5.3 MICROSCALE MODELING NEEDS FOR DIGITIZED SURFACE FEATURE MORPHOLOGY – URBAN AND RURAL

Ronald M. Cionco
US Army Research Laboratory
White Sands Missile Range, NM 88002

1. INTRODUCTION

The most recent report (Ching et al, 2005) on the effort to define and consolidate the needs of all agencies for digitized morphological data sets as required by meteorological and diffusion modelers and users reflects a very strong emphasis on meso-scale and CFD model requirements. The development of a plan for this 'standardized' National Data Base (of Morphology)' as currently described may not include data types required as inputs to micro-scale models and similar analyses that numerous federal agencies, military entities, academia, and private industry so desperately need. Organizations and agencies that do or should focus on micro-scale modeling and analyses include US Army small area field operations, US Department of Agriculture, US Forest Service (USDA), Urban Forest Centers, city planers of new urban development, energy and nuclear facilities, first responders (HAZMAT, etc), and more generally speaking, Homeland Security entities. I should note that not all of these organizations have come to that realization. If a National Plan for a 'standardized' data base is to be achieved, then it must satisfy the needs, at the very least, for all federal groups: civilian and military.

So what is the point of this discussion?
- Point one is that the microscale data is not being included in the Proposed National Data Base. Its present form will include only mesoscale and CFD equivalent data sets.
- Point two is that the coarse, 1KM mesoscale information can not be subdivided to say a 10 x 10 array of finer morphology values to satisfy microscale requirements. We also know that the mesoscale approach has been to parameterize the underlying surface features as single values of roughness, heat flux, albedo, etc. These parameterizations do not readily match the required microscale type of data in resolution, variety, and scale.
- Point three is that the ultra high CFD resolution of near exact building measurements and footprints can not be aggregated into larger, coarser cells of a 100m x 100m (or 50m x 50m) in an easy and accurate manner. An additional problem is that the co-existing undefined areas of 'morphology' will become a non-quantifiable part of the 100m x 100m cell in many cases. The effort to define these unknowns has not yet been implemented.
- Point four is that there are numerous organizations that do or should operate on the microscale; they will not have access to their scale of morphology data sets such as the mesoscale and CFD modelers will have.

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*Corresponding author address: Ronald M. Cionco ATTN: AMSRD-CI-EM, US Army Research Laboratory White Sands Missile, NM 88002

2. METEOROLOGICAL SCALES VERSUS MORPHOLOGY TYPES

The scope of this National Data Base must include the meso-scale and the micro-scale domains and the three sub-division of each scale (alpha, beta, and gamma) as proposed some years ago by Orlanski (1975).

2.1 Meteorological scales

Although Orlanski divided the macroscale, mesoscale, and microscales into three subdivisions, we will concern ourselves only with the meso-beta, meso-gamma, micro-alpha, micro-beta, and micro-gamma scales. These scales represent what could be the intended scope of the National Data Base Project for standardized morphological data sets:

- meso-beta grid spacing > 2km
- meso-gamma grid spacing nominally of 1km
- micro-alpha grid spacing of 50 to 100m
- micro-beta grid spacing of 50 to 100m with vertical canopy elements
- micro-gamma grid spacing of a few meters to define individual structures

2.2 Morphology types by scales

The characteristics, properties, and format of digitized surface feature morphology for micro-scale usage differ from the coarse grid size and limited morphology types of the meso-scale as well as the ultra-high resolution of the CFD scale's building dimensions and footprints and their certain disregard for morphology other than just buildings. The CFD scale can be assigned to the micro-gamma scale.

Our community uses names that tend to convey different expressions of surface features. Land use is used extensively and land use/land cover is meant to be more definitive. They define the functional aspects of the surface features. Neither of these terms truly defines the physical quantification of these surface features for use as inputs into wind and diffusion models/codes. For example, the land use category of Urban or Built-up land does not provide quantifiable information that models require in a digital format to compliment grided terrain elevation as input information. According to urban geographers, the term ‘morphology’ describes the surface features in a structural way that can be quantified for model input. This is the type of digital data that can be input into meteorological and diffusion models/codes.

