DETERMINING WIND RESOURCES AS A FUNCTION OF SURFACE ROUGHNESS AND HEIGHT FROM NASA GLOBAL ASSIMILATION ANALYSIS

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ABSTRACT

Wind resources increase dramatically above the Earth's surface and higher wind turbine hub heights are more achievable through modern mechanical engineering. As a result, wind farms are being considered in more locations with moderate, but predictable wind resources in areas of varying surface conditions. This paper describes a global data set and an Internet application that can be employed to estimate wind resources at heights from 10 to 300 meters above the surface of the earth using meteorological data assimilation products as input. The global data set, available from NASA's Prediction of Worldwide Energy Resource project, is comprised of new estimates of surface roughness exponents that can be used in the Gipe power law, based on high-resolution International Geosphere and Biosphere Project scene types, and global wind on a 1°x1° grid at 50 meters above the surface of the earth calculated from NASA's meteorological data assimilation products. This application takes into account heights above the Earth's surface and vegetation types at the Earth's surface, but does not resolve topography or elevation differences within each 1°x1° region. Examples of wind estimates obtained from the web site using the Gipe power law compare favorably to estimates obtained using the European logarithmic method.

1. INTRODUCTION

The NASA Prediction of Worldwide Energy Resource (POWER) Project continues to develop useful renewable resource data sets, building on the success of the Surface meteorology and Solar Energy (SSE) data set and web site (http://eosweb.larc.nasa.gov/sse/). This paper provides estimates of surface roughness exponents for a wider range of vegetation types than has been available in the past. These values should assist in converting airport-measured wind speed data to various vegetation conditions. In addition, the usefulness of the Gipe power law [1] to adjust SSE wind speeds to varying heights is described and compared to a meteorological data assimilation product that contains wind speed data at 110 meters above the surface of the earth. The European logarithmic method approach [2] was tested and compared to the results obtained from the Gipe power law for further evaluation.

2. BACKGROUND

SSE wind speed data is based on the NASA Version 1 Goddard Earth Observing System (GEOS-1) satellite and modeled reanalysis data set described in Takacs, Molod, and Wang [3]. Global wind speeds at 50 meters above the surface of the earth were derived using equations provided by GEOS-1 project personnel and data values from the first layer above the surface of the earth. A correction to the GEOS-1 values was made in several regions where surface vegetation types were incorrect in the original GEOS-1 data set [4]. The height of SSE wind speed data are above the soil, water, or ice surface and not above the "effective" surface in the upper portion of vegetation canopies. The time period of GEOS-1 data used in the current SSE data set is from July 1983 through June 1993. January wind speed at 50 meters above the surface of the earth averaged for the 10-year period is shown in figure 1.

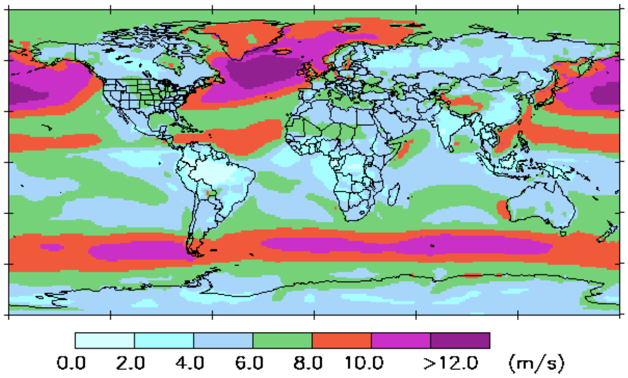

Fig. 1: January wind speed at 50 meters above the surface of the earth for all vegetation types

The GEOS-1 data is on a 2.5°x2.0° longitude/latitude grid system. Bilinear interpolation was used to provide global data on a 1°x1° grid. Procedures in Gipe [1] were used to provide wind velocities closer to the surface of the earth, in particular, 10 meter values for airport-type surfaces. Comparison with ground site data yielded bias values between -0.2 and +0.2 m/s and RMS (including bias) values in the range of 1.3 m/s [4]

The ratio of 10 meter to 50 meter velocities (V10/V50) for 17 vegetation types was established for each month [5]. With this information, the SSE 50 meter velocities can be adjusted to 10 meter velocities for the vegetation type at any site as long as the topography is level.

