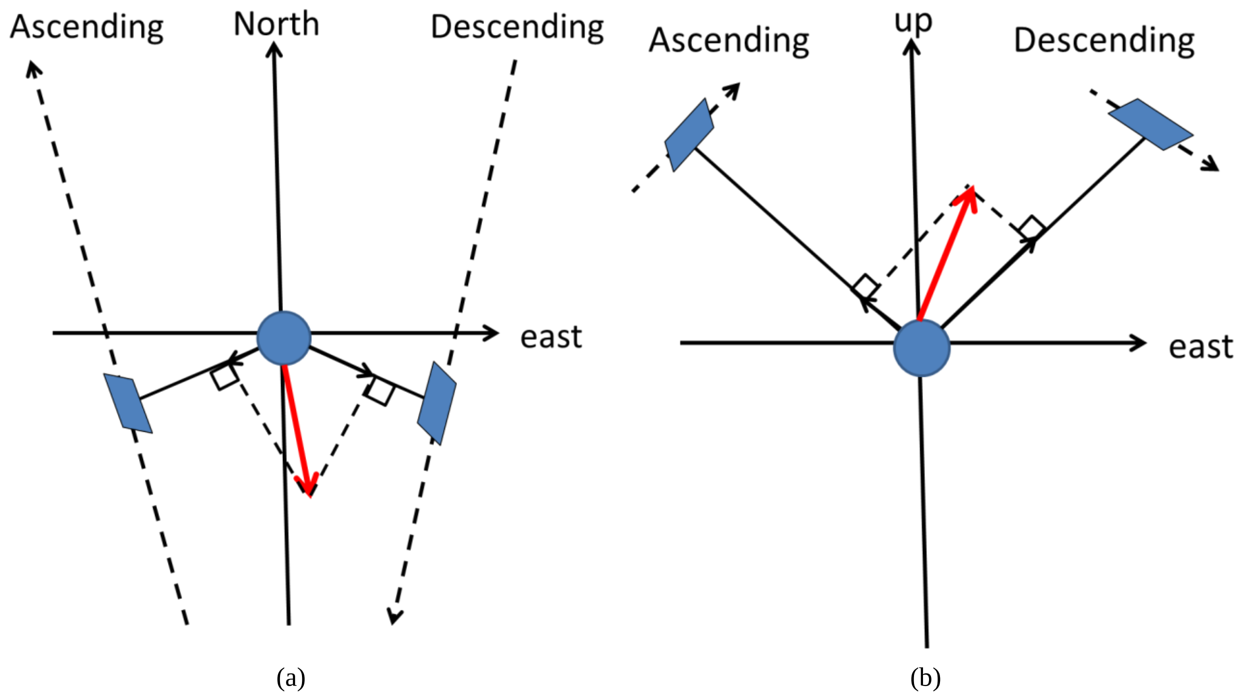
Figure 2. Flowchart of the used algorithm

3.1 PSI

PSInSAR selects PSs that are phase-stable pixels and reduce the main errors such as temporal and geometrical decorrelation and atmospheric artifacts in conventional processing methods by using only PSs. In this research, we generated 23 interferograms based on January 2009 data as the ascending master image and 13 interferograms based on November 2009 data as the descending master image, respectively. We referred to Maruo et al., 2016 for the PSI method. In this method, by conducting not only amplitude analysis but also phase analysis proposed by Hooper et al., 2007 for the PSCs selection, we can select reliable PS in small number of SAR images.

3.2 Ascending-descending combining

In this work, we referred to 2.5-D deformation analysis (Fujiwara et al., 2000) for the approach of ascending-descending combination. 2.5-D deformation analysis is a method to combine displacements observed along two LOS vectors and divide the displacement to vertical and horizontal land subsidence components. Notably, the vertical and horizontal displacement is two-dimensional displacement parallel to one plane spanned by the two vectors. The vertical displacement inclines by the angle 85° with the elevation and in this paper we regard it as a vertical displacement. In addition, in ascending-descending combination, we usually divide only pixels in which the ascending and descending results are present. However, there are not such pixels because of effect of projective transformation parameters in geocoding and difference of the resolution of a SAR image. Thus, in this work we merge ascending result point with the nearest descending point within 100 m.



