International Conference
Analysis and Management of Changing Risks for Natural Hazards
18-19 November 2014 l Padua, Italy

Abstract code: A02

Impacts of climate change on debris flows – what are some of the challenges?

T. Turkington[1], J. Ettema[1], J.P. Malet[2], A. Remaître[2], C. van Westen[1]

[1]ITC, University of Twente, Enschede, Netherlands
[2] Institut de Physique du Globe de Strasbourg, University of Strasbourg, Strasbourg, France

Corresponding author details:
Thea Turkington, University of Twente email: t.a.r.turkington@utwente.nl

Keywords:
Climate change, downscaling, debris flows, uncertainty

Extended Abstract (10 pages max):

INTRODUCTION

While changes in temperature and precipitation will likely affect debris flows, developing relevant future climate projections remains challenging. Three of these challenges are considered in this work: linking past debris flows with the meteorological trigger, how to approach the necessary downscaling of global climate projections, and finally, dealing with uncertainty. To illustrate each of the three challenges, examples are taken from two European alpine catchments: Barcelonnette in the French Alps, and Fella River in NE Italy.

CHALLENGES LINKING CLIMATE CHANGE AND DEBRIS FLOWS

Linking past debris flows and meteorological triggers

To develop climate projection, the hazards should be linked with meteorological properties or conditions that climate models are able to reproduce. Rainfall intensity-duration thresholds are often applied to determine minimum rainfall conditions under which debris flows may occur (see Guzzetti et al. (2008) for a review of different methods). However, while debris flows are often preceded by intense rainfall, capturing the rainfall in mountains catchments can be difficult due to the lack of rain gauges or poor coverage by weather radar in mountainous regions.

The relationship between measured precipitation and debris flow (DF) events is different for Fella River and Barcelonnette. One similarity though, is that for both areas, the rain gauges are all in the bottom of the valleys, rather than on the slopes where the debris flows originate and where potentially the rainfall is more intense. In Barcelonnette, this results in few debris flow events being associated with extreme 1-day rainfall, although some rain was recorded before most events (Figure 1 – Barcelonnette (a)). Furthermore, some of the events occur during the spring, where snowmelt is also a contributing factor, and is often not captured in rainfall thresholds. In the case of Fella River, most debris flows and shallow landslides occur in the late summer and autumn, as well as daily precipitation totals are higher than in Barcelonnette. This results in all DF events being associated with heavy or extreme 1-day rainfall, and few of the most extreme rainfall events with no debris flows or shallow landslides reported (Figure 1 Fella (a)).

When measure precipitation and DF cannot to be linked, there are other possibilities. Previous work demonstrated how atmospheric variables, such as specific humidity (Q) and estimates of atmospheric instability (CAPE) can be used as proxies for rainfall (Turkington et al., 2014). Figure 1 Barcelonnette (b) shows how by using Q and CAPE instead of daily rainfall, more debris flow events are associated with extreme values. For Fella, using CAPE and Q is also possible (Figure 1 Fella (b)); however, the most accurate threshold uses CAPE and 1-day rainfall (not shown).

