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Adapting the German transport system to climate change and extreme weather events – First case study results connected to extreme precipitation

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Abstract

A well developed, functional transport infrastructure that offers unrestricted use is of great importance for Germany as a transport nation in the centre of Europe. To address recent challenges like climate change and extreme weather events and to act towards a resilient transport system, knowledge and abilities available in German agencies are combined in a 'Network of Experts' under the umbrella of the German Ministry of Transport and Digital Infrastructure. Thereby, the transfer of knowledge and technology across disciplines is promoted and the dialogue between experts in the areas of science, politics, administration and economy is fostered. This contribution introduces the structure of the network and presents first results connected to precipitation extremes. Using the case study of the December 2014 flood in Schleswig Holstein the performance of precipitation indices for the evaluation of flooding events is presented. Future increases in the frequency of heavy precipitation in winter are posing potential risks to land based infrastructures and may limit shipping. These results are confirmed by hydrological modelling, where an increasing number of days above a flood threshold and a decreasing number of days below a low-flow threshold are simulated for an ensemble of climate projections at the gauge of Kaub/Rhine. The analyses provide a first basis for the development of approaches to impact assessment for road, rail and waterway transport.

Keywords: impact assessment; natural hazards; climate risks; climate services; climate change adaptation; road; rail; waterway; heavy precipitation; flood; low flow; climate indices

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1. Introduction

There is growing concern about the impacts of climate change on many parts of the socioeconomic system. Several extreme events like floods (e.g. 2002: Kundzewicz et al. (2005), 2013: Belz et al. (2014)), low flow situations (e.g. 2003: Koehler et al. (2006), 2011: Kohn et al. (2014)), storms (e.g., series of thunderstorms in May/June 2016 (Piper et al., 2016)) and landslides resulted in disruptions of the transport infrastructure or transport limitations and high socioeconomic losses in many regions of Germany (e.g. Scholten (2010); Scholten and Rothstein (2012)). Some of these events affected more than one mode of transport posing the potential risk of more serious impacts on the transport of goods and passengers. This highlights the importance of an intermodal perspective in addressing global warming challenges in the transport sector.

With the continued warming of the Earth surface (IPCC, 2013) the adverse effects of climate change on transportation are expected to increase in the following decades (Colin et al., 2016; Doll et al., 2014a; Doll et al., 2014b; Hendrickx and Breemersch, 2012; Matulla et al., 2017; Michaelides et al., 2014). Thus, adapting the transport system to the expected changes in climate and related extreme events is necessary, especially since transport infrastructure is generally long-lived, particularly with regard to routes and assets like bridges, tunnels, and embankments (Doll et al., 2014b; EEA, 2014). These challenges are addressed by a series of research programs financed by the German Federal Ministry of Transport and Digital Infrastructure (BMVI). Starting in 2009 the KLIWAS programme investigated specific effects on the German waterways (BMVI, 2015). Likewise, the AdSVIS program with the RIVA project (Auerbach et al., 2014; Korn et al., 2017) addressed road specific issues including a risk analysis. Starting in 2016, the expertise and competencies of six departmental research institutes have been pooled in a new program focusing on “Adapting transport and infrastructure to climate change and extreme weather events” (http://www.bmvi-expertennetzwerk.de/EN, BMVI (2017)). Integrating the perspectives of road, railway and waterway transport, the program fosters the interdisciplinary exchange of knowledge and skills. Thereby it creates the potential for innovative solutions for climate change adaptation and a sustainable development of the German transport system in a dialogue between science, policy and practice.

In this paper, first details of the integrated research framework and preliminary results are presented. On this basis, challenges and perspectives are discussed with respect to the assessment of robust estimates of past, current and future risks arising from natural climate variability and anthropogenically enhanced climate change.

2. Objectives and structure of the “BMVI Network of Experts”

The German Government aims at providing a safe and resilient transport system that is developed sustainably, as mobility is an important foundation for our entire social development. In order to transfer the knowledge and technology across disciplines the Federal Ministry of Transport and Digital Infrastructure (BMVI) united its departmental research facilities and specialist authorities in a network (called Network of Experts “Knowledge – Ability – Action”, http://www.bmvi-expertennetzwerk.de/EN). Together, seven Federal authorities address complex challenges affecting strategic planning at the level of the transport network as well as technical adaptation measures to traffic routes and individual buildings. Thereby, expertise in climate sciences (Germanys Meteorological Service Deutscher Wetterdienst [DWD], Federal Maritime and Hydrographic Agency [BSH]) is combined with practical knowledge on the modes of transport (road: Federal Highway Research Institute [BASt]; rail: Federal Railway Authority [EBA]; waterways: Federal Institute of Hydrology [BfG], and Federal Waterways Engineering and Research Institute [BAW]; goods: Federal Office for Goods Transport [BAG]). Challenges addressed by the network during the first funding period (2016–2019) are climate change, sustainability, energy transition, digitalisation and ageing transport infrastructures.

