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WORKING PAPER

ASSESSING PHYSICAL RISKS FROM CLIMATE CHANGE: DO COMPANIES AND FINANCIAL ORGANIZATIONS HAVE SUFFICIENT GUIDANCE?

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EXECUTIVE SUMMARY

Highlights

- Climate-related physical risks can lead to significant financial impacts, but methods for assessing those potential risks are still nascent. Whether companies and financial organizations have the guidance and resources needed to assess the range of physical hazards documented in the latest climate science remains an important question.
- This paper analyzes climate-related physical risk assessment guidance from leading corporate disclosure initiatives to examine whether existing publicly available guidance aligns with climate science and provides consistent terminology and robust methodologies for risk assessment.
- The analysis reveals that the guidance does not provide complete coverage of physical climate hazards or refer to a comprehensive set of metrics for quantifying physical climate risk.
- These gaps indicate the absence of a shared robust understanding and approach to identifying and assessing physical climate risks. This could result in unmanaged risks, reduced resilience, and ultimately financial losses.
- Several actions could help address these gaps and facilitate more meaningful physical climate risk assessments: a more accessible translation of climate science by the Intergovernmental Panel on Climate Change (IPCC); more accessible, practical, and open-source scientific datasets on climate-related hazards; and an open-source, science-based physical climate risk assessment framework that provides a standardized taxonomy for physical climate hazards with corresponding guiding principles and methods to quantify hazards, exposure, and vulnerability.

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Context

The financial implications of physical risks from climate change are coming into sharper focus. The increasing frequency and/or intensity of climate hazards—including floods, tropical cyclones, heatwaves, droughts, and wildfires—are already leading to financial losses. The science indicates that these hazards are only going to get worse (IPCC 2018).

And yet, the existing methods for assessing climate-related physical risks are still nascent. A growing body of corporate sustainability disclosure guidance offers a solid starting point for companies and financial organizations, and the analytical tools from commercial data providers are improving. But it is unlikely that publicly available guidance fully equips companies and financial organizations to assess the range of potential physical climate hazards documented by climate science.

About This Working Paper

The purpose of this paper is to provide companies and financial organizations with a common understanding of climate-related physical risks according to climate science, to identify gaps in the publicly available guidance to assess those risks, and to propose potential resources that would facilitate better risk assessment and, in turn, risk management. The findings are relevant for companies, financial organizations, environmental, social, and governance (ESG) ratings agencies, climate data and analytical service providers, disclosure initiatives, and others seeking to assess exposure to physical risks from climate change, as well as climate scientists and policymakers seeking to influence the private sector.

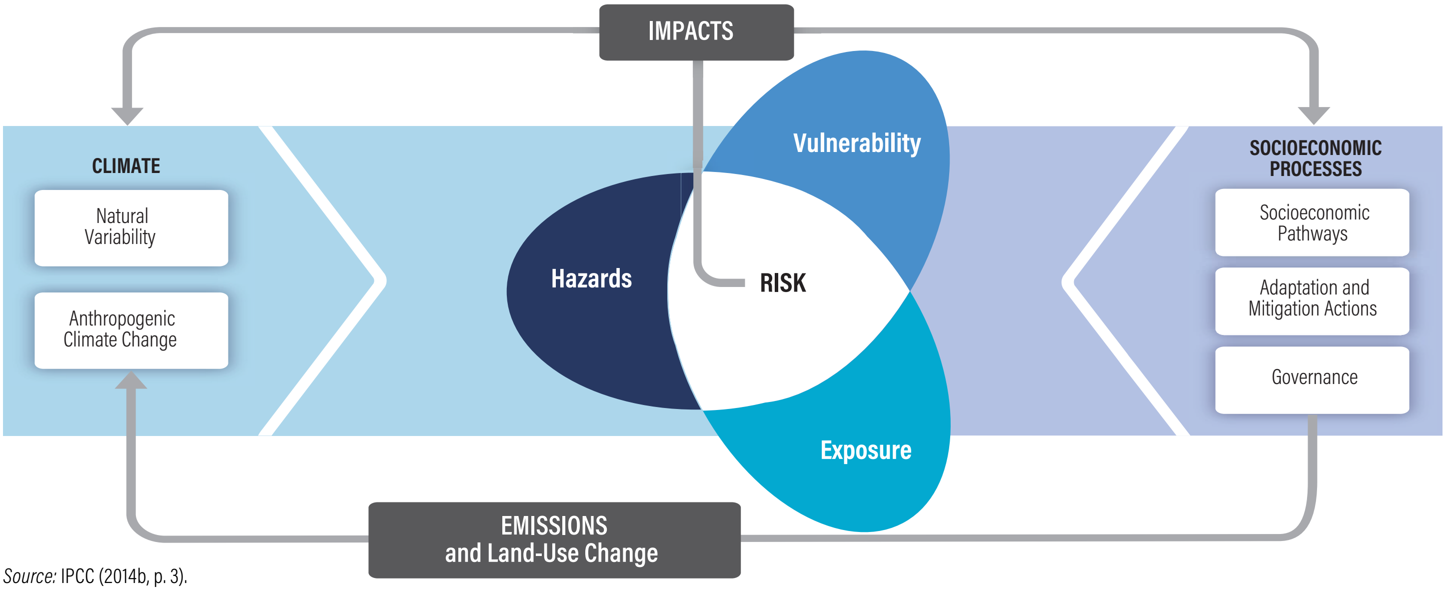
The paper outlines a comprehensive list of physical climate hazards included in the IPCC's assessments and then uses a framework to analyze physical risk assessment guidance from disclosure initiatives. Our analysis focuses on leading disclosure initiatives because they provide publicly available assessment guidance to inform their recommended disclosures, including guidance for assessing physical climate risk. We reviewed guidance documents from six prominent disclosure initiatives: CDP, the Climate Disclosure Standards Board (CDSB), the EU Non-financial Reporting Directive (NFRD), the Global Reporting Initiative (GRI), the Sustainability Accounting Standards Board (SASB), and the Task Force on Climate-Related Financial Disclosures (TCFD). The framework evaluates the extent to which the guidance (1) *defines physical risk*, (2) *provides broad qualitative guidance*, (3) *identifies physical climate hazards*, and (4) *provides specific metrics*. The third and fourth questions are oriented around the IPCC's climate risk function, which provides a basis for assessing physical climate risks (see Figure ES-1). According to the IPCC's function, risk of climate-related impacts results from the interaction of climate-related hazards with the vulnerability and exposure of human and natural systems (IPCC 2012; updated in 2014).

Key Findings from Analysis of Disclosure Guidance

The guidance across initiatives contains inconsistent terminology that rarely aligns with that of the IPCC. Most initiatives neither clearly distinguish between key terms related to physical risk nor use them consistently across the guidance. Furthermore, most initiatives do not provide a clear, science-based framework for assessing physical climate risk similar to the IPCC's climate risk function.

Some hazards highlighted by the IPCC are missing or receive little attention from the guidance. Certain hazards are well covered, while others are entirely absent. The most frequently referenced IPCC-highlighted hazards are sea level change, water stress, and sustained temperature rise. Table ES-1 lists IPCC-highlighted hazards that have low coverage or are not explicitly referenced in any disclosure guidance.

Figure ES-1 | The Intergovernmental Panel on Climate Change's Physical Climate Risk Function



Source: IPCC (2014b, p. 3).

Table ES-1 | Physical Climate Hazards with Low or No Coverage across Disclosure Initiatives

	HAZARD	COVERAGE LEVEL ACROSS DISCLOSURE INITIATIVES	EXAMPLES OF FINANCIAL DAMAGE
Chronic hazards	Ocean acidification	None	The cost of production loss for global mollusk production alone is estimated at over $100 billion, with an assumption of increasing demand for mollusks and expected income growth combined with a business-as-usual emission trend toward the year 2100 (Narita et al. 2012).
Chronic hazards	Ice melt/ permafrost melt	None	In Arctic communities, nearly 4 million people and 70% of current infrastructure in the permafrost domain are at risk of thawing by 2050 (Hjort et al. 2018).
Acute hazards	Extreme precipitation	Low	Extreme precipitation is the major contributor to other water-related hazards, including floods, droughts, landslides, and so on.
Acute hazards	Extreme winds	Low	The National Oceanic and Atmospheric Administration estimates financial damage resulting from the derecho that ravaged the U.S. Midwest in 2020 at around $7.5 billion (Henson 2020).
Acute hazards	Extreme sea level	Low	Impending sea level rise could affect coastal cities like New York and expose roughly $73 billion of property to potential losses (Advisor's Edge 2019).
Acute hazards	Tornadoes	None	In 2019 alone, tornadoes caused over $3 billion in economic damage in the United States (Duffin 2020).
Acute hazards	Hail	None	Multiple hail storms affected the Midwest in April 2020, causing an estimated $2.9 billion in damage to homes, vehicles, and businesses (Schnackenberg 2020).
Acute hazards	Dust storms	None	In West Africa, economic growth was reduced by 3% per standard deviation increase in dust exposure over two years, and agricultural yields decline in the year of impact on average over 2% (Foreman 2020).
Acute hazards	Landslides	Low	In 2011, rebuilding from severe landslides in Brazil that killed 647 people cost an estimated $1.2 billion (Brasileiro 2011).

Notes: Coverage is determined by an explicit reference to a given hazard within the guidance documents. ***High*** coverage indicates that the hazard was clearly and directly referred to in the guidance documents of three or more initiatives; ***low*** coverage indicates that the hazard was clearly and directly referred to in the guidance documents of one or two (out of six) initiatives; ***none*** indicates that the hazard was not referred to in the guidance documents of any initiative. The use of broad terms, like ***storms***, is not counted under the various hazards that such events may cover. The list of hazards was developed by WRI based on a review of reports by the Intergovernmental Panel on Climate Change. Our sample includes guidance documents from CDP, the Climate Disclosure Standards Board, the EU Non-financial Reporting Directive, the Global Reporting Initiative, the Sustainability Accounting Standards Board, and the Task Force on Climate-Related Financial Disclosures.

Source: WRI authors based on IPCC (2014a, 2014b).

The guidance does not provide or refer to a comprehensive set of metrics for quantifying each of the factors of physical climate risks across all hazards. Assessing risks from specific physical hazards requires metrics or detailed methods to (a) measure the hazard in physical terms, (b) measure the entity's exposure and vulnerability to the hazard, (c) quantify the potential impacts from the hazard, and/or (d) quantify overall risk for the hazard. Across the guidance, most hazards lack a full set of metrics to assess each of the factors in the IPCC's climate risk function (hazard, vulnerability, exposure, impact, and risk). Many of the referenced metrics are composite in nature, meaning they appear to incorporate more than one factor in the IPCC's risk function. However, it is sometimes unclear whether these composite metrics provide full information for each factor in the physical climate risk function. The guidance also offers several hazard-agnostic metrics that do not explicitly refer to a specific physical hazard.

Hazards related to water stress and flooding have the most extensive set of metrics and data sources. In addition to the metrics for assessing the severity of these hazards, the initiatives cite multiple metrics for assessing a company's exposure and vulnerability to them. For most other hazards, the guidance documents do not provide hazard-specific metrics for any part of the risk function (hazard, exposure, vulnerability, impact, or risk).

Implications

The gaps we identified suggest that the body of leading disclosure guidance does not fully equip companies and financial organizations with a common approach to systematically identify and assess the complex set of physical climate risks. Companies and financial organizations that rely on these publicly available resources to inform risk assessment may be overlooking aspects of physical climate risk.

Additional resources could improve the capacity of companies and financial organizations to assess climate-related physical risks. Ensuring that these resources are open-source should foster a stronger collective understanding, promote harmonization, facilitate access by a wider range of companies and financial organizations around the world, and instill more rigor through transparency.

These resources include the following:

Thorough open-source translations of the IPCC's climate science geared toward the private sector. The guidance documents do not provide a complete picture of hazards covered by climate science. To provide greater clarity and address these gaps, research organizations should develop publicly available synthesis reports of IPCC literature for private sector audiences, ideally in collaboration with the IPCC. We recognize that this is a fast-growing area with many developments in process.[1] As organizations continue to work on translations and other tools for private sector physical climate risk assessments, they should continue to solicit input directly from the scientific community.

High-quality, open-source, and peer-reviewed datasets that convert scientific data on physical climate hazards into a usable format relevant for decision-making. For example, CDP, SASB, and the TCFD refer to the Aqueduct Risk Atlas in their guidance. While our paper did not examine the relationship between data availability and quality of related guidance for each hazard, we noted greatest coverage for hazard areas for which relevant open-source data are readily accessible. Further research could identify specific gaps in high-quality, peer-reviewed, and open-source data across hazards.[2] From there, research organizations should develop additional open-source, peer-reviewed, and transparent data resources. Sustainability and climate data providers should draw on these resources as the foundation of analytical tools that convert data into usable inputs for corporate and financial risk assessments.

Greater clarity into why there may be hazard coverage gaps within disclosure guidance. If the disclosure guidance does not cover the 18 hazards listed in this paper, the disclosure initiatives should provide a clear rationale for the exclusion. For example, the guidance should note if the hazard is excluded because it is considered immaterial, because it is considered a subcategory of another hazard, or because the necessary data for a meaningful assessment are not available.

A science-based framework to serve as a standard foundation for performing comprehensive and objective physical climate risk assessments. This would facilitate more accurate physical climate risk assessment across the private sector and aid those with less climate expertise and/or access to outside commercial resources. Initiatives that develop physical climate risk assessment guidance should collaborate to develop this framework. It should include a taxonomy of physical climate hazards, a function for assessing physical climate risks, a consistent set of principles, and, ultimately, metrics for assessing exposure and vulnerability to all hazards identified by the IPCC. Precedents for standard measurement guidance exist in other sustainability areas. For example, the GHG Protocol provides standardized frameworks for businesses and governments to measure and manage greenhouse gas (GHG) emissions. Since their development, these accounting methods have become critical inputs for broader decision-making frameworks, including the Science Based Targets Initiative, which provides a set of robust methodologies for measuring emissions reductions. The development of a standard physical risk framework could take a similar iterative path.

1. INTRODUCTION

As scientific knowledge advances, and we bear collective witness to extreme weather and other climate-related events, the threats posed by climate change are coming into greater focus. For businesses, the impacts of a changing climate can lead to financial losses—damaging property and other assets while also disrupting operations, supply chains, and the broader social and economic systems upon which businesses depend. While many businesses have taken steps to measure, disclose, and reduce greenhouse gas emissions, fewer are taking steps to manage the risks associated with the physical impacts of climate change (Nelson 2019). It is unclear whether companies and financial organizations wanting to take this next step have enough knowledge and resources to assess these risks in a systematic manner.

The purpose of this paper is to provide companies and financial organizations with a common understanding of climate-related physical risks according to climate science, to identify gaps in publicly available guidance to assess those risks, and to propose potential resources that would help meet needs for better assessment and management. The paper's findings are relevant for companies, financial organizations, environmental, social, and governance (ESG) ratings agencies, climate data service providers, disclosure and reporting initiatives, and others seeking to assess exposure to physical risks from climate change, as well as climate scientists and policymakers seeking to influence the private sector.

Context: The Business Case and Current Guidance

Business Case for Assessing Climate-Related Physical Risks

Companies are already experiencing the financial impacts of climate change. In the fall of 2019, for example, powerful typhoons wreaked havoc in Tokyo and nearby regions. These storms, which are becoming increasingly intense with rising ocean temperatures in the region (Kang and Elsner 2016), caused millions of dollars in damage to physical assets, including the destruction of a fleet of bullet trains and extensive damage to crops and farmland (*Japan Times* 2019a, 2019b; Yamada et al. 2019). Meanwhile, on the other side of the Pacific, California's largest electric utility, Pacific Gas and Electric (PG&E), filed for bankruptcy in 2018 after facing liability claims for billions of dollars from catastrophic wildfires, which have become more frequent and destructive due to climate-related droughts (Diffenbaugh et al. 2015; Gold et al. 2019).

As we look toward the future, scientific evidence points to a warmer world with more frequent and intense climate hazards and accompanying economic damage (IPCC 2018). Even if we meet the ambitious goals of the Paris Agreement—maintaining temperature increases to well under 2 degrees Celsius (°C)—we can expect to see increased risks to health, livelihoods, food security, water supply, and economic growth (IPCC 2018). Given these expectations and the material risks they pose, physical climate risks are something businesses and financial organizations cannot afford to ignore.

However, translating scientific knowledge into a business context is challenging. Major hurdles include accounting for the uncertainty in the timing, duration, and magnitude of potential climate hazards, the ambiguity in how these hazards may affect a company and its financial performance, and gaps in necessary data inputs for assessing risk exposure. While standard methods to assess climate-related physical risks have yet to emerge, a growing body of relevant corporate disclosure guidance offers a starting point.

Physical Climate Risk Disclosure Guidance

Several voluntary reporting frameworks have emerged to facilitate standard disclosure and greater transparency on sustainability issues in corporate reporting.[3] To inform meaningful disclosure, the frameworks provide guidance for measuring and assessing sustainability issues, including climate-related physical risks. Regardless of whether companies and financial organizations produce the recommended disclosures, the guidance signals which climate-related physical risks to focus on and how to assess those risks as part of the process of producing disclosures.

The most prominent disclosure guidance for assessing climate-related physical risks comes from CDP (formerly known as the Carbon Disclosure Project), the Climate Disclosure Standards Board (CDSB), the Global Reporting Initiative (GRI), the Sustainable Accounting Standards Board (SASB), the Task Force on Climate-Related Financial Disclosures (TCFD), and the EU Non-financial Reporting Directive (NFRD). Their frameworks approach sustainability reporting from various vantage points and serve slightly different purposes, as outlined in Appendix A, Table A1.

Collectively, these initiatives provide a valuable set of publicly available resources to guide climate-related risk assessment and disclosure. But research efforts designed to test and advance the approaches for assessing the financial impacts of physical climate risks indicate that gaps remain.[4] This paper revisits the guidance from existing frameworks to further explore the gaps in resources for identifying and assessing the entire set of physical risks forewarned by climate science.

How This Paper Is Structured

The paper begins by presenting a baseline summary of physical climate hazards according to climate science literature from the Intergovernmental Panel on Climate Change (IPCC). We then analyze the guidance available through existing disclosure initiatives. We examine the extent to which the initiatives' coverage of physical hazards aligns with climate science, and whether they reference robust methodologies for assessing physical risks for recommended disclosures. From this assessment, we identify gaps in existing disclosure guidance and establish where further work is needed to enable companies and financial organizations to accurately assess physical risks.

2. APPROACH

Review of Physical Climate Hazards in IPCC Reports

We developed a comprehensive list of physical hazards posed by climate change based on a review of recent literature from the IPCC. The IPCC is the UN body tasked with providing regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation (IPCC 2020). We focused on IPCC reports because the body is widely recognized as the top authority on climate science (Australian Government n.d.; Joyce 2018).

To develop our list of physical climate hazards, we included events or trends that are physical *and* climate-related. In this context, *physical* refers to the abiotic (nonliving) components of natural ecosystems. Physical climate hazards are natural processes or phenomena of atmospheric, hydrological, or oceanic nature (WMO and UNESCO 2013; World Bank 2020). These hazards can be measured in physical terms and quantified by indices such as degrees Celsius (temperature), meters per second (wind), millimeter (precipitation), square kilometer (burned areas of wildfire), and the Standardized Precipitation Index (drought).[5] We classified the hazards into two categories, acute and chronic, aligning with the framework developed by the TCFD (see glossary for definitions) (TCFD 2017).

