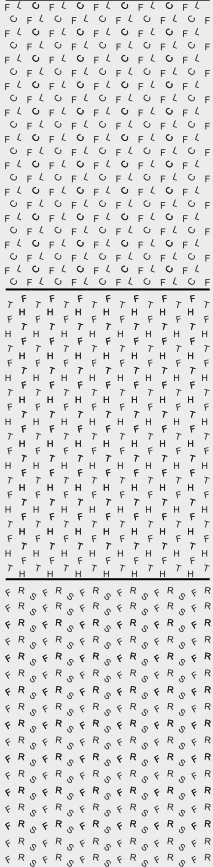# Supercomputing for Climate-informed Urban Planning

21 October 2021

Dr Heiko AYDT
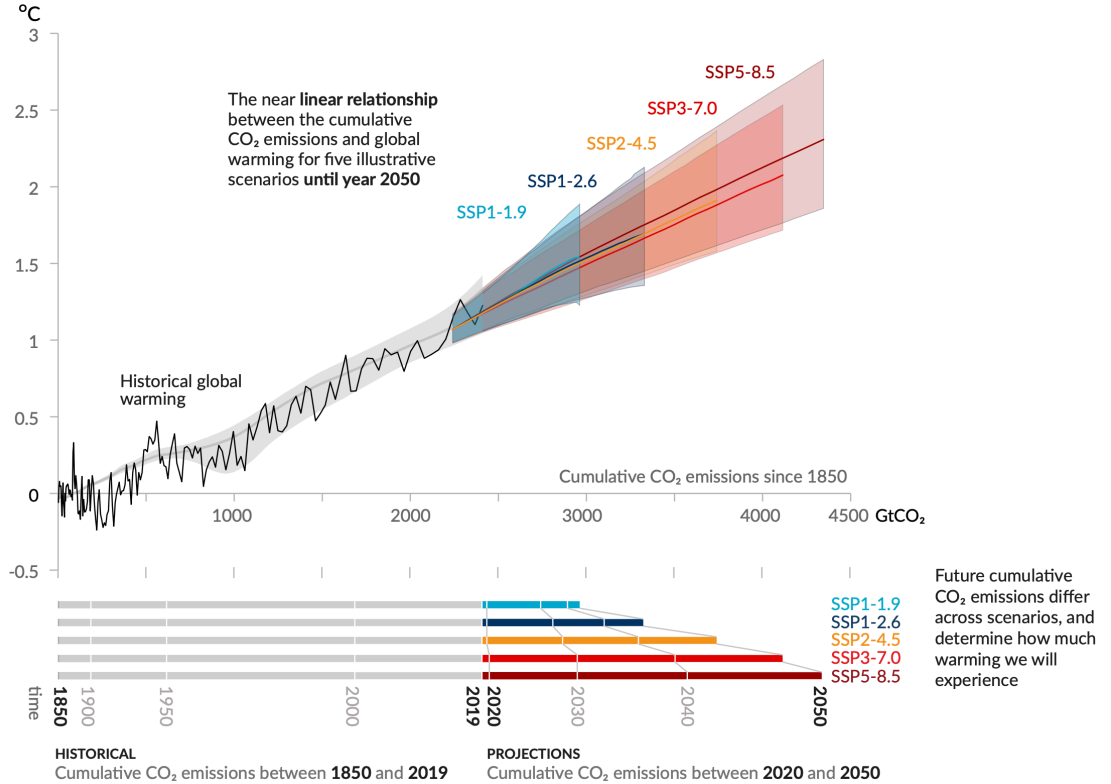Lead Investigator for Digital Urban Climate Twin R&D
Singapore-ETH Centre (SEC)

CREATE   (SEC) SINGAPORE-ETH CENTRE   CAMBRIDGE CARES   NUS National University of Singapore   SMU SINGAPORE MANAGEMENT UNIVERSITY   SMART Singapore-MIT Alliance for Research and Technology   TUMCREATE   COOLING SINGAPORE

Urban Heat Challenge

Global climate change is causing temperatures to increase…

Image: IPCC, 2021: Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. In Press.
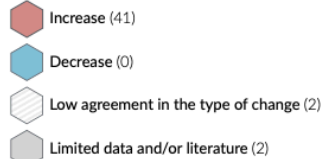
COOLING SINGAPORE

URBAN HEAT CHALLENGE | Global Climate Change

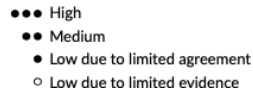Singapore – just like any other city – is subject to the regional effects of global climate change.

In South-East Asia we can observe more extreme weather events:
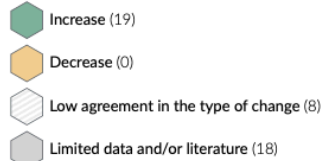
- Heat waves

- Heavy rainfall

a) Synthesis of assessment of observed change in **hot extremes** and confidence in human contribution to the observed changes in the world's regions
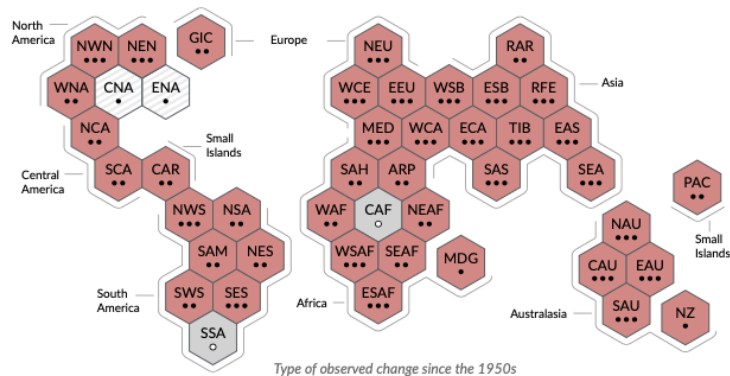
b) Synthesis of assessment of observed change in **heavy precipitation** and confidence in human contribution to the observed changes in the world's regions

COOLING SINGAPORE

PASSIVE CONTRIBUTORS

Heat that is trapped in the city (e.g., thermal storage of built environment, lack of vegetation and natural ventilation).

ACTIVE CONTRIBUTORS

Heat emissions inside the city (e.g., industry, building air conditioning, transport).

