AC3 to RC3

In Short, this paper will be adapted according to balanced, objective and appropriate suggestions of all reviewers. We are confident that this will offer more valuable data to the international community and further enhance the awareness of the DS subsidence and sinkholes related hazards.

Here are specific answers to your comments which are presented first In ***Italics***

1. *The title of the paper and the expected product of this study is a vulnerability map (section 4.4). The definition of vulnerability is the degree of (potential) exposure to damage, and in this respect a vulnerability map should show levels of potential (future) damage, in areas that were damaged and in those that were not damaged yet.*

What is shown here are damage classification maps of specific areas that cannot serve as vulnerability maps for future planning in any nearby or other areas in NE Dead Sea. The workflow for preparation of such maps is described in page 8 and Fig. 3 and includes InSAR, vegetation, wells data, salinity variations and more methods, but the maps shown in Fig. 10 were not prepared by any of these methods and a resulting vulnerability map is not shown in the paper. The proposed approach is said to have been proved several times before (page 8, lines 28-30) but no references are given for the reader to understand what has been actually done before.

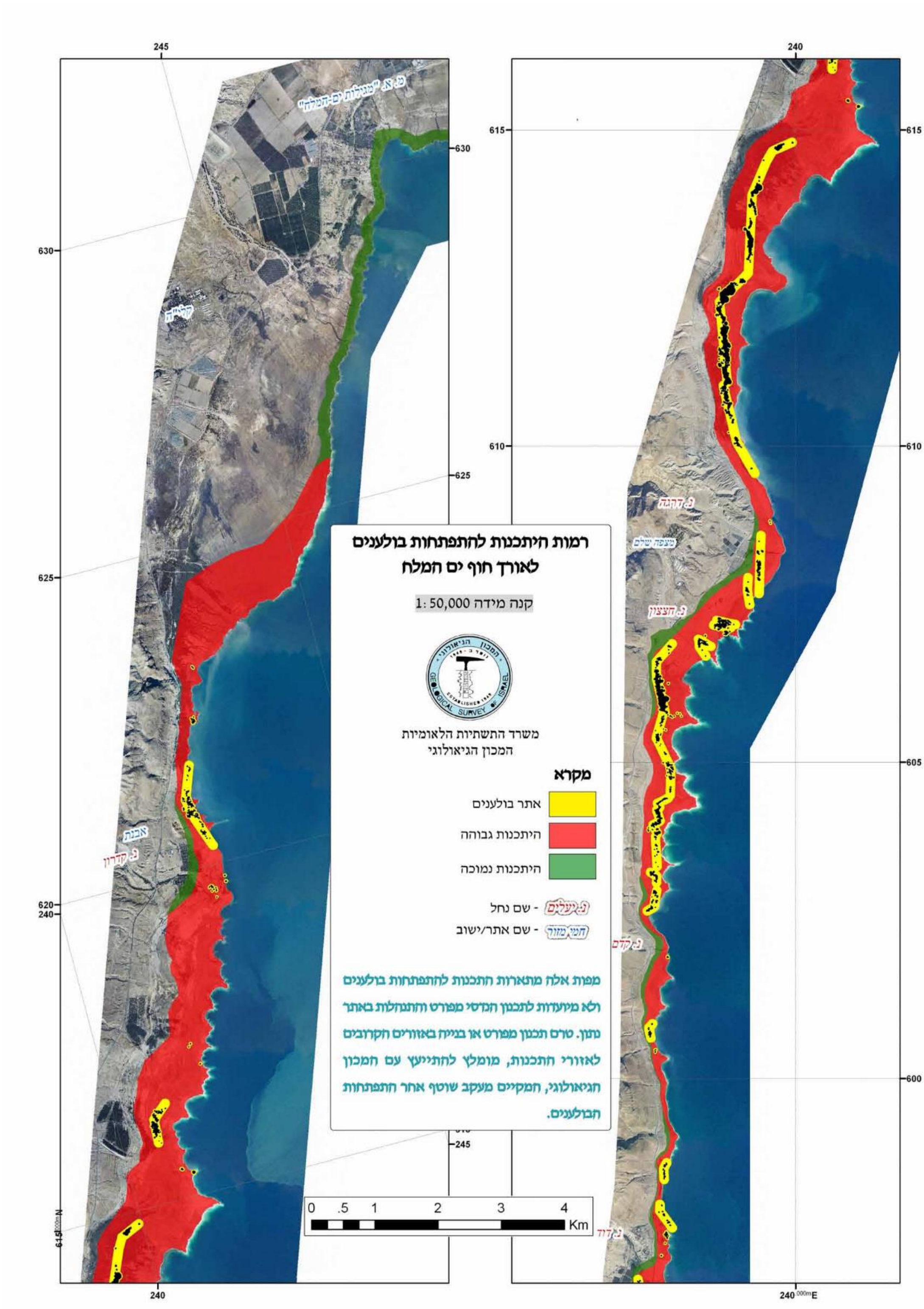
In response to what was justly signaled by your review and the two previous ones RC1 and RC2 we modified the scope of the work, our new revised version puts very much less emphasis on the vulnerability, the title of the paper was modified the word vulnerability is replaced by “exposition” a more realistic one, liberating our paper from the vulnerability issue as a very narrow technical term, exposition being more appropriate for meeting the main objective of our work at this stage (i.e. provoking more awareness of planers and decision makers involved in the development of the Jordanian DS shore).

