Course 2022-2023 in Sustainable Finance
Lecture 12. Physical Risk Modeling

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[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.

Physical risk and investors

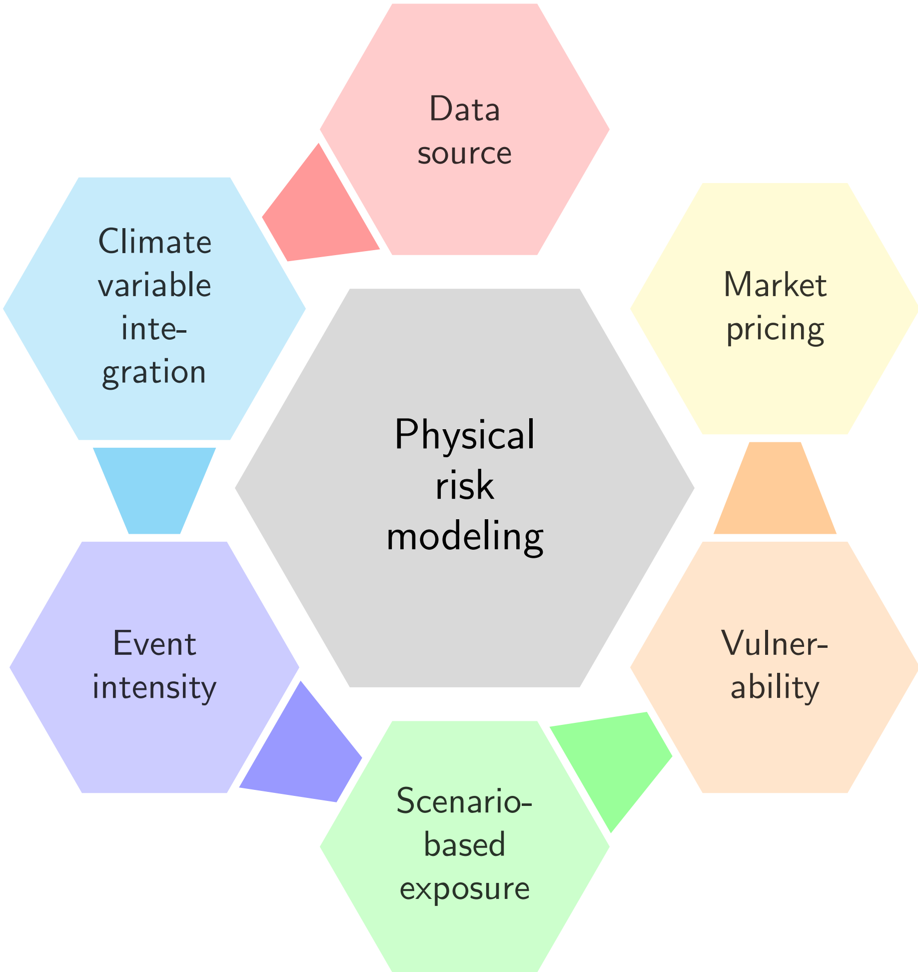
"Responsible investors have paid more attention to the transition risk than to the physical risk. However, recent events show that physical risk is also a big concern. It corresponds to the financial losses that really come from climate change, and not from the adaptation of the economy to prevent them. It includes droughts, floods, storms, etc." (Le Guenedal and Roncalli, 2022).

