Climate Change and Changing Runoff in South East Europe

Deborah Lawrence
Tom Andersen
Ingjerd Haddeland

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Climate Change and Changing Runoff in South East Europe

Report on the Statkraft workshop, Belgrade, 26 – 27 May, 2009

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Climate Change and Changing Runoff in South East Europe

Commissioned by: Statkraft Development AS

Authors: Deborah Lawrence[1], Tom Andersen[2], Ingjerd Haddeland[1]

[1]Norwegian Water Resources and Energy Directorate (NVE)
[2]Statkraft Energi, AS, Norway

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Abstract: This report provides an overview of recent work related to climate change impacts on runoff in South East Europe, based on a workshop held in Belgrade, 26-27 May, 2009, initiated and organised by Statkraft Development, AS.
Key words: Climate scenarios, regional climate modelling, precipitation, runoff, hydrological models, Balkans

Norges vassdrags- og energidirektorat
Middelthunsgate 29
Postboks 5091 Majorstua
0301 OSLO

Telefon: 22 95 95 95
Telefaks: 22 95 90 00
Internett: www.nve.no

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Preface

The NVE Hydrology Department participated in a workshop entitled 'Climate Change and Changing Runoff in South East Europe', held in Belgrade, Serbia on 26 – 27th May, 2009. The workshop was initiated and organised by the Norwegian power company Statkraft and included participants and presentations from the hydrometeorological and related institutions of Albania, Bosnia and Herzegovina, Croatia, Hungary, Macedonia, Montenegro, Serbia and Turkey. Participants from Bjerknes Centre for Climate Research (University of Bergen, Norway), Wegener Center for Climate and Global Change (University of Graz, Austria) and the NVE Hydrological Modelling Section also presented research pertaining to climate change, both its global causes and its regional impacts. This report summarises the presentations from the workshop. Material and references from a previous literature search for Statkraft on the topic of 'possible future climate changes in south-eastern Europe and their hydrologic implications' are also included. The work by NVE has been supported by contract numbers 4500047486 and 4500047487 with Statkraft Development AS.

Oslo, November 2009

Morten Johnsrud

Director

Hege Hisdal

Section Manager

Summary

Substantial evidence exists for the occurrence of human-induced global temperature change as a consequence of increases in atmospheric greenhouse gases, most notably CO_2. Based on the IPCC 2007 AR4 multi-model ensemble of GCMs, the annual mean temperature in the south-eastern region of Europe (SEE) is expected to increase by 2.0º to 2.5º (under the A1b SRES emission scenario) by 2080-2099 relative to 1980-1999. The projected increase for summer months (JJA) is much higher and is in the range of 3.5º to 4.5º. Annual precipitation is expected to decrease by -0.3 to -0.4 mm/day. The decrease in precipitation exhibits a strong seasonality, with the largest decreases in the summer and smaller decreases in the winter. In some localities within the SEE region, moderate increases in the winter precipitation are projected.

Regional climate model (RCM) simulations provide a higher spatial resolution and a better treatment of local topography than GCMs. Several recent projects have produced RCM simulations for Europe, including the SEE region. The EU CLAVIER project is applying an ensemble of RCM simulations for the period 1951-2050. Model output has been further adjusted and refined to a 10 x 10 km grid. The SINTA project is a collaboration between Serbian and Italian institutions. Regional climate modelling on a 25 km grid for a reference period 1961-1990 and two scenario periods 2001-2030 and 2071-2100 has been undertaken in this project. In addition to these two projects, RCM results from the recent EU PRUDENCE and ENSEMBLES projects also have model domains which cover the SEE region.

Projected changes in average annual runoff based on the IPCC 2007 GCM ensemble indicate a decrease of 20 to 40% in the SEE region by 2090-2099, relative to a 1980-1999 reference period. A decrease is considered to be very likely based on the level of agreement between models. Published applications of large-scale hydrological models indicate a decrease in annual runoff in the SEE region by the 2020s. However, results vary significantly within the region and are also highly dependent on the individual GCM used. Seasonal changes in runoff for individual countries in the SEE region, extracted from a global application of the VIC hydrological model, indicate a reduction in runoff throughout most of the year. Summer decreases of >50% by 2071-2100 (relative to a 1961-1990 reference period) are projected in many areas. An increase in winter runoff is seen in some areas, particularly those with a significant winter snowfall under the current climate. The RCM outputs from the CLAVIER project have been used as input for hydrological simulations within the Tisza river basin in Hungary. Those results illustrate the spatial variability in runoff response to future climate change and highlight the importance of using hydrological models to determine local runoff response.

Reports from individual countries in the SEE region all generally indicate an increase in observed mean annual temperature within the region. Analyses of precipitation and runoff records are less conclusive, often due to the limited record length relative to timescales for natural climatic variability. A tendency towards a decrease in precipitation and runoff is, however, reported in many cases. More detailed and comprehensive analyses of observed historical trends and of anticipated changes based on RCM scenarios and hydrological modelling could make a significant contribution to the assessment of climate change impacts on runoff in the SEE region.

1 Introduction

1.1 Background

The south-eastern region of Europe (hereafter referred to as SEE) faces significant challenges with respect to water management in the face of anticipated changes in climate and increasing water stress (*e.g.* see Arnell, 2004). Simultaneously, there exists considerable potential for the further development of hydropower, which could be of benefit in meeting growing electricity demands within the region with renewable energy sources. The optimum use of this resource is, however, dependent on an understanding of the likely impacts of climate change on water availability over the next 50 to 100 years. Accordingly, a workshop was initiated and organised by Statkraft on the topic 'Climate Change and Changing Runoff in South East Europe'. The objective of the workshop was to bring together scientists from the meteorological and hydrological institutions within the region with other international researchers involved in climate change research. The workshop was held in Belgrade, Serbia, on 26 – 27th May, 2009, and included participants from Albania, Austria, Bosnia and Herzegovina, Croatia, Hungary, Macedonia, Montenegro, Norway, Serbia and Turkey. This report summarises the presentations from the workshop. Material and references from a recent literature search on the topic 'possible future climate changes in south-eastern Europe and their hydrologic implications' are also included. A list of presentation titles and workshop participants is given in the Appendix.

The report is organised as follows: In the remainder of this introductory section, an overview of Statkraft and its activities is given. This is followed by a brief review of the evidence and causes of human-induced climate change and projected changes in precipitation and temperature within the SEE region based on the IPCC 2007 report. Regional climate modelling with domains covering the SEE region is then presented, followed by a section on projected climate change impacts on runoff. Evidence for historical changes in temperature, precipitation and runoff in the SEE region, as reported by workshop participants, is then reviewed on a country-by-country basis. The final section provides concluding remarks with respect to workshop outcomes and planned further work.

1.2 About Statkraft

Statkraft is Europe's largest renewable energy company. The Group develops and generates hydropower, wind power, gas power and district heating, and is a major player on the European power exchanges. Statkraft also develops marine energy, osmotic power, solar power, and other innovative energy solutions. Through the ownership of other companies, Statkraft supplies energy and heating to more than 600,000 customers in Norway. In 2008 Statkraft posted gross operating revenues of EURO 3.1 billion (NOK 25 billion). The group employs 3,200 staff in more than 20 countries.

In the Nordic region, The Statkraft Group operates more than 200 hydropower plants, 11 district heating facilities and three wind farms. In the UK and central Europe, Statkraft operates 12 hydropower plants and three gas power plants, and several wind power projects are under development.

In Southeast Europe and Turkey, Statkraft is involved in several hydropower development projects and is also focusing on solar power and electricity trading.

