A 2-D urban canopy model development and its application on future climate study

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3. Department of Geography, National Taiwan University

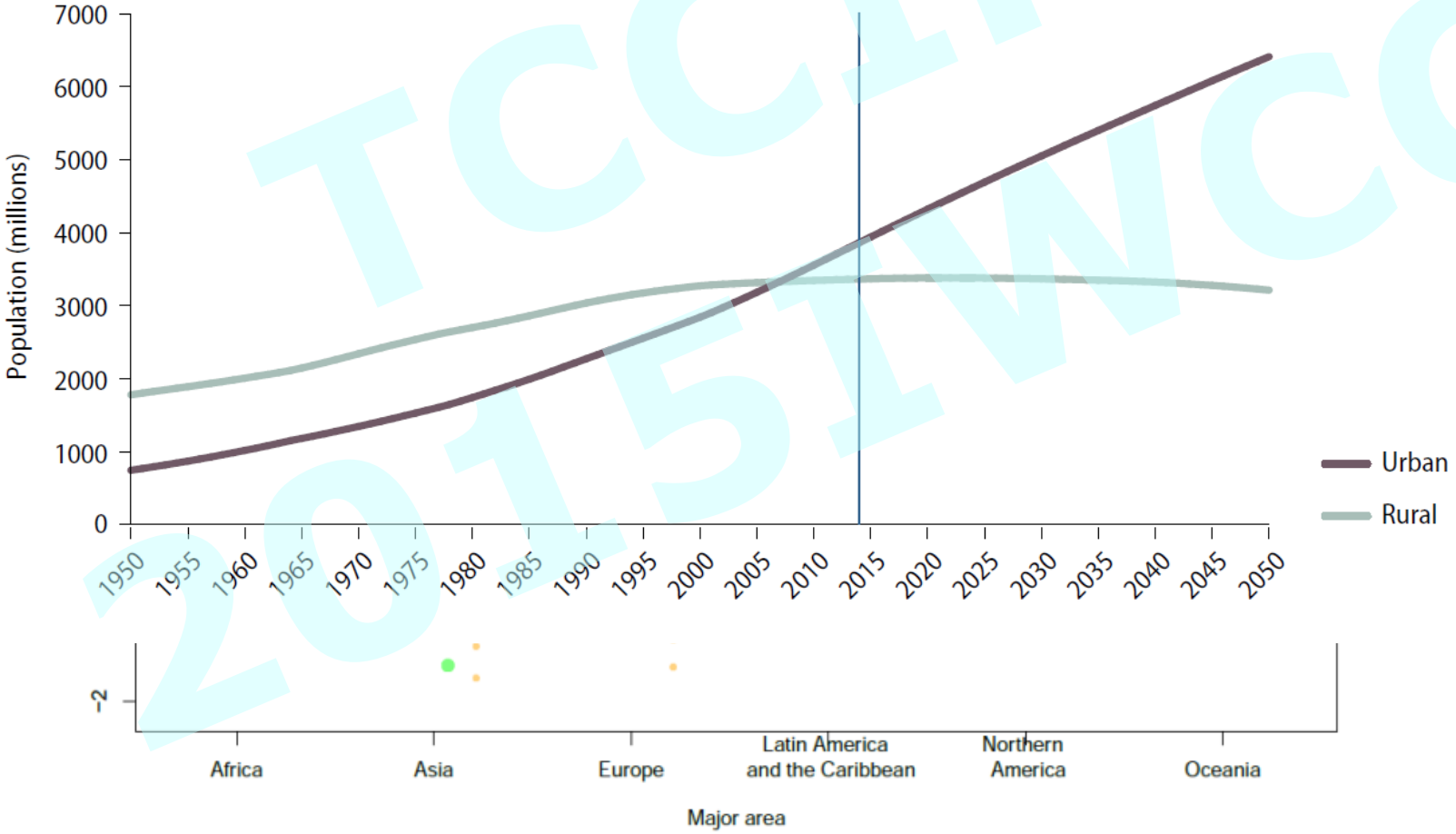
Workshop on high-resolution climate simulation, projection, application
20 Jan, 2015

World Urbanization Prospects

A majority of the world's population lives in urban areas

Figure 2.

Urban and rural population of the world, 1950–2050



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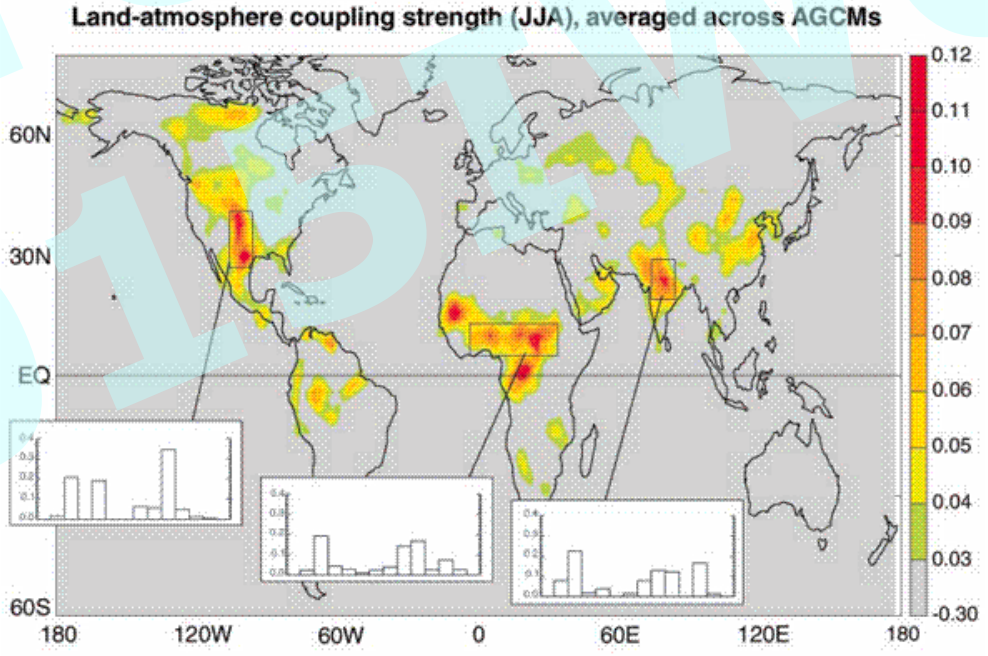
The importance of land use change

Science
AAAS

The Importance of Land-Cover Change in Simulating Future Climates
Johannes J. Feddema, *et al.*
Science **310**, 1674 (2005);
DOI: 10.1126/science.1118160

Science
AAAS

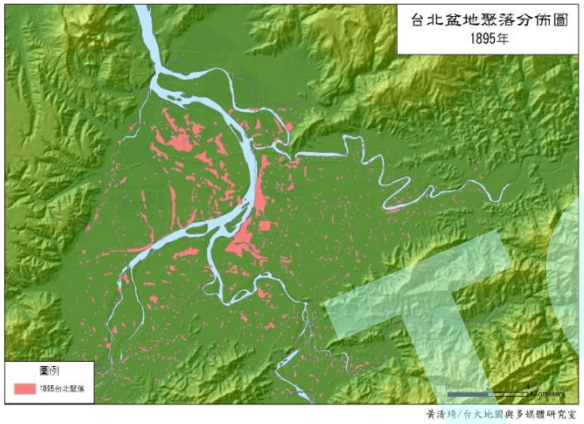
Regions of Strong Coupling Between Soil Moisture and Precipitation
Randal D. Koster, *et al.*
Science 305, 1138 (2004);
DOI: 10.1126/science.1100217



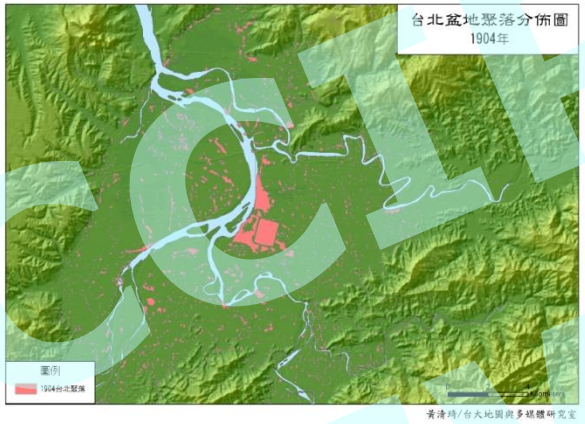
Koster et al., 2004, Science

Urbanization History of Taipei

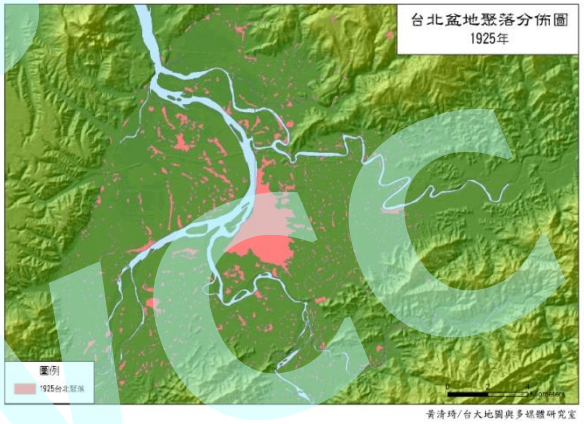
1895



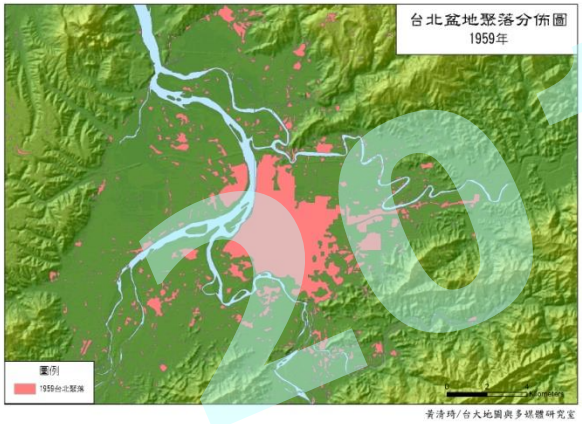
1904



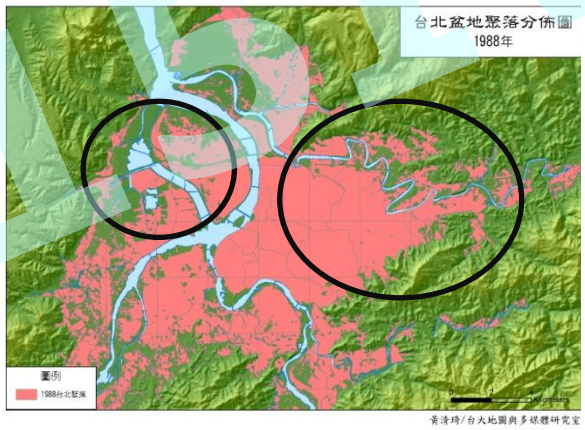
1925



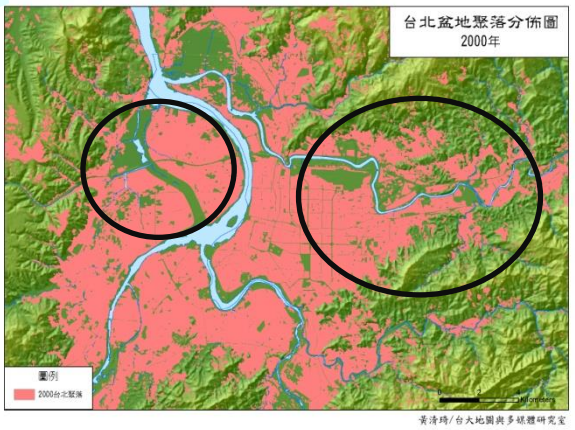
1959



1988

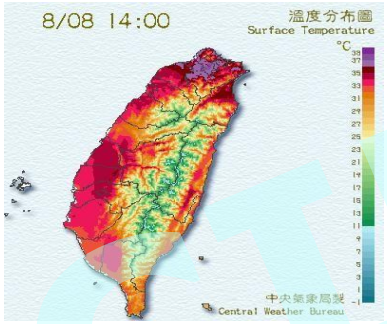


2000



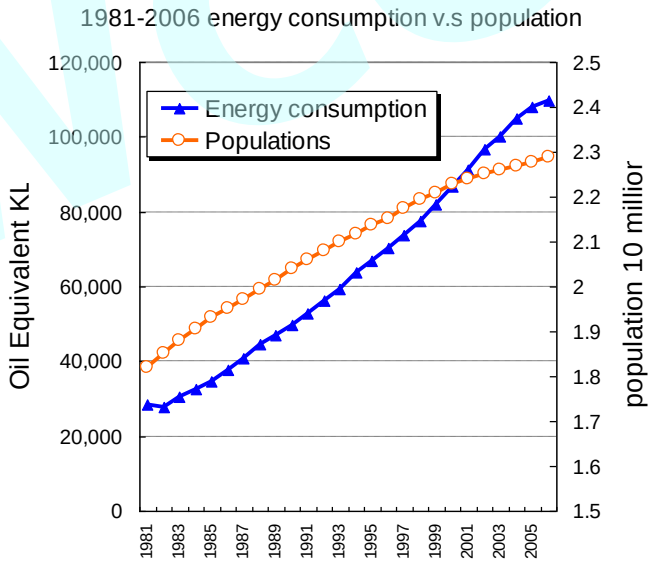
(provided by Prof. Lai Chun Kuei, NTU)

Heat wave in Taipei



Urban heat island effect:

Elevated temperatures in urban environments. (Photo: NASA)



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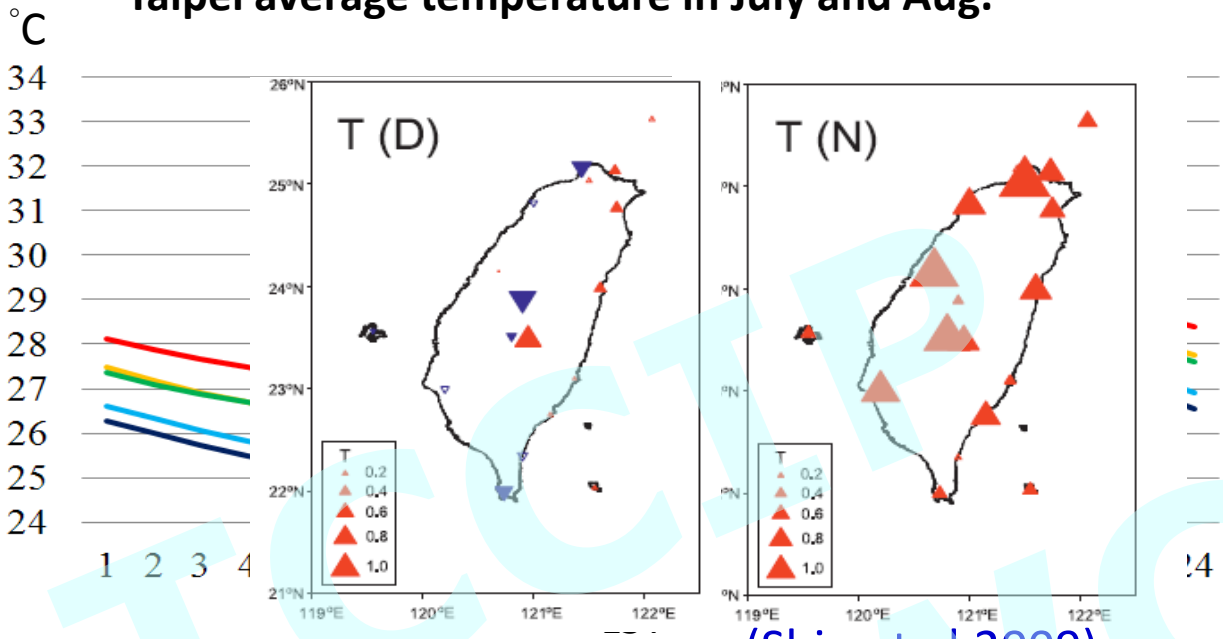
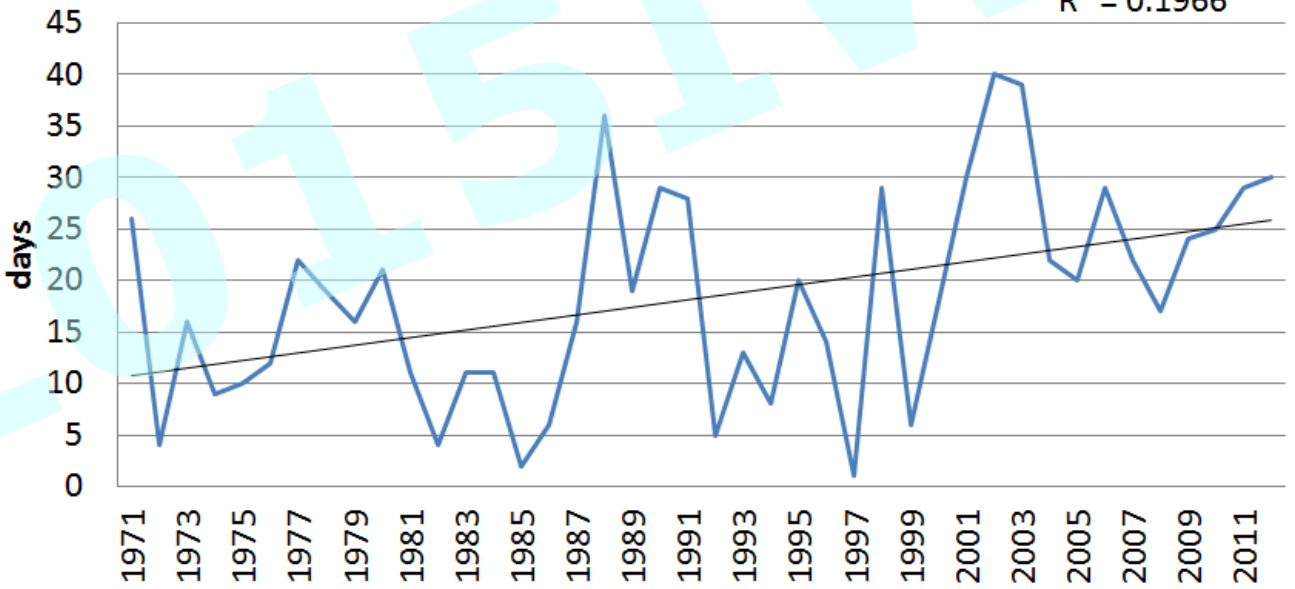
Taipei average temperature in July and Aug.