Chronic risk

Acute risk

Statistical modeling of physical risk

Figure 1: Physical risk modeling



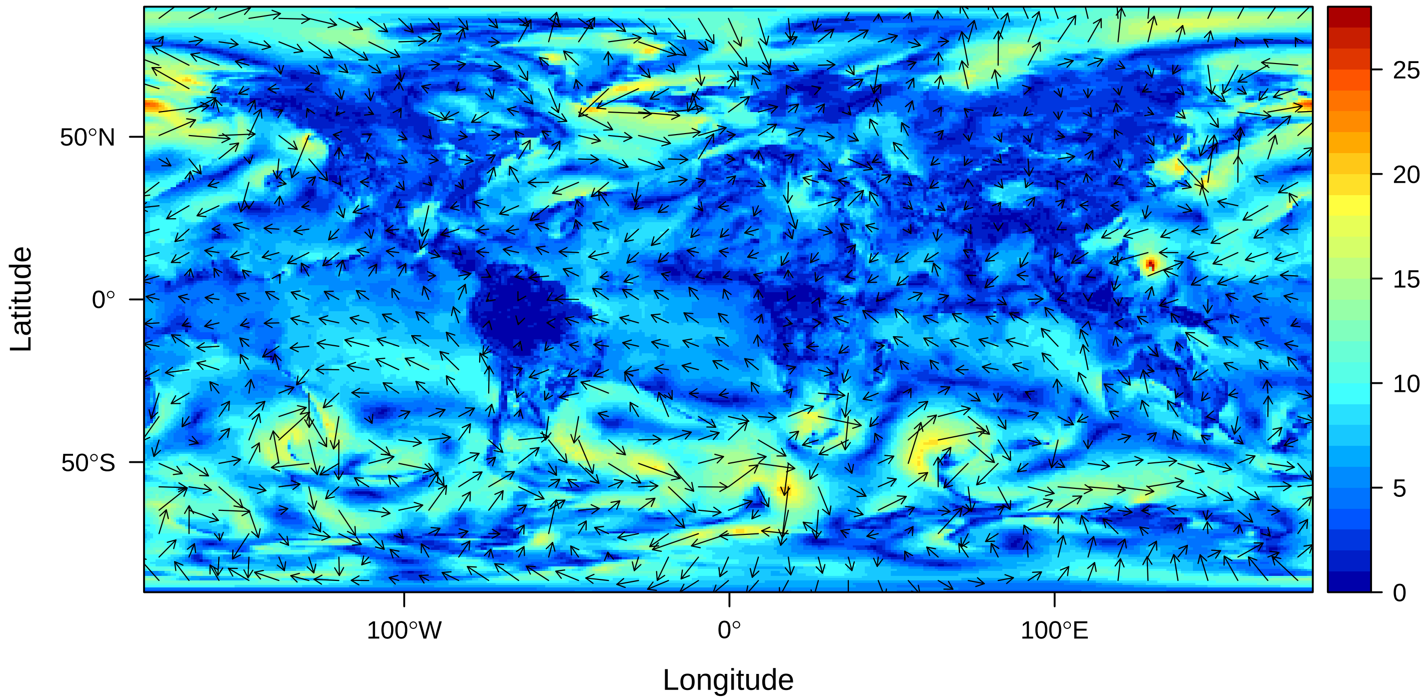
Statistical modeling of physical risk

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



Source: Modern-Era Retrospective analysis for Research and Applications, Version 2, Global Modeling and Assimilation Office, NASA.

*This is a slice of the MERRA-2 reanalysis at a height of 10 meters on 7$^{\mathrm{th}}$ 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:

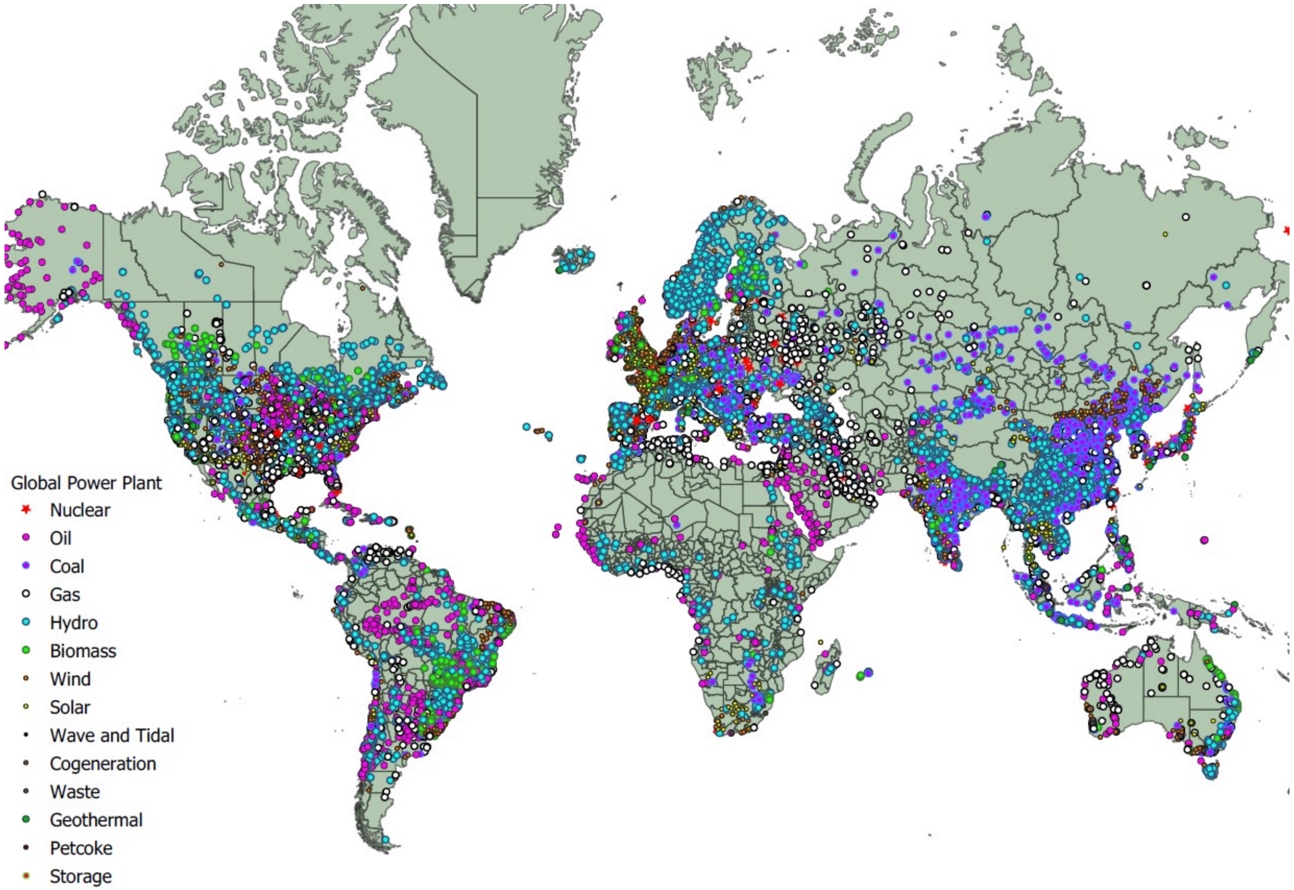
$$\Psi(t) = \sum_{j=1}^{n} x_j \Psi_j(\lambda, \varphi, t)$$

