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ANALYSIS OF EXISTING CLIMATE MODEL RESULTS OVER EUROPE

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Summary

DMI has studied a methodology for assessing the skill of a regional climate model (RCM) in describing the full distribution of intensities of a variable, such as precipitation, and the projected change in the distributions for the A2 climate scenario. The results are presented in a DMI report (Boberg et al., 2007), which is also posted on the internal web pages of the WATCH project, and in Boberg et al., 2008). The key results are:

- Most of the RCMs perform well in describing the distribution of precipitation, with a skill of around 0.8—0.9, where one is a perfect score and zero is no skill at all.
- The comparison of the A2 scenario precipitation distributions with the control shows a shift to more extreme intensities. This shift is present in all of the PRUDENCE RCMs.
- The crossing point between a reduction of the lower precipitation intensities and an increase in the higher intensities is quite constant for the different RCMs, at around x mm/day, and it is also consistent with different driving general circulation models (GCMs) for one RCM.
- A statistical study showed the changes in the shift to be significant up to extreme precipitation intensities of about 60 mm/day.

MPI-M has performed an analysis of climate change signals in the hydrological cycle and the 2m temperature over Europe as projected by the MPI-M global and regional climate models. The study is posted on the internal web pages of the WATCH project, and in a paper published in Climate Dynamics (Hagemann et al. 2008). The key results are:

- Notable differences in the robustness of the climate change signals between the GCM and RCM simulations are related to a stronger warming projected by the GCM in the winter over the Baltic Sea catchment and in the summer over the Danube and Rhine catchments.
- The results indicate that the main explanation for these differences is that the finer resolution of the RCM leads to a better representation of local scale processes at the surface that feed back to the atmosphere.
- An improved RCM representation of the land sea contrast and related moisture transport processes over the Baltic Sea catchment.
- An improved RCM representation of soil moisture feedbacks to the atmosphere over the Danube and Rhine catchments.
In collaboration between DMI and MPI-M, a study of the relationship between precipitation intensity and temperature has been initiated. Both observational and regional climate data will be studied. Initial results show that there is indeed a clear relationship in the winter months, with more intense precipitation for higher temperatures.

MPI-M performed an analysis of GCM results over Europe similar to the analysis of RCM results by Hagemann and Jacob (2007) conducted in the PRUDENCE project (Christensen and Christensen 2007). The analysis focused on those GCMs where daily data are available in the CERA database of the World Data Centre for climate, or where the GCM simulations were conducted by a member of the WATCH consortium. These GCMs were chosen as their data may potentially be used to force hydrological models within WATCH.

Some details on the studies performed in WP 3.2 will be given in the sections A, B, and C, while section D comprises the whole analysis conducted with the GCM results over Europe.
A. Improved confidence in climate change projections of precipitation evaluated using daily statistics from the PRUDENCE ensemble

DMI has studied a methodology for assessing the skill of an RCM in describing the full distribution of intensities of a variable such as precipitation, and the projected change in the distributions for the A2 climate scenario. The method used is based on that presented by Perkins et al. (2007), and calculates the overlap of two normalized precipitation intensity spectra. The skill of the PRUDENCE RCMs in comparison to the ECA observational data set (Klein Tank et al., 2002) was calculated and it was shown that all of the models matched the observations by about 80—90%. Some models always perform in the higher range and some always in the lower.

In a study of future (A2 scenario) changes in the precipitation spectrum it was found that all of the PRUDENCE models show a shift to more extreme precipitation, independent of the driving GCM. It was also found that the crossing point between increasing higher intensities and decreasing lower intensities was rather consistent between the different models, with an exception for the HadRM model. A statistical study showed the change in the precipitation intensities to be significant up to about 60 mm/day (Fig 3.2.1.1).

![Normalized precipitation change](image)

**Fig 3.2.1.1: Difference in the distribution of precipitation intensity between the A2 scenario and the control of the DMI HIRHAM RCM forced by the HadAM3H GCM. (From Boberg et al., 2008)**

The results are presented in a DMI report (Boberg et al., 2007), which is also posted on the internal web pages of the WATCH project, and in the manuscript Boberg et al. (2008).

