Downscaling Climate Change Signals to Urban Environments

Calvin Cheung and Gabriel Lau
Observed change in average surface temperature 1901–2012

Trend (°C over period)
Urban Climatic Maps

UC-AnMap

UC-ReMap

UCPZ 1
UCPZ 2
UCPZ 3
UCPZ 4
UCPZ 5
Downscaling

• Dynamical downscaling
  – Using Weather Research and Forecasting Model (WRF) to simulate regional climate based on GCMs and larger scale products
  – Example 1 – Downscaling reanalysis into 1km for Hong Kong region
  – Example 2 – Downscaling reanalysis into 5km for Taiwan region (collaboration with RCEC, TW)

• Statistical downscaling
  – Using statistical methods to predict local scale variables:
    • Climate variable: temperature, humidity, precipitation
    • Variables affecting the urban environment: thermal comfort
  – Mapping large scale climate pattern with local variables
Example 1 – Downscaling reanalysis into 1km for Hong Kong region
(Domains and resolution)

Domain 1: 27 km
Domain 2: 9 km
Domain 3: 3 km
Domain 4: 1 km
Example 1 – Downscaling reanalysis into 1km for Hong Kong region
(Land use specification)
Example 1 – Downscaling reanalysis into 1km for Hong Kong region (Model output vs. Observation)

Comparison Temperature at 2m (WRF) and surface temperature (Station data)

Hong Kong Airport

King’s Park

(Based on 2011 data)
Example 1 – Downscaling reanalysis into 1km for Hong Kong region
(Diurnal cycle studies 1 - Temperature)

<table>
<thead>
<tr>
<th>Station</th>
<th>T2 @ 3pm-3am</th>
</tr>
</thead>
<tbody>
<tr>
<td>HKO</td>
<td>2.9 °C</td>
</tr>
<tr>
<td>SHA</td>
<td>3.2 °C</td>
</tr>
<tr>
<td>TKL</td>
<td>5.7 °C</td>
</tr>
<tr>
<td>HKS</td>
<td>2.9 °C</td>
</tr>
<tr>
<td>WGL</td>
<td>2.1 °C</td>
</tr>
<tr>
<td>JKB</td>
<td>3.8 °C</td>
</tr>
<tr>
<td>CCH</td>
<td>3.4 °C</td>
</tr>
<tr>
<td>KP</td>
<td>3.0 °C</td>
</tr>
<tr>
<td>TYW</td>
<td>6.1 °C</td>
</tr>
<tr>
<td>HKA</td>
<td>3.1 °C</td>
</tr>
<tr>
<td>TPO</td>
<td>3.5 °C</td>
</tr>
<tr>
<td>VP1</td>
<td>2.4 °C</td>
</tr>
</tbody>
</table>
Example 1 – Downscaling reanalysis into 1km for Hong Kong region (Diurnal cycle studies 2 – wind fields affected by terrain height)
Example 1 – Downscaling reanalysis into 1km for Hong Kong region
(Diurnal cycle studies 2 – wind fields affected by terrain height)

Lantau Island

Kowloon and HK Island

Shatin, Tai Po and Sheung Shui
Example 2 – Downscaling reanalysis into 5km for Taiwan region (collaboration with RCEC, TW)

WRF system run by RCEC:

Domain 1: 15 km
Domain 2: 5 km (Cover Hong Kong region and most region in Pearl River Delta)

4 sets of downscaled data:

1. 1979 to 2003 (CFSR)
2. 1979 to 2003 (20C3M)
3. 2015 to 2039 (A1B)
4. 2075 to 2099 (A1B)

2, 3 & 4 are IPCC scenarios run by ECHAM5 GCM
Example 2 – Downscaling reanalysis into 5km for Taiwan region
(Land use specification)
Example 2 – Downscaling reanalysis into 5km for Taiwan region (future climate projections)

Future - Past, for JJA seasonal mean temperature at 2 m


- Climate change signal provided by the model
- Extreme events such as heat waves, cold surge and precipitation
- To understand the ability and limitations of the model
Statistical downscaling of local climate variables
(Temperature, humidity, precipitation)

