September 27, 2016
International Training Workshop on Natural Disaster Reduction
National Science and Technology Center for Disaster Reduction
Taipei, Taiwan

# Heat Vulnerability Assessment for Health Risk Reduction

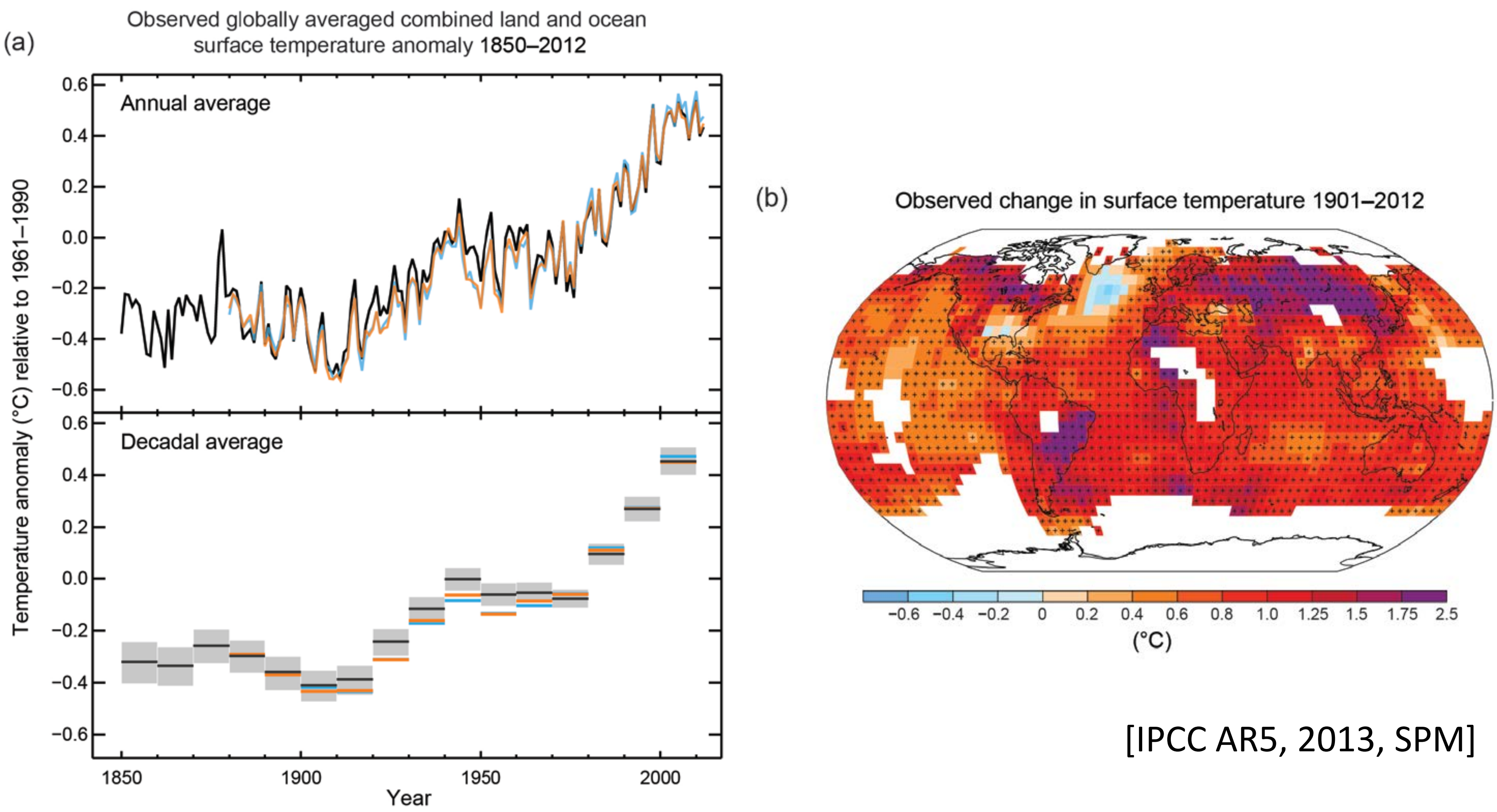
**Dr. Shih-Chun Candice LUNG**

**Executive Director, Integrated Research on Disaster Risk (IRDR), International Center of Excellence-Taipei (ICoE-Taipei)**

**Research Fellow, Research Center for Environmental Changes**

**Academia Sinica, Taipei, Taiwan**

# Global Climate Change




[IPCC AR5, 2013, SPM]

Heatwave

# Heat Stress






# Health Impacts of Climate Changes and Potential Intervention Points

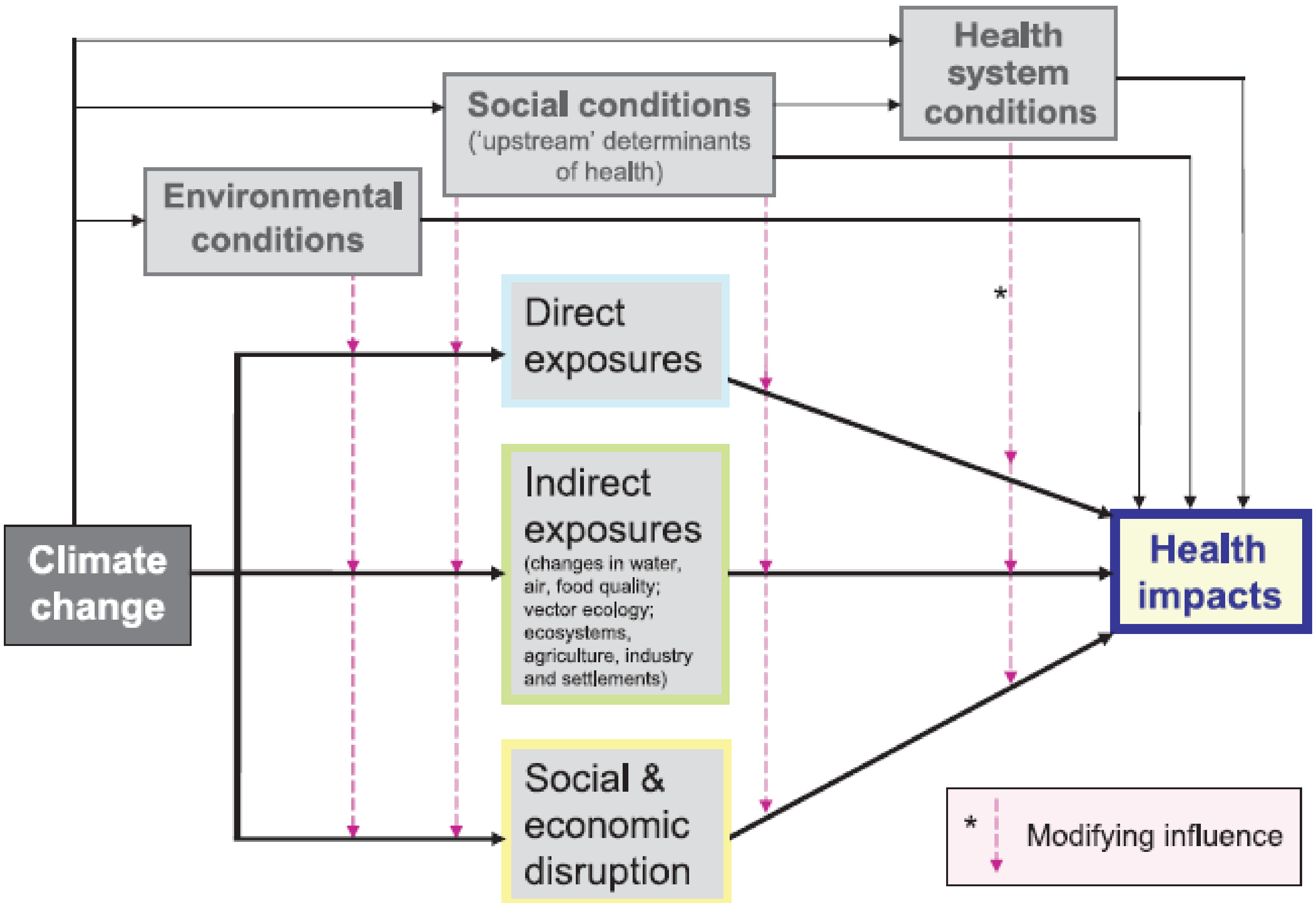



**Figure 8.1.** *Schematic diagram of pathways by which climate change affects health, and concurrent direct-acting and modifying (conditioning) influences of environmental, social and health-system factors.*

