TECHNICAL DOCUMENTATION

Physical Risk: Heat Stress

Scientific Climate Ratings
An EDHEC Venture

V1.00.01 – July 2025

About Scientific Climate Ratings

Scientific Climate Ratings is a new venture born from EDHEC's Climate Finance applied research ecosystem. It delivers forward-looking ratings that quantify the financial materiality of climate risks for infrastructure companies and investors worldwide. Leveraging high-resolution geospatial data, proprietary climate risk models, and the world's largest financial dataset for infrastructure assets, Scientific Climate Ratings evaluates both transition risks (linked to the shift toward a low-carbon economy) and physical risks (arising from climate hazards such as floods, storms, heatwaves, and wildfires).

The ratings offer a dual perspective:

- Potential Climate Exposure Ratings assess current exposure to future climate risks under a "continuity" scenario, reflecting the most likely pathway based on today's global policies and trends.
- Effective Climate Risk Ratings go further by integrating climate risk data into financial valuation models across multiple scenarios — each weighted by its probability of occurrence — to estimate the financial effects of climate-related risks until 2035 and 2050.

While initially focused on infrastructure, Scientific Climate Ratings will soon extend its methodology to the listed equities segment, applying the same scientific rigor and forward-looking approach to a broader set of financial assets.

Scientific Climate Ratings aims to set a new standard in climate risk management — driving informed and responsible decision-making for a more resilient future.

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This document summarises the development of the physical risk damage model on **Thermal Heat Stress**, which is part of the ***Potential Climate Exposure Rating (PCER)*** and the ***Effective Climate Risk Rating (ECRR)***. It explains the general approach, provides the data sources used, justifies the methodology, and presents the results. For general information on the Scientific Climate Ratings, please see the respective technical documentations.

All procedures were developed by the *EDHEC Climate Institute*, hereafter referred to as ECI or "we."

1. General Approach

In the context of climate change, thermal stress refers to the detrimental impacts on living organisms and systems caused by excessive temperature conditions. It is further classified into varying degrees of heat or cold stress. **Extreme heat stress** occurs with heat wave periods that consistently bring abnormally high temperatures, while **extreme cold stress** occurs with consistent periods of abnormally low temperatures (Utah State University). The rise in global temperatures due to climate change is projected to exacerbate thermal stress globally. Particularly, the duration, frequency, and intensity of hot days are expected to increase with global warming (IPCC, 2023). This trend is anticipated to impact labour productivity significantly, with projections suggesting an average decline of 33 percent in Africa, 25 percent in Asia, and 17 percent in the Americas under a scenario of 3 degrees Celsius warming (Dasgupta et al., 2021).

Heat stress risk and its impact can be understood in three categories: direct physical damage, disruptions, and operational issues. **Direct physical damage** includes instances such as the deformation of road surfaces or buckling rail tracks. However, most infrastructure assets are designed to withstand extreme temperatures, which makes physical damage less of a concern.

On the other hand, **disruptions** occur when heat stress affects supply chains, transportation networks, and energy systems, leading to delays, shortages, and financial losses. However, disruptions are complex to quantify as they depend on external factors like supply chain interdependencies and adaptive responses. Such disruptions are often indirectly measured from a macroeconomic perspective. According to the National Bureau of Economic Research, a 1-degree Celsius increase in global temperature leads to a 12 percent decline in global GDP (Bilal & Känzig, 2024). Burke et al. (2015) confirm that climate warming is projected to reduce global economic output substantially. While these findings highlight the broader economic vulnerabilities associated with rising temperatures, we do not explicitly calculate the economic impact of heat stress, as the climate scenarios we use for our projections already incorporate the effects of climate warming on GDP.[1]

Instead, we focus our heat stress assessment on **operational issues**, where heat stress impacts chronic health risks that directly affect worker productivity. Extreme heat can impair employees' ability to perform, leading to increased costs for companies due to **disrupted operations and revenue losses** (Zhang & Shindell, 2021). These direct effects on human health and productivity represent the most immediate and quantifiable risks for businesses.

[1] Similarly, revenues are modelled directly from the sector-level revenue projections in each climate scenario, and hence, already include the impact of temperature changes through built-in damage functions (considering the increase of average temperature and its intra-annual variability). Integrating the indirect impact of heat through economic channels would thus be double counting. Therefore, we consider these impacts as already included in the revenue variable.

