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Executive Summary

The EnviroGRIDs project explores a number of approaches to conduct environmental studies based on existing climate data. The WP3 consider climate scenarios for the Black sea basin by exploiting available datasets. Unfortunately, these datasets are not so numerous as far as the resolution, diversity, location, and future scenarios are concerned. The more readily comprehensible sources of regional data for this project are provided by the two European projects PRUDENCE and ENSEMBLES as described further in this report. Although these projects produced outputs that are relevant to enviroGRIDS few drawbacks prevent from using their full potential. Nevertheless, developing a method for characterising climate change in the Black-Sea catchment is of particular interest in task 3.2. The key issue of this task focuses mainly on climate scenarios. Numerical climate simulations depend highly on the greenhouse gas emission scenarios which determine their concentrations in the atmosphere that drive the evolution of the climate system. Climate scenarios have evolved using assumptions that are based on more solid grounds than the ones developed until quite recently. These scenarios have been developed in conjunction with our understanding of the main factors causing the emissions of greenhouse gases. Interestingly enough, all these lead to a global climate warming. Global warming will also impact to the Black Sea Basin. Consequently, the regional energy and water cycles are going to be modified in response to this warming. Temperature and precipitation are the main descriptors of climate that also serve as inputs to most hydrological and other impact models and thus deserve much attention. For a number of reasons, however, even state-of-the-art regional climate model outputs may not be appropriate to feed hydrological as well as other impact models. Among other things, the horizontal resolution is yet too coarse to drive the local and regional hydrological cycles in a realistic manner as the current simulated baseline climate shows temperature and precipitation biases. Consequently, one must rely on other methodologies to generate long term climate data to feed in subsequent models. One of these is based on the so-called “delta” method, which may be considered as a surrogate for future projections. This method yet requires the simulated outputs of regional climate models, but only to compute differences (*i.e*. deltas) on the basis of the distributions of variables such as temperature, precipitation, *etc*. These deltas may then be used to perturb available observation time series to produce extra series representative of local future climates. These can thus be used to drive hydrological and other impact models. However, a practical recommendation would be to foster the development of a “PRUDENCE-like” project using high resolution models with their computational domains centered over the Black Sea basin.

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1. Preamble

A scenario is a plausible description of a possible future state of the world. A set of scenarios is often adopted to reflect, as well as possible, the range of uncertainty in projections. A scenario family has the same demographic, politico-societal, economic and technological storyline. A storyline is a narrative description of a scenario (or a family of scenarios), highlighting the main scenario characteristics and dynamics, and the relationships between key driving forces[1].

In what follows, climate scenarios are not numerical predictions such as weather forecasts but possible representations of the future state of the climate that are consistent with assumptions about future emissions of greenhouse gases (GHG), aerosols and other pollutants. These scenarios also depend on our understanding of the effect of increased atmospheric concentrations of these gases on the climate system. A climate scenario is thus a reasonable suggestion of what the future could be like over decades or centuries, given specific sets of assumptions. These assumptions include future trends in energy demand, emissions of greenhouse gases, land use change as well as assumptions about the response of the climate system over long enough time scales (Fig. 1).

Therefore, the selection of scenarios is subject to controversy, unless the fundamental uncertainties inherent in future projections are properly addressed in the impact analysis[1]. There are two main uncertainties in determining future climate: the trajectories of future emissions of greenhouse gases and aerosols, and the response of the global climate system to any given set of future emissions [Meehl *et al.*, 2007]. These uncertainties normally are elucidated via application of global climate models (GCMs), which provide information at relatively coarse spatial resolutions. Greater interest in, and concern about, the details of climate change at regional scales has provided the motivation for the application of Regional Climate Models (RCMs), which introduces additional uncertainty [Christensen *et al*., 2007a]. These uncertainties in fine-scale regional climate responses, in contrast to uncertainties of coarser spatial resolution global models in which regional models are nested, now have been documented in numerous contexts [Christensen *et al.*, 2007a] and have been found to extend to uncertainties in climate impacts [Wood *et al.*, 2004; Oleson *et al*., 2007].

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[1] Source : //www.ipcc.ch/

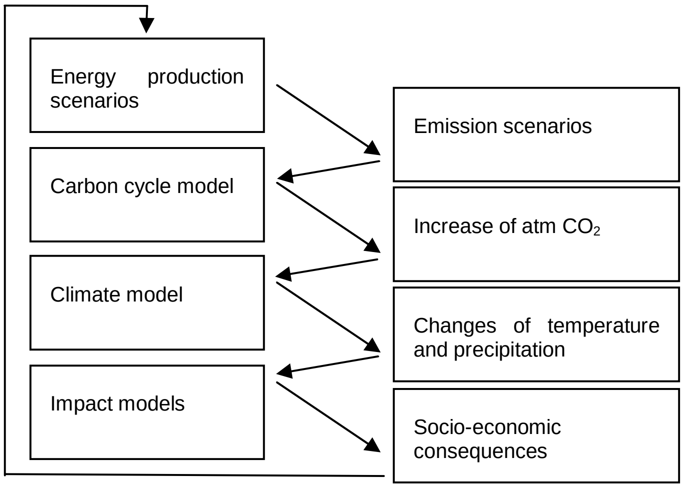

Figure 1. The chain of processes leading to numerical climate projections.

2. Why should we care about climate scenarios?

Scenarios are essential tools for the evaluation of future developments in complex systems, such as basins or catchments, which often are insufficiently understood and have high scientific uncertainties. Climate scenarios are mainly used in impact, adaptation planning, vulnerability and adaptation assessments of climate change (*e.g*. Adger *et al*. 2005), and these are strongly linked with the future concentrations of atmospheric greenhouse gases which will likely cause a historically unprecedented shift in climate. Recent data shows that the CO_2 concentration in the atmosphere is increasing at a high rate. In the 1960s, the average annual increase was only 37% of what it was in 2000 through 2007. The evolution of GHG concentrations in the atmosphere is thus likely to increase in the future and the 2007 fourth Assessment Report (AR4) compiled by the Intergovernmental Panel on Climate Change (IPCC) indicated that “changes in atmospheric concentrations of greenhouse gases and aerosols, land cover and solar radiation alter the energy balance of the climate system”, and concluded that “increases in anthropogenic greenhouse gas concentrations is very likely to have caused most of the increases in global average temperatures since the mid-20th century”. In other terms, GHG concentrations are at the basis of any future climate scenario and drive to a large extent the evolution of climate at the global and regional scales. Now the question is who and how these scenarios have been devised.

2.1 A historical note

In order to devise any climate scenario, one should keep in mind that the projections of future climates including the various states of the Atmosphere, the Hydrosphere, the Cryosphere, the Lithosphere, and that of the Biosphere (GARP, 1975) need to be adequately addressed with physically-based numerical models. While the first four sub-systems are being handled in a relatively successful manner, the "human-behaviour" compartment of the Biosphere is far from being understood and resolved in these models. This latter compartment includes economical, demographical, and social activities that are indeed rather difficult to represent and to predict. Human activities have been recognised to having much influence on the greenhouse effect through the release in the atmosphere a large amount of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4) *etc.*, as well as aerosol loading, which affect the planet's temperature and thus perturb the global climate system.

At the regional scale, particularly in the Black Sea basin, climate change is expected to exacerbate the stresses on water resources from population growth and economic and land-use change, including urbanisation. Current research suggests a significant future increase in heavy rainfall events, even though the mean rainfall is projected to decrease. The resulting increased flood risk poses challenges to society, physical infrastructure and water quality.

Do these impacts depend on climate scenarios? Perhaps the severity of the impacts has a positive relation with the rate of increase of GHG in the atmosphere but the fundamental question is what climate scenario is the most likely to occur.

As Spencer (2008) describes them in many details, climate "scenarios" has a history linked to scientific developments that occurred in the 19th Century with the seminal work of J. B. Joseph Fourier, who is also generally credited with the discovery of the greenhouse effect around 1824, a phenomenon demonstrated earlier by H. B. de Saussure at the end of the 18th Century. In 1896, S. A. Arrhenius speculated that changes in the levels of carbon dioxide in the atmosphere from human industries could substantially alter the surface temperature through the greenhouse effect. He was influenced by the work of others, including Fourier. He was the first to predict that emissions of carbon dioxide from the burning of fossil fuels and other combustion processes would cause global warming. He estimated that a doubling of CO_2 would cause a temperature rise of 5 to 6°C. Arrhenius expected a doubling of CO_2 over the next 3000 years! Nowadays, this scenario can no longer be supported since the level of CO_2 is expected to increase at a much higher rate by the end of the 21st Century. The equations and data available to 19th-century scientists were far too poor to allow an accurate calculation. In 1938, G. S. Callendar argued that the level of CO_2 was increasing and raising global temperature. As for the future, Callendar estimated that a doubling of CO_2 could gradually bring a 2°C rise in future centuries. In the mid 1950s, Gilbert N. Plass published a series of articles on the effects of carbon dioxide as a greenhouse gas, and the potential implications of scenarios where an increased concentration of CO_2 in the atmosphere for global warming. The articles were partly based on advanced calculations that used early electronic computers. The theoretical physicist Lewis D. Kaplan decided it was worth doing extensive numerical computations and, in 1952, he showed that in the upper atmosphere, adding more CO_2 must change the balance of radiation significantly. Consequently, the implication of a changing climate was slowly shaping up.

