ENVIRONMENTAL PROGRAMMING

ASSIGNMENT 8

Mapping Lifetime Exposure to Climate Extremes from Land Fraction Data

ASSISTANT : AMAURY LARIDON
PROF. DR. IR. ELGA SALVADORE

2025-2026

1 Introduction

With climate change, it is well established that the intensity and frequency of extreme climate events, such as heatwaves, droughts, and floods, are projected to increase. Until recently, the impacts of climate change were typically communicated by stating, for example, that by 2100 a given country is likely to experience a certain number of heatwaves. A common output from impact models is the percentage of each grid cell in the model affected by a specific climate extreme in a given year.

To make these outputs more tangible and impactful for human perception, the method of *lifetime exposure to climate extremes* has been developed [1]. This approach integrates demographic data with climate data to track the actual lifetime experience of a typical individual. In other words, for a specific region or country, it estimates how many extreme climate events, such as heatwaves, a generation will experience over their lifetime. This method allows for more effective communication of different climate projections and underscores the importance of societal choices aimed at drastically reducing greenhouse gas emissions.

In this project, you will work with two datasets. The first contains the annual percentage of each country affected by heatwaves. The second provides, for generations born between 1960 and 2020 across 177 countries, the number of heatwaves they are expected to experience throughout their lifetime.

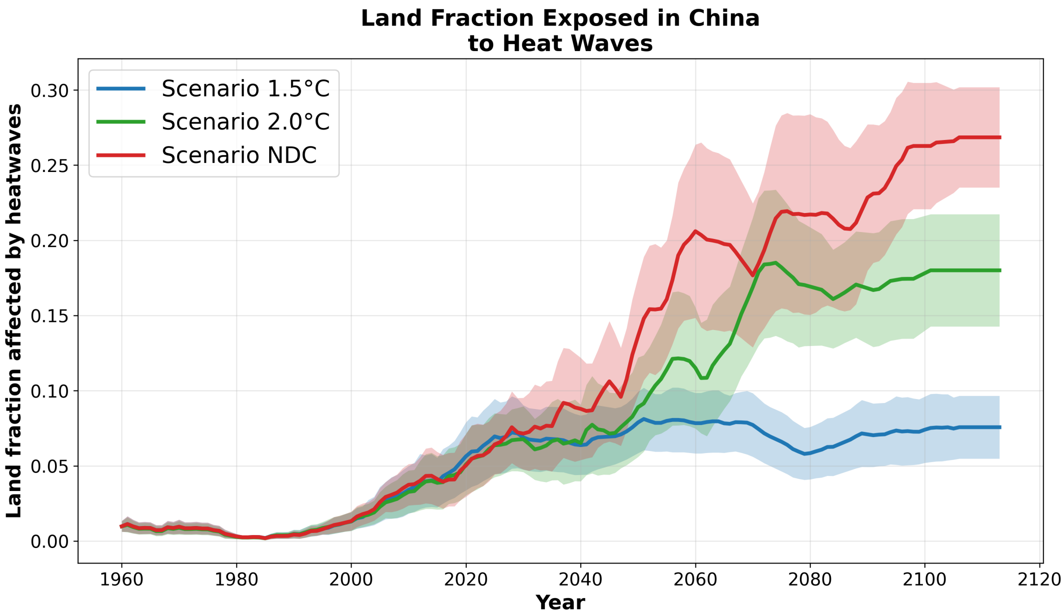

Figure 1: *Land fraction exposed to heatwaves in China under three different warming scenarios. Solid lines represent the multi-model mean across all climate impact models, while shaded areas indicate the uncertainty range corresponding to ± one standard deviation around the mean.*

This project will allow you to learn and improve your skills in:

- Handling large climate impact datasets.
- Using a `Jupyter Notebook` to analyze and visualize data.
- Working with `dataframe` and `dataset` structures.
- Using libraries such as `numpy, pandas, geopandas`, and `xarray`.
- Creating maps using `.geojson` objects and `matplotlib`.

2 Assignment

2.1 Datasets

All datasets can be downloaded from project directory.

