Urbanization and regional climate changes

都市化與區域氣候變遷

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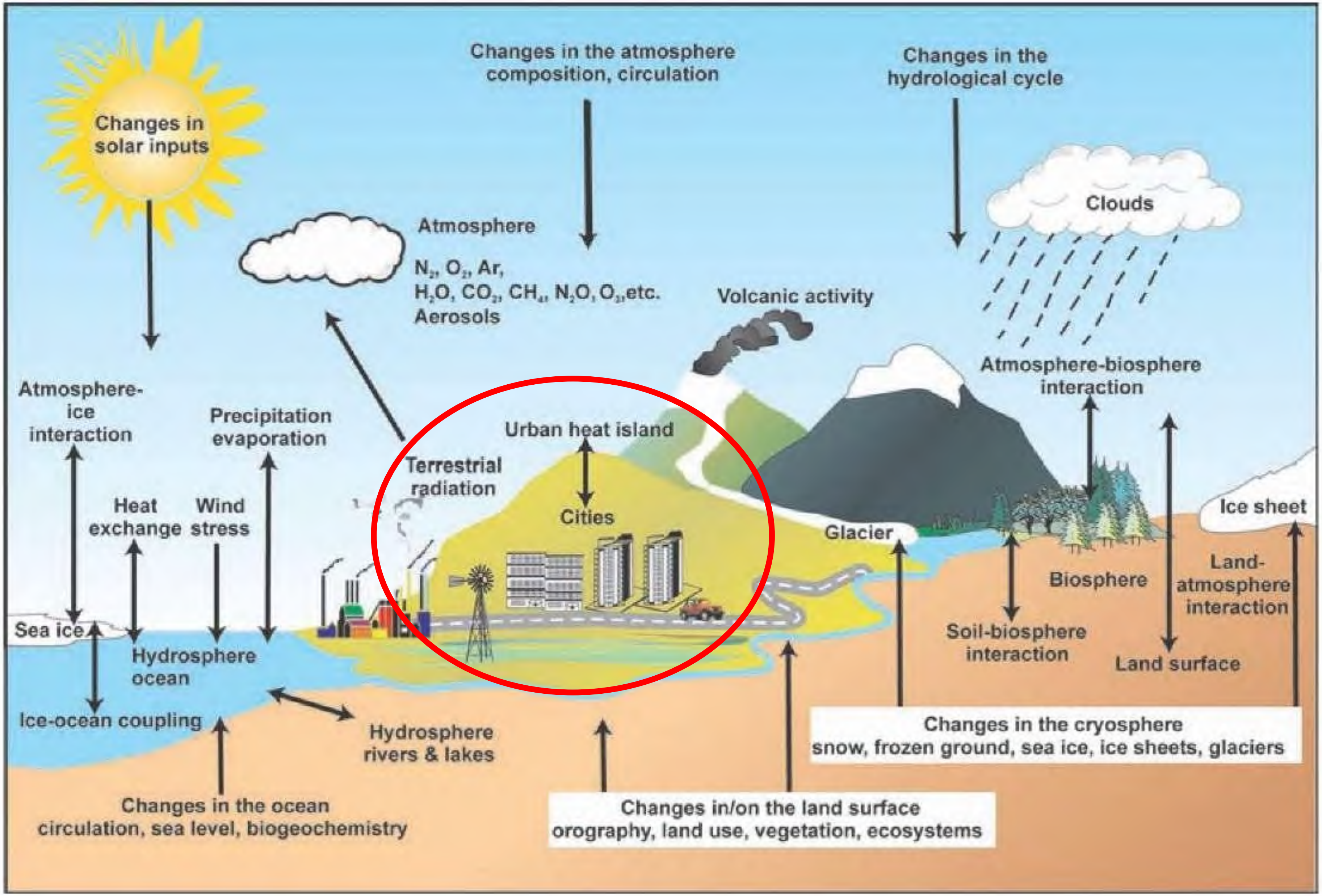
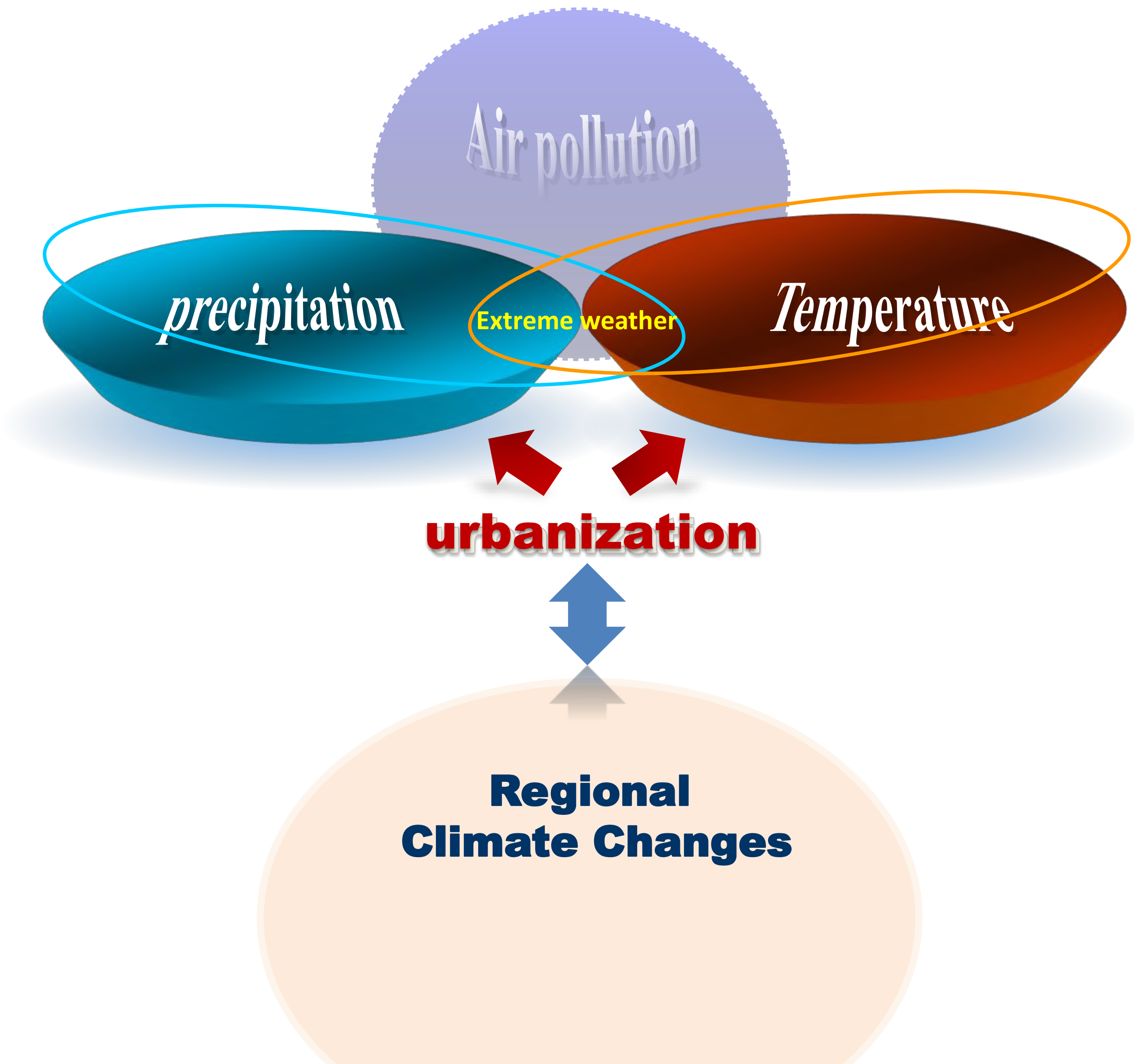
中央研究院 環境變遷研究中心

31 Oct., 2018 CWB

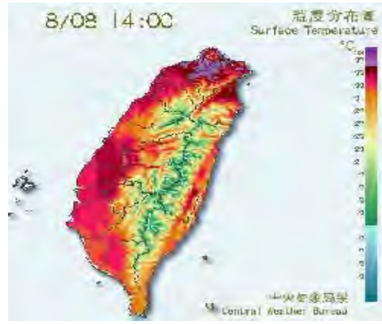
Climate system

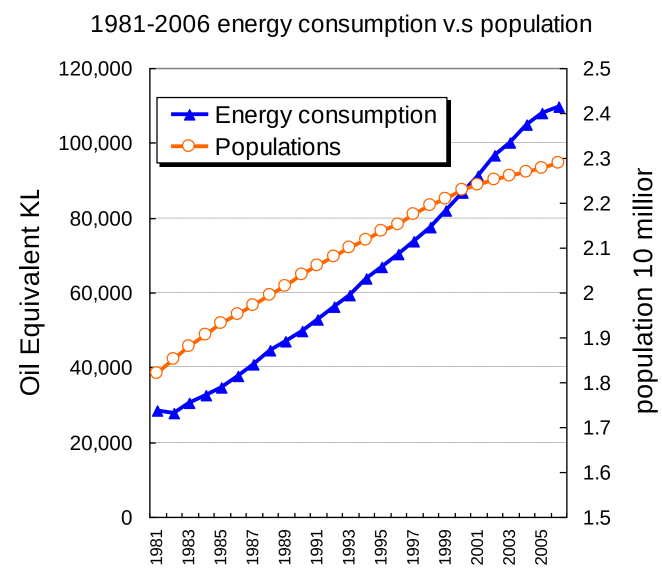


Outline


Air pollution
precipitation
Extreme weather
Temperature
urbanization
Regional
Climate Changes

Heat wave in Taipei





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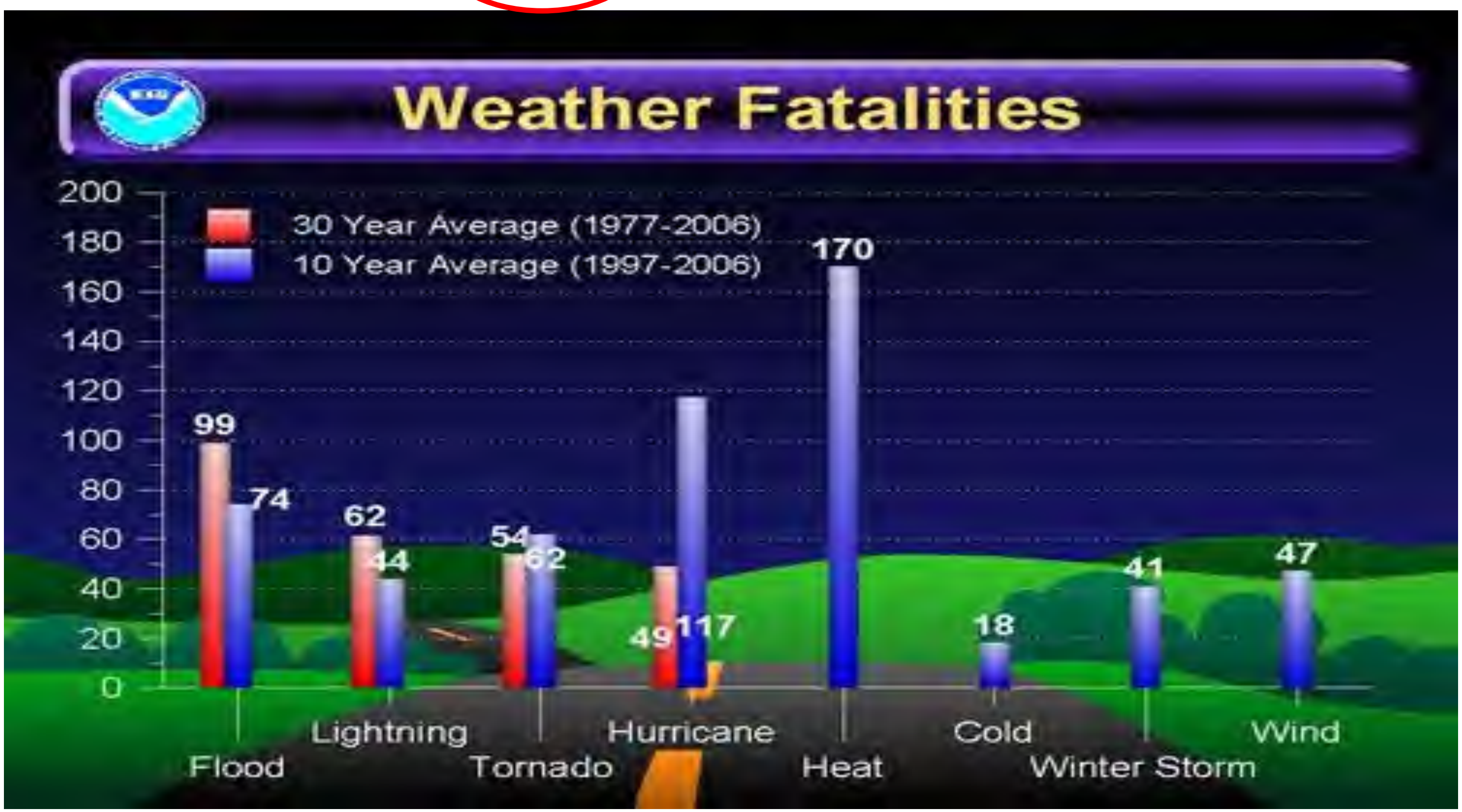
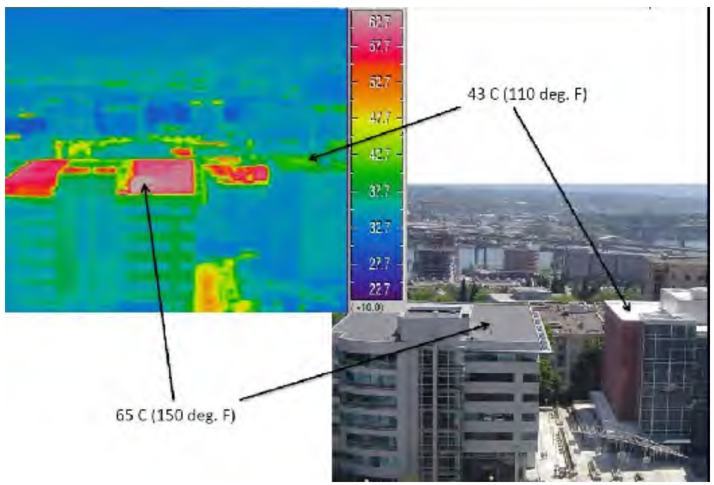
More Than 2,300 People Have Now Died in India's Heat Wave

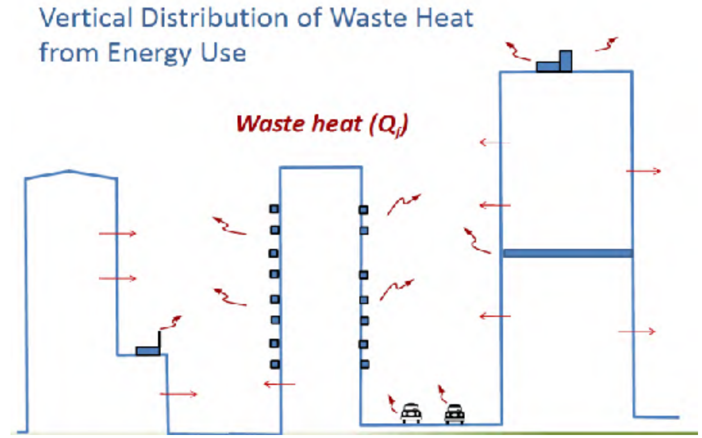
Rohit Inani / New Delhi @josefkisdrunk

June 2, 2015

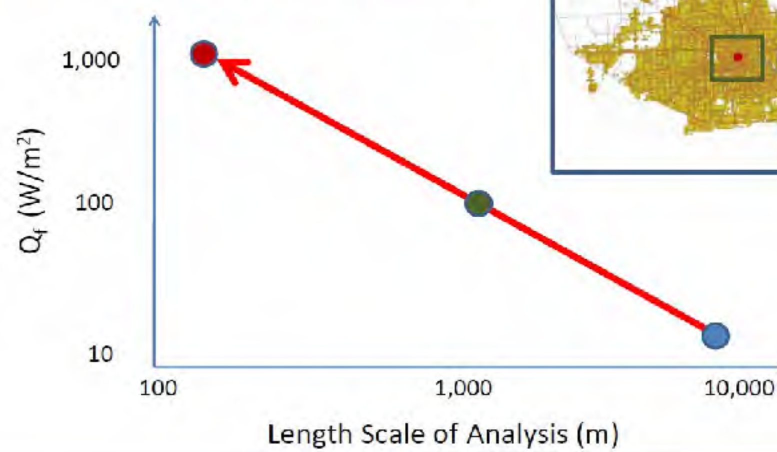


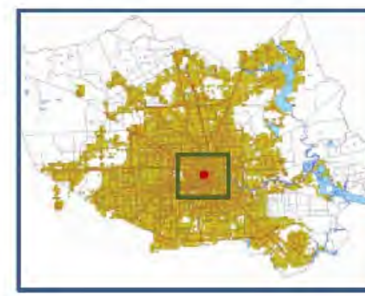
Background- Urbanization and urban heat island effect





- Magnitude depends upon scale of interest
  - City scale ~ 10's W/m^2
  - Urban core ~ 100's W/m^2
  - Downtown building scale ~ 1000's W/m^2





(Sailor D.J. 2011)

