Conducting Climate Change Risk Assessments for Companies
Lessons Learned
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ABSTRACT: As the private sector becomes increasingly aware of the risks associated with climate change, climatologists have been engaging with companies to assess climate change risks and opportunities. Here, we outline how we have collaborated with a Fortune 500 company to assess the physical risks of climate change to their facilities. We provide a template for a climate change report card that we generated for >100 facilities globally. This report card is designed to communicate risk to company leadership and local facility managers. We believe that by sharing our experiences, climate scientists will be able to quantify and communicate climate risk more effectively to the private sector.

KEYWORDS: Climate change; Adaptation; Communications/decision making; Resilience; Risk assessment; Societal impacts
As companies become aware of climate change–related risks to their business operations, they are increasingly interested in completing climate change risk assessments. In a 2020 review of 1,651 public companies’ annual reports or financial filings, the Task Force on Climate-Related Financial Disclosures (TCFD) found that the average rate of climate-related financial disclosures across their 11 recommended disclosures was 32%: an increase of 13% from 2018 (TCFD 2021). The increases were greatest in the materials and buildings industry and were generally greater in carbon-intensive industries (TCFD 2021). This interest provides opportunities for climate scientists to lend their expertise to companies such as those in materials and buildings, energy, and consumer goods industries. The private sector can benefit from working with climatologists because it helps them understand and prepare for the risks they are facing, as well as identify opportunities for adjustment and growth. These collaborations also benefit climatologists, including those who work in the private sector, consulting (e.g., certified consulting meteorologists), and universities, by providing business opportunities, supporting consulting activities or creating research positions for students and postdoctoral researchers. Demand for climate-related experience and skills are increasing and so are the job opportunities for climatologists.

Differences between information companies need and what climatologists typically produce necessitates a shift in the approaches to data generation and presentation. However, because the results of industry-funded climate risk projects generally are not publicly released, the process and deliverables from these collaborations are not readily available. To aid our peers in embarking on their own partnerships with the private sector, here we outline our process for conducting a climate change risk assessment for a major construction materials company.

What companies need
Businesses are increasingly interested in assessing how climate change will influence their physical and transition risks; in some jurisdictions, these assessments are mandatory starting in 2022. This involves fulfilling climate-related reporting requirements, understanding where their assets and/or production are at risk, and identifying where they may be able to expand. For example, many companies are guided by the TCFD or the Carbon Disclosure Project (CDP) reports (TCFD 2021; CDP 2022). These structures provide guidance for businesses across a range of industries to evaluate their climate and environmental risks and impacts. Questions from the CDP questionnaire (CDP 2022) include the following:

- “Have you identified any inherent climate-related risks with the potential to have a substantive financial or strategic impact on your business?”
- “Does your organization use climate-related scenario analysis to inform its strategy?”
- “Does your organization’s strategy include a transition plan that aligns with a 1.5°C world?”

Engaging with climate experts to conduct forward-looking climate scenario analyses and risk assessment allows the company to give an affirmative answer to these questions.
In addition to reporting requirements, companies want to understand where their assets and production, including supply chains, are at risk. This information can help company leadership understand how to best allocate resources to protect their assets and maintain their operations (i.e., business continuity). In addition to understanding physical risks, companies also need to understand how indirect impacts of climate change may affect their workforce and production. This includes understanding how facility staffing may be impacted, or how production speed may be impacted by changes in local weather conditions that can be attributed to climate change. Finally, companies are interested in identifying market-related risks and opportunities. This includes identifying locations where conducting business is no longer viable as well as locations where there is opportunity to increase sales due to climate-related changes or changes in the regulatory environment. Understanding the physical and market-related risks and opportunities enables businesses to better prepare for the future.

**How we addressed their climate information needs**

We addressed the company’s needs using a two-pronged approach designed to follow the TCFD recommendations. In the first project, we quantified physical climate-related risks to the company’s infrastructure. In the second, we investigated climate change risks and opportunities.

