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Development and testing of methods to assess the impact of climate change on flood and drought hazards at the European scale

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Abstract

The Joint Research Centre aims to develop knowledge and tools in support of the EU Climate Change Strategy that was recently put forward in the Commission's Communication "Winning the Battle Against Global Climate Change" (COM(2005) 35). In view of this, an important research topic of the Land Management Unit of the IES is to assess the impact of climate change on the occurrence of hydrological extremes such as floods and droughts. This requires an integrated approach that couples simulations of the current climate and of the future climate for different scenarios of greenhouse gas emissions by the end of the 21st century with a hydrological model. An integrated modelling framework is currently being developed and tested at the Weather Driven Natural Hazards group of the Land Management Unit to translate regional climate change signals into changes in hydrological hazards. The framework combines detailed regional climate predictions for Europe with a physically-based spatially distributed rainfall-runoff model. This document provides an outline of the procedure, as well as a state-of-the-art overview of techniques for downscaling climate information to the appropriate scale for hydrological impact assessment. Initial results are presented for a pilot study in the Meuse basin.

Content

1. Introduction

During the last 100 years global climate has warmed by an average of 0.6ºC, owing in part to human induced greenhouse gas emissions. Based on different scenarios of future greenhouse gas emissions, projections of climate models indicate another 1.4 to 5.8 ºC of warming over the next century (IPCC, 2001a). The projected change in climate will significantly impact the hydrological cycle. A warmer climate will increase evaporation, the intensity of water cycling, and result in greater amounts of moisture in the air. It is expected that the magnitude and frequency of extreme weather events will increase, and that hydrological extremes such as floods and droughts will likely be more frequent and severe.

The Joint Research Centre aims to develop knowledge and tools in support of the EU Climate Change Strategy that was recently put forward in the Commission's Communication "Winning the Battle Against Global Climate Change" (COM(2005) 35). In view of this, an important research topic of the Land Management Unit of the IES is to assess the impact of climate change on the occurrence of hydrological extremes such as floods and droughts. This will be accomplished by developing an integrated modelling framework that combines regional climate predictions for Europe with the LISFLOOD model. LISFLOOD is a distributed, partially physically-based rainfall-runoff model that has been devised to simulate the hydrological behaviour in large European catchments (De Roo et al., 2000), with emphasis on predicting floods and droughts. Owing to its general nature, LISFLOOD is optimally suited for simulating the different hydrological regimes across Europe.

Projections of future climate change are typically obtained from coupled Atmosphere-Ocean General Circulation Models (AOGCM). Because they require time steps of minutes but are used to predict climate change on time scales of months to centuries, their horizontal resolution is typically at least 100 km. As a result, their treatment of physical processes is approximate. Due to the coarse spatial resolution AOGCMs also fail to explicitly capture fine-scale climatic structures needed for climate change impact studies and policy planning at the regional or sub-regional scale (e.g., catchment or basin scale). To resolve this problem, regionalization or downscaling methods can be used, which enhance regional detail and provide climatic information at regional scales.

The downscaled predicted climate for current conditions and for different scenarios of greenhouse gas emissions by the end of the 21st century will be used as input to LISFLOOD, after taking due account of any systematic bias in the regional climate data. Runoff statistics for the two periods will provide a means to estimate changes in the frequency and severity of hydrological extremes under different scenarios of future greenhouse gas emissions.

The aim of this document is to present the current status of the integrated modelling framework that is being developed to assess the impact of climate change on flood and drought hazards at the European scale. The document is organised as follows. Section 2 presents a general overview of existing downscaling methods, with details of the underlying principles to generate regional climate information. In Section 3 details about existing regional climate data sets for Europe are presented. Section 4 describes the integrated modelling framework that couples the regional climate model data with the hydrological model LISFLOOD. Some initial results of a pilot study in the Meuse catchment are presented in Section 5. Conclusions and an overview of current and further work are presented in Section 6.

2. Overview of downscaling methods

Typically, AOGCMs are run with a grid resolution of approximately 2.5° (~300 km). However, regional climate is often affected by forcings and circulations that occur at much finer scales, such as for example those due to topography, land-use characteristics, inland water bodies, land-ocean contrasts, and snow. These processes are characterised by a range of spatial and temporal variability scales and can be highly non-linear. The general philosophy behind the regionalization or downscaling techniques is to use input data from AOGCMs and account for regional characteristics to produce more detailed regional climatic information. The overview presented below is largely based on the excellent overview on regional climate information of the IPCC Third Assessment Report, Climate Change Report 2001: The Scientific Basis.

2.1 Coupled AOGCMs

The first option is to use the climate change information provided by transient runs of the AOGCM without further regionalisation. The main advantage is that the internal physical consistency is maintained, and the ready availability of data for a large number of variables from the full range of currently available AOGCM experiments. The main drawback is that coupled AOGCMs cannot provide direct information at scales smaller than their resolution, neither can they capture the detailed effects of forcings acting at the sub-grid scales. This can introduce bias in the climate simulations at the AOGCM resolution.

Analyses of transient simulations with AOGCMs (e.g., New et al., 1999; Boer et al., 2000; Giorgi and Francisco, 2000) have shown that average climatic features are generally well simulated at the planetary and continental scale. At the regional scale, area-average biases in the simulation of present day climate are highly variable from region to region and across models. Seasonal temperature biases are typically within the range of ± 4°C. Precipitation biases are mostly between -40 and 80%. Model performance was poorer at the finer scales, particularly in areas of strong topographical variation. AOGCM performance is generally improving because of both increased resolution and improvements in the representation of physical processes.

2.2 High resolution and variable resolution Atmosphere Global Circulation Models (AGCM)

For applications where regional information on climate is required for at most several decades, simulations are feasible at resolutions of 50 to 100 km with variable resolution models. This implies identifying periods of interest within transient AOGCM simulations and modelling these with a higher or variable resolution AGCM to provide additional detail (e.g., Bengtsson et al., 1995; Cubasch et al., 1995; May and Roeckner, 2001). The AGCM is used to provide a reinterpretation of the atmospheric response to the anomalous atmospheric forcing experienced in a transient

AOGCM simulation. Hence, both this forcing and its accumulated effect on the ocean surface have to be provided to the AGCM. The use of high or variable resolution AGCMs is based on the idea that relatively high resolution information can be obtained globally or regionally without having to perform the whole transient simulation with high resolution models. The resulting simulations are globally consistent, and the use of higher resolution can lead to improved simulation of the general circulation in addition to providing regional detail. A weakness of these methods is that they generally use the same formulations as at the coarse resolution for which they have been optimised to reproduce current climate. Some processes may be represented less accurately when finer scales are resolved and so the model formulations would need to be optimised for use at the higher resolution. Another drawback is that feedback effects from fine to larger scales are represented only as generated by the area of interest, which may yield an improper description of fine-to-coarse scale feedbacks. Also, a sufficient minimal resolution must be retained outside the high resolution area of interest in order to prevent a degradation of the simulation of the whole system.

