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Natural Hazards and Earth System Sciences
Discussions

Interactive comment on "Quaternary lava tubes distribution in Jeju Island and their potential deformation risks" *by* Jungrack Kim et al.

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(Please use attached supplement rather than this comment form as the figure are nor clearly demonstrated)

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.

(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.

(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.

(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 intercomparison 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

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The manuscript by Kim et al. presents an original application of various and current methods as such InSAR, machine learning, and field data. The objective is clear and particularly interesting for several readerships ranging from Earth observation to spatial exploration. I am enthusiastic about the possible applications and the estimation of risks on Jeju Island. The choice of Jeju Island is ideal for this study allowing the identification of many targets (lave tubes), supported by robust previous studies.

Answer : We appreciate the reviewer's useful comments. We tried to address the reviewer's concerns as below.

(1) However, the excepted signals should be low or spontaneous, such as loading effects and/or brittle deformation. The InSAR observation is therefore adequate (spatial/temporal revolution) and the application of both methods (PS/SBAS) allows to have a cross-validation of results, needed on low signals.

Answer : Agree. We expected the brittle deformation over lava tube is only a few mm

level and PS results fit on such hypothesis. In this manuscript, our point to employ PS together with SBAS (NSBAS) is not for cross-validations, but to scoop potential LTDPs by bounding them along with regional deformation of NSBAS. Please see (3) in the general comment and other involved discussion bellows, especially in (13).

(2) The organization of the manuscript is missing: for example, the 3.2 section contains results and methods. Overall, the results and methods are mixed in sections. So, I recommend completely restructuring the manuscript using simple sections (geological context/method/results/discussion/conclusion).

Answer : We reconstructed the structure as we stated in (5) of the general comments.

(3) The core of this manuscript is InSAR method, and I am unable to understand the used methods from the text. For example, I did not understand the compensation of orbital errors and why to use this substraction: (line 253). I think the InSAR section needs many improvements adding the accurate workflow (my main questions concern InSAR and PS/SBAS processors, used DEM, used orbital files, the processing parameters, etc)

Answer : The procedure of time series analysis is now summarized as the processing flow chart and involved texts. We also append an exemplary case over Seogwipo city where the regional subsidence is obvious together with flow chart to help readers to understand. The description to orbital error correction is quite important because otherwise NSBAS will have significant orbital ramp. It's based on network deramping algorithm implemented in GiANT (Generic InSAR Analysis Toolbox) .We now describe more details of orbital error correction part with a few more references (Biggs et al. 2007; Cavalie et al. 2008; Lin et al. 2010; Jolivet et al. 2012). DEM, orbital file, processing parameter were also descried in section 3.2 in depth.

(4) Why are there two periods for PS and SBAS? Why are the ascending data not used?

Answer : Due to the processing load of SBAS, we only constructed small temporal period of PS to SBAS in previously draft. Now we extend SBAS processing comparable temporal period (2017/06-2018/08). Thus the exaggeration of deformation in NSBAS were corrected in our new outcomes. Full SBAS processing 2016 to 2018 (about 700 pairs) was quite impossible due to the system load of CPU resources.

(5) Specifically, some descriptions in the manuscript are wrong: line 130, the optimal data set is defined as being Sentinel-1, this is only true for this study; line 134: there is a shortest revisiting time than Sentinel- 1. line 134: the adjective "unique" is used to describe the IW mode while the StripMap mode is available.

Answer : Those mistakes will be corrected (revisiting time= 6 days).

(6) Moreover, I am not convinced by the use of SBAS: the SBAS processing allows to increase the spatial resolution of results, by adding some source of uncertainties (e.g. multilooking) and other issues currently discussed in the literature, (e.g. bias). My recommendation is a proofreading by an InSAR specialist to rewrite the method sections and correct errors. For the SBAS, I recommend extending the network and using more interferograms.

Answer : The biggest merit of SBAS for this study is the densification of observations compare to PS. In particular, we employed NSBAS rather than SBAS which allow the inversion of disconnected observations, thus the point density of NSBAS is maximized and the regional deformation measurements is derived. In comparison to NSBAS, the measurements of PS likely are over scatterers such as natural rocky objects and sparely populated artificial structures, considering the surface geomorphology over Jeju island. If those scatterers exist on the top of brittle in-stabilities over lava tube, it will be LTDPs. Therefore we claim that NSBAS and PS observations have different natures and usages as we explained in the general comments and flow chart (attached Fig. 2). This base will be also updated in the draft clearly.