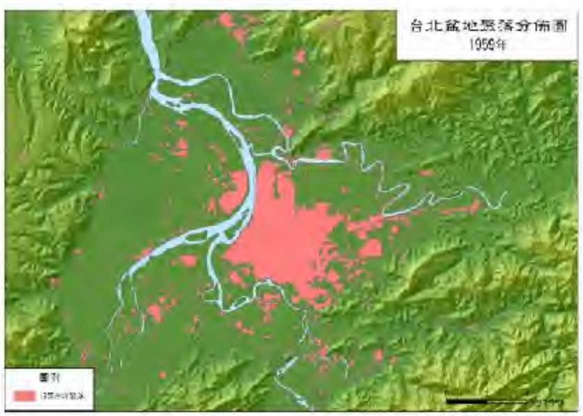
Urbanization History of Taipei

1895

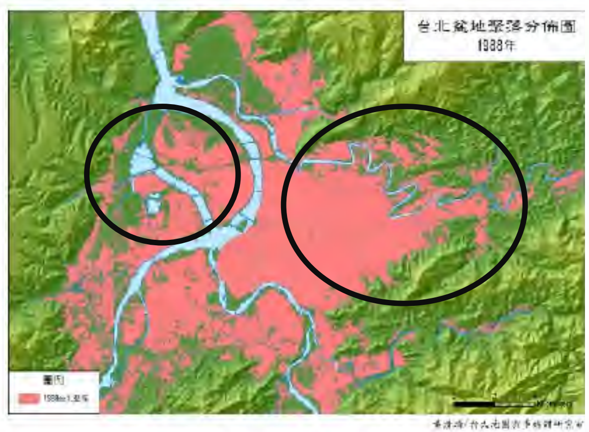
1904

1925

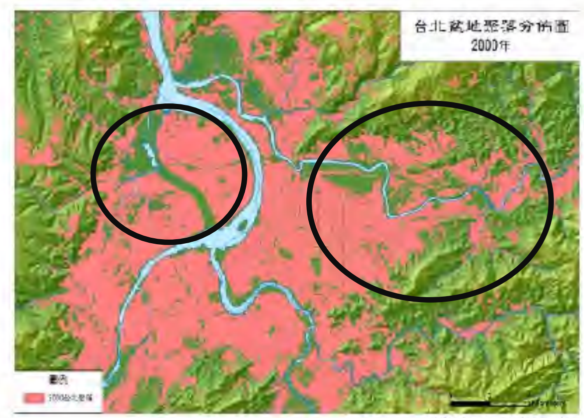
1959



1988

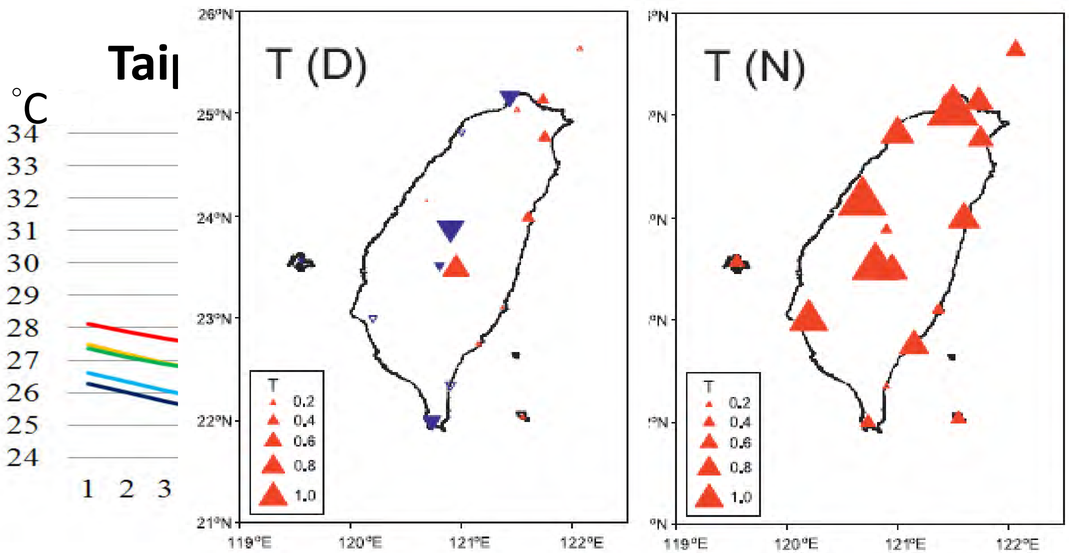


2000

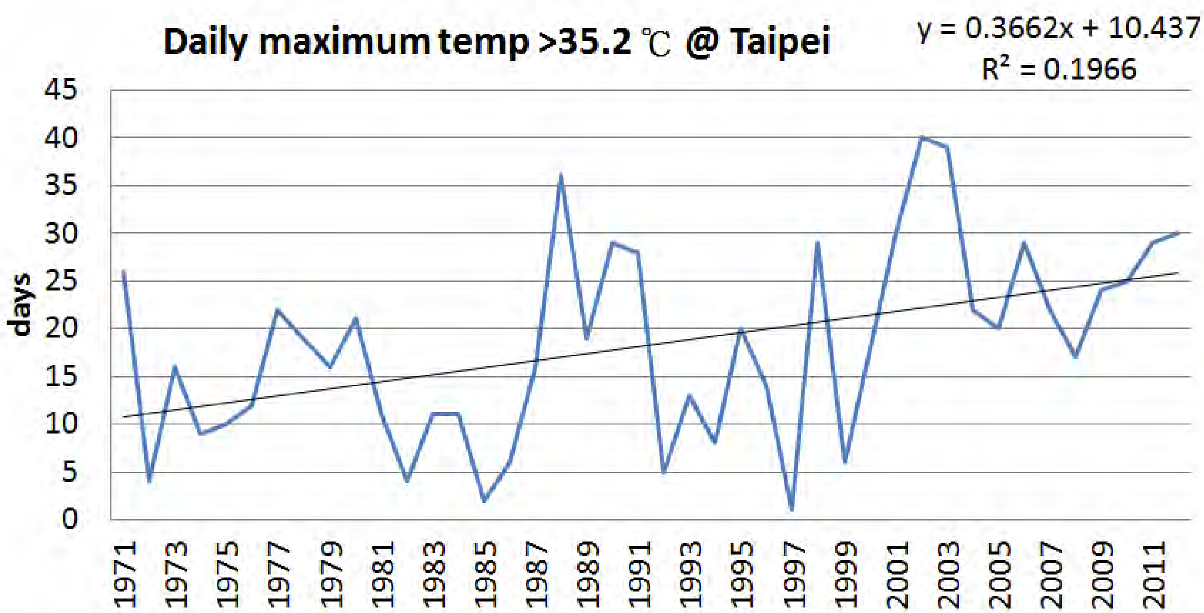


(provided by Prof. Lai Chun Kuei, NTU)

Urban heat island effect and heat waves in Taiwan



(Shiu et al.2009)

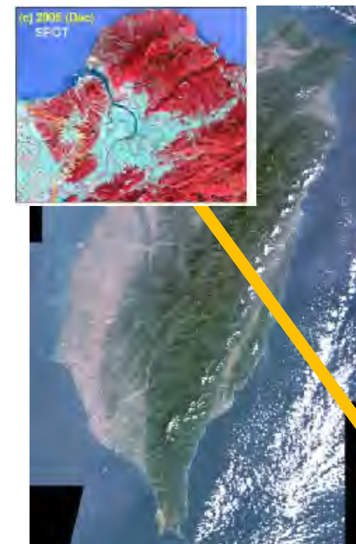


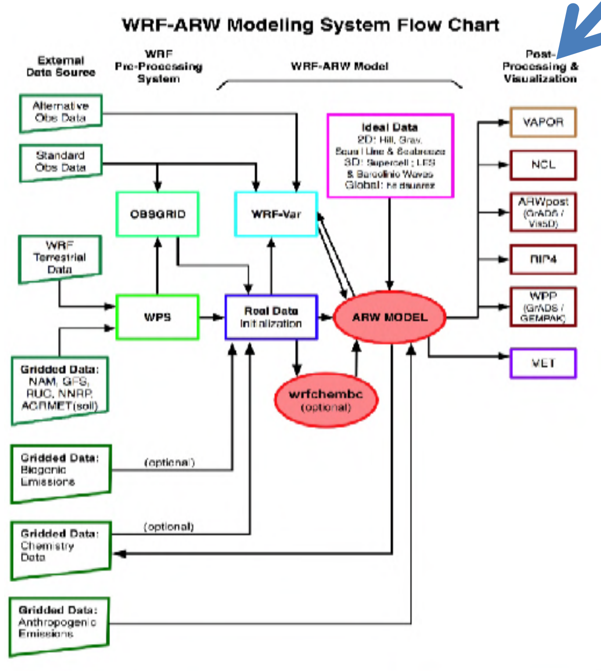
Model improvement

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

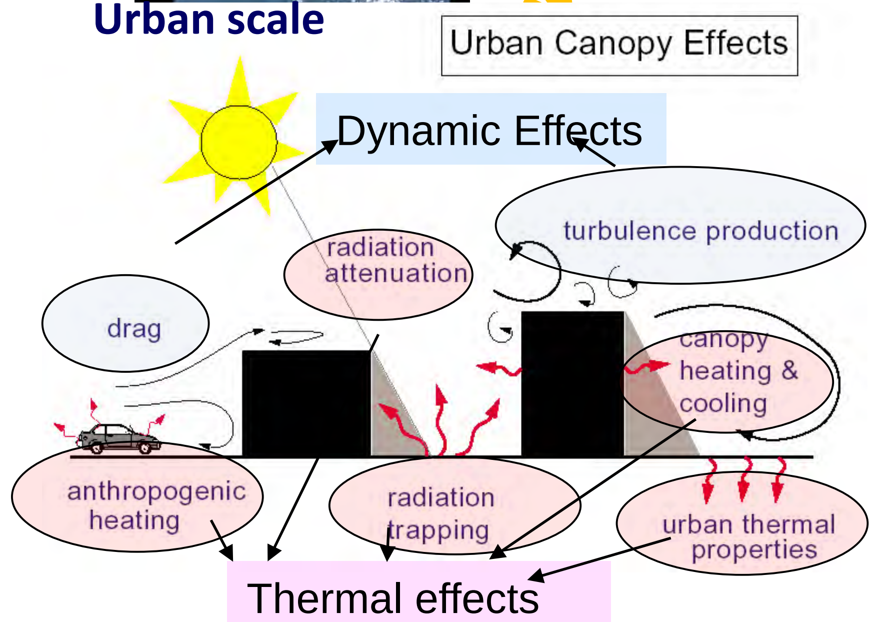
Regional scale

Local scale



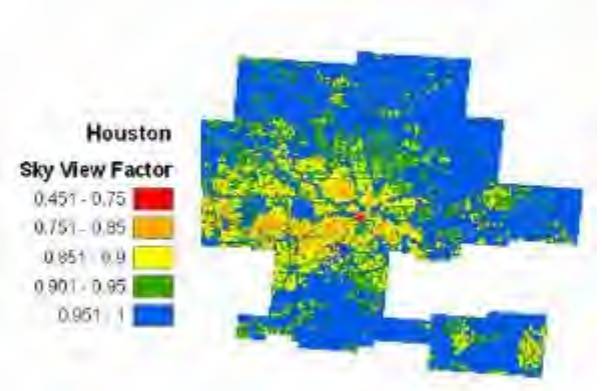


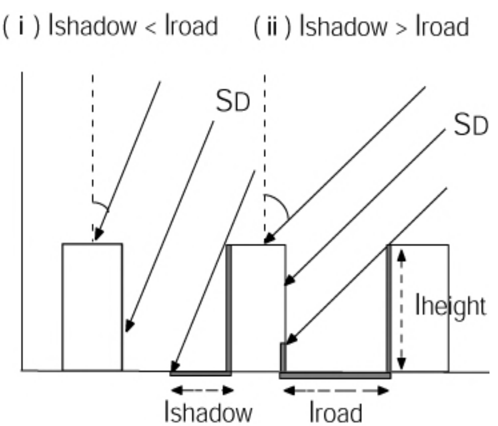
Urban scale



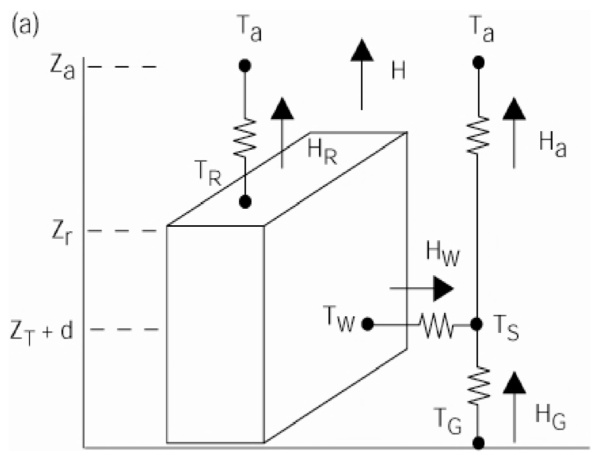
WRF/Urban Canopy Model

- Single layer Urban-Canopy Model (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

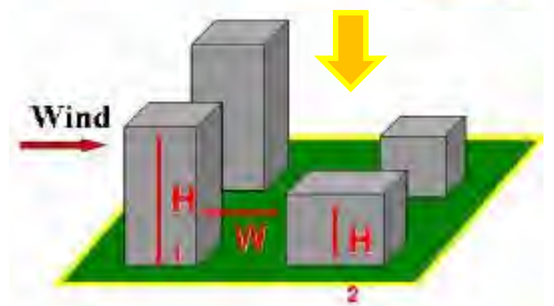




Shadow and Radiation Trapping



Temperatures and Thermal Transfer



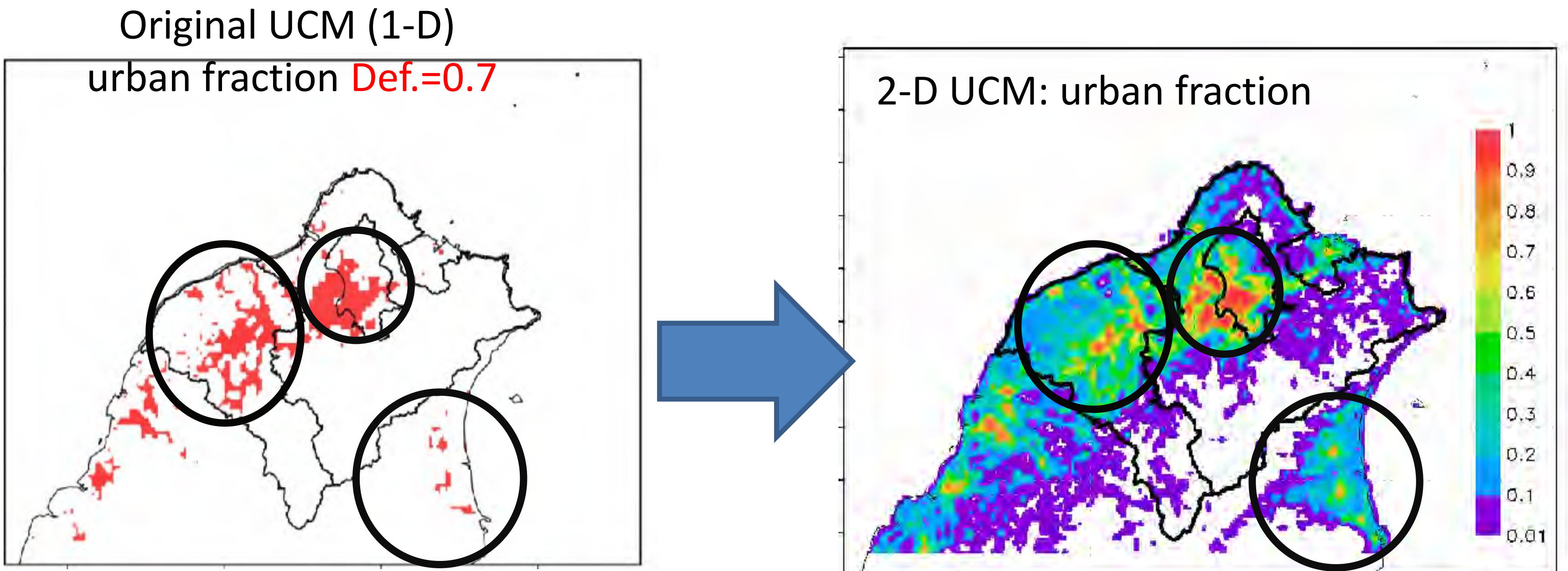
Defined and implemented urban canopy parameterizations such as height-to width ratios and sky view factors into model formulations

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

- **Original UCM :**

  Urban Fraction is fixed, for instance 0.7, or given in three types of urban

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



（1km resolution）

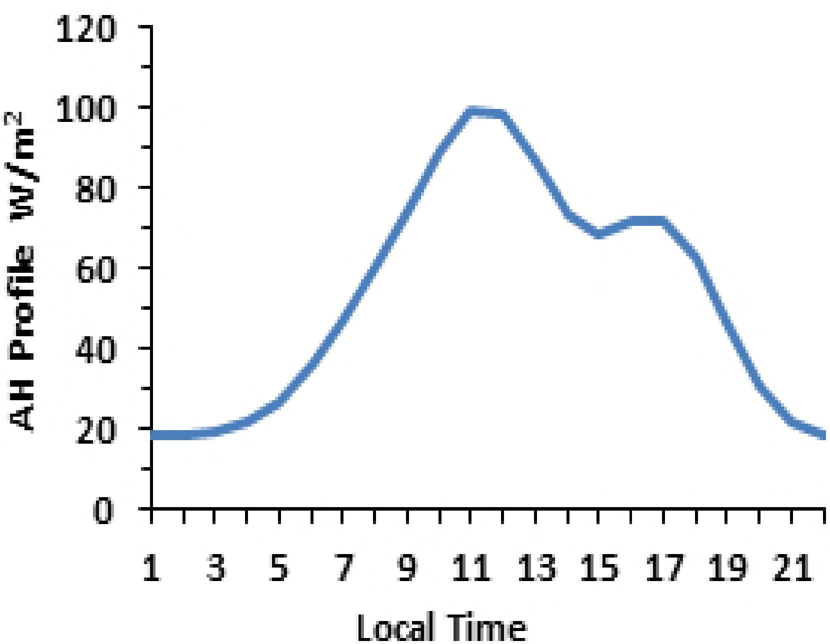
(Lin et al. 2016)

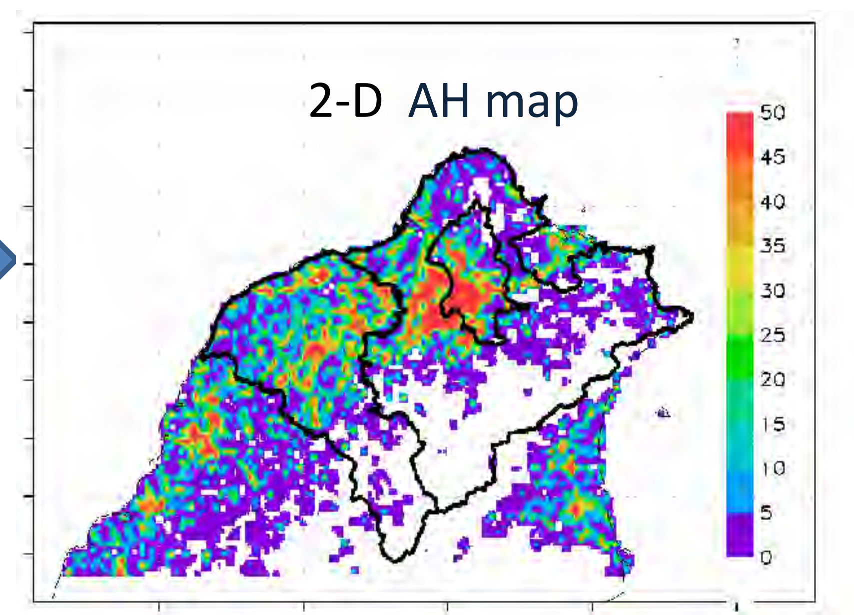
2-D Urban Canopy Model (UCM) model
-Anthropogenic heat

- **Original UCM :**

Anthropogenic heat(AH) is fixed, for example, 50W/m²

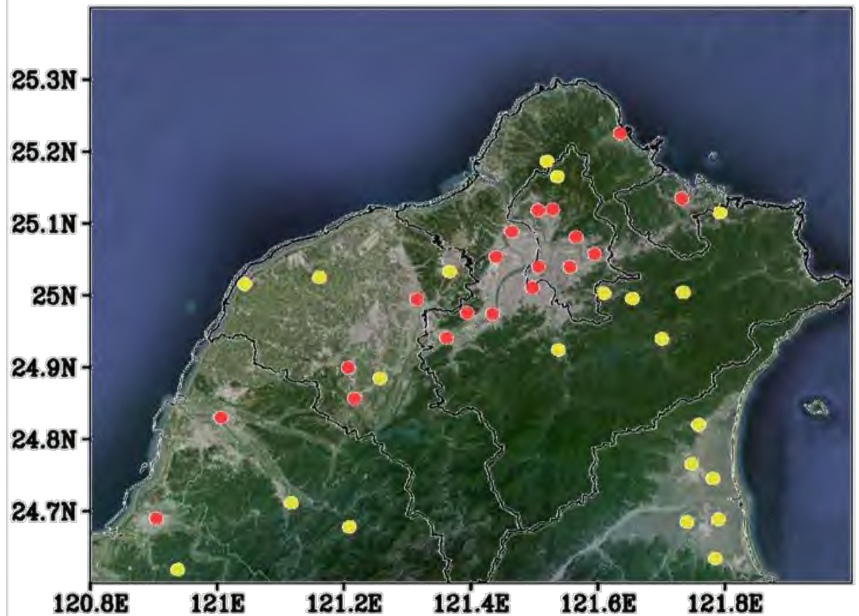
- **2-D UCM :**
  - **Anthropogenic Heat**
    - **2-D anthropogenic heat is generated from 100 m resolution of building density (2006),**
    - **The maximum AH value is *50 W/m²*.**