<table>
<thead>
<tr>
<th>Calibration period</th>
<th>Local-scale climatic variables</th>
<th>Large-scale climatic variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Past Climate</td>
<td>Observation data</td>
<td>Reanalysis</td>
</tr>
<tr>
<td></td>
<td>1971/1/1-2000/12/31</td>
<td>1971/1/1-2000/12/31</td>
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<tr>
<td></td>
<td>Hong Kong Observatory</td>
<td>NCEP/NCAR Reanalysis</td>
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<tr>
<td></td>
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<tr>
<td>Validation period</td>
<td></td>
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<tr>
<td>Current Climate</td>
<td>Projection of current climate</td>
<td>Reanalysis</td>
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<tr>
<td></td>
<td>2001/1/1-2010/12/31</td>
<td>2001/1/1-2010/12/31</td>
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<td></td>
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<td>NCEP/NCAR Reanalysis</td>
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<td>Projection periods</td>
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<tr>
<td>Future Climate</td>
<td>Generate the future</td>
<td>GCMs simulation of Future</td>
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<td></td>
<td>climate statistics in local-scale</td>
<td>climate scenarios:</td>
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<tr>
<td></td>
<td></td>
<td>A1b (2046-2065, 2081-2100)</td>
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<tr>
<td></td>
<td></td>
<td>B1 (2046-2065, 2081-2100)</td>
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<td>GISS-ER</td>
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<td>GFDL-CM2.1</td>
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<td></td>
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<td>MRI-CGCM2.3.2</td>
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</tbody>
</table>
Statistical downscaling of local climate variables
(Climate chart of Hong Kong in 2046 - 2065)
Statistical downscaling of local climate variables
(Climate chart of Hong Kong in 2081 - 2100)
**Universal Thermal Climate Index (UTCI)** - measuring thermal comfort, both hot and cold, for short and long term outdoor exposure

- Simulate by RayMan model, inputting average daily values of:
  - Temperature (downscaled variable)
  - Relative humidity (downscaled variable)
  - Wind speed (downscaled variable)
  - Solar radiation
  - Site characteristics (such as location and sky view factor)

**Stress category**

<table>
<thead>
<tr>
<th>UTCI (°C)</th>
<th>Stress Category</th>
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<th>Stress Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 46</td>
<td>Extreme heat stress</td>
<td>1 to 9</td>
<td>Slight cold stress</td>
</tr>
<tr>
<td>39 to 46</td>
<td>Very strong heat stress</td>
<td>-12 to 0</td>
<td>Moderate cold stress</td>
</tr>
<tr>
<td>33 to 38</td>
<td>Strong heat stress</td>
<td>-26 to -13</td>
<td>Strong cold stress</td>
</tr>
<tr>
<td>27 to 32</td>
<td>Moderate heat stress</td>
<td>-39 to -27</td>
<td>Very strong cold stress</td>
</tr>
<tr>
<td>10 to 26</td>
<td>No thermal stress</td>
<td>(\leq -40)</td>
<td>Extreme cold stress</td>
</tr>
</tbody>
</table>

**Statistical downscaling of local climate variables**

*Projection of thermal comfort*
Shifting from no thermal stress to more heat stress

- Higher occurrence of very hot heat stress
- Less cold stress.
- Scenario A1B has the most severe change, especially in 2081 to 2100

Cheung & Hart (2014). Climate change and thermal comfort in Hong Kong. IJB.
• Southeast China (SEC) rainfall is affected by a number of climate systems, such as monsoon, PDO, IOD, ENSO etc.

• Important to check whether GCM can reproduce co-variability between SEC rainfall and large scale circulation

• If such linkage is found, then ultimately circulation variables such as sea level pressure (SLP) and geopotential height, can be used as predictors for statistical downscaling.
Statistical downscaling using climate pattern
(Prediction of precipitation)

Winter rainfall
- Suppressed rainfall in Southeast China (SEC) associated with large scale positive sea level pressure (SLP) anomaly
- Strong SLP gradient → stronger northerly surface wind (stronger winter monsoon)
- Enhanced northerly flow → brings cold and dry continental air to SEC
- Reduced amount of precipitation in SEC
Statistical downscaling using climate pattern
(Prediction of precipitation)

Summer rainfall
- Negative anomaly SLP covering Indochina to SEC is associated with enhanced rainfall in the region
- Lower than normal SLP conducive of occurrence of rainfall in SEC
Thank You