Introduction *Keynote*: Framing the Key Issues on Climate Adaptation and Coastal Climate Impacts

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Outline of Session

1) Climate change impacts space heterogeneously—implications for physical risks in coastal areas

2) Three questions from investors seeking regional solutions to climate risks

3) Sectoral adaptation to physical climate risks in coastal areas: energy, agriculture, infrastructure, productivity

4) DATA IN ACTION: Application--how to extract and use granular climate data for projecting the regional economic cost of physical climate risks in coastal areas

5) Final word.

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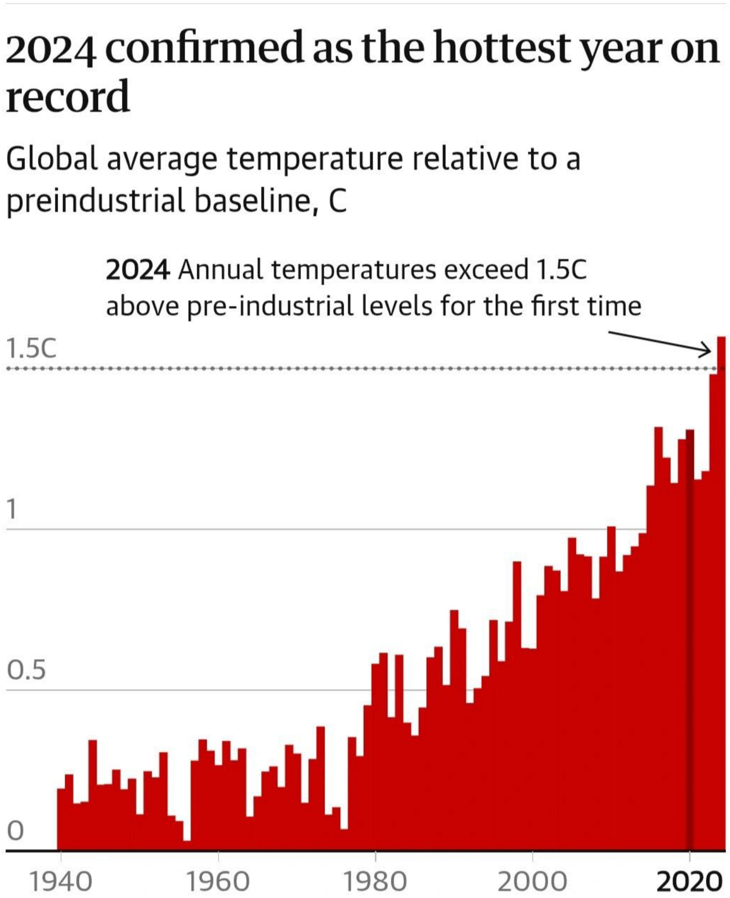
Global Metrics Distort Our Understanding of Climate Risk

Fig. 1: Global average deg. C temperature relative to a pre-industrial baseline.

Source: Guardian graphic. Copernicus, ERA5. Relative to a 1850-1900 baseline.



▶ *In practice …*

Climate change impacts space heterogeneously

But geography is a fixed statistic, unlike climate.

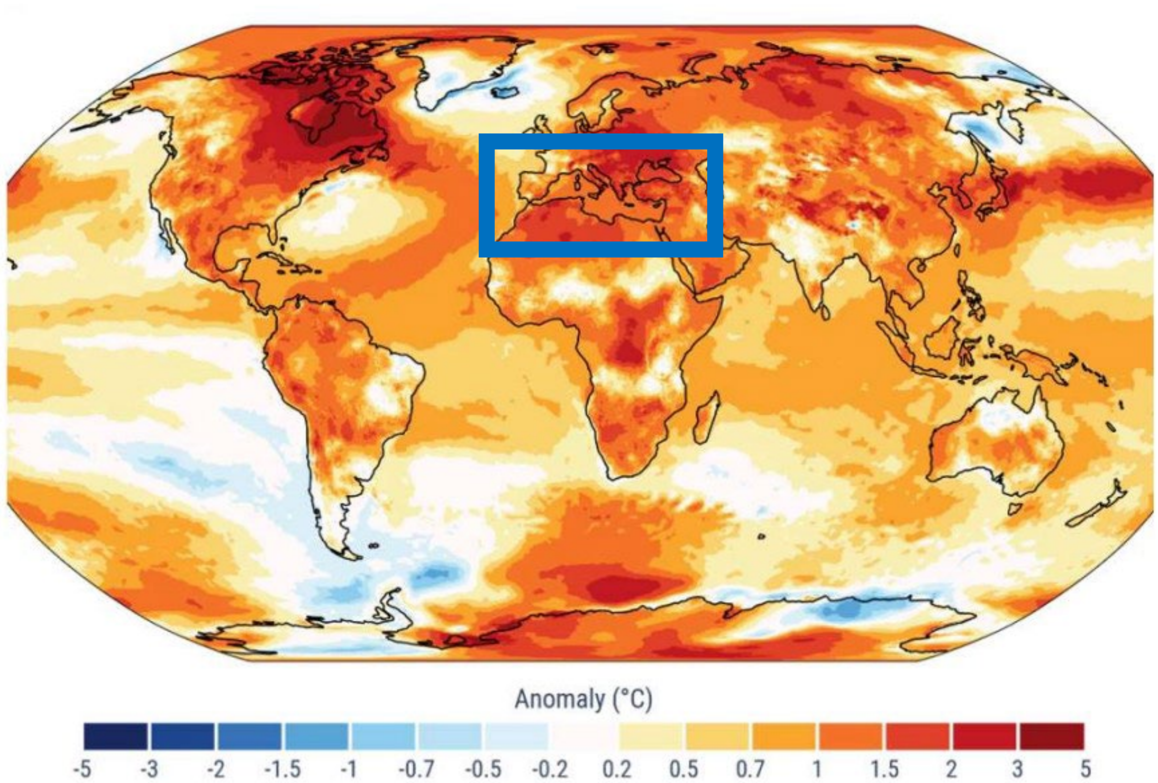
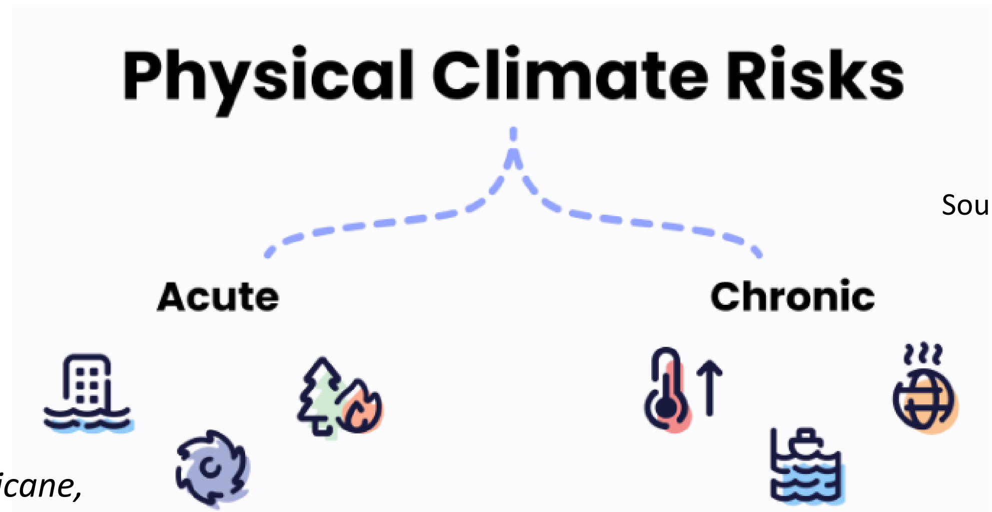


