

Reporting Summary

Nature Portfolio wishes to improve the reproducibility of the work that we publish. This form provides structure for consistency and transparency in reporting. For further information on Nature Portfolio policies, see our [Editorial Policies](#) and the [Editorial Policy Checklist](#).

Statistics

For all statistical analyses, confirm that the following items are present in the figure legend, table legend, main text, or Methods section.

n/a Confirmed

- ☐ ☒ The exact sample size (n) for each experimental group/condition, given as a discrete number and unit of measurement
- ☒ ☐ A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly
- ☐ ☒ The statistical test(s) used AND whether they are one- or two-sided
Only common tests should be described solely by name; describe more complex techniques in the Methods section.
- ☒ ☐ A description of all covariates tested
- ☐ ☒ A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons
- ☐ ☒ A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals)
- ☐ ☒ For null hypothesis testing, the test statistic (e.g. F , t , r) with confidence intervals, effect sizes, degrees of freedom and P value noted
Give P values as exact values whenever suitable.
- ☒ ☐ For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings
- ☒ ☐ For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes
- ☒ ☐ Estimates of effect sizes (e.g. Cohen's d , Pearson's r), indicating how they were calculated

Our web collection on [statistics for biologists](#) contains articles on many of the points above.

Software and code

Policy information about [availability of computer code](#)

Data collection DSSAT version 4.6 (<https://github.com/DSSAT/dssat-csm.git>).

Data analysis All data analyses and the preparation of figures are done using Matlab (version 2022b) and R (version 4.3.1). Related codes are deposited in figshare at <https://doi.org/10.6084/m9.figshare.30846617>.

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Portfolio [guidelines for submitting code & software](#) for further information.

Data

Policy information about [availability of data](#)

All manuscripts must include a [data availability statement](#). This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A description of any restrictions on data availability
- For clinical datasets or third party data, please ensure that the statement adheres to our [policy](#)

Data availability

CHELSA-W5E5 is accessible at <https://chelsa-climate.org/>. The GGCMI Phase 3 crop calendar is accessible under the DOI: 10.5281/zenodo.5062513. A dataset of wheat yield at a 4-km resolution during 1982–2020 (named GlobalWheatYield4km) is accessible at <https://doi.org/10.6084/m9.figshare.10025006>. The soil data

that support the simulation with crop model (DSSAT) in this study are accessible at <https://doi.org/10.7910/DVN/1PEEY0>. Fertilizer inputs is accessible at <https://doi.org/10.5281/zenodo.4954582>. GGCM Phase 3 model outputs are accessible at <https://data.isimip.org/search/query//tree/ISIMIP3a/OutputData/agriculture/>. GGCM Phase 1 model outputs are accessible at <https://zenodo.org/communities/agmip/records?q=&l=list&p=1&s=10&sort=newest>. Subnational crop yield statistics are available at depositories listed in Supplementary Table 4. Irrigated and rainfed wheat harvested area is accessible at https://www.uni-frankfurt.de/45218031/Data_download_center_for_MIRCA2000. Emergency Events Database (EM-DAT) are accessible at <https://www.emdat.be/>. Spatial Production Allocation Model (SPAM) is accessible at <https://doi.org/10.7910/DVN/PRFF8V>. A dataset of crop yield at a 5-minute resolution during 1982–2015 (named GlobalCropYield5min) is accessible at <https://doi.org/10.17632/hg8wzgx4yp.3>. GSWP3-W5E5 is accessible at https://data.isimip.org/search/simulation_round/ISIMIP3a/product/InputData/climate_forcing/gswp3-w5e5/. Wheat experimental data from agro-meteorological stations and corresponding weather data from meteorological stations are accessible at <http://data.cma.cn>. GLASS LAI dataset is accessible at <https://glass-product.bnu.edu.cn/introduction/LAI.html>. GIMMS LAI4g dataset is accessible at <https://zenodo.org/records/8281930>. GLOBMAP LAI dataset is accessible at <https://zenodo.org/records/4700264>.