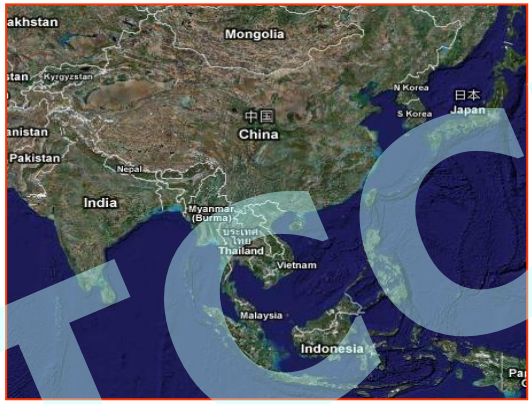
(Shiu et al.2009)

Daily maximum temp >35.2 ℃ @ Taipei

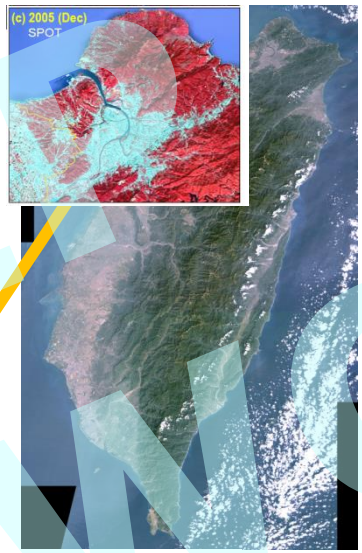


Cross scale modeling system: From regional to urban scale (WRF-UCM)

Regional scale

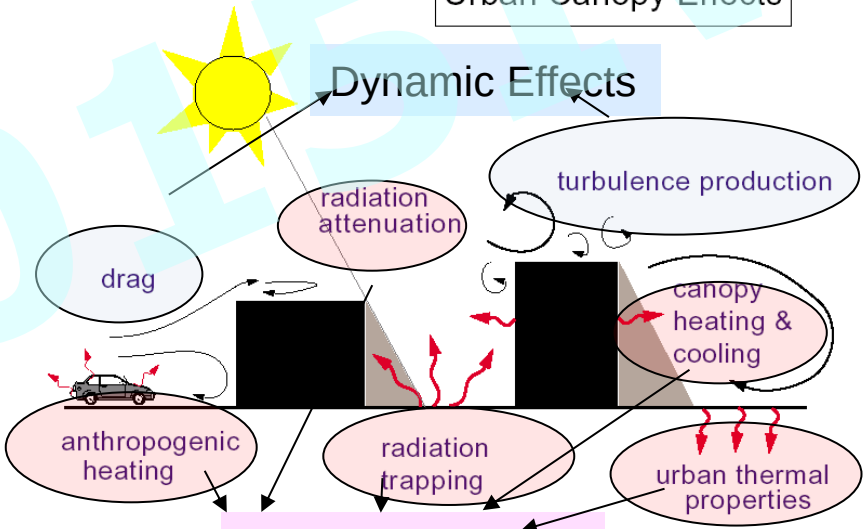


Local scale



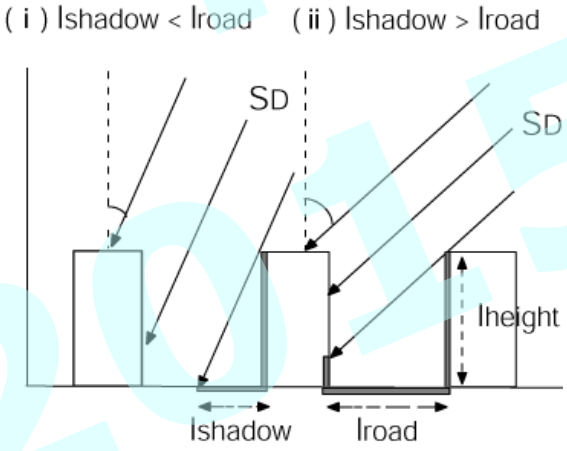
Urban scale

Urban Canopy Effects

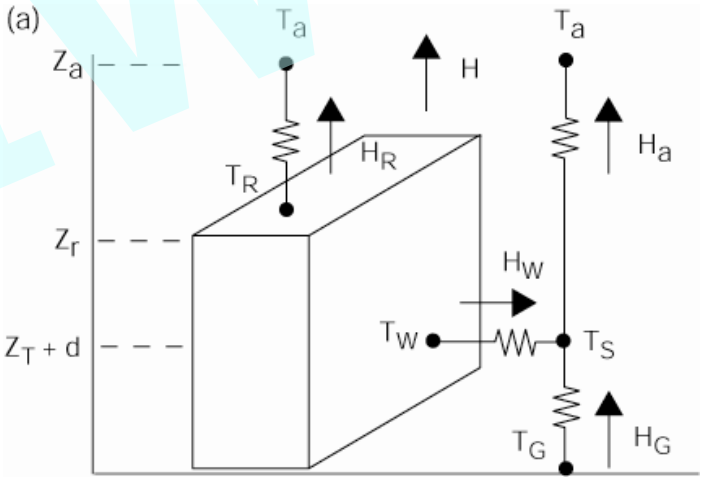


WRF/Urban Canopy Model

- Single layer Urban-Canopy Model (1-D) (UCM, Kusaka et al., 2004)
- **UCM** treats man-made surfaces
  - urban geometry (orientation, diurnal cycle of solar azimuth), symmetrical street canyons with infinite length
  - Shadowing from buildings and reflection of radiation
  - Anthropogenic heating
  - Multi-layer roof (HR), wall (HW) and road (HG) models



Shadow and Radiation Trapping



Temperatures and Thermal Transfer

(Kusaka et al., 2004)

Atmospheric Environment 42 (2008) 5635–5649

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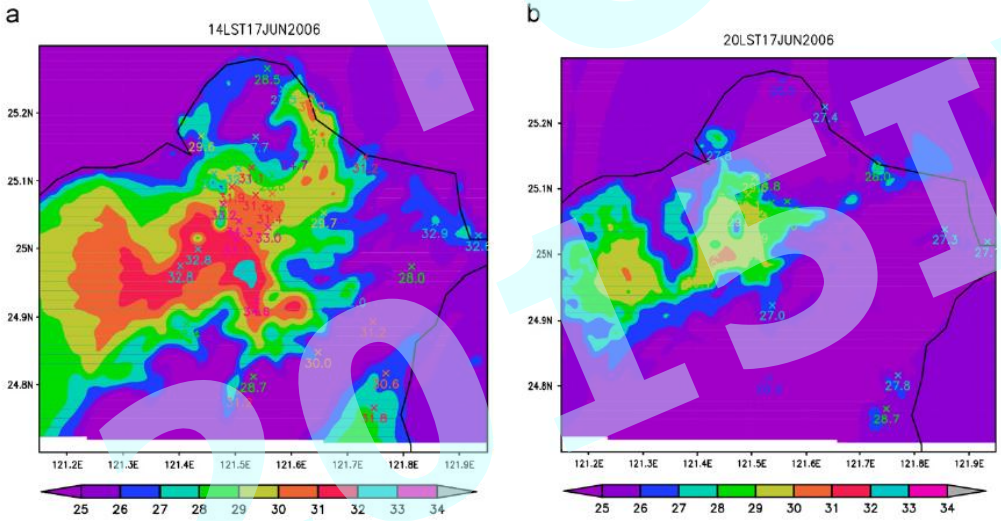
Urban heat island effect and its impact on boundary layer development and land–sea circulation over northern Taiwan

Chuan-Yao Lin [a,*], Fei Chen [b], J.C. Huang [a], W.-C. Chen [a], Y.-A. Liou [c], W.-N. Chen [a], Shaw-C. Liu [a]



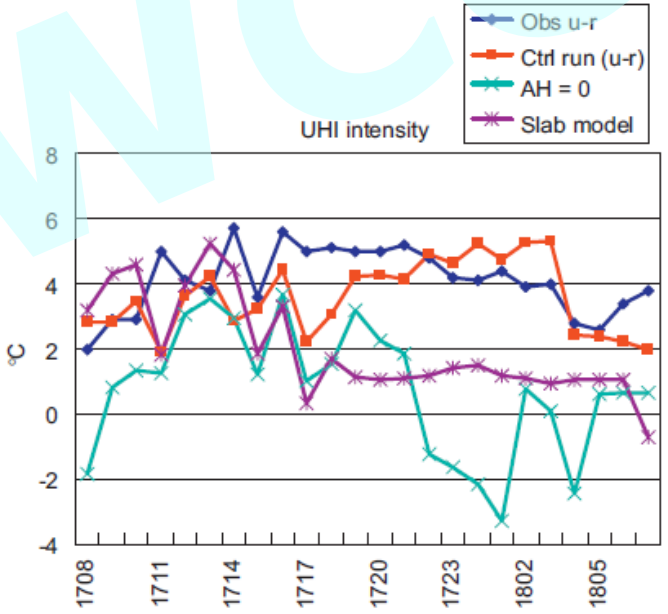
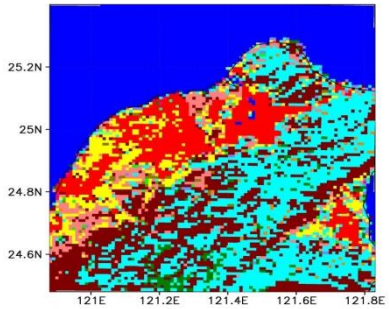


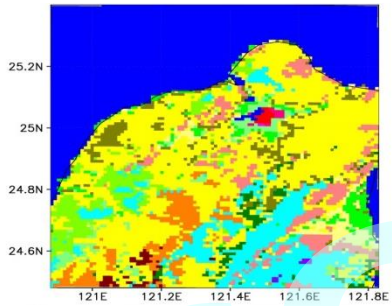
Fig. 10. The time series of urban heat island intensity among observation and control run, case AH0, and case SLAB.

(Lin et al. 2008 A.E.)

WRF-Noah UCM model study the summer thunderstorm

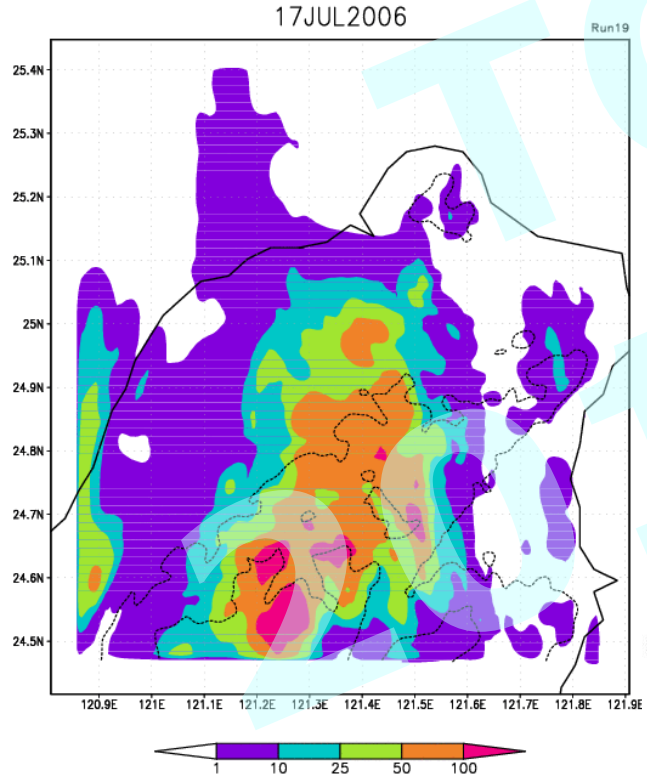


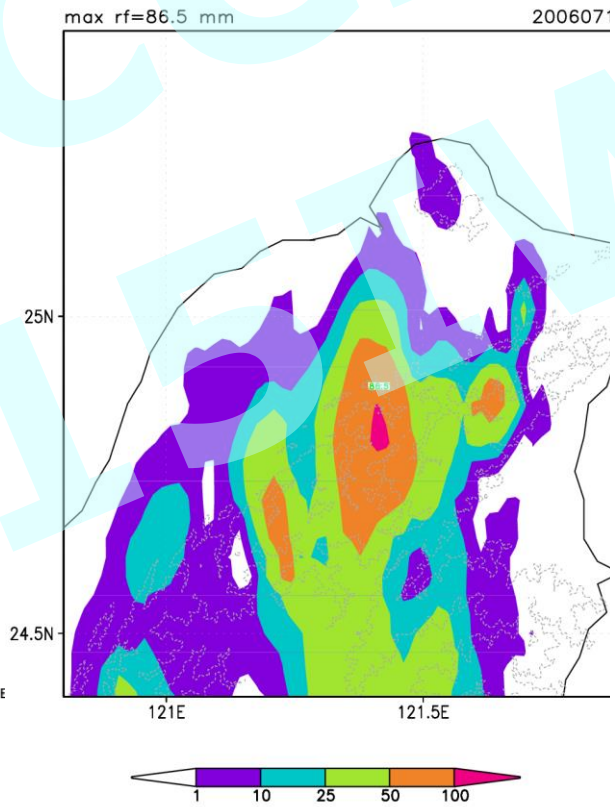
MODIS

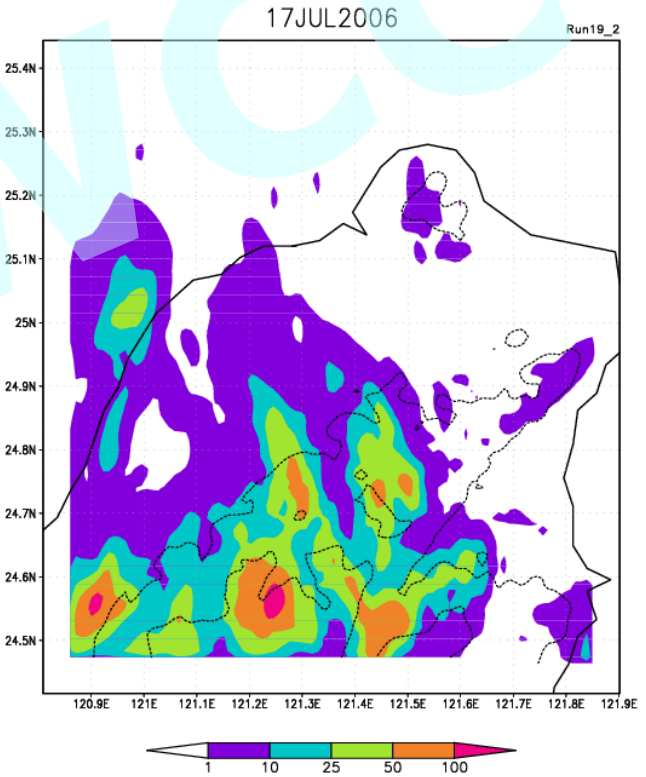


Original
WRF-USGS

Observation







(Lin et al. 2011, JAMC)

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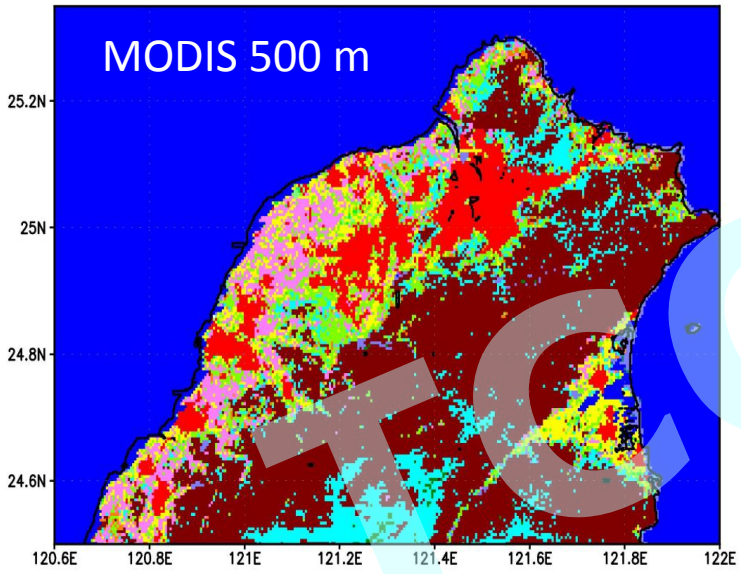
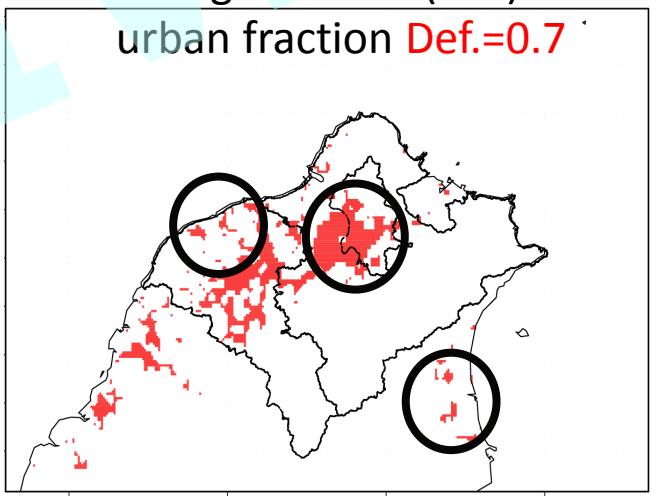
MODIS Land use classification in Taiwan



urban
DryInd Crop.
Irrg. Crop.
Mix. Dry/Irrg. C.P.
Crop./Grs. Mosaic
Crop./Wood Mosc
Grassland
Shrubland
Mix Shrb./Grs
Savanna
Decis. Broadlf.
Decis. Needlf.
Evergrn. Braodlf.
Evergrn. Needlf
Mixed Forest
Water bodies

Original UCM (1-D)
urban fraction Def.=0.7



1km resolution, generated from100 m resolution from National Land Surveying and Mapping Center.

