Mapping of Topographic Effects on Maximum Sustained Surface Wind Speeds in Landfalling Hurricanes

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Project Synopsis

While the effect of large-scale topography, such as that found on Hispaniola, on the overall structure of a hurricane passing over such topography is reasonably well understood, forecasters at the Tropical Prediction Centre/National Hurricane Centre (TPC/NHC) currently have no means available to them to assess the impact of small-scale topography on surface wind speeds in hurricanes making landfall over such terrain. This project uses the MS-Micro linear model for boundary layer flow over small-scale topography, described by Walmsley *et al.* (1982), Taylor *et al.* (1983), and Walmsley *et al.* (1986), in combination with the US Geological Survey's National Elevation Dataset (NED) to map the effects of topography on surface wind speeds at a height of 10 m for Puerto Rico and the US Virgin Islands. The intended primary outcome of the project is a set of maps showing contours of speed-up factors that can then be used by a forecaster to assess the effects of topography on maximum sustained surface wind speeds in hurricanes making landfall in Puerto Rico or the US Virgin Islands. It is anticipated that a successful conclusion to the project would lead to an improved ability to forecast maximum sustained surface wind speeds in areas with significant topography as identified in TPC/NHC hurricane forecaster priority TPC-6.

Progress Report

With the release by NASA of the report by Chock *et al.*(2002) attention has been focussed on the comparison of the measured speed-up values obtained in the wind tunnel contained in this report with those calculated using MS-Micro at the same locations. The wind tunnel study was undertaken using a boundary layer wind tunnel and involved making measurements at an equivalent full-scale height of 18 m above the surface using 1:6000 scale models of portions of the islands of O'ahu and Kaua'i in the Hawaiian island chain, together with a major portion of the island of Guam. Measurements at each of the locations considered were made for 16 wind directions spaced at 22.5 degree intervals. The total number of locations considered in the study was 358 on the islands of O'ahu and Kaua'i, with a further 90 locations on the island of Guam, which when the 16 wind directions are taken into account yields a total of 7168 data points for comparison purposes. The wind tunnel test data were presented in the form of tabulated mean velocities by direction relative to the measured gradient height wind speed in the wind tunnel. These values were then used in combination with a reference flat terrain value measured upstream of the topographic models to calculate a set of measured speed-up factors for comparison with those obtained using MS-Micro.

Previous validation studies of MS-Micro have focussed on its application to the flow over relatively low slope isolated hills. These validation studies have included comparison with the results of both field (see for example Salmon *et al.*(1988b) and Salmon *et al.*(1988a)) and wind tunnel studies (Teunissen *et al.*(1988)). In general these studies have found that MS-Micro tends to predict the observed speed-up on the upwind face and crest of the hill very well, but that on the lee slope of the hill it tends to under-predict the magnitude of the reduction in the wind speed. This is primarily because in this region non-linear effects associated with the formation of a wake and possible flow separation become significant, and Ms-Micro is unable to predict these effects because it is a linear model. In limited tests using the results of a wind tunnel study of boundary layer flow over two-dimensional complex terrain (Miller and Davenport (1998)) it was found to over-predict the measured speed-up. This is due to the fact that in more complex terrain the flow over a particular hill is affected by the wake of the upstream hill, and the net effect of the interaction of the wake of the upstream hill with the flow over the hill being considered is to reduce the speed-up relative to that for an isolated hill of the same shape.

The application of MS-Micro to the terrain found on the three islands considered in the wind tunnel study of Chock *et al.*(2002) then provides a rather severe test of the capabilities of MS-Micro to model the flow over such terrain. Figure 1 shows a scatter plot of the MS-Micro calculated speed-up factors versus those obtained from the wind tunnel measurements of Chock *et al.*(2002) for the islands of O'ahu and Kaua'i for all wind directions considered. Several features can be noted. Firstly there is considerable scatter in the results, but on the whole when the speed-up factor is greater than 1.0 (wind speeds are higher than the equivalent value above flat terrain) MS-Micro tends to over-predict the expected speed-up. Similarly, when the speed-up factor is less than 1.0 (wind speeds are lower than the equivalent value above flat terrain) MS-Micro tends to under-predict the reduction in wind speed. Both of these effects are not unexpected in view of the results of previous validation studies.

Breaking down the results in a little more detail in just over 60% of cases MS-Micro over-predicts the measured speed-up by more than 10%, in about 20% of cases it is within 10% of the measured value, and in the remaining 20% of cases it under-predicts the speed-up factor by more than 10%. On average, for all the locations considered MS-Micro over-predicts the measured speed-up factor by 20%. The speed-up factors calculated using MS-Micro are thus conservative, in the sense that they provide an upper bound on the likely wind speeds to be found in regions of complex topography in hurricanes.

