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Accessible Climate and Impact Model Output for Studying the Human and Environmental Impacts of Nuclear Conflict

Cheryl Harrison[1*], William Faulkner[2], Joshua Coupe[1,3], E. Kesse Asante[1], Charles Bardeen[4], Victoria Garza[1], Jonas Jägermeyr[5,6,7], Nicole S. Lovenduski[3], Alan Robock[8], Karen Rojas[1], Kim Scherrer[9], O. Brian Toon[10], Lili Xia[8]

1. Department of Ocean and Coastal Science, Center for Computation and Technology. Louisiana State University, Baton Rouge, Louisiana
2. Science Policy Research Unit, University of Sussex
3. Department of Atmospheric and Oceanic Sciences and Institute of Arctic and Alpine Research,
4. NSF National Center for Atmospheric Research
5. Columbia University, Climate School, New York, NY 10025, USA
6. NASA Goddard Institute for Space Studies, New York, NY 10025, USA
7. Potsdam Institute for Climate Impact Research (PIK), Member of the Leibniz Association, 14412, Potsdam, Germany
8. Department of Environmental Sciences, Rutgers University, New Brunswick, New Jersey
9. Department of Biological Sciences, University of Bergen, Norway
10. Laboratory for Atmospheric and Space Physics, University of Colorado

*chsharrison@gmail.com

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Abstract

Nuclear winter refers to the suite of physical and biological consequences that may follow nuclear conflict, particularly the cooling and darkening of Earth's surface due to black carbon soot in the upper atmosphere. While the associated changes in temperature, precipitation, and food system productivity have been the subject of climate modeling for decades, the outputs of models used to project these effects are stored in large files with formats unfamiliar to the broader research community. This paper introduces a standardized, user-friendly repository of simulated nuclear conflict climate impact data designed to lower barriers for non-specialist researchers. The data product provides simplified, spreadsheet-ready datasets derived from established Earth System Model simulations and includes variables relevant to human and environmental impacts: temperature, precipitation, ultraviolet radiation, crop yields, fish catch, and sea ice thickness for a range of nuclear conflict scenarios. This repository aims to facilitate interdisciplinary research into the long-term consequences of nuclear detonations to support policy development.

1. Introduction

Nuclear winter—the global cascade of consequences following nuclear conflict—emerged as a scientific concept in the 1980s. Early research, backed by private and government sponsors, focused mainly on the physical effects of stratospheric black carbon (BC) soot from a U.S.–Soviet nuclear war on the atmosphere (Turco et al. 1983; Thompson and Schneider 1986; Endal 1985; National Research Council 1985). Following the Cold War's end in the early 1990s, interest waned, and few new studies appeared. In 2007, a second wave of nuclear winter research began to emerge, introducing a new scenario: a regional India–Pakistan conflict involving 100 warheads of 15 kilotons of explosive power—each roughly the size of the Hiroshima bomb (Toon et al. 2007; Robock et al. 2007a) - which would inject 5 Tg BC into the lower stratosphere. The second wave of work, in addition to updating simulations of temperature, precipitation, and insolation (Reisner et al. 2018; Coupe et al. 2019), also simulated stratospheric ozone loss (Mills et al. 2008; Stenke et al. 2013; Mills et al. 2014), agricultural decline (Xia and Robock 2013; Xia et al. 2015), and the effects of smoke composition on the climate response (Pausata et al. 2016). Four different climate models, all found global cooling for more than a decade after the injection of 5 Tg BC into the lower stratosphere, unprecedented in recorded human history (Robock et al. 2007; Stenke et al. 2013; Mills et al. 2014; Wagman et al. 2020).

Food system impacts from nuclear winter have recently gained prominence as an existential risk (Jägermeyr et al. 2020; Xia et al. 2022). A growing body of research explores how to reduce human vulnerability to "abrupt sunlight reduction scenarios" (Boyd and Wilson 2023; Pham et al. 2022; Rivers et al. 2022). Much as the early nuclear winter modeling paralleled emerging debates on the scientific validity of anthropogenic climate change, today's attention to food resilience resonates with current discussions of climate change adaptation and geoengineering (Egeland 2025; Van Buuren et al. 2025; Chan et al. 2025; Wieners et al. 2023; Roberts et al. 2025). This paper contributes to that evolving agenda by releasing simplified versions of key datasets. We hope to support inquiry into what remains a critically understudied area: the global consequences of nuclear conflict.

Nuclear conflict is widely perceived as immensely destructive, but often without a holistic appreciation of the nature and timing of the destructive effects. Most often considered are the direct effects of nuclear detonations in populated areas, where blast damage, fire, and radiation could kill millions and destroy vast swaths of infrastructure (Cochrane and Mileti 2010). Less discussed are long-term effects, especially the global climatic changes which could have far-reaching repercussions for the entire world, including in countries entirely uninvolved in the initial conflict (Coupe et al. 2019; Xia et al. 2022; NAS 1985; Robock et al. 2007a, 2007b; Hess 2021). While the potential global human and environmental effects of nuclear conflict are large, funding for impact studies has been elusive and largely restricted to a narrow group of philanthropic sources and U.S. nuclear-weapons-focused national labs. Significant questions remain uninvestigated (NASEM 2025). Understanding the myriad impacts that a post-nuclear conflict global cooling event would trigger requires a broad range of expertise across multiple disciplines.

With the aim of facilitating interdisciplinary efforts to understand the environmental and human impacts of nuclear conflict, here we introduce the first unified repository of data from nuclear conflict climate simulations designed to facilitate use of these data in, for example, human health, economics and political science. The climate simulations use a state-of-the-art Earth system climate model to simulate the environmental effects of nuclear conflict for a number of scenarios. These scenarios (Table 1) range in the amount of soot injection into the stratosphere: five India/Pakistan conflict scenarios that inject 5, 16, 27, 37 and 47 Tg of soot, respectively, and one US/Russia conflict scenario that injects 150 Tg of soot (1 Tg is 1 million metric tons, equivalent to three Empire State Buildings or four supertankers full of crude oil). The soot amounts were generated from plausible scenarios for nuclear conflict following input from military and policy experts, and assume different levels and number of weapons used. See Toon et al. (2019) for further details on scenario development.

Table 1. Nuclear conflict scenarios used to produce this dataset. Each scenario represents war between two nations, with a varying number of weapons of different sizes. The soot load is the amount of black carbon injected into the stratosphere. This soot blocks sunlight, reducing the intensity of light that reaches the surface, creating a radiation anomaly at the surface (W/m^2). Light reduction lasts for approximately 10 years in all scenarios, with the largest impacts in years 2-5 following the war. See Toon et al. (2019) and Coupe et al. (2019) for more scenario details. Note there are many other scenarios that could produce this stratospheric soot injection (Toon and Robock, 2025) and the climate impacts depend on the amount of soot, not the geographical origin.