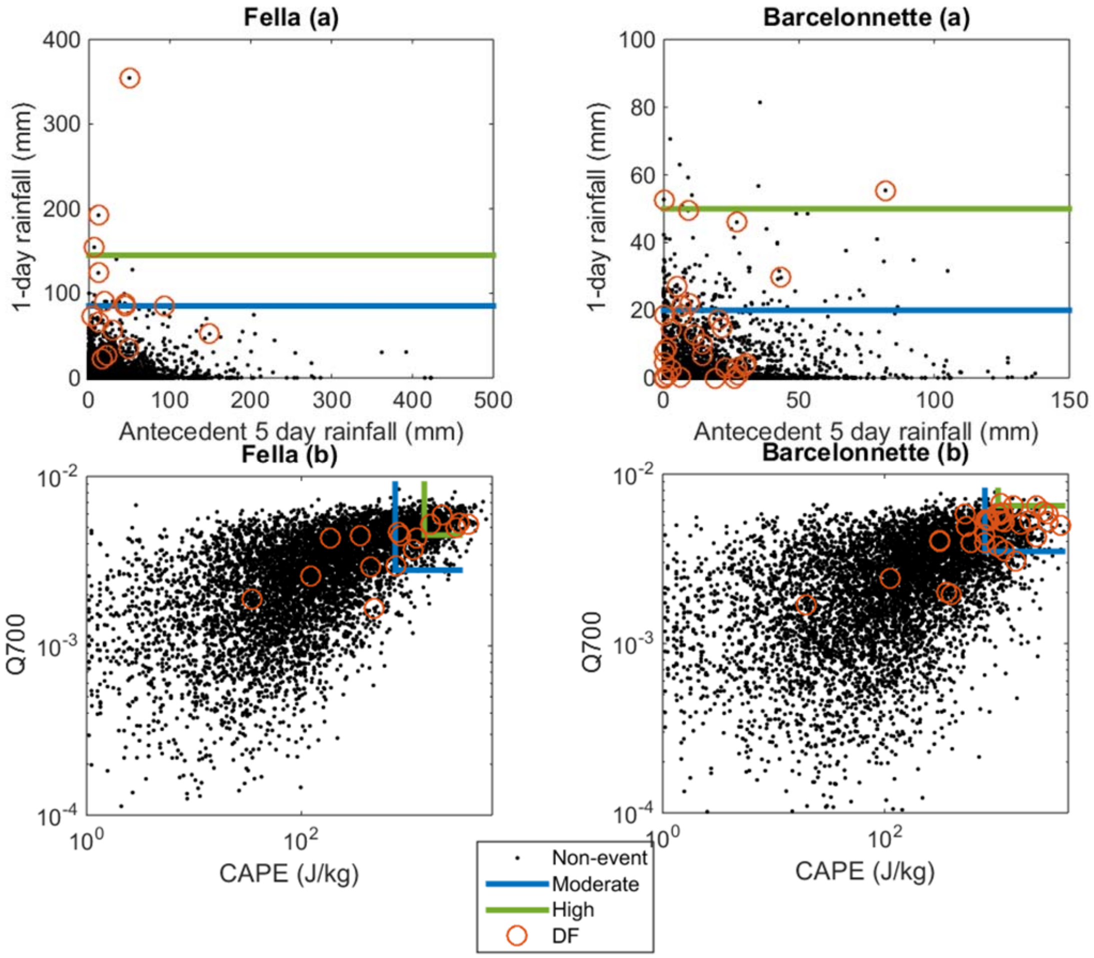

Figure 1 Rainfall events with dates of debris flows circled. For Fella (left), the inventory also includes shallow landslides. The blue and green lines give the moderate and high thresholds for debris flows respectively. The high threshold represents the threshold where the highest percentage of days above the threshold are associated with DF events, while the moderate threshold is similar with the added condition that at least 50% (Fella) or 30% (Barcelonnette) DF events are also above the threshold.

While rainfall or atmospheric variables can be used to link debris flows and climate, it is important to recall that there are other influencing factors. Other influencing factors, such as land cover, make the precise meteorological trigger dependant on the catchment. Using hourly precipitation data can improve the results, however, changes in sub-daily precipitation depends on the length of the observed record, and the ability to obtain climate projections at this resolution. In the end, once a link between the local climate and debris flows is achieved, it can be used as a basis for the climate projections.

Downscaling of global climate projections

General Circulation Models (GCMs) are often at a much coarser scale than most debris flow source areas, with variables available at daily or coarser time-scales. By downscaling global projections, changes in the relevant meteorological variables can be examined at a finer scale. This is especially important for mountainous regions where orographic processes are not always adequately captured in the global models. However, there are a variety of downscaling techniques, each with different assumptions, and potentially producing different results. Three different methods are demonstrated here for the two case study areas based on the thresholds shown in Figure 1: dynamical downscaling, statistical downscaling and atmospheric variables. Further information on the first two downscaling methods for precipitation can be found in Maraun et al. (2010).

