General Responses

We appreciate all reviewer's helpful comments to acknowledge our weakness especially regarding description of InSAR processing and consequent logical deployment. We concentrated to enhance involved contexts.

Those few need to be identified first.

1) Ascending mode time series observations of Sentinel-1 do not exist (refer attached Fig. 1). Therefore, we can't apply combined interpretations of ascending & descending mode such as horizontal/vertical decompositions. Together with expected weak surface deformations by lava tube collapse, the absence of ascending mode time series data leads us to adopt a sort of data fusion for focusing the candidate of LTDPs among many PS observations, i.e., ML approach together with NSBAS as stated in 2). We identified absence of ascending mode in text.

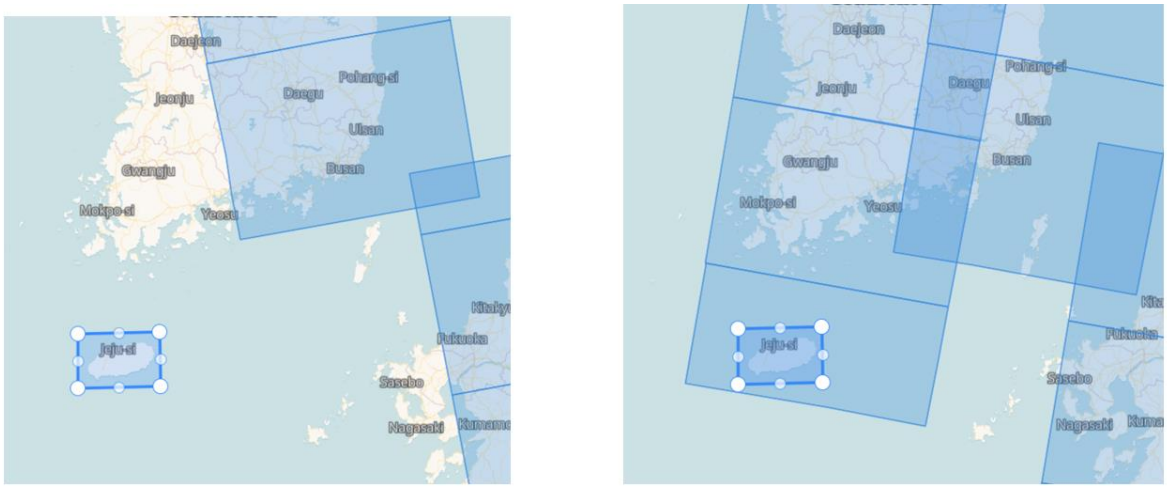


Fig. 1

2) Therefore, we needed to find a way to classify suspicious LTDPs among only descending PS observations. As all reviewers appointed out, the estimated deformation signals by PS analysis are weak and the ascending mode are absent. The employment of NSBAS was for searching aligned LTDP on specific background deformations; thus NSBAS was not used for LTDP detection directly but for the regional classification of LTDP. Spatial analysis and ML applications played the same role too. Therefore the data processing flow can be described as attached Fig. 2.