Physical climate hazards can have nonphysical cascading impacts on interconnected ecological, social, financial, and economic systems (Woetzel et al. 2020). This includes, for example, changes in species distribution (e.g., disappearance of pollinators or pest-controlling species), changes in disease (e.g., distribution of tropical diseases), and changes in economic growth rate. While these cascading impacts can cause further adverse consequences, they are nonphysical in nature and therefore fall outside the scope of our physical climate hazard classification. However, given that they are outcomes of physical climate hazards, they remain an important component of physical risk assessment. We assume that a comprehensive risk assessment of underlying hazard(s) would account for all relevant cascading impacts (for example, an assessment of drought risk would capture changes in agricultural productivity, where relevant). At the same time, we acknowledge that significant challenges remain to assessing risks related to cascading impacts from climate change and that future research in this area will be important.

Our hazard classification also excludes monsoon systems and large-scale, dominant modes of climate variability such as El Niño–Southern Oscillation (ENSO), the North Atlantic Oscillation/Northern Annular Mode (NAO/NAM), and the Southern Annular Mode (SAM). Hazards (such as temperature and precipitation) capture the effects of these climate phenomena (assuming they are measured with adequate frequency).

We reviewed the following six most recent IPCC reports that include an examination of physical hazards:

- Special report: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (2012)
- Contribution to Fifth Assessment Report of the IPCC (AR5): *Climate Change 2013: The Physical Science Basis* (2013)
- Contribution to the Fifth Assessment Report of the IPCC (AR5): *Climate Change 2014: Impacts, Adaptation, and Vulnerability* (2014)
- Special report: *Global Warming of 1.5°C* (2018)
- Special report: *The Ocean and Cryosphere in a Changing Climate* (2019)
- Special report: *Climate Change and Land* (2019)

Other groups have also developed classifications of physical hazards, notably, the EU Technical Expert Group on Sustainable Finance (TEG). The TEG's classification is comprised of four major hazard groups: water, temperature, wind, and mass movements. It is further divided into chronic and acute hazards within each group (TEG 2020). We did not adopt this classification because some hazards cannot be classified into a single hazard group. For example, wildfires are in the temperature-related group, but wind, water (dryness), and vegetation could all influence wildfires (USDA 2018). We arrived at a slightly different list of hazards from the TEG's classification. The difference could be due to subjectivity in summarization from IPCC reports and different scopes of literature review, as the TEG (2020) only reviewed the AR5 report. Appendix B provides an overview of the TEG's classification. Appendix C summarizes our key insights of physical hazards from IPCC reports.

Analysis of Disclosure Guidance

Scope

Disclosure guidance: Disclosure initiatives share a common objective of providing resources to help companies (and in some cases financial organizations) communicate sustainability performance in a consistent, transparent, and credible manner. While the desired output from disclosure guidance is reporting, the guidance also helps preparers identify and assess issues to be reported on, and often recommends methodologies and metrics. Collectively, such initiatives provide one of the few sources of publicly available and widely accepted guidance on physical climate risk assessment and therefore serve as an important indicator of the state of publicly available guidance. For this reason, they are the focal point of this research.

This guidance also plays an influential role in shaping the agenda of physical risk assessment. By recommending specific sustainability issues for disclosure, the initiatives send a strong signal about risk and in turn influence which physical climate hazards garner attention. By taking a closer look at the guidance, we can gain insight into the signals that companies and financial organizations are receiving about physical climate risk.

To be sure, disclosure initiatives are not the only source of physical risk guidance. A growing number of commercial climate data service providers offer proprietary risk analytics and related services (for a summary, see Acclimatise and UNEP-FI 2020). Many private sector entities rely on these services to supplement existing risk management processes, but not all companies or financial organizations can afford these services. Further, unlike the disclosure initiatives, which are not-for-profit endeavors, these analytics firms have commercial interests and therefore operate under a different set of incentives. For these reasons, we do not include these resources in our review. There is also a growing body of resources and process-oriented guidance targeted at asset owners and asset managers. For example, a recent report by the Institutional Investors Group on Climate Change provides practical guidance for investors on assessing and managing both risks and opportunities associated with physical climate hazards (IIGCCC 2020). These resources fall outside the scope of this research.

Inclusion criteria: We analyzed guidance from prominent disclosure initiatives that

- provide publicly available disclosure guidance;
- include explicit coverage of corporate disclosures related to climate change, including climate-related physical risk;[6]
- are applicable to any type of corporate organization; and
- have broad geographic focus.

To be included for consideration, the guidance had to have been published by August 2020. Using these criteria, we identified guidance from six initiatives for analysis, introduced earlier: CDP, CDSB, NFRD,[7] GRI, SASB, and the TCFD.[8]

Focus of analysis: While the disclosure guidance in our sample provide various resources for a range of sustainability and climate themes, this study exclusively focuses on their coverage of physical climate risks in their publicly available guidance documents. Other aspects of the guidance are not considered. Further, while the ultimate purpose of the guidance under review is to inform effective disclosure, we exclusively examine the extent to which the guidance informs comprehensive risk assessment. The quality of disclosure is not within our scope.

Given that our aim is to understand the state of publicly available resources for physical climate risk assessment, our analysis centers on the collective body of existing guidance. Under this approach, we do not evaluate the strength of individual disclosure frameworks or provide a comparative assessment of the guidance across initiatives.

Analytical Framework

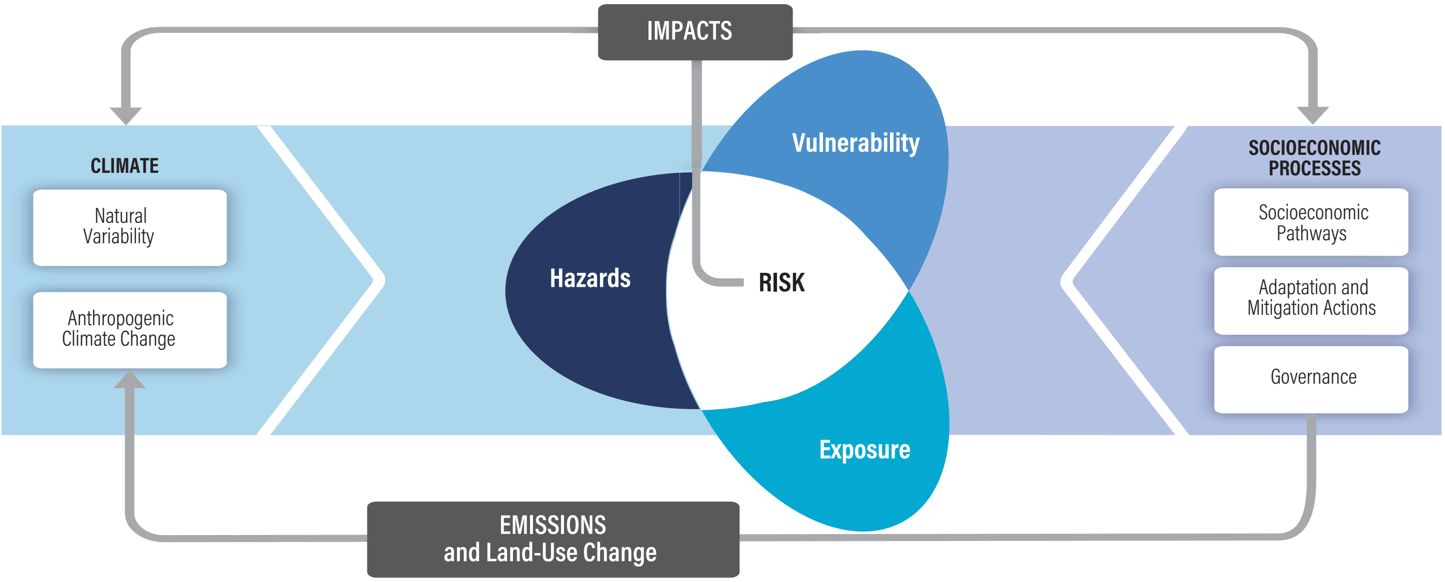
We developed a framework to analyze each initiative's physical climate risk guidance across its relevant guidance documents. We used the analytical framework to evaluate the extent to which a given document provides the following guidance:

- *Defines physical risk*. Defines physical climate risk and distinguishes among the concepts of hazards, exposure, vulnerability, impacts, and risk—in alignment with the IPCC's climate risk framework.
- *Provides broad qualitative guidance*. Considers physical climate risk across different dimensions (e.g., value chain, geographies, time horizons).
- *Identifies physical climate hazards*. Covers the full range of physical climate hazards, as included by recent IPCC reports.
- *Provides specific metrics*. Aids companies' granular, quantitative assessments across the different factors that influence the risk of climate-related impacts.

The paper's analytical framework comprises 18 indicators across the four categories. Appendix D provides an overview of the full framework as well as explanations of each indicator.

Our analytical framework draws on the IPCC's climate risk function (2012; updated in 2014) which provides a strong foundation for physical climate risk assessment. Physical climate risk is a function of the probability of a given hazardous event or trend occurring (at a given magnitude), the level of exposure, and the level of vulnerability.[9] The level of exposure and vulnerability determines the impacts of the risk should the specific hazard occur. Impacts, in this function, include the potential financial consequences of the occurring hazard for the business or financial organization (see Figure 1). These three factors of risk—potential occurrence of hazards, level of exposure, level of vulnerability—are essential building blocks for comprehensively assessing physical climate risk and its impacts.[10] The third and fourth pillars in our analytical framework consider the degree to which the disclosure frameworks incorporate these factors into physical risk assessment guidance.

Figure 1 | **The Intergovernmental Panel on Climate Change's Climate Risk Function: Physical Climate Risk and Associated Impacts Are a Function of Hazards, Exposure, and Vulnerability**



Source: IPCC (2014b, p. 3).

While other risk assessment frameworks are available to the private sector, we used the IPCC's risk function to inform our analytical framework because of its explicit focus on physical climate risk. However, we recognize that for the private sector, understanding physical climate risk is one component of a broader risk management approach. Various resources are available to help businesses leverage existing enterprise risk management processes to identify, assess, and manage sustainability-related risks like those stemming from climate change. For instance, the Committee of Sponsoring Organizations of the Treadway Commission (COSO) and World Business Council for Sustainable Development partnered to produce guidance on integrating ESG risks into COSO's enterprise risk management framework. This guidance suggests using relevant resources to assist in the identification and assessment of ESG risks, and it cites the IPCC as a resource when discussing assessment approaches to measure risk severity.

Just after we finalized the research for this paper, the TCFD published a new report that provides additional guidance on managing and disclosing climate-related risks in line with the TCFD (2020) recommendations. Rather than prescribing specific risk management frameworks or approaches, the guidance focuses on integrating climate-related risks into companies' existing risk management processes and disclosing information about those processes. This report, which is not included in our analysis, warrants consideration alongside the findings of our paper.

Framework Application

We applied the framework to each initiative's disclosure guidance, gathering data from relevant guidance documents, to complete responses for each indicator (see Appendix E for the full list of documents reviewed). To ensure consistent application across the sample, we conducted two independent reviews for each initiative. The full framework application results can be found online at https://files.wri.org/s3fs-public/disclosure-guidance-review-framework.xlsx.

To ensure that we reviewed the correct set of documents and to get feedback on our approach, we conducted a combination of semistructured interviews and written requests for feedback with staff from each disclosure initiative. We also invited representatives from each disclosure initiative to review the results of the framework application, as well as a draft of the paper, during the external review process for this working paper.

Using the results of the framework, we took stock of indicator responses across initiatives and analyzed the extent to which the identified metrics cover the range of physical climate hazards identified in our IPCC review. This analysis helps to highlight gaps in metrics and methodologies across the five identified physical climate risk factors and across the range of hazards.

3. REVIEW OF PHYSICAL CLIMATE HAZARDS IN IPCC REPORTS

We identified 18 types of physical hazards included in the six IPCC reports. Seven of them are chronic and 11 of them are acute physical hazards (see Table 1).

Some physical hazards are well understood by scientists and can be quantitatively simulated under numerous future scenarios, while others can only be qualitatively assessed. IPCC reports provide a confidence metric to qualitatively evaluate the validity of each key finding, based on the type, amount, quality, and consistency of evidence and the degree of agreement.[11] If a finding can be quantified probabilistically, IPCC reports add a likelihood term—a calibrated language scale—to communicate assessed probabilities.[12] Only 10 of the 18 physical hazards have findings with assigned likelihood terms, most of them related to temperature and water.[13] There is usually high or very high confidence—high validity—for findings with a likelihood term (IPCC 2014a).

Most findings in IPCC reports are at the regional or global level. Findings in IPCC reports on physical risk hazards, including observations and future projections,

Table 1 | **WRI's Classification of Physical Climate Hazards Included in Intergovernmental Panel on Climate Change (IPCC) Reports**

CHRONIC PHYSICAL HAZARDS	
NAME	**DEFINITION**
Change in precipitation patterns	Increase or decrease in precipitation annually and seasonally.
Ice melt/permafrost melt	Progressive loss of sea ice, glacier, or ground (soil or rock and included ice and organic material) that remains at or below 0°C for at least two consecutive years.
Ocean acidification	A reduction in the pH of the ocean, accompanied by other chemical changes (primarily in the levels of carbonate and bicarbonate ions), over an extended period, typically decades or longer.
Sea level change	Change to the height of sea level, both globally and locally (relative sea level change) at seasonal, annual, or longer time scales due to (1) a change in ocean volume as a result of a change in the mass of water in the ocean (e.g., due to melt of glaciers and ice sheets), (2) changes in ocean volume as a result of changes in ocean water density (e.g., expansion under warmer conditions), (3) changes in the shape of the ocean basins and changes in Earth's gravitational and rotational fields, and (4) local subsidence or uplift of the land.
Sustained temperature rise	A gradual increase in overall temperature.
Water stress	High ratio of total water withdrawals to available renewable surface and groundwater supplies.

ACUTE PHYSICAL HAZARDS		
NAME	**DEFINITION**	**EXTREMES CATEGORY**
Drought	A period of abnormally dry weather long enough to cause a serious hydrological imbalance. *Drought* is a relative term and must refer to the particular precipitation-related activity that is under discussion.	Driven by multiple atmospheric variables and/or surface properties
Dust storm	The result of terminal winds raising large quantities of dust into the air and reducing visibility at eye level (1.8 meters) to less than 1,000 meters.	Driven by multiple atmospheric variables and/or surface properties
Extreme precipitation	Precipitation that is rare (unusually low or high) in a particular place and at a particular time of year. An extreme event would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations.	Weather and climate variables

Table 1 | **WRI's Classification of Physical Climate Hazards Included in Intergovernmental Panel on Climate Change (IPCC) Reports (Cont'd)**

ACUTE PHYSICAL HAZARDS		
NAME	**DEFINITION**	**EXTREMES CATEGORY**
Extreme sea level (storm surge)	The temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions (low atmospheric pressure and/or strong winds).	Driven by multiple atmospheric variables and/or surface properties
Extreme temperatures	Temperature that is rare (unusually low or high) in a particular place and at a particular time of year. An extreme event would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations.	Weather and climate variables
Extreme winds	Wind speed that is rare (unusually low or high) in a particular place and at a particular time of year. An extreme event would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations.	Weather and climate variables
Flood	The overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas that are not normally submerged.	Driven by multiple atmospheric variables, and/or surface properties
Hail	A form of precipitation consisting of solid ice.	Driven by multiple atmospheric variables and/or surface properties
Landslides	A mass of material that has moved downhill because of gravity, often assisted by water when the material is saturated.	Driven by multiple atmospheric variables and/or surface properties
Tornadoes	A violently rotating column of air touching the ground; usually attached to the base of a thunderstorm.	Driven by multiple atmospheric variables and/or surface properties
Tropical cyclones	The general term for a strong, cyclonic-scale disturbance that originates over tropical oceans. Distinguished from weaker systems (often named tropical disturbances or depressions) by exceeding a threshold wind speed. A tropical storm is a tropical cyclone with 1-minute average surface winds between 18 and 32 m s^{-1}. Beyond 32 m s^{-1}, a tropical cyclone is called a hurricane, typhoon, or cyclone, depending on geographic location.	Weather and climate phenomena that are extremes themselves
Wildfires	Uncontrolled fires that burn in wildland vegetation, often in rural areas.	Driven by multiple atmospheric variables and/or surface properties

Note: Categories of acute physical hazards (extremes) are adapted from IPCC (2012).

Source: WRI authors, based on a review of reports from the IPCC (2014a, 2012, 2018, 2019a, 2019b).

are usually described for a given geographical area (for example, global or the Mediterranean) in a certain time period. Future projections are made using climate models to simulate changes based on a set of scenarios and are usually presented in IPCC reports as heat maps.

Physical hazards that are driven by multiple variables and surface properties are less understood because of their complexity, especially some acute physical hazards. Acute physical hazards are event-driven, and these events have not been consistently recorded for a long enough duration to produce sufficient observational evidence to determine a causal relationship between the hazard and human-induced climate change (IPCC 2014a). In addition, the incomplete understanding of the physical mechanisms linking some hazards (for example, tropical cyclones) to climate change creates difficulties for scientists seeking to simulate those events into the future using climate scenarios (IPCC 2012; Knutson et al. 2017). A growing body of climate attribution studies yield useful findings about human influence on physical hazards (AMS 2019; Schiermeier 2018).

IPCC reports provide examples of how some sectors are vulnerable to climate change, including tourism, agriculture, insurance, health care, transport, real estate, and utilities (IPCC 2014b). The risks of climate-related impacts increase with the rates and magnitudes of temperature rise, sea level change, and other dimensions of climate change (IPCC 2015). To help demonstrate how these risks translate to a business context, Appendix F lists some of the impacts of various physical-climate hazards across different sectors, as outlined by IPCC reports.

The next generation of climate models will improve the understanding of the complex interactions between climate and socioeconomic factors. IPCC's Sixth Assessment Report (AR6), to be released in 2021, will use outputs from the sixth and latest phase of the Coupled Model Intercomparison Project (CMIP6) (IPCC 2017). CMIP6's climate projections will be based on an updated set of representative concentration pathways (RCPs: scenarios based on different greenhouse gas concentration trajectories), plus, for the first time, a set of shared socioeconomic pathways (SSPs: scenarios based on different socioeconomic assumptions). SSPs and RCPs would each become an axis in a matrix forming the new scenarios (O'Neill et al. 2016).

There is enough evidence showing that the world had already warmed by 1°C in 2017 relative to the period 1850–1900 and that climate change has already affected ecosystems, human well-being, and business (IPCC 2018). The effects on companies can be varied and widespread, including supply chain disruptions, reduced productivity, or legal liabilities. Appendix G provides a few real-world examples of how severe weather events, which are expected to become more frequent and intense in the coming decades, have already caused negative financial impacts for companies. These include PG&E's bankruptcy following wildfires in California, disruptions in the hard drive industry from flooding in Thailand, and losses in electricity generation resulting from heatwaves and droughts in Europe. In the next section, we assess whether companies and financial organizations have the guidance they need to adequately assess climate-related physical risks.

4. ANALYSIS OF PHYSICAL RISK GUIDANCE FROM DISCLOSURE INITIATIVES

Our analysis of existing physical risk guidance from leading disclosure initiatives revealed several insights about the body of guidance.

