

# Climate Change Information System for UHI for Planning and Design A Singapore Case Study

Tian Kuay LIM, Singapore



A Multi-agency Initiative (Urban Redevelopment Authority, National Parks Board, Housing Development Board, Building Control Authority, Singapore Land Authority, Land Transport Authority, Jurong Town Corporation, Information Development Agency and Ministry of National Development/Ministry of the Environment & Water Resources)

# Singapore - City in a Garden



Highly urbanised city: Population: 5.2 Million, Land Area: 714 sq km

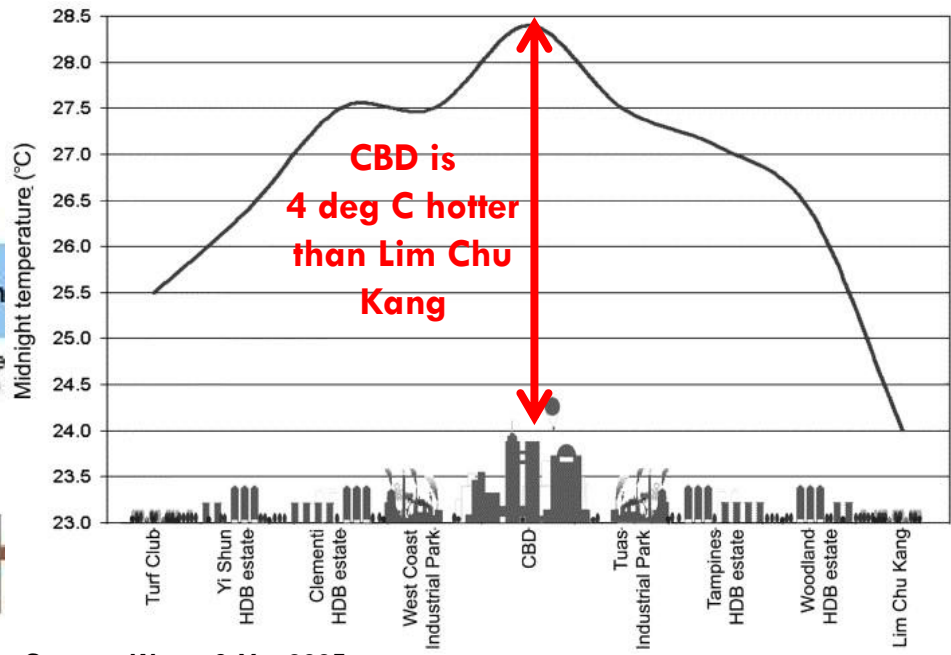
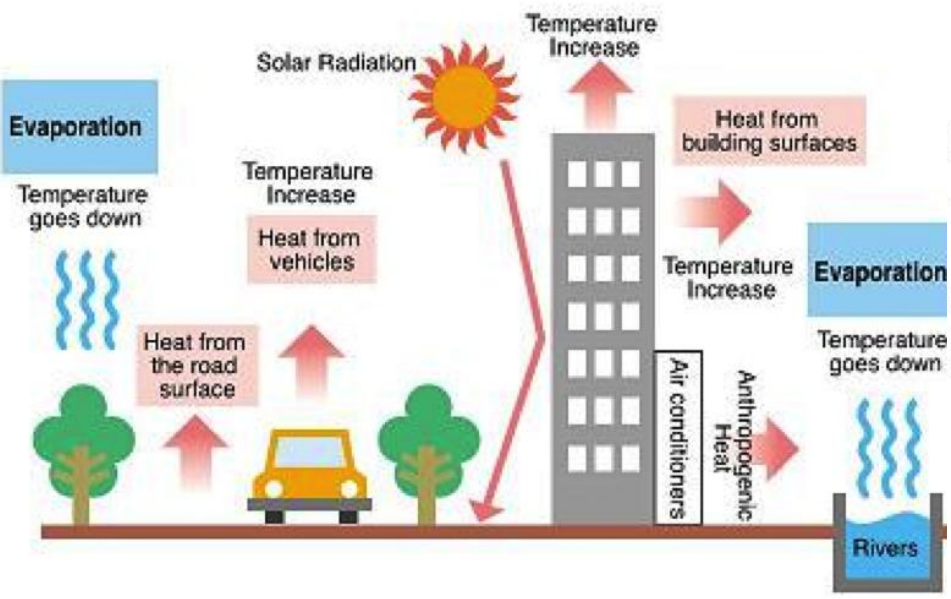
- Tropical weather, High-rise Buildings & Rich Urban Forestry

- Environmental Stresses & Climate Change Impacts, include:

Urban Wind Channels ► Urban Heat Island Effects (*Heat Ventilation*)

# BACKGROUND: UHI- A CONSEQUENCE OF URBAN DEVELOPMENT

- Trapping of heat within urban canyons
- Increased heat storage from man-made materials
- Less vegetation and evapotranspiration
- Anthropogenic heat release
- Poor air movement and reduced heat transfer



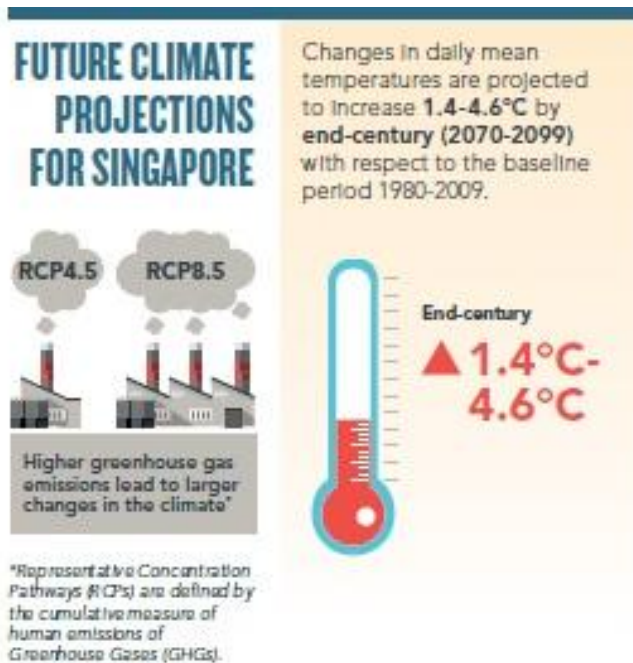
Source: Wong & Yu, 2005



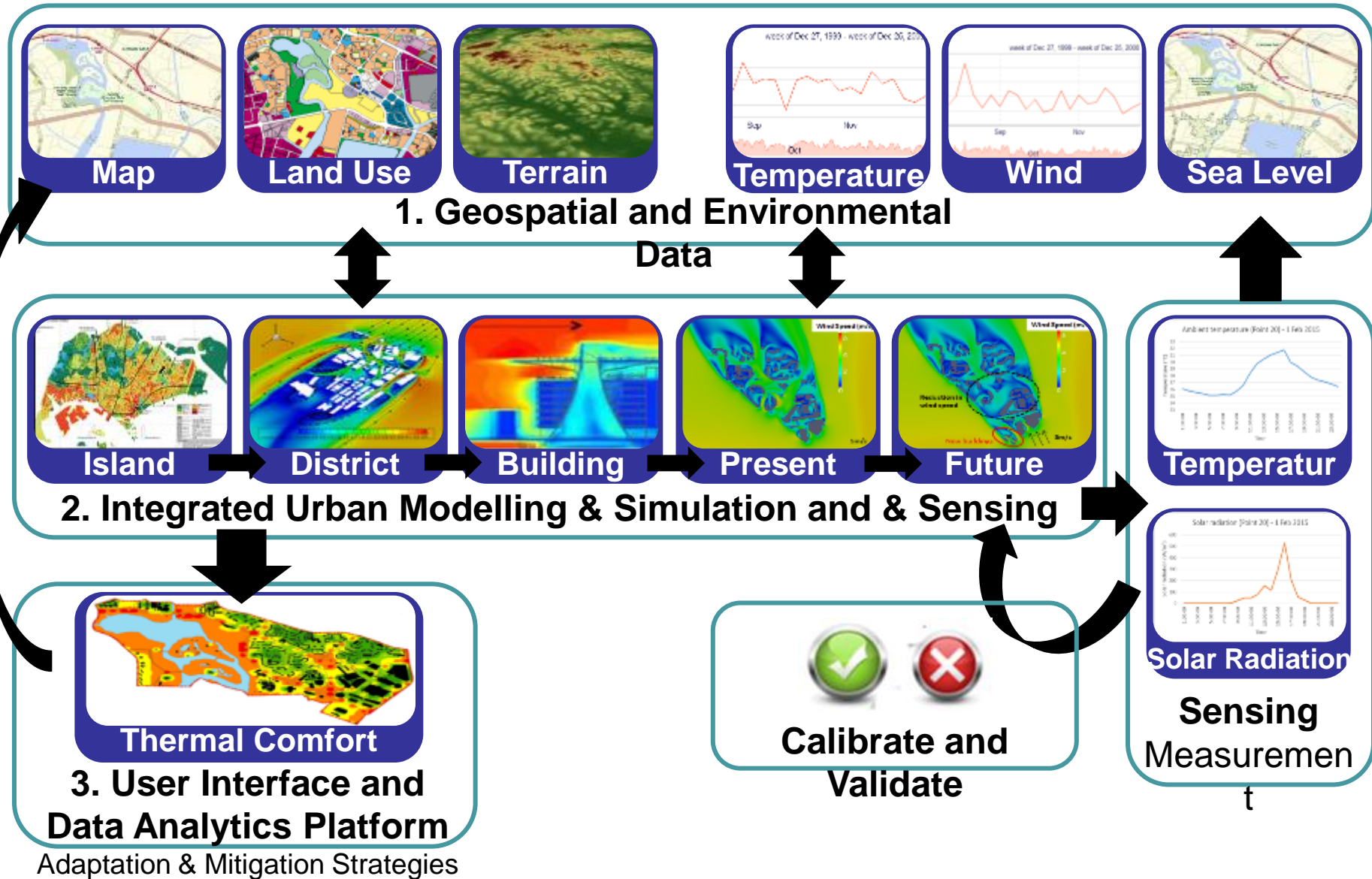
# BACKGROUND: UHI- A CONSEQUENCE OF URBAN DEVELOPMENT

- Due to combined effects of climate change (global warming) + further intensification of urban developments
- Negative impacts on thermal comfort, health and building energy use for cooling

## Singapore's UHI could worsen in future



# Integrated Adaptation Planning and Design (Combined effects of UHI + global warming)





# Urban Heat Island Effect Assessment

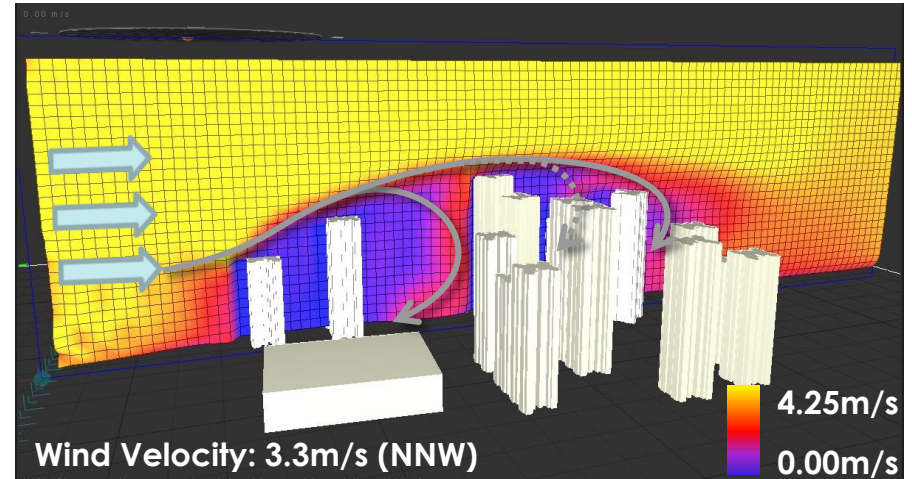
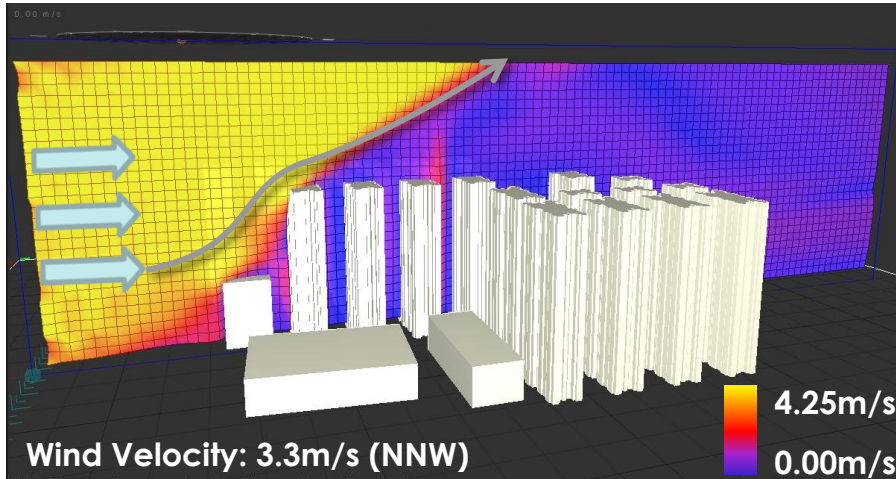
**BAU: GPR 5.6**

