Available online at www.sciencedirect.com

ScienceDirect

Procedia Earth and Planetary Science 16 (2016) 166 – 176

Procedia
Earth and Planetary Science

The Fourth Italian Workshop on Landslides

Assessing the potential effects of Climate Changes on landslide phenomena affecting pyroclastic covers in Nocera area (Southern Italy)

Alfredo Reder[a,b]*, Guido Rianna[a], Paola Mercogliano[a,c], Luca Pagano[b]

[a]*Regional Models and geo-Hydrological Impacts,CMCC Euro-Mediterranean Center on Climate Change, Via Maiorise, Capua 81043, Italy*
[b]*Dipartimento di Ingegneria Civile, Edile ed Ambientale, University "Federico II", Via Claudio 21, Napoli 80125, Italy*
[c]*CIRA – Centro Italiano Ricerche Aerospaziali, Via Maiorise, Capua 81043, Italy*

Abstract

The effects of Climate Changes (CC) on natural hazardsinduced byweather forcing representan issue which has beenwidely debated inthe last years.Climate projections allowed to detect clear indications about the future trend of the main atmospheric forcing although affected by significant uncertainties concerning the magnitude. However, the crucial role played by the specific geomorphological contexts makes much more challenging understanding how such variations could affect occurrence and magnitude of landslide hazards. These factors help understanding because it is often unreliable carrying out assessments on large areas but is often necessary trying to evaluate the potential effects of CC on geo-hydrological hazards at slope scale.The main aim of this paper is the definition of a framework for the evaluation of potential variations of occurrences of landslide events affecting slopes of NoceraInferiore (Southern Italy) under the effect of CC. Such slopeshave been affected in recent years, inseveral occasions, by flowslide phenomena inducing large economic lossesand fatalities. The framework, consisting of two macro components, is tested to check its predictive capability of landslide behavior. It is then applied to provide a prediction of "potential" events for near and long time horizon scenarios. The study highlightspotential variations (increases) in triggering frequency under the effect of different concentration scenarios and time horizons.

Peer-review under responsibility of the organizing committee of IWL 2015

*Keywords:*climate change; flowslide, pyroclastic soil, threshold; scenario

* Corresponding author. Tel.: +39 0823 623164.
E-mail address: alfredo.reder@cmcc.it

Peer-review under responsibility of the organizing committee of IWL 2015
doi:10.1016/j.proeps.2016.10.018

1. Introduction

The WMO[1] has estimated at global scale a remarkable increase (+20%, 370,000 persons) over the period 2001-2010 compared to the previous period 1991-2000 in the number of fatalities due to disasters directly induced by extreme weather events. However, as pointed out by ISDR[2], developing countries experienced the overwhelming majority of victims (95% in the period 1970-2008) while developed countries suffered the greatest losses in terms of costs and assets.

Different causes are recognized as responsible of such increasing trends: e.g., variations in magnitude and frequency of extreme weather events induced by Climate Changes (CC), increase in exposure due to rapid urbanization processes in hazardous areas, variations of land use (often resulting in increase of impervious areas) in susceptible areas. The relative significance of these factors is often hard to detect, not only for objective reasons,e.g. the complexity of socio-economic and geomorphological contexts, but also for subjective ones,such as political opinions[3]. In this perspective, the evaluations of ongoing or future trends of natural disasters at global, regional or local scale are often carried out through simplified analysis, in which only the effect of the variation of a single forcing is taken into account, while those related to the other ones are assumed negligible or of lesser importance[4].

In this regard, the evaluation of the effects of CC on the variations of weather forcing inducing geo-hydrological hazards has received an increasing interest during the last years,fostering a fruitful debate in the scientific community[4,5,6].

For the Italian domain, for example, several studies have been carried out in last years: Vezzoli et al[7] analyzed the potential variations induced by CC under two RCPs in 2100 in future discharges of Po River.Comegna et al[8]and Rianna et al[9] estimated the variations (essentially, decelerations) in slow slope movement rates affecting the clayey slopes respectively for Costa dellaGaveta (Basilicata Region) and Orvieto (Umbria Region).Gariano et al[10]assessed at large scale for Calabria Region the changes in occurrence of rainfall-induced landslides in the 20th century, but without discriminating between natural and anthropic variations in hazards. Finally, concerning the Alpine area, Stoffel et al[11] studied the changes in frequency, seasonal distribution and number of shallow landslide occurrences in Piedmont (North-Western Italy) from 1900 to 2011 retrieving two periods with a significant increase in landslide occurrences in 1980-2011, potentially associated to increases in air temperature inducing snow melting processes.

In this study, a modeling chain is proposed and adopted for the evaluation of potential variations of occurrences of landslide events affecting slopes of NoceraInferiore (Southern Italy) under the effect of CC. Oversuch slopes, pyroclastic covers mantling carbonate massifs have been historically affectedby slope instability phenomena,which caused remarkable economic damages and, in some cases, fatalities. The concurrent expected increase in urbanization[12]and then in exposed assets entails that the development of adequate adaptation strategies (in terms of land use planning or disaster management) represents a crucial issue for the area.