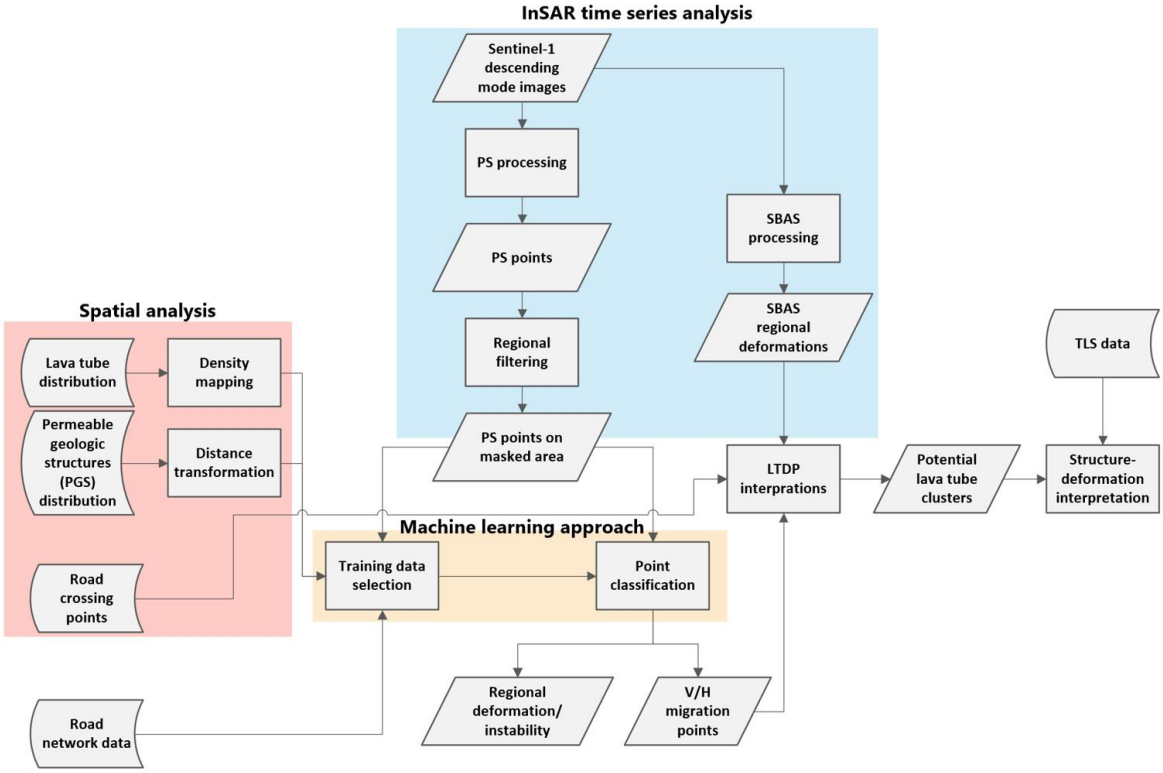
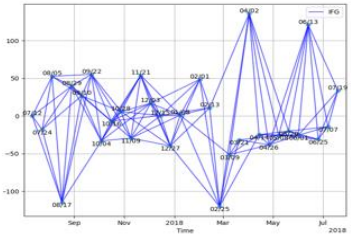


Fig. 2

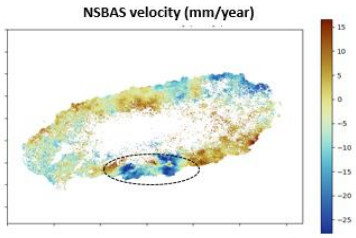
3) In the previous draft, we used only few InSAR pair for NSBAS analyses for the definition of regional deformation. Herein we took the reviewers advice and re-established new NSBAS networks in overlapped period with PS analysis (see attached Fig. 3 (a)). The extracted NSBAS deformation maps have improved 30 by 30 meters resolution. The observations in new NSBAS results are as bellows

- The results are quite different according to the NSBAS processing parameter settings (attached Fig. 3 (b), (c) and (g)). The more strict criteria (higher loop threshold and phase coherence) of error filtering, the more similar SBAS outcomes to PS (attached Fig. 3 (f)) in the deformation point distribution and patterns.

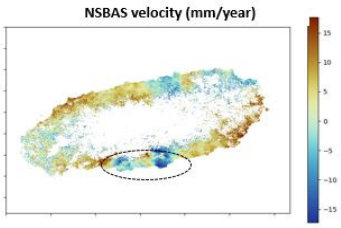
- We propose NSBAS results employed in this approach represents the regional deformations. For instance, the regional deformation in Seogwipo sediments induced by the loading of heavy construction were well defined in NSBAS results (ellipse part in attached Fig. 3). Thus it can be used to classify the candidate LTDPs. In the same manner, the LTDPs were bounded spatially over NSBAS regional deformations and interpreted accordingly as shown in Figure 8 (in draft). Application of ML algorithm can be more stably established in the pre-filtered candidates by NSBAS and spatial analysis mask. The concept of this approaches are now more clearly summarized in the modified figures and text in section 3.