2. *The title and many places in the text use the term "salt karst". In many places along the Dead Sea (the entire west coast and possibly also the southern east coast), a layer of salt is dissolved and salt karst sensu-stricto develops*.

Two comments regarding this:

1). the salt layer has not been found along the entire west coast, especially in the NW part. The map below (left) indicates low probability to find out a salt layer because of the absence of boreholes data available and also because of the important quantity of water existing in the underground. The mudflat at the opposite of Sweimeh is felt as not affected. Additional information can be found here: Abelson, M., Y. Yechieli, G. Baer, G. Lapid, N. Behar, R. Calvo, and M. Rosensaft (2017), Natural versus human control on subsurface salt dissolution and development of thousands of sinkholes along the Dead Sea coast, J. Geophys. Res. Earth Surf., 122, doi:10.1002/ 2017JF004219.

Michael Ezersky extrapolated (logically) the presence of the salt layer to the Northern DS and the whole Eastern DS coast but this is not attested by evidences from boreholes since they do not exist.

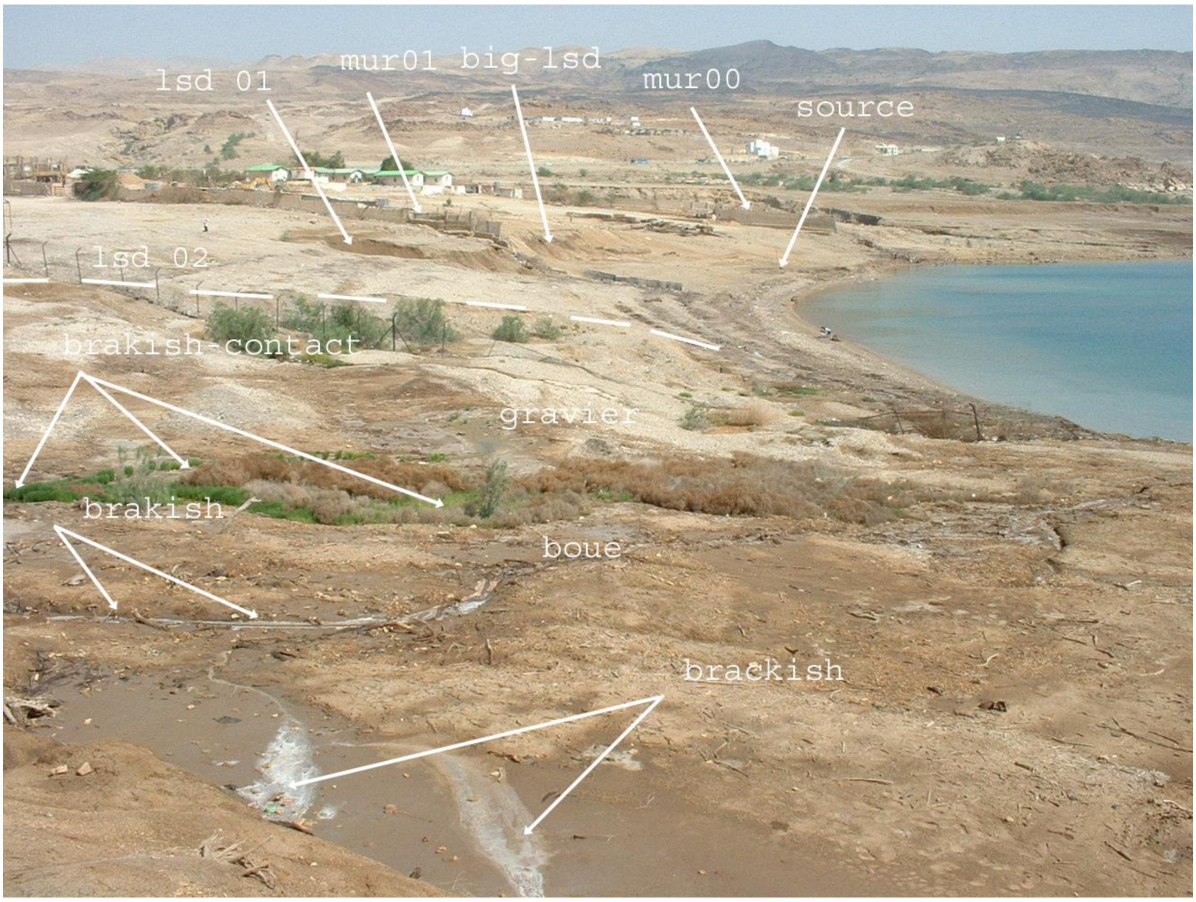


2). Besides, in the Dead Sea area, sinkholes do not need a salt layer to exist. The dissolution of salt remains in the soil matrix or the dissolution of salt lens can trigger the mechanism of cavities formation. This statement is based on numerous observations done in the Sweimeh area from 2004 onwards (example pictures 1-7).

Consequently, there is no "karst sensu-stricto" nor "karst sensu-lato". There is a salt karst system where sinkholes can be created in at least two ways: salt layer dissolution and salt remains dissolution.