Also please see our base regarding Seogwipo city's deformation in answer (13).

Moreover, NSBAS processing is updated with new interferogram networks, thus the analyses described in the figure will be more robust.

(7) Finally, I can propose to add the ascending data even if the island is not fully covered.

Answer : Ascending mode time series observations of Sentinel-1 do not exist. .

(8) This addition should improve the machine learning results without strong assumptions about the displacement components.

Answer : We interpreted “the machine learning results without strong assumptions about the displacement components “ as unsupervised processing. However, it doesn’t present any meaningful outcomes to distinguish LTDP. At the moment, we proposed that machine learning approaches trained by the spatial analysis and geological context is the best.

(9) The method of spatial analysis of lava tube distributions is also not clear for me. The uses of kriging and interpolations require to have assumptions concerning the spatial evolution of the variables and nothing allows me to verify these hypotheses.

Answer : We disagree. The data sets of Sumgol distribution we applied kriging were extracted with intensive survey. So there are no spatial distortions that require detailed modeling of variables. Kriging is just introduced as gridding method because it doesn’t make triangular artifacts. Natural Neighbor or other methods produced similar products. Thus we claim ordinary kriging is sufficient enough for the purpose of this study.

(10) Laser scanning methods are not described and are seldom used in the manuscript.

Answer : Please see (4) in the response to general comment.

(11) All the figures of results are difficult to read. The units of maps are missing, and the legends are not complete.

Answer : Those component are corrected.

(12) Firstly, a modification of color scales is mandatory to allow a good visualisation of displacements.

Answer : Those component are corrected.

(13) However, the LOS velocities from PS results are low< 1 mm/yr and therefore less than uncertainties.

Answer : First of all, color range of Figure 4 PS result was re-controlled to distinguished high deformation points as shown in attached Fig. 3 (f) of general comment. In fact, the deformations of LTDP over road crossing points are not that small (please see Figure 7) which were used as training vector of ML. On the contrary, we have known that Jeju island has no known big deformation sources except Seogwipo city, so please note that velocity of PS should be very small. Thus the overall very small deformation values in Figure 4 is as we expected, and the robust of PS analysis was proved. It means the deformation can be few mm/year or more. The major issue is how we can distinguish LTDP among many PS points which do not have strong deviations. It’s why we introduce ML and bounds by NSBAS regional deformation patterns.

(14) But most noticeable is the difference between the PS and SBAS results. Even though the observation periods are different, I presume a similarity between the PS and SBAS results but the SBAS map shows velocities between <-10 mm/yr and > 10 mm/yr on a period covered by PS results. These transitory signals would be visible on time-series, but it is not clear. I recommend to propose a real comparison between PS and SBAS results, on a single figure for example.

Answer : Now you can see improved PS and NSBAS presentation in attached Fig. 3 (f) and (g). In new NSBAS results, we introduce more interferogram pairs, the deformation range of PS and NSBAS become closer. However, on the base stated in (6), we argue that PS and SBAS can’t be directly compared as the target deformation in PS

is over ground scatterers including small number of LTDPs. Moreover, the deformation observed by NSBAS is regional as seen in Seogwipo sediment case. If we used very strict error filtering criteria in NSBAS processing, the distribution of deformation points became similar to PS as shown in attached Fig. 3. However, the two results were not directly comparable as NSBAS and PS point did not populate in exactly same locations. We will state such base and experiments in new section 3.

Especially we would like to emphasize the deformation pattern in NSBAS Seogwipo city as shown in the attached figures 3 of general comment. Seogwipo city is the only sediment basin in Jeju and known as regional subsidence caused by heavy reconstruction. NSBAS results in 2017-2018 period of this study as well as 2020 period (it was provided as a complementary data set in Fig. 3 (e)) all demonstrated strong subsidence. It proved the reliability of NSBAS processing as well as the characteristics of NSBAS to detect regional deformations as we intended. PS are also showing many subsidence points in Seogwipo city (attached Fig. 3 (f)) as the whole area's deformation would induce the scatterers deformation behaviors. We described this point together with quantized analysis in section 4 as a base of NSBS and PS connection.

