Assessing the Risk of Heat-stressed Mortality due to Global Warming Using Multi-GCM Approach

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Introduction

- **Warming impact on heat-stressed mortality**
  - Climate change and variability will bring the higher death probability of heat-stressed mortality
  - V-shape relation with daily $T_{\text{max}}$ and mortality rate

- **Heat-stressed impact assessment using Multi-GCMs**
  - Representing the level of confidence in impact caused by GCM predictions
  - Finding the responses of impact to climate change and variability
  - Finding the risk probabilities with different future
  - Finding the threshold temperature for assessing adaptation capacity
Daily $T_{\text{max}}$ vs. Heat Mortality (1)

- “V”-shaped relation between daily $T_{\text{max}}$ and Mortality (Honda et al. 1998, 2006)
- Using daily mortality data of 47 prefectures in Japan during 1972-1995
Daily $T_{\text{max}}$ vs. Heat Mortality (2)

- OT in East Asian countries (the 85th percentile of daily $T_{\text{max}}$ as OT)
- Define relative excess mortality using 30-yr (1971-2000) daily $T_{\text{max}}$ for base period

![Graph showing Estimation of OT from daily $T_{\text{max}}$](image)

<table>
<thead>
<tr>
<th>Country</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>C</td>
</tr>
<tr>
<td>Korea</td>
<td>K</td>
</tr>
<tr>
<td>Taiwan</td>
<td>T</td>
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<tr>
<td>Japan</td>
<td>J</td>
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C: China  
K: Korea  
T: Taiwan  
J: Japan

Relative excess mortality

- Average mortality during the period
- Daily mortality at OT

Mortality rate (deaths/day)

Daily maximum temperature, $T_{\text{max}}$
Daily $T_{\text{max}}$ vs. Heat Mortality (3)

- Defining excess mortality, (Takahashi et al., 2007):

$$\text{Den}_{\text{ADNE}}_{\text{grid}, y} = \text{Den}_{\text{PN}}_{\text{grid}} \times \text{Rel}_{\text{ADNE}}_{\text{ADNO}}_{\text{grid}, y} \times \text{Rel}_{\text{ADNO}}_{\text{ADN}}_{\text{base}} \times \text{ADR}_{\text{cnt}}$$

$$= (a_1 \times N_1 + a_2 \times N_2) / 365$$

$$\left[ \frac{\text{deathpop}}{\text{km}^2 \cdot \text{yr}} \right] = \left[ \frac{\text{persons}}{\text{km}^2} \right] \times \left[ \frac{\text{deathpop}}{\text{yr}} \right]_{\text{ADNE}} \times \left[ \frac{\text{deathpop}}{\text{day}} \right]_{\text{DDNO}} \times \left[ \frac{\text{deathpop}}{\text{pop} \cdot \text{day}} \right]_{\text{ANL}_{\text{base}}}$$

$$\times \left[ \frac{365 \text{day}}{\text{yr}} \right]$$

**DenPN:** Population density
**RelADNEADNO:** Relative excess mortality
**DDNO:** Daily mortality at TO
**ADNE:** Annual sum of daily excess mortality, DDNE
**RelADNOADN:** Ratio of mortality at TO to the annual average mortality of Japan

**OPT**$_{\text{base}}$: Daily mortality at TO in Japan

**ADR:** Annual average mortality of the country

**N1:** Annual number of days on which $T_{\text{max}} > TO$ and $T_{\text{max}} < TO + 5 \, ^{\circ}\text{C}$

**N2:** Annual number of days on which $T_{\text{max}} > TO + 5 \, ^{\circ}\text{C}$
Extreme CC Effect on Mortality

- Changes in distribution?
  \[ \mu^{o.f} = \mu^{m.f} + (\mu^{o.p} - \mu^{m.p}) \]
  \[ \sigma^{o.f} = \sigma^{m.f} \frac{\sigma^{o.p}}{\sigma^{m.p}} \]
  o: observation, m: model, f: future, p: present

- Bias correction:
  - Statistical method (Piani et al. 2009)
  - Quintile mapping (Wood et al. 2004)
  - Morphing (Belcher et al., 2005)
  - Rank matching, histogram equalization, daily scaling, delta method, relative ratio etc.
AR4 Climate Projections

