We express our gratitude to the Reviewer, which pointed out some weaknesses of the manuscript and gave us insights to improve it.
In the following text, we provide a point-to-point reply (AA – authors' answers) to every referee comment (RC).

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RC - In this paper the authors have demonstrated using the mean soil moisture and SIGMAU approach for improvement of regional scale landslide early warning system in the Emilia Romagna Region (Northern Italy). Authors have attempted to reduce numbers of false and missed alarms by the back analysis using landslide events, soil data and rainfall data from the period of 2011 and 2014. From the content as a whole it can be seen that described method and procedure can be integrated into the landslide warning system but further tests are needed before.

AA - The referee centered the point: we performed a back analysis to reduce false and missed alarms by integrating soil moisture measures into a warning system based on rainfall thresholds. We believe that our work proves, with the evidence of data, that the approach is feasible and a reduction of alarms can be obtained. This outcome represents an important intermediate step in our research activity, this is why we selected the "short communication" manuscript type when submitting our work.

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RC - The objectives defined by the authors are quite clear and paper is good structured and the reader can distinguish between material and methods, results and discussion.

AA – Thank you for appreciating the structure of the manuscript.

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RC – The drawback in this manuscript is lack of detailed review of literature about the importance of the soil moisture and antecedent rainfall period that significantly influence on triggering landslides. The authors just mentioned the Italian researches and totally overlooked the important researches form the other European and non-European countries where different natural background prevails as well different climate regime (Kim et al., 1992; Heyerdahl et a., 2003; Crozier, 1999; Glade et al., 2000; Aleotti, 2004, Chleborad, 2003, Zezere, 2005, Jemec Aufli˘c and Komac, 2013, etc.).

AA – We agree with the Referee and we are aware of this drawback. Unfortunately, the manuscript typology (short communication) gave us some limitations (text length, number of references) and we decided to focus the introduction on a limited number of works, with a background similar to our case of study (regional scale analysis, application to EWS). We agree with Referee's comment and in the revised version of the manuscript, we fully addressed this comment, providing an extended literature review with insights on almost all the suggested references (the ones published in international journals). In addition, some Italian references were

deleted to devote more space to works from other parts of the world and to limit the total number of references as requested in the “short communication” manuscript typology.

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RC – The authors should also improve mean soil moisture values by means of reviewing also rainfall events that not triggered landslides where amount of rainfall was above the rainfall threshold (..)

AA – What the referee calls “rainfall events that not triggered landslides where amount of rainfall was above the rainfall threshold”, is reported in the text as “false alarms”. They are fully considered in the test performed by means of the back analysis. Maybe a misunderstanding has arisen because we didn’t define missed alarms and false alarms in the previous version of the text. Now we have modified the text accordingly. In addition, please note that the use of MSM threshold described in 3.1 would never be capable of reducing the false alarms committed by SIGMA, as it acts like a cut-off. In a few words, it reduces the alarms issued by SIGMA, but it does not allow SIGMA to issue additional alarms.

PEVIOUS VERSION OF THE TEXT

A back analysis performed for the years 2009-2014 over the 7 test TUs shows a marked reduction of false alarms: false alarms in the first warning level decrease from 320 to 231 (-28%), false alarms in the second warning level decreases from 169 to 141 (-17%) and false alarms in the third warning level decreases from 13 to 5 (-62%). To correctly evaluate the effectiveness of a EWS, the improvement concerning false alarms should be weighed against the behavior concerning missed alarms. We verified that the introduction of the MSM threshold causes the increase of false alarm counts only by 1. The already mentioned event occurred in 01/06/2013, consisting in three landslides (lowest alarm level according to Lagomarsino et al., 2013). Since this was a very minor event and since lowering the MSM threshold to 54% would result in an almost total loss of the benefits in terms of false alarm reduction, the 75% threshold was considered successfully tested and the 01/06/2013 event was considered an acceptable tradeoff in the light of a general improvement of the warning system.

MODIFIED VERSION OF THE TEXT

A back analysis performed for the years 2009-2014 over the 7 test TUs shows a marked reduction of false alarms (days in which the rainfall thresholds are exceeded but no landslides are reported): false alarms in the first warning level decrease from 320 to 231 (-28%), false alarms in the second warning level decreases from 169 to 141 (-17%) and false alarms in the third warning level decreases from 13 to 5 (-62%). To correctly evaluate the effectiveness of a EWS, the improvement concerning false alarms should be weighed against the behavior concerning missed alarms (days in which the rainfall thresholds are not exceeded but landslides are reported). We verified that the introduction of the MSM threshold causes the increase of missed alarm counts only by 1: the already mentioned event occurred in 01/06/2013, consisting in three landslides (lowest alarm level according to Lagomarsino et al., 2013). Since this was a very minor event and since lowering the MSM threshold to 54% would result in an almost total loss of the benefits in terms of false alarms reduction, the 75% threshold was considered successfully tested and the 01/06/2013 event was considered an acceptable tradeoff in the light of a general improvement of the warning system.