**Physical risks.** The first step in assessing the physical risk to facilities was to determine which climate variables to include. We identified these through conversations with the company’s sustainability team about the nature of past physical damage, using these narratives and insurance reports to establish the main climate features associated with damage. During these conversations, we developed templates for the risk report cards and shared them with the sustainability team to ensure that we were including an appropriate number of variables and communicating risk effectively. An example report of the final climate-related variables for each of the >100 facilities globally are shown in Fig. 1. We found that including pairs of variables representing both the frequency and severity of climate events (e.g., drought, extreme rainfall) best represented the projected risk at each site. For each facility location provided by the company, the baseline conditions for each variable were calculated for a historical period (1951–70) and averaged across several global climate models from the Coupled Model Intercomparison Project phase 6 (CMIP6) (Eyring et al. 2016). Projected changes were quantified using the same models for three future 20-yr time periods, named by the center year: 2026 (2016–35), 2036 (2026–45), and 2051 (2041–60). Additional variables (e.g., tropical cyclone frequency and hail frequency) were calculated for select sites using additional data. We selected the models, scenarios, and time periods based on the company’s reporting needs and our climatological expertise, ultimately delivering projected impacts from three scenarios (SSP1–2.6, SSP2–4.5, SSP5–8.5) and four time periods. The three scenarios represent a spectrum of climate scenarios, with SSP1–2.6, SSP2–4.5, and SSP5–8.5 representing mean warming of 2.0°, 3.0°, and 5°C by 2100, respectively, with various rates of economic development and technological advancement.

Because of the geographical heterogeneity and quantity of facility locations, we did not undertake downscaling. Rather, we communicated this to the company in our discussion of uncertainty. Others undertaking similar work may find more room in the budget for downscaling or bias correction, depending on the company’s needs and number of facilities.

Conversations about deliverables revealed that the company desired results to be presented with the following characteristics: comparable and/or standardized across all sites, limited to a single page per site, and accompanied by a summary report as well as data files for further exploration. We delivered the data in three formats to meet these requirements. First, for each site, we developed report cards showing percentage changes in each variable, for two time periods and all three SSPs (as shown in Fig. 1). Coastal sites exposed to risk from tropical...
cyclones had an extra section in their report card showing that information. The report card figures were generated programmatically in MATLAB and exported to a separate program for customizable annotation. Second, data files were generated to accompany the report cards. These accompanying data files contained all the data, including the climate variables in original units and as percentage change for all model scenarios and time periods.

The third deliverable for the physical risk project was a written report. This report summarized and interpreted the findings for each of the climate variables. For each variable, we included maps of ten sites with the largest absolute and percentage changes. Additional

Fig. 1. An example of the report card generated for each of the >100 facilities globally.

Emissions scenarios describe trajectories of greenhouse gas concentrations through 2100.
In the low emissions scenario, greenhouse gas emission rates are reduced substantially.
In the moderate emissions scenario, greenhouse gas emissions peak in 2040 and decline thereafter.
In the high emissions scenario, greenhouse gas emissions continue to rise through 2100.

*The historical reference period is 1951-1970. The short-term change is a 20-year window centered on 2036. The long-term change is a 20-year window centered on 2051.
figures were provided as needed to further describe and explain the results. In this report, we also addressed the issue of uncertainty in climate models. Because the report was intended to be disseminated throughout the company, from site managers to executives, brevity and clarity were their top priorities in the discussion of results. We experimented with various methods for communicating uncertainty. The company selected what is shown in Fig. 1 as most appropriate for their leadership. Therefore, our analysis provided company leaders with a quick visual representation of the uncertainty associated with emissions scenarios and time periods. In our project report we also provided a discussion of other sources of uncertainty and a description of how the results should and should not be applied.

The written report also contained calculations of overall risk to all facilities. We calculated risk for each site based on the five types of weather and climate events that had caused insured losses in the past, based on the assumption that these variables will be responsible for the majority of future damage. These variables are shown in Table 1. We initially quantified risk in two ways. First, we calculated relative risk for each site. To do this, we ranked all 100+ sites by the 2051 magnitude of each of the five variables. We then averaged these variable ranks at each site, producing a single risk value relative to the other 100+ facilities. Second, we calculated relative increase in risk by 2051. Here the sites were ranked based on the percentage increase compared to the historical period. Both variations were presented as maps, as shown in Fig. 2 for an example of the relative 2051 risk magnitude.