By the mid 1950s, researchers were arguing that it was important to measure atmospheric CO_2 much more accurately. In the early 1960s, C. D. Keeling measured the level of carbon dioxide in the atmosphere: it was rising fast. Researchers began to take an interest. They found that this gas plays a crucial role in climate change, so that the rising level could affect our future. Consequently, alternate climate scenarios were shaping up. An emerging carbon-cycle community began to talk with atmospheric scientists who pursued interests in weather and climate prediction. One valuable example of this overlap of interests was a calculation published by Princeton computer specialists in 1967: the first reasonably solid estimate of the global temperature change that was likely if the amount of CO_2 in the atmosphere doubled (Manabe and Wetherald, 1967). Crude models of climate change became common during the 1960s, and some of them showed plausible possibilities.

Digital computers were reaching a point where they might be able to include many aspects of the Earth's climate system. For analyzing climate under current conditions, supercomputer models *(i.e.* GCMs) took over the field toward the end of the 1970s. During the 1980s, many scientists started to realise that the Earth was getting warmer. Averaged over the entire planet, for doubling the atmospheric the CO_2 concentration as this figure was a metric for comparison of the model sensitivity, a number of GCMs with horizontal resolution of roughly 5°x5° with 10 vertical levels, predicted a warming of about 3.5°C. The results made a considerable impact on scientists and through them on policy-makers and the public. There was also progress in building aerosols into climate models. When Mount Pinatubo erupted in the Philippines in June

1991, sharply increasing the amount of sulphuric acid haze in the stratosphere world-wide, few research groups undertook tests for global climate models. The ability of modelers to reproduce Pinatubo's cooling effects was a particularly strong reason for confidence that the GCMs were sound.

However, by the end of the 1980s, doubling the atmospheric the CO_2 concentration in the model's atmosphere was considered too crude a change for a realistic evaluation of climate warming to occur in the 21^{st} Century. Consequently, the IPCC developed new long-term emission scenarios in 1990 and 1992. These scenarios have been widely used in the analysis of possible climate change, but in 1995, these scenarios were again updated. The evaluation recommended that significant changes in the understanding of driving forces of emissions and methodologies should be addressed. These changes in understanding relate to the carbon intensity of energy supply, the income gap between developed and developing countries, and to sulphur emissions. Consequently, this led to a decision to develop a new set of scenarios. This task was given to the group that worked on a Special Report on Emission Scenarios (SRES). The scenarios then were alternative views of how the future might develop and may influence future GHG emissions and to assess the associated uncertainties. These scenarios were then the main drivers of global and regional climatic changes of the following years.

2.2 The Intergovernmental Panel on Climate Change

All pieces of work mentioned above powerfully influenced the first Intergovernmental Panel on Climate Change (IPCC) report, appointed by the world's governments. The IPCC is a scientific intergovernmental body established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), two organizations of the United Nations, tasked to evaluate the risk of climate change caused by human activity. It bases its assessment mainly on peer reviewed and published scientific literature. The IPCC published its first assessment report in 1990 (FAR), a supplementary report in 1992 (SR), a second assessment report (SAR) in 1995, and a third assessment report (TAR) in 2001. A fourth assessment report (AR4) was released in 2007.

Projections of temperature change are obtained by running a climate model with the past forcings combined with consistent projected forcings to 2100. The number of model runs to be made is determined by the number of future emissions scenarios. The emissions scenarios of the IPCC quantifying global greenhouse gas emissions up to the year 2100 have significantly changed during their evolution from the First (1990, SA90), through the Second (1995, IS92), to the Third Assessment Report on Climate Change (2000, SRES) (IPCC, 1990b, 1995, 2001). The latest series from 2000, published in the Special Report on Emissions scenarios (SRES) (IPCC, 2000), has not yet been updated—it was used as the basis for the Fourth Assessment Report (IPCC, 2007). In the TAR and AR4, analyses of the performances of regional climate models were also taken into account. These reports essentially mention the following ideas:

(FAR) The executive summary of the first report says they are certain that emissions resulting from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases, resulting on average in an additional warming of the Earth's surface. They calculate with confidence that CO_2 has been responsible for over half the enhanced greenhouse effect. The climate projections were first carried out using equilibrium simulations with carbon dioxide concentrations where termed (1 x CO_2) and (2 x CO_2), with roughly 300 ppmv of equivalent atmospheric CO_2 for the control period and twice that amount for the future period. The equivalent CO_2 concentration is necessarily higher than observed CO_2 concentration since it represents the climate forcing due to CO_2 and also the forcing associated with all other greenhouse gases. The "business-as-usual" scenario gives an effective doubling of CO_2 by about 2020, and an effective quadrupling by about 2080. Also, a scenario "B" assumes an effective doubling of CO_2 to about 2040. Regional changes – GCM estimates from pre-industrial to 2030 assuming a "Business-as-usual" scenario for Southern Europe (35-50°N, 10°W-45°E), give a warming of about 2°C in winter and from 2 to 3°C in summer. Scenario "B" gives results which are about 15% lower. There is some indication of increased precipitation in winter, but summer precipitation decrease by 5 to 15%, and summer soil moisture by 15 to 25%. Confidence level is low, especially for the change in precipitation and soil moisture. Few coupled ocean-atmosphere models were run with a gradual increase in greenhouse gas, and the global rise in temperature is an approximately constant fraction of the equilibrium rise corresponding to the instantaneous forcing for a time that is earlier by a fixed offset. The regional patterns of temperature and precipitation change are generally similar to those of an equilibrium simulation, though uniformly reduced in magnitude.

(SR) The 1992 supplementary report was an update, requested in the context of the negotiations on the Framework Convention on Climate Change at the Earth Summit in Rio de Janeiro in 1992. The major conclusion was that research since 1990 did "not affect our fundamental understanding of the science of the greenhouse effect and either confirm or do not justify alteration of the major conclusions of the FAR". It noted that transient (time-dependent) simulations, which had been very preliminary in the FAR, were now improved, but did not include aerosol or ozone changes. Consequently, six alternative scenarios (IS92a to f) were published. The assumptions for the IS92 scenarios came mostly from the published forecasts of major international organisations or from published expert analyses. These embodied a wide array of assumptions affecting how future greenhouse gas emissions might evolve in the absence of climate policies beyond those already adopted. The different worlds that the scenarios imply, in terms of economic, social and environmental conditions, vary widely and the resulting range of possible greenhouse gas futures spans almost an order of magnitude. The premises for the IS92a and IS92b scenarios most closely resemble and update those underpinning the original SA90 scenario used in FAR. IS92a has been widely adopted as a standard scenario for use in impact assessments, although the original IPCC recommendation was that all six IS92 emissions scenarios be used to represent the range of uncertainty in emissions.

(SAR) The Summary for Policy Makers of the scientific report contains the following features: 1) greenhouse gas concentrations have continued to increase; 2) anthropogenic aerosols tend to produce negative radiative forcings; 3) climate has changed over the past century (air temperature has increased by between 0.3 and 0.6 ℃ since the late 19th century; this estimate has not significantly changed since the FAR; 4) The balance of evidence suggests a discernible human influence on global climate (considerable progress since the FAR in distinguishing between natural and anthropogenic influences on climate, because of: including aerosols; coupled models; pattern-based studies); 5) climate is expected to continue to change in the future (increasing realism of simulations increases confidence; important uncertainties remain but are taken into account in the range of model projections).

(TAR) The TAR estimate for the climate sensitivity is 1.5 to 4.5℃; and the average surface temperature is projected to increase by 1.4 to 5.8°C over the period 1990 to 2100, and the sea level is projected to rise by 0.1 to 0.9 meters over the same period. The wide range in predictions is based on scenarios that assume different levels of future CO_2 emissions. The Special Report on Emissions Scenarios (SRES) was a report prepared by the IPCC for the TAR in 2001, on future emission scenarios to be used for driving global circulation models to develop climate change scenarios. It was used to replace the IS92 scenarios used for the SAR in 1995. Each scenario then has a range of possible outcomes associated with it. The most optimistic outcome assumes an aggressive campaign to reduce CO_2 emissions; the most pessimistic is a “business-as-usual” scenario. Other scenarios fall in between (see Fig. 2):

A1: A world of rapid economic growth and rapid introductions of new and more efficient technologies

A2: A very heterogeneous world with an emphasis on family values and local traditions

B1: A world of “dematerialization” and introduction of clean technologies

B2: A world with an emphasis on local solutions to economic and environmental sustainability

