Mapping Drought Risk (Wheat) of the World

Xingming Zhang, Hao Guo, Weixia Yin, Ran Wang, Jian Li, Yaojie Yue, and Jing'ai Wang

1 Background

Drought is one of the disasters that most widely affect and damage agricultural production in the world. Nearly half of the countries in the world bear severe drought (UNDP 2004; Moss et al. 2008). There is very serious drought in North America, Mexico, central and southern part of Africa, part of South America, and in northern part of China (IPCC 2012). Research shows that under the background of climate warming many regions in the world have an increasing risk of future drought because of the reduced precipitation and aggravating evaporation (IPCC 2012, 2013).

Agricultural drought risk, which is defined as the possible yield loss of crops exposed to drought, can be considered as the probability of the occurrence of agricultural drought and the negative impact on agricultural production (Yin et al. 2014). The drought risk of food production was assessed based on drought frequency and intensity, production levels, and adaptability at global scale (Li et al. 2009). Assessing and mapping maize drought risk of the world were made based on GEPIC-Vulnerability-Risk (GEPIC-V-R) model (Yin et al. 2014).

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In this study, the wheat yield loss risk of drought at global scale is assessed and mapped based on the GEPIC-V-R model developed by Yin et al. (2014). The vulnerability of wheat to drought is simulated at grid level (0.5° × 0.5°), which improved the spatial resolution compared with the work of Yin et al. (2014).

2 Method

Figure 1 shows the technical flowchart for mapping wheat yield loss risk of drought of the world.

2.1 Model

In the GEPIC-V-R model (Yin et al. 2014), drought risk is treated as the function of hazard, vulnerability of exposure, and environment (Eq. 1).

$$R = f(E, H, V) = H\{\langle P, h_E\rangle\} \times V\{\langle l_E, h_E\rangle\} \quad (1)$$

where E is the sensitivity of environment; H is the drought; V is vulnerability; P is the occurrence probability of drought; h_E is the drought intensity index; and l_E is the loss rate. $H\{\langle P, h_E\rangle\}$ is the drought intensity under a certain probability. $V\{\langle l_E, h_E\rangle\}$ determines the relationship between h_E and l_E.

GEPIC-V-R model is a crop risk assessment model for large scale (i.e., regional, national, continental, and global) with functions to fit vulnerability curves and calculate risk. In this model, there are four modules: model calibration module, hazard module, vulnerability module, and risk calculation module (Yin et al. 2014).

Data for assessing the wheat yield loss risk by drought of the world consist of crop growth environment data (Appendix III, Environments data 2.1, 2.2, and 2.7, Appendix III, Hazards data 4.15), crop management data

P. Shi and R. Kasperson (eds.), *World Atlas of Natural Disaster Risk*, IHDP/Future Earth-Integrated Risk Governance Project Series,
DOI 10.1007/978-3-662-45430-5_12

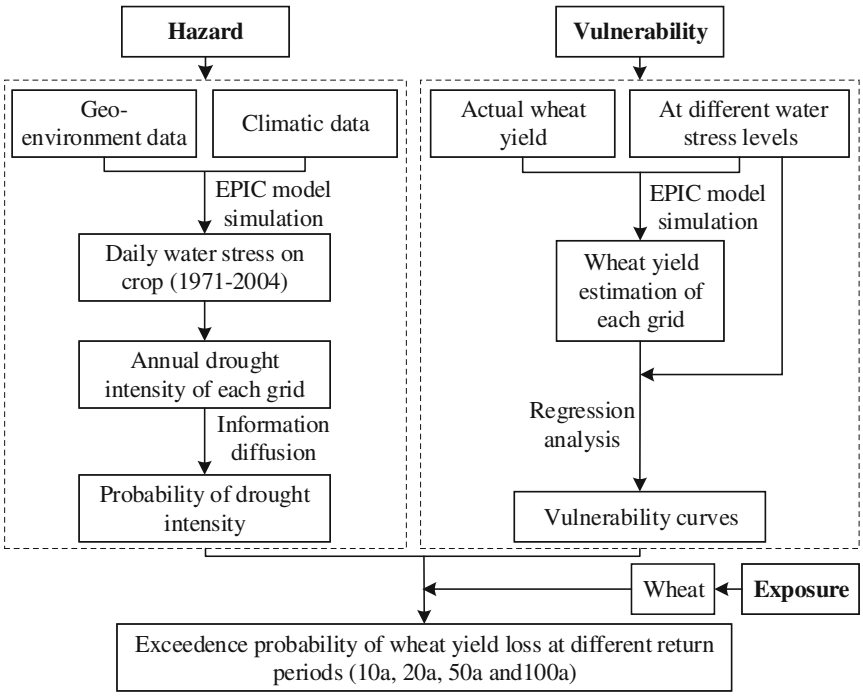


Fig. 1 The technical flowchart for mapping wheat yield loss risk of drought of the world

(Appendix III, Environments data 3.13–3.16), crop species attribute data (Appendix III, Environments data 3.18), and actual yield data (Appendix III, Environments data 3.17).

2.2 Spatial Resolution

Compared with the work of Yin et al. (2014), the vulnerability of wheat to drought is simulated at grid level (0.5° × 0.5°) instead of the regional level which greatly improves the spatial resolution. Furthermore, the wheat exposure is calculated and mapped at 5′ × 5′ grid level in this study, instead of 0.5° × 0.5° grid level done by Yin et al. (2014).

3 Results

3.1 Intensity

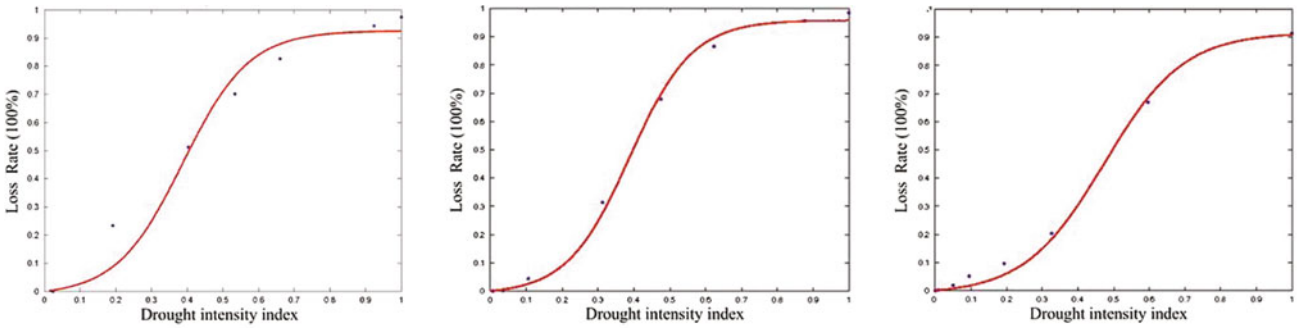
Areas with high value of drought intensity on spring wheat is mainly distributed in Mongolian Plateau, Indian River plains in Asia, Mexican plateau in North America and Andes Mountains in South America, Mediterranean coast, the Great Rift Valley, and Orange River Basin in Africa. Areas with high value of drought intensity on winter wheat is mainly distributed in the hemisphere of 30°N–60°N, including the Hindu Kush Mountains in Central Asia, Great Britain, Paris Basin and North European Plain in Europe, and the Rocky Mountains in America.

3.2 Vulnerability

Based on the GEPIC-V-R model, vulnerability curves of wheat to drought for each grid (0.5° × 0.5°) are fitted (Fig. 2).

3.3 Risk

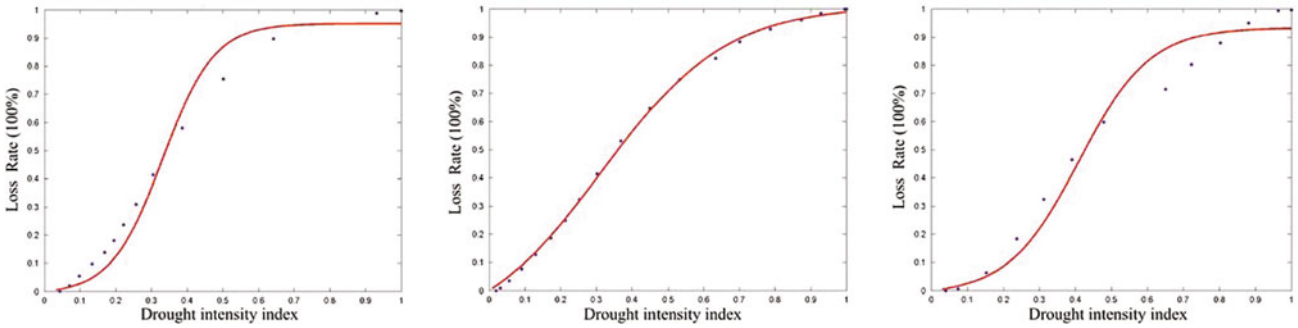
By zonal statistics of the expected risk result, the expected annual wheat yield loss risk of drought of the world at national level is derived and ranked (Fig. 3). The top 1 % country with the highest expected annual wheat yield loss



0.5°×0.5° grid (central coordinate: 101.75°W, 38.25°N) in North America (winter wheat)

0.5°×0.5° grid (central coordinate: 116.75°E, 38.75°N) in East Asia (winter wheat)

0.5°×0.5° grid (central coordinate: 1.75°E, 49.75°N) in West Europe (winter wheat)



0.5°×0.5° grid (central coordinate: 61.75°W, 34.25°S) in South America (spring wheat)

0.5°×0.5° grid (central coordinate: 68.75°E, 29.75°N) in Middle Asia (spring wheat)

0.5°×0.5° grid (central coordinate: 107.75°W, 51.75°N) in North America (spring wheat)