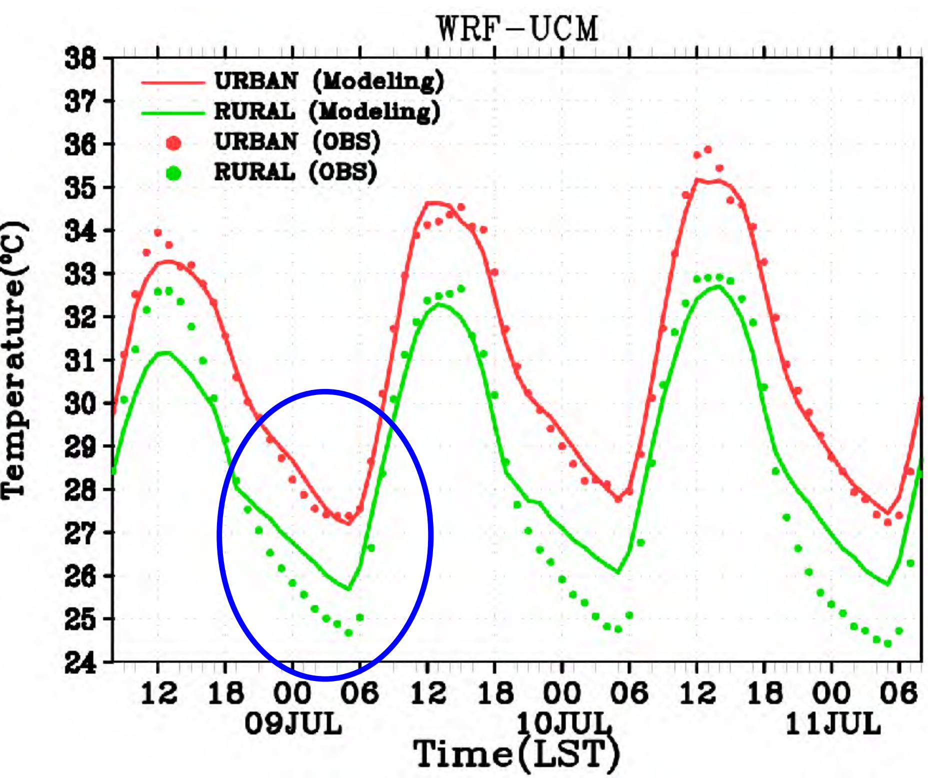


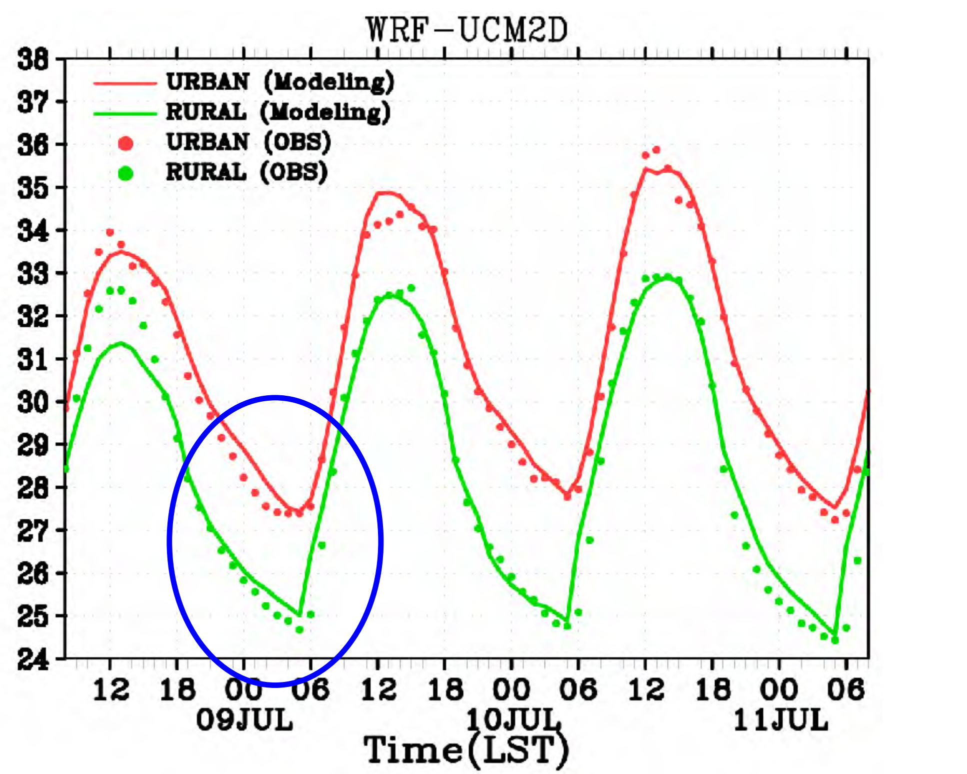
resolution）

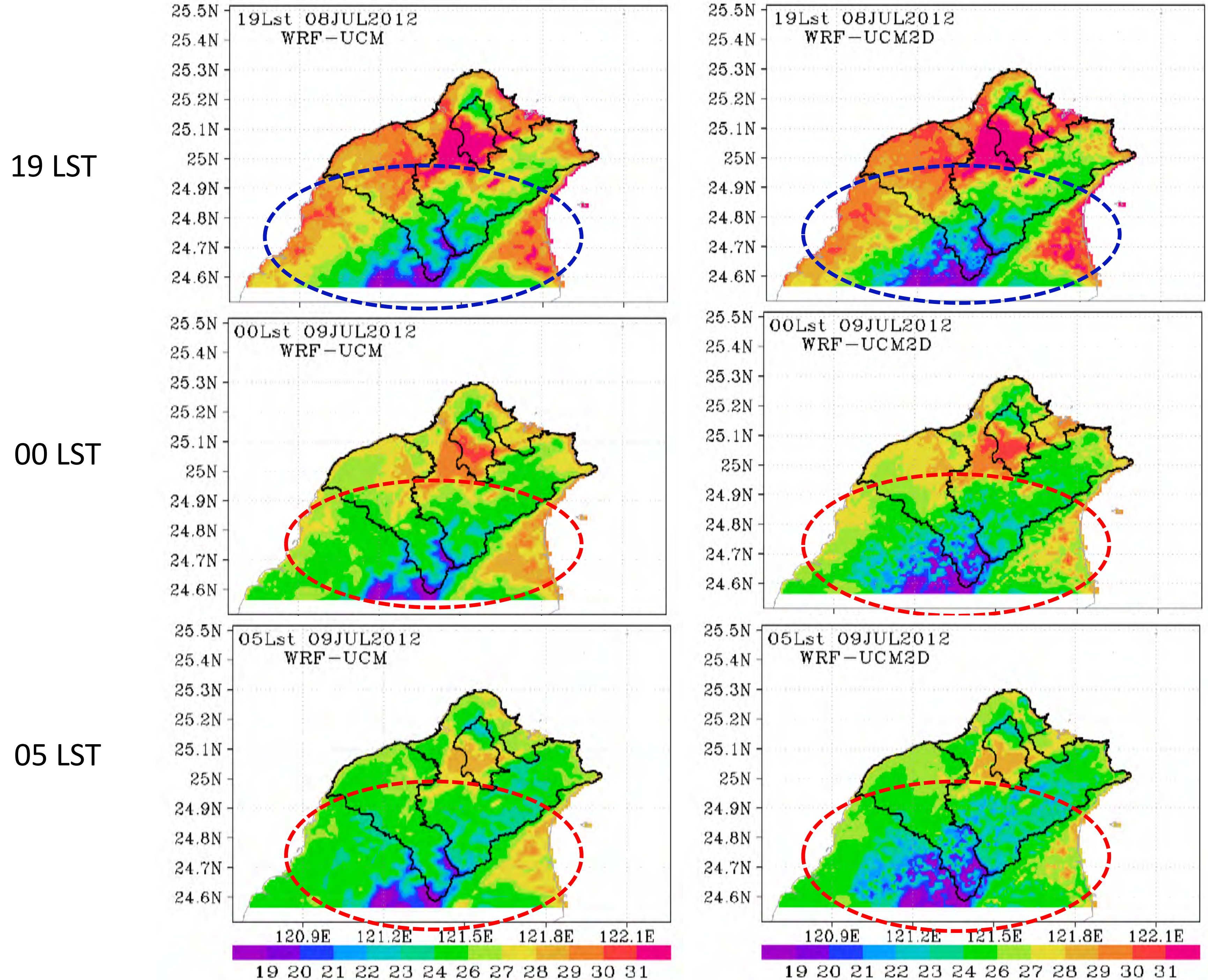
(Lin et al. 2016)



Urban (red dots)
Non-urban (yellow dots)







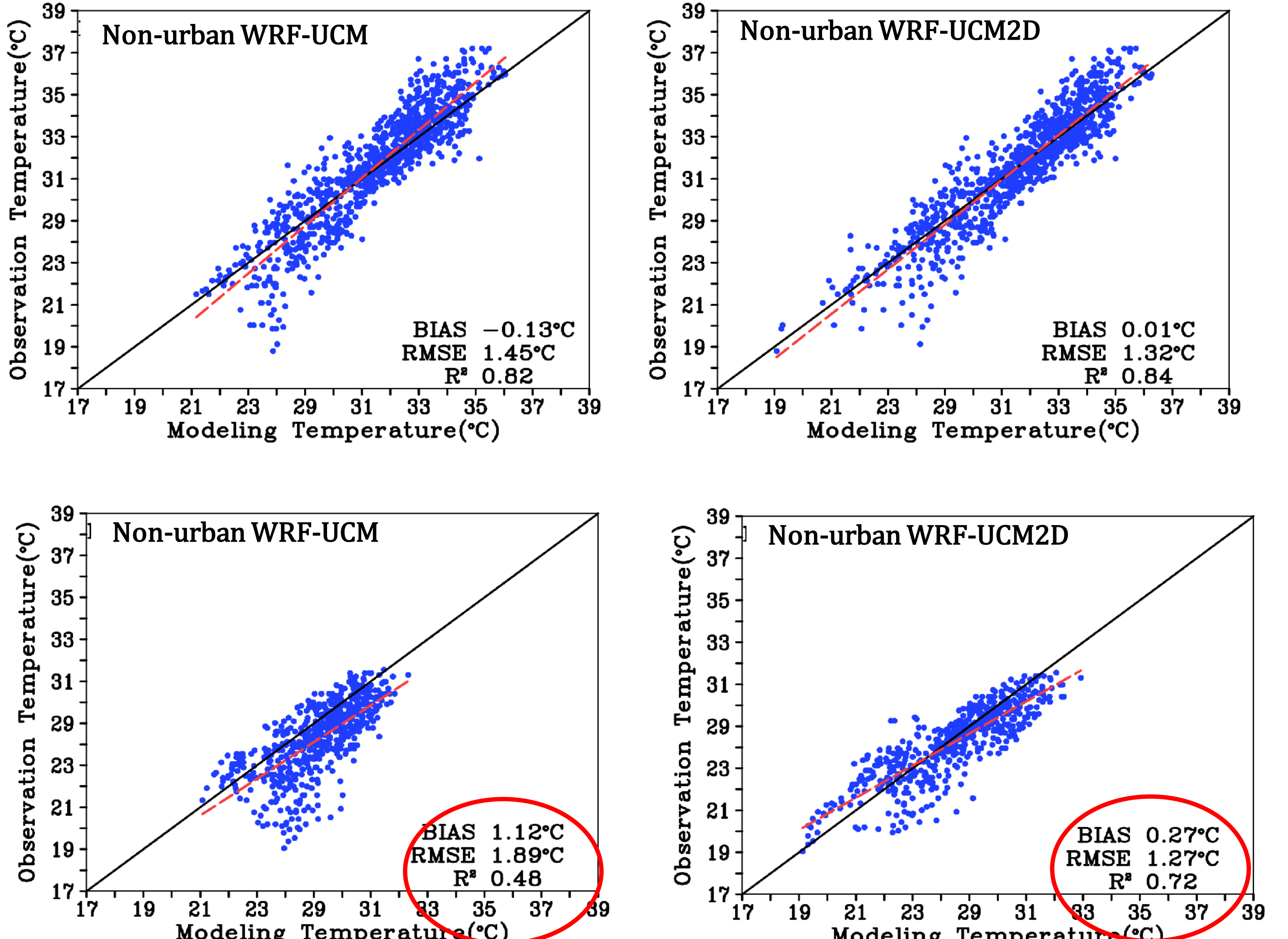
19 LST
00 LST
05 LST
19Lst 08JUL2012
WRF−UCM
19Lst 08JUL2012
WRF−UCM2D
00Lst 09JUL2012
WRF−UCM
00Lst 09JUL2012
WRF−UCM2D
05Lst 09JUL2012
WRF−UCM
05Lst 09JUL2012
WRF−UCM2D
25.5N
25.4N
25.3N
25.2N
25.1N
25N
24.9N
24.8N
24.7N
24.6N
120.9E
121.2E
121.5E
121.8E
122.1E
19 20 21 22 23 24 26 27 28 29 30 31

Model evaluation for 21 non-urban stations

WRF-UCM | **WRF-UCM2D**

daytime

nighttime



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www.atmos-chem-phys.net/16/1809/2016/
doi:10.5194/acp-16-1809-2016

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Impact of an improved WRF urban canopy model on diurnal air temperature simulation over northern Taiwan

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[2]Graduate school of Life and Environmental Sciences, and Center for Computational Sciences, University of Tsukuba, Tsukuba, Japan
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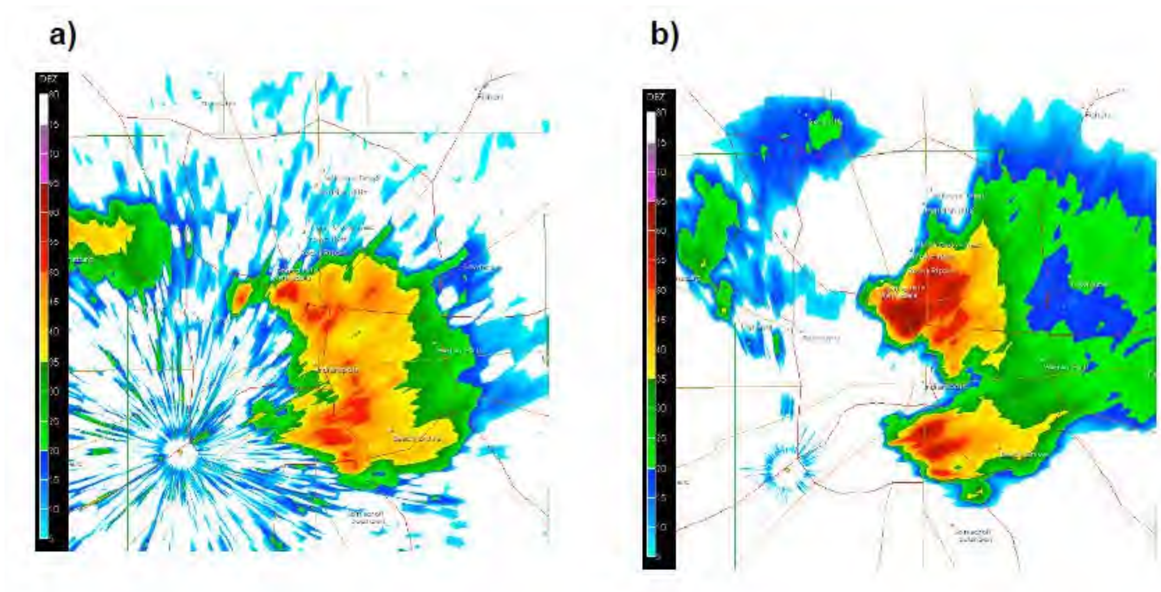
I: Urbanization and Precipitation

UHI effect impact on precipitation:

- Precipitation max over urban: Calm condition
- Precipitation enhanced at downwind: weak regional winds (many papers)
- Moving regional storm: Cities can split convective storm, and change the behavior of convective precipitation, and enhance downstream precipitation. (Bornstein and LeRoy,1990; Bornstein and Lin ,2000; Baik et al., 2001; Niyogi et al. 2011)

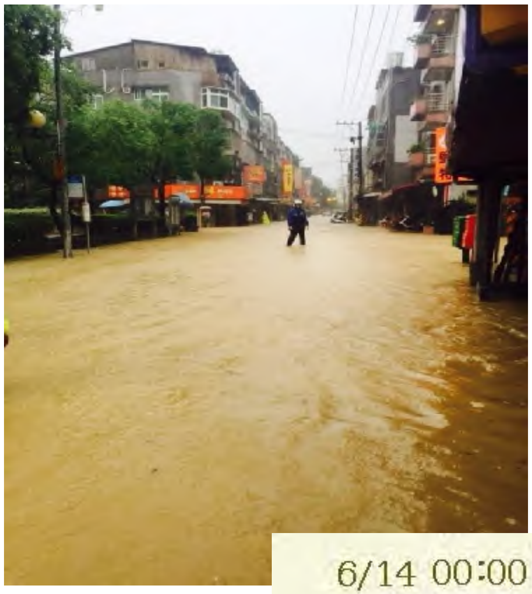


(Niyogi et al. 2011)

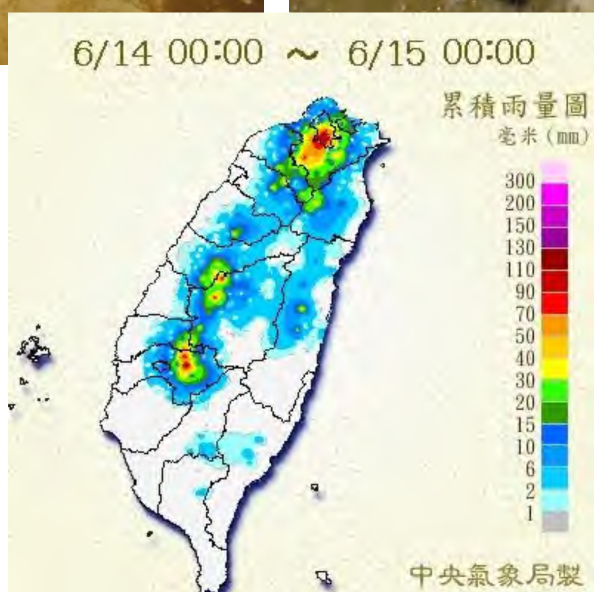
- Urban reduces precipitation: less evaporation, higher sfc temperature, sensible heat fluxes, and aerosol. Zhang, Chen, Miao (2009) JGR