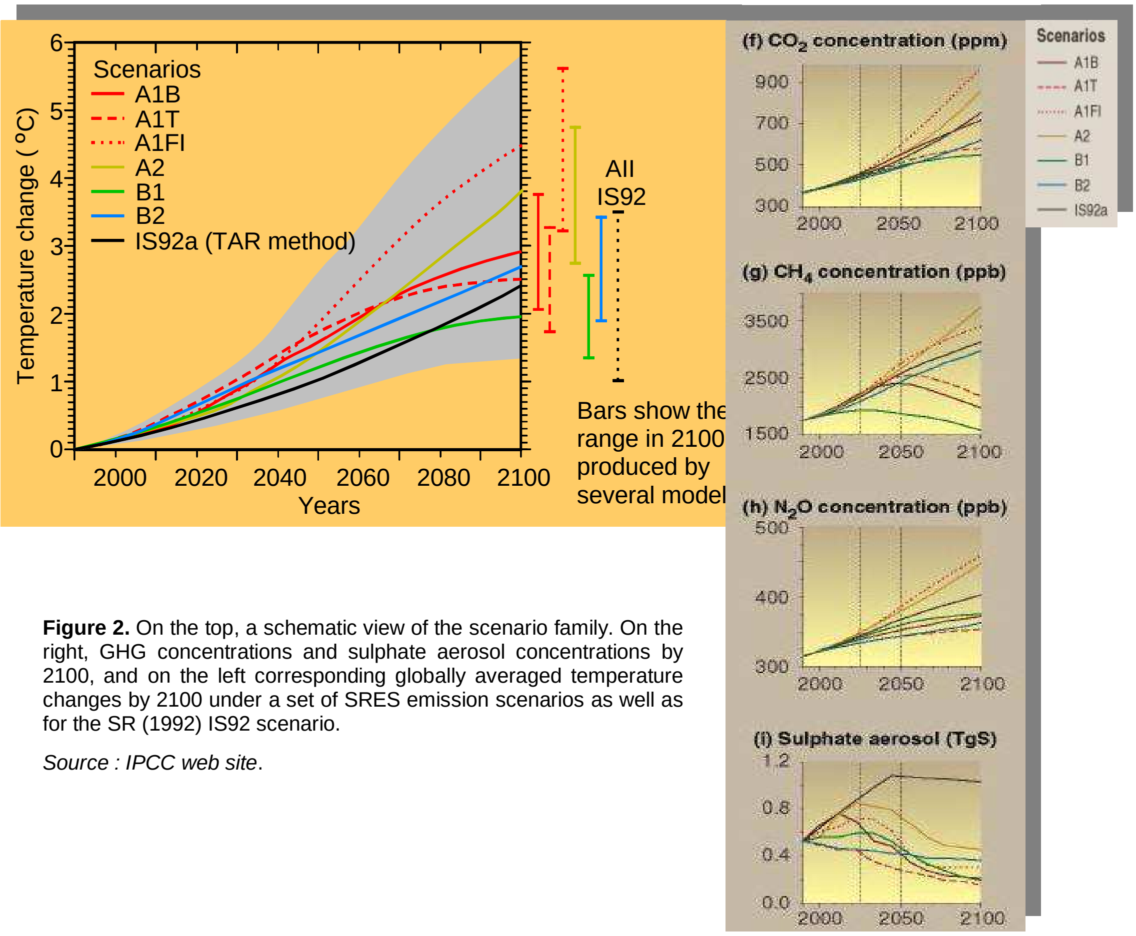

Figure 2. On the top, a schematic view of the scenario family. On the right, GHG concentrations and sulphate aerosol concentrations by 2100, and on the left corresponding globally averaged temperature changes by 2100 under a set of SRES emission scenarios as well as for the SR (1992) IS92 scenario.

Source : IPCC web site.

TAR assessed regional climate information from Atmosphere-Ocean General Circulation Models (AOGCMs) and techniques used to enhance regional detail. These techniques have been substantially improved since the SAR published in 1996 and have become more widely applied. They fall into three categories: high and variable resolution Atmosphere General Circulation Models (AGCMs); regional (or nested limited area) climate models (RCMs); and empirical/statistical and statistical/dynamical methods. The techniques exhibit different strengths and weaknesses and their use depends on the needs of specific applications. Results from regional studies indicate that at finer scales the changes can be substantially different in magnitude or sign from the large area average results. A relatively large spread exists between models, although attribution is unclear.

AR4 The Fourth Assessment Report (AR4) was completed in early 2007. Increasingly reliable regional climate change projections were made available for many regions of the world due to advances in modelling and understanding of the physical processes of the climate system. Atmosphere-Ocean General Circulation Models remain the primary source of regional information on the range of possible future climates. A clearer picture of the robust aspects of regional climate change is emerging due to improvement in model resolution, the simulation of processes of importance for regional change and the expanding set of available simulations. Advances have been made in developing probabilistic information at regional scales from the AOGCM simulations, but these methods remain in the exploratory phase. Downscaling methods have matured since the TAR and have been more widely applied, although only in some regions has large-scale coordination of multi-model downscaling of climate change simulations been achieved.

Climatic change in Mediterranean and Europe shows robust findings for the projected regional change over the 21st century. These changes are assessed as likely to very likely taking into account the uncertainties in climate sensitivity and emission trajectories (in the SRES B1/A1B/B2 scenario range) discussed above. Annual mean temperatures in Europe are *likely* to increase more than the global mean. Seasonally, the largest warming is *likely* to be in northern Europe in winter and in the Mediterranean area in summer. Minimum winter temperatures are *likely* to increase more than the average in northern Europe. Maximum summer temperatures are *likely* to increase more than the average in southern and central Europe. Annual precipitation is *very likely* to increase in most of northern Europe and decrease in most of the Mediterranean area. In central Europe, precipitation is *likely* to increase in winter but decrease in summer. Extremes of daily precipitation are *very likely* to increase in northern Europe. The annual number of precipitation days is *very likely* to decrease in the Mediterranean area. Risk of summer drought is *likely* to increase in central Europe and in the Mediterranean area. The duration of the snow season is *very likely* to shorten, and snow depth is *likely* to decrease in most of Europe.

Nowadays, although, atmosphere-ocean GCMs remain the main source of information on the range of possible future climates on the global scale, aspects of regional climate change emerged due to the development of Regional Climate Models, or RCMs. These RCMs are mostly driven by GCM outputs for current as well as for future climate according to various emission scenarios described by SRES.

2.3 The EU projects PRUDENCE and ENSEMBLES

For a thorough assessment of climate change over the Black Sea basin, the most relevant sources of regional information are provided by RCMs. In addition, to provide hydrological model useful information to simulate the water cycle of the Black sea basin, high resolution climate data is therefore required.

Two European projects can be mentioned for their application to enviroGRIDS.

2.3.1 PRUDENCE

The first is the European Commission's 5th Framework program for Energy, environment, and sustainable development whose project "Prediction of Regional scenarios and Uncertainties for Defining European Climate change risks and Effects", or PRUDENCE, involved more than 20 European research groups. The main objectives of this project were to provide dynamically downscaled high-resolution (*i.e.*, grid spacing ~50 km) climate change scenarios for Western Europe at the end of the 21st century. Each PRUDENCE experiment consisted of a control simulation representing the period 1961 to 1990 and future climates in Europe were assessed according to IPCC-SRES emission scenarios representing 2071 to 2100 [Christensen *et al*. (2007), Déqué *et al*. (2005) and http://prudence.dmi.dk, among others].

On the website, daily, monthly and seasonal data are public. Daily data, which are fairly suited for impact studies include: T_{2m} (2-meter temperature in K), P (precipitation in mm/day), C (total cloudiness as a fraction), E (evapotranspiration in mm/day), S_L (snow water equivalent in mm), R (total runoff in mm/day), W_s (soil moisture in mm), p_s (surface pressure in hPa), p_{msl} (mean sea level pressure in hPa), T_{2max} (daily maximum 2-meter temperature in K), T_{2min} (daily minimum 2-meter temperature in K), V_{10m} (10-meter wind speed in m/s), V_{10max} (10-meter daily maximum wind speed in m/s), q_{2m} (2-meter specific humidity in kg/kg), R_{Snet} (net shortwave radiation in W/m^2), R_{Sdown} (downward shortwave radiation in W/m^2), R_{Lnet} (net longwave radiation in W/m^2), R_{Ldown} (downward longwave radiation in W/m^2).

A number of RCMs participated to this project among which the Danish (HIRHAM), the Swiss (CHRM), the German (CLM, REMO), the British (HadRM), the Dutch (RACMO), the Spanish (PROMES), the Italian (regCM), The Swede (RCAO), and the French (ARPEGE, global variable mesh), among others. As an example, the surface grid mesh of one of these models, HIRHAM, is displayed in Fig. 3.

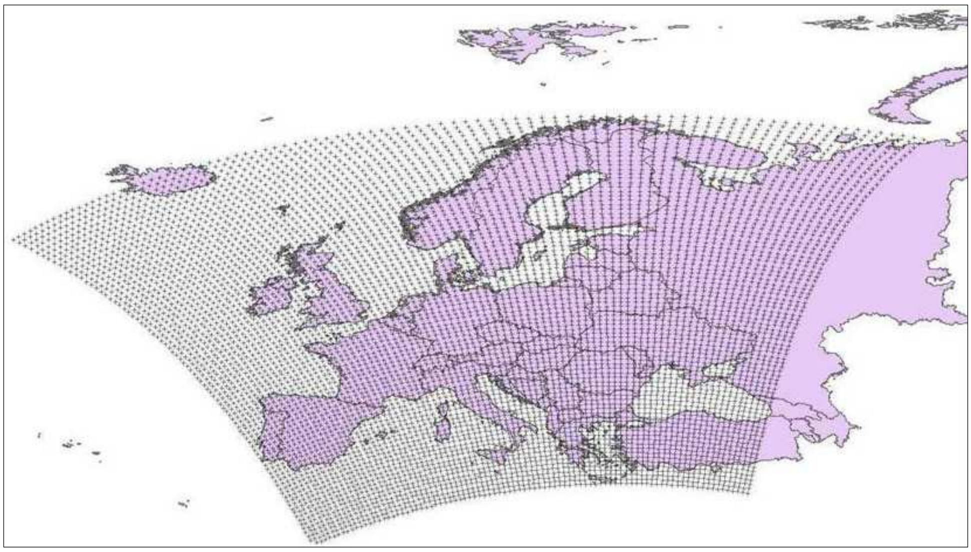

Figure 3. Surface grid mesh of RCM HIRHAM use in the context of the PRUDENCE project for which a number of daily variables are available.

As an example, ensemble means for the seasonal 2-m air temperature and precipitation changes for few of the countries in the catchment are shown below in Table 1.

Regional Climate Model seasonal projections of 2-m air temperature and precipitation over the computational domain are displayed in Figure 3 and 4.

