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The Utility of Surface Roughness Datasets in the Modeling of United States Hurricane Property Losses

Kimberly J. Mueller
Risk Management Solutions, Newark, CA

Dr. Auguste Boissonade
Risk Management Solutions, Newark, CA

Dr. Craig Miller
Boundary Layer Wind Tunnel Laboratory, University of Western Ontario, London, Canada

1. INTRODUCTION

Catastrophe risk management companies are interested in modeling the wind field of a landfalling hurricane at the highest level possible. A high resolution wind field model is a critical component for assessing prospective property losses in affected costal and inland areas. During a landfalling hurricane, the wind speeds at a particular location change direction and intensity as the hurricane approaches, and are further impacted by surface roughness features upwind as the storm interacts with land. In order to model wind speeds as accurately as necessary to assess property losses, a high degree of precision in modeling terrain and land use features is required. This paper focuses on the model sensitivity to using different datasets and remote sensing techniques in order to obtain an accurate representation of the surface features when modeling surface friction on wind.

Currently, the Risk Management Solutions United State Hurricane Model (RMS USHU) uses National Land Cover Data (NLCD 92), derived from high resolution satellite data, to approach the problem of accurately modeling the land terrain features and the effect of surface roughness on wind speeds. This study attempts to quantify the sensitivity within the model to using different remote sensing data and techniques. Use of 15m resolution ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) data of 2000 or more recent vintage are investigated for updating and refinement, in particular within the urban areas. Furthermore, an attempt is made to assess the heights of the land cover features (natural such as trees and man-made such as structures) using National Elevation Data in conjunction with SRTM (Shuttle Radar Topography Mission) first return topography data. Each of these three datasets are used to derive an estimate of underlying surface roughness features, which are then employed within the RMS USHU. Results are presented from the perspective of modeled loss sensitivity.

* *Corresponding author address*: Kimberly J. Mueller, Risk Management Solutions 7015 Gateway Blvd, Newark, CA 94560; kmueller@rms.com

2. RMS HURRICANE MODEL

In order to calculate the effects of surface roughness changes on both mean and gust wind speeds, a surface roughness database containing information on both the surface roughness and its geographical variation is required. This is achieved through the use of a ground roughness database that identifies a number of different land use/land cover types. Each land use/land cover type is subsequently mapped to a characteristic roughness length value based primarily on the classification schemes of Wieringa and the updated Davenport scheme proposed by Wieringa. The RMS Roughness Classes are defined as follows, each with a unique associated roughness length:

Figure 1. RMS 10 Category roughness classification scheme

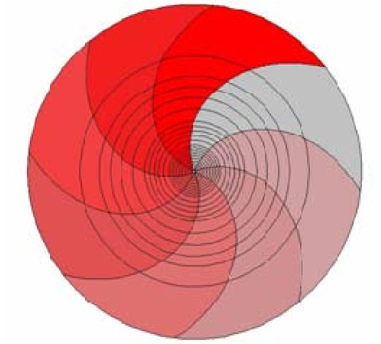


Figure 2. Illustration of the sampling technique used to define multi-directional roughness in the RMS US Hurricane model

A time-stepping wind field model is used to model the impact of surface roughness on winds along eight directions up to 80 km upwind. This is accomplished through the use of a roughness sampling tool developed at RMS. Figure 2 above is an illustration of the tool, which samples the average roughness of sectors of increasing size, spiraling away from a specific point out to 80 km. A corresponding roughness coefficient for each of the eight directions is stored at each point. Hurricane winds, at 10 m above the ocean/land surface, are modeled at 15 minute intervals as the storm traverses land, and the highest wind speed at each point in the lifetime of the storm passage is determined. Once a maximum wind speed at a point is determined, the roughness coefficient corresponding to the maximum wind direction is applied to determine a surface wind speed.