Fig. 2 Examples of vulnerability curve of wheat to drought

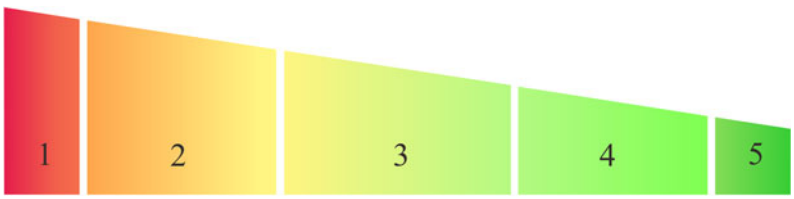
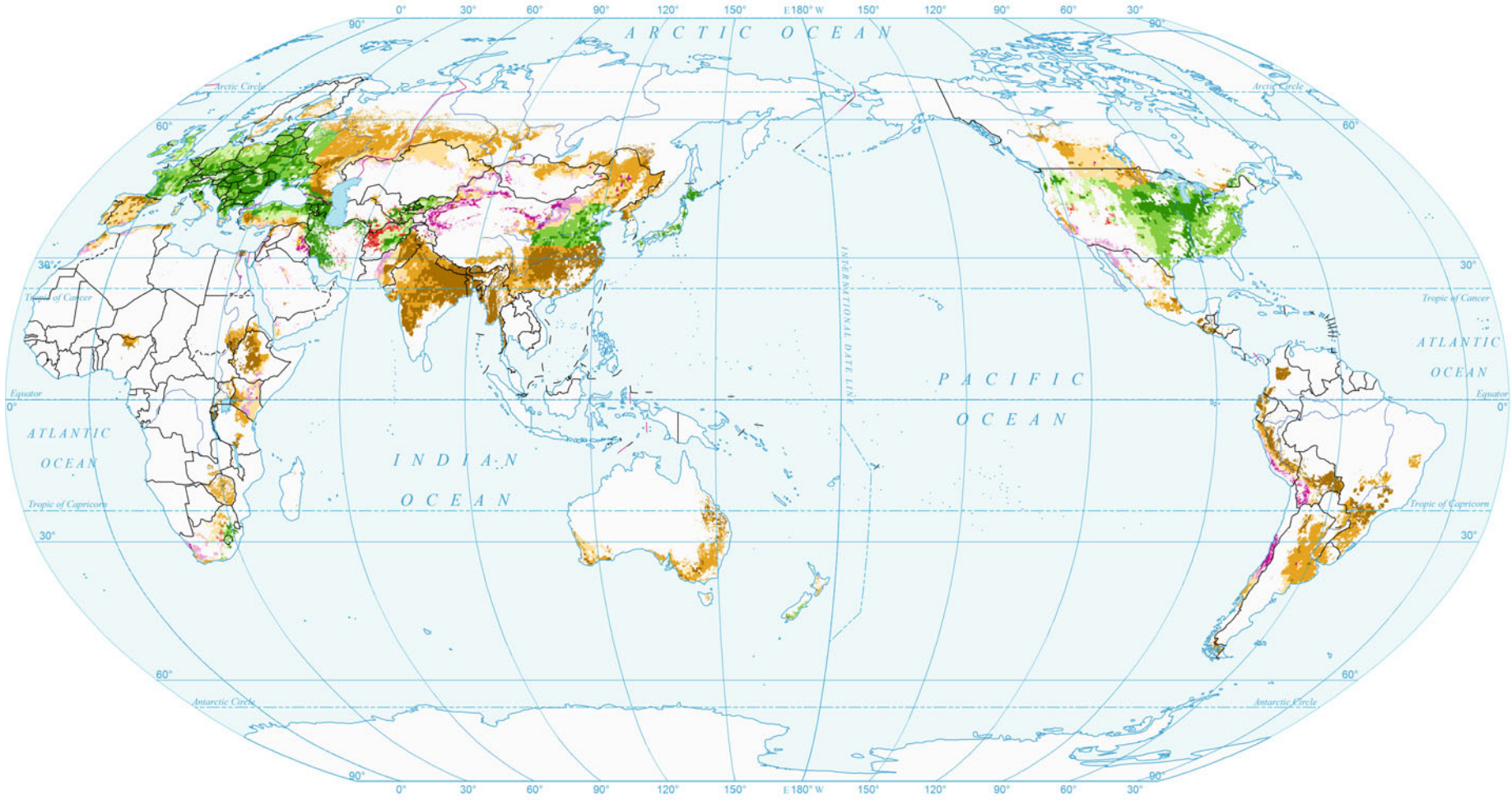


Fig. 3 Expected annual wheat yield loss risk of drought of the world. *1* (0, 10 %]. China, Russia, USA, Kazakhstan, Canada, Kenya, Mongolia, Pakistan, Mexico, Chile, South Africa, and Afghanistan. *2* (10, 35 %]. Argentina, Spain, Peru, Bolivia, Australia, India, Turkey, Morocco, Iraq, Ethiopia, Kyrgyzstan, Turkmenistan, Germany, Algeria, Saudi Arabia, Syria, Uzbekistan, Italy, Egypt, Iran, Zimbabwe, United Kingdom, Yemen, Portugal, Tajikistan, Brazil, Sudan, Greece, and Poland. *3* (35, 65 %]. Finland, Uruguay, France, Tanzania, Jordan, New Zealand, Ukraine, Lebanon, Burma, North Korea, Eritrea, Libya, Israel, the Netherlands, Gaza Strip, Sweden, Tunisia, Denmark, Nepal, Lesotho, Norway, Belarus, Paraguay, Ireland, Oman, Nigeria, Lithuania, Niger, Belgium, Azerbaijan, Uganda, Ecuador, Latvia, Estonia, and South Sudan. *4* (65, 90 %]. Malawi, Bosnia and Herzegovina, Armenia, Czech Republic, Serbia, Japan, Georgia, Zambia, Montenegro, Romania, Macedonia, Kuwait, Bhutan, Bulgaria, Croatia, Botswana, Mali, Guatemala, Honduras, Hungary, Luxembourg, South Korea, Slovenia, Madagascar, Thailand, Albania, Vietnam, Somalia, and Swaziland. *5* (90, 100 %]. Slovakia, Austria, Laos, Bangladesh, Switzerland, Cameroon, San Marino, Mozambique, Moldova, El Salvador, Colombia, and Burundi

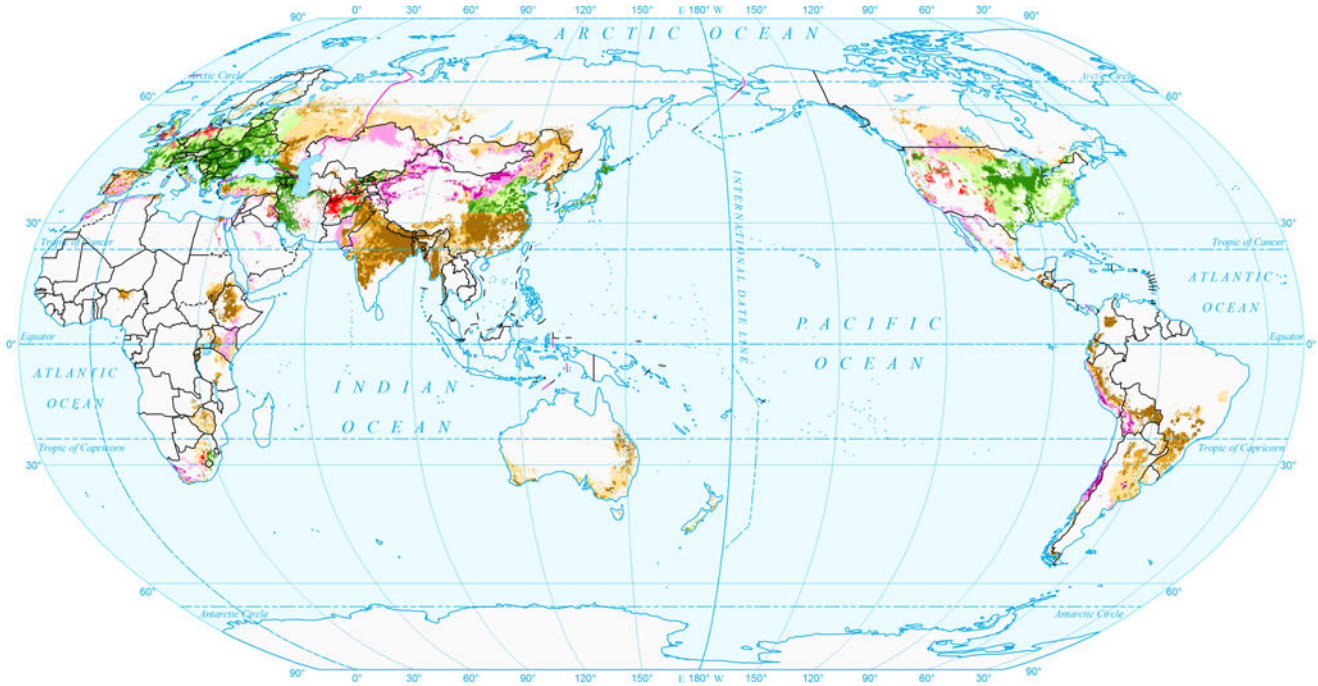
risk of drought is China, and the top 10 % countries are China, Russia, USA, Kazakhstan, Canada, Kenya, Mongolia, Pakistan, Mexico, Chile, South Africa, and Afghanistan.

4 Maps

Global Expected Annual Drought Intensity for Wheat
(0.5°×0.5°)



Global Drought Intensity for Wheat by Return Period (10a)
(0.5°×0.5°)