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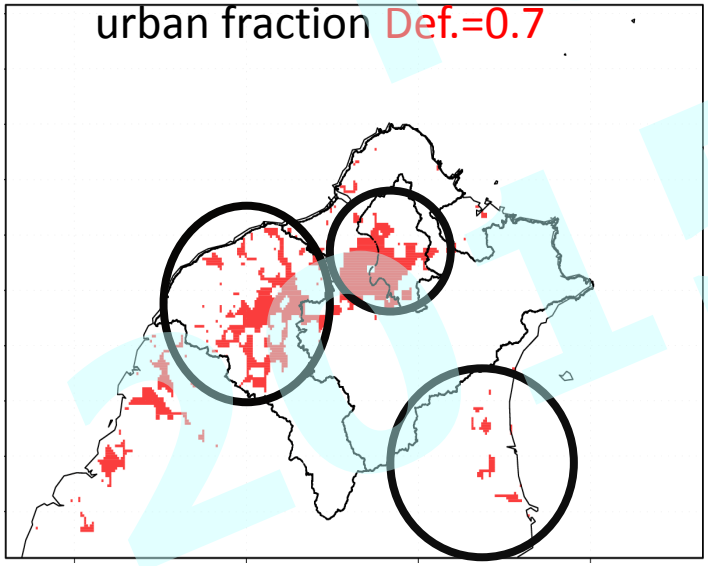
2-D Urban Canopy Model (UCM) model -Urban Fraction

- **1-D UCM :**

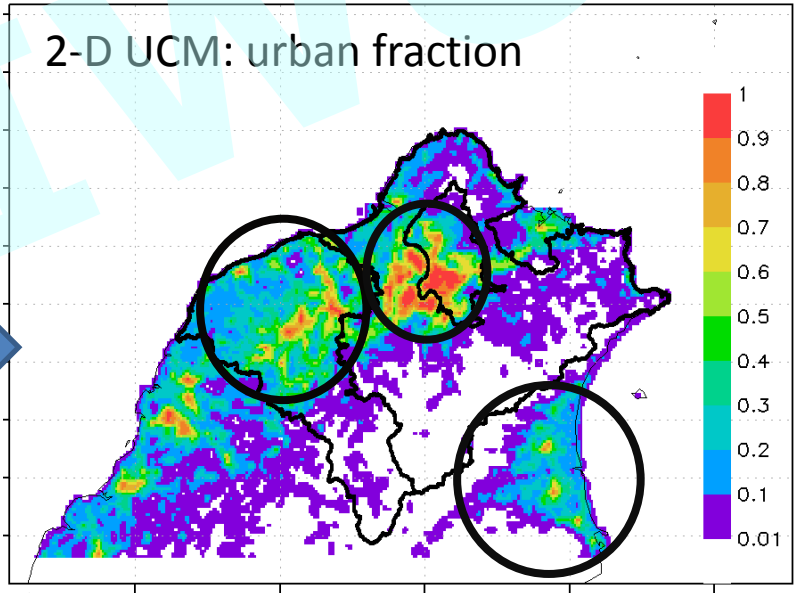
  Urban Fraction is fixed =0.7

- **2-D UCM :**
  - 2-D urban fraction : generated from 100 m resolution from National Land Surveying and Mapping Center.

Original UCM (1-D)
urban fraction Def.=0.7



2-D UCM: urban fraction



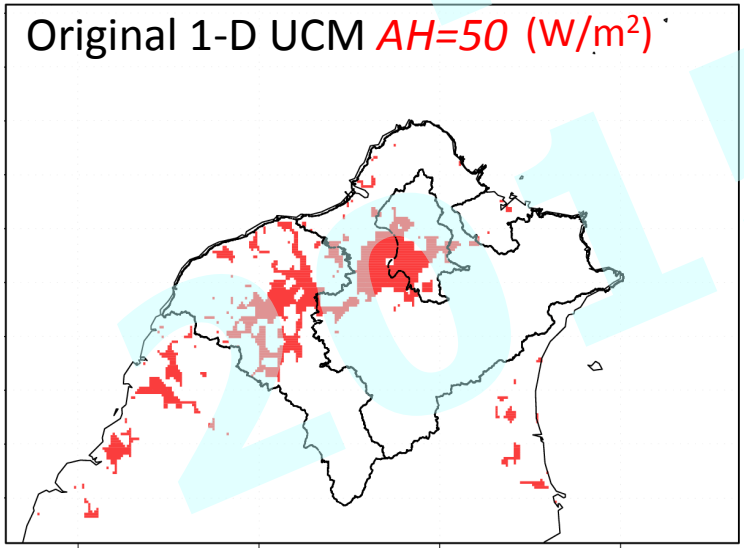
（1km resolution）

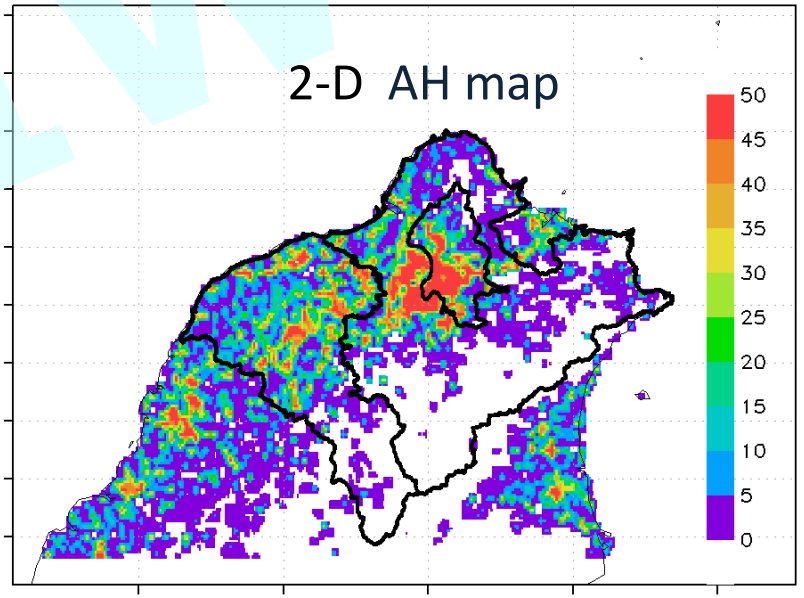
2-D Urban Canopy Model (UCM) model -Anthropogenic heat

- **1-D UCM :**

  Anthropogenic heat(AH) is fixed= 50W/m²

- **2-D UCM :**
  - **Anthropogenic Heat**
    - **2-D anthropogenic heat is generated from 100 m resolution of building density (2006),**
    - **The maximum AH value is *50 W/m²*.**





（1km resolution）

Heat Wave case study

- 2012/07/10
- Taipei: 38.3℃

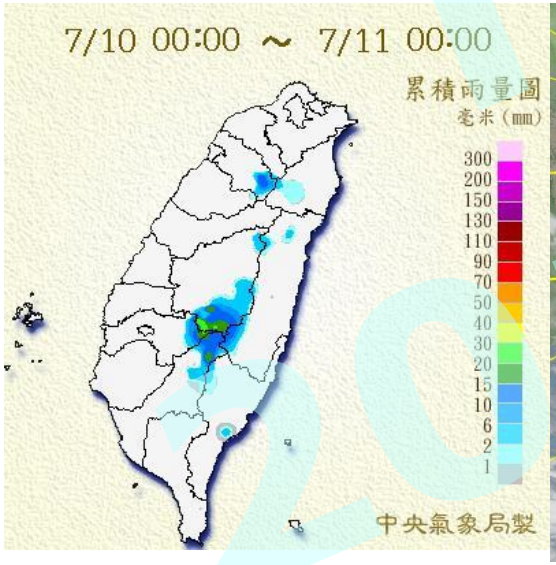
熱死人了 北基4老人猝死

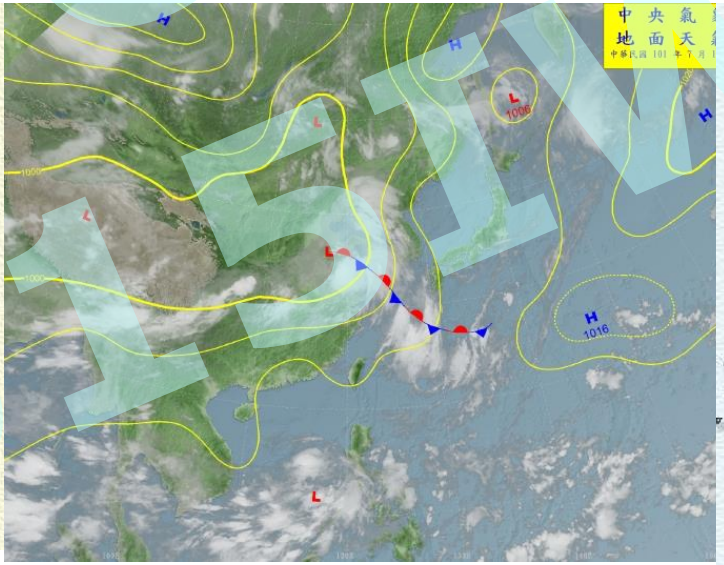
自由時報 自由時報－2012年7月12日 上午4:25

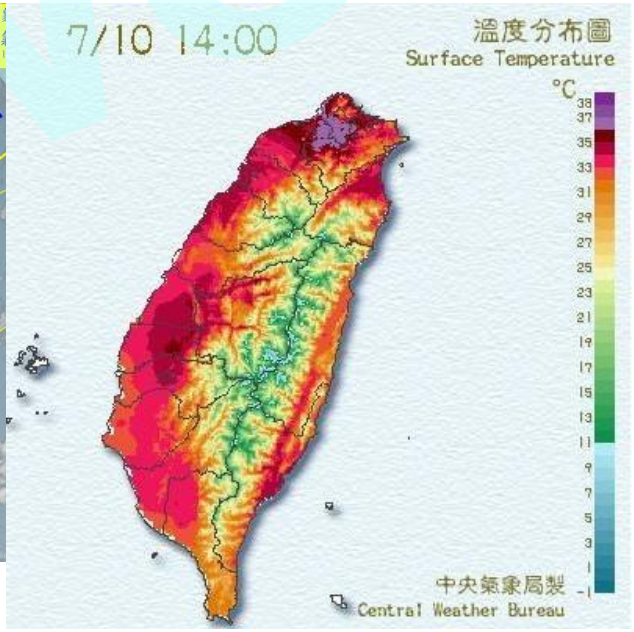
〔自由時報記者吳岳修、林嘉東、林嘉琪、陳曉宜、盧賢秀、邱奕統／綜合報導〕熱浪持續襲台，中暑事件頻傳，前天台北市最高溫達卅八．三度當天，光是萬華區就有三名老人猝死，檢警初查均未發現自殺或外力介入跡象，不排除是「熱死」的可能。基隆昨天高溫卅五．四度，創下基隆今年最高溫紀錄，但也傳出一起老婦人疑似熱死事件。

北市萬華區 一天就傳3憾事

家住台北市環河南路的七十五歲曹姓老翁，疑因天氣太熱睡不著覺，十日凌晨四時許在家中客廳乘涼，悶熱導致身體不適



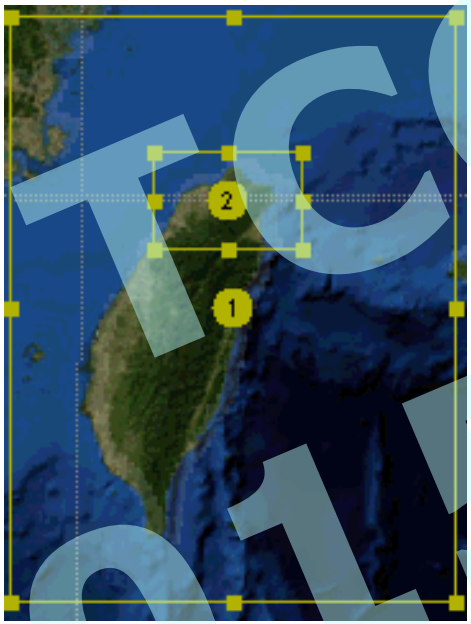


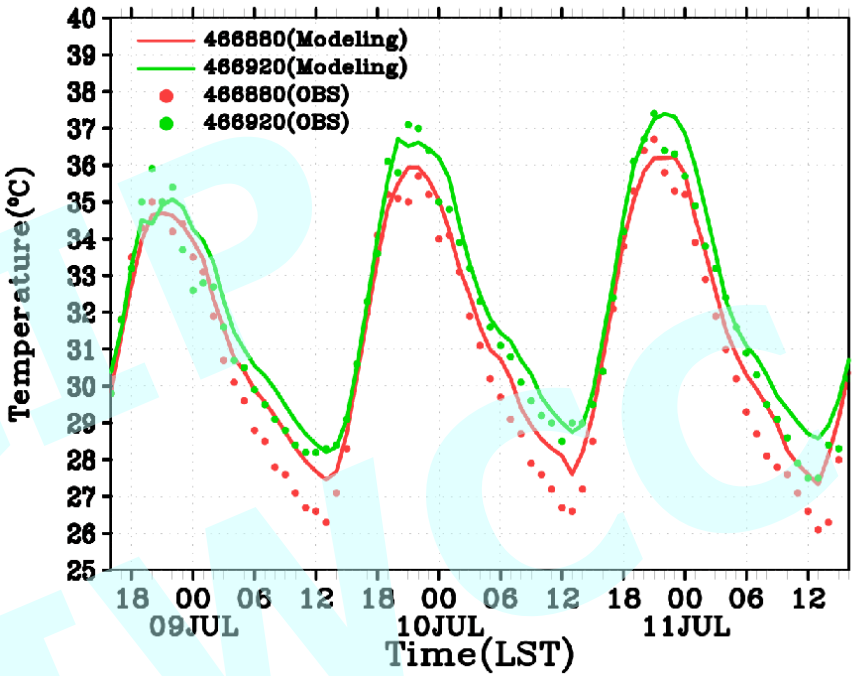


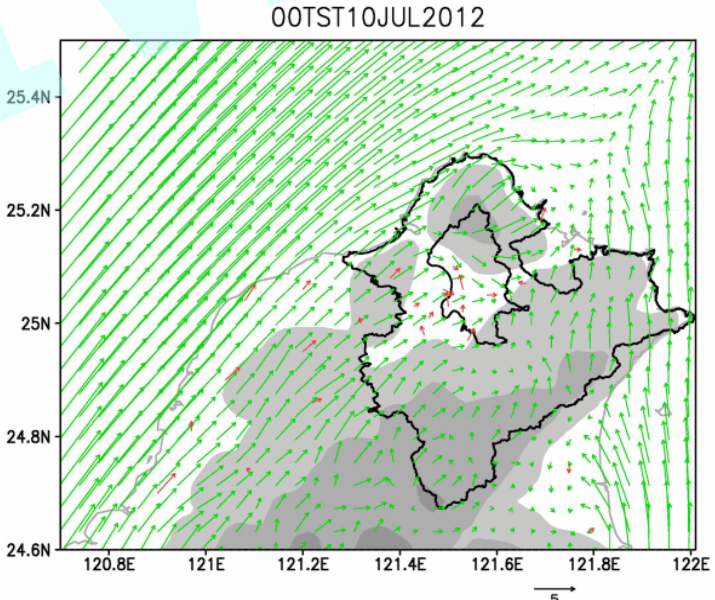
Obs. data

Model Evaluation (WRF-UCM2D)