Here, we are introducing first results of the topic “Adapting transport and infrastructure to climate change and extreme weather events”. Within this topic knowledge about the spatial pattern of observed and expected future climate change impacts is generated and connected with evaluations about the vulnerability and criticality of transport infrastructure in order to develop, test and implement specific adaptation options for gradual climatic changes and extreme weather events. The scientific work is structured into nine closely interrelated sub-projects, each coordinated by one of the involved partner institutions (Fig. 1).

Within the sub-project “scenario development” a common framework for the impact analyses in the hazard specific sub-projects is agreed and a consistent set of scenario data, including climate, land use and transport scenarios is created and provided. Accordingly, an ensemble of regional climate projections is processed for the user-specific needs and provided to all partners. Additionally, oceanic and hydrological data including derived products are created and distributed. Based on these data specific impact analyses are done within four sub-projects focusing on floods, storms, landslides and waterway specific hazards affecting navigability and water quality. The results of these impact studies obtained for different modes of transport and different climate hazards are integrated into a GIS-based assessment method to evaluate the exposure, sensitivity and criticality of transport infrastructure. This method aims at providing information relevant to climate change adaptation at the network level and for specific sections of the transport network. Based on classification and evaluation systems current climate impacts on infrastructure are represented and projected into the future. Those assessments of potential risks under current and future climate conditions are a valuable support for decisions on the (re)construction and management of transport infrastructures. Finally, guidelines for the handling of the addressed hazards and specific adaptation options are developed. They target at tailoring technical guidelines and rules, adjusting management practices and developing new materials and technical constructions. The impact assessment is complemented by regional case studies integrating different risks and encompassing different modes of transport in higher detail. These studies are conducted in several inland and coastal focus areas that allow addressing specific, intermodal risks like those posed by sea level rise in coastal areas or those connected to widespread flooding or low flow situations in the inland. These focused analyses allow the application of specific impact models and to identify cause-effect relationships that may be transferred to a larger scale.

In the following section selected approaches applied and first results obtained within some of these sub-projects are introduced. Thereby, the focus is on the evaluation of extreme precipitation and flooding events that have high relevance for all land and water based modes of transport. A statistical and climatological evaluation approach for studying flooding events is introduced (exemplarily done for the “Coastal focus area”), future changes in the frequency of heavy precipitation events are assessed (analysis done within the sub-project “Scenario development” and application potential within sub-project “Flooding hazards”) and the status quo of projected impacts of hydrological change on navigability (within sub-project “Navigability and water quality”) is illustrated. Further analyses with respect to the waterway transport forming a bridge between the sub-projects “Navigability and water quality” and “Adaptation options” are introduced by Kikillus et al. (2018). First results with respect to the development of a landslide susceptibility map (sub-project “Landslides”) are presented by Knobloch et al. (2018).

