Global Urban-Scale Land-Atmosphere Modeling with the Land Information System

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1. INTRODUCTION

In general, land surface modeling seeks to predict terrestrial water, energy, momentum, and in some cases biogeochemical exchange processes by solving the governing equations of the soil-vegetation-snowpack medium. Land surface data assimilation seeks to synthesize data and land surface models to improve our ability to predict and understand these processes. The ability to predict terrestrial water, energy and biogeochemical processes is critical for applications in weather and climate prediction, agricultural forecasting, water resources management, hazard mitigation and mobility assessment. However, until recently, global land-atmosphere modeling at urban scales was infeasible due to limits in computational and observational resources.

NASA's Goddard Space Flight Center has developed a Land Information System (LIS; http://lis.gsfc.nasa.gov) capable of modeling global land-atmosphere interactions at spatial resolutions down to 1km. LIS is a high-performance Land Data Assimilation System (LDAS; Rodell et al., 2003; Mitchell et al., 2003) and consists of several land surface models run offline using observationally-based precipitation, radiation and meteorological inputs, and surface parameters including MODIS-based Leaf Area Index (LAI, Figure 1). The high spatial resolution of LIS makes it capable of resolving urban areas, and a key area of ongoing work is updating land surface models to represent the impacts of engineered surfaces (buildings, roads, parking lots, sidewalks, etc.) on mesoscale land-atmosphere interactions, including water, energy, and momentum fluxes. LIS has now been demonstrated at a 5km resolution globally. In this preprint, we present an analysis of urban thermal and radiative impacts for cities around the world, including results from a case study for the city of Houston, TX.

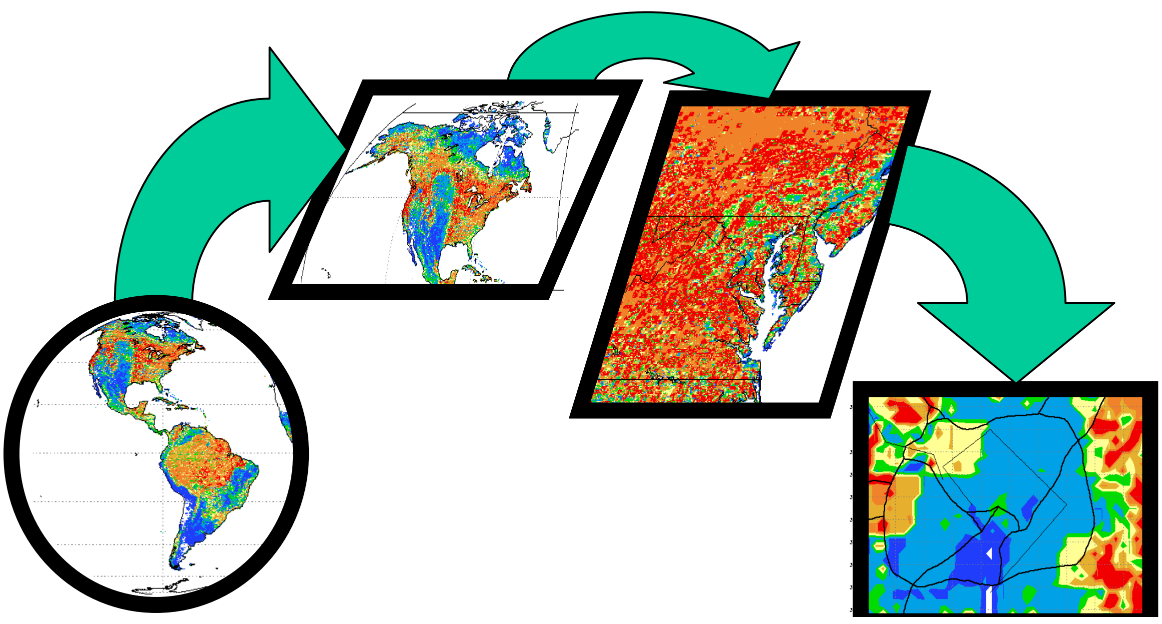

Figure 1. 1km resolution global MODIS Leaf Area Index product. As shown, this product is capable of resolving global urban areas, such as the Washington, D.C., Metro area shown.

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2. APPROACH

2.1. *The Land Information System (LIS)*

In order to predict water, energy and biogeochemical processes using (typically 1-D vertical) partial differential equations, land surface models require three types of inputs: 1) initial conditions, which describe the initial state of land surface; 2) boundary conditions, which describe both the upper (atmospheric) fluxes or states also known as "forcings" and the lower (soil) fluxes or states; and 3) parameters, which are a function of soil, vegetation, topography, etc., and are used to solve the governing equations.

