Why do actuaries need to model climate risk and how they can do it?

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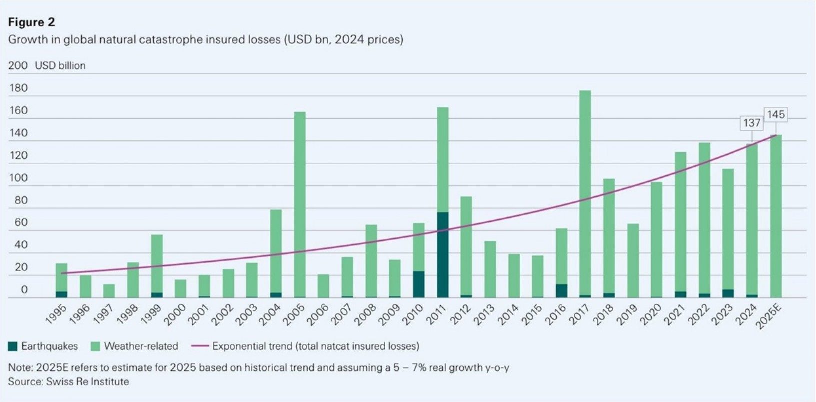
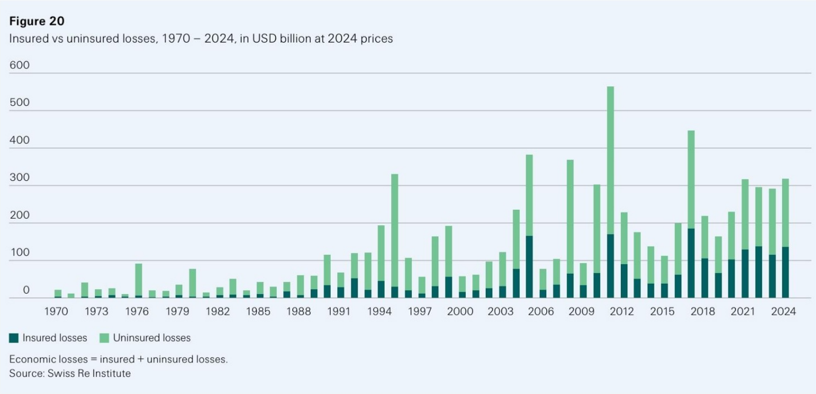
Global natural catastrophe insured losses (1995–2024)



Source : (Banerjee et al., 2025, Swiss Re)

Protection gaps for natural catastrophes (2015 – 2024)



Source : (Banerjee et al., 2025, Swiss Re)

Industry outlook

- Climate change challenges some fundamental principles of insurance : risk insurability, pooling, diversification, and risk transfer (Charpentier, 2008; Thistlethwaite and Wood, 2018; Courbage and Golnaraghi, 2022).
- Optimistic perspectives suggest that the insurance business could find in it an opportunity, through the development of new technical solutions (Rao and Li, 2023; Savitz and Gavriletea, 2019; Wagner, 2022).
- Pessimistically, climate change has forced already the strategic withdrawal of insurers in certain US markets, such as in California (Blood, 2023, APNews).

Impact on insurance costs

- In the Property & Casualty insurance sector, (Holzheu et al., 2021, SwissRe) forecasts increased frequency and severity of events due to climate change that will cost 30% to 63% more in insured catastrophe losses by 2040.
- This cost increase could even reach 90%–120% in specific markets, such as China, the UK, France and Germany.
- In all cases, it is important to add an actuarial perspective on the study of climate change and its impact on the insurance industry.

How to quantify climate risk?

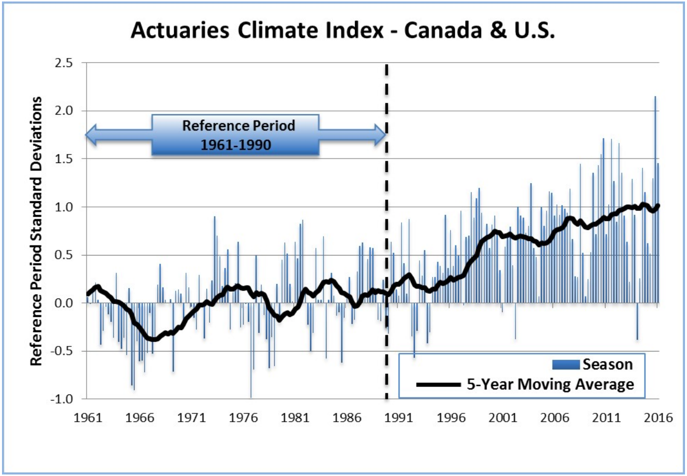
Several approaches have been proposed. For example:

- Climate indices: see the National Oceanic and Atmospheric Administration (NOAA) climate indices list.
- The Actuarial Climate Index^{TM} (ACI).
- Climate risk measures : like the climate–related expected shortfall, see (Piluso et al., 2025, IREF).

