



Mapping Global Crop Exposure to Extremely High Temperature

Yaojie Yue, Peng Su, Yuan Gao, Puying Zhang, Ran Wang, Anyu Zhang, Qinghua Jiang, Weidong Ma, Yuantao Zhou, and Jing'ai Wang

1 Introduction

The increasing temperature with global warming will have great impacts on major cereal crop cultivation (Peng et al. 2004; Fahad et al. 2019). Among various impacts, the crop exposure to extremely high temperature, which is based on the land suitability for crop cultivation, may ultimately pose a great threat to food security.

The crop disaster exposure is one of the primary drivers of food system instability (Change 2018), and its response to climate change is critical to understanding the impact of climate change on food security. Recent studies have provided evidence for changes in the yield of major cereal crops due to disaster exposure and identified significant impacts of climate change globally, either at the country level or at the 0.5° grid level (Osborne and Wheeler 2013; Iizumi and Ramankutty 2016). However, from the perspective of disaster exposure, research on crop exposure to certain hazards

(e.g., extreme heat) with the changes of climate and social conditions is still lacking.

As an important part of the atlas, the maps of global crop exposure to extremely high temperature are intended to evaluate the changes in the global staple crop yield risk from three aspects—mean yield, interannual yield variability, and lower extreme yield—under the RCP2.6-2030s, RCP2.6-2050s, RCP4.5-2030s, RCP4.5-2050s, RCP8.5-2030s, and RCP8.5-2050s scenarios. The crop yield risk was measured by multi-model ensemble (MME) simulation using global high spatial resolution (0.25°) climate forcing data. To enable such MME simulation, the development of emulators of global gridded crop models (GGCM) is required (Lobell and Burke 2010; Holzkämper et al. 2012; Oyebamiji et al. 2015; Raimondo et al. 2020). The present results may provide crucial information for climate risk assessment and effective adaptations.

2 Method

2.1 Wheat Exposure Calculation

The quantification process of wheat exposure to extreme high-temperature hazard is as follows (Jiang et al. 2019): A high-temperature day is recorded when the maximum temperature of the current day reaches or exceeds 30°C, and if this lasts for 3 days or more, it is recorded as a heatwave event (Deng et al. 2009; Chen et al. 2016).

The high-temperature days (HD) refer to the accumulation of total high-temperature days of heatwave events in each grid. The calculation formula is as follows:

$$HD = \sum_{i=1}^n D_i \quad (1)$$

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where n refers to the frequency of heatwaves and Di refers to the days corresponding to the i th heatwave event.

Estimating the intensity of the heatwave hazard impacts on wheat involves first calculating the intensity (I), which represents the daily maximum temperature exceeding the temperature threshold (30°C) of each high-temperature day within heatwave events and for each grid; then, we sum up all I s. The details of this calculation are as follows:

$$\text{HI} = \sum_{d_h}^{d_m} I \quad (2)$$

$$I = \begin{cases} 0 & T_{\max} < T_h \\ T_{\max} - T_h & T_{\max} \geq T_h \end{cases} \quad (3)$$

where d_h and d_m represent the heading period and mature period of wheat, respectively; T_{\max} represents the daily maximum temperature; I represents the daily temperature ($^\circ\text{C}$) exceeding the temperature threshold during heatwave events; and T_h represents the high-temperature threshold.

The extreme high-temperature exposure of wheat is calculated as follows: The exposure range of wheat is the spatial superposition of the distribution range of wheat and the hazard range, and the areal value in the range represents the exposure value, which is the annual wheat harvest area.

2.2 Rice Exposure Calculation

The quantification process of rice exposure to extreme high-temperature hazard is as follows: A high-temperature event is recorded when the maximum temperature of the current day reaches or exceeds 30°C (Melillo et al. 1995; Janetos 1997). The accumulative high-temperature stress of high-temperature events during the growth period (GHTS) was used as the high-temperature hazard intensity. The calculation process can be divided into two steps: (1) according to the abovementioned high-temperature standard, determine the high-temperature event and calculate the high-temperature stress (HTS) of the day, and then estimate the GHTS by calculating the total HTS during the whole growth period (Eqs. 4 and 5).

$$\text{HTS}_i = \begin{cases} 0 & T_i \geq 30^\circ\text{C} \\ 1 - \sin\left[\frac{\pi}{2} \times \left(\frac{T_i - T_h}{T_o - T_h}\right)\right] & T_i \geq 30^\circ\text{C} \end{cases} \quad (4)$$

$$\text{GHTS} = \sum_{i=1}^n \text{HTS}_i \quad (5)$$

where T_i is the daily average temperature of the i th high-temperature event during the growth period; T_h is the base temperature during the growth period; T_o is the optimum temperature during the growth period; n is the frequency of high-temperature events during the growth period; and HTS_i is the daily high-temperature stress value of the i th high-temperature event.

The extreme high-temperature exposure of rice is calculated as follows: The exposure range of rice is the spatial superposition of the distribution range of rice and the hazard range, and the areal value in the range represents the exposure value, which is the annual rice harvest area.

2.3 Maize Exposure Calculation

Maize exposure calculation applies the same method as rice exposure calculation. A high-temperature event is recorded when the maximum temperature of the current day reaches or exceeds 37°C (Melillo et al. 1995; Janetos 1997). The accumulative high-temperature stress of high-temperature events during the growth period (GHTS) was used as the high-temperature hazard intensity.

The extreme high-temperature exposure of maize is calculated as follows: The exposure range of maize is the spatial superposition of the distribution range of maize and the hazard range, and the areal value in the range represents the exposure value, which is the annual maize harvest area.

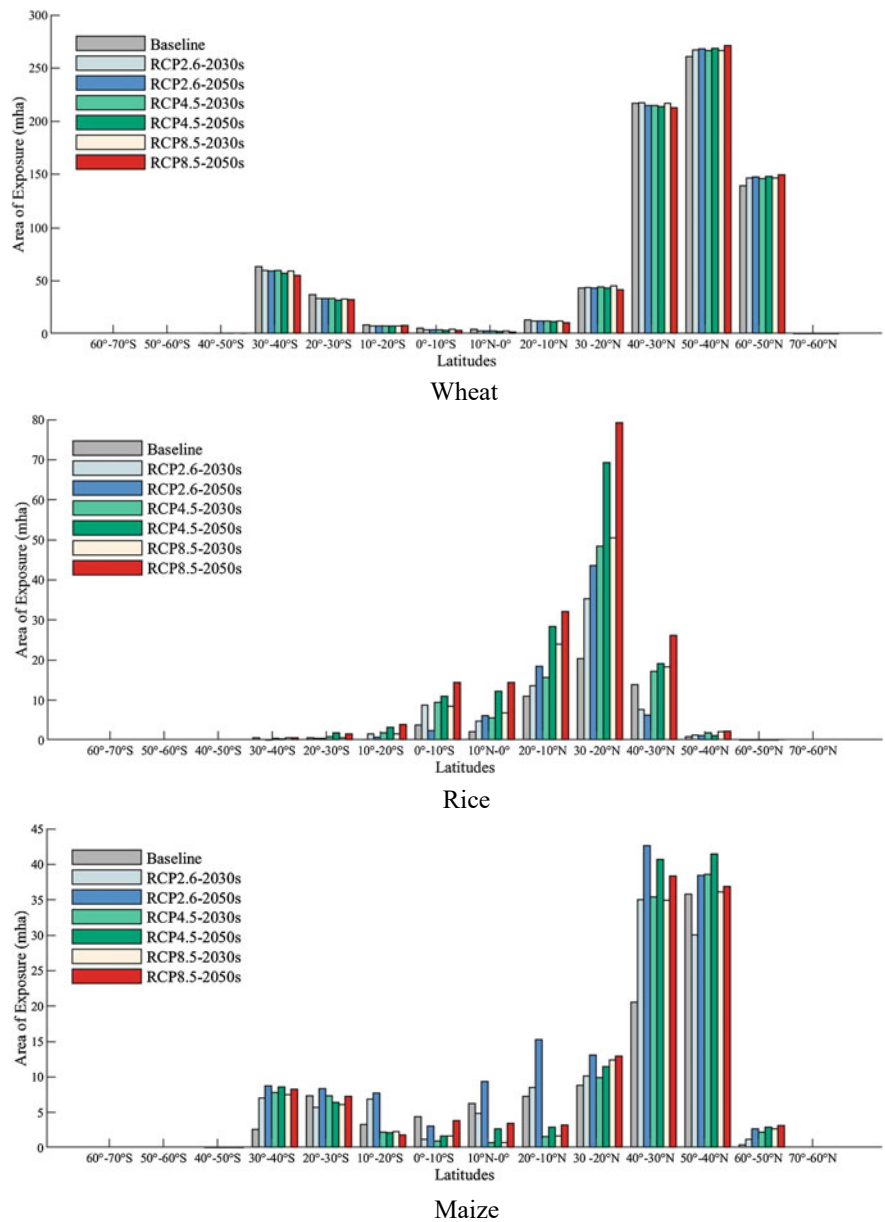
3 Results

3.1 Latitudinal Distribution of Crop Exposure to High Temperature

The latitudinal distributions of the exposure of the three crops to high temperature in the historical period (red bar) and the RCP8.5-SSP3 scenario (medium term) (blue bar) are shown in Fig. 1.

During the two study periods, the exposures of the three crops are mainly concentrated in the northern hemisphere. The most important areas for wheat, rice, and maize exposure to extreme high temperature are between 40°N – 50°N , 20°N – 30°N , and 40°N – 50°N , respectively. The comparison of the exposure areas in the two periods shows that under the RCP8.5-SSP3 scenario, the exposure areas of the three crops in the northern hemisphere will move to higher latitudes and the exposure areas of rice and maize will have a significant increase.

