PROJECT FINAL REPORT

Grant agreement no.:	212250
Project acronym:	ACQWA
Project title:	Assessing Climatic change and impacts on the Quantity and quality of Water
Funding Scheme:	Collaborative Project (CP) - Large-scale integrating project (IP)
Period covered:	from 01.10.2008 t0 31.03.2014

Project co-ordinator name:	Prof. Martin Beniston
Project co-ordinator organisation:	UNIVERSITE DE GENEVE
Phone:	+41 22 379 07 69
Fax:	+41 22 379 07 44
E-mail:	Martin.Beniston@unige.ch
Project website address:	www.acqwa.ch

1. Final publishable summary report

1.1 Executive summary

The overarching goal of the ACQWA project has been to quantify and assess the consequences of shifts in temperature and precipitation patterns, as well as the behaviour of snow and ice in many mountain regions in a changing climate. These transformations of mountain climates and environments are expected to change the quantity, seasonality, and possibly also the quality of water originating in mountains and uplands. As a result, shifts in water availability will affect both upland and populated lowland areas. Economic sectors such as agriculture, tourism or hydropower may enter into rivalries if water is no longer available in sufficient quantities or at the right time of the year. The challenge of the ACQWA project has thus been to estimate as accurately as possible future changes in order to prepare the way for appropriate adaptation strategies and improved water governance.

The project identified the vulnerability of water resources in mountain regions such as the European Alps, the Central Chilean Andes, and the mountains of Central Asia (Kyrgyzstan) where declining snow and ice are likely to strongly affect hydrological regimes in a warmer climate. Model results were then used to quantify the environmental, economic and social impacts of changing water resources in order to assess how robust current water governance strategies are and what adaptations may be needed in order to alleviate the most negative impacts of climate change on water resources and water use.

Current generations of state-of-the-art models were applied to various interacting elements of the climate system, that include regional atmospheric processes in complex terrain, snow and ice, vegetation, and hydrology. Results from the suite of models have enabled to project shifts in water regimes in a warmer climate in the case-study regions mentioned above. Observations, targeted models, and methodologies from the social sciences were applied to the impacts analyses on sectors such as tourism, agriculture and hydropower which will certainly be strongly impacted upon by changing water regimes. The results from these different approaches then served to develop a portfolio of recommendations for adaptation and updated water governance strategies.

In summary, the ACQWA project explored specific science and policy themes that included in particular the following elements:

- An integrated modelling approach to enable accurate projections of changes in the seasonality and quantity of runoff in the river basins under scrutiny in the ACQWA project;
- Identification of key economic impacts on a number of important water-relevant sectors, including the possible compounded effect of changing frequencies and intensities of extreme events;
- An assessment of the possible rivalries between economic actors that will be faced with changing water resources;
- A portfolio of possible water governance strategies to alleviate future problems of water allocation and use, of relevance to upcoming revisions of the EU Water Framework Directive.

1.2 Summary description of project context and objectives

Beniston and Stoffel (2014) have emphasized the fact that mountains are recognized as "sentinels for environmental change", in the sense that they exhibit dynamics in physical and biological systems that are often more readily identifiable than in other geographical entities of the globe (e.g., Loarie et al., 2009; Engler et al., 2011; Gobiet et al., 2014). The study of cryospheric, hydrologic, geomorphic and socio-economic change in sensitive mountain regions enables to further our understanding of how an important part of the terrestrial environment responds to, is affected by, and may adapt to rapid and sustained changes in temperature and precipitation regimes (Beniston, 2009; IPCC, 2013).

The importance of mountain regions as a provider of numerous ecosystem services was already recognized at the United Nations Conference on Environment and Development (UNCED, Rio de Janeiro, Brazil, 1992); mountain regions were included under Agenda 21 of the UNCED conference, which mentions under its Article 13 (UN, 1992) that "*Mountains are important sources of water, energy, minerals, forest and agricultural products and areas of recreation. They are storehouses of biological diversity, home to endangered species and an essential part of the global ecosystem. From the Andes to the Himalayas, and from Southeast Asia to East and Central Africa, there is serious ecological deterioration. Most mountain areas are experiencing environmental degradation.*"

Among these visible impacts, changes in glacier length and volume are perhaps the most spectacular manifestations of climate impacts in mountains; currently and with few exceptions, mountain glaciers from the equatorial to the high latitudes are experience glacier shrinkage (Paul, 2011; Bolch et al., 2012), highlighting the fact that this is a global phenomenon. Shifts in mountain snow-pack behavior in the past decades has also been observed, with collateral impacts on the timing of snow-pack melting and thus of surface runoff (e.g., Beniston, 2010), and also an influence on the start of the vegetation period for certain mountain plant species (e.g., Gottfried et al., 2012).

More subtle changes are reported for mountain ecosystems, in part because of the longer timescales involved in biological systems compared to mountain cryospheric systems, for example, and also because certain species are more adaptable than others (Dubuis et al., 2013), thus resulting in greater difficulties in attributing cause-to-effect relationships of climate change. In mountains, the transitions between biological entities and vegetation (ecotones) can occur over short distances, contrarily to what takes place in lowland plains (e.g., Gosz, 1993). Many changes in vegetation patterns related to sustained shifts in environmental conditions can be identified in these ecotone transition zones, as shown for example by Gottfried et al. (2012) at the boundary between high alpine vegetation and the snowline.

Finally, mountains are also the locale for numerous socio-economic activities, in particular tourism, agriculture, industry, mining, and energy (hydropower). These sectors are all sensitive to climate change, since climate exerts the essential controls on the availability of snow for ski tourism (e.g., Uhlmann et al., 2009; Morrison and Pickering, 2013), or of water for mountain agriculture, hydropower, and for mineral exploitation (e.g., Finger et al., 2012; Fuhrer et al., 2014; Gaudard et al., 2014), for example. However, it should be emphasized here that low priorities to sustainable land-use and natural resource management in many mountain regions in the world implies that changes in forest resources, mountain agriculture and water resources are driven not only environmental change but also by economic and demographic factors (Beniston, 2003).

It is in this context of rapid dynamics of environmental and social change in mountain regions that the ACQWA project (Assessing Climate impacts on the Quantity and quality of Water) was developed, in response to the first call for climate-relevant projects under the 7th European Union Framework R&D Programme (EU-FP7). The large integrating project, coordinated by the University of Geneva from 01.10.2008 – 31.03.2014 under EC contract nr 212250, brought together a consortium of 30 partners in 10 countries and on three continents for a total of 37 different research, public, or private research entities representing over 100 scientists.

The overarching goal of the project was to assess the vulnerability of water resources in mountain regions where snow and ice represent a major input of water for rivers originating in mountains, and where declining snow amounts and receding glaciers in a warmer climate are likely to have profound impacts on hydrological regimes. Future shifts in temperature and precipitation patterns, and changes in the behavior of snow and ice in many mountain regions will change the quantity, seasonality, and possibly also the quality of water originating in mountains and uplands (Sorg et al., 2012; Immerzeel et al., 2013). As a result, changing water availability will affect both upland and populated lowland areas (Hill et al., in press; Sorg et al., in press). The challenge of the ACQWA project has thus been to estimate as accurately as possible future changes in water availability, and the impacts these changes may impose on a range of water-dependent economic systems (Fig. 1).

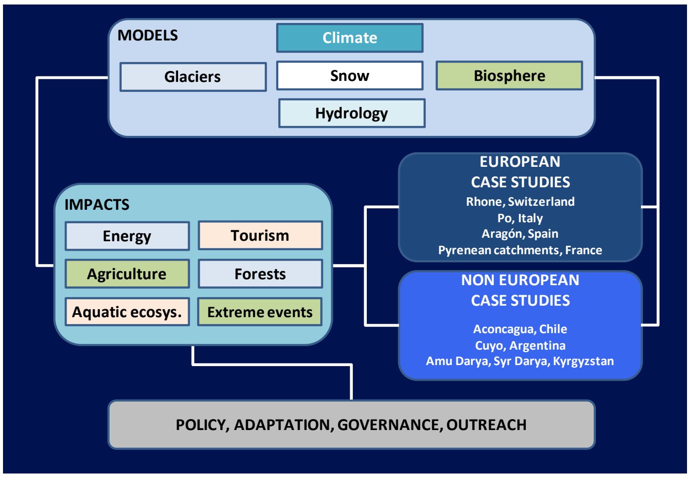

Figure 1: Structure of the ACQWA project and its main components

The flow diagram in Fig. 1 illustrates the broad structure of the ACQWA project. Current generation of state-of-the-art models (e.g., Themessl et al., 2010; Gobiet et al., 2014; Heinrich et al., 2013) were applied to various interacting elements of the climate system, that include regional atmospheric processes in complex terrain, snow and ice, vegetation, and hydrology in order to project shifts in water regimes in a warmer climate in mountain regions as diverse as the European Alps, the Central Andes of Chile and Argentina, and the mountains of Central Asia (Kyrgyzstan). Observations, targeted models, and methodologies from both the social and the natural sciences were then applied to conduct analyses of climate impacts on sectors such as tourism, agriculture and hydropower which could be strongly influenced by changing water regimes. Because these economic sectors and other water-dependent industries may well enter experience conflicts of interests and rivalries if water is no longer available in sufficient quantities or at the right time of the year, a further goal of the ACQWA project was thus to define a portfolio of proposals to pave the way for appropriate adaptation strategies and improved water governance (Hill and Allan, in press; Hill and Engle, 2013). These are designed to help alleviate the more negative impacts of climatic change on water resources and to reduce the risks of conflict between the economic actors most affected by these changes.

The focus on water has been the key element of the ACQWA proposal, because it is an essential resource for human populations, animal and plant communities. Water is relevant in every aspect of mountain systems, in the physical, biological and socio-economic systems. It directly influences the energy supply (hydropower), tourism (snow, water usage, glaciers), forestry and agriculture (productivity changes with changes in water supply, need for irrigation) and services from natural and semi-natural ecosystems. Changes in any of these compartments resulting from shifts in temperature and precipitation regimes are expected to result in feedbacks on water availability.

Achieving sustainable water use poses particular challenges for policy making because of its nature as a public good and because it often has both upstream/downstream and trans-boundary/transnational characteristics. Any changes in climate affecting precipitation and the behavior of snow and, where relevant, glaciers, will have a major influence on the seasonality, amount, and quality of surface runoff. The main changes are thus expected in the surface water systems, which have been comprehensively analyzed in the ACQWA project, in order to quantify the changes affecting the streamflow regimes, which may lead to uneven temporal distribution of the resource throughout the year. In this respect, the project has mainly concentrated on surface waters, both because mountain regions are in general depending on them rather than on groundwater, and given that the configuration of topography and landscape that do not allow the presence of sizeable alluvial deposits necessary for groundwater systems to develop.

A changing climatic regime could alter the frequency and the magnitude of a wide range of geomorphic processes related to extreme precipitation events that could in particular increase the severity of floods and debris flows (e.g., Stoffel and Beniston, 2006). Extreme precipitation events would in addition contribute to larger rates of erosion, discharge and sedimentation. A further factor responsible for decreased slope stability in a warmer climate is the reduced cohesion of the soil through permafrost degradation, particularly in the higher elevations in the Alps. Deglaciation can in some instances lead to problems of water accumulation behind unstable moraines that, if they fail, result in intense flooding and debris flows referred to as glacier-lake outburst floods (GLOFs) that put communities and infrastructure at risk. Similarly, hanging glaciers also pose a threat that is taken seriously in zones where glaciers are located above villages and major communication routes (Funk, 2006). In their retreat, these glaciers reveal a large quantity of unstable rubble and, sometimes ice that could result in severe down-slope flow of material. Given changes in the distribution of population with more extensive and intensive land use, particularly from tourism, any increase in the number and intensity of natural disasters could have proportionally higher human costs. By taking into account the impacts of extreme events within the hydrological cycle, the ACQWA project has acknowledged the fact that resulting natural hazards could contribute to the disruption of access to, and use of, water for many economic purposes.

Shifting precipitation patterns by season and sharply curtailed glacier mass in the mountains will lead to modifications in hydrological regimes and will also mean glaciers will no longer feed water into river catchments at a time of the year when precipitation amounts are low and the snow-pack has completely melted. These changes will have significant impacts on several key socio-economic sectors in mountain regions, particularly since these are also subjected to various other forces that influence their viability. There will in addition be cascading effects on downstream areas. Climatic changes will affect overall land use patterns, which in turn feed back into effects on water and carbon fluxes. Mountain agriculture has been under pressure from lower-cost production in lowland areas. Potential increases in drought conditions will only serve to increase its vulnerability. Forests' crucial role in protecting against erosion and protecting biodiversity and water storage are potentially threatened. As a result of shifting seasonality of precipitation and glacier melt, the reduction in capacity to store water could also diminish the potential for hydroelectric production just as European-wide efforts are being initiated to reduce dependence on fossil-fuel based energy sources. Not only mountain regions, but the entire European electrical grid could thus be affected. Some rivers, such as those that flow from the northern part of the Alps, may dry up partially or completely towards the end of the summer; this is already the case in the Mediterranean mountains, where the drought situation may well worsen. Although the energy potential of the Alps has by now largely been exploited, this is not the case for other regions of the world where this usage has barely been tapped (Romerio, 2002). By investigating the challenges of managing crucial but often limited water resources in many of the mountain regions that have been studied, the ACQWA project has aimed to better understand social and economic issues such as changes in social arrangements among mountain populations and their downstream neighbours, energy production in regions where water is underused as a means of helping abate greenhouse-gas emissions, and environmental issues such as the future evolution of water supply for use in domestic, tourist, or agricultural sectors.

Climatic change leading to shifts in hydrological regimes has the potential to increase competition over water that will be available at different times and in different quantities. Water is difficult to allocate because of its public good features, which are aggravated by upstream potential to capture the resource and by the fact that flowing water may cross internal and international borders. Changing land cover and land use will generate significant shifts in the amount and seasonality of water resources. For example, deforestation causes an increase in the average annual discharge, and an acceleration of runoff during rainstorm events, also enhancing erosion and downstream sediment supply. Changing social patterns and economic incentives have resulted in major land-use changes in many mountains of the world and, in some instances, have exacerbated the risks associated with excessive runoff and erosion potential.

The AQCWA project has sought to address such issues, particularly in regions with significant social change, for example resulting in land abandonment as farming loses attractiveness and spontaneous vegetation colonizes previously-managed terrain. Conflicting water use, for example between agriculture and hydropower, or between hydropower and tourism, as the resource diminishes through reduced precipitation in some areas and glacier retreat in others, has also been investigated within the ACQWA context (Hill et al., 2014). This has been achieved to acknowledge the fact that new water resource management is not just a matter of adjusting to shifts in the physical environment but is also associated with social changes generated by changing types and levels of water use and new market conditions affecting the distribution of the resource. These different issues have been tackled in the ACQWA project through a number of work packages (WPs), namely:

- **WP1: Coordination and administration**

- **WP2: Climatic and socio-economic drivers of change**

This WP provided a quantitative description of the primary (or direct) drivers such as climate change, and of the indirect socio-economic drivers, with relevance to mountain water resources.

- **WP3: Modelling climate change impacts on water resources, including extremes**.

The focus of this WP was to develop the climate scenarios at the regional and local scale and to model the effects of climatic change on water resources at the basin scale, using state-of-the-art cryosphere, biosphere, and hydrological models.

- **WP4: Impacts on natural and socio-economic systems, adaptation strategies, and policy issues**

The impacts, adaptation and policy WP investigated the manner in which changing water resources and water use may influence a range of sectors. It was also designed to consider a portfolio of adaptation and other response strategies, and to revisit current water governance issues with a view of improving water resource management.

- **WP5: Dissemination, outreach and training**

This WP was dedicated to project-specific workshop activities, publications, exchange of young scientists within the network, and public and stakeholder outreach activities.

1.3 Description of the main S&T results/foregrounds

The ACQWA S&T description will focus on the principal results emerging from the project, pertaining to the following elements:

- The ACQWA case-study regions
- Regional climate change in the ACQWA-case study areas
- Climate impacts by the middle of the 21st century on natural environmental systems that determine water availability: snow and ice; hydrology; extreme events
- Impacts on socio-economic systems (hydropower, agriculture, tourism) and semi-managed systems (forests, aquatic ecosystems)
- Lessons to be learned from the non-European case-study areas

A more complete description of the scientific results, including policy-relevance and possible adaptation strategies, is available in a 100-page ACQWA Science and Policy Brief (Beniston et al., 2013), and a shorter focus is provided in the introduction to the Special Issue of *Science of the Total Environment* dedicated to the project by Beniston and Stoffel (2014).

Case study regions used in the ACQWA project

Fig. 2 shows the main case-study areas investigated in the context of the ACQWA project. The Rhone and Po river basins in the European Alps have been used as a common "test ground" for model investigations, where the different methodological approaches have converged to the basin scale through appropriate up- or down-scaling techniques. Both basins represent ideal case-study areas, as they comprise all the elements of the natural environment that have been modeled (snow, ice, vegetation, hydrology) and have a wealth of data to enable models to be validated. At the same time, these are highly regulated watersheds, where economic activities related to hydropower generation, irrigated agriculture, and tourism take place in the context of a climate that is at the borderline between Mediterranean and Continental, and are therefore particularly vulnerable to climatic change (Beniston, 2003). The boundaries of the Rhone catchment study-area include the alpine segment, running from the Rhone Glacier in Central Switzerland to Lake Geneva. The boundaries of the Po case-study area used in the ACQWA project do not extend as far as the Adriatic Sea, for reasons of data access and hydrological model constraints. The investigations have thus focused more on the flows from the Alps of Piemonte and Val d'Aosta, with the "ACQWA Po" boundary that is limited to Cremona, on the Po River south of Milan and the western segment of the basin (Coppola et al., 2014). Regional climate model results, however, cover the entire basin as illustrated in the map on Fig. 1.

Figure 2: The principal ACQWA case-study regions: the Swiss Rhone and Italian Po basins, the Chilean Aconcagua basin, and the Kyrgyz catchments of Central Asia

Some of the methodologies developed in the intensive investigations of the European alpine catchments have been applied to the Aconcagua Basin in Chile, where receding glaciers already today pose a genuine threat to water availability (Pellicciotti et al., 2014). Investigating the coping strategies of Chilean economic sectors affected by changes in the quantity and seasonality of water resources can help highlight the types of problems that could arise in the Alps in coming decades (Hill et al, 2014). In Central Asia (Kyrgyzstan), on the other hand, the same processes of ice-mass wasting in the headwaters of the Syr Daria or Amu Daria rivers involve much larger glaciers (Sorg et al., 2012). During the 21st century, the meltwaters from the Tien Shan could potentially represent a source of economic opportunity, for example through the development of hydropower as a source of foreign revenue, but also a risk in view of the political instability and rivalries between different independent states of former USSR (Sorg et al., 2014).

Other research-specific case-study areas, not shown in Fig. 2 comprise the Aragón Basin in Spain for interdisciplinary investigations pertaining to agriculture and energy in a context of changing land-use and climate (Lopez-Moreno et al., 2014); and French Pyrenean watersheds for aquatic ecosystem studies in a hydrology, habitat and biota framework (Khamis et al., 2014a). These are located in the Cauterets region in the vicinity of the French Pyrenees National Park. By analogy with the other non-Alpine case study regions, some of the issues addressed in the Pyrenees in today's world are likely to be those that will arise in the European Alps in tomorrow's world.

Regional climate change in the ACQWA-case study areas

The high-resolution simulations carried out within the EU-FP6 ENSEMBLES project (www.ensembles-eu.org) formed the basis for the focused modelling work and climate impacts assessments within ACQWA. Two principal simulations were chosen from the ENSEMBLES multi-model dataset (namely ICTP_RegCM and MPI_REMO, both driven by ECHAM5-r3) and used by all partners. In addition, several impacts studies used the entire ENSEMBLES dataset in order to identify more completely climate-induced uncertainties. The IPCC (2001) A1B greenhouse-gas scenario through to the mid-21st century was applied across all the individual case studies to have a common scenario referenced period for all projections and impacts studies. The 2050s was set as the principal time horizon for the project, as this is a period in the future which is not too far removed from the time-scales typical of forward economic planning and decision-making. Using the ENSEMBLES simulations from a set of 22 high resolution regional climate models (RCMs), climate data in the regions of interest was compiled up to the year 2050. The ENSEMBLES RCMs were used with a horizontal grid spacing of 25 km, and the lateral boundary conditions were provided by eight different global climate models (GCMs). The restriction of using only the A1B emission scenario, rather than other scenarios or a range of emission futures, is of minor importance since the uncertainty due to the choice of emission scenario remains fairly small in the first half of the 21st century (Gobiet et al., 2014).

Results by 2050 using the multi-model mean climate change signals exhibit stronger warming along the Alpine ridge, especially in summer. The high sensitivity of the Alps becomes even more evident in the rather small Rhone case-study region located in the Valais region of south-central Switzerland, with projected median warming over 1.5°C in winter (DJF) and close to 2°C in summer (JJA). Warming is projected by all models of the dataset and for all seasons; the uncertainty of the projected changes is larger in summer and autumn than in winter and spring (Gobiet et al., 2014). In-depth analyses of this data suggests that the choice of the GCM that drives the RCM initial and boundary conditions has by far the largest effect on the total uncertainty, contributing more than 75% to the overall variance in most cases (Im et al., 2010).

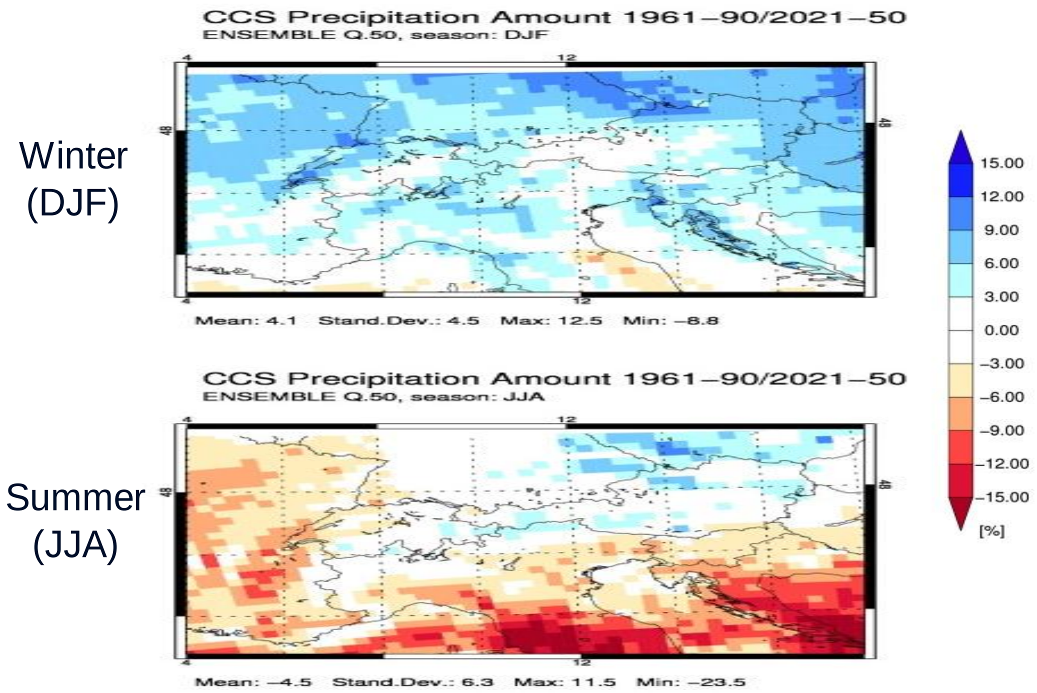

Figure 3: Alpine-scale precipitation change in winter and summer by 2050.
(Source: A. Gobiet, University of Graz, Austria).

The massive presence of the Alpine ridge as a dividing feature between Mediterranean and Atlantic or Continental climates clearly influences the spatial distribution of precipitation and the projections of change, as seen in Fig. 3. In the Rhone catchment, the summer decrease and winter increase are small through to 2050, although these changes may well amplify into the second half of the 21st century as shown by a number of earlier studies (e.g., Beniston, 2006). In the Po catchment, temperature and precipitation changes are somewhat more marked than in the Rhone catchment to the north. Between the decades 2001-2010 and 2041-2050, increases of temperature according to different RCM simulations range from 2 - 3°C, and the variation of mean annual precipitation ranges from 1-10%, mainly in the winter and early spring period. Accelerated melting periods, earlier in the year, and likely increases in summertime evapotranspiration will inevitably counter the influence of the larger amounts of summer precipitation on river discharge that are projected for the region.

In the Andean zone of Central Chile, the Aconcagua catchment is projected to experience warmer winters and decreasing precipitation which, as in other mountain regions, will affect the behavior of the mountain snowpack and lead to changes in the timing of snow and glacier melt (Pelliciotti et al., 2014).

In the Central Asian republic of Kyrgyzstan, available climate simulations project by 2050 decreases in summer precipitation by around 5% and increases in winter precipitation around 8%. Temperature increases of between 2.5 and 4.5°C are projected for all seasons in the region. Overall, extreme events will tend to increase, in particular at both ends of the moisture spectrum with more summer droughts and winter or spring flood events (Sorg et al., 2012).

Snow and glacier response to climatic change

- *Remote-sensing of changes in snow cover*

Remote sensing provides a unique opportunity to address the question of snow cover regime changes at regional scales. Since the availability of daily optical satellite data at the end of the 1980s (NOAA-AVHRR), methods have been developed to compute changes in the surface area of snow cover (SCA) and snow cover duration (SCD). The main parameters analyzed are the timing and duration of the melting season under current and future climate conditions. In this context, a remote sensing database of snow cover dynamics over a time period of 10 hydrological years (2000-2010) was compiled (Dedieu et al., 2014). It focused on the four watersheds of the ACQWA project, namely the upper Rhone (5’300 km^2) in Switzerland, the upper Po (37’800 km^2) in Italy, the Aconcagua in Chile (5’800 km^2) and the Syr Darya source region in Kyrgyzstan (110’000 km^2). The satellite data were provided by the MODIS Terra MOD-09 images and the MOD-10 snow products (NSIDC).

