Climate Research and Adaptation Strategies – Examples from the European Alps

Gernot R. Koboltschnig

1 Introduction

There is no doubt, the world's climate is changing. But, as soon as we are interested in the impacts at a special location and a certain time in future uncertainties grow tremendously. Concerning meteorological parameters affected by climate change IPCC already uses verbal phrases to describe uncertainties (IPCC 2007). The highest degree of certainty ("virtually certain"), and therefore the most reliable proof of climate change can be found for the temperature increase. The uncertainty for other climate components is much higher. Simple physically based assumptions seem to be able to describe further effects (e.g. warmer temperature – increased water vapour – increased precipitation – more floods). But the climate system is more complex. Concerning the impact on increasing Alpine natural hazards such as flood or debris-flow magnitudes and frequencies there is no clear and direct relation at the first glance. For the Danube River in Austria it was found out that there is an upward trend for floods. But, a deeper insight shows that "small floods" are responsible for this trend. It is more likely that – beside other reasons – river regulation measures for flood protection and hydropower use lead to a channelization of the river and a reduction of retention areas, which result in a reduced flow time (Blöschl and Merz 2008).

Nevertheless, it is more complicated to respond to the question, whether or not there is an increase of natural hazards on the regional level because commonly floods and debris flows in torrential catchments are triggered by convective rainfall events with high intensities while floods in rivers are triggered by larger scale precipitation. When comparing long-term trends of annual, seasonal or monthly

G.R. Koboltschnig (✉)
International Research Society INTERPRAEVENT, c/o Department for Water Management, Provincial Government of Carinthia, Flatschacher Strasse 70, 9020 Klagenfurt, Austria
e-mail: gernot.koboltschnig@ktn.gv.at

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precipitation data a correlation (at least for Austria) with short-term effects, such as heavy rainfall events or drought periods, can be seen (Böhm 2009). This correlation is not entirely clear in the moment but is the only possibility to use long term and reliable time series to get evidence for extreme events.

This chapter gives an overview of possible climate change impacts on natural hazard based on actual studies by Böhm (2009) with a focus on available long term observations, Blöschl and Merz (2008) and Blöschl et al. (2008) focusing on new ways for the estimation of design values for flood protection measures.

2 Climatic Aspects

When talking about climate change we normally think about the long term temperature increase, which globally was nearly 1°C within the past 100 years. Due to several circumstances we can assume that the global warming is not only a natural effect. Primarily emissions of CO_2, CH_4 and N_2O are responsible for the greenhouse effect (IPCC 2007). There are regional deviations from this global +1°C trend. Especially in the greater Alpine region the warming is about double (Auer et al. 2007). The most significant fact is that warmer air has the ability to absorb more water vapour than colder air (at sea level 5 g/m³ at 0°C, 10 g/m³ at 10°C and 30 g/m³ at 30°C). Therefore more precipitation can be expected. But at this point an important uncertainty has to be taken into account: Where will this additional water be transported to and where will it go down as precipitation?

Due to long term meteorological observations in the Alps we already know about huge regional differences of precipitation. A long-term, homogenized database of observed historical meteorological data can help to understand possible future changes. Within the HISTALP project (Auer et al. 2007), which was supported and elaborated by 13 states in and around the Alps, time series of the main meteorological variables (monthly data of temperature, pressure, precipitation, sunshine and cloudiness) were homogenized and analysed. Monthly precipitation time series go back to 1800. Due to this long term observations and the regional differences which came out it was possible to subdivide the greater Alpine region into four major sub-regions (see Fig. 1). Austria is part of all of the four sub-regions.

Relative changes of monthly precipitation for the four sub-regions can be seen in Fig. 2. For the long term trend detection the fat lines are of special interest. From 1860 to 1980 there was a reverse development of precipitation trends in the Alps. There was an increase in NW but a decrease in SE. All in all a decrease in precipitation can be seen in the two southern sub-regions. But, the bandwidth of extreme up- and downward amplitudes did not change so far in these 200 years of instrumental observations.