Dom1=3km
Dom2=1km



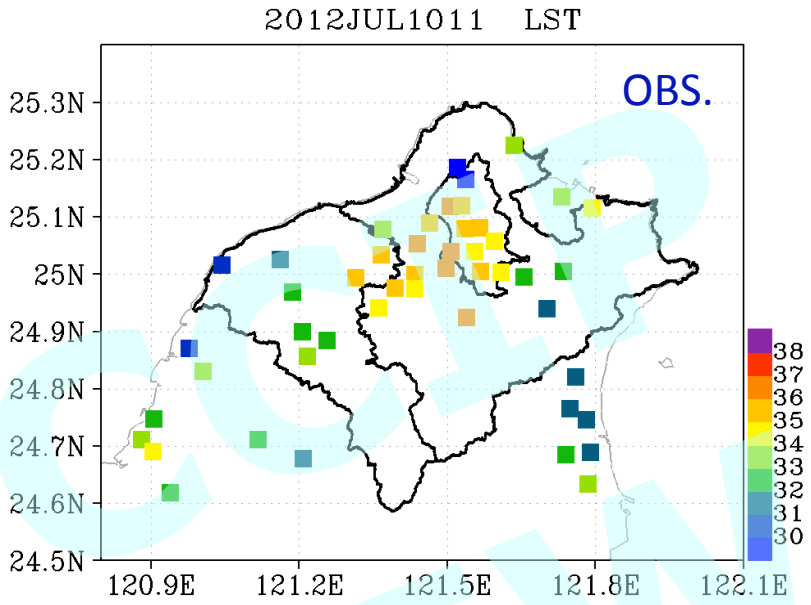


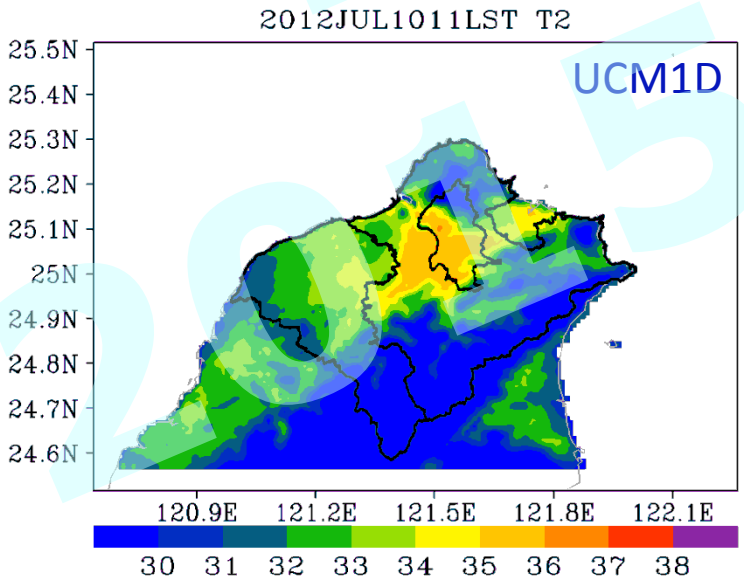


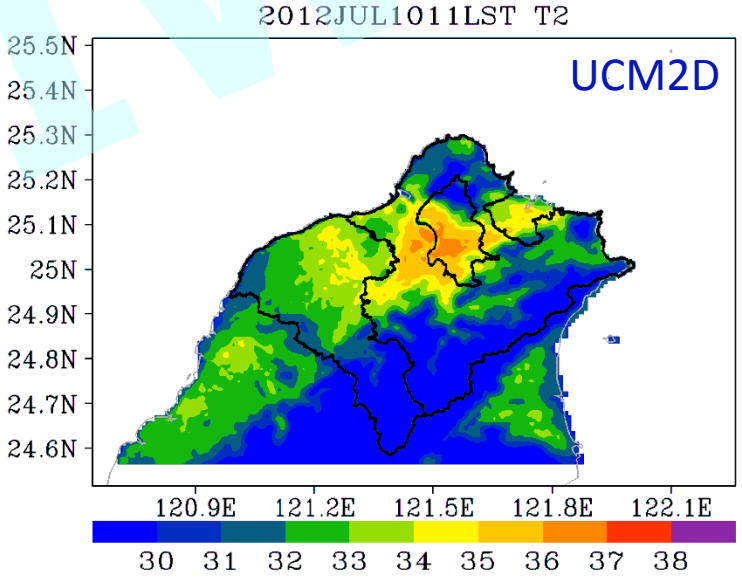
NCEP-GFS/WRF-UCM2D

TCCIP 2015 TWCG

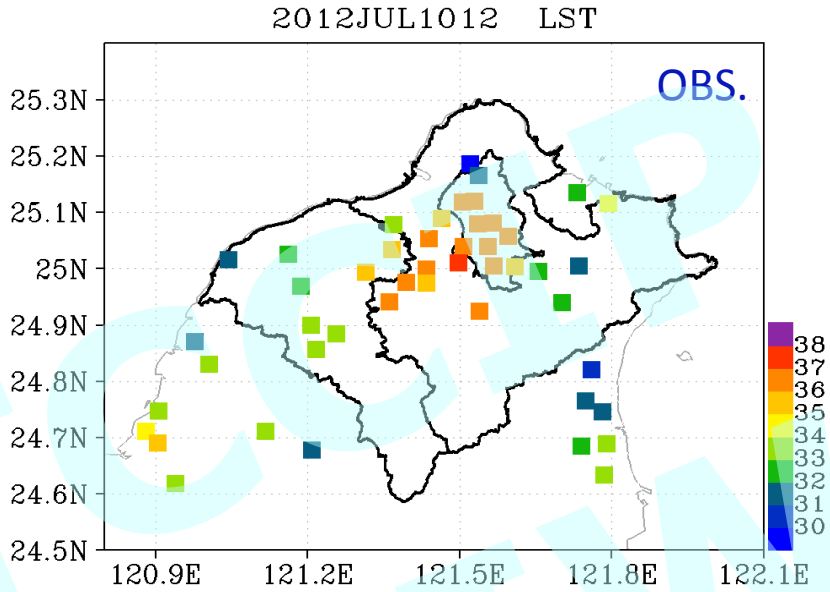
Model Evaluation

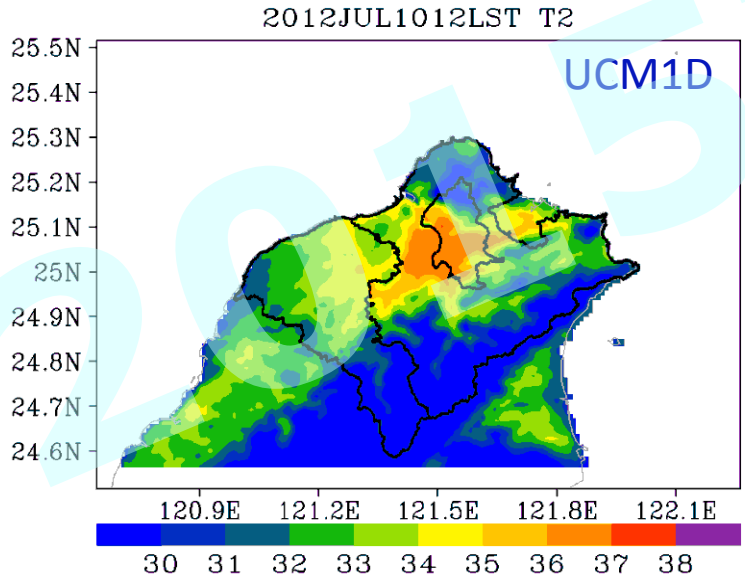


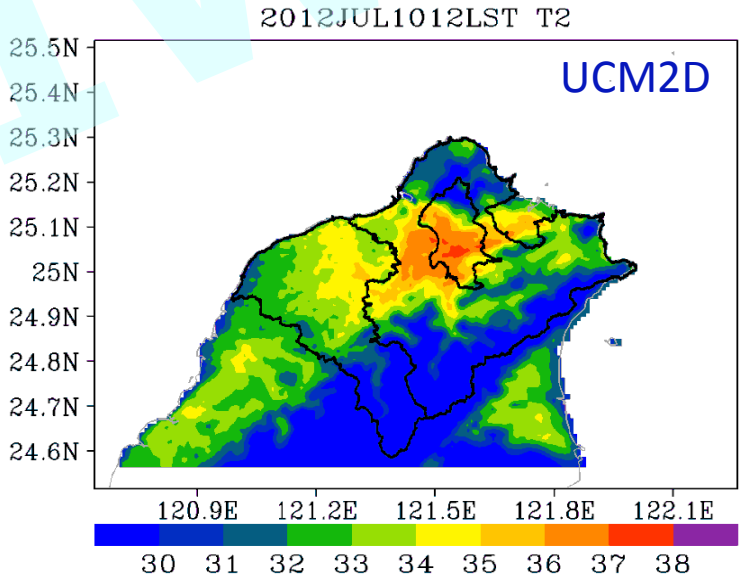




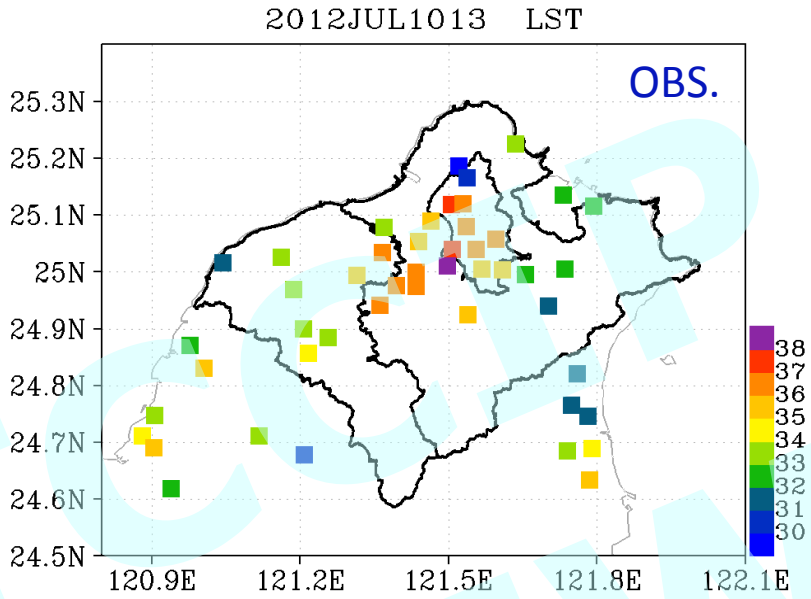
Model Evaluation

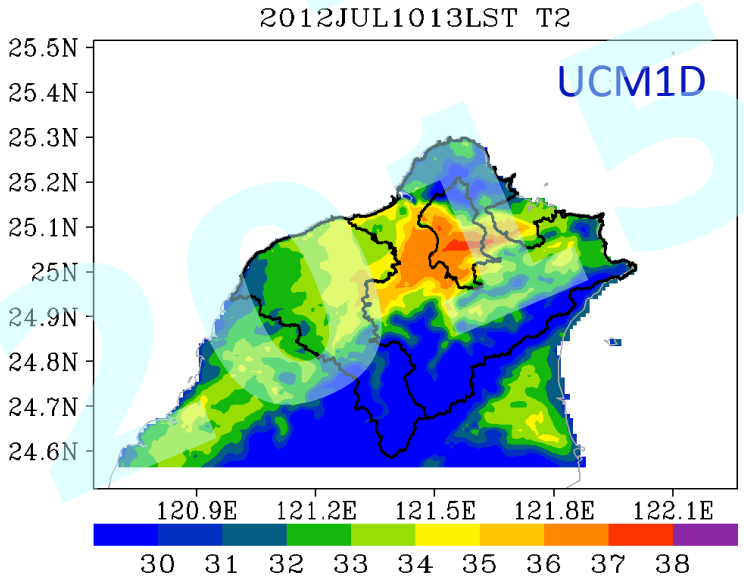


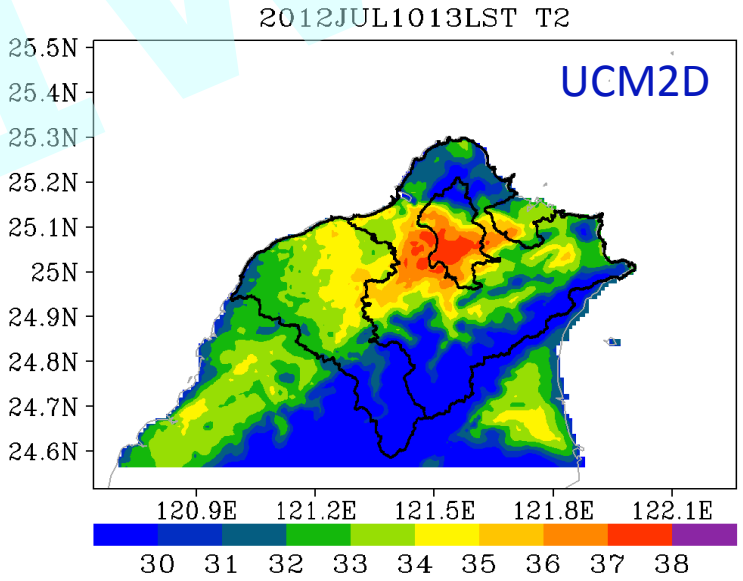




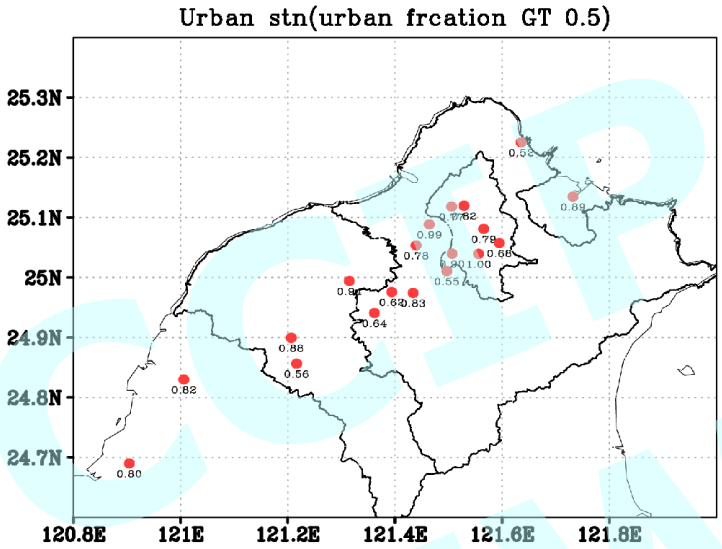
Model Evaluation



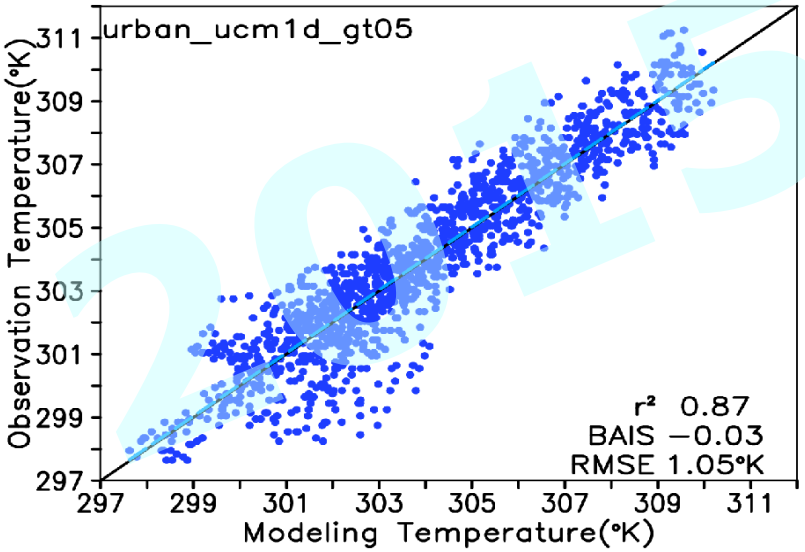




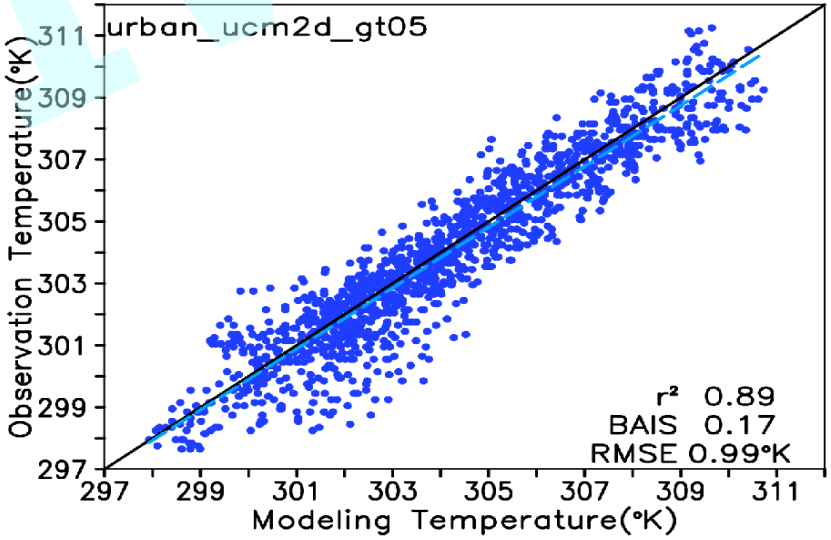
