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Incorporating a detailed global anthropogenic heat emission dataset into an earth system model (CESM2)

Alvin C.G. Varquez, Unubold Erdenebeleg, Manabu Kanda

Department of Transdiciplinary Science and Engineering

Tokyo Insitute of Technology

I.Introduction

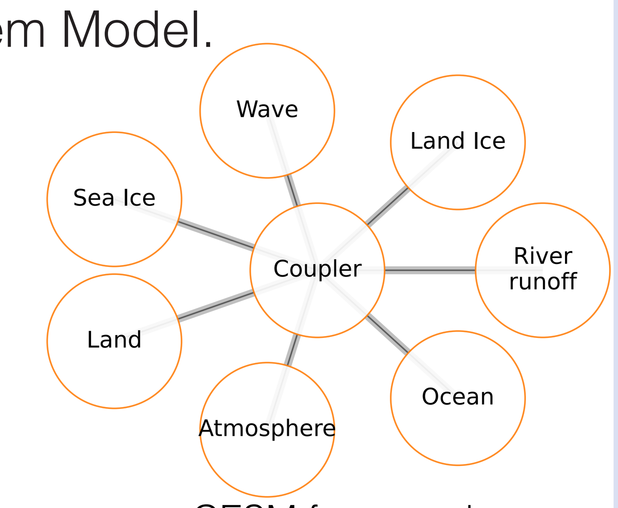
Anthropogenic heat emission (AHE) (Grimmond, 1992; Oke et al., 2017) is an additional source of heat from the surface released to the atmosphere. AHE is mainly caused by the utilization of energy to sustain human life and its operations. It varies across locations and time (i.e. hours, months, years). Multiple observational and numerical studies have confirmed the local-to-regional effects of AHE due to its direct influence on the surface-energy balance within cities, which in turn propagates to its regional environment. Further investigation of its global effects are presented.

On numerical models

Regional climate models are numerical models that can simulate spatio-temporal 3D distributions of climate for a desired region, given surface/lateral boundary and 3D initial conditions. AHE can be introduced as hourly-varying surface boundary condition to influence the land surface models coupled in those models. Recently, earth systems models that can model not only climate but almost all physical have are becoming available. Among such model is the Community Earth System Model.

Community Earth System Model (CESM)

Fully-coupled (ESM), community, GCM supported by NFS and maintained by NCAR and CGD. Provides climate projections for CMIP. **Version 2.1.3 (Danabasoglu et al., 2020)**



CESM framework

Globally-available AHE datasets

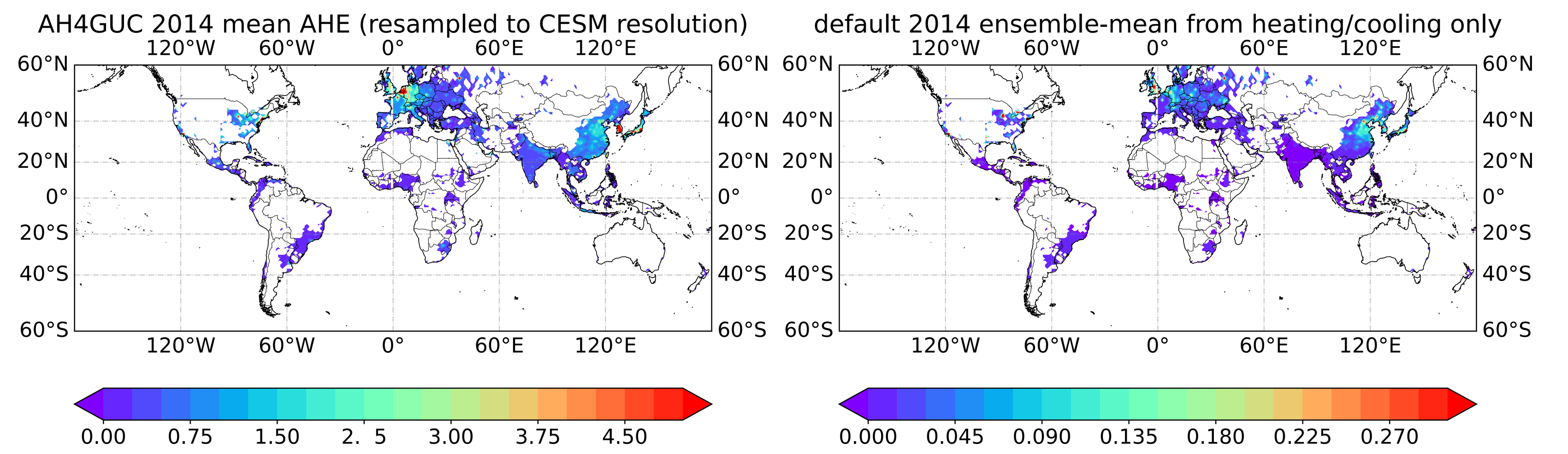
Multiple top-down-derived global AHE datasets have been released for the public. **AH4GUC dataset**, derived from various geospatial datasets (e.g. VIITS sattelite), was used.