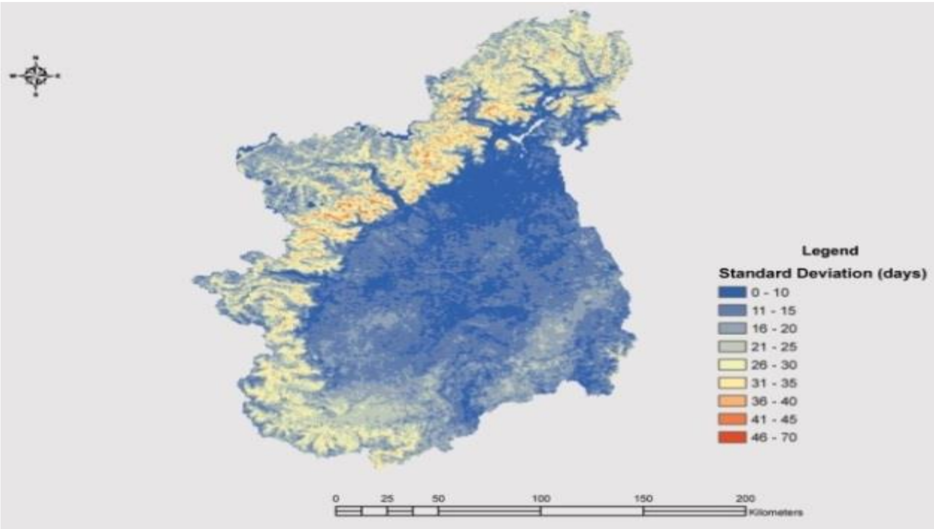

Figure 4: Annual standard deviation of snow cover in the Po Basin

The results rely on previous studies already conducted in different regions to reconstruct time series of snow cover at the regional scale and to analyze snow regime trends under the current climate change context. The specific added values of work within ACQWA include a novel and original method for climate impact detection, as well as scientific results for regions with crucial lack of information (Kyrgyzstan, Chile). Significant progress has been made in using statistical tools to assess the interannual variability of snow cover.

Maps of standard deviation highlight sensitive regions where strong temporal and spatial variability becomes a significant proxy of climate change related to recent changes in temperature, as shown for example in Fig. 4.

- *Changes in snow cover in the alpine part of the Rhone catchment*

Numerical simulations to assess the future course of seasonal snow cover under the influence of climate change were performed during the ACWQA project using the detailed snowpack model CROCUS coupled to the land surface model ISBA. In contrast to snowpack components of most land surface schemes within GCMs/RCMs and hydrological models, CROCUS explicitly accounts for internal processes occurring within the snowpack such as compaction, phase change/refreezing and snow metamorphism. During the ACQWA project, the model was driven by atmospheric fields from the RCM REMO at a horizontal resolution of 10x10 km² and run for a century, from 1950 to 2050. Regardless of the metric used to characterize the time evolution of snow conditions, the main outcome from the ACQWA-based study is that the seasonal snow cover in Alpine regions is most likely to decline within the next decades (Fig. 5), essentially as a result of increases in temperature (e.g., Beniston, 2012). This leads to a shift in the snow/rain partitioning towards relatively more rain and less snow precipitation. Such changes are seen to occur particularly at mid-altitude locations, between 1000 and 2000 m elevation above sea-level, which are most sensitive to air temperature fluctuations around the freezing point. The results obtained using the detailed snowpack model Crocus are consistent with the conclusions drawn from other impact models that use simpler snow schemes.

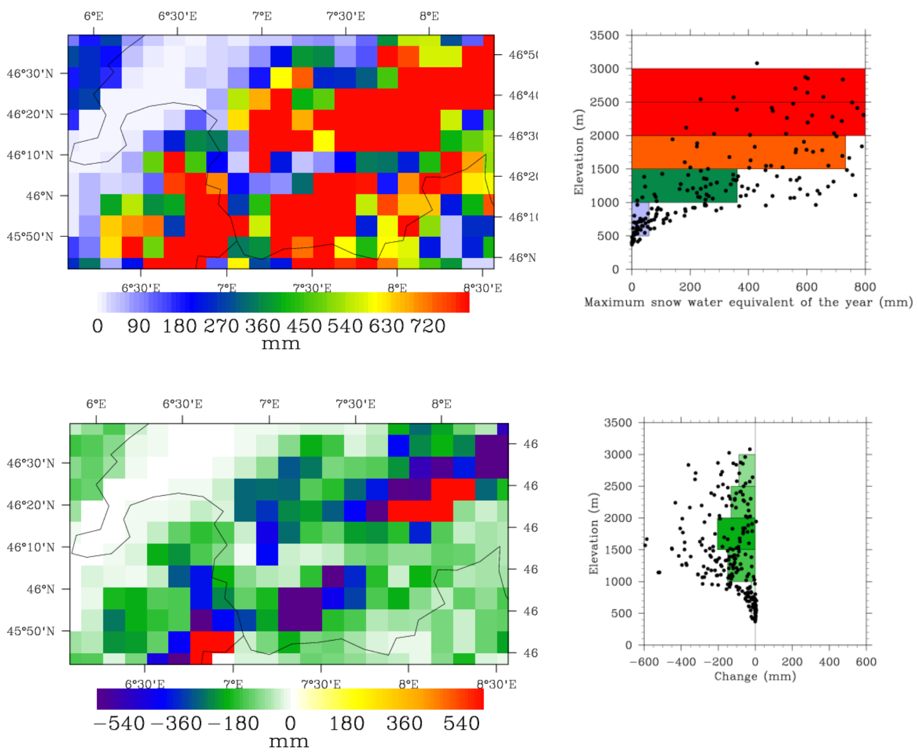

Figure 5: Upper left map mean snow water equivalent (SWE_{max}; mm); right: altitudinal profile of SWE_{max} for 1950-1969 period. Lower left: map of changes in SWE_{max} changes (mm) between 1950-1969 and 2030-2049;right: changes in altitudinal profiles. Dots in the right-hand figures refer to individual simulation grid points, whose average value over a given altitude band is provided as bars.

- *Glacier changes in the Rhone and Po catchments*

Understanding the glacier response to climate change in mountain regions is extremely relevant for water resources management. Future glacier response is also important to identify the boundary conditions for the evolution of the glacier hazard potential. Climate modifications can indeed influence stream flow regimes, increase downstream landslide and flood risk, and have an impact on hydropower production and other water uses, which strongly depend on melt water. The modelling of glacier response to climate change was carried out at the glacier scale by means of state-of-the-art continuous mass balance models for six different glaciers characterized by different morphological and surface characteristics and representative of the greater Alpine region. The models developed and implemented within the ACQWA project accounted for, in a spatially distributed fashion and at sub-daily temporal scales, accumulation and ablation processes as well as glacier evolution (Finger et al., 2012). The results thus allowed to quantify how glaciers tend to modify in response to changes in climate in order to reach the equilibrium with the current climate. Changes of the mass budget of a glacier and of glacier geometry (surface area, length and volume), were modeled at the highest level of detail in relation to knowledge of glacier behaviour and to the need of long-term modelling under stochastic climate scenario forcing.

The predictions of ice volume evolution suggest a progressive glacier retreat for the period 2001-2050 and a related ice volume reduction (see Fig. 6 for the Rhone Glacier, source of the Rhone River, in south-central Switzerland). Regardless of glacier features and future meteorological conditions, at no time in the coming decades are stationary conditions for ice volume attained, for any of the glaciers investigated. Ablation is generally sufficient to melt the entire amount of snow accumulated during the winter season over the remaining glacierized area and does not lead to changes in the mass balance trend.

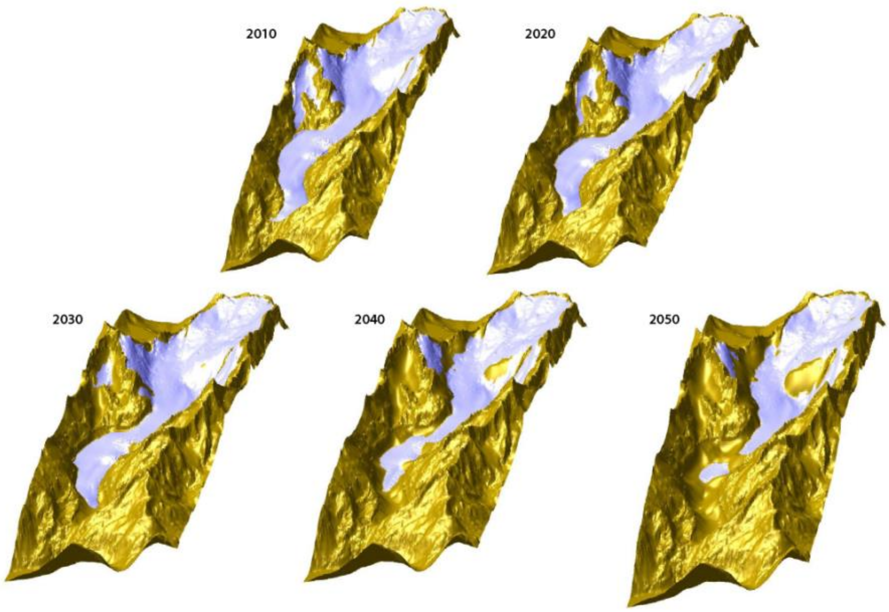

Figure 6: 3-D representation of the extent of the Rhone Glacier between 2010 and 2050 (Source: P. Burlando, ETH-Zurich, Switzerland).

An interesting result concerns the behaviour of glaciers and/or glacier areas, which are covered by a thick layer of debris. Their response to climate change shows a slower negative mass balance in comparison to debris-free glaciers. The debris cover tends to insulate the ice beneath, thus preserving the ice. The thin ice thickness located at high elevation and directly in contact with the atmosphere tends to disappear, leading to a scenario in which most of the remaining glacier surface is located at low elevations and is not exposed, but covered by a mantle of rock debris. This result points to the importance of including debris-covered areas in realistic simulations of future evolution of glaciers.

No significant variations in the mean spatial snow melt rates over the simulated decades were observed. However, the variability introduced by spatial stochastic climate forcing allows for spatial changes to occur. Some simulations showed that in some decades high snow melt rates at low elevations could compensate for low rates at higher elevations; in addition, higher snow melt rates were obtained at high elevation, due to increased temperatures in the future, whereas no snow melt occurred at low elevations as a result of the earlier disappearance of snow and the higher fraction of liquid precipitation events. Snow melt contribution to the runoff hydrograph, as well as its variability, thus reflect the characteristics of the meteorological forcing, indicating the importance of accounting for climate scenarios that are localized, spatially variable and highly resolved in time (Fatichi et al., 2014).

A progressive shift and change in shape of the ice melt rate frequency distribution was identified across all melting seasons. This is due to new melt events during times of the day that in the current and past climate did not generally lead to melting. Thus, anticipated ice exposure in spring generates low melt rates, as temperature is not high enough to cause higher melt rates. In summer, more frequent melt occurrence at night is related to higher night temperatures or when the solar radiation contribution is still low, such as during early mornings and late afternoons. Low melt increase is also observed in autumn in some decades and can likely be associated to melt at night. Higher frequency of high ice melt rates was also observed in the last two decades investigated (2031 to 2050) both in spring and summer, due to significantly higher temperature and reduced elevation range of the reduced area of glacier cover. In general, the overall ice melt rate is more variable than snow melt due to the transition of most of the investigated glaciers to small scale glaciers. In this respect, the timing of the transition and, more generally the impact of climate forcing, is significantly influenced by the glacier morphology, the initial ice thickness distributed over a large elevation range and by the intensity of the local climate change signal, which can be different from the large scale patterns simulated by GCMs and RCMs. The ice melt contribution to runoff in glacierized catchments tends accordingly to disappear gradually. An exception is represented by the Aletsch Glacier, the largest alpine glacier situated in south-central Switzerland, where no large changes for the simulated decades (2001 to 2050) are observed in the ice melt hydrograph.

The gradual disappearance of ice volume induced by climate change may confine glaciers to higher elevations causing a possible reduction of the speed of glacier retreat. A key role in this respect is played by the winter accumulated precipitation, which can mitigate (high accumulation) or enhance (low accumulation) the glacier retreat and the backward shift of the accumulation area.

- *Stability of glaciers*

Three different types of instabilities can be identified according to the thermal properties of the interface between the ice and the bedrock (Failletaz et al., 2012). If cold, the maturation of the rupture is associated with changes in surface velocities and the seismic activity generated by the glacier which, if known, can have predictive value. For the other types of instabilities, water plays a key role in the initiation and the development of an instability leading to rupture. If the ice/bed interface is partly temperate, the presence of melt-water at the interface reduces its basal resistance, which enhances the instability but also renders its prediction difficult. The third type of instability concerns steep temperate glacier tongues which experience enhanced basal motion during the summer melt period. Although instabilities of this nature are still difficult to forecast, a novel numerical model that includes water flow in a sub-glacial drainage network has been developed that has predictive capability. In the context of climate change, the stability of some alpine glaciers may be affected in the near future due to changes in the thermal regime at the ice/bedrock interface. Although some presently-hazardous glaciers may present a lower risk in the near future because of their retreat, some others may evolve towards a critical situation and present a genuine hazard for communities and infrastructure lower down in the valleys. A timely identification of such transitions towards potentially critical hazards is today a challenge that the ACQWA project has contributed to improving.

The modelling techniques developed and used in the ACQWA project represent a step forward with respect to existing literature as they allowed to highlight some important aspects of the impact of climate change on future glacier evolution (Failletaz et al., 2012). The key elements of the added value include: (*i*) the identification of the important role played by distributed in space and highly resolved in time localized scenarios, which explicitly model the internal variability of future climate, in modulating the glacier evolution trajectory jointly with the influence of glacier morphology, altitudinal range and ice thickness; (*ii*) a quantification of the evolution trajectories of different representative glaciers by means of statistical descriptors of ice- and snow-melt changes following ensemble based simulations by means of advanced mass balance glacier models; (*iii*) a decomposition of the mechanisms by which glacierized catchments will change their runoff regime, also showing relative changes of the runoff components and how these depend on the local climate and the glacier configuration (size, aspect, shape, etc.); (*iv*) the quantification of the role of debris cover in modifying the glacier retreat pattern in space and time, thus highlighting the importance of including this component in glacier evolution assessments for more realistic predictions.

Hydrological response to climatic change

- *Distributed basin-scale responses to climate scenarios (Rhone Catchment)*

The physically based distributed modelling methodology, as one approach to assessing changes in hydrology, allowed to model the response of the (upper) Rhone river to a high number of stochastically downscaled ensemble members at hourly temporal resolution and with a spatial discretization of 250x250 m, also keeping the highest detail of representation of anthropogenic disturbances, such as hydropower, water abstraction and irrigation. This level of detail is unprecedented, particularly for studies in Alpine regions, and represents a new basis, as compared to existing studies, for investigating options for adaptation policies. The results show how climate change effects on stream flow propagate from high elevation headwater catchments to the river in the major valley, highlighting the damping effect of the river network on the mean and on the extremes, even when the latter show large increases in the upper river reaches. The simulations also indicate that changes in the natural hydrological regime imposed by the existing hydraulic infrastructure are likely larger than climate change signals expected by the middle of the 21th century in most of the river network (Fatichi et al., 2014).

Results suggest that internal (stochastic) climate variability is a fundamental source of uncertainty, typically larger than the projected climate change signal. Therefore, climate change effects in stream flow mean, frequency and seasonality are masked by possible natural climatic fluctuations in large part of the analyzed regions (Fatichi et al., 2014). Simulations also identify regions where strong precipitation increase in the February to April period leads to flow larger than natural climate variability during the melting season. Despite the strong uncertainties induced by stochastic climate variability, an elevation dependence of climate change impacts on stream flow could be identified, with a severe reduction due to the missing contribution of water from ice melt at high-elevation and a damped effect downstream. The presence of reservoirs and river diversions tends to decrease the uncertainty in future stream-flow predictions that are conversely very large for highly glacierized catchments. Despite uncertainty, reduced ice cover and ice melt are likely to have significant implication for aquatic biodiversity and hydropower production. A decrease of August-September discharge and an increase of hourly-daily maximum flows appear as the most robust projected changes for the different parts of the Rhone catchment. This will have a significant impact on hydropower production and management. Water abstraction and irrigation needs, as described by the available data, will likely be marginally affected, as they represent a very small fraction of the use of the available water resources. However, while local changes may be of some relevance, it is unlikely that major changes in total runoff for the entire upper Rhone basin will occur in the decades up to 2050.

- *Distributed basin-scale responses to climate scenarios (Po Basin)*

The most common approach to assess the hydrologic impacts of global climate change involves the use of climate models to simulate climatic effects of increasing atmospheric concentrations of greenhouse gases, and hydrological models to simulate water-related impacts of climate change. River discharges and their temporal distributions are strongly affected by high mountain areas that are particularly sensitive to global warming. Therefore the quality of hydrological impact investigations, even for larger catchments, depends on the capability to model those specific processes in mountains.

Comparison of parsimonious and fully physically based models showed that simpler models, despite their approach for computing evapotranspiration based only on temperature, are sufficiently robust and accurate to perform hydrological impact investigations of climate change for alpine river basins investigated in the ACQWA project (Ravazzani, 2013). The bias resulting from the approximation of the method implemented to compute evapotranspiration is lower than uncertainty associated with different climate models, however.

Impacts of climate change on hydrological processes were assessed by comparing hydrological model results for the upper Po river basin driven by two different regional climate models (REMO and RegCM3) for the decade 2041-2050 with respect to the decade 2001-2010. Increase of temperature ranges between 15.2 and 17.5%, while variation of mean annual precipitation ranges from 1.1 to 9.6%. Precipitation increase is mainly concentrated in the period from January through March, and causes an increase of snow water equivalent during this period, followed by an accelerated melting period in the mountains. The rise in temperature causes an increase of actual evapotranspiration, mainly in the summer period that counteracts the influence of the larger amounts of summer precipitation on river discharge. Impacts of climate change on flow duration curves of mountain tributaries of the Po River, as provided by different regional models, exhibit a general decrease of discharge for high durations (low flows) and an increase in discharge for low durations (high flows). The two climate models yield different results for the impact on flow duration curves in Po the Po river basin. In particular, the REMO model data results in an increase in discharge for both low and high durations, while use of the RegCM model data yields a decrease in discharge for both low and high durations except for the period ranging from 12 to 58 days.

- *Modeling changes in the Po, Rhone and Kyrgyz catchments with the CHyM model*

In order not to depend on one single model, the effects of predicted climate changes on Hydrological cycle of Po and Rhone catchments have been studied by forcing the CHyM hydrological distributed model with 8 different climate scenarios simulated by RegCM and REMO regional climate models. A further simulation with the RegCM model has also been used to simulate the future hydrological scenario on the Kyrgyzstan catchments. The future discharge trend has been analyzed for the whole drainage network, obtaining a map of such effects for different seasons (Coppola et al., 2014).

Downscaling of climatic scenario at hydrological scale can be considered an important challenge after the downscaling from GCMs to RCMs models. The results show that the simulated effects of climate change on the hydrological cycle appear to be considerably different for the Po and Rhone basins and also for different regions within the same basin. The same conclusions can be reached using the 8 different simulated climatic scenarios. The decrease of water resources is shown to be more critical for the entire flood plain during the fall season, leading to a loss of 200 m^3/sec at the outlet of the Po River. The decrease of flow discharge is estimated to be more than 50% of the seasonal average for a large portion of the drainage network (Im et al. 2010). The effects of climate change on the hydrological cycle appear less evident in the high part of the Rhone valley and, more generally, in the higher part of the Alpine region (Fig. 7). The situation is quite different for Kyrgyzstan, where, for a large portion of simulated domain, increases in discharge during winter months and decreases of water availability during summer are observed.

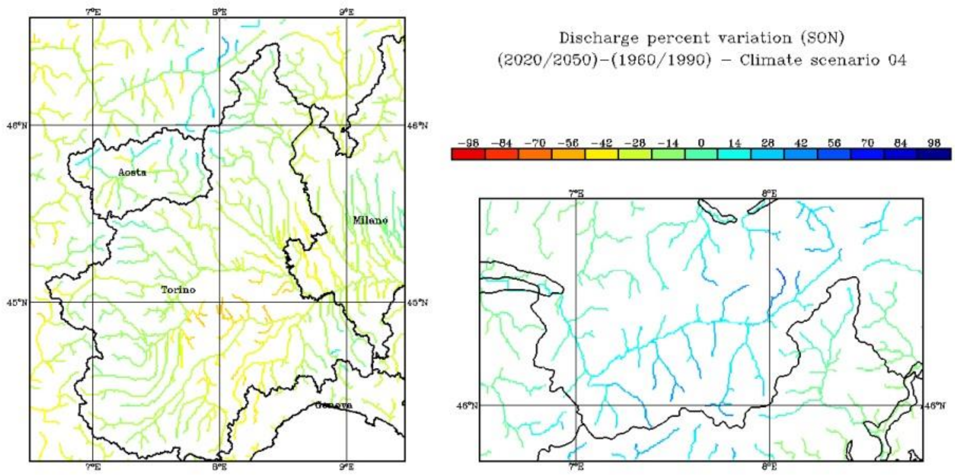

Figure 7. 30-year mean discharge difference (%) in the Po basin (left) and Rhone basin (right).

Extreme events

Extremes of heat and moisture can have a strong bearing on the rate of snow melt, glacier retreat, and thus on water regimes in mountain watersheds (floods and droughts and associated impacts on a number of water-dependent economic sectors). Geomorphic hazards can add an extra burden on local economies by damaging buildings, disrupting communicating routes and potentially rivers themselves (silting, damming, etc.). A focus on extreme events and natural hazards was thus an important focus of the ACQWA project.

- *Novel statistical methods to deal with extreme events*

Weather and climate extremes affect societies and ecosystems and sometimes induce fatalities and large financial losses. To reduce the impact of such events and to improve risk assessment studies, it is essential to obtain accurate statistical features of extremes. In the framework of the Extreme Value Theory, a new method has been established, based on Generalised Probability Weighted Moments and Kernel regression (Naveau et al., 2011).

Novel statistical methods were proposed to analyze extreme events, to develop new algorithms to implement such methods and to apply those approaches to hydrological and climate data. Among many byproducts of this project, three specific topics were highlighted: spatial clustering of weekly maxima of hourly French rainfall, non-stationary analysis of heavy precipitation in Switzerland, and the study of global changes in seasonal extreme precipitation (Kallache et al., 2011). For the first topic, one of the main objectives of statistical climatology is to extract relevant information hidden in complex spatial-temporal climatological datasets. To identify spatial patterns, the most well-known statistical techniques are based on the concept of intra and inter clusters variances (like the k-means algorithm or EOF's). As analyzing quantitatively extremes like heavy rainfall has become more and more prevalent for climatologists and hydrologists during the last decades, finding spatial patterns, simple and fast clustering tools tailored for extremes have been lacking. In this context, a novel algorithm based on multivariate extreme value theory was proposed. Comparing with classical clustering on weekly maxima of hourly precipitation recorded in France (Fall season, 92 stations, 1993-2011) shows that other patterns, specific to extremes events, were missing when employing traditional approaches.

The second example dealt with the inference of high rainfall return levels in a situation of non-stationarity in space and time. A new estimation technique of such high return levels based on semi-parametric approaches within the mathematical framework of Extreme Value Analysis was implemented (Smith et al., 2013).

The third example focused on exploring how anthropogenically-warmed climate is expected to sustain a larger increase of precipitation extremes. Here, new evidence was provided on global seasonal precipitation extremes for the 21^{st} century, using 8 new high- resolution global climate model simulations. In the mid and high latitudes of both hemispheres, a significant intensification of extremes is evident in all seasons at the end of the century (Toreti et al., 2013).

The method provided an accurate estimation of heavy, extreme daily precipitation by statistically modeling exceedances above a high threshold and handling for spatio-temporal non-stationarities. The method is fast (no optimization is required) and flexible (non-parametric) and can be applied to large data sets from catchment area series to global climate models. Importantly, the method is computationally inexpensive (Naveau et al., 2011).

A similar approach was applied to high resolution CMIP5 Global Climate Models. Results show a remarkable intensification of extreme precipitation events at the end of the 21st century (especially under the RCP8.5 scenario) in all seasons. A parallelized R package of the method has been developed and is available for use by hydrologists, climatologists, engineers. This part of ACQWA research enabled the development of a state-of-the-art fast and flexible methodology that takes into account spatio-temporal non-stationarities in the statistical modeling of the daily precipitation exceedances distribution. The method can be also applied to large data sets. The new methodology allows in a computationally inexpensive approach to accurately characterize the statistical features of extreme precipitations, such as the return values illustrated in Fig. 8 for Switzerland (Stucki et al., 2012).

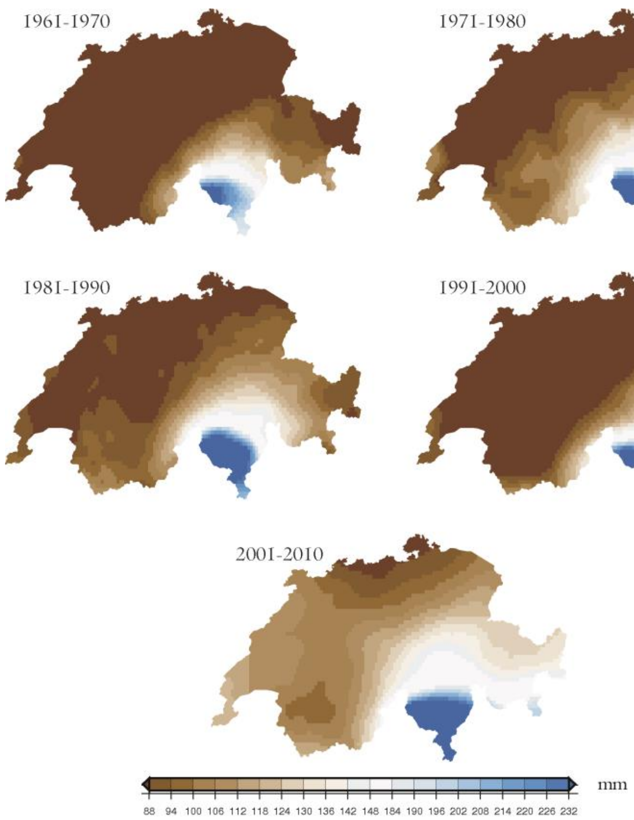

Figure 8. 50-year return levels of precipitation (mm) for Switzerland, 1961-2010. Spatial-temporal differences are evident with the north-south gradient and the tendency towards higher return levels in the 1980s as well as the recent decade over the Upper Rhone valley.

- *Hot spells in the Rhone valley*

In order to achieve a better understanding of the potential impacts of climate and climate change over the target areas, temperature extremes carefully and accurately studied. Here and for the first time, warm spells both in winter and summer were identified and analyzed for the last six decades (1951-2009) over the Upper and Southern Rhone valley by applying a recently developed approach (Toreti et al., 2012).