Fig. 2: Surface air temperature anomalies in 2024

Source: ERA5 – reference period is 1991-2020. Credit: C3S/ECMWF

Coastal Areas facing Climate Change



Source: dClimate (2023).

Wildfire, hurricane, storm surge, wind gusts, extreme rainfall

Sea level rise, coastal erosion, changes in precipitation and temperature patterns

-Acute risks: Extreme weather events such as hurricanes, floods, wildfires, and heatwaves that can cause immediate damage to infrastructure, supply chains, and economic activity.

-Chronic risks: Longer-term shifts in climate patterns, including rising temperatures, sea-level rise, prolonged droughts, and ecosystem changes, which gradually affect sectoral productivity, asset values, and financial stability.

Severity of the risk impacts for a physical asset

= **Exposure** + **vulnerability/sensitivity**

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Three Questions from Investors Seeking Regional Solutions to Climate Risks

- 1. How big are future climate shocks, how do they distribute spatially and scale up globally?
- 2. How much will it cost?
- 3. Who will have to pay for it?

This is where data granularity (extraction & usage) find its contribution.

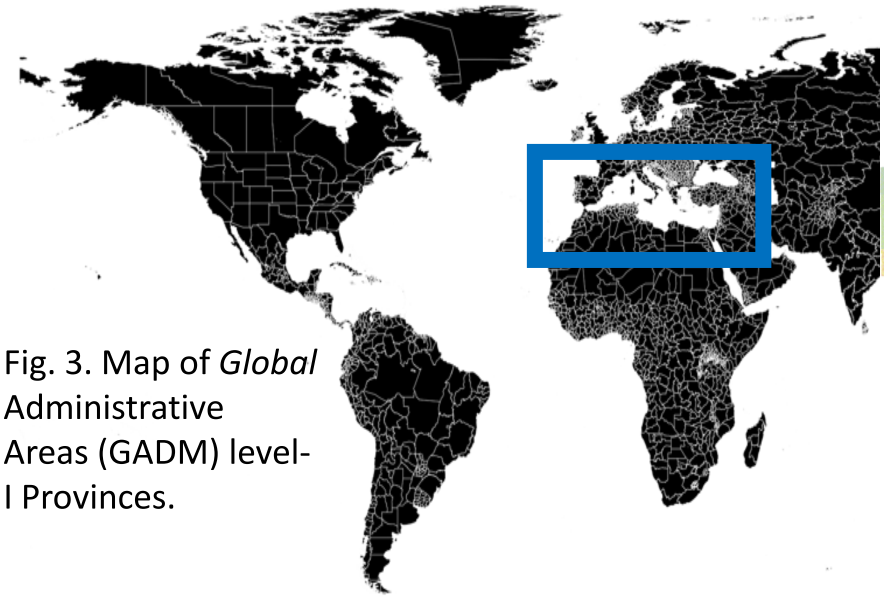
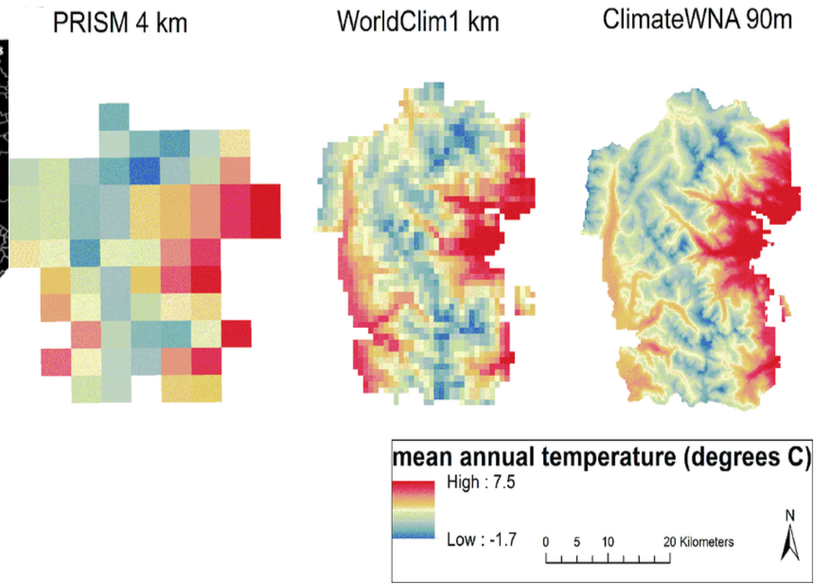


Fig. 3. Map of *Global* Administrative Areas (GADM) level-I Provinces.



Source: EDHEC Climate Institute using https://gadm.org/data.html & West et al (2013)

What Do We Already Know?

- ✓ Increasing frequency + intensity of climate shocks
- ✓ Their distribution across locations is heterogeneous. e.g., January 2025: Wildfires in Los Angeles, California; snowstorms in Texas.
- ✓ Burgeoning availability of highly-resolved climate, infrastructure and economic information → *we are swimming in data,* and one must exploit this **Spatial Momentum**.

▶ Why should we use these granular data? **Because we can.**

▶ Remember, supporting the shift towards **Funding Coastal Adaptation** requires local estimates of:

(1) climate risk exposure + **(2)** adaptation cost

current and *future*.

