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

JHT Mid-Year Progress Report
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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

Much of the effort during the first six months of the project has been focussed on two main areas. These are the processing of the topographic data required as part of the input to MS-Micro, and the development of software that will allow MS-Micro to be run in an efficient manner for a large number of locations with minimal user interaction, and the post-processing of the output data. One result of the focus on these two areas has been a delay in the preparation of a document summarizing the effects of topography on surface wind speeds for forecasters at the TPC/NHC.

Topographic data for Puerto Rico and the US Virgin Islands has been extracted from the US Geological Survey's (USGS) National Elevation Dataset (NED) using the USGS' Seamless Data Distribution System (http://seamless.usgs.gov). As delivered this data consists of an array of elevations above mean sea level in metres defined on a regular horizontal grid. The horizontal grid itself is defined using a lat/long coordinate system with grid intervals of 1 arc-second in both horizontal (east-west) and vertical (northsouth) directions. Prior to input to MS-Micro the horizontal grid on which the elevation data are defined must first be transformed from a geographic (lat/long) coordinate system to an appropriate projected coordinate reference system such that the horizontal dimensions of the grid are defined in metres, rather than degrees of latitude or longitude.

For Puerto Rico and the US Virgin Islands the selected projected coordinate reference system is SPCS83 Puerto Rico and the US Virgin Islands (metres), which uses a Lambert Conic Conformal (2SP) transformation to convert the grid point coordinates from lat/long to projected coordinates. The equations used for the transformation as those given in EPSG (2005), with the relevant projection parameters taken from the EPSG geodetic parameter database. Software has been written to read an input ESRI ArcGrid file, which is the format that the data is delivered in from the USGS' Seamless Data Distribution System, and to then transform the grid point coordinates from latitude/longitude to the selected projected coordinate reference system. The grid point coordinates and associated elevation data are then written to an XYZ ASCII data file, which is used to create a Surfer binary grid file with the grid point coordinates defined in metres, rather than latitude/longitude, for input to MS-Micro. At the latitude of Puerto Rico and the US Virgin Islands the original 1 arc-second spacing of the horizontal grid corresponds to a horizontal spacing of approximately 30 m in both directions in the selected projected coordinate reference system.

In its original form MS-Micro consists of a suite of stand-alone executables that are used to pre-process the topographic data and create runtime input files before then running the main program that calculates the actual speed-up factors and wind direction deviations due to the underlying topography. For each point of interest the executables must be run interactively with a significant amount of user interaction required both during execution and in the post-processing phase to extract the required information from the output solution files. In order to run MS-Micro efficiently for a large number of locations with minimal user interaction software has been developed to allow a master topography data covering a much larger region to be specified, together with a second file containing the coordinates of the locations and the elevation above ground at which the speed-up factors are to be calculated, as well as specifying runtime settings for the horizontal grid dimensions, base terrain roughness length, and wind directions to be considered.

Although in principle it is possible to use MS-Micro to calculate speed-up factors over a region, rather than at specific locations, because the program uses a horizontal grid with dimensions of 5-8 km along a side, in practice the results need to be interpreted with caution away from the centre of the grid. This is because MS-Micro transforms the horizontal components of the equations of motion into the Fourier domain prior to solution, and the resulting boundary conditions require that the horizontal domain is split into an outer region that is flat and an inner region where the original topography is unchanged. Between the two regions there is a blending region where the topography is modified so that there is a smooth transformation between outer and inner grid regions.

Previous experience has shown that speed-up factors at locations near the edge of the inner grid region tend to be influenced by the modified topography within the blending region, which means that the resulting values need to be treated with caution. The strategy employed in this case is to generate a grid of regularly spaced points covering the region of interest, and then to run MS-Micro in such a way that each grid is located at the centre of the input topography grid. This approach is computationally more expensive, but it has the advantage that it avoids the need to make decisions about the validity of the calculated speed-up factors near the edges of the inner grid.

Using the software that has been developed MS-Micro can be run automatically for a large number of sites with minimal user interaction. For each grid point the software first extracts a sub-grid of the specified dimensions from the master topography data file centred on the grid point location, before creating the required runtime input files and then running MS-Micro. Following the completion of each MS-Micro run the software then extracts the speed-up factor and wind direction deviation at the grid point location for each wind direction considered, before writing the information to an ASCII text file. The latter is subsequently used by additional post-processing software that has been written to create a set of Surfer binary grid files containing the speed-up factors for each wind direction, as well as the largest speed-up factor calculated at each location irrespective of wind direction, for plotting of the speed-up factors. This allows the end user to simply consider the largest speed-up factor irrespective of wind direction, or to take directionality into account when considering the effects of the underlying topography on surface wind speeds.

