Linkages between the Urban Environment and Earth's Climate System

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Although currently only 1.2% of the land is considered urban, the spatial coverage and density of cities are expected to rapidly increase in the near future. The United Nations estimates that by the year 2025, 60% of the world's population will live in cities. Human activity in urban environments alters atmospheric composition; impacts components of the water cycle; and modifies the carbon cycle and ecosystems. However, our understanding of urbanization on the total Earth-climate system is incomplete. The U.S. Climate Change Science Program (CCSP) strategic plan states "…a world that is more populated, urban, and interconnected than ever…A more integrated understanding of the complex interactions of human societies and the Earth System is needed." Several issues or questions raised in the CCSP echo the aforementioned statement about the urban environment-climate system linkage:

1. How are land-use and land-cover are linked to climate and weather?
2. How do climate variability and change affect land use and land cover, and what are the potential feedbacks of changes in land use and land cover to climate?
3. How do the primary and secondary pollutants from the world's megacities and large-scale, non-urban emissions contribute to global atmospheric composition?
4. How are estimates of atmospheric composition and related processes to be used in assessments of the vulnerability of ecosystems to urban growth and long-range chemical transport?
5. What are climatic effects of temperature on air quality, particularly in urban heat islands and other regional settings, and the potential health consequences?

Additionally, a recent U.S. Weather Research Program report stated that there is a substantial need for more observational and modeling work to improve basic understanding of weather and climate impacts in the urban zone. Recent and upcoming international meetings in Lodz, Poland and Vancouver, British Columbia underscore the global interest in understanding the linkages between the urban environment and the climate system. Over fifty scientists from various interdisciplinary backgrounds and seven nations convened in San Francisco last December at the Fall American Geophysical Union meeting to discuss current data, scientific approaches and recent results on observing and modeling components of the urban environment.

To understand the urban-climate system linkage, an interdisciplinary effort combining in-situ and remote sensing, modeling, and human dimension assessments is ultimately required. Yet, modeling the Earth's climate system has been hampered by at least two reasons: (i) poor representation of the urban environment in global and regional climate models (GCMs and RCMs), and (ii) the difficulty obtaining detailed information on urban characteristics. Annemarie Schneider emphasized the need for new urban representation methodologies because common surrogate data sources for global cities in models, the Digital Chart of the World urban data is outdated, while the satellite nighttime lights data overestimates urban extent due the "blooming." With the advance of satellite observations (http://earth.nasa.gov), as discussed by Michael King, adding urban environmental factors into climate models becomes feasible and essential. Currently, an urban classification is not included in most of the major GCM/RCM's land surface models. This exclusion renders the models inadequate for realistically simulating urban modifications to climate. Robert Dickinson highlighted some of the benefits and challenges of including "urbanizing" climate models.

Modeling efforts at regional scales and smaller typically have poor urban classifications as well. Yet, at these scales the urban impact on weather and climate processes can be of first order significance. Sue Grimmond, Tim Oke, Sarah Roberts and other discussed recent advances with the implementation and verification of new capabilities like the Town Energy Balance (TEB) model. TEB uses local canyon geometry with surface and substrate radiative, thermal, moisture and roughness properties to simulate the effects produced by urban canopy. These processes are subsequently integrated to resolve the local scale surface energy balance in mesoscale atmospheric models.

