CCR 2021
SCIENTIFIC REPORT

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CCR develops natural catastrophe impact models in partnership with leading scientific organisations in France and Europe.

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CCR RÉASSUREUR PUBLIC

« CCR IS PURSUING ITS MODELLING EFFORTS TO SUPPORT STATE RISK MANAGEMENT. »

ANTOINE QUANTIN,
Chief Underwriting Officer, Public Reinsurance & Guaranty Funds

As an essential link in the State's risk management system, CCR has been equipped for many years with a modelling chain that allows it to translate the intersection of a hazard, whether natural or man-made, with economic stakes into a financial impact.
This platform is essential for the efficiency of the compensation and risk prevention systems and to support the State in its reflections on the management of extreme risks. It has been developed and enriched over the years thanks to scientific partnerships with leading players in France, whether research centres, universities, or *Grandes Écoles*. Through these partnerships and feedback from events, CCR's research and development teams contribute to the ongoing improvement of the models and their relevance.
Given CCR's central role in covering natural catastrophe risks, our efforts are focused primarily on the latter. This is all the more necessary in a context of climate change, the first effects of which are now being felt, to quantify and if possible, reduce the many uncertainties.
2020 was thus shaped by numerous developments in the field of natural catastrophe modelling, with in particular the submission of two PhD theses, which were brilliantly presented in early 2021. Beyond France, CCR has also developed a flood impact model in Morocco for the FSEC (*Fonds de solidarité contre les événements catastrophiques*) in the framework of a call for projects submitted by the World Bank, showing CCR's implication in international cooperation.
But the platform developed by CCR has shown its value far beyond natural catastrophes. In the current pandemic context, CCR has been heavily involved in modelling the economic impacts of a pandemic in order to support the public authorities' thought process on the possible introduction of a non-damage business interruption cover scheme. Extensive studies have also been carried out to improve knowledge of the impacts of climate risks on crops in current and future climates. Here again, the results obtained are valuable to support the public authorities' thought process on the major issue of risk management in agriculture for our country.
This innovation capacity will be essential to meet the challenges facing public action and to grasp new opportunities in its field of action. The challenge is therefore to continue and extend CCR's research activities to inform public authorities, our partners and insurance companies. /

CONTENTS

« CCR'S STRATEGIC PLAN REINFORCES THE KEY ROLE OF MODELLING. »

DAVID MONCOULON,
Head of Department R&D Modelling -Cat and Agriculture- Public Reinsurance and Guaranty Funds Division

For the 2020-2025 period, CCR recently adopted a new strategic plan. This plan confirms the essential role of modelling both for steering the natural catastrophe compensation scheme and for supporting the public authorities in managing major risks, whether in terms of compensation or prevention.

CCR is thus strengthening its role as an expert in assessing the economic consequences of catastrophes and as a contributor to the French government's risk management. To fulfil these missions, CCR has set two major objectives for its modelling platform:

- on the one hand, to industrialise and automate model development processes, in order to facilitate the integration of new risks or new applications;
- to maintain the scientific relevance of the models, through research and development activities, in particular the co-supervision of doctoral theses in partnership with leading laboratories, thus ensuring the training of tomorrow's experts.

The year 2022 will thus be shaped by the beginning of a thesis on the risk of geotechnical drought - shrinking and swelling clay soils, in partnership with Météo-France and BRGM. The three aspects of the occurrence of a SSC claim will be addressed: the weather component, the soil component and the building vulnerability component. This thesis will continue until 2024.

In the field of seismic risk modelling, a new thesis will be set up with the *École Nationale Supérieure de Géologie of Nancy*. It is a continuation of previous research on the development of a stochastic earthquake generator for the French territory. It will focus on the dynamics of seismic wave propagation on the territory after an earthquake, in particular through physical modelling.

In the field of risk modelling in the French Overseas Territories, CCR intends to acquire an automated processing chain to carry out an anticipated assessment of damage in the event of cyclonic events which may reach the islands.

In addition, in partnership with RTE (*Réseau de transport électricité*), CCR will produce a study on the exposure of the French network to the risk of flooding in the current climate and in 2050 climate. This work will provide new insights into financial exposure in the event of a major event.

Finally, CCR will continue to support the public authorities' discussions on risk management in agriculture, following on from the work carried out during the *Varenne de l'eau*. The third year of a thesis on the subject in partnership with Agrocampus Ouest and Météo-France is coming to an end and the work will continue in 2022, particularly on the risk of frost. /

FLOOD RISKS AND COASTAL FLOADING

On 3 October 2020, flood waters broke over Saint-Martin-Vésubie in the south-east of France, after the heavy rains and floods that just hit the Alpes-Maritimes.

Immediate prediction of flash flood impacts • p.07

Flash floods are difficult to anticipate events that causes heavy damage and human life losses, especially in south-eastern France. In this context, the PICS research project aims to design and test forecasting systems designed to estimate flood impacts with up to 6 hours of anticipation.

Les phénomènes de crues soudaines sont des événements difficiles à anticiper qui engendrent très régulièrement de lourds dommages et des pertes de vies humaines, notamment dans le sud-est de la France. Dans ce contexte, le projet de recherche PICS vise à concevoir et à expérimenter des systèmes de prévision capables de représenter les impacts des crues avec jusqu'à 6h d'anticipation.

Jean-Philippe Naulin and Olivier Payrastre

Modelling rainfall runoff • p.11

CCR's experience in damage analysis and flood modeling has demonstrated that flood claims were not only due to river overflows. The hypothesis raised here is that a significant amount of damage is actually resulting from rainfall runoff.

L'expérience de CCR en termes d'analyse des dommages et de modélisation des inondations, a démontré que les sinistres n'étaient pas uniquement dus aux débordements de cours d'eau. L'hypothèse soulevée ici est donc celle de dommages consécutifs au ruissellement pluvial.

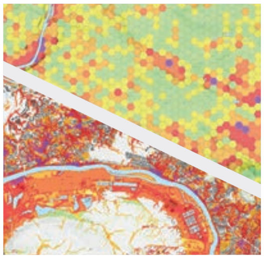
Thomas Onfroy and David Moncoulon

Modelling financial losses due to the risk of flooding in Morocco • p.17

In 2020, a consortium composed of CCR, Risk Weather Tech and Atmoterra has been developed to model the flood risk exposure of Morocco, in the frame of a project funded by the World Bank.

En 2020, un consortium composé de CCR, Risk Weather Tech et Atmoterra s'est formé afin de modéliser le risque d'inondation au Maroc, dans le cadre d'un projet financé par la Banque Mondiale.

David Moncoulon, Jean-Philippe Naulin, Thomas Onfroy, Roxane Marchal, Thomas Guedez
With the contribution of Abderrahim Chaffai and Abderrahim Oulidi



Summary mapping of the impact of floods in Metropolitan France • p.22

In 2020, CCR produced a summary map, homogeneous on the metropolitan territory, representing the impact of flooding phenomena by overflow, storm runoff and marine submersion. The map is based on a multicriteria analysis result of geomatics process, has been obtained from the intersection of a historical loss indicator based on both CCR probabilistic flood hazard modeling and on an analysis of the territories vulnerability to flooding.

CCR a produit en 2020 une cartographie de synthèse, homogène sur le territoire métropolitain, représentant l'impact des phénomènes d'inondation par débordement, ruissellement pluvial et submersion marine. Résultat d'une analyse multicritères issue de traitements géomatiques, elle a été obtenue à partir du croisement d'un indicateur de sinistralité historique et d'un indicateur de sinistralité potentielle, basé sur la modélisation probabiliste de l'aléa inondation et sur une analyse de la vulnérabilité.

Thomas Onfroy and Nathalie Orlhac

Analysis of uncertainties in the coastal flooding hazard model • p.30

This PhD research is based on the development of a method based on metamodelling in order to analyse the uncertainty and sensitivity of models for estimating flooded areas during marine submersions. The metamodel is based on a kriging method coupled with a functional PCA. It was applied to two impact models implemented in the Boucholeurs area, flooded by Xynthia in 2010. This method can be applied to other hazards such as floods.

Ce travail de thèse repose sur le développement d'une méthode basée sur la métamodélisation afin d'analyser l'incertitude et la sensibilité de modèles d'estimation des zones inondées lors de submersions marines. Le métamodèle repose sur une méthode de krigeage couplée avec une ACP fonctionnelle. Il a été appliqué sur deux modèles d'impact mis en œuvre dans la zone des Boucholeurs, inondée par Xynthia en 2010. Cette méthode peut être appliquée sur d'autres périls tels que les inondations.

Élodie Perrin Tran Vi-vi and Jean-Philippe Naulin

Immediate prediction of flash flood impacts

Jean-Philippe Naulin[1], Olivier Payrastre[2]
(1) Cat & Agriculture Risk Modelling R&D Department, CCR
(2) Université Gustave Eiffel

INTRODUCTION

France is regularly hit by flash floods that cause significant damage and can result in casualties. Floods costed €554 million per year on average in insured losses between 1982 and 2020 [1] , more than half of which were related to flash floods according to CCR claims data. In view of climate change, these catastrophes may become more frequent in the coming decades [2]. To deal with these phenomena, it is important to set up warning and crisis management systems capable of anticipating the consequences of events. However, these systems are particularly difficult to implement as they face several operational constraints. The first is the quick evolution of flood-generating weather events which limits the time available for anticipation. The second constraint is the multiplicity of small streams that can react very quickly to intense rainfall (with response times often limited to a few dozen minutes). Finally, the third challenge is caused by the diffuse nature of the exposed risks, spread over a very large area. Initial systems, such as APIC (*Avertissement pluie intense à l'échelle de la commune*) or Vigicrues Flash are currently operational, although they do not yet provide complete coverage of the French territory.

The PICS project, funded by the *Agence nationale de la recherche* (ANR-French National Research Agency), aims to design innovative impact forecasting and modelling chains adapted to flash flood phenomena. These chains are divided into 4 components (Figure 1). The first is the immediate prediction of precipitation with a lead time of up to six hours. This forecast feeds into hydrological models allowing to anticipate flows on small streams, with a catchment area of less than 500 km². The third dimension involves modelling flooded areas in a fine way on a large number of small streams. Finally, these model outputs are cross- >

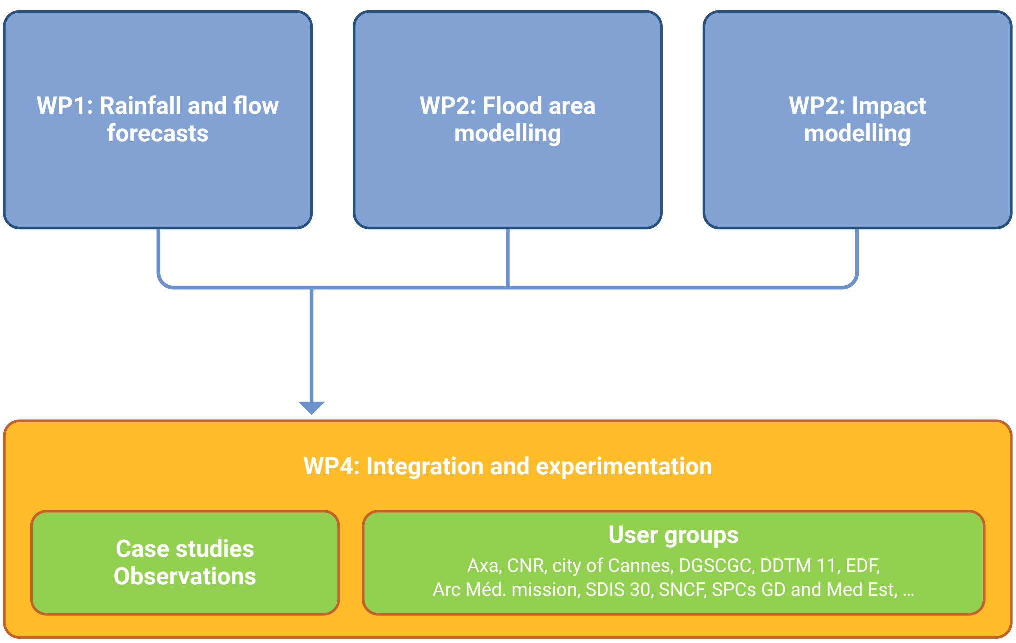


Figure 1 – Summary figure illustrating the content of the PICS project.

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> referenced with exposure data to assess the flooding impacts. The partners in this project are the Université Gustave Eiffel, Cerema, INRAE, Geosciences Rennes, Météo-France, CNRS, SHAPI, IGE and CCR. Each of them contributes to the project by providing their knowledge and tools on one of the four aspects mentioned above: rainfall, rainfall-runoff modelling, flood or flood-impact modelling. Different operational players are also involved in the project within a user group. This group is composed of flood forecasting services, crisis managers, emergency services, insurers and infrastructure managers. Its objective is to guide decisions on the constitution of modelling chains, according to the operational needs expressed.

FORECASTING PRECIPITATION AND FLOW RATES

Given the sudden nature and poor predictability of intense rainfall events, the project focuses on very short-term forecasting (0 - 6 hours). To do this, the latest operational models of Météo-France are used. These include weather models such as AROME-PE and AROME-PI (nowcasting), and also the PIAF product, which combines radar observations with AROME-PI model outputs. These products can be deterministic, by proposing a single future rainfall scenario or can be set-based, by proposing a set of scenarios to take into account the uncertainty of the forecast. Precipitation observations from weather radars are also used in the project.
Several rainfall-runoff hydrological models, which simulate flood flows as a function of predicted rainfall and soil moisture conditions, are implemented in the project. These models are suitable for small streams, which often have no hydrometric station to validate or correct the predicted flow. These include the following models: GRDSI [3], SMASH [4], Cinecar [5] and ISBATOP [6].

ESTIMATING FLOODED AREAS

Several methods for estimating overflow are used in the project. They all use IGN's RGE Alti 5m DTM, which provides very fine spatial resolution. These methods are automated in such a way that they can be applied to a very large number of streams, while keeping computation times reasonable. Three main methods were compared: Flodoos, Cartino and Hand-MS [7]. The first two models were found to be particularly effective in estimating the areas impacted by overflow during flash floods (Figure 2). These models are also used to simulate different flood scenarios associated with fixed return periods.

IMPACT MODELLING

Taking the issues into consideration is important to assist crisis managers and guide decision-making. Several major challenges are considered and modelled. Finally, synthetic indicators are also studied to represent the intensity of the crisis according to the type of challenge.
The population: The Debrieff simulator, implemented by the IGE [8], is a tool that makes it possible to reproduce the behaviour and dynamics of populations during a flood on the scale of a commune. This tool uses the role of people before the crisis (e.g. Individuals that are mobile, at work, isolated at home, etc.) to infer behaviour during the crisis. The simulator can be particularly useful to analyse the potential consequences of a flash flood in a urban area.
Insured property: For several years, CCR has been implementing models to estimate insurance losses caused by natural disasters. These tools are applied for all of France and have a lower spatial resolution than the models used in PICS. The objective of CCR is to develop a damage model adapted to flash floods based on the very fine hazard data simulated in the project. The model also allows for the modelling of runoff damage outside the overflow areas of the main streams (Figure 3).
Networks: The RoadIno method developed by Université Gustave Eiffel [5, 9] is also implemented in the PICS project. It identifies the risk of road network disruption at intersections between roads and the hydrographic network based on hazard.

CONCLUSION

The different tools developed in the project can be combined to form real forecasting chains to meet the specific needs of users. From a scientific point of view, this project will enable progress to be made in the methods of forecasting flash floods and their impacts, particularly in ungauged areas. From an operational point of view, the project will help various stakeholders involved in the management of these floods to acquire more effective forecasting tools. The tools developed in the PICS project could, for example: facilitate future developments of the Vigicrues Flash service dedicated to flash floods; help promote the use of hydrometeorological forecasts by crisis managers; help managers of structures and infrastructure to produce forecasts adapted to their issues; or improve the ability of insurance and reinsurance companies to act effectively after each event, by anticipating expected losses./

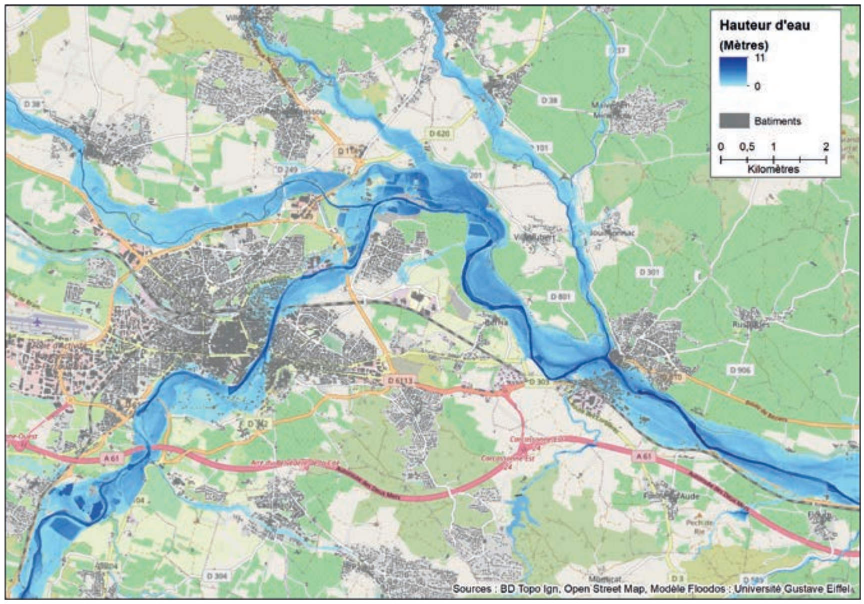

Figure 2 – Flooding estimated by the Floodos model for the Aude River flood (2018).

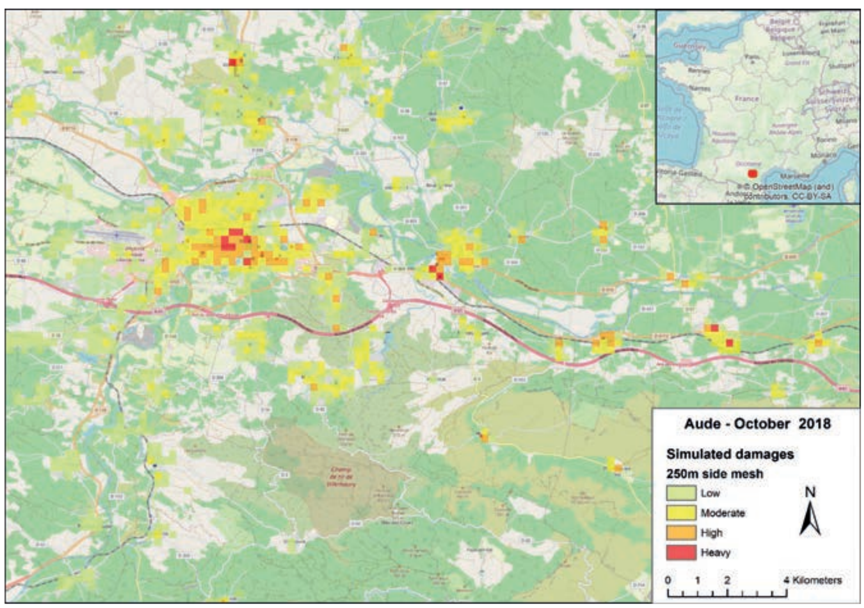

Figure 3 – Example of damage simulation to insured property
for the Aude River floods of 15 October 2018.

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PICS

Prévision Immédiate Intégrée des Impacts des Crues Soudaines

THE PARTNERS

The PICS project is made possible by a grant from the ANR (No.ANR-17- CE03-0011). The project is part of the HyMeX programme (www.hymex.org) on the water cycle and extreme climate events in the Mediterranean. It is part of the overall hydrological forecasting theme of the international HEPEX initiative (www.hepex.org). We would also like to thank the members of the PICS project and the user group who agreed to be involved in this project.

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CITATION

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Modelling rainfall runoff

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INTRODUCTION

CCR's experience in flood modelling, which is at the heart of its R&D activities, has shown that a significant proportion of flood losses are not only due to overflows occurring in major riverbeds, but also to rainwater runoff. CCR has a financial impact estimation model, which is regularly updated and used to assess the damage to insured property when floods occur in France. This operational model is calibrated on a selection of historical events that have occurred in France since 1999. For the determination of the cost of an actual event, precipitation and evapotranspiration data are acquired from the Publithèque of Météo-France. For probabilistic modelling, the events are drawn from a catalogue of a thousand dummy events spread over 400 years of precipitation in the ARPEGE-Climat model of Météo-France. The flood model, including the modelling of overflow and water levels within the major riverbed, combined with a vulnerability module and a damage module, makes it possible to estimate the cost of events and to measure the exposure to flood risk of the French State, CCR and insurance companies. The model is also used in studies on the impact of climate change, such as the study carried out in partnership with Météo-France in 2018 for Metropolitan France and for the French Antilles and Reunion Island in 2019. To strengthen prevention measures and the understanding of runoff risk, specific studies have been carried out, such as the one conducted on the Bièvre watershed in partnership with the Institut Paris Région or on behalf of local authorities such as EPTB Seine Grands Lacs and Entente Oise-Aisne. The model is also regularly applied in the case of studies on the risk exposure of insurers or during research projects such as ANR (PICS) and H2020 (NAIAD). Work remains to be done to model, on the scale of the French territory, flooding due to saturation of the rainwater network and to the rise of the sewerage networks that occurs during intense bad weather in the most waterproofed sectors.

METHODOLOGY

From a methodological point of view, the runoff model makes it possible to simulate surface water runoff at any point in the territory when the precipitation intensity exceeds the infiltration and water retention capacity of the soil, considering the different land cover patterns. This is done for all catchment areas including therefore ungauged water streams. The hydrological catchment areas are reconstructed from a Digital Terrain Model (IGN's DTM) with a 25-metre resolution and geomatic processing dedicated to hydrology such as ArcGIS tools ArcHydro [2]. Thus, the surface runoff is distributed over the slopes of the DTM. For the simulation of real events, the precipitation is acquired from the Météo-France Publithèque according to the data available the day after the event daily, hourly rainfall and potential evapotranspiration). As for the probabilistic runoff model, it is made up of a catalogue of a thousand dummy events simulated from 400 years of precipitation from the ARPEGE-Climat climate model of Météo-France [3].

The surface flows are distributed on the DTM slopes according to the different directions of the preferential flows. This routing of flows within each sub-catchment area is facilitated by a flow direction algorithm integrated into the model in addition to the DTM. In addition to meteorological and topographical data, input data such as different land cover patterns are fed into the runoff model (Figure 1).

The land cover patterns of the Corine Land Cover layer with a 250-metre resolution are used in hazard generation as they allow the application of a surface roughness coefficient according to different land cover types (according to the Manning-Strickler formula to estimate the average velocity of a liquid). Effective rainfall is then differentiated from infiltration rainfall according to land cover types.

In addition to its use during the occurrence of events, the runoff model can be adapted to carry out studies and analyses of exposure to hydrological risks on finer scales, on the territory of a commune or of small catchment areas, with the use of more precise input data when available. This was the case for the experimental study on flood risk in the Bièvre catchment area (Val-de-Marne and Hauts-de-Seine) conducted in partnership with the Institut Paris Région (IPR). As part of this project, detailed land use data from the Institut Paris Région and data on sewerage networks (network layout and rainwater pipe sizing) provided by the Val-de-Marne Department of Environmental and Sanitation Services were integrated into the flood model and used to simulate the hazard in the Bièvre

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> catchment area [4]. An indicator of exposure to hydrological risks, resulting from the crossing of the runoff hazard, due to the rise of the networks and based on the geolocated disasters of the storm of July 2001 in the Greater Paris region was produced within the framework of the study (Figure 2).
The CCR rainfall-runoff model is also used in applied research projects, such as the study on the impact of climate change in France carried out in 2018 for Metropolitan France and in 2019 for the French Overseas departments in partnership with Météo-France and a company called Risk Weather Tech. During this study, the runoff model was transposed to the French Overseas Territories so that it could be used in a similar way to its application in Metropolitan France. The intensity of runoff flows at different return periods was mapped for the French Antilles and for Reunion Island (Figure 3).

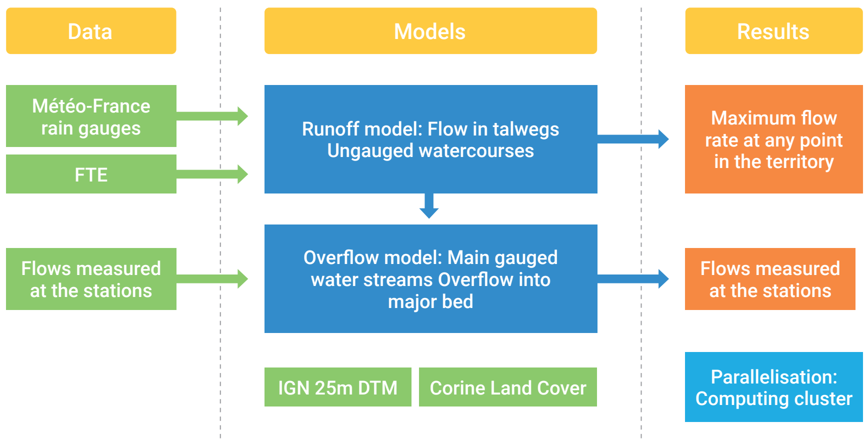

Figure 1 – Functional diagram of the CCR flooding model (CCR, 2019).

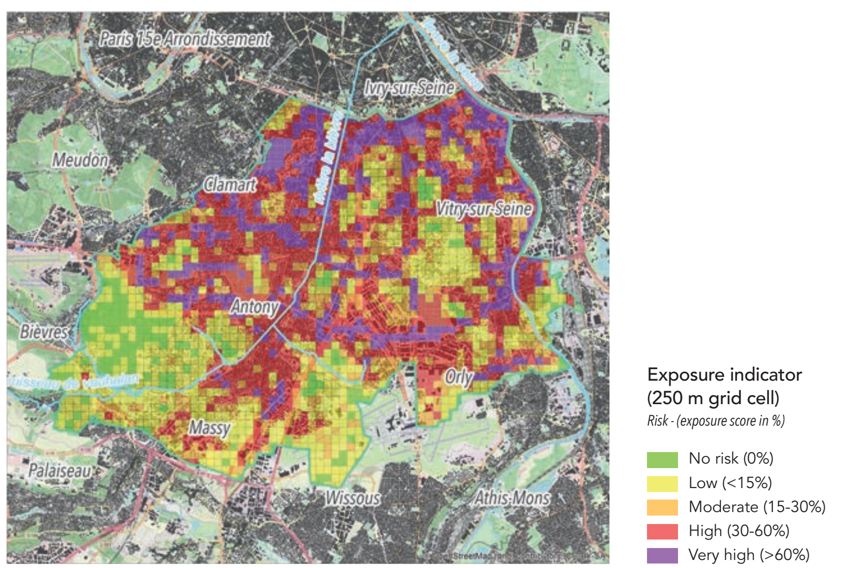

Figure 2 – Hydrological risk exposure indicator aggregated to a 250m grid cell (CCR, 2018).

RESULTS

The runoff model thus allows the simulation of surface water flows for each sub-catchment at any point in the territory in case of a rainfall event and for the simulation of a thousand dummy events to generate a probabilistic hazard catalogue. When an intense rainfall event occurs on a given territory, the runoff model reproduces the surface runoff from the precipitation data with an output value, for each DTM grid cell and for all ungauged streams, corresponding to the maximum flow rate reached during the event. The routing of flows implemented in the model allows the flows distributed on the DTM slopes to converge downstream, towards the talwegs.

These operational results from the monitoring of climate-related events are presented in the form of hazard mapping modelled with a resolution of 25 metres. The simulation of torrential floods occurring in December 2019 in south-western France in the commune of Bielle (Pyrénées-Atlantiques) illustrates this type of hazard map (Figure 4). To provide insurers and the French State with an estimate of the damage to insured property within 5 to 7 days, this hazard is validated according to press and field reports, and then cross-referenced with the vulnerability data available in the CCR databases. This includes geolocated personal and business risk data provided by insurers which is regularly updated by CCR.

For the probabilistic simulation, the event catalogue produces a distribution of the maximum runoff rate for each 25-metre grid cell across the country for five return periods of a hazard (from less than 10 years to more than 200 years). The intensity ofa hazard is thus estimated at any point on the territory for a given return period. Due to the infiltration func-

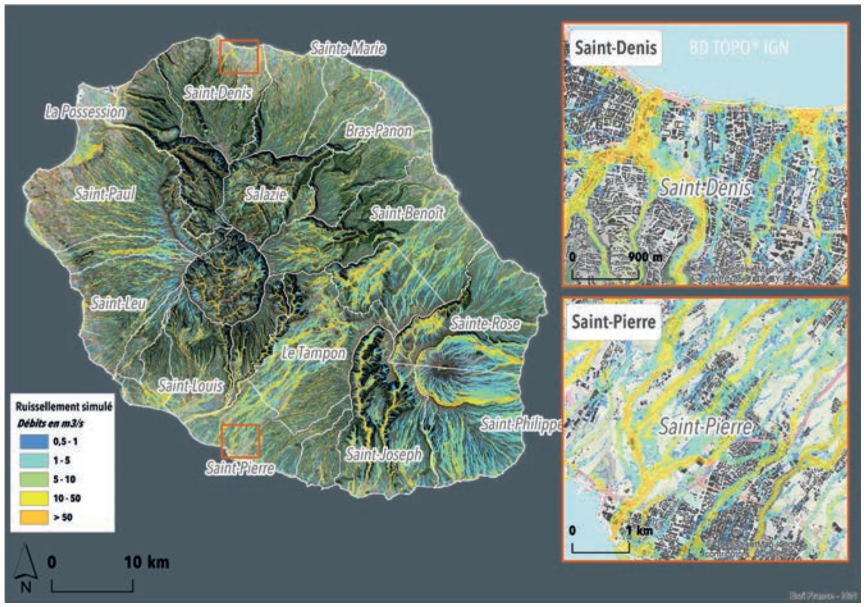

Figure 3 – Modelled runoff rates for a dummy event on Reunion Island (CCR, 2019).

