Exploring the Impact of Alternative Urban Design Scenarios on Microclimate Using QUIC-EnvSim

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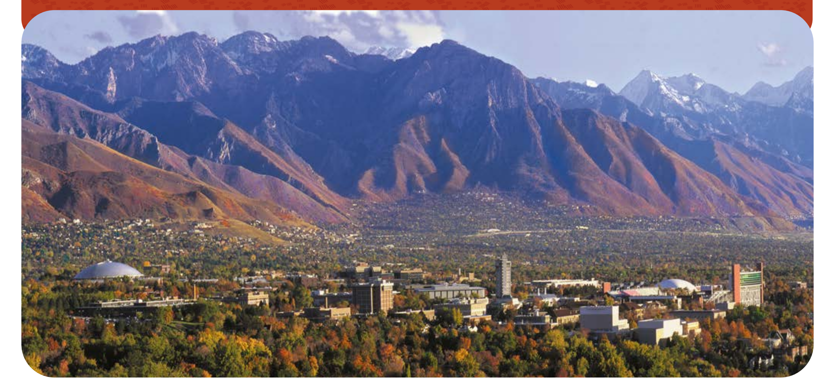


Abstract

QUIC EnvSim (QES) is a building resolving (2-5m) urban microclimate modeling tool capable of rapidly computing time-averaged fields of velocity, turbulence variables, temperature, moisture, and scalar concentrations in around the built environment. The tool has been developed to take advantage of computer graphics hardware and ray-tracing techniques to compute radiation balances in complex urban geometries. Additional use of graphics processing units (GPUs) facilitates the rapid solution of other transport quantities in the atmosphere and through urban surfaces. With this system, simulation domains on the order several square kilometers can be simulated on a single high-end workstation. Previous work and presentations on QES have focused on verification and validation of components of the system. In this presentation, we show the power of QES to help explore different real world design scenarios and investigate the effects small-scale place based design changes on various urban scales. In particular, simple surface flux scenarios of urban greening (i.e., albedo changes and vegetative fraction) at the building and neighborhood scales for Salt Lake City, UT USA are presented and evaluated.

The GEnUSiS Project

Green **En**vironmental **U**rban **Si**mulations for **S**ustainability[a]

Overall Project Objective

To use large-scale simulation science to investigate the impact of Green Infrastructure projects on urban energy use and microclimate.

What is Green Infrastructure (GI)

We use the broad definition of Srinivasan et al.[b]: The incorporation of "green spaces and environmentally conscious construction in the built environment."

Specific Questions

- How do GI projects affect urban microclimate across scales?
- Can GI projects be implemented in an optimal way that minimize their land-use while maximizing their impact on urban energy/water use?
- Is it possible for cities to implement reasonable GI projects that can significantly alter urban heat island effect?
- Can an interactive decision-making, immersive visualization tool be developed to help decision-makers sift & select optimum GI projects?

Approach

Heterogeneous Computing

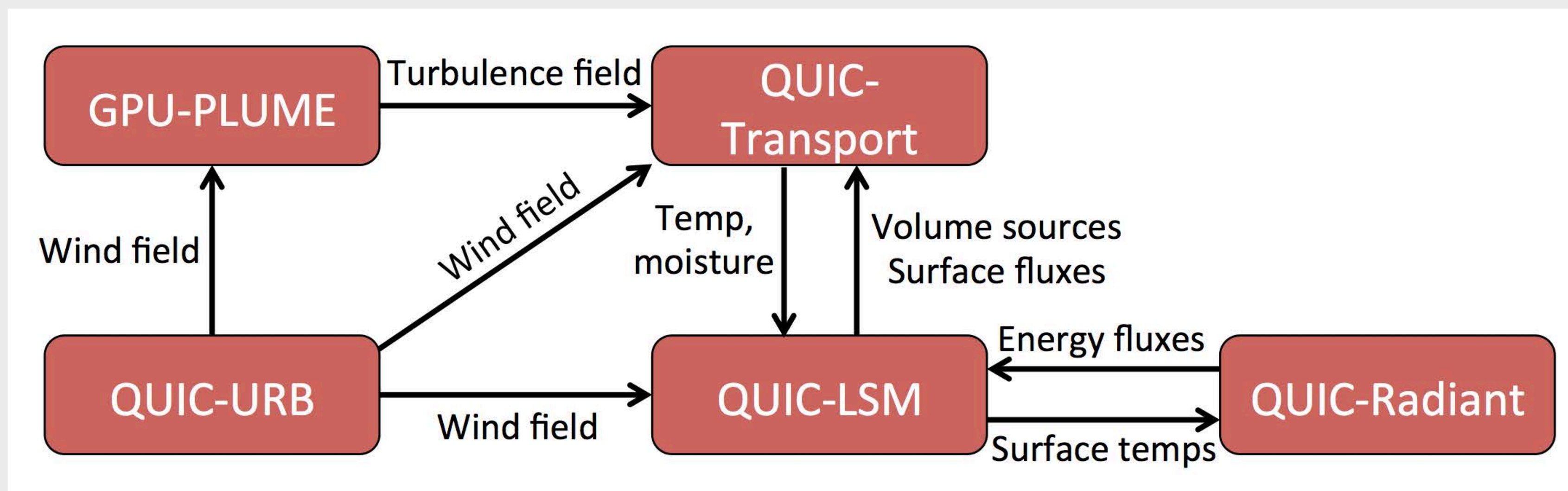
Integrated GPU (Graphics Processing Unit) & CPU computing

