Future Changes in Extreme Heatwaves over the CORDEX-East Asia Phase 2 Domain under RCP and SSP Scenarios

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Motivation & Objective

- Due to the acceleration of global warming, an increase in extreme heat events has been observed in most regions worldwide. The death toll from heatwaves continues to rise, and the World Health Organization (WHO) has identified heatwaves as one of the most significant threats to human health in the 21st century.

- The unprecedented heatwave continues to be renewed in Asia : Not only the frequency and intensity of heatwaves increasing but also the timing of heatwaves is diversifying.

- Heatwave broadly impacts on not only the human health, but also ecosystem, societies, and economies. To effectively prepare for the heatwave damage, it is essential to understand the impact of climate change on East Asia heat waves.

- This study focuses on extreme heatwaves with high intensity and long duration.
  - To identify the vulnerable regions and periods to extreme heatwave in present-day over East Asia including the Korean peninsula, China, Japan, Mongolia, India, and Indochina
  - To project the impact of regional climate change on the spatial and temporal extent of extreme heatwave over East Asia, as the impacts of climate change will not be uniform across the globe

Data & Method

- 12 general circulation model (GCM) and regional climate model (RCM) chains participating in CORDEX-East Asia phase2

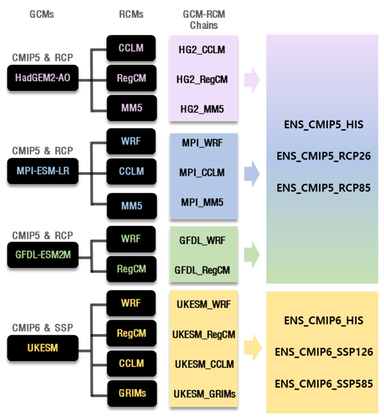


Figure 1. Twelve GCM-RCM chains.

- Domain & eight sub-domains

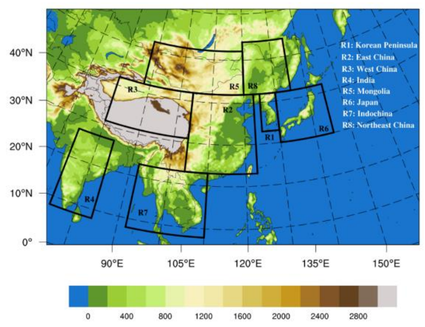


Figure 2. The CORDEX-East Asia phase 2 domain and topography (unit: m). Boxed areas indicate the eight sub-domains (R1-R8).

- Analysis Variables

  Daily maximum temperature, which is calculated as the highest value among the 3-hourly temperature data

- Bias correction: Variance Scaling

  : a method to correct the both mean and variance of the variable *(Teutschbein and Seibert, 2012)*

Variance scaling method improves the performance of the temperature simulations

Figure 3. Taylor diagrams of the 25-year (1981–2005) mean daily maximum temperature during the heatwave period in East Asia derived from ENS_ALL_HIS.

- ERA5 Reanalysis data
  - For model performance evaluation and bias correction
  - The gridded daily maximum temperature simulated by GCM-RCM chains are interpolated into ERA5 grid(0.25° x 0.25°) using simple inverse distance weighting.

- Heatwave Period: April to September

  Heatwaves occur in July and August in most regions of East Asia including the Korean Peninsula, China, Mongolia and Japan, and those occur from April to June in India, Indochina *(Piver et al., 1999; Thawillarp et al., 2015; yuan et al., 2016; Mishra et al., 2017; Thirumalai et al., 2017; Gau et al., 2018; Kumar and Mishara 2019; Rachutorn et al., 2019 ; Yeo et al., 2019).*

- Forcing Scenarios

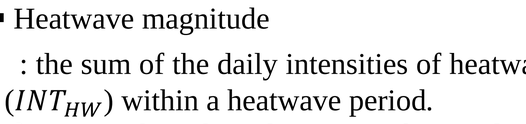
  Representative Concentration Pathway scenario were used forcing scenarios for CMIP5 GCMs