1.3 Evidence for human-induced global temperature change *vs.* natural climate variability

Asgeir Sorteberg, Bjerknes Centre for Climate Research (Norway), opened the technical presentations for the workshop with a thorough review of current evidence for global warming as a consequence of recent increases in atmospheric greenhouse gases. Of the potential contributors, CO_2 is overwhelmingly dominant as the likely cause of a change in radiative forcing over the past 250 years. The sensitivity of the climate system to increased CO_2 is high due to the presence of internal feedbacks. Recent estimates of the likely global temperature response to a doubling of atmospheric CO_2 indicate a mean increase of 3 – 4 ºC, but vary between 2ºC and 11ºC. Temperature records covering the period 1850 – 2008 indicate a temperature anomaly of ~ 0.4º in recent years (Figure 1.1).

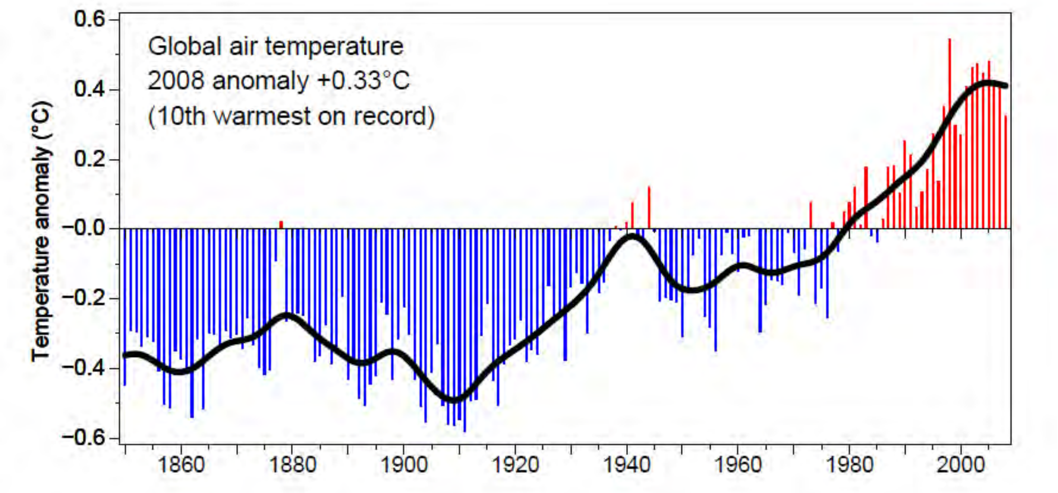


Figure 1.1 Global temperature anomaly over the period 1850-2008 (Source: http://www.cru.uea.ac.uk/; Climate Research Unit, 2009)

Observed trends in temperature over the period 1979-2005 indicate a global temperature increase of 0.17ºC per decade, with land areas experiencing larger increases than the global average (Northern Hemisphere land: 0.32ºC/decade, and the Arctic region: 0.44ºC/decade). Reconstructions of temperature over the past 1300 years from ice cores indicate a clear positive anomaly in the late 20th century. A comparison of modelled temperatures over a similar period supports the hypothesis of a change in external forcing as the principal cause of the recent temperature trend, exceeding natural climate variability. In addition, the current growth rate in CO_2 emissions has been preliminarily estimated by the CDIAC as 3.2 – 3.3% (over the period 2000-2005), which is higher than any of the SRES emission scenarios (*e.g.* 2.13% for A2 and 2.42% for A1b, over the period 2000-2010, from Raupach, 2007). Global temperature change contributes to changes in both atmospheric circulation patterns and in the atmosphere's water holding capacity. Therefore, changes in current precipitation patterns are also expected as a consequence of increased global air temperature.

1.4 Global climate model (GCM) projections for temperature and precipitation

1.4.1 General projections from the IPCC 2007 report

The IPCC 2007 Fourth Assessment Report (AR4) presents a set of global climate projections (reported in Meehl, *et al*., 2007) based on a multi-model ensemble of comprehensive AOGCMs (Atmosphere-Ocean General Circulation Models). These models were run using three of the six SRES marker scenarios: B1, A1b and A2, representing 'low', 'medium', and 'high' emissions, respectively. Based on that published summary, the SEE region will experience an increase in annual mean surface temperature (Meehl, *et al*., 2007; Fig. 10.12) with the magnitude of the increase varying with the emissions scenario and time horizon considered (Table 1).

	B1	**A1b**	**A2**
2011-2030	0.5º - 1.0º	0.5º - 1.0º	0.5º - 1.0º
2046 - 2065	1.5º - 2.0º	2.0º - 2.5º	2.0º - 2.5º
2080 - 2099	1.5º - 2.0º	3.5º - 4.0º	4.0º - 4.5º

Table 1. Projected increase in annual mean surface temperature in the SEE region relative to the 1980-2000 control period. Source of data: Meehl, et al., 2007; Fig. 10.12

The values given in Table 1 exceed the global averages, as is true for Europe in general (Christensen, *et al*., 2007). On a seasonal basis (Meehl, *et al*., 2007; Fig. 10.9), the mean surface temperature in SEE is projected to increase by 2.5º - 3.5º in the winter (months DJF) and by 3.5º - 4.5º in the summer (months JJA) under the A1b scenario.

Precipitation is expected to decrease significantly in the SEE region. The results from individual GCMs, however, produce more widely varying projections for precipitation than for temperature. On an annual basis, precipitation is expected to change by -0.2 to -0.4 mm/day in SEE by 2080-2099 under the A1b scenario (Figure 1.2; from Meehl, *et al*., 2007; Fig. 10.12). The occurrence of a decrease is considered to be very likely in that at least 80% of the GCMs agree on the sign of the change in this region. The decrease exhibits a pronounced seasonality. In the winter months the change in precipitation is between +0.2 and -0.2 mm/day in the region, while in the summer months a change of between -0.3 and -0.6 mm/day is projected.

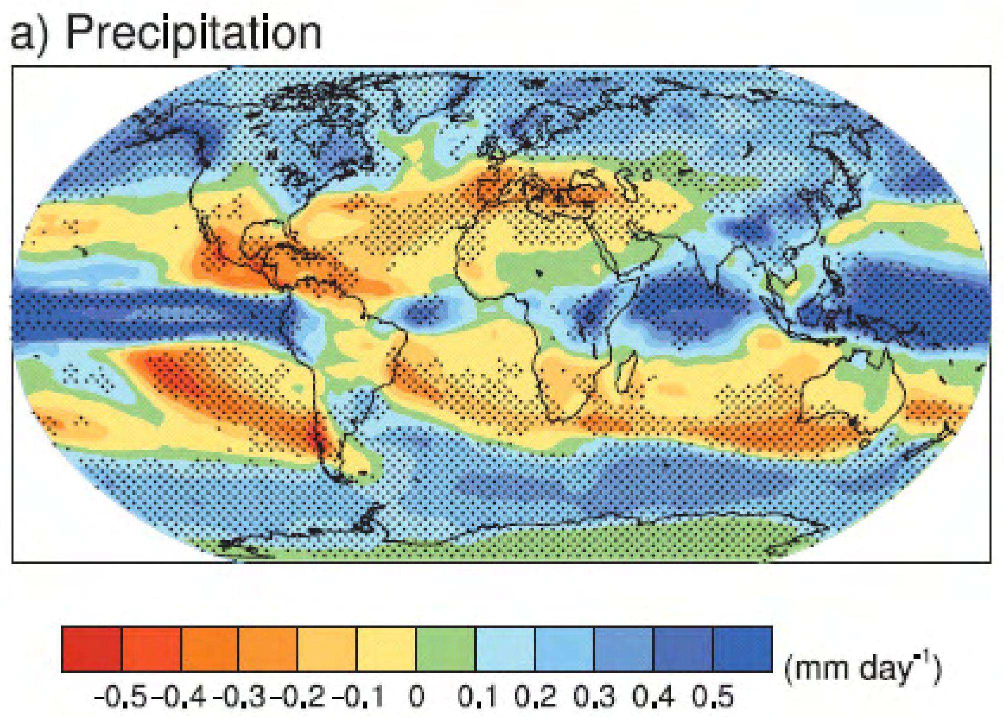


Figure 1.2 Multi-model mean changes in precipitation (mm day^{-1}). To indicate consistency in the sign of change, regions are stippled where at least 80% of models agree on the sign of the mean change. Changes are annual means for the SRES A1B scenario for the period 2080 to 2099 relative to 1980 to 1999. (From Meehl, et al. 2007, Figure 10.12).