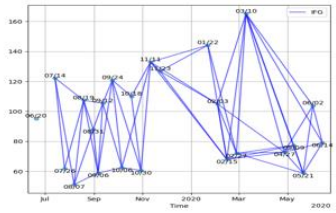
(a) Connection graph for NSBAS 2017/07-2018/07



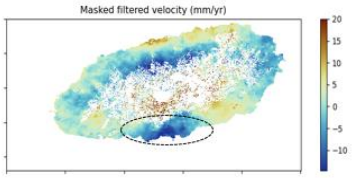
(b) Loop th 1.5, phase coh 0.25 (2017/07-2018/07)



(c) Loop th 1.8, phase coh 0.35 (2017/07-2018/07)



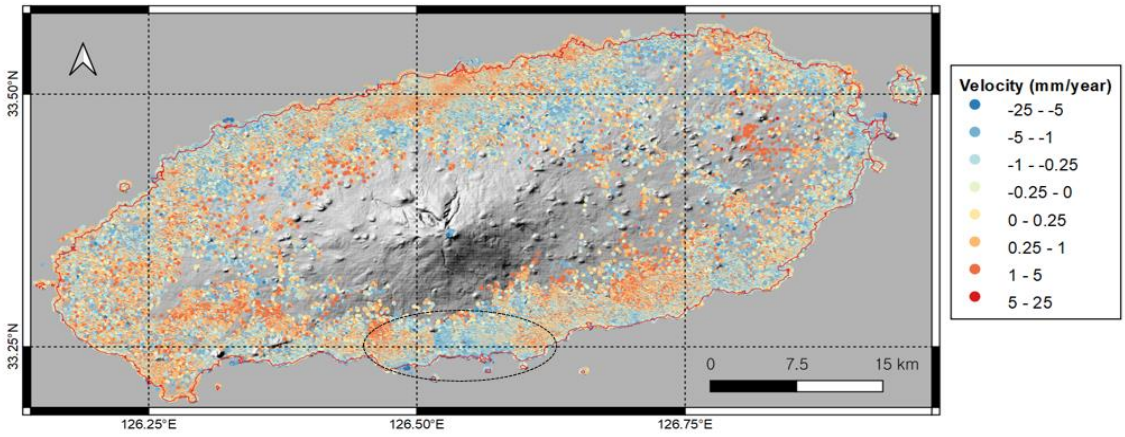
(d) Connection graph for NSBAS 2019/06-2020/06 Complementary processing for the inter-comparison



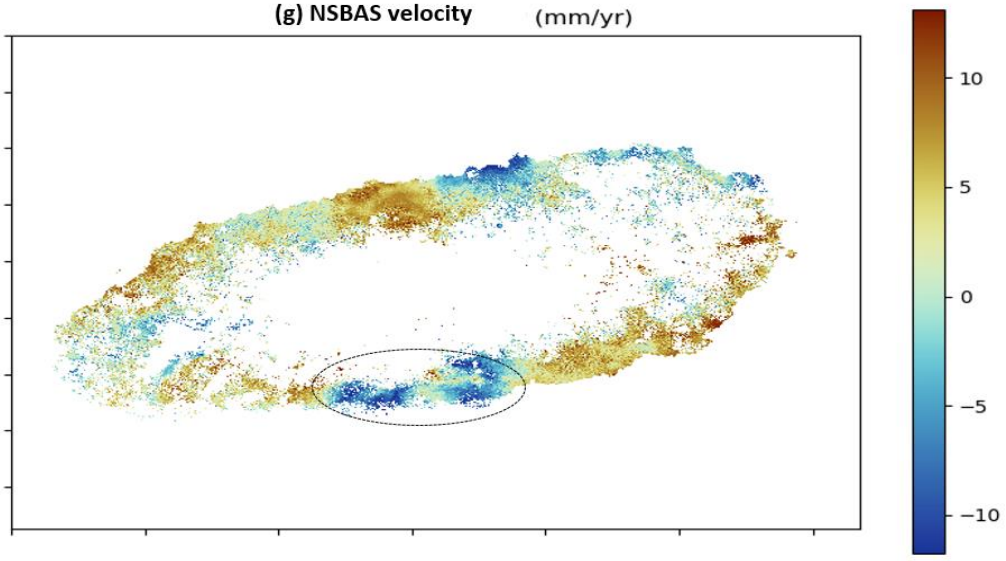
(e) Loop th 1.5, phase coh 0.35 (2019/06-2020/06)