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 3: 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`

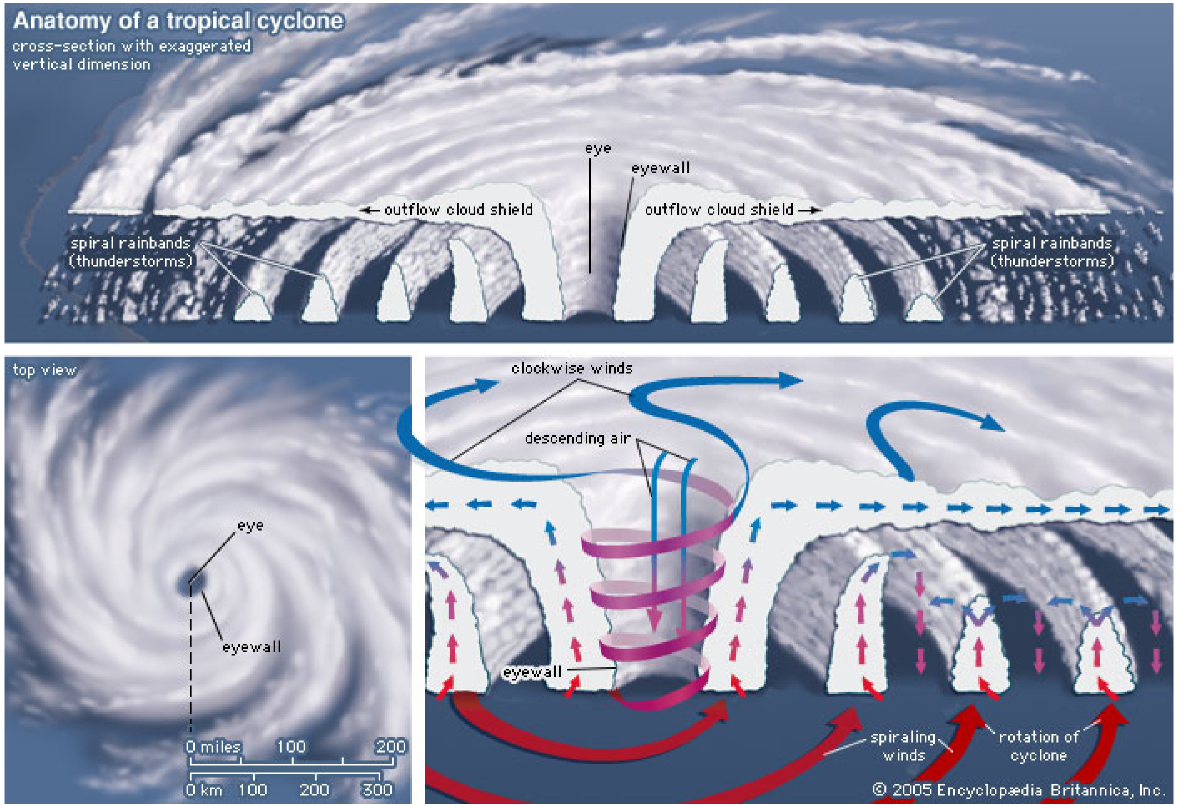
Two main modules:

- 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 4: What is a cyclone?

