Workshop on Visualisation in Environmental Sciences (EnvirVis) (2013)
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Short Papers

Determining and Visualizing Potential Sources of Floods

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Abstract

In this paper, we visually analyze spatio-temporal patterns of different hydrologic parameters relevant for flooding. On the basis of data from climate simulations with a high resolution regional atmosphere model, several extreme events are selected for different river catchments in Germany. By visually comparing the spatial distribution of the main contributions to the run-off along with their temporal evolution for a time period in the 20th and the 21th century, impacts of climate change on the hydrological cycle can be identified.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Picture/Image Generation—Viewing algorithms

1. Introduction

In densely populated regions, extreme weather events may have a strong economical and societal impact. Strong storms, like hurricane Katrina in summer 2005, or flooding, like the Elbe flood in the Czech Republic and in Germany in 2002, can cause many casualties and are economically very expensive. It is of utmost interest to better understand such events as well as to estimate possible future changes in their strength and frequency for given future scenarios.

With global coupled atmosphere-ocean general circulation models (AOGCM), climate researchers simulate the most important processes in the climate system. By forcing the model with observed greenhouse gas concentrations, changes in the climate from 1850 to 2000 can be simulated and compared with observations. To estimate the bandwidth of potential future changes in the climate, model simulations for different greenhouse gas emission scenarios are made.

In a second step, the results of these AOGCM simulations are used as forcing for a dynamical downscaling process: for a selected region, the coarse global model data and the corresponding CO_2 concentration are taken as boundary condition for a new simulation with a regional climate model with much higher spatial resolution (global model: $\approx$ 250 km sampling, regional model $\approx$ 25 km). Due to the better resolved topographic features and dynamical processes, a more detailed and realistic regional climate is simulated.

In this paper, we use two time periods of multivariate data from a regional model, each consisting of daily values over 30 years in order to study potential flood conditions for two different climates. For both time periods we visualize the behavior of certain interesting parameters in the catchment basins of several German rivers (see Fig. 1).

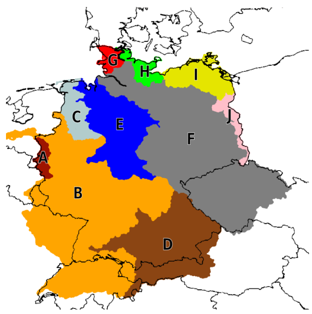


Figure 1: *Catchment basins: A: Mass, B: Rhine, C: Ems, D: Danube, E: Weser, F: Elbe, G: Eider, H: Schlei/Trave, I: Warnow/Peene, J: Oder.*

2. Related Work

Several indicators for the identification of extreme climate events have been defined and are widely used for the analysis of observations as well as for simulation data (see [SR08] and references). We use the Rx5day index [ZAH*11] to analyze and compare persistant precipitation events for both time periods.

In order to investigate possible changes in the hydrological cycle due to climate change, we have selected RCM data

DOI: 10.2312/PE.EnvirVis.EnvirVis13.065-069

Table 1: *Daily mean comparison of the parameters accumulated over the river's catchment basins as described in Sec. 3.*

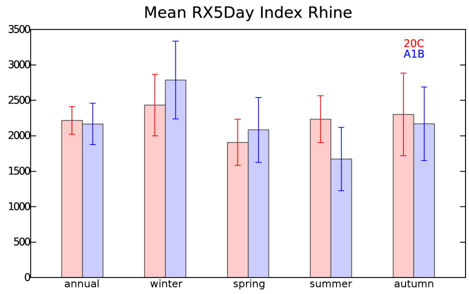
		Soil Water Content 20C / A1B	Snow Melting 20C / A1B	Precipitation 20C / A1B	Surface Runoff 20C / A1B
Rhine	Winter (Dec, Jan, Feb)	0.0036 / 0.0035	0.382 / 0.232	2459 / 2813	339.3 / 305.6
	Spring (Mar, Apr, May)	0.0031 / 0.0031	0.394 / 0.221	1891 / 2069	417.9 / 278.2
	Summer (Jun, Jul, Aug)	0.0028 / 0.0026	0.109 / 0.010	2248 / 1700	251.6 / 164.2
	Autumn (Sep, Oct, Nov)	0.0032 / 0.0029	0.100 / 0.050	2275 / 2124	182.1 / 175.6
Elbe	Winter (Dec, Jan, Feb)	0.0034 / 0.0033	0.267 / 0.088	1302 / 1508	225.3 / 100.2
	Spring (Mar, Apr, May)	0.0029 / 0.0029	0.085 / 0.037	1153 / 1292	96.0 / 68.4
	Summer (Jun, Jul, Aug)	0.0027 / 0.0025	0.000 / 0.000	1163 / 1366	89.7 / 110.5
	Autumn (Sep, Oct, Nov)	0.0029 / 0.0027	0.025 / 0.006	1308 / 1300	63.3 / 57.78