Only a few modelling studies have been carried out for a limited number of regions using this technique. Though many aspects of the models' dynamics and large-scale flow are improved at higher resolution, this is not uniformly so geographically and across models. Substantial underlying errors are often still present in high-resolution versions of current AGCMs. High resolution AGCMs could potentially be used to obtain forcing fields for higher resolution RCMs or statistical downscaling, thus effectively providing an intermediate step between AOGCMs and regional and empirical models.

2.3 Regional climate models (RCMs)

These models employ initial conditions, time-dependent lateral meteorological conditions and surface boundary conditions derived from GCMs or the analysis of observations to generate high resolution climate predictions (e.g., Jones et al., 1997; Machenhauer et al., 1998; Christensen, 1999; McGregor et al., 1999; Kato et al., 2001; Giorgi et al., 2004; Wang et al., 2004). The global model is used to simulate the response of the global circulation to large-scale forcings, whereas the RCM (i) accounts for sub-GCM grid scale forcings in a physically-based way; and (ii) enhances the simulation of atmospheric circulations and climate variables at fine spatial scales. RCMs can provide high resolution (10 to 20 km or less) and multi-decadal simulations and are capable of describing climate feedback mechanisms acting at the regional scale. A high horizontal resolution is especially important for the simulation of the hydrologic cycle (Christensen et al., 1998). The main limitations of these models are the effects of systematic errors in the driving fields provided by the global models, and the lack of two-way interactions between the regional and global climate.

A number of RCM systems are currently available with the capability of high-resolution, multi-decadal simulation in a variety of regional settings. Nested RCMs have shown marked improvements in their ability to reproduce present day average climate, with some of this improvement due to better quality driving fields provided by the GCMs. Seasonal temperature and precipitation biases in state-of-the-art RCMs are generally less than 1 to 2°C and a few percent to 50-60% of observed precipitation, respectively. At the daily time-scale, it seems that RCMs tend to simulate too many light precipitation events compared with the observations (Christensen et al. 1998; Kato et al., 2001). However, the statistics of heavy precipitation events are more realistic than those produced by GCMs, and sometimes RCMs capture extreme events that are entirely absent in the driving global model (Christensen et al., 1998; Jones, 1999).

Depending on the quality that is required the simulations of RCMs may be used directly as input for other applications, or a correction of the bias may first be necessary. This is typically obtained by comparing the model predictions with other estimates of the regional or local climate, often based on the spatial interpolation of meteorological observations. The model data are then adjusted accordingly, for example by adding or subtracting the average temperature difference or applying a scaling factor to the precipitation amounts. However, a serious problem concerning RCM evaluation is a general lack of good quality high-resolution observed data, particularly in areas with significant orographic effects. Overall, there is strong evidence that regional models consistently improve the spatial detail of simulated climate compared to GCMs because of their better representation of sub-GCM grid scale forcings, especially in regard to the surface hydrologic budget.

2.4 Statistical downscaling

Statistical downscaling methods derive regional or local climate information by first determining a statistical model which relates a set of large-scale atmospheric predictor variables and circulation characteristics to local station-scale meteorological series. Then the predictors from an AOGCM simulation are fed into the statistical model to predict the corresponding local and regional climate characteristics. A range of statistical downscaling models, from regressions to neural networks and analogues, has been developed for regions where sufficiently good data sets are available for calibration. These methods are computationally inexpensive, and thus can be easily applied to output from different GCM experiments. The major theoretical weakness of statistical downscaling is that their basic assumption is not verifiable, i.e., that the statistical relationships developed for present day climate also hold under the different forcing conditions of possible future climates. In addition, data with which to develop relationships may not be readily available in remote regions or regions with complex topography. Another caveat is that these empirically-based techniques cannot account for possible systematic changes in regional forcing conditions or feedback processes. The possibility of tailoring the statistical model to the requested regional or local information is a distinct advantage.

When using statistical downscaling for assessing regional climate change, three implicit assumptions are made:

- The predictors are variables of relevance to the local climate variable being derived and are realistically modelled by the GCM.
- The transfer function is valid under altered climatic conditions, which cannot be proven in advance
- The predictors fully represent the climate change signal.

A diverse range of downscaling methods has been developed, but, in principle, these models are based on three techniques:

1. Stochastic weather generators (e.g., Richardson, 1981; Wilks, 1992; Gregory et al., 1993; Katz, 1996; Wilks and Wilby, 1999), which are random number generators of realistic looking sequences of local climate variables, that may be conditioned upon the large-scale atmospheric state. Two of the more common approaches are the Markov Chain approach (e.g., Richardson, 1981; Lettenmaier, 1995; Hughes et al., 1999; Bellone et al., 2000) and the spell length approach (e.g., Roldan and Woolisher, 1982; Racksko et al., 1991; Wilks, 1999).
2. Transfer functions, where a direct quantitative relationship is derived through, for example, regression (e.g., Kim et al., 1984; Wigley et al., 1990; von Storch et al., 1993). The more common transfer functions are derived from regression-like techniques (e.g., Sailor and Li, 1999; Chen et al., 1999; von Storch and Zwiers, 1999) or piecewise linear or non-linear interpolation methods (e.g., Biau et al., 1999; Brandsma and Buishand, 1997; Buishand and Brandsma, 1999). An alternative approach is based on Artificial Neural Networks that allow the fit of a more general class of statistical model (Hewitson and Crane, 1996; Trigo and Palutikof, 1999).
3. Weather typing or pattern-based approaches (e.g., Lamb, 1972; Hay et al., 1991, Bardossy and Plate, 1992; Lettenmaier, 1995; Wilby, 1995; Conway et al., 1996) based on the more traditional synoptic climatology concept, and which relate a particular atmospheric state or ‘weather class’ to a set of local climate variables. The frequency distributions of local or regional climate are then derived by weighting the local climate states with the relative frequencies of the weather classes. Climate change is then estimated by determining the change of the frequency of weather classes.

Weather generators provide realistic sequences of high temporal resolution events. With transfer functions, statistics of regional and local climate may consistently be derived from GCM generated data. Techniques based on weather typing serve both purposes, but are less adapted to specific applications. As statistical techniques combine existing empirical knowledge, statistical downscaling can describe only those links that have been observed in the past. Thus, it is based on the assumption that presently found links will prevail under different climate conditions.