The paper initially describes the geological features and the landslide events historically known in the study area (§ 2). Subsequently, a procedure to couple climate change data and impact model for the hazard assessment is proposed (§ 3). Finally,the main findings are displayed for climate simulations (§ 4.1) and integrated hazard assessments(§ 4.2) providing some hints about “potential” hazard variations due to climate change.

2. Description of study area: the NoceraInferiore case-history

NoceraInferiore is a town of Campania Region (Southern Italy) located at the base of the LattariMts (Fig. 1). Its slopes are covered by pyroclastic deposits resulting from several eruptions of Somma-Vesuvius over the last 10,000 years. According to the macrozoningproposed by Picarelli et al[13],for the LattariMtstwo subareas are detectable. In particular, the Northern sector of the mountains (Fd zone in Fig. 1) is characterized by pyroclastic covers with thicknesses hardly exceeding 2 m (in recent years, such area experienced large flowslides) while the Southern sector (Fe zonein Fig. 1) is characterized by pyroclastic covers less than 1 m thick (only small flowslides have been detected in recent years). In both cases the covers rest on fractured limestones.

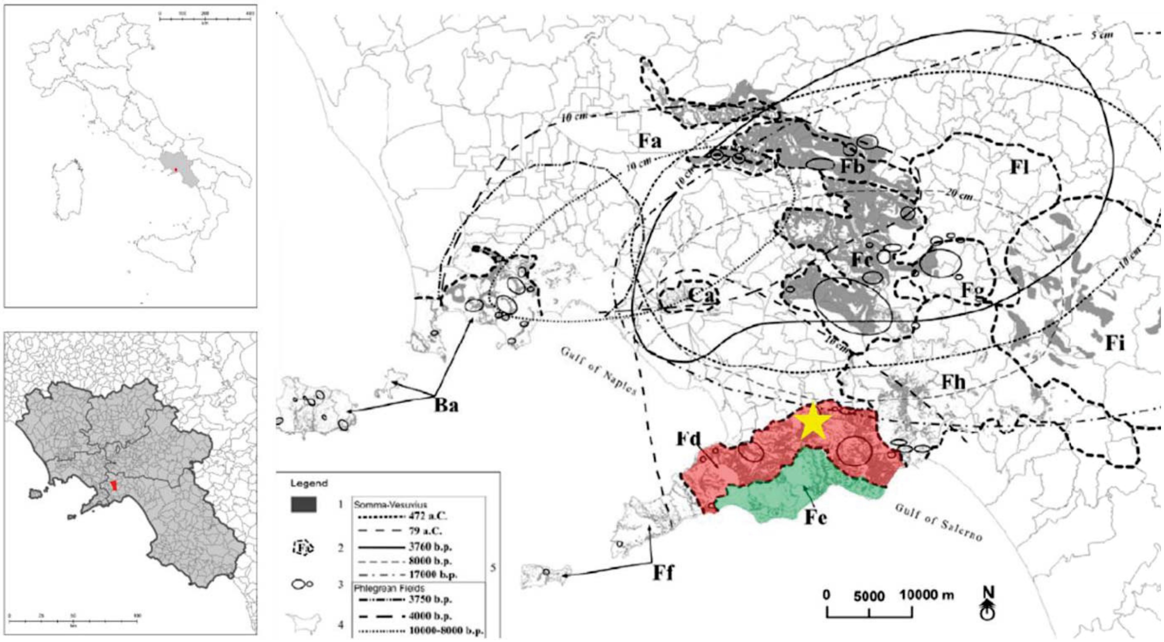

Fig. 1. Macrozoning of pyroclastic deposits (modified from Picarelli et al[13]): Phlegrean area (Ba); Caserta Mts. and southern slope of the Avella Mts. (Fa); Avella, Roccarainola and Cervinara Mts. (Fb); Pizzo d'Alvano, Monteforte and Mugnano Mts. (Fc); Northern sector of Lattari Mts. (Fd); Southern sector of Lattari Mts. (Fe); Sorrentina peninsula and Capri island (Ff); Irpinia hills (Fg); Salerno Mts. (Fh); Picentini Mts. (Fi); North-eastern sector of the Irpinia hills (Fl). Red and green areas correspond respectively to Fd zone and Fe zone where the test case is located; black circles indicatemain occurred events

Since 1960, the Nocera area was affected by several events of rainfall-induced landslides that have induced huge economic losses and sometimes also fatalities (Table 1). All landslides occurred in the wettest period of the year (November-March)with two events in March.