Scenario	Characteristics
RCP8.5	Greenhouse gas emission as current trend
RCP2.6	Instantaneous greenhouse gas reduction

  Shared Socioeconomic Pathway scenario were used forcing scenarios for CMIP6 GCM

Scenario	Characteristics
SSP5-8.5	Fossil-fueled development
SSP1-2.6	Sustainability

- Analysis Period



- Heatwave Threshold

  - The daily heatwave threshold is defined as the 90th percentile of daily maximum temperature (Tmax) with-in a 31-day window centered on each Julian day (i.e., 15 days before and after the day) for the reference period (1981-2010) *(Russo et al., 2015)*.

  - Heatwave is defined as a period where the Tmax is above daily heatwave threshold for three or more consecutive days.

- Heatwave intensity

$$INT_{HW} = \begin{cases} \frac{T_{max} - T_{max30y25p}}{T_{max30y75p} - T_{max30y25p}} & (T_{max} > T_{max25y25p}) \\ 0 & (T_{max} \le T_{max25y25p}) \end{cases}$$

  $Tmax$: the daily maximum temperature on day when a daytime heatwave occurs

  $Tmax_{25y25p}$ and $Tmax_{25y75p}$: the 25th and 75th percentiles, respectively, for annual maximum values from daily maximum temperatures during the reference period.

  (Russo et al., 2015)

- Heatwave magnitude

  : the sum of the daily intensities of heatwave (INT_{HW}) within a heatwave period.
  → HWM has the advantage of considering both the daily intensity and duration of heatwave *(Russo et al., 2015).*

- Extreme Heatwave

  Extreme heatwave with high intensity and long duration (HWM95p heatwave) is defined as a heatwave in which HWM is higher than the 95th percentile of the HWM for the reference period.

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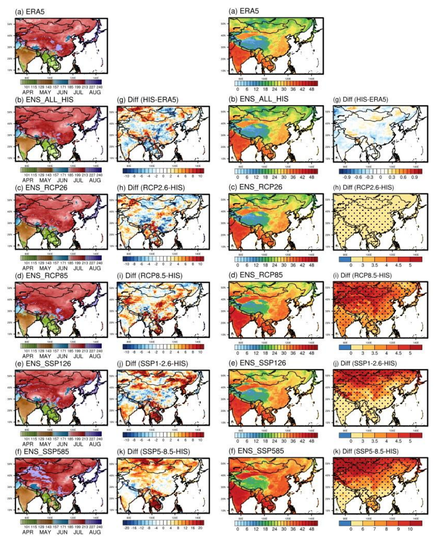
Reference) Kim et al. (2023) Future changes in extreme heatwaves in terms of intensity and duration over the CORDEX-East Asia Phase Two domain using multi-GCM and multi RCM chains, Environmental Research Letters, 18, 034007.

Results

- Evaluation of present-day simulated Tmax and Future changes in Tmax

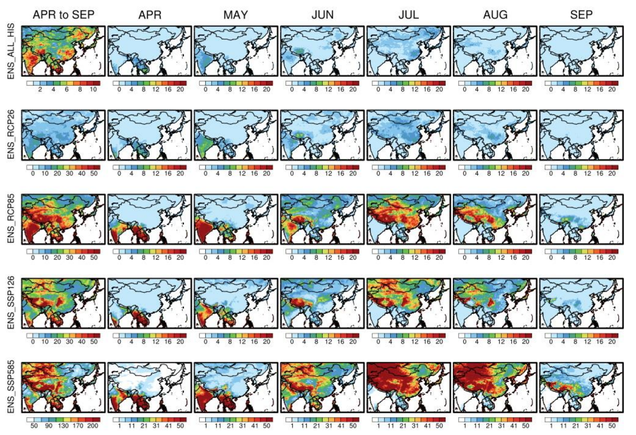


- The Julian-day when the Tmax is the highest in July or August in the Korean Peninsula, China, Mongolia, and Japan, and it is the highest in April or May in India and Indochina.
- Tmax is relatively high in India and Indochina and low in West China where the Tibetan Plateau is located.
- In all scenarios, Tmax increases over the whole of East Asia, particularly in the high-latitude regions than in India and Indochina, which already experience extreme temperatures in Historical Simulation