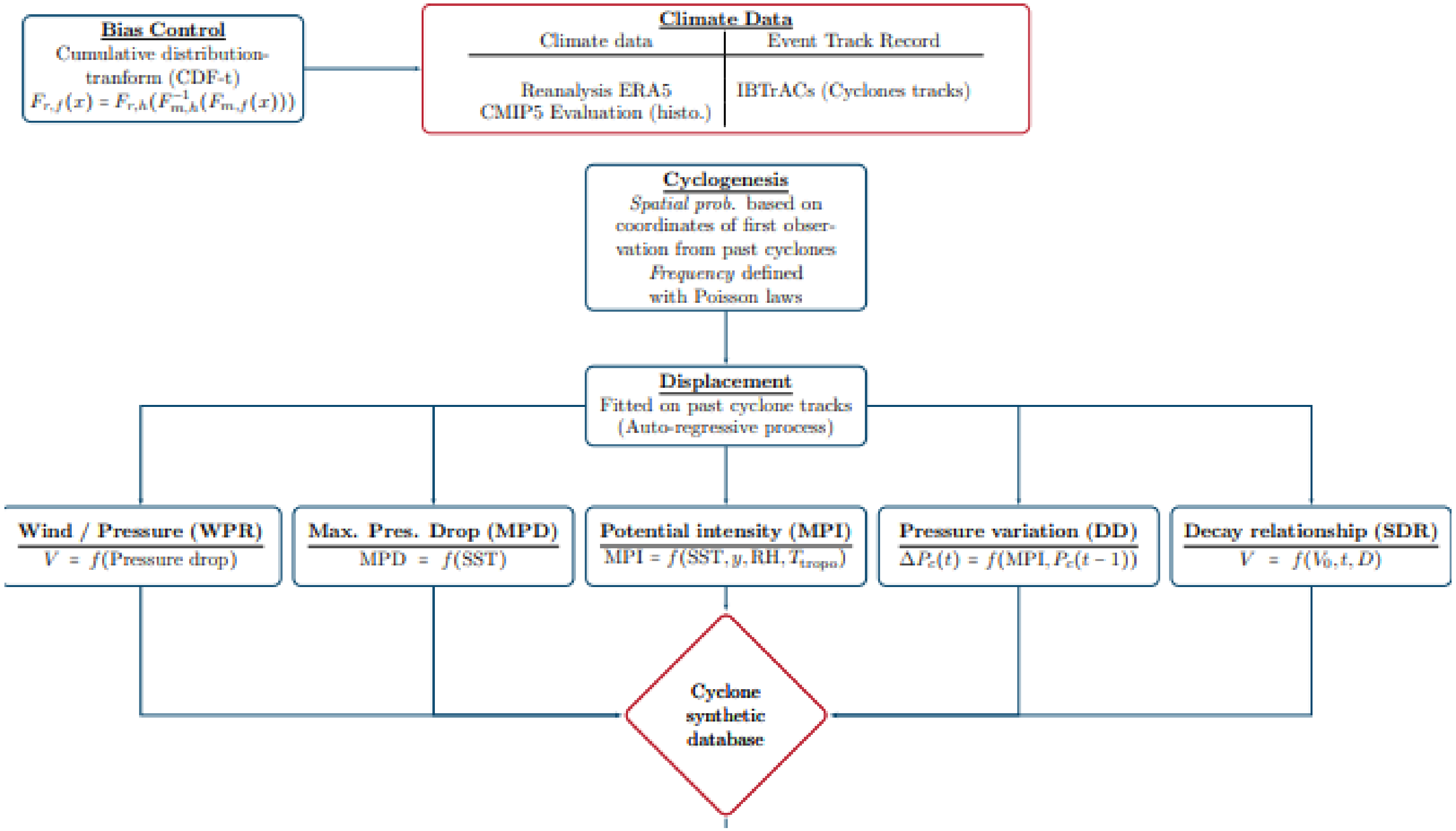


Source: `www.geosci.usyd.edu.au/users/prey/teaching/geos-2111gis/cyclone/cln006.html`

Applications

Tropical cyclone damage modeling

Figure 5: Modeling framework (Module 1)

