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Natural Hazards and Earth System Sciences
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Interactive comment on "GB-InSAR monitoring and observational method for landslide emergency management: the Montaguto earthflow (AV, Italy)" *by* F. Ferrigno et al.

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AUTHORS INTRODUCTION The authors are grateful to the three anonymous reviewers for their suggestions which will greatly improve this work. After evaluating all received comments, it is agreed that their contents are fully shareable and contain high scientific standing. Furthermore, the precious value of referee's suggestions is confirmed by the analogy among the several comments that authors will fully take in consideration. In order to provide an exhaustive answer for all, and to guarantee a sharing discussion, we will proceed in this document to replay in detail to each referee. It is also stated that the annotated PDF documents (received by the Anonymous referees

2 and 3) will be completely taken into consideration during the manuscript editing and, since a lot of inconsistences were about the English grammar, the author's purpose is to submit the paper to an English native speaker review, to correct existing and to avoid further grammar and syntax errors. Please use the attached PDF version, to avoid any loss of formatting.

Anonymous Referee #1 General comment The paper describes a continuous GB-InSAR monitoring of a landslide, focusing on the use of this tool for understanding the cinematic of the phenomenon, and on these bases design and build safety measures for risk mitigation and long term stabilization work. The GB SAR data processing and analysis described is plan, and it does not contain outstanding innovative or original aspects with respect to the state of the art of this topic. Although the direct link between GBSAR monitoring and Observational Method has not previously discussed, the content of the paper from this point of view is poor; in addition the operational aspects are not deeply discussed, missing a real comparison of the proposed approach with respect to the conventional monitoring. For example, the advantages of using the GBSAR monitoring, which allows obtaining undoubted spatial and temporal performances and fully remote observations, should be compared to the performances of optical sensors. As an example the authors claim that the proposed technique can produce savings in cost and time on engineering projects, but it must also consider that the cost of a GBSAR system dedicated to a single monitoring site for three years can be high. As far as the reading of the manuscript is concerned, it is difficult and several sentences are confused and unclear: an accurate rewriting is demanded. Some specific items are here below indicated. I suggest to improve the, poor, reference section, especially with papers focused on the same landslide monitoring if available.

GB-InSAR and Observational Method: One of the reasons that stimulated this paper was actually that the link between the GB-InSAR monitoring system and the Observational Method was never previously discussed anywhere. Thus we had the possibility to present an innovative study on this topic, and since we agree with your opinion about the lack of a deep discussion, our purpose is to improve this section adding more operational aspect as changing of work plans based on the monitoring data interpretation. An example that can we briefly describe now concerns the realization of three main cross trenches located in the landslide toe area, in the medium-low part and in the upper zone. The monitoring data analysis was essential for their location and effectiveness statement of two of them. GB-InSAR and optical sensor performed: As regards the comparison between the GB-InSAR monitoring and the optical sensors, since the nature of the data obtained from these different techniques is not really comparable, we intend to focus this topic on the description of the limits and advantages of the two monitoring systems, describing better that the aim of the monitoring activities was to show the performances of an integrated monitoring system supporting the work plan and not the techniques comparison. In particular, due to the landslide size, the GB-InSAR system seemed more suitable to detect the landslide unstable sectors giving an aerial data, which is essential to design or change the work plan. The optical sensors system, represented in this case by the use of RTS (Robotic Total Station), is able to acquire punctual displacements data very useful to monitor single points and/or the structural setting of the realized structure and works on the landslide.

Savings and costs: The Montaguto landslide damage in terms of cost, on the basis of the Department of Civil Protection evaluations, due to the rail way and the road interruption caused an estimated loss of about 400 kEuro/day. To guarantee the restore of the infrastructure it was necessary in the same time: to remove the landslide accumulation, to stabilize the landslide and to guarantee the operating workers safety. The cost-benefit analysis led to the implementation of an integrated monitoring system capable to monitor and address the design work. This aspect will be described in the amended manuscript.

