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APPLICABILITY OF DIGITAL TERRAIN ANALYSES TO WIND ENERGY PROSPECTING AND SITING

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ABSTRACT

The recent publication of the Digital Elevation Model (DEM) database by the U.S. Geological Survey (USGS) has provided a unique opportunity for the developrnent of cost-effective wind energy prospecting technology. This database contains terrain elevation values on a Latitude-Longitude grid with a resolution of 3 arc-seconds (about 90 m) for the contiguous United States, Hawaii, and Puerto Rico. This database has been coupled with software that will produce shaded-relief maps on a laser printer in a format compatible with the state wind power maps in the U.S. wind energy atlas. By providing a much higher resolution of the terrain features than was possible when the U.S. atlas was prepared, these maps can be useful in general wind prospecting activities. As highly resolved as the 90-m DEM data seem to be when compared to the atlas grid, they still appear to be too coarse to resolve terrain features in the detail required for local wind flow characterization and wind plant layout. Gridded terrain data at about 10-m resolution are available from the USGS for some areas of the United States. In areas where these data are unavailable, they may be generated by digitizing and gridding the contours from a 1:24,000-scale USGS map over the area of interest. Comparisons of terrain profiles from cross sections of the 10-m and 90-m data provide an indication of the effect of resolution on the reliability of terrain feature representation. Oblique views of the terrain in shaded-relief format provide a dramatic enhancement of the shape and relative position of features of interest.

INTRODUCTION

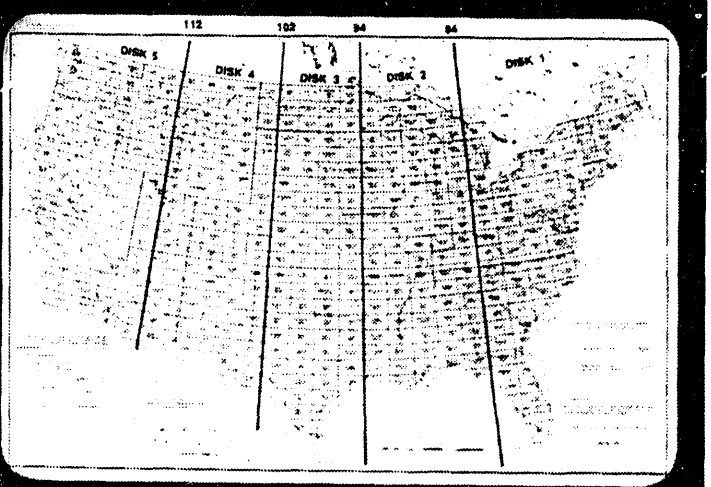
In 1991 the USGS published a unique map, with a comprehensive accompanying document, depicting the landforms of the contiguous United States in shaded relief format (1). The publication of the map signaled the availability of the DEM database containing the 3-arc-second terrain height data to the general public. Since terrain configuration is one of the crucial factors in the wind resource distribution (2), this database provided a unique opportunity for improving wind prospecting effectiveness. The shaded-relief analyses techniques have also proven valuable, at a higher resolution, in evaluating local flow characteristics at a wind turbine site (3). To accommodate the large number of shaded relief reproductions used in the poster presentation, the major portion of this paper is composed of black and white photocopies of the original poster panels.

U.S. Geological Survey DEM Terrain Elevation Data Base

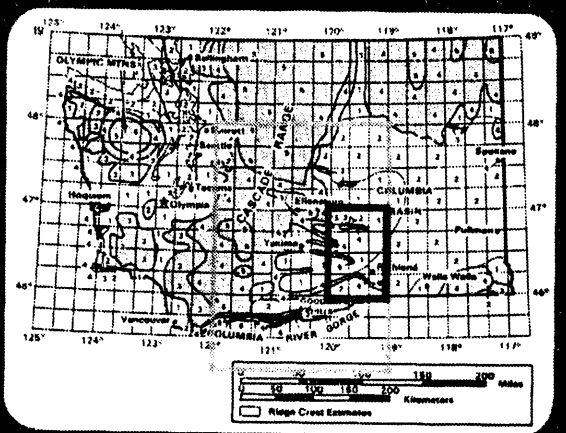
Shaded Relief Map from Digital Terrain Data

This digital shaded-relief portrayal of the land forms of the coterminous United States was produced by the USGS using terrain heights with a horizontal separation of about 800 m. The resolution in the complete database is defined by a separation of 3 arc-seconds (90 m in the latitudinal direction) between terrain height values.

