RMS WHITE PAPER

Modeling Future European Flood Risk

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Executive Summary

Flooding is one of the main climate hazards affecting Europe. It accounted for 31% of economic losses and 28% of the insurance claims from natural catastrophes across the continent between 1980 and 2017, and recent research suggests that climate change could cause extreme flood events to become more frequent over the next decades. As a result, there is growing demand from the insurance industry, financial markets, corporates and governments to account for the effects of climate change in their decision-making. RMS® is committed to supporting our clients in these efforts by providing a rigorous analytical basis for decision-making, which combines our long-standing catastrophe modeling expertise with ongoing research into the effects of climate change on physical climate risks.

This report explores the latest scientific understanding of the effects of climate change on flood risk in Europe, and possible implications on losses caused across the continent. This analysis is conducted based on the latest RMS, high-definition modeling capabilities for the peril, the Version 2 RMS Europe Inland Flood HD Models, and projections for future precipitation patterns based on four different greenhouse gas emission scenarios and two time horizons (2050 and 2090).

The analysis shows that mitigation and adaption measures have the potential to effectively counteract, and in some cases even reverse, the increase in flood risk caused by climate change. However, if no such measures are taken then results show that average annual flood losses for present-day exposure in Europe could increase by up to 75% by the middle of the century, under the most severe emission scenario analyzed. In general, larger increases in future losses are observed in northern Europe relative to southern regions.

This report shows preliminary results and insights from ongoing RMS research on the climate change impacts on flood risk and other climate perils. These results constitute an interim update and are not a formalized RMS view of risk.

Introduction

Flooding is one of the most significant natural hazards affecting Europe, occurring almost anywhere and ranging from localized events to massive floods spanning multiple countries. Based on data from Munich Re, flooding accounts for 31% of economic losses and 28% of the insurance claims caused by natural catastrophes across the continent for the period 1980–2017 (European Environment Agency, 2019). As a result, it has long been considered a key climate risk that is being carefully managed by the (re)insurance industry. At the same time, flood impacts are also subject to increasing scrutiny from the broader financial markets, real estate investors and corporates, who can be exposed to significant – and frequently unexpected – losses from flooding due to an absence or insufficiency of flood insurance coverage.

In August 2020, RMS released the Version 2 RMS Europe Inland Flood HD Models on Risk Modeler™, providing a high-resolution modeling solution across 14 European countries. The model is based on a continuous simulation of precipitation and rainfall-runoff over a period of 50,000 years, producing over 800,000 flood events across more than 8,500 catchments and all sources of inland flood risk (fluvial, pluvial, snowmelt, etc.). Building upon the latest RMS high-definition modeling capabilities, the model explicitly captures antecedent conditions as well as spatial and temporal correlations.

In line with all RMS products, the model was developed to represent the current climate and is suitable to analyze risk over a one-to-five-year time horizon, as relevant to most insurance contracts. Model results are based on the latest science and can be used with a high level of confidence to understand current levels of risk and enable insurers, reinsurers, financial services, corporates and governments to make informed investment decisions. The RMS modeling philosophy underpinning this approach remains unchanged: it is to base catastrophe models on the physics of weather (i.e., short-term atmospheric conditions) and climate (i.e., longer-term average conditions), combined with interpolation and extrapolation of the historical climate record.

While any impacts of climate change from the pre-industrial era to the recent past are implicitly captured by this approach, explicit deviations from the historical record over which a model is calibrated are only made if sufficient credible evidence is available to conclude that risk is changing or has changed with a high level of confidence. For example, this is the case for storm surge and wildfire, where targeted model adjustments are made to reflect such changes. For other perils, such as flood risk in Europe, there is too much remaining uncertainty to incorporate such adjustments into the RMS reference view of risk at this time.

However, this does not preclude value in leveraging the capabilities of existing models to examine the potential impact such trends could have on both present-day and future risk. This report shows preliminary results and insights of such an application: using the Version 2 RMS Europe Inland Flood HD Models to investigate *future* flood risk across Europe.

The future evolution of flood risk under climate change is an active area of ongoing research at RMS. **The results presented in this paper constitute an interim update on this research and are not a formalized RMS view of risk. RMS will continue to review and refine these results as part of our ongoing commitment to analyze the implications of climate change on future risk.**

While *present-day* risk is not the focus of this paper, RMS also closely analyzes the latest available research on the potential impacts climate change may have already had, and we continuously reassess the level of scientific consensus and credibility on the topic.

Climate Change Impacts on Future European Flood Risk: State of Science

Inland flooding in Europe is strongly driven by precipitation and can therefore be expected to change if the nature of precipitation itself changes. One simple argument that such precipitation changes may occur due to climate change is that as the atmosphere warms it increases the maximum amount of moisture that the air can potentially hold, via a relationship known as the Clausius-Clapeyron equation. If the amount of moisture that the air holds does indeed increase, then this may increase precipitation, all other factors being equal. Such increases in precipitation may be further compounded by climate change impacts on flooding mechanisms (for example, snow and ice melt, or estuarine fluvial risk impacted by sea level rise).

While these high-level arguments are generally well-accepted in the scientific community, the exact nature and magnitude of climate change driven precipitation changes, and resulting implications for flood risk at a regional, national, and local level remain uncertain and are a topic of ongoing scientific research and debate.