Model evaluation for 19 urban stations



UCM1D



UCM2D

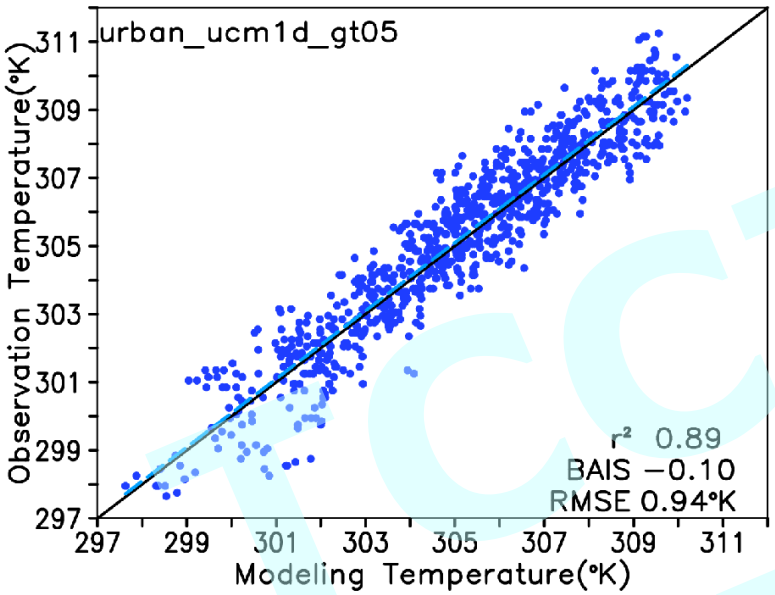


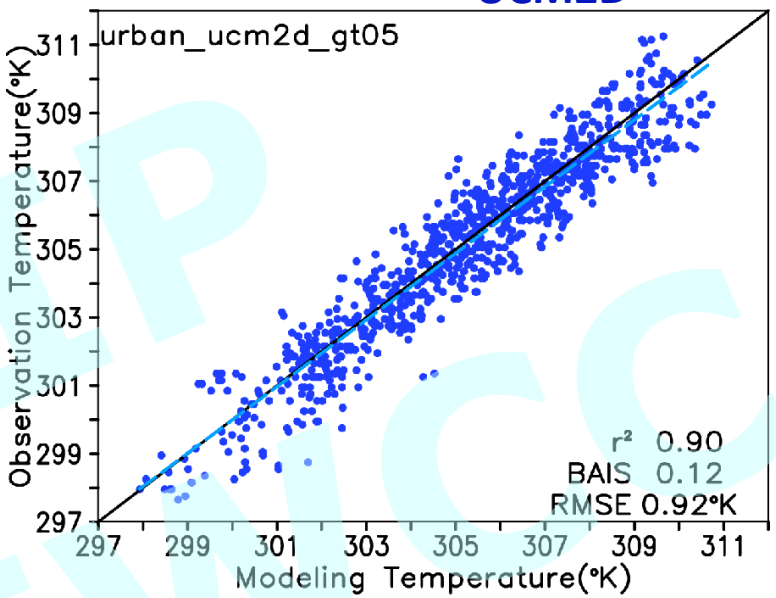
Model evaluation at 19 urban stations

UCM1D

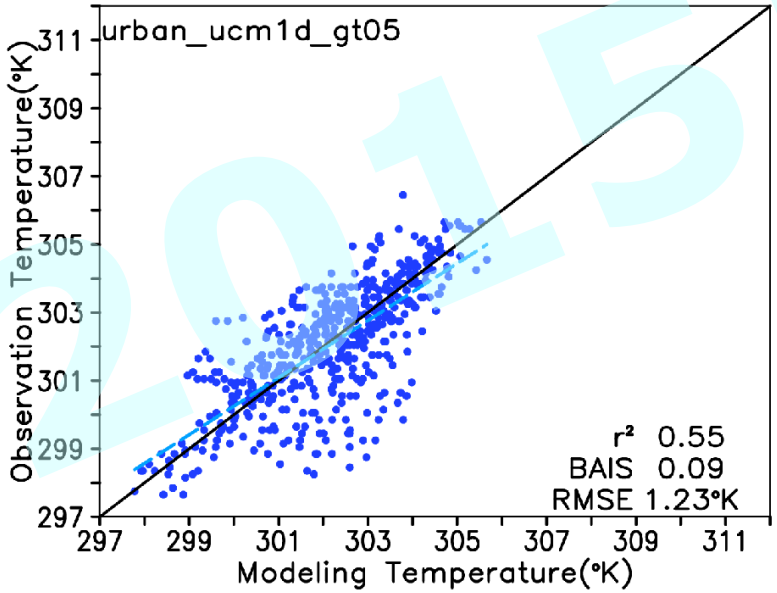
UCM2D

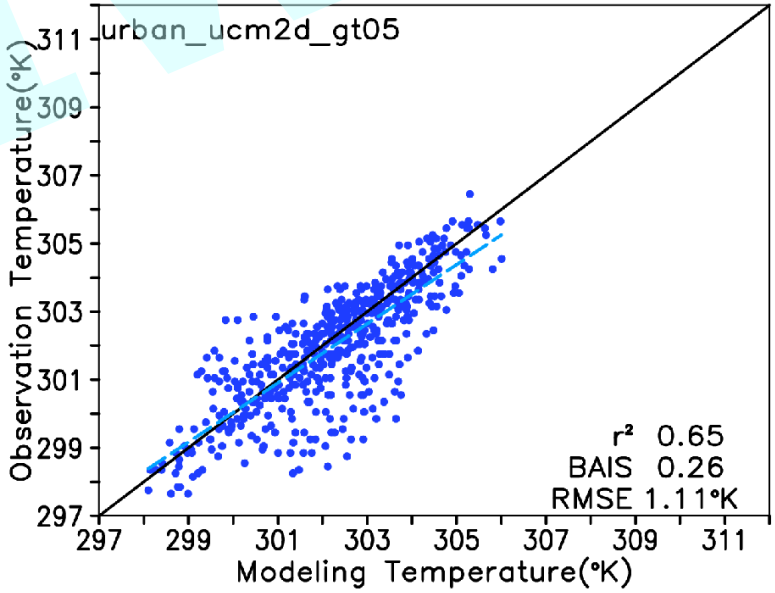
daytime



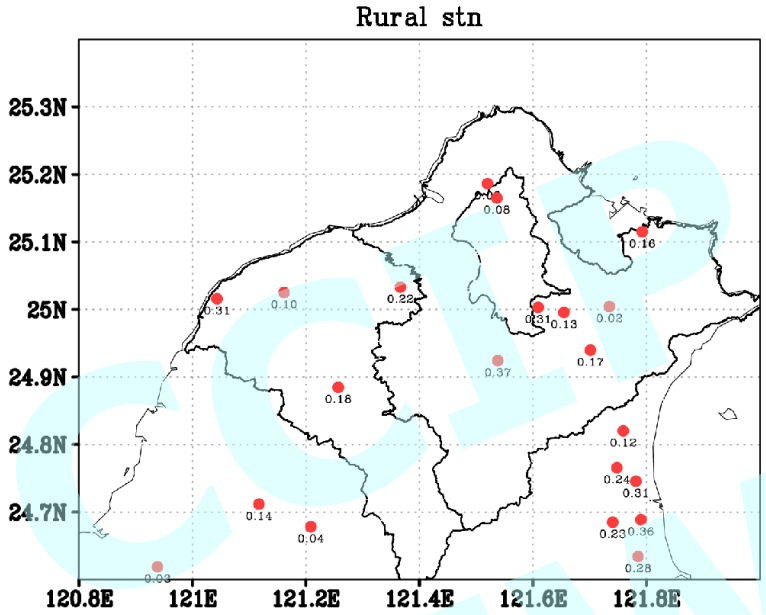


nighttime

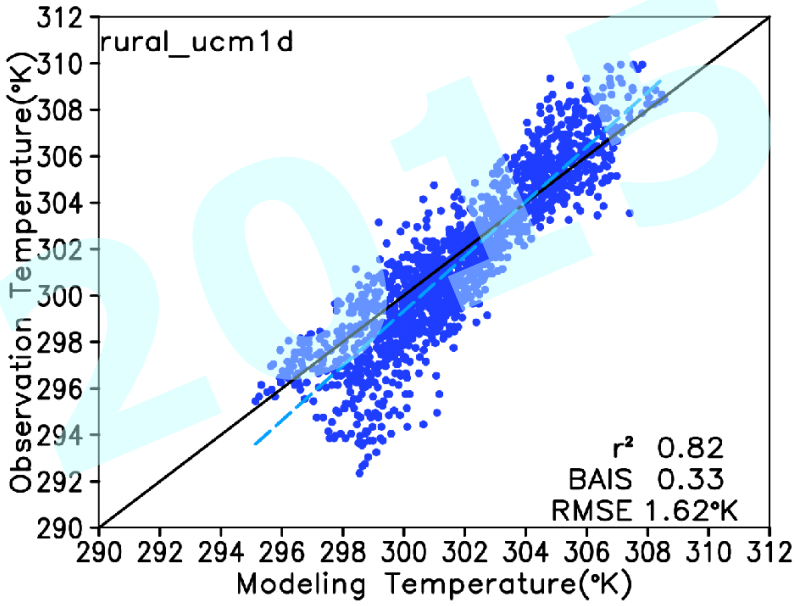




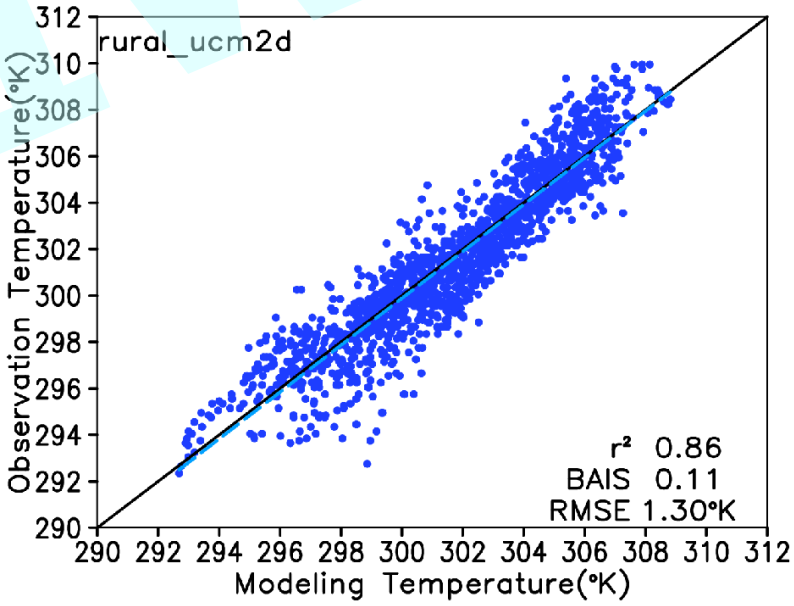
Model evaluation for 21 non-urban stations



UCM1D



UCM2D

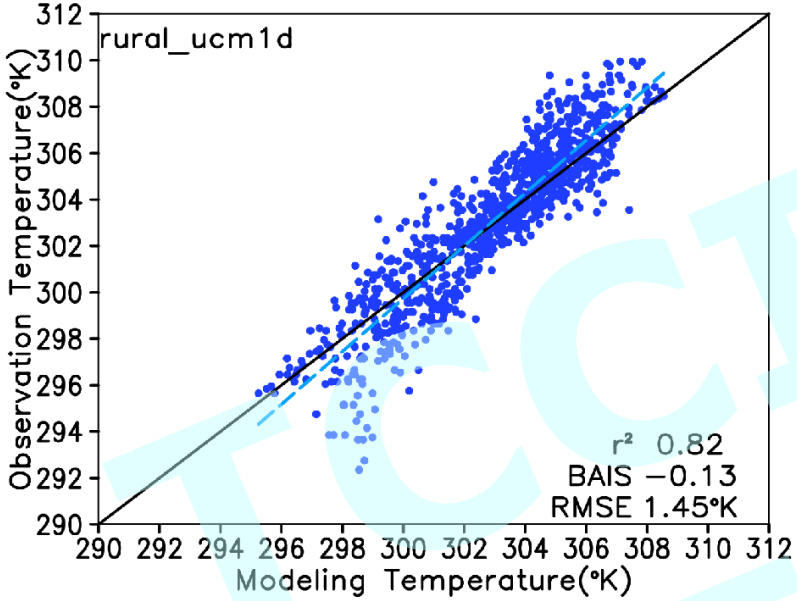


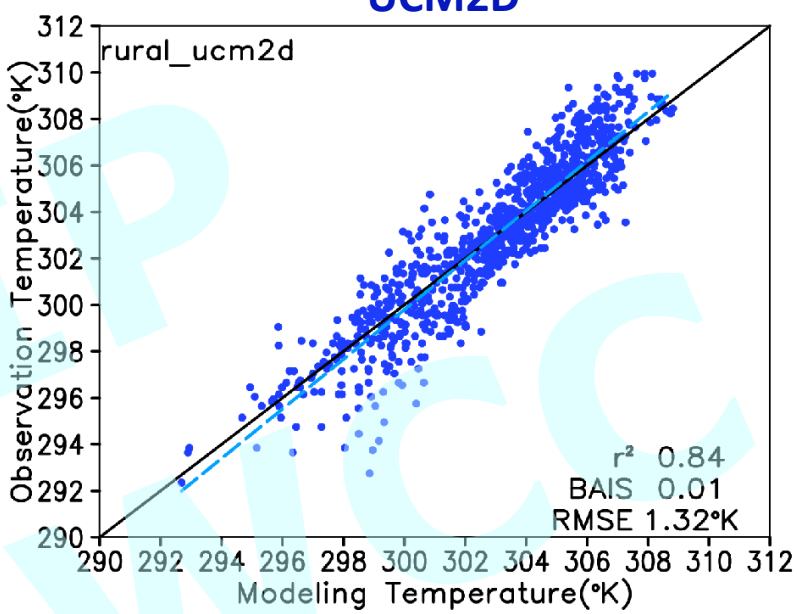
Model evaluation for 21 non-urban stations

