6 How uncertain are regional climate change scenarios? Examples for Europe and the Alps

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6.1 Introduction

Climatologists are confronted with the task to produce useful information for decision making and planning in view of global climate change. Information on likely climatic changes is required at the spatial scale at which most climate impacts occur and are most clearly perceived by the public, i.e. at a scale of a few to a few thousands of kilometers. This scale is termed here as the "regional scale", in contrast to the global scale at which Global Climate Models (GCM) operate.

The needed information is normally provided in the form of scenarios. These are internally consistent, quantitative, more or less plausible prescriptions of possible future space-time evolutions of the climate system (IPCC-TGCIA, 1999). Climate scenarios are a means to account for uncertainty due to "unknowable" knowledge, such as the future global socio-economic development. At the same time, each individual scenario is subject to substantial uncertainties due to limitations in the available knowledge, data and computing power (see also CARTER et al., 1999).

In this context the questions arise: How large is the uncertainty extant in the presently available scenarios of future climatic change for a particular region such as Europe or the European Alps? And how should one deal with that uncertainty in the context of climatic impact assessments?

The present paper addresses these questions based on the results from two large review studies that are dealing with regional climate change scenarios for the North Atlantic/European sector and the Alps. In the next two sections the main results of the two studies are presented. Then these results and their implications for climate and climate impact research are discussed. The paper ends with some conclusions and recommendations for future research.

6.2 Scenarios of atmospheric circulation changes for the North Atlantic and Europe

The first review study (GYALISTRAS, 2000a) focused on possible future changes in the atmospheric circulation in the North Atlantic/European sector as simulated by GCMs. The study examined the specialist literature from ca. 1975 until the end of 1999.

Relevant results were found in 50 out of initially selected 140 publications that dealt with the simulation of climatic changes by GCMs. The data base finally analyzed consisted of 33 simulations that have been carried out at 7 modelling centers using 24 different GCMs.

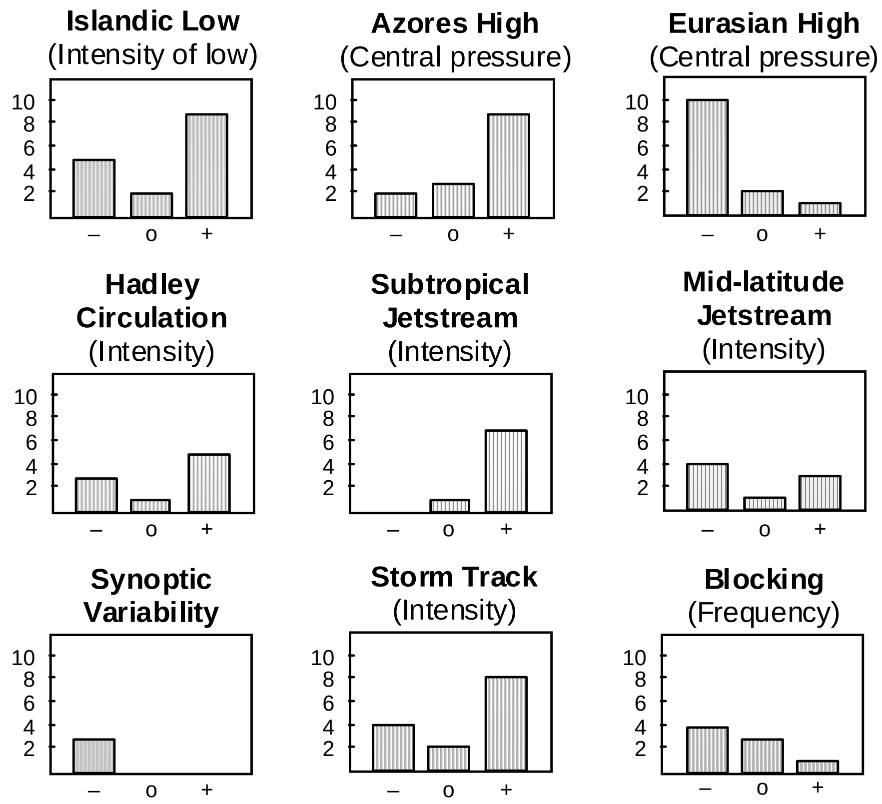

Fig. 6-1 Summary of changes in selected features of the atmospheric circulation in the North Atlantic/European sector, as simulated by different GCMs. Shown are the found numbers of studies for which the respective type of change was reported in the literature for the period 1975–1999. All data refer to the winter season and reflect the GCMs' response to a doubled CO_2 or time-dependent greenhouse-gas only forcing. The signs "–", "o", and "+" refer to a decrease, no change or increase of the respective feature's intensity or frequency. After GYALISTRAS (2000a).

