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INTRODUCTION

The work, reported here, is part of Workpackage 1, Task 2.1. This task deals with the potential impact of changing climate on catchment mass fluxes. Existing meteorological, hydrological, biogeochemical and palaeolimnological data together with data from future climate scenarios are used to evaluate, how the components of the water cycle and catchment mass fluxes respond to past and predicted future changes in regional climate.
Long-term data series of air temperature and precipitation at selected key sites have been collated and evaluated for possible time trends. Predicted future changes of temperature and precipitation towards the end of this century have been estimated from climate scenario data, which were derived from the RCAO model of SMHI (Sweden) for the SRES scenarios A2 and B2 (Räisänen et al., 2004).
Here we concentrate on the impact of changing air temperature and precipitation on the water cycle at five key sites, i.e. the catchments of Valkea-Kotinen (Finland), Čertovo Lake (Bohemian Forest, Czech Republic), Skalnaté pleso (Tatra Mountains, Poland), Lakes Boden and Lakes Paione (Italy), and Piburger See (Tyrol, Austria). Results and experiences from the 5 sites are reported as follows:

CASE STUDIES

A. Water balance components and application of the HBV-model Valkea-Kotinen (SYKE)

1. Site description

Valkea-Kotinen is an intensively studied small (30 ha) headwater catchment situated in a remote, unmanaged forested area in southern Finland (Table 1). It is located in a protected conservation area and only receives background levels of air pollution (Ruoho-Airola et al. 1998; Ukonmaanaho et al. 1998). Typical of glaciated boreal terrains, the catchment contains areas of forested mineral soil (higher elevations), peatland (lower elevations and adjacent to the lakes and streams) and a discharge lake with stream. The mineral soils are predominately Podzols developed in shallow glacial drift (till) deposits (Starr and Ukonmaanaho, 2001). The forest cover at Valkea-Kotinen consists mainly of old-growth mixed stands of Norway spruce and deciduous species (birch and aspen) with large individuals of Scots pine present. The catchment contains a single discharge lake having a mean depth of 3m. Its water and that of the outlet stream are humic (average total organic carbon (TOC) concentrations = 17mg L^{-1}), having low pH (4.5) and alkalinity (−40 ueq L^{-1}).

Table 1. Characteristics of the Valkea-Kotinen catchment

Latitude and longitude	61◦14_N, 25◦04_E
Elevation (of lake) (m a.s.l.)	156
Relative relief (m)	40
Phytogeographic zone	Southern boreal
Area (ha)	30
Forest covered (ha)	24
Main species	*Picea abies*
Age (years)	155–190
Peatland (forested and open) (ha)	7
Lake area (ha)	4
Mean annual temperature (◦C)	4.5
Mean annual precipitation (mm)	637
Vegetation period (>5 ◦C) (days)	112
Bedrock geology	Mica gneiss
Surface deposit thickness (m)	0–3
Soil types	Histosols, Podzols with transitions to Cambisols

Streamwater samples have been taken since 1989 from a gauging weir installed just below the catchment boundary. Grab samples for chemical analysis are taken weekly during the spring (snowmelt) peak runoff period, once a month during summer, and bimonthly during autumn. Daily temperature and precipitation observations are available from the nearby Finnish Meteorological Institute weather station Lammi, where data recording started in 1965. Other stations in the region have longer records. Runoff measurements at the weir at Valkea-Kotinen started in 1990.

2. Water balance components and HBV-modelling at Valkea-Kotinen

2.1 Background

The SYKE work in Task 2.1 comprises: i) time series analysis using both standard methods and advanced statistical techniques such as neural network based modelling, and ii) the application of the dynamic INCA-C model for estimating the impact of climate change on fluxes and processes of organic carbon. INCA-C is a dynamic mass-balance modelling tool for predicting catchment carbon fluxes. It is an extension of the INCA framework currently used for modelling nitrogen and phosphorus transport (Wade et al. 2002a, b). INCA-C explicitly models dissolved organic and inorganic carbon in soil, open water and sediments. It also tracks particulate organic carbon. INCA-C is currently being developed and Valkea-Kotinen ha been chosen as one of the test sites. The INCA-C modelling work is carried out in close collaboration with Martyn Futter, Trent University, Canada.

For these tasks, and based on previous work (e.g. Moldan et al. 2001, Forsius et al. 2005, Holmberg et al. 2006) a comprehensive data base on meteorological variables, hydrology, catchment characteristics and soil and water chemistry has been compiled for the Valkea-Kotinen site. Mean monthly values for key meteorological and hydrological variables for the control period (1961-90) for the 3rd order river basin including Valkea –Kotinen are presented in Tables 2-4.

2.2 Calibration of the HBV-model

Analysis of future climate change impacts on mass fluxes of chemical elements requires modelling of the water balance components. The hydrological model HBV (Sælthun 1996) forms an integrated part of the INCA-C model system, and a good hydrological calibration is essential for the INCA-C model performance. As a first phase of the modelling work, the HBV model routine has therefore been applied at the Valkea-Kotinen site using the available long-term data for hydrological and meteorological variables (daily data). The model was tested using both daily and monthly values. Measured and modelled flows and soil moisture deficits are shown here to illustrate the current model performance (Figs. 1 and 2). These initial model test runs are promising and in most cases the model performance is rather good. Some problems remain particularly in predicting late autumn runoff values (Fig. 1). Both the HBV and INCA-C modelling work is currently in progress and the aim is to produce a manuscript for a scientific paper during winter 2006/2007.

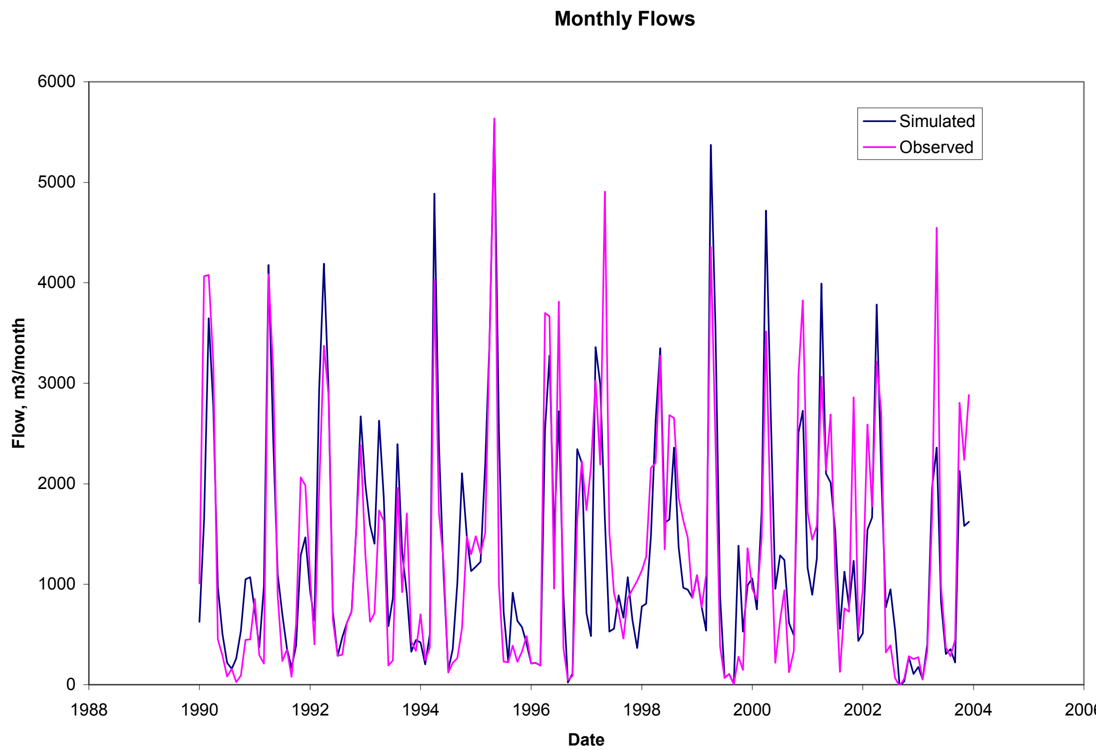

Figure 1. Observed and simulated monthly flows at the Valkea-Kotinen site using the HBV-model.

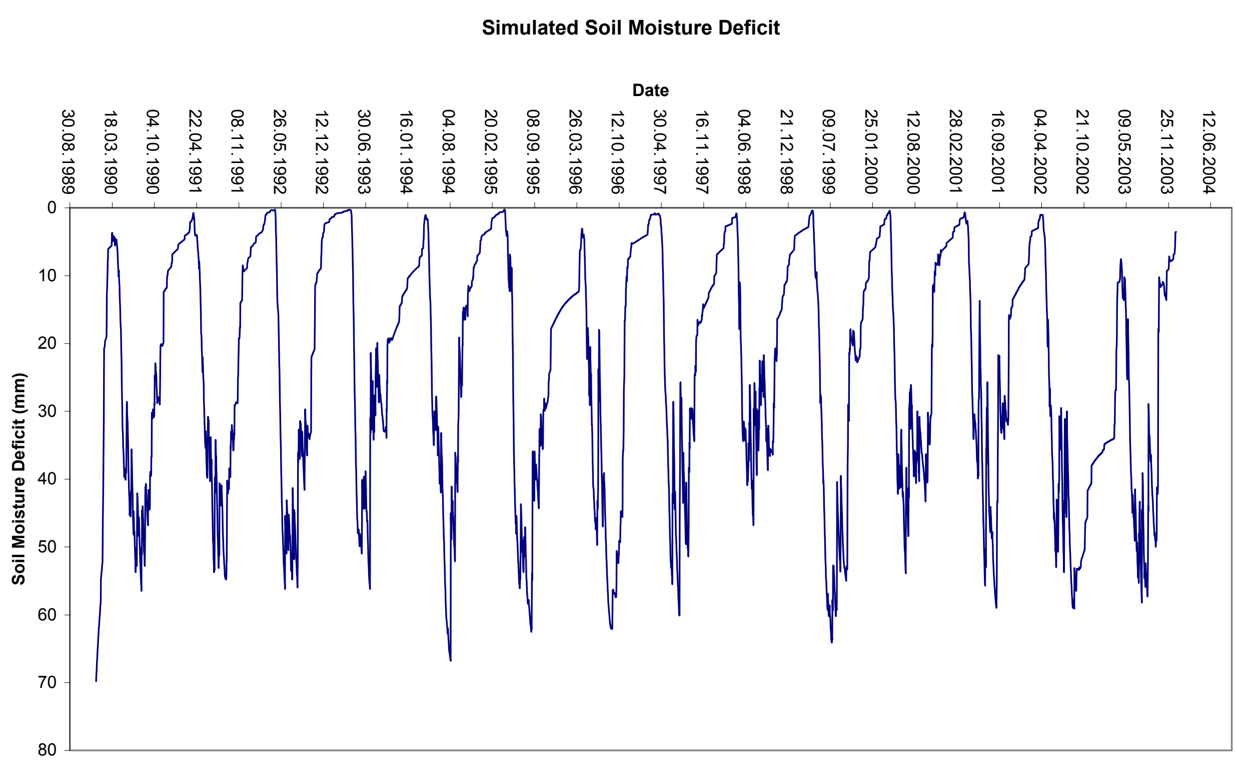

Figure 2. Simulated soil moisture deficit at the Valkea-Kotinen site using the HBV-model.

2.3 Preliminary climate change simulations using the HBV-model at Valkea-Kotinen

In addition to the site-specific HBV-model calibration described in section 2.2 above, some first climate change simulations for Valkea-Kotinen have also been carried out with a Finnish version of the HBV-model system, which is used for operational hydrological forecasting (Huttunen and Vehviläinen 2001). Results of two global circulation models were used: HadAM3 and ECHAM4/OPYC3 (Max Planck Institute für Meteorologie), as well as two different SRES-emission scenarios of the IPCC: A2 and B2. Of these scenarios A2 represents a more pessimistic future with high emissions, and B2 a more optimistic lower emission scenario. From these models and scenarios, downscaled results, obtained from the RCAO-model of the Swedish Rossby Centre on a 0,5 degree grid resolution, were used for the HBV-simulations for the years 2071-2100. In the HBV-simulations, both the temperature and precipitation changes were assumed to directly follow the change given by the climate scenarios ('delta-change method'). The model runs were carried out at the 3rd order river basin which includes the Valkea-Kotinen sub-catchment.

The estimated changes in temperature and precipitation for Valkea-Kotinen for the different models and scenarios are presented in Table 2. As can be seen, there are large differences in the results, reflecting the uncertainties regarding the future predictions. Large changes in both temperature and precipitation are predicted, particularly for the winter months.

Table 2. Mean monthly air temperatures and precipitation for Lake Valkea-Kotinen (3rd order river basin) in the control period (1961-1990) and their expected changes between the control and simulation (2071-2100) periods, as predicted by the HadAM3 (HA) and ECHAM4/OPYC3 (EC) models for the A2 and B2 scenarios.