The 3 arc-second terrain height data was derived from the 1:250,000 scale contour maps available from the USGS. The contour maps cover the U.S. in 1°x2° Latitude-Longitude blocks as shown on the map to the right. The digital height data was purchased for the contiguous United States, Hawaii, and Puerto Rico by the Pacific Northwest Laboratory (PNL) on 5 CD-ROM disks in 1°x1° blocks.



Prospecting Application With Windpower Maps



The Latitude-Longtude grid on the state wind power maps may be used to identify an area of interest. The 1 x1° box outlined in red on the wind power map of the state of Washington was selected to present an actual-size sample of the the 950 basic shaded-relief maps prepared by PNL. **These maps are now available to the public through the American Wind Energy Association (AWEA) for any area of the United States.**

The area outlined in blue represents nine 1°x1° blocks that have been produced individually at the 90 m resolution. The individual blocks were pasted together to produce a composite map covering several promising wind energy locations that appear on the state wind power map.

SHADED-RELIEF OF USGS DIGITIZED TERRAIN
Dashed lines represent grid from PNL altas

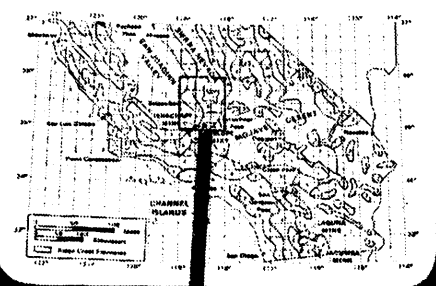
SHADED-RELIEF OF USGS DIGITIZED TERRAIN
Dashed lines represent grid from PNL altas

A Closer Look at 90 m Resolution

To examine the applicability of the 90 m resolution to detailed wind characterization at a particular site, PNL applied a successive "zooming in" process to a 1°x1° block containing the Tehachapi Pass area in southern California. As the map area decreases, the pixel size increases causing a severe loss of detail in the portrayal of specific terrain features. The crude appearance of the shaded-relief analysis can be improved by using an interpolation technique to fill in the coarse grid of USGS terrain values before performing the shaded-relief analysis. The result of applying this approach is shown in the last map in the sequence.

Even though the interpolation approach can improve the appearance of the shaded-relief analysis, the accuracy of the terrain feature representation will still be limited by the accuracy of the original 1:250,000 scale contour maps and the methods used to generate the DEM data.

Southern California Annual Average Wind Power



1

Shaded-Relief of USGS Digitized Terrain

Dashed lines represent grid from PNL atlas

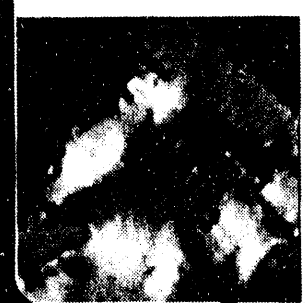
2

Tehachapi Area [illegible] Site Locations

TCS - Turbulence [illegible] terization System

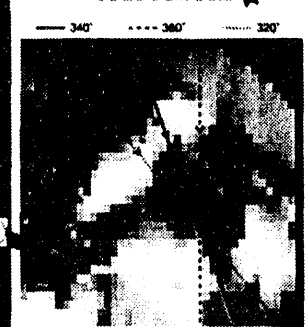
3

TCS Site #3 -
Spline Interpolation of DEM Data



4

TCS Site #3
USGS DEM Data



Comparison of Terrain Features at 10 and 90 m Resolution

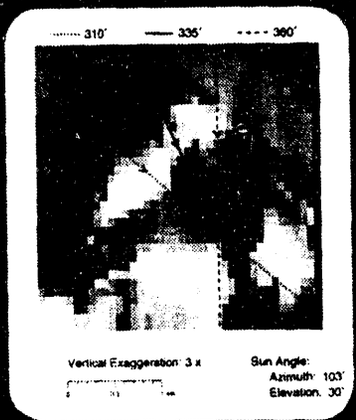
Ⓐ Digitized USGS 1:24,000 Coutour Map TCS Site #3

