

Chapter II: Climate Change Scenarios to 2100 and Implications for Forest Management

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Introduction

The global climate is currently warming and this trend is expected to continue towards an even warmer world, associated partly with drastic shifts in precipitation regimes (IPCC 2007). The global temperature has been warming by ca. 0.6°C ($\pm 0.2^{\circ}\text{C}$) during the 20th century (IPCC 2001), but the land areas have shown a higher increase in temperature within the same period. Here, we report on the current state of the art in climate model projections for Europe, with an outlook to the soon available 5th IPCC assessment report.

It is challenging to project how the climate might look like in 50–100 years, a duration that is relevant for forest management. In climatology many models are used in ensemble mode to generate possible climate futures. Each model and each simulation can be considered one possible representation of how the climate might evolve during the 21st century. For forest management and decision-making, we have to live with the fact that no exact forecast is possible. Rather, we have to implement our planning based on projected trends including their uncertainty. The periodic reports by the Intergovernmental Panel on Climate Change (IPCC) summarize the state of the art of how scientists see the development of the future climate and the associated impacts on ecosystems, economy and society. Now, the 5th assessment report is approaching, and some comparisons to the last two reports are already possible. The 3rd Assessment Report (IPCC 2001) had assumed that the global climate might be warming by 1.4 – 5.9°C , with no probabilities given for different increases, and with extreme scenarios projecting even far higher temperature increases. The 4th assessment report (IPCC 2007) provided a more narrow range of the likely future climate stating that temperatures will likely be between 2.0 and 4.5°C warmer than during the 1961–1990 period (with a likelihood of 66%). It also said that temperature increases by more than 4.5°C cannot be excluded (see Rogelj et al. 2012), but that the most likely temperature increase by 2100 is 3.0°C . First comparisons from global climate modeling studies for the 5th IPCC assessment report project an increase of 2.4 – 4.9°C as medians from three different scenarios of radiative forcing (following different emission scenarios that are similar to those used in earlier reports). A fourth scenario is added that assumes a more rigorous and rapid reduction of greenhouse gases than was ever used before, predicting a median temperature increase of only 1.1°C during the 21st century. Overall, the model simulations for the 5th IPCC assessment report expect that the likelihood of having global temperature increase exceeding 4.9°C is 14%, thus also likely, but that the most likely warming scenario at the global scale is still 3.0°C . Thus, in general, the newest scenarios do project similar

average warming trends as we have seen in the 4th IPCC assessment report, although some scenarios point to somewhat higher warming trends than were calculated for the 4th report (see Rogelj et al. 2012). Figure 1 shows global climate data simulations for the 4th and 5th assessment report.

The global climate is simulated using so-called general circulation models (GCM), which project the climate future on physics-based processes and first-principles. For regional applications such as e.g. Europe, such GCM model output has a too coarse spatial resolution, usually in the range of 1°–2.5° Lat/Lon per model cell. In order to obtain more realistic climate projections at a regional to local scale, two types of downscaling are often combined. First, so-called regional climate models (RCM) are calculated to certain larger regions of the World (e.g. all or parts of Europe). These models contain the same physical mechanisms as the GCMs, are fed by GCM output, and simulate the climate development within the study region by using GCMs data as boundary input to the study region. The output of these models is at high temporal and moderate spatial resolution, ranging typically between 5–50 km per cell. This is a much better spatial representation of the climate in regions and the output is somewhat sensitive to mountains and their effects on the climate system, though often the output is still too coarse for management and decision-making. Therefore, a further statistics-based downscaling procedure is applied (Pielke and Wilby 2012) in order to scale the output from RCMs to finer spatial resolution ranging from e.g. 100 m to 1 km, which can be considered well-suited for management applications.

Climate projections for the MOTIVE project

For the MOTIVE project, we have used five different RCMs driven by four different GCMs resulting in six GCM/RCM combinations in order to study the impact of likely climate changes on forest species and ecosystems. Table 1 gives an overview of the models used, which originate mostly from the ENSEMBLES EU project, using GCM runs that were calculated for the 4th IPCC assessment report (IPCC 2007).