Month	Temperature change between the control and simulation period (simulation – control, ΔT °C).					Precipitation increase between the control and simulation period (simulation to control ratio).				
	Control °C	HAA2 ΔT	HAB2 ΔT	ECA2 ΔT	ECB2 ΔT	Control mm	HAA2 ratio	HAB2 ratio	ECA2 ratio	ECB2 ratio
JAN	-8.5	5.6	3.3	7.5	6.2	43	1.28	1.26	1.67	1.68
FEB	-8.4	3.9	3.1	6.4	5.3	31	1.01	0.93	1.53	1.29
MAR	-4.2	4.5	3.5	5.0	3.8	32	1.07	1.06	1.44	1.27
APR	2.0	4.3	2.8	3.8	3.2	32	1.13	0.98	1.19	1.06
MAY	8.7	2.9	1.3	3.0	2.5	45	1.28	1.45	1.10	1.05
JUN	13.5	3.0	0.7	3.1	2.2	82	1.09	1.10	1.03	1.01
JUL	15.1	2.9	1.8	3.7	2.7	85	0.89	0.97	0.80	0.86
AUG	13.4	3.7	2.6	3.8	2.9	89	0.85	1.02	0.95	1.08
SEP	8.3	4.1	3.1	4.4	3.2	69	1.19	0.99	1.34	1.31
OCT	3.7	4.5	3.4	5.7	4.5	63	1.09	1.15	1.51	1.41
NOV	-1.5	5.7	3.9	5.7	4.5	59	1.31	1.23	1.37	1.25
DEC	-5.8	4.1	2.8	5.0	3.9	53	1.13	1.11	1.23	1.18
YEAR	3.2	5.8	4.6	7.3	5.6	706	1.54	1.25	1.61	1.43

Using these climate change scenarios the HBV-model was then run at the 3rd order basin which includes Valkea-Kotinen, and mean monthly values for evapotranspiration, snow water equivalent, and runoff for the 2071-2100 scenario period are presented in Tables 3 and 4, respectively. A decrease in snow water equivalent is predicted, despite the predicted precipitation increases (Table 3). An increase in runoff during the winter months is predicted for all scenarios, as well as an increase in total yearly runoff. However, the decreasing amount of snow results in a smaller runoff peak during the snowmelt period in spring (Table 4).

The HBV-modelling work is still ongoing, and the results will in a later stage be used for estimating changes in material fluxes. Results of the two current HBV-model versions will also be compared.

Table 3. Mean monthly evapotranspiration (ET; mm) and snow water equivalent (SWE; mm of water equivalent) at Lake Valkea-Kotinen (3rd order river basin) in the control period (1961-1990) and their average (± standard deviation) changes (ΔET and ΔSP, respectively) in the simulation (2071-2100) period, as predicted on the basis of the HadAM3 (HA) and ECHAM4/OPYC3 (EC) models for the A2 and B2 scenarios.

Month	Evapotranspiration (mm)					Snow water equivalent (mm)				
	Control ET (mm)	**HAA2 ΔET ±SD**	**HAB2 ΔET ±SD**	**ECA2 ΔET ±SD**	**ECB2 ΔET ±SD**	**Control SnWE (mm)**	**HAA2 ΔSP ±SD**	**HAB2 ΔSP ±SD**	**ECA2 ΔSP ±SD**	**ECB2 ΔSP ±SD**
JAN	0±0	1±1	1±1	1±1	1±1	58±33	-49±33	-45±31	-51±32	-48±32
FEB	0±0	1±2	1±2	2±2	2±2	78±39	-60±38	-57±37	-67±38	-63±38
MAR	1±2	8±7	7±7	10±8	9±7	89±45	-75±42	-70±41	-83±42	-79±42
APR	18±10	17±5	16±5	17±6	17±5	65±42	-63±38	-61±36	-65±41	-63±38
MAY	66±9	0±6	-1±6	1±6	0±6	12±15	-12±15	-12±15	-12±15	-12±15
JUN	70±10	-4±6	-2±5	-5±6	-6±5	0±1	0±1	0±1	0±1	0±1
JUL	59±8	4±3	6±3	1±3	0±3	0±0	0±0	0±0	0±0	0±0
AUG	52±8	2±2	4±2	0±2	0±2	0±0	0±0	0±0	0±0	0±0
SEP	27±4	0±1	2±1	0±1	1±1	0±0	0±0	0±0	0±0	0±0
OCT	10±2	3±1	4±1	3±1	4±1	1±1	-1±1	0±1	-1±1	0±1
NOV	1±1	2±1	3±1	4±1	2±1	8±10	-8±10	-7±9	-8±10	-7±10
DEC	0±0	27±15	2±1	2±1	2±1	30±20	-27±20	-23±17	-27±19	-25±18
YEAR	315±18	40±11	45±11	36±12	33±11	29±14	-25±12	-23±12	-27±12	-25±12

Table 4. Mean monthly runoff (Q; mm) from the Lake Valkea-Kotinen catchment (3rd order river basin) in the control period (1961-1990) and its average (± standard deviation) change (ΔQ; mm) in the simulation (2071-2100) period, as predicted on the basis of the HadAM3 (HA) and ECHAM4/OPYC3 (EC) models for the A2 and B2 scenarios.

Month	**Control Q (mm)**	**HAA2 ΔQ ± SD**	**HAB2 ΔQ ± SD**	**ECA2 ΔQ ± SD**	**ECB2 ΔQ ± SD**
JAN	13 ± 5	31 ± 21	25 ± 19	40 ± 24	33 ± 22
FEB	11 ± 6	21 ± 13	19 ± 13	34 ± 16	31 ± 17
MAR	12 ± 12	24 ± 14	20 ± 14	39 ± 21	34 ± 19
APR	39 ± 18	2 ± 28	2 ± 27	8 ± 27	6 ± 28
MAY	62 ± 26	-32 ± 21	-32 ± 19	-26 ± 22	-29 ± 20
JUN	36 ± 12	-3 ± 9	-1 ± 8	-3 ± 9	-6 ± 8
JUL	31 ± 12	4 ± 4	6 ± 4	2 ± 4	-1 ± 4
AUG	27 ± 11	1 ± 4	4 ± 4	-2 ± 4	-2 ± 4
SEP	26 ± 11	-2 ± 4	2 ± 3	-3 ± 4	0 ± 3
OCT	27 ± 14	2 ± 3	1 ± 3	5 ± 4	6 ± 4
NOV	25 ± 12	9 ± 10	9 ± 10	20 ± 14	19 ± 13
DEC	18 ± 11	23 ± 13	18 ± 11	32 ± 15	26 ± 12
YEAR	338± 85	82 ± 31	77 ± 30	151 ± 39	121 ± 35

B. The potential impact of changing air temperature of and precipitation on the water balance in the Bohemian Forest, Czech Republic

Jan Turek, Josef Hejzlar and Jiří Kopáček (HBI-BCASCR)

1. Site characteristics

The study area (Čertovo Lake; 13°12' E; 49°10' N) is situated in the Bohemian Forest, Czech Republic at elevation of 1028 m above see level (a.s.l.). Čertovo Lake is a dimictic, oligotrophic lake of glacial origin, with surface area of 10.5 ha, maximum depth of 36 m, mean depth of 17.9 m, and lake volume of 1.852×10^6 m^3 (Švambera, 1939). The lake has seven surface tributaries and one surface outlet. The Čertovo Lake catchment (87.5 ha including the lake) is steep, with a maximum local relief of 315 m, and almost completely forested with 90–150 years old Norway spruce.

2. Climatic and hydrologic data

Precipitation and throughfall deposition were sampled at the Čertovo Lake catchment in 1992-2005. Precipitation was collected in an open area without trees (2 samplers) at an elevation of 1175 m, <1 km north of the lake catchment. Throughfall was sampled at two forest plots (9 samplers each) at elevations of 1045 and 1330 m a.s.l. within the catchment. Rain was sampled in two-week intervals, and snow in four-week intervals. Runoff from the Čertovo Lake catchment and air temperature (T_{AWS}) were monitored at a gauging station, equipped with a calibrated weir situated ~150 m downstream of the lake (~1000 m a.s.l.) in 1997-2005, using an MS16 automatic recording station (J. Fiedler, České Budějovice; readings in 15-minute intervals). Water balance was obtained (and successfully checked by Cl^- balance) for 8 hydrological years from 1998 through 2005 (Kopáček et al., 2000, 2001, 2006).

Long-term climatic data are from the Czech Hydrometeorological Institute. We used the following Bohemian Forest stations: (1) Churáňov station, situated in the central part of the Bohemian Forest ~50 km east of Čertovo Lake at 13°37' E, 49°04' N, and 1122 m a.s.l.: the 1961-2005 database includes daily data on air temperature (records at 7, 14, and 21 h; $T_{CH\text{-}7h}$, $T_{CH\text{-}14h}$, and $T_{CH\text{-}21h}$, respectively), precipitation, snow pack, relative humidity, cloudiness, and wind velocity. (2) Špičák station, situated ~2 km north-east of Čertovo Lake (13°14' E, 49°11' N, 960 m a.s.l.): the 1964-2005 database includes daily data on precipitation and snow pack. The long-term climatic records and our measurements in the study site were used to reconstruct temperature and precipitation at Čertovo Lake in 1961-1990 (control period).

2.1 Modelling mean daily air temperature at Čertovo Lake in the 1961-2005 period

Mean daily air temperatures at Čertovo Lake were reconstructed from the Churáňov data by Kettle et al. (2003) as follows. First, average daily air temperatures at Čertovo Lake ($T_{CT\text{-}d}$) were obtained as an arithmetic mean of the 15-minute interval T_{AWS} data. Second, the $T_{CT\text{-}d}$ data were divided into months and a separate equation (1) was derived for each month to achieve best fit with the Churáňov data:

$$T_{CT-d} = a + b\,T_{CH-7h} + c\,T_{CH-14h} + d\,T_{CH-21h} \quad (1)$$

For the individual parameters *a*, *b*, *c*, and *d* see Kettle et al. (2003). The models give an average daily error of 0.72°C for the mean daily air temperature at Čertovo Lake, but as with all linear regression models, the predictions tend to underestimate extreme events (Kettle et al., 2003). This model was used to reconstruct mean daily air temperatures at Čertovo Lake back to 1961.

2.2 Modelling monthly precipitation data at Čertovo Lake in the 1961-2005 period

Monthly precipitations at Čertovo Lake were reconstructed from the Špičák data as follows. First, monthly precipitations at Čertovo Lake in the 1992-2005 period were set equal to (i) precipitation measured in the open area without trees (to avoid evaporation from canopies) from May to October and (ii) to throughfall deposition (to include vertical deposition like rime in the canopies, and to avoid blowing out the snow from the samplers in the open area) from November to April. Second, separate regression equations were derived for each month to achieve best fit with the Špičák data. This model was used to reconstruct monthly precipitation at Čertovo Lake back to 1961. Third, the missing Špičák data in the 1961-1963 period were derived from the Churáňov data, using linear regressions between the Špičák and Churáňov data calculated on monthly basis for the 1964-2005 period.

2.3 Climatic scenarios

Modelled trends of the major climatic parameters come from two Global circulation models HadAM3 (HA) and ECHAM4/OPYC3 (EC). Each model simulated data for the control period (1961-1990) and two scenarios of CO_2 emissions into the atmosphere (A2 and B2; Fig. 1), for the simulation period (2071-2100). The resulting data were downscaled by regional climate model RCAO (www.prudence.dmi.dk), providing four scenarios for the simulation period (HAA2, HAB2 and ECA2, ECB2).

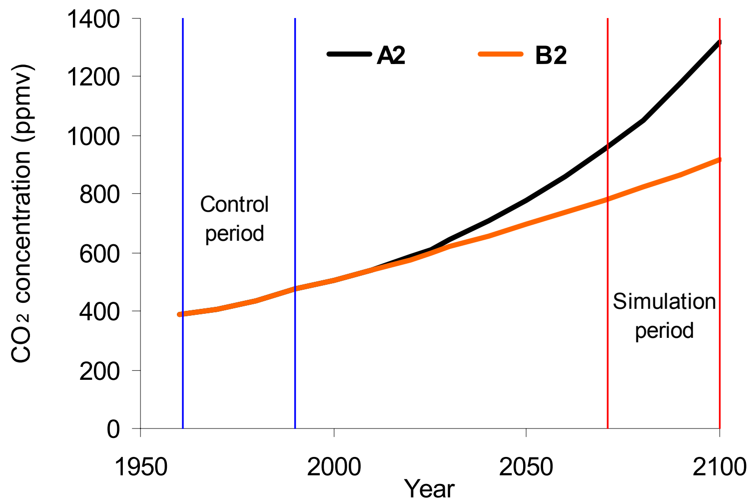

Figure 1. Two scenarios (A2, B2) of equivalent global CO_2 emissions. Control and simulation period of RCAO runs are marked with blue and red vertical lines, respectively. Data are from the Intergovernmental Panel on Climate Change (www.ipcc.ch).

The results are available for 50 by 50 km grids. We used monthly mean air temperature, and precipitation for the grid including the Bohemian Forest, with the centre at 13°51'14" E and 49°1'55" N. The average elevation of this grid was 705 m a.s.l.

3. Modelling of the hydrological cycle

Trends in individual components of the water balance in the Čertovo catchment-lake ecosystem were simulated using the Hydrologic Simulation Program–Fortran (HSPF). The HSPF is a conceptual lumped model, solving the components of water balance in 3 zones above ground and 4 zones in soil horizons (Bicknell et al., 2001). The model was run in daily steps to better simulate development of snow pack, using air temperature, precipitation, and potential evapotranspiration. The daily data on air temperature were obtained from the monthly averages as follows: The monthly average temperatures were attributed to the middles of the months and linear interpolation between two adjacent months was used to calculate daily data during these periods. Daily precipitation was calculated from the monthly data, divided by number of days. Potential evapotranspiration (PET) was calculated according to Penman-Monteith equation (Monteith 1965) in daily steps, using the recalculated daily air temperatures at Čertovo Lake and the daily averages for relative humidity, cloudiness, and wind velocity measured at Churáňov station. The daily data were aggregated to monthly values.

3.1 Calibration of HSPF

The HSPF parameters were set to achieve best fit with the measured runoff in the 1997-2004 period as follows: (i) A day-degree method for snow accumulation and melt was used. (ii) The most sensitive parameter of infiltration rate was set to 0.55 mm hr^{-1}. (iii) The capacities of soil storages (lower zone nominal storage and upper zone nominal storage) were set to minimum, due to the used stable precipitation input and evapotranspiration output during a month, caused by the disaggregation of monthly averages. The fit between HSPF simulated runoff and the measured data at the Čertovo Lake outlet was reasonably successful (Fig. 2), with Nash-Sutcliffe (1970) coefficient of model efficiency = 0.74 and mean monthly absolute error = 29 mm. However, the timing of the simulated melting did not always fit precisely the observed data, and the simulated baseflow was lower than the observed data during a drought in summer 2003 (Fig. 2 – left). Despite this bias, the HSPF simulation reasonably estimated water balance for the whole calibration period, with the cumulative error of the runoff = 75 mm for 1997 through 2004. Consequently, we used the HSPF simulation to estimate potential differences in the hydrological cycle between the 1961-1990 and 2071-2100 periods.