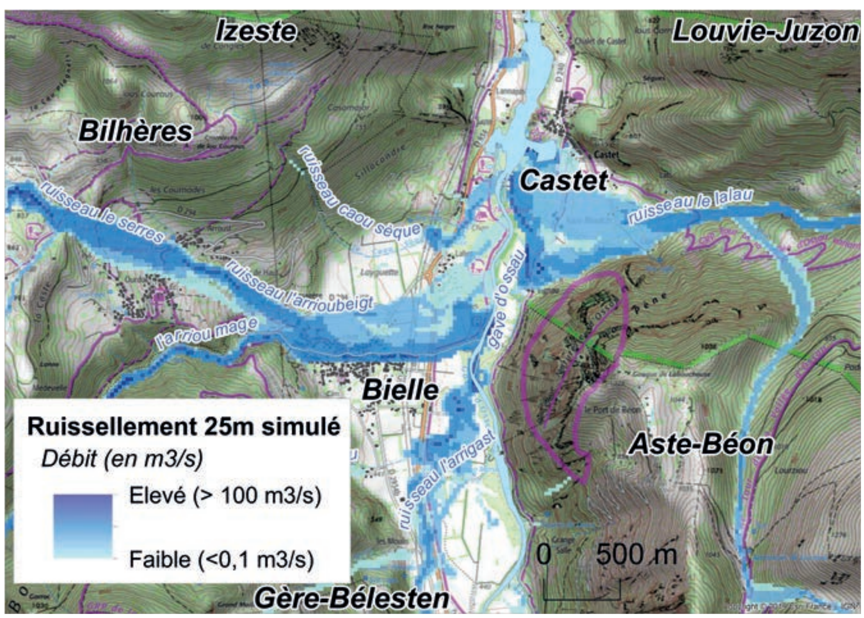

Figure 4 – Torrential flooding in December 2019 in Bielle - Pyrénées-Atlantiques (CCR, 2019).

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tion and the consideration of land use patterns, the spread of surface runoff appears to be more prominent in sealed areas than in vegetated areas (Figures 5(a),5(b)). The results of the probabilistic runoff hazard are shared in the form of intensity classes of simulated flows for each return period which are then provided to insurers or to local authorities for specific requests from EPTBs (French Public Territorial Basin Establishments) for example, so that they can benefit from a mapping of the exposure of their risk portfolios or territory to rainfall runoff phenomena (Figure 6). The average annual losses modelled for flood perils (overflow and runoff phenomena) under the Nat Cat regime which are aggregated at commune level, are also transmitted to insurers and local authorities within the framework of agreements.

The data from the CCR databases (claims and insurance policies geolocated at the address), crossed with the runoff hazard in terms of flow rates or return periods, make it possible to calibrate the damage curves. This makes it possible to estimate the cost of events and to measure the exposure to flood risk of the French State, CCR and insurance companies. Therefore, these curves can be calibrated locally and can be applied to assess the performance of hazard reducing prevention strategies on insured losses and to estimate losses by 2050. For an event of the same type as the one that occurred in the Brague catchment area in October 2015, a 20% reduction in runoff would reduce the damage suffered (for private property, owners of individual houses) from €3.3M to €2.8M [5].

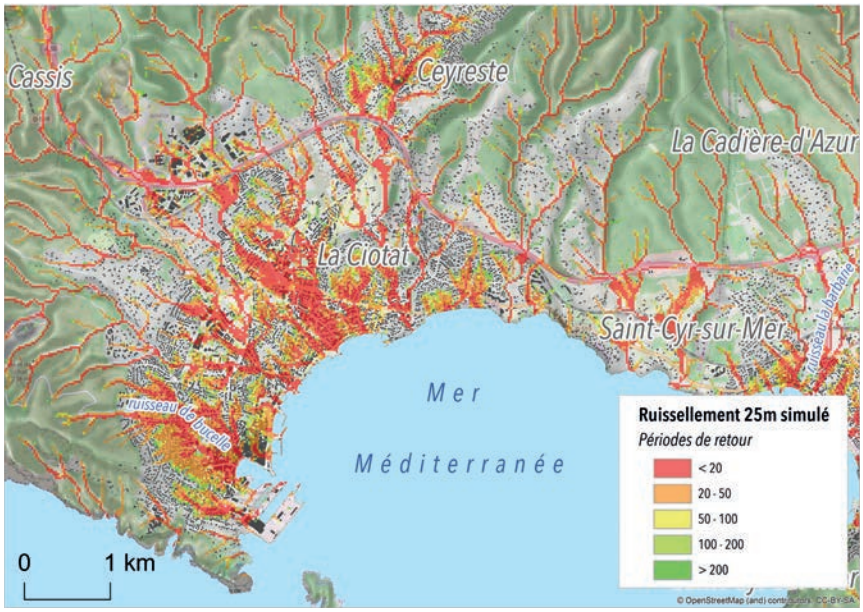

Figure 5 – (a) Probabilistic runoff hazard in the area of La Ciotat (Bouches-du-Rhône).

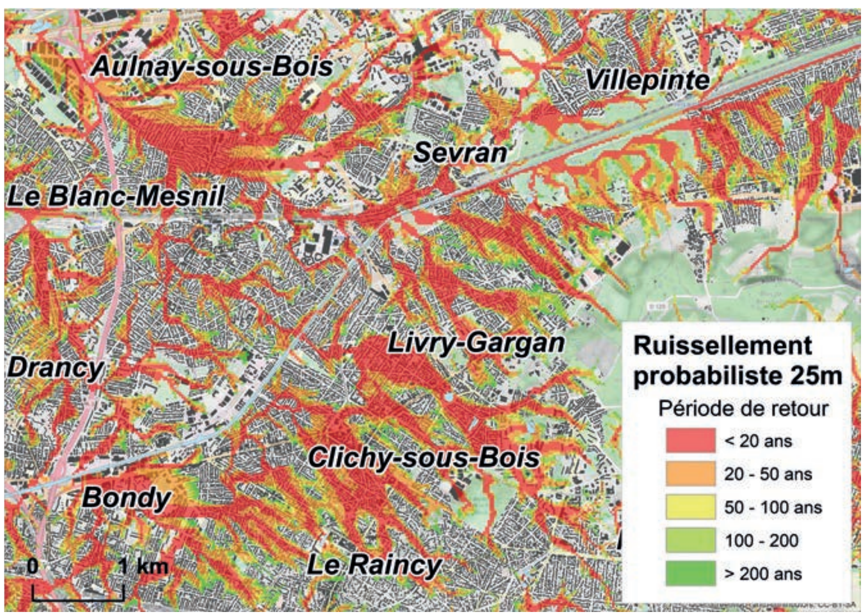

Figure 5 – (b) Probabilistic runoff hazard in Seine-Saint-Denis (CCR, 2019).

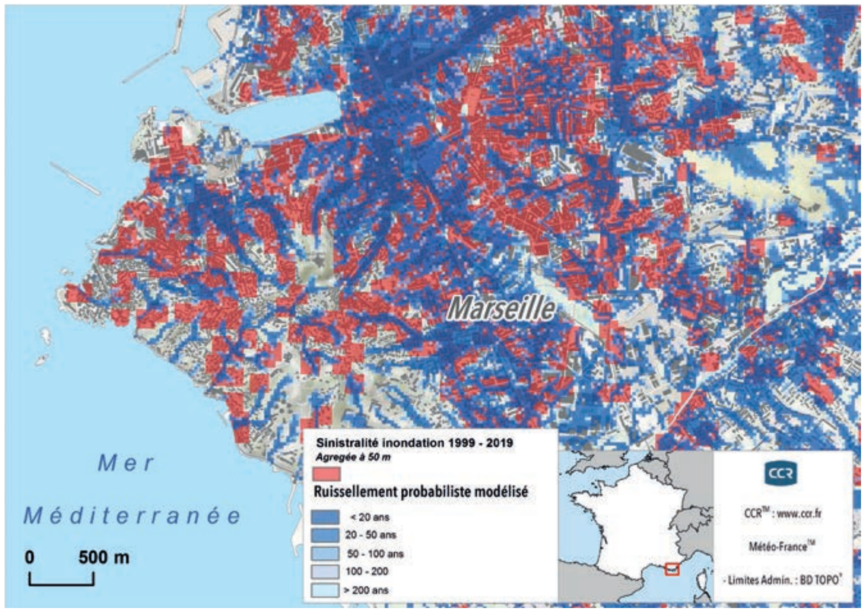

Figure 6 – Layering simulated probabilistic runoff and flood loss data (1999 - 2019) in the city centre of Marseille (CCR, 2020).

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> CONCLUSION

CCR's flood model simulates actual and potential events to estimate the amount of insurance damage due to overflow and runoff flooding. The model is used operationally when a flood occurs in a given area and its results are provided in studies carried out as part of research projects or when requested by local basin authorities. In the future, finer scale input data can be integrated into the modelling chain to reduce uncertainties related to the accuracy of data on topography or land use for example. Finally, it is important to be able to perpetuate the partnerships already established with local authorities and public basin establishments (such as EPTBs for example) but also to set up new ones to access local data and model the flood hazard at the finest possible scale on the French territory./

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Modelling financial losses due to flood risk in Morocco

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INTRODUCTION

Morocco is significantly exposed to natural catastrophes, such as earthquakes and floods that can cause severe human and economic losses. Recently, Morocco introduced a new compensation scheme for natural and man-made disasters by creating the Solidarity Fund against Catastrophic Events (FSEC - *Fonds de solidarité contre les événements catastrophiques*). The tasks of this organisation are defined by the provisions of Moroccan Law 110-14 once a catastrophic event is declared as such by the Head of Government. This scheme has an allocation component, which provides compensation to individuals who do not have insurance cover. In this context, public risk management agencies, including the FSEC, need an up-to-date modelling platform to assess flood losses. Supported by the World Bank, the FSEC tendered a call for projects to develop a comprehensive Cat model for flood risk. In 2020, a consortium was formed, composed of Risk Weather Tech for meteorological modelling, Atmoterra for data collection and information on warning systems, and CCR for the development of the Cat model, from hazard to damage. The project lasted seven months. This project was divided into 5 theme-based parts:
(1) inventory of existing flood models specific to Morocco; **(2)** collection of geographical data and creation of databases including historical events; analysis of warning systems; **(3)** training of users to the Cat model; **(4)** development of the Cat model; **(5)** model maintenance and future collaborations.
This paper focuses specifically on the methods used to develop a comprehensive Cat model of flood risk for the entire Moroccan territory. The inventory of pre-existing models, the collection of data and the meteorological model were used as inputs to the Cat model.

METHODOLOGY

The collection of information and geographical data in GIS format was used as input to the Cat flood model, which is based on three distinct models: hazard, vulnerability, and damage. During the first months of the project, the following databases were set up:
- a database of historical flood events in Morocco;
- a geographical database (meteorological, hydrological, vulnerability of issues, insurance data, the assessment of landslide hazards, etc.);
- summary sheets were provided to the FSEC for each geographic data set used in the project;
- Data collection, control and quality assessment were monitored by the consortium during the first months of the project.
A geodatabase in GIS format was put together and a solution for sharing data with the FSEC was implemented. Finally, a GIS web interface hosted on an Esri Portal allowed the data used in the flood modelling and simulation results to be shared from an online mapping application.
The flooding model developed can operate in two distinct ways. The first is deterministic modelling. This estimates the impact of an actual event when it occurs. This can be useful, for example, in forecasting losses following an actual flood and in carrying out provisioning studies. The hazard model will therefore be based on physical data relating to an actual event. The second mode of operation is probabilistic modelling. This time the aim is to study dummy but probable events, representative of a very long simulation period (for example 1,000 years). This modelling has many uses. It can be used to measure financial exposure and thus carry out pricing studies, to analyse the overall exposure of a territory and to carry out prevention actions in the most exposed areas.

The hazard model

The first model is the hazard model. Its objective is to physically characterise the impact of an event. In the case of floods, this can be by estimating river overflows, precipitation and runoff responsible for damage. A distinction is made between deterministic hazards, calculated for actual events, and probabilistic hazards, based on a large number of dummy events.

Modelling deterministic hazard

This type of modelling is carried out in three successive stages. The first is to estimate the precipitations of the most significant past events. For this purpose, a selection of events from the ERA5 meteorological database was made and a fine simulation of precipitation was carried out using the WRF meteorological model. This downscaling allowed an estimation of precipitation with a 1 km^2 grid cell and a

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floods
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1-hour time step (Figure 1). The precipitation data was then fed into a rainfall-runoff model to generate maximum flow maps. For this purpose, the rainfall-runoff model SCS Curve Number [1] was used with a resolution of 100 m.
In a third step, flow data are used by an overflow model based on the Hand method [2], to estimate the maximum water heights reached during an event. The spatial resolution of this overflow model is 30 m.

Modelling probabilistic hazard
The main difference between the probabilistic and deterministic hazard comes from the precipitation scenario used. A stochastic method, based on the frequency analysis of ERA5 precipitation data, was developed. This method ultimately generates precipitation for 795 events over 1,000 years of simulations.
Once the precipitation has been simulated, an estimate of the flows and overflows is carried out in the same way as for the deterministic model.

The vulnerability model

The second model is the vulnerability model. It allows the location of exposed properties to be estimated in terms of value, characteristics such as the nature of the property (house, flat, industry, etc.), the type of occupation (tenant, owner) and many other elements describing the property (age, type of construction, number of floors, etc.). This vulnerability model was built from three data sources:
1. The site of the General Tax Directorate, which contains a city-by-city database of property prices (a city is defined as the urban area of a province). Data on construction costs are also available.
2. Demographic and socio-economic data of the population of Morocco according to the 2014 general population and housing census. This data is shared by the Haut-Commissariat au Plan (HCP), which published in 2019 a 10% sample of data from the 2014 general census [3]. It is a census conducted on Moroccan households which contains a number of variables relevant to build the portfolio.
3. Finally, the third source of data is a 2016 survey by the Moroccan Ministry of Housing and Urban Policy (MHPV) [4]. This survey contains a great deal of information on Moroccan housing, including the surface area of buildings.

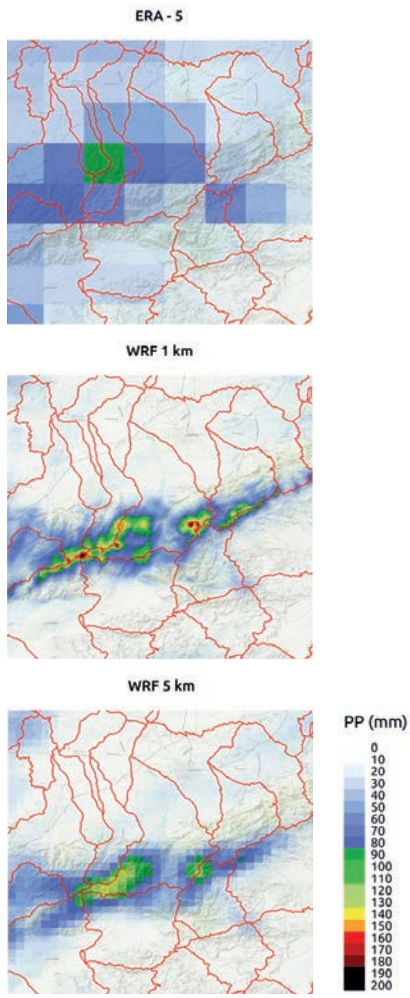

Figure 1 – Cumulative rainfall during the 16 to 29 October 1999 event in ERA-5 reanalysis (~ 30 km resolution), WRF box with 5-km resolution and WRF box with 1-km resolution.

The damage model

The objective of the damage model is to calculate the amount of loss based on hazard and vulnerability. For each property, the amount of damage D is estimated by multiplying the property value V by the destruction rate DR. This destruction rate is derived from the damage curves of the MnhPRA (Morocco natural hazards Probabilistic Risk Analysis) model. The above model is a probabilistic, multiperil Cat model developed by RMSI Pvt. Ltd in collaboration with the HCP between 2009 and 2013 [5]. The financial part of the model, XCat, was developed in 2017. This model is used to inform the government of the financial and tax implications for the consideration of the draft law establishing the natural catastrophe coverage scheme. It is well documented with a QGIS interface to run simulations and visualise results. Table 1 summarises the advantages and inconveniences of the flooding part of MnhPRA compared to the model developed by the consortium in 2020.

RESULTS

Hazard model

The results of the hazard model allow to visualise in GIS map format the computed overflows and flows for each event (Figure 2). Flooding is then modelled in terms of water levels and runoff rates over the catchment areas affected by the flood. Regarding the probabilistic hazard model, the simulated hazard maps are analysed to estimate, for each pixel, the return period of the flood as shown in Figure 3 on the agglomeration of Marrakech.

Damage model

The damage model incorporates the insurance/reinsurance coverage terms such as thresholds or deductibles. As part of the implementation of the flood compensation scheme, the following package was put in place:
- when an owner's house is affected, the amount of compensation is calculated according to Article 40 of Law No. 110-14, which includes the loss of residence and the loss of enjoyment. The loss of residence corresponds to the minimum between the value of damage D, 70% of the rebuilding cost and a limit of MAD 250 000. Loss of use is calculated as 6 times the rental value of the property (between MAD 1,000 and 4,000);
- for tenants, the amount of compensation is set at 3 times the rental value, which must also be included in the MAD 1,000 and 4,000 bracket.

Finally, it should be noted that for a property to be compensated, it must be considered uninhabitable.
The result of the damage model is an estimate of losses at the level of a property, an administrative entity (commune, province, etc.) or the country.

	Hazard Module	**Vulnerability Module**	**Damage module**
Advantages	Multi-hazard	Detailed risk types (29 risk types)	Ability to produce a multitude of charts Meets the needs of the insurance sector
Inconveniences	Focus on certain areas (or catchment areas) Daily time step 90m resolution Limited catalogue of historical events	Relatively old socio-economic data (2000s for the oldest) Property values are the same per province regardless of the type of risk Works on older operating systems (under W-XP and W7) Maintainability of the QGIS interface	Lack of interaction between the hazard and damage part Probabilistic loss modelling only
Consortium approach	Single-peril modelling of flood risk over Morocco: integration of small catchment areas and a fine time step to model flash floods Robust meteorological model to refine the data Resolution 30 m to 10 m Deterministic modelling of an event based on weather conditions of said event (not an event catalogue) Probabilistic model based on the generation of a catalogue of dummy events	Consideration of the specificities of the FSEC's beneficiary component: portfolio developed solely on the risks covered by the scheme. i.e. uninsured private risks for loss of main residence (compensation of the owner for the rehabilitation of the building) or for deprivation of use (for owners and tenants) Property values assessed by risk type and by province For the insurance component, the buildings and contents are insured, compensation is limited to MAD 3.3 billion.	Transparency and specific continuous training for the use of the developed model User-friendly interface, with source codes available (R or other software to be defined during the industrialisation phase of the model)

Tableau 1 – Advantages and inconveniences of the flooding part of MnhPRA compared to the model developed by the consortium in 2020.

floods
Cat modelling
financial losses
Morocco
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> **Computation interface**

For users to carry out analyses and simulate damage, a modelling interface was developed using a Shiny R package. This interface namely allows:
- to estimate losses on an actual event;
- to carry out exposure analyses;
- to estimate annual average losses and probabilistic loss distributions (EP-curve);
- to map these probable losses by commune or by province.

It also allows the user to update the vulnerability data, change the damage curves used, change the insurance penetration rates, etc. Figure 4 shows an illustration of the probabilistic losses obtained by the interface.

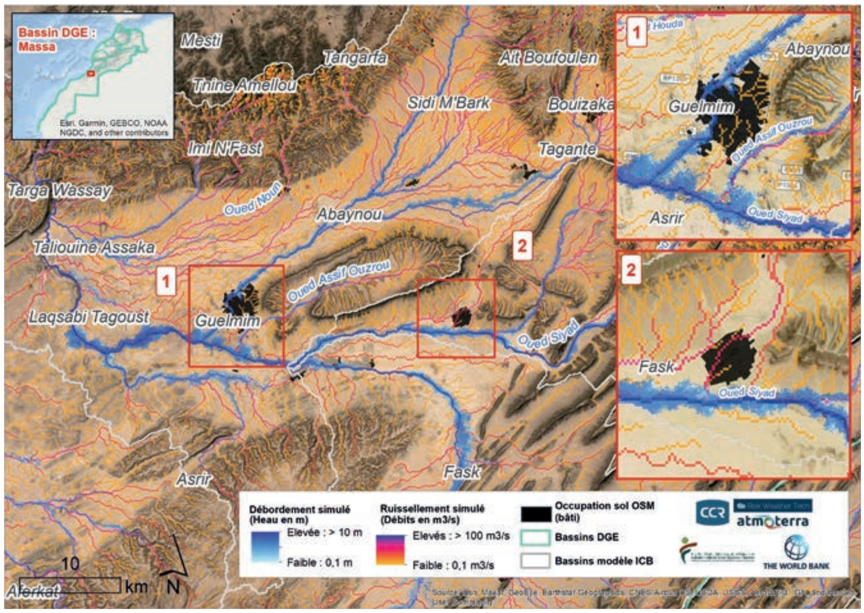

Figure 2 – Example of simulated water levels and flows for the November 2014 event.

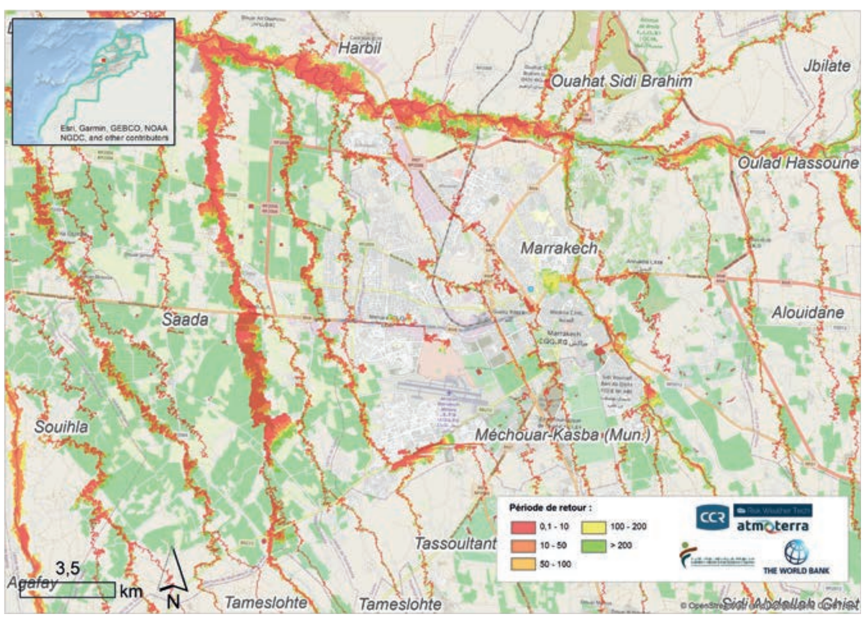

Figure 3 – Representation of probabilistic hazard for the metropolitan area of Marrakech.

THE PARTNERS

Risk Weather Tech and CCR are partners, namely in projects related to modelling the consequences of climate change on insured losses. As for the independent consulting firm Atmoterra, this project initiated a first collaboration during the set-up of the project 'Actuarial modelling of financial losses from Flood Risk in Morocco - Selection No. 1267599, World Bank' and its development.

CONCLUSION

The model developed as part of this study has enabled the Moroccan authorities and the FSEC to have a Cat model that allows them to better understand and estimate the exposure of the national territory to flood risk. The consortium's experience in data collection, meteorological models and modelling the economic impact of natural hazards were also discussed with Moroccan risk management stakeholders. The study of warning systems could provide decision-making elements to select the most suitable systems for the catchment areas and to integrate these elements for prevention.

Future improvements to the model may be made, such as the integration of new data on property exposure, the development of a claims database with the inclusion of climate change. A new, efficient and adequate vulnerability model could also be developed. This work is being pursued in the context of a long-term collaboration with the World Bank, the OECD and the FSEC, notably on the analysis of extreme risks in financial terms./

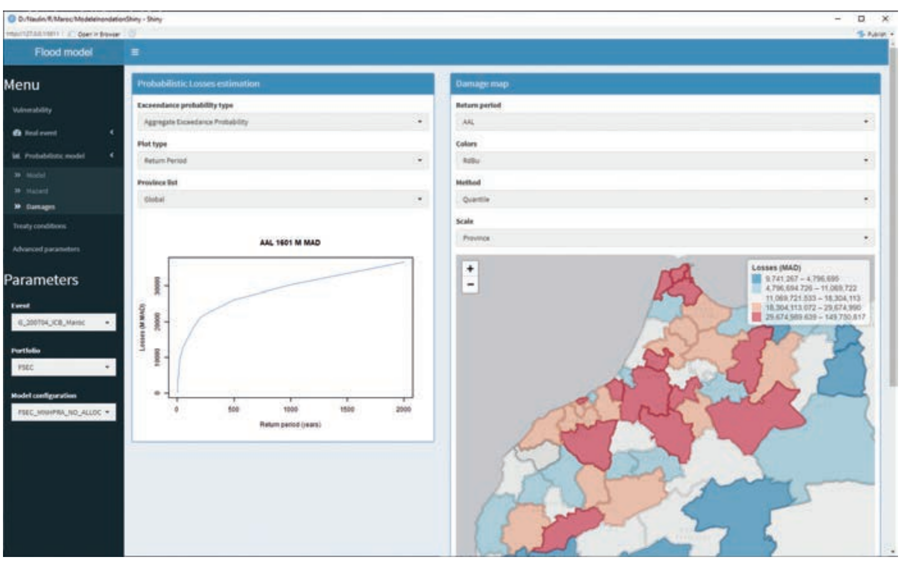

Figure 4 – Calculation interface and example of simulated probabilistic losses for Morocco.

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Summary mapping of the impact of floods in Metropolitan France

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INTRODUCTION

In 2020, CCR put together a summary mapping of the impact of floods in France. This mapping was developed from the results of the CCR probabilistic flood model, geolocated historical flood loss data and an analysis of the vulnerability of territories to flooding, based on the OSO Théia land cover map with a 10-m resolution [1]. This work aims to make a summary map of the potential impact of floods in Metropolitan France accessible to different types of audiences (individuals, companies, local authorities, insurers, government services, etc.), based on the cross-referencing of relevant risk measurement indicators.
The summary map of the impact of floods (Figure 1), is now available online on the Nat Cat CCR portal for the public: catastrophes-naturelles.ccr.fr. This mapping provides a qualitative measure of the impact of flooding phenomena: main river overflow [2], surface runoff over the entire hydrographic network [2], coastal flooding and historical disaster areas. This new mapping, usable and understandable by all, is based on digital data that is available online on a regional scale, thus contributing to prevention policies and strengthening the culture of flood risk.
This article describes the method adopted to produce the summary map, based on layering modelling and insurance data,

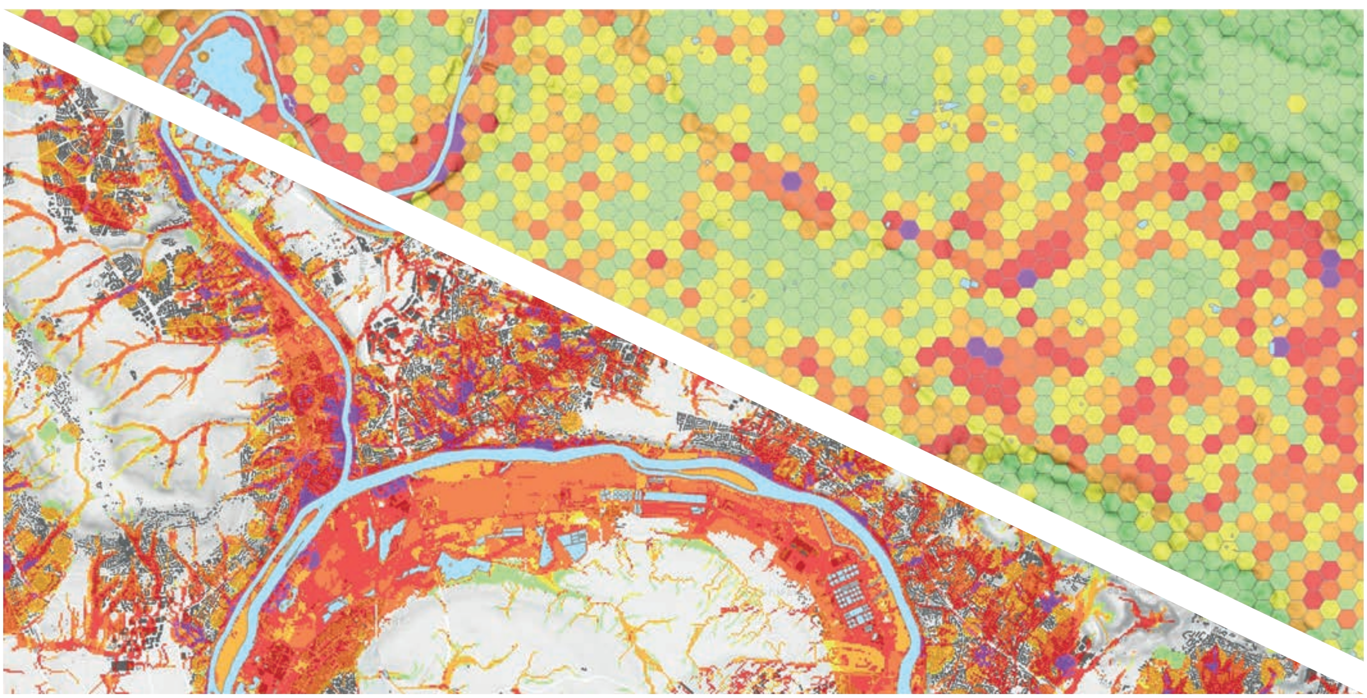


Figure 1 – CCR Map of the impact of floods. Results at 25 m and resampling of results in hexagons with 250 m resolution (CCR, 2020).

configured, and mapped in GIS (geographic information system). The multi-criteria analysis conducted by CCR provides information on the impact level of floods on the entire metropolitan territory in a uniform way.

METHODOLOGY

A multi-criteria analysis allows the following two indicators to be cross-referenced to produce the summary map of the impact of floods:

1. An actual loss indicator using historical claims from the CCR database.

2. A potential loss indicator calculated by combining the following information:

- flood hazard frequency based on CCR probabilistic modelling;
- vulnerability of territories to floods based on "OSO Théia" land cover data.

The spatial layering of scores for each indicator allowed us to obtain a corresponding sum of the impact of floods at all points in the territory in a uniform way (Figure 2).

Actual loss indicator

The claims in the CCR databases correspond to the addresses affected by one or more flooding events over the 1995 - 2019 period for private and professional property insured under the natural catastrophe scheme. The number of events and the cost of damage to the property are also known for each address affected. This indicator was thus configured in GIS using the location of the addresses affected, the number of flooding events that occurred at each address and the total cost of the claim(s) (an address may have been affected by a flood one or several times). A score from 1 to 6 is then assigned based on the total cost and the number of flood events that occurred for each property affected, as shown in the weighting matrix.

For reasons of confidentiality and to be layered on the other indicators of the analysis, the claims represented as geolocation points were aggregated by a spatial analysis method of accumulation by neighbourhood [3]. This tool performs a neighbourhood operation that calculates a grid in which the value of each output cell is a function of the values of the input point features that lie in the rolling estimate of a specified neighbourhood. The average of all values in this neighbourhood was selected as the indicator (Figure 3).

Potential loss indicator

a. CCR Probabilistic flood hazard frequency

Probabilistic modelling is implemented by CCR to measure the financial exposure of the insurance market and the State to flooding. The frequency of flood occurrences is mapped in hazard return periods (RP), on 25 m x 25 m grid cells over the metropolitan territory as a whole (Figure 4). To build this indicator, a score related to the RP of the hazard was assigned (Figure 5).

b. Vulnerability of territories to flooding based on "OSO Théia" land cover data.