The review showed that the GCMs do not agree on the sign of the putative changes for many important circulation features. In particular, opposite changes were reported for features related to wintertime storm activity, namely the intensities of the Icelandic Low, the mid-latitude jetstream and the storm track under a greenhouse-gas only forcing; some agreement, however, was obtained with regard to a possible intensification of the Azores and Eurasian High pressure systems and the subtropical jetstream (Fig. 6-1).

The models seem also to agree upon a general northward shift of circulation patterns, at least for wintertime and under a greenhouse-gas only forcing (Fig. 6-2).

The review revealed some major knowledge gaps: from a total of 151 statements that were found on possible future circulation changes only 43 statements applied to the summer, only a few ones to the transition seasons, and only 23 statements referred to simulations that considered in addition to a greenhouse-gas forcing a forcing by aerosols (cf. Fig. 6-2).

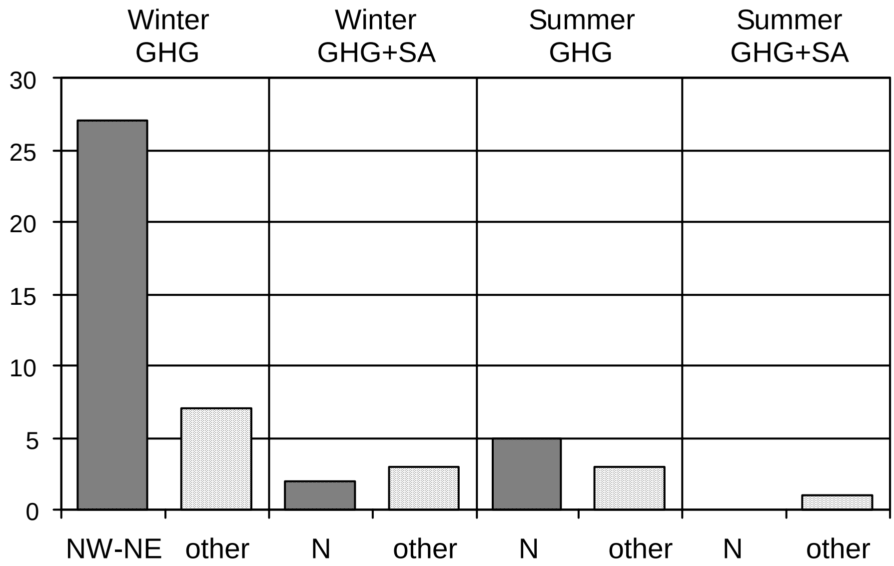

Fig. 6-2 Summary of changes in the position of atmospheric circulation features (such as the Icelandic Low, the Azores High, the storm track etc.) in the North Atlantic/European sector, as simulated by different GCMs. Shown are the found numbers of studies for which the respective type of change was reported in the literature for the period 1975–1999. GHG: greenhouse-gas only forcing; GHG+SA: forcing by greenhouse-gases and sulphate aerosols; NW, NE, N: displacement of a feature in a northwesterly, northeasterly, or northerly direction. After GYALISTRAS (2000a).

6.3 Scenarios of temperature and precipitation changes for the European Alps

In a second review paper, GYALISTRAS (2000b) analyzed the extant scenarios dealing with possible future temperature and precipitation changes in the European Alps. The review considered 21 scenarios which were published during the period from 1992 to early 2000.

The scenarios represented all major approaches to estimate regional climatic changes from GCMs: 4 scenarios were derived based on the direct use of GCM gridpoint data, 3 scenarios were obtained from time-slice experiments with high- or variable-resolution GCMs, 7 scenarios stemmed from simulations with regional climate models, and 8 scenarios were obtained with the aid of statistical downscaling techniques.