Terminology and Alignment with IPCC's Physical Risk Function

The definitions of physical climate risk and other key concepts related to physical climate risk vary across initiatives and in most cases do not align with those used by the IPCC. While most initiatives include a definition of physical climate risk in the guidance documents, the term *physical risk* is often used colloquially to describe physical climate hazards. While some of the guidance documents reference key factors in the IPCC's risk function—like *hazard*, *exposure*, *vulnerability*, and *impacts*—most do not clearly define these terms or use them in a consistent manner (Appendix H outlines relevant definitional language for each initiative).

Moreover, most guidance documents do not clearly outline the relationship between the factors in the IPCC's risk function. As highlighted in Section 2 above, the IPCC presents physical climate risk as a function of the probability of hazardous events occurring multiplied by the level of exposure and vulnerability; with the impacts of the risk (adverse consequences) determined by exposure and vulnerability should the hazardous event or trend occur. None of the physical risk guidance documents consistently draw on this foundation, or any other clearly defined risk framework, to guide comprehensive physical risk assessment.

Coverage of Physical Climate Hazards

Certain hazards are well covered in guidance, others are not referenced at all. The most frequently referenced IPCC-highlighted hazards are sea level change, water stress, and sustained temperature rise. Five IPCC-highlighted hazards are not mentioned in any guidance documents: dust storms, ocean acidification, ice melt/permafrost melt, tornadoes, and hail. It is unclear if these hazards were considered but intentionally excluded, and if so for what reason. Table 2 displays the coverage levels of the 18 IPCC hazards across the initiatives.

Some initiatives also mention other hazards outside of the 18 physical hazards identified in our IPCC review. These include the use of broader terms for hazards such as *storms*, *extreme weather events*, and *changing weather patterns*, as well as cascading impacts

Table 2 | **Coverage of Physical Climate Hazards in Guidance Documents**

	HAZARD	COVERAGE LEVEL[a]
IPCC: Chronic physical hazard	Change in precipitation patterns	High
	Ice melt/permafrost melt	None
	Ocean acidification	None
	Sea level change	High
	Sustained temperature rise	High
	Water stress	High
	HAZARD	**COVERAGE LEVEL**
IPCC: Acute physical hazard	Extreme temperatures	High
	Extreme precipitation	Low
	Extreme winds	Low
	Drought	High
	Floods	High
	Extreme sea level (storm surge)	Low
	Tornadoes	None
	Hail	None
	Dust storms	None
	Landslides	Low
	Wildfires	High
	Tropical cyclones	High

Notes: Coverage level is determined by an explicit reference to a given hazard within the guidance documents. High coverage indicates that the hazard was clearly and directly referred to in the guidance documents of three or more initiatives; low coverage indicates that the hazard was clearly and directly referred to in the guidance documents of one to two initiatives; none indicates that the hazard was not referred to in the guidance documents of any initiative. The use of broad terms, like storms, is not counted as coverage of the various hazards that fall within that category. The list of hazards was developed by WRI based on a review of reports by the Intergovernmental Panel on Climate Change. Our sample includes guidance documents from CDP, the Climate Disclosure Standards Board, the EU Non-financial Reporting Directive, the Global Reporting Initiative, the Sustainability Accounting Standards Board, and the Task Force on Climate-Related Financial Disclosures.

[a] We found no linkage between low or no coverage and low or no likelihood information in IPCC reports.

Source: WRI authors.

that result from physical hazards. Most cascading impacts referenced in the guidance relate to changes in ecosystem productivity, such as variation in agricultural yield and growing season, declining ecosystem services, and biodiversity loss (see Box 1).

Scope of Guidance, Metrics, and Data

The physical risk guidance provided by disclosure initiatives is wide-ranging in scope, informing assessment of physical risk across various dimensions. For example, the guidance not only focuses on risks within an organization's direct business operations and assets but also throughout different parts of its value chain (supply chains, downstream value chain, etc.), and across geographic locations. The initiatives consistently underscore the importance of including forward-looking assessment across different timescales as part of the physical risk assessment. They suggest using scenario analysis to inform such assessment.

Some guidance documents refer to specific metrics and data sources to inform quantitative risk assessments—but, collectively, they do not provide or refer to a comprehensive set of resources for quantifying physical climate risk.[14] This would include metrics or detailed methods to assess each of the factors in the IPCC's risk function: the underlying hazard in physical terms; the entity's exposure and vulnerability to the hazard; potential impacts of the hazard; and/or a

Box 1 | Disclosure Guidance Coverage of Cascading Impacts from Physical Climate Hazards

Widespread evidence shows that impacts from physical climate hazards can spread through interconnected ecological, social, financial, and economic systems (IPCC 2014b). Cascading impacts can happen when a hazard's impact flows to domains beyond the one directly affected because of interactions and feedback loops between them (Lawrence et al. 2020). These impacts form an important part of the physical climate risk analysis. They include consequences such as shifting growing seasons, changes in species distribution, increased spread of disease, and changes in employment and economic growth rate.

Cascading impacts can have wide-ranging effects within biological and human systems. Some impacts can be intermediaries of large, complex, and interconnected systems and can have a ripple effect on people's livelihoods and businesses. For example, in biological systems, changes in the distribution of marine species and invasive weeds can cause declines in food production, which can drive increases in food prices, leading to higher risk of undernutrition, especially in poor regions (IPCC 2014b).

In human systems, for example, increased risks of food-, water-, or vector-borne diseases can have negative impacts on human health, which can lead to lost work capacity and reduced labor productivity (IPCC 2014b). Although there is no direct evidence that climate change is influencing the spread of COVID-19 as of 2020, climate change increases the risk of pandemics (Harvard University 2020). In addition, physical climate hazards may overlap with pandemics, including the COVID-19 pandemic, disrupting efforts to contain diseases and delaying recovery (Martinez-Diaz and Sidner 2020). Physical climate hazards can also increase the risk of violent conflict and reduced economic growth, which can pose risks to companies and financial organizations (IPCC 2014b).

The disclosure guidance is heavily focused on what we consider physical climate hazards. However, most initiatives also include some coverage of cascading impacts. Across the initiatives we found reference to the following cascading impacts:

- Biodiversity loss
- Changes in land and soil productivity
- Changes in species distribution
- Declining ecosystem services
- Deforestation
- Human disease
- Increased ecosystem vulnerability
- Variation in agricultural yield and growing seasons

Among these referenced hazards, only two were noted by more than one initiative: changes in species distribution and human disease.

Source: WRI authors.

complete risk metric. For most hazards, we did not find a reference to a full set of specific metrics for assessing these factors.

In many cases, the referenced metrics are composite in nature, meaning they incorporate several factors of risk as outlined in the IPCC's risk function (hazard, vulnerability, exposure, impact, and risk). It is difficult to tell the extent to which these composite metrics cover each of the distinct factors of the IPCC's risk function and aid in meaningful risk assessment.

The guidance documents only reference physical hazard metrics and data for five hazard areas: flooding, sea level change, sustained temperature rise, water stress, and changes in precipitation patterns.[15] There are no references to metrics that measure the occurrence of any other hazards (as shown in Table 3).

Table 3 | **Physical Hazard Metrics Referenced within Guidance Documents (Exhaustive)**

	HAZARD	PHYSICAL METRICS REFERENCED	DISCLOSURE INITIATIVE
IPCC: Chronic physical hazard	Sustained temperature rise	Indicative change in average surface temperature (2016–35 and 2046–65)	TCFD
	Change in precipitation patterns	Indicative precipitation maps (2016–35 and 2046–65)	TCFD
	Water stress	Baseline water stress	CDP, SASB, TCFD
		Water depletion	CDP
		Indicative water supply and demand map 2030	TCFD
	Sea level change	Projected ensemble mean sea level change (model projection averages) from 1986–2005 to 2081–2100	TCFD
	Ocean acidification	None	None
	Ice melt/permafrost melt	None	None
IPCC: Acute physical hazard	Extreme temperatures	None	None
	Extreme precipitation	None	None
	Extreme winds	None	None
	Drought	None	None
	Flood	100-year flood zone	SASB
		Designated flood zone	TCFD
	Extreme sea level (storm surge)	None	None
	Tornadoes	None	None
	Hail	None	None
	Dust storms	None	None
	Landslides	None	None
	Wildfires	None	None
	Tropical cyclones	None	None

Notes:

CDP = formerly Carbon Disclosure Project; SASB = Sustainability Accounting Standards Board; TCFD = Task Force on Climate-Related Financial Disclosures.

This table presents quantitative metrics for assessing relevant climate data to understand the physical climate hazards. It does not include metrics for assessing exposure or vulnerability to these hazards, or the impact from these hazards (examples of which are presented in Table 5). Our sample includes guidance documents from CDP, the Climate Disclosure Standards Board, the EU Non-financial Reporting Directive, the Global Reporting Initiative, the SASB, and the TCFD.

Source: WRI authors.

Hazards related to water stress and flooding have the most extensive set of hazard, vulnerability, and exposure metrics and data sources. In addition to the metrics for assessing the severity of water stress and flooding, the disclosure initiatives cite multiple metrics for assessing a company's exposure and vulnerability to them (shown in Table 4). But for most other hazards, not only are there no references to metrics for measuring the hazards (as shown in Table 4) but there are also few examples of hazard-specific metrics to inform other parts of the risk assessment (exposure, vulnerability, impact, or risk) for these hazards (shown in Table 5). In fact, we found that 16 hazards identified in our IPCC review lack hazard-specific metrics.

The guidance documents offer several hazard-agnostic metrics (metrics that do not explicitly refer to a single physical hazard and may apply to more than one hazard). In theory, if approached methodically and with significant expertise in relevant issues and resources, these could inform an accurate assessment of hazards for which hazard-specific metrics are not provided. Nearly all the impact metrics that we identified are hazard-agnostic, with a few exceptions. A sample of metrics referenced in the guidance documents is shown in Table 5.

Table 4 | **Sample Metrics for Assessing Water Stress and Flooding (Not Exhaustive)**

HAZARD	HAZARD METRIC	EXPOSURE/VULNERABILITY METRIC
Water stress	▪ Baseline water stress	▪ Amount/percentage of (fresh) water withdrawn in areas of high/extremely high baseline water stress
	▪ Water depletion	▪ Total volume of fresh water handled in operations
Flooding	▪ 100-year flood zone	▪ Value of mortgage loans in 100-year flood zones
	▪ Designated flood zone area	▪ Area of buildings, plants, properties located within a designated flood zone or flood hazard zone

Note: Our sample includes guidance documents from CDP, the Climate Disclosure Standards Board, the EU Non-financial Reporting Directive, the Global Reporting Initiative, the Sustainability Accounting Standards Board, and the Task Force on Climate-Related Financial Disclosures.

Source: WRI authors.

Table 5 | **Sample Exposure, Vulnerability, and Impact Metrics Referenced in Guidance Documents (Not Exhaustive)**

	RELEVANCE	METRIC	DISCLOSURE INITIATIVE
Exposure and vulnerability	Hazard-specific: Flooding	Number of lots/lodging facilities/properties/mortgage loans located in designated (or 100-year) flood zones.	SASB, TCFD
		Wastewater treatment capacity located in 100-year flood zones.	SASB
	Hazard-specific: Water stress	Percentage of water withdrawn in areas of high/extremely high baseline water stress.	SASB, TCFD, CDP
		Percentage of products/ingredients sourced from (or produced in) areas of high/extremely high baseline water stress.	SASB, TCFD, CDP

Table 5 | **Sample Exposure, Vulnerability, and Impact Metrics Referenced in Guidance Documents (Not Exhaustive) (Cont'd)**

	RELEVANCE	METRIC	DISCLOSURE INITIATIVE
Exposure and vulnerability	General: may apply to multiple hazards	Assets committed in regions likely to become more exposed to acute or chronic physical climate risks.	EU
		Total number (or percentage) of facilities exposed to water risk.	SASB
		Percentage of revenue dependent on water-intensive agricultural commodities.	CDP
		Locations within a coastal zone.	TCFD
		Percentage of land by cover type (e.g., grassland, forest, cultivated, pasture, urban).	TCFD
		Number of incidents of noncompliance with physical and/or cybersecurity standards or regulations (Sector: Electric Utilities and Power Generators).	SASB
Impact	Hazard-specific: may apply to water stress, flooding, drought, extreme precipitation, etc.	Total and potential financial impact (figure, min, max, magnitude) of the water-related detrimental impacts experienced.	CDP
	Hazard-specific: may apply to landslides, flooding, wildfires, etc.	Total and potential financial impact (figure, min, max, magnitude) for forest-related detrimental impacts experienced by your organization.	CDP
	General: may apply to multiple hazards	Total amount of monetary losses attributable to insurance payouts from modeled natural catastrophes, by type of event and geographic segment (Sector: Insurance).	SASB, EU
		Total expected loss and loss given default attributable to mortgage loan default and delinquency due to weather-related natural catastrophes, by geographic region.	SASB
		Number of unplanned service disruptions (Sector: Telecommunications).	SASB
		Potential financial impact (figure, min, max, magnitude) for risks identified with the potential to have a substantive financial or strategic impact on your business (Sector: All).	CDP
		Potential financial impact (figure, min, max, magnitude) of the water-related detrimental impacts experienced (Sector: All).	CDP
Risk	Hazard-specific: (none found)	-	-
	General: may apply to multiple hazards	Provide details of risks identified with the potential to have a substantive financial or strategic impact on your business: Likelihood Magnitude of impact Potential financial impact figure/minimum/maximum	CDP
		Probable maximum loss of insured products from weather-related natural catastrophes.	SASB

Notes: CDP = formerly Carbon Disclosure Project; SASB = Sustainability Accounting Standards Board; TCFD = Task Force on Climate-Related Financial Disclosures.

The table does not represent an exhaustive list of metrics referenced by the disclosure frameworks. Our sample includes guidance documents from CDP, the Climate Disclosure Standards Board, the EU Non-financial Reporting Directive, the Global Reporting Initiative, SASB, and the TCFD.

Source: WRI authors, based on a review of guidance documents from disclosure initiatives.

5. IMPLICATIONS

The gaps identified in our analysis suggest room for improvement in publicly available guidance and other resources for identifying and assessing physical climate risks. Companies and financial organizations that rely on disclosure guidance to guide physical risk assessment may be overlooking important aspects of physical risks. This could potentially lead to unmanaged risks, reduced resilience, and ultimately, financial losses.[16]

Our findings point to several developments that could increase the capacity of companies and financial organizations to identify and assess climate-related physical risks. Ensuring that resources are open-source should foster a stronger collective understanding, facilitate access by a wider range of companies and financial organizations around the world, and instill more rigor through transparency.

These resources include the following:

Thorough open-source translations of the IPCC's climate science geared toward the private sector. Our review indicates that the guidance from disclosure initiatives does not provide the private sector with a complete picture of climate science. The guidance helps provide an aggregate picture but misses potentially important nuances. For example, the absence of a clear, consistent physical climate risk function within the guidance may leave users without a clear understanding of the relationship between the key factors that determine risk. This is important because companies and financial organizations need information on each of these factors to fully assess the risk (Impax Asset Management 2020).

- *Research organizations should help synthesize IPCC literature for the private sector*. The IPCC already distills its analysis for policymakers. To help the private sector keep pace with the latest advances in climate science, research organizations should produce similar publicly available synthesis reports for the private sector audiences, ideally in collaboration with the IPCC. For example, these actors could collaborate to translate the IPCC's risk function into something more accessible and practical for companies. They should also consider translating advances in climate data, modeling, and attribution, which—by improving our ability to understand and quantify risks from climate-related events and trends—could help businesses and financial organizations adopt more robust physical risk assessment practices. This echoes similar calls for the modeling community to collaborate with industry players to make mitigation scenarios more useful to businesses and financial institutions (Weber et al. 2018), which is an area of rapid development.[17]
- *Disclosure initiatives and other organizations that develop physical climate risk assessment guidance should also continue to solicit input directly from scientists*. Disclosure initiatives tend to engage more heavily with representatives from the business and finance communities; to sharpen guidance on physical climate risk, they should take a more proactive approach to engaging with climate scientists.

High-quality, open-source, peer-reviewed datasets that convert scientific data on physical climate hazards into accessible and actionable formats for business and finance stakeholders.[18] An existing example is the Aqueduct Risk Atlas, which CDP, SASB, and the TCFD refer to in their guidance. While the relationship between data availability and the quality of related guidance for each hazard was beyond the scope of this research, we noted a correlation between hazard coverage across the disclosure initiatives and data availability. For example, water-related hazards—which have publicly available, readily accessible data—have the greatest coverage across initiatives.[19] This could relate to the availability of water-related research, data, and tools already in the public domain that convert scientific data for private sector actors. Another explanation for the high coverage is that water-related hazards represent a major risk to a large group of companies.

Further research is required to identify specific needs for additional high-quality, peer-reviewed, and open-source data and analytical tools for each hazard. Some efforts are already underway.[20] Further research is also needed on third-party data and service providers, given that many companies and financial organizations rely on these resources to inform their physical risk assessments. A thorough analysis of the scientific soundness of these services would help provide a more comprehensive understanding of the state of data resources.

- *Sustainability and climate data providers should focus on developing company- and investor-focused open-source data resources that cover the full range of physical climate hazards.* These data resources should expand beyond the well-covered hazards related to water. Raw outputs of climate models usually have low spatial resolution (43–248 miles), so an important task for data providers will be to downscale climate models and scenarios to finer resolution, or leverage models that are downscaled by scientists, based on the best available science (Navarro-Racines et al. 2020). Beyond downscaling the climate models, these data resources should present hazard data that are converted into usable inputs for business risk assessment (for example, translating scientific data into a quantitative hazard index).

Greater clarity from disclosure initiatives about why hazard coverage gaps may exist. Without an explanation in the disclosure guidance, it is unclear whether the exclusion is intentional or the result of misalignment with climate science (a problematic oversight).

- *Disclosure initiatives and other organizations that develop physical climate risk assessment guidance should refer to the full list of physical climate hazards outlined in this paper and provide a rationale for not covering any hazards on the list.* For example, for guidance that is oriented toward material issues note if a hazard is not material, if the hazard does not have enough accessible data to do a meaningful assessment, or if it simply is excluded because there is a very low level of confidence that the hazard will occur. If a broader category of hazards (e.g., “extreme weather”) is assumed to represent multiple subhazards, these hazards should be spelled out.

An open-source, science-based framework that provides a standard taxonomy for physical climate hazards with corresponding guiding principles and methods to quantify hazards, exposure, and vulnerability. Every company and financial organization faces a unique set of risks, shaped by context-specific factors such as sector of operations, location of assets, dependence on natural capital, exposure of supply chain, and adaptive capacities. While risk assessment will not look the same for all private sector entities, a common framework that serves as a standard foundation for undertaking physical climate risk assessment would help guide more complete, objective, and consistent assessment across physical climate risks. It will also aid those with less climate expertise and/or access to commercial resources.

- *Initiatives working to advance physical climate risk assessment guidance should collaborate to develop a science-based framework for assessing physical climate risks.* Building on current efforts (see EBRD and GCA 2018), this framework would include a taxonomy of physical climate hazards (for example, the one in this paper), a function for assessing the risk of climate impacts (for example, the one provided by the IPCC), as well as a consistent set of principles and ultimately metrics for assessing exposure and vulnerability to different hazards. It should also include methods for quantifying probabilities and impacts in a given region as part of a meaningful risk calculus and resources to inform forward-looking assessment across various timescales and scenarios. This would serve as a valuable starting point for physical risk assessment, which companies and financial organizations would further supplement with more detailed assessment methodologies—tailored to different business contexts and sectors. Once developed, disclosure initiatives should incorporate these elements into their guidance documents to promote consistent and widespread use.