We downscaled basic RCM output variables such as monthly temperature and precipitation to finer spatial resolution, typically to 1 km or 100 m cell size. The method used can be called the “anomaly-approach”, where we scale the deviation of the future compared to current climate from coarser to finer resolution. This is an efficient method, since anomalies do not depend much on altitudinal lapse rates. Once downscaled, the anomalies are added to an existing high-resolution climate map such as those available from Worldclim (Hijmans et al. 2005) or from national mapping campaigns (e.g. Zimmermann and Kienast 1999). The most important step here is to generate anomalies appropriately. First, we need to know the reference period of the high-resolution climate maps. Worldclim is mapping e.g. average monthly values of the 1950–2000 period. Next, we generate the monthly climate anomalies for given periods in the future. To calculate the anomaly of each projected future

IPCC AR4/5 data comparison, Anomaly 2071-2100 to 1980-1999

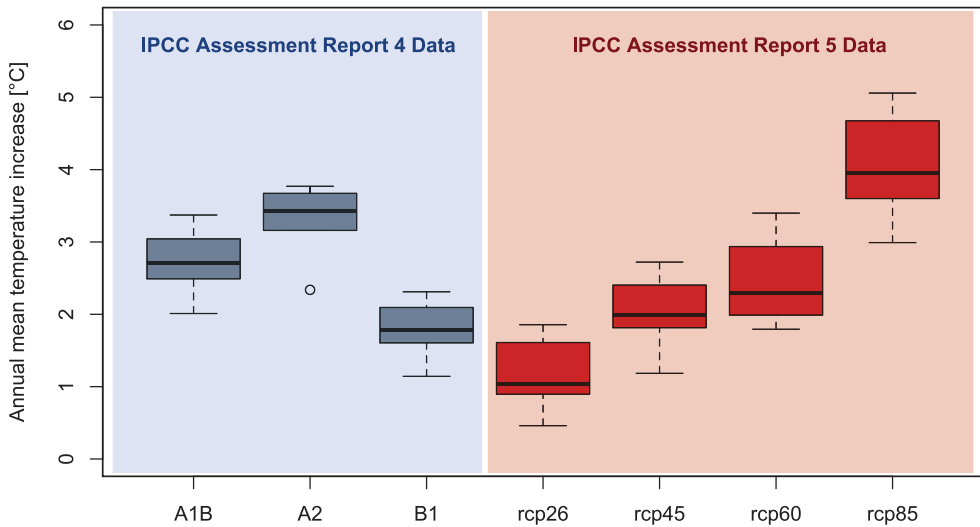


Figure 1. Comparison of global circulation model (GCM) simulations for the 4th (steelblue) and the 5th (maroon) IPCC assessment report (AR). It indicates the larger spread of possible climate futures projected with AR5 data, compared to AR4, despite simulating the same global mean climate.

Table 1. Climate models used to assess the impact of climate change on forest ecosystems and tree species ranges in the MANFRED project. RCM models are labeled in bold face, while the GCMs used to feed the RCMs are in normal font.

Model RCM /GCM	Scenario:	A1B	A2	B1	B2
CLM /ECHAM5, run by MPI		x	x	x	—
RACMO2 /ECHAM5, run by KNMI		x	—	—	—
HADRN3 /HadCM3, run by HC		x	—	—	—
HIRHAM3 /Arpège, run by DMI		x	—	—	—
RCA30 /CCSM3, run by SMHI		x	x	—	x
RCA30 /ECHAM5, run by SMHI		x	x	x	—

climate month of any RCM relative to the current climate, we use the simulated time series outputs for the re-analysis period of 1950–2000 from each RCM. By this, we avoid the projection of modeled bias in RCMs should the recent past be wrong compared to climate station measurements. We are only interested in projecting the relative difference between simulated recent past and simulated futures. Once anomalies are generated, we interpolate these anomalies to the high resolution of existing climate maps such as Worldclim and add them to these maps to project the future climate changes to the representations of the existing climate.