1.4.2 GCM projections reported by workshop participants

Workshop participants from Macedonia, Montenegro, Serbia and Turkey presented projections for their respective countries, which were obtained from GCMs.

Suzana Alcinova Monevska, Hydrometeorological Institute, Republic of Macedonia, presented the results of two sets of analyses. These have been undertaken in conjunction with the country's first (2003) and second (2008) National Communications on Climate Change under the UN Framework Convention on Climate Change. For the first report, output from 6 GCMs run under the IS92a and IS92c emission scenarios indicated a mean increase in average annual temperature of 1.0 (IS92c) to 2.5ºC (IS92a), and a mean decrease in average annual precipitation of 5% (IS92c). More recent work (undertaken for the Second National Communication by Klemen Bergant, Centre for Atmospheric Research, Slovenia) is based on 4 GCMs and 6 SRES scenarios. The results indicate an annual temperature increase of 2.7 to 5.4ºC and a decrease in precipitation of 5 to 21% by 2100. Projected summer temperature increases are in the range of 3.7 to 7.6ºC, and precipitation decreases of 21 to 53% are also projected for the summer season. These newer projections indicate larger changes than those in the First National Communication, and this is due to the use of the SRES emission scenarios. The GCM outputs have also been empirically downscaled for the region. These refined results indicate larger temperature increases in the winter and summer (especially in the south-eastern portion of Macedonia which is characterised by a sub Mediterranean climate).

Smaller precipitation increases in the winter are projected, relative to those obtained directly from the GCMs.

Mirjana Ivanov, Hydrometeorological Institute of Montenegro, also presented IPCC projections for Montenegro, which indicate an increase in average temperature of 2ºC in winter and 2 - 3ºC in summer. A decrease in precipitation of 5 – 15% is projected for the warmer months of the year.

Mihajlo Andjelic, Republic Hydrometerological Service of Serbia, presented estimates from GCMs projecting a maximum increase in mean annual temperature of 3.3ºC (with mean and minimum increases of 2.2 and 1.4ºC, respectively) for Serbia. Projected decreases in mean annual precipitation are 16%, 7% and 3% (maximum, mean and minimum, respectively).

Figures illustrating GCM results for Turkey and the larger SEE region were presented by Atilla Gurbuz (General Directorate of Electrical Power Resources, Survey and Development Administration in Turkey). These results point towards a summer temperature increase of 4.5 - 5ºC and a decrease in summer rainfall of up to 50% by 2071, under the A2 emissions scenario. The impact on runoff is anticipated to be quite dramatic in the southern half of Turkey, with the south-western third of the country lying within an anticipated zone of 'extreme flow reduction'. This will result in a significant reduction in water availability by 2025.

2 Regional climate modelling for the SEE region

2.1 The EU CLAVIER project

Andreas Gobiet, Wegener Center for Climate and Global Change, University of Graz (Austria) presented an overview of regional climate modelling which is being undertaken as part of the EU FP6 CLAVIER (Climate Change and Variability: Impact on Central and Eastern Europe) project (http://www.clavier-eu.org). Regional climate model (RCM) simulations are run at a higher spatial resolution for smaller areas than GCMs and can, therefore, be used for more detailed regional precipitation and temperature projections. The CLAVIER project focuses on Bulgaria, Hungary and Romania. The RCM model domains, however, also cover the entire SEE region.

The CLAVIER model ensemble is simulating the period 1951-2050 using three regional climate models (REMO5.7 from ECHAM5, REMO 5.0 from ECHAM5, and LMDZ from IPSL/ECHAM5). Grid cell sizes are 25 and 30 km. The RCM outputs are further adjusted to a 10 km grid using empirical/statistical error correction and an additional refinement for topography. The direct RCM outputs often have large summer temperature biases (*e.g.* 3 - 4ºC in Serbia), as well as winter precipitation biases. For example, there is approximately a 75% overestimation in mountainous areas of Bosnia and Herzegovina and of Montenegro. After adjustment, the results are in much better agreement with observations for the current climate. The mean temperature trend reported by A. Gobiet for the CLAVIER model ensemble is 1.5ºC/60 years (with a model range of 0 to +4ºC/60 years). This trend was found to be statistically 'highly significant'. Projected trends in precipitation were not found to be significant in most regions relative to background variability, although the analysis considered only Hungary, Bulgaria and Romania. However, a tendency for drier summers and wetter winters is found in the results.

Gábor Bálint, VITUKI Environmental Protection and Water Management Research Institute (Hungary), also presented climate projections for the Danube basin. Projections are based on the refined REMO 5.7 model results from the CLAVIER project. An increase in mean annual temperature of up to 1.8ºC by 2021-2050 (relative to the 1961-1990) and a decrease in mean annual precipitation of up to 15% were illustrated for the SEE portion of the Danube basin. Summer decreases in precipitation are expected throughout the SEE region. Possible increases in winter precipitation are, however, projected for some areas.

2.2 The SINTA project

The SINTA project (Guialdi *et al*., 2008; Rajkovic and Durdjevic, 2008) has applied regional climate modelling for the Mediterranean and the Balkans regions in a collaborative project between Italian and Serbian institutions. Vladimir Durdjevic, University of Belgrade, presented an overview of this project. The project has undertaken dynamical downscaling of the global SX-G model to a 25-km grid using the EBU-POM model (EBU – Eta Belgrade University atmospheric model; POM – Princeton Ocean Model). The regional model was run for a reference period 1961-1990 and two scenario periods, 2071-2100 (based on the A1b and A2 SRES scenarios) and 2001-2030 (based on the A1b scenario). Results indicate an increase in the average annual temperature of 0.9 – 1.1ºC for the period 2001-2030 (A1b scenario) and 3.6 – 3.8ºC (A2 scenario) for the period 2071-2100 for the SEE region. Changes in the average annual precipitation range from -10 to +5% for the near future period (2001-2030; A1b) and -15 to +5% for the end of the 21st century (2071-2100; A2; reproduced as Figure 2.1 below).

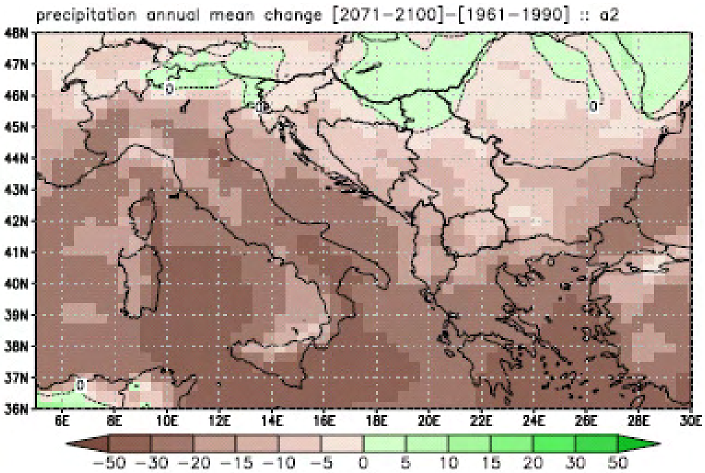


Figure 2.1 EBU-POM regional results for percentage change in precipitation by 2071-2100 relative to the 1961-1990 control period, based on the A2 emission scenario. Source: Vladimir Djurdjevic and Borivoj Rajkovic, Institute of Meteorology, University of Belgrade.