Differences between existing schemes of morphological types among the three scales are briefly described below:

a.) Meso-beta and gamma usually has for the above grid spacing 7-8 very generic land use types (derived from USGS); the CALMET model, in particular, has 14 generic land use categories (derived from USGS) and associated geophysical parameters; the EPA Houston Project has some 20 quantifiable characteristics of Urban Canopy Parameters (UCP derived from Burian et al, 2003);

b.) Micro-alpha and beta typically have 17 building types and some 20+ other physical features such as grass, shrubs, several tree-types, and simple surfaces such as bare soil, water surfaces, marsh, and impervious surfaces (streets, highways, parking areas, and gathering spaces); physical heights and footprints, where appropriate, are also part of the data per each element derived from Cionco and Ellefsen,(1998); and

c.) Micro-gamma for the CBD-centric, CFD scale typically addresses only building dimensions and footprints (derived by NGA from LIDAR flyover data), however, all other morphological features are undefined; recently the FEM3MP modelers (Chan et al, 2005) are attempting to include vegetation types to compliment the building data.

The scheme derived for the Houston urban domain is a much-improved way to quantify urban canopy elements. It will have to be expanded to include other co-existing morphology types such as bare soil, water surfaces, marsh areas which each have different surface drag and thermo properties that the models may also address.

The Salt Lake City domain is offered to compare land use and morphology distributions for different grid resolutions in graphical form. Figure 1 presents part (380Km x 380Km) of a large mesoscale domain centered on Salt Lake City. Grid spacing of CALMET’s plotted land use data is 2.5Km. The land use areas are coded as red for urban/built-up land (that is buildings), green for forested land, yellow for rangeland, brown for barren land, blue for small water bodies, and white for perennial snow or ice areas. Clearly, the mesoscale requires both rural and urban land use information for its analysis. The Great Salt Lake is prominent and to the northwest of Salt Lake City. Note the 10Km x 10Km box imposed over the downtown area. We will focus on the limited area in subsequent figures. Figure 2 is a close-up of the middle section of figure 1 so that one can more easily discern the coarseness of the 2.5km grided data. The 10Km x 10Km box shows a four x four array of land use information. Figure 3 zooms in even closer so that we can inspect land use information with 1Km resolution within the same10Km x 10Km box. The same color code is applicable in this figure as given for Figures 1 and 2. Even at 1Km resolution, there are only two dominant types of land use: urban and rangeland areas (along with one cell each of forested land and barren land).

Shifting to the CFD scale of the same 10Km x 10Km box, the LIDAR flyover images are reduced to near-exact building dimensions and footprints on the order of meters. Figure 4 displays the individual buildings and their pin-point locations. Shades of red are used to offer some idea of building heights of the CBD given in modest increments. The remaining areas of white are undefined areas of urban and rural morphology. Along with the individual buildings, one can easily discern well-organized street paths and highways and the appearance of city blocks. But what are the other urban elements that are not represented?

Before we move to the microscale and its morphological properties and characteristics, a discussion of this topic is offered in order to understand yet another representation and classification scheme for surface land features when addressing grid spacing of 100m and 50m. It should become apparent that the coarseness of the mesoscale information cannot be readily subdivided with finer microscale cells. Nor can the ultra high resolution of the CFD scale data be aggregated to the microscale’s 100m and 50m-grid spacing especially when much of a selected domain can contain areas of undefined elements.

3. STRUCTURE OF MICROSCALE DATA

In that the scope and formats of the morphology data for both the mesoscale and the CFD scale are more commonly known, a short discussion of the scope and formats of microscale morphology also may be helpful. The present scheme is a combination of present model requirements described by Cionco and earlier work by Ellefsen (1990-91) that are reported as the essence of papers by Cionco and Ellefsen (1998 and 2002).

3.1 Components of the morphology data base

The basis of the Army scale data base is composed of some 20+ morphological properties and characteristics and Ellefsen’s Urban Terrain Zones (UTZ). The data are identified and documented for a grided array of cells that are typically 100m x100m cells and more recently for 50m x 50m cells. For either resolution, the procedure is the same as given below. See the Tables of attributes and building types that follow for details.

