CIRCLE-2
Climate Change and Mountain Areas
Climate Change Impacts and Response Options in Mountainous Areas

An overview of the CIRCLE-Mountain Research Projects (2010-2013)
Mountains are an important part of the global system. Because of their vertical extent, climate varies with elevation and thus differs from those in adjacent lowland areas. Their verticality also generates habitat and species diversity over short horizontal distances.

Undoubtedly, global change and climate change in particular may change the capacity of mountain landscapes to generate wealth and to provide livelihood for resident populations and for distant but nonetheless dependent populations. Such impacts will add further environmental pressures on both social and natural systems in these regions, stressing the need to promptly conduct proactive climate adaptation plans.

Due to its transnational relevance, climate change response policies in mountainous areas must emphasise multilateral research efforts that are able to include the biophysical, social, cultural and economic aspects of these regions. Research on climate adaptation in these areas, including its socio-economic aspects, are thus of prime interest for several European countries with relevant mountainous systems.

Mountains cover 36% of Europe’s area and are home to 17% of the continent’s population. Both mountain populations and the far greater numbers of people that are living outside of mountain areas, need to be considered, when projecting future climate conditions and evaluating climate change impacts, vulnerability and adaptation. Europe’s population is dependent on mountain resources like “water towers” and ecosystem services and thus are affected by changes deriving from climate change in mountain (e.g. river discharges, mountains as tourism destinations).

According to the recent IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX, 2012) “there is high confidence that changes in heat waves, glacial retreat, and/or permafrost degradation will affect high mountain phenomena such as slope instabilities, movements of mass, and glacial lake outburst floods. There is also high confidence that changes in heavy precipitation will affect landslides in some regions.” “There is low confidence regarding future locations and timing of large rock avalanches, as these depend on local geological conditions and other non-climatic factors.”

Also “There is very high confidence that, during the last decade, most ice was lost from glaciers in Alaska, the Canadian Arctic, the periphery of the Greenland ice sheet, the Southern Andes and the Asian mountains. Together these areas account for more than 80% of the total ice loss (IPCC AR5, 2013).”

The objective is to develop and strengthen the coordination of national and regional research programmes and help reduce fragmentation across the European Research Area (ERA). Under the ERA-NET scheme, programme ‘owners’ (typically ministries or regional authorities) and ‘managers’ (typically research councils or other research agencies) can identify research programmes they wish to coordinate or open up and develop joint activities including the support of joint calls for transnational projects. Having evolved from a focus on climate impacts to climate adaptation, CIRCLE-2 comprises 34 institutions from 23 countries (http://www.circle-era.eu/np4/home.html) that work together to:

- support a common research agenda and joint programming, for example on foresight activities helping to structure a common language and framework for policy relevant adaptation research;
- fund adaptation research though transnational joint calls and other joint activities contributing to a durable cooperation between European climate research programmes and their funders;
- make available existing knowledge on adaptation and foster the production of research along identified needs contributing to the development of a European knowledge base on climate change.
Created in 2002 by the European Commission (EC), the ERA-Net (European Research Area Networks) mechanism has played a major role in connecting European research centres: this allows for funders of research projects at the national level to coordinate research on the European scale and to generate common calls for projects. The ERA-Net CIRCLE (Climate Impact Research and response Coordination for a Larger Europe) is a European network dedicated to coordinating research on adaptation to climate change (for more detail, see page 3). It operates based on geo-thematic sub-networks — the Mediterranean region, the Nordic region, and mountainous region — for which knowledge of the various impacts resulting from climate change and the possible adaptation solutions requires an integrated and shared approach.

Four calls for research projects have been launched within the CIRCLE framework, corresponding to the three geo-thematic groups:

- “Water resource management in Mediterranean coastal areas”, 2007
- “The Consequences of climate change for policy development in the Nordic countries”, 2007
- “Adaptation in Mountainous regions”, 2009
- “Adaptation to Climate Change from a natural and social science perspective: Water in coastal Mediterranean areas”, 2013

CIRCLE-2 MOUNTain projects
In 2009, CIRCLE-2 MOUNTain partners launched the third CIRCLE joint call dedicated to “Climate change impacts (natural and anthropogenic factors) and response options in mountainous areas”.

