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Improving urban climate adaptation modeling in the Community Earth System Model (CESM) through transient urban surface albedo representation

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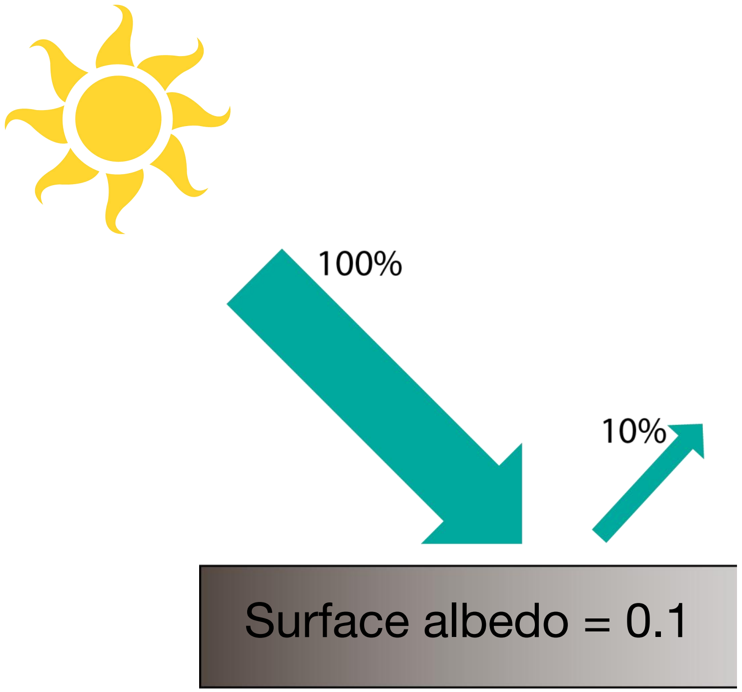
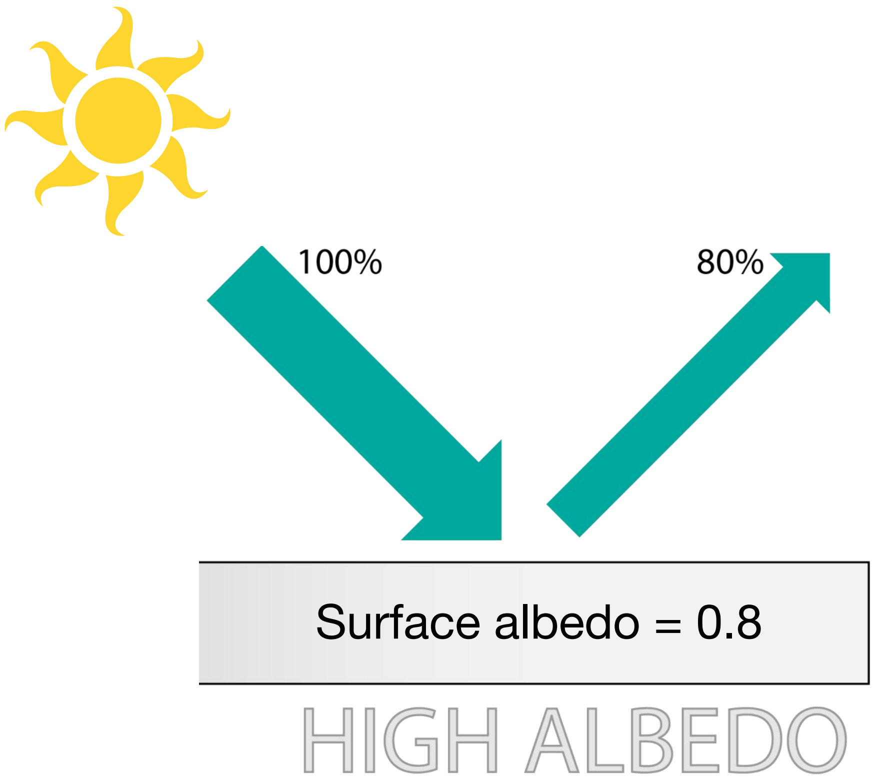
Albedo



Albedo describes the **reflection** ability of **solar radiation** on a surface.

High albedo



Higher albedo reflects more solar radiation and **cools** the surface.

Why urban high albedo?


MATERIALS

Ultra-white ceramic cools buildings with record-high 99.6% reflectivity

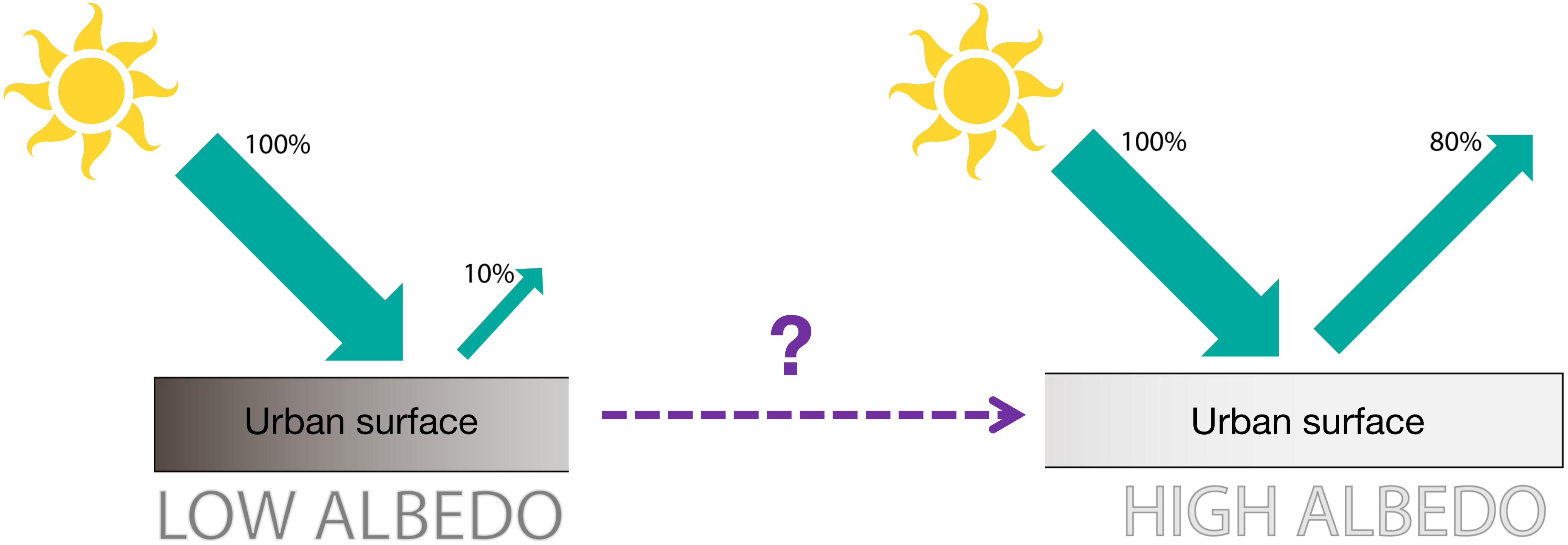
By Michael Irving
November 12, 2023

VIEW 2 IMAGES

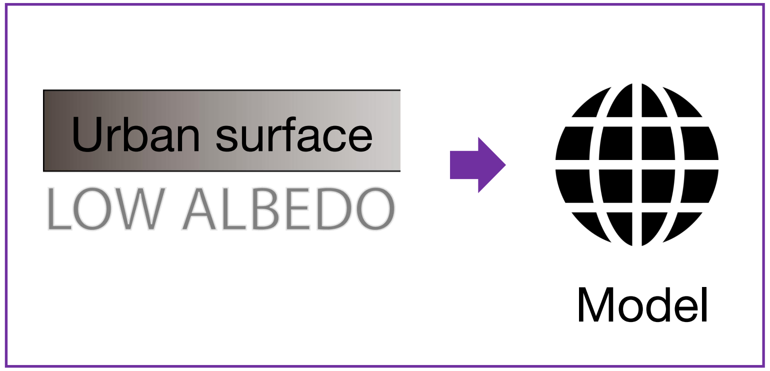
https://newatlas.com/materials/ultra-white-ceramic-cools-buildings-record-high-reflectivity/