Any future changes in precipitation due to climate change – just as the level to which climate itself will change – will be heavily dependent on how quickly and efficiently greenhouse gas emission reduction strategies are adopted. Projected changes in atmospheric greenhouse gas concentrations vary over a wide range and are dependent on socioeconomic development and climate policy. The four Representative Concentration Pathways (RCPs) published by the Intergovernmental Panel on Climate Change (IPCC) in its *Fifth Assessment Report* describe future greenhouse gas concentrations based on different possible efforts to reduce emissions: a best case where the most stringent mitigation is put into place and emissions reach a peak by 2020 (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0), and one extreme scenario (RCP8.5) where high levels of emission continue to occur unchecked (see Figure 1). RCP4.5 is a well-established and frequently quoted scenario for a "medium" trajectory of greenhouse gas concentrations; however, recent reports suggest a more rapid rate of temperature increase than projected under RCP4.5. No action from current-day baselines results in a scenario somewhere between RCP6.0 and RCP8.5. The IPCC *Sixth Assessment Report*, due to be published in 2021, will examine these greenhouse gas concentration scenarios in the context of Shared Socioeconomic Pathways (SSPs), which describe alternative socioeconomic developments (e.g., on population, urbanization, GDP) between now and the end of the century.

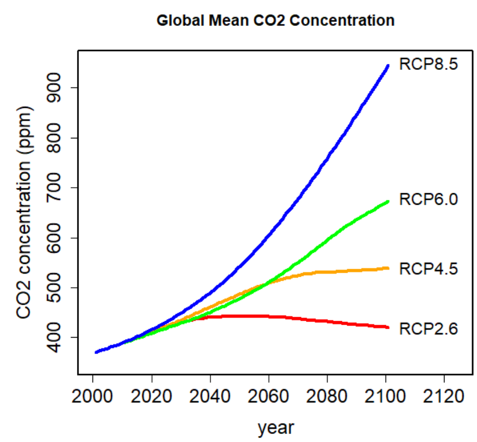

Figure 1: IPCC representative concentration pathways (RCPs) for CO2 (data: World Meteorological Organization)

For a given greenhouse gas concentration pathway, climate scenarios can be generated using global climate models (GCMs). GCM results can then be downscaled to higher resolution using regional climate models (RCMs). GCMs and RCMs generate projections for climate variables such as temperature, rainfall and wind speed. Climate model results are only approximate, and different climate models give different results. This has led to the use of ensembles of climate models that capture the range of points of view represented by different climate models, and whose mean can be used as a consensus view across the set of models incorporated into the mean. The level of spread around this mean across results from individual models underlying the ensemble gives an indication of the level of confidence and consensus in the ensemble-wide mean (with lower spread, relative to the mean, suggesting higher confidence). Results from climate model ensembles are typically used in the major reports on climate change. For example, the Coupled Model Intercomparison Project 5 (CMIP5) ensemble was used by the IPCC to inform its *Fifth Assessment Report*, and the CMIP6 ensemble is being used in the ongoing preparation of the IPCC's *Sixth Assessment Report*. Specific to Europe, the EURO-CORDEX[1] ensemble is a well-established ensemble underlying several key studies, including the European Union's European Environment Agency 2017 report on climate change and the impacts of climate change for Europe (European Environment Agency, 2017; henceforth, EEA report).

The EEA report finding that extreme daily precipitation amounts are becoming more frequent in northern and eastern Europe in both winter and summer, and less frequent in southern Europe in summer, are the key results that are broadly consistent across a number of models and studies. However, the projected magnitude of changes, as well as the evolution of precipitation for other seasons and parts of Europe, vary substantially across different climate models, as well as regions and seasons. For example, the EEA report cites climate modeling results that imply little change in extreme summer precipitation in the north of the U.K., while the EURO-CORDEX results show clearly increasing extreme summer precipitation in the north of the U.K. Comparing results across modeling studies in any detail is further complicated by the fact that different authors focus on different time periods, different variables, different units, and different seasons, and they use different plotting conventions.

While research to date does not provide a clear and sufficiently detailed scientific consensus on how climate change will impact precipitation patterns, and therefore flood risk, in Europe, it certainly has shown that there is significant potential for climate change to alter flood risk in the future. To help clients explore and prepare for the impacts of such potential changes on their future loss experience, RMS is conducting active research on climate change conditioned views of European flood risk. This report provides an interim update on this ongoing area of research at RMS.

Climate Change Modeling Methodology

Precipitation Data

This study analyzes potential future changes in flood risk due to changes in precipitation. Projections of future precipitation were obtained from the EURO-CORDEX model ensemble, made available to RMS by CMCC (Centro Euro-Mediterraneo sui Cambiamenti Climatici, Italy). The ensemble consists of 10 GCM simulations from three different GCMs, downscaled using seven different RCMs.

The data describes changes in the 95th percentile of daily maximum precipitation for each season, on a 0.11-degree resolution grid across Europe (see Figure 2). Changes are reported for the target period 2041–2070, relative to the base period 1981–2010, and are based on the RCP4.5 emissions scenario.

[1] EURO-CORDEX is the European branch of the international Coordinated Downscaling Experiment (CORDEX) initiative, sponsored by the World Climate Research Program. (https://www.euro-cordex.net/).