CONTRIBUTORS TO THE URBAN HEAT ISLAND (UHI) EFFECT

THERMAL STORAGE

POWER PLANT

RADIATION

URBAN CANYON

PEOPLE

INDUSTRY

LACK OF VEGETATION

TRANSPORT & TRAFFIC

AIR CONDITIONING

5

COOLING SINGAPORE
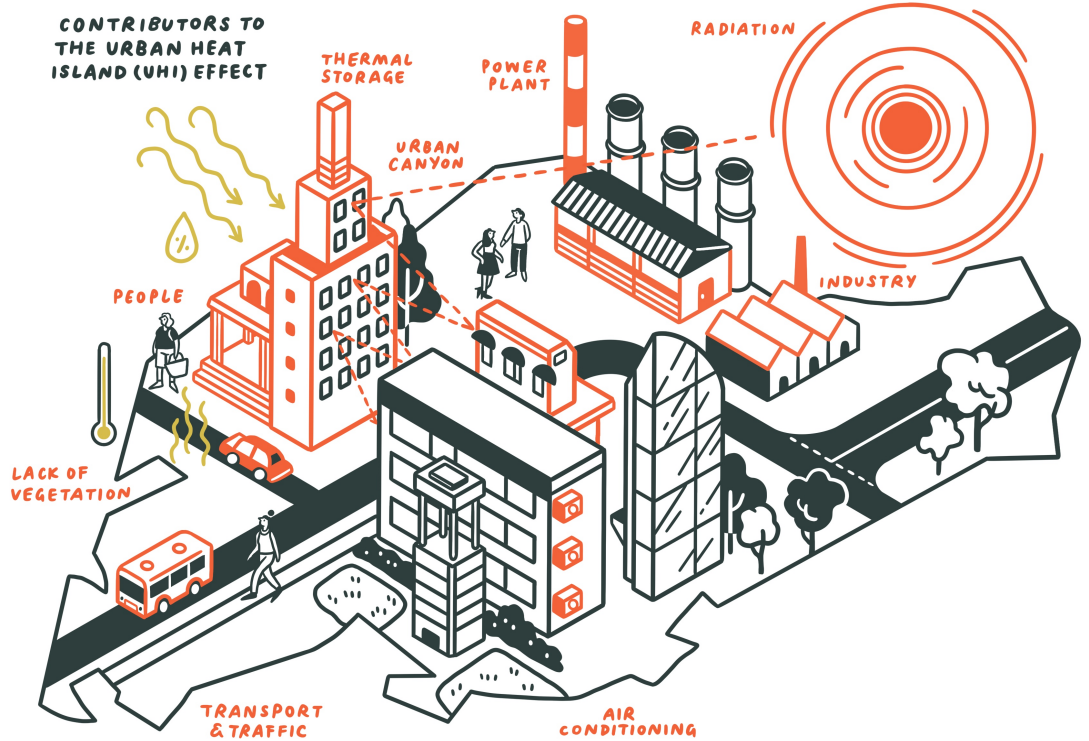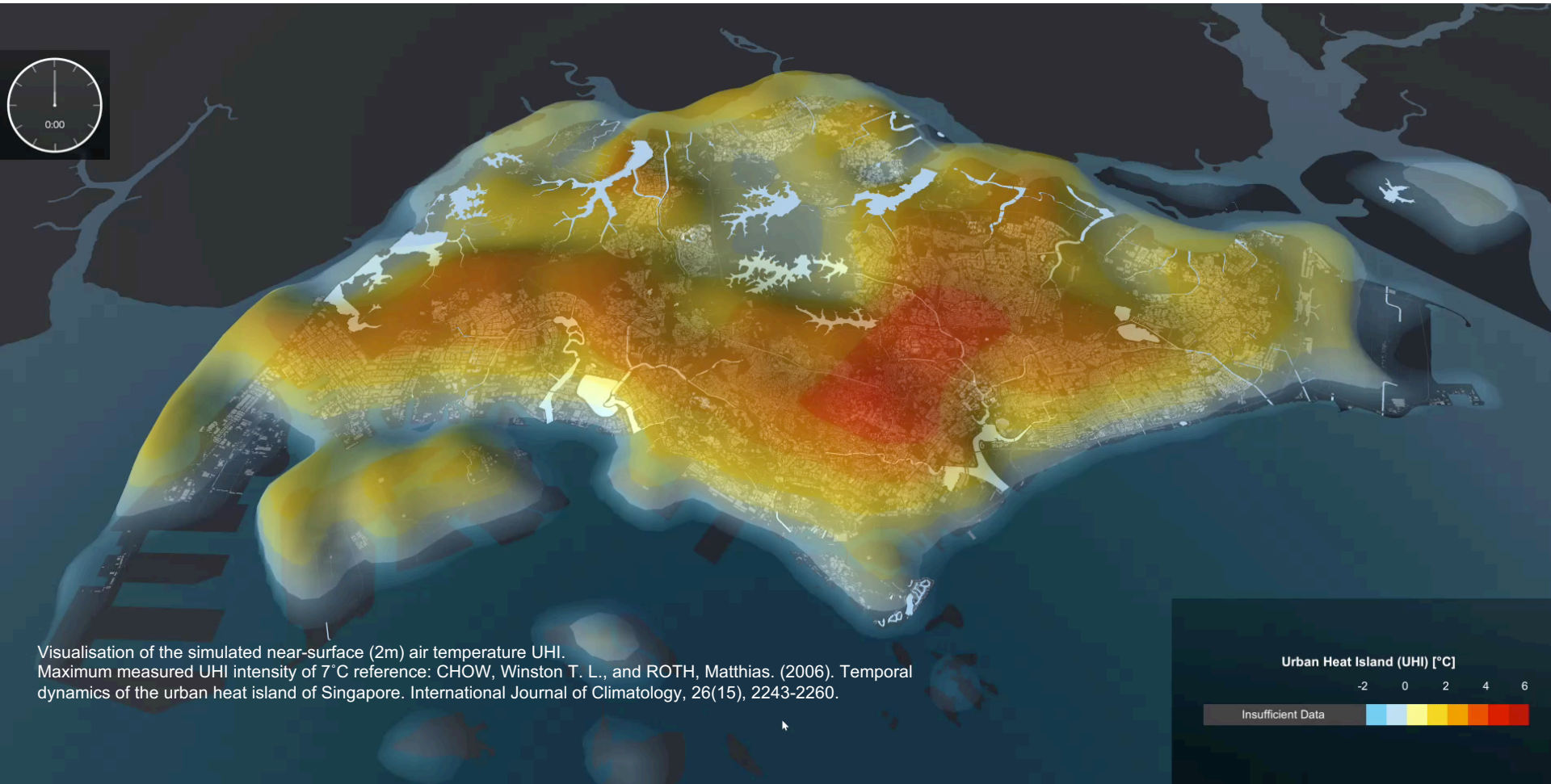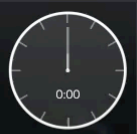
Visualisation of the simulated near-surface (2m) air temperature UHI.
Maximum measured UHI intensity of 7°C reference: CHOW, Winston T. L., and ROTH, Matthias. (2006). Temporal dynamics of the urban heat island of Singapore. International Journal of Climatology, 26(15), 2243-2260.