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Sectoral adaptation to physical climate risks in coastal areas: energy, agriculture, infrastructure, productivity

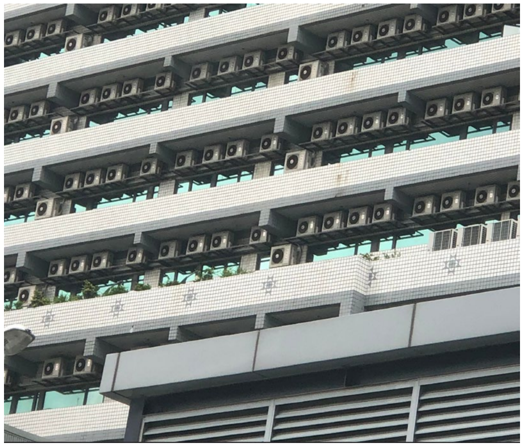
Climate change impacts **sectors heterogeneously** as well.
In coastal areas, we must think beyond land losses.

Adaptation to Physical Climate Risks in Coastal Areas (I): Energy Productivity

▶ **Demand/Chronic side:** Energy consumption for indoor cooling and heating is an adaptation to outdoor temperature + specific-humidity variability.

▶ Climatically-driven shifts in the distribution of extreme heat events, making them more frequent and intense over time, reduce building's energy productivity and thus triggering peak and total electricity demand for space cooling in the summer → leaving an ambiguous net annual effect on energy systems → **Adaption will modify how mega-cities in coastal areas use energy.**

▶ **Supply/Acute side:** Hurricane Maria in Puerto Rico (2018)—shut-down of coastal power plant & disruption of electricity supply



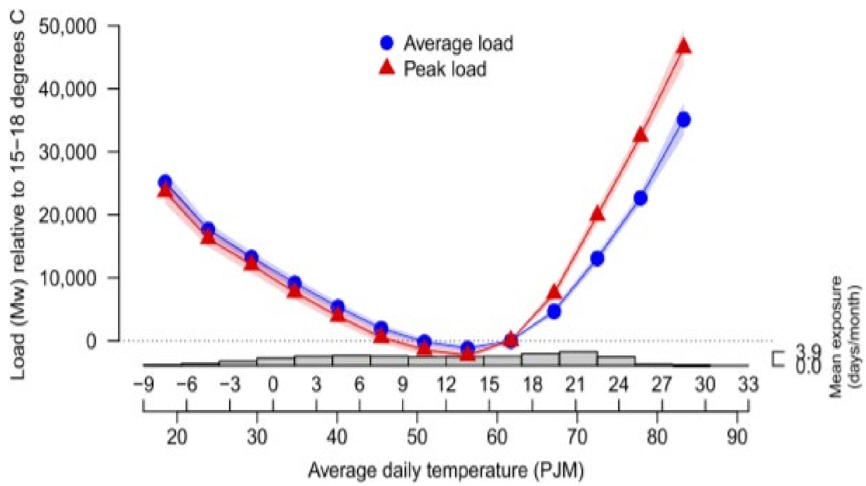


Fig. 4: **Energy demand** responses to temperature.

(Source: Auffhammer et al (PNAS, 2017), https://www.pnas.org/doi/10.1073/pnas.1613193114)

Adaptation to Physical Climate Risks in Coastal Areas (II): Cropland Productivity

▶ The global food production systems is about to face critical pressure <u>between</u>:

▶ Weather change + soil salinization-driven crop yield declines modulated by farmers' adaptation on the ground (pesticides, shift in crop varieties and planting calendars, **<u>irrigation</u>**—endogenous to the climate itself!), and causing secular shocks to land productivity, crop calorie supply, food & land prices.

▶ The potentially offsetting effect of increasing atmospheric CO2 → driving biomass fertilization and mitigating future temperature-driven cropland productivity losses.

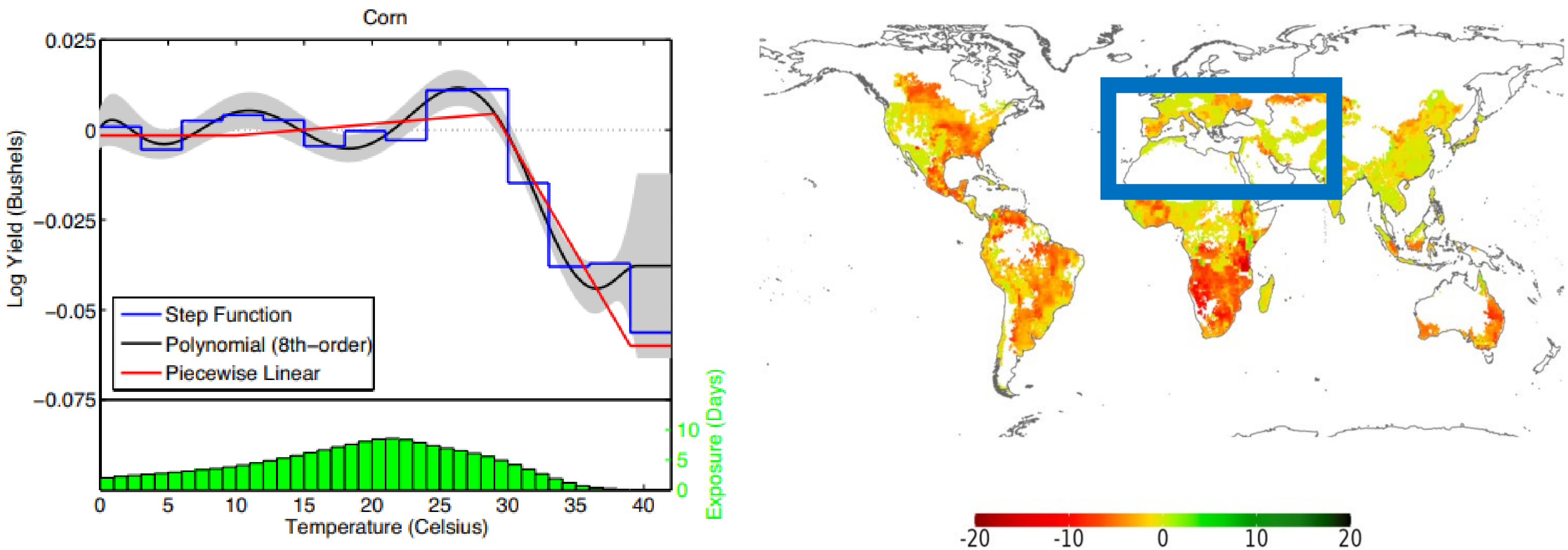


Fig. 5: **Crop yield** responses to growing season temperature (left) and projected **crop calorie supply** losses circa-2050 in a SSP5-RCP8.5 environment.

(Source: Schlenker and Roberts (PNAS, 2009), https://www.pnas.org/doi/10.1073/pnas.0906865106 & EDHEC Climate Institute.)

Adaptation to Physical Climate Risks in Coastal Areas (III): Infrastructure Assets

▶ Infrastructure: facing sea level rise and storm surges, investments in hard infrastructure like seawalls and revetments, levees and dikes, dune reinforcement, as well as construction-restricted zoning and building codes.