[IPCC, 2007]

# Background

- Under climate change, heat waves are expected to occur more frequently with record-breaking extremes under climate changes [IPCC 2014]
  – 2015 could be the hottest year on records [US NOAA, 2015]
- Increased total and cardiovascular mortality were observed worldwide during prolong heat waves [IPCC 2014]
  – More than 2000 and 1200 deaths in India and Pakistan, respectively, in 2015 heat waves

# European Heat Wave in 2003

### Box 8.1. The European heatwave 2003: impacts and adaptation

In August 2003, a heatwave in France caused more than 14,800 deaths (Figure 8.2). Belgium, the Czech Republic, Germany, Italy, Portugal, Spain, Switzerland, the Netherlands and the UK all reported excess mortality during the heatwave period, with total deaths in the range of 35,000 (Hemon and Jougla, 2004; Martinez-Navarro et al., 2004; Michelozzi et al., 2004; Vandentorren et al., 2004; Conti et al., 2005; Grize et al., 2005; Johnson et al., 2005). In France, around 60% of the heatwave deaths occurred in persons aged 75 and over (Hemon and Jougla, 2004). Other harmful exposures were also caused or exacerbated by the extreme weather, such as outdoor air pollutants (tropospheric ozone and particulate matter) (EEA, 2003), and pollution from forest fires.

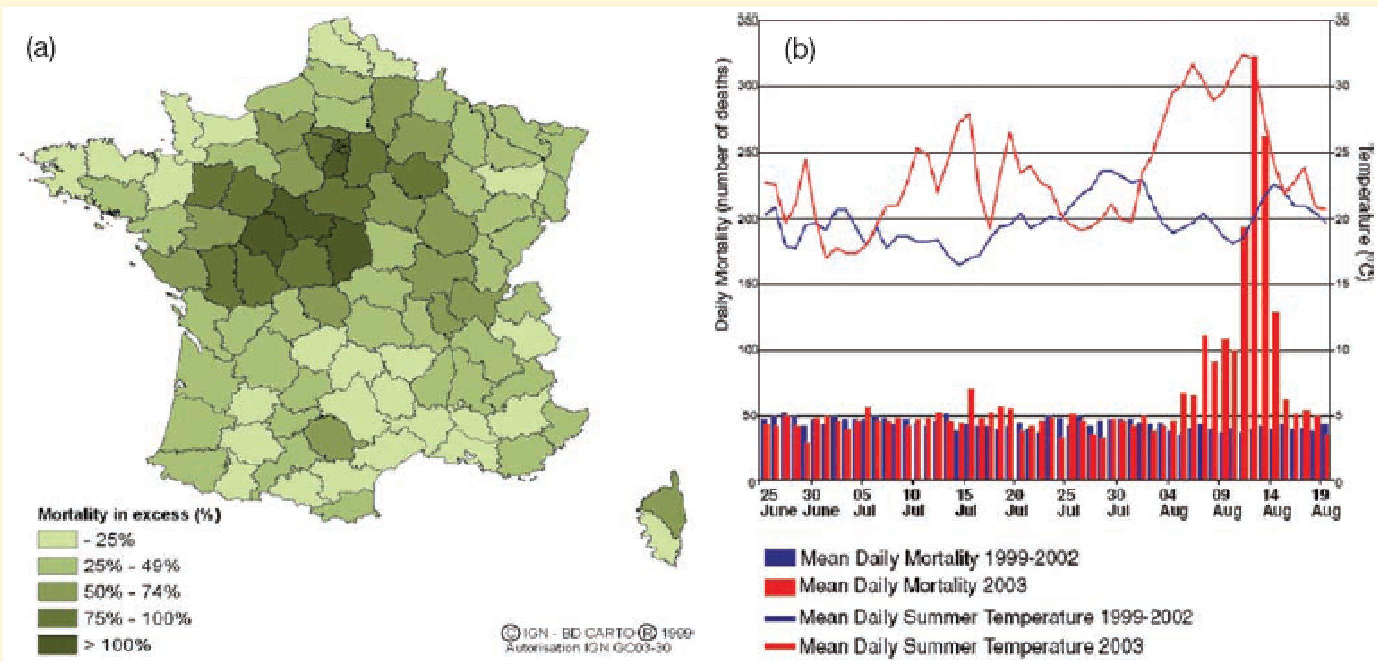



**Figure 8.2.** *(a) The distribution of excess mortality in France from 1 to 15 August 2003, by region, compared with the previous three years (INVS, 2003); (b) the increase in daily mortality in Paris during the heatwave in early August (Vandentorren and Empereur-Bissonnet, 2005).*

## Table 1.2 Additional deaths attributable to climate change,[a] under A1b emissions and the base case socioeconomic scenario, in 2030

| Region | Undernutrition[b] | Malaria | Dengue | Diarrhoeal disease[c] | Heat[d] |
|---|---|---|---|---|---|
| Asia Pacific, high income | | 0 (0 to 0) | 0 (0 to 0) | 1 (0 to 2) | 1488 (1208 to 1739) |
| Asia, central | 473 (–215 to 1161) | 0 (0 to 0) | 0 (0 to 0) | 111 (49 to 150) | 740 (364 to 990) |
| Asia, east | 1155 (–5313 to 7622) | 0 (0 to 0) | 39 (23 to 48) | 216 (95 to 298) | 8010 (5710 to 9733) |
| Asia, south | 20 692 (–39 019 to 80 404) | 1875 (1368 to 2495) | 197 (101 to 254) | 14 870 (6533 to 20 561) | 9176 (7330 to 10 620) |
| Asia, south-east | 3348 (–2635 to 9331) | 550 (398 to 779) | 0 (0 to 0) | 765 (336 to 1105) | 2408 (1629 to 3192) |

[WHO, Quantitative Risk Assessment of the Effects of Climate Change on Selected Causes of Death, 2030s and 2050s, 2014]

# Health Impacts of Heat Stress

- Higher mortality and morbidity of cardiovascular diseases during high temperature periods worldwide
- Increases in total hospital admission and total mortality
- Vulnerable populations: elderly and people with pre-existing diseases
- Other health impacts such as heat stroke
- Significant impacts due to heat-stress are expected worldwide if there is no adequate adaptation measures under climate change