(15) The distinction between the previous results and the new results provided by this study is not clear.

Answer : Academic study regarding lava tube instability is only in Walthan and Park (2002) and a few local publications. We more described the difference between our approach and theirs in section 2.1 and section 5 as the reviewers suggested.

(16) The difference between the results and interpretations are not clear. It is mandatory to separate observations and interpretations/speculations.

Answer : New structuring in section 4 and 5 addressed it. Please see (5) in the general comment.

(17) The example of Manjang cave is very interesting to describe the study and the

Laser Scanning result is an asset.

Answer : True. The laser scanning of Manjang cave has never conducted due to the lack of local government's interest. Thus the rough sketch in Figure 9 is all we can find. We hope this draft's publication is a clue to persuade local government.

(18) The last part of the manuscript is not acceptable as is. But I am confident that the modifications of the InSAR parts (methods and results) should improve the discussion section.

Answer : We updated NSBAS outcomes and make clear connection to PS and consequent LTDP detection. We are quite confident about the accuracy of PS products as the potential LTDP by PS (see Figure 7) fit the outcomes of GPS surveys on the road-crossing points of lave tube conducted by a local researcher. In previous draft we couldn't cite this work as the survey of road-crossing points were reported as an internal report to local government and the author of GPS survey didn't agree to mention his work before completion of local government's task. We are persuading and may cite this as private communications.

(19) To summarise, I recommend to better structure the manuscript and to propose a precise description of methods (mandatory when the study focus on low signals).

Answer : The structure of draft was reorganized by the reviewer's suggestion. See (5) in the general comment.

(20) I also suggest modifying the SBAS network and adding the ascending data to improve the time series results and allow a cross validation of InSAR displacements. Another solution is to not use the SBAS results and just use the PS results in both directions (ascending and descending). I actually think the ascending data should be a strong improvement for this study.

Answer : We agree. SBAS network upgrading was done. Ascending/descending combination for decomposition is not possible due to the lack of ascending mode. Please

see (1) in response to general comment.

(21) This simplification could improve the clarity of the manuscript. After these modifications, the understanding of the results and interpretations should be clearer. The potential interest is very high for a large audience (and for public actors). I hope my recommendations will improve the quality of the manuscript making a high-quality publication. Major revisions required.

Answer : We will rewrite/reorganize the draft with improved NSBAS results and more bases promptly after this answer sheet is approved by the editor and reviewers.

Please also note the supplement to this comment:
https://nhess.copernicus.org/preprints/nhess-2020-321/nhess-2020-321-AC1-supplement.pdf

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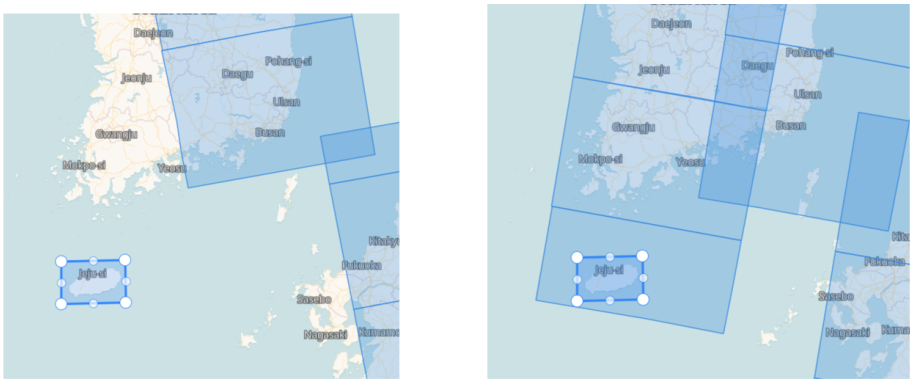

Fig. 1.