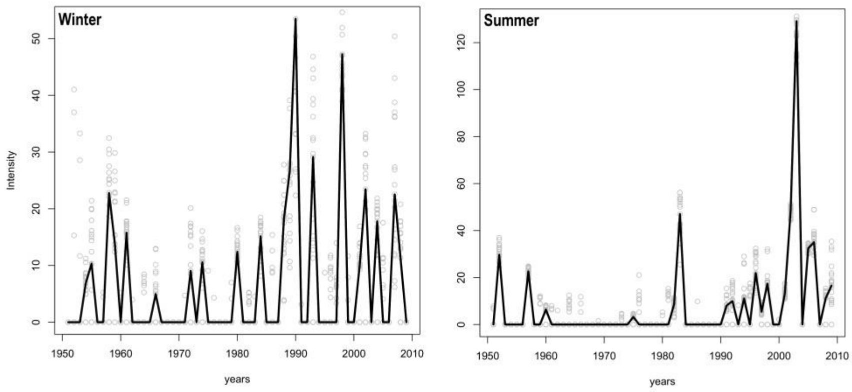

Figure 9:Intensity of winter and summer warm spells from 1951-2009 in the Upper Rhone Valley. Grey dots are associated with values of intensity calculated for each grid point. The black solid line represents the median of the values.

The approach is based on the identification of consecutive sequences of days (with a certain tolerance) with daily maximum temperature above a station-specified threshold. An increase in the intensity and frequency seems to have affected the two areas in the last 30 years in both seasons, especially after 1990 (Christidis et al., 2012). Furthermore, the higher intensity of the warm summer spell in the Southern Rhone valley, especially at the end of the period, can be highlighted. Finally, the 1983, 2003 and 2006 summer events are clearly visible in both valleys (Fig. 9).

The application of the state-of-the-art methods to recently released data sets gave the possibility to identify, estimate and analyze for the first time warm spells over the target areas both for winter and summer. The approach can be easily adapted for other regions of the world and it is available to the climate community (e.g., Hegerl et al., 2011).

- *Hydrologically-relevant geomorphologic hazards*

Changes in temperature and precipitation are likely to have a range of secondary effects on the occurrence of natural hazards, in particular also in mountain environments. However, while theoretical understanding exists for increased mass-movement activity as a consequence of predicted climate change, impacts can hardly be detected currently in observational records. One of the most obvious consequences of climate change at higher elevations is the glacier downwasting and related formation of ice-marginal lakes, ice avalanches and gravitational processes originating from the debuttressing of previously glacierized walls and hillslopes (Jomelli, 2012; Stoffel and Huggel, 2012). Glacier downwasting is likely to promote many rock slope failures at rather short future time scales, probably in the order of decades. Important effects of climate change on slope stability are also related to the warming and thawing of permafrost. Slopes currently underlain by degrading permafrost will probably become less stable at progressively higher altitudes with ongoing climate change. The probability of rock instability and the incidence of large (>10^6 m^3) rockfalls will likely increase in a warming climate. A large number of recent slope failures have been documented in permafrost areas, related to increasing temperatures.

The impact of climate change on hydrologically-relevant geomorphologic hazards was further investigated by the development of (i) the slope stability component of the distributed hydrological model used for climate change impact analysis and (ii) an advanced slope stability model, which can simulate the effect of climate change on the occurrences of shallow landslides at high resolution in time and space.

The soil slip simulation tool that was implemented in the distributed hydrological model during this study is based on the concept of the infinite slope model (Tiranti et al., 2013). This model is aimed at exploring the ability to reproduce the slope response using a coarse terrain resolution at large catchment scales (river basin mesoscale, of the order of hundreds of km^2) and thus for large scale simulations that are aimed at predicting hazard changes at the regional scale.

The second model was developed to investigate more in detail and at finer spatial scales the stability of slopes and their dependence on the detailed description of the involved hydrological and geotechnical processes. The HYDROlisthisis model is aimed at fine spatial scale resolution (of the order of the meter) and thus suitable for local scale (i.e., hill-slope and catchment scales of the order of 10 km^2 at most) investigations of slope stability response to climate change forcings. The model consists of an hydrological and a geotechnical component, which are coupled together. The hydrological component takes into account the 3D variably saturated flow through soil, surface runoff, and hysteresis of the Soil Water Retention Curve (SWRC), topography-dependent solar radiation, potential evapotranspiration and root water uptake. The geotechnical component, which is based on a multidimensional limit equilibrium analysis, considers simple earth pressure conditions acting on the lateral sides of the soil column. These forces are computed using the coefficients of active, passive and at rest pressure, which are computed taking into account unsaturated conditions (Stoffel et al., 2014).

Both models showed, when applied to case studies, to be able to capture the observed slope instabilities at the scale for which they were developed. In particular, they showed significantly-better performance than statistical models, especially because they explicitly account for the spatial and temporal variability of the soil water dynamics, which is a key variable in the triggering of shallow landslides. This result is particularly valuable in the context of analyzing the shallow landslide hazard potential due to climate change, as they can explicitly account not only for the changes of the climatic forcing, but also for the consequences that this can have on the soil water dynamics and the related soil-vegetation medium response.

Climate and land use impacts on water availability and management: The case of the Aragón river basin, Pyrenees

Water availability is probably the main constraint for the development of modern agriculture, industry and tourism in the Ebro valley. The work developed within the ACQWA project provides robust information to water managers and policy makers concerning the response of river flows under projected environmental change. The study provides advance warning concerning limitations to maintain current water demand even if the regulation capacity is increased in headwater areas. Moreover, the study suggests that controlling land cover may be a mitigation strategy to minimize the probable reduction of available water resources (Lopez-Moreno et al., 2014).

A warming between 1-2°C and a decrease of precipitation between 5-20% is projected for the Spanish Pyrenees according to climate model simulations using the IPCC A1B scenario for the 2021-2050 period. A noticeable increase of warm events during winter months is also expected in the region. In the Pyrenees, an increase of 1ºC implies a 20% decrease in snow accumulation at 2000 m above sea level. This sensitivity increases at lower altitudes and decreases at upper elevations.

According to observed land cover change and the analysis of current aerial photography and remote sensing data, a scenario of land cover for the middle of the 21st century in the Pyrenees has been developed. Shrub areas are projected to evolve toward pine forests, with a 100 meters rise in the tree line and an increase of the shrub areas in the subalpine areas.

Increased vegetation in the basin could decrease annual stream flow in the Upper Aragón river basin by 16%, mainly in early spring, and autumn. Projected climate change could decrease annual stream flow by 13.8%, mainly in late spring and summer. Combined effects of forest regeneration and climate change may thus to reduce annual stream flows by 29.6%. Simulating the management of the main reservoir of the region using the modeled hydrological data, it is likely that serious difficulties to meet the current water demand, based on its current storage capacity (476 hm^3) will emerge. If the current project to enlarge the reservoir to a capacity of 1059 hm^3 is completed, the potential exists to apply multi-annual stream flow management, which will enhance the capacity to maintain the current water supply. However, under future climate and land cover scenarios, reservoir storage will rarely exceed half of the expected capacity, and the river flows downstream of the reservoir may be dramatically reduced (Lopez-Moreno et al, 2014).

Impacts on the hydropower sector

- *The Swiss Rhone catchment*

This research provided an analysis of the hydropower future in the context of climate change, opening of the electricity market to competition, decarbonisation of the energy system and, in some countries such as Switzerland and Germany, even phasing out of nuclear energy. The case study of the hydropower installation of Mattmark, located in the Rhone catchment represents the focal point of the analysis conducted in the context of ACQWA (Gaudard and Romerio, 2014). In addition, the study encompasses Swiss and European dynamics, in particular those related to energy policy and markets. The first part of the research, devoted to Mattmark, provides quantitative results, whereas the Swiss and European analyses are mainly qualitative.

The main interest of this study was to highlight the link between climate change, electricity markets and energy policy. In particular, it shows how electricity generation is affected by climate change, the opening of the electricity market to competition, as well as the development of micro and super-grids, new storage technologies and intermittent energy resources such as solar and wind energy. These factors also influence the added value created by hydropower, which represents an important source of revenue in mountain regions. The analysis takes into consideration the electricity demand, which is affected only modestly by climate change. The impact of its variation on the wholesale power market is estimated by means of econometric tools. Microeconomic models and techniques based on operational research are used to simulate the markets' behaviour, hydropower reservoir management, as well as electricity generation.

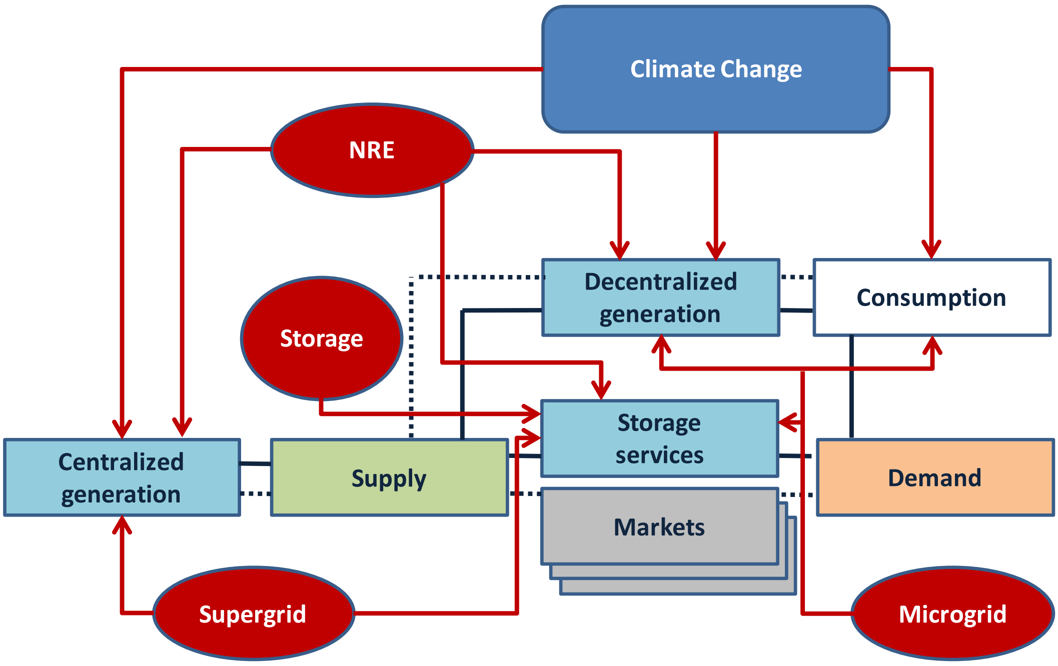

Figure 9: Multiple constraints on electricity markets

In Fig. 10 (Gaudard et al., 2014), red boxes represent the drivers that are transforming the electricity system, which includes centralized and decentralized generation; storage services; consumption; supply and demand; flows of power through the electric lines (plain lines) and flows of information, notably price signals (dotted lines). Spot, future, balancing and ancillary services markets will determine the value of hydropower. Climate change will affect hydropower because of the possible reduction in surface water flows and seasonal shifts in water availability. The technological, economical and behavioural changes in the electricity system are, however, expected to exert a stronger impact on hydropower.

The outcome of the research conducted on the Mattmark site provides key information to decision-makers about the factors that will determine the future output and value of hydropower. Despite the margins of uncertainty, public bodies and private or public companies may use this information in the definition of their policies and strategies. The particular case of the renegotiation of the concessions for water rights, which represents a topical issue in several Alpine regions, is particularly relevant. In the case of Switzerland, most of the concessions will come to an end between 2030 and 2060. It should be mentioned here that, thanks to its flexibility, hydropower and reservoirs play a very important role in ensuring the security of electricity supply and the network’s stability in Europe.

- *The Po Basin*

Climate change can influence hydropower production in two ways: directly, through changes in precipitation and, as a consequence, in inflows; and indirectly through the electricity load because energy consumption varies with air temperature. This could be very important in determining the management of hydropower reservoirs and may cause conflicts with concurrent water uses.

In particular, reservoir management is aimed to provide the water resource when it is needed, transforming the natural regime, with its modulation across the year and its random fluctuations, in a regulated and more useful flow.

The main results from the ACQWA focus on the Po Basin have been summarized by Maran et al. (2014) as follows:

1. A large local variability in electricity production, which follows an analogous rainfall pattern: a reduction of 10% is estimated in the Val d’Aosta while a 20% increase is expected in the Toce valley;
2. The monthly modulation of power production throughout the year is expected to change: in both areas, the greater variability in summer inflows will affect the filling of hydropower reservoirs and, in some years, it will not be possible to use all the storage capacity.
3. the interannual variability of production is projected to increase.

All these effects are mostly the consequence of greater variability in river flows and the decrease in snow fall. The effects on hydropower production of variations in energy prices, i.e., the other major forcing factor, were also studied. The two Italian small case studies are very similar: in general, larger volumes of water are stored in winter and greater quantity of water are used in Spring, corresponding to a higher energy production in this period (Fig. 11).

Thanks to the collaborations of the ACQWA project, universities, research centers and private companies have had the possibility to deal with a high quantity of data produced by climatological and hydrological models at large spatiotemporal scales. These data allowed the implementation of detailed management models, simulating the management of hydropower plants. Large areas of north-western Italy were analyzed and an assessment of the impacts of climatic change on the water and electricity sectors in these zones has been made available.

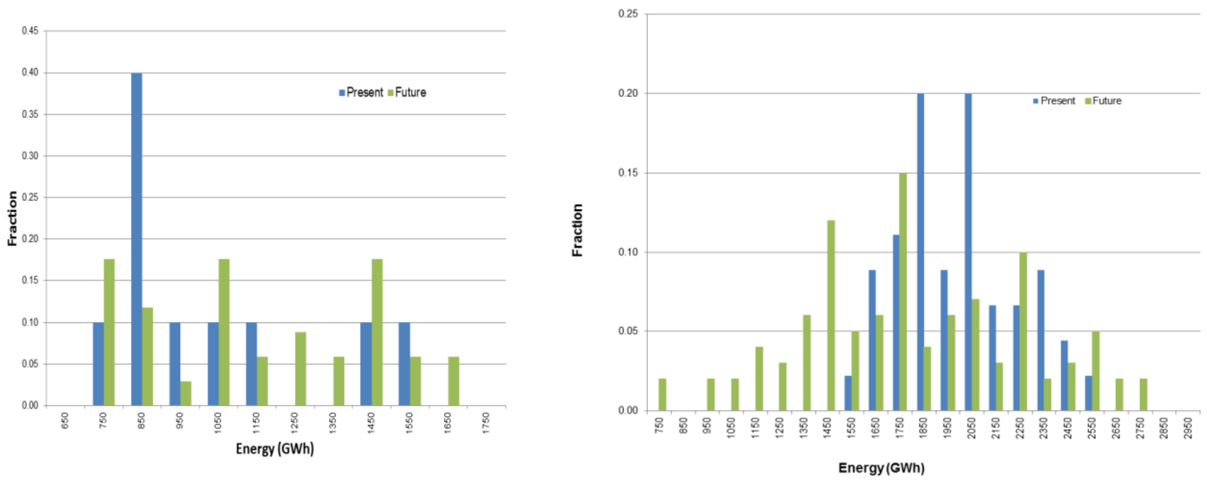

Figure 11: Frequency distribution of yearly production for the Toce (left) and the Valle d'Aosta (right) networks

However, new storage capacity implies the construction of new dams and reservoirs that could modify heavily the natural landscape of the Alpine region and are not easily accepted by local communities. This potential for conflict calls for the development and implementation of methodologies and processes to increase the adaptive capacity of water governance and management systems. ACQWA results could be used as an important aspect to be considered in decision making procedures regarding the development of new infrastructures for the water sector.

Impacts on the agricultural sector

- *The Swiss Rhone catchment*

In the Swiss Rhone catchment, irrigation has historically been important. Today, about 11'000 ha of land is irrigated with over half occupied by grasslands used for livestock production, followed by orchards and vineyards. This allocation of irrigation reflects the economic importance of the production of livestock and permanent crops, while arable crops play a minor role (Fuhrer and Jasper, 2012).

Over the past decades, a trend was identified towards a higher frequency of extreme droughts on timescales shorter than 2 months, whereas for longer timescales, no clear indications of a change over time could be found. For the future, the mean of several agro-climatic indices even suggest a shift towards warmer and rather wetter mean conditions during the growing seasons, but an increase in risks caused by high temperature (i.e., heat stress). The thermal growing season becomes longer, with potentially positive effects on pasture and livestock production, most pronounced at mountain sites, whereas at the valley bottom, a trend occurs towards increasing risks of frost in permanent crops due to an asynchronous change in the beginning of the growing season and late frost occurrence, and in heat stress for livestock (Fuhrer et al., 2014).

With increasing temperatures, water consumption through crop evapotranspiration increases, thus leading to additional irrigation needs to maintain optimal yields. This concerns much of the lower part of the valley, but also the pasture-dominated south-facing slopes, especially on soils with low water holding capacity. Simulations reveal a moderate average increase in water requirement for irrigation in 2021-2050 relative to 1981-2009. In the currently driest areas, additional potential water requirements from 1981-2009 to 2021-

2049 would range between 0 and +200 mm per average growing season, depending on the climate scenario. During extremely dry years, such as 2003 or 2011, the increase would be much higher and could exceed the water availability in surface waters of smaller catchments with a nival runoff regime. An example would be the catchment of the Sionne (27.7 km^2) where water is drawn through water channels ('Suonen') for grassland irrigation, and where discharge is controlled by snowmelt and rain. A much reduced area could be irrigated under these low-flow conditions, which may become more frequent in the future. At the catchment-scale, the estimated mean total water requirement is 32×10^6 m^3 per year (1981–2009), and a 45% increase during the 2003 European heat wave in the driest area of the catchment. With an extreme scenario, the increase is about 44% by 2050, which is consistent with the values of 2003 as shown by Smith et al. (2012).

Coping with climate change in agriculture requires knowledge of possible trends in agro-climatic conditions, with a focus at the smaller scales such as catchments or sub-catchments where decisions are taken. At those scales, risks from water shortage during parts of the season are likely to become more important in the long-term future, particularly in view of a drastic decrease in glacier volume and snow cover. The methodology developed in this project can help to identify emerging water conflicts. Given the importance of grazed pastures in the mountain zones for their economic, ecological and cultural role, it can be expected that agricultural policy will continue to support the maintenance of this extensive form of agricultural production, which requires irrigation. In other parts of the valley, maintenance or even expansion of the production of high-value crops such as grapevines and fruit trees, or even vegetables, would continue to use water for irrigation. However, the amount is much smaller than for pastures, given the smaller surface area concerned, and the shorter length of the irrigation period. Moreover water resources at the valley bottom are much larger and may not be subject to the same extent to inter- and inner-annual variability on the timescale considered because the dependence on rain and snow is less than in sub-catchments with a nival regime. And, technical measures to optimize and control irrigation, or building reservoirs would be easier to implement.

Thus, in the shorter-term, the demand for water for irrigation will increase and put pressure on smaller rivers in catchments with little or no water supply from glaciers, particularly in years with limited precipitation and snowmelt during springtime. In the sub-catchments concerned, water management will play an even more essential role under future climate conditions than in the past. This improved water management should include both regulations regarding the allocation of water to different users of the same source, installation and management of reservoirs, and technical measures to improve the efficiency of irrigation by avoiding losses of distribution systems, evaporative losses, and excessive runoff due to over-application of water (Smith et al., 2012).

An important result of this assessment is that until 2050 major agro-climatic risks under climate change will likely be caused by high temperatures rather than by increased drought. Situations with high temperatures may have negative effects on both crop and livestock production. Measures to cope with this risk could include the use of additional water for cooling purposes, shifting crop cultivation windows, and shifts in cultivar selection in both arable crops and permanent crops (grapevines, fruit trees). In addition, extending the grazing period and shifting of grazing zones to higher and/or cooler parts of the catchment could help to avoid heat stress in animals. However, such shifts in intensification of grassland use may have negative consequences for other ecosystem services such as biodiversity, soil carbon storage, and nitrogen retention. Thus, coping with heat stress in livestock production will require careful consideration of the sensitivity of alpine grassland ecosystems to intensification (Fuhrer et al., 2014).

- *The Po Basin*

A basin-wide enquiry for the Po Basin has looked into the optimal policy that might facilitate adaptation to climate change in agriculture, in particular policies that can help to smooth water input fluctuations. The different roles of farmers and the public sector in adapting to these changes have been addressed. The first and most fundamental level of adaptation to climate change in agriculture occurs at the level of the local farmer. Farmers undertake strategies to adapt to the form of climate change that they are able to foresee, through observation of the recent trends in indicators such as average temperatures and average precipitation. However, they can do little to respond to the greater uncertainty inherent in climate change. Farmers' adaptation to expected climate change will often take the form of investment in assets to shift water temporally, using locally appropriate water storage techniques (Bozzola and Swanson, 2014). It might also be possible for water management to be pursued through more efficient irrigation practices. Because of the low costs and relative abundance of the water resource in the Po basin, farmers have traditionally relied on inefficient irrigation methods, which are still one of the main causes of waste of fresh water resources. Local farmers adopt strategies to cope with expected climate change, but the important question for policy makers concerns the role of governance in supporting adaptation.

A key question here is the role that remains for policy in light of local adaptation. Evidence is given by this study that there are some impacts of climate change that farmers' adaptations do not reach at present. Despite the farmers' observed investments to adapt to mean changes in climate, variability in climate continues to impact crop yields. Table 1 shows the results of a simple correlation analysis of the relationship between variability in temperature, precipitation (during the months March to August) and agricultural yields in the Po basin.

Log Yields	Precipitation anomalies	Temperature anomalies
Maize	-0.16***	0.02
Barley	-0.28***	-0.15***
Soft Wheat	-0.43***	-0.1*
Sugar Beet	-0.21***	-0.2***
Soya	-0.23***	0.08

*Table 1: Correlation between crops yields and standard deviation of precipitation and temperature. Significance Levels of the correlation coefficients at: ***1%; **5%; *10%.*

The negative correlation between agricultural yields and observed anomalies indicates that agricultural production has suffered when unanticipated climatic variability occurs. In short, farmers' adaptations appear to be based on individual (farmer-based) forecasts deriving from current trends in observed weather patterns, but are not responding to the increasing variabilities (Bozzola and Swanson, 2014).

Impacts on mountain tourism: the case of Valais, Switzerland

This part of the ACQWA project has investigated the climate-related and socio-economic drivers of winter tourism in the Swiss canton of Valais, as well as its expected water consumption in the future. Winter tourism is amongst the main economic sectors within the canton. The most significant finding is the industry's exposure to reduced snow cover. A report by the OECD published in 2007 depicted Valais as showing little vulnerability to the reduction of snow cover. However, instead of approaching the tourism industry at the cantonal level, a more regional/local approach of the canton (48 resorts grouped into 17 regions) has been adopted. By comparing two average winters (2004-06) with a snow-poor winter with average economic conditions (2006-07) and a snow-rich winter at the beginning of the current economic crisis (2008-09), the study reveals high disparities between the resorts. This is an indication that vulnerability assessments and, more particularly, adaptation measures should be considered at a much lower level than has been done so far (Schaub and Andonova, 2012).

Valais seems to be more exposed or vulnerable to climate change than previously expected. Although the canton witnessed a smaller reduction in skier days than other regions during snow-poor winters, some resorts were strongly affected. And just in removing the biggest resort of the canton (Zermatt) from the statistics, the impact of the exceptionally warm winter of 2005-06 appears to be much bigger: Instead of losing only 4.9% in the number of skiers, the canton would have lost 7.8%. If the hotel sector proved less exposed to a snow-poor winter than the cable-car companies, the accommodation sector is facing serious difficulties in some regions when longer trends and socio-economic factors are taken into account. The canton could consider some support to the hotel sector so that they reach a "critical mass" of tourists, a strategy adopted by Austria, for instance.

The study can be seen partly as a "wake-up call" in many respects. The main political implications of these findings are that policy-makers need to take into account the big disparity existing between regions, and how vulnerable small and medium size resorts can be to the changes that are expected to impact tourism in years to come. The main challenges are to find ways for increasing cooperation amongst and within resorts and touristic regions, improve the promotion of the canton in general (the label "Valais Excellence" and the website of "Valais Tourism" constitute a good start in this respect), and more vitally, the ability to consider alternatives to skiing during warmer winters, especially for more vulnerable regions
.

For the regions themselves, it would be advantageous to build further winter-sport infrastructure exclusively in snow-reliable regions (thus increasing their center of gravity) and to adopt a more integrated structure. The target – the type and origin of population they would like to attract for winter holidays – should be chosen carefully. More generally, stakeholders should be aware of potential changes in the tourists' preferences –a major unknown for the next decades. The future water consumption of the tourism industry can only be estimated. It can be said that the current coordination between the hydroelectric sector and the cable-car companies – in which the first sells water to the second for artificial snow-making purposes – should be maintained and perhaps even increased in some cases. More studies should be led to determine whether the current law on artificial snow in the canton should be improved in the future. In addition, the type of tourists (according to: age, country of origin, and the social class) they expect to attract should be considered. The preference of a high social class can change within a small time frame, and it is uncertain whether the middle class would continue its skiing activities at the same level as it does currently, or even if it can afford this time of recreation in the future.

Impacts on mountain forests

Climate change has the potential to substantially alter the provisioning of essential ecosystem services, and mountain regions are likely to be both particularly vulnerable and heterogeneous in their response to climate change. To date, few studies have attempted to quantify the impact on mountain ecosystems under a wide range of climate scenarios, including novel "2° scenarios" that are based on the assumption of an early stabilization of greenhouse gas concentrations in the atmosphere. Similarly, although mountain ecosystem services are crucial both locally (e.g., forest-mediated protection of human infrastructure from avalanches or rockfalls) and regionally (e.g., impact of ecosystems on runoff generation), there is a scarcity of studies focusing on shifts in ecosystem services.

A systematic assessment of climate change impacts on mountain forest properties and the ecosystem services they provide was performed in the context of the ACQWA project (Wolf et al., 2012). The focus was on five ecosystem services (carbon storage, runoff, timber production, diversity, and protection from natural hazards); four regionally downscaled climate scenarios that cover a wide range of possible future conditions were used; three complementary, state-of-the art models of forest dynamics that were used to simulate a wide range of forest properties were employed; and the simulations in two climatically contrasting case study areas (catchments) of the European Alps at several spatial scales, from the stand to the entire catchment, were performed.