2.5 Summary of regionalisation methods

For all downscaling or regionalisation techniques the AOGCM information is the starting point. Hence, a foremost requirement in the simulation of regional climate is that the AOGCMs simulate well the circulation features that affect regional climates. Modelling evidence clearly indicates that topography, land use, and the surface hydrological cycle strongly affect the surface climate signal at the regional to local scale. This implies that the use of AOGCM information for impact studies at the regional or local scale needs to be taken cautiously, especially in regions characterised by pronounced sub-GCM grid scale variability in forcings, and that suitable regionalisation techniques should be used to enhance regional climate predictions. Different techniques may be most suitable for different applications and different working environments. High resolution AGCMs offer the primary advantage of global coverage and two-way interactions between the regional and global climate. However, due to the computational cost, the resolution increase that can be expected from these models is limited. RCMs can capture physical processes and feedbacks occurring at the regional scale, but they are affected by the errors of the AOGCM driving fields, and they do not represent regional to global climate feedback. Statistical downscaling techniques offer the advantages of being computationally inexpensive, of providing local information, and of offering the possibility of being tailored to specific applications. However, these techniques have limitations inherent in their empirical nature. The combined use of different techniques may provide the most suitable approach in many instances.

3. Regional climate data for climate change impact studies

In recent years, under the umbrella of several EU funded projects (e.g., PRUDENCE, STARDEX (FP5) and ENSEMBLES (FP6)), a series of regional climate change scenarios for 2071-2100 have been developed for Europe. The spatial resolution of these regional climate model projections ranges from 50 to 25 km.

Recently, the Danish Meteorological Institute (DMI) concluded an ambitious project where the resolution was doubled once more, approaching a grid size of 12 km covering the whole of Europe. The DMI experiment consists of simulations for two

30-year time slices, corresponding to a 30-year control run with a greenhouse gas forcing corresponding to 1961-1990 and a scenario run corresponding to 2071-2100. The modelling domain and the average changes in temperature and precipitation between the control and scenario run are shown in Figures 3.1-3.3. The 30-year climatology for the present appeared to be in better agreement with observations than a previous 15-year experiment using ECMWF reanalysis data.

The scenario used in this climate model experiment is A2, which assumes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities with slowly converging fertility patterns across regions, resulting in continuously increasing global population. Economic development is primarily regionally oriented. This scenario assumes less international cooperation (globalization) and less environmental awareness and sustainable development than the other IPCC scenarios (IPCC, 2001b).

Simulations were done with the regional climate model HIRHAM (Christensen et al., 1996). The lateral boundaries, sea surface temperature (SST) and sea ice extent come from the HadAM3H high-resolution atmosphere model, which itself has been driven by low-resolution observed SST/sea-ice extent for the first time slice, and observations plus a climate change signal for the future period. The climate change signal in SST/sea-ice extent comes from the global coupled atmosphere-ocean HadCM3 model (Gordon et al., 2000; Pope et al., 2000). Since this setup generated a very large heating of the Baltic Sea, the DMI used a modified future signal in SST/sea ice extent for this area. The origin of these data is the Rossby Centre regional atmosphere-ocean (RCAO) model (Döscher et al. 2002) of the Swedish Meteorological and Hydrological Institute (SMHI), which has a slab-ocean model (this means treating the ocean as though it were a layer of water of constant depth and heat transports within the ocean being specified and remaining constant while climate changes) of the Baltic sea interacting with their regional atmospheric model.

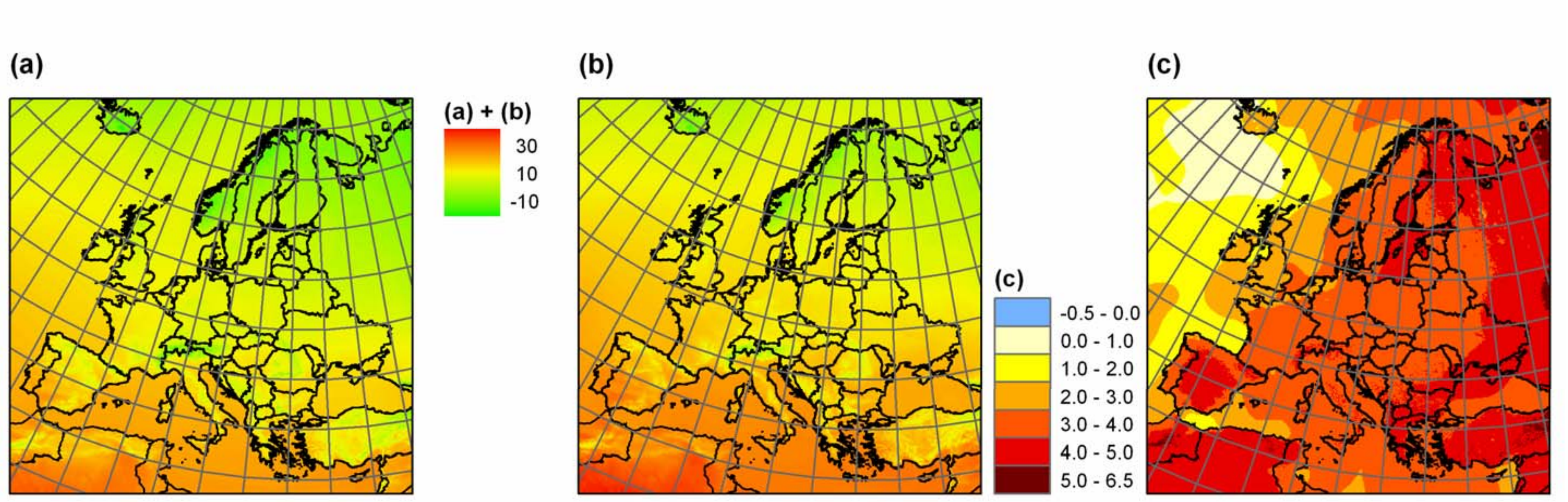

Figure 3.1. Average annual temperature over Europe in degrees Celsius as simulated by the regional climate model HIRHAM: (a) control period (1961-1990); (b) scenario period (2071-2100); (c) difference (scenario minus control).