The grammar specific annotations will be taken into consideration and are fully accepted, other significant detailed comments are reported below. Page 7249 Line 15: what is the resolution power of the GB-InSAR systems???I did never found this word.

GB-InSAR technique is particularly suitable for monitoring of landslides that occur in a small area and that are characterized by a fast evolution: 1. high SAR image sampling frequency (few minutes); 2. operation under any weather and lighting condition; 3. complete remote operability, because it does not require the installation of target sensors on the monitored slope; 4. accuracy in the displacement measurement ranging from few tens of millimetres to few millimetres; 5. continuous areal monitoring of the whole slope with a high pixel resolution (from half to a few meters based on the distance); 6. long-range operability (up to 4 km). The statement "resolution power" doesn't seem correct actually: the maximum velocity displacement reached by the landslide was of about 3 m/day, referring to this data end with respect to the GB-InSAR characteristics this velocity was quite high, so the Montaguto case study represents a very interesting benchmark for the application of this technique. This part will be explained in the right way. Page 7251 (Pag.5) Line 6: I think that only a few of readers can know who "Borboni" are; if the authors like to put this historical note, please add a reference. The following reference will be added: "Il Mattino, ediz. Avellino del 20/7/2009; Vincenzo Grasso – Montaguto e la lezione dei Borboni"

Page 7252 Line: 2: I disagree with the use of the word "deformation field". The technique is able to provide one component of the displacement. The selection of an opportune observational geometry only allows to optimize the estimate of the displacement when it maintains along a specific direction coincident to the line of sight. For example I guess that due to the complexity of the landslide, modelling it is not possible using only the GBSAR data. Were there installed other sensors capable of measuring the vectorial displacements? Is the GBSAR monitoring assisted by modelling or not? The nature of displacement measurements is the 1D LOS component. The statement "deformation field " was intended to refer to the surficial deformation field: in fact, the products of the GB-InSAR system are interferograms, consisting in 2D images, showing an aerial distribution of the occurred deformation. To better explain this concept, the term "deformation field" will be expressed in a different and more correct form. Actually there was another monitoring system represented by the displacement measurement based on topographic techniques using robotic total stations. This will be presented in more detail and a comparison with GB-InSAR will also be added (see previous point). within the performed activities a coupled hydrological and stability model was also implemented, investigate possible correlations between the GB-InSAR data and the model behaviour. For briefness, and since those data will be presented in a paper that is currently in preparation, they cannot be mentioned in this work. The limitation of this technique is that only the displacement component parallel to the line of sight (LOS) can be measured, therefore the location of the installation point is crucial. The radar system needs to be placed in order to make the sensor LOS as parallel as possible to the expected direction of the landslide motion. In this particular case, the radar system was placed in order to make the sensor LOS as parallel as possible to the expected direction of the landslide motion, in fact the angle between the line of sight and the real direction of movement is very small, the high precision (submillimeter) of the instrument contributes to minimize this limit, detecting even the minimum deformations.

Line 13-15: what do you mean with "installation method?" please clarify it; the remaining part of the sentence is totally undecipherable The SAR images properties acquired with the GB-InSAR technique, and in particular the spatial resolution, are linked to the parameters of measurement and the characteristics of the installation location such as the distance between the sensor and the observed scene. This will be clarified in the manuscript.

Line 18: What is a "visual calibration"??? Since during the first stages of the monitoring activity a DTM of the investigated are was not available yet, the comparison between optical images and interferograms was crucial relating to the detection of the unstable areas, especially of the landslide toe portion. Text will be amended accordingly