Urban Heat Island (UHI) [°C]

-2   0   2   4   6

Insufficient Data

Digital Urban Climate Twin

COOLING
SINGAPORE
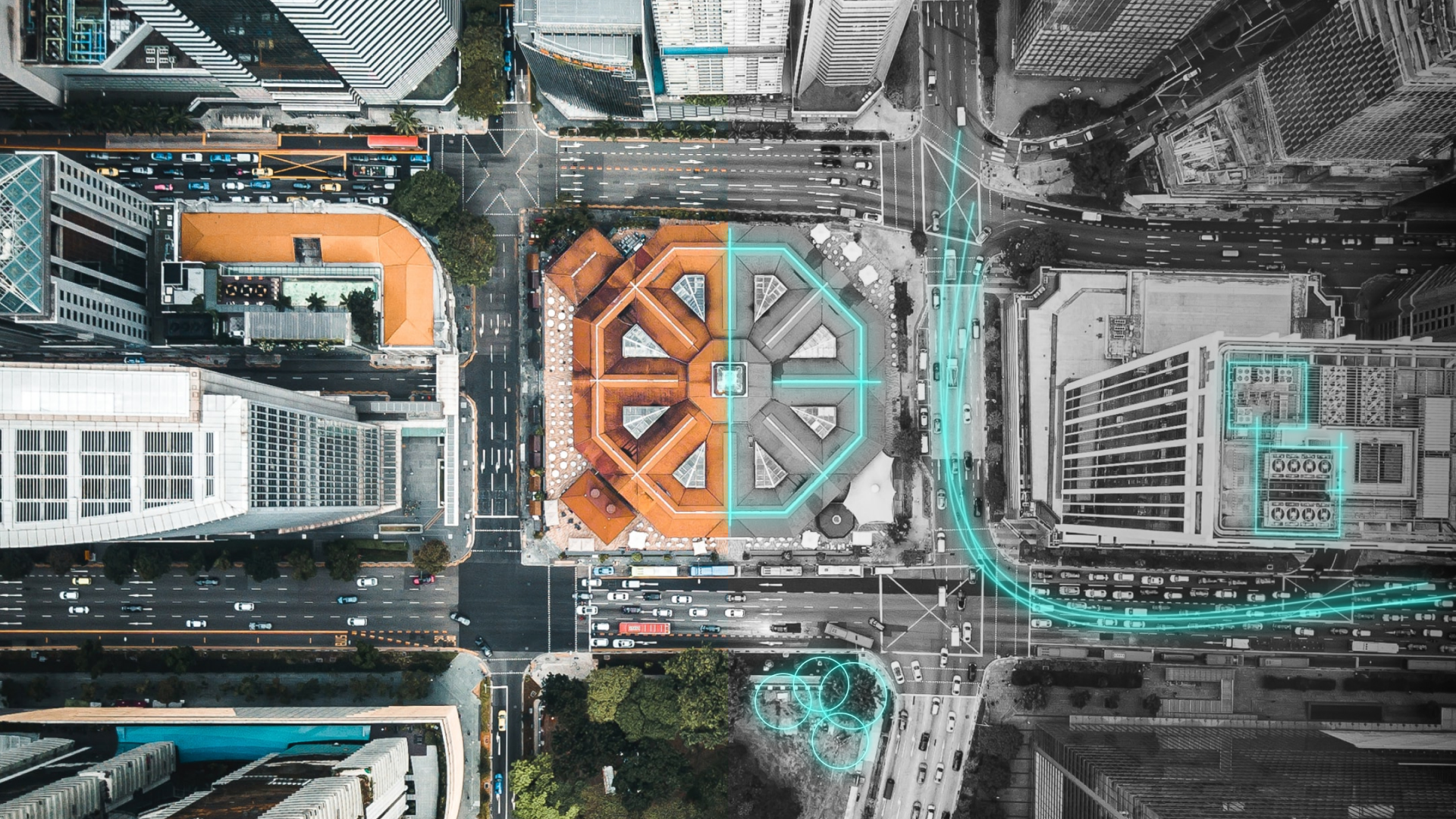
DIGITAL URBAN TWIN

A composition of specialised computational models, each representing an urban element of interest (e.g., buildings, traffic, air conditioning, microclimate).

Not only geometry and textures for the purpose of visualisation – but also dynamic behaviour for the purpose of simulating cause and effect.

Can be used to conduct what-if analyses and perform experiments with a city *in-silico* that would otherwise not be possible in the real world.
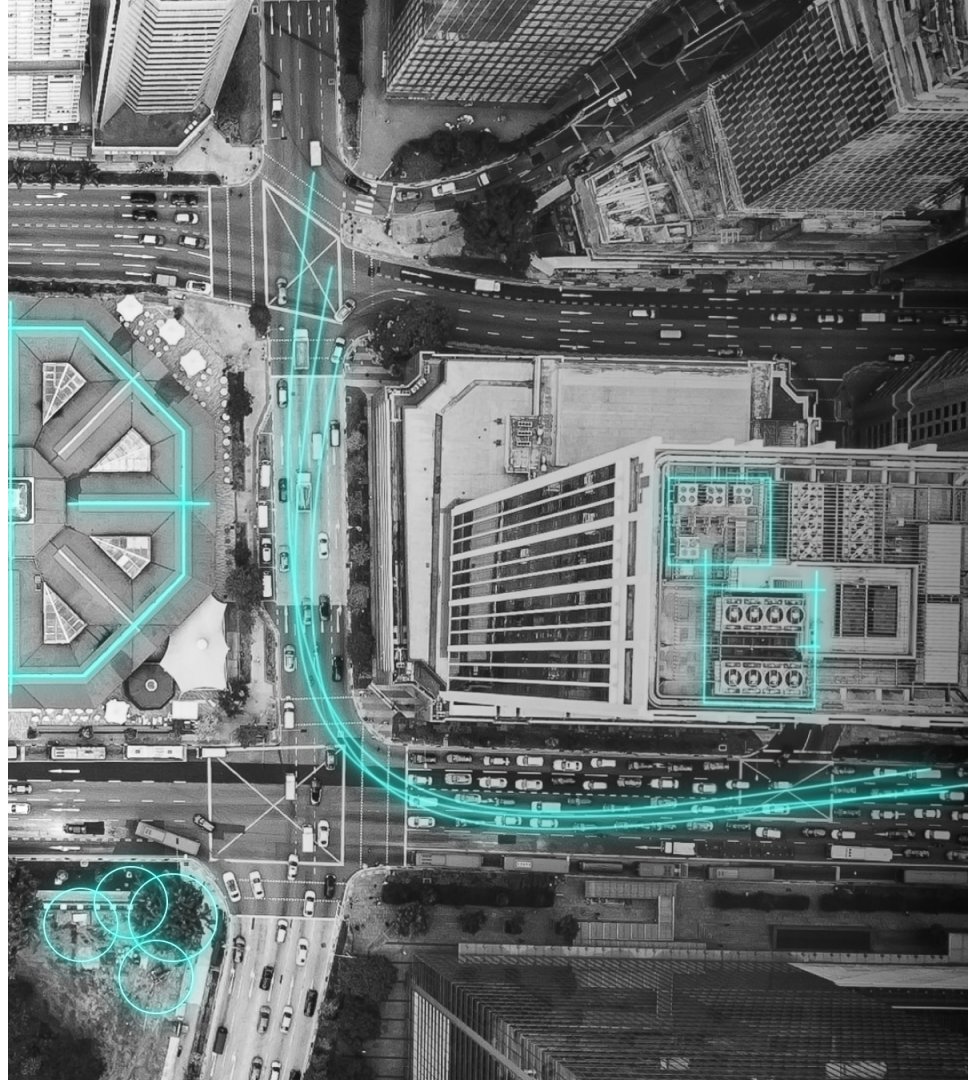
DIGITAL URBAN CLIMATE TWIN

A Digital Urban Twin specifically built to study the **urban climate** for a particular city of interest.