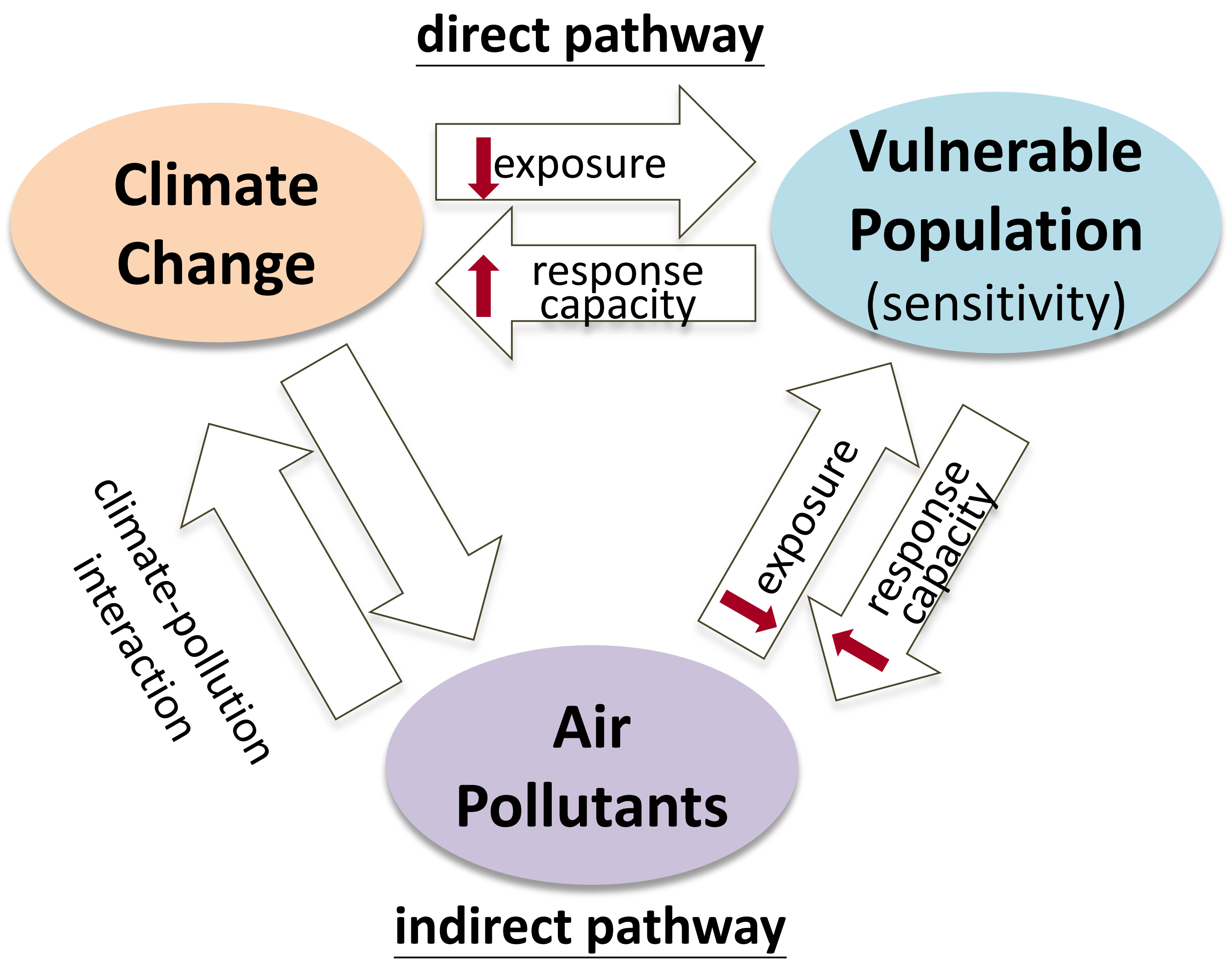
# Taiwan Situation

- 1.4 ℃ (1897-2008) increase in Taiwan [CWB, 2011] compared to 0.74 ℃ (1906-2005) increase of global mean [IPCC 2007]
- In Taipei, mortality in respiratory and cardiovascular diseases was increased by 1.1 (0.3–1.9)% and 9.3 (4.1–14.8)% , respectively, per 1℃ increase >31.5 ℃ [Chung et al. STE, 2009];
- Mortality increased in Taiwan were modified by social-economic factors [Wu et al., OEM, 2010].
  – Districts with more medical resources, higher urbanization levels, and more economic opportunity had lower mortality increases while districts with higher percentages of susceptible and aborigine populations had higher mortality increases

# Definitions

- Disaster Risk=Frequency* Exposure* Vulnerability
  - Vulnerability include sensitivity and response capacity [IPCC AR5, 2014]
- In this presentation
  - Vulnerability: Exposure, sensitivity, and response capacity [Clark et al., Harvard University 2000]

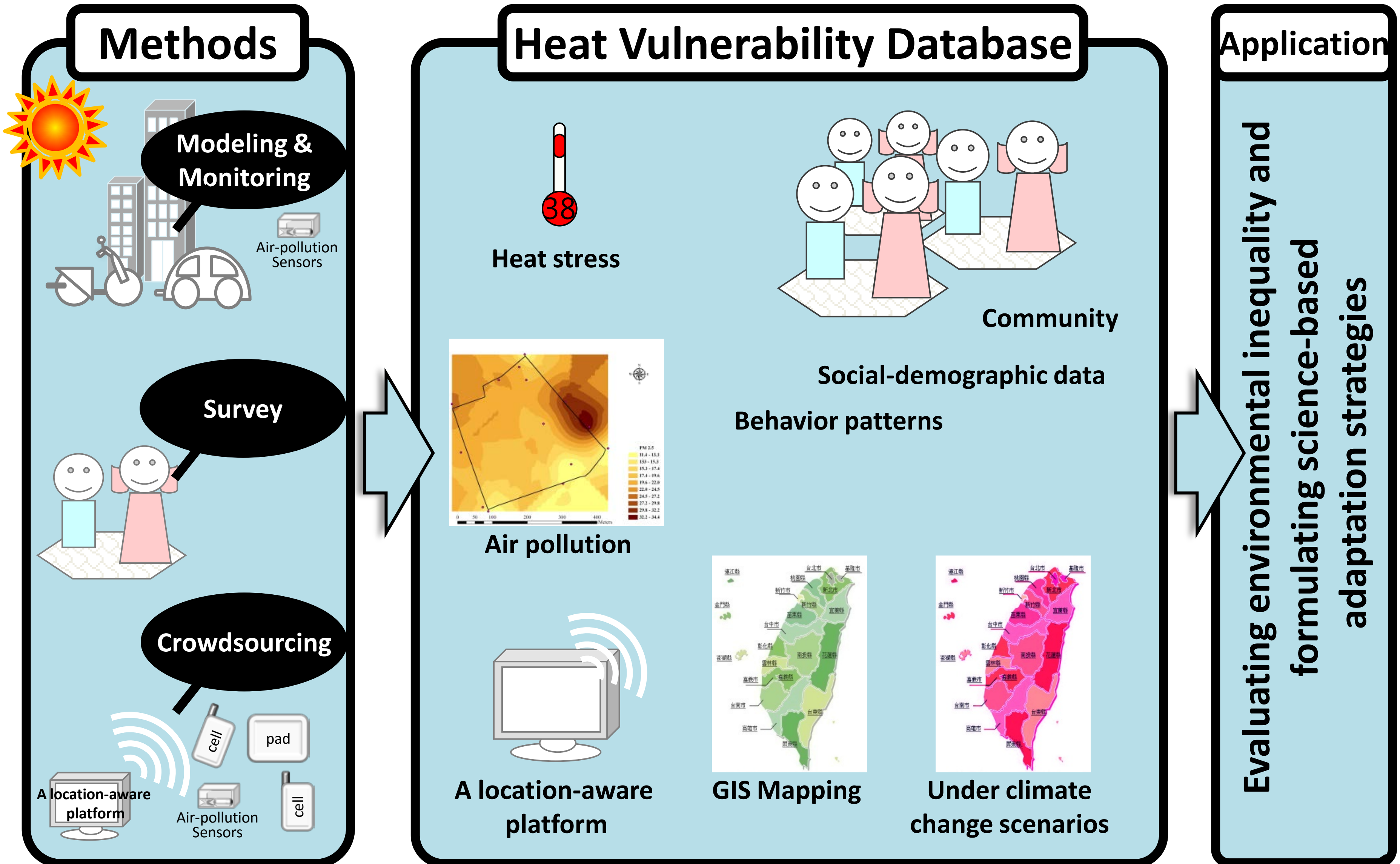
# Heat Vulnerability Assessment



# Heat Vulnerability Assessment Objectives

- Investigate vulnerability factors, including physical (heat), chemical (air pollutants), socio-demographic, behavioral, and community factors
  - controllable factors of heat stress and air pollutant exposures on hot days
  - distribution and characteristics of vulnerable population with low response capacities
- Formulate science-based adaptation strategies
  - Establish an effective heat-stress early warning system
  - design intervention program aiming to moderating controllable factors to reduce health risks
  - better urban planning on infrastructure to reduce Urban Heat Island (UHI) effects