2.3 The EU PRUDENCE and ENSEMBLES projects

In addition to the two projects on regional climate modelling reported at the workshop, two recent EU-funded projects have also generated and evaluated RCM applications within Europe: PRUDENCE (Prediction of Regional Scenarios and Uncertainties for Defining European Climate Change Risks and Effects; http://prudence.dmi.dk/main.html) and ENSEMBLES. Within the PRUDENCE project, A2 and B2 emission scenarios were considered for the period 2071-2100, relative to a 1961-1990 reference period, for various combinations of 10 RCMs and 4 GCMs. In most cases, the RCMs are based on a 50 by 50 km grid, thus somewhat coarser than the more recent work reported above. The project ended in 2004, and the model simulations are now available to the general research community for use. Further details, including some results that have been aggregated on a country by country basis for Europe (Christensen, 2004) are available on the PRUDENCE website.

As a follow-up to the PRUDENCE project, the EU-funded ENSEMBLES project (http://ensembles-eu.metoffice.com/) is generating higher resolution RCM simulations (up to 20 by 20 km) for the near future period 2020-2050, based on the A1b emissions scenario. Model simulations from this project are only now becoming available, but should provide a valuable source of input data for use in catchment models. Further downscaling to the catchment scale will in most cases still be required.

Although RCM simulations, in principle, provide better precipitation and temperature projections at the regional scale, work within the PRUDENCE project identified particular problems with simulations over south-eastern Europe (Christensen, *et al*., 2007). The RCMs, in many cases, overestimated summer warming and drying and interannual variability in summer temperatures in this region (Hagemann, *et al*., 2004; Jacob, *et al*., 2007). This overestimation was determined based on comparisons with global data, such as the ECMWF Reanalysis (ERA) data or the CRU dataset (Mitchell and Jones, 2005), for historical periods. The problem is also seen in GCMs, but in some studies, it has been found to occur to a lesser extent with GCMs than with RCMs.

Various reasons have been suggested for the discrepancies in summer temperatures, including differences between GCM and RCM model physics which impact the coupling between the models, and deficiencies in the land surface model, particularly the soil moisture component (*e.g.*Van den Hurk *et al*., 2005). A depleted soil moisture store, for example, limits evaporative cooling, leading to enhanced warming and drying. Recently published work (Hagemann, *et al.,* 2009), compares the outputs of the ECHAM (GCM) with REMO (RCM) simulations. These models share similar atmospheric model physics, thus avoiding some of the problems arising when very different GCMs and RCMs are coupled. In this case, the GCM results produced a stronger drying and a greater reduction in summer precipitation, relative to the RCM simulations. The difference is attributed to the better representation of land surface processes within the RCM (in this case, REMO). This is a general topic which has been further pursued within the ENSEMBLES project, and the outcomes are of particular relevance to projected trends in the SEE region.

3 Projected climate change impacts on runoff

3.1 General projections from the IPCC 2007 report

Projected changes in water balance components, such as runoff, evapotranspiration and soil moisture are available directly from the output of climate models, both global and regional. These are, though, generally considered to be rough estimates, only suitable for considering large-scale spatial patterns of average annual values. Based on the IPCC AR4 scenarios, average annual runoff is expected to change by -20 to -40% in the SEE region by 2090-2099, relative to the 1980-1999 reference period (Fig. 2.10 in Bates, *et al*., 2008, reproduced as Figure 3.1 below). This analysis is based on the median of the results of 12 GCMs run with the A1b scenario. The SEE region lies within the domain where at least 90% of the models are in agreement with respect to the sign of the change. Decreased runoff in the region is therefore considered to be very likely. The percentage reduction corresponds to a decrease of 0.2 mm/day in most of the SEE region and up to 0.3 mm/day in the southernmost portion of the SEE.

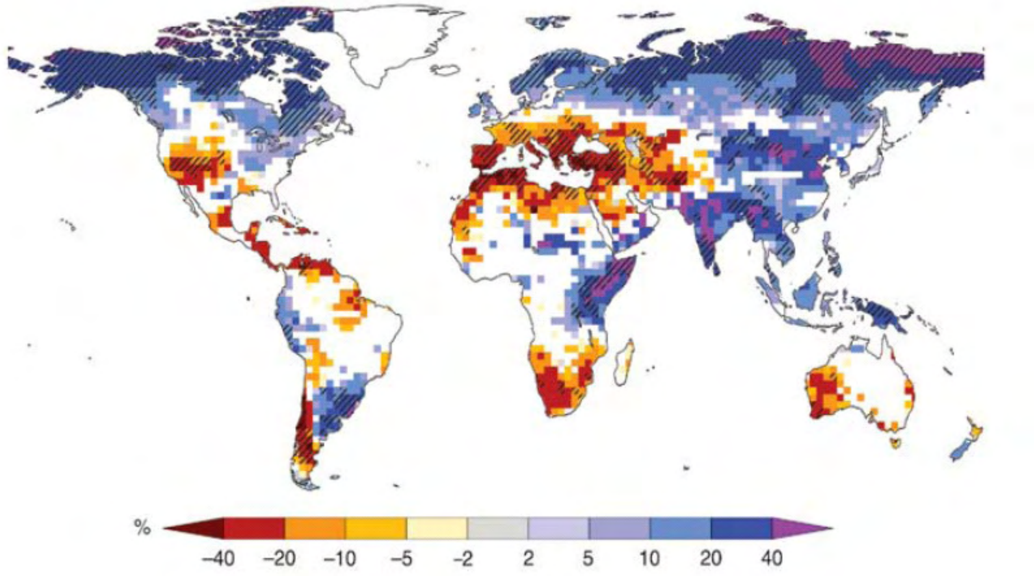


Figure 3.1 Large-scale relative changes in annual runoff for the period 2090-2099, relative to 1980-1999. White areas are where less than 66% of the ensemble of 12 models agree on the sign of the change, and hatched areas are where more than 90% of models agree on the sign of the change (from Bates, et al., 2008, Figure 2.10; after Milly, et al., 2005).

Projected changes in evaporation and soil moisture are also available from the GCM results, although their reliability is limited by the physics used in the GCMs to describe land surface processes. Based on the global scale projections, soil moisture within the SEE region is expected to decrease by 5 to 15% (annual mean), with the largest decreases occurring along the Adriatic coast. The change in annual mean evaporation varies between -0.1 and +0.2 mm/day in the SEE region. The increases are expected to occur along the Adriatic Coast, which is consistent with the reduction in soil moisture expected in this region.

3.2 Projections based on water balance estimates from GCM output

Expected changes in runoff can, in principle, also be estimated by establishing statistical relationships between precipitation, temperature and runoff for historical periods. Projected runoff is then estimated by using GCM or RCM outputs for precipitation and temperature in the empirical equation for runoff. Water balance calculations were used to estimate an expected decrease in average annual runoff for Serbia of between 21 and 63% (varying according to the P and T changes considered), as reported by workshop participant Mihajlo Andjelic. Similarly, projected changes in the annual discharge in three major basins in Macedonia, the Vardar, the Treska and the Bregalnica, are 7, 18 and 24%, respectively, by the year 2100 (as reported by workshop participant Suzana Alcinova Monevska).