  The development of this framework could follow an iterative process similar to the evolution of efforts to measure and manage greenhouse gas (GHG) emissions. It would start with a set of basic guiding principles and methods to measure hazards, exposure, and vulnerability in a thoughtful, consistent manner, as the GHG Protocol has done in the context of GHG emissions. Over time, these accounting methods could be built into broader decision-making frameworks, just as the GHG Protocol has become a key component of emissions-reduction strategies under the Science Based Targets Initiative. This approach would help foster more robust, standardized assessments of physical climate risks and their impacts.

Together these resources would increase the capacity of companies and financial organizations to assess climate-related physical risks in a consistent and comprehensive manner.

6. CONCLUSION

This paper set out to provide companies and financial organizations with a common understanding of climate-related physical risks according to climate science, identify gaps in guidance to assess those risks, and propose potential resources that would help meet needs for better assessment. Our research revealed gaps in both the coverage of physical climate hazards as well as the specificity of guidance for physical climate risk assessments (for instance, quantitative metrics). These findings are relevant for companies; financial organizations; environmental, social, and governance (ESG) ratings agencies; climate science data providers' disclosure or reporting initiatives; and others seeking to assess exposure to physical risks from climate change; as well as climate scientists and policymakers.

Going forward, it will be important for climate scientists and organizations that develop guidance for physical climate risk assessments to come together to address the gaps. This will help ensure that companies and financial actors properly recognize, measure, and manage physical climate risks, driving greater resilience and, to the extent possible, future-proofed business and financial decisions.

APPENDIX A. VOLUNTARY DISCLOSURE FRAMEWORKS

Table A1 | **Introduction to Voluntary Disclosure Frameworks That Provide Climate-Related Physical Risk Guidance**

INITIATIVE	DESCRIPTION	ISSUE FOCUS	PRIMARY AUDIENCES		ORIENTATION	APPLICABILITY
			PREPARERS	USERS		
CDP	A global environmental disclosure system that supports companies, cities, states, and regions in measuring and managing their sustainability risks and opportunities.	Climate change, water security, deforestation	Companies, governments. Preparers respond to specific CDP questionnaires.	Companies, government, investors, civil society	Financial risks and opportunities, impact	General and industry-specific
Climate Disclosure Standards Board (CDSB) Framework	An approach to help organizations prepare and present environmental and climate change information in mainstream corporate reports.	Environment, climate change, natural capital (air, water, land, minerals, forests, biodiversity, ecosystem health)	Companies. Preparers use the framework to integrate relevant information into their annual financial filings.	Investors	Financial risks and opportunities, impact	General
EU Non-financial Reporting Directive, Climate-Related Reporting Guidelines	Supplements the general EU guidelines on nonfinancial reporting with climate-related reporting guidelines that assist companies in disclosing climate-related information in a relevant, useful, consistent, and more comparable manner.	Climate change	Companies. EU-based companies follow nonfinancial reporting guidelines for disclosures in management reports or annual financial filings.	Companies, investors, employers, civil society	Financial risks and opportunities; impact	General
Global Reporting Initiative (GRI) Standards	Standards designed to help businesses, governments, and other organizations understand and communicate the impact of business on critical sustainability issues.	Climate change, human rights, governance, and social well-being	Companies. Preparers follow specific standards for sustainability disclosures in sustainability reports.	Government, investors, civil society	Impact	General
Sustainability Accounting Standards Board (SASB) Standards	Industry-specific, globally applicable standards that enable businesses to identify, manage, and report financially material sustainability information.	Environment, social capital, human capital, business model and innovation, leadership and governance	Companies. Preparers follow specific standards for sustainability disclosures in annual financial filings, annual reports, sustainability reports, on corporate websites, and elsewhere.	Investors	Financial risks and opportunities	Industry-specific
Task Force on Climate-Related Financial Disclosures (TCFD) Recommendations	Recommendations for voluntary, consistent, climate-related financial disclosures that provide information on climate-related risks and opportunities that is useful in decision-making and draws on standards and metrics from existing reporting protocols.	Climate-related financial risks	Companies, financial organizations. Preparers follow recommendations for climate-related disclosures in annual financial filings.	Financial organizations (asset managers, asset owners, lenders, insurers)	Financial risks and opportunities	General and industry- specific

Notes: CDP = formerly Carbon Disclosure Project.

In October 2020, the TCFD released new guidance on risk management integration and disclosure. This report is not included in our analysis as it was published after our research and review phases were complete (TCFD 2020).

Sources: CDP, CDSB, EU Non-financial Reporting Directive, GRI, SASB, and TCFD websites.

APPENDIX B. CLASSIFICATION OF PHYSICAL HAZARDS BY THE EU TECHNICAL EXPERT GROUP ON SUSTAINABLE FINANCE

The EU Technical Expert Group on Sustainable Finance (TEG) developed a classification of physical climate-related hazards (Table B1). The classification included four major physical hazard groups and was further divided into chronic and acute hazards. It was based on the Synthesis Report of the IPCC Fifth Assessment Report (AR5), which distills the findings of the three Working Group contributions to AR5.

Table B1 | **EU TEG Classification of Physical Hazards**

	TEMPERATURE-RELATED	WIND-RELATED	WATER-RELATED	SOLID MASS-RELATED
Chronic	Changing temperature (air, freshwater, marine water)	Changing wind patterns	Changing precipitation patterns and types (rain, hail, snow/ice)	Coastal erosion
	Heat stress		Precipitation and/or hydrological variability	Soil degradation
	Temperature variability		Ocean acidification	Soil erosion
	Permafrost thawing		Saline intrusion	Solifluction
			Sea level change	
			Water stress	
Acute	Heat waves	Cyclones, hurricanes, typhoons	Drought	Avalanche
	Cold waves/frost	Storms (including blizzards, dust storms, and sandstorms)	Heavy precipitation (rain, hail, snow/ice)	Landslide
	Wildfires	Tornadoes	Floods (coastal, fluvial, pluvial, groundwater)	Subsidence
			Glacial lake outbursts	

Source: TEG (2020).

APPENDIX C. REVIEW OF PHYSICAL CLIMATE HAZARDS IN IPCC REPORTS

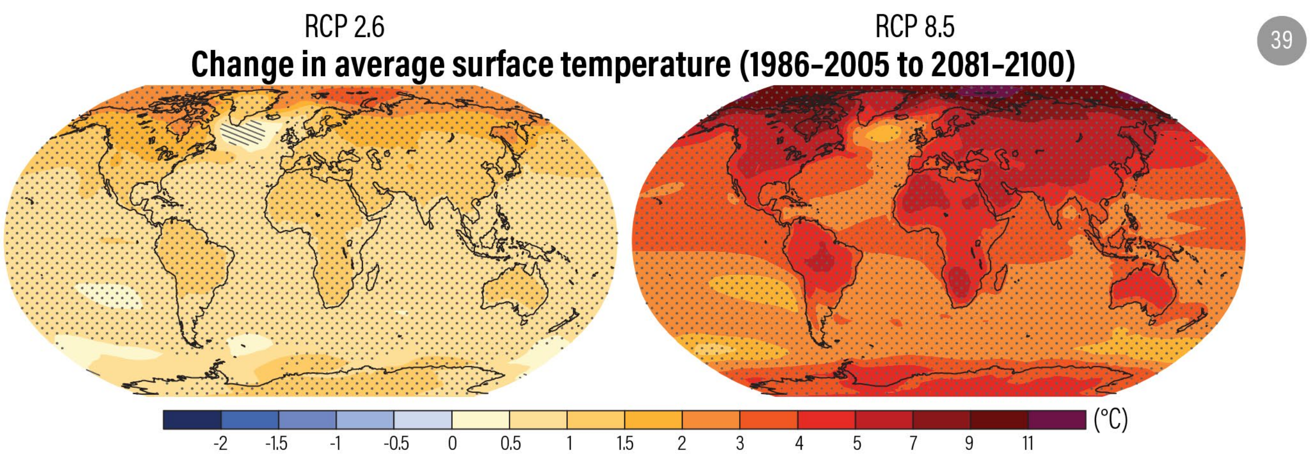
This appendix presents a summary description of the following physical climate hazards, as covered in the IPCC Reports.

- Sustained temperature rise and extreme temperatures
- Change in precipitation patterns, extreme precipitation, flooding, landslides, drought, water stress
- Sea level change, extreme sea level (storm surge), ocean acidification
- Tropical cyclones
- Tornadoes, hail, extreme winds, dust storms
- Ice melt/permafrost melt
- Wildfires

Sustained temperature rise and extreme temperatures

Temperature-related physical hazards were well documented in IPCC reports because multiple independently produced temperature datasets had existed since 1880. These datasets helped to build a scientific consensus on the relationship between global warming and the increasing atmospheric concentration of greenhouse gases (IPCC 2014a). They showed a global warming of 0.87°C for the decade 2006–2015 over the 1850–1900 period and a warming of 1.53°C for land surface for the same period (IPCC 2019a).[21]

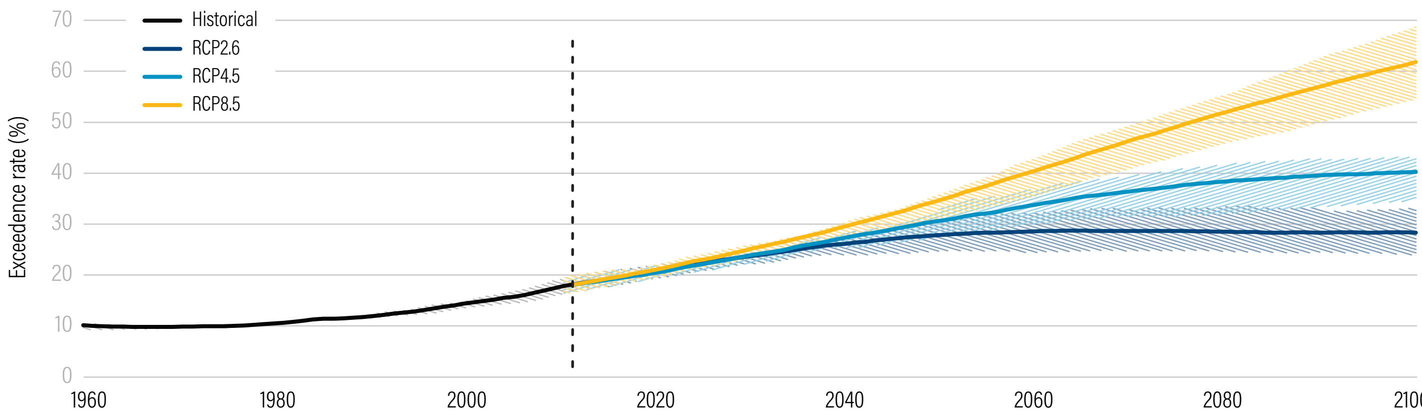
Figure C1 | **Coupled Model Intercomparison Project Phase 5 (CMIP5) Multimodel Mean Projections* for the 2081–2100 Period under the RCP2.6 (Left) and RCP8.5 (Right) Scenarios for Change in Annual Mean Surface Temperature**



Note: * The average of the model projections available. Stippling (dots) indicates regions where the projected change is large compared to natural internal variability (i.e., greater than two standard deviations of internal variability in 20-year means) and where 90% of the models agree on the sign of change. Hatching (diagonal lines) shows regions where the projected change is less than one standard deviation of natural internal variability in 20-year means. The number of models used to calculate the multimodel mean is indicated in each panel.
Source: IPCC (2015, p. 12).

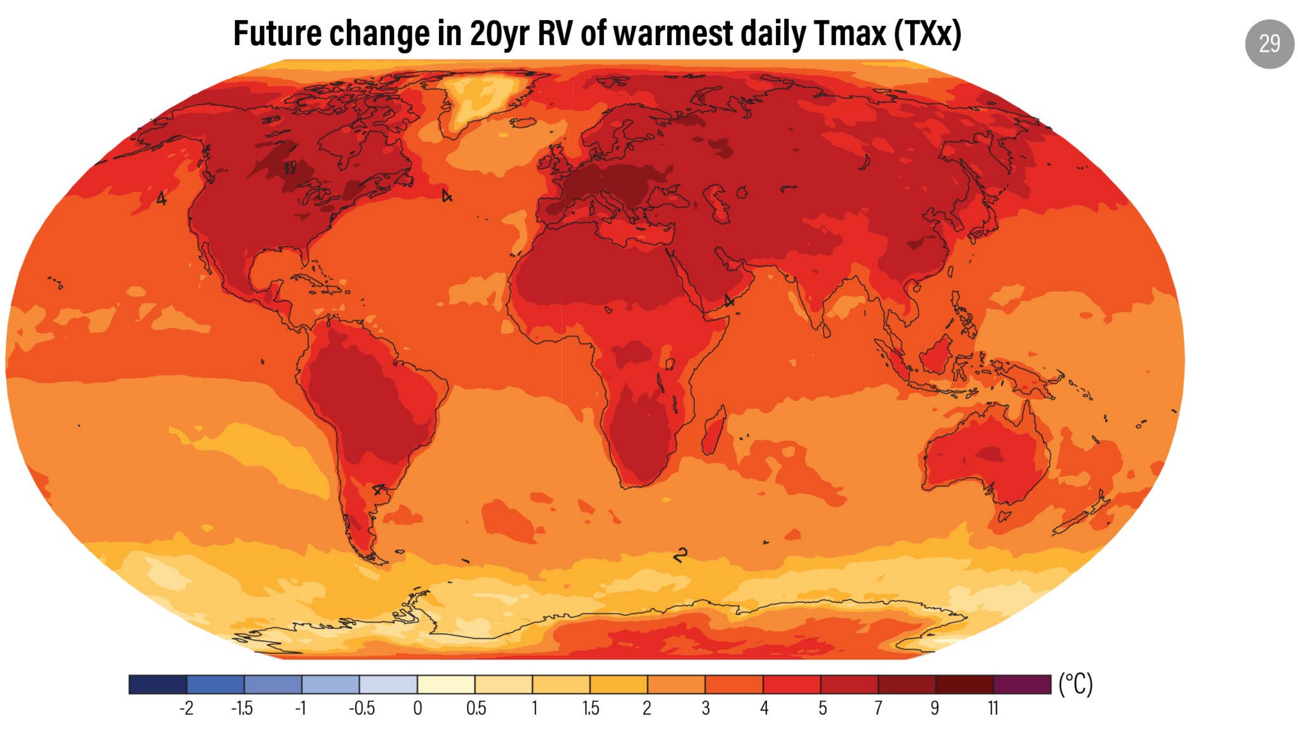
Climate models unequivocally project continued global warming in future climate scenarios, including the stringent mitigation scenario (RCP2.6). Dots on Figure C1 show regions where 90 percent of climate models agree on the sign of change. The models also project more frequent and more intense temperature extremes, such as heat waves, especially in high-emission scenarios (e.g., RCP8.5) (Figures C2 and C3). A current 1-in-20-year maximum temperature event will likely become an annual or a 1-in-2-year event in many regions by the end of the 21st century in high-emission scenarios (IPCC 2014a).

Figure C2 | Global Projections of the Occurrence of Warm Days—Percentage of Days Annually with Daily Maximum Surface Air Temperature (Tmax) Exceeding the 90th Percentile of Tmax for 1961 to 1990



Note: Results are shown from CMIP5 for the RCP2.6, RCP4.5, and RCP8.5 scenarios. Solid lines indicate the ensemble median, and shading indicates the interquartile spread between individual projections (25th and 75th percentiles).
Source: IPCC (2014a, p.111).

Figure C3 | The Change from 1986–2005 to 2081–2100 in 20-Year Return Values of Daily Maximum Temperatures Based on the CMIP5 RCP8.5 Scenario



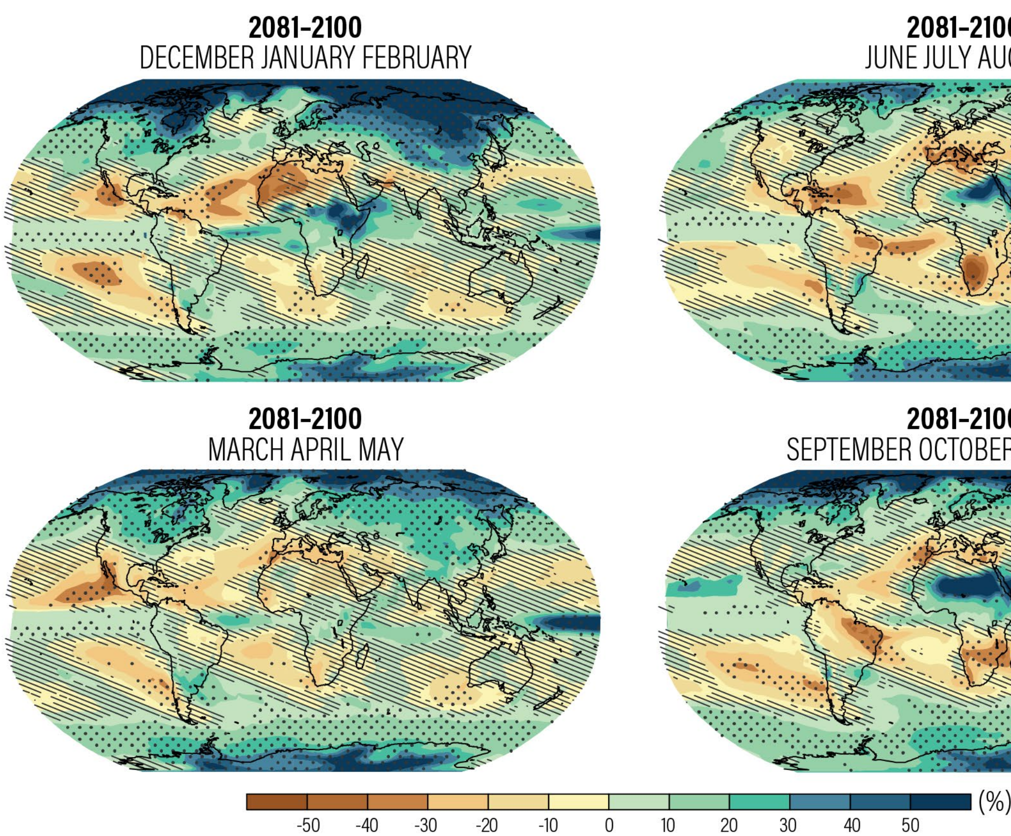
Note: The number of models used to calculate the multimodel mean is indicated in the top right corner.
Source: IPCC (2014a, p.111).

Change in precipitation patterns, extreme precipitation, flooding, landslides, drought, water stress

Although global precipitation on average is projected to increase in a warming climate, the changes will not be uniform seasonally and geographically (Figure C4). Unlike a relatively uniform warming climate across seasons, climate projections of precipitation changes show strong seasonal patterns. In some regions, the sign of the precipitation changes vary with the season. Geographically, the contrast of seasonal precipitation between dry and wet regions will increase in a warmer climate over most regions.[22] For example, under the RCP8.5 scenario, climate models project decreased precipitation in many areas already experiencing drying conditions, including the Mediterranean, the Caribbean, Central America, the southwestern United States, and South Africa, while they project increased precipitation in high latitudes and many midlatitude wet regions (IPCC 2014a).