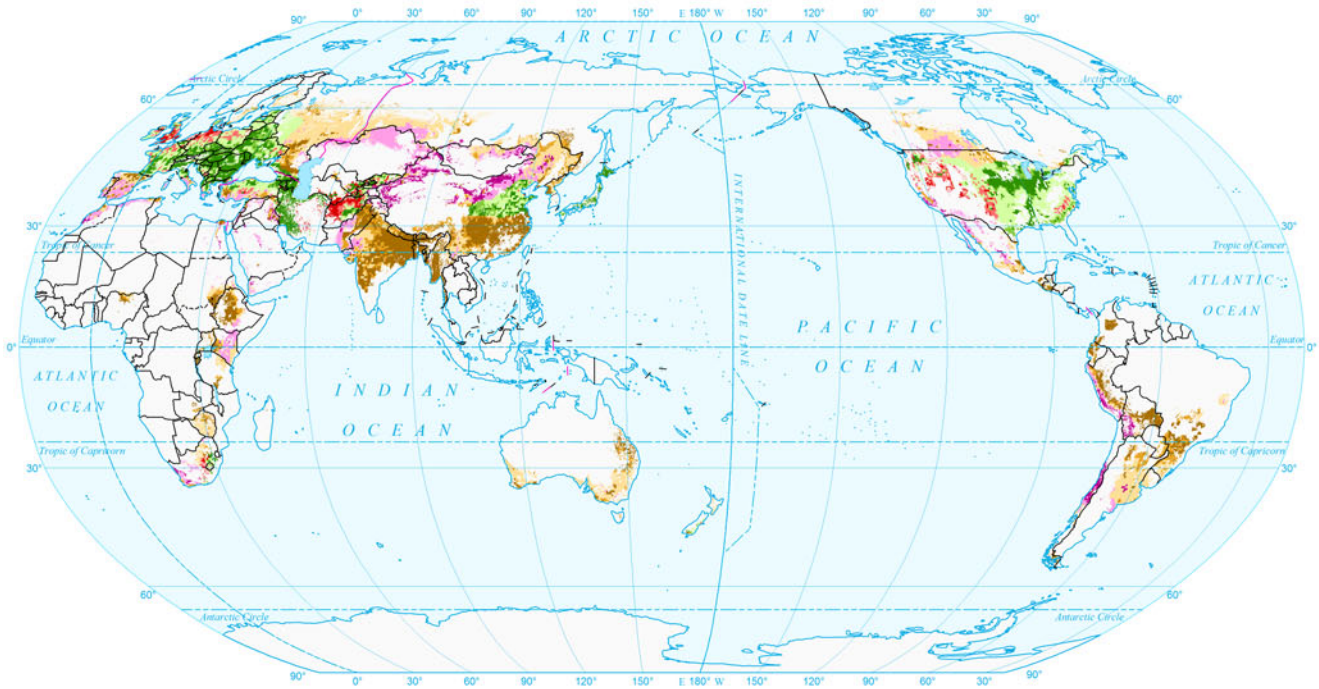


Intensity Index for Spring Wheat >0.70 0.45-0.70 0.20-0.45 0.01-0.20 ≤0.01

Intensity Index for Winter Wheat >0.35 0.25-0.35 0.10-0.25 0.01-0.10 ≤0.01

0 1 000 2 000 miles
0 1 000 2 000 kilometers

Global Drought Intensity for Wheat by Return Period (20a)
(0.5°×0.5°)

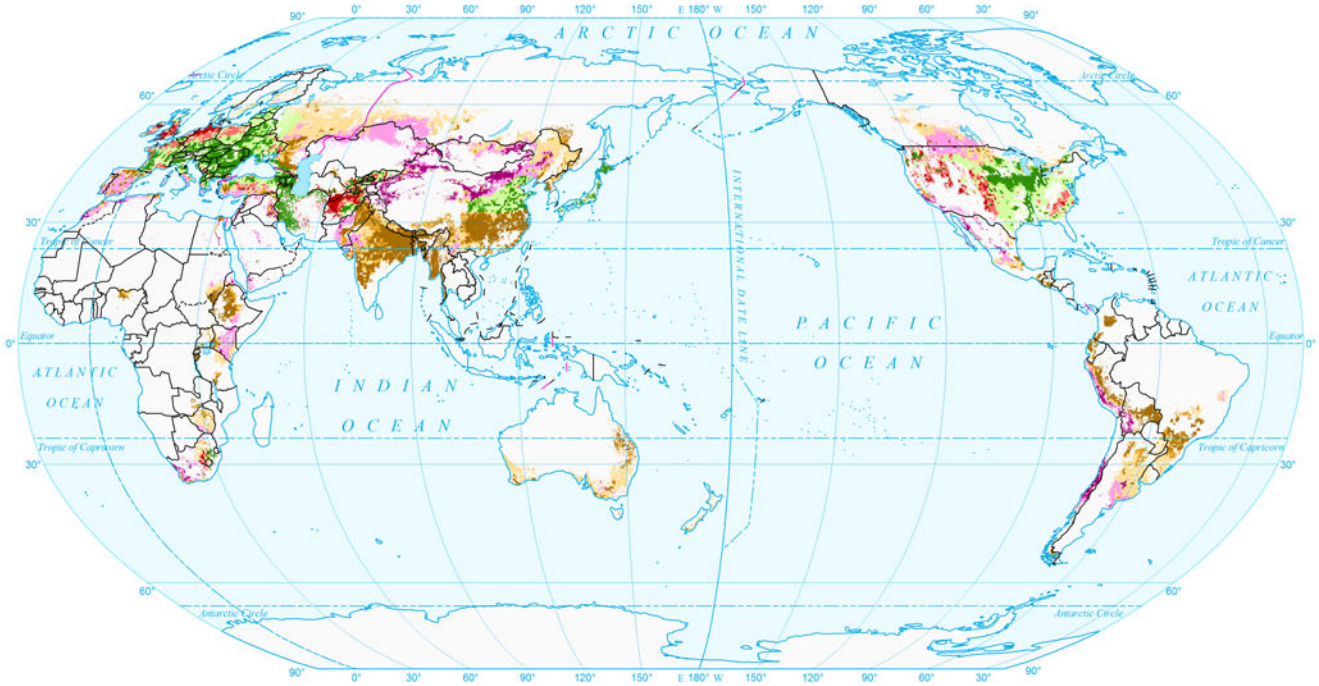


Intensity Index for Spring Wheat >0.70 0.45-0.70 0.20-0.45 0.01-0.20 ≤0.01

Intensity Index for Winter Wheat >0.35 0.25-0.35 0.10-0.25 0.01-0.10 ≤0.01

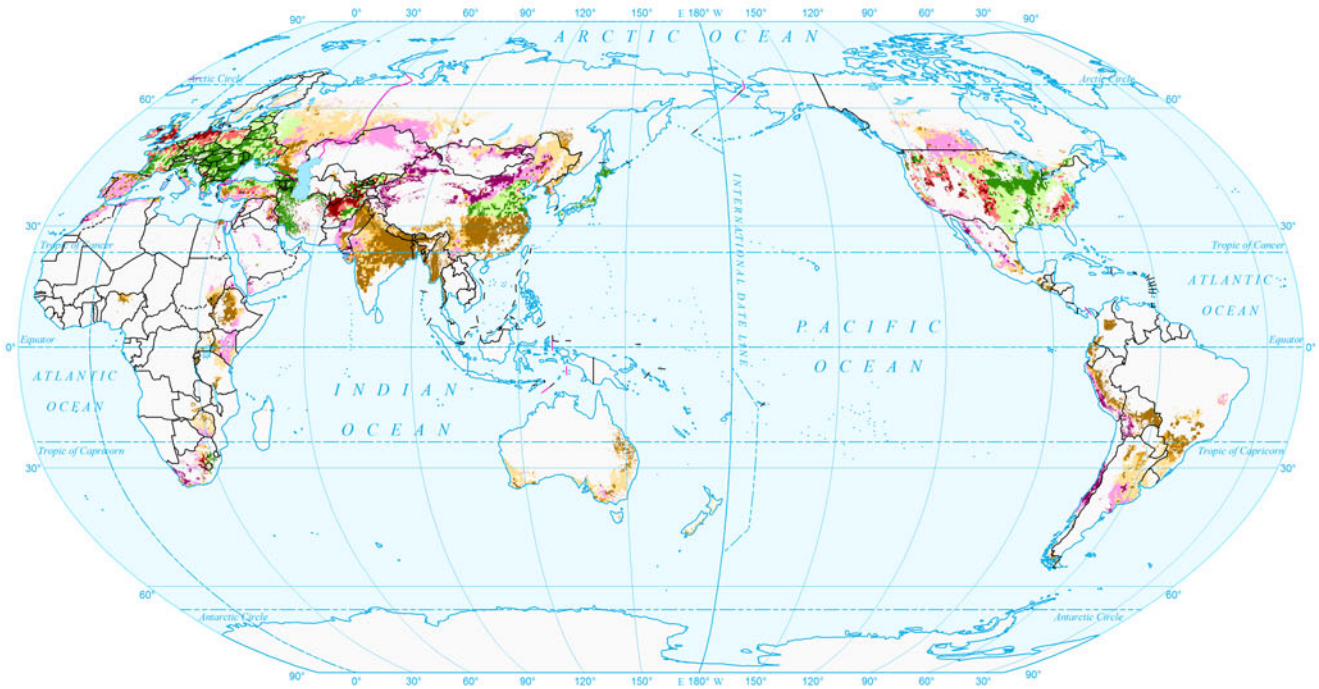
0 1 000 2 000 miles
0 1 000 2 000 kilometers

Global Drought Intensity for Wheat by Return Period (50a)
(0.5°×0.5°)



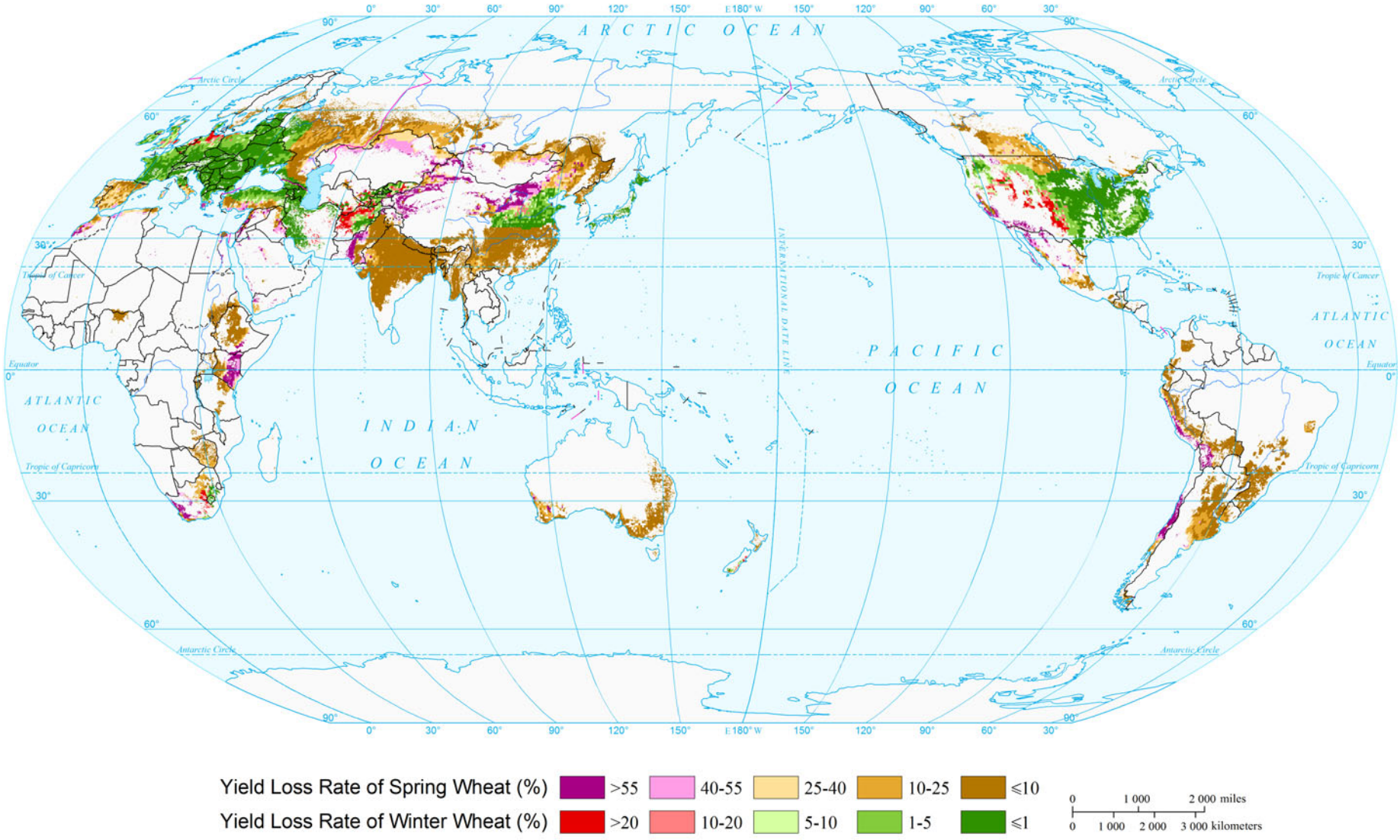
Intensity Index for Spring Wheat >0.70 0.45-0.70 0.20-0.45 0.01-0.20 ⩽0.01
Intensity Index for Winter Wheat >0.35 0.25-0.35 0.10-0.25 0.01-0.10 ⩽0.01
0 1 000 2 000 miles
0 1 000 2 000 kilometers