Unfortunately, not all the Black Sea catchment is covered by the computational grids of the RCMs participating in this project. The eastern end is chopped off from the Sea of Azov, Caucasus, Georgia, western Turkey and Don Catchment is lacking. As it can be seen in Figures 3, 4 and 5, the eastern boundary of the catchment is close or outside the computational domain. Consequently, the temperature, the precipitation and other model variables can only partially be used for further impact assessments or for use as inputs in hydrological models for the Black Sea catchment.

Table 1[2]. Ensemble averages "< >" of annual and seasonal changes of 2-m air temperature and precipitation for few countries of the Black Sea catchment. These means encompass all GHG emission scenarios (Source, PRUDENCE : `//prudence.dmi.dk`).

	ANNUAL	DJF	MAM	JJA	SON
Romania <T>	1.5℃	1.4℃	1.2℃	1.7℃	1.4℃
<pcp>	-2.2%	+3.4%	-0.2%	-9.6%	-2.9%
Slovenia <T>	1.4℃	1.2℃	1.1℃	1.7℃	1.4℃
<pcp>	-0.6%	+10.3%	0.0%	-9.7%	-0.9%
Slovakia <T>	1.4℃	1.3℃	1.2℃	1.6℃	1.4℃
<pcp>	-0.6%	+7.5%	+1.3%	-7.3%	-2.5%
Serbia & <T>	1.4℃	1.4℃	1.2℃	1.8℃	1.4℃
Monte. <pcp>	-3.3%	+2.4%	-2.6%	-11.2%	-3.3%
Moldova <T>	1.5℃	1.5℃	1.3℃	1.7℃	1.5℃
<pcp>	-1.7%	+3.5%	+0.9%	-8.7%	-2.3%
Hungary <T>	1.4℃	1.3℃	1.1℃	1.7℃	1.5℃
<pcp>	-0.3%	+9.0%	+0.9%	-8.2%	-1.9%
Croatia <T>	1.4℃	1.3℃	1.1℃	1.8℃	1.4℃
<pcp>	-1.8%	+7.7%	-2.1%	-11.5%	-2.1%
Bulgaria <T>	1.4℃	1.3℃	1.2℃	1.8℃	1.4℃
<pcp>	-3.9%	-1.0%	-2.5%	-11.3%	-2.5%
Bosnia- <T>	1.4℃	1.3℃	1.2℃	1.8℃	1.4℃
Herz. <pcp>	-3.0%	+4.4%	-3.2%	-12.0%	-3.1%
Belarus <T>	1.4℃	1.6℃	1.3℃	1.3℃	1.4℃
<pcp>	+1.3%	+8.8%	+2.5%	-2.9%	-2.4%
Austria <T>	1.4℃	1.2℃	1.2℃	1.6℃	1.4℃
<pcp>	-0.5%	+4.9%	+2.3%	-5.6%	-1.6%

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[2] As a first attempt to generate a comprehensive assessment of expected changes in mean temperature and precipitation for Europe, an analysis based on all the PRUDENCE simulations has been conducted on a country-by-country basis. In order for this analysis to be independent of specific choices of emission scenario, a pattern scaling technique has been applied and the changes are expressed relative to a 1 ℃ global warming (Source : PRUDENCE website).

Figure 4. Seasonal 2-m air temperature changes (℃); source (PRUDENCE).

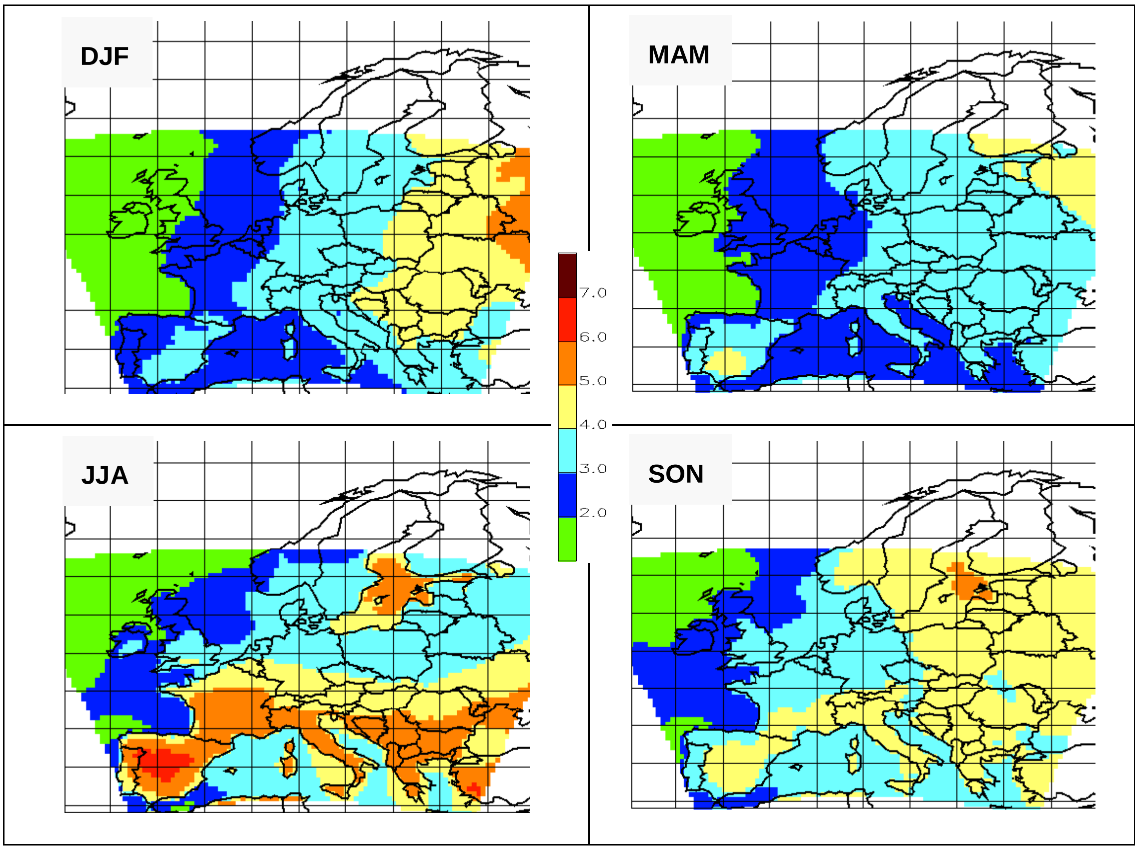
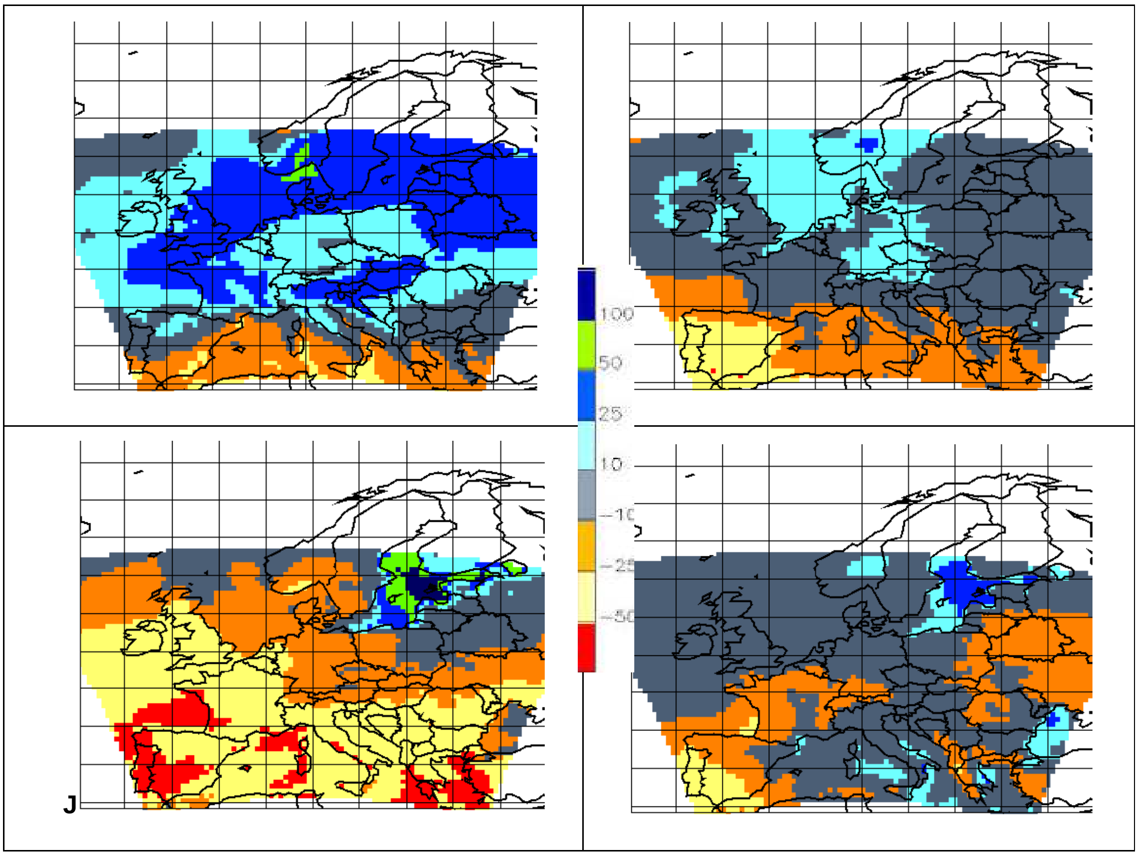


Figure 5. Seasonal precipitation changes (%); source (PRUDENCE).