The insights gained from experimentation, and what-if analysis in particular, can be used to support research as well as **urban planning and climate-informed policy**.

DIGITAL URBAN CLIMATE TWIN

SIMULATE 'WHAT IF' SCENARIOS

Source: H. Aydt (2020). Cooling Singapore – Towards Urban Climate Design and Management in Indicia 03, editors: S. Cairns and D. Tunas (forthcoming)
Image: Idea Ink (2020)

10

COOLING
SINGAPORE
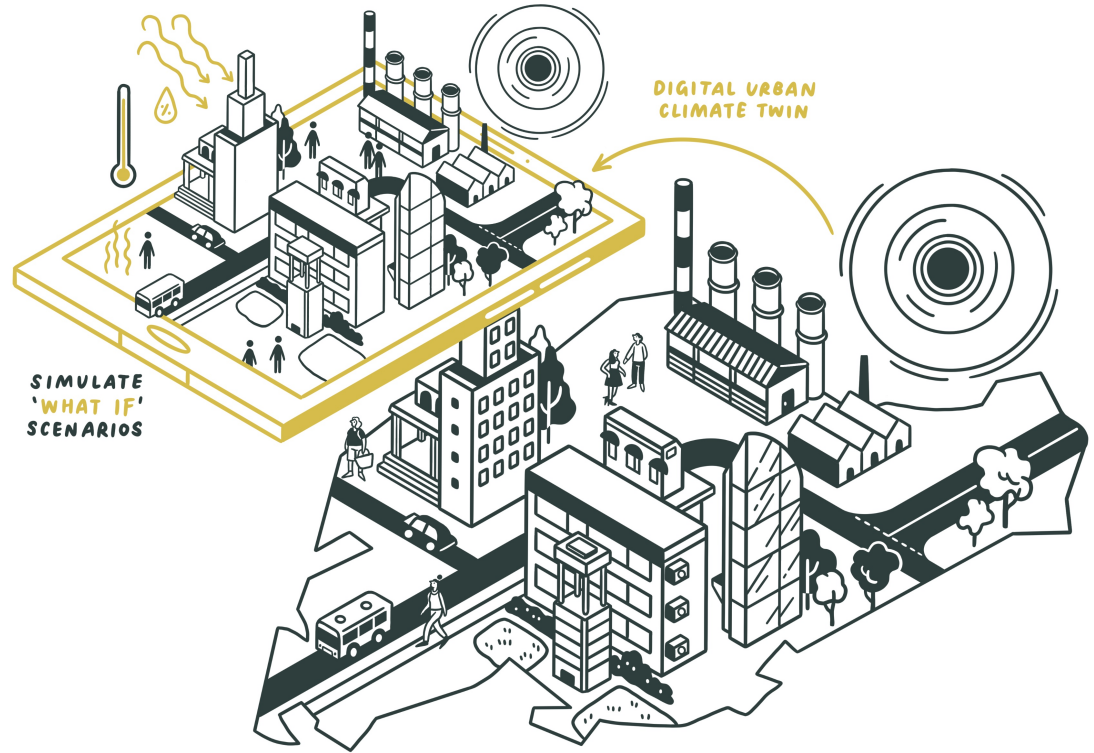
The Need for Supercomputing

COOLING
SINGAPORE

Planners and decision makers need to understand the potential impact of their decisions before they are implemented.

The Digital Urban Climate Twin is a tool that makes this possible. Users can experiment with what-if scenarios.

1 TRANSLATE SCENARIOS

2 SIMULATE

ITERATIVE DESIGN-SIMULATION LOOP

3 ANALYSE & MODIFY

4 REPEAT SIMULATION PROCESS

5 IMPLEMENT

COOLING SINGAPORE
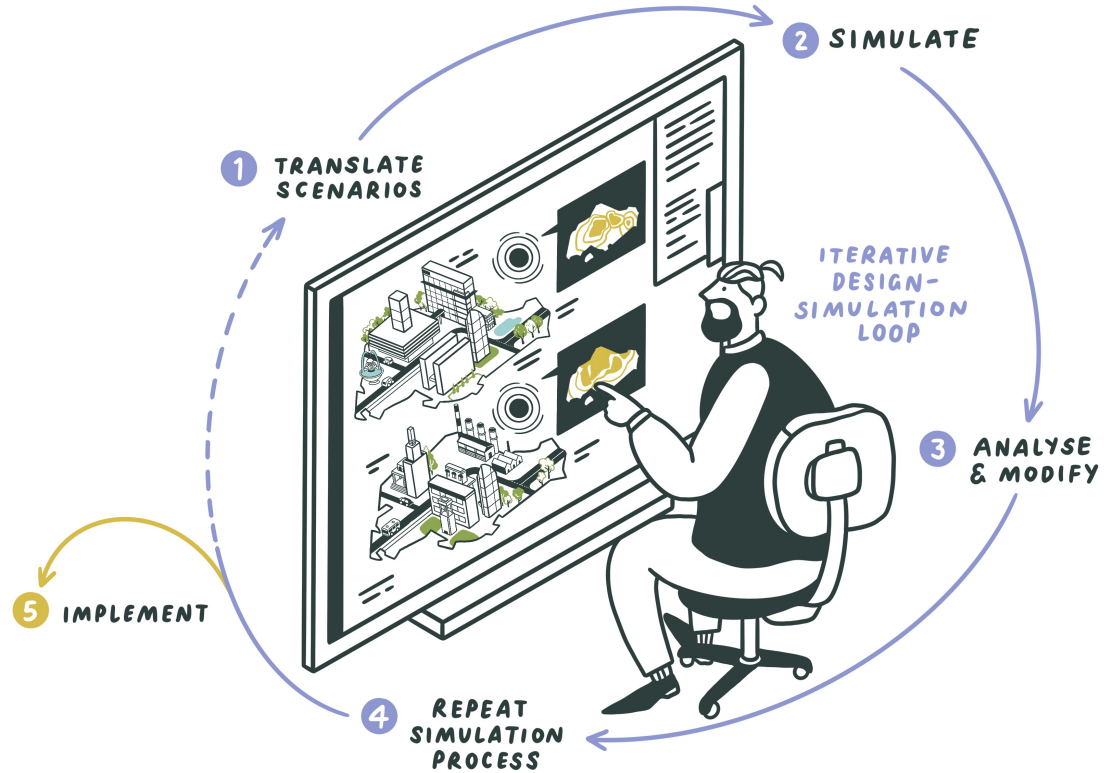
In general, the DUCT consists primarily of two types of model components:

- **Urban Climate Models**

- **Anthropogenic Heat Emission Models**

A single what-if scenario involves a number of models. **Which configuration of models to use depends on the scenario**.