Global Drought Intensity for Wheat by Return Period (100a)
(0.5°×0.5°)

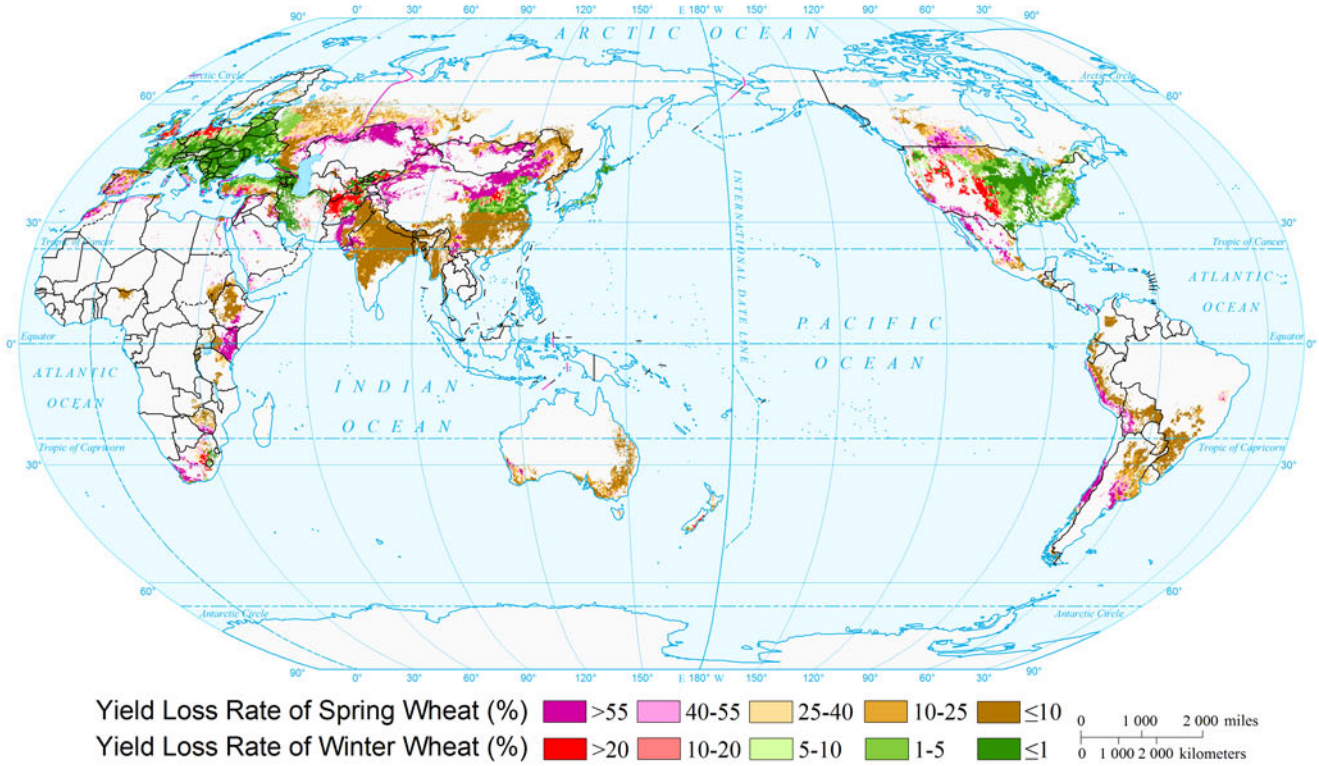


Intensity Index for Spring Wheat >0.70 0.45-0.70 0.20-0.45 0.01-0.20 ⩽0.01
Intensity Index for Winter Wheat >0.35 0.25-0.35 0.10-0.25 0.01-0.10 ⩽0.01
0 1 000 2 000 miles
0 1 000 2 000 kilometers

Expected Annual Wheat Yield Loss Risk of Drought of the World (0.5°×0.5°)

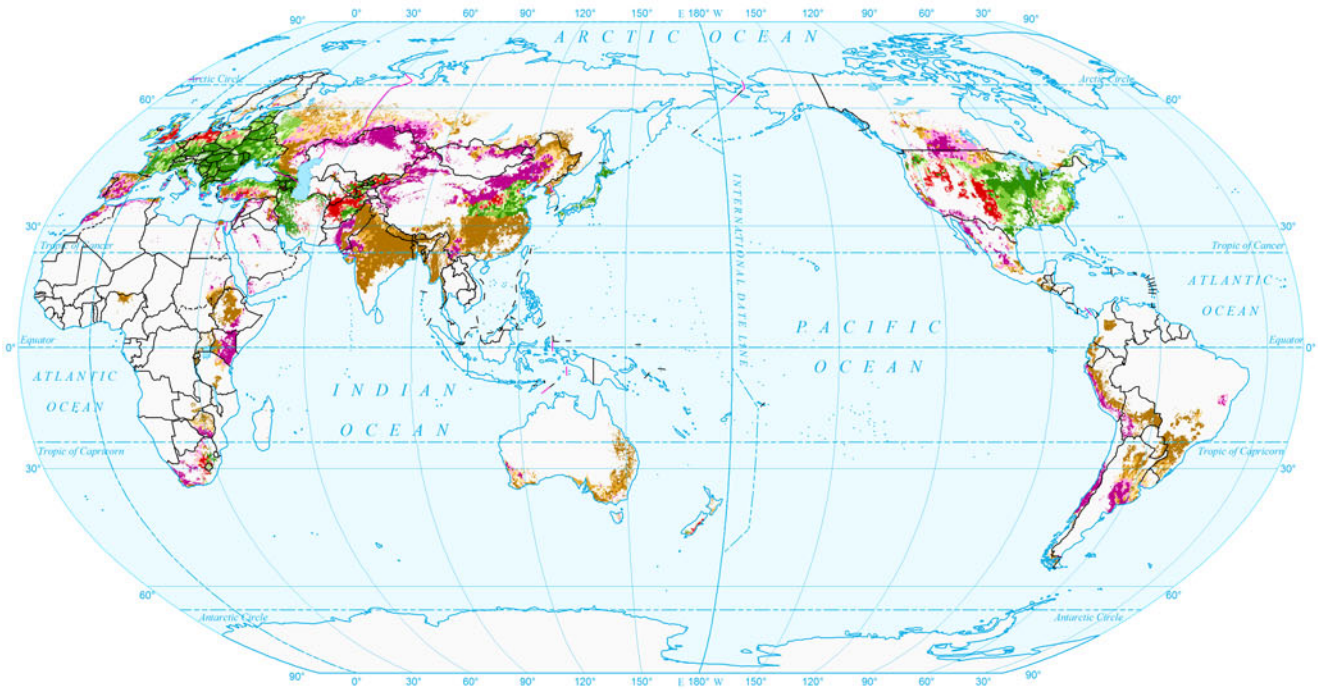


Wheat Yield Loss Risk of Drought of the World by Return Period (10a)
(0.5°×0.5°)



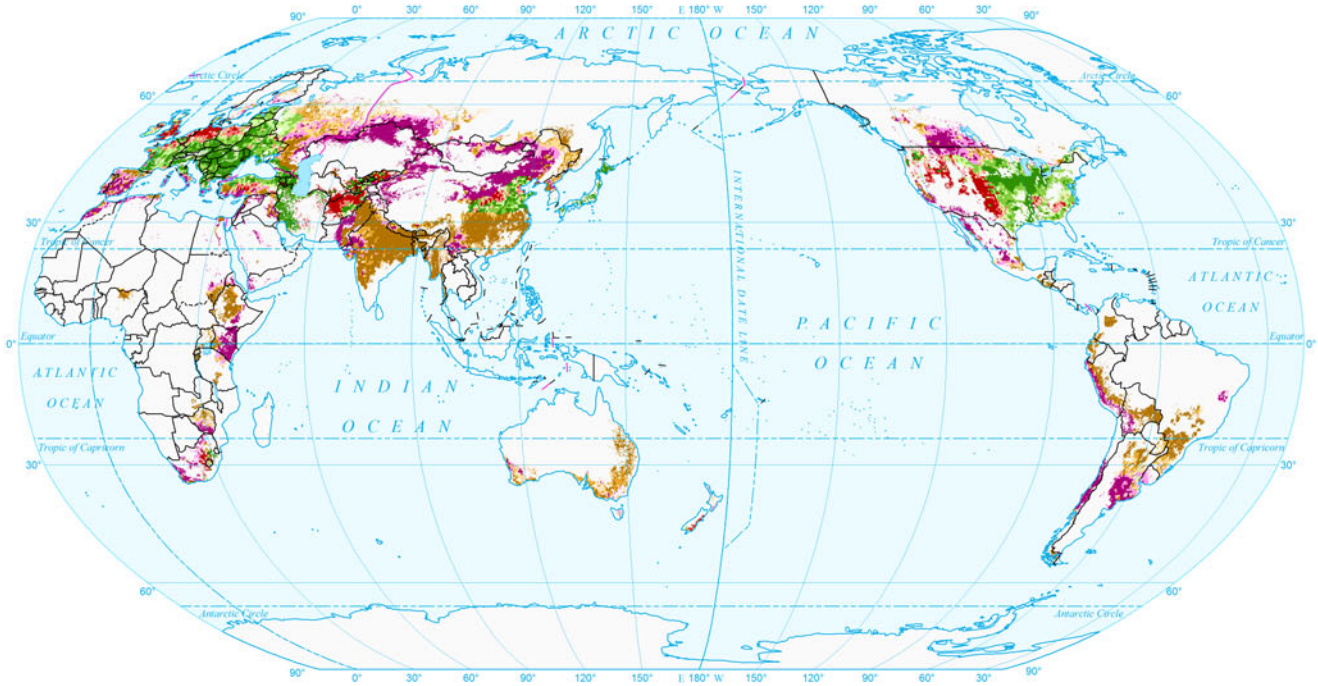
Yield Loss Rate of Spring Wheat (%) >55 40-55 25-40 10-25 ≤10
Yield Loss Rate of Winter Wheat (%) >20 10-20 5-10 1-5 ≤1
0 1 000 2 000 miles
0 1 000 2 000 kilometers

