PERSPECTIVE ON URBAN CANOPY MODELING FOR WEATHER CLIMATE AND AIR QUALITY APPLICATIONS

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1. INTRODUCTION

Climate changes, limited resources and increasing population are major issues impacting society and our environment. Current models available for weather, climate and air quality applications are powerful state-of-science modeling systems can be employed as assessment tools to address the impact of these issues. This extended abstract of this poster includes highlights from and summarizes major points of a recently published paper (Ching 2013) which reviews examples of community-based publically available modeling systems, and given that urban areas are now home to more than half the worlds population, a focus on their utilization for urban applications. Such models will require special attention to the complexities and high degree of spatial inhomogeneities of the underlying surface areas. Such applications optimally require relatively fine grid meshes and scale appropriate science description for the varied and complex land surface atmospheric processes commensurate to the fine scale land surface variability structure. For this poster, limitations as well as innovative opportunities specific to the optimal operations of these urban systems, with focus on fine mesh size and data needs and an initial collaborative prototype as an effort to develop a worldwide urban database for global coverage of city specific gridded morphology are identified and discussed.

2. COMMUNITY-BASED STATE-OF-SCIENCE MODELS FOR WEATHER: U-WRF AND CLIMATE: CAM-CLMU AND AIR QUALITY CMAQ AND WRF-CHEM.

Here, we focus on mature, major worldwide community-based modeling systems for climate and weather e.g., the Community Atmospheric Models' Urban Climate and Land Use CLM-U climate (CESM) and the Weather Research and Forecasting (WRF) system, (WRF: www.WRF.com), weather modeling systems. There are also similarly configured community systems for air quality, e.g., the Community Multiscale Air Quality (CMAQ) (cmaq-model.org) and WRF-Chem (acd.ucar.edu/WRF-Chem). These powerful state-of-science based systems provide a framework for meeting the challenges of population growth, climate changes, air quality, urban sustainability, livability, and human comfort confronting decision makers and society. These systems are generally similarly designed; they each have a set of requisite preprocessors with interface links to the core system and post-processing systems. State-of-science in both preprocessors and core is maintained in timely updates called "Versions"; these updates come from contributions from their respective communities. Major attributes of each system include a dynamic development framework for introducing science upgrades, options for multi-scale applications (with domain nests), and that they are open source. These systems, and their versions, are available as downloads; user-friendly setup and controls allow choices of available science options, and updates to documentation provide transparency to the underlying science. Each system provides community support infrastructure through annual workshops and tutorial services at NCAR and for CMAQ and affiliated models, by the CMAS Center in Chapel Hill, NC, www.cmascenter.org. The feedback between meteorology and chemistry core processing and the means to assimilate data are on-going challenges that are currently being addressed.

Customized applications throughout the world are nuanced, and each of these model tools

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will in large part be dependent on the input data. Each system has provisions for requisite data inputs including initial and boundary conditions and emissions (air quality systems), and static information such as land use classes, terrain, vegetation, be it through available standard table lookups derived from a variety of data sources including remotely sensed data from satellites as well as from customized inputs. The set up and application of each system requires that their specific requirements need to be understood and fulfilled; e.g., (a) model outcomes are scale dependent; the response time scale differs for different applications. (b) Specifics regarding data forms, as well as their availability and spatial/temporal coverage will affect model outcomes and (c) We cannot depend on remote sensing (e.g., satellite data alone, as their outputs may not be representing what is needed. With care, both systems can be set up for appropriately addressing specific issues, thus, meeting the requirements of being fit for purpose.

There are at least three major considerations when applying these modeling tools for urban modeling applications. First, the spatial complexity of the underlying surfaces must be addressed, and a similar regard for emission details for air quality modeling. Second, the grid resolution must be commensurate with the desired outcome; spatial gradients of both the inputs and thus the output fields tend to be highly complex in urban areas. So, for any grid resolution, the unresolved subgrid information content can be quite large

