Replies to comments of Reviewers #1, #2 and #3

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We have appreciated all the comments and suggestions provided.

We agree with most of the comments that we considered very constructive and useful to improve the quality of the manuscript. We addressed all suggestions preparing a new version of the manuscript.

Our replies to general and specific comments of Reviewers #1, #2 and #3 are listed below.
Anonymous Referee #1

General comment / remark:

Overview
Two different warning systems against rapid landslide phenomena hazard are shown in present work. The work is, in general, well written but has two main deficiencies:
1) Some details about phenomena and warning thresholds are missing
2) A final comparison between warned phenomena and those occurred is missing

R: We thank Reviewer #1 for point out these deficiencies of the manuscript. We agree with the opinion of the Reviewer #1 and we provided a better explanation in the correspondent chapters. Thank you.

Landslide phenomena “warned” by the two systems seem different.
In the case of ARPA Piemonte shallow landslide, deep landslides and channelized debris flows. ARPA Piemonte has three different forecasting approaches: one for each type of phenomenon. In the case of Norwegian Forecasting Service, the “warned” phenomena are: shallow landslide, debris avalanches, slushflows and debris flows. In this case, the writer supposes that debris flow is landslide induced debris flow. Is it right?
Then, the writer suggests a section after the introduction where all the “warned” phenomena are briefly introduced and schematized. This section would help the reader to focus the phenomena, increasing the value of the work.

R: We thank Reviewer #1 for this comment to our manuscript. The landslide phenomena warned by the two systems are the same, mainly shallow landslides and channelized debris flows, but we agree that, this has not been clearly explained in the manuscript. We improved description of landslide processes object of the study in the introduction.

About Norwegian Forecasting Service, there is an unique threshold for all the type of landslides. Authors should justify this.

R: We thank Reviewer #1 for this comment to our manuscript. Yes, we use only one threshold for all landslide types. The Section 4.2 has been improved.

At the end a comparison between launched warnings and occurred phenomena should very useful for understanding the effectiveness of the warning systems. As in the case above, this should increase the value of the work and consequently its diffusion.

R: Done. Thank you.

Specific comments:

Abstract
Sentences at lines 14-17 (“In Italy,.................in Northwestern Italy.”) are redundant. Just write that in Italy the landslide hazard assessment is not national but provided by the Regional Agency for Environmental Protection and that in present paper it is shown the work of ARPA Piemonte.

R: Revised. Thank you.
Sentence at lines 24-27 is too long.

**R:** Revised. Thank you.

**Introduction**

Sentences at lines 7-16 (“The spatial occurrence……..shallow landslides”) appears confuse. At the beginning rainfall and snowmelt induced landslide are introduced. After that rapid mass movements are introduced and rainfall and snowmelt induced landslide becomes a subcategory of them. Finally, there are the shallow landslides. Authors should to identify all the phenomena they warn to avoid confusion in the reader.

**R:** We completely revised the Introduction according to reviewer suggestions.

At line 19, you could insert the reference Thiene et al., (2016).

**R:** Revised. Thank you.

**The Vb cyclones**

About line 14 of page 3, are you sure about” eastern part of the Alps to NorthWest?”; maybe it could be the contrary.

**R:** This sentence has been revised. Thank you.

**The landslide forecasting services in …**

At line 14 of page 9: “is not based only on a threshold” but also on……..

**R:** Revised. Thank you.

**Piemonte’s landslide forecasting service**

About the use of DEFENSE. What type of weather radar is used? In some cases after using movable weather radar it could be possible reliably estimate the rainfall depth. In a mountain environment in many cases, radar estimates could be not reliable due to the high spatial variability of rainfall and the distance from the fixed weather radar (Germann et al., 2006; Rabiei and Haberlandt, 2015; Bernard et al., 2016).

Authors should introduce some details and cautions on the use of weather radar in a mountain environment.

**R:** Revised and added references on weather radar process chain.

**The Norwegian Forecasting Service**

This section is a bit confused and should be reorganized and rewritten. Initially, it is stated that the daily assessment is built on thresholds, real time observations and landslide events (occurring
during the event?) previous occurred landslides (inventory) and susceptibility maps. It is reasonable that the inventory of landslide be used for determining the threshold. Is not it? Moreover, also runoff is simulated (by which model?): which is the scope if the threshold combine rainfall and snow with the soil saturation degree? In other words, it is better only describe what it is strictly related to the landslide warning. At last most references are not in English language. Therefore, some detail about model could be written in an appendix.

R: We thank Reviewer #1 for this comment to our manuscript. The Norwegian national landslide early warning system is a relatively new system that became operational in 2013. We must admit that one of the major deficiency of the Norwegian system is that, for being operational, we have delayed the publication of scientific English articles that describe entirely the method. Only part of it has been described in conference proceedings and in another article (Piciullo et al., 2017). The system recently has been described in another article submitted to the same special issue and it is under discussion and under revision process. We revised the Section 4.2, providing a clearer description of the system, models and thresholds describing only what is relevant for landslide warning and providing the correct references, eliminating also some irrelevant ones.

**Antecedent condition**
At line 6 of page 13, it is better 5 days instead of 120 hours.

R: Revised. Thank you.

**Piemonte**
What is ECMWF at line 12 of page 14?

R: Revised. Thank you.

In the sentences of pages 15-16 a big emphasis is addressed to the occurred flood and the reaching of warning level in the hydrological network. The writer think that this is eccentric respect to the main object of this work, the landslide forecasting. Therefore, the writer suggests the authors to give a brief description of occurred flood and stress the description of occurred phenomena related to the landslide hazard object of forecasting.

R: Revised. Thank you.

**Warning levels**
The first sentence states that to each warning level corresponds a measure. Is it true? In this case further details will be useful.

R: We thank Reviewer #1 for this comment to our manuscript. Here, we should have used the word “recommended action” instead. Revised.

About debris flows warned (see line 5 of page 20) which radar was used?

R: Revised.

**Suggestions for references:**
R: We thank Reviewer #1 for these recommended references. Added.

- Bernard M., Stancanelli L., Berti M., Simoni A., Gregoretti C., Lanzoni S. (2016) Field results from the runoff generated debris flows occurred at Rovina di Cancia (Venetian Dolomites) XXXV Convegno di Idraulica e Costruzioni Idrauliche – Bologna
Anonymous Referee #2

General comment / remark:

I have read and carefully evaluated the manuscript “Regional landslide forecasting in Piemonte (Italy) and in Norway: experiences from 2013 late spring”, submitted to NHESS by Tiranti et al. The manuscript describes a large cyclone system that struck two very different and distant test sites (Norway and northern Italy). Plenty of details are provided about the event, the related hazard and how it was managed in the two sites. The topic is very interesting and completely centered on the scopes of the journal and of the special issue.

R: We thank Reviewer #2 for finding this manuscript interesting and for the positive feedback. However, what we have here is more a couple of (interesting) event reports than a “real” research paper. Since NHESS does not consider manuscript types such as reports, technical notes, event descriptions and so on, my recommendation is to perform “MAJOR REVISIONS” in order to better highlight and discuss the interesting scientific and research outcomes that I saw in the manuscript. I want to stress that I consider this manuscript a very interesting contribution and that it has a very good potential. It just needs to be put in the right perspective (research-oriented paper instead than an event report). My subsequent comments are aimed to this change of perspective. I encourage the authors to carry on and adjust the manuscript to make it become a high-quality research article.

R: We thank Reviewer #2 for this comment. The manuscript in our opinion is unique, because for the first time two operational systems are compared, looking at what happened and experiences. However, we must admit that we have difficulties to organize the manuscript in a way that we could balance between research and event description. We totally agree that the article, as it is presented, is not a real research article, resembling most to a technical note. We agree that the manuscript needs a major revision if should be presented as research article, and we agree that is worth to try to change it. The manuscript has been completely revised according to reviewers hints.

1 The English is fully understandable and good (although I identified some minor errors). I am not a native speaker, however I suggest to check the text again and especially to split long sentences. They may be hard to follow.

R: Done. Thank you.

2 The manuscript is very rich of details. At the beginning I was positively impressed, but after several pages it got quite boring: the description of the event and of the EWS infrastructures are very good but sometimes the scientific content and the research aspect were missing. And I think those are the main things that NHESS readers are expecting form a research paper. I suggest reducing the description (maybe using a few tables?) and to let research topics stand out from the text (see e.g. my following comments).

R: We thank Reviewer #2 for this comment We tried to follow the valuable remark, however the complexity of topic requested some explanations.

3 Another issue is that the two cases of study stay always kept separated. There must be a point in the manuscript when things are put together and a synthesis is made to highlight new findings of
scientific interest. Maybe a discussion section? Or maybe the tables I suggested at the previous comment could be a synoptic table where differences and similarities from the two sites are highlighted (maybe also replacing long descriptions from the text)?

R: We thank Reviewer #2 for this comment. We added a table, summarizing similarities and differences between the two approaches to landslides EWSs.

4a The idea of comparing the effects of the same perturbation system in two very different places, very distant each other, is fascinating. This should be better stressed and discussed in the manuscript: if the authors go beyond a simple description, this topic has a good research potential.

R: The authors appreciated reviewer remark and they tried to stress it in the paper.

4b Moreover, the analytic comparison of different EWS is a very interesting and quite unexplored topic in the international literature. To my knowledge, only a few works have been published on this topic (e.g. Baum and Godt, 2010; Lagomarsino et al., 2015; Zezere et al., 2015). This is something that should be stressed by the authors to increase the appeal of their work and to correctly place it in an existing research direction that certainly needs to be further expanded.

R: Reviewed. Thank you.

5 A very interesting outcome I saw in your work is that many local or territorial EWS can be integrated in a network, thus providing some sort of a continental or global EWS. Hypothetically, if EWS1 issues an alarm, it could serve as a pre-alarm for EWS2 ... and so on. Your case of study seems to meet this hypothesis. From my point of view, this could be a relevant part of the work. Especially if you connect it with the topic of the lead time (see specific comment).