This indicator is based on OSO land cover data ("*Occupation des sols*" in French of the Centre of Scientific Expertise) produced by the Théia cluster (CNES/CESBIO) in 2018. Developed from ESA

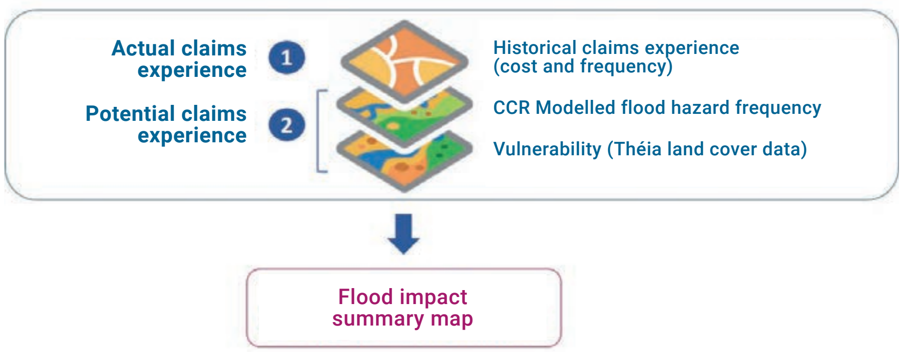


Figure 2 – Methodology for the preparation of the flood impact summary map

flood
impact map
indicator
claims experience
hazard
land cover

> Sentinel-2 optical satellite imagery with 10m resolution, this is the most accurate land use data available to date for Metropolitan France.
To each of the 25 classes of the OSO Théia layer, a score taking into account the sensitivity of the different land cover types to flooding was assigned [4].
Overlaying the scores of the OSO Théia indicator with the scores of the indicator based on the frequency of the CCR flood hazard mitigates or amplifies the impact of the hazard according to different land use types (Figure 6).

RESULTS

The summary map results from the layering of the two indicators presented above. The multi-criteria analysis carried out consists in summing up the scores of each indicator at any point in the territory (for each 25m grid cell). This provides information on the impact of flooding on the entire metropolitan territory.
This result corresponds to a reclassification of the "raw" score (sum of the scores of the two indicators). On output, six classes appear. The impact of flooding is characterised as very low (1) to major (6) (Table 1). The water surfaces (permanent waters of IGN's TOPO BD) appear on the map but were not taken into account in the multi-criteria analysis.
The total area of the flood impact map is 105,691 km², or 19% of the metropolitan territory. Most of it is impacted by "moderate" and "high" levels covering 88,117 km² or 16% of the territory. The "major" impact level represents 0.2% of the territory (1,012 km²). 0.2% of the territory is subject to a major impact of flooding phenomena and may seem low, but it is the densely urban and industrial areas that remain the most affected by this haz-

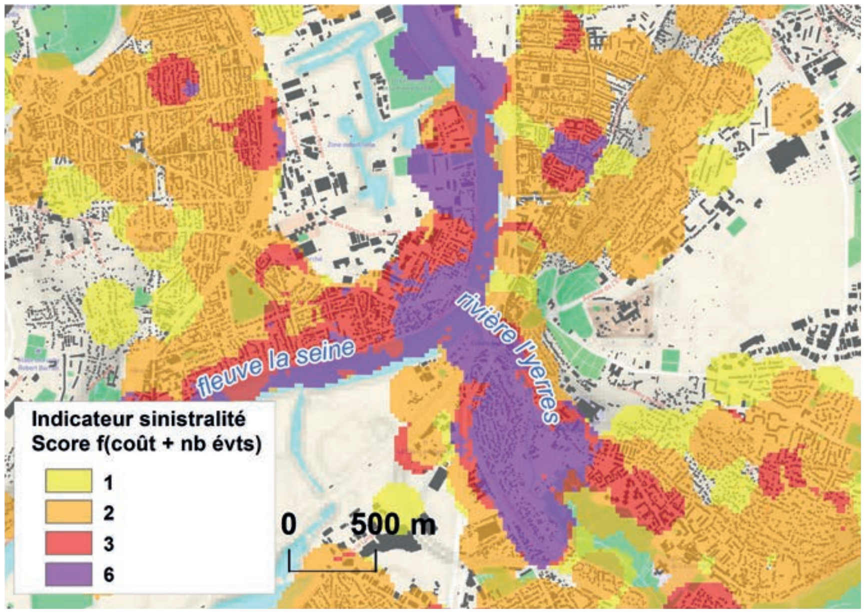


Figure 3 – Aggregated data for the development of the second indicator.

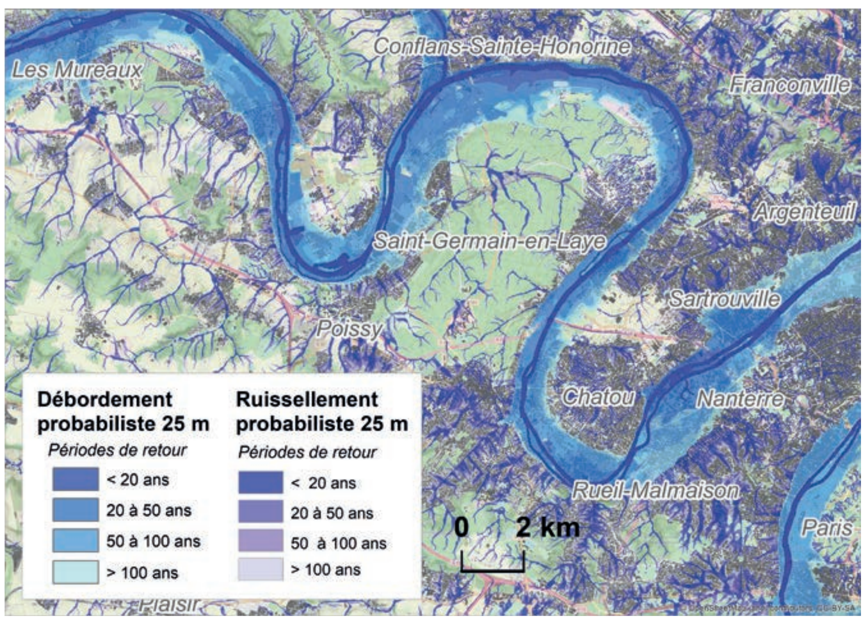
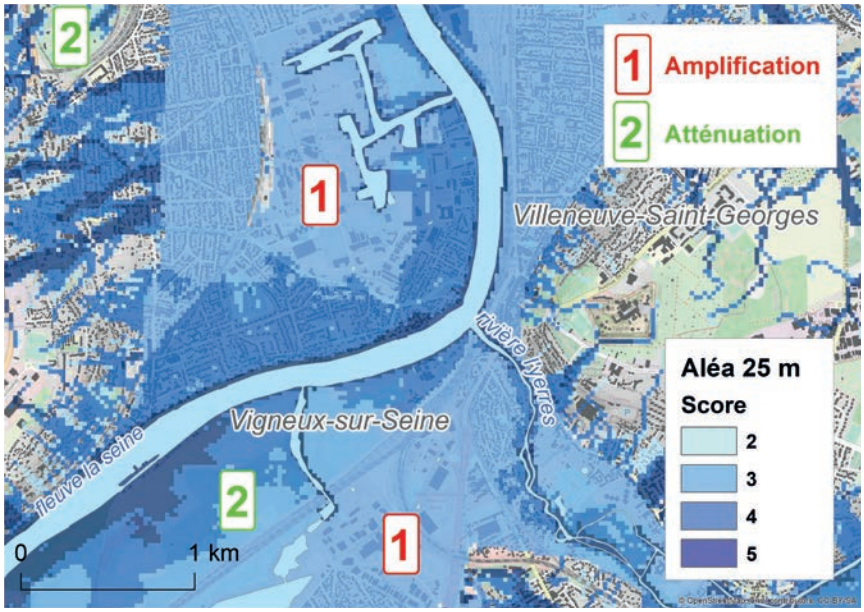


Figure 4 – Simulated probabilistic overflow and runoff in the Seine watershed downstream of Paris.

Hazard return period	Score
200-year RP	2
100 to 200-year RP	3
20 to 100-year RP	4
<20-year RP	5

Figure 5 – Score assignment based on flood hazard frequency.



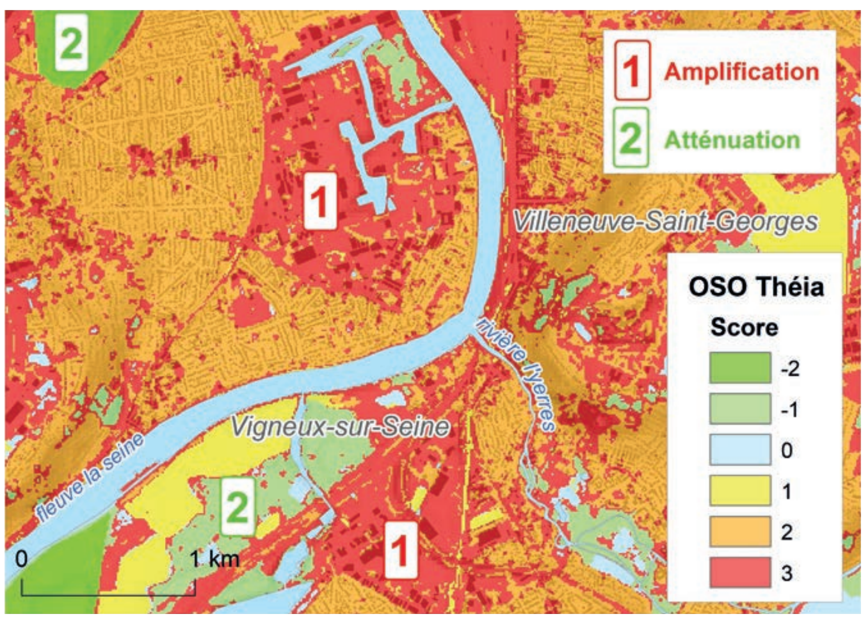


Figure 6 – Impact of the OSO Théia indicator on flood hazard amplification or mitigation.

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flood
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hazard
land cover

> ard in Metropolitan France. If we refer to OSO Théia 2018 land cover data, we find 20,566 km² of urban centres and industrial and commercial areas throughout Metropolitan France. In the end, according to the multi-criteria analysis with 25 m resolution, 5% (1,012 out of 20,566 km²) of the areas occupied by dense urban fabric and industrial and commercial sites are subject to the impact of major floods. Figure 7 shows the result of the analysis on one of the loops of the Seine downstream of Paris.

The mapped result of the multi-criteria analysis is then resampled (tessellation principle) into 62,500 m² of hexagonal grid cells (area equivalent to a 250 m x 250 m square) for confidentiality and to be able to disseminate it to a wide audience. Square gridding is the most common type of shape used for the representation of various phenomena in GIS, however hexagons are better suited for resampling analyses [4]. This is because hexagons reduce the distortion caused by the edge effects inherent in the shape of a square grid, as the perimeter to area ratio of the hexagon is lower than that of a square.

Compared to square grid cells, hexagons therefore benefit from a better consideration of existing spatial dynamics before resampling. For each 25 m grid cell on the impact map containing a score of 1-6, each output hexagon now contains the average of the scores of the 25 m grid cells within the hexagon's footprint.

For all hexagons where the majority of the 25 m grid cells are zero values (score of 0), the average will produce the lowest score (score of 1). Water surfaces are shown for mapping purposes only. The latter were not taken into account in the resampling, nor in the multi-criteria analysis.

Raw score	Reclassified score	Flood impact map	Surface area in km²	% of the territory
-2 to 1	1	very low	3,074	0.6%
1 to 2	2	low	5,358	1.0%
2 to 4	3	moderate	45,740	8.3%
4 to 6	4	high	42,377	7.7%
6 to 8	5	very high	8,130	1.5%
8 to 14	6	major	1,012	0.2%
-	-	water surfaces	8,010	1.5%
		Total area impact map	**105,691 km²**	**19%**
		Total area of France	**548,499 km²**	

Table 1 – Reclassification of the summed scores and legend of the impact map with 25 m resolution.

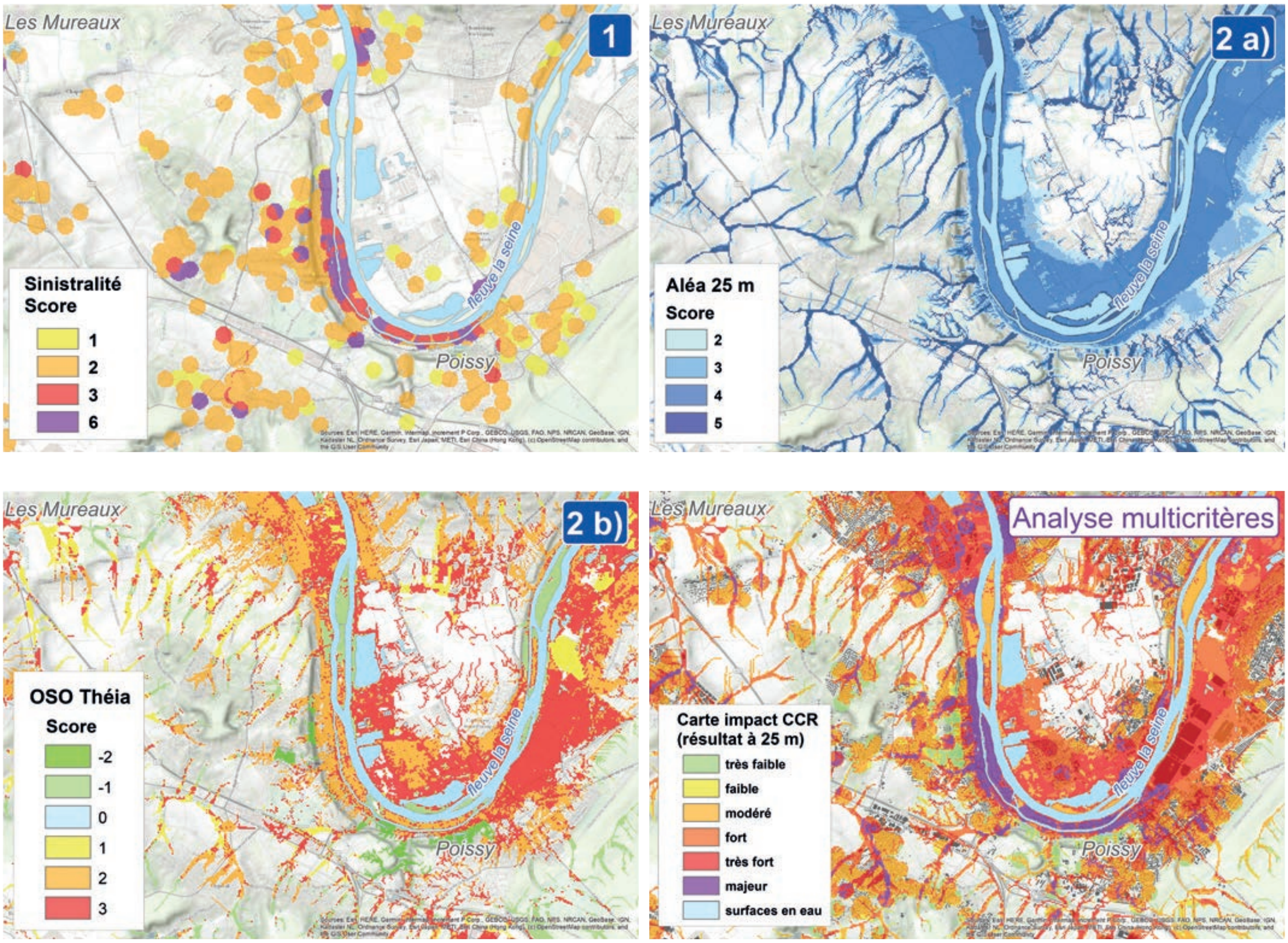

Figure 7 – Summary map of the impact of floods.

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flood
impact map
indicator
claims experience
hazard
land cover

> CONCLUSION

The multi-criteria analysis carried out on the basis of two CCR indicators of observed and potential losses makes it possible to characterise flood risk in a uniform way on the metropolitan territory from this summary map. The use of land cover with 10-m resolution (OSO Théia) allows the mitigation or amplification of risk by distinguishing urbanised areas from natural or agricultural areas. To contribute to prevention policies and share its knowledge of flood risk, CCR disseminates these results with a resolution of 25 m, for professionals, on its secure web platform called Espace Pro CCR. A resampled version at 250 m is available on its public portal: catastrophes-naturelles.ccr.fr.

These indicators will be updated regularly with new claims recorded and will follow the ongoing improvement of the CCR flood model to provide up-to-date information. It is envisaged to take into account in this synthesis mapping a hazard scenario resulting from the CCR work on climate change by 2050 and to extend the analysis to ultra-marine territories./

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Analysis of uncertainties in the coastal flooding hazard model

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INTRODUCTION

Modelling the areas submerged during coastal flooding is a difficult exercise, fraught with uncertainty. These uncertainties come from the data that feed the model, such as offshore wave or sea-level forcing or the elevation of the digital terrain model (DTM). Others come from model parameters such as soil roughness. Therefore, a thesis in applied mathematics on the analysis of uncertainties in the coastal flooding model was presented in 2021, in partnership with the BRGM and École des Mines de Saint-Étienne [1]. The objective is to identify and rank the sources of uncertainty to prioritise the features that can be improved in the model. Sensitivity analysis (SA) methods make it possible to carry out this identification and ranking, namely by defining sensitivity indices measuring the influence of one or more model inputs on the variability of outputs. One of the most widely used indices is the Sobol index [2] which is based on the variance decomposition of the output. This article presents the approach used during the thesis and the metamodelling results.

METHODOLOGY

There are two problems in calculating the Sobol index. The first is that its estimation requires a very large number of model simulations that can take several days or even weeks. The second problem is that the model output, consisting of the maximum water heights simulated during an event, is a spatial data with strong discontinuities.

To overcome the first problem, it is possible to build a proxy model, called a metamodel. Methods exist such as linear regression, Gaussian Process Regression (GPR), etc. However, whatever the metamodelling methods, the second problem remains. Thus, a method was developed to build a metamodel while taking into account the spatial properties of the observed maps. Once the metamodel is operational, it is possible to obtain a sufficient number of simulations to estimate the Sobol indices. However, the issue of spatial data is also relevant for SA. As with the metamodel, processing each map location individually would be computationally time consuming and irrelevant. Furthermore, it is interesting to summarise the influence of one or more inputs on the whole predicted water level map into one index. A specific index was therefore developed for this case study.

Two hazard models to estimate the maximum water heights the models used by CCR, based on Lisflood-FP [3, 4] , and by BRGM, based on the work of Lazure and Dumas, 2008 [5], are analysed. The inputs to these two models have sources of in- sources of uncertainty:

- marine forcing, corresponding to the water level at sea which varies over time;
- the Digital Terrain Model;
- hydraulic connections and soil roughness.

Some of these variables can be considered as continuous variables, e.g. roughness, while others are categorical variables such as hydraulic pipes which can be activated or not. The damage model also has other sources of uncertainty such as the estimated value of the asset or its position. The objective of this work is to estimate the influence of each of these variables and the associated uncertainty on the impact model.

Metamodel construction and sensitivity analysis on continuous variables

To develop the uncertainty estimation method, the first developments focused on the case of continuous variables, corresponding to marine forcing. The objective is to measure the impact of marine forcing parameters such as tide and surge on the extent of flooding and associated water levels.

The objective of metamodelling is to replace a physical model with a much faster mathematical model to test a large number of possible variations of the initial model. The metamodel is a mathematical function that will estimate the outputs of the impact model for a set of input data based on the observation of a limited number of simulations. In the case of spatial outputs, a classic approach is to:

- **{1}** summarise the calibration maps into a small number of variables (between 1 and 10 variables) by principal component analysis (PCA);
- **{2}** build a meta-model (linear regression, GPR, neural network etc.) for each of the variables;
- **{3}** for a new set of inputs, predict these

variables using the metamodels built in **step {2}**;
- **{4}** build the map associated with these predicted variables, which corresponds to the estimation of the maximum water heights during an event.

In practice, however, **step {1}** is difficult to apply due to the size of the map. Furthermore, PCA does not consider the spatial dependency between the different locations and the evenness of the maps. To overcome these drawbacks, a modification of **step {1}** was carried out by performing a wavelet-based functional PCA. Functional PCA here amounts to a classical PCA, not on the locations, but on the wavelet coefficients. The wavelet-based decomposition allows to consider the spatial structure of the maps by studying the frequencies of the water levels and their locations.

Sensitivity analysis on mixed variables

Once the methodology had been tested on the basic case of continuous variables, the work was extended to all the variables in the hazard model, including both continuous and categorical variables. The variables selected are the following:
- Marine forcing, corresponding to a binary categorical variable. Both possibilities are BRGM forcing and CCR forcing;
- roughness coefficients: there are 12 different land cover types in the area under study. For each type, a different roughness coefficient can be assigned. These coefficients correspond to continuous variables;
- hydraulic connections: there are seven different hydraulic connections which are considered as binary categorical variables; these connections can be activated or not.

a. Site location

b. Parametrisation of temporal forcing

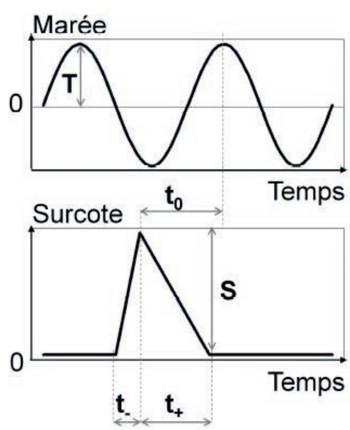

Figure 1 – Location of the site (a) and schematic diagram of the parameters tested (b).

RESULTS

The study site chosen is the Boucholeurs. This site, located on the French Atlantic coast near La Rochelle, was severely affected by Cyclone Xynthia in 2010. As shown in Figure 1, five variables were considered: tidal range (T), atmospheric surge (S), surge and tide phasing (t0), surge rise time (t) and fall time (t+). In the end, the model forcing is composed of the sum of the tide and the surge. This forcing was used to feed the CCR and BRGM overflow models. 500 calibration events were simulated per model by varying these 5 parameters. Once these events were simulated, a metamodel was calibrated on each of the models and a sensitivity analysis was performed.

Once the metamodel is in place, it is possible to obtain as many simulations as necessary to estimate the Sobol indices and thus perform the SA. The Sobol index is one of the most commonly used sensitivity indices, to assign an indicator influence of one or more model inputs on the variability of the model output. The closer the index is to 1, the more influence the parameter has. The influence of the parameters can thus be ranked in descending order of the index values. In the thesis, an adaptation of this index was made based on the work of Lamboni et al., 2011 [6].

Figure 2 shows the indices calculated for each variable. The first order indices are the value of the influence of the input alone, while the total indices are the value of the influence of the input in interaction with the other inputs of the model. The tidal range seems to be the most influential parameter with about 70% influence alone. Then the second influential parameter is the phasing between the surge and the tide (t0). The latter seems to have more influence in interaction with

coastal flooding
flooding
metamodel
sensitivity analysis

> the other inputs (about 25% of total influence). Finally, the less important parameters, in decreasing order of influence, seem to be the surge rise and fall times (equivalent influence), and the surge. This result can be explained by the fact that a surge can be significant and if it is out of phase with the tide, it does not induce any risk of coastal flooding. The variable corresponding to the DTM was not retained, despite its definite importance on the sensitivity of the results. Indeed, the DTM is a map with an error interval at each location of the map and it would be costly to vary this error at each location.
Sensitivity indices are obtained with the CCR and BRGM models on these mixed variables. This result highlights significant differences between the models. The CCR model is mainly influenced by marine forcing and, to a lesser extent, by the roughness in urban areas (roughness A) The BRGM model is heavily influenced by marine forcing and two hydraulic connections.

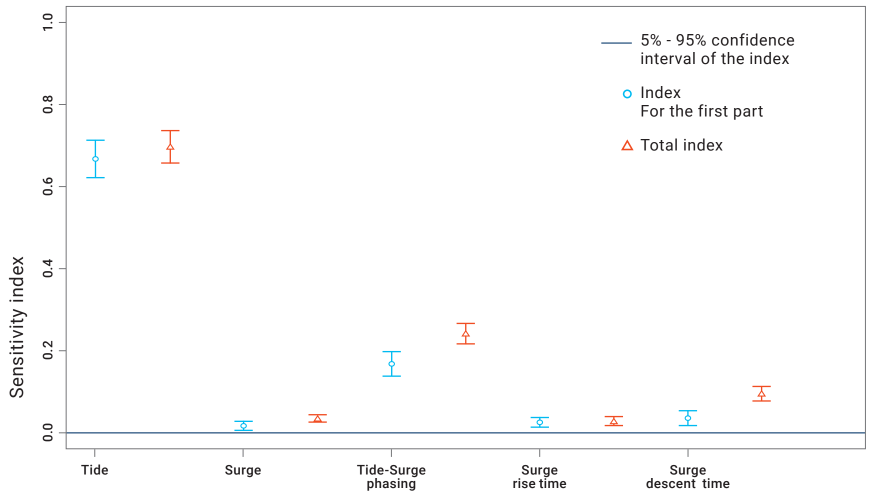

Figure 2 – Sensitivity indices obtained for each input of the BRGM model.

CONCLUSION

The work carried out focused on the sensitivity analysis of a flooding model, generating spatial outputs. To obtain the number of simulations necessary to perform the sensitivity analysis, a metamodel based on wavelet-based functional PCA was built and a sensitivity index adapted to the spatial data was defined. It was shown that the metamodelling method developed in the thesis has a predictive capacity that is not only better, but also five times faster than the standard PCA method. The final sensitivity index obtained made it possible to prioritise the parameters of the BRGM and CCR impact models on two test cases located in the Boucholeurs area: one studying the sensitivity of wave forcing on the detection of a flood and its extent, the other studying the sensitivity of different impact model parameters (forcing, soil roughness, hydraulic connections) on the estimated extent of the flooding during Cyclone Xynthia in 2010. This work led to the development of a package for the R software: GpOutput2D. Finally, it is possible to consider different flooding model settings, for example by changing the DTM within the metamodel./

THE PARTNERS

The thesis was co-financed and supervised by BRGM, ARMINES Saint-Étienne and CCR. ARMINES is a contractual and linked research association by State-approved agreements to its partner schools, such as MINES ParisTech and the Écoles des Mines network. The BRGM is a public industrial and commercial institution. One of its specialities is in the field of geosciences applied to coastal oceanography and coastal flooding.

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DROUGHT RISKS

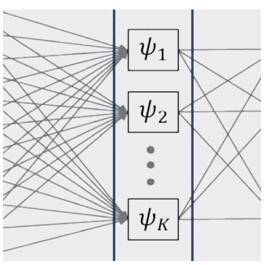
House with cracks due to drought (shrinking and swelling clay soils)

Geotechnical drought modelling • p.36

During the year 2020, work on swelling and shrinking clay soils modelling was structured around three main areas, including i) a feedback on the 2020 event, the fifth major event in a sequence that began in 2016, ii) a specific project on characterizing the claims on the basis of data science methods, and iii) the structuring of a multi-year research project with Météo-France and BRGM to provide a new understanding of the phenomenon linking the atmosphere, the soil and buildings.

Durant l'année 2020, les travaux de modélisation de la sécheresse ont été structurés autour de trois axes forts comprenant i) un retour d'expérience sur la sécheresse 2020, cinquième événement marquant d'une séquence débutée en 2016, ii) un travail de caractérisation de la sinistralité sur la base de méthodes relevant des datasciences et iii) la structuration d'un projet de recherche pluriannuel avec Météo-France et le BRGM pour apporter une nouvelle compréhension du phénomène liant l'atmosphère, le sol et les bâtis.

Pierre Tinard and David Moncoulon



Sequential *Super Learning* to forecast geotechnical drought damage • p.40

The purpose of this study is to estimate the damage due to a geotechnical drought. It is conducted by developing a dedicated sequential super-learning algorithm, which is adapted to the spatio-temporal dependency structure available in the data. A theoretical analysis of this machine learning procedure provides interesting guarantees for the performance of the sequential super learner. The exploitation of the algorithm on the data available to CCR provides very relevant results.

L'objet de ces travaux est l'estimation des dommages liés à une sécheresse géotechnique. Elle est menée en développant un algorithme de super learning séquentiel dédié, qui est adapté à la structure de dépendance spatio-temporelle présente dans les données. Une analyse théorique de cette procédure de machine learning offre des garanties intéressantes quant aux performances du super learner séquentiel. L'exploitation de l'algorithme sur les données dont CCR dispose fournit des résultats très pertinents.

Geoffrey Ecoto, Thierry Cohignac, and Antoine Chambaz

Geotechnical drought modelling

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INTRODUCTION

The year 2020 is part of a cycle of intense geotechnical droughts that began in 2016 and continued until 2021. Northern France was affected in 2020 in a very intense way that hadn't been seen since 2016. In contrast, the central regions of the territory experienced continuous Cat recognition over the same period. In fact, the work of estimating this event led us to estimate the impact on the average costs of successive recognitions or the absence of recognition for several years, even though commune-based requests for Cat recognition from the State had been formulated. In addition to considering the specificities of this event, data science work, carried out as part of a Master 2 internship at the Université Gustave Eiffel, aimed to categorise our database of approximately 270,000 claims collected from insurers by trying to highlight typical claim contexts linked to construction characteristics and environment of the houses[1].

The string of major events since 2016 and the increasingly severe intensities of the events as witnessed in 2018 and 2019 motivated a multi-year research project between Météo-France, the BRGM and CCR within the framework of a PhD thesis. This work will begin at the end of 2021 and will be positioned on the three fields of expertise of each of the partners, respectively the atmosphere, the soil and the damage related to the interactions of the first two.

(1) 4,958 known applications of communes at the beginning of September 2021

EVOLUTION OF THE AVERAGE COSTS OF CAT RECOGNITION

The repeated sequences of events affecting the same communes over the years led us to question the evolution over time of the average costs of claims per recognised commune. In our opinion, the main factors influencing this average cost are:

- the stock of unfit houses: i.e. single-family houses that have not been underpinned in the past;
- the evolution of the claim undergoing another drought episode before its effective recovery;
- the effect of continuous settlement whether due to a single drought episode or a succession of episodes.

Conversely, drought episodes that have not been recognised as Nat Cat in the commune (because their intensity was below the eligibility thresholds) may have occurred, causing damage to buildings that are not subject to compensation. Due to the difficulty of dating a claim precisely, when the commune is recognised, there is a risk that damage prior to the year of recognition is considered.

Over the 1989 - 2015 period, the data available for the study of the two antagonistic effects mentioned above are broken down as shown in Table 1 (see below).

The claims data collected from insurers and the actuarial work carried out by CCR make it possible to estimate the average cost of a Cat Nat recognition per year and per commune. As an example, aggregated by fiscal year, the figure below shows the change in the average cost per recognised commune over the period from 1989 to 2015 (in € 2020).