Third, and for the remainder of this discussion, we focus on the specialized data requirements for urban modeling. Commensurate with current urban models, models are cast in terms of the underlying urban morphology in each grid. Given the existence of urban building-street canyons and the interspersed vegetation, the fundamental equations for flow, thermodynamics and radiation are required, and moisture has now been recast with treatment for the influences of these morphological features using urban canopy parameterizations or UCPs (Dupont et al., 2004; Otte et al., 2004 Martilli et al., 2002). A schematic of this framework is shown in Fig. 1. A relatively large effort to provide gridded UCPs has been undertaken in the Prototype NUDAPT project (Ching et al., 2009). On September 11, 2001, the terrorist attack in NYC and Washington DC prompted the need for the USA to be proactive in developing advanced modeling tools for urban applications. A survey conducted by the Board of the Urban Environment (BUE) of the American Meteorological Society (AMS) resulted in an Initiative to the Office of the Federal Coordinator for Meteorology (OFCM) for a supporting database to the MM5, now WRF. The US Environmental Protection Agency (USEPA) responded, and in a collaboration of representatives from private, academic and public agency(s), formed a Consortium to develop an initial prototype of an urban modeling database. This Consortium embraced the concept of a community-based system and called their implementation the National Urban Database and Access Portal Tools (NUDAPT). Elements of this Prototype included a detailed effort by the USEPA for the collection and processing of a special urban canopy dataset of urban canopy parameters for Houston TX. Other agencies contributed and the National Building Statistics Database (NBSD) (Burian et al., 2007) emerged with leadership and guidance of Mike Brown of Los Alamos National Laboratory. NBSD was derived from airborne lidar data of buildings data for 44 (of the 133 cities) collected by USA Federal agencies under the auspices of the Nunn-Luger -Domenici Act (Defense against Weapons of Mass Destruction Act of 1996). The resulting sets of UCPs were gridded at 1 km and 250 meter grids; they focused on each city's high-density building districts. Recently, NCAR agreed to host this data set and make it available to its community mesoscale modeling system, the WRF. A current effort to implement and deploy the NUDAPT gridded UCPs for 44 USA cities into the WRF model (Glotfelty et al., 2012) is shown in Fig. 2. This effort has been completed and available to be used in the 2013 WRF release.

Greater specificity on surface composition such as building roof and wall construction materials are essential for accurate modeling of the all important urban surface energy components (Fig 3) used in the CLM-U (Jackson et al., (2010), the urban subcomponent of the Community Environmental System Model are being implemented at NCAR; Fig. 4 provides the climate modeling database framework for this implementation. CLM-U is highly detailed, including for example, much and comprehensive information on buildings and structural materials such as highly modernized "green materials" as well as from locally sourced materials common to their geographic locations, with different thermal properties. Given the CLM-U scale of coverage, geographic and population density information on a global basis covering all climatic regions is introduced. CLM-U is thus designed to be able to predict the degree and characteristic of each city's urban metabolism and thus their cities and their own unique heat islands, thermal canopy layers and climates.

Currently in NUDAPT, the spatial coverage of the gridded UCP is in each of the cities is limited, and while large in numbers, only covers 44 USA cities. As a base map, it does provide a capability for dynamic growth scenarios. There is need for improvement to the specification of urban land use fractions; in particular, LU schemes in models (dominant vs fractional) need to be reviewed**.** In CLM-U, while the current tables are highly detailed, coverage is worldwide, and the quality of inputs varies greatly. In general, extensibility to more cities and greater areal coverage is a high priority for mesoscale and climate models. Further efforts to explore the merging and enhancing capabilities of existing CLM-U and NUDAPT is highly desirable, especially to enhance it with geometric morphology (NUDAPT) and urban properties (CLM-U) from each system. Ideally, and for the purpose of utilizing the power of these new urban modeling systems as planning and assessment tools, it would be highly desirable for obtaining and generating a database coverage of UCPs and detailed materials for buildings and other urban morphological structures for cities, worldwide, and especially for those in developing countries. In the next section, we explore and suggest several innovations and technologies that can potentially be employed to achieve this objective.

3 WUDAPT: CONCEPTUAL FRAMEWORK FOR URBAN DATABASES ON A GLOBAL SCALE

In this section, we explore the generic requirements for meeting the urban data requirements for both WRF-U and CLM-U. Our objective is to make real the capabilities of WRF-U and CLM-U as modeling tools capable of providing robust assessments for urban planners dealing with major issues including climate change, population growth for their specific urban area of concern, and for any and all urban areas in the world. For this worldwide scope, we suggest the term WUDAPT for World-Wide Urban Database and Access Portal tools, which has similarity but a wider scope and somewhat different development strategies to NUDAPT.