Dynamical downscaling

Dynamical downscaling physically models the climate at finer resolutions than the global scale GCMs. Recently, new data became available through the CORDEX project, with multiple regional climate models (RCMs) for Europe and other areas around the globe (Jacob et al., 2014). Figure 2 shows the change in number of days above the moderate and high threshold rainfall threshold from Figure 1 for each of the study areas based on different combinations of RCMs, GCMs, and emission scenarios. In Fella, for both the moderate and high thresholds, the number of events either remains constant, or increases. Under the high threshold, where every event between 1990 and 2011 was associated with one or more debris flows, two models show and increase in frequency by a factor of five. For Barcelonnette however, the RCM projections are less consistent. For the moderate threshold, some RCMs indicate and increase in frequency, while for others, there is possibly a decrease. The high threshold events are similar to Fella though, where the projections show a constant number of events or an increase.

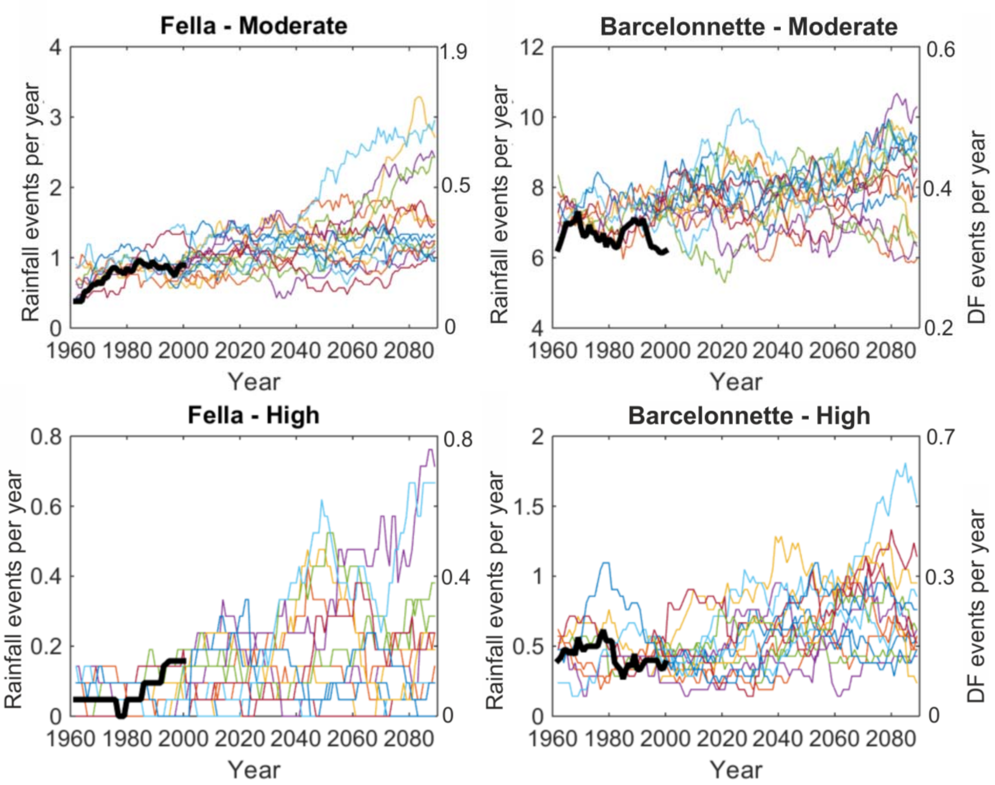

Figure 2 Future projections for different rainfall events for Fella (left) and Barcelonnette (right). The moderate and high thresholds are the same as those in Figure 1. The observed frequency of rainfall events is given in black. The equivalent number of DF events based on the empirical relationship is given on the right y-axes.

Statistical downscaling

Statistical downscaling uses the relationship between large scale atmospheric conditions (predictor) and the local scale variable (predictand) to predict how the predictand, in this case precipitation, may change in the future. The basic assumption being that the relationship between the predictand and the predictor holds true under future conditions as well as for the present. There are a variety of different statistical downscaling techniques. For this paper two different statistical downscaling techniques were used: analogues and generalised linear models (GLMs). Weather typing splits the data into different groups or 'weather types' based on the synoptic conditions separated using k-means clustering. Different atmospheric clustering methods are reviewed in Huth et al. (2008). For GLMs, the predictand is assumed to be a linear combination of the predictors, where the predictand does not necessarily have to be normally distributed, such as is the case for precipitation (Fealy and Sweeney, 2007).