References:
B. Improved regional scale processes reflected in projected hydrological changes over large European catchments

MPI-M has performed an analysis of climate change signals in the hydrological cycle and the 2m temperature over Europe as projected by the MPI-M global and regional climate models. The considered global ECHAM5/MPIOM simulations comprise three control simulations for the past century covering the period 1860-2000, and nine simulations for the future climate (2001-2100) using greenhouse gas and aerosol concentrations according to the three IPCC scenarios B1, A1B and A2. For each scenario three simulations were performed. The global simulations were dynamically downscaled over Europe using the RCM REMO at 0.44° horizontal resolution (about 50 km), whereas the physics packages of the GCM and RCM largely agree. The regional simulations comprise the three control simulations (1950-2000), the three A1B simulations and one simulation for B1 as well as for A2 (2001-2100). The robustness of the climate change signal (in 2071-2100 compared to 1961-1990) projected by the GCM and RCM was analysed focusing on the large European catchments of Baltic Sea (land only), Danube and Rhine. In this respect, a robust climate change signal designates a projected change that sticks out of the noise of natural climate variability. Catchments and seasons were identified where the climate change signal in the components of the hydrological cycle is robust, and where this signal has a larger uncertainty. Notable differences in the robustness of the climate change signals between the GCM and RCM simulations are related to a stronger warming projected by the GCM in the winter over the Baltic Sea catchment and in the summer over the Danube and Rhine catchments. The results indicate that the main explanation for these differences is that the finer resolution of the RCM leads to a better representation of local scale processes at the surface that feed back to the atmosphere, i.e. an improved representation of the land sea contrast and related moisture transport processes over the Baltic Sea catchment, and an improved representation of soil moisture feedbacks to the atmosphere over the Danube and Rhine catchments. The results are published by Hagemann et al. (2008), which was also posted on the internal web pages of the WATCH project.

Reference

C. Study on the relation of daily maximum 2m temperature and precipitation

In collaboration between DMI and MPI-M, a study of extreme precipitation in observations and in RCMs has been initiated. The hypothesis tested is whether there is a clear relationship between the maximum daily temperature and the daily amount of precipitation for different regions of Europe, and for different seasons. It is thereby the commonly stated connection between increasing temperature and more extreme precipitation, following the Clausius-Clapeyron relationship, which we are testing.

Initial results show that there is indeed a relationship between the daily maximum two meter temperature and the daily precipitation during the winter months, with higher precipitation intensities for higher maximum temperatures, see Figure 3.2.1.2. In summer the relationship is almost reversed, although much weaker. For the models we perform the same analysis for the convective and stratiform components separately, and find that in January both precipitation components have the same temperature relationship, while in July the stratiform precipitation shows the reverse relationship with more intense precipitation for lower maximum temperatures, while the convective precipitation does not show any relationship at all with temperature (not shown).
Figure 3.2.1.2: Scatter plots of the daily mean precipitation (vertical axis) and the daily maximum two meter temperature (horizontal axis) for gridded observations (left), the HIRHAM (middle) and REMO (right) RCMs. The top row shows results for January, and the bottom row for July, both for the whole of Europe. The green line in each plot shows the distribution of maximum temperatures multiplied by 100. There is a clear temperature dependence on the precipitation in January, with higher precipitation intensities for higher maximum temperatures. In July the dependence is weaker and almost reversed. Note that in these plots one can also see the “zero degree” problem that occurs in several climate models. This problem is caused by the simulated temperature in the near surface staying close to zero as snow is melting, much more so than in observations.
D. Changes of the hydrological cycle over Europe as projected by several GCMs

For the 4th assessment report of the Intergovernmental Panel on Climate Change (IPCC), a large ensemble of coupled atmosphere/ocean general circulation models (GCMs) has been used to conduct an ensemble of transient climate simulations. These were generally conducted for the 20th and 21st century. Within the EU project WATCH (Water and Global Change) it is planned to use some of these GCM simulations to force hydrology model. In order to allow a first evaluation of these simulation, an analysis of GCM results over Europe was performed by MPI-M similar to the analysis of RCM results by Hagemann and Jacob (2007) conducted in the PRUDENCE project (Christensen and Christensen 2007). The analysis focused on those GCMs where daily data are available in the CERA database of the World Data Centre for climate, or where the GCM simulations were conducted by a member of the WATCH consortium. These GCMs were chosen as their data may potentially be used to force hydrological models within WATCH. The analysis concentrated on the hydrological cycle and the 2m temperature. The simulated present day climate (1961-1990) was considered as well as the climate change signals by comparing the mean projected climate at the end of the 21st century (2071-2100) to a control period representing current climate (1961-1990).