UCM1D

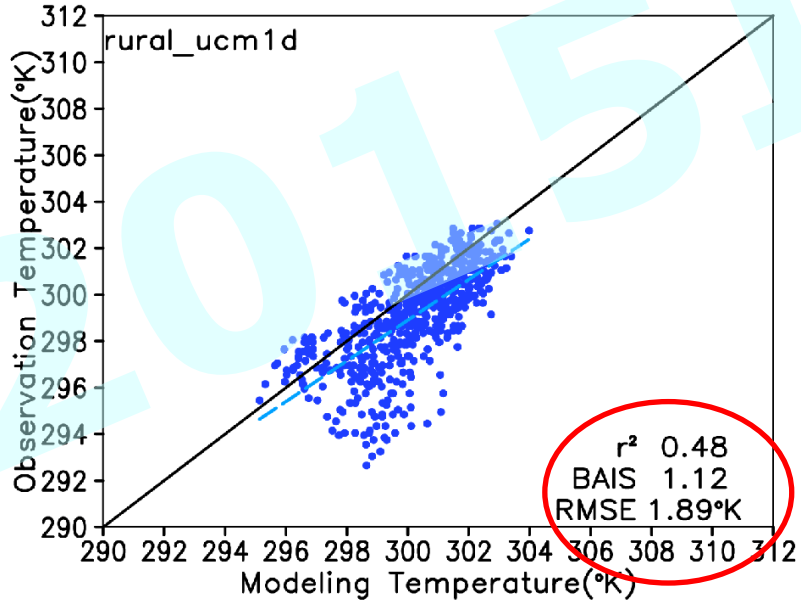
UCM2D

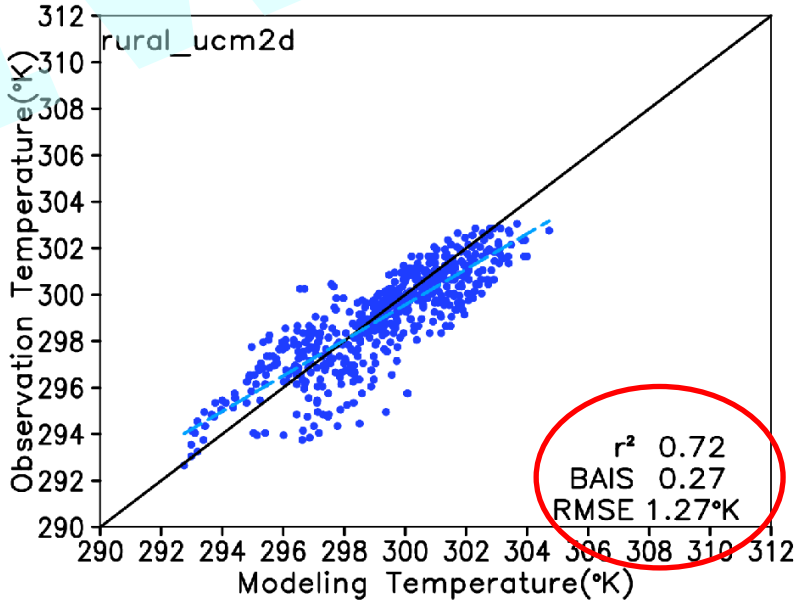
daytime



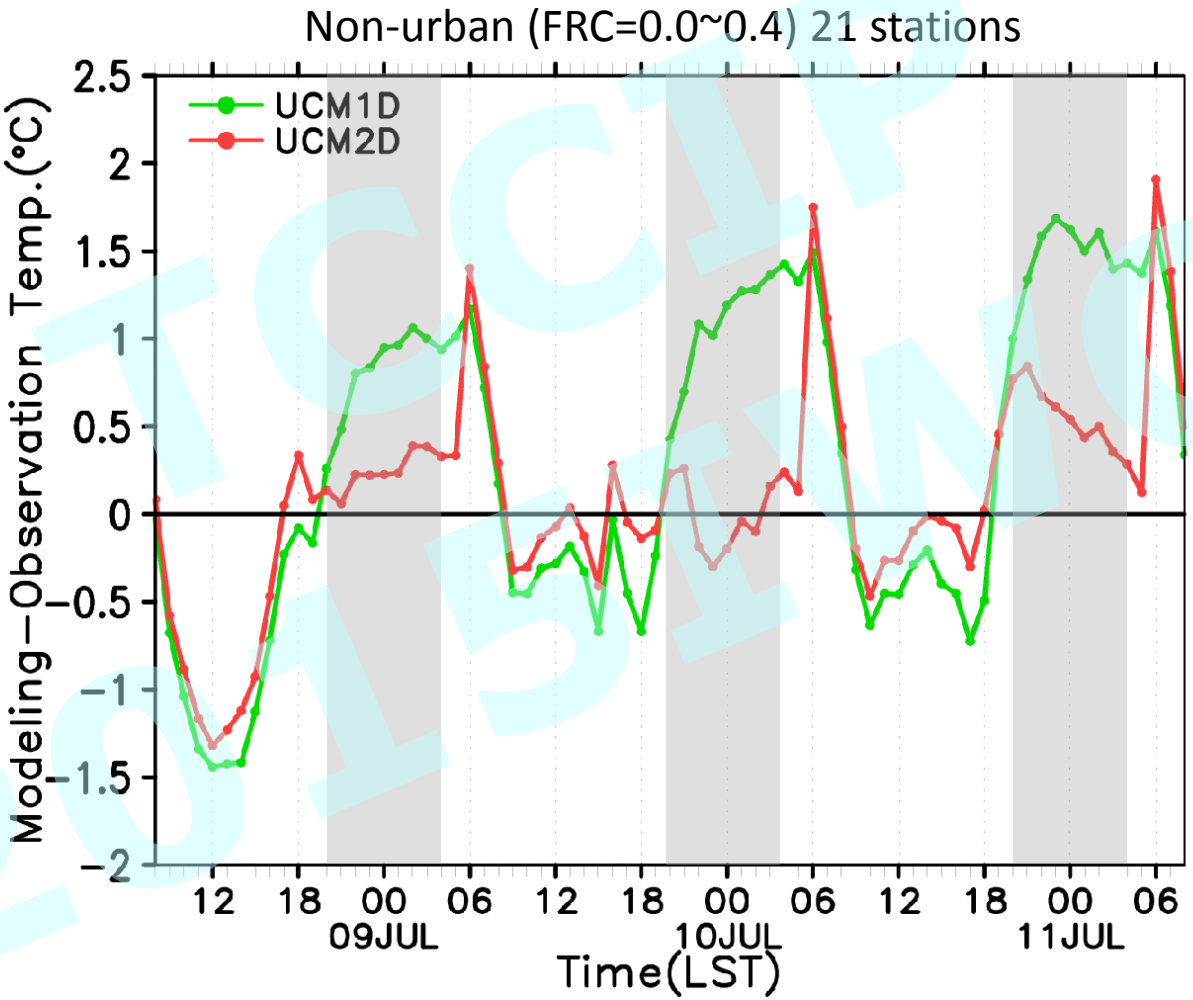


nighttime

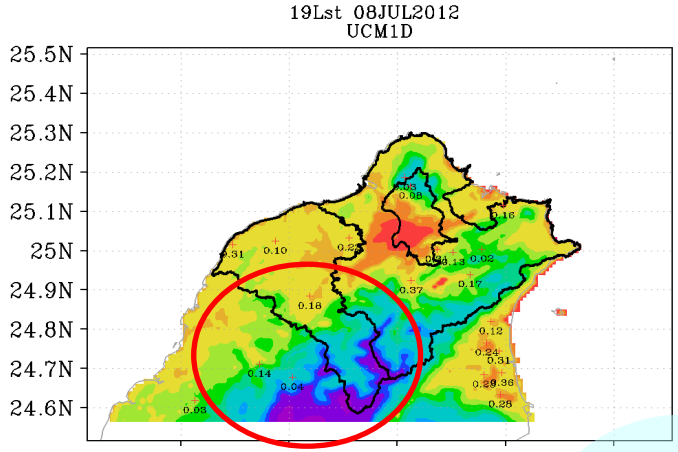


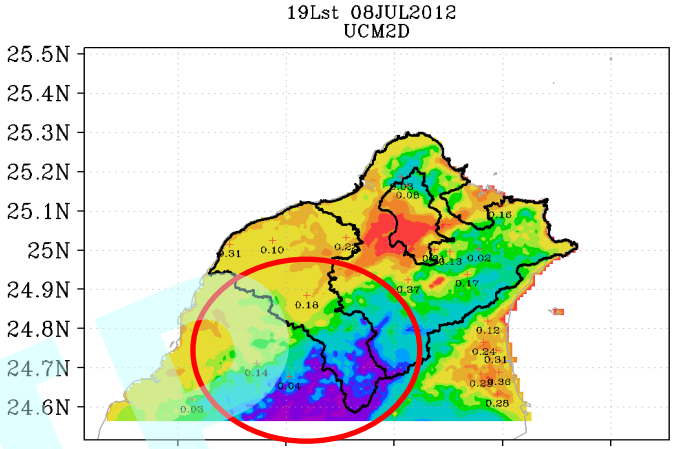


Temperature difference between modeling and observation at 21 non-urban stations

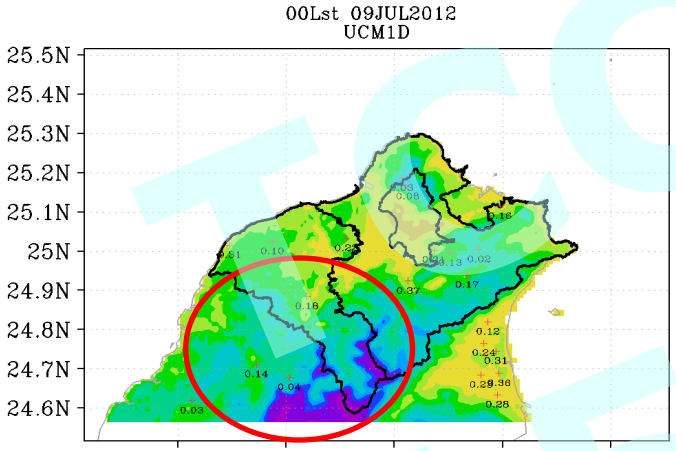


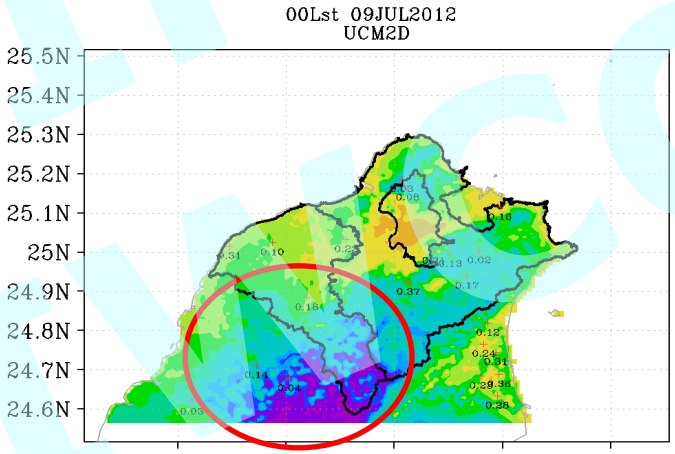
19 LST



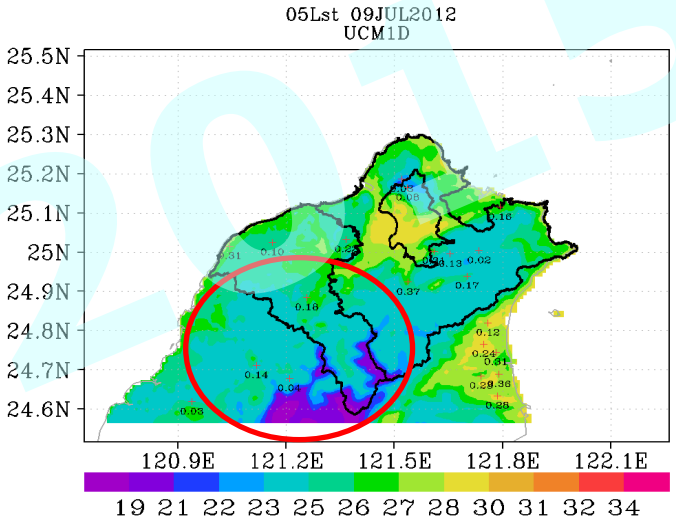


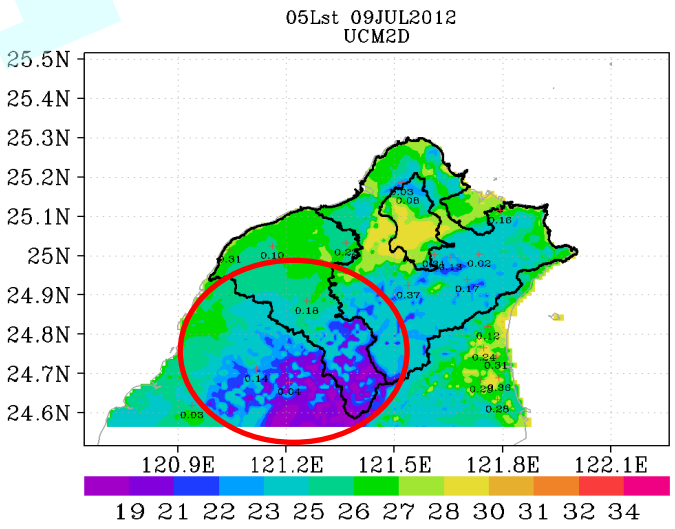
00 LST

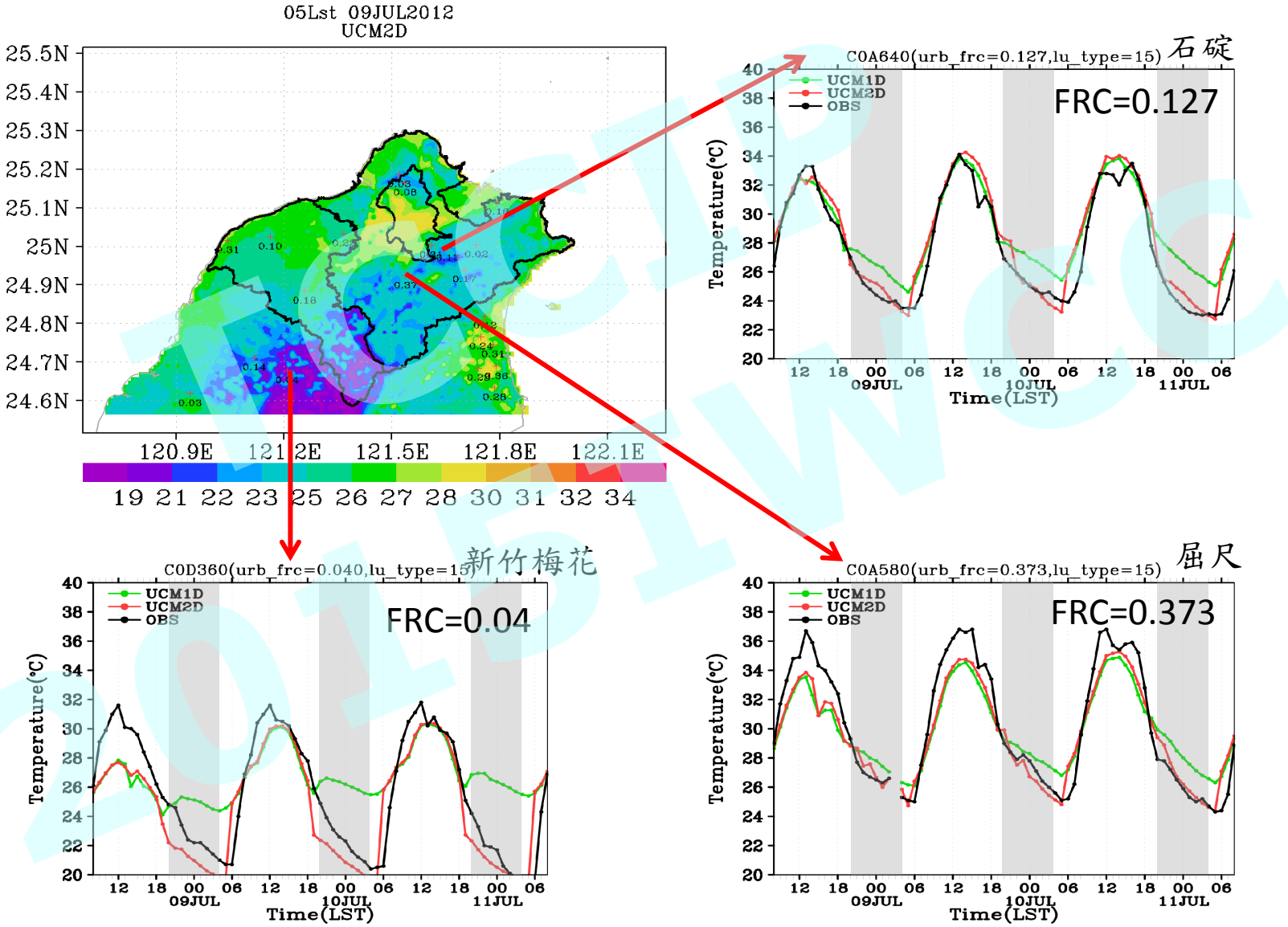




06 LST

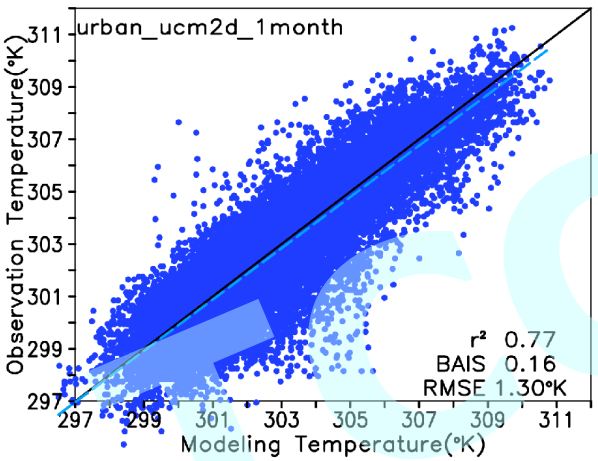


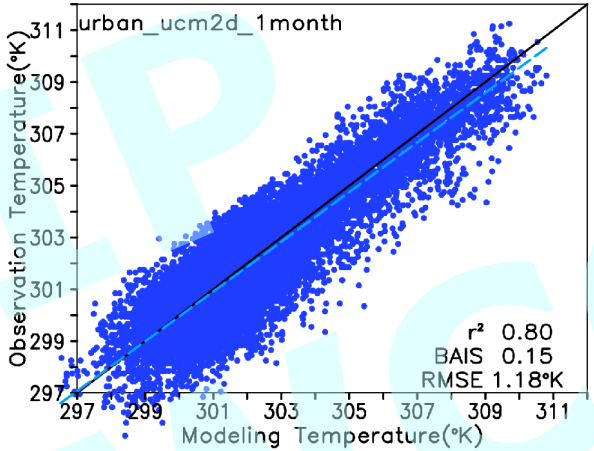


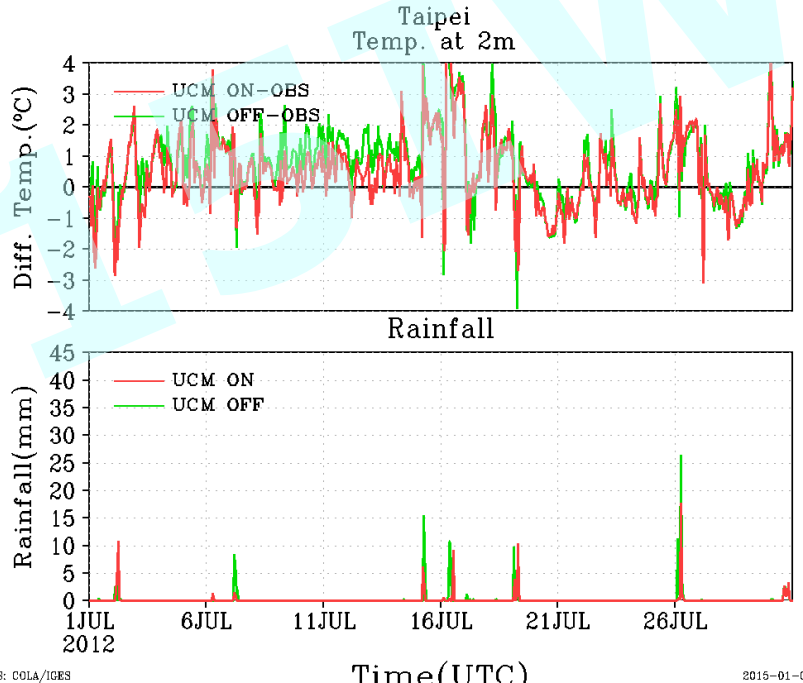

05Lst 09JUL2012
UCM2D
25.5N
25.4N
25.3N
25.2N
25.1N
25N
24.9N
24.8N
24.7N
24.6N
120.9E
121.2E
121.5E
121.8E
122.1E
19 21 22 23 25 26 27 28 30 31 32 34
C0A640(urb_frc=0.127,lu_type=15)
石碇
FRC=0.127
C0D360(urb_frc=0.040,lu_type=15)
新竹梅花
FRC=0.04
C0A580(urb_frc=0.373,lu_type=15)
屈尺
FRC=0.373
UCM1D
UCM2D
OBS
Temperature(°C)
Time(LST)
09JUL
10JUL
11JUL

2012 July

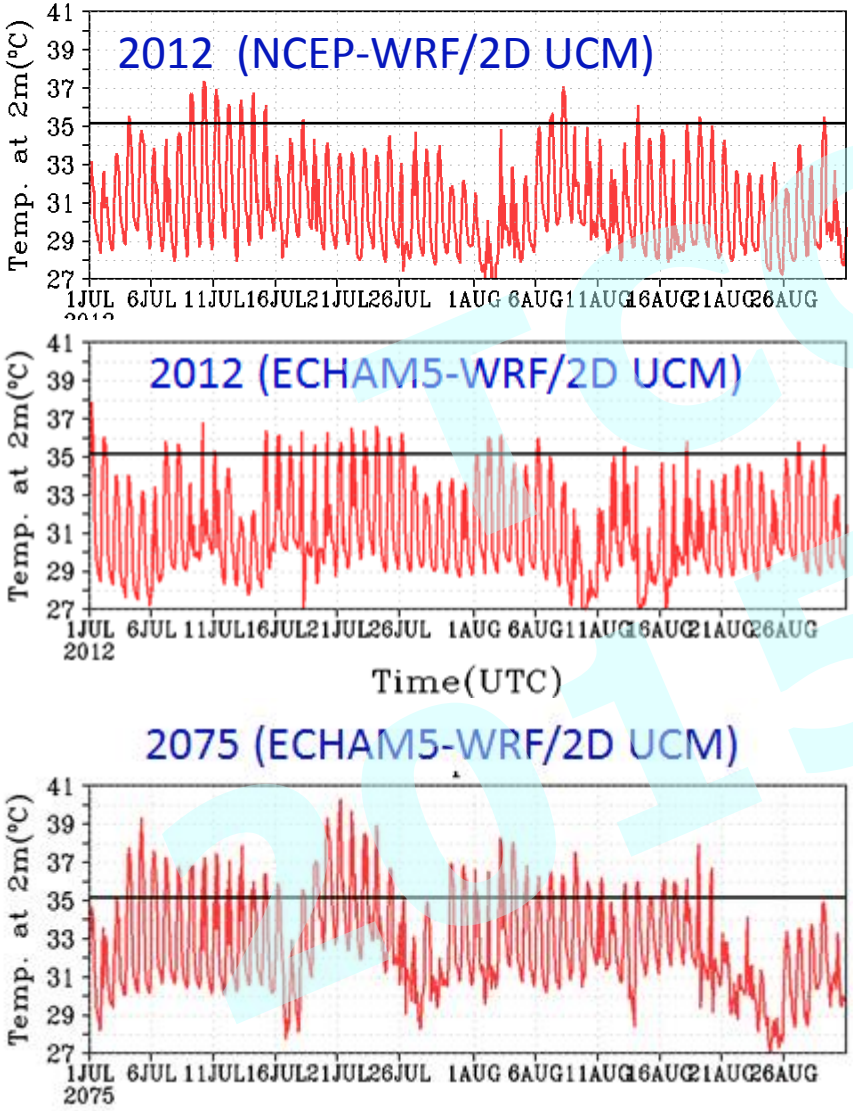
(excluded temp. data once rainfall)



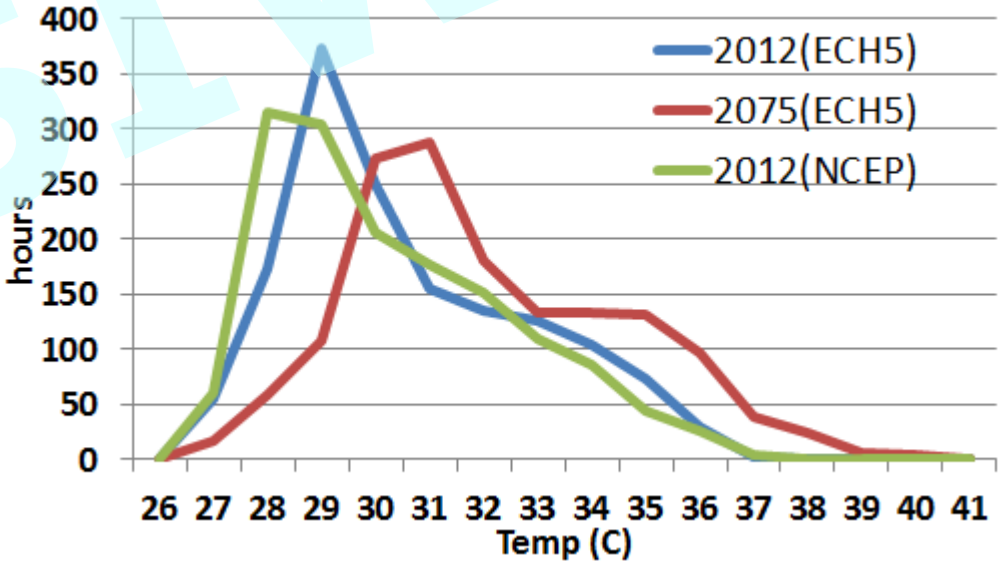




Summer (Jul. and Aug.) air Temperature in 2012 and 2075



	2012 NCEP	2012 ECH5	2075 ECH5
Daytime mean Temp.	31.67	32.00	33.45
Nighttime mean Temp.	29.25	29.45	31.11
DTR	2.42	2.55	2.34
>=35.2℃ total hours	62	87	267