Table 1. List of landslide events occurred in the Nocera area since 1960

Date (dd/mm/yyyy)	Daily trigger precipitation (mm)
08/12/1960	87.1
04/11/1961	111.2
06/03/1972	77
10/01/1997	110
04/03/2005	205.6

In the area two rain gauges allow monitoring rainfalls. The first one, installed at about 3 km from the area most affected by the phenomena, recorded daily precipitation from 1950 to 1999 (during which four events, 1960, 1961, 1972 and 1997, occurred). After the last onein 1997, a second rain gauge was installed with acquisition at time resolution of 10 minutes, andit represents the reference for the event of 4th March 2005. Table 1 reports also the trigger daily precipitation for the five events.

Concerning the precipitation height occurred on the trigger day, the events of 1960 and 1972 (respectively 87.1 mm and 77 mm) are characterized by the lowest values; higher daily cumulative values were observed forthe 1961 and 1997 events (respectively 111.2 mm and 110 mm); finallythe 2005 event is marked by a much greater precipitation height (205 mm). However, in this case, the proper timing of the event is known and the landslide event occurred at about 5 p.m. after a cumulative value of about 159 mm.

3. A modeling chain to couple climate simulation and impact model for hazard assessment

In order to assess the potential effect of CC on weather forcing inducing landslide phenomena, simulation chains consisting of two macro components are proposed and also found in other works[7] (Fig. 2).

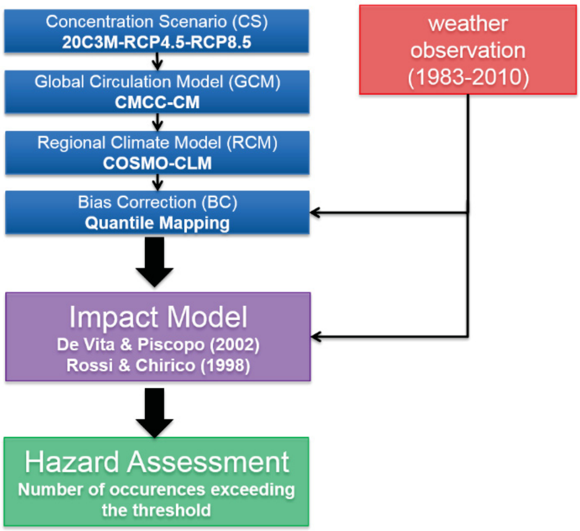

Fig. 2. Framework of modeling chain for landslide hazard assessment

The first component provides atmospheric forcing. In this regard, it features three elements:

a) Concentration Scenarios (CS), through socio-economic models taking into account demographic dynamics, variations in land use and economic growth/development, provide assessments about the future releases into the atmosphere of greenhouse gases, aerosols and other pollutant (climalterant gases). In order to standardize the scenarios and then make easy the comparison between different climate projections, IPCC has selected four reference concentration scenarios, known as Representative Concentration Pathways (RCP) followed by a numerical suffix (specifically, 2.6, 4.5, 6 and 8.5) providing the potential effect of related scenarios in terms of increase in radiative forcing at 2100 compared to preindustrial era (1750). In this work, RCP 4.5, a “mid-road scenario”, and RCP8.5, the more pessimistic one, have been considered.

b) The CS force the General Circulation Model (GCM) allowing to assesslarge scale atmospheric patterns at global scalebut, due to huge computational costs, with horizontal resolution not higher than 70-80 km.In this work, the CMCC-CM model[14], characterized by a horizontal resolution of about 80 km, has been adopted.However, for impact studies at regional/local scale, an improved characterization of orography and mesoscale/small scale atmospheric processes is no permitted atsuch low resolution values. Then, the GCM outputs are subjected to downscaling approaches through statistical or dynamical tools. In the present case a dynamical approach through a Regional Climate Model (RCM) has been used: more specifically, a simulation over the Italian domain with the RCM COSMO-CLM at horizontal resolution of 8 km has been performed to downscale the GCM output. Further details about thisclimate modeling chain, concerning the validation performed on a recent pastperiod and future projections are available in Bucchignani et al[15] and Zollo et al[16] respectively for mean and extreme values of the main weather forcing.

c) Although the performance of this RCM are consistent with SOTA simulations (e.g. CORDEX project) and, in some cases,showrelative improvements, the limitations in the orographic representations (and associated atmospheric patterns) and in sub grid processes for which physical parametrizations are required, often lead to not negligible errors, mainly for some weather forcing (e.g. precipitation or wind) and for extreme values, preventing a proper adoption of such dataas input for impact studies. To cope with such issues, recently several statistical approaches, known as “bias correction techniques”, have been proposed[17,18,19]. The quantile mapping techniqueshave been proven outperforming the other ones[20,21]. It allows to partly remove the systematic biases of climate modeling, not only in terms of average values, but for the entire PDF.However, the assumptions and the limitations of thesestatistical approaches, used in cascade to physically based ones, should be clearly taken into account by impact modelers. In this work, among the quantile mapping approaches, a non-parametric model characterized by high flexibility has been selected[19]. The weather forcing data provided by such a simulation chain are then used as input for impact models. In this regard, only daily precipitations values are required for the selected impact models.

