The current and futur costs of tropical cyclones: a case study from La Réunion

ReNovRisk - Impact & Transfert

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Introduction

Motivation - I

- Tropical Cyclones (TC) are a natural **destructive** phenomena.
  - During the 2000-2009 period the cost of TC amounts to US$ 466 billion worldwide. (EMDAT 2019)
- Surveys about the economics of natural disasters indicate that **losses** due to TC **increase** over time (Cavallo & Noy, 2011).
  - Trend mainly explained by economic and demographic growth (Botzen et al., 2019)
  - More people and assets are now located in exposed areas (e.g. the coastline). (Kellenberg & Mobarak, 2008)
- **Global warming** is likely to **alter** the **frequency**, the **genesis**, the spatial extent and the characteristics of the **most extreme TC** (Knutson et al., 2020).
  - What's about the losses due to TC ?

Motivation - II

- La Réunion knew many **TC events** inducing important **losses**.
  - "1948", Jenny 1962, Firinga 1989, Dyna 2002.
  - No study investigating the risk of TC at the island level.
- **Data limitation** partly explains this lack of investigation.
  - No "significant" TC' events since 2002.

Question of the paper

How would the economic losses associated with tropical cyclones on La Réunion vary in a warmer climate ?

Challenges

Methodological challenges are threefold :

1. **Historical** data on TC cover a **short period** and **high quality** data are fairly **recent**.
    - Looking at past events is inappropriate since the most extreme events are uncommon from a statistical viewpoint.
    - Issue more acute when focusing on a small island.
2. **Historical data** observations alone are likely to be **uninformative** about the characteristics of TC in a **future** and warmer climate.
    - The variation in future costs of TC is a key indicator when engaging adaptation policies.
3. The **extent** of the **economic damage** depends on the physical characteristics of TC as well as the **spatial distribution** of economic assets.
    - We need to proxy the repartition of economic activity at a detailed spatial level.

What we do

- We **do not rely** on **historical** data but on **simulated** (or synthetic) TC.
- We use **synthetic TC** obtained from t**wo climate scenario** :
  1. For a climate environment **similar** to what have been **observed** during the **30 years**.
  2. For a climate environment corresponding to an **anticipated** and **median** scenario of **global warming**.
- We **proxy economic activity** (or economic value) at a **local level** using **night-light** data obtained from satellite.
- We estimate the **losses** due to each TC of each scenario.
- We estimate the **annual expected losses** due to TC under both scenario.

Data

The spatial extent of economic activity - I

- We use **nighttime** satellite **images** from the the sensors of the Visible Infrared Imaging Radiometer Suite (VIIRS).
- We use **daily nightlight** data for 2018 and **aggregate** them to obtain **annual average**.
  - The "famous" black marble data of Roman et al. (2018)
- Very **high resolution** data : cells of about 500m of horizontal resolution (Reunion $\approx$ 10,000 pixels).

The spatial extent of economic activity - II

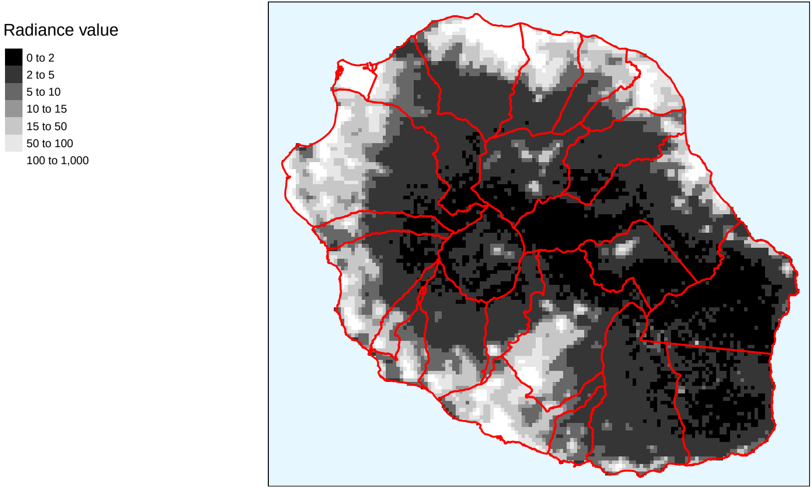


Figure – Mean value of daily night-light per pixel for La Réunion in 2018.