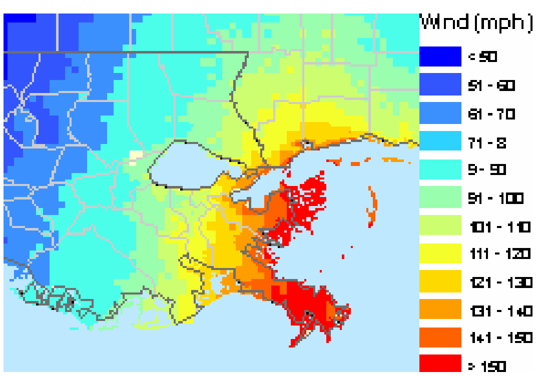


Figure 3. Katrina wind field footprint as modeled by the RMS USHU Model

To best serve the insurance industry, this surface wind speed must then be translated into metrics that are useful from a financial loss perspective. To do this, the RMS USHU vulnerability model correlates surface wind speed with a mean damage ratio that is unique for structures with specific combinations of construction, occupancy, vintage and number of stories. Finally, the RMS USHU financial model translates damage ratios into metrics useful to insurance companies. On an event-wise basis, quantities such as gross and ground up loss are important. However, insurance companies are also interested in setting premiums and managing exposure accumulations independent of specific events. To do this, the hurricane model will run on each event in the RMS historical and stochastic database, and an average annual loss number (AAL) is derived. This number helps insurance companies understand how vulnerable their portfolio is to a “typical” hurricane season; typical being defined by history.

3. CASE ONE

In the subsequent study, the above procedure is undertaken to produce estimates of AAL, changing only the manner in which roughness lengths are derived. Two test areas in hurricane prone regions were selected; the city of Galveston, Texas, as well as New York City. These regions were selected based on the criteria of being vulnerable to landfalling hurricanes, as well as having a high level of exposure. AAL at a zip code level is presented for each zip code within a 50 km radius of both test cities.

The starting point for the creation of the surface roughness database currently in use for the RMS USHU model is NLCD’92, derived from Landsat Thematic Mapper satellite imagery. It provides coverage of the entire continental United States at a horizontal resolution of 30 meters, using a 21-class land cover classification scheme. The database was developed by United States Geological Survey (USGS). Each land use/land cover type is subsequently mapped to a characteristic roughness length value based primarily on the classification schemes of Wieringa and the updated Davenport scheme proposed by Wieringa. The RMS classification scheme groups one or more of the processed NLCD’92 database classes into a single class, based on the roughness length associated with each particular NLCD’92 class. NLCD’92 classes that have a similar effect on the surface wind speed when the roughness length is considered are grouped into a single classification.

These roughness lengths are incorporated into the RMS USHU model, and figures 4 and 5 illustrate relative AAL for Galveston and New York City. Notice that these AAL values (normalized to a value of $100) are calculated using a uniform exposure for each zip code, and do not reflect actual property values. Table 1 following the text contains normalized AAL values aggregated to the county level for both Galveston and New York City. Notice that higher AAL in Galveston indicates a greater risk. This risk is a combination of physical exposure to high wind, as well as historical frequency of events.

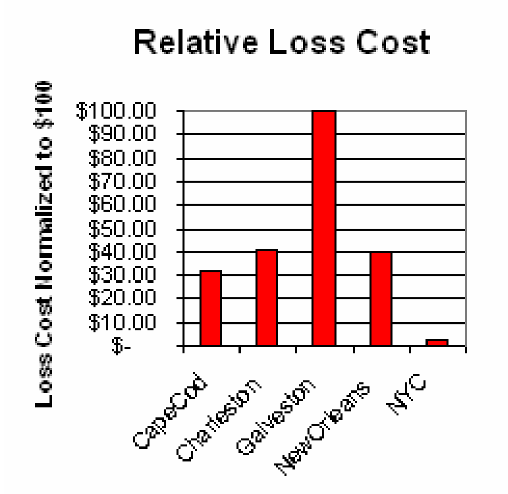
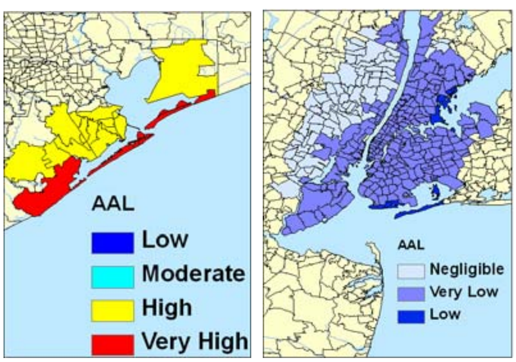


Figure 4. Average Annual Loss normalized to $100 for several major cities in the US. Notice the sizable difference in risk between the two areas of this study.