Depending on the scenario, you may have to conduct not one, but **many simulation runs – each using a different set of parameters**.

Input: What-if scenario parameters

Processing / Simulation: Federation of Models

Output: Climatic Data

Land-use Data → Land-use Model → Local Climate Zone (LCZ) Map

Meteorological Data*

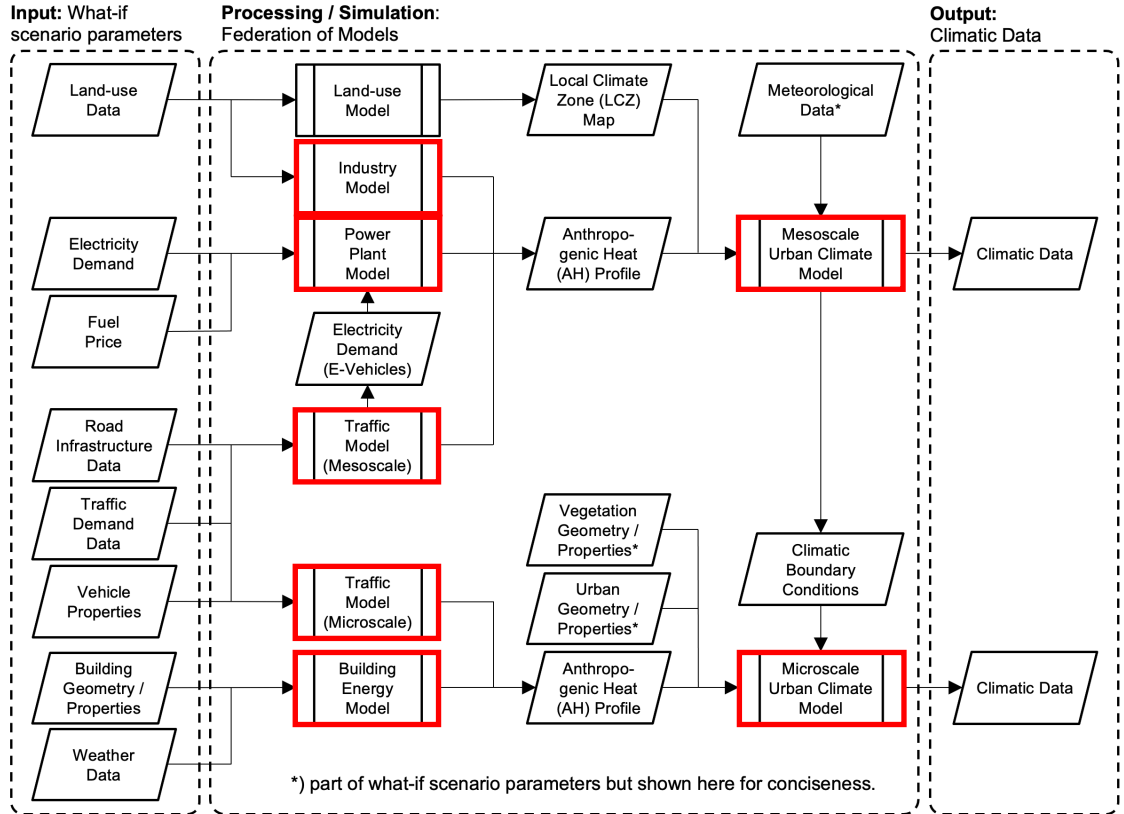Electricity Demand, Fuel Price → Industry Model, Power Plant Model → Anthropo-genic Heat (AH) Profile → Mesoscale Urban Climate Model → Climatic Data

Electricity Demand (E-Vehicles)

Road Infrastructure Data, Traffic Demand Data → Traffic Model (Mesoscale)

Vehicle Properties → Traffic Model (Microscale)

Vegetation Geometry / Properties*

Urban Geometry / Properties*

Climatic Boundary Conditions

Building Geometry / Properties, Weather Data → Building Energy Model → Anthropo-genic Heat (AH) Profile → Microscale Urban Climate Model → Climatic Data

*) part of what-if scenario parameters but shown here for conciseness.
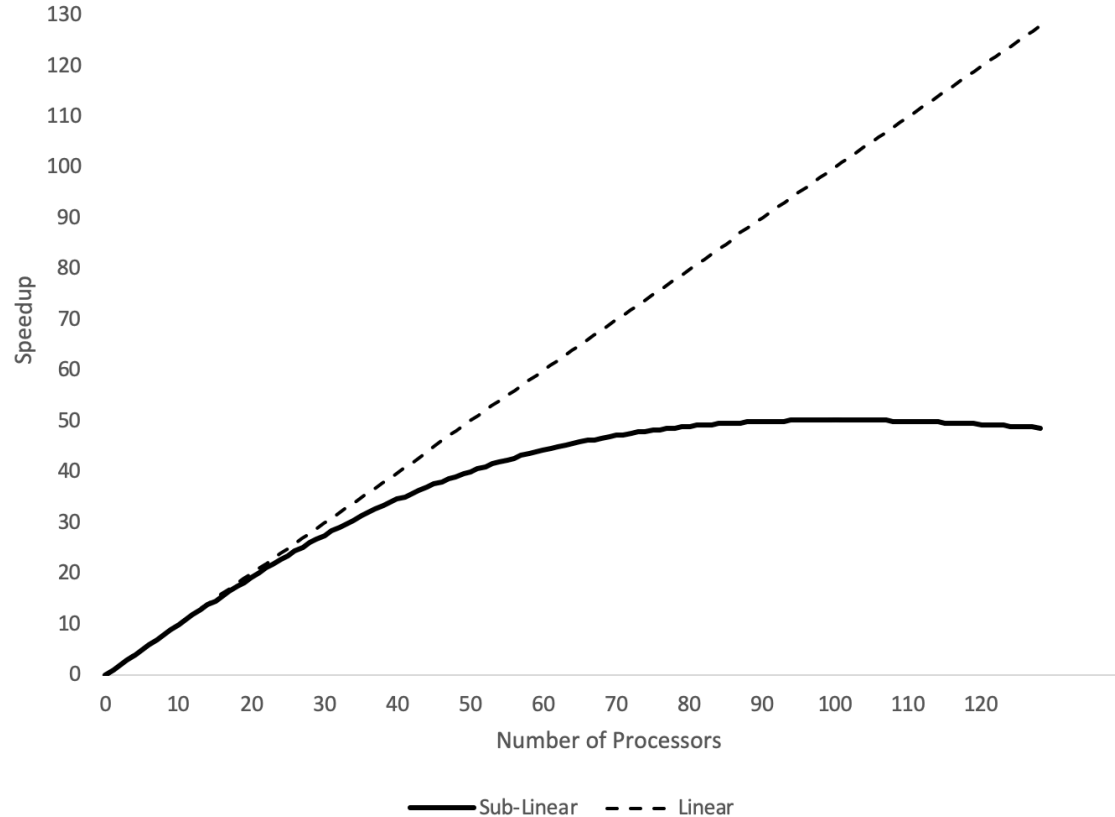
COOLING SINGAPORE

The Bad

The speed up we can achieve for a single simulation run is limited.

