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WIND-GEN: A STATISTICAL DATABASE AND GENERATOR FOR WIND DATA

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SUMMARY:

WIND-GEN consists of a statistical wind database derived from historical weather records and a generator to simulate wind speed and direction on a daily basis. It also has the capability of simulating sub-daily wind speeds. The database was developed for use with the Wind Erosion Prediction System (WEPS) under development by USDA-ARS scientists and is suitable for simulating daily wind data as required by WEPS. This paper also describes the database parameters and how they can be derived from historical wind data.

KEYWORDS:

Climate, models, simulation, weather, wind

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ABSTRACT*

WIND-GEN consists of a statistical wind database as well as programs to simulate wind direction and speed. The WIND-GEN database was produced for use with the Wind Erosion Prediction System (WEPS) under development by USDA-ARS scientists and is designed for simulating daily wind direction and speed as well as sub-daily wind speed from the database parameters. The current implementation of the WIND-GEN database as well as the programs that manipulate the database and generate daily wind information are presented. Descriptions of database parameters are provided as well as explanations of how these parameters can be derived from historical wind data. Because local extension of the WIND-GEN database is expected, relevant factors relating to the suitability of a given set of historical wind data for inclusion into WIND-GEN are also outlined. Future modifications and potential extensions to the WIND-GEN database are discussed.

INTRODUCTION

The U.S. Department of Agriculture (USDA) has appointed a team of scientists to take a leading role in developing the Wind Erosion Prediction System (WEPS) (Hagen, 1991). This process-based wind erosion model will replace the wind erosion equation (WEQ) currently used by the USDA Soil Conservation Service (Argabright, 1991). WEPS requires input of daily climatic data, including daily wind speed and direction. In addition, WEPS also requires estimates of wind speed changes during the day under susceptible wind erosion conditions. Because no single daily climatic generator incorporates all of these features, WIND-GEN was developed.

The WIND-GEN database was built up through analysis of wind and related statistical data records contained in the Wind Energy Resource Information System (WERIS) (Elliot et al., 1987) database at the National Climatic Data Center in Asheville, NC. The WERIS database was designed specifically for use in wind energy applications and represents 975 locations in the United States, Puerto Rico, and Pacific Islands. Data records in WERIS that were considered unsuitable for use in WEPS as described in Skidmore and Tatarko, 1991. The WIND-GEN database currently consists of statistical parameters for 678 locations in the United States (Figure 1).

The WERIS database is not all-inclusive. It only contains data through 1978. In addition, other wind data records are available in the United States (Agricultural Experiment Stations, other research sites, etc.) as well as abroad. Therefore, other historical data sets exist that may be suitable for use in WIND-GEN. Because regional and orographic effects can dramatically affect wind speed and direction even over relatively short distances, local historical wind data are expected to be necessary to provide accurate simulation of characteristic wind data from a statistically based wind generator.

A set of utility routines has been coded to manipulate the WIND-GEN database as well as generate daily wind direction and speed. A menu-driven user interface has been developed that queries for and collects user inputs required for the WIND-GEN wind generator and produces a daily wind data file. Additional utilities are useful for converting historical wind data records into required statistical parameters needed for incorporation into the WIND-GEN database.

The WIND-GEN utilities and statistical database to be used in WEPS are described in this paper. The development of WIND-GEN and how the WERIS wind records were used to create WIND-GEN are described elsewhere (Skidmore and Tatarko, 1990, 1991). This paper describes the procedures

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necessary to use typical historical wind data records and to compute the necessary WIND-GEN database statistical parameters. Therefore, a short description of each of the WIND-GEN database parameters is provided, as well as the specific steps required to compute those parameters from historical wind data sets. Finally, criteria useful in determining the suitability of local historical wind data as sources for extending the WIND-GEN database are presented along with a list of possible future enhancements to WIND-GEN.