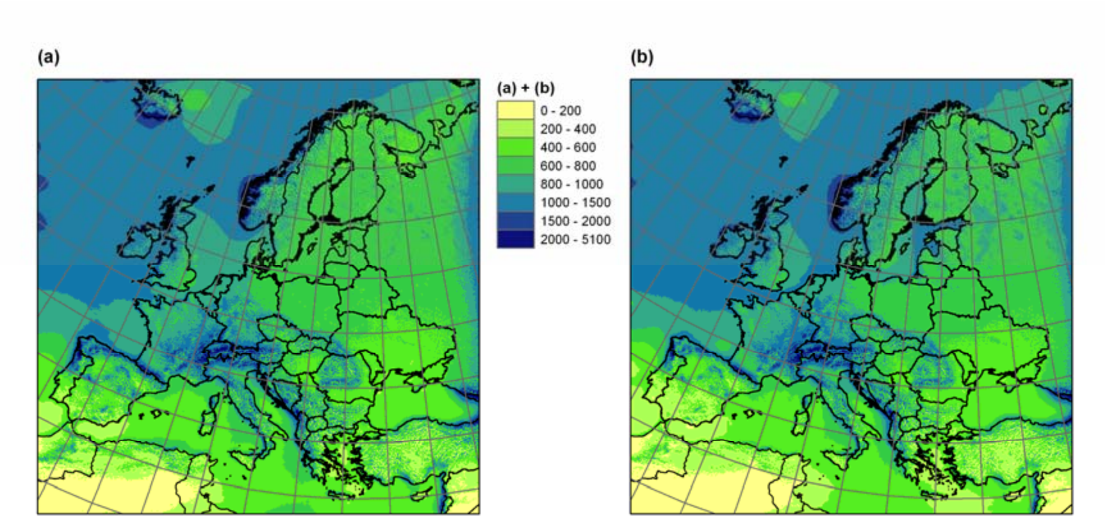

Figure 3.2. Annual precipitation over Europe in mm as simulated by the regional climate model HIRHAM: (a) control period (1961-1990); (b) scenario period (2071-2100).

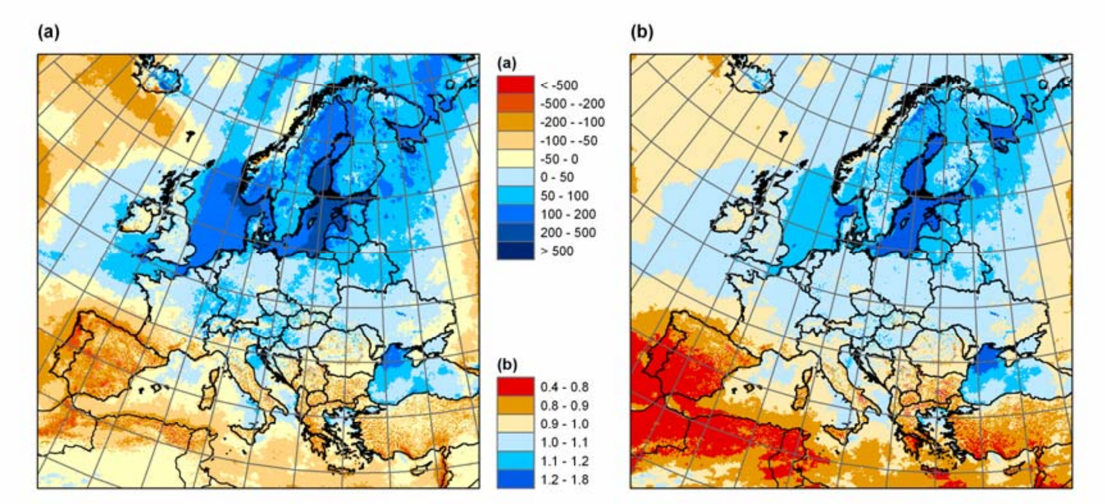

Figure 3.3. Difference in annual precipitation over Europe as simulated by the regional climate model HIRHAM: (a) absolute difference in mm between the control and scenario period; (b) relative difference (scenario divided by control).

The DMI climate dataset includes the following fields for the control (1961-1990) and future period (2071-2100):

t2m	2-meter temperature (K)
t2max	Daily maximum 2-meter temperature (K)
t2min	Daily minimum 2-meter temperature (K)
td2m	2-meter dew point temperature (K)

precip	Precipitation (mm/day)
SWnet	Net SW radiation (W/m^2) positive
LWnet	Net LW radiation (W/m^2) positive
w10m	10-meter wind speed (average length of the wind vector) (m/s)
evap	Evaporation (mm/day)
snow	Snow water equivalent (mm)
runoff	Total runoff (mm/d)
soilw	Soil moisture (mm)

The above fields have been provided by Ole Bøssing Christensen of the DMI and are currently stored on the data server of the WDNH group. The first 8 fields will be used as input for LISFLOOD simulations, whereas fields 9-12 will be used for comparison purposes only.

Other fields in the dataset include:

Clcov	Total cloudiness (Fraction)
Psurf	Surface pressure (hPa)
MSLP	Mean sea level pressure (hPa)
w10max	10-meter daily maximum wind speed (m/s)
SWdown	Downward SW radiation (W/m^2) positive
LWdown	Downward LW radiation (W/m^2) positive downward

4. Integrated modelling framework RCM - LISFLOOD

To assess the impacts of climate change on flood and drought hazards an integrated modelling framework is being developed and tested. The framework is depicted in Figure 4.1. The hydrological model LISFLOOD is one-way coupled with the regional climate model (i.e., there is no feedback from the hydrological model back to the climate model). It will be explored whether correction factors that make use of meteorological observations need to be applied in order to avoid adverse effects from systematic RCM biases. Hydrological simulations on the basin scale using LISFLOOD typically run with a grid spacing of 1 to 5 km. This implies that there is still a scale-discrepancy between the forcing climate data and the hydrological simulation scale. It will be investigated if further downscaling of the regional climate data using statistical methods is required to bridge the remaining scale gap. After bias corrections and possible further downscaling, the regional climate data for both time slices will serve as input to the LISFLOOD model. Changes in runoff statistics will be analysed employing extreme value analysis. This will yield an assessment of the expected changes in flood and drought hazard, resulting from the emission scenario and regional climate model used. The derived changes in hazards can then be combined with estimates of the vulnerability and exposure to yield an assessment of the changes in flood and drought risks.