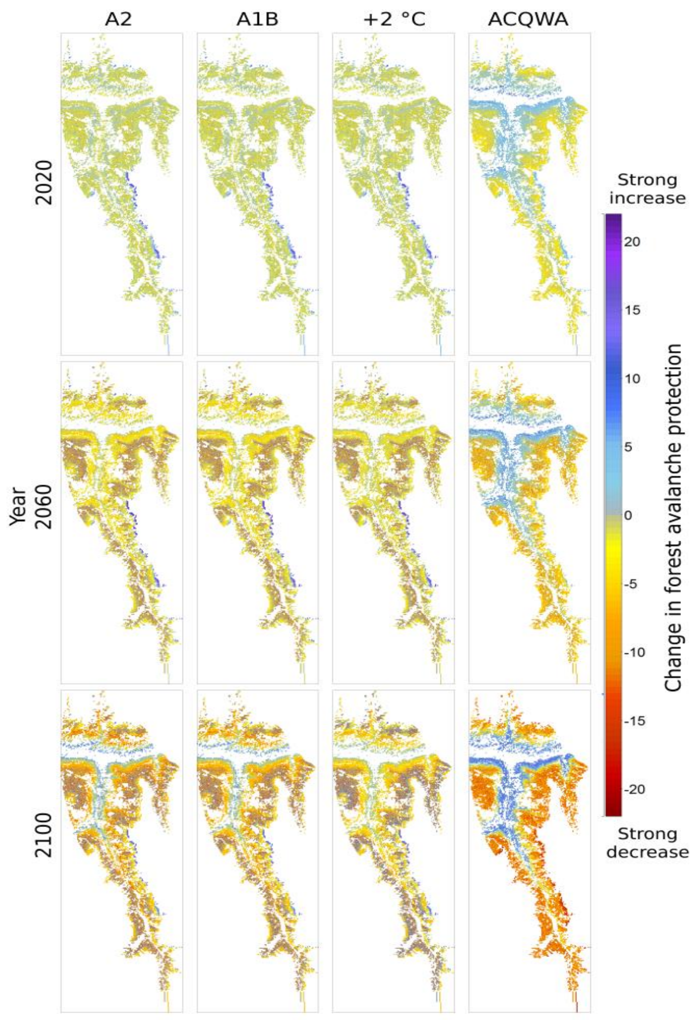

Figure 12: Changes in forest-derived avalanche protection in the Saas valley (part of the Rhone catchment) under four climate scenarios as projected using the forest landscape model LandClim. Changes are shown as normalized difference compared to 2010 levels.

The results suggest that the sensitivity of mountain forest ecosystem services to a 2 °C warmer world depends heavily on the current climatic conditions of a region, the strong elevation gradients within a region, and the specific ecosystem services in question (Fig. 12). Model projections show that large negative impacts will occur at low and intermediate elevations in dryer/warmer regions. Here, relatively small climatic shifts result in negative drought-related impacts on forest ecosystem services (Manusch et al., 2013).

In contrast, at higher elevations, and in regions that are initially cool-wet, our simulations suggest that forest ecosystem services will be comparatively resistant to a 2 °C warmer world. It was furthermore found that considerable variation exists in the vulnerability of forest ecosystem services to climate change, with some services such as protection against rock-fall and avalanches being sensitive to 2 °C global climate change, but other services such as carbon storage being reasonably resistant. While these results indicate a heterogeneous response of mountain forest ecosystem services to climate change, the projected substantial reduction of some forest ecosystem services in dry regions suggests that even a 2 °C increase of global mean temperature cannot be seen as a universally "safe" boundary for the maintenance of mountain forest ecosystem services (Elkin et al., 2013)

The results achieved in the ACQWA context rely on research activities that were begun more than a decade ago and benefited considerably from the funding made available in ACQWA in the sense of a synthesis and further development of existing approaches. Beyond this, the added value of the project was the availability of state-of-the-art climate scenarios and the comprehensive focus of the study, as ACQWA has always emphasized cross-sectoral activities rather than isolated impact assessments of individual components of mountain systems.

Impacts on mountain aquatic ecosystems

- *Mountain lakes in the Gran Paradiso National Park, Valle d'Aosta, Italy*

During the ACQWA project, measurements of the physical, chemical and biological parameters in 20 high-altitude, ultra-oligotrophic lakes in the Gran Paradiso National Park (PNGP) were undertaken. All these lakes are characterized by extreme seasonality; most are naturally fishless, while some were stocked with fish about forty years ago (Tiberti et al., 2012). Both fishless and stocked lakes were sampled in order to determine the effects of introduced fish and of the interplay between the introduction of alien species, strong seasonality and shifts in environmental conditions. Among the different measurements, zooplankton densities at different depths in order to gain insight on their vertical distribution, their migratory behavior along the water column and the response of zooplankton to vertical abiotic gradients (e.g., light intensity and UV gradients). The PNGP measurements were complemented by the development of deterministic one-layer models to simulate the dynamics of high-altitude lake ecosystems, in order to estimate the response of the lake ecosystems to climate and environmental change (temperature, duration of ice cover, etc). These observational and modeling studies have enabled some of the first quantitative determinations of the effects of introduced fish and of the interplay between stocking and environmental change (Tiberti et al., 2013).

- *Impacts on Pyrenean aquatic ecosystems*

In mountainous river basins, the water source balance (i.e., the contribution of rainfall, glacier-melt, snowmelt, and groundwater to flow) is extremely sensitive to climate change. Projected warming is likely to alter stream flow quantity/quality regimes and modify in-stream physico-chemical habitat. As a result, biodiversity patterns of alpine running water organisms are highly likely to be altered, as vulnerable species must either adapt physiologically and/or genetically or migrate to more suitable habitats to persist (Finn et al., 2013).

As part of the ACQWA project an inter-disciplinary approach was adopted to investigate alpine stream ecosystem responses to climate change. Both the drivers of change (i.e., climate) and responses to change (i.e., hydrology – habitat – biota) were quantified using a combination of scenario simulation, space for time substitution surveys and in-situ experimental work. Macro-invertebrate community structure and function, population genetics, habitat characteristics and water source contributions were recorded at 26 sites representing a gradient of glacial influence, across five river basins in the French Pyrenees. Contemporary river flow, habitat, taxonomic and genetic patterns were related to both glacier cover and melt-water contribution to bulk discharge. Downscaled climate data was then used to drive (i) a watershed simulation (TOPKAPI) of river flow and glacier/snow melt dynamics and (ii) a water temperature regression model. Temperature and hydrological projections were then linked to observed patterns to predict future hydro-ecological change (Khamis et al., 2013a).

Further work, to improve understanding of finer scale hydrological and biological process , investigated; (i) the response of an alpine spring community to the introduction of a large bodied invertebrate predator (predicted to expand its range) and (ii) the inter-annual variability of the heat budget and thermal dynamics of a glacier-fed river reach.

Until now application and testing of the water source contribution approach as a hydro-ecological management tool, has been limited to single river basins. Results from this study highlight the utility of this approach for both management and prediction of climate driven ecosystem change. Furthermore, knowledge transfer between project partners enabled the successful completion of watershed simulations for a glacierized river basin in the relatively data poor Pyrenees, where until now few simulations have been conducted. This provided a unique insight into future hydrological and physico-chemical habitat change and the potential implications for biodiversity. Quantification of melt-water contribution enabled the identification of climate sensitive macro-invertebrate taxa which are expected to exhibit considerable range contraction as glacier retreat (Khamis et al., 2013b). Trait profiles of glacial stream taxa were also recorded and were shown to have the potential to act as indicators of changing water source dynamics (i.e., reduced glacier contribution to discharge), particularly when comparing sites from multiple biogeographic regions. Improved process understanding from experimental work and high resolution hydro-meteorological observations could prove valuable for further development of deterministic temperature models and species distribution models.

The Pyrenees represent the southern limit of contemporary glaciation in Europe, and only small cirque glaciers remain of the extensive ice cover which existed during the Little Ice Age. Thus, findings here can be viewed as a future analogue for mountain ranges which currently have significant glacier cover but which will shrink in the future. The successful application of the water source approach in a changing cryosphere across multiple river basins highlights its potential for use in future alpine conservation planning. Furthermore, the coupling of hydrological simulation and space for time surveys has a potential to inform future baseline conditions and could prove valuable for determining appropriate climate adaption conservation strategies (Khamis et al., 2014b).

Lessons learned from non-European regions

- *Central Andes, Aconcagua Catchment, Chile*

Chile represents a highly contrasting case to the European basins, from both a physical and a governance perspective. Water rights are a marketable commodity with minimal environmental regulation and no sectorial prioritization. Government institutions are highly centralized, with limited agency and capacity of water managers at the regional level. Increasing drought periods (from a combination of reduced summer runoff and altering precipitation patterns) are likely to compound current issues relating to the overuse of surface and groundwater from both legal and illegal abstractions in the Aconcagua Basin (Hill and Allan, 2014).

Major challenges from the governance perspective relate to the accuracy and applicability of monitoring data; lack of available, accurate, systematized and accessible information on water rights, water judgments, water market and prices, health and availability of water resources; climate data and uncertainty calculations are not used in planning; constricted agency and capacity of technical experts at the regional level; lack of trust and agreement on scientific studies and hydrological data that blocks concensus building; lack of a formal flexible conflict resolution mechanism.

A common thread across the different case studies are the challenges or opportunities presented by regional networks, actors and the differing levels of trust that can be capitalized for more integrated and longer term planning of water resources management. In the Aconcagua, there are a number of institutions that could be fostered to improve adaptive capacity. The Mesa del Agua is a collaborative attempt to strengthen inter-sectoral cooperation for the Aconcagua Project that should be made more inclusive with a broader, climate-related, goal orientation. While there is potential flexibility through the water rights system, denoting flexibility and autonomy to react quickly to changing conditions in the river, improvements to trust between river sections and more expedient and flexible conflict resolution mechanisms could greatly enhance its role in adaptation to drought conditions (Hill and Allan, 2014).

- *Water governance in the Mendoza watershed in Cuyo, Argentina*

During the ACQWA project, an analysis of the institutional environment in Argentina, its attributes and functionalities was undertaken, against the requirements to adequately respond to expected impacts on water resources and governance (Girón et al. 2014). Further, research focused on how the inherent constraints resulting from a dysfunctional institutional system have a potential to undermine adaptive capacity and adaptation actions to climate change. During the last three decades a weak institutional context created problems of credibility, coordination and cooperation and has had severe impacts on the quality of public policies. A weak institutional context is defined by low enforcement of the rules and/or by an application that is broadly discretional and one in which institutional change is frequent and radical. Hence, Argentina's public policies tend to be unstable, poorly coordinated, weakly enforced, and highly rigid, and the decision making process lacks credibility. This persistent environment of instability, policy volatility, political short-termism and precarious enforcement pervades the water governance regime across scales and in the case study area, even in a formally highly decentralized federal system (as in other regions and sectors affected by the impacts of climate change). The decision making context, including drivers of water use, in a complex governance landscape, reinforces informational and cognitive, financial, social and cultural barriers to implement adaptation efforts and enhance adaptive capacities to improve the resilience of the social-ecological system. The scientific evidence that under projected climate change conditions the water resources of the Mendoza region could be reduced in a significant way thus requires the adoption of adaptive governance principles whose application is obstructed by rigidity, lack of cooperation and coordination, serial replacement (as opposed to predictable law and institutional structures) and fragmented or truncated learning processes and knowledge creation and dissemination.

- *Climate change impacts on Kyrgyzstan*

Within the ACQWA project, the Syr Darya river basin in the Tien Shan ranges have been chosen as a pilot area for a specific case study. The goal is to illustrate the impact of climate change on a transboundary river, where complex responses result from asymmetric power relations and less robust institutions. Kyrgyzstan has the role of a water tower as many rivers – such as the Syr Darya – originate within the country's territory. The difficulty for the Central Asian states is to apply the principles of equitable use of water and to agree on a balanced reservoir management, which would allow the generation of energy in winter – benefiting upstream countries such as Kyrgyzstan – and irrigation for large-scale agriculture in summer – benefiting downstream countries such as Uzbekistan. Current challenges in the water operating regime are likely to be exacerbated by climate change impacts as water shortages during summer become more frequent with expected decreases in summer precipitation and reduced glacial meltwater releases due to smaller glacier volume (Sorg et al., 2012).

The Tien Shan mountains are located in the center of the Eurasian continent; the distance to the nearest sea exceeds 1500 km. Arid and semi-arid climate conditions result from atmospheric flows coming from the Atlantic and the Arctic, which lose major parts of moisture over the European territories and Siberia. Research within the framework of the ACQWA project and based on previous studies under the UNFCCC have demonstrated that the most probable climate change scenario fits the emission scenario B2-MESSAGE. By 2050, Kyrgyzstan will thus experience an increase in average annual temperature by +2.5°C and an increase in annual precipitation sums by +2.5%, with increasing amounts in winter and decreasing amounts in summer.

Sorg et al. (2012) show that these climate changes may have various impacts, in particular water shortages exacerbated by a decrease in glacial meltwater releases in the long-term due to reduced glacier volume. Glacier shrinkage is most pronounced in peripheral, lower-elevation ranges near the densely populated forelands, where summers are dry and where snow and glacial meltwater is essential for water availability. Under the high greenhouse-gas emissions SRES A2 scenario, 28-35% of today's glacier volume in the Syr Darya catchment may melt by 2050.

Furthermore, shifts in seasonal runoff maxima have already been observed in Kyrgyzstan, and summer runoff will probably further decrease if precipitation and discharge from thawing permafrost bodies do not compensate sufficiently for water shortfalls. Runoff may decrease by 15%. Currently, however, river runoff in the formation zone of the Syr Darya basin is increasing due to intensive glacier melting. This trend is likely to continue up to 2025. After 2025, however, contribution of glaciers to river runoff in the headwaters of the Syr Darya will decrease irreversibly; as a consequence, the total hydropower potential of the Syr Darya basin may decrease by up to 15%.

1.4 Potential impact

The ACQWA project was formulated in response to the first call for climate-relevant projects under the EU 7th R&D Framework Programme (FP7). The philosophy of the project was based on the need to accurately assess the vulnerability of water resources in high-elevation, mid-latitude populated mountain regions. In such regions, declining snow and ice in a warmer climate are likely to strongly affect hydrological regimes, in terms of quantity, seasonality, and also quality. As a consequence of changing water availability, both upland and populated lowland areas will be affected. Rivalries and conflicts of interest may emerge as economic sectors such as agriculture, tourism or hydropower compete for water that may no longer available in sufficient quantities or at the right time of the year for these sectors to function. The challenge for the ACQWA project was thus to estimate as accurately as possible future changes in order to prepare the way for appropriate adaptation strategies and improved water governance. The project has enabled a suite of state-of-the art models to be applied, adapted, or developed to address many of the issues related to a changing physical world and to the socio-economic impacts that these changes will inevitable generate. Model results have also been used to assess how robust current water governance strategies are and what adaptations may be needed to alleviate the most negative impacts of climate change on water resources and water use.

Introduction

As the evidence for human induced climate change becomes clearer, so too does the realisation that its effects will have impacts on socio-economic systems and terrestrial ecosystems with multiple implications for society. Mountains are recognised as very sensitive physical environments with local populations that are highly exposed to rapid changes in the resource base on which their economic livelihoods are dependant. Moreover, policy priorities for alpine regions are often set by downstream actors, leading to trade-offs across different policy contexts that have the potential to be further exacerbated by changes in the hydro-climatic environment. While governance is well recognised as a core issue in current water resource related challenges, to date there is still a paucity of information on how adaptable water governance regimes in mountain areas could be to hydro-climatic changes impacts and the socio-economic impacts that these changes imply.

Large integrating projects generally represent a step forward in furthering our understanding of various complex processes and interactions between environmental, economic, social, and technological systems. The ACQWA project is no exception to this rule, and the five years of research has indeed enabled a number of issues to be refined and clarified, but has also identified problem areas that would need to be addressed in future investigations of this nature.

In January 2011, the ACQWA project organised a workshop in Riederalp, Switzerland, where over 25 EU projects focusing on water resources and water management were represented. Institutional and financial obstacles to data access for use in modelling exercises were identified, and gaps in scientific knowledge that contribute to uncertainty were highlighted. A working paper was subsequently published in 2012 in Environmental Science and Policy[1] to report on the main conclusions of this crucial meeting. The discussions summarised in the paper have identified a number of sectors where these gaps often represent barriers to successful research outcomes, and suggested ways and means of alleviating some of these difficulties. A major issue that has been raised is that of data for research purposes. Policies aimed at ensuring free and unrestricted access to data, especially those generated by the numerous research projects that focus on issues of water availability, quality and management have been recommended. Implementation of the recommendations formulated in the Environmental Science and Policy paper may help pave the way for a more rapid and efficient production of research results that are of importance for policy guidance at the local, national and supra-national (EU) levels.

Socio-Economic Implications

ACQWA utilised advanced modelling techniques to quantify the influence of climatic change on the major determinants of river discharge at various time and space scales, and analyse their impact on society and economy. The main focus was to develop continuous transient scenarios from the 1960s up to 2050. By focussing on developing scenarios of change up to 2050 for a set of river basins, the project aims to develop climate information downscaled to temporal and spatial scales that are more useful to the challenges decision

[1] Beniston, M., Stoffel, M., Harding, R., Kernan, M., Ludwig, R., Moors, E., Samuels, P., Tockner, K., 2012: Obstacles to data access for research related to climate and water: implications for science and EU policy-making. *Environmental Science and Policy*, 17, 41-48.

makers face (Beniston et al., 2011). This shortened modelling horizon allows for a more realistic assessment of the potential impact on the governance and socio-economic system components.

Key findings for different socio-economic sectors and themes

The following sections highlight the key findings from the ACQWA project with regards to socio-economic implications in key sectors across the case studies, namely, hydropower, agriculture and tourism (Fatichi et al., 2013a; Fatichi et al., 2013b; Fuhrer and Jasper, 2012; Fuhrer et al., 2013; Gaudard et al., 2013; Gaudard and Romerio, 2013; Gaudard et al., 2014; Gobiet et al., 2014; Hill Clarvis et al., 2013b; Stoffel et al., 2013; Toreti et al., 2013). In mountain regions, climate change takes on particular significance since snow and ice melt represent a large stream-flow component and a vital local resource for freshwater supply, hydropower generation, irrigation, tourism activities, and other industrial uses. Glaciers and snow pack act as vital natural storage systems, storing water as snow and ice through the wetter winter periods and releasing these provisions as flows during the drier summer months. Changes in precipitation and temperature will therefore impact both the quantity and timing of water available across these different sectors. Changes in the frequency or intensity of hazards (e.g. floods, glacier lake outburst floods, rock falls and landslides) are also likely to have a range of socio-economic implications as temperature and precipitation changes affect slope stability, glacier melt, snow melt and the zero isotherm.

Hydropower

- Variability in glacier retreat patterns (size, aspect, shape, debris cover, etc.) has consequences for the management of hydropower plants and dams, which depend primarily on snow- and ice-melt.
- Reduction in surface water flows and seasonal shifts in water availability (more availability of water in the earlier months of the year and a longer summer period with lower run-off) will impact hydropower. Climate change also indirectly affects electricity load because energy consumption varies with air temperature.
- Technological, economic and behavioural changes in the electricity system are, however, expected to exert a stronger impact on hydropower.
- In the Po region, greater variability in river flows and decrease in snow fall will affect the filling of hydropower reservoirs (e.g., decreasing ability to use all the storage capacity) and increase the inter-annual variability of electricity production.
- Storage-hydropower plants are a more flexible technology with modifiable production periods, whose revenues are less vulnerable to shifts in seasonality than run-of-river.
- While more even contribution from runoff might advantage reservoir management, a decrease in total annual runoff expected for reservoirs fed by ice melt is likely to negatively affect production.

Agriculture

- Until 2050 major agro-climatic risks will likely be caused by high temperatures rather than by increased drought (negative effects on both crop and livestock production).
- With increasing temperatures, water consumption through crop evapotranspiration increases is likely to lead to additional irrigation demands to maintain optimal yields (e.g. +10% in July at Visp across a range of climate scenarios up to 2049).

- High demand for water for irrigation will put additional pressure on small rivers in catchments with little or no water supply from glaciers, while larger water sources in valley may not be subject to the same extent of variability.
- In drier areas with low summer precipitation (e.g. valley floor and the south-facing slopes), potential water shortages for crop growth would be likely, requiring more irrigation to maintain optimal crop yields (max. +35%).
- In extremely dry years irrigation requirement could potentially exceed surface water availability in smaller catchments with a nival runoff regime (e.g. Sionne) where water is drawn through small irrigation channels for grassland irrigation.
- In the upper Rhone valley, improved water management should include both regulations regarding the allocation of water to different users of the same source, installation and management of reservoirs, and technical measures to improve the efficiency of irrigation by avoiding losses of distribution systems, evaporative losses, and excessive runoff due to over-application of water.
- Shifts in intensification of grassland use may have negative consequences for other ecosystem services such as biodiversity, soil carbon storage, and nitrogen retention.

Tourism

- A more local approach to winter tourism exposure to climate change in the Rhone catchment (comparing across average winters, a snow-poor winter with average economic conditions and a snow-rich winter at the beginning of the current economic crisis) reveals high disparities between mountain resorts and a higher vulnerability than regional approaches have suggested.
- Although Valais witnessed a smaller reduction in skier days than other regions during snow-poor winters, some resorts were strongly affected, with a large disparity in the vulnerability of resorts (e.g., small and medium resorts).
- The hotel sector is less exposed to a snow-poor winter than the cable-car companies, but faces difficulties in some areas when longer trends and socio-economic factors are taken into account.
- There is a real need to increase cooperation among and within resorts and touristic regions, enhance co-ordination of water uses (e.g., between hydro and cable-car companies), to improve the promotion of the Canton in general, to improve the ability to consider alternatives to skiing during warmer winters (notably in more vulnerable regions), and to improve current regulation on artificial snow-making.

Policy and Governance Implications

These impacts therefore need to be taken into account in the rules, rights and policies that structure the way in which water resources are managed across its multiples uses as well as the methods for protecting society from hydro-climatic related hazards. However, traditional governance and management approaches have often unsuccessfully coped with current internal or stochastic climate variability. Practitioners and scholars therefore not only need to address current rules and practices for managing historical challenges within the current envelope of uncertainty, but also to assess the adaptability of current frameworks for managing water resources and hazards to future climate change impacts.

In the Po basin, despite the farmers' observed investments to adapt to mean changes in climate at local level, unanticipated variability in climate continues to impact crop yields. Policy interventions (integration or water resources, water storage) must therefore deal with residual uncertainty remaining after local adaptation to climate change (Bozzola and Swanson, 2013). In the Upper Rhone basin, the increasing heterogeneity of precipitation and late summer reductions in run-off from reduced glacier melt are likely to further exacerbate current local critical situations, bottleneck periods for local water supply, which are themselves related to: high levels of autonomy at municipal level that block longer term catchment scale planning and smoothing of bottleneck periods; lack of formal mechanisms to manage competition across catchment areas; lack of rules on emerging challenges and uses(Hill Clarvis et al., 2013b).

Earlier snow melt and shifting glacier melt patterns are likely to impact the inflexible and long term user rights that govern uses such as hydropower by introducing an extra layer of uncertainty and shifting the hydrological baselines upon which fixed and un-integrated rules and policies are based on at different governance scales and across different sectors (Hill Clarvis et al., 2013a). In response to climate change impacts as well as the continuing challenges concerning uncertainty, adaptation strategies are recommended that are no-regret, flexible and iterative, that allow for safety margins and redundancy in new investments, take a long term and social and green infrastructural approach (to complement grey infrastructure), and that integrate both adaptation and mitigation requirements.

In addition to the challenges of communicating and adapting to different scales of climate related challenge (i.e. internal or stochastic variability versus increased uncertainty and variability from climate change impacts), water resources governance and management adaptation must also deal with a number of other scale based challenges. These include: trade-offs across risk response when short term adaptation actions potentially undermining long term social-ecological resilience (Adger et al., 2011; Hill and Engle, 2013); balancing out proactive and reactive responses, as well as responses to multiple forms of stress at different magnitudes of physical change and scales of governance (Hill, 2013a); trade-offs between narrowly defined adaptation policies and other policy frameworks and economic sectors;

Cross-scale and sector trade-offs need to be better understood in the process of developing adaptation and broader environmental policy, plans and projects that address the impacts of climate change (Adger et al., 2011; Hill and Engle, 2013). Furthermore, downscaling climate and socio-economic impacts to finer temporal and spatial scales can give decision makers a clearer view of how these tensions might play out in a future climate, and therefore allow them to better prepare for and respond to them.

At the European level, while European climate change and adaptation policy is still in its infancy, reflection of how to account for climate change impacts is happening in relation to the Floods Directive and the next round of River Basin Management Planning for 2015 according to the Water Framework Directive. In Switzerland, a comprehensive climate change adaptation policy is in early development at the federal level. However, water resources use and management transcends multiple policy frameworks, and underlying trade-offs across different policy frameworks and sectors must still be better accounted for and remediated as we move into an era of potentially less manageable pressures from the hydro climatic environment.

Outreach and societal implications

Societal Implications: Understanding and managing uncertainty

Not only are the driving forces of climate highly uncertain, but fundamental scientific knowledge gaps limit the reliability of model projections (Hallegatte, 2009) with uncertainties in how climatic and non-climatic pressures will interact on different aspects of hydrology and ecology (Wilby et al., 2010). Traditional decision making tools, water management and infrastructure have however tended not to be developed to take account of the broader levels of uncertainty produced by climate change projections (Hallegatte, 2009). Despite scientific efforts focussed on the reduction of uncertainty, through enhanced data collection and modelling

(Schneider and Kuntz-Duriseti, 2002), the uncertainty surrounding the specificity of climate change impacts remains a major challenge to planning and managing for future hydro-climatic conditions. However, policy makers, decision makers and water managers are increasingly recognising the need to develop better tools to manage and cope with both existing and increasing levels of uncertainty from climate variability and climate change impacts (Hallegatte, 2009).

While in many areas better managing for current and future levels of uncertainty is key, effective monitoring and data provision remains a critical component to remediating challenges relating to the current lack of knowledge and data on hydro-climatic, other environmental criteria and usage particularly in nations that are most at risk with the least data infrastructure. This is and should remain a core component of the on-going work on climate services, WMO standards and data sharing at international as well as national levels. While this is vital in developing countries, wealthier nations should not cease to continue to maintain and where possible improve their own monitoring and data infrastructure.