One of the other issues affecting the interpretation of the results from MS-Micro can also be clearly seen in Figure 1, and that is deciding on a limiting value for the maximum allowable speed-up factors obtained using it. As MS-Micro is a linear model it tends to predict increasingly larger speed-up factors as the slope increases, whereas in reality non-linear effects such as flow separation provide an upper bound on the maximum speed-up factor. Examination of the speed-up factors measured in the wind tunnel suggests that a practical limit for the maximum allowable speed-up factor is in the range 1.8-2.0.

Finally, Figure 2 presents a scatter plot of the MS-Micro calculated speed-up factors versus those obtained from the wind tunnel measurements of Chock *et al.*(2002) for the island of Guam for all wind directions considered. In this case the results are completely at variance with those obtained from the previous comparison shown for the islands of O'ahu and Kaua'i and previous validation studies. In particular there are is significant body of points where the speed-up factors measured in the wind tunnel are significantly higher than those calculated using MS-Micro, as indicated on the scatter plot. Closer examination of the locations where these speed-up factors were measured showed that the majority of them were located on the flat central plateau of Guam, away from areas of significant topography.

The wind tunnel models used in the study of Chock *et al.*(2002) were constructed using terracing, rather than smoothed contours, and it is suspected that the use of this form of construction in relatively flat areas can lead to significant errors in the measured speed-ups, particularly if the measurement location is situated near the edge of one of the terraces. This is because the edge of the terrace acts as an escarpment producing highly localized speed-ups that are not representative of the general flow characteristics over the modelled topography. This effect tends to be washed out when the topography being modelled is relatively high when compared to the height of the terracing used to construct the model, which is why the effects cannot be seen in the results for the islands of O'ahu and Kaua'i.

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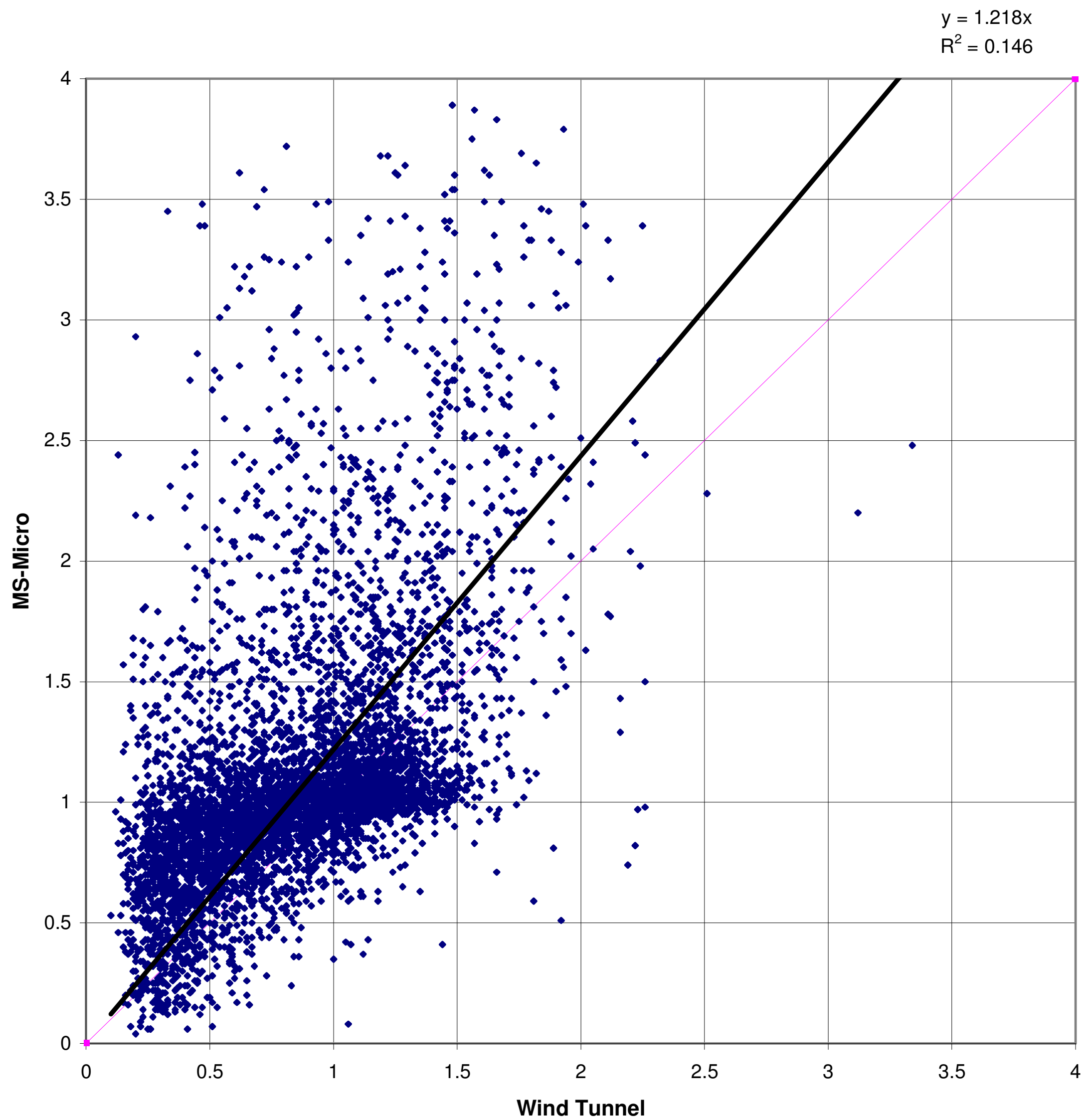

