Course 2024–2025 in Sustainable Finance
Lecture 15. Physical Risk Modeling

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November 2024

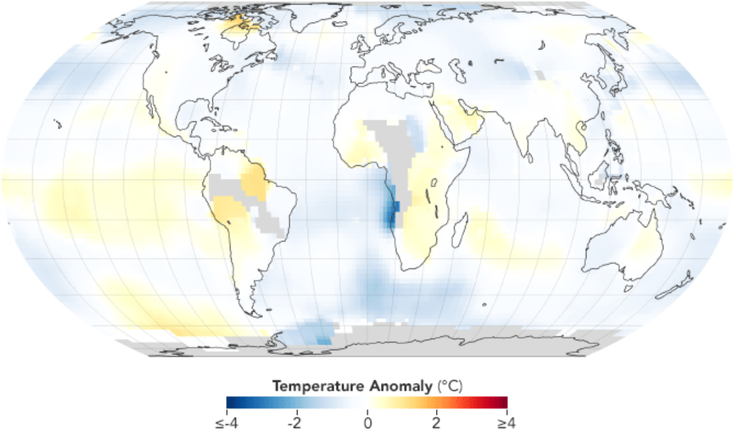
[1]The opinions expressed in this presentation are those of the authors and are not meant to represent the opinions or official positions of Amundi Asset Management.

Agenda

- Lecture 1: Introduction
- Lecture 2: ESG Scoring
- Lecture 3: Impact of ESG Investing on Asset Prices and Portfolio Returns
- Lecture 4: Sustainable Financial Products
- Lecture 5: Impact Investing
- Lecture 6: Biodiversity
- Lecture 7: Engagement & Voting Policy
- Lecture 8: Extra-financial Accounting
- Lecture 9: Awareness of Climate Change Impacts
- Lecture 10: The Ecosystem of Climate Change
- Lecture 11: Economic Models & Climate Change
- Lecture 12: Climate Risk Measures
- Lecture 13: Transition Risk Modeling
- Lecture 14: Climate Portfolio Construction
- **Lecture 15: Physical Risk Modeling**
- Lecture 16: Climate Stress Testing & Risk Management

Prologue: Global temperatures (1900-2023)

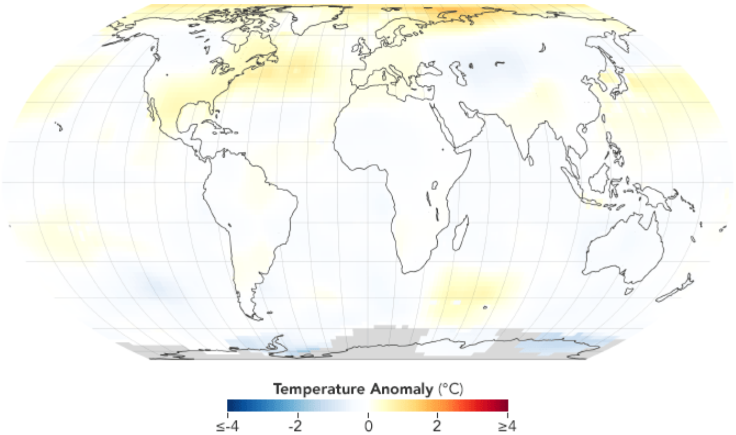
Figure 1: Global temperatures (1900-1904)



Source: `earthobservatory.nasa.gov/world-of-change/global-temperatures`.

Prologue: Global temperatures (1900-2023)

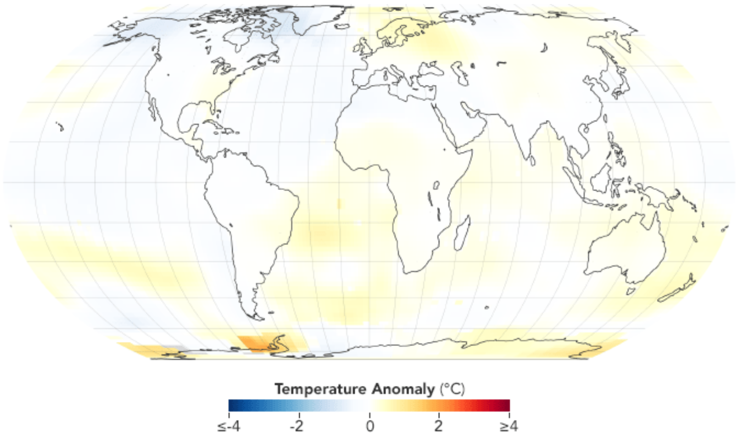
Figure 2: Global temperatures (1950-1954)



Source: `earthobservatory.nasa.gov/world-of-change/global-temperatures`.