On the basis of this data (Figure 1), the characterisation of multiple recognitions in the same commune showed a 14% decrease in the average cost of a recognition.

However, when recognition is granted after a commune has been applying for recognition for several years without being eligible, our study has shown a 35% increase in the average cost of recognition in comparison to the average costs previously observed.

These results were applied in CCR's estimation of the 2020 event loss experience and communicated to the market in December 2020. The breakdown based on the applications of communes known to date for the year 2020 is as shown in Tables 2 and 3 (see opposite).

A sequence of recognitions leads to a reduction in the output cost of the CCR model of around 13% for the communes concerned; the absence of recognition over one or more years leads to an increase in the output cost of the CCR model of around 4% for the communes

Number of applications from communes	Number of Nat Cat recognitions	Number of claims identified by CCR
56,878	41,662	174,759

Table 1 – Status of Nat Cat claims, recognitions and losses to date.

concerned. All in all, on the basis of this work, the market cost is currently estimated at between €1 and €1.2 billion.

CHARACTERISATION OF MACHINE LEARNING AND DEEP-LEARNING

Over the years, CCR has been able to collect from its clients around 270,000 drought claims linked to a commune-based Nat Cat recognition order. To characterise claims beyond their cost, we enriched the data with indices relating to the building or its environment. As an example, and without limiting this list, the following parameters were added to the initial data:
- height of the building and/or number of above-ground levels,
- floor area of the building,
- altitude,
- local slope,
- age of building,
- the nature of the materials making up the walls and roof,
- thermal zoning (building regulations) to which the building belongs,
- ratio of the surface area occupied by the building to the total surface area of the plot,
- urban density (townhouse, residential area, detached house, etc.),
- indicator of exposure to groundwater rebound reflecting soil type
- zoning of soil with shrink-swell capacity as defined by the BRGM.

Only geolocated claims that could be linked with certainty to a building in the house category were retained.
In the end, after cleaning and enriching the initial data, nearly 100,000 claims served as the basis for work based on data science methods.
To complete this vision focused on build-

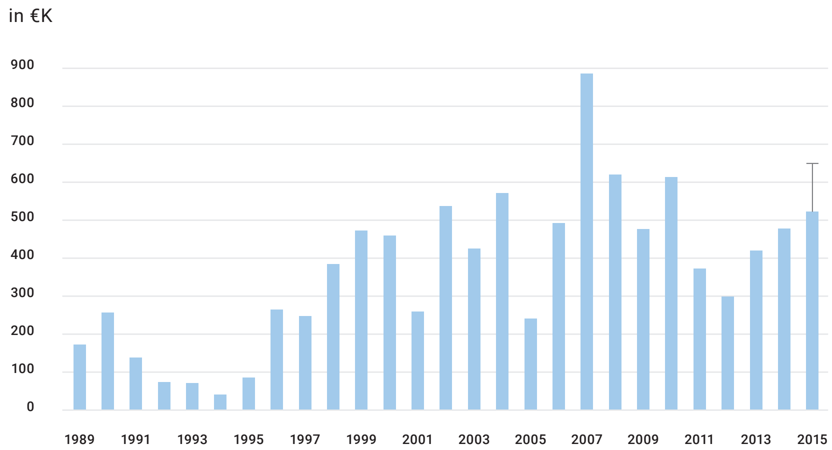

Figure 1 – Evolution of the average cost, in €2020 of the recognition of a geotechnical drought on a commune over the 1989 - 2015 period.

Number of Nat Cat recognitions since 2016	Number of communes concerned in France	Number of eligible communes having applied in 2020
1	5,443	1,961
2	1,651	845
3	96	35
Total	**7,190**	**2,841**

Table 2 – Status of previous recognitions (2016 - 2019) for communes recognised in 2020.

Number of applications made without recognition since 2016	Number of communes concerned in France	Number of communes recognised under the 2020 drought
1	1,366	183
2	369	27
3	82	6
4	20	2
Total	**1,837**	**218**

Table 3 – Status of applications without recognition (2016 - 2019) of recognised communes in 2020.

>

drought
shrinking-swelling clay soils
deep learning
claims
modelling

> ing vulnerability, information related to the Soil Wetness Index (SWI) produced by Météo-France[2] were associated to each claim to quantify the intensity of the event. Our first work used classical and proven machine-learning methodologies such as decision trees and their combination in the form of random forests. The advantage of these methods is that both the understanding of the implemented algorithm and the interpretation of the results are easy (Figure 2).
Other deep learning methods were used. They use neural network to, in our case, implement newer and more powerful algorithms that provide a more refined view of the classification of claims.
The model used is based on the implementation of networks of thousands of densely layered neurons for which information communicates with each other through activation functions of the ReLu type in our case [3] (Figure 3). The loss is evaluated using cross-entropy and a softmax activation function is used to retrieve a probability distribution. Finally, each neuron is assigned a probability p (Bernoulli law) of being dropped at each stage of the calculation, making the network less stable from time to time, but avoiding overlearning bias, the main pitfall of these methods.
At this stage of the work, some variables clearly emerge with regards to characterising the loss experience:
- the year of construction with an over-representation of costly claims (underpinning) for houses built between the mid-1970s and the mid-1980s,
- the height of the building, especially for single or two-storey houses if the building material is brick or millstone,
- the area occupied by the building in relation to the area of the plot of land on

(2) Data available at the time of the study in 2020.

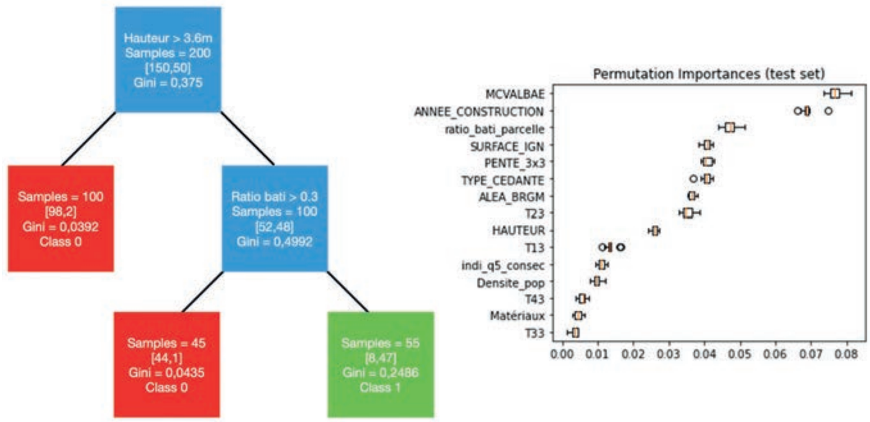

Figure 2 – On the left, an example of a decision tree and the distribution of data according to building height and building surface area/parcel ratio variables.
On the right, visualisation of the type and weight of variables in the classification decision of a random forest.

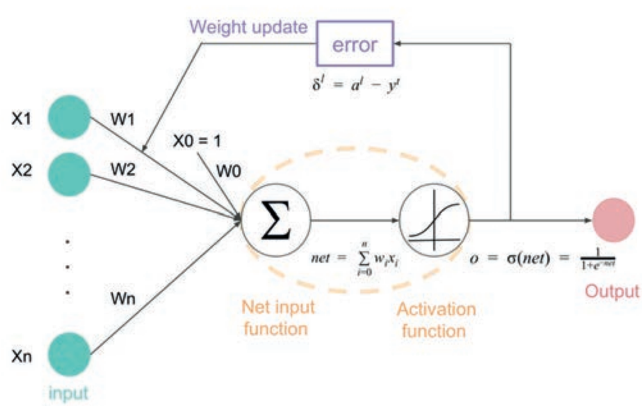

Figure 3 – General operation of the network with inputs and output.
Activation functions within the layer itself and between layers are implemented.

which it is built.
Exploration of the detailed drought assessment reports would help to substantiate these results.
This initial work based on data science methods has made it possible to characterise the loss experience on the basis of parameters linked to the type of buildings, their environment or the intensity of the event. Although meteorological data seem to be the best mastered to date, in-depth work must be carried out to improve information on loss experience and on the atmosphere-soil-building linking.

TOWARDS A BETTER UNDERSTANDING OF THE PHENOMENON

As part of a multi-year research project based on a PhD thesis starting in 2021, Météo-France, the BRGM and CCR wish to develop new tools for estimating the damage caused by the phenomenon by revisiting the physical characterisation of the atmosphere/soil/building interactions. In addition to a better characterisation of the claims experience, the work will make it possible to further determine the exposure of the French territory to droughts that have not occurred to date but are physically possible, particularly in the context of confirmed global warming. It will also support public risk prevention policies.
In practice, a new atmosphere/soil interaction model will be built based on the Météo-France ISBA model and the BRGM's geotechnical models and will be evaluated locally with regard to soil/building interactions on BRGM's instrumented sites. The current operational chain for monitoring the phenomenon will be improved by integrating, for example, an index of interannual vegetation variability.
Validation on a regional scale will be carried out by ensuring the coherence of developments throughout France in relation to the claims experience collected and enriched by CCR with all relevant information, such as that relating to the physical vulnerability of buildings.
Eventually, a new global tool to characterise the phenomenon, covering meteorological, geological and vulnerability aspects, will be developed./

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CITATION

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Sequential *Super Learning* to forecast geotechnical drought damage

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(2) MAP5 (UMR CNRS 8145), Université de Paris
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INTRODUCTION

The purpose of this work (which is the subject of an ongoing thesis) is to estimate the damage caused by geotechnical droughts. It is conducted by developing machine learning techniques. The unusual nature of the regions affected by this peril in recent years has been striking, but the intensity of its subsequent occurrences has been even more unexpected. In addition to the spatial dependencies induced primarily by the meteorological characteristics of the phenomenon under study, it is also necessary to consider the temporal dynamics of the underlying process. It is therefore necessary to adapt machine learning methods to consider the spatio-temporal dependencies of drought hazard. We propose an original extension of the super learning method [1] which differs from the original method both in terms of its structure and in the validation scheme which governs the learning. Theoretical guarantees illustrate the relevance of this. The results obtained on geotechnical drought are presented and commented.

METHODOLOGY

Super learning

Super learning is a method of set-based learning, i.e. a method of aggregating learning algorithms. Given a collection of basic learning algorithms (called base learners), the training of the super learner algorithm allows it to learn the best convex combination of the predictions made by the base learners once they are trained. The training of the super learner is based on a cross-validation pattern which generically consists of repeatedly alternating learning and validation on disjointed subsets of data. Theoretical analysis of the super learner ensures that its performance is essentially as good as that of the best base learner.

Training the super learner algorithm can also allow it to learn the best possible prediction from the predictions made by the trained base learners and from covariates through an algorithm (called a meta learner) dedicated to combining them. For example, a regression tree algorithm can be trained to make predictions from trained base learners and descriptions of French communes (including insured values and local weather conditions).

In the spirit of super learning, given a collection of meta learners, the best meta learner can be learned by a super learner (called in this context an "overarching super learner"). Figure 1 illustrates the architecture of our proposed dual layer super learner.

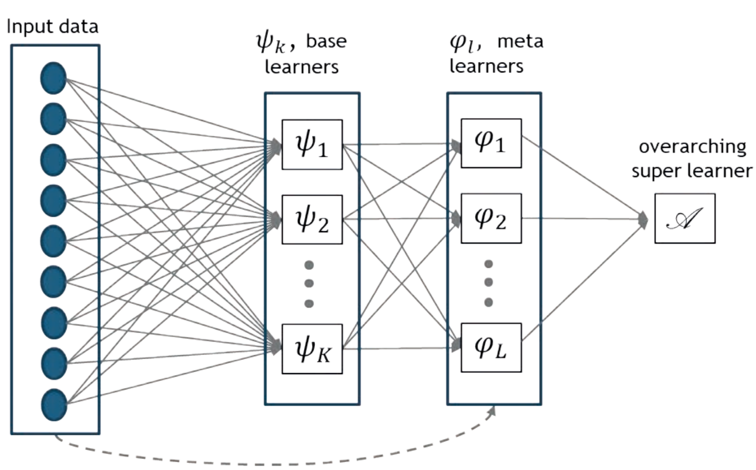

Figure 1 – Dual layer super learner.

Drought from the perspective of a spatio-temporal process: sequential validation

The temporal dimension of the studied phenomenon comes mainly from the dependency observed between the cost of a commune being recognised two consecutive years in respect of a drought. In addition, weather conditions in the year following the occurrence of a drought claim may aggravate it.

The spatial dimension of the drought hazard mainly stems from the meteorological nature of the phenomenon, which induces spatial dependency between communes. This spatial dependence is also due to the vulnerability in the insofar as there are clusters of insured goods on the French territory. By virtue of these dependencies, we adopt a sequential cross-validation scheme [2]. Iteratively, all data prior to a year t is used as training data, data related to year t is used as validation data, and then t is incremented. Since no algorithm has access to data subsequent to the validation exercise, sequential validation allows for the time dependency contained in our dataset to be considered. The spatial dimension is controlled within the framework of theoretical developments.

Study of the sequential super learner

An original theoretical analysis provides guarantees for the performance of our sequential super learning algorithm. Let $\psi_1,\ldots,\psi_K$ be the K base learners, $\psi_{\tilde{k}}$ the (optimal) oracle algorithm, $\psi_{\hat{k}}$ the algorithm identified by the sequential super learner. Let $\mathcal{A}$ be the set of communes and $\mathcal{G}$ a dependency graph of French communes (which incorporates, among other things, joint borders between communes). The degree $deg(\mathcal{G})$ of $\mathcal{G}$ (plus the maximum number of edges starting from a node of $\mathcal{G}$) quantifies the strength of the dependency. Under assumptions typical of super learning analyses, using a Janson concentration inequality [3], we obtain the following (simplified) result: for a coefficient $\beta \in (0,1]$ (the existence of which is assumed), for $\mathcal{J} = |\mathcal{A}| / t^{\beta}.deg(\mathcal{G}))$ (a quantity of information), for any $\varepsilon > 0$ possibly small,

$$\text{Risque}\,(\psi_{\hat{k}}) < (1+\varepsilon)\,.\,\text{Risque}\,(\psi_{\tilde{k}}) + \text{constante}\,(\varepsilon)\,.\,\left(\log(\text{J}.\log(\mathcal{J}^2)) \Big/ \mathcal{J}^2\right)^{\frac{1}{2-\beta}}$$

This inequality is interpreted as a guarantee that the performance of the sequential super learner is essentially as good as that of the best base learner. Compared to the similar result of Benkeser et al, [4], our analysis (i) relies on a less restrictive set of assumptions and (ii) takes advantage of the fact that the communes are indeed dependent on each other but that the quotient $\mathcal{J} = |\mathcal{A}| / deg(\mathcal{G})$ is potentially big.

IMPLEMENTATION AND RESULTS

The implementation of the dual-layer sequential super learner was done using R programming language [5]. It is in line with the implementation of the Super Learner package [6], which is a reference. The latter has been adapted to consider the original proposed validation scheme, and to add the 'meta' and 'overarching' layers. In addition, a collection of 27 base learners was put together. It includes ridge, lasso and elastic net regression algorithms [7], algorithms based on MARS models (Multivariate Adaptive Regression Splines, [8]), on support vector regression [9] and random forests [10] and neural networks [11]. Similarly, a collection of 48 meta learners was put together.

The training data was collected from databases used for the portfolios and claims of CCR's ceding companies from 1990 to 2017. This data was mainly enriched with the SWI (Soil Wetness Index) computed by Météo-France which quantifies soil moisture on the territory for each year, and the clay content of the soil as provided by the BRGM (*Bureau de recherches géologiques et minières*). This information was then aggregated by commune and further enriched (insured values, climate zones, vegetation, average age of buildings, ground slope, to name a few).

The predictions of the overarching super learner are shown in Figure 3 for the years 2007 to 2017. It appears that the

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natural catastrophes
space-time dependencies
machine learning
drought
super learning

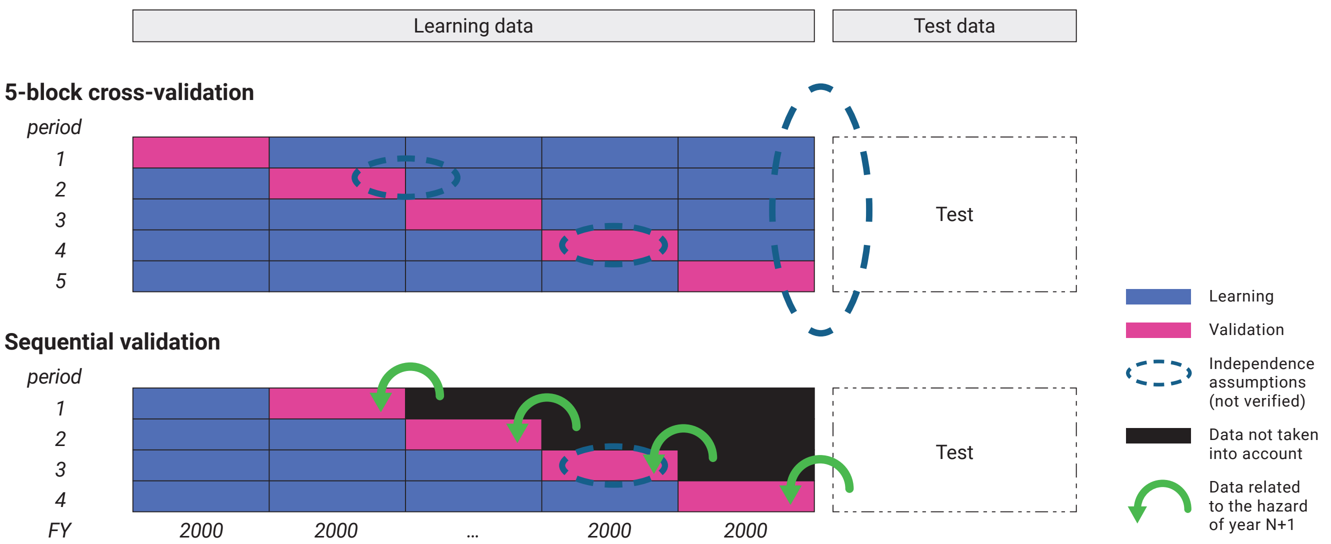

Figure 2 - Cross-validation and Sequential validation.

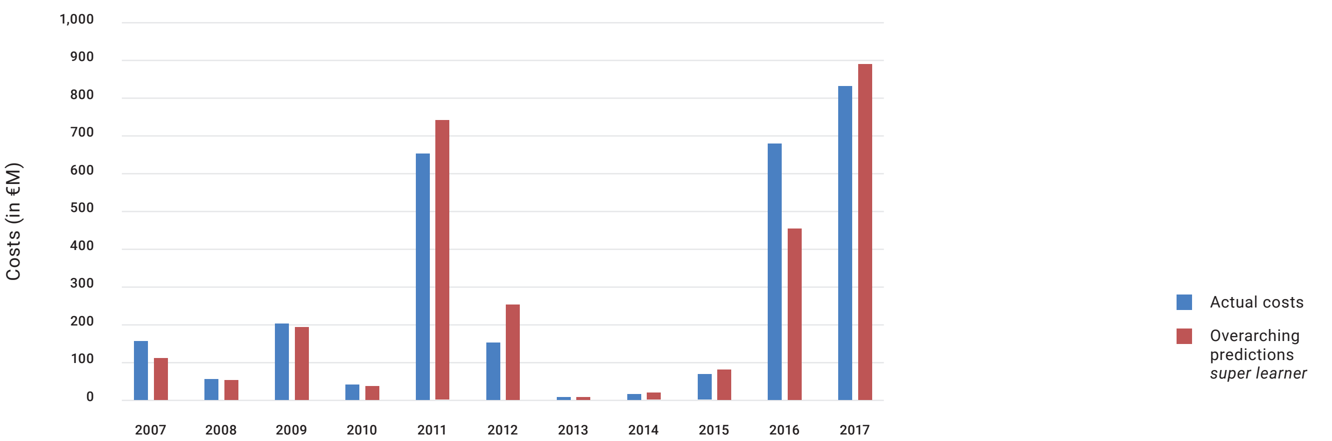

Figure 3 - Super learner overarching predictions and actual costs.

THE PARTNERS

In 2018, a thesis was initiated by CCR in partnership with the Université de Paris. This thesis, entitled "Modelling and targeted machine learning applied to natural disasters". The aim of this thesis is to use new findings in statistical learning to improve predictions of damage following the occurrence of a natural disaster.

> proposed algorithm is able to provide globally accurate predictions of the costs of a drought event. However, the prediction for 2016 (and to a lesser extent the one for 2012) is inconsistent with actual costs. It is therefore necessary to analyse these differences, which may arise, for example, from the management policy of the ceding companies affected, or from the estimate of the insured values in these same areas.

CONCLUSION

This work presents a two-layer sequential super learning method to forecast the damage resulting from the occurrence of a geotechnical drought event. The theoretical performance of this algorithm has been studied. This set-based algorithm allows for both spatial and temporal dependencies of the phenomenon under study to be considered. Once implemented, this super learner extension was exploited to predict drought damage, with interesting results./

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CITATION

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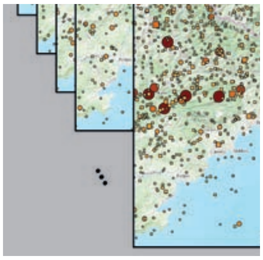
GEOLOGICAL RISKS

On 11 November 2019, an earthquake with a moment magnitude of 5.2 occurred near Montélimar in the Rhône Valley. The epicentre which was located in Le Teil (Ardèche), caused significant damage.

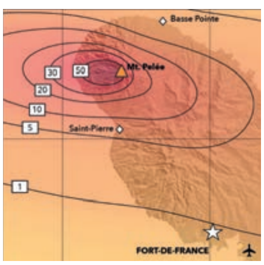


Stochastic earthquake generator • p.46

In order to estimate seismic hazard and precisely characterize involved earthquakes, one can generate synthetic earthquakes over large period of time and observe their impact on a given site. This approach takes into account past seismicity and its uncertainties. This paper proposes to adapt the generator methodology for application in low-to-moderate seismic areas by implementing a recurrence model for earthquakes and a new way to localize synthetic earthquakes in space and time.

Une des façons d'estimer l'aléa sismique tout en définissant clairement les séismes impliqués est de produire des séismes synthétiques sur de longues périodes temporelles et d'observer leur impact sur un site donné. Pour ce faire, la sismicité passée ainsi que les incertitudes associées sont analysées. Cet article propose d'adapter la méthode du générateur de séismes synthétiques au contexte de sismicité faible à modérée en implémentant un modèle de calcul de la récurrence des séismes et une nouvelle approche de génération des séismes synthétiques dans le temps et dans l'espace.

Corentin Gouache, Jean-Marc Montel, Pierre Tinard, and François Bonneau



Reassessing volcanic hazard in Martinique • p.50

Assessing volcanic hazard requires an extensive knowledge of the eruptions likely to happen in the considered area. This study allows reconstructing of the eruptive history of the Mount Pelée, the only active volcano in Martinique, and experimental and numerical modeling of Plinian eruptions. This combined approach leads to a new volcanic hazard map, including for the first time the Plinian eruptions of Mount Pelée.

Caractériser l'aléa volcanique nécessite une connaissance approfondie des éruptions susceptibles de se produire sur un territoire. Cette étude permet de reconstruire l'histoire éruptive de la montagne Pelée, seul volcan actif de la Martinique, ainsi que de modéliser expérimentalement et numériquement les éruptions pliniennes. Cette approche intégrée débouche sur une nouvelle carte d'aléa volcanique prenant en compte pour la première fois les éruptions pliniennes de la montagne Pelée.

Audrey Michaud-Dubuy

Stochastic earthquake generator

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INTRODUCTION

In Metropolitan France, earthquakes are very rare and since the introduction of the Nat Cat scheme in 1982, they have accounted for barely one percent of the cumulative loss experience. However, earthquakes, sometimes located beyond borders, have had devastating impacts on the metropolitan territory. These include Basel (1356), Bagnères-de-Bigorre (1660), Ligure (1887) and Lambesc (1909). Moreover, the recent earthquake in Le Teil (2019) reminds us of the sudden and unpredictable nature of seismicity. It also shows that seismicity concerns the entire French territory.
Although it is currently impossible to predict the occurrence of earthquakes, the scientific community has taken to calculating annual probabilities of reaching or exceeding a certain level of seismic hazard. However, some fields, such as insurance, need to better identify the earthquakes that produce this hazard to set aside sufficient funds to compensate potential claimants. One way of estimating seismic hazard while clearly defining the earthquakes involved is to produce synthetic earthquakes over long periods of time and observe their impact on a given site [1, 2]. For this purpose, past seismicity and associated uncertainties are analysed. Metropolitan France is far from the main tectonic plate boundaries. As a result, the origin of its seismicity is more difficult to understand than in active regions along plate boundaries. In addition, there is less seismic data available (earthquakes, stress accumulation in the ground, faults, focal mechanisms etc.). These observations are two of the main obstacles to characterising the seismic hazard in a low-to-moderate seismic area.
This article presents an earthquake generator suitable for low-to-moderate seismicity. It is based on a description of past seismicity using the interevent-time method assessing the temporal distribution of events [3, 4]. The generator is then organised around three stages: (i) the generation of main earthquakes in time and magnitude, (ii) the location in space of these main earthquakes and (iii) the generation of aftershocks produced by the main earthquakes. Finally, seismic risk is calculated using a set of weighted ground motion prediction models. Annual exceedance probabilities are finally estimated by observing the hazards that synthetic earthquakes produce over a million years, a period of time considered sufficient to best explore the {frequency-magnitude} distribution (FMD) and spatial distribution of synthetic earthquakes.

METHODOLOGY

The French historical catalogue (1310 - 1964, Figure 1a) FCAT [5] is analysed to define the temporal behaviour of French seismicity. This behaviour is expressed as a FMD of main earthquakes. The latter are independent of each other and are therefore to be contrasted from the aftershocks which are dependent on them. It is accepted that the largest earthquakes are distributed according to the Poisson law
In our work, the FMD of main earthquakes is calculated using the interevent-time method. The latter defines the FMD by quantifying, for each magnitude, the proportion of main earthquakes in a given catalogue and effectively discarding aftershocks that do not follow a Poisson distribution. Thus, it is a {proportion of main earthquakes - magnitude} distribution (FMD) that is established. To compensate for the lack of observed data at the highest magnitudes, the FMD is estimated for France as a whole. In addition, an implementation of the original interevent-time method is proposed to stabilise the results when less than 50 data are available. In the end, this step provides the earthquake generator with a DPM and a FMD.
The earthquake generator includes three main stages. Firstly, the main earthquakes are generated in time (year) and magnitude over a million years. For this purpose, a Poisson distribution with a parameter depending on the magnitude is used. This parameter is derived from the FMD of main earthquakes. Then, once the main synthetic earthquakes are associated with their year of occurrence and their magnitude, they are located in space. For this purpose, a spatial density map is used. Faults in stable regions (far from tectonic plate boundaries) such as Metropolitan France can remain inactive for very long periods of time as shown by the earthquake in Teil [6, 7, 8]. However, given that the fault network is more or less well distributed in stable regions, Calais et al., 2016 [9] propose that strong earthquakes are more spatially distributed than suggested by current seismicity. Thus, we

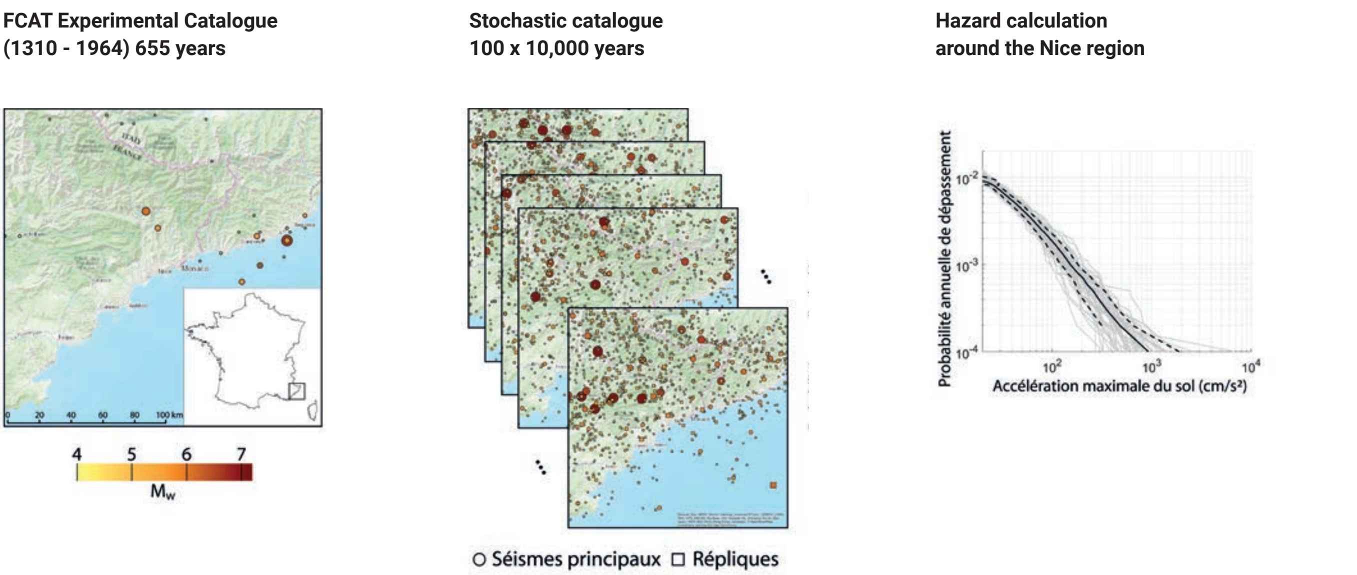

Figure 1 – General diagram for the estimation of annual exceedance probabilities around Nice. a: The FCAT experimental catalogue is analysed using the interevent-time method adapted to regions with low-to-moderate seismicity. This analysis provides the proportion - magnitude and frequency - magnitude distributions of main earthquakes to the earthquake generator. b: A set of 100 stochastic 10,000-year catalogues of main earthquakes and synthetic aftershocks is then produced. c: Seismic risk is calculated using weighted ground motion prediction models. The observation of the hazards produced by all the generated earthquakes gives the annual exceedance probability.

decided to choose the fault line map (BD Charm) to produce the spatial density map. To ensure consistency in the location of earthquakes at the highest magnitudes, regionalisation is applied. Each region is characterised by a maximum allowable magnitude from past seismicity (FCAT). The location of a main earthquake of magnitude M can only be done in regions where the maximum magnitude is greater than or equal to M.

Finally, the possibility of producing aftershocks is left for each main earthquake. This possibility depends on the magnitude of the main earthquake according to Bath's law [10] as well as on the DPM of main earthquakes. From this perspective, the proportion of aftershocks (complementary to the proportion of main earthquakes) is assimilated to the probability of an aftershock. If aftershocks are produced, they are simulated in the same year as the main earthquake and in the vicinity of the main earthquake.