Studying the impact of a possible changing precipitation on the extremes of precipitation is of highest interest. A possibility to show that is to analyse the variability of precipitation. Table 1 displays the relative change of the variability of air temperature and precipitation. The two southern sub-regions have been

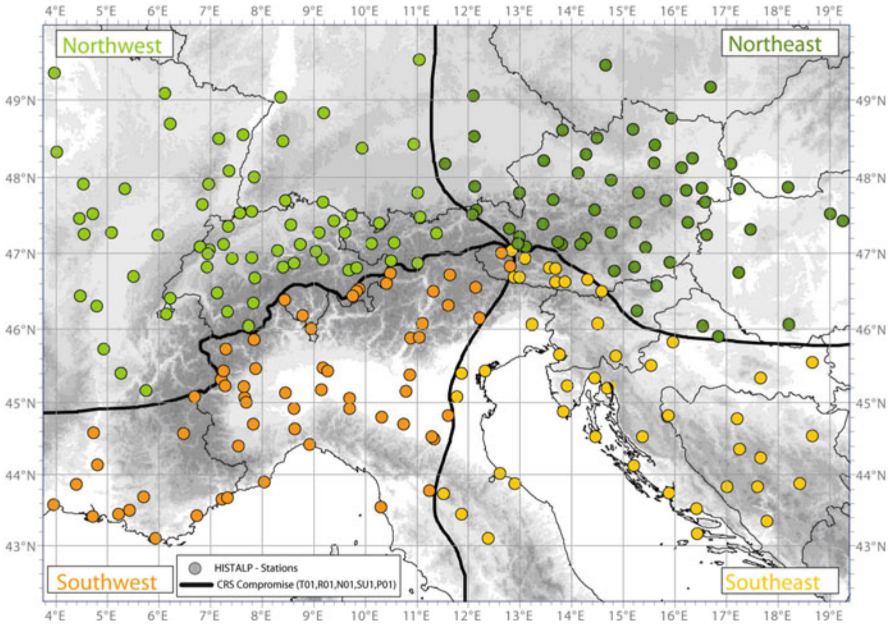

Fig. 1 The greater Alpine region (GAR) in south-central Europe with its five principal horizontal and vertical "coarse resolution subregions" (CRSs) and the network of HISTALP-stations (*dots* with different colours for regions) of long climate time series. The network consists of low and high elevation stations (figure after Böhm 2009 with the permission of the author)

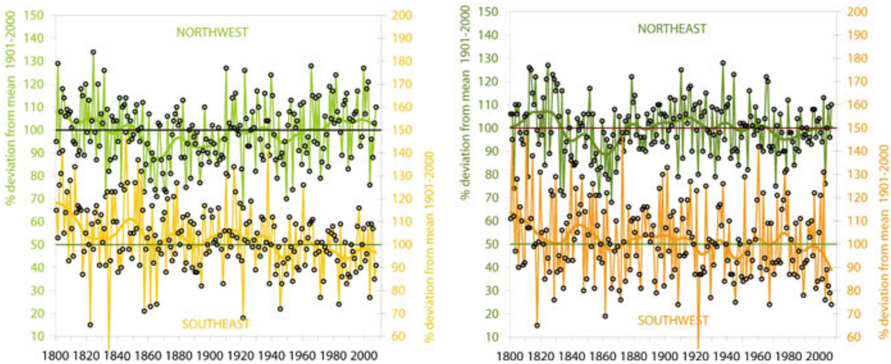

Fig. 2 Regional annual precipitation series 1800–2007 in the greater alpine region. *Left chart*: CRS-Northwest (*green*) and CRS-Southeast (*yellow*), *right chart*: CRS-Northeast (*green*) and CRS-Southwest (*orange*). Single years and 30-years smoothed (Gaussian low pass), anomalies in percent of twentieth century means (figure after Böhm 2009 with the permission of the author)

combined to one region to have enough long term time series available. Concerning air temperature it can be clearly seen that the climate in the twentieth century is of a more settled type during all seasons. Concerning precipitation it is not so clear but generally the variability is decreasing, especially in spring. Only in the NW, a

Table 1 Relative changes (in respect to the nineteenth century mean) of annual and seasonal climate variability (90% interquantile range of the detrended values) from nineteenth to twentieth century in three subregions of the GAR in respect to the two climate elements temperature and precipitation