Fig. 1 Latitudinal distribution of the exposure of wheat, rice, and maize to extreme high temperature (unit: million ha)



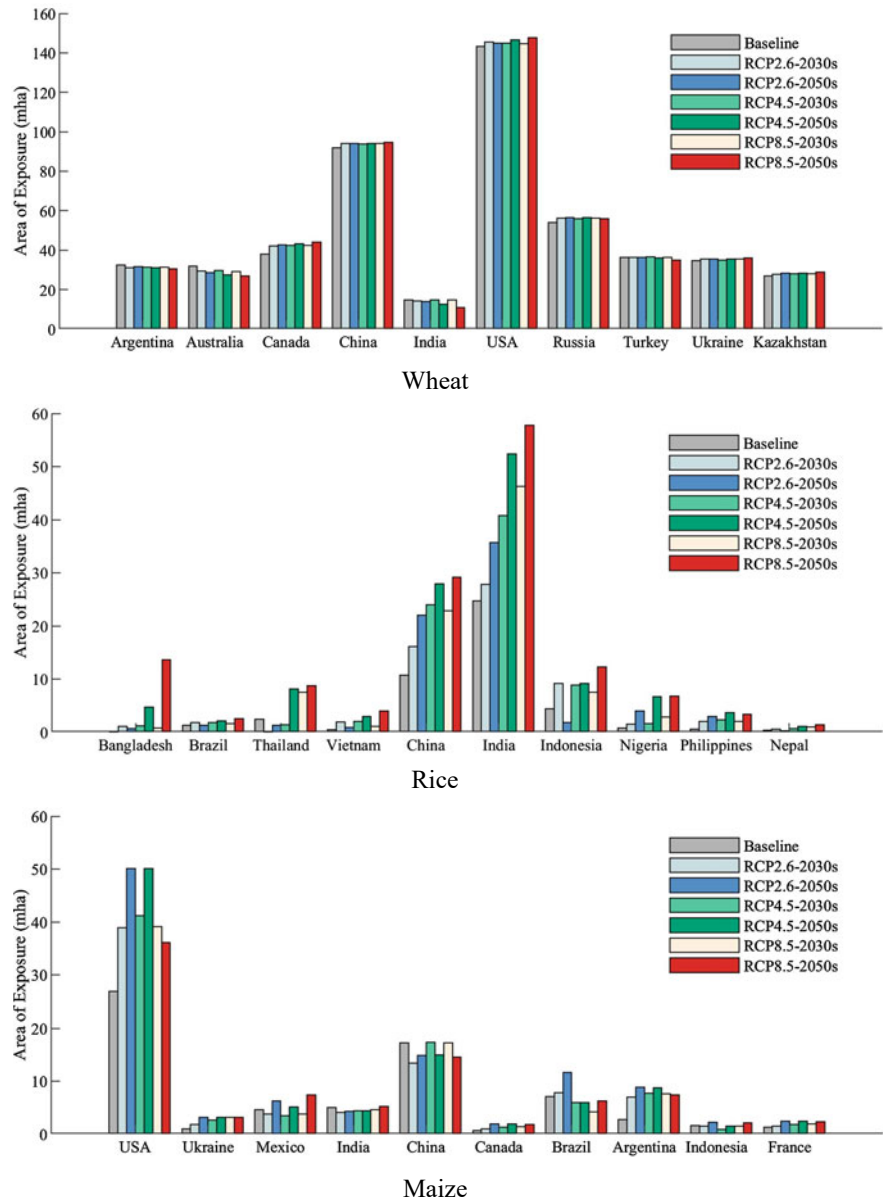
3.2 Countries Distribution of Crop Exposure to High Temperature

Figure 2 shows the ranking of the top 20 countries based on the statistics of the area of crop exposure to high temperature in each country in the historical period and under the RCP8.5-SSP3 scenario.

In both periods, the United States’ wheat exposure area ranks the highest, followed by China. The rice exposure area of India ranks the highest, and China’s rice exposure area is

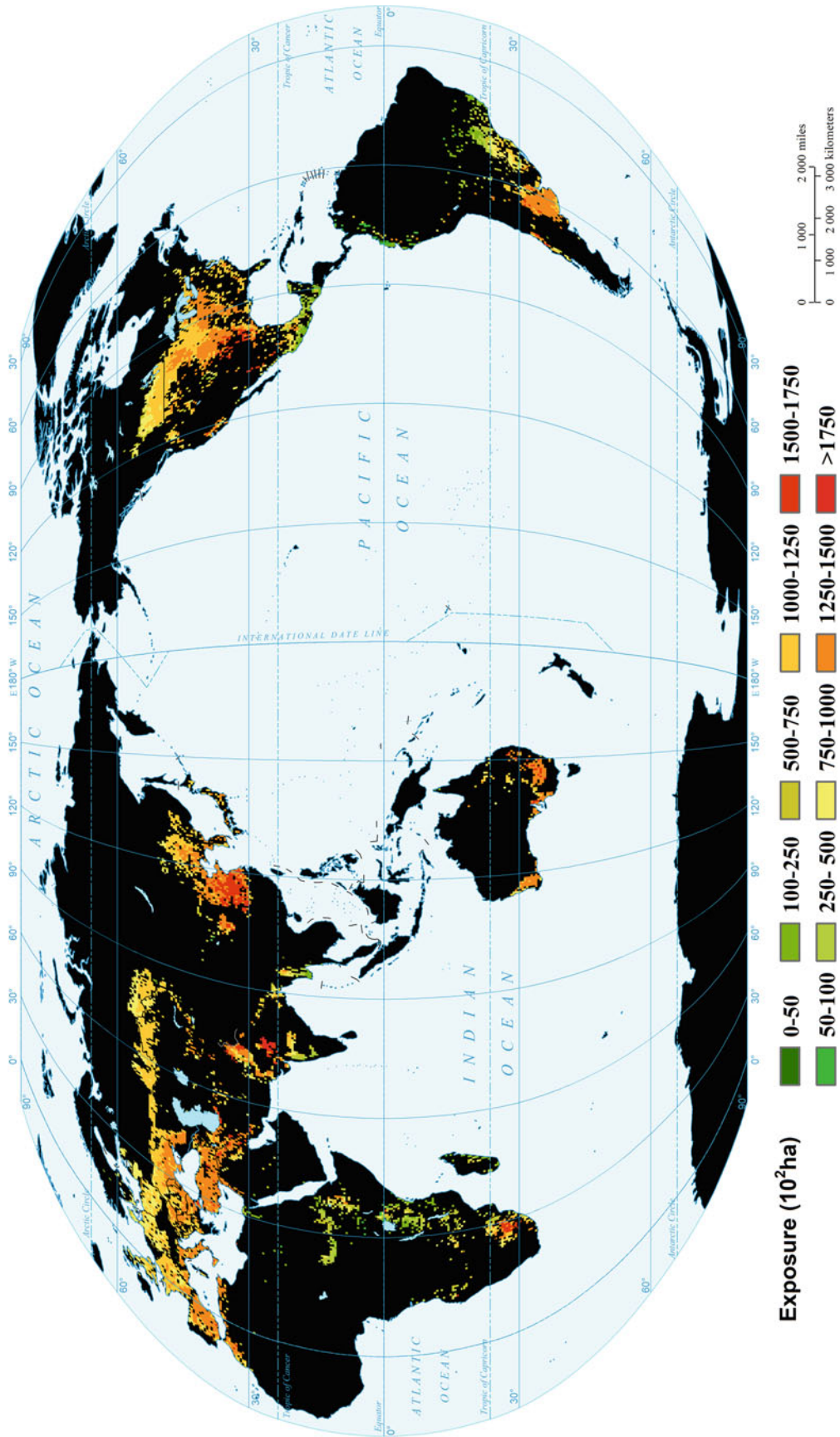
the second largest. The maize exposure area of the United States ranks the highest, and China’s maize exposure area is the second largest. Under the RCP8.5-SSP3 scenario, the exposure area of all crops in China will increase, and the exposure area of rice is about three times that of the historical period. It indicates that China will be seriously exposed to extreme high temperature in the future, and the country should be prepared to prevent risks and reduce losses.

Fig. 2 Ranking of the top 20 countries by the area of crop exposure to extreme high temperature (unit: million ha)