CIRCLE-2 MOUNTain supported the assessment of needs related to climate change and adaptation in countries with strong ties to mountain systems, promoting research cooperation in scientific and policy areas in and around Europe. CIRCLE-2 MOUNTain was supported by research funding organisations from Austria, France, Sweden and Spain.

As visualised on the map (Figure 2), the following four projects successfully fulfilled their aims:

- Two projects worked on landslide risks, namely ARNICA and ChangingRISKS
- One focused on mountain ecosystems, namely CAMELEON
- One project focused on glacier hazards, namely EURAS-CLIMPACT

Figure 1: CIRCLE-2 network of 34 partner institutions from 23 different countries

Figure 2: CIRCLE-2 MOUNTain projects and test sites (source: Markus Leitner, EAA)
The general objective was to determine the potential impacts of future climate change on debris flows/landslides (DF) activity in the Alps. Moreover linear infrastructures are particularly vulnerable to such natural hazard. They are an essential component of the economic activity of these mountainous areas and transborder exchanges, which gives a highly strategic character to them. The vulnerability of the networks was also addressed in the project.

As input for the analysis of future natural hazards activity, localized climate scenarios in the study regions for parameters triggering DF were required. The analysis conducted by Graz University (Austria) focused on heavy precipitation events exceeding a certain threshold per day (e.g., 10 mm/day). In addition, for precipitation events of different duration (one to three days) the role of temperature has been investigated in order to separate rain from snowfall. 24 regional climate simulations (RCSs) for the 21st century served as basis for the analysis. All simulations are based on the A1B emission scenario. An empirical-statistical downscaling and error-correction method (quantile mapping) has been applied on a daily scale to improve the skill of the RC Models in representing local climate at station scale. As one result it could be demonstrated that quantile mapping is able to significantly improve the quality of the simulation of extreme precipitation. After error correction, the entire ensemble of 24 simulations was used to estimate the bandwidth of possible future climate. Statistics of the climate change signals are assessed to time horizon of close future (2050) and far future (2100). Results show in the different regions that potentially triggering precipitation events are expected to become more frequent in most seasons, except in July and August. However, also in the summer months the frequency of very intense precipitation events (above 30 mm/day) should increase at some stations. In addition summer temperature should increase as well.

LGP aimed to document the impacts of current and future climate change on DF occurrence in the French Alps and to document the vulnerability of national network related to such process. To this end, LGP used a DF database constituted by local stakeholders from historical archives composed of 565 debris flow events Flow events since the spring of 1970, in the north and south of the French Alps.

Climatic causes of debris flow events inter-annual variability were explored. Results revealed distinct climatic variables responsible for changes in the number of debris flows per year in the two regions. The influence of temperature and extreme precipitation changes from the north to the...
south of the French Alps. An innovative model was also developed to estimate the most influential among geomorphic or climatic variables in debris flow activity. This model showed that debris flow occurrence probability in the French Alps depends mainly on climatic variables compared with geomorphic characteristics as lithology land cover or land use for instance. Regardless of the RCS used, in the two regions a significant increase in the annual probability of debris flows was predicted in both the near and far future.

The reference case study is represented by a set of study basins (2-10 km² wide) in Southern Tyrol, located in the Eastern Italian Alps. The analysis was based on a coupled hydrological-stability model to study the control on shallow landslides in different precipitation regimes. RCSs were used as a reference. Results show a step increase in susceptibility to shallow landslides in the fall season but a decrease in summer season. This is mainly due to the increase of the percentage of liquid precipitation for the storms and a moisture decrease respectively.