Extreme precipitation events will become more intense and more frequent as global average surface temperature increases. Climate models project 20 percent more precipitation in very wet five-day periods globally under the RCP8.5 scenario by the end of 21st century, while some regions could have heavier precipitation (Figure C5).

Figure C4 | **Multimodel CMIP5 Average Percentage Change in Seasonal Mean Precipitation Relative to the Reference Period 1986–2005 Averaged over the Period 2081–2100 under the RCP8.5 Forcing Scenario**



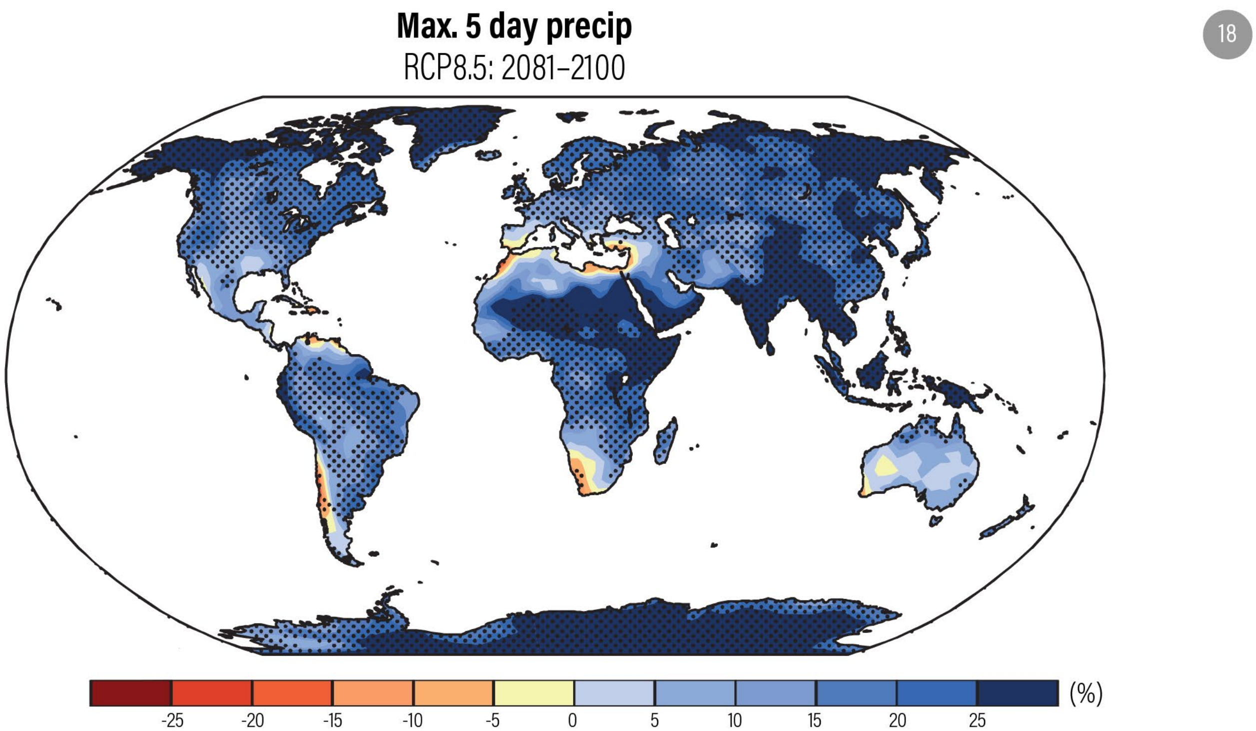
Note: Hatching indicates regions where the multimodel mean change is less than one standard deviation of internal variability. Stippling indicates regions where the multimodel mean change is greater than two standard deviations of internal variability and where at least 90% of models agree on the sign of change. The number of models used to calculate the multimodel mean is indicated in each panel.

Source: IPCC (2014a, p. 1078).

Although intense and/or long-lasting precipitation is one of the main causes of floods, other factors—including dams and land use—may alter flood probability (IPCC 2012). Due to the difficulty of separating contributions caused by climate change from those caused by human regulation of river systems, evidence is lacking regarding the trend in the magnitude and frequency of floods on a global scale. However, increasing trends in extreme precipitation detected recently imply greater risks of flooding in some regions (IPCC 2014a).

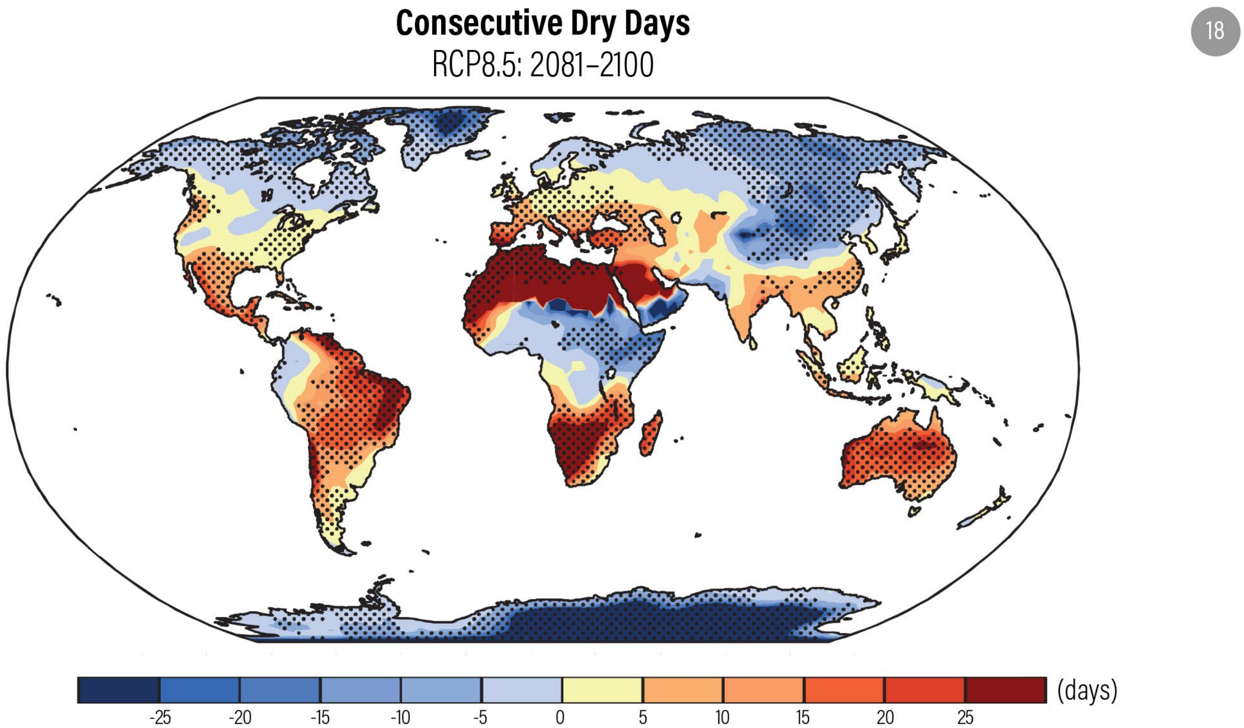
Climate models also project substantial increases in droughts in the Mediterranean, Central America, Brazil, South Africa, and Australia. Figure C6 shows projected changes of a drought index at the end of the 21st century measured by the length of the longest period of consecutive days without rain.[23] Drought could be defined from multiple perspectives depending on stakeholders; for example, soil moisture drought affecting crop production and hydrological drought affecting water supplies. Drought projections could be highly dependent on how drought is characterized using drought indices (IPCC 2012). Assessments of drought should consider most relevant indices related to exposures.

Figure C5 | **Projected Percentage Changes from the CMIP5 Models in the Annual Maximum Five-Day Precipitation Accumulation Relative to the 1981–2000 over the 2081–2100 Period in the RCP8.5 Scenario**



Note: Stippling indicates grid points with changes that are significant at the 5% level using a Wilcoxon signed-ranked test. The number of models used to calculate the multimodel mean is indicated in the top right corner.
Source: IPCC (2014a, p.1038).

Figure C6 | **Projected Change in Annual CDD (the Maximum Number of Consecutive Dry Days when Precipitation Is Less than 1 Millimeter) over the 2081–2100 Period in the RCP8.5 Scenario (Relative to the 1981–2000 Reference Period) from the CMIP5 Models**



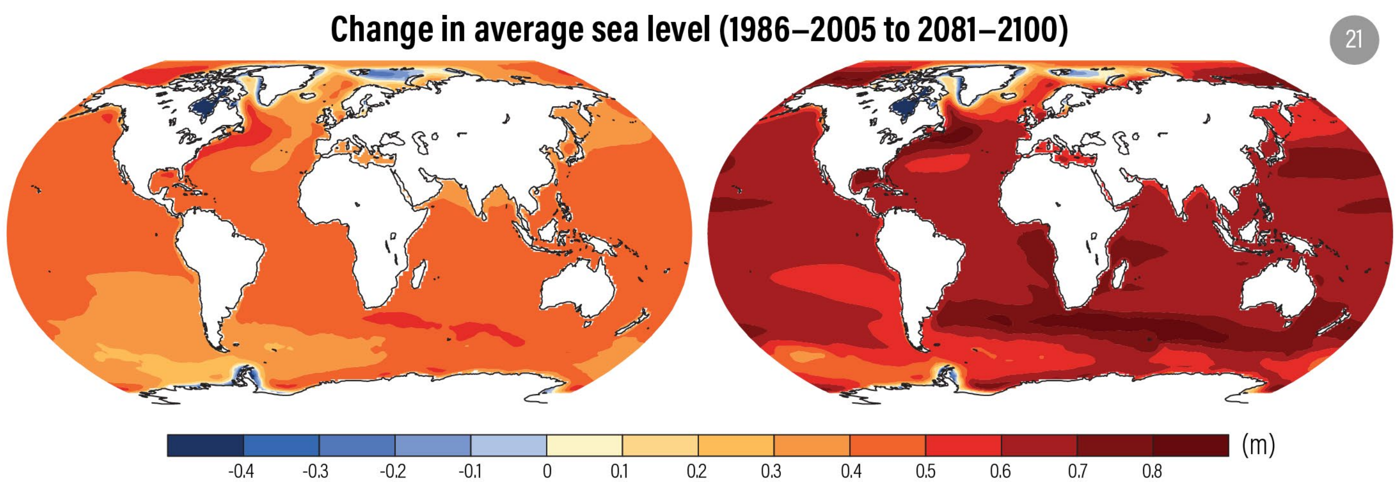
Note: Stippling indicates grid points with changes that are significant at the 5% level using a Wilcoxon signed-ranked test. The number of models used to calculate the multimodel mean is indicated in the top right corner.
Source: IPCC (2014a, p.1038).

Climate change is only half of the driver in influencing water stress through water supply. Water demand also has implications. Climate change drives changes in water supply, and socioeconomic factors drives changes in water demand. The latter are expected to have a greater influence than climate change (IPCC 2018). According to projections, 1 to 6 billion more people will live in water-stressed areas because of the combined effect of changes in water supply and demand (IPCC 2019a).

Sea level change, extreme sea level (storm surge), ocean acidification

Sea level change will accelerate during the 21st century and will not be uniform across regions. The observed rate of sea level change was 0.08 inch/year (2.0 millimeters/year) during 1971–2010. Under all climate scenarios, the rate of sea level change increases. The rate of rise for RCP8.5 during 2081–2100 of 0.3–0.6 inch/year (8–16 millimeters/year) will result in a 1.5–2.7 feet (0.45–0.82 m) rise in global mean sea level relative to the period 1986–2005 (Figure C7) (IPCC 2015). By the end of the 21st century, sea level change will have strong regional patterns, and many regions will experience different sea level change from the global average due to dynamic ocean circulation changes, changes in the heat content of the ocean, mass redistribution in the entire Earth system, and changes in atmospheric pressure. For example, the sea level change in North America could reach 30 percent above the global average values (IPCC 2014a). Sea level change will pose increasingly adverse impacts on coastal areas and ecosystems, including coastal erosion. A rise in mean sea level usually causes the shoreline to recede inland due to coastal erosion (IPCC 2014b).

Figure C7 | **CMIP5 Multimodel Mean Projections for Change in Average Sea Level (1986–2005 to 2081–2100 under the RCP2.6 (Left) and RCP8.5 (Right) Scenarios**

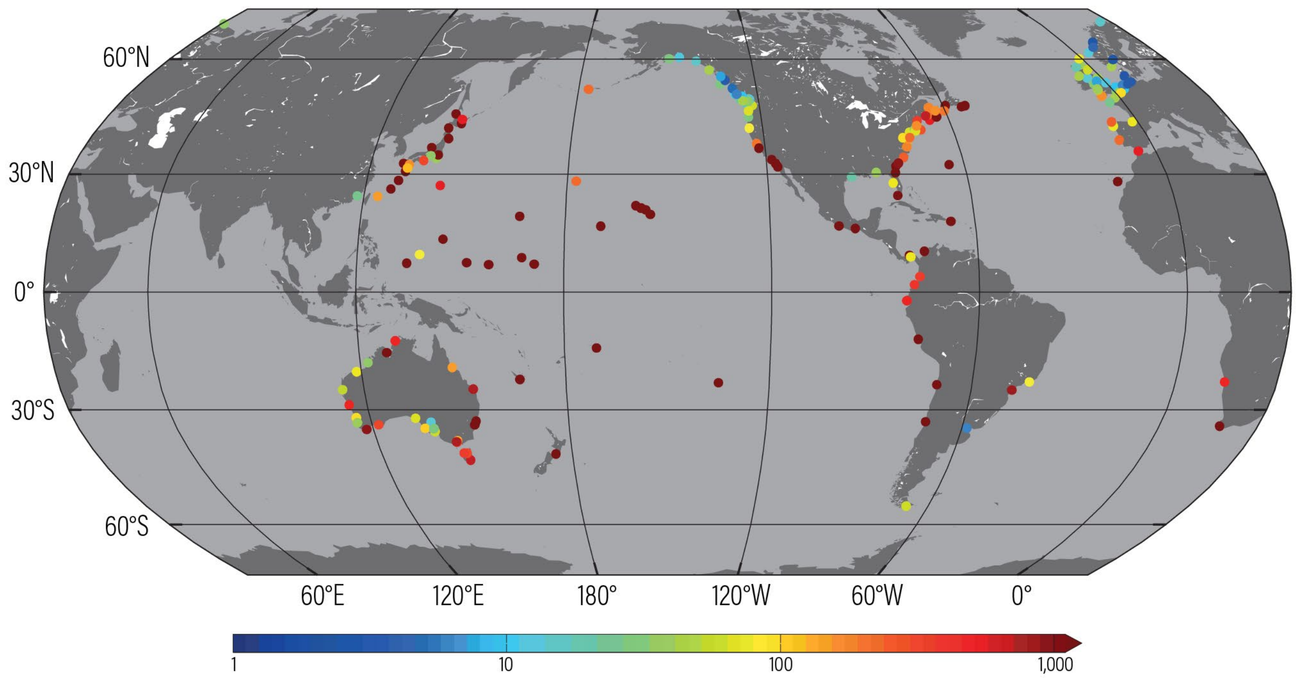


Note: The number of CMIP5 models used to calculate the multimodel mean is indicated in the upper right corner of each panel.
Source: IPCC (2015, p.61).

As a consequence of sea level change, coastal flooding or extreme sea level events, which are currently rare (e.g., with a return period of 100 years), will occur annually or more frequently at most locations for RCP8.5 by the end of the century. Because sea level change elevates the platform for storm surges and tides, a small increase in sea level can significantly increase the frequency and intensity of flooding. For example, storm surge levels for tropical cyclones will be higher because of sea level change, assuming all other factors are unchanged (IPCC 2019b). Figure C8 shows the estimated multiplication factor by which the frequency of sea levels exceeding a given height will be increased under the RCP4.5 scenario. Many coastal areas in the lower latitudes, East Asia, and the U.S. East Coast could experience a multiplication factor greater than 100. This indicates that what was currently a once-in-a-hundred-year flooding event will happen annually or more frequently due to sea level change.

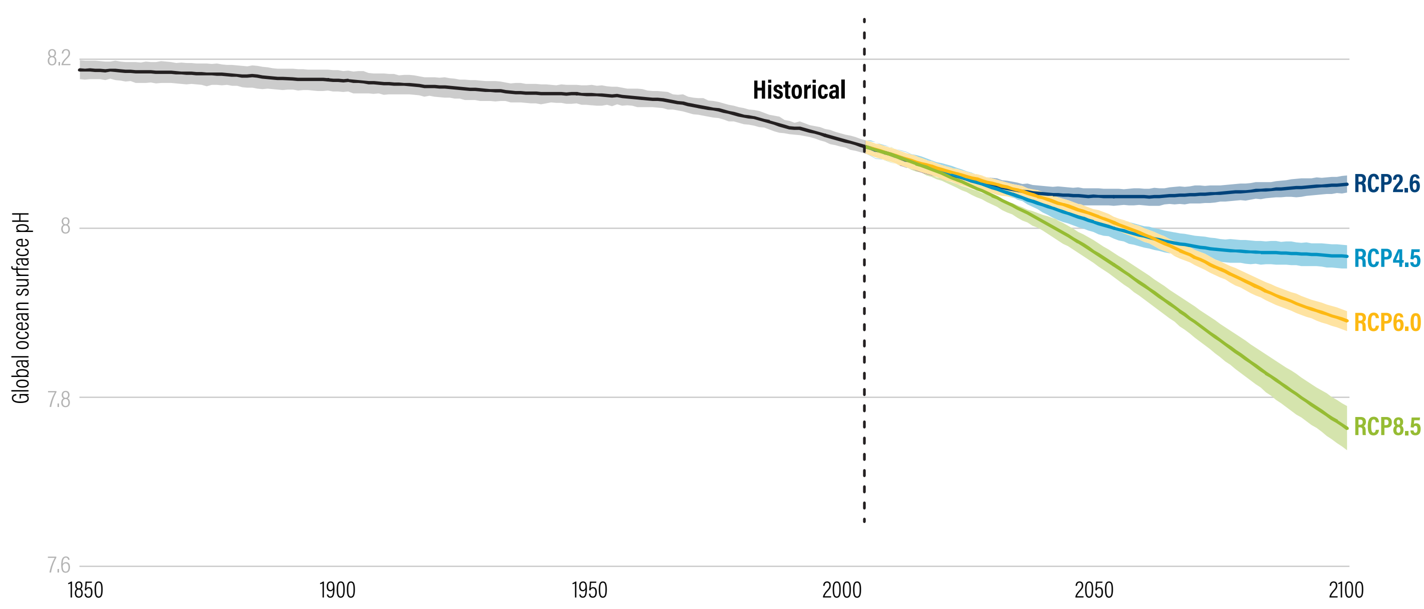
The ocean will also continue to absorb CO_2 emitted to the atmosphere, with higher uptake in higher CO_2 concentration climate scenarios. The CO_2 uptake results in a gradual acidification of the ocean. The ocean pH (a measure of acidity, a decreasing value means acidification) has decreased 0.1, from 8.2 to 8.1, since the preindustrial era. Climate models project worldwide increased ocean acidification by the end of 21st century, with the decrease in ocean pH for RCP2.6 of 0.065 and 0.31 for RCP8.5 (Figure C9) (IPCC 2014a). Ocean acidification could fundamentally change biological and chemical process of the ocean, including affecting shell formation for corals and shellfish (IPCC 2014a).