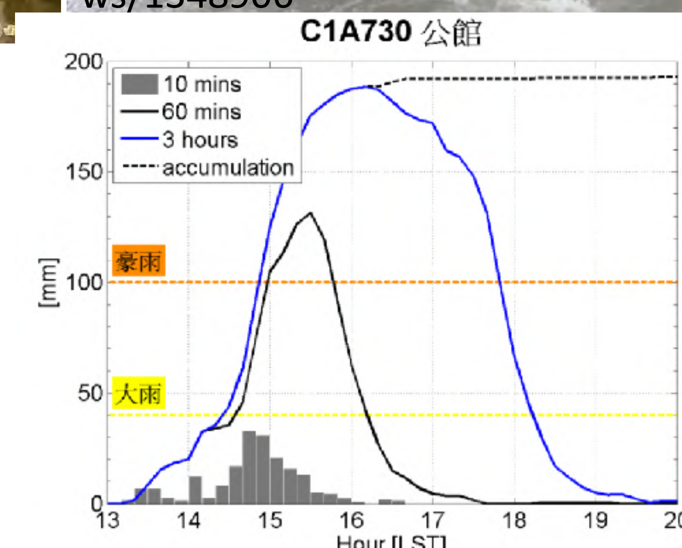
Taipei Flash flood case

14 June, 2015



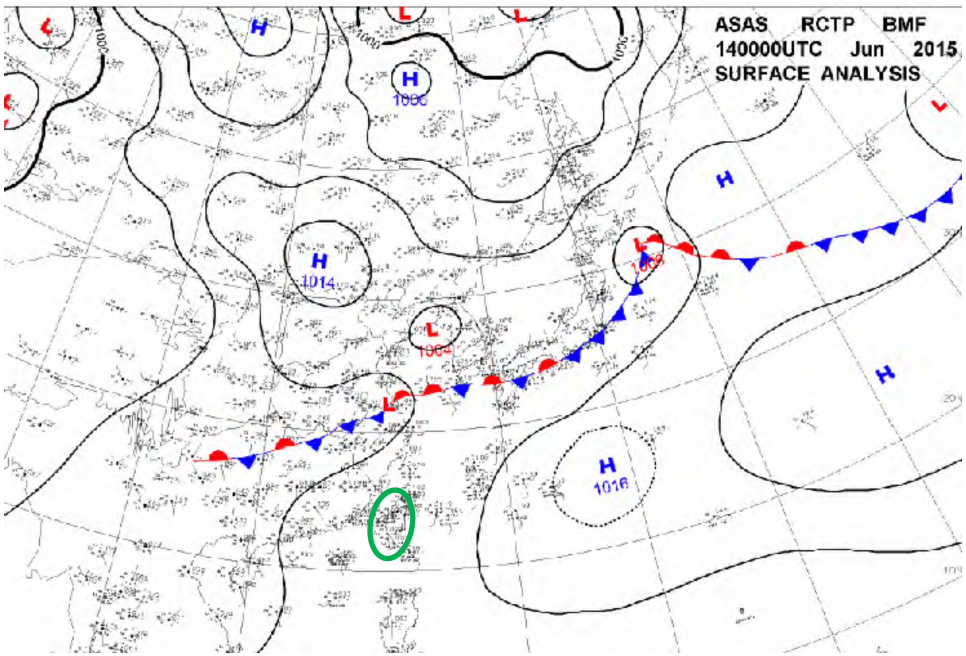
http://news.ltn.com.tw/news/life/breakingnews/1348906

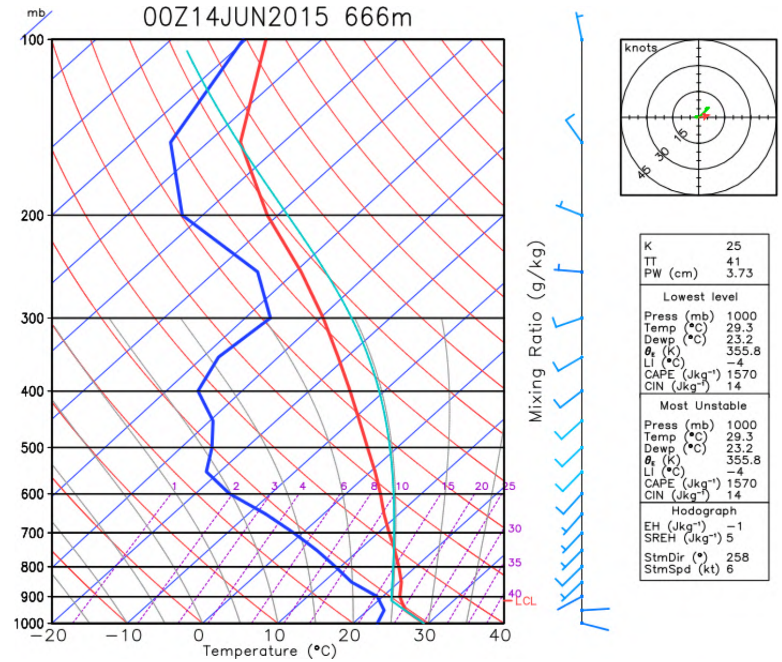


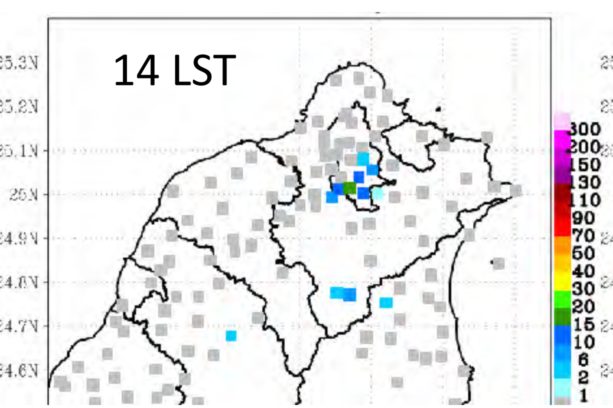


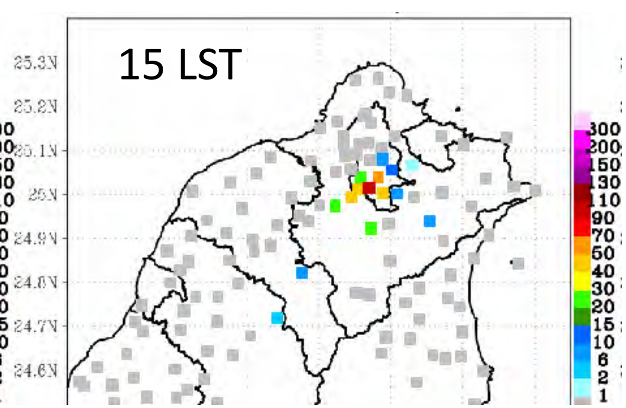
(from Jou et al.2016)

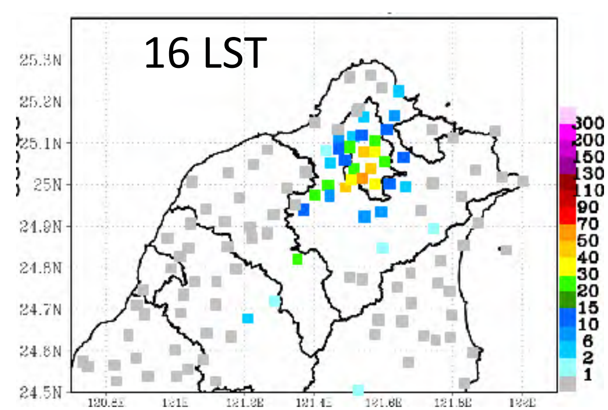
Taipei Flash flood case (14 June,2015)



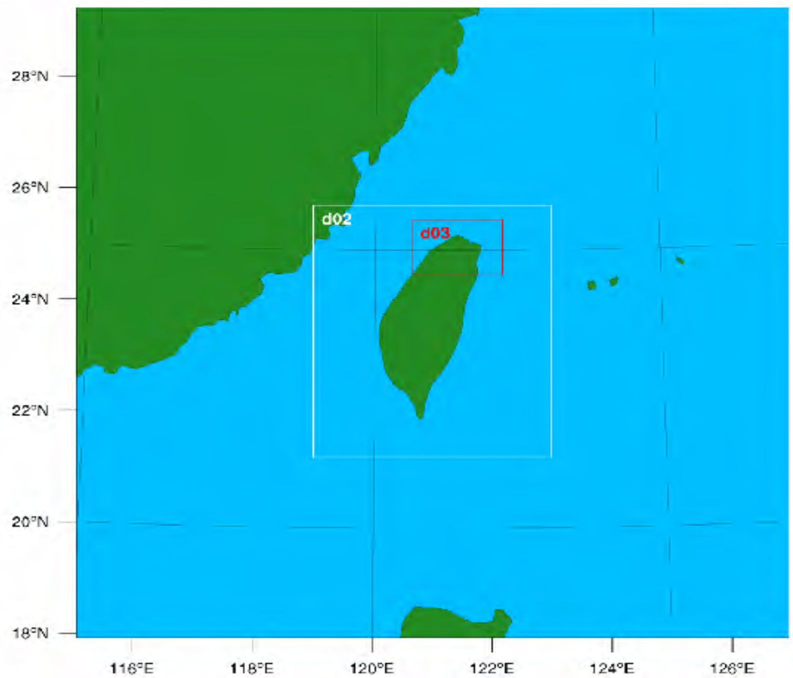








Model domains and configures



D01: 6 km, 211x211;

D02: 2 km, 211x253;

D03: 666m, 241x166

Version WRF 3.9

Met. IC, BC: ERA5 dataset

Microphysics : WSM 5-class scheme

Long-wave radiation : RRTM

Short-wave radiation : RRTM

Surface layer : Revised MM5 Monin-Obukhov scheme (Jimenez, renamed in v3.6)

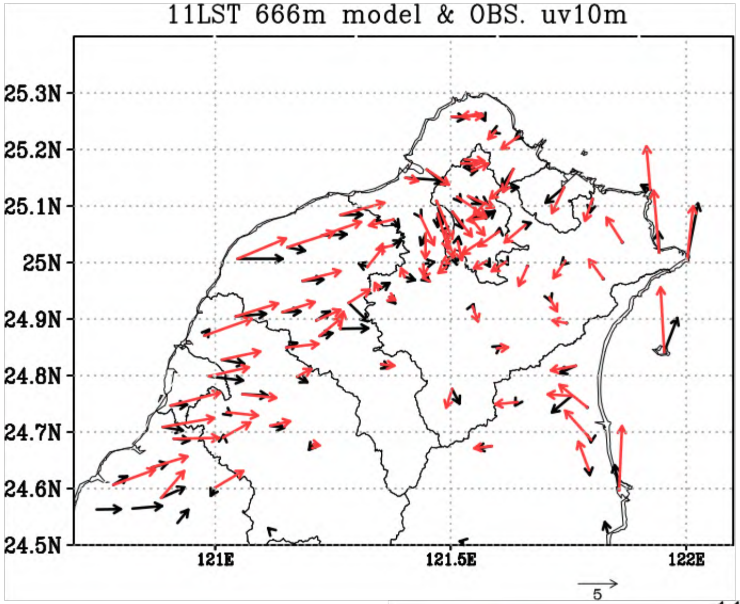
Land-surface model : Unified Noah LSM

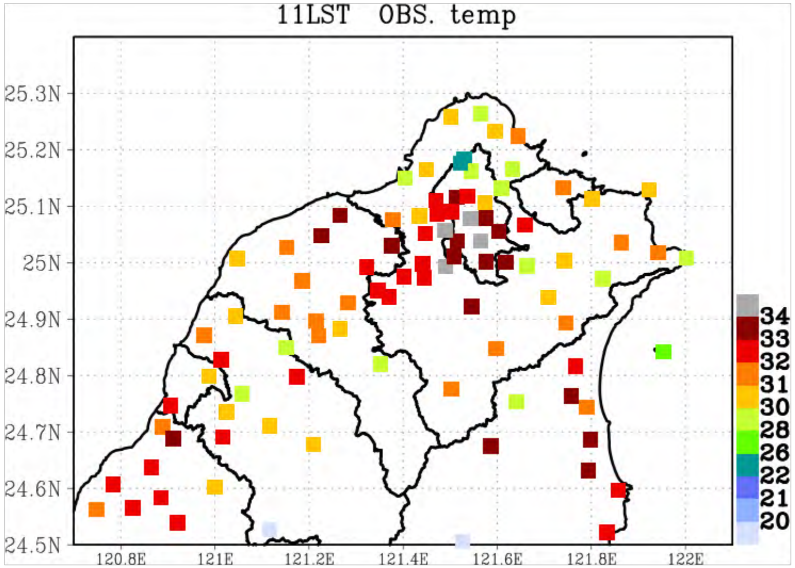
Boundary layer scheme : YSU scheme

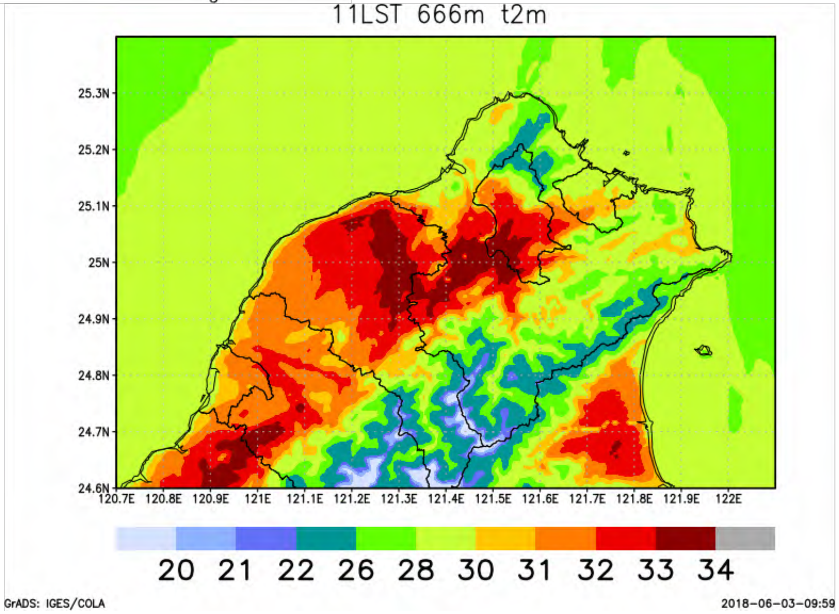
Cumulus : Grell-Freitas ensemble scheme(only Do1 and D02)