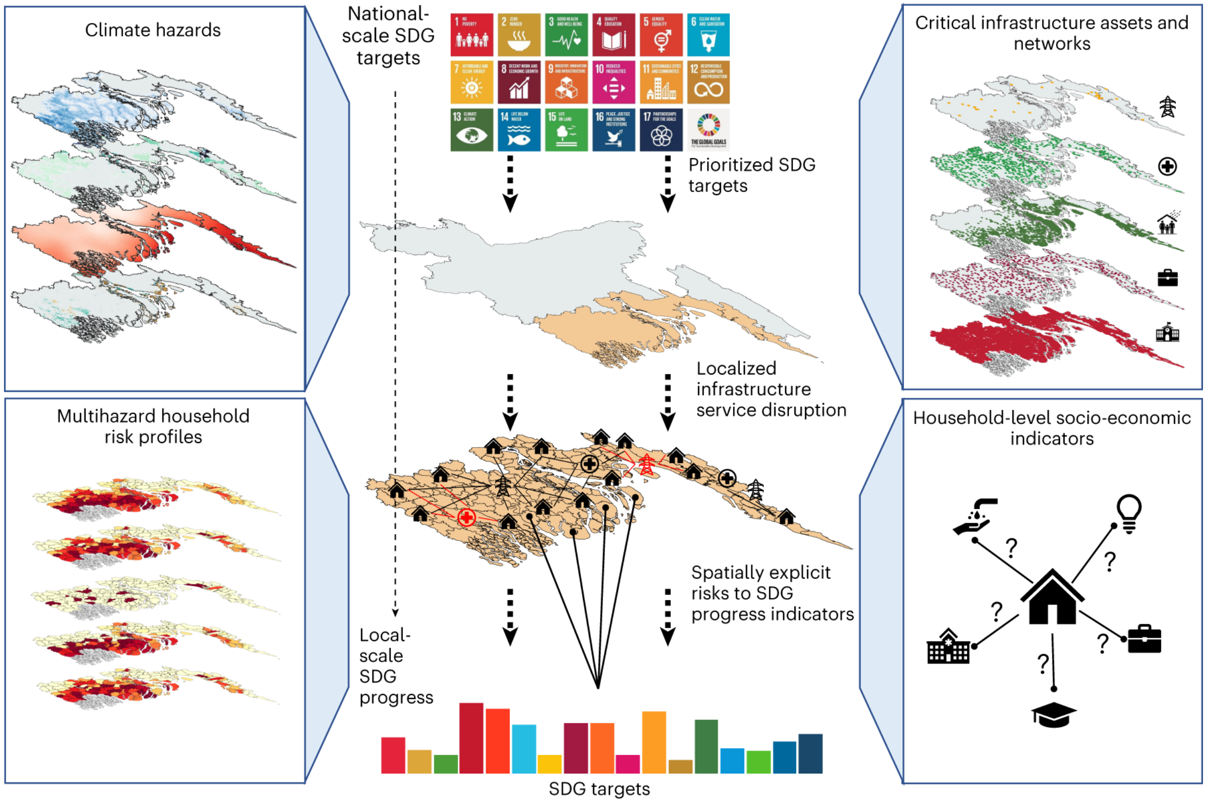


Fig. 6: A multihazard spatial assessment of households' critical infrastructure exposure with potential implications for achieving priority SDG indicators in Bangladesh's coastal region.

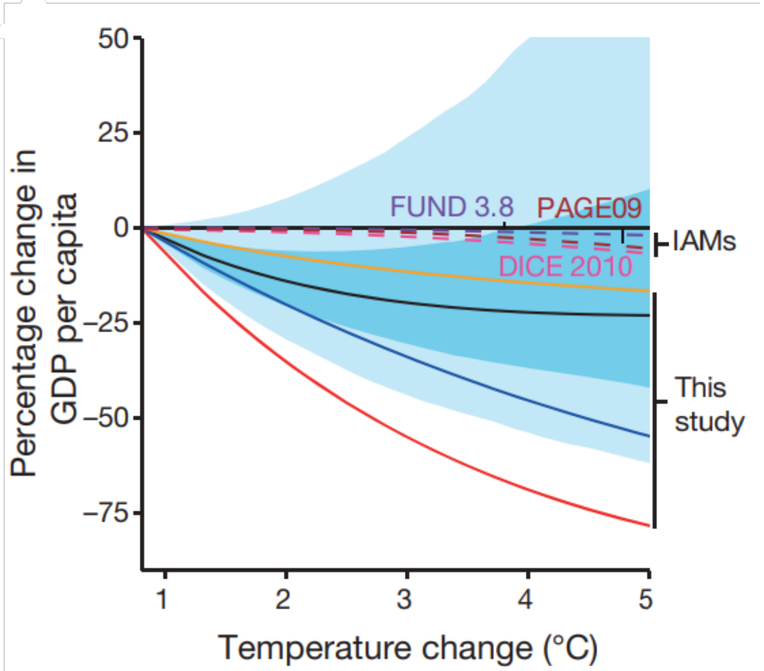
(Source: Adshead et al (2024, Nature): https://www.nature.com/articles/s41558-024-01950-2)

Local → Sector → Macro-Productivity Damages

▶ Recorded at the **micro-level**, these **productivity losses** from temperature fluctuations over the short-run **scale (aggregate) up**, in the long-term, **into macro-productivity damages** at the **country-level** (Hsiang, 2010; Heal and Park, 2013).

▶ Climate shocks propagates through the TFP (i.e., Cobb-Douglas production function $Y_t = A_t {K^{\alpha}}_t {L^{1-\alpha}}_t$) and carries cumulative (and cascading) effects on the long-term GDP trajectory (Dell et al, 2012; Hsiang and Jina, 2014). Productivity shocks, even transient, disrupt investment rates in new assets.

▶ One can design and calibrate an aggregate damage function modelling Ω as % change in output of the potentially non-linear effects of temperature.



$$E \rightarrow \Delta T \rightarrow \Omega$$

Fig. 7: Pioneer damage function estimates.

Notes: Globally averaged projected GDP per capita losses in 2100 (SSP5) for different levels of global mean temperature increase, relative to pre-industrial temperatures.
(Source: Burke et al (Nature, 2015): https://www.nature.com/articles/nature15725)

→ Critical piece to globally commercialized climate scenarios (e.g., https://www.oxfordeconomics.com/)

Accounting for physical climate damages in macroeconomic scenarios

- Why are we doing this?

- Perhaps the most important component of Integrated Assessment Modeling (IAM) of climate change (e.g., NGFS Phase-V) is the **damage function**.