Actuarial climate indices

- The actuaries climate index™ (ACI) is linked to climate risks, a bit like the Consumer Price Index (CPI), which tracks the price variations of a basket of goods and services over time.
- Actuaries quantify and manage different types of risk. The ACI measures climate risk on the basis of a basket of extreme climate events and on variations of sea and ocean levels.
- An index increase points to an increased number of extreme climate events.

North American seasonal ACI values



Source : ACI Explore

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2. ACI historical developments

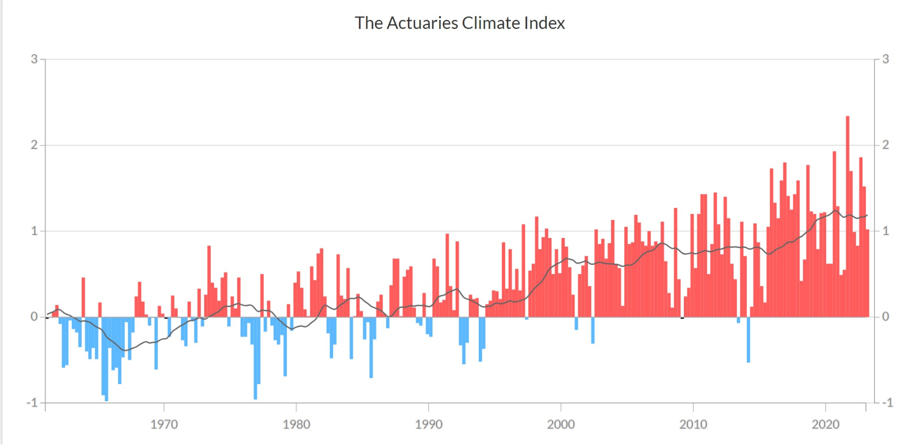
2.1 The North American ACI

Launched in April 2019, version 1.0 (current version is 1.1) [a].

- The ACI is a pedagogical tool to help inform actuaries, decision makers, and the public in general, on climate trends and their potential consequences of climate change in the US and Canada.
- An objective measure of observed climate extremes and sea levels.
- A tool to follow climate trends, updated every 3 months, separately for 12 regions, for the 2 countries, and for the North American continent.

[a] Version 2.0 is currently in development

Actuaries climate index™ (ACI)



Source : (Zhou et al., 2023, AIAE)

2.2 The UK and Australia

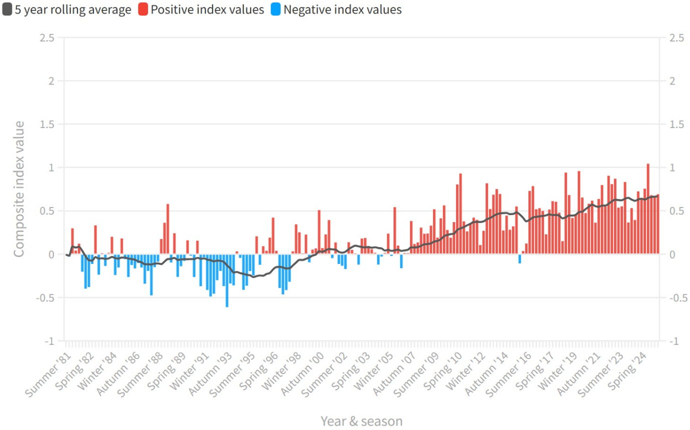
The UK

(Curry, 2015, IFA) considers extending the ACI to the UK and to Europe. He concludes that the definition and methodology could be applied in these regions as is, but requires appropriate data for the region.