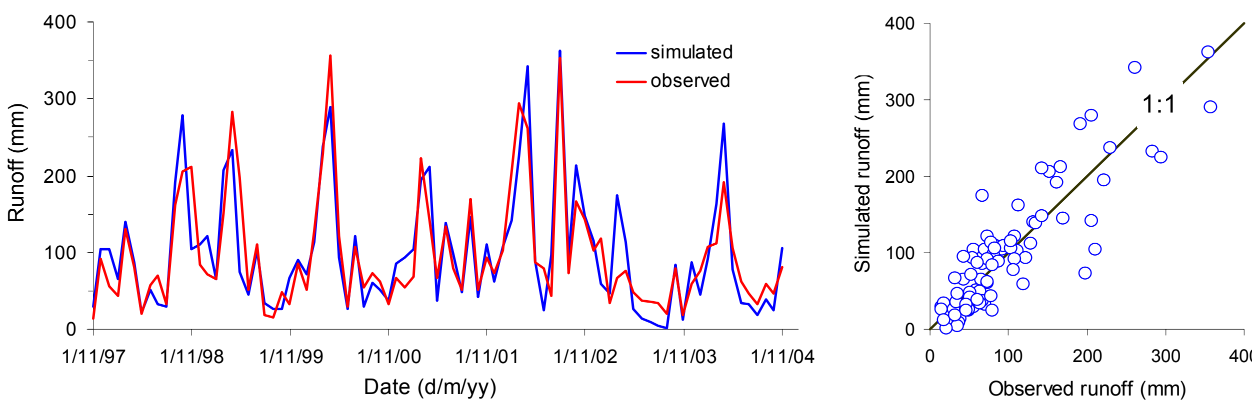

Figure 2**.** Comparison of simulated and observed runoff (monthly averages) from the Čertovo Lake catchment during calibration period 1997–2004 (left). Right: Observed monthly runoff vs. simulated monthly runoff.

3.2 Modelling of the control period 1961-1990

The calibrated model was used to simulate runoff from the Čertovo Lake catchment with the following results. The variability in monthly precipitation was similar during both the control and the shorter calibration period, because of two extreme events - floods in 2002 and dry and hot summer 2003 (Fig. 3 – upper panel). The variability in the mean monthly air temperature was also similar for both periods, but the control period was on average 0.9 °C colder (Fig. 3 – lower panel). The annual average temperatures at Churáňov station varied from 3.1 to 5.6 °C (with average of 4.2 °C) in 1961-1990 and from 4.5 to 5.9 °C (with average of 5.1 °C) in 1997-2005. The average annual courses of temperature were almost identical for the control and calibration periods, while those of precipitation differed, being higher in January-March and July-October and lower in April during the calibration period (Fig. 4). Due to the similarity in frequency distribution of the input data (Fig. 3 – right), the frequency distribution of the HSPF simulated monthly runoff was also similar for both periods (Fig. 5).

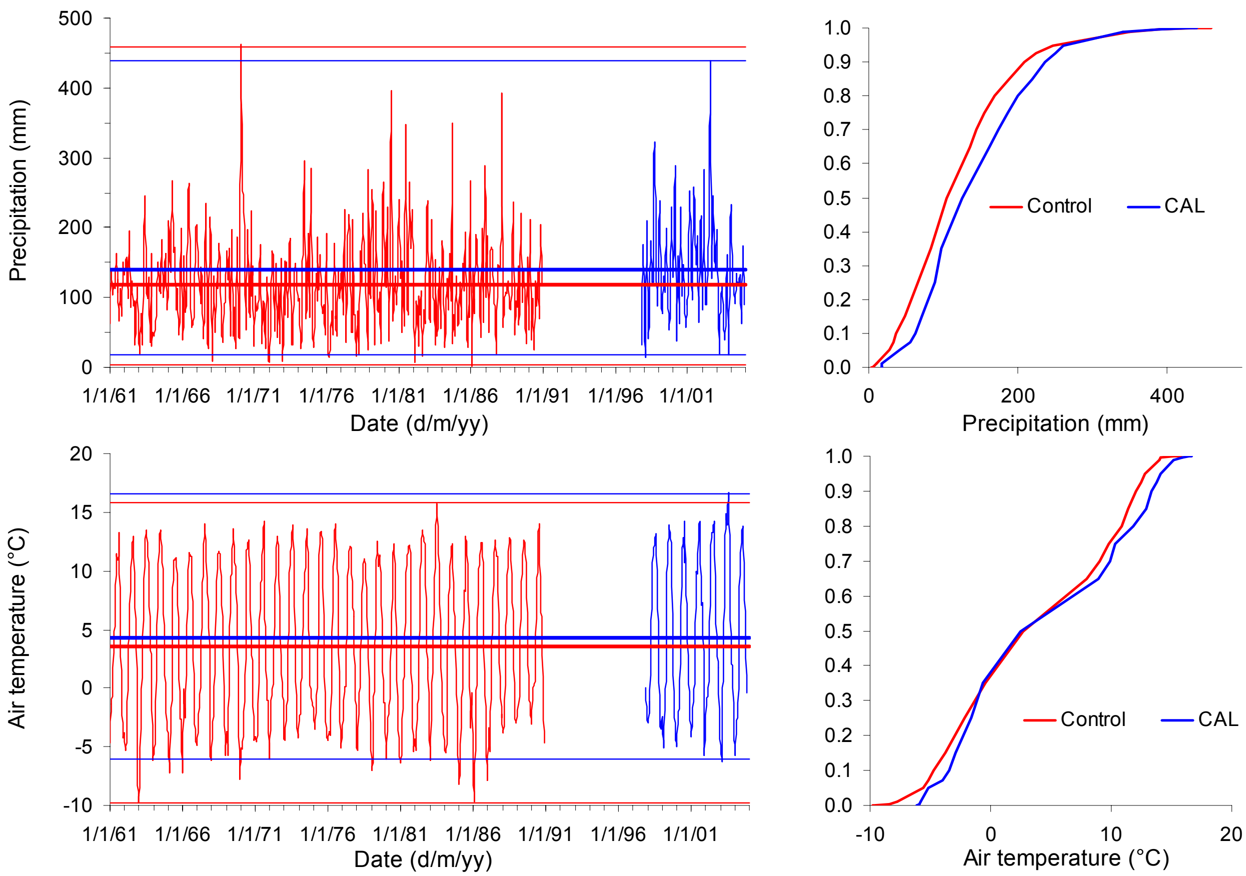

Figure 3. Monthly precipitation (upper panel) and monthly average air temperature (lower panel) at Čertovo Lake in the control (1961–1990) and calibration (CAL; 1997–2004) period (left). Horizontal lines represent average, minimum, and maximum values for the respective period. Right: cumulative frequency diagram of monthly precipitation and monthly average air temperature during the control and calibration periods.

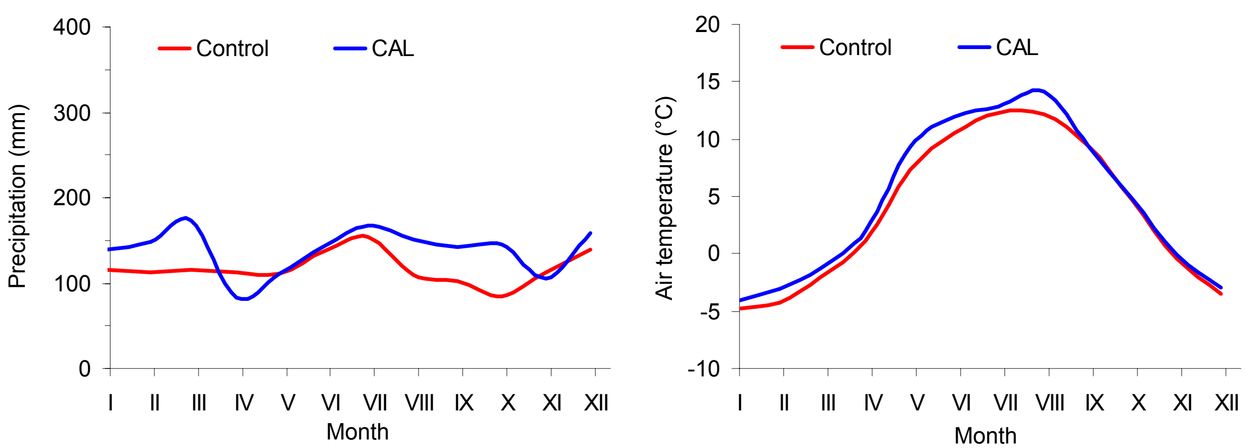

Figure 4. The average annual courses of temperature and precipitation in the control (1961–1990) and calibration (CAL; 1997–2004) period.

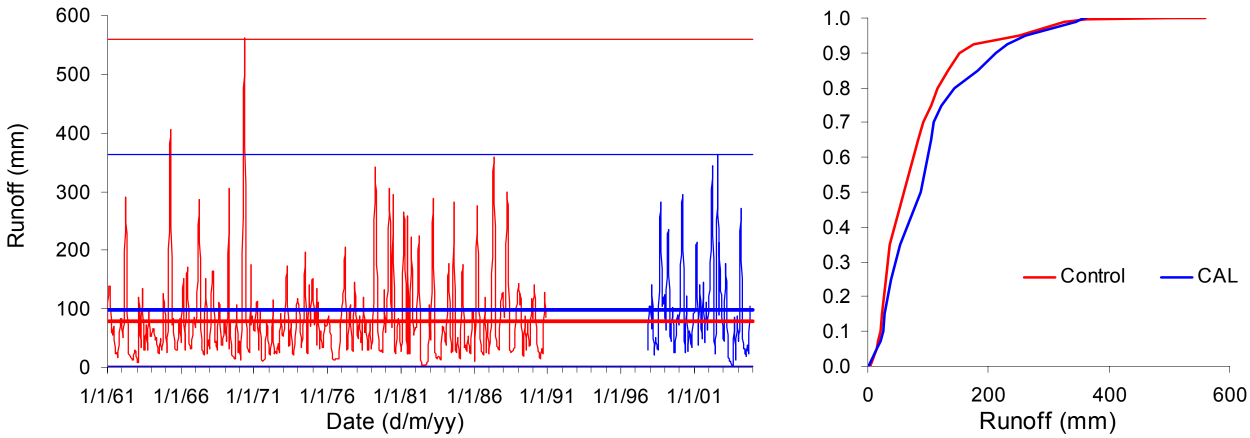

Figure 5**.** Monthly average runoff from the Čertovo Lake catchment in the control (1961–1990) and calibration (CAL; 1997–2004) period (left). Horizontal lines represent average, minimum, and maximum values for the respective period. Right: cumulative frequency diagram of monthly average runoff during the control and calibration periods.

3.3 Modelling of the simulation period 2071-2100

The major problem of the modelling was associated with transformation of the control and simulation trends (provided by the HA and EC models) to the study site, because the models show the average change in the climatic parameters between the two periods, and do not reflect the real time series of temperature and precipitation events. Consequently, we did not find any significant relationship between the 1961-1990 data on air temperature and precipitation at Čertovo Lake and the HA and EC controls on the monthly, seasonal, or yearly basis. Statistical distribution of data was similar only for air temperature but the variability in monthly precipitation was up to 3 times higher at Čertovo Lake than in the HA and EC controls.

Table 1. Mean monthly air temperatures and precipitation at Čertovo Lake in the control period (1961-1990) and their expected changes between the control and simulation (2071-2100) periods, as predicted by the HadAM3 (HA) and ECHAM4/OPYC3 (EC) models for the A2 and B2 scenarios.

Month	Temperature change between the control and simulation period (simulation – control, ΔT °C).					Precipitation increase between the control and simulation period (simulation to control ratio).				
	Control °C	HAA2 ΔT	HAB2 ΔT	ECA2 ΔT	ECB2 ΔT	Control mm	HAA2 ratio	HAB2 ratio	ECA2 ratio	ECB2 ratio
1	-4.8	6.7	4.5	5.0	3.8	116	1.20	1.12	1.02	1.10
2	-4.2	5.8	3.7	5.8	5.8	113	1.33	1.40	1.22	1.33
3	-2.0	4.7	3.5	5.9	4.7	116	1.35	1.43	1.05	1.06
4	1.2	5.1	3.2	5.4	3.5	112	0.90	1.07	0.81	0.87
5	7.4	4.3	3.0	4.5	3.0	111	1.01	1.01	0.92	0.99
6	10.5	4.6	3.7	6.1	4.0	138	0.99	0.90	0.73	0.84
7	12.3	6.1	4.7	8.2	4.6	153	0.79	0.80	0.50	0.87
8	12.2	7.7	5.9	10.3	6.7	110	0.58	0.63	0.35	0.61
9	9.4	6.7	5.2	6.3	4.4	102	0.84	0.82	0.83	0.99
10	4.7	5.6	3.9	5.1	3.4	84	1.16	1.11	1.07	1.11
11	-0.4	4.9	4.5	4.9	4.3	113	0.86	0.86	1.13	1.10
12	-3.5	5.7	4.4	5.2	4.6	140	1.19	1.27	1.39	1.32
Year	3.6	5.7	4.2	6.1	4.4	1409	1.02	1.03	0.92	1.02

Because we were not able to find any reasonable statistical transformation of the HAA2, HAB2, ECA2, and ECB2 scenarios to the Čertovo Lake, we used a simplified approach to estimate an average change between the control and simulation periods at the study site as follows: First, we focused on the data for air temperature and precipitation that have the most important impact on the hydrological cycle in the HSPF simulations. Changes in other climatic data (relative humidity, cloudiness, and wind velocity) were not assumed in this simplified estimation. Second, we calculated the average air temperature and precipitation for each month during the control period (for Čertovo Lake and controls of the HA and EC models) and simulation periods (HAA2, HAB2, ECA2, and ECB2). Third, we assumed that a change, similar to that predicted by the individual scenarios, would occur also at Čertovo Lake. This change was calculated for each month as (i) the difference between the average air temperature predicted by the HAA2, HAB2, ECA2, and ECB2 scenarios and their respective HA and EC controls, and (ii) the ratio of the average precipitation predicted by the HAA2, HAB2, ECA2, and ECB2 scenarios to their respective HA and EC controls. Then, the four scenarios were calculated for Čertovo Lake as the (i) sums of the average air temperature at Čertovo Lake during the control period and the respective change in the scenarios, and (ii) products of the average precipitation at Čertovo Lake during the control period and the respective ratios, obtained for the individual scenarios (Table 1). Fourth, the monthly averages of air temperature and precipitation were transformed to daily data, used for the PET estimation, and together with the PET data used for the HPSF simulation as described for the control period. The other parameters of the HSPF, successfully set for the calibration period, remained unchanged.