From the point of view and intended use of this morphology, some 20+ properties and characteristics have been developed to provide reasonable quantitative sets of information for a microscale high-resolution wind model

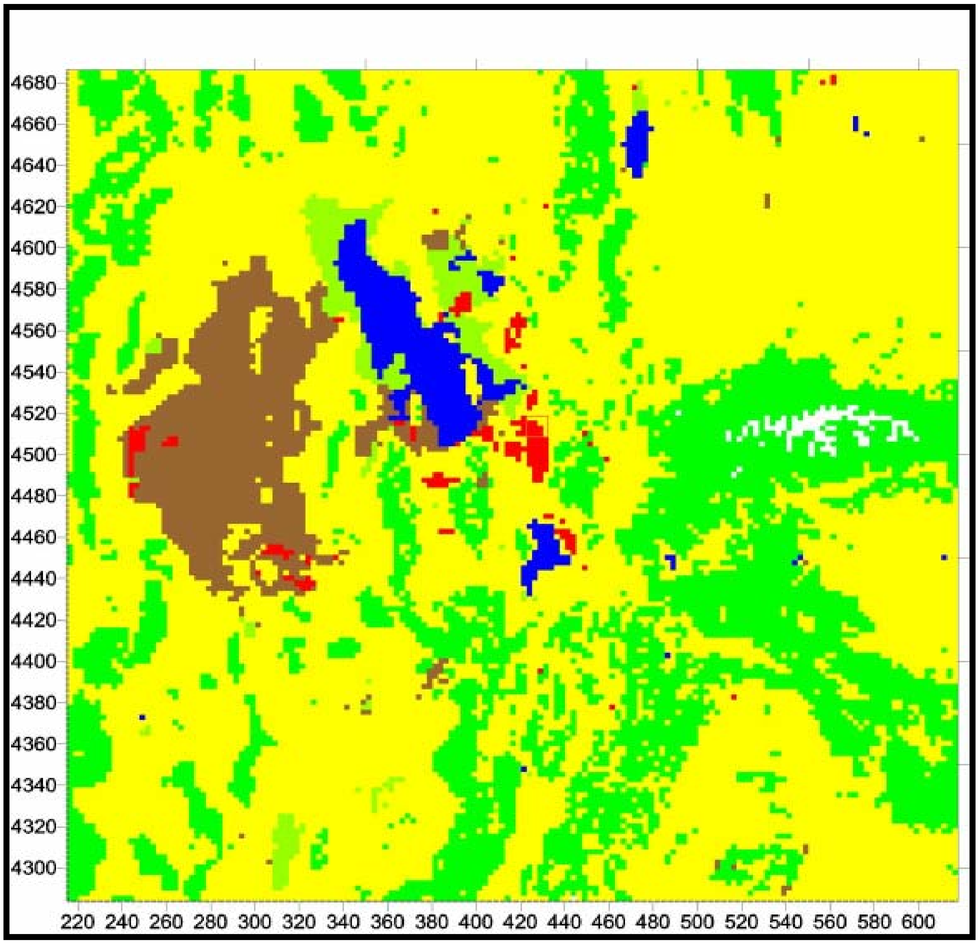


Figure 1. The Mesoscale domain of land use for 2.5Km grid spacing within an area of 380Km x 380Km centered on Salt Lake City, UT. (Red = urban, Green = forest, Yellow = range land. Blue = water. Brown = barren land, White = perennial snow or ice areas)

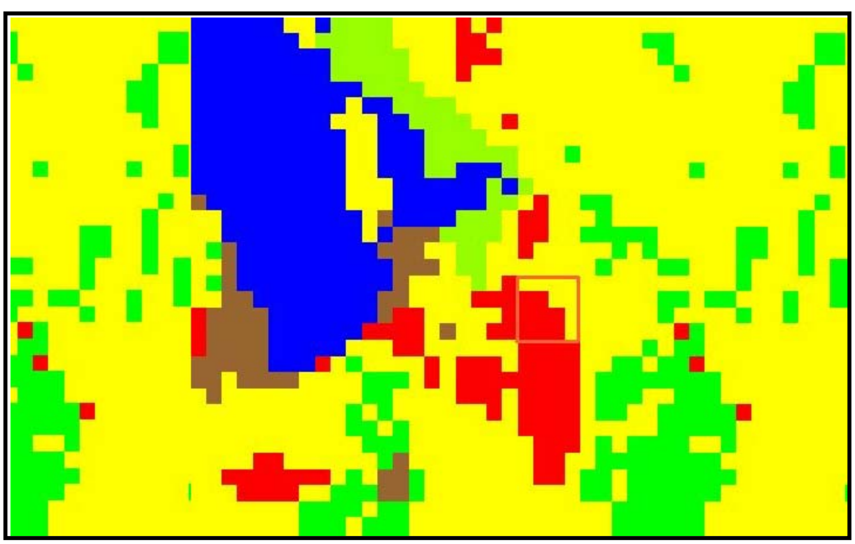


Figure 2. A close in view of the Figure 1 mesoscale area of land use such that the 10Km x 10Km box centered on Salt Lake City is discernable with the same2.5 grid spacing