The scenarios showed a surprisingly large spread for the possible change in the seasonally and regionally (entire Alpine region) averaged temperature under a given global mean temperature change in the driving GCM simulations (Fig. 6-3, left).

For precipitation the scenarios did not agree on the sign of the future change. This was found to be the case for all seasons, except perhaps for winter (Fig. 6-3, right).

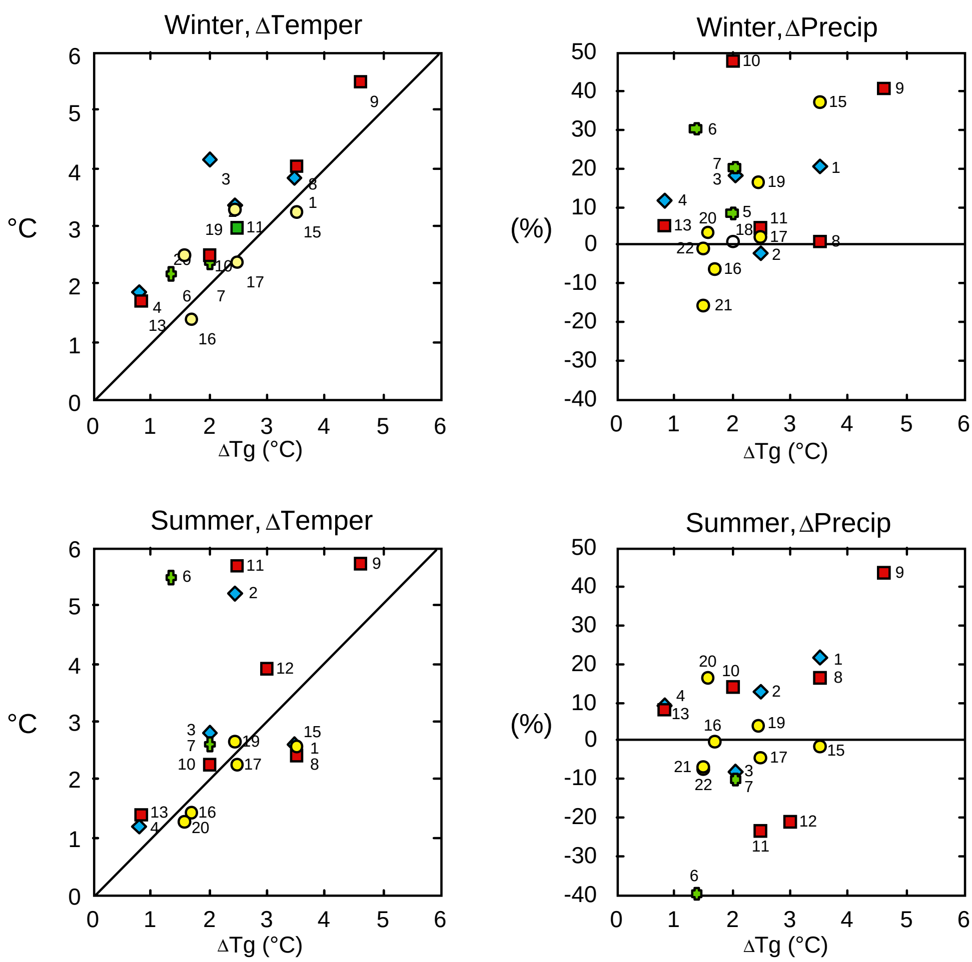

Fig. 6-3 Scenarios for changes in the seasonally and regionally averaged temperature (left) and precipitation (right) in the Alpine region. ΔTg: Change in the globally and annually averaged near-surface temperature from the driving GCM simulation. The scenarios were constructed as follows: ◆: direct use of GCM gridpoint data; ✚: time-slice experiment with a high- or variable-resolution GCM; ■: simulation with a regional climate model; ○: use of a statistical downscaling technique. After GYALISTRAS (2000b).

Further the review showed that the uncertainties introduced due to the use of different forcing scenarios, GCMs and regionalization procedures were in the same order of magitude.