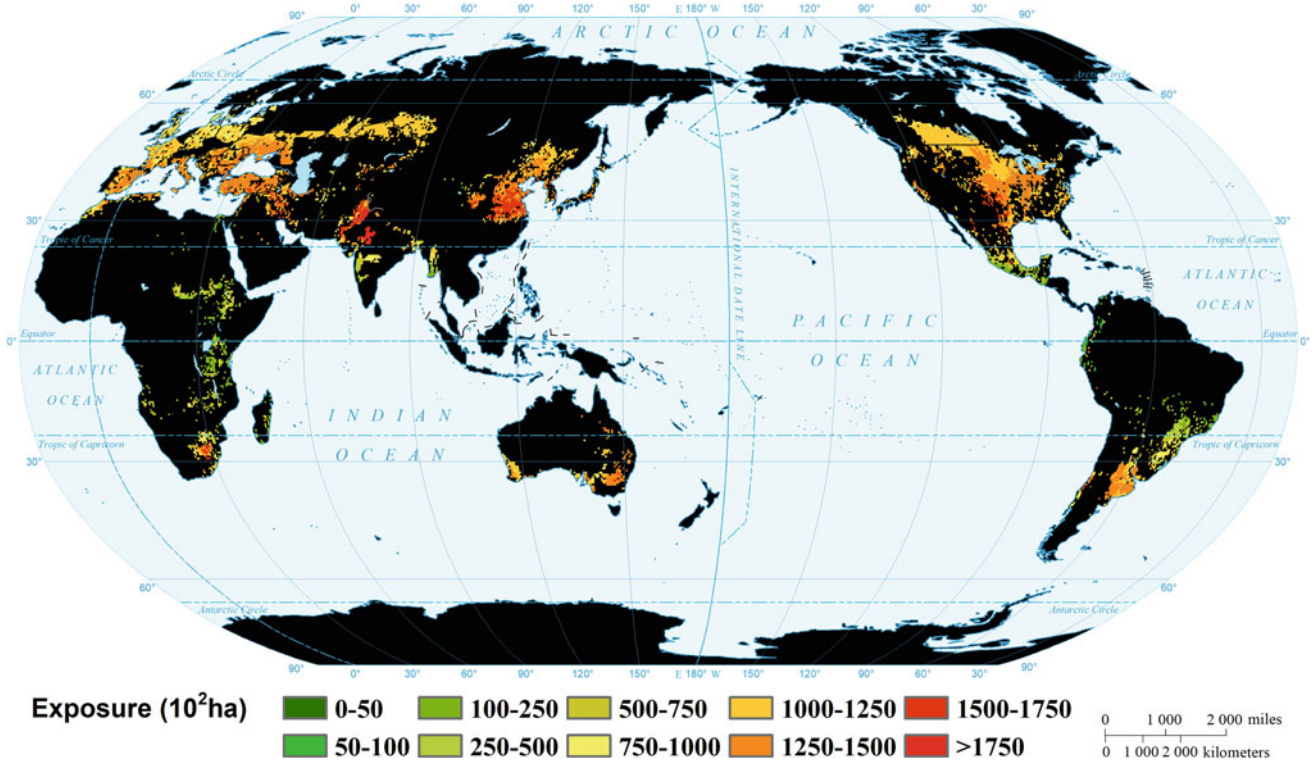


4 Maps

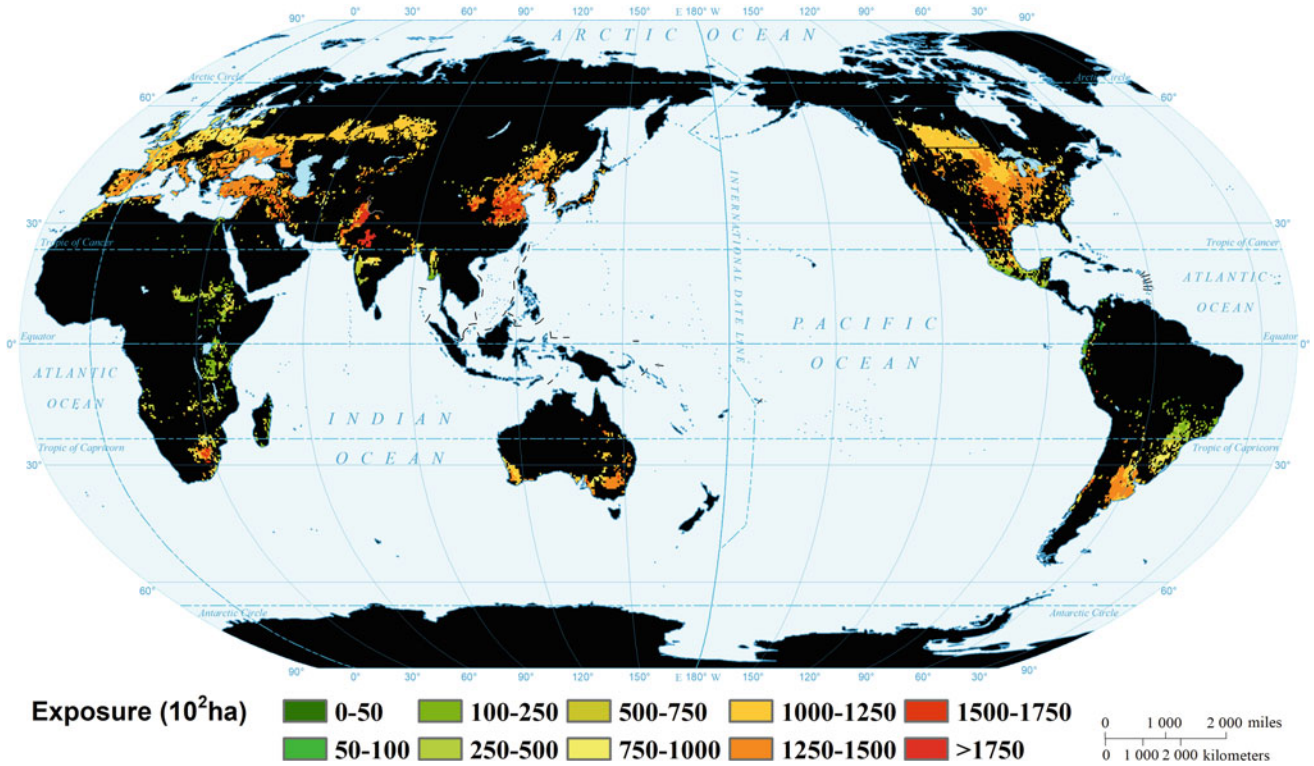
Global wheat exposure to extremely high temperature (Baseline)



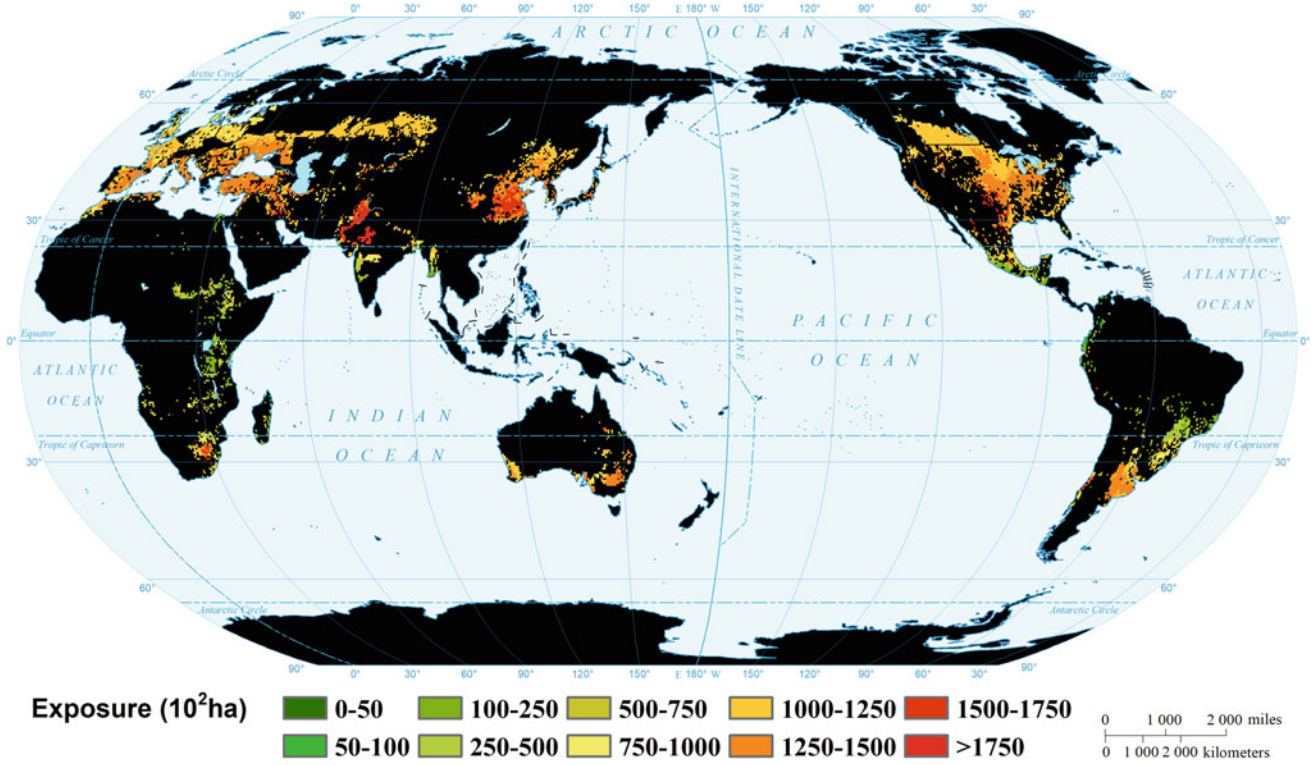
Global wheat exposure to extremely high temperature (2030s, RCP2.6-SSP1)



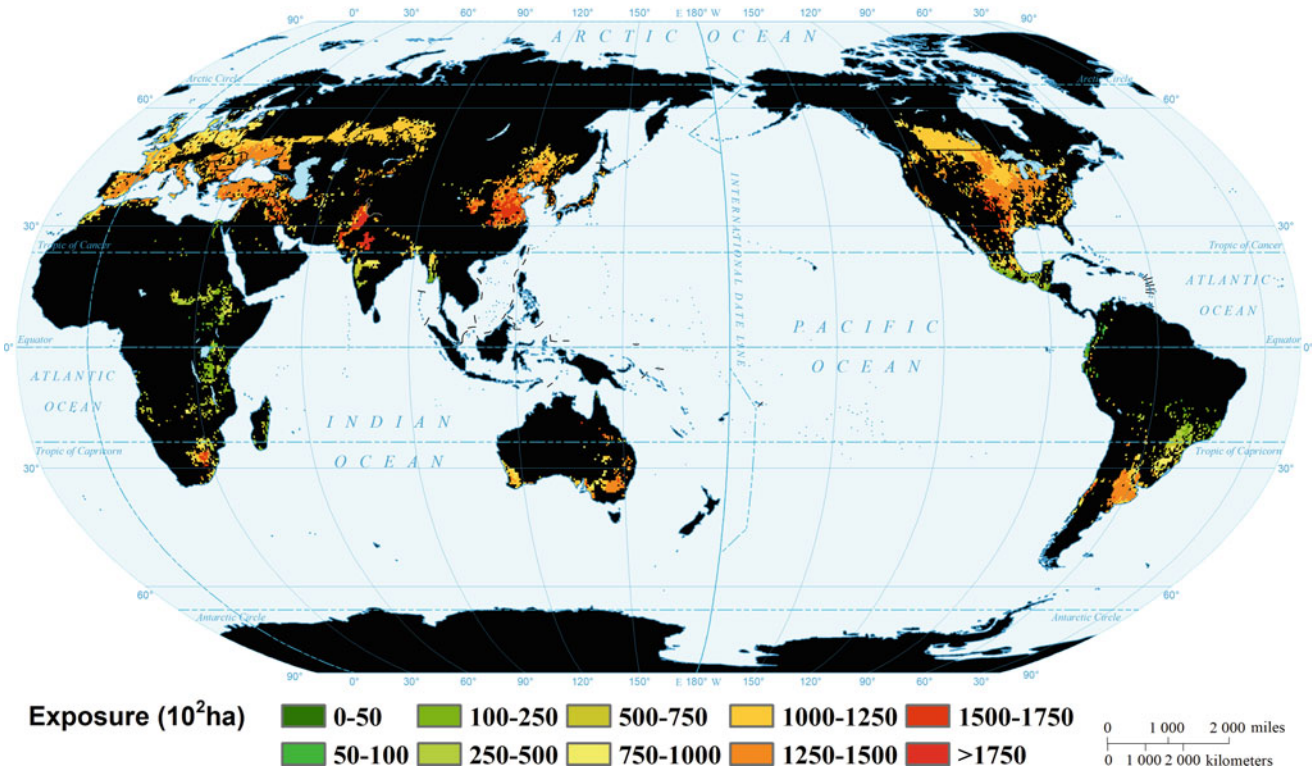
Global wheat exposure to extremely high temperature (2030s, RCP4.5-SSP2)