Synthetic TC - I

- Synthetic TC are obtained from Emanuel (2011)' methodology.
- Given **large-scale** meteorological **variables** derived from **climate models** and a high-resolution coupled ocean-atmosphere cyclonic system model, **synthetic systems** are randomly **launched** in space.
- This technique "downscales" the characteristics of TC, and allows to quantify the influence of climate on TC' activity.
  - The data allow us to obtain wind fields associated to each cyclonic system.
- We have 2,000 "current" TC and 2,000 "future" TC simulated by the CNRM-6 climate model and the median scenario of global warming RCP 8.5.
  - The current median scenario was the worst 10 or 15 years ago.

Synthetic TC - II

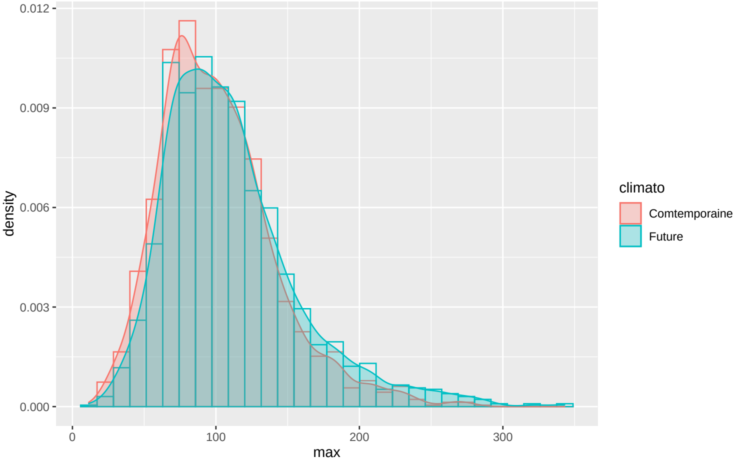


Figure – Contemporaneous and future averages of maximum wind speed per pixel.

Methodology

From winds to damages... - I

We translate wind speed on pixel c from the cyclonic event i into damages using the **index** of **destruction** f_{ci} of Emanuel (2011) :

$$f_{ci} = \frac{v_{ci}^3}{1 + v_{ct}^3} \quad \text{with } v_{ci} = \frac{MAX\left(W_{ci} - \bar{W}, 0\right)}{W^* - \bar{W}}. \tag{1}$$

- $\bar{W}$: minimum wind speed value above which economic damages are observed. ($\bar{W} = 93$ km/h). W^* : threshold at with half of the economic value of a given cell c is destroyed ($W^* = 270$ km/h).
  - We lack strong evidence to pick the values of these two parameters.
- The damage function captures that below $\bar{W}$ no significant damage could be observed together with **damages increase non-linearly** with wind speed.
  - For high wind levels, the fraction of economic loss cannot exceed 1.

Remark

Our **damage function** is **theoretical**, we are not aware of an the existence of an **empirical** damage function for La Réunion.

From winds to damages... - II

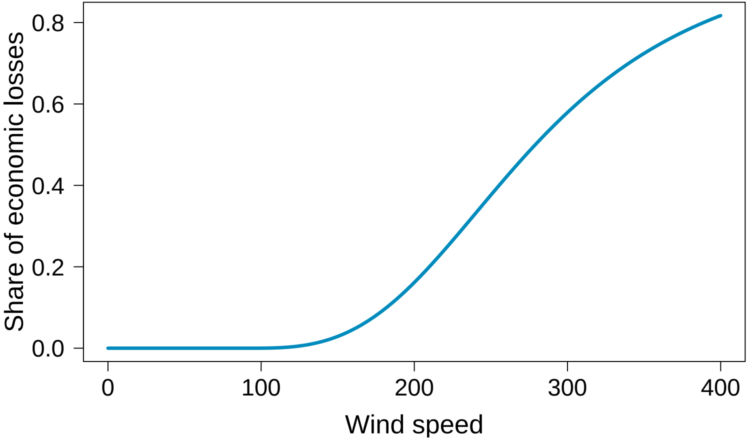


Figure – Index of the share of economic losses due to wind speed.

Underlying assumptions

- f_{ci} only captures **direct losses** (Emanuel, 2011).
- We only take into account **one hazard** associated to TC : the wind.
  - Other hazards (inundations, landslides...) are more difficult to model but are correlated with wind speed (even not perfectly).
  - Vast majority of insurance claim payments are due to wind speed rather than rainfall, landslides, or storm surges (CCR, 2020).
- We assume that **pixels' sensitivity** to wind speed is the **same** "today" and in the "future".
  - Our estimation can be seen as an upper bound because adaptation policies (if any) are likely to decrease the losses due to wind speed.
- We assume that the **spatial distribution** of **economic activity** is the **same** "today" and in the "future".
  - We do not forecast future economic growth.
  - Our estimation can be seen as a lower bound because future economic growth is likely to increase the economic value of exposed assets.