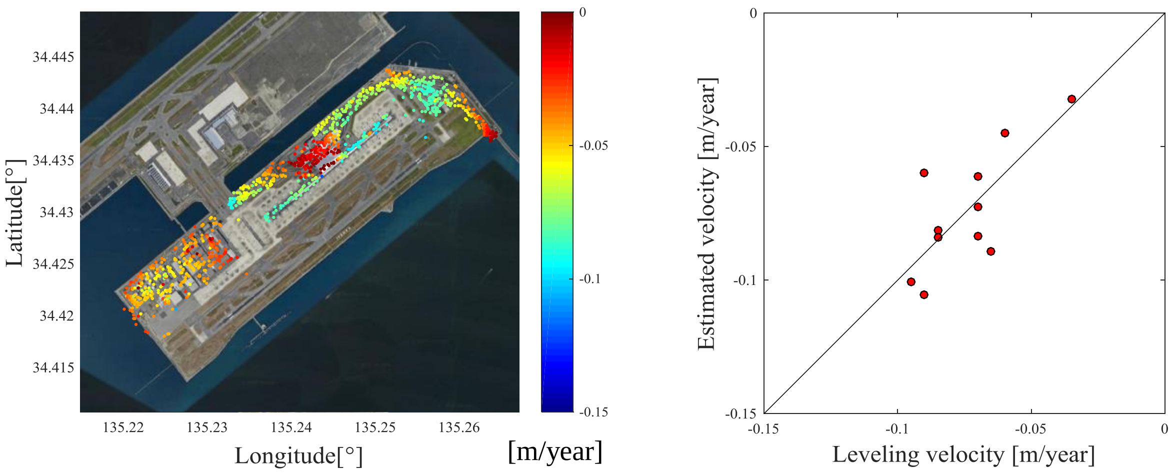
(a) (b)

Figure 3. Observation from ascending-orbit and descending-orbit. The red arrows represent real displacement, and the black arrows represent the displacement observed along the line-of-sight. (a) A ground plan, and (b) an elevation

4. RESULT

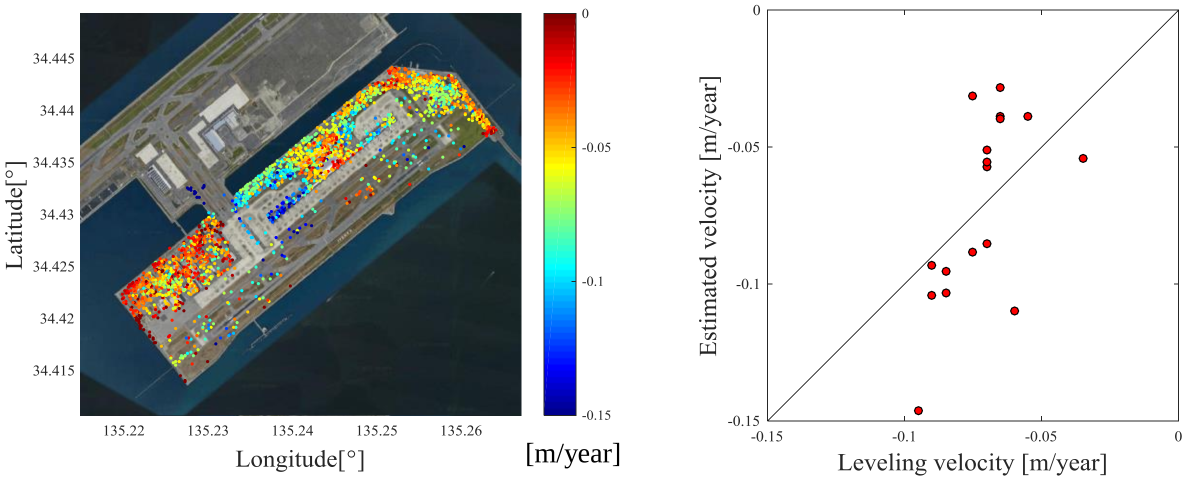
First, Figure 4(a) show the velocity field in a vertical direction in m/year, estimated by PSI technique with ascending-orbit data at Kansai Airport, and Figure 5(a) show the result estimated with descending-orbit data, respectively. The ascending result showed that the deformation rates ranging was different between -0.12 m/year (subsiding) and 0.036 m/year (uplifting), and the descending result showed that the deformation rates ranging was different between -0.37 m/year (subsiding) and 0.073 m/year (uplifting). We compared deformation velocity of the nearest PS point and the leveling data measured by Kansai Airports in annual leveling survey to validate the result of PSI. Note that the estimated displacement is obtained only along the radar line-of-sight (LOS) direction, thus in comparison with the leveling data we used the displacement divided by cosine as the vertical displacement, assuming that the horizontal displacement is zero. Figure 4(b) and, 5(b) shows the ascending and descending PSI estimation vs. leveling data, respectively. The accuracy of the ascending PSI compared with 11 leveling station was the root mean squared error (RMSE) of 0.014 m/year, and the accuracy of the descending PSI compared with 17 leveling station was the RMSE of 0.027 m/year.

