Future warming scenario and impacts study over Taiwan: Results from ECHAM5/MPIOM-WRF dynamical downscaling

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**CO₂ 400 ppm MILESTONE**

- Long-lived, heat-trapping gas
- Hit 400 ppm this month during annual May peak
- Last time we were at this level, human life did not exist

![Graph of Atmospheric CO₂ at Mauna Loa Observatory](image)

**Atmospheric CO₂ at Mauna Loa Observatory**

- Scripps Institution of Oceanography
- NOAA Earth System Research Laboratory

![Graph showing CO₂ Concentration (ppm) over years](image)

**1960 - 2010**
Global mean temperature near-term projections relative to 1986–2005

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.

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>A2</td>
<td>0.64</td>
<td>1.65</td>
<td>3.13</td>
<td></td>
</tr>
<tr>
<td>A1B</td>
<td>0.69</td>
<td>1.75</td>
<td>2.65</td>
<td>3.36</td>
</tr>
<tr>
<td>B1</td>
<td>0.66</td>
<td>1.29</td>
<td>1.79</td>
<td>2.10</td>
</tr>
<tr>
<td>Commit*</td>
<td>0.37</td>
<td>0.47</td>
<td>0.56</td>
<td></td>
</tr>
</tbody>
</table>

B1: 1.1−2.9 °C
A1F1: 2.4−6.4 °C
1. Increasing rainfall is expected for most of EA in general
2. Decreasing rainfall is found in mid-China and Japan
3. Change of rainfall is evident in Winter

Change rate of projected monthly rainfall climatology (2020~2039) A1B

1. Decreasing in DJF and MAM
2. Increasing in JJA and SON

Statistical Downscaling
ECHAM5-WRF dynamical downscaling

ECHAM5: domain: 192x96 \( \Delta x = 1.875 \) degree

WRF:
- Domain1: 301x301 \( \Delta x,y = 15 \) km FDDA
- Domain2: 382x400 \( \Delta x,y = 5 \) km, vertical 45 levels

75 years simulation:
- 1979-2003; 2015-2039; 2075-2099
Why Dynamic downscaling?
Why dynamical downscaling?

• Existing Global climate models (GCMs) typically run at a scale of 200 km which is too coarse for application regional or local

• Especially for variables that depend on regional topographic, such as precipitation, surface wind and temperature

• Dynamical downscaling with regional climate model is an essential component to fill the gap between GCMs and regional application
Model evaluation (1979-2003)

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.

<table>
<thead>
<tr>
<th></th>
<th>WRF(15 KM)-TCCIP</th>
<th>WRF(5 KM)-TCCIP</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIAS</td>
<td>Plain</td>
<td>1.97</td>
</tr>
<tr>
<td></td>
<td>Mountain</td>
<td>0.11</td>
</tr>
<tr>
<td>RMSE</td>
<td>Plain</td>
<td>2.24</td>
</tr>
<tr>
<td></td>
<td>Mountain</td>
<td>1.53</td>
</tr>
</tbody>
</table>

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.
Figure 3. Seasonal variations of average air temperature during 1979–2003. Upper panel: temperature observed by TCCIP, and bottom panel: temperature obtained by ECHAM5/MPIOM-WRF at 5-km resolution dynamic downscaling. Spring (MAM), Summer (JJA), Autumn (SON), Winter (DJF).
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.
Computer Resources

The HPC cluster with HP Blade System BL2x220c blade servers with 256 nodes (2048 cores) via InfiniBand interconnection

2 x 3.0GHz Xeon Quad-Core 5450 CPU

The performance of the HPC benchmark is expected to reach around 24 TFlops

1 month simulation/5 days (128 CPU)

75 years’ simulation = 1.5 year computer time
75 TB storage
Application example: Heat wave over Taiwan
Temperature variations:

Taipei

Taichung

Kaohsiung

2001-2010 data for Taipei.
Heat wave definition

- Definition: Daily maximum temperature:
- Hot day threshold: daily maximum temperature above their respective 95th percentile for the whole simulation period.
- Heat wave event: a hot spell of at least 3 consecutive hot days.

![Table](https://example.com/table.png)

Table 1. The heat wave (HW) criteria air temperature (95 percentile daily maximum air temperature), HW events, HW days and HW duration in the past four decades during 1971-2010 for Taipei, Taichung and Kaohsiung.