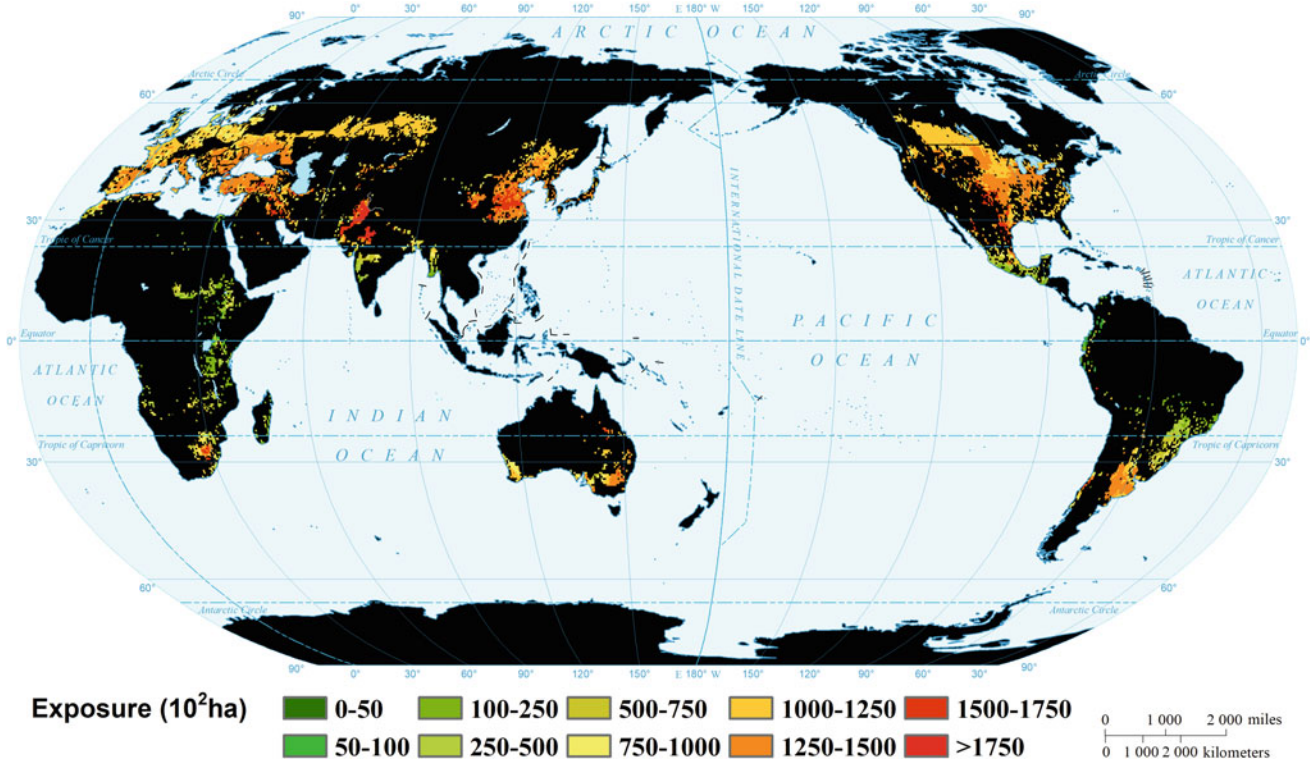
Global wheat exposure to extremely high temperature (2030s, RCP8.5-SSP3)



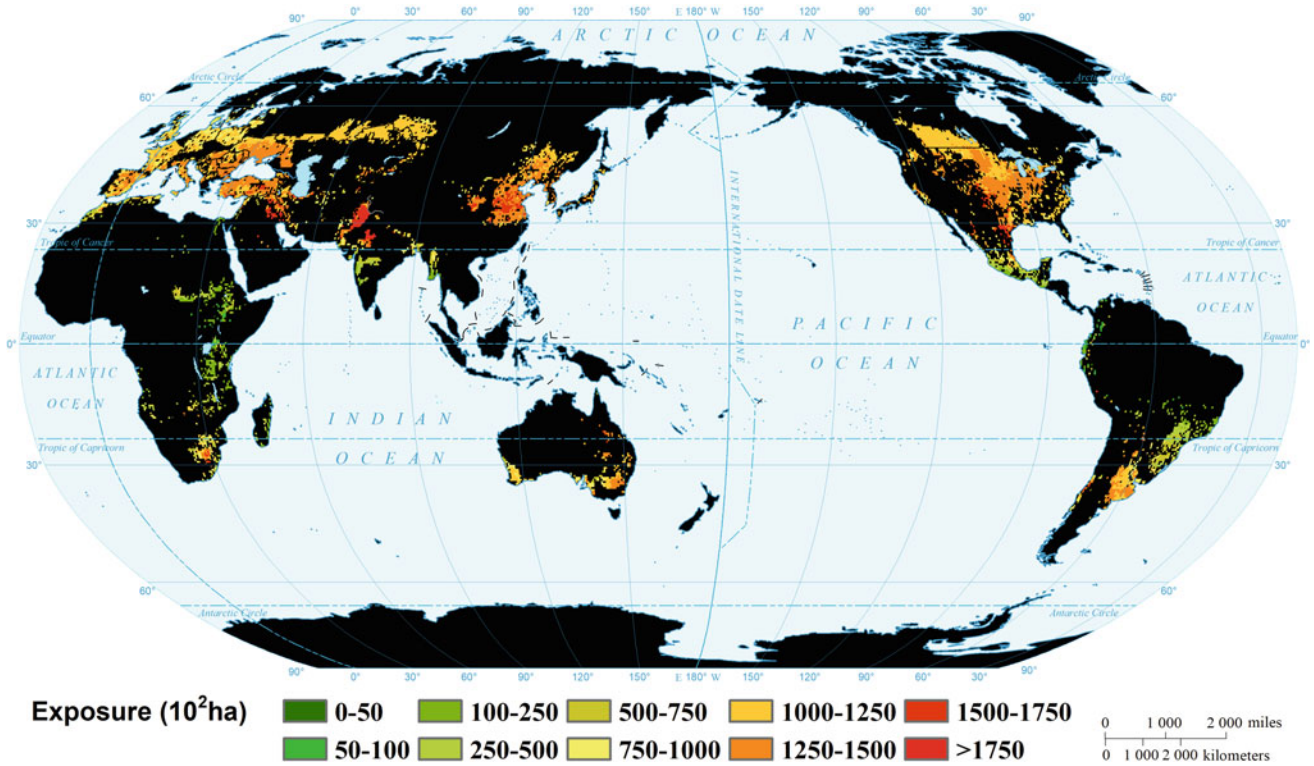
Global wheat exposure to extremely high temperature (2050s, RCP2.6-SSP1)



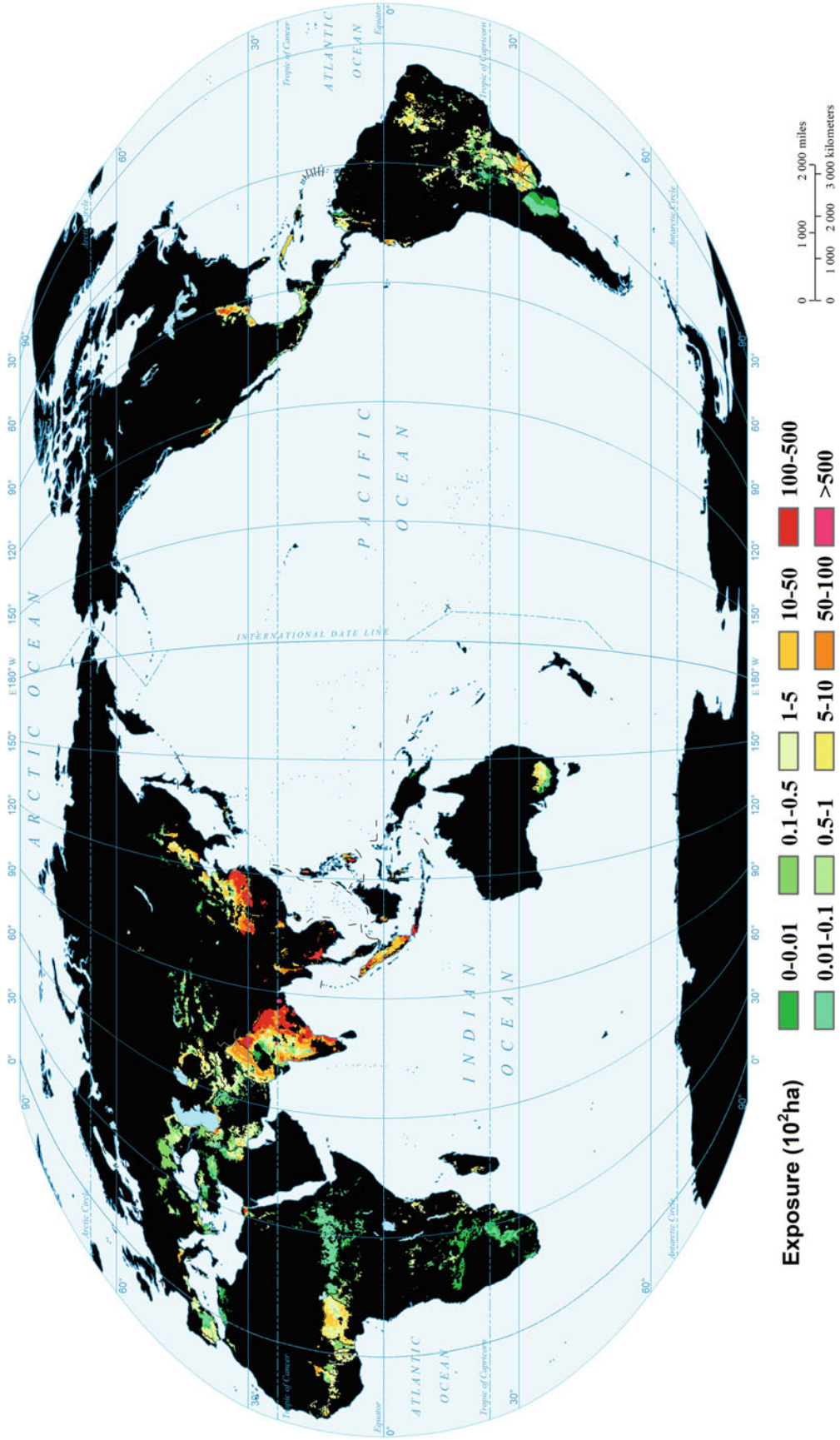
Global wheat exposure to extremely high temperature (2050s, RCP4.5-SSP2)