1. Models

For the 4th assessment report of the Intergovernmental Panel on Climate Change (IPCC), several coupled atmosphere/ocean GCM simulations have been performed. For the past climate, observed concentrations of greenhouse gases and aerosols were prescribed. For the future climate, these concentrations were prescribed according to the three IPCC scenarios B1, A1B and A2 (Nakićenović et al., 2000). At the time of the present studies, the GCM data of five climate centres fulfilled the requirements mentioned above.

a) MPIM (Max Planck Institute for Meteorology)
The coupled atmosphere/ocean GCM ECHAM5/MPIOM (Roeckner et al. 2003, Jungclaus et al. 2006) has been used to conduct an ensemble of climate simulations. These simulations comprise three control simulations for the past century covering the period 1860-2000, and nine simulations for the future climate (2001-2100). The coupled model was run without flux correction at T63 (about 1.9° or 200 km grid size) horizontal resolution and 31 vertical levels in the atmosphere, and about 1.5° horizontal resolution and 40 vertical layers in the ocean. For the past climate (1860-2000), observed concentrations of CO2, CH4, N2O, CFCs, O3 (tropospheric and stratospheric), and sulphate aerosols were prescribed, thereby considering the direct and first indirect aerosol effect. Three realizations were yielded by the use of slightly different initial conditions at the start of the simulations in 1860. For the future climate (2001-2100), also three simulations were performed for each scenario using the initial conditions in 2001 taken from the three different control simulations.

b) CNRM (Centre National de Recherches Météorologiques, Météo France)
The coupled GCM CNRM-CM3 has been used to conduct the climate simulations, which comprises of the sub-models ARPEGE-Climat version 3 for the atmosphere (Déqué et al. 1994; Déqué and Piedeliève 1995; Royer et al. 2002), OPA 8.1 for the ocean (Madec et al. 1998) and GELATO 2 for sea-ice (Salas-Mélia 2002). In the atmosphere, a triangular truncation T63 with a linear reduced Gaussian grid equivalent to T42 quadratic grid horizontal resolution (2.8 ° ~ 300 km) and a progressive hybrid sigma-pressure vertical coordinate with 45 layers have been used. The ocean had a resolution of about 2° in longitude, a resolution varying in latitude from near 0.5° at the equator to roughly 2° in Polar regions, and 31 vertical levels. The distributions of marine, desert, urban aerosols, sulphate aerosols were specified, whereas for aerosols, only the direct effect of anthropogenic sulphate aerosols was
taken into account. One simulation for the control climate and for each scenario is considered in the present study.

c) **UKMO** (Hadley Centre for Climate Prediction and Research, United Kingdom Met Office)
The coupled GCM HadCM3 (Gordon et al. 2000; Pope et al. 2000) has been used to conduct the climate simulations. The coupled model was run without flux correction at a resolution of 2.75° longitude by 3.75° latitude and 19 vertical levels with hybrid coordinates in the atmosphere, and 1.25° x 1.25° horizontal resolution and 20 vertical levels in the ocean. Three modes of sulphate aerosols (Aitken, accumulation and dissolved in cloud droplets) with explicit parameterizations of transfers between the different modes are taken into account. SO2 and DMS are injected at appropriate levels. The direct radiative effect from scattering and absorption is taken into account. The indirect effect was implemented by prescribing cloud changes calculated by offline models (see Johns et al., 2003). One simulation for the control climate and for each scenario is considered in the present study.