The growing body of work on climate change and climate change impact projections, adaptation and adaptive capacity have developed a broad set of principles, determinants and indicators for adaptive governance and management of water resources. However, there remains a need for clearer guidance on practicable mechanisms and actions at different levels of policy making, institutions and water management (Folke, 2011). This could help better guide the concrete changes that need to be made in governance and management frameworks to improve their sustainability and adaptability. Often there has been too much focus on the technological aspects of water resources management and adaptation and not enough on the governance and social infrastructural aspects of water systems (Adger et al., 2009; Hill, 2013b).

Outreach

The ACQWA project has produced over 280 scientific publications, a number of special issues in top tier journals such as Science of the Total Environment and Environmental Science and Policy, and over 130 instances of dissemination and outreach activities at academic conferences, public presentations, policy maker briefing sessions, newspaper and magazine articles and television news stories.

Conclusion

There is a clear need for a more integrated and comprehensive approach to water use and management. In particular, beyond the conventional water basin management perspective, there is a need to consider other socio-economic factors and the manner in which water policies interact with, or are affected by, other policies at the local, national, and supra-national levels. As an example, it is unclear whether current EU water policies are consistent with energy, agriculture, and other industrial policies.

The problems highlighted during the Riederalp meeting and summarised in the Environmental Science and Policy paper are also related to the inconsistencies between physical and socio-economic data and models. For example, figures related to water use may not be available at the temporal and spatial detail required by hydrologic models. Hydrological information is often based on basins whereas economic (and social) data is aggregated into administration regions. Thus, economic and physical data are often incompatible, because they are collected by different entities for different purposes. Future research should thus address the development of compatible data sets and the conversion between different data formats, as well as the development of toolboxes for up-scaling, downscaling and bias correcting data. Furthermore, the use of water in production processes is often not mediated by the market. The use of economic flexibility mechanisms in the allocation of water resources is quite rare, despite their potential in improving the efficiency of water resources allocation. More research and policy initiatives in this direction are thus necessary.

Finally, many scientists working in large integrated projects highlight a large gap between Science and Policy. This is certainly at least partly due to problems of communicating in an appropriate manner the key research results that would be of use to policy-relevant strategies. Awareness of this problem is increasing within the EC and other policy institutions, and hopefully this new momentum will be sustained over time so that conclusions from EU and other water-relevant projects will be widely incorporated into future policies at the local, national, and supra-national levels. Ultimately, the implementation of guidelines, maybe even an EU Directive, on the good governance of data (sharing) could be envisaged as a possible framework, providing advice and general rules on data formats and standards, data storage after project completion or the general terms of access.

1.5 References

Adger, W., Dessai, S., Goulden, M., Hulme, M., Lorenzoni, I., Nelson, D., Naess, L., Wolf, J., Wreford, A., 2009. Are there social limits to adaptation to climate change? Climatic Change 93, 335-354.

Adger, W.N., Brown, K., Nelson, D.R., Berkes, F., Eakin, H., Folke, C., Galvin, K., Gunderson, L., Goulden, M., O'Brien, K., Ruitenbeek, J., Tompkins, E.L., 2011. Resilience implications of policy responses to climate change. WIREs Climate Change 2, 757-766.

Beniston, M., 2003: Climatic change in mountain regions: a review of possible impacts. Climatic Change, 59, 5-31

Beniston, M., 2006: The August 2005 intense rainfall event in Switzerland: not necessarily an analog for strong convective events in a greenhouse climate. Geophysical Research Letters, 33, L5701

Beniston, M., 2009. Trends in joint quantiles of temperature and precipitation in Europe since 1901 and projected for 2100. Geophysical Research Letters 36, L07707.

Beniston, M., 2010. Impacts of climatic change on water and associated economic activities in the Swiss Alps. Journal of Hydrology, doi:10.1016/j.jhydrol.2010.06.046

Beniston M**,** 2012: Is snow in the Alps receding or disappearing? WIRES Climate Change 3, 349–358.

Beniston, M., and Stoffel, M., 2014: The EU/FP7 ACQWA Project: Assessing the impacts of climatic change on mountain water resources. Science of the Total Environment, in press.

Beniston, M., Stoffel, M., Hill, M., 2011. Impacts of climatic change on water and natural hazards in the Alps: can current water governance cope with future challenges? Examples from the European "ACQWA" project. Environmental Science and Policy 14 734-743.

Beniston, M.**,** Stoffel, M., an Hill, M. (Editors), 2013: The EU/FP7 ACQWA Project: Assessing climate impacts on the quantity and quality of water. ISBN Nr 978-2-8399-1286-0, 100 pp., University of Geneva.

Bolch, T., Kulkarni, A., Cogley, G., Frey, H., Fujita, K., Huggel, C., Kargel, J., Paul, F., Scheel, M., Bajracharya S., Stoffel, M. (2012): The state and fate of Himalayan glaciers. Science 336: 310–314.

Bozzola, M., Swanson, T., 2013. Policy Implications of Climate Variability on Agriculture: Water Management in the Po River Basin, Italy. Environmental Science & Policy In Press.

Christidis N, Stott PA, Jones GS, Shiogama H, Nozawa T, Luterbacher J, 2012: Human activity and anomalously warm seasons in Europe. International Journal of Climatology 32, 225–239

Coppola, E., Verdecchia, M, et al., 2014: Changing hydrological conditions in the Rhone and Po Catchments. Science of the Total Environment, in press

Dedieu JP, Lessard-Fontaine A, Ravazzani G, Cremonese E, Shalpykova G, Beniston M, 2014. Shifting mountain snow patterns in a changing climate from remote sensing retrieval. Science of the Total Environment, in press

Dubuis, A., Rossier, L., Pottier, J., Pellissier, L., Vittoz, P., and Guisan A., 2013. Predicting current and future spatial community patterns of plant functional traits. Ecography. doi: 10.1111/j.1600-0587.2013.00237.x

Elkin, C., Guiterrez, A.G., Leuzinger, S., Manusch, C., Temperli, C., Rasche, L., Bugmann, H., 2013. A 2°C warmer world is not safe for ecosystem services in the European Alps. Global Change Biology. 19:1827-1840

Engler, R., Randin, C.F., Thuiller, W., Dullinger, S., Zimmermann, N.E., Araujo, M.B., Pearman, P.B., Le Lay, G., Piedallu, C., Albert, C.H., Choler, P., Coldea, G., De Lamo, X., Dirnböck, T., Fatichi, S., Ivanov, V.Y., Caporali, E., 2013a. Assessment of a stochastic downscaling methodology in generating an ensemble of hourly future climate time series. Climate Dynamics 40, 1841-1861.

Faillettaz J, Funk M, Sornette D, 2012, Instabilities on Alpine temperate glaciers: new insights arising from the numerical modelling of Allalingletscher (Valais, Switzerland). Natural Hazards and Earth System Sciences 12, 2977–2990

Fatichi, S., Rimkus, S., Burlando, P., Bordoy, R., Molnar, P., 2013b. Elevational dependence of climate change impacts on water resources in an Alpine catchment. Hydrology and Earth System Science Discussion 10.

Finger D, Pellicciotti F, Konz M, Rimkus S, Burlando P, 2011, The value of glacier mass balance, satellite snow cover images, and hourly discharge for improving the performance of a physically based distributed hydrological model, Water Resources Research 47, doi:10.1029/2010WR009824.

Finger D, Heinrich G, Gobiet A, Bauder A, 2012. Projections of future water resources and their uncertainty in a glacierized catchment in the Swiss Alps and the subsequent effects on hydropower production during the 21st century, Water Resources Research 48, W03903.

Finn DS, Khamis K, Milner AM, 2013. Loss of small glaciers will diminish beta diversity in Pyrenean streams at two levels of biological organization. Global Ecology and Biogeography 22, 40–51.

Fuhrer, J., Jasper, K., 2012. Demand and supply of water for agriculture: influence of topography and climate in pre-alpine, mesoscale catchments. Natural Resources 3, 145-155.

Fuhrer J, Smith P, Gobiet A, 2014. Implications of climate change scenarios for agriculture in alpine regions – A case study in the Swiss Rhone catchment. The Science of the Total Environment, doi:10.1016/j.scitotenv.2013.06.038.

Funk, M., 2006: On the instability of avalanching glaciers. Journal of Glaciology, 52, 31-48

Gaudard L, Romerio F, Dalla Valle F, Gorret R, Maran S, Ravazzani G, Stoffel M, Volonterio M, 2014. Climate change and hydropower: Comparison of case studies and methodologies. Science of the Total Environment, in press.

Gaudard, L., Gilli, M., Romerio, F., 2013. Climate Change Impacts on Hydropower Management. Water Resour Manage 27, 5143-5156.

Gaudard, L., Romerio, F., 2013. The future of hydropower in Europe: Interconnecting climate, markets and policies. Environmental Science & Policy In press.

Gaudard, L., Romerio, F., Dalla Valle, F., Gorret, R., Maran, S., Ravazzani, G., Stoffel, M., Volonterio, M., 2014. Climate change impacts on hydropower in the Swiss and Italian Alps,. Science of the Total Environment In press.

Gégout, J.C., Gomez-Garcia, D., Grytnes, J.A., Heegaard, E., Hoistad, F., Nogués-Bravo, D., Normand, S., Puscas, M., Sebastià, M.T., Stanisci, A., Theurillat, J.P., Trivedi, M.R., Vittoz, P., Guisan, A., 2011. 21st century climate change threatens mountain flora unequally across Europe. Global Change Biology 17(7), 2330-2341

Girón, G., Schwank, J., and Escobar, R., 2014: SWAT as a tool to evaluate the preparedness of the legal and institutional framework to face climate change impacts in Mendoza, Argentina. Environmental Science and Policy, in press

Gobiet, A., Kotlarski, S., Rajczak, J., Stoffel, M., Heinrich, G., Beniston, M., 2014. 21st Century Climate Change in the European Alps – A Review. Science of the Total Enviroment In press.

Gosz, J. R., 1993: Ecotone hierarchies. Ecological Applications, 3, 369-376.

Gottfried, M., Hantel, M., Maurer, C., Toechterle, R., Pauli, H., and Grabherr, G., 2011: Coincidence of the alpine-nival ecotone with the summer snowline. Environmental Research Letters 6, 014013.

Hallegatte, S., 2009. Strategies to adapt to an uncertain climate change. Global Environmental Change 19, 240-247.

Hegerl G, Luterbacher J, González-Rouco JF, Tett SFB, Crowley T, Xoplaki E, 2011. Influence of human and natural forcing on European seasonal temperatures. Nature Geoscience 4, 99–103.

Heinrich G, Gobiet A, Mendlik T, 2013. Extended regional climate model projections for Europe until the mid-21st century: combining ENSEMBLES and CMIP3. Climate Dynamics, doi:10.1007/s00382-013-1840-7.

Hill, M., 2013a. Adaptive Capacity of Water Governance: Cases from the Alps and the Andes. Mountain Research and Development 33, 248-259.

Hill, M., 2013b. Climate Change and Water Governance: Adaptive Capacity in Chile and Switzerland. Springer, Heidelberg, Germany.

Hill, M., Engle, N.L., 2013. Adaptive Capacity: Tensions across Scales. Environmental Policy and Governance 23, 177–192.

Hill M, Allan AA, 2014, Adaptive capacity in a Chilean context: a questionable model for Latin America. Environmental Science and Policy, in press.

Hill M, Engle NL, 2013. Adaptive capacity: Tensions across scales. Environmental Policy and Governance 23, 177–192.

Hill Clarvis, M., Allan, A., Hannah, D.M., 2013a. Water, resilience and the law: From general concepts and governance design principles to actionable mechanisms. Environmental Science & Policy.

Hill Clarvis, M., Fatichi, S., Allan, A., Fuhrer, J., Stoffel, M., Romerio, F., Gaudard, L., Burlando, P., Beniston, M., Xoplaki, E., Toreti, A., 2013b. Governing and Managing Water Resources under

Changing Hydro-Climatic Contexts: The Case of the Upper Rhone Basin. Environmental Science and Policy In Press.
Im E-S, Coppola E, Giorgi F, Bi X, 2010. Local vs. remote effects of climate change over the Alpine region: A study with a high resolution regional climate model with a surrogate climate change scenario. Geophysical Research Letters, 37, L05704.
Immerzeel, W.W., Pellicciotti, F., Bierkens, M.F.P., 2013. Rising river flows throughout the twenty-first century in two Himalayan glacierized watersheds. Nature Geoscience 6, 742-745.
IPCC, 2001: Emission scenarios, in the Intergovernmental Panel on Climate Change Third Assessment Report. Cambridge University Press, Cambridge, UK.
IPCC, 2013: The Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.
Jomelli V, 2012. Alpine debris flows. Science and Technology 4, 162–164.
Kallache M, Vrac M, Naveau P, Michelangeli P-A, 2011. Non-stationary probabilistic downscaling of extreme precipitation. Journal of Geophysical Research 116, D05113.
Khamis K, Brown LE, Hannah DM, Milner AM, 2013a. Disturbance theory predicts aquatic biodiversity response to alpine glacier retreat. Journal of Animal Ecology, submitted.
Khamis K, Brown LE, Hannah DM, Milner AM, 2013b. Predation modifies macroinvertebrate community structure in alpine stream mesocosms. Freshwater Science, submitted.
Khamis K, Hannah DM, Brown LE, Tiberi R, Milner AM, 2014a: Climate change and alpine aquatic ecosystem response. Science of the Total Environment, submitted.
Khamis K, Hill M, Hannah DM, Milner AM, Brown LE, Castella E, 2014b: Alpine aquatic ecosystem conservation policy in a changing climate. Environmental Science and Policy, submitted
Loarie, S. R., Duffy, P. B., Hamilton, H., Asner, G. P. Field, C. B., Ackerly, D. D., 2009. The velocity of climate change. Nature 462, 1052-1055.
Lopez-Moreno, J.I., Zabalza, J., Vicente-Serrano, S.M., Revuelto, J., Gilaberte, M., Azorin-Molina, C., Morán Tejeda, E., García-Ruiz, J.M., Tague, C., 2014: Impact of climate and land use change on water availability and reservoir management; Scenarios in the upper Aragón River, Spanish Pyrenees. Science of the Total Environment, in press.
Manusch, C., Bugmann, H. and Wolf, A., 2013. Tree species shifts partly counteract negative climate change effects on carbon storage. Regional Environmental Change, submitted.
Maran S, Volonterio M, Gaudard L, 2014. Climate change impacts on hydropower in an Alpine catchment, Environmental Science and Policy, in press.
Morrison, C., Pickering, C. M., 2013. Perceptions of climate change impacts, adaptation and limits to adaption in the Australian Alps: the ski-tourism industry and key stakeholders. Journal of Sustainable Tourism 21, 173-191.
Naveau P, Zhang Z, Zhu B, 2011. An extension of max autoregressive models, Statistics and Its Interface 4, 253–266.
Paul, F., 2011: Melting glaciers and icecaps. Nature Geoscience, 4 (2), 71-72
Pellicciotti, F., Ragettli, S., Carenzo, M., McPhee, J., in press. Changes of glaciers in the Andes of Chile and priorities for future work. Science of the Total Environment
Ravazzani G, 2013. MOSAICO, a library for raster based hydrological applications. Computers & Geosciences 51, 1–6.
Romerio, F., 2002: European electrical systems and Alpine hydro resources. Gaia, 3, 200-202.
Schaub, A., and Andonova, L., 2012: Tourism and climate change in Valais: present and projected water consumption and adaptation. Presentation at the 2012 ACQWA Project General Assembly Meeting, Trieste, Italy, September 4, 2012.
Schneider, S.H., Kuntz-Duriseti, K., 2002. Uncertainty and Climate Change Policy, In: Schneider, S.H., Rosencranz, A., Niles, J.O. (Eds.), Climate Change Policy: A Survey. Island Press, Washington D.C.
Smith I, Toreti A, Naveau P, Xoplaki E, 2013. A fast non-parametric inference for heavy precipitation. Water Resources Research, in press.
Smith PC, Calanca P, Fuhrer J, 2012. A simple scheme for modeling irrigation water requirements at the regional scale applied to an Alpine river catchment. Water 4, 869–886.
Sorg, A., Bolch, T., Stoffel, M., Solomina, O., Beniston, M., 2012: Climate change impacts on glaciers and runoff in Tien Shan (Central Asia). Nature Climate Change 2, 725–731.

Sorg A, Mosello B, Shalpykova G, Allan A, Hill M, Stoffel M: Coping with changing water resources: The case of the Syr Darya river basin in Central Asia. Environmental Sciences and Policy, in press.

Stoffel, M., Beniston, M., 2006. On the incidence of debris flows from the early Little Ice Age to a future greenhouse climate: a case study from the Swiss Alps. Geophysical Research Letters 33, L16404.

Stoffel M, Huggel C, 2012. Effects of climate change on mass movements in mountain environments. Progress in Physical Geography 36, 421–439.

Stoffel, M., Mendlik, T., Schneuwly-Bollschweiler, M., Gobiet, A., 2013. Possible impacts of climate change on debris-flow activity in the Swiss Alps. Climatic Change, 1-15.

Stoffel M, Tiranti D, Huggel C, 2014. Climate change impacts on mass movements – Case studies from the European Alps. Science of the Total Environment, in press.

Stucki P, Rickli R, Martius O, Brönnimann S, Wanner H, Grebner D, Luterbacher J, Croci-Maspoli M, 2012. Five weather patterns and specific precursors determine extreme floods in Switzerland. Meteorologische Zeitschrift 21, 531–550.

Themessl MJ, Gobiet A, Leuprecht A, 2010. Empirical-statistical downscaling and error correction of daily precipitation from regional climate models, International Journal of Climatology 31, 1530–1541.

Tiberti R. von Hardenberg A, 2012. Impact of alien fish on Common frog (Rana temporaria) close to its altitudinal limit in alpine lakes. Amphibia Reptilia 33, 303–307.

Tiberti R, Metta S, Austoni M, Callieri C, Morabito G, Marchetto A, Rogora M, Tartari GA, von Hardenberg J, Provenzale A, 2013. Ecological dynamics of two remote alpine lakes during ice-free season. Journal of Limnology 72, 401–416.

Tiranti D, Rabuffetti D, Salandin A, Tararbra M, 2013. Development of a new translational and rotational slides prediction model in Langhe hills (north-western Italy) and its application to the 2011 March landslide event. Landslides, doi:10.1007/s10346-012-0319-7

Toreti A, Kuglitsch FG, Xoplaki E, Luterbacher J, 2012: A novel approach for the detection of inhomogeneities affecting climate time series. Journal of Applied Meteorology and Climatology, doi:10.1175/JAMC-D-10-05033.1.

Toreti, A., Naveau, P., Zampieri, M., Schindler, A., Scoccimarro, E., Xoplaki, E., Dijkstra, H.A., Gualdi, S., Luterbacher, J., 2013. Projections of global changes in precipitation extremes from Coupled Model Intercomparison Project Phase 5 models. Geophysical Research Letters 40, 4887–4892.

Uhlmann, B., Goyette, S., and Beniston, M., 2009: Sensitivity analysis of snow patterns in Swiss ski resorts to shifts in temperature precipitation and humidity under condition of climate change. International Journal of Climatology, 29, 1048-1055

UN, 1992: Earth Summit: Agenda 21. The United Nations Programme of Action from RioThe final text of agreements negotiated by governments at the United Nations Conference on Environment and Development (UNCED), 3-14 June 1992, Rio de Janeiro, Brazil. 294 pp.

Wilby, R.L., Orr, H., Watts, G., Battarbee, R.W., Berry, P.M., Chadd, R., Dugdale, S.J., Dunbar, M.J., Elliott, J.A., Extence, C., Hannah, D.M., Holmes, N., Johnson, A.C., Knights, B., Milner, N.J., Ormerod, S.J., Solomon, D., Timlett, R., Whitehead, P.J., Wood, P.J., 2010. Evidence needed to manage freshwater ecosystems in a changing climate: Turning adaptation principles into practice. Science of the Total Environment 408, 4150-4164.

Wolf A, Lazzarotto P, Bugmann H, 2012. The relative importance of land use and climatic change in Alpine catchments. Climatic Change 111, 279–300.

2. Use and dissemination of foreground

A plan for use and dissemination of foreground (including socio-economic impact and target groups for the results of the research) shall be established at the end of the project. It should, where appropriate, be an update of the initial plan in Annex I for use and dissemination of foreground and be consistent with the report on societal implications on the use and dissemination of foreground (section 4.3 – H).
The plan should consist of:

- Section A

This section should describe the dissemination measures, including any scientific publications relating to foreground. **Its content will be made available in the public domain** thus demonstrating the added-value and positive impact of the project on the European Union.

- Section B

This section should specify the exploitable foreground and provide the plans for exploitation. All these data can be public or confidential; the report must clearly mark non-publishable (confidential) parts that will be treated as such by the Commission. Information under Section B that is not marked as confidential **will be made available in the public domain** thus demonstrating the added-value and positive impact of the project on the European Union.

Section A (public)

This section includes two templates

- Template A1: List of all scientific (peer reviewed) publications relating to the foreground of the project.
- Template A2: List of all dissemination activities (publications, conferences, workshops, web sites/applications, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters).

These lists are cumulative, which means that they should always show all publications and activities from the beginning until after the end of the project. Updates are possible at any time.

Template A1: list of scientific (peer reviewed) publications, starting with the most important ones										
NO.	**Title**	**Main author**	**Title of the periodical or the series**	**Number, date or frequency**	**Publisher**	**Place of publication**	**Year of publication**	**Relevant pages**	**Permanent identifiers**	**Is/Will open access provided to this publication?**
1	Climate Change and International Law: Exploring Linkages between Human Rights, Environment, Trade and Investment	Aerni, P	German Yearbook of International Law				2011			
2	Inner Alpine conifer response to 20th century drought swings	Affolter, P	European Journal of Forest Research	129			2010	289-298		
3	Evolution of vegetation activity on vegetated, eroded, and erosion risk areas in the central Spanish Pyrenees, using multitemporal Landsat imagery, Earth Surface Processes and Landforms	Alatorre LC	Earth Surface Processes and Landforms	36			2010	309–319		
4	"Regional Disparities in Climate Vulnerability of Winter Tourism: The Case of the Swiss Canton of Valais."	Andonova, Liliana; A.P Schaub	Working paper (MIMEO)							Y

5	"Climate change and winter tourism in Valais: The expected socioeconomic and climate impacts, and the expected water-related impacts of adaptation."	Andonova, Liliana; A.P Schaub	CIES Research Paper Series		CIES Geneva	Geneva (CH)	2014 Forthcoming		http://graduateinstitute.ch/home/research/centresandprogrammes/cies/research-papers.html	Y
6	Dendrogeomorphic reconstruction of past debris-flow activity using injured broad-leaved trees	Arbellay E	Earth Surface Processes and Landforms	35			2010	399–406		
7	The Hot Summer of 2010: Redrawing the Temperature Record Map of Europe	Barriopedro D	Science	332			2011	220–224		
8	Precipitation manipulation experiments – challenges and recommendations for the future	Beier, C	Ecology Letters	15			2012	899-911		
9	The EU-FP7 ACQWA Project: exploring issues of water in vulnerable mountain regions.	Beniston, M.	Earth and Environmental Science	6			2009	22009		No
10	Trends in joint quantiles of temperature and precipitation in Europe since 1901 and projected for 2100.	Beniston, M.	Geophysical Research Letters	36	American Geophysical Union		2009	7707		Np
11	Will snow-abundant winters still exist in the Swiss Alps in an enhanced greenhouse climate?	Beniston, M.	International Journal of Climatology	29	Royal Meteorological Society		2010	1257-1263		No
12	Decadal-scale changes in the tails of probability distribution functions of climate variables in Switzerland	Beniston, M.	International Journal of Climatology	29	Royal Meteorological Society		2009	1362-1368		No
13	Impacts of climatic change on water and associated economic activities in the Swiss Alps	Beniston, M.	Journal of Hydrology	46	Elsevier Publishers		2010	291-296		No
14	Exploring the behavior of atmospheric temperatures under dry conditions in Europe: evolution since the mid-20th century and projections for the end of the 21st century	Beniston, M.	International Journal of Climatology	33	Royal Meteorological Society		2009	1362-1368		No

15	Is snow in the Alps receding or disappearing?	Beniston, M.	WIRES Climate Change	3	Wiley Publishers		2012	349-358		No
16	European isotherms move northwards by up to 15 km/year: using climate analogues for awareness-raising	Beniston, M.	International Journal of Climatology		Royal Meteorological Society		2013	In press		No
17	Impacts of climatic change on water and natural hazards in the Alps: can current water governance cope with future challenges?	Beniston, M.	Environmental Science and Policy	14	Elsevier Publishers		2011	734-743		No
18	Obstacles to data access for research related to climate and water: implications for science and EU policy-making	Beniston, M.	Environmental Science and Policy	17	Elsevier Publishers		2012	41-48		No
19	Assessing the impacts of climatic change on mountain water resources.	Beniston, M.	Science of the Total Environment		Elsevier Publishers			In press		No
20	Frequency and spread of debris floods on fans: A dendrogeomorphic case-study from a dolomite catchment in the Austrian Alps	Bollschweiler M	Geomorphology	118			2010	199–206		
21	Tree rings and debris flows – trends and challenges	Bollschweiler M	Progress in Physical Geography	34			2010	625–645		
22	Variations in debris-flow occurrence in an Alpine catchment – a reconstruction based on tree rings	Bollschweiler M	Global and Planetary Change	73			2010	186–192		
23	Debris-flood reconstruction in a pre-alpine catchment in Switzerland based on tree-ring analysis of conifers and broadleaved trees	Bollschweiler M	Geografiska Annaler	93			2011	1–15		
24	Changes and trends in debris-flow frequency since ad 1850: Results from the Swiss Alps	Bollschweiller M	The Holocene	20			2010	907–916		
25	Glacier response to climate change in northwestern Italian Alps	Bonanno R	Regional Environmental Change	submitted			2013			
26	Hydrogeomorphic response to extreme rainfall in headwater systems: flash floods and debris flows	Borga M	Journal of Hydrology	submitted			2013			