It should be noted that the described use of the MSM threshold is not capable of reducing the missed alarms committed by SIGMA, as it acts like a filter. To obtain a reduction of both missed and false alarms, a more radical modification of SIGMA is depicted in the next section.

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RC – (…) as well indicate why each TU has the same MSM value.

AA – Please note that in every moment, MSM is different for each TU. What is equal in each TU is the MSM value used as a threshold in the EWS. When we took this decision, we had two options: (1) a MSM threshold value different for each TU; (2) same MSM threshold value in each TU. In an optimal condition, we agree with the referee that the first option would be preferable. However, a threshold value requires experimental data (i.e. landslide events) to be correctly defined. We had the problem of several TUs with only few landslide events. For example, TU21 has only 4 landslide events. A purposely developed threshold would be characterized by a very weak empirical correlation. In our opinion, a threshold calibrated against only 4 events cannot be considered valid and cannot be safely used in an operational warning system. We therefore decided to renounce at the "detail" of the personalized threshold in favor of a more robust threshold generalized for the whole test area. Please also note that the tests performed on the back analysis highlighted that our choice reached the objective of reducing false alarms. We modified the text to consider this issue and to address the Referee's comment.
PREVIOUS VERSION OF THE TEXT
We decided to modify SIGMA algorithm using a threshold based on MSM = 75%, equal for all TUs. Basically, the modified version of the algorithm checks the MSM value and uses the module of rainfall only if MSM>75%. Under this threshold, no landslide is expected and the original SIGMA algorithm based on rainfall thresholds does not starts. Above the threshold, landslides could be expected if particular rainfall conditions are verified, therefore SIGMA algorithm is launched.

MODIFIED VERSION OF THE TEXT
We modified SIGMA algorithm adding a cut-off threshold defined as MSM = 75%. Basically, the modified version of the algorithm checks the MSM value and uses the module based on rainfall thresholds only if MSM>75%. Under this threshold, no landslide is expected and the SIGMA algorithm does not start. Above the MSM threshold, landslides could be expected if particular rainfall conditions are verified, therefore SIGMA algorithm is launched. The MSM threshold is equal for all TUs because in some TUs the landslide dataset contains only a few events (e.g. only 4 landslide events in TU21) and a dedicated MSM threshold value would be characterized by a very weak empirical correlation that would prevent a safe use in the RSLEWS. We therefore decided to renounce at the "detail" of the personalized threshold in favor of a more robust MSM threshold generalized for the whole test area.

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RC – According to the above mentioned facts the present paper will be ready for publication after major revisions.
Here are listed specific comments that I would recommend the authors makes.

AA – We deeply modified the text, addressing all issues reported in the previous general comments and in the specific comments hereafter. As a result, sections 1 and 3.1 have been deeply modified. Also sections 2, 3.2 and 4 and have been modified according to the suggestions of Referee#2. All amendments will be highlighted in the revised text.

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RC – Page 1 Line 25: Cardinali et al. 2006 is not listed in the chapter of References

AA – Since we were criticized to have used too many Italian references, and since we need to reduce the reference number, this reference was removed.

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RC – Page 3 Line 9: Please explain how you know “under which landslides never triggered”. Have you done any correlation that for the defined MSM threshold landslides never occurred?

AA – Yes, we did a correlation and we empirically verified what we stated. The revised text is more clear on this point, providing a more in-depth description and showing data. Of course, we refer to the landslides reported in the dataset.

PREVIOUS VERSION OF THE TEXT:

We compared all landslide occurrences in the years 2009-2014 and MSM (mean soil moisture) at each TU. We verified that for each TU a threshold MSM value can be identified under which landslides are never triggered, independently from the rainfall amount.

MODIFIED VERSION OF THE TEXT:

We compared all landslide occurrences in the years 2009-2014 and MSM (mean soil moisture) at each TU. We verified that for each TU a threshold MSM value can be identified under which landslides have never been reported, independently from the rainfall amount (threshold MSM). In addition, we verified that in general TUs have similar threshold MSM, with a few exceptions. Threshold MSM is 75% in TU23 and TU22, 76% in TU18, 78% in TU17, 79% in TU19. In TU21, the threshold MSM is 88%: the value higher than all other TUs can be partially explained with the scarcity of data: only 4 landslide events are included in the testing dataset of TU21. TU20 presents a landslide event with 54% MSM. If we consider this event as an outlier and we exclude it from the analysis, the value is 75% also for TU20.