The main software components of LIS are:

· 1. LIS driver: A model control and input/output system (consisting of a number of subroutines, modules written in Fortran 90 source code) that drives multiple offline one-dimensional land surface models (LSMs).

· 2. Land surface models: LIS includes 3 different land surface models, namely, the NCAR Community Land Model (CLM; Dai et al. 2002; Zeng et al. 2002), the community Noah land surface model (Ek et al., 2003), and the Variable Infiltration Capacity (VIC) model (Liang et al., 1996).

As described in detail in the on-line documentation and software design documents available at http://lis.gsfc.nasa.gov, the LIS driver executes the 1-D land surface models above on vegetation-based "tiles", which at grid resolutions coarser than 1km simulate sub-grid variability. In the results shown here, the model grids and the tiles are identical, either at 5km or 1km.

. 2.2. *Computational Considerations*

Clearly, executing global offline 1km or even 5km land surface models is a substantial effort. As shown in Table 1, the number of land grid points increases with increasing resolution from approximately 10^5 to 10^8. These increasing resource requirements, as stated earlier, have effectively prohibited high-resolution, urban scale global modeling. To meet this "Grand Challenge", the LIS software has undergone substantial redesign and parallelization, although even in single-processor mode, we have been able to achieve a factor of 10 reduction in memory and factor of 5 speedup compared to the most recent LDAS code, as shown in Table 2.

Table 1. Number of land grid points, and associated disk space and memory requirements for the LDAS system versus spatial resolution, based on the original LDAS code.

Resolution	1/4 deg	5 km	1 km
Land Grid Points	2.43E+05	5.73E+06	1.44E+08
Disk Space/Day (Gb)	1	28	694
Memory (Gb)	3	62	1561

Table 2. Reduction in memory and execution time on a single processor (GSFC SGI O200 "dew") for LIS v1.0 relative to LDAS May 2003 version for one day, 1/4 degree global run with the Noah land surface model.

	Memory	Wallclock time	CPU time
	(MB)	(minutes)	(minutes)
LDAS May 2003 Version	3169	116.7	115.8
LIS v1.0 (Milestone F)	313	22.0	21.8
reduction factor	10.1	5.3	5.3

. 2.3. *Modeling Configuration*

The focus of the modeling effort at this time is the year 2001, with a particular emphasis on the summer months. We have been experimenting with varying degrees of model spinup time, in addition to various forcing options, as described in detail by Rodell et al., 2003. In this preprint, we present results using only model-derived forcings from the NCEP GDAS.

3. RESULTS

Figure 2 illustrates latent heat flux from a typical ¼ degree resolution run of LIS with the VIC model, and here we focus on the southeastern U.S. portion of the global domain. Although certain areas of low evaporation and therefore low latent heat flux are evident, the Baltimore-Washington area, and the nearby Chesapeake Bay are not immediately evident at this resolution.

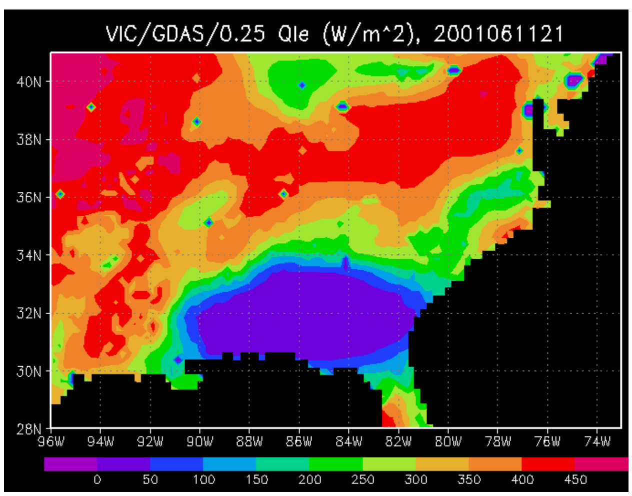

Figure 2. Latent heat flux (Qle) from the VIC model from a ¼ degree resolution global run using GDAS forcing.

