HELPS: an R package to project future Heat Effects on Labor Productivity by Sector

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Summary

Labor productivity, especially in outdoor sectors like primary agriculture, is highly sensitive to weather variations and heat stress. Understanding how labor productivity responds to key heat stress factors, such as temperature and humidity, is essential for evaluating future Earth system scenarios and their Multi-Sector Dynamic (MSD) impacts. However, global economic and MSD modeling often operate at more aggregate temporal and spatial resolutions than Earth System Models. This resolution disparity highlights the need for tools to connect the fine-scale insights of Earth System Models with the more aggregate scales of economic models. The HELPS R package is designed to generate high-quality data on biophysical labor productivity losses due to heat stress, tailored for modeling applications. HELPS processes high-resolution atmospheric data to calculate heat stress metrics, such as Wet-Bulb Globe Temperature (WBGT), and translates them into physical work capacity (PWC) estimates across various scenarios. The package further provides functions to aggregate data temporally and spatially, incorporating crop calendars and harvested area information to provide relevant measures of heat-induced PWC losses for agricultural labor. We demonstrate the application of HELPS by generating regional heat-induced agricultural labor productivity losses for major crop sectors, which serve as input data for the Global Change Analysis Model (GCAM), enabling more comprehensive evaluations of biophysical impacts on agriculture systems. While HELPS is designed to support MSD modeling needs, users can customize output to benefit a broad set of research applications.

Statement of need

Rising evidence of the adverse impact of heat stress on labor (Orlov et al., 2020), particularly for outdoor agricultural work (De Lima et al., 2021), underscores the critical need to quantify human heat stress exposure and heat-induced loss of PWC, particularly under hotter and more humid futures. Such quantification is essential for evaluating the MSD impact of biophysical shocks under different socioeconomic and Earth system scenarios and for guiding adaptation strategies to enhance resilience in vulnerable sectors, such as agriculture. We developed a code base to generate data for our paper studying heat-induced labor productivity loss and its implication for global agriculture (Sheng, Zhao, et al., 2025). The HELPS R package, built upon the existing code base, provides a comprehensive tool for quantifying heat stress levels and the resulting PWC losses that is easy to use for global economic and MSD modeling.

To our knowledge, three existing R packages, HeatStress (Casanueva et al., 2020), heatmetrics (Spangler et al., 2022), and meteor (Hijmans & Nelson, 2023), deliver related outputs. These packages provide functions to calculate heat stress levels using various heat stress metrics, i.e., WBGT, Universal Thermal Climate Index (UTCI), humidex, and heat index. The meteor package further translates heat stress to PWC using the labor-heat response functions from

Smallcombe et al. (2022) and Foster et al. (2021). However, their estimates represent a single set of impacts that do not account for variations in labor heat exposure across crop types and management practices and need further processing to meet the spatial and temporal resolution demands of some research and modeling applications.

HELPS fills this gap by introducing relevant datasets for meaningful temporal and spatial aggregation. Exposure of agricultural labor to heat stress is subject to the time and location of production activities. HELPS integrates crop calendars (Jägermeyr et al., 2021) and the latest global harvested area data from the Spatial Production Allocation Model (SPAM) data (IFPRI, 2024) to align the measurements of heat stress and PWC measurements to observed agricultural practices. HELPS allows users to generate output for relevant administrative or environmental boundaries, enhancing its usability across research and modeling applications. HELPS estimates distinguish between irrigated and rainfed systems for 46 SPAM crops and can be expanded to other crops with available calendars and harvested area data. This granularity ensures that HELPS's outputs capture the most meaningful heat stress impacts on crop labor across regions, management practices, and crop commodities. With uncertainty in heat-induced PWC losses introduced by the choices of heat stress metrics (Buzan & Huber, 2020; Kong & Huber, 2022; Schwingshackl et al., 2021) and labor-heat response functions (Foster et al., 2021; Smallcombe et al., 2022), HELPS offers default heat stress function (HS) and labor-heat-response (LHR) functions while also allowing users to incorporate customized functions, ensuring the package provides output aligning with established methods and can keep up with future literature advancement. HELPS helps the integrated human–Earth modeling community quantify labor heat stress impacts more flexibly by offering customizable functions for estimating heat stress and PWC, and by highlighting crop-specific measurements that integrate crop calendar and harvested area data across multiple temporal and spatial resolutions to meet diverse research needs.