Below are some pictures taken from 2004 to 2009. They attest that various types of water are found in the area of the Holiday Inn based on salt dissolution all along underground paths. Some springs are sweet, other rather brackish, and other are highly salty.

A water sampling campaign took place about ten years ago in the southern DS and results published in Landslides along the Jordanian Dead Sea coast triggered by the lake level lowering. February 2010. Environmental Earth Sciences 59(7):1417-1430.



Picture 1: April 2004 © Damien Closson & Najib Abou Karaki

Lateral injection of water creates different types of sliding.

Picture 2: April 2004 © Damien Closson & Najib Abou Karaki

From a year to another the amount of water fluctuates a lot.

Picture 3: May 2005 © Damien Closson & Najib Abou Karaki

Metric sinkholes are found in many places. They do not result from the dissolution of a salt layer.

Picture 4: May 2005 © Damien Closson & Najib Abou Karaki

Picture 5: May 2005 © Damien Closson & Najib Abou Karaki

Decametric sinkholes have been observed in the Holiday Inn.

Picture 6: 29 April 2009 © Damien Closson & Najib Abou Karaki

Sinkholes were wide enough to swallow an excavator.

Picture 7: May 2009 © Damien Closson & Najib Abou Karaki

All these features are salt karst feature sensu-stricto and they have been created without the dissolution of a salt layer. The soil conditions are similar to the ones found in the NE corner of the DS.

What is described here as the cause for landslides, subsidence and sinkholes is chemical and mechanical erosion of interstitial salt that remained between the grains when the DS level dropped and was washed by fresh groundwater. This is not salt karst.