**All 40 Storey HDB Blocks**



**Improved scheme: GPR 4.2**

**Height differentiated HDB Blocks**

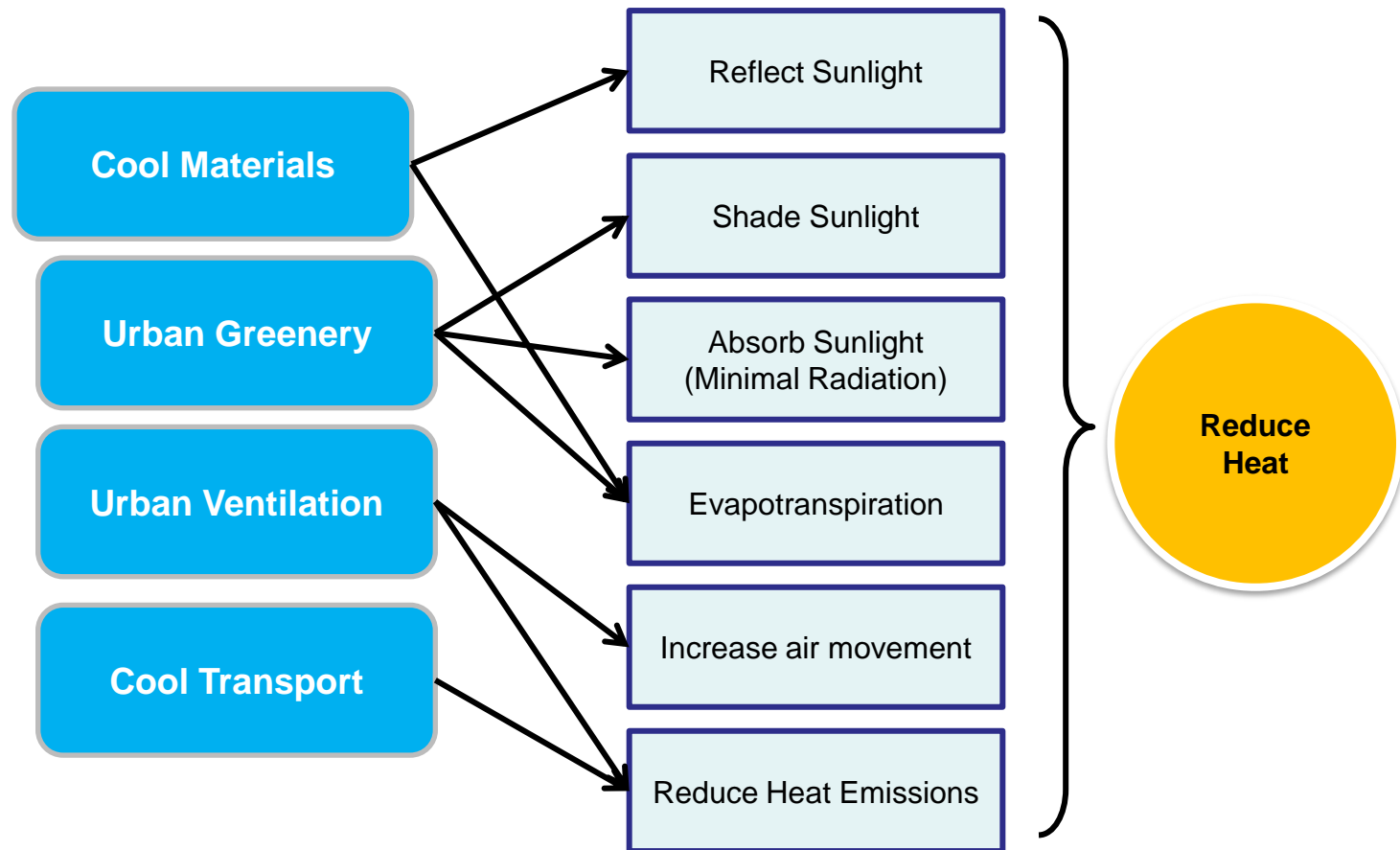


How will the development of a new town affect the wind flow and comfort (thermal) in adjacent towns? Wind corridors; good ventilation; parks, open spaces and greenery?

# Integrated Adaptation Planning and Design

## (Combined effects of global warming + UHI)

- Need for climate-sensitive planning and design upfront
- UHI and global warming mitigation covers different aspects of our built environment, and involves different agencies.



# Thermal Comfort Assessment Framework

## (1) Integrated, Coupled Multi-scales Urban Model

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### **Incorporates Location as an Element for Decision-making**

Location-Specific Thermal Comfort Stress Assessment uses integrated, coupled multi-scales models:

- (i) weather/climate & environment models (1~0.1 km resolution);
  - **GSM/RSM/MSM**: Horizontal aspects 10km (regional domain) to (1~0.1 km resolution);
  - Coupling of Land Surface Model (NOAH) to Urban Canopy Model – (Development)

- (ii) urban modeling (1~10 metre resolution)

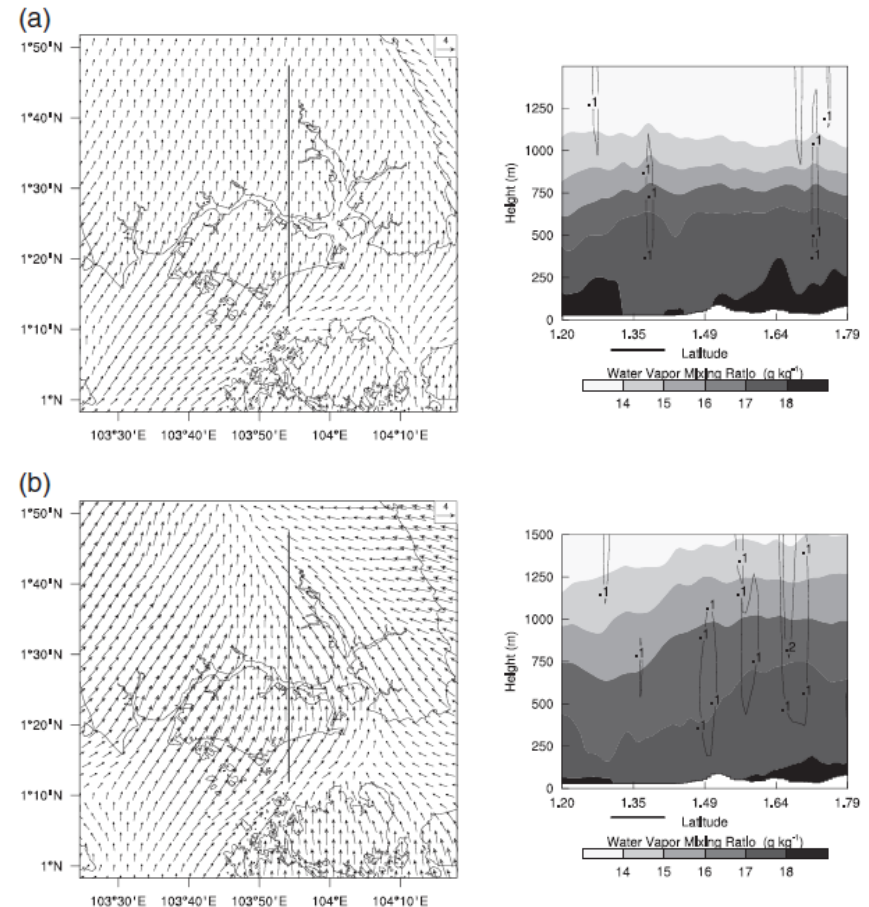
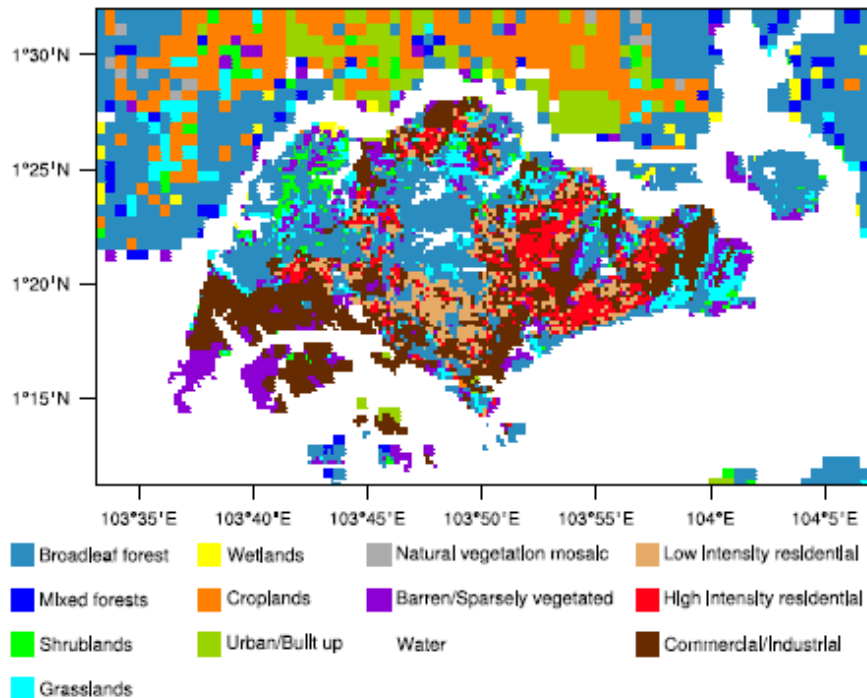
Based on OpenFoam and CFD code: Mass conservation and momentum equations were solved together with specific model equations, such as energy balance, turbulence such as Spalart Allmaras turbulence model, etc.



# Coupling of Land Surface Model to Urban Canopy Model (Development- Preliminary Results)

The effects of land use type and anthropogenic heat (AH) and its diurnal variation on the thermal and wind environment such as coupling the Noah Land Surface Model (*Chen and Dudhia, 2001*) to the *Single-Layer Urban Canopy Model* (*Kusaka et al., 2001; Kusaka and Kimura, 2004*) using a *tile-approach* (*Tewari et al., 2006*).

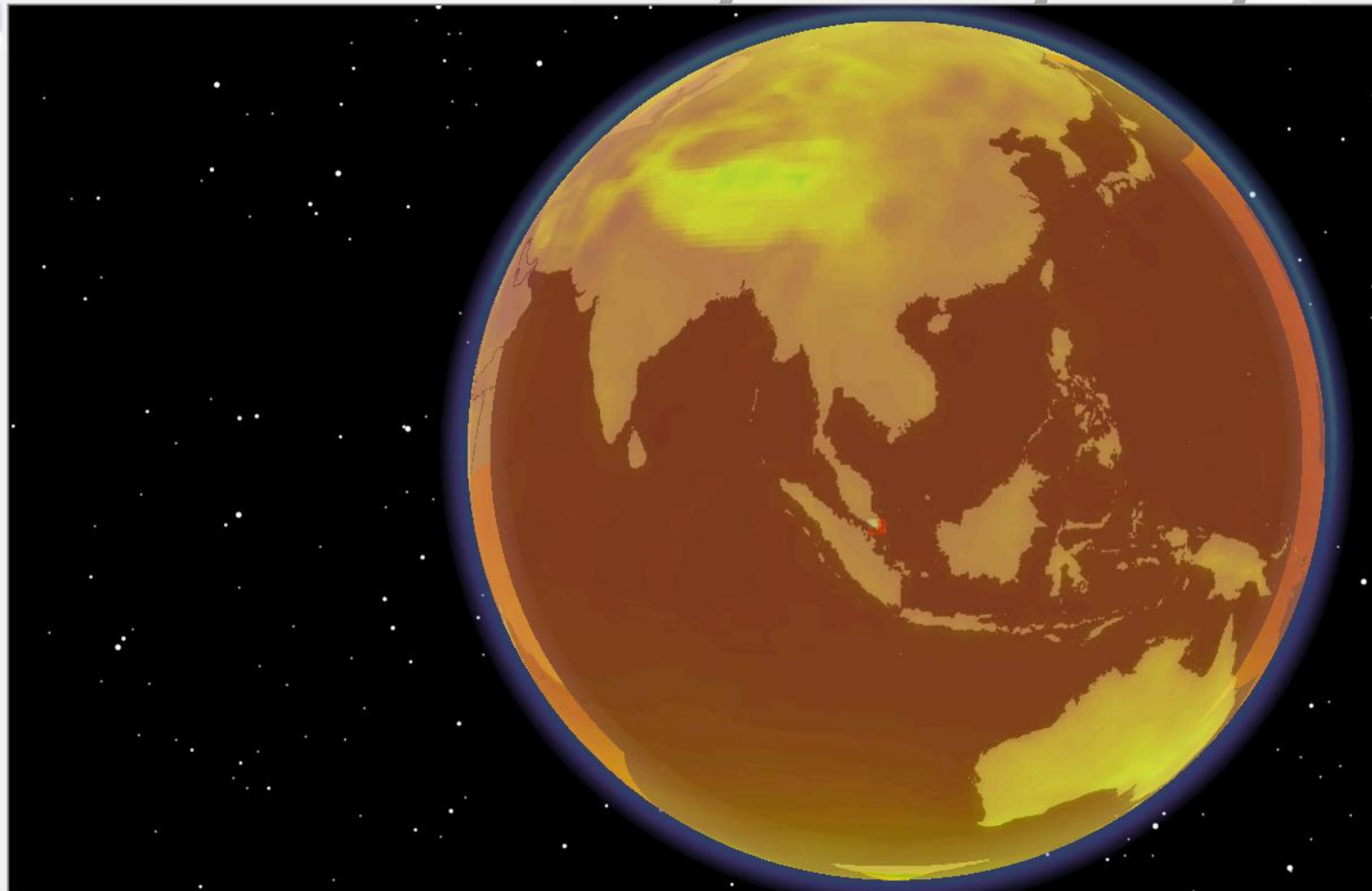
Land Use/Land Cover Map



Sea breeze evolution in domain d04 at (a) 11:00 LT and (b) 17:00 LT. (Left) 10 m wind field.