It is well known that urban areas modify the surface energy balance and coupled boundary layer processes through the creation of an urban heat island (UHI). Study of UHIs has primarily focused on mid-latitude cities like St. Louis or London. The San Francisco meeting featured one of the first comprehensive studies of temperature and humidity distributions of a tropical city, Singapore, Malaysia. Preliminary findings suggest that there are significant differences in the magnitude and timing of the peak UHI in Singapore compared to mid-latitude cities. Menglin Jin discussed how satellite-derived skin temperature indicated that the largest urban impacts in terms of skin temperature are observed over the latitudinal band of 30-60 N, where most cities are located. In addition, her results showed that urban regions decrease surface albedo by 3-5% and decrease surface emissivity by 1-2%. Christina Milesi used satellite-derived temperatures and vegetation to illustrate that nighttime land surface temperatures consistently increased with the fractional impervious surface area. Others like Lela Preshad discussed how satellite temperature and vegetation measurements had revealed the emergence of urban-induced microclimates in Phoenix. Neighborhoods with low mean income, high Hispanic populations, and low educational attainment were hotter than high-income, non-Hispanic areas. Urban core areas with high income also correlate strongly with high amounts of vegetation (R=-.637) and have significantly lower surface and air temperatures than model projected UHIs. The suggestion is that neighborhoods with the means to alter their environments can produce amenable microclimates. Researchers from Japan even suggested that urban surfaces perturb not only surface temperatures but sub-surface temperatures as well. Surface thermal perturbations translate to atmospheric processes through fluxes in the boundary layer. Recent or planned campaigns like Basel Urban Boundary Layer Experiment (BUBBLE), Joint Urban 2003, and Houston Environmental Aerosol Thunderstorm project (HEAT) have enabled new capabilities to observe, characterize, and understand critical flux processes. BUBBLE was the first deployment of a new dual-channel infrared radiometer (DCIR) that measures the directional infrared radiation in two wavelength bands and produces a direct measurement of longwave radiative flux divergence. The meeting was also a forum for summarizing the most significant findings from measurements of energy, mass, and momentum exchanges taken during field campaigns across North America, Europe, and Africa.

There was also renewed debate on how the urban environment might affect precipitation variability. In recent decades, the literature has revealed evidence of urban-impacted precipitation processes. A range of scientists like Steve Burian, Parastou, Hooshialsadat, Marshall Shepherd, and Robert Bornstein discussed results corroborating and extending previous literature evidence of enhanced precipitation activity over and downwind of cities. Several mechanisms have been proposed to explain urban-impacted rainfall: enhanced convergence, boundary layer destabilization, increased aerosols, interaction with existing, or physical alteration. Daniel Rosenfeld suggested that urban particulates act to delay conversion of cloud water into precipitation. This is manifested in different ways under different circumstances. Orographic precipitation is suppressed, with some downwind compensation. Convective precipitation processes are delayed to greater heights in the clouds, respectively delaying the downdraft and allowing the clouds to invigorate further. This causes, in dry and unstable conditions, reduced precipitation due to very low precipitation efficiency, and in tropical and moist subtropical conditions, enhanced storm vigor (increased updrafts, rainfall, lightning). An important result of Rosenfeld's presentation is that it provides evidence of convergence in both the UHI-dynamics arguments and aerosol-microphysics arguments.

Human-related activities related to transportation, energy production, and industrial processes are the likely the sources for "urban" aerosols. A compelling body of evidence using ground and satellite data showed that aerosol optical thickness peaks during the middle of the week in New York City. This cycle is hypothesized to be related to increased transportation activity at the beginning of the business week. Emerging observational and modeling capabilities might be benchmarked in the decision support processes of the operational and applications communities. For example, it was demonstrated that satellite-derived columnar aerosol loading has shown good correlation (R=0.8-0.9) with Environmental Protection Agency (EPA) PM2.5 (particulate matter with particle size less than 2.5 mm) at the surface in urban areas like Houston, New York and Chicago.

Even the carbon cycle is sensitive to the urban environment. Urban land transformation in the U.S. has reduced the amount of carbon fixed through photosynthesis by 1.6 percent of pre-urban values, according to March Imhoff. This reduction nearly offsets the 1.8 percent gain made by the conversion of land to agricultural use. This is a striking fact given that urbanization covers less than 3% of the land in the U.S., while agricultural lands approach 29%. Using satellite data and a terrestrial carbon model, the impact of urbanization on net primary productivity (NPP) and its consequences on carbon balance and food production has been quantified. Urbanization is taking place on the most fertile lands and has a disproportionately large overall negative impact on regional and even continental scale NPP. In terms of biologically available energy, the loss of NPP due to urbanization alone is equivalent to the caloric requirement of about 6 percent of the U.S. population annually.

Urbanization will increase globally to reflect population migration to cities. The complexities of the Earth system are well known, but the relative influences and feedbacks of human-induced and natural forcings are not. Therefore, the renewed focus on the urban environment is timely and critical.