Building scale Heat-stress and health impact assessment by land cover based on BioCAS-PT

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1 Abstract

Heat stress is evaluated not only by temperature but also by humidity, solar irradiation, and individual activity. In this study, we simulated the temperature (TA) and the mean radiant temperature (Tmrt) of 10 m spatial resolution considering the topography, land use, height of buildings and vegetation using BioCAS. These data were combined with the heat budget model of the human body to calculate the perceived temperature (PT). Then, the thermal environment of the residential area and the forest area by the administrative district was compared. In addition, we analyzed the rate of excess mortality according to the intensity and duration of the heat-wave using the event-based vulnerability analysis method (Scherer et al. 1999).

The RMSE for TA and PT were 1.44°C and 1.58°C during the heat-wave days in 2016. The maximum differences of the reference station from the each district mean were 1.0°C (TA) and -4.1°C (PT). On the other hand, the maximum difference of TA by land cover was smaller than PT. The maximum difference of PT for the forest in each district was up to -6.3°C. This shows that PT is more sensitive to the effects of building and forest. The areas where the maximum excess mortality rate occurred were analyzed as regions 1 & 3 using the TA and as region 6 using the PT. That is, the PT determined that paved road and barren ground are more vulnerable to heat-wave than densely built-up areas. (Location of regions; see section 4)

2 BioCAS-PT Forecasting System

- Simulation of Temperature at high resolution (10 m)
  - Climate impact Assessment System (CAS)
    - The main concept is that the total air temp. deviation is the combination of Meso-scale temp. Dev. (MD) and Local-scale temp. Dev. (LD), which are estimated by urban climate model (500m) and Geo-empirical model (10m), respectively.

- Calculation of the maximum temperature for heatwave days
  - Using the averaged TD for heat-wave days(TD) and TA at reference station (Seoul, #108), we can get T_max(8)

- Simulation of Perceived Temperature at high resolution (10 m)
  - DTM, DSM, LC, Meso-scale TA
  - RH, WS, (SR for SWG) at ref. station (#108)

- Heat-wave event analysis (2000-2016)

3 Event-based heat-stress risk model

- Excess Mortality Rate (EMR) model (using Scherer(1999)'s method)
  - STEP 1. Input data
    - Daily PT_max (°C) & Daily mortality rate (p, daily mortality / annual population * 10^6)
  - STEP 2. Determination of the heat-wave event
    - Heat-wave event: Days with PT_max above PT_base at least 3 consecutive days
      - Threshold (PT_base): 15 ~ 44°C, 1°C interval
    - Maximum number of lag day (L_max): 0 ~ 14 days. L_max is two-times of event duration
  - STEP 3. Magnitude of each heat-wave event
    - Magnitude(M_t): Accumulated PT_max during the heat-wave events
      - Regression analysis and T-test for M_t with PT_base by each event
      - Regression analysis and T-test for M_t with PT_base by each event
      - PT_base calculated using Scherer(1999)’s method
  - STEP 4. Determination of the optimal threshold and lag day
    - Calculating the mean total mortality rate (p_max) of each event
      - PT_base = log(M_t) + 10/100
      - Regression analysis and T-test for M_t with PT_base by each threshold and lag-day
      - PT_base = log(M_t) + 10/100
  - STEP 5. Defining the increasing rate of excess mortality(I_REM, %), i.e. heat-stress risk
    - I_REM = increasing rate of excess mortality(p_max) from the base mortality(p_b)

4 Heat-stress and Health impact assessment

- Climatic maximum range of variables in Seoul (1983-2018)
  - Forecast skill test of BioCAS (2016)
    - RMSE of BioCAS-TA_max: 1.44°C (Janicke, 2017)
    - RMSE of BioCAS-PT_base: 1.58°C
  - Estimation of the # of total deaths (1991-2016)
    - Total deaths = (p_b + p_max) * 10^6 / population * D

- Verification of the estimated total deaths
  - Hazard (TA, PT)
    - Risk (I REM)

- Thermal hazard & risk by land cover
  - Hazard (TA, PT)
    - Heat-wave & event analysis

