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Evaluation of building-scale heat-stress analysis system (BioCAS) based on mortality observation in Seoul

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How do you assess the Impact of heat stress by urban development?

- 2002 : Before the construction

- 2011 : After the new town development

- Heat vulnerability?
- Ventilation condition?


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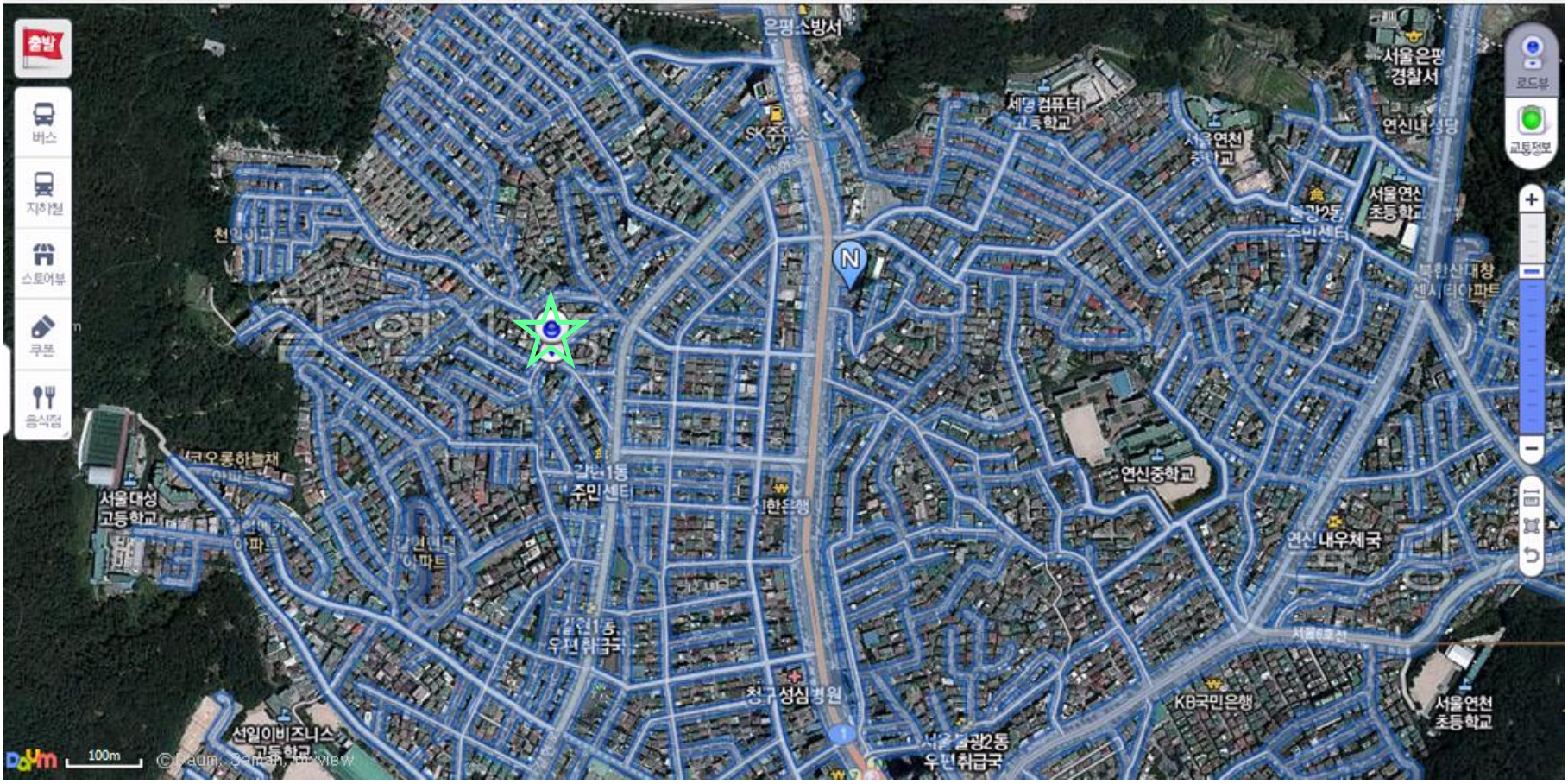
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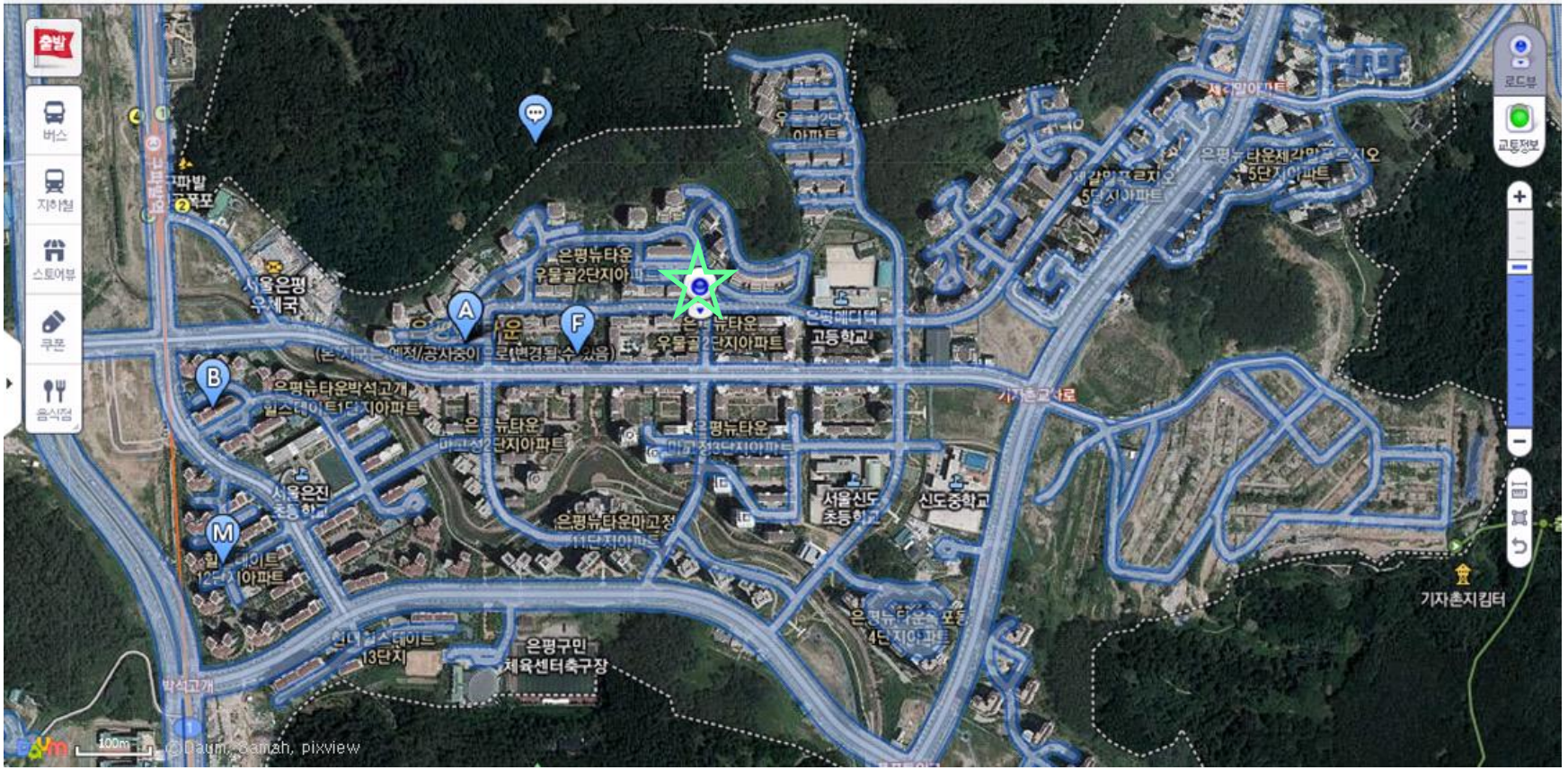
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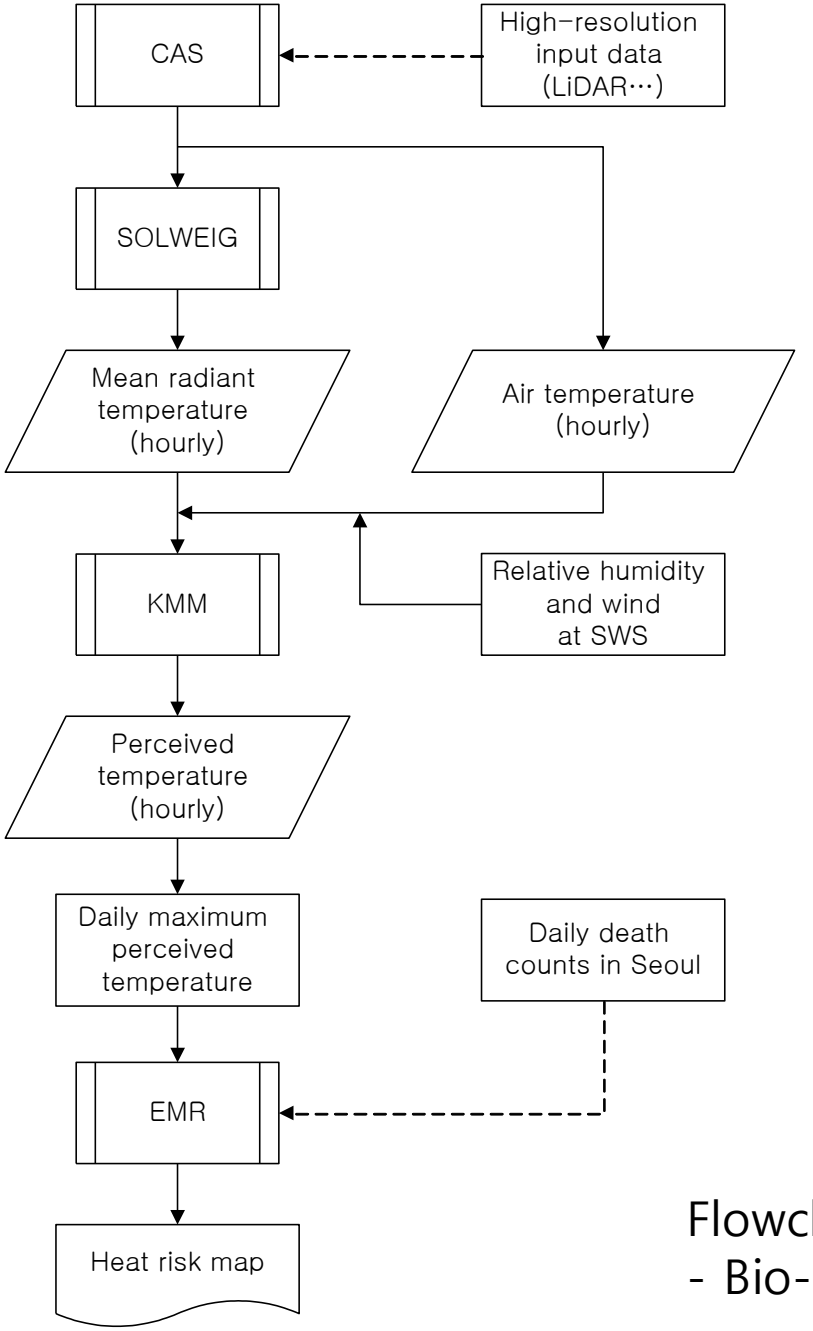
Mortality increase during heat waves

- 80 more people (24 July, 1994 in Seoul)
- ~3000 more people (1994 in Korea)

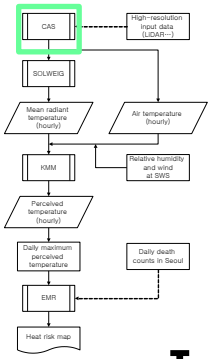
- Can we assess the impact of temperature increase as **mortality increase** by the construction of buildings or parks?