Because of a need to more closely evaluate and compare the turbulence at sites in terms of the upwind terrain features at the U.S. Department of Energy (DOE) Turbulence Characteristics System (TCS) sites, the contours over square areas, 3 km on a side, were digitized from USGS 1:24,000 scale maps. These contour maps, like the one for TCS site 3 (A), were used to produce grids of terrain heights with a 10 m spacing.

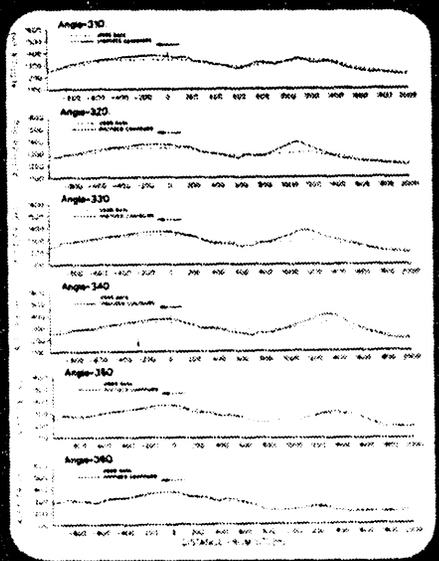
The shaded-relief analysis was applied to the gridded data to produce maps like the one for TCS site 3 shown below the contour map (B). Some very unique turbulence conditions at this site (location indicated by the black dot on the maps) occur when the winds come from 330° to 340° over the hill about 1 km away. This terrain feature is easily identified on the shaded-relief map with 10 m resolution.

Ⓑ TCS Site #3 10m Resolution

Ⓒ TCS Site #3 DEM 90m Resolution



Ⓓ Cross Sections of TCS Site #3



The same hill may be identified on the shaded-relief map of this same area derived from the DEM 90 m resolution data (C). This analysis is shown in both raw and interpolated form on the previous panel. A more quantitative comparison of the profile of the representation of this feature from the two different data sources is provided by showing a series of cross-section plots through the site location (D).

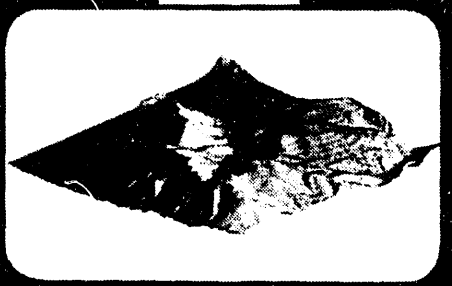
Oblique Views of Terrain Features in Shaded - Relief

Plan View for TCS Site #3

The shaded-relief plan-view maps with 10 m resolution provide a fairly detailed depiction of the way the terrain features reflect illumination from a directed light source. It is this effect that causes most observers to perceive a 3-dimensional quality in the map. This perception can be dramatically enhanced by combining the shaded-relief analysis with an oblique mesh plot of the terrain surface. The result of this combination is illustrated in the 3 views derived from the plan view of TCS site #3.

Plots of this type allow a much more definitive assessment of the size and shape of a particular terrain feature than is possible with the plan view or cross-sections. They also provide a much better perspective of relative heights of the terrain features.

View from A



View from B

View from C

Conclusions

- The 1 x1 ° shaded relief maps from the USGS DEM database is a worthwhile supplement to the U.S. wind atlas and can be a valuable tool for preliminary prospecting.
- Detailed siting activities and wind flow analyses require finer resolution than 90 m in complex terrain. The resolution requirements for flatter terrain have yet to be determined.
- Oblique views of terrain features in shaded relief have the potential of being a flexible and powerful tool for terrain analyses relevant to wind energy development.

ACKNOWLEDGMENTS

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