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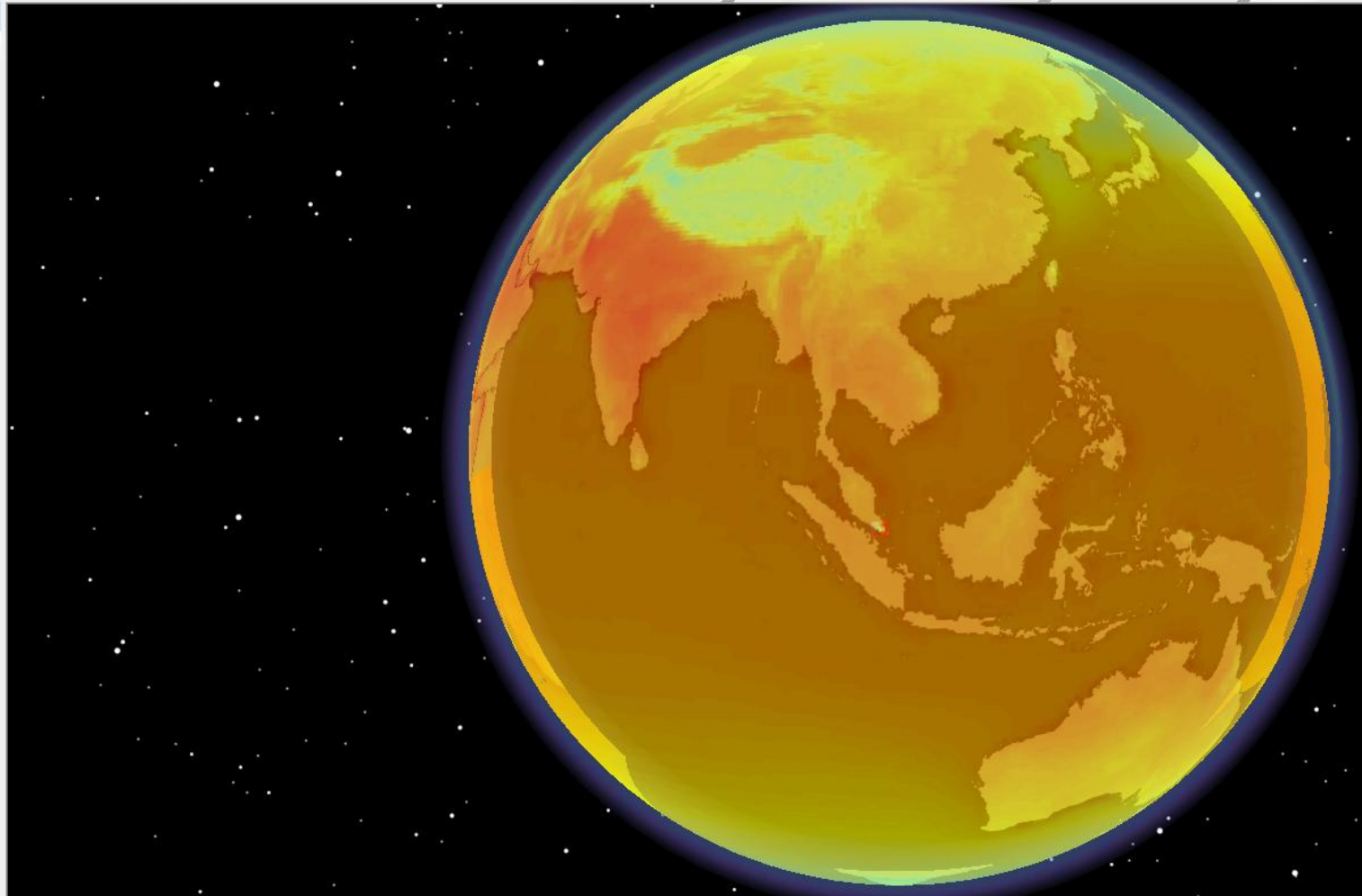
- 25052008\_23hrs
- 26052008\_02hrs
- 26052008\_05hrs
- 26052008\_08hrs
- Global Temperature
  - 23052008\_08hrs
  - 23052008\_14hrs
- Value
  - High : 43.0685
  - Low : -72.7371
- 23052008\_20hrs
- 24052008\_02hrs
- 24052008\_08hrs
- 24052008\_14hrs
- 24052008\_20hrs
- 25052008\_02hrs
- 25052008\_08hrs
- 25052008\_14hrs
- 25052008\_20hrs
- 26052008\_02hrs
- RCP 8.5
- RCP 4.5
- World Regions



QUEST- Generate higher resolution of 40km Global temperatures (for baselines study) from the coarser resolution of 200km from NCEP Reanalysis.

Table of Contents

- Globe layers
  - Modelling\_Simulation
  - DSM Themes
  - Simulation Results
  - Jurong Lake District
  - Local Temperature
  - Regional Temperature
  - Global Temperature
  - RCP 8.5
    - Global\_180.5d, 1997, MaxTerr Value
      - High : 45.6948
      - Low : -50.7652
    - Global\_180.5d, 1998, MaxTerr
    - Global\_180.5d, 2015, MaxTerr
    - Global\_180.5d, 2030, MaxTerr
    - Global\_180.5d, 2050, MaxTerr
    - Global\_180.5d, 2080, MaxTerr
    - Global\_180.5d, 2100, MaxTerr
  - RCP 4.5
  - World Regions



QUEST- Access to IPCC AR5 Global Climate Projections for the study of climate change impacts.

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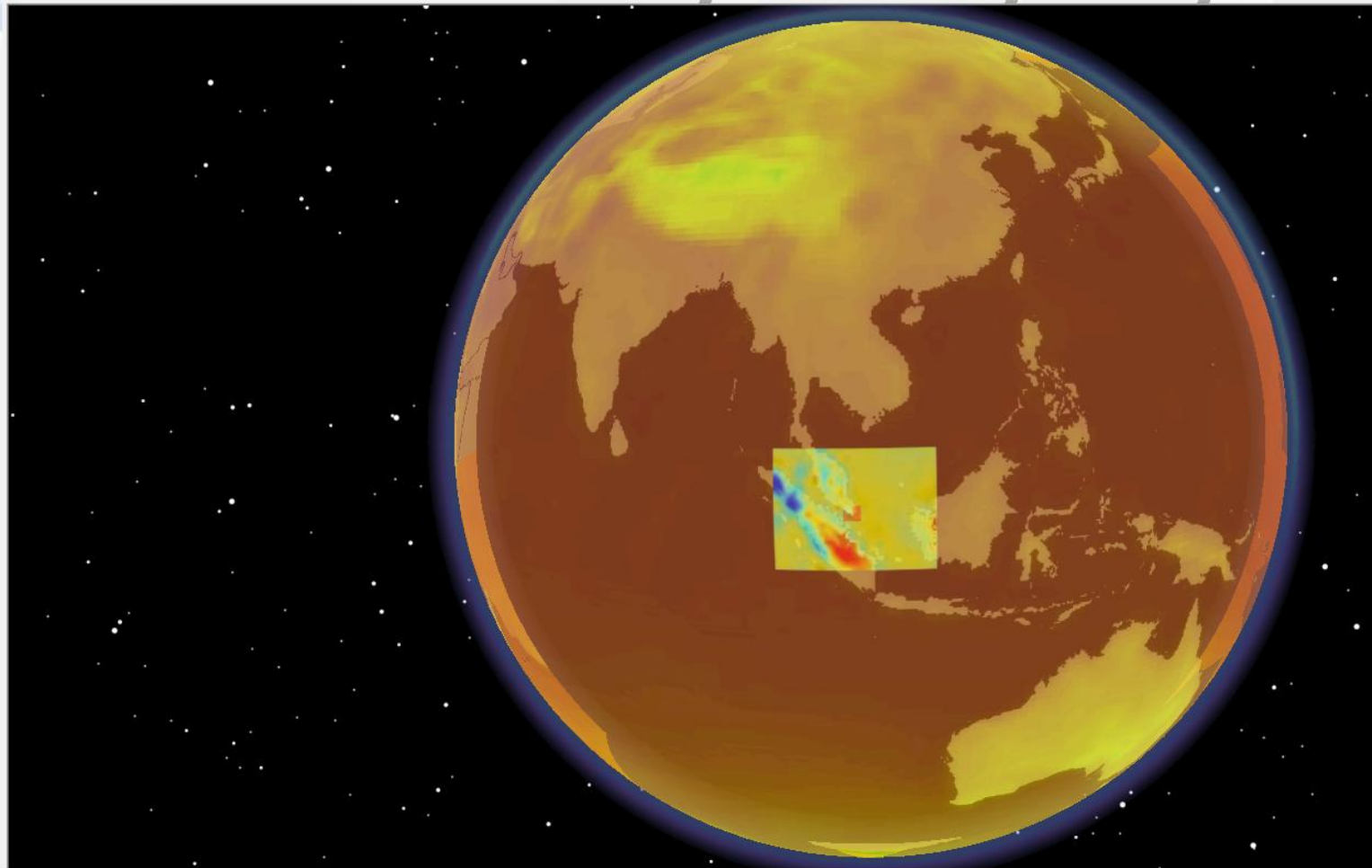
- 25052008\_02hrs
- 25052008\_05hrs
- 25052008\_08hrs
- 25052008\_11hrs
- 25052008\_14hrs
- 25052008\_17hrs
- 25052008\_20hrs
- 25052008\_23hrs
- 26052008\_02hrs
- 26052008\_05hrs
- 26052008\_08hrs
- Global Temperature
- 23052008\_08hrs
- 23052008\_14hrs

Value

High : 43.0685

Low : -72.7371

- 23052008\_20hrs
- 24052008\_02hrs
- 24052008\_08hrs
- 24052008\_14hrs
- 24052008\_20hrs
- 25052008\_02hrs
- 25052008\_08hrs



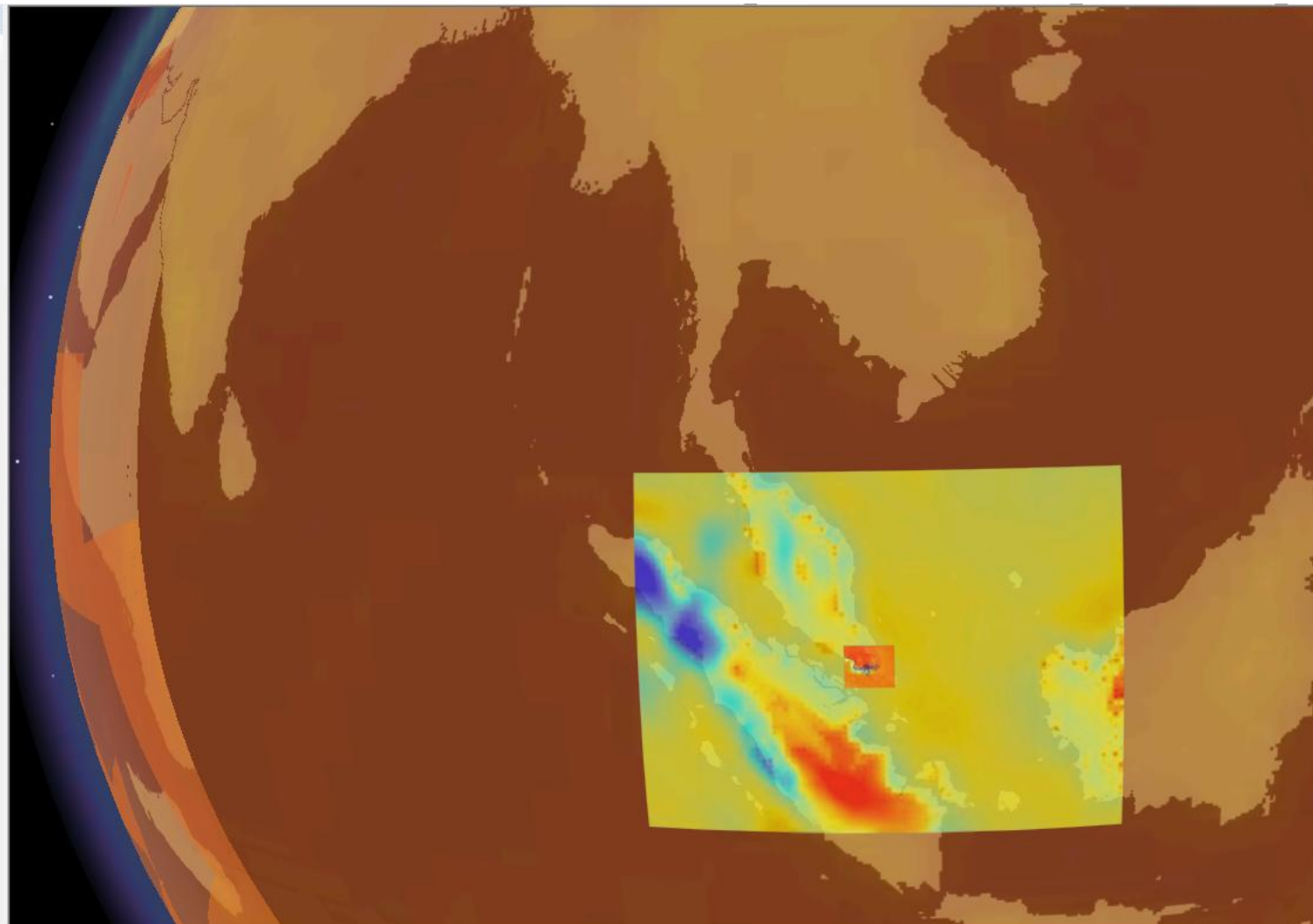
QUEST- Generate higher resolution of 10km regional temperatures (baseline study) over SE Asia from the coarser resolution 40km global model.