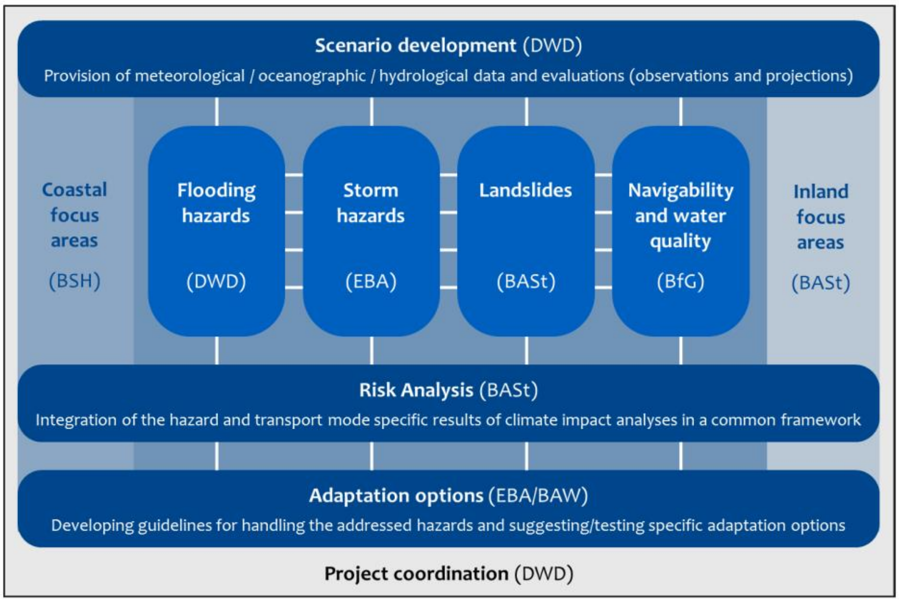

Fig. 1 Organizational flowchart of the project work

3. Example case studies

3.1 Study area

The study area covers Germany including international basin parts of its major rivers which are used as waterways (the Odra is not included in the current programme). Fig. 2 gives an overview and shows the positions of example case study sites mentioned in the text below.

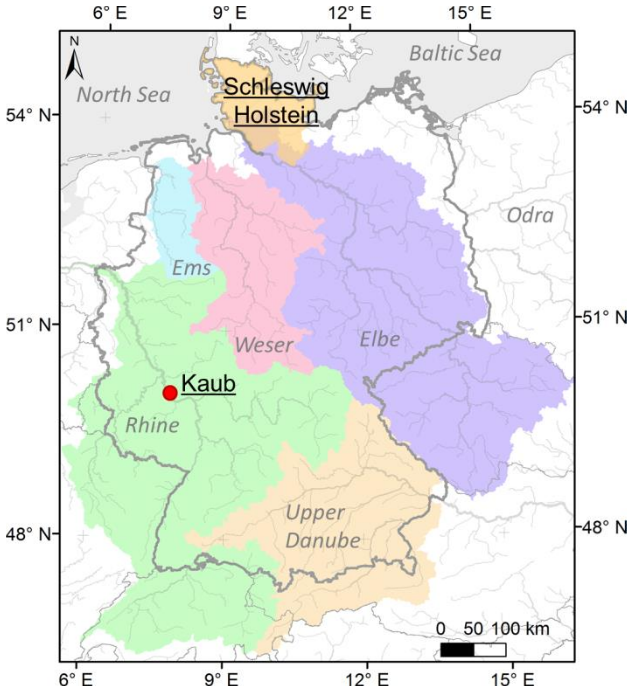

Fig. 2. Overview map of the study area and the sites discussed in this paper.

3.2 Evaluating flooding events using precipitation indices

One possible way to describe and evaluate flooding events without the need of explicit hydrological modelling is based on precipitation indices (e.g., Schröter et al. (2015)). The idea behind this approach is to separate the main precipitation event at the onset of the flood, here the maximum 3-day event precipitation sum (R3d), from antecedent moisture conditions. Since soil moisture data are rarely available, a reliable surrogate variable has to be introduced. The antecedent precipitation index (API) can be obtained directly from weighted precipitation sums over the last m =30 days prior to the R3d by adding a depletion factor "k" that approximates the decrease in soil moisture due to evapotranspiration and percolation to deeper soil layers following Equation (1):

$$API(x, y) = \sum_{i=1}^{30} k^i \, R_i(x, y, (m - i)) \qquad (1)$$

Here, *i* marks the day prior to the R3d, $k = 0.9$ the depletion constant, and $R_i(x, y)$ the daily precipitation sum at each point of the gridded precipitation dataset (REGNIE daily precipitation sums in 1 km resolution; Rauthe et al. (2013)). By using this method, only daily precipitation sums are needed as input data for both R3d and API. Therefore, the method is extremely cost effective and can easily be applied to each climate model precipitation output which is of major importance for estimating possible future changes.

In a preliminary case study (Schade, 2017), the December 2014 flood in Schleswig-Holstein, Germany (Fig. 2) was investigated to test the applicability of the above described indices on a regional scale. The German coastal regions are of particular importance for adaptation related research since they are affected by both, meteorological and hydrological factors and their extremes: Wind, precipitation, water level (incl. sea level rise), etc. All of these factors can cause flooding, individually or in combination (dyke breaks or other structural failures are not considered here). In this special case, persistent westerly general weather circulations led to prolonged rainfall in Schleswig-Holstein without additional high seaside water levels due to storm surges. Drainage was possible at all times, additional freshwater runoff, e.g. due to melting processes, was not observed. Therefore, it can be concluded that the combination of prolonged precipitation (depicted by API) and the extreme precipitation event from 21st – 23rd December (depicted by R3d) was the cause for this flooding event.