R: We thank Reviewer #2 for these positive suggestions. We stressed in the work and above all in the conclusions.

6 Following my previous comment and comment #3, you could add a figure showing the timeline of the cyclone. That is, a horizontal line representing time, and bars and signs of different colors showing the temporal evolution of: 1- the rainfall event; 2- the effects to the ground in terms of hazard (floods and, above all, landslides); 3- the alarms issued in the two cases of study. Something like that would strengthen the idea.

R: We thank Reviewer #2. We tried to satisfy your request, but trying not to stretch the manuscript too much.

Specific comments:

ABSTRACT
The abstract should be revised. Usually abstracts are used to summarize what the article is about. Form this abstract it clearly stands out that this article is about describing an event, not about presenting a relevant research outcome. I suggest to perform all due modifications to the text and then to change the abstract reducing the description of the event and to better stress the research outcomes of the manuscript.
R: Reviewed. Thank you.

Line 14-15. I think that in Italy every region has a “body” in charge for the hazard assessments. In some regions it is ARPA, in other it may be another institution. Please also note that this kind of detail is better placed in the test site description or EWS description, not in the Abstract.

R: Reviewed. Thank you.

INTRODUCTION
In my opinion, the authors should identify a gap in the existing state of the art and declare how this work fills the gap and which contribution is provided. Another approach could be to review the literature, to formulate a hypothesis and to check if it is met in the two cases of study.

R: Reviewed. Thank you.

Line 21 : : :system is operational since 1994: : :

R: Reviewed. Thank you.

Line 32 “the same meteorological condition” is not exact in my opinion. How you described later, the meteorological conditions varied from Italy to Norway. Maybe “struck by meteorological events belonging to the same perturbation system”?

R: Reviewed. Thank you.

SECTION 2
LINE 3: I suggest rephrasing with “In particular, Central Europe: : : are sources of : : :”

R: Reviewed. Thank you.

SECTION 3
Fig.2. In the caption, use Fig. Instead of Figu. And consider explaining that “TO” stands for “Torino”.

R: Reviewed. Thank you.

SECTION 4.2
I think there is a little confusion. I understand that this is a complex system but it is not clear how you combine very different inputs (thresholds, meteo observations, susceptibility maps, models and expert knowledge) before arriving to the hazard assessment.

R: Changed according to suggestions of all reviewers.

Line 11. How you observe rainfall conditions? Radars like in the previous test site or rain gauges?

R: Done.

Line 13. Which models?
R: Improved description. Thank you.

Line 19. Maybe this is the name of the threshold system or the warning system, rather than the name of the threshold?

R: Done.

Line 21. Which threshold? Can you provide a threshold equation like you did in the previous test site?

R: We thank Reviewer #2 for this question that allow us to explain better the thresholds in use. The thresholds are used as a strong indicator for increased landslide hazard, at a regional scale. Since the thresholds are based on daily values only, they are not comparable to traditional ID-thresholds. Also, since the thresholds were derived from tree-classification technique, the threshold consists of several linear equations generating thresholds with a latter shape. Currently, Norway is divided into three climate domains, each having individual thresholds, however it is based on the same combination of hydrometeorological conditions (water supply and soil water saturation, fig. 6A). The domains are SE-Norway (dry continental climate), southern-most part of S-Norway (medium wet climate with sparse soil coverage) and the rest of Norway (wet coastal climate). Threshold analysis and development is in progress, and new domains are expected in the future. Also, a paper documenting the work is being prepared. Generally speaking, thresholds indicate increased landslide hazard when values of water supply are higher than 6-8% of the mean annual precipitation combined with a simulated soil water saturation degree higher than 60% (Fig. 6A). The spatial distribution of the thresholds is visualized as raster data (with 1-km² resolution) at xgeo.no. A regional impact displayed is required to consider issuing a warning. Xgeo.no is a web portal that assist experts in the daily forecast of floods, snow avalanches and landslides (Fig. 6d). Here, prognosis and simulated parameters are daily published for the next six days (Devoli et al., 2014). Reviewed according to the comment.

Line 31. Twice a day

R Done.

SECTION 5.2.1
Page 16 lines 7-8: please check the sentence.

R: Done.

SECTION 5.3
Line 8: please check the sentence.

R: Done.

DISCUSSION
The paper misses a discussion of scientific aspects. That should be the core of a research paper. In the discussion section all data gathered and showed in the previous sections should be put together to highlight new findings (if any). Which lessons have been learnt? How the results of this work can be used by the scientific community? Which advances to the state of the art have been achieved?
CONCLUSIONS
Lines 9-11. To be honest, it is not completely clear to me how the Norwegian forecasting service works. Especially in the Norwegian case study, it is not clear which models have been used, how they are integrated together, what is automated and what is left to expert judgement. Of course, references have been provided, but I think it is better to have a few more details to understand the scientific base of the tools operated here.

Page 26, line 2. “susceptible to that”. I suggest rephrasing.

Line 6 “back analysis”. The paper does not present a back analysis (i.e. the modeling of a past event), just a description/report of the event.

Lines 8-9. This is one of the most interesting findings of you work. There is a constant struggle in the scientific community to increase the lead time of forecasting systems.

Here you show that you can increase it enormously by putting different forecasting services in a network. You should set the stage properly to this sentence, touching this issue in the abstract, in the introduction and in the discussion. Also lines 22-26 are connected with this point.

Suggestions for references:

REFERENCES
This manuscript has a very large number of references. But I see many references that are not “robust” references e.g. they are written in Italian or Norwegian, they are reports or conference abstracts. I suggest limiting this kind of references to the essential ones and to give priority to peer-reviewed articles written in English and published in international journals.

In addition, consider adding references to papers contained in the same special issue and already published in NHESS or in NHESSD: some of them are very well connected with your case of study or with the topic of your manuscript.


R: Done.

Anonymous Referee #3

General comment / remark:
The article describes two landslide warning systems adopted by two regional forecasting services located in Norway and Italy, respectively. The purpose of the work is sharing the experiences from the two different systems, which is an interesting and promising target. However, I have some concerns on the effective scientific contribution of the paper to the NHESS journal readers, at least in its actual form. My impression is that the presentation is not well oriented to a sound scientific analysis. Probably, the submission as a technical note, would be more appropriate.

R: We thank Reviewer #3 for this positive comment. We agree that in the present form the article is closer to a technical note than a research article. Based on these comments and those from reviewer #1 and #2 we changed the manuscript emphasizing research topics.

Please, read in the following my main concerns.

1. The analyzed study cases are interesting. In section 6 the observed events are describe, as well as the occurred landslides. I wonder why a validation is not presented. I suggest to add an objective evaluation of the system results by using objective metrics, such as AUC, ROC, etc.

R: We thank Reviewer #3 for finding this case interesting. We agree that a section, in which the systems and cases are better compared, and results validated, is missing. However, the main focus of the paper is to present that the same weather system caused landslides in two different regions in Europe and experience with the warning messages issued, by two quite similar forecasting services. More extensive validation of impacts (type of landslides and economic consequences) could be part of another article.

2. The two case studies share the same triggering meteorological event. However, the geology and the susceptibility to landslide may be different. I would describe the effects of the same event by emphasizing the similarity and/or the differences of the effects on the two areas and of the two warning systems. Are the types of landslide the same (which actually depend more on the type of soil and slope)? Which are the main differences in terms of areas prone to landslides??This would add more value to the choice of describing these two case studies together.

R: We thank Reviewer #3 for this comment. Yes, we agree that the geological, topographic similarities and differences of the two regions, also in terms of landslide processes could have been better presented and eventually discussed the susceptibility of the regions instead of a detailed geological description. We better explained similarities in the landslide processes and warning systems, according also to the comments from reviewer#1.
3. With regard to the Piemonte’s landslide forecasting service, 3 different systems are described; however, it is not clear how and if the three systems interact and how the overall service operate. Does the use of one or other model depend on a presusceptibility analysis or are they applied to the entire area anyway?

R: Done.

4. Literature review lacks of some contributions in the specific field of early warning system for landslide. I suggest to add some contributions at p2L11. (i.e. Baum and Godt, 2010; Liao et al., 2010; Segoni et al., 2015; Pumo et al., 2016).

R: Done

Specific comments:

Please, read in the following my minor comments.

1. P3L2: revise verb of the sentence.

R: Done

2. P3L17: you could include also April.

R: Typos error. We limited our discussion to May rainfalls.

3. P5: description of geology is very technical. To facilitate the not geological reader, authors could emphasize the relation of the types of geology domains with the rainfall triggered landslide (as done in the Norway case). E.g. which are the domains most susceptible to rainfall-triggered landslides?

R: Done.

4. Fig.2a: a map of DEM with hillshade would be more useful and direct. Please improve the quality of the figure and locate Italy in Europe.

R: Done.

5. Fig.2b: to not geological readers, the map of the geological domains does not give information about the propensity to landslides. Actually, it would be preferable to show the slope distribution, which have a clear correlation with landslide, or maybe simplifying the map. Please improve the quality of the figure.

R: Done. We compared geological settings with landslides density map.

6. Fig. 4: . Please improve the quality of the figure and locate Norway in Europe. Again, DEM and slope distribution would be more helpful than fig.4a.

R: Done.
7. P9L20: remove ‘slope phenomena’; it is specified later.

R: Done.

8. P13L3-8: initial conditions are mentioned: please specify at the beginning the selected period for the analysis otherwise it is not clear to what the initial conditions refer to. Description is a bit generic (e.g. “temperature lower than the normal”, p13L3). Do you have statistics? Could you quantify?

R: “Initial condition” stands for “Antecedent conditions”. Corrected.

9. P13L6: is this an annual maximum? Same for p13L10 (“the winter was cold”), too generic.

R: Clarified.

5. P14, Section 5.2: authors state that the analyzed event had significant impacts in southern Italy. This is in contrast with the choice of Piemonte (northern Italy) as study case! I suggest to modify the sentence.

R: Modified according reviewer hint.

10. P14L8: In the abstract the period April 27 – May 19 is mentioned. Please, be clear with the selected period.

R: Revised.