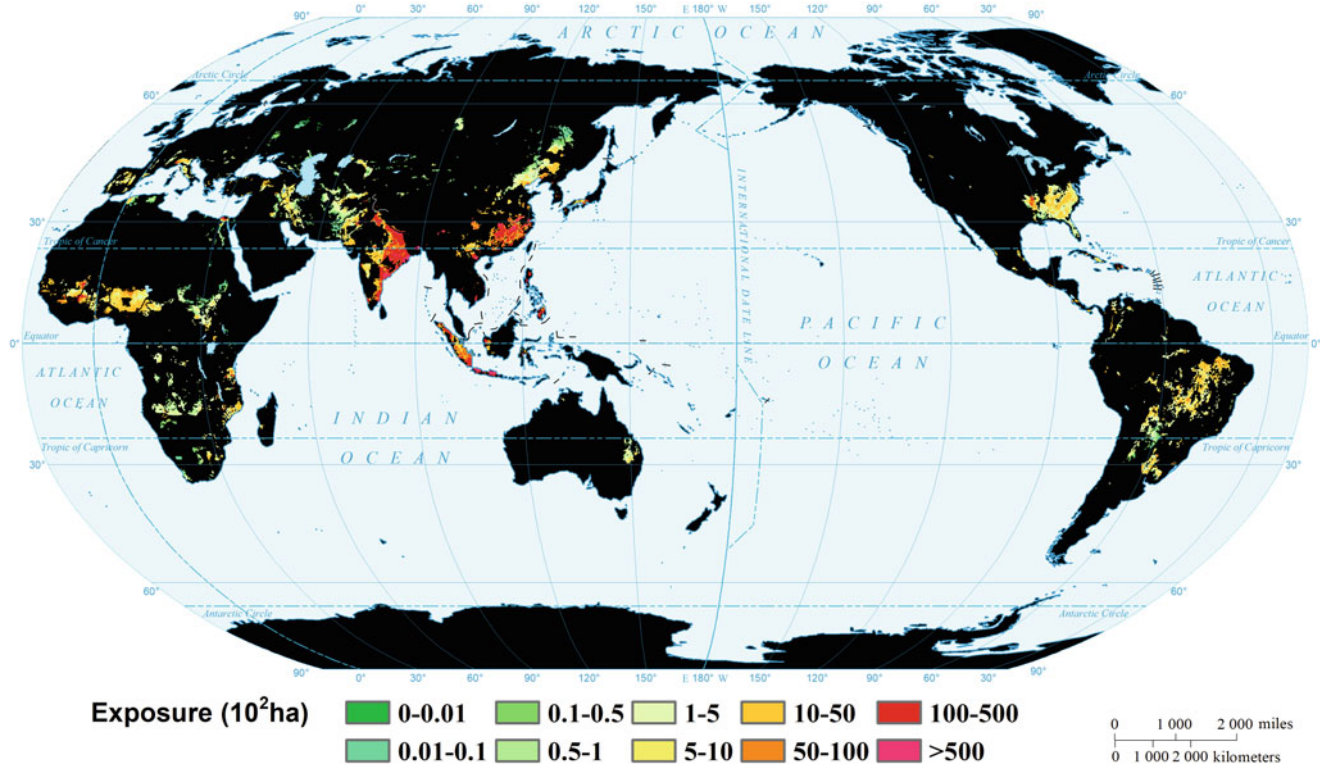
Global wheat exposure to extremely high temperature (2050s, RCP8.5-SSP3)



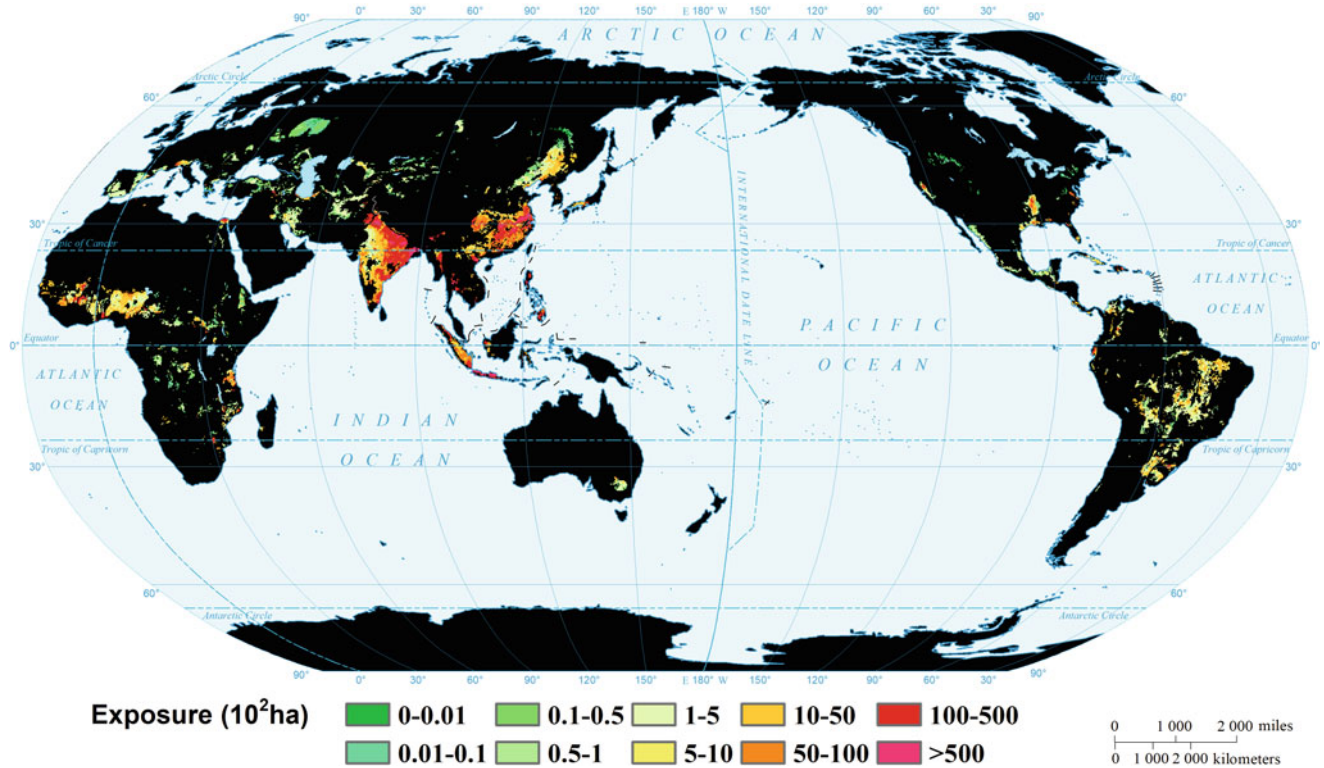
Global rice exposure to extremely high temperature (Baseline)



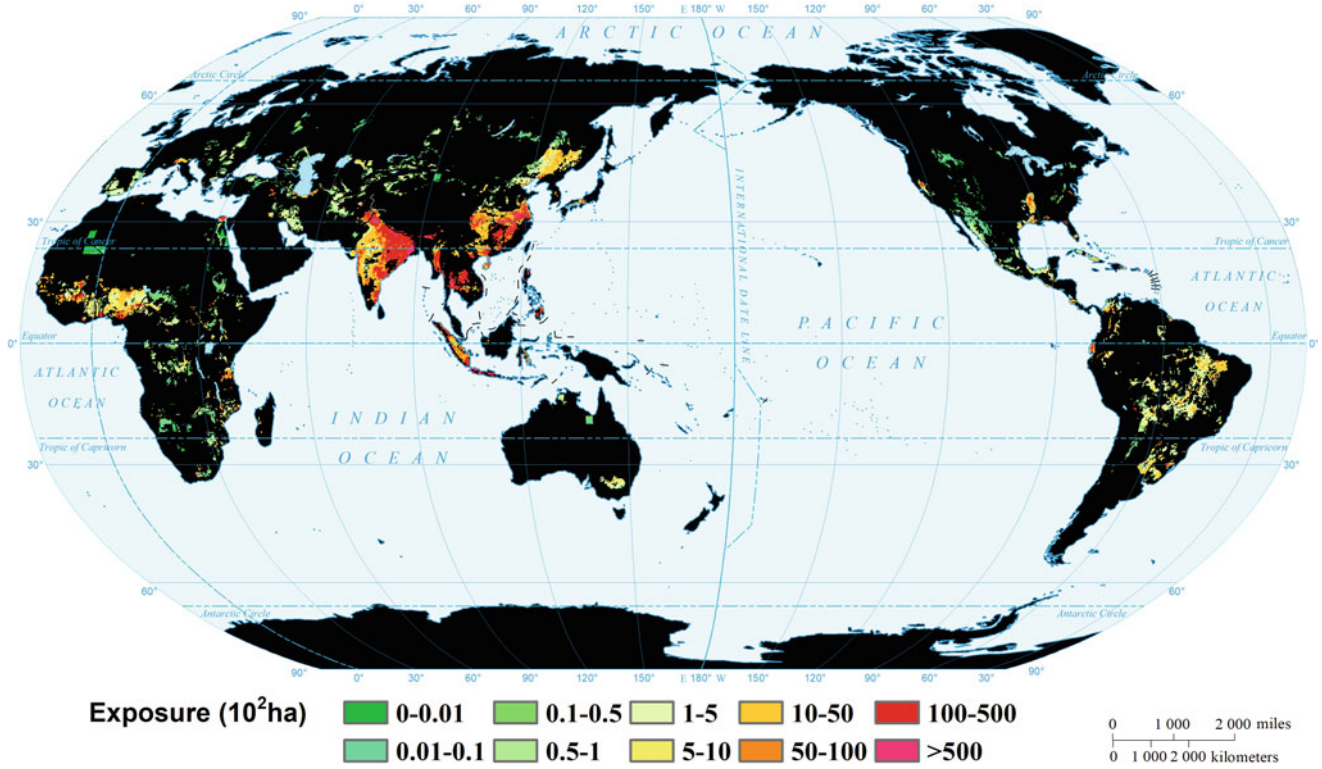
Global rice exposure to extremely high temperature (2030s, RCP2.6-SSP1)



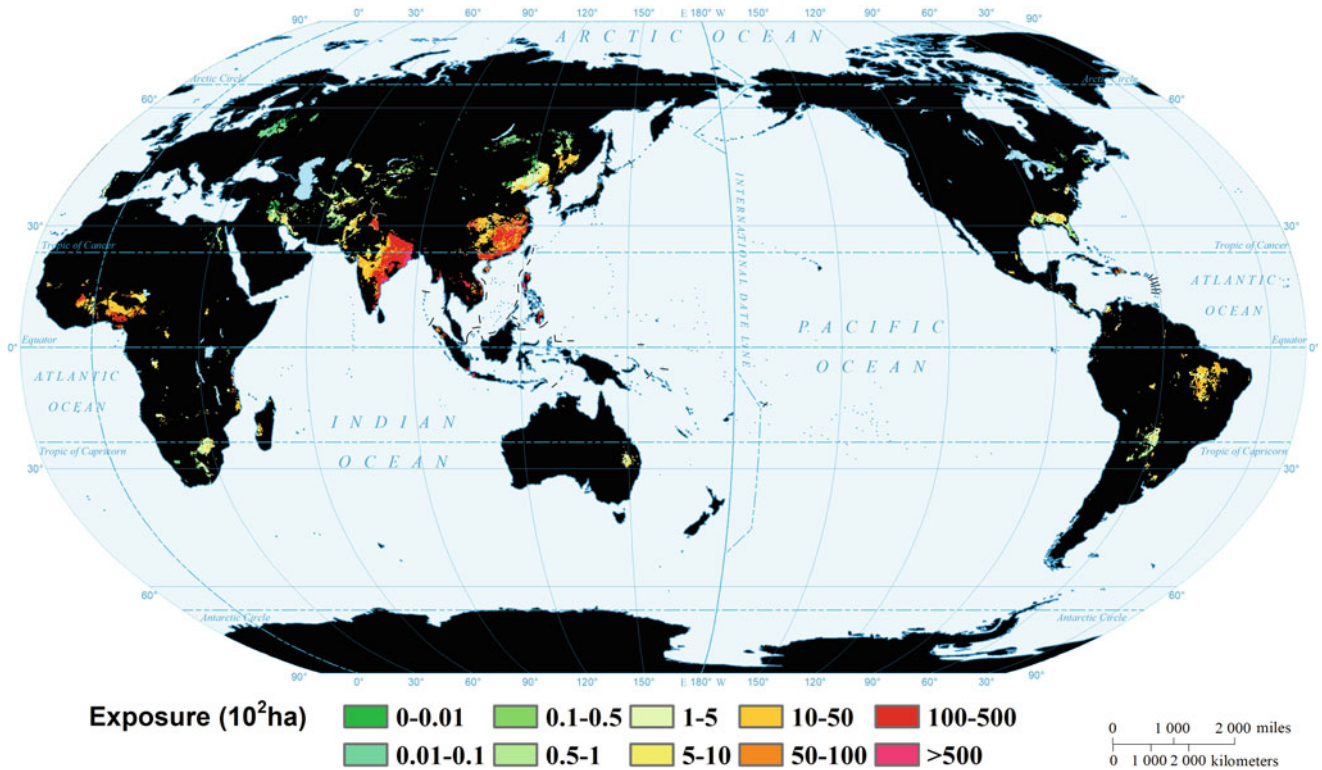
Global rice exposure to extremely high temperature (2030s, RCP4.5-SSP2)