BioCAS:
Impact Assessment System for Heat Stress

- Integration of four models:
  - Climate Analysis Seoul (CAS, T)
    - ➢ Evaluated by weather observation
  - Solar Radiation (SOLWEIG, T_{mrt})
  - Klima-Michel Model (KMM, PT)
  - Excess Mortality Rate (r_{EM})
  - ➢ Published: Needs extensive evaluation on the health impact
- ➢ Evaluation by observed health impact
  - Mortality and No. of hospital visits of patient by heat waves at district level in Seoul

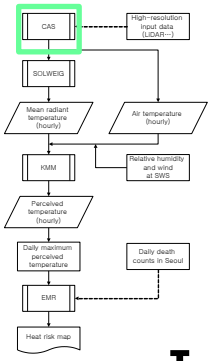


Flowchart of the BioCAS
- Bio-Climatic impact Assessment System



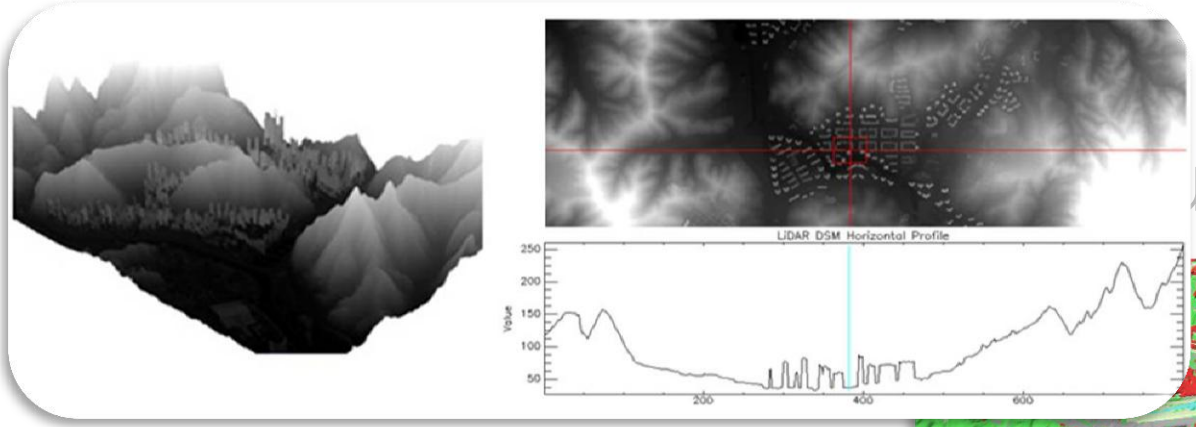
Climate Analysis Seoul (CAS)

- Input: Airborne LiDAR and satellite images for hi-res DEM & Land Cover
- Process: meso-scale wind conditions, thermal load of buildings and vegetation
- Output: temperature distribution, building configuration (for SOLWEIG)



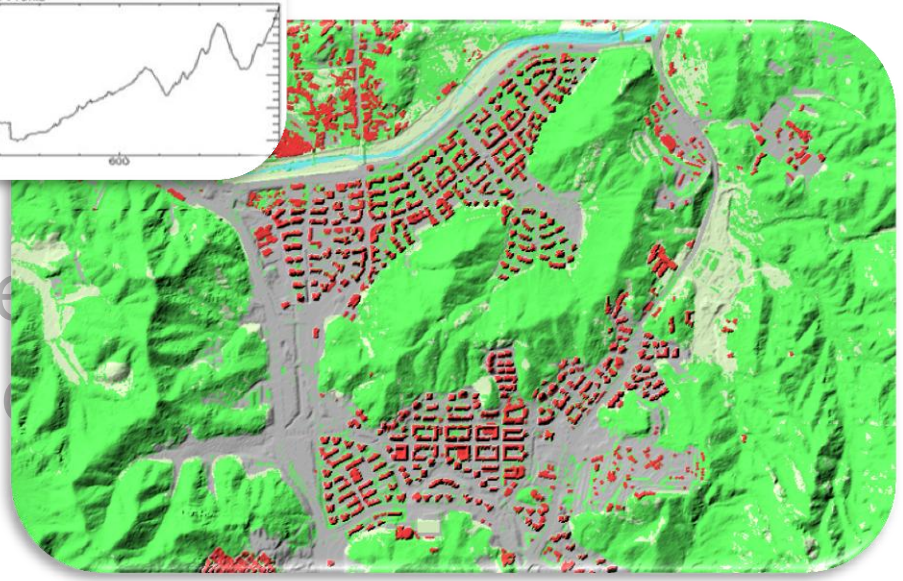
Climate Analysis Seoul (CAS)

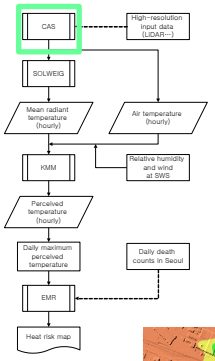
- Input: Airborne LiDAR and satellite images for hi-res DEM & Land Cover



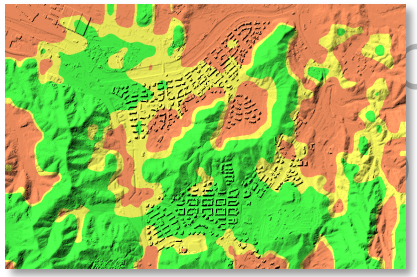
ildings and

- Output: temperature
building configurati

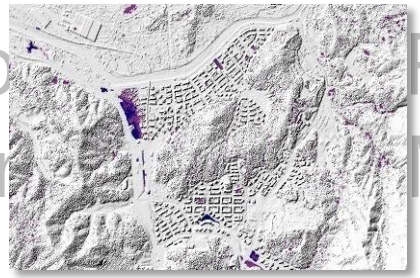




Climate Analysis Seoul (CAS)

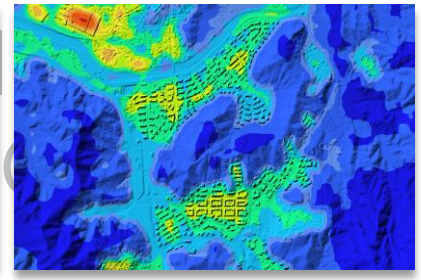


Meso-scale wind



Cold air stagnation

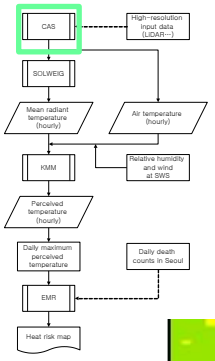
Surface influence



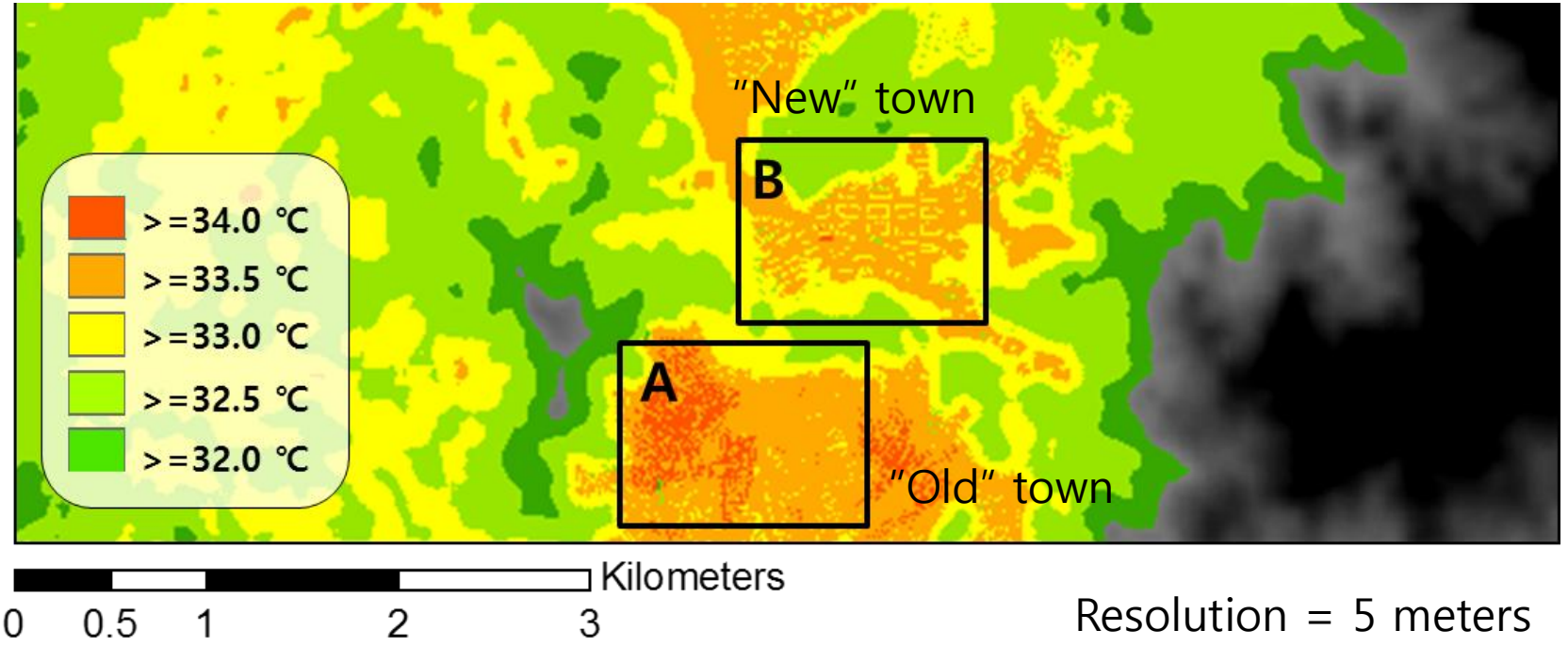
Total air temperature

- Process: Thermal Load of buildings and vegetation, Wind Conditions

Model optimization by high density observation
- more than 30 observational sites
  - temperature & humidity observation (1.5m):18 sites
  - wind observation (3.0m): 6 sites
  - T-RH observation at 4 heights: 12 sites
  - Satellite and thermal infrared images



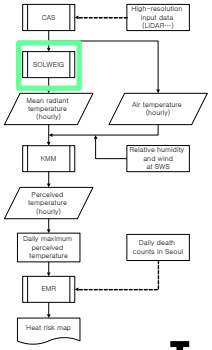
Climate Analysis Seoul (CAS)



Resolution = 5 meters

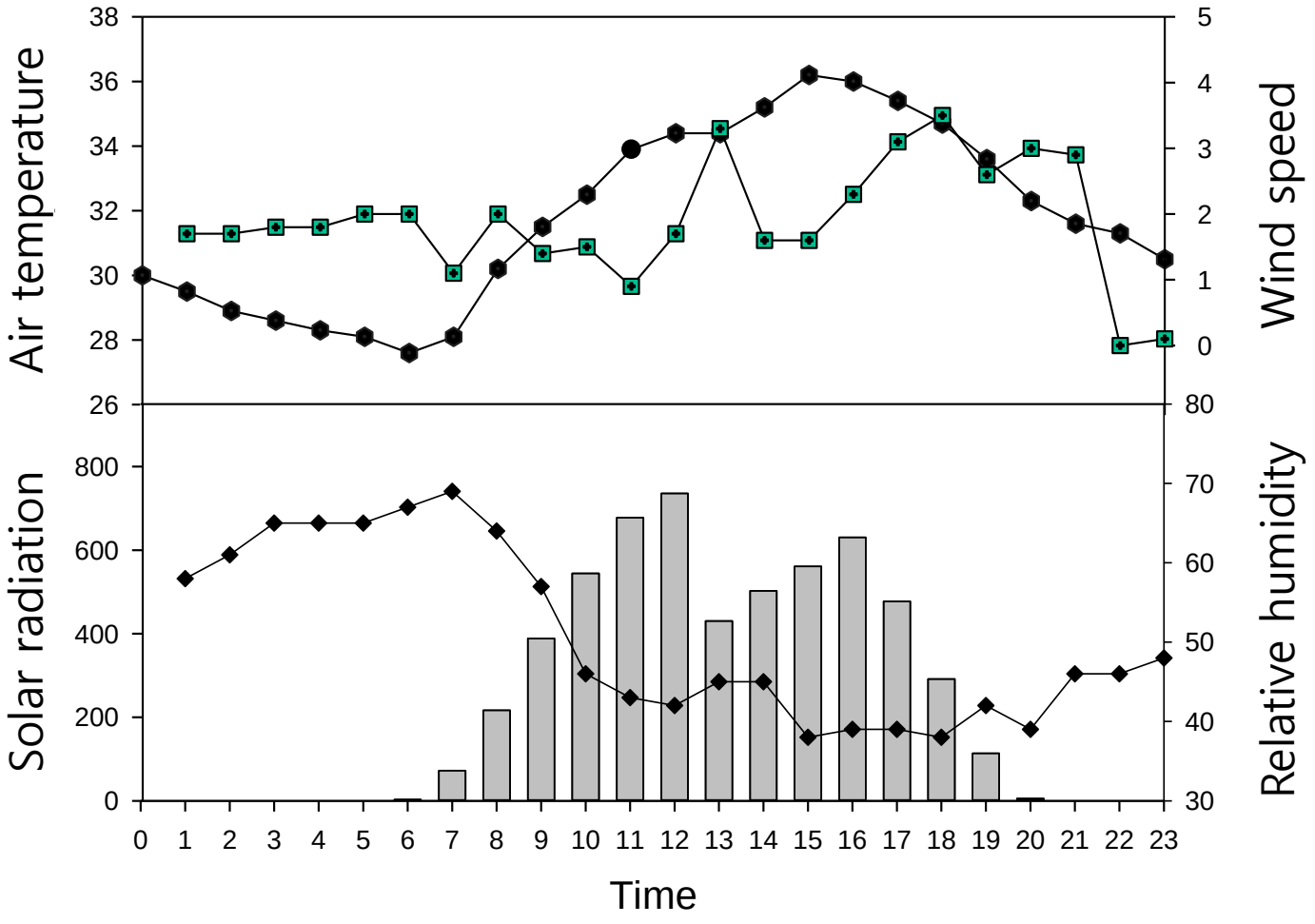
- Output: temperature distribution, (+building configuration for SOLWEIG)