11. P15L5: Please, specify the duration of recorded rainfall.

R: Done.

12. Is fig.8 important? How about reporting the maxima precipitation daily intensity or the total precipitation?

13. Fig.9: you could add the historical hyetograph measured in one station (e.g. in Turin).

R: Done.

14. Fig.11: please improve quality of figures. Please note that the colors in the map (e.g., light green) do not correspond with those in the legend (e.g. yellow or orange). Is there any transparency effect? Please, solve it, for example, by removing background colors.

R: Done

Suggestions for references:


R: Done. Thank you.
Comparison of the landslide forecasting services in Regional landslide forecasting in Piemonte (Italy) and in Norway, illustrated by events in experiences from 2013 late spring 2013

Davide Tiranti¹, Graziella Devoli², Roberto Cremonini⁴, Monica Sund⁵, Søren Boje²
¹Regional Agency for Environmental Protection of Piemonte (ARPA Piemonte), Department of Natural and Environmental Risks, Torino, 10135, Italy
²Norwegian Water Resources and Energy Directorate (NVE), Section for forecast of flood and landslide hazards, Oslo, 0368, Norway
³Department of Geosciences, University of Oslo, Oslo, 0316, Norway

Correspondence to: Davide Tiranti (davide.tiranti@arpa.piemonte.it)

Abstract

A few countries in the world operate systematically national and regional forecasting services for rainfall-induced landslides (i.e. debris flows, debris avalanches and shallow slides), among them: Norway and Italy. In Norway, the Norwegian Water Resources and Energy Directorate (NVE) operates a landslide forecasting service at national level. In Italy the Regional Agency for Environmental Protection, ARPA-Piemonte, is responsible for issuing landslide warnings for the Piemonte region, located in Northwestern Italy. A daily national hazard assessment is performed, describing both expected awareness level and type of landslide hazard for a selected warning region. Both services provide regular landslide hazard assessments founded on a combination of quantitative thresholds and daily rainfall forecasts together with qualitative expert analysis. Daily warning reports are published at http://www.arpa.piemonte.gov.it/rischinnaturali and www.varsom.no.

On spring 2013, the ARPA Piemonte, and the NVE issued warnings for hydro-meteorological hazards due to the arrival of a deep and large low-pressure system, called herein “Vb cyclone”. This kind of weather system is known to produce the largest floods in Europe. Less known is that this weather type-pattern can trigger landslides as well.

In this study, we present the experiences acquired in late spring 2013 by NVE and ARPA Piemonte.

The meteorological perturbation Vb cyclone influenced the weather in Europe, and in both countries, for a long period time from the end of April until the beginnings of June 2013. However, mayor affectations were observed in the first half part of this period in Piemonte, while in Norway, major damages were reported across a period from 15th May to 2nd June 2013. From 27th April to 19th May 2013, more than 400 mm rain in Piemonte caused severe floods and diffused landslides. In Norway it brought warm winds with high temperatures that caused intense snow melt over a large area, and a lot of rain especially in the Southeastern Norway. This initiated a large flood along Glomma river and several landslides. Floods and landslides produced significant damages to roads and railways along with buildings and other infrastructure in both countries.

This case study shows that large synoptic pattern can produce different natural hazards across Europe, from sandstorm at low-latitudes, to flood and landslides when the system moves across the mountain regions. These secondary effects were effectively
forecasted by the two landslides warning services, operating across Europe. The landslide risks were also properly communicated to the society with some days in advance. This analysis has allowed to establish a fruitful international collaboration between Arpa Piemonte and NVE and the future exchange of experiences, procedures and methods under similar events. This event case study shows that large synoptic pattern can produce different natural hazards across Europe, like sandstorm at low latitudes, and flood and landslides when the system moves across the mountain regions. Moreover, comparing two EWSs that operate in different countries, the study demonstrates their effectiveness in issuing warnings in case of large-scale synoptic forcing. Furthermore, it raises the need of strictly international collaborations between operational. They can be predicted with some days in advance and even weeks, for the case of Norway. It is important that the different forecasting services follow the system since the initial stage to be better prepared. Services on landslides warning.

1 Introduction

One of the targets proposed by the Sendai Framework (UN, 2015) is to substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information to people by 2030 (UN, 2015). It also emphasizes that there is need for enhancing preparedness, response, rehabilitation and reconstruction, in order to prevent natural disaster risk and that, response actions must be focused within and across sectors, by States, at local, national, regional and global level. UNISDR (2009) defined an early warning system (EWS) as “a set of capacities needed to generate and disseminate timely and meaningful warning information to enable individual, communities and organization threatened by a hazard to act appropriately and in sufficient time to reduce the possibility of harm or loss”. To be efficient, EWSs should include four elements: the knowledge of the physical mechanisms that cause the hazard and the exposed elements at risk; the technical capacity to continuously monitor the hazard and to develop changing scenarios to issue warning; the communication of the warning and the capacity to translate the prediction into warning and action plans (Cloutier et al 2015). Worldwide there are many EWSs currently operated for various types of natural hazards, including landslide hazards. Landslides represent a serious hazard in many countries, causing yearly significant loss of lives (Petley 2012; Haque et al., 2016) and large damages to infrastructures. Landslides are defined as “the movements of a mass of rock, debris or earth down a slope” (Cruden and Varnes, 1996) and are classified based on the failure mechanisms and the type of material (Hung et al., 2014). However, other parameters like rate of movement (e.g. velocity), size, depth of sliding surface, among others, can be used to classify them. Using the velocity as a criteria, the so-called “rapid landslides” are those with velocity >1.8 m/hr, and being “extremely rapid” the ones with velocity larger than 5m/sec (Cruden and Varnes, 1996). Sometimes it can is sometime be usefull to classify landslides based on the type of triggering factors, thus expressions like “earthquake-induced landslides”, “rainfall-induced landslides”, “precipitation-induced landslides”, “weather-induced landslides” and “snowmelt-induced landslides” are often used in literature (Baum and Godt 2001; Calvello, 2017; Katsura et al 2008; Rodriguez et al 1999; Havenith et al., 2016). The landslides triggered by intense rainfall events, both short- or long-duration, are in general called “rainfall-induced landslides” or “precipitation-induced landslides, while if abundant snowmelt is causing them, as the term
“snowmelt-induced landslides” is often used. The expressions “weather-induced landslides” or “rainfall-snowmelt-induced landslides” has been used as general term to include both landslides triggered by rainfall and/or those triggered by snowmelt, especially in high-mountainous areas covered by snow where they can occur simultaneously especially during spring.

The landslide types triggered by rainfall and snowmelt episodes are usually in the category of slide- and flow-type landslides based on Hungr et al. (2014). The following types are commonly observed:

- **a)** soil slides (e.g. clay/silt planar slides) and debris slides (e.g. gravel/sand/debris slides) are usually of small size (<5000 m³), shallow slides with a sliding surface 1-2 m deep that occur within the soil material or at contact with the underlying less permeable bedrock (as also observed by Zêzere et al., 2015). They are planar slides, however, a few rotational ones may occur, especially in clay/silted soils.

- **b)** Debris avalanches occur often in open slopes, initiating as shallow planar soil- or debris slide.

- **c)** Debris flows and debris floods occur usually in steep channels, starting as stream bed erosion or by a soil slide, debris slide or debris avalanche from a steep bank, entraining material downslope. See Hungr et al., (2014) for more details.

These three types develop in steep slopes and are characterized by high rate of movement, varying from rapid to extremely rapid events. They occur in different types of soil, residual soils, colluvial, pyroclastic, fluvial and tills deposits or organic soils. Close to infrastructures and to buildings, soil slides may occur in artificial loose fills. They are triggered by short duration rainfall events due to rapid infiltration and percolation of water in the thin soil material.

Debris flows are known to be the most destructive ones, because of their high velocity and long runouts, but debris avalanches are also quite destructive as they usually occur in clusters and due to their potential to spread out in the depositional area. Soil- and debris slides, even if relatively shallow and of small size, occur in clusters, causing significant damages to infrastructures and even loss of lives if they occur close to inhabited areas. They occur over a large area all at the same time and often simultaneously with floods making damages much more extensive.

The occurrence of these types of landslides has become more frequent and, as population and infrastructures have increasingly expanded into landslide-prone areas, their impacts on society have become more dramatic. Recent studies shows that these could be potentially enhanced under a changing climate (Stoffel et al., 2014; Gariano and Guzzetti, 2016 and reference therein).

Effective landslide warnings have become essential elements of integral risk management worldwide, since they are a cost-effective risk mitigation measure and in some regions the only suitable option for a sustainable landslide risk management (Glade and Nadim, 2014). EWSs for landslides are designed to detect events that precede a landslide in time to issue an imminent hazard warning (Di Biagio and Kjeckstad 2007) and initiate actions to mitigate and to reduce the potential damages and allow people to get to safety.

The development of landslide EWSs has not been uniform worldwide, and a few public resources have been invested in the past for their establishment, probably because the landslides losses are perceived as private economical losses, like in USA (Baum and Godt, 2010). Apart from the case of Hong Kong, where the first landslide EWS was organized in 1977 and still operative since then (Chan et al., 2003), in other countries, is at the end of the 1990s that most of the EWS started to be
developed (D’Orsi et al., 1997). In the 1980s, in USA, there were two attempts of EWSs. The first recorded debris flow early warning attempt was done in the spring of 1984 in the state of Utah, while in The San Francisco Bay area of California the first experimental operating landslide EWS started in 1985, but a decade later were closed, because of loss of personnel and lack of adequate funding (Baum and Godt, 2010).