Water balance methods were also used in a study in Albania which estimated expected changes in mean annual and seasonal runoff (Demiraj, *et al*., 2004; Bruci, 2004). That study was based on six GCMs run under several emission scenarios, from which an average GCM output was generated. Precipitation and temperature series from model output were downscaled to 40 climatological stations in Albania using the 'inverse distance' method. Two simple statistical models, relating precipitation, an index value of evapotranspiration based on temperature, and runoff, were calibrated with respect to mean annual runoff in 18 Albanian catchments. The results indicate a decrease in annual runoff of 6.3 to 13.6% by 2025, and 28.2 to 47.2% by 2100 (for a temperature increase of 3.6ºC and a precipitation decrease of 12.5%).

3.3 Large-scale applications of hydrological models

3.3.1 Results from published model applications

The impact of future climate change on runoff and other hydrological components, such as snow storage and soil moisture, can also be assessed by applying hydrological models at global, regional or more local scales. Several global and continental-scale applications of hydrological models aimed at assessing anticipated changes in water availability and water stress resulting from climate and global change have been published in recent years (*e.g*. Arnell, 1999, 2003; Vorösmarty *et al*., 2000; Alcamo *et al*., 2003; Döll *et al*., 2003). These models consist of land surface water balance calculations at the scale of individual grid cells and may or may not include routing of surface water. Large-scale models are generally run with a spatial resolution 0.5º by 0.5º, using input data for current conditions from global datasets (*e.g.* CRU data; Mitchell and Jones, 2005). Future climate is simulated by applying delta change factors, derived from GCMs, to the data series representing the reference period (*e*.g. 1961-1990). Results suitable for a rough analysis of projected changes within the SEE region are, in principal, generated in these model runs.

The application of the hydrological model of Arnell (2003, 2004), for example, uses 19 scenarios representing different GCMs, emission scenarios and initial conditions as climate input data. The results indicate that more than half of the scenarios considered show a decrease in runoff in south-eastern Europe by the 2020s (Arnell, 2003; Figure 10). Changes in the average annual runoff based on an application of the WaterGAP hydrological model run under two GCMs, ECHAM4 and HadCM3, for the A2 emissions scenario are illustrated in the IPCC (2007) AR4 chapter on Europe (Alcamo *et al.,* 2007a). Results based on the ECHAM4 GCM indicate a change in runoff of +5 to -25% in the SEE region by the 2020s. By the 2070s, the entire region exhibits a reduction of at least 25%, with some grid cells having a reduction in runoff of greater than 50%. Modelling based on the HadCM3 GCM indicates less extreme changes, with most of the region characterised by a reduction in runoff of 5 to 25% by the 2070s. Some grid cells in the region of Serbia, though, exhibit small increases in runoff.

3.3.2 Results for the SEE region from the VIC hydrological model

Results of a global application of the VIC hydrological model (model description in Nijssen *et al*., 2001), aggregated on a country-by-country basis for the SEE region were presented by Deborah Lawrence (Norwegian Water Resources and Energy Directorate). The model application is being undertaken by Ingjerd Haddeland (also of the Norwegian Water Resources and Energy Directorate) as part of an intermodel comparison for the GWSP (Global Water System Project, www.gwsp.org) and the EU FP6 WATCH (Water and Global Change (www.eu-watch.org) projects. Results from that work for the SEE region were extracted for presentation at the workshop. Hydrological modelling for a reference period (1961-1990) is based on input data from the CRU global dataset *v*. 2.1 (Mitchell and Jones, 2005). Delta change factors derived from two alternative GCMs (HadCM3 and ECHAM5) run under two emission scenarios (A1b and B1) for the period 2071-2100 were used to transfer the future climate signal to the input data series.

The projected monthly runoff for the current climate and future scenarios is illustrated in Figure 3.2 for countries within the SEE region and Turkey. The monthly change in runoff relative to the current climate is also shown. The results indicate a reduction in runoff throughout the region for most of the year, with summer decreases of > 50% in many cases. The southern portion of the region, represented by Albania, Macedonia and Turkey, exhibit decreased runoff in all months of the year relative to the control period for all scenarios. Countries with mountainous regions experiencing significant winter snow storage under the current climate, show marked decreases in runoff during the current snowmelt period (*e.g.* month of April) under a future climate. In some countries (*e.g*. Montenegro, Bosnia and Herzegovina) winter runoff is expected to increase. Modelled changes in snow water equivalent support this change in the timing of peak runoff in that a decrease in snowfall and storage is projected throughout the region. A higher fraction of precipitation will fall as rain, rather than snow, during winter months.

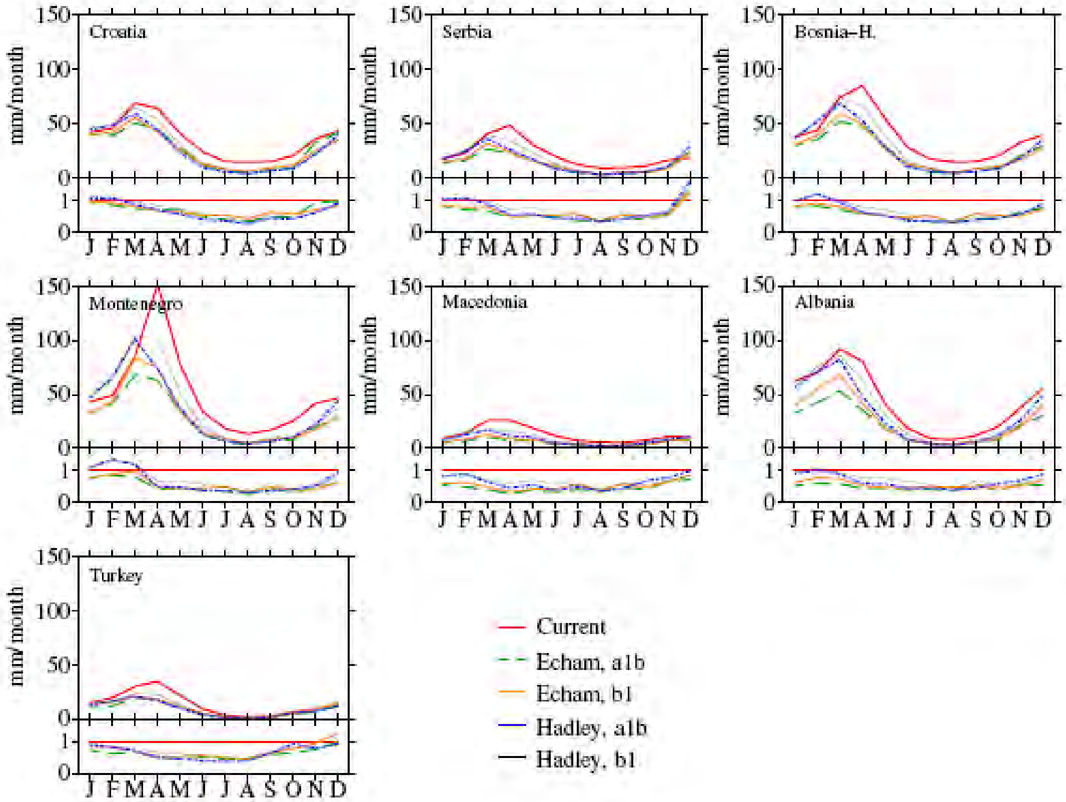


Figure 3.2 Monthly runoff for current (1961-1990) and future (2071-2100) periods extracted from a global-scale application of the VIC hydrological model based on a 0.5º x 0.5º grid cell size. Percentage change relative to the current climate is illustrated in the lower portion of each figure. Input data for the current period is derived from the CRU global data set v. 2.1 (Mitchell and Jones, 2005). Future periods were simulated by applying delta change factors from the GCM outputs indicated. Source: Ingjerd Haddeland, NVE

3.4 Catchment-scale applications of hydrological models

3.4.1 Hydrological modelling of Tisza river subcatchments in the CLAVIER project

Catchment-scale applications of hydrological models are now used in much of Europe to evaluate projected climate change impacts on runoff and other water balance components. These applications are run at a higher spatial resolution than the large-scale modelling described above. If suitable daily data are available as model input timeseries and for calibration, these models can be used to generate daily values of discharge. Their application in high-resolution climate impact studies is also dependent on the availability of downscaled climate scenario data suitable for the scale of the model application. Gábor Bálint (Hungary) presented hydrological simulations for source area subcatchments of the Tisza river basin (tributary to the Danube, which it enters in Serbia). These simulations are being undertaken within the CLAVIER project, using the REMO RCM model output described previously in Section 2 of this report.