Line 24: Considering the topic of the paper, this theme demands some details to evaluate the advantages of the prosed technique with respect to conventional approaches. A brief description and a reference, if available, about the other monitoring tools is important. "Other 3-D displacements products for the Montaguto landslide were obtained with other high-technology applications, such as multi-temporal airborne LiDAR data (Ventura et al., 2011): even if the detail the latter technique is higher (particularly in terms of georeferencing), the GB-InSAR data have great benefit from frequent data collection, which is often unaffordable for airborne LiDAR." As previously outlined the description of the others monitoring system used in this case study and similar will be discussed and specific references will be added. (Allasia, P., Manconi, A., Giordan, D., Baldo, M., and Lollino, G.: ADVICE: A New Approach for Near-Real-Time Monitoring of Surface Displacements in Landslide Hazard Scenarios, Sensors, 13, 8285–8302, 2013. - Guadagno, F.M., Forte, R., Revellino, P., Fiorillo, F., Focareta, M., 2005. Some aspects of theinitiation of debris avalanches in the Campania Region: the role of morphologicalslope discontinuities and the development of failure. Geomorphology 66, 237–254. Guerriero, L., Revellino, P., Coe, J.A., Focareta, M., Grelle, G., Albanese, V., Corazza, A., Guadagno, F.M., 2013a. Multi-temporal maps of the Montaguto Earth Flow in Southern Italy from 1954 to 2010. J. Maps 9 (1), 135–145.)

Page 7254 (pag8) Line 9: not clear. It is important to explain how the methodology has been adapted with the changing conditions of the landslide. "From the beginning, the methodology used in the monitoring activities for the production and interpretation phases, and use of the interferograms, has been subjected to many variations induced by the landslide's evolution" During the first monitoring days the displacements velocity reached the value of 2.9 m/day, the use of interferograms processed on a time interval 4 of minutes was able to detect the occurred displacement. Thanks to the works performed and with the beginning of the dry season the displacement started to decrease: the time interval of 4 minute was not able anymore to detect the occurred displacement; therefore interferograms of 4 hours and later of 24 hours were used to analyse the data. The monitoring activity was also characterized by the emission of a daily report, in which the velocity displacement and the significant data were described, also the frequency of the reports was adapted to the works management needs and to the unstable areas variation in terms of changes in the displacements rates.

Page 7259 Line 14 : sentence not clear “The GB-InSAR approach has proved to be very useful for the application of the OM during the emergency phase. It supports quick delineation of the slide, and provides the basis for stabilization and excavation planning and design” The sentence will be rephrased as follows: “The GB-InSAR approach has proved to be very useful for the application of the OM during the emergency phase. It allowed a quick delineation of the slide and, through the detection of the more unstable areas, supported the stabilization and excavation planning and design. The day-to-day comparison between the works in progress and the Gb-InSAR data allowed to detect and to evaluate the landslides response end evolution.”

Figure 10: The figure plots, in linear scale, the accumulated displacement while the legend probably refers to the instantaneous displacement. On these bases I disagree with the term used and the graphic representation. Considering the curve and the linear scale of the axes, the use of the term displacement acceleration is correct only in the transition point, that is to say when the colour changes from green to red. Acceleration means change of velocity. In the red sectors acceleration is different from zero only in correspondence to the point where the accumulated displacement starts to increase (i.e. decrease considering the negative sign). The effect of the acceleration is to change the slope of the curve: the velocity changes from zero, horizontal line, to an (roughly speaking) approximately constant positive value, inclined lines or change the slope. If the landslide maintains an acceleration, the velocity increases linearly with time and the accumulated displacement does not show a linear trend. So I suggest to refer to acceleration, only in correspondence to the point where the slope of the curve changes from zero to a positive value, using only lines and not coloured areas; analogously deceleration occurs when the slope decrease or ceases: the landslide does not move and the accumulated displacement is constant. The different coloured areas of the plot can only indicate the condition: landslide in motion/steady. Authors agree with this observation. The focus of this diagram was to show the interval time in which the velocity increased (even with a linear trend) (red area) with respect to the previous interval time (red areas) in which the landslide state was stable. From a graphic point

of you, the figure will be modified with regards to the legend, but keeping unchanged the use of the red and green areas.

