# EXPERIENCE WITH THE DERIVATION OF CLIMATIC CHANGE SCENARIOS IN THE ALPINE REGION[1]

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### Abstract

We investigated the climatic input requirements of four selected climatic change impact case studies in the Alpine region, dealing with the distribution of plant species, potential natural forest vegetation, forest succession, and low-elevation grassland-ecosystems, respectively. Then we analyzed the currently used methods to provide the required climatic inputs in the form of climatic change scenarios, as well as the choice of the most appropriate method for a particular type of application. We argue that arbitrary adjustments and past climatic change analogues are suitable to obtain first iterations of climatic change scenarios, whereas, after refinement of the impact models, downscaling techniques or direct numerical modeling should be used. The very detailed and likewise diverse climatic input requirements of the impact case studies demonstrated the need to derive scenarios in an application-specific manner. The capability of a statistical downscaling technique to cover at reasonable expenses both, high-resolution spatial, as well as long-term temporal aspects of climatic change, was demonstrated with two examples. The successful application of the downscaling technique to the climatically complex Alpine region suggests its potential usefullness for other mid-latitude regions of the globe as well.

## 1. Introduction

Since a forecast of future climate is not possible, descriptions of possible future climatic changes can only be given in the form of climatic change (CC) scenarios. Several approaches to derive such scenarios for regional impact assessments have been proposed till now (cf. Giorgi & Mearns, 1991; Schär et al., 1995).

In the present contribution, the climatic input requirements of four selected climatic impact case studies currently undertaken at Swiss research institutions are first summarized. Then, the merits and demerits of several methods to derive regional CC scenarios are discussed, and illustrated with two examples.

## 2. Climatic Change Scenarios

A scenario can be generally described as "a logical and plausible (but not necessarily probable) set of events, both serial and simultaneous, with careful attention to timing and correlations wherever the latter are salient" (Ayres, 1969). Specifically, CC scenarios are internally consistent descriptions of conceivable spatio-temporal evolutions of (some aspects of) climate. CC scenarios are merely pojections into the future, i.e. means to assess uncertainties by spanning the range of possible futures, given a set of assumptons currently understood to be relevant for the evolving system under study.

CC scenarios are useful for basic research, since they provide convenient starting points to study the behaviour, sensitivity, and plausibility of any statistical or dynamic models that describe climate-dependend processes. On the other hand, scenarios are essential for any analyses of potential impacts of CC. In particular, they allow to examine in as far predictions for a specific impact sector are possible, given a particulart evolution of future climate, or in as far a particular impact system would remain unaffected, independent of the exact form of a future climatic change.

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## 3. Scenario Requirements in the Alpine Region

Table 1 summarizes the climatic input, respectively CC scenario requirements of four selected research projects in the Alpine region[3].

Obviously, each application requires specific combinations of climatic input data. Though there is an overlap with regard to temperature and precipitation, the two parameters are still needed at different time scales and resolutions. In particular, for one case study (forest succession) scenarios which are reaching far into the future are required.

The needed spatial resolution is generally high. In this connection, the studies focusing on plant distributions and grassland ecosystems requiring higher spatial detail then those focusing on forests. The annual cycles of the meteorological variables must be in all cases resolved, at least for the duration of the vegetation season. For one case study (grassland ecosystems), even the daily cycles have to be resolved.

Further, different measures of climate or weather variability must be provided for each study. These are either long-term extremes (in the case of the plant distributions), or interannual and within-season standard deviations, which, together with additional parameters such as auto- and cross-correlations, are needed to stochastically generate the weather sequences that drive the dynamic impact models (last two case studies).

| Case study | Model type of impact system | Spatial resolution | Time window of projections | Temporal resolution | Time of the year | Input data |
|---|---|---|---|---|---|---|
| Distribution of plant species in the Alpine belt | Statistical | Test regions, 100 m | future time period, e.g. 2030-50 | 1 season (1 month) | Win.. Aut | E[T](s), E[R](s),<br>Min[T]Win, Max[T]Sum,<br>N≥0cm[H](m) |
| Distribution of potential natural forest vegetation | —" – | Switzerland, 1 km | —" – | 1 month | Jan.. Dec | E[T](m), E[R](m) |
| Forest succession and soil dynamics | Dynamic | Represen-tative locations, Europe | present... 2100+ (3000) | —" – | —" – | T, R (y,m)<br>(E[T](m), E[R](m),<br>Cov[T,R](m), ... ) |
| Low-elevation grassland ecosystems | —" – | Represen-tative locations, Switzerland | present.. 2030+ | 1 hour | Mar.. Nov | T, R, S, W, U (y,m,d,h)<br>(E[T](h), E[R](d),<br>Cov[T,T(d-1)], E[R](h)... ) |

Table 1: Climatic input requirements of selected climatic change impact case studies in the Alps. T = Temperature, R = Precipitation, S = Radiation, W = Windspeed, U = Air Humidity, H = Snow Height; y = year, s = season, m = month, d = day, h = hour; X(y,m,...) = realization of random variable X for year y, month m, etc.; E[X](i) = expected value of X for period i; N≥z[X](i) = number of days within period i at which X exceeds the threshold value z; Min/Max[X](i) = absolute min./max. of X within month or season i. Cov[X,Y] = covariance matrix of X and Y. Adapted from Schär et al. (1995).