Table of Contents

- Globe layers
  - Modelling\_Simulation
  - DSM Themes
  - Simulation Results
  - Jurong Lake District
  - Local Temperature
    - coastline\_2009
    - Airtemp\_CMCC\_CM
    - 23052008\_08hrs
    - 23052008\_11hrs
    - 23052008\_14hrs
    - 23052008\_17hrs
    - 23052008\_20hrs
    - 23052008\_23hrs
    - 24052008\_02hrs
    - 24052008\_05hrs
    - 24052008\_08hrs
    - 24052008\_11hrs
    - 24052008\_14hrs
    - 24052008\_17hrs
    - 24052008\_20hrs

Value  
High : 29.7989  
Low : 16.9876

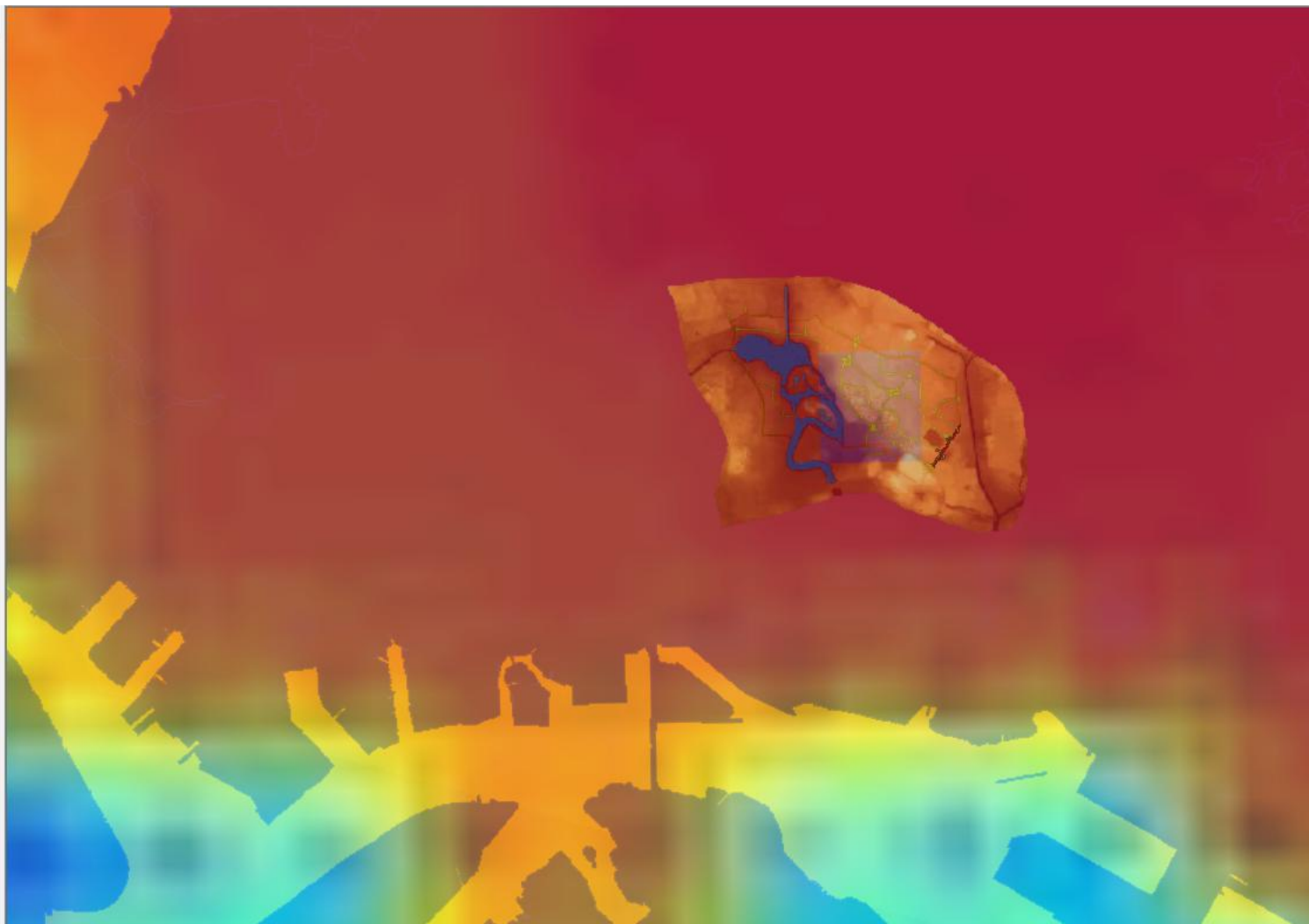


QUEST- Generate higher resolution of 1km local temperatures (baseline study) over Singapore and its surrounding region based on the coarser global and regional resolution with resolution of 40km and 10km respectively.

Table of Contents

- Jurong Lake District
  - Wind\_50m
  - Wind\_30m
  - Wind\_10m
  - tsvtmin\_c
  - tsvtavgd\_c
  - tsvtmax\_c
  - tsvtmax
  - tsvtavg\_n\_c
  - tsvtavg\_c
  - Temperature\_Diff\_2m
  - Temperature Add 100m
  - Temperature Add 50m
  - Temperature Add 25m
  - Temperature Add 15m
  - Temperature Add 10m
  - Temperature 100m
  - Temperature 50m
  - Temperature 25m
  - Temperature 15m
  - Temperature 10m
  - Temperature\_2m

Value  
High : 39  
Low : 34



QUEST- Generate of 2m street-level temperatures (baseline study) over JLD from the coarser resolution 1km local model.

Table of Contents

- Temperature Add 25m
- Temperature Add 15m
- Temperature Add 10m
- Temperature 100m
- Temperature 50m
- Temperature 25m
- Temperature 15m
- Temperature 10m
- Temperature\_2m
- Value
- High : 39
- Low : 34
- Temperature 5m
- Temperature Surface
- JLD\_Sensor
- JLD\_Roads
- JLD\_Buildings
- JTCSummit\_MultiPatch
- Multipatch
- CFD\_Buildings
- CFD\_Additional\_bldgs
- JLD\_LAI\_Vegetation



QUEST- Sensors installed over JLD for Calibration and Validation of the 2m street-level temperatures (baseline study) over JLD.





QUEST- Access to the observations from Sensors installed over JLD for Calibration and Validation of the 2m street-level temperatures (baseline study) over JLD.



# Modelling & Simulation of UHI for Urban Planning & Design (Workflow)

- Define Domain of Interest;
- Data Extraction;
- Setting up of scenarios for Simulation
  - Edit existing buildings/structures
  - Add new buildings/structures
  - Select the environmental conditions
  - Select the simulations to run
  - Select the outputs for the simulations

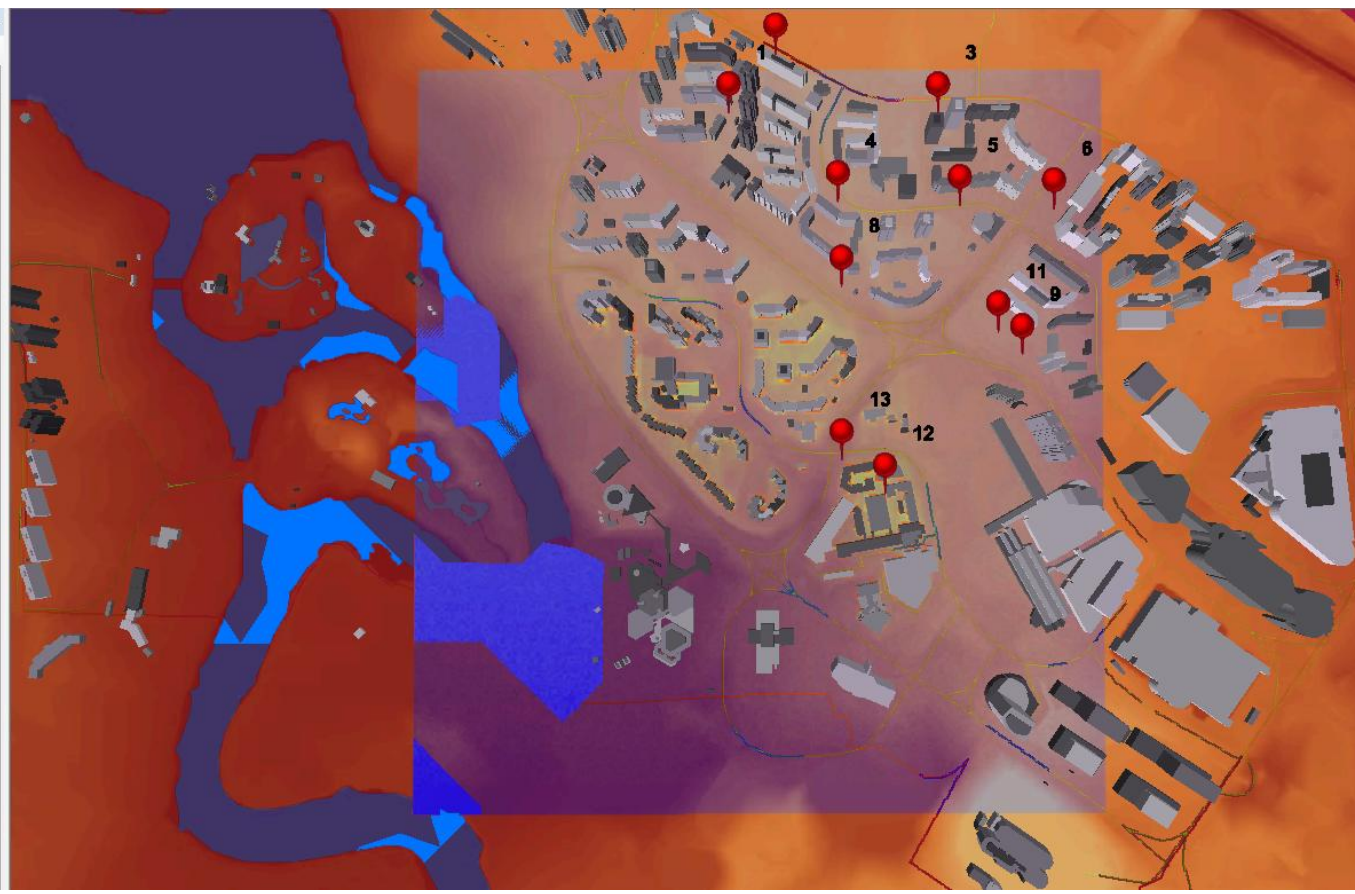
The image displays a software interface for environmental simulation, divided into three main sections:

- Simulation Configuration (Left Panel):**
  - Simulation(Landuse Scenarios):** Includes checkboxes for Existing Building, With New Building, Road Surface, Existing Building (M...), Greenery, and Waterbodies.
  - Simulation(Environmental Scenarios):** Features a 'Specific Day/Time' selector and a 'Baseline' section with options for NE Moonsoon, SW Moonsoon, Inter Moonsoon (Aug - Oct), and Inter Moonsoon (Mar - May). A 'Baseline Month of the Year' dropdown is also present.
  - Climate Change Scenarios:** Includes checkboxes for AR5 - RCP 8.5, AR5 - RCP 4.5, AR4 - A2, and Threshold Scenarios.
  - Simulation:** A checkbox for 'Temperature and Wind' is checked.
- Table of Contents (Middle Panel):**
  - Globe layers:** A tree view showing the simulation hierarchy.
    - C:\CLICIS\Domain
      - Modelling\_Simulation (checked)
    - D:\CLICIS\_RISKMAP\BCA-RiskMap
      - A1\_2100\_Inland (checked)
      - A1\_2100\_Coast (checked)
    - C:\CLICIS\CFD\_Buildings\Simulation
      - diff\_temp5\_10 (checked)
  - Value Legend:** A color scale from blue (Low: 0) to red (High: 38.97).
  - Temperature Outputs:** A list of simulation outputs, including Temperature\_2m, Temperature\_5m, Temperature Surface, Temperature\_Add\_2m, Temperature Add 5m, Temperature Add Surf, Temperature\_Diff\_2m, and Temperature Add 100m.
- 3D Map View (Right Panel):**
  - Shows a 3D model of a city area with buildings and terrain.
  - A cyan rectangular box highlights a specific urban area.
  - Red location pins are placed on the map, labeled with numbers 8, 9, 11, 12, and 13.