Figure 4. Spatial distributions of the Julian days with the highest five-day moving average daily maximum temperature (5D_Tmax) derived from (a) ERA5, (b) ENS_ALL_HIS, (c) ENS_RCP26, (d) ENS_RCP85, (e) ENS_SSP126 and (f) ENS_SSP585.

Figure 5. Spatial distributions of average daily maximum temperatures for a total of 61 days, before and after 30 days from the Julian day with the highest 5 days moving average daily maximum temperature derived from (a) ERA5, (b) ENS_ALL_HIS, (c) ENS_RCP26, (d) ENS_ RCP85, (e) ENS_SSP126, and (f) ENS_SSP585.

- Future Changes in Heatwave Intensity



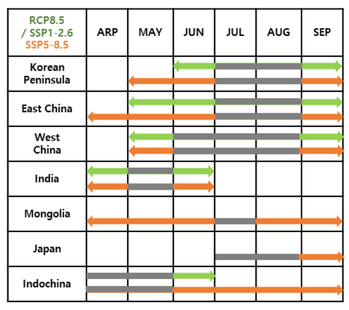
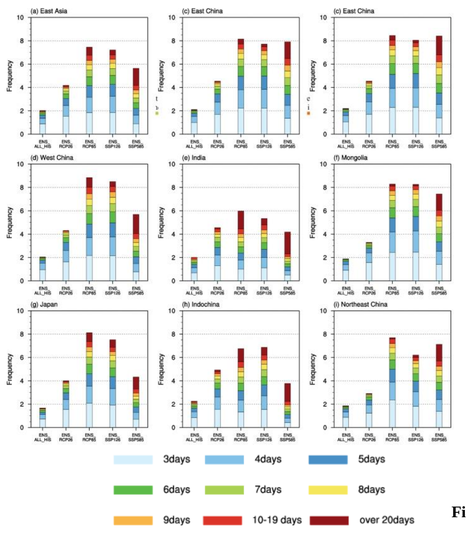


Figure 6. Spatial distributions of the monthly accumulated daily intensity of heatwaves during the heatwave period derived from ENS_RCP26, ENS_RCP85, ENS_SSP126 and ENS_SSP585.

- Intensity is relatively high in some parts of China, India, and Indochina
- Intensity is the highest in July or August in the Korean Peninsula, China, Mongolia, and Japan, and it is the highest in April or May in India and Indochina.
- The regional and temporal differences in the intensity will become larger
- Intensity increases even when heatwaves do not occur in present-day

