Abstract

This research work deals with the identification of flood event drivers in North-Western Italy, both through a statistical analysis of streamflow annual maxima and the application of a conceptual semi-distributed hydrological model. The work provides different perspectives on how to study extreme events at the regional scale, focusing on a set of non-regulated catchments located in North-Western Italy, within the Alpine region.

After a preliminary analysis of the study area and the main data used, in Chapter 2 a correlation analysis between climate and flood indices at different temporal scales is widely discussed. In particular, annual maximum flows, extracted from the daily streamflow series, are correlated with the standard Climate Change Indices (ETCCDI) of precipitation and temperature, which are commonly used in climate research. A temporal correlation analysis, performed in order to identify which climate drivers better explain the interannual variability of floods, is followed by a spatial correlation analysis of temporal trends of the variables, with the aim of capturing the influence of climate (decadal) variability on the tendency of annual maximum discharges. The results show that, while at the annual timescale floods are highly correlated with indices of precipitation extremes, the tendencies of discharge maxima seem to be better explained by the mean precipitation over the catchment. A following step of the work involves the characterization and classification of different runoff event types over the region, which potentially allows to study how different flood event types regionally change over time.

To this aim, in the second part (Chapter 3-4) a conceptual semi-distributed hydrologic model is calibrated over the study area, first with locally observed discharge data and then regionally, by using the PArameter Set Shuffling (PASS) procedure (Merz et al., 2020), a robust and well documented regionalization procedure that allows to transfer the information contained into locally calibrated parameters and catchment descriptors to the entire domain. In this work, PASS is implemented with a

decision tree machine learning algorithm for the regionalization of model parameters. In particular, the advantage of using snow information in the calibration procedure is further investigated. In addition, a newly developed R package, useful to make the application of the procedure more flexible, is presented, together with examples of application based on a well known comprehensive U.S. hydrologic database that is publicly accessible. It appears from the results that PASS can be efficiently used for the regionalization of model parameters in the study area, by providing consistent relationships among climatic or geomorphological characteristics and model parameters while confirming the effect of reduction of parameter equifinality. The inclusion of snow in the model efficiency function doesn't significantly improve model simulations but provides more consistent results for snow parameters and, overall, less uncertain model simulations.

In Chapter 5, the regionally calibrated model is used for identifying, characterizing and classifying runoff events in the same study region. The aim is to extend the observed dataset in space and time in order to get a timeseries of spatially distributed simulated events spanning 60 years from 1961 to 2020. First, the ability of the model in reproducing observed runoff event characteristics (i.e. runoff coefficient, event duration, event peak time, event peak, event volume) is evaluated by comparing model simulations with observations in gauged sites. Then, regionally distributed runoff event characteristics for the period 1961-2020 are obtained by considering a wider catchment dataset, i.e. the European Catchments and Rivers Network System (ECRINS, 2012), over which the model with regionally calibrated parameters is applied. The results for the gauged catchments show that the model is able to properly capture the spatial pattern of observed runoff characteristics, in particular runoff event peak and volume, with a median Nash-Sutcliffe Efficiency (NSE) greater than 0.5, while the performance for runoff coefficient, duration and peak time is lower. It is worth noting that the value of the runoff coefficient, event peak and event volume is maximum in the southern and northeastern part of the region, in catchments located at medium elevation in the proximity of Alps and Apennines. Consistent results are also obtained by running the model in a distributed mode in ungauged sites. By using several climatic indicators describing different event features of the observed data that are not limited to discharge (i.e., type of inducing event, space-time organization, wetness state of the catchment and spatial interaction of precipitation and soil moisture), the first-order controls of event runoff response are identified in the gauged catchments using the framework presented in Tarasova et al. (2020), and this reveals four distinct clusters (sub-regions) with homogeneous event type frequency. In particular, cluster 1 mainly consists of lowland catchments where intensity-dominated and local volume-dominated events under dry conditions constitute a relevant quota of total events, suggesting that the main runoff generation mechanism is a local one with possible infiltration excess or event-fed saturation. These mechanisms indicate that convective activity is a very likely phenomenon leading to floods in these catchments. Cluster 2 includes catchments that are located both in lowland and at medium elevation. The fraction of events characterized by the presence of snow is higher compared to the previous cluster and extensive and steady rainfall events, both intensity and volume-dominated, are dominant types for this cluster. This indicates the potential occurrence of orographic slow-moving storms. The third cluster covers a large portion of the Alpine range, from South-West to North, and includes all high elevation catchments strongly impacted by snow processes and large valley catchments characterized by high-elevation zones. Indeed, the majority of events in this cluster is represented by mixture of rainfall and snowmelt and a moderate fraction is given by pure snowmelt events. Finally, cluster 4 includes catchments located all over the region at quite high elevation, both along the Alps and the Apennines. This cluster has some similarities with cluster 2 but the fraction of events impacted by snow processes is much higher and extensive volume-dominated events during dry conditions prevail, suggesting extensive event fed-saturation as a major runoff generation mechanism, with possible event-induced connectivity. By applying the same framework regionally in ungaged sites using simulated events that span the period 1961-2020, we find that the spatial pattern of event type occurrence as obtained by the model is coherent with the event typology from observed discharges and reflects the hydroclimatic conditions of the area. The main differences concern cluster 1, which shows a higher quota of unsteady events (mainly volume-dominated), and cluster 3, in which the fraction of snowmelt events overcomes that of rain-on-snow events. The event types classification allows to better explain the spatial distribution of event characteristics. The highest values of runoff coefficient, event peak and volume are found for catchments of cluster 2 or 4, where rain-on-snow events and orographic slow-moving storms, with an extensive and steady structure, play a role in the runoff generation. Instead, catchments pertaining to cluster 1 and 3, showing lower values of these characteristics, are strongly impacted by either local runoff events that massively depend on the intensity of inter-event evapotranspiration and on soil moisture state, unsteady volume-dominated events and mixture of rainfall and snowmelt events.

Finally, Chapter 6 is dedicated to final Discussion and Conclusions.

This Thesis represents a contribution to the hydrological community by providing insights on the added value of using regionally calibrated distributed hydrological models to describe flood events in a snow-dominated area, compared to a standard statistical analysis of extremes. It is also provided a coded version of an established regionalization procedure, to allow a flexible use of such models for a variety of hydrological regimes. Future research can build upon the time-series of simulated events and the results of event classification to study the possible spatial and temporal correlations among climate variables and specific flood event types.