Anonymous Referee #2 General comment The article deals with monitoring works on an earthflow in southern Italy, performed through Ground Based Interferometric Synthetic Aperture Radar techniques. There are several things that I think should be better addressed in the article; in the following paragraphs, I will try to explain them, whilst several specific comments and corrections are in the attached file. The Montaguto landslide is never properly described in the paper. Starting from the introduction, it seems that the reader should know where it is, what it is, as well as the setting where the landslide developed. This does not allow the reader unfamiliar with Italian landslides and geology to understand what is stated in the manuscript. Therefore, I strongly invite the Authors to introduce a specific section where: i) briefly describe the landslide, indicating its typology; ii) put the landslide in the overall context of the area, even by quoting previous works (are earthflows the only type of landslide there? Are all of this size? Are they typical only of this part of Italy? What are the main triggers? Etc.); iii) indicate the main morphometric features, as well as volume, area, and depth of the landslide. I believe this section is necessary to the reader, while in the present manuscript Authors seem to take for granted that anybody knows where the Montaguto landslide is, and what type of slope movement is.

In order to better describe the landslide, based on your suggestion, authors are providing to enrich the entire section "The Montaguto landslide" following and focusing on the description of all the landslide aspects that are currently missing. We also intend to add one more figure showing the Geological setting with: the location of the landslide area and the geological map of the study area and structural map of Italy. Road SS 90: I am not sure what that means, but I believe it is a state road. If that is correct, I would indicate throughout the article "state road 90", rather than "road SS90" It is as you supposed, the term "SS" means State road. this will be explained in the revised version. The monitoring data should be presented in greater details, and the figures included in the paper should deserve much greater focus of what they have in the present form of the manuscript. In addition, comparison with the same, or similar, methodologies and techniques in other landslides could deserve at least some lines of comment. The different sectors identified through monitoring should be described within the framework of the main kinematical zones of the landslide, as I guess these features should have also been identified in the field. At this regard, Authors could refer to works on similar landslides (starting from the very famous Slumgullion earthflow, see Parise et al., 2003; Coe et al., 2003). But, in addition, an effort should be done to compare these subdivision to what reported in previous works about Montaguto landslide. Guerriero et al., 2013, and Lollino et al., 2014, are included in the reference list, but in the manuscript they were never properly quoted in order to compare the outcomes from the different methodologies. This should be done, and should become an important part of the discussion/conclusion sections. Further, another more recent work (Guerriero et al., 2014) has not been considered at all. It should be discussed, too, or at least quoted.

The monitoring data will be presented in greater details, giving greater focus to the relative figures. As concerns the comparison with others applied methodology, the landslide that better suit this topic is the Slumgullion landslide, more references and comment will be considered accordingly.

Authors also agree about the necessity to refer to works on the same landslide. Please, find as follow the works authors are considering for the revision phase:

Allasia, P., Manconi, A., Giordan, D., Baldo, M., and Lollino, G.: ADVICE: A New Approach for Near-Real-Time Monitoring of Surface Displacements in Landslide Hazard Scenarios, Sensors, 13, 8285–8302, 2013. F. Calò, D. Calcaterra, A. Iodice, M. Parise, M. Ramondini Assessing the activity of a large landslide in southern Italy by ground-monitoring and SAR interferometric techniques International Journal of Remote Sensing, 33 (11) (2012), pp. 3512–3530 Crostella, A., Vezzani, L., 1964. La geologia dell'Appennino Foggiano. Boll. Soc. Geol. Ital. 83, 121–141 (in Italian). D'Argenio, B., Pescatore, T., Scandone, P., 1975. Structural pattern of the Campania-lucania