d) **IPSL** (Institut Pierre Simon Laplace)
The coupled GCM IPSL-CM4 has been used to conduct the climate simulations, which comprises of the sub-models LMDZ-4 in the atmosphere (Hourdin et al. 2006), ORCA in the ocean (based on OPA model; Madec et al. 1998 and LIM for sea ice (Fichefet and Morales Maqueda 1997; Goosse and Fichefet 1999). The coupled GCM was run at 2.5° x 3.75° horizontal resolution with 19 vertical levels in the atmosphere, and on a quasi-isotrope tri-polar grid with 31 vertical levels in the ocean (2 poles in the northern hemisphere, one over Canada and the other over Siberia), thereby using a 2° resolution Mercator grid with enhanced meridional resolution in the vicinity of the equator and in Mediterranean and Red seas (1°). With regard to prescribed aerosols, the direct effect of sulphate aerosols was taken into account, as well as the first indirect effect. One simulation for the control climate and for each scenario is considered in the present study.

e) **BCCR** (Bjerknes Centre for Climate Research)
The coupled GCM Bergen Climate Model (BCM) Version 2 (Furevik et al. 2003) has been used to conduct the climate simulations, which comprises of the sub-models ARPEGE-Climat version 3 for the atmosphere (Déqué et al. 1994; Déqué and Piedelièvre 1995; Royer et al. 2002), and the NERSC largely modified version of MICOM Version 2.8 for the ocean and sea ice (Bleck et al. 1992). In the atmosphere, a triangular truncation T63 with a linear reduced Gaussian grid equivalent to T42 quadratic grid horizontal resolution (2.8 ° ~ 300 km) and a progressive hybrid sigma-pressure vertical coordinate with 31 layers have been used. The ocean model had 35 vertical layers and approximately square horizontal grid cells with 1.5° grid spacing along the equator. Near the equator the meridional grid spacing is gradually decreased to 0.5° at the equator. The distributions of marine, desert, urban aerosols, sulphate aerosols were specified, whereas for aerosols, only the direct effect of anthropogenic sulphate aerosols was taken into account. One simulation for the control climate and for each scenario is considered in the present study.

2. **Validation of the hydrological cycle in the control simulations**

For the validation of the simulated hydrological cycle, several large European catchments are considered (Figure D1), i.e. the Baltic Sea catchment (land points only are considered in the following if not stated otherwise) representing a maritime climate (about 1.8 Million km²), the Danube catchment representing a continental climate (about 800000 km²), and the Rhine catchment (about 160000 km²) that is located in a transition zone of both climates. The latter is also largely influenced by Alpine snow processes and climate. The validation focused on common climate model problems, such as those investigated by Hagemann et al. (2004) for several RCM simulations driven by data from the 15 years re-analysis of ECMWF (ERA15; Gibson et al., 1997). These problems comprise the overestimated
precipitation in winter and spring over the Baltic Sea catchment and the summer drying problem over the Danube catchment.

![Baltic Sea catchment](image)

**Figure D1** Large river catchments of Europe at 0.5° resolution.

### 2.1 Annual means

Figure D2 - 4 compare the annual mean precipitation, evapotranspiration and runoff of all GCMs and their multi-model mean to observations. Precipitation observations are the mean of CMAP (Xie and Arkin, 1997) and GPCP (Adler et al., 2003) precipitation data. CMAP precipitation data are not corrected for the systematic undercatch of precipitation gauges, which is especially significant for snowfall. For GPCP data, a correction has been applied which is known to be overestimated by a factor of about 2 (Rudolf and Rubel, 2005) so that the actual precipitation amounts are expected to be in between GPCP and CMAP. The observed annual mean evapotranspiration was calculated from the difference of the mean observed precipitation minus the observed climatological discharge (Dümenil Gates et al. 2000). The latter is used in the comparisons to simulated runoff.

While MPIM and CNRM overestimate precipitation (Figure D2) by about 10% over the Baltic Sea catchment, the other three GCMs are relatively close to the mean observation. Over the Danube and Rhine catchments all GCMs except MPIM have a wet bias between 10-30%. MPI has a smaller wet bias (+7%) over the Rhine catchment and a strong dry bias (-16%) over the Danube catchment.