Yi et al. 2015: Estimating spatial patterns of air temperature at building-resolving spatial resolution in Seoul, Korea. IJC (online first)



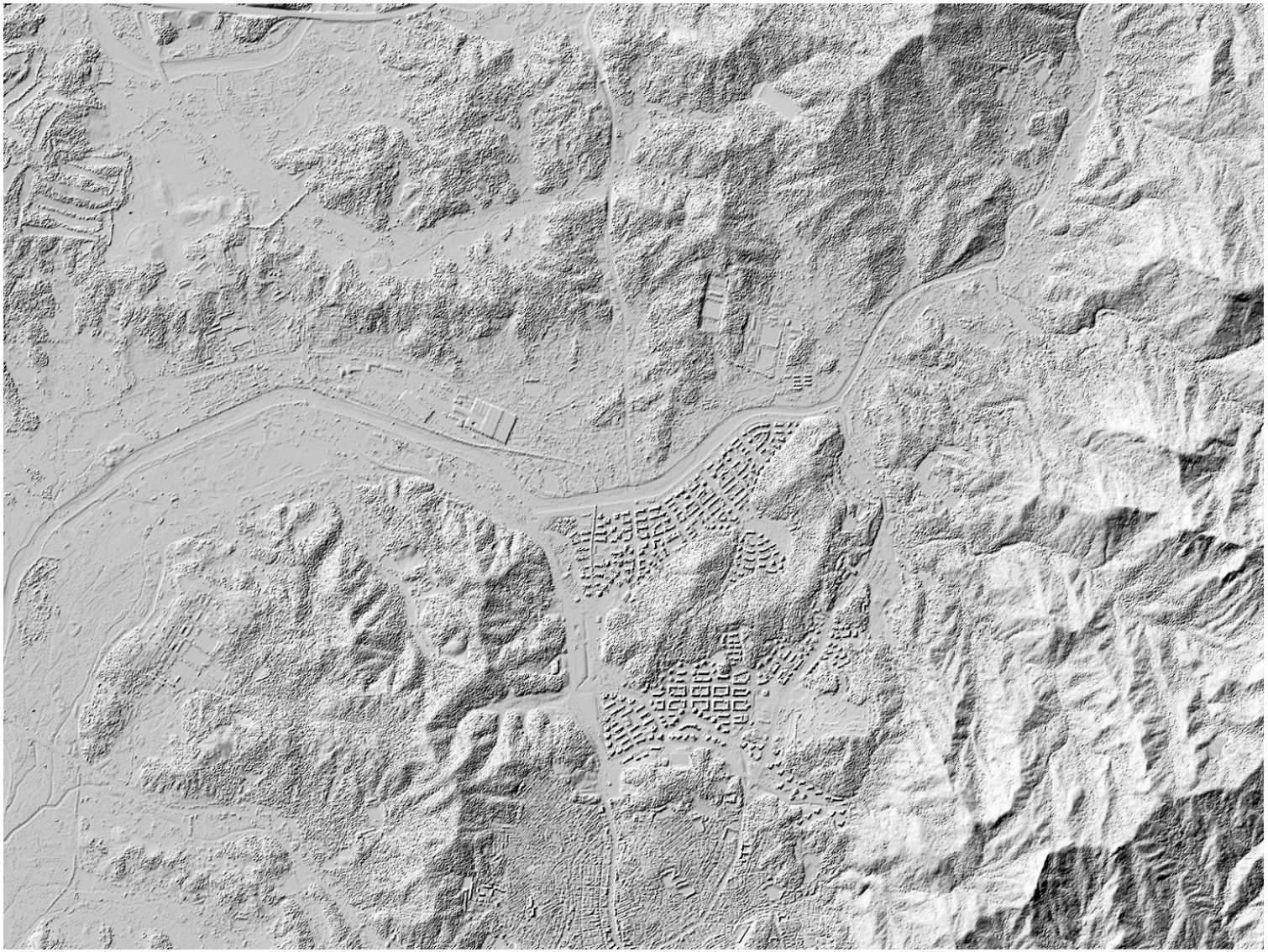
Solar Long Wave Environmental Irradiance Geometry (SOLWEIG)

- Input: building configuration from CAS
  hourly T, RH, Solar Rad at SWS
- Process: sky view factor, solar angle, shadow
- Output: mean radiant temperature (T_{mrt})

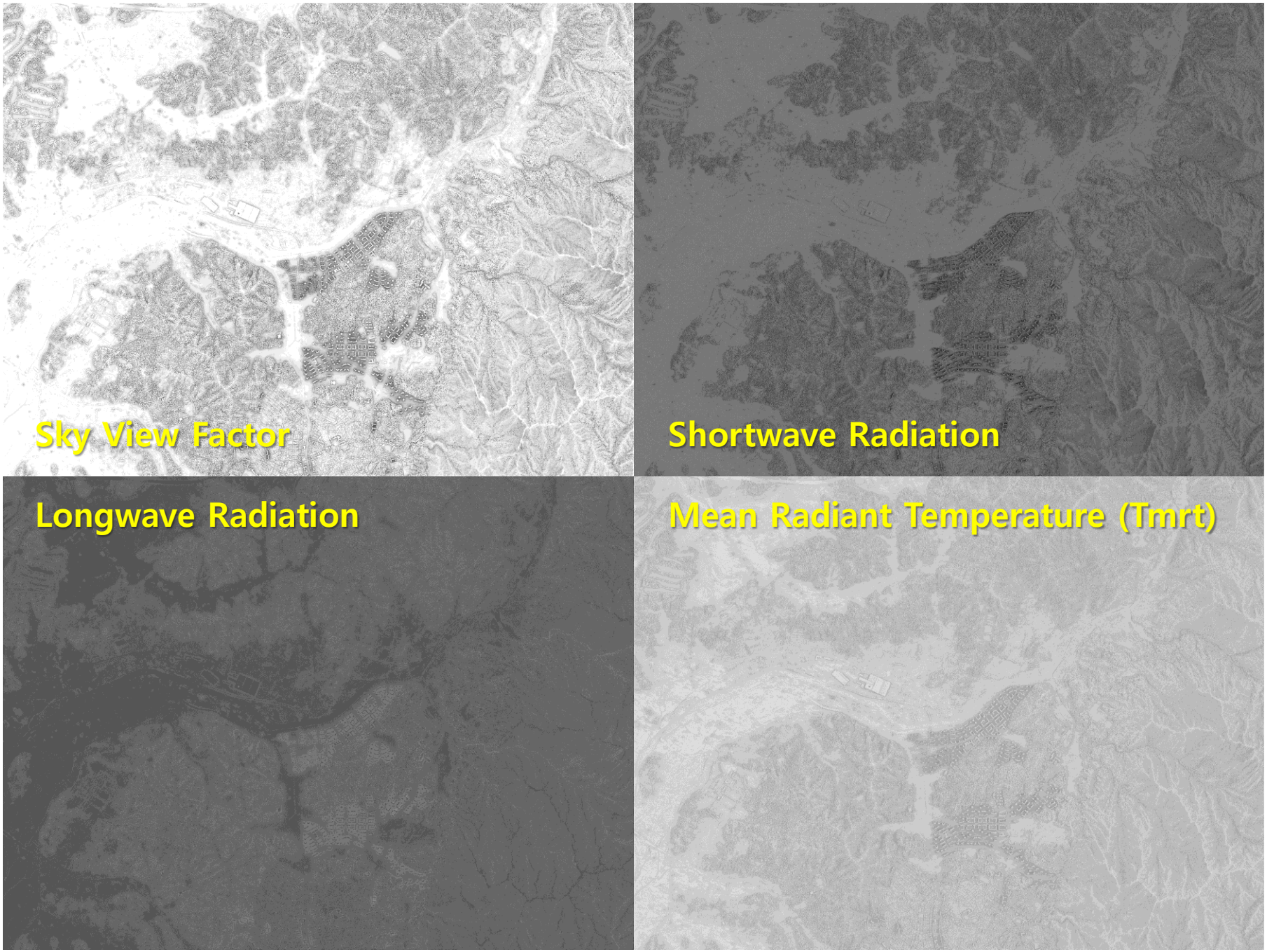


Hourly weather conditions observed at the reference station SWS during the heat event on August 5, 2012

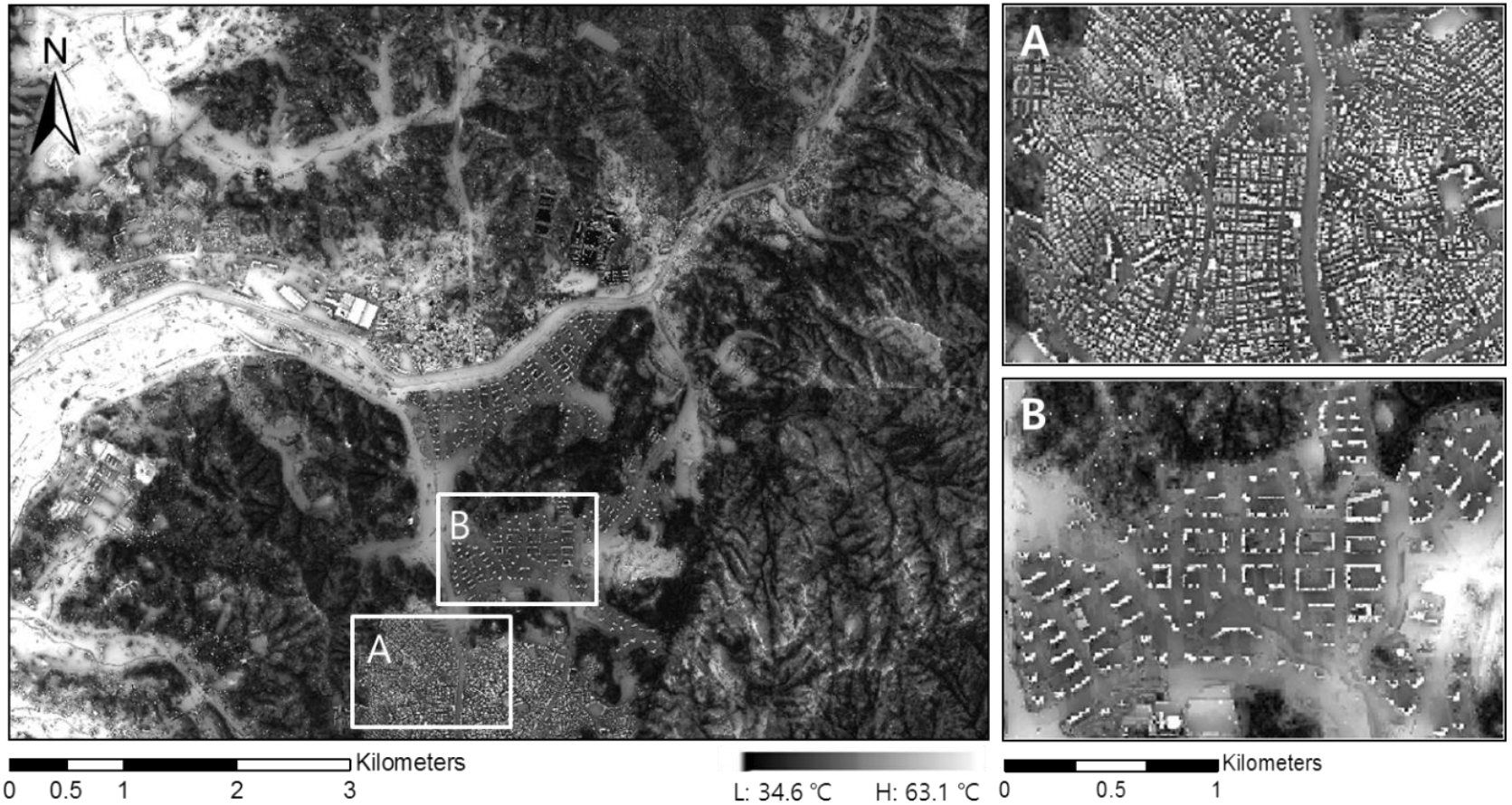
Digital Surface Model (DSM) from CAS



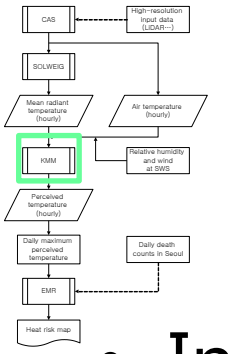
Produced by TUB using CAS (CAP v2.1); data source: NIMR