Tables 2 and 3 summarise the resulting average monthly and annual changes in the individual components of water balance in the Čertovo catchment-lake ecosystem between the control and calibration periods, resulting from the HAA2, HAB2, ECA2, and ECB2 climate scenarios. The approach used did not allow us to simulate climatic data for individual years between 2071 and 2100, but only to simply evaluate the average change in hydrological cycle at Čertovo Lake between the control and simulation periods. Consequently, the variability in the data presented thereafter is hypothetical, being simulated by the HSPF with the new scenarios of air temperature and precipitation on the basis of the control period. The variability is, however, useful to show the significance of individual average changes.

Table 2. Mean monthly evapotranspiration (ET; mm) and snow pack (SP; mm of water equivalent) at Čertovo Lake in the control period (1961-1990) and their average (± standard deviation) changes (ΔET and ΔSP, respectively) in the simulation (2071-2100) period, as predicted on the basis of the HadAM3 (HA) and ECHAM4/OPYC3 (EC) models for the A2 and B2 scenarios.

Month	Evapotranspiration (mm)					Snow pack (mm of water equivalent)				
	Control ET (mm)	**HAA2 ΔET ±SD**	**HAB2 ΔET ±SD**	**ECA2 ΔET ±SD**	**ECB2 ΔET ±SD**	**Control SP (mm)**	**HAA2 ΔSP ±SD**	**HAB2 ΔSP ±SD**	**ECA2 ΔSP ±SD**	**ECB2 ΔSP ±SD**
1	0	26±16	10±12	16±15	8±10	117	-115±83	-97±64	-109±77	-93±62
2	0	22±16	10±14	22±16	21±16	176	-173±118	-134±98	-169±114	-157±103
3	3	36±12	24±13	40±12	34±13	200	-199±163	-159±128	-199±164	-197±161
4	28	30±13	27±11	29±13	26±12	131	-131±169	-119±138	-131±169	-131±169
5	67	11±16	7±14	10±18	7±14	29	-29±74	-28±70	-29±74	-29±74
6	80	17±12	11±12	14±22	11±14	1	-1±5	-1±5	-1±5	-1±5
7	90	13±21	10±17	-7±30	12±15	0	0±0	0±0	0±0	0±0
8	80	-7±18	-4±18	-29±16	-5±18	0	0±0	0±0	0±0	0±0
9	55	11±14	7±12	10±13	11±9	0	0±0	0±0	0±0	0±0
10	41	14±7	10±5	12±7	9±4	0	0±0	0±0	0±0	0±0
11	10	28±9	26±8	30±9	27±9	10	-10±9	-10±9	-10±9	-10±9
12	0	27±15	18±14	23±15	18±14	57	-57±37	-52±33	-56±36	-52±33
Year	453	228	157	168	179	60	-60±55	-50±45	-59±54	-56±51

Table 3. Mean monthly runoff (Q; mm) from the Čertovo Lake catchment in the control period (1961-1990) and its average (± standard deviation) change (ΔQ; mm) in the simulation (2071-2100) period, as predicted on the basis of the HadAM3 (HA) and ECHAM4/OPYC3 (EC) models for the A2 and B2 scenarios.

Month	Control Q (mm)	HAA2 ΔQ ± SD	HAB2 ΔQ ± SD	ECA2 ΔQ ± SD	ECB2 ΔQ ± SD
1	68	36 ± 87	32 ± 69	24 ± 73	39 ± 68
2	67	56 ± 120	56 ± 65	50 ± 116	78 ± 127
3	118	-4 ± 120	43 ± 129	-38 ± 96	-25 ± 98
4	187	-132 ± 83	-98 ± 102	-143 ± 83	-135 ± 82
5	111	-71 ± 113	-62 ± 95	-79 ± 117	-72 ± 114
6	59	-20 ± 26	-23 ± 28	-39 ± 39	-29 ± 33
7	65	-29 ± 37	-27 ± 33	-49 ± 68	-24 ± 26
8	36	-17 ± 23	-17 ± 23	-26 ± 24	-18 ± 22
9	46	-22 ± 21	-21 ± 21	-28 ± 22	-14 ± 13
10	47	-10 ± 15	-9 ± 11	-18 ± 14	-7 ± 10
11	74	-32 ± 22	-30 ± 22	-9 ± 31	-3 ± 30
12	81	36 ± 89	46 ± 82	65 ± 103	55 ± 86
Year	958	-209	-110	-290	-155

4. Impact of predicted climatic changes on the hydrological cycle in the Bohemian Forest

All scenarios predict a significant increase in air temperature in 2071-2100 compared to the control period 1961-1990 (Table 1). The average annual air temperature is assumed to increase by 4.2 to 6.1 °C, with the maximum increase in summer months (July to September). The most important change will, however, occur in winter (December to March), because the average monthly air temperatures (–2 to –4.8 °C in the control period) are expected to increase by 3.5 to 6.7 °C, i.e., mostly above the freezing point. All the scenarios predict significant changes in the seasonal cycle of precipitation. While there will be negligible changes on the annual basis (except for ECA2 scenario, which gives 8% lower precipitation amounts), precipitation will significantly increase (on average by 17-31% in the individual scenarios) in December-March, but will decrease (on average by 18-44%) in July-September (Table 1). The temperature increase and change in precipitation distribution will significantly affect all hydrological components of the ecosystem, like water accumulation in snow pack, soil water storage, evapotranspiration, and runoff (Fig. 6). On the annual basis, evapotranspiration will 35-50% increase (maximum for the HAA2 scenario; Table 2).

The annual runoff will decrease on average by 11-30% (with the minimum and maximum for the HAB2 and ECA2 scenarios, respectively), compared to the control period (Table 3). Besides, the runoff seasonality will change significantly due to the following reasons: (1) The amount of water accumulated in snow will significantly decrease throughout winter according to the HAB2 scenario, while the snow pack will be almost absent in the lake catchment according to the other scenarios (Fig. 6). More rain in winter will increase water storage in soil compared to the control period, and will cause (together with higher air temperature) higher evapotranspiration (Table 2). The net result of these changes will be elevated runoff during winter and its substantial decline in April. In contrast, during the control period, there was low winter discharge followed by a peak runoff in April due to the snowmelt. (2) Despite the highest increase in temperature in July-September (Table 1), evapotranspiration will increase only slightly due to lower precipitation and substantially decreased water storage in soil. The net result of these changes will be lower runoff (according to all scenarios) than during the control period (Fig. 6).

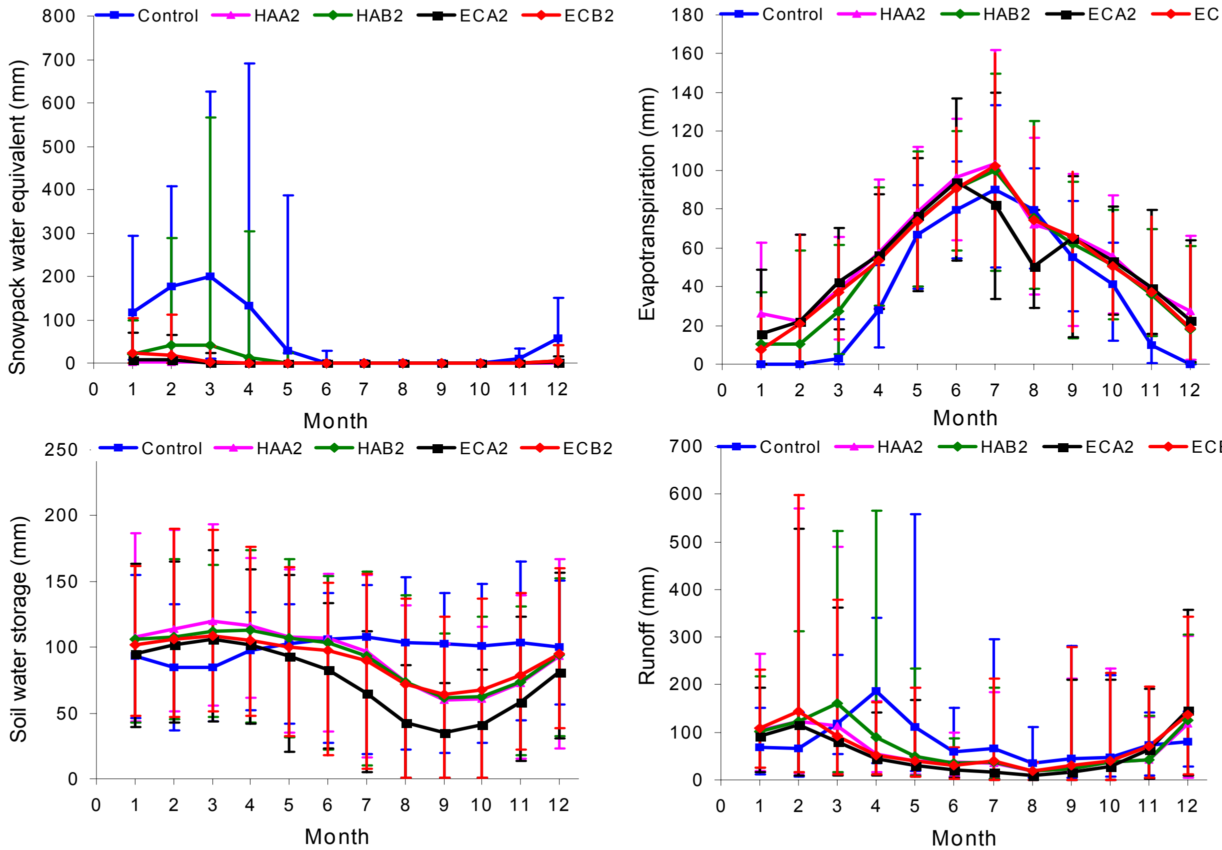

Figure 6. Seasonal cycle of monthly mean data on snow pack water equivalent, soil water storage, evapotranspiration, and outflow at Čertovo Lake in the control period (Control, 1961-1990) and in the simulation (2071-2100) period, as predicted on the basis of the HadAM3 (HA) and ECHAM4/OPYC3 (EC) models for the A2 and B2 scenarios. Vertical lines represent variability in the data during 30-year period.

The changes in seasonal distribution of precipitation and increase in air temperature will significantly affect important hydrologic parameters like snowfall to precipitation ratio and runoff coefficients (runoff to precipitation ratio) and their frequency distribution (Fig. 7).

5. Conclusions

(1) No significant relationships were found between the 1961-1990 trends in air temperature and precipitation in the Bohemian Forest and the HA and EC controls for the related grid on the monthly, seasonal, or yearly basis. Consequently, we used a simplified approach to estimate average changes between the control and simulation periods for the Čertovo Lake catchment on the basis of the average differences between the HAA2, HAB2, ECA2, and ECB2 scenarios and their respective HA and EC controls. Then, the simulation scenarios for the Čertovo Lake catchment were prepared on monthly basis for air temperature and precipitation.

(2) The new scenarios were used for the HPSF simulation. In the previous step, the HSPF was calibrated to achieve best fit with the measured hydrological data at Čertovo Lake in the 1997-2004 period.

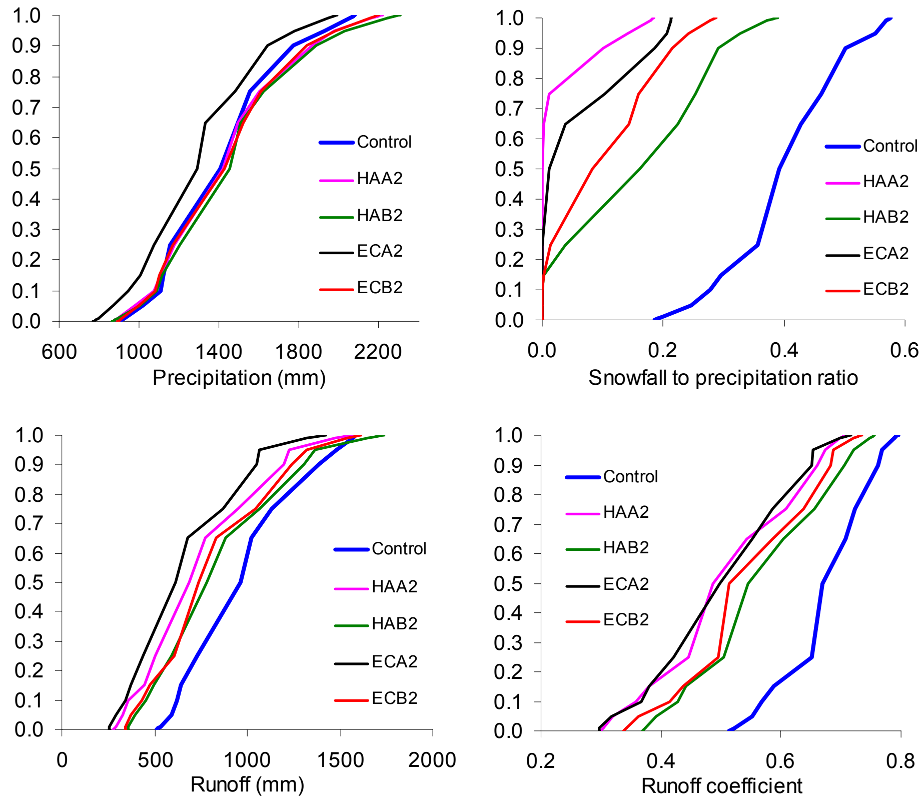

Figure 7. Cumulative frequency diagrams of annual precipitation, outflow, snowfall to precipitation ratio and runoff coefficients (runoff to precipitation ratio) at Čertovo Lake in the calibrating (2071-2100) period, as predicted on the basis of the HadAM3 (HA) and ECHAM4/OPYC3 (EC) models for the A2 and B2 scenarios.