Soot load	Warring Nations	Max Radiation Anomaly	Description
5 Tg	India and Pakistan	-10.9 W/m^2	100 15 kt weapons
16 Tg	India and Pakistan	-31.1 W/m^2	250 15 kt weapons
27 Tg	India and Pakistan	-46.9 W/m^2	250 50 kt weapons
37 Tg	India and Pakistan	-57.8 W/m^2	250 100 kt weapons
47 Tg	India and Pakistan	-68.7 W/m^2	500 100 kt weapons
150 Tg	Russia and U.S.	-115.3 W/m^2	Nuclear superpower conflict 4400 100 kt weapons

While results from some climate simulations of nuclear conflict and associated impact studies have been made available through a series of scattered repositories (e.g., Coupe et al. 2019; Xia et al. 2022), the file formats (gridded matrix data in binary NetCDF, Network Common Data Form) require significant memory and specialized software packages, presenting hurdles for broad usability. Here we provide data as standardized tables that can be analyzed using common consumer spreadsheet programs. These tables contain variables regarding temperature, precipitation, surface ultraviolet (UV) radiation, agricultural crop yields, expected fish catch, and sea ice thickness in major ports (Table 2). Data have been aggregated at the country or port scale on monthly time frequency, reshaped into a standardized table format, and enhanced with additional useful variables. The code for aggregating, reshaping, and standardizing these tables forms part of the final data product (see Table 5).

Table 2. Available datasets with the smallest (most disaggregated) geographic and time units, and forcing scenarios for each (Table 1). See Table S1 for more details.

Dataset	Geographic Unit	Time Unit	Forcing Scenario (Tg)
1. Temperature	Country	Month	0 (control), 5, 16, 27, 37, 47, 150
2. Precipitation	Country	Month	0 (control), 5, 16, 27, 37, 47 150
3. UV	Country	Month	0 (control), 150
4a. Agriculture (AgMIP)	Country	Year	5
4b. Agriculture (CLM)	Country	Year	5, 16, 27, 37, 47, 150
5. Fisheries	Country	Year	5, 16, 27, 37, 47, 150
6. Sea Ice	Port	Month	37, 47, 150

This paper is organized as follows. Section 2 summarizes the physical processes that lead to nuclear winter and the environmental effects. Section 3 outlines how the data was produced and describes the resulting data products. Section 4 outlines suggestions for research using the data products, with an open invitation for interdisciplinary engagement.

2. Nuclear Winter

The process through which nuclear conflict may impact global climate and ultimately humans and the environment has multiple steps, visually represented in Figure 1. In the initial 'local' phase, roughly one-third of the energy from a given nuclear detonation is released as visible light and heat that rapidly warms materials within line-of-sight of the explosion (Glasstone and Dolan 1977), leading to combustion (Brown et al. 2023; Eden 2004). The area heated by the detonation varies significantly with its altitude and total yield, but many simultaneous ignitions can quickly merge into a single large fire. One of the few historical benchmarks is Hiroshima, where the firestorm ignited by the detonation of 'Little Boy' on August 6, 1945 consumed 13 square kilometers (Hess 2021). While the nuclear blast and associated fires can cause extreme local damage, the resulting black carbon 'soot' (this paper uses the terms 'BC' for black carbon and 'soot' interchangeably), a component of the smoke generated by the fires, will lead to global environmental impacts. Large fires can generate many metric tons of BC, which the heated air lofts to higher altitude as part of the smoke plume. Further, because the BC absorbs radiation, it can heat up further and 'self-loft' higher into the atmosphere, as is seen in large wildfires (e.g., Yu et al. 2019). Thus some of the BC can rise above the lowest layer of the atmosphere, the troposphere, where clouds and precipitation form, and into the much drier stratosphere.

Once in the stratosphere, BC particles rapidly spread across the globe over the course of weeks, and would linger for years, for a few reasons. First, the diameters of these tiny particles are commonly measured in microns, or thousandths of a millimeter (approximately one-tenth the size of a grain of flour), and thus although they do inevitably succumb to gravity's pull and fall back to the ground, even extremely gentle air movement can keep them afloat (Brown et al. 2023). Second, precipitation, the main mechanism of removing BC from air in the troposphere, does not occur in the stratosphere. Third, sunlight warms the jet-black BC particles, which create tiny pockets of warmer, buoyant air around them and 'self-lofts' the particles to higher altitudes, thus increasing their residence time in the stratosphere (NASEM 2023; Robock et al. 2007a, 2007b). Finally, strong, consistent winds in the stratosphere efficiently mix the air and disperse the BC globally within weeks (Coupe et al. 2019).

A veil of lingering soot in the stratosphere causes four main physical effects:

(a) **Reduced Sunlight:** Black carbon (BC) particles absorb sunlight, preventing it from reaching the lower atmosphere and there is less sunlight for photosynthesis.

(b) **Reduced Temperature:** Less sunlight causes average surface temperatures to fall.

(c) **Reduced Precipitation:** Cooler temperatures reduce the hydrologic cycle. Average precipitation rates decline.

(d) **Depleted Ozone Layer:** Sunlight absorbed by BC heats up the stratosphere, depleting ozone and increasing ultraviolet (UV) radiation on the surface. The timing and magnitude of UV increase depends on the level of initial soot. Increased UV radiation reaches the surface through the thinner stratospheric ozone layer when soot aerosols begin to fall out of the atmosphere and let in more sunlight.