- `ds_lfe_percountry.pkl` : Pickle object that contains the dataset associated with the *land fraction annually exposed* for the different hazards at the country level.
- `ds_le_percountry.pkl` : Pickle object that contains the dataset associated with the *lifetime exposure value* for the different hazards at the country level for the 2020 birth cohort.
- `gdf_country_borders.pkl`: GeoDataFrames that contain the geometrics objects associated to the country borders.

2.2 Tasks

1. Create a Jupyter Notebook named `land_fraction_and_lifetime_exposure.ipynb`. In the first markdown cell, provide a comprehensive description of the notebook's purpose and include relevant references.
2. Download the object `ds_lfe_percountry.pkl` from the project repository and load it into your notebook. Display its structure, coordinates, and variables.
3. Generate a figure showing the multi-model mean (`mmm`) of the land fraction exposed annually for a specific country.
    - Use the following variables from the dataset: `mmm_15_sm, mmm_20_sm, mmm_NDC_sm`. These correspond to the multi-model mean under scenarios limiting global warming to $1.5°C$, $2°C$, and following the Nationally Determined Contributions (NDC) plans[1].

[1] These are the national climate contributions submitted by each country under the Paris Agreement. According to the IPCC [2], current NDCs would result in a global mean warming of approximately $2.4°C$ to $2.8°C$ by 2100 relative to pre-industrial levels.

- Add shaded areas representing the uncertainty across models using the variables `std_15_sm, std_20_sm, std_NDC_sm`. A sample figure is shown in Figure 1.
- Write a script in your notebook to display and save the figure, allowing the selection of the country of interest. Produce at least three figures for the following countries: Belgium, China, and Nigeria.
- The temporal coordinate of the dataset `ds_lfe_percountry` is given by `time_ind`, representing the 154 annual time steps of the climate model simulations used to generate the dataset. Create a new variable containing the actual years from 1960 to 2113 to display on the x-axis in your figures.

4. Analyze these figures and provide a physical interpretation of the results.
5. Download the object `ds_le_percountry.pkl` and inspect its structure, coordinates, and variables to understand its contents.
6. Create similar figures as in Figure 1, but this time for the three greenhouse gas emission scenarios, displaying the lifetime exposure to heatwaves for birth years between 1960 and 2020.
   - Use the variables `mmm_15, mmm_20, mmm_NDC` for the multi-model mean and `std_15, std_20, std_NDC` to represent uncertainty across models.
   - Generate at least the figures for Belgium, China, and Nigeria.
7. Compare the lifetime exposure figures at the national level with the annual land fraction exposure figures. Discuss your conclusions.
8. To visualize differences between countries in lifetime exposure to heatwaves for the generation born in 2020, create a map. By default, display data under the NDC warming trajectory.
   - Load the object `gdf_country_borders.pkl`.
   - Using this `GeoDataFrame` and the dataset `ds_le_percountry`, construct a color map representing the `mmm` for each country.
   - For the five countries with the highest lifetime exposure, as well as Belgium (for comparison), add a small annotation box on the map displaying the best estimate of lifetime exposure (`mmm`) and the confidence interval (using the standard deviation variables, assuming a normal distribution).
   - To enhance readability, offset overlapping annotation boxes and add arrows connecting the boxes to their corresponding countries.

9. Produce additional maps showing differences between the emission scenarios, illustrating the number of additional heatwaves a given generation would experience under different warming scenarios.

10. Create a bar plot of the ten countries where children born in 2020 are expected to experience the most heatwaves under the NDC scenario.

11. For the NDC scenario, produce a map comparing the number of heatwaves experienced by children born in 2020 versus the generation of their grandparents born in 1960.

    It is important to maintain a well-organized notebook, with a dedicated cell for loading modules at the top, and markdown titles and subtitles for the different steps of your workflow. Comment your code thoroughly.

12. Once you have completed all these steps in the notebook `land_fraction_and_lifetime_exposure.ipynb`, you will already have created a notebook that allows users to follow, step by step, the process you have implemented. Based on all these code cells, create a Python script `land_fraction_and_lifetime_exposure.py`, in which you define functions for the different code blocks, and a final function `land_fraction_and_lifetime_exposure()` that calls the previously defined functions to execute them.