27	Recent glaciers variations at the Aconcagua basin, central Chilean Andes.	Bown, F., A. Rivera & C. Acuña	Annals of Glaciology	48			2008	pp. 43-48		No
28	Climate Change, Smoothing with Water Stock and Impact on the Agricultural Sector in the Po Valley (Italy)	Bozzola, Martina	Proceedings of the First Annual Conference of the Italian Society for Climate Sciences.	PROCEEDIN G Climate change and its implications on ecosystem and society 23-24/09/2013	Italian Society for the Climate Sciences (SISC)	Lecce, Italy	2013	1057-1075	ISBN 978-88- 97666-08-0	Y
29	Policy Implications of Climate Variability on Agriculture: Water Management in the Po River Basin, Italy.	Bozzola, Martina; Timothy Swanson	Environmental Science & Policy	SI: ACQWA Policy Implications	Elsevier Publishers (Amsterdam)		2014	In Press		
30	European floods during the winter 1783/1784: scenarios of an extreme event during the 'Little Ice Age'	Bradzil R	Theoretical and Applied Climatology	100			2010	163–189		
31	European climate of the past 500 years: new challenges for historical climatology	Bradzil R	Climatic Change	101			2010	7-40		
32	A fifty year record of winter glacier melt events in southern Chile, 38º–42ºS	Brock, B., F. Burger, A. Rivera and A. Montecinos	Environmental Research Letters	7			2012	doi:10.1088/1748-9326/7/4/045403		yes
33	Extreme winds at northern mid-latitudes since 1871	Brönnimann S	Meteorologische Zeitschrift	21			2012	13–27		
34	Predicting river ecosystem response to glacial meltwater dynamics: a case study of quantitative water sourcing and glaciality index approaches	Brown LE	Aquatic Science	72			2010	325–334		
35	Influence of the sunspot cycle on the Northern Hemisphere wintertime circulation from long upper-air data sets	Brugnara Y	Atmospheric Chemistry and Physics	13			2013	6275–6288		

36	Debris flow triggering meteorological conditions in the nortern french Alps	Brunstein D	Ice and Snow	117			2012	105–109		
37	Is there memory in precipitation?	Bunde A	Nature Climate Change	3			2013	174-175		
38	2500 years of European climate variability and human susceptibility	Büntgen U	Science	331			2011	578–582		
39	Tree-ring indicators of German summer drought over the last millennium	Büntgen U	Quaternary Science Reviews	29			2010	1005–1016		
40	Die Referenzverdunstung und ihre Anwendung in der Agrarmeteorologie	Calanca, Pierluigi	Agrarforschung Schweiz	No 2			2011	pp. 176 – 183		
41	500-year temperature reconstruction in the Mediterranean Basin by means of documentary data and instrumental observations	Camuffo D	Climatic Change	101			2010	169–199		
42	Regional climate models downscaling in the Alpine area with multimodel superensemble	Cane D	Hydrol Earth System Sciences	17			2013	2017-2028	doi:10 5194/hess-17-2017-2013	
43	A statistical rainfall-runoff mixture model with heavy-tailed components	Carreau J	Water Resoures Research	45			2009			
44	Neural Computation in Paleoclimatology: General methodology and a case study	Carro-Calvo L	Neurocomputing	10			2013			
45	The impact of climate change on the water resources of the eastern Mediterranean and Middle East region: modeled 21st century changes and implications	Chenoweth J	Water Resources Research	47			2011	225–239		
46	Human activity and anomalously warm seasons in Europe	Christidis N	International Journal of Climatology	32			2012			
47	Dynamic coupling of regional atmosphere to biosphere in the new generation regional climate system model REMO-iMOVE	Christof Wilhelm	Geoscientific Model Development Discussion	No 6, 2013	Copernicus Publications	Göttingen	2013	pp. 3085–3135	http://www.geosci-model-dev-discuss.net/6/3085/2013/gmdd-6-3085-	yes

									2013.pdf	
48	Economic transformation in Hungary and Poland’	Colaiuda, V.	European Economy	No 43, March 1990	Office for Official Publications of the European Communities	Luxembourg	1990	pp. 151 - 167		yes/no
49	Approximating the conditional density given large observed values via a multivariate extremes framework with application to environmental data	Cooley D	Annals of Applied Statistics	6			2012	1406–1429		
50	A distributed thermodynamic model for energy and mass balance computation: FEST–EWB	Corbari C.	Hydrological Processes	No 25(9) 2011	Wiley	New Jersey	2011	pp. 1443-1452	http://onlinelibrary.wiley.com/doi/10.1002/hyp.7910/abstract	no
51	Elevation based correction of snow coverage retrieved from satellite images to improve model calibration	Corbari C.	Hydrology and Earth System Sciences	No 13 2009	European Geosciences Union	Germany	2009	pp. 639-649	http://www.hydrol-earth-syst-sci.net/13/639/2009/hess-13-639-2009.html	yes
52	Land surface temperature representativeness in a heterogeneous area through a distributed energy-water balance model and remote sensing data	Corbari C.	Hydrology and Earth System Sciences	No. 14 2010	European Geosciences Union	Germany	2010	pp. 2141–2151	http://www.hydrol-earth-syst-sci.net/14/2141/2010/hess-14-2141-2010.html	yes

53	High resolution quantitative reconstruction of erosion rates based on anatomical changes in exposed roots (Draix Alpes de Haute-Provence) – critical review of existing approaches and independent quality control of results	Corona C	Geomorphology	125			2011	433–444		
54	Investigating the dynamics of an Alpine glacier using probabilistic icequake locations(Triftgletscher, Switzerland)	Dalban-Canassy, P.	Journal of Geophysical Research - Earth Surface	Vol. 118			2013		Doi:10.1002/ jgrf.20097	yes/no
55	Seismic activity and surface motion of a steep temperate glacier: a study on Triftgletscher, Switzerland	Dalban-Canassy, P.	Journal of Glaciology	Vol.58, No. 209			2012	513-527	Doi:10.3189/ 2012JoG11J 104	
56	Hazard assessment investigations due to recent changes in Triftgletscher, Bernese Alps, Switzerland	Dalban-Canassy, P.	Natural Hazards and Earth System Sciences	Vol. 11			2011	2149-2162	Doi:20.5194/ nhess-11- 2149-2011	
57	Shifting mountain snow patterns in a changing climate from remote sensing retrieval	DEDIEU, Jean-Pierre	Science of the Total Environment (STOTEN)	12 vol/year	Elsevier	USA	2013	In Press	Jean-Pierre DEDIEU	NO
58	Simple additive effects are rare: a quantitative review of plant biomass and soil process responses to combined manipulations of CO2 and temperature	Dieleman WIJ	Global Change Biology	18			2012	2681-2693		
59	Monthly seasonal and annual temperature reconstructions for Central Europe derived from documentary evidence and instrumental records since AD 1500	Dobrovolny P	Climatic Change	101	69-107		2010			
60	An assessment of the role of homogenization protocols in the performance of daily temperature series and trends: application to Northeastern Spain	El Kenawy A	International Journal of Climatology	33,	Willey		2013	87–108		yes

61	Trend and variability of temperature in northeastern Spain (1920-2006): linkage to atmospheric circulation temperature series and trends: application to Northeastern Spain	El Kenawy A	Atmospheric Research	106	Willey		2012	159-180		yes
62	Anomalously severe cold nights and warm days in northeastern Spain: their spatial variability, driving forces and future projections.	El Kenawy A	Global and Planetary Change	33,	Elsevier		2013	87–108		yes
63	A 2°C warmer world is not safe for ecosystem services in the European Alps	Elkin C	Global Change Biology	19			2013	1827-1840		
64	The Irish famine of 1740–1741: famine vulnerability and "climate migration	Engler S	Climate of the Past				2013	1161–2013		
65	Testing the hypothesis of post-volcanic missing rings in temperature sensitive dendrochronological data	Esper J	Dendrochronologia	11, 2			2013			
66	Orbital forcing of tree-ring data	Esper J	Nature Climate Change	2			2012	862–866		
67	European summer temperature response to annually dated volcanic eruptions over the past nine centuries	Esper J	Bulletin of Volcanology	75			2013	736		
68	Numerical modeling of a gravity-driven instability of a cold hanging glacier: reanalysis of the 1895 break-off of Altelsgletscher, Switzerland	Faillettaz J	Journal of Glaciology	57			2011	817–831		
69	Instabilities on Alpine temperate glaciers: new insights arising from the numerical modelling of Allalingletscher (Valais, Switzerland)	Faillettaz J	Natural Hazards and Earth System Sciences	12			2012	2977–2990		
70	Does internal climate variability overwhelm climate change signals in streamflow? The upper Po and Rhone basin case studies	Fatichi S	Science of the Total Environment	submitted			2013			

71	Elevational dependence of climate change impacts on water resources in an Alpine catchment	Fatichi S	Hydrology and Earth System Sciences Discussion	10			2013	3743–3794			
72	Reconciling observations with modeling: the fate of water and carbon allocation in a mature deciduous forest exposed to elevated CO2	Fatichi S	Agricultural and Forest Meteorology				2013	174–175			
73	Projections of future water resources and their uncertainty in a glacierized catchment in the Swiss Alps and the subsequent effects on hydropower production during the 21st century	Finger D	Water Resources Research	48			2012				
74	The value of glacier mass balance satellite snow cover images and hourly discharge for improving the performance of a physically based distributed hydrological model	Finger D	Water Resources Research	47			2011		doi:10 1029/2010WR009824		
75	Projections of future water resources and their uncertainty in a glacierized catchment in the Swiss Alps and the subsequent effects on hydropower production during the 21st century	Finger, D.	Water Resources Research	No. 48, W03903, 2012	John Wiley & Sons		2012	DOI: 10.1029/2011WR010733	http://onlinelibrary.wiley.com/doi/10.1029/2011WR010733/abstract		
76	Loss of small glaciers will diminish beta diversity in Pyrenean streams at two levels of biological organization	Finn DS	Global Ecology and Biogeography	22			2013	40–51			
77	Demand and supply of water for agriculture: influence of topography and climate in pre-Alpine mesoscale catchments	Fuhrer J	Natural Resources	3			2012	145–155			
78	Implications of climate change scenarios for agriculture in alpine regions – A case study in the Swiss Rhone catchment	Fuhrer J	The Science of the Total Environment	38, 6			2013		doi:10 1016/jscitotenv		

79	Implications of climate change scenarios for agriculture in alpine regions – A case study in the Swiss Rhone catchment.	Fuhrer, J	The Science of the Total Environment	Available online 5 July 2013	Elsevier		2013	doi:10.1016/j.scitotenv.2013.06.038		
80	Demand and supply of water for agriculture: influence of topography and climate in pre-alpine, mesoscale catchments.	Fuhrer, Jürg	Natural Resources.	No. 3			2012	pp. 145-155	doi:10.4236/nr.2012.33019	yes
81	Implications of climate change scenarios for agriculture in alpine regions – a case study in the Swiss Rhone catchment.	Fuhrer, Jürg	The Science of the Total Environment				In press		Doi:10.1016/j.scitotenv.2013.06.038	
82	North Atlantic atmospheric circulation and surface wind in the Northeast of the Iberian Peninsula: uncertainty and long term downscaled variability	García-Bustamante E	Climate Dynamics	38			2012	141–160		
83	Relationship between wind power production and North Atlantic atmospheric circulation over the northeastern Iberian Peninsula	García-Bustamante E	Climate Dynamics	40			2012	935–949		
84	From plot to regional scales: Interactions of slope and catchment hydrological and geomorphic processes in the Spanish Pyrenees	Garcia-Ruiz, JM	Geomorphology	120	Elsevier		2010	248-257		yes
85	Land cover changes and shallow landsliding in the flysch sector of the Spanish Pyrenees	Garcia-Ruiz, JM	Geomorphology	124	Elsevier		2010	250-259		yes
86	Mediterranean water resources in a global change scenario.	Garcia-Ruiz, JM	Earth-Science Reviews	105	Elsevier		2011	121-139		yes
87	The effects of land uses on soil erosion in Spain	Garcia-Ruiz, JM	Catena	81	Elsevier		2010	1-11		yes
88	Climate change impacts on hydropower in the Swiss and Italian Alps	Gaudard L.	Science of the Total Environment	In press	Elsevier		2013		DOI 10.1016/j.scitotenv.2013.10.012.	

89	The future of hydropower in Europe: Interconnecting climate, markets and policies,	Gaudard L. and Romerio F	Environmental Science and Policy	In press	Elsevier		2013		DOI: 10.1016/j.envsci.2013.09.008.	
90	Climate change impacts on hydropower in the Swiss and Italian Alps	GAUDARD, L.	Science of the Total Environment	Article in press	Elsevier		2013			
91	Extracting common pulse-like signals from multiple ice core time series	Gazeaux J	Computational Statistics and Data Analysis	58			2013	45–57		
92	Inferring change points and nonlinear trends in multivariate time series: Application to West African monsoon onset timings estimation	Gazeaux J	Journal of Geophysical Research	116			2011			
93	Atmospheric temperature changes over the 20th century at very high elevations in the European Alps from englacial temperatures	Gilbert A.	Geophysical Research Letter		AGU		2013	2102–2108	doi:10.1002/grl.50401	no
94	Modeling firn near-surface temperature in a cold accumulation zone (Col du Dôme, French Alps): from physical to semi-parameterized approach	Gilbert A.	The Cryosphere		copernicus		submitted			yes
95	Sharing environmental data through GEOSS	Giuliani G	International Journal of Applied Geospatial Research	2			2011	1–17		
96	OWS4SWAT: Publishing and sharing SWAT outputs with OGC standards	Giuliani G	International Journal of Advanced Computer Science and Applications	submitted			2013			
97	21st century climate change in the European Alps—A review	Gobiet, A.	The Science of the Total Environment	Available online 15 August 2013	Elsevier		2013		https://www.sciencedirect.com/science/article/pii/S0048969713008188	

98	Debris flow activity related to current climate conditions in the French Alps: a regional investigation based on Safran reanalyzed data	Grancher D	Geomorphology	in press			2013			
99	Solar influences in climate	Gray LJ	Reviews in Geophysics	48			2010			
100	A folding method for extreme quantiles estimation	Guillou A	Revstat - Statistical Journal	8			2010	21–35		
101	Madogram and asymptotic independence among maxima	Guillou A	Reviews of Statistics	in press			2013			
102	Why climate sensitivity may not be so unpredictable	Hannart A	Geophysical Research Letters	36			2010	L16707		
103	Disconcerting learning on climate sensitivity and the uncertain future of uncertainty	Hannart A	Climatic Change	in press			2013			
104	An improved Bayesian Information Criterion for multiple change-point models	Hannart A	Technometrics	54			2012	256–268		
105	Influence of human and natural forcing on European seasonal temperatures	Hegerl G	Nature Geoscience	4			2011	99–103		
106	The future of dry and wet spells in Europe: a comprehensive study based on the ENSEMBLES regional climate models	Heinrich G	International Journal of Climatology	32			2011	1951–1970		
107	Governing and managing water resources under changing hydro-climatic contexts: The case of the upper Rhone basin.	Hill Clarvis, M.	Environmental Science & Policy		Elsevier Publishers		2013	In press		No
108	Water, Resilience and the Law: From General Concepts and Governance Design Principles to Actionable Mechanisms	Hill Clarvis, M.	Environmental Science & Policy		Elsevier Publishers		2013	In press		No
109	Adaptive Capacity in a Chilean Context: A Questionable Model for Latin America.	Hill Clarvis, M.	Environmental Science & Policy		Elsevier Publishers		2013	In press		No

110	Adaptive Capacity of Water Governance: Cases from the Alps and Andes	Hill, M.	Mountain Research and Development	33 (3)	BioOne		2013	248-259	http://dx.doi.org/10.1659/MRD-JOURNAL-D-12-00106.1	Yes
111	Adaptive Capacity: Tensions across Scales	Hill, M.	Environmental Policy and Governance	23 (3)	Wiley Publishers		2013	177–192	DOI: 10.1002/eet.1610	No
112	Climate Change and Water Governance	Hill, M.			Springer	Heidelberg, Germany	2013			No
113	Navigating Complex Choices in Adaptive Capacity and Water Governance. Adaptive capacity in two contrasting water governance regimes in relation to flooding and drought: The cases of Aconcagua in Chile, and the Rhone in Switzerland	Hill, M.	PhD Thesis		University of Geneva	Geneva, Switzerland	2012			Yes
114	Characterising adaptive capacity in water governance arrangements in the context of extreme events.	Hill, M.	Climate Change and the Sustainable Management of Water Resources.		Springer Verlag	Berlin, Germany.	2011	339-366		No
115	Assessing adaptive capacity of water governance regimes under climatic uncertainty	Hill, M.	Hydrocomplexity: New Tools for Solving Wicked Water Problems	338	IAHS		2010			No
116	Converging Threats: Assessing socio-economic and climate impacts on water governance	Hill, M.	International Journal of Climate Change Management and Strategies	2 (3)			2010	242-263		No
117	Bridges and barriers to adaptive capacity: A comparative study of Swiss and US States.	Hill, M.	Regional Environmental Change		Springer		2013	In press		
118	Cloud cover does not clearly affect the diurnal vertical distribution of crustacean zooplankton in naturally fishless alpine lakes	Iacobuzio R	Zooplankton and Benthos Research	6			2011	210–214		

119	Validation of a high-resolution regional climate model for the alpine region and effects of a subgrid-scale topography and land use representation	Im E	Journal of Climate	23			2010	1854–1873		
120	Local vs remote effects of climate change over the Alpine region: A study with a high resolution regional climate model with a surrogate climate change scenario	Im E-S	Geophysical Research Letter	37			2010			
121	Alpine debris flows.	Jomelli	Science and Technology	4			2012	162-164.		no
122	What is the most influent among geomorphic or climatic component in DF activity: A hierarchical analysis	Jomelli	Geomorphology	submitted	Elsevier					No
123	Impacts of future climatic change (2070-2099) on the potential occurrence of debris flows: a case study in the Massif des Ecrins (French Alps)	Jomelli V	Climatic Change	97			2009	171–191		
124	High-resolution paleoclimatology of the last millennium: a review of current status and future prospects	Jones PD	The Holocene	19			2009	3–49		
125	Non-stationary probabilistic downscaling of extreme?precipitation	Kallache M	Journal of Geophysical Research	116			2011			
126	Spatial assessment of precipitation deficits in the Duero basin (central Spain) with multivariate extreme value statistics	Kallache M	Water Resources Research	in press			2013			
127	Disturbance theory predicts aquatic biodiversity response to alpine glacier retreat	Khamis K	Journal of Animal Ecology	submitted			2013			
128	Predation modifies macroinvertebrate community structure in alpine stream mesocosms	Khamis K	Freshwater Science	submitted			2013			

129	Climate change and alpine aquatic ecosystem response	Khamis K	Science of the Total Environment	submitted						
130	Alpine Aquatic Ecosystem Conservation Policy in a Changing Climate	Khamis, K.	Environmental Science & Policy		Elsevier Publishers		2013	In press		No
131	Hybrid wavelet denoising procedure of discontinuous surfaces	Kim D	IET Image Processing	5			2011	684–692		
132	Homogenization of daily maximum temperature series in the Mediterranean	Kuglitsch FG	Journal of Geophysical Research-Atmospheres	114			2009	D15108		
133	Heat wave changes in the eastern Mediterranean since 1960	Kuglitsch FG	Geophysical Research Letters	37			2010	L04802		
134	Multidecadal changes in winter circulation-climate relationship in Europe: frequency variations within-type modifications and long-term trends	Küttel M	Climate Dynamics	36			2011	957–972		
135	The importance of ship log data: reconstructing North Atlantic European and Mediterranean sea level pressure fields back to 1750	Küttel M	Climate Dynamics				2010		doi:101007/s 00382-009-0577-9	
136	Steamflow response and sediment yield after farmland abandonment: results from a small experimental catchment in the central Spanish Pyrenees.	Lana-Renault	Pirineos Revista de Ecologia de Montana	165	CSIC		2010	97-114		
137	Steamflow response and sediment yield after farmland abandonment: results from a small experimental catchment in the central Spanish Pyrenees	Lana-Renault N	Pirineos Revista de Ecologia de Montana	165			2010	97–114		
138	Escorrentia y erosion tras el abandono de tierras de cultivo en montana: resultados de la esaction experimental	Lasanta, T	Pirineos Revista de Ecologia de Montana	81	CSIC		2010	115-133		yes

139	Escorrentia y erosion tras el abandono de tierras de cultivo en montana: resultados de la esaction experimental	Lasanta, T	Pirineos Revista de Ecologia de Montana	81	CSIC		2010	115-133		yes
140	Sensitivity analysis of a process-based ecosystem model: pinpointing parameterization and structural issues	Leuzinger S	Journal of Geophysical Research – Biogeosciences	118			2013		doi:10 1002/jgrg	
141	Die Auswirkungen des globalen Wandels auf Schweizer Wälder aus ökophysiologischer Sicht	Leuzinger S	Schweizerische Zeitschrift für Forstwesen	161			2010	2–11		
142	Water relations of climbing ivy in a temperate forest	Leuzinger S	Planta	233			2011	1087–1096		
143	Do global change experiments overestimate impacts on terrestrial ecosystems?	Leuzinger S	Trends in Ecology and Evolution	26			2011	236–241		
144	Experimental versus modelled water use in mature Norway spruce (Picea abies) exposed to elevated CO2	Leuzinger S	Frontiers in Functional Plant Ecology	229			2012		doi: 103389/fpls	
145	A sink-limited growth model improves biomass estimation along boreal and alpine treelines	Leuzinger S	Journal of Global Ecology and Biogeography				2013		doi:101111/geb	
146	Klimawandel und Wasserwirtschaft: Auswirkungen und Adaptation in der Schweiz	Lindberg E					2010			
147	Mediterranean climate: background information	Lionello P	In: Lionello P (ed). The Climate of the Mediterranean Region: From the past to the future		Elsevier		2012			
148	High-resolution fingerprints of past landsliding and spatially explicit probabilistic assessment of future activations: Aiguettes landslide, Southeastern French Alps	Lopez Saez J	Tectonophysics	4, 20			2013		doi:101016/jtecto	
149	Climate change increases frequency of shallow spring landslides in the French Alps	Lopez Saez J	Geology	41			2013	619–622		

150	Dendrogeomorphic reconstruction of past landslide reactivation with seasonal precision: the Bois Noir landslide, southeast French Alps	Lopez Saez J	Landslides	9			2012	189–203			
151	Probability maps of landslide reactivation derived from tree-ring records: Pra Bellon landslide, souther French Alps	Lopez Saez J	Geomorphology	138			2012	189–202			
152	Mapping of erosion rates in marly badlands based on a coupling of anatomical changes in exposed roots with slope maps derived from LiDAR data	Lopez Saez J	Earth Surface Processes and Landforms	36			2011	1162–1171			
153	Debris-flow activity in abandoned channels of the Manival torrent reconstructed with LiDAR and tree-ring data	Lopez Saez J	Natural Hazards and Earth System Sciences	11			2011	1247–1257			
154	Impact of climate change on snowpack in the Pyrenees: Horizontal spatial variability and vertical gradients	López-Moreno, JI	J. Hydrology	374			2009	284-296			
155	Estimation of reference evapotranspiration in a mountainous Mediterranean site using the Penman-Monteith equation with limited meteorological data.	López-Moreno, JI	Pirineos Revista de Ecologia de Montana	164	CSIC		2009	juil.31			
156	Effects of sample and grid size on the accuracy and stability of regression-based snow interpolation methods,	López-Moreno, JI	Hydrological processes	24	Willey		2010	1914-1928			
157	Trends in daily precipitation on the northeastern Iberian Peninsula, 1955-2006.	López-Moreno, JI	Int. J. Climatology	30	Willey		2010	1026-1041			

158	Stability of the seasonal distribution of precipitation in the Medirerranean region: Observations since 1950 and projections for the 21st century, Geophysical Research Letters 36, L10703.	López-Moreno, JI	Geophysical research Letters	36	American Geophysical Union		2009	L10703		
159	Impact of climate evolution and land use changes on water yield in the Ebro basin. Hydrology and Earth System Sciences 7, 2651–2681.	López-Moreno, JI	Hydrology and earth Surface Processes	7	European Geophysical Union		2011	2651-2681		
160	Effects of climate change on the intensity and frequency of heavy snowfall events in the Pyrenees.	López-Moreno, JI	Climatic Change	105	Springer		2011	489-508		
161	NAO effects on combined temperature and precipitation winter modes in the Mediterranean mountains: Observed relationships and projections for the 21st century.	López-Moreno, JI	Global and Planetary Change	77	Elsevier		2011	62-76		
162	Impact of climate and land use change on water availability and reservoir management: Scenarios in the Upper Aragón river, Spanish Pyrenees.	López-Moreno, JI	Science of the Total Environment Journal	In press	Elsevier		2013			
163	The impact of droughts and water management on various hydrological systems in the headwaters of the Tagus River (central Spain)	Lorenzo-Lacruz J	Journal of Hydrology	386			2010	13-26		
164	Rock-glacier dynamics and magnitude-frequency relations of debris flows in a high- elevation watershed: Ritigraben, Swiss Alps	Lugon R	Global and Planetary Change	73			2010	202–210		
165	A review of 2000 years of paleoclimatic evidence in the Mediterranean	Luterbacher J	In: Lionello P (ed). The Climate of the Mediterranean Region. From the past to the future		Elsevier		2012		doi: 10:1016/B978-0-12-416042-2	00002-1

166	Circulation dynamics and its influence on European and Mediterranean January-April climate over the past half millennium: results and insights from instrumental data, documentary evidence and coupled climate models	Luterbacher J	Climatic Change				2010		doi:10.1007/s10584-009-9782-0	
167	Climate Change in Poland in the Past Centuries and its Relationship to European Climate: Evidence from Reconstructions and Coupled Climate Models	Luterbacher J	In: Przybylak et al (eds), The Polish Climate in the European Context: A Historical Overview				2010		doi: 10.1007/978-90-481-3167-9_1	
168	A model for high-altitude alpine lake ecosystems and the effect of introduced fish	Magnea	Ecological Modelling	251			2013	211–220		
169	Tree mortality in dynamic vegetation models – A key feature for accurately simulating forest properties	Manusch C	Ecological Modelling	243			2012	101–111		
170	Tree species shifts partly counteract negative climate change effects on carbon storage	Manusch C	Regional Environmental Change	submitted			2013			
171	Climate change impacts on hydropower in an alpine catchment	Maran, S.	Environmental Science & Policy	Accepted for publication	Elsevier		2013			no
172	A methodology for the assessment of climate change effects on hydropower	Maran, S.	Proceedings of VI EWRA International Symposium - Water Engineering and Management in a Changing Environment	III SERIE VOL. 6	QUADERNI CSEI Catania	Catania	2011	p. 23	ISSN 2038-5854	no
173	A methodology for the assessment of climate change effects on hydropower	Maran, S.	VI EWRA International Symposium – Water Engineering and Management in a Changing Environment	June 29 – July 2, 2011		Catania	2011			
174	Safety concept for hazards caused by ice avalanches from Whymper hanging glacier in the Mont Blanc massif	Margreth S	Cold Region Science and Technology	69			2011	194-201		