Produced by TUB using SOLWEIG; DSM data source: NIMR



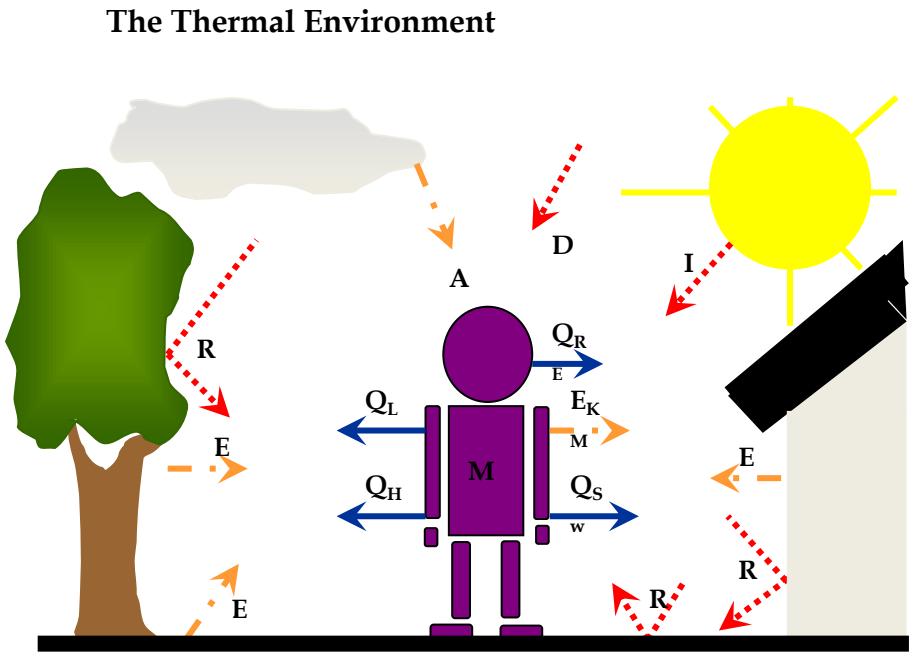
T_{mrt} at DR Eunpyeong during a heat wave event on August 5, 2012 12:00KST
A: old town, B: new town



Klima-Michel Model (KMM)

- Input: T, T_{mrt}, RH, Wind speed

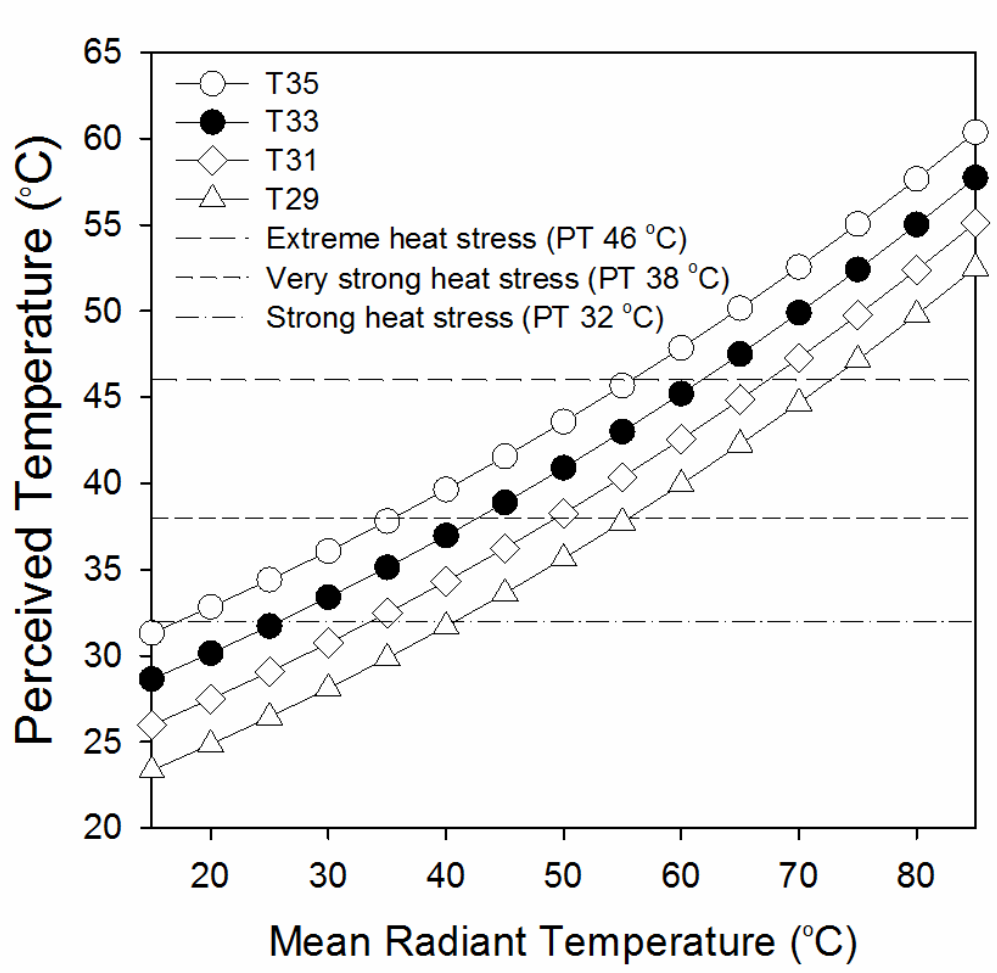
- Process
  - Thermal balance between the human body and the environment



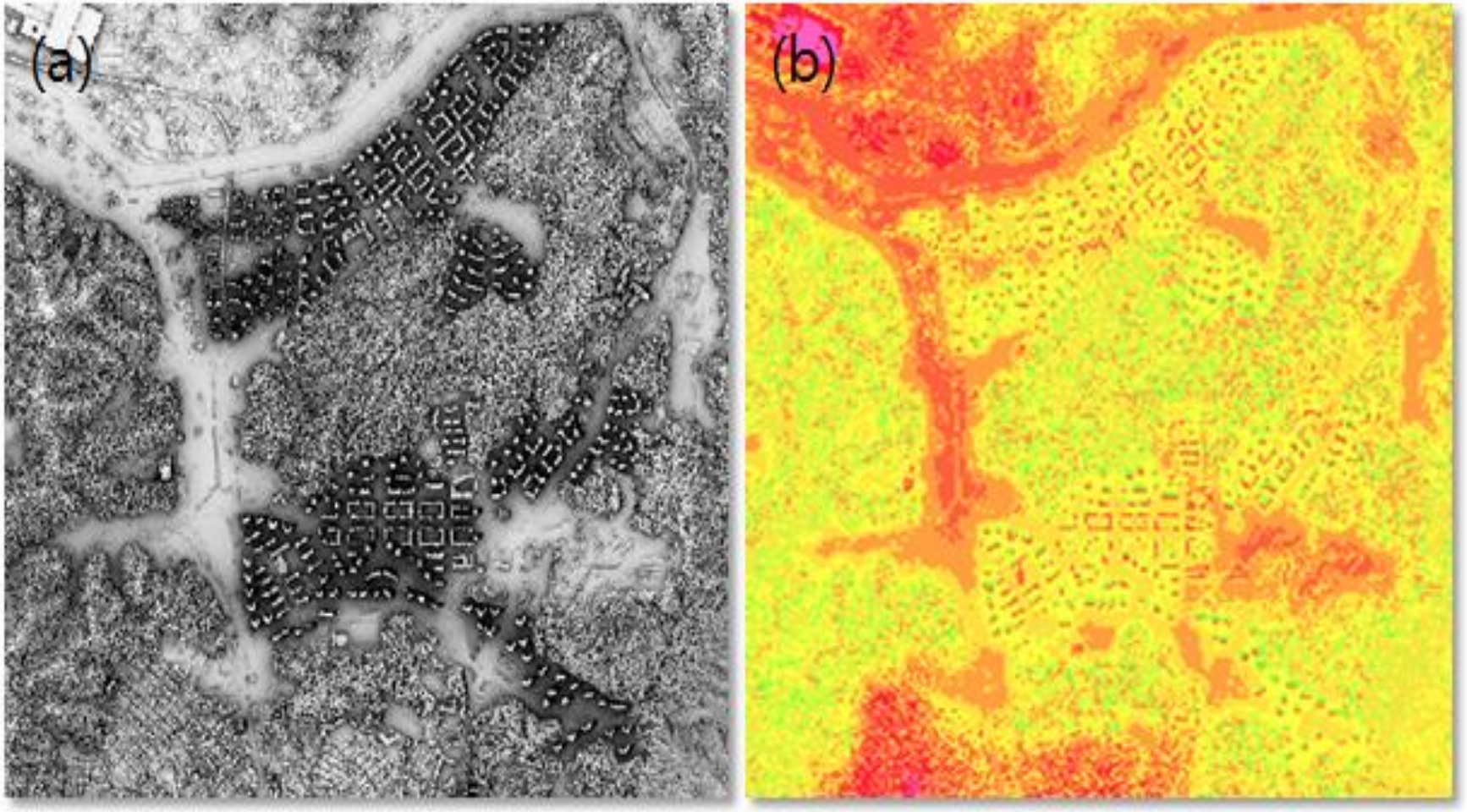
- Output: Perceived temperature (PT)

Perceived Temperature (PT)

- PT calculates heat stress according to radiation (T_{mrt})



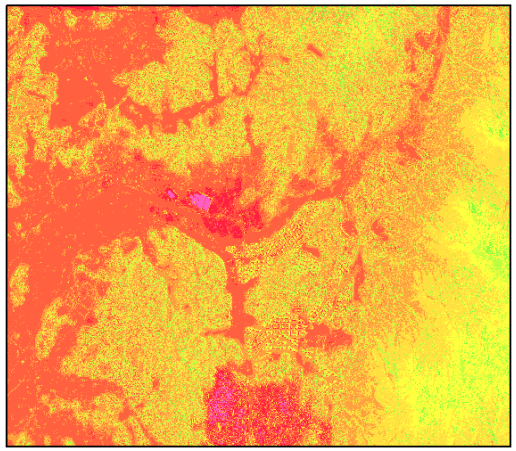
T_{mrt} and PT



Produced by TUB (a, T_{mrt}) and NIMR (b, PT) on a heat wave event of Aug. 5, 2012, 12:00 KST