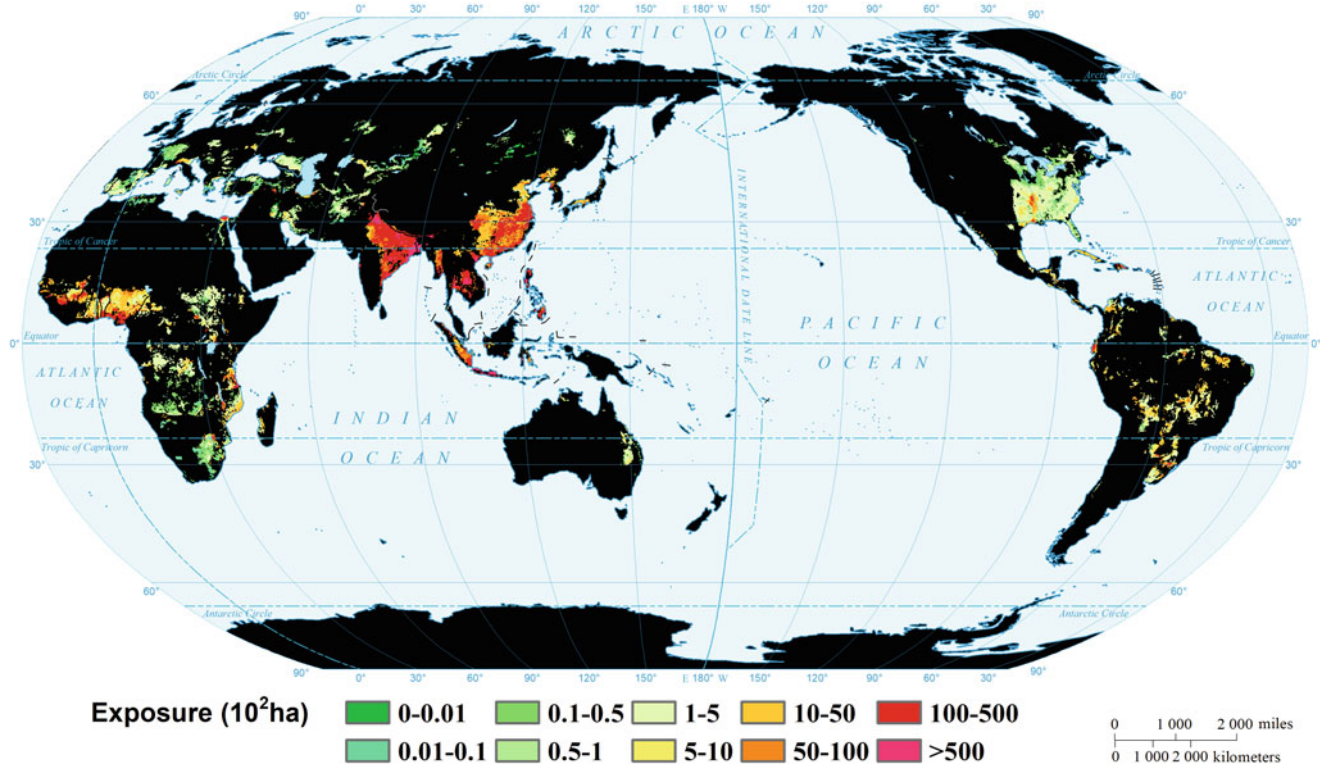
Global rice exposure to extremely high temperature (2030s, RCP8.5-SSP3)



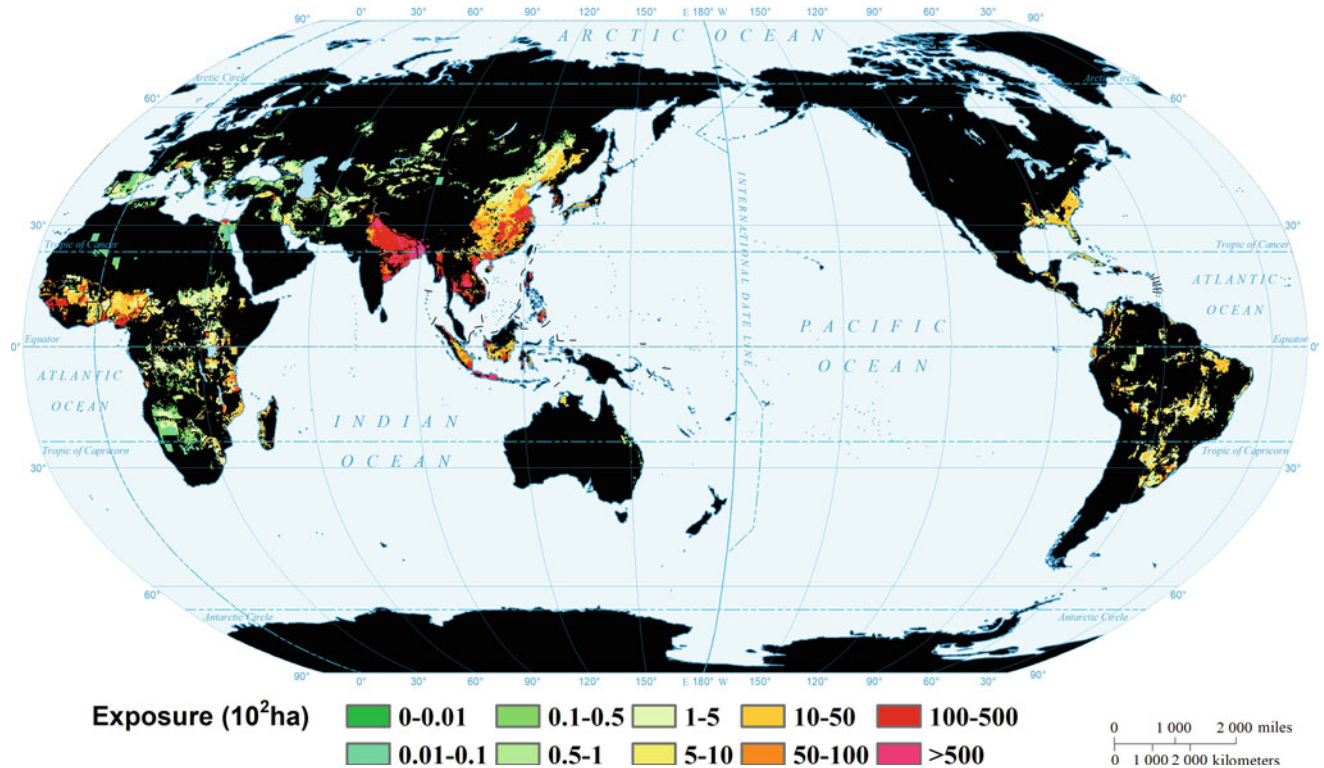
Global rice exposure to extremely high temperature (2050s, RCP2.6-SSP1)



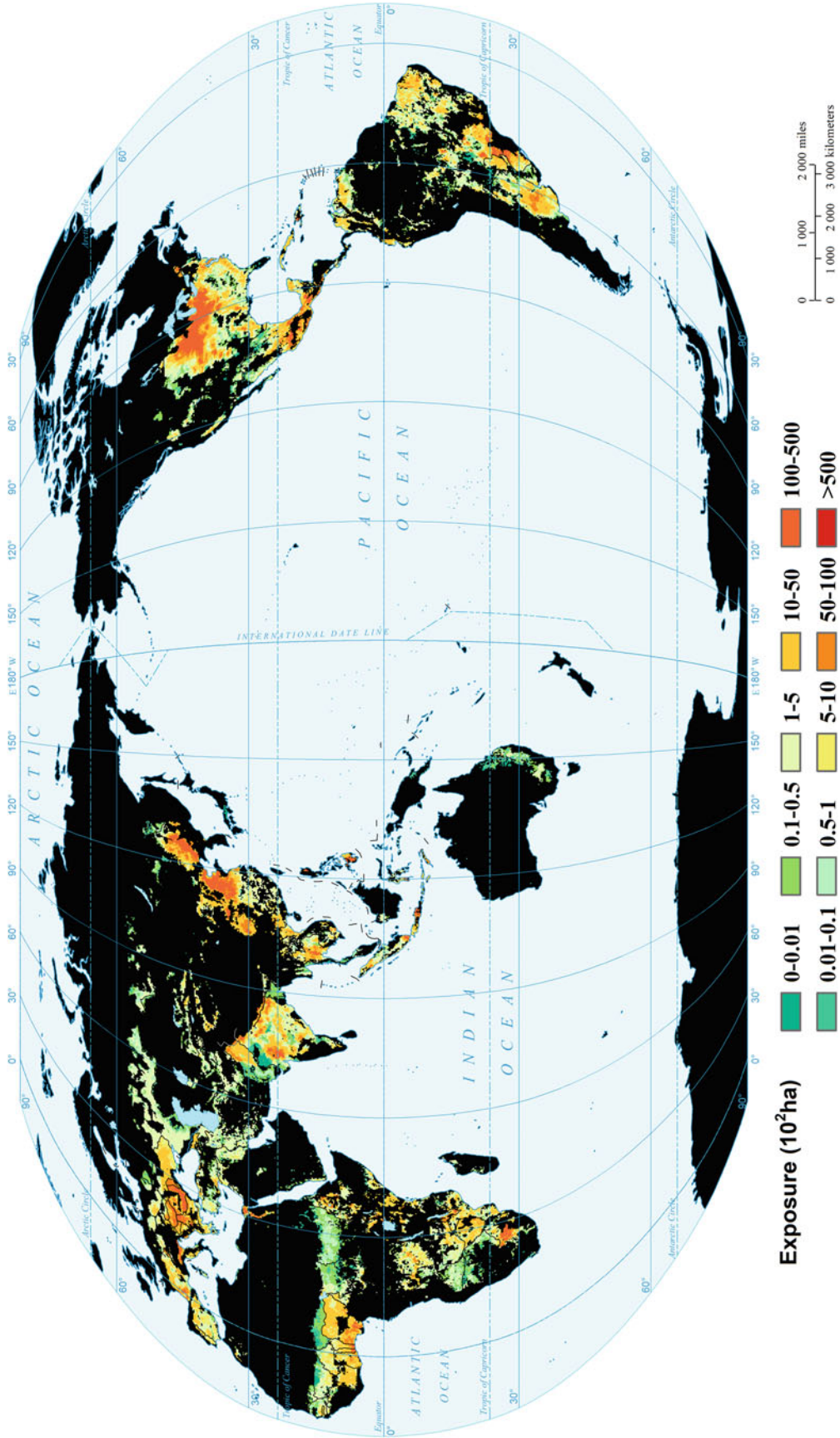
Global rice exposure to extremely high temperature (2050s, RCP4.5-SSP2)