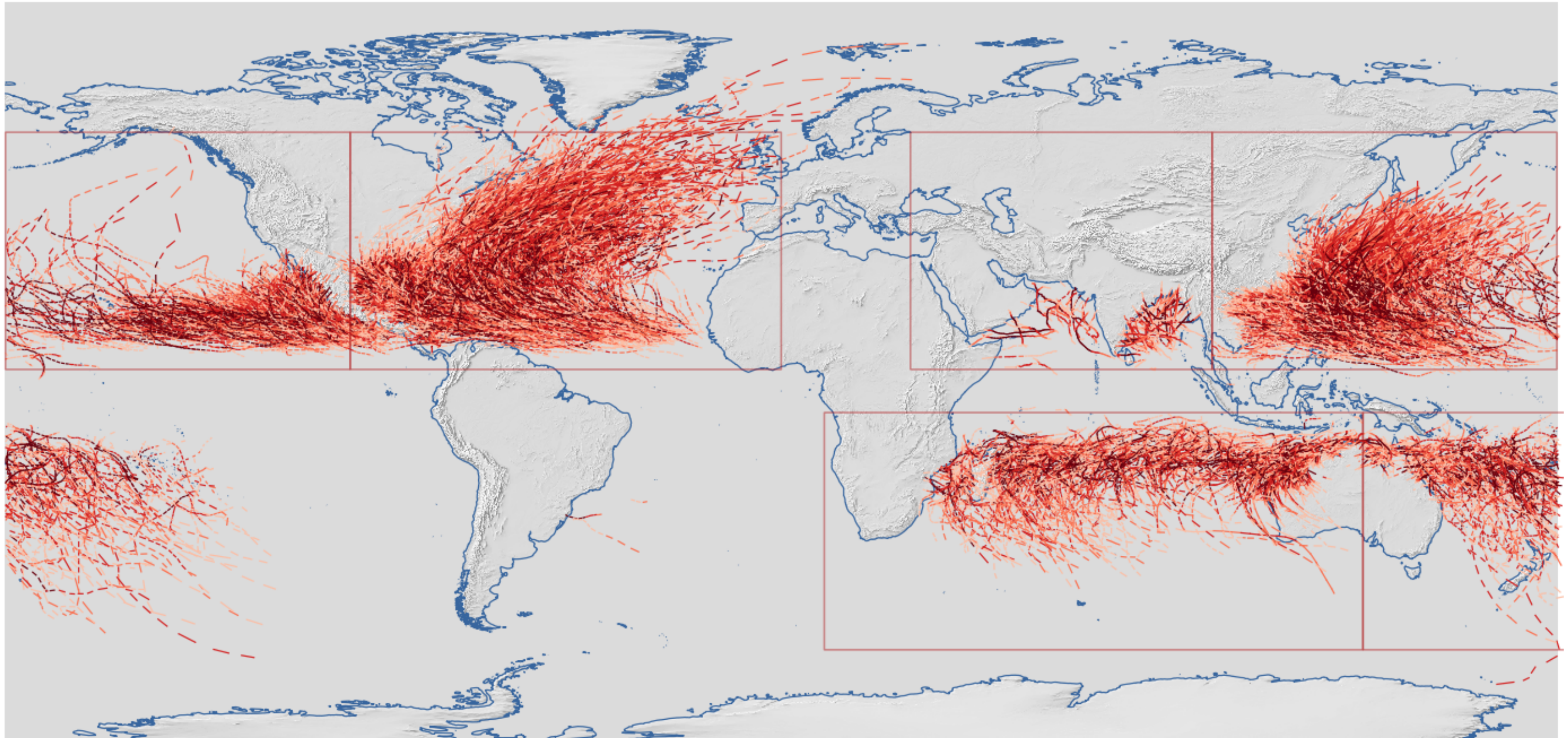


Source: Le Guenedal *et al.* (2021).

Applications

Tropical cyclone damage modeling

Figure 6: 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):

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

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

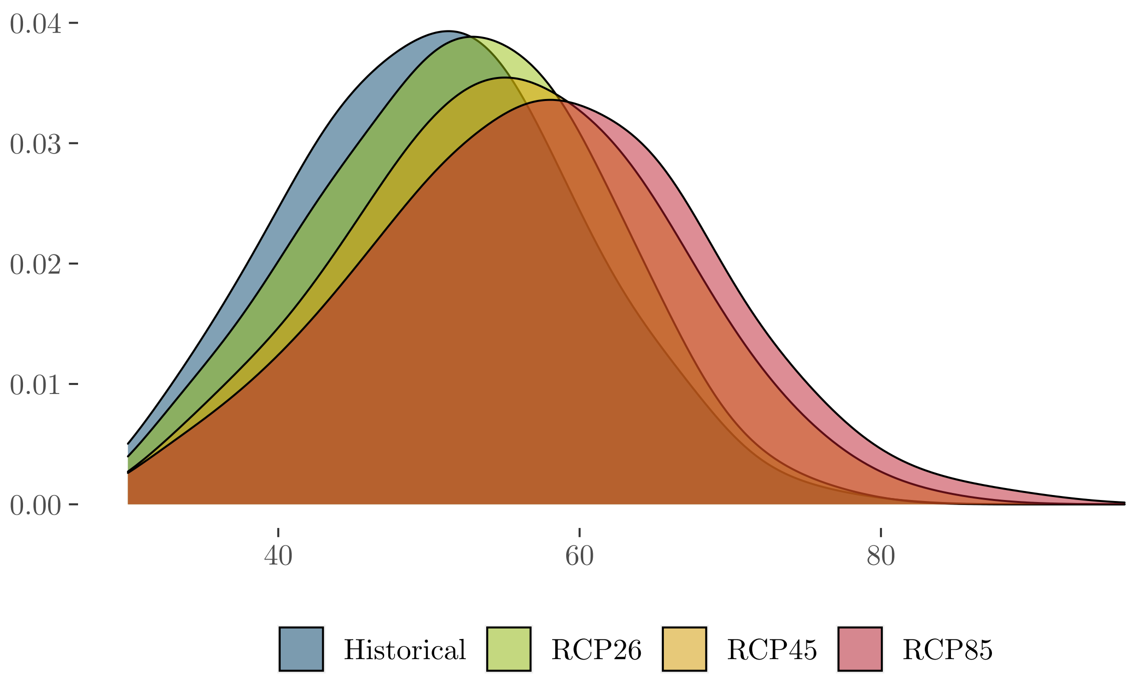
$$V(t_L) = V_b + (R \cdot V_0 - V_b)e^{-\alpha t} - C$$