Wheat Yield Loss Risk of Drought of the World by Return Period (20a)
(0.5°×0.5°)



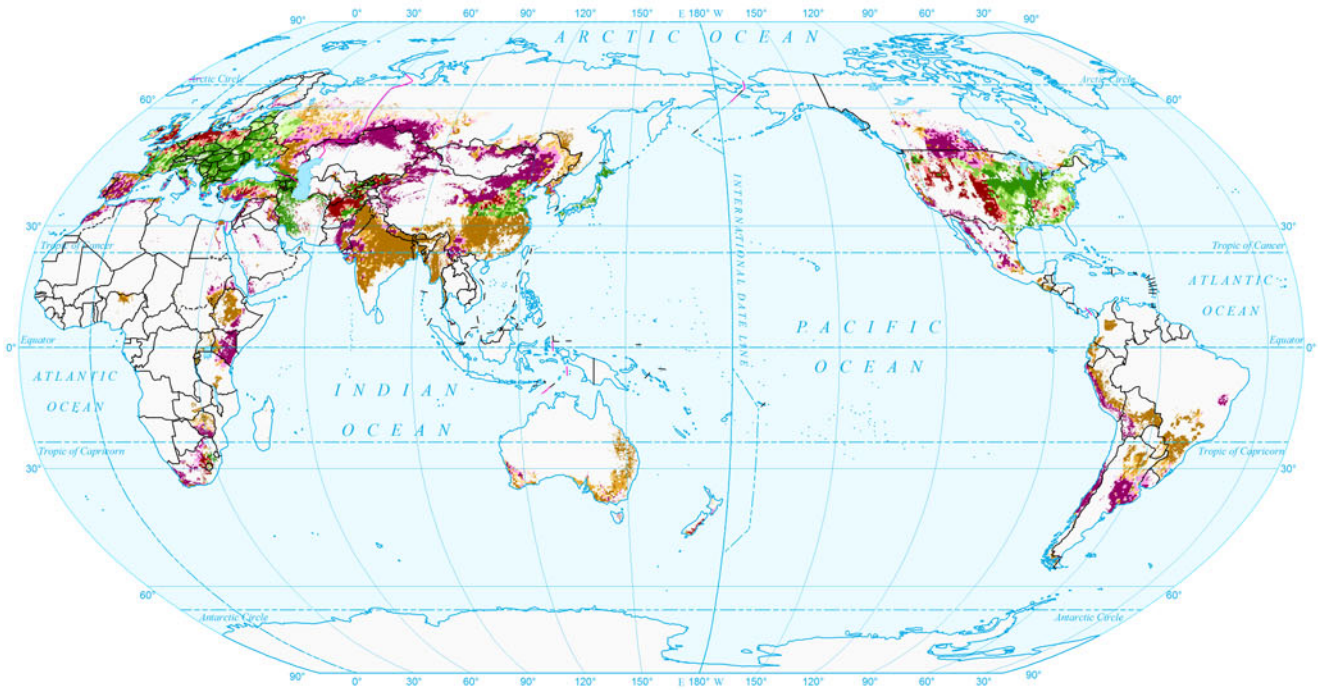
Yield Loss Rate of Spring Wheat (%) >55 40-55 25-40 10-25 ≤10
Yield Loss Rate of Winter Wheat (%) >20 10-20 5-10 1-5 ≤1
0 1 000 2 000 miles
0 1 000 2 000 kilometers

Wheat Yield Loss Risk of Drought of the World by Return Period (50a)
(0.5°×0.5°)

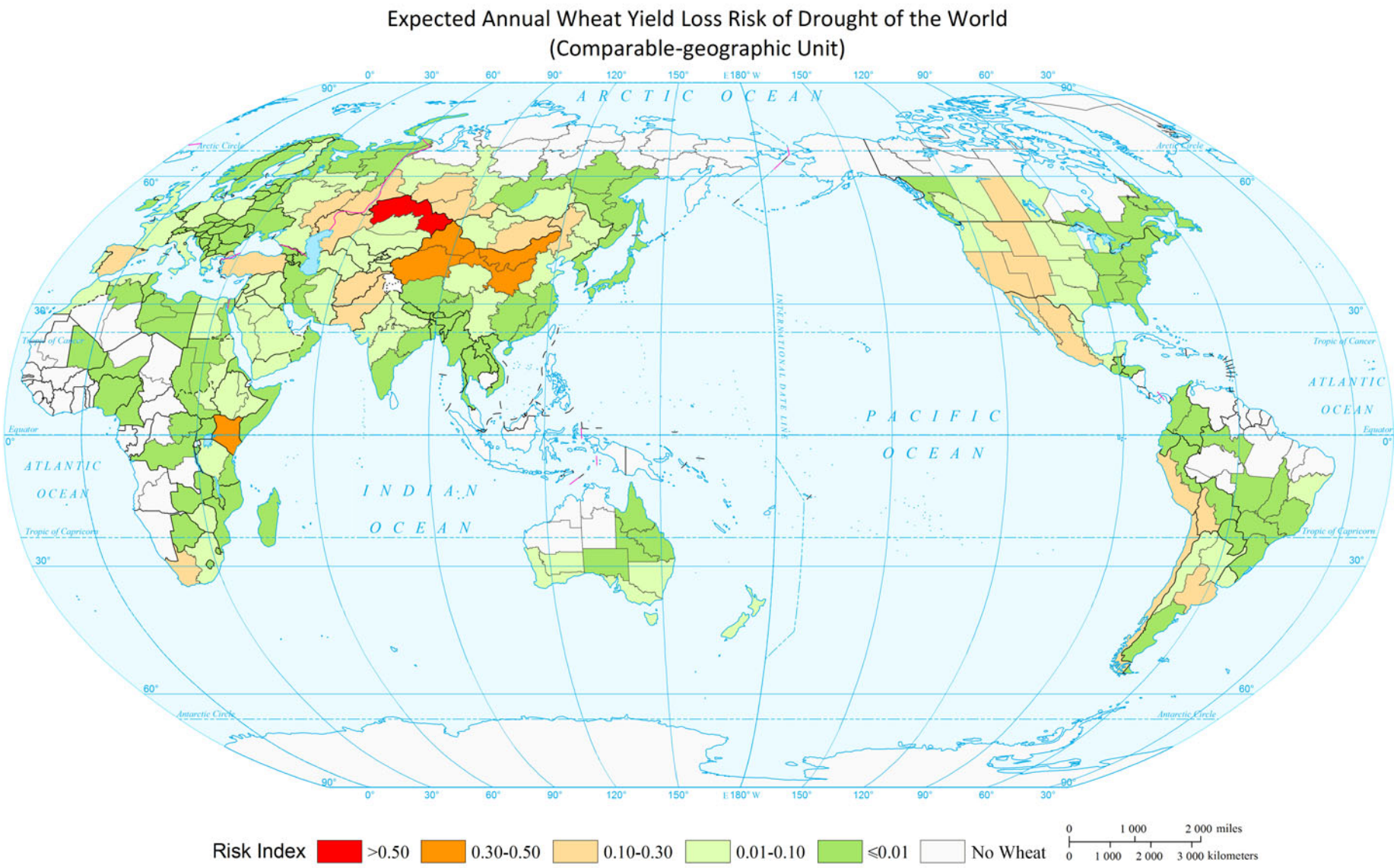


Yield Loss Rate of Spring Wheat (%) >55 40-55 25-40 10-25 ≤10
Yield Loss Rate of Winter Wheat (%) >20 10-20 5-10 1-5 ≤1
0 1 000 2 000 miles
0 1 000 2 000 kilometers