	NE	NW	S	NE	NW	S	NE	NW	S	NE	NW	S	NE	NW	S	
	SPR.	SPR.	SPR.	SUM.	SUM.	SUM.	AUT.	AUT.	AUT.	WIN.	WIN.	WIN.	YEAR	YEAR	YEAR	
TEMP.	−16.0	−14.9	−13.2	−20.0	−7.6	−2.3	−3.2	−9.7	+0.3	−7.4	−12.0	−6.2	−28.9	−23.8	−11.5	%
PREC.	−6.1	−3.0	−9.0	+1.7	+8.9	−2.4	−0.3	+14.1	−5.8	+8.8	+13.5	−2.6	−4.6	+5.3	−3.7	%

Table after Böhm (2009) used with the permission of the author region with increasing precipitation (see Fig. 2) the variability is increasing as well. Historical long term trends even for seasonal characteristics are comparable to what we expect in future of the next 100 years (Böhm 2009).

All these analyses have been done on historical long term series of monthly data. In the moment Austrian climatologists have started to analyse daily precipitation series. Böhm (2009) states that it already can be shown that there is a close correlation between the long term trend of yearly and monthly series and the trend of extreme events such as heavy rainfall or dry spells. This means that in the western part of Austria with increasing precipitation more heavy rainfall events are possible but together with less dry spells. For the south-eastern part of Austria the opposite is possible. Nevertheless we have to be careful because the extremes of the extremes, which can lead to large scale flooding are by definition very seldom events, and can statistically not be analysed using these "short" time series. Furthermore we know that events of 50 and 500 years return period are very close concerning their absolute values.

3 Hydrological Aspects

A typical method to simulate possible future floods and trends for runoff is to model runoff based on climatic projections. Based on the change of climatic variables precipitation and temperature, floods will appear more often or not. But, do we take into account that floods use to appear in a higher temporal density during flood decades? Known as the Hurst effect (Hurst 1951 cited after Blöschl and Montanari 2010) there are different periods with a lower and higher numbers of flood events in well and long term observed catchments. If we are interested in future changes of design values, one has to take into account uncertainties of current design values due to short observation periods. To exceed these uncertainties the magnitude of a possible climate change impact must be of an implausible value. Therefore Blöschl and Montanari (2010) make hydrologists aware to rely on their knowledge on processes instead of blindly trusting model results. Especially trends in observed runoff time series lead us to extrapolate these trends into future. Considering the Hurst effect and the possibility of flood decades the question is if it is feasible to do so?

One of the main problems for the planning of flood protection and torrent control measures is the uncertainty of the design flood definition. The usual system based on calculated discharge values, which are the result of statistical analyses for the given return period has the main problem that values will always change the more observations are available. Although a new initiative of reconsidering the methods for the statistical determination of design values was started in Austria (Sereing 2009; Mayer et al. 2009) the last innovation has been to additionally serve flood protection planners with an uncertainty bandwidth for design values. This is an appropriate and correct way for hydrologists but does not solve the problem for planning engineers. Very often the upper limit of the design value bandwidth is taken as "the truth". Merz and Blöschl (2008) describe a new approach and call