White roof in New York City. https://www.c40.org/

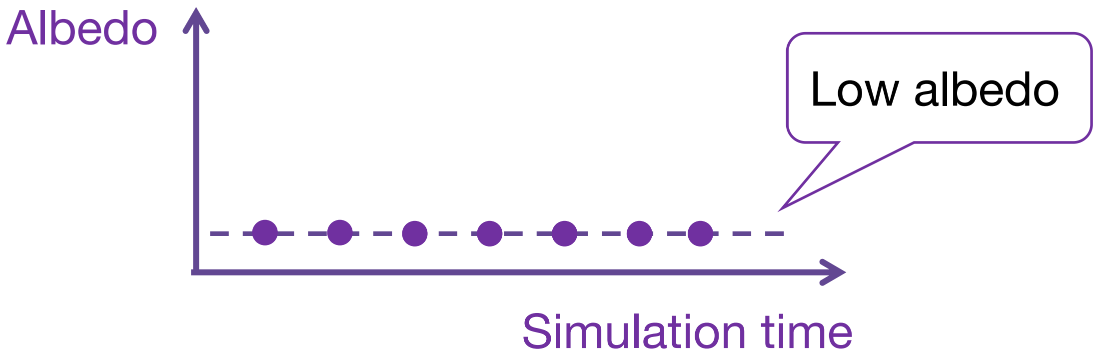
How to quantify albedo-induced cooling effects?



Current models statically prescribed urban surface albedo.



A control simulation with a low/default albedo (static)



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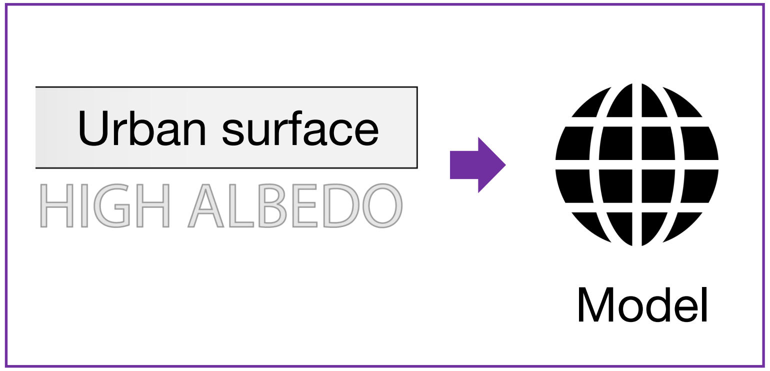
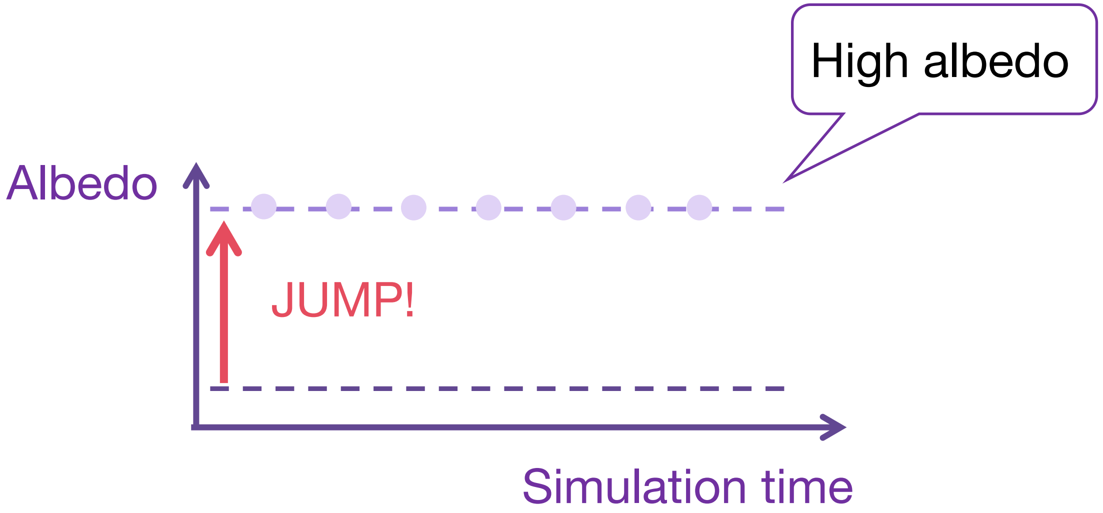


An experimental simulation with a high albedo (static)



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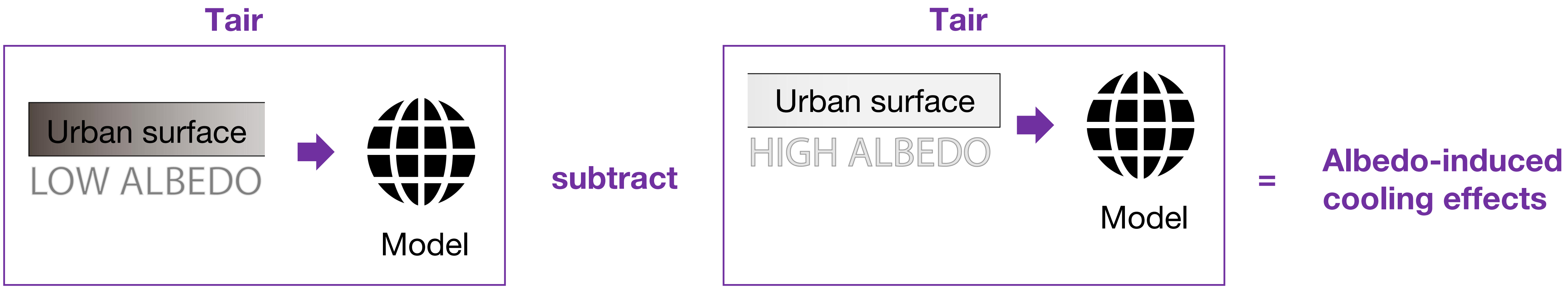
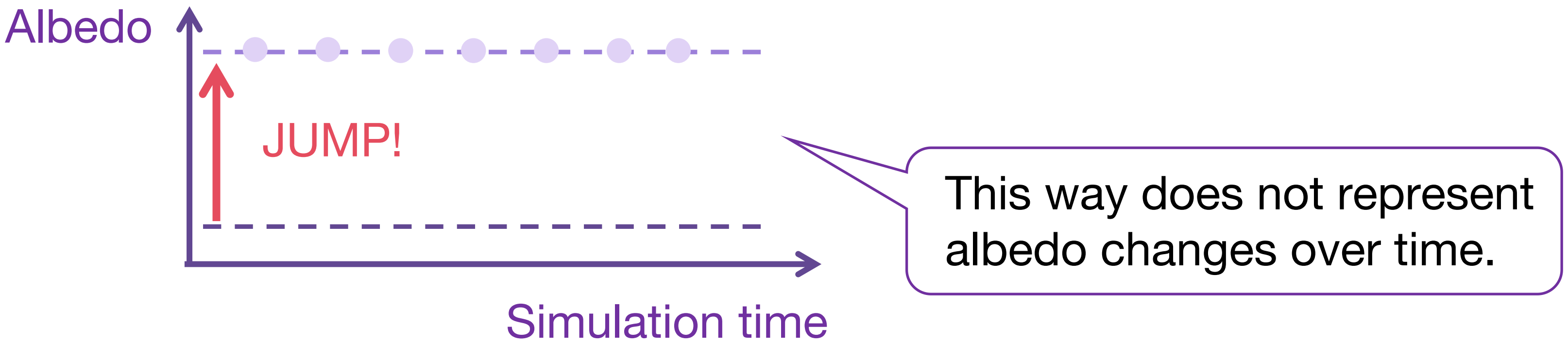