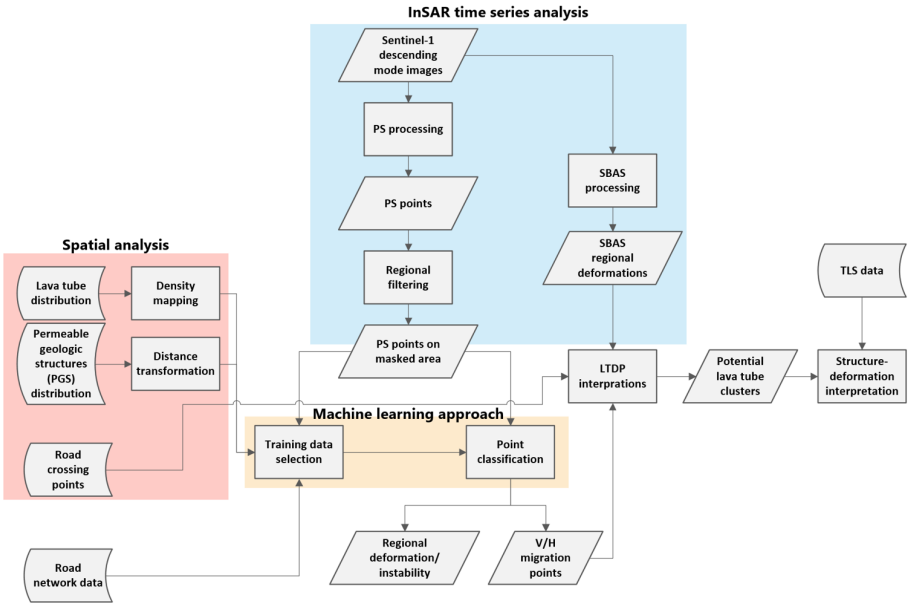
InSAR time series analysis
Sentinel-1 descending mode images
PS processing
PS points
Regional filtering
PS points on masked area
SBAS processing
SBAS regional deformations
Spatial analysis
Lava tube distribution
Density mapping
Permeable geologic structures (PGS) distribution
Distance transformation
Road crossing points
Road network data
Machine learning approach
Training data selection
Point classification
Regional deformation/ instability
V/H migration points
LTDP interpratations
Potential lava tube clusters
TLS data
Structure-deformation interpretation

Fig. 2.

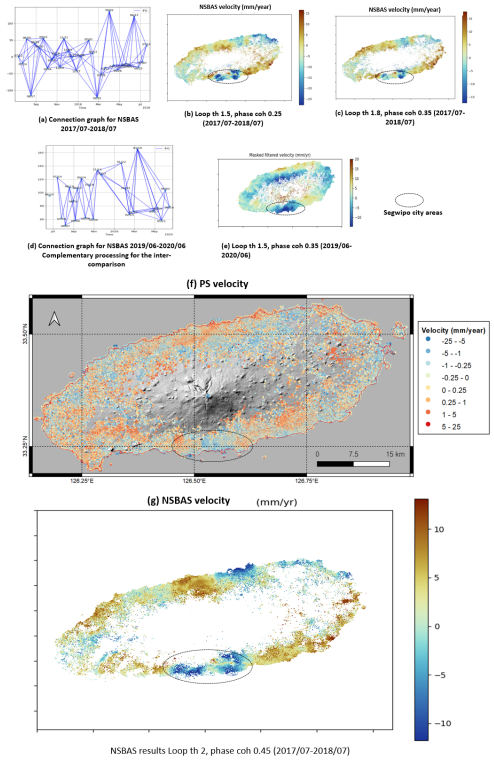
(a) Connection graph for NSBAS 2017/07-2018/07
(b) Loop th 1.5, phase coh 0.25 (2017/07-2018/07)
(c) Loop th 1.8, phase coh 0.35 (2017/07-2018/07)
(d) Connection graph for NSBAS 2019/06-2020/06 Complementary processing for the inter-comparison
(e) Loop th 1.5, phase coh 0.35 (2019/06-2020/06)
Segwipo city areas
(f) PS velocity
Velocity (mm/year)
-25 - -5
-5 - -1
-1 - -0.25
-0.25 - 0
0 - 0.25
0.25 - 1
1 - 5
5 - 25
(g) NSBAS velocity (mm/yr)
NSBAS results Loop th 2, phase coh 0.45 (2017/07-2018/07)

Fig. 3.