2.3.2 ENSEMBLES

The second project, from the European Commission's 6th Framework Programme under the thematic "Global Change and Ecosystems", called ENSEMBLES, involved sixty six partners from across Europe has been studying the likely effects of climate change across Europe (Hewitt 2005). It developed an ensemble prediction system for climate change based on the principal state-of-the-art, high resolution, global and regional Earth System models, validated against quality controlled, high resolution gridded datasets for Europe, to produce for the first time, an objective probabilistic estimate of uncertainty in future climate at the seasonal to decadal and longer timescales.

The ENSEMBLES project developed an ensemble climate forecast system for use across a range of timescales (seasonal, decadal and longer) and spatial scales (global, regional and local). The model system is evaluated by making hindcasts for the 20th Century, which will be compared against quality-controlled, high-resolution datasets for Europe. The model system is intended to be used to construct probabilistic scenarios of future climate change and climate variability for quantitative risk assessments, to provide policy-relevant information on climate change and its interactions with society. This project uses global general circulation models (GCMs) to perform historical simulations for 1860-2000 and climate change projections for the 21st Century using the IPCC-SRES forcings, the so-called A2, A1B, and B1 scenarios. The GCM outputs then serve as inputs to drive a number of RCMs as was the case in the PRUDENCE project but this time higher spatial resolution is employed.

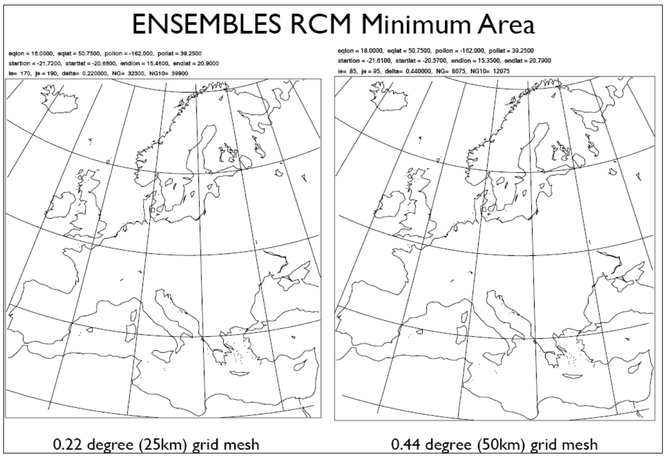


Figure 6. Computational domains used by RCMs in the ENSEMBLES project.

As is the case for the PRUDENCE project, the model's computational grid is unfortunately not encompassing the entire Black Sea catchment in all integration as far as the minimum area is concerned as shown in Figure 6.

The RCM simulations is conducted first at ~50km (horizontal resolution of 0.44º latitude and longitude) and then at ~25km (horizontal resolution of 0.22º). The ensuing ensemble of results (see Figure 7 as an example) allows quantifying the uncertainty in the climate projections by using statistical techniques.

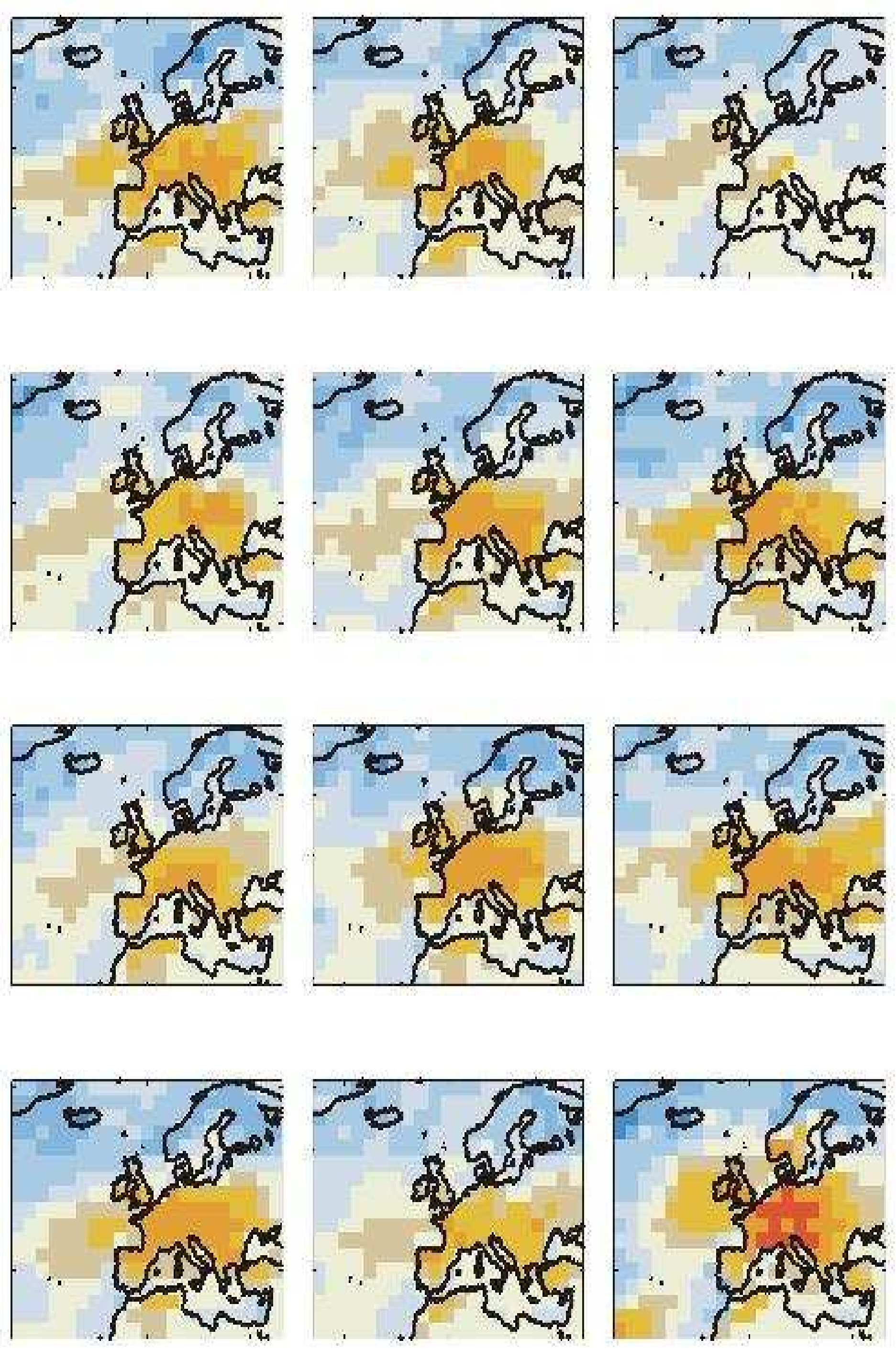


Figure 7. An example of the predicted change in summer-average precipitation over Europe from a small ensemble of model simulations (Source : Hewitt, 2005).

3. Overview of available datasets relevant for enviroGRIDS

Meteorological and climate information relevant for the enviroGRIDS community may be provided by different sources of information about the atmospheric environment among which local observations from national meteorological networks, gridded reanalyses (*e.g*. NCEP-NCAR, ECMWF), as well as by simulated outputs from numerical models performed in the framework of European programs (*e.g.*, PRUDENCE, ENSEMBLES). Global Climate Model (GCM) outputs are not considered here as a primary source of data since their computational grids are much too coarse to resolve the fine scale atmospheric flow and surface details of the Black Sea basin. However, climate projections performed with GCMs are required to produce the necessary outputs which are driving subsequent RCMs.

Observations and RCM outputs form a common basis to conduct hydrological as well as a number of other environmental studies. However, RCM outputs, such as temperature, precipitation, winds, pressure, *etc*., may not be readily appropriate for use as raw inputs in these impact studies. The reason for this is that they often have systematic errors that could biases the inputs of subsequent impact models thus hindering the quality of their results. This is often the case for many outputs from the control simulations to any further experiments with the same model. Using some simple working hypotheses one can formulate techniques that employ these outputs reasonably so that they could yet be exploited by hydrological and other impact models.

Therefore, in the context of the enviroGRIDS project, it is proposed as a quick and easy approach, to consider the so-called “delta” method which, on the basis of available RCM outputs, to compute changes in any climate variable and to combine these changes with similar observed variable. The fundamental aspects of such a method are described below.

3.1 Observational networks

Meteorological observations and climate information can be compiled on the basis on local observations (irregular space intervals as shown in Fig. 7), (re)analysis gridded data, and simulated model outputs (regular grids). A set of common measurements to all stations are expected to be recorded such as air 2-m temperature, precipitations, 10-m windspeed and direction, humidity, *etc*. so that these time series can readily be used in diagnostic impact studies. However, these are restricted to actual climate and must therefore be “perturbed” to be representative of future climate, especially if one would avoid using “raw” model outputs. As can be seen on figure 8, observations at a number of stations in the Black Sea catchment need to be accounted for, for use in impact studies.

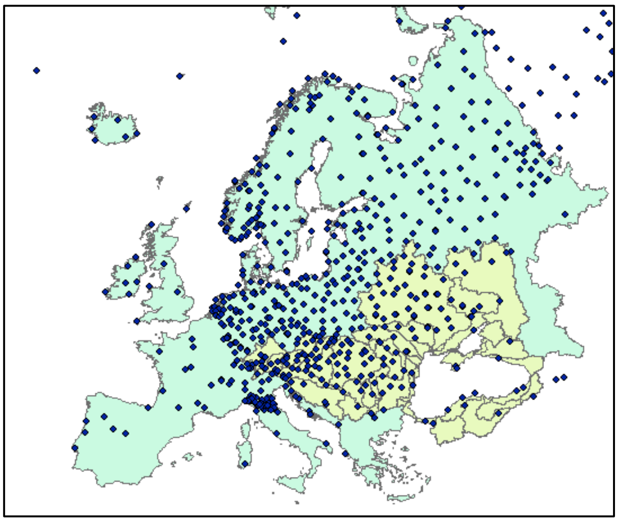


Figure 8. European observational networks. Courtesy: Elham Rouholahnejad & Karim Abbaspour, EAWAG enviroGRIDS WP4.