Australia

- In November 2018, the Actuaries Institute Australia defines the AACI.
- Revised in 2025 they use a simplified version of the ACI, with 4 climate variables instead of 6, and more recent reference period : 1981–2010.

Australian Actuaries climate index (AACI)



Source : AACI component graphs and data

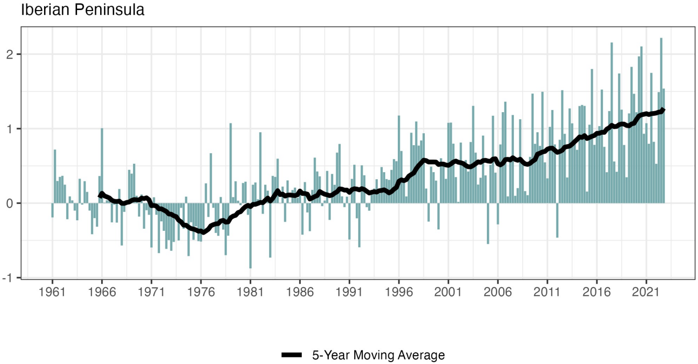
2.3 The Turkish ACI (TrACI)

- (Nevruz et al., 2022, IAD), published in the journal of the Turkish Statistical Institute, defines an ACI using the North American methodology, but for climate data only from the Ankara province.
- TrACI is defined over a different reference period (1981–2010). The paper reports TrACI values from 1981 to 2021, without including the sea level information, arguing that Ankara is not on the coastline.

2.4 The ACI for the Iberian Peninsula

- A first draft a Spanish version of the ACI was introduced in an oral presentation of the Spanish Institute of Actuaries (IAE).
- First defined over a different reference period (1975–1995 in general and 1993–2000 for sea levels).
- Their temperature variables differed also, see IAE (2023). It is now being standardized to ACI definitions, but is not yet available publicly.
- (Zhou et al., 2023, AIAE) use the North American ACI methodology and climate data for the Iberian Peninsula from the Copernicus ERA5–Land reanalysis database, see (Muñoz-Sabater et al., 2021, Copernicus), to compare the values and trends of this first European index to the North American ACI.

Iberian seasonal ACI values (IACI)



Source : (Zhou et al., 2023, AIAE)

For more details about the IACI

Anales del Instituto de Actuarios Españoles

4ª Época, Número 29, Año 2023/37-59

ON THE DEFINITION OF AN ACTUARIAL CLIMATE INDEX FOR THE IBERIAN PENINSULA

ACERCA DE LA DEFINICIÓN DE UN ÍNDICE CLIMÁTICO ACTUARIAL PARA LA PENÍNSULA IBÉRICA

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ABSTRACT

Climate change is defined as a long-term shift in climate patterns affecting the planet globally. The main consequences of climate change are a rise in average temperatures in many regions, and an increase in the frequency and intensity of extreme weather events, such as floods, droughts, storms, or hurricanes. Climate change is associated also with a rise in sea levels, more frequent and severe wildfires, a loss of biodiversity, and many other disruptions with serious economic impacts. These new risks are increasingly affecting both the frequency and severity of claims in different insurance branches. To help insurance companies predict and manage these new risks, actuaries have defined the Actuaries Climate Index™ (ACI), which combines information from several important weather variables from historical records of the United States and Canada. The ACI shows a significant increasing trend over the years. It is important to note, however, that the impact of climate change is not the same in all parts of the planet: different regions and countries are affected in different ways. Therefore, it is important to check if the ACI is as useful to assess climate risk outside the United States and Canada. In this paper, we follow the North American ACI methodology

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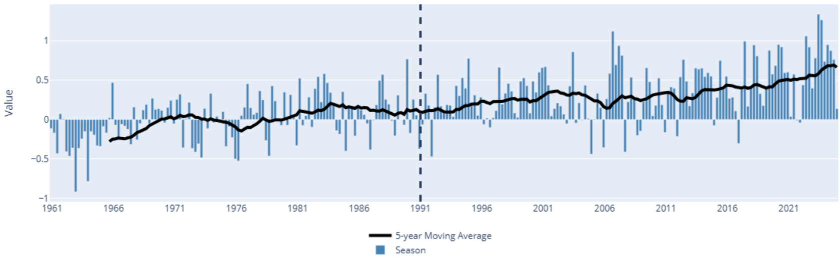
See also the R–package