The second component is represented by the impact models adopted for the hazard assessment. In this work, two empirical impact modelshave been used to assess the landslide hazard for the Nocera area, based on the statistical interpretation of the rainfallevents that in the past have triggered a landslide in suchspecific geomorphological context. Indeed, manystudies have shown thatthe triggering could be induced by the coupled effect of a heavy precipitation event (acting as triggering factor) with a cumulative rainfall in the antecedent period (acting as predisposing factor), which creates the conditions for slope failure in materials(e.g. volcanic)capable to store a large amount of water, due to high porosity values (about 70%) and mineralogical properties. Nevertheless, the cover thicknesses not exceeding 2 m, the bottom boundary conditions and the very steep slope angles (often higher than 35°) also concur to determine such precipitation patterns as those “effective” for slope failure[22,23].

The first model is the empirical threshold proposed by De Vita & Piscopo[24] (Fig. 3a). This threshold, based on the correlation between P1 (daily trigger precipitation) and P59 (antecedent precipitation over 59 days), is conceived as an empirical tool valid only for the Lattari-Salerno Mountains geomorphological context.

The second model is the warning system stated by Rossi & Chirico[25](Fig. 3b) after the well-known Sarnolandslide event (5th May 1998). By the statistical interpretation of historical events occurred in Campania, Rossi & Chirico proposed different empirical thresholds (“alert” and “alarm” levels) based on the correlation between the trigger precipitation PE (assumed as the sum of daily event and pre-event precipitation) and the antecedent precipitation PA (in this caseassumed as cumulative precipitation since1 September to the triggering event). In this study, only the “alarm” level has been considered.

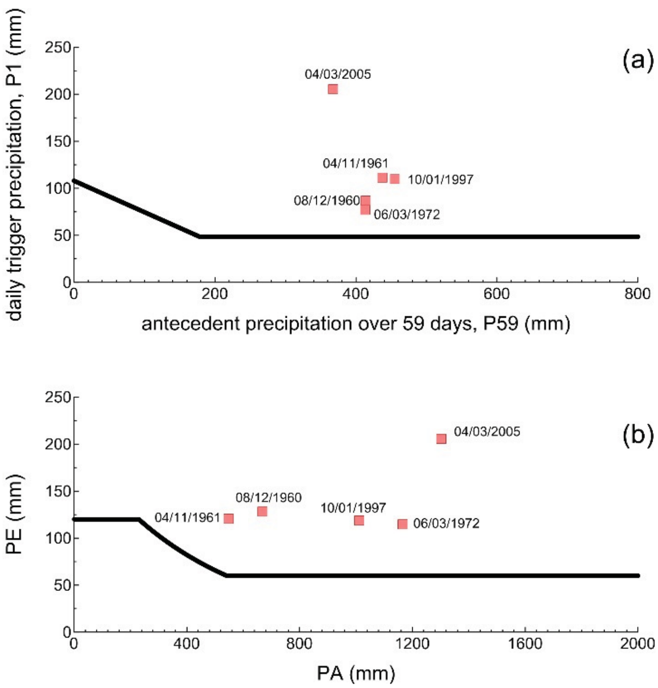

Fig. 3. Empirical hydrological models: the red squares identify events occurred in the Nocera area since 1960 (modified from De Vita & Piscopo[24] and Rossi & Chirico[25])

It is worth noting that such approaches represent expeditious approaches suitable to be used also by not highly skilled personnel; in this perspective, they have to neglect (or take into account in indirect way) further geotechnical aspects (slope morphology, internal structure, shear strength and permeability function of soil) playing a crucial role in slope stability[23].

The two impact models are forced in the first step, by observed rainfall data, and successively by the climate modeling chain on the same time span to validate the entire modeling chain; finally they are forced by rainfall values on future time spans, in attempting to provide estimates on variations in occurrence of landslide events.

4. Results

4.1. Climate model outputs

In the first stage, the performance of the proposed climate modeling chain is evaluated through the comparison with observed data on the current period. To this aim, climate models are forcedbyvalues of gases concentration from the 20C3M dataset. According to WMO indications, the time span is assumed to be 30 years long (1981-2010) in attempting to properly take into account interannual variability; unfortunately, over this time span, the available observed precipitation dataset covers only the period 1983-2008. Moreover since 2006, the 20C3M dataset is replaced by the RCP4.5 scenario (negligible differences in rainfall patterns could be retrieved using RCP8.5).

Figure 4 displays,on monthly scale, the average cumulative precipitation and the average maximum daily precipitation for observed values, raw and bias corrected RCM outputs over the current period.