Urban canopy model:2D

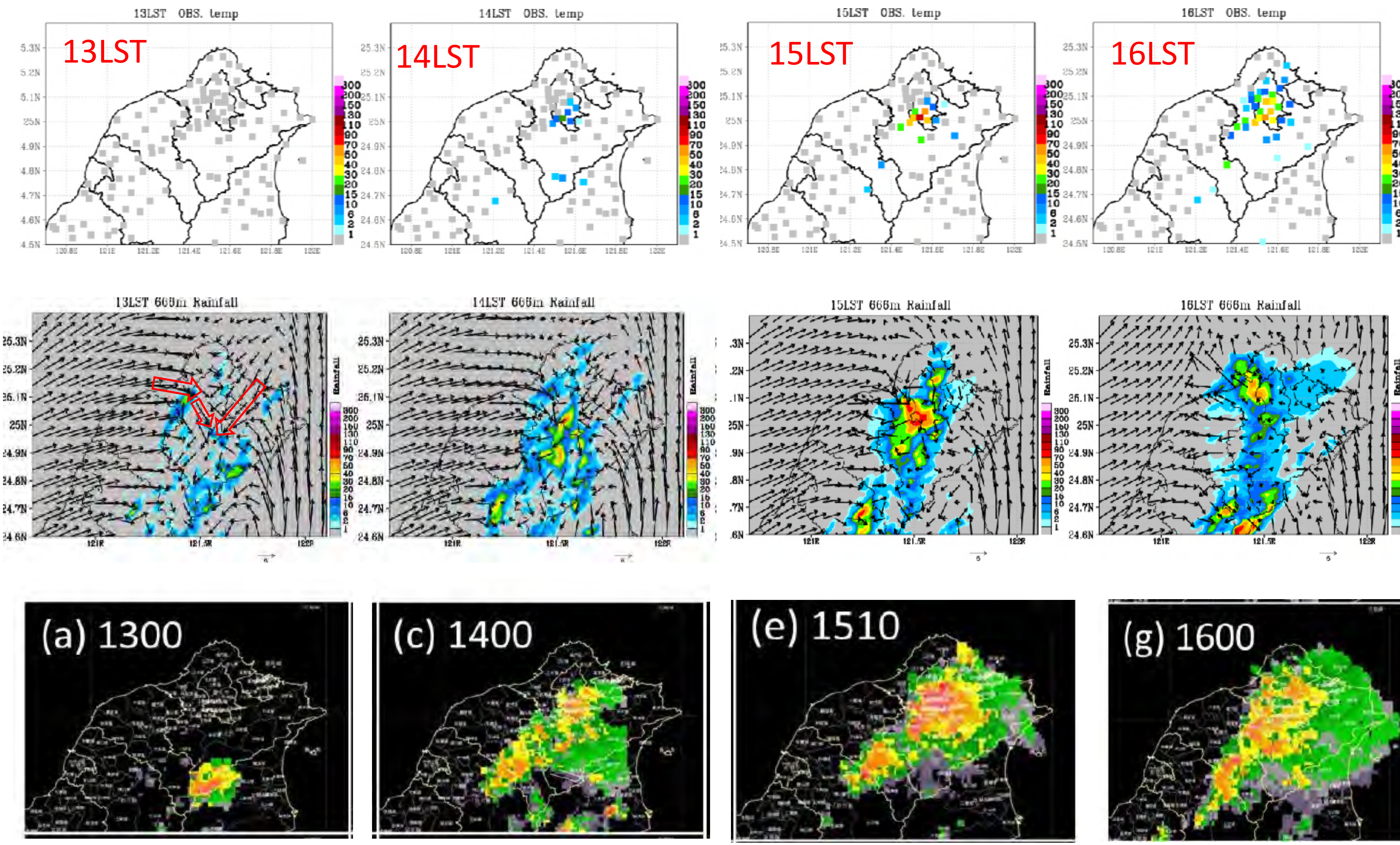
Model evaluation







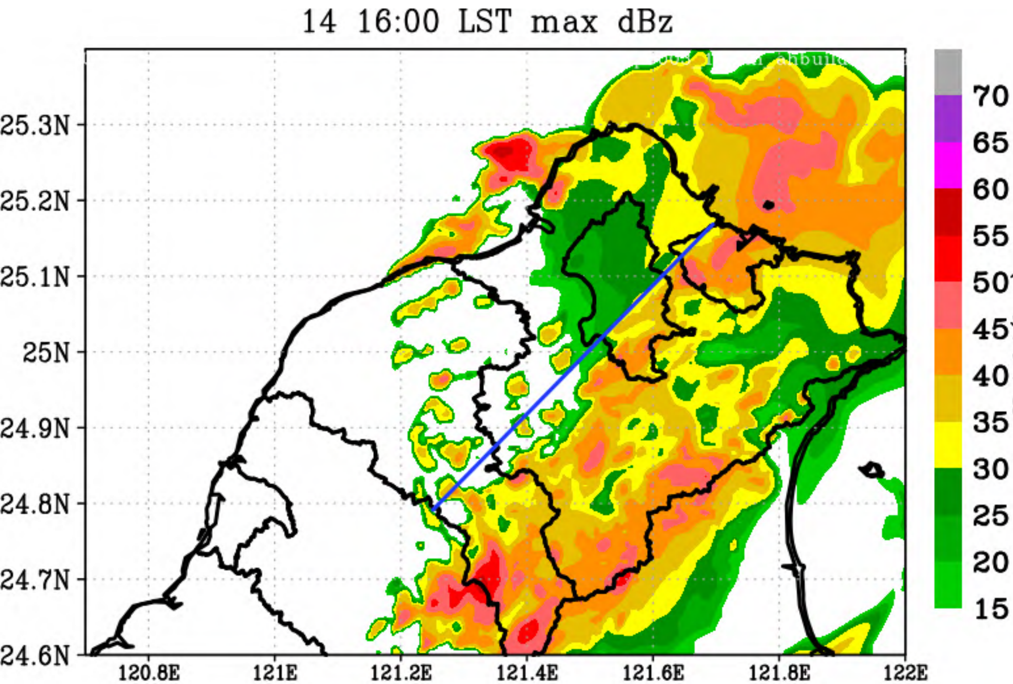
Precipitation and Radar reflectivity

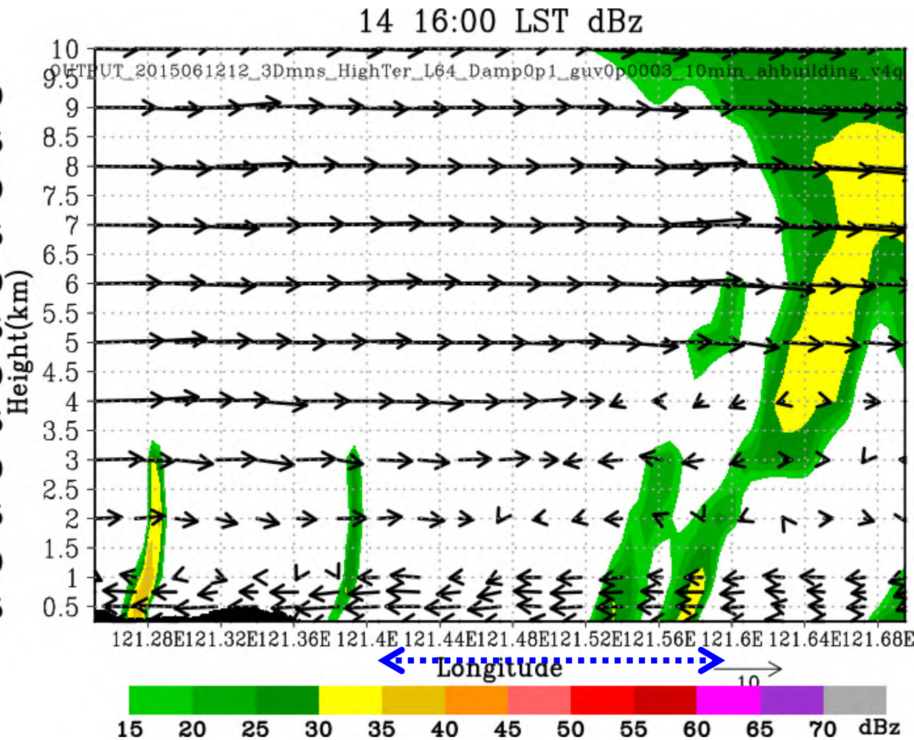


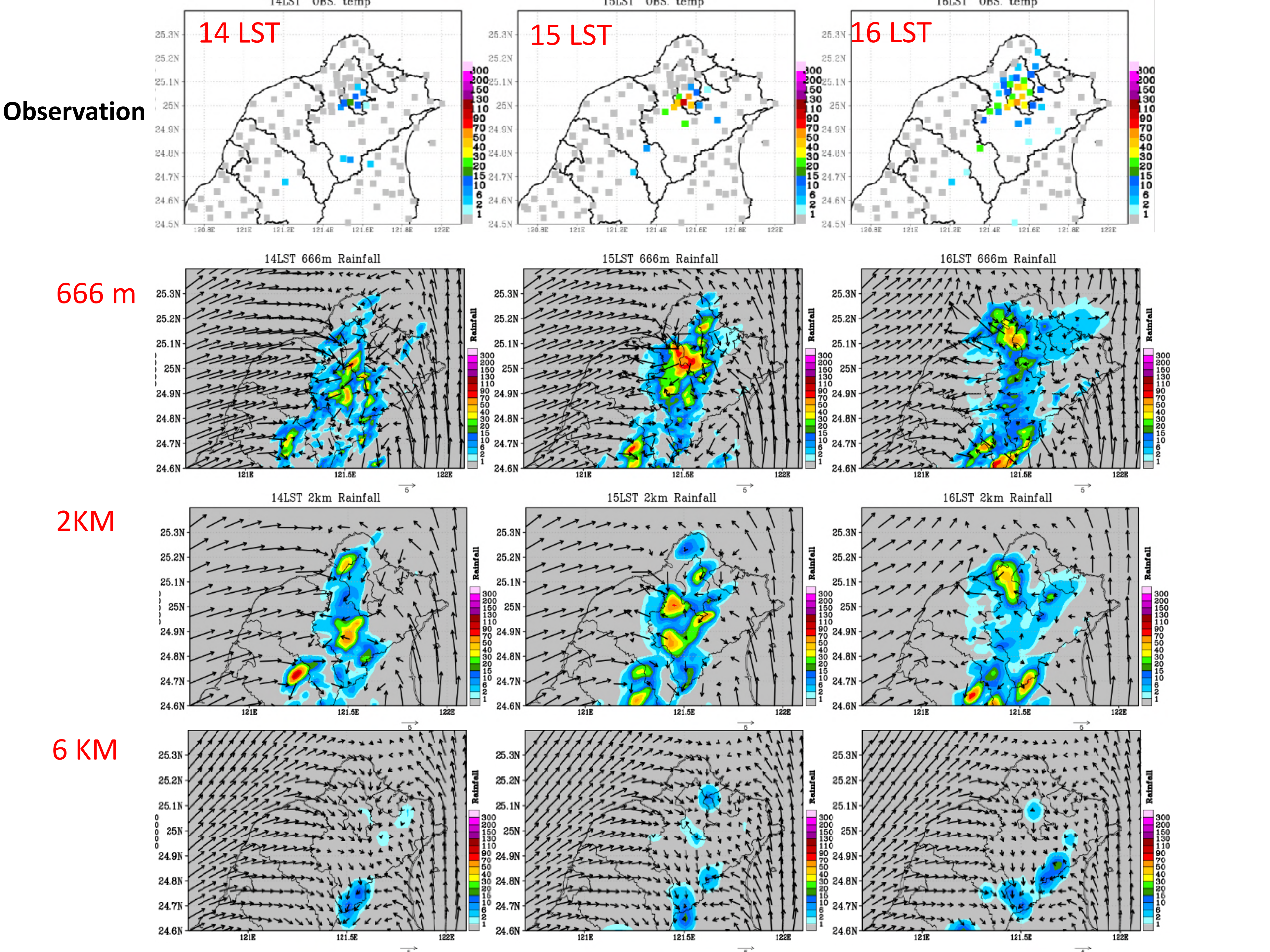
(Radar figures source: Jou et al. 2016)

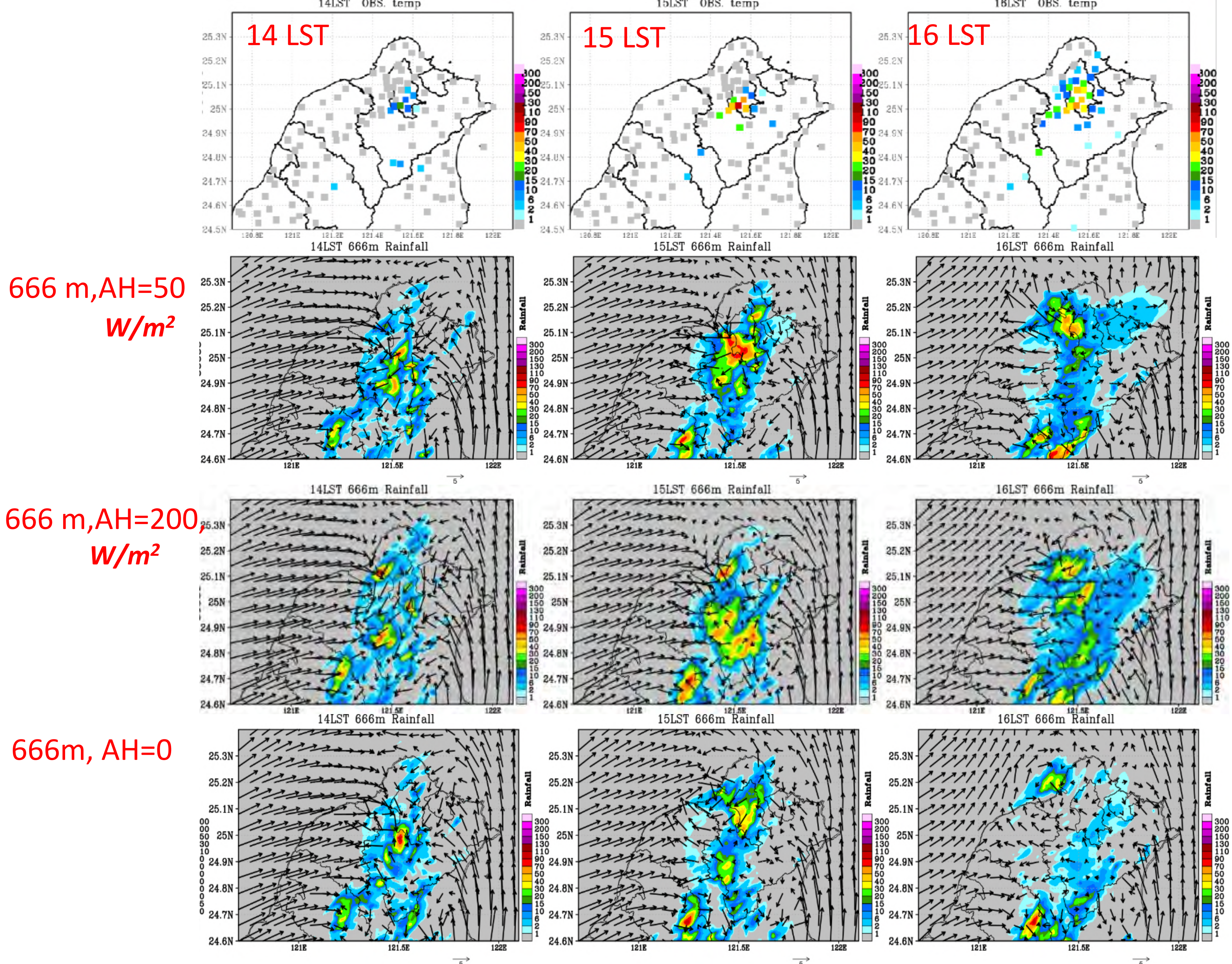
Simulation Radar Reflectivity

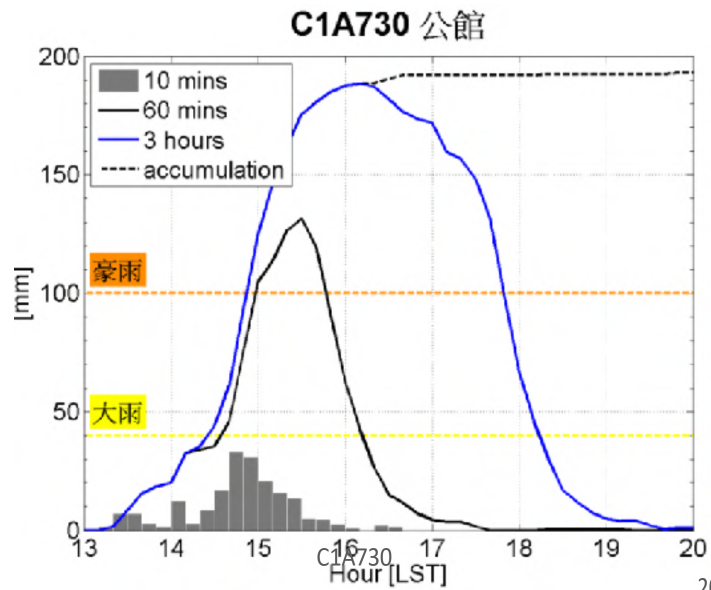
12:10 ~ 16:00 LST



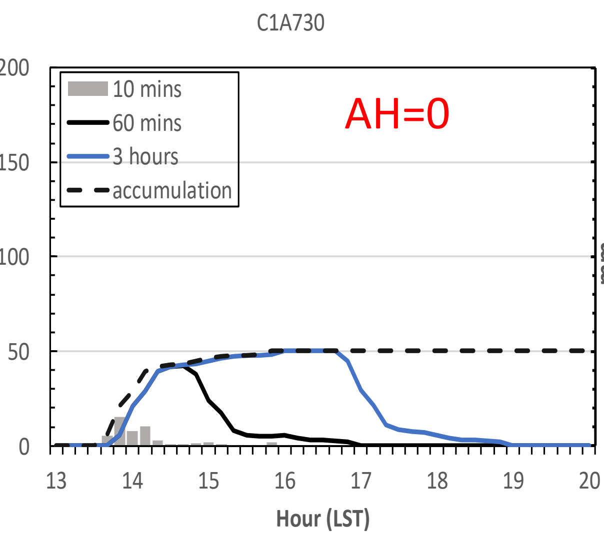


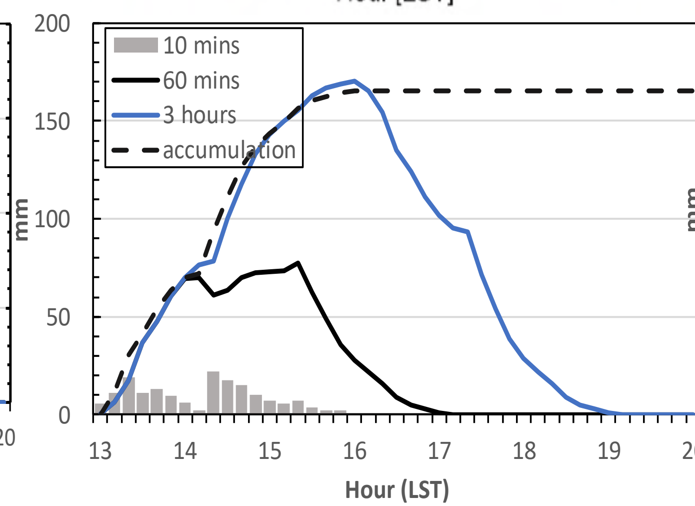

Observation
14 LST
15 LST
16 LST
666 m
14LST 666m Rainfall
15LST 666m Rainfall
16LST 666m Rainfall
2KM
14LST 2km Rainfall
15LST 2km Rainfall
16LST 2km Rainfall
6 KM
Rainfall

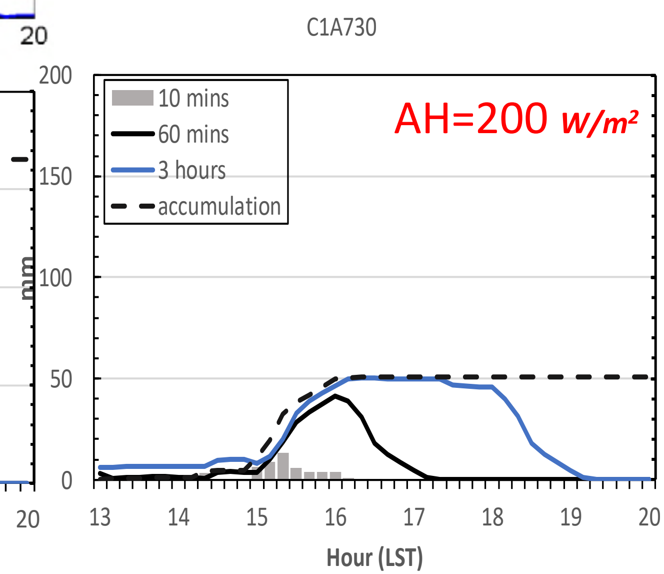

14 LST
15 LST
16 LST
14LST OBS. temp
15LST OBS. temp
16LST OBS. temp
666 m,AH=50 W/m²
666 m,AH=200, W/m²
666m, AH=0
14LST 666m Rainfall
15LST 666m Rainfall
16LST 666m Rainfall
Rainfall



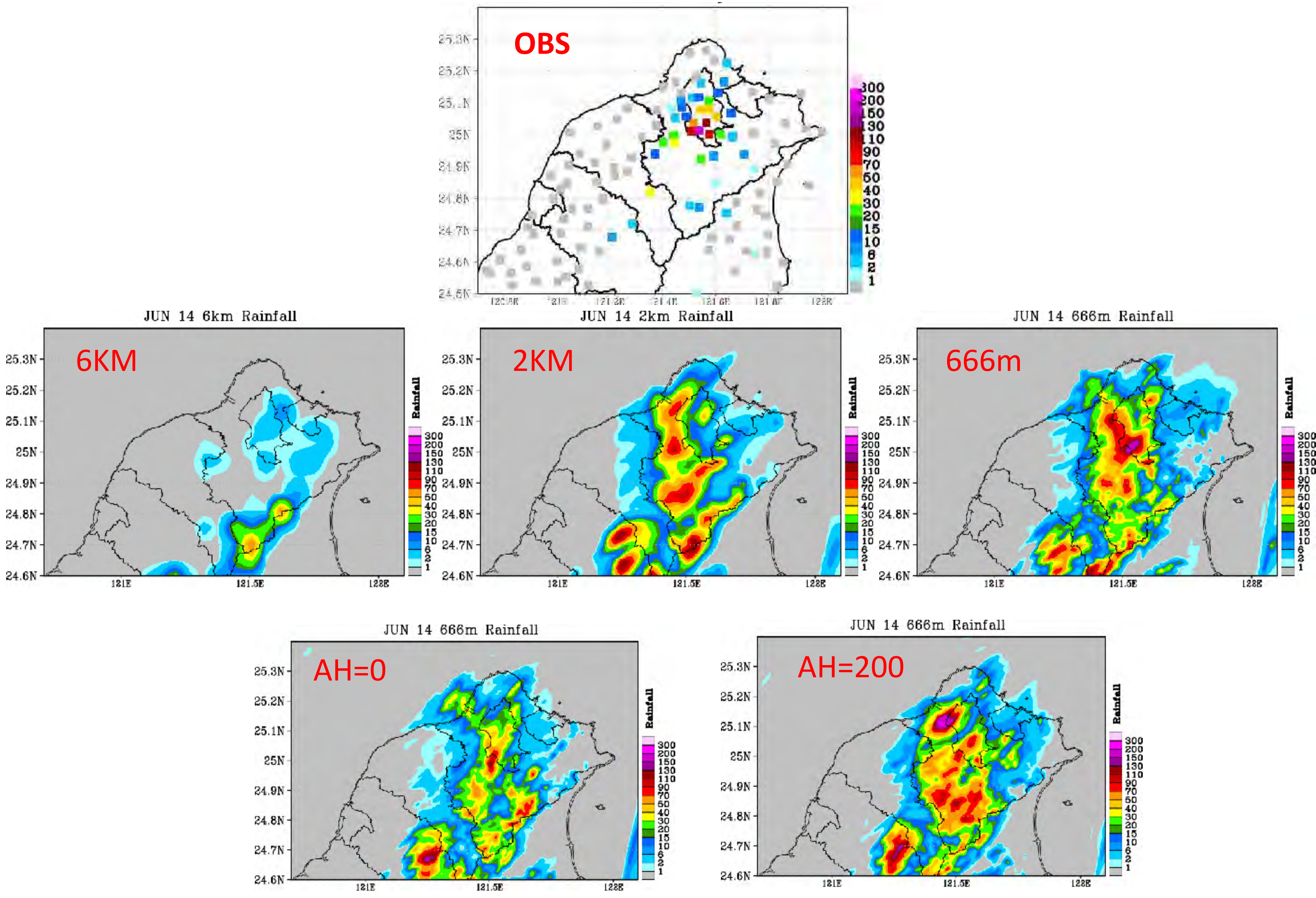
(OBS,source: Jou et al.2016)







Accumulation Rainfall



Summary I

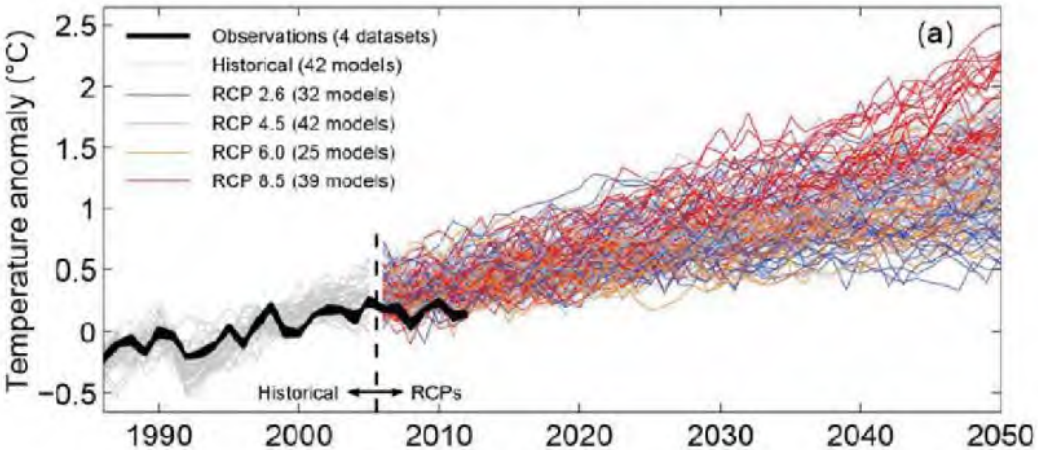
- The correct and detail land use classification is crucial for the urban heat island modeling study.