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Assessment of heat stress related mortality in major Korean cities

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INTRODUCTION

- Intense heat waves cause increase in mortality and morbidity due to local climate conditions in urban areas.
- Heat stress can be generated as the human body attempts to retain normal temperature through sweating under heat exposure (Parsons, 2003).
- However, the vulnerability appears differently between populations, depending on climate, culture, infrastructure (housing), age structure, and other factors (Korevaar and Hajat, 2008).
- Therefore, it is necessary to regionally assess the heat-related impact such as mortality in order to issue heat warnings effectively.
- To investigate relative risk by heat-stress, this study quantifies heat-related mortality in 6 major cities using daily maximum Perceived Temperature (PTmax) in South Korea.
- Moreover, results of PTmax are compared with results of daily maximum temperature (TXmax), which is the thermal index currently used in severe weather warning system of Korea Meteorological Administration (KMA), and are applied to impact-based forecasts, which consider hazard and vulnerability as well.

DATA & METHODS

- The PT considered not only air temperature, humidity, wind speed but also long and shortwave radiation, and human-related factors such as activity (Meier, 2007) and clothing (0.5 clo, summer) (Jendritzky et al., 2000; Staiger et al., 2012).
- This study assume that heat stress is one of the major processes leading to excess deaths by heat wave (Scherer et al., 2014).

Event-based analysis (Scherer et al., 2014)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat-stress event (C8)</td>
<td>Consecutive days (N8 days) which PTmax or TXmax exceeds a certain threshold temperature (T90, 29°C〜50°C)</td>
</tr>
<tr>
<td>Magnitude of heat-stress events (M9)</td>
<td>M9 = Σ_k=1^n(Tmax(k)−T90) / accumulated daily intensities = -The common log (log(M9, +1)) was used to D(0) and D(1) means lengths and start day of heat events, respectively.</td>
</tr>
<tr>
<td>Mean total mortality rate of each event (p9(r)), 18/day</td>
<td>p9(r) = D(0) / D(1)</td>
</tr>
<tr>
<td>T90 and L90 (based on p9(r) and p9(r)-value of a two-sided t-test)</td>
<td>T90 = β0 + log(M9) and L90 = β1 + log(M9)</td>
</tr>
<tr>
<td>Excess mortality rate (PM9)</td>
<td>PM9 = β0 + log(M9) + c1, where c1 is a base mortality rate which is intercept ct(10^0.25) rate of increase in excess mortality</td>
</tr>
</tbody>
</table>

RESULTS

Assessment of heat stress related mortality in major Korean cities

Verification of excess mortality model (2000-2016)

- Observed total deaths: The event-based total deaths from Korean Statistical Information Service
- Simulated total deaths: excess mortality rate (PM9) → excess deaths → total deaths

<table>
<thead>
<tr>
<th>Study area</th>
<th>Seoul</th>
<th>Incheon</th>
<th>Daegu</th>
<th>Daejeon</th>
<th>Gwangju</th>
<th>Busan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (°C)</td>
<td>29.3</td>
<td>26.7</td>
<td>26.1</td>
<td>24.6</td>
<td>24.4</td>
<td>21.6</td>
</tr>
<tr>
<td>TXmax (°C)</td>
<td>33.1</td>
<td>27.5</td>
<td>26.4</td>
<td>24.2</td>
<td>24.0</td>
<td>21.8</td>
</tr>
<tr>
<td>PM9 (°C)</td>
<td>6.6</td>
<td>5.3</td>
<td>4.8</td>
<td>4.3</td>
<td>3.9</td>
<td>3.3</td>
</tr>
</tbody>
</table>

Daily variability: PT > Ta

- Peak time of PT shows at different hours by city. The annual excess mortality is high in Daegu, which has high intensity and c1.

SUMMARY

- The T90p and c1 by city differ depending on climate and age structure of the city. These results affect different annual and monthly excess mortality rates by c1.

Test bed of impact-based forecasts in NIMS

- The excess mortality rate is proportional to the heat intensity and rate of increase in excess mortality by city. The annual excess mortality is high in Daegu, which has high intensity and c1.

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