WIND-GEN Database Statistical Parameters

The WIND-GEN database consists primarily of monthly statistical wind speed and wind direction parameters. The WIND-GEN database records currently contain the following information:

1. The Weather Bureau, Army, Navy (WBAN) station number.
2. The station site. This usually consists of a city and state designation.
3. The station location. This consist of the site's latitude, longitude, and altitude. The latitude and longitude coordinates are given in degrees and minutes. The altitude is specified in meters above sea level.
4. The beginning and ending dates of data used to derive the statistical parameters for a single database record (yyyymmdd format).
5. Monthly wind direction distributions for the 16 cardinal directions and calm.
6. Monthly Weibull shape and scale parameter pairs that specify the wind speed distribution for each of the 16 cardinal directions.
7. Hour of maximum hourly mean wind speed for each month.
8. Monthly average air density.
9. Monthly average number of recorded sightings of blowing dust.
10. Average ratio of maximum mean hourly to minimum mean hourly observed wind speeds for each month.

WIND-GEN Utility Programs

To deal with any database, a user needs the ability to add, delete, and modify the database itself as well as extract desired information based on specified selection criteria. Currently, the set of utilities (names listed in bold-face) developed to manipulate the WIND-GEN database consists of:

1. **wind_chk** - Searches for the specified wind database record, by WBAN number, and presents the record contents in a table format with a descriptive header. This routine is useful for viewing or extracting copies of individual WIND-GEN database records in a more "user-friendly" format than the native WIND-GEN database format.
2. **wind_wdb** - Extracts selected station records to create secondary WIND-GEN databases. This routine is useful for creating subsets of the master WIND-GEN database file. Many uses of WIND-GEN are expected to be regional in nature and will not require access to all WIND-GEN database records. Wind_wdb provides a method to select only the specified stations by reading an input list file containing the desired station WBAN numbers and/or state codes.
3. **wind_idx** - Generates an indexed listing of stations in a WIND-GEN database. The index file consists of the WBAN numbers for each record along with their respective index number or byte offset (i.e. location of record within the WIND-GEN database file); station name and state; site location statistics (latitude, longitude, and altitude); and beginning and ending dates of historical data used. The computed index values can be used by several of the WIND-GEN utilities to speed up access to specified records within a WIND-GEN database. The

contents of a WIND-GEN index file also provide a useful summary of the records contained in a WIND-GEN database.

4. **wind_gen** - Generates daily simulated wind data from specified station database parameters. This is the actual WIND-GEN generator program. It generates a daily wind data file consisting of day, month, year, wind direction, maximum and minimum hourly mean wind speeds for each day, monthly hour-of-day when maximum mean hourly wind speed occurs, and monthly average air density. Daily wind simulation is always initiated on the first day of a year and produced in multiples of one full calendar year. Leap years are accounted for, so the starting date is important with respect to the daily wind data file. An option may be selected that produces sub-daily wind speeds for those days which the maximum wind speed exceeds a user specified threshold. For sub-daily output, the user must also specify the number of time steps desired for each day (e.g., 96 for wind speeds generated on 15-minute intervals).
5. **wind_cvt** - Converts hourly wind speed and direction data into WIND-GEN database statistical parameters. This routine is useful for anyone that has suitable historical wind data that they want to use as a basis for wind simulation through wind_gen. The required inputs are the date, time, wind speed, and wind direction for each observation of the historical record. Output consists of the statistical parameters in the format necessary to run wind_gen. Details of specific procedures and computations performed by wind_cvt are discussed later.

All of these utilities are coded in the C programming language and are available for both DOS and UNIX operating systems. In addition to these utilities, a DOS menu-driven user interface (cli_wind) has been developed to allow the user to specify options and select the nearest (or desired) station in the WIND-GEN database to generate the daily wind data files. WEPS also will be using CLIGEN, the climate generator used for WEPP (Water Erosion Prediction Project), for other climatic inputs (Nicks and Lane, 1989). Therefore, cli_wind will also have an option for generating these other climatic inputs through CLIGEN.