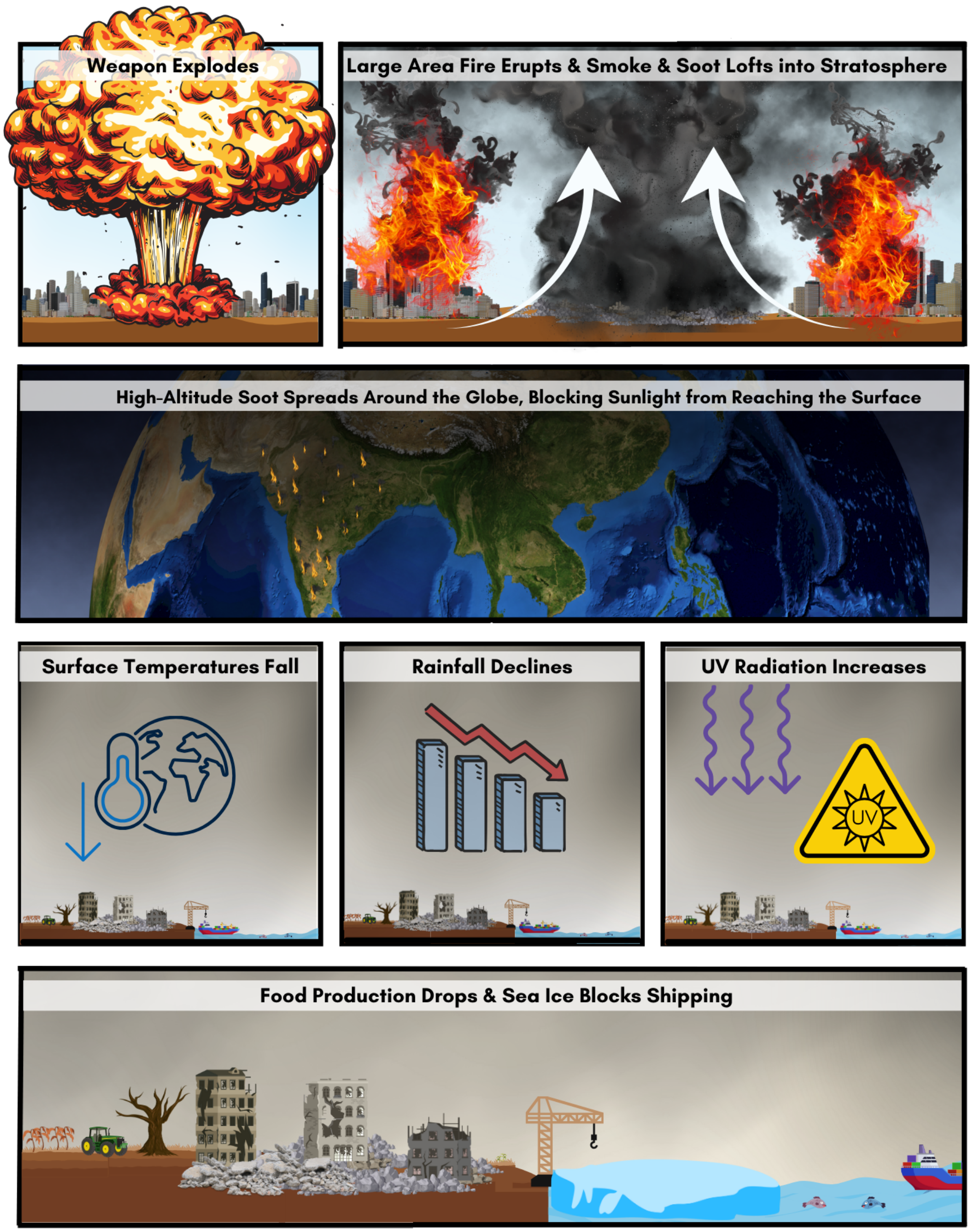

Figure 1: Nuclear Winter Mechanisms and Impacts. When a nuclear weapon is detonated in a region with sufficient fuel loading, the resulting firestorm can lift soot into the stratosphere, where it disperses globally over a few weeks. The soot, or black carbon, blocks sunlight, decreasing temperature and precipitation and depleting ozone. UV increases due to ozone loss, with timing and magnitude depending on the war scenario. These climate impacts in turn reduce terrestrial and marine food production and result in expanded sea ice, which could block major ports.

The magnitude and duration of these physical effects depends on assumptions about the numbers, size, and explosive power of the weapons, and amounts, locations, and types of combustible material (often termed ‘fuel loading’) in target areas (NASEM 2025). Fuel loading determines the smoke composition (May et al. 2014), penetration into the stratosphere, which also depends on local weather, and assumptions about how BC particles aggregate and disaggregate in the stratosphere (May et al. 2014; Redfern et al. 2021; Bardeen et al. 2021). Similar to large scale volcanic eruptions in the geological record (Sigl et al. 2015), multi-year climate impacts, from a few years to a decade, are expected for temperature, precipitation, and ozone, with much longer scale recovery times for the ocean and cryosphere, and possibly new climate states lasting hundreds to thousands of years for very large nuclear conflict cooling events, similar to the Little Ice Age (Mills et al. 2014; Harrison et al. 2022).

The physical consequences outlined above entail worldwide stresses on the biosphere. Organisms would suffer from the cold and any that depend on photosynthesis (e.g., plants, phytoplankton) would have less available sunlight (Coupe et al. 2019; Toon et al. 2019). For land plants, decreased precipitation would vie with concurrently reduced evaporation (due to colder temperatures), producing regional patterns of increased or decreased soil water availability, although these effects are less well understood (NASEM 2025). In addition, enhanced UV is likely to have negative effects on plant growth and reproduction (Bardeen et al. 2021; Coupe et al. 2024). Many of the affected organisms constitute the base of many food chains, including those that supply humans with food crops, livestock feed, and seafood (Xia et al. 2015; Jägermeyr et al. 2020; Scherrer et al. 2020; Xia et al. 2022). What is not known is how human systems, such as global trade, energy sectors, and migration,would respond to these impacts.

3. Data Development and Description

3.1 Dataset Development

The datasets presented here are the end result of five broad steps: (1) select nuclear conflict scenarios to be modeled, (2) run simulations of a chosen nuclear conflict scenario in an Earth System Model (ESM), and for some data use the outputs of the ESM simulation to force a secondary model, for example of agricultural crops, (3) aggregate and average the model outputs to create smaller, tabular datasets, (4) standardize the resulting table formats, and (5) add useful variables.

3.1.1 Selecting Nuclear Conflict Scenarios

Before simulating any configuration of an ESM, one must decide on the ‘scenario,’ i.e., the version of the future (or past) that is of interest. Here, a scenario is defined by the amount of BC entering the stratosphere as a result of fires set by nuclear explosions in trillions of grams (teragrams, Tg; Table 1). The highest impact scenario considered is a nuclear conflict between the United States and Russia involving between 3100 and 4400 nuclear weapons with yields between 100 and 500 kilotons (kt), which lofts 150 Tg of soot into the stratosphere. This scenario has served as the starting point for multiple studies (Robock et al. 2007b); the datasets presented here include the scenario using the most recent modeling from Coupe et al. (2019). Other scenarios represent more recent thinking about India-

Pakistan nuclear conflict scenarios with fewer weapons and lower yields. These scenarios were derived through extensive consultation with experts, and when simulated, result in 5 to 47 Tg of BC in the stratosphere (Toon et al. 2019). Because BC delivered to the stratosphere is globally dispersed within weeks (see Section 2), where the nuclear conflict occurs has only a minor effect on its wider atmospheric impacts. Given that the exact location of a potential future nuclear conflict is indeterminable, the scenarios present in the data permit analyses spanning a wide range of possibilities.

Table 3: Glossary of Common Modeling Terms. For further discussion of modeling vocabulary, see Shoeman et al. (2023).