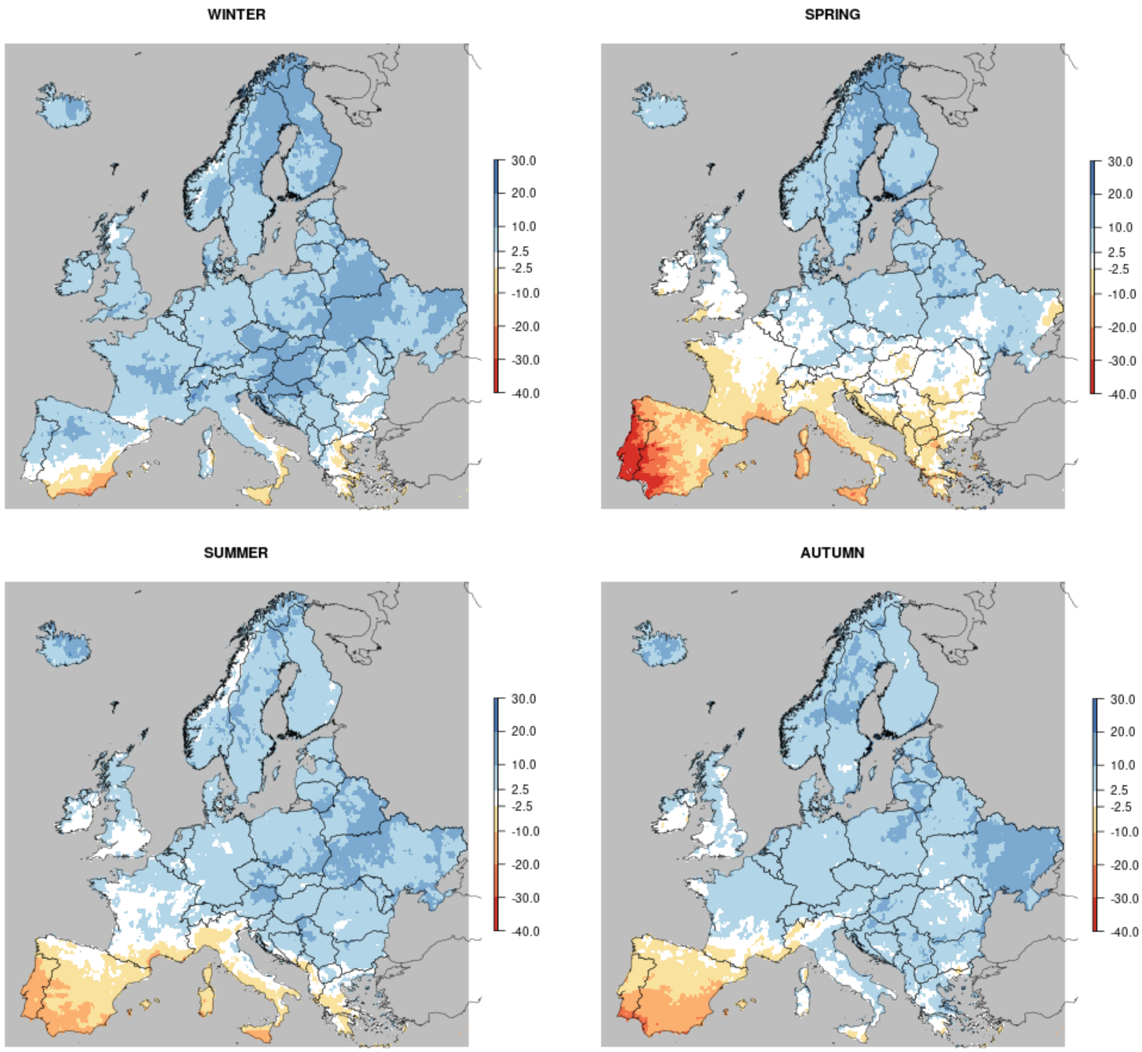

***Figure 2: Projected percentage change in seasonal precipitation (expressed as the 95th percentile of daily maximum precipitation) by 2041–2070, relative to the base period 1981–2010, under RCP4.5 scenario (source: RMS, based on data from EURO-CORDEX ensemble mean) *Note this figure was updated by RMS on December 21, 2020.**

We have assumed that the effects of climate change precipitation patterns can be adequately represented by changes in this variable, i.e., the 95th percentile of daily maximum precipitation, reported by EURO-CORDEX. The assumption that a single variable can capture all relevant impacts of climate change is an approximation, and a different choice of variable, or the use of multiple variables, may lead to different results. Moreover, possible non-linear feedbacks (such as increased evapotranspiration as a result of increased temperatures leading to drier antecedent conditions) are unaccounted for. However, the chosen 95th percentile of daily maximum precipitation captures changes in precipitation extremes, which are most relevant to the targeted application to catastrophe losses.

In line with the broad scientific consensus described in Section 3, the EURO-CORDEX results suggest increasing extreme precipitation for most of the year in northern and central Europe. They suggest more complicated seasonally varying changes to extreme precipitation further south. For instance, in southern France these results show an increase in extreme precipitation in winter but decreases the rest of the year. In Italy, they show a mixed pattern of increases and decreases, varying by season and region. Different models within the EURO-CORDEX ensemble show somewhat variable, but not completely different, pictures, with their level of agreement varying by region as well as season. Overall, however, regional and temporal trends in the EURO-CORDEX results can be interpreted to be in line with key findings from other studies. In particular, annual precipitation is projected to increase in northern and central Europe and to decrease in southern Europe. In addition, extreme one-day precipitation events are projected to be more frequent across most of Europe, with the strongest increase in frequency occurring in northern and eastern Europe in winter.