The Ugly

Marginal increase in performance, not only wastes a lot of computing resources but also energy!

The Good

Different what-if scenarios are independent from each other and can run concurrently.
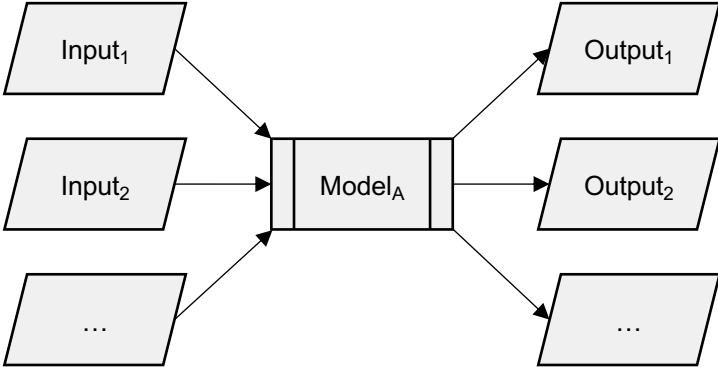
COOLING SINGAPORE

Bridging the Gap

**COOLING
SINGAPORE**

SAAS APPROACH

Make running simulations as easy as interacting with web services: user provides the input, trigger simulations and collect the output when the job is done.

SAAS MIDDLEWARE

Building a Digital Urban Twin requires 'putting together' a variety of computational models. This requires a middleware:

Middleware

Middleware is computer software that provides services to software applications beyond those available from the operating system. It can be described as "software glue". Middleware makes it easier for software developers to implement communication and input/output, so they can focus on the specific purpose of their application. **Wikipedia**

COOLING
SINGAPORE

WORKFLOWS

Working with a Digital Urban Twin (e.g., what-if analysis) requires running multiple models as part of (potentially) complex workflows.
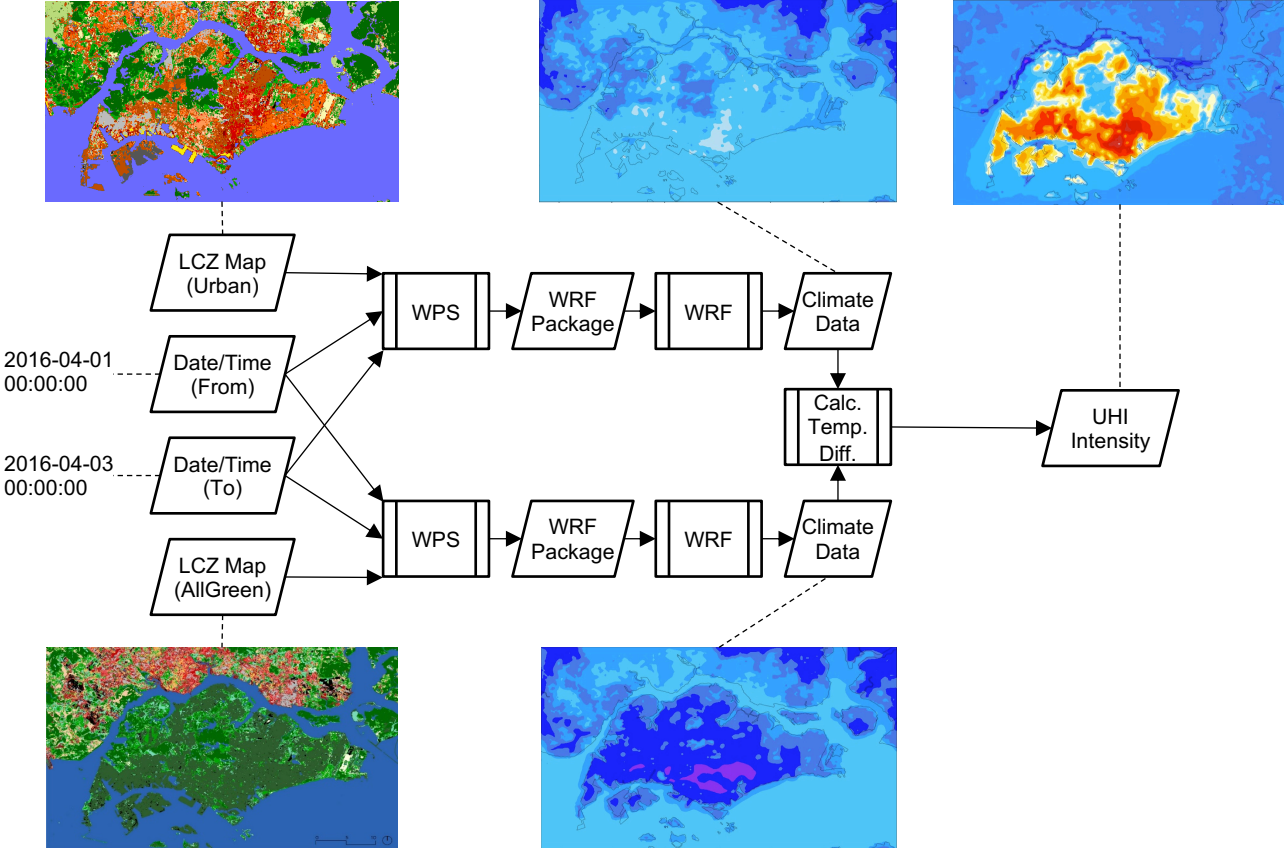
Take care of the technical complexities of 'putting things together' so **users can focus on the what-if analysis rather than the how-to-get-stuff-to-work part**.