Initial testing of the software described above was carried out using a digital elevation model (DEM) of Bermuda that was already defined in an appropriate projected coordinate reference system, and covered a relatively small area allowing for checks to be easily made at each stage. The speed-up factors were calculated on a grid of regularly spaced points with an interval of 100 m between grid points in both horizontal and vertical directions. Speed-up factors were calculated at an elevation of 10 m above local ground for 12 wind directions spaced at 30^{o} intervals and centred on 0^{o}, 30^{o}, 60^{o}, etc.. For Puerto Rico and the US Virgin Islands a larger grid interval will be used because of the size of the areas to be covered, and the need to balance the horizontal resolution of the speed-up factors with the computational effort required to calculate them. Figure 1 shows the largest calculated speed-up factor irrespective of wind direction, while Figure 2 shows a close-up of the region indicated in Figure 1 overlaid on a map of the topographic contours at 10 m intervals. An examination of Figure 2 clearly shows the influence of the underlying topography on the speed-up factors, the largest calculated value indicating an increase of 70% in the mean wind speed relative to that found at a height of 10 m above flat terrain.

Other Issues

The original project proposal called for the results of the wind tunnel study of Chock *et al.* (2002), in which surface wind speeds were measured at over 400 locations on scale models of selected areas of O’ahu and Kaua’i in the Hawaiian Islands and Guam, to be used to validate the mapping of speed-up factors using MS-Micro. An initial approach to NASA’s Centre for Aerospace Information for a copy of this report revealed that the original sponsors of the study, NASA's Goddard Space Flight Centre, have classified this report as limited. As a result a request for a copy of this report under the Freedom of Information Act has been placed with NASA's Goddard Space Flight Centre. To date a response to this request has not been received, beyond an acknowledgement that the request has been noted.

Future Work

The primary focus over the next month will be the completion of the document summarizing the effects of topography on surface wind speeds for forecasters at the TPC/NHC. At the same time a start will be made on the calculation of speed-up factors for the US Virgin Islands, with the intention of producing a initial set of speed-up factor maps for these islands by the end of April, with maps for Puerto Rico to follow before the revised year end date of 7 July, 2006, as per Chris Landsea's recent communication. If it proves possible to obtain a copy of Chock *et al.* (2002), a start on the validation of the calculated speed-up factors against the wind tunnel measurements reported in this study may also be made ahead of schedule.

References

Chock, G.Y.K., J.A. Peterka, and L. Cochran, (2002): Orographically amplified wind loss models for Hawaii and Pacific insular states, NASA Centre for Aerospace Information, Hanover, MD.

Taylor, P.A., J.L. Walmsley, and J.R. Salmon, 1983: A simple model of neutrally stratified boundary-layer over real terrain incorporating wavenumber-dependent scaling, *Boundary-Layer Meteorol.*, **26**, 169-189.

Walmsley, J.L., J.R. Salmon, and P.A. Taylor, 1982: On the application of a model of boundary-layer flow over low hills to real terrain, *Boundary-Layer Meteorol.*, **23**, 17-46.

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EPSG, 2005: Guidance note 7 part 2 - Coordinate conversions and transformations including formulas (available for download from http://www.epsg.org**).**

