Impact of city size on precipitation-modifying potential

Paul E. Schmid[1] and Dev Niyogi[1]

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[1] This study investigates how increasing city size affects local weather modification potential using an innovative new method: the real atmosphere, idealized land-surface (RAIL) method. The RAIL method simplifies the land surface by making a flat, homogeneous land surface for a control simulation. Using the Regional Atmospheric Modeling System, an instance of weak linear convection was simulated over three nested grids with a minimum grid spacing of 0.75 km. Using the RAIL method, cities of radius 5 to 40 km were placed in the path of the simulated precipitation to study the impact. For the weak-convection case, the urban area effects showed urban heat island and urban moisture depression effects and produced regions of both precipitation suppression and invigoration downwind of the city. Modification increased up to a radius of 20 km and more slowly after indicating a threshold city size for urban modification on thunderstorms. **Citation:** Schmid, P. E., and D. Niyogi (2013), Impact of city size on precipitation-modifying potential, *Geophys. Res. Lett.*, *40*, doi:10.1002/grl.50656.

1. Introduction

[2] Urban areas are different enough from their surroundings to significantly modify their local climates. Steel and concrete buildings in urban cores absorb and radiate more heat than their surroundings, raising the temperature in city centers and creating the urban heat island (UHI) effect. The temperature increase also affects the surface energy balance, typically increasing sensible heat flux and reducing latent heat flux [*Shepherd*, 2005; *Shepherd et al.*, 2010b]. This can reduce the surface moisture in a city center creating the urban moisture depression.

[3] Precipitation around urban areas is affected by two factors: the urban-rural land-surface discontinuity and the effect of urban aerosols on cloud development. The heat island in the urban center creates rising air and convergence near the urban center, similar to a land-sea breeze [*Hidalgo et al.*, 2008]. These regions of rising and subsiding air trigger convection in stable air, but suppress existing systems [*Bornstein and Lin*, 2000; *Lo et al.*, 2007]. The combination of warmer temperatures and reduced moisture near city centers tends to decrease precipitation near city centers, but may act to increase precipitation slightly upwind and broadly downwind of a city [*Lin et al.*, 2008; *Hand and Shepherd*, 2009]. As city size increases, it can have an increased impact on storm modification. This is important both to present-day forecasts and to understanding the impact of growing cities on their local environments [*Shepherd et al.*, 2010a; *Aliaga et al.*, 2013].

[4] The urban aerosol effects are more complex and can affect precipitation both near the city and downwind [*van den Heever and Cotton*, 2007; *Jin et al.*, 2005]. The particular distribution of urban aerosols may act to suppress convection, invigorate it, or both in different downwind regions [*Rosenfeld et al.*, 2008; *Tao et al.*, 2012]. The combined effects of land-surface discontinuity and aerosols produce regions of both increased and decreased precipitation seen in long-term observations [*Changnon et al.*, 1976; *Kishtawal et al.*, 2010; *Niyogi et al.*, 2011].

2. Methodology

[5] This study uses the Regional Atmospheric Modeling System [*Pielke et al.*, 1992; *Cotton et al.*, 2003], a nonhydrostatic, cloud-resolving modeling system, capable of simulating the land-surface interaction with thunderstorms. The Town Energy Budget [*Masson*, 2000] urban canopy model has been coupled to the Land Ecosystem-Atmosphere Feedback parameterization version 3 (LEAF-3) [*Walko et al.*, 2000; *Walko and Tremback*, 2005], with two urban land-surface types to represent a dense urban core and typical suburban land surface. The microphysical parameterization uses the bin-emulating Colorado State University scheme with 7 two-moment hydrometeor types and two modes of nucleating aerosols [*Meyers et al.*, 1997; *Saleeby and Cotton*, 2004] and a binned riming scheme [*Saleeby and Cotton*, 2008], representing what is observed in urban areas [*Hobbs et al.*, 1980].

[6] For all simulations, the small (CCN - cloud condensation nuclei) and large (GCCN - giant cloud condensation nuclei) aerosol modes are initialized homogeneously in space, varying in height, with maximum values of $1000\,\mathrm{cm}^{-3}$ and $1000\,\mathrm{m}^{-3}$, respectively, typical values for an urban area. A chemistry model, the Simple Photochemical Module (SPM) [*de Freitas et al.*, 2005], is attached to the model, but not coupled with the cloud physics in order to track particle dispersion (typical of CCN and GCCN) near the urban area independently of en(de)trainment. The model utilized *Klemp and Wilhelmson* [1978] lateral boundary conditions, *Mellor and Yamada* [1982] turbulence closure, and the *Harrington* [1997] radiative parameterization in all grids described below.

[7] Given the shortcomings of urban-thunderstorm sensitivity modeling, this study introduces a new technique: the real atmosphere, idealized land-surface (RAIL) method. The RAIL method initializes the atmospheric component of a numerical model with 3-D, heterogeneously variable data, but keeps the land component as simple as possible. In order to minimize nonurban effects, the terrain is completely flat (200 m above sea level), and only three land-surface types are used: crops and two urban types. The "control" for this

[1]Department of Earth and Atmospheric Sciences, Purdue University, West Lafayette, Indiana, USA.

Corresponding author: P. E. Schmid, Department of Earth and Atmospheric Sciences, Purdue University, 550 Stadium Mall Dr., West Lafayette, IN 47906-2051, USA. (pschmid@purdue.edu)

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