Comparing the EURO-CORDEX results with observational data for the last few decades shows some agreement in the general pattern of a larger increase in extreme precipitation in northern Europe compared to southern Europe but shows differences at the regional level. For instance, recent station recordings used in the EEA report show lower extreme precipitation in most of Germany in winter, while the EURO-CORDEX modeling results show increasing extreme precipitation in Germany in winter in the future. However, it should be noted that this is not entirely a like-for-like comparison since observational data is influenced by both climate change trends and climate variability, while the EURO-CORDEX ensemble mean is only influenced by climate change trends.

Overall, the EURO-CORDEX results – as with any currently available precipitation projections for Europe – should clearly be treated as uncertain, as the scientific consensus on the topic continues to evolve. Nevertheless, EURO-CORDEX is the most extensive climate modeling study of European climate attempted, and the results are therefore the most definitive view on future European climate at this point in time. CORDEX models, from which the EURO-CORDEX results are derived, also underpin the most recent publications from the IPCC, including its *Fifth Assessment Report*.

Model Set-up

The impact of climate change driven shifts in precipitation patterns projected by the EURO-CORDEX model ensemble on flood losses experienced across Europe is analyzed based on the Version 2 RMS Europe Inland Flood HD Models (henceforth, 'RMS EUFL HD Models'). The model domain spans over 8,500 catchment areas across 14 European countries: Austria, Belgium, Czech Republic, France (including Monaco), Germany, Hungary, Italy (including San Marino and Vatican City), Liechtenstein, Luxembourg, Poland, Republic of Ireland, Slovakia, Switzerland, and the U.K.

Flood losses are defined as insured damage to property structures and contents, as well as losses due to business interruption, based on RMS' view of insured exposure as captured in the RMS Industry Exposure Database (IED) for European flood risk. Changes in losses to total exposure, as captured by the RMS Economic Exposure Database (EED), is also discussed (see the "Results and Discussion" section below). These exposure databases describe the RMS best estimate of total (in case of the EED) and insured (in case of the IED) property exposure for residential, commercial, industrial and agricultural uses across Europe at postcode resolution.

For each exposure dataset, RMS has simulated 50,000 annual periods of flood losses in Europe using the RMS EUFL HD Models to define a reference "baseline" view of flood risk.

The model allows users to modify certain assumptions and output resolutions, which have been leveraged to examine the impacts of climate change on flood risk from different perspectives:

- The reference view used throughout this paper is the RMS reference view of risk. It combines all sources of flooding (fluvial, pluvial, snowmelt, etc.) and uses the default fluvial flood defense assumptions incorporated in the RMS EUFL HD Models.
- Future change in flood risk can be expected to prompt strategies to mitigate impacts and losses from flooding, for example through changes to building codes and practices. The ability in the RMS EUFL HD Models to adjust default assumptions on building characteristics, e.g., the presence of site-specific flood protection, has been leveraged to produce an alternative view of the future risk under improved building practices.
- In addition to Europe-wide results, climate change effects were analyzed at different geographic resolutions including at the regional and national level. The RMS EUFL HD Models are generally able to generate results down to location level, but such results are beyond the scope of this paper.

Further background and motivation for each perspective is provided in the corresponding presentation and discussion of results below, in the "Results and Discussion" section.

Model Implementation of Climate Change Scenarios

The hazard metric reported in the EURO-CORDEX dataset, the seasonal change in the 95th percentile of daily maximum precipitation, is used directly to inform adjustments to the RMS EUFL HD Models, which explicitly capture this variable.

The reported hazard changes were adjusted to span different time horizons and emissions scenarios, as follows:

- The reference period of the EURO-CORDEX data (1981–2010) was adjusted to match the calibration period of the RMS model (1979–2010).
- The future target period of the EURO-CORDEX data (2041–2070) was adjusted to match the two time horizons presented in this paper: 2050 and 2090.
- Results were adjusted to represent three further emissions scenarios (RCP2.6, RCP6.0, and RCP8.5), in addition to the emission scenario underlying the EURO-CORDEX analysis, RCP4.5.

These adjustments were made based on projected differences in global mean surface temperature (GMST) under different time horizons and emission scenarios, as shown in Figure 3. Past GMST observations were compiled by NASA; future GMST values are calculated as the ensemble mean from the CMIP5 model ensemble (Taylor et al., 2012). While adjusting precipitation changes based on GMST, or any single variable, is clearly a simplification of the complex climatological processes driving precipitation patterns, modeling climate change as a function of GMST is a commonly used assumption in climate science. Frequently, it is the only feasible option to obtain a suite of comparable results across different timelines and emission pathways.

The output of the above adjustments are projections for changes in seasonal 95th percentiles of daily maximum precipitation for all four RCPs (RCP2.6, RCP4.5, RCP6.0, and RCP8.5) and two time horizons (2050 and 2090) – yielding a total of 8 possible future scenarios, each of which is described by a specific RCP and time horizon.