Galveston, TX **New York City**

Figure 5. Average Annual Loss estimates by zip code for the Galveston, TX (left) and New York City (right) metro areas

Importantly, NLCD defines Low Intensity Residential as areas that include a mixture of constructed materials and vegetation. Constructed materials account for 30-80 percent of the cover. Vegetation may account for 20 to 70 percent of the cover. NLCD defines High Intensity Residential as highly developed areas where people reside in high numbers. Vegetation accounts for less than 20 percent of the cover. Thus, the main distinction between high and low intensity residential is *building spatial density*, rather than structure height.

4. CASE TWO

For Case Two, an attempt is made to quantify the physical height of both man-made and natural structures, such as tree canopy and residential housing structures. It may not be sufficient to merely define an area as low or high intensity residential given that urban and suburban housing characteristics vary greatly by region within the United States. For instance, urban areas in Manhattan and large cities in the northeast consist mainly of multi-story brownstone buildings, while in Miami and much of the Gulf Coast, urban areas consist mainly of single level, single family residences. The physical height of structures does affect the manner in which wind is translated within the boundary layer. It seems necessary, therefore, to quantify this value for accurate estimates of roughness length in primarily residential areas.

To do this, the ASTER data is overlaid with a metric, "Delta_Height", derived by isolating the height of both mad-made and natural structures. A bare earth topography from the USGS 1-ARC second National Elevation Dataset is subtracted from the Shuttle Radar Topography Mission (SRTM) first return topography to produce an estimate of the height of existing vegetation or structure, called delta_Height. This analysis is done at 30 meter horizontal resolution. At this point, all of the pixels that are considered RMS suburban or high density suburban are aggregated, and subjected to a delta_Height thresholding technique. These residential pixels are re-calibrated to low-rise (<10m), medium-rise (10-20m), high-rise (20-50m) and skyscraper (>50m) based on an average feature height above bare earth.

Figure 6A is an illustration of delta_Height derived for Manhattan. Features such as the East River, and the Lake in Central Park clearly show up as being zero feet above the bare earth surface. Many of the high rise residential buildings on the upper east side are calibrated to the medium or high rise categories.

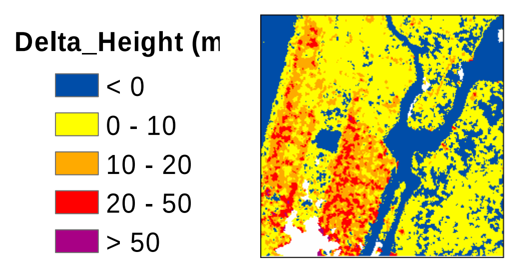


Figure 6A. Delta_Height calculated for upper Manhattan.

A threshold of 10 m, or approximately two stories, was chosen to represent low-rise and is mapped to the RMS suburban roughness category. Medium rise, at 10 to 20 m would adequately represent brownstone type structures in the 3 to 4 story range, and is mapped to the RMS high density suburban roughness category. Anything above 4 stories in height will be considered high-rise or skyscraper. Whether these thresholds are the most accurate in terms of surface roughness categorization is still being studied. However, for the purposes of this study, each of these height classes is mapped to a unique RMS roughness class, with a unique associated roughness length.

The left panel in figure 6B illustrates the current NLCD mapped roughness classes for the same area in New York. Notice that the majority of the area is mapped to RMS high density suburban. The panel on the right is the NLCD + delta_Height derived roughness classes. Notice that much of the area that was considered high density suburban has been re-calibrated to suburban, and hence will have a smaller associated roughness length.

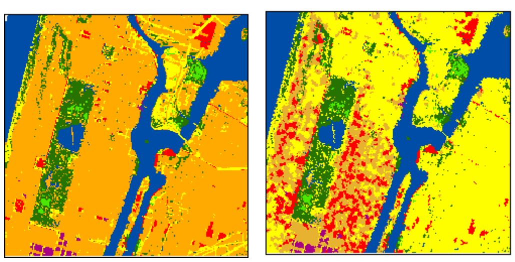


Figure 6B. NLCD Derived Roughness (left), and the delta_Height re-calibrated roughness (right). Please refer to Figure 1 for the roughness class legend.

For Case Two, these re-calibrated roughness lengths are implemented within the RMS USHU model, and AAL values are calculated. On average, losses increase for each zip code in the test area. Note that this is not considered an "improvement" to the current model, but rather illustrates the inherent sensitivity in the model to changes in surface roughness. Please refer to Chart 1 following the article for results of all three sensitivity tests. Losses can vary by as much as 20% to 30% in certain counties in NYC. Because the risk is very low there, small changes in loss drive large impacts from a sensitivity perspective.