WIND-GEN Database Suitability Guidelines

Wind data sets to be used in WIND-GEN should meet the following guidelines:

1. The period of historical record should be at least 5 years in length.
2. The anemometer height and location should be known.
3. The anemometer location and observational frequency should have remained constant for the period of record.
4. The number of observations per day should be greater than or equal to 8 (i.e., observation intervals should be every three hours or less).
5. Each observation should include the date, time, wind speed in meters per second, and direction based on a 16-point compass (i.e. N, NNE, NE, ENE, E, ESE, ..., NNW).

Where more than one data set is available for a given location, they may be combined with caution, provided conditions and methods of data acquisition are the same. For example, data for which the anemometer locations are different should not be combined. If a choice is to be made between two data sets within the same locale, one should pick the site with the best combination of the following:

- maximum number of hours per day when observations were taken,
- longest period of record,
- 1-hour versus 3-hour observations, and

- best location of anemometer using the following criteria:
  (ground mast > beacon tower > roof top > unknown).

Determination of WIND-GEN Database Statistical Parameters (wind_cvt)

A suitable wind historical record should be analyzed to determine the joint frequency of occurrence of wind speed and direction by month. We recommend that wind speed frequency distributions be based on speed class intervals of 1 m/s (1 ± 0.5, 2 ± 0.5, 3 ± 0.5, ...). For winds less than 0.5 m/s, a frequency for a 'calm' speed class is also calculated. The frequency distributions produced are in the form of a three-dimensional array representing 17 wind directions (16 plus calm), the number of speed classes, and 12 months. The monthly wind direction distributions can then be determined by summing the frequency for each speed class by direction.

Before further analysis, the wind speed classes should be adjusted to a 10-meter reference height. We used the following:

$$u_2 = u_1(z_1/z_2)^{1/7} \quad (1)$$

where u_1 and u_2 = wind speeds at heights z_1 and z_2, respectively (Elliot, 1979).

Calm periods then should be eliminated and the frequency in each speed group normalized to give a total of 1.0 for each of the 16 directions. Each frequency distribution by month and direction should be fit to the two-parameter Weibull distribution (Takle and Brown, 1978; Corotis et al., 1978).

$$F(u) = 1 - \exp[-(u/c)^k] \quad (2)$$

where:

F(u) = cumulative Weibull distribution function,
u = wind speed,
c = scale parameter (units of velocity), and
k = shape parameter (dimensionless).

This will produce two 16 x 12 arrays (16 directions by 12 months) of scale and shape parameters. A description and example of the procedure for obtaining the Weibull parameters for March at Lubbock, TX are given by Skidmore and Tatarko (1990).

WIND-GEN also requires the ratio of maximum to minimum wind speeds for all winds by month. The monthly average wind speed for each hour should be calculated by taking the sum of the wind speeds for each hour and dividing by the corresponding number of wind speed observations for that hour during the desired month over the entire period of record. The maximum and minimum wind speeds are then selected from the 24 available, and the ratio is determined. The hour at which the maximum wind speed occurred also should be recorded.

Enhancements for WIND-GEN

It is anticipated that WIND-GEN will be regularly enhanced to provide better and more capabilities to simulate wind speed and direction. Some of the improvements envisioned include:

- The capability of adding data from international sites to the database.
- A program to produce summary statistics of selected simulated data (e.g. monthly and yearly means, standard deviations, etc.).
- Inclusion of additional summary statistics into the database to allow wind_gen to generate other wind information not currently supported. For example, Weibull shape and scale parameters for total wind (ignoring direction) for each month would allow direct determination of summary information such as average monthly wind speed.
- The capability for graphical outputs of selected simulated data.

CONCLUSIONS

WIND-GEN consists of a statistical wind database derived from historical weather records and a generator to simulate wind direction and speed on a daily basis. It also has the capability of simulating sub-daily wind speeds. The database was developed for use with the Wind Erosion Prediction System (WEPS) under development by USDA-ARS scientists and is suitable for simulating daily data as required by WEPS. This paper describes the database parameters and utility programs for generating simulated wind data. Suitability guidelines for the inclusion of historical data to the WIND-GEN database as well as procedures for converting this data to WIND-GEN database statistical parameters are presented. Anticipated enhancements are also listed.

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Figure 1. Location of WIND-GEN stations in the conterminous United States.