GENERAL COMMENTS

1. Although the focus is on the local-scale problem linked to a sinkhole-related land sub- sidence, the results appear significant and could be of interest to NHESS audience. However, the readers unfamiliar with the study area (like me) may not fully appreciate the problem and the presented results, because of the insufficient background and contextual information. So, I suggest adding an overview geomorphological or geo- logical map including also lithology and sinkhole distribution, as well as some more explanations in the text. Also the area covered by PS maps in figs 2 and 4 is so small that one misses the context. Please show larger areas in addition to the two small area zooms.

We have added a geological map, a geological cross-section and the following sentences to the Introduction section.

"*The Cenozoic bedrock in the analysed area of the Ebro Valley consist of subhorizontally lying halite- and glauberite bearing evaporites of the Zaragoza Formation (Salvany, 2009)(Figure 02). Subsurface dissolution results in the development of numerous sinkholes affecting both the evaporitc bedrock and the alluvial cover (e.g., Galve et al., 2009; Pueyo-Anchuela et al., 2015). Active subsidence associated with these sinkholes produce costly damage to human structures (e.g., Gutiérrez et al., 2009, 2014). The dissolution-induced ground deformation can be studied quantitatively using InSAR techniques as illustrated by previous works (Castañeda et al., 2009, 2011; Gutiérrez et al., 2011; Galve et al., 2015).*"

The caption of the new figure briefly introduces the geological setting of the study area.

"*From the geological point of view, the railway tracks crosses the central sector of the Ebro Cenozoic Basin and is underlain by subhorizontally lying evaporites of the Oligo-Miocene Zaragoza Gypsum Formation (Quirantes, 1978). This formation is composed of gypsum, anhydrite, glauberite and halite units (Salvany, 2009). Sinkholes are caused by subsurface dissolution and the consequent deformation and/or internal erosion of the overlying sediments. Detailed descriptions on the dissolution and subsidence processes in the study area can be found in Gutiérrez et al. (2008), Galve et al. (2009) and Acero et al. (2015).*"

2. I also suggest to complement the work by considering the temporal resolution of DInSAR-based results, which is related to satellite re-visit times. This is important when contemplating the use of DInSAR for monitoring and early warning purposes (you can find more information on this issue in References below).

The added table (Table 01) contains the information requested by the referee 1# and additional information relevant to the potential readers of the paper.

3. Finally, some as- pects of the DInSAR data and derived results should be better explained (or relevant references provided) to make them understandable for the general NHESS audience, who may not be very familiar with radar interferometry. Below I indicate specific points that should be clarified and make some additional suggestions for paper improvement.

SPECIFIC ISSUES

Section 1 – Introduction

4. SAR interferometry has been used to study sinkholes also outside of Spain (for exam- ple in Israel, USA). Perhaps it would be useful to cite some relevant examples.

Relevant research papers on sinkhole detection and monitoring using InSAR technology have been included in the Introduction section.

5. Line 57 why "respectively"?

Corrected.

Section 2 - SAR data & processing

6. Consider adding a table with ENVISAT and ALOS data characteristics, including spatial resolution, incidence angle, etc.

Done.

7. In the text you mention full and medium resolution data, but do not clarify the actual resolution. Further, we learn the ALOS PS map had a 25x25m ground resolution, but the resolution of ENVISAT PS map is not given.

The resolution of the data is provided in the added Table 01.

8. Need to clarify what is meant by "Current Displacement rate values" and explain >2 mm/yr and >4 mm/yr velocity thresholds.

References supporting the selected thresholds for C-band and L-band have been added (see Sandwell et al., 2007; Meisina et al., 2008; Bianchini et al., 2013). Based on our detailed mapping of the sinkholes (cf. Galve et al., 2009, 2015), we consider that 4 mm/yr is an adequate threshold for the L-band displacement data. There is a good correspondence between the distribution of settlement rates considered as valid and the mapped sinkholes with geomorphic and/or structural evidence of activity.

Section 3 - DInSAR results

9. The results shown in figs 2-4 are derived from ENVISAT and ALOS data, and you should explain the reasons for using different satellite images for the two sites, which are located very close (2km) to each other (Fig. 1). Limited spatial or temporal cover- age, or?

We used ENVISAT and ALOS data for the two sites but we show the best results obtained in each studied profile. We clarified this point adding the following sentence:

"*We analysed ALOS and ENVISAT data in each profile but only the best results are shown; ALOS measurements in the Castejón-Zaragoza railway line and ENVISAT PS points in the Madrid-Zaragoza profile (Figure 04).*"

10. Please explain also the meaning of negative displacement rates.

The text "(negative rate values indicate subsidence)" has been added.

Section 4 – Discussion

11. The discussion regarding the differences in density of radar targets obtained from ENVISAT and ALOS data is of interest but remains unconvincing (and even potentially misleading), because neither the actual numbers nor the actual significance of the density estimates are not provided. What areas were considered and how was PS density calculated? Please quantify and explain.