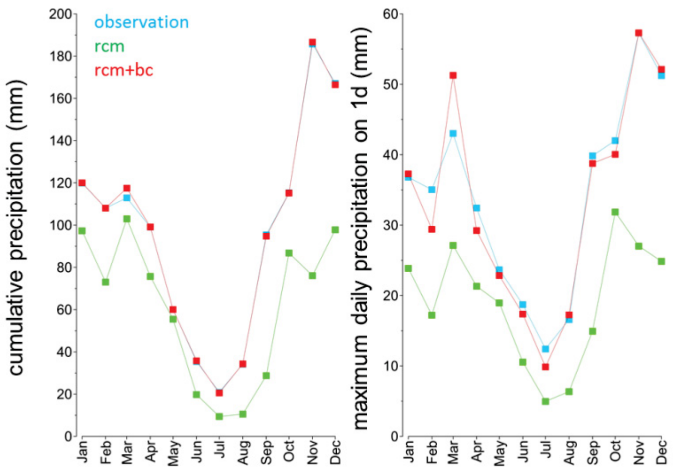

Fig. 4. (a) Average cumulative precipitation and (b) average maximum daily precipitation of observed values (light blue), RCM outputs (green) and RCM+BC outputs (red) over the current period

The RCM outputs is able to satisfactorily reproduce the seasonal patterns, but underestimates both cumulative and maximum daily precipitation;however, by adopting the bias correction procedure (RCM+BC), biasesarealmost fully removed for both mean and maximum values.

Concerning future periods,two time interval are considered: “near time horizon” 2021-2050 and “long time horizon” 2071-2100. Table 2and Table 3 report, on seasonal scale, the climate change signal asa ratio between future and current period respectively in terms of cumulativeand average maximum dailyprecipitation for both RCPs.

The climate change signal projected under RCP4.5 scenario outlines an increase during Autumn and Winter and a decrease during Spring and Summer for both cumulative and maximum daily precipitation (except for maximum daily precipitation during Summer over 2021-2050).

Concerning the RCP8.5 scenario, the climate signal points out that over 2021-2050 precipitation increases during Autumn and Winter (except for maximum daily precipitation during Autumn) and decreases during Spring and Summer; on the other hand, over 2071-2100 the precipitation strongly increases during Winter while decreases slightly during Autumn and strongly during Spring and Summer (indeed during Summer precipitation reduces approximately by60%).

Table 2. Signal of climate change for seasonal cumulative precipitation

Concentration Scenario	Time horizon	Sep-Oct-Nov	Dec-Jan-Feb	Mar-Apr-May	Jun-Jul-Aug
RCP4.5	2021-2050	1.15	1.14	0.88	0.90
	2071-2100	1.26	1.05	0.86	0.71
RCP8.5	2021-2050	1.08	1.06	0.80	0.95
	2071-2100	0.96	1.30	0.67	0.39

Table 3. Signal of climate change for maximum daily precipitation

Concentration Scenario	Time horizon	Sep-Oct-Nov	Dec-Jan-Feb	Mar-Apr-May	Jun-Jul-Aug
RCP4.5	2021-2050	1.09	1.16	0.93	1.09
	2071-2100	1.29	1.09	0.97	0.92
RCP8.5	2021-2050	0.95	1.19	0.76	0.99
	2071-2100	1.22	1.48	0.90	0.71

4.2. De Vita & Piscopo[24]

Figure 5 shows the pairs of point P59-P1 (daily precipitationP1 > 1 mm) retrieved by adopting the precipitation observed over 1983-2008 (Fig. 5).

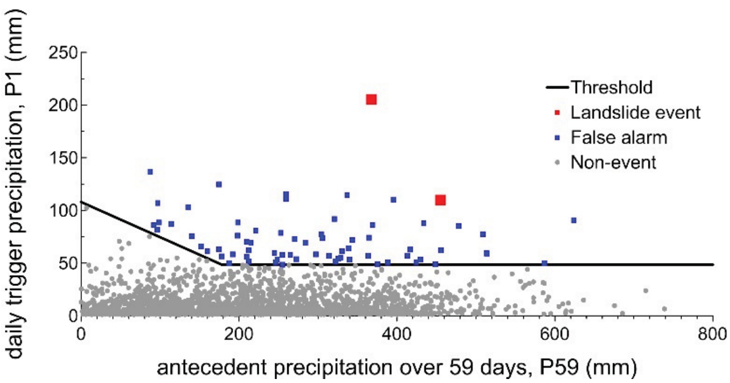

Fig. 5. Hazard assessment through the De Vita &Piscopo threshold[24] for the precipitation data recorded over 1983-2008: red, blue and grey dots correspond respectively to landslide events, false alarm and non-event

Concerning the observed data, the model is able to detect the two landslide events that actually occurred on 10/01/1997 and 04/03/2005.However, beyond the threshold line discriminating the landslide, also 70 events of 2122 wet days are wrongly recognized as potential events then representinga substantial number of false alarms. The likelihood of success of this model to reproduce the landslide occurrences is equal to the ratio between the number of true successes (2 events) and the number of "potential" successes (70 events). The percentage ratio is equal to 2.86%.