**COOLING
SINGAPORE**

BRIDGING THE GAP | DUCT Applications
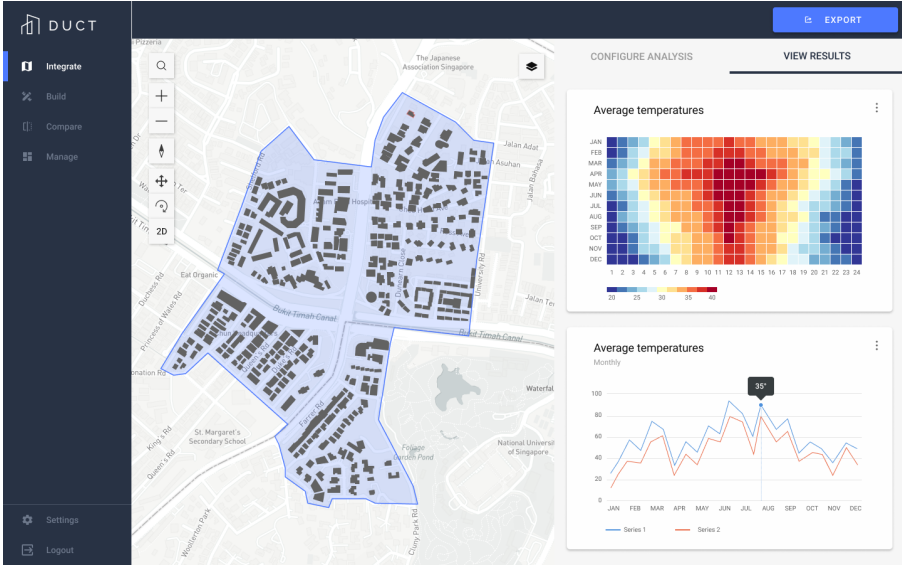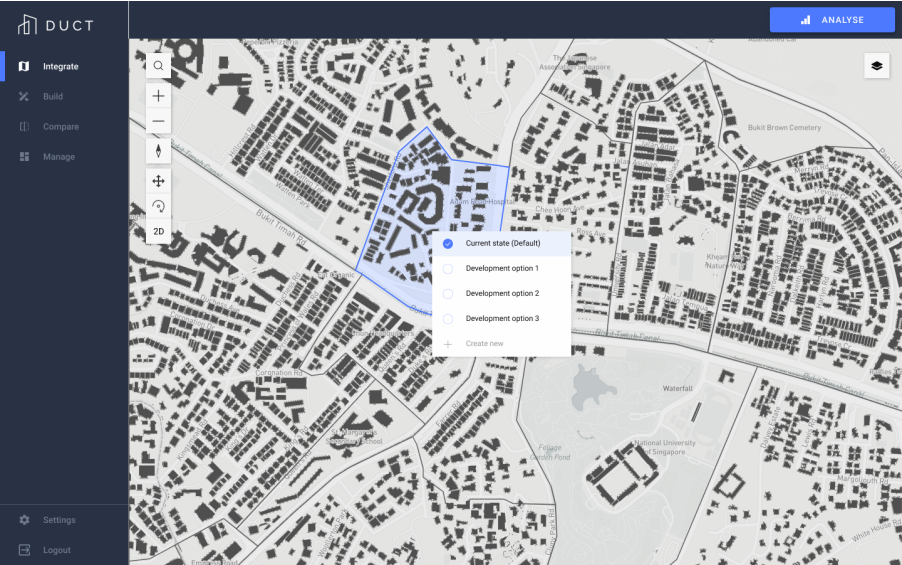
DUCT Applications will be tailored to the needs of end users. These include urban planners, designers and decision makers at Singapore's government agencies. It also includes researchers in Cooling Singapore and beyond.

COOLING
SINGAPORE

BRIDGING THE GAP | From supercomputing to policy

POLICY

Masterplans/Roadmaps

EXPLORATION

What-if Scenarios

APPLICATION

DUCT Applications

COMPUTATION

DUCT Federation of Models

INFRASTRUCTURE

SaaS Middleware

Cloud (e.g., Google, Amazon, …)

Intranet (e.g., SEC, URA, …)

Supercomputer (e.g., NSCC, CSCS)

1 TRANSLATE SCENARIOS
2 SIMULATE
3 ANALYSE & MODIFY
4 REPEAT SIMULATION PROCESS
5 IMPLEMENT

ITERATIVE DESIGN-SIMULATION LOOP

Urban Master Plan
Land-use Model
Local Climate Zone (LCZ) Map
Meteorological Data*

Industry Model

Electricity Demand
Power Plant Model
Anthropo-genic Heat (AH) Profile
Mesoscale Urban Climate Model
Climatic Data (Mesoscale)

Fuel Price

Electricity Demand (E-Vehicles)

Road Infrastructure Data
Traffic Model (Mesoscale)

Traffic Demand Data

Vegetation Geometry / Properties*
Climatic Boundary Conditions

Vehicle Properties
Traffic Model (Microscale)
Urban Geometry / Properties*

Building Geometry / Properties
Building Energy Model
Anthropo-genic Heat (AH) Profile
Microscale Urban Climate Model
Climatic Data (Microscale)

Weather Data

*) part of what-if scenario parameters but shown here for conciseness.