Apenines. In: Ogniben, L., Parotto, M., Praturlon, A. (Eds.), Structural Model of Italy. Quaderni de "La Ricerca Scientifica", 90. Consiglio Nazionale delle Ricerche, Roma, pp. 313–327 (in Italian). Guadagno, F.M., Forte, R., Revellino, P., Fiorillo, F., Focareta, M., 2005. Some aspects of theinitiation of debris avalanches in the Campania Region: the role of morphologicalslope discontinuities and the development of failure. Geomorphology 66, 237–254. Guerriero, L., Revellino, P., Coe, J.A., Focareta, M., Grelle, G., Albanese, V., Corazza, A., Guadagno, F.M., 2013a. Multi-temporal maps of the Montaguto Earth Flow in Southern Italy from 1954 to 2010. J. Maps 9 (1), 135–145. Matano, F., 2002. Le Molasse di Anzano nell'evoluzione tettono-sedimentaria messinianadel margine occidentale della microzolla apula nel settore Irpino-Dauno dell'orogenesud-appenninico. Mem. Soc. Geol. Ital. 57, 209–220 (in Italian). Patacca E., Scandone P. (2007) – Geology of the Southern Appennines. Boll. Soc. Geol. It., 7, 75-119. Pescatore, T., Russo, B., Senatore, M.R., Ciampo, G., Esposito, P., Pinto, F., Staiti, D., 1996. La successione messiniana della valle del Torrente Cervaro (Appennino Dauno, Italia Meridionale). Boll. Soc. Geol. Ital. 115, 369–378 (in Italian). Revellino, P.; Grelle, G.; Donnarumma, A.; Guadagno, F.M. Structurally controlled earth flows of the Benevento province (Southern Italy). Bull. Eng. Geol. Environ. 2010, 69, 487–500. âĂČ

Anonymous Referee #3

1. In Section 2, the Authors incorrectly describe the mechanisms that control the landslide motion. The Authors state that "the main acceleration of the landslide occurs when the source slide becomes unstable: due to saturation, which causes increased driving forces caused by temporary increases in pore pressure and the weight of the slide mass". The statement about the pore pressure increase is incorrect. Increased pore pressure does not increase the driving forces, it decreases the resisting forces (or frictional strength) by reducing the grain-to-grain contact of the landslide material. Also, how significant is the increased weight due to the saturation of the slide? Does this really play a major role in causing acceleration at this landslide? It's also important

NHESSD
3, C3332–C3345, 2016

to include more references in this section since the Authors do not show most of the described data. 2. The Authors state " A kinematic wave propagates through the soil mass to advance the toe into the stream". What does this statement mean? Are the Authors referring to the propagation of pore pressure through the slide body? 3. In Section 2, the Authors state that structural, lithologic, and hydrologic controls cause the earthflow to "move slowly and intermittently", but do not explain how these factors conspire to govern landslide motion. Please elaborate. 4. The GB-InSAR data starts in May 2010, two months after the major 'surge' occurred. Are there other forms of data from March 2010? It would be instructive to show the entire 'surge' period from start to finish. 5. In Section 3, the Authors state that the GB-InSAR provides a 2D deformation field. However, I thought GB-InSAR provides only line-of-sight (i.e. 1D) deformation. Are you referring to line-of-sight and time? Please clarify. 6. There is no discussion of error in the data. How do you quantify the error in the GB-InSAR data? 7. Figure 10: The periods of acceleration and deceleration do not seem correct. Acceleration is the second derivative of the displacement time series. There are inflection points along the displacement time series that mark the change between positive and negative curvature.

1) In order to better describe the landslide based on your and other referee's suggestions, authors are providing to enrich the entire section "The Montaguto landslide" following and focusing on the description of all the landslide aspects that are currently missing and describing in the correct way the statement about the pore pressure now incorrect. The section, concerning the also the landslide kinematic will refers to the follow works : Guadagno, F.M., Forte, R., Revellino, P., Fiorillo, F., Focareta, M., 2005. Some aspects of the initiation of debris avalanches in the Campania Region: the role of morphological slope discontinuities and the development of failure. Geomorphology 66, 237–254. Guerriero, L., Revellino, P., Coe, J.A., Focareta, M., Grelle, G., Albanese, V., Corazza, A., Guadagno, F.M., 2013a. Multi-temporal maps of the Montaguto Earth Flow in Southern Italy from 1954 to 2010. J. Maps 9 (1), 135–145.