Term	Explanation
Earth System Model (ESM)	A comprehensive modeling framework that integrates multiple components — such as atmosphere, ocean, land, and ice — to model interactions in the Earth's climate system.
Component (or Sub-Model)	A specialized module within an Earth System Model designed to simulate a particular domain.
Scenario	A defined set of conditions describing a possible future or past, used as a basis for modeling. In this paper, scenarios vary by the amount of black carbon (BC) soot released into the stratosphere.
Simulation	A single run of a model under one scenario, using a fixed set of starting parameters ("initial conditions"). It produces one set of outcome data.
Model Ensemble	A collection of simulations run for the same scenario. Some ensembles use a single model with slightly different initial conditions, while others compare results from multiple models simulating the same scenario. The ensemble approach helps researchers understand the sensitivity of results to internal climate variability, such as random weather variations or El Niño cycles, or to different model assumptions, increasing confidence in the reliability of the findings.

3.1.2 Modeling the Global Environmental Consequences of Nuclear Conflict

ESMs simulate the global climate and biosphere using a set of connected 'components' that model, for example, the atmosphere, ocean, cryosphere (ice), and land processes (for a brief explanation of modeling vocabulary, see Table 3; Schoeman et al. 2023). Each component of an ESM represents its own sub-model, with its own grid and parameterizations. These different components are connected via a 'coupler' that passes information, such as temperature, from one component to another. These components are forced by different inputs; in this case the main forcing is black carbon into the atmospheric component. After the ESM simulation is completed, the resulting output files can then be used as forcing inputs for models that simulate further impacts, for example agriculture and fisheries (Rosenzweig et al. 2017; Novaglio et al. 2024).

Here all nuclear conflict scenarios were simulated using the Community Earth System Model (CESM; Hurrell et al., 2013). The CESM1 configuration used here includes the Whole Atmosphere Community

Climate Model (WACCM) atmospheric component, the Community Land Model (CLM), the Parallel Ocean Program (POP) model, and the Community Ice CodE (CICE) for sea ice. Additionally, two sub-components within WACCM permitted the simulation of the aggregation and disaggregation of BC particles in the stratosphere using the Community Aerosol and Radiation Model for Atmospheres (CARMA; Bardeen et al. 2017) and how changes to stratospheric ozone affect ultraviolet radiation reaching the surface, the Tropospheric Ultraviolet and Visible model (TUV; Bardeen et al. 2021).

The datasets presented here (Tables 2 & 4) include results from two agricultural crop yield modeling efforts. The first agricultural dataset from Jägermeyr et al. (2020) uses a multi-model ensemble approach (Table 3) to test whether after a regional nuclear conflict scenario (5 Tg of BC in the stratosphere; Table 1) the changes in agricultural yields would be detectable, given the variabilities in models and model configurations. The 'Agriculture AgMIP' dataset therefore represents the projected changes in crop yields averaged across six global process-based crop models (EPICBOKU, GEPIC, LPJmL, pDSSAT, PEPIC, and PROMET) from the Agriculture Model Intercomparison and Improvement Project (AgMIP; Rosenzweig et al. 2017) and two ESM simulations with different CESM model configurations (Toon et al. 2019, Mills et al. 2014). The ESM forcing for this dataset has been bias-corrected using observational data, so that it has high fidelity with historical agriculture timeseries. The crops simulated are corn, rice, soybeans, and wheat. The best usage of this dataset is to study agriculture impacts with estimates of uncertainty for a nuclear-conflict-driven cooling event.

The second agricultural dataset, from Xia et al. (2022), simulates corn, rice, soybeans, spring wheat, and grass, with the last used to estimate pasturage for grazing animals, using an offline process-based crop model in the CLM version 5. This dataset includes all nuclear conflict scenarios (Table 1), and is best used to compare different levels of nuclear- conflict- driven cooling on impacts related to food availability.

Marine fish catch from Scherrer et al. (2020) uses the BiOeconomic mArine Trophic Size-spectrum (BOATS) marine ecosystem model, which simulates fishing effort and fish catch through a component that depends on fish price, cost of fishing, catchability, and fisheries regulation (Carozza et al. 2016). BOATS uses an internal ecological parameter ensemble that is fit to historical catch observations (Galbraith et al. 2017); here we provide the mean and standard deviation over this parameter spread (Table 4).

Xia et al. (2022) combined crop model outputs with the Scherrer et al. (2020) fisheries model output to estimate total food insecurity by country, year, and nuclear conflict scenario. In that study food availability from agriculture and fisheries was translated into food insecurity assuming that countries completely ceased trading in all war scenarios. Further, assumptions were made about the fate of livestock (whether they were continued to be fed with grain or it was used for humans) and food waste reduction over current levels. Thus, there are many opportunities to explore other socioeconomic responses and scenarios.

The final dataset contains thickness of sea ice present in major world ports, following findings in Harrison et al. (2022) that sea ice expanded into regions that are normally ice-free. Blocked or limited access to port facilities could have major impacts on global shipping and affect regional food security. This could be included into trade scenarios, for example.

Temperature, precipitation, UV and sea ice are provided at monthly time frequency (Table S1), counting the number of months after the nuclear war. In each scenario, the war is simulated to start on May 14th in an arbitrary year in the modern era (nominally 2000). Agricultural and fisheries data are provided as yearly data products, in years since the war, with agriculture data being calendar year (January through December) and fisheries being June-May. Each dataset is provided for different time periods, depending on the relevant analysis time for that dataset and scenario, ranging from 10 years for the Xia et al (2022) dataset, to 15 years for the UV data, to 29 years for sea ice in the 150 Tg case, at which point it was determined this would be a permanent new state for arctic sea ice (Harrison et al., 2022).

3.1.3 Simplifying Model Outputs

Earth System Model outputs efficiently store the large amounts of data generated, but are not necessarily user-friendly for subsequent analysts, particularly those unfamiliar with the data formats. ESM and secondary impact model outputs are largely in 'NetCDF' binary format designed to efficiently use memory and enable storage of large files. Whereas a spreadsheet contains two-dimensional data stored in rows and columns, a typical NetCDF file contains three-dimensional, four-dimensional, or n-dimensional 'arrays.' For example, to simulate the temperature of a given volume of air in the atmosphere requires at least four dimensions: latitude, longitude, altitude, and time (days, months, or years elapsed since the start of the simulation).

Our goal in producing the data here was to convert the model outputs into two-dimensional datasets and reduce them to a size that fits within the limits of a single worksheet in current versions of Excel and Google Sheets. We achieved this goal via the following steps:

- Select only the variables of most interest. For example, from precipitation model outputs we removed variables for humidity, pressure, and wind velocity, but kept the total precipitation rate.
- For temperature, precipitation, and UV datasets: select only the 'surface' layer (i.e., when thinking about human impacts, we do not care as much about high-altitude variables).
- Convert the model outputs to 2-D format, producing large tables.
- Overlay geographic 'masks' onto the 'grid cells' that are the standard geographic unit of model outputs (this process is sometimes called a 'geospatial join') and average the variables of interest over the grid squares that fell within the geographic areas of interest (e.g., country, exclusive economic zone (EEZ), port). For regions like countries and EEZs, an area weighted average was performed to account for varying size of ESM grid cells as for example, they adapt to the Earth's curvature. See Figure 2 for a visualization of gridded data overlaid on the country of Mexico. In this example, data from the model's outputs for the beige grid squares would be averaged.