(3) The general results were similar for all scenarios. Despite the fact that the annual precipitation will change only negligibly, significant changes are predicted in the annual runoff (11-30% decrease) and in its seasonal distribution. The runoff will increase in winter, discharge maxima associated with snowmelt will disappear, and the summer baseflow will decrease. The major reasons for this change are (i) the increase in average annual air temperature by 4.2 to 6.1 °C and reduction or absence of snow accumulation in the catchment during winter and (ii) precipitation will increase (on average by 17-31% in the individual scenarios) in winter and decrease (by 18-44%) in summer. Because the major climatic parameters are similar for all the Bohemian Forest lakes (they are situated in a relative vicinity, at similar elevations, and in catchments of similar morphology as Čertovo Lake), we assume that the results of this study are applicable for the whole Bohemian Forest lake-district.

(4) The simulated hydrological changes can implicate the following consequences for the catchment-lake ecosystems of the Bohemian Forest lakes: (i) Less water in soil (mostly in the upper horizons) and higher temperature in summer will have adverse effect on the dominating Norway spruce vegetation. (ii) Higher discharge in winter and disappearance of snowmelt events can reduce the associated acid peaks and reduce the severe lake water acidification in spring. (iii) Longer periods of summer droughts and high temperature will impact the mineralisation of soil organic C, N, and S and affect their turnover in catchments.

C. An estimation of global change impact on parameters of hydrological equation in the Tatra Mts., Slovakia, Poland.

Anna Benčoková, Evžen Stuchlík*, David Hardekopf*, Jan Turek** and Jiří Kopáček***

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1. Temperature

We found a significant correlation (r = 0.9) between monthly averages of temperature in Skalnaté pleso (SkCo) and modelled data HadAM3 (HACo) and ECHAM/OPYC4 (ECCo) for the reference period 1961 – 1990. Seasonal or annual averages do not correlate. Comparison of the modelled data for the reference and predicted period resulted in calculation of additive factors, which were applied to original data set from Skalnaté pleso representing the reference period 1961 – 1990 due to estimation of temperature in the predicted period 2071 – 2100.

1.1 Temperature in Skalnaté pleso in 1961 – 2002

There was no trend in temperature during the reference period 1961 – 1990 while slightly growing trend was found in the period 1991 – 2002. Mean value was for about 0.6 °C higher in this period than in the reference period (Fig. 1).

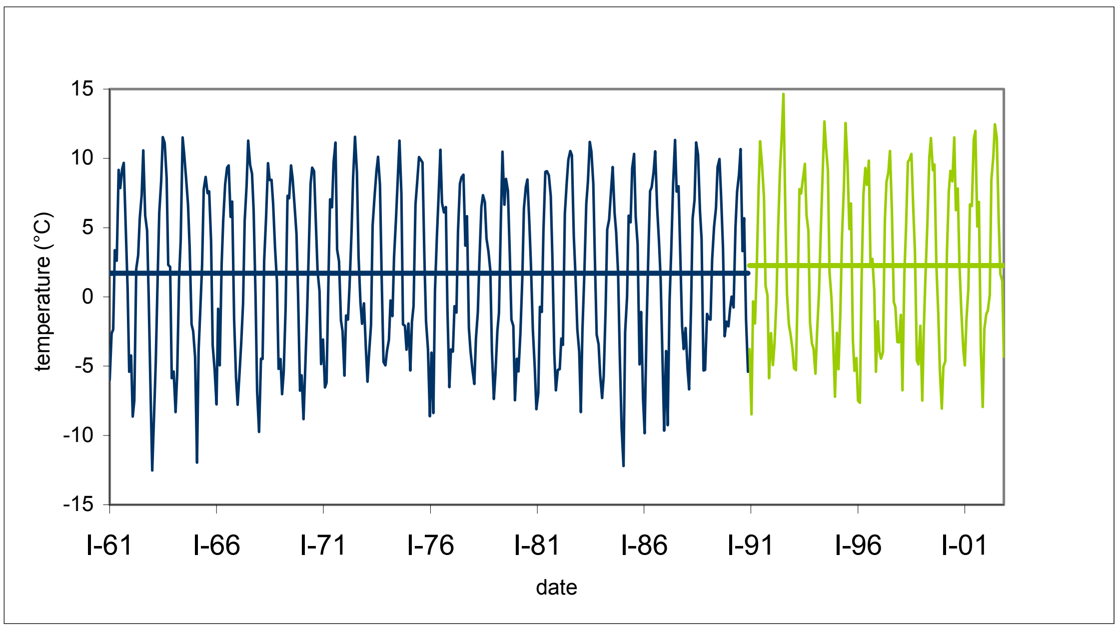

Figure 1. Monthly means of temperature in Skalnaté pleso during the reference period 1961 – 1990 (blue) and in 1991 – 2000 (green). Lines represent means for the related periods.

1.2 Seasonal pattern of temperature in Skalnaté pleso and data from the models during the reference period 1961 –1990

The seasonal pattern of temperature was similar in data set from Skalnaté pleso with modelled data sets for the reference period (Fig. 2).

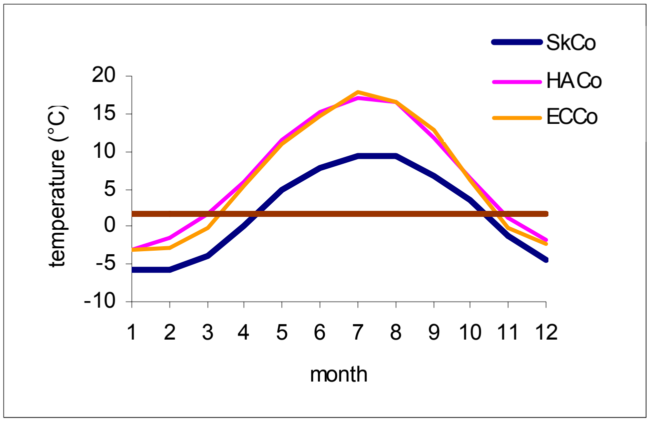

Figure 2. Mean monthly values of temperature in Skalnaté pleso (SkCO) and the modelled values (HACo, ECCo) in the reference period 1961 – 1991. The horizontal line represents yearly mean of temperature at this site for the same period.

1.3 Prediction of temperature in Skalnaté pleso in 2071 -2100

The models predict an increase of annual mean of temperature from 2.6 up to 5.8 °C. Summer months (June – September) contributes the most significant way to this increase but a noticeable elevation of temperature is supposed even for period from December to March (Fig. 3).

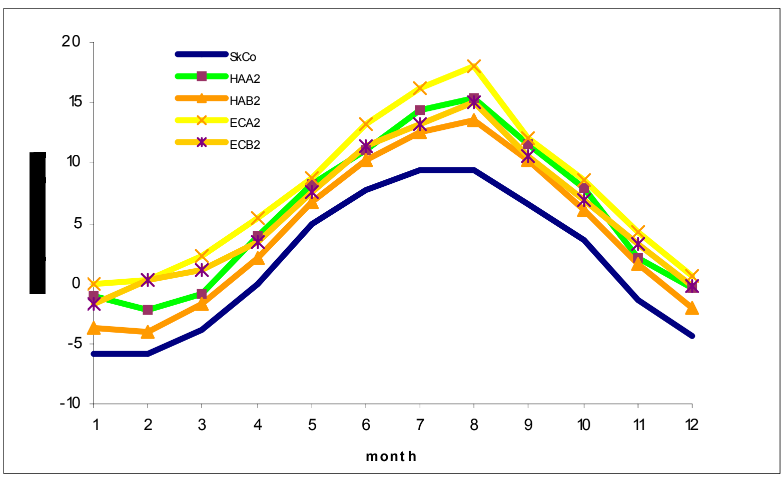

Figure 3. Monthly means of temperature during the reference period 1961 – 1990 (SCCo) and modelled values based on an application of different scenarios in the period 2071 - 2100.

1.4 Validation of employed models and scenarios by Kopacek's method of linear interpolation

Modelled data sets were used to calculate mean values for both reference and predicted period. Trend was obtained by linear connection of these two points. The second point for real data set from Skalnaté pleso was calculated as mean values for the period 1991-2002.

Scenarios	**Annual mean temperature (°C)**
HAA2	5.8
HAB2	4.3
ECA2	7.5
ECB2	5.9
SkP	4.8

Table 1. Annual mean temperature in Skalnaté pleso in the period 2071 -2100. Based on Kopacek's linear interpolation (see above).

The comparison suggests that scenario B2 of model HADAM3 provided value (4.3 °C), which was the closest to the trend based on the real data set from Skalnaté pleso (SkP, 4.8 °C).

2. Precipitation

There was no correlation between original and modelled data for the reference period at any time step (seasonal, monthly, and annual). We calculated monthly means for all data sets, and comparing (multiplicative) factors between modelled data during reference and predicted period were applied to the original data of Skalnaté pleso in 1961 - 1991 to estimate the situation in the future.

2.1 Precipitation in Skalnaté pleso during 1961 – 2002

There was no significant trend in monthly amount of precipitation during 1961-1991, but there was a growing trend resulting in significant increase of precipitation during 1991-2002 (12%, Fig. 4).

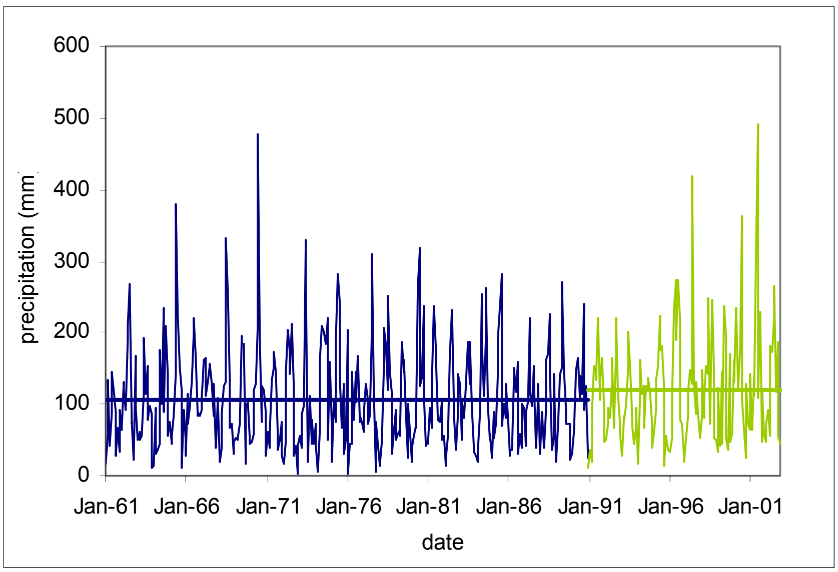

Figure 4. Monthly values of precipitation in Skalnaté pleso during the reference period 1961 – 1990 (blue) and in 1991 – 2000 (green).Lines demonstrate means for the related periods.

2.1 Seasonal distribution of precipitation in Skalnaté pleso and model data of 1961 –1990

A typical seasonal pattern of precipitation in the Tatra Mts. with maximum during summer is quite different from the modelled data sets for the reference period (Fig. 5). Absolute values of the modelled data are also much higher than the original data from Skalnaté pleso. If we consider the well known fact that amount of precipitation is in the Tatra Mts. positively correlated with altitude, then the modelled data related to altitude 915 m a.s.l. should be much lower and more or less equal even to values from the the Tatra Mts. low altitude stations such as Tatranská Lomnica (840 m a.s.l.) or Starý Smokovec (1018 m a.s.l.).

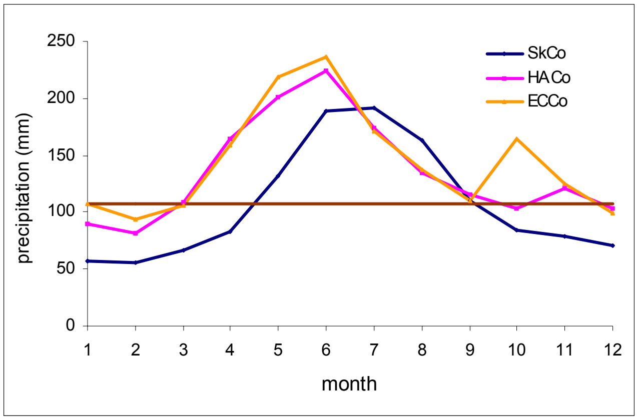

Figure 5. Monthly means of precipitation calculated for the referenced period 1961 – 1991. SkCo – data from Skalnaté pleso, HACo, ECCo - modelled data. Horizontal line represents monthly mean for the whole period in Skalnaté pleso.

2.2 *Prediction of precipitation in Skalnaté pleso in 2071 - 2100*

Estimated values for the predicted period indicate that we can expect just a little change of annual amount of precipitation (1% - 14.5%) but the seasonal distribution of precipitation may change completely (Fig. 6). Higher precipitation can be expected during the winter period from December to March (12 - 30%) while it will probably decrease in summer months from June – September (19 – 33 %).