Prologue: Global temperatures (1900-2023)

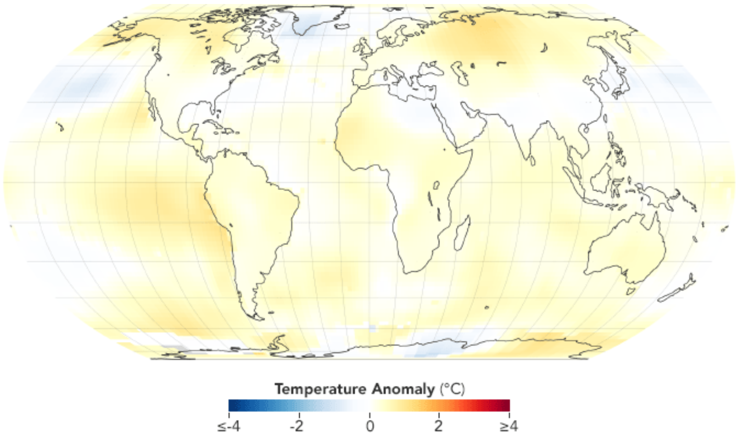
Figure 3: Global temperatures (1970-1974)



Source: `earthobservatory.nasa.gov/world-of-change/global-temperatures`.

Prologue: Global temperatures (1900-2023)

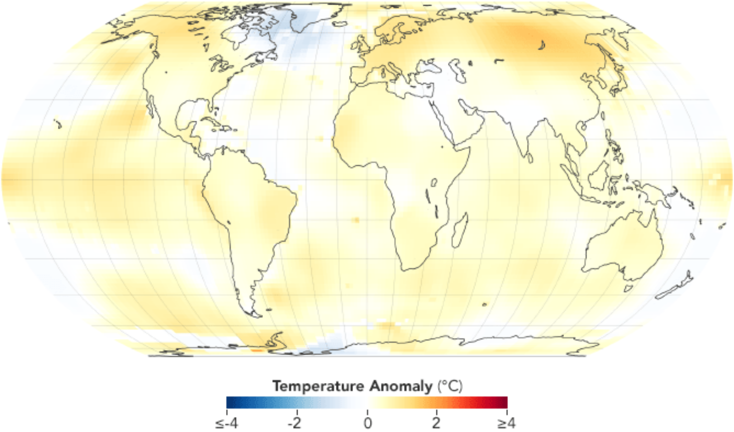
Figure 4: Global temperatures (1980-1984)



Source: earthobservatory.nasa.gov/world-of-change/global-temperatures.

Prologue: Global temperatures (1900-2023)

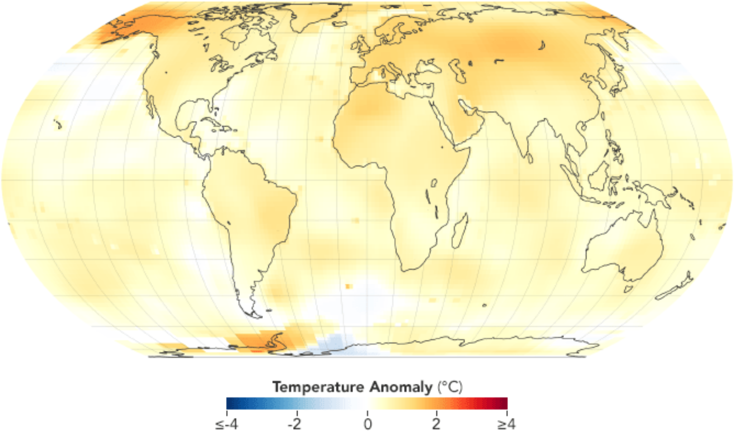
Figure 5: Global temperatures (1990-1994)



Source: earthobservatory.nasa.gov/world-of-change/global-temperatures.