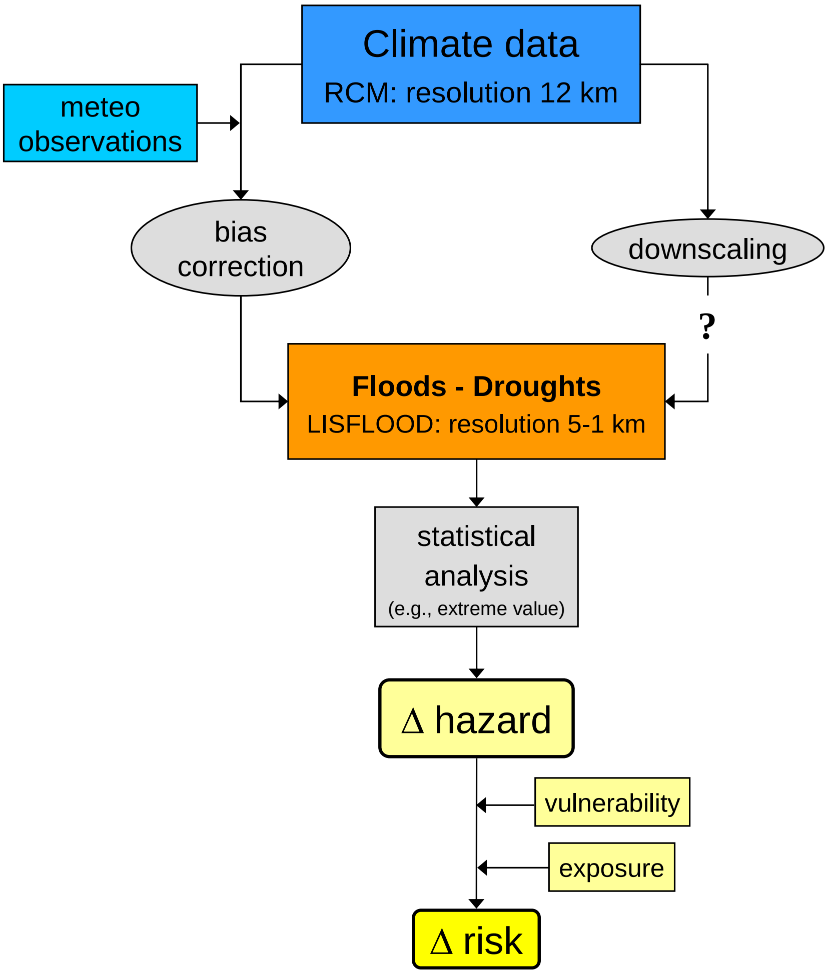

Figure 4.1. Schematic overview of the integrated modelling framework to assess the impact of climate change on the flood and drought risk.

5. Pilot study basin: the Meuse catchment

The Meuse catchment upstream of Borgharen (see Figure 5.1) serves as a pilot study case for the development and implementation of the integrated modelling framework. This part of the Meuse catchment covers an area of approximately 21,000 km^2 and is situated in Belgium, France, and the Netherlands. The Meuse is fed mainly by rain all year round; hence flows are generally highest in winter, with relatively low flows during the summer. The topography of the area is hilly with the elevation varying from 50 m to 700 m. The substrata are largely impervious, resulting in precipitation that is discharged quickly into the river. The predominant land use types are forest, agriculture (cultivated patterns and pasture), moor and heath.

In the model, the area was discretised in 1 by 1 km grid blocks. Daily observed discharges are available for the Borgharen gauging station. The model was run with a daily time step. The LISFLOOD model was calibrated for the Meuse catchment employing the Shuffled Complex Evolution Metropolis - UA (SCEM-UA) algorithm (Feyen et al., 2005). The simulation period in the calibration spanned 1/10/1992-30/09/1995. The first year was used as a warming-up period, hence only predicted discharges for the last two years were used for the calibration. For validating the model, observations from 10/1/1990-30/9/1992 were used.

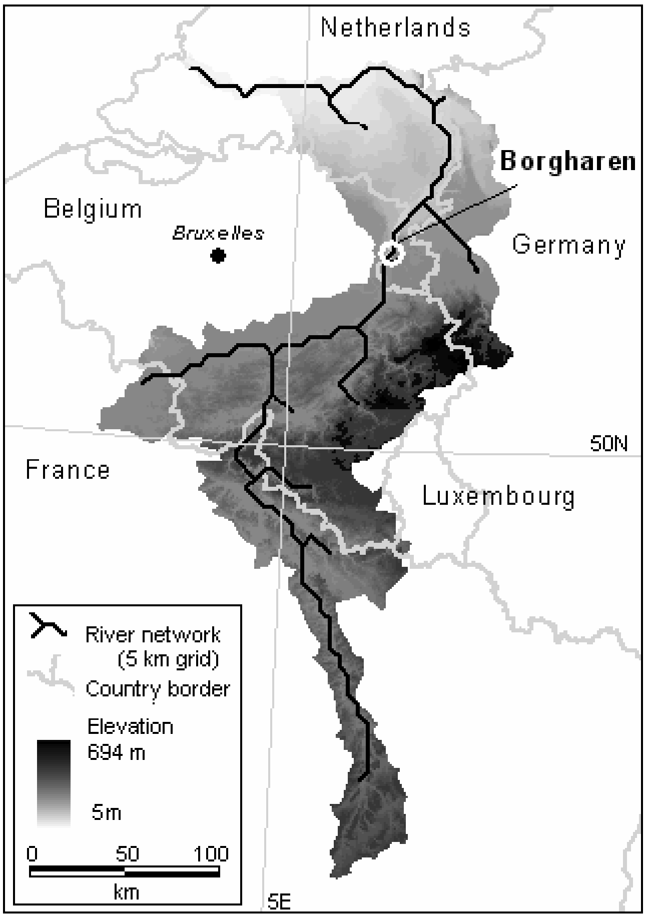

Figure 5.1. Location of the Meuse catchment, with grey-scale overlay of the topography.

To investigate whether the HIRHAM regional climate data exhibit any systematic bias the data have been compared with two observation-based estimates of the climatological conditions in the Meuse Basin: the MARS meteorological database of gridded daily observations at approximately 20 synoptic weather stations (available from the JRC Crop and Yield Monitoring Activity), and a high-resolution set of meteorological observations at more than 100 stations in the Meuse area. Both datasets cover different periods (MARS: 1990 – 2004; station observations: 1978 – 1994) and in the interpolation to the 1 km grid of LISFLOOD the temperature and vapour pressure data were corrected for elevation differences. The DMI dataset contains 30 years of simulated climatology from the regional climate model HIRHAM (see section 2) corresponding to 1961 to 1990. It is important to realize that these simulations did not reproduce the actual, historical weather conditions in this period, but only the statistical properties of the climate. A direct, day-to-day validation of the data with observations is therefore not feasible.

Since no altitude correction has been applied to the HIRHAM data, a plot of the annual average temperature in the Meuse Basin does not contain the fine details shown by the observation-based datasets. However, the broad geographical patterns are well reproduced (Figures 5.2–5.3). The differences from the MARS temperatures are generally less than 1ºC. Both datasets are slightly warmer than the high-resolution station observations that are better able to capture any local-scale orographic effects. Unlike the MARS dataset, however, the RCM does reproduce some areas of higher annual precipitation shown in the station observations, although not always at the right location (Figures 5.4–5.5). The differences in precipitation are more significant than in temperature, but averaged over the entire Meuse basin the HIRHAM estimate of the annual precipitation is very close to the estimate based on the high-resolution station observations (Table 1).