A control simulation with a low albedo

An experimental simulation with a high albedo



Conversation for the feasibility of urban high albedo

Urban high albedo could mitigate urban heat by **X.X ° C for XX (locations)**.

Scientist, modeling community

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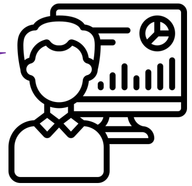

Scientist, modeling community

Thanks. I know the cooling effects now.
BUT HOW?

A broader community (e.g., architects, policy-makers)

- How much reflective material should be used in a **year/decade**?
- Where to install (e.g, roof, wall, pavement)?
- What is the priority (e.g., high density, low income) in my case study area?

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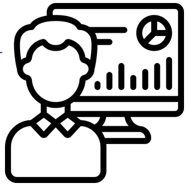

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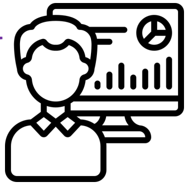

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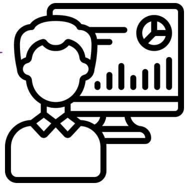

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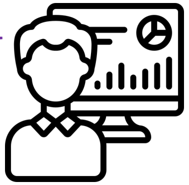
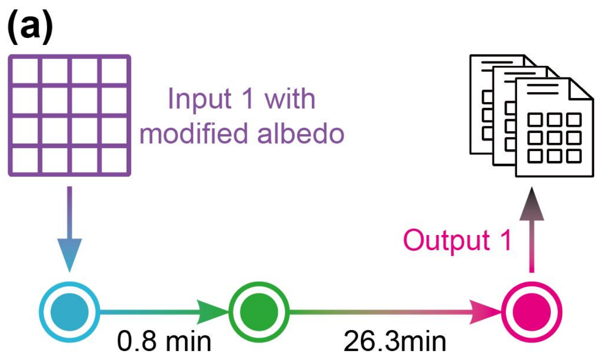
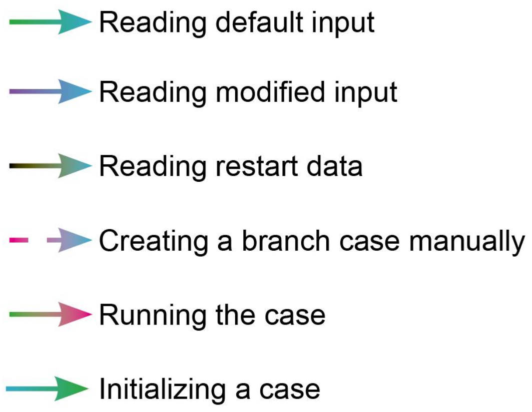


To mimic the adaptive action of urban high albedo through modeling, we need to quantify the albedo-induced cooling effects with **time awareness at global scale**.

Interrupting simulations to progressively change urban albedo.





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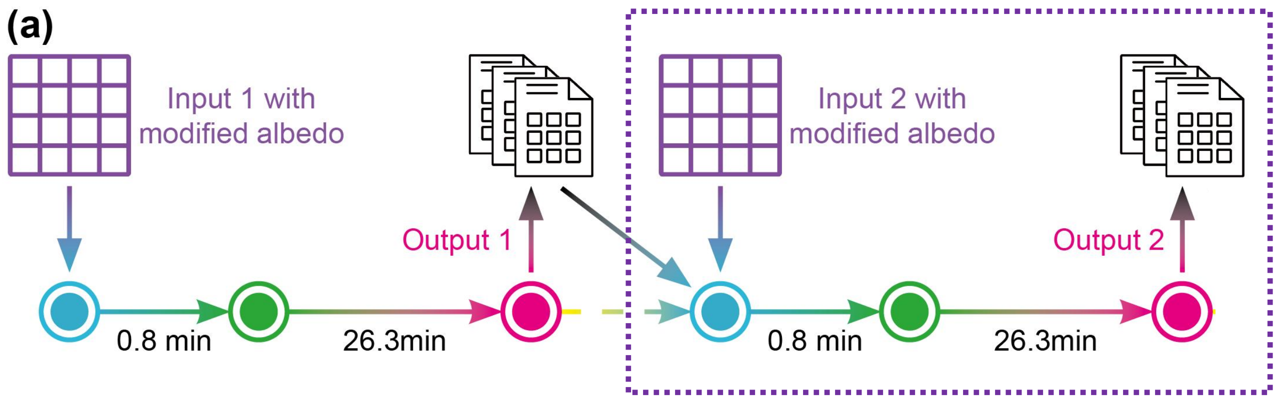
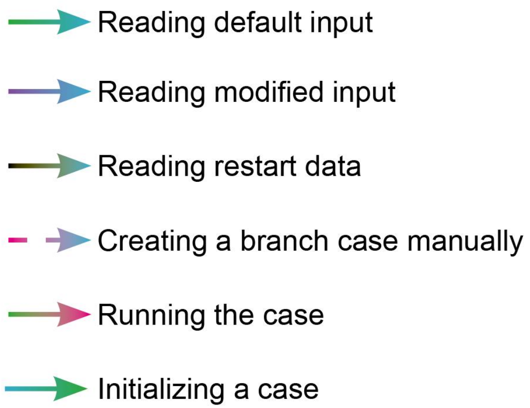
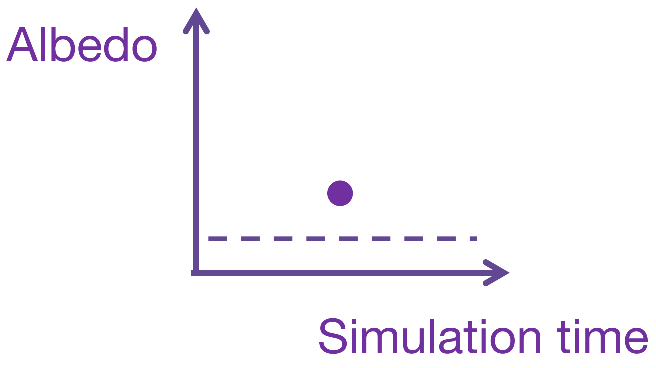