Prologue: Global temperatures (1900-2023)

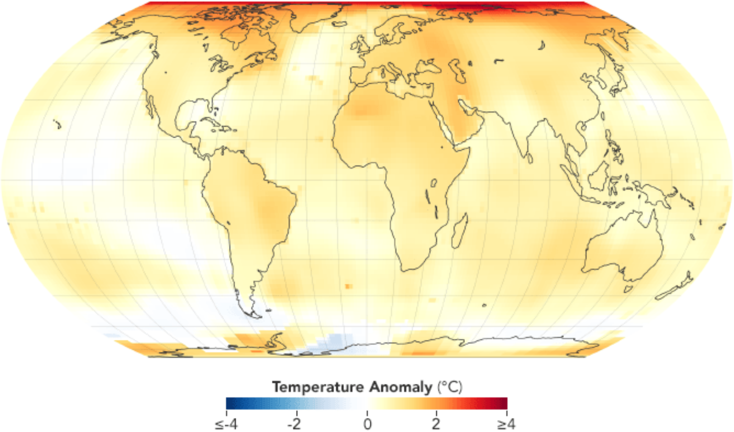
Figure 6: Global temperatures (2000-2004)



Source: `earthobservatory.nasa.gov/world-of-change/global-temperatures`.

Prologue: Global temperatures (1900-2023)

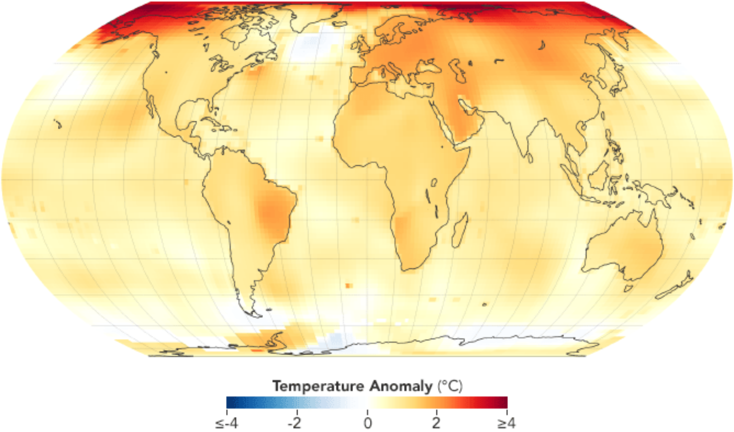
Figure 7: Global temperatures (2010-2014)



Source: `earthobservatory.nasa.gov/world-of-change/global-temperatures`.

Prologue: Global temperatures (1900-2023)

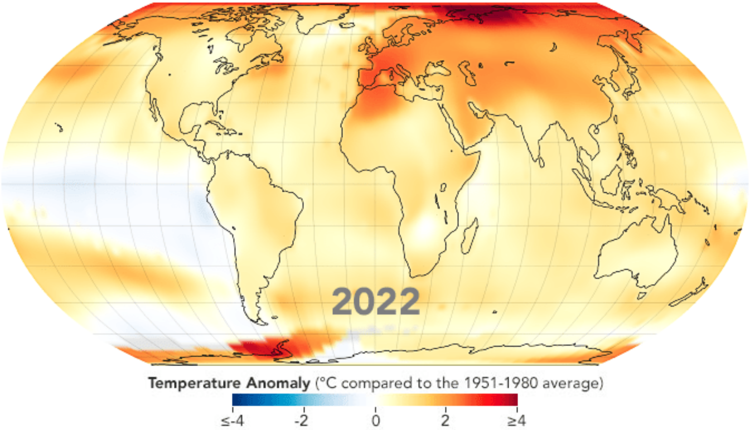
Figure 8: Global temperatures (2015-2019)



Source: `earthobservatory.nasa.gov/world-of-change/global-temperatures`.

Prologue: Global temperatures (1900-2023)

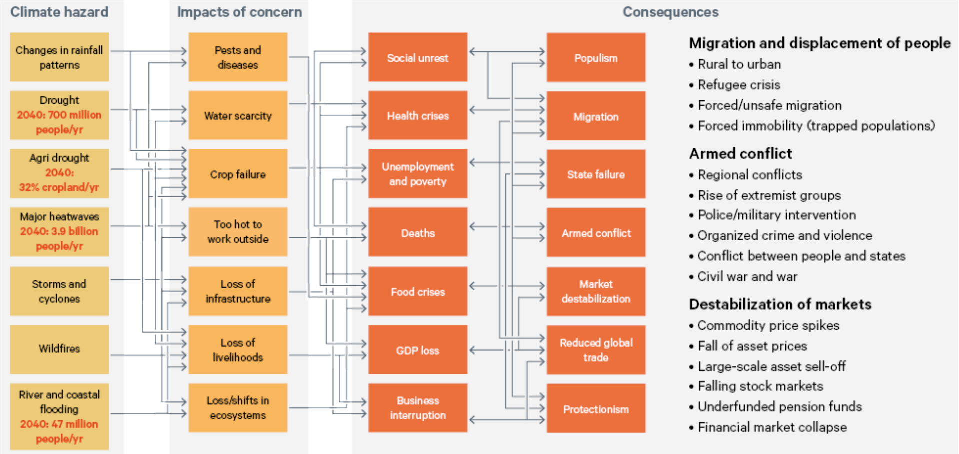
Figure 9: Global temperatures (2022)