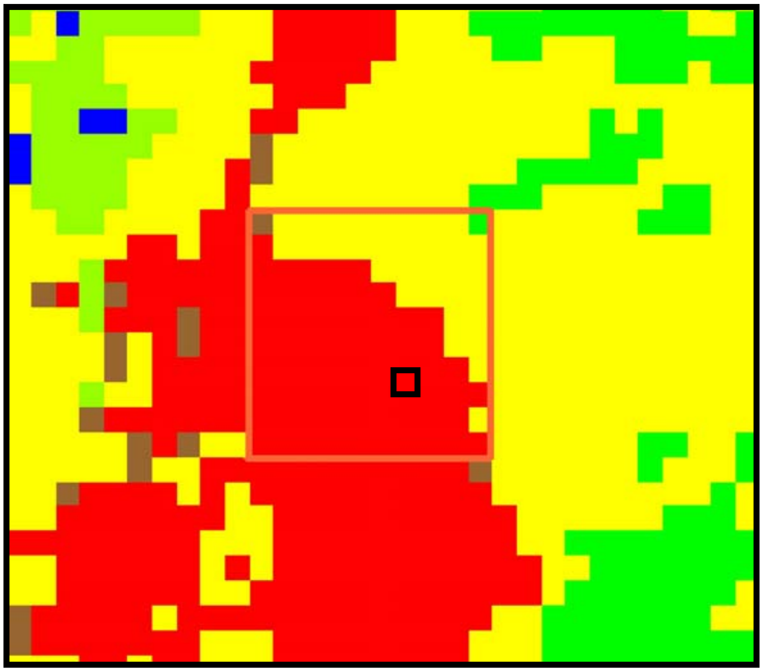


Figure 3. Even closer view of the land use map centered on Salt Lake City now with 1Km-grid spacing using the same color codes of Figure 1. Take note of small black box for future discussion.

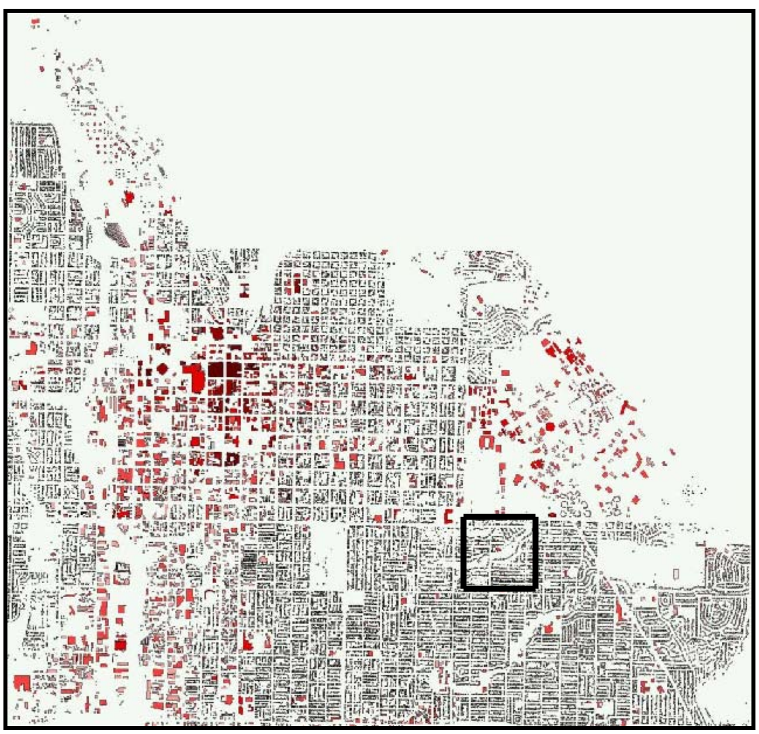


Figure 4. A map derived from the LIDAR fly over of central Salt Lake City showing only individual buildings while all other areas (white) are undefined morphology. Shades of red are indicative of taller buildings. The domain size is 10Km x 10Km. Note the black box for later discussion.