Table 2: *Number of extreme runoff events.*

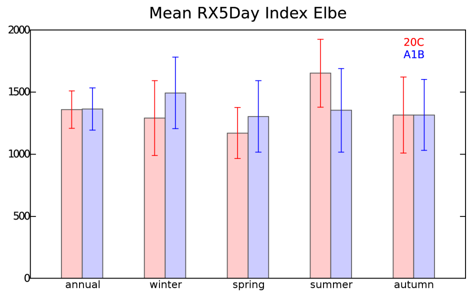
	20C (1961-1990)	A1B (2071-2100)
Rhine	8	4
Elbe	11	4

Table 3: *Mean summed surface runoff during the extreme events (see Tab. 2) in the river's catchment basins.*

	20C (1961-1990)	A1B (2071-2100)
Rhine	4646	3500
Elbe	3200	1985



(a)



(b)

Figure 2: *Comparison of the mean and the standard deviation of the Rx5Day index for the 20C and A1B run, 2(a) for Rhine, and 2(b) for Elbe*

of a greenhouse gas scenario simulation. We took two subsets of the data, representing the climate at the end of last century (1961-1991) and that at the end of this century for IPCC scenario A1B (2071-2100). For the assessment of the statistics of extreme events for the current climate or the recent past, observational data (e.g. [KTK03]) can be used. In the age of climate change, there is a large public interest in possible future changes of the strength and frequency of climate extremes as well as their temporal and spatial distribution, which can only be assessed on the basis of climate simulations (eg. [THAM06]).

An overview of visualization techniques used in climate research is given by [NSBW08]. For this paper, we will adapt the concept of the *Theme River* in order to depict the temporal behavior of time series data (see [HHN99] and [HHWN02]), because it allows to study the interdependence of several attributes. It is used, for example, in [BKH*04] to study several attributes in order to identify hot summers.

3. Data and Methodology

We are focusing on extreme weather events with potential to cause flooding in the context of changing climate. In order to get a reasonably resolved data set for our purpose, we selected a climate simulation with the RCM (Regional Climate Model) "CLM" [HBF*08]. CLM is a community model for the German climate research, originally based on the LM forecast model of the German National Meteorological Service (DWD) and later modified for climate simulations by various research groups [RWH08] (see also `http://www.clm-community.eu/`). The model was forced by results of global climate simulations with the coupled atmosphere ocean general circulation model (AOGCM) ECHAM5-MPIOM, which were carried out as a contribution to IPCC AR4 [IPC07]. In order to look at changes in the extreme weather statistics related to climate change, we selected the time period 1961-2000 from an experiment with historical forcing data (20C) and the time period 2071 to 2100 from the IPCC scenario A1B simulation.

