EXHIBIT

344

FILED
April 4, 2017
Data Center
Missouri Public
Service Commission

DESCRIPTION OF THE MESOMAP SYSTEM

MLA Exhibit No. 344
Date 3.22.17 Reporter MC
File No. EA.2016.0358

April 2012

DESCRIPTION OF THE MESOMAP® SYSTEM

The *MesoMap* system has three main components: models, databases, and computer systems. These components are described below.

Models

At the core of the *MesoMap* system is MASS (Mesoscale Atmospheric Simulation System), a numerical weather model that has been developed over the past 20 years by Truewind Solutions partner MESO, Inc., both as a research tool and to provide commercial weather forecasting services. MASS simulates the fundamental physics of the atmosphere including conservation of mass, momentum, and energy, as well as the moisture phases, and it contains a turbulent kinetic energy module that accounts for the effects of viscosity and thermal stability on wind shear. As a dynamical model, MASS simulates the evolution of atmospheric conditions in time steps as short as a few seconds. This creates great computational demands, especially when running at high resolution. Hence MASS is usually coupled to a simpler but much faster program, *WindMap*, a mass-conserving wind flow model. Depending on the size and complexity of the region and requirements of the client, *WindMap* is used to improve the spatial resolution of the MASS simulations to account for the local effects of terrain and surface roughness variations.

Data Sources

The MASS model uses a variety of online, global, geophysical and meteorological databases. The main meteorological inputs are reanalysis data, rawinsonde data, and land surface measurements. The reanalysis database – the most important – is a gridded historical weather data set produced by the US National Centers for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR). The data provide a snapshot of atmospheric conditions around the world at all levels of the atmosphere in intervals of six hours. Along with the rawinsonde and surface data, the reanalysis data establish the initial conditions as well as updated lateral boundary conditions for the MASS runs. The MASS model itself determines the evolution of atmospheric conditions within the region based on the interactions among different elements in the atmosphere and between the atmosphere and the surface. Because the reanalysis data are on a relatively coarse, 200 km grid, MASS is run in several nested grids of successfully finer mesh size, each taking as input the output of the previous nest, until the desired grid scale is reached. This is to avoid generating noise at the boundaries that can result from large jumps in grid cell size. The outermost grid typically extends several thousand kilometers.

The main geophysical inputs are elevation, land cover, vegetation greenness (normalized differential vegetation index, or NDVI), soil moisture, and sea-surface temperatures. The global elevation data normally used by *MesoMap* were produced by the US Geological Survey in a gridded digital elevation model, or DEM, format from a variety of data sources.[1] The land cover classifications are taken from the MODIS global 1 km. The model translates both land cover and NDVI data into physical parameters such as surface roughness, albedo, and emissivity. The nominal spatial resolution of all of these data sets is 1 km. Thus, the standard output of the *MesoMap* system is a 100-400 gridded wind map, dependent on the availability of high-resolution topographical and land cover data.

Computer and Storage Systems

The *MesoMap* system requires a very powerful set of computers and storage systems to produce detailed wind resource maps in a reasonable amount of time. To meet this need AWST has created a distributed processing network consisting of about 80 Intel Dual Quad Core Xeon processors (640 total cores) and 50 terabytes of hard disk storage. Since each day simulated by a processor is entirely independent of other days, a project can be run on this system up to 640 times faster than would be possible with any single processor. To put it another way, a

[1] The US Defense Department's high-resolution Digital Terrain Elevation Data set is the principal source for the global 1 km elevation. Gaps in the DTED data set were filled mainly by an analysis of 1:1,000,000 scale elevation contours in the Digital Chart of the World (now called VMAP).

typical *MesoMap* project that would take two years to run on a single processor can be completed in about a week.

The Mapping Process

The *MesoMap* system creates a wind resource map in several steps. First, the MASS model simulates weather conditions over 366 days selected from a 15-year period. The days are chosen through a stratified random sampling scheme so that each month and season is represented equally in the sample; only the year is randomized. Each simulation generates wind and other weather variables (including temperature, pressure, moisture, turbulent kinetic energy, and heat flux) in three dimensions throughout the model domain, and the information is stored at hourly intervals. When the runs are finished, the results are compiled into summary data files, which are then input into the *WindMap* program for the final mapping stage. The two main products are usually (1) color-coded maps of mean wind speed and power density at various heights above ground (see figure below) and (2) data files containing wind speed and direction frequency distribution parameters. The maps and data can then be compared with land and ocean surface wind measurements, and if significant discrepancies are observed, adjustments to the wind maps can be made.