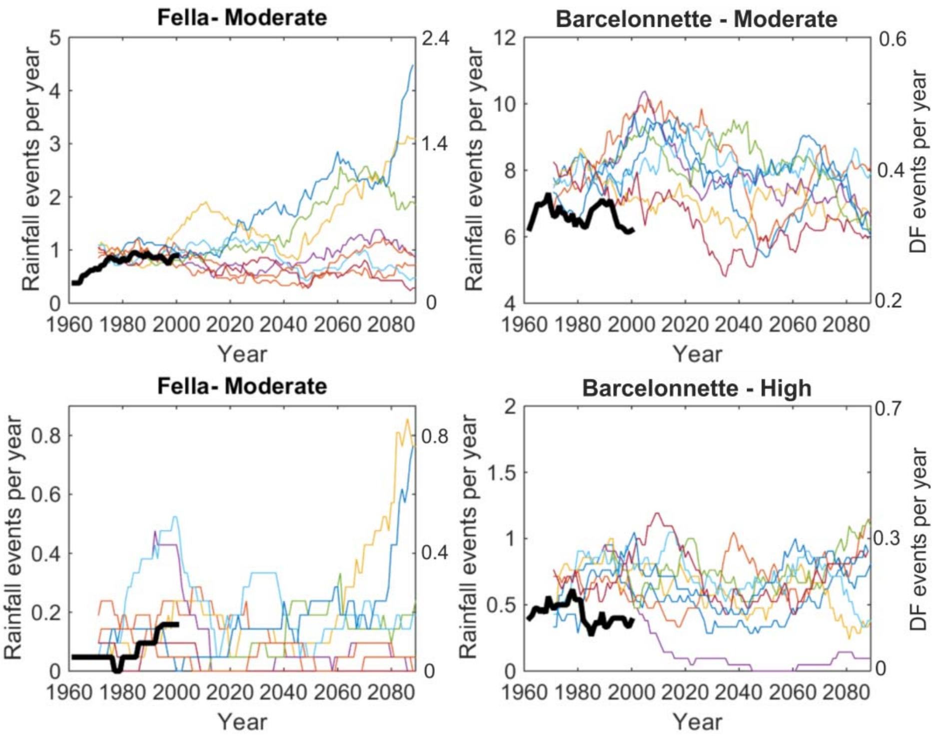

Figure 3 Future projections for different rainfall events for Fella (left) and Barcelonnette (right) using statistical downscaling. The moderate and high thresholds are the same as those in Figure 1 and Figure 2. The observed frequency of rainfall events is given in black. The equivalent number of DF events based on the empirical relationship is given on the right y-axes.

For the two study areas, statistical downscaling also produces a range in change in frequency for the rainfall events (Figure 3). The spread of results using statistical downscaling is similar to those in Figure 2 for Fella River (Figure 3 left), with either no change, or an increase in frequency. For Barcelonnette, most of the projections show little change in the frequency of events (Figure 3 right). This is different for the Barcelonnette-High threshold events in Figure 2, where based on dynamical downscaling the projections have a tendency towards an increase in rainfall events, while based on SD it is generally constant, or in one case, a strong decrease.

Atmospheric variables

The two previous methods are based on changes in precipitation; however, the relationship between daily measured precipitation and debris flows for Barcelonnette was not as strong as when using atmospheric variables (Figure 1). Therefore, it is possible that future projections of debris flows may differ from those obtained using precipitation.

Starting with only two GCMs and one future scenario (RCP85) from the CMIP5 project (Taylor et al., 2011), Figure 4 shows the change in Q700 and CAPE for Barcelonnette, based on the thresholds found in Figure 1 Barcelonnette (b). The increase in number of events is much great than any of the projections in Section 3.1 and 3.2, which focused on changes in precipitation. However, this is only a preliminary result. It is possible that these projections are outliers, and that by including more GCMs and scenarios, the increase in number of events on average is much lower. Furthermore, using a finer scale RCM data may show that CAPE on a finer spatial scale does not change as dramatically as averaged over a larger area. Further work using more projections and finer scale models is needed before substantial conclusions can be made. Even so, Figure 4 demonstrates the potential for intense local convection to increase, while overall precipitation decreases.

