THE CONSEQUENCES OF CLIMATE CHANGE ON THE COST OF NATURAL CATASTROPHES IN FRANCE UP TO 2050

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CCR

EDITORIAL

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Established more than 40 years ago, the natural catastrophe (Nat Cat) compensation scheme has successfully achieved the targets set by French legislators in 1982. These goals include ensuring widespread insurance coverage at a sustainable cost, delivering suitable compensation to individuals and businesses impacted by perils, facilitating a swift return to normalcy, and fortifying the resilience of the French population and economy.

In addition to compensating claims, the Nat Cat scheme has improved knowledge of these risks, which were relatively poorly understood in 1982, and has made a major contribution to funding prevention.

Although the scheme has performed effectively thus far, it is now grappling with the challenges posed by climate change. Consecutive years have witnessed elevated claims attributed to geotechnical drought, providing a glimpse into the anticipated claims experience over the medium term.

Climate change is overturning traditional actuarial approaches, with the use of the historical claims experience and even complex physical modelling reaching their limits due to the changing and non-stationary nature of the climate. In order to gain a better understanding of the upheavals ahead, CCR has been working for several years with its scientific partners, first and foremost Météo-France, on an ambitious project to model and forecast the consequences of climate change in terms of insured losses under the Nat Cat scheme.

Building upon previous studies released in 2015, 2018, and 2020, this latest research leverages recent advancements in damage modelling. It also considers the impact of recent and ongoing reforms to the scheme. The results of the study will be used to feed discussions on the need to adapt the Nat Cat scheme to the rising claims rate in the wake of climate change, with a view to ensuring its long-term survival. They may also be used to guide public prevention policies in order to contain the rise in losses.

CCR anticipates a 40% rise in claims experience by 2050 due to the effects of climate change. When factoring in alterations to insured stakes, this estimate increases to 60%. The drift already observed in the claims experience and the projections for 2050 shows the need to review how the scheme is financed by adjusting the Nat Cat additional premium to enable the scheme to return to technical equilibrium and for CCR to fully play its role as a shock absorber. The necessary increase is estimated at +7pp in the short term, followed by a further 3pp increase to take account of future climate change between now and 2050.

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1. SUMMARY OF THE STUDY

In recent years, France has faced a series of significant meteorological events, ranging from the Seine River flooding in 2016 to Hurricane Irma in 2017. Additionally, there has been a sequence of extraordinary droughts spanning from 2016 to 2020, including the notable geotechnical drought of 2018 and the nearly ubiquitous geotechnical drought of 2022, marked by an unprecedented intensity. As a result, France has experienced notably elevated levels of insured economic losses in recent years. This series of events is a reminder of the French territory's exposure and our society's vulnerability to natural risks.

To adapt our public risk management policies, it is imperative to quantify these extreme weather-related events in terms of both frequency and intensity, while considering the influence of climate change. The Caisse Centrale de Réassurance (CCR) is the public reinsurer in France that offers unlimited coverage for major natural disasters (floods, geotechnical drought, earthquakes, coastal flooding and hurricanes/cyclones) under the natural catastrophe compensation scheme, with a state guarantee. Against this backdrop, CCR has actively established partnerships with reputable scientific organisations, with Météo-France at the forefront, to enhance its expertise in evaluating the economic impacts of natural catastrophes. This positions CCR as a valuable contributor to the French government's risk management initiatives.

Since COP 21 in 2015, CCR has carried out several studies aimed at estimating changes in insured losses due to climate change in France. This report follows on from three studies published in 2015, 2018 and 2020 respectively. This report seeks to leverage the ongoing enhancements in modelling tools to offer a comprehensive overview of loss figures based on two greenhouse gas emission scenarios endorsed by the IPCC. The first scenario, RCP 4.5, represents an intermediate pathway with emissions initially rising, reaching a plateau, and eventually declining throughout the 21st century. The second scenario, RCP 8.5, portrays a sharp and continuous increase in emissions up to 2050. The impact of climate change has been studied with respect to the three main hazards covered by the Nat Cat scheme: fluvial floods and run-off, coastal flooding and geotechnical drought. The other two major hazards covered by the scheme (earthquakes and cyclones) are integrated to provide a multiperil vision.

The outcomes of this study encompass the modelling chain developed by CCR, rooted in a robust understanding of weather-related phenomena and regional risk exposure. Additionally, it incorporates an innovative climate simulation methodology, known as the constant climate simulation, developed by Météo-France. This methodology enables the simulation of a diverse array of hydrometeorological events under various scenarios projected for 2050. It facilitates the analysis of the frequency and intensity of extreme events which are inherently rare by definition. The combination of these two areas of expertise forms a comprehensive modelling chain, encompassing meteorological phenomena and extending to the estimation of the impact of hazards on future losses to insured property.

The study highlights four main results:

- Since 2000, the climate has changed and we are already seeing a shift in claims, with an increase in average annual losses. While the number of claims related to flooding has held steady, there has been a noteworthy 23% surge in average annual losses attributed to geotechnical drought between Climate 2000 and the present day, primarily driven by climate change. Added to this is the effect of recent and ongoing reforms (the Baudu Law and the Law known as "3DS"), bringing the overall increase in drought claims to 56%;
- Regardless of the IPCC RCP scenario considered, hazard-related losses are projected to increase by 2050 driven by a rise in the intensity of climate-related events;
- The surge in insured stakes in the future, especially in high-risk regions, further amplifies the cost of damages;
- Irrespective of the scenarios, geotechnical drought emerges as the most concerning hazard, considering both the magnitude of losses it incurs and the projected escalation expected in the future.

There are, however, some differences in the evolution of hazards according to IPCC scenarios. The intensity of geotechnical drought is greater under IPCC's RCP 8.5 scenario. The increase in losses is estimated at 162% as a result of the hazard, and 190% if changes in insured stakes are considered for 2050. The increasing duration of severe extreme events in the future prompts consideration for the establishment of a comprehensive national prevention policy. Simultaneously, an upsurge in flood damage is foreseen, with a more pronounced impact expected under the RCP 4.5 scenario. This increase is attributed to the heightened frequency of rapid flooding events.

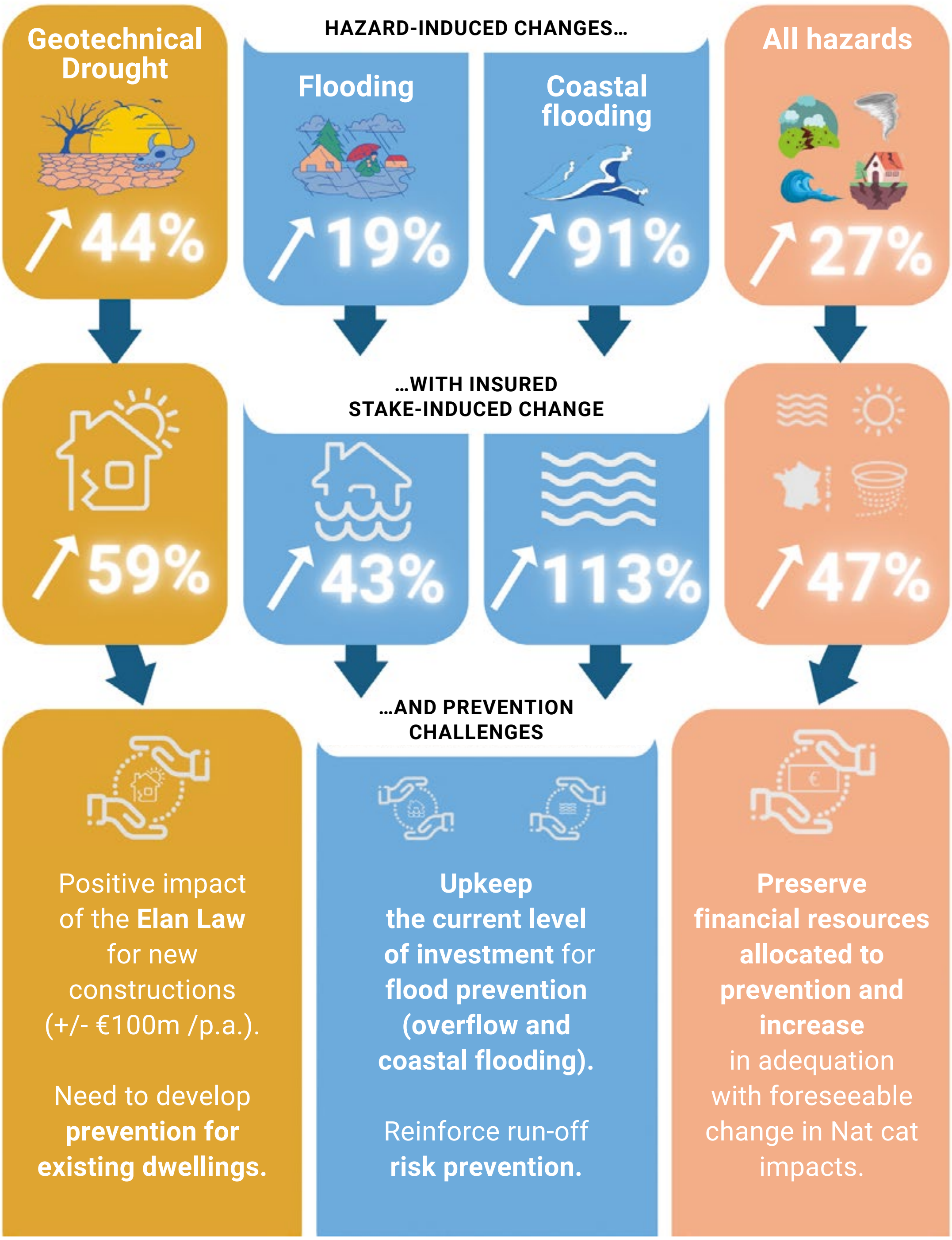
Ultimately, the elevation in sea levels is anticipated to result in a heightened occurrence and intensity of coastal flooding. Overall, it is projected that losses will escalate by 27% to 62% by the year 2050 solely due to the impacts of climate change.

Faced a surge in insured losses, the natural catastrophe compensation scheme must confront the challenge posed by climate change to uphold the principle of national solidarity upon which it is founded. There are three possible ways of ensuring the long-term future of the scheme:

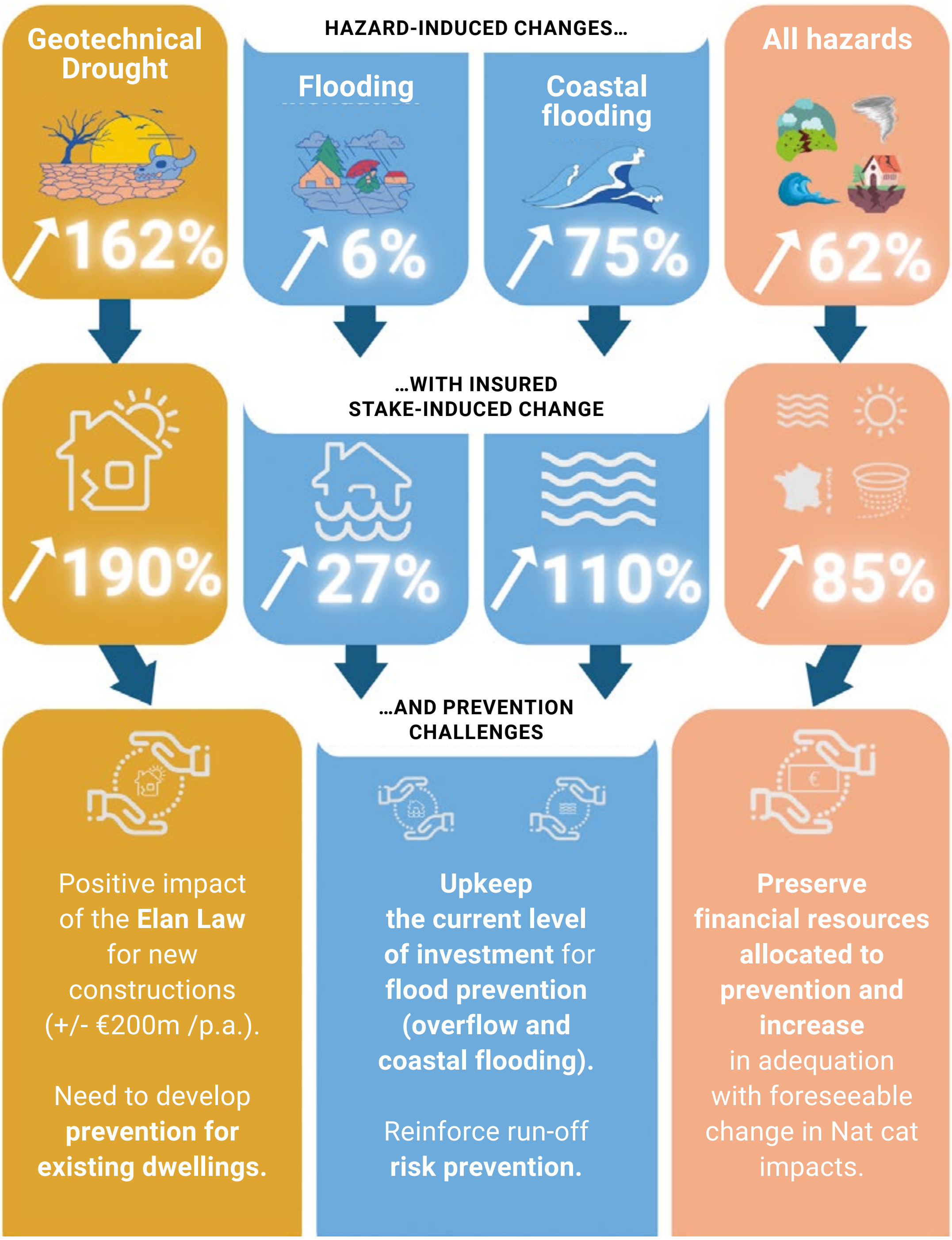
- Increase prevention, specifically regarding geotechnical drought and run-off;
- Refocus the criteria for recognising natural catastrophes on the original legislative principle, i.e. covering events of abnormal intensity;
- Increase the Nat Cat additional premium, to enable the Nat Cat scheme to return to technical equilibrium and CCR to play its role as a shock absorber.