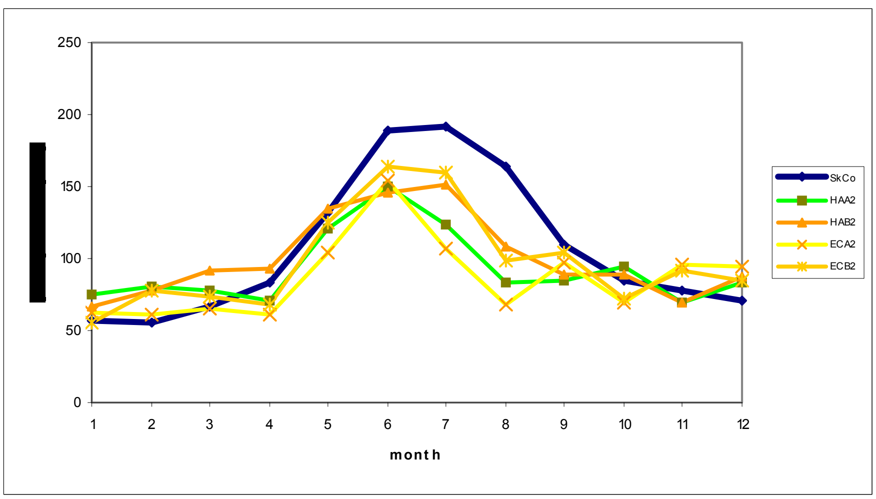

Figure 6. Annual distribution of precipitation (monthly values) in Skalnaté pleso during the reference period 1961 – 1990 (SKCo) and recalculated values predicted by different scenarios of HadAM3 and ECHAM4 models in 2071 - 2100.

3. Evapotranspiration

The models suppose an increase of evapotranspiration on the annual level from about 21% to 51%. The most significant change can be expected from December to March (39% - 104%). Evapotranspiration is a very complex parameter and relative changes calculated in 915 m a.s.l. do not need to be the same as in Skalnaté pleso (1778 m a.s.l.) The best estimation of evapotranspiration in the future could be again based on the length of snow-cover. Because of an overlap between snow-cover period and the period with predicted the most significant change of evapotranspiration we do not suppose a significant change of evapotranspiration in the predicted period.

	Recent E (mm)	Multiplicative factors				Prediction of E in Skalnaté pleso (mm)			
Month	**Skalnaté pleso**	**HAA2 to HACO**	**HAB2 to HACO**	**ECA2 to ECCO**	**ECB2 to ECCO**	**accor. to HAA2**	**accor. to HAB2**	**accor. to ECA2**	**accor. To ECB2**
1	16	1.82	1.36	2.09	1.64	28	21	33	25
2	14	1.65	1.39	2.39	2.30	23	19	33	32
3	16	1.53	1.24	1.98	1.79	24	19	31	28
4	15	1.22	1.15	1.39	1.25	18	17	21	19
5	62	1.12	1.09	1.10	1.05	70	68	69	65
6	60	1.11	1.11	1.18	1.12	66	67	71	68
7	62	1.08	1.07	1.07	1.07	67	66	67	66
8	62	1.01	1.04	0.93	1.05	63	65	57	65
9	60	1.05	1.04	1.02	1.05	63	62	61	63
10	16	1.15	1.10	1.17	1.17	18	17	18	18
11	15	1.33	1.28	1.74	1.66	20	19	26	25
12	16	1.85	1.70	2.02	1.73	29	26	31	27
Year	**414**	**1.33**	**1.21**	**1.51**	**1.41**	**489**	**466**	**518**	**501**

Table 2. Estimation of mean monthly values of evapotranspiration (mm) in Skalnaté pleso based on snow-cover length and its possible change in the future according to different scenarios (HAA2, HAB2, ECA2, ECB2).

3.1 Evapotranspiration according to empirical relation of Hamon

$$PET_m = 2{,}98 N_m \left(\frac{e_d}{T_m + 273{,}3} \right)$$

N_m - absolute maximum of daily sunshine in Skalnaté pleso
e_d - vapour pressure deficit
T_m – mean monthly temperature

The mean value of evapotranspiration was 254 mm for the reference period 1961 – 1990, which agrees with a published data. Increase of predicted evapotranspiration varied between 17% and 32 % (Fig. 7).

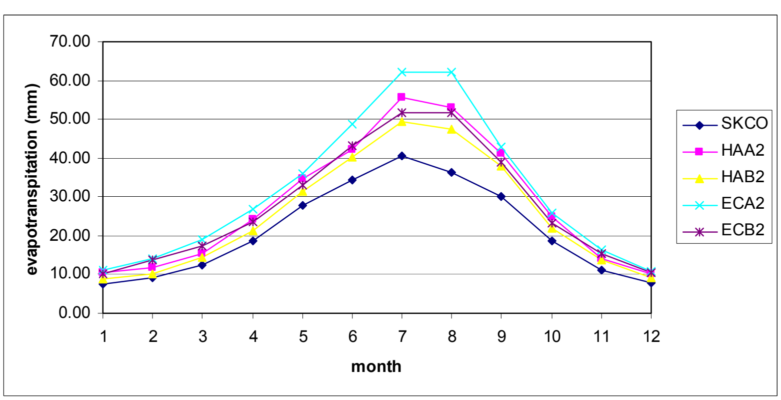

Figure 7. Mean monthly values of evapotranspiration calculated according to Hamon during the reference (SKCo) and predicted period.

4. Discharge

Discharge was calculate as difference between precipitation and evapotranspiration. The models predicted the drop in annual discharge from 12% to 35% with the maximum (down to 90%) during summer months. Increase of discharge is supposed during winter period (up to 50%, Fig. 8)

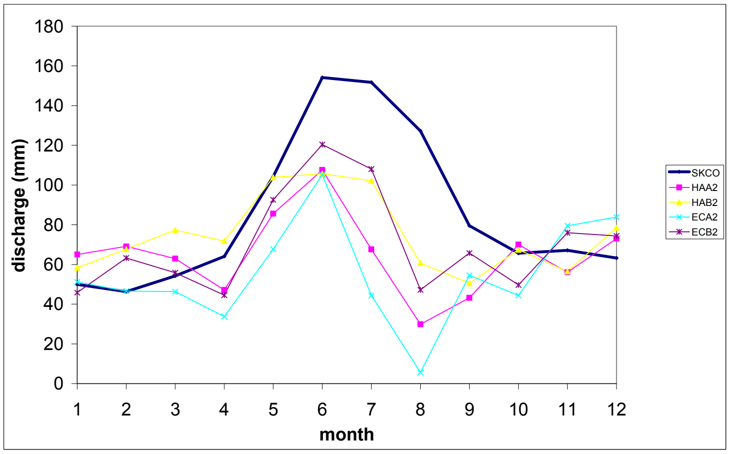

Figure 8. Actual (1961 – 1990) and predicted by different scenarios of the models HadAM3 and ECHAM4 (2071 – 2100) in Skalnaté pleso.

D. Lake catchments in the alpine/subalpine area of North Western Italy (CNR)

1. Recent trends of temperature and precipitation in the alpine/subalpine areas of NW Italy

Alpine lakes included in WP1 (Lakes Boden and Lakes Paione) are located in North-Western Italy, in the Italian part of the Lake Maggiore watershed. Long-term data collected at 11 stations in this area have been tested for trends in temperature and precipitation. The data available covered a period of about 30 years for six of the stations and 60-70 years for five sites. Data (maximum and minimum temperatures, precipitation amount, snow cover) were collected on a daily basis, and monthly, annual and seasonal values calculated. Snow cover data were analysed only for the high altitude site of Toggia, located very close to the Lakes Boden, to investigate the effect of climate warming on snowpack dynamics.

It is a well-known fact that the southern side of the Alps is characterised by a strikingly different climatological pattern from that of the northern side: higher temperature, higher number of sunny hours, fewer rainy days, but generally more intense precipitation. These differences are due to the fact that the southern slopes are shielded by the mountains from the air masses of marine origin which affect Central Europe. Usually wet winds coming from the Atlantic do not directly affect the Lake Maggiore area and the valleys located North-West of the lake, and so do not bring precipitation to the region. The dominant meteorological pattern determining the major precipitation in the subalpine area is produced by air masses coming from the South (SW to NE) and climbing over the Alps. In contrast, the air masses coming from the North generally cause precipitation only in the area close to the border (Val Formazza, where the Boden Lakes are located). When moist air masses cross the Po plain, they produce intense orographic precipitation on colliding with the first of the high ground. The intensity of this precipitation is accentuated in this area by the absence of pre-alpine foothills.
The results of the analysis clearly showed increasing trends of temperature at most sites, with different significance for minimum and maximum temperatures and for the different seasons. Trends of Tmin and T max at three different sites, representative of different altitude, are shown in Fig 1. Trend slopes were always high and ranged between 0.03-0.04 C° and 0.10-0.16 °C per year. Trends proved to be more significant at lower sites, and mainly affected the spring and summer temperatures. Examination of the longest data series suggests that it is mainly in the last 30 years that this tendency towards warming has emerged.

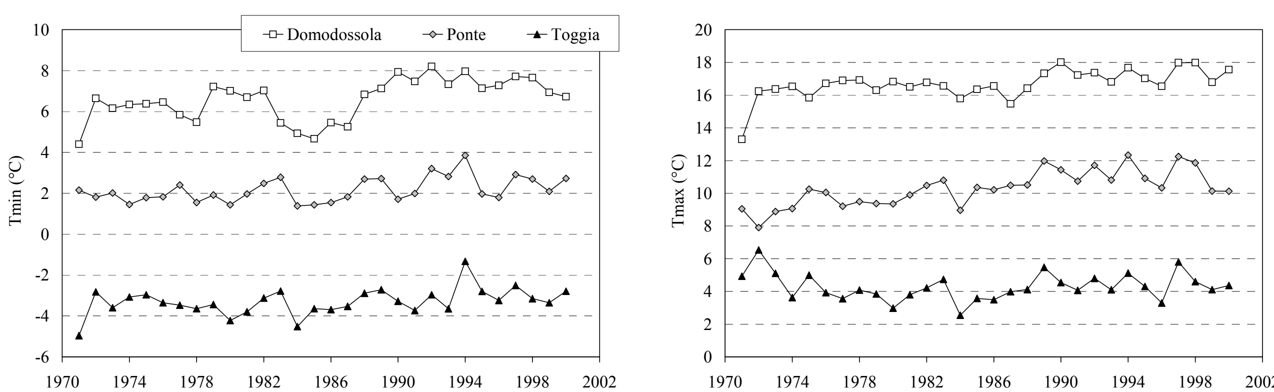

Figure 1. Tmin and Tmax at three sites in the last 30 years: Domodossola 270 m., Ponte 1300 m Toggia 2200 m

No significant trend was found for precipitation amount, apart from a decrease recorded at one site. The analysis of data on a daily basis at four stations showed that precipitation volume has been quite constant in the last 70 years, while the number of rainy days per year has been decreasing, a particularly striking trend over the last 25-30 years (Fig. 2). These results lead to the hypothesis that there has been an increasing occurrence of stormy precipitation events in the last decades.

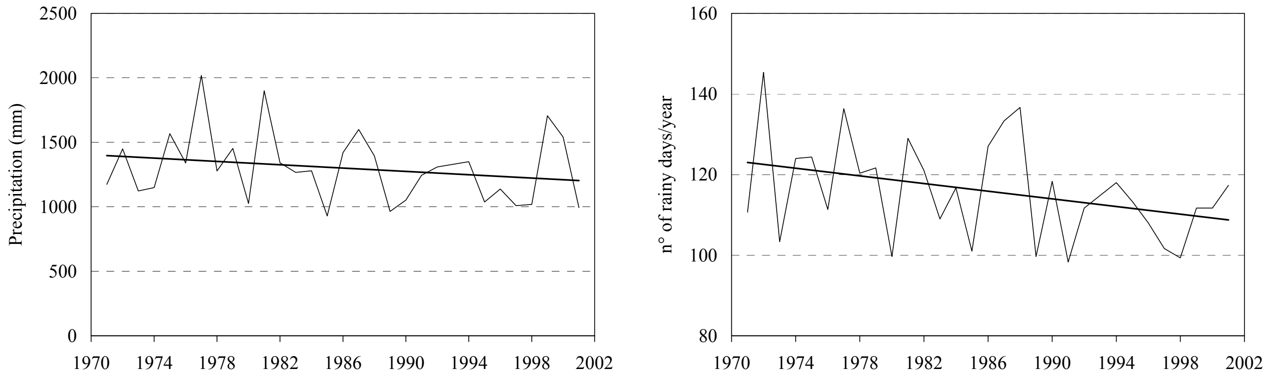

Figure 2. Trends of precipitation amount and number of rainy days per year in the last 30 years. Average values of three different sites.

Snow depth at the study site of Toggia has gradually decreased since 1932, notwithstanding periodic fluctuations (Figure ZZ). The main change occurred in the mid 60s, when mean snow depth values fell from about 110 to 90 cm. The duration of snow cover did not show a univocal trend, but decreased form 1932 to 1950, then increased until the mid 1980s, decreasing again during the last 15 years (Fig. 3). Snow reduction seems to be most pronounced in the most recent period (1985-2000), both in terms of amount of snow and its duration in time. The fact that wider areas are not being covered by snow but are being exposed to weathering processes affects the export of solutes from the catchments of lakes and streams, with consequences for the chemistry of surface waters. Furthermore, snowmelt episodes may become more frequent in winter, altering the typical pattern of snow accumulation followed by melting in spring.