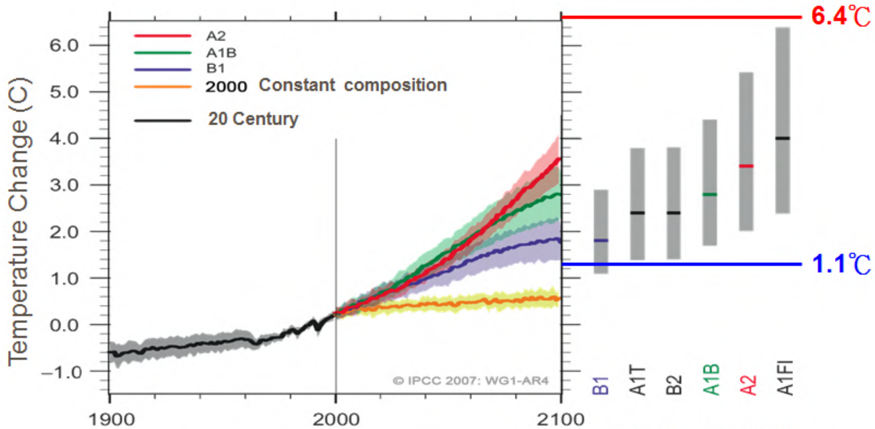
- With the improved WRF-UCM2D model, the oversimplified results can be avoided with the percentage of urbanization in the model grid nets more accurately identified according to the actual land use and building density for AH, not only in the city center but also in rural small towns.

- Numerical study also suggests that the heat-island effect could perturb thermal and dynamic processes and hence affect the location of precipitation in northern Taiwan.

II: Regional climate change

Global mean temperature near-term projections relative to 1986–2005





(IPCC AR4, 2007)

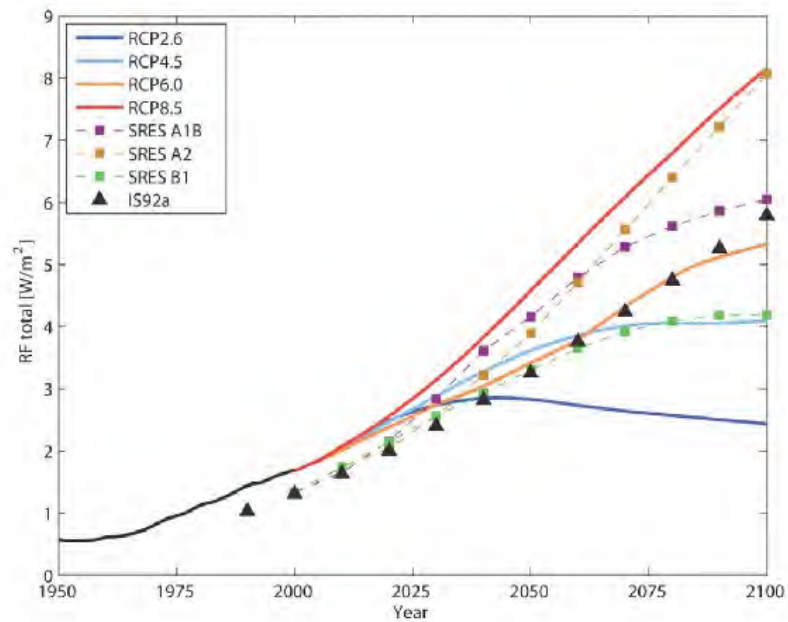


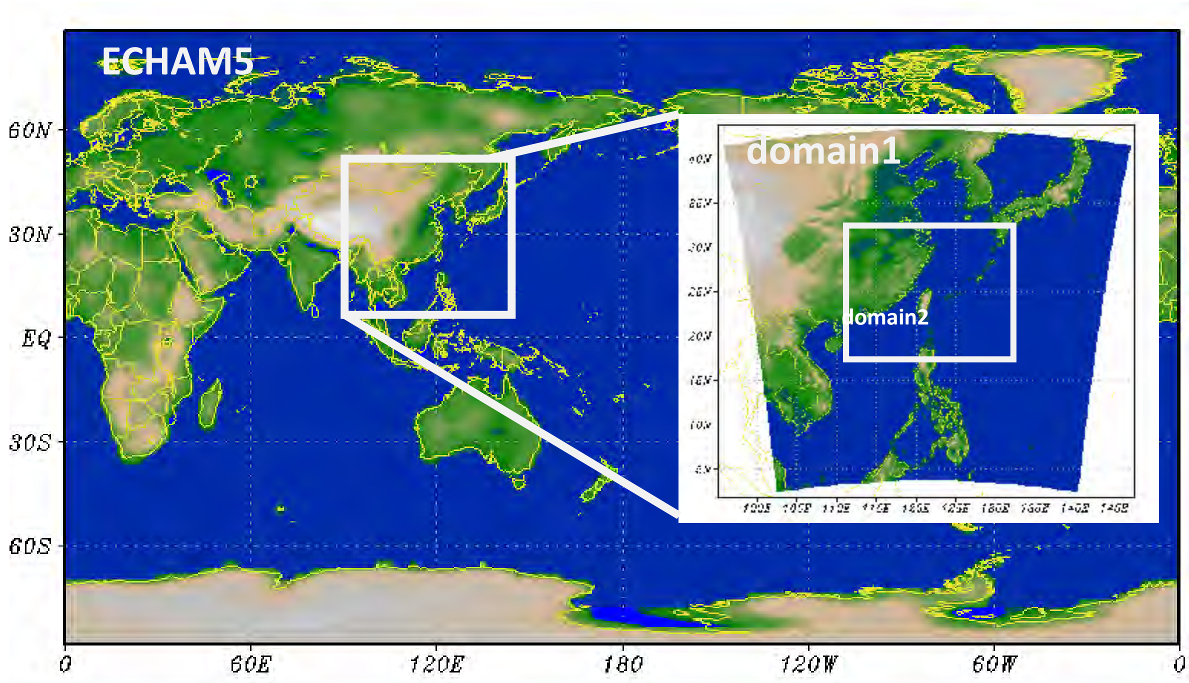
Figure 1.15: Historical and projected total anthropogenic RF (W m^{-2}) relative to preindustrial (~1765) between 1950 and 2100. Previous IPCC assessments (SAR IS92a, TAR/AR4 SRES A1B, A2 and B1) are compared with representative concentration pathway (RCP) scenarios (see Chapter 12 and Box 1.1 for their extensions until 2300 and Annex II for the values shown here). The total RF of the three families of scenarios, IS92, SRES and RCP, differ for example for the year 2000, resulting from the knowledge about the emissions assumed having changed since the TAR and AR4.

	Global mean warming (°C)			
	2011–2030	2046–2065	2080–2099	2180–2199
A2	0.64	1.65	3.13	
A1B	0.69	1.75	2.65	3.36
B1	0.66	1.29	1.79	2.10
Commit[a]	0.37	0.47	0.56	

B1: 1.1~2.9 ℃

A1F1: 2.4~6.4 ℃

ECHAM5-WRF dynamical downscaling



ECHAM5: domain:192x96 Δx=1.875 degree

WRF:

Domain1 : 301x301 Δx,y=15km FDDA

Domain2 : 382x400 Δx,y=5km, vertical 45 levels

75 years simulation:

1979-2003; 2015-2039; 2075-2099

Dynamic downscaling results Evaluation

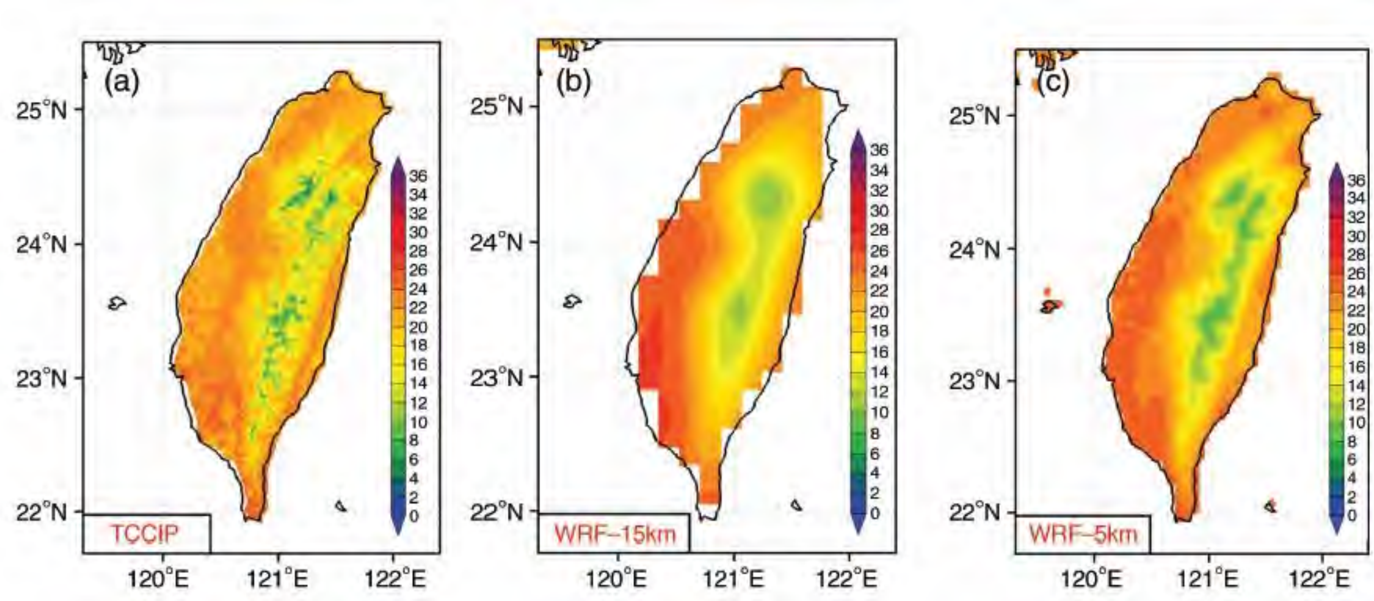


Table 1. Bias and root mean square error (RMSE) (unit: °C) of mean surface air temperature over plain (altitude < 500 m) and mountain (altitude > 500 m) in Taiwan during 1979–2003.

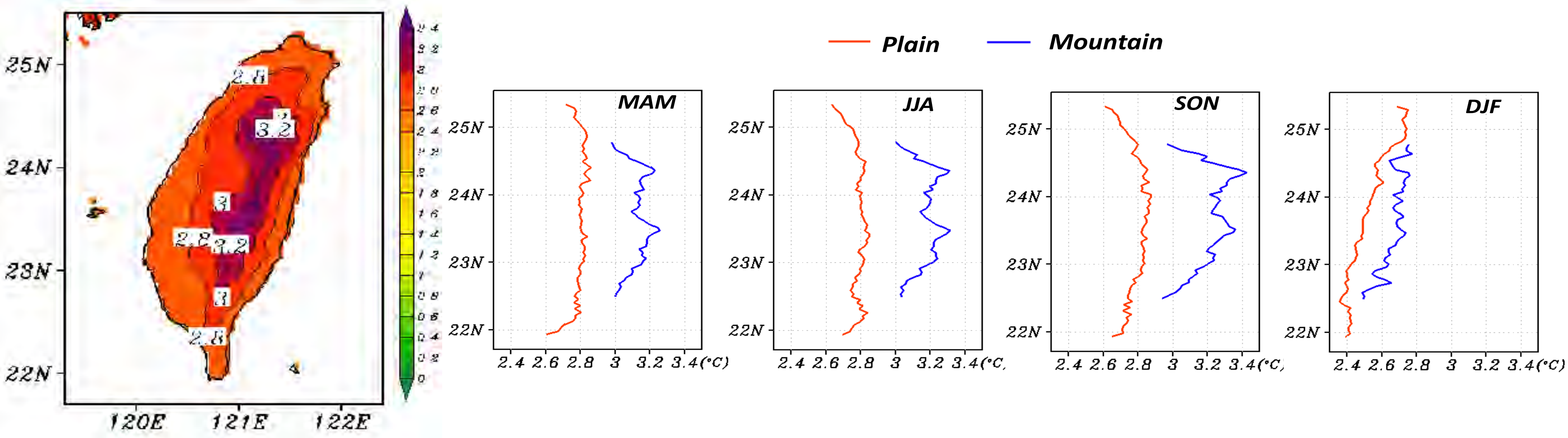
		WRF(15 KM)-TCCIP	WRF(5 KM)-TCCIP
BIAS	Plain	1.97	1.31
	Mountain	0.11	−0.18
RMSE	Plain	2.24	1.80
	Mountain	1.53	1.23

BIAS describes the mean error between dynamic downscaling results and TCCIP observation data. RMSE is the measurement of the differences between dynamic downscaling results and TCCIP observation data.

(Lin et al. 2015)

Results from ECHAM5-WRF

(2075-2099)-(1979-2003)



- **The projected warming trend shows altitudinal variations with more significant temperature increase in mountain areas (altitude > 1000 m) than in plain areas (altitude < 500 m) and greater increase in the distant future 2075-2099.**

- **During winter, the projected warming trend shows latitudinal variations with more significant temperature increase in northern Taiwan than in southern Taiwan**

(Lin et al. 2015, IJOC)

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RMetS
Royal Meteorological Society

Altitudinal and latitudinal dependence of future warming in Taiwan simulated by WRF nested with ECHAM5/MPIOM

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nature climate change

Elevation-dependent warming in mountain regions of the world

Mountain Research Initiative EDW Working Group*

There is growing evidence that the rate of warming is amplified with elevation, such that high-mountain environments experience more rapid changes in temperature than environments at lower elevations. Elevation-dependent warming (EDW) can accelerate the rate of change in mountain ecosystems, cryospheric systems, hydrological regimes and biodiversity. Here we review important mechanisms that contribute towards EDW: snow albedo and surface-based feedbacks; water vapour changes and latent heat release; surface water vapour and radiative flux changes; surface heat loss and temperature change; and aerosols. All lead to enhanced warming with elevation (or at a critical elevation), and it is believed that combinations of these mechanisms may account for contrasting regional patterns of EDW. We discuss future needs to increase knowledge of mountain temperature trends and their controlling mechanisms through improved observations, satellite-based remote sensing and model simulations.

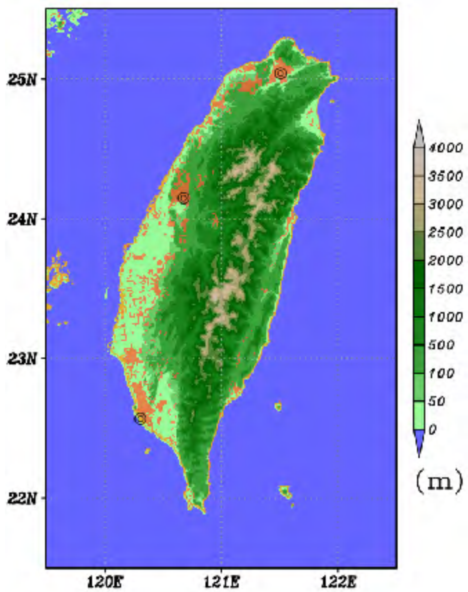
Regional climate change -Heat waves

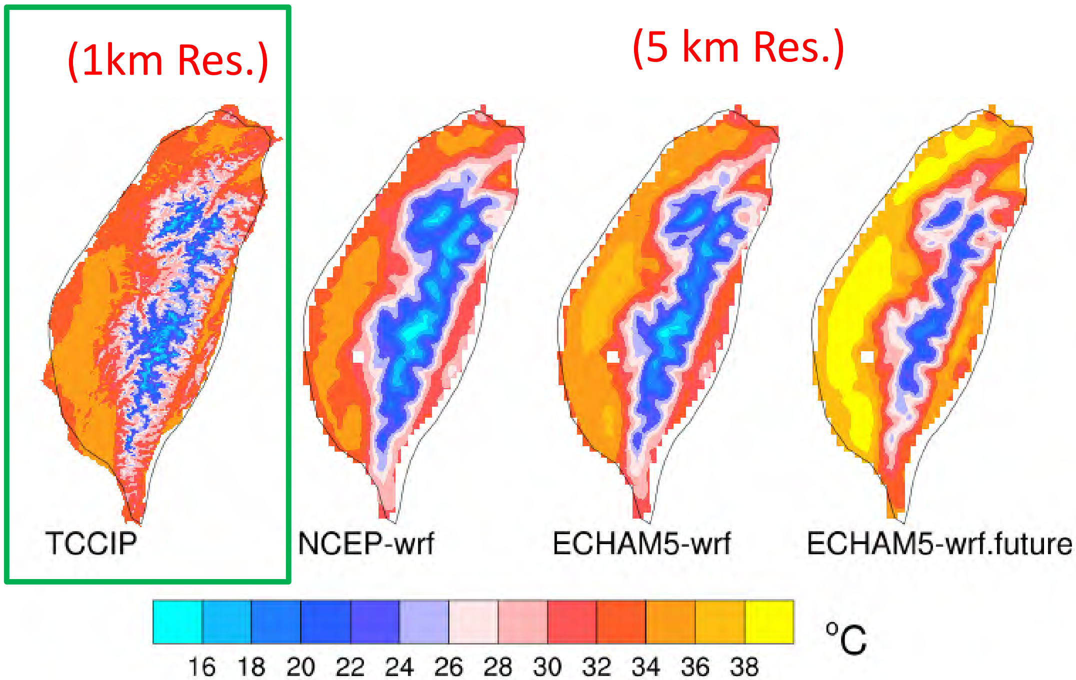
Definition: Hot day and Heat waves

Daily maximum index: Tmax is derived by averaging the daily surface maximum air temperature over plain (altitude<500m)