These combined solutions would enable the society to navigate and respond to potential future risks.

Change in the average annual claims by 2050 compared with 2023 climate in France - **RCP 4.5**



Change in the average annual claims rate by 2050 compared with 2023 climate in France - **RCP 8.5**



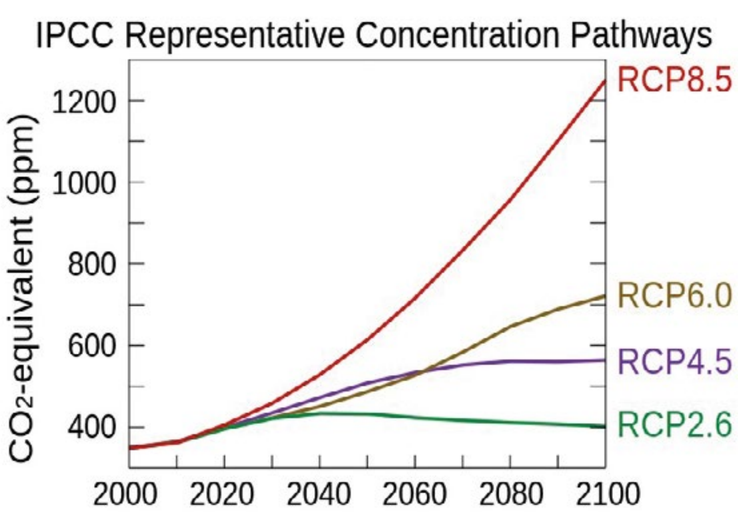
2. INTRODUCTION

Greenhouse gases play an important role in climate regulation. Since the 19th century, human activity (especially the combustion of fossil fuels) has increased the amount of greenhouse gases in the atmosphere. This shift has in turn modified the climate balance. Since 1988, the Intergovernmental Panel on Climate Change (IPCC) has been analysing global climate change and the impact of these changes on populations and ecosystems according to different greenhouse gas concentration scenarios. These scenarios are presented in Figure 1.

This study by CCR focuses on two scenarios proposed by the IPCC:

- The RCP (Representative Concentration Pathways) 4.5 scenario, with a temperature difference of 1.5°C between 2050 and 2000 in France. Given the adaptation and mitigation policies that have been put in place, this scenario is more likely than the scenarios with very high emissions or, on the contrary, those with very high reductions in emissions. It can be considered as a median scenario.

Figure 1: Changes in greenhouse gas concentrations under various IPCC RCP scenarios (Source IPCC).



• The RCP 8.5 scenario, with a temperature difference of 1.9°C between 2050 and 2000 in France. It corresponds to a scenario with high greenhouse gas emissions throughout the 21st century. It is therefore used to estimate an upper limit for the progression of insured losses.

These RCP scenarios are based on the CMIP5 climate change trajectory assumptions. Since then, new assumptions have been formulated in the CMIP6 catalogue to include socio-economic developments (SSP). Météo-France data predate these new scenarios. However, for regional simulations, and specifically for impact studies, RCP scenarios are still the reference. By studying two RCP scenarios, it is possible to provide a range for estimating the evolution of the claims experience, thereby incorporating the uncertainty surrounding the trajectories of climate change. As shown in Figure 1, trajectories of greenhouse gas concentrations diverge starting from the mid-century, with the differences amplifying over subsequent decades.

The aim of this study is to measure the impact of climate change on the main climate perils covered by the Nat Cat scheme: flooding from run-off and overflow, coastal flooding, and geotechnical drought. The other two major hazards covered by the scheme (earthquakes and cyclones) are integrated to provide a multiperil vision. Damage estimates consider mudslides and landslides triggered by flooding, both of which are also covered by the Nat Cat scheme. Avalanches, landslides not resulting from flooding, tsunamis and volcanic eruptions are excluded from this study. These events account for a very small proportion of the historical claims experience.

In this study, climate projections are made until the year 2050, which is a suitable timeframe for studying changes in insured stakes and public policies. In addition, the reference climate data provided by Météo-France is that of Climate 2000.

Nevertheless, climate variations are already noticeable today, specifically heat waves. There have been 22 heat waves in the last twelve years, compared with 24[1] over the period from 1947 until 2000. The same impact is observed for the average claims experience. In fact, the average cost of annual damage caused by drought over the period from 2016-2020 exceeds €1.3 billion, compared with €350 million over the period from 2000-2015. The consequences of climate change are already visible today, so this new study also looks at the drift in claims experience between Climate 2000 and the current climate.

In this study, the analysis of damage focuses on 4 climates: Climate 2000, the current climate (2023 vision) and Climate 2050 according to the two selected IPCC RCP scenarios.

1 - Heat waves and climate change | Météo-France (meteofrance.com)

3. GENERAL METHODOLOGY : CLIMATE SIMULATIONS UP TO 2050 TO ASSESS INSURED LOSSES

3.1 - Météo-France climate simulations

The general model

Météo-France tailored its ARPEGE-Climat atmospheric climate model to align with the requirements specified by CCR for estimating the risks across Europe for both Climate 2000 and Climate 2050. The aim was to generate a comprehensive series of **constant-climate** data, spanning a sufficient duration to enable robust statistical analyses across a broad spectrum of events, including extreme events that are inherently rare due to their rare occurrence.

A constant climate simulation combines a continuous climate time series (400 years in this case), simulated around a single target year. The advantage of this approach is that it describes the internal variability of the climate set over the target year and provides a diverse range of events for analysis. These 400 simulations should therefore be considered as potential representations of the target year, each with its corresponding probability of occurrence. In addition, the size of the sample enables the calculation of robust and reliable statistics`. With 400 potential Climate 2000 years and 400 Climate 2050 years, it is thus possible to analyse the frequency and intensity of extreme events and to study the evolution of the profile of these events in the future. The choice of greenhouse gas scenarios and target years is made according to user interests.

Météo-France therefore carried out three 400-year simulations:

- on Climate 2000[2] ;
- on Climate 2050 according to the IPCC[3] RCP 4.5 scenario;
- on Climate 2050 according to the IPCC[4] RCP 8.5 scenario.

To obtain an interesting horizontal resolution over Europe, the grid of the ARPEGE-Climat model has been narrowed down over this continent (~20 km) and expanded at the antipodes. The climate is determined by greenhouse gas concentrations over the target year. The internal variability of the climate is given by forcing sea surface temperature using 400-year series taken from the work of the IPCC. The SURFEX surface module models land-atmosphere exchanges. The time step of the model is 10 minutes. The archiving of more than 80 parameters of interest is scheduled over a predefined area covering Europe and North Africa.

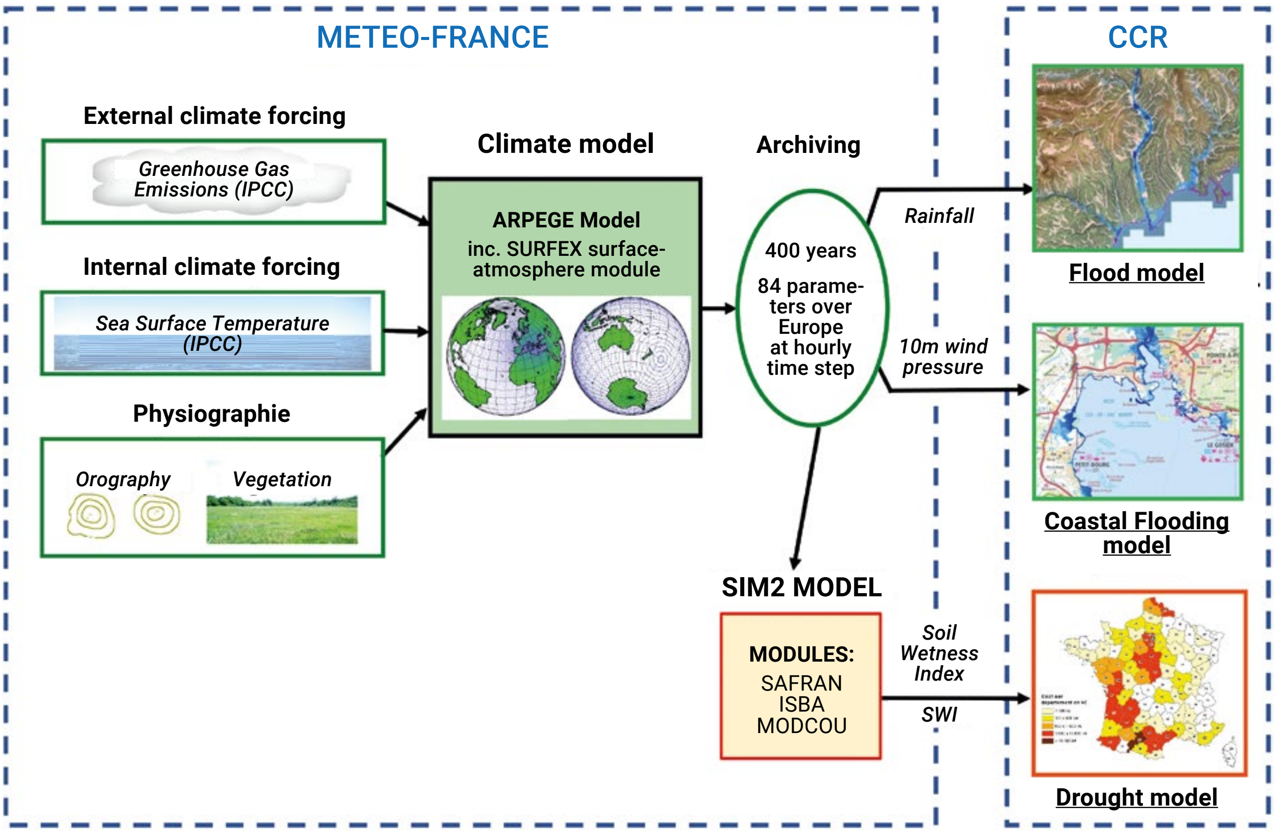
2 - CO_2 concentration: 369 ppm
3 - CO_2 concentration: 486 ppm
4 - CO_2 concentration: 540 ppm

The data thus obtained from Météo-France's ARPEGE-Climat model is used to feed the hazard models developed by CCR, as shown in Figure 2.

Precipitation data fed the CCR flooding model and the horizontal components of wind speed at 10m and atmospheric pressure fed the CCR coastal flooding model.

To simulate geotechnical drought, Météo-France implemented its SAFRAN-ISBA-MODCOU hydro-meteorological model (SIM2) as presented below.

Figure 2: Constant-climate data production concept used by CCR impact models.



The SIM2 model in France

To obtain surface data with a <10km resolution on France, Météo-France downscaled its SIM2 land-atmosphere model. The SIM2 model includes the SAFRAN module (analysis of meteorological variables), ISBA module (modelling of land-atmosphere exchanges: evaporation, run-off, infiltration, snow cover, etc.) and MODCOU module (hydrological model). The input data required for SIM2 were interpolated to a horizontal resolution of 8 km over France. Biases are corrected on the basis of the SAFRAN reanalysis, which serves as a historical climatological reference for the period from 1984 to 2013, before being fed into the SIM2 model. The outputs of this model include the Soil Wetness Index (SWI) which feeds CCR's geotechnical drought model.

Correcting modelling bias

All atmospheric numerical models exhibit biases, which can vary depending on the time of year. These biases stem from the choices and approximations made in solving the equations governing the evolution of atmospheric parameters, as well as from the varying levels of complexity employed to represent meteorological phenomena. Without bias correction, the simulated data cannot be compared with known historical values, whether for statistics such as averages or standard deviations, or for extreme values.

Model biases are estimated by comparing them with reference climatological data derived from observations or "reanalyses", which consider all the observations available over several decades.

The method to correct biases in past or current climate consists in bringing the distribution of the simulated data closer to that of the climatological data taken as a reference, for an approximately identical climate. The method to correct future climate bias is generally based on the assumption that the model experiences the same type of bias under future climate as under historical climate.