As a result, the changing DF regime may have a seasonally differentiated impact on the transport network failure probability, which results in different system vulnerability, given the different kind and volume of traffic. It was shown that the moisture profile at the regional level at the end of the summer months has a critical effect on road and railway network failure, both in terms of expected failure timing and probability of failure. Further, it is seen that, with changing climate, the system reliability is likely to decrease during the fall season due to the increased probability of liquid storms at high altitude in basins directly connected with the study transportation network. On the contrary, the reliability during the summer months is increased, due to the decreased probability of landslide triggering storms. These results were discussed and analysed together with the stakeholders and local government representatives, considering the potential impact in terms of risk assessment and risk communication. The role of different methodologies to mitigate the failure risk was considered, including structural and non-structural approaches. The project conducted in different alpine regions revealed that risk perception induced by debris flows differs from other natural hazards such as floods. Except for a few sites regularly affected, it is not perceived as having strong impacts unlike floods probably because these impacts have a reduced spatial extent. However a lot of roads are impacted by this process with sometimes very important economic consequences and our study demonstrated that the Alpine road network is vulnerable. In the three countries analyses were conducted with stakeholders to reduce risk for specific catchment areas. However, at local scale it is still very difficult to estimate a debris flow occurrence probability because of lack of precipitation measurements at hourly time scale, and lack of observation of debris flow volume to determine an accurate frequency-magnitude relationship.

Results on debris flow occurrence, frequency and reach of events have been used by stakeholders and decision makers for operational purposes. In particular, and in view of the imminent risks of debris flows in several of the torrents in the Zermatt valley, Dendrolab.ch has participated in discussions with local communities, state agencies and the Swiss Federal Office for the Environment to perform cost-benefit analyses for the protection of the villages and the transportation network. The results of Arnica will indeed have consequences on future land-use planning and the operation of railway and road operations, and were used to develop and position structural and non-structural decisions with the best balance between prevention and rehabilitation.
Variables responsible for debris flow and shallow landslides triggering differ according to the spatial and temporal scale considered. At a daily time scale the triggering depends mainly on extreme rainy events which threshold changes from place to place and from the date of the last debris flow event. Years with numerous debris flows depend also on temperatures. Regardless of the climate model used, a significant increase in the probability of debris flows occurrence or run out is predicted in both the near future and in the distant future for the different regions. This is because potentially triggering conditions are expected to become more frequent. Possible seasonal shifts of high debris flow activity may also be expected.

Publications


Landslides across the Alpine countries are recognized by practitioners, politicians and scientists as having a major socio-economic impact, and may represent a significant risk for the population and the properties in particular locations. Even if many scientific advances have been made in numerous fields of landslide research in the last 10 years, there is no consensus reached on an integrated concept and methodology for landslide risk assessment adaptable to a large range of climatic, environmental and socio-economic conditions, applicable to perform scenario analysis taking into account global changes (climate, land use, socio-economic development), and directly connected to the practical demands of the stakeholders.

ChangingRISKS intended to develop an advanced understanding of how global changes (related to both environmental and climate change as well as socio-economic developments) would affect the temporal and spatial patterns of landslide hazards and associated risks in two territories of the Alps, and how these changes can be assessed, modelled and communicated (through mapping procedures) to stakeholders. The project work is focused on two mountain study areas located in France (Barcelonnette Basin, South East France) and in Austria (Waidhofen/Ybbs, Lower Austria). From a scientific viewpoint the main outcome was the development of a generic methodology for quantitative landslide hazard, vulnerability and risk assessment taking into account changing patterns in the conditioning factors. From a technical viewpoint, the main outcome consisted in the setting up of reliable solutions for mapping landslide susceptibility, hazard, vulnerability and risk in a quantitative framework, through the development and implementation of a GIS-based experimentation and demonstration platform.

The Barcelonnette basin (France) consists of a 350 km² area, situated in the south-eastern part of France in the département Alpes-de-Haute-Provence around the municipality of Barcelonnette. It is located in a mountainous area, altitudes range from 1100m to 3100m a.s.l, and the lithology consist mainly in black marls, sedimentary sheet thrusts and moraine deposits. The Basin is located in the dry intra-Alpine zone, characterized by a mountain climate with a marked interannual rainfall variability (735 ± 400 mm over the period 1928-2010) and 130 days of freezing per year, a continental influence with significant daily thermal amplitudes (≥ 20°) and a Mediterranean influence with summer rainstorms yielding more than 50 mm.h⁻¹ on occasion.