3. ANALYSIS

3.1 Surface Roughness Exponents

Previous analysis that resulted in the V10/V50 ratios for various vegetation types was extended to develop a global data set of estimated surface roughness exponents that can be used in the Gipe power law to adjust wind speed data to various heights above the ground. The first step was to calculate the monthly surface roughness exponents from the V10/V50 ratios for all 17 vegetation types. The Gipe power law (equation 1) was used to solve for the surface roughness exponents.

(1) $V = V_O * (H / H_O)^{\alpha}$ where:

V_O = wind speed at the original height

V = wind speed at the new height

H_O = original height

H = new height

α = surface roughness exponent

The solution to finding the surface roughness exponent is given in equation 2.

(2) $\alpha = \mathrm{LOG}((V10 / V50)) / \mathrm{LOG}(10.0 / 50.0)$

The next step was to find a global data set of surface types to relate to the SSE vegetation types. NASA's Clouds and the Earth's Radiant Energy System (CERES) mission and Surface and Atmospheric Radiation Budget (SARB) working group have developed the CERES/SARB surface map [6] from the International Geosphere and Biosphere Project (IGBP) 1 km scene type data set. The CERES/SARB surface map has 18 scene types at a resolution of 10 minutes of latitude and longitude (figure 2).

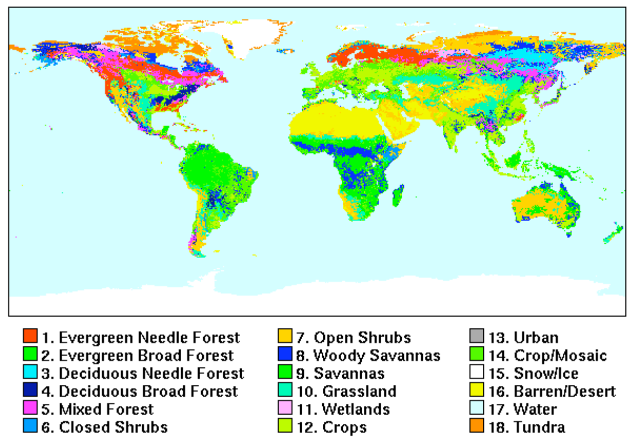

Fig. 2: CERES/SARB surface map

The surface roughness exponents corresponding to each IGBP scene type of the 10 minute CERES/SARB surface map were summed and averaged over each 1°x1° region to develop a global monthly averaged surface roughness exponent data set that has the same resolution as all SSE data sets. The annual average of the monthly surface roughness exponents is shown in figure 3.

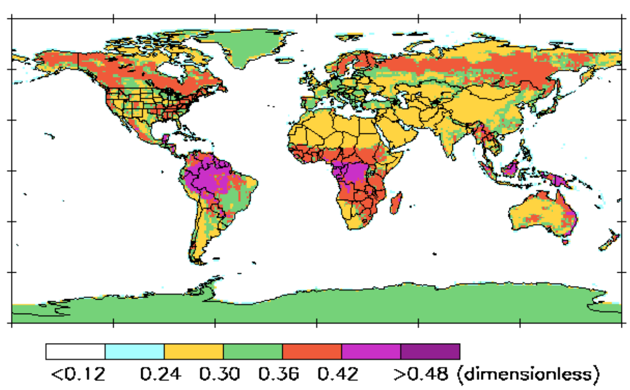

Fig. 3: Annual average surface roughness exponent for all IGBP scene types

Surface roughness exponents are available for some vegetation types that are not included in the CERES/SARB surface map. Table 1 relates the SSE vegetation types to IGBP scene types and provides the corresponding monthly surface roughness exponents. SSE vegetation types 7 through 10 have the same surface roughness exponent. IGBP scene types 6, 7, 10, 12, 16 and 18 fall within that same category.