3.2 - Simulating climate hazards

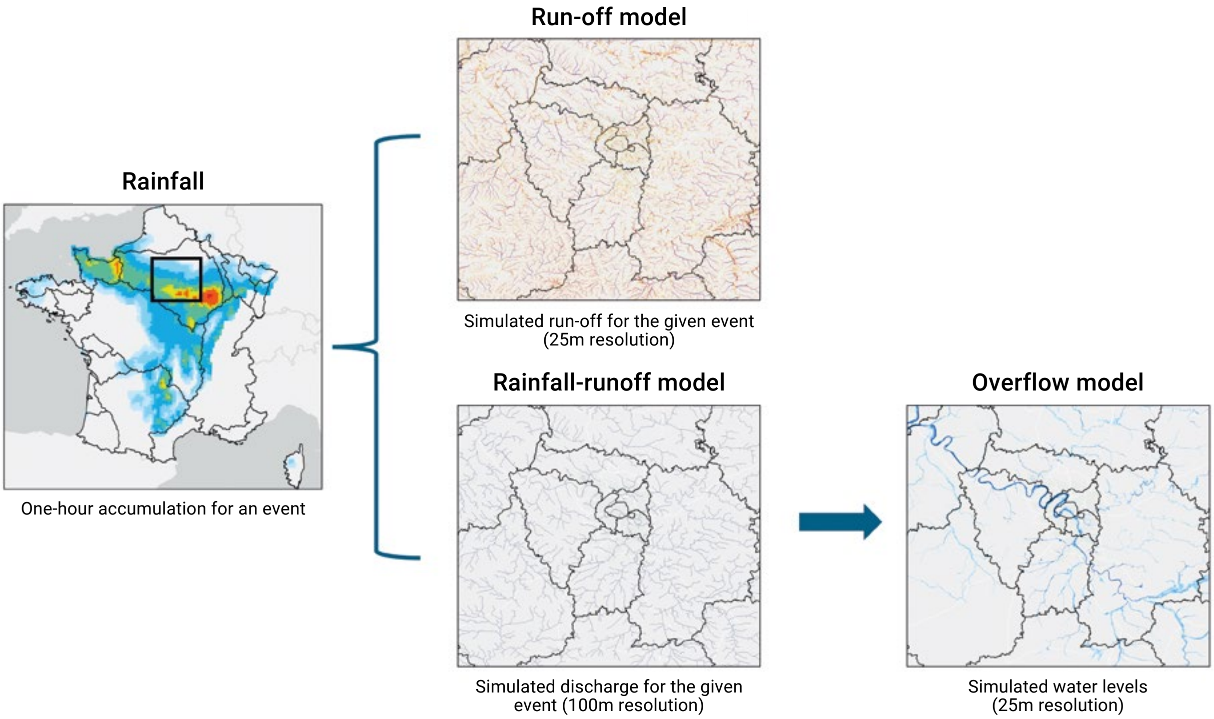
Floods

Model architecture

Flood hazard modelling requires the development of three models:
- a run-off model, which estimates the quantities of water that will run off the ground at any point on the territory ;
- a rainfall-runoff model that estimates discharge on main rivers;
- an overflow model (fed by the rainfall-runoff model) which quantifies the water level caused by flooding.

These models, illustrated in Figure 3, are fed by the same precipitation data and operate over the duration of an event.

Figure 3: Modeling chain employed to simulate flood hazards on the scale of an event.

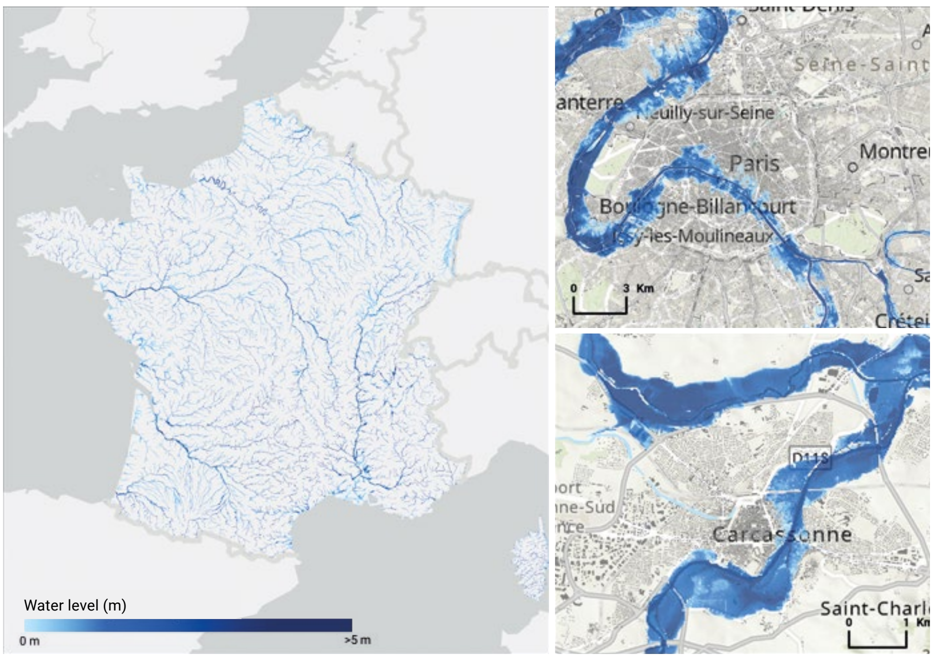


The first step in simulating the flood hazard is to identify severe events on the basis of rainfall data from the climate scenarios. This identification is carried out at catchment scale. Once the event has been identified, the rainfall-runoff simulation is carried out. During this simulation, the model estimates discharge on a 100m grid over Metropolitan France. This rainfall-runoff model is initialised by the rainfall over the 10 days preceding the event.

At the same time, a rainfall-runoff model has been implemented by INRAE (GR[5] type model) on all climate data. This model has a daily time step, and it simulates the discharge continuously over approximately 1,000 stations covering all of France. The discharge simulate by this model, can be used to adjust the outputs of the CCR rainfall-runoff model, specifically for large rivers.

The discharge simulated on the rivers feed the overflow model, which converts the discharge into water levels before propagating these on a Digital Terrain Model (DTM). The IGN® 25m DTM was used for this study. This propagation is ensured by a 2D hydraulic model, based on the equations of the Lisflood FP model[6]. Figure 4 shows the simulated overflow for a 200-year return period.

Figure 4: Overflow model outputs for a 200-year return period for Metropolitan France and details of outputs for the cities of Paris and Carcassonne for Climate 2000.



The run-off model is a 2D rainfall-runoff model spatialised on the same DTM as the overflow at a 30-second time step, which takes into account topography and land use (Corine Land Cover data).

The flood model developed by CCR simulates two types of hazards (run-off and overflow) on a fine scale, to consider all the hydrological phenomena that cause damage to insured property. This methodology generates a unified map for the entire country of France with a 25m resolution.

5 - Perrin, C., Michel, C., Andréassian, V., 2003. Improvement of a parsimonious model for streamflow simulation. Journal of Hydrology, 279 : 275-289. doi: 10.1016/S0022-1694(03)00225-7.
6 - Bates PD, Horritt MS, Fewtrell Tj, 2010, A simple inertial formulation of the shallow water equations for efficient two dimensional flood inundation modelling, Journal of Hydrology, Volume 387, Issues 1–2, 7 June 2010, Pages 33-45.

Rainfall analysis

The rainfall that feeds the flood hazard model plays an important role in the development of hydrological hazards under future climate. This is why a specific comparative analysis of rainfall for Climate 2000 and Climate 2050 was carried out. This analysis incorporates different rainfall accumulation durations (6 hours and 21 days) over several return periods. The choice of the duration of accumulated rainfall helps to explain the behaviour of run-off phenomena resulting from short-duration accumulations and those of river overflow resulting from longer-duration accumulations.

The preliminary findings of the analysis on rainfall trends indicate that rainfall is not uniformly increasing across Metropolitan France in the context of climate change. There are indeed major regional disparities that could lead to a reduction in exposure to flooding in certain areas in the future, particularly around the Mediterranean region.

Figure 5 illustrates the rainfall ratio between Future Climate (RCP 4.5) and Climate 2000 for accumulations of 6 hours and 21 days for a 50-year return period. Rainfall over 6 hours is projected to increase by an average of 12% between 2000 and 2050. Additionally, 17% of the territory is impacted by an increase of more than 20% in 6-hour rainfall. Rainfall over 21 days is anticipated to increase by an average of 7% in the future, with only 1% of the territory expected to be affected by a change of more than 20% in rainfall. These same trends are observed when comparing the future climate under the RCP 8.5 scenario and the climate in 2000 (Figure 6). However, a greater reduction in 21-day rainfall was observed in the south of France with 22% of the territory experiencing a negative change in 21-day rainfall.

Comparative analysis of the duration of accumulated rainfall is an important step in understanding the development of run-off and overflow phenomena in the future. It highlights the importance of looking at the future evolution of two different types of events: flash floods and slow-rise floods.

Figure 5: Cumulative rainfall ratio between Climate 2050 - RCP 4.5 et Climate 2000 for the 50-year return period. Total over 6 hours (left) et 21 days (right).

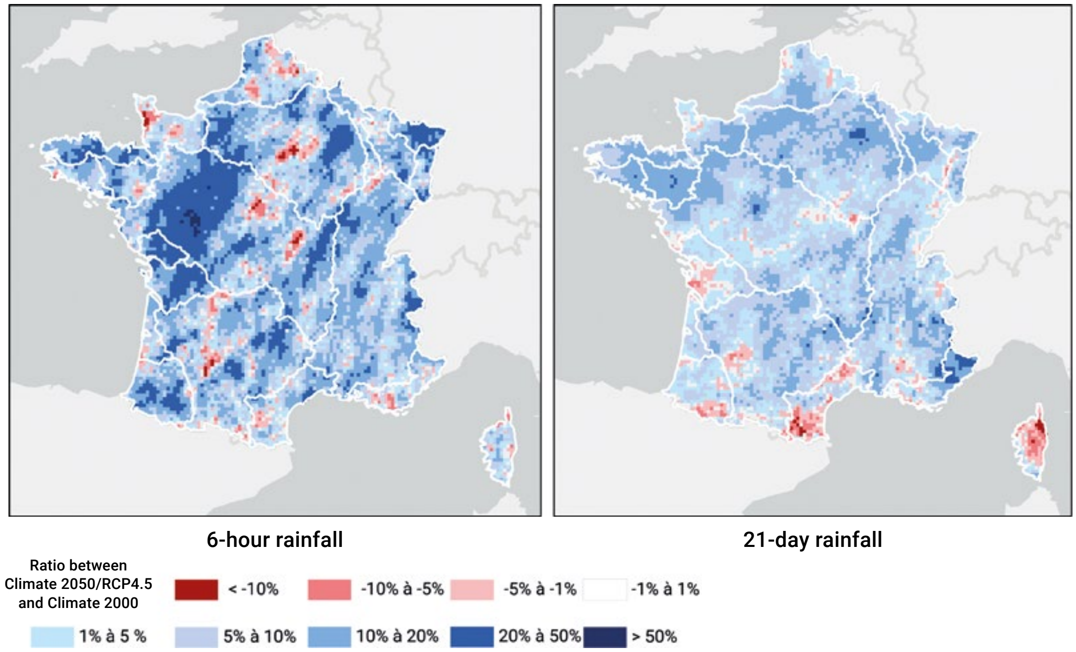
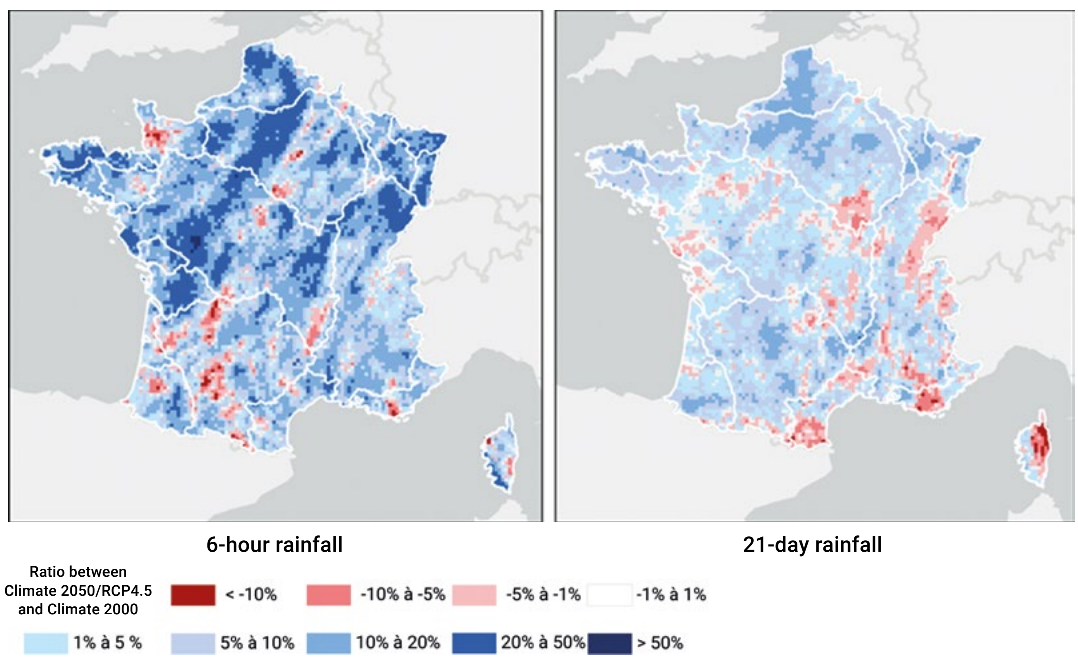


Figure 6: Cumulative rainfall ratio between Climate 2050 - RCP 8.5 and Climate 2000 for the 50-year return period. Total over 6 hours (left) and 21 days (right).