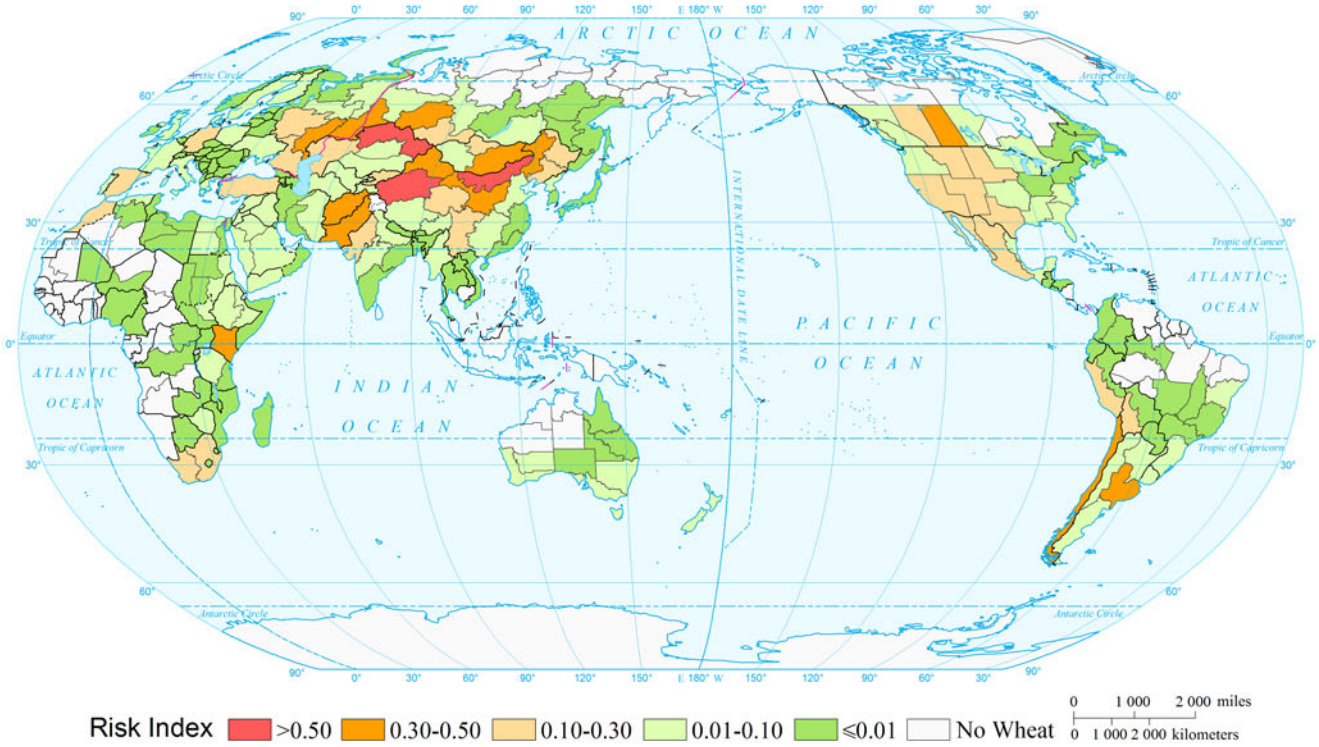
Wheat Yield Loss Risk of Drought of the World by Return Period (100a)
(0.5°×0.5°)



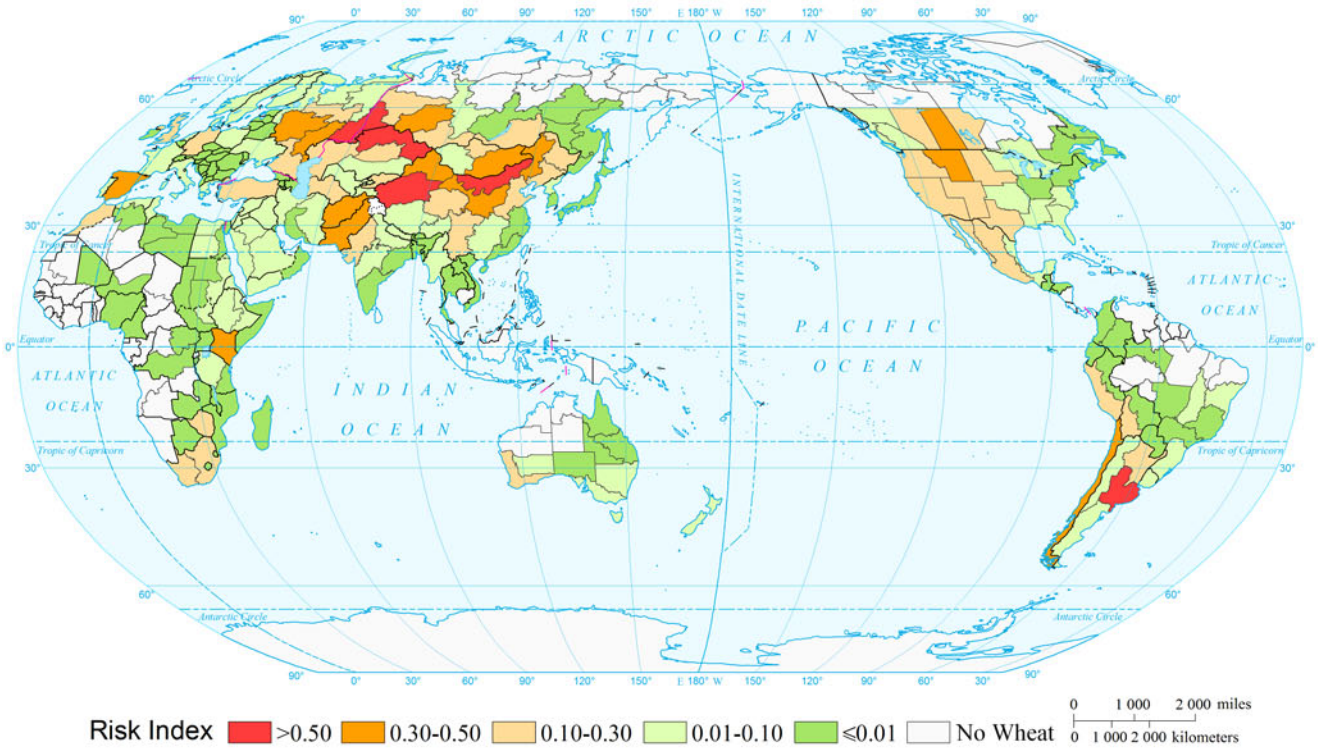
Yield Loss Rate of Spring Wheat (%) >55 40-55 25-40 10-25 ≤10
Yield Loss Rate of Winter Wheat (%) >20 10-20 5-10 1-5 ≤1
0 1 000 2 000 miles
0 1 000 2 000 kilometers


Expected Annual Wheat Yield Loss Risk of Drought of the World
(Comparable-geographic Unit)
ARCTIC OCEAN
PACIFIC OCEAN
ATLANTIC OCEAN
INDIAN OCEAN
ATLANTIC OCEAN
Arctic Circle
Tropic of Cancer
Equator
Tropic of Capricorn
Antarctic Circle
INTERNATIONAL DATE LINE
Risk Index
>0.50
0.30-0.50
0.10-0.30
0.01-0.10
≤0.01
No Wheat
0 1 000 2 000 miles
0 1 000 2 000 3 000 kilometers

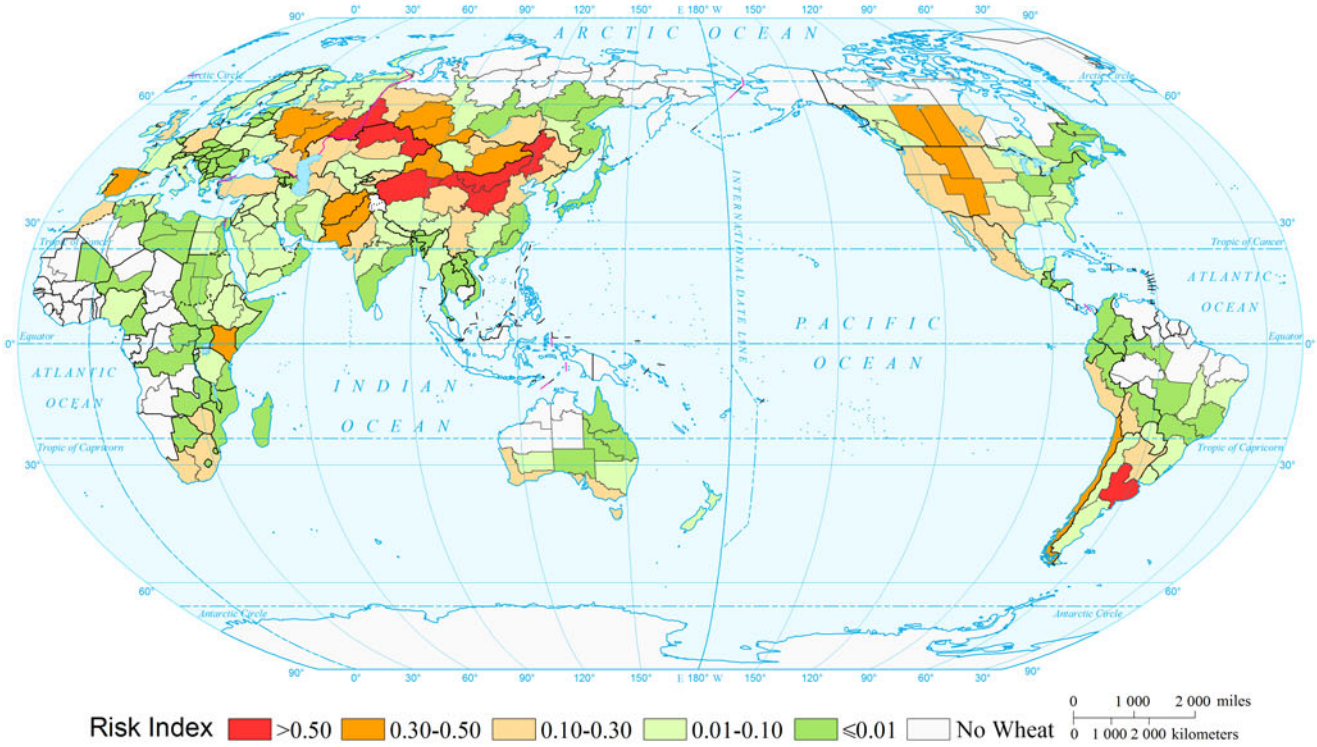
Wheat Yield Loss Risk of Drought of the World by Return Period (10a)
(Comparable-geographic Unit)