EWSs are technical feasible for some types of landslides. Overview and classification of existing landslides EWSs are presented in Thiebes et al., 2012, Bazin et al., 2012 and later Stähli et al. (2015). These last authors have proposed an overview and a classification of existing early warning systems for rapid mass movements (e.g. debris flows and snow avalanches) where three main categories are identified: (i) alarm, (ii) warning and (iii) forecasting. Another recent summary of existing weather-induced landslides EWSs is presented in Calvello (2017) in which the systems are distinguished in local and territorial. The literature shows that many local early warning systems exist at specific sites, for rockslides, deep-seated complex landslides and debris flows where extensive monitoring instrumentation provides detailed information (i.e. Bardoux et al 2009; Blikra et al., 2013; Cardellinotti-Cardinaletti et al., 2011; Michoud et al., 2013 and references therein). The territorial (or also called regional) EWSs have acquired importance in the last 15-20 years and especially after the Hyogo framework for Action (2005-2015), adopted by the World Conference on Disaster Reduction (UN-ISDR 2005). They are mainly constrained to forecast the occurrence of rainfall-induced landslides (i.e. Osanai et al., 2010; Baum and Godt, 2010; Tiranti and Rabuffetti, 2010; Jakob et al., 2012; Liao et al., 2010; Huang and Hong 2010; Jakob et al., 2012; Lagormarsino et al 2013; Ponziani et al., 2013; Pumo et al., 2015; Segoni et al., 2014; Lagormarsino et al 2013; Tiranti and Rabuffetti, 2010; Ponziani et al., 2013; Huang and Hong 2010; Ortigao et al., 2001; Pumo et al., ).

Many countries have spent last decades working on preparing the technical basis for early warnings, by understanding landslide initiation, defining rainfall thresholds, installing real-time monitoring instruments and organize prototypes of landslide warning systems, but a few of them operate systematically effective territorial landslide warnings services became operational. The countries that made those efforts are those ones where landslides historically represent a significant hazard, or in developing countries were little resources are available for physical mitigation measures, but for the latter documentation is often missing. In agreement with other authors, e.g. Segoni et al., 2015; in general the potential of EWSs is not yet fully exploited by governments and decision-makers.

A broad range of literature exists on the definition of empirical rainfall thresholds for the possible landslide initiation or description of components of systems. The thresholds are based on rainfall, soil moisture or hydrological conditions that when reached or exceeded are likely to trigger a landslide (Ref…). The threshold may refer rainfall, soil moisture or hydrological conditions with various types and extents of slope failures. In the prevention of rainfall- and snowmelt induced landslides at regional/territorial level, the recognition of the relationship between large-scale patterns and landslides occurrence is important to investigate. The synoptic weather and landslides occurrence has been demonstrated in a few works (Ref…). This because large-scale meteorology… Large-scale patterns such as the El Niño and the North Atlantic Oscillation (NAO) change slowly and have been shown to have an impact in both the precipitation regime and the temporal occurrence of different landslide types in different areas of the world have been demonstrated. In 2005, Trigo et
al. found connections between the North Atlantic Oscillation (NAO) index and the occurrence of landslides in Portugal. Wood et al. (2014) investigated the distribution of debris flows in Iceland was also investigated by Decaulne and Sæmundsson (2007). Large synoptic weather systems (LSWS) mainly influence the occurrence of debris flows in Iceland. The occurrence of landslides in Norway is proposed in Devoli et al. (2014) and Boje et al. (2014); Devoli et al. (2017) are not national but in each administrative region has its own regional landslide threshold and definition. In this study, we present two examples of territorial forecasting and warning services for rainfall and snowmelt-induced landslides successfully operating in Piemonte, north-western Italy, and in Norway. Norway and Italy have a long tradition of flood forecasting, but only in (relatively) recent years, efforts are made to design, develop and operate landslide forecasting services, often in synergy with flood and/or snow avalanche forecasting. The Norwegian Water Resources and Energy Directorate (NVE) operates a landslide forecasting and warning service at national level (in Norwegian “Jordskredvarsling”) since 2013. The service is relatively new. Since its beginnings, the attention has been on the establishment and implementation of the service at national level, instead of describing its function to an international audience. The emphasis has been on the establishment and training of forecasters, on the development of existing web tools used for flood and snow avalanche forecasting to contain landslide related parameters and thresholds, on the establishment of routines, implementation and updating landslide thresholds and definition of warning and performance evaluation criteria (Colleuille et al., 2017; Devoli et al., 2014; Boje et al., 2014; Boje et al., 2014; Devoli et al., 2017). The performance of the service was recently tested using the Event, Duration, Matrix Performance (EduMaP) in Piciullo et al. (2017) and the description of the entire service is proposed in (Krøgli et al., in review, 2017; submitted).

In Italy, the landslide hazard assessment and warning system (Regional Environment Agency (Regional Agency for Environmental Protection, ARPA)) is responsible of the daily landslide hazard assessments and emission of landslide warnings. An important role in the implementation of EWSs in the Region Piedmont is played by the Regional Water Resources and Energy Directorate (Zêzere et al., 2015). In this study, we compare two examples of forecast and warning services for rainfall and snowmelt-induced landslides successfully operating in Piemonte, north-western Italy, and in Norway. The main objective of this study is to show how the
In this study, we present two examples of territorial local forecasting and warning services for rainfall and snowmelt-induced landslides successfully operating in Piemonte, northwestern Italy, and in Norway. In this analysis, we explain that the weather synoptic systems, known as Vb cyclones, are often responsible of intense rainfall events, and the associated high temperatures producing intense snowmelt in many European countries at the same time during spring, triggering not only large floods but also a large number of landslides. Quite often forecasting services focus on the analysis of the climatic and meteorological conditions in their own region, forgetting that the rainfall can be part of larger processes and landslide can occur across municipalities, regions and even countries at the same time. An example is the landslides triggered by Hurricane Mitch in 1998 across the Central America countries (i.e., Bucknam et al., 2001; Cannon et al., 2002) or the landslides triggered by the storm Desmond the 4th and 5th December 2015 in the UK and in Norway. Specifically, the study discusses how cooperation between countries multidisciplinary EWS and increased forecast leading times knwoled of where pattern can enhance the time factor to improve the early warning want also. The work also shows how the two services are organized and how operated using landslide forecasting experiences from spring 2013 and compare them, showing similarities and differences. In this analysis, we explain that the weather synoptic system, known as Vb cyclones, are often responsible of intense rainfall events, and the associated high temperatures produce intense snowmelt in many European countries at the same time during spring, triggering not only large floods but also a large number of landslides. Landslides triggered by rainfall and snowmelt are not isolated events or restricted to a specific single slope, but they may have a regional distribution. Quite often forecasting services focus on the analysis of the climatic and meteorological conditions in their own region, forgetting that the rainfall can be part of larger processes and landslide can occur across municipalities, regions and even countries at the same time. An example is the landslides triggered by Hurricane Mitch in 1998 across the Central America countries (i.e., Bucknam et al., 2001; Cannon et al., 2002) or the landslides triggered by the storm Desmond the 4th and 5th December 2015 in the UK and in Norway.

Although the two areas are located at different latitudes, both ones are characterized by complex orography and similar geologic surficial processes. Moreover, according to Peel et al. (2007), both Norwegian and Italian Alps belong to the same Köppen–Geiger climate class. Hereafter, the two regions are described.

3.1 Piemonte region, Italy

The Piemonte region is complex from a geomorphological and geological point of view. Its territory is shaped by mountain environments (Western Alps and subordinate Appennine with peaks ranging from 1000 to 4800 m asl), hills (Torino Hill, Monferrato hills and Langhe with an elevation range of 400-700 m asl), and alluvial plains (200-300 m asl), surrounded by the Alps and Apennines on three sides (Fig. 12a). The Western Alps are characterized by a complex double-verging structure with...
asymmetrical transversal cross-section (Roure et al., 1990, 1996; Pfiffner et al., 1997), subdivided into three main structural sectors. (1) Southalpine domain characterizes the Internal sector (the collisional system upper plate consists in Hercynian and pre-Hercynian bedrock formed by lower continental and upper mantle rocks). (2) Helvetic–Dauphinois domains constitute the External sector, representing the European foreland zone, formed by Hercinian intrusive massifs system and Mesozoic flysch cover. (3) Frontal thrust of Pennidic domain and the Insubric front (Malusà and Vezzoli, 2006) bound the Axial sector formed by Hercynian and pre-Hercynian continental rocks and Hercynian metasedimentary formations, oceanic lithosphere rocks and ocean fronting continental boundaries and orogenic flysch units. During the Quaternary, wide glaciers occupied alpine valleys and modeled by glacial pulsations. Locally, glacial landforms and deposits were modified by Holocene fluvial/torrential processes, associated with widespread landslides (Soldati et al., 2006).

The geology of hilly environment is mainly formed by Oligocene-Miocene sedimentary strata, originated during the Tertiary Piemonte Basin where the lowest term of sedimentary sequence is formed by shallow-sea deposits, while deep marine environment (turbidite deposits up to 4 km thickness) represents the upper part of the sedimentary sequence. The stratigraphic succession is due to Oligocene marine transgression made by the alternation of marls, sandstones and shales (about 5-50 cm thickness); strata dipping NW with 8°-15° inclination. Sin-sedimentary tectonics controlled the thickness and lateral interdigitations of the stratigraphic successions. The northward movement of the Padan thrust belt (Falletti et al. 1995) caused the progressive uplifting of the basin followed since Langhian. The sedimentary sequence lies on alpine metamorphic units by unconformity (Biella et al. 1987, 1992; Gelati and Gnaccolini 1988). Appennine units are poorly represented within the borders of Piemonte, mainly represented by Ligurian, Subligurian and Epiligurian units (Fig. 12b).

Fig. 12: A) Physiography of Piemonte. "TO" stands for Torino; B) Slope distribution of Piemonte; C) Density distribution of shallow landslides (from 1962 to 2016) compared with the Geological/structural sketch map of Piemonte: 1. Quaternary; ALPS: 2. Austroalpine domain (pre-Alpine crystalline basement and Palaeozoic cover); 3. Pennidic domain (Permian–Mesozoic–Tertiary
metamorphic cover; 4. Pennidic domain (Helmhinitoid Flysch Units); 5. Penninic domain (pre-Triassic crystalline basement); 6. Helvetic domain (Permian–Mesozoic cover); 7. Helvetic domain (pre-Alpine crystalline basement and Carboniferous cover); APENNINE and HILLS: 8. Internal margin foredeep deposits; 9. Epiligurian Sequences (episutural basins deposits unconformably covering the Ligurian units); 10. Epiligurian Sequences (“Oligo-Miocene” of Langhe); 11. Ligurian and Subligurian Units (nappes, locally ophiolitic-bearing); a. Front of tectonic units (limits of different paleogeographic domains); b. Neotectonic deformation zones.