PT: 15:00 – 20:00 Aug. 5, 2012

15:00



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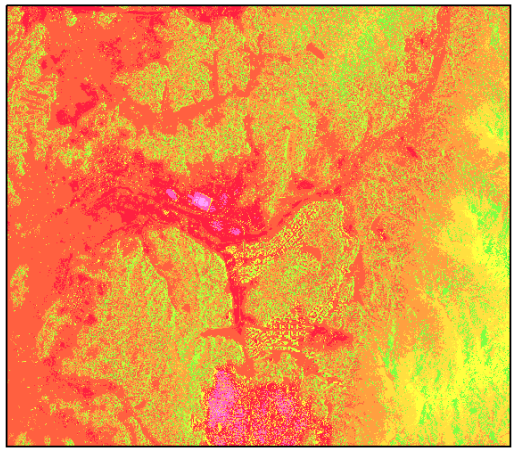

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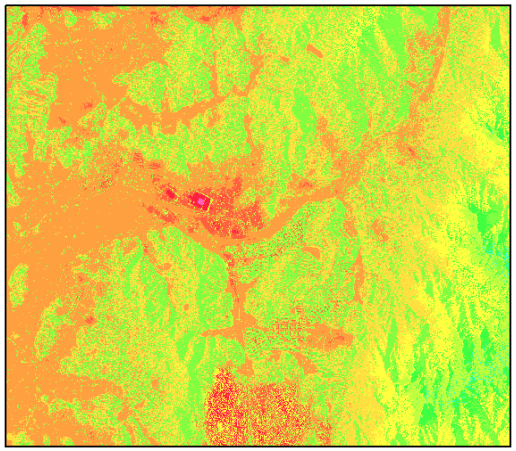

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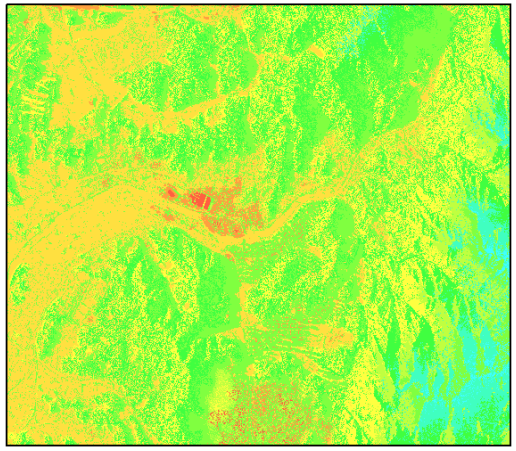

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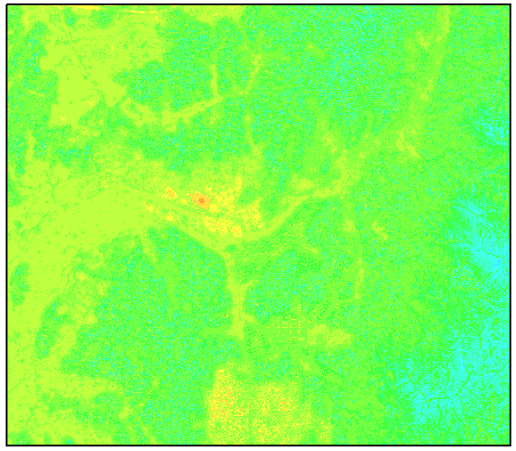

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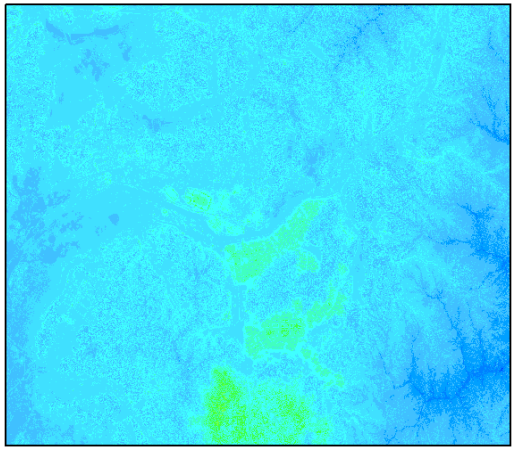
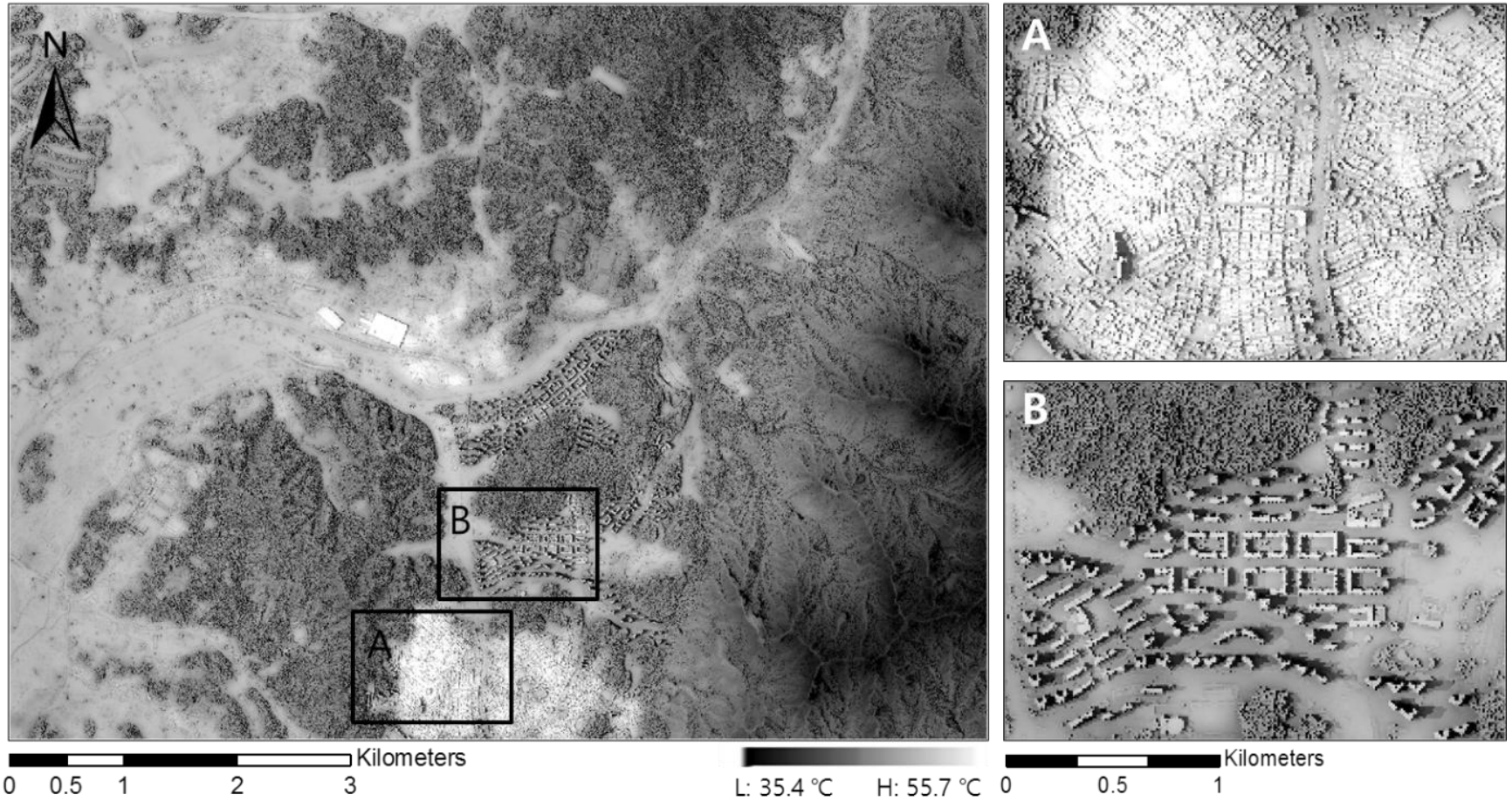
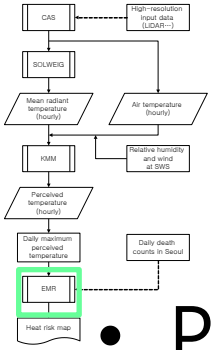




Maximum PT, PT_{max} at the DR during the heat wave event on August 5, 2012
A: old town, B: new town



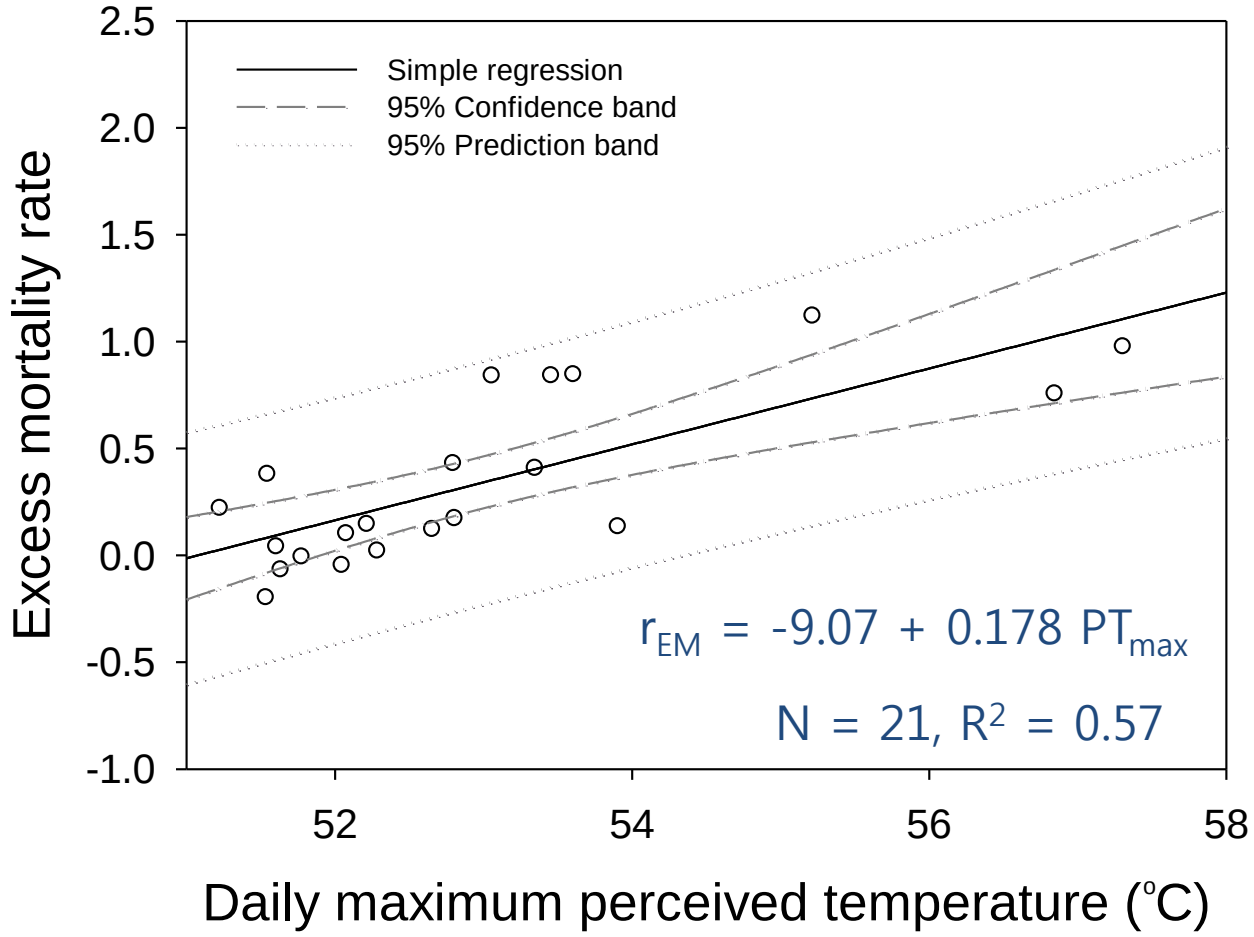
Excess Mortality Rate (r_{EM})

- Purpose: quantify the risk of a heat wave
- Model development
  - $Y(r_{EM})$: increase in daily mortality rate relative to the expected base mortality rate*
  - $X(PT_{max})$: daily maximum PT

ICD Code	Causes of the death
E00~99	Endocrine, nutritional and metabolic disease
F00~99	Mental and behavioral disorders
G00~99	Diseases of the nervous system
I00~99	Diseases of the circulatory system
J00~99	Diseases of the respiratory system
R00~99	Symptoms, signs and abnormal clinical and laboratory findings, NEC

* Daily base mortality rate was estimated as *Kysely* (2004).