The required data has been provided in the new Table 01. The point density can be calculated directly from the values indicated in the table.

12. Furthermore, the suggested explana- tion of the differences in ENVISAT and ALOS PS densities are weak, because some of the controlling factors are not considered. The issue of radar target density (as well as that of quality and reliability of DInSAR and multi-temporal interferometry results) have been dealt with in detail in a recent review paper by Wasowski & Bovenga (2014a). In particular, in addition to the critical influence of the ground cover and land use, the number and distribution of radar targets depends also on the number of images used, the adopted processing parameters (and algorithm type), the selected coherence threshold, and on the spatial resolution of radar imagery. The recent remote sensing literature shows that in comparison to medium resolution imagery (e.g. ENVISAT), the use of high resolution data (e.g., COSMO-SkyMed and TerraSAR-X) can lead to more than 10-fold increases in radar target densities (e.g. Bovenga et al, 2012). Again, this aspect is discussed in detail by Wasowski & Bovenga (2014a,b), who also provide practical examples to show how high resolution radar data can lead to greater quantity (high target density) and quality information for the assessment of transportation infrastructure instability in landslide-prone environments.

We rewrote the paragraph taking into account the comments and suggestions of the reviewer.

"*Railways are linear features commonly laying on relatively flat surfaces that behave as adequate reflectors for the spaceborne SAR systems, providing spatially dense and temporarily stable coherent scatterers (Hanssen et al., 2009; Shi et al., 2014). Chen et al. (2012) illustrate the strong backscattering of railways in ALOS PALSAR and ENVISAT ASAR amplitude images, compared with the surrounding features. The density of natural reflection points depends on the land cover, the number of images used in the InSAR analysis, the adopted processing parameters (and algorithm type), the selected coherence threshold, and the spatial resolution of radar imagery (Wasowsky et al., 2014). In our case, the area occupied by the ENVISAT displacement points along the Madrid-Zaragoza profiles (NW-SE orientation) is higher than the area covered by the pixels of the ALOS displacement map. On the contrary, ALOS data showed the best distribution of measurement points along the Castejón-Zaragoza section(NE-SW orientation). This difference apparently suggests some impact of the relative orientation of the railway tracks with respect to the flight path of sensors. However, in our case, both the ENVISAT and ALOS data correspond to ascending paths and, consequently, the differences observed between the two DInSAR displacement rate maps cannot be attributed to the course of the satellites*."

We also added the following sentence in the next paragraph.

"*High-resolution imagery can provide a point density ten times higher than medium-resolution data (Bovenga et al., 2012).*"

13. Line 182-185 Unclear what you wanted to say

We rephrased the sentence.

Original: "*DInSAR analyses focused on the railway tracks or specific sections of the infrastructure would provide better results than the deformation values presented in this work, derived from a regional investigation with a limited spatial resolution (Galve et al., 2015)*."

Corrected: "*We obtained good results using InSAR data derived from a regional investigation (see Galve et al., 2015). Detailed analyses focused on railway tracks or on specific sections of the infrastructure should provide higher density and more accurate deformation data than in the profiles presented in this paper.*"

14. L207 higher critical baseline – you are probably referring to SBAS processing. This should be made clear.

Clarified:

"*This was probably due to the longer wavelength of the former and the higher critical baseline applied to generate the ALOS interferograms of SBAS method (Lanari et al, 2004). This resulted in higher coherence, especially in zones with high deformation gradients and in man-made features such as the railway embankment.*"

Lanari, R., Mora, O., Manunta, M. 2004. A small-baseline approach for investigating deformations on full-resolution differential SAR interferograms. IEEE Transactions on Geoscience and Remote Sensing, 42, 1377-1386.

Section 5 – Conclusions

15. Line 234 high resolution surface velocity maps from ENVISAT and ALOS data – potentially confusing, because the ENVISAT and ALOS data are generally considered as medium resolution and high resolution is "reserved" for TerraSAR-X and COSMO-SkyMed data.

The term "*high*" was changed by "*medium*".

16. L248-249 but on demand high resolution radar satellite data are also expensive

We indicate "*could be an alternative*". We do not mean that is always cheaper than other monitoring techniques.

17. L250 medium-high risk situation – not very informative

We changed "*medium-high risk situation*" by "*dangerous subsidence rates (according to the admissible deformation of the railway track)*".

18. L254-256 future studies. . . - why future? There are already a number of examples published in scientific literature.

We clarified this point adding the following expression: "*in our study area*".

Figures

19. Fig 2b and 4a – explain dotted white line

Done.

20. Fig 4d – what does blue-grey color stand for?

We indicated in the figure caption the following: “Dark grey and light grey zones indicate sections built on sinkholes classified as active and inactive, respectively”.