Select the environmental conditions  
 Select the simulations to run  
 Select the outputs for the simulations

Table of Contents

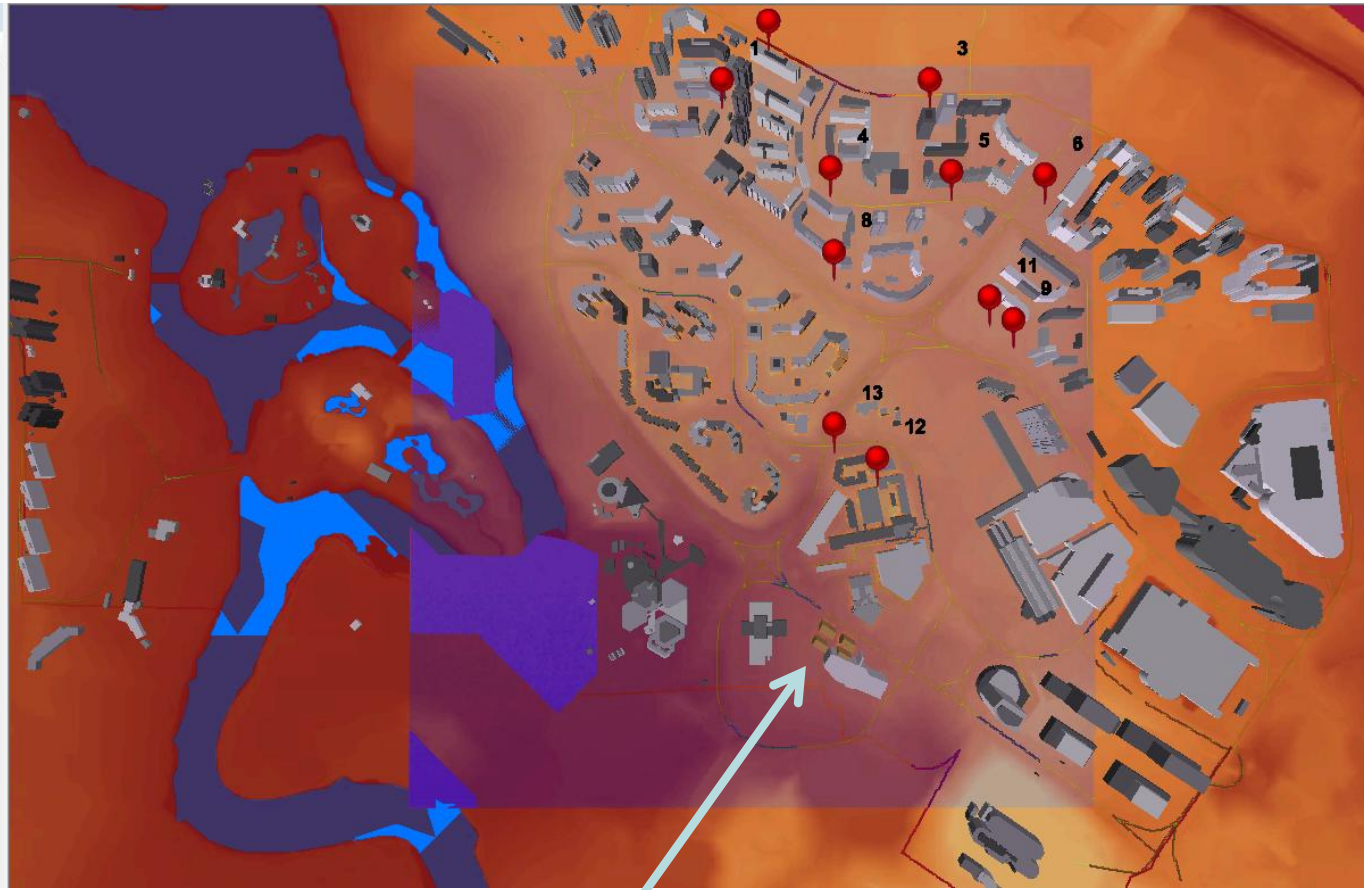
- Globe layers
  - Modelling\_Simulation
    - DSM Themes
    - Simulation Results
      - Temperature Difference 2m
        - Value
        - High : 4.92784
        - Low : -0.35408
      - Temperature\_Add\_2m
        - Value
        - High : 39
        - Low : 34
      - Temperature\_2m
        - Value
        - High : 39
        - Low : 34
      - Temperature 5m
      - Temperature Surface
      - Temperature Add 5m



Simulation Results: 2m Temperatures for Existing Buildings Scenario

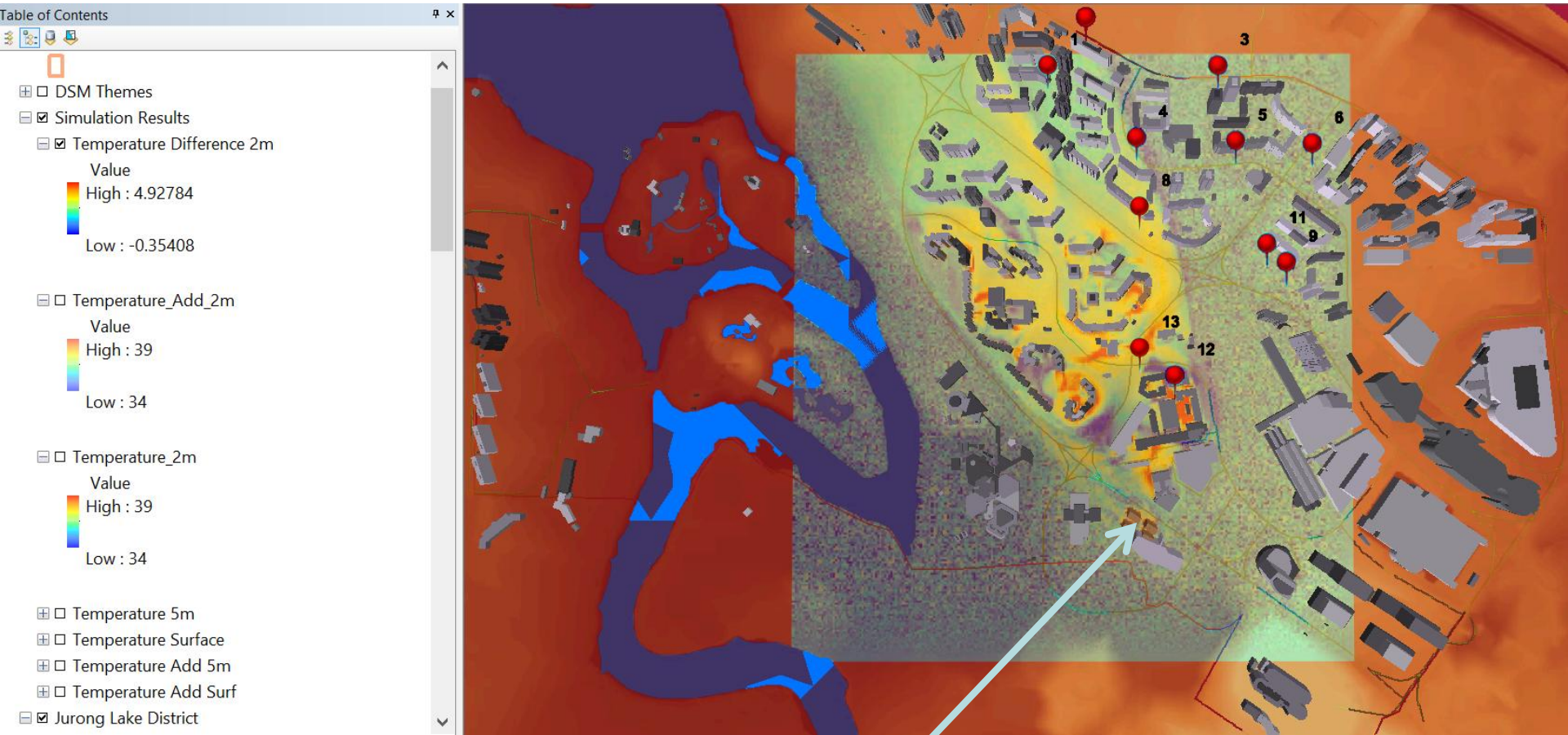
Table of Contents

- DSM Themes
- Simulation Results
  - Temperature Difference 2m
    - Value
    - High : 4.92784
    - Low : -0.35408
  - Temperature\_Add\_2m
    - Value
    - High : 39
    - Low : 34
  - Temperature\_2m
    - Value
    - High : 39
    - Low : 34
  - Temperature 5m
  - Temperature Surface
  - Temperature Add 5m
  - Temperature Add Surf
- Jurong Lake District



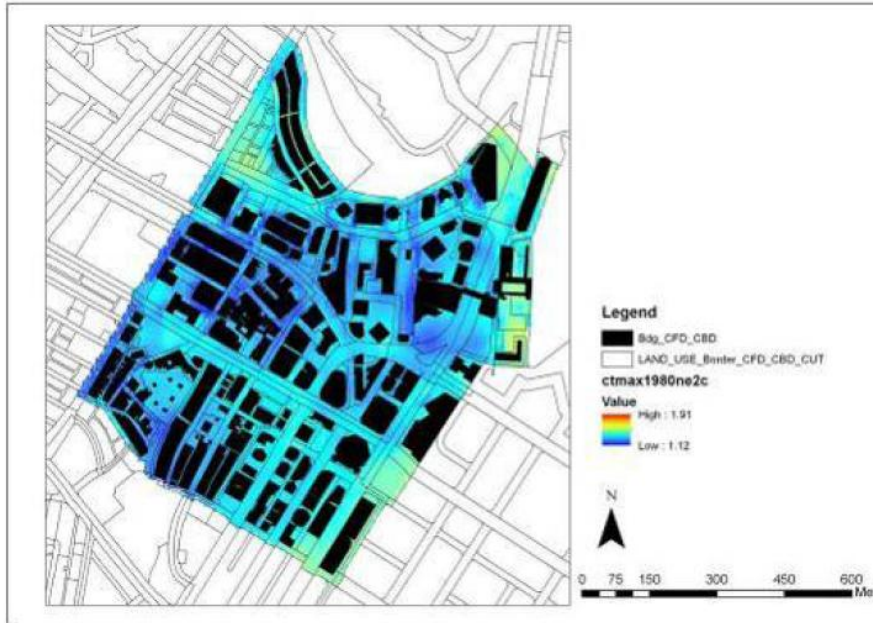
Simulation Results: 2m Temperatures with **additional** New Buildings Scenario



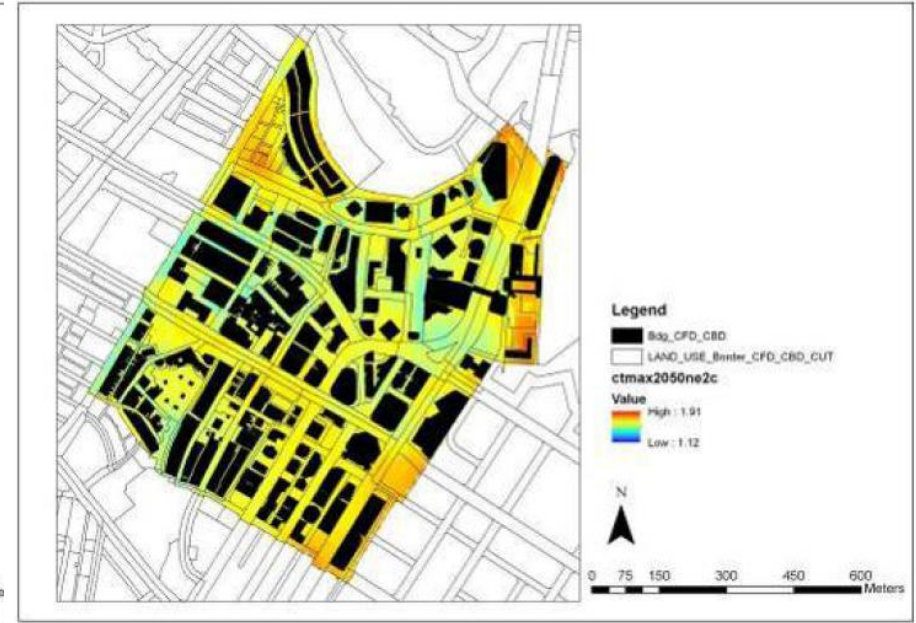


Simulation Results: Comparison of the 2m Temperatures for the two scenarios (i) Existing Buildings Scenario; (ii) Adding New Buildings Scenario

# Thermal Comfort Assessment/Simulation



TSV map during daytime (Tmax) (Current)

