Using Statistical Downscaling to Quantify the GCM-Related Uncertainty in Regional Climate Change Scenarios: A Case Study of Swedish Precipitation

Dehong CHEN1,2, Christine ACHBERGER1, Joumi RÄISÄNEN3, and Cecilia HELLMÖRD1

1 Earth Sciences Centre, Gothenburg University, Gothenburg, Sweden
2 Laboratory for Climate Studies/National Climate Center, China Meteorological Administration, Beijing, China
3 Department of Atmospheric Sciences, University of Helsinki, Finland

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ABSTRACT

There are a number of sources of uncertainty in regional climate change scenarios. When statistical downscaling is used to obtain regional climate change scenarios, the uncertainty may originate from the uncertainties in the global climate models used, the skill of the statistical model, and the forcing scenarios applied to the global climate model. The uncertainty associated with global climate models can be evaluated by examining the differences in the predictors and in the downscaled climate change scenarios based on a set of different global climate models. When standardized global climate model simulations such as the second phase of the Coupled Model Intercomparison Project (CMIP2) are used, the difference in the downscaled variables mainly reflects differences in the climate models and the natural variability in the simulated climates. It is proposed that the spread of the estimates can be taken as a measure of the uncertainty associated with global climate models. The proposed method is applied to the estimation of global-climate-model-related uncertainty in regional precipitation change scenarios in Sweden. Results from statistical downscaling based on 17 global climate models show that there is an overall increase in annual precipitation all over Sweden although a considerable spread of the changes in the precipitation exists. The general increase can be attributed to the increased large-scale precipitation and the enhanced westerly wind. The estimated uncertainty is nearly independent of region. However, there is a seasonal dependence. The estimates for winter show the highest level of confidence, while the estimates for summer show the least.

Key words: Statistical downscaling, global climate model, climate change scenario, uncertainty

1. Introduction

Climate varies at a variety of spatial scales. Regional (around $10^3$ km) is important for many climatic processes. Also, this is a scale that has a great implication for many applications. For example, to enable impact assessments of climate change on agriculture, forestry and energy production, regional climate change scenarios are needed. Such scenarios are not readily available from General Circulation Models (GCMs) with their current resolution (a few $10^2$ km). Therefore various techniques of downscaling GCM scenarios have been developed (Hewitson and Crane, 1996). Two commonly used methodologies are statistical downscaling and nesting of regional climate models (RCMs) within GCMs (Murphy, 2000; Fan et al., 2005).

Statistical downscaling has been extensively used to derive regional climate change scenarios in addition to dynamical downscaling in Nordic countries (Hansen-Bauer et al., 2005). It is essential that any future scenario include an assessment of the uncertainties associated with the prediction (Gioia and Francisco, 2000; Christensen et al., 2001). There are various techniques developed for estimating uncertainty (Katz, 2002). When statistical downscaling is used to derive future climate changes, uncertainties in the regional scenarios can be caused by uncertainty associated with the driving general circulation model (GCM), errors in the historical data used to build

*E-mail: deliang@gvc.gu.se
the downscaling model, the model (both GCM and statistical model) misrepresentations (Bodenstet, 2001; 2002), and shortcomings of the driving forcings to the GCM. One important source of uncertainty comes from the uncertainty in the GCM predictions that mainly results from the uncertain projection of future greenhouse gas emissions, omission of other climate forcings, stochastic fluctuations of the climate system, and model deficiency. The last problem may to some extent be evaluated by comparing the models’ ability to simulate the present climate (e.g., Busuioc et al., 2001a). However, it is difficult to assess how well a model simulates future climate.

One way to evaluate the uncertainty in regional climate scenarios associated with GCMs is to examine the difference between scenarios obtained by forcing the same predictors from different GCMs with the same statistical downscaling model. The standardized experiments of the CMIP2, the second phase of the Coupled Model Intercomparison Project (Meehl et al., 2000), provide an excellent opportunity to study the impact of the various GCM outputs on the statistically downscaled scenarios. This case study provides an application of this idea to Swedish precipitation scenarios by using a total of 17 GCMs from CMIP2.

Recently, statistical downscaling techniques have been successfully used in Sweden to construct future regional climate scenarios (e.g., Linderson et al., 2004). Although the dynamical downscaling with a regional climate model gives comparable results with that of the statistical downscaling over Sweden (Hellström et al., 2001) and the dynamical downscaling has the advantage of being physically based, the statistical downscaling does have the advantage of being simple and computationally inexpensive. This feature is utilized here to help assess the uncertainties in the precipitation scenarios for Sweden that are associated with the GCMs of the CMIP2.

2. Models and data used

2.1 The downscaling model and the data used

In this study, a regression-based model was used. A number of large-scale variables were tested for their usefulness to describe the relation between monthly large-scale circulation and precipitation data and local monthly precipitation statistics in Sweden. Multiple regression was applied to establish links between the predictors (large-scale climate variables) and predictand (local precipitation statistics). All the models were developed using the same predictors regardless of season or region. Monthly models were developed to account for variations in the precipitation-forming processes that may depend on season. The statistical downscaling models link monthly precipitation at the 42 Swedish stations shown in Fig. 1 with the large-scale atmospheric circulation and precipitation over Northern Europe shown in Fig. 2. The circulation is described by three indices containing information about geostrophic wind and vorticity over Scandinavia. They include the westerly (u) and southerly (v) components of the geostrophic wind and the total vorticity (σ). Figure 2 plots the predictor region with Sweden in the center. For a detailed description of the definition and calculation of the indices, the reader is referred to Chen (2000). This set of atmospheric circulation indices now covers the period of 1750–2000, which provides a useful climatology to study impacts of large-scale atmospheric forcing on regional climate and environment (Blencker and Chen, 2003; Omscheidt and Chen, 2001; Chen and Li, 2004). Many studies have dealt with the link between circulation and surface climate in the Nordic countries. The atmospheric circulation patterns including the zonal and meridional flows and the cyclonic/anticyclonic patterns largely influence the temporal variability of precipitation in Sweden (Busuioc et al., 2001b; Johansson and Chen, 2003). These studies justify the use of the three indices as the vorticity describes the strength of the cyclonic/anticyclonic circulation. The fourth predictor, the large-scale precipitation, is an average over the area between 55°N and 70°N and between 10°E and 25°E (Fig. 2). In developing a statistical downscaling model for precipitation in southern Sweden, Linderson et al. (2004) also used the large-scale precipitation as a predictor in order to capture the eventual signal from climate change and other processes besides the atmospheric circulation. The model development and validation closely follows Hellström et al. (2001) and Hellström and Chen (2003), with the only difference being that the forth predictor is precipitation rather than humidity. We use precipitation instead of humidity because of the data availability from the CMIP2 project. However, the large-scale precipitation and humidity have a similar function in carrying the climate change signals for the statistical model.

The statistical downscaling model was developed for each month for anomalies of the monthly predictors and predictand (precipitation). The NCEP reanalysis data (Kalnay et al., 1996) were used to create the predictors for the period 1958–1997. The precipitation data used for fitting the statistical model and for verification of the control simulations are the monthly time series of measurements at 42 Swedish stations from 1958 to 1997. The data have been homogenized/corrected through the North Atlantic Climatological Dataset (NACD) program (Frich et al., 1996). The data have recently been updated and provided by the Swedish Meteorological and Hydrological Institute (SMHI). For details of the model development and verification, the reader is referred to Hellström et al. (2001).