Besides the three impact categories, thermal stress affects sectors differently, as some industries are more vulnerable to extreme temperatures than others. For example, industries like agriculture, forestry, fishing, mining and extraction, and construction involve physically demanding tasks and require clothing or personal protective equipment that limits heat dissipation and impairs sweat evaporation (Borg et al., 2021; Kjellstrom et al., 2016; Parsons, 2002). Accordingly, we need to consider the sector, work environment, and type of physical activity when calculating risks from operational issues.

To quantify physical risks stemming from extreme heat stress, our approach follows a stepwise progression from sourcing inputs on assets and hazards to the geospatial transformation. This results in quantified physical metrics, representing the potential damage for each asset. Figure 1 summarises our approach, which we elaborate on in the methodology sections.

Figure 1: General approach for calculating physical hazard risks

2. Data Sources

To provide quantified extreme heat risk metrics for specific physical assets, three key data points are needed:

- We include **financial information** for each identified asset (e.g., total asset value and revenue) as extracted from *infra*Metrics[2] to quantify the financial impact of each physical risk on the asset.
- Global **climate hazard information** (e.g., hazard maps) illustrates which areas would be affected to what extent by a particular hazard and, hence, specifies the proximity to a potential hazard. Table 1 provides details on the considered climate hazard information that is based on a global temperature database.
- We also use **detailed asset boundaries** to define each asset's size and geolocation. These boundaries are prepared, checked, and updated regularly.

Combined, these inputs are proxies for an asset's *exposure* (i.e., the presence of assets in settings that could be adversely affected by hazard events) and account for its *vulnerability* (i.e., the propensity of an asset to be adversely affected by a hazard event) to an extreme heat stress event.

[2] infraMetrics is EIPA's index and data platform, offering asset-level investment metrics for private infrastructure across more than 20 markets by sector, business risk, and corporate structure peer groups. In our models, we update this data on a quarterly basis.

Table 1: Sources for extreme heat stress hazard maps

Hazard type	Hazard unit	Maps resolution	Underlying data and models
Extreme heat stress	Wet Bulb Globe Temperature (WGBT)	Global 25km by 25km	The Wet Bulb Globe Temperature (WBGT) is a composite temperature metric that combines air temperature and relative humidity to assess direct thermal stress for each day from 1990 to 2060. In line with Zhang and Shindell (2021), we calculate the WGBT based on a daily average near-surface temperature and daily relative humidity using NASA's Earth Exchange (NEX) dataset NEX-GDDP-CMIP6, which offers climate projections from 1950 to 2100 (Thrasher et al., 2022).

Overall, we prioritise reputable, open-source data providers for worldwide temperature information. To allow for model uncertainty, we include various climate models that consider different climate scenarios and take the median of the respective values.

3. Methodology

We adopt the framework previously established by Bouwer (2013) and Muis et al. (2015), who consider three main factors when measuring physical risks:

- the changing nature of hazards (due to climate change and natural weather variations),
- assets' vulnerability (the probability that assets will be damaged due to a hazard), and
- their exposure (the placement and characteristics of assets that could be impacted by hazards).

In the case of extreme heat stress, we measure vulnerability not as physical damage to an asset but as an operational disruption that can be quantified in companies' revenue losses. The following sections explain the steps for calculating physical risks from extreme heat stress, from identifying the location to measuring the loss, and projecting the loss increase in climate scenarios.

3.1. Data Preprocessing

To derive expected operational losses from extreme heat, we require several data preprocessing steps:

1. First, the asset's geolocation is used to identify the exact temperature and daily heat stress (measured in WGBT) for that location.
2. Knowing an asset's location, sector, and daily WGBT, we can calculate the ability to work and the respective ratio of daily work loss.
3. Finally, we aggregate the daily data into the average annual work loss for each asset.

The WBGT is a comprehensive measure of heat stress that includes humidity level, wind speed, solar radiation, and air temperature. Hence, unlike basic temperature readings, the WBGT provides a more accurate assessment of how environmental conditions affect human heat stress (Zhang &

Shindell, 2021). Numerous studies have found that increases in WGBT correspond directly to decreased productivity (Li et al., 2016; Singh et al., 2016). Accordingly, the WBGT is a useful measure for workplace safety as it reflects the actual thermal strain on workers.