And the IACI values

2.5 The French FACI

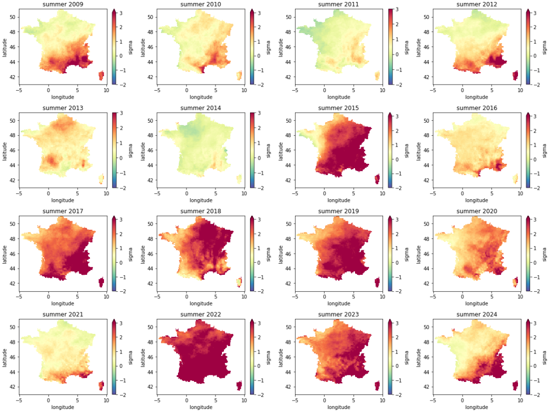
- (Garrido et al., 2023, preprint) calculate the French Actuarial Climate Index (FACI) with data extracted from the same ERA5–Land reanalysis database used for the IACI (Muñoz-Sabater et al., 2021, Copernicus).
- It is computed for over 10,000 cells forming the French grid of 0.1^o of latitude $\times$ 0.1^o of longitude (about 123.2 km^2).

French seasonal ACI values (FACI) 1961 – 2024



Source: (Garrido et al., 2023, preprint, version 2)

FACI T90 component : summers 2009 – 2024



Source: (Garrido et al., 2023, preprint, v2)

For more details: https://hal.science/hal-04684634/

See the R–package

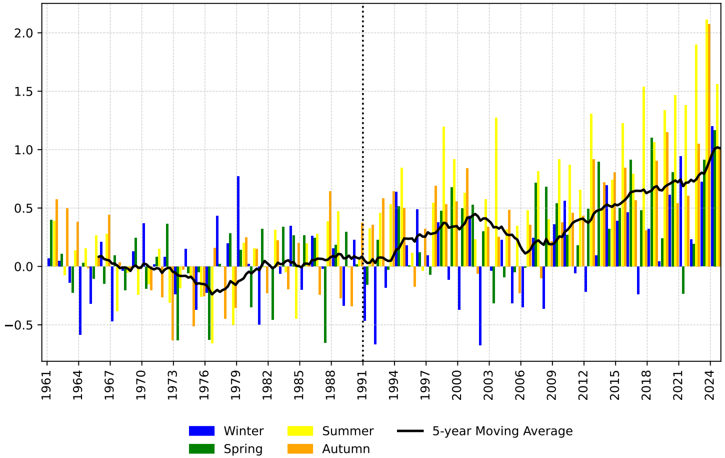
Or the Python–package

Source: (Garrido et al., 2024, Green book, CNP)

2.6 The Italian ITACI

- (Rogo et al., 2025, Risks) calculate the Italian Actuarial Climate Index (ITACI) with data extracted from the same ERA5–Land reanalysis database used for the IACI (Muñoz-Sabater et al., 2021, Copernicus).
- It is computed over the 80 km^2 cells forming the Italian grid of 0.1^o of latitude $\times$ 0.1^o of longitude.
- In this study the sea level component is assigned a different weight, depending on the number of kilometers of coastline if the region as compared to the total number for Italy.

Italian seasonal ACI values (ITACI) 1961 – 2024



Source: (Rogo et al., 2025, Risks)

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2.7 The South African ACI (SAACI)

- Marais and Moutanabbir (2025), published in the journal of the South African Actuarial Journal (SAAJ), defines an ACI using the North American methodology and the same reference period of 1961–1990.
- SAACI uses ERA5 reanalysis high resolution climate data, and sea–level values from PSMSL, like the other ACI 's above.
- SAACI values are provided at the provincial and national level.

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- Apart from being a pedagogical tool, the ACI can be combined to climatic scenarios to predict future values.
- The first applications are in non–life insurance, agricultural insurance, in reinsurance or to parametric insurance (see Zhou et al., 2024, Glob.Pol.).
- Covéa has incorporated FACI to its climate risk model, thanks to the Masters thesis of Marion Favrot, who is alternating with ISFA at U. de Lyon.
- Our DIALog project focused first on the effects of climate change on human mortality and morbidity (see Garrido et al., 2024, Green book, CNP).
- New applications are being published frequently now; here is a brief overview of ACI and other indices applications.