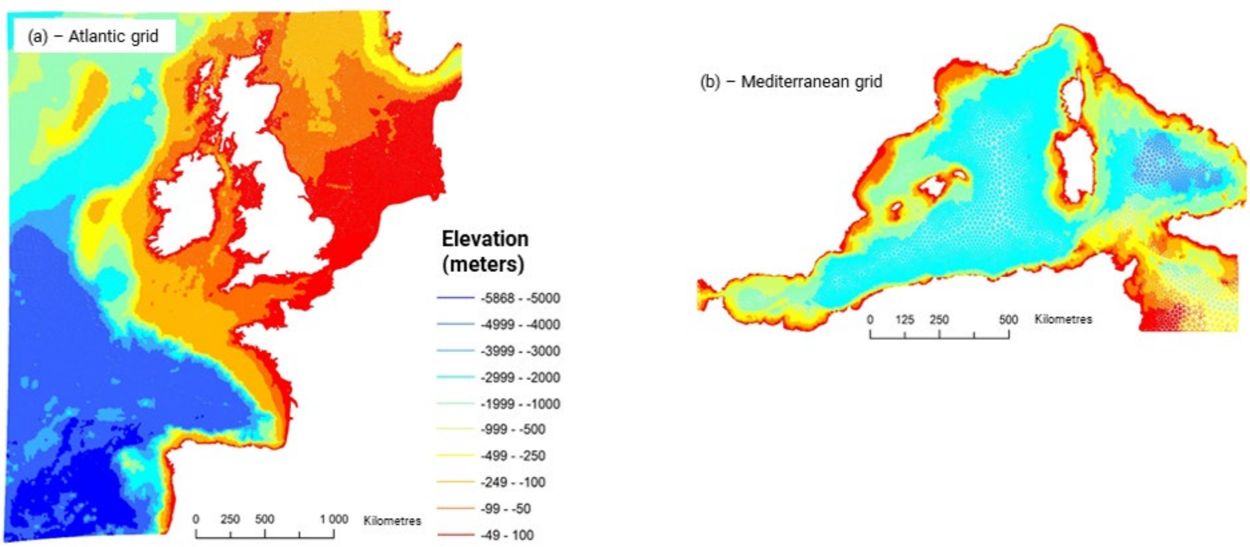
Coastal flooding

Model architecture

Coastal flooding refers to floods in coastal areas coming from the sea due to severe meteorological and tidal conditions, which may include a high tidal range and/or the formation of a low-pressure system. The coastal flooding hazard model is built in three stages:

- the simulation of offshore water levels uses atmospheric pressure and wind speed fields from the ARPEGE-Climat model, available with a 3-hour time step and a 0.5° spatial resolution. These fields feed the Telemac-2D[7] hydrodynamic model, which calculates the propagation of water sea levels under the impact of tides and weather conditions. This model is divided into two sectors (Figure 7) covering the Atlantic, Channel and North Sea on the one hand, and the Mediterranean region on the other. The model's grid size ranges from 5 km offshore to 250 m near the coast;
- at the same time as estimating sea levels, a wave simulation is carried out using the Tomawac model[8]. The outputs of the wave model are used to estimate the increase in mean water level on the coastline due to wave setup. They are also used to estimate bank run-up, i.e. the quantity of water that rises on a shoreline under the impetus given to it by a wave setup;
- from the Telemac-2D and Tomawac outputs, the Lisflood hydrological rainfall-runoff model, also used for the flood hazard, propagates the water onto the DTM. This model operates at a spatial resolution of 25 m and a time step of one second.

Figure 7: Illustration of the simulation grid of the Telemac2D model.



7 - EDF R&D 2014. 2D hydrodynamics, TELEMAC-2D Software - Realease 7.0, User manual, 134 pages.
8 - EDF R&D 2016. TELEMAC Modelling System, TOMAWAC Software - Realease 7.1, User manual, 59 pages.

Sea level rise

One of the major consequences of climate change is rising sea levels. This rise is likely to significantly impact the coast, amplifying the intensity and frequency of coastal flooding phenomena. In order to assess this impact on France, the simulations carried out for the current climate scenario are combined with two sea level rise assumptions corresponding to the IPCC RCP 4.5 and RCP 8.5 scenarios[9]. This report is based on an estimated rate of sea level rise between 2010[10] and 2050 of between 4 and 5.5 mm per year for the RCP 4.5 scenario and between 4 and 7 mm per year for the RCP 8.5 scenario. The acceleration in sea-level rise is initially comparable in the early years for both scenarios, but it amplifies over time. This results in a projected 20-cm rise by 2050 for the first scenario and a 23-cm rise for the second scenario. These increases correspond to the average values projected by the climate models.

Geotechnical drought

A drought can be characterised as a water deficit in at least one component of the hydrological cycle. This water deficit can result in a change in soil wetness.

This results in a change in the volume of clay soils, the dynamics of which are known as clay shrinkage and swelling. This phenomenon is associated with the strong affinity of specific clay minerals in the soil for water molecules. These minerals swell in wet weather and shrink in dry conditions. These ground movements have the potential to impact building foundations, leading to damage through subsidence. The indicator used to evaluate this water deficit is the uniform Soil Wetness Index (SWI), reflecting the moisture content of surface soils. This indicator is calculated by Météo-France on the basis of monthly variables and an 8km grid over Metropolitan France (approximately 8,900 cells). To ascertain the abnormality of a drought, a ten-year criterion (10-year return period) was applied to characterise abnormal Soil Wetness Index (SWI) values. This criterion is consistent with the preparatory work for the implementation of the Decree of 8 February 2023 relating to the '3DS' Law. This criterion is applied to identify extreme drought events for Climate 2000 and Climate 2050.

Summary of indicators used to model climate hazards

The models developed at CCR can be used to simulate each of the climate-related hazards covered by the natural catastrophe compensation scheme, providing a multi-hazard view of the risk exposure in Metropolitan France and the French overseas territories. This simulation of climate-related events is based on the development of indicators that accurately represent the physical phenomena for each hazard. These explanatory variables are summarised in Table 1. In order to take a multi-hazard view, the cost of damage is assessed for earthquakes (in Metropolitan France) and cyclones (in the French West Indies and Réunion island) by modelling these two hazards. These two hazards are a notable exception to the others, as the hazard modelling does not consider climate change according to the IPCC RCP scenarios.

Claim-modelling related to earthquakes and cyclones is the same as for the perils discussed above. The methodology used simulates hypothetical events that are nevertheless plausible events over a relatively long period to include extreme events, based on the observation of past events. In both cases, space-time laws are calibrated on the basis of these past events in order to generate hypothetical events. Within the hazard modules, these hypothetical events are respectively characterised by maximum ground accelerations (cm/s²) and wind speeds (km/h), as summarised in Table 1.

Table 1: Details of the explanatory variables used for each of the risks modelled.

Hazard	Explanatory variable	Resolution
Geotechnical drought	SWI	8 km (Safran grid)
Overflow flooding	Water level (m) Maximum discharge on rivers	25m 100m
Flooding and run-off	Run-off rate (m^3/s) Cumulative rainfall (mm)	25m 1km
Coastal flooding	Water level (m) Surge (m)	25m 25m
Earthquake	Maximum ground acceleration (cm/s^2)	250m
hurricanes/Cyclones	Wind speed (km/h)	250m

Thus, the modelling chain set up at CCR simulates the hazards of drought, flooding and coastal flooding and their development up to 2050, taking into account the impact of climate change. This modelling is based on climate variables output by the ARPEGE-Climat model from Météo-France according to the IPCC RCP 4.5 and 8.5 scenarios. The hazard modules developed for each peril can be used to simulate fine-scale climate hazard variations across Metropolitan France, in order to describe the area's exposure to climate risks in terms of frequency and intensity. This modelling is cross-referenced with a vulnerability module that incorporates the location and characterisation of insured stakes. The final stage in the modelling chain is the simulation of losses using the hazard and vulnerability modules. This loss module can be employed to evaluate the financial impact of natural catastrophes at the level of individual properties, municipalities, or entire regions.

In order to estimate the overall exposure of French territory to the hazards covered by the Nat Cat scheme, two complementary models are included in the analysis: the earthquake model and the cyclone model (Overseas France). These two hazards do not use data from the ARPEGE-Climat model as inputs, but they incorporate a projection of the insured stakes up to 2050.

9 - IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.
10 -The year 2010 corresponds to the year in which the DTM was created and is therefore used as a reference year for the consideration of sea-level rise.

3.3 - Simulating insured losses

Methodology for estimating damage

The methodology used to estimate the claims experience associated with a hazard, such as a flooded area, is known as a damage model. The quantum of damages depends both on the presence of insured stakes in the area (private individuals, farmers, industrials, other professionals) and the vulnerability of these stakes to the hazard in question. The different types of buildings are not equally sensitive to the same level of hazard, which results in differences in the amount of damage observed. A damage model is therefore based on two pillars:

- Knowledge of these stakes;
- Knowledge of their vulnerability to a given hazard.

The creation of a damage model is based on a database containing information on insured stakes and a historical claims experience. This loss experience is used to calibrate damage models, which make the link between hazard and vulnerability. CCR calibrates the damage model for each peril by establishing the relationship between the hazard simulated by the models, the values of the insured stakes, and the amounts of claims observed in actual past events. The quality of a damage model and its calibration is therefore closely related to the quality and richness of the database used. It should be noted that the models also include the simulation of claims related to motor vehicle damage.

The database used by CCR in this study was compiled from information supplied annually by insurers. It provides a particularly comprehensive overview of the distribution of insured values and claims across France under the natural catastrophe compensation scheme.

The damage models developed by CCR for each hazard can be used to adjust two functions to calculate:

- Damage frequency, which expresses the probability that a property located in a hazard zone will actually suffer damage;
- the destruction rate, i.e. the ratio between the loss amount and the insured value of the damaged property.

This methodology makes it possible to estimate the number of claims and the loss amount following the occurrence of a climate-related hazard.

By simulating all the events that occur over the course of a year, the damage models developed at CCR provide an estimate of the average annual damage and an assessment of the loss experience following extreme events in the future, based on the related hazards and insured stakes. The established methodology allows for the discernment of the evolution of insured losses, distinguishing between the portion attributed to climate change (i.e., the evolution of the hazard) and the contribution from the evolution of insured values.

Considering the inflation shock and ongoing reforms

Climate change is causing changes to the intensity and frequency of climate-related events, resulting in increased damage. To accurately ascertain the proportion of the increase in the cost of damage solely attributable to the hazard, the models need to integrate the impact of inflation in recent years into the cost of damage. To do this, CCR models the claims experience in constant 2023 euros

In addition to the impact of inflation, the natural catastrophe scheme is subject to periodic reforms, affecting both the procedure for recognising natural catastrophes and the method for compensating claims. These reforms change the quantum of damages covered by the various players in the system. In recent years, two reforms have modified the Nat Cat scheme:

- The law of 28 December 2021 on compensation for natural catastrophes presented by Deputy Stéphane Baudu, strengthened the scheme by making the natural catastrophe procedure more transparent, facilitating and promoting compensation for victims and stepping up efforts to prevent natural hazards. In order to encompass this change in regulations, the simulated damage is adjusted to encompass the impacts of this law, particularly the incorporation of rehoming costs;
- The law of 21 February 2022 known as “3DS” relating to Differentiation, Decentralisation and Deconcentration, which has given the government the right to take any measure to improve the way in which damage caused by the shrink-swell phenomenon is covered. Against this backdrop, the Decree of 8 February 2023 sets out the conditions for the compensation of losses resulting from the shrink-swell phenomenon. This new system modifies the criteria for recognising geotechnical drought hazard. The new recognition criteria are integrated into the modelling chain.

The modelling chain put in place at CCR simulates the impact of climate hazards from a multi-peril perspective, and their consequences on insured stakes by quantifying the amount of insured damage. This assessment of the claims experience takes into account the latest changes to the Nat Cat compensation scheme, as well as the impact of inflation in recent years.

4. PROJECTION OF INSURED STAKES TO 2050

To analyse the impact of climate change on insured damages up to 2050, a study of the evolution of the French population is required. The aim is to estimate the number of insured stakes, their geographical distribution and their insured value, regardless of their type (private or professional). The projection scenarios developed for this study of future vulnerability are a plausible representation of the insured stakes in 2050 and correspond to the INSEE's base case scenario.

4.1 - Insured property owned by private individuals

Historically (according to INSEE data between 2006 and 2019), the number of dwellings has continued to grow at a virtually linear rate (+1.2% p.a.). However, the proportion of main residences (82% in 2019) has fallen by 2% since 2006, to the benefit of unoccupied dwellings (8%). Private property includes houses (57%) and flats (43%), with these proportions remaining stable over time.

The previous CCR study was based on demographic projections from INSEE's Omphale model[11] to see how these insured stakes would evolve by 2050. The base scenario applies the national trends observed for net migration, fertility and increases life expectancy at the level of the French departments. These projections were used in the current study. The results suggest a decrease of 4.8 million people by 2050 compared to the projections used in the previous climate study.

4.2 - Insured property owned by professionals

To study changes in the number of stakes insured by professionals, a difference is made between agricultural goods and other goods. Two variables need to be analysed to understand agricultural trends up to 2050. The first variable is the number of farms, based on ten-yearly data from the French Ministry of Agriculture and Food Sovereignty (MASA), which forecasts a 10% reduction in the number of farms between 2020 and 2030, giving a total of 350,000 farms in 2030. The second is the number of farming buildings, which, according to CCR data, has tended to increase historically. However, these two variables are not correlated. To develop the scenario, a 0.1% growth rate per annum was defined by applying the trend in Nat Cat premiums from France Assureurs to the number of buildings and their insured value.

The SIRENE database was used to project the number of industrial stakes and other professional stakes (i.e. services, shops)[12]. Growth is moderate over the 2013-2022 period (+3.3% for industrial stakes and +4% for other professionals).

The increase in insured value was also 4% over the same period for industrial stakes, but fell for other professionals (-1.25% over the same period).

11 - Demographic forecasts Omphale | Insee.
12 - The Sirene register and its distribution.

4.3 - Overseas France

For the 2050 projection of insured property in the French overseas territories, the same methodologies as those presented above have been applied. The difference lies in the increase in insured stakes for private individuals over time. This information is provided by France Assureurs each year. The trend is projected and analysed up to 2050 for each overseas territory covered by the Nat Cat scheme (Guadeloupe, Martinique, Saint-Martin, Saint--Barthelemy, Reunion Island).