Table 1. Physical attributes for urban and rural morphology categories.

Building type (using 17 **U**rban **T**errain **Z**one categories noted in Table 2)
Building density (percent of ground cover per cell, usually 100m x 100m)
Building height, in meters (as 3m per story)
Building orientation (to the nearest 15 degrees)
Roof pitch (flat or pitched)
Roof reflectivity (bright or dark)
Impervious surface reflectivity (bright or dark)
Impervious surface (percent of ground covered within a cell)
Bare ground (percent of cover within a cell
Cropland (percent of cover within a cell)
Grassland (percent of cover within a cell)
Marsh (percent of cover within a cell)
Water (percent of cover within a cell)
Coniferous trees (percent of ground covered by tree canopy within a cell)
Coniferous trees, height in meters (to the nearest 5 meters)
Broadleaf evergreen trees (percent within a cell)
Broadleaf evergreen trees, height in meters (to the nearest 5 meters)
Broadleaf deciduous trees (percent within a cell)
Broadleaf deciduous trees, height in meters (to the nearest 5 meters)
Mixed trees (percent within a cell)
Mixed trees, height in meters (to the nearest 5 meters)
Shrubs (percent within a cell)
Shrubs, height in meters (generalized as two meters)
Special features (such as desert vegetation/cactus, etc)

Note that properties, such as those listed below, have operational applications (pitched roof and building orientation) as well as higher order meteorological considerations (albedo, solar incident angles):

Building orientation (to the nearest 15 degrees)
Roof pitch (flat or pitched)
Roof reflectivity (bright or dark)
Impervious surface reflectivity (bright or dark)

The 17 UTZ categories as the ‘Building type’ noted in Table 1 describe the character and relative spacing of buildings in several urban configurations as follows:

Table 2. Urban Terrain Zone categories* derived by Ellefsen

A1 Attached buildings, High-rise, office (old city core)
A2 Attached buildings, apartments (near old city core)
A3 Attached buildings, apartments, and abutted-wall houses near core
A4 Attached buildings, factories not set back from street
A5 Attached buildings, commercial not set back from street

Dc1 Detached, close-set high-rise office building, hotels
Dc2 Detached, close-set apartment buildings
Dc3 Detached, close set houses (in both older and newer parts of city)
Dc4 Detached, close-set factory along railroad and docks
Dc5 Detached, close-set commercial low-rise buildings along string streets

Do1 Detached, open-set modern shopping centers w parking
Do2 Detached, open-set, planned apartment units with associated parking
Do3 Detached, open-set houses, usually on large lots
Do4 Detached, open-set factory/storage low-rise buildings in industrial parks
Do5 Detached, open-set, modern, commercial, street malls along streets
D06 Detached, open set administrative, cultural, educational, government sites
D07 Detached, open set complex, unusual structures, monuments etc

* Note that not all UTZ categories occur in all cities and some flexibility is required to accommodate

special and unusual features. The specific nature of these UTZ can be helpful for on-the-ground operations in very local situations. Groups such as the first responder (HAZMAT incidents etc), the Field Army and other organizations will be better informed as to what type of urban structure they must address and control.

It is also worth noting that even at the one-hectare (100m x 100m cells) resolution, some generalization of urban features must be made. Resolution of a quarter hectare (50 x 50 meters) would be a more suitable scale for the actual size of most urban features, but it would be a very laborious effort. Efforts should be made to automate the extraction and digitization of future microscale level morphological features.

3.2 Data as model input

Information given in Tables 1 and 2 can be treated as the final data set or as an 'intermediate' data set that is required to generate the final data set to be formatted for model input. This data set presently can be readily recorded in spreadsheet format. An example is given in Table 3 with UTM coordinates (northing and easting) for each cell as the UTZ type of Table 2 and the 20+ properties of Table 1. The spreadsheet shows that more than one morphology feature may co-exist within a 100m or 50m cell. That is to say within the same cell, grass areas can be adjacent to trees stands or buildings and streets and parking lots (impervious surfaces) can be adjacent to buildings and so on.