3.2 Gridded reanalysis data sets at ECMWF and at NCEP-NCAR

The data relevant for enviroGRIDS to perform climate scenarios may come, for some specific applications, from gridded reanalysis data. Reanalysis provide for global atmospheric data casts on a number of vertical levels as well as surface data.

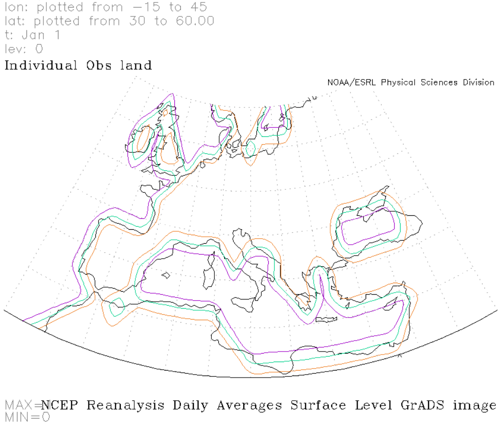
The European Centre for Medium-Range Weather Forecasts (ECMWF), an international organisation based at Reading England, proposes a re-analysis project in two phases: the first, ERA-15 (Gibson *et al*., 1997), generated re-analyses from December 1978 to February 1994, and the second, ERA-40, begins in 1957 (the International Geophysical Year).

The data assimilation system used for ERA-15 had characteristics that may be found at the following URL: `www.ecmwf.int/research/era/ERA-15/index.html`. The externally prescribed forcing of the re-analyses, in addition to the observations, came from the ocean surface temperature (SST) analyses and the ocean ice cover, determined from SMMR and SSM/I satellites data. ERA-15 data are available to ECMWF Member States through the MARS archive, to University users within the U.K. through BADC, to University users in Germany through MPI, and to the UCAR community through NCAR. NCAR also have a web page describing their holdings of ECMWF re-analysis data. Further information concerning access to data can be obtained from ECMWF's Data Services. A limited number of fields are available on the ECMWF public data server.

ERA-40 is a new European re-analysis which improved upon the earlier re-analyses (Uppala *et al.*, 2005). It produces and disseminates analyses with higher horizontal resolution, a much more extensive and accurate description of the stratosphere, and finer resolution of the planetary boundary layer. It provides a wider range of analysed fields. It will use an advanced but operationally-tested variational data assimilation system with a refined numerical model. ERA-40 uses new externally-produced analyses of sea-surface temperature (SST) from the UKMO (pre-1981) and NCEP (post-1981). It also adopts sea-ice distributions agreed externally by a WCRP-sponsored working group comprising representatives of UKMO, NCEP and the ACSYS community. UKMO and NCEP have ensured their SST analyses are consistent in the sea-ice margins.

The NCEP/NCAR Reanalysis reanalysis data set is a continually updating gridded data set representing the state of the Earth's atmosphere, incorporating observations and numerical weather prediction (NWP) model output dating back to 1948. It is a joint product from the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR). The data is available for free download from the NOAA Earth System Research Laboratory at URL `www.esrl.noaa.gov/psd/`.

Figure 9.



Although providing a wealth of information as far back as 1948, the information provided by such reanalyses are yet coarse grained (approx. 250 km grid spacing) and the archival frequency (6 hr, daily, monthly) may not be suited for a number of impact studies. Figure 9 displays how the land-sea mask is resolved in such reanalyses. As can been seen by the coloured contours, the Mediterranean Sea, the Atlantic coastlines and the Black Sea are poorly resolved; consequently this is an indication of the low resolution employed in the techniques and models producing reanalysis data.

3.3 Climate scenarios (PRUDENCE and ENSEMBLES) useful for enviroGRIDS

In order to provide useful information to simulate the hydrological cycle of the Black sea basin for current and future climates, observed time series but also long-term high-resolution simulated climate data are required. These may come from the observational networks and from the PRUDENCE the ENSEMBLES projects available to the scientific communities. However, as mentioned in Section 2.3.1, although this project give an access to more RCM outputs with enhanced horizontal resolutions, the computational grids are roughly the same as these used in the PRUDENCE project, as shown in figure 10.

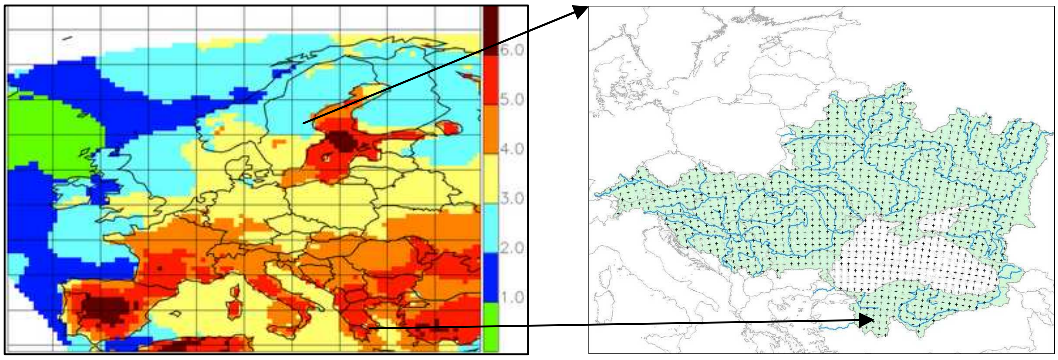


Figure 10. Computational domain of the HIRHAM RCM and a subset showing the location of the gridpoints used for impact studies in the Black Sea catchment.

Downscaled information is required in enviroGRIDS due to the limitations of coarse spatial resolution in GCMs. However, hydrological processes such as local snowpack accumulation and melting cannot be studied accurately with raw RCM outputs. Resolution limits the accuracy of representation of small-scale processes. A major example is precipitation. The occurrence of heavy downpours is an important climate feature for certain impacts, but these events are often localized on a scale smaller than a grid box. In many situations, an area the size of a grid box may experience flooding rains at some points while others receive no rain. Consequently, at the scale of a grid box, one should ideally want to remove biases.

A simple approach developed for bias removal which is still popular today is called the "delta" method. This method may be considered as a simple downscaling technique. RCM outputs are used to determine future change in climate with respect to the model's present-day climate, typically a difference for temperature and a percentage change for precipitation. Then, these changes are applied to observed historical climate data for input to an impacts model. The working hypothesis of this method is that it assumes that future model biases for both mean and variability will be the same as those in present-day simulations.

A number of studies have exploited this method such as in hydrology (Quilbé *et al*. 2008; Wood *et al.*, 2004, among others)

4. A simple method to infer local changes in temperature and precipitation for use in impact models: an example using the IPCC SRES A2 climate scenario

The above-mentioned data sources for use in the context of enviroGRIDS may be nevertheless be exploited in a number of impact studies in the Black Sea basin even though the model grid is somewhat truncated at the eastern. In addition, raw model outputs may not be appropriate as they have biases when compared to observations. However, it is yet possible to reasonably use these in a mode as described below.

4.1 Rationale

In order to drive the SWAT model in view to compute the change in the hydrological regime of the Black Sea catchment following global climate change over the period 2071-2100 relative to the 1961-1990 baseline, one can use observed or model-generated quantities such as *T* (temperature) and *P* (precipitation) valid at a number of stations. However, the simulated *T* and *P* during the baseline period may have biases that are not so easy to remove. Consequently, and among other things, a direct coupling of the SWAT and a given high-resolution RCM is not yet recommended. In addition, driving SWAT with raw RCM of current and future climate outputs can lead to problems not so easy to overcome. Consequently, it may be useful to derive a technique to emulate a changing climate by perturbing observations in using the so-called “delta-method”. This method yet requires simulated quantities that serve only to compute the changes (*i.e.* the deltas).

RCM simulated outputs can be used as such or in conjunction with observations so as to produce temperature and precipitation representative of a “future” period of the 21th Century, for example. The later technique is based on the so-called “delta” method and this can be written schematically as follows:

$$\Psi \quad = \quad \Psi_{obs} + \text{or} \times \Delta\,\Psi_{sim} \qquad (1)$$

where surface variables in Eq. (1), Ψ, Ψ_{obs}, and Ψ_{sim} are a function of time and space, *i.e.*, $\Psi = \Psi(\varphi, \lambda, z, t)$, and all the Δ may represent perturbations computed on the basis of model outputs between a future state ($\Psi_{sim,2}$) according to a given scenario and a state corresponding to current climate ($\Psi_{sim,1}$), *e.g.*, $\Delta = \Psi_{sim,2} - \Psi_{sim,1}$, or $\Psi_{sim,2} / \Psi_{sim,1}$ if additive or multiplicative corrections are considered respectively. There are a number of techniques allowing determining the values of Δ. These deltas, also function of time and space, can be partitioned into “quantiles” thus allowing all Ψ_{obs} to be “perturbed” in a more meaningful and realistic manner (refs to be cited), more accurate than perturbing only the mean values of Ψ.