Different sectors experience WBGT in varying degrees, depending on a sector's level of work intensity. Work intensity varies due to the physical demands, environmental exposure, and protective gear requirements depending on the task. Accordingly, sectors with heavy work (e.g., construction, agriculture, or emergency services) are most vulnerable to productivity losses related to WBGT. In contrast, office and service sectors experience minimal impact as long as the work remains in climate-controlled environments. Overall, we differentiate between light, medium, and heavy work intensity for each TICCS sector subclass[3], depending on the level of manual work and exposure to non-climate-controlled environments.

To calculate the impact of WBGT on workers' productivity, we compute the daily ability to work (Kjellstrom et al., 2016; Zhang & Shindell, 2021). Figure 2 summarises the general relationship between the daily WBGT, work intensity, and the effect on work ability.

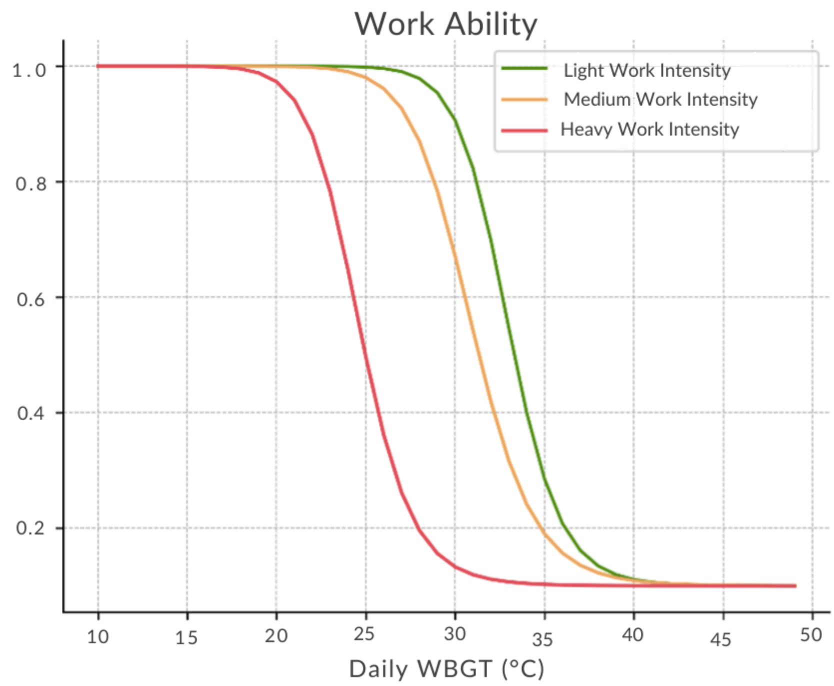

Figure 2: Relationship between daily WGBT and the ability to work

[3] The Infrastructure Company Classification Standard (TICCS) provides investors with a frame of reference for approaching the infrastructure asset class. It offers an alternative to investment categories inherited from the private equity and real estate universe, which are less informative when classifying infrastructure investments (Scientific Infra, 2022).

3.2. Expected Loss from Extreme Heat Stress

In order to estimate annual operational losses and related costs, we aim to calculate the losses in work ability in a given year that can then be related to the assets' revenues to measure the direct impact of heat stress.

Three steps are needed to calculate this indicator for a given scenario:

1. First, we calculate an asset's **average work ability** for each year and various climate model outputs. To integrate the impact of climate model uncertainty and retrieve one final annual time series, we calculate the median value of the average annual work ability from each model.
2. Next, to estimate the **loss in work ability** for each year, we calculate the ratio between a given year and a reference year. A positive value indicates a decrease and loss in work ability, while a negative value indicates the opposite.
3. Finally, we convert the work ability ratio into revenue loss to derive an asset's **expected operational losses**. As a worker's productivity does not directly translate into revenues, we apply a production-to-loss ratio that explains how much a work ability loss impacts revenues. This ratio depends on the labour share of production (Manyika et al., 2019).

4. Results

Our findings are precise and widely applicable, spanning across various sectors and countries.

4.1. Work Ability Calculations

Figure 3 illustrates the average work ability over a historical period between 1990 and 2014, focusing on a global (Fig. 3a) and a European perspective (Fig. 3b). These historical average conditions should already be captured in assets' valuations, assuming that adaptation measures have been implemented to address heat-related operational issues. Notably, regions with lower work ability are predominantly located in equatorial latitudes due to their higher exposure to heat and humidity – the indicators used to measure heat stress. Consequently, humid areas such as the Amazon, Central Africa, and Southeast Asia experience significant impacts.