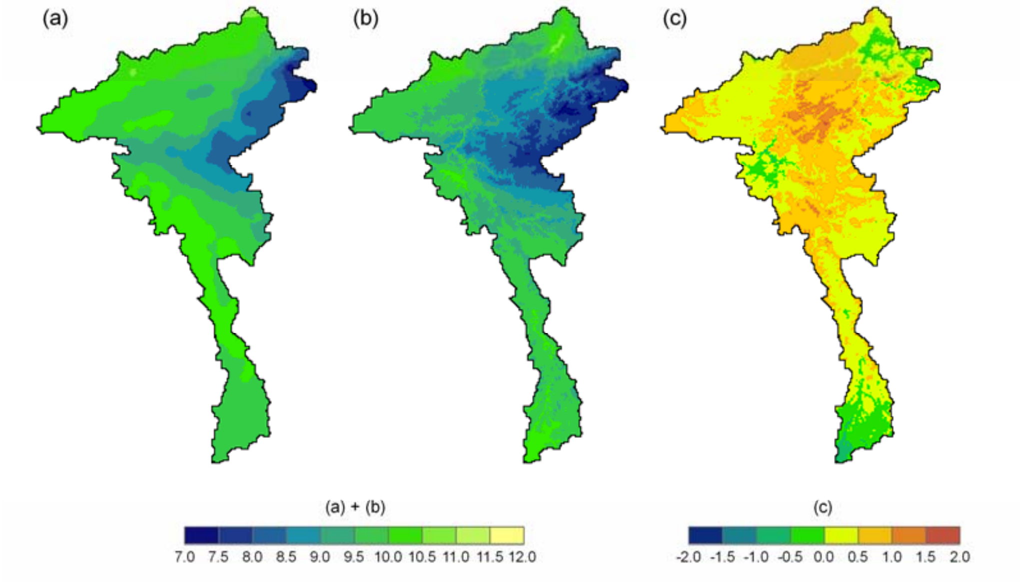

Figure 5.2. Average annual temperature in the Meuse Basin in ºC (a) as simulated by the RCM HIRHAM (1961-1990); (b) based on high-resolution station observations (1978-1994); (c) the difference between the two estimates (HIRHAM minus observations).

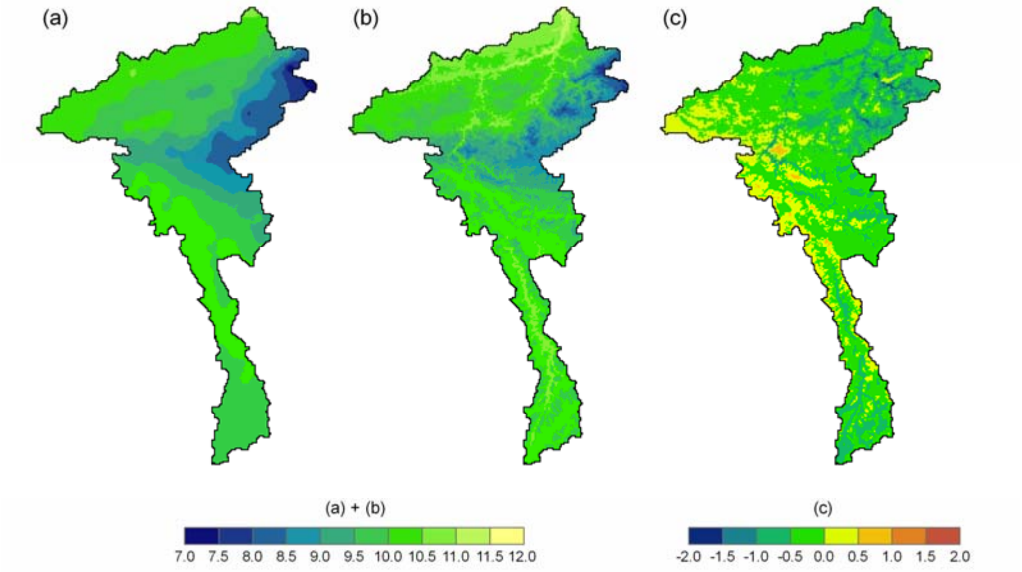

Figure 5.3. Average annual temperature in the Meuse Basin in ºC (a) as simulated by HIRHAM (1961-1990); (b) based on the MARS meteorological database (1990-2004); (c) the difference between the two estimates (HIRHAM minus MARS).

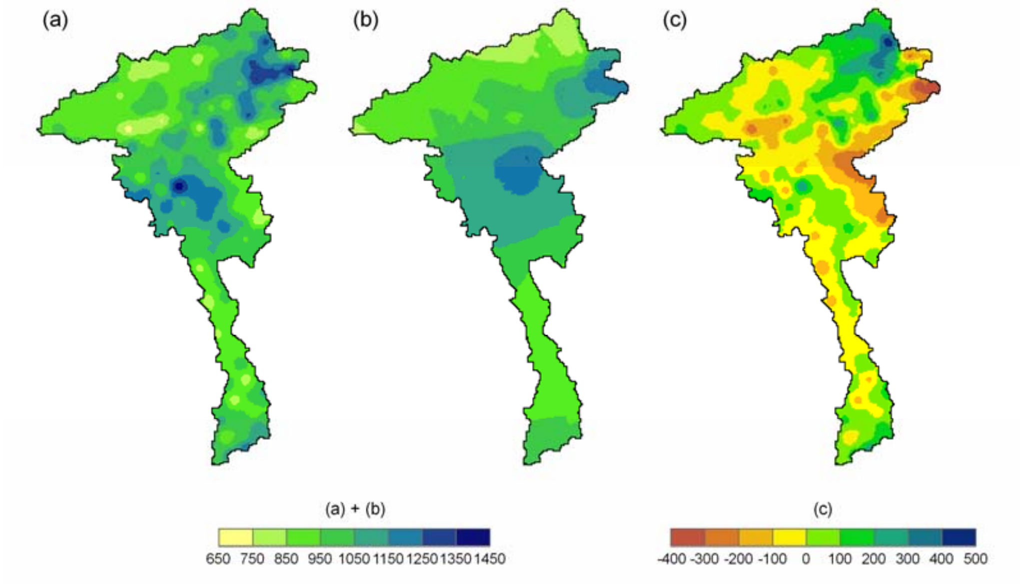

Figure 5.4. Average annual precipitation in the Meuse basin in mm (a) as simulated by HIRHAM (1961-1990); (b) based on high-resolution station observations (1978-1994); (c) the difference between the two estimates (HIRHAM minus observations).