Source: earthobservatory.nasa.gov/world-of-change/global-temperatures.

Definition

Figure 10: Systemic risk dynamics of climate-related physical risks



Source: `www.chathamhouse.org/2021/09/climate-change-risk-assessment-2021`.

Physical risk and insurance companies

Physical risk and investors

Physical risk and investors

Responsible investors have paid more attention to transition risk than to physical risk. But recent events show that the physical risk is also a major concern. This is the financial losses that actually result from climate change, rather than from adapting the economy to avoid them. It includes droughts, floods, storms, etc.

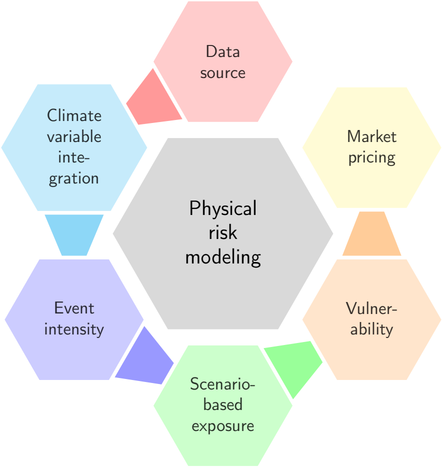
General circulation models

- Community Earth System Model (CESM)
- European Centre Hamburg Model (ECHAM)
- Hadley Centre Global Environment Model (HadGEM)
- Institut Pierre Simon Laplace Climate Model (IPSL-CM)
- Max Planck Institute Earth System Model (MPI-ESM)
- Norwegian Earth System Model (NorESM)
- Coupled Model Intercomparison Project (CMIP Phase 6)

Chronic vs. acute risk

Statistical modeling of physical risk

Figure 11: Physical risk modeling



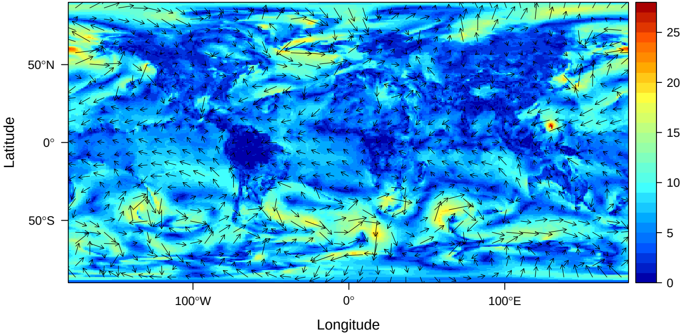
Statistical modeling of physical risk

Climate variable and data source

- The climate data source is the set $\Theta_s = \{\theta(\lambda, \varphi, z, t)\}$
- $\theta = (\theta_1, \ldots, \theta_k)$ is a vector of k climate variables such as temperature, pressure or wind speed
- Each variable θ_k has four coordinates:
  1. Latitude λ
  2. Longitude φ
  3. Height (or altitude) z
  4. Time t
- Three types of sources:
  1. Meteorological records
  2. Reanalysis
  3. Historical simulations by a climate model

Statistical modeling of physical risk

Figure 12: Slice* of wind speed (07/11/2013, tropical cyclone Haiyan)



Source: MERRA reanalysis, Global Modeling and Assimilation Office, NASA.