TABLE 1: THE SURFACE ROUGHNESS EXPONENT FOR VARIOUS VEGETATION TYPES

IGBP Type	Veg Type	Northern Hemisphere Month	1	2	3	4	5	6	7	8	9	10	11	12
2,13	1	35-m broadleaf-evergreen trees (70% coverage)	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
	2	20-m broadleaf-deciduous trees (75% coverage)	0.34	0.35	0.36	0.37	0.39	0.42	0.44	0.42	0.39	0.37	0.36	0.35
	3	20-m broadleaf and needleleaf trees (75% coverage)	0.51	0.47	0.43	0.41	0.39	0.38	0.38	0.41	0.43	0.46	0.48	0.50
1,5	4	17-m needleleaf-evergreen trees (75% coverage)	0.43	0.39	0.36	0.34	0.35	0.36	0.37	0.37	0.37	0.38	0.39	0.41
3	5	14-m needleleaf-deciduous trees (50% coverage)	0.41	0.39	0.37	0.35	0.35	0.34	0.34	0.38	0.42	0.44	0.44	0.43
4,8, 9,11	6	Savanna:18-m broadleaf trees (30%) & groundcover	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41
6,7,10, 12,16,18	7	0.6-m perennial groundcover (100%)	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
	8	0.5-m broadleaf shrubs (variable %) & groundcover	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
	9	0.5-m broadleaf shrubs (10%) with bare soil	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
	10	Tundra: 0.6-m trees/shrubs (variable %) & groundcover	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
	11	Rough bare soil	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
14	12	Crop: 20-m broadleaf-deciduous trees (10%) & wheat	0.28	0.30	0.23	0.35	0.35	0.35	0.35	0.35	0.35	0.33	0.31	0.29
15	20	Rough glacial snow/ice	0.35	0.33	0.30	0.28	0.28	0.28	0.28	0.28	0.30	0.33	0.34	0.35
		Smooth sea ice	0.18	0.15	0.12	0.09	0.09	0.09	0.09	0.12	0.15	0.19	0.19	0.19
17	0	Open water	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
		"Airport": flat ice/snow	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
		"Airport": flat rough grass	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15

3.2 Gipe Power Law and European Logarithmic Method

The usefulness of the Gipe power law to adjust SSE wind speed data to varying heights was analyzed. GEOS-1 data files readily available for comparison were the upper air prognostic fields, U and V, at 18 levels for all months in 1986. Prognostic quantities represent instantaneous values every six hours (00Z, 06Z, 12Z, 18Z)[7]. The pressure levels are 1000, 950, 900 millibars, and so on. Lower pressure levels (higher altitudes) are beyond the needs of the renewable energy industry. The corresponding pressure altitude (altitude above sea level) of the above pressure levels equal 110, 540, and 988 meters, respectively. Monthly averaged SSE 50 meter wind speeds for 1986 were elevated to 110 meters using the SSE surface roughness exponents in the Gipe power law. Four months (seasonal) of SSE and GEOS-1 wind speed data at 110 meters above the surface of the earth are plotted in figure 4.