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RC – Line 14: Please explain and add why you set MSM =75% equal for all TUs? There is no evidence for this. Moreover if the geological setting in each TU is different there must be a difference in MSM values per TUs then.

AA – Actually, we found enough evidence but we acknowledge that we did not show it adequately in the previous version of the text. Now we deeply modified the text, showing data and enhancing the description.

In brief, there are two reasons why we set 75% for all TUs:

- In almost all TUs MSM thresholds are very similar (75%-79%)
- Significantly higher MSM can be found in TU21, but taking this value as a threshold is not feasible because it would be calibrated against a very scarce test sample (see also answer to general comment on this issue).

About the question “why 75%?”, the Referee is absolutely right: why choosing a 75% threshold if a lower value (73%) is found?. This comment allowed us to identify a typo in the text: In the sentence “The MSM threshold varies generally from 73% (TU 23) to 88% (TU 21)”, the number 73 was wrong (probably just a typo): the correct value is “75% (TU 23)”. That explains why we used the 75% value: because it was the lowest threshold found in our test dataset (of course excluding the

outlier). Now the old sentence is not part of the text anymore because we deeply modified the section: all MSM threshold values are listed and it could be seen that 75% is the lowest MSM threshold.
In addition, stimulated by this comment, we searched for a correlation between MSM threshold values and environmental characteristics of the TUs (average slope, average and prevailing aspect class, lithology). We didn't find a clear correlation, maybe just because the MSM threshold range is very narrow (75-79%). This outcome strengthened our belief that the 88% outlier is not due to environmental characteristics but to the scarcity of data. Hence, one more reason to adopt a single threshold value for the whole test area.

PREVIOUS VERSION OF THE TEXT:

As a consequence, taking this limit into account could prevent SIGMA from committing false alarms in case of abundant rainfalls outside the rainy season, when the soil is dry. The MSM threshold varies generally from 73% (TU 23) to 88% (TU 21). The only exception to this rule is TU 20, where an event of 3 landslides occurred in 01/06/2013 with a MSM of 54%, although all the other landslides of the TU occurred with MSM equal or higher than 75%.

We decided to modify SIGMA algorithm using a threshold based on MSM = 75%, equal for all TUs. Basically, the modified version of the algorithm checks the MSM value and uses the module of rainfall only if MSM>75%. Under this threshold, no landslide is expected and the original SIGMA algorithm based on rainfall thresholds does not starts. Above the threshold, landslides could be expected if particular rainfall conditions are verified, therefore SIGMA algorithm is launched.

MODIFIED VERSION OF THE TEXT:

In addition, we verified that in general TUs have similar threshold MSM, with a few exceptions. Threshold MSM is 75% in TU23 and TU22, 76% in TU18, 78% in TU17, 79% in TU19. In TU21, the threshold MSM is 88%: the value higher than all other TUs can be partially explained with the scarcity of data: only 4 landslide events are included in the testing dataset of TU21. TU20 presents a landslide event with 54% MSM. If we consider this event as an outlier and we exclude it from the analysis, the value is 75% also for TU20.

As a consequence, taking a MSM threshold into account could prevent SIGMA from committing false alarms in case of abundant rainfalls outside the rainy season, when the soil is dry. Therefore, we modified SIGMA algorithm adding a pre-filter threshold based on MSM = 75%. Basically, the modified version of the algorithm checks the MSM value and uses the module based on rainfall thresholds only if MSM>75%. Under this threshold, no landslide is expected and the SIGMA algorithm does not start. Above the MSM threshold, landslides could be expected if particular rainfall conditions are verified, therefore SIGMA algorithm is launched. The MSM threshold is equal for all TUs because in some TUs the landslide dataset contains only a few events (e.g. only 4 landslide events in TU21) and a dedicated MSM threshold value would be characterized by a very weak empirical correlation that would prevent a safe use in the RSLEWS. In addition, if we exclude the outliers, all TUs are characterized by small variations in MSM threshold values (from 75% to 79%). We therefore decided to renounce at the "detail" of the personalized threshold in favor of a more robust MSM threshold generalized for the whole test area.

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RC – Linguistic alterations In general the manuscript is written in acceptable English, but some sentences have to be rewritten. Nonetheless, the entire document should be revised by a native speaker.

AA – After all amendments, the text will be revised by an expert.

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On behalf of all authors,
Samuele Segoni