A High-Resolution Urban Canopy/Land-Surface Modeling System

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Introduction: Heterogeneities in land-surface characteristics that occur in transitions from a large coastal city to the suburbs and then to the rural countryside can significantly alter the lower portion of the atmosphere through mechanical and thermodynamical interactions. For example, urban-rural interfaces, both upwind and downwind of the urban region, are often preferred zones for the initiation of atmospheric convection or modification of ongoing convection.[1] Changes in the vertical profile of atmospheric static stability in the lowest portion of the atmosphere due to such heterogeneous surface forcing can have an important impact on transport and dispersion of potentially harmful chemical/biological agents. Thus, with a large percentage of the world's population living in coastal urban areas and an increasing emphasis of Naval fleet operations in coastal regions, an accurate characterization of high-resolution processes in numerical weather prediction models will greatly improve local forecasts for populations at risk as well as military operations.

Modeling System: To address these issues, the Marine Meteorology Division has developed new urban canopy and land-surface sub-models that are integrated into the Navy operational mesoscale numerical weather prediction model COAMPS®.* The sub-models use high-resolution land-surface databases characterizing differing vegetation and soil types,[2] time-varying sea surface temperature (SST), as well as building morphologies, anthropogenic heating, and street and roof characteristics.[3] The vegetation and soil component uses an advanced canopy resistance formulation to accurately determine the effectiveness for soil moisture to be released to the atmosphere via transpiration, which is one of the most efficient means of water loss from the vegetated land surface. The urban canopy acts as a friction source, represented via modified aerodynamic drag in the momentum equations, as well as a source of turbulence production to account for turbulence wake generation of turbulence kinetic energy. The urban thermal effects are from heat fluxes from rooftop, street, and building wall reflections.

Results: Because of its complex coastal land-surface characteristics, spatially and temporally varying atmospheric conditions, and prominent threat profile, the New York City (NYC) metropolitan area is chosen as a test bed to evaluate the new system. One particular feature of interest is the evolution and interaction of the sea breeze with the urban environment. Figure 6 shows a COAMPS® simulation of transport in the NYC region of five near-surface tracers continuously released starting at 00 UTC for a period in April 2005. This simulation clearly illustrates the complexities that can result in less than 24 hours. Winds generally from the west at 03 UTC transport all plumes rather uniformly to the east. However, winds shift to southeasterly by 21 UTC with the onset of the sea breeze and the plumes, though generally transported to the northwest, display significant differences. The influence of differing land and urban forcing on vertical velocity and stability profiles is clearly indicated in the increased vertical dispersion of the plume originating from Rockefeller Center as compared to the Financial District. Further evidence of the land-surface and urban effects is shown in Fig. 7, which illustrates the deformation and horizontal retardation of the propagation of the sea breeze front in Brooklyn and the vicinity of JFK airport. A vertical cross-section of two COAMPS® simulations (with and without the urban component of the sub-system) through the southern tip of Manhattan (Fig. 8) illustrates the urban canopy effects on the vertical stability and low-level wind flow. The local vertical circulation in the boxed region is enhanced using the urban component. In addition, high-resolution SST variations, such as induced by river run-off from the Hudson and East Rivers along with local discharge from storm drains, can result in SST anomalies that further alter the overlying atmospheric circulation.

Summary: The Marine Meteorology Division has developed new urban canopy and land-surface sub-models within COAMPS®. With this new modeling capability, the Navy will be able to analyze and predict atmospheric conditions in urban coastal areas at very high spatial resolution (~1 km) that has not been achieved before, thereby improving the prediction of the transport and dispersion of chem-bio agents, the performance of naval weapon sensors and systems, and human well-being and security. In addition, the Marine Meteorology Division participated in the second field experiment of the Department of Homeland Security New York City Urban Dispersion Program that occurred on August 6-24, 2005, in midtown Manhattan. This program provides a dense array of high resolution observations in a complex urban environment to better validate the new system. We will be using the observations taken in the NYC experiments and other upcoming field experiments to further our understanding of the complex urban environment and

*COAMPS® (Coupled/Ocean Atmosphere Mesoscale Prediction System) is a registered trademark of the Naval Research Laboratory.

to improve our capability to model the processes that generate these complex environmental states.

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References

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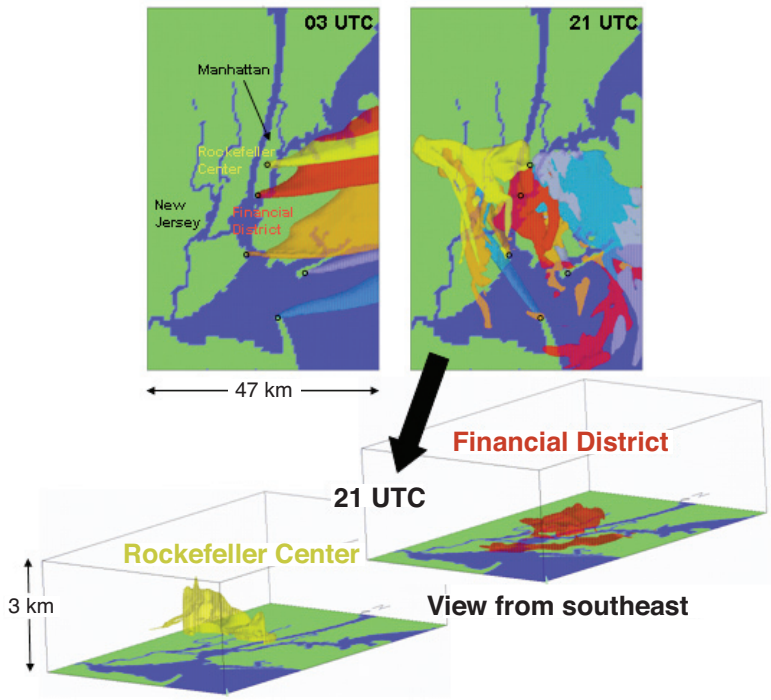