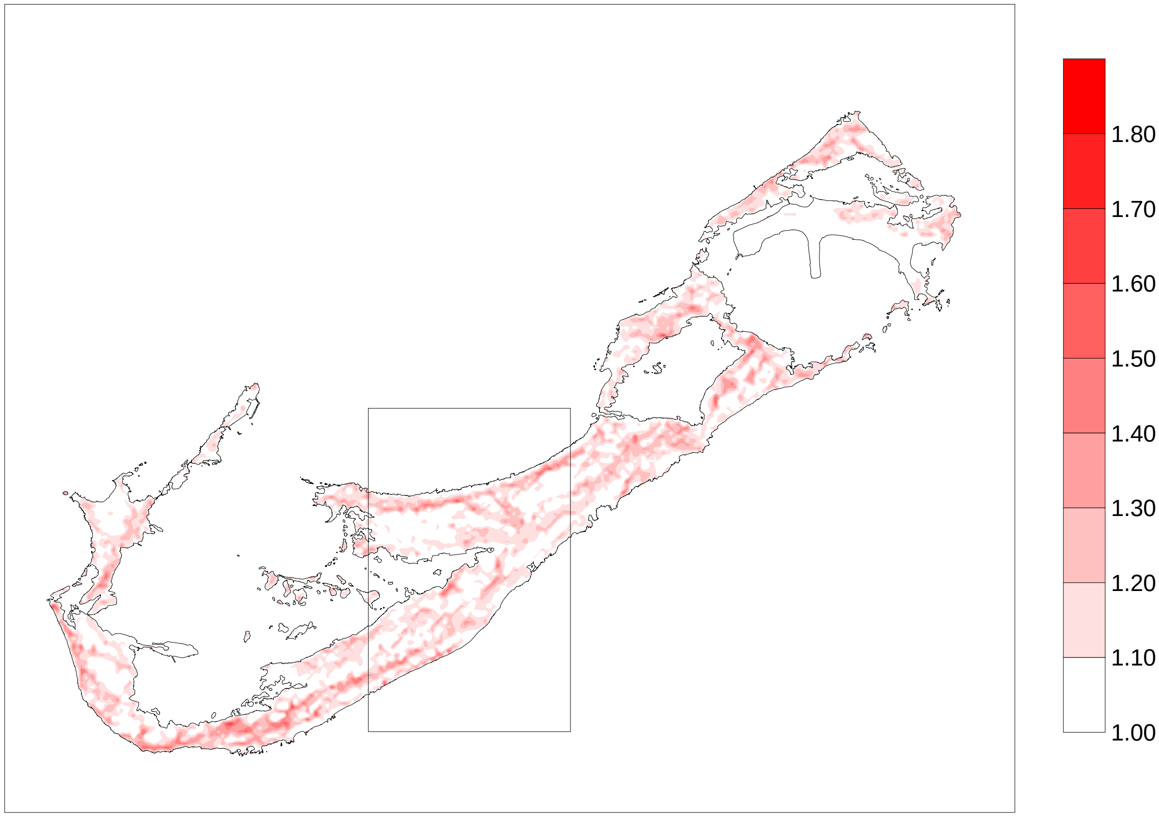

Figure 1: Calculated speed-up factors, irrespective of direction, for Bermuda

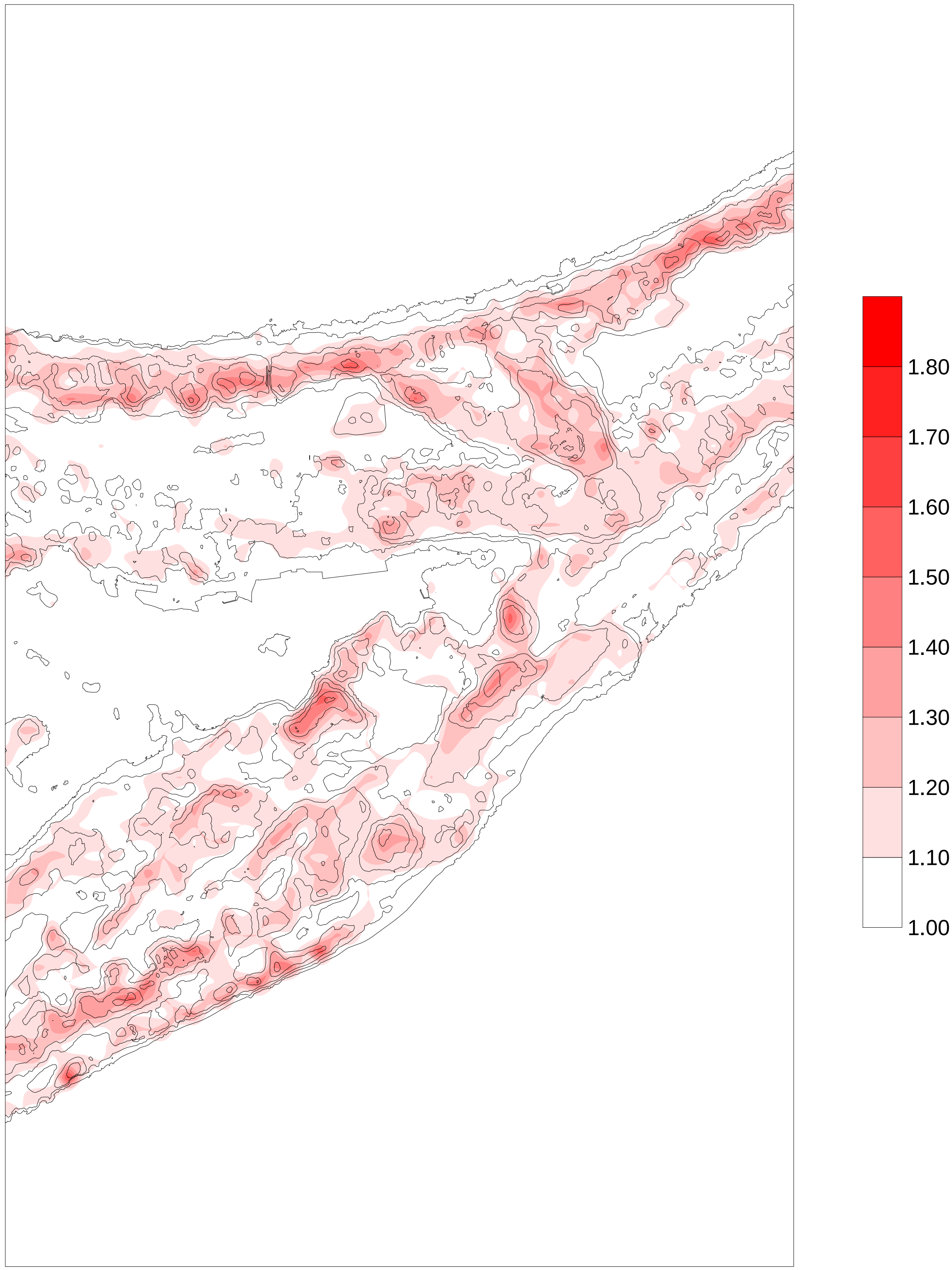

Figure 2: Close-up of the calculated speed-up factors, irrespective of direction, for the region indicated in Figure 1, overlaid on a map of the topographic contours at 10 m intervals.