The actual land cover/use is the result of the presence of severe hydro-geomorphological processes in connection with important changes in human activities in the last centuries with high deforestation rate and the introduction of agricultural practices till the 18th century. In the 19th...
century, reforestation and dam building for torrent correction marked the landscape as a result of landslide activities and torrential events largely threatening the human activities. After the 2nd World War, urbanization and progressive agricultural abandonment are the main drivers of changes in the land cover and land use. As a consequence, the recent development of urbanization and tourism activities has led to an intense use of previously unoccupied and most of the time landslide susceptible slopes. The landslide hazard is high in this area, the slopes being notably affected by severe gullying and both shallow and deep-seated large landslides.

The municipality and district Waidhofen/Ybbs is located in the south western part of Lower Austria. The area comprises around 130 km² and stretches from 356m to 1115m a.s.l. Waidhofen/Ybbs has a population of 11,500 inhabitants. The yearly precipitation ranges from 800mm in the northern part to around 2000mm in the southern part of the district. The land cover in Waidhofen/Ybbs contains mainly forest and agricultural areas. In the southern part forest is prevalent whereas in the northern part there is extensive grassland and acreage. The district capital can be regarded as a regional centre, according to the spatial planning regulations in Austria. The city itself is located in the central part where the Ybbs formed a flood plain, which enabled the small city to develop. The lithology is composed of Limestone, Flysch, the Klippenzone and Dolomite. The history of natural hazards dates back to 1312 with floods from the Ybbs River, which occurred repeatedly over the past centuries. However the first rock fall was reported as early as 1589. Additionally debris flows blocking roads or rail tracks were also reported regularly. Landslides were only reported more recently in the archives. From the 1950s onwards, the building ground register was started, where all events related to earth science were collected and catalogued. However, this register only includes events that were reported due to caused damages.

From this time onwards landslides were reported on a regular basis, however, still always related to landslide damages.

Influences of climate change and land-use/cover changes on landslide activity have been analysed by different methods (statistical, empirical and physically-based methods) on the two test sites: the Barcelonnette basin and the Waidhofen/Ybbs valley. The changes in land use/cover have an influence on landslide activity, as can be depicted in the susceptibility analysis carried out in Waidhofen/Ybbs.

Concerning the changes induced by climate, even if the sites present different contexts in view of landslide causes (climate, landslide sizes), the analyses show that climate change is likely to induce similar trends in landslide activity. Based on the IPCC A1B scenario and on the resulting climate change scenario at local scale, the different models predict a very probable increase in landslide activity. This change would materialize either as an increase in the frequencies of landslides or as an increase in surface of the potentially unstable areas. However, these models require precise data, and so climate models should be adapted to such resolutions, like in this study. The results differ from the predictions provided by larger scale models. These differences might be explained by the finer calibration processes used for local scale analysis and also to the finer climate model used, which, for example, take into account the influence of topography on climate (mostly on precipitation). In order to improve the analyses performed in this study, several points would be interesting to consider in further studies:

• Use of different assessment methods at the different sites in order to improve the robustness of the analyses;

• Integration of other IPCC scenarios in order to have a wider variety of potential future climate;
• Consideration of the future evolution of the DEM and the lithology due to landslides or to human interventions.

The comparisons of risk exposure among the two study sites (for the actual and future situation) have been carried out for assessing landslide risk evolution with climate change scenarios through the construction of Potential Damage Index maps. The application of the method depends on data availability taking into account that if climate change scenarios and land cover evolution scenarios can be developed quite accurately, the scenarios of population and human activity evolution are rougher at such scales.

Even though, the two studies of landslide risk assessment on the French and Austrian sites seem to tend to a similar trend: an increase of landslide risk. This increase in risk is more or less important depending on the considered sites and parameters. Due to a high level of uncertainties on population and traffic evolution scenarios, precautions need to be taken with the figures. Regarding the influence of hydrology and land use changes on the factor of safety, a methodology has been developed to obtain simplified and rapid estimations of possible unstable slopes. Further development would be the production of abacus for a wide range of land use (and associated vegetation) and then the analysis of the impact of climate change through the vegetation change.

