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# 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).

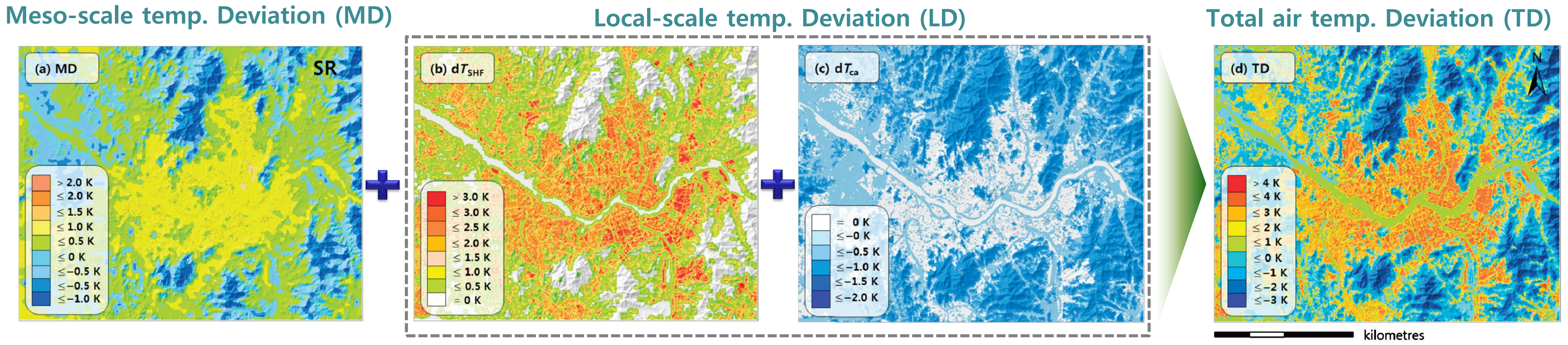
The RMSE for TA and PT were 1.44°C and 1.58°C during the heat-wave days in 2016. The maximum differences of the reference station from the each district mean were 1.0°C (TA) and -4.1°C (PT). On the other hand, the maximum difference of TA by land cover was smaller than PT. The maximum difference of PT 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 & ⑤ 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.

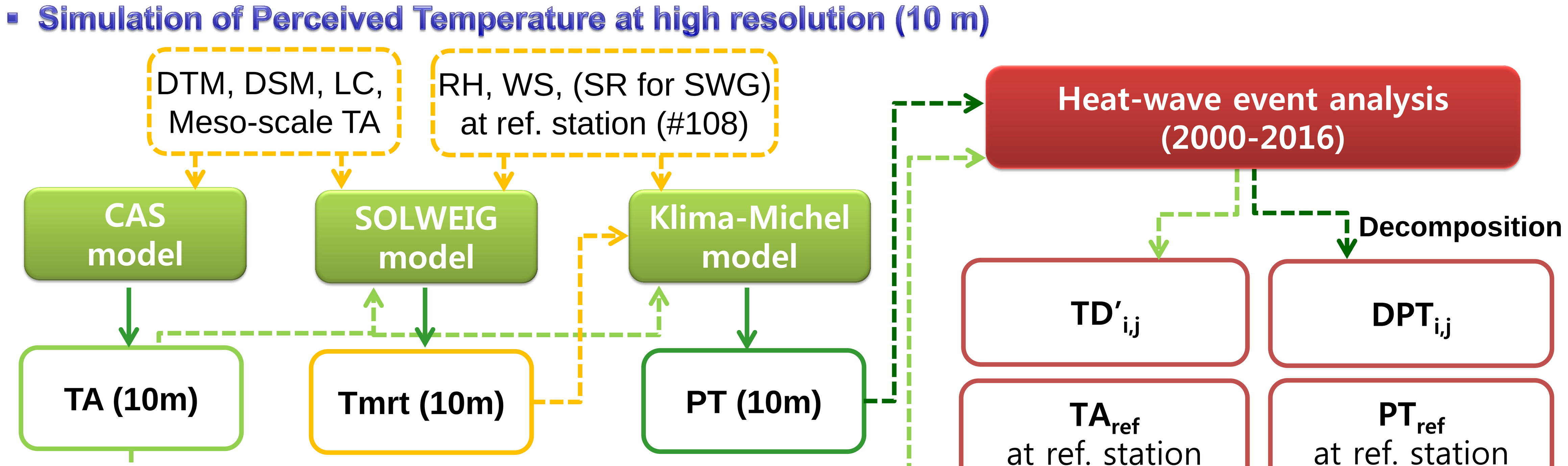



✓ **Calculating the maximum temperature for heat-wave days**

- Using the averaged TD for heat-wave days(TD') and TA at reference station (Seoul, #108), we can get $T_{max}$

$$T_{max,ij} = T_{max,ref} + TD'_{ij} + \varepsilon$$

▪ **Simulation of Perceived Temperature at high resolution (10 m)**




▪ **Forecast of maximum TA & PT for heat-wave days**

✓ **Estimation of the $TA_{ref}$, $PT_{ref}$ from the KMA's operational NWP output and combination with TD' and DPT**