Fig. 3 shows the return periods exceeding 5-year values for R3d and API during the December 2014 flood. It can be seen that almost all of Schleswig-Holstein was affected by either the one or the other. Especially high values were exceeded for R3d north of Hamburg (Fig. 3a). Furthermore, almost all inland gauges exceeding their highest high-water values, return periods (HW200, HW100, HW10), and discharges (HQ200, HQ100, HQ50) during this flood are located exactly in the areas with either R3d or API exceeding their respective 5-year return periods (see LKN–SH and LLUR–SH (2015), their Fig. 7, 8, 46, 80).

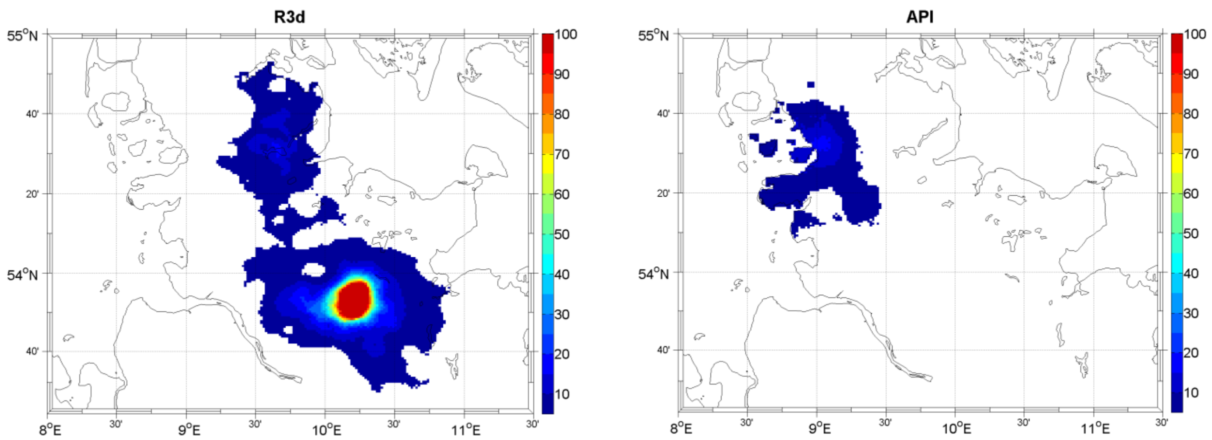

Fig. 3. Return periods (base period 1960–2009) for 3-day event precipitation sum (R3d) from 21st – 23rd December and antecedent precipitation index (API) during the December 2014 flood in Schleswig-Holstein, Germany, calculated from REGNIE daily precipitation sums

Based on these results, tense present and future situations for the management of the Kiel Canal (North and Baltic Seas Canal) and, successively, the German coastal regions are investigated within the BMVI Network of Experts with respect to their severity, criticality, and changes thereof. Trend analyses of R3d and API already indicate an increasing risk of flood prone situations in Northern Germany in recent decades (Schade, 2017). Additional information concerning wind surges and sea level rise are part of ongoing research as well. Results can be expected to lead to improved adaptation measures to flooding under climate change conditions wherever catchments have to be drained and (transport) infrastructure may be harmed.

3.3 Projected changes in extreme precipitation events

Studying meteorological extremes is a challenging task, but highly essential due to the nonlinear correlation between the intensity of an extreme event and the potential damage. First of all, extreme events are by definition rare events. This narrows the sample size and therefore limits the detectability of significant statistical trends or even the direction of a trend. While the field of extreme value analysis delivers a broad spectrum of methods (Coles, 2001), the outcome of a specific classical extreme value analysis depends to a certain extent on the selected extreme value distribution model and model parameters. This may result in an unknown degree of overconfidence, when interpreting the outcome and drawing conclusions for further applications (Coles et al., 2003).

Besides these technical issues concerning the selection and configuration of the distribution model, one should be aware of the three main sources of uncertainties that climate projections come along with (Hawkins and Sutton, 2011). The so called scenario uncertainty describes the limited predictability of the future, since it is only possible to make certain assumptions about developments in the 21st century. Another source of uncertainty comes from the climate model itself, since various models driven by the same radiative forcing data produce different climate responses (Palmer et al., 2005). The reason for these differences originates from the respective model physics, which for instance vary in the parameterization of not explicitly resolvable physical processes. Finally, the internal climate variability describes the natural fluctuations of the climate system without any change in radiative forcing, which decreases the reliability of the projection in the short run (Raisanen and Palmer, 2001). A very important aspect when considering these uncertainties is the dependence on the respective climate variable. For instance, the internal climate variability is significantly more important for the climate projection of precipitation than for temperature (Hawkins and Sutton, 2011).