Features

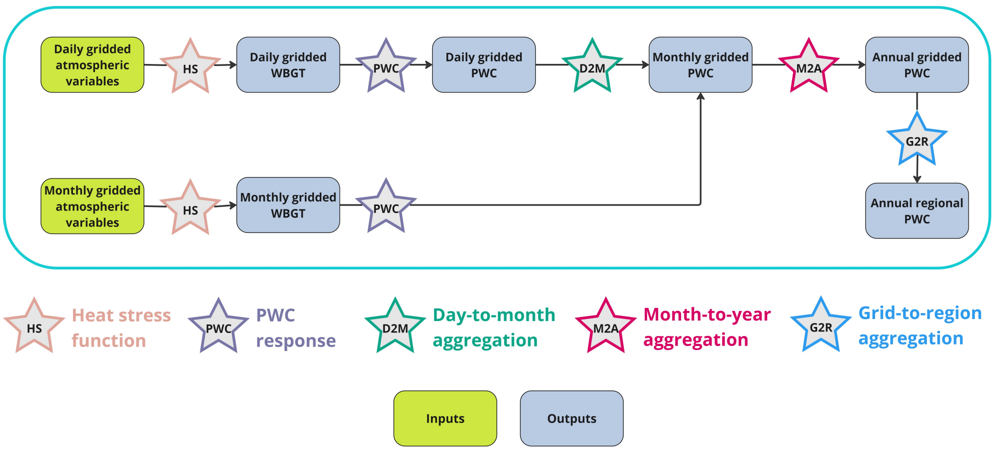

Figure 1: HELPS package schematic. HELPS processes daily and monthly input data at 0.5-degree grid resolution. Stars denote package functions.

HELPS processes daily or monthly 0.5-degree grid-level atmospheric projections from Earth System Models and generates outputs tailored to diverse research needs through five key functions (Figure 1). The HeatStress function translates atmospheric variables, such as temperature, relative humidity, and air pressure, into heat stress levels. It also includes a sector argument to filter and retain only the grids relevant to a specific sector. For example, Figure 2.a presents grid-level WBGT for grids with rain-fed maize harvested area. The PWC function further translates the heat stress level to the PWC (Figure 2.b). The DAY2MON function aggregates daily values into monthly means (Figure 2.c), and the MON2ANN function further aggregates monthly values into annual means, incorporating monthly weights aligned with the sector's production cycle (Figure 2.d). Grid-level outputs from HELPS can be further aggregated to user-defined regional levels using the G2R function.

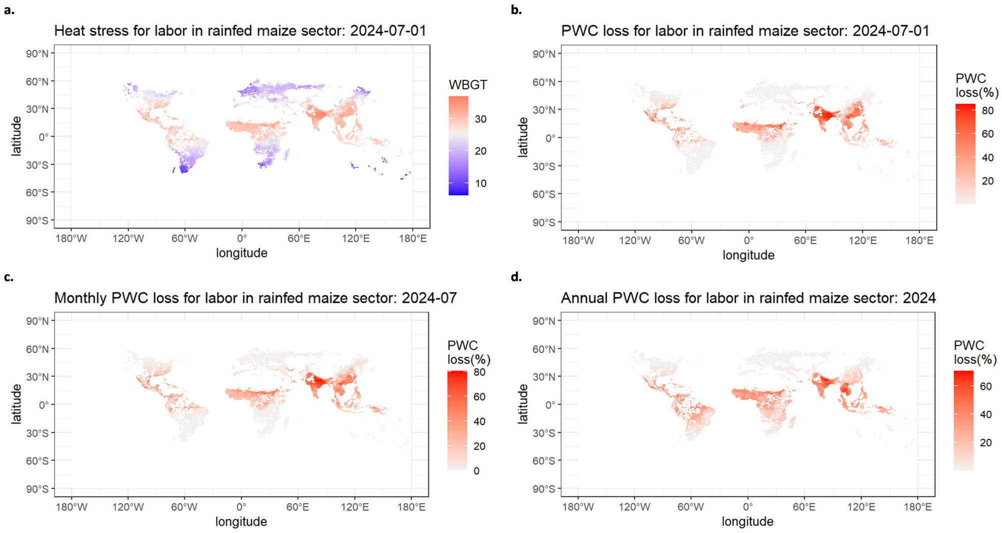

Figure 2: Example plots of outputs from the HELPS package. (a) daily grid-level WBGT for rain-fed maize labor on 2024-07-01. When WBGT is greater than 25 degrees, human physical work capacity (PWC) starts to decrease. WBGT = 25 is in grey, above 25 is in red, and below 25 is in purple; (b-d) grid-level heat-induced PWC loss for rain-fed maize labor, at daily (b), monthly (c), and annual (d) levels. Grids shown in panels b-d are grids with rain-fed maize harvested area.