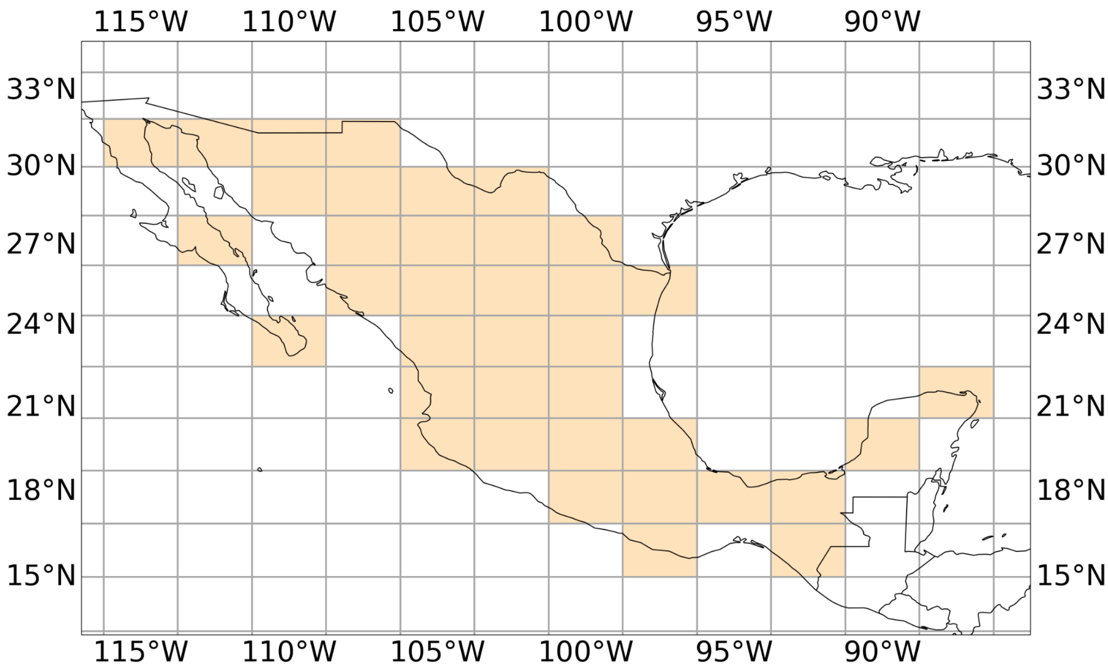

Figure 2: Example of a geographic mask overlaying gridded data for Mexico. The model grid shown here is for the atmospheric component of the Earth system model, which has cells that are 1.9° × 2.5° in size. Grid cells that are majority over land and within Mexico (beige) are averaged together, weighted by their area, to create a country level mean data product.

3.1.4 Standardizing & Adding Useful Variables

With the simplified model data in hand, the next step was to run each dataset through an R script (see Data Availability) with the aim of increasing usability. We (a) merged and reshaped tables into standard database format, (b) cleaned the data, and (c) added useful new variables and metadata. The simplified model outputs, having come from a variety of models and configurations, contain a variety of organizational schema with different units of analysis. For each thematic dataset, all data were compiled into a single table and reshaped into the first normal form, which is a set of formatting requirements that make the data more usable and comparable (Amato 2023). The cleaning process for each thematic dataset involved a combination of standardizing variable names, ensuring variables were in the proper class (character, numeric, date, etc.), standardizing the order of variables, and converting units. To the merged, reshaped and cleaned datasets we then joined additional useful variables (e.g., using 'date' to add 'months.elapsed' and 'season.n.hemisphere,' and using 'country.iso3' to add 'country.land.area.sq.km').

3.2 Dataset Description

The first two tabs of the main data product are (a) a README, and (b) a 'variables' table with variable metadata for all datasets including units and definitions. The subsequent tabs contain the seven datasets which comprise the main data product. Table 4 presents the datasets available in the repository alongside their formats and a brief description.

Table 4: Available datasets by theme, alongside their variables and units

Theme	Tab Name in Data Product	Variable(s)	Unit	Notes
Surface Temperature	temperature	surface.temp	°C	Degrees Celsius
		surface.temp.stdev	°C	Degrees Celsius
Surface Precipitation	precipitation	precip.rate	mm / month	Millimeters per month
		precip.stdev	mm / month	Millimeters per month
Surface Ultraviolet Radiation (UV)	uv	uva	W / m^2	Watts per square meter
		uvb	W / m^2	Watts per square meter
		uvindex	UV Index	*
		uvindexmax	UV Index	Maximum average UV index over time period
Agriculture Crop Yields (AgMIP)	agriculture.agmip	Pct.change.yield.[crop]	%	Percentage change in yield of a given crop relative to control scenario
		mean.yield.[crop]	tons / hectare	Metric tons per hectare
		cesm.model.configuration	"mills" or "toon"	CESM model configuration Mills et al. (2014) or Toon et al. (2019)
Agriculture (CLM)	agriculture.clm	pct.change.yield.[crop]	%	Percentage change in yield of a given crop relative to control scenario
		mean.yield.[crop]	t / ha	Metric tons per hectare
Fish Catch	fish.catch	mean.catch	t wB	Tons of wet biomass caught

		mean.catch.per.1000.sq.km	t wB / 1000 km^2	Tons of wet biomass per 1000 square kilometers
		mean.catch.change	t wB	Change in tons of wet biomass caught
		mean.pct.catch.change	%	Percentage change of wet biomass caught relative to control scenario
		std.dev.catch	t wB	Standard deviation of the tons of wet biomass caught
		std.dev.catch.change	t wB	Standard deviation of the change in tons of wet biomass caught
		std.dev.pct.catch.change	%	Standard deviation of the percentage change in tons of wet biomass caught
Sea Ice	sea.ice	sea.ice.thickness.meters	m	meters
*UV Index is a unitless number constructed to indicate the level of health risk presented by exposure to direct sunlight at the surface (World Health Organization 2022).				

Each dataset contains variables to permit analyses using the dimensions of time (month, season, year), geographic unit (country, exclusive economic zone), and soot injection scenario (Table 1). Some datasets include variables for theme-specific breakdowns such as individual crops in the agricultural datasets. Table 4 summarizes the combinations of these dimensions for each thematic dataset.

Instead of removing outliers we added an ‘outlier.flag’ variable for each variable of concern such that the outliers may be easily filtered out of analyses when desired. We defined outliers using the interquartile range (IQR) method and specified the multiplier as 1.5 following Tukey (1977). The R script imports the IQR multiplier from the configurations table for each dataset to facilitate user-defined outlier ranges. All variable sources, formats, ranges, units, and definitions are available in the Variables table of the final data product.