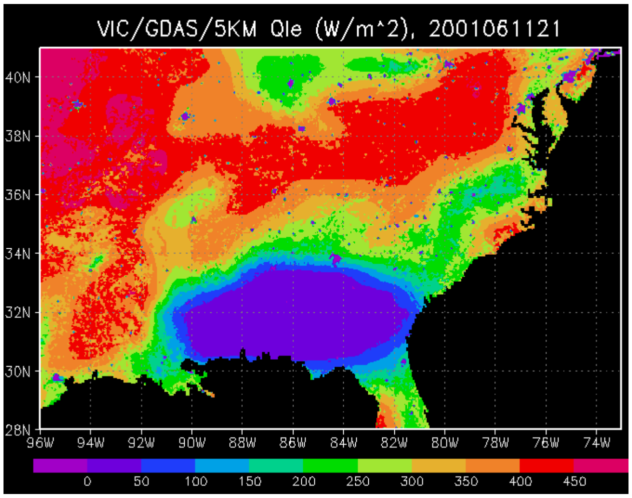

Figure 3. Same as Figure 2, but for 5km resolution.

Figure 3 illustrates the same domain for a global 5km execution of the same model. As one can clearly see, not only is the separation of Baltimore and Washington evident, but also other large and medium urban areas including Atlanta, Houston and Richmond and Petersburg, Virginia, for example, are now visible.

A key issue illustrated by these figures is that the VIC model tends to assign nearly zero latent heat flux (evaporation) to urban areas. This leads to the next set of results, which explore the variability in their urban area representation

Figure 4 shows the latent heat fluxes predicted by three land surface models in LIS at 15 (left column), 18 (middle column) and 21 UTC (right column). As noted in the caption, the Houston urban area results in substantially different latent heat fluxes depending on the model, with VIC effectively setting latent heat flux to zero, and CLM having no urban signal. Figure 5, which shows the corresponding sensible heat flux, suggests that the boundary layer structure and heights in a coupled land-atmosphere simulation would be quite different between the three models. These experiments will be discussed in more detail at the conference.

4. CONCLUSIONS

NASA's Goddard Space Flight Center has developed a Land Information System (LIS; http://lis.gsfc.nasa.gov) capable of modeling global land-