- **TA** at Seoul station based on MOS (Model Output Statistics)
- **Bias-corrected PT** at Seoul station using **LENS** (Limited-area ENSemble prediction system) and **M. Belorid's scheme**

(* Visit to a poster of 'Development of impact-based forecasting system for heat waves in Korea integrated with LENS')

## 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 mean population * $10^6$)

❑ **STEP 2. Determination of the heat-wave event**

- **Heat-wave event** : Days with $PT_{max}$ **above $PT_{th}$ at least 3 consecutive days**
- **Threshold ($PT_{th}$)** : 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**($M_{evt}$) : Accumulated $PT_{max}$ during the heat-wave events

$$M_{evt_i} = \sum_{k=d_i}^{d_i+D_i-1}(T_{max}(k) - T_{th})$$

❑ **STEP 4. Determination of the optimal threshold and lag days**

- Calculating the **mean total mortality rate ($\bar{p}_{evt}$)** of each event

$$\bar{p}_{evt_i} = \frac{1}{D_i+Li}\sum_{k=d_i}^{d_i+D_i+Li-1}(p)$$

- Regression analysis and T-test for $M_{evt}$ and $\bar{p}_{evt}$ by each threshold and lag-day

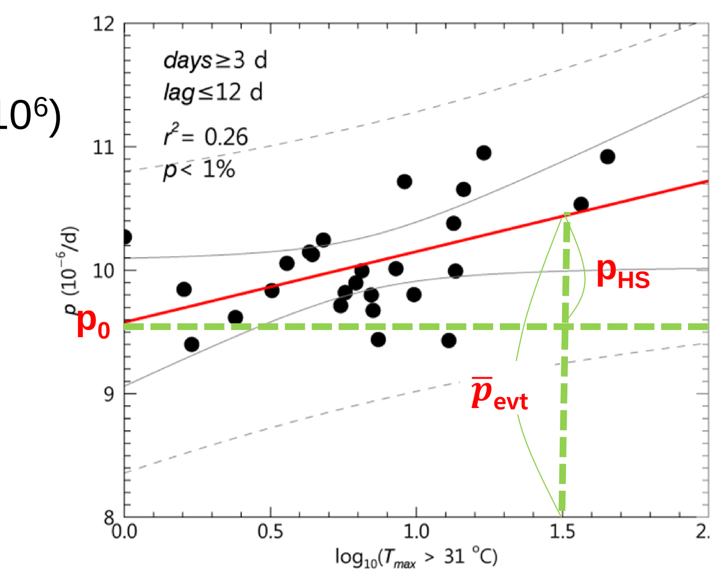
$$\bar{p}_{evt_i} = log_{10}(M_{evt_i}+1) \times c + p_0 \,, \quad (\, \bar{p}_{evt_i} = p_{HS} + p_0 \,)$$

❑ **STEP 5. Defining the increasing rate of excess mortality(I_REM, %), i.e. heat-stress risk**

- **I_REM** : Increasing rate of excess mortality ($p_{HS}$) from the base mortality ($p_0$)

$$I\_REM = p_{HS}/p_0 \times 100$$

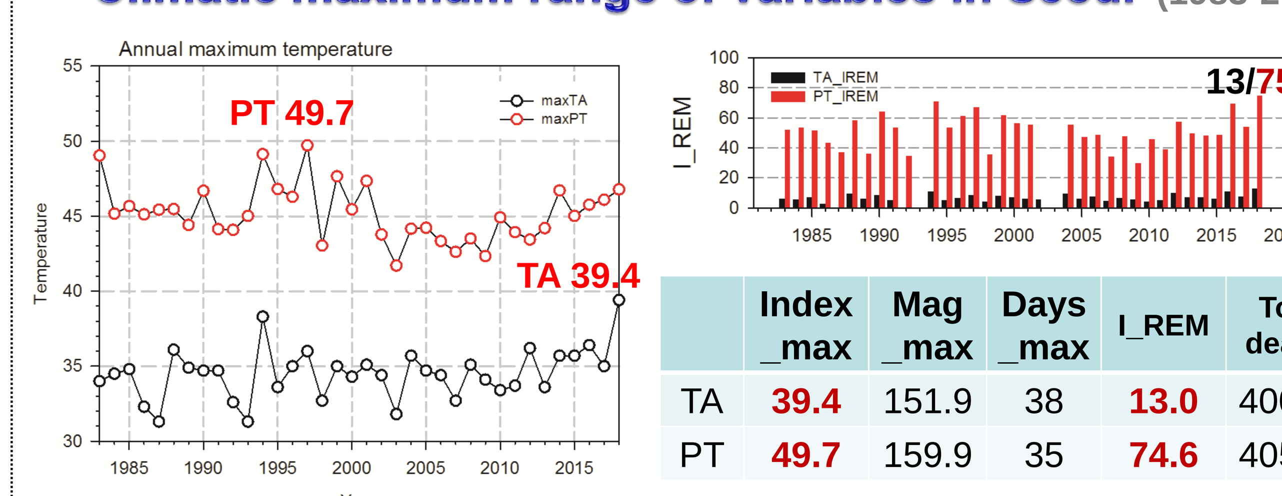
Regression analysis for $M_{evt}$ & $\bar{p}_{evt}$




| | Threshold ($T_{th}$) | Base mortality ($p_0$) | Gradient of $\bar{p}_{evt}$ (c) |
|---|---|---|---|
| OBS_TA_REM Jänicke (2017) | 31 | 9.58 | 0.57 |
| OBS_PT_REM Kang (2018) | 39 | 6.83 | 2.31 |