Similarly to the European circulation scenarios, the Alpine scenarios were found to reflect but a limited sample of GCMs and global forcing scenarios: All regional scenarios were produced from only 8 global simulations with 6 different GCMs. The newest GCM simulations use to produce the scenarios dated back to 1997. Only 5 scenarios took the aerosol forcing into account, and this was always the case based on one and the same global simulation.

6.4 Which scenarios are most trustworthy?

The future global socio-economic development is fundamentally uncertain such that it is not possible to attach any objective probabilities to individual global forcing scenarios or the associated climate change projections (NAKICENOVIC et al., 2000). Nevertheless, given a specific forcing scenario the question arises which of several available regional climate scenarios should be trusted more and which less.

GCMs are being constantly improved such that usually scenarios that are based on newer versions of the same climate model can be considered more trustworthy than older ones. However, beyond that, the intercomparison of scenarios which were derived using different global models or regionalization techniques poses many difficulties.

One main reason lies in the complexity of the climate system. As a consequence, the models may produce diverging projections due to subtile differences in the evaluation of the balance between different, counteracting factors. The contradictory changes obtained with regard to some European circulation features (Fig. 6-1) provide an example:

The diverging results have to do with the fact that most GCM scenario runs show a decrease in the equator-to-pole temperature gradient near the earth's surface and an increase in the upper troposphere. This leads to a decrease in baroclinicity at lower levels and an increase aloft. In some models the first effect dominates, thus leading to a less stormy climate, whereas in other models the second effect is more important, thus leading to the opposite result.

A second reason relates to the fact that under global warming most GCMs simulate a general increase in the water vapour content of the atmosphere. This contributes on the one hand to a more efficient poleward energy transport by the atmosphere, but on the other hand it also increases the latent energy available for the formation of cyclones. In some GCMs the first effect is responsible for a slowing down the circulation and a reduction in the number of cyclones. In other models, however, the second effect dominates and gives rise to an increased number and/or intensity of cyclones (see also the more detailed discussion in GYALISTRAS, 2000a).

Similar problems occur when one attempts to compare the outcome of different regionalization techniques. In some instances the differences between the various regional scenarios can be traced back to plausible causes, such as major differences in the driving GCM simulations. However, in many cases the complexity of the regionalization procedures, as well as limitations of the observational or modelled data base make a more detailed evaluation and comparison of the available scenarios very difficult (GYALISTRAS, 2000b).

In some instances the reasons for the simulated changes are not even properly understood. For example, the result shown in Fig. 6-3 can be explained to some extent by the above-mentioned reduction of the equator-to-pole temperature gradient near the earth's surface, and possibly also by the assymetric warming of the two hemispheres. Some theoretical arguments can also be put forward (see discussion in

GYALISTRAS, 2000a). However, to our knowledge, the causes for a possible northward shift of the circulation have not been investigated in more detail up to now.

Methodical problems also aggravate the assessment of the scenarios. For instance many climate change simulations extend only over relatively short periods of time, which makes it difficult to distinguish systematic effects from natural variability in the simulations; or the considered forcings, temporal and spatial windows, and analysis procedures vary strongly across studies (GYALISTRAS, 2000a, b).

In summary, due to several fundamental and methodical problems, our ability to distinguish between more and less realistic regional scenarios for a given global forcing is at present very limited. Every GCM or regionalization technique has its specific advantages and limitations, and different models may evaluate the regional effects of the same basic changes in the climate system in equally plausible, yet widely differing ways.

In this situation the following two extreme possibilities have to be envisaged with regard to regional climate change, or at least selected aspects of it:

1. The contradictory scenarios are all equally appropriate because the long-term regional-scale response of the climate system is fundamentally indeterminable.

2. The true system's regional response is actually robust, but several of the used models or procedures are wrong.

The reality could lie somewhere inbetween: future changes in, say, the intensity of the North Atlantic/European storm track or the Alpine summertime precipitation could indeed depend very sensitively on the details of the future radiative forcing, the dynamics of small-scale processes, chance events, or a combination of several of these factors. At the same time some models may simply be too coarse or too incomplete to capture a possible deterministic signal correctly.