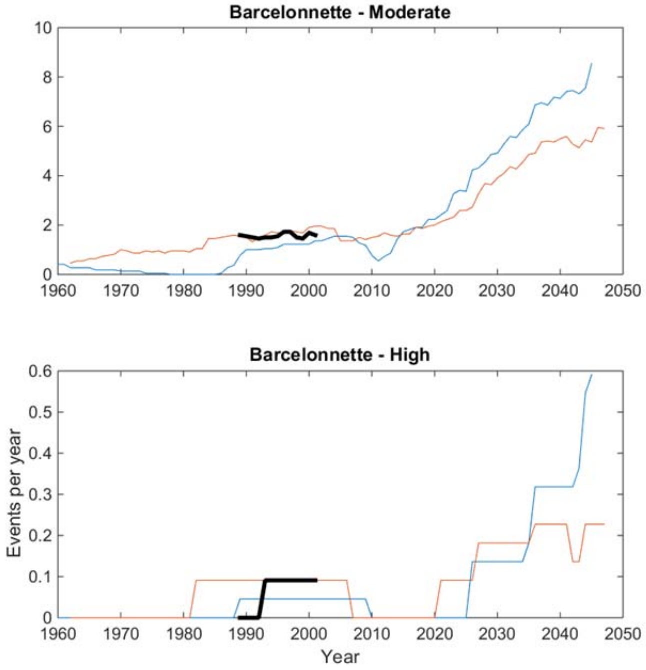

Figure 4 Number of events per year based on the approximate CAPE value and Q700 for two projections. The observed number of events 1979-2010 is shown in black. The top figure is for the moderate threshold in Figure 1 Barcelonnette (b), and the lower for the higher threshold in Figure 1 Barcelonnette (b).

DISCUSSION

The results presented here show a wide range of future projections. The spread comes from the different sources of uncertainty in climate modelling, including from the models themselves, emission scenarios, as well as the observations. By also investigating changes at finer scales, there is also often a large spread in results from more variability in the observations. Furthermore, for debris flows, there is also the uncertainty in the link between the meteorological trigger and the debris flow events. Not considered in this work were other changes, such as land cover, to debris flows in the area.

Due to the spread of future projections, it is important to use multiple GCMs, downscaling techniques, and even meteorological triggers, to capture the spread. Other studies have found similar results. Looking at groundwater recharge, Crosbie et al. (2011) found that downscaling technique, GCM, and to a lesser extent the hydrological model, all impacted the results. Schmidli et al. (2007) also found differences in future precipitation for the European Alps using RCMs and statistical downscaling. Therefore, when considering climate change impacts for debris flows, multiple GCMs, as well as downscaling techniques should be taken into account.

A challenge then becomes how to incorporated climate projections into risk assessments. While it may be unrealistic to include all the different projections when considering climate impact assessments, the results can be used as markers for sensitivity studies. Furthermore, a sub-set of the projections could be used, including some of the projections that show the most dramatic shifts, as these may be more relevant in risk assessment (Raff et al., 2009).

CONCLUSION

This work introduced different challenges in developing projections of debris flows for two study areas: Fella River, NE Italy, and Barcelonnette, France. These challenges included linking debris flows and the triggering conditions, as well as downscaling large scale climate projections. The work considered only rainfall-triggered debris flows, while snowmelt also plays a role in triggering events in the two areas, an area for future research. Future projections for Fella showed that debris flows triggers may remain constant or increase, while for Barcelonnette, it depended on the method used. In the end, the results here showed that the projections differ not only from different downscaling techniques and driving scenarios, but also the meteorological trigger chosen. Therefore, care is needed for both assessing how the climate may change, as well as how the climate interlinks with the debris flow or other natural hazard.