The full Data Product has three components (Table 5):

1. Aggregated & Simplified Datasets: A Google Sheets file containing all the simplified data tables, a table of metadata for all variables in all datasets, and a Readme with further notes and advice for analysis.
2. Aggregated & Simplified Datasets (CSV): A folder containing a .csv file for each tab of the G-Sheets file described above.
3. Code Base: A Github repository containing a Readme, licensing information, the jupyter notebook used to aggregate and simplify the model outputs, and the R code used to reshape, standardize, and add useful variables to the final data tables.

Table 5. Data Products & Formats

Name	Format	Notes
Aggregated & Simplified Datasets	Excel (.xlsx)	Tab names: - readme - variables - temperature - precipitation - uv - agriculture.agmip - agriculture.clm - fish.catch - sea.ice
Individual Datasets	Comma Separated Values (.csv)	File names are the same as tab names above.
Code Base	Github Repository	Contains its own Readme file with further information for those with coding knowledge wishing to reproduce the final data tables.

4. Potential Dataset Use and Reuse

4.1 Use Exemplars

To maximize accessibility to a broad audience, the data product is designed to permit analysis with spreadsheet programs, i.e. without requiring coding expertise. Users can generate and visualize univariate and bivariate statistics with formulas and/or pivot tables. For example, Figures 3-5 were created in Excel in about five minutes each; they show the average monthly temperature and temperature anomaly (difference from the business-as-usual scenario) in New Zealand for four soot injection scenarios ranging from 5 to 150 Tg, and the UV index for the Control and 150 Tg scenarios. Alone these figures strongly evince the key conclusion that nowhere, not even a geographically isolated country deep in the Southern Hemisphere is immune to nuclear winter's primary effects. Further examination reveals that while the temperature changes in the 150 Tg scenario are bigger than in the 47 Tg case, they are not the three times more severe. This evidence supports the idea that in more extreme cases, the stratosphere becomes 'saturated' such that each additional ton of BC makes a smaller and smaller difference to conditions on the ground (National Academies of Sciences, Engineering, and Medicine et al. 2023; Toon et al. 2019).

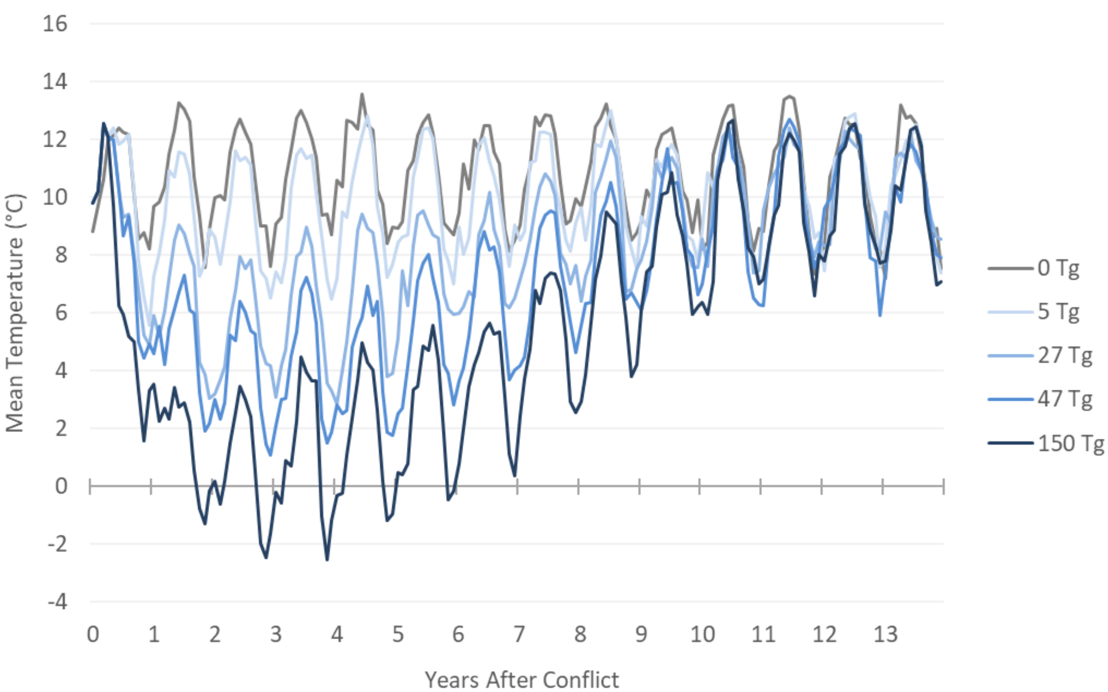

Figure 3. Average Monthly Temperature in New Zealand for selected Soot Injection Scenarios

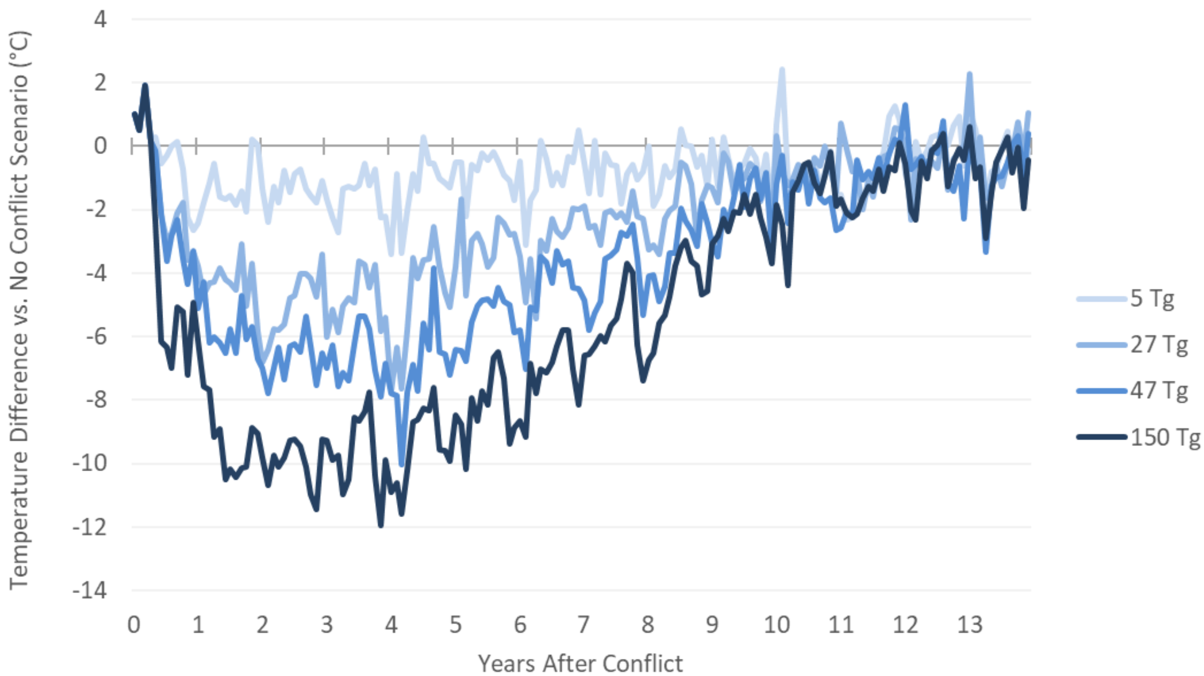

Figure 4. Temperature Difference from Control (no nuclear conflict) for New Zealand by Soot Injection Scenario