The latest statement is wrong. This is salt karst (pictures 5-7). Besides, the pictures above are just a few samples of what we have observed since 1991 along the Eastern DS coast.

Furthermore, the proposed mechanism is speculative in its basis and has not been proved by any of the methodologies used here.

The observations in the field are unambiguous (picture 1 foreground). They attest that our hypothesis is correct. Besides, predictions based on such hypothesis have been verified several times.

What can be the size of a cavity that is formed from such salt remains?

Based on our field observations they range from 1 m to 12 m (see pictures 5-7).

If fresh water dissolves that salt, it should show chemical evidence for dissolution in the springs, such as Na/Cl ratios, density, etc. Without such evidence the entire theory cannot hold.

Just have a look at picture 1 and you will understand that salt dissolution is obvious.

3. On page 9 the authors write that the velocity map supports the hypothesis that the subsidence is the result of chemical erosion and that the landslides and sinkholes are consequences of mechanical erosion by underground water flows. No other mechanism (e.g., consolidation-driven subsidence; gravity-driven landslides) is even considered (or rejected) and no independent evidence is shown to prove this hypothesis (see also section 2 above).

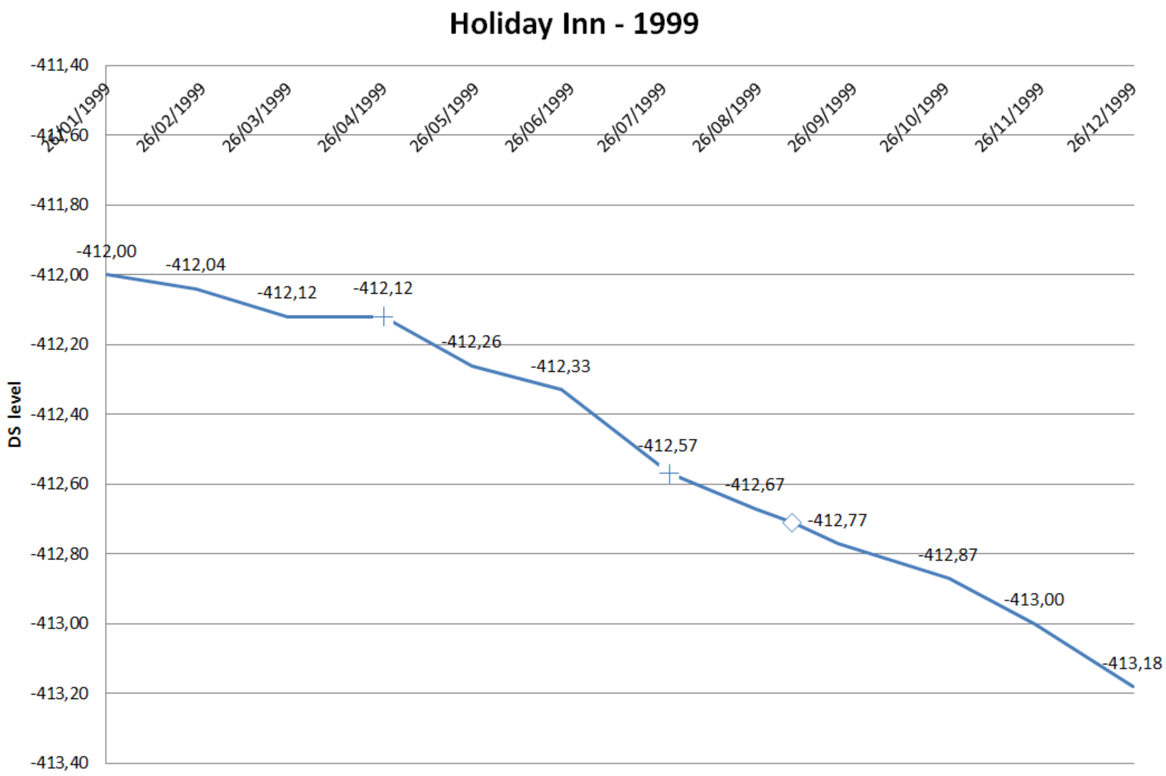
This problem had been tackled around 10 years ago. Results have been published here: Landslides along the Jordanian Dead Sea coast triggered by the lake level lowering. February 2010. Environmental Earth Sciences 59(7):1417-1430.