# Conceptual Framework



# Science-Policy Dialogue (Co-Design)

| | Governmental Agencies | Year | Policy/Program |
|---|---|---|---|
| Central Government | Central Weather Bureau | 2010, 2013, 2015 | Establish heat warning system |
| | Ministry of Health and Welfare | 2009, 2012-2015 | Prevent heat-stress of vulnerable population |
| | Ministry of Labor | 2012, 2013, 2015 | Prevent heat-stress of outdoor workers |
| | Environmental Protection Administration | 2011-2015 | Set guidelines in Environmental Impact Assessment |
| Taipei City Government | Sustainable Development Committee | 2007-2015 | Set guidelines for city planning |
| | Department of Environmental Protection | 2007-2015 | Establish heat warning advisory |
| | Department of Transportation | 2010-2015 | Set guidelines for transportation planning |

# Trans-disciplinary Integration Framework

Formulate Science-based Adaptation Strategies to Reduce Health Risks

# Trans-disciplinary Integration Framework

| i | Conduct **Community-Based Field Works and Surveys** |
|---|---|
| ii | Apply **Crowdsourcing Technology** to Collect Behavior Patterns and Environmental Data |

| Physical/Chemical Environmental Factors | Behavioral Factors | Social-Demographic & Community Factors |
|---|---|---|

**Formulate Science-based Adaptation Strategies to Reduce Health Risks**

# Trans-disciplinary Integration Framework

**i** Conduct **Community-Based Field Works and Surveys**

**ii** Apply **Crowdsourcing Technology** to Collect Behavior Patterns and Environmental Data

- Physical/Chemical Environmental Factors
- Behavioral Factors
- Social-Demographic & Community Factors

**iii** Extract Key Factors and Link to Township Factors in the National Database

**Vulnerability Mapping under Current and Future Climate Scenarios**

**iv** Formulate Science-based Adaptation Strategies to Reduce Health Risks

- **Warning System,** Pollution Control, & **Urban Planning**
- **Urban Planning** and intervention to promote **Behavior Change**
- Social Support for **Vulnerable Communities**

# The New York Times

**SundayReview** | OPINION

# The Deadly Combination of Heat and Humidity

By ROBERT KOPP, JONATHAN BUZAN and MATTHEW HUBER JUNE 6, 2015

## JUNE 6, 2015 New York Times

**By ROBERT KOPP, JONATHAN BUZAN and MATTHEW HUBER**

http://www.nytimes.com/2015/06/07/opinion/sunday/the-deadly-combination-of-heat-and-humidity.html?emc=eta1&_r=0

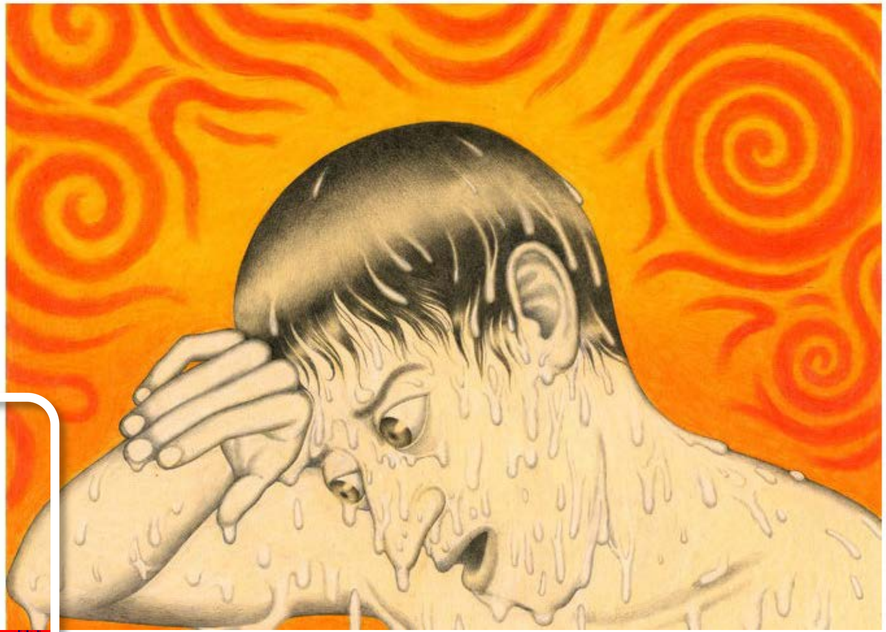
EuroWEATHER - Heat and discomfort index

## HEAT AND DISCOMFORT INDEX

HUMIDEX INDEX OF APPARENT TEMPERATURE ( degree C )

| | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 42° | 48 | 50 | 52 | 55 | 57 | 59 | 62 | 64 | 66 | 68 | 71 | 73 | 75 | 77 | 80 | |
| 41° | 46 | 48 | 51 | 53 | 55 | 57 | 59 | 61 | 64 | 66 | 68 | 70 | 72 | 74 | 76 | |
| 40° | 45 | 47 | 49 | 51 | 53 | 55 | 57 | 59 | 61 | 63 | 65 | 67 | 69 | 71 | 73 | |
| 39° | 43 | 45 | 47 | 49 | 51 | 53 | 55 | 57 | 59 | 61 | 63 | 65 | 66 | 68 | 70 | |
| 38° | 42 | 44 | 45 | 47 | 49 | 51 | 53 | 55 | 56 | 58 | 60 | 62 | 64 | 66 | 67 | |
| 37° | 40 | 42 | 44 | 45 | 47 | 49 | 51 | 52 | 54 | 56 | 58 | 59 | 61 | 63 | 65 | |
| 36° | 39 | 40 | 42 | 44 | 45 | 47 | 49 | 50 | 52 | 54 | 55 | 57 | 59 | 60 | 62 | [illegible] |
| 35° | 37 | 39 | 40 | 42 | 44 | 45 | 47 | 48 | 50 | 51 | 53 | 54 | 56 | 58 | 59 | 61 |
| 34° | 36 | 37 | 39 | 40 | 42 | 43 | 45 | 46 | 48 | 49 | 51 | 52 | 54 | 55 | 57 | 58 |
| 33° | 34 | 36 | 37 | 39 | 40 | 41 | 43 | 44 | 46 | 47 | 48 | 50 | 51 | 53 | 54 | 55 |
| 32° | 33 | 34 | 36 | 37 | 38 | 40 | 41 | 42 | 44 | 45 | 46 | 48 | 49 | 50 | 52 | 53 |
| 31° | 32 | 33 | 34 | 35 | 37 | 38 | 39 | 40 | 42 | 43 | 44 | 45 | 47 | 48 | 49 | 50 |
| 30° | 30 | 32 | 33 | 34 | 35 | 36 | 37 | 39 | 40 | 41 | 42 | 43 | 45 | 46 | 47 | 48 |
| 29° | 29 | 30 | 31 | 32 | 33 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 45 | 46 |
| 28° | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 |
| 27° | 27 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 |
| 26° | 26 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 34 | 35 | 36 | 37 | 38 | 39 |
| 25° | 25 | 25 | 26 | 27 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 34 | 35 | 36 | 37 |
| 24° | 24 | 24 | 24 | 25 | 26 | 27 | 28 | 28 | 29 | 30 | 31 | 32 | 33 | 33 | 34 | 35 |
| 23° | 23 | 23 | 23 | 24 | 25 | 25 | 26 | 27 | 28 | 28 | 29 | 30 | 31 | 32 | 32 | 33 |
| 22° | 22 | 22 | 22 | 22 | 23 | 24 | 25 | 25 | 26 | 27 | 27 | 28 | 29 | 30 | 30 | 31 |

| | |
|---|---|
| Up to 29 C° | No discomfort |
| From 30 to 34 C° | Slight discomfort sensation |
| From 35 to 39 C° | Strong discomfort. Caution: limit the heaviest physical activities |
| From 40 to 45 C° | Strong indisposition sensation. Danger: avoid efforts |
| From 46 to 53 C° | Serious danger: stop all physical activities |
| Over 54 C° | Death danger: imminent heatstroke |