Hot day: > = 95th percentile of this set of Tmax

Heat waves: hot spell lasting at least three consecutive days

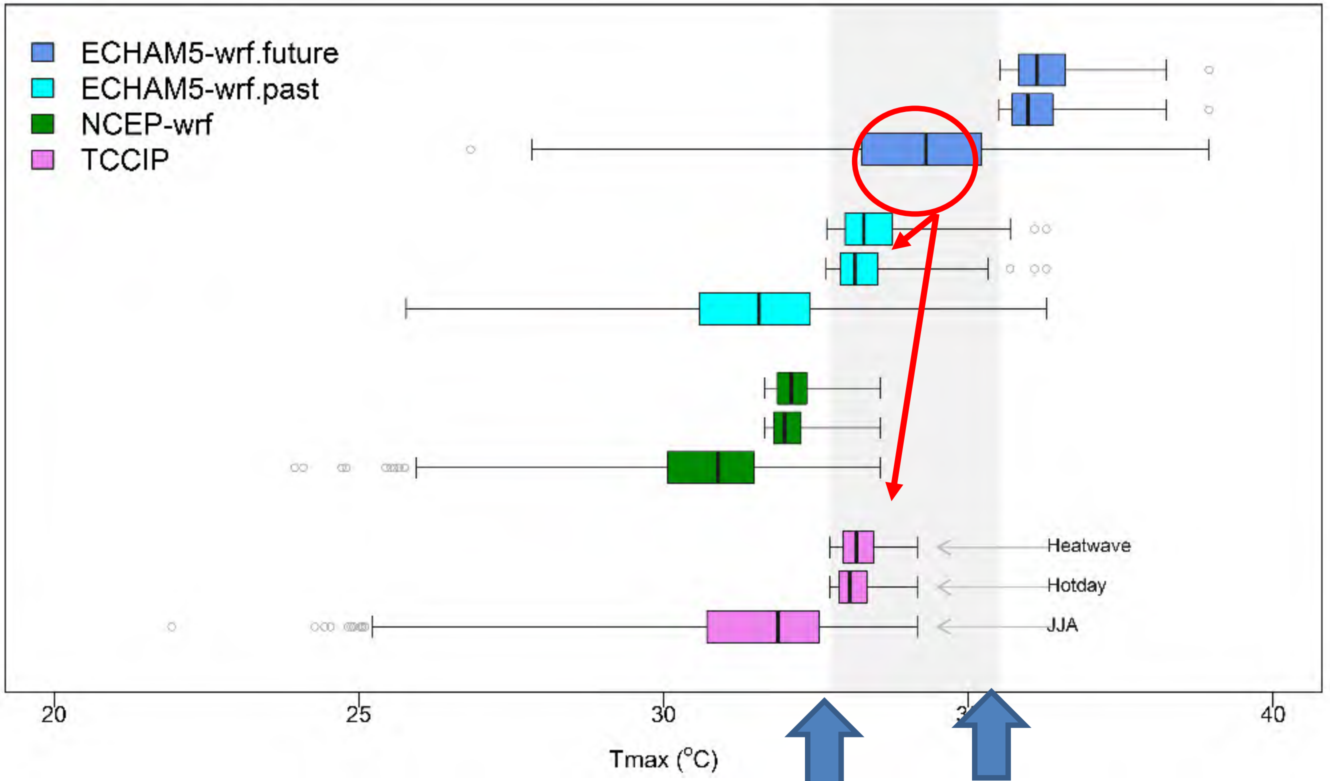




Composite daily maximum temperature of all heat wave days among four data sets

(Kueh, Lin et al. 2017 ERL)

- *box-and-whisker plots showing the plain-averaged daily Tmax for three subsets*

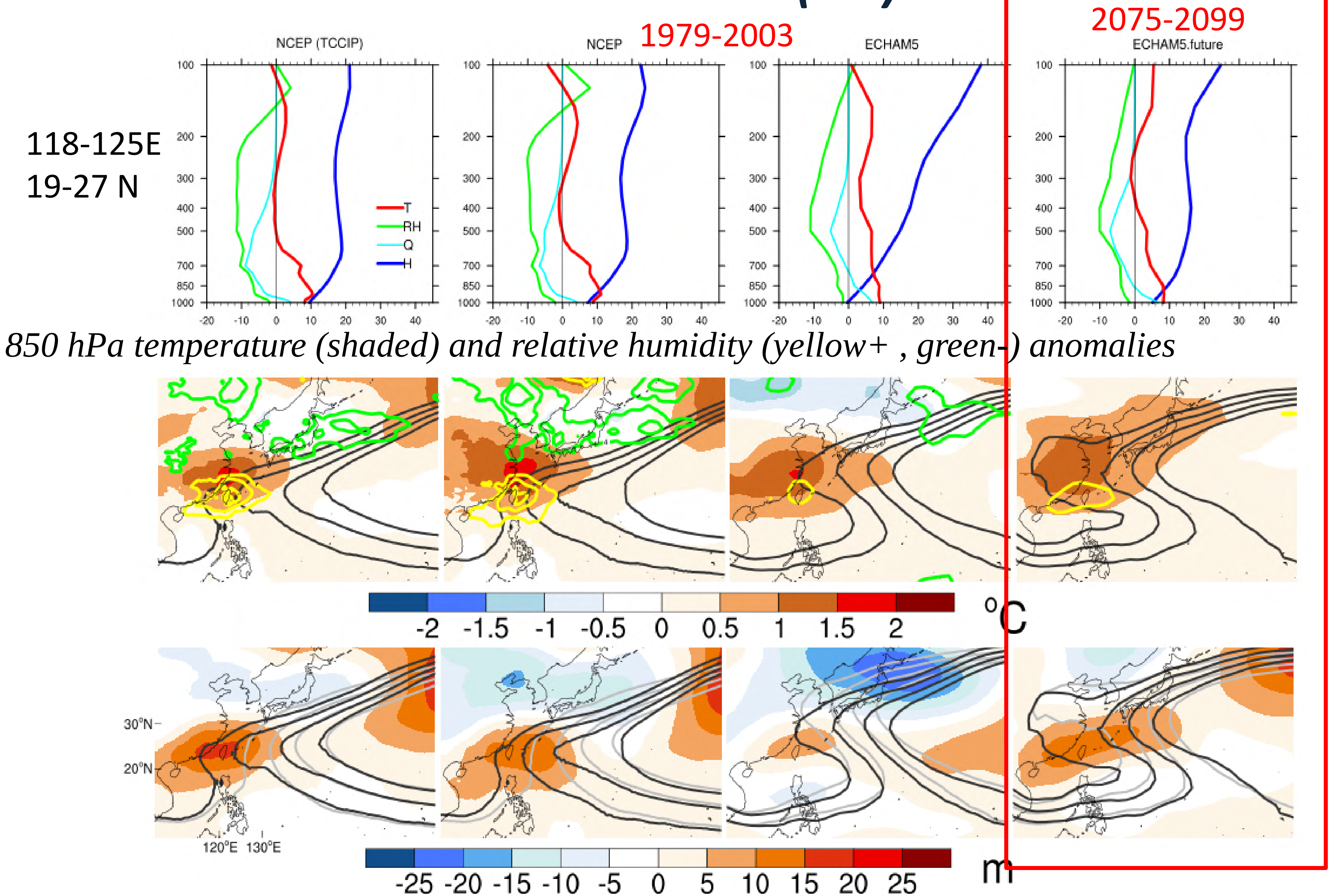


the 95th percentiles of Tmax obtained from TCCIP and ECHAM5-wrf (future),

The current abnormal conditions would become normal in the future.

(Kueh, Lin et al. 2017 ERL)

Composite anomalies of all heat wave days for each dataset (JJA)



850 hPa geopotential height anomalies(shaded).

(Kueh, Lin et al. 2017 ERL)

Heat waves- WBGT estimation

- Why Wet-bulb globe temperature (WBGT):

--Fischer and Schar (2010), the climatic factors contributing to enhanced morbidity and mortality were a combination of extremely high temperature and relative humidity.

--WBGT is an accepted international standard of heat stress, including T, RH, wind speed and solar radiation.

- Wet Bulb Globe Temperature (WBGT):

$WBGT = 0.7T_w + 0.2T_g + 0.1T_d$ (1)

Where Tw denotes natural wet-bulb temperature (°C) ; Tg = Globe thermometer temperature (°C) and Td = Dry-bulb temperature (°C) ;

Stull R. (2011):

$$\mathrm{Tw} = \mathrm{T}\,\mathrm{atan}\left[0.151977(RH\% + 8.313659)^{\frac{1}{2}}\right] + \mathrm{atan}(T + RH\%) - \mathrm{atan}(RH\% - 1.676331) + 0.00391838(RH\%)^{3/2}\,\mathrm{atan}(0.023101RH\%) - 4.686035$$

Tonouchi et al. (2006):

$$T_g - T_d = 0.017 * S - 0.208 * U$$

Where T_g is globe temperature (°C), T_d is dry bulb temperature (°C). S is a solar radiation (W/m^2) and U is wind speed (m/s)

Heat waves- WBGT estimation

- Japan Sports Association (2006), WBGT ≥ 31 °C means danger for sports and exercise outdoor while WBGT ranging between 28 and 30 °C is at the alert level.
- US army:

分類 Category	WBGT °F	WBGT °C	旗幟顏色 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:美國陸軍)

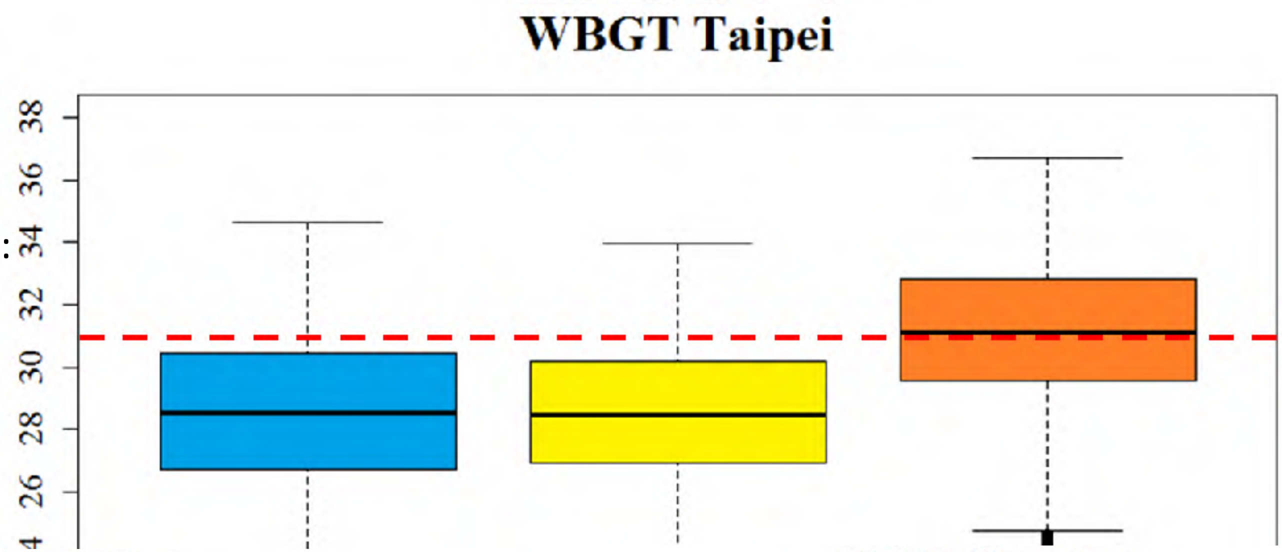
WBGT estimation from Observation and ECHAM5-WRF during summer (JA)

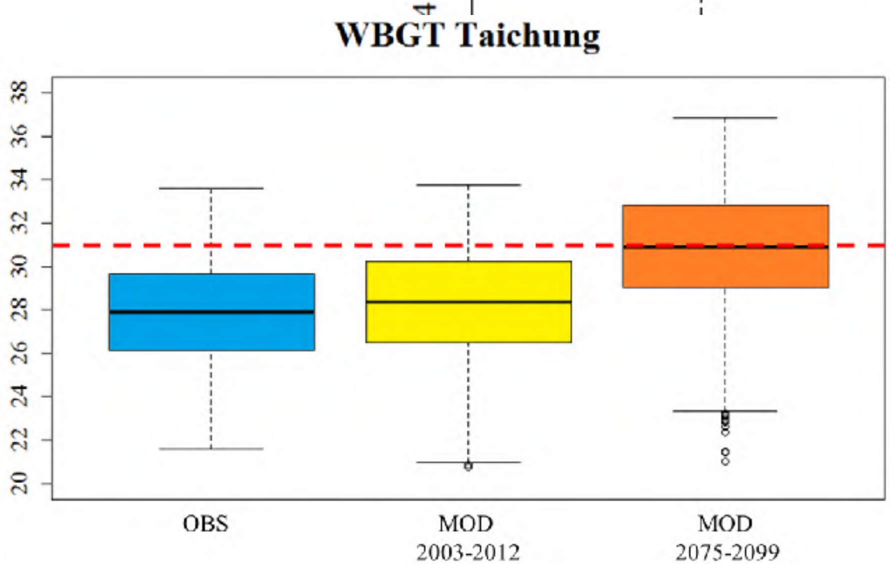
2003-2012 WBGT >31 °C:

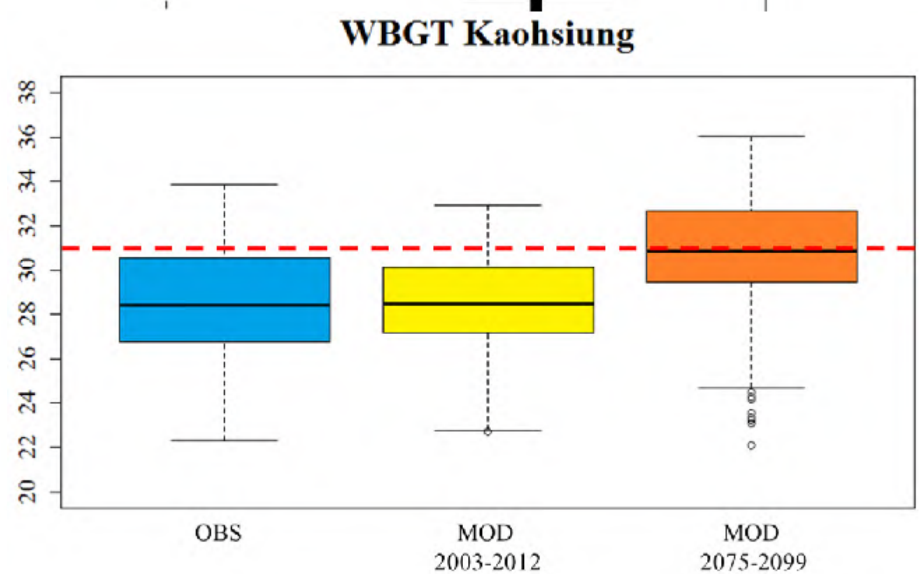
Taipei : 10.74%

Taichung: 4.22%

Kaohsiung: 11.28%



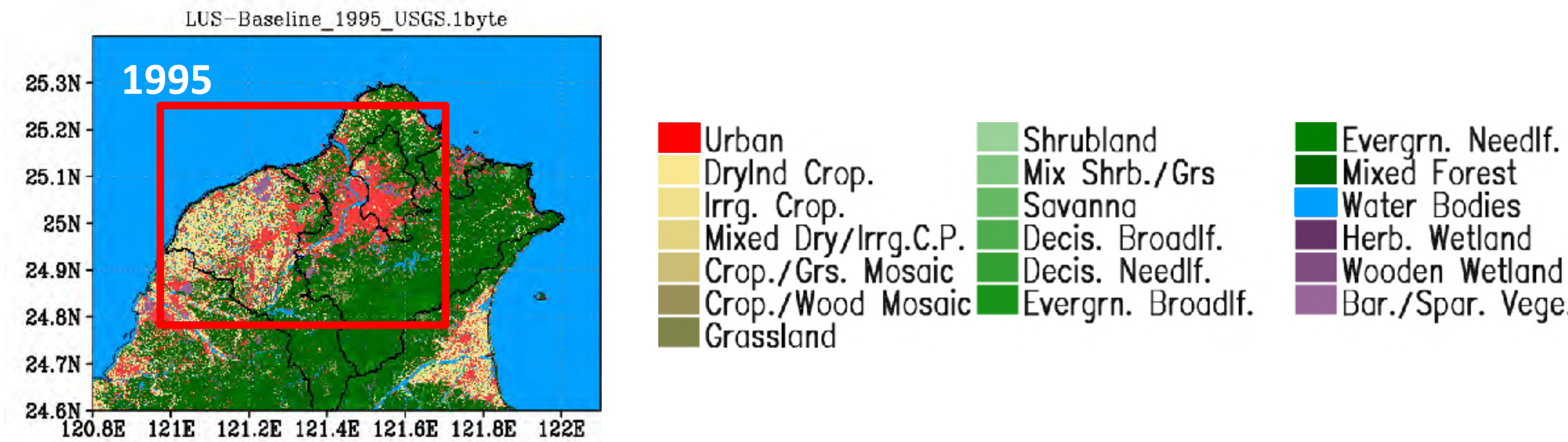


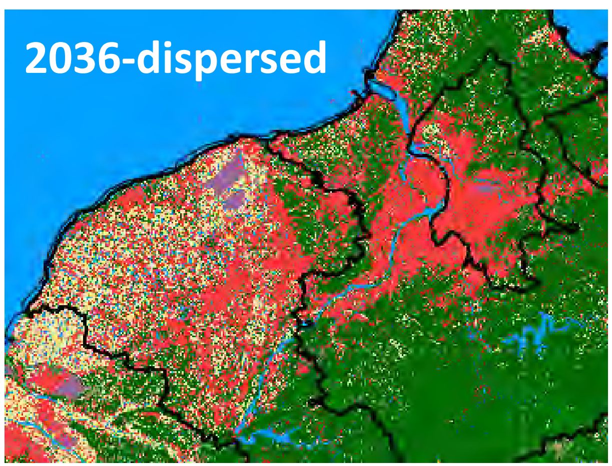


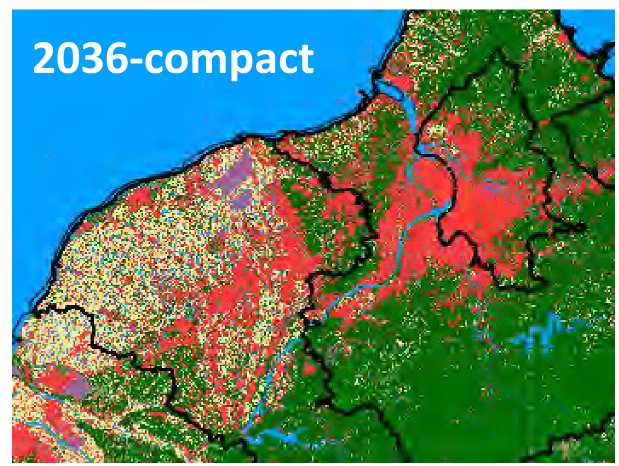
(Lin et al., 2017 Climatic Change)

Regional climate change and urban planning

Projection urban planning scenario





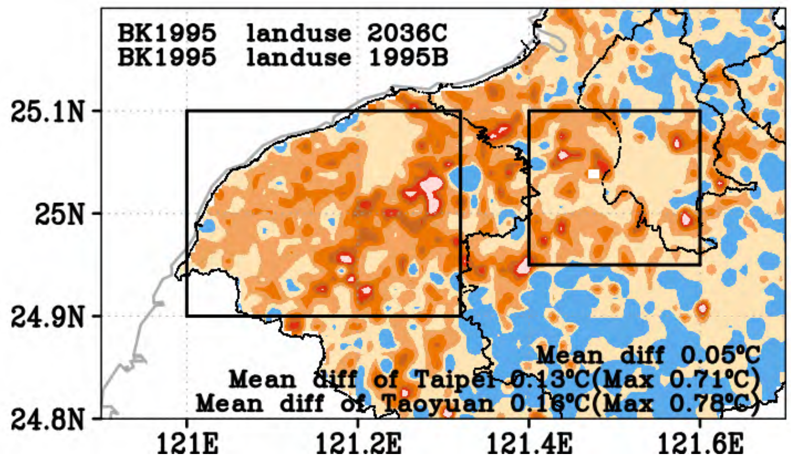


(by Prof. 詹士樑&陳 亮全)

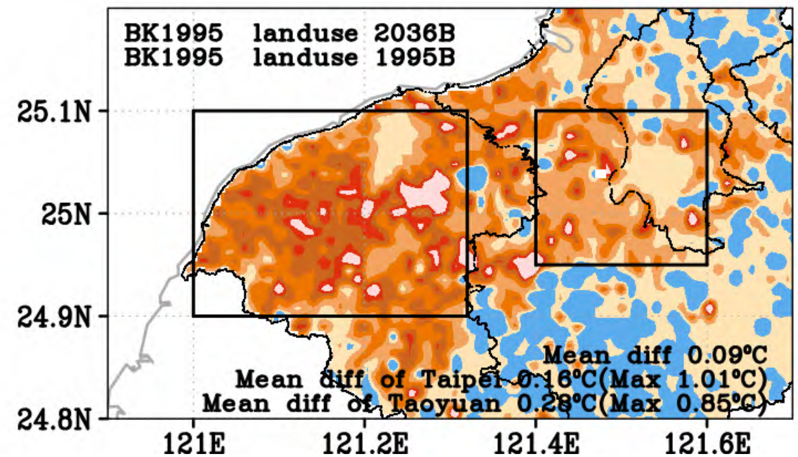
(paper in prep.)