Aggregation

We derive total economic losses F_i at the island level for cyclonic event i, by applying the following formula :

$$F_i = \sum_{c=1}^{C} \frac{nl_c}{NL} \times f_{ci} \tag{2}$$

Where :

- C corresponds to the total number of cells characterizing La Réunion in terms of night light.
- nl_c is the average brightness value of cell c in 2018.
- $NL = \sum_{c=1}^{C} nl_c$ is the total "brightness" value observed in La Réunion in 2018

Results

A look on synthetic TC - I

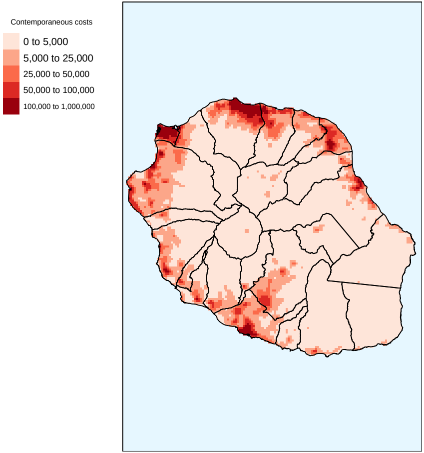
	Contemporaneous	Future	Δ in %
% of TC with 0 damage	**48.88**	**42.88**	-12.27
Percentile 50%	0.00	0.00	–
Percentile 60%	0.00	0.01	–.
Percentile 70%	0.03	0.10	–
Percentile 75%	0.08	0.24	–
Percentile 80%	0.19	0.55	–
Percentile 90%	1.15	2.76	–
Percentile 95%	3.76	7.66	–
Percentile 99%	17.44	31.76	–
Percentile 100%	40.26	67.75	–
Mean	**0.76**	**1.43**	**89.56**
Standard deviation	3.20	5.33	–
$\frac{\text{Standard deviation}}{\text{Mean}}$	4.21	3.73	–

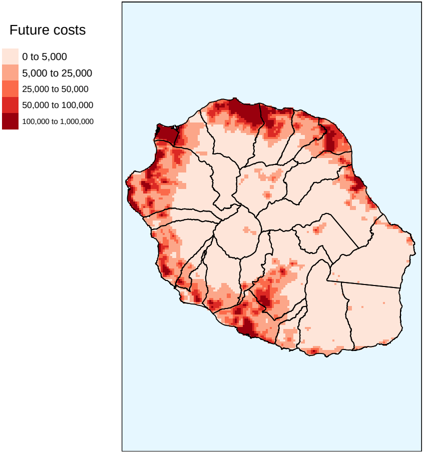
Table – Summary statistics of TC losses generated by 2,000 contemporaneous and future cyclonic systems.

Sources : Black marble nightlight products of Roman et al. (2018) and authors' own calculation

Notes : Damages ares expressed in percentage of the total brightness of La Réunion.

A look on synthetic TC - II





Moving to annual statistics - I

- Previously, we compute the total cost per cyclonic event without considering the annual occurrence of TC.
  - Economic agents, especially insurers, rely on expected annual losses.
- **Hypothetical years** : drawing from a Poisson distribution a number x representing the **number** of TC events "attached" to that year.
  - The parameter λ of the Poisson distribution correspond to the average number of cyclonic systems circulating around La Réunion.
- For each year, we **randomly select** (with replacement) the corresponding number of TC from the corresponding pool of TC.
  - We then **sum the total costs** from each selected TC.
- For both climate environment, we **repeat** the last steps 100,000 times.

Remark

Sensitivity analyses are conducted to consider different scenario.

Moving to annual statistics - II

	Contemporaneous	Future	Δ in %
% years with 0 cost	**85.80**	**84.20**	**-1.86**
Percentile 80%	0.00	0.00	–
Percentile 90%	0.01	0.04	–
Percentile 95%	0.34	0.86	–
Percentile 99%	6.90	12.55	–
Percentile 100%	43.01	67.89	–
Mean	**0.23**	**0.43**	**86.96**
Standard deviation	1.82	3.05	–
$\frac{\text{Standard deviation}}{\text{Mean}}$	7.91	7.09	–
Return period of damage >0	**7.00**	**6.00**	–

Table – Summary statistics of annual cost generated 100,000 years of simulation of contemporaneous and future climates.