ACKNOWLEDGEMENTS

This work was undertaken as part of the EU FP7 Marie Curie ITN project CHANGES. Data used in this study were provided by Météo France, and the Hydraulic Service, FVG, Italy. And we also acknowledge the World Climate Research Programme's Working Group on Regional Climate, and the Working Group on Coupled Modelling, former coordinating body of CORDEX and responsible panel for CMIP5. We also thank the climate modelling groups for producing and making available their model output.

REFERENCES

CROSBIE, R. S., DAWES, W. R., CHARLES, S. P., MPELASOKA, F. S., ARYAL, S., BARRON, O. & SUMMERELL, G. K. 2011. Differences in future recharge estimates due to GCMs, downscaling methods and hydrological models. *Geophysical Research Letters,* 38**,** n/a-n/a.

FEALY, R. & SWEENEY, J. 2007. Statistical downscaling of precipitation for a selection of sites in Ireland employing a generalised linear modelling approach. *International Journal of Climatology,* 27**,** 2083-2094.

GUZZETTI, F., PERUCCACCI, S., ROSSI, M. & STARK, C. 2008. The rainfall intensity–duration control of shallow landslides and debris flows: an update. *Landslides,* 5**,** 3-17.

HUTH, R., BECK, C., PHILIPP, A., DEMUZERE, M., USTRNUL, Z., CAHYNOVÁ, M., KYSELÝ, J. & TVEITO, O. E. 2008. Classifications of Atmospheric Circulation Patterns. *Ann NY Acad Sci,* 1146**,** 105-152.

JACOB, D., PETERSEN, J., EGGERT, B., ALIAS, A., CHRISTENSEN, O., BOUWER, L., BRAUN, A., COLETTE, A., DÉQUÉ, M., GEORGIEVSKI, G., GEORGOPOULOU, E., GOBIET, A., MENUT, L., NIKULIN, G., HAENSLER, A., HEMPELMANN, N., JONES, C., KEULER, K., KOVATS, S., KRÖNER, N., KOTLARSKI, S., KRIEGSMANN, A., MARTIN, E., VAN MEIJGAARD, E., MOSELEY, C., PFEIFER, S.,

PREUSCHMANN, S., RADERMACHER, C., RADTKE, K., RECHID, D., ROUNSEVELL, M., SAMUELSSON, P., SOMOT, S., SOUSSANA, J.-F., TEICHMANN, C., VALENTINI, R., VAUTARD, R., WEBER, B. & YIOU, P. 2014. EURO-CORDEX: new high-resolution climate change projections for European impact research. *Regional Environmental Change,* 14**,** 563-578.

MARAUN, D., WETTERHALL, F., IRESON, A. M., CHANDLER, R. E., KENDON, E. J., WIDMANN, M., BRIENEN, S., RUST, H. W., SAUTER, T., THEMEßL, M., VENEMA, V. K. C., CHUN, K. P., GOODESS, C. M., JONES, R. G., ONOF, C., VRAC, M. & THIELE-EICH, I. 2010. Precipitation downscaling under climate change: Recent developments to bridge the gap between dynamical models and the end user. *Rev. Geophys.,* 48**,** RG3003.

RAFF, D. A., PRUITT, T. & BREKKE, L. D. 2009. A framework for assessing flood frequency based on climate projection information. *Hydrol Earth Syst Sci,* 13**,** 2119-2136.

SCHMIDLI, J., GOODESS, C. M., FREI, C., HAYLOCK, M. R., HUNDECHA, Y., RIBALAYGUA, J. & SCHMITH, T. 2007. Statistical and dynamical downscaling of precipitation: An evaluation and comparison of scenarios for the European Alps. *Journal of Geophysical Research: Atmospheres,* 112**,** n/a-n/a.

TAYLOR, K. E., STOUFFER, R. J. & MEEHL, G. A. 2011. An Overview of CMIP5 and the Experiment Design. *Bulletin of the American Meteorological Society,* 93**,** 485-498.

TURKINGTON, T., ETTEMA, J., VAN WESTEN, C. J. & BREINL, K. 2014. Empirical atmospheric thresholds for debris flows and flash floods in the southern French Alps. *Nat. Hazards Earth Syst. Sci.,* 14**,** 1517-1530.