COOLING SINGAPORE

BRIDGING THE GAP | From supercomputing to policy

POLICY

Masterplans/Roadmaps
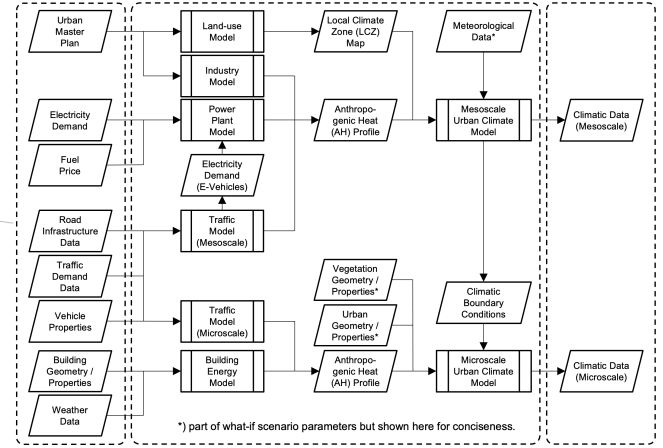
EXPLORATION

What-if Scenarios

APPLICATION

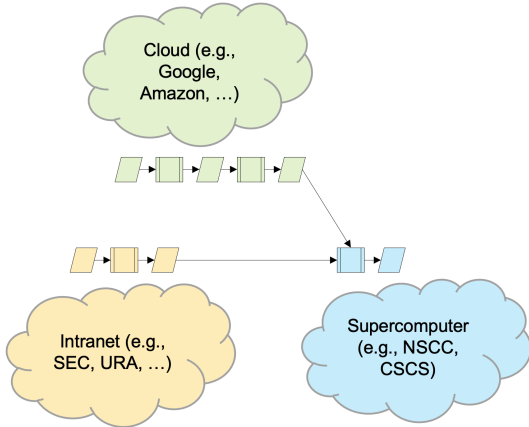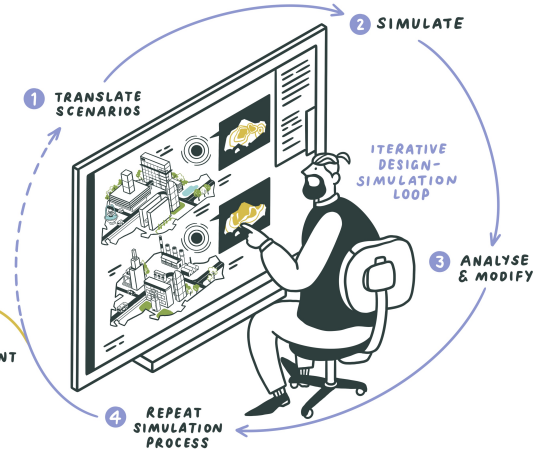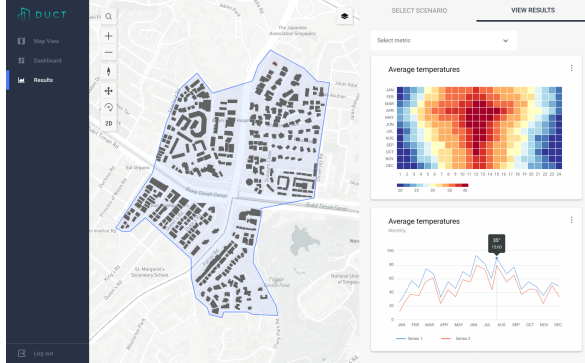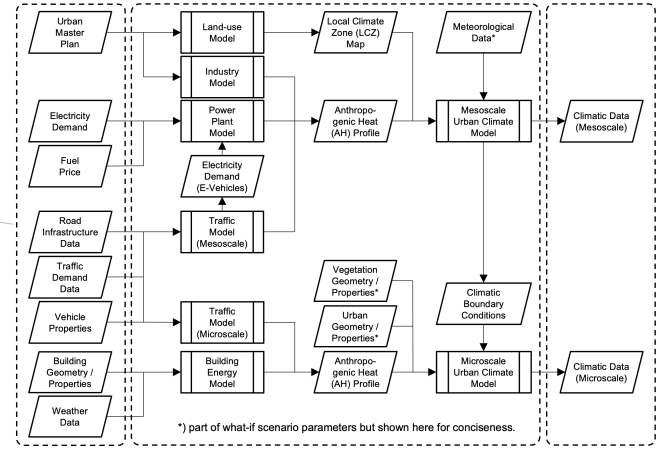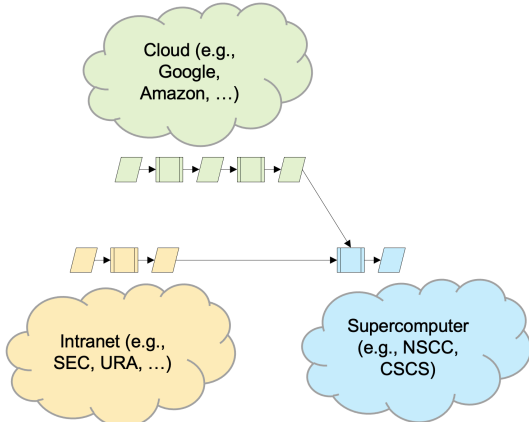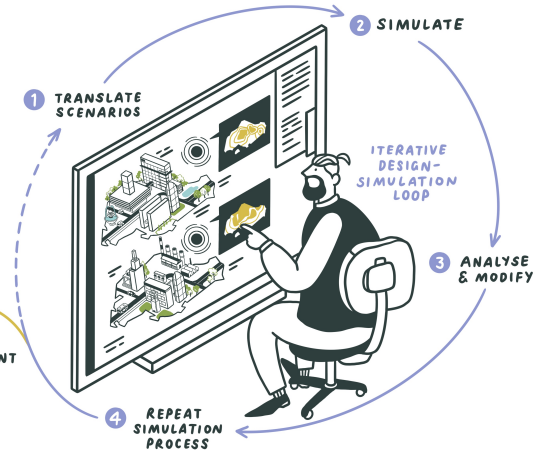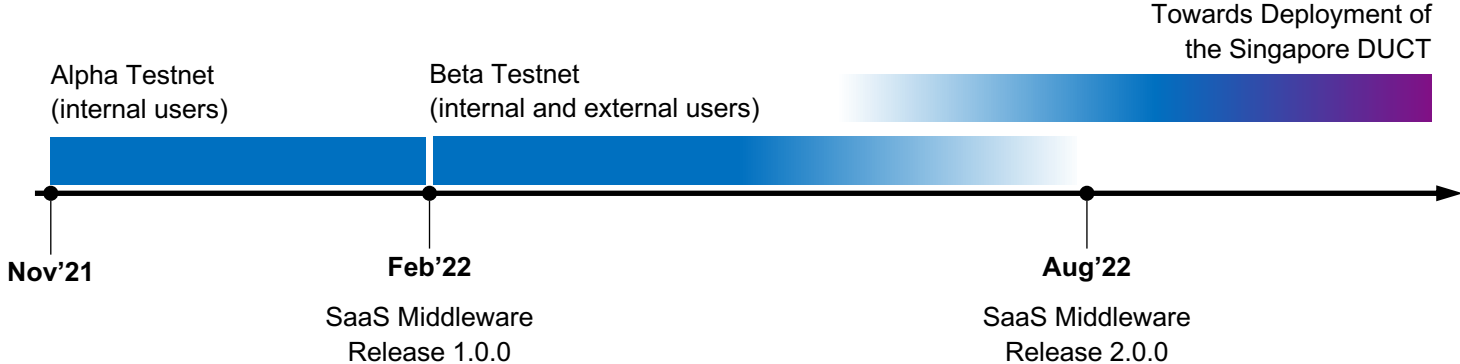DUCT Applications

COMPUTATION

DUCT Federation of Models

INFRASTRUCTURE

SaaS Middleware

Cloud (e.g., Google, Amazon, …)

Intranet (e.g., SEC, URA, …)

Supercomputer (e.g., NSCC, CSCS)

1 TRANSLATE SCENARIOS
2 SIMULATE
ITERATIVE DESIGN-SIMULATION LOOP
3 ANALYSE & MODIFY
4 REPEAT SIMULATION PROCESS
5 IMPLEMENT

Urban Master Plan

Land-use Model

Local Climate Zone (LCZ) Map

Meteorological Data*

Industry Model

Electricity Demand

Power Plant Model

Anthropo-genic Heat (AH) Profile

Mesoscale Urban Climate Model

Climatic Data (Mesoscale)

Fuel Price

Electricity Demand (E-Vehicles)

Road Infrastructure Data

Traffic Model (Mesoscale)

Traffic Demand Data

Vegetation Geometry / Properties*

Climatic Boundary Conditions

Vehicle Properties

Traffic Model (Microscale)

Urban Geometry / Properties*

Building Geometry / Properties

Building Energy Model

Anthropo-genic Heat (AH) Profile

Microscale Urban Climate Model

Climatic Data (Microscale)

Weather Data

*) part of what-if scenario parameters but shown here for conciseness.

21

COOLING SINGAPORE

Future Work

COOLING
SINGAPORE

Roadmap

Alpha Testnet
(internal users)

Beta Testnet
(internal and external users)

Towards Deployment of
the Singapore DUCT

Nov'21

Feb'22

SaaS Middleware
Release 1.0.0

Aug'22

SaaS Middleware
Release 2.0.0

Website

RUNNER

Run models, monitor simulation progress and preview the results as they become available at real-time.

BUILDER

Build and customise your own urban scenarios to investigate impacts on the future urban climate.

COOLING
SINGAPORE

FUTURE WORK | UHI is a problem for many cities around the world

Summer Daytime
Urban-Rural Surface
Temperature Difference

Legend:
-2.0°C
-1.5°C
-1.0°C
-0.5°C
0.0°C
0.5°C
1.0°C
1.5°C
2.0°C
2.5°C

COOLING
SINGAPORE

coolingsingapore.sg