As shown in Fig. 2B, the main occurrence of shallow landslides (density interpolation map of 33000 shallow landslides occurred from 1962 to 2016) is in correspondence of the Epiligurian Sequences (“Oligo-Miocene” of Langhe - hilly environment), the Helvetic domain (pre-Alpine crystalline basement and Carboniferous cover - Northwestern Alps), the Penninic domain (pre-Triassic crystalline basement - Northern Alps), the Internal margin foredeep deposits (hilly environment) and the Epiligurian Sequences (episutural basins deposits unconformably covering the Ligurian units - Torino Hill) TO stands for Torino.

The spatial distribution of annual rainfall shows high precipitation in the northern areas with more than 2,100 mm per year, and low in the eastern part of the plains with less than 700 mm per year (Fig. 2B). The monthly distribution of precipitations in Piemonte shows a bimodal distribution, with two high peaks during spring and fall, and two minimums, during winter and summer. Four rainfall regimes (three continental ones and one Mediterranean) can be distinguished;

- Prealpine: dry season during winter, main maximum during spring and secondary maximum during fall;
- Subcoastal: dry season during summer, main maximum during fall and a secondary maximum during spring;
- Subalpine: dry season during winter, main maximum during fall and secondary maximum during spring;
- Subcontinental: dry season during winter, main maximum during fall and a secondary maximum during summer.
**Fig. 23:** Mean Annual Precipitation (MAP) in Piemonte from 1913 to 2012 (source: Arpa Piemonte).

### 32.2 Østlandet region, Norway

The region Østlandet in southeastern Norway also has a complex geomorphological and geological setting. The region includes eight administrative counties (Fig. 4a). The highest mountains are located in the northern and western part of the area with maximum elevations up to 2469 m. asl, observed in the Jotunheimen area. The region is mostly hilly, with dominant landforms represented by glacially scoured valleys directed N-S in the eastern sector, while NW-SE in the western sector that congregate on to the Oslofjord (Fig. 3a). The valleys Østerdalen and Gudbrandsdalen are the longest in the country. The region contains also some very large areas of lowland surrounding the Oslofjord. The longest river and watercourses, Glomma, and
the biggest lake, Mjøsa, are also located in this region. Southeastern Norway contains extensive areas with forest and rich arable land. From a geological point of view, this region is dominated by bedrock of the Baltic shield, characterized by Precambrian basement rocks (e.g. granites, granodiorite, gneisses, amphibolites, rhyolite, gabbro, diorite and meta-sediments). In the northern sector rocks within the Caledonian orogen (e.g. sandstone, schist, amphibolite, micaschist, phyllite conglomerate) prevail. Cambro-Silurian sedimentary rocks (e.g. shale, limestone, phyllite) and Permian volcanic rocks (syenite, granite monzonite, porphyritic rocks and basalt) occur within the Oslo Graben (Solli and Nordgulen, 2006).

Quaternary deposits that cover the bedrock are mainly left by glacial processes. Continuous till deposits cover large areas of the hilly mountains and valley sides and floors, with a variable thickness from 0.5 to a couple of meters. The bottom of the valleys is mainly covered by thick fluvial and glaciofluvial deposits. Till deposits have a large heterogeneity in terms of granulometry and composition. The amount and the composition varies as function of the bedrock, in some places the till deposits are covered by landslide deposits occurred after glaciation. Marine clay deposits are observed in the southern sector of the region. Most of the rainfall-induced landslides in the region occur in proximity of steep slopes, (Fig. 3b) covered by till deposits, especially where there is a large clay mineral that reduce the water infiltration and provide more surfical runoff. The red areas in Fig. 3c, show were landslides susceptibility is high in the region. Two sectors are most prone to landslides: the steep slopes of N-S and NW-SE oriented glacially scoured valleys, covered by till deposits, where mainly debris flows and debris avalanches are observed, and the southern sector, where marine clay deposits are prevalent. Here clay slides may form and also quick clays slides, these triggered mainly by human activities.
Based on Köppen classification, the climate of the region is varying from a Tundra type (ET) in the Northwestern part, to Subarctic (Dfc) in the central part. The Warm-summer humid continental type (Dfb) and Oceanic type (Cfb) are mainly observed in the southern sector and along the southern coastline. In this region, the climate is mainly characterized by cold winter and warm summer. The amount of precipitation in form of rainfall and snow varies depending on the area (i.e. valley floor and mountain), but in general this area is the driest of Norway with low precipitation and mostly during summer. Deficit of precipitation are observed at Skjåk where the annual precipitation is of about 317 mm (water equivalent) or Biri with 754 mm annual precipitation. The area has a normal stable snow cover during winter, with normal annual maximum (1971-2000) around 1000 mm in the mountain (Fig. 45). The annual medium temperature ranges from -7°C in the mountain area to 7°C in the coastal area.
4.3 The landslide forecasting services in Piemonte region and in Norway

Following, According to Calvello (2017), the warning services, herein presented are classified as “territorial” (Calvello, 2017), and, based on Stähli et al. (2015), they can be classified as both “forecasting-type” and “warning-type” services (Stähli et al., 2015), because they predict the level of danger and the occurrence of multiple landslides over a warning area and at regular intervals (e.g., daily), but also because data interpretation and the initial alert area is based on predefined thresholds. Experts consult models, thresholds and they analyze sensor data observations to decide and forecast the...
regional danger levels, which are communicated widely in a bulletin. The main goal of the services is to save lives, to reduce landslide risk for roads, railways and settlements, also increasing safety and predictability. In addition, to contributing to a better foundation for emergency preparedness at local level, the service provides continuous information on the situation conditions and expected development to national and regional authorities and the public.

As stated in section 1, both the services are designed to forecast the occurrence of rainfall- and snowmelt induced landslides, as indicated in chapter section 1.5, in particular i.e. shallow soil slides, landslides and debris slides, debris avalanches, and debris flows (Hungr et al., 2014). However, the Norwegian one service is also responsible for the warning of slushflows (Hestnes, 1985). Tab. 1 summarizes the main characteristics of the services herein described, showing similarities and differences.

Tab. 1 – Characteristics of the EWSs from Arpa Piemonte and NVE

<table>
<thead>
<tr>
<th>EWS</th>
<th>Piemonte, Italy</th>
<th>Norway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operators</td>
<td>Arpa Piemonte (Regional government)</td>
<td>NVE (National government)</td>
</tr>
<tr>
<td>Activated</td>
<td>1994-2008</td>
<td>2013</td>
</tr>
<tr>
<td>Status</td>
<td>Operative (daily)</td>
<td>Operative (daily)</td>
</tr>
<tr>
<td>Type of landslide types</td>
<td>Shallow translational slide; channelized debris flow; rotational slide; shallow landslide; channelized debris flow; debris avalanches; debris flows</td>
<td>Shallow translational slide; channelized debris flow; debris avalanches; slushflows</td>
</tr>
<tr>
<td>Type of triggering</td>
<td>Rainfall and snowmelt</td>
<td>Rainfall and snowmelt</td>
</tr>
<tr>
<td>Thresholds for different type of landslides</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Threshold parameters</td>
<td>Rainfall from rain gauge</td>
<td>Water supply (rain + snowmelting) and soil moisture, interpolated from HBV model (Beldring et al., 2003)</td>
</tr>
<tr>
<td>Type of thresholds</td>
<td>1D thresholds for Alpine and Hilly environments for shallow landslides; Radar hourly intensity rainfall thresholds for debris flows in alpine catchments; Antecedent precipitation thresholds for translational/rotational slides in hilly environment</td>
<td>1D and 2D thresholds; Water supply vs. degree of soil saturation; Water supply vs. degree of soil saturation + landslide susceptibility; Water supply vs. degree of soil moisture + soil frost; Water supply vs. degree of soil saturation + landslide susceptibility; Hydmet Soil frost: Water supply vs. degree of soil moisture + soil frost</td>
</tr>
<tr>
<td>Regional/local thresholds</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Tabella formattata...
<table>
<thead>
<tr>
<th>Methods for thresholds obtained</th>
<th>Statistical approach (Tiranti and Rabuffetti, 2010; Tiranti et al., 2013; Tiranti et al., 2014)</th>
<th>Statistical approach (Boje et al., 2014) Simulated from HBV model (Balbi et al., 2014)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weather forecast Meteorological input</td>
<td>COSMO I7 NWP model: for the first three day with 6h resolution; Weather Radar QPE and Storm Tracking nowcasting (COSMO I7 NWP model: for the first three days) with six hour resolution;</td>
<td>AROME MetCoOp model for the first 3 days as raster maps 1-km² resolution; AROME MetCoOp model for the first 3 days, provided with a 24h and 3h resolution; EC model for the remaining 3 days as raster maps 1-km² resolution</td>
</tr>
<tr>
<td>Monitoring instruments</td>
<td>Multisensor weather ranges (~400); two weather radars</td>
<td>Multisensor weather gauges (~400); Groundwater level (~80); water discharge (~350); other instruments (snow water equivalent; soil water content and soil temperature)</td>
</tr>
<tr>
<td>Released warning</td>
<td>Before 1:00PM</td>
<td>Before 11:00AM and before 3:00PM</td>
</tr>
<tr>
<td>Forecast valid</td>
<td>From 1:00PM to 12:00AM</td>
<td>From 7:00AM the day of publication to 7:00AM the following day (8AM to 8AM Daylight Saving Time)</td>
</tr>
<tr>
<td>Warning days</td>
<td>36 h (D0 and D1)</td>
<td>3 first days (D0, D1 and D2)</td>
</tr>
<tr>
<td>Warning zones</td>
<td>Fixed (catchment)</td>
<td>Variable (county/group of municipalities)</td>
</tr>
<tr>
<td>Warning levels</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Warning web page</td>
<td><a href="http://www.arpai.piemonte.gov.it/rischinnaturali">http://www.arpai.piemonte.gov.it/rischinnaturali</a></td>
<td><a href="http://www.varsom.no">www.varsom.no</a></td>
</tr>
<tr>
<td>Broadcast media</td>
<td>Internet</td>
<td>Internet, CIM (Crisis Information Management)</td>
</tr>
<tr>
<td>Available susceptibility map</td>
<td>1:100000 scale (Tiranti and Rabuffetti, 2010); Alpine catchments (Tiranti et al., 2014)</td>
<td>Catchment level (Bell et al., 2014)</td>
</tr>
<tr>
<td>Landslide database</td>
<td>&gt;35000 landslides and debris flows</td>
<td>&gt;57000 mass movements</td>
</tr>
<tr>
<td>Monitoring</td>
<td>More than 400 multisensor weather gauges; two weather radars</td>
<td>Groundwater; water discharge</td>
</tr>
<tr>
<td>Warning days</td>
<td>36 h (D0 and D1)</td>
<td>3 first days (D0, D1 and D2)</td>
</tr>
<tr>
<td>Warning levels</td>
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<td>4</td>
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</tr>
<tr>
<td>Released warning</td>
<td>Before 1:00PM</td>
<td>Before 11:00AM and before 3:00PM</td>
</tr>
</tbody>
</table>