Focusing on precipitation several studies have investigated the current global and regional behaviour and the effects of climate change. An increase of the global average rainfall has been detected since the beginning of the 20th century (New et al., 2001). This increase is also accompanied with more frequent extreme rainfall events (Alexander et al., 2006; Groisman et al., 2005). Moreover, a statistically significant association between the increase of globally averaged temperature and the growing probability/likelihood of heavy precipitation has been identified, which delivers a strong indication of a further increase of extreme rainfall events if the global temperature rises as projected in the 21th century (Allen and Ingram, 2002; Westra et al., 2013; Westra et al., 2014). However, the changes are highly variable between regions and seasons. Thus, a generalization of the physical link between temperature and precipitation on small spatial and temporal scales is not possible (Giorgi and Bi, 2009; van den Besselaar et al., 2013).

In order to meet the challenges listed above we use a multi-model ensemble of climate simulations and apply a non-parametric estimation technique (kernel density estimator with an Epanechnikov-kernel; Dalelane and Deutschländer (2013)) to obtain the temporal development of precipitation extremes. The studied ensemble encompasses daily climate simulations from the EURO-CORDEX project (Jacob et al., 2014) in a horizontal resolution of 0.11° (~12 km). It enables the evaluation of the range of projected precipitation extremes and increases the robustness of results. Within the fifth phase of the Coupled Model Intercomparison Project (CMIP5; Taylor et al. (2012)) new greenhouse gas emission scenarios – the so called Representative Concentration Pathways (RCPs) – have been introduced to specify the radiative forcing used for climate model projection runs (Moss et al., 2010; van Vuuren et al., 2011). The RCPs consist of four greenhouse gas concentration pathways (RCP2.6, RCP4.5, RCP6.0, RCP8.5) based on a range of projections of future population growth, technological development, and societal response.

In order to quantify changes in the frequency of future extreme precipitation events a threshold needs to be set to distinguish between extreme and non-extreme events. The peaks over threshold method (POT) is applied for this purpose using reference period 1950/1970–2005 (historical climate model runs) for the percentile calculation. Precipitation events above the 90th (return period: 10 days), the 95th (20 days) and 99th (100 days) percentile of daily precipitation sums are selected. To each of the selected events a kernel function is applied to assign a time weighted occurrence probability. This means with a certain probability the event could have also occurred somewhat before or after the recorded day. Finally, the time weighted occurrence probabilities are aggregated to a kernel density to receive a time dependent probability of a certain threshold exceedance frequency for the historical and projected climate simulation runs.

This method comes along with some specific benefits, but also with some limitation in comparison to classical extreme value theory analysis. For instance, the induced uncertainty of model selection and parameter estimation is omitted. Thus large outliers in the time series have no relevance due to the focus on threshold exceedance and the meaninglessness of very high or even unrealistic absolute values. Further, no special treatment of non-stationary time series is needed. The only determining factor of the final kernel density is the temporal distribution of the events themselves, the type of kernel and its area of influence on the adjacent days of the time series (bandwidth). A large bandwidth of the kernel results in a smoother kernel density and thus suppresses potential internal short term climate variability. The bandwidth is adjusted to the threshold magnitude and the season. In our study a bandwidth of 3,500/ 4,500/ 5,500 days is used for the 90th /95th /99th percentile for annual analyses. It appears plausible that the method of kernel density estimation is somehow limited with respect to the estimation of very high and rare extreme events that demand very wide bandwidths.

First results for events exceeding the 99th percentile of daily precipitation totals for the winter (Fig. 4a) and the summer (Fig. 4b) season show distinct seasonal differences in the projected changes of occurrence frequency until the end of the 21st century. Averaged over entire Germany a huge increase (doubling to tripling) in the frequency of heavy precipitation events is projected for winter, especially by simulations for the so called “high-end or business as usual” scenario RCP8.5. The more moderate scenarios show significantly lower increases of 50 % (RCP4.5) or only 25 % (RCP2.6) (median of the respective ensemble; note that only three ensemble members were available).