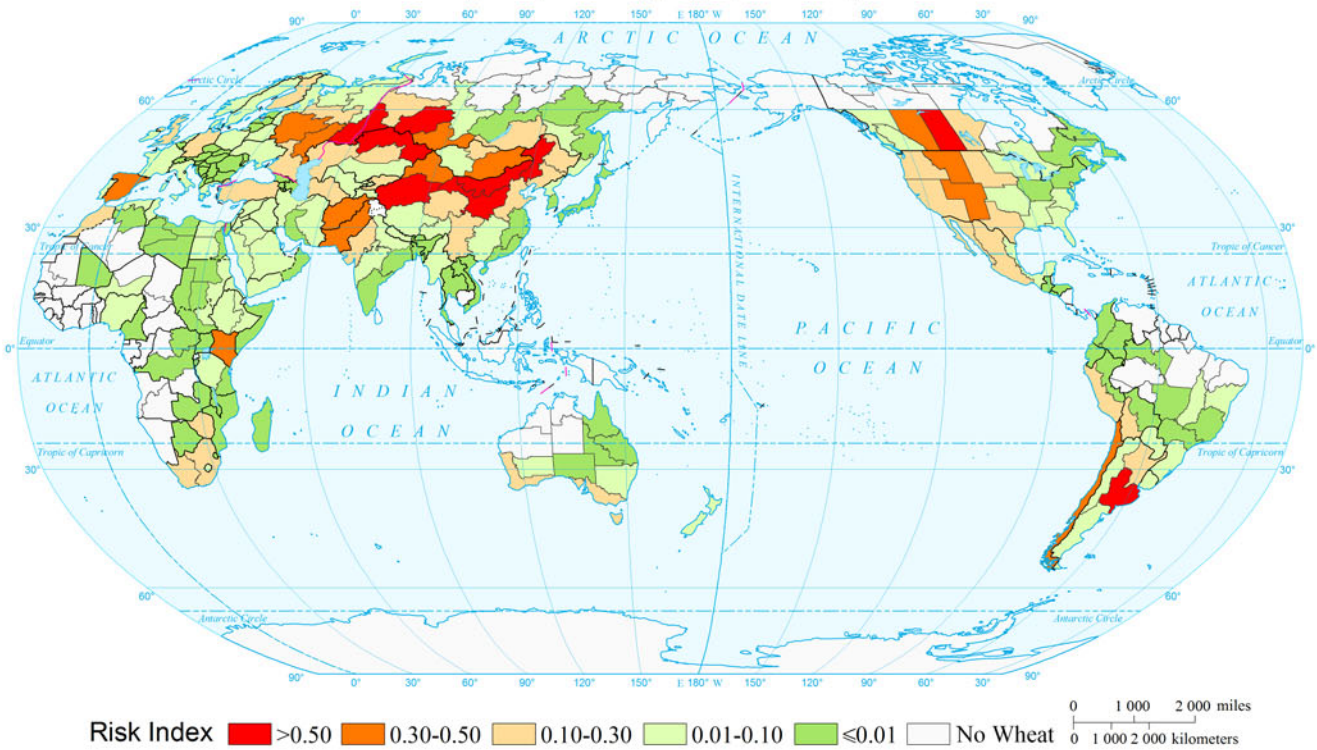
Wheat Yield Loss Risk of Drought of the World by Return Period (20a)
(Comparable-geographic Unit)

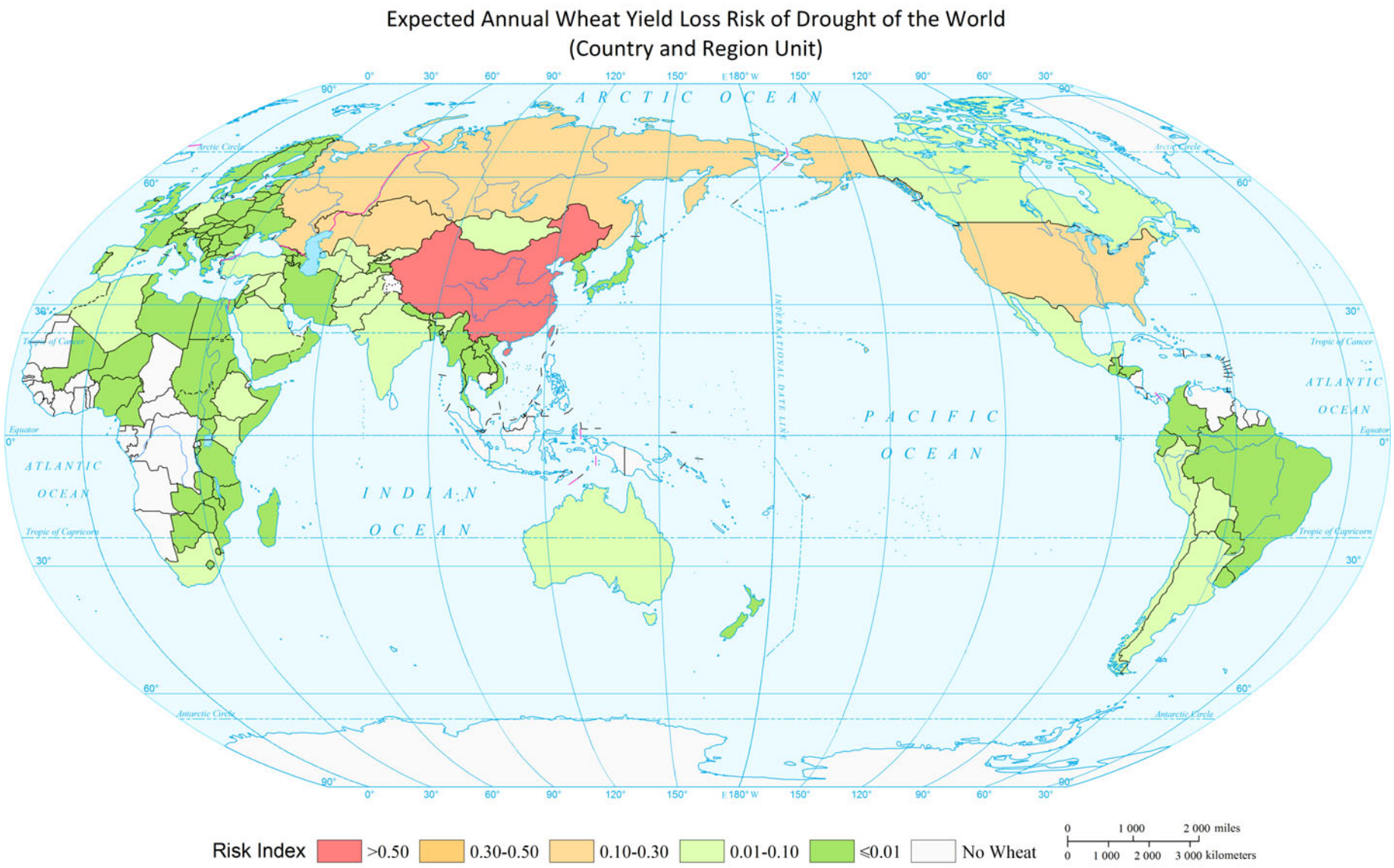


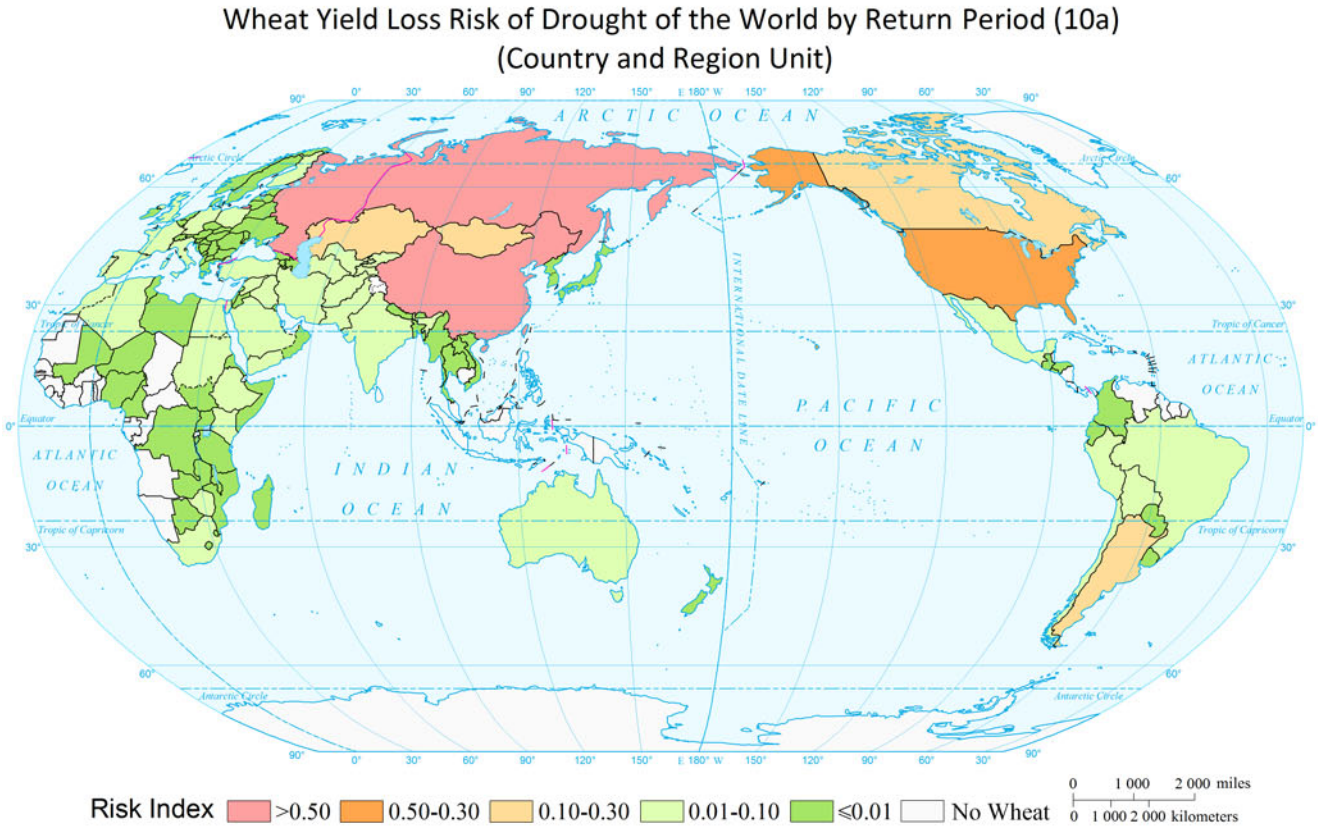
Wheat Yield Loss Risk of Drought of the World by Return Period (50a)
(Comparable-geographic Unit)



Wheat Yield Loss Risk of Drought of the World by Return Period (100a)
(Comparable-geographic Unit)




Expected Annual Wheat Yield Loss Risk of Drought of the World
(Country and Region Unit)
ARCTIC OCEAN
PACIFIC OCEAN
ATLANTIC OCEAN
INDIAN OCEAN
ATLANTIC OCEAN
Arctic Circle
Tropic of Cancer
Equator
Tropic of Capricorn
Antarctic Circle
INTERNATIONAL DATE LINE
Risk Index
>0.50
0.30-0.50
0.10-0.30
0.01-0.10
≤0.01
No Wheat
0 1 000 2 000 miles
0 1 000 2 000 3 000 kilometers