In parallel, vulnerability analysis (physical and social vulnerability) of possible buildings impacted by landslide displacements has been developed. Stakeholders were directly involved in the research to define, for each site, several land use change scenarios for the near future (2030) based on different hypotheses about climate change and the socio-economic development of each region, as example here, the Vercors Plateau (France) and the Eastern Alps (Stubai valley, Austria), representing contrasting historical and climatic contexts.

Firstly, the project has allowed us to synthetize an unprecedented dataset of climate and ecological data for the three targeted regions. High resolution maps of historical land cover changes since 1950 were created using a reference dataset of climate and ecological data for the three targeted regions.

The combination of climate and land use changes has triggered important land cover mutations in European mountains over the last 50 years. These landscape modifications may accelerate in the 21st century with the expected climate change. The linkages between vegetation dynamics and primary productivity of mountain ecosystems and their ability to mitigate carbon emissions are still poorly understood. CAMELEON aimed to improve our knowledge of the carbon cycling of mountain ecosystems, with the objectives:

• to understand how land use changes translate into changes in plant functional diversity
• to model the carbon cycling in mountain ecosystems at the landscape scale using detailed accounts on climate forcing and plant functional diversity and
• to forecast the potential changes in the carbon stocks and fluxes in mountain ecosystems.

Our project targets three long-term mountain research areas located in the Eastern Pyrenees (Alinya valley, Spain), the South-Western Alps (Vercors plateau, France) and the Eastern Alps (Stubai valley, Austria), representing contrasting historical and climatic contexts.

The project included the creation of a comprehensive collection of environmental datasets and a long-term monitoring platform to track and model the impacts of landscape modifications on plant functional diversity and carbon cycling in mountain ecosystems. The project also aimed to improve our understanding of the linkages between vegetation dynamics and primary productivity of mountain ecosystems and their ability to mitigate carbon emissions.

Our project targets three long-term mountain research areas located in the Eastern Pyrenees (Alinya valley, Spain), the South-Western Alps (Vercors plateau, France) and the Eastern Alps (Stubai valley, Austria), representing contrasting historical and climatic contexts.
The ORCHIDEE model has been previously calibrated for the three sites using remote sensing data and in situ flux measurements. The three sites exhibit contrasted responses. For Stubai, we found a relatively large increasing trend in productivity both for the historical period and for the future. This induces an increase of carbon storage, even if the increase of productivity is partly cancelled by the increase of soil respiration. The opposite trend was found for Alinya, after a productivity increase during the historical period, there is an expected progressive decrease due to increasing summer droughts under climate change scenarios. This led to a carbon loss after 2050. The French Alps showed an intermediate response with increasing trend in productivity both for the historical period and for the future. This induces an increase of carbon storage, even if the increase of productivity is partly cancelled by the increase of soil respiration.

As an example, Figures 14 and 15 show the impact of climate, CO2 and land use changes on future carbon fluxes (Gross Primary Productivity, Total Ecosystem Respiration, Net Ecosystem Exchange). For Stubai, the first driver of productivity increase is temperature, followed by the CO2 fertilization effect. For Alinya, on the contrary, climate has a negative effect for Alinya mainly driven by the decrease of precipitation. This negative effect is partly compensated by the positive effect of CO2. For Stubai, the increase of productivity should allow the increase of the animal production for more than 30%.

A second set of simulation was conducted to see how the grassland system can adapt to the projected change in grassland productivity in particular in term of sustainable animal number that can be produced for each region. Climate effect on carbon cycling should be counterbalanced by projected land use changes that mainly consist in a decrease of intensively managed (cut) grassland surfaces and an extension of forested areas. For Alinya, the projected increase of droughts in the future should decrease the potential of animal production. Nonetheless, the land use trend since historical times in Alinya suggests strong pasture abandonment and thus increased forested area. For Vercors, the trend is more complex as animals are only in the mountains during summer whereas they stay in the La Crau plain (South of France) during winter. As for Alinya, La Crau should experience an increase of droughts.

This will limit the possible increase of animal productivity, even if grassland productivity should increase in Vercors. This situation could be compensated by the increase of the grazing season length in Vercors. Hence current animal pressure could be maintained for the future in this area.