Figure C8 | **The Estimated Multiplication Factor (Shown at Tide Gauge Locations by Colored Dots), by which the Frequency of Flooding Events of a Given Height Increases Using Regional Projections of Mean Sea Level for the RCP4.5 Scenario**



Note: A multiplication factor value of 100 means that what is currently a once-in-a-hundred-year flooding event will happen every year due to a rise in mean sea level.
Source: IPCC (2014a, p.1201).

Figure C9 | **Time Series (Model Averages and Minimum to Maximum Ranges) of Multimodel Surface Ocean pH for the Scenarios RCP2.6, RCP4.5, RCP6.0, and RCP8.5 in 2081–2100**

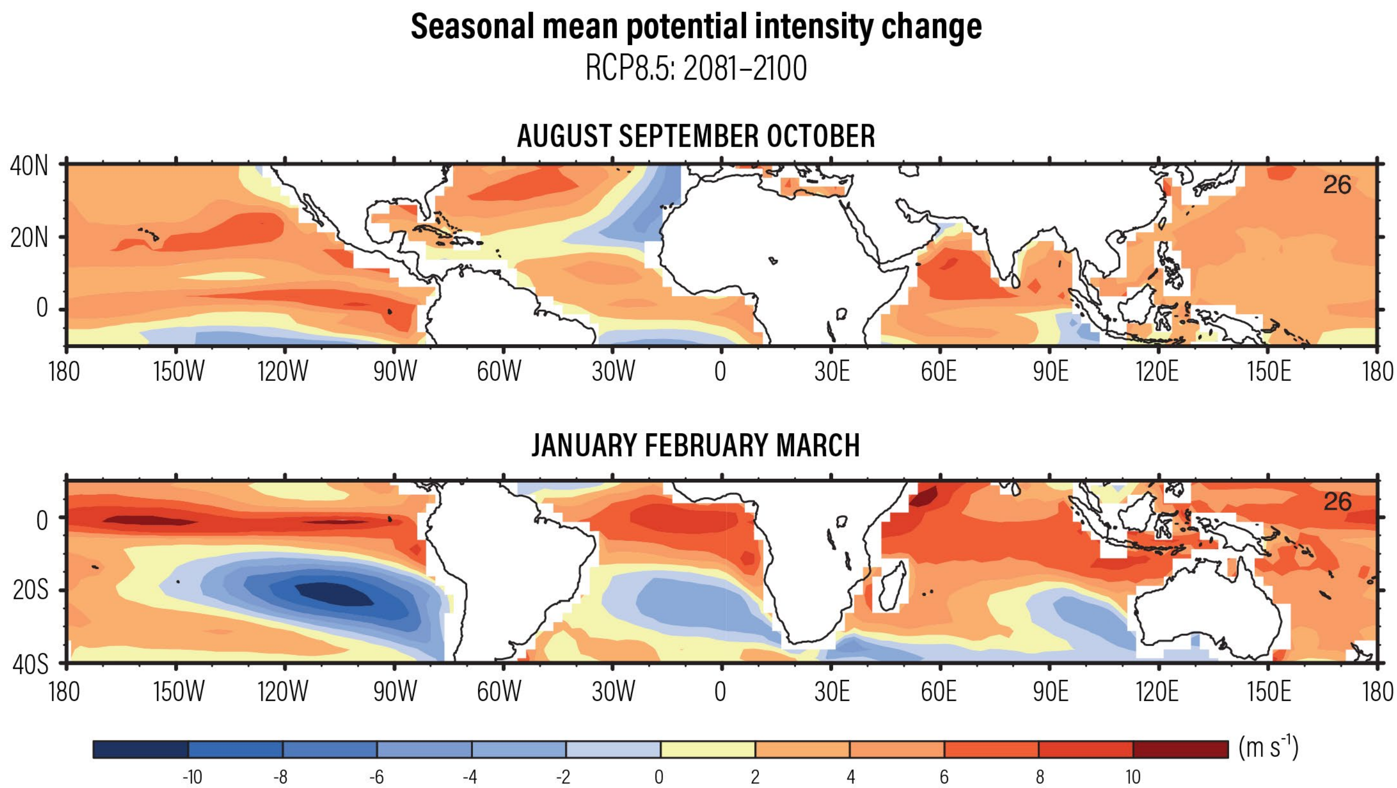


Note: The number of CMIP5 models to calculate the multimodel mean is indicated in the figure above each line.
Source: IPCC (2014a, p.95).

Tropical cyclones (also called hurricanes or typhoons depending on geographic location)

Climate projections indicate that the global frequency of tropical cyclones likely will not increase, but that their intensity—measured by maximum wind speed and rain rates—likely will by the end of the 21st century (Figure C10) (IPCC 2014a). The average intensity of tropical cyclones will increase by 1–10 percent assuming a 2°C global temperature rise, while average tropical cyclone precipitation rates will increase by at least 7 percent per degree Celsius sea surface temperature warming. The proportion of tropical cyclones that reach Category 4–5 levels would also increase (IPCC 2019b). However, the understanding and projections of climate change on tropical cyclone activity are limited at the regional level by insufficient historical evidence and higher uncertainties in regional sea surface temperature projections (IPCC 2014a).

Figure C10 | **Change in Seasonal Mean Tropical Cyclone Potential Intensity for End of the Century RCP8.5 (2081–2100) Minus Historical Control (1986–2005) in CMIP5 Multimodel Ensembles**



Notes: (Top) August to October, 10°S to 40°N and (bottom) January to March, 40°S to 10°N. Potential intensity computation uses the method of Bister and Emanuel (1998) applied to monthly means fields to compute the potential maximum surface wind speed (m/s^{-1}) of tropical cyclones. The seasons for each panel are the historical high frequency periods for tropical cyclones in each hemisphere. The number of models in the ensemble appears in the upper right of each panel.
Source: IPCC (2014a, p.14SM-9).

Tornadoes, hail, extreme winds, dust storms

The availability and robustness of studies on some extreme physical hazards has been hampered by the lack of high-temporal resolution and consistent observations. There is limited evidence and low agreement in the scientific literature on global historical trends and understanding of tornadoes, hail, extreme winds (with the exception of changes associated with tropical cyclones), and dust storms. Even when available, data can be inconsistent over time or across different regions. For example, the trend of increasing tornado occurrence since 1950 in the United States mainly reflected increased population density and increased numbers of people living in remote areas, which resulted in better observations and reporting. These data limitations, combined with the inability or high uncertainties of climate models to simulate climate variables, resulted in very limited projections of these extreme hazards in the future (IPCC 2012).

Ice melt/permafrost melt

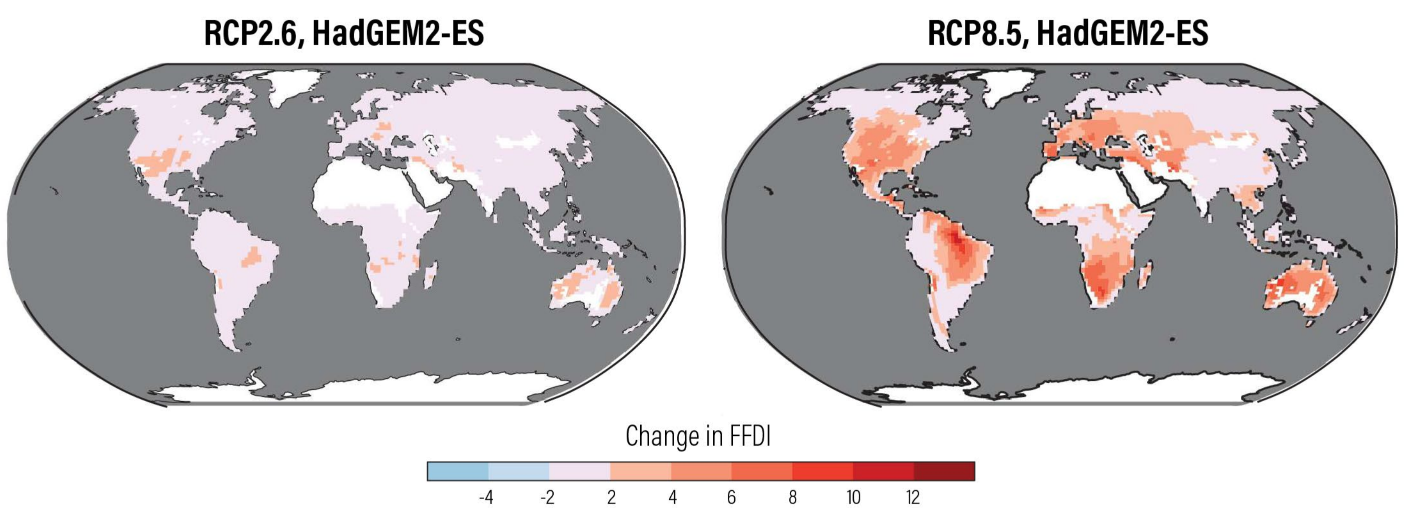
Over the past two decades, Arctic sea ice and permafrost thickness and extent have continued to decrease due to substantial warming in polar regions. The projected warming would result in continued loss of sea ice and reduction of permafrost. The Arctic Ocean could become nearly ice-free in September before 2050, and the area of permafrost near the surface is projected to decrease by 81 percent by 2100 under RCP8.5 (IPCC 2014a). These changes would have clear impacts on marine ecosystems, vegetation, and human infrastructure. For example, 70 percent of Arctic infrastructure is at risk from permafrost thaw by 2050 (IPCC 2019b).

Wildfires

Climate has been a major driver of wildfires through precipitation, temperature, and the latter's interaction with vegetation productivity and structure (e.g., grass or forest), which affect fuel availability and flammability, respectively. Driven by climate change, increased drought and temperature are expected to increase the risk and severity of wildfires (IPCC 2019a). For the lowest-emissions scenario (RCP2.6), the risk of wildfires is projected to change little, but it will be substantial for the high-emissions scenario (RCP8.5) (Figure C11) (IPCC 2014b). North America, South America, Central Asia, southern Europe, southern Africa, and Australia will face a significant increase in wildfires, especially under the RCP8.5 scenario.

While climate change has played an increasing role in driving wildfires, human activity is also an important part of the complex set of factors influencing them. Humans, the top cause of fire ignition globally, also influence fires by managing fuels (e.g., forest management) and actively extinguishing them. Even assuming that the rate of wildfires remains unchanged in the future, human exposure to wildfires could still increase because of expansion into areas already under high risk of fire. The complex interactions between climate and socioeconomic factors make projecting future wildfires a major challenge (IPCC 2019a).

Figure C11 | **Projected Changes of 30-Year Annual Mean McArthur Forest Fire Danger Index Simulated with the Hadley Centre Global Environmental Model Version 2 Earth System Configuration by 2070–99 Relative to 1970–99**



Source: IPCC (2014b, p. 304).

APPENDIX D. OVERVIEW OF FRAMEWORK FOR ASSESSING DISCLOSURE INITIATIVE GUIDANCE ON PHYSICAL CLIMATE RISKS

INDICATOR	EXPLANATION	RESPONSE TYPE
A. Definition of Physical Climate Risk		
1. Does the initiative provide a definition of physical climate risk?	Outlining a clear definition of physical climate risk is a definitive first step to providing clear and useful guidance. Without a clear definition, issuers may end up with different interpretations of what they are being asked to assess and disclose. Comparing definitions across initiatives helps to determine whether the same issue is being analyzed consistently.	Select "yes," "no," or "to some extent" with comments from WRI.
2. Does the initiative clearly distinguish between the concepts of hazards, exposure, vulnerability, impacts, and risk—in alignment with the IPCC's disaster risk function?	The Intergovernmental Panel on Climate Change outlines a widely accepted climate-related disaster risk function that defines "hazard," "exposure," and "vulnerability" as three distinct factors of "(disaster) impacts" and their likelihood; that is, the "disaster risk" (IPCC 2012). It provides a useful conceptual framework for analyzing a company's physical climate risks. Clearly differentiating between each of these factors can help companies and financial organizations assess and understand how each of the different risk factors contributes to risk and, therefore, how to manage and mitigate risk.	Select "yes," "no," or "to some extent" with comments from WRI.
B. Physical Climate Hazard Identification		
1. Which physical climate hazards does the initiative reference?	There is no widely accepted taxonomy of physical climate hazards for use by companies or investors (though the classification provided in the EU taxonomy may fill this need). As such, companies that rely on disclosure initiative guidance to inform their physical climate risk assessments may analyze only those hazards that are referenced by the initiative. Comparing the list of referenced hazards across initiatives helps determine the level of guidance that is given across initiatives across the range of physical climate hazards.	List hazards with comments from WRI.
2. Does the initiative reference metrics that can be used to assess physical climate hazards?	Climate data are notoriously complex and difficult to assess (Zhou et al. 2019). Providing guidance on the type of data that can be used to measure changes in the climatological system can provide a useful starting point for robust physical climate risk assessment. Referencing specific metrics can also help ensure consistency in the use of climate data across different companies' assessments.	List metrics with comments from WRI.
2a. If yes, does the initiative reference corresponding data sources that can be used to quantify the metrics provided?	Referencing specific data sources, such as the IPCC, can help ensure that companies are using appropriate and robust climate data in their physical climate risk assessments.	Select "yes" or "no" with comments from WRI.
C. Physical Climate Risk Assessment		
1. What type of qualitative guidance does the initiative provide on how to assess physical climate risks?	Many disclosure initiatives provide guidance that does not relate to disclosing a specific numerical or otherwise measurable metric to assess and disclose physical climate risks. This type of guidance can include, for example, language on how a company should disclose information (e.g., disclosing information that is forward-looking) or on what a company should disclose (e.g., the different climate hazards that affect its different business lines). This qualitative guidance can give context to the quantitative metrics that disclosure initiatives often also recommend.	Respond to the subindicators from C1a to C1e.
1a. Does the initiative provide guidance to help assess physical climate risks to an organization's direct business operations and assets?	Physical climate hazards can impact different aspects of a company's value chain, including its own internal operations as well as its supply chains and customers. Providing guidance that can help companies understand how physical climate risks can affect each different aspect of a company's value chain is important to promoting robust physical climate risk assessment.	Select "yes" or "no" with comments from WRI.
1b. Does the initiative provide guidance to help assess physical climate risks to different parts of an organization's value chain (e.g., supply chains, downstream value chain, etc.)?	Physical climate hazards can impact different aspects of a company's value chain, including its own internal operations as well as its supply chains and customers. Providing guidance that can help companies understand how physical climate risks can affect each different aspect of a company's value chain is important to promoting robust physical climate risk assessment.	Select "yes" or "no" with comments from WRI.

INDICATOR	EXPLANATION	RESPONSE TYPE
1c. Does the initiative provide guidance to help assess physical climate risks to an organization in different geographical locations?	Physical climate hazards can vary widely across geographies. Robust physical climate risk assessments should analyze hazards across each geography upon which a company's value chain depends (EBRD and GCECA 2018).	Select "yes" or "no" with comments from WRI.
1d. Does the initiative provide guidance to facilitate forward-looking physical climate risk assessments?	Physical climate hazards are expected to change significantly in the future. For example, tropical cyclones are expected to become increasingly strong. Robust physical climate risk assessments should analyze hazards using different forward-looking climate scenarios (IPCC 2014a).	Select "yes" or "no" with comments from WRI.
1e. Is the initiative's physical climate risk guidance common and applicable across all industries, designed to assess industry-specific physical climate risks, or designed to provide both industry-specific and common and widely applicable guidance?	Physical climate hazards can affect different industries in different ways (IPCC 2014b). Industry-specific guidance can result in more meaningful physical climate risk assessment and disclosure by providing companies with information that is more relevant to their business.	Select "industry-specific," "common and applicable across all industries," or "both" with comments from WRI.
2. Does the initiative provide quantitative guidance (i.e., metrics) on how to assess exposure and vulnerability to physical climate hazards?	Exposure metrics can help assess which parts, if any, of a company's value chain (e.g., assets, operations, supply chain, customers, etc.) could be impacted by physical climate hazards due to their geographic location. These metrics should link part of a company's value chain (e.g., physical assets) with specific physical climate hazards (e.g., tropical cyclones). Vulnerability metrics can help assess the propensity of different parts of a company's value chain to suffer negative impacts when exposed and then impacted by physical climate hazards. These metrics should assess specific characteristics of a company's value chain (e.g., water intensity) that may make that part of the value chain more or less likely to suffer negative impacts from physical climate hazards.	Select "yes" or "no" and list metrics with comments from WRI.
2a. If yes, does the initiative provide guidance to help quantify the metrics provided?	This indicator evaluates whether a disclosure initiative references methodologies or other guidance that issuers of disclosures can use to quantify exposure and/or vulnerability metrics, if provided. Doing so can help to ensure that companies quantify the referenced metrics properly and consistently.	Select "yes," "no," or "to some extent" with comments from WRI.
3. Does the initiative reference metrics that can be used to help assess impacts from physical climate hazards?	Impact metrics can help assess the negative effects to a company's value chain from either historical or potential future physical climate hazards. These metrics should assess the negative consequences of physical climate hazards for a company (e.g., financial losses or magnitude of disruptions to operations).	Select "yes" or "no" and list metrics with comments from WRI.
3a. If yes, does the initiative provide guidance to help quantify the metrics provided?	This indicator evaluates whether a disclosure initiative references methodologies or other guidance that issuers of disclosures can use to quantify impact metrics, if provided. Doing so can help to ensure that companies quantify the referenced metrics properly and consistently.	Select "yes," "no," or "to some extent" with comments from WRI.
4. Does the initiative reference metrics that can be used to help assess physical climate risks?	Risk metrics can help assess the likelihood of potential future negative impacts from physical climate hazards, and thus should incorporate aspects of both likelihood and impacts. Concepts from the financial sector, such as expected loss, represent good examples of risk metrics.	Select "yes" or "no" and list metrics with comments from WRI.
4a. If yes, does the initiative provide guidance to help quantify the metrics provided?	This indicator evaluates whether a disclosure initiative references methodologies or other guidance that issuers of disclosures can use to quantify risk metrics, if provided. Doing so can help ensure that companies quantify the referenced metrics properly and consistently.	Select "yes," "no," or "to some extent" with comments from WRI.

Source: WRI authors.

APPENDIX E. DISCLOSURE GUIDANCE DOCUMENTS REVIEWED FOR SIX DISCLOSURE INITIATIVES

AUTHORING INITIATIVE	DOCUMENT(S)	DATE PUBLISHED
CDP	CDP Climate Change 2020 Reporting Guidance	December 2019
	CDP Water Security 2020 Reporting Guidance	December 2019
	CDP Forests 2020 Reporting Guidance	December 2019
Climate Disclosure Standards Board (CDSB)	CDSB Framework for Reporting Environmental and Climate Change Information	December 2019
EU Non-financial Reporting Directive (NFRD)	Guidelines on Reporting Climate-Related Information	June 2019
Global Reporting Initiative (GRI)	Consolidated Set of GRI Sustainability Reporting Standards 2019	December 2019
Sustainability Accounting Standards Board (SASB)	SASB Industry Standards (77 industry-specific documents)	November 2018
	SASB Climate Risk Technical Bulletin	October 2016
Task Force on Climate-Related Financial Disclosures (TCFD)	Final Report: Recommendations of the Task Force on Climate-Related Financial Disclosures	June 2017
	Annex: Implementing the Recommendations of the Task Force on Climate-Related Financial Disclosures	June 2017
	Technical Supplement: The Use of Scenario Analysis in Disclosure of Climate-Related Risks and Opportunities	June 2017

Source: WRI authors.