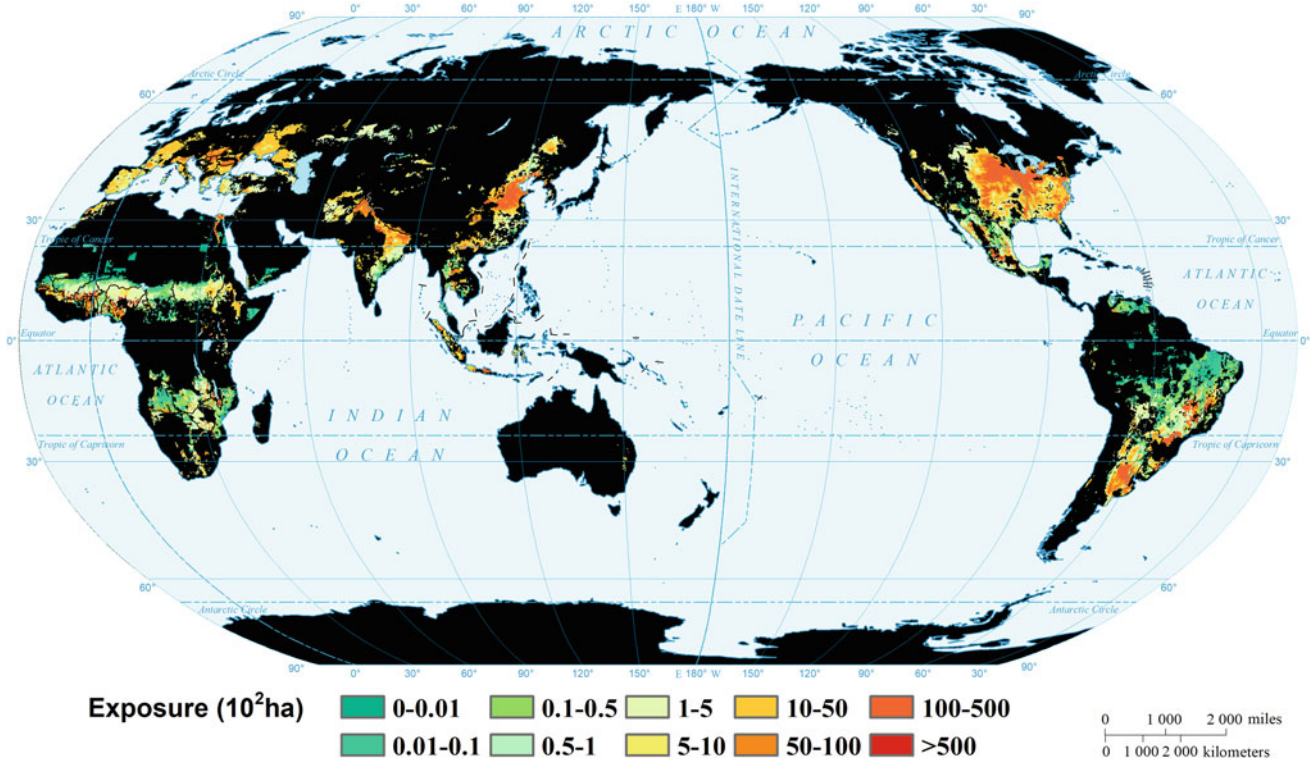
Global rice exposure to extremely high temperature (2050s, RCP8.5-SSP3)



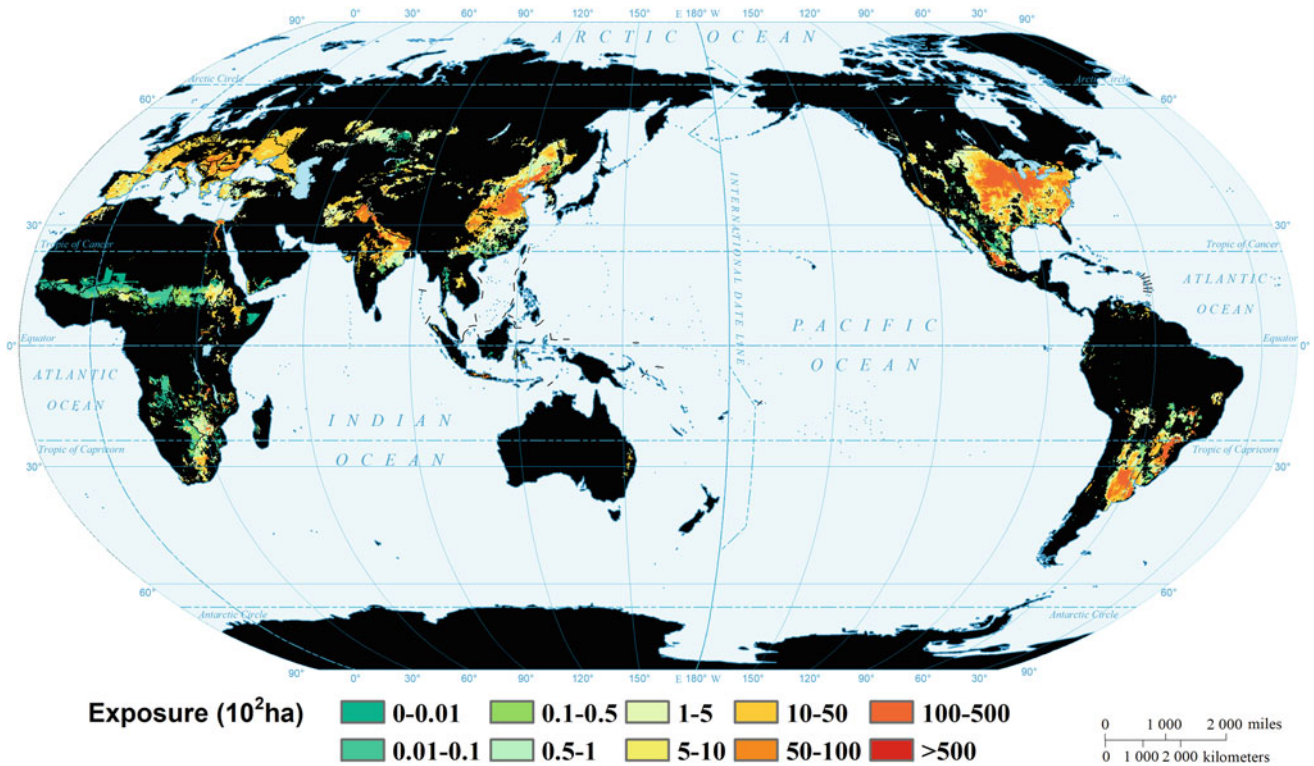
Global maize exposure to extremely high temperature (Baseline)



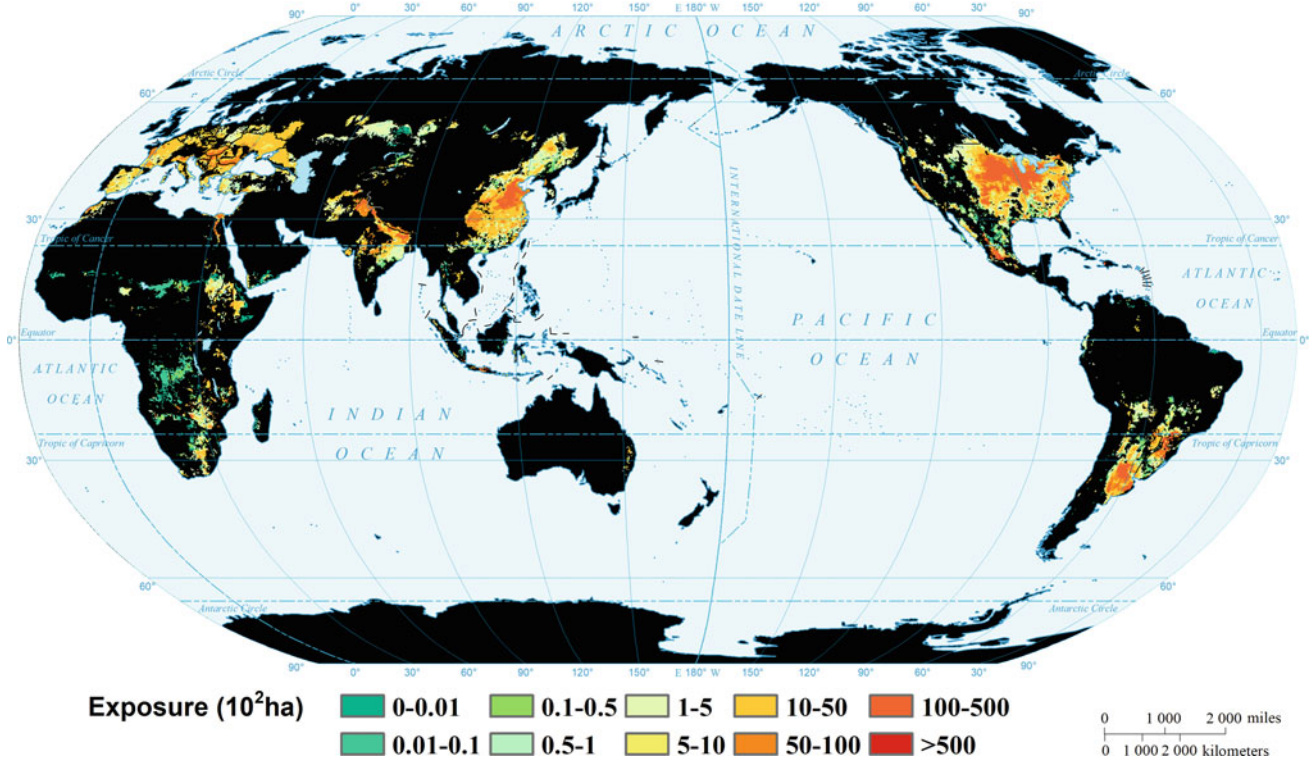
Global maize exposure to extremely high temperature (2030s, RCP2.6-SSP1)