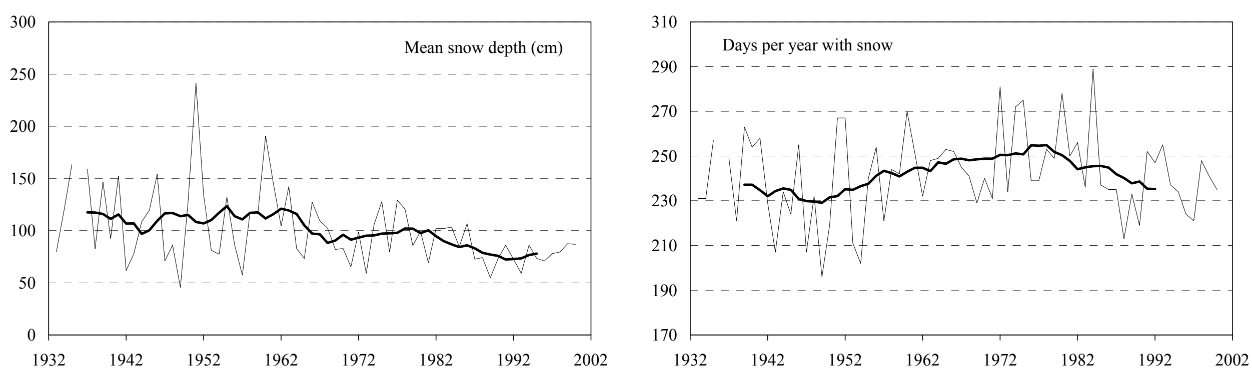

Figure 3. Trends of mean snow depth values and days per year with snow at the station of Toggia Thick line: ten-point running average.

The analysis of both temperature and precipitation data at the study sites showed how local differences may have some impact on climatic regime. Local climatic changes may differ considerably from the general trends, due to several factors, such as altitude, exposure, orientation and shape of the valleys. As a consequence, results obtained from the analysis of meteorological data at a limited spatial scale should be considered with caution, because they may not necessarily be significant indicators of large-scale variations.

2. Trends in meteorological parameters at Lakes Paione

An Automatic Weather Station (AWS) has been in operation at Lake Paione Superiore since 1997. Measured variables are: air temperature, relative humidity, solar radiation, wind speed and direction, precipitation. Parameters are measured every 10 minutes, stored and then transferred via radio as mean hourly values. Unfortunately the available data do not cover a time period long enough to evaluate eventual trends in meteorological data and their effect on lake chemistry.

A long-term series of air temperature data (since 1870) is available for the station located in the town of Domodossola, at the mouth of the Bognanco Valley, where the Paione Lakes are located. These data proved to be well correlated to those collected by the AWS at LPS in 1997-2002 ($R^2 = 0.93$, $p<0.001$). Hence mean temperature at LPS before 1997 was calculated through a linear regression from the data series of Domodossola. Results are shown in figure 4 as mean annual values. An upward trend of air temperature is evident since 1970, with the 1990s as the warmest decade of the whole record. The highest values of the period were recorded in 1992 and 2003 (2.6 °C, compared to a long-term average of 1.5 °C).

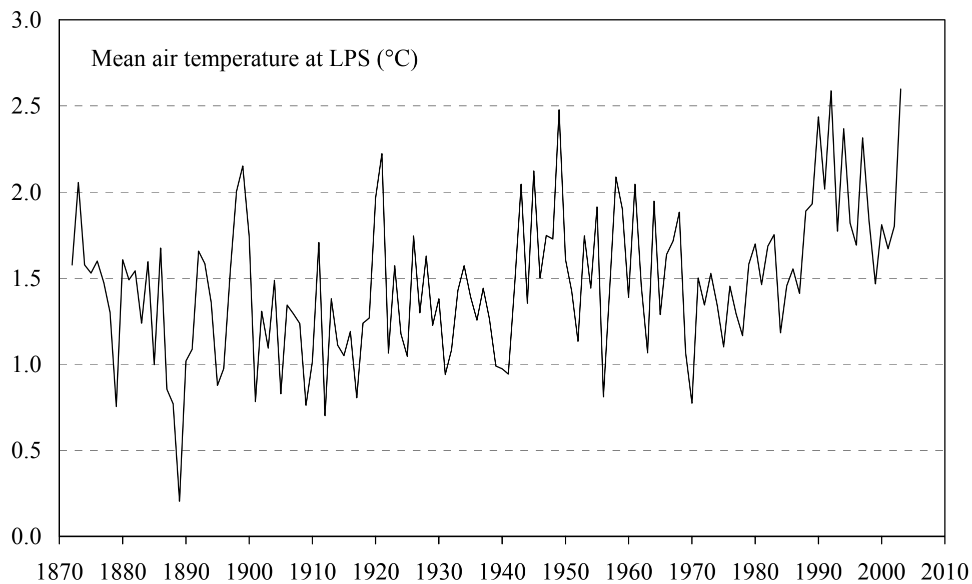

Figure 4. Trend of air temperature (mean annual values) at LPS.

3. Long-term change in the annual water balance of Lake Paione Superiore (LPS)

In the course of a previous research project, a water balance was performed for Lake Paione Superiore in the hydrological year 2000-2001, using measured data of precipitation amount and water level. By estimating potential evaporation with different methods, this balance allowed to estimate the annual discharge from the lake and the theoretical retention time. Precipitation data at LPS are collected on a regular basis by an AWS since 1996. We used these data and the estimated parameters to extend the balance calculation also to the years between 1996 and 2000 and after 2001 (Tab. 1).

The highest precipitation amount, highly above the long-term mean value for this area, was recorded in 2000-2001. The elevated input recorded in that year led to an estimated retention time of 14 days only. The latest years of the record (2003-2005) were characterised by reduced precipitation amounts (1490-1560 mm) compared to the previous years. Calculated retention time increased from about 20 days in 1996-2002 to 26-27 days in the last few years (Tab. 1).

Some studies provided evidence that longer water renewal times, as those predictable in a warmer and drier climate, could lead to a decline of SO_4 and NO_3 concentrations and an increase in base cations and alkalinity (Schindler *et al*., 1990; Webster and Brezonik, 1995). The analysis of long-term data available for a few alpine lakes in Central Alps showed an increase of solute contents in the last few years (Rogora *et al*., 2003). This trend may be attributed to both enhanced weathering rates due to climate warming and increased residence times.
Most General Circulation Models (GCMs) predict a general decrease of precipitation in the Alps for the next decades, and an increasing frequency and severity of droughts (IPCC 2001). According to meteorological and hydrological data collected at LPS, this scenario will lead to higher retention time in alpine lakes in the next future, with eventual effects on hydrochemistry and biota.

Table 1. Water balance for LPS in different years. RT: retention time.

Hydrological year	Precipitation mm	Discharge mm	RT days
1997-98	1638	1134	24
1998-99	1960	1456	21
1999-2000	1932	1429	21
2000-01	2925	2422	14
2001-02	1889	1345	22
2002-03	1486	1486	27
2003-04	1507	1507	27
2004-05	1557	1557	26

4. Climate scenarios (temperature and precipitation) for the study area

Statistical DownScaling Model (SDSM) was used to generate climate scenarios (temperature and precipitation) for LPS area. SDSM is a decision support tool for assessing local climate change impacts using a statistical downscaling technique. It generates single-site scenarios of daily surface weather variables under current and future regional climate forcing. SDSM is described in Wilby et al. (2002). Both the software for SDSM and the manual can be downloaded from: https://co-public.lboro.ac.uk/cocwd/SDSM/
To calibrate the models, we used measured daily data of temperature and precipitation collated at some sites in the area of WP1 sites since 1960s. As an example, annual mean values of temperature and precipitation at the high-altitude site of Toggia (2200 m a.s.l.) are shown in Fig 5. Both the control period (1961-2001) and the forecast simulation (2002-2099) are shown. Two scenarios were generated, corresponding to HadCM3 model, A2 and B2 experiments. Predictor files were downloaded from: http://www.cics.uvic.ca/scenarios/sdsm/select.cgi
Both scenarios predict a sharp increase of air temperature and a decrease of precipitation amount. According to the "worst" case scenario, mean temperature will passed from the present value of 0.7 °C (mean value of 1995-2004) to 4.0 °C in 2090-2100 (2.9 °C according to the B2 scenario) (Fig. 5). A moderate decrease is predicted for precipitation, from about 1100-1200 mm to 800-900 mm. However, for the latter variable, seasonal variability and extreme episodes (e.g. reduced precipitation in winter, increasing frequency of dry periods or heavy rainfalls) will be more important than the overall decrease in precipitation.

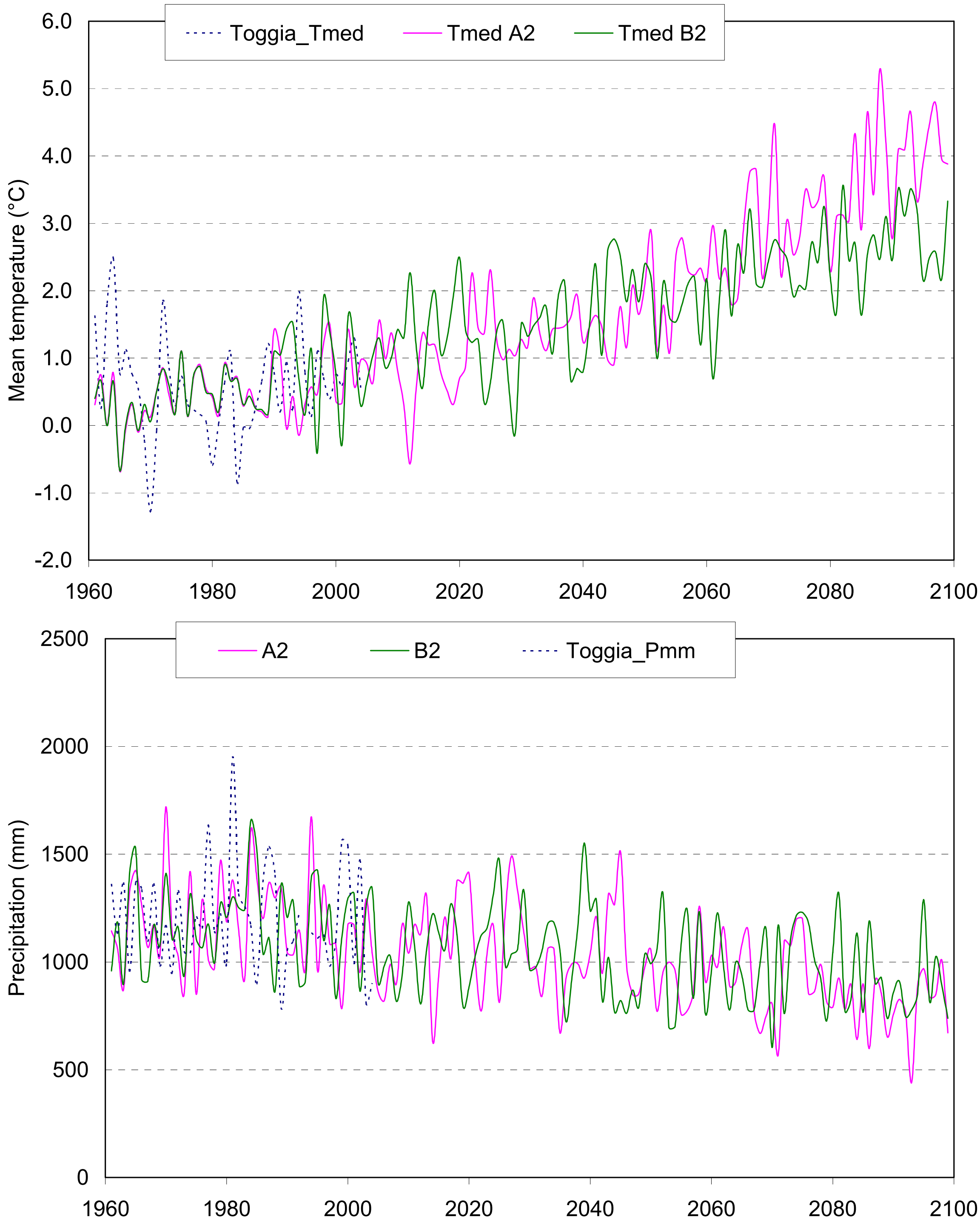

Figure 5. Climate scenarios (temperature and precipitation) at the site of Toggia (2200 m a.s.l.). Model HadCM3, A2 and B2 experiments.

E. Water balance under current and predicted future climate at Piburger See, Austria (UIBK)

1. Site description

Piburger See is an intensively studied headwater lake situated at the base of a steep forested mountain catchment in the Eastern Alps in Tyrol (Table 1). It is located in a protected nature conservation area and receives low levels of air pollution. The lake has suffered from cultural eutrophication but has been successively restored during the 1970s and 1980s to oligo-mesotrophic levels (Tolotti & Thies 2002).
The mean depth of Piburger See is 14 m. Despite the coniferous forest catchment, lake waters are rather clear (average dissolved organic carbon (DOC) concentrations of 2 mg L^{-1}) and well buffered (alkalinity: 500 ueq L^{-1}) at neutral pH (7), while conductivity is moderate (70 µS cm^{-1}).

Table 1: Characteristics of Piburger See and its catchment

Latitude and longitude	47°11' N, 10°53 E
Elevation of lake (m a.s.l.)	913
Lake volume (m^3)	1.8×10^6
Maximum depth (m)	24
Lake water retention time (yr)	2
Lake area (ha)	13
Elevation of catchment (m a.s.l.)	913 – 2400
Catchment area (km²)	1.6
Forest cover (%)	82
Main tree species	*Picea abies*
Mean annual air temperature (°C)	6.2
Mean annual precipitation (mm)	700
Vegetation period at lake level (days)	180
Bedrock geology	gneiss, granite

2. Temperature and precipitation

2.1 Measured data 1961- 2005

Long-term data of air temperature and precipitation are available from Umhausen (1041 m), a meteorological station in the vicinity of the catchment of Piburger See. The station is run by the ZAMG (Central Institute for Meteorology and Geodynamics, Austria) with daily data since 1961.
The mean annual air temperature at Umhausen is 6.2 °C for the reference period 1961-1990 and ranges from –2.9°C in January to 15.2 °C in July. During 1991-2005 temperature has increased in spring and summer compared to the reference period by up to 0.8 °C, but has decreased in autumn and winter with the maximum decrease of 0.9 °C in September (Table 2). Average annual air temperature has remained unchanged compared to 1961-1990.
Annual precipitation is 686 mm for the reference period and maximum values of about 100 mm/month occur on average in summer (Table 2). During the period 1991-2005 annual precipitation slightly increased by 8% to 742 mm, and there was tendency of increasing precipitation in spring and autumn (March, October) compared to the reference period.