Variations in the weighting of risk scores were then determined based on different aspects of the insured losses suffered by each climate variable. These variations in risk scores were weighted by 1) the frequency of the climate event triggering insurance claims for the company as shown in Table 1, 2) the gross insured losses as represented in the historical insurance claims, and 3) the inflation-adjusted gross losses as represented in the historical insurance claims. These weighting schemes enable company leadership to evaluate risk based on both the frequency and magnitude of damage.

**Climate change risk and opportunity assessment.** The second part of the project identified climate change–related risks and opportunities for the company 5, 10, and 15 years from now for multiple climate change scenarios. This analysis leveraged much of the same data used for the physical risk assessment. Assessing climate change–related risks includes identifying where operations are vulnerable to weather-related disruptions and potential changes in the regulatory environment; assessing opportunities includes identifying new markets or increasing product demand due to changes in weather and climate. We utilized historical sales data provided by the company to project climate-related market opportunities and growth. For this, we developed data-driven statistical and machine learning models that captured the relationships between historical sales data and climate variables and then predicted future sales based on CMIP6 climate projections.

We assessed future physical risk and vulnerability to the company’s physical infrastructure by leveraging their past weather-related insurance claims. For this, we estimated the cost per event in the historical record, then applied these cost estimates to climate

<table>
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<tr>
<th>Insurance claims weighting: Number of claims</th>
<th>Category</th>
<th>Number of claims</th>
<th>Weight</th>
<th>Report variable</th>
</tr>
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<tbody>
<tr>
<td>Wind</td>
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<td>0.19</td>
<td>Magnitude of extreme winds</td>
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</tr>
<tr>
<td>Flood</td>
<td>10</td>
<td>0.28</td>
<td>Maximum 5-day precipitation</td>
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<tr>
<td>Hail</td>
<td>3</td>
<td>0.08</td>
<td>Number of hail days</td>
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<tr>
<td>Severe weather</td>
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<tr>
<td>Tropical cyclone</td>
<td>4</td>
<td>0.11</td>
<td>Tropical cyclone intensity</td>
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projections based on changes in frequency and severity of these events in CMIP6 model projections. This assessment assumes constant infrastructure, and does not account for changes to the facilities, technology, material supply, and physical landscape. It is possible to develop more realistic projections for each facility that account for site-specific mitigation and hardening, but this requires substantially more time and effort. Future work with this company may focus on undertaking this type of modeling at their most vulnerable facilities.

We also considered indirect impacts of weather and climate on the company. Indirect effects, such as staffing issues (i.e., can employees safely commute to work during/after storms?) and employee health (i.e., increases in heat stress), are more difficult to quantify, but are important to the company’s operations. Because indirect effects are not quantifiable in the same ways as physical risks, we gathered relevant information through conversations with the company’s sustainability team, shown in Table 2 divided into two main categories: 1) impacts to staffing and personnel, and 2) impacts to the company operations. This assessment can be augmented by interviews with the managers of each facility who are familiar with the impacts of flooding, power outages, and other weather-related impacts on their personnel and facility operations.

**Lessons learned**
While many aspects of climate change risk assessments are similar to academic climate change research, the different audiences and purposes of corporate risk assessments necessitate some differences in methods and procedure. One difference to bear in mind is that a company may be interested in specific time periods that are useful for their business decisions or their reporting.
obligations. For example, the CDP asks companies to define short-, medium-, and long-term horizons. In the private sector, these are typically defined differently than by climatologists. In our case, the company considered short term as 1–3 years, medium term as 3–6 years, and long term as 6–100 years. Climate scientists embarking on collaborations should contemplate how to adjust their methods to best represent changes on time scales that are relatively short by academic standards. Similarly, companies committed to reporting climate impacts may require specific climate model scenarios be included in the commissioned research. In this case, the company requested low-emissions or “best case” scenarios to be included in the assessment, despite the low probability of achieving this scenario. Recognizing this early in the project may have influenced how we designed our report, figures, and methods of data delivery. On the other hand, companies may not be interested in some aspects of climate change that are typically studied by climate scientists. For instance, companies are interested in the aspects of climate change that are most directly tied to their operations. Therefore, changes in mean annual precipitation or temperature, while routinely reported in climate change reports and peer-reviewed literature, may have limited utility for a company interested in assessing risk to their supply chain or employees’ safety. Therefore, it is important early in the process to learn about how weather and climate affects company operations so that the climate change risk assessment can be tailored to their needs.