*This is a slice of the MERRA-2 reanalysis at a height of 10 meters on 7$^{\text{th}}$ November 2013. The red dot is the location of the eye of the tropical cyclone Haiyan, which affected more than 10 million people in the Philippines

Statistical modeling of physical risk

Event intensity sensitivity

- We first have define the sensitivity of the intensity of extreme events to climate change
- Let $\mathbb{E}\left[I\left(\Theta_s\left(C\right)\right)\right]$ be the expected intensity of the event in the scenario associated with the GHG concentration C
- The sensitivity of the event is equal to:

$$\Delta I\left(C\right)=\mathbb{E}\left[I\left(\Theta_s\left(C\right)\right)\right]-I\left(\Theta_s\left(C_0\right)\right)$$

  where $I\left(\Theta_s\left(C_0\right)\right)$ is the current intensity or the reference intensity in a scenario where climate objectives are met
- For instance, we know that the maximum wind of tropical cyclones increases by more than 10% in scenarios with a high GHG concentration

Statistical modeling of physical risk

Asset exposure

- The asset value of the portfolio can then be written as:

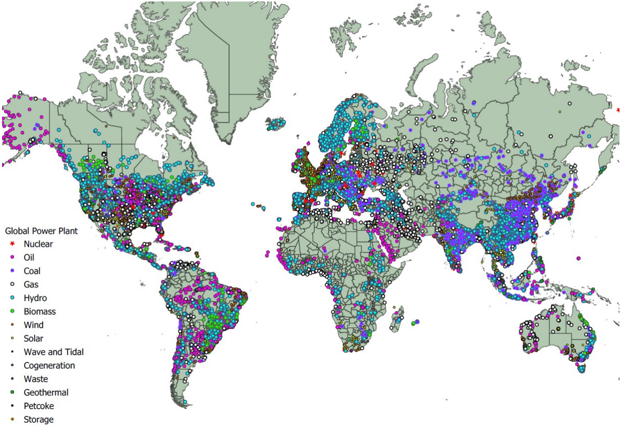
$$\Psi(t) = \sum_{j=1}^{n} x_j \Psi_j(\lambda, \varphi, t)$$

where $\Psi_j(\lambda, \varphi, t)$ is the geolocated asset value estimated at time t and x_j is the weight of asset j in the portfolio

- This requires the geolocation of the portfolio

Statistical modeling of physical risk

Figure 13: Geolocation of world power plants by energy source



Source: Global Power Database version 1.3 (June 2021).

Statistical modeling of physical risk

Vulnerability

- The damage function $\Omega_j(I) \in [0, 1]$ is the fraction of property loss with respect to the intensity
- It is generally calibrated on past damages (insurance claims, economic loss, etc.) and disasters

Statistical modeling of physical risk

Market pricing

- The physical risk implied by the concentration scenario C is equal to:

$$\Delta \mathcal{L}oss\left(t, C\right) = \beta \cdot \mathcal{DD}\left(t, C\right) = \beta \sum_{j=1}^{n} x_j \Psi_j\left(\lambda, \varphi, t\right) \Omega_j\left(\Delta I\left(t, C\right)\right)$$

- $\Delta \mathcal{L}oss\left(t, C\right)$ is the relative loss due to the events on the portfolio
- β is the transmission factor of the direct damage $\mathcal{DD}\left(t, C\right)$ on the underlying to the loss of financial value in the investment portfolio
- For example, if the facilities of an energy producer are damaged at 50%, the securities issued by this company will be impacted at $50\% \times \beta$

Climate hazard location

Asset location

Applications

Tropical cyclone damage modeling

Le Guenedal, Drobinski, and Tankov (2021), Measuring and Pricing Cyclone-Related Physical Risk under Changing Climate, *Amundi Working Paper*, `www.ssrn.com/abstract=3850673`

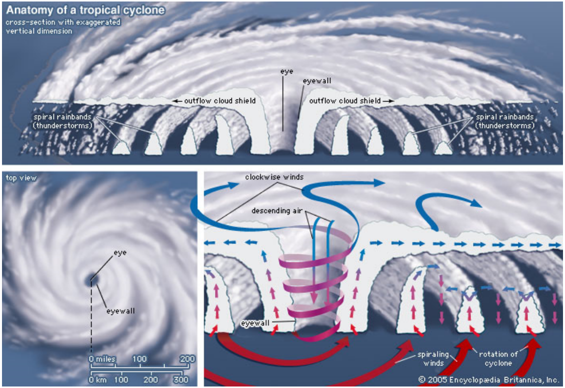
Two main modules:

- Simulation and generation of tropical cyclones under a given climate change scenario
- Geolocation of assets, damage modeling and loss estimation

Applications

Tropical cyclone damage modeling

Figure 14: What is a cyclone?