Figure 4 illustrates the loss in work ability between the historical period (1990–2014) and a representative average projected for 2030, again highlighting differences on a global (Fig. 4a) and European level (Fig. 4b). The most significant losses in work ability over time are concentrated in tropical regions, particularly in areas such as Southeast Asia, the southern United States, North and Central region of South America, Central Africa and India. In North Africa, Egypt emerges as a hotspot with particularly high losses in work ability in the Mediterranean region. These patterns are driven by increased heat stress and are closely linked to rising temperatures and humidity levels in these regions, as a result of climate change.

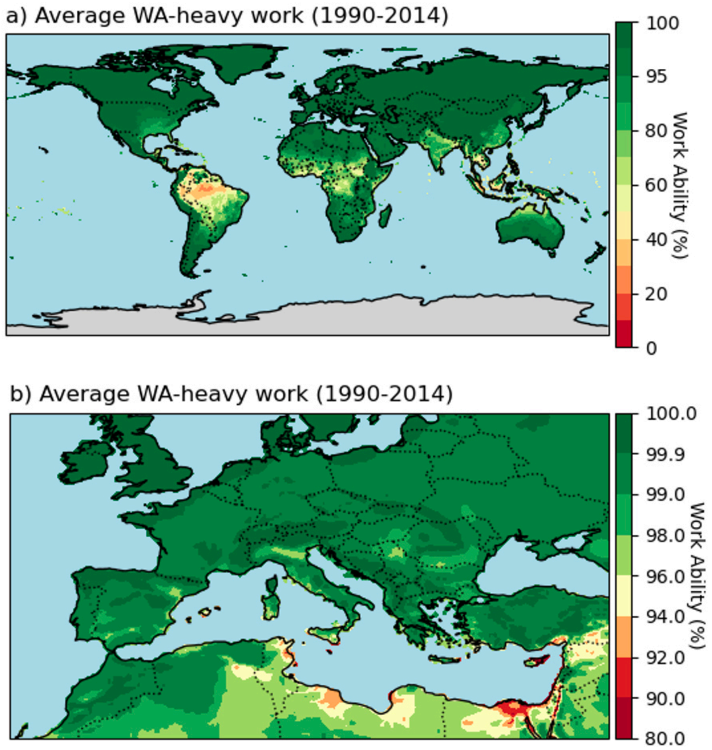

Figure 3: *Representation of the average ability to work for a historical period (1990-2014) on a global scale (a) and in Europe (b)*

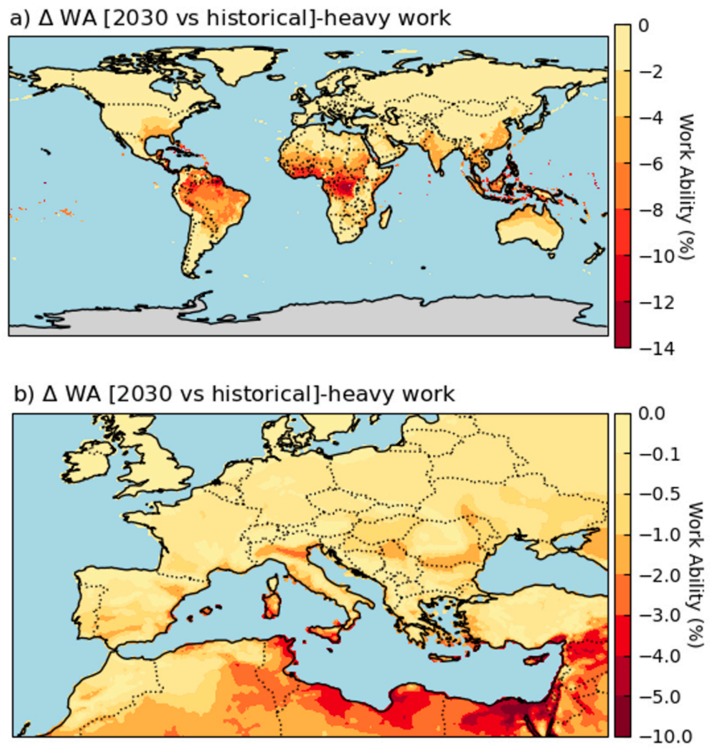

Figure 4: *Representation of work ability loss between the historical period (1990-2014) and a representative average for 2030 on a global scale (a) and in Europe (b)*

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