Wheat Yield Loss Risk of Drought of the World by Return Period (10a)
(Country and Region Unit)
ARCTIC OCEAN
ATLANTIC OCEAN
PACIFIC OCEAN
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Arctic Circle
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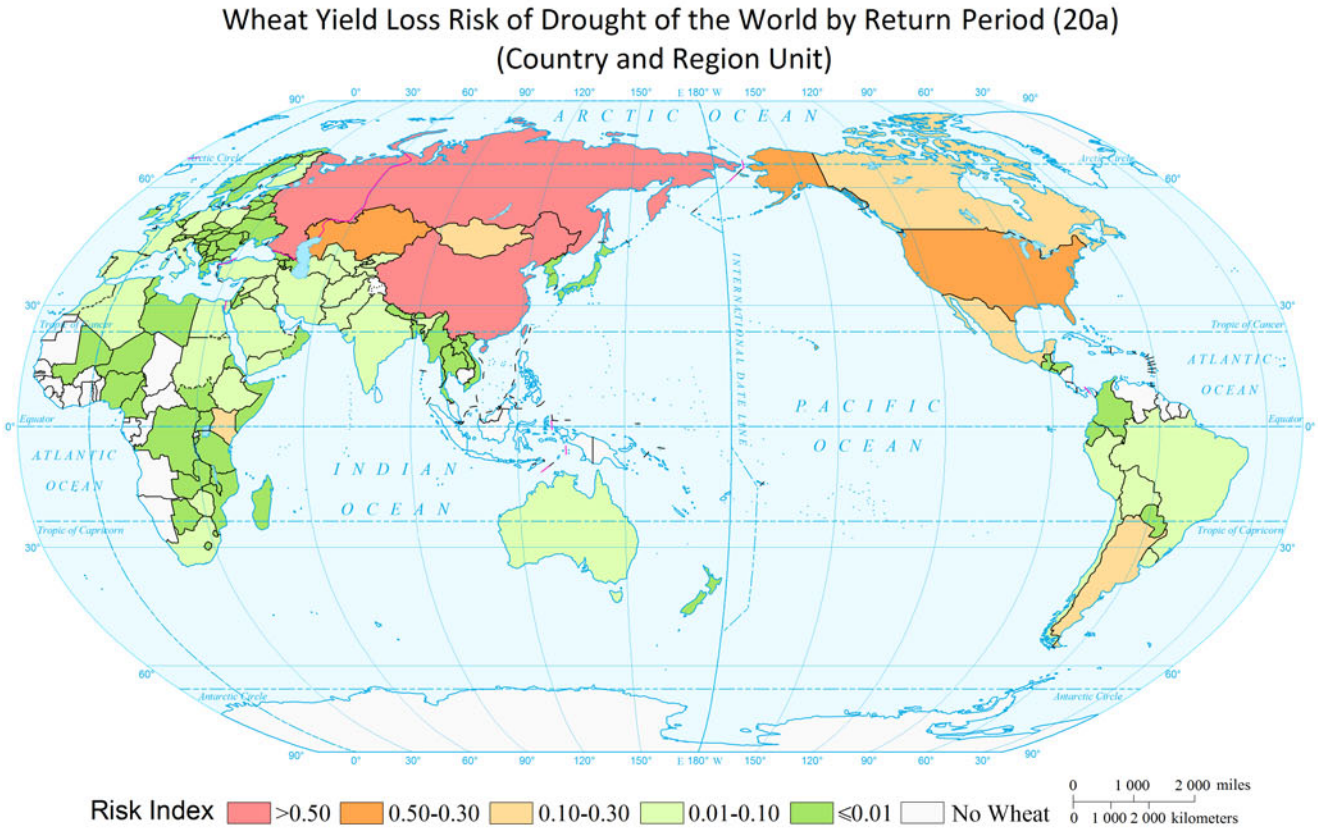
Equator
Tropic of Capricorn
Antarctic Circle
Risk Index
>0.50
0.50-0.30
0.10-0.30
0.01-0.10
≤0.01
No Wheat
0 1 000 2 000 miles
0 1 000 2 000 kilometers


Wheat Yield Loss Risk of Drought of the World by Return Period (20a)
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ARCTIC OCEAN
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0.01-0.10
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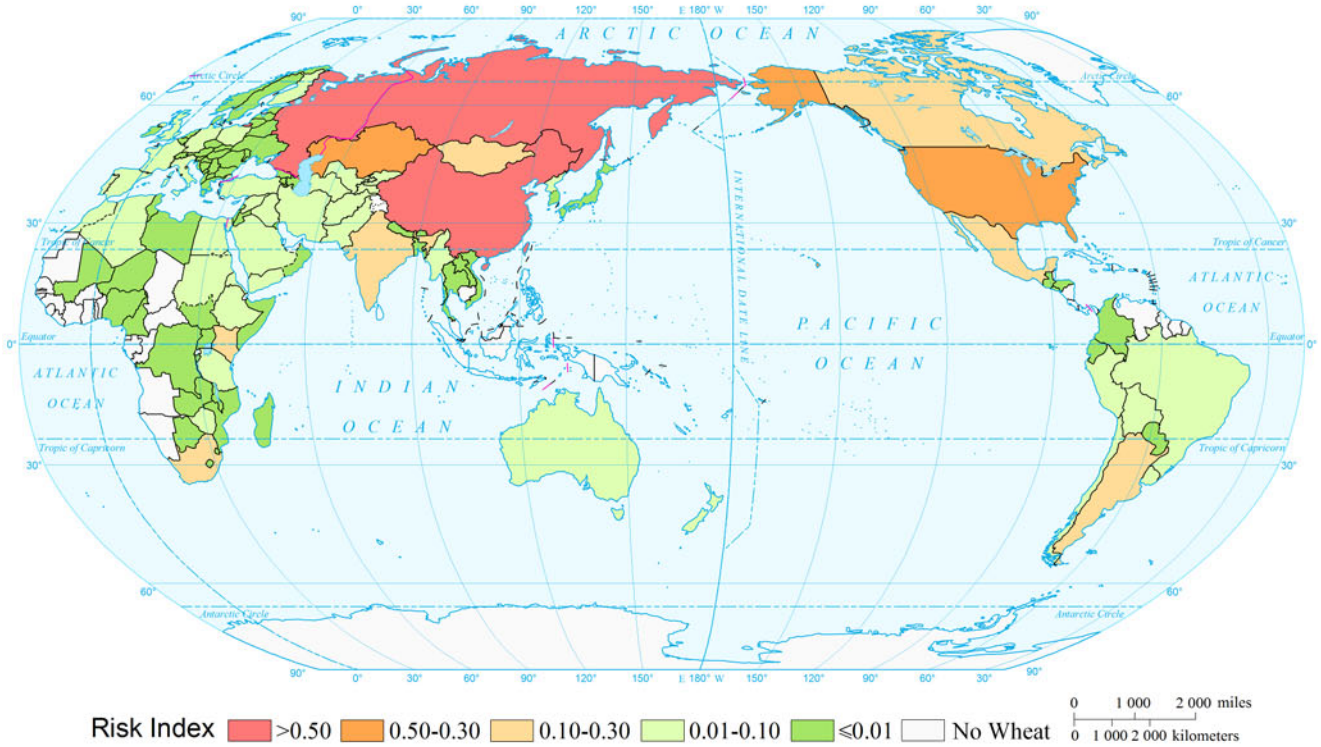
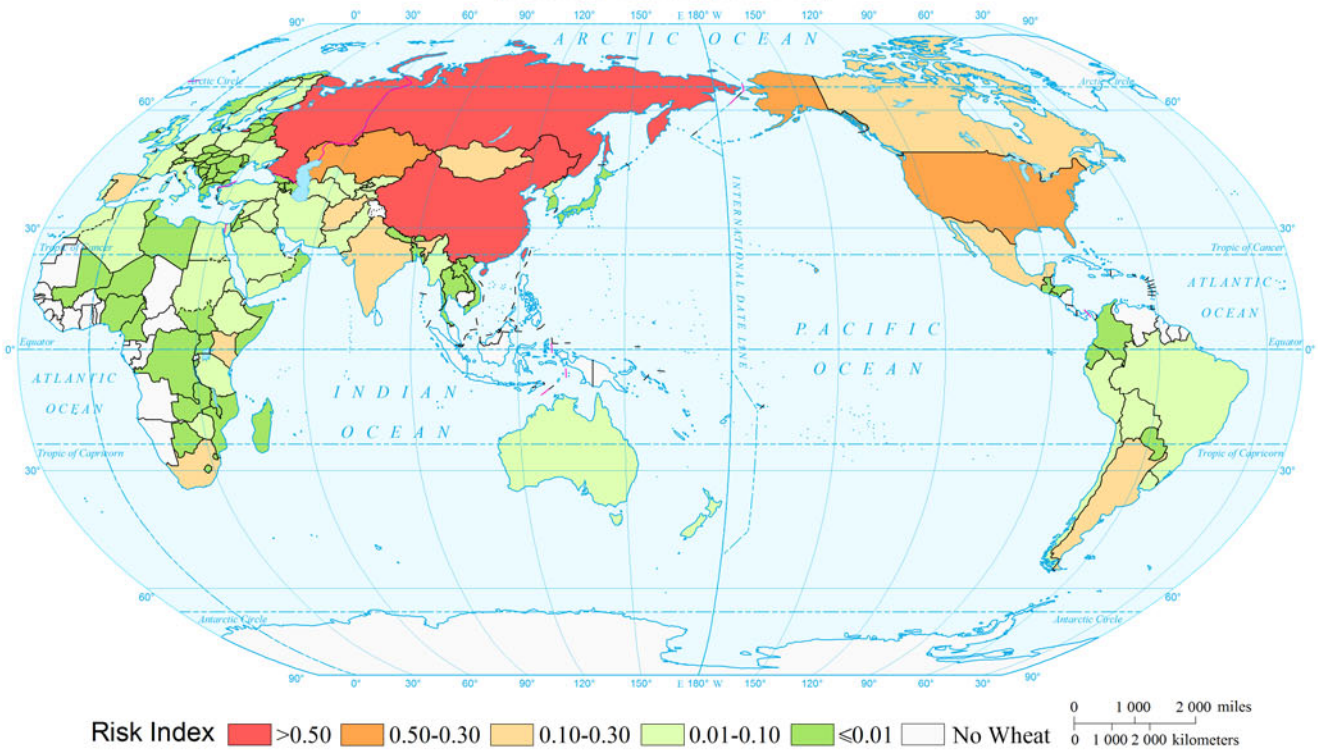
Wheat Yield Loss Risk of Drought of the World by Return Period (50a)
(Country and Region Unit)



Wheat Yield Loss Risk of Drought of the World by Return Period (100a)
(Country and Region Unit)



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