- After all, **without damages, there is no reason to control emissions.**

- This applies to coastal countries and areas who need to simultaneously manage **adaptation and transition investments** over **distinct temporal windows**: immediate and long-term.

NGFS
Central Banks and Supervisors Network for Greening the Financial System

OXFORD ECONOMICS

ipcc

Regional|Coastal|Asset x sectoral insights climate damages and adaptation costs: who can the main users be?

Granular data enable to quantify the economic/financial implications of physical climate risks → comparative informational advantage (or *'first-mover'*) to:

▶ **Policy makers**, who can secure long-term energy supply contracts for cities (sector-wide risk assessment), ensure the future insurability of their infrastructure & potential relocation (asset-specific risk assessment), plan incentives to physical asset owners in highly-exposed districts etc.

Regional|Coastal|Asset x sectoral insights climate damages and adaptation costs: who can the main users be?

▶ **Investors & asset owners**, who can protect themselves against value losses in their equity portfolios or holdings (Portfolio risk management), anticipate revenue declines (e.g., from productivity losses) or rising production costs (e.g., more inputs required to get the same output) (Investment Prioritization), anticipate the emerging crisis of insurability for certain assets (e.g., Pacific Palisade fires etc.) underlying their financial instruments, either as collateral (e.g., for mortgages) or as cash-generators (e.g., in infrastructure); + anticipate increasing legal exposure on these issues — such as inadequate disclosure of climate risks likely to become a liability in the future (‘*judiciarisation*’)

▶ **Concerned citizens**, who need to know where the physical climate dangers really lie.

Q & A

DATA IN ACTION--APPLICATION

Extraction and use of granular climate data for projecting the regional economic damage of physical climate risks

<u>Application:</u> Extraction and use of granular climate data for projecting the regional economic damage of physical climate risks

<u>Step 1:</u> Large-scale processing of historical economic and climate information.

<u>Step 2:</u> Empirical estimation of temperature-output functions using the historical dataset spanning the last 50 years assembled in *Step 1*

<u>Step 3:</u> Combining future climate change simulations from NASA, with the climate-GRP functions empirically-quantified in *Step 2*, project future climatically-driven changes in outcomes

<u>Step 4:</u> Decomposition and distribution of resulting projected damages obtained in *Step 3* over time, space, climate scenario, global climate model, etc.

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Step 1: Large-scale processing of historical climate information

▶ Using HPC, we handle large-scale processing of high-resolution time- and spatially downscaled historical 3h 0.25-degree gridded surface climatic exposure (and air column-averaged satellite/remote sensing measurements) from NASA's Global Land Data Assimilation System (GLDAS) reanalysis data; e.g., Temperature and precipitation;

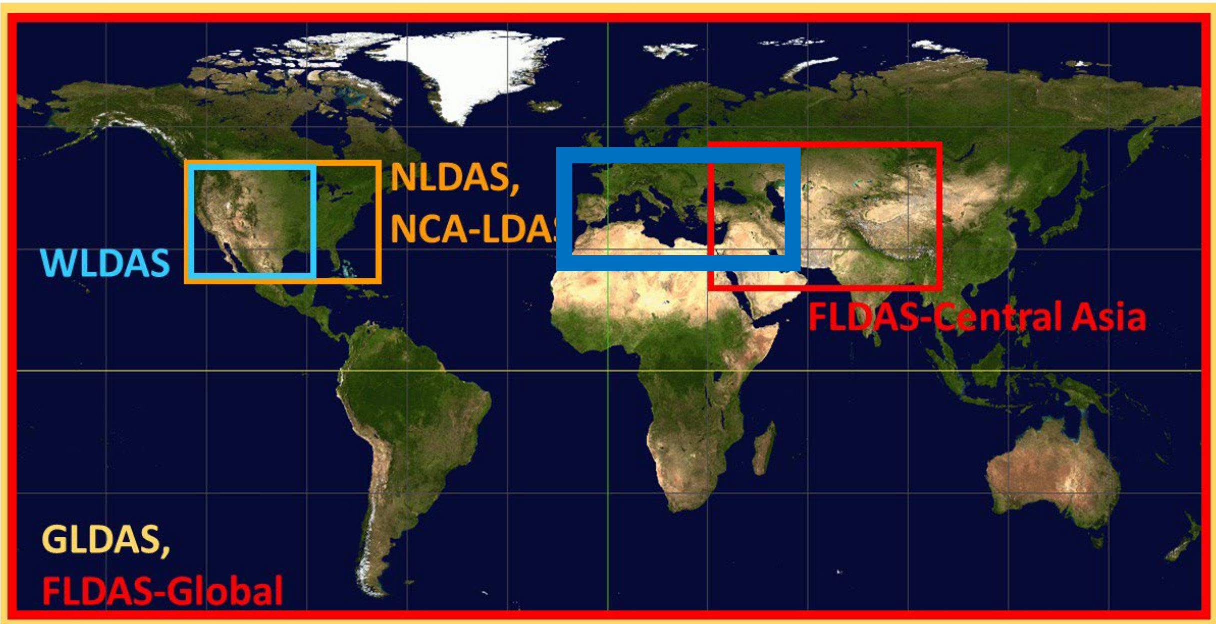

Fig. 8. Snapshot of the geographic coverage of NASA's Land Data Assimilation System products.
Source: NASA's LDAS: https://ldas.gsfc.nasa.gov/data

Step 1: Matching Climate Data with Economic Boundaries (III)

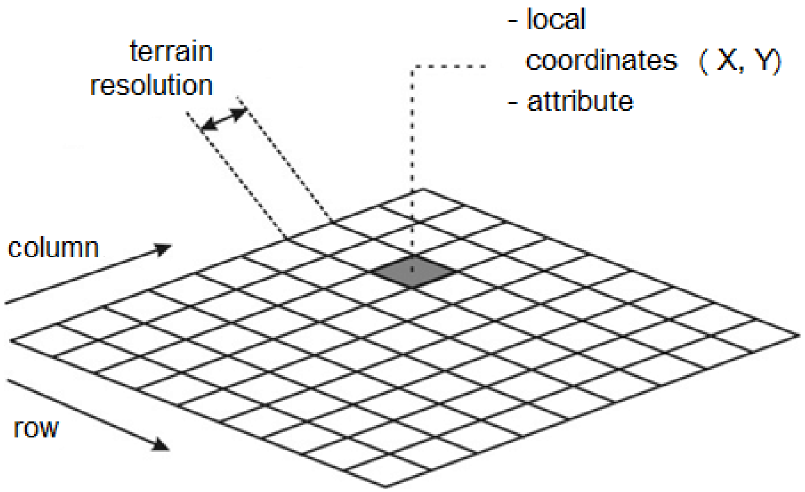

Fig. 9. We spatially intersect GLDAS grid-cell coordinates with the different sub-national administrative region identifiers in which they fall.