Figure 1: Scatter plot of MS-Micro predicted speed-up factors versus speed-up factors measured in the wind tunnel study of Chock *et al.*(2002) for the islands of O'ahu and Kaua'i

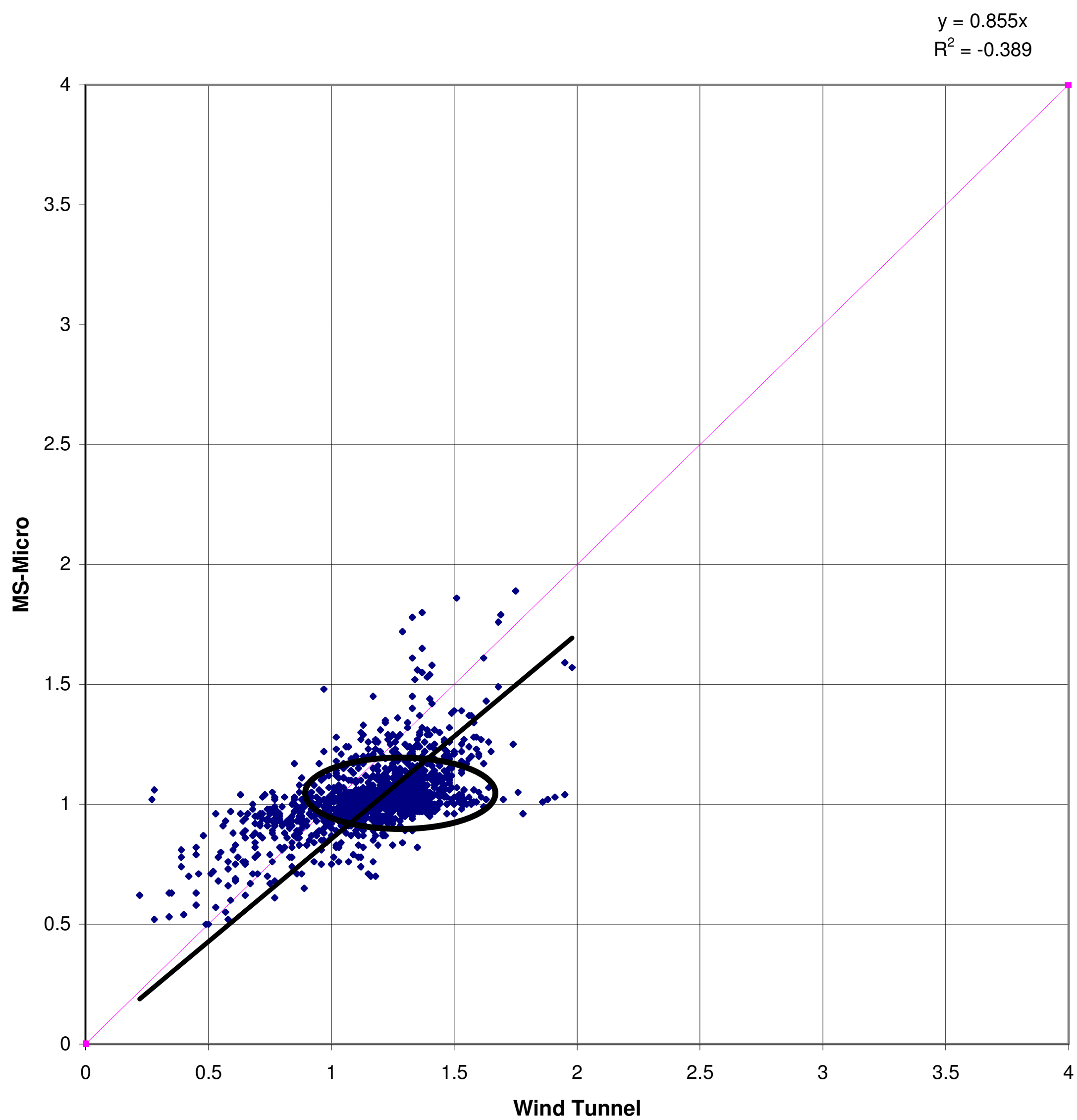

Figure 2: Scatter plot of MS-Micro predicted speed-up factors versus speed-up factors measured in the wind tunnel study of Chock *et al.*(2002) for the island of Guam