Excess Mortality Rate (r_{EM})



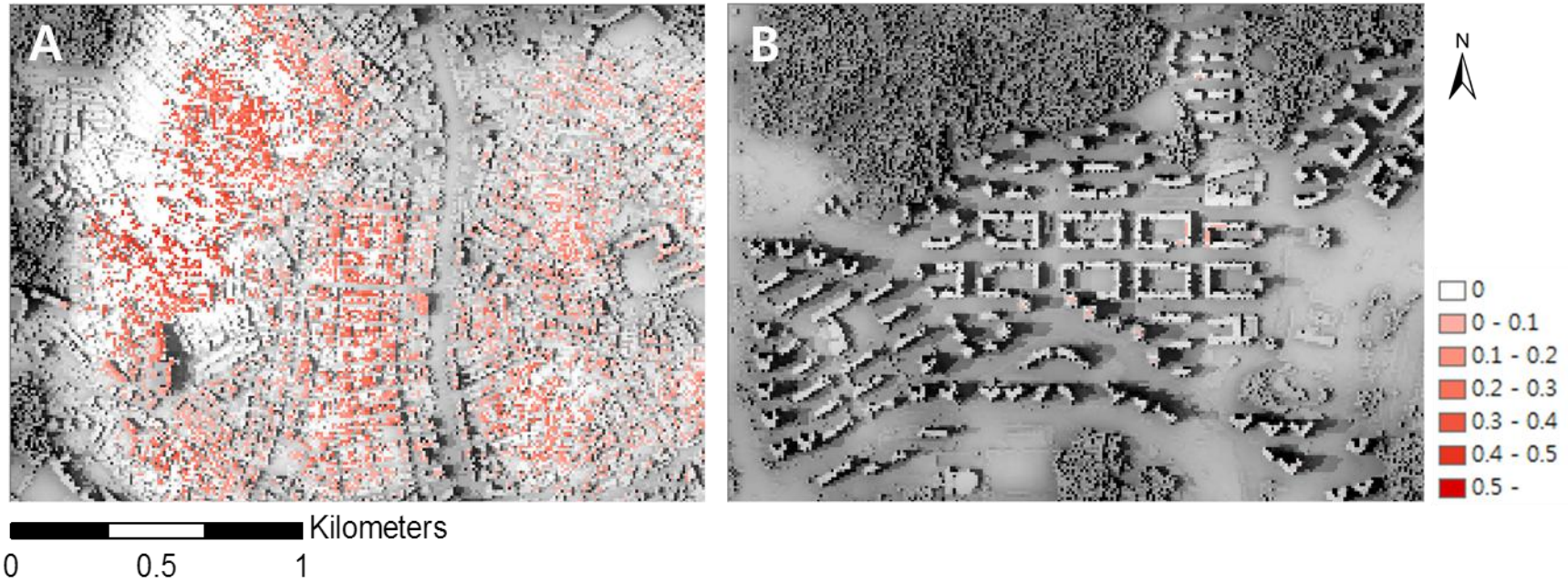
Impact Assessment of an Urban Development

- Heat Wave Event: Aug. 5, 2012
  - Hourly weather conditions from SWS
- Re-development Area: DR of CAS
  - Old and New town areas are included
  - TD & TD′ from CAS, T_{mrt}, PT, and r_{EM}

DR: Detail Region
CAS: Climate Analysis Seoul
TD: Total Temperature Deviation
TD′: Temperature Distribution
PT: Perceived Temperature
T_{mrt}: Mean Radiant Temperature
r_{EM}: Excess Mortality Rate

Assessment of a new town area

"Old" town vs. "New" town

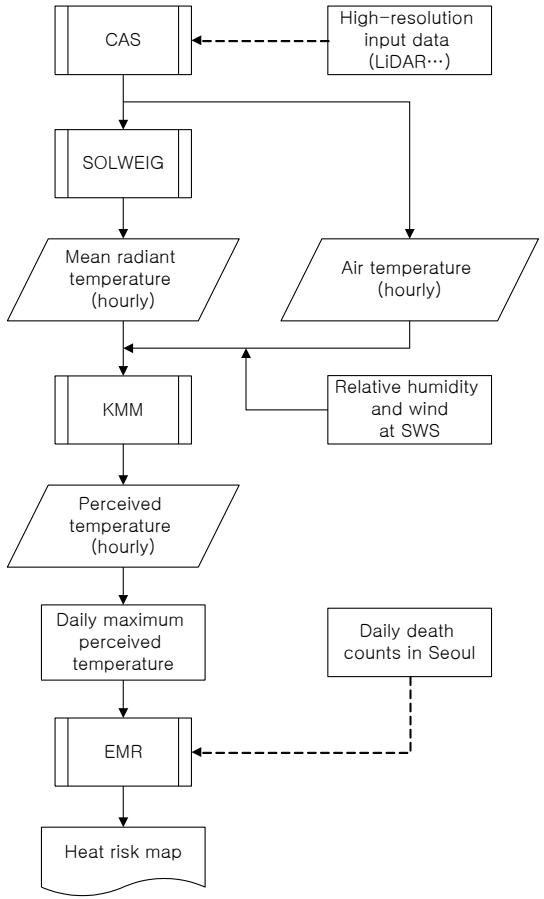


Area	Minimum	Maximum	Mean	Std. dev.	Area: $r_{EM} > 0$
Old town (A)	0	0.507	0.023	0.069	14.3 %
New town (B)	0	0.086	~ 0	0.001	0.1 %

* Record high r_{EM} = 1.12 (25 July, 1994)
(112% increased mortality)

BioCAS : a New Tool for Bio-Climatic Impact Assessment

- Biometeorological models were integrated with high resolution climate analysis system for impact assessment of heat stress over complex urban area.



Kim et al. 2014: BioCAS: Biometeorological Climate impact Assessment System for building-scale impact assessment of heat-stress related mortality. DIE ERDE 145 (1-2): 62-79

Evaluation of the BioCAS at the Whole City Area of Seoul

- Challenges:
  - **Scalability**: Impact assessment over the entire Seoul at very high resolution of 5 m is challenging.
  - **Validity**: Evaluation of the assessed impact based on observed human response is also very challenging.

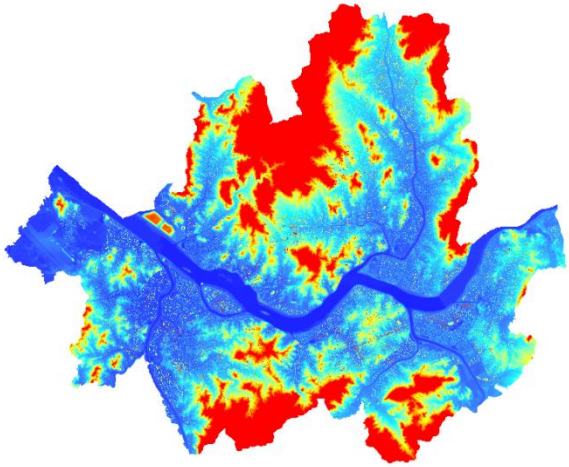
➢ The evaluation was performed at district-level by comparing the mortality difference and estimated heat wave impact.

Evaluation of BioCAS based on Health Impact at District Level

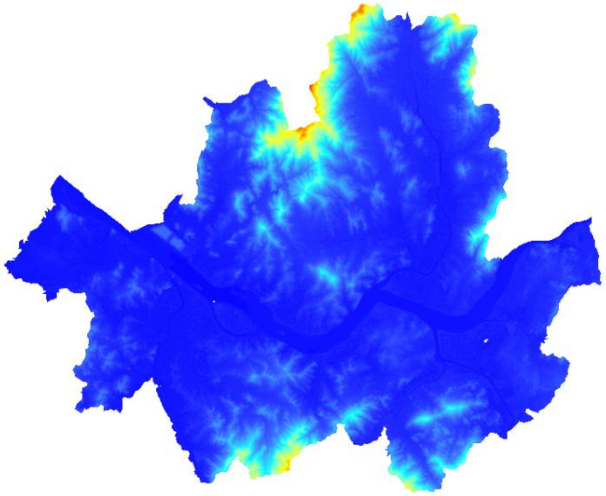
- BioCAS analysis
  - Entire Seoul area (SR)
  - Heat wave event date: Aug. 5, 2012
- Analysis data and period
  - Daily mortality: 2004 – 2013 (10 years)
  - Daily visits by patients: 2006 – 2011 (6 years)
  - Heat specific deaths and visits only
- Statistical comparison
  - Correlation analysis between PT_{max} / r_{EM} and observed mortality / hospital visits by patients

Evaluation: BioCAS over SR

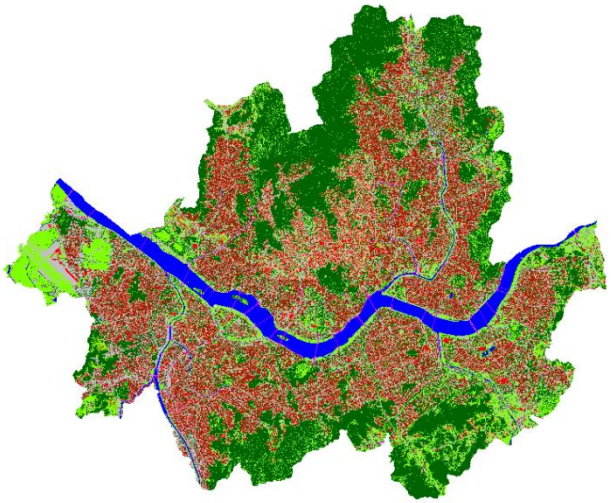
- Input data @ < 5 m resolution (37 x 30 km)



Digital Building Model



Digital Vegetation Model



Land Cover

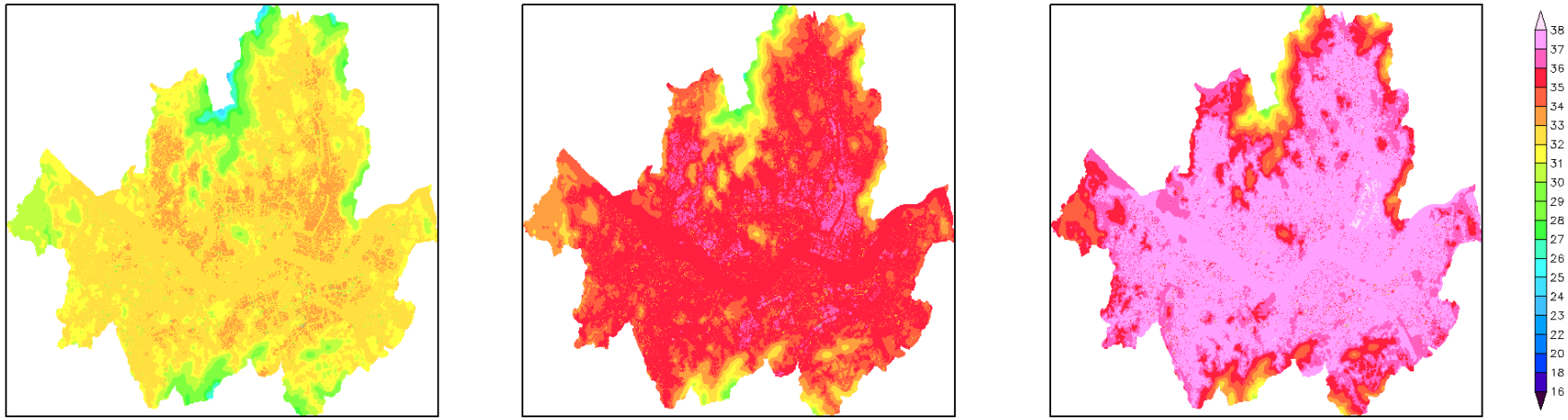
- Computational problem → run @ 25 m res.