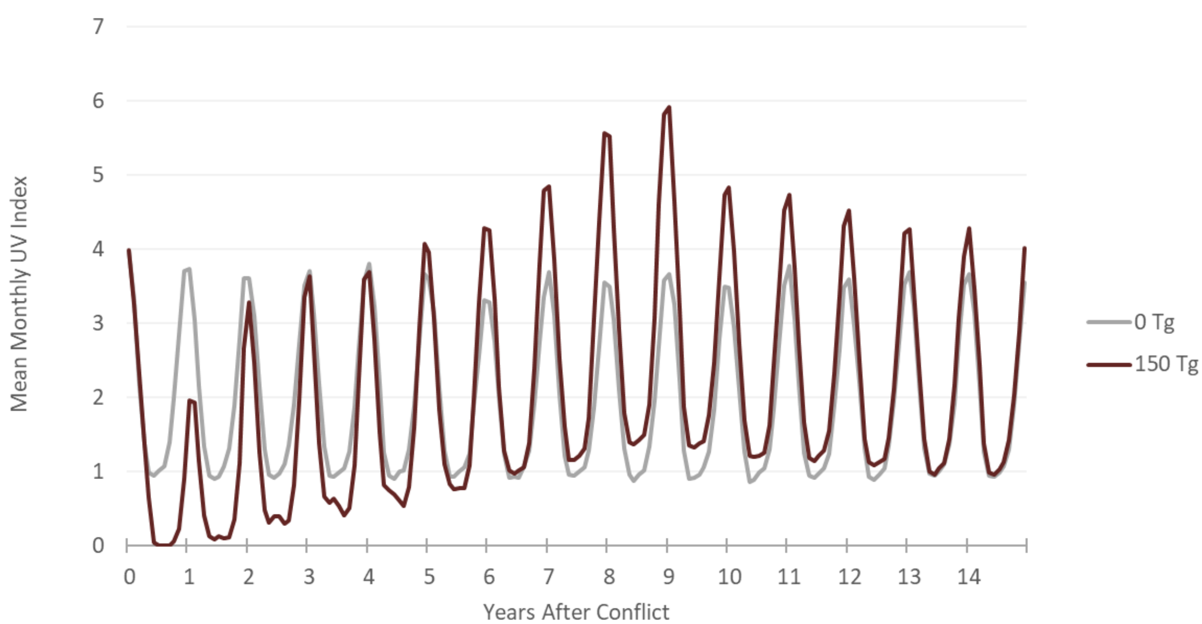

Figure 5. UV index for New Zealand for the Control (no nuclear conflict) and 150 Tg scenario.

A powerful form of visualization for geographic data is a choropleth map or geospatial heatmap. Figure 6 exemplifies this diagram style, showing the percentage change in harvest yields (tons/hectare) for four crops for year 3 of the 37 Tg India-Pakistan nuclear conflict scenario, adapted from Xia et al. (2022). Countries with large areas of land across high latitudes, such as Canada and Russia, are severely impacted, experiencing greater than 50% reductions across all crops. These dynamics have not been explored from the standpoint of global trade, security, rebuilding or further conflict.

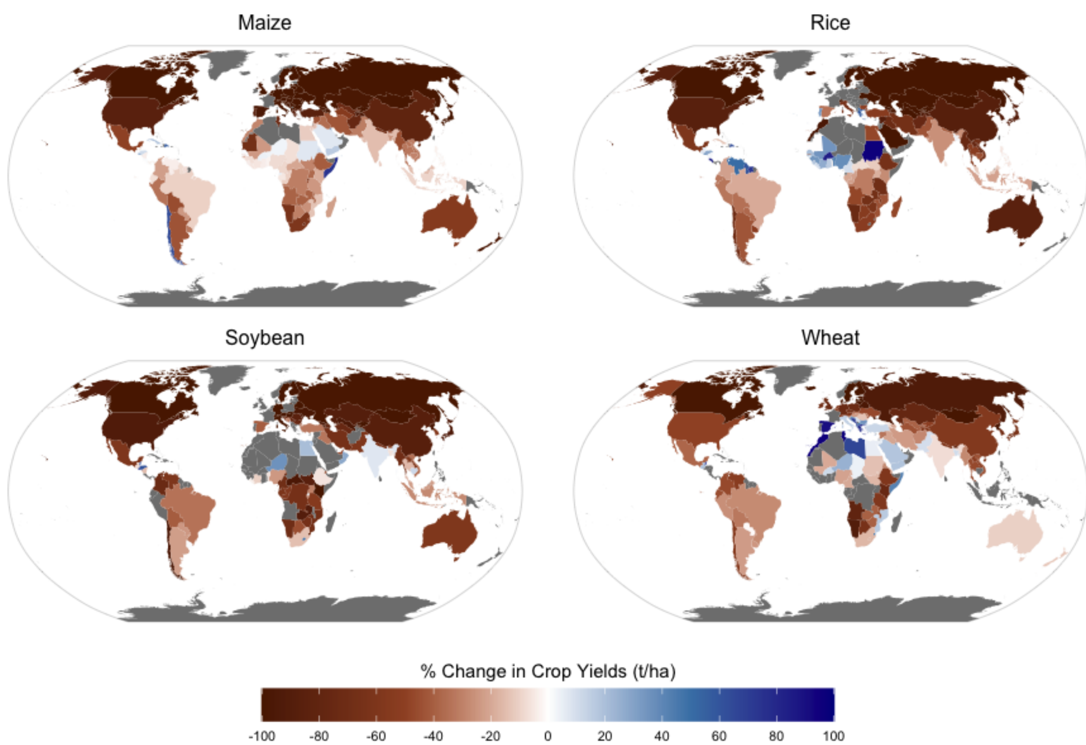

Figure 6. Percent change of crop production for four major crops (maize, rice, soybean, and wheat) by country level for the 37 Tg scenario.