Apart from the research design, we also encountered unexpected obstacles in the design of report cards. In particular, through conversations with the client we learned that they wanted the report cards to be comparable across all variables and all 100+ facilities, so that a person reviewing the report cards could easily identify the variable of greatest concern at each site as well as compare changes between sites. The sustainability team recommended the use of percentage change for each variable, which allowed for all variables to be shown on the same axis, and relative to each site. However, the large climatological differences

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<th>Human Aspect</th>
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<td></td>
<td>High temperatures</td>
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<td>Staffing/access to work</td>
<td>Obstructed roads; damage to personal vehicles</td>
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<td>Employee health</td>
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<td>Equipment, machinery</td>
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<td>Waste management</td>
<td>Power outages from fire or fire risk</td>
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<tr>
<td>Energy supply</td>
<td>Power outages from fire or fire risk</td>
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between locations (e.g., Scandinavia versus tropical Asia) made these comparisons and their interpretation difficult, particularly with threshold-based variables. For example, we found that surface temperatures exceeding 90°F (32°C) was an important threshold for employee safety, and thus changes in the number of days with maximum temperature exceeding 90°F would be important for facility management. However, while showing the percentage change in number of hot days worked well for facilities in warm climates, this metric was not effective for facilities in cooler regions, as small absolute changes in the number of days exceeding 90°F were represented as large relative changes due to the small denominator. Standardized anomalies or other metrics may have been better suited to a global study. Furthermore, some climate risks, such as tropical cyclone frequency or number of days below freezing temperature, are only important for some facilities, complicating their inclusion on report cards. Thus, while designing report cards to be comparable across all sites is a laudable goal, it may not be practical.

Data availability was a key limitation in this project. For our physical risk assessment, we could only assess the risks that we knew had caused damage to their manufacturing facilities. While records of the company's insured losses for U.S. facilities were provided, this information was not readily available for facilities in other countries; thus, anecdotal evidence had to be used to inform our understanding of damage. Similarly, for the climate change–related risk and opportunity assessment, we could only assess vulnerability and opportunity based on the information they provided. The internal knowledge or market research that a company is allowed to share with an external consultant/research team may be limited. This makes it more difficult to develop robust projections.

While company datasets were lacking in certain areas, they were thorough in others. For example, the company with which we worked had previously acquired a proprietary industry dataset and was allowed to share it with us for our research. We were able to develop novel methods to draw relationships between our climate data and their regional sales data. The opportunity to explore these proprietary data illuminated new questions and areas of research that may not have been apparent had we been limited to traditional climatological data sources. In this way, the synthesis of climate and industry datasets benefited both the client company as well as the climate experts commissioned to undertake the project.

Finally, there are important ethical considerations to consider when undertaking research for the private sector. Some of the key issues that need to be negotiated and defined include nondisclosure agreements (What can the company and university researchers publicly present/discuss about the project?), intellectual property rights, and publication rights (Can the results of the research be published? If so, where and how? Do they require preapproval by the company?). It is also important to document and disclose any potential conflicts of interest. At our institution, all industry-funded research is negotiated between the institution and the company. Therefore, contract language is generated by the institution, not the researcher. Issues of intellectual property, publication rights, indemnification, and any restrictions on data sharing are defined in the contract. Investigators are required to complete ethics training and submit conflict of interest disclosures prior to starting any research project (including industry-funded research). The specifics regarding how these issues are handled will vary by institution and by project. Therefore, climate researchers should consult with experts at their institution so that they have a thorough understanding of all ethical considerations before starting an industry project.

In summary, we have experienced firsthand how important weather and climate information is to business operations. Close collaboration between climatologists and the private sector will ensure that they have better information about climate risks and opportunities and therefore can make better decisions. This article leverages our recent collaboration with
a Fortune 500 company to highlight our process, results, and limitations. As climate risk assessments become more mainstream, and the processes involved are discussed more publicly than have been historically, companies may begin collecting information and climatologists may begin designing deliverables in ways that allow these assessments to be thorough, insightful, and beneficial to all involved.

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