1 Landslides + snow avalanches + submarine landslides
43.1 Piemonte’s landslide forecasting service

The Regional Warning System for Geo-Hydrological hazards of ARPA Piemonte includes three independent slope phenomena early warning systems (EWSs), based on empirical rainfall thresholds and designed ad hoc for different typology slope processes, whose triggering is generally determined by precipitation with different intensities over different accumulation periods and durations:

- **DEFENSE (DEbris Flows triggEred by storms – Nowcasting SystEm)** is operated to forecast channelized debris flows occurrence in small alpine basins. DEFENSE works by the intersection in GIS environment between alpine catchments, classified by the Clay Weathering Index, and instantaneous rainfall intensity (mm/h) provided by the weather radar using a storm-tracking algorithm (Tiranti et al., 2014). The use of quantitative precipitation estimations (QPEs) by the C-band weather radar is limited to alpine areas where the radar visibility is good and uncertainties limited. More details on the operational weather radar operated by ARPA Piemonte can be found in Davini et al. 2011; Cremonini and Bechini 2010.

- **SMART (Shallow landslides Movements Announced through Rainfall Thresholds)** is operated to forecast shallow landslides in mountain area (zone 1) and hilly environments (zone 2). Thresholds equations in the two zones are:

\[
I = 25D^{0.45} \quad \text{(Zone 1)} \tag{1}
\]

\[
I = 40D^{0.65} \quad \text{(Zone 2)} \tag{2}
\]

Where \(I\) is the rainfall mean intensity (mm/h) and \(D\) is the rainfall duration (h). More details are reported in Tiranti and Rabuffetti (2010).

- **TRAPS (Translational/Rotational slides Activation Prediction System)** is operated to forecast deep-seated translational and rotational slides in the hilly environment. TRAPS analyses the 60-days antecedent precipitations, measurement including water deriving from snow melting (Tiranti et al., 2013).
ARPA Piemonte daily evaluates EWSs response to issue a regional warning to Civil Protection municipalities and citizens on slope processes occurrence. All the EWSs responses are displayed and managed through a WebGIS interface (Fig. 5) that allows a real-time estimation of hazard scenarios induced by observed and/or forecasted weather conditions. All the Piemonte EWSs are operative 24h/7d and automatic warnings are issued by e-mail and SMS to experts when the threshold is reached and/or exceeded.

Fig. 5: Examples of EWSs WebGIS interface. a) DEFENCE: storm’s cells are ellipses, lines are storms’ path, yellow polygon is the catchment affected by debris flow triggering rainfall intensity; b) SMART: dots represent the rain gauges linked to shallow landslides triggering thresholds; c) TRAPS: polygons represent the areas characterized by different probability for translational landslides activation (white = low/null probability; yellow = medium probability; red = high probability); d) an example of SMART thresholds (red dashed line) representation related to accumulated rainfall (blue area) recorded by rain gauges; e) an example of TRAPS diagram: blue dots are the
The landslide assessment is done by a forecaster who daily consults the weather forecasts, the landslides thresholds and others relevant hydro-meteorological parameters. This information is available in form of raster data with 1-km$^2$ resolution and presented as thematic maps at link xgeo.no, a web portal that assist experts in the daily forecast of floods, snow avalanches and landslides (Krogli et al., in review 2017; Krogli et al., submitted). Here, weather prognosis, forecasted thresholds and hydro-meteorological parameters, are published daily for the next six days. The portal also visualized past interpolated weather observations, thresholds and others parameters. Besides the thematic maps, the forecaster on duty may need to consult real-time hydro-meteorological observations, in particular groundwater level or water discharge values at specific stations within the possible warning area. These data are also available in the same web portal xgeo.no.

The weather prognosis, temperature and precipitation, are obtained from AROME MetCoOp model (used in the Scandinavian regions as short-term forecast model for the first 3 days) and EC model (a global long-term European model, for the remaining 3 days). They are provided with a 24h and 3h resolution. Temperature and precipitation are also used as input variables in two hydrological models (Krogli et al., in review 2017; Krogli et al., submitted). The main model is a distributed version of the conceptual HBV-model (Beldring et al., 2003) that divide the country in grid-cells, each one modelled as a separate basin with a corresponding water balance simulation. From temperature and precipitation as input variables, the model simulates forecasted hydro-meteorological variables like, rainfall and snow melting, water supply, degree of soil saturation, ground water level compare to normal, soil frost depth, water feed capacity, etc. In addition to HBV, the second model tool, used in addition to HBV, is a physically based model, S-Flow, developed by NVE, that simulates water and heat dynamics in a column of layered soil covered by vegetation. The model uses also temperature and precipitation, but it requires also wind speed, relative air humidity and solar radiation as input data.

Unlike other countries, Norway does not use the classical Intensity-Duration thresholds. Based on Guzzetti et al. (2002), the threshold used in Norway can be classified as “other thresholds”, because they are based on analysis of historical landslides and water supply (e.g. rain and snowmelt) and the degree of soil water saturation (Fig. 6a and 6c). Both parameters are simulated from HBV model (Fig. 6b and 6c). The first parameter is the water supplied to the soil from rain and snowmelt and is expressed as percent of yearly normal water supply in the reference period 1981-2010, and is the product of simulated snow_melt and interpolated precipitation. The second parameter is the degree of soil saturation described as percent between the present soil water content compared to the maximum soil water content in the same reference period. The thresholds were derived using tree classification system. Generally, the thresholds indicate increased landslide hazard when values of water supply are higher than 6-8% of the mean annual precipitation combined with a simulated soil water saturation degree higher than 60% (Fig. 6a and 6c). Three thresholds are used to separate conditions similar to warning levels of green, yellow, amber and red level. Since the thresholds were derived from tree-classification technique, the threshold consists of several linear equations generating...
thresholds with a latter shape. The thresholds are unique for all landslide processes. They were derived initially for the entire country, from few storms events in south Norway (Colleuille et al., 2010), but, recently, the thresholds were defined for specific regions (Boje et al., 2014; Boje, 2017). In particular, they were defined for three topographic-geological and climate domains, SE-Norway, dry continental climate; S-Norway, medium wet climate with sparse soil coverage, and the rest of Norway, wet coastal climate. Threshold analysis and development is an ongoing work, and new domains are expected in the future. The spatial distribution of the thresholds is visualized as raster data (with 1-km² resolution) at xgeo.no (Fig. 6d). A regional impact displayed is required in order to consider issuing a warning. Recently the thresholds has been combined with landslide susceptibility maps at catchment levels and a better thresholds is available that help to reduce the area of warning. Expert knowledge is fundamental in the daily landslide hazard assessment, and to decide the final level assessment and the extension of the warning level. An organization flow chart is presented in Piciullo et al., 2017. The warning area is not a fixed zone but can be a single county, a group of counties or a group of municipalities. The forecast is valid from 7AM the day of publication to 7AM the following day (8AM to 8AM Daylight Saving Time). The assessment is done by utilizing observations and prognoses developed by the Norwegian Meteorological Institute (MET Norway), and the service has daily communication with the meteorologist on duty. The service also works closely with the Norwegian Flood Forecasting Service and the assessment of slushflows is carried out with support from the Norwegian Avalanche Centre. The service is established in cooperation with the Norwegian Public Road Administration (NPRA) and the Norwegian Railway Administration (Bane NOR) (Krøgli et al., submitted).
Fig. 6a: Landslide thresholds and WebGIS interface xgeo.no. a) national landslide thresholds based on simulated degree of soil saturation and water supply obtained from HBV model; b) Map of simulated degree of soil saturation. The percent describes the relationship between today's soil water storage compared to the maximum soil water storage simulated with the HBV-model in the reference period 1981-2010; c) Map of simulated water supply (rain and snowmelt) the last 24 hours as percent of yearly normal water supply in the period 1981-2010, and is the product of simulated snow melt and interpolated precipitation; d) The web interface xgeo.no with the Hydmet landslide thresholds map in the background. The map represents the national landslide thresholds presented in a) and, obtained combining the maps in b) and c). The maps in b), c) and d) are examples from the 22nd May 2013 and extracted from xgeo.no.