NHESSD

3, C3332–C3345, 2016

2) This statement refers to the description of the Earthflows kinematic described in HUNGR et. al 2013: As defined by Keefer and Johnson (1983), earthflows constitute a transporting agent between a source slide area and an eroding toe. The source can be one or a series of rotational or compound slides or a weathering and eroding steep face in weak rock. The body of the earthflow slowly deforms, or fails along multiple shear surfaces, producing lobate, flow like morphology. Acceleration ("surging") occurs when the source slide becomes destabilized, usually by a temporary increase in pore pressure. As material in any part of the earthflow tongue accelerates, it over-rides or compresses soil masses downslope, increasing pore pressure through undrained loading (Hutchinson and Bhandari 1971). In this way, a kinematic wave propagates through the soil mass, to advance the toe into a stream, a water body, or another erosional sink. In the manuscript this section will be reported in a more comprehensive way.

3) This section will be discussed elaborating its contents. The references with the previously published paper (Lollino et al. 2014, Allasia et al 2013, Guadagno et al 2005) will enrich this aspect.

4) Unfortunately, there was no real-time monitoring system during the initial reactivation phase. The only available data acquired in September 2009 (six months earlier) consist in a LIDAR survey

5) It is agreed the necessity to clarify this point, since this discussion took part even among the other referees. The nature of deformation measurements is the 1D LOS component. The statement referring the 2D deformation field concerned to the products of the GB-InSAR system that are represented by the processing of interferograms consisting in 2D images and showing an areal distribution of the occurred deformation.

6) Referring to GB-InSAR monitoring it use to talk about the data accuracy, more than error in the data. The displacement accuracy that can be estimated in this case study ranging between 0.5-0.7 mm. Furthermore during the emergency phase the displace-

ment rate (with its maximum value of 3 m/day) was much greater of the displacement accuracy. Authors think that can be more exhaustive a deep description of the technique limitation . (Noferini et al., 2007). Some limitations of GB-InSAR are listed below - GBSAR interferometry requires, as necessary condition, coherent data. This is a critical issue in several application scenarios, especially for D-GBSAR. For this reason, it is recommended to carry out a feasibility study before planning any new D-GBSAR survey. In some cases the lack of coherence can be overcome by deploying artificial CRs, e.g., see Luzi et al. (2010a) or Iglesias et al. (2013). - A critical limitation of the technique is related to the ambiguous nature of the interferometric phases, which can cause biased deformation estimates, especially in those areas that suffer the largest displacements (Crosetto et al., 2014). This limitation is especially problematic for D-GBSAR measurements. A non-interferometric GBSAR approach has been recently proposed, which is less sensitive to deformation but yields aliasing-free deformation estimates (Crosetto et al., 2014; Monserrat et al., 2013). - The applicability of the technique is limited by the LOS nature of the GBSAR sensor: displacements perpendicular to the LOS cannot be measured. In some scenarios, e.g., monitoring vertical displacements in a completely flat area, this constraint can strongly limit the usability of the technique. In addition, the 1D LOS nature of deformation measurements represents a limitation with respect to other techniques that can provide 3D deformation measurements, like total stations, GPS, etc.

7) authors agree with this observation. The focus of this diagram was to show the interval time in which the velocity increased (even with a linear trend) (red area) with respect to the previous interval time (red areas) in which the landslide state was stable. From a graphic point of you, the figure will be modified with regards to the legend, but keeping unchanged the use of the red and green areas.

Please also note the supplement to this comment:
http://www.nat-hazards-earth-syst-sci-discuss.net/3/C3332/2016/nhessd-3-C3332-2016-supplement.pdf

NHESSD
3, C3332–C3345, 2016

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