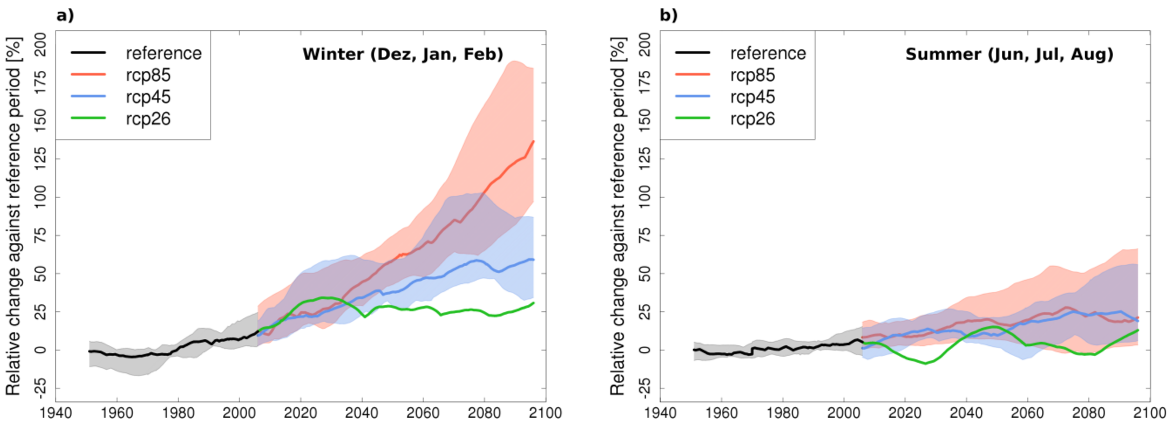

Fig. 4. Time series (smoothing via Kernel estimator) of the seasonal frequency (winter (a) and summer (b)) of daily precipitation events above the 99th percentile for three RCP-scenarios (RCP2.6, RCP4.5, and RCP8.5); regional average over Germany. Shading indicates the 15th to 85th percentile range and the line indicates the median. (Status as of November 2016, ongoing work within the Network of Experts)

For the summer season there are only slight differences between the three RCP scenarios with no or only a slight increase in the frequency of extreme precipitation events. These results confirm the conclusions of a previous study by Deutschländer and Dalelane (2012) that based on two RCMs and the A1B greenhouse gas scenario (comparable with today's RCP6.0 scenario) presented an increase in the frequency of extreme precipitation events during winter and no change during summer.

3.4 Projected impact of hydrological change on navigation conditions

In Central Europe, a major part of inland navigation takes place on free flowing rivers (Rhine, Ems, Weser, Elbe, Odra rivers and the Upper Danube; Fig. 2). The hydrological regime (here characterised by the typical timing and intensity of high and low flow periods during a year) of these waterways is to a large degree dependent on the hydro-meteorological conditions in the upstream part of the river catchments. Therefore, modelling and analysing the impact of natural climate variability and anthropogenically enhanced climate change on hydrological regimes and navigation conditions has a long tradition in waterway related research.

Precursor projects of the research programme presented here are, e.g., the KLIWAS research programme (BMVI, 2015) or the EU project ECCONET. Results with regard to hydrological change and its impact on navigation conditions have been published by Nilson et al. (2012) for Rhine and Upper Danube rivers and Nilson et al. (2014) for the Rhine, Elbe, and Upper Danube rivers. These findings are the starting point for the current research activity. The basic principles of evaluation, such as application of a climate multi-model ensemble and a complex model chain covering all relevant processes will remain unchanged in the current research programme. These principles have been well accepted by practitioners and decision makers as they allow for an in-depth uncertainty assessment with respect to target variables that are relevant for the transport sector. However, during the work in the 'Network of Experts', parts of the processing and evaluation framework will be updated, refined, and extended with respect to data, methods, and presentation tools (see below).

Inland waterway transport on German rivers is restricted or even interrupted during flood situations if the water level in a river stretch exceeds certain thresholds (so called "highest navigation water level", HSW, HSW-I/HSW-II). These thresholds are defined for representative gauging stations in official rules (police regulations). There are no such strict regulations for low flow periods. However, the restrictions of inland waterway transport are obvious, if the water depth drops below certain thresholds and vessels can sail with reduced load only. From the perspective of ship operators, these thresholds depend on the specific properties of the vessels (e.g. minimum draught plus safety margin). From the perspective of waterway managers, they depend on the fairway depth that has to be made available for the ship operators for a certain number of days per year. In Germany, the latter depths are usually defined with respect to the so called "equivalent low water level" (GlW). This is a water level in a river section that is undershot at most at 20 ice free days per year on average. The water levels for the Rhine River are determined and regularly reviewed by the Central Commission for the Navigation of the Rhine (CCNR).