Benefits of using GPU for Computation

- Highly parallel vector processors (5000+ "cores")
- Allows for high-performance computing on a desktop
- Utilizes SIMD (Single Instruction Multiple Data) execution model
- Affords direct visualization of the data!
- Various software development kits (SDKs) available (e.g., CUDA & OptiX from NVIDI)
- Can interoperate with C, C++, Fortran, and other programming languages
- Conceptually similar to parallel supercomputing (but on desktop)

QUIC EnviSim Overview

QUIC EnvSim: Quick **U**rban **I**ndustrial **C**omplex **Env**ironmental **Sim**ulation (QES) – a robust, low-cost numerical simulation system that can represent a wide range of urban microclimate physical processes over a wide range of scales.

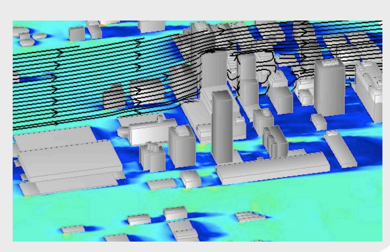


Above: Illustration of the interaction of the various models that compose the QES system.

QUIC-URB

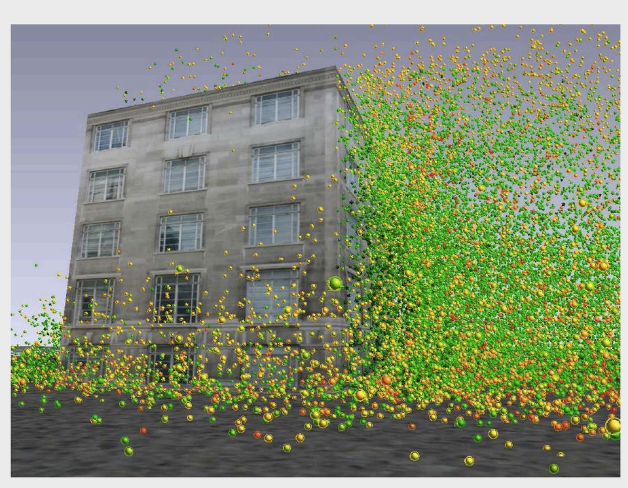
Urbanized 3D diagnostic wind model[c]

- Uses empirical parameterizations & mass conservation
- Basic parameterizations developed using wind-tunnel datasets for simple building configurations
- For complex building configurations, parameterizations applied by dividing a complex building configuration into series of simple (rectangular parallelepiped-shaped) building configurations, & superimposing the resulting flow fields



GPU-Plume

Urbanized Langrangian dispersion model designed to run on the GPU. Computes the turbulence field based on the mean momentum field from QUIC-URB[d]



Land Surface Model (LSM)

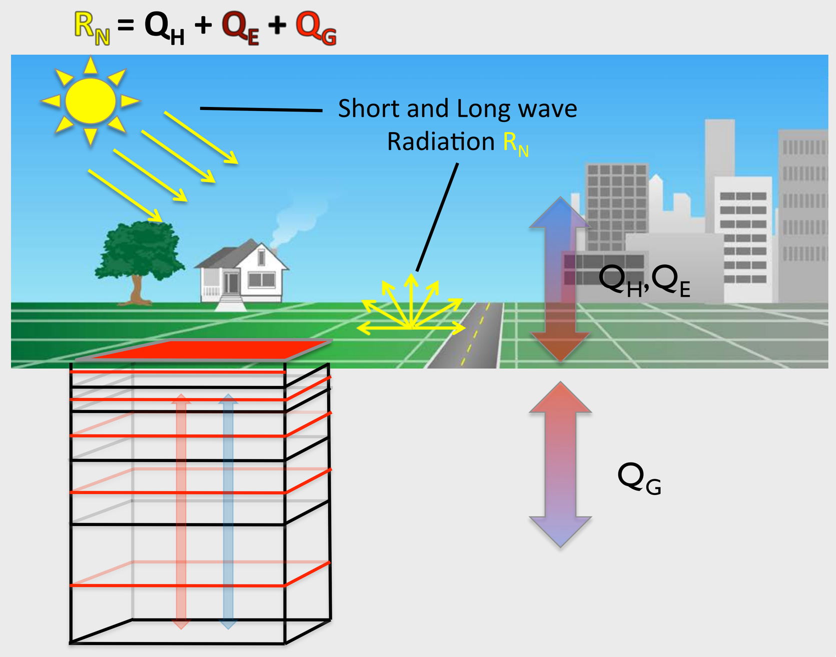
QES's LSM is modular so that different models can easily be used for the different components of the surface energy balance. For example, sensible (Q_H) and latent (Q_E) heat fluxes can be computed using three different models. The primary LSM models that are implemented on a "patch" by "patch" basis are:

- Simple LSM
- Force-restore LSM
- Finite difference LSM

The models are currently being tested an coupled to the complete system. They are also being implemented so that they take advantage of GPU acceleration.

Surface Energy Budget

$R_N = Q_H + Q_E + Q_G$



QUIC-Transport

RANS first-order K-theory closure, finite volume scheme for moisture and heat transport or a general scalar ξ through the urban atmosphere.

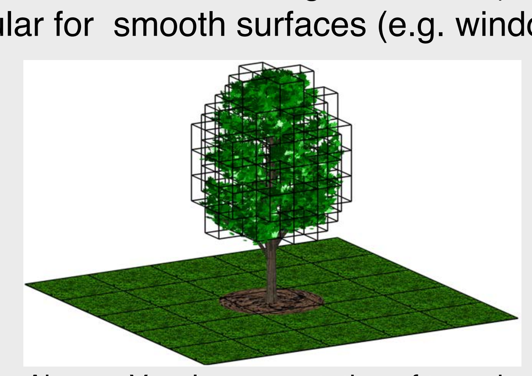
$$\frac{\partial \bar{\xi}}{\partial t} + \bar{u}_i \frac{\partial \bar{\xi}}{\partial x_i} = \frac{\partial}{\partial x_i}\left[(\alpha + K_\xi) \frac{\partial \bar{\xi}}{\partial x_i} \right] + S_\xi$$

- Driven by wind and turbulence fields generated by QUIC-URB and GPU Plume
- Uses CUDA and MPI (currently, faster than real time on 10-core CPU)

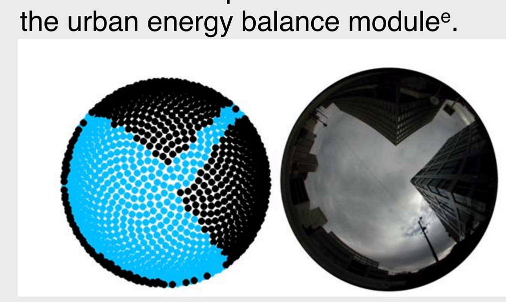
QUIC-Radiant

Explicit shortwave and longwave radiation to and from buildings and vegetation using a novel ray tracing technique[e,f]

- Utilizes NVIDIA's OPTIX Ray Tracing "engine" – GPU calculations
- Rapid Reflection and Sky View Factor computations
- Diffuse reflectance for rough surfaces (e.g. brick)
- Specular for smooth surfaces (e.g. windows)



Above: Voxel representation of trees in the urban energy balance module[e].



Above: Simulated sky view -"Fish-eye" view and actual view in Salt Lake City[g]

Salt Lake City Simulation

Simulation Parameters:
Resolution: 5 m uniform
Number of buildings: 220
Number of Trees (for vegetation case): 1,333
Domain: 1.15 km x 1.15 km x 250 m
Partial Diurnal Cycle: 1 January 2012
Time steps: 5 minute quasi-steady LSM steps, QES Transport (~0.1 seconds)

GPU: NVIDIA Titan Z (6 GB video RAM)

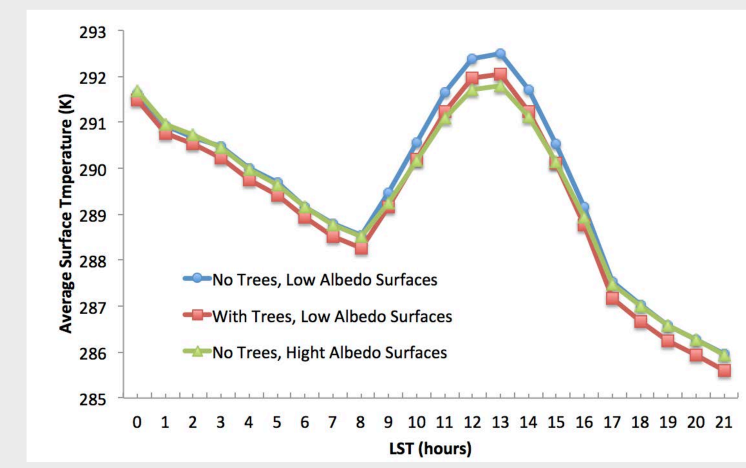
Boundary conditions:
Temperature: periodic in lateral and floating gradient at the top
Winds: constant, power-law profile