## 4 Heat-stress and Health impact assessment

▪ **Climatic maximum range of variables in Seoul** (1983-2018)




| | Index_max | Mag_max | Days_max | I_REM | Total deaths |
|---|---|---|---|---|---|
| TA | 39.4 | 151.9 | 38 | 13.0 | 4000.2 |
| PT | 49.7 | 159.9 | 35 | 74.6 | 4059.4 |

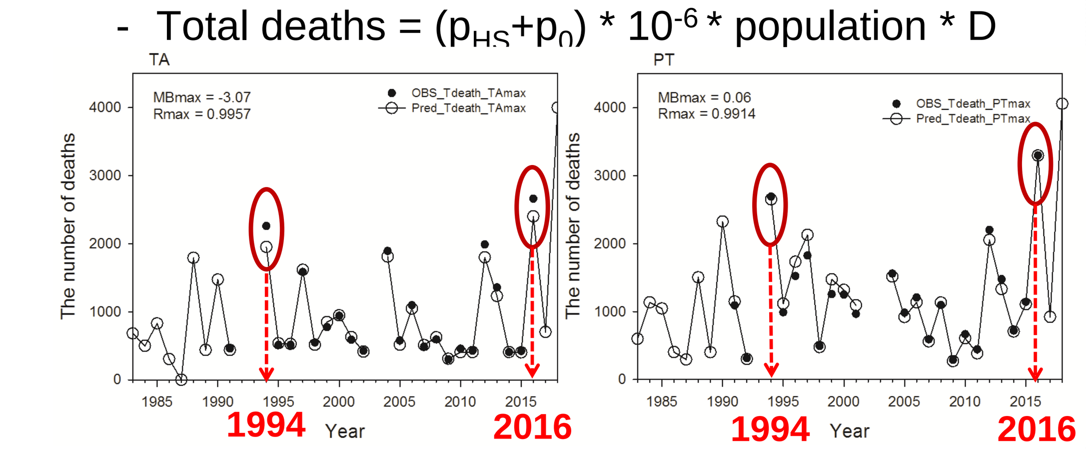
▪ **Verification of the estimated total deaths**

✓ **Forecast skill test of BioCAS (2016)**

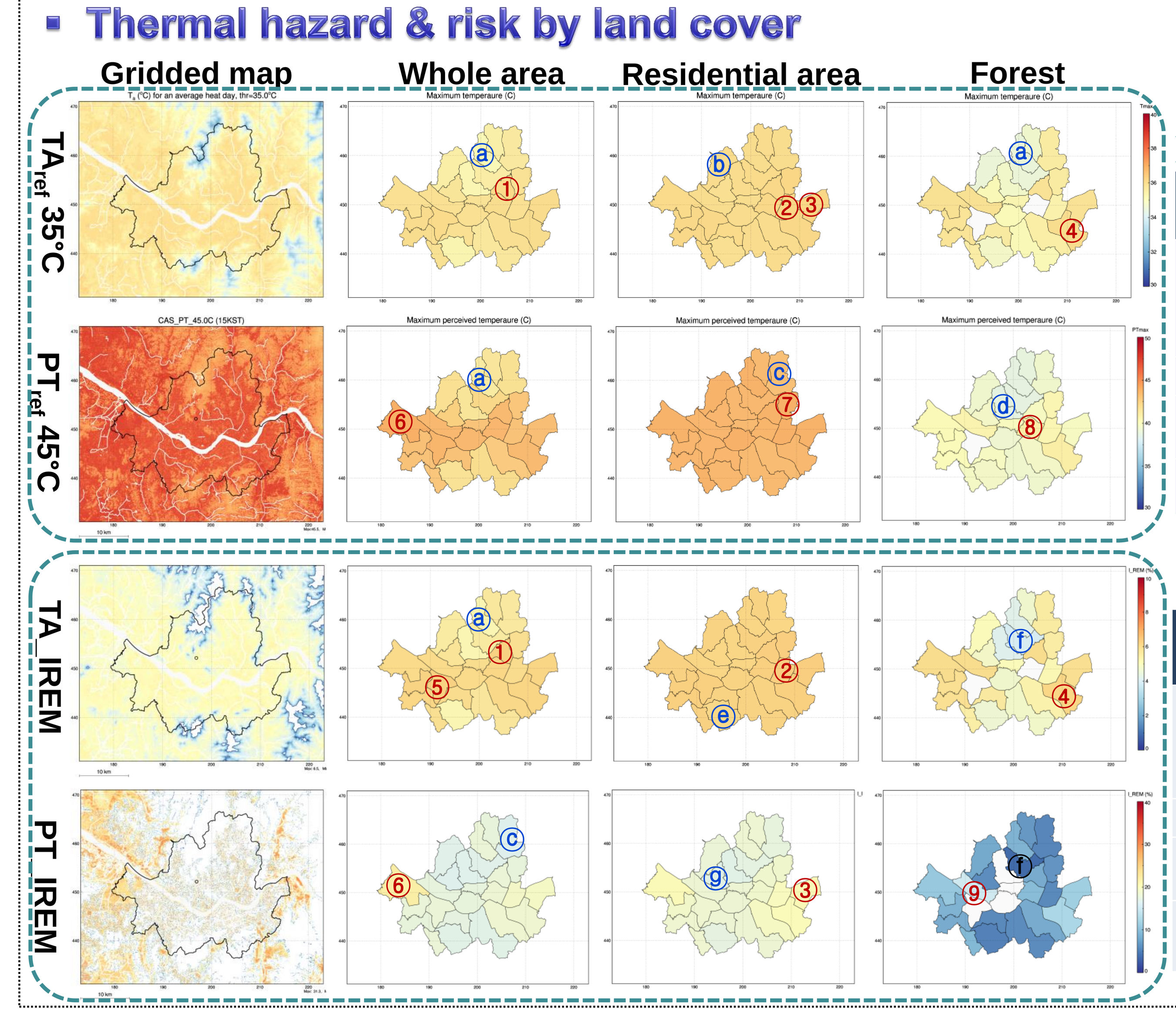
- RMSE of BioCAS-$TA_{max}$ : 1.44°C (Janicke, 2017)
- RMSE of BioCAS-$PT_{max}$ : 1.58°C