It is important for the clarity of your work to maintain a well-organized structure in your notebook, with a cell for loading modules at the top, and markdown titles and subtitles for the different steps of your manipulations and displays. Do not forget to thoroughly comment on your code.

2.3 Optional Tasks

1. Explore the datasets further and consider creating other figures and computing other statistics to enhance understanding and analysis.

2. Develop a simple graphical user interface (GUI) to interactively execute your code. Tip: You are free to use any open access Python package and free to design and create the layout of the interface. I suggest you to try Tkinter (https://wiki.python.org/moin/TkInter) but this is just a suggestion, many other options are available.

   Again, internet is an incredible source of information (docs, videos, tutorials...), e.g. https://www.geeksforgeeks.org/python/create-first-gui-application-us Just to list some websites and youtube videos...

   - https://www.youtube.com/watch?v=eJRLftYo9A0&list=PLQVvvaa0QuDclKx-QpC9wntn index=8
   - http://sebsauvage.net/python/gui/

- https://www.tutorialspoint.com/python/python_gui_programming.html
- https://docs.python.org/3/library/tkinter.html
- http://www.tkdocs.com/tutorial/index.html

2.4 Libraries

These are the Python libraries that you will likely need to complete all the tasks

- xarray
- pickle
- matplotlib
- os
- cartopy
- geopandas
- sys
- numpy
- pandas
- scipy
- regionmask
- textwrap

3 Submission and Report

Develop a software that solves the steps described in the previous section in a collaborative way using GitHub desktop (or GitHub CLI). Submit a link to your GitHub repository on the dedicated space on the CANVAS page of the course by 21st of December 2025. Make sure the online GitHub repository contains: (1) all the Python codes you have developed to accomplish the tasks described in section 2.2, (2) a Jupyter Notebook to present and run your code (user manual/tutorial like), (3) a section of the Jupyter Notebook de-scribing the use of Generative AI, (4) a section of the Jupyter Notebook describing the contributions of each team member (if not clear from the GitHub contributions), (5) a flow chart of your codes (it can be included in the Jupyter Notebook), (6) a .yml file of the envi-ronment you have created for your project.

3.1 Need Clarification?

Please contact Amaury Laridon and Elga Salvadore via the dedicated CANVAS forum. You may post questions, share your code, or request an appointment for an online session.

3.2 Evaluation Criteria

EVALUATION MATRIX Assignment	Point
1) Does your software perform the required tasks providing the correct result(s)?	10 points
2) Is your code readable?	± 0.5 point
3) Are the name of the variables\functions\modules meaningful?	± 0.5 point
4) Are the data types appropriate for values the hold?	± 0.5 point
5) Are there too many code repetitions?	± 0.5 point
6) Does your code have a coherent structure?	± 0.5 point
7) Is the Jupyter Notebook clear, to the point and complete?	± 1 point
8) Is your code easy to use?	± 1 point
9) Is there a good balance of comments and code in the scripts?	± 0.5 point
10) Code reuse: are existing codes used appropriately? Code generation: appropriate use of Generative AI for programming	± 1 point
11) Code reuse: Did you forget to properly citing the source of codes you are reusing? Did you let ChatGPT (or similar) generate part of your code without mentioning it in your Jupyter Notebook?	- 3 point
12) How flexible is your code? For example, if I use a different data set with a different file name, would it still be working?	± 0.5 point
13) How easy would be for the next user to adapt/modify your code?	± 0.5 point
14) Is there any documentation (within the Jupyter Notebook and .yml file)? Did you create a flow chart?	± 1 point
15) Did you develop a GUI for your code?	Up to 2 points

References

[1] Wim Thiery, Stefan Lange, Joeri Rogelj, Carl-Friedrich Schleussner, and Gudmundsson et al. Intergenerational inequities in exposure to climate extremes. *Science*, 374(6564):158–160, October 2021. Publisher: American Association for the Advancement of Science.

[2] Katherine Calvin, Dipak Dasgupta, Gerhard Krinner, and Mukherji et al. IPCC, 2023: Climate Change 2023: Synthesis Report, Summary for Policymakers. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland. Technical report, Intergovernmental Panel on Climate Change, July 2023.