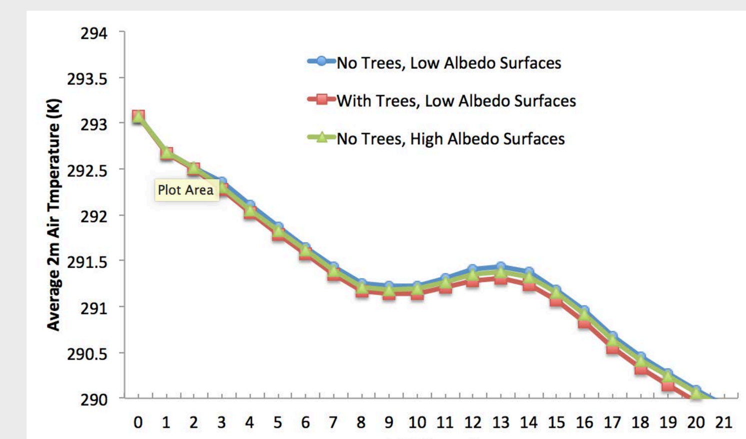
Urban Design Test Scenarios:

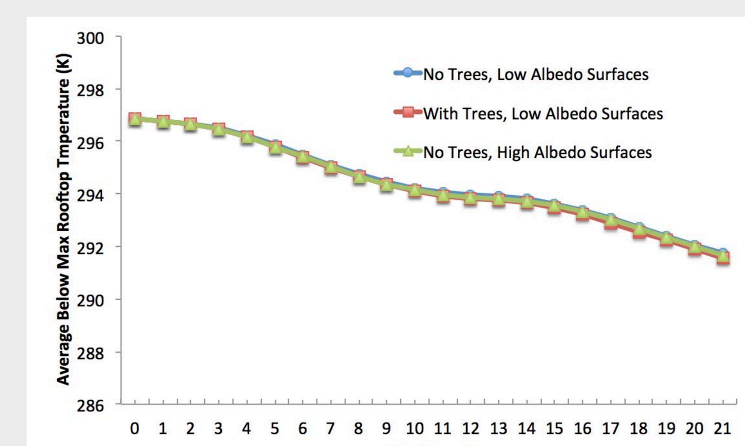
Case	Vegetative Fraction	Rooftop Albedo
1	0	0.05
2	0.02	0.05
3	0	0.9

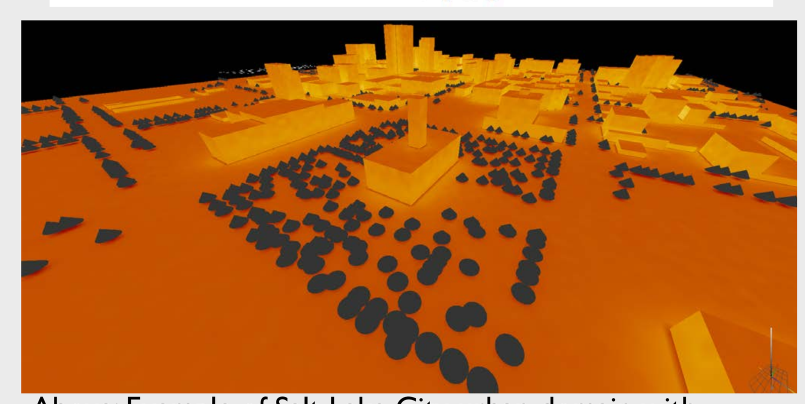
Alternate Scenario Results

Simulations were run with our simple LSM and vegetation, but evapotranspiration was turned off. Hence, only the impact of shading is reflected in the vegetation results.









Above: Example of Salt Lake City urban domain with vegetation case with 1333 trees. Shown are contours of surface temperature.

Summary

- Previously the individual models that make up the QUIC EnviSim tool had been verified and validated, here we have demonstrated the capabilities of the fully integrated system.
- QUIC EnviSim can be used in a time evolving mode to better understand the effects of local urban form modifications on larger urban scales
- Three urban scenarios were compared with vegetation and changing albedo. Results showed the highest daytime temperatures for the low albedo case.
- Future work will include evapotranspiration in the vegetation energy balance in a addition to shading.

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