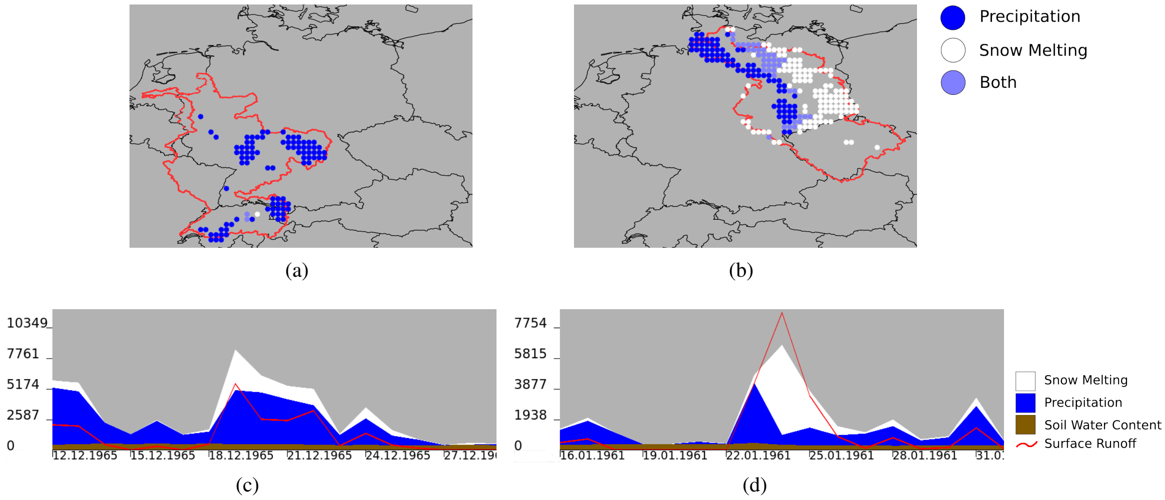


Figure 3: *Simulation 20C : Marked positions inside the catchment basins (top row) and behavior of parameters (bottom row) for 2 extreme events. 3(a) and 3(c) Rhine Dec 1965, 3(b) and 3(d) Elbe Jan 1961.*

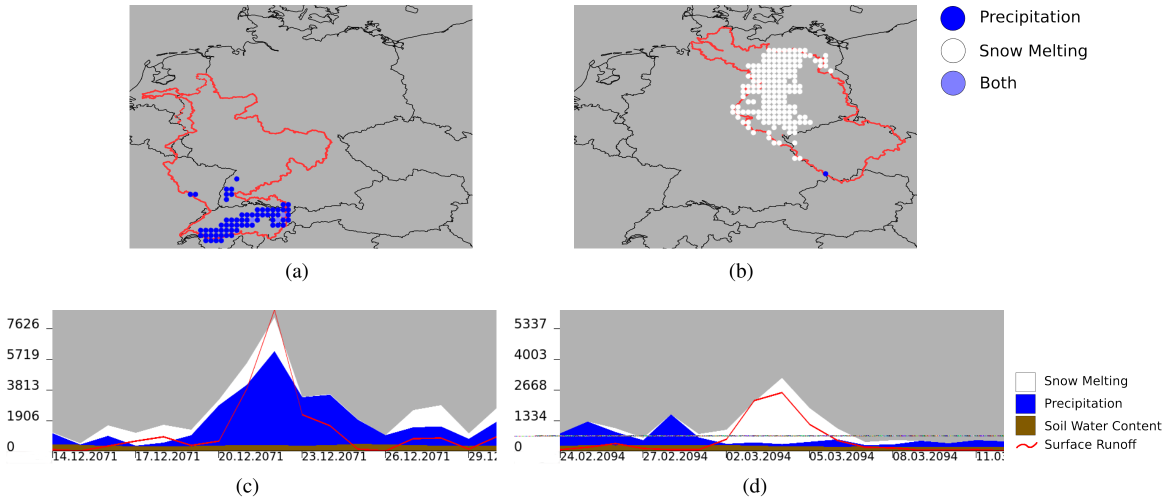


Figure 4: *Simulation A1B : Marked positions inside the catchment basins (top row) and behavior of parameters (bottom row) for two extreme events. 3(a) and 3(c) Rhine Dec 2071, 3(b) and 3(d) Elbe Feb/Mar 2094.*

We used daily CLM data for Europe on a regular grid (data stream 3) with a spacing of 0.2° (approx. 20 km). We have taken a cutout of 65 x 50 grid points centered on Germany. It ranges from 4.6°E to 17.2°E latitude and from 46°N to 56°N longitude.

Key factors for flooding are precipitation and the surface runoff, which depends on several factors such as the duration, rate and type of precipitation, melting of snow and ground properties such as the soil water content of the surface layer. The higher the soil water amount, the smaller the fraction of the precipitation which can be infiltrated into the soil, and hence the larger gets the fraction of precipitation directly contributing to the runoff. Floods can occur when large volumes of runoff flow into rivers in a short period of time. The negative gradient of the surface snow amount, an indicator for snow melting, also contributes to the surface runoff.

To identify an extreme event for a specific catchment basin, we sum up the values for surface runoff within that region r for every timestep t. We call this value RUNOFF_{rt}. The sum for the values for precipitation and snow melting is computed the same way and called PRECIP_{rt} and $\mathrm{DELTA\_SNOW}_{rt}$, respectively. The soil water content (in contrast to the other parameters) is averaged over region r.

We use the 95th percentile of $RUNOFF_{rt}$ for all t as threshold for region r. If the surface runoff exceeds this threshold at least n times within at least m days, such an event is found. The values for n and m can be adjusted for convenience. This approach is similar to [FMB*99], where the the days within a specific period are counted where the amount of precipitation exceeds a certain percentile; but the key index in this paper is the surface runoff.