175	Correlation between the footprint size and the exogenous variables measured by eddy covariance station in the Po Valley, Italy	Masseroni D.	Italian Journal of Agrometeorology	No. 16(1) 2011	Italian Association of AgroMeteorology	Italy	2011	pp. 25-36		no
176	Turbulence integral length and footprint dimension with reference to experimental data measured over maize cultivation in Po Valley, Italy	Masseroni D.	Atmosfera	No. 25(2) 2012	Universidad Nacional Autónoma de México	Mexico	2012	pp. 183-198	http://www.revistas.unam.mx/index.php/atm/article/view/30971	no
177	Adaptation of precipitation index for the estimation of antecedent moisture condition in large mountainous basins	Miliani F	Journal of Hydrologic Engineering	16			2011	218–227		
178	The changing roles of temperature and precipitation on snowpack variability in Switzerland as a function of altitude	Morán-Tedeja E	Geophysical Research Letters	40			2013	2031–2036		
179	Recent evolution of combined temperature-precipitation modes in the Spanish mountains and sensitivity of snow cover	Morán-Tejeda E	Regional Environmental Change				2012		doi:10 1007/s10113-012-0380-8	
180	Timing and duration of European larch growing season along altitudinal gradients in the Swiss Alps	Moser L	Tree Physiology	30			2009	225–233		
181	Cascading climate effects and related ecological consequences during past centuries	Naef-Daenzer B	Climate of the Past	8			2012	1527–1540		
182	A non-parametric entropy-based approach to detect changes in climate extremes	Naveau P	Journal of the Royal Statistical Society		submitted		2013	Series B		
183	An extension of max autoregressive models	Naveau P	Statistics and Its Interface	4			2011	253–266		

184	An extended network of documentary data from South America and its potential for quantitative precipitation reconstructions back to the 16th century	Neukom R	Geophysical Research Letters				2009		doi: 10 1029/2009GL038351	
185	Multi-centennial summer and winter precipitation variability in southern South America	Neukom R	Geophysical Research Letters				2010		doi: 10 1029/2010GL043680	
186	Multiproxy summer and winter surface air temperature field reconstructions for southern South America covering the past centuries	Neukom R	Climate Dynamics				2010		doi: 10 1007/s00382-010-0793-3	
187	Debris Flow activity related to current climate conditions in the French Alps: a regional investigation based on Safran reanalyzed data.	Pavlova	Geomorphology	accepted	Esevier					no
188	Debris flow triggering meteorological conditions in the nortern french Alps	Pavlova	Ice and Snow,	117		Moscow	2012	105-109		No
189	Debris flow occurrence and meteorological factors in the French Alps: a regional investigation	Pavlova	Debris flow hazards mitigation		Hamilton & Prestininzi	La sapienza,	2011	127-135		no
190	Impact of future climate change on debris flow occurrence in the French Alps	Pavlova	Climatic Change	submitted						No
191	A study of the energy balance and melt regime on Juncal Norte Glacier, semi-arid Andes of central Chile, using melt models of different complexity	Pellicciotti F	Hydrological processes	22			2008	pp. 3980–3997		no
192	The meteorological framework and the cultural memory of three severe winter-storms in early eighteenth-century Europe	Pfister C	Climatic Change	101			2009	1–6		
193	Added value of convection permitting seasonal simulations	Prein AF	Climate Dynamics				2013		doi: 10 1007/s00382-013-1744-6	

194	Added value of convection permitting seasonal simulations	Prein, A.F.	Climate Dynamics		Springer		2013	doi: 10.1007/s00382-013-1744-6.	http://link.springer.com/article/10.1007/s00382-013-1744-6	
195	Exploring debris-flow history and process dynamics using an integrative approach on a dolomitic cone in western Austria	Procter E	Earth Surface Processes and Landforms	37			2012	913–922		
196	A regional reconstruction of debris-flow activity in the Northern Calcareous Alps, Austria	Procter E	Geomorphology	132			2011	41–50		
197	A snapshot of policy and research considerations about water and climate change	Quevauviller P	AQUAmundi	4			2010	23-28		
198	Water sustainability and climate change in the EU and global context - Policy and research responses	Quevauviller P	Issues in Environmental Science and Technology 31	31			2010			
199	Integration of research advances in modelling and monitoring in support of WFD river basin management planning in the context of climate change	Quevauviller P	Science of the Total Environment	440			2012	167–177		
200	Streamflow modeling in a highly managed mountainous glacier watershed using SWAT: the upper Rhone River watershed case in Switzerland	Rahman K	Water Resources Management				2013		DOI: 10 1007/s11269-012-0188-9	
201	Getting a virtual forester fit for the challenge of climatic change	Rasche L	Journal of Applied Ecology	48			2011	1174–1186		
202	Adaptation of Precipitation Index for the Estimation of Antecedent Moisture Condition in Large Mountainous Basins	Ravazzani G.	Journal of Hydrologic Engineering	No 16(3) 2011	American Society of Civil Engineers	Virginia	2011	pp. 218–227	http://ascelibrary.org/doi/abs/10.1061/%28ASCE%29HE.1943-5584.0000307	no

203	Modified Hargreaves-Samani Equation for the Assessment of Reference Evapotranspiration in Alpine River Basins	Ravazzani G.	Journal of Irrigation and Drainage Engineering	No. 138(7) 2012	American Society of Civil Engineers	Virginia	2012	pp. 592–599	http://ascelibrary.org/doi/abs/10.1061/%28ASCE%29IR.1943-4774.0000453	
204	Design hydrograph and routing scheme for flood mapping in a dense urban area	Ravazzani G.	Urban Water Journal	No. 6(3) 2009	Taylor & Francis	UK	2009	pp. 221–231		no
205	Macroscopic cellular automata for groundwater modelling: A first approach	Ravazzani G.	Environmental Modelling & Software	No. 26(5) 2011	Elsevier	Netherland	2011	pp. 634–643	http://www.sciencedirect.com/science/article/pii/S1364815210003154	no
206	MOSAICO, a library for raster based hydrological applications	Ravazzani G.	Computers & Geosciences	No. 51 2013	Elsevier	Netherland	2013	pp. 1–6	http://www.sciencedirect.com/science/article/pii/S0098300412002853	no
207	An energy-balance model for debris-covered glaciers including heat conduction through the debris layer	Reid TD	Journal of Glaciology	56			2010	903–916		
208	Assessing ice cliff dynamics and the net ablation due to backwasting on debris-covered Miage glacier, Italian Alps	Reid TD	Journal of Glaciology	submitted			2013			
209	Including debris cover effects in a distributed model of glacier ablation	Reid TD	Journal of Geophysical Research	117			2013			
210	A plant's perspective of extremes: terrestrial plant responses to changing climatic variability	Reyer CPO	Global Change Biology	19			2013	75-89		
211	A note of caution when interpreting parameters of the distribution of excesses	Ribereau P	Advances in Water Resources	34			2011	1215–1221		

212	Book Review. In the Shadow of Melting Glaciers. Climate change and Andean Society	River, A.	Hist. Geo Space Sci	2			2011	pp. 97–98		yes
213	Estimación de volúmenes de hielo mediante radio echo sondaje en Chile Central	River, A.	Serie Informes Técnicos, DGA	288	Dirección general de Aguas (DGA)	Santiago Chile	2012	173 pp.		yes
214	Estimación de Volúmenes de Hielo en Glaciares de Chile Central.	River, A.	Serie Informes Técnicos, DGA	264	Dirección general de Aguas (DGA)	Santiago Chile	2011	143 pp.		yes
215	Variaciones de glaciares en Chile, según principales zonas glaciológicas	River, A.	Serie Informes Técnicos, DGA	261	Dirección general de Aguas (DGA)	Santiago Chile	2011	142 pp		yes
216	Recent glacier variations on active ice capped volcanoes in the Southern Volcanic Zone (37º 46ºS), Chilean Andes	Rivera, A. and F. Bown	Journal of South American Earth Sciences	45			2013	pp. 345-356		no
217	Glacier responses to recent volcanic activity in Southern Chile.	Rivera, A., F. Bown, D. Carrión and P. Zenteno	Environmental Research Letters	7			2012	Doi:10.1088/ 1748-9326/7/0140 36		yes
218	Hypsometry	Rivera, A., F. Cawkwell, C. Rada & C. Bravo	Encyclopaedia of Snow Ice and Glaciers		Springer	The Netherlands	2011	pp. 551-554		no
219	Palaeolimnological evidence for an east–west climate see-saw in the Mediterranean since AD 900	Roberts N	Global and Planetary Change	84–85			2012	35–47		
220	Mixture model for multivariate extremes	Sabourin A	Computational Statistics and Data Analysis	in press			2013			
221	Validation of the present day annual cycle in heavy precipitation over the British Islands simulated by 14 RCMs	Schindler A	Journal of Geophysical Research	117			2012		doi:101029/2 012JD01782 8	
222	Changes in the annual cycle of heavy precipitation across the British Isles within the 21st century	Schindler A	Environmental Research Letter				2012		doi: 10 1088/1748-9326/7/4/04 4029	

223	Hydrometeorological triggers of periglacial debris flows in the Zermatt valley (Switzerland) since 1864	Schneuwly-Bollschweiler M	Journal of Geophysical Research – Earth Surface	F02033			2012			
224	How to improve dating quality and reduce noise in tree-ring based debris-flow reconstructions	Schneuwly-Bollschweiler M	Quat Geochronology	5			2013		doi:10 1016/jquageo	
225	La variabilidad temporal de la respuesta hidrologia en un pequena cuenca mediterranea forestrada del pirineo central	Serrano-Muela P	Pirineos	165			2010	193–213		
226	Irrigation water requirements in the Swiss Rhone catchment under climate change: Spatial and hot spot analysis	Smith Pascalle Christine	(in prep.)							
227	A simple scheme for modeling irrigation water requirements at the regional scale applied to an Alpine river catchment	Smith, Pascalle Christine	Water	No 4			2012	pp. 869 – 886		yes
228	Irrigation water requirements in the Swiss Rhone catchment under climate change: Station-scale bias correction and uncertainty analysis	Smith, Pascalle Christine	Climatic Change				under review			
229	Modelling irrigation demand from two grasslands in Switzerland under contrasting climatic conditions and soil properties	Smith, Pascalle Christine	International Environmental Modelling and Software Society(iEMSs)	International Congress on Environmental Modelling and Software, Modelling for Environment's Sake, Fifth Biennial Meeting	David A. Swayne, Wanhong Yang, A. A. Voinov, A. Rizzoli, T. Filatova (Eds.)	Ottawa, Canada	2010		http://www.iemss.org/iemss2010/. index.php?n=Main.Proceedings	
230	Climate change impacts on glaciers and runoff in Central Asia.	Sorg, A.	Nature Climate Change	2 (10)			2012	725-731	doi:10.1038/nclimate1592	No

231	Coping with changing water resources: The case of the Syr Darya river basin in Central Asia	Sorg, A.	Environmental Science and Policy				In press			No
232	The days of plenty will soon be over in glacierized Central Asian catchments	Sorg, A.	PNAS				Submitted			No
233	The interactions between vegetation and erosion: new directions for research at the interface of ecology and geomorphology	Stoffel M	Earth Surface Processes and Landforms	37			2012	23–36		
234	Magnitude-frequency relationships of debris flows – A case study based on field surveys and tree-ring records	Stoffel M	Geomorphology	116			2010	67-76		
235	Effects of climate change on mass movements in mountain environments	Stoffel M	Progress in Physical Geography	36			2012	421–439		
236	Hydrogeomorphic processes and vegetation: Disturbance process histories dependencies and interactions	Stoffel M	Earth Surface Processes and Landforms	37			2012	9–22		
237	Dating and quantification of erosion processes based on exposed roots	Stoffel M	Earth-Science Reviews	123			2013	18–34		
238	Mass movements and tree rings: A guide to dendrogeomorphic field sampling and dating	Stoffel M	Geomorphology	12, 17			2013		doi:10 1016/jgeomorph	
239	Climate change impacts on mass movements – Case studies from the European Alps	Stoffel M	Science of the Total Environment	submitted			2013			
240	Possible impacts of climate change on debris-flow activity in the Swiss Alps	Stoffel M	Climatic Change	in review			2013			
241	Rainfall characteristics for periglacial debris flows in the Swiss Alps: past incidences – potential future evolutions	Stoffel M	Climatic Change	105			2011	263–280		

242	Spatio-temporal variability in debris-flow activity: a tree-ring study at Geisstriftbach (Swiss Alps) extending back to AD 1736	Stoffel M	Swiss Journal of Geosciences	103			2010	283–292		
243	Five weather patterns and specific precursors determine extreme floods in Switzerland	Stucki P	Meteorologische Zeitschrift	21			2012	531–550		
244	Debris-flow activity and snow avalanches in a steep watershed of the Valais Alps (Switzerland): Dendrogeomorphic event reconstruction and identification of triggers	Szymczak S	Geomorphology	116			2010	107–114		
245	Empirical-statistical downscaling and error correction of daily precipitation from regional climate models	Themessl MJ	International Journal of Climatology	31			2010	1530–1541		
246	Evidences of zooplankton vertical migration in stocked and never stocked alpine lakes in Gran Paradiso National Park (Italy)	Tiberti R	Oceanological and Hydrobiological Studies 40	40			2011	36-42		
247	Impact of alien fish on Common frog (Rana temporaria) close to its altitudinal limit in alpine lakes	Tiberti R	Amphibia Reptilia	33			2012	303–307		
248	Preliminary studies on fish capture techniques in Gran Paradiso alpine lakes: towards an eradication plan	Tiberti R	Journal of Mountain Ecology	in press			2013			
249	Ecological dynamics of two remote alpine lakes during ice-free season	Tiberti R	Journal of Limnology	72			2013	401–416		
250	Geomorphology and hydrochemistry of 112 Alpine lakes in the Gran Paradiso National Park, Italy	Tiberti R	Journal of Limnology	69			2010	242–256		
251	Morphology and ecology of Daphnia middendorffiana Fisher 1851 (Crustacea Daphniidae) from four new populations in the Alps	Tiberti R	Journal of Limnology	70			2011	239–247		

252	The past ecology of Abies alba provides new perspectives on future responses of silver fir forests to global warming	Tinner W	Ecological Monographs				2013		doi: 10 1890/12-2231	
253	Estimation of rainfall thresholds triggering shallow landslides for an operational warning system implementation	Tiranti D	Landslides	7			2010	471–481		
254	Development of a new translational and rotational slides prediction model in Langhe hills (north-western Italy) and its application to the 2011 March landslide event	Tiranti D	Landslides				2013		doi:10 1007/s10346-012-0319-7	
255	Estimation of rainfall thresholds triggering shallow landslides for an operational warning system implementation	Tiranti, D. Rabuffetti	Landslides	No 7, Vol. 4, December 2010	Springer	-	2010	pp. 471-481	http://dx.doi.org/10.1007/s10346-010-0198-8	no
256	Development of a new translational and rotational slides prediction model in Langhe hills (north-western Italy) and its application to the 2011 March landslide event	Tiranti, D. Rabuffetti, A. Salandin, M. Tararbra	Landslides	No 10, Vol. 2, May 2013	Springer	-	2013	pp. 121-138	http://dx.doi.org/10.1007/s10346-012-0319-7	no
257	A novel approach for the detection of inhomogeneities affecting climate time series	Toreti A	Journal of Applied Meteorology and Climatology				2012		doi:10 1175/JAMC-D-10-05033	
258	A note on the use of the standard normal homogeneity test to detect inhomogeneities in climatic time series	Toreti A	International Journal of Climatology	31			2011	630–632		
259	A novel method for the homogenization of daily temperature series and its relevance for climate change analysis	Toreti A	Journal of Climate				2010		doi: 10 1175/2010JCLI3499	
260	Atmospheric forcing of debris flows in the southern Swiss Alps	Toreti A	Journal of Applied Meteorology and Climatology 52	52			2013	1554–1560		

261	Characterisation of extreme winter precipitation in Mediterranean coastal sites and associated anomalous atmospheric circulation patterns	Toreti A	Natural Hazards and Earth System Sciences 10	10			2010	1037–1050		
262	Global changes in seasonal extreme precipitations	Toreti A	Geophysical Research Letters	submitted			2013			
263	Particle filtering for Gumbel distributed daily maxima of methane and nitrous oxide	Toulemonde G	Environmetrics	24			2013	51–62		
264	Sensitivity analysis of snow patterns in Swiss ski resorts to shifts in temperature precipitation and humidity under condition of climate change	Uhlmann B	International Journal of Climatology	29			2009	1046–1055		
265	Modelling runoff in a Swiss glacierized catchment – Part I: methodology and application in the Findelen basin under a long-lasting stable climate	Uhlmann B	International Journal of Climatology	33			2012	1293–1300		
266	Modelling runoff in a Swiss glacierized catchment – Part II: daily discharge and glacier evolution in the Findelen basin in a progressively warmer climate	Uhlmann B	International Journal of Climatology	33			2012	1301–1307		
267	Claim of solar influence is on thin ice: are 11-year cycle solar minima associated with severe winters in Europe?	van Oldenborgh GJ	Environmental Research Letters				2013		doi:10 1088/1748-9326/8/2/02 4014	
268	Daily atmospheric circulation events and extreme precipitation risk in northeast Spain: role of the North Atlantic Oscillation, the Western Mediterranean Oscillation, and the Mediterranean Oscillation.	Vicente-Serrano SM	Journal of Geophysical Research	114	American Geophysical Union		2009	D08106		

269	Multiscalar drought index sensitive to global warming: The standardized precipitation evapotranspiration index, Journal of Climate	Vicente-Serrano SM	J Climate	23	American Meteorological Society		2010	1696-1718		
270	Challenges for drought mitigation in Africa: The potential use of geospatial data and drought information systems	Vicente-Serrano SM	Applied Geography	34	Elsevier		2011	471-486		
271	A new global 0.5 gridded dataset (1901–2006) of a multiscalar drought index: Comparison with current drought index datasets based on the Palmer Drought Severity Index	Vicente-Serrano SM	Journal of hydrometeorology	11	American Meteorological Society		2012	1033-1043		
272	Acidification determines changes in forest growth in Pinus halepensis forests under semiarid Mediterranean climate conditions,	Vicente-Serrano SM	Agricultural and Forest Meteorology 150, 614–628.	150	Elsevier		2012	614-628		
273	Comparison of regression techniques for mapping fog frequency: application to the Aragon region (northeast Spain).	Vicente-Serrano SM	International journal of Climatology	30	Willey		2011	935-945		
274	Extreme winter precipitation in the Iberian Peninsula in 2010: anomalies, driving mechanisms and future projections, Clim. Res. 46:51-65	Vicente-Serrano SM	Climate Research	46	Inter-research		2011	51-65		
275	A Pseudoproxy Evaluation of Bayesian Hierarchical Modelling and Canonical Correlation Analysis for Climate Field Reconstructions over Europe	Werner JP	Journal of Climate	26			2013	851-867		
276	The largest floods in the High Rhine basin since 1268 assessed from documentary and instrumental evidence	Wetter O	Hydrological Sciences Journal	56			2011	733–758		
277	Multi-variable error correction of regional climate models	Wilcke, R.A.I.	Climatic Change	120(4)	Springer		2013	871-887, doi:10.1007/s10584-013-0845-x.	http://link.springer.com/article/10.1007/s10584-	

									013-0845-x	
278	Estimating the potential impact of vegetation on the water cycle requires accurate soil water parameter estimation	Wolf A	Ecological Modelling	222			2011	2595–2605		
279	The relative importance of land use and climatic change in Alpine catchments	Wolf A	Climatic Change	111			2012	279–300		
280	Large-scale atmospheric circulation driving extreme climate events in the Mediterranean	Xoplaki E	In: Lionello P (ed) The Climate of the Mediterranean Region. From the past to the future.			Elsevier	2012		doi: 10 1016/B978-0-12-416042-2 00006-9	
281	Raspredelenie prizemnoy temperatury v Kyrgyzstane [Surface temperature distribution in Kyrgyzstan]	Yakimov V	Proceedings of the Voeikov Main Geophysical Observatory	(submitted)			2013			no
282	Background conditions influence decadal climate response to strong volcanic eruptions	Zanchettin D	Journal of Geophysical Research				2013		doi:10 1002/jgrd 50229	
283	Delayed winter warming: A robust decadal response to strong tropical volcanic eruptions?	Zanchettin D	Geophysical Research Letters				2013		doi: 10 1029/2012GL054403	

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES								
NO.	Type of activities[2]	Main leader	Title	Date/Period	Place	Type of audience[3]	Size of audience	Countries addressed
1	Conference	Beniston, M.	Climate change impacts on mountain water resources: emerging results from the EU “ACQWA” Project	December 10 2013	Montreal, Canada	University	50	Canada
2	Conference	Beniston, M.	Impacts of climatic change on mountain water resources	April 2, 2013	New Delhi, India	Academic	150	India
3	Conference	Beniston, M.	Issues pertaining to water quality and water quantity in vulnerable mountain regions: a focus on the EU-FP7 "ACQWA" Project	April 26.28, 2010	Lillle, France	Academic, Stakeholders, EC Policymakers	100	EU
4	Conference	Beniston, M.	Vulnerability of water resources in mountain regions: a focus of the EU/FP7 “ACQWA” Project	December 1, 2009	La Serena, Chile	Academic	40	South America
5	Conference	Beniston, M.	Current and future climatic extremes in the Alps	December 14, 2010	Cambridge, UK	Academic	100	EU
6	Conference	Beniston, M.	Changing water mountain resources in a warming climate,	December 14, 2011	Giessen, Germany	Academic	50	EU
7	Conference	Beniston, M.	Exploring possible changes in water in mountain regions vulnerable to climate within th EU-FP7 "ACQWA" Project	December 15, 2010	Birmingham, UK	Academic	50	EU
8	Conference	Beniston, M.	Data gaps in research related to water and climate	February 2, 2011	Geneva, Switzerland	Academic, Stakeholders	50	Global
9	Conference	Beniston, M.	Mountain water resources in a changing climate	February 20, 2013	Valle d’Aosta, Italy	Academic	120	EU
10	Radio Interview	Beniston, M.	Radio-Télévision Suisse	February 8, 2011				
11	Newspaper interview	Beniston, M.	Le Temps, Geneva; Le Nouvelliste, Sion	February 9, 2012				

[2] A drop down list allows choosing the dissemination activity: publications, conferences, workshops, web, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, Other.

[3] A drop down list allows choosing the type of public: Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias, Other ('multiple choices' is possible).