Table 3. Example of morphology data recorded as physical attributes of Table 1 and building types of Table 2 for 50m cells and their UTM coordinates

10 LINEAR CELLS **422500/4513000 UTM**	**2250**	2255	2260	2265	2270	2275	2280	2285	2290	2295
	1345	1345	1345	1345	1345	1345	1345	1345	1345	1345
UTZ type 1-17	8	17	8	12	14	12	12	12	12	14
Building density/footprint %	30	0	10	20	30	20	30	40	20	40
Building height in meters	6	0	6	9	6	6	6	6	6	9
Building orientation in degrees	180	0	180	90	180	90	90	90	90	180
Roof pitch: 1 flat, 2 pitch	2	0	2	1	1	1	1	1	1	1
Roof reflect: 1 bright, 2 dark	1	0	1	1	1	1	1	1	1	1
Impervious surface %	20	30	60	60	70	60	20	10	40	60
Impervious surf. reflectivity 1 bright, 2 dark	2	2	2	2	2	2	2	2	2	2
Marsh %	0	0	0	0	0	0	0	0	0	0
Bare ground %	0	0	0	0	0	0	0	0	0	0
Grassland %	10	50	10	0	0	0	10	20	30	0
Water %	0	0	0	0	0	0	0	0	0	0
Coniferous trees %	0	0	0	0	0	0	0	0	0	0
Coniferous trees height in meters	0	0	0	0	0	0	0	0	0	0
Broadleaf Deciduous trees %	40	20	20	20	0	20	40	30	10	0
Broadleaf Deciduous trees height in meters	12	12	12	12	0	12	12	12	12	0
Mixed trees %	0	0	0	0	0	0	0	0	0	0
Mixed trees height in meters	0	0	0	0	0	0	0	0	0	0
Shrubbery %	0	0	0	0	0	0	0	0	0	0
Shrubbery height in meters	0	0	0	0	0	0	0	0	0	0

In the case of the less complex first order models, morphology data of lesser detail can be useful as well. In some cases, microscale wind models may not yet use each piece of the information recorded for each cell. The modeler may have to devise a prioritization test of features to best represent the dominant feature in each cell (100m, 50m, or so). The dominant feature type assigned to a cell is a function of element height and footprint, after these other factors can be considered. Some Army microscale models use the dominant feature level of complexity as input of digitized morphology along with terrain elevation at the same grid resolution. Figure 5 is a map of an example set of microscale, dominant feature morphology data for the same 10Km x 10Km area of Salt Lake City with 50m-grid resolution. The color codes of these features are the same as figures 2 and 3 with the additional designation of white areas to represent impervious surfaces such as streets, highways, parking lots, gathering spaces etc. Note that although some semblance of street structure may appear in Figure 5, streets and other roads are not maintained as continuous features because of the grid resolution used. The Interstate highway, however, does maintain its wide north-south path along the left side of the figure.

Relative to the 10Km x 10KM domain with 1Km resolution shown in Figure 3, Figure 5 graphically depicts that vegetation types clearly dominate the space within this same modeling domain. Buildings given in red, of course, are also prominent, especially in the downtown. In the residential areas, trees may be determined to be the more dominant feature than the low-rise homes underneath them. An example of this is given in Figure 6, where the dark green tree foliage hides numerous rooftops and some trees even overhang onto the adjacent streets. The prioritization criteria are based upon what feature interacts most prominently with the surface layer airflow. The porous nature of the taller tree crown has a large drag (surface and form) effect upon the wind field and extracts large amounts of momentum before the wind penetrates downwind to the level of the house structure.

Recalling that Figure 4 shows only the individual buildings and large areas of undefined morphology, Figure 7 depicts which features occupy those undefined areas. This is basically the negative image of the buildings-only domain based upon the dominant feature concept. If we color code impervious surfaces as gray, all vegetation types as green and yellow, bare soil as brown, and water surfaces as blue, the remaining white spaces are the new undefined spaces that actually locate cells of buildings (when they dominate). It should be evident that even the CFD scale of morphology truly must incorporate all non-building morphology types to properly represent the real domain for meteorological and diffusion analyses.