- **Whole period:** Taipei=35.2; Taichung=34.3; KH=33.3
Heat waves variation

Taipei (JA)

\[ y = 0.2468x + 2.2654 \]
\[ R^2 = 0.1694 \]

Taichung (JA)

\[ y = 0.0481x + 4.8885 \]
\[ R^2 = 0.0043 \]

Kaohsiung (JA)

\[ y = 0.3245x + 1.2731 \]
\[ R^2 = 0.1175 \]
Heat wave index: 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 (Wet Bulb Globe Temperature): used in national (e.g. UK, China, Japan, USA, Australia etc.) and regional (e.g. European)
- Consider **temperature, humidity, wind speed and solar radiation** on the perception of temperature

\[
\text{WBGT} = 0.7 \times T_{\text{nwb}} + 0.2 \times T_g + 0.1 \times T_a
\]

- **Tg :** black globe thermometer
- **Tnwb :** natural(unventilated) wet-bulb temperature
- **Ta: (shade) air temperature**

-used across the globe to control heat stress in many contexts including military, industrial, domestic, sporting and commercial application.
WBGT estimation

WBGT = 0.7T_w + 0.2T_g + 0.1T_d  \hspace{1cm} (1)

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

Stull R. (2011):

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

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/m²) and U is wind speed (m/s)
WBGT estimation from Observation during summer (JA)

- 95\textsuperscript{th} percentile

<table>
<thead>
<tr>
<th>Year</th>
<th>Location</th>
<th>WBGT (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003-2012</td>
<td>Taipei</td>
<td>32.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>WBGT (°C)</th>
<th>Cease Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>31-35</td>
<td>The skin temperature exceeds the ambient temperature. In principle, exercise should be stopped.</td>
</tr>
<tr>
<td>28-31</td>
<td>Danger</td>
</tr>
<tr>
<td>25-28</td>
<td>Cease heavy exercise</td>
</tr>
<tr>
<td>21-24</td>
<td>Extreme Caution</td>
</tr>
<tr>
<td>21-18</td>
<td>Active resting needed</td>
</tr>
<tr>
<td>21-18</td>
<td>Caution</td>
</tr>
<tr>
<td>21-18</td>
<td>Active water intake needed</td>
</tr>
<tr>
<td>21-18</td>
<td>Almost Safe</td>
</tr>
<tr>
<td>21-18</td>
<td>Appropriate water intake needed</td>
</tr>
</tbody>
</table>

(Ref: 美國陸軍)

Fig. 3 Exercise guideline for preventing heat disorders proposed by the Japan Sports Association.
WBGT: Wet Bulb Globe Temperature (Source: Kawahara, et al., 1994)
WBGT estimation from Observation and ECHAM5-WRF during summer (JA)

2003-2012 WBGT >31 °C:
Taipei: 10.74%
Taichung: 4.22%
Kaohsiung: 11.28%
Application: Future warming and cooling energy estimation
• The annual cooling energy consumption in the time slices of the 2000s, 2020s, 2050s, and 2080s are respectively 35.1, 46.0, 55.8, and 63.9 kWh/m²-y. The average ratios of increase are 31%, 59%, and 82% over that of the 2000s.
Spatial distribution of cooling energy variation in three time slices

(a) 1979-2003

(b) 2015-2039

(c) 2075-2099

2015-2039: 0.07-21.64 kWh/m²-year about 24% increase
2075-2099: 1.36-39.08 kWh/m²-year about 184% increase
Increase in residential cooling energy by the UHI effect

UHI 效應在都會及城鎮地區的冷氣能耗
在過去時期分別提高了 6.58 kWh/m²-yr (61%) 和 5.03 kWh/m²-yr (46%)，
在近未來時期為 6.89 kWh/m²-yr (52%) 和 5.26 kWh/m²-yr (40%)，以及
在遠未來為 7.99 kWh/m²-yr (27%) 和 6.06 kWh/m²-yr (21%)
Future urban planning and Regional Climate Changes
Future Urban planning scenarios

(by Prof. 詹士樑 & 陳亮全)
Impact of future urban planning on air temperature

2036Compact - 1995Baseline

2036Dispersed - 1995Baseline

2036Dispersed - 2036Compact
Impact of future urban planning and climate change on air temperature

Daytime

Nighttime
References:


Thank you !!!!
Impact of future urban planning and climate change on air temperature

1995 baseline

2036 compact

2036 dispersed

PGW+1995 baseline

PGW+2036 compact

PGW+2036 dispersed
Impact of farm pond (埤塘) fill-up on air temperature in Taoyuan

(Provided by Prof. 詹士樑 & 陳亮全)
Impact of farm pond (埤塘) fill-up on air temperature in Taoyuan

Farm pond change +
Land use fixed 2036D

PGW+ farm pond change +
(land use fixed (2036 D)

PGW+ farm pond change +
land use(1995D → 2036D)