Here we demonstrate an example of producing heat-induced agricultural labor productivity loss inputs for the Global Change Analysis Model (GCAM) (Calvin et al., 2019; Sheng, Edmonds, et al., 2025). Figure 3 illustrates the spatial aggregation of heat-induced PWC loss for the rain-fed maize sector in 2024. Panel (a) presents country-level results, while panel (b) shows the same data aggregated to GCAM regional water basins, which represent more spatially detailed modeling units. The spatial patterns highlight regions where labor productivity is most affected by heat stress, and the projected temporal changes in PWC can be directly applied as labor productivity adjustments in GCAM or other global economic models.

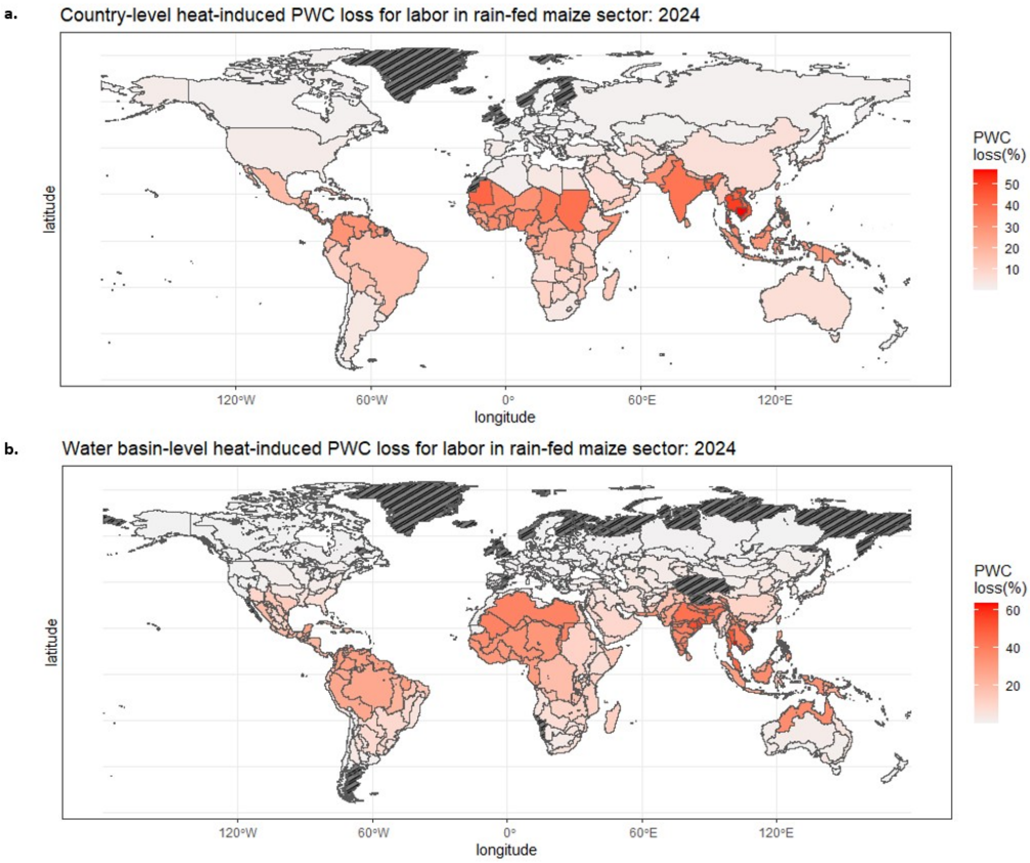

Figure 3: Spatial aggregation of HELPS output for the rain-fed maize sector in 2024. (a) Aggregated to country level; (b) aggregated to GCAM regional water basin level. Striped areas indicate missing (NA) values, representing regions with no rain-fed maize harvested area. Colors denote percentage loss in physical work capacity (PWC) due to heat exposure.

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