access

Current Objectives

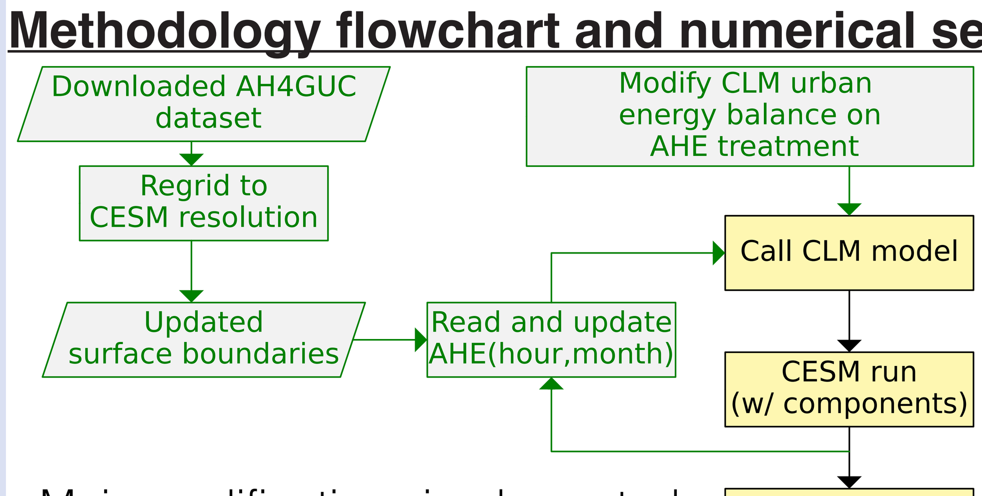
- Incorporate (prescribe) an hourly-varying global-scale AHE dataset into an Earth Systems Model (CESM2)
- Investigate global effects of AHE on simulated global climate using default and prescribed anthropogenic heat emission settings
- Discuss ongoing challenges and future direction of the research.

II. Methodology



AHE is only considered in the urban cells of CESM2. The annual global-average values (L) of AH4GUC were ~30x larger than the simulated values (R) by CLM.