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



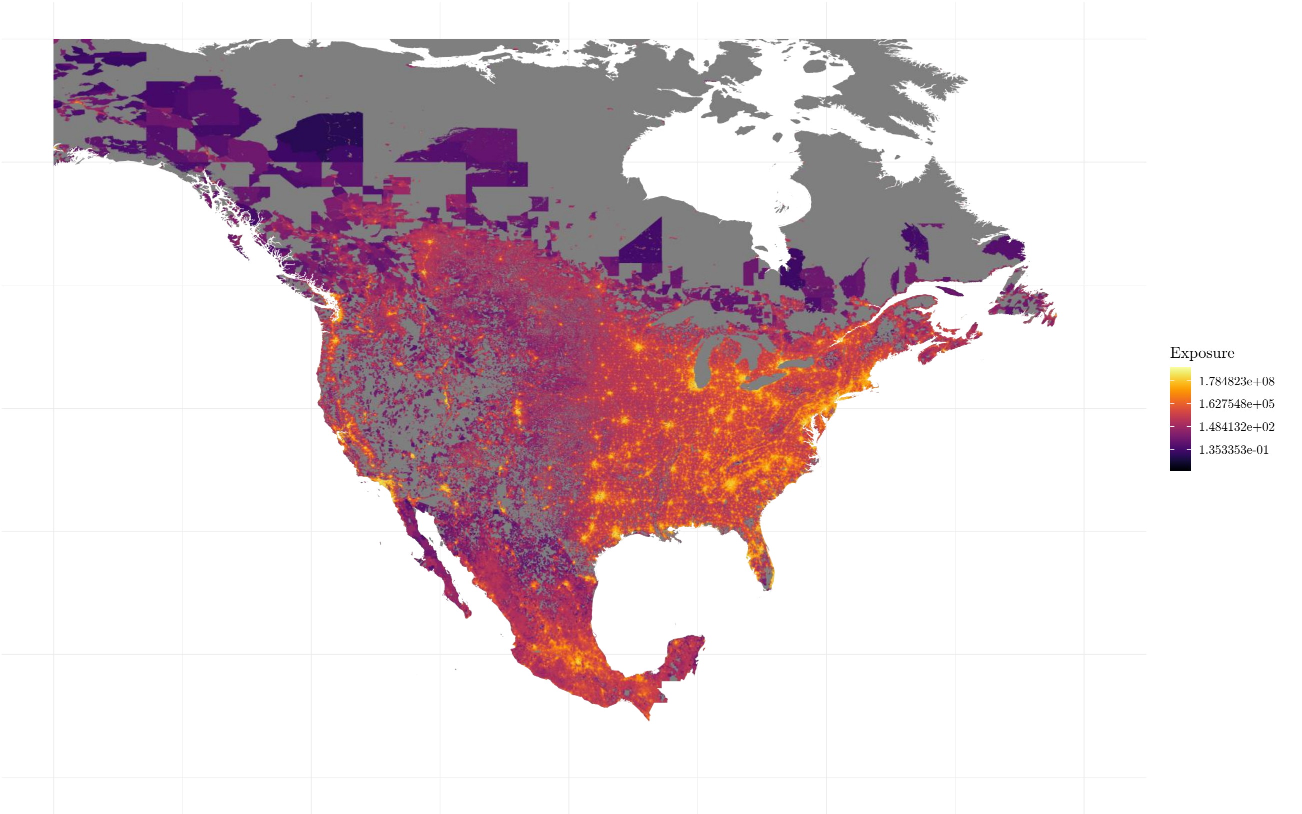
Source: Le Guenedal *et al.* (2021).

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

Applications

Tropical cyclone damage modeling

Figure 8: GDP decomposition of North America (or physical asset values) (Litpop database)