24 The Vb cyclones

Floods and landslides are important secondary effects of high-impact weather events, like tropical and extra-tropical cyclones, as they are accompanied by extremely strong winds and heavy precipitations. Central Europe and the northern Alpine region are exposed to high-impact events associated to the Vb cyclones (Messmer et al., 2015). This type of cyclone was mentioned by Köppen (1881) and later defined by Van Bebber (1882 and 1891) who proposed a cyclone classification based on the main storm circulation trajectories in Europe (Messmer et al., 2015; Roald, 2008), describing one of them as Vb. In later classifications like the GWL/SVG classification proposed by James (2007) this synoptic weather regime is known as 11 TM.
«Tief Mitteleuropa=Low (Cut-Off) over Central Europe», while in the GWT classification is known as “TME Central European low”.
The origin of Vb cyclones is either the Bay of Biscay, the Balearic or the Ligurian Sea, where moisture uptake occurs. The cyclone moves eastward over the southwestern part of France and over the Mediterranean Sea, where it refills with moisture and energy. Then, Vb cyclones move across Northern Italy and the Adriatic Sea before they turn northward to the Black Sea or Saint Petersburg, and finally to North-West towards Scandinavia (Fig. 71).
The Vb cyclones are characterized by very warm and humid air masses from the central Atlantic and Mediterranean, with cold air masses linked to depressions in the northern part of the Atlantic forming a quasi-stationary front with extremely heavy rainfall (Fig. 71). The synoptic configuration is linked to blocking anticyclones in the North Atlantic and over Finland or the Kola Peninsula. This type of weather circulation occurs typical on July or August, but in recent years it has been observed in late spring (April, May and June).
Most of these studies on Vb cyclones have presented case studies of floods induced by Vb cyclones, and focusing on analyzing the source of moisture, while few studies focused on analyzing the decrease or increase of number of cyclones. A description of the basic climatology of this weather type is provided in Messmer et al. (2015), given insight into the Vb cyclones variability and investigating their physical mechanisms.
These cyclones transport large amounts of atmospheric moisture to the central Europe and northerly side of the Alps, thus triggering extreme precipitation events (Messmer et al., 2015). The potential of transporting extreme precipitations to central Europe is especially high if these cut-off low systems are positioned in the northern or eastern parts of the Alps (Awan and Formayer, 2016). There is agreement among authors on the large-scale dynamics of Vb events, which indeed seem to determine whether a Vb cyclone delivers high precipitation or not (Messmer et al., 2015). Even if they are rare events, 2.3 per year (Messmer et al., 2015), the Vb cyclones are highly relevant for Europe because of their potential to produce extensive precipitation and subsequent floods, particularly, during the warm season, and often in Austria, Switzerland, Germany, Poland and the Czech Republic. The Vb cyclones are well known, among hydrologists and meteorologists, to have caused most of the largest floods in Central Europe, in the Elbe, Danube, or the Rhine catchments and in the Alpine area, like the: “1000-year flood” in 1342 in rivers Elbe, Danube, and Main; the Oder flood in July/August 1997; the flood in Elbe and Danube in August 2002; the floods in Austria and Switzerland in August 2005. Less mentioned in international literature is the fact that this type of weather is responsible of extensive floods events and of triggering landslides, also in the southern sector of the Alps and in Norway. Roald (2008, 2012 and 2015) documented many flood events caused by Vb cyclones in southeastern Norway, like the flood in July 1789, the one in 1860 and the more recently the flood in June 2011, among others.
5 Meteorological conditions in late spring 2013

The meteorological perturbation pattern that affected Europe in late spring 2013 started at the end of April 2013 and lasted until the beginnings of June 2013. In Piemonte major impacts were observed in the first half of this period, while in Norway from 15th May to 2nd June 2013.

5.1 Antecedent conditions

The analysis of the initial conditions shows that the winter 2012/2013 was relatively cold (-0.23 °C respect the 1977-2001 average temperature) and dry (-52% respect 1977-2001 average precipitation) in both countries with temperature lower than normal while the period from March to May it was still cold in Piemonte from March to May, but wetter than in Norway. On March, Antecedent conditions in Piemonte were characterized by rainfalls in Piemonte were above normal with +30% above normal on March and heavy precipitations happened on the end of April. Between 27th April and 1st May 2013 several rain gauges in northwestern Piemonte recorded more than 200-250 mm in five days (against 175 mm average April precipitation).

At the end of the spring the recorded anomaly in precipitation was +65%, resulting the second wettest season in Piemonte since 1900.
In southeastern Norway, the period January-April 2013 was cold and dry than normal and characterized by cool air from North (Roald, 2015). The average temperature was 2-3° below the normal in this area especially in the interior northwestern part close to the mountains. The spring arrived late. The period January-April was characterized by precipitation deficit in many areas. The precipitation was 90% of the normal in the entire country, however southeastern Norway received only 25% to 50%. In southeastern Norway, the winter 2012-2013 was cold, especially on January and March, and characterized by cool air from North (Roald, 2015). The spring arrived late. The period January-April was characterized by precipitation deficit in many areas. The snow depth was lower than normal and thus ground frost deeper than normal. In May, the warm air from south and south-east initiated snow melt in the mountains. Fig. 7-8 shows the snow distribution in Norway during April-May 2013. By On the middle May, there was still snow at elevation higher than cover above 700m asl and more snow depth than normal in the western part of the area. On May the precipitations were +200-500% above average, especially in the western parts of the area.

Fig. 7-8: Snow distribution a) middle of April, b) end of April and c) middle May, Norway (source: xgeo.no)

5.2 Meteorological conditions during the period analysed

The meteorological perturbation Vb atmospheric pattern influenced the weather in Europe, and in particular in Italy and Norway, for a long period during spring 2013, from the end of April until the beginnings of June 2013. In retrospect, it could be observed that the Vb weather regime was relatively easy to follow across the Mediterranean Sea. In the initial phase, the Vb cyclone was responsible of strong winds (up to 120 km/h) that produced sandstorms at Malta and southern Italy (particularly in Sicily and Calabria region), the 15th and 16th May 2013 with some impacts to the population (Meteoweb,
While the system moved toward Northern Europe, it was responsible of producing intense rainfall in proximity of the western Alps. The Vb system continued to Northern Europe bringing warm air at higher latitudes and rainfall when it arrived in southern Norway.

5.2.1 Piemonte

From 15th May 2013 to 19th May 2013, an intense cold front affected Piemonte, causing abundant precipitations, a general increase of rivers discharge and vast areas of Piemonte were affected by floods and landslides.

On 15th May 2013, a trough blunder on Western Europe conveyed warm and wet flows from south towards Piemonte, causing widespread precipitations that intensified especially in Northern Piemonte and on the border areas with Liguria. Fig. 8-9 shows the mean sea level pressure analysis by the global numerical weather prediction model operated by the European Centre for Medium-range Weather Forecast (ECMWF) on 16th May 2013 at 00:00 UTC. The main low-pressure system is centered over the North Sea, while a secondary low one is near North Africa coasts: the isobars determine intense southern humid air-flow from Mediterranean Sea towards Scandinavian Peninsula.
Widespread moderate locally strong localized precipitations affected Piemonte during night. In the Po valley were recorded on average 30-40 mm rainfall with 45.6 mm maximum over 24 hours. About 20-25 cm fresh snow were recorded in the Alps above 2000 m asl. On 16\textsuperscript{th} May 2013, the low-pressure area, responsible for severe weather, gradually moved towards Biscay Bay, continuing to convey wet and unstable air over Piemonte. However, an increase of atmospheric pressure in Ligurian Gulf caused an attenuation of meridional flows and a general attenuation of precipitations. In the late evening, the cold front associated with the low-pressure crossed Piemonte, causing instability and convective rainfall, more intense over the northwestern footpath. Close to Turin (TO in Fig. 2a), the Po river reached the alarm level meanwhile downstream the river approached warning thresholds. The minor hydrographic network reached also warning levels close to Turin and in the southern catchments. On 17\textsuperscript{th} May afternoon, the cold sector, which affected Piemonte over past 48 hours passed, favoring a general attenuation in the rainfalls. However, atmospheric post-frontal instability caused sparse thunderstorms, particularly on the western foothills, where the interactions between southern flows and alpine foothills caused strong connection with abundant hail: hourly precipitation rates reached even 40 mm. Discharges of minor hydrological network increased as result of severe thunderstorms.

On 18\textsuperscript{th} May 2013, the occluded front passed Piemonte from west to east. The wet airflow remained intense from the south, the sea level pressure increased, favoring the precipitation exhaustion, except for northern Piemonte where rainfall terminated during central hours. The rainfalls between Saturday and Sunday resulted in significant increases in rivers discharge both in northern and southern basins. Attention levels of were reported on secondary hydrological network, particularly in the basins near Turin. In the upper part of Tanaro catchment also attention levels were recorded. Po river levels stabilized around attention levels upstream and downstream Turin in the morning and in the afternoon sections in the afternoon. Over the entire period, more than 300 mm fell in western areas with peaks of 350 mm in 96 hours (Fig. 9, 10). The return period for 3-6 hours rainfall accumulation were about 20 years. Finally, several catchments recorded more than 600 mm considering rainfall accumulations since 1\textsuperscript{st} March 2013 to mid-May, several catchments recorded more than 600 mm.
As example of rainfall distribution during the event, the isogram recorded by the Camparient rain gauge (red dot in the accumulated rainfall map) is showed.

5.2.2 Norway

It is well known, in Norway, that Vb cyclones can produce the largest floods during spring (Roald, 2008). Therefore, the flood forecasting service at NVE, pays attention, each year, to these weather conditions in southern Europe. The arrival of the Vb cyclone on May 2013 was forecasted with some weeks in advance by mentioning the possible arrival of a warm weather system from south (as it was indicated in a “situation report” published the 3rd May). The temperature starts to increase around the 5th May in the mountain area, starting the snow melt process. A short decrease in temperature was observed on 14th - 15th May and 22nd May before and in correspondence of the two main rainfall episodes. The temperature reached the highest peak on 18th and 19th May, causing significant snow melting in the area. Due to the arrival of several warm air fronts the temperatures continued to increase constantly until the end of May.