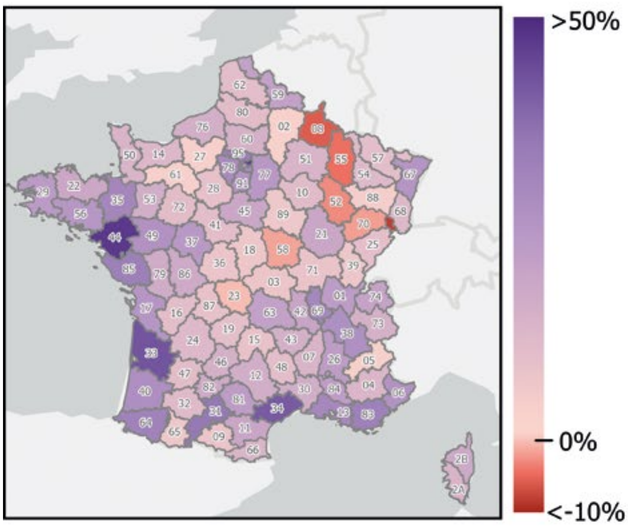
4.4 - Summary

The scenario used includes INSEE projections of the average trend in insured personal property and distinct average trends in insured professional property (+3.3% for industrial property and +4% for other professionals) and their insured values (+4% and -1.25% respectively). This scenario highlights heterogeneous territorial dynamics as shown in Figure 8. As a result, the number of insured properties is expected to grow significantly in certain regions, specifically along the Atlantic and Mediterranean coasts and within the Greater Paris region. Conversely, certain regions, such as specific French departments in the Grand-Est region, may experience a decline in the number of insured properties or remain relatively stable.

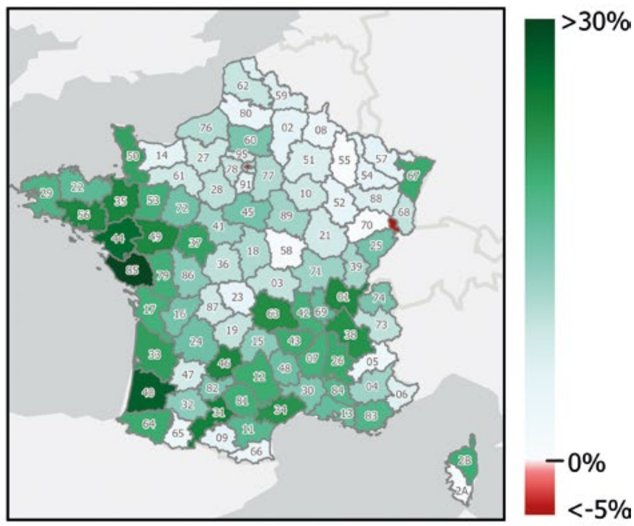
For the 2050 projection of insured stakes, the scenario adopted leads to a 19% increase in the number of insured stakes and a 12% increase in insured values.

Figure 8: Example of the spatialisation of the base case scenario on French territory used in the damage model: change in the number of insured properties and in the insured value (%) by 2050 of the insured properties of private individuals and professionals.

Change (%) in the number of insured stakes between 2022 and 2050



Change (%) in the insured value between 2022 and 2050



5. IMPACT OF CLIMATE CHANGE ON NAT CAT CLAIMS

5.1 - Flooding in 2050

Evolution of the hazard

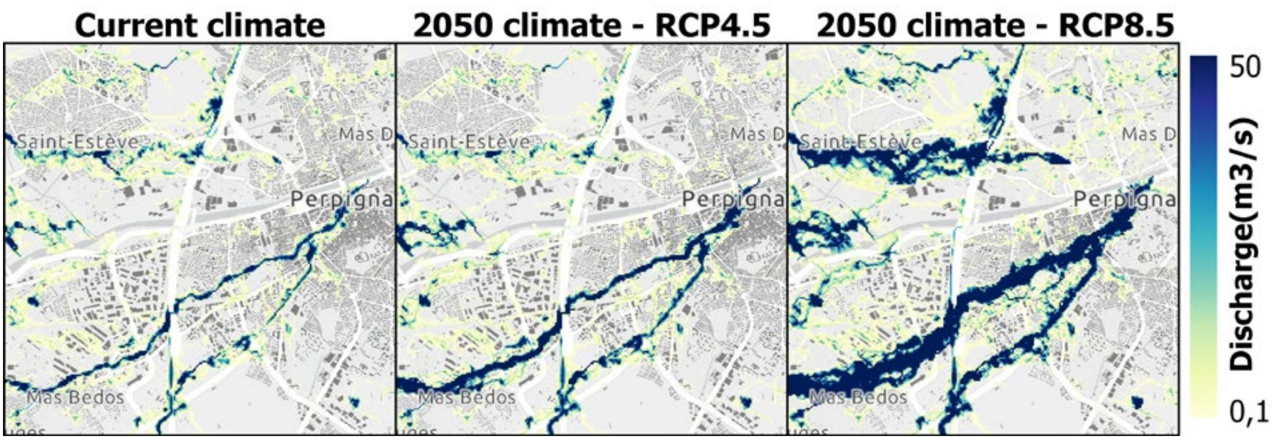
Flood modelling relies on the simulation of numerous meteorological events across 400 potential years. Each of them differs in terms of duration, intensity and geographical location. It is however possible to identify a number of trends by looking at the summary results presented in Table 2.

Table 2: Changes in the scale of the area affected by overflow and run-off and in discharge between Climate 2000 and the future climate, by return period.

	Change in run-off surface		Average change in daily discharge		Change in overflow surface area using	
Return period	RCP 4.5 vs Climate 2000	RCP 8.5 vs Climate 2000	RCP 4.5 vs Climate 2000	RCP 8.5 vs Climate 2000	RCP 4.5 vs Climate 2000	RCP 8.5 vs Climate 2000
20 years	+ 29%	+ 39%	+ 4.4%	+ 0.9%	+ 0.8%	+ 3.3%
50 years	+ 24%	+ 37%	+ 5.6%	- 0.3%	+ 1.6%	+ 2.0%
100 years	+ 19%	+ 33%	+ 5.8%	+ 0.1%	+ 1.8%	+ 2.0%
200 years	+ 12%	+ 14%	+ 7.0%	+ 1.6%	+ 2.1%	+ 1.9%

These results show a significant run-off trend increase. This increase is greater in the RCP 8.5 scenario than in the RCP 4.5 scenario. This result can be explained by the increase in high intensity episodes in the future, but of short duration (i.e. flash floods). Figure 9 (next page) illustrates this trend for the city of Perpignan, where a sharp increase in run-off can be observed for the RCP 4.5 and RCP 8.5 scenarios in areas already impacted by Climate 2000.

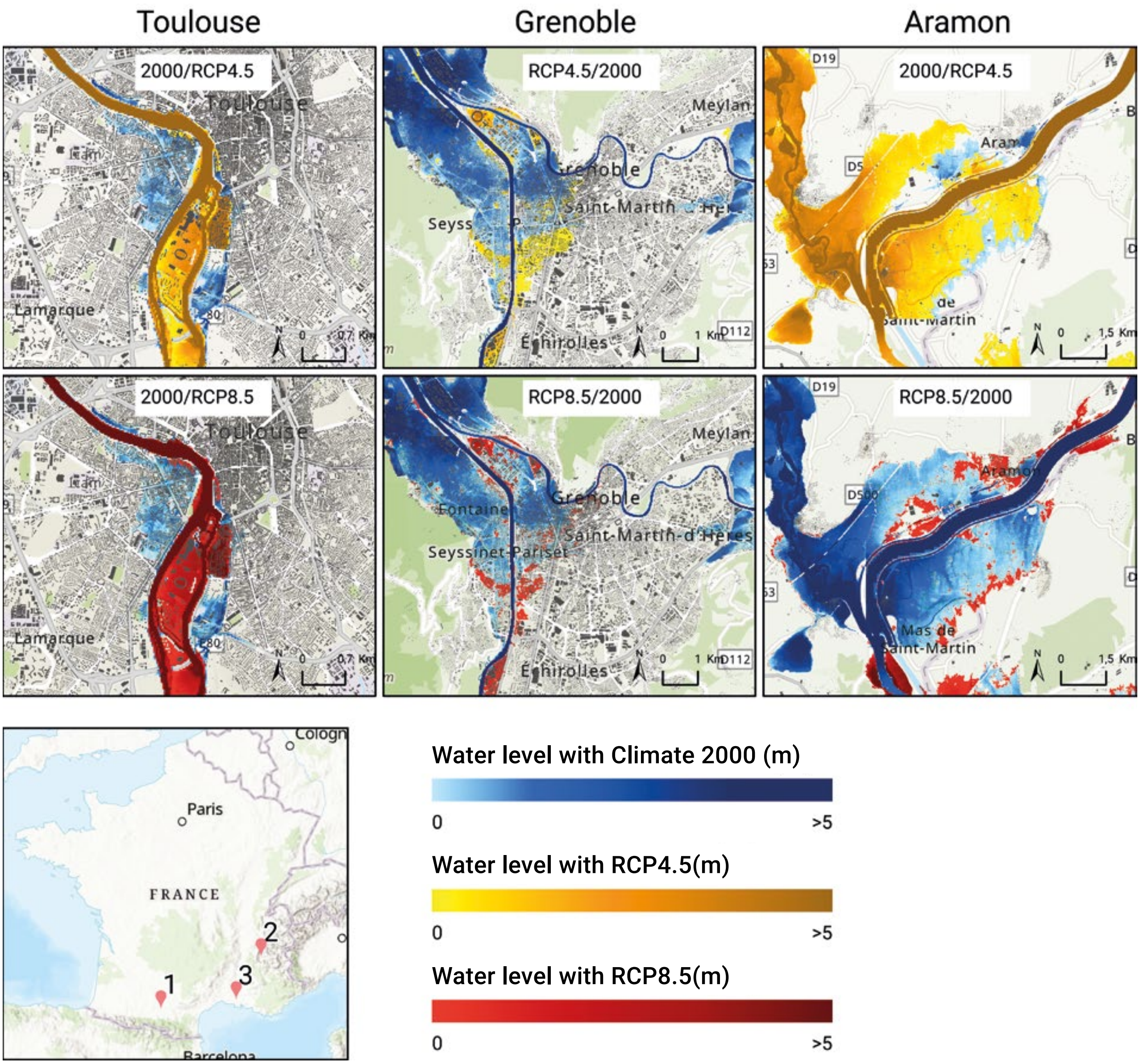
Figure 9: Comparison of flows and areas impacted by run-off for a 50-year return period in Perpignan (66) under Climate 2000 and Climate 2050 (RCP 4.5 and RCP 8.5).



At the same time, the opposite trend can be observed for overflow, with a very slight increase in flooded areas in the future according to the RCP 4.5 scenario and a slight decrease according to the RCP 8.5 scenario. This trend is consistent with the average flow rates shown in Table 2. This increase is greater under RCP 4.5 scenario than under RCP 8.5 scenario, where there is even a decrease for a return period of 50 years. The average change masks contrasting trends between stations. As a result, we often see a reduction in flows on major rivers such as the Seine, the Rhône and the Garonne. This evolution is visible in the RCP 8.5 scenario and to a lesser extent in the RCP 4.5 scenario. This decrease can be explained by a reduction in long-duration rainfall events, which generate slow flooding in some basins.

Figure 10 uses three examples of cities to illustrate the different trends that can be observed, depending on the climate scenario, particularly when looking at long return periods.

Figure 10: Comparison of the areas impacted by overflow under Climates 2000 and 2050 (RCP 4.5 and RCP 8.5) for a 50-year return period for the cities of Toulouse, Grenoble and Aramon.



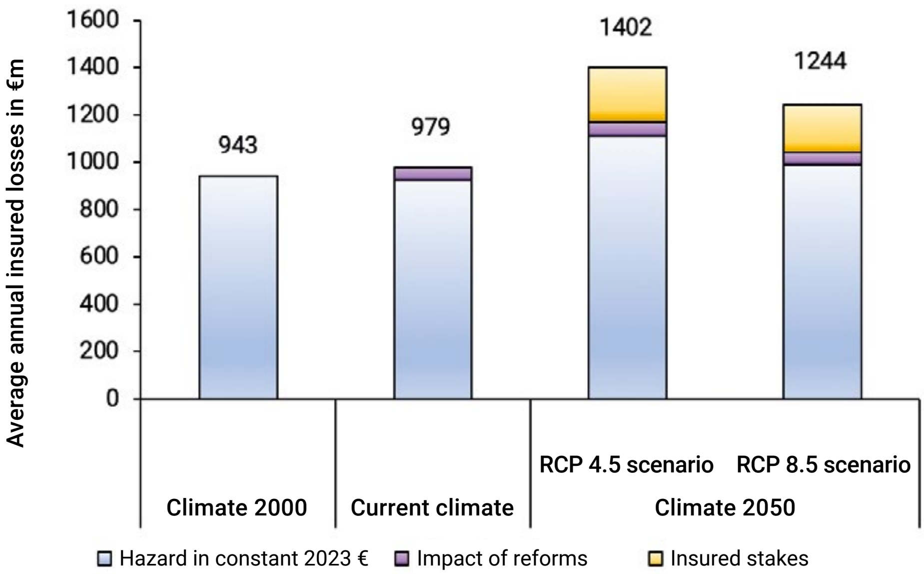
Damage trends

The damage modelling developed by CCR gives an estimate of average annual costs as shown in Figure 11. The simulated average annual insured loss under Climate 2000 amounts to €943 million, factoring in inflation and the motor claims experience. This figure is consistent with CCR's current climate vision, which is based on a historical claims experience. The RCP 4.5 scenario would result in a 19% increase in claims compared with the current climate, considering solely the impact of the hazard. The RCP 8.5 scenario would be less severe (6% increase in average annual insured losses).

This difference in severity can be explained by the overflow hazard, which is less extensive in the latter scenario.