The fact that highest subsidence is found in the exposed muddy plains may support the consolidation mechanism. Furthermore, how do the authors prove the existence of mechanical and chemical erosion and how do they distinguish between them and relate each mechanism to a different phenomenon (landslide, sinkhole, subsidence).

This issue was analyzed in depth and the results published here: Sustainable development and Anthropogenic induced geomorphic hazards in subsiding areas. Anthropogenic sustainable development in subsiding areas. September 2016, Earth Surface Processes and Landforms, DOI: 10.1002/esp.4047.

4. The proposed mechanism for landslides is also by "increased lateral water injection into soft sediments on a slope balance profile created under the DS level. . ..favored by a sudden drop of the DS level that usually occurs during the dry period" (page 12, lines 3-5). There are continuous monthly measurements of the DS level since 1976, and if the authors looked at these results they would have found that there is no sudden drop in the DS level in any of the 3 periods, and on the contrary, from February to May 2009, the level even rose by about 3 cm. This speculation adds to the previous ones and gives the impression that although the damage observations are clear, the mechanism is far from being explained.

We do not interpret the actual data in the same way. The graph "Holiday Inn 1999" clearly show a drop from –412.12 to –412.57 in only 3 months... 45 cm of base level drop for an already unstable system is an important parameter to keep in mind. It was even 65 cm at the moment of the landslide.



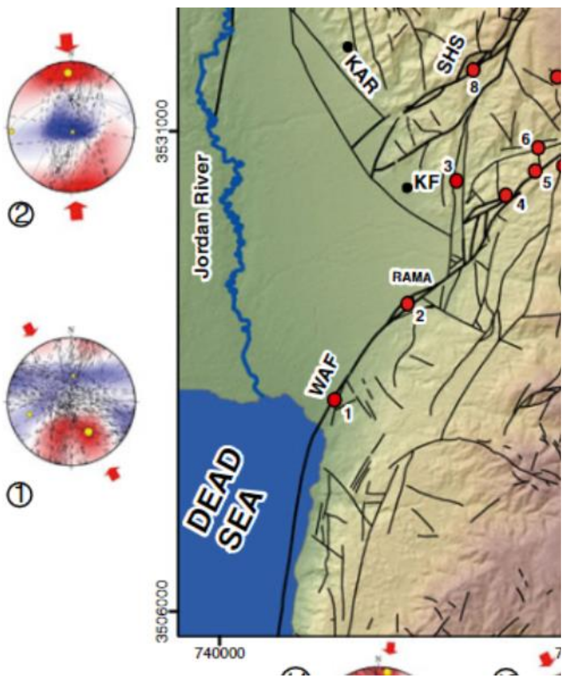
6th September 1999.

5. *Subsidence is also interpreted as a consequence of permeability increase due to fractures, but no evidence is given that certain areas are more fractured than others.*

This issue had been tackled and documented by Mohammad Al-Awabdeh in his thesis and related publications:

e.g. Mohammad Al-Awabdeh, J. V. Pérez-Peña, J. M. Azañón, Jorge Pedro Galve et al. Stress analysis of NW Jordan: New episode of tectonic rejuvenation related to the Dead Sea transform fault. April 2016, Arabian Journal of Geosciences 9(4):264. DOI: 10.1007/s12517-015-2239-z

Mohammad Al-Awabdeh, J. V. Pérez-Peña, J. M. Azañón, Jorge Pedro Galve et al. Quaternary tectonic activity in NW Jordan: Insights for a new model of transpression–transtension along the southern Dead Sea Transform Fault. April 2016, Tectonophysics. DOI: 10.1016/j.tecto.2016.04.018



Detailed datasets have been used to link InSAR deformations with mapped structural features.