The first rainfall arrived on 15th - 16th May and most of in the easterly counties of Telemark and Buskerud (Fig. 10a). In Eggedal station were measured 60 mm in 24 hours. In this area, many hydrologic stations reach the flood level (Fig. 10b) and in Eggedal the water discharge was the fourth highest since registration started in 1972, resulting in a big flood.
Precipitations started in the western counties, moving eastward. A second and more significant rainfall episode occurred on the 22nd and 23rd May affecting mainly the Glomma and Østerdalen catchments in the eastern sector of the region (Fig. 11d). This initiated a large flood along Glomma river. In Østerdalen were measured 50-60 mm that day, while in Gudbrandsdalen values ranged from 50 mm to 93 mm. An overview of the rainfall and temperature distribution during May 2013 in the Gudbrandsdalen area is presented in Fig. 11c. The two rainfall episodes, in addition to the incoming snowmelt, were responsible for the increase of groundwater in the region and to produce high water discharge in many of the rivers in the area (Fig. 11e). In Folla river a 100-year return period was measured, while in Numedalslågen and Skien catchments a 30-year return period flood was observed (Roald, 2015). In Drammen river at Begna, Etna and Dokka station the flood reaches the 50-year return period (Fig. 11f). At Gausdal and Gudbrandsdal river the flood was estimated to be between 50 and 100-year return period. The Vb situation persisted from 15th May – 2nd June and caused also intense rainfall and urban flood in the capital Oslo on the 2nd of June.

The warning levels indicate the landslide hazards and generally the actions that a recipient should undertake to reduce potential damages. Both services at ARPA Piemonte and NVE use four similar levels symbolized by the typical traffic lights colors, summarized in the Tab. 24. Even if the numbering of the levels is different, the meaning of the he-warning is similar. Emergency response authorities should be prepared to implement emergency plans, mitigation measures, carry out evacuations and other contingency responses. Hazard and risk maps are mandatory to help local authorities to prioritize the implementation of measures.
Tab. 24 – Warning levels in use in Italy and Norway, with their respective local names.

<table>
<thead>
<tr>
<th>Warning level</th>
<th>Italy</th>
<th>Norway</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>3</td>
<td>4</td>
<td>Very high landslide hazard. Many landslides and several of large dimensions may occur; their long runout and extent may result in damage to settlements and infrastructure. Red level is an extreme situation that occurs very rarely. Emergency response authorities should have implemented emergency plans, appropriated safety measures, such as closed roads, and carry out evacuations. Follow authorities’ recommendations.</td>
</tr>
<tr>
<td>Orange</td>
<td>2</td>
<td>3</td>
<td>High landslide hazard. Many landslides and some of large dimensions are expected. Incidents that can impact infrastructure and roads may occur. Emergency response authorities should increase vigilance, and should be prepare to implement emergency plans, evaluating the needs for evacuation and carrying on safety measures. Exposed roads may be closed off. Pay attention to media and follow recommendations from the authorities.</td>
</tr>
<tr>
<td>Yellow</td>
<td>1</td>
<td>2</td>
<td>Moderate landslide hazard, primarily small slides may occur, on artificial slopes that may affect roads, railways or along river embankments. Sparse debris avalanches or debris flows (also of large dimensions) may also occur causing damage to infrastructure and people, but primarily on a local scale. Emergency authorities should increase vigilance and pay attention to weather conditions and landslide forecasts. Preventive measures are recommended.</td>
</tr>
<tr>
<td>Green</td>
<td>0</td>
<td>1</td>
<td>Generally safe conditions. Debris avalanches, debris flows, shallow slides and slushflows are not expected at this level.</td>
</tr>
</tbody>
</table>

In Norway, warning levels are updated two times a day. The warning messages are sent from 66 h to a few hours ahead.

On 15th May 2013 the first warnings in Northwestern Alps and in central hilly areas about possible debris flows and landslides were issued by ARPA Piemonte (Fig. 11). Then, according to observed precipitations and updated NWP outputs, the warning levels remained stable over Alps, while alerted hilly areas reduced. According to observed rainfall occurred during 18th May and the first hours on 19th May 2013, warning for local floods, debris flows and landslides was newly issued for central Piemonte.
Landslide warnings issued from the 15th to the 20th May 2013 in Piemonte region (source: Arpa Piemonte).

A first flood warning was sent in Norway the 14th May 2013, followed by a first landslide warning (orange level) on 15th May, for parts of the southeastern region. A yellow level was kept from 16th to 20th May. On 21st May the level was increased to orange and on 22nd May was also added a red warning level (Fig. 12). Different landslide warnings were issued every day.
until the end of May as shown in the Fig. 13. From 16th May until the end of May a yellow warning was also sent for Northern Norway.

The severity of the rainfall and snowmelt episode that occurred on 22nd May was clearly detected with some days in advance when the Hydmet map shows that landslide thresholds would be exceeded (Fig. 13).
In Piemonte, after these rainfall events, about 320 slope phenomena have been reported (300 landslides and 20 channelized debris flows) (Fig. 14). The main landslide types occurred were wide shallow landslides, deep-seated rotational slides in alpine and hilly areas, and subordinated reactivation of some translational slides in hilly environment. The territory hit by slope and flood processes (Fig. 15) covers an area of 3,700 km² with about 420,000 inhabitants. In affected areas, important connecting routes are sited, including international ones. Due to severe phenomena occurred, numerous cases of traffic interruptions by landslides and flood were reported, as well as flooding of buildings, deposition of coarse alluvial sediments on roads, bridges jammed by debris flows, roadside walls collapse, erosion of roads surface, urban flooding and people trapped in cars. Rainfall event caused wide discomforts and damages to the community, both in relation to normal social cohabitation and economic wealth.
**Fig. 1415:** Some examples of slope phenomena recorded during rainfall event. a) Road interrupted by a debris flow; b) a building hit by small rotational slide; c) shallow landslides on a road (source: Regione Piemonte).
Fig. 15: A) Landslide processes occurred during the rainfall event. B) Reported landslide damages (source: Arpa Piemonte).

Fig. 17 shows the warning areas issued (in yellow) and the municipalities where landslides were reported (in red): the derived contingency table gives a probability of detection (POD) equal to 0.70 (benchmark equal to 1) and a false alarm ratio (FAR) equal to 0.63 (benchmark equal to 0).
Fig. 17: Warning issued and observed wide landslides area during the event.
In Norway, more than 100 landslides were recorded in the database (www.skredregistrering.no) in this region between 15\textsuperscript{th} May and 7\textsuperscript{th} June. Mainly the events that reached roads and railway were recorded, but we believe that many more have occurred, but they have not been reported due to their location in less inhabited areas. Fig. 10a-11a shows the spatial distribution of landslides during the first rainfall event and Fig. 10d-11d shows the landslides occurred during the second rainfall event. In both figures are also indicated the areas where the road was blocked because of flood. The landslides observed were mainly debris flows and a combination of debris slides and debris flows, however most of them have been reported generically as landslides in soil (Fig. 16). There were many shallow slides in artificial cuts, mainly translation of small dimensions or along river sides. A few slushflows were also reported, especially in the northern sector of the region in the mountains. The landslides events and floods produced significant damages to roads, railway and private buildings and the economic losses were estimated around ~170 M\textsuperscript{I} € (~1.5 bill NOK) for 22\textsuperscript{nd} May. Many places were evacuated for several days. There were 350 cases of damage and 23 municipalities asked for mitigation measures in Hedmark and Oppland. The same system triggered landslides and floods in Northern of Norway, but this is outside the scope of this paper.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Figures.png}
\caption{Flood and landslides at Kvam, Nord Frøn, Oppland county 22\textsuperscript{nd} May 2013. A) and B) Flood and flood damages at Kvam; C) Debris slide at Ringebu; D) debris flow at Veikleåadalen E) shallow debris slide and debris flow deposits at Kvam; F) Debris flow at Veikleåadalen (Source: NVE).}
\end{figure}

7 \textbf{Conclusions}
Two territorial landslide forecasting and warning services operating in two European countries, Italy and Norway, have been presented and compared. They were designed to predict rainfall- and snowmelt induced landslides, general term used to refer to rapid mass movements, like shallow translational and rotational slides, channelized debris flows, debris avalanches. The Norwegian system is also able to predict slushflows. The organization of both services started at governmental level in the late 2000’s as part and in synergy with flood and snow avalanches forecast services. Using statistical methods landslide thresholds were derived. Rainfall ID thresholds are used in Piemonte defined for the different types of landslides, while in Norway a unique threshold based on water supply (rain and snowmelt) and soil moisture is used for all type of landslides and for the entire country. However, regional adaptation of the thresholds are in progress. Landslide thresholds can be visualized in form of maps in their respective web interfaces and expert tools. Daily landslide hazard assessments are made on the basis of expert knowledge combined with quantitative thresholds, regular rainfall forecasts and real-time observations. Both services use four warning levels, that are published and disseminated through internet. Information from news, field survey are used to verify the landslide occurrence. The evaluation of the performance of the systems is under development.

7 Discussions and conclusions

- Even if the Piemonte and Norway forecasting services worked separately, they could emitted accurate warning messages at regional level that were extremely useful for road and railway administrations and municipalities. Based on these messages, the stakeholders could prepare the implementation of activated timely emergency plans, mitigation measures, carry out evacuations and other contingency responses before the events.

It is important that the different forecasting services follow the system since the initial stage to be better prepared.

by the Norwegian Water Resources and Energy Directorate (NVE) in two ways:

a) creating a network of experts working in the prevention of rainfall-induced landslides that were gathered together during an international workshop in Oslo in October 2016 to establish a forum for exchange of knowledge, challenges and best practices among those working with operational forecasting services for rainfall-induced landslides (Devoli, 2017);

b) promoting collaborations with specific institutions to study specific events: besides the one described herein with ARPA Piemonte, NVE is collaborating with the British Geological Survey to compare forecasting experiences and to better understand “westerly” synoptic systems, that move across the Atlantic in the autumn, causing landslides in UK and in Norway (like the storm Desmond, the 4th and 5th December 2015, described in Dijkstra et al., 2016 and Boje et al., 2016).

This study demonstrates the good skill and usefulness of shallow landslides EWSs in case of large synoptic forcing like Vb cyclones in different countries. However, international collaborative efforts among natural hazards prediction centres operating in different countries are mandatory, because they can improve knowledge in natural hazards associated to these large synoptic systems increasing forecasting services effectiveness.
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