# Heat-Health Warning System

- UK
  - heat-health watch is issued if daily maximum temperature is above certain threshold (mean + 5℃) for consecutive 5 days, collaboration of Met Office and Public Health England
- USA
  - excessive heat warning/advisories is issued by National Weather Service based on Heat index (HI) considering temperature and humidity; dangerous level: HI>105F
- Canada
  - heat warning is issued by Environment Canada based on Humidex which considers temperature and humidity; dangerous level: Humidex >45
- Japan
  - Warning is provided by the collaboration of Japan Meteorological Agency and National Institute for Environment based on wet bulb globe temperature (WBGT) considering temperature, humidity, wind speed, and radiation, dangerous level: WBGT>31
- **Taiwan (no heat-health warning system yet), should use an index considering temperature, humidity, wind speed, and radiation**
  - WBGT is used by Ministry of Labor to prevent heat-stress of workers
- WBGT is listed in ISO 7243 (1989) as a human heat-stress index

**WBGT outdoor=**

**0.7×Wet-Bulb-Temperature + 0.1×Dry-Bulb -Temperature + 0.2×Globe-Temperature**


**Residential areas mixed with commercial activities**

Various heat and air pollutant sources, such as vehicles, restaurants, night markets and temples





# High-level (>10m) Monitoring Sites


Hi-vol sampler


NO/$NO_2$

Real-time $PM_{2.5}$ Monitor


$O_3$

# Street-level Monitoring Sites


Personal PM sampler

# Other On-site Instruments

Heat stress monitor

Weather station

Micro-sensors

$CO_2$


$PM_{10}$/$PM_{2.5}$/$PM_1$ monitor


Polycyclic Aromatic Hydrocarbons

Black Carbon

# Advantage of WBGT

- Physiologically-based heat-stress index
- Used worldwide for more than 50 years as an index to prevent heat-stress of workers, considering T, RH%, wind speed, and radiation
- Increasing evidences of WBGT-heat-stress relationships for the general public
  - e.x. total mortality increased significantly as WBGT ≧ 35℃, hospital admission in all causes also increased significantly as WBGT ≧ 33℃ in Taiwan (Lin et al., 2012, Sci Total Environ)
- Which one (WBGT, temperature, HI, and Humidex) is the best heat-stress index explains heart-rate variability (HRV, a predictor for cardiopulmonary mortality) ?
  - *WBGT!* (P.C. Huang, Master thesis, Fu jen Catholic University (2013))
- Disadvantage:
  - Weather agencies did not measure globe temperature which is essential to assess WBGT

# Heat Stress Index

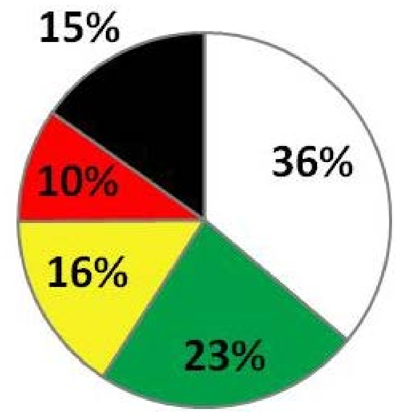
$$\text{WBGT outdoor} = 0.7 \times \text{Wet-Bulb-Temperature} + 0.1 \times \text{Dry-Bulb-Temperature} + 0.2 \times \text{Globe-Temperature}$$

- **Validated a theoretical formulas to use routine measurements of weather stations to estimate WBGT**
- **Applied weather forecast models to forecast WBGT**

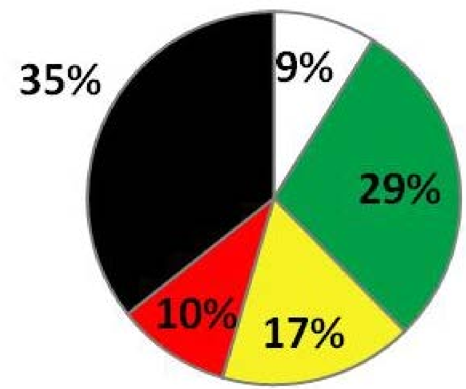
| Category | WBGT °F | WBGT °C | Flag color |
|---|---|---|---|
| 1 | <= 79.9 | <= 26.6 | White |
| 2 | 80-84.9 | 26.7-29.3 | Green |
| 3 | 85-87.9 | 29.4-31.0 | Yellow |
| 4 | 88-89.9 | 31.1-32.1 | Red |
| 5 | => 90 | => 32.2 | Black |

(Ref: USA army)

**Weather stations**

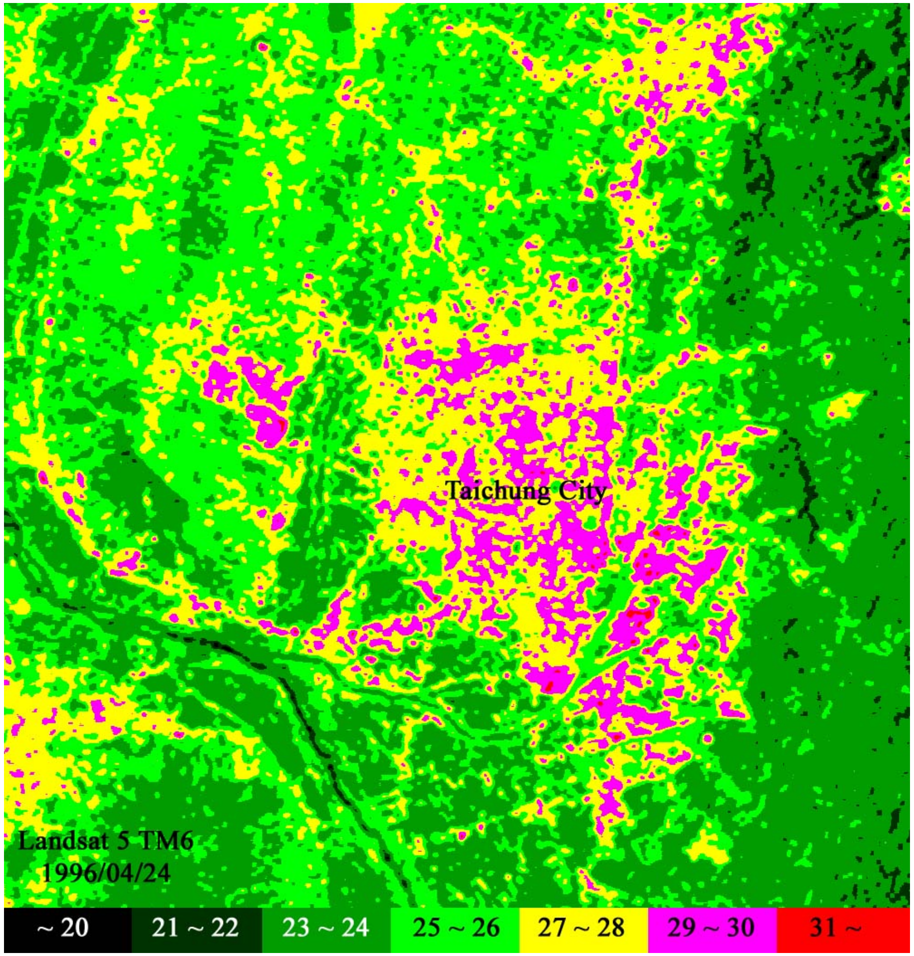



**Street-level sites**



# Urban Heat Island

(Landsat IR image,25 km X 25 km) (from CSRSR NCU)