Finally, ground motion prediction models are applied to all the generated earthquakes to compute seismic risks (acceleration, speed, etc.) (e.g. maximum soil moisture) that they produce. These models are weighted using accelerations from the European RESORCE database [11]. The weights depend on the magnitude of the earthquake and the distance from the site. For each simulated year, the maximum hazard produced by all synthetic earthquakes at the study site is listed. This list of maximum annual hazards is then sorted from highest to lowest. The hazard has an annual probability of being exceeded of 1/10,000 which makes it the 100th hazard in the list of maximum annual hazards. In other words, this hazard has been exceeded at least 100 times over the observation period of one million years making it an annual probability of being exceeded equal to 10-4 (Figure 1c).

RESULTS

The application of the interevent-time method to France revealed a FMD defined by two power laws instead of one as recommended by the Gutenberg-Richter law (1944) (GR law). The latter states that the log10 of the cumulative number of earthquakes is proportional to the magnitude with a coefficient of about 1. Our results attest to a first power law with coefficient 0.75 for M≤5.5 and a sec- >

> ond power law with coefficient 1.25 for M≥5.6. This implies that the strongest main earthquakes are less frequent than a GR law of coefficient 1 would suggest. Table 1 summarises the return periods associated with these earthquakes according to their magnitude M.

As far as the earthquake generator is concerned, it manages to reproduce the spatial density given as input and is in agreement with the region-based approach used. Moreover, despite the use of few parameters, the generator reproduces the aftershock production law classically used in seismicity. The latter links the number of aftershocks produced by a main earthquake to the earthquake's magnitude. However, the generator fails to reproduce the main earthquake DPM provided as input. Figure 1b shows examples of synthetic catalogues of 10,000 years around Nice.

The ground motion prediction models used in this study are the same as those applied in the study by Martin et al, 2018 [12], Ak14 [13], Am14 [14], Bi14 [15], Bo14 [16] and DC15 [17]. The DC15 and Am14 models were developed from French data and are the most represented in our weighting model with respectively 29% and 23% of the control of hazard calculation. This is followed by the European models of Ak14 (22%) and the global model of Bo14 (20%). The European Bi14 model, which was formulated using data in RESORCE, only accounts for 6% of the control of hazard calculation in our weighting model. The hazard resulting from our weighting model is on average 10% higher than the hazard calculated with the weighting model of Martin et al., 2018 [12].

Finally, once the earthquakes have been generated and the hazards they produce have been computed, the {annual - hazard} probability curves are estimated (Figure 1c). These curves are consistent with recent French studies [12, 18, 19]. These results are in line with the trend of decreasing seismic hazard estimation over the last 20 years. The consideration of aftershocks does not significantly impact hazard estimation (<10%). However, the choice of the weighting model, ground motion prediction models and regionalization can affect hazard estimation by up to 30%.

CONCLUSION

The approach proposed in this study allows the production of synthetical earthquake catalogues based on {proportion - magnitude} and {magnitude} distributions {frequency - magnitude} of major earthquakes, a spatial density map of fault patterns and a regionalization. In addition, ground motion prediction models are weighted according to earthquake-to-site distance and earthquake magnitude using acceleration data. The entire procedure results in {annual - hazard} probability curves, consistent with the input data and recent studies. The main results of this study are (i) obtaining lower frequencies of main earthquakes than with the use of GR law but more consistent with knowledge of seismicity in Metropolitan France and (ii) a calculation of the hazard on average 10% higher with our prediction model than with that of reference [12]. In view of the final results, the underestimation implied by the low frequencies is probably compensated by the overestimation of the seismic hazard calculation./

M ≥	4	4.5	5	5.5	6	6.5	7
Return period	0.5 ± 0.04	1.2 ± 0.18	3 ± 0.4	7.2 ± 0.73	40 ± 6	168 ± 98	2 510 ± 1 855

Table 1 – Mean return periods and standard deviations of main earthquakes according to their magnitude M.

THE PARTNERS

ASGA is French not-for-profit organisation. Created on 24 May 1955, its purpose is to the development of teaching and research in the fields of Earth Sciences. ASGA has supported and managed the RING project since 1989.
This project is supported by an international consortium of 14 industrial sponsors including CCR since 2018 and more than 140 academics. This consortium, managed by ASGA, is attached to the GeoRessources laboratory, and supported by the ENSG Nancy within the Université de Lorraine.

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CITATION

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Reassessing volcanic hazard in Martinique

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INTRODUCTION

Within the framework of the ORSEC (*Organisation de la réponse de sécurité civile*) plan, departmental hazard maps are drawn up in order to visualise the areas threatened by natural phenomena such as floods, earthquakes or volcanic eruptions. In Martinique, volcanic risk comes mainly from Mount Pelée, the only active volcano on the island in 127,000 years. Unlike volcanoes described as having effusive eruptions, such as Piton de la Fournaise on Réunion Island, which regularly produces lava flows with little impact on the population, volcanoes with explosive eruptions such as Mount Pelée display sporadic activity, often less than one eruption per century. The type of explosive eruption is also variable: they can produce lava domes, the destruction of which is generally associated with *nuées ardentes* (as in 1902 in Martinique), but also columns of plinian ash and/or pyroclastic flows. These characteristics - their low frequency, their phenomenological variability, their destructive potential - make it particularly difficult to assess the hazard and also to prevent and manage the associated risks.
The reassessment of volcanic hazard in Martinique is now crucial since the current hazard map, built by the BRGM in 1998 [1], does not consider the dynamics of the most powerful explosive volcanic eruptions, known as "Plinian eruptions". Eruptions of this type produced by Mount Pelée are still largely unknown. However, these eruptions represent a major danger as they are assessed by the projection into the atmosphere of a column of gas and ash several tens of kilometres high, which can change dynamics during an eruption. The column can either scatter its volcanic fragments in the main wind direction, threatening the many islands of the Lesser Antilles, or it can collapse under its own weight, forming devastating and potentially deadly pyroclastic flows for the populations living near the volcano.
Improving both our knowledge of past eruptions of Mount Pelée and our understanding of the dynamics of these eruptions is therefore essential to forecast future eruptions and assess volcanic hazard in Martinique.

METHODOLOGY

To understand the destructive potential of Mount Pelée in the future, it is necessary to improve our knowledge of the volcano's past eruptions and their temporal frequency. For this purpose, two field campaigns were carried out in 2017 and 2019 (axis 1 in Figure 1). The study of deposits from past eruptions involves several steps: the identification of the deposits on the flanks of the volcano, their description (thickness, lithology, presence of current or erosion patterns, etc.), the correlation of the various deposits with each other, and finally their dating by the carbon-14 method. These different steps, often challenging because of complex terrain in context, allow us to establish a chronology of the different volcanic events that have occurred in the past, but it is also crucial to know the characteristics of each of these eruptions. The use of physical models of eruption columns combined with descriptions and rock sampling carried out in the field makes it possible to determine the ejected volumes, column heights, eruptive flow rates, phase durations and grain sizes of the various eruptions. It is thus possible to draw a picture of the eruption scenario most likely to occur in the future.
As this scenario may include collapse of the eruptive column and the production of pyroclastic density flows, it is necessary to study the conditions controlling the transition from one regime to the other. The modification of the PPM 1-D plume model allows us to study the impact of the granulometry of the volcanic fractions on the transition from a stable Plinian column to a collapsing fountain (axis 2). The effect of wind is then considered by means of novel laboratory experiments that simulate turbulent jets forming in a windy environment (axis 3). Indeed, the mixing of atmospheric air and eruption column due to wind is still poorly understood. However, the density of the column and therefore its stability depends on the efficiency of this mixing. Laboratory work produces analogues of small-scale eruptions by injecting a mixture of ethanol and ethylene glycol (the analogue of a volcanic column) into a tank filled with fresh water (representing the atmosphere). The device controls the flow rate injected, the speed of "wind" (modelled by a rail moving the source), and the differences in density between the jet and the water in the tank. Forty experiments are carried out, and the jet trajectories traced from the films can then be directly related to the quality of the mixing between the column and the atmospheric air. This empirical parameter is then implemented in the PPM model to produce a new regime diagram.

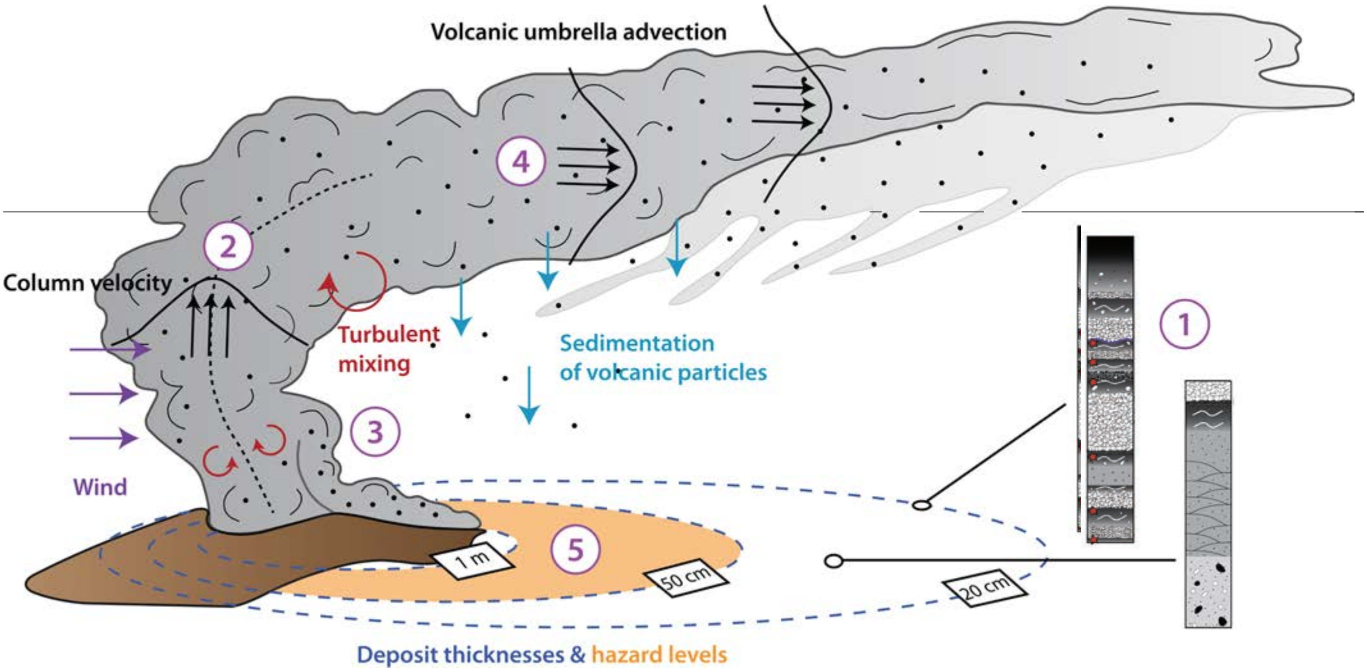

Figure 1 – Diagram summarising the different axes of this study around Plinian eruptions, with Mount Pelée as the target volcano: 1) field study in Martinique, 2) physical modelling of an eruption column through the 1-D PPM model, 3) experimental modelling of turbulent jets s ubjected to wind, 4) modelling ash dispersal with the 2-D HAZMAP model, and 5) characterisation of the Plinian volcanic "ash fallout" hazard.

The final step is to construct the Plinian volcanic hazard map (i.e. the "ash fallout" hazard). Monthly wind profiles from forty years of wind data in Martinique (ERA-Interim), combined with sixteen eruption scenarios based on theoretical predictions from the 1-D model, are implemented in the 2-D volcanic ash dispersion model HAZMAP [2] (axis 4). Each eruptive scenario has a probability of occurrence based on the past eruptive history of Mount Pelée. By combining the areas affected by each eruption scenario, the new volcanic hazard map for "ash fallout" is obtained (axis 5).

RESULTS

Recognition and analysis of the deposits of past eruptions of Mount Pelée have allowed the reconstruction of its eruptive history for the last 24,000 years (it was previously only known for the last 5,000 years). This new chronology, including 6 major explosive eruptions previously unknown, allows us to estimate that a Plinian eruption occurs every 1,800 years on average in Martinique [3]. Reconstruction calculations of the eruptive parameters of the newly discovered eruptions reveal that they are very similar to each other, both in volume and power (column heights, flow rates, duration), suggesting that Mount Pelée reproduces a very similar pattern with each eruption. A future Plinian eruption of Mount Pelée will therefore most likely be rated 4 out of 8 on the Volcanic Explosivity Scale (VEI), which corresponds to an ejecta volume of about 1 km3. This eruption would produce an eruption column some 20 km high for a few hours, with very likely alternating phases between a stable column dispersing ash over large distances, and a collapsing column producing pyroclastic flows. It would therefore be a medium-powered eruption, but its impact would already be significant on the scale of the island of Martinique or even the Lesser Antilles arc, depending on the direction of the prevailing winds.

One of the new eruptions found in this study, the eruption of Bellefontaine 14,000 years ago, is a good illustration of the relevance of winds for the study of volcanic hazard [4]. During this eruption, the ash was dispersed not in the usual direction of the trade winds (towards south-west) or counter-trade winds (towards north-east), but due south, towards present-day Fort-de-France. A detailed study of the winds over the last forty years has shown that this unusual wind direction is due to a change in the path of the tropical jet stream, which occurs regularly throughout the year with a 5% maximum probability in the shoulder seasons (May and November).

In parallel with this extensive field work, the improvement of the 1-D volcanic plume model PPM allowed for the quantification of the impact of volcanic fragment granulometry on plume stability [5]. The results of this study show that the high porosity of volcanic pumice fragments contained in the column contributes to stabilise the eruption column and limits the formation of pyroclastic flows. Laboratory experiments simulating turbulent jets in windy environments have shown that wind also has a stabilising effect [6]. It >

volcanic hazard
Mount Pelée
plinian eruptions
modelling
tephrostratigraphy

> promotes turbulent mixing between the atmosphere and the eruption column and increases the column's field of stability. The new regime diagram proposed as a result of these modelling results can be used for a rapid assessment of the Plinian hazard in the event of an eruption.
The final result of this study is the new Plinian volcanic hazard map built from 192 ash dispersion simulations (16 eruption scenarios x 12 monthly wind profiles) performed with the HAZMAP model (Figure 2a). In the same way as the map currently used in the ORSEC plan, this new map indicates that the northern part of the island (where the volcano is located) is the area of maximum exposure to "ash fallout" hazard. However, the new map also predicts ash thicknesses greater than a millimetre in the very south of the island, on the Saint-Anne peninsula, which was considered safe on the former map. To facilitate the reading of this new map, it is combined with critical thickness thresholds associated with possible destruction published in the literature [7,8] (Table 1, Figure 2b). It can be seen that even though the modelled thickness in the south of the island may seem trivial, it still leads to a need for maintenance of the electricity, drinking water and wastewater networks. Similarly, Fort-de-France International Airport, a key structure in crisis management, could be closed quickly after the onset of a major eruption of Mount Pelée. Finally, the area closest to the volcano, from which the vast majority of Martinique's drinking water is supplied, could be totally destroyed. These results, although they only concern ash fallout, highlight the need to continue this work of reassessing volcanic hazard in Martinique. Indeed, these simulations already show that even the extreme south of Martinique would not be spared in the event of a future eruption of Mount Pelée. Today, the Prefecture of Martinique is working in agreement with several local and national players to rewrite the ORSEC Volcano plan for Martinique. These new simulations for the scattering of ashes will be included.

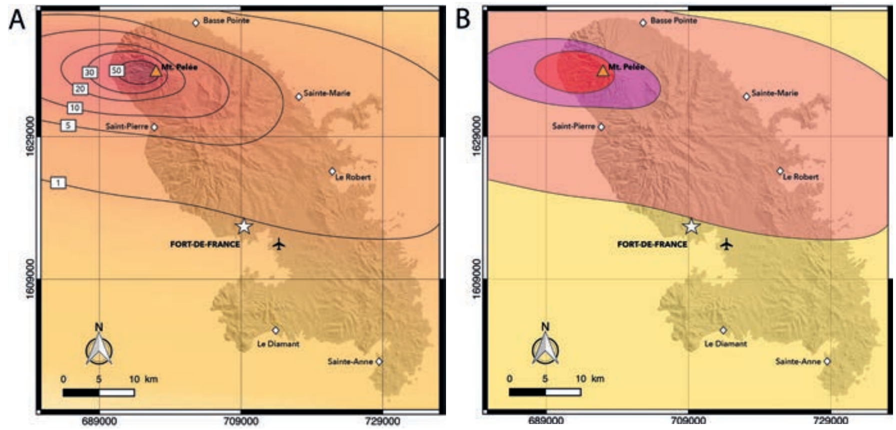

Figure 2 – New volcanic ash fallout hazard map, obtained by combining the results of 192 ash dispersion simulations. The hazard level is based on A the simulated thickness of the deposit in centimetres, and B showing 4 levels of intensity ranging from red (very high, I4), pink (high, I3), orange (medium, I2), to yellow (low, I1). These levels depend on on critical thickness thresholds beyond which infrastructure is damaged (see Table 1).

I0	None	Th < 1mm	No damage
I1	Low	1 mm < Th < 1 cm	Maintenance required on the networks (electricity, water, etc.), airport closure
I2	Average	1 cm < Th < 15 cm	Major repairs to networks
I3	High	15 cm < Th < 30 cm	Networks need to be completely rebuilt, poor quality roofs collapse extensively
I4	Very high	Th > 30 cm	All types of roofs collapse on a large scale

Table 1 – Intensity levels (I0 to I4) used to build the 'ash fallout' hazard map in Figure 2, and the corresponding exposure levels, ash thickness thresholds (Th) and infrastructure damage.

THE PARTNERS

This study was conducted by A. Michaud-Dubuy as part of her thesis entitled "*Dynamique des éruptions pliniennes: réévaluation de l'aléa volcanique en Martinique*" under the supervision of Prof E. Kaminski and Dr G. Carazzo at the Institut de Physique du Globe de Paris (IPGP, Université de Paris). The IPGP oversees certified observation services in volcanology through its permanent observatories in Guadeloupe, Martinique, and Reunion.

CONCLUSION

The study of the volcanic deposits from Mount Pelée reveals that its Plinian eruptions differ only in their axis of product dispersion. Including wind in volcanic eruption models is therefore a priority. Laboratory experiments reproducing an explosive eruption have been developed to quantify wind forcing on atmospheric air and eruption column mixing. These results, combined with the study of the impact of granulometry on the stability of eruption columns, make it possible to establish a new transition law between the two eruption regimes validated by field data in Martinique. This integrated approach finally makes it possible to draw up a new volcanic hazard map for Martinique, taking into account for the first time the Plinian eruptions of Mount Pelée. This map will be integrated into the new ORSEC Volcano plan currently being drafted, at the request of the Prefecture of Martinique./

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CITATION

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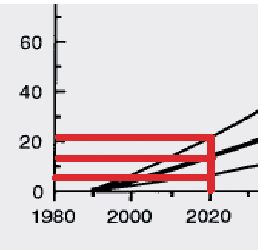
CLIMATE CHANGE


Dry maize field
with young maize plants.


Flooding in Carcassonne (Aude)
hit by the storm Gloria on 23 January 2020.

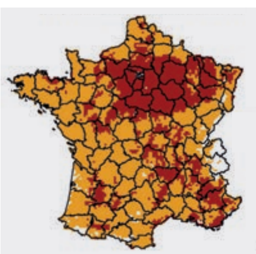


Climate change: a multi-hazard approach • p.57

This article summarises the results of two CCR studies on the consequences of climate change on natural disasters under the IPCC RCP 4.5 and 8.5 scenarios. These results can be compared with the international literature on the topic, since the first IPCC's report in 1990.

Cet article effectue une synthèse des résultats des deux études CCR portant sur les conséquences du changement climatique sur les catastrophes naturelles selon les scénarios RCP 4.5 et 8.5 du GIEC. Ces résultats peuvent être mis en regard avec les publications internationales sur le sujet, depuis le premier rapport du GIEC de 1990.

David Moncoulon, Roxane Marchal, Jean-Philippe Naulin and Dorothée Kapsambelis

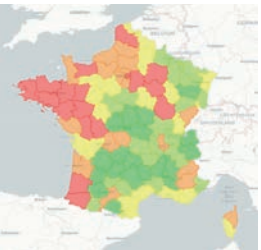


Modelling the impact of droughts and excess water on crop production by 2050 • p.62

Extreme climatic hazards lead to high crop losses in crop production and weaken the economy of farms. This article presents the modelling of extreme risks of droughts and excess water and their consequences on crop losses for grasslands, soft winter wheat and winter barley. This study provides key figures on the vulnerability of crops to these risks as well as the exposure of the territory today and by 2050.

Les aléas climatiques extrêmes engendrent de fortes pertes de récoltes sur les productions végétales et fragilisent l'économie des exploitations agricoles. Cet article présente la modélisation des risques extrêmes de sécheresses et d'excès d'eau et leurs conséquences sur les pertes de récoltes des prairies, blé tendre d'hiver et orge d'hiver. Cette étude apporte ainsi des éléments chiffrés sur la vulnérabilité des cultures face à ces risques ainsi que l'exposition du territoire aujourd'hui et à horizon 2050.

Dorothée Kapsambelis, David Moncoulon and Jean Cordier



Understanding the consequences of climate change: the example of the ACPR pilot exercise • p.67

In 2020, CCR participated in the pilot climate exercise led by the ACPR. This innovative, novel and ambitious exercise brought together the banking and insurance sectors to assess the consequences of climate change up to 2050. Physical and transition risks are analysed in order to understand the exposure of these sectors. This work is in line with the policies of the Law on Energy Transition and Green Growth and the 2015 Paris Agreement.

En 2020, CCR a participé à l'exercice pilote climatique dirigé par l'ACPR. Cet exercice novateur, inédit et ambitieux a rassemblé le secteur bancaire et assurantiel autour de l'évaluation des conséquences du changement climatique à horizon 2050. Les risques physique et de transition sont analysés afin de comprendre l'exposition de ces secteurs. Ce travail s'inscrit dans le contexte des politiques de la Loi sur la transition énergétique et la croissance verte et l'Accord de Paris de 2015.

Thierry Cohignac

Climate change: a multi-hazard approach

David Moncoulon[1], Roxane Marchal[1], Jean-Philippe Naulin[1], Dorothée Kapsambelis[1]
(1) Cat & Agriculture Risk Modelling R&D Department, CCR

INTRODUCTION

Climate change is at the heart of current society's concerns. The events that have occurred over the last few years, recurrent droughts, exceptional floods, very large-scale hurricanes, alert us to the risk of a continuous increase in the exposure of our territories to these perils. Indeed, the Intergovernmental Panel on Climate Change (IPCC) states in its latest report (IPCC, 2021) that there will be a significant increase in the number of heat waves, particularly in urban areas, in the coming decades. In addition, the IPCC warns of an increase in extreme precipitation events in the future and the resulting flooding. Despite a decrease (in the south of France) or a slight increase (in the rest of the country) in annual rainfall totals, the increase in maximum daily precipitation is estimated at around 20% over the entire country (RCP 8.5). Sea level rise will increase the risk of coastal flooding, and hence the risk of flooding in coastal towns, with a high degree of confidence.

In 2015, for COP 21, CCR carried out a study on the estimation of the consequences of climate change according to the IPCC RCP 4.5 scenario [3] on insured losses in Metropolitan France. Representative Concentration Pathways (RCP) are the four scenarios for the trajectory of greenhouse gas (GHG) emissions. The RCP 4.5 scenario corresponds to a GHG concentration of ~500 ppm in 2050 and ~660 ppm in 2100; with a temperature increase of between 1.6-2.5°C in 2050 and between 2.1-3.5°C in 2100. It corresponds to a so-called optimistic scenario, with a stabilisation of GHG emissions at a low level until 2050 and then a decrease until 2100.

In 2018, a second CCR study was carried out on the estimation of insured damage due to climate change under the RCP 8.5 scenario [4], i.e. a change in GHG concentration of around 600 ppm in 2050 and over 1370 ppm in 2100, and a global temperature increase of between 1.9 and 3.0°C in 2050 and between 3.3 and 5.7°C in 2100 [5]. This scenario is still considered the most pessimistic and corresponds to a continuation of the increase in GHG emissions at the current rate.

The comparison between these two scenarios and their consequences is necessary to guide risk management policies for prevention actions. The modelling chain set up at CCR simulates drought, flooding, coastal flooding and hurricanes (French Overseas Territories) and their consequences on insured property. Instead of using post-event observation data as input, as is the case for estimating the impact of events that have already occurred, CCR used the outputs of the ARPEGE-Climat model of Météo-France according to IPCC 4.5 and 8.5 scenarios. CCR has also extended its modelling expertise by investigating the consequences of climate change on crop losses due to drought and excess water. This innovative modelling then makes it possible to simulate the change in insured losses according to a multi-hazard approach to extreme climate events linked to climate change by 2050.

METHODOLOGY

The ARPEGE-Climat model by Météo-France

As early as 1990, Météo-France developed a global climate forecasting and evolution model: the ARPEGE-Climat model. This model was then improved to include various IPCC scenarios. Initially, over Europe, the model had a spatial resolution of 20 km and climate stability was ensured by climate forcing through sea surface temperature series and by maintaining GHG concentrations at the values defined by the chosen scenario. The time step of the model is 10 minutes, the data is recorded with a 1-hr time step for most of the meteorological parameters. The ARPEGE-Climat model simulates 400 repetitions of year 2000 climate and 400 repetitions of year 2050 climate for the two IPCC scenarios 4.5 and 8.5. This methodology allows climate variability to be considered. The repetition of events provides for the analysis of extreme scenarios in terms of frequency and intensity. Precipitation data from ARPEGE-Climat feed the flood model developed at CCR and the horizontal components of wind speed at 10 m and atmospheric pressure

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> feed the coastal flooding model.
In addition, Météo-France has implemented the SAFRAN-ISBA-MODCOU model (SIM2). This model is fed by a dozen meteorological parameters derived from climate simulations and calculated on an 8 x 8 km grid over Metropolitan France. The outputs of this model include the Soil Wetness Index (SWI) which feeds the geotechnical drought model developed at CCR.

The modelling chain developed by CCR

Meteorological data from Météo-France's ARPEGE-Climat model are used to feed the impact models developed by CCR. These models all include a hazard module that simulates climate events, a vulnerability module that includes the location and description of insured assets and a damage module that makes it possible to assess the cost of natural disasters at the level of the asset, the commune or the territory as a whole.
The agro-climate model developed by CCR uses public data on crop yields provided by the French Ministry of Agriculture and Food.
The multi-hazard approach allows the dependence of climate hazards and their consequences to be considered by using ARPEGE-Climat to produce climate years (at hourly time steps over the entire territory with an 8 km grid cell) that include extreme precipitation, droughts and storms.

INSURED LOSSES IN METROPOLITAN FRANCE AND FRENCH OVERSEAS TERRITORIES

Impact of climate alone

The consequences of climate change on insured losses can be analysed by hazard and/or according to a multi-hazard approach. The analysis of the development of insured losses under scenarios 4.5 and 8.5 is presented in Table 1. The impact of climate change is more important on coastal flooding phenomena regardless of the RCP scenario considered. The damage to insured property increases for each peril, according to IPCC scenario 8.5. This increase is significant for geotechnical droughts.

Combined impact of hazard and vulnerability changes

The calculation of a "claims to premiums" ratio, incorporating the change in concentration of insured stakes in areas at-risk, shows that claims would increase by 50% by 2050 under the RCP 8.5 scenario. This figure is 35% due to the change in frequency and intensity of climate-related hazards and 15% due to the concentration of insured property in risk-prone areas.
Claims experience would increase by 35% by 2050 according to RCP 4.5, with 20% due to changes in hazard frequency and 15% due to vulnerability.
These overall figures conceal regional disparities in insured loss trends by 2050. Indeed, the work carried out shows an increase in insured losses on the Atlantic coast (>60%) and the Greater Paris region (>40%). However, the insured loss trends would be 30% on the Mediterranean rim, all perils combined.
The study by climate hazard shows territories particularly exposed to certain perils. In fact, floods have caused a 60% increase in insured losses on the Atlantic coast and in the Greater Paris region, and a decrease in losses of up to 25% in the Massif Central. Coastal flooding particularly affects the departments of Vendée and Charente-Maritime and to a lesser extent the Mediterranean coastline. Geotechnical droughts impact the whole territory in a relatively homogeneous way.
The French Overseas Territories are also highly exposed to climate risks, particularly hurricanes. These events can be significant and result in major human and economic losses.
This was the case in 2017, when Hurricane Irma hit the islands of Saint-Martin

Raw score	**Floods**		**Coastal flooding**		**Geotechnical drought**		**All perils**	
Scenario	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Change in average annual insured losses in 2050	+ 20%	+ 38%	+ 60%	+ 82%	+ 3%	+ 23%	+ 20%	+ 35%

Tableau 1 – Change in average annual losses per peril due to climate change on current insured values.