The trend of increasing AAL that accompanies the incorporation of delta-Height data is likely due to the fact that many residential areas that were considered high intensity residential, and were thus mapped into RMS high density suburban roughness class, are being "bumped down" to RMS suburban roughness class because they do not satisfy the 10 m height threshold. The suburban roughness class has a smaller roughness length, thus the modeled effects of surface friction are less. With the effect of surface friction lowered, the wind speed should be slightly higher than for Case One, thus losses should be higher, which is consistent with test results (see Chart 1).

5. CASE THREE

The roughness data derived from NLCD'92 is almost 14 years old and it may be necessary to update this data for areas experiencing significant urban growth in recent years. For this purpose, Case Three will utilize the high resolution LULC data derived from 15 m resolution ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) images. ASTER is an imaging instrument flying on Terra, a satellite launched in December 1999 as part of NASA's Earth Observing System. In contrast to the 21-class NLCD classification scheme, ASTER actually utilizes 30 LULC classes. These 30 classes are then mapped into the existing 10 RMS roughness classes, again grouping ASTER classes that behave similarly from a surface roughness perspective. Figure 7 is an illustration of typical urban and suburban growth that has taken place in the last decade.

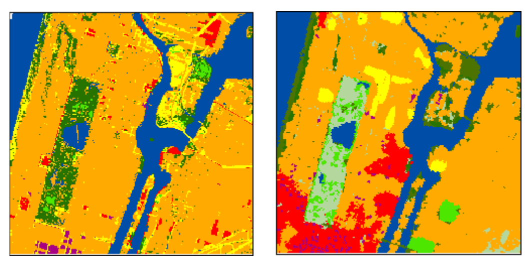


Figure 7. NLCD Derived Roughness (left), and ASTER Derived Roughness (right).

Like NLCD'92, the ASTER LULC classes differentiate low and high intensity residential mainly by the percentage of vegetation, and the spatial density of structures, thus "delta-height" is used to re-calibrate the suburban classes by height. Chart 1 plots the variation in normalized loss that occurs in several counties within the test areas as a result of the implementation of ASTER data.

These results are somewhat difficult to interpret. It seems intuitive that incorporation of ASTER data will result in greater build-up. Thus, as cities grow, surface roughness becomes more significant. Whether this has a positive or negative effect on loss is interesting, and requires further investigation. Roughness affects the mean wind as well as the gustiness. Increasing roughness should act to slow the mean wind at the surface, however the gustiness may increase, which will lead to heavier damage. This is an area of ongoing investigation, and will results will be further presented.

In conclusion, the sensitivity of the model to changes in surface roughness characteristics is important to quantify. This study is not undertaken to determine the "best" data or methodology, but rather to investigate how losses change in response to changes in surface roughness. This is an ongoing study, as the individual effects of surface roughness on the mean wind and the gustiness are further investigated.

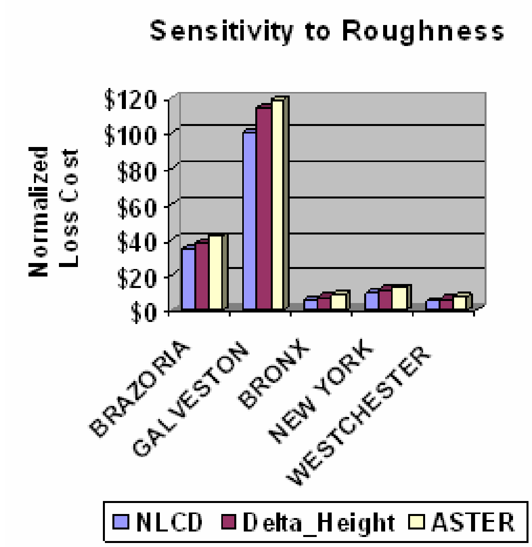


Chart 1. Sensitivity results for several counties in Galveston and NYC. AAL values are normalized to a maximum of $100 for Case One in Galveston.

References

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Wieringa, J. (1992), 'Updating the Davenport terrain roughness classification', J. Wind Engin. Industr. Aerodyn., 41 (1992), 357-368.