FIGURE 6
COAMPS® simulations of the 10 mg m^{-3} concentration isosurface at 03 and 21 UTC for continuous passive tracer releases at 2 m above ground level for five locations in the New York City region starting at 00 UTC April 18, 2005 (top), and the view from the southeast at 21 UTC for Rockefeller Center and the Financial District (bottom).

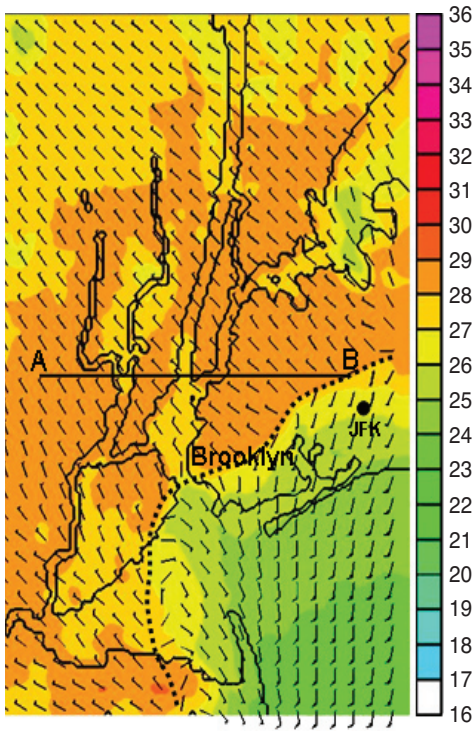

FIGURE 7
COAMPS® simulation of the 10-m winds and 2-m air temperature (deg C; color) valid 00 UTC August 5, 2004. The sea breeze front is indicated by the dashed line. The horizontal grid spacing is 444 m and every fifth wind barb is shown.

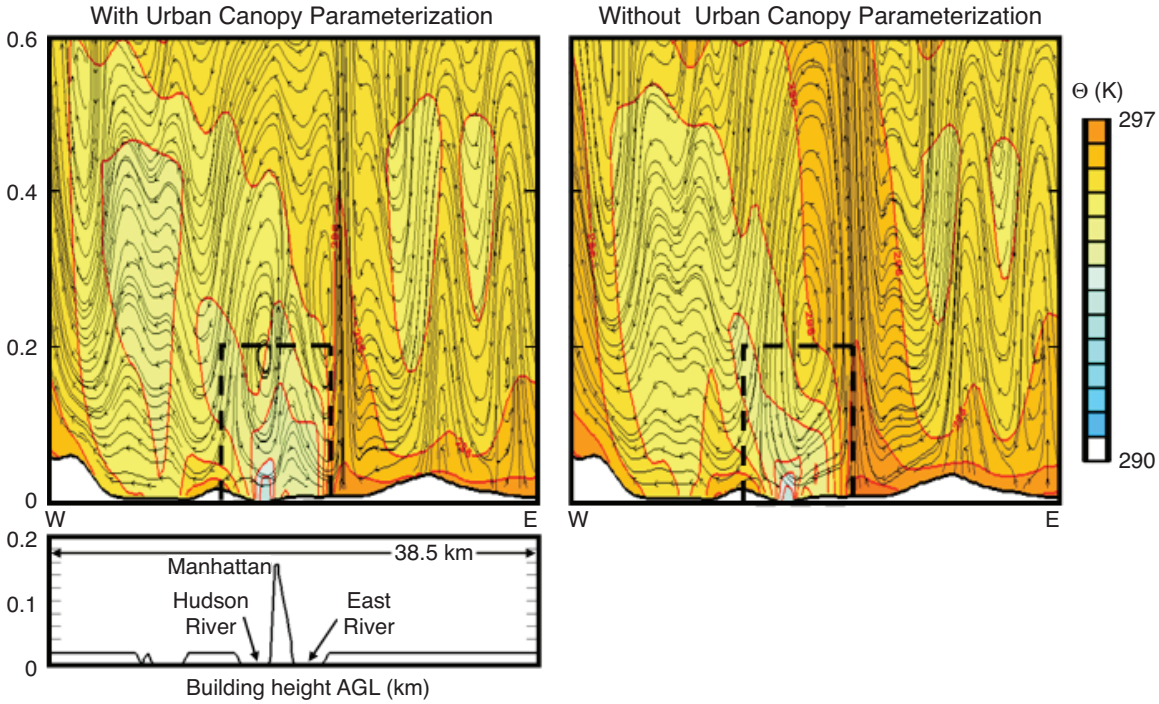

FIGURE 8
COAMPS® simulation of the wind streamlines and potential temperature (color) for the east-west cross section (A-B shown in Fig. 7) through the southern tip of Manhattan valid 17 UTC July 4, 2004. The left panel uses the COAMPS® urban parameterization with the building profile as shown below. The right panel does not use the urban parameterization. Note the differences in structure in the dashed region over the lowest 200 m of the atmosphere in the vicinity of the Hudson and East Rivers.