▶ Which we **(1) <u>spatially aggregate</u>** + **(2) <u>temporally collapse</u>** to the spatial resolution and time-frequency of our sub-national GDP realizations;

▶ Administrative areas' real gross regional product per capita data are taken from the MCC-PIK Database of Subnational Economic Output (DOSE) containing 1,661 sub-national regions.

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Step 2: Econometric estimation of temperature-output response functions

- We now have a panel estimation dataset linking:
- Year-to-year historical records of gross regional product (GRP) per capita with plausibly exogenous fluctuations in climate factors over matching time periods; and accounting for persisting effects
- We exploit two sources of climate-induced variation (interannual and cross-section) with a panel Fixed Effects (FEs) Ordinary Least Square (OLS);

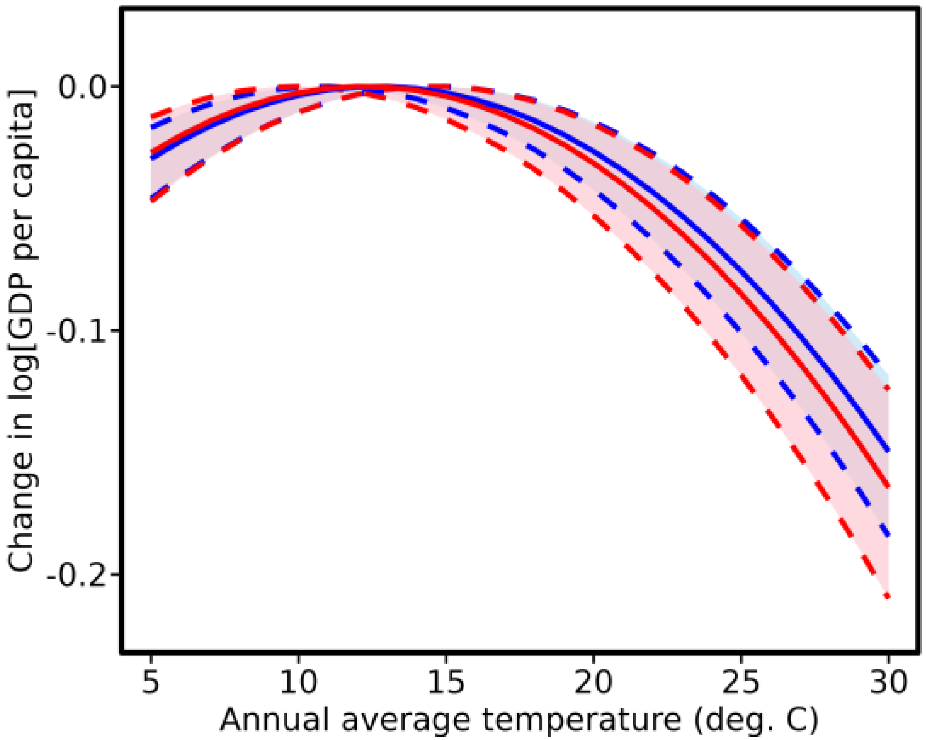

Fig. 10. Global non-linear log[Gross Regional Product per capita] responses to administrative province annual average temperature exposure per year [deg. C]; EDHEC Climate Institute (red) vs. Burke et al 2015 (blue). (Source: our elaboration at EDHEC Climate Institute).

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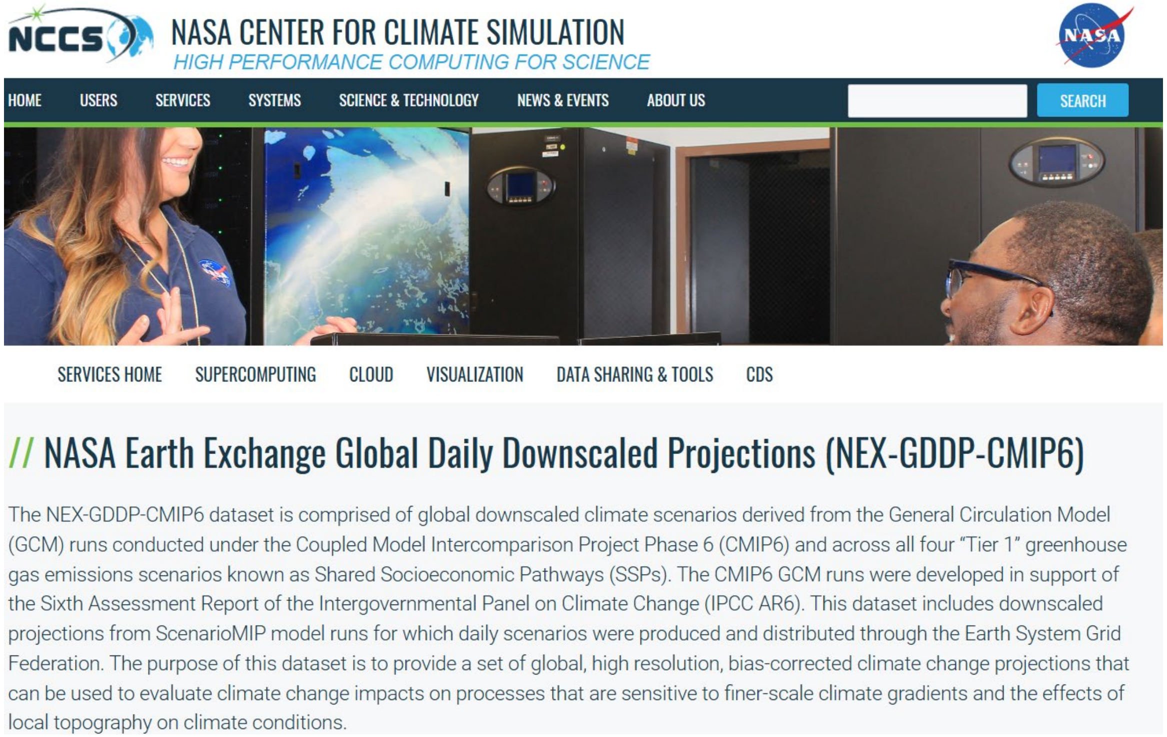
Step 3: Projections of future climatically-driven changes in outcomes (I)

- We can compute projections of future climate change-driven changes in regional economic output, by:

- Combining an ensemble of future climate change simulations from NASA;

- With our regional GDP model; which we have empirically calibrated prior in *Step 2* using real historical data spanning the last 50 years.