Climate model results by subcatchment indicate decreases in precipitation in the spring and summer seasons in all subcatchments. Annual decreases in all subcatchments, excepting the Upper Tisza region, are also projected. Hydrological model results indicate large increases in winter runoff and small increases in total annual runoff for subcatchments in the Upper Tisza region. Subcatchments in the Upper Central region show moderate to large increases in winter runoff and decreases in spring and summer runoff. The net result in this region is a small to moderate decrease in annual runoff. The Lower Tisza is characterised by winter increases in runoff, and decreases throughout the rest of the year, leading to a decrease in total annual runoff. The work presented demonstrates an effective method for examining spatial variation in climate change impacts on runoff, using a refined regional climate model and hydrological modelling.

3.4.2 An example of hydrological model applications from the Nordic region

Climate input data, downscaled from regional climate models, has also been used as input to hydrological models to examine future trends in runoff in the Nordic region. Hege Hisdal, Norwegian Water Resources and Energy Directorate, presented an overview of recent work involving the application of hydrological models (HBV and related versions of this model). Climate input data for this work was derived from the RegClim HIRHAM and Rossby Centre RCAO regional climate models, based on the HadAM3H and ECHAM4/OPYC3 GCMs run under the SRES A2 and B2 emission scenarios. The hydrologic simulations were conducted by the national hydrological institutes of each of the Nordic countries in conjunction with the Climate and Energy Project, 2002-2006, funded by Nordic Energy Research. The compiled results, which illustrate changes in runoff (annual and seasonal), annual evaporation, snow water equivalent and soil moisture, between a reference period (1961-1990) and a future period (2071-2100) have been presented and published in the form of a series of maps for the Nordic region (Beldring *et al*., 2006). This and related work involving local downscaling of climate model data demonstrate the benefits of using high-resolution climate input data in conjunction with calibrated hydrological models to assess future changes in runoff. In addition, ensemble modelling of hydrological outcomes can be used to evaluate a range of climate scenarios and hydrological models and to illustrate uncertainties in the hydrological projections.

3.4.3 Data requirements for detailed hydrological modelling

Detailed hydrological modelling of climate change impacts on runoff is dependent on the availability of regional climate model results and on local observational data for precipitation, temperature and river discharge. Section 2 of this workshop summary outlines potential sources of regional climate model outputs associated with recent and continuing research projects in Europe and in the SEE region. Local observational data, is also necessary, both for the refinement of regional climate model 'signals', and for the calibration of hydrological models relative to historical data. Several workshop presentations, including those from Albania (Molnar Kolaneci), Bosnia and Herzegovina (Darko Borojevic and Nada Rudan), Croatia (Kreso Pandzic), Macedonia (Suzana

Alcinova), Montenegro (Ivana Pavicevic) and Serbia (Mihajlo Andjelic and Tatjana Savic), provided some information regarding data availability in individual countries. These data, in many cases, contributed to the analyses of historical changes described in the following section, and can also potentially serve as a basis for detailed modelling of climate impacts in future work.

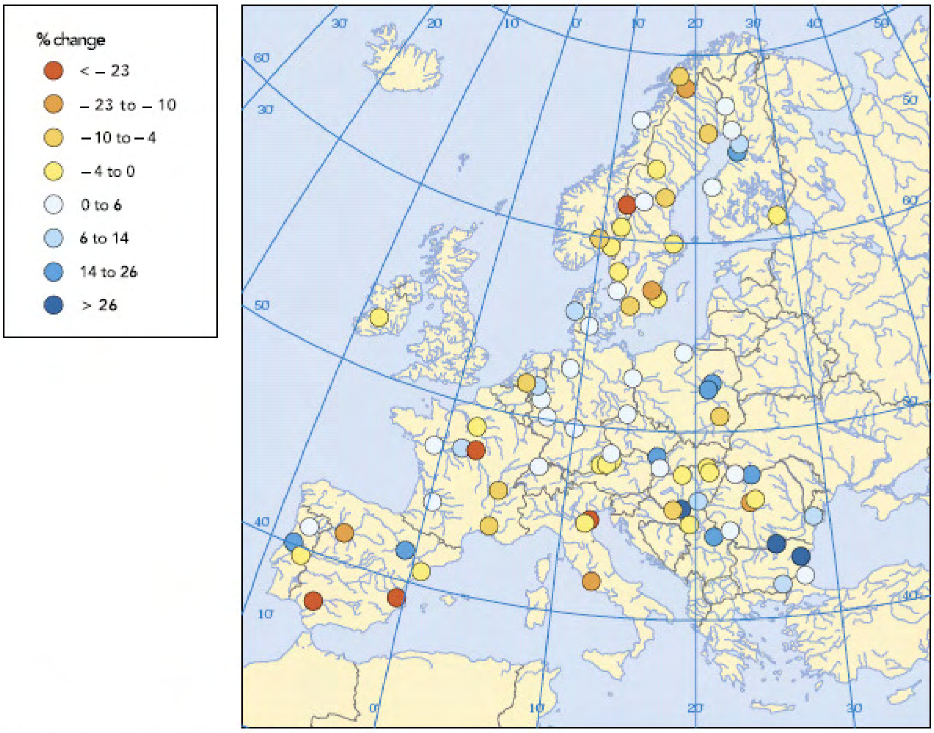
4 Observed historical changes in the SEE region

4.1 General results from the IPCC and other published sources

Spatial patterns of observed change in annual and seasonal surface temperature are presented in the IPCC AR4 report at the global scale (Trenberth, *et al*., 2007), based on GHNC station data compiled by Smith and Reynolds (2005). Linear trends in the annual temperature change are fitted for two periods: 1901 – 2005 and 1979 – 2005 (Trenberth, *et al*., 2007; Figures 3.9 and 3.10). The SEE region lies within a zone where the annual surface temperature change is 0.0 – 0.8 (ºC per century) based on the period 1901 – 2005, and 0.1 – 0.5 (ºC per century) based on the period 1979 – 2005. On a seasonal basis, the only season in which the results are statistically significant within the SEE region is summer (JJA). An observed increase of 0.3 to 0.5 (ºC per century) was found based on the period 1979 – 2005.

The change in annual precipitation has also been analysed from the GHNC data (Trenberth, *et al*., 2007; Figure 3.13) and indicates a decrease of 0 – 15% (per century) for the period 1979 – 2005 for the SEE region. The change, though, was not found to be statistically significant. The analysis of Norrant and Douguédroit (2005) indicates that the eastern portion of the Mediterranean area has experienced a negative trend in precipitation over the period 1950 – 2000. Earlier work summarised in Parry (2000) also indicates a decrease in annual precipitation within southern Europe (by up to 20% over the period 1900 – 2000), although the SEE region exhibits zones of both increasing and decreasing precipitation (European Environment Agency, 2004, Map 3.3). Summer precipitation, however, shows decreases of up to 30% in the SEE region, and this is significant at the 90% level.