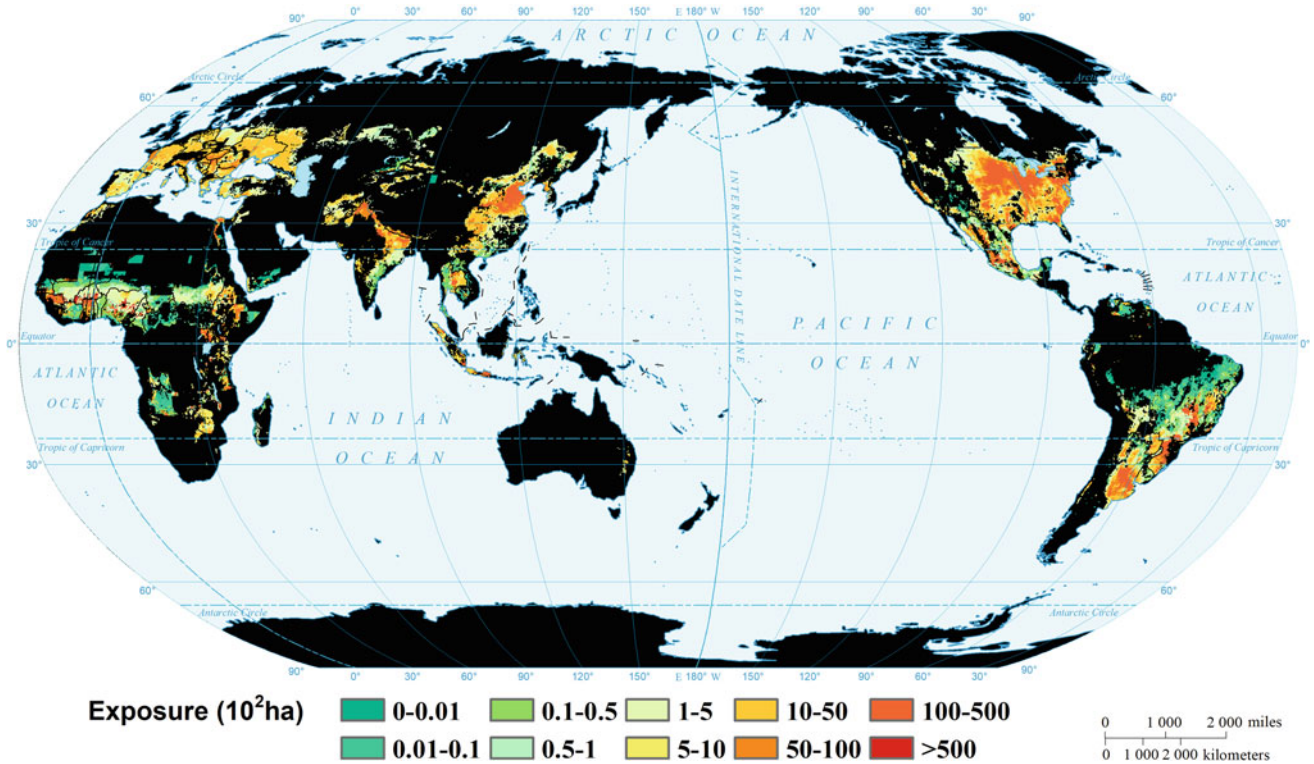
Global maize exposure to extremely high temperature (2030s, RCP4.5-SSP2)



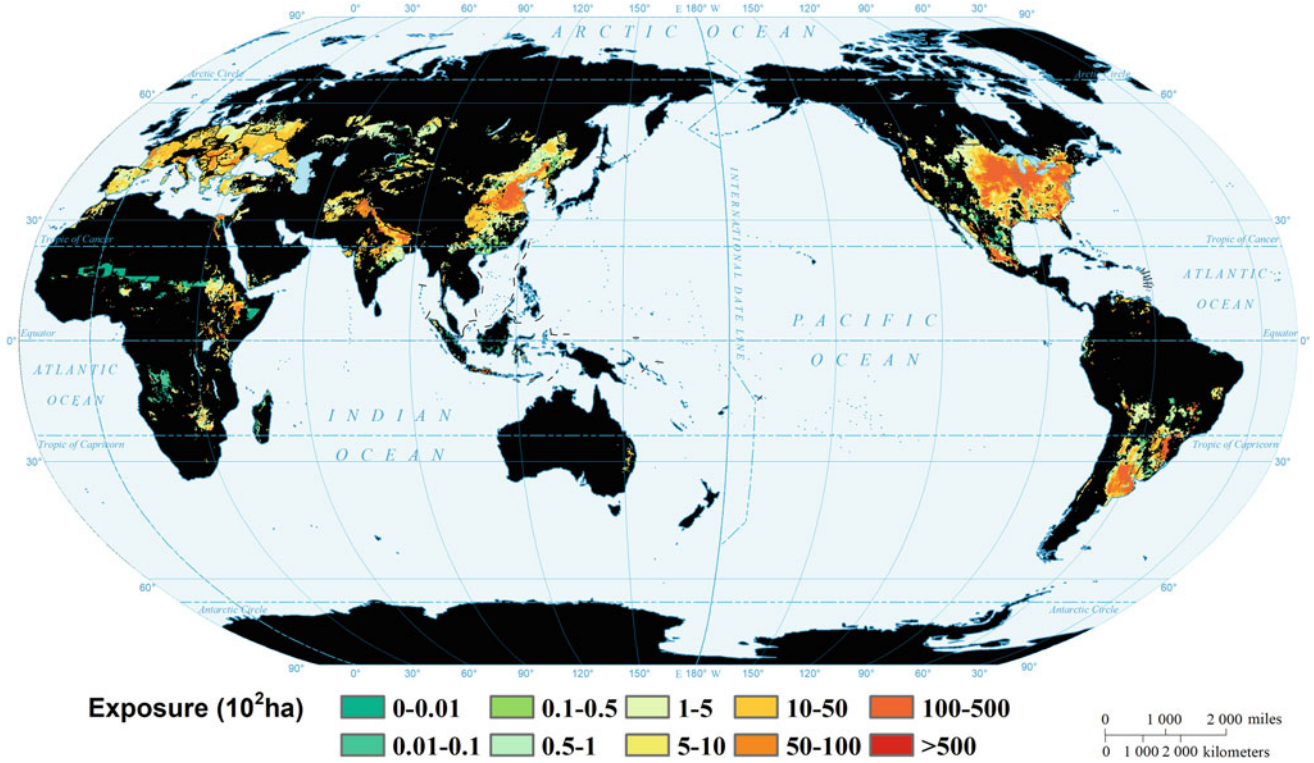
Global maize exposure to extremely high temperature (2030s, RCP8.5-SSP3)



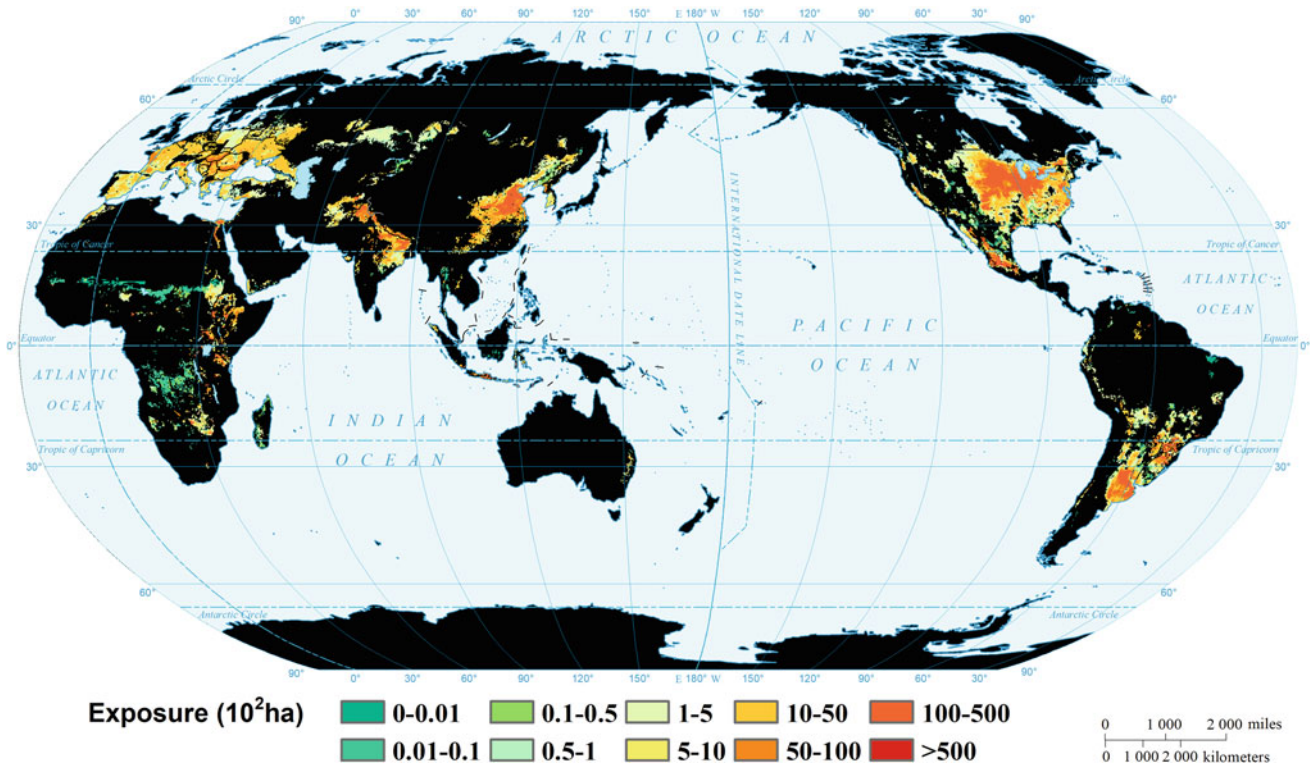
Global maize exposure to extremely high temperature (2050s, RCP2.6-SSP1)



Global maize exposure to extremely high temperature (2050s, RCP4.5-SSP2)



Global maize exposure to extremely high temperature (2050s, RCP8.5-SSP3)



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