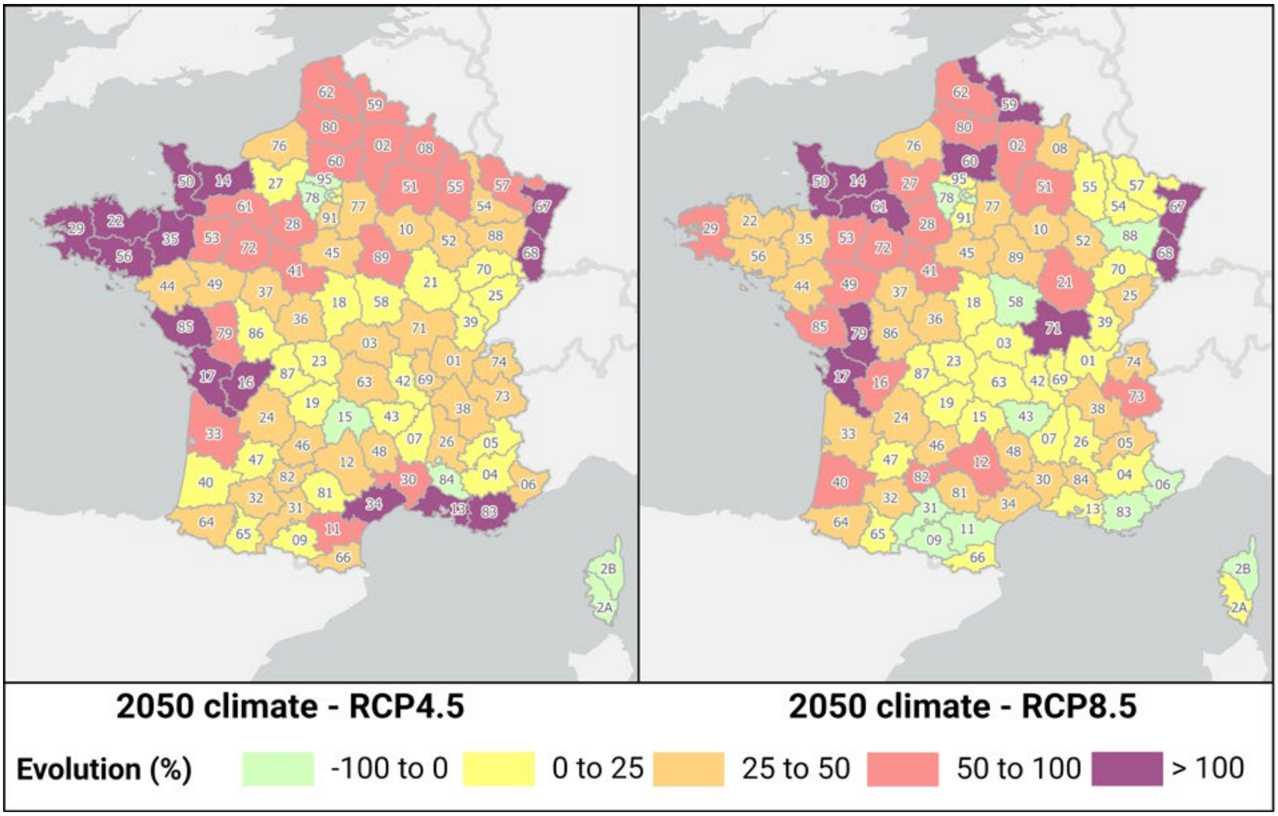
Finally, projecting vulnerability up to 2050 would lead to an additional increase in the average annual cost of damage of around 20%, regardless of the scenario considered. Overall, the increase in damage by 2050 would amount to 43% for the RCP 4.5 scenario and 27% for the RCP 8.5 scenario.

Figure 11: Comparison of average annual insured losses due to floods between Climate 2000, current and future climates (RCP 4.5 and 8.5).



The simulated damage trend maps show different trends between the RCP 4.5 and RCP 8.5 scenarios, although in both cases almost all of France would see an increase in damage (Figure 12). For example, the increase in claims on the Mediterranean arc is greater for RCP 4.5 than for RCP 8.5. The same is true for Brittany and Normandy. In contrast, the Alps are expected to be more affected according to RCP 8.5.

Figure 12: Comparison of changes in average annual insured losses by French department due to flooding between the current climate and Climate 2050 (RCP 4.5 and RCP 8.5).



Climate 2050 is expected to lead to an increase in flash floods caused by intense, short-duration rainfall. It is not possible, however, to identify a uniform trend across Metropolitan France for the flow rates of major watercourses under future climate. The increase in average annual losses due to this hazard could range between 6% and 19% according to the IPCC scenarios. The increase in insured property could lead to an additional 20% rise in damage under the two IPCC scenarios.

5.2 - Coastal flooding in 2050

Evolution of the hazard

Currently, coastal floodings are less frequent compared to floods triggered by overflow and run-off. The peak of a tide with high coefficients and the formation of a low-pressure system must coincide to generate a significant event. A 400-year sample is therefore insufficient to characterise the most extreme flooding events that could occur.

The results presented in Table 3 show the evolution of submerged surfaces between Climates 2000 and 2050. In the RCP 4.5 scenario, the flooded areas increase by around 15%, regardless of the return period. However, according to the IPCC RCP 8.5 scenario, flooded areas are greater for events with a very high return period (>100 years). This increase is thus mostly related to sea level rise. It is also influenced by the selection of rare scenarios in the simulation set, each of which affects different sections of the coastline.

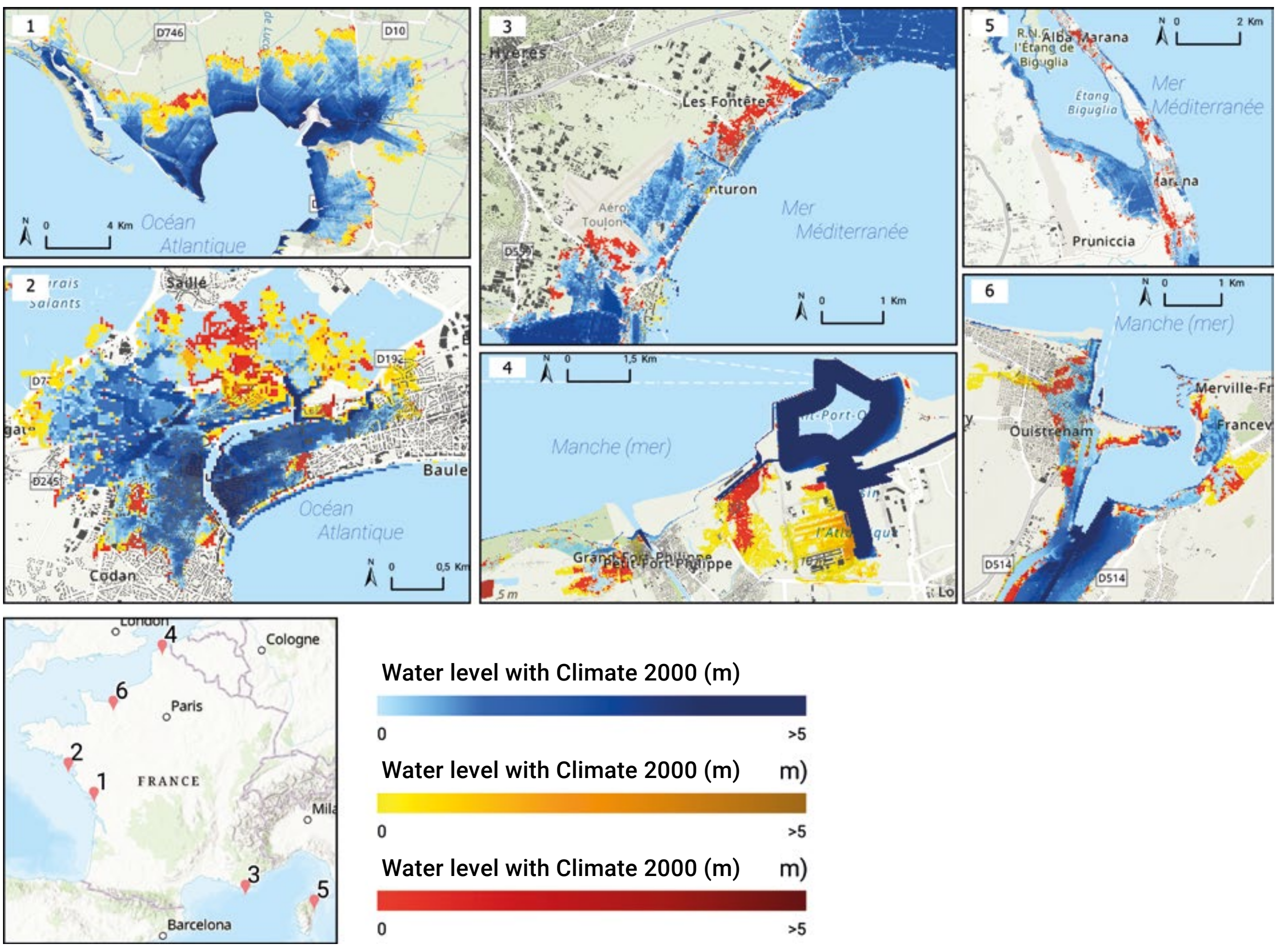
Table 3: Variations in the scale of submerged areas between current and future climates, by return period.

Return period	Changes between future RCP 4.5 climate and Climate 2000	Changes between future RCP 8.5 climate and Climate 2000
20 years	+ 15.6%	+ 15.4%
50 years	+ 15.1%	+ 15.5%
100 years	+ 15.0%	+ 24.9%
200 years	+ 14.7%	+ 27.0%

A geographical analysis of the results shows that, depending on the RCP scenario, the most exposed areas may not be identical. Indeed, for a 50-year return period, the RCP 4.5 scenario is more severe in the English Channel than the RCP 8.5 scenario, which is itself more severe in the Bay of Biscay and in the Mediterranean region (Figure 13). Given the infrequency of these events, the analysis of these results is hampered by a sampling effect, and it is not possible to conclude that there are general trends towards greater increases than others in certain sectors, depending on the scenario.

However, it can be said that rising sea levels are likely to significantly expand the areas vulnerable to coastal flooding by 2050.

Figure 13: Illustration of simulated flooding for the three climate scenarios on 6 coastal sectors for a return period of 50 years for Climate 2000 and Climate 2050 (RCP 4.5 and RCP 8.5).



Damage trends

The average annual damage simulated for Climate 2000 is €68m, including the effect of the Baudu Law, which is close to the current climate version. The RCP 4.5 scenario is projected to result in a 91% increase, while the RCP 8.5 scenario is expected to lead to a 75% increase in average annual claims compared to the current climate.

Although the RCP 8.5 scenario appears to be somewhat less severe than RCP 4.5 concerning average annual costs, it exhibits greater severity for the highest return periods (beyond 50 years). This result should be compared with the trends observed for hazards (Table 3), which clearly explain this distribution of costs. By projecting insured values to 2050, the disparity between the two scenarios would narrow down, resulting in an increase in losses of approximately 110% in both cases.

Figure 14: Comparison of average annual insured losses due to coastal floodings between Climate 2000, current and future climates (RCP 4.5 and RCP 8.5).

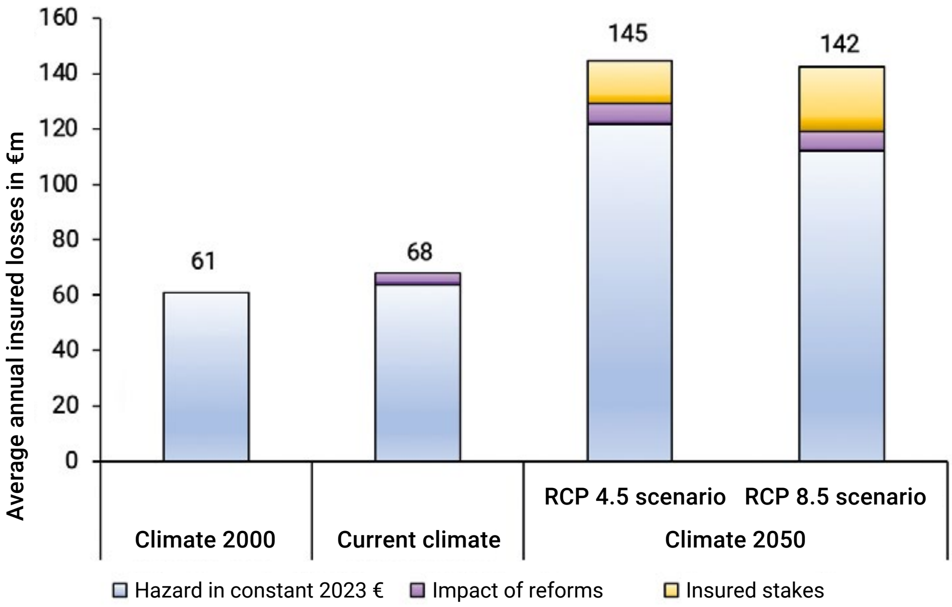
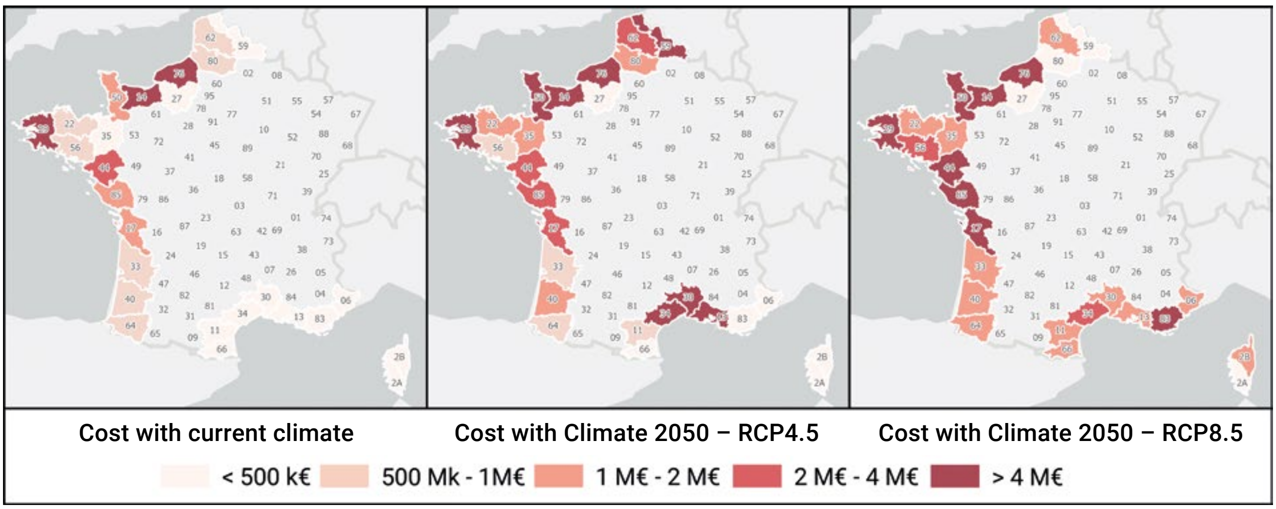


Figure 15 shows the breakdown of average annual insured losses by French department simulated by the model. A substantial surge in damage is expected to impact the majority of French departments by the year 2050. However, the increase varies according to each scenario. Under the RCP 4.5 scenario, a more pronounced escalation in damage is anticipated in the English Channel and North Sea, whereas under the RCP 8.5 scenario, increased damage is expected in the Bay of Biscay. The Mediterranean would also see a significant increase in simulated damage, particularly under the RCP 8.5 scenario. As noted earlier, it is advisable to exercise caution when interpreting the differences between the two 2050 scenarios, considering the limited timeframe and the infrequent occurrence of coastal flooding. In addition, sea level rise is likely to lead to a very significant increase in damage.