Step 3: Projections of future climatically-driven changes in outcomes (II)



Source: https://www.nccs.nasa.gov/

▶ To do so: process and extract high-resolution simulations of climate change driven shifts in temperature and precipitation exposure from NASA's Earth Exchange Global Daily Downscaled Projections (NEX-GDDP CMIP6); which we subset over our area of interest.

▶ NEX-GDDP CMIP6: ensemble of 30 distinct global climate models (GCMs) simulated under the Coupled Model Intercomparison, Phase VI (CMIP6) exercise, whose outputs are biased-corrected and downscaled in time (to days) and space (to a 0.25 deg. grid).

Step 3: Projections of future climatically-driven changes in outcomes (III)

Fig. 11. Picture of computer cabinets located in the German Climate Computing Centre which form the supercomputer "Mistral“ (Source: Felix König).

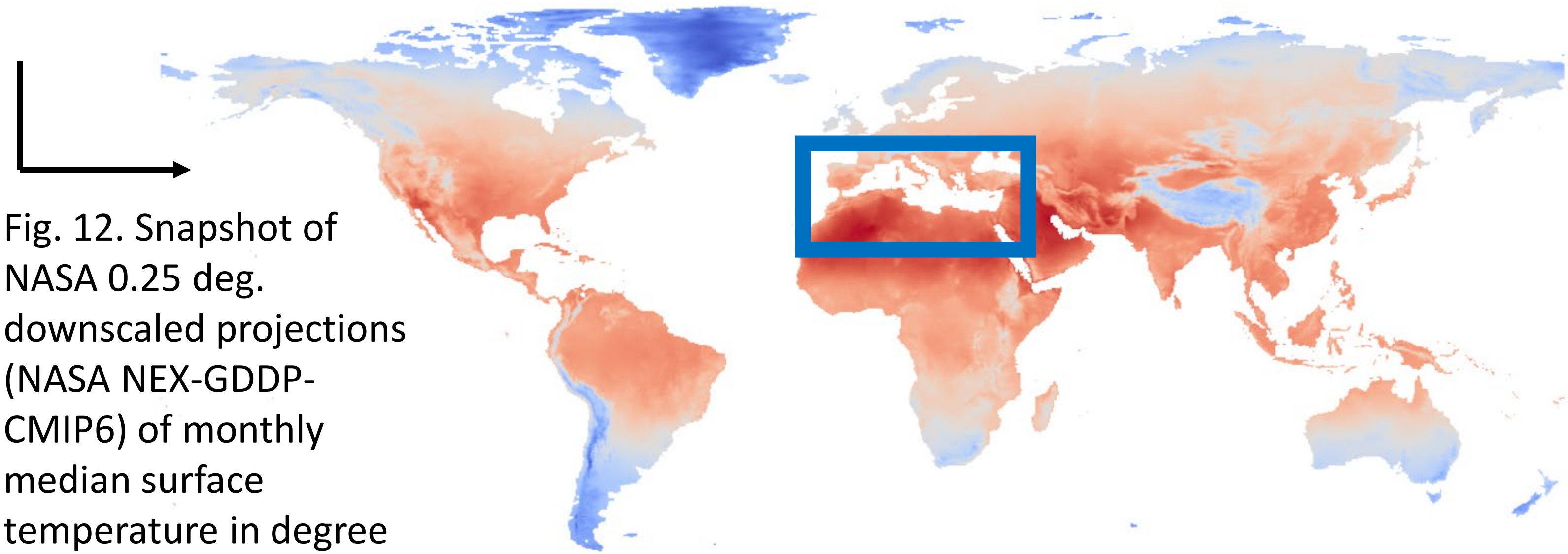


Fig. 12. Snapshot of NASA 0.25 deg. downscaled projections (NASA NEX-GDDP-CMIP6) of monthly median surface temperature in degree Kelvin for 2050 (Source: ASDI).

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Step 4: Decomposition and distribution of resulting projected impacts (I) → Regionally-Informed Damage Functions

▶ For each administrative region, one can predict future economic damages distributed across:

1) Climate components (e.g., temperature, precipitation etc.);
2) Intensity of effects (e.g., long stochastic average vs. extreme weather);
3) Persistence (e.g., short-run, lagged long-run);
4) 30 CMIP6 Global Climate Models (GCMs);
5) 4 RCP/SSP scenarios (e.g., SSP2.RCP4.5, SSP5.RCP8.5 ect.);
6) Epochs: 2030, 3035, …, 2100; … → *totaling ~25 M. dim*.

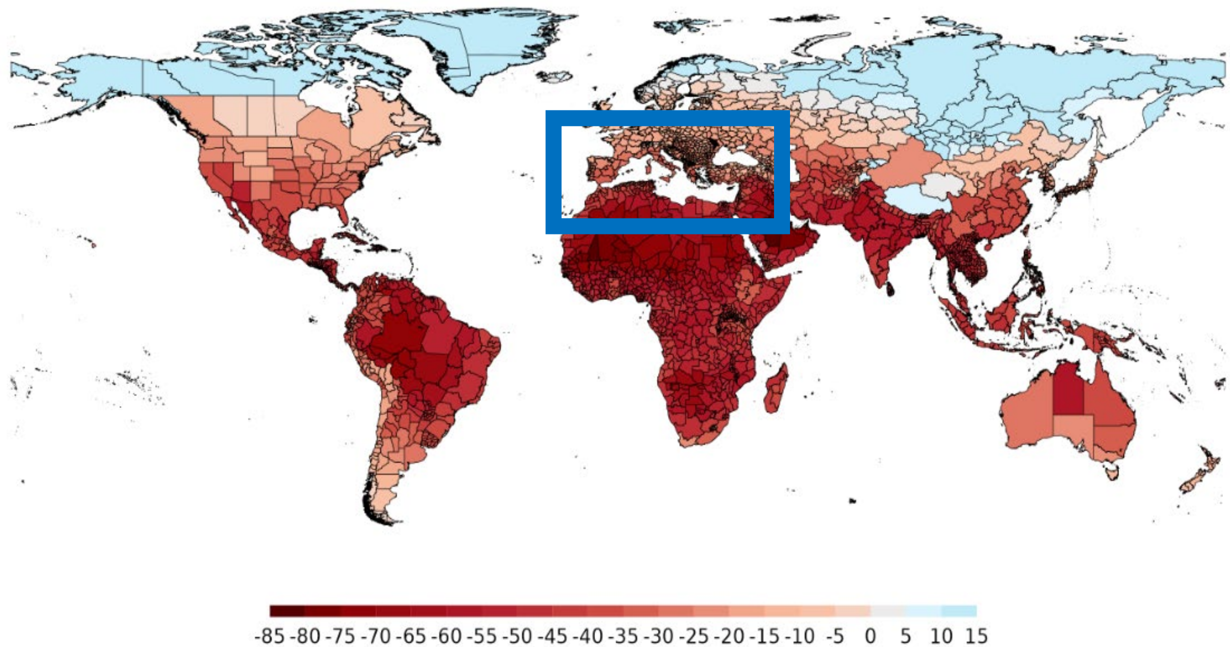


Fig. 13: Province-level projections of climatically-driven *average temperature* shift impacts (%) on gross regional output per capita, epoch 2099 compared to historical baseline (Source: EDHEC Climate Institute).