6. Geological setting: The reference provided for the Lisan Formation is Landmann et al., 2002. This formation has been defined much earlier (Begin et al., 1974 and 1980).

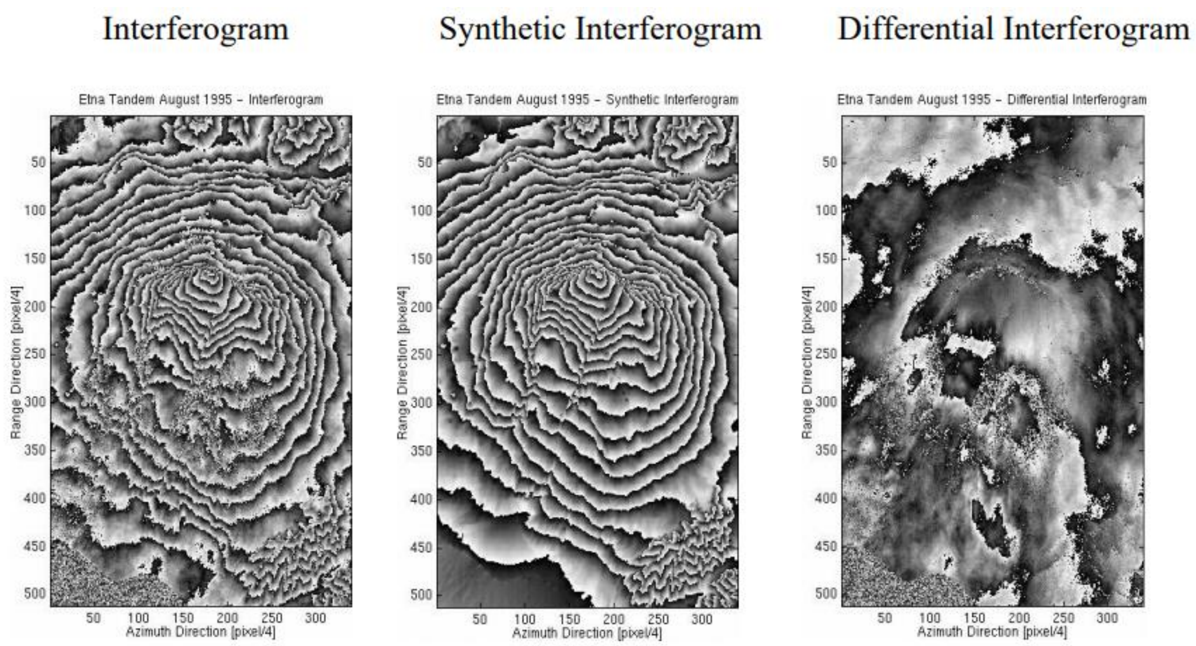
The history of Lake Lisan is recorded in its deposits, known as the Lisan Formation. This term was first used by Louis Lartet (1869) **Essai sur la Géologie de la Palestine, Masson Paris.** (https://www.worldcat.org/title/essai-sur-la-geologie-de-la-palestine/oclc/493602635) However, many others have mentioned these deposits (e.g., Picard, 1943; Quennell, 1956; Bentor and Vorman, 1960; Bender, 1968).

In a similar manner the fact that the Dead Sea Transform is an active structure has been shown long before Al-Awabde et al., 2016 (e.g, by Garfunkel, Freund, De Sitter, and many others in the second half of the 20th century). Citations should refer to the earliest or to the key papers that mention the feature.