Figure 15: Comparison of simulated average annual insured damage by French department for current climate scenario (left), 2050 - RCP 4.5 (centre) and 2050 - RCP 8.5 (right).



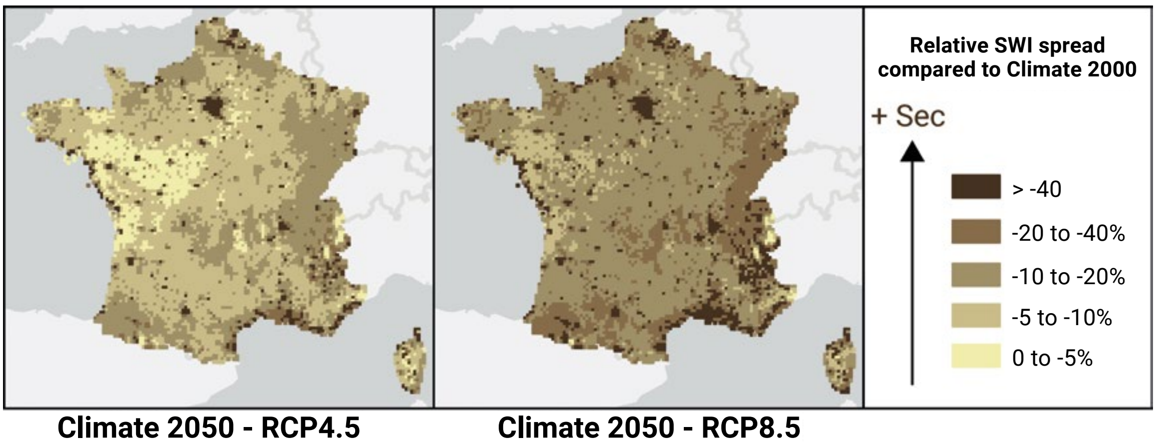
Rising sea levels are expected to lead to a significant increase in average annual damage (between 75% and 91%). Due to the rarity of this phenomenon, it is more difficult to identify a change in the frequency and intensity of meteorological depressions that would lead to an increase in the modelled claims experience. The increase in the number of insured goods along the coast would further accentuate the damages.

5.3 - Geotechnical droughts by 2050

Evolution of the hazard

The outcomes for geotechnical drought show widespread drying throughout Metropolitan France by 2050 (see Figure 16). The water deficit observed is notably high under the RCP 8.5 scenario. On average across Metropolitan France, the annual minimum SWI falls by 20% under the RCP 4.5 scenario and by 40% under the RCP 8.5 scenario. In addition, the results presented in Figure 16 show that the Mediterranean region is overexposed to the risk of geotechnical drought.

Figure 16: Difference of the mean minimum annual SWI between Climate 2050 and 2000 (RCP 4.5 and RCP 8.5).



Extreme events become more intense. Indeed, the water deficit during ten-year, twenty-year, and fifty-year droughts is projected to be approximately 10% higher in a future RCP 4.5 climate compared to the climate of 2000. Meanwhile, in a future RCP 8.5 climate, the water deficit is expected to be around 20% higher than under Climate 2000. **Droughts such as those of 2003 and 2022 would see their return period significantly reduced in the future** (Table 4).

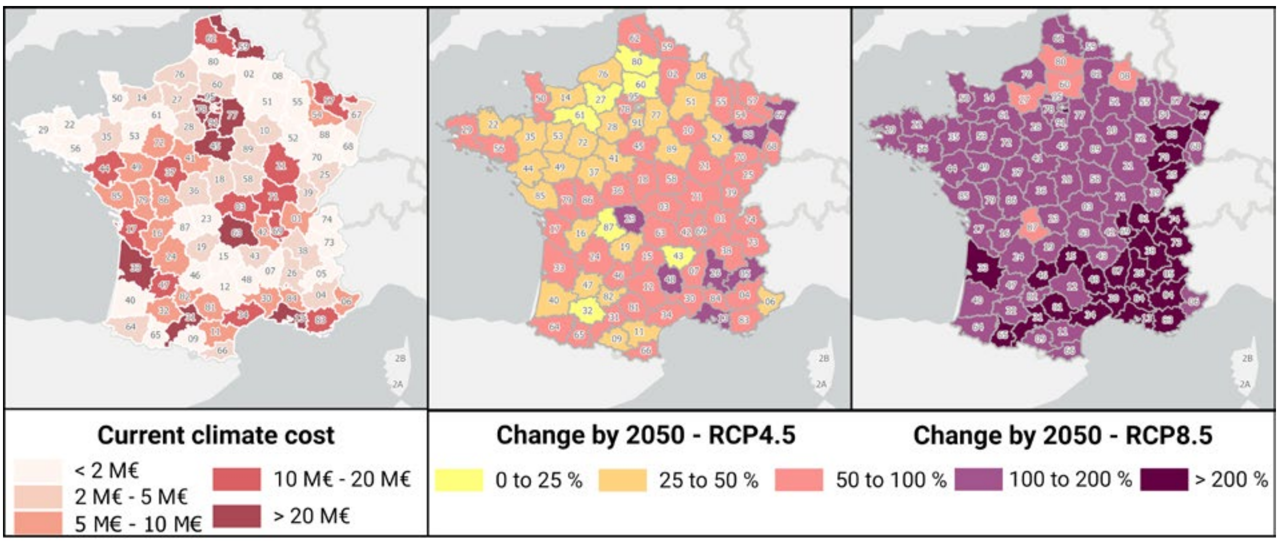
Table 4: The return period for extreme droughts akin to those in 2003 and 2022 is analysed for Climate 2000, the current climate, and future scenarios (RCP 4.5 and RCP 8.5).

	Climate 2000	Current climate	2050 horizon - RCP 4.5	2050 horizon - RCP 8.5
2023 drought return period (years)	27	12	8	4
2022 drought return period (years)	44	25	12	6

Damage trends

Figure 17 shows the breakdown by French department of the average annual cost of damage caused by the clay shrink-swell phenomenon. In today's climate, the greatest damage are located in central and southern France, where clay soils are most prevalent. In terms of future climate, regardless of the simulated IPCC scenario, damage increases significantly throughout Metropolitan France. Under the RCP 4.5 scenario, it is projected that average annual losses would surge by 50% to 100% in the southern half of France and the eastern regions. Conversely, the north-western quarter is expected to experience a more moderate increase in damage. Under the RCP 8.5 scenario, average annual losses are projected to double across nearly the entire territory. The southern regions of France are anticipated to face pronounced exposure, with average annual damages projected to increase by at least 3 times.

Figure 17: Breakdown of average annual costs due to geotechnical drought by French department in Metropolitan France in today's climate (left). Changes in the cost of drought between the current climate and Climate 2050 - RCP 4.5 (centre) and Climate 2050 - RCP 8.5 (right).

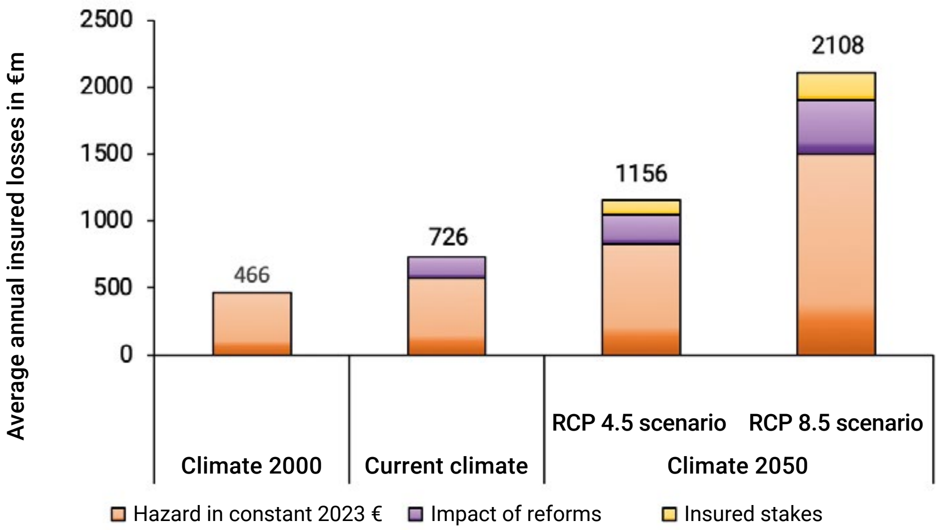


The rise in the cost of damage due to extreme events is also notably significant. The cost of damage resulting from a five-year drought, according to the RCP 8.5 scenario, would indeed amount to €7.5 billion, representing a 40% increase compared to the current climate.

Figure 18 shows the change in average annual insured losses in mainland France between Climate 2000, the current climate and the future climate according to the two IPCC scenarios. Recent years have been marked by an unusual sequence of droughts. Thus, between the current climate and Climate 2000, the rise in damage solely attributed to the impact of the hazard is 23%.

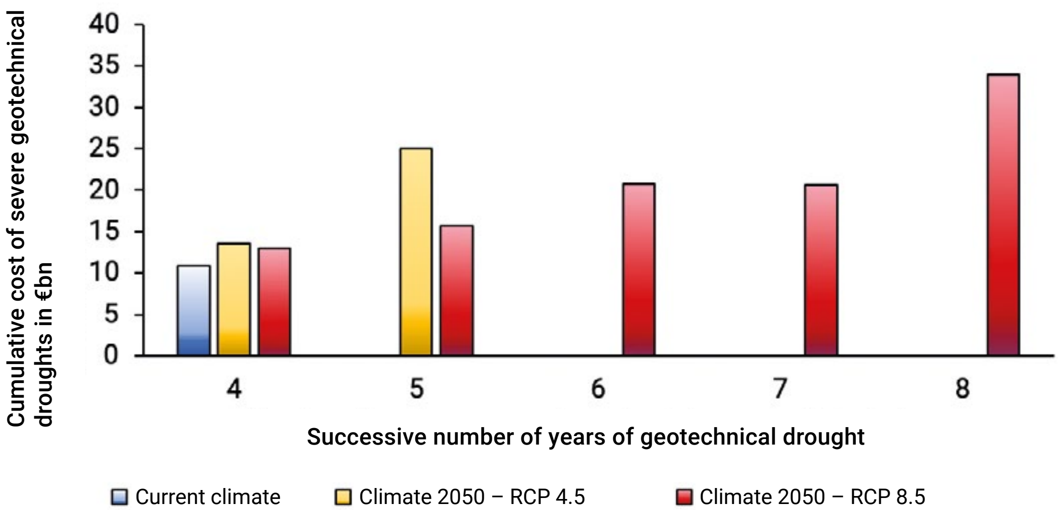
In addition to this impact, the 3DS reform has led to greater compensation for risk related to clay shrinkage and swelling. Therefore, considering the influence of the reforms, the average annual damage sees a substantial increase (+56%) from the current climate to Climate 2000. In the future climate, as a result of increased exposure to the risk of drought, and an increase in the number of properties insured in high-risk areas, average annual losses increase by 59% between the current climate and 2050 in the RCP 4.5 scenario, and by 190% under the RCP 8.5 scenario.

Figure 18: Comparison of average annual insured losses due to geotechnical drought between Climate 2000, current and future climates (RCP 4.5 and RCP 8.5).



The frequency of drought cycles, wherein each year incurs a cost exceeding €1 billion, rises with the projected future climate, as illustrated in Figure 19. If we consider a single four-year cycle for which the cost is greater than €1bn in current climate, it is forecasted that there would be four such cycles by 2050 under the RCP 4.5 scenario and nine under the RCP 8.5 scenario. Drought cycles are expected to lengthen; for example, under the RCP 8.5 scenario, there could be up to eight successive years of intense drought, an unprecedented cycle in past observations. A multi-year drought of such magnitude would result in cumulative costs of €34 billion over 8 years, averaging around €4.2 billion per year.