In particular, we discuss and explore two key properties (worldwide in scope and yet retaining and characterizing the unique characteristic of each and every urban area) and several recent technical innovations making possible this desired community database. The first property of WUDAPT is its worldwide coverage of necessary gridded information about urban morphology and composition, and in this respect, the IAUC has the potential to play a critical role (Fig.7). The second (MRA) is an innovative new technology, (Mouzourides, et al., 2012) which provides the ability to retain and quantify the unique character of each and every city, and as a function of grid size. Cities are unique; it is an interesting exercise to attempt to define the character and attributes of any given urban area (Fig.5). For many, cities have historical and cultural merits; for others it might be the seat of geopolitical power, or an important center of commerce. These characterizations are qualitatively based. We are now aware of a promising new capability with the ability to quantify “uniqueness”. Based on Wavelet theory, and using various combinations of morphological parameters, the multi- resolution analysis technique (Mouzourides et al., 2012, 2013) provide grid scale characterizations called “Approximations” of properties of urban morphological fields and important subgrid descriptions called “Details” at each grid scale (Fig 5). Further, the subgrid information provides the basis for sequentially finer grid characterizations, and its concomitant subgrid details. Current UCPs in mesoscale models attempt to capture major and important “structural” and “material” features with urban canopy parameters controlling momentum, thermodynamics and energetics of the flow. Mesoscale models with urban options may treat UCPs differently, via categorization using dominant land use vs fractional-mosaic (partitioning) approaches. Important aspects of subgrid “details” are ignored; future improvements to models might include the incorporation of sub-grid morphological features perhaps aggregated into canopy parameterizations that have some “meaning” in the forcing equations. The MRA provides an innovative means to perform forensic analyses and descriptions of any urban area, in essence, the DNA-like description of a city (Mouzourides, 2012, 2013). For models, the MRA provides gridded and scaled attributes as well as subgrid information and for a hierarchy of grid sizes. The MRA can, in principle, provide a powerful means to explore and utilize information at the subgrid scale to inform the mesoscale analyses, a very powerful resource for multi-scale modeling studies.

(b) Conceptual proposal (Fig. 8) for an international database of urban parameters for advanced community weather and climate models. When viewed by urban planners around the world, grid models can provide important tools to provide guidance when dealing with all issues to which they are confronted. State-of-science community-based models are available, and their science basis and capabilities continue to be advanced. What are required are the all important model inputs to apply these models successfully. Look-up table based on land use classification schemes provide default values; gridded inputs reflecting actual values at each grid in the modeling domain are preferable, and studies show that their use provides significantly superior model results. We ponder a strategy and tactical approaches to meet this challenge; and outline a conceptual framework and an implementation strategy by which to achieve this goal. At the outset, we seek model domain-wide gridded urban canopy parameters and details on materials in building and morphological structures. This can be a costly venture; to address this problem, we suggest the following implementation framework based upon incorporating elements of Local Climate Zones (LCZ) described in Stewart and Oke, (2012), (Fig 6) remotely sensed information such as that found in Google Earth, and the use of Geo-Wiki technology (Fritz et al., 2012). Conceptually, a tactical strategy would be to (a) map LCZ parameters onto model grids, rectifying the broad ranges of canopy parameters in LCZ with remotely sensed databases such as those available in Google Earth (b) presume or develop relationships linking the gridded LCZ to a set of UCPs and (c) adapt for use by local observers using specialized mobile geo-referenced (GPS) APPs, the urban Geo-Wiki system. The latter step provides an on-site, "boots-on-the-ground" strategy to obtain quantitative details and or verification of the critical urban canopy parameters and material contents for the different morphological features. The advantages are that:

- LCZ are relatively quick, expedient and inexpensive to generate; this results in huge cost benefits and potential worldwide scope.
- Makes possible use of advanced meso-urban modeling tools in areas with little data and resources to generate such data.
- Data generated for each city can yield significant model improvement over current lookup table schemes.

The resulting grid-by-grid data will include the desired suite of parameter information including building heights, street widths, urban content and areal extent (fraction) of urbanization. Information is relayed and downloaded to a database system and with standardization and final quality assurance; a database is created for a city. In principal, by engaging a network of international urban partners in collaboration, it is conceivable to expand this database to cities in all parts of the world, the coverage only dependent on the level and extent of community involvement (Fig 8).

4. SUMMARY AND PATH FORWARD:

An initial "proof of concept" implementation for Dublin, Ireland utilizing this approach is shown in Fig 9. Moving forward, we contemplate preparatory efforts (Prototype) to consist of testing the full development and deploying of the steps outlined in Fig 7 for Dublin, and if possible, one or two other cities. An important component in this activity would be the setting up of the database system. Initially, several interested collaborators from different cities around the world are now engaged in efforts to help develop and streamline the implementation procedure based on their efforts for their city of interest. Subsequently, we envision the scope of this effort to expand; after an assessment of the Prototype, by extending a general invitation to our urban community to become engaged to achieve the desired worldwide database coverage (Fig 8). An important element in this overall scheme is to grow the acceptance and support of the Community, including users and sponsors. In this stage, we can anticipate the database to grow in coverage as the benefits of participation in this community system become apparent. Further, since urbanization is dynamic as current cities evolve and new ones are created, updates will be necessary, but achievable given that each city will have their initial baseline datasets.