Adopting as input the RCM-BC precipitation data over 1981-2010, the threshold returns 77 events over 2514 wet days. Assuming that the likelihood of success retrieved through back-analysis of historical data remains the same,the number of potential failure events is equal to 2.20.

Table 4 shows the temporal distribution, on seasonal scale, of theprecipitation events exceeding the threshold,retrieved adopting the observed data and the simulated data.

Table 4. Temporal distribution of the events of precipitation exceeding the threshold over current period

	Sep-Oct-Nov	Dec-Jan-Feb	Mar-Apr-May	Jun-Jul-Aug
Observed data	30	29	11	0
Simulated data	31	31	14	1

For the observed data, the events exceeding the threshold are concentrated mainly during Autumn and Winter. The most critical months are November and December, both characterized by 17 events.In Spring the number of events decreases (concentrated particularly in March and April) while the threshold is never exceeded during Summer. Similar dynamics, on both seasonal and monthly scale, are reproduced by the bias corrected climate model.

Assuming that alsofor the future projections the likelihood of success is the same, it is possible to assess the variations in hazard under RCP4.5 and RCP8.5 scenarios (Table 5).

Table 5. Hazard assessment for future projections of climate change

Concentration Scenario	Time horizon	Wet days	Events of precipitation exceeding the threshold	Potential failure events
RCP4.5	2021-2050	2391	109	3.11
	2071-2100	2258	125	3.57
RCP8.5	2021-2050	2410	90	2.57
	2071-2100	1938	119	3.40

Table 5 points out that climate changescould increase the number of "potential" failure events. Moving from the near time to the long time horizon, the number of eventstends to increase for both Concentration Scenarios. Moving from RCP4.5 to RCP8.5 a slight reduction in the number of successes can be retrieved.

The future projections exhibit a reduction in the number of wet days, but an increase in the number of events that could "potentially exceed the threshold".Analyzing the temporal distribution of these events (Table 6), RCP4.5 is characterized by an increase during Autumn and Winter and a decrease for the 2021-2050 period during Spring; on the other hand, RCP8.5 shows a strong increase for the 2071-2100 period during Winter and a decrease during Spring. For both Concentration Scenarios, the precipitation events exceeding the threshold do not change during Summer.

Table 6. Temporal distribution of the events of precipitation exceeding the threshold over future period

Concentration Scenario	Time horizon	Sep-Oct-Nov	Dec-Jan-Feb	Mar-Apr-May	Jun-Jul-Aug
RCP4.5	2021-2050	50	50	8	1
	2071-2100	58	51	16	0
RCP8.5	2021-2050	31	49	9	1
	2071-2100	38	72	9	0

4.3. Rossi & Chirico[25]

Fig. 6 shows the pairs of point PA-PE (PE with at least one day with P1 > 1 mm) retrieved by adopting the precipitation observed over 1983-2008 (Figure 5).

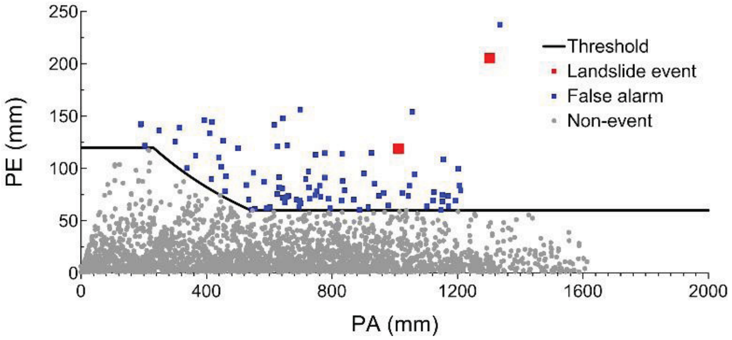

Fig. 6. Hazard assessment through the Rossi & Chirico threshold[25] for the precipitation data recorded over 1983-2008: red, blue and grey dots correspond respectively to landslide events, false alarm and non-event

Concerning the observed data, the model is able to detect the two landslide events that actually occurred on 10/01/1997 and 04/03/2005 (red squares); however, it also returns many false alarms. Specifically, for 3215wet days, 95 events exceed the threshold. The likelihood of success of this model to reproduce the landslide occurrences is equal to the ratio between the number of true successes (2 events) and the number of "potential" successes (95events). The percentage ratio is equal to 2.11%.

Adopting as input the RCM-BC precipitation over 1981-2010, the threshold returns 121 events over 3727 wet days. Assuming that the likelihood of success retrieved through back-analysis of historical data remains the same, the number of potential failure events is equal to 2.55 (slightly higher).