✓ **Estimation of the # of total deaths (1991-2016)**

- Total deaths = ($p_{HS}$+$p_0$) * $10^{-6}$ * population * D




▪ **Thermal hazard & risk by land cover**




➤ Hazard (TA, PT)

| TA | Whole | Resid. | Fores. |
|---|---|---|---|
| Range ($Ta_{dis.}$ - $TA_{ref}$) | +0.1 ~ **+1.0** | +0.9 ~ **+1.1** | -0.5 ~ +0.9 |
| Diff. | 0.9 | 0.2 | 1.42 |
| Max | ①동대문구 | ②광진구 /③강동구 | ④송파구 |
| Min | ⓐ강북구 | ⓑ은평구 | ⓐ강북구 |

| PT | Whole | Resid. | Fores. |
|---|---|---|---|
| Range ($PT_{dis.}$ - $PT_{ref}$) | **-4.1** ~ -2.1 | -1.9 ~ -1.3 | **-6.3** ~ -4.2 |
| Diff. | 2.84 | 0.64 | 2.1 |
| Max | ⑥강서구 | ⑦중랑구 | ⑧성동구 |
| Min | ⓐ강북구 | ⓒ노원구 | ⓓ종로구 |

➤ Risk (I_REM)

| TA_IREM | Whole | Resid. | Fores. |
|---|---|---|---|
| Range ($TA_{dis.}$ - $TA_{ref}$) | +0.6 ~ +1.6 | +1.5 ~ +1.7 | -0.6 ~ +1.5 |
| Diff | 1.0 | 0.2 | 2.1 |
| Max | ①동대문/ ⑤영등포구 | ②광진구 | ④송파구 |
| Min | ⓐ강북구 | ⓔ관악구 | ⓕ성북구 |

| PT_IREM | Whole | Resid. | Fores. |
|---|---|---|---|
| Range ($PT_{dis.}$ - $PT_{ref}$) | -9.7 ~ -4.7 | -9.2 ~ -5.9 | -22.8 ~ -11.0 |
| Diff | 5.1 | 3.3 | 11.8 |
| Max | ⑥강서구 | ③강동구 | ⑨마포구 |
| Min | ⓒ노원구 | ⓖ서대문구 | ⓕ성북구 |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# Assessment of heat stress related mortality in major Korean cities


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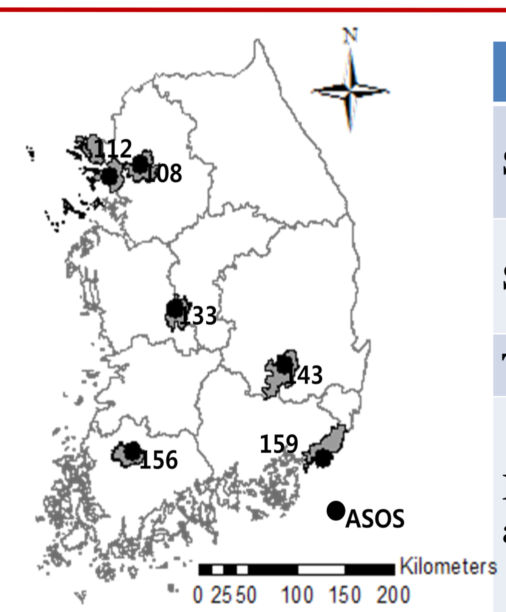
## INTRODUCTION