Then, we propose the most important benchmarks; Quennell 1958 , Garfunkel et al. 1981. Although saying that the DST is an active structure is an evidence given the huge number of publications dealing with the whole spectrum of seismic activity, instrumental, historical, archaeo and paleoseismicity. Abou Karaki (1987 and references therein including Willis, Seiberg, ,Abel, Arieh, Ben-Menahem, Shapira, Mamoun, El-Isa, Taher, Poirrier and Taher, Hoffstetter.. etc)

7. *InSAR: In page 3 the authors write that they analyse both D-InSAR and A-DinSAR. In page 5 the authors write that the derived products are intensity and coherence maps, interferograms, differential interferograms (what is the difference between the two?), …*

As illustrated below, an interferogram (left and middle) gathers information about the topography, the phase delay caused by the atmosphere, and the ground movements between two acquisitions. Once the topographic phase is removed, only the displacements and the atmospheric phase delay remain (differential interferogram). When the atmospheric conditions are favorable, the ground displacements appear. One can add that when the perpendicular baseline is very short (a few meters) between the two acquisitions, then the interferogram and the differential interferogram are equivalent.



(a) What is A-DInSAR and where are all the other radar products mentioned in the paper (including time series that were mentioned again on page 8 line 12)?

The term A-DInSAR stands for Advanced DInSAR, which is a category of techniques used to process multi-temporal stacks of SAR images. Another term often used in literature is Multi-Temporal InSAR (MT-InSAR). The two main A-DInSAR approaches are the Permanent Scatterers (PS) and Small Baseline Subset (SBAS), the latter was used in this study.

During the SBAS processing chain, a series of intermediate products are derived for each interferometric pairs. These products are generally used to check the quality of specific interferograms or in specific dates to better explain surface changes. The difference between an interferogram and a differential interferograms is that in the second the phase related to the topography is removed with an external DEM.

These products are generally not showed in scientific journals as a whole, because: 1) the huge amount of intermediate data produced (even thousands, depending of the number of SAR images used and the number of connections); 2) they are often meaningful if taken one by one; 3) they can be of difficult interpretation.

The final product of the A-DInSAR analysis is the time-series for each of the detected point. These can be showed as a map of mean velocity values (in mm/yr) or cumulative displacements (in mm). Figure 4 presented in the manuscript, shows the final product of the SBAS processing of the available Sentinel-1/2 images as mean velocity map projected along the vertical direction. For each of those points, it is possible to extract the displacement time-series.

Examples of time-series extracted for some selected points in significant areas will be added to the text.

(b) InSAR measures satellite to ground line of sight (LOS) displacements, while Fig. 4 shows vertical velocities. How were the LOS measurements converted to vertical velocities, and how did the authors take into account possible horizontal movements (particularly important in cases of landslides) that could also be components of the measured displacements? (c) As InSAR is one of the major techniques, some elaboration should be added regarding to the noise level, the elevation model (DEM) used in the processing, incidence angles, etc. This is particularly important because velocities lower than 10 mm/year are also interpreted as real (Fig. 4 and page 11, lines 21-23).

The measured velocities are projected from LOS to the vertical direction according to the incidence angle calculated at the location of each point. The formula used is simply "$V_{def} = LOS_{def}/\cos\theta$", where V_{def} is the deformation calculated along LOS and θ is the incidence angle of each point.

As written in the text, the DEM used for all the InSAR processings is the SRTM DEM with a resolution of around 30 x 30 m. Unfortunately, this is the only DEM available for the area. Unfortunately, the Dead Sea level drop and the consequent change in

topography elevation occurred between 2000 and 2018 is not compensated by the DEM. Anyway, the SBAS stacking technique is able to make height corrections of the difference between the observed and the DEM elevations based on the perpendicular baselines of the generated interferograms. This helps in minimizing the errors related to the absence of a more recent DEM.
A table with the main features of the SAR datasets used in the work will be added to the text.

(d) West of the 2000 shoreline there is no SRTM DEM (page 7, line 17), so how was topography corrected for these important areas (where most of the subsidence occurs). The coastline of February 2000 should be shown on Fig. 4 so that the reader could get an impression of where topo corrections were made and where not (or made by another way).

As said in the previous comment, the SBAS algorithm is able to compensate for “inaccuracies” in the used DEM in order to minimize the topographic errors in the recently exposed areas of the DS.

The coastline of February 2000 will be added to Figure 4.

We will of course adequately care for the discussion and conclusions of this paper. Thank You