Evaluation: BioCAS over SR

- BioCAS analysis over Seoul city (SR)
  - Distribution of T, T_{mrt}, PT, PT_{max}, and r_{EM} @ 25 m resolution
  - Heat wave event date: Aug. 5, 2012
  - Other conditions were set as the same as in the impact assessment of the new town
- Data aggregation for the 25 districts
  - PT_{max} and r_{EM}
  - Over the entire district area / over residential area only

Evaluation: BioCAS over SR

- Temperature of Seoul on Aug. 5, 2012
  - Estimated by CAS



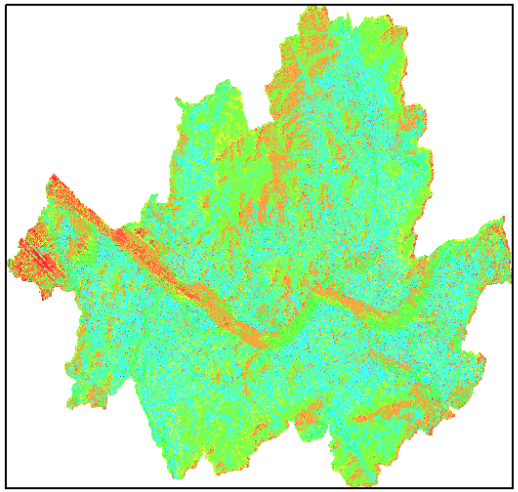
09:00 LST

12:00 LST

15:00 LST

Evaluation: BioCAS over SR

- Mean Radiant Temperature (T_{mrt}) on Aug. 5, 2012
  - Estimated by SOLWEIG



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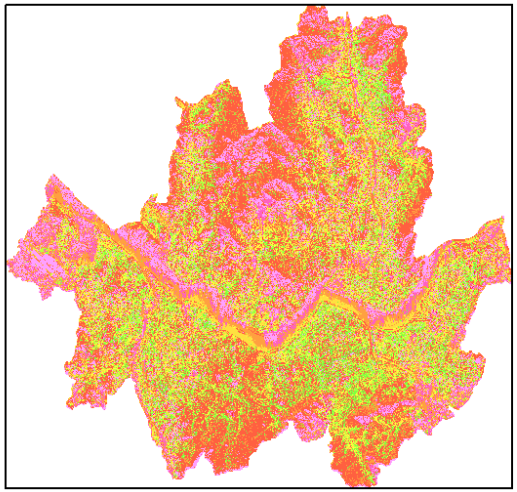
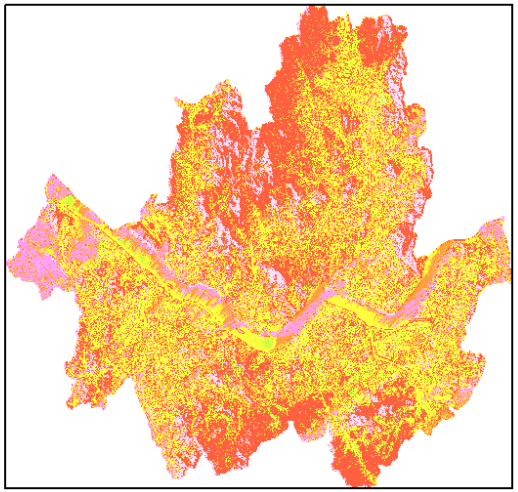


12:00 LST



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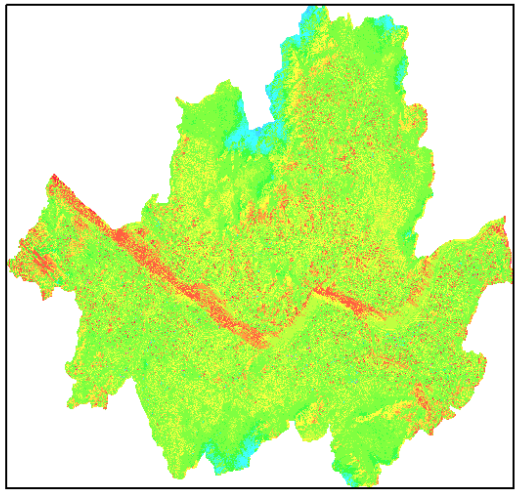
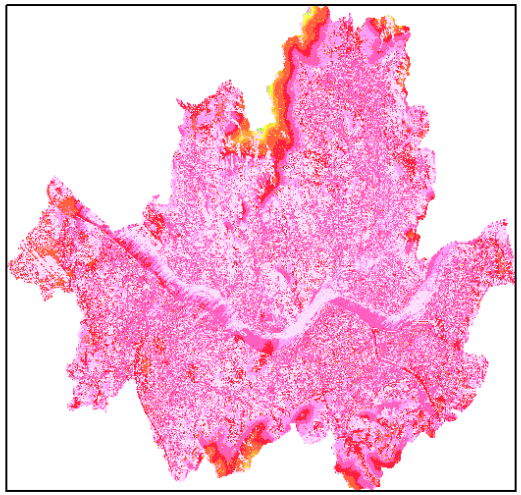
Evaluation: BioCAS over SR

- Hourly Perceived Temperature (PT) of Seoul on Aug. 5, 2012
  - Estimated by KMM



09:00 LST

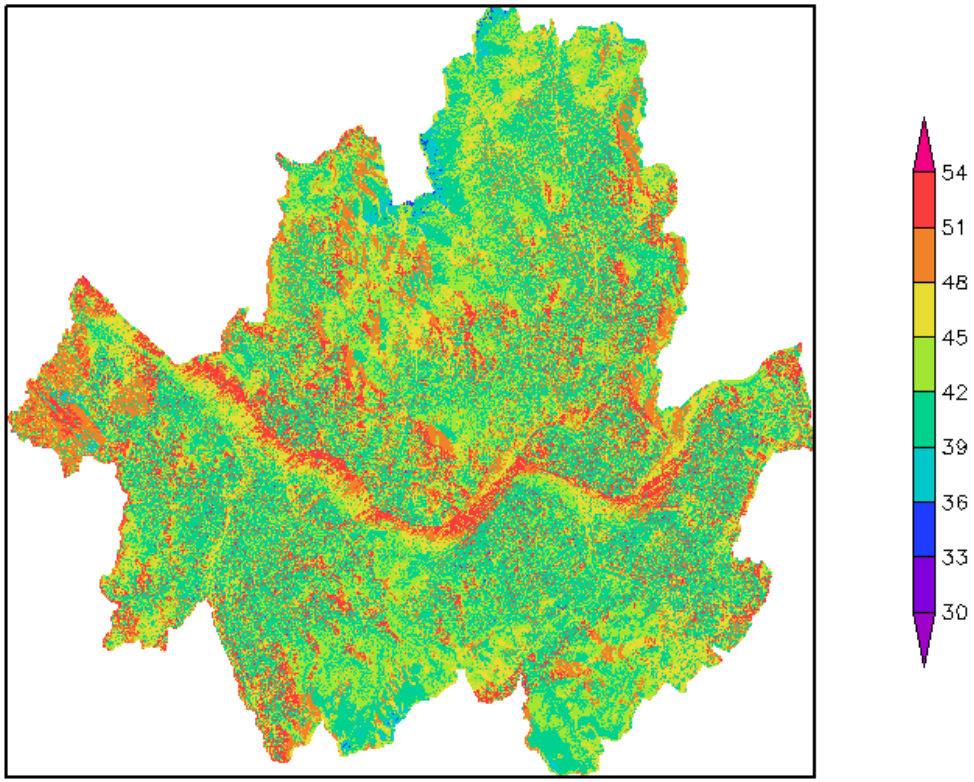
12:00 LST



15:00 LST

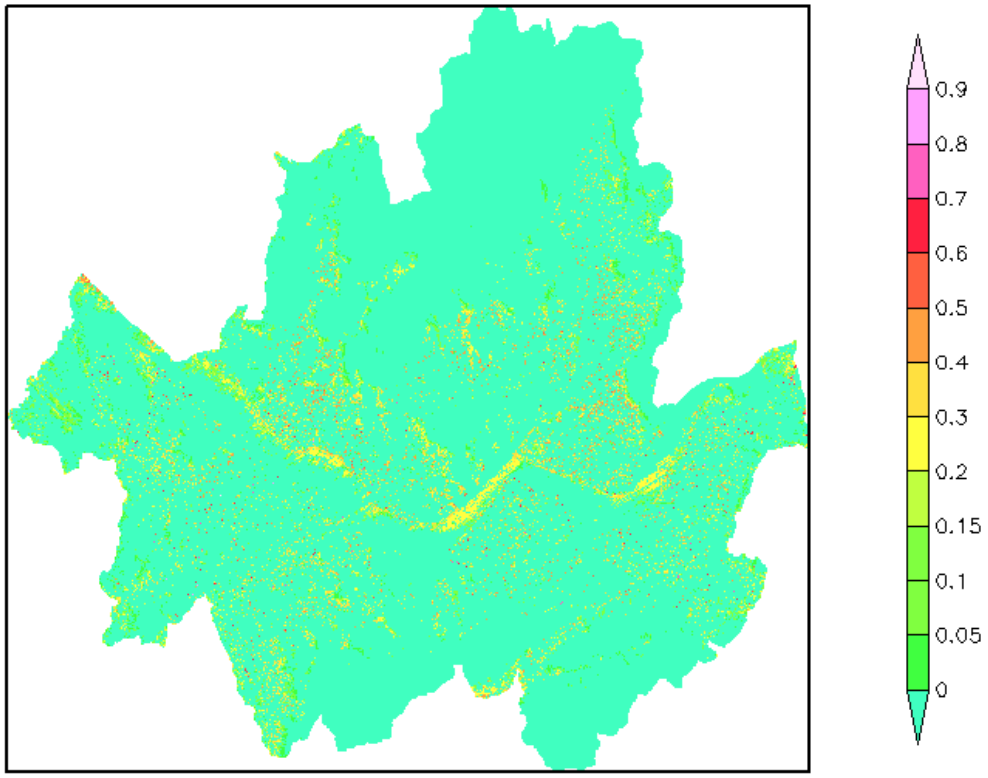
Evaluation: BioCAS over SR

- Daily Max PT (PT_{max}) of Seoul
  - Estimated by the KMM



Evaluation: BioCAS over SR

- Excess Mortality Rate (r_{EM})
  - Estimated by the EMR

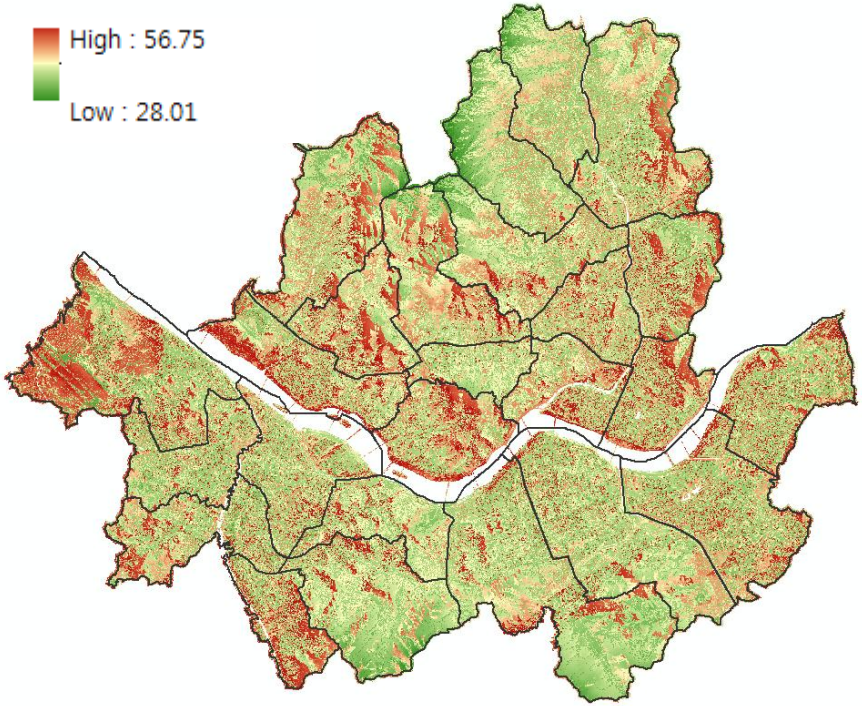


Evaluation: BioCAS over SR

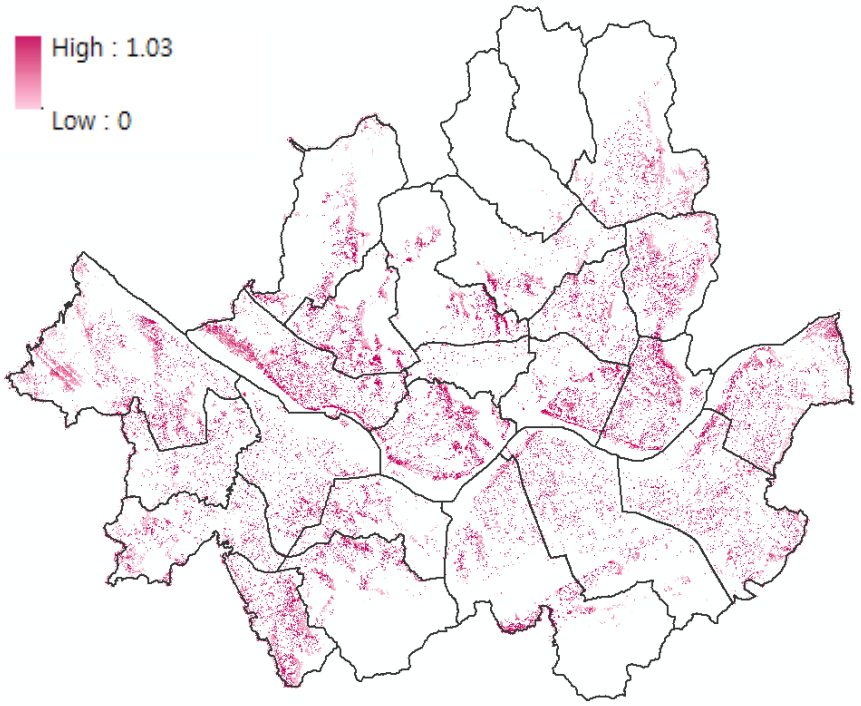
- Data aggregation for the 25 districts
  - PT_{max} and r_{EM}
  - Over the entire district and over residential area only