Land use change impacts on air temperature

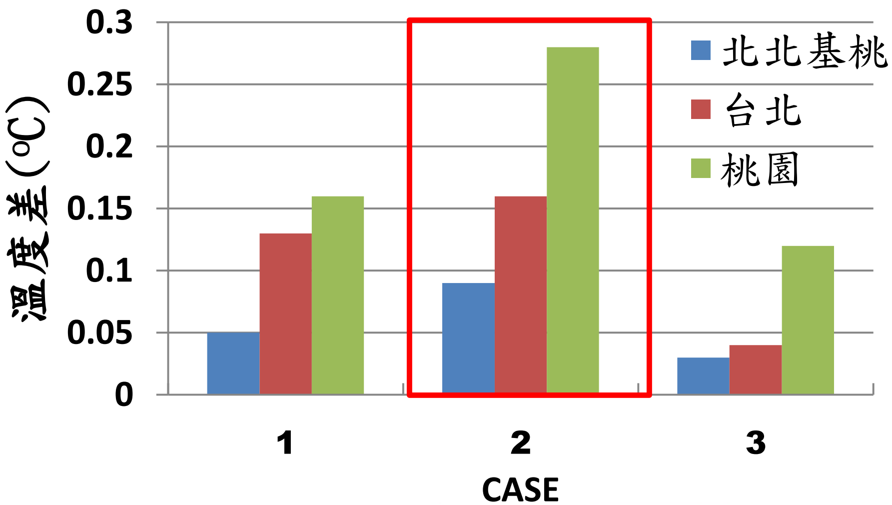
1.Temp.difference-compact



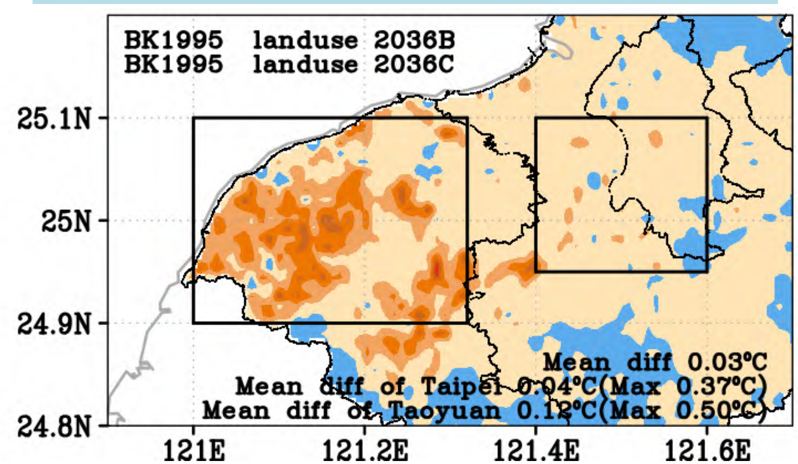
2.Temp.difference-dispersed



Temp. difference in Northern Taiwan

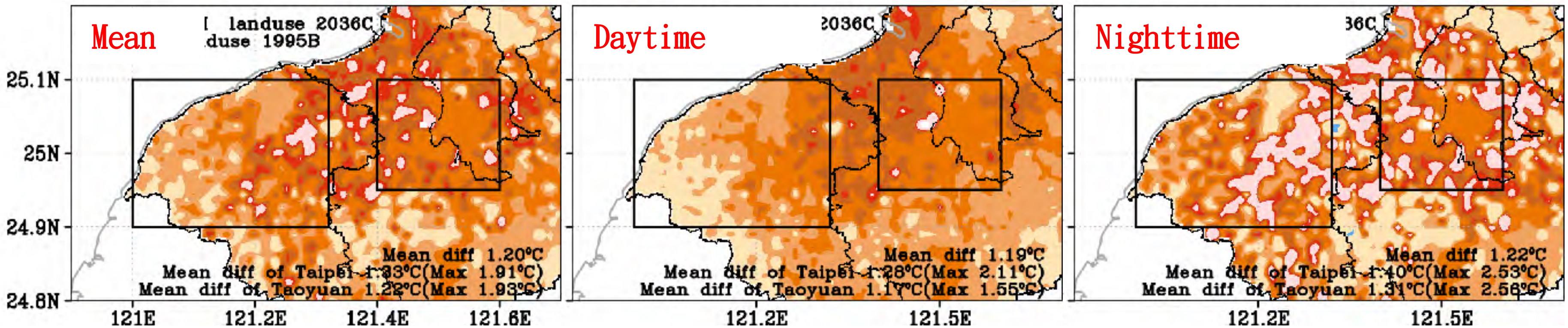


3.Temp. difference (dispersed-compact)

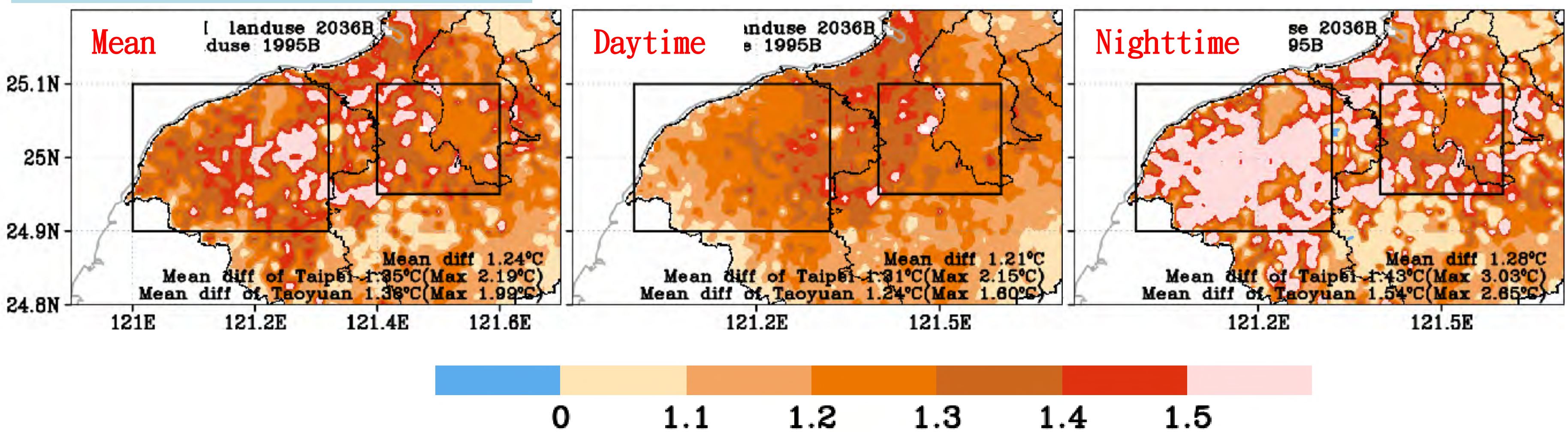


Land use change and future warming impact on air temperature

Future warming& compact

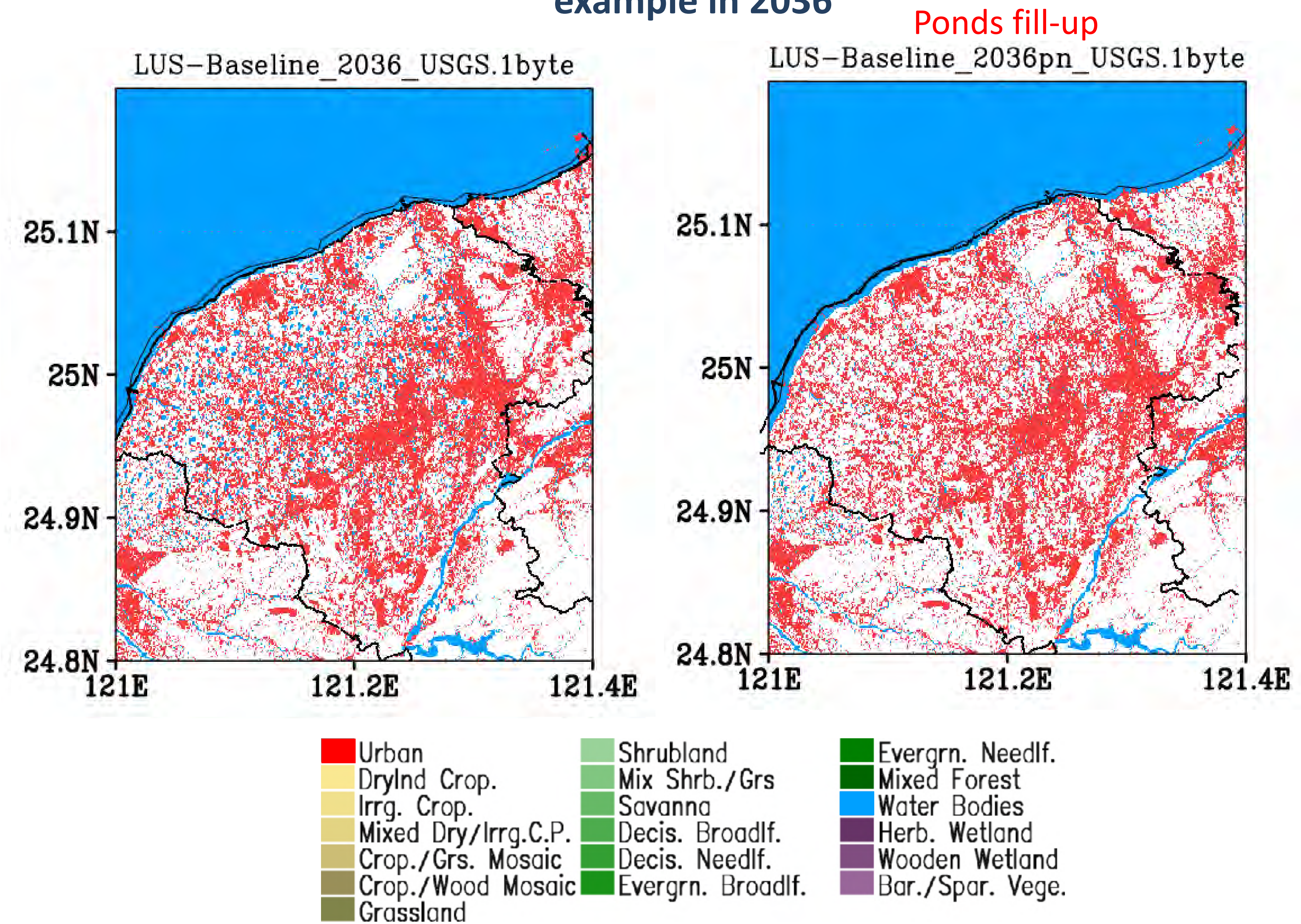


Future warming & dispersed



Ponds fill-up scenario impacts on temperature-

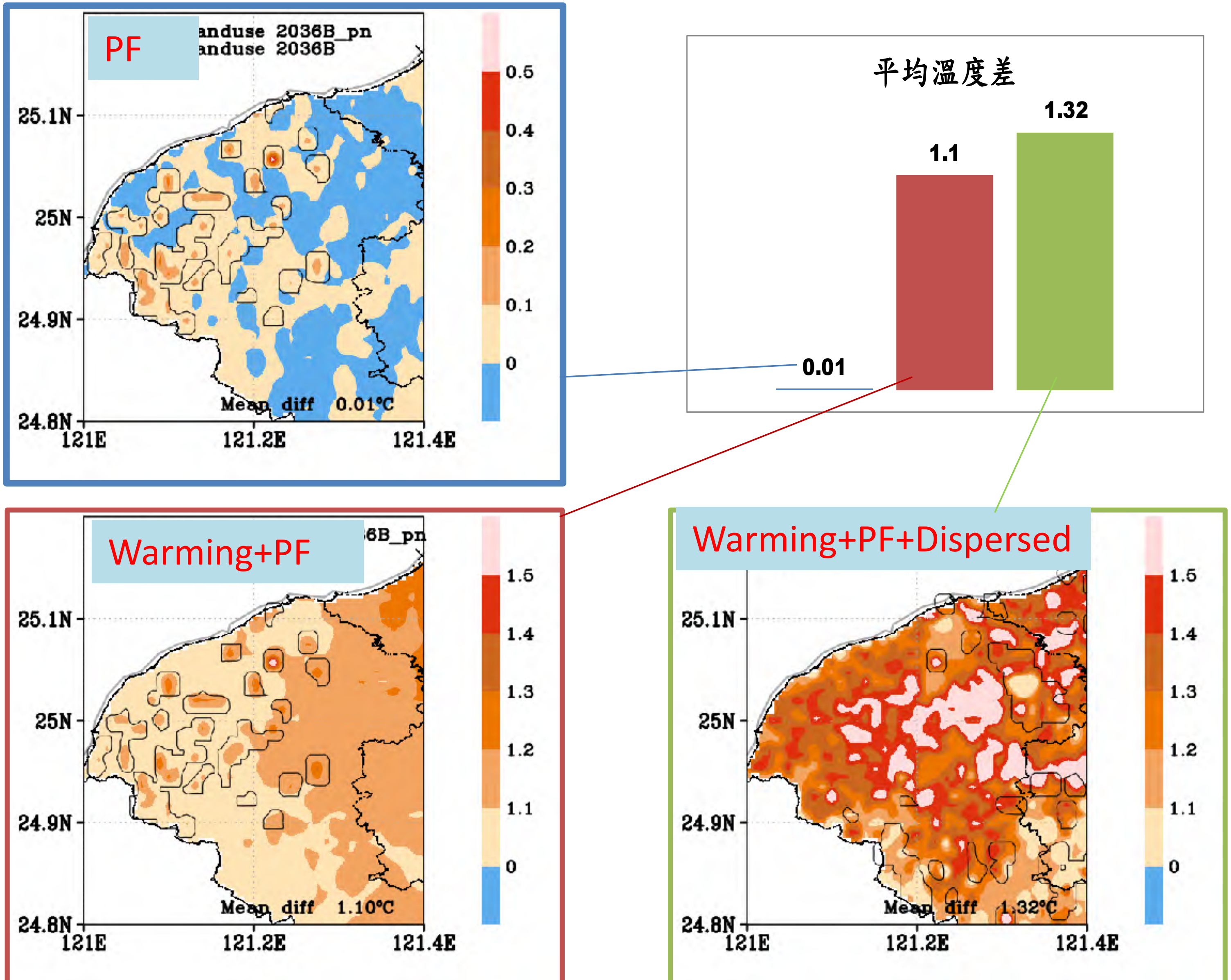
example in 2036



(Provided by Prof. 詹士樑&陳 亮全)

Ponds fill-up scenario impacts on temperature-

example in 2036



PF=Ponds fill-up

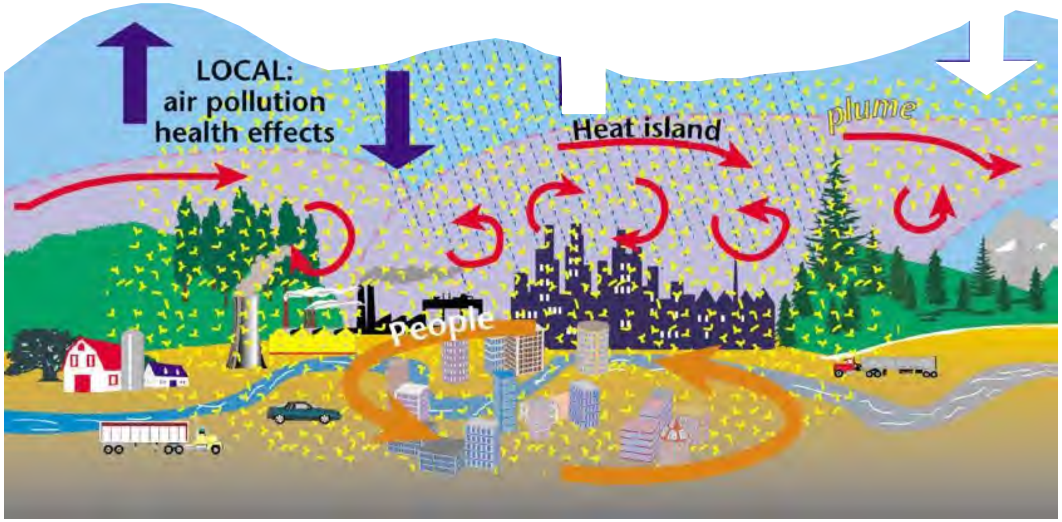
Summary II

- The projected warming trend shows altitudinal variations with more significant temperature increase in mountain areas (altitude > 1000 m) than in plain areas (altitude < 500 m) and greater increase in the distant future 2075-2099.

- During winter, the projected warming trend shows latitudinal variations with more significant temperature increase in northern Taiwan than in southern Taiwan.

- The current abnormal conditions would become normal in the future. Under the global warming trend, the WBGT in three cities indicated that the heat stress for 50% of the days in July and August by 2075-2099 will be at danger level (WBGT $\geq$ 31 °C)

Summary



(photo:WMO, “GURME” project)