The development of climate anomalies was done by (a) first averaging the monthly time series of minimum (T_{min}), average (T_{ave}), maximum (T_{max}) temperature and precipitation (Pr_{cp}) over the period of 1951–2000 for each RCM run used, since these represent the same base period of Worldclim maps. Then we used monthly RCM outputs to calculate monthly anomalies relative to the 1950–2000 period means per month. We developed monthly anomalies: (a) by subtracting current from future climate for temperatures, and (b) by dividing future by current climate for precipitation. The latter results in ratios of change, which avoids negative precipitation values that could else result after downscaling if the difference method is used. All climate anomalies are first calculated at the spatial resolution of the RCM output, and is then scaled the medium resolution of 1 km by a bilinear interpolation (and in a second interpolation step to 100 m if necessary). Figure 2 illustrates the projected climate change trend from the six used RCM simulations by the example of the annual and seasonal (summer and winter half) means, and by the uncertainty in projected summer climates.

For temperature, we observe a general warming trend in the range of 1.1 to 4.1 °C, with least warming in the winter half in Atlantic regions (+1.5°C), and highest warming in the Boreal North (winter; +4°C) and Mediterranean South (summer; +3.5°C). The Alps generally face higher warming trends than the surrounding mainland, specifically in the winter months. The uncertainty among the six models is lowest in Southwestern Europe, increases towards North and East, and is highest in Eastern Europe. For precipitation, the trends show a similar and even clearer segregation between North and South. Winters are projected to become significantly wetter in Northern Europe (+30%), and to a lesser degree also in Central Europe (+15%), while Southern Europe is projected to become slightly drier (-15%). Summers are projected to become significantly drier in Southern Europe (-35%), and to a lesser degree also in Central Europe (-20%), while Northern Europe is projected to become slightly wetter (+20%). The uncertainty among the six models is highest in the (sub-) Mediterranean regions, in the Alps and in the far North of Europe.

General implication for forest management

For forest management, the projected climate anomalies may require specific actions to avoid significant loss in timber value. Least changes are likely required for (the far) Northern Europe. Here, the evaporative demand of a warming climate is balanced by higher precipitations both in winter and summer. Forest productivity can be expected to increase, and more thermophilic species may soon find suitable habitats in this region.

For Central Europe, the projections are still quite unclear. While there is a general warming trend projected, the models disagree as to the magnitude of warming, and whether precipitation will increase or decrease. But even if no changes in total precipitation amount will occur, there are likely to be two effects relevant to forest management. First, evaporative demands due to warmer temperatures can likely not be fully balanced, specifically because