Past and future changes of river flow corresponding to the water level thresholds HSW and GlW have been assessed for the 19^{th}, 20^{th} and 21^{st} centuries based on long-term observed flow series (1825 to 2010) and an ensemble of flow projections (1950 to 2100). In the ECCONET project, the latter was generated using 27 combinations of:

- SRES greenhouse gas emission scenarios (here primarily A1B, few A2 and B1; Nakicenovic et al. (2000)),
- Six different coupled global climate model simulations based on phase 3 of the Coupled Model Intercomparison Project (CMIP3; Meehl et al. (2007)) that was the basis of the fourth assessment of IPCC (2007),
- Nine different regional climate model simulations coordinated primarily within the EU-ENSEMBLES project (van der Linden and Mitchell, 2009).

A simple bias correction (linear scaling; Lenderink et al. (2007)) was applied to the climate projection data before hydrological simulations using semi-distributed conceptual models (e.g. for HBV-SMHI for the Rhine River; Eberle et al. (2005)) were done.

Exemplary results are displayed for the gauging station Kaub in Fig. 5a for high flow and in Fig. 5b for low flow situations (Nilson et al., 2012). The station Kaub is situated on the Middle Rhine River (Fig. 2), one of the most important inland navigation routes in Europe. In particular, this river stretch represents a bottleneck with regard to low flow situations. The graphs show 30-year running means of annual numbers of days above/below the flows corresponding to HSW and GlW. Note that the high flow threshold chosen here reflects the so called HSW-I (RheinSchPV, 2016). When water levels (or flows) exceed this threshold vessels are forced to reduce speed and to navigate in the centre of the fairway for safety reasons and in order to reduce wave impact on the river banks. In the reference period (1961–1990) this value is exceeded at about 11 days per year on average.

The higher HSW-II that leads to an interruption of navigation was not used because the modelling framework and the data sample at hand were regarded as less suitable to simulate such high flows. The low flow threshold was calculated as the 95th percentile of the flow duration curve, i.e. it is undershot on about 18 days per year on average. It is hence very close to the definition of GlW (20 days).

The long-term observation series reveals a high multi-decadal variability since the mid of the 19th century. Though the earlier part of this series has to be interpreted with some care (e.g. inhomogeneities due to non-climatic change such as river training works in the 19th century), the number of days above the currently valid flood threshold seems to have continuously increased since the turn of the 19th an 20th century from approximately 5 days to 10 days per year. This overall tendency seems to continue in the future. However, the spread of the ensemble of flow projections is large, ranging from 10 days to 20 days in the near future, and 10 days to 30 days in the distant future with only few members showing larger increases or decreases.

With respect to the low flow indicator, past changes point to a more or less continuous increase in the number of days below the threshold until around 1950, followed by a strong and fast shift towards more favourable conditions for navigation. In the recent past (after 1981–2010, centred at 1995, end of the black line in Fig. 5b) the number of days below the threshold was particularly low. Changes simulated for the near future mostly remain within the span covered by the observations. A majority of the ensemble members shows less low flow days than in the reference period 1961–1990. On the other hand, for the distant future a high number of members points towards a deterioration of navigation conditions and/or higher efforts for the waterway management.

Though this kind of information has already proven to be valuable for waterway managers as well as waterway users, significant improvements may still be achieved:

- First, the ensemble displayed here represents the state of climate modelling in preparation of the fourth IPCC assessment report (IPCC, 2007) with subsequent regional climate modelling (van der Linden and Mitchell, 2009) and needs to be updated with the most recent climate simulations associated with the fifth IPCC assessment report of IPCC (2013) and the regional climate models compiled by the CORDEX activity (Jacob et al., 2014).
- Second, the ensemble of projections offered here accounts for uncertainty in the climate module of the model chain only. Within the current programme, we intend to account for uncertainty in hydrological modules, too, at the same time improving the quality of simulated snow, flood-generating and evaporation processes.
- Third, during ECCONET and KLIWAS, individual hydrological models were used for each river catchment (Rhine, Elbe, Danube). They will be replaced by one overarching modelling system (LARSIM ME) covering entire central Europe, allowing spatially more consistent simulations and better comparisons between regions and flow regimes.
- Fourth, the bias correction method will be replaced by a more advanced version that is better capable of retaining correlations between different hydro-meteorological variables (air temperature, precipitation, and global radiation) and of covering higher extremes.