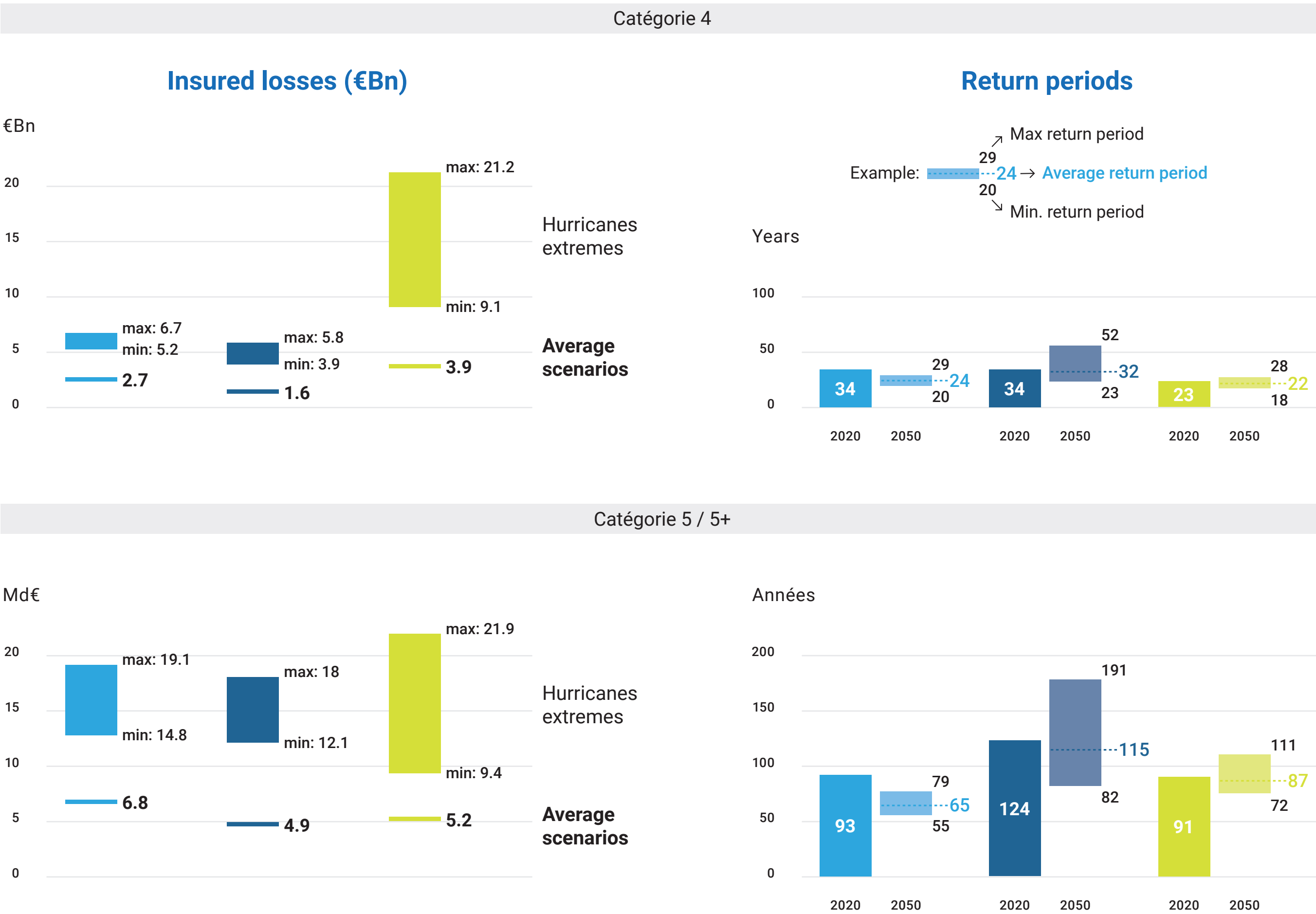

Figure 1 – Potential damage and associated return periods by hurricane category and by island.

and Saint-Barthélemy, causing €2 billion in insured losses. Since the integration of the cyclonic wind hazard into the Nat Cat regime in 2000, no event of this magnitude had occurred.

In 2020 [7], CCR conducted a specific study on the risk of hurricanes in the French Overseas Territories. It provided insights into the exposure of these territories to extreme events, in both current and future climates. Projections to 2050 of rare events such as hurricanes include many uncertainties. Interpretation of the ARPEGE results on the scale of territories such as the French Antilles or Réunion island did not allow us to conclude on a change in frequencies. It was nevertheless possible to reconstruct major events from the simulated trajectories and to measure the exposure of the territories to events having not yet occurred to date. For example, for Guadeloupe the insured losses for category 5/5+ hurricanes are between €12.1 and €18 billion. The average of scenarios is €4.9 billion (Figure 1).

Results on agriculture and forestry

Crop production is particularly impacted by climate risks due to climate change. The results obtained indicate that the number of droughts of an intensity equal, on average, to those of 2003 and 2011 (i.e. on average, about 27% yield losses in grassland and 11% losses in soft winter wheat) will double by 2050.In 2020, CCR and students from EURIA in Brest worked on the development of a Cat model for forest fire risk in Metropolitan France. The study based on RCP 4.5 and the use of the use of machine learning models has shown an increase in the Mediterranean arc's exposure to this risk. By 2050, the exposure of territories further north, such as Brittany, Pays de la Loire, Centre-Val de Loire and the Atlantic coast (Landes Forest), tends to increase.

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Discussion

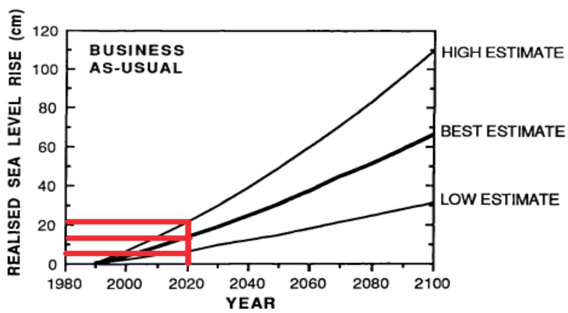
The results of these studies can be compared with a review of the literature on the subject. A historical review of the different IPCC reports and a comparison with actual observations was made. The first IPCC report [8] was particularly good at anticipating the rise in global temperature. Indeed, in terms of CO_2 concentration rates, the 1990 business-as-usual A scenario [was] reached in 2020. The same applies to the estimation of sea level rise (Figure 2).

CONCLUSION

Understanding today's and tomorrow's exposure to natural risks makes it possible to test the sustainability of the Nat Cat scheme and to propose possible adaptation measures to maintain its financial balance based on solidarity. Improving knowledge of the climate challenges faced by all territories can provide essential information for risk prevention. Pursuing the modelling of other hazards such as forest fires or mountain risks (glacier outbursts, new avalanche corridors, melting of permafrost etc.) will allow us to better anticipate risks in all territories./

Reference period	Number of events	Cost of damages
1980 - 1990	4.212	$1.63 trillion
2000 - 2019	7.348	$2.97 trillion

Table 1 – Significant increase in the number of recorded natural disasters and their costs due to climate change between two reference periods. Source: UNDRR, 2021.



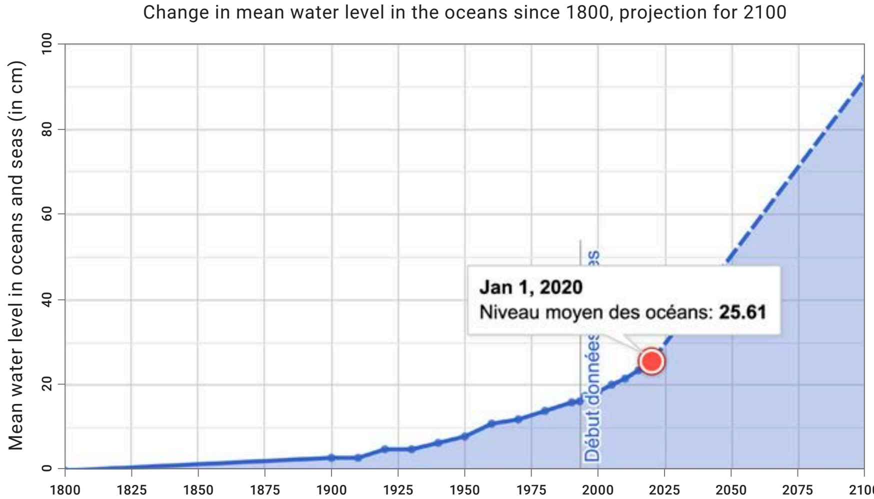


Figure 2 – Potential damages and associated return periods by hurricane category and island
(top figure) IPCC 1990 sea level rise estimates;
(bottom figure) The current rise as recorded by notre-planet.info from CSIRO Marine and Atmospheric Research data.

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CITATION

Moncoulon D., et al, Climate change: a multi-peril approach. In CCR 2020 Scientific Report; CCR, Paris, France, 2021, pp. 57-61

Impact modelling of droughts and floods on crop production by 2050

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(2) Agrocampus Ouest, Economics and Management, SMART-LERECO

INTRODUCTION

In France, many climate-related events have had a major impact on agricultural production at national level in the past. Droughts and floods have caused the greatest losses on field crops and grasslands over the last twenty years. The 2003 drought caused losses of 15% for soft winter wheat and more than 30% for grassland. Floods in 2016 resulted in record losses for soft winter wheat of 28%. These risks are considered by the OECD as "catastrophic", i.e. of extreme magnitude and intensity with relatively low frequency [1]. Climate experts are warning that territories will be more exposed to these extremes due to climate change. Several studies indicate that the frequency, intensity and length of heat waves will increase over the 21st century [2-4]. The Mediterranean region is particularly prone to extreme droughts [2].

In France, risk management measures in agriculture are being studied to stabilise farming income and increase resilience for the next Common Agricultural Policy programme (2023-2027). A better understanding of these extreme hazards and their impacts in terms of crop losses is necessary to feed the thought process of risk management in agriculture.

This article provides figures on the evolution of the frequency and intensity of the above-mentioned extreme events and their consequences on crop losses for soft winter wheat, winter barley and grasslands up to 2050. These three crops were selected because they represent 63% of the useful agricultural area, France being the leading producer of cereals (26% of total production) and the 2nd largest producer of dairy cattle (24.5 MT of milk) in Europe. This research work is part of a PhD thesis in partnership with Météo-France, CCR and the Agrocampus Ouest Institute, the aim of which is to model the climate-event hazards of drought and excess water linked to climate change on crop production in France up to 2050.

METHODOLOGY

Data used

The data on crops are taken from the AGRESTE public database, which references yields and surface areas by crop and by department from 1989 to 2020 for soft winter wheat and winter barley, and from 2000 for grassland. Crop losses (%) are calculated using the 5-year rolling Olympic average as the reference yield.

Climate-related data on precipitation and evapotranspiration over the period are taken from the database over the 1989-2018 period on an 8 x 8 km grid throughout France. Evapotranspiration is calculated according to the Penmann-Monteith equation.

Links between climate and crop losses

To study the impact of climate change on crop production it is necessary to link climate data to crop losses. For this purpose, a new climate index was created, based on the cumulative ten-day water balance anomaly, which represents extreme drought and excess water events and is correlated with crop losses in soft winter wheat, winter barley and grassland [5]. The index is calculated on the 8 x 8 km grid for all of France. This grid is cross-referenced with the graphical land reference register (RPG / référentiel parcellaire graphique) to take land use into account. For each crop studied, the index is calculated on the grid cells containing the agricultural plots concerned and the index is averaged to obtain an annual and departmental index value.

Then, the modelling set up at CCR allows for each value of the index (in mm) to be matched with a value of crop losses (in %). Indeed, the damage model is calibrated on historical data by adjusting two damage curves that predict the occurrence of claims and the amount of losses in case of a claim. Thus, the more extreme the values of the climate index, the greater the crop losses and the greater the probability of a disaster occurring. The model is validated by comparing the crop losses calculated from the AGRESTE database and those simulated using the climate index values for each year and each department, over the 1989-2018 period. An experiment is carried out, allowing the selection of parameters that minimise the errors between actual and simulated crop losses. Once the best results per crop have been obtained from the historical data, it is then possible to move on to 2050 modelling.

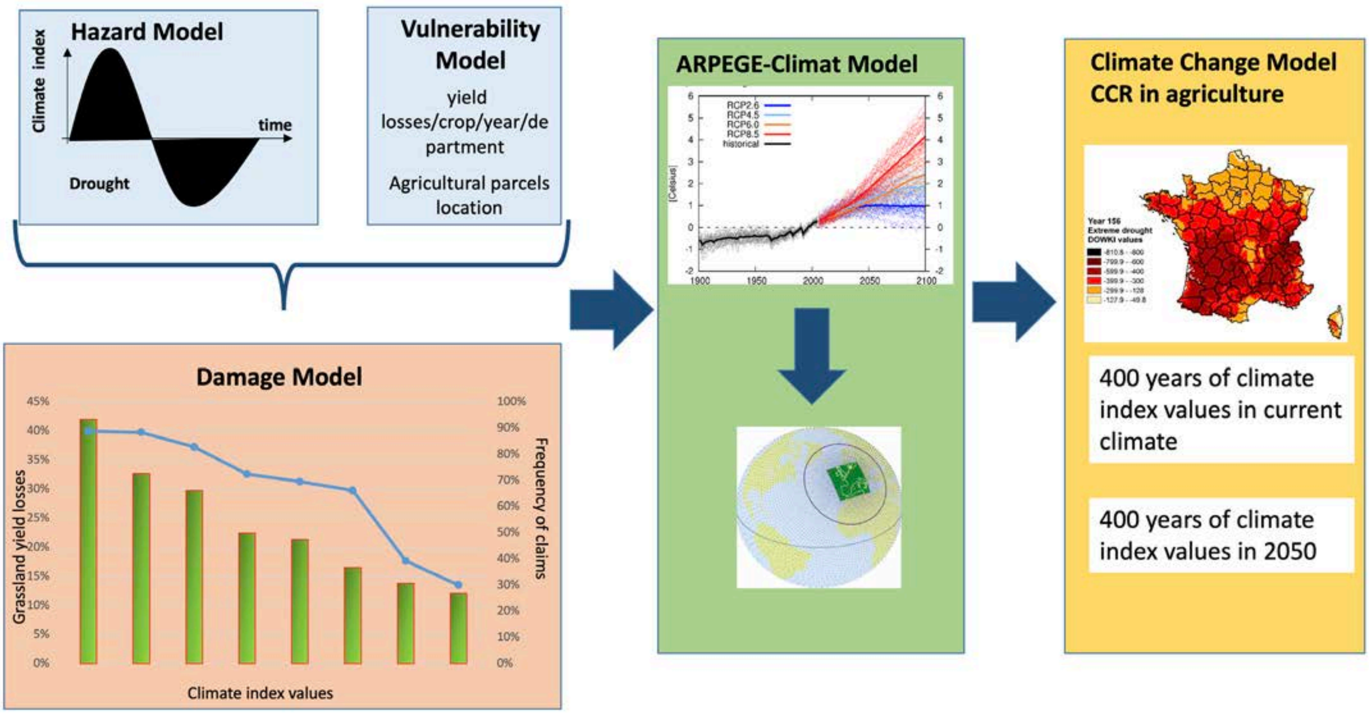

Figure 1 – From Kapsambelis D., Moncoulon D, Risques No.126, 2021 Modelling chain implemented: from climate modelling to crop losses by 2050.

Modelling the impact of climate change

To model climate change, the ARPEGE-Climat model of Météo-France is used. This simulates 400 repetitions of year 2000 climate and 400 repetitions of year 2050 climate under IPCC scenario 8.5. This method makes it possible to consider a wide range of possible scenarios for year 2000 climate and future climate with all types of profiles (extreme and non-extreme) and to take into account a large part of annual climate variability. The simulations of the ARPEGE-Climat model provide 400 precipitation values and 400 evapotranspiration values on 8 x 8 km grid cells over the whole of France, from which the climate index is recalculated.

Once the climate index has been calculated, it is possible to simulate crop losses (%) by French department and to deduce the frequency and intensity of extreme drought and excess water events and their consequences on agriculture. The modelling chain is summarised in Figure 1.

RESULTS

Climate-related hazards over the historical period

The study of historical crop losses shows that soft winter wheat and winter barley are sensitive to extreme drought and excess water events and grassland only to extreme drought risks. The droughts that caused the most losses were those of 2003 and 2011. The drought of 2003 caused nationwide losses of more than 30% for grassland and more than 10% for soft winter wheat and winter barley. Excessive water in 2016 caused record crop losses in soft wheat, amounting to 28%

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> nationally. The results for these three years are shown in Figure 2.

Extreme droughts in 2050

The comparison of the annual mean values of the climate index between year 2000 climate and future climate shows water balance anomaly worsening by 40%. The study of 10-year droughts shows an increase in their frequency and intensity. Indeed, extreme droughts with a 10-year return period with year 2000 climate would have a 6-year return period with future climate. Extreme droughts would therefore double by 2050. Moreover, water deficit is increasing throughout Metropolitan France as shown in Figure 3. This increase in water deficit is combined with an increase in ten-year crop losses of 35% for grassland, 75% for soft winter wheat and 79% for winter barley on a national scale. According to the figure above, the northern half of France is experiencing a greater increase in the intensity of extreme droughts compared to the south of France. However, the Mediterranean region has the highest drought intensities.

Extreme water excess in 2050

A comparison of the average annual values of the climate index between year 2000 climate and future climate shows no significant change, with water balance increasing by only 5% over Metropolitan France. However, this value hides significant regional differences. Indeed, the climate index of excess water shows a decrease of its values between 25% and 50% on the Mediterranean rim, while the values increase in the northern half of France. The catastrophic 2016 flood would have a return period of 50 years with year 2000 climate and the same return period in 2050. Figure 4 shows the evolution of excess water over 10 years and its consequences on soft winter wheat and winter barley. French farms do not seem to see their exposure to this extreme risk increase by 2050, which leads to a stagnation in crop losses.

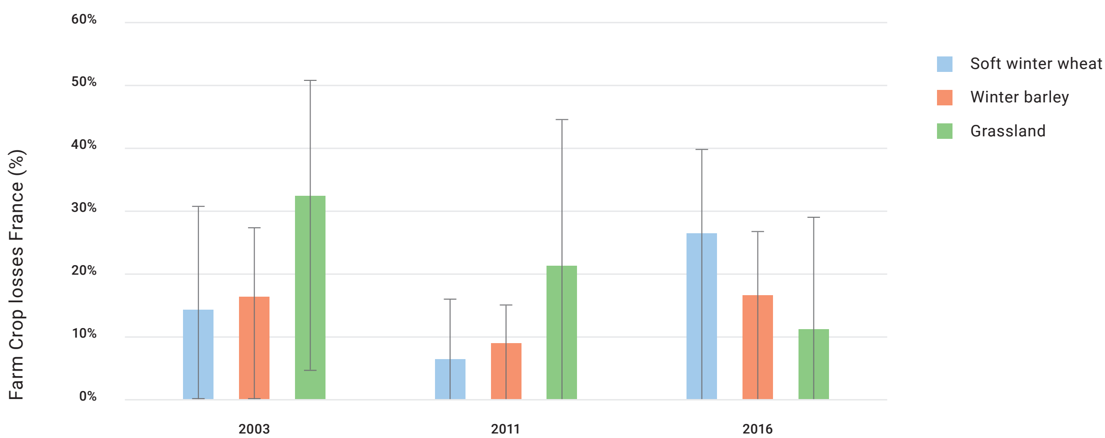

Figure 2 – Crop losses on French farms for the years 2003, 2011 and 2016 for soft winter wheat, winter barley and grassland.

CONCLUSION

The modelling chain set up at CCR models the climate up until 2050 and its consequences on crop losses. This innovative methodology makes it possible to forecast risk exposure and propose appropriate measures to protect farmers financially in the future. Research shows an increased exposure of cereals and grasslands to the risk of extreme droughts. Their frequency would double by 2050. The increase in the water deficit is significant in the northern half of France, with the risk tending to spread evenly across the country. However, the Mediterranean region remains the most exposed territory to very severe droughts and records the most crop losses on cereals and grasslands. For excess water, there is an increase in the ten-year risk in the northern half of France, but this increase is less significant than for drought risks. This work provides figures that can help the current thought process on the development of risk management policies in agriculture./

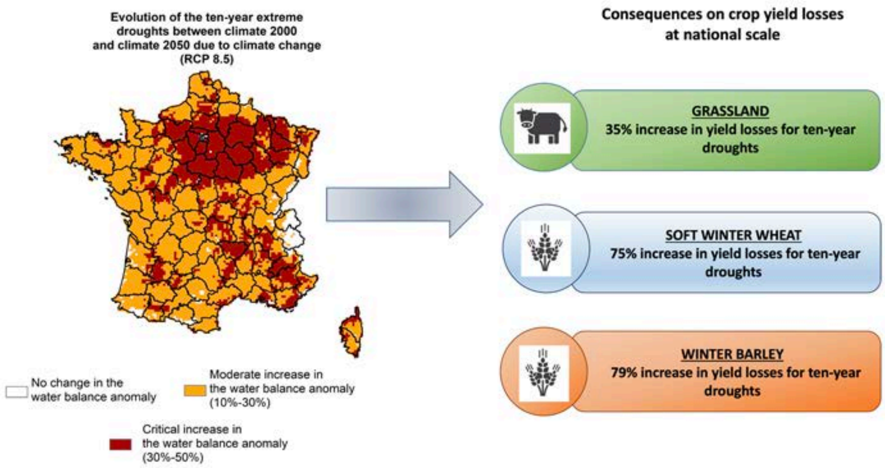

Figure 3 – Evolution of the intensity of extreme ten-year droughts measured by the increase in the water balance anomaly (%) between current and future climate (2050) due to climate change according to IPCC 8.5 scenario and consequences on losses of grassland, soft winter wheat and winter barley crops.

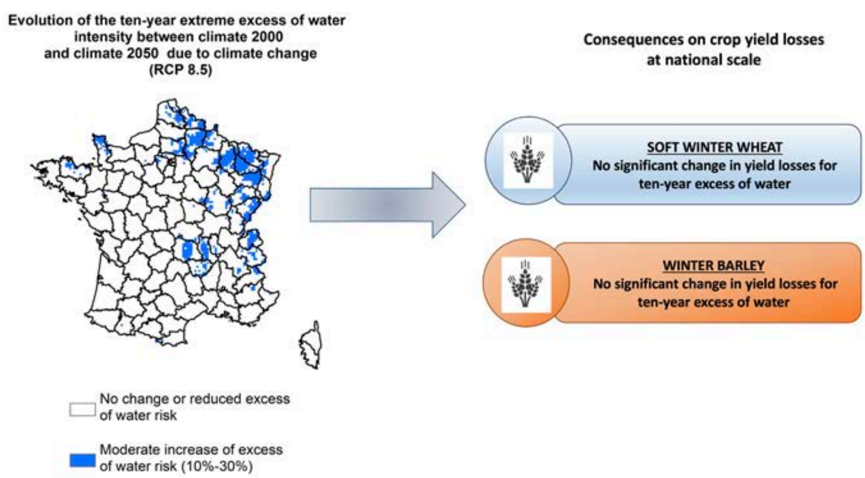

Figure 4 – Evolution of the intensity of extreme decadal excess water measured by the increase in the water balance anomaly (%) between current and future climate (2050) due to climate change according to IPCC 8.5 scenario and consequences on losses of soft winter wheat and winter barley crops.

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THE PARTNERS

The "SMART-LERECO" Joint Research Unit has been officially created on 1 January 2017, following a scientific project that brought together economists from the UMR SMART in Rennes and the UR LERECO in Nantes. This UMR currently brings together about sixty people (including thirty researchers and teacher-researchers) from the INRAE EcoSocio department and from Agrocampus Ouest.

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Understanding the consequences of climate change: the example of the ACPR pilot exercise

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INTRODUCTION

The climate pilot exercise conducted by the *Autorité de contrôle prudentiel et de résolution* (ACPR) in 2020 is unprecedented and ambitious. It is the first time that a supervisor organises such a comprehensive and demanding climate change risk assessment exercise with the banking groups and insurers under its responsibility. Its novel and ambitious nature lies in the timeframe over which the risks are assessed (30 years), the methodologies used (scenario analysis broken down by economic sector), its innovative hypotheses (in particular the dynamic balance sheet), its coverage of physical and transition risks, and finally, the fact that the participating institutions directly assess their risks on the basis of common assumptions. Physical risk is defined by the increase in natural catastrophes; transition risk is linked to changes in energy or risk reduction policies that can suddenly affect market logic [1]. This exercise was conducted between July 2020 and April 2021, divided into a preparation phase and a work phase.

The aim of the exercise was to engage and raise as much awareness as possible on the issue of climate change among financial institutions. It brought together nine banking groups and fifteen insurance groups to allow participants to compare themselves on the basis of common assumptions.

Beyond these educational objectives, the aim was to measure the vulnerability of financial institutions to climate change risk using economic scenarios inspired by the work of the Network for Greening the Financial System (NGFS) of the Banque de France (Figure 1). For the physical risk, the ACPR considered the IPCC's 8.5 scenario (the so-called "business as usual" scenario corresponding to a +4°C increase in 2100).

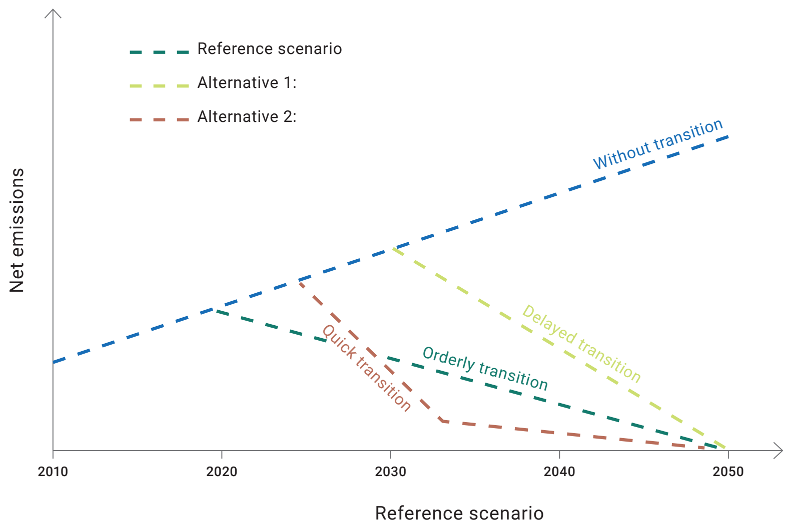

Figure 1 – Economic scenarios.

CCR'S INVOLVEMENT

As an expert in modelling physical risks (natural catastrophes), the ACPR asked CCR to measure the impact of climate change on the insurance portfolios of the insurers participating in the exercise.

To this end, CCR set up a specific modelling chain for the pilot exercise, based on the results of long-standing climate change modelling research [2,3]. The modelling chain was integrated into the Daitaku tool (DSS) to automate the processes for each insurance portfolio and hazard type. Exposure maps up to 2050 at town level, as well as other indicators, were generated automatically via the platform.

CCR thus provided insurers with an estimate of the impact of climate change in terms of insured losses on their portfolios for the perils affected by climate change (floods, coastal flooding, droughts and cyclones), taking into account the evolution of the hazard as well as the distribution of the population and businesses by 2050.

In addition, CCR provided technical assistance to insurers in interpreting the sometimes complex modelling results.

>

climate change
insurance
pilot exercise
ACPR

PILOT EXERCISE RESULTS

The pilot exercise reveals an overall 'moderate' exposure of French banks and insurance companies to climate change risk [4]. However, this conclusion must be put into perspective given the uncertainties regarding both the speed and the impact of climate change [5, 6]. It is also dependent on the assumptions, the scenarios analysed and the methodological difficulties raised by the exercise. This moderate exposure should also be considered in relation to other countries that are more exposed than France and Europe (where the main exposures of French financial institutions are). Specifically for natural disasters, the conclusions are clear as CCR predicts an overall increase of 50% in S/P by 2050 [2, 7]. This increase in claims must be taken into account in the financing of a scheme that has already been under strain for several years. Regional disparities in the development of claims also raise the problem of the insurability of certain territories in the more or less long term. This is highlighted in Figure 2, which shows the evolution of multi-peril (non-auto) losses due to hazard and vulnerability changes at town level for an insurer-specific portfolio. For this example, the communes located on the Atlantic coast are the most exposed to these developments (between +60% and +120%).

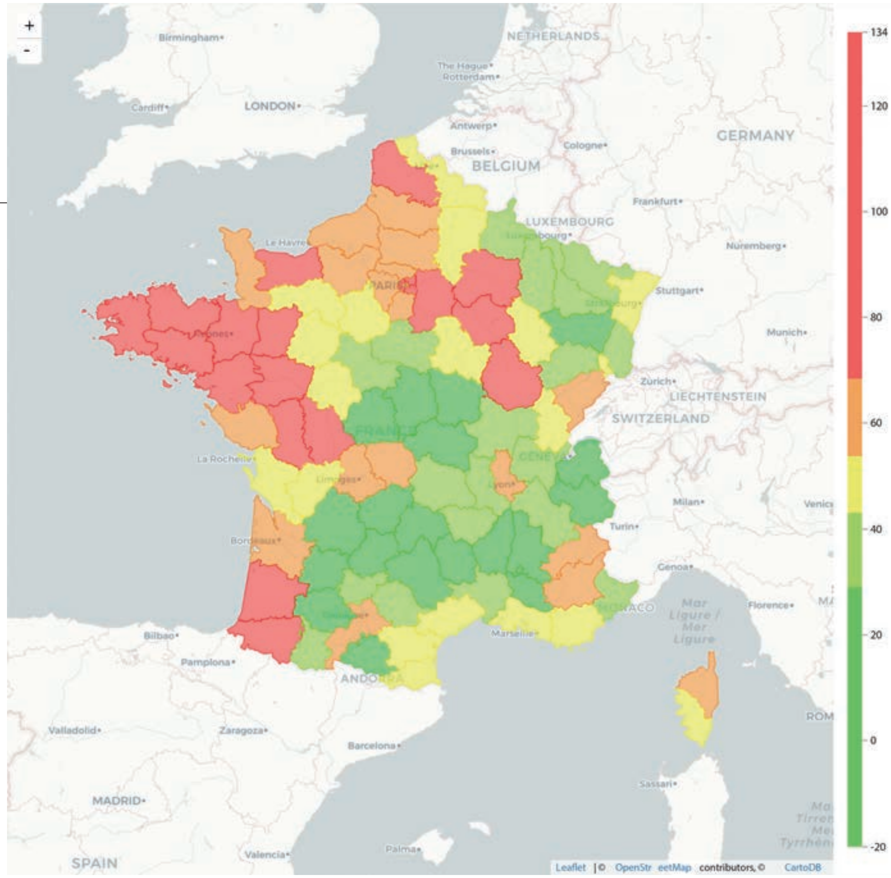

Figure 2 – Change in multi-peril (non-auto) losses due to hazard and change in geographic population distribution (%) in 2050. Example of the result on an insurer's portfolio.

CONCLUSION

The strong involvement of insurers and banks enabled the ACPR to validate the initial educational objective. The ACPR plans to repeat this type of exercise at a frequency yet to be defined, while participating in other similar initiatives at European level. The natural catastrophe scheme will have to meet this challenge to preserve the principle of solidarity on which it is based, namely by increasing the prevention efforts of all stakeholders./

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NAT CAT EXPOSURE

Mercure Hotel in Marigot surrounded by water and debris in St. Martin on 6 September 2017 after Hurricane Irma.

Mercure Hotel partially rebuilt on 27 February 2018.

Geolocated estimate of the surface of individual dwellings by Monte Carlo Kriging • p.72

The surface of a real estate good is a key ingredient in the process of estimating its insurable value. However, this variable might not be systematically available. The main objective here is to provide a method using the available information for each individual in a spatial area to estimate the surface of housings when not available. To do so, the theory of geostatistics and Kriging is applied. Since the real estate good scan be located to the same reference point, the method of Monte-Carlo Kriging is developed to estimate the surface.

La surface d'un bien immobilier est un élément clé dans l'estimation de sa valeur assurée. Elle n'est cependant pas systématiquement disponible. L'objectif ici est d'utiliser l'information fournie pour chaque individu dans une zone afin d'estimer la surface des biens pour lesquels celle-ci n'est pas renseignée. Pour cela, des méthodes géostatistiques sont suggérées. Les biens pouvant être localisés parfois au même point, la méthode de Krigeage Monte-Carlo est développée pour estimer la surface.