Then, Figure 6(a) show the velocity field in a vertical direction in m/year, estimated from ascending-descending combination at Kansai Airport. The 2.5-D analysis result showed that the deformation rates ranging was different between -0.18 m/year (subsiding) and 0.032 m/year (uplifting). We also validated the result of 2.5-D analysis in the same method as mentioned above. Figure 6(b) shows the 2.5-D analysis estimation vs. leveling data. The accuracy of the ascending-descending combination compared with 7 leveling station was the RMSE of 0.015 m/year.



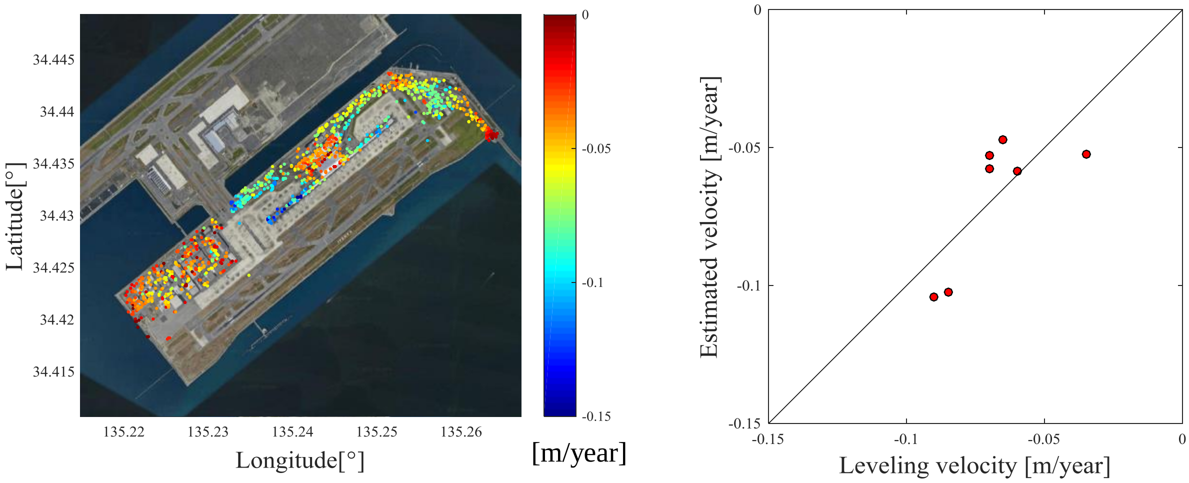
(a) (b)

Figure 4. Velocities estimated from ascending data. (a) Mean velocity field in m/year, estimated by PSInSAR technique, and (b) validation result with leveling surveying data.



(a) (b)

Figure 5. Velocities estimated from descending data. (a) Mean velocity field in m/year, estimated by PSInSAR technique, and (b) validation result with leveling surveying data.



(a) (b)

Figure 6. Results of 2.5-D analysis. (a) Mean velocity field in m/year, estimated from ascending-descending combination, and (b) validation result with leveling surveying data.

5. DISCUSSION

The RMSE of the velocities estimated from ascending data was 0.014 m/year and the RMSE of the velocities estimated from descending data was 0.027 m/year. Thus, the accuracy of ascending result was better than that of descending result. In addition, the result of the ascending-descending combination showed the same tendency as the leveling data, and the RMSE was 0.015 m/year. It has demonstrated the reliability of the result for the estimation of land surface estimation.

On the other hand, the RMSE of the vertical result estimated by the ascending-descending combination was 0.001 m/year bigger than the RMSE of ascending result calculated assuming that the horizontal displacement is zero. Main reasons for this can be considered as follows. Firstly, the reason may be mainly due to the low accuracy of the descending result, because the vertical and horizontal land subsidence components are estimated from the ascending and descending result. In this study, ascending analysis used 24 images and descending analysis used 14 images. As a result, the accuracy of the descending analysis can be wrong. Secondly, matching pixels in proceeding of ascending-descending combination may be wrong. Although in this work we merge ascending result point with the nearest descending point within 100 m, we may match pixels that represent the wrong location among ascending- and descending- orbit SAR images. In the comparison with the annual leveling data, we also may compare different scatterers with leveling point.

6. CONCLUSION

In this work, we estimated the vertical and horizontal land subsidence components in Kansai International Airport from the ascending and descending results estimated by PSI. As a result, we compared with the annual leveling data the vertical displacement estimated from the ascending-descending combination. The RMSE was 0.015 m/year and it has demonstrated the reliability of the result. Further investigation is necessary to improve the accuracy of PSI with the descending-orbit data, match pixels that represent the identical location among ascending- and descending- orbit SAR images, and to validate the estimated horizontal displacement.

7. REFERENCE

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