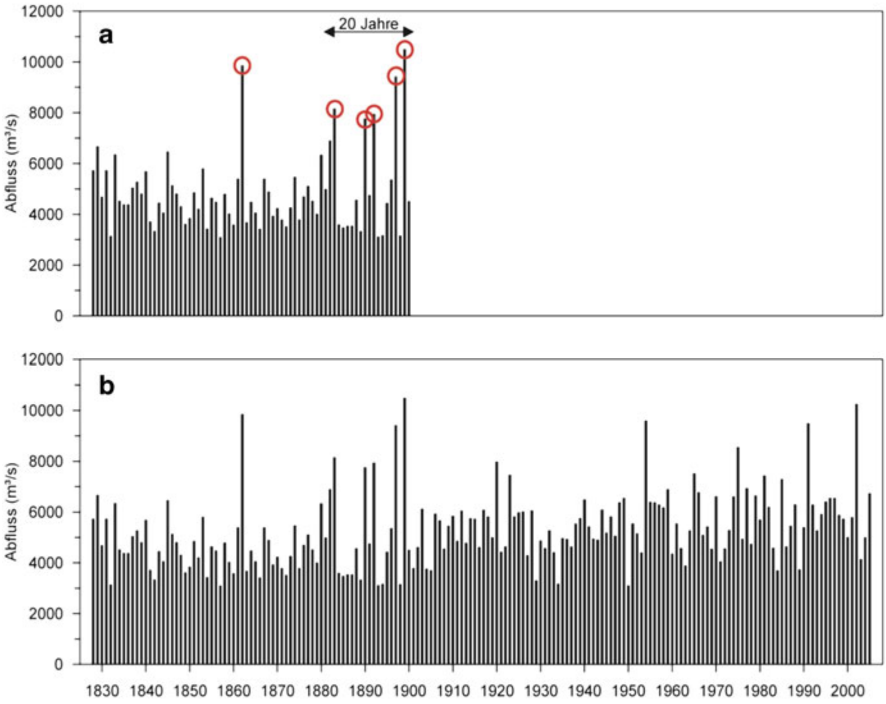

Fig. 3 (**a**) Annual floods of river Danube in Vienna for 73 years, five of the six highest floods appeared in the past 20 years. (**b**) Entire time series from 1828 to 2005 (figure after Blöschl and Merz 2008 with the permission of the authors)

it the "extreme value hydrology" instead of extreme value statistics. Hence, the information basis is extended and the expert knowledge can be implemented based on objective documents. Climate change in this consideration is another uncertainty. In most cases the climate signal is much smaller in comparison to uncertainties coming from extrapolations used in statistical analyses of events with higher return periods (e.g. 100 year or more). An example, which can occur using limited time series, is shown in Fig. 3. Figure 3a is a time series of 73 years, which is normally a very long period of hydrological observations and could be perfectly used to calculate statistical parameters. If a trend analysis is performed we could see that five out of the six highest annual floods appear in the end of the observation period. An extrapolation would predict even higher floods in future. The time series in Fig. 3a starts in 1828 and ends in 1900. Figure 3b shows the entire time series of observations from 1828 to 2005 of the gauging station at river Danube in Vienna. There is no more trend for higher floods detectable. But there is a higher frequency of small flood events observable. Even this trend is most probably not caused by climate change. It is more likely being a consequence of technical river regulations measures, which cut natural flood plains and decreased the overbank flow of smaller floods (Blöschl and Merz 2008; Böhm 2008). All in all the flow time of river Danube has dramatically been increased by technical measures.

A possibility to differentiate between trends coming from land cover changes and climate change was proposed by Blöschl et al. (2007). They found out that land cover changes affect only smaller areas and climate change affects smaller and larger areas. Hence, trends have to be compared for areas of different scale. While on the one hand changes in the flood regime induced by technical measures are mostly reproducible regime changes induced by climate change must not be reproducible. Therefore Blöschl and Merz (2008) recommend to explicitly identifying uncertainties instead of trying to make forecasts for these changes.

Land cover change can be influenced by climate change too. Glacierized areas will show different behaviour due the continuous retreat of glaciers. Actual studies in Austria have shown that glacier melt has rather a balancing influence during low flow conditions than on floods (Koboltschnig et al. 2008). It is more likely that the timing of snow accumulation and snowmelt will change in future.

As the uncertainties of climate change concerning floods are too big to make serious forecasts a good possibility to be prepared for possible future changes is to simulate scenarios, which lie in a manageable bandwidth. Within the "Floodrisk II" project (Habersack et al. 2009), which has been elaborated after the heavy 2002, 2005 and 2006 floods in Austria, Blöschl et al. (2008) did scenario analyses for two catchment areas in the north and the south of the Alps to see a possible upward shifting of floods due to climate change. They concluded that based on a plausible climate change input scenario floods could increase but uncertainties in the scenario definition as well as uncertainties in the modelling have to be taken into account. Based on the analysis of available flood discharge observations information on the significance for the determination of design values were derived and approximations for the uncertainties could be given. It has shown that there is always a possibility for flood decades.