Note, all four case studies are concerned with impacts on biological systems. Compared to other impact sectors such as hydrology, energy supply, or tourism, these studies are amongst those that pose the most stringent scenario requirements (Schär et al., 1995). In addition, due to the particular topographical and climatic complexity of mountains such as the Alps, there is a general need for high-spatio-temporal detail. Thus, it is possible that CC scenario derivation methods which would satisfy the above requirements, would be usefull for other types of impact studies, and for other mid-latitude regions as well.

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[3] All shown projects are from the Swiss research programs "Climate Changes and Natural Disasters" (NFP 31) and "Swiss Priority Program Environment: Environmental Dynamics" (SPPU Module 1).

## 4. Methods to Derive Scenarios

The following basic approaches to construct regional CC scenarios can be distinguished (Schär et al., 1995):

(1) *Arbitrary adjustments*. Based on climatological considerations, scenarios are derived by arbitrarly adjusting, e.g. shifting by a fix amount, available measurements of the climatic/meteorological inputs required by an impact model. The adjustments should draw upon analyses of the spatio-temporal behaviour of the climatic inputs, the role of atmospheric circulation patterns for regional climate, and indications from General Circulation Models (GCMs) (cf. Robock et al., 1993).

(2) *Analogue techniques*. Two large-scale climatic states – typically a warmer and a colder one – are identified, and the associated regional CCs, as inferred from paleoclimatic data (e.g. Flohn & Fantechi, 1984), or instrumental records (e.g. Pittock & Salinger, 1982), are considered as analogues for possible future changes.

(3) *Gridpoint based methods*. The gridpoints of a numerical climate model in the vicinity of the region of interest are first identified, and climatic changes simulated at these gridpoints are applied, e.g. interpolated and subsequently added, or transfered by means of empirical equations, to regional observed values (e.g. Kim et al., 1984; Bach et al., 1985; Karl et al., 1990; Wigley et al., 1990).

(4) *Downscaling techniques*. First, an empirical relationship between observed large-scale atmospheric states (e.g. as given by atmospheric anomaly fields, or synoptic weather types) and simultaneous measurements of the regional variables of interest is established. Then, this relationship is used to predict changes in the regional variables from GCM-simulated atmospheric states (e.g. von Storch et al., 1993; Gyalistras et al., 1994; Wanner, 1994).

(5) *Direct numerical modeling*. Regional CC scenarios are obtained either by increasing the horizontal resolution of present GCMs, or by using in a nested mode dynamical models with enhanced resolution over the region of interest (limited area models, LAMs). The lateral boundary conditions from a driving GCM can be fed into a LAM either continuously (Giorgi & Mearns, 1991; Beniston, this volume), or for representative atmospheric states, which are then used to compose regional climates from a corresponding set of LAM-simulations (Frey-Buness, 1993; Heimann, this volume).

## 5. Selection of Scenario Derivation Method

A detailed discussion of the merits and demerits of the methods (1)-(5) can be found in Schär et al. (1995). Here, only the following two major aspects regarding the selection of a scenario derivation method will be addressed: the feasibility of the method to produce the scenarios required by a particular application, and the degree of potential realism, respectively internal consistency that is achieved in the resulting scenarios.

Internal consistency is the key property of any CC scenario. A scenario should, first, be consistent on the regional scale, namely spatially, temporally, and between the weather variables for a given point in time and space. For example, if a location gets much heat, its surroundings are likely to be warmed as well, and under the warmer conditions more precipitation can be expected to fall as rain. Second, a scenario should be consistent with the available estimates of future global climatic change. Since such estimates are typically obtained from GCMs, a good scenario should for example consistently reflect the regional effects of GCM-simulated, large-scale changes in the atmospheric circulation.

There are typically two stages within CC impact studies: the impact model development and verification phase, and the phase of extensive model applications. Since the purely empirical methods (1) and (2) do not consistently consider the global-scale causes of future climatic change, their main use lies in obtaining at comparatively small expenses first, regionally consistent scenarios for initial tests and sensitivity analyses. For assessing possible regional impacts of global CC the GCM-based methods (4) and (5) are appropriate. These require larger efforts, but preserve consistency with global CC.