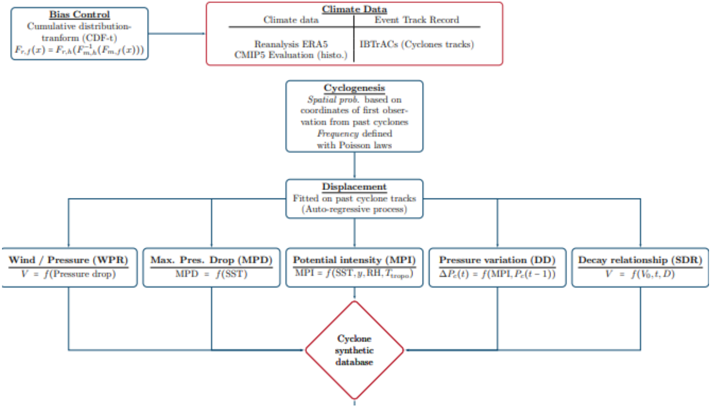


Source: www.geosci.usyd.edu.au/users/prey/teaching/geos-2111gis/cyclone/cln006.html

Applications

Tropical cyclone damage modeling

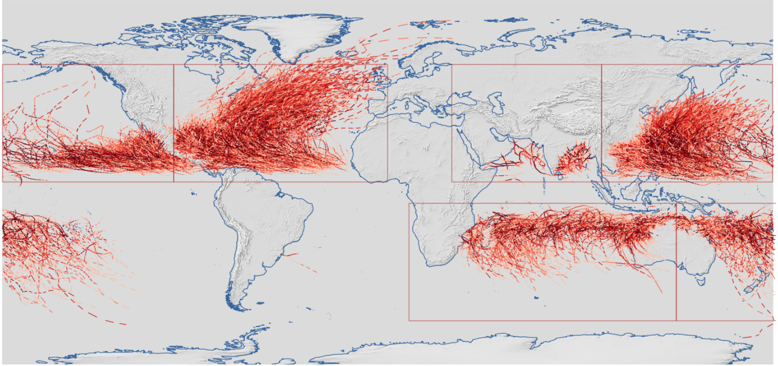
Figure 15: Modeling framework (Module 1)



Source: Le Guenedal *et al.* (2021).

Applications
Tropical cyclone damage modeling

Figure 16: Sample of storms (ERA-5 climate data)



Source: Le Guenedal *et al.* (2021).

Applications

Tropical cyclone damage modeling

Physics of cyclones

1. Wind pressure relationship (Bloemendaal *et al.*, 2020):

$$V = a\left(P_{\mathrm{env}} - P_c\right)^b$$

2. Maximum potential intensity (Holland, 1997; Emanuel, 1999):

$$MPI = f\left(y, SST, T_{tropo}, MSLP, RH, P_c\right)$$

3. Maximum pressure drop (Bloemendaal *et al.*, 2020):

$$MPD \sim P_{\mathrm{env}} - P_c = A + Be^{C(\mathrm{SST} - T_0)} \qquad T_0 = 30^o\mathrm{C}$$

4. Pressure incremental variation (James and Mason, 2005):

$$\begin{aligned}\Delta_t P_c(t) &= c_0 + c_1 \Delta_t P_c(t-1) + c_2 e^{-c_3(P_c(t) - MPI(x,y,t))} + \varepsilon(P_c, t) \\ \varepsilon(P_c, t) &\sim \mathcal{N}\left(0, \sigma^2_{P_c}\right)\end{aligned}$$

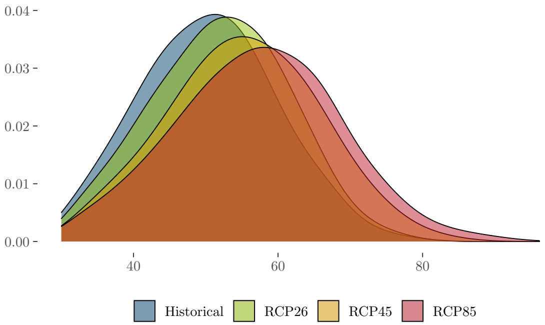
5. Decay function (Kaplan and DeMaria, 1995):

$$V(t_L) = V_b + (R \cdot V_0 - V_b)e^{-\alpha t} - C$$

where $C = m\left(\ln \frac{D}{D_0}\right) + b$, $m = \tilde{c}_1 t_L \left(t_{0,L} - t_L\right)$ and $b = d_1 t_L \left(t_{0,L} - t_L\right)$

Applications
Tropical cyclone damage modeling

Figure 17: Maximum wind speed in m/s (2070-2100)