Extended model validation and sensitivity studies, as well as rigorous comparisons of models and regionalization techniques could help to resolve these issues and, ultimately, to determine the most realistic scenarios under a given global forcing.

6.5 Explosion of uncertainty in impact studies?

Does the uncertain climate change information of the kind shown above necessarily lead to an explosion of uncertainty when one is interested in studying possible, specific impacts of climate change? We argue that this does not have to be so:

Firstly, because uncertainties in the projection of future climate vary strongly by parameter, region and time of the year, such that no general statements can be made. For example, as discussed above, present-day GCMs yield contradictory results with regard to possible changes in the frequency or intensity of mid-latitude storms over the North Atlantic and Europe. However, a northward shift of atmospheric circulation patterns (Fig. 6-3) would suggest for the Alps – which are located south of the tail end of the strom track – a less stormy climate, quite independently from a possible increase or decrease of storminess in more northern regions.

A second reason why uncertainties do not necessarily have to pile up is that the impacted system may be relatively insensitive to climate change, or at least to the changes portrayed in the relevant scenarios of future climate change. For example, extended simulations with a detailed snow model showed that snow cover in Switzerland at locations below ca. 2700 m.a.s.l. is generally temperature-limited. As a result, sensitivity studies with the snow model yielded for these locations always a decrease of snow depth and duration, independently of the exact formulation of the warming scenario used to drive the model (GYALISTRAS et al., in prep.).

Of course, most systems impacted by climate are very complex, such that their response has to be evaluated for each region and impact of interest anew, and this may lead to other results than in the above example.

6.6 Should the main goal be to reduce the uncertainties?

A second question that arises in view of the large uncertainties in the scenarios is: Should the main goal of climate and climate impact researchers be to reduce these uncertainties?

I think that the answer should be no, for several reasons: Firstly, because due to the complexity of the socio-economic and climatic systems the potential for surprise is, and will always remain, very large. Acccordingly, strategies for dealing with an uncertain climatic future have to be elaborated anyway. Secondly, because the available time and means for adaptation to climate change are limited, such that there is a need for action in spite of the many uncertainties present. And last but not least, because non-climatic factors can be often as important as climatic influences when a specific impact is being considered.

The last point is nicely illustrated by the study of BÜRKI (2000): According to his study, Swiss winter tourism industry makes substantial investments in order to maintain or increase its supply for downhill skiing facilities. At the same time it was found that tourists are likely to respond to less favourable snow conditions with reduced demand for skiing. This could lead to a disastrous competition between ski resorts, independent of the details of future climate change (BÜRKI, 2000). In this case it seems more important to focus on the development and implementation of sound adaptation strategies rather than to put the main effort into a further reduction of purely climatological uncertainties.

6.7 Conclusions

Except for the sign of the temperature change and perhaps a general northward shift of major atmospheric circulation patterns the climate's evolution in Europe and the Alps must be considered very uncertain. However, given a sufficiently large number of scenario studies it is at least possible to give a quantitative estimate of the uncertainty range (Fig. 6-3).

There are major gaps in our knowledge, e.g. regarding the climatic effects of sulfate aerosols, the modelling of the global and regional climate, and the form and magnitude of regional climatic changes in the transition seasons systems. The lack of relevant information is probably even more acute for world regions which have not been studied as intensively as Europe.

There are also major methodical problems which indicate a clear need for systematic intercomparisons of models, scenario construction methods and scenarios. Corresponding projects should explore a wide range of global forcing scenarios, climate models, and regionalization procedures using standardized analysis tools.

Climatologists and climate impact analysts should not only aim at minimizing uncertainties, but also at maximizing the robustness of their results. The production of robust results requires that a wide range of climate scenarios is constructed and used to study the likely impacts. Robust results are per definition relatively insensitive to the input assumptions used to generate them and may therefore show very large uncertainty bounds.

Nevertheless, the establishment of large uncertainties does not necessarily present a trivial result because it is impossible to predict the outcome of a complex, state-of-the-art, quantitative assessment before this assessment has actually been carried out. In the end, the value of uncertain information must also be judged by the way it is perceived and used outside the field of climate research.

6.8 References

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