the first albedo change



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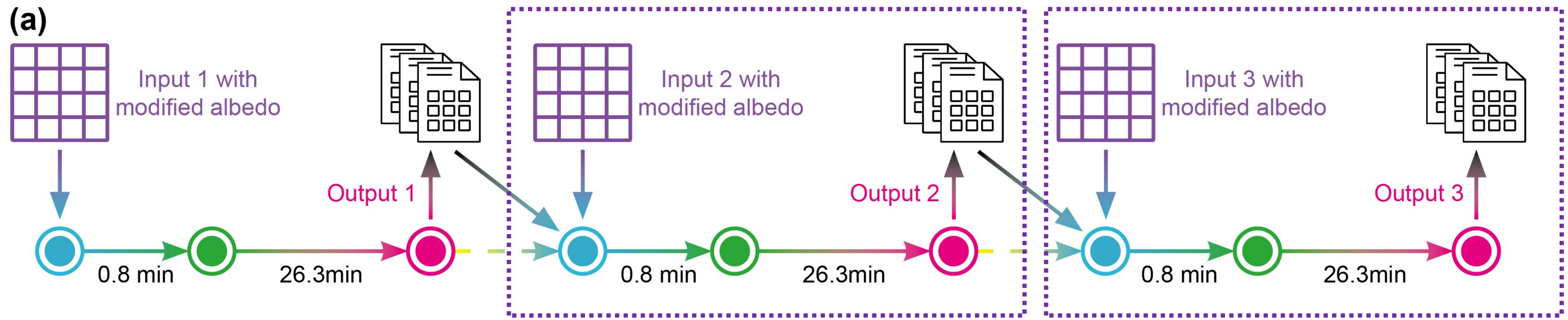
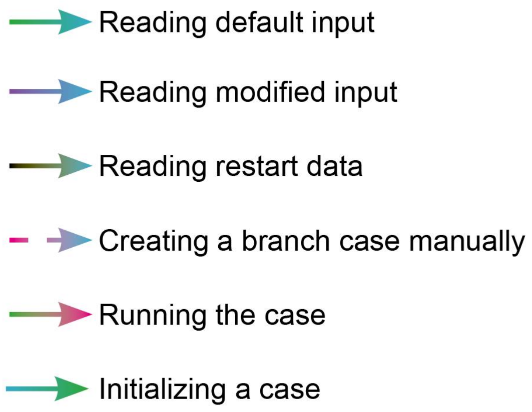
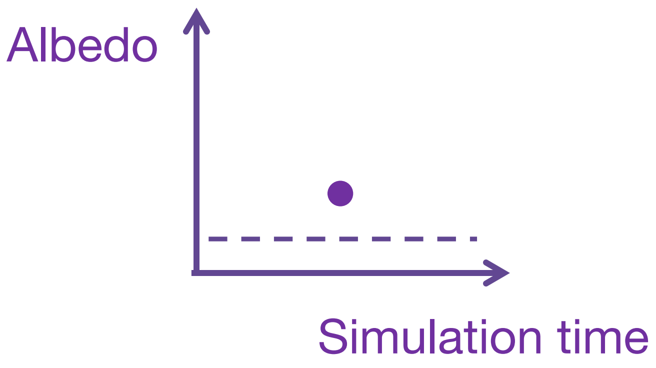
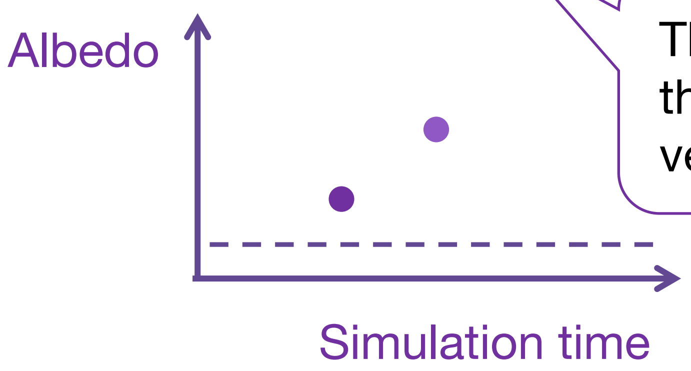