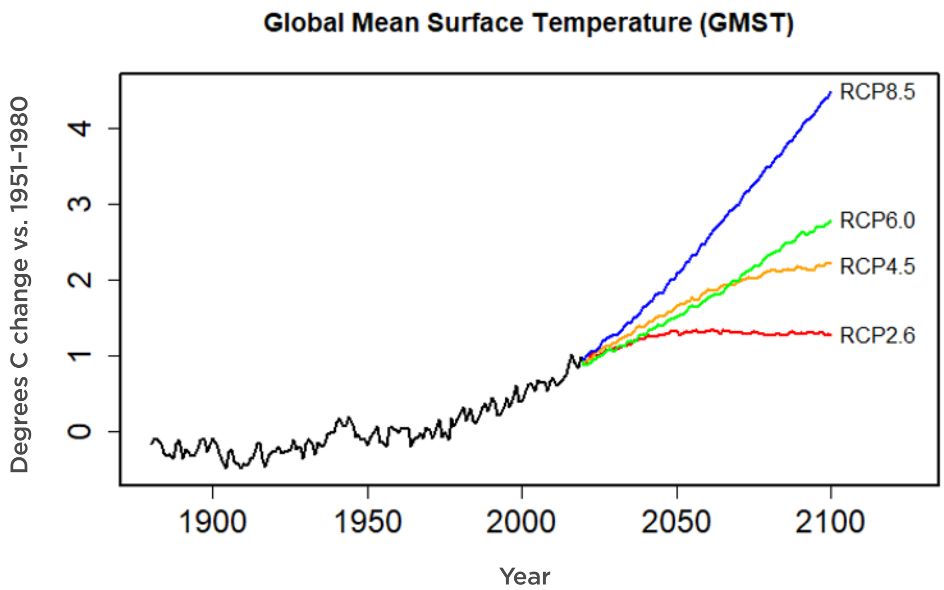

Figure 3: Global mean surface temperature over time for different RCP scenarios.
(source: RMS, based on NASA's Goddard Institute for Space Studies [GISS] and CMIP5 data)

The precipitation changes for each scenario were then implemented in the RMS EUFL HD Models as follows:

1. In order to generate a baseline view of risk, the RMS EUFL HD Models were used to simulate 50,000 continuous years of precipitation and resulting flood losses. The results are captured in a baseline year loss table (YLT), containing 50,000 equally-weighted annual periods.

2. For a given scenario (combination of emissions pathway and time horizon), each simulated year in the reference YLT is then assigned a weight–with weights above their original value (= 1/50,000) denoting that the precipitation modeled for the associated simulated year is projected to become more likely under this scenario, and vice versa. Weights for each simulated year were derived such that the projected future distribution of precipitation for the scenario is suitably matched by the modeled distribution across the corresponding reweighted set of simulated years.

3. A new climate change adjusted YLT is re-sampled for each scenario, based on its corresponding year weights developed in the previous step. A year contained in the original reference YLT may appear multiple times (or not at all) in such climate change adjusted YLT, depending on the weight it is assigned.

4. Finally, new loss statistics are derived from the climate change adjusted YLTs and compared to the original baseline YLT in order to analyze changes in risk under each of the 8 scenarios.

This method effectively represents climate change impacts on modeled risk by reweighting simulations in the RMS baseline view of risk. If the impacts of climate change are very severe, entirely new kinds of events or years may occur that may not be fully represented by the range of events in the current model. However, given the wide range of events captured by the model, this is only a potential limitation for the most severe climate change scenarios far in the future (e.g., RCP8.5, in 2090), for which hazard changes themselves also remain highly uncertain.

Results and Discussion

This section describes the key loss results from the climate change modeling exercise conducted by RMS for the peril of flood risk in Europe. These results provide an interim update on the ongoing research and development work conducted by RMS on the impacts of climate change on natural catastrophe risk, and they do not constitute a finalized RMS climate change view for European flood risk.

Modeled changes in flood losses presented in this section are based on the RMS view of total insured losses across Europe and expressed in terms of relative change from the RMS reference view of modeled losses, defined by the RMS EUFL HD Models. The reference view is calibrated against observations from the period 1979-2010, and recent claims data, and it continues to reflect the RMS best estimate of the long–term loss experience from flood events.

An analysis of corresponding changes to total (insured and uninsured) losses gave consistent results, indicating the insured and uninsured losses can be expected to increase at similar rates under the different climate change scenarios analyzed, all other factors assumed equal. In particular, the analysis does not assume any changes to the underlying exposure, including the number, location, value, building characteristics and insurance coverage of properties analyzed. Working with such constant exposure assumption is useful to investigate the impact of climate change on European flood losses in isolation of other non-stationary factors. However, in practice future risk will depend on a combination of different – and frequently interlinked – drivers of change, of which climate change is only one. One further such factor, a potential future adaptation of building practices, is discussed in more detail towards the end of this section.

Overview of Europe-Wide Results

Future changes in flood losses due to climate change are presented under four RCPs (RCP2.6, RCP4.5, RCP6.0, and RCP8.5) and two time horizons (2050 and 2090).

Assuming no change in the value and distribution of exposure and current defense levels, losses are projected to increase across all scenarios. The range of Europe-wide changes between the most optimistic (RCP2.6) and pessimistic (RCP8.5) emission pathways for each time horizon is provided in Table 1. More detailed results across all four RCPs and a range of return periods are provided in Figure 4.

	2050		2090	
	AAL	RP 200	AAL	RP 200
Lower Bound (RCP2.6)	+ 34%	+ 31%	+ 33%	+ 31%
Upper Bound (RCP8.5)	+ 75%	+ 66%	+ 264%	+ 161%

Table 1: Modeled climate change impact on annual average and annual aggregate insured losses at the 200-year return period (RP) by 2050 and 2090 under RCP2.6 and RCP8.5 (percentage change from reference view)