Segwipo city areas

(f) PS velocity



(g) NSBAS velocity (mm/yr)



NSBAS results Loop th 2, phase coh 0.45 (2017/07-2018/07)

Fig. 3

4) All laser scanning tasks were completed in 2015 by a private company by the contact with the local government and delivered to the Korean Speleological Society for the academic studies. However, we found the laser data have those problems

   - Missing of meta data
   - Georeferencing accuracy was very poor; it doesn't fit to known ground landmarks
   - Large number of height points have data faults

   Originally we intended to use laser scanning data on road crossing points and to model brittle deformation with laser 3D point over there. Then we could make an inter-comparison between the modelled deformation and InSAR observations. However, due to the above problems, our laser applications were limited only for shape analysis to roughly estimate deformation as shown in L.550-555 and Figure 9 (in draft). We have searched original laser scanning file but failed to trace. Thus we only can introduce some detailed of laser scanning data in section 2.2 of revised draft. At this moment it is all we can do.

5) We propose to re-write the draft including above context –

   1. Introduction
   2. Test sites and data sets
      2.1 Geological background
         (1) The section is fully rewritten as the first and second reviewers suggested to be involved precedent studies.
         (2) New figure (Figure 1 (c) in revised draft) is appended to demonstrate the places of target lave tubes and their photos.
         (3) Text is checked by a geologists who has background in lava geomorphology.
      2.2 Data sets
         (1) More description of TSL and new NSBAS data sets.
   3. Methods
         (1) Two data processing flow charts (overall and InSAR processing flow) are appended.
         (2) InSAR processing flow is shown with exemplary case and detailed background as the reviewer suggested.
   4. Results
      4.1 Spatial analysis of lava tube distribution
      4.2 InSAR processing
         (1) All InSAR processing results is concentrated in this section.
         (2) NSBAS/PS comparison centered on Seogwipo is introduced.
   5. Interpretation and discussion
   6. Conclusion

All other proposed revisions considering the reviewer's comments are listed as below

==========

The manuscript presents an original application of a number of combined methods including

InSAR, machine learning, field mapping, spatial analysis. I think it's a good job but it needs to be presented properly. It is written in a confusing way, I had a lot of difficulty reading the different parts of the text. The geological background is very poorly written and the presentation of the data is confusing and further complicated by an excess of acronyms.

I recommend two things: 1) a good revision of English, and

Answer:
The revised draft will be applied to rigorous proofreading, once after revision is accepted.

2) A rereading done by people other than the authors who can help simplify the text.

Answer:
A geologist who has specialty in lava geomorphology conducted additional proofreading.

For the rest, I think it is a really very interesting job and that it can have a good result in terms of audience. Attached you will find a pdf with the main comments.

Answer:
We very much appreciate for reviewer's comments and encouragement. In follows, we addressed reviewer's comments.

Comments noted in the pdf file:

L17 : In this study the overall distribution of the Jeju lava tube network and the potential collapsing risk have been investigated.

Answer : Corrected as suggested.

L19 : lava flow unit

Answer : Corrected as suggested.

L 20 : The risk is always linked to the presence of anthropogenic constructions. Perhaps you meant that the presence of artificial artifacts, causing the load on the lava flows, can induce to collapse.

Answer:
Proposed to be changed "Secondly, the risk of collapse is high especially when heavy loads are applied by artificial structures around the undisclosed lava tube network."

L40 : it is not very clear what you mean

Answer : Delete "induced in deformation mode"

L 50 : The more than 200 lava tubes distributed on an area of 1850 km2 in Jeju are up to 4-11 km long lava, showing a large variety of cave structures presenting all sorts of development stages (Son, 2019).