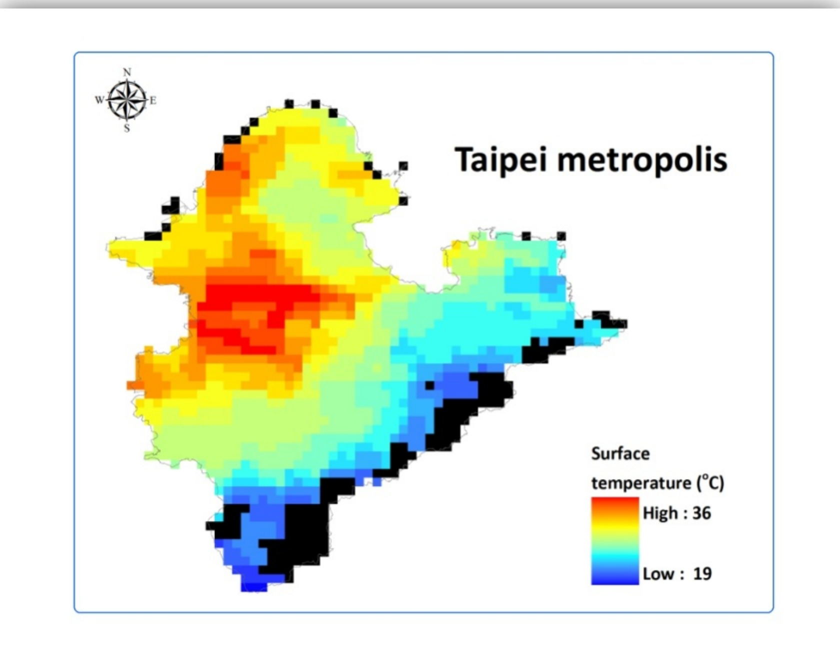

Taichung, Taiwan

# Role of Urban Planning

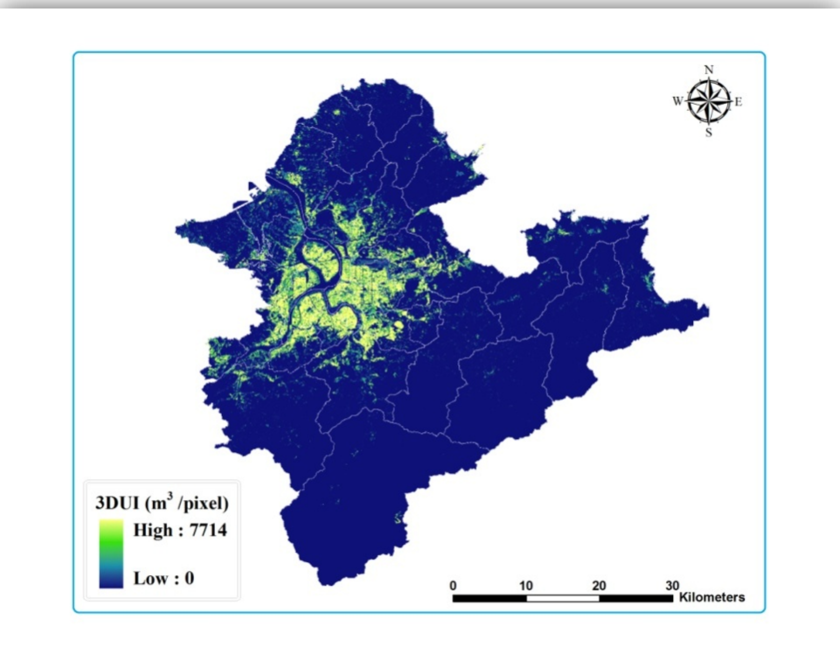

- Urban Heat Island (UHI) effect aggravates the temperature increase in urban areas
  - Megacities are the most vulnerable areas during heat w [IPCC 2014]
  - Taipei City had a record-high 39.3℃ on August 8, 2013
- Residential housings with only one or two floors (low-floor buildings) in Taipei are usually built before 1960
  - Insulation is not very good; easily get hot during heat waves
- Urban renewal may be an opportunity to construct buildings with better insulation
  - Less heat-stress exposure on hot days without air-conditioning
  - Less energy consumption with air conditioning
  - UHI effect maybe reduced if constructed with materials with less heat absorption capacity