4.1.1) Steps to compute the temperature perturbations or “deltas”

- Download (ftp) the daily temperature files simulated by the HIRHAM RCM for the control (HC1) and for the SRES A2 scenario (HS1) from the PRUDENCE official web site. The native data format is “netCDF”.
- Use MATLAB (or another software) to extract temperatures and to convert theses values into ASCII format for a number of grid points located in the Black Sea catchment. Two parameters are needed to identify the latitude and longitude indices.
- For each grid point, compute the means as follows:

$$\begin{aligned} \overline{T}_{1,i} &\quad \frac{1}{30}\sum_{j=1}^{30} T_{1,i,j} \\ \overline{T}_{2,i} &\quad \frac{1}{30}\sum_{j=1}^{30} T_{2,i,j} \end{aligned} \qquad (2)$$

where $T_{1,i,j}$ is the temperature values for the period (1961-1990) for day i (i = 1, 360) at year j (j =1, 30) at a given station, same for $T_{2,i,j}$ over the period (2071-2100), so that $\overline{T}_i$'s represent the daily averages over 30 annual cycles at a station (*i.e.*, a particular grid point).

- Partition the average year into mean seasons: DJF, MAM, JJA, and SON, so that series of seasonal temperatures can be extracted as follow for the period 1961-1990:

$$\begin{aligned} \overline{T}_{DJF} &= \overline{T}_{1,i}(i=1, 90); \qquad \overline{T}_{MAM} = \overline{T}_{1,i}(i=91, 180); \\ \overline{T}_{DJF} &= \overline{T}_{1,i}(i=181, 270); \quad \overline{T}_{DJF} = \overline{T}_{1,i}(i=271, 360) \end{aligned} \qquad (3)$$

- For each seasonal temperature series compute the nine percentiles n = 10, 20, … 90 (*i.e.*, deciles), $PC_{T,s,n}$ where subscript T stands for temperature, s for season (DJF, MAM, JJA, SON) and n for the given percentile. Consequently, thirty six percentiles are computed.

- Compute “preliminary deltas” on the basis of temperature exceedances as follow:

$$\begin{aligned} \Delta_{T,DJF,n} &= \frac{1}{N}\sum_{j=1}^{90}\left(\overline{T}_{2,i} - \overline{T}_{1,i}\right) \quad \text{if } \overline{T}_{1,i} \le PC_{T,DJF,n} \quad n = 1, 9 \\ \Delta_{T,MAM,n} &= \frac{1}{N}\sum_{j=91}^{180}\left(\overline{T}_{2,i} - \overline{T}_{1,i}\right) \quad \text{if } \overline{T}_{1,i} \le PC_{T,MAM,n} \quad n = 1, 9 \\ \Delta_{T,JJA,n} &= \frac{1}{N}\sum_{j=181}^{270}\left(\overline{T}_{2,i} - \overline{T}_{1,i}\right) \quad \text{if } \overline{T}_{1,i} \le PC_{T,JJA,n} \quad n = 1, 9 \\ \Delta_{T,SON,n} &= \frac{1}{N}\sum_{j=271}^{360}\left(\overline{T}_{2,i} - \overline{T}_{1,i}\right) \quad \text{if } \overline{T}_{1,i} \le PC_{T,SON,n} \quad n = 1, 9 \end{aligned} \qquad (4)$$

Theoretically, N = 9 following the computation of “deciles”. These Δ’s would now serve to perturb the temperature observations to be representative to these of the future at this particular station during the 21st Century.

- The main question is now, how to perturb individual temperatures for the period 1961-1990 on the basis of mean deltas partitioned into seasons and into deciles to represent these of the period 2071-2100 ? Many methods can be envisaged. The method applied in the present context can be described schematically as follows:

$$T'_{2,i,j} \quad = \quad T_{1,i,j} + (1+R)\Delta_T \qquad (5)$$

where $T'_{2,i,j}$ are temperatures for the period (2071-2100) at a particular day i and year j, $T_{1,i,j}$ the current series (1961-1990), Δ_T the computed deltas, and R the randomness or some meteorological noise we want to introduce to better reproduce the daily variability. The latter may be parameterized as follow:

$$R \quad = \quad R^* \sigma_{\Delta T}^{1/2} \qquad (6)$$

where $\sigma_{\Delta T}^{1/2}$ is the standard deviations of Δ_T computed on the basis of seasonal deciles, and R^* the noise computed on the basis of a random number (white or Gaussian noise) scaling the deviations $\sigma_{\Delta T}^{1/2}$.

In order to "validate" this approach, Eq (4) has been tested with R^* defined as Gaussian noise on the original temperature series (1961-1990). The following figures are showing the mean annual cycle and frequency distributions of the temperatures at the same grid point (shown in figure above).

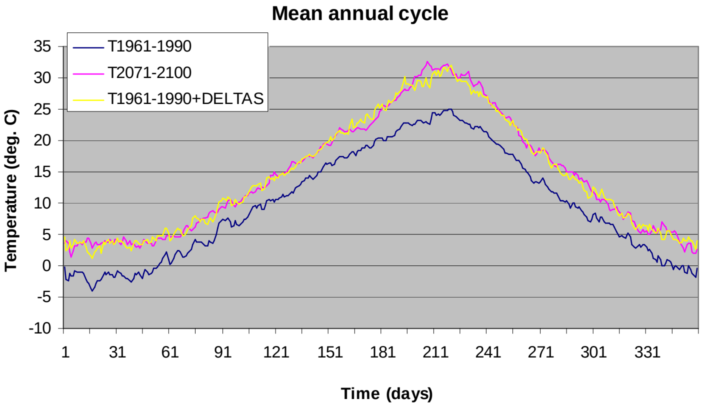


Figure 11. Daily-mean temperatures averaged over the 1961-1990 and 2071-2100 periods simulated by HIRHAM on a grid point in Crimea. Superimpose on these, the daily mean temperatures as produced by the delta method.

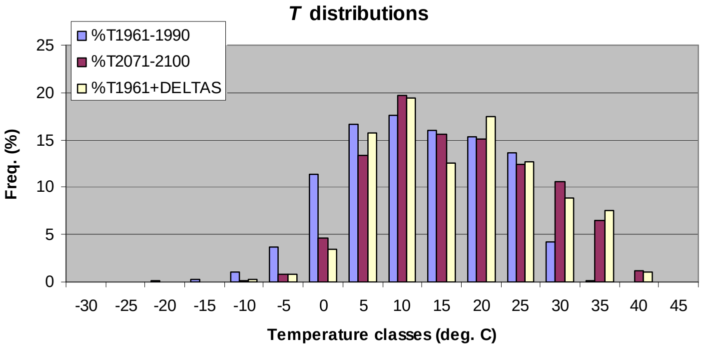


Figure 12. Frequency distributions of the daily-mean temperatures averaged over the 1961-1990 and 2071-2100 periods simulated by HIRHAM on a grid point in Crimea. Superimpose on these, the distribution of the daily mean temperatures as produced by the delta method.

$$\overline{T'}_{2,i} \quad \frac{1}{30}\sum_{j=1}^{30}\left[T_{1,i,j}+(1+R)\Delta_T\right] \tag{7}$$

Where the means and standards deviations for these are:

$\overline{T_1}$ = T avg (1961-1990) : 9.9℃ and 8.7℃

$\overline{T_2}$ = T avg (2071-2100) : 14.5℃ and 9.3℃

$\overline{T'_2}$ = T avg (1961-1990) + Δ_T : 14.4℃ and 9.2℃

As can be seen above, this method can provide for a reasonable approximation to reproduce the temperature over the period (2071-2100) on the basis of these of the period (1961-1990) perturbed by deltas.

The question now arises as to how to perturb observations? Eq (4) may be slightly modified to account for the intensity of the perturbation to be applied as follow:

$$T'_{2,i,j} = T_{1,i,j} + (1+R)\lambda\Delta_T \tag{8}$$

where λ is a parameter scaling the intensity of the perturbation with time. As a first approximation, this parameter can be determined as changing linearly with time as

$$\lambda \quad = \quad \lambda(n_t) \quad = \quad \frac{n_t}{39'600} \tag{9}$$

where t_n is the time in terms of the number of days elapsed after Jan 1st 1976 (half time between 1961 and 1990). The slope is one over the number of days between 1976 and 1086 (110 years with 360 days per year). So, the perturbation is zero at the beginning increasing linearly to 1 at year 2086.

4.1.2) Steps to compute the precipitation perturbations or “deltas”

- Download (ftp) the daily precipitation files simulated by the HIRHAM RCM for the control (HC1) and for the SRES A2 scenario (HS1) from the PRUDENCE official web site. The native data format is “netCDF”.

- Use MATLAB (or another software) to extract precipitations and to convert theses values into ASCII format for a number of grid points located in the Black Sea catchment. Two parameters are needed to identify the latitude and longitude indices.

- For each grid point, compute the precipitation means as follows:

$$\begin{aligned} &\overline{P}_{1,i} \quad \frac{1}{30}\sum_{j=1}^{30} P_{1,i,j} \\ &\overline{P}_{2,i} \quad \frac{1}{30}\sum_{j=1}^{30} P_{2,i,j} \end{aligned} \tag{10}$$

where $P_{1,i,j}$ is the temperature values for the period (1961-1990) for day i (i = 1, 360) at year j (j =1, 30) at a given station, same for $P_{2,i,j}$ over the period (2071-2100), so that $\overline{P}_i$ ’s represent the daily averages over 30 annual cycles at a station (*i.e.*, a particular grid point).