Answer : Corrected as suggested.

L57 : I would use the term “critical: or “danagerous”

Answer: Corrected as suggested.

L71 : There are conflicting theories about the origin of volcanism on Jeju Island. One theory interprets the entire island as a shield volcano (Kim and Choi, 2012), while another suggests that it is a basaltic volcanic field (Brenna et al., 2011; Brenna et al., 2012a; Brenna et al., al., 2012b)

Answer : Corrected as suggested.

L80 : The alkali-basalts lava effusion on land started about 1 Ma years ago and continued until Holocene (Koh et al. 2008; Koh and Park 2010b; Koh and Park 2010a)

Answer : Corrected as suggested.

L 82 : I don't understand what you mean, I would ask you to reformulate the sentence.

it's all very confusing. Also, perhaps such a thorough detail does not even serve much to this study, I would focus on the effusive activity that you will generate tubes and write just a few sentences about the previous geological evolution.

Answer : All above corrections were done as the reviewer suggested. The text was simplified as “The geologic structure indicated that the activity of alkali basaltic lava effusion started about 1 Ma years ago and continued until Holocene (Koh et al. 2008; Koh and Park 2010b; Koh and Park, 2010a)”

L 91 : I would insert some pictures with photos of the lava tubes. I would introduce modify figure 1 by inserting photos and some pie diagrams showing the distribution of the different tubes.

Answer : Figure 1 (c) is now appended to show the places and their photos in major lava tube which were used in our study.

L 132 : please add the website

Answer : Web address (https://scihub.copernicus.eu/) is now appended.

L 141 : Please add references related to PS and SBAS

Answer : Corrected including the reference reviewer suggested.

L 173 : I would also introduce it in the geological background

Answer : Corrected.

L 194 : please consider also:

Answer : Blue fronted references are now appended to introduce SBAS technique.

Casu, F., Manconi, A. (2016). Four-dimensional surface evolution of active rifting from spaceborne SAR data, Geosphere, 2016, doi: 10.1130/GES01225.1

Casu F, Manzo M, Lanari R (2006) A quantitative assessment of the SBAS algorithm performance for surface deformation retrieval from DInSAR data. Remote Sens. Environ. 102(3–4): 195–210

Casu, F., Elefante, S., Imperatore, P., Zinno, I., Manunta, M., De Luca, C., & Lanari, R. (2014). SBAS-DInSAR parallel processing for deformation time-series computation. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 7(8), 3285-3296.

Casu, F., Manconi, A., Pepe, A., & Lanari, R. (2011). Deformation time-series generation in areas characterized by large displacement dynamics: The SAR amplitude pixel-offset SBAS technique. IEEE Transactions on Geoscience and Remote Sensing, 49(7), 2752-2763.

De Luca C., Zinno I., Manunta M., Lanari R., and Casu F. (2017). Large areas surface deformation analysis through a cloud computing P-SBAS approach for massive processing of DInSAR time series, Remote Sens. Environ., vol. 202, pp. 3–17, Dec. 2017.

Lanari R, Mora O, Manunta M, Mallorquí JJ, Berardino P, Sansosti E (2004a) A small baseline approach for investigating deformations on full resolution differential SAR interferograms. IEEE Trans Geosci Remote Sens. 42:1377–1386

Lanari, R., Lundgren, P., Manzo, M., Casu, F. (2004b) Satellite radar interferometry time series analysis of surface deformation for Los Angeles, California. Geophys Res. Lett. 31(23):L23 613–1–L23 613–5.

All references listed below were cited in the text.

L 300 : I didn't understand why you only used one orbit. By combining asc and desc you would have avoided this assumption that they will also be true but that they decrease the quality of the article.

Answer : Ascending mode time series observations of Sentinel-1 do not exist. Therefore, we can’t apply combined interpretations of ascending & descending mode such as horizontal/vertical decompositions.

Please refer to (1) and (2) in the general comments.