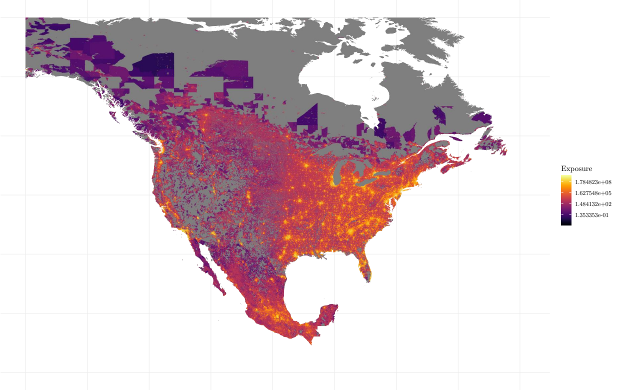
Source: Le Guenedal *et al.* (2021).

The cyclone simulation database must be sensitive to the climate change scenario

Applications

Tropical cyclone damage modeling

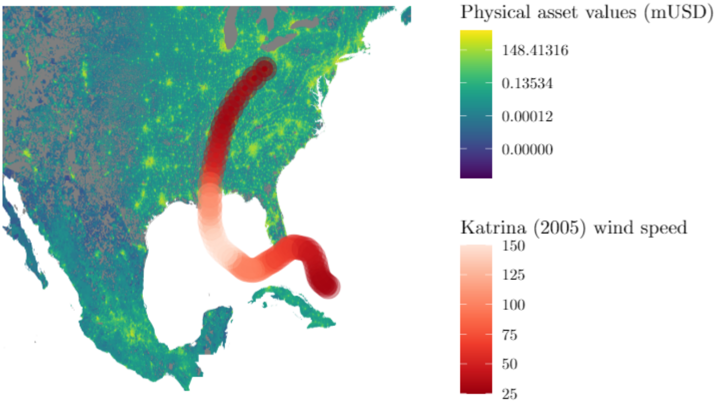
Figure 18: GDP decomposition of North America (or physical asset values) (Litpop database)



Source: Le Guenedal *et al.* (2021).

Applications
Tropical cyclone damage modeling

Figure 19: The case of Katrina (2005)

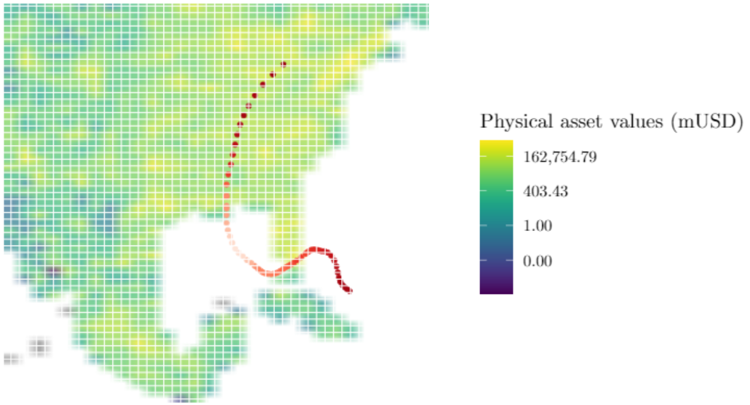


Source: Le Guenedal *et al.* (2021).

Applications

Tropical cyclone damage modeling

Figure 20: The grid approach

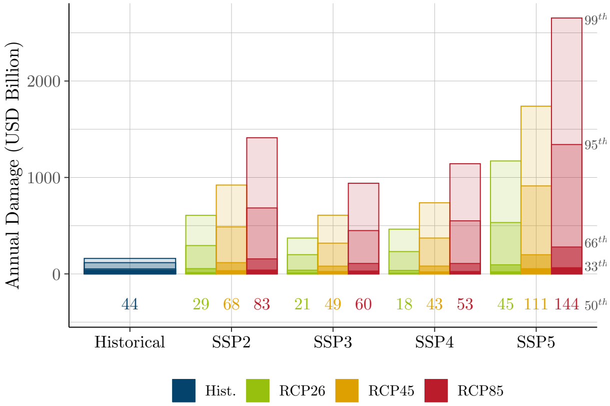


Source: Le Guenedal *et al.* (2021).

Applications

Tropical cyclone damage modeling

Figure 21: Average global losses



Source: Le Guenedal *et al.* (2021).