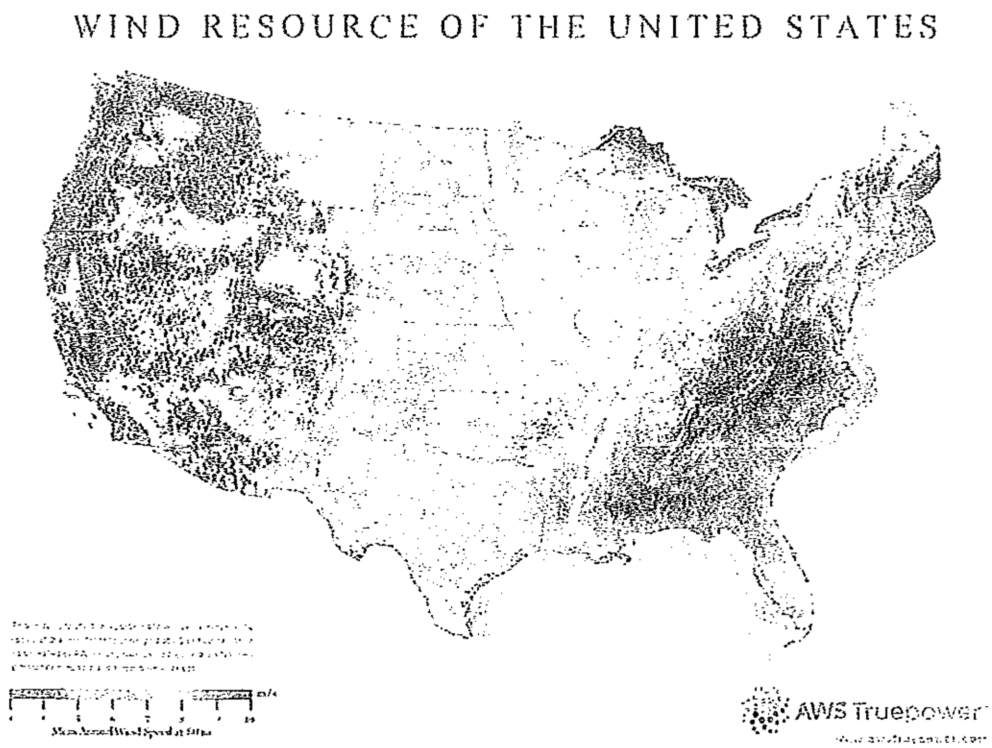

Figure. Wind Resource Map of United States created with MesoMap® system by AWS Truepower.

Factors Affecting Accuracy

In our experience, the most important sources of error in the wind resource estimates produced by *MesoMap* are the following:

- Finite grid scale of the simulations
- Errors in assumed surface properties such as roughness
- Errors in the topographical and land cover data bases

The finite grid scale of the simulations results in a smoothing of terrain features such as mountains and valleys. For example, a mountain ridge that is 2000 m above sea level may appear to the model to be only 1900 m high. Where the flow is forced over the terrain, this smoothing can result in an underestimation of the mean wind speed or power at the ridge top. Where the mountains block the flow, on the other hand, the smoothing can result in an overestimation of the resource as the model understates the blocking effect. The problem of finite grid scale can be solved by increasing the spatial resolution of the simulations, but at a cost in computer processing and storage.

Errors in the topographical and land cover data can obviously affect wind resource estimates. While elevation data are usually reliable, errors in the size and location of terrain features nonetheless occur from time to time. Errors in the land cover data are more common, usually as a result of the misclassification of aerial or satellite imagery. It has been estimated that the global 1 km land cover database used in the MASS simulations is about 70% accurate. Where possible, more accurate and higher resolution land cover databases should be used in the *WindMap* stage of the mapping process to correct errors introduced in the MASS simulations. In the United States, we use a 30 m gridded Landsat-derived land cover database for this purpose.

Even if the land cover types are correctly identified, there is uncertainty in the surface properties that should be assigned to each type, and especially the vegetation height and roughness. The forest category, for example, may include many different varieties of trees with varying heights and density, leaf characteristics, and other features that affect surface roughness. Cropland may be virtually devoid of trees and buildings, or it may have many windbreaks. Uncertainties like these can be resolved only by acquiring more information about the area through aerial photography or field observation. However this is not practical when (as in this project) the area being mapped is very large.