the first albedo change

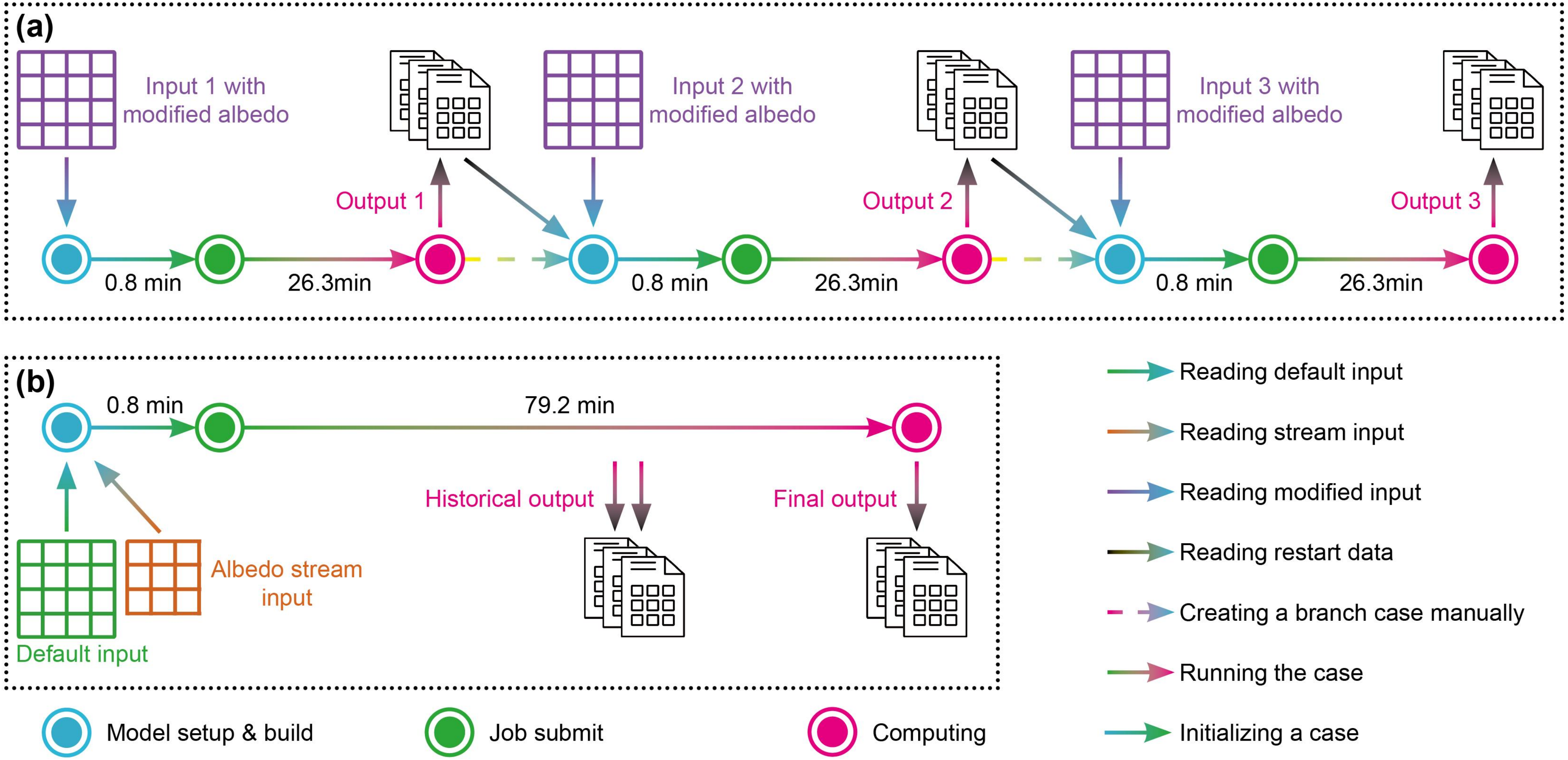
the second albedo change



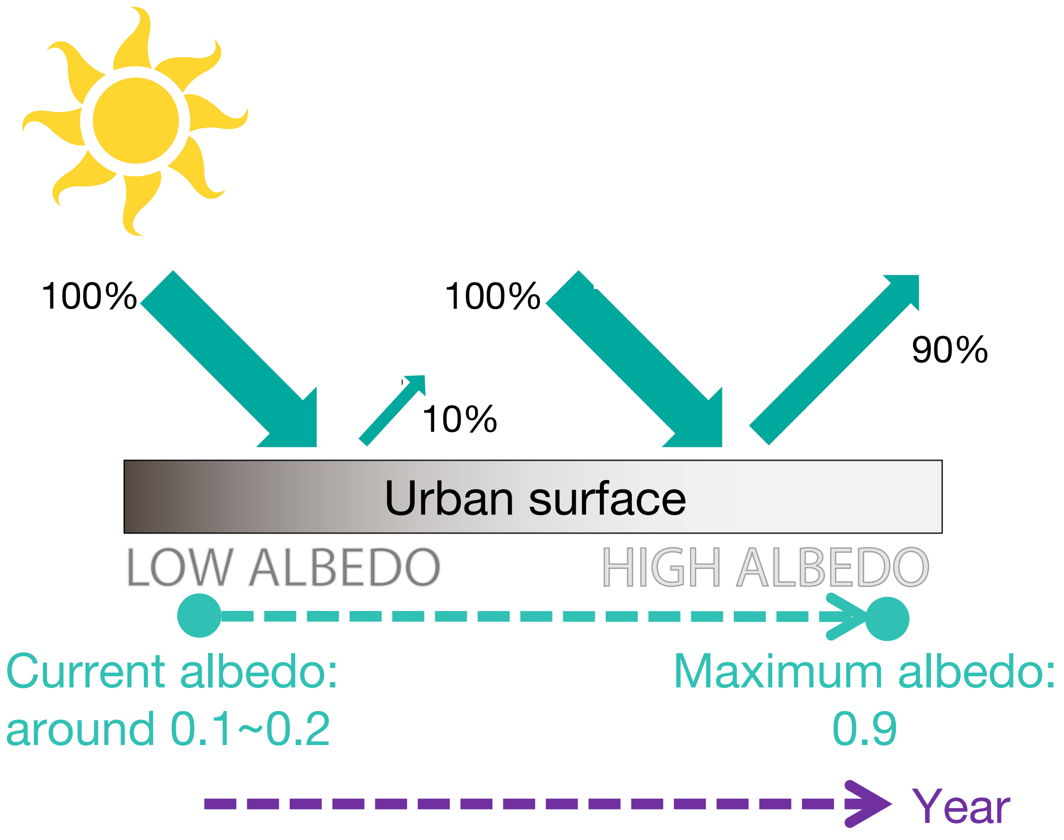


This way is realistic but the set-up process is very complicated.

Prescribing transient urban albedo in a simulation.



We developed a new functionality to prescribe transient urban albedo in CESM.



Advantages:

- Realistically mimic adaptive actions of installing white roof, cool pavement, etc.
- Simplified model set-up processes.
- Global-to-city scale simulations for comparison.

Why CESM

- A state-of-the-art global climate model with explicit urban modelling capacities.
- Multi-scale urban climate simulations under the uniformed model configuration.
    - **Cross-region comparison and climatic knowledge transfer**
- Global simulation
- Regional simulation
- Single-point simulation

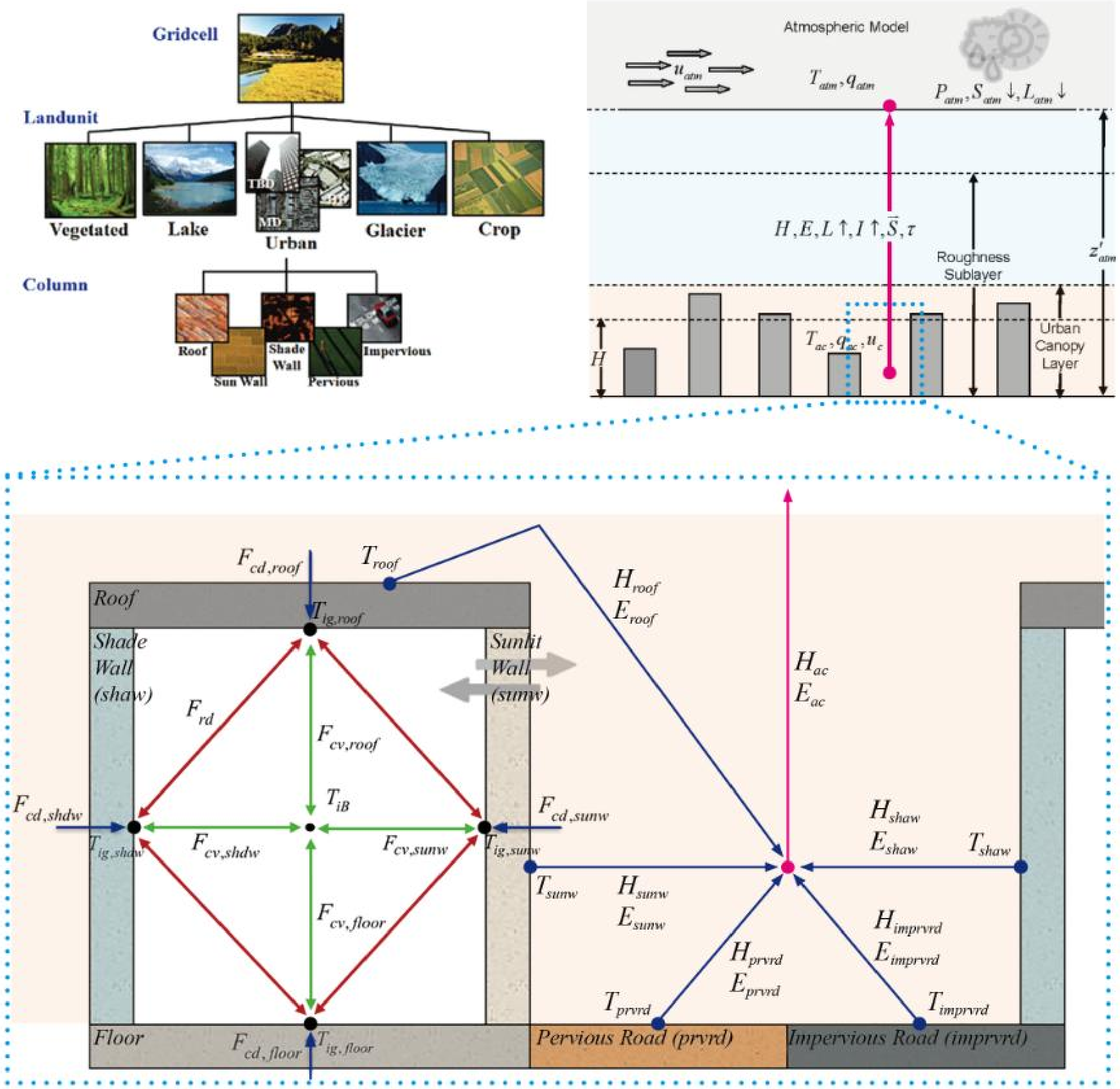
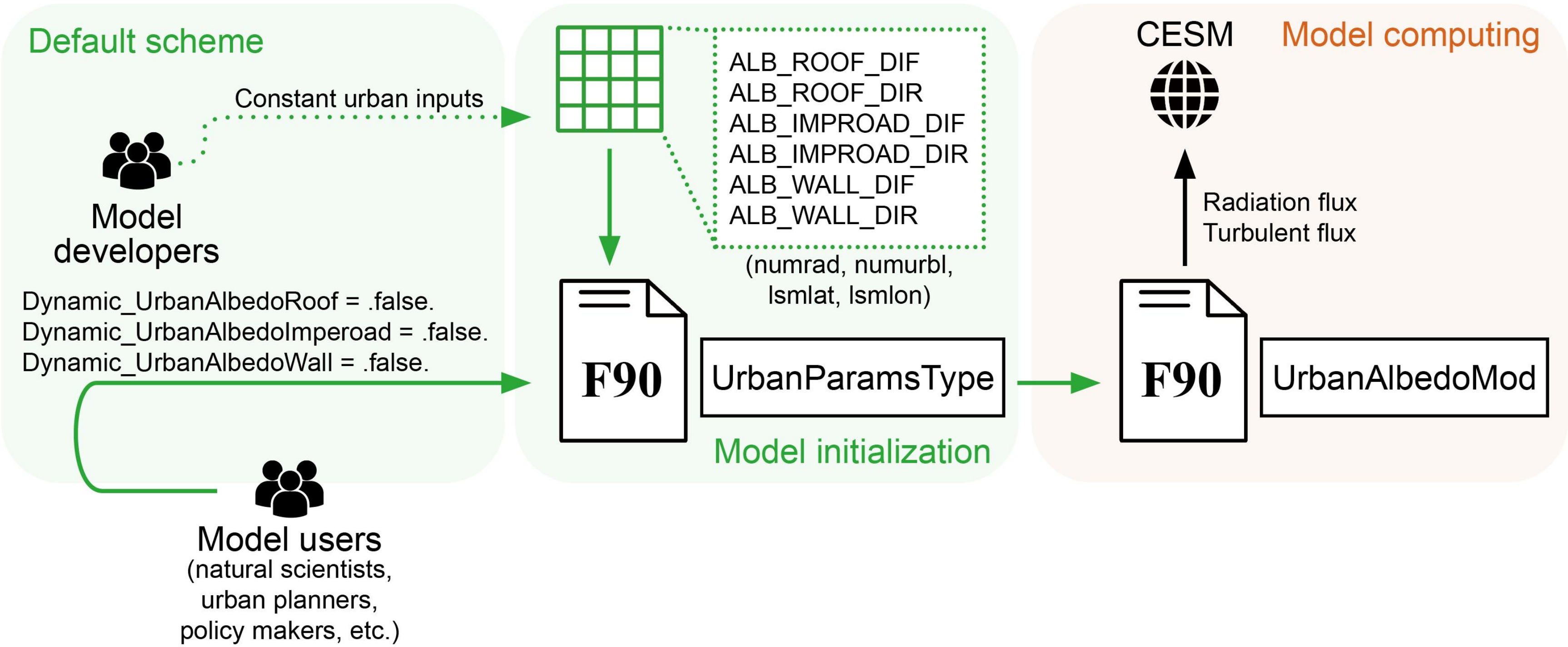