Applications

Tropical cyclone damage modeling

Table 1: Average increase of financial losses per year

SSP	RCP 2.6	RCP 4.5	RCP 8.5
SSP2	+43%	+153%	+247%
SSP5	+157%	+360%	+543%

Source: Le Guenedal *et al.* (2021).

Remark

- There are simulations that lead to annual losses that easily exceed 2 or 3 trillion dollars per year
- 1 Katrina = $180 billion in 2005

Floods

Drought

Water stress

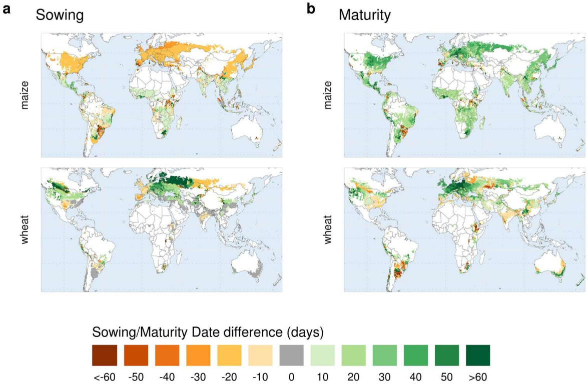
Extreme heat

Wildfire

Agriculture and food security

Crop calendar adjustment

Figure 22: Crop calendar adjustment*

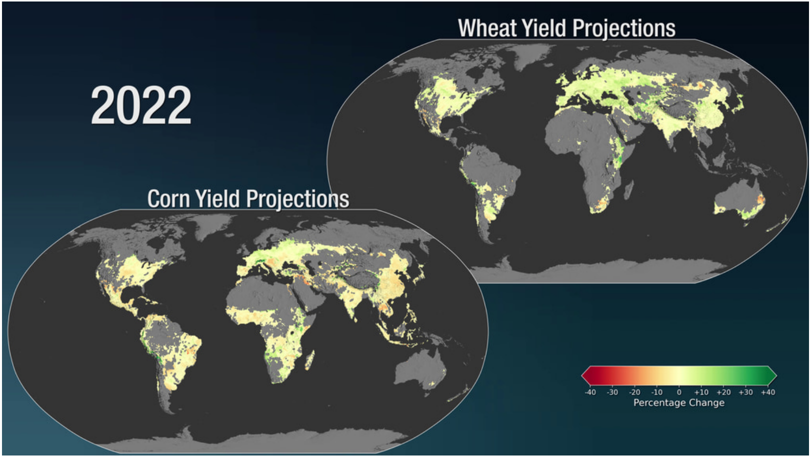


Source: Minoli *et al.* (2022).

*Differences (days) in simulated average sowing (a) and maturity (b) dates between timely adaptation and no adaptation scenarios for the same climate period (2080-2099, RCP6.0)

Crop yields

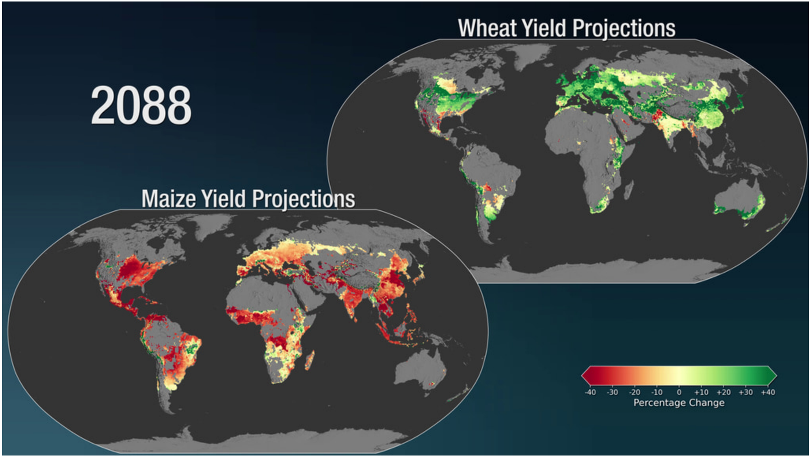
Figure 23: Crop yield* (2088 vs. 2022)



Source: Jägermeyr *et al.* (2021) & https://svs.gsfc.nasa.gov/4974.

Crop yields

Figure 24: Crop yield* (2088 vs. 2022)



Source: Jägermeyr *et al.* (2021) & https://svs.gsfc.nasa.gov/4974.

Agriculture productivity

Changes in growing seasons

Land management

Infrastructure costs

Insurance costs

Biodiversity risk

Health risk

Migration risk

Productivity risk

Water risk