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6. FIGURES

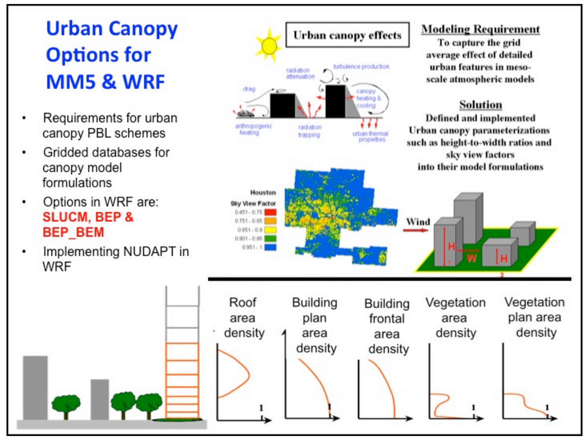

Fig. 1: Urban canopy in models

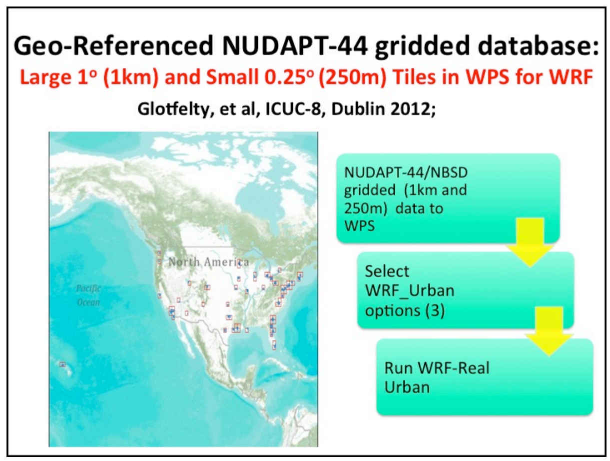

Fig. 2: NUDAPT 44 gridded database for WRF.

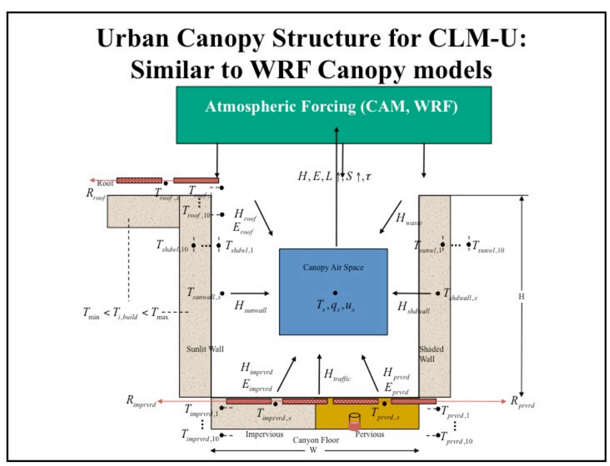

Fig 3: Urban canopy structure for CLM-U.