Ongoing study

- HiRAM-WRF/2D-UCM downscaling
- ECHAM5-WRF/2D-UCM downscaling
- Improve and examine land use classification and parameters(albedo, skyview, thermal conductivity, building height…..)
- Anthropogenic heat estimation
- Applications of different urban types' (gather or dispersion) scenario in the future urban climate

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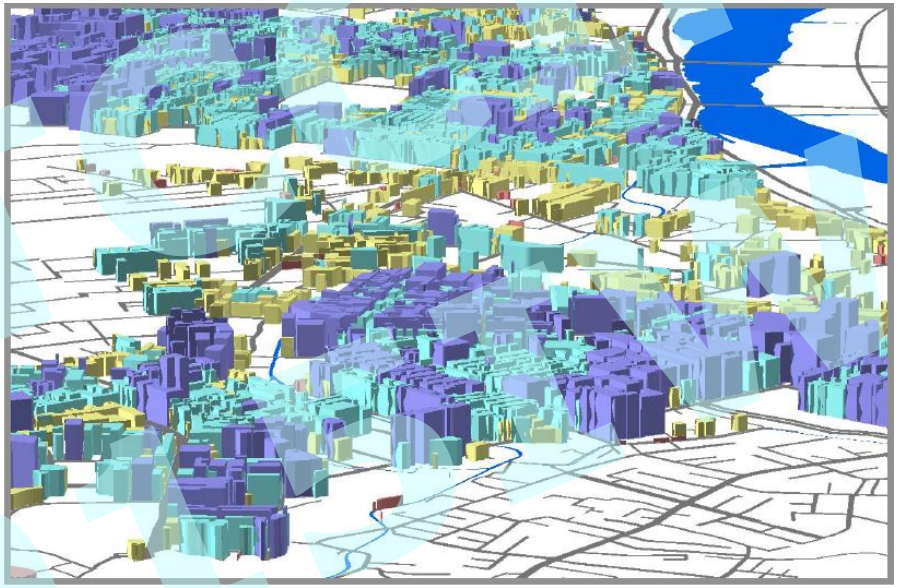
Ongoing study

- Consider urban height in UCM2D

e.g.



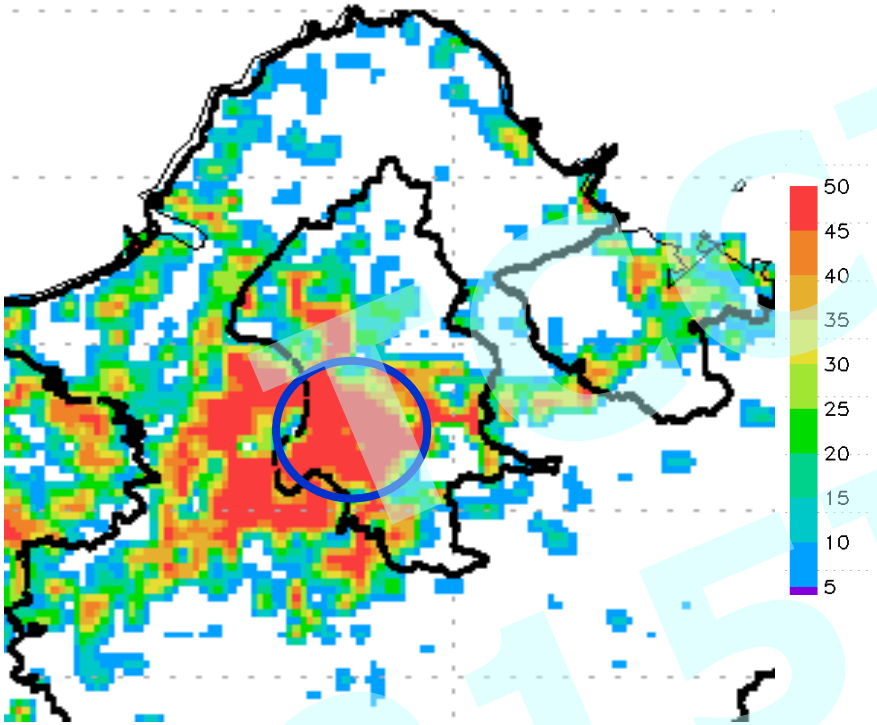
(Wu. et al. 2011)

Illustration of 3-D street canyon modeling using 3DUI

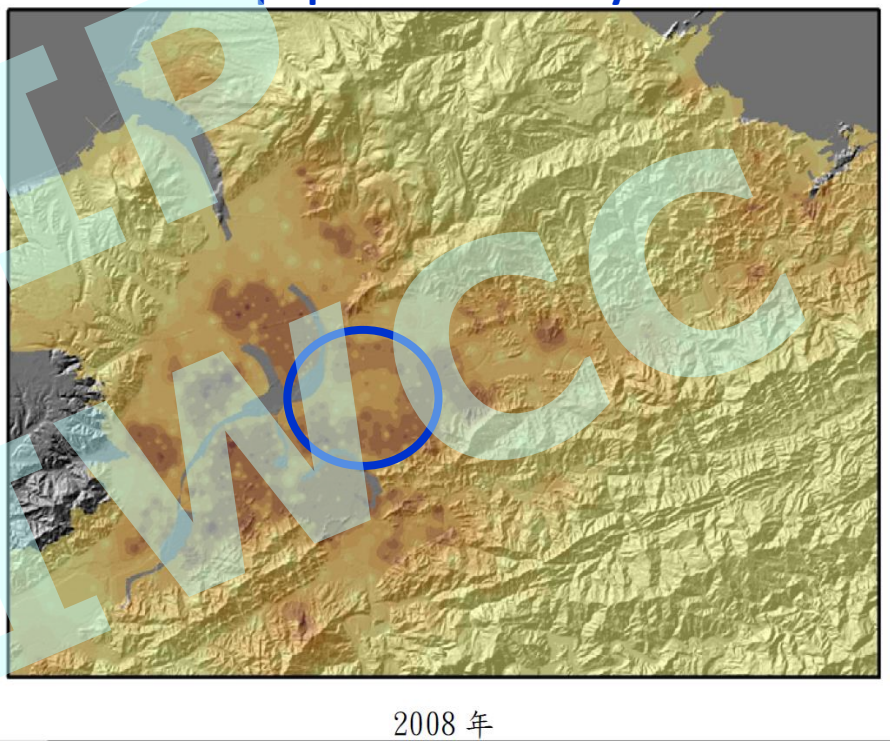
Where $3DUI_i$ (m^3/pixel) is the 3-D Urbanization Index of pixel *i*, $Hdsm_i$ (m) and $Hdem_i$ (m) denote the elevation recorded in DSM and DEM of pixel *i*, respectively, and A_i (m^2) is the size of pixel *i* **(5 m × 5 m = 25 m^2)**.

Uncertainty of anthropogenic heat estimation

AH from building density



population density



(Tsai K.H. NTNU, 2010 MS thesis)

AH sources: industry, buildings, vehicles, metabolism

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AHF Estimation from Air pollutants

- The new method suggested by the Lee et al. (2014) for gridded AHF estimation

$$Y_{AHF}^{CO} = 2.55 \times x_{CO}^{0.64} \quad (1)$$

$$Y_{AHF}^{NO_x} = 8.32 \times x_{NO_x}^{0.69} \quad (2)$$

$$\boldsymbol{Y_{AHF} = \alpha Y_{AHF}^{CO} + (1-\alpha) Y_{AHF}^{NO_x}} \quad \boldsymbol{(3)}$$

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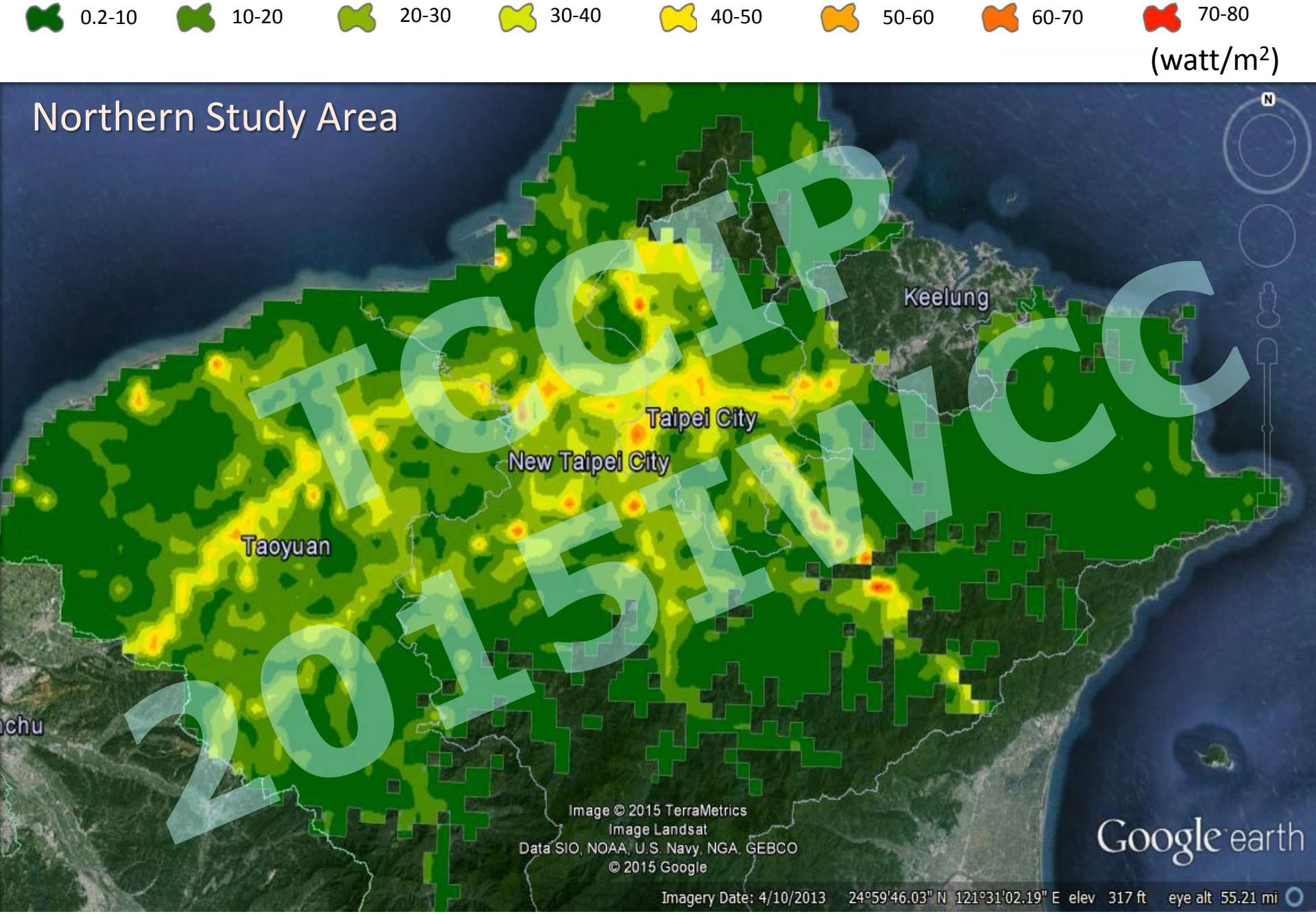
0.2-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
(watt/m²)
Northern Study Area
Keelung
Taipei City
New Taipei City
Taoyuan
TCCIP
2015TWCC
Image © 2015 TerraMetrics
Image Landsat
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2015 Google
Google earth
Imagery Date: 4/10/2013 24°59'46.03" N 121°31'02.19" E elev 317 ft eye alt 55.21 mi

Thank you !!!

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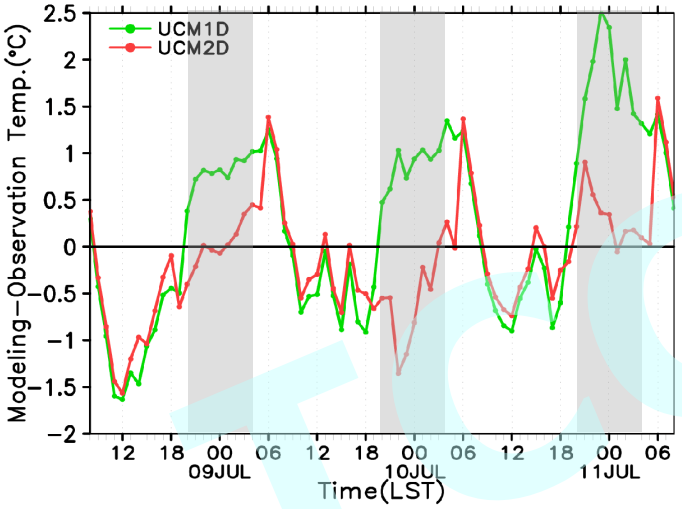
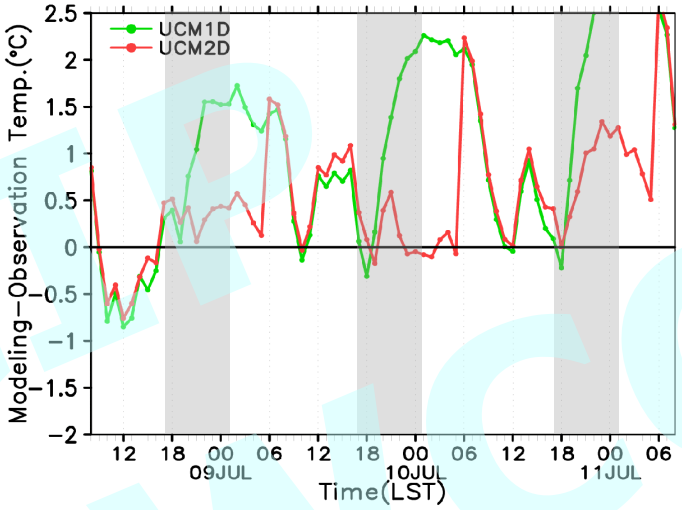
2015IWCC