# Taipei, Taiwan

# Develop/validate 3-D Urbanization Index

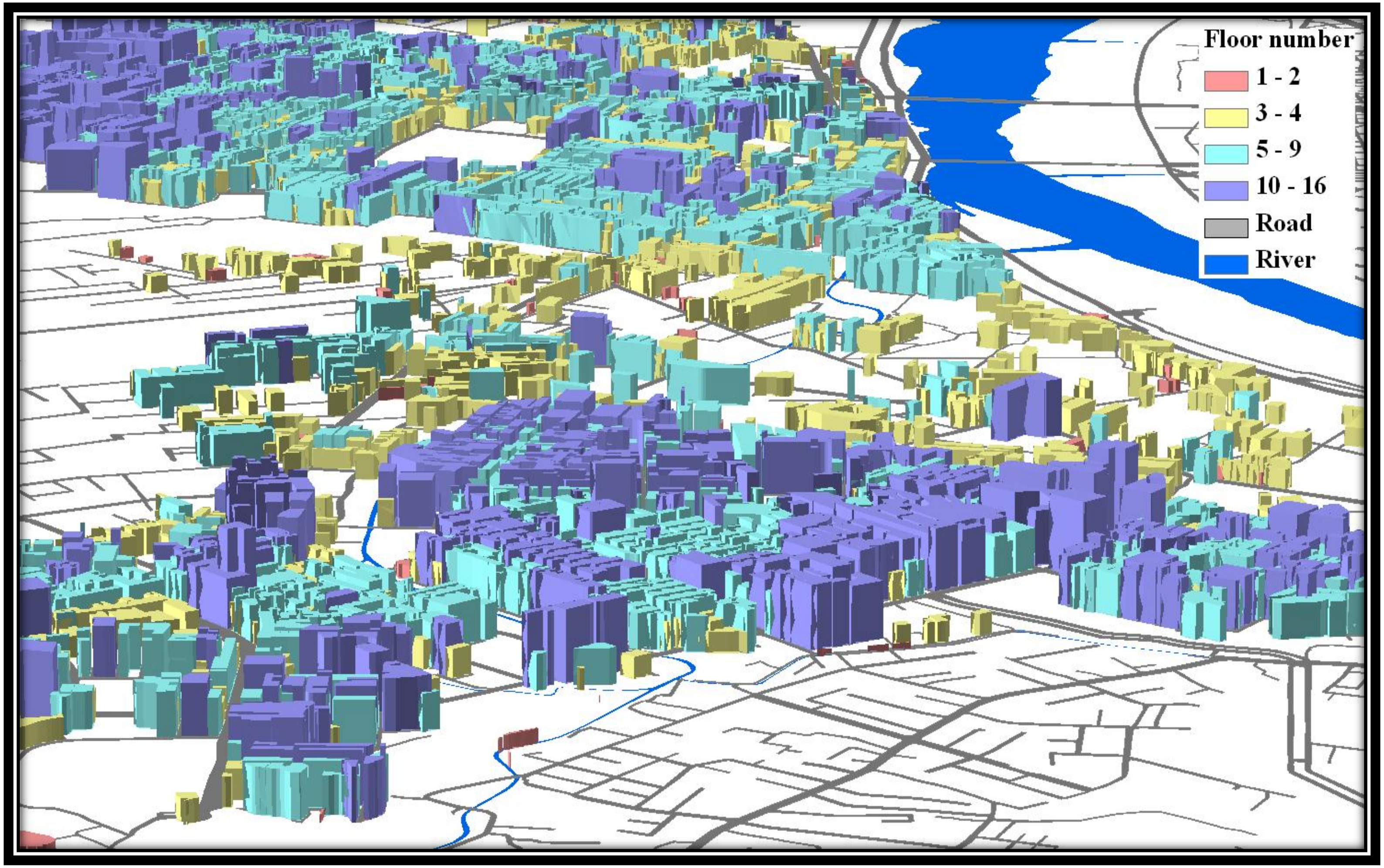



Temperature spatial variation in Taipei from Satellite



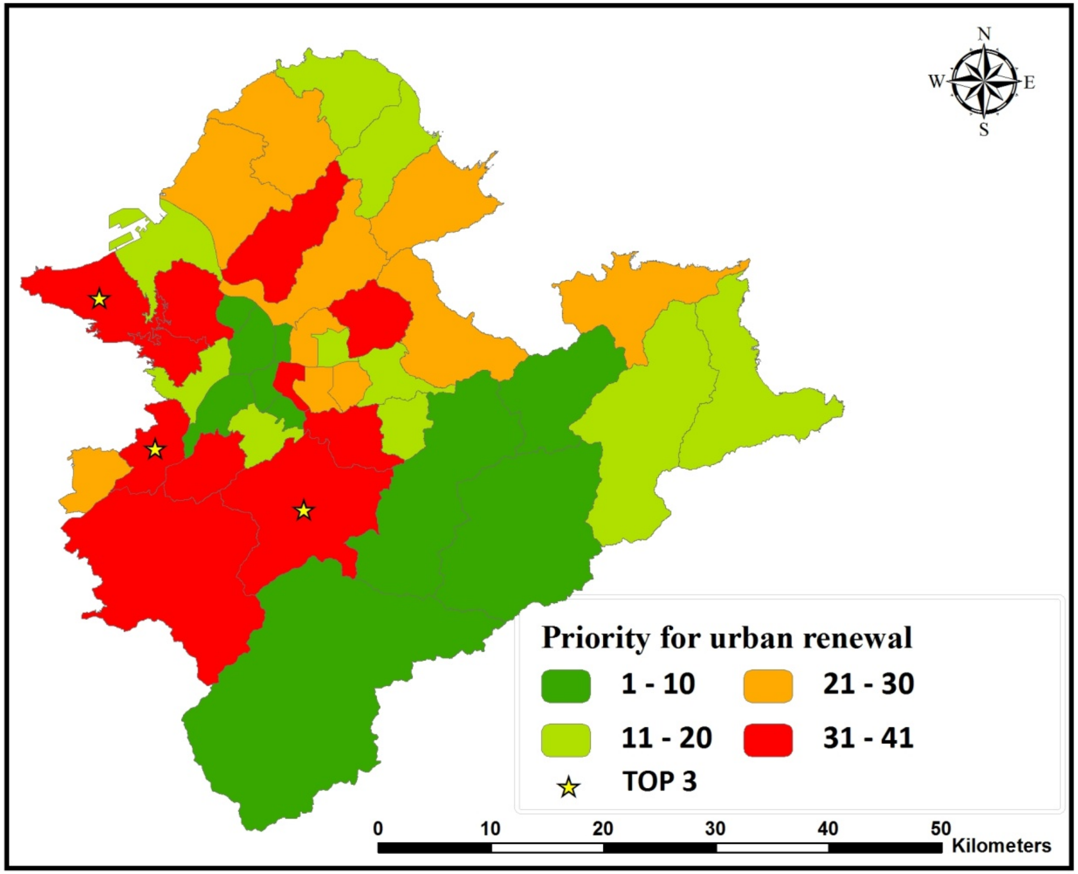

3DUI distribution in Taipei with **High correlation** ($R^2$=0.6-0.8) of temperature from Satellite

- **3D urbanization index** (3DUI )[Wu et al., 2013; Wu & Lung 2015]
  - Based on 5-m resolution of digital terrain models, considering 3-D building volumes
  - As a fine-resolution indicator for temperature distribution




**Example of 3D mapping of buildings with different number of floors** **[Wu & Lung, 2012, JESEE]**

# Priority for Urban Renewal in Taipei Metropolitan




Considering both percentage of low-floor housings and heat exposure in each district

# Surveys for Response Capacity

| | Phone interview | Face-to-face interview | Crowdsourcing | |
|---|---|---|---|---|
| | | | Internet survey | Mobile survey |
| Completed interviews | Wave 1:1,044<br>Wave 2: 1,134 | 2,018 with 513 household monitoring | 4,111 | 8,702 |

- Household environmental monitoring (n=513) (T, RH%, heat-stress index)
  - Most elderly and housewives stay at home did not turn on air-conditioning
  - Highest top 3% households had temperature of 41.1(SD1.8) ℃
- In short, elderly in urban communities experience high heat-stress

# Face-to-face Interview in 2013

- Hot season in Taiwan：
  - July 6 to Sep. 7
  - In Chinese solar terms: 小暑→大暑→立秋→處暑→白露
- Two questionnaires : 212 questions and one 24-hr diary
- Household WBGT monitoring
  - T, RH% and light intensity
  - By 25 well-trained interviewers, first time in Taiwan

# Characteristics of Vulnerable Population

| Individual Response Capacity | Major Characteristics |
|---|---|
| **Long** working hour outdoors | •Male<br>**•Short education years**<br>**•Workers in Agriculture, Transportation, Construction and manufacturer workers**<br>**•Rural** areas<br>•Part-time workers |

| Community Response Capacity | Major Characteristics |
|---|---|
| **Low** Social Support | **•Higher percentages of high-education** residents<br>**•Urban** areas<br>•Infrequent visit to community center or activities<br>•Unsatisfactory to community |

Heatwave

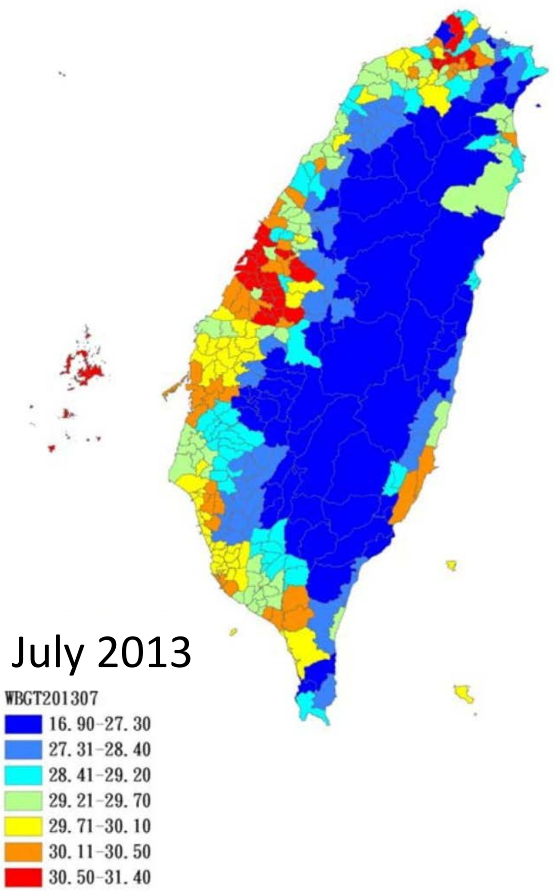
# Vulnerability Index for Heat-Stress

**Vulnerability=E+S+(8-R), classified from low (1) to high (7)**

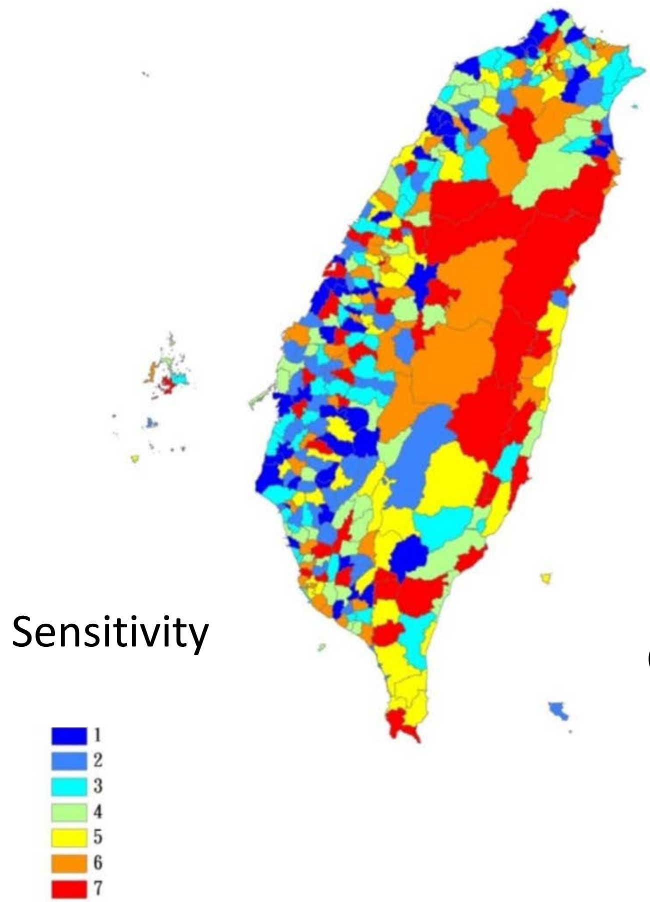
| Aspect | Sub index | Description | Score | Index equation |
|---|---|---|---|---|
| Exposure (E) | E1 | Heat stress | 1 - 7 | E = (E1+E2)/2 |
| | E2 | Air pollution | 1 - 7 | |
| Sensitivity (S) | S1 | Demographic factor | 1 - 7 | S = (S1+S2)/2 |
| | S2 | Pre-existing disease status | 1 - 7 | |
| Response Capacity (R) | R1 | Individual level | 1 - 7 | R = (R1 +R2)/2 |
| | R2 | Community level | 1 - 7 | |