Example 1 : ACI correlations with weather based indices for weather derivatives and crop insurance

- (Cheung et al., 2024, NAAJ) "Cointegration analysis of crop yields and extreme weather factors using actuaries climate index with application of bonus–malus system". It is a dependence analysis between crop yields and extreme meteorological factors based on the ACI. Technique: error correction model (ECM).
- (Yavrum et al., 2026, Risks) "Comparative analysis of weather–based indexes and the actuaries climate index™ for crop yield production and weather–derivative pricing". It applies the ACI to define and manage weather derivatives. The aim is to highlight the ACI's potential as a dependable benchmark for pricing weather–related financial instruments, as a competitor to the usual weather-based indexes. Techniques: functional PCA, GLMs, GAMs, XGB.

Example 2 : IACI – hailstorms for crop insurance in Spain

Article

On the influence of climate change on hail risk in Spanish crop insurance.

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‡ These authors contributed equally to this work.

Abstract: There is a growing concern about climate change being a serious threat to insurance business sustainability. Knowing if climate warming is a cause for claims and losses increase, and how this cause-effect relationship will develop in the future are two open major questions. In this article, we answer both questions by particularizing the geographical area of Spain, and a precise risk, hailstorm in crop insurance in the line of business of wine grapes. We measure climate change thanks to the Spanish Actuarial Climate Index (SACI). We use a database containing all the claims caused by hail risk in Spain from 1990 to 2022. With homogenized data, we consider as dependent variables the monthly number of claims, monthly number of loss costs equal to one, and monthly total losses. The independent variable is the monthly Spanish Actuarial Climate Index (SACI). We try to explain the former through the latter using regression and quantile regression models. Our main finding is that climate change as measured by SACI explains these three dependent variables. We also give an estimation of the increase of the monthly total losses Value at Risk, corresponding to a future increase in climate change measured in units of SACI. Spanish crop insurance managers should carefully incorporate these conclusions into their decision-making process to keep this line of business sustainable in the future.

Keywords: Climate change; Crop insurance; Hail risk; Quantile regression; Regression (List three to ten pertinent keywords specific to the article; yet reasonably common within the subject discipline.)

Citation: Zhou, N.; Vilar-Zanón, J.L. On the influence of climate change on hailstorm risk in Spanish crop insurance. *Journal Not Specified* **2023**, *1*, 0. https://doi.org/

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1. Introduction

According to the United Nations Climate Action Forum, *Climate change refers to long-term shifts in temperatures and weather patterns. Such shifts can be natural, due to changes in the sun's activity or large volcanic eruptions. But since the 1800s, human activities have been the main driver of climate change, primarily due to the burning of fossil fuels like coal, oil and gas. Burning fossil fuels generates greenhouse gas emissions that act like a blanket wrapped around the Earth, trapping the sun's heat and raising temperatures* [1]. This process is a long-term one, affecting human beings in many instances as their lives, properties, transportation infrastructures, etc (see for instance [2],[3],[4]). As the insurance business spreads through all aspects of economic and individual human life giving protection against all sorts of claims, substituting random losses by sure indemnities, the question of *how climate change is affecting the insurance business* has arisen as a critical one for its present management and future sustainability.

During the last years, many extremal events like fires, floods, droughts, storms, and pandemics have negatively affected the balance sheet of insurance companies to the point of motivating their retreat from some lines of business in some geographical areas where the losses have increased to unaffordable bounds (see for instance [5]). In the scientific world, the concern about insurance business sustainability has mobilized lots of efforts to

Source: (Zhou et al., 2024, Risks)

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Example 2 : Interpretation and other studies

Percentage increase in the 99th percentile of loss for every 0.1-unit increase in pSACI (techniques: mixed linear and quantile regression models):

- In the province of La Rioja, 21,96%.
- In the province of Cuenca, 20,79%.
- In the province of Albacete, 19,62%.
- In the province of Ciudad Real, 19,61%.
- In the province of Toledo, 17,80%.

Consistent with prior research in the wine economics literature, on the impact of weather events on insurance in the viticulture sector in Spain. See (Martínez-Salgueiro, 2019, WEP), who uses weather-based indices, as a meteorological risk management alternative in viticulture.

Example 3 : Parametric insurance based on FACI

The rating formula for a basic parametric insurance is defined by 3 variables: the entry point E, the exit point X and the marginal value of 1 extra index unit, say IU.