APPENDIX F. EXAMPLES OF SECTORAL RISKS FROM CLIMATE CHANGE AND CORRESPONDING CLIMATE-RELATED HAZARDS PROVIDED BY IPCC REPORTS

These examples are summarized from the IPCC's Fifth Assessment Report (AR5) published in 2013 and 2014. The AR5 report is the most recent IPCC report that has extensive discussion on sectoral impacts from climate change; see particularly Chapter 10, "Key Economic Sectors and Services," of IPCC (2014b). A vast literature has documented and analyzed sectoral impacts and risks from climate change since the AR5 report was published. The examples below only include materials and findings from IPCC reports to be consistent with the scope of this paper. They may not include recent findings or be comprehensive.

SECTOR	KEY IMPACT	CLIMATE-RELATED HAZARD
Consumer discretionary	Increased tourism demand at higher altitudes and latitudes.	Sustained temperature rise
	Reduced attractiveness of coastal tourism facilities as a result of artificial coastlines, a protection measure against sea level rise.	Sea level change, extreme sea level
Consumer staples	Declines in average yields, crop suitability, and product quality because of higher temperatures, heat stress, drought, or floods, and may result in higher prices.	Sustained temperature rise, extreme temperatures, drought, extreme precipitation
	Reduced animal feeding and growth rates due to high temperatures; reduced milk yields and increased mortality because of heat stress.	Sustained temperature rise, extreme temperature
	Increased production of important fishery resources in some areas but decreased production in others because of increasing temperatures.	Sustained temperature rise
	Negative impacts on important invertebrate species, including species responsible for building coral reefs that provide essential habitat for many fished species, due to increased acidification.	Ocean acidification
Financials	Increased losses and loss variability (reduced profits) for property insurers as a result of more severe and/or frequent extreme weather events and/or hazard types.	Tropical cyclones, extreme precipitation, floods, wildfires
	Indirect value losses of assets / loan portfolios as a result of physical damage.	All climate-related hazards
Health care	Increased demands for health care services (including mental health) and facilities related to treatment of infectious diseases, temperature-related events, and extreme weather events.	Sustained temperature rise, tropical cyclones, extreme precipitation, floods, wildfires
Industrial	Increased road, rail, and bridge maintenance cost as a result of increased temperature, precipitation, floods, and freeze-thaw cycles, and melting of permafrost.	Sustained temperature rise, extreme temperatures, change in precipitation patterns, extreme precipitation, floods, ice melt/permafrost melt, tropical cyclones
	Reductions in vessel cargo capacities and increases in shipping costs as a result of fall in inland water levels, increased frequency of floods, or increased storminess.	Floods, drought
Real estate	Changing demand for housing on the coastlines of developed countries due to changes in weather and climate extremes and sea level change.	Tropical cyclones, extreme precipitation, sea level change
Utilities	Increased costs of building in resiliency to municipal and industrial water systems to adapt to anticipated future changes; for example, more frequent heavy-rainfall events.	Change in precipitation patterns, extreme precipitation
	Reduced energy demand for heating and increased energy demand for cooling in the residential and commercial sectors.	Sustained temperature rise
	Reduced power generation or temporary shutdown of thermal power plants as a result of decreasing volume and increasing temperature of water for cooling.	Sustained temperature rise, change in precipitation patterns, extreme temperatures, extreme precipitation
	Increased/reduced power output for hydropower plants as a result of increase/decrease in average water availability.	Change in precipitation patterns
	Reduced integrity and reliability of pipelines and electricity grids as a result of melting permafrost and climate-related extreme events.	Tropical cyclones, extreme precipitation, floods, wildfires, ice melt/permafrost melt

Source: WRI authors based on IPCC (2014a, 2014b).

APPENDIX G. REAL-WORLD EXAMPLES OF CLIMATE-RELATED PHYSICAL IMPACTS

Pacific Gas and Electric bankruptcy and wildfires in California (United States)

In 2017 and 2018, transmission lines owned and operated by PG&E triggered a series of wildfires in California, including the deadliest and most destructive fire in California's history, the Camp Fire, which killed 85 people and destroyed nearly 19,000 structures in 2018 (CAL FIRE 2019, 1). With billions of dollars in potential liabilities from these wildfires, PG&E filed for bankruptcy protection in early 2019, the sixth-largest corporate bankruptcy by assets in U.S. history (Gold et al. 2019). These wildfires ultimately costed PG&E at least $24.5 billion, the total value of three major settlements with individual victims, insurance creditors, and local governments (PG&E Corporation 2019).

These wildfires were driven by an exceptional and explosive fire environment promoted by climate change, while PG&E's aging equipment acted as ignition points. During the winter of 2016–17, precipitation was much above normal, exceeding the 90th percentile ranking, across California, creating an above-average fuel crop. The summer of 2018 was drier and warmer than average, causing fuels to dry out to record levels. For example, the overall average temperature in July 2018 reached record high levels (Herring et al. 2020). In the coming decades, human-induced warming will likely continue to increase wildfires in California (Williams et al. 2019).

Disruptions in the hard drive industry and flooding in Thailand

In the summer of 2011, Thailand experienced severe flooding that resulted in more than 680 deaths and affected more than 13 million people. The manufacturing sector bore about 70 percent of the total $46.5 billion in damage and losses. The flood caused severe disruptions to the hard drive industry, shutting down about 45 percent of the industry's global assembly capacity for five months. Western Digital, the number one company in the global hard drive segment, suffered $235 million losses in property and equipment damage, in addition to disrupted manufacture capacity (*Informa* 2012; Western Digital Corporation 2012). The losses exceeded the limits of Western Digital's insurance policies, which covered only $123 million, and it temporarily lost its market dominance (Western Digital Corporation 2014).

The 2011 flood did not cause the largest submerged area, but it was the longest flood in Thailand history, lasting 158 days (Promchote et al. 2016). It caused unprecedented damage and was considered the worst flood since 1961 (World Bank 2012). The monsoon rainfall and the tropical cyclone frequency in 2011 were not unusual. A combination of factors contributed to this flood, including a substantial increase in premonsoon rainfall and a continual sea level rise in the Gulf of Thailand. Both of these two factors were linked to climate change, suggesting increasing risks of similar flooding in the future (Promchote et al. 2016).

Losses in electricity generation and heatwaves and droughts in Europe

From 2017 to 2019, different parts of Europe experienced record-breaking heatwaves and droughts (Hodari and Parkin 2018; Kew et al. 2019; Patterson and Harris 2019). The combined effect of heat and scarce water resulted in severe disruptions of electricity generation. Électricité de France, the French power generation company, halted several nuclear reactors during summer heatwaves in 2018 and 2019 to keep plants from overheating rivers (Patterson and Harris 2019). In 2017, hydropower production at Iberdrola, the Spanish utility that relied heavily on hydropower for its liberalized power business, tumbled to 43 percent of 2016's power generation level. The earnings before interest, taxes, depreciation, and amortization for its liberalized power business in Spain, where hydropower generation was the main source of revenue, dropped from €1.5 billion in 2016 to €902 million in 2017 (Iberdrola 2018).

Since 2000, Europe has experienced multiple heatwaves and droughts, especially after 2015 (Hanel et al. 2018). The Europe-wide drought trends were driven by the north-south difference in precipitation and by increasing temperatures throughout Europe (Stagge et al. 2017). The north-south difference in precipitation led to decreased drought frequency in northern Europe and an increase for southern Europe, while the increasing temperature throughout Europe drove plant transpiration and direct evaporation. Scientists found that climate change increased the chances of heatwaves by 3 to 10 times in many parts of Europe (World Weather Attribution 2019).

APPENDIX H. DEFINITIONAL LANGUAGE OF PHYSICAL CLIMATE RISKS FROM SIX DISCLOSURE INITIATIVES

DISCLOSURE INITIATIVE	DOCUMENT	RELEVANT LANGUAGE
CDP	CDP Climate Change 2020 Reporting Guidance	*"Physical risks emanating from climate change can be event-driven (acute) such as increased severity of extreme weather events (e.g., cyclones, droughts, floods, and fires). They can also relate to longer-term shifts (chronic) in precipitation, temperature and increased variability in weather patterns (e.g., sea level rise)."*
	CDP Water Security 2020 Reporting Guidance	*"Risk driven by water stress or scarcity (too little water), flooding (too much water) or pollution (lower water quality)."*
Climate Disclosure Standards Board (CDSB)	CDSB Framework for Reporting Environmental and Climate Change Information	*"Physical risks including the known or expected effects of: changes to resource quality or availability, particularly in the organisation's natural capital dependencies; changing weather patterns; sea level rise; shifts in species distribution; changes in water availability and quality; change in temperature; and variation in agricultural yield and growing seasons."*
EU Non-financial Reporting Directive	Guidelines on Reporting Climate-Related Information	*"Physical risks are risks to the company that arise from the physical effects of climate change." They include "acute physical risks, which arise from particular events, especially weather-related events such as storms, floods, fires or heatwaves, that may damage production facilities and disrupt value chains" and "chronic physical risks, which arise from longer-term changes in the climate, such as temperature changes, rising sea levels, reduced water availability, biodiversity loss and changes in land and soil productivity."*
Global Reporting Initiative (GRI)	Consolidated Set of GRI Sustainability Reporting Standards 2019	*"Physical risks and opportunities can include: the impact of more frequent and intense storms; changes in sea level, ambient temperature, and water availability; impacts on workers—such as health effects, including heat-related illness or disease, and the need to relocate operations."*
Sustainability Accounting Standards Board (SASB)	SASB Climate Risk Technical Bulletin	*"Acute physical risks are the impacts of more frequent and more severe catastrophic weather events (e.g., more intense droughts, extensive wildfires, greater precipitation, higher wind speeds, etc.). . . . Chronic physical risks are the impacts of more intense and sustained carbon emissions to the atmosphere, as well as the progressive impacts of increasing temperatures, changing precipitation patterns, and rising sea levels, among others."*
Task Force on Climate-Related Financial Disclosures (TCFD)	Final Report: Recommendations of the Task Force on Climate-Related Financial Disclosures	*"Physical risks resulting from climate change can be event-driven (acute) or longer-term shifts (chronic) in climate patterns. . . . Acute physical risks refer to those that are event-driven, including increased severity of extreme weather events, such as cyclones, hurricanes, or floods. Chronic physical risks refer to longer-term shifts in climate patterns (e.g., sustained higher temperatures) that may cause sea level rise or chronic heat waves."*

Source: CDP, CDSB, EU Non-financial Reporting Directive, GRI, SASB, TCFD, adapted by WRI.

GLOSSARY

The following table presents definitions for key terms used in this paper.

Exposure	The presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected.
Financial organization	An umbrella term referring to any institution whose primary business involves financial and monetary transactions. This includes banks, insurance companies, asset owners, and asset managers.
Hazard (physical climate hazard)	The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. In this report, the term *hazard* usually refers to climate-related physical events or trends or their physical impacts.
Impacts	The effects on natural and human systems of extreme weather and climate events and of climate change. The term refers to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. Impacts are also referred to as *consequences* and *outcomes*.
IPCC's risk function	A framework that conceptualizes risk of climate-related impacts as resulting from the interaction of climate-related hazards with the vulnerability and exposure of human and natural systems. This relationship is depicted by an equation: the probability of hazardous events occurring multiplied by the impacts of their occurrence (risk = probability × consequence). Within this equation, the impacts (consequences) are a product of the level of vulnerability and exposure.
Materiality	A business, financial, legal, and regulatory term used to distinguish information that is of financial, economic, reputational, and legal significance to an organization. Within the last decade, the concept has been adopted within a sustainability reporting context. The term carries different meanings across different reporting standards and frameworks. Broadly speaking, *materiality* describes any information that informs the evaluation and analysis under consideration, whether related to value creation or performance.
Metrics	Metrics provide means for quantitative measurement. They can present data in numerical terms or in grades (e.g., high, medium, low). *Hazard metrics* are metrics for the measurement of the potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. *Exposure metrics* are metrics designed to assess the degree to which a company's value chain (e.g., assets, operations, supply chain, customers) has the potential to be impacted by physical climate hazards due to its geographic location. These metrics should link part of a company's value chain (e.g., physical assets) with specific physical climate hazards (e.g., tropical cyclones). *Vulnerability metrics* are designed to assess the propensity of different parts of a company's value chain to suffer negative impacts when exposed to and then impacted by physical climate hazards. These metrics should assess specific characteristics of a company's value chain (e.g., water intensity) that may make that part of the value chain more or less likely to suffer negative impacts from physical climate hazards. *Impact metrics* are metrics designed to assess the negative effects on a company's value chain from either historical or potential future physical climate hazards. These metrics should assess the negative consequences of physical climate hazards for a company (e.g., financial losses or magnitude of disruptions to operations). *Risk metrics* are a function of hazard, exposure, and vulnerability. They are designed to assess the likelihood of potential future negative impacts from specific physical climate hazards (e.g., the risk of sea level rising by an average of 1 meter). Risk metrics should incorporate aspects of both the likelihood of the hazard occurring and the impacts of its occurrence, whereby impacts are determined by exposure and vulnerability to the given hazard. Concepts from the financial sector, such as expected loss in lending, represent good examples of risk metrics. The key difference between risk metrics and impact metrics is that the former include a measure of uncertainty.

Physical climate risk	The potential for negative consequences from physical climate events or trends. *Acute physical risks* refer to those that are event-driven, including increased severity of extreme weather events, such as tropical cyclones or floods. *Chronic physical risks* are longer-term shifts in climate patterns (e.g., sustained higher temperatures) that may cause sea level change or chronic heat waves.
Risk	The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability or likelihood of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. The term *risk* is often used to refer to the potential, when the outcome is uncertain, for adverse consequences on lives; livelihoods; health; ecosystems and species; economic, social, and cultural assets; services (including environmental services); and infrastructure.
Vulnerability	The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

Sources: Business Roundtable (2015); Corporate Reporting Dialogue (2016); IPCC (2014a); TCFD (2017).

ENDNOTES

1. Some examples include the SENSES Project and Oliver Wyman's Transition Check, created in partnership with the UN Environment Programme Finance Initiative (UNEP-FI) to help private sector audiences understand climate risk scenarios.
2. A recent report by Acclimatise and UNEP-FI (2020) provides further insight into the state of the data for physical climate risk assessment. The report describes the outputs of the UNEP-FI banking pilot project and presents technical guidance and information on the resources available to support forward-looking, scenario-based assessments of physical risks and opportunities. It includes a review of data and portals on climate and climate-related extreme events, as well as proprietary tools and analytics for physical risk assessment.
3. Companies, investors, and regulators are increasingly concerned about the material impacts of climate change on company performance, the economy, and financial markets at large. At the same time, there is increasing stakeholder interest in the impact that companies are having on the economy, society, and the environment. Together, these interests are fueling a growing demand for consistent, comparable, and reliable data on corporate sustainability and climate issues.
4. The frameworks do not necessarily contain all the guidance preparers might need. This is especially the case with respect to assessing physical climate risks. To address these gaps, other initiatives have stepped in to develop new approaches for measuring the potential financial impacts of physical climate risks, in alignment with the disclosure guidance. This includes, among others, the pilot project led by UNEP-FI to test scenario-based models for estimating climate impacts on the corporate lending portfolios of leading banks (UNEP-FI and Acclimatise 2018). This project found that gaps in publicly accessible data and tools impeded analysis of potentially important physical risks and that the banks faced challenges with the methodologies tested, which were not ideally matched to banks' internal capacities for in-house implementation.
5. These hazards are included regardless of likelihoods or confidence levels in IPCC reports. This limited scope was similar to recent efforts by institutions, such as by the European Bank for Reconstruction and Development and the European Commission (EBRD and GCA 2018; TEG 2020).
6. For example, our analysis did not cover disclosure requirements from regulators such as the U.S. Securities and Exchange Commission, which mandates the disclosure of information that is material to investor decision-making but does not explicitly reference climate-related disclosures (Herren Lee 2020).

7. While the guidance of the EU Non-financial Reporting Directive is specific to organizations within the European Union, we consider the guidance to meet our inclusion criterion of being globally applicable because the European Union represents a sufficiently large and influential market.
8. In October 2020, the TCFD published new guidance to help companies integrate climate-related risks into existing risk management processes and disclose relevant information in alignment with the TCFD recommendations (see TCFD 2020).
9. This function does not capture potential variability in the hazard outcome but rather assesses the potential risk stemming from a given hazard outcome (e.g., global mean sea level rise of 1 m).
10. The IPCC's climate risk function provides a useful schema for conceptualizing physical climate risk (de Sherbinin 2014) and has traction in the investment community (Impax Asset Management 2020, 18).
11. A level of confidence is expressed using five qualifiers: very low, low, medium, high, and very high.
12. The following terms have been used to indicate the assessed likelihood in IPCC reports: virtually certain (99–100 percent probability), very likely (66–99 percent probability), likely (66–100 percent probability), about as likely as not (33–66 percent probability), unlikely (0–33 percent probability), very unlikely (0–10 percent probability), and exceptionally unlikely (0–1 percent probability) (IPCC 2014a).

    Direct comparisons between assessment of uncertainties in findings in IPCC (2012) and those in the AR5 and IPCC (2018) are difficult because of the application of the revised guidance note on uncertainties, as well as other factors (IPCC 2014a).
13. Physical hazards with findings with assigned likelihood terms are sustained temperature rise, change in precipitation patterns, sea level change, ocean acidification, ice melt/permafrost melt, extreme temperatures, extreme precipitation, drought, extreme sea level (storm surge), and tropical cyclones.
14. As stated previously in this paper, the disclosure frameworks serve various functions in the disclosure ecosystem and do not all seek to provide the same types of resources to companies. For example, the CDSB Framework provides a general set of principles and requirements that are applicable across sectors and jurisdictions but does not provide specific metrics for disclosure. For this reason, CDSB is the only disclosure framework for which we do not note referenced metrics in Table 4 or Table 5. For the TCFD, standard setting is beyond the remit of the initiative. The framework includes a set of illustrative metrics, but to avoid duplicating efforts it refers companies to well-established reporting protocols rather than providing a set of standard metrics. In the case of SASB, which has developed a set of metrics for financially material physical climate risks, the guidance advises companies to discuss governance, strategy, and risk management for issues where no hazard-specific metric is available.
15. Data sources referenced for these metrics include the International Energy Agency, the IPCC, the World Business Council for Sustainable Development's Global Water tool, World Resources Institute's Aqueduct tool, the World Wildlife Fund's Water Risk Filter, the UN Food and Agriculture Organization's Global Agro-ecological Zones data, and the U.S. Federal Emergency Management Agency.
16. A recent analysis by BlackRock (2019), for example, found that in some sectors, investors are underpricing risk from weather events like tropical cyclones and wildfires.
17. For example, the SENSES Project recently launched a toolkit to improve finance and policy decision-makers' understanding of climate change scenarios; and the UNEP-FI, Oliver Wyman, and a consortium of 16 banks developed a new webtool, Transition Check, that integrates the latest climate scenarios to enable institutions to evaluate transition risk.
18. Existing examples can be found on platforms such as the Global Risk Data Platform, ThinkHazard, Aqueduct Risk Atlas, PREPdata, and Resource Watch.
19. For example, Aqueduct, a global water risk-mapping tool that helps companies, investors, governments, and other users understand where and how water risks and opportunities are emerging worldwide, is referenced in guidance from CDP, SASB, and the TCFD.
20. This includes a recent analysis under the TCFD Banking Pilot Project that reviews available climate data and portals relevant for physical risk assessments for banks' loan portfolios (Acclimatise and UNEP-FI 2020).
21. Global warming is an increase in combined surface air and sea surface temperatures.
22. Specific regions, especially along the equator and on the poleward edges of the subtropical dry zone, are exceptions.
23. Precipitation less than 1 millimeter (IPCC 2014a).