Research involving human participants, their data, or biological material

Policy information about studies with [human participants or human data](#). See also policy information about [sex, gender \(identity/presentation\), and sexual orientation](#) and [race, ethnicity and racism](#).

Reporting on sex and gender

Use the terms *sex* (biological attribute) and *gender* (shaped by social and cultural circumstances) carefully in order to avoid confusing both terms. Indicate if findings apply to only one sex or gender; describe whether sex and gender were considered in study design; whether sex and/or gender was determined based on self-reporting or assigned and methods used. Provide in the source data disaggregated sex and gender data, where this information has been collected, and if consent has been obtained for sharing of individual-level data; provide overall numbers in this Reporting Summary. Please state if this information has not been collected. Report sex- and gender-based analyses where performed, justify reasons for lack of sex- and gender-based analysis.

Reporting on race, ethnicity, or other socially relevant groupings

Please specify the socially constructed or socially relevant categorization variable(s) used in your manuscript and explain why they were used. Please note that such variables should not be used as proxies for other socially constructed/relevant variables (for example, race or ethnicity should not be used as a proxy for socioeconomic status). Provide clear definitions of the relevant terms used, how they were provided (by the participants/respondents, the researchers, or third parties), and the method(s) used to classify people into the different categories (e.g. self-report, census or administrative data, social media data, etc.) Please provide details about how you controlled for confounding variables in your analyses.

Population characteristics

Describe the covariate-relevant population characteristics of the human research participants (e.g. age, genotypic information, past and current diagnosis and treatment categories). If you filled out the behavioural & social sciences study design questions and have nothing to add here, write "See above."

Recruitment

Describe how participants were recruited. Outline any potential self-selection bias or other biases that may be present and how these are likely to impact results.

Ethics oversight

Identify the organization(s) that approved the study protocol.

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☐ Life sciences ☐ Behavioural & social sciences ☒ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Ecological, evolutionary & environmental sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description

We provide a novel approach to reduce the uncertainties in assessing climate impacts on wheat productivity by jointly refining the model structure and parameterization of the widely used DSSAT CERES-Wheat model at 10-km resolution. The simulation performances of the improved model versions were compared with the outputs from the Global Gridded Crop Model Intercomparison (GGCMI) at subnational and national scales. We also evaluate the model's capability in simulating yield losses from droughts, heatwaves, and their compound events, and investigate the annual dynamics of extreme weather impacts and adaptation.

Research sample

The historical data (1981-2015), including weather, crop calendar, soil, and fertilization data, were used to drive crop model simulation at 10-km resolution, which is described in method. The cultivar parameters were calibrated to the GGCM Phase 3 crop calendar and GlobalWheatYield4km. For model comparisons, national yield statistics were collected from FAO, while subnational-level census data were obtained from ~11000 administrative unit level 2 (ADM2) and 3 (ADM3) for the 54 countries. A database of extreme weather events was compiled from EM-DAT.

Sampling strategy

We used all available samples.

Data collection

All the data used for this study were downloaded from international organizations and public databases.

Timing and spatial scale	Crop model simulations run from 1981 to 2015 at 0.1° spatial resolution. We also investigate the robustness and scalability of the proposed calibration framework at 0.5° spatial resolution or by using other independent data (i.e., experimental data at site scale and statistical data).
Data exclusions	No data were excluded.
Reproducibility	We have provided data source information, and replication of methods can be realized through rerunning the simulation with the exact scripts and model version which deposited in figshare.
Randomization	n/a
Blinding	n/a

Did the study involve field work? ☐ Yes ☒ No

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

Methods

n/a	Involved in the study	n/a	Involved in the study
☒	☐ Antibodies	☒	☐ ChIP-seq
☒	☐ Eukaryotic cell lines	☒	☐ Flow cytometry
☒	☐ Palaeontology and archaeology	☒	☐ MRI-based neuroimaging
☒	☐ Animals and other organisms		
☒	☐ Clinical data		
☒	☐ Dual use research of concern		
☒	☐ Plants		

Plants

Seed stocks	n/a
Novel plant genotypes	n/a
Authentication	n/a