- 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 (Kovats 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 ($PT_{max}$) in South Korea.
- Moreover, results of $PT_{max}$ are compared with results of daily maximum temperature ($Ta_{max}$), 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




| | Definition |
|---|---|
| Study area | Seoul (#108), Incheon (#112), Daejeon(#133), Daegu (#143), Gwangju (#156), Busan (#159) |
| Study period | 1 Jan. 2000 ~ 31 Dec. 2016 (over a 17 year period) |
| Thermal indices | $PT_{max}$ and $Ta_{max}$ |
| Mortality (all-cause) and population data | Mortality rate ($p$, $10^{-6}$/day) $= \frac{daily\ mortality}{annual\ population} \times 10^6$ (Korean Statistical Information Service) |

※ The **PT** considers not only air temperature, humidity, wind speed but also long and shortwave radiation, and human-related factors such as activity (M=135 W m⁻², $v_w$=4 km h⁻¹) and clothing (0.5 clo, summer) (Jendritzky et al., 2000; Staiger et al., 2012).

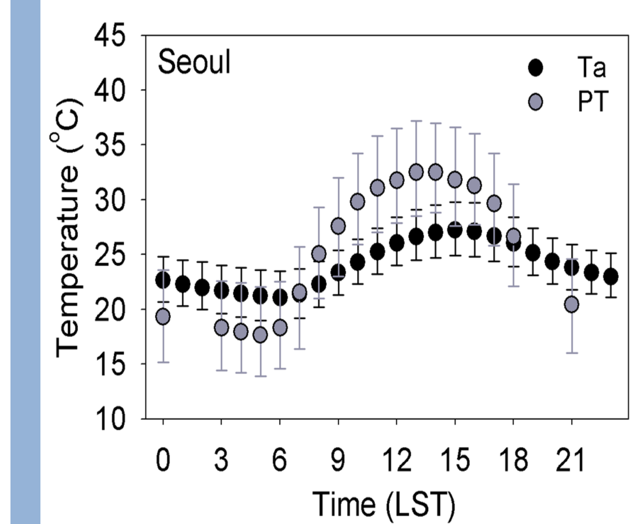
※ This study assume that heat stress is one of the major processes leading to excess deaths by heat wave (Scherer et al., 2014).

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

| | Variable | Definition |
|---|---|---|
| Step 1 | Heat-stress event (*evt*) | consecutive days (N≥3days) which $PT_{max}$ or $Ta_{max}$ exceeds a certain threshold temperature ($T_{th}$, 21℃~50℃) |
| | Magnitude of heat-stress events (***$M_{evt}$***) | $m_{evt_i} = \sum_{k=d_i}^{d_i+D_i-1}(T_{max}(k) - T_{th})$ → cumulated daily intensities → The common logarithm ($\log(M_{evt_i}+1)$) was used. → $D_i$ and $d_i$ means lengths and start day of heat events, respectively. |
| Step 2 | The mean total mortality rate of each event (**$\bar{p}(evt_i)$, $10^{-6}$/day**) | $\bar{p}(evt_i) = \frac{1}{D_i + L_i}\sum_{k=d_i}^{d_i+D_i+L_{max}-1} p(k)$ → **$\bar{p}(evt_i)$** was calculated considering $D_i$ of each event and maximum lag days ($L_{max}$, 0~14 days) |
| Step 3 | ***$T_{th}$*** and ***$L_{max}$*** (based on **r²** and **p-value** of a two-sided t-test) | $\bar{p} = \log_{10}(M_{evt}+1) \times c_1 + p_0$ → $p_o$ (cap/10⁶·d): a base mortality rate which is intercept → $c_1$ (cap/10⁶·d): rate of increase in excess mortality |
| Step 4 | Excess mortality rate (***$p_{HS}$***) | $p_{HS} = \bar{p} - p_0 = c_1 \times \log_{10}(M_{evt}+1)$ |