A final comparison is made based upon which land use and morphology features exist within a specific 1Km x 1Km box for each of the scales. On the mesoscale, Figure 3 shows that this black box is designated as ‘all urban use’ as shown in Figure 8a. For the CFD scale given in Figure 4, only buildings are located in the black box within this residential urbanized area now shown in Figure 8b. For the 50m-resolution microscale given in Figure 5, a mix of buildings, grass, trees, and partial streets co-exist on the microscale as depicted in Figure 8c. Clearly the trees are the dominant features on the microscale in this same 1km x 1km box. These comparisons strongly suggest the need for different resolutions of land use and morphology data within the National Database. These data sets must be customized for each of the three scales to meet the model input requirements and insure that the models can properly address their specific applications and simulation requirements.

4. SUMMARY

Several points can be drawn from this discussion.

1. To be fully representative of modeler’s needs, the National Data base must also be a source for microscale morphological data sets as a complement to the already accounted for mesoscale and CFD scale features.
2. Even at the highest resolution, the mesoscale at 1km cannot definitively discern morphology for the 10 x 10 data point arrays that micro-scale models require for computations on the 100m-grid spacing. As for morphology type data for CFD purposes, one could consolidate data points to a somewhat coarser resolution (~100m or so), but then the undefined areas of non-buildings would be missing within such a reverse engineered data set. It is clear that one cannot go top down from mesoscale to satisfy the mircoscale need, nor can one go bottom up from CDB-centric CFD data (from building only data and considerable areas of undefined cells) to satisfy the micro-scale needs.
3. In addition to certain Army scale field operations, organizations and agencies that do or should focus on micro-scale modeling and analyses include US Department of Agriculture, US Forest Service (USDA), Urban Forest Centers, city planers of new urban development, energy and nuclear facilities, first responders (HAZMAT incidents etc), and more generally speaking, Homeland Security entities. Their concerns tend to be very local situations where reasonable detail is required to support their activities.
4. Very simply it is shown that the mesoscale model requires land use data while microscale and CFD scale models use quantifiable morphology.
5. Efforts should be made to automate the extraction and digitization of future microscale level morphological features.

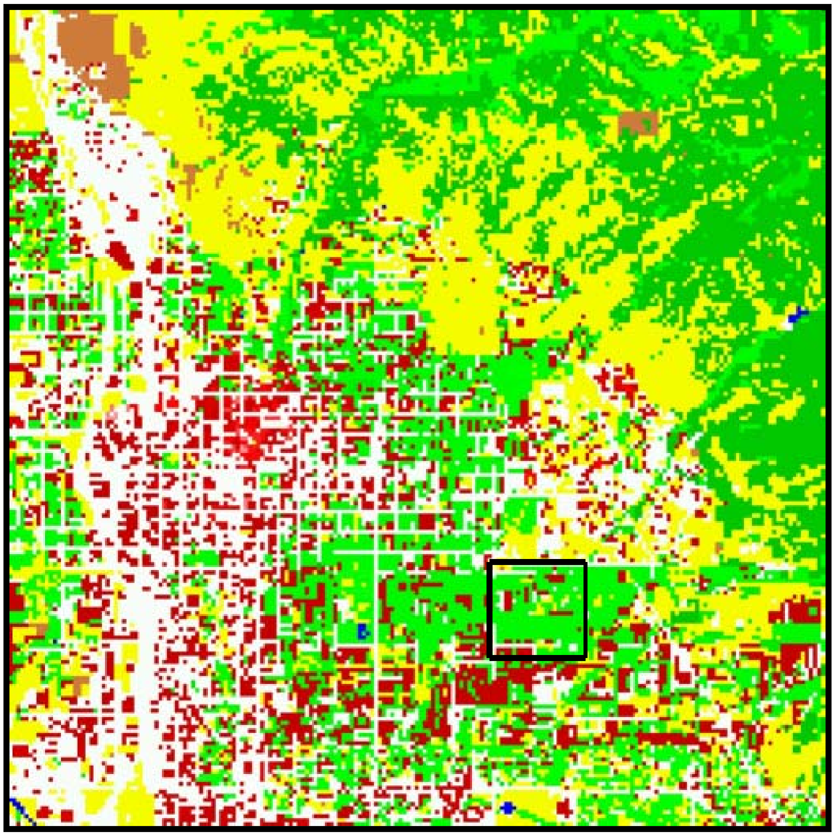


Figure 5. A map of the dominant feature morphology with 50mcells resolution for the same 10Km x 10Km domain. (red = buildings, green = trees, yellow = grass/range land, brown = bare soil, blue = water, white = impervious surfaces (streets, roads, parking lots, etc). Note the small black box for future discussion.