Methodology flowchart and numerical settings

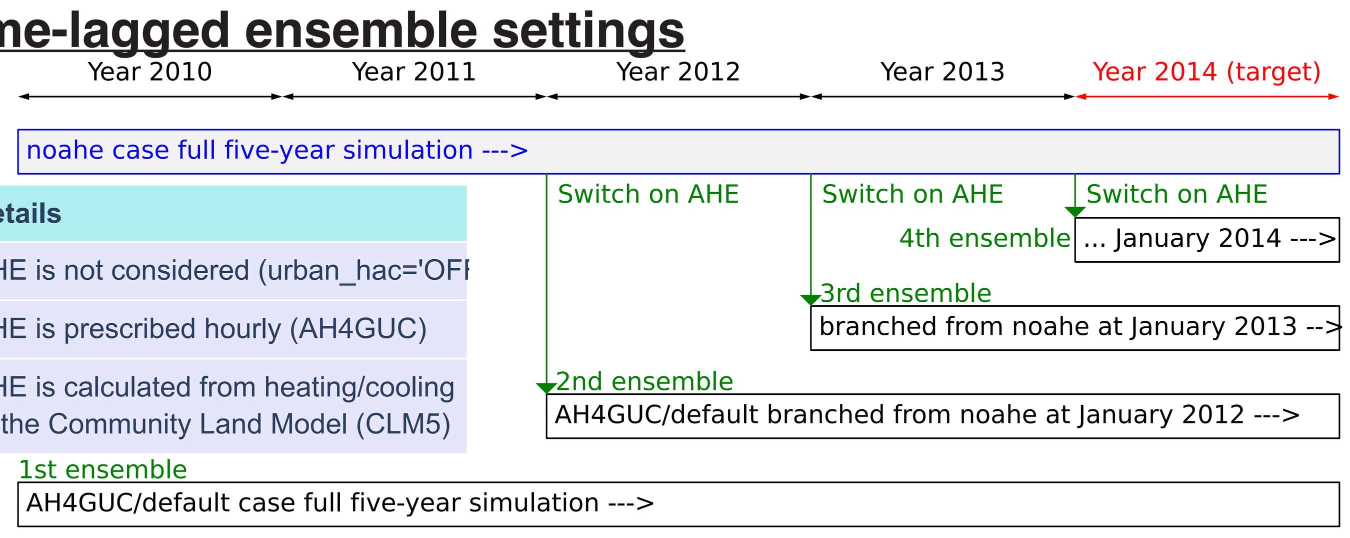


Main modifications implemented in the land surface model.

Community Land Model 5.0 (CLM5; Lawrence et al., 2019) is CESM's default land surface model.

Numerical Setting	Technical Details
Grid resolution	*f09_f09_mg17*, CESM's scientifically supported 0.9×1.25 degree grid.
Initialization	January 2010
CESM Component Set	FHIST compset as follows. **Atmosphere**: *CAM6.0*, active **Land**: *CLM5.0*, active **Sea-ice**: *DOCN*, prescribed **Ocean**: *CICE*, prescribed **River runoff**: MOSART **Land-ice**: CISM2 no evolve **Wave**: *Stub*, inactive
Machine	TSUBAME supercomputer 3.0