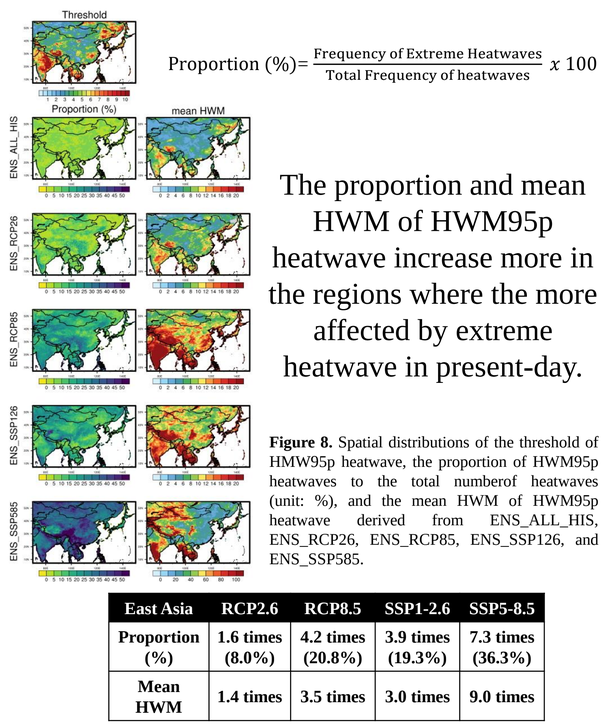
- Future Changes in Heatwave Duration



- RCP2.6 scenario: Most heatwaves last three or four days
- RCP8.5 and SSP1-2.6 scenarios
  - In most regions: : Most heatwaves last three or four days
  - India & Indochina: HWF>10days = HWF3days, HWF4days
- SSP5-8.5 scenario: Heatwaves last more than 10 days frequently occur
- Heatwaves lasting more than 20 days, which do not occur everywhere in East Asia in Historical simulation, occur
  - RCP2.6: India and Indochina
  - RCP8.5, SSP1-2.6, SSP5-8.5: all East Asia
- Long-lasting heatwaves will occur more often
- Averaged duration of heatwaves in East Asia will be 2-3 weeks

Figure 7. Climatology of heatwave frequency at various durations over eight sub-domain (unit: events).

- Future Changes in Extreme Heatwave



$$\text{Proportion (\%)} = \frac{\text{Frequency of Extreme Heatwaves}}{\text{Total Frequency of heatwaves}} \times 100$$

The proportion and mean HWM of HWM95p heatwave increase more in the regions where the more affected by extreme heatwave in present-day.

Figure 8. Spatial distributions of the threshold of HMW95p heatwave, the proportion of HWM95p heatwaves to the total numberof heatwaves (unit: %), and the mean HWM of HWM95p heatwave derived from ENS_ALL_HIS, ENS_RCP26, ENS_RCP85, ENS_SSP126, and ENS_SSP585.

East Asia	RCP2.6	RCP8.5	SSP1-2.6	SSP5-8.5
Proportion (%)	**1.6 times (8.0%)**	**4.2 times (20.8%)**	**3.9 times (19.3%)**	**7.3 times (36.3%)**
Mean HWM	**1.4 times**	**3.5 times**	**3.0 times**	**9.0 times**

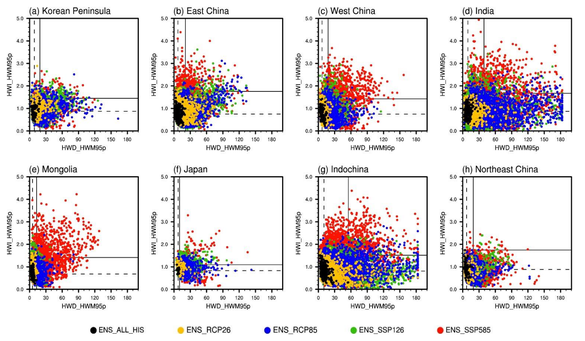
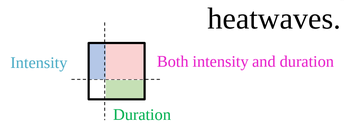


Figure 9. Scatter plots for HWM95p heatwave duration (HWD_HWM95p) and the average of daily intensity of heatwave within a HWM95p heatwave period (HWI_HWM95p) over eight sub-domains.

The main reason for the increase in the HWM of extreme heatwaves is the increased duration rather than the daily intensity of the heatwaves.



Maximum HWI_HWM95p or HWD_HWM95p in Historical
Averaged HWI_HWM95p or HWD_HWM95p in Historical
* HWD_HWM95p: HWM95p heatwave duration
* HWI_HWM95p: Averaged daily intensity within the HWM95p heatwave period

Summary

If the current greenhouse gas emissions continue, East Asia will experience unprecedented heat stress, as the spatial and temporal extent of Extreme heatwave, which rarely occur during present-day, will be expanded over all regions by the end of the 21st century. The temporal and regional disparities of heatwave damage will be much more prominent, as extreme heatwaves become stronger and more frequent in the regions and during the periods that are more affected by heatwaves in the present-day.