Figure 6. An aerial photo of the approximate area indicated in the black boxes of figures 3, 4, and 5 above. Although this is a residential area, tree crowns cover many of the roof tops and over hang onto to streets.

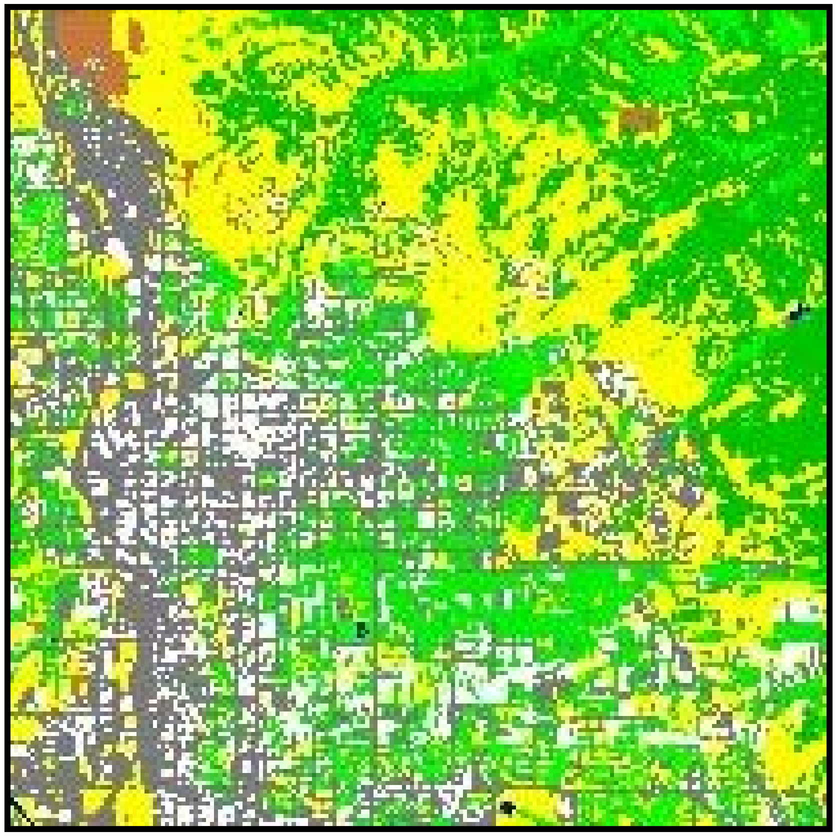
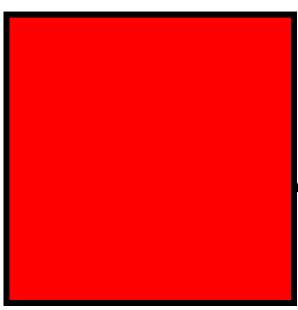


Figure 7. A revised image of Figure 5 where impervious surfaces are now coded gray and the buildings are coded white (where they are the dominant feature). This is basically a negative of Figure 3 in that undefined areas are now identified by the co-existing morphological features.

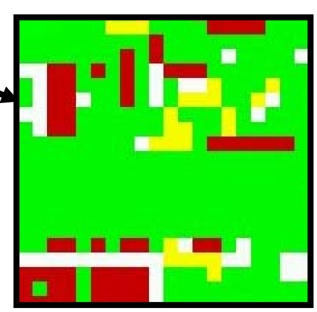


Figures 8a, b, and c are the small 1Km x 1Km boxes noted in Figures 3, 4,and 5. Clearly a feature's degree of importance changes with the meteorological scale.

Figure 8a shows the mesoscale box of only Urban land use taken from Figure 3

Figure 8b depicts the CFD scale of buildings and undefined areas from Figure 4

Figure 8c maps the dominant features with 50m-cell resolution from Figure 5. All morphology types are being represented for better analyses and simulations.



6. It should be evident that even the CFD scale of morphology truly must incorporate all non-building morphology types to properly represent the real domain for meteorological and diffusion analyses.
7. Comparisons of mesoscale, microscale, and CFD scale morphology that exist within a 1Km x 1Km domain for Salt Lake City strongly suggest that land use and morphology data within the National Database must be customized for each of the three modeling scales according to their specific applications and model requirements.

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