Though (3) is a frequently used approach, its use can generally not be recommended. This is because numerical climate models generally yield reliable results only at a spatial scale above several gridpoint-distances, which is particularly crucial with regard to a mountainous region such as the Alps (cf. Grotch & MacCraken, 1991; Gyalistras et al., 1994). Accordingly, if the horizontal resolution of a high-resolution model (5) is not several (say, four to ten) times higher than the spatial resolution required, method (4) should be used.

The consistency requirements for a CC scenario also depend on the particular impact study considered. For example, for the first two case studies in Table 1 preferable are methods which yield optimally consistent scenarios in space. On the other hand, for the other two case studies, which use dynamic models driven by time series of meteorological variables, the temporal consistency is more important. Certainly, precise consistency requirements can often be determined only iteratively, based on sensitivity tests which scrutinize the impact models as well (Fischlin et al., 1995)

## 6. Examples

Fig. 1 shows a CC scenario for the Swiss summer temperature field under a doubling of atmospheric CO2. The map was produced by method (4), i.e. by statistically downscaling (Gyalistras et al., 1994) large-scale mean sea-level pressure and near-surface temperature anomalies as simulated by the Hamburg ECHAM1-T21/LSG-GCM (Cubasch et al., 1992) individually to the 40 Swiss climatological stations at which at least 50 years of data were available.

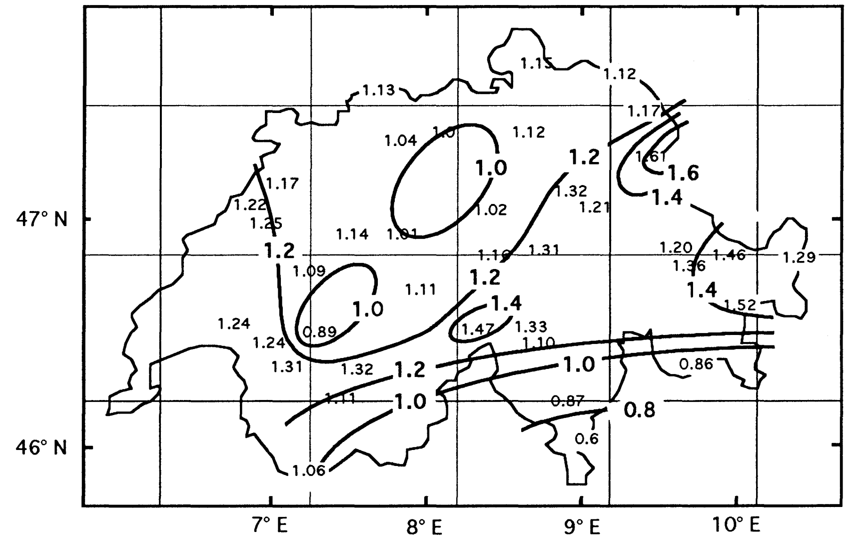

Fig. 1: A "2xCO2" scenario for changes in summer mean temperature in the Swiss region derived by method (4). Shown are deviations from the 1931-80 mean as statistically downscaled from a "2xCO2" experiment performed with the ECHAM1-T21/LSG-GCM. (Contour lines drawn by hand). For comparison, the grid of the MM4-LAM (ca. 70x70 km latitude-longitude) over Central Europe is also shown.

The scenario specifies the strongest temperature increases in eastern Switzerland and at the main ridge of the Alps (1.2-1.6 °C). In western Switzerland and the Jura mountains the anomaly amounts to 1.2-1.3 °C. Warming is more modest in the Swiss Plateau (1-1.1 °C), and shows a decrease towards the southern slope of the Alps (less than 0.8 °C). The distribution of the warming resembles the observed spatial patterns of interannual variability of the Swiss summer temperature field, as identified by means of a conventional EOF-analysis (not shown).

The spatial detail of this scenario compares favourably with the resolution attained by state-of-the art high-resolution GCMs, or even LAMs (Fig. 1). For example, the latitude-longitude resolutions of the Hadley Center UKHI-GCM (Viner & Hulme, 1993), the Hamburg ECHAM1-T106-GCM (Beniston, this volume), and of the NCAR MM4-LAM (Giorgi et al. 1992) amount over Central Europe to ca. 280 km x 220 km, 120 km x 80 km , and 70 km x 70 km, respectively. Note, the spatial detail of the scenario given in Fig. 1 can be further increased based on spatial interpolation techniques (Gyalistras & Fischlin, 1995).

Fig. 2 shows time-dependent scenarios derived according to (4) for the two Swiss locations Bern (565 m.a.s.l., 7.4° E 46.9° N) and Lugano (273 m.a.s.l., 9° E 46° N). These scenarios were also based upon a simulation with the ECHAM1-T21/LSG-GCM, but under the time-dependent IPCC "Business-As-Usual" scenario for atmospheric greenhouse gas concentrations (Houghton et al., 1990; Cubasch et al., 1992; Gyalistras et al., 1994).