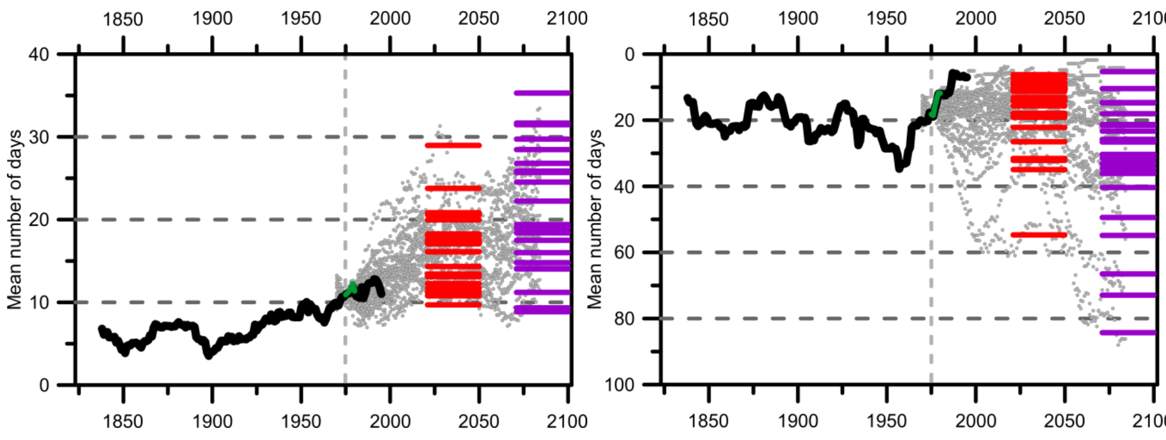

Fig. 5. 30-year moving average of the annual number of days a) above a flood threshold (corresponding to HSW-I) and b) below a low-flow threshold (corresponding to GlW) at the gauge of Kaub/Rhine up to 2100. The value of each 30-yr average is plotted with the central year of the period on the abscissa. Reference periods 1961–1990 (plotted in 1975) are marked by vertical dashed lines. Observed data (black line), and the reference run of the hydrological model HBV134 (driven by observed climate data, green line) are given for comparison. Horizontal red and purple lines mark values for two future periods representing the "near" (2021–2050) and the "distant" future (2071–2100). The cloud of grey dots represents the overall ensemble. Source: (Nilson et al., 2012).

4. Conclusions and Outlook

It was shown that the indices R3d (maximum 3-day precipitation total) and API (antecedent precipitation index) are suitable for evaluating flooding events without the need of explicit hydrological modelling by using the December 2014 flood in Schleswig Holstein as an example. The API was shown to be a reliable surrogate variable for the rarely available soil moisture data. Future trends in the occurrence frequency of heavy precipitation events have been assessed by applying a non-parametric estimation technique (kernel density estimator) to an ensemble of RCP-based regional climate projections. Season depend increases in the frequency of extreme precipitation events have to be expected for the end of the 21st century. The impact of hydrological change on navigation conditions was explored using hydrological models for an SRES-based ensemble of regional climate models. The preliminary results presented here suggest an increase in heavy precipitation and high flow conditions in future decades that potentially pose risks to Germany's transport infrastructure. The introduced methods and modelling frameworks have been demonstrated to be adequate for assessing the future impacts of climate change and extreme weather events on the German transport infrastructure. Subsequently, specific impact analyses will be carried out using an ensemble of regional climate projections under the RCP scenarios RCP2.6 (compares to the 2°C goal), RCP4.5 (similar to SRES B1) and RCP8.5 ("Business as usual").

Other hazards that are evaluated within the Network of Experts are storm risks, landslides and waterway specific hazards like water quality affecting the management of waterways. Based on the upcoming integrated assessment of climate impacts specific modal and intermodal adaptation options are developed and tested. Thereby, three types of adaptation measures are addressed. First, technical regulations and directives are assessed with respect to how well they are integrating climate aspects. Second, technical adaptation options are explored. This includes for instance the adaptation of road surface materials to a higher spread of extreme temperatures or constructive aspects connected to changes in flooding or storminess. The third category comprises the adaptation of management practices like changes in the water and sediment management connected to altered flow conditions. Finally, the awareness of the necessity to act under uncertainty needs to be developed further in politics and administration.

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