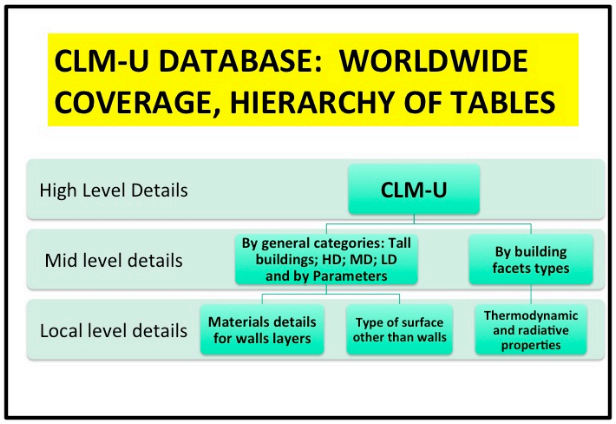

Fig 4: Data Tables for CLM-U

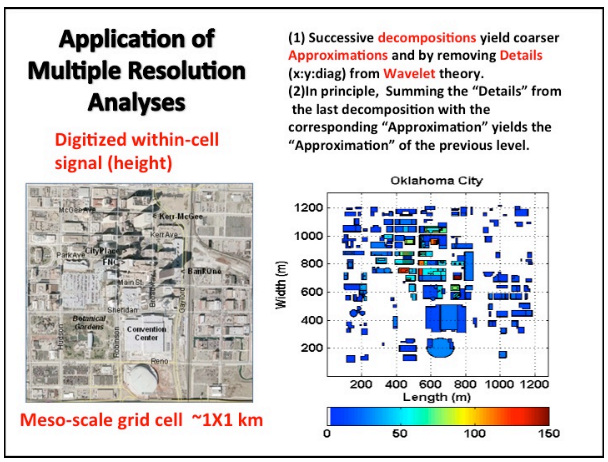

Fig 5: MRA Methodology

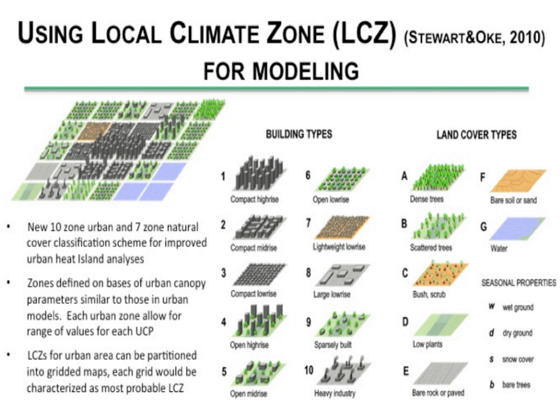

Fig 6: Local Climate Zones (LCZ)

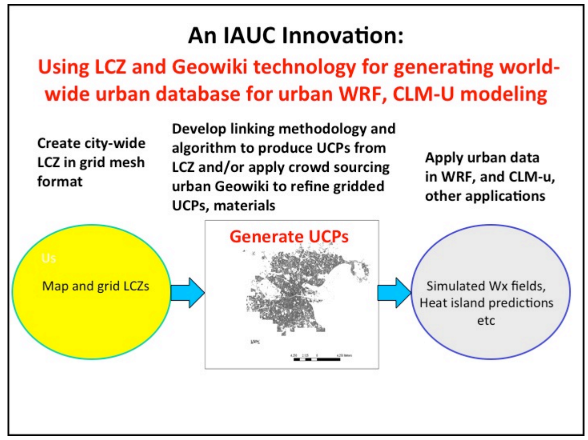

Fig 7: IAUC Innovative Project for a worldwide urban canopy database

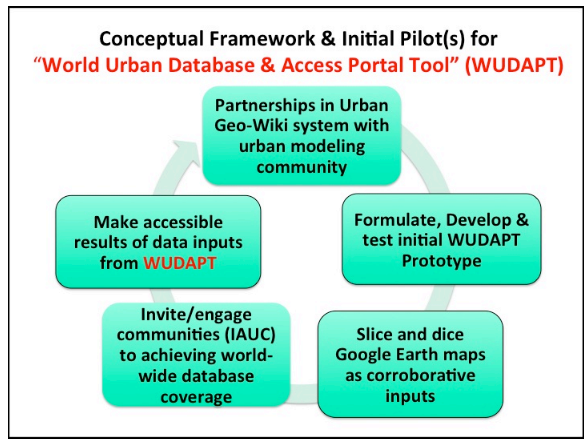

Fig 8: WUDAPT Conceptual Framework

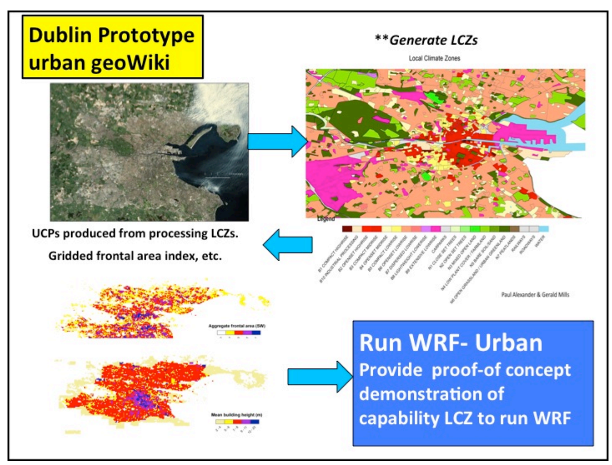

Fig 9: WUDAPT Prototype demonstration