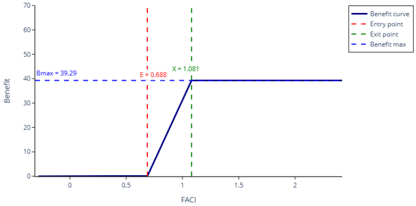
The insurance benefit payments are determined by :

$$B = IU \ x \ \mathbb{1}_{[I>E]} \ x \ \min\{I - E, X - E\},$$

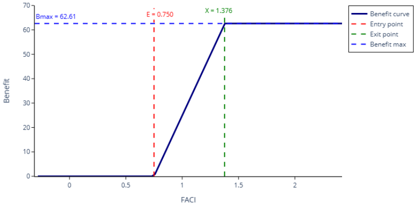
where B is the benefit value, $\mathbb{1}_{[A]}$ is an indicator function of event A and I is the index value.

This linear benefit formula is the most common on the market.

Example 3 : Parametric insurance benefit examples



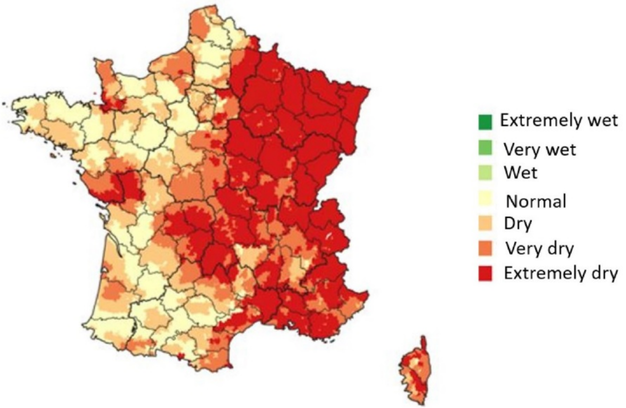
E = median
X = 75%-percentile ,



E = mean
X = 90%-percentile ,

Source: (Garrido et al., 2023, preprint)

Example 4 : Standardized Soil Wetness Index, Météo–France, 2018



Source: (Heranval et al., 2023, EAJ)

Example 5 : Impact of heat waves on excess mortality

What is excess mortality?.

- The actuarial approach consists in removing the seasonality and the improvement trend from the oberved mortality. What is left is considered excess mortality. On this basis it can be compared to climate extremes, socio—economic and/or environmental variables.
- Another approach consists in using mortality data by cause of death, to identify those due to heat wages.

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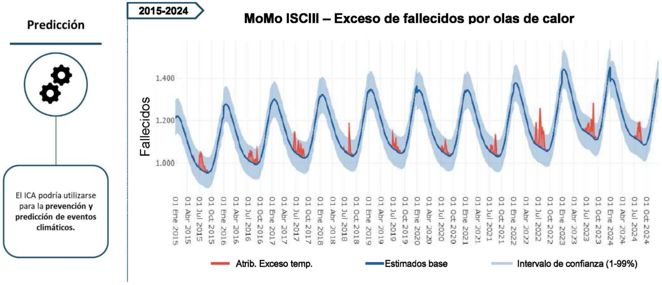
Example 5 : Impact of heat waves on mortality in Spain

Using climate date from the Spanish meteorological agency (AEMET), the Spanish Institute of Actuaries (IAE) studied also the impact of extreme high temperatures on excess mortality.



Source: IAE -– working group on climate risk

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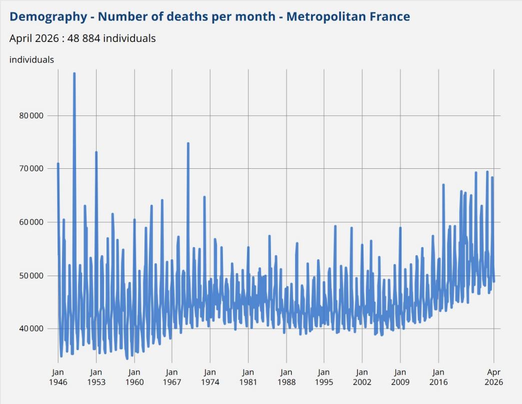
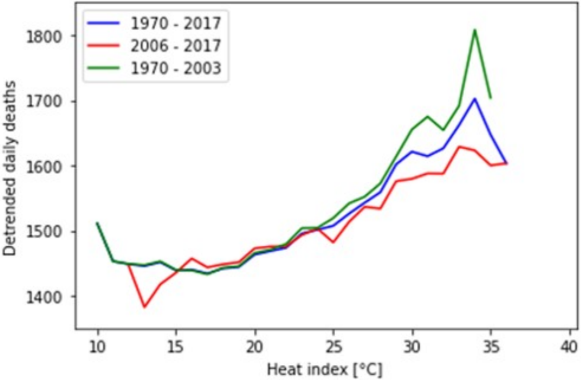
Example 6 : Mortality per month in France, 1946 – 2026