Step 4: Decomposition and distribution of resulting projected impacts (II) → Regionally-Informed Damage Functions

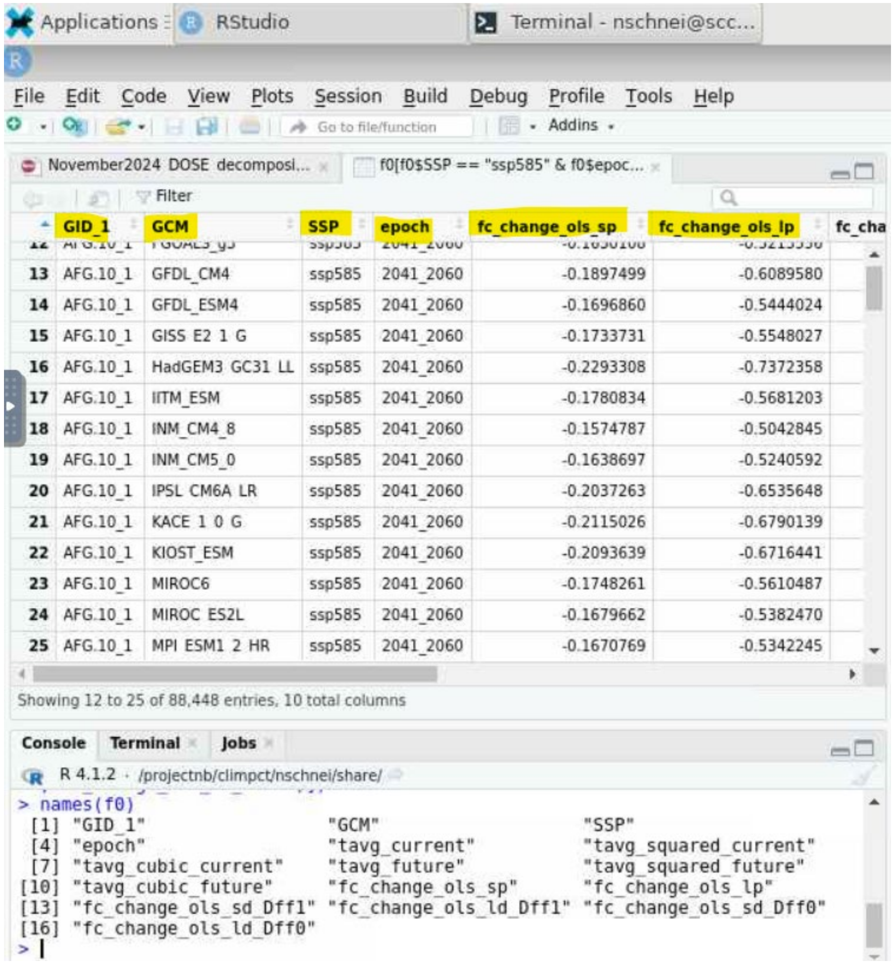
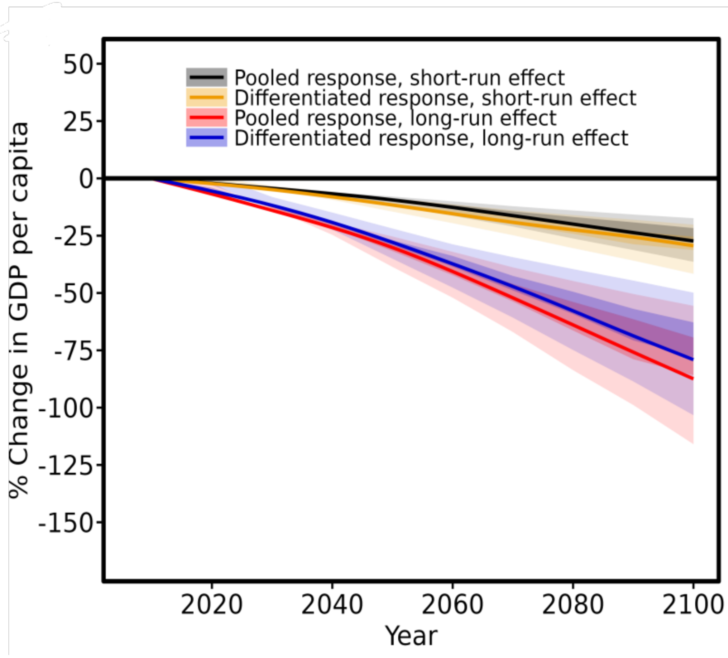


Fig. 14. Projected climate-shift impacts (%) on per capita GRP, future epochs relative to constant historical 1985-2004 temperature means, intermediate midpoint between SSP5-8.5 vigorous and SSP2-4.5 warming scenarios (Source: EDHEC Climate Institute).

Temporal, spatial and model granularities combined enable us to *feature uncertainty in our final product.*



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Final Word

- **Recall the three Questions:**

  1. How big are future climate shocks, how do they distribute spatially and scale up globally?

  2. How much will it cost?

  3. Who will have to pay for it?

- **Solution:** answering these can be achieved by not only accessing, but more importantly integrating granular data into empirical models (1 → 2 → 3).

- Advertised predictions of global economic damages **have deeper granular origins one can unveil through data.**

- To inform investors, strengthen the capacity of coastal cities and industries to meet their HETEROGENEOUS ADAPTATION INVESTMENT NEEDS for the future.

About us:

The EDHEC Climate Institute (ECI) focuses on helping private and public decision-makers manage climate-related financial risks and make the most of financial tools to support the transition to a low-emission economy that is more resilient to climate change.

It has a long track record as an independent and critical reference centre in helping long-term investors to understand and manage the financial implications of climate change on asset prices and the management of investments and climate action policies.

The institute has also developed an expertise in physical risks, developing proprietary research frameworks and innovative approaches. ECI is also conducting advanced research on climate transition risks, with a focus on supply chain emissions (Scope 3), consumer choices, and emerging technologies.

As part of its mission, ECI collaborates with academic partners, businesses, and financial players to establish targeted research partnerships. This includes making research outputs, publications, and data available in open source to maximise impact and accessibility.

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