Figure 19: Cumulative costs of intense multi-year droughts (4 consecutive years or more) on the current climate and in the future (RCP 4.5 and 8.5).

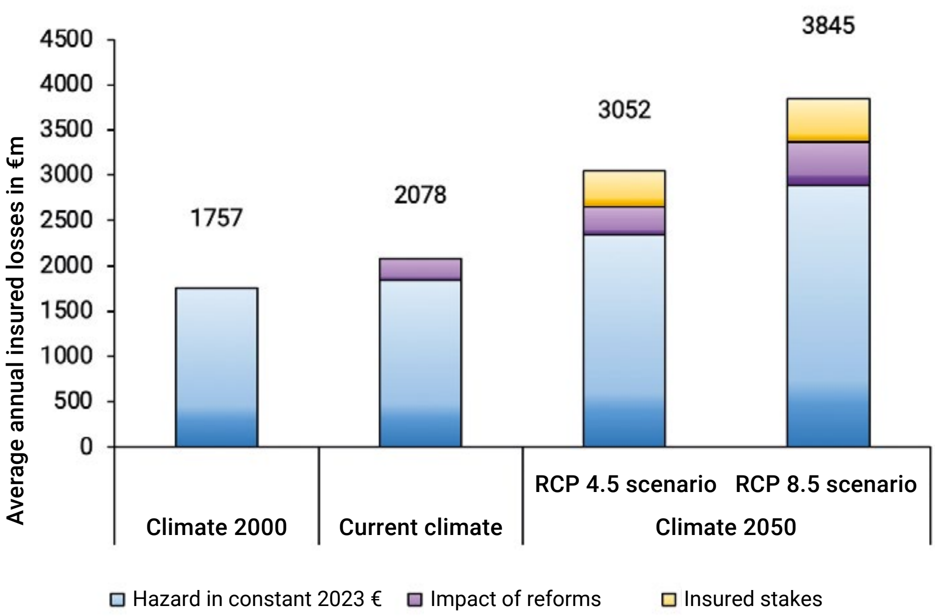


The risk of geotechnical drought will increase in the future, with greater exposure across Metropolitan France. The increase in average annual losses due to this hazard would range between 44% and 162% according to the IPCC scenarios. Projecting the insured stakes into the future accentuates these changes.

6. COST ASSESSMENT OF CHANGES IN MULTIPERIL LOSSES

To consider all the perils covered by the natural catastrophe compensation scheme, a multiperil analysis of damage, including earthquakes and cyclones, is carried out. This damage assessment is shown in Figure 20. It shows a rise in damage ranging from 27% to 62%, attributable solely to the hazard. The projection of insured stakes up to 2050 shows an increase in average annual claims ranging from 47% to 85% (i.e. an additional 20% increase). The amount of damage is expected to exceed €3 billion in 2050 regardless of the IPCC RCP scenario considered. It is important to note that the escalation in damage is closely correlated with the heightened exposure of Metropolitan France to the risk of geotechnical drought, which is experiencing a notable increase in both frequency and intensity

Figure 20: Comparison of average annual insured losses for all perils between Climate 2000, current and future climates (RCP 4.5 and 8.5).



The significant surge in average annual losses conceals an even greater increase in extreme losses. Analysis of intense droughts such as that of 2003 shows that their frequency will triple in the future under the RCP 8.5 scenario. In addition to these increases in frequency and intensity, projections show a growing number of multi-year events.

7. A NEED TO STRENGTHEN CLIMATE RISK PREVENTION TO LIMIT THE INCREASE IN LOSSES

As France undertakes measures to adapt to climate change - illustrated by initiatives like the proposed Reference Warming Trajectory for Adaptation to Climate Change (TRACC) - **it becomes imperative for natural risk prevention policies to consider potential shifts in response to this looming threat.**

Over the past twenty-five years, a series of risk prevention tools have already helped to mitigate the consequences of catastrophes. The results presented in this modelling study partly take into account, implicitly, the impacts of these past investments in reducing the cost of natural catastrophes. For example, without the Flood Risk Prevention Plans (PPRi) that have been in place since 1995, it is anticipated that the annual cost of flooding could surge by several hundred million euros by the year 2050[13]. However, most of the measures, such as the PPRi or the Flood Prevention Action Programmes (PAPI), produce their effects over time.

The long-term impacts of the prevention efforts undertaken in recent years, along with the continued implementation of prevention measures in the future, will help in mitigating the projected increase in damage by 2050. For instance, sustaining the existing level of investment by the fund for the prevention of major natural hazards (in french FPRNM) in reinforcing hydraulic structures (€96 million/year) would potentially curtail the estimated average annual loss by 2050, as indicated in a prior study[14], to €130 million. The provisions outlined in the ELAN Law regarding the construction of new homes in clay soil zones, effective since 2020, are anticipated to result in annual savings of approximately €100 to €200 million in claims related to geotechnical drought.

13 - Caisse Centrale de Réassurance (2023), Efficacité des Plans de Prévention des Risques d'inondation sur le coût des dommages assurés : estimation des impacts passés, présents et futurs.
14 - Caisse Centrale de Réassurance (2022), Rapport au ministre de l'Économie, des Finances et de la Souveraineté industrielle et numérique sur le régime d'indemnisation des catastrophes naturelles.

These figures fall nonetheless short of the expected increase in claims between now and 2050: **simply extending current efforts to prevent natural hazards will not be enough to stem the rise in the cost of damage from natural catastrophes between now and 2050.** To counter this rise, prevention policy requires increased financial resources, and probably needs to be reshaped in several respects. While some adjustments have been made to consider rising sea levels, this remains an isolated example.

Initially, **prevention policy must adapt to shifts in the relative weight of threats**. Whereas historically, flooding was the main threat in terms of observed damage, geotechnical drought appears to be the most worrying threat in the future. Therefore, **formulating a drought prevention policy is crucial**, emphasizing attention not only on new constructions but also on the existing building stock, with a specific focus on the most vulnerable structures.

In terms of flooding, the study emphasizes a notable surge in run-off phenomena across a significant portion of the territory. Until now, flood prevention policy has focused primarily on overflows. If efforts to prevent flooding are to be sustained, at the very least to maintain the current level of protection, **it would appear necessary to consider a prevention policy that specifically addresses the issue of run-off**. This implies concentrating efforts on small watercourses and vulnerable urban areas to adapt them to high-intensity but short-duration events. This could lead to a more scattered distribution of the investment required.

On the whole, the changes in climate and the consequences of natural catastrophes considered in this study, and particularly the uncertainty surrounding them, suggest that it is worth **questioning all the existing measures for preventing natural hazards**. The aim of such a review would be to identify which prevention strategies need to be adjusted and to outline the methods and timeline for implementing these adaptations. For instance, the methodology used for creating hazard maps in risk prevention plans should be scrutinised to incorporate anticipated changes, along with standards, funding mechanisms, and governance approaches. This analysis raises some delicate questions. For example, should preventive measures be based on the most unfavourable climate scenario, potentially leading to over-sizing regulatory constraints or investments? Our study shows that developments will not necessarily be uniform across the metropolitan area: as a result, the choices made in response to the various questions raised could be based on different local approaches.

Natural risk prevention policy is being challenged by the various possible changes in the climate. It is essential to consider **our ability to deal with such changes if we are to contain the impact of an increase in the intensity and frequency of certain extreme natural phenomena**.

8. DISCUSSION ON METHODOLOGY

The aim of this study is to estimate the impact of climate change on the three main types of damage (floods, coastal flooding, drought) under the Nat Cat scheme until 2050.

To do so, we used meteorological data supplied by Météo-France, which represents 400 years of data for Climate 2000 and Climate 2050 on wind, precipitation, atmospheric pressure and soil wetness. Climate 2050 data incorporates two IPCC climate change scenarios: RCP 4.5 (median scenario) and RCP 8.5 (pessimistic scenario), with reality probably lying somewhere between the two.

This study also aims to estimate the Nat Cat all-perils claims experience up to 2050. This is why it also takes into account earthquakes that are not affected by climate change and cyclonic winds in today's climate.

It does not include damage caused by perils not covered by the Nat Cat scheme (namely storms and hail), or damage caused by events that would not get Nat Cat recognition (namely floods and drought of normal intensity).

Certain perils covered by the Nat Cat scheme are also not taken into account like volcanism, landslides and avalanches (phenomena that account for a very small proportion of historical claims).

- We have chosen to work solely with data from Météo-France, which has the advantage of covering a period of 400 years, and to study two climate change scenarios RCP 4.5 and RCP 8.5. The ARPEGE model of Météo-France encounters challenges in accurately reproducing potentially significant non-linear phenomena, such as glacier melting.
- For geotechnical drought, an R&D version of the Météo-France SIM model was used. This version differs from the version of the SIM-uniform model used for the Nat Cat recognition criteria. However, a new version of the ISBA surface module is about to be integrated by the Nat Cat commission. This new version will be closer to the chain used for the study.
- Moreover, the year 2022, characterised by extreme drought, has not been factored into the calibration of the CCR models.

This study provides a snapshot that considers the data and knowledge available to us to date. It incorporates current regulations and anticipated changes to Nat Cat recognition criteria, in particular the implementation of the 3DS Drought Decree.

It also takes into account changes in the insured stakes, i.e. changes in the population and the number of businesses, which logically increase the quantum of claims. However, it does not include any inflation projections to 2050 or changes in insured values.

9. CONCLUSION AND OUTLOOK

While CCR's operational activity in the field of natural catastrophe compensation requires the modelling of risks in today's climate, particularly for provisioning and pricing purposes, forecasting the potential impacts of climate change is essential to estimate future changes in claims experience and to put forward the required adaptation measures.

Building upon the studies conducted in 2015, 2018, and 2020, this study serves as a consolidation of the work carried out within CCR on the issue of climate change. It incorporates recent advances in terms of damage modelling, as well as the impacts of recent and ongoing reforms to the scheme (Baudu Law and 3DS Decree).

IPCC's RCP 8.5 scenario provides an upper bound for the impacts of climate change by 2050. The RCP 4.5 scenario remains a target, but it could be exceeded if greenhouse gas emissions are not brought under control in the coming years.

This new study therefore provides a framework for the expected increase in the claims ratio by 2050 as a result of climate change. It is forecasted to range between 27% and 62% depending on the RCP scenario considered. In addition to this increase, one must consider the impact of the rise in insured stakes, resulting in an anticipated increase in claims ranging between 47% and 85%. If the RCP 4.5 scenario represents the median projection, it can be estimated that, on average, the increase in claims should be around 40% solely due to climate change and approximately 60% when accounting for changes in insured stakes.

This new study also provides a mid-term assessment of the 2000-2050 period. It objectively assesses the claims drift already observed as a result of climate change since 2000, particularly in terms of geotechnical drought. For instance, model estimates indicate that the number of claims due to drought has already increased by 23% since 2000 solely due to climate change. This increase must be combined with the effects of the Baudu and 3DS laws, which led to a 56% increase in drought claims.

This report confirms the need to implement a series of adjustments to ensure the sustainability of the scheme, which contributes to the resilience of the French economy and its regions.

Of course, these results show the need to continue the prevention efforts that have been underway for many years, and which are yielding results, especially in mitigating flooding from overflow. They also show the need to develop the prevention of run-off risk, which is likely to increase sharply due to the increase in extreme storm phenomena, but above all due to geotechnical drought on existing buildings, with the ELAN Law making it possible to limit the risk on new constructions, which only represent a small portion of the stakes.

Another approach to adapting the scheme is to realign the criteria for recognising the state of natural catastrophe with the original legislative principle, ensuring that only events of abnormal intensity are covered. The impacts of frequent events could be controlled by developing prevention or, where appropriate, by having the private market cover it.

Finally, the drift already observed in the claims experience and the forecasts for 2050 show the need to review how the scheme is financed by adjusting the Nat Cat additional premium to enable the scheme to return to technical equilibrium and for CCR to fully play its role as a shock absorber. The necessary increase is estimated at +7pp in the short term, followed by a further 3-pp increase to take account of future climate change between now and 2050.

Of course, there are still uncertainties surrounding this work. CCR will pursue its studies on climate change in collaboration with its long-standing partners, with Météo-France at the forefront, aiming to lower these uncertainties and enhance the precision of its forecasts. Examples of possible improvements include the use of a multi-model approach to compare different views of risk, an increase in the number of simulations to reduce sampling bias and better capture extreme events, and projections beyond 2050 to better grasp the differences in impacts between the various greenhouse gas emission trajectories, which become progressively more pronounced in the second half of the 21st century, working according to levels of warming corresponding to the TRACC rather than a given timeframe. Finally, it would be interesting to analyse the impact of climate change on damage caused by events not currently covered by the Nat Cat scheme (hail, crop losses in agriculture, direct and indirect farming losses). This analysis could help the French State in its deliberations on the management of extreme risks.

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Fonds cartographiques :

Figure 4 : Esri, Intermap, NASA, NGA, USGS, HERE, Garmin, Foursquare, FAO, METI/NASA, Instituto Geográfico Nacional, GeoTechnologies, NOAA

Figure 3,5,6,7,12,15,16,17 : Esri, Garmin, FAO, NOAA, USGS

Figure 9, 10: ICGC, Instituto Geográfico Nacional, Esri, HERE, Garmin, Foursquare, GeoTechnologies, METI/NASA, USGS, Intermap, NGA,

Figure 13 : OpenStreetMap (and) contributors, Esri, Intermap, NASA, NGA, USGS, HERE, Garmin, Foursquare, FAO, METI/NASA, GeoTechnologies

We dedicate this report to David Moncoulon, Head of CCR’s R&D and Modelling Department, who passed away last July.

David Moncoulon and his team made a major contribution to this study and, more generally, to the understanding of natural catastrophes in France. This knowledge and understanding are essential for today and the future.

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