Table 2. Average temperature and precipitation at Umhausen for 1961-1990 and 1991-2005, and change between the two periods.

Month	Temperature 1961-1990 °C	Temperature 1991-2005 °C	Temperature Change °C	Precipitation 1961-1990 mm	Precipitation 1991-2005 mm	Precipitation Change %
1	-2.9	-3.1	-0.2	36	28	-22
2	-1.6	-2.0	-0.4	31	27	-12
3	1.8	2.4	0.6	38	48	28
4	5.9	5.7	-0.2	38	43	12
5	10.3	11.0	0.7	67	61	-8
6	13.2	14.0	0.7	86	99	15
7	15.2	15.5	0.3	100	112	12
8	14.5	15.3	0.8	107	115	7
9	11.8	10.9	-0.9	60	65	8
10	7.1	6.5	-0.6	40	56	41
11	1.5	1.2	-0.3	47	52	12
12	-2.2	-2.5	-0.3	37	35	-5
Year	6.2	6.2	0.0	686	742	8

2.2 Climate scenario data for 2071-2100

Modelled data of temperature and precipitation for both the control (1961-1990) and the scenario period (2071-2100) were downloaded for the agreed climate models and emission scenarios (i.e. HadAM3 and ECHAM4 as GCM, RCAO as Regional Climate Model, scenarios A2 and B2) from the PRUDENCE web-page (http://www.prudence.dmi.dk/).

The grid covering the catchment of Piburger See has an average elevation of 1563 m. The elevation difference of about 500 m to the meteorological station of Umhausen (1041 m) was reflected in a temperature difference of about -3 °C between modelled mean annual air temperature for 1961-1990 and the respective observed mean value at Umhausen. The discrepancy between modelled grid data and measured data was even more pronounced for precipitation, with modelled grid values being about three times higher than the average measured precipitation. The difference in elevation between the Piburger See grid and Umhausen may – among others - again account for this deviation. In order to eliminate the elevation effect, we have selected the RCAO grid, which lies next to the grid of Piburger See (Fig. 1) and better fits with its average height of 914 m to the elevation of Umhausen (1041 m). Considering a grid size of ~50 km x 50 km, the projected climate change is not expected to differ much between the two grids.

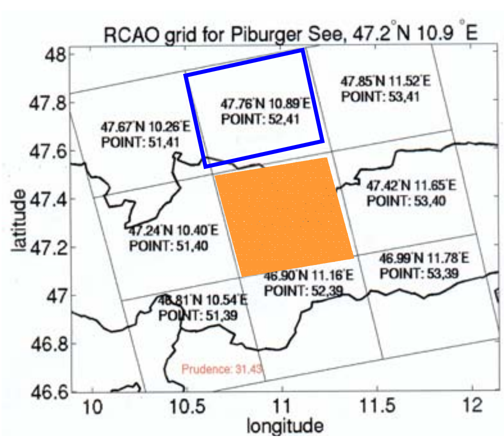

Figure. 1. Position of the RCAO grid for Piburger See (shaded). The grid situated to the north (marked with a blue rectangle) has been selected to estimate the projected future climate change.

RCAO data for the control period 1961-1990) nicely follow the average seasonal distribution of air temperature at Umhausen with a tendency to warmer temperatures during the winter months (Table 3). The projected increase in air temperature ranges between about 3 and 6 °C depending on the GCM and SRES scenario. The Hadley-Centre-Model generally shows a smaller increase than the ECHAM4 model, and the increase is about 1.5 °C higher for the A2 scenario compared to the annual mean under B2.

Table 3. Mean monthly air temperature for the control period (1961-1990) and changes in air temperature between the control and the scenario period (2071-2100) for the emission scenarios A2 and B2 and both GCMs.

Month	Umhausen 1961-1990 °C	HadAM3 Control °C	HadAM3 A2-Control °C	HadAM3 B2-Control °C	ECHAM4 Control °C	ECHAM4 A2-Control °C	ECHAM4 B2-Control °C
1	-2.9	-1.0	4.5	2.3	-1.1	5.5	4.4
2	-1.6	0.8	2.9	0.5	-1.2	5.9	6.1
3	1.8	2.3	2.6	1.2	1.0	6.4	5.1
4	5.9	5.2	3.7	1.7	5.2	5.9	3.9
5	10.3	10.2	3.2	2.1	9.4	5.2	3.4
6	13.2	14.0	3.9	3.0	13.4	6.4	4.2
7	15.2	15.9	5.4	4.1	16.4	8.4	4.8
8	14.5	15.2	7.2	5.4	15.3	10.3	6.8
9	11.8	11.9	5.3	3.7	12.1	6.4	4.8
10	7.1	7.0	4.2	2.5	6.3	5.2	3.5
11	1.5	2.7	3.5	3.0	1.5	4.9	4.4
12	-2.2	0.0	3.9	2.5	-0.9	5.5	5.0
Year	6.2	7.0	4.2	2.7	6.5	6.3	4.7

Contrary to air temperature, RCAO data do not fit to the mean seasonal distribution of precipitation in the lake catchment. While the average year has its maximum precipitation during summer, both GCM models show higher precipitation during autumn and winter and minimum amounts during July and August. For the control period, only the HadAM3 model gives the right annual amount of precipitation, while the ECHAM4 model overestimates annual precipitation.

Table 4. Mean monthly precipitation for the control period (1961-1990) and changes in precipitation (%) between the control and the scenario period (2071-2100) for the emission scenarios A2 and B2 and both GCMs.

Month	Umhausen 1961-1990 mm	HadAM3 Control mm	HadAM3 A2/Control %	HadAM3 B2/Control %	ECHAM4 Control mm	ECHAM4 A2/Control %	ECHAM4 B2/Control %
1	36	66	50	9	105	-8	12
2	31	55	79	43	97	4	18
3	38	57	80	30	88	-4	4
4	38	68	38	0	95	-18	-11
5	67	62	52	-6	99	-11	-9
6	86	56	32	-19	99	-38	-19
7	100	49	0	-38	78	-64	-28
8	107	49	-28	-46	76	-68	-49
9	60	46	2	-29	80	-26	-10
10	40	52	58	8	110	-3	2
11	47	69	13	-15	117	4	-2
12	37	69	40	13	86	39	28
Year	686	698	36	-3	1131	-14	-4

The projected change in annual precipitation by the end of this century is negligible with the exception of the HadAM3 model and the A2 scenario, which gives an increase of 36% (Table 4). Generally, the models indicate a seasonal shift in precipitation with increasing amounts in winter and a decrease in summer.

3. Modelled water balance components at Piburger See

Discharge and evapotranspiration have been derived from the hydrological model of GWLF (Generalized Watershed Loading Functions model) (Haith and Shoemaker, 1987; Schneiderman et al., 2002). GWLF is a lumped parameter model, it uses daily air temperature and precipitation as driving variables and simulates the daily hydrologic water balance.
The model performance is shown in Figure 2 with the comparison of measured and modelled daily streamflow during one hydrological year. There are some discrepancies during the melting period (mid April to the beginning of June), but annual amounts of both measured and modelled streamflow equal with ~ 180 mm yr^{-1}.

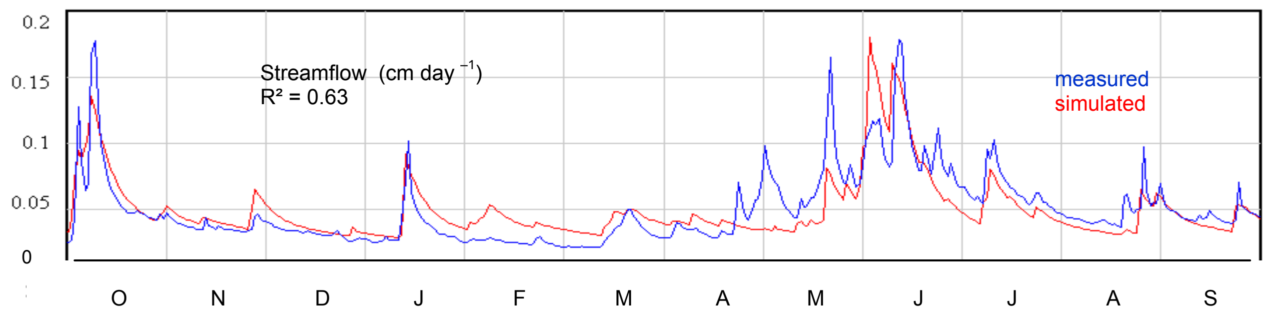

Figure 2. Measured and modelled streamflow (GWLF) for the hydrological year October 2003 – September 2004.

There have been no major changes in annual amounts of streamflow and evaporation between the reference period of 1961-1990 and the period 1991-2005. The average streamflow ranges around 180 mm yr^{-1} and annual evapotranspiration is modelled to about 370 mm yr^{-1}.

To evaluate the projected impact of changing air temperature and precipitation on discharge and evaporation, the GWLF model was run with daily RCAO data of air temperature and precipitation for both the control and the scenario period. Due to the discrepancy in the seasonal distribution of RCAO precipitation and measured precipitation (see above), we have applied the so-called delta-change method (Räisänen, 2007), i.e. we have compared the average values of the control period with those of the scenario period assuming that the bias in simulated present-day and future climates tends to be compensated.
For the HadAM3 model, annual discharge is simulated to increase up to 20% by the end of the twenty-first century, while applying RCAO data from the ECHAM4 model to the GWLF hydrologic model shows a decrease of annual discharge by about 40%. The overall change in the seasonal distribution of discharge is similar for both models and emission scenarios. Discharge is modelled to increase in the winter half year, which may be attributed to the projected higher air temperatures and a reduction in the seasonal snow cover, while average summer discharge is modelled to decrease (Figure 3). Generally, modelled changes are more pronounced applying ECHAM 4 data compared to HadAM3 data.
Evaporation is modelled to increase under future climate scenarios. GWLF model runs reveal an average increase between 20 and 30 % by the end of this century compared to the control period. Only under HadAM3 and A2 annual evaporation is expected to slightly decrease to a value below 300 mm yr^{-1}.

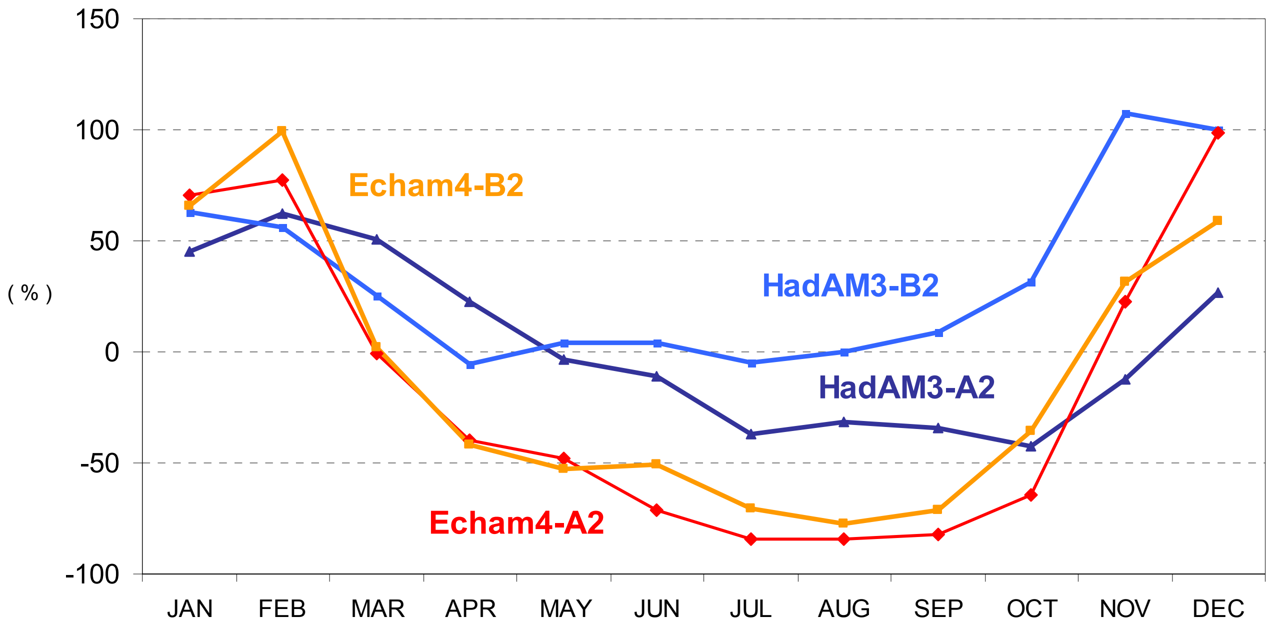

Figure 3. Differences (%) in GWLF modelled streamflow between control (1961-1990) and scenario period (2071-2100).

SUMMARY

Different approaches and models have been applied to downscale climate scenario data to site level and to derive discharge and evaporation.

All sites experience a projected increase in air temperature of up to several degrees C by the end of this century. The pattern of change in precipitation is more complex. An increase in precipitation is only projected at the Finish site, while little change in annual precipitation may be expected at the Czech and the Austrian site. There, the major change will be in the seasonal distribution in precipitation. At the Italian site precipitation will most likely decrease. Rising air temperature causes evaporation to increase at all sites, but only at the Finish site also discharge is modelled to increase. At the other sites annual discharge tends to decrease with major changes in the seasonal pattern.

Generally, modelling work is still ongoing at all sites and feeds into the evaluation of climate change impacts on mass fluxes. There is also a cross-link to work of WP4.

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