Luc Rongiéras and Émilie Chautru

Scientific findings from a multidimensional RETEX on Hurricane Irma (ANR TIREX project) • p.76

The TIREX project is a continuation of the first collective missions carried out in October 2017 in the West Indies following the three hurricanes, Irma, José and Maria. The objective is to complete the analysis of impacts and strengthen the monitoring of territorial reconstruction, by promoting comparative analysis between territories of the Northern Caribbean, and formalizing RETEX methods. It proposes to participate in the improvement of hurricane warning, to identify vulnerability factors, to strengthen the adaptation capacities of territories and societies in a context of climate change.

Le projet TIREX s'inscrit dans la continuité de premières missions collectives réalisées en octobre 2017 aux Antilles suite aux trois ouragans : Irma, José et Maria. L'objectif est de compléter l'analyse des impacts et de renforcer le suivi de la reconstruction territoriale. Ceci est effectué en favorisant l'analyse comparative entre territoires du nord des Antilles et en formalisant des méthodes de RETEX. Il se propose de participer à l'amélioration de l'alerte cyclonique, à l'identification des facteurs de vulnérabilité et au renforcement des capacités d'adaptation des territoires et des sociétés dans un contexte de changement climatique.

Frédéric Leone and Jérémy Desarthe

Geolocated estimate of the surface area of individual dwellings by Monte Carlo Kriging

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(2) MINES ParisTech

INTRODUCTION

When estimating the insured values of individual dwellings, the importance of knowing the surface area of the dwellings in the CCR portfolio becomes obvious. Indeed, the surface area is often used in the rebuilding cost estimates of various insurers.
However, surface area information is not systematically filled in for each individual in the database. It is therefore suggested that a method be proposed to estimate this quantity using available information. For this purpose, the nature of the dwelling, i.e. whether it is a house, a flat or a building, is often indicated. The use of the property, i.e. whether it is owner-rented, tenant-rented, owner-occupied, or a co-ownership, is also sometimes available. The number of rooms is also often available for houses and apartments, and there is a significant linear correlation with the surface area. Finally, the two-dimensional location is systematically provided. The proposed method consists of constructing a surface estimator using geostatistical theory [1] and Kriging, taking into consideration spatially close individuals and their location. However, the available locations sometimes refer to the same points. This leads to computational issues for surface area estimation by Kriging.
To overcome this problem, Monte-Carlo Kriging is introduced, consisting in simulating the locations randomly within a radius close to their reference, calculating the Kriging weights for each of the simulations, and averaging the results.
This method is then applied for each type: flat, house, building. To use the information on the number of rooms when available, a linear model is calculated between the surface area and the number of rooms. Monte Carlo Kriging is then applied to the residuals in question if the number of rooms is given, or directly to the surface area otherwise.

METHODOLOGY

Geostatistics, and in particular Kriging, consist in studying the spatial dependence of an object called random function [2] on a predefined area, in order to propose an estimate at a point as a linear combination of the data at other locations. The weights of the linear combination, also called Kriging weights, are calculated to ensure an unbiased condition and a minimum estimation variance. For this, it is necessary to know the variogram of the random function, a tool defined at two points x,y as half the variance of the deviation of the random function between these two points. Under the stationarity assumption [1], which is assumed locally here, the variogram [2] becomes a function of the distance between the two points. It is then easy to calculate the Kriging weights.
However, the locations are not known exactly and are sometimes gathered on the same points, leading to algorithmic complications. This complication is reflected on the one hand in the estimation of the variogram, and on the other hand in the direct calculation of the Kriging weights. For the estimation of the variogram, two proxies are calculated. The first is obtained by averaging the data located at the same point, this is the aggregated variogram. The second is the average of the variograms calculated by simulating the locations around their reference positions, the simulated variogram. An adjustment method is then proposed to obtain a variogram providing better Kriging results. It is called the corrected variogram.
Once the variogram is obtained, we need different locations to obtain Kriging weights. Therefore, we perform p simulations of sets of positions around their reference, in a disk of radius ρ. For each simulation the Kriging weights are calculated, and the Monte Carlo Kriging estimator is obtained by averaging the Kriging weights over the location hazard. The Monte Carlo Kriging estimator theoretically converges almost surely to the linear combination minimising the estimation variance related to the location uncertainty. The random function considered here takes different forms. In particular, if the number of rooms is available for a targeted location, the random function models the residuals of the linear model of the surface area over the number of rooms, in order to use the information related to the number of rooms and the spatial correlation of the remaining hazard separately. Monte Carlo Kriging is therefore applied to

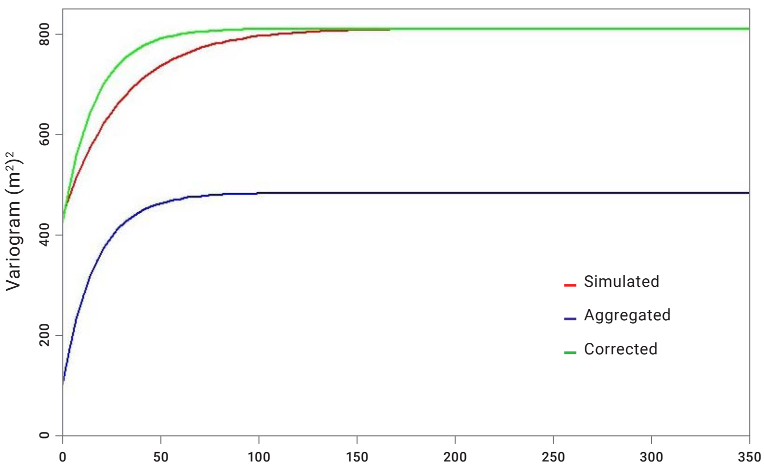

Figure 1 – Substitute variograms of the surface area of flats in Lyon.

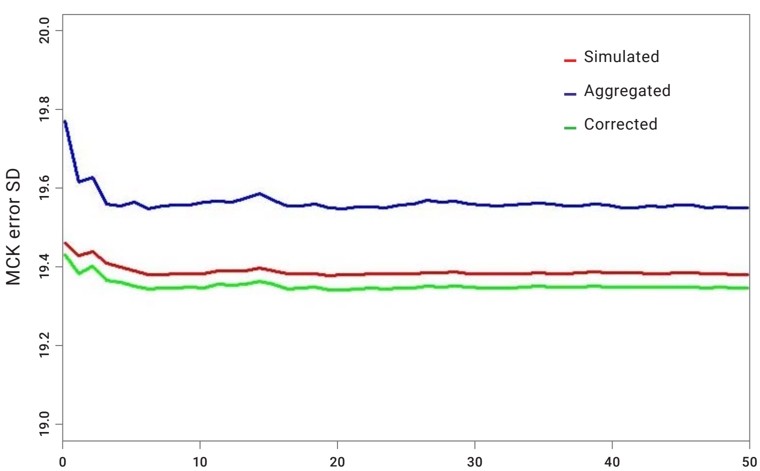

Figure 2 – Standard deviation of Monte Carlo Kriging estimates by simulation number and variogram.

the residuals. However, if the number of rooms is not entered, the estimation method is applied directly to the surface area. Each type of dwelling is considered separately.

RESULTS

The Monte Carlo Kriging method is applied locally on different areas for surface area estimation: the city of Lyon, the Oise department (60), and in Corsica (2A and 2B). It is chosen to carry out the calculations on the surface area and also on the residuals of the linear model of the surface area over the number of rooms. It should also be noted that if the city of Lyon is considered as a sufficiently homogeneous territory to assume local stationarity throughout the territory, this is not the case for the other territories considered. For this reason, the communes in Corsica and Oise were separated into three categories, according to their population, based on population quantiles per commune. This classification makes it possible to homogenise sub-regions where stationarity is more easily identifiable. Class A includes communes with small populations, class B those with medium populations, and class C those with larger populations. Finally, for this study, it was chosen, when the number of data allowed it, to separate the cases by use. Then it is possible to calculate the standard deviation of the estimate for each case. Monte Carlo Kriging is compared via this indicator to the method returning the mean over each sample considered. The corrected variogram is used to obtain the following results.
The table shows the efficiency of the Monte Carlo Kriging method, both for the estimation of the surface area directly and for the residuals, especially in Lyon and in

insured values
surface area
geostatistics
Kriging
Monte-Carlo

> the Oise region. In Corsica, it was more difficult to capture the adequate spatial correlation and to extract a satisfactory variogram. There may be many reasons for this. Corsica's heterogeneity may still be too great, and the territories should be subdivided into spatially smaller and more homogeneous clusters. Note that any such action requires sufficient data to be able to estimate the variogram in each local cluster. It is also possible that the distribution of the location of the dwellings, which are mostly close to the coast, biases the variogram estimates.

The Monte Carlo Kriging method depends on a number of parameters, including the choice of variogram considered for the estimation. A study was carried out on apartments in the city of Lyon which highlights the proposed variogram proxies. Figure 1 compares the aggregated, simulated and area-corrected parametric variograms. The corrected variogram is obtained by adjusting the parameters of the simulated variogram. In particular, the nugget effect, i.e. the value of the variogram for small differences in locations requires an adjustment because the random dispersion around the reference point introduces a bias in its estimation: the nugget effect is overestimated. Figure 2 shows the change in the standard deviation of the surface area as a function of the number of simulations considered and the variogram chosen for the estimation. It appears that the variogram-corrected estimator converges the fastest, even though the difference with the other proxies is particularly small.

Territory	Type	Classe	Usage	Variable	SD MCK (m^2)	SD Moyen (m^2)
Lyon	Apartment	C	Tenant	Residuals	7.92	12.05
Lyon	Apartment	C	Tenant	Surface area	13.54	24.59
Lyon	Apartment	C	Resident	Residuals	10.89	15.35
Lyon	Apartment	C	Resident	Surface area	18.57	31.41
Lyon	Apartment	C	Owner	Residuals	6.45	10.29
Lyon	Apartment	C	Owner	Surface area	10.25	21.34
Lyon	House	C		Residuals	22.30	30.11
Lyon	House	C		Surface area	34.25	131.28
Oise	Apartment	C		Residuals	8.72	12.87
Oise	Apartment	C		Surface area	14.94	23.88
Oise	Apartment	B		Residuals	9.95	12.16
Oise	Apartment	B		Surface area	13.04	22.37
Oise	House	C		Residuals	16.09	31.33
Oise	House	C		Surface area	21.89	51.58
Oise	House	B		Residuals	16.54	34.40
Oise	House	B		Surface area	22.42	50.75
Oise	House	A		Residuals	20.85	39.94
Oise	House	A		Surface area	20.51	57.40
Corsica	Apartment	C		Residuals	10.53	12.75
Corsica	Apartment	C		Surface area	22.99	27.96
Corsica	Apartment	B		Residuals	11.23	13.75
Corsica	Apartment	B		Surface area	28.66	30.35
Corsica	House	C		Residuals	24.79	29.20
Corsica	House	C		Surface area	49.32	54.76
Corsica	House	B		Residuals	24.22	27.86
Corsica	House	B		Surface area	45.60	54.56

Tableau – Results of the Monte Carlo Kriging method in Lyon, Oise and Corsica.

THE PARTNERS

The estimation of insured values is the subject of a thesis in collaboration with CCR and the Geosciences Centre of MINES ParisTech, directed by Hans Wackernagel and supervised by Emilie Chautru at MINES ParisTech and Georges Farah at CCR. The thesis is affiliated to the ISMME doctoral school (DS 621).

CONCLUSION

The Kriging Monte Carlo method seems to be a good compromise to propose a local estimate of the surface area of dwellings. It can be applied to different territories, provided that the initial assumptions are respected. The case of Corsica shows the limits of the method, the extension of which to the non-stationary framework may prove useful in the future.
The method is also sensitive to a number of parameters, in particular the number of simulations, the simulation radius, and the choice of variogram. The study of the sensitivity with respect to parametrisation allows the estimation of the surface area to be optimised./

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Scientific findings from a multidimensional RETEX on Hurricane IRMA (ANR TIREX project)

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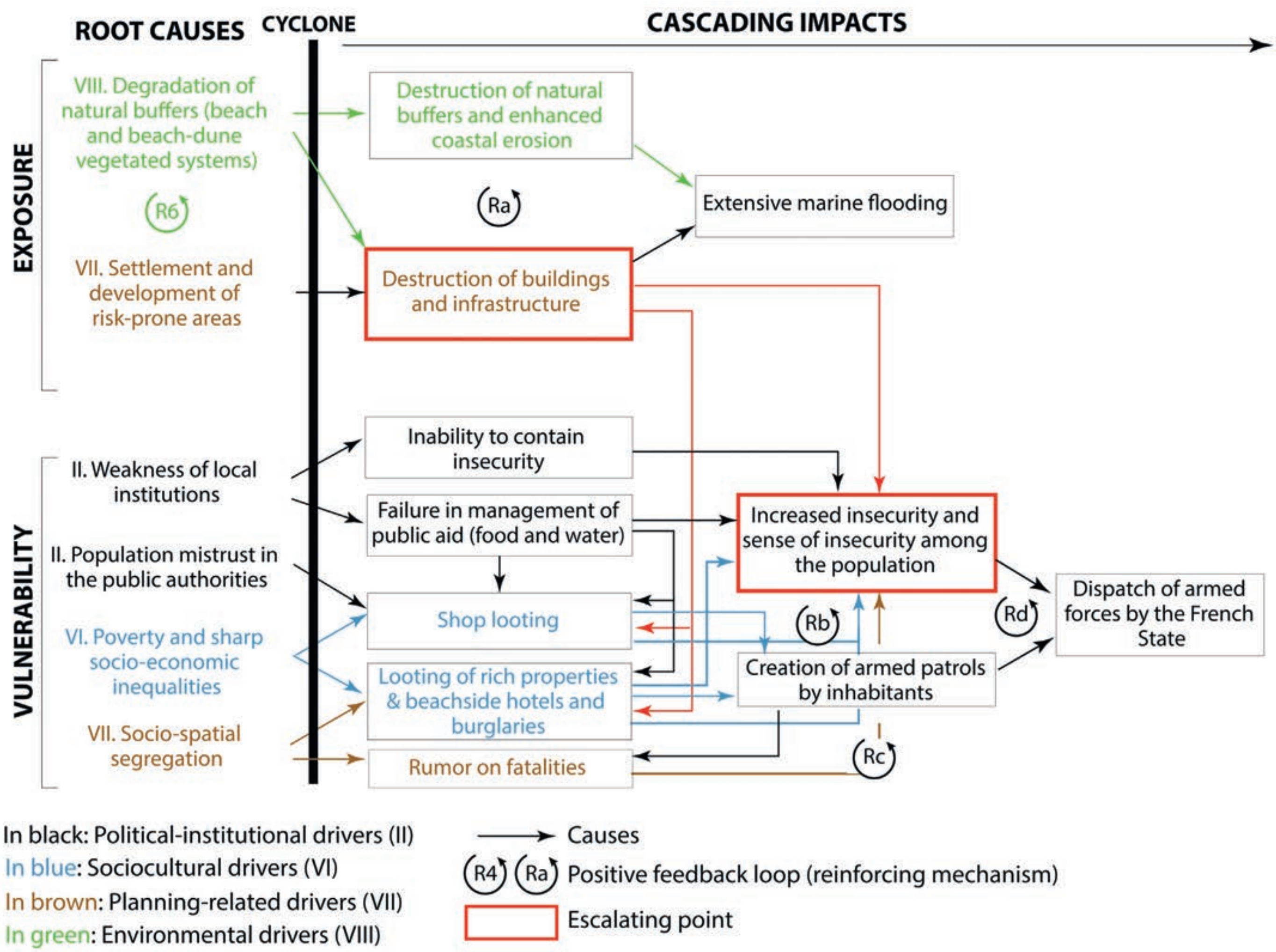
INTRODUCTION

On the night of 5-6 September 2017, Hurricane Irma hit the French Antilles, and more specifically the northern islands of Saint-Martin and Saint-Barthélemy. A Category 5 hurricane on the Saffir-Simpson scale, Irma was characterised by wind gusts in excess of 300 km/h and flooding of the coastline and low-lying areas of the island of Saint-Martin.
The islands of Saint-Martin and Saint-Barthélemy were hit hard. In total, eleven people died and the damage was considerable [1]. Communication and energy networks were largely damaged. Damage to insured property amounted to more than €2 billion for territories where only 40% of the population has home insurance. Irma was the most significant event since the natural catastrophe compensation scheme was introduced in 1982.
Following the hurricane season shaped by high intensity hurricanes (Harvey, José, Irma, Maria), the French National Research Agency launched the OURAGAN programme for which the Tirex project was selected. Coordinated by Prof. Frédéric Léone, this project brings together several research establishments and organisations to build multidimensional feedback for local stakeholders to enable them to anticipate their adaptation to the impacts of future extreme climate events.

METHODOLOGY

TIREX is organised in complementary tasks combining the skills of all the members of the group (history and geography of risks, spatial analysis, geomorphology, political science, scientific mediation, atmospheric physics, modelling, climatology). TIREX has a pre-operational dimension that consists in supporting players in risk management and reconstruction, including the population, through the transfer and implementation of results. The consolidation, dissemination and recovery of the project results are adapted to the cultural and geographical context of the targeted territories. They involve innovative knowledge transfer and education tools, based on participatory approaches, situation scenarios, online and interactive digital tools, story maps, good practice guides, regular workshops, etc. The project includes the latest knowledge on future climate change in the Caribbean provided by the ongoing C3AF programme on climate change and its consequences in the Caribbean (https://c3af.univ-montp3.fr/).
Task 1 (Territorial vulnerability trends 1950-2017): analysis of the archives made it possible to list historical hurricanes and describe their impacts. A literature review and three interview campaigns (linked to Task 3) were carried out among the population (cohort follow-up) providing elements on the factors of risk production as well as the assessment of vulnerabilities and pre-disaster resilience capacities.
Task 2 (Impacts and resilience of coastal environments): numerical models were implemented to reproduce the wind, precipitation, waves, and coastal floods of Hurricane Irma. A Bathymetry campaign was carried out at several sites to fill in the current lack of data on shallow waters. The models made it possible to map wave heights and to better understand the strong contrasts in the impacts of hurricanes on certain coves. At the same time, we are studying the impacts and readjustments on Anguilla and on Tortola and Anegada. The analysis of damage to buildings using UAVs was compared with data provided by rapid mapping agencies (Copernicus, Sertit) to assess spatial reliability of this data acquired by photointerpretation of satellite imagery.
Task 3 (Crisis management and monitoring of territorial reconstruction): analysis of crisis management and monitoring of reconstruction is continuing through regular missions in the French Antilles (six missions since the hurricane). Privileged contacts were established with institutions, not-for-profit organisations, and inhabitants. The first results made it possible to highlight the influence of social media in spreading rumours about the number of deaths, which intensified the management of the crisis a few days after the hurricane. A targeted study of teenagers in Saint-Martin, through classroom sessions, monitored the role of this particularly vulnerable age group during the recovery phase.
Task 4 (Consolidation of tools for the transfer of RETEX findings): the first interactive mapping products are available via an online platform and are enriched with story maps, all of which are implemented on a website dedicated to the transfer of results and allowing to revisit 2017's hurricane season online (https://tirex.univ-montp3.fr/). Further transfer



actions are planned by means of a serious game for local authorities simulating a virtual hurricane crisis. A guide for preventive territorial reconstruction is available in the form of a binder of fact sheets presenting the different methods of RETEX and its findings. In this respect, a reflexive approach leads us to question the definition of RETEX and what it can contribute to knowledge on risks and to prevention policies. In so doing, the thought process also addresses the limits of the RETEX, which is a major expectation of the TIREX project, particularly regarding previous RETEX conducted in the region (e.g. Hurricane Lenny in 1999).

cyclone # hurricane
impacts
rebuilding
RETEX
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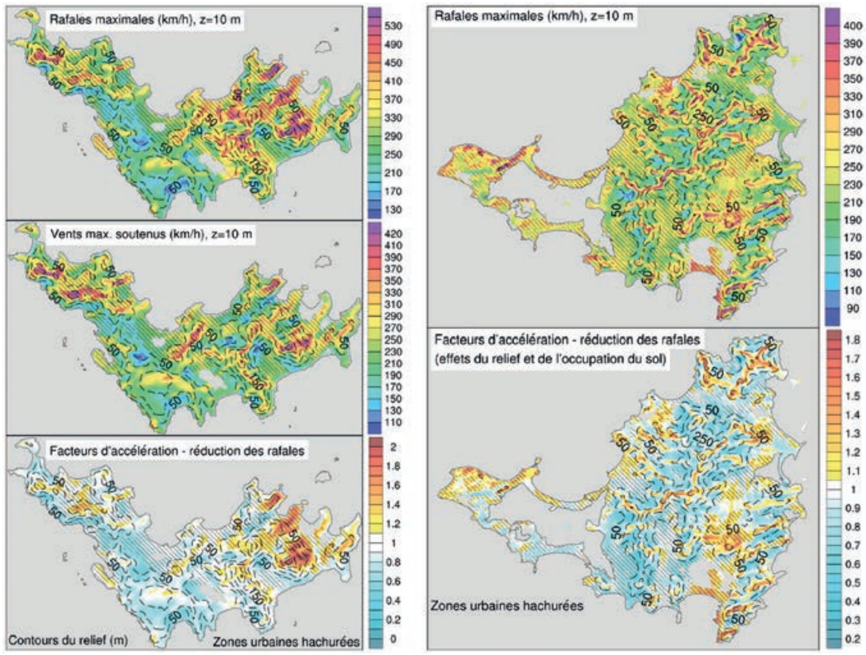

Figure 2 - WRF simulations with 30 m - resolution: max. wind gusts (km/h)
max. sustained winds 1 min (km/h), acceleration factors, gust reduction in Saint-Barthélemy (left)
and Saint-Martin (right) (Cécé et al., 2020)

> RESULTS

By involving researchers from different backgrounds, it is possible to understand the event in all its dimensions and to enrich our knowledge of the risks and vulnerabilities on an island far from its mainland. The main findings and results are structured around the following main axes:

1/ Trajectories of territorial vulnerability 1950 - 2017

The analysis of the exposure of territories over time has made it possible to reconstruct vulnerability trajectories and to understand the mechanisms and factors involved in producing risks [2]. Saint-Martin is characterised by its insularity but also by its distance from the mainland and the other France of the Antilles, namely Guadeloupe - to which it was administratively attached until 2007 - and Martinique. This double remoteness has built the economic and political specificity of the territory of Saint-Martin. The development of tourism from the 1960s onwards has contributed to making the area more vulnerable due to the massive urbanisation of the coastline. This development has also been shaped by strong socio-spatial disparities which translate into vulnerabilities in terms of housing construction [3].

2/ Impacts and resilience of coastal environments

The careful study of the impacts and consequences of the hurricane was a fundamental step. It is essential to make the most exhaustive diagnosis possible to rebuild a more resilient territory adapted to climate change. Thus, high-resolution numerical modelling of cyclonic phenomena has made it possible to recreate cyclonic weather conditions and associated meteorological and marine hazards, in relation to the damage produced [4, 5].
The different results show that floods (pond overflow, surface runoff and coastal flooding) have complex kinetics. While seafront urbanisation has limited coastal flooding, soil sealing has increased flooding through surface runoff [6]. Moreover, winds modelled with an unprecedented resolution of 30m showed amplification effects along the ridge lines and gusts of up to 400 km/h. Correlations with damage intensities on buildings have shown a critical damage threshold reached around 200 km/h [4]. This damage was much more extensive in Saint-Martin than in Saint-Barthélemy due to much more vulnerable building structures. Indeed, data provided by the European Satellite Service Copernicus (2018) show that only 16% of the architectural heritage of Saint-Barthélemy suffered significant damage (compared to 54% in Saint-Martin), while the most serious damage concerned only 5% of buildings in Saint-Barthélemy (compared to 30% in Saint-Martin). However, our own drone and field surveys have shown a lack of reliability of these damage data obtained by photointerpretation of satellite images in the aftermath of the catastrophe [7].
A diachronic analysis of the geomorphology of the various sites selected also highlighted the consequences for the coastline. In general, the beaches of Saint-Martin have experienced a significant decrease in surface area. The presence of vegetation or coral reefs has locally reduced the damage either by blocking debris or reducing wave height on the coast [5]. In other territories, such as the island of Dominica, river flooding has contributed to beach nourishment and the formation of flood deltas.

3/ Crisis management and follow-up of territorial reconstruction

The analysis of the crisis management and post-disaster recovery of Hurricanes

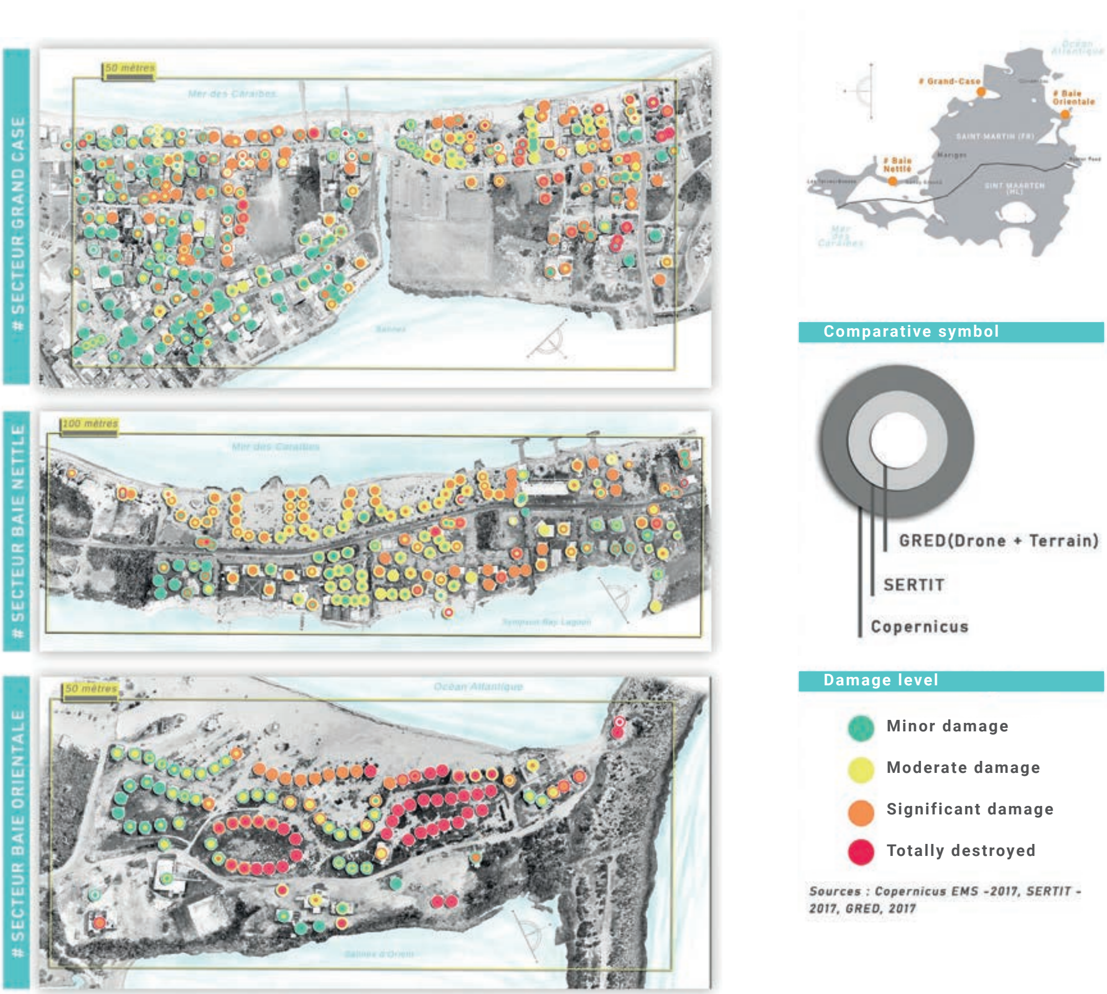

Figure 3 - Comparison of the three sources of damage diagnostics (satellite for Copernicus and SERTIT, drone and field for GRED) (Saint-Martin) showing the uncertainties in estimating damage by satellite (Léone et al., 2021).

Irma, José and Maria provides food for thought on learning processes. The theme of post-Irma waste production and management was particularly invested in as it is a major challenge in the reconstruction process. Thus, the cubic measurements obtained by drone and statistical processing of available data allowed us to assess the total weight of debris produced by Irma on Saint-Martin at 1.7 tonnes per inhabitant [8]. In addition, within the framework of the project, a geo-indicator to monitor the reconstruction process was established at a sufficiently fine scale to understand certain spatial logics and reveal certain contrasts. As a result, in July 2019 (22 months after Irma), 40% of the heavily damaged buildings in Saint-Barthélemy were completely restored, compared to only 22% in Saint-Martin. The rebuilding effort was faster in Saint-Barthélemy with 19% of the buildings rebuilt (compared to 11.5% in Saint-Martin) in March 2018, seven months after Irma struck [3]. These contrasts can be explained by the much lower total volume of damage in Saint-Barthélemy, but also by the greater recovery capacity. In addition, systematic surveys led on business locations showed an overall and average business recovery that was 1.5 times faster in Saint-Barthélemy with 81 days of closure compared to 123 in Saint-Martin. Horeca activities were the first to recover, followed by transport activities. According to these same surveys, the delays accumulated on Saint-Martin are mainly due to the intensity of the damage to the associated buildings, but are also due to the massive looting that occurred on this island in the aftermath of Irma (41 businesses or shops looted, i.e. 24.7%). This >

cyclone # hurricane
impacts
rebuilding
RETEX
Lesser-Antilles

> looting sometimes caused more losses than the hurricane itself, not to mention the trauma it caused [3].

CONCLUSION

To consolidate RETEX findings and to ensure their transmission to local populations and decision-makers, the main useful results of the TIREX project were formatted on different interactive mapping media and story maps, making it possible to revisit this disaster. One of the challenges of RETEX is to preserve the memory of past hurricanes, to draw lessons from them for prevention, crisis management and the sustainable reconstruction of the affected territories. The website that preserves this experience is available online. It is open to the public, with an educational purpose but it also pays tribute to all the inhabitants who testified about their own experience of this disaster https://tirex.univ-montp3.fr/ index2.html. We thank them for this./

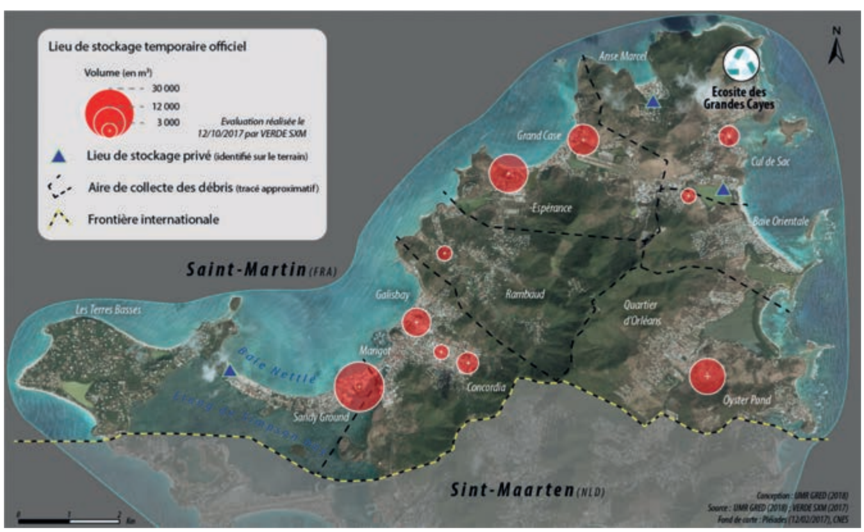

Figure 4 - Assessment of debris deposits and volumes generated by Hurricane Irma on Saint-Martin (Vinet et al., 2020).