CNRM largely overestimates evapotranspiration (Figure D3) over all three catchments, which points to a general problem in the CNRM-CM3 model. The other models show small biases over the Baltic Sea catchment with UKMO showing the largest negative bias (-13%). Over the Danube catchment, MPIM and IPSL have also only small biases, while UKMO and BCCR have positive biases of +15% and +17%. Over the Rhine catchment all GCMs overestimate evapotranspiration.

Figure D4 shows how the biases in precipitation and evapotranspiration add together in the runoff. For the Baltic Sea catchment, the wet precipitation bias of MPIM and the negative evapotranspiration bias of UKMO lead to wet runoff biases. For CNRM, the large positive biases in precipitation and evapotranspiration are compensating each other, so that the runoff bias is negligible. As for precipitation and evapotranspiration, IPSL and BCCR have only small runoff biases over the Baltic Sea catchment. The positive biases over the Rhine catchment are compensating each other for all GCMs except for IPSL where the wet precipitation bias is leading to a wet runoff bias. Over the Danube catchment, the latter applies for IPSL, too, as well as for UKMO and BCCR. For MPIM, the dry precipitation bias leads
to dry runoff bias. CNRM also shows a dry runoff bias as its overestimation in evapotranspiration is exceeding the positive precipitation bias.

Different to previous multi-model studies (e.g. Jacob et al. 2007, Hagemann and Jacob 2007, Reichler and Kim 2008), the multi-model mean is not always closer to the observations than the different GCMs. This is mainly related to the fact that the random ensemble of five GCMs is too small to form a sufficient multi-model ensemble. Thus, a strong bias in one of the GCMs may spoil the multi-model mean.

**Figure D2** Annual means precipitation over the catchments of Baltic Sea, Danube and Rhine. The observed precipitation was calculated from the mean of CMAP and GPCP data.

**Figure D3** Annual mean evapotranspiration over the catchments of Baltic Sea, Danube and Rhine. The observed evapotranspiration was calculated from the difference of the mean precipitation (mean of CMAP and GPCP data) minus the observed climatological discharge.
2.2 Monthly means

Over the Baltic Sea catchment (Figure D5), all GCMs except MPIM show a significant cold bias compared to CRU (Climate Research Unit, Mitchell and Jones 2005) data that extends from autumn to spring. For UKMO, this cold bias is also visible in the summer. As mentioned in Section 2.1, the actual precipitation amounts are expected to be in between GPCP and CMAP. Here, the common model bias of too much precipitation in the winter and spring (e.g. Hagemann and Jacob 2007) becomes visible in the spring. Further noteworthy biases are a common (except UKMO) wet bias in October, the large dry bias of IPSL, the small dry bias of BCCR and the wet bias of CNRM in the summer. A comparison of simulated evapotranspiration to ERA40 data reveals that the CNRM summer evapotranspiration is much larger than for ERA40 and the other GCMs while IPSL seems to be somewhat on the low side. This seems to be connected to the summer precipitation bias of the two GCMs, suggesting a too enhanced hydrological cycle of CNRM and a too week hydrological cycle of IPSL in the summer over the Baltic Sea catchment. The comparison of the simulated GCM runoff (without lateral routing) to observed discharge indicates a too late snowmelt peak for all GCMs except MPIM as this peak is expected to be about one month earlier in the runoff field than in the discharge after the lateral transport into the Baltic Sea (see e.g. Hagemann et al. 2004). This delayed snowmelt is directly related to the cold bias in the corresponding GCMs.