Table 7 shows the temporal distribution, on seasonal scale, of the precipitation events exceeding the threshold, retrieved adopting the observed data and the simulated data. Table 7. Temporal distribution of the events of precipitation exceeding the threshold over current period

	Sep-Oct-Nov	Dec-Jan-Feb	Mar-Apr-May	Jun-Jul-Aug
Observed data	14	52	27	2
Simulated data	22	61	34	4

For the observed data, the events exceeding the threshold are concentrated mainly during Winter and Spring. The most critical months are December, January and March, characterized respectively by 30, 15 and 21 events. Similar dynamics, on both seasonal and month scale, are reproduced by the bias corrected climate model.The Rossi & Chirico threshold seems to beable to managein a more proper waythe effect of antecedent rainfalls, concentrating the potential events in months when they actually occurred.

Assuming that alsofor the future projections the likelihood of success remains the same, it is possible to assessquantitatively the variations in hazard due to climate changes for RCP4.5 and RCP8.5 (Table 8).

Table 8. Hazard assessment for future projections of climate change

Concentration Scenario	Time horizon	Wet days	Events of precipitation exceeding the threshold	Potential failure events
RCP4.5	2021-2050	3548	173	3.64
	2071-2100	3350	186	3.92

RCP8.5	2021-2050	3560	151	3.18
	2071-2100	2903	182	3.83

According to the results retrieved by adopting the Rossi & Chirico model, Table 8 points out that under the effect ofclimate changes the number of “potential” failure events could increase. Moving from the near time to the long time horizon, the number of potential events tends to increase for both Concentration Scenarios. Also in this case, moving from RCP4.5 to RCP8.5 a slight reduction in the number of events can be retrieved.

The future projections exhibit an increase both in the number of wet days and in the number of events that could “potentially exceed the threshold”. Analyzing the timedistribution of these events (Table 9), both Concentration Scenarios are characterized by a strong increase during Autumn and Winter and a decrease during Spring.

Table 9. Temporal distribution of the events of precipitation exceeding the threshold over future period

Concentration Scenario	Time horizon	Sep-Oct-Nov	Dec-Jan-Feb	Mar-Apr-May	Jun-Jul-Aug
RCP4.5	2021-2050	51	92	21	9
	2071-2100	75	73	32	6
RCP8.5	2021-2050	40	85	22	5
	2071-2100	36	120	22	4

5. Conclusion

An integrated modeling chain for estimating the future variations in occurrences of landslide phenomena is proposed and applied to the NoceraInferiore test case,which experienced, in last years, several major landslide phenomena induced by intense precipitation events. To this aim, the reliability of every element of the modeling chain is tested, the entire framework is validated and finally is applied to provide assessments on future time spans. On short and long time horizons and under both RCPs scenarios, an increase in frequency is recorded. Being a function of the assumed effective rainfall patterns inducing the events, the increase could be higher underRCP4.5 than under RCP8.5. It is worth noting that, in this case, a single climate chain is adopted while, for managing the current significant uncertainties in modeling, an “ensemble approach” should be preferred. The proposed framework, already adopted for different geo-hydrological hazards in several geo-morphological contexts, confirms its suitability also for analyzing the occurrence of landslides in coarse grained soils.

As a further result, the research permits estimating also the predictive capabilities of the two empirical approaches. For both cases, a large number of false alarms is returned (on average, 2-3 potential events for year are returned). It is basically due to the high number of simplifying assumptions underlying the approaches and that could play a crucial role (e.g. the evapotranspiration effects on the antecedent time window, the rainfall patterns, and singularities in stratigraphy).The next step is the adoption of the same framework, but using as impact model a physically based approach able to take into account, in a more proper way, the processes regulating the slope-atmosphere interaction and the geomorphological features.

References

1. WMO.*The Global Climate 2001-2010: A Decade of Climate Extremes*. WMO-No.1103, Geneva, Switzerland, WMO; 2013.
2. ISDR. *Global Assessment Report on Disaster Risk Reduction*. Geneva, Switzerland, UN; 2013.
3. Marshall G. *Don't Even Think About It: Why Our Brains Are Wired to Ignore Climate Change*. Bloomsbury USA; 2014.
4. Coe JA,Godt JW. Review of approaches for assessing the impact of climate change on landslide hazards. In: Eberhardt E, Froese C, Turner AK, Leroueil S, editors. *Landslides and Engineered Slopes, Protecting Society Through Improved Understanding: Proceedings of the 11th International and 2nd North American Symposium on Landslides and Engineered Slopes, Banff, Canada, 3-8 June*.London: Taylor & Francis Group; 2012. v. 1. p. 371-377.
5.Maraun D et al. Precipitation downscaling under climate change: recent developments to bridge the gap between dynamical models and the end user. *Rev Geophys* 2010;**48**:RG3003.
6.Fowler HJ, Blenkinsop S, Tebaldi C. Linking climate change modelling to impacts studies: Recent advances in downscaling techniques for hydrological modelling. *Int J Climatol*2007; **27**:1547–1578.