Temperature difference between modeling and observation

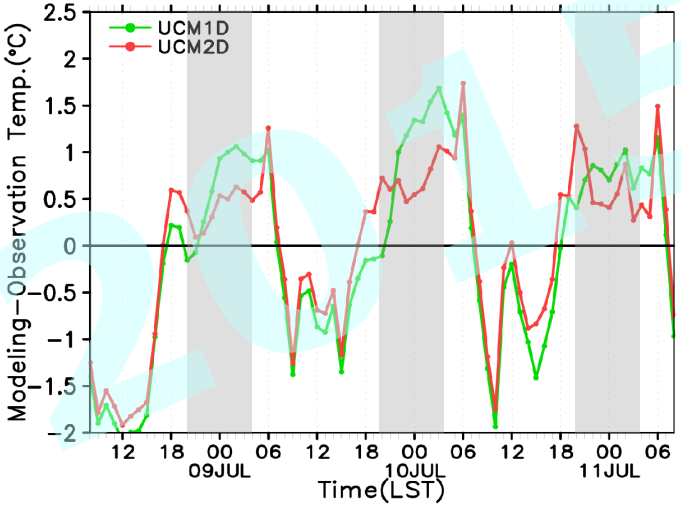
Non-urban (FRC=0.0~0.1) 6stations



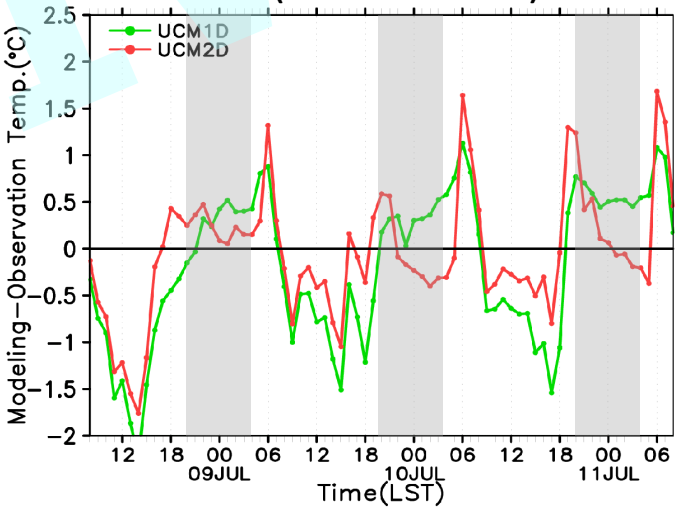
Non-urban (FRC=0.1~0.2) 6 stations



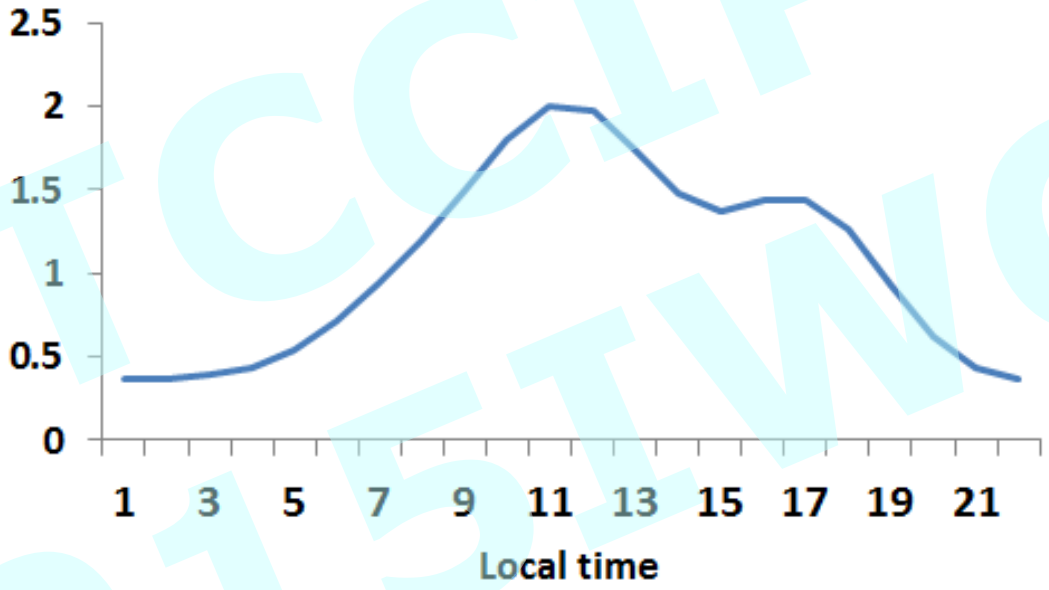
Non-urban (FRC=0.2~0.3) 4 stations



Non-urban (FRC=0.3~0.4) 5 stations



AH profile



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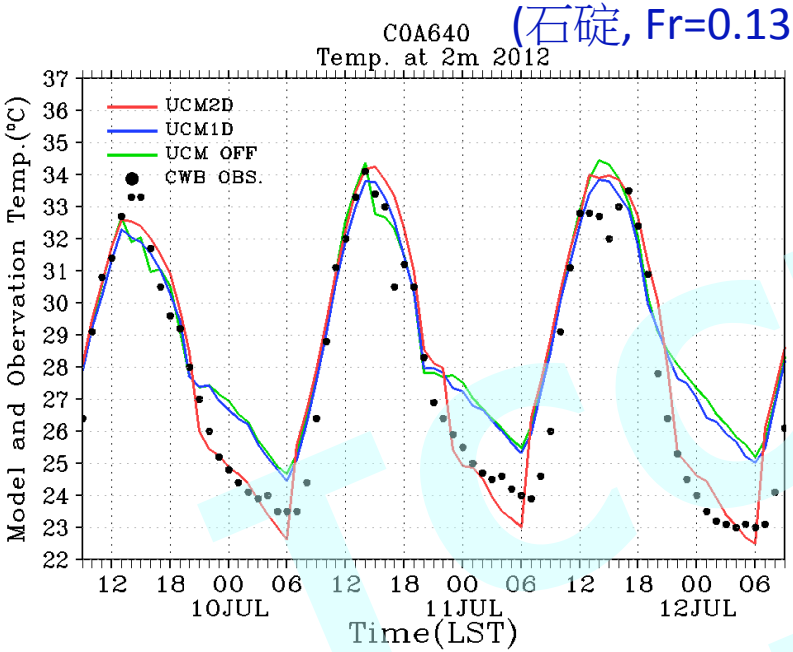
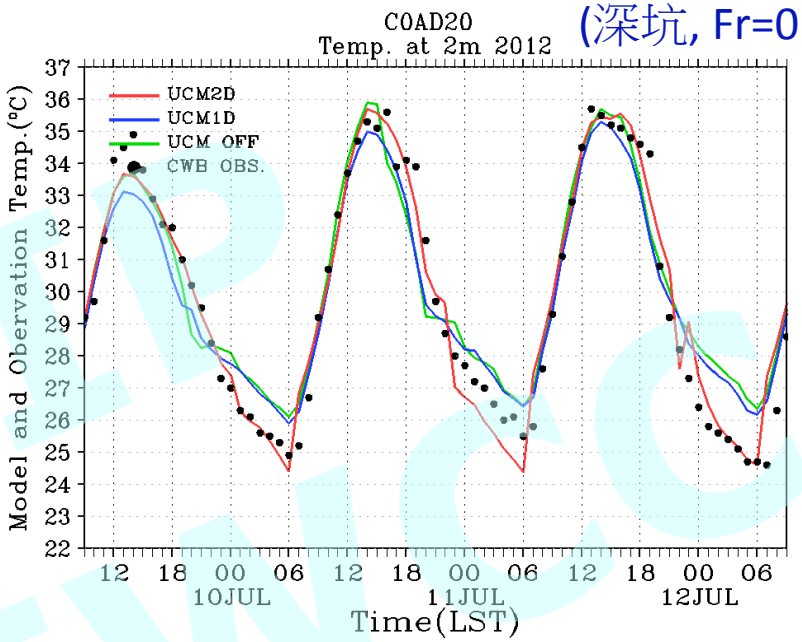
2012 (7/10-12)

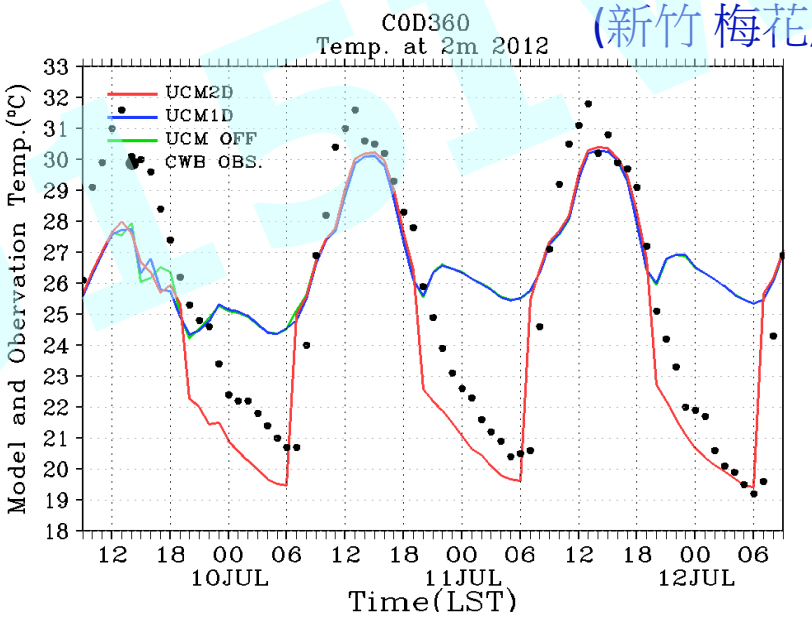
(石碇, Fr=0.13)



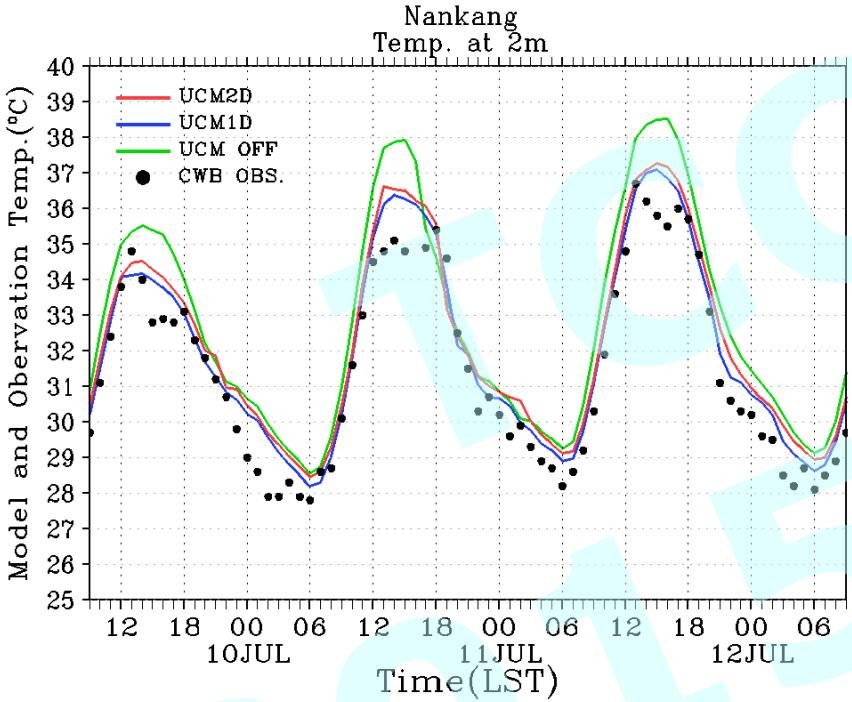
(深坑, Fr=0.3)

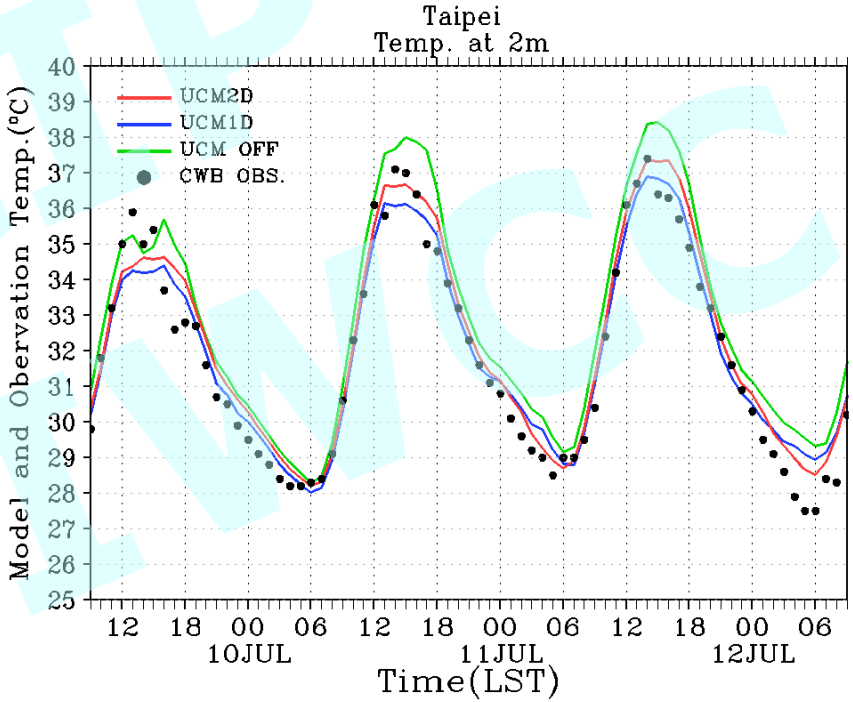


(新竹 梅花, Fr=0.04)



2012 (7/10-12)





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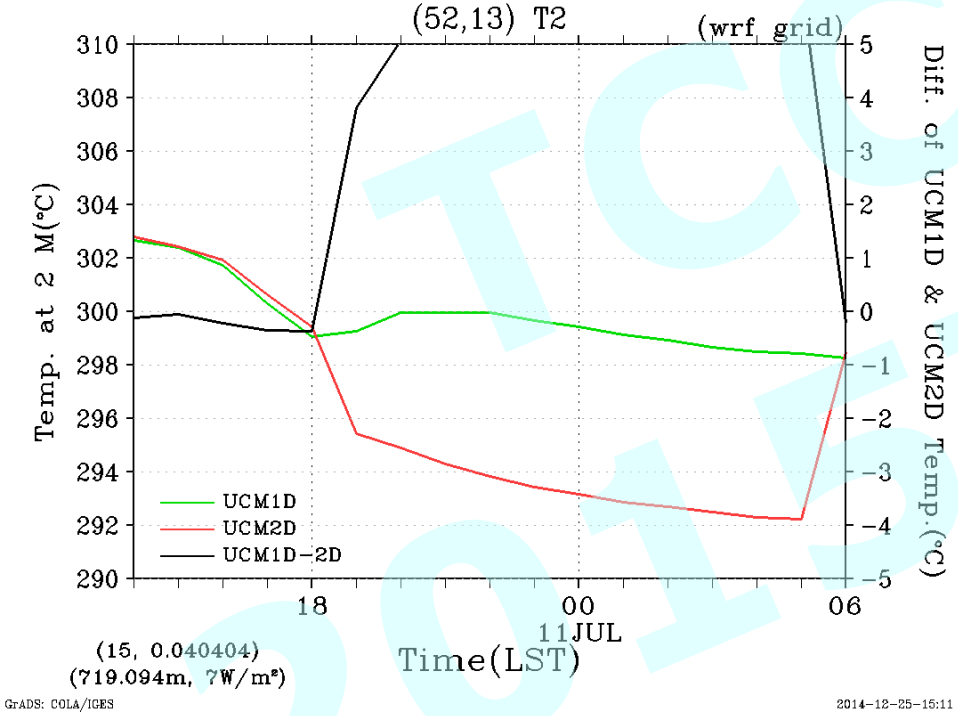
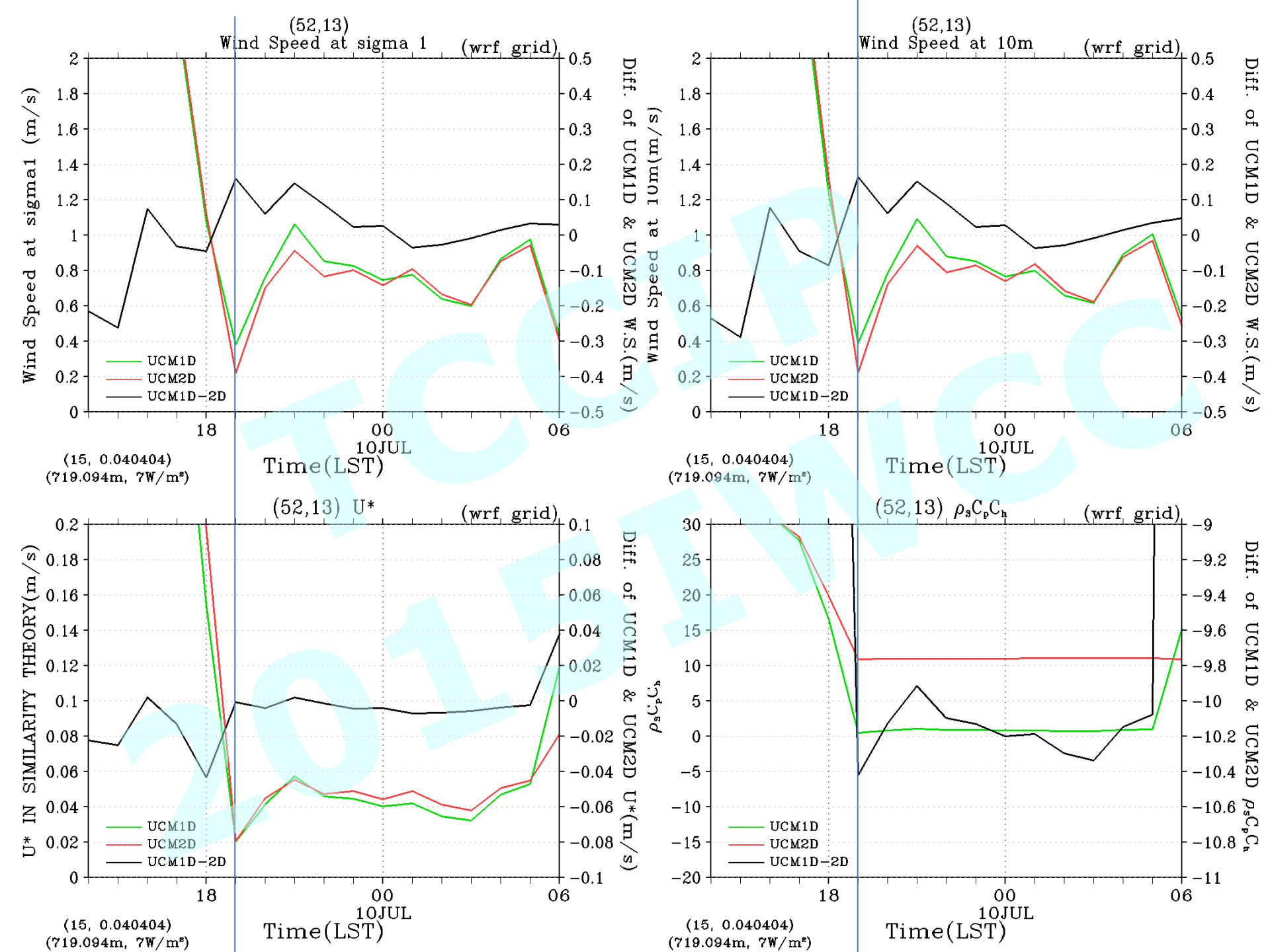


$$F_{SH}=\rho_s C_p C_h (T_{SK}-T_{2m})$$

- F_{sh} 可感熱通量
- ρ_s 空氣密度
- C_p 定壓比容
- C_h 地面熱交換係數
- T_{SK} 地表溫度
- T_{2m} 地表兩米溫度

TCCIP 2015TCC


(52,13)
Wind Speed at sigma 1
(wrf grid)
Wind Speed at sigma1 (m/s)
Diff. of UCM1D & UCM2D W.S.(m/s)
UCM1D
UCM2D
UCM1D-2D
18
00
06
10JUL
Time(LST)
(15, 0.040404)
(719.094m, 7W/m²)
(52,13)
Wind Speed at 10m
(wrf grid)
Wind Speed at 10m(m/s)
Diff. of UCM1D & UCM2D W.S.(m/s)
UCM1D
UCM2D
UCM1D-2D
18
00
06
10JUL
Time(LST)
(15, 0.040404)
(719.094m, 7W/m²)
(52,13) U*
(wrf grid)
U* IN SIMILARITY THEORY(m/s)
Diff. of UCM1D & UCM2D U*(m/s)
UCM1D
UCM2D
UCM1D-2D
18
00
06
10JUL
Time(LST)
(15, 0.040404)
(719.094m, 7W/m²)
(52,13) $\rho_s C_p C_h$
(wrf grid)
$\rho_s C_p C_h$
Diff. of UCM1D & UCM2D $\rho_s C_p C_h$
UCM1D
UCM2D
UCM1D-2D
18
00
06
10JUL
Time(LST)
(15, 0.040404)
(719.094m, 7W/m²)