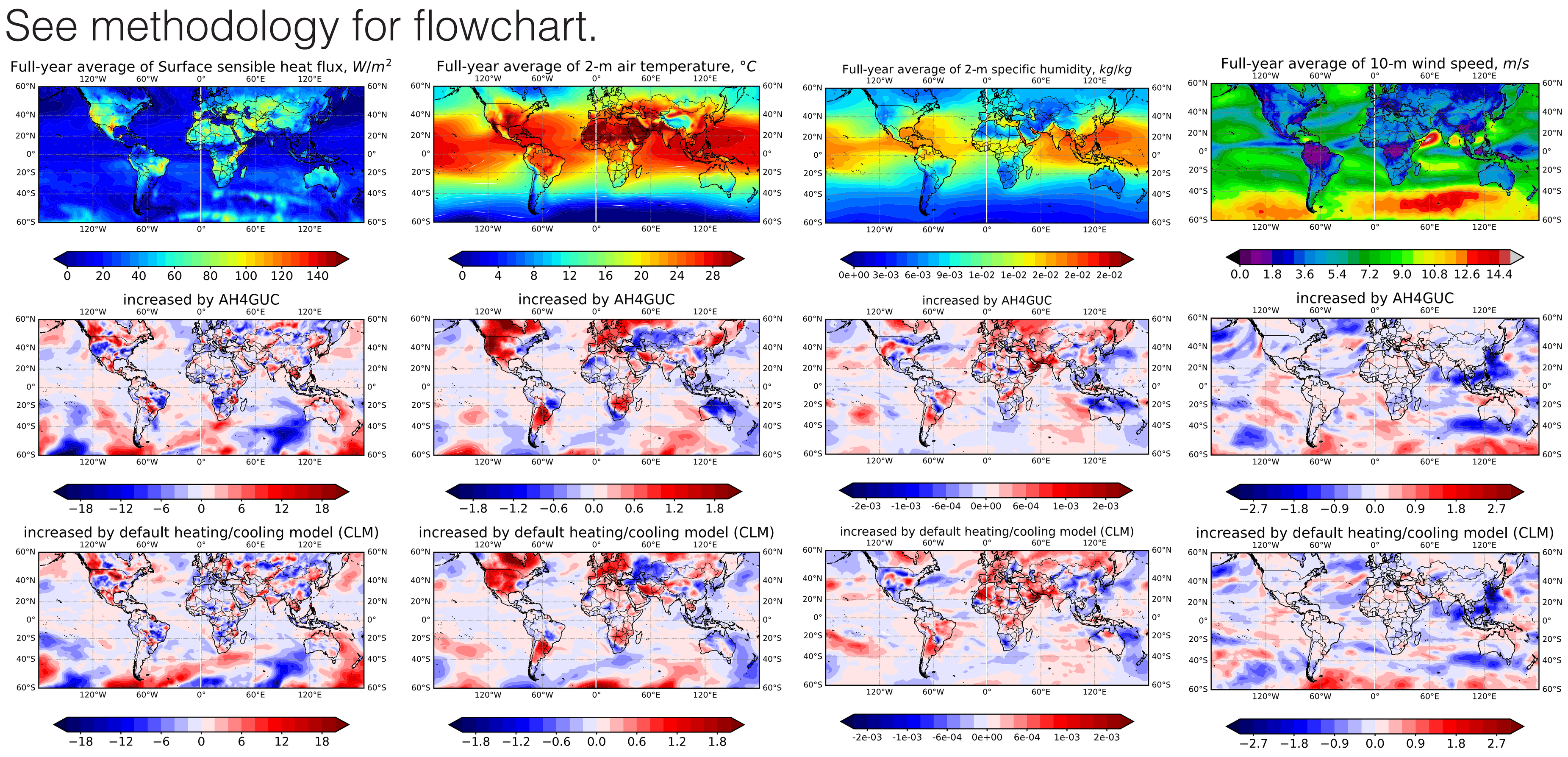
Cases and time-lagged ensemble settings



Case	Details
noahe	AHE is not considered (urban_hac='OFF
AH4GUC	AHE is prescribed hourly (AH4GUC)
default	AHE is calculated from heating/cooling of the Community Land Model (CLM5)

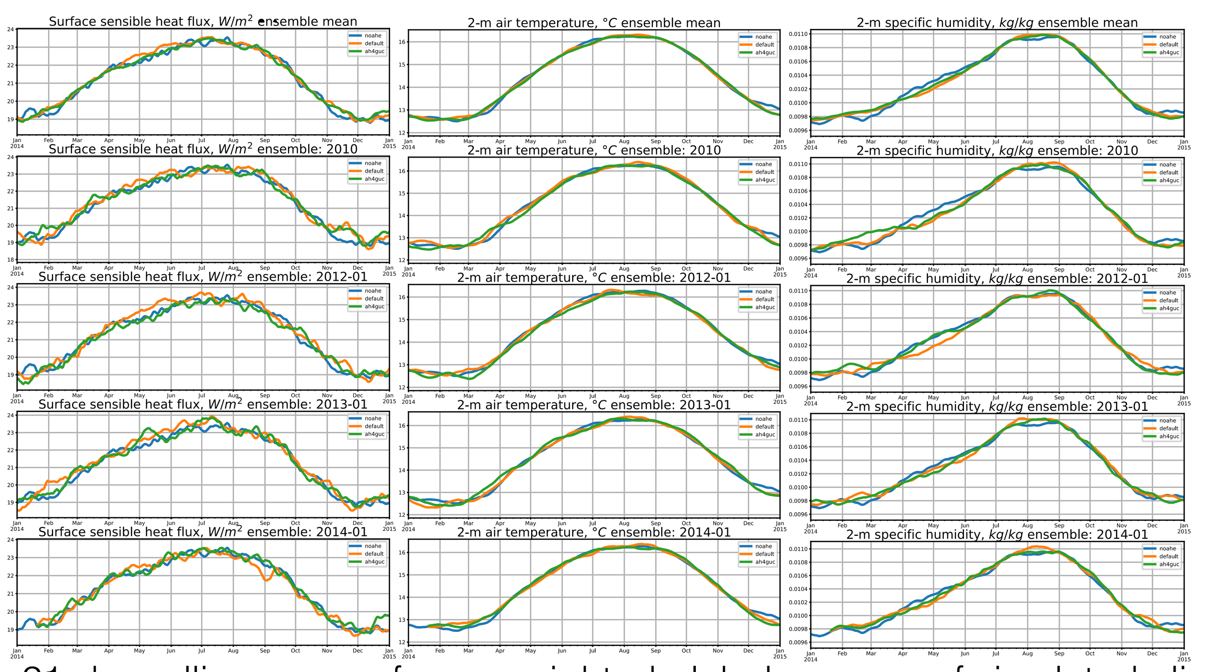
III. Findings

Time-lagged ensembles weregenerated by branching off from the "noahe" case. See methodology for flowchart.