12	Conference	Beniston, M.	Problems of missing data and scientific information in the EU "ACQWA" Project	January 12-15, 2011	Riederalp, Switzerland	Academic	40	EU
13	Conference	Beniston, M.	Changing water resources in regions dominated by snow and ice	January 27-29, 2010	Washington DC, USA	Academic, Stakeholders	100	Global
14	Conference	Beniston, M.	Exploring the tails of the distributions of climate variables in Switzerland and Europe	January 31, 2009	Riederalp, Switzerland	Academic	50	EU
15	Conference	Beniston, M.	Socio-Economic implications of changing water resources in a warmer climate in vulnerable mountain regions	July 11-15, 2011	Lewiston, USA	Academic	200	Global
16	Conference	Beniston, M.	Extreme climate and weather events in Europe and the Alps for current and greenhouse climates	July 13, 2009	Athens, Greece	Academic, Students	100	EU
17	Newspaper interview	Beniston, M.	Le Temps, Geneva	July 28, 2012				
18	Conference	Beniston, M.	Water resources and climate change in vulnerable mountain regions	July 4, 2011	Singapore	Academic, Stakeholders	500	Global
19	Conference	Beniston, M.	Water and climate in vulnerable mountain regions: an overview of the EU/FP7 "ACQWA" Project	July 6, 2010	Brussels, Belgium	Academic, EC Stakeholders	40	EU
20	Conference	Beniston, M.	EU water-related projects and their recommendations for science, policy, and outreach	July 7, 2010	Brussels, Belgium	EC Policymakers	50	EU
21	Conference	Beniston, M.	Possible changes in mountain water: emerging results from the EU "ACQWA" Project	June 25, 2013	Boston, USA	Academic	50	USA
22	Television programme	Beniston, M.	EURONEWS	March 11-17, 2010				
23	Conference	Beniston, M.	Water resources in vulnerable mountain regions	March 16, 2009	Waterloo, Ontario, Canada	Academic, Students	100	Global
24	Conference	Beniston, M.	Extreme events in a changing alpine climate	March 16, 2012	Istanbul, Turkey	Academic	100	Near East
25	Conference	Beniston, M.	Modeling strategies for the EU-FP7 “ACQWA” project	March 17, 2009	Waterloo, Ontario, Canada	Academic, Students	100	Global
26	Conference	Beniston, M.	Water resources in mountain regions under conditions of retreating snow and ice	March 26, 2012	Belgrade, Serbia	Academic	50	Central Europe
27	Conference	Beniston, M.	Potential impacts of climatic change	May 27, 2009	Milano, Italy	Academic,	150	EU

			on mountain water resources			Stakeholders		
28	Conference	Beniston, M.	Climate impacts on water resources in mountain regions	May 31, 2011	Mangalia, Romania	Students	50	Central and Eastern Europe
29	Conference	Beniston, M.	Exploring shifts in water availability and use in the Alps in a warmer climate	May 5, 2011	Bayreuth, Germany	Academic	100	EU
30	Conference	Beniston, M.	Mountain water resources in a changing climate	May 7, 2013	Belgrade, Serbia	Academic	50	Central Europe
31	Conference	Beniston, M.	Impacts of climatic change on the frequency and intensity of extreme events in the Alpine Region	November 22-23. 2010	Lyon, France	Academic	100	EU
32	Newspaper interview	Beniston, M.	Le Temps, Geneva; La Tribune de Genève; 24-Heures, Lausanne; La Liberté, Fribourg	November 30, 2008				
33	Conference	Beniston, M.	Climatic extremes and their evolution in a warmer climate	November 30, 2009	Santiago, Chile	Academic	40	South America
34	Television Interview	Beniston, M.	Radio-Télévision Suisse	October 1, 2008				
35	Newspaper interview	Beniston, M.	Revue Technique Suisse	October 10, 2013				
36	Conference	Beniston, M.	Impacts of climatic change on mountain hydrology where snow and ice are a major component of the hydrological cycle	October 12, 2010	San Diego, USA	Academic	200	Global
37	Conference	Beniston, M.	Climate change impacts on mountain water resources	October 23, 2013	Lecco, Italy	Academic	250	EU
38	Conference	Beniston, M.	An overview of the EU/FP7 ACQWA Project	October 24, 2013	Lecco, Italy	Academic	250	EU
39	Conference	Beniston, M.	Changes in water resources and economic impacts in the Swiss part of the Rhone River Basin (EU/FP7 ACQWA Project Results)	October 24-28, 2011	Denver, USA	Academic, Stakeholders	1000	Global
40	Newspaper interview	Beniston, M.	Terre et Nature, Lausanne	October 3, 2013				
41	Conference	Beniston, M.	Impacts of climatic change on Alpine hydrology	October 7,2010	Munich, Germany	Academic	200	EU
42	Conference	Beniston, M.	An overview of water resources in vulnerable mountain regions	October 8-10, 2008	Wengen, Switzerland	Academic, Stakeholders	60	EU
43	Conference	Beniston, M.	Exploring changes in mountain water	September 11,	Losby Gods, Norway	Academic,	100	Scandinavia

			resources in a changing climate	2012		Stakeholder		
44	Conference	Beniston, M.	Extreme climatic events in the Alps in current and future climates,	September 13, 2012	Oslo, Norway	Academic	100	Scandinavia
45	Conference	Beniston, M.	Understanding processes of water vulnerability and adapting to changing water resources	September 2, 2009	Geneva, Switzerland	Academic, Policymakers	500	Global
46	Conference	Beniston, M.	Links between dry conditions and atmospheric temperatures in Europe: 20th century observations and 21st century projections	September 27, 2012	Salamanca, Spain	Academic	100	EU
47	Television Interview	Beniston, M.	RAI Regione Aosta	September 29, 2009				
48	Conference	Beniston, M.	Overview of the key results of the EU/FP7 "ACQWA" Project	September 4, 2013	Geneva, Switzerland	Academic	80	EU, Switzerland
49	Radio Interview	Beniston, M.	Radio-Télévision Suisse	September 6, 2013				
50	Newspaper interview	Beniston, M.	Le Temps, Geneva	September 7, 2013				
51	Research Seminar, IHEID, Department of International Economics	Bozzola, M. : “Climate Change, Smoothing with Water Stock and Impact on the Agricultural sector in the Po Valley (Italy)”.	Research Seminar, IHEID, Department of International Economics	4th June 2012	Geneva (CH)	Scientific Community	15	CH
52	Research Seminar, Centre for International Environmental Studies	Bozzola, M. Presented: “Climate Change, Smoothing with Water Stock and Impact on the Agricultural	Research Seminar, Centre for International Environmental Studies.	26 april 2014	Geneva (CH)	Scientific Community	15	CH

		sector in the Po Valley (Italy)".						
53	Research Seminar, IHEID, Department of International Economics	Bozzola, M. Presented: "Impacts of Climate Variability on Agriculture: Implications for Water Management in the case of the Po Basin, Italy."	Research Seminar, IHEID, Department of International Economics	22nd October 2012	Geneva (CH)	Scientific Community	15	CH
54	Summer School/Research Seminar	Bozzola, M. Presented: "Climate Change, Smoothing with Water Stock and Impact on the Agricultural Sector in the Po Valley (Italy)"	CMCC-ICCG Summer School on "Climate Change Impacts and Policy in the Mediterranean Basin"	May 20th -24th 2013	Venice (IT)	Scientific Community	25	IT
55	Conference	Bozzola, M. Presented: "Climate change, smoothing with water stock and impact on the agricultural sector in the Po valley (Italy)"	First SISC Annual Conference of the Italian Society for Climate Sciences	September 23rd -24th 2013	Lecce (IT)	Scientific Community Medias	30	IT
56	Conference	Bozzola, M.	The Italian Association of	8th-9th	Ferrara (IT)	Scientific Community	25	IT

		Presented: "Climate Change, Smoothing with Water Stock and Impact on the Agricultural sector in the Po Valley (Italy)".	Environmental and Resource Economists (IAERE) First Annual Conference (Ferrara, IT).	February 2013				
57	Poster	Colaiuda, V.	Evaluation of possible effects induced by climate change on the water resources: calibration on the Po basin and extention to the small basins of Central and South Italy	5 October 2012	L'Aquila - Italy	Scientific Communities, Policy Makers, Medias	100	Italy
58	Conference	Dalban-Canassy, P.	Alpine glaciological meeting	26 February 2009	Innsbruck, Austria	Scientific Community		
59	workshop	Dalban-Canassy, P.	Glacier Hazard workshop, Boku	10-13 November 2009	Vienna, Austria	Scientific Community		
60	conference	Dalban-Canassy, P.	Swiss geoscience meeting	21 November 2009	Neuchatel, Switzerland	Scientific Community		
61	conference	Dalban-Canassy, P.	Triggering of Rapid Mass Movements in Steep Terrains – Mechanisms and Risks	11-16 April 2010	Monte Verita, Switzerland	Scientific Community		
62	Conference	Dalban-Canassy, P.	European Geophysical Union	2-7 May 2010	Vienna Austria	Scientific Community		
63	conference	Dalban-Canassy, P.	International Glaciological Society Symposium	21-25 June 2010	Sapporo, Japan	Scientific Community		
64	conference	Dalban-Canassy, P.	Swiss geoscience meeting	12 November 2011	Zurich Switzerland	Scientific Community		
65	conference	Dalban-Canassy, P.	Alpine glaciological meeting	4 February 2012	Zurich Switzerland	Scientific Community		
66	conference	Dalban-Canassy, P.	DGG	6 March 2012	Hamburg Germany	Scientific Community		
67	conference	Dalban-Canassy, P.	European Geophysical Union	22-27 April 2012	Vienna Austria	Scientific Community		
68	Talk	Dalban-	ISTerre	8 June 2012	Grenoble, France	Scientific Community		

		Canassy, P.						
69	conference	Dalban-Canassy, P.	Swiss geoscience meeting	15-16 November 2012	Bern Switzerlan	Scientific Community		
70	conference	Dalban-Canassy, P.	American Geophysical Union	9-13 December 2012	San Francisco, USA	Scientific Community		
71	conference	Dalban-Canassy, P.	Alpine glaciological meeting	14-15 February 2013	Grenoble France	Scientific Community		
72	European Geophysical Union CONFERENCE (EGU)	DEDIEU, J.P.	Snow cover retrieval over Rhone and Po river basins from MODIS optical satellite data (2000-2009). Geophysical Research Abstracts, Vol. 12, SRef-ID: EGU2010-A-5532.	02-07 May 2010	Vienna (Austria)	International	International	International
73	European Geophysical Union CONFERENCE (EGU)	DEDIEU, J.P.	Snow cover monitoring in the Kyrgyz Republic through MODIS time series (2000-2010). Geophysical Research Abstracts, Vol. 14, SRef-ID: EGU2012-A-1148. 2012.	22-27 April 2012	Vienna (Austria)	International	International	International
74	ACQWA Final Event	Fuhrer, J.	Climate change and Agriculture in the Rhone Catchment	04 September 2013	Geneva, Switzerland	Scientific community/Public	50	International
75	ACQWA Stakeholder Information Event	Fuhrer, J.	Auswirkungen des Klimawandels auf die Landwirtschaft	06 September 2013	Visp, Switzerland	Public	50	Switzerland
76	C2SM Symposium The Water cycle in a Changing Climate	Fuhrer, J.	Implications of climate change scenarios for agriculture in alpine regions- a case study in the Swiss Rhone catchment	1-2 July 2013	Zurich, Switzerland	Scientific community	150	International
77	Conference	Garcia-Ruiz, JM	European Conference on Nanotechnologies	26 February 2010				
78	Conference	Garcia-Ruiz, JM	Planet under pressure	April 2011	London	Scientific, policy makers	100	international
79	Conference	Garcia-Ruiz, JM	Environmental Security, Geological Hazards and Management.	April 2013	La Laguna (Spain)	Scientific-Stakeholders	100	International
80	Conference	Garcia-Ruiz, JM	American geophysical Union	December 2012	San Francisco (US)	Scientific	90	International
81	Conference	Garcia-Ruiz, JM	Mountains Under Watch	February 2013	Val Aosta, Italy	Scientific	200	International
82	Conference	Garcia-Ruiz, JM	International Symposion on Climate Change in the Pyrenees;Lessons from the ACQWA Project	November 2013	Pamplona, Spain	Scientific, Policy makers, Stakeholders, Media,	300	International (France-Spain)

						Civil Society		
83	EGU Conference : Poster presentation	Gilbert. A.	Secular atmospheric temperature changes at very high elevation in the Mont Blanc area from englacial temperatures	April 2013	Vienna (Austria)	Scientific Community		international
84	Addax Petroleum World Environment Day Talk	Hill, M.	Glacial Trends Past, Present and Future Alps and Beyond	June 5, 2013	Geneva, Switzerland	Private Sector	30	EU, Switzerland
85	Conference	Hill, M.	World Water Week, Workshop 7 'Resilience, Uncertainty and Tipping Points', Incorporating Uncertainty to Climate Change into Governance Assessments: Lessons Learnt from 2 case studies in the Alps and Andes	5-10 September 2010	Stockholm, Sweden	Academic	30	Switzerland, Chile
86	Workshop	Hill, M.	EAWAG PhD Seminar on Water Governance in Switzerland, Adaptation and Adaptability.	17 September 2012	Dubendorf, Switzerland.	Academic and Practitioners	40	Switzerland, Chile
87	Conference	Hill, M.	Resilience Conference, Easing the Tension: Easing the tension: mobilising adaptive capacity across different scales and dynamics by looking through a lens of choice creation – lessons learnt from empirical research in Chile, USA and Switzerland.	12-17 March 2011	Tempe, Arizona, USA.	Academic	40	Switzerland, Chile
88	Conference	Hill, M.	Global Change and the World's Mountains, Assessing adaptive governance to manage climatic uncertainty in the context of 2 mountain basins: Case studies from the Aconcagua Basin, Chile & Rhone Basin, Switzerland.	26-30 September 2010	Perth, Scotland.	Academic	20	Switzerland, Chile
89	Conference	Hill, M.	IHDP Open Meeting 2009, Poster presentation in 'Institutionally Challenged' Session.	26-30th April 2009	Bonn, Germany.	Academic	100	Switzerland, Chile
90	Conference	Hill, M.	European Parliament ECRA Science Briefing, Climate Change in the European Mountains.	15 October, 2013	Brussels, Belgium.	Policy Makers	50	EU, Switzerland
91	Conference	Hill, M.	Planet under Pressure: Poster	26-29 March	London, UK	Academic	3000	Switzerland, Chile

			Presentation					
92	5em rencontre géorisques.	Jomelli	Impacts possibles des changements climatiques futurs sur les debris avalanches.	03.02.2009	Montpellier	Scientific		International
93	7th international Conference of Geomorphology	Jomelli	Climatic and geomorphic factors controlling the activity of debris flows: a hierarchical analysis.	6-11 August 2011	Melbourne Australia,	Scientific		International
94	Poster	Lombardi , A.	Possible changes in the frequency of flood occurrences in the Po and Rhone valleys	09-13 Sepetember 2013	Reading (UK)	Scientific Communities	200	International
95	Conference	Maran, S.	A methodology for the assessment of climate change effects on hydropower	June 29th Ð July 2nd, 2011	Catania (IT)	Scientific	50	world
96	Newspaper article	S. Maran	L'effetto serra influisce sull'dro alpino	13 December 2010	Quotidiano Energia (www.quotidianoenergia.it)	Electicity operators		Italy
97	5th international conference on debris flows	Pavlova	Debris flow occurrence and meteorological factors in the French Alp	14-17 /06/2011	Padoua Italia,	Scientific		International
98	Conference: Debris Flows: Disasters, Risk, Forecast, Protection.	Pavlova	Meteorological and geomorphological factors, affecting debris flow activity in the French Alps (regional investigation). Russia,	17-19.04.2012.	Russsia, Moscow,	Scientific		international
99	Journées des jeunes géomorphologues JJG	Pavlova	Comment les laves torrentielles se déclenchent dans les Alpes françaises	26-28.01.2012	Strasbourg	Scientific		National
100	8th IAG International Conference on Geomorphology.	Pavlova	Geomorphological and climate context of debris flow regional occurrence in the Northern French Alps	27- 31.08. 2013	Paris	Scientific		International
101	4th International Conference on Monitoring, Simulation, Prevention and Remediation of Dense and Debris Flow,	Pavlova	Current and future changing of debris flow activity in French Alps.	29-31.05.2012	Dubrovnik/Croatia,	Scientific		International

102	EGU	Pavlova	Debris flows and climate relationships in the north French Alps	5-8 April 2011	Vienna	Scientific		International
103	Conference	Ravazzani G	European Geosciences Union General Assembly 2009	19 – 24 April 2009	Vienna, Austria	Scientific Community		
104	Conference	Ravazzani G.	11th PLINIUS Conference in Mediterranean Storms	7 Sep 2009 - 11 Sep 2009	Barcelona, Spain	Scientific Community		
105	Conference	Ravazzani G.	European Geosciences Union General Assembly 2010	02 – 07 May 2010	Vienna, Austria	Scientific Community		
106	Conference	Ravazzani G.	European Geosciences Union General Assembly 2013	07 – 12 April 2013	Vienna, Austria	Scientific Community		
107	Conference	Ravazzani G.	European Geosciences Union General Assembly 2012	22 – 27 April 2012	Vienna, Austria	Scientific Community		
108	Conference	Rivera, A.	International Glaciological Conference Ice and Climate Change: A view from the South	1-3 February 2010	Valdivia, Chile,	Scientific community	250	Worldwide
109	Presentation	Rivera, A.	AGU Meeting of the Americas	14-17 May 2013	Cancun, México.	Scientific community	Hundreds	Wordlwide
110	Presentations	Rivera, A.	IAVCEI Volcano-Ice Interactions on Earth and Other Planets Conference III	18-22 June 2012	Anchorage, Alaska, USA.	Scientific community	50	Wordlwide
111	Web	Rivera, A.	www.glaciologia.cl	2011-2013	Valdivia, Chile	Civil Society	Thousands	Worldwide
112	Poster	Rivera, A.	WCRP OSC Climate Research in Service to Society	24-28 October 2011	Denver, Colorado, USA.	Scientific community	Hundreds	Wordlwide
113	Posters	Rivera, A.	IGS International Symposium on Glaciers and Ice Sheets in a Warming Climate	24-29 June 2012	Fairbanks, Alaska, USA.	Scientific community	Hundreds	Wordlwide
114	Presentation	Rivera, A.	Status of Chilean glaciers	26 – 30 August 2012	Valdivia, Chile	Scientific community	50	Latin America
115	Conference	Rivera, A.	Reconstructing Climate Variations in South America and the Antarctic Peninsula over the last 2000 years". II International Symposium	27-30 October 2010	Valdivia, Chile,	Scientific community	150	Worldwide
116	Exhibition	Rivera, A.	Los Glaciares de Chile	3-10 February 2013	Valdivia, Chile	Civil Society	Hundreds	Chile
117	Poster	Rivera, A.	EGU General Assembly	3-8 April 2011	Vienna, Austria.	Scientific community	Hundreds	Wordlwide
118	Poster	Rivera, A.	AGU Fall Meeting	9-13 December 2013	San Francisco, California, USA.	Scientific community	Hundreds	Wordlwide
119	Presentation	Rivera, A.	Defense Committee of the Chilean Senate	August 1, 2013	Valdivia, Chile	Policy Makers	7	Chile
120	Presentation	Rivera, A.	Special commission on mining	July 11 2013	Chilean Congress,	Policy Makers	20	Chile

			activities impact on snow and ice		Valparaiso, Chile			
121	Presentation	Rivera, A.	Special commission about a new Chilean Glacier law	June 10 2013	Chilean Congress, Valparaiso, Chile	Policy Makers	15	Chile
122	Research Seminar, Centre for International Environmental Studies.	Schaub, A.	Presented: "Climate change and winter tourism in Valais. Vulnerability, potential impacts and the policy-relevant consequences for adaptation".	Fall 2012	Geneva (CH)	Scientific Community	15	CH
123	Dissemination of ACQWA project details during the meeting with the World Bank Regional Director for Central Asia (Mr. Saroj Kumar Jha)	Shalpykova, G.	Meeting on the Central Asian energy and water issues	25 January 2013	Bishkek, Kyrgyzstan	Donors, scientific and NGOs communities		Kyrgyzstan, Tajikistan and Uzbekistan
124	Meeting of the "Begleitende Expertengruppe" (BEG) sub-group for Agroscope's Research Department „Environmental resources and agriculture" (oral presentation)	Smith, P.	A simple approach for estimating irrigation demand in the heterogeneous Rhone basin:effect of climate, soil & crop type	26 October 2011	Zürich, Switzerland	Expert Panel	20	Switzerland
125	8th international NCCR Climate Summer school (poster)	Smith, P.	Modelling future irrigation demand from agricultural land of alpine catchments in response to climate change	31 August 2009	Grindelwald, Switzerland	PhD/Postdocs	70	International
126	Conference (oral presentation)	Smith, P.	International Congress on Environmental Modelling and Software, Modelling for Environment's Sake, Fifth Biennial Meeting (iEMSs), Session 19. Modelling climate change impacts: water resources and agriculture	6 July 2010	Ottawa, Canada	Scientific community		International
127	Conference (presentation)	Sorg, A.	Swiss Geoscience Meeting	16 – 17 November 2012	Berne	Scientific Community	~50	Kyrgyzstan

128	Workshop	Sorg, A.	lecture on CERAH DAS/MAS course “Environment and Humanitarian Crises”	17 October 2012	Geneva	Other (students)	~30	Kyrgyzstan
129	Exhibition	Sorg, A.	Glacier music (Goethe Institute)	18 May - 16 June 2013	Bishkek, Dushanbe, Almaty, Tashkent	Civil Society, Medias	~100	Kyrgyzstan
130	Press release	Sorg, A.	Researchers analyze melting glaciers and water resources in Central Asia	27 July 2012	Geneva	Civil Society, Medias		Kyrgyzstan
131	Conference (poster)	Sorg, A.	American Geoscience Union	3 – 7 December 2012	San Francisco	Scientific Community	~100	Kyrgyzstan
132	Conference (presentation)	Sorg, A.	European Geoscience Union	7 – 12 April 2013	Vienna	Scientific Community	~100	Kyrgyzstan
133	Thesis	Sorg, A.	Impacts of climate change on glaciers, rock glaciers and water availability in the Tien Shan mountains, Central Asia (PhD thesis)	January 2014	Geneva	Scientific Community		Kyrgyzstan
134	Articles in popular press	Sorg, A.	Various articles following the press release from 27 July 2012 (NZZ, Tages Anzeiger, Le Temps, Der Standard, Blogs)	July / August 2012	-	Civil Society, Medias		Kyrgyzstan
135	Conference	UniGRAZ	European Conference on Nanotechnologies	26 February 2010				
136	Summer School	Verdecchia, M.	International Summer School on Atmospheric and Oceanic Sciences on “Climatoc Change andImpacts on Natural and Protected Areas	From 30 August to 30 September 2010	L'Aquila - Italy	Scientific Communities, Policy Makers, Medias	50	Europe
137	EGU Conference : Poster presentation	Vincent C.	Englacial temperatures increasing and impact on the stability of an hanging glacier in Mont Blanc area	May 2010	Vienna (Autria)	Scientific Community		international
138	Conference	Wilhelm, C.	Modeling land cover changes with the regional model REMO-iMOVE for Europe	4.4.2011	EGU 2011, Vienna	Scientific Community	100+	EU
139	Conference	Wilhelm, C.	Modeling the CO2 physiological forcing at regional scale	17.-21.9.2012	3ICESM, Hamburg	Scientific Community	200+	EU

Section B (Confidential[4] or public: confidential information to be marked clearly)
Part B1

The applications for patents, trademarks, registered designs, etc. shall be listed according to the template B1 provided hereafter.

The list should, specify at least one unique identifier e.g. European Patent application reference. For patent applications, only if applicable, contributions to standards should be specified. This table is cumulative, which means that it should always show all applications from the beginning until after the end of the project.

TEMPLATE B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.					
Type of IP Rights[5]:	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant (s) (as on the application)

[4] Note to be confused with the "EU CONFIDENTIAL" classification for some security research projects.

[5] A drop down list allows choosing the type of IP rights: Patents, Trademarks, Registered designs, Utility models, Others.

Part B2

Please complete the table hereafter:

Type of Exploitable Foreground[6]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[7]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
	Ex: New superconductive Nb-Ti alloy			*MRI equipment*	*1. Medical 2. Industrial inspection*	*2008 2010*	*A materials patent is planned for 2006*	*Beneficiary X (owner) Beneficiary Y, Beneficiary Z, Poss. licensing to equipment manuf. ABC*

In addition to the table, please provide a text to explain the exploitable foreground, in particular:

- Its purpose
- How the foreground might be exploited, when and by whom
- IPR exploitable measures taken or intended
- Further research necessary, if any
- Potential/expected impact (quantify where possible)

[19] A drop down list allows choosing the type of foreground: General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of R&D results via standards, exploitation of results through EU policies, exploitation of results through (social) innovation.

[7] A drop down list allows choosing the type sector (NACE nomenclature) : http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

1.4 Report on societal implications

Replies to the following questions will assist the Commission to obtain statistics and indicators on societal and socio-economic issues addressed by projects. The questions are arranged in a number of key themes. As well as producing certain statistics, the replies will also help identify those projects that have shown a real engagement with wider societal issues, and thereby identify interesting approaches to these issues and best practices. The replies for individual projects will not be made public.

A General Information *(completed automatically when **Grant Agreement number** is entered.*	
Grant Agreement Number:	212250
Title of Project:	Aseesing Climate Change Impacts on the Quantity and Quality of
Name and Title of Coordinator:	Prof. Martin Beniston

B Ethics	
1. Did your project undergo an Ethics Review (and/or Screening)? • If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	***No***
2. Please indicate whether your project involved any of the following issues (tick box) :	***YES***
RESEARCH ON HUMANS	
• Did the project involve children?	
• Did the project involve patients?	
• Did the project involve persons not able to give consent?	
• Did the project involve adult healthy volunteers?	
• Did the project involve Human genetic material?	
• Did the project involve Human biological samples?	
• Did the project involve Human data collection?	
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	
• Did the project involve Human Foetal Tissue / Cells?	
• Did the project involve Human Embryonic Stem Cells (hESCs)?	
• Did the project on human Embryonic Stem Cells involve cells in culture?	
• Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	
• Did the project involve tracking the location or observation of people?	
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	
• Were those animals transgenic small laboratory animals?	
• Were those animals transgenic farm animals?	
• Were those animals cloned farm animals?	
• Were those animals non-human primates?	

RESEARCH INVOLVING DEVELOPING COUNTRIES	
• Did the project involve the use of local resources (genetic, animal, plant etc)?	
• Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	
DUAL USE	
• Research having direct military use	No
• Research having the potential for terrorist abuse	

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator	3	2
Work package leaders	0	6
Experienced researchers (i.e. PhD holders)	13	41
PhD Students	18	31
Other	0	0

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	**59**
Of which, indicate the number of men:	67%

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project?	x ○	Yes No

6. Which of the following actions did you carry out and how effective were they?

		Not at all effective				Very effective
❑	Design and implement an equal opportunity policy	○	○	○	○	○
x	Set targets to achieve a gender balance in the workforce	○	○	○	x	○
❑	Organise conferences and workshops on gender	○	○	○	○	○
❑	Actions to improve work-life balance	○	○	○	○	○
○	Other:					

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

○ Yes- please specify

x No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

○ Yes- please specify

x No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

○ Yes- please specify

x No

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

○ Main discipline[8]: 1.4

○ Associated discipline[8]: 1.5 | ○ Associated discipline[8]: 4.1

G Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)*	x ○	Yes No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

x No

○ Yes- in determining what research should be performed

○ Yes - in implementing the research

○ Yes, in communicating /disseminating / using the results of the project

11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?	○ x	Yes No

12. Did you engage with government / public bodies or policy makers (including international organisations)

○ No

[8] Insert number from list below (Frascati Manual).

x Yes- in framing the research agenda

○ Yes - in implementing the research agenda

x Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

x Yes – as a **primary** objective (please indicate areas below- multiple answers possible)

○ Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)

○ No

13b If Yes, in which fields?

Agriculture		Energy Environment		. Research and Innovation .	

13c If Yes, at which level?

- x Local / regional levels
- x National level
- x European level
- x International level

H Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	**283**
To how many of these is open access[9] provided?	**16%**
How many of these are published in open access journals?	**75%**
How many of these are published in open repositories?	**25%**
To how many of these is open access not provided?	
Please check all applicable reasons for not providing open access:	
x publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ❑ no suitable open access journal available ❑ no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other[10]: ……………	

15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*	**0**

16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	**0**
	Registered design	**0**
	Other	**0**

17. How many spin-off companies were created / are planned as a direct result of the project?	**2**
Indicate the approximate number of additional jobs in these companies:	**10**

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

❑ Increase in employment, or	❑ In small & medium-sized enterprises
❑ Safeguard employment, or	❑ In large companies
❑ Decrease in employment,	❑ None of the above / not relevant to the project
x Difficult to estimate / not possible to quantify	

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:*
Difficult to estimate / not possible to quantify	x

[9] Open Access is defined as free of charge access for anyone via Internet.

[10] For instance: classification for security project.

I	Media and Communication to the general public		
20.	**As part of the project, were any of the beneficiaries professionals in communication or media relations?**		
	○ Yes	x No	
21.	**As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?**		
	○ Yes	x No	
22	**Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?**		
x	Press Release	x	Coverage in specialist press
x	Media briefing	x	Coverage in general (non-specialist) press
x	TV coverage / report	x	Coverage in national press
x	Radio coverage / report	x	Coverage in international press
x	Brochures /posters / flyers	❑	Website for the general public / internet
❑	DVD /Film /Multimedia	x	Event targeting general public (festival, conference, exhibition, science café)
23	**In which languages are the information products for the general public produced?**		
x	Language of the coordinator	❑	English
x	Other language(s)		

***Question F-10*:** Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES
1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]
1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)
1.3 Chemical sciences (chemistry, other allied subjects)
1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)
1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY
2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)
2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]
2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES
3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)

3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)
3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES
4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)
4.2 Veterinary medicine

5. SOCIAL SCIENCES
5.1 Psychology
5.2 Economics
5.3 Educational sciences (education and training and other allied subjects)
5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES
6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)
6.2 Languages and literature (ancient and modern)
6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]