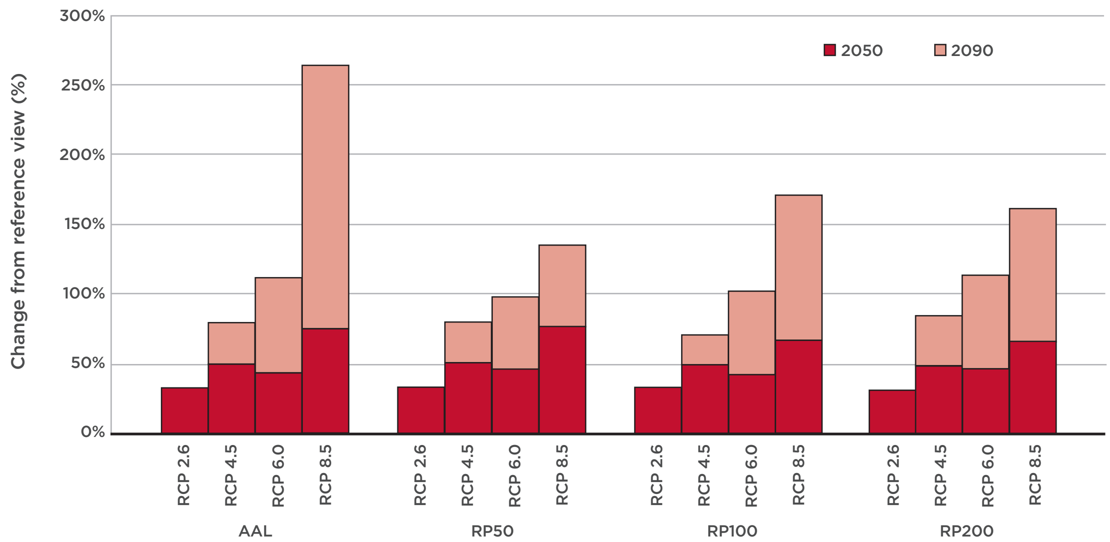

Figure 4: Modeled climate change impact on annual aggregate insured losses by 2050 and 2090 under different emission scenarios (percentage change from reference view)

The range of projected climate change impacts across different RCP scenarios becomes wider over time: relative changes in flood losses start to diverge in 2050 and differ significantly by 2090. This broadening range of future losses is consistent with the projected CO_2 concentration and GMST change associated with each RCP scenario (see Figure 1 and Figure 3). Under RCP2.6, losses peak in 2050 and start to slightly reduce between 2050 and 2090. For the three more-severe RCPs, the projected losses increase throughout the entire period up until 2090. For 2050, changes under the RCP4.5 scenario are more pronounced than under RCP6.0, in line with the higher CO_2 concentration and GMST under RCP4.5 (compared to RCP6.0) until roughly 2060. By 2090, increases under the RCP6.0 scenario have overtaken those under RCP4.5. In the most severe scenario (RCP8.5) the modeled losses continue to sharply increase throughout the second half of the 21st century, with changes in flood losses rising from 75% in 2050 to more than 200% in 2090 (based on average annual losses). These results are driven by the unchecked increase in emissions and resulting change in GMST of ~4^0C by 2090 under this scenario.

Regional Trends

The Europe-wide projected increases in flood losses shown in Table 1 and Figure 4 were subsequently analyzed at a more granular resolution to compare potential variability in results across different European regions.

The projected hazard changes from the EURO-CORDEX model ensemble show some clear regional variations (see Figure 2). Most notably, the increase in extreme precipitations is more pronounced in northern Europe than in southern Europe, in particular during the key winter season. Table 2 contrasts loss changes from the reference view between two European regions, defined by a northwest (NW)/southeast (SE) divide along a France-Switzerland-Germany axis.[2]

[2] Northwest (NW) is defined as Belgium, France, Germany, Ireland, Liechtenstein, Luxembourg, Switzerland, U.K.; Southeast (SE) is defined as Austria, Czech Republic, Hungary, Italy, Poland, Slovakia.

	Average Annual Loss				200-Year Return Period Loss			
	2050		2090		2050		2090	
Region	NW	SE	NW	SE	NW	SE	NW	SE
RCP2.6	35%	26%	35%	26%	31%	22%	31%	23%
RCP4.5	52%	40%	85%	62%	51%	31%	90%	42%
RCP6.0	47%	34%	118%	86%	39%	28%	123%	52%
RCP8.5	80%	58%	276%	212%	76%	40%	175%	63%

Table 2: Modeled climate change impact on annual average and annual aggregate insured losses at the 200-year return period (RP) by 2050 and 2090 by region and under different emission scenarios (percentage change from reference view)

The relative change in projected flood losses is consistently greater in the northwestern region. The drivers of these differences become clear when looking at country-level results, as shown in Figure 5.

The increase in northwestern Europe is driven by changes in three key countries, which contribute nearly two-thirds to modeled average annual loss across Europe in the reference view – U.K., France and Germany. All three countries see notable increases in modeled flood losses over time, which are particularly strong in Germany where losses more than double by 2050 under RCP8.5.

The change in flood loss in southeast Europe is driven by Italy, the key driver of insured risk in this region: Italian losses increase by <60% by 2050 even under the most severe RCP8.5 scenario, and therefore fall notably below the average change across Europe.

Results can be expected to further vary within individual countries, in particular for regions in central Europe. For example, EURO-CORDEX results for precipitation changes suggest divergences across different regions within France and Italy – generally suggesting a notable increase in precipitation across the northern half of each country and less pronounced increases, or even decreases, for the southern halves. Similarly, the impacts of climate change on flood risk are likely to vary seasonally, both in magnitude and – at least for some regions – also in their directionality (see Figure 2).