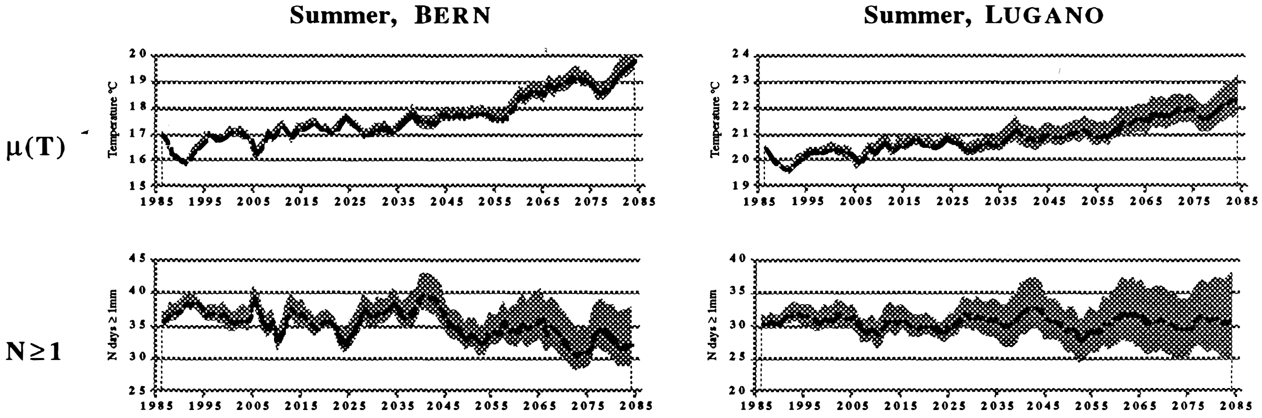

Fig. 2: Time-dependent climatic change scenarios derived for two Swiss locations in summer by method (4). Shown are possible future evolutions (5-year running means) of mean temperatures (top) and numbers of days with precipitation above 1mm (bottom). Values at scenario year 1985 ca. correspond to the 1901-40 long-term means. Changes relative to these means were statistically downscaled from an IPCC "Business-As-Usual" experiment performed with the ECHAM1-T21/LSG-GCM. Grey areas give empirical 90% intervals for uncertainties of the downscaling procedure.

Similar to the scenario from Fig. 1, a strong regional differentiation was obtained: at the northern slope of the Alps (Bern) a strong temperature rise occurs, which is accompanied by a decrease in the probability of wet days (ca. -12%/100 yrs). At the southern slope (Lugano), the warming is smaller, and no notable trend in the probability of wet days is projected.

The derivation of these location-specific scenarios required on a modern workstation only a few minutes of computing time. Such time-dependent estimates could not have been obtained from high-resolution numerical simulations (5) which (due to computational constraints) must be restricted to the simulation of a few annual cycles at best.

Since the used downscaling procedure relies upon physically meaningfull statistical relationships (Gyalistras et al., 1994) and yields plausible changes, the given scenarios can be considered to provide a means for much more consistent impact assessments than the direct use of gridpoint-scale climate model results, i.e. method (3). Of course, different patterns of change could have been obtained due to the use of other driving GCMs (Schär et al., 1995).

It should be noted that the shown scenarios partially rely upon (linear) extrapolations. Therefore, wherever possible, the use of the physically based models (5) should be considered too. In particular, approach (5) has the potential to provide physically much more consistent descriptions of possible future extreme events (e.g., individual storms) than the statistical methods (4). Yet, the enormous computing requirements of (5) do not allow to estimate the probabilities of such events. One possibility to do this would be to generate a large number of daily (or even hourly) weather sequences by means of stochastic weather generators, using parameters adjusted according to (4) (Mearns et al. 1984; Wilks, 1992).

## 7. Summary & Conclusions

A comparison of the climatic input requirements of four climatic change impact case studies in the Alpine region showed that it is hardly feasible to construct only one type of climatic change scenario which would satisfy all present scenario needs, and underlines the necessity to derive application-specific scenarios.

It was argued that the suitability of each presented scenario derivation method depends on the following factors: (a) the purpose of the scenarios (development of impact models vs. actual impact studies); (b) the required spatial vs. temporal consistency; (c) the required extents of the temporal and spatial windows vs. the resolution in time and space; (d) the specific input needs, e.g. scenarios for mean conditions vs. scenarios of extreme events.

Two scenarios for the climatically very complex Alpine region were used to demonstrate that downscaling techniques allow to reconcile at intermediate efforts the conflicting requirements between high spatial detail and the need for long-term (several decades to centuries) time-dependent climatic change information. The obtained results suggest that, at least in a complex terrain, downscaling techniques could be usefull for detailed CC impact studies in other mid-latitude regions of the globe as well.

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