Source: INSEE – Number of deaths per month – Metropolitan France

Example 6 : Impact of heat waves in France, 1970 – 2017



Source: (Garrido et al., 2024, Green book, CNP)

Survey of current research, climate vs mortality – I

Current research on the impact of climate extremes on life and health insurance :

- (Milhaud and Gouthon, 2024, preprint) "Impact of above–average heat on mortality: extension of longevity models to account for global warming". Techniques: Seklecka's extension of Lee–Carter model.
- (Madaniyazi et al., 2024, Lancet) forecast the seasonality of mortality under climate change.
- (Shen et al., 2024, SR) Mortality rate prediction in European population clusters. Techniques: deep learning and multiscale analysis.
- (Raynal and Loisel, 2025a, AAS) "Mortality modeling for short term climate stress test in France : impact of extreme heat". Techniques: clustering, Poisson regression.

Survey of current research, climate vs mortality – II

- (Loisel et al., 2025, preprint) "Recommendations and challenges regarding the construction of climate change impact scenarios in health and life insurance".
- (Bégin et al., 2025, IME) model seasonal mortality, including climate effects. Technique: age–period–cohort approach.
- (Morreeuw, 2025, thesis) actuarial Master's thesis "Prédiction de la mortalité estivale française par l'UTCI", supervised by Anani Olympio (CNP, Paris). Techniques: regression, random forest.
- (Guibert et al., 2025, IJF) "Impact of climate change on mortality: An extrapolation of temperature effects based on time series data in France". Technique: DLNM.

Survey of current research, climate vs mortality – III

- (Barigou et al., 2025, preprint) "Mortality Modeling and Forecasting with the Actuaries Climate Index". Techniques: GLMs, GAMs, XGB.
- (Robben et al., 2026a, JRSS) studies the short–term association between environmental factors, like weather and air pollution, and weekly mortality rates in small European regions.
- (Robben et al., 2026b, IME) "Granular mortality modeling with temperature and epidemic shocks: a three–state regime–switching approach".
- (Zheng et al., 2026, AAS) "A brief review of deep learning methods in mortality forecasting".

Survey of current research, climate vs mortality – IV

Also on other topics:

- (Raynal and Loisel, 2025b, preprint) "Risk averse asset allocation in a context of climate change with reinforcement learning and hidden Markov models".
- (Albrecher and Loisel, 2026, EAJ) "The insurance of climate–related physical risks: challenges and opportunities for actuaries".

Conclusions – I

- Hopefully, the recent indices calculated for Spain, Portugal, France and Italy constitute one more step towards the definition of a European index.
- New ACIs are currently in the design stage, for instance for Marocco (A. Bouchaikh, G. Ghazzali and A. Oulidi, Atlantic Re, Casablanca), for Turkiye (Cem Yavrum, A. Sevtap Selcuk-Kestel, Middle East Technical U., Ankara), for Saudi Arabia and for the UK.
- Covéa, the lasgest P&C insurer in France, has incorporated FACI to its climate risk model, thanks to the Masters thesis of Marion Favrot, who is alternating with ISFA at U. de Lyon.
- We are revisiting the choice of variables included in these ACI's, the choice of reference period and the quantiles chosen (90/10%); using time penalized trees (TPTs) to rank variable importance.

Conclusions – II

- The use of standardized anomalies (Z–scores) is also under review. With Alejandro Balbás, Silvia Mayoral and Rosa Rodriguez (U. Carlos III, Madrid) we use a risk measure approach to climate risk.
- The North American ACI joint Task Force is working on a redesign (version 2.0); see the CAS presentation and the video recording Data Disclosure for the Actuaries Climate Index™.

Thank you for your attention!

Any questions?

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