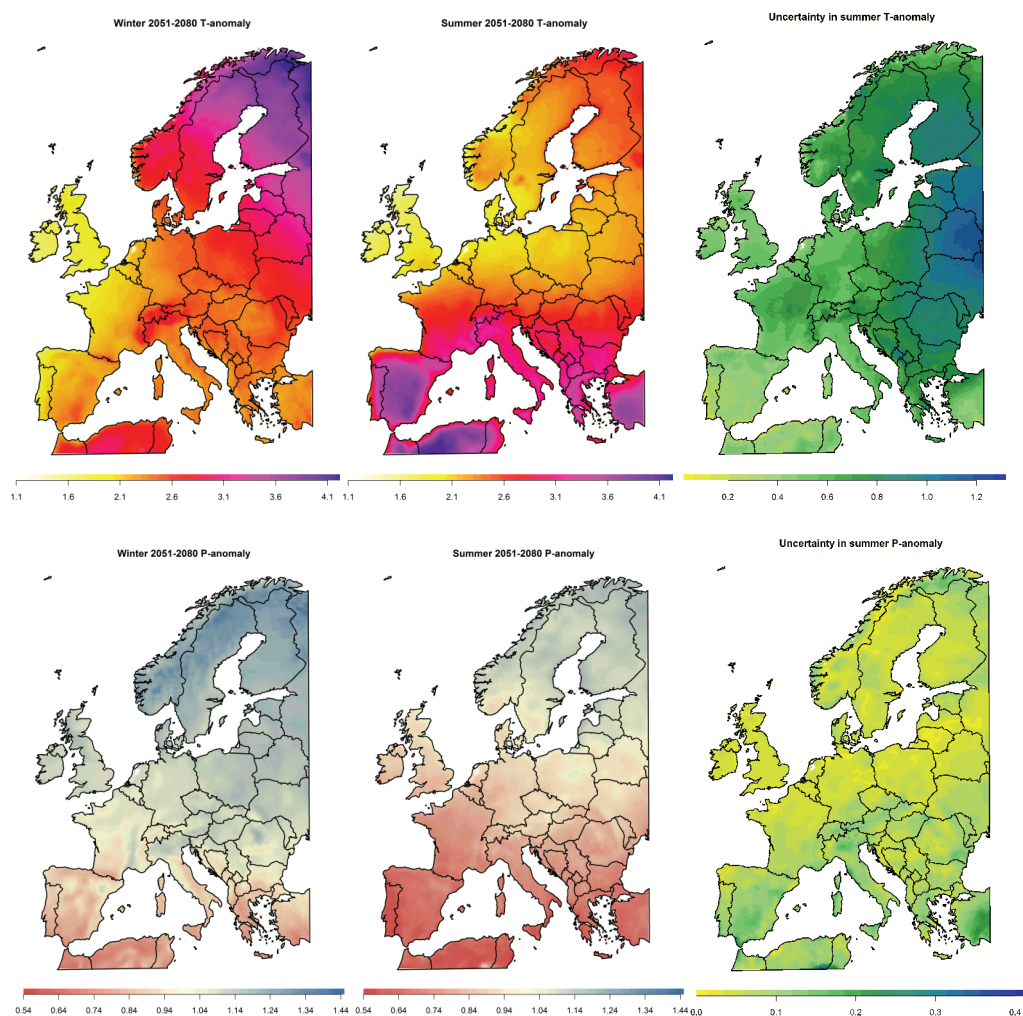


Figure 2. Climate anomalies for the A1B scenario by 2080 (deviations of the 2051–2080 period from the current, i.e. 1961–1990 climate) averaged over the six RCM models used to assess the impact of climate change on forest ecosystems and tree species ranges in the MOTIVE project. Top row: Anomalies for winter and summer temperature (in °C), and uncertainty (in °C) of summer temperature among all 6 RCMs used; Second row: Anomalies for winter and summer precipitation (in % compared to current), and uncertainty (in %) of summer precipitation among all 6 RCMs used.

summers become slightly drier, the result will be a net water loss for tree growth; the general tendency is a climate seasonality shift towards a more Mediterranean-type climate, away from a summer maximum and winter minimum in rainfall towards two rainfall peaks in spring and fall, with comparably dry summers. In some regions (especially towards the Atlantic coast), this trend is less pronounced, and both the changes in rainfall and in temperature are dampened by the proximity to the ocean.

Most severe changes with negative consequences for timber production can be expected for the Mediterranean region and its neighboring areas in Southern Europe. Here, precipitation is decreasing both in summer and winter, and temperatures are increasing in both seasons more (winter) or less (summer). This will result in much drier growth conditions, and is likely to have severe effects on the already water-limited forests. Only (and not shown in figures), the temporal variability for this region is specifically high with regards to rainfall, so that we may still expect some wet years in-between very dry years. This may mean that natural forest regeneration may still be possible.

While the general climate trends are still uncertain, as seen from the uncertainty maps originating from 6 RCM models, projections of climate extremes are even more difficult to make or to foresee. Several models, and even more so the deviation among models, are projecting that both the climate variability and the uncertainty of projections will become larger towards the end of the 21st century. In general, we can expect that both temperature and precipitation extremes will increase. This has the consequence that forest management becomes more difficult, because a larger range of possible conditions will need to be considered in the planning and decision-making.

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