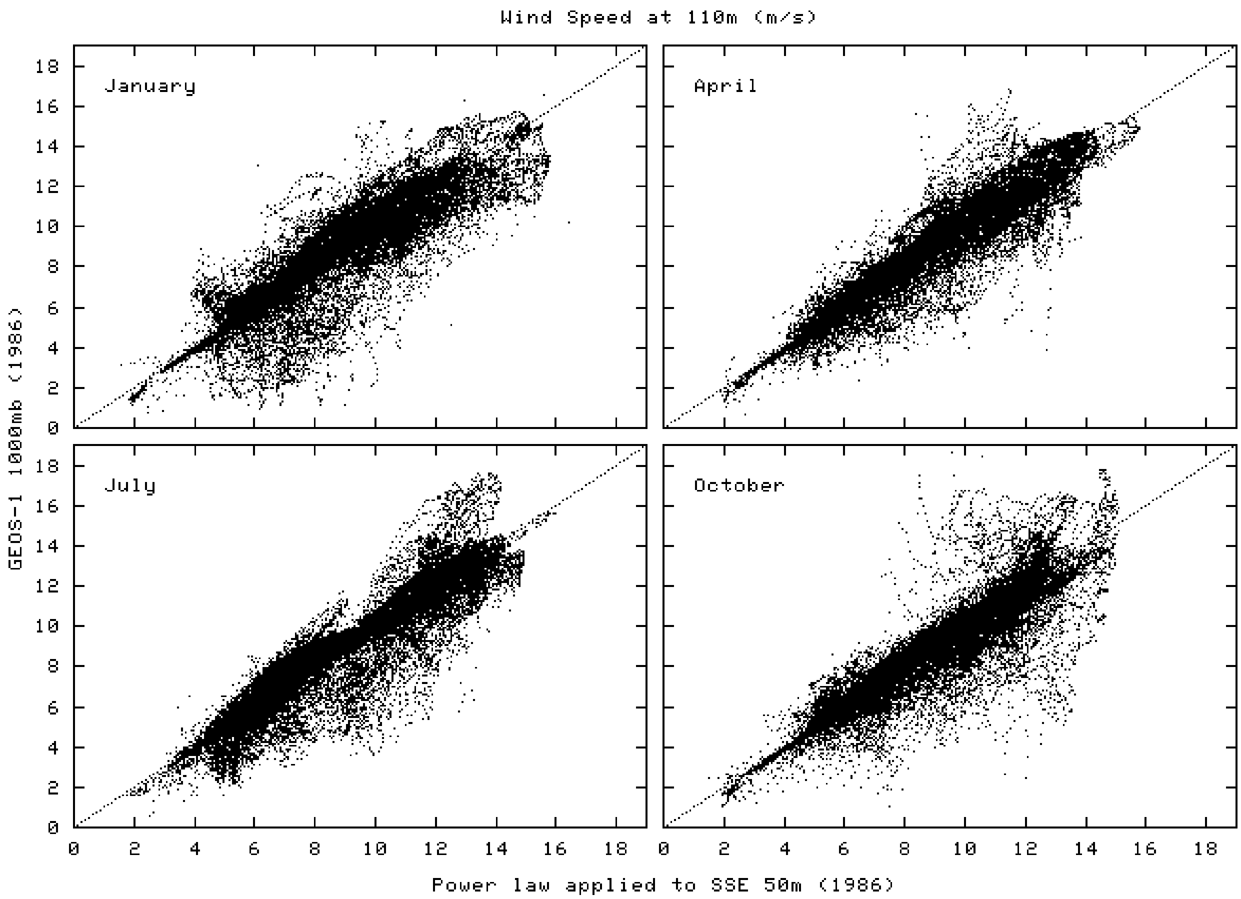

Fig. 4: Seasonal comparison of SSE and GEOS-1 wind speed at 110 meters

The European logarithmic method of adjusting heights of wind speed data (equation 3, Ref. 2) was also tested to support the validity of the SSE global surface roughness exponent data set and use of the Gipe power law to adjust wind speed data to varying heights.

(3) $V = V_{ref} * \ln(Z / Z_o) / \ln(Z_{ref} / Z_o)$ where:

V = wind speed at height Z above ground level
V_{ref} = reference speed, i.e. a wind speed we already know at height Z_{ref}
Z = height above ground level for the desired velocity, V
Z_o = roughness length in the current wind direction
Z_{ref} = reference height, i.e. the height where we know the exact wind speed V_{ref}

The coefficients for the European logarithmic method are in terms of roughness length, based on roughness class. A surface classification comparable to the "Airport: flat rough grass" vegetation type was used in the European logarithmic method to elevate the 1986 monthly averaged SSE 50 meter wind speed data to 110 meters. The roughness length for the surface classification, "Completely open terrain with a smooth surface, e.g. concrete runways in airports, mowed grass, etc.", is 0.0024. In the future we will endeavor to relate the European logarithmic method roughness lengths to the surface roughness exponents described in table 1.

Results from both methods described above were statistically compared to GEOS-1 1000-millibar (110 meter) wind speed data (table 2). The GEOS-1 1000-millibar (110 meter) data is available for approximately 60% of the globe. Consequently, the comparison of SSE 50 meter wind speed data elevated to 110 meters using the Gipe and European methods was made at the same locations.