For the Danube (Figure D6) and Rhine (Figure D7) catchments, it was of interest whether the prominent summer drying problem shows up in the GCM simulation, i.e. the too warm and dry simulation of summer time climate over Central and Eastern Europe (see, e.g., Hagemann et al. 2004). While over the Danube catchment (Figure D6), a summer warm bias can be seen for IPSL, CNRM and largest for BCCR, this is not really the case over the Rhine catchment (Figure D7) as only IPSL shows a noteworthy warm bias of about 1 K in July. Regarding precipitation, MPIM has strong dry bias that extends from late spring to early autumn over both catchments, while from the other GCMs only CNRM and UKMO have a small dry bias in August/September over the Danube catchment. This strong dry bias of MPIM is also affecting its simulated evapotranspiration over the Danube catchment that is distinctively lower than for the other GCMs and ERA40 for the second half of the year. Here, the largely
underestimated precipitation provides the soil with too little moisture so that the soil becomes too dry so that too little moisture is available for evapotranspiration. As for the Baltic Sea catchment CNRM evapotranspiration is clearly on the high side and IPSL evapotranspiration is on the low side for the Danube and the Rhine catchments. For the latter, ERA40 and MPIM are close to IPSL. Considering the dry bias of MPIM and its effect on the evapotranspiration over the Danube catchment suggests that the evapotranspiration is probably also too low for ERA40, IPSL and MPIM over the Rhine catchment. With regard to runoff the large unrealistic snowmelt peak of BCCR can be noted as well as the probably too large runoff values of ISLP in the late autumn and winter. For BCCR, the error comes from the snow parameterization of the ARPEGE model, which is too snow-conservative by maintaining high albedo and weak conductivity as found by Hagemann et al. (2004) for the stretched version of ARPEGE used for regional studies. As CNRM does not show this bias, the error seems to be corrected in their ARPEGE version.

In summary it can be stated that a large spread exists between the simulated hydrological variables of the five GCMs. As mentioned in Section 2.1, the multi-model mean is not always closer to the observations than the different GCMs.

Figure D5 Monthly means of a) 2m temperature difference to CRU2 data, b) precipitation, c) evapotranspiration, d) runoff over the Baltic Sea catchment for the control climate period 1961-90. Note that Obs_act in panel d) designates the observed discharge while the other curves show the total simulated GCM runoff without lateral routing.
Figure D6  Monthly means of a) 2m temperature difference to CRU2 data, b) precipitation, c) evapotranspiration, d) runoff over the Danube catchment for the control climate period 1961-90. Note that Obs_act in panel d) designates the observed discharge while the other curves show the total simulated GCM runoff without lateral routing.

Figure D7  Monthly means of a) 2m temperature difference to CRU2 data, b) precipitation, c) evapotranspiration, d) runoff over the Baltic Sea catchment for the control climate period 1961-90. Note that Obs_act in panel d) designates the observed discharge while the other curves show the total simulated GCM runoff without lateral routing.
3. Future changes in the A2 scenario simulations

3.1 Annual mean changes

Figure D8 shows the simulated future changes in the annual mean precipitation over the catchments of the Baltic Sea, Danube and Rhine.

For the Baltic Sea catchment and the Danube catchment, the five GCMs agree well in the direction of the change. For the first, the multi-model ensemble mean predicts an increase of about +9%, and a reduction of about -10% for the second. Except for BCCR, the GCMs also project a reduction of precipitation (between -3% to -6%) over the Rhine catchment. But as BCCR projects a pronounced increase (+11%), the multi-model mean projects only a small reduction of less than -2%.

With regard to evapotranspiration (Figure D9), clear increases are predicted for the Baltic Sea (about +9%) and Rhine (about +7%) catchments. For the latter, IPSL is somewhat an outlier as it projects a small (-1%) reduction in evapotranspiration for the Rhine catchment. For the Danube catchment, all GCMs except BCCR (+4%) project a reduction in evapotranspiration yielding a -4% reduction in the multi-model mean.

The changes in precipitation and evapotranspiration add up together in the change in runoff shown in Figure D10. In general the five GCMs agree in projecting a runoff increase over the Baltic Sea catchment (+9%) and a runoff decrease over the Danube (-24%) and the Rhine (-11%) catchments. The only exception is BCCR that projects a small runoff increase (+5%) over the Rhine catchment.

For the scenarios B1 and A1B the projected changes are similar to the projected A2 changes, which can also be obtained from Figure D11 where the multi-model mean annual changes are shown for the scenarios B1, A1B and A2.

![Figure D8](image)

**Figure D8** Annual mean changes in precipitation over the catchments of Baltic Sea, Danube and Rhine.
Figure D9  Annual mean changes in evapotranspiration over the catchments of Baltic Sea, Danube and Rhine.