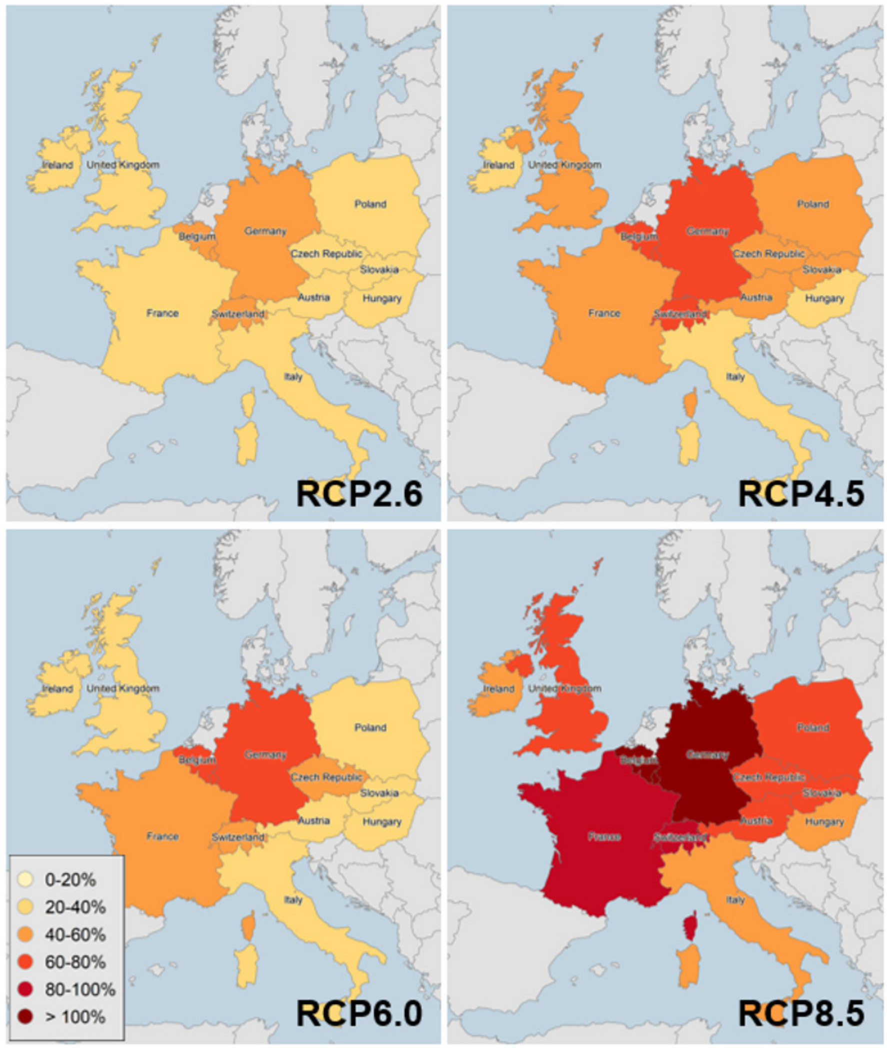

Figure 5: Modeled climate change impact on European flood average annual insured losses by 2050, by country and under different emission scenarios (percentage change from reference view)

Potential Adaptation Impacts

Flood risk will evolve as a result of changes in a variety of factors. The climate change impact on precipitation patterns examined in this paper so far is one key aspect, but certainly not the only one. Notable other factors can be expected to include changes in both the total amount of exposure as well as in its distribution (e.g., trends towards increasing urbanization and concentration of assets), changes in building practices and evolution of insurance practices. Some of these factors are closely interlinked. For example, one might expect that increases in precipitation will prompt adaptions in building practices and/or codes in response to the increased flood hazard posed by higher precipitation levels. In this section, we examine the impact of one simple example of such possible future changes: a raise in ground floor elevation. Specifically, we re-model both reference and future flood losses for the same set of exposures as used previously (i.e., the RMS view of insured exposure today), but now we assume a (generally higher) uniform ground floor elevation of 1 meter above ground level across all properties. While raising the ground floor to the same standard across all existing building stock, as assumed in this exercise, is not realistic–nor cost–effective and desirable - it is a simple, effective way to illustrate the general potential of mitigation and adaptation to "counteract" loss increases caused by climate change in isolation. In particular, it highlights the importance of considering climate change alongside other non-stationary risk factors and can be used to inform building standards which are optimally cost-effective under future climate conditions. Whether, which, and at what scale such standards will be implemented over the coming decades remains uncertain and may vary significantly across different parts of Europe.

Model results show that losses under the "mitigated" view of a ground floor at 1 meter above ground level are roughly 40% lower than the default model view, which reflects present-day building practices. Combining the increase in losses seen due to climate change impacts on precipitation with these reductions gained from adaptations in ground floor elevation results in the overall loss changes shown in Figure 6. Raising ground floors to 1 meter above ground elevation not only reduces future loss increases due to climate change, but keeps projected losses in 2050 below or close to the reference view for even the most severe emission scenario analyzed. By 2090, the impacts of climate change are too large for the raise in ground floor elevation to fully counteract them; nevertheless, the increase in risk is far less pronounced than in the default model view. For example, average annual losses increase by "only" 6% under the RCP4.5 emissions scenario, instead of the notably larger increase of 80% projected if no mitigation measures are adopted. This (albeit simplistic) example powerfully demonstrates the ability to counteract and even outperform future loss increases due to climate change if other non-stationary factors impacting risk – such as building standards – are adapted effectively.