TABLE 2: MONTHLY COMPARISON OF WIND SPEED AT 110 METERS FOR 1986

Month	Number	GEOS-1 1000mb	Gipe method			European method		
		Average	Average	Bias	RMS	Average	Bias	RMS
Jan	41244	8.20	8.29	-0.09	1.12	8.18	0.01	1.12
Feb	42024	7.63	7.83	-0.21	0.99	7.73	-0.10	1.00
Mar	41844	8.05	8.24	-0.18	0.97	8.14	-0.09	0.95
Apr	41566	8.17	8.19	-0.02	0.82	8.09	0.08	0.81
May	42232	7.69	7.83	-0.13	0.87	7.73	-0.04	0.83
Jun	41314	7.94	8.07	-0.13	0.80	7.98	-0.04	0.75
Jul	41164	8.02	8.12	-0.10	0.98	8.03	-0.01	0.93
Aug	41002	7.97	8.00	-0.03	0.82	7.92	0.05	0.77
Sep	40508	7.89	8.03	-0.14	0.94	7.93	-0.04	0.89
Oct	40454	7.92	8.05	-0.13	1.03	7.95	-0.03	1.01
Nov	40588	8.15	8.20	-0.06	0.93	8.10	0.05	0.93
Dec	39510	8.50	8.45	0.05	0.89	8.34	0.16	0.89
Annual	493450	8.01	8.11	-0.10	0.93	8.01	0.00	0.91

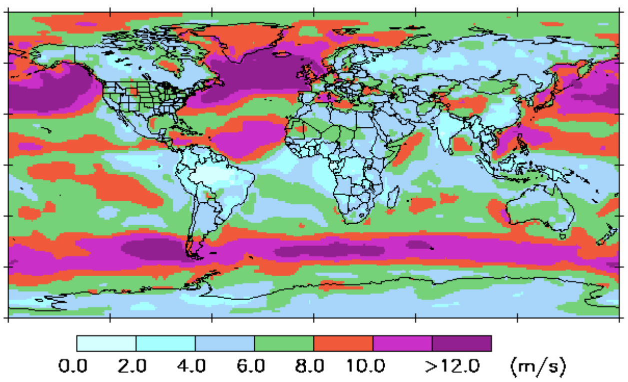

Fig 5a. Gipe power law applied to the January SSE 50 meter wind speed to elevate it to 110 meters using the SSE surface roughness exponents

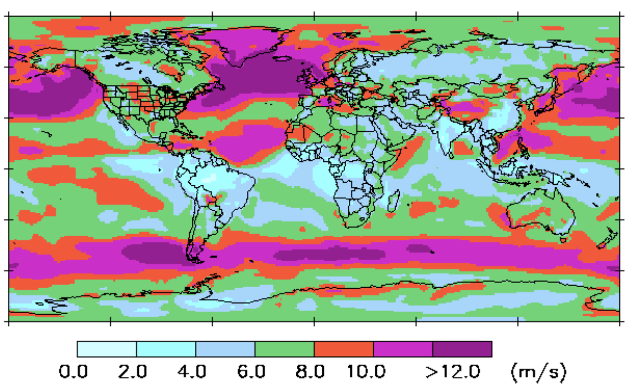

Fig 5b. European logarithmic method applied to the January SSE 50 meter wind speed to elevate it to 110 meters using a roughness length of 0.0024

The global plot of January wind speed at 110 meters using the SSE surface roughness exponents in the Gipe power law (figure 5a) is comparable to the results of using a roughness length equal to 0.0024 in the European logarithmic method (figure 5b). A comparison of figures 1 and 5 shows the effect of height on wind velocity in January 1986.

4. CONCLUSIONS

The SSE 1°x1° surface roughness exponent data set developed from high-resolution IGBP scene type data provides a method for determining the available wind resources at various heights anywhere on the globe. Applying the Gipe power law to 50 meter wind velocities from global meteorological assimilation products provides results in wind velocity estimates that compare favorably to those obtained using the European logarithmic method. Both of these methods were shown to produce consistent results in estimating the winds at 110 meters relative to winds at this height from the assimilation when using surface types and roughness lengths consistent with the assimilation. This indicates that the Gipe and European methods are consistent with the physics of the assimilation model.

Table 1 is a powerful tool that permits a user to understand the variability of wind velocity due to different vegetations. The SSE web site application permits the user to view wind velocity variability for 17 vegetation types and at any height from 10 to 300 meters for any specified 1°x1° degree region.

The web site also provides global or regional plots of monthly averaged wind speed estimates at 100 meters and 150 meters. The values were calculated from SSE monthly averaged 50 meter wind speed data using SSE surface roughness exponents in the Gipe power law for each 1°x1° region.

Work to improve these estimates of winds at this resolution is continuing using a new GEOS long-term assimilation that will extend from present back to 1983. Similar validation and testing of these new products will be performed with available surface and upper air wind measurements.

5. ACKNOWLEDGEMENTS

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