4.2 Future Potential

The data product we are supplying can be used to facilitate a variety of exploratory studies. We hope by concentrating datasets on diverse thematic topics within a single data product will encourage interdisciplinary investigation. In general, while physical scientists continue to probe the causal mechanisms and physical effects of nuclear winter, we perceive a broad opportunity for social scientists to delve into how such conditions would change human society, what can be done to augment resilience (especially where measures may align with efforts to improve resilience to other hazards like greenhouse-gas-based climate change), and how knowledge of the potential consequences of nuclear conflict affects political, communal, and individual decision-making. Table 6 below captures a non-exhaustive sample of potential research questions to which our data might be applicable.

Table 6. Potential Research Questions for Investigation

Discipline/Area	Research Questions
Ecology, Agricultural Research	• What plant breeding experiments might be most relevant to developing resilient cultivars? • How would altered UV-A & UV-B levels affect crop yields? • What types of seed storage and distribution networks might reduce vulnerability? • What regions have the most potential to provide a variety of plant resources for balanced human nutrition? • Which pests & diseases would be of most concern and what might be done to prepare for them? • What local agricultural knowledge would be useful for resilience planning?
Economics	• What insights from this data might be used to predict migration patterns? • How would expansion of sea ice affect shipping? • What types of economic networks in which places might demonstrate resilience, facilitating survival and recovery?
Human Impacts	• How would human societies respond at the country, regional, and household scale to food shortages? • What is the risk of hypothermia across the scenarios, and how would this compound with food insecurity? • What predictions could be made regarding the altered ranges and transmission vectors of human pathogens?
Political Science	• Which types of governments would suffer most and in which scenarios? • What influence might these patterns have on the forms of government that might emerge during and after a nuclear winter event? • If governments in countries that are affected by nuclear winter wished to stage the resources that might allow them to govern in exile, where should they do so? • How are the effects of nuclear conflict most effectively communicated to increase understanding among political/societal decisionmakers? • What types of narratives increase understanding among which communities and social networks?

5. Conclusions

Nuclear winter remains a critical but underexamined risk to global society. While substantial progress has been made in simulating the atmospheric and climatic consequences of nuclear conflict, questions of human vulnerability, societal resilience, and global adaptation remain understudied (NASEM 2025). This paper introduces data products consolidated from the outputs of major nuclear winter modeling efforts into formats more accessible to diverse researchers. By converting complex model outputs into spreadsheet-ready tables and providing standard metadata, this resource aims to expand the community of scholars working on questions related to this important topic.

Our future vision is to host a holistic repository of datasets relevant to nuclear winter, provide advice on their analysis to interested users, and create new aggregations and analyses for diverse audiences and user groups. We welcome input on additional datasets that users would find helpful. We encourage interdisciplinary use of the datasets and hope to foster collaboration, improve understanding of user needs, and support efforts to quantify and mitigate the long-term consequences of nuclear conflict on food systems, economies, governance, and society at large.

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Conflicts of Interest

The authors affirm that there are no competing financial or personal interests that may have impacted the design, execution, or interpretation of this work.

Data Availability Statement

Data sets are archived on Open Science Framework, and scripts used to process the datasets and visualize them (as in Fig. 6) are available on GitHub. Due to ethical considerations, access to the datasets and scripts will be provided to users who submit an application including a description of the intended use. To sapply, please use this link: (link will be inserted after review)[1]

[1]For access and dataset correspondence at this stage please contact william@fluxrme.com

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Supporting Information

Table S1. Main Data Product - Dataset Dimensions & Associated Publications. Geographic and time unit columns denote the smallest (most disaggregated) unit available in the dataset. The climate forcing scenario represents the total mass of black carbon soot lofted into the stratosphere in teragrams (Tg). The last two columns display the publication presenting the Earth system simulation and scenario details, and the publication presenting the analysis or secondary impacts modeling, respectively (see Section 2.1.2).

Theme	Dataset Tab/File Name	Geographic Unit	Time Unit	Climate Forcing Scenario (Tg)	Associated Publication: Earth System Simulation Reference	Association Publication: Analysis & Discussion
Temperature	temperature	Country	Month	150 Tg	Coupe et al. (2019)	Coupe et al. (2019)
				47 Tg	Toon et al. (2019)	Toon et al. (2019)
				37 Tg	Toon et al. (2019)	Toon et al. (2019)
				27 Tg	Toon et al. (2019)	Toon et al. (2019)
				16 Tg	Toon et al. (2019)	Toon et al. (2019)
				5 Tg	Toon et al. (2019)	Toon et al. (2019)
				0 (control)	Toon et al. (2019)	Toon et al. (2019)
Precipitation	precipitation	Country	Month	150 Tg	Coupe et al. (2019)	Coupe et al. (2019)
				47 Tg	Toon et al. (2019)	Toon et al. (2019)
				37 Tg	Toon et al. (2019)	Toon et al. (2019)
				27 Tg	Toon et al. (2019)	Toon et al.(2019)
				16 Tg	Toon et al. (2019)	Toon et al. (2019)
				5 Tg	Toon et al. (2019)	Toon et al. (2019)
				0 (control)	Toon et al. (2019)	Toon et al. (2019)
UV	uv	Country	Month	150 Tg	Coupe et al. (2019)	Bardeen et al. (2021)
				0 (control)	Coupe et al. (2019)	Bardeen et al. (2021)
Agriculture	agriculture.agmip	Country	Year	5 Tg	Mills et al. (2014)	Jägermeyr et al.

						(2020)
				5 Tg	Toon et al. (2019)	Jägermeyr et al. (2020)
Agriculture	agriculture.clm	Country	Year	150 Tg	Coupe et al. (2019)	Xia et al. (2022)
				16 Tg	Toon et al. (2019)	Xia et al. (2022)
				27 Tg	Toon et al. (2019)	Xia et al. (2022)
				37 Tg	Toon et al. (2019)	Xia et al. (2022)
				47 Tg	Toon et al. (2019)	Xia et al. (2022)
				5 Tg	Toon et al. (2019)	Xia et al. (2022)
Fish Catch	fish.catch	EEZ (exclusive economic zone)	Year	150 Tg	Coupe et al. (2019)	Scherrer et al. (2020)
				16 Tg	Toon et al. (2019)	Scherrer et al. (2020)
				27 Tg	Toon et al. (2019)	Scherrer et al. (2020)
				37 Tg	Toon et al. (2019)	Scherrer et al. (2020)
				47 Tg	Toon et al. (2019)	Scherrer et al. (2020)
				5 Tg	Toon et al. (2019)	Scherrer et al. (2020)
				0 (control)	Toon et al. (2019)	Scherrer et al. (2020)
Sea Ice	sea.ice	Port	Month	150 Tg	Coupe et al. (2019)	Harrison et al. (2022)
				47 Tg	Toon et al. (2019)	Harrison et al. (2022)
				37 Tg	Toon et al. (2019)	Harrison et al. (2022)