- Partition the average year into mean seasons: DJF, MAM, JJA, and SON, so that series of seasonal temperatures can be extracted as follow for the period 1961-1990:

$$\begin{array}{llll} \overline{P}_{DJF} = \overline{P}_{1,i}\left(i=1,90\right); & \overline{P}_{MAM} = \overline{P}_{1,i}\left(i=91,180\right); \\ \overline{P}_{DJF} = \overline{P}_{1,i}\left(i=181,270\right); & \overline{P}_{DJF} = \overline{P}_{1,i}\left(i=271,360\right) \end{array} \qquad (11)$$

- For each seasonal precipitation series compute the nine percentiles n = 10, 20, … 90 (*i.e.*, deciles), $PC_{T,s,n}$ where subscripts P stands for precipitation, s for season (DJF, MAM, JJA, SON) and n for the given percentile. Consequently, thirty six percentiles are computed.
- Compute “preliminary deltas” on the basis of precipitation ratios as follow:

$$\begin{array}{lll} \Delta_{P,DJF,n} = \frac{PC_{2,T,DJF,n}}{PC_{1,T,DJF,n}}; & n=1,9 \\ \Delta_{P,MAM,n} = \frac{PC_{2,T,MAM,n}}{PC_{1,T,MAM,n}} & n=1,9 \\ \Delta_{P,JJA,n} = \frac{PC_{2,T,JJA,n}}{PC_{1,T,JJA,n}} & n=1,9 \\ \Delta_{P,SON,n} = \frac{PC_{2,T,SON,n}}{PC_{1,T,SON,n}} & n=1,9 \end{array} \qquad (12)$$

Nine “deciles” per season are yet computed. These Δ’s would now serve to perturb the precipitation observations to be representative to these of the future at this particular station during 21^{st} Century.

- The main question is now, how to perturb individual precipitation for the period 1961-1990 on the basis of mean deltas partitioned into seasons and into deciles to represent these of the period 2071-2100 ? Many methods can be envisaged. The method applied in the present context can be described schematically as follows:

$$P'_{2,i,j} = P_{1,i,j} \times N\,\Delta_P \qquad (13)$$

where $P'_{2,i,j}$ are future precipitations (2071-2100) at a particular day i and year j, $P_{1,i,j}$ the current series (1961-1990), Δ_P the computed deltas, and N some meteorological noise we want to introduce to better reproduce the variability. The latter may be parameterized as a fixed number to be prescribed ideally as $N > 0$.

In order to “validate” this approach, Eq (12) has been tested with $N \in [1.0, \ldots, 1.5]$ on the original temperature series (1961-1990). The following figures are showing the mean annual cycle and frequency distributions of the precipitations at the same grid point (shown by the red arrow above):

$$\overline{P'}_{2,i} \quad \frac{1}{30}\sum_{j=1}^{30}\left[P_{1,i,j}\times N\,\Delta_T\right] \tag{14}$$

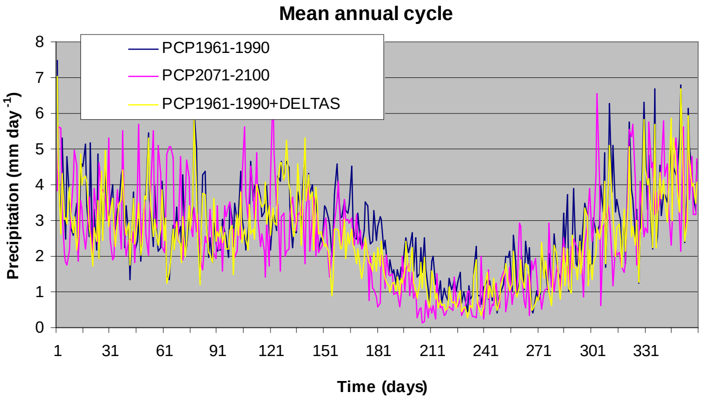


Figure 13. Daily-mean precipitations averaged over the 1961-1990 and 2071-2100 periods simulated by HIRHAM on a grid point in Crimea. Superimpose on these, the daily mean precipitations as produced by the delta method.

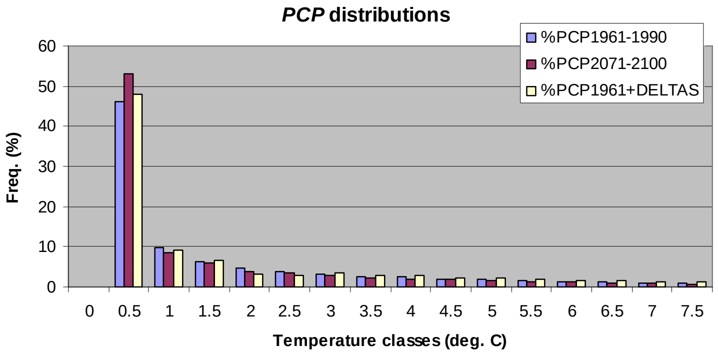


Figure 14. Frequency distributions of the daily-mean precipitations averaged over the 1961-1990 and 2071-2100 periods simulated by HIRHAM on a grid point in Crimea. Superimpose on these, the distribution of the daily mean precipitations as produced by the delta method.

Where the means and standards deviations for these are:

$\overline{P_1}$ = P avg (1961-1990) : 2.8 mm d^{-1} and 1.3 mm d^{-1}

$\overline{P_2}$ = P avg (2071-2100) : 2.5 mm d^{-1} and 1.4 mm d^{-1}

$\overline{P'_2}$ = P avg (1961-1990) + Δ_P : 2.5 mm d^{-1} and 1.2 mm d^{-1}

As can be seen above, this method can provide for a reasonable approximation to reproduce the precipitation over the period (2071-2100) on the basis of these of the period (1961-1990) perturbed by deltas.

• The question now arises as to how to perturb observations? Eq (4) may be slightly modified to account for the intensity of the perturbation to be applied as follow:

$$P'_{2,i,j} \quad = \quad P_{1,i,j} \times N\,\lambda\,\Delta_P \tag{15}$$

where λ is a parameter scaling the intensity of the perturbation with time. As a first approximation, this parameter can be determines as changing linearly with time as

$$\lambda \quad = \quad \lambda(n_t) \quad = \quad \frac{n_t}{39'600} \tag{16}$$

where t_n is the time in terms of the number of days elapsed after Jan 1st 1976 (half time between 1961 and 1990). The slope is one over the number of days between 1976 and 1086 (110 years with 360 days per year). So, the perturbation is zero at the beginning increasing linearly to 1 at year 2086.

5) Outlook

5.1 Use of available RCM outputs in impact studies

As described above in this report, RCM outputs archived in the context of the PRUDENCE and the ENSEMBLES project may be used to drive a number of impact studies over the Black Sea basin although the temporal and horizontal resolutions are not currently optimal and the computational grids do not cover entirely this catchment.

On way to overcome this problem within reasonable time limits is to use simple methods to infer local climate change information by using the "delta" approach as described above. Another method would be to run high resolution RCMs with their computational grids centered over the Black Sea basin.

5.2 Application of the delta-method to perturb the *T* and *P* observations

A method has thus been set up to perturb the temperature and precipitation observation time series in order to "emulate" a changing climate $\Psi = \Psi_{obs} + \Delta\Psi_{sim}$. This method has been validated in the sense that it reproduces satisfactorily the future simulated temperature and precipitation on the basis of baseline values. It needs only few parameters (scaling factors) that depend on local characteristics. Consequently, the deltas computed on the basis of Eqs (4) and (10) will serve as the basis to perturb observations in order to produce time series extending to the end of the 21st Century, thus allowing to drive hydrological model such as SWAT without having to couple it with a RCM. The deltas may be computed with the approach described above according to other emission scenarios than the A2. All the require RCM outputs are available on the PRUDENCE web site (http://prudence.dmi.dk/). The main outcome using this "delta" method, is that it allows computing long time series of any variable (Ψ) provided that observations and model outputs (current and future) are available. This method does not require any intensive computational resources so it can be implemented on personal computers.

This method can be extended to perturb other climate variables as well, as long as they are properly resolved and saved in RCM archives as for example: daily minimum and maximum temperatures, specific humidity (or a typical moisture variable), windspeed, downward solar radiation, *etc*.

5.3 Developing climate scenarios for Eastern Europe

One major recommendation that would be useful for climate and other hydrological studies is related to the development of a "PRUDENCE-like" project for Eastern Europe in which a number of high resolution RCMs would run on a common computational grid centered over the Black Sea. The actual PRUDENCE computational grids are somewhat close to the Eastern boundary of the Black Sea basin and this may introduce additional uncertainties in the simulated outputs such as temperature and precipitation so it is recommended to use these with caution.

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Abbreviations and Acronyms

AR4	forth Assessment Report on climate change of the IPCC
CH_4	Methane
CO_2	Carbon dioxide
ECMWF	European Centre for Medium-Range Weather Forecasts
ENSEMBLES	Project of the 6th European Commission Framework Programme under the thematic “Global Change and Ecosystems
FAR	First assessment report on climate change of the IPCC
GCM	Global Climate Model
GHG	Greenhouse Gases
IPCC	Intergovernmental Panel on Climate Change
N_2O	Nitrous oxyde
NCEP-NCAR	National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR)
ppmv	parts per million (10^6) by volume
PRUDENCE	Prediction of Regional scenarios and Uncertainties for Defining European Climate change risks and Effects
RCM	Regional Climate Model
SAR	Second Assessment Report on climate change of the IPCC
SR	Supplementary Report on climate change of the IPCC
SRES	Special Report on Emission Scenarios
SWAT	Soil Water Assessment Tool

TAR	Third Assessment Report on climate change of the IPCC
UNEP	United Nations Environment Programme
WMO	World Meteorological Organization