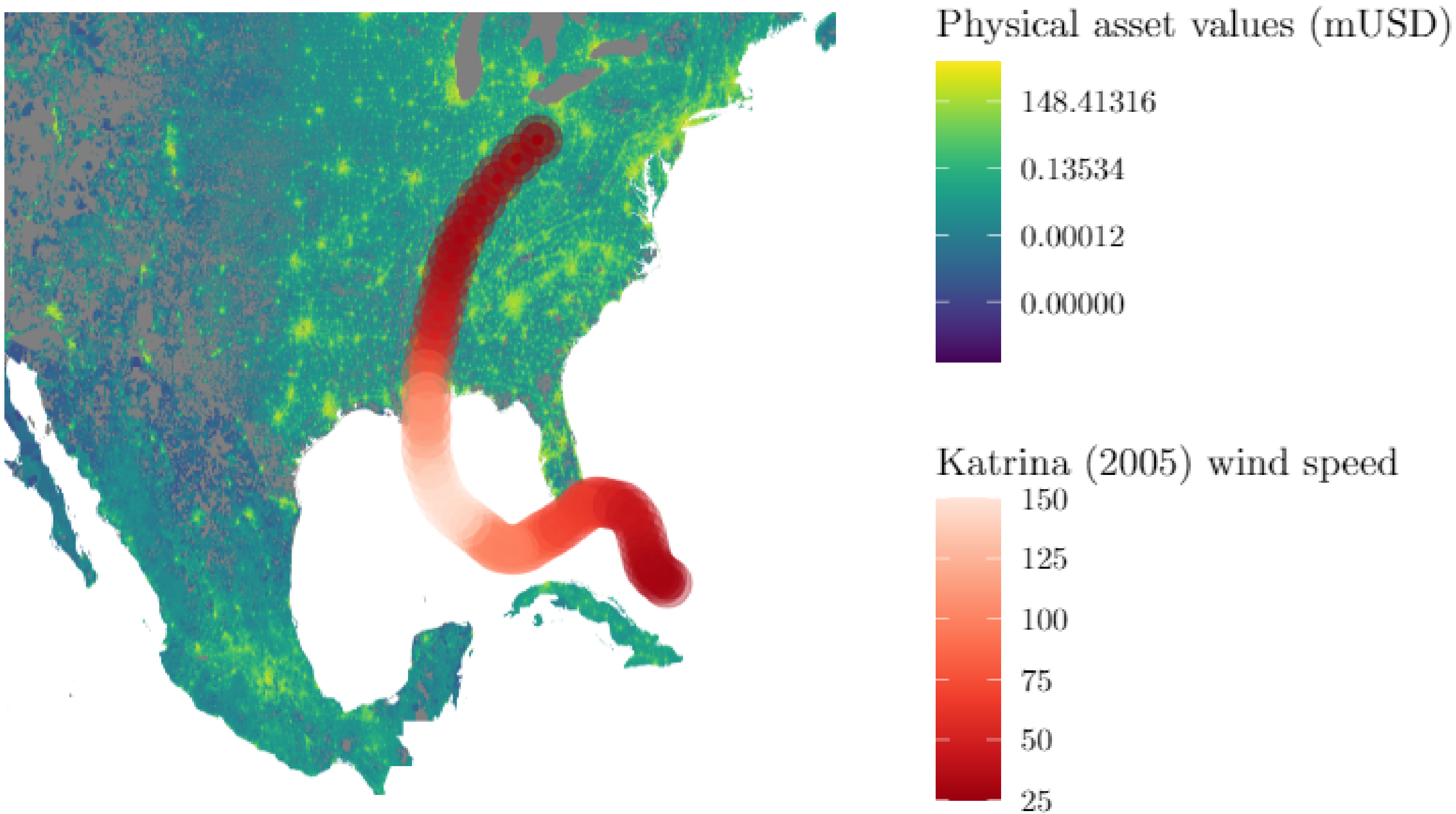


Source: Le Guenedal *et al.* (2021).

Applications

Tropical cyclone damage modeling

Figure 9: The case of Katrina (2005)