7. Vezzoli R, Mercogliano P, Pecora S, Zollo AL, Cacciamani C. Hydrological simulation of Po River (North Italy) discharge under climate change scenarios using the RCM COSMO-CLM. *Sc Total Environ* 2015;**521-522**:346-358.
8. Comegna L, Picarelli L, Bucchignani E, Mercogliano P. Potential effects of incoming climate changes on the behaviour of slow active landslides in clay. *Landslides* 2013; **10**:373-391.
9. Rianna G, Zollo AL, Tommasi P, Paciucci M, Comegna L,MercoglianoP. Evaluation of the effects of climate changes on landslide activity of Orvieto clayey slope. *Proced 20 Earth Plane. Sci* 2014;**9**:54-63.
10. Gariano SL, Petrucci O, Guzzetti F. Changes in the occurrence of rainfall-induced landslides in Calabria, southern Italy, in the 20th century. *Nat Hazards Earth SystSci* 2015;**15**:2313-2330.
11. Stoffel M, Tiranti D, Huggel C. Climate change impacts on mass movements - Case studies from the European Alps. *Sci Total Environ*2014; **493**:1255-1266.
12. Santini M, Valentini R. Predicting hot-spots of land use changes in Italy by ensemble forecasting. *Regional Environ Chang* 2011, **11(3)**: 483-502.
13.Picarelli L, Santo A, Di Crescenzo G, Olivares L. Macro-zoning of areas susceptible to flowslide in pyroclastic soils in Campania Region. In: Chen Z, Zhang J-M, Ho K, Wu F-W, Li Z-K, editors. *Landslides and Engineered Slopes. From the Past to the Future, Xi'an, China*. CRC press; 2008. v. 2. p. 1951-1957.
14. Scoccimaro E, Gualdi S, Bellucci A, Sanna A, Fogli P, Manzini E, Vichi M, Oddo P, Navarra A. Effects of Tropical Cyclones on Ocean Heat Transport in a High Resolution Coupled General Circulation Model. *J Clim* 2011;**24**:4368-4384.
15. Bucchignani E, Montesarchio M, Zollo AL, Mercogliano P. High-resolution climate simulations with COSMO-CLM over Italy: performance evaluation and climate projections for the XXI century. *Int J Climatol* 2015; doi: 10.1002/joc.4379.
16. Zollo AL, Rillo V, Bucchignani E, Montesarchio M, Mercogliano P. Extreme temperature and precipitation events over Italy: assessment of high resolution simulations with COSMO-CLM and future scenarios. *Int J Climatol.* 2015; doi: 10.1002/joc.4401.
17. Piani C, Haerter J, Coppola E. Statistical bias correction for daily precipitation in regional climate models over Europe. *TheorApplClimat* 2010;**99**:187-192.
18. Teutschbein C, Seibert J. Bias correction of regional climate model simulations for hydrological climate-change impact studies: Review and evaluation of different methods. *J Hydrol* 2012; **456-457**:12-29.
19. Villani V, Rianna G, Mercogliano P, Zollo AL. Statistical approaches versus weather generator to downscale RCM outputs to slope scale for stability assessment: a comparison of performances. *Electron J GeotechEng* 2015:**20(4)**:1495-1515.
20. Gudmundsson L, Bremnes JB, Haugen JE, Engen-Skaugen T. Technical Note: Downscaling RCM precipitation to the station scale using statistical transformations - a comparison of methods. *Hydrol Earth SystSci* 2012; **16**:3383-3390.
21. Lafon T, Dadson S, Buys G, Prudhomme C. Bias correction of daily precipitation simulated by a regional climatemodel: A comparison of methods.*Int JClimatol* 2012;**33**:1367-1381.
22. Di Crescenzo G, Santo A. Debris slides-rapid earth flows in the carbonate massifs of the Campania region (Southern Italy): morphological and morphometric data for evaluating triggering susceptibility. *Geomorphology* 2005;**66**:255-276.
23. Pagano L, Picarelli L, Rianna G, Urciuoli G. A simplified approach for timely prediction of precipitation-induced landslides in unsaturated pyroclastic soils. *Landslides* 2010;**7(3)**: 273-289.
24. De Vita P, Piscopo V. Influences of hydrological and hydrogeological conditions on debris flows in peri-vesuvianhillslopes. *NatHaz and Earth SystSc* 2002;**2**: 27-35.
25. Rossi F, Chirico GB. *Definizione delle soglie pluviometriche d'allarme*. National Group for Defence from Hydrogeological Catastrophes - National Research Council (G.N.D.C.I.-C.N.R.), 2.38 Operative Unit, Salerno, 1998. Department of Civil Engineering, University of Salerno, Italy.