## RESULTS

### Time series of PT and Ta (2000~2016 JJAS, ●: Mean, Bar(top): Q1, Bar(bottom): Q3)



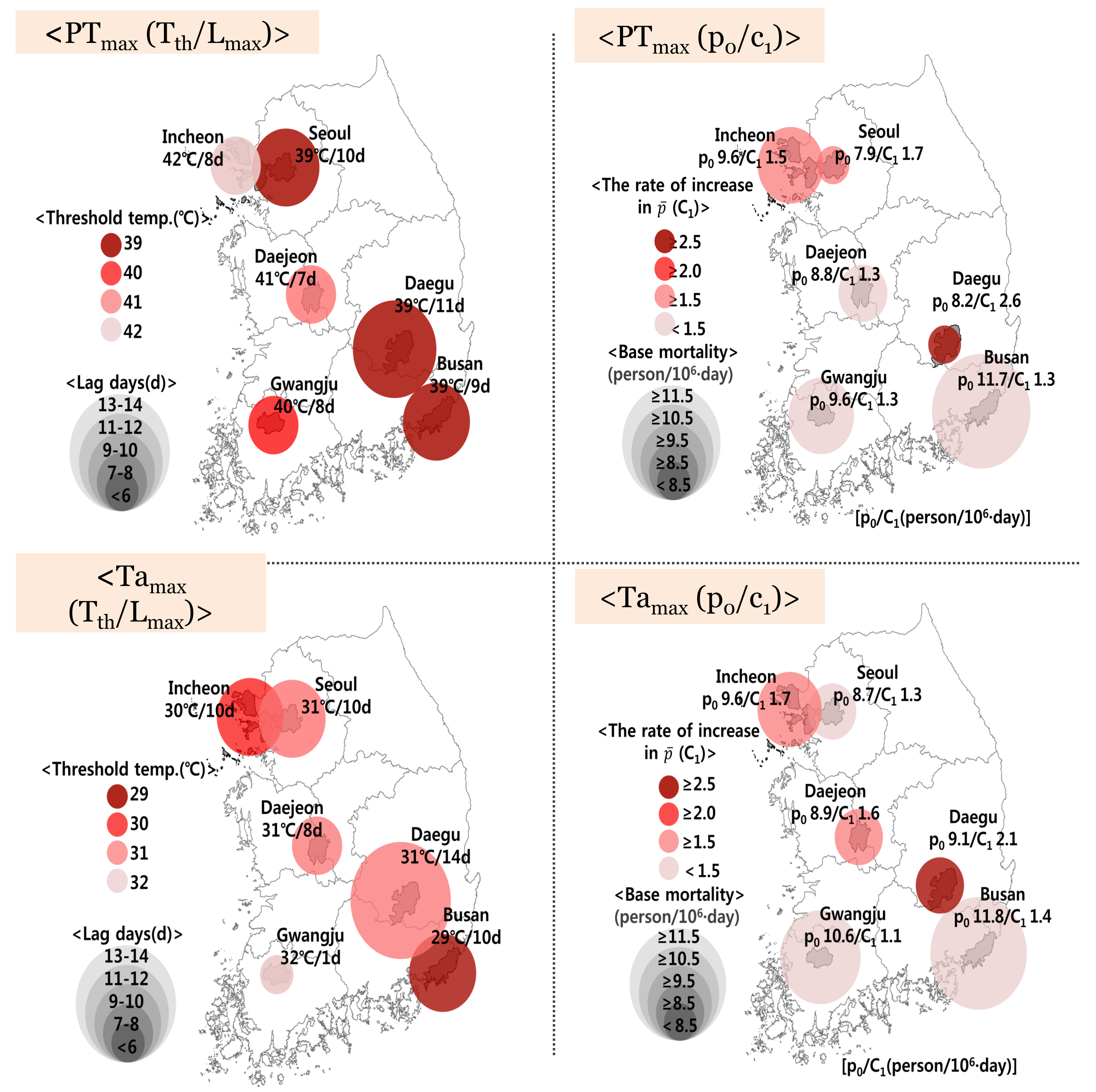

※ Mean of daily maximum temperature in summer (JJAS)

| | $PT_{max}$ (℃) | $Ta_{max}$ (℃) |
|---|---|---|
| Seoul | 25.1 | 24.0 |
| Incheon | 25.1 | 23.3 |
| Daejeon | 26.7 | 23.9 |
| Daegu | 26.1 | 24.6 |
| Gwangju | 27.2 | 24.4 |
| Busan | 25.0 | 23.6 |

Daily variability: PT > Ta

Peak time of PT shows at 13LST due to the influence of Tmrt.

### Statistically highly significant result from the event-based analysis



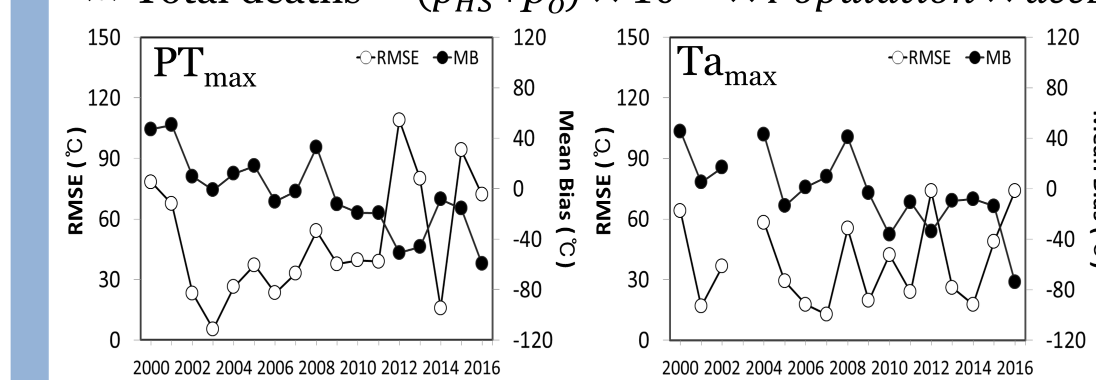

(***: p < 0.05; **: p < 0.1, and *: p<0.15)

