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: Engagement & Voting Policy
- Lecture 7: Extra-financial Accounting
- Lecture 8: Awareness of Climate Change Impacts
- Lecture 9: The Ecosystem of Climate Change
- Lecture 10: Economic Models & Climate Change
- Lecture 11: Climate Risk Measures
- Lecture 12: Transition Risk Modeling
- Lecture 13: Climate Portfolio Construction
- Lecture 14: Physical Risk Modeling
- Lecture 15: 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 (1950-2023)

Figure 2: Global temperatures (1950-1954)

Source: earthobservatory.nasa.gov/world-of-change/global-temperatures.
Prologue: Global temperatures (1950-2023)

Figure 3: Global temperatures (1970-1974)

Source: earthobservatory.nasa.gov/world-of-change/global-temperatures.
Figure 4: Global temperatures (1980-1984)

Source: earthobservatory.nasa.gov/world-of-change/global-temperatures.
Prologue: Global temperatures (1950-2023)

Figure 5: Global temperatures (1990-1994)

Source: earthobservatory.nasa.gov/world-of-change/global-temperatures.
Prologue: Global temperatures (1950-2023)

**Figure 6**: Global temperatures (2000-2004)

Source: earthobservatory.nasa.gov/world-of-change/global-temperatures.
Prologue: Global temperatures (1950-2023)

Figure 7: Global temperatures (2010-2014)

Source: earthobservatory.nasa.gov/world-of-change/global-temperatures.
Prologue: Global temperatures (1950-2023)

Figure 8: Global temperatures (2015-2019)

Source: earthobservatory.nasa.gov/world-of-change/global-temperatures.
Figure 9: Global temperatures (2022)

Source: earthobservatory.nasa.gov/world-of-change/global-temperatures.
Figure 10: Systemic risk dynamics of climate-related physical risks

- **Migration and displacement of people**
  - Rural to urban
  - Refugee crisis
  - Forced/unsafe migration
  - Forced immobility (trapped populations)

- **Armed conflict**
  - Regional conflicts
  - Rise of extremist groups
  - Police/military intervention
  - Organized crime and violence
  - Conflict between people and states
  - Civil war and war

- **Destabilization of markets**
  - Commodity price spikes
  - Fall of asset prices
  - Large-scale asset sell-off
  - Falling stock markets
  - Underfunded pension funds
  - Financial market collapse

Physical risk and insurance companies
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

- Data source
- Climate variable integration
- Event intensity
- Scenario-based exposure
- Market pricing
- Vulnerability
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 $\theta_k$ has four coordinates:
  1. Latitude $\lambda$
  2. Longitude $\varphi$
  3. Height (or altitude) $z$
  4. Time $t$
- Three types of sources:
  1. Meteorological records
  2. Reanalysis
  3. Historical simulations by a climate model
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\textsuperscript{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.
Event intensity sensitivity

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

$$\Delta I(C) = E[I(\Theta_s(C))] - I(\Theta_s(C_0))$$

where $I(\Theta_s(C_0))$ 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.
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.
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.
Market pricing

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

$$\Delta \text{Loss} (t, C) = \beta \cdot \DD (t, C) = \beta \sum_{j=1}^{n} x_j \Psi_j (\lambda, \varphi, t) \Omega_j (\Delta l (t, C))$$

- $\Delta \text{Loss} (t, C)$ is the relative loss due to the events on the portfolio
- $\beta$ is the transmission factor of the direct damage $\DD (t, C)$ 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


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?

Applications
Tropical cyclone damage modeling

Figure 15: Modeling framework (Module 1)

Source: Le Guenedal et al. (2021).
Figure 16: Sample of storms (ERA-5 climate data)

Source: Le Guenedal et al. (2021).
Physics of cyclones

- Wind pressure relationship (Bloemendaal et al., 2020):
  \[ V = a(P_{\text{env}} - P_c)^b \]

- Maximum potential intensity (Holland, 1997; Emanuel, 1999):
  \[ MPI = f(y, SST, T_{\text{tropo}}, MSLP, RH, P_c) \]

- Maximum pressure drop (Bloemendaal et al., 2020):
  \[ MPD \sim P_{\text{env}} - P_c = A + Be^{C(SST-T_0)} \quad T_0 = 30^\circ\text{C} \]

- Pressure incremental variation (James and Mason, 2005):
  \[ \Delta_t P_c(t) = c_0 + c_1 \Delta_t P_c(t-1) + c_2 e^{-c_4(P_c(t)-MPI(x,y,t))} + \varepsilon(P_c, t) \]
  \[ \varepsilon(P_c, t) \sim \mathcal{N}(0, \sigma_{P_c}^2) \]

- Decay function (Kaplan and DeMaria, 1995):
  \[ V(t_L) = V_b + (R \cdot V_0 - V_b)e^{-\alpha t} - C \]
  where \( C = m \left( \ln \left( \frac{D}{D_0} \right) \right) + b, \)
  \[ m = \bar{c}_1 t_L (t_{0,L} - t_L) \] and \[ b = d_1 t_L (t_{0,L} - t_L) \]
The cyclone simulation database must be sensitive to the climate change scenario.

Source: Le Guenedal et al. (2021).
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

Applications
Tropical cyclone damage modeling

Table 1: Average increase of financial losses per year

<table>
<thead>
<tr>
<th>SSP</th>
<th>RCP 2.6</th>
<th>RCP 4.5</th>
<th>RCP 8.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSP2</td>
<td>+43%</td>
<td>+153%</td>
<td>+247%</td>
</tr>
<tr>
<td>SSP5</td>
<td>+157%</td>
<td>+360%</td>
<td>+543%</td>
</tr>
</tbody>
</table>

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
Drought
Water stress
Extreme heat
Wildfire
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<th>Modeling of physical risk</th>
<th>Agriculture and food security</th>
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<tr>
<td>Extreme weather modeling</td>
<td>Insurance and economic costs</td>
</tr>
<tr>
<td>Impact of climate-related physical risks</td>
<td>Other risks</td>
</tr>
</tbody>
</table>

Agriculture and food security
Crop calendar adjustment

Figure 22: Crop calendar adjustment*

*a 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)

Source: Minoli et al. (2022).
Crop yields

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

Crop yields

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

Agriculture productivity
Changes in growing seasons
Land management
Infrastructure costs
Insurance costs
Biodiversity risk
Health risk
Migration risk
Productivity risk
Water risk