Evaluation: BioCAS over SR

- Data aggregation for the 25 districts
  - Over the entire district



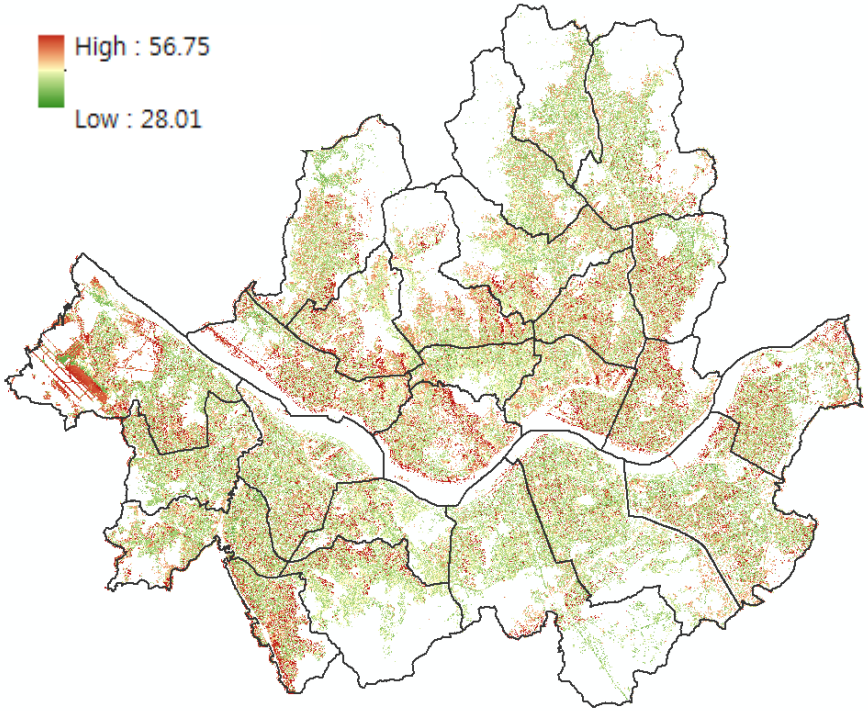
PT_{max} by district



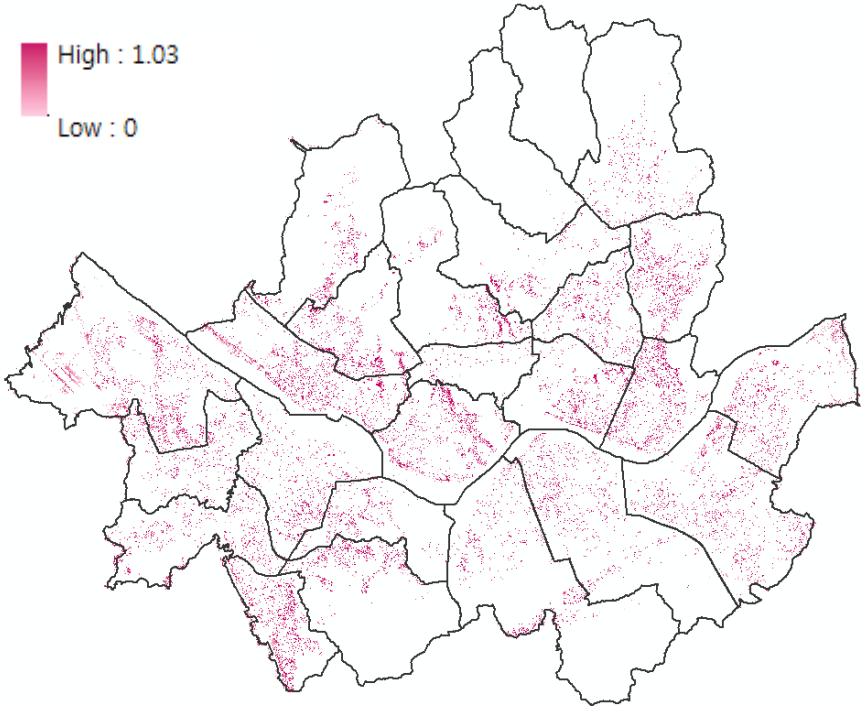
r_{EM} by district

Evaluation: BioCAS over SR

- Data aggregation for the 25 districts
  - Over residential area only



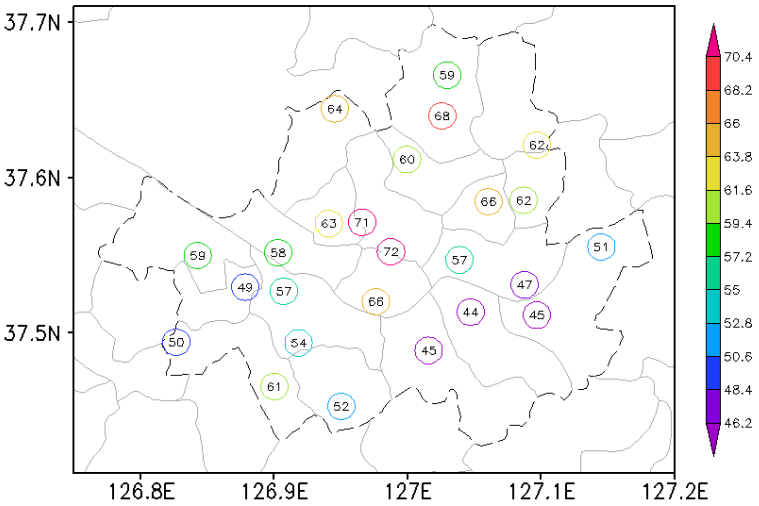
PT_{max} by district



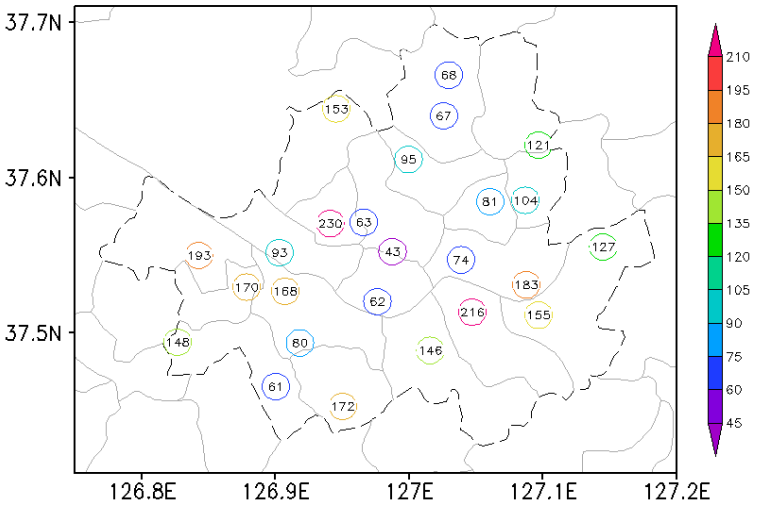
r_{EM} by district

Evaluation: Mortality and hospital visit by patients data

- Analysis data and period
  - Daily mortality: 2004 – 2013 (10 years)
  - Daily visits by patients: 2006 – 2011 (6 years)
  - Heat specific mortality and # of visits only



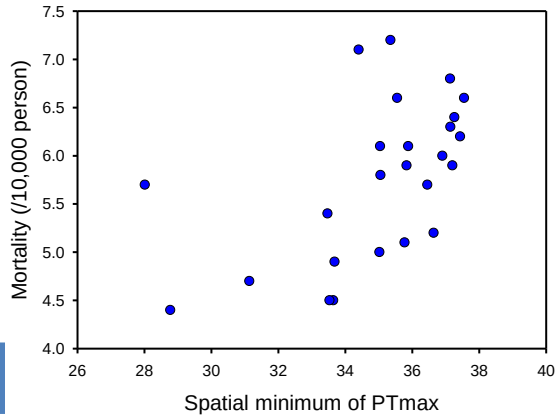
Mortality (2004-2013)



No. of Patients (2006-2011)

Evaluation: Statistical Comparison

- Pearson's correlation coefficients
  - Estimated PT_{max} @ residential area vs. observed mortality / visits



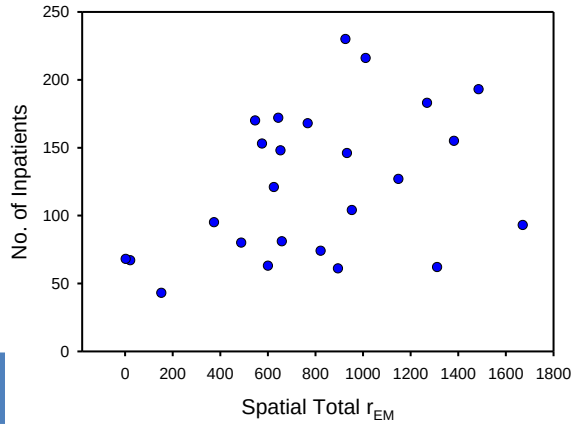
PT_{max}	Spatial		
	Minimum	Maximum	Mean
Mortality	0.53**	-0.584**	0.234NS
(p)	(0.007)	(0.002)	(0.26)
Hosp. Visits	-0.340NS	0.422*	-0.017NS
(p)	(0.10)	(0.036)	(0.93)

  - Min. and Max. of the spatial PT_{max} distribution were positively correlated to mortality and # of visits by patients, but mean was not.

➢ Spatial averaging of PT_{max} may not explain heat-induced vulnerability.

Evaluation: Statistical Comparison

- Pearson's correlation coefficients
  - Estimated r_{EM} vs. observed mortality / visits by patients



r_{EM}	Spatial		
	Maximum	Mean	Total
Mortality	-0.105^{NS}	-0.243^{NS}	0.11^{NS}
(p)	(0.62)	(0.24)	(0.60)
Hosp. Visits	0.515**	0.0723^{NS}	0.387*
(p)	(0.009)	(0.73)	(0.06)

  - Max. and Total of the spatial r_{EM} distribution were positively correlated to # of visits by patients, but mean was not.

➢ Spatial averaging of r_{EM} also may not explain heat-induced vulnerability.

➢ The r_{EM} model needs update based on observed data at district-level.

Conclusion

- First evaluation of bio-climatic impact assessment system (BioCAS) based on real-world observed human response to heat waves.

- It was evaluated at district-level by comparing the mortality and hospital visits by patients to the assessed heat impact.
  - Spatial maximum or minimum of heat wave impact was more important than mean values.

- The evaluation demonstrated that the **localized heat wave vulnerability** **by buildings and vegetation** did cause deaths and other health problems.
  - Building-resolving analysis is essential for bio-climatic assessment!