Sources : Black marble nightlight products of Roman et al. (2018) and authors' own calculation

Notes : Damages ares expressed in percentage of the total brightness of La Réunion.

Moving to annual statistics - II

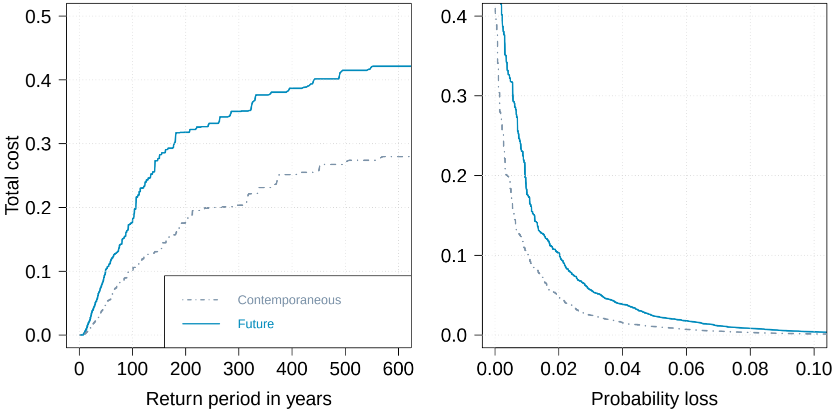


Figure – Return period and exceedance probability curves for current and future climate.
Sources : Black marble night light data Roman et al. (2018), synthetic tropical cyclones Emanuel (2011) and authors' own calculations.

Sensitivy analyses

1. Changing λ.
   - Incertainty about the future exposition of La Réunion.
   - Some evidence suggests that in a warmer climate environement the total number of TC would decrease but that most extreme events could be more intense : La Réunion would be less exposed to TC.
   - Others evidence suggests that global warming could modify the genesis and path of TC so that previously less exposed areas could be more exposed in the future : La Réunion would be more exposed to TC.

     More. ? ▷

2. Changing sequentially $\bar{W}$ and W^*.
   - Increasing W^* and $\bar{W}$ in a future environment implicitly assumes that adaptation behaviour take place. More. ? ▷

Conclusion

Concluding remarks

- Relying on synthetic data and estimating economic value on the ground by nightlight, we estimate the current and the future cost of TC.
- Direct losses associated to TC are likely to increase in a future and warmer climate environment.
  - By around 90%.
- This suggests that policy makers should engage in strong policies to reduce the costs due to TC.
- The approach of the present paper can be improve in many ways by considering different kinds of “objects” and other damage functions.
  - A stimulating area of improvements would be to construct an empirical damage function for La Réunion.
  - What’s about multi-hazards modeling ?

Thank you for your attention !

Annexes

Changing λ

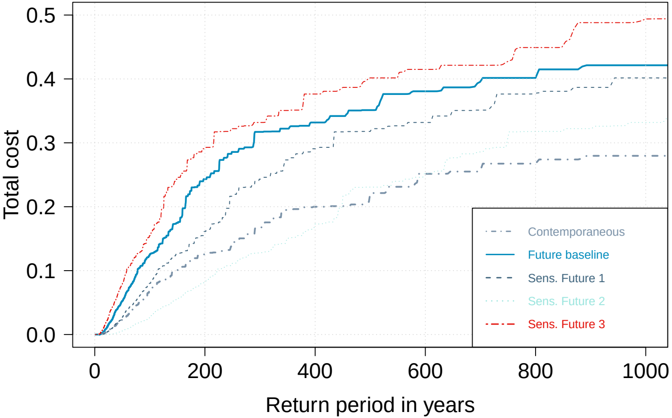


Figure – Return periods for different calibrations of λ. Back ◁

Notes : In the scenario labeled "Rob Future 1," the parameter λ is set to 0.375. In the scenario labeled "Rob Future 2," the parameter λ is set to 0.175.

Increasing W^*

	Contemporaneous	Future	Δ in %
% years with 0 cost	85.80	84.23	-1.83
75%	0.00	0.00	–
80%	0.00	0.00	–
90%	0.00	0.02	–
95%	0.19	0.48	–
99%	3.99	7.52	–
100%	28.61	54.11	–
Mean	0.14	0.27	92.86
Standard deviation	1.15	2.06	–
$\frac{\text{Standard deviation}}{\text{Mean}}$	8.21	7.63	–
Return period of damage >0	5.00	4.00	–

Table – Robustness - Summary statistics of annual cost generated with 100,000 years of simulation of contemporaneous and future climates with $W^* = 320$. Back ◁