Projected changes in runoff for the SEE region based on climate and hydrological modelling all point towards a decrease in runoff under a future climate, particularly during summer periods. Evidence for historical changes in runoff in response to climate change, however, can be very difficult to extract from discharge records due to the effects of land use changes and river regulation, in addition to natural climatic variability. At the continental scale, there is evidence for a decrease in the average annual runoff in southern Europe based on global analyses (Milly, *et al*., 2005), and this is supported by the pattern of decreases observed in the Mediterranean region (*e.g.* as illustrated by Map 3.11, EEA, 2004; reproduced as Figure 4.1 below). The data points from the SEE region exhibit moderate increases and decreases, however, as well as stations with minimal change



Note: The observed time periods differ between stations.
Source: CEDEX, Spain, 2003, based on UNESCO, 1999.

Figure 4.1 Changes in mean annual river discharges over the twentieth century. Source: European Environment Agency, 2004.

The changes reported above are based on large-scale analyses and thus, only provide an overview of regional or, in the case of runoff, subcontinental scale changes. The following paragraphs summarise workshop presentations evaluating evidence for changes in temperature, precipitation and/or runoff in individual countries within the SEE region based on observational data. In each case, different methods and reference periods have been used, so it is generally not possible to make direct comparisons between the results reported by individual participants.

4.2 Reports from individual countries

4.2.1 Albania

Molnar Kolaneci, Institute of Energy, Water and Environment (Tirana) presented a study evaluating patterns of precipitation and runoff in Albania over the period 1931-2007. Precipitation from 7 stations (all with records from 1951 and three with records from 1931) were analysed using 5, 10 and 20-year moving averages. More recent years appear to be drier relative to the period 1951-1981. Similar techniques were applied to runoff data, and a decrease in runoff in recent years is observed in some rivers (see Figure 4.2 below, for example), but not in all rivers. The observed trends, though, have not been analysed for significance. It was proposed by Molnar Kolaneci that the current drier conditions could in fact be part of a natural cycle of variability, rather than a product of human-induced climate change. Andreas Gobiet (University of Graz, Austria) responded to this suggestion by pointing out that the observed trends are fully consistent with climate model projections. The magnitude of changes resulting from natural variability is expected to be similar to that associated with human-induced climate change over the short-term.

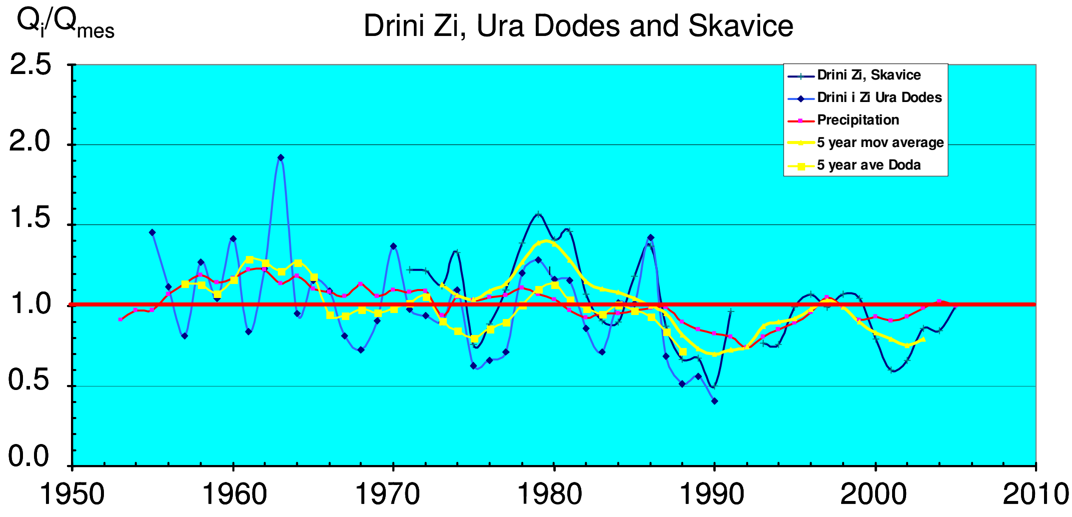


Figure 4.2 Scaled annual discharge in the Drini Zi at Ura Dodes and Skavice. Five-year moving averages for discharge and annual precipitation are also illustrated. Source: Molnar Kolaneci, Institute of Energy, Water and Environment, Tirana, Albania.

4.2.2 Bosnia and Herzegovina

Nada Rudan, Republic Hydrometeorological Institute (Banja Luka) has compared the monthly average temperatures in the two most recent years, 2007 and 2008, with monthly averages for a reference period, 1961-1990, at four stations. The monthly temperatures for the period January – August were higher in all months than the reference period averages. In 2008, the temperatures were higher for all months of the year. The mean summer temperature at Banja Luka has increased over the period 1957-2008. A comparison of seasonal precipitation during the most recent decade with ‘climate normals’ at 7 stations indicates increases in autumn and winter precipitation and decreases in spring and summer precipitation at most stations. Analysis of a long-term precipitation record at Trebinje for the periods 1920-1970, 1951-1980 and 1997-2008 indicates a decrease in the annual mean from 2125 mm (1920-1970) to 1649 mm (1951-1980) to 1591 mm (1997-2008).

Dzenum Zulum, Federal Meteorological Institute (Sarajevo) provided a presentation which reports a comparison of annual precipitation during a reference period (1961-1990) with a recent (1991-2008) period at 12 stations. Seven of the stations show a small increase in precipitation in recent years, and five exhibit a decrease. Trends in annual precipitation were fitted for two stations with long records (Sarajevo, 1888-2008) and Mostar (1923-2007). The results indicate a tendency towards a minimal increase in precipitation over the period of record. There is also some evidence that heavy rainfall events have been registered more frequently in recent years at the Sarajevo station.

Darko Borojevic, Republic Hydrometeorological Institute (Banja Luka), Hydrology Sector, has compared discharge records for the most recent decade (1999-2008) with a reference period (1961-1990) at Banja Luka gauging station. The results indicate higher discharges in March and April and lower discharges in May, June, July and August in the recent (1999-2008) decade, relative to the reference period. The observed pattern of discharge follows the pattern of precipitation at Banja Luka.

4.2.3 Croatia

Kreso Pandzic, Meteorological and Hydrological Service (Zagreb) presented results illustrating long-term variations in water balance components for Croatia. The analysis was based on monthly data at 24 stations (Zagreb for period 1862-2000; 23 other stations for period 1951-2000). A 25-year moving average was applied to the data, and spatial autocorrelation based on the distance between stations was also accounted for. The results tend to indicate an increase in annual temperature and a decrease in precipitation over the periods considered. The results for precipitation, though, are highly variable between stations and local increases are also observed. Potential and actual evapotranspiration (estimated using Palmer's procedure) appear to have increased since the 1960s and the 1930s, respectively. Estimated runoff for the Sava river basin exhibits significant decreases, particularly since the 1960's, as illustrated in Figure 4.3. Comparison of the estimated runoff and observations of river discharge at Zagreb indicates a good correspondence between the estimates derived from Palmer's procedure and observed trends in runoff (Pandzic, *et al.,* 2009).