The CAMELEON project was the first attempt to provide reliable and comparative regional-scale simulations of carbon dynamics in European mountain ecosystems that incorporate our best ecological knowledge of these biodiversity hot-spots. The project is a milestone towards a better understanding of climate and land use change impacts on carbon cycle in European mountains.
The objectives of the project were:

- to set-up an empiric downscaling-method for regionalization of reanalysis data (NCEP) and GCM model data in Europe;
- a simulation of glacier fluctuation for the time period 1948-2010 for quantification of glacier variations in Central Asia,
- to calculate changes of future glacier melt and runoff during the 21st century,
- a geohazard assessment and proposal of mitigation strategies to reduce the climate induced georisks, and
- a close cooperation with stakeholders.

After a test phase of climate modelling based on reanalysis data and statistical downscaling in the Austrian Alps this model was transferred to high-mountain climatological stations in Central Asia for which mostly only limited time series of precipitation and air temperature were available. Local climate data from these stations was calculated using global reanalysis data of NCEP (1948-2012) and global model data of ECHAM5 (2001-2050). The then calculated climate data at local scale were used to drive GERM, the glacio-hydrological glacier evolution runoff model. GERM was calibrated with known mass balance data, and validated with local runoff data. Future glacier development was simulated for IPCC scenarios A1B, A2 and B1 until 2050.

Consequently since the end of the 1980s the glaciers of all underlying investigation areas in the European Alps and in Central Asia retreated rapidly, a process, which basically accelerated since LIA during the last 150 years.

Climate warming increases glacier melt and reduces permafrost areas, which result in significant environmental changes such as instable slopes or the formation of glacier lakes, which can cause glacier lake outburst floods (GLOF), in total increasing the geohazard potential in the near future. In 1996 the remote Northern Inylchek Glacier in eastern Kirgizstan rapidly advanced by three kilometres within two months only initiating a second GLOF this year. Time series analysis of remote sensing data of glaciers in the Central Tien Shan revealed that compared to the climate change induced glacier retreat simultaneously sudden glacier advances occur, so called glacier surges, the cause of which is poorly understood, and which make up an underestimated geo-risk.

It is well known that Central Asia is heavily influenced by earthquakes and many slope structures in the glaciated eastern central Tien Shan were described as of neotectonic origin. The structural geologic, and geomorphologic studies in the surroundings of the Global Change Observatory “Gottfried Merzbacher” led to the conclusion, however, that multiple slope terraces along the Inylchek Valley were of sedimentary origin, not caused by earthquakes, and therefore this geohazard potential was assessed by far too high in this region.

Before, during and after EURAS-CLIMPACT, contact with Kyrgyz stakeholders such as the Kyrgyz Ministry of Emergency Situations (MES), focused on information exchange. 
on glacier retreat, the potential increase of climate induced and non-climate induced geo-hazards, the implementation of data driven early warning systems, on follow up studies for concrete planning of mitigation measures, and on their socioeconomic implications.

The helicopter excursion and field work during our 2012 Bishkek Workshop caused many discussions between stakeholders from the Austrian project group and Kyrgyz ministries, National Academy of Sciences, universities, and governmental representatives as well as local people suffering from the regular floods. The following impressions give an idea of the work on site in Kirgizstan.

Numerous discussions with international colleagues at the Central Asian Institute of Applied Geosciences (CAIAG), the National Kyrgyz Academy of Sciences, institutes of numerous universities, and several UNDP offices on Disaster Risk Reduction in Slovakia, Kazakhstan and Kyrgyzstan finally led to research cooperation between the European Commission and Central Asia. GÉANT and CAREN (Central Asian Research and Education Network), respectively, which are operated by DANTE (Delivering of Advanced Network Technology to Europe) recently announced the Vienna University project EURASCLIMPACT as a case study of pan-European Internet-network research.

Publications


Figure 21 (following pages): EURAS-CLIMPACT field work and stakeholder involvement in the Tien Shan mountains in the Kyrgyz Republic (source: Hermann Häusler, University Vienna)

The Adygine Glacier with its Proglacial lakes (source: Stefan Reisenhofer, ZAMG)
EURAS-CLIMPACT field work and stakeholder involvement in the Tian Shan mountains in the Kyrgyz Republic (source: Hermann Häusler, University Vienna)
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