Abstract. Arctic environments are generally believed to be highly sensitive to human-induced climatic change. In this paper, we explore the impacts on the hydrological system of the sub-arctic Tana Basin in Northernmost Finland and Norway. In contrast with previous studies, attention is not only given to river discharge, but also to the spatial patterns in snow coverage and evapotranspiration. We used a distributed water balance model that was coupled to a regional climate model in order to calculate a scenario of climate change by the end of this century. Three different model experiments were performed, adopting different approaches to using the climate model output in the hydrological model runs. The results were largely consistent, indicating a much shorter snow season and, accordingly, decreased sublimation, an increase in evapotranspiration, and a shift in the annual runoff peak. As the snow-free season is extended, the amount of solar radiation that is received during this period increases significantly. The results also show important local differences in the hydrological response to climate change. For example, in the scenario runs, the snow season was more than 30 days shorter at higher elevations, but in some of the river valleys, this was up to 70 days.

1. Introduction

Climate models generally agree that the greatest warming due to the enhanced greenhouse effect might occur at northern high latitudes, and in particular in the winter season. In addition, the precipitation over high latitude regions is mostly expected to increase, both in summer and in winter (Houghton et al., 2001). Although the combined effect of higher temperatures and precipitation is still uncertain, it seems likely that snow cover in these areas will decrease, and evapotranspiration will increase (Everett and Fitzharris, 1998). For the Nordic region, regional climate simulations, performed by the Swedish Meteorological and Hydrological Institute (SMHI, 1998), predict that by the end of this century the mean annual temperature in Northern Fennoscandia (i.e. Scandinavia and Finland) may have risen by 3–4 °C. Consequently, the growing season – which is defined as the number of days with daily mean temperature above 5 °C – will be extended by 30–60 days. Mean annual precipitation in Northern Fennoscandia is also expected to increase, by 10–40%, and the snow season may be shortened by 50 days (SMHI, 1998).

Hydrological processes in the arctic and sub-arctic ecosystems are highly sensitive to changes of these magnitudes (Nijssen et al., 2001; Dankers, 2002; Van der
Linden, 2002). At the regional or landscape scale, the impact of climate change on the hydrological system can be studied by using hydrological models, that generally operate on a much higher spatial resolution than global or regional climate models. Consequently, they are able to give much more detailed information on the consequences of changes in climate and hydrology for the ecosystem of a certain region. However, previous studies on the impact of climate change on northern hydrology primarily focused on river discharge, and treated snow cover in a lumped way (e.g. Van Blarcum et al., 1995; Van der Linden, 2002). Furthermore, the hydrological models that are used in regional-scale studies are all too often empirical in nature. In particular, snowmelt is frequently modelled by a highly empirical temperature-index approach that relates air temperatures above a certain threshold to snowmelt rates (Ferguson, 1999). Likewise, evapotranspiration is often simulated by empirical models such as the Thornthwaite and Mather (1955, 1957) model that was developed for temperate environments. Especially in the arctic and sub-arctic regions these empirical models may be inappropriate: not only is the hydrological system dominated by snowmelt in spring, and, to a lesser extent, by evapotranspiration by summer, but at these latitudes the solar radiation shows a pronounced seasonal pattern as well. In Northern Scandinavia for example, the potential solar radiation in mid-April is only 58% of that in mid-May (Dankers, 2002). Whether the empirical relations that are found for current climatic conditions remain valid if, for example, snowmelt happens one month earlier, is questionable.

The aim of this study is to present a more reliable and thorough assessment of the impact of climate changes on sub-arctic hydrology. For this purpose, a climate change scenario for the end of this century, taken from the regional climate model (RCM) HIRHAM4 (Christensen et al., 1998) that was driven by the global model ECHAM/OPYC (Roeckner et al., 1999), was used as input in the hydrological model TANAFLOW (Dankers, 2002). This model has been developed for the Tana River Basin in Northern Fennoscandia and since it uses physically based descriptions of snow accumulation, snowmelt, and evapotranspiration, it is believed to be more robust than empirical models. It should therefore be able to simulate these processes realistically, also under different climate and radiation conditions. What is more, since the model is fully distributed and runs at a higher spatial resolution than any climate model, it is able to give detailed spatial information at a scale that is more relevant to the ecological and hydrological processes in the landscape.

2. Study Area

The Tana River Basin is situated in the northernmost part of Fennoscandia (see Figure 1) and has a catchment area of approximately 16,000 km$^2$ (Mansikkaniemi, 1970). The Tana River (in Finnish Tenojoki) is one of the largest rivers in