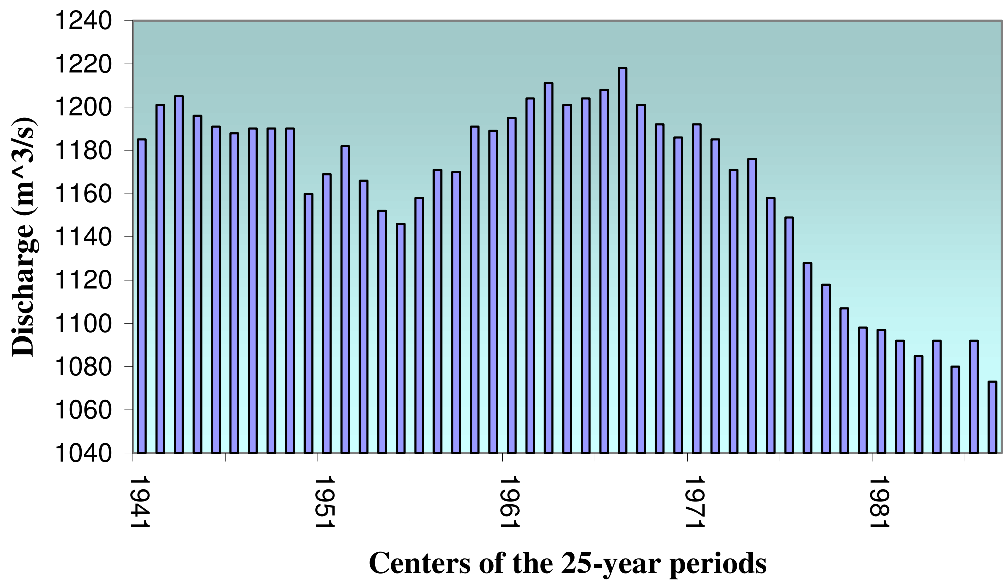


Figure 4.3. 25-year moving averages of river discharge for the Sava river at Zagreb based on discharge data for the period 1931-2000. Source: Krešo Pandžić, Meteorological and Hydrological Service of Croatia.

4.2.4 Macedonia

Suzana Alcinova Monevska, Hydrometeorological Institute of Macedonia, reported an analysis of average annual temperature at Skopje and Bitola for the period 1926-2000. The results indicate decreases in temperature during the period 1926-1991 and an increase over the period 1992-2000. There is, however, considerable variability between years. Annual precipitation records for period 1926-2000 suggest a slight decrease at Bitola (eastern region of Macedonia) and minimal change at Skopje. Inter-year variability, however, dominates the observed series.

4.2.5 Montenegro

Mirjana Ivanov, Hydrological and Meteorological Service of Montenegro, presented an analysis of seasonal temperatures at Podgorica and Kolasin, comparing a recent 15-year period (1991-2005) with the 1961-1990 reference period. Summer temperatures in the recent period at both stations lie within the 97 – 98 percentiles of the distribution of summer temperatures during the reference period. Other seasons exhibit minimal changes. A similar analysis of precipitation indicates a possible recent increase in autumn precipitation relative to the reference period.

4.2.6 Serbia

Tatjana Savic, Republic Hydrometeorological Service of Serbia, presented maps of the spatial distribution of 50-year linear trends in annual temperature and precipitation based on data from all of the principal stations in Serbia for the period 1950-2004. The maps illustrate temperature increases of up to 0.8-1.0ºC per 50 years in the western portion of the country and slight decreases (of -0.2 to -0.4ºC) in the southeast. Precipitation appears to have increased in the western portion of the country (by up to 150-180 mm/yr), and decreased by up to -150 mm in the eastern portion of the country. In general, precipitation appears to have decreased in most of the southern half of Serbia.

4.2.7 Turkey

Atilla Gurbuz, General Directorate of Electrical Power Resources, Survey and Development Administration in Turkey, reported evidence for a slight increase in average annual air temperature in Turkey over the period 1941-2007, a possible decrease in average annual precipitation over the same period, and a more marked decreases in estimated total runoff for the country since 1970. A trend line for temperature over the period 1941-2007 was fitted. Since 1993, values for all but one year lie above the trend line. Evaluation of precipitation anomalies over the same period indicate that the occurrence of years with higher precipitation have possibly decreased since the 1960's. Droughts are possibly more frequent, although the dominant trend for droughts is one of periodic recurrence every 16-18 years. Analysis of streamflow records indicates a decrease in mean flows for rivers in the western, middle and southern regions of Turkey during the past 39 to 73 years. It is also observed that the lengths of wet periods have become shorter and that the intensities of dry periods have increased. It is estimated that surface water availability has decreased by 8% in recent years.

5 Concluding remarks

Although the range of results presented for both observed and modelled changes in temperature, precipitation and runoff is quite large, there is a general consensus that an increase in average annual temperature and decreases in annual precipitation and runoff are likely within the SEE region under a future climate. In many cases, evidence for these changes in recent years is already observed, as exemplified by the reports from individual countries in the previous section. Results for the region on a seasonal basis point towards likely increases in mean temperature and decreases in mean precipitation in summer months. Projections for the winter season are much more variable. Similarly, spatial variability in runoff response to changes in temperature and precipitation is considerable. This variability reflects, for example, differences in the potential for snow storage, as well as the impacts of variable topography, atmospheric circulation patterns and land cover. The use of hydrological modelling in conjunction with downscaled and corrected RCM scenarios is required for impact analyses which are relevant at a more local level than is reported here.

This report represents the conclusion of the first phase of a Statkraft project, the goal of which has been to develop an overview of climate change in the SEE region over the next 20-50 years and its consequences on runoff and the hydropower potential. This work has benefitted significantly from the many presentations contributed by representatives from the national and regional hydrometerological and climatological institutes in the SEE region. The second phase of this project will undertake more detailed hydrological modelling for selected catchments in the SEE region. This phase will involve the compilation of the scenario, observational and other data required for such modelling, in collaboration with the hydrometeorological institutions in the region. The goal of this phase is the estimation of anticipated future annual and seasonal patterns of runoff in the selected catchments. This is an outcome of relevance to a range of water management issues and applications.

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EU CLAVIER project - http://www.clavier-eu.org

EU ENSEMBLES project - http://ensembles-eu.metoffice.com/

EU PRUDENCE project - http://prudence.dmi.dk/

Appendix – List of workshop presentations

Country/Region	Presented by	Presentation
Albania	Molnar Kolaneci	*"Changes in precipitation and runoff in the hydrographic territory of Albania in the last 50 years"* by M. Kolaneci and V. Mustaqi
Austria	Andreas Gobiet	*"Climate change modeling and results from SEE – The CLAVIER project"* by A. Gobiet, D. Jacob and the CLAVIER Team
Bosnia and Herzegovina		*"Precipitation in Bosnia and Herzegovina"* by Dženan Zulum *"Precipitation and temperature trends in Republic of Srpska"* by Nada Rudan *"Runoff at Vrbas basin"* by D. Borojević
Croatia	Kreso Pandzic	*"Long-term variations of the water balance components for Croatia"* by K. Pandžic, D.Trninić, T. Likso, and T. Bošnjak
Hungary	Gábor Bálint	*"Climate Change Impact Studies to Design Adaptation Measures in Central and Eastern Europe"* by G. Bálint and the CLAVIER Team
Macedonia	Suzana Alcinova Monevska	*"Climate Change Research in Republic of Macedonia in the XXI Century"* by S. Alcinova Monevska, P. Ristevski, B. Unevska
Montenegro	Ivana Pavicevic	*"Climate Change and Changing Runoff in South East Europe"*
	Mirjana Ivanov	*"Observed trends of Temperature and Precipitation in Montenegro"*
Norway	Hege Hisdal	*"Climate change and hydrological modelling in the Nordic countries"* by H. Hisdal, D. Lawrence and S. Beldring
	Deborah Lawrence	*"Hydrologic effects of climatic change in SEE. What do we know?"* by I. Haddeland and D. Lawrence
	Asgeir Sorteberg	*"Climate variability and human-induced climate change: background and implications"* by A. Sorteberg
	Tom Andersen	*"Statkraft and climate change effects on runoff in SEE"*

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