Fig. Community Earth System Model (CESM), and its land components, CTSM, with a urban model, CLMU.

How to use it?

Default configuration:

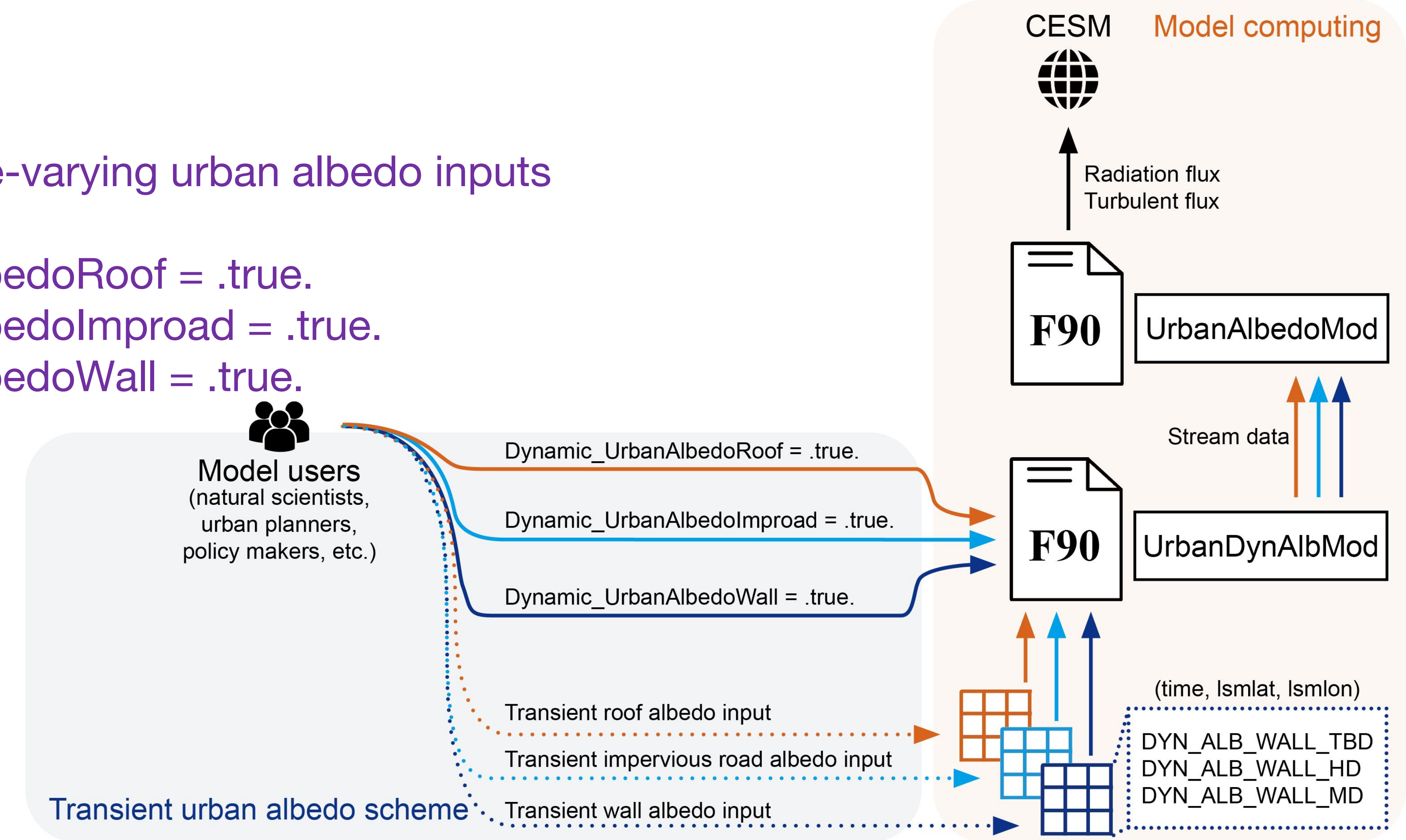
- Static urban albedo
- No additional action needed



How to use it?