# Mapping for three vulnerability determinants (a) WBGT exposure (July 2013), (b) sensitivity, and (c) response capacity

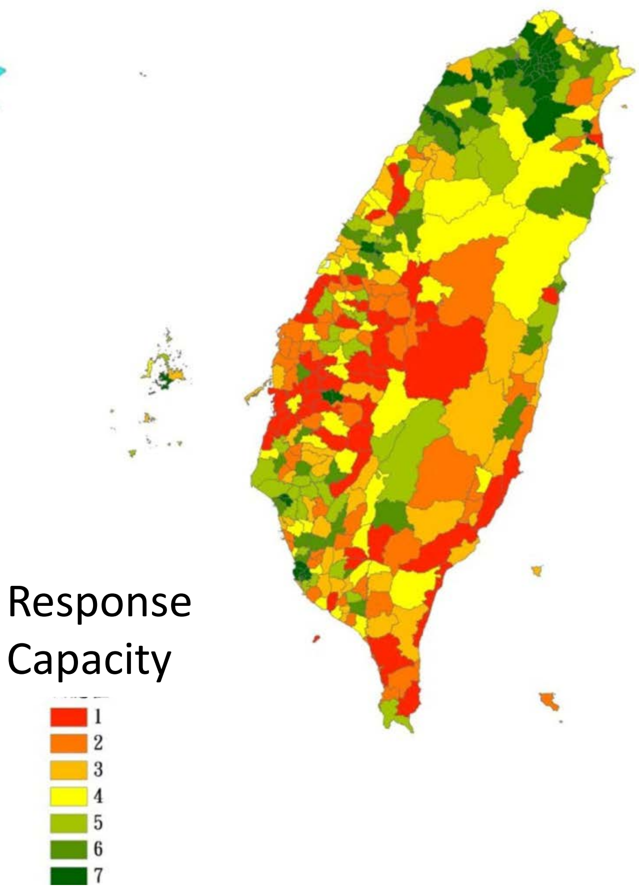
**(a)** Exposure (E): WBGT exposure



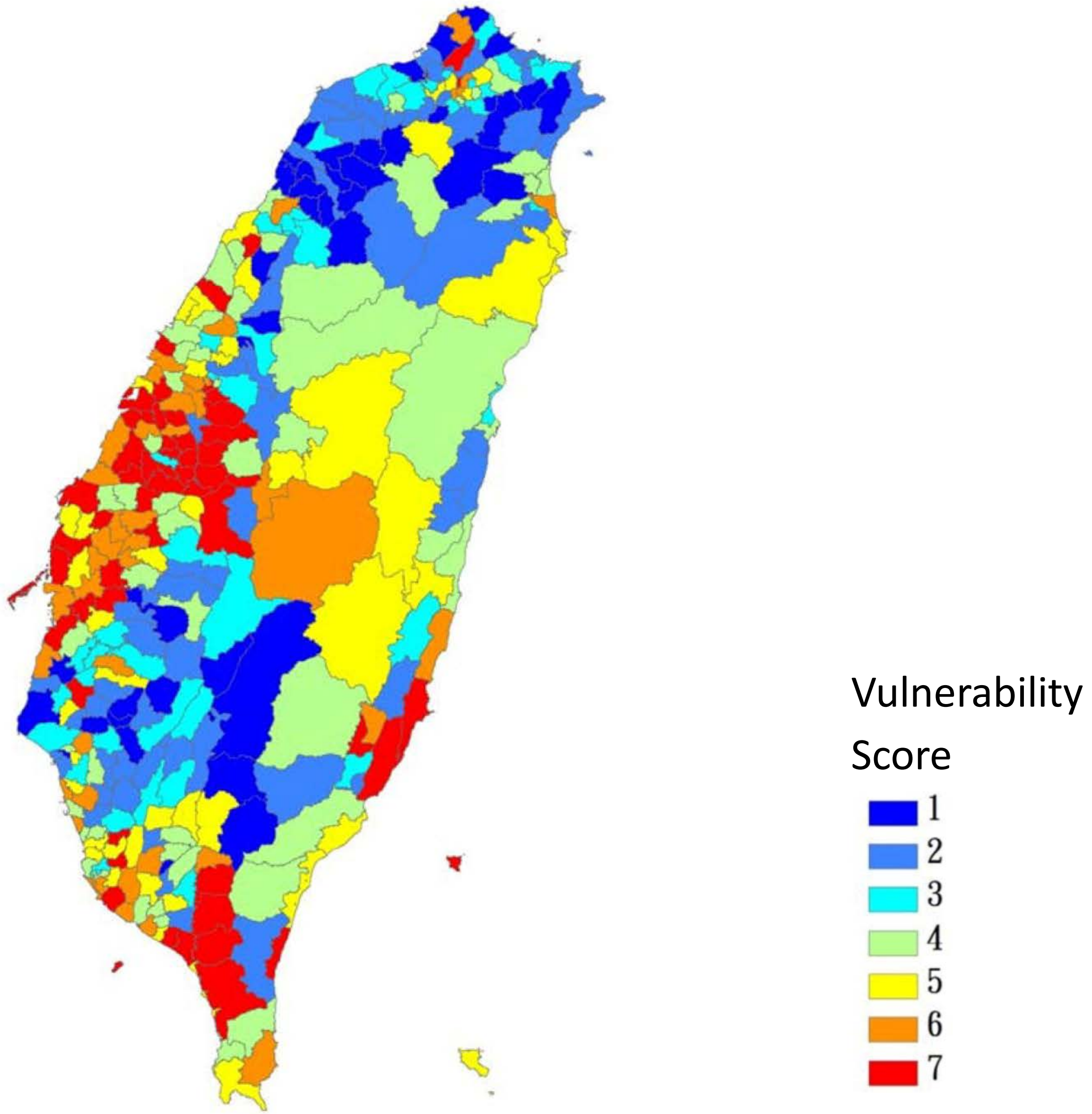

**(b)**Sensitivity (S)




**(c)** Response Capacity (R)



# Mapping for overall heat vulnerability index in Taiwan, townships with higher scores are more vulnerable



# Summary and Conclusion

- Established a trans-disciplinary integration framework to facilitate science-policy dialogue
- Evaluated heat-stress vulnerability factors in exposure and response capacity and identified characteristics of vulnerable population
- Provided scientific evidences to assist in heat warning system establishment, urban renewal priority settings, and public health intervention programs to reduce health risks from heat stress
- It is essential to formulate effective adaptation strategies to reduce health risks due to heat-stress

September 27, 2016
International Training Workshop on Natural Disaster Reduction
National Science and Technology Center for Disaster Reduction
Taipei, Taiwan

# Heat Vulnerability Assessment for Health Risk Reduction

***Thank you very much for your attention!***

**Shih-Chun Candice LUNG**
**sclung@rcec.sinica.edu.tw**