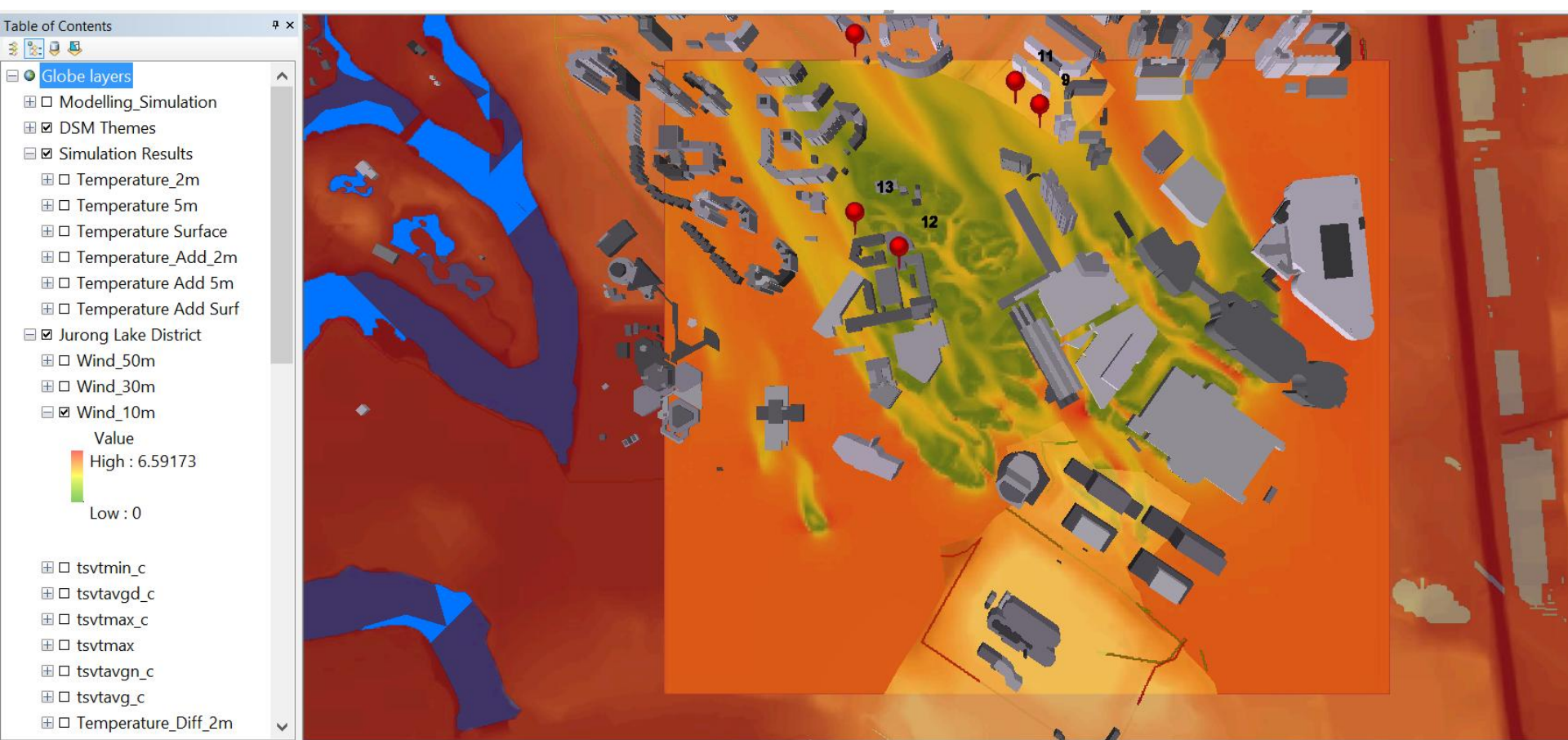


TSV map during daytime (Tmax) (2050, A2)

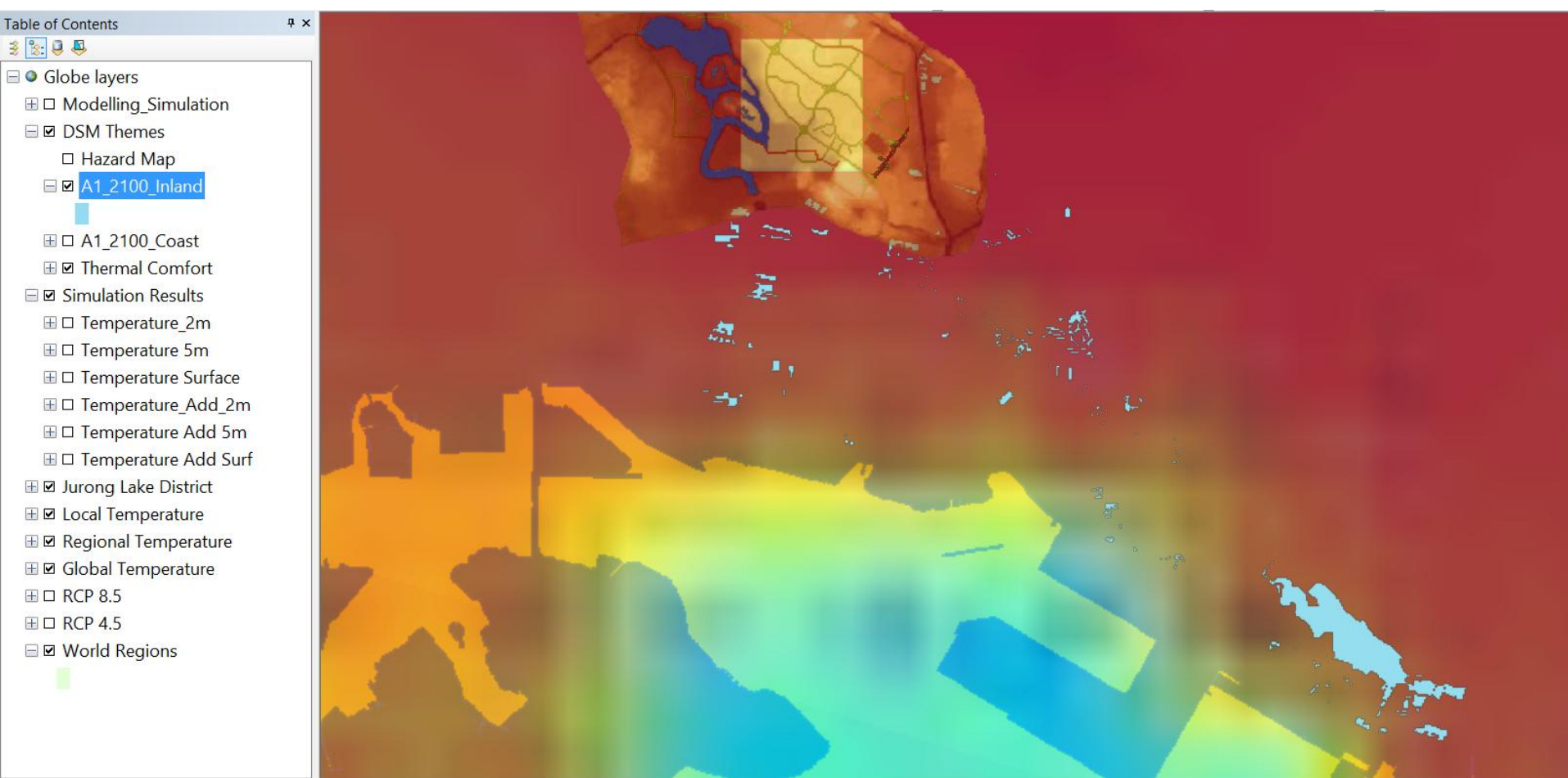
TSV range	Ta range (°C)	Perception (reference to ASHRAE 7-point scale)
-3~-2	Not applicable	cold to cool
-2~-1	22.4~25.4	cool to slightly cool
-1~0	25.4~28.5	slightly cool to neutral
0~1	28.5~31.6	neutral to slightly warm
1~2	31.6~34.7	slightly warm to warm
2~3	34.7-37.7	warm to hot



# Examples of other factors for Urban Planning and Design



Various Information Layers such as wind at 10m height, etc., for Decision Support Module

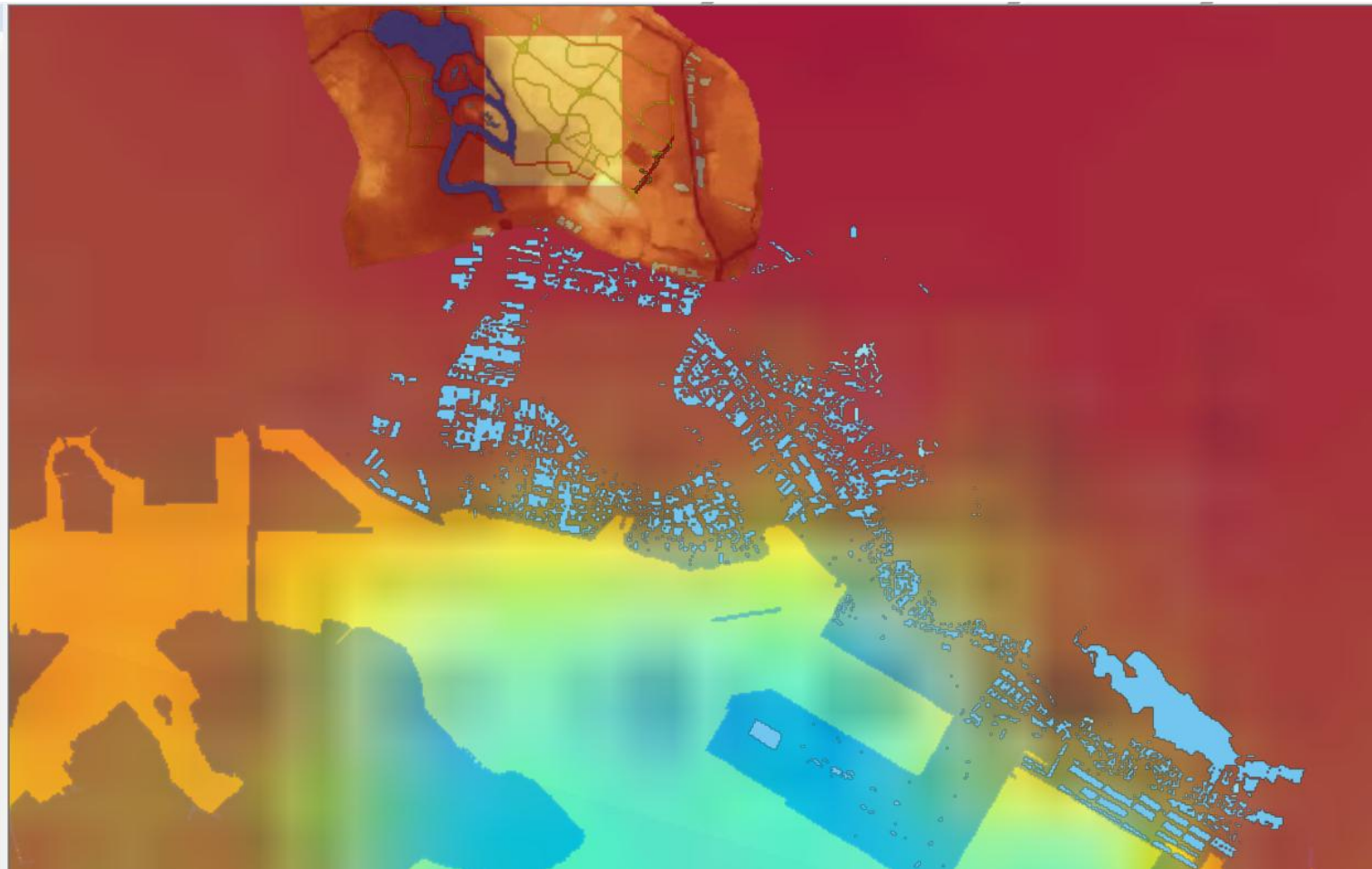


Various Information ayers such as Inland Indundation A1\_2100 ,for Decision Support Module



Table of Contents

- Globe layers
- Modelling\_Simulation
- DSM Themes
  - Hazard Map
  - A1\_2100\_Inland
  - A1\_2100\_Coast
  - Thermal Comfort
- Simulation Results
  - Temperature\_2m
  - Temperature 5m
  - Temperature Surface
  - Temperature\_Add\_2m
  - Temperature Add 5m
  - Temperature Add Surf
- Jurong Lake District
- Local Temperature
- Regional Temperature
- Global Temperature
- RCP 8.5
- RCP 4.5
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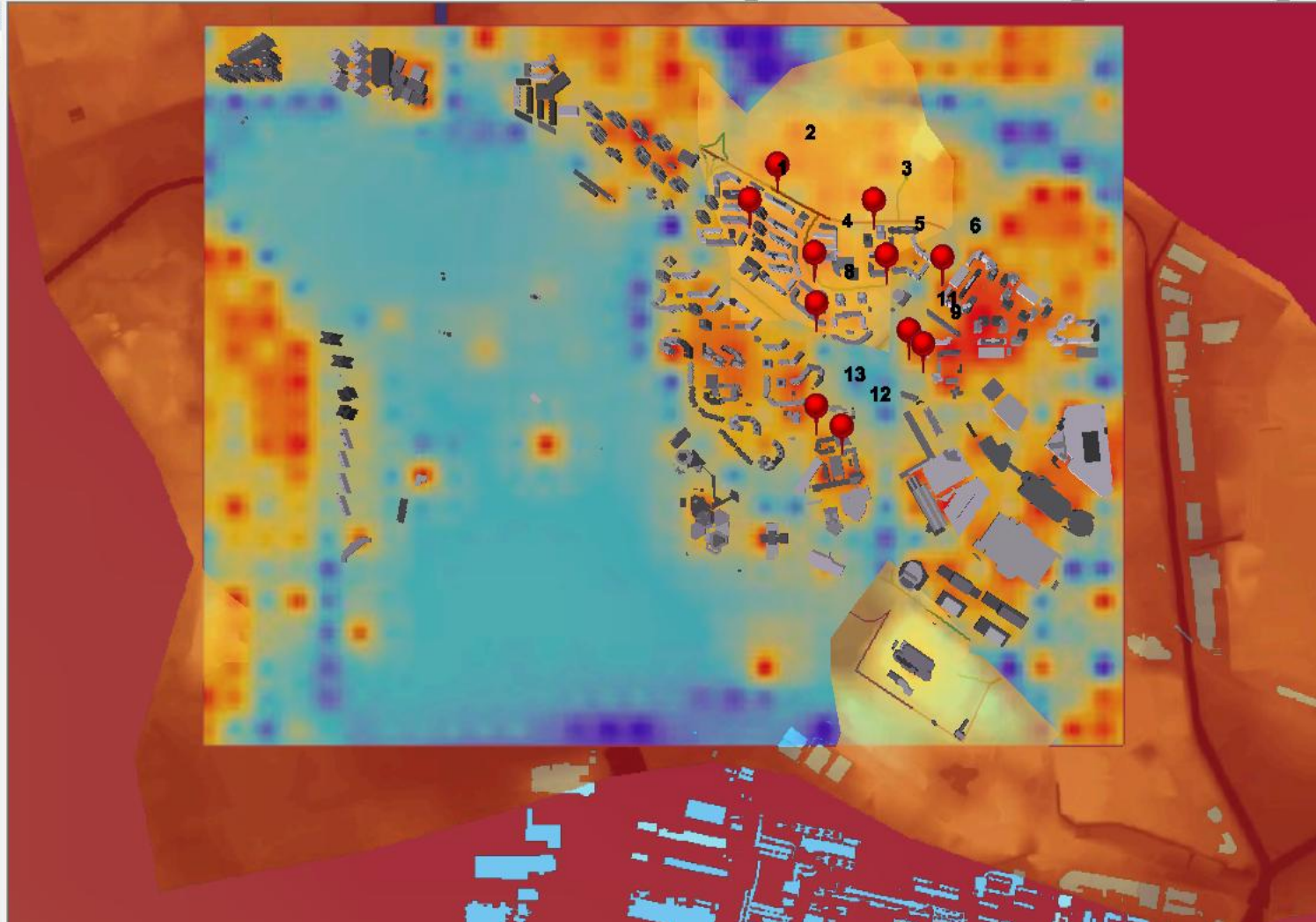
Various Information layers such as coastal Inland Indundation A1\_2100 ,for Decision Support Module