4 Climate Change Impacts on Natural Hazards and Adaptation Measures

Due to the above mentioned climatic background we know that meteorological parameters (air temperature, precipitation) do not show the same trend for observed time series and we have seen a different degree of certainty concerning future model predictions. Regarding various types of natural hazards we should be aware that there is a long chain of dependencies and uncertainties from a changing climate to the impact on natural hazards. The central question is: how and where can climate change have an impact on natural hazards? For Southern Germany coupled climate and hydrological models have predicted an upward trend for precipitation and flooding (KLIWA 2006). As a consequence and adaptation measure design values for flood protection measures have now to be increased generally by 15% in Bavaria and similar in Baden-Württemberg (KLIWA 2006). Based on a large Austrian study (BMLFUW 2010) where no clear and direct impact on flooding due to climate change has been detected the decision was taken not to do any general

Fig. 4 Completes adaptation works at Hoher Sonnblick observatory (3,106 m a.s.l.) to reduce problems of permafrost degradation (picture by Schöner W.)

adaptation for design values in Austria. In the beginning of the climate change discussion increasing trends of damages caused by natural hazards, e.g. shown by MunichRe (2010), were correlated with increasing air temperature. Nowadays we know that this was primarily caused by an increasing damage potential. Furthermore in the USA an increase of Hurricane activities and damages seemed to occur especially in the past decade. By applying two normalization methods for damage records from 1900 to 2005, which on the one hand provide an estimate of the damage that would occur if storms from the past made landfall under another year's societal conditions and on the other hand use changes in inflation and wealth at the national level and changes in population and housing units at the coastal county level, Pielke et al. (2008) showed that there is no remaining absolute trend in absolute Hurricane damage. A similar result was shown investigating the European storminess (Matulla et al. 2008). There is no increasing trend for the storminess. Concerning water related natural hazards such detailed investigations need to be performed in future.

Hence, there is a need to study the trend and the degree of certainty of each climatic parameter, which can have an influence or the ability to change the behaviour of natural hazards separately, before implying a general trend of natural hazards to be increased in future. We also need to know if an impact is significant compared to the uncertainties of past observations and model simulations.

A sub project of the AdaptAlp project (Adaptation to Climate Change in the Alpine Space, www.adaptalp.org) had the goal to find adaptation strategies against natural hazards in the European Alps, which already had to be applied in the past due to the impact of climate change (Schöner and Binder 2010). The main requirement for these case studies to be analysed was that there must have been an observed climate change impact. As the degree of certainty is the highest for the air temperature change and therefore the hardest fact, Schöner and Binder (2010) searched for examples where the air temperature increase was the cause for an increasing natural hazards endangerment. All examples of implemented adaptations to climate change were found in high alpine areas. The description goes from naturally dammed glacier lakes, which had to be drained to reduce the risk of spontaneous outburst floods (e.g. thermo karstic lakes in Wallis/Switzerland or the glacier Rochemelon in France) to problems of permafrost degradation where the underground had to be stabilized using concrete injections and retaining walls (e.g. Hoher Sonnblick observatory in Austria, see green ovals in Fig. 4). Several examples can be found in alpine terrain beneath permafrost degradation zones, where hiking tracks had to be displaced to reduce the endangerment of rock fall (Behm et al. 2006).

5 Conclusions

- It is most likely that the knowledge on the impact of climate change is quite consolidated for the parameter air temperature but not that good for precipitation.
- All meteorological parameters can show different regional behaviour. Due to long term historical time series analyses for the Alps future regional differences can be expected.
- It seems to be possible that historical short-term extreme values of precipitation (e.g. daily values) are represented in monthly precipitation observations. This method, which was applied for historical data could be used for simulations of future scenarios. An extrapolation on the “extremes of the extremes” will not be possible.
- To be able to make hydrological conclusions based on climatic simulations all uncertainties, which appear in the methodological approach, have to be taken into account. Therefore the extrapolation of trends for future floods has to be handled with care.
- Uncertainties for the determination of hydrological design values, starting with instrumental, mathematical and statistical uncertainties, have to be explicitly identified instead of trying to make forecasts for climate change impacts on hydrological design values.
- Uncertainties, which grow during the process of design value determination, seem to exceed the expected increase due to the impact of climate change.
- The adaptation to climate change has already taken place, as hydrological design values have always to be reconsidered as soon as the knowledge on observed flood data grows.

- As the most significant climate change in the European Alps in the past and in future regards an increase of air temperature, impacts on and an increase of natural hazards are most likely to be found for temperature sensitive processes.
- To increase the preparedness for the unexpected it is useful to work with “what if” scenarios covering the range given from climate models. Results should be communicated as scenarios and not predictions.
- Especially under “climate change-research-conditions” the knowledge on dominant processes being able to trigger natural hazards – including realistic (hard fact) climate change impacts on them – is more and more necessary and needed instead of blindly relying on any model outputs.

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