THE PARTNERS

The ANR TIREX project (2018-2022): Transfer of findings from scientific feedback to strengthen individual and collective response and adaptation capacities in a context of climate change (Lesser Antilles - 2017 hurricane season)
Link to the project website: https://tirex.univ-montp3.fr/
Link to the project story maps: https://arcg.is/1KXmn1

The TIREX project partners:

- Laboratoire Gouvernance, Risque, Environnement, Développement (GRED)
- Laboratoire de Recherche en Géosciences et Énergies (LARGE)
- LC2S Laboratoire Caribéen de Sciences Sociales (LC2S)
- Laboratoire de Géographie Physique : Environnements Quaternaires et Actuels (LGP)
- Laboratoire Littoral, Environnement et Sociétés (LIENSs)
- Météo-France Direction interrégionale Antilles Guyane (DIRAG)
- Caisse Centrale de Réassurance (CCR)

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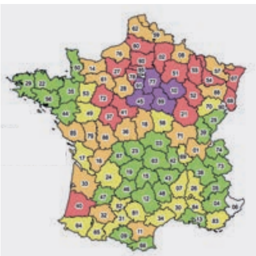
Léone F., Desarthe J., Scientific findings from a multidimensional RETEX on Hurricane IRMA(ANR TIREX project), In CCR 2020 Scientific Report; CCR, Paris, France, 2021, pp. 76-81

PROCESSING AUTOMATION

CCR integrates new technologies and artificial intelligence into its production processes.



Data processing for comprehensive weather insurance in agriculture • p.84

This article presents the data processing optimization work carried out as part of the monitoring mission of the multi-risk climate insurance entrusted to CCR by the Ministry of Agriculture and Food. The method consists of using a platform to automate data processing and statistical and cartographic analyses. The indicators developed to measure the evolution of the insurance portfolio and the main results for the 2019 campaign are also presented.

Cet article présente les travaux d'optimisation de traitements de données réalisés dans le cadre de la mission de suivi de l'assurance multirisques climatique confiée à CCR par le ministère de l'Agriculture et de l'Alimentation. La méthode consiste en l'utilisation d'une plateforme permettant l'automatisation du traitement des données et des analyses statistiques et cartographiques. Les indicateurs développés pour mesurer l'évolution du portefeuille assurantiel ainsi que les principaux résultats sur la campagne 2019 sont également présentés.

Dorothée Kapsambelis, Stéphane Busson, Roxane Marchal and David Moncoulon

Data processing for comprehensive weather insurance in agriculture

Dorothée Kapsambelis[1], Stéphane Busson[2], Roxane Marchal[1], David Moncoulon[1]
(1) Cat & Agriculture Modelling, R&D Department, CCR
(2) Information Systems Department, CCR

INTRODUCTION

Farms are subject to many risks, including climate-related risks. These affect the quantity and quality of production. Farmers assess the risk to which they are exposed and adopt management strategies to minimise their risk. Farmers choose risk management methods according to their perception of risk and the intrinsic characteristics of their individual farm. Among the tools available to farmers is comprehensive weather insurance introduced in 2005. These contracts cover the various vegetation sectors against the following climate-related risks: hail, frost, flooding or excess water, drought and storm. For example, claims are no longer covered by the National Agricultural Risk Management Fund (FNGRA or *Fonds national de gestion des risques en agriculture*) in arable farming since 2009 and in viticulture since 2010. Crop insurance consists of three levels: a basic contract subsidised at 65% with a trigger threshold and a 30% deductible, a second level subsidised at 45% with a 25% deductible, with additional unsubsidised coverage making up the third level. Today, this insurance is emerging as a pillar of risk management and the latest consultations between the different market players, led by Deputy F. Descrozaille, propose to strengthen the use of this tool by farmers.
The annual data is transmitted by the insurers to the French Ministry of Agriculture and Food (MAA), which has called on CCR since the 2015 campaign to monitor the development of crop insurance. These studies are carried out within the framework of an agreement financed by the MAA and the EAFRD for a period of seven years. The studies are published on the MAA website for each campaign in the form of summary notes [1]. The objective of these analyses is to provide indicators measuring the take-up rate of this product and the characteristics of the insured farms. CCR designs and manages a geographic database of policies and claims.
To carry out the numerous statistical and mapping analyses, CCR has set up a multi-stage data processing chain. This methodology targets the operations carried out on the database to create queries for automated data cleansing and the automatic generation of summary analysis tables and maps. This article presents the methodology developed and the results for efficient data processing automation and the indicators developed to monitor crop insurance. The results of the 2019 crop insurance campaign are also presented.

PRODUCTION OF KEY INDICATORS AND PROCESSING AUTOMATION

Definition of the indicators

The analysis of the development of comprehensive weather insurance is carried out at several levels and is based on insurance indicators, characterisation of insured French farms, farm characteristics and public risk management policy. The different indicators are presented in Figure 1. All indicators are studied at national, regional and departmental level.
The analysis is also carried out at different levels of crop production: from cultivation types (arable crops, viticulture, arboriculture, grasslands, vegetables) to crop types (e.g. soft wheat).
The insurance database is also cross-referenced with the benefit payment databases provided by the MAA (allocations to young farmers, benefits for dairy cattle, benefits for goats, benefits for sheep, etc.). This cross-referencing allows the creation of a classification of insured farms according to their level of insured capital. We therefore get information on the crops insured on livestock farms, on the specialisation or diversification of insured farms, on the proportion of young farmers insured.
In addition, the different information on the evolution of the insured portfolio is compared with the evolution of the climate and risk prevention practices to understand the changes in the portfolio from one campaign to the next.

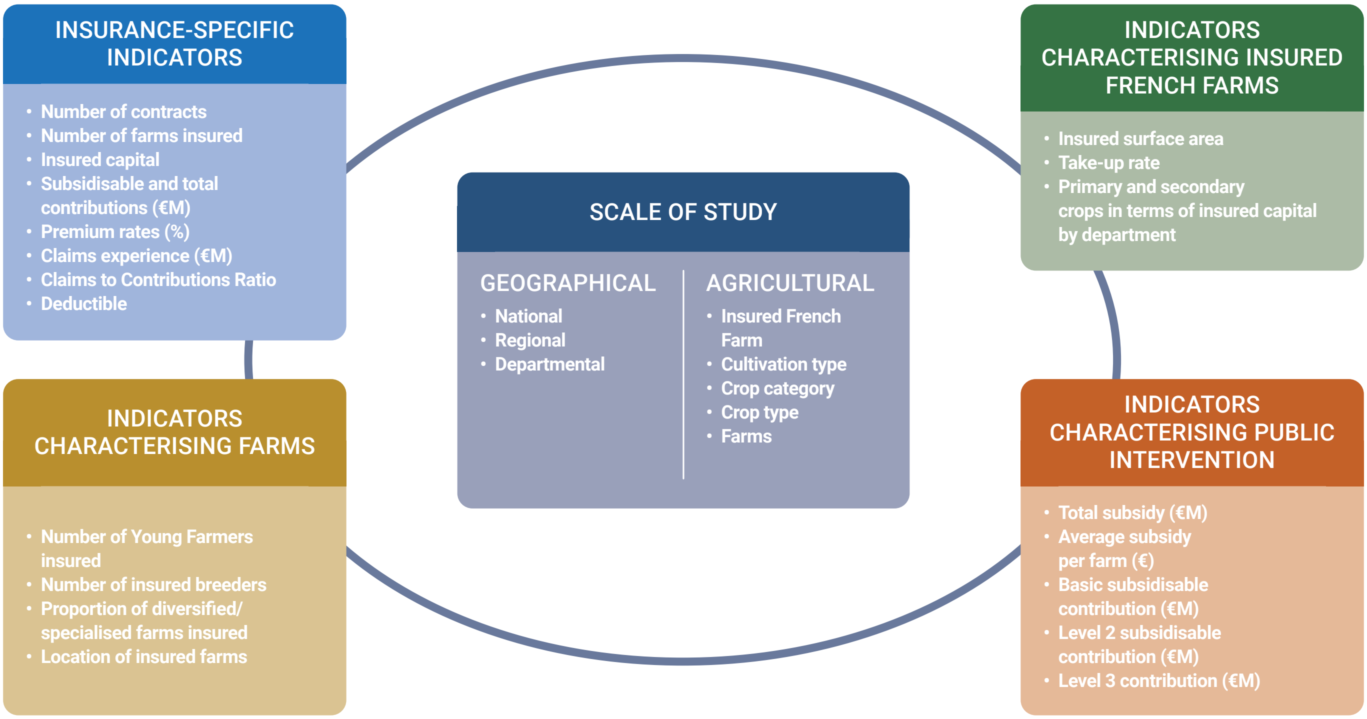


Figure 1 - Example of Indicators developed for the monitoring study of comprehensive weather insurance.

Data processing automation

The source data is provided by the MAA in the form of Excel files. This data is analysed, cleaned, and prepared before being processed by a Data Science platform (Dataiku) through formatting, standardisation, enrichment and creation of indicators. Data processing operations are carried out using visual recipes, interacting with the database and without the use of computer coding methods. These first steps consisting in cleaning the database are essential to obtain studies of better quality.

For example, the analyses published by CCR are carried out by crop category: cereals and fodder, oilseeds, protein crops, industrial crops, vegetables, viticulture, arboriculture, grassland. However, some crop types are misclassified in the categories presented in the original files. The methodology implemented allows for the fast detection of errors and the quick reclassification of crop types without generating bias or oversights. Once the data is processed, the results are stored in a relational database. The monitoring of crop insurance includes recurrent analyses of indicators the evolution of which is studied from one campaign to the next. To speed up data analysis, SQL queries were automatically executed thanks to computer programming. These queries allow the global analysis of the different indicators developed. The use of the database then only involves specific cases of evolution of certain indicators.

Finally, the creation of a computer code to extract and read the data on an interface linking the mapping software to the database allows the automatic generation of over a hundred maps in a few minutes. >

data processing
crop insurance
mapping
indicators

2019 KEY FIGURES FOR CROP INSURANCE

In Metropolitan France, 13.1% of farms were insured in 2019, representing 57,236 policyholders. Insurance is more developed in the northern half of France in terms of insured surface areas, with higher take-up rates (Figure 2). This is due to the diversity of the portfolio in terms of agricultural specialisation. Indeed, the vast majority of the portfolio is made of arable crops (about 90% of the insured surface areas) and are grown mainly in Northern France. The take-up rate of insurance is 29.7% (excluding grassland) in 2019.
The take-up rates by crop category are presented in Figure 3 with their year-on-year change. Since 2017, they have been increasing overall, despite varying growth rates across crop categories. In the case arboriculture and grassland, crop insurance has been struggling to develop for several years. The classification of insured farms shows a large portion of farms specialising in arable crops, in line with the results presented earlier. The proportion of diversified farms continues to increase, and these are mainly farms growing all four categories of arable crops (cereals, oilseeds, protein crops, industrial crops). Livestock farmers are present in the portfolio mainly in the category of farms with low insured capital (less than €35,000). They tend to insure their arable crops.
Finally, the study of the 2019 claims experience shows negative results across all cultivation types (C/TC ratios greater than 100%) (Table 1). However, there were no extreme losses in grassland, unlike 2018, which was shaped by a major drought in north-eastern France. The most affected departments in 2019 are in the northern half of France due to drought and in the south-west and the Rhône Valley due to the spring frost in May 2019.

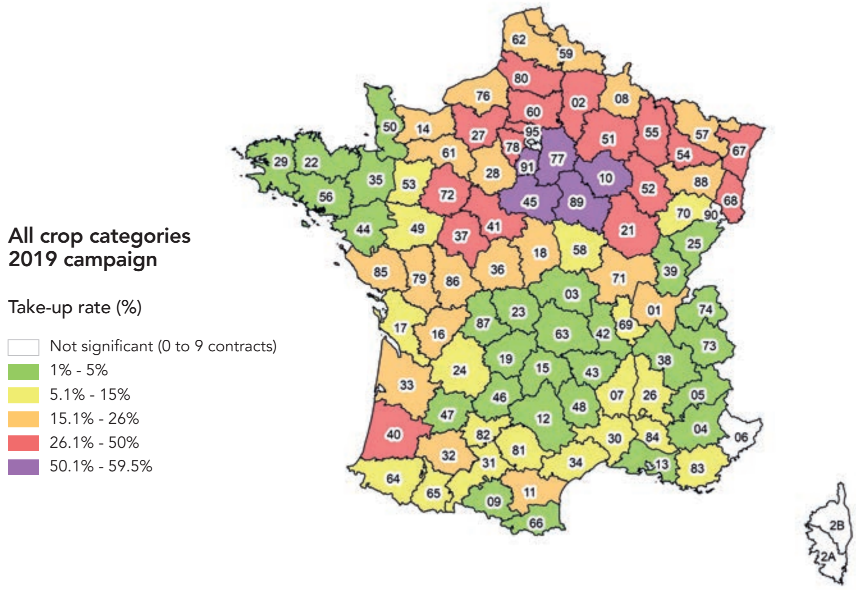


Figure 2 - Distribution of take-up rates by department for all crop categories combined - 2019 Crop insurance.

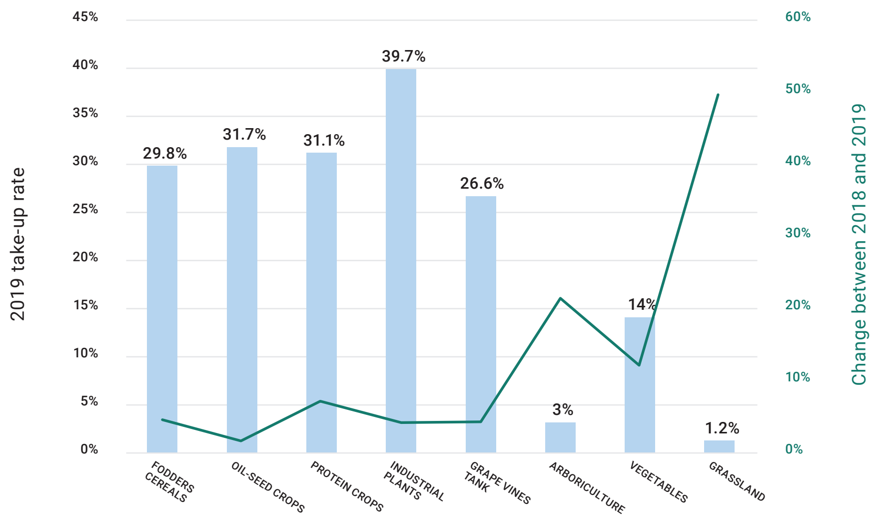


Figure 3 - Crop insurance take-up rate by crop category 2019 and change compared to 2018.

MINISTÈRE
DE L'AGRICULTURE
ET DE L'ALIMENTATION
Liberté
Égalité
Fraternité

THE PARTNERS

To monitor the development of crop insurance, the French Ministry of Agriculture and Food has been using CCR's services since the 2015 campaign.

CULTIVATION TYPES	2019 Claims experience (€M)	Claims to total contrib. ratio 2019	Reminder 2018 C/TC
Grandes cultures	269.4	122%	112%
Prairies	6.5	149%	447%
Viticulture	140	176%	74%
Arboriculture	6.4	115%	77%

Table 1 – Sinistralité 2019 par types de cultures et rapport entre sinistres et cotisation totale (S/C)

CONCLUSION

The indicators developed by CCR make it possible to measure the evolution of the crop insurance portfolio (in terms of the characteristics of insured farms, the insured farm in France and data specific to the insurance field). Some indicators related to public-private partnerships (e.g. subsidy amounts) are under scrutiny by public authorities. To carry out the studies for the French Ministry of Agriculture and Food within a few months of the data being provided, CCR set up a data processing chain. The methodology implemented ensures the homogeneity of the studies from one campaign to another by significantly reducing processing times and ensuring high data quality.
These figures, provided annually by CCR to MAA, are published on their website and serve as a reference to support discussions on risk management in agriculture./

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CITATION

Kapsambelis D., et al, Data processing for comprehensive weather insurance in agriculture. In CCR 2020 Scientific Report; CCR, Paris, France, 2021, pp. 84-87

HEALTH RISKS

In March 2020, the Covid-19 pandemic started spreading around the world like wild fire.
On 17 March, France froze with the first lockdown that disrupted the lives of the French.

Modelling operating losses following a pandemic-related administrative closure • p.90

In 2020, following the Covid-19 pandemic and lockdown, CCR has developed a first model to estimate the economic losses.

En 2020, suite à la pandémie de Covid-19 et au confinement généralisé, CCR a développé un premier modèle d'estimation des pertes économiques consécutives à ces fermetures administratives.

David Moncoulon, Thierry Cohignac and Dorothée Kapsambelis

Modelling operating losses following a pandemic-related administrative closure

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(1) Cat & Agriculture Risk Modelling R&D Department, CCR
(2) Reinsurance & Public Funds Division, CCR

INTRODUCTION

The fight against the spread of the Covid-19 virus required the implementation of administrative measures restricting a significant part of the country's economic activities for public health reasons. Companies in the sectors affected by these measures had to suspend all or part of their business, resulting in a significant drop in revenue over the period with some companies facing no revenue at all. This highlighted the challenges of covering business interruptions caused by an exceptional event such as a pandemic. A working group involving all the stakeholders concerned was therefore set up on 27 April 2020 by Bruno Le Maire, the French Minister of the Economy, Finance and Recovery. Led by the French Treasury, this working group brought together, in addition to government departments, parliamentarians and representatives of companies, insurance and reinsurance companies, insurance distributors and actuaries. As a public reinsurer, CCR was involved in the discussions on the creation of a "Health Catastrophe" type scheme. The work carried out by CCR focused on the insurability of this risk and on modelling the economic cost of pandemic-type events. We present here the principles of the region-based stochastic model developed by CCR in the framework of this working group.

MÉTHODOLOGIE

The dual objective of the model created is to model the losses related to the administrative closure of companies following the Covid-19 pandemic and to study the feasibility of setting up financial protection for companies through insurance in the form of a public-private partnership. The approach used is a region-based simulation of administrative closures over different periods of time. The objective is to determine the severity of the lockdown scenarios from the economic data and the frequency of these scenarios by simulating 1,000 stochastic dummy events crossed with the RMS database.

Structure of the model

Figure 1 shows the structure of the model created. It is based on three modules.

The hazard module calculates the intensity of the pandemic at the chosen local scale and the frequency of occurrence of the event. The duration of the event is also determined in days. The model is carried out on a regional scale in France. Thus, the probability of a region being affected depends on its demographics, population density per square kilometre and the number of available ICU beds per capita in each region. The intensity of the hazard is therefore determined by the duration of the lockdown, the rate of business interruption and the distribution by industry and region.

The vulnerability module calculates the operating losses due to administrative closure by industry. The data used to model business losses related to administrative closures comes from the INSEE public database, ESANE 2017. This database provides accounting, financial and employment information by industry. It includes among other data, the number of companies, the number of employees, pre-tax revenue, etc. The profit and loss accounts by type of company (microenterprises, small and medium-sized enterprises (SMEs), intermediate-sized enterprises (ISEs) or large enterprises (LEs)) and by industry are also listed. These give us information on all detailed expenses, commercial margin, EBITDA, etc. They are used to calculate the adjusted gross margin (gross margin minus wages and financial expenses) by industry and by company size. Finally, and to assess the impact of lockdown on the national economy, it was necessary to cross-reference the economic data of companies with the number of administrative closures by industry and the related unemployment rate. This data was identified in the 20 April 2020 report of Sciences Po, OFCE following the 20 March 2020 lockdown. This data allows us to calculate a drop in activity (%) by economic sector. The different economic sectors studied represent 66% of the market. There are eight of

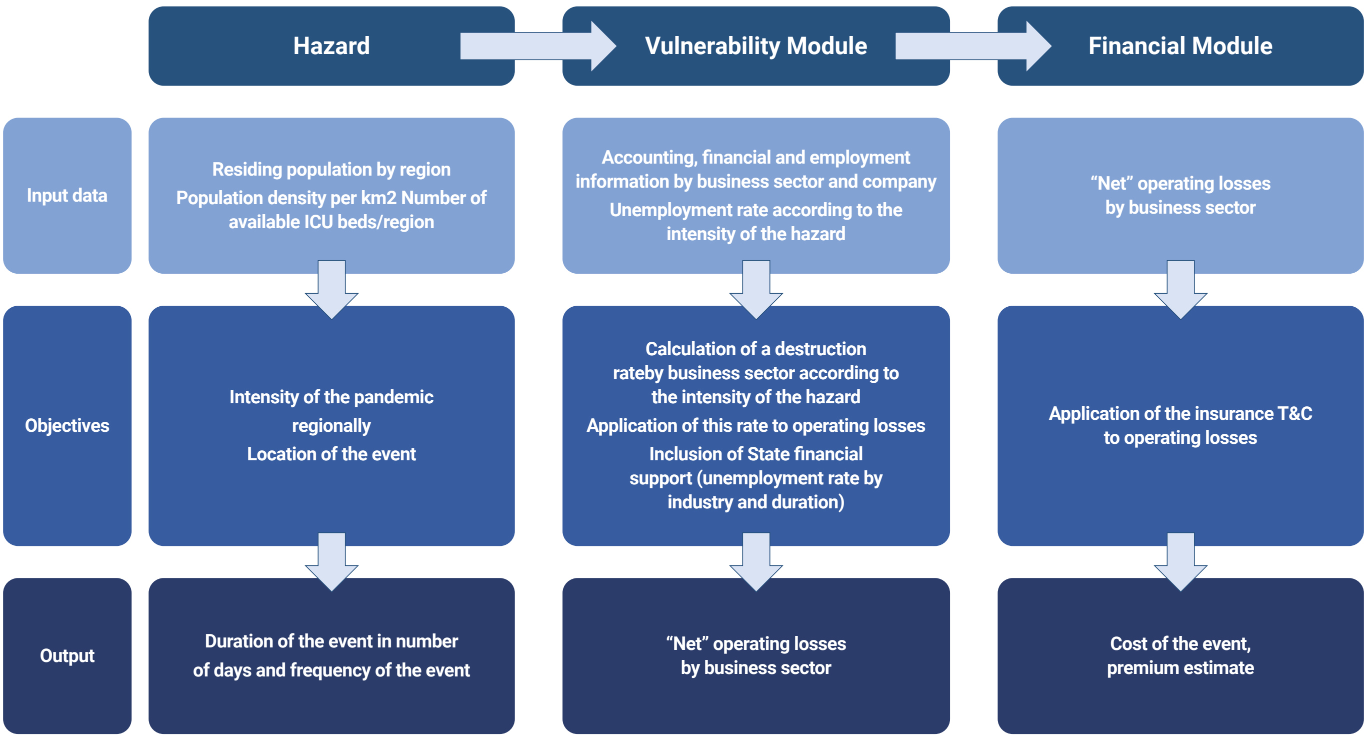

Figure 1 – Structure du modèle pandémie.

them: transport equipment, electronics, construction, trade, transport and storage, accommodation and catering (horeca), information and communication, financial and insurance activities. An extrapolation to the whole market is then made.

In addition, the gross domestic product (GDP) by industry and by region (INSEE database, 2015) is also used to calculate the share of GDP for each region to measure the economic consequences of lockdown scenarios by region.

Finally, **the financial module** allows the integration of business interruption insurance terms and conditions, i.e. deductible thresholds and limits. The model developed assumes that all companies are covered by the compensation scheme to strengthen solidarity between economic sectors and avoid any anti-selection. A maximum coverage period (based on the lockdown period due to Covid-19) is also applied as well as a deductible of a few days.

Stochastic modelling

A catalogue of dummy pandemic events is generated, defined according to their duration (varying between 15 and 60 days of administrative closure) and the number of regions affected. Arbitrarily, it is considered that if the number of regions affected is greater than 7, i.e. one third of the regions, then all of Metropolitan France is affected by the pandemic event. Cross-referencing with the RMS Pandemic event catalogue enables the return period of any such event affecting France to be estimated. The return period is 25 years. This modelling allows us to calculate the average cost of an event and the maximum loss.

pandemic
covid-19
operating losses
economic losses

RESULTS

Stochastic modelling can be used to quantify the average cost of a pandemic with a lockdown. This amounts to €6.5 billion for Metropolitan France. Furthermore, the maximum loss would be €30 billion. These results are calculated for variable lockdown periods between 15 and 60 days.
As an example, the details of the estimated business losses for the Horeca sector are detailed in Table 1. These figures represent an average loss of €7,056 per microenterprise, €123,818 per SME and €8.79m for ISEs and LEs.
The total operating loss representing 66% of the market is estimated at €38bn by the model developed. Extrapolated to 100% of the market, this loss comes up to €58bn for 60 days of lockdown as shown in Table 2. Thus, the systemic nature of health disasters leads to economic losses that cannot be insured on an indemnity basis. For this reason, the financial module incorporates a lump sum approach to insurance, which is simple and quick to implement, making it possible to envisage a financial balance for the scheme while providing financial assistance to companies within a relatively short timeframe.

Sector	Horeca
Number of companies	256,539
Revenues (€M)	99,628
Furlough rate	75%
Gross margin excluding wages covered by furlough schemes, excluding pre-tax results (€M)	44,231
% decline in activity (OECD)	90%
Loss over 8 weeks (€M)	**4,690**
Average per company (€)	**18,282**

Table 1 – Loss of business in Metropolitan France for the Horeca industry following a 60-day lockdown in the context of a health crisis.

Sector	Revenues (€M)	Drop in business (%)	Estimated loss (€M)
Industry - Transport equipment	243,130	-69	2,334
Industry - Electronics	122,354	-61	1,908
Construction	295,139	-79	5,353
Trade	1,315,219	-55	12,619
Transport and storage	214,835	-63	7,580
Horeca	99,628	-91	4,690
Information and communication	195,830	-34	3,722
Financial and insurance activities	43,186	0	0
Total sectors covered	**2,529,293**		**38,207**
TOTAL	**3,830,221**	**-35**	**57,858**

Table 2 – Business interruption extrapolated to the entire market in Metropolitan France following a 60-day lockdown in the context of a health crisis.

CONCLUSION

Although the principle of creating a health (or exceptional) catastrophe coverage scheme has been temporarily ruled out by the government, CCR's modelling work has provided a first scientific step towards a better understanding of the economic impact of pandemic risk. Aware of the uncertainties involved in modelling such a risk, CCR will pursue its efforts to make the first results obtained more reliable and to strengthen its expertise on the subject in the service of the State for the use and benefit of all./

CITATION

Moncoulon D., et al,
Modelling operating losses following a pandemic-related administrative closure.
In CCR 2020 Scientific Report; CCR, Paris, France, 2021, pp. 90-93

CCR NAT CAT AWARD

Inaugurated in 2015, the CCR Nat Cat Award acclaims innovative and original doctoral theses devoted to the study of natural catastrophes and its application to the insurance and risk prevention professions.

The CCR Nat Cat Award is open throughout the European Union to any research in the field of geosciences or economic and social sciences. To apply for the 2022 CCR Nat Cat Award, young researchers must have completed or presented a thesis between 1 July 2020 and 31 December 2021. The winner is chosen by a jury comprised of academics, experts from the research and insurance sectors, and representatives of CCR.

At the CCR CAT Day, the annual meeting of the French insurance market, the winner presents his or her work and is awarded a €5,000 prize./

2020 Winner
See the video

For more information
prixccrcat@ccr.fr

PRIX CAT NAT

2021 Winner
See the video

2021 Winner
Odile PLATTARD,
"Rethinking the evacuation of a coastal population in an urban environment in a multi-hazard context: the STEP model".

2020 Winner
Audrey MICHAUD-DUBUY,
"Dynamics of Plinian eruptions: Reassessing volcanic hazard in Martinique".

2019 Winner
Fanny BENITEZ,
"Coping or living with catastrophes? Adaptive capacities and capabilities in individual and territorial resilience trajectories within the Caribbean space".

2018 Winner
Kenji FUJIKI,
"Prospective study of the social impacts of a major flood in the Greater Paris region. Socio-spatial disparities in the care of Greater Paris populations in crisis and post-crisis situations: a mapped and quantified analysis of household needs, from evacuation to reconstruction".

2017 Winner
Elif ORAL,
"Multidimensional modelling of seismic wave propagation in linear and non-linear media".

2016 Winner
Vanessa MULOT,
"Marine spoof: New challenges, new legal practices".

2015 Winner
Camille ANDRÉ,
"Analysis of damages related to coastal flooding and assessment of costs incurred to homes based on insurance data".

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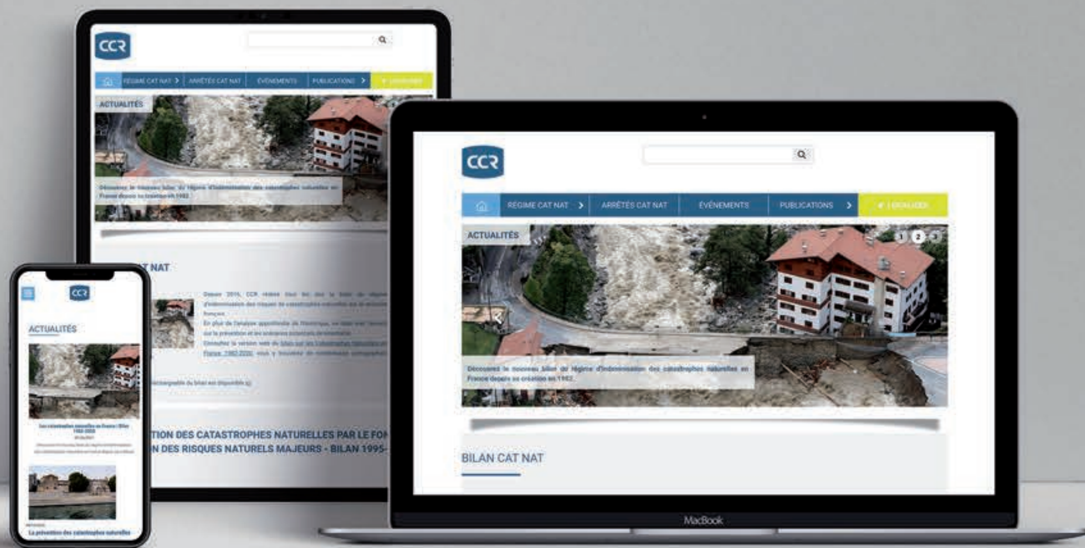

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