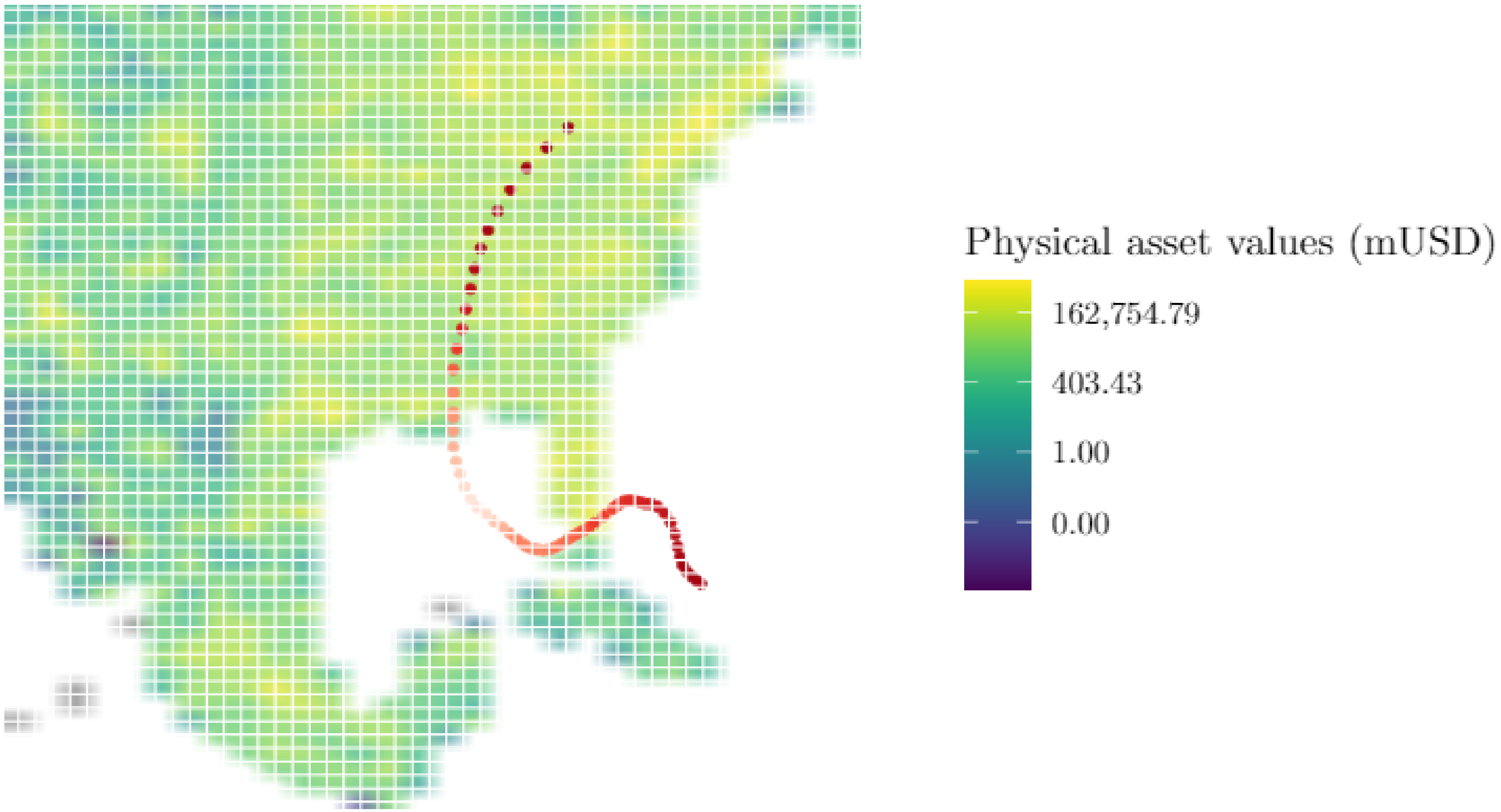


Source: Le Guenedal *et al.* (2021).

Applications

Tropical cyclone damage modeling

Figure 10: The grid approach

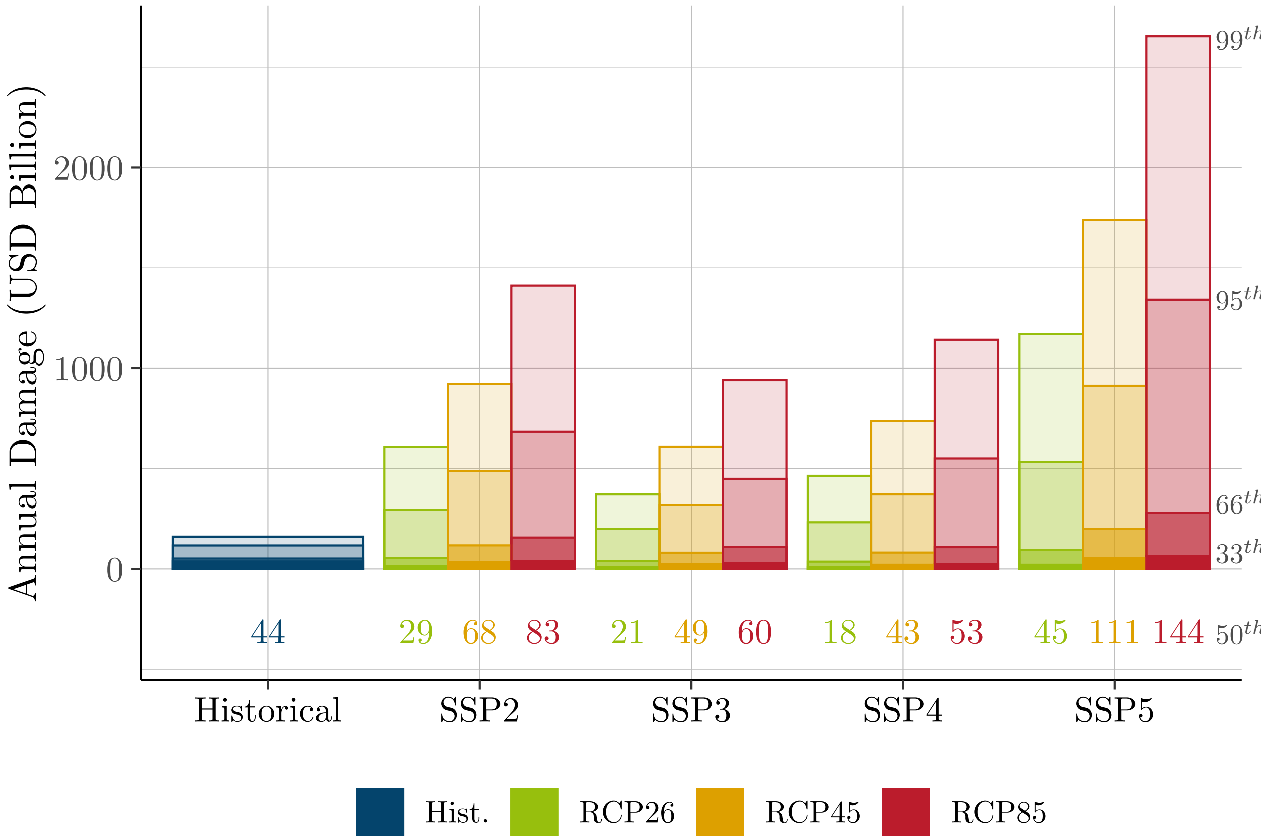


Source: Le Guenedal *et al.* (2021).

Applications

Tropical cyclone damage modeling

Figure 11: 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