Transient urban albedo:

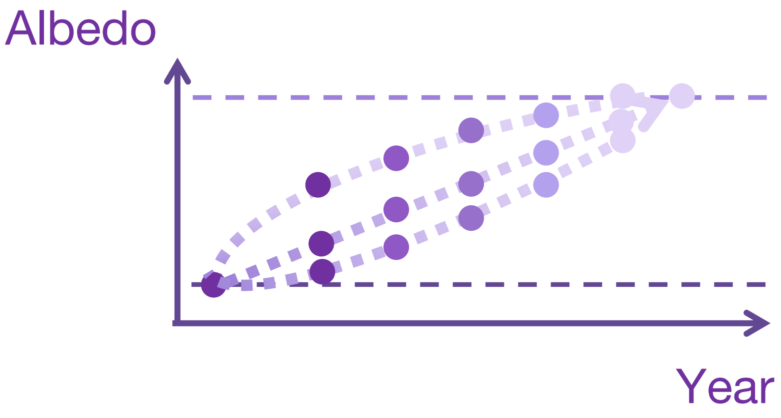
- Step 1: Customize time-varying urban albedo inputs
- Step 2: Add namelists
  - Dynamic_UrbanAlbedoRoof = .true.
  - Dynamic_UrbanAlbedoImproad = .true.
  - Dynamic_UrbanAlbedoWall = .true.

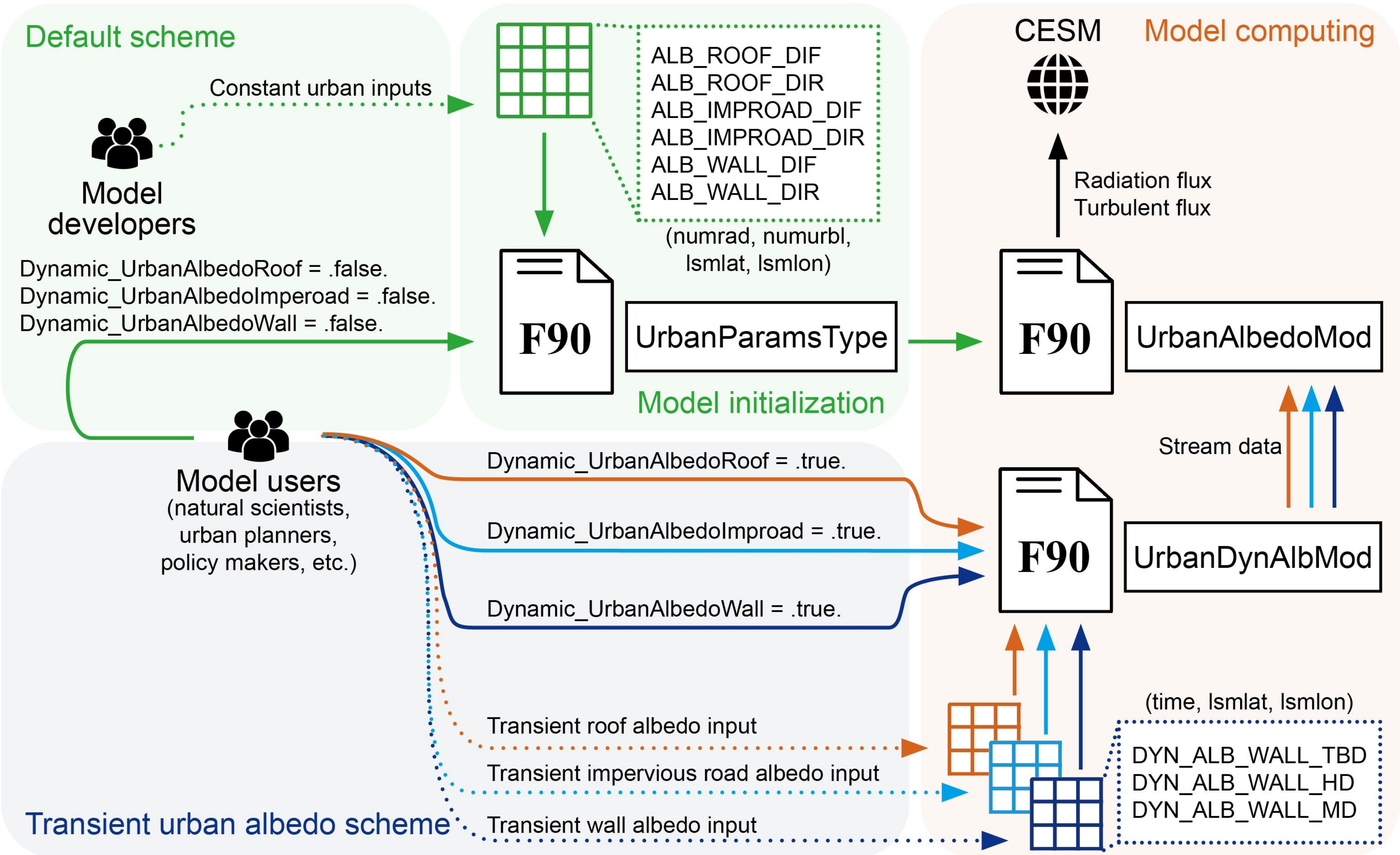


How to use it?

Customizing urban albedo variations in:

- Magnitude
- Timestep





Experiment design

Table 2. Urban climate adaptation strategies under varying urban albedo configurations.

Simulation name	Input data description	Roof albedo	Wall albedo	Impervious road albedo	Pervious surface albedo
CNTL	Static urban albedo	□	□	□	□
ROOF_0.9	Static high albedo of roof	0.9	□	□	□
ROOF_DA	Transient albedo of roof	■	□	□	□
WALL_DA	Transient albedo of wall	□	■	□	□
IMPROAD_DA	Transient albedo of impervious road	□	□	■	□
ROOF_IMPROAD_DA	Transient albedo of horizontal built surfaces	■	□	■	□
ROOF_IMPROAD_WALL_DA	Transient albedo of vertical and horizontal built surfaces	■	■	■	□

Hypothesis:
- Urban albedo increases by 0.01 per year globally (model-user-customized).

Model version: CESM 2.1.4
Grid spacing: 0.9 ° latitude by 1.25 ° lontitude
Component set: Land only (offline)
Period: 2015-2099, SSP-3.70 scenario