Figure D10  Annual mean changes in runoff over the catchments of Baltic Sea, Danube and Rhine.
3.2 Monthly mean changes

Figure D12, D13 and D14 show the projected monthly mean changes in 2m temperature and the hydrological fluxes for the catchments of Baltic Sea, Danube and Rhine, respectively. The projected changes for temperature are similarly varying as projected in the PRUDENCE RCM ensemble (Hagemann and Jacob 2007; Graham et al., 2006). Over the Baltic Sea catchment (Figure D12), one maximum of temperature change is obtained, which is predicted for the winter. But over the Danube (Figure D13) and the Rhine catchment (Figure D14) two maxima of temperature change are predicted in the model mean that are located in the winter and summer, whereas the winter maximum is less pronounced than the summer maximum. Here, BCCR and IPSL are deviating from the general behaviour. BCCR projects a summer maximum in the temperature change that is lower than the projected change in the winter, and IPSL has a third maximum in spring that projects about the same warming as in the summer.

In the projected changes in the hydrological cycle, a gradient in the signal becomes obvious. Over the Baltic Sea catchment (Figure D12) a significant precipitation increase is predicted for the winter half of the year (October-April) while the changes remain comparatively weak in the summer half (April-September), with a general reduction around August in BCCR, UKMO and strongest in CNRM. Here, IPSL shows a deviating behavior with projected precipitation decreases in the spring. This spurious behavior is also seen in the projected evapotranspiration change where IPSL is the only GCM that projects a decrease in spring. Generally the GCMs project an increase in evapotranspiration throughout the year except for the summer, with the largest increase in the winter. As for precipitation, CNRM and BCCR show a decrease in summer around August that is compensating the projected increases by the other three GCMs in the multi-model mean. As the absolute increases of precipitation are exceeding the increases in evapotranspiration, the runoff is also generally projected to increase in the winter half year. Only UKMO projects a decrease for the whole summer and autumn. The GCMs also tend to agree on a projected reduction of runoff in the late spring/early summer. BCCR projects a very strong relative runoff increase of more than 500% in the winter that is related to the very low winter runoff values simulated for the current climate (see Figure D5).
For the Rhine catchment (Figure D14), a precipitation increase is projected only for the winter and early spring, and only a small increase of winter precipitation is projected over the Danube catchment (Figure D13). In addition, a significant decrease of precipitation is projected in the summer for both catchments. Here, all models largely agree except for BCCR and IPSL in the Rhine catchment, which do not show a noteworthy future summer drying. IPSL is also showing an odd behavior in the projected evapotranspiration changes, where it differently to the other GCMs projects an evapotranspiration decrease in the winter and no reduction in the summer over both catchments. The other GCMs largely agree in their projected increases in the winter and projected decreases in the summer due to the projected summer drying except for BCCR and MPIM in the Rhine catchment. Here, BCCR projects no change during summer and early autumn while MPIM projects an evapotranspiration increase in the summer and a decrease in autumn, thereby partially agreeing with IPSL. The different changes in precipitation and evapotranspiration lead to pronounced reductions in runoff throughout the year except for the winter. These reductions are robust across the GCMs, only in the winter there is no common signal projected by the GCMs. For the Danube, CNRM and MPIM project a reduced runoff also during the winter while UKMO and BCCR project a winter increase, which is even relatively large for BCCR. The latter increases also apply to the Rhine catchment where the other three GCMS project almost no change in the winter runoff.

Figure D12  Monthly mean changes of a) 2m temperature, b) precipitation, c) evapotranspiration, and d) runoff over the Baltic Sea catchment for the A2 scenario in 2071-2100 compared to 1961-90.
Figure D13  Monthly mean changes of a) 2m temperature, b) precipitation, c) evapotranspiration, and d) runoff over the Danube catchment for the A2 scenario in 2071-2100 compared to 1961-90.

Figure D14  Monthly mean changes of a) 2m temperature, b) precipitation, c) evapotranspiration, and d) runoff over the Rhine catchment for the A2 scenario in 2071-2100 compared to 1961-90.
References


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