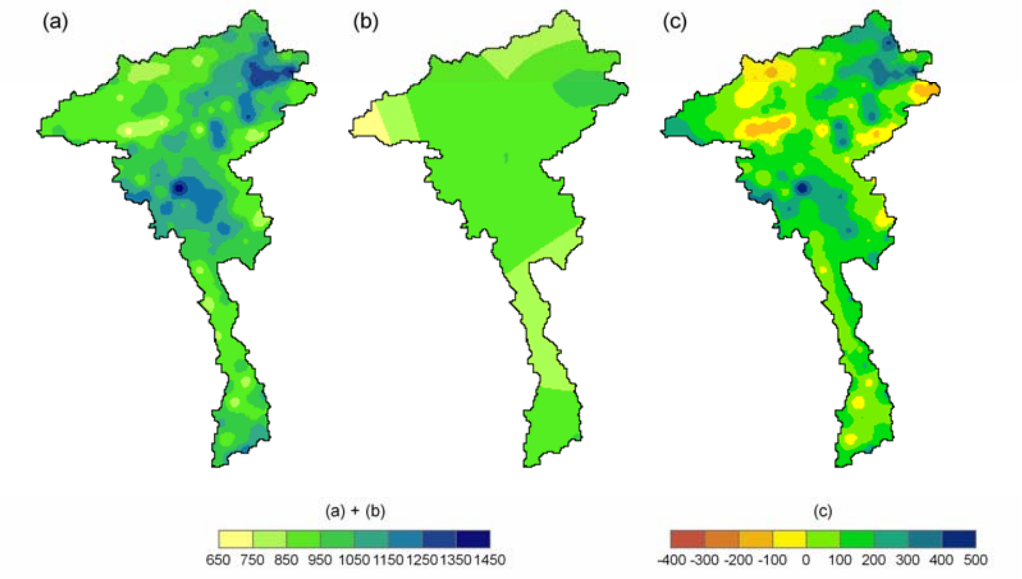

Figure 5.5. Average annual precipitation in the Meuse basin in mm (a) as simulated by HIRHAM (1961-1990); (b) based on the MARS meteorological database (1990-2004); (c) the difference between the two estimates (HIRHAM minus MARS).

Table 1. Water balance characteristics of the Meuse basin in the three model experiments with LISFLOOD. Note that observations of river discharge were only available up to 1998 and that the Nash-Sutcliffe coefficient cannot be calculated for the HIRHAM simulations, as explained in the text.

Source of meteorology		**Met. stats**	**MARS**		**HIRHAM**
Period		1978-1994	1990-2004	1990-1997	1961-1990
Climatology					
Temperature	(ºC)	9.2	9.9	9.8	9.6
Precipitation	(mm)	993	885	842	998
LISFLOOD					
Soil evaporation	(mm)	44	37	34	84
Transpiration	(mm)	351	334	328	447
Interception loss	(mm)	100	88	83	96
Total evaporation loss	(mm)	495	458	446	628
Observed discharge	(m^3/s)	257		207	237
	(mm)	384		309	354
Simulated discharge	(m^3/s)	331	285	262	251
	(mm)	495	426	392	370
Simulated / observed runoff		1.29		1.27	1.04
Observed runoff / rainfall		0.39		0.37	0.36
Simulated runoff / rainfall		0.50	0.48	0.47	0.37
Change in storage	(mm)	4	1	4	0
Nash-Sutcliffe coefficient		0.84		0.90	

The three different sources of climatological information (station observations, MARS and HIRHAM) were used as input into the hydrological model LISFLOOD, to explore to what extent the differences between them are influencing the simulations of both the water balance and the hydrological extremes. The simulated river discharge of the two experiments using the observation-based datasets can be compared directly to the observed runoff. As shown in Figures 5.6–5.7, the river discharge, in particular the runoff peaks, is simulated very well, except for the low-flow periods in summer when river discharges are generally somewhat overestimated. The HIRHAM-driven run represents the average discharge patterns of the Meuse river fairly well (see Figure 5.8), and the annual water balance is even closer to observed than the two observation-based runs (see Table 1). The cause of this is a much higher evaporation loss, which is primarily due to more transpiration. Further analysis of the data is required to explain these observations. The representation of the meteorological and hydrological extremes also requires further investigation.

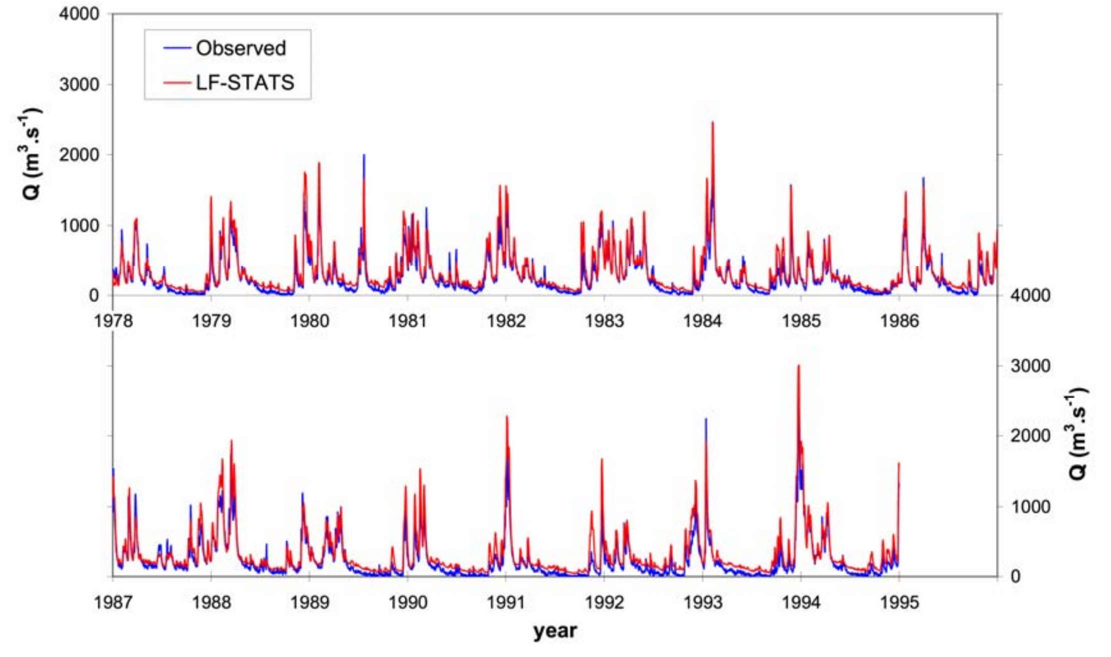

Figure 5.6. Observed discharge of the Meuse River at Borgharen and discharge simulated by LISFLOOD using high-resolution station observations for meteorological input.