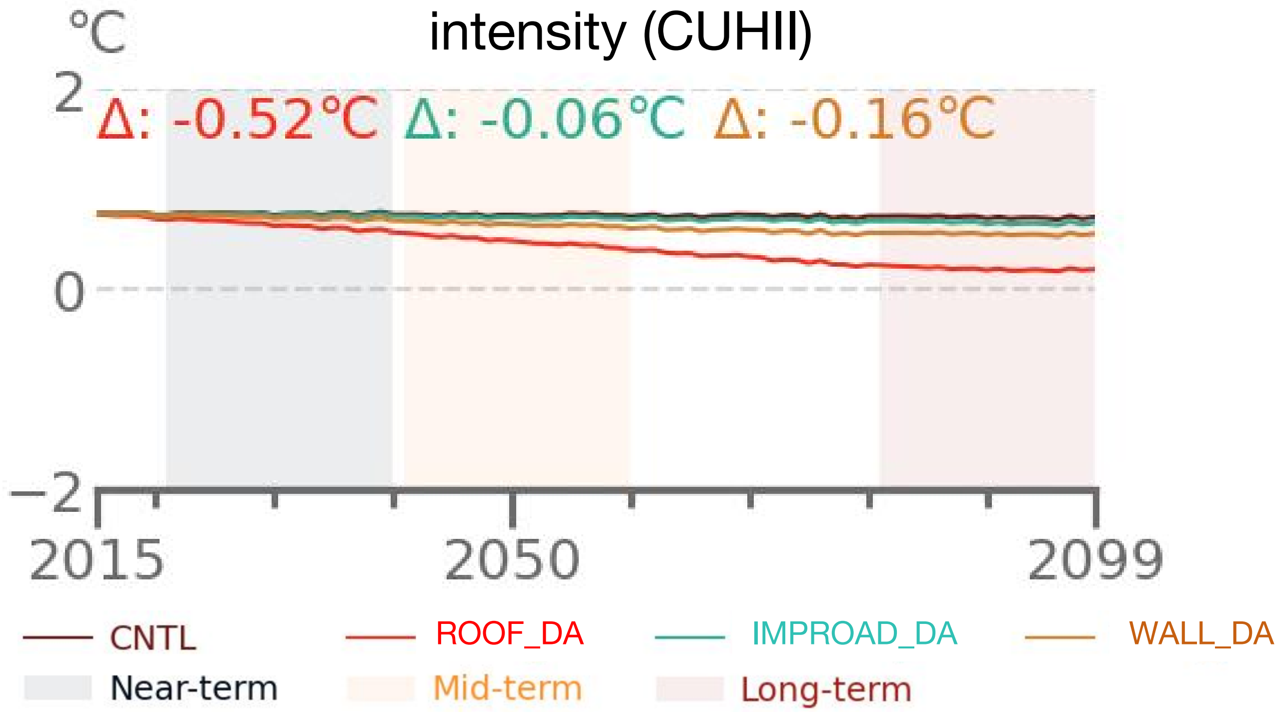
Increasing the roof albedo is more effective at cooling than increasing wall and impervious road albedo.

Global mean CUHII reduction:

- 0.01 Roof albedo -> ↓ 0.009 ° C
- 0.01 Wall albedo -> ↓ 0.004 ° C
- 0.01 Impervious road albedo -> ↓ 0.001 ° C

Heat is trapped in the urban canyon.

Annual mean air urban heat island intensity (CUHII)



Better cooling effects in tall building district (TBD) than high-density (HD) and medium-density (MD).

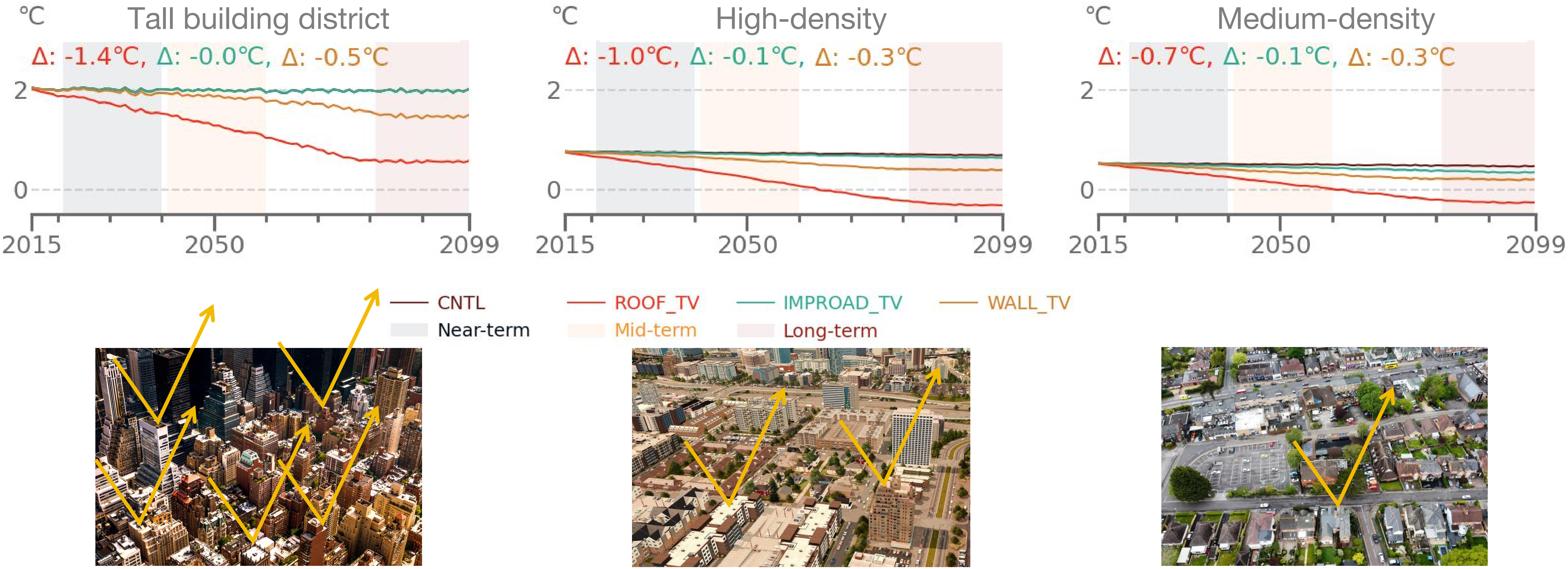


Fig. Comparisons among urban land-unit typs (TBD, HD, MD).

Spatial variations of temperature reduction over latitudes

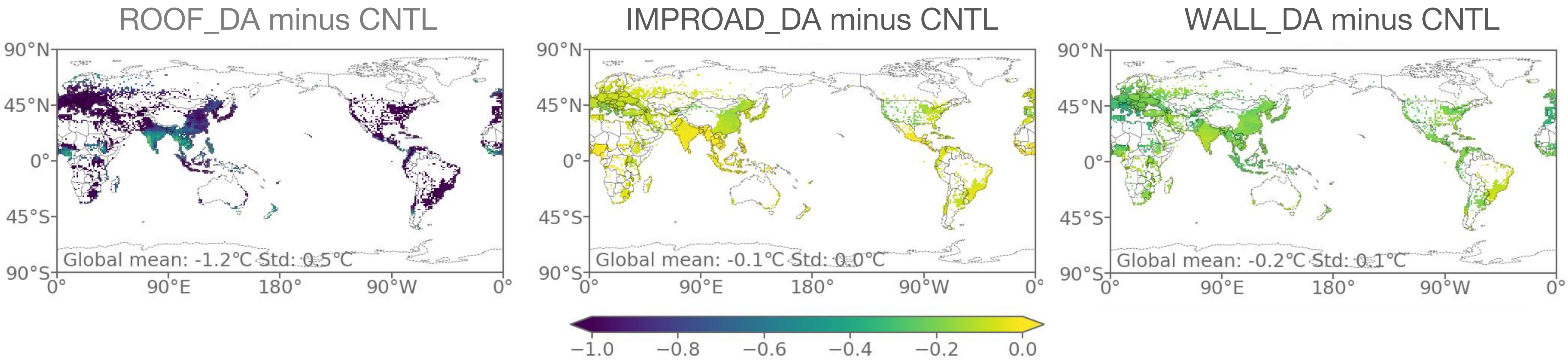


Fig. Ground surface temperature reduction during June-July-August of 2040 (the end of near-term).

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Implications for urban design and planning

- Give priority to increase roof albedo than other urban surface;
- Give priority to increase albedo in tall building districts;
- High albedo is not an universal strategy for mitigating urban heat;
  - Be cautious about wintertime spatial heating in high latitude regions;

Future work

- Transient albedo under different SSP scenarios to mitigate urban heat;
- Combined effects of transient urban fraction and transient albedo to balance urban land changes and surface energy;
- Atmosphere-land interactions due to continuously increasing urban albedo in **WRF-CTSM** (in preparation).

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