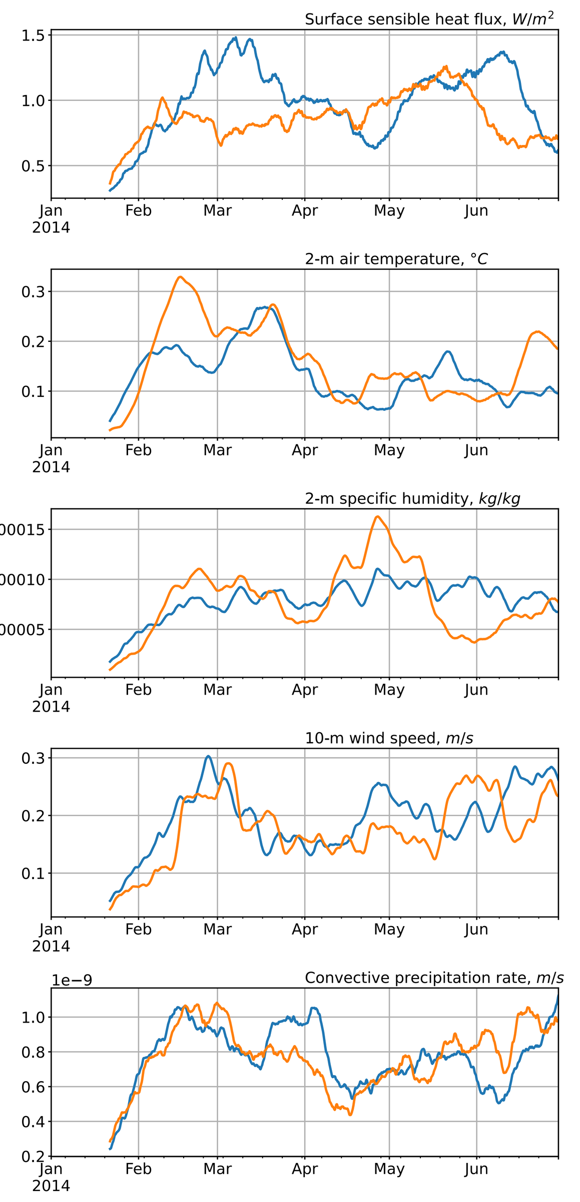


Top rows corresond to full-year average from the noahe case. Lower rows are ensemble means of the full-year average difference between AHE cases and noahe cases. Red (blue) colors mean increase (decrease) attributed to AHE.

- Non-linear, dynamic effects (e.g. divergence of moisture) causes significant differences in the climate parameters extending beyond the urban boundaries.


21-day rolling-mean of area-weighted global average of simulated climate five years after start date January 1, 2010 across each ensemble.

- Area-weighted global AHE for AH4GUC and default are 0.046 W/m2 and 0.0016 W/m2, respectively. Despite this, no significant global-average differences in simulated sensible heat flux, 2-m air temperature, 2-m specific humidity, and near-surface wind speeds.
- Similar tendencies across ensembles. See above figures for selected climate variables.
- It takes a little more than a month (right figure) since branching until AHE released into the atmosphere reaches (possibly) equilibrium effects.
- While there is no clear temporal trend of AHE effects, their simulated effects can be as significant as the undesirable futuristic green house effect.



21-day rolling-mean of the area-weighted global average climate parameters. The values are calculated by subtracting the noahe case statistics from the AHE case statistics. Notice the similarities in scale between ah4guc and default.

IV. Prevailing questions / Prospects

- Group the effects of AHE on the climate across regions, zones, or various land/ocean cover. Explain the dynamics of heat-transport from the urban areas to earth as a whole.
- Multi-year statistics are needed to generalize the global effects. Extend the simulation cases for up to more than a decade of simulation. Develop models to increase/decrease the AH4GUC corresponding to climate-change scenarios (ScenarioMIPs).
- Introduce an option to release the AHE directly as excess surface sensible heat flux of the amtospheric component (i.e. Community Atmosphere Model [CAM])
- Intercomparison is underway with 14-km NICAM model (Japan-based GCM maintained by AORI, JAMSTEC and AICS) in collaboration with Dr. Masuo Nakano (JAMSTEC), Dr. Makoto Nakayoshi (Tokyo University of Science) and Dr. Yuya Takane (AIST)
- Explain GCM's strong sensitivity at the polar regions. Test other component sets.

V. References

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