| | $PT_{max}$ | | | | | | $Ta_{max}$ | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $T_{th}$ (℃) | $L_{max}$ (d) | *evt* (1/yr) | Heat days (d/yr) | $P_o$ | $c_1$ | $T_{th}$ (℃) | $L_{max}$ (d) | *evt* (1/yr) | Heat days (d/yr) | $P_o$ | $c_1$ |
| Seoul | 39*** | 10 | 2.5 | 16.6 | 7.9 | 1.7 | 31*** | 10 | 2.8 | 14.9 | 8.7 | 1.3 |
| Incheon | 42*** | 8 | 1.5 | 10.0 | 9.6 | 1.5 | 30** | 10 | 2.4 | 14.2 | 9.6 | 1.7 |
| Daejeon | 41*** | 7 | 3.4 | 21.8 | 8.8 | 1.3 | 31*** | 8 | 2.9 | 18.5 | 8.9 | 1.6 |
| Gwangju | 40*** | 8 | 3.8 | 30.0 | 9.6 | 1.3 | 32*** | 1 | 2.7 | 17.5 | 10.6 | 1.1 |
| Daegu | 39*** | 11 | 3.3 | 28.1 | 8.2 | 2.6 | 31*** | 14 | 5.1 | 36.1 | 9.1 | 2.1 |
| Busan | 39* | 9 | 3.2 | 22.6 | 11.7 | 1.3 | 29** | 10 | 3.5 | 27.3 | 11.8 | 1.4 |

### 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 ($p_{HS}$) → excess deaths → total deaths

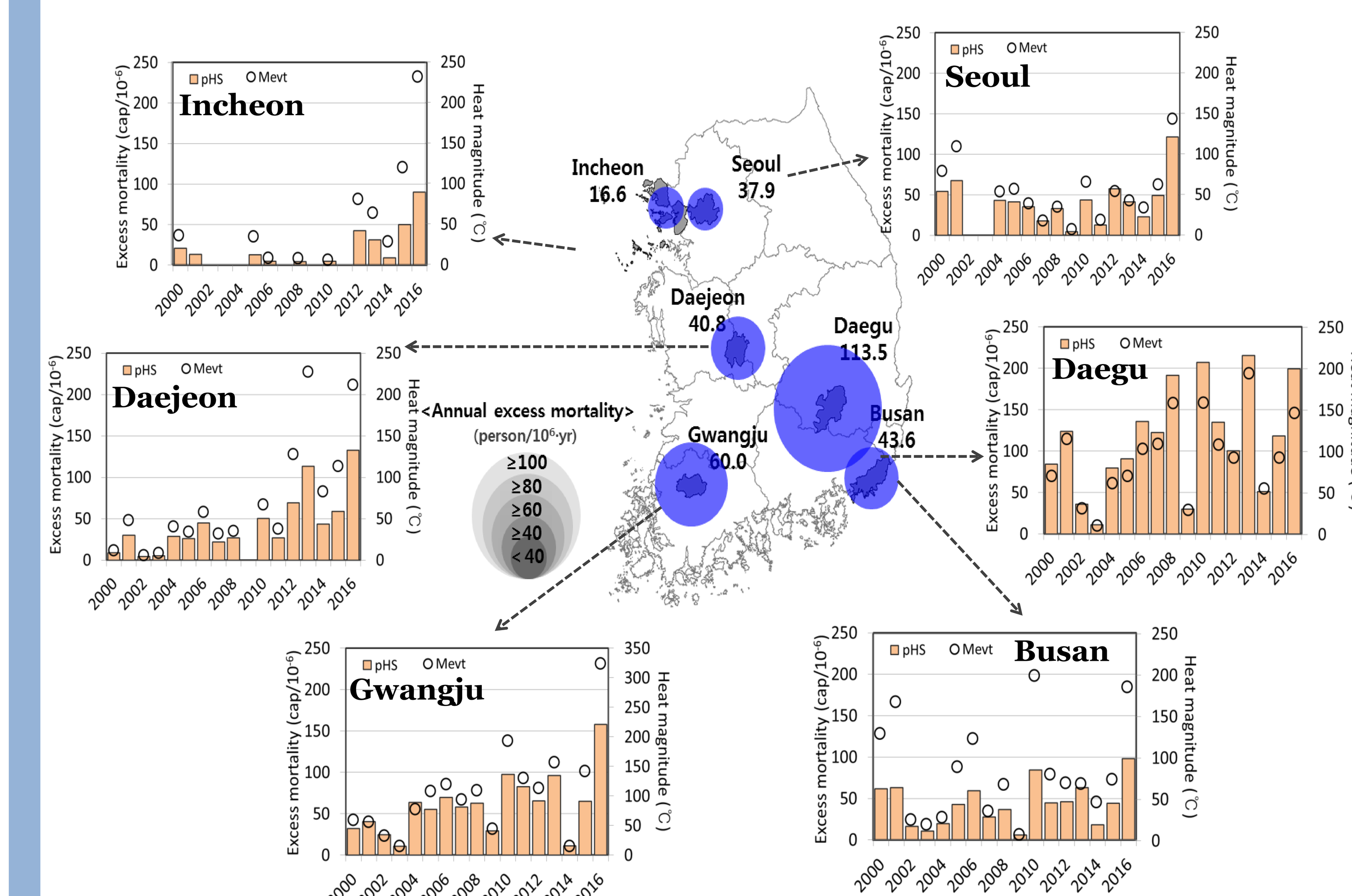
※ Total deaths $= (p_{HS}+p_o) \times 10^{-6} \times Population \times accD$ (**$p_0$**: base mortality rate, **accD**: Cumulative days of each heat-stress event)