Next, we identify positions within r that contribute a significant amount of precipitation and/or snow melting to that extreme event. Whether a parameter contributes significantly to an event is determined by the threshold

$$p = \left[1 - \left(\Sigma/(d \cdot max)\right)\right] \cdot max_r, \tag{1}$$

where d is the duration (in days) of the extreme event, Σ is the sum of the parameter ($PRECIP_{rt}$ or $DELTA\_SNOW_{rt}$) for all t during the extreme event, max is the dataset's maximum value of the parameter, and max_r is the daily maximum of that parameter during the extreme event and within region r. This formula ensures that the threshold adapts to the magnitude of the parameter, for example in a dataset with a high amount of precipitation, the threshold for a significant contribution is higher than for a dataset with a low amount of precipitation. That is because the formula relates the maximum amount (max_r) that occured during the extreme event to the theoretical maximum ($d \cdot max$).

To improve the interaction with a dataset, in our software, this threshold can be adjusted, although we found it gives a good first impression of which positions within r contribute significantly to an extreme event. As another depiction and tool to investigate the data that provides temporal context, the chronoligical behavior of all four parameters around that time span is shown (see Fig. 3 and Fig. 4).

4. Results

Based on the evaluation of climate data or more precisely the change in climate data, we want to study extreme events and their causes in the catchment basins of several German rivers. Here, we will put our main focus on the 2 rivers with the biggest catchment basins, namely Rhine and Elbe.

A comparison of the daily means of the catchment basin's accumulated parameters between the two simulations is shown in Table 1. Table 2 shows the number of the extreme runoff events for the 2 rivers for each simulation. In Table 3, we can see the mean of the four parameters (summed over the catchment basins) of these extreme events. Additionaly, Fig. 2 shows the mean Rx5Day indices as well as the standard deviation.

We will study one characteristic event for each river in each of the two simulations in more detail as a show case for our program. We are interested in events with a duration of at least five days ($m = 5$) where the 95th percentile of the surface runoff is exceeded at least three times ($n = 3$), see Sec. 3. Figure 3 shows the visualization for the 20C run and Fig. 4 for the A1B run. The top row depicts which position inside each catchment basin contributes a significant amount of precipitation and/or snow melting to raise the surface runoff. Positions marked in dark blue are characterized by heavy precipitation, positions in white by heavy snow melting, and positions in light blue by both. The bottom row shows the behavior of the four parameters for that time ($\pm$ 7 days). The three parameters soil water content (brown), precipitation (blue), and snow melting (white) are displayed using a theme river. The height of the theme river is a good visual indicator for extreme events. Additionally, the surface runoff is displayed as a time line in red. The label on the y-axis specifies the accumulated amount of the surface runoff.

5. Discussion

As seen in Figs 3 and 4, the software not only helps the user to identify a potential extreme event but also assists in the analysis of the different contributions causing the extreme events. This allows to classify a flood event by its causes. In 3(a), we can see that the high surface runoff is mostly caused by heavy precipitation in Franconia, the Rhine/Main area, as well as precipitation and snow melting in Switzerland. Figure 3(b) shows that the respective extreme event is mainly caused by heavy precipitation in the middle/western part of the catchment basin, whereas strong snow melting occured mainly in the middle/eastern part. Fig. 4 also shows the causes for two example events in the A1B simulation: heavy precipitation and snowfall mainly in Switzerland (Fig. 4(a)), whereas strong snow melting in Lower Saxony and Brandenburg lead to the event in (Fig. 4(b)). The timeline gives additional help in order to understand the causes of the extreme events by providing information about the temporal course of the parameters during that event. However, a detailed study on different events and their patterns as well as the impact of different starting parameters is beyond the scope of this paper.

Comparing the two simulations reveals that the surface runoff significantly decreases from the 20C to the A1B simulation; not only during extreme events (see Table 3) but also in general (see Table 1). Since the parameters *soil water content* and *precipitation* do not notably undergo any big changes, we can conclude that the heavy decrease of snow melting causes this effect. The snow melting in A1B simulation is reduced by 40%–65% of its mean value in the 20C simulation. This is explained by the fact that the surface snow amount in general decreases in the A1B simulation, which is most likely caused by increasing mean temperature [IPC01]. Furthermore, Fig. 2 shows the impact of climate change on extreme precipitation, or, more specifically, the Rx5Day index and its variability. The winter months become more humid, whereas it will be more arid during the summer months.

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