REFERENCES

Acclimatise and UNEP-FI (UN Environment Programme Finance Initiative). 2020. "Charting a New Climate: State-of-the-Art Tools and Data for Banks to Assess Credit Risks and Opportunities from Physical Climate Change Impacts." https://www.unepfi.org/wordpress/wp-content/uploads/2020/09/Charting-a-New-Climate-UNEP-FI-TCFD-Banking-Physical-Risk.pdf.

Advisor's Edge. 2019. "BlackRock Finds Climate Risks Are Underestimated by Investors." April 4. https://www.advisor.ca/news/industry-news/blackrock-finds-climate-risks-are-underestimated-by-investors/.

AMS (American Meteorological Society). 2019. "New Research Examines Climate Change's Role in 2018 Extreme Weather Events." https://www.climate.gov/news-features/understanding-climate/new-research-examines-climate-change%E2%80%99s-role-2018-extreme-weather.

Australian Government. n.d. The Intergovernmental Panel on Climate Change (IPCC). Department of Industry, Science, Energy, and Resources. Available at https://www.industry.gov.au/about-us/intergovernmental-panel-on-climate-change. Retrieved December 10, 2020.

Bister, M., and K.A. Emanuel. 1998. "Dissipative Heating and Hurricane Intensity." *Meteorology and Atmospheric Physics* 65 (3): 233–40. doi:10.1007/BF01030791.

BlackRock. 2019. "Getting Physical: Scenario Analysis for Assessing Climate-Related Risks." https://www.blackrock.com/ch/individual/en/insights/physical-climate-risks.

Brasileiro, A. 2011. "Brazil Flood-Hit Villages Need at Least $1.2 Billion." *Bloomberg.com*, January 17. https://www.bloomberg.com/news/articles/2011-01-17/brazil-cities-hit-by-landslides-floods-will-need-1-2-billion-to-recover.

Business Roundtable. 2015. "The Materiality Standard for Public Company Disclosure: Maintain What Works." https://s3.amazonaws.com/brt.org/archive/reports/BRT.The%20Materiality%20Standard%20for%20Public%20Company%20Disclosure.2015.10.29.pdf.

CAL FIRE (California Department of Forestry and Fire Protection). 2019. "CAL FIRE Investigators Determine Cause of the Camp Fire." https://www.fire.ca.gov/media/5121/campfire_cause.pdf.

Corporate Reporting Dialogue. 2016. "Statement of Common Principles of Materiality of the Corporate Reporting Dialogue." https://corporatereportingdialogue.com/wp-content/uploads/2016/03/Statement-of-Common-Principles-of-Materiality.pdf.

de Sherbinin, A. 2014. "Climate Change Hotspots Mapping: What Have We Learned?" *Climatic Change* 123 (1). https://link.springer.com/article/10.1007/s10584-013-0900-7#:~:text=By%20identifying%20likely%20climate%20change,number%20of%20goals%20in%20mind.

Diffenbaugh, N.S., D.L. Swain, and D. Touma. 2015. "Anthropogenic Warming Has Increased Drought Risk in California." *Proceedings of the National Academy of Sciences of the United States of America* 112 (13): 3931–36.

Duffin, E. 2020. "Economic Damage Caused by Tornadoes in the U.S. 2019." *Statista*, July 22. https://www.statista.com/statistics/237409/economic-damage-caused-by-tornadoes-in-us/.

EBRD (European Bank for Reconstruction and Development) and GCECA (Global Centre of Excellence on Climate Adaptation). 2018. *Advancing TCFD Guidance on Physical Climate Risks and Opportunities*. London: EBRD. http://427mt.com/wp-content/uploads/2018/05/EBRD-GCECA_final_report.pdf.

Foreman, T. 2020. "The Effects of Dust Storms on Economic Development." http://timforeman.net/duststorms.pdf.

Gold, R., K. Blunt, and K. Chin. 2019. "PG&E Prepares for Bankruptcy amid Wildfire Fallout." *Wall Street Journal*, January 14. https://www.wsj.com/articles/pg-e-initiates-chapter-11-reorganization-for-utility-11547465293?mod=article_inline.

Hanel, M., O. Rakovec, Y. Markonis, P. Máca, L. Samaniego, J. Kyselý, and R. Kumar. 2018. "Revisiting the Recent European Droughts from a Long-Term Perspective." *Scientific Reports* 8 (1). https://doi.org/10.1038/s41598-018-27464-4.

Harvard University. 2020. "Coronavirus and Climate Change." May 19. https://www.hsph.harvard.edu/c-change/subtopics/coronavirus-and-climate-change/.

Henson, B. 2020. "Iowa Derecho in August Was Most Costly Thunderstorm Disaster in U.S. History." *Washington Post*, October 17. https://www.washingtonpost.com/weather/2020/10/17/iowa-derecho-damage-cost/.

Herren Lee, A. 2020. "'Modernizing' Regulation S-K: Ignoring the Elephant in the Room." U.S. Securities and Exchange Commission. Public statement, January 30. https://www.sec.gov/news/public-statement/lee-mda-2020-01-30.

Herring, S.C., N. Christidis, A. Hoell, M.P. Hoerling, and P.A. Stott. 2020. "Explaining Extreme Events of 2018 from a Climate Perspective." *Bulletin of the American Meteorological Society* 101 (1): S1–S134. https://doi.org/10.1175/BAMS-ExplainingExtremeEvents2018.1.

Hjort, J., O. Karjalainen, J. Aalto, S. Westermann, V.E. Romanovsky, F.E. Nelson, B. Etzelmüller, and M. Luoto. 2018. "Degrading Permafrost Puts Arctic Infrastructure at Risk by Mid-century." *Nature Communications* 9 (1): 5147. https://doi.org/10.1038/s41467-018-07557-4.

Hodari, D., and B. Parkin. 2018. "Global Heat Wave Toasts Wheat and Prices Soar." *Wall Street Journal*, August 4. https://www.wsj.com/articles/global-heat-wave-toasts-wheat-and-prices-soar-1533391201.

Iberdrola. 2018. *Integrated Report, February 2018*. https://www.iberdrola.com/wcorp/gc/prod/en_US/inversores/docs/IA_IntegratedReport18.pdf.

IIGCC (Institutional Investors Group on Climate Change). 2020. *Understanding Physical Climate Risks and Opportunities: A Guide for Investors*. https://www.iigcc.org/download/understanding-physical-climate-risks-and-opportunities-a-guide-for-investors/?wpdmdl=3388&masterkey=5ec7bf8e65a02.

Impax Asset Management. 2020. "Physical Climate Risks: Designing a Resilient Response to the Inevitable Impact of Climate Change." https://impaxam.com/wp-content/uploads/2020/09/20200924_physical_climate_risk.pdf.

Informa. 2012. "Western Digital Shakes Off Thai Flood Impact, Retakes Hard Drive Market Lead in Q2—Omdia." August 12. https://technology.informa.com/409551/western-digital-shakes-off-thai-flood-impact-retakes-hard-drive-market-lead-in-q2.

IPCC (Intergovernmental Panel on Climate Change). 2012. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change*. Edited by C.B. Field, V. Barros, T.F. Stocker, and Q. Dahe. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9781139177245.

IPCC. 2014a. *Climate Change 2013: The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by T. Stocker. Cambridge: Cambridge University Press.

IPCC. 2014b. *Climate Change 2014: Impacts, Adaptation, and Vulnerability: Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by C.B. Field and V.R. Barros. Cambridge: Cambridge University Press.

IPCC. 2015. *Climate Change 2014: Synthesis Report*. Edited by R.K. Pachauri and L. Mayer. Geneva: IPCC.

IPCC. 2017. "Chair's Vision Paper." https://www.ipcc.ch/site/assets/uploads/2018/09/220520170356-Doc.-2-Chair-Vision-Paper-.pdf.

IPCC. 2018. *Global Warming of 1.5°C: An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty*. Edited by V. Masson-Delmotte, P. Zhai, H.-O. Portner, D. Roberts, J. Skea, P. Shukla, A. Pirani, et al. Geneva: IPCC. https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Res.pdf.

IPCC. 2019a. *Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*. Edited by V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, E. Calvo Buendía, P.R. Shukla, et al. Geneva: IPCC. https://www.ipcc.ch/site/assets/uploads/2019/11/SRCCL-Full-Report-Compiled-191128.pdf.

IPCC. 2019b. *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*. Edited by H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, et al. Geneva: IPCC. https://www.ipcc.ch/site/assets/uploads/sites/3/2019/12/SROCC_FullReport_FINAL.pdf.

IPCC. 2020. "About the IPCC." https://www.ipcc.ch/about/.

Japan Times. 2019a. "Ten Hokuriku Shinkansen Line Trains Worth ¥32.8 Billion Sustain Damage after Yard Is Flooded in Typhoon Hagibis." October 13. https://www.japantimes.co.jp/news/2019/10/13/national/ten-trains-used-hokuriku-shinkansen-line-sustain-damage-yard-flooded/#.XaV2iJNKhTYhttps://www.apnews.com/06689e6a9c294d9cb1fa70b44edb69a6.

Japan Times. 2019b. "Farm Damage from Typhoon Hagibis Tops ¥100 Billion." October 26. https://www.japantimes.co.jp/news/2019/10/26/national/farm-damage-typhoon-hagibis-tops-%C2%A5100-billion/#.Xn4fd4hKhPZ.

Joyce, C. 2018. "Climate Report Warns of Extreme Weather, Displacement of Millions without Action." National Public Radio, October 8. https://www.npr.org/2018/10/08/655360909/grim-forecast-from-u-n-on-global-climate-change.

Kang, N.-Y., and J.B. Elsner. 2016. "Climate Mechanism for Stronger Typhoons in a Warmer World." *Journal of Climate* 29: 1051–57.

Kew, S.F., S.Y. Philip, G. Jan van Oldenborgh, G. van der Schrier, F.E.L. Otto, and R. Vautard. 2019. "The Exceptional Summer Heat Wave in Southern Europe 2017." *Bulletin of the American Meteorological Society* 100 (1): S49–S53. https://doi.org/10.1175/BAMS-D-18-0109.1.

Knutson, T., J.P. Kossin, C. Mears, J. Perlwitz, M.F. Wehner, D.J. Wuebbles, D.W. Fahey, et al. 2017. "Detection and Attribution of Climate Change." Chapter 3 of *Climate Science Special Report: Fourth National Climate Assessment*, vol. 1. U.S. Global Change Research Program. https://doi.org/10.7930/J01834ND.

Lawrence, J., P. Blackett, and N.A. Cradock-Henry. 2020. "Cascading Climate Change Impacts and Implications." *Climate Risk Management* 29: 100234. https://doi.org/10.1016/j.crm.2020.100234.

Martinez-Diaz, L., and L. Sidner. 2020. "Key Investments Can Build Resilience to Pandemics and Climate Change." World Resources Institute (blog), April 15. https://www.wri.org/blog/2020/04/coronavirus-pandemic-climate-change-investments.

Narita, D., K. Rehdanz, and R.S.J. Tol. 2012. "Economic Costs of Ocean Acidification: A Look into the Impacts on Global Shellfish Production." *Climatic Change* 113 (3): 1049–63. https://doi.org/10.1007/s10584-011-0383-3.

Navarro-Racines, C., J. Tarapues, P. Thornton, A. Jarvis, and J. Ramirez-Villegas. 2020. "High-Resolution and Bias-Corrected CMIP5 Projections for Climate Change Impact Assessments." *Scientific Data* 7 (1): 7. https://doi.org/10.1038/s41597-019-0343-8.

Nelson, M. 2019. "How Climate Change Disclosures Reveal Business Risks and Opportunities." Ernst and Young, January 9. https://www.ey.com/en_gl/assurance/climate-change-disclosures-revealing-risks-opportunities.

O'Neill, B.C., C. Tebaldi, D.P. van Vuuren, V. Eyring, P. Friedlingstein, G. Hurtt, R. Knutti, et al. 2016. "The Scenario Model Intercomparison Project (ScenarioMIP) for CMIP6." *Geoscientific Model Development.* 9 (9): 3461–82. https://doi.org/10.5194/gmd-9-3461-2016.

Patterson, S., and L. Harris. 2019. "Europe Logs Record Heat, Struggles to Conserve Water." *Wall Street Journal*, July 25. https://www.wsj.com/articles/its-europes-turn-to-swelter-heat-low-rainfall-strain-water-supply-11564054776.

PG&E (Pacific Gas and Electric) Corporation. 2019. "In Final Major Settlement, PG&E Reaches Agreement to Resolve Individual Claims Relating to the 2017 and 2018 Wildfires and the 2015 Butte Fire; PG&E Has Now Reached Settlements with All Major Groups of Wildfire Claimants; PG&E Achieves Fully-Funded Equity Backstop Commitments; Company on Path to Making Major Changes Necessary to Exit Bankruptcy Ahead of June 30, 2020, Deadline." Press release, December 9. http://www.pgecorp.com/news/press_releases/Release_Archive2019/191209press_release.shtml.

Promchote, P., S.-Y. Simon Wang, and P.G. Johnson. 2016. "The 2011 Great Flood in Thailand: Climate Diagnostics and Implications from Climate Change." *Journal of Climate* 29 (1): 367–79. https://doi.org/10.1175/JCLI-D-15-0310.1.

Schiermeier, Q. 2018. "Droughts, Heatwaves and Floods: How to Tell When Climate Change Is to Blame." *Nature* 560 (7716): 20–22. https://doi.org/10.1038/d41586-018-05849-9.

Schnackenberg, M. 2020. "Top Billion-Dollar Disasters in 2020." KWWL, October 18. https://kwwl.com/2020/10/17/top-billion-dollar-disasters/.

Stagge, J.H., D.G. Kingston, L.M. Tallaksen, and D.M. Hannah. 2017. "Observed Drought Indices Show Increasing Divergence across Europe." *Scientific Reports* 7 (1). https://doi.org/10.1038/s41598-017-14283-2.

TCFD (Task Force on Climate-Related Financial Disclosures). 2017. *Final Report: Recommendations of the Task Force on Climate-Related Financial Disclosures*. https://www.fsb-tcfd.org/publications/final-recommendations-report/.

TCFD. 2020. "Guidance on Risk Management Integration and Disclosure." https://assets.bbhub.io/company/sites/60/2020/09/2020-TCFD_Guidance-Risk-Management-Integration-and-Disclosure.pdf.

TEG (EU Technical Expert Group on Sustainable Finance). 2020. *Financing a Sustainable European Economy. Taxonomy Report: Technical Annex*. Brussels: European Commission. https://ec.europa.eu/info/sites/info/files/business_economy_euro/banking_and_finance/documents/200309-sustainable-finance-teg-final-report-taxonomy-annexes_en.pdf.

UNEP-FI and Acclimatise. 2018. "Navigating a New Climate: Assessing Credit Risk and Opportunity in a Changing Climate—Outputs of a Working Group of 16 Banks Piloting the TCFD Recommendations." https://www.unepfi.org/wordpress/wp-content/uploads/2018/07/NAVIGATING-A-NEW-CLIMATE.pdf.

USDA (U.S. Department of Agriculture). 2018. "Wildfire Risk and Fuels Management." USDA Western Wildland Environmental Threat Assessment Center. June. https://www.fs.fed.us/wwetac/brief/wildfire-risk-and-fuels-management.php.

Weber, C., D.L. McCollum, J. Edmonds, P. Faria, A. Pyanet, J. Rogelj, M. Tavoni, et al. 2018. "Mitigation Scenarios Must Cater to New Users." *Nature Climate Change* 8 (10): 845–48. https://doi.org/10.1038/s41558-018-0293-8.

Western Digital Corporation. 2012. "Form 10-K." http://investor.wdc.com/static-files/80b96cdf-c966-44bc-a745-d3c5846ee49a.

Western Digital Corporation. 2014. "Form 10-K." http://investor.wdc.com/static-files/f89af5fe-52a8-47b4-a1d5-2631d5e3c4a6.

Williams, A.P., J.T. Abatzoglou, A. Gershunov, J. Guzman-Morales, D.A. Bishop, J.K. Balch, and D.P. Lettenmaier. 2019. "Observed Impacts of Anthropogenic Climate Change on Wildfire in California." *Earth's Future* 7 (8): 892–910. https://doi.org/10.1029/2019EF001210.

WMO (World Meteorological Organization) and UNESCO (UN Educational, Scientific, and Cultural Organization). 2013. *International Glossary of Hydrology / Glossaire international d'hydrologie / Mezhdunarodnyĭ gidrologicheskiĭ slovar' / Glosario hidrológico internacional*.

Woetzel, J., D. Pinner, H. Samandari, H. Engel, M. Krishnan, B. Boland, and C. Powis. 2020. *Climate Risk and Response: Physical Hazards and Socioeconomic Impacts*. https://www.mckinsey.com/~/media/mckinsey/business%20functions/sustainability/our%20insights/climate%20risk%20and%20response%20physical%20hazards%20and%20socioeconomic%20impacts/mgi-climate-risk-and-response-full-report-vf.pdf.

World Bank. 2012. "Thai Flood 2011 Overview: Rapid Assessment for Resilient Recovery and Reconstruction Planning." http://documents.worldbank.org/curated/en/677841468335414861/pdf/698220WP0v10P106011020120Box370022B.pdf.

World Bank. 2020. "Climate and Disaster Risk Screening Tools: Key Terms." https://climatescreeningtools.worldbank.org/content/key-terms-0.

World Weather Attribution. 2019. "Human Contribution to the Record-Breaking July 2019 Heatwave in Western Europe." August 2. https://www.worldweatherattribution.org/human-contribution-to-the-record-breaking-july-2019-heat-wave-in-western-europe/.

Yamada, K., K. Takeuchi, and S. Kurimoto. 2019. "Typhoon Blows Hole in Japan's Aging Power Grid." *Nikkei Asian Review*, September 14. https://asia.nikkei.com/Economy/Natural-disasters/Typhoon-blows-hole-in-Japan-s-aging-power-grid.

Zhou, L., J. McClamrock, G. Christianson, D. Krishnan, and T. Luo. 2019. "Financial Implications of Parched Power: Insights from an Analysis of Indian Thermal Power Companies." World Resources Institute. https://files.wri.org/s3fs-public/financial-implications-parched-power_2.pdf.

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ABOUT WRI

World Resources Institute is a global research organization that turns big ideas into action at the nexus of environment, economic opportunity, and human well-being.

Our Challenge

Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our Vision

We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our Approach

COUNT IT

We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT

We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT

We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.