- Downscaling of monthly $T_{\text{max}}$ with Morphing method
  - ‘shift’ ($\mu$ change) and ‘stretch’ ($\sigma$ change) of monthly CMIP3
  - c: 1980s(1971-2000): Monthly CRU (0.5) + Daily ECMWF ERA40 (1.0)
  - f: 2080s(2071-2100), [2020s (2011-2040), 2050s(2041-2070)]

$$T_f(d) = \bar{T}_o(m) + (\bar{T}_f(m) - \bar{T}_c(m)) + \frac{\sigma_f}{\sigma_c} \cdot [T_o(d) - \bar{T}_o(m)]$$

<table>
<thead>
<tr>
<th>GCM</th>
<th>Originating group(s)</th>
<th>Model name</th>
<th>Scenario</th>
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<tbody>
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<td>BCC-CM1</td>
<td>A1B (20 GCMs)</td>
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<td>BCCR-BCM2.0</td>
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<td>Me’ te’ orologiques</td>
<td>CNRM-CM3</td>
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<td>FGOALS-g1.0</td>
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<td>Institut Pierre Simon Laplace</td>
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<td>IPSL-CM4</td>
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Research Framework

Observation Data
- Monthly CRU 0.5°
- Daily ECMWF-R40 1.0°

Multi-GCMs
- CMIP3 Monthly/Daily with more than 2-3° res.
- Current-20C3M
- Future-A1B, A2, B1

Bias Correction/Downscaling
- higher spatial res.
- Monthly to Daily

Bias Corrected Climate Inputs
- with GCM skill score for non-equal weighted impact

Probabilistic representation of HIP and Risk
- for years 2020s, 2050s, 2080s

Heat Impact (HIP) Assessment
- Impact of equally weighted GCMs’ impact

Model Construction
- Daily mortality data for the 47 prefecture of Japan (DDN<sub>pref,y,d</sub>)
- Daily maximum temperature data for the 47 prefecture of Japan (T<sub>max</sub><sub>pref,y,d</sub>)
- Formula to estimate optimal temperature, relative excess mortality, and density of excess mortality due to heat stress
- Number of days on which Tmax is higher than TO (N<sub>1grid,y</sub>, N<sub>2grid,y</sub>)
- Relative excess mortality due to heat stress (RelADNEADNO<sub>grid,y</sub>)
- Density of excess mortality due to heat stress (DenADNE<sub>grid,y</sub>)
- Excess mortality due to heat stress by country

Climate DB Preparation
- Observed monthly climate data set (ObsMT<sub>grid,y,m</sub>)
- Observed daily climate data set (ObsT<sub>max</sub><sub>grid,y,d</sub>)
- Monthly climate model output (ModT<sub>max</sub><sub>grid,y,m</sub>)
- Present and future daily maximum temperature (T<sub>max</sub><sub>grid,y,d</sub>)
- Annual average mortality rate by country (ADR<sub>cnt</sub>)
- Population density (DenPN<sub>grid</sub>)
- Administration boundaries

Resolution of spatial data: 1.125°, 0.5°, 2.5°
Optimal Temperature

(85th $T_{\text{max}}$ during 1971-2000)

(°C)
Excess mortality density due to heat stress in the existing condition (upper) and the future (lower)

Current (1971-2000)

Ensemble mean of SRES-A2
17 GCMs (2071-2100)

(deaths/km²)
Rate of change of excess mortality due to heat stress (SRES-A2, 2071-2100)

Changes in ensemble mean of SRES-A2 17 GCMs

-100 0 200 400 600 800 (%)
Ensemble mean and normalized dispersion
(Mean and Coefficient of variation, CV)

Changes in annual mean daily maximum temperature and excess mortality years from the existing condition (1971-2000) to the future (2071-2100) using the SRES A2 scenario (17 GCMs)
Future Consideration

- Assessing the extreme effect of temperature on impact
  - Comparison of BCDS methods to produce the daily extremes of Tmax
  - Comparison of AR4-GCMs mean and variability effects on mortality

- Defining the impact responses with GCM uncertainties
  - Uncertainty of GCM projections (AR4) and scenarios (SRES A1b A2, B2)
  - Defining skill of GCMs and scoring for impact with changes in mean and variation of Temperature.
  - Transfer GCM uncertainty to impact and Skill scoring

- Defining the risk by using the probabilistic distribution of impact
  - Developing the impact response function with uncertainty
  - Defining the adaptability (risk threshold) based on OT
  - Producing the impact probability and assessing the risk