Table of Contents

- A1\_2100\_Inland
- A1\_2100\_Coast
- Thermal Comfort
  - diff\_temp5\_10
- Simulation Results
  - Temperature\_2m
  - Temperature 5m
  - Temperature Surface
  - Temperature\_Add\_2m
  - Temperature Add 5m
  - Temperature Add Surf
- Jurong Lake District
  - Wind\_50m
  - Wind\_30m
  - Wind\_10m
  - tsvtmin\_c
  - tsvtavgd\_c
  - tsvtmax\_c
  - tsvtmax

Value  
 High : 1.42985  
 Low : 0.832278

- tsvtavgd\_c

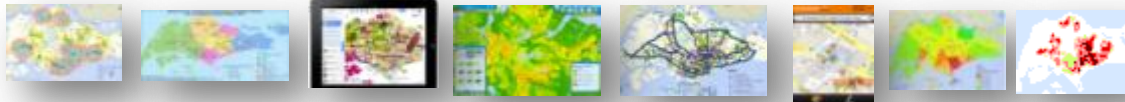


Combination of Various Information Layers such as Inland Indundation A1\_2100 , Coastal, thermal comfort, etc. for Decision Support Module

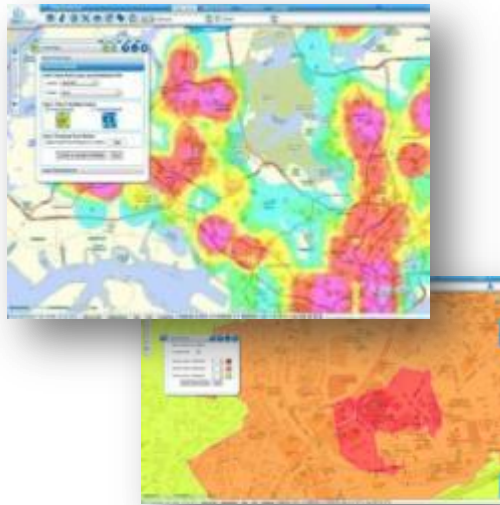


# COMMON GEOPLATFORMS FOR WOG DATA SHARING

**AGENCY  
SPECIFIC  
SYSTEMS**

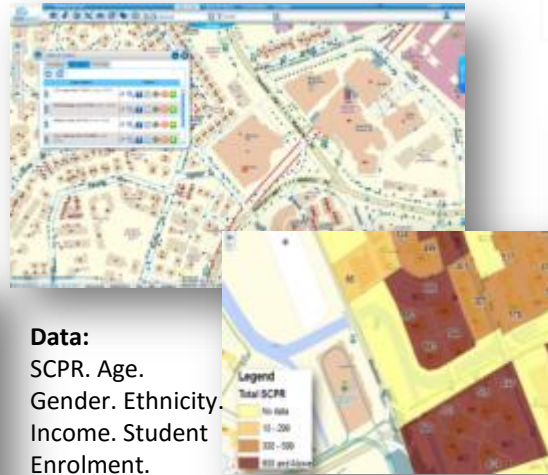


**GEO ANALYTICS**



Heatmap. Service Area. Routing.  
Proximity Search.

**GEO DATA**

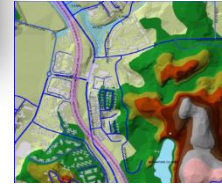


**Data:**  
SCPR. Age. Gender. Ethnicity.  
Income. Student Enrolment.  
Household with Domestic  
Workers. Car Ownership.  
Construction Sites.  
Workers' Dorm

Fine grained data in  
Aggregated Data Zones  
(ADZ) for detailed  
analysis





**Climate Change  
Comm (CLICIS)**

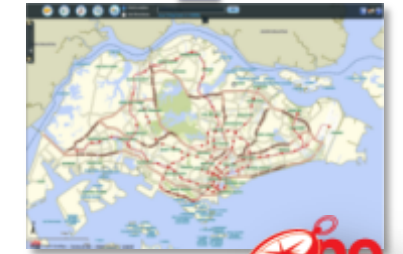


**SHARES**

NGO:  Educational Institutions



General Public  Businesses 



Multi-Window  
Public Access

**Common Platforms:**



**Restricted**



**Presenter: MaryIn Lim**

# Summary

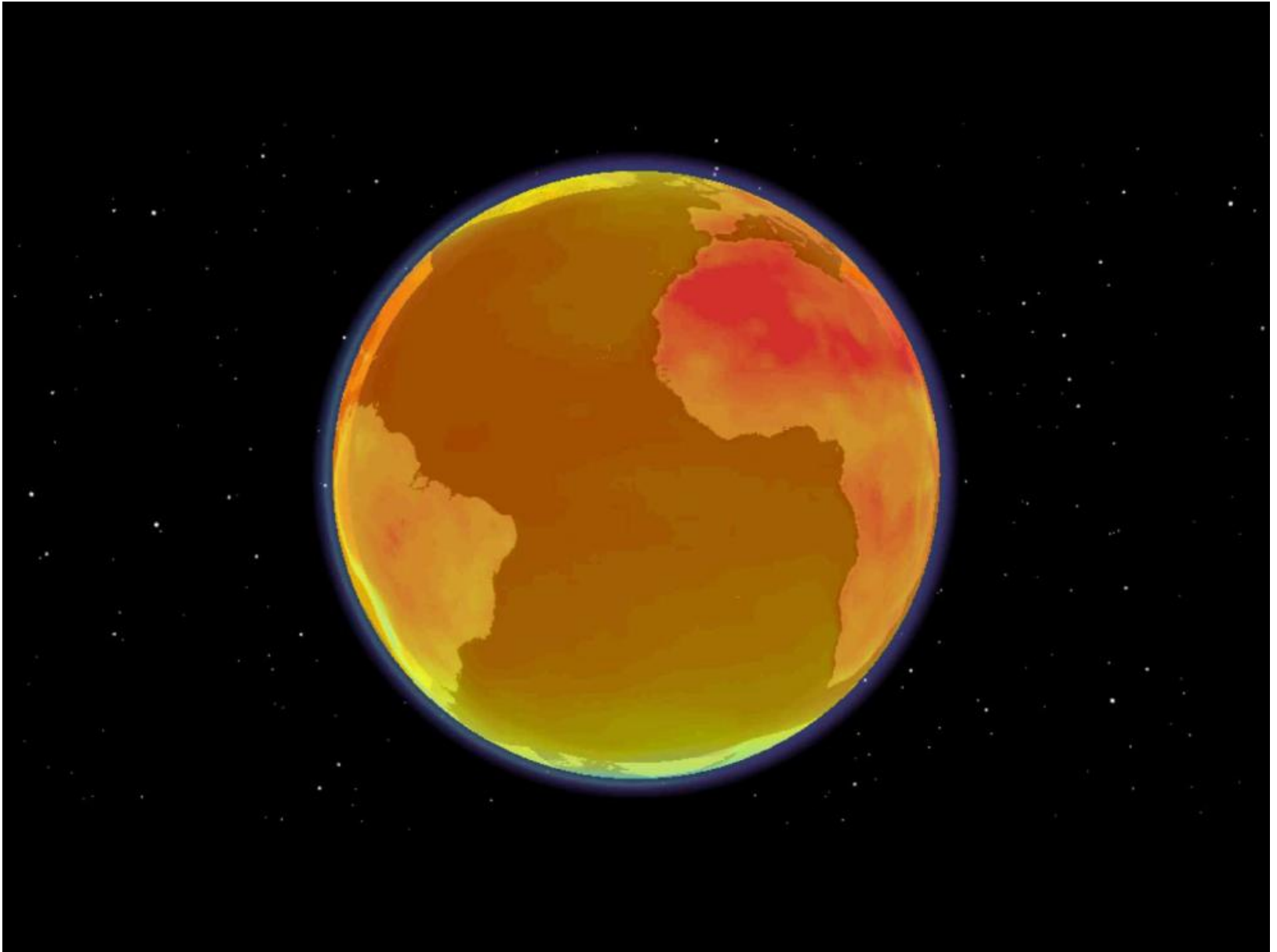
A GIS-based UHI/Thermal Comfort Assessment Framework (based on integrated coupled multi-scales atmospheric-urban-thermal comfort modelling) provides an effective platform to support climate-sensitive design and planning for Singapore with following key functionalities:

- 1) Data & Information Access & Retrieval
- 2) Planning, Design & Adaptation



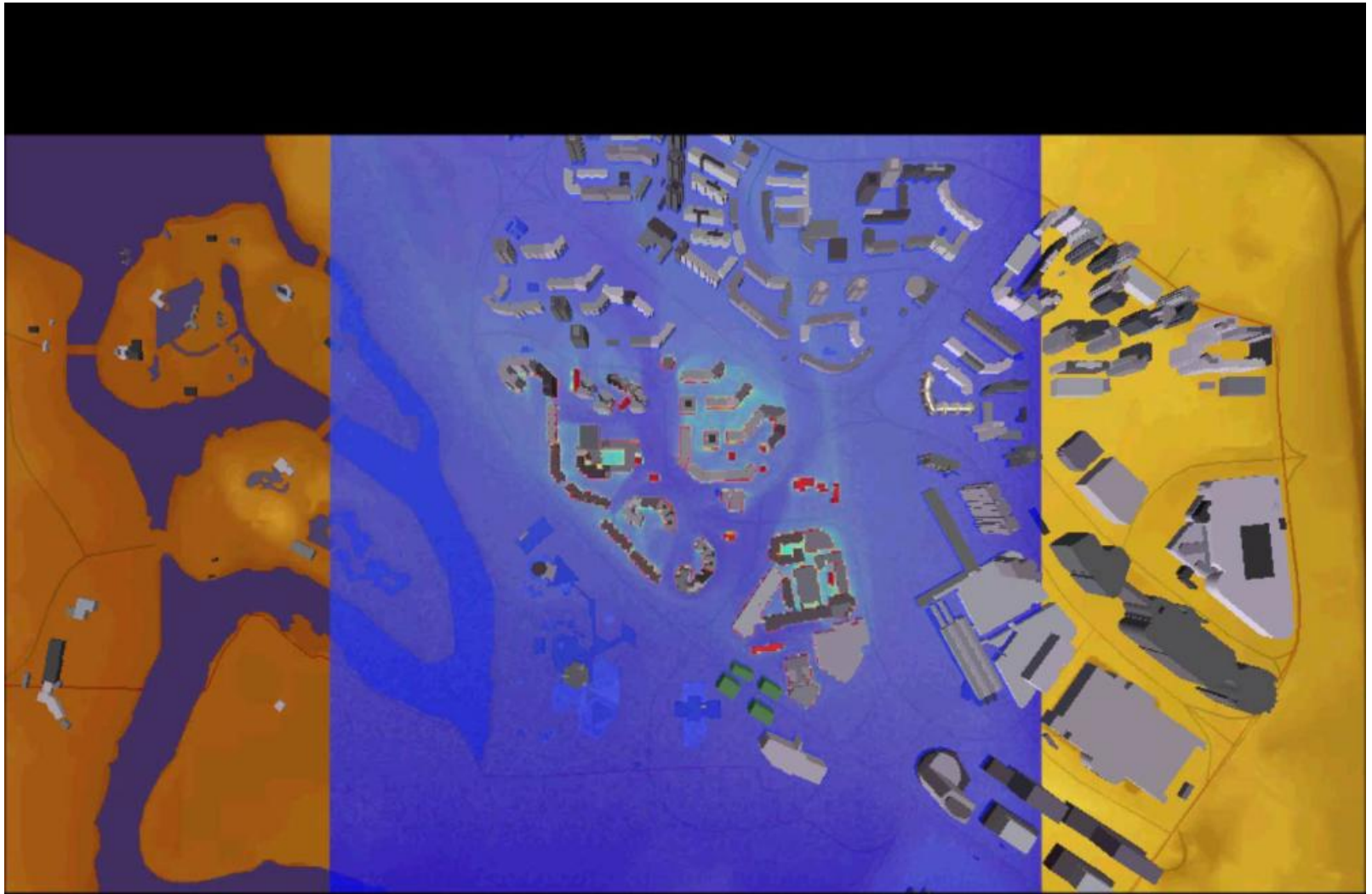
# Summary

Data & Information Access & Retrieval



# Summary

Planning, Design & Adaptation



# **Areas for Development and Collaboration**



# A 3D GIS-based Modelling and Simulation Tool for Planning & Design of Sustainable Cities





# Urban Planning

**HOUSING**  
“Good living environments,  
a variety of housing options”

**ECONOMY**  
“A vibrant economy,  
quality jobs near homes”

**RECREATION**  
“A green and blue tapestry  
and an active population”

**IDENTITY**  
“Making Singapore home”

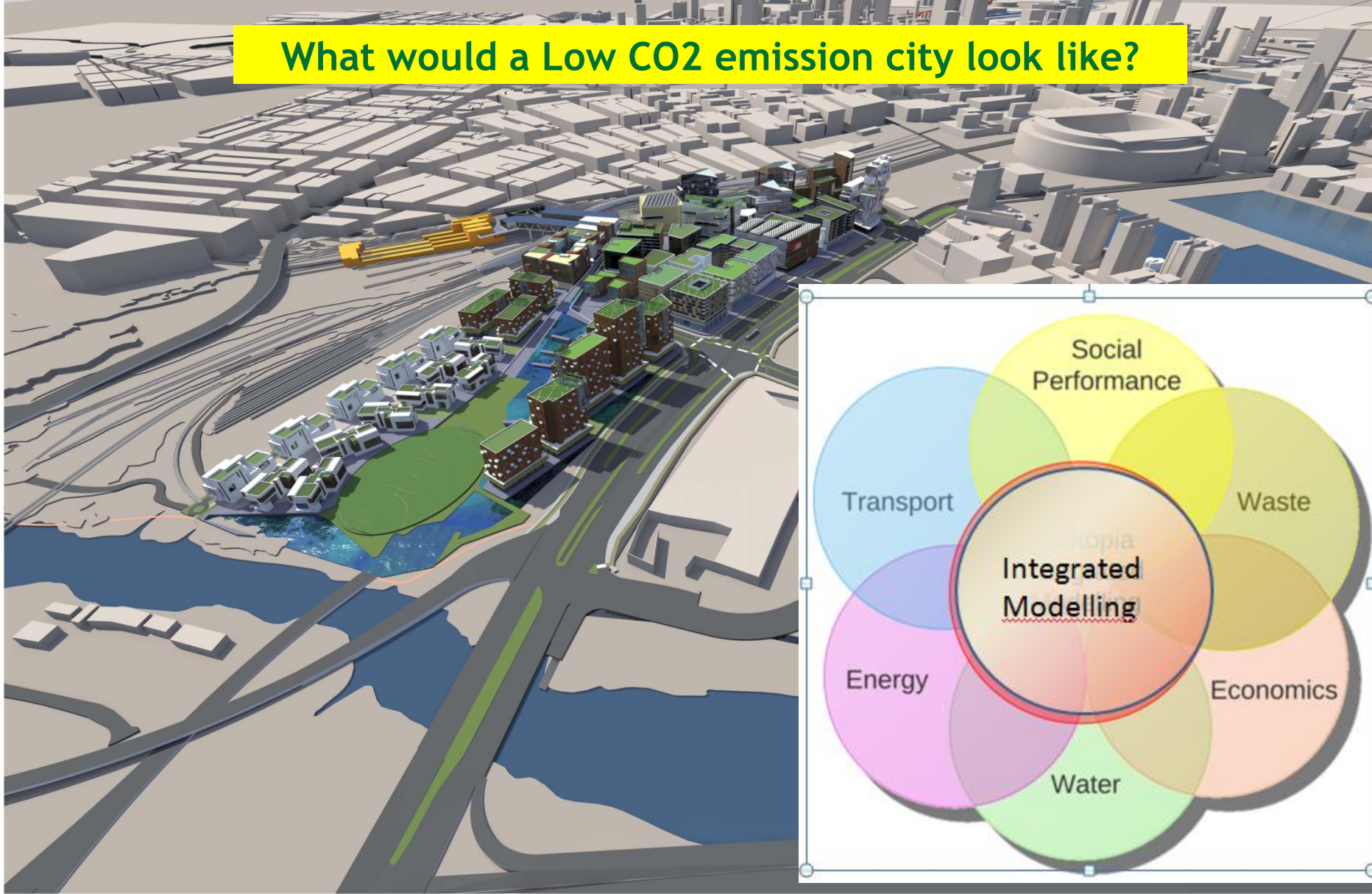
**TRANSPORT**  
“Enhanced connectivity,  
greater accessibility”

**PUBLIC SPACES**  
“Building communities”

“driven by the vision of an inclusive, highly liveable, economically vibrant and green home for all Singaporeans”



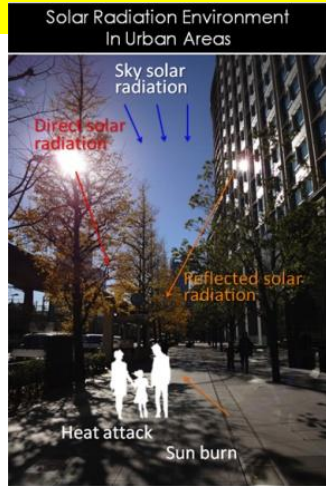
What would a Low CO2 emission city look like?



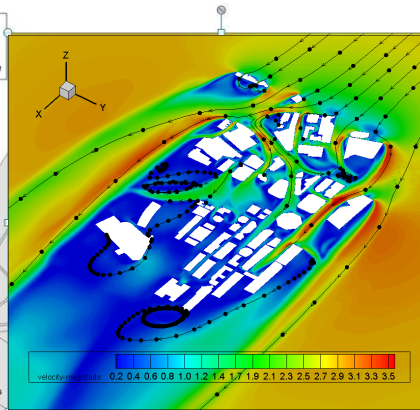
**Integrated Modelling Platform**



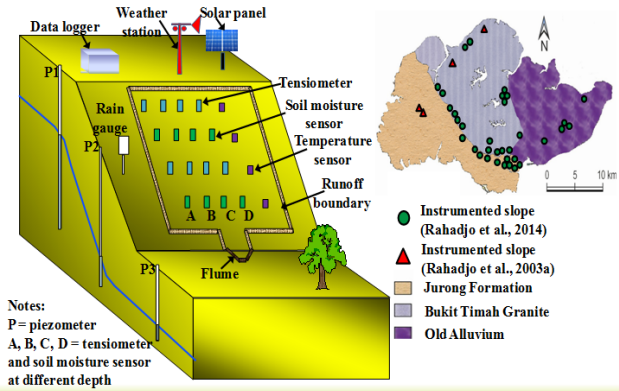
# Modeling & Simulation (M&S) for Adaptation Planning (Biodiversity)



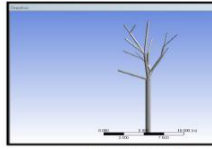
**Legend**  
● Root failure  
● Trunk failure



## Field Instrumentation for Assessment of the Effect of Climatic Conditions on Slope Stability in Singapore

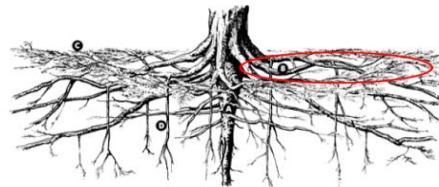


### Trees above ground



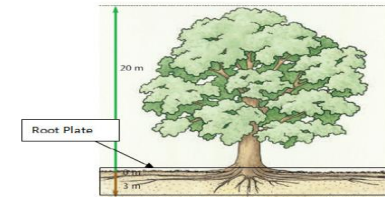
Siam Avenue engineering grade 1	
Height (m)	18.513
Canopy width (m)	6.200
Volume (m <sup>3</sup> )	5.316
Density (kg/m <sup>3</sup> )	900
Weight (kg)	4784.4
Centroid X (m)	-5.14152
Centroid Y (m)	-0.1765
Centroid Z (m)	8.1805
Depth of centroid (ft)	19.2
Stem bending moment (kNm)	8.6

### Trees below ground



Lateral Roots – Help support and anchor the tree, may extend far out beyond crown spread

### Uprooting modes– Flat Root



A flat root system is basically a "flattened" heart root (Dobson, 1995)

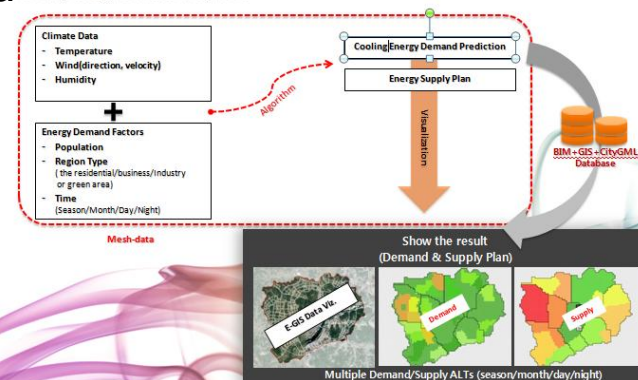
## Cooling Energy Demand

Cooling Energy Demand in city level



Precinct Area = 9 ha  
Plot Ratio = 10  
Max GFA = 630,000 m<sup>2</sup>

Site Area 9ha	
SS Floor Area	1,183,113 m <sup>2</sup>
Plot Area	630,000 m <sup>2</sup>
Plot Ratio	1.878
ST	50
SVF	0.562
ECG <sub>U</sub>	0.0435 Wh/m <sup>2</sup>
ECG	5,407.8 MWh/Yr
SG <sub>U</sub>	0.1219 Wh/m <sup>2</sup>
SG	15,141.8 MWh/Yr
FAIG <sub>U</sub>	0.1331 Wh/m <sup>2</sup>
FAIG	16,284.5 MWh/Yr
SCL <sub>U</sub>	1.430 Wh/m <sup>2</sup>
SCL	176,570.8 MWh/Yr
	280.71 KWh/m <sup>2</sup> /Yr





# An Assessment & Visualisation Tool

A 3D visualization of a city's carbon footprint. The city is represented by a grid of buildings of varying heights and colors. The colors range from green (low carbon footprint) to red (high carbon footprint). The buildings are arranged in a grid pattern, with some taller buildings in the center. The background is a light blue sky with a grid of streets. A black circle highlights a specific area of the city. A purple box with white text is overlaid on the image.

3D Carbon Accounting Tool

# (I) Environmental Information

## Study of climate change and climatic baselines on UHI/Thermal Comfort

- (a) Access to oceanic, atmospheric, and geophysical data archives, which includes the **archive of Global Synoptic Observation Data from 1901-Present** of synoptic (hourly, 3-hourly, and 6-hourly climate data) from across the globe as well as global precipitation analyses (monthly, pentad, and daily) from surface and satellite measurements for 1979 onwards. (NCEP/NCAR Reanalysis I: 1948-present (~200km); NCEP/DOE Reanalysis II: 1979-near present (~200km); NOAA-CIRES 20th Century Reanalysis version 2 (20CRv2): 1871-2012 (~200km); NCEP Climate Forecast System Reanalysis (CFSR) (~38km): 1979-present; Real-time NCEP Global Forecast System (GFS): 2015-present (~13km)
- (b) Use of the datasets for the study of climate change and climatic baselines on UHI and thermal comfort; Sharing of research and studies on heat stress index.
- (c) Customisation of the global/regional datasets and optimisation of integration of the downscaled global/regional climate data for the study of climate change and climatic baselines on UHI and thermal comfort for ANY typical city planning and design;
- (d) Optimisation of GSM/RSM/MSM/Urban Model for urban planning and design.

## (II) Modeling for Urban Environment

- NOAH (NOAH land surface model)
  - ✓ Developed in **N**CEP, **O**SU, **A**ir force, **H**ydrologic Research Lab
  - ✓ NOA1: maximum one-vegetation type considered in each cell
  
- Coupling of Land Surface Model to Urban Canopy Model – NCEP RSM/MSM  
The effects of land use type and anthropogenic heat (AH) and its diurnal variation on the thermal and wind environment such as coupling the Noah Land Surface Model (*Chen and Dudhia, 2001*) to the *Single-Layer Urban Canopy Model* (*Kusaka et al., 2001; Kusaka and Kimura, 2004*) using a *tile-approach* (*Tewari et al., 2006*).



# (III) Use of Environmental Information for *Integrated* Planning & Design of Sustainable Cities

- (a) Integration of Built and Natural Environment Datasets, incorporating environmental datasets, sensing and simulation such as urban materials; greenery types; scenario modelling (environment and climate) at various scales (island, precinct and building scales); 3D wind, temperature, thermal comfort;*
- (b) Analytical and 3D visualisation tools and services to support planners and managers in understanding the complex nature of urban development;*
- (c) Intelligent Disaster Decision Support System (IDDSS) for urban planning, integrating a smart geospatial information platform with an advanced optimisation and simulation engine to facilitate discovery and then integrate and analyse the data to develop simulation and optimisation models;

**THANK YOU**