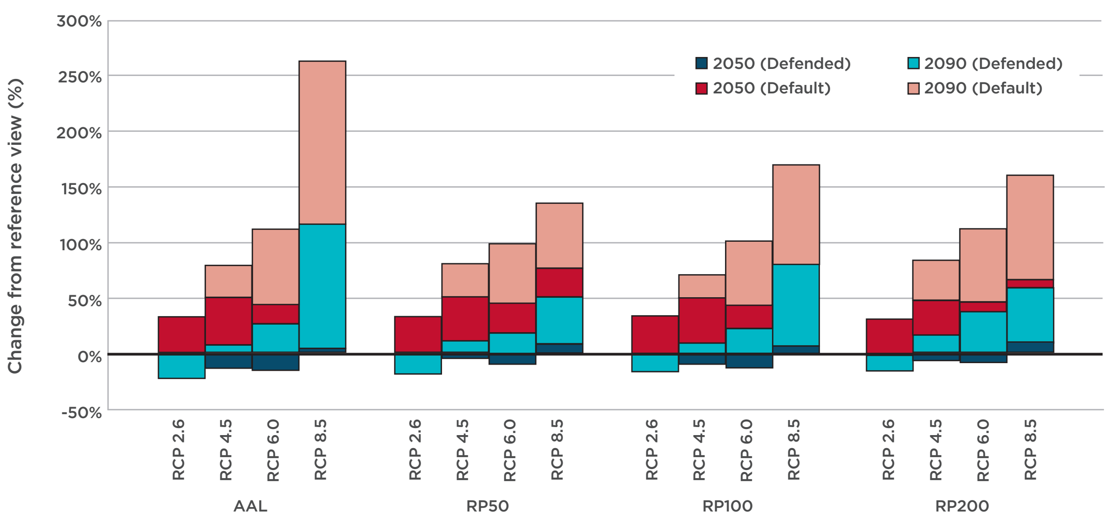

Figure 6: Modeled climate change impact on annual aggregate insured losses by 2050 and 2090 under different emission scenarios (% change from reference view); comparison of results under default and sensitivity ground floor elevation assumptions (ground floor uniformly set to 1 meter above ground level)

Conclusions and Future Outlook

Flood risk contributes almost a third to the total average annual loss from natural catastrophes in Europe today. The results presented in this paper show that the impact of climate change on precipitation patterns could significantly increase flood risk across Europe over the coming decades: average annual losses across Europe are projected to increase by 34% to 75% in 2050 and 33% to over 200% in 2090, depending on which future pathway of greenhouse gas emissions is assumed.

Regional results show that the impact of climate change on future losses is particularly significant in northwestern Europe, including France and Germany, whereas southern countries such as Italy and Hungary are experiencing comparatively smaller changes. The general increase in flood risk across Europe, as well as key features of its spatial distribution, are in line with recent scientific publications (EEA Report, 2017; IPCC AR5). While open questions and uncertainty remain around the magnitude of changes in future precipitation, as well as more detailed spatial and seasonal patterns, the future increases in risk suggested by the analysis can be expected to have notable impacts at local, regional, national and transnational level. The insurance industry is a key stakeholder who will have to be prepared to manage such a changing risk landscape. However, it is certainly not the only one. Similarly, policy makers, businesses, investors and residents will all be impacted by changes in flood risk – through increased damage to their assets, as well as implications on insurance availability and pricing.

Climate change driven increases in precipitation will not be the only factor changing European flood risk in the future. While analyzing this factor in isolation is extremely useful to understand potential climate change impacts on this peril, it does not provide a realistic and holistic view of how flood risk may look in Europe in the future. For example, changes in risk in developed countries, such as the projected climate change driven increases in flood risk across Europe, can be expected to be met with adaptation measures, including changes in the location of assets, building codes and defense systems. The type and level of future adaption will depend on the observed (as well as perceived) changes in flood risk and the pathway governments, businesses and communities choose when reacting to such changes. This report highlights the importance such adaptation strategies will have on future risk, using a change in ground floor elevation to 1 meter above ground as a simple example. The modeled reduction in losses gained under this scenario is able to effectively counteract, and even outperform, future increases in risk due to the precipitation changes alone.

Given its long-standing central role in analyzing and managing catastrophe risk, the insurance industry is not only a key stakeholder affected by climate change driven increases in risk; it is also ideally placed to embrace the challenges and opportunities such changes present. For example, proactive education and incentivization for risk-reducing adaptation measures among its present and potential future customers could have a dramatic effect on 'future-proofing' a portfolio to the impacts of climate change. Understanding potential future changes in risk – due to both climate change and other nonstationary factors – is a critical first step to inform such initiatives and align business strategy around it.

Irrespective of which future emission pathway we follow or what exactly the resulting impacts on precipitation across Europe will look like, in order to effectively manage flood risk in the (still uncertain) future, collaboration and innovation across different stakeholders will be more important than ever.

Future Outlook

RMS is committed to supporting clients in better understanding, and responding to, the potential impacts of climate change on their business. This paper provides an update on the ongoing RMS research into the impacts on one peril region: European flood risk. Changes in flood risk due to climate change have long been suggested by the scientific community; however, at the present moment, the exact implications remain uncertain. RMS will continue to closely monitor the evolution of scientific understanding and consensus on the impacts of both future climate change – as analyzed in this paper – as well as past climate change, which may have already altered risk to the present day.

We have also undertaken several consulting engagements for clients to assist them in better understanding their possible exposure to physical risks from climate change in the future. If you would be interested in exploring a similar engagement, please contact your RMS service representative.

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