| | $PT_{max}$ (Person) | $Ta_{max}$ (Person) |
|---|---|---|
| RMSE | 54.5 | 45.3 |
| MB | -2.4 | -1.0 |

### Excess mortality rate($p_{HS}$) based on $PT_{max}$

$p_{HS} = c_1 \times \log_{10}(M_{evt}+1)$



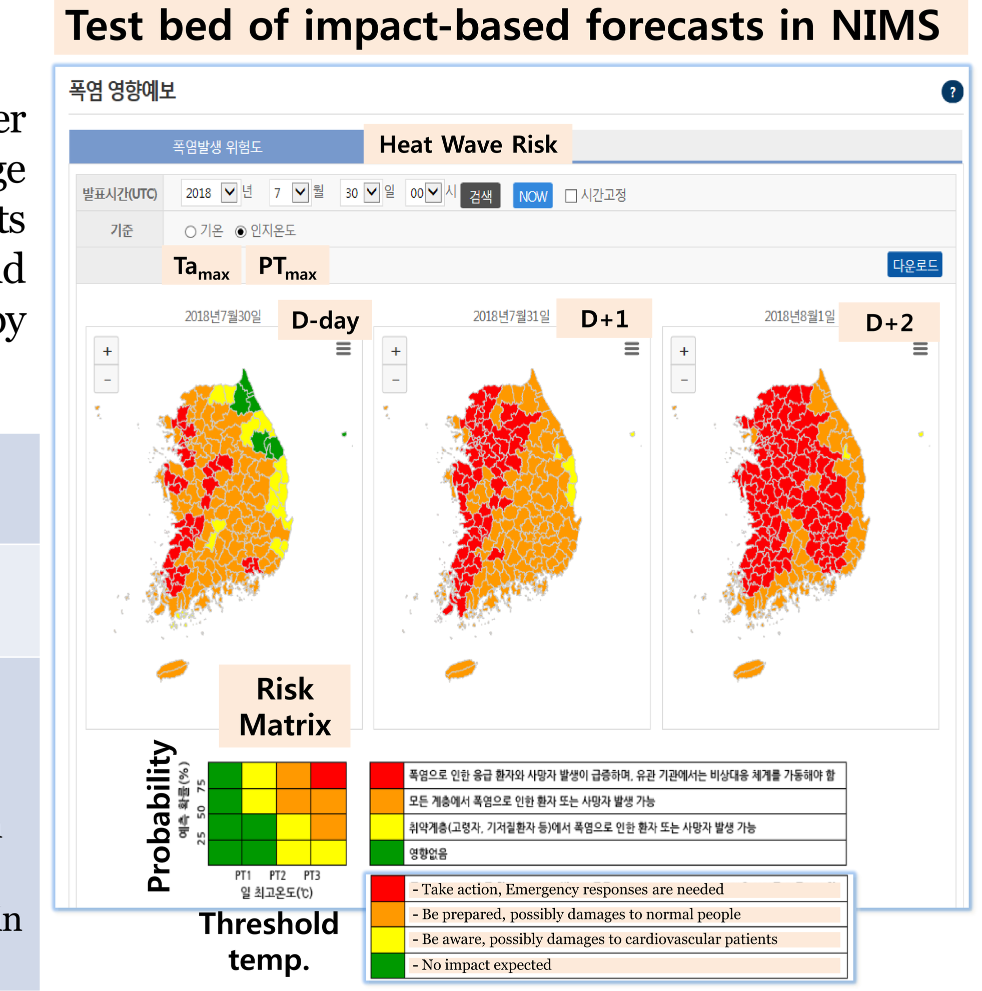

- The excess mortality rate is proportional to the heat intensity and rate of increase in excess mortality by city. The annual excess mortality is high in Daegu, which has high intensity and $c_1$.

## SUMMARY

- The $T_{th}$, $p_o$, and $c_1$ by city differ depending on climate and age structure of the city. These results affect different annual and monthly excess mortality rates by city.

| | |
|---|---|
| Vulnerable cities | Daegu and Gwangju |
| Vulnerable year | 2016 in most cities (2013 in Daegu) |
| Causes of vulnerability | • High number of *evt* and magnitude of heat-stress events<br>• High population over 65 in Daegu and Busan<br>• High population under 14 in Gwangju |

### Test bed of impact-based forecasts in NIMS





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