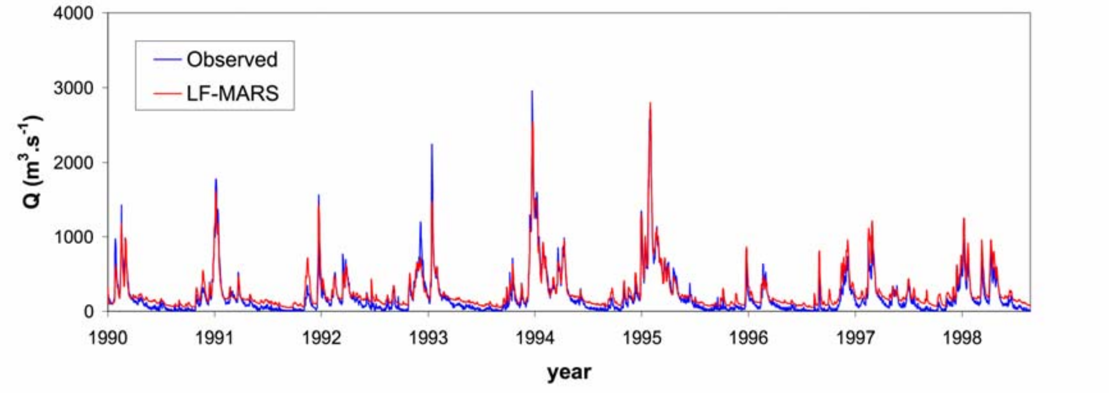

Figure 5.7. Observed discharge of the Meuse River at Borgharen and discharge simulated by LISFLOOD using the MARS database for meteorological input.

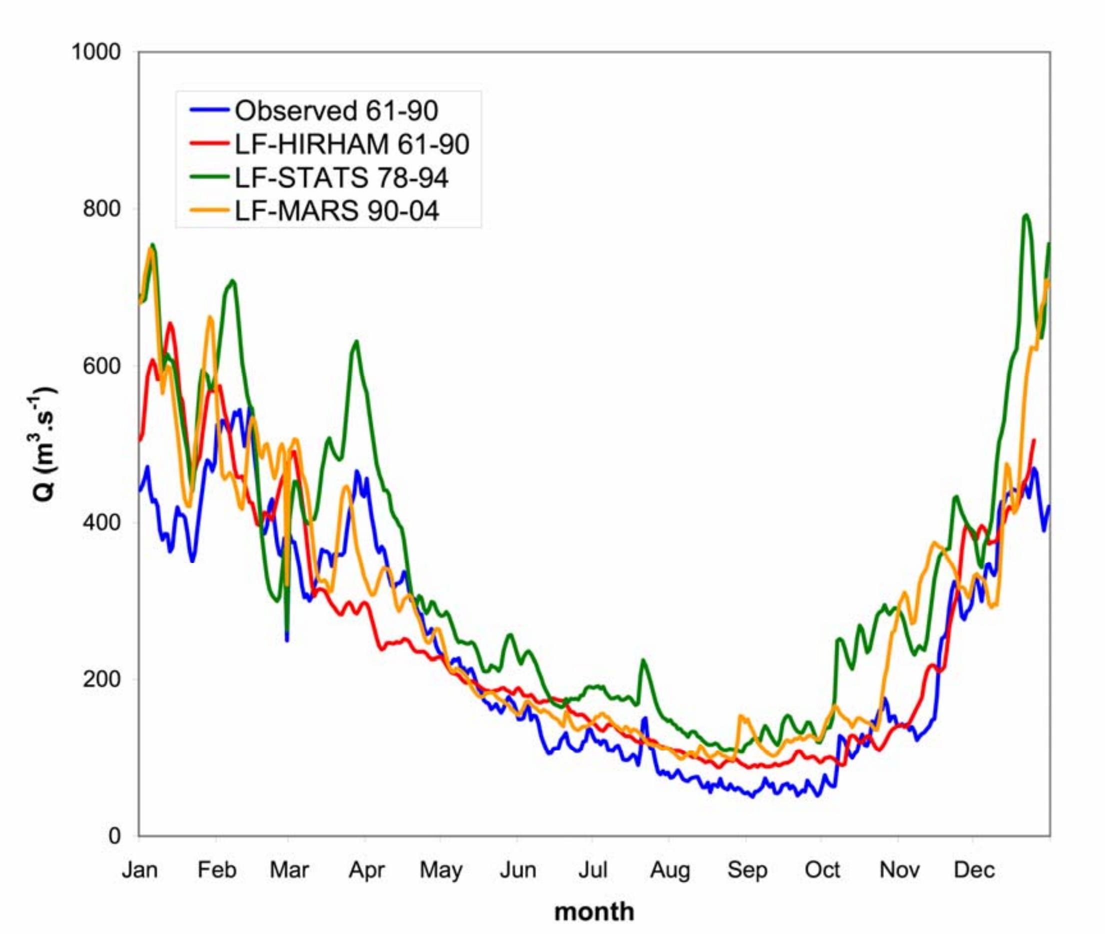

Figure 5.8. Average discharge of the Meuse River at Borgharen as simulated by LISFLOOD driven by the HIRHAM data, compared with the two observation-based model runs and the observed river runoff.

6. Conclusions and further work

Climate change is expected to affect the seasonality and inter-annual variability of many climates, and the frequency and magnitude of extreme events. Coarse resolution global climate models are inherently incapable of providing a realistic simulation of extreme events and the detailed spatial pattern of precipitation and temperature over heterogeneous areas, in particular areas of complex topography. They are also unable to resolve small-scale regional and local circulations or represent processes at a high temporal resolution. Regional climate models can capture physical processes and feedbacks occurring at the regional scale and are currently the best solution for assessing the regional impact of climate change on hydrological extremes.

An integrated modelling framework is being developed that encompasses a regional climate model, a spatially distributed hydrological rainfall-runoff model, and a bias-correction (with further statistical downscaling if required) for a one-way coupling of the two models. The final step involves statistical analysis of the runoff simulations for the control and future period. The objective of this modelling chain is to translate regional climate change signals into changes in hydrological hazards (with focus on floods and droughts) in terms of runoff statistics. The model chain is being developed for the Meuse catchment upstream of Borgharen, for which a well-calibrated hydrological model exists. Once the model chain has been developed for the pilot Meuse catchment, it will applied to other catchments across Europe for which the hydrological model has been calibrated.

Current work focuses on

- comparing the control run climate data with observed climate time series to determine bias corrections that can account for systematic errors in the precipitation and temperature fields generated by the regional climate model
- determining whether further downscaling is required to bridge the remaining gap between the climate and hydrological model scales
- if further downscaling is required, evaluate different statistical downscaling techniques to optimally downscale the climate forcing data

Future work will focus on

- using state-of-the-art statistical methods (e.g., extreme value analysis) to summarize the runoff statistics and determine any changes in the occurrence and severity of hydrological extremes between the control and future period
- transferring the developed model chain to other European catchments (e.g., with a more pronounced variation in topography, where other bias corrections factors may apply)
- obtaining and using regional climate data that are based on other (than A2) greenhouse gas emission scenarios

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