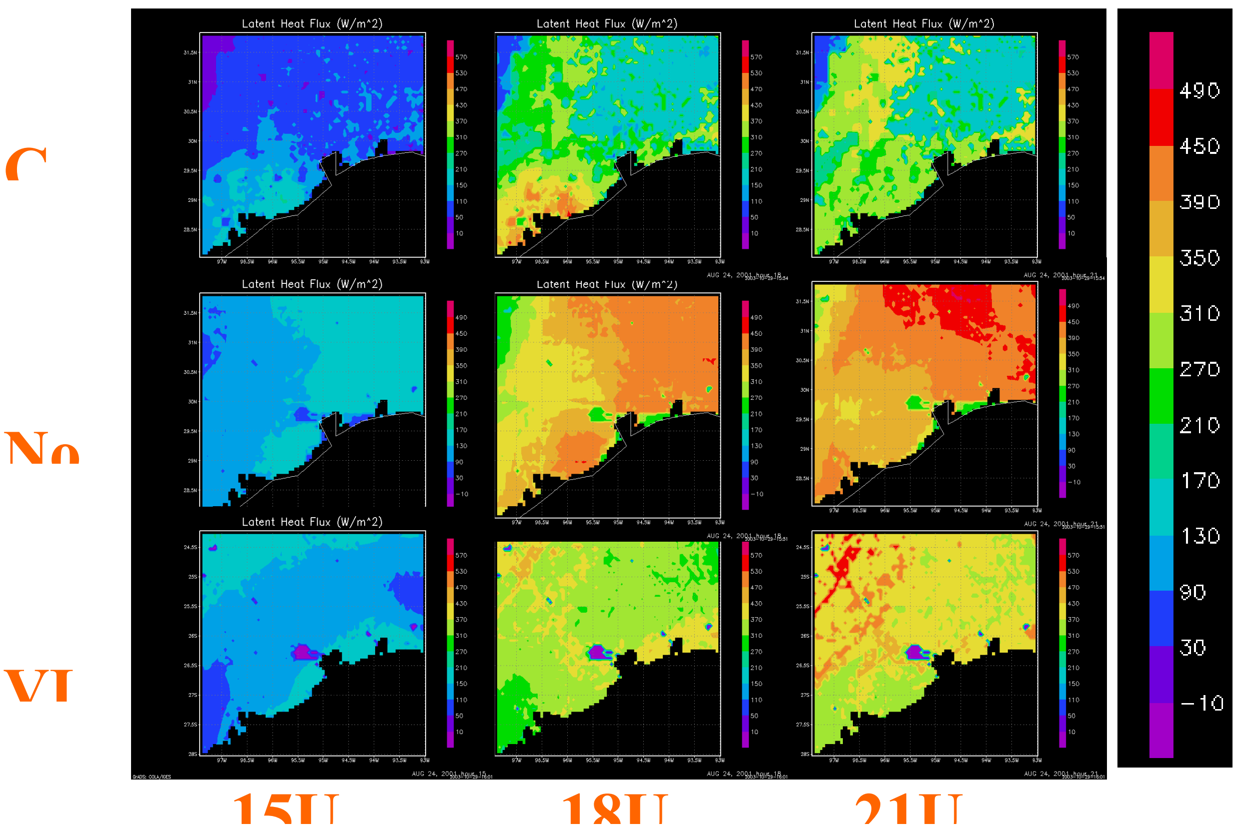

Figure 4. Daytime evolution of latent heat fluxes (Qle) from the CLM (top row), Noah (middle row), and VIC (bottom row) models for 15 UTC (left), 18 UTC (center) and 21 UTC (right). The VIC model seems to consistently predict zero or near-zero latent heat fluxes in the Houston urban area, while Noah predicts reduced fluxes, and CLM shows no urban signal.

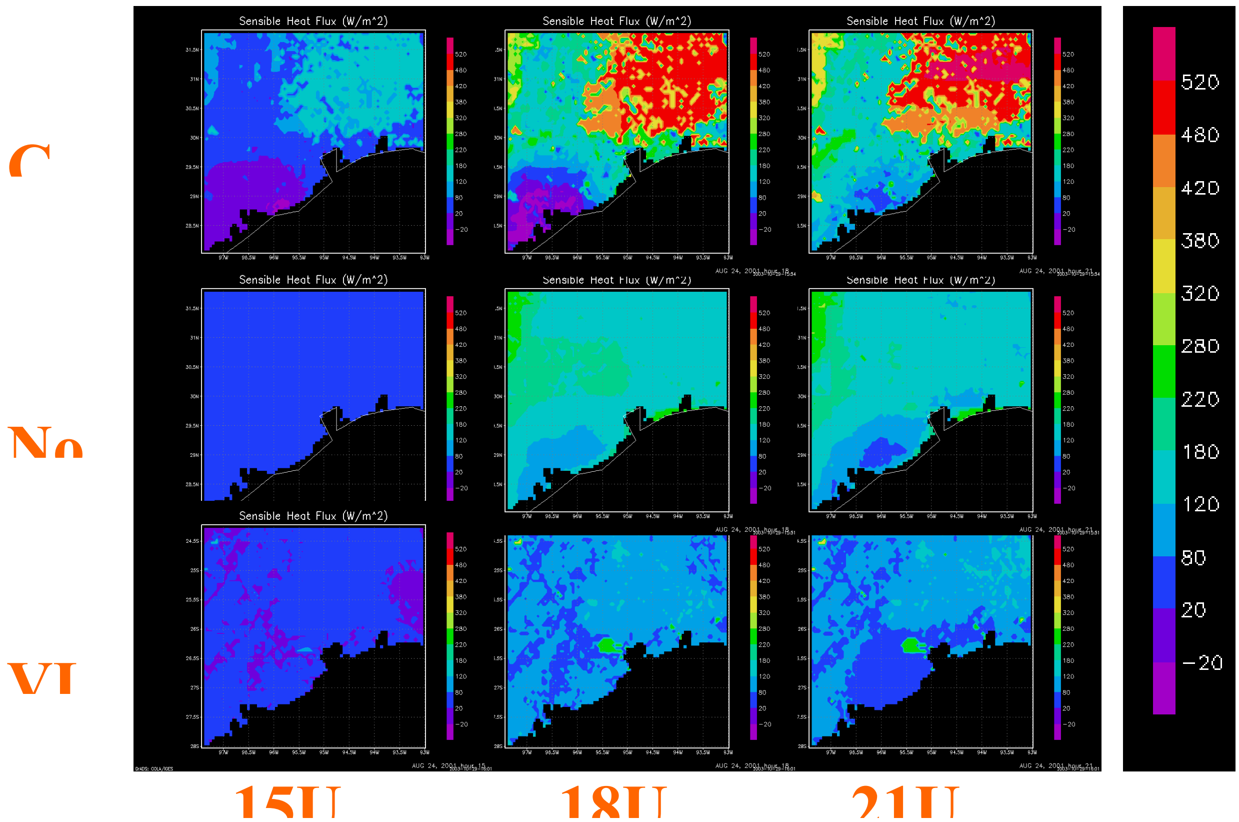

Figure 5. Same as Figure 4, but for Sensible Heat Flux (Qh). Contrast between the Houston urban area less than in Figure 4, but a very large Qh is seen to the NE of Houston.

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5. ACKNOWLEDGEMENTS

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