DEVELOPMENT OF AN ARCHITECTURAL DATA SET FROM SATELLITE DATA

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1. INTRODUCTION

In the U.S. alone, buildings account for 65% of electricity use and 36% of total energy consumption. U.S. Buildings also account for 36% of carbon dioxide emissions and 30% of greenhouse gas emissions (Environmental Building News, 2001). An international Department of Energy scientist (Dr. Douglas Balcomb) has noted that industry now has the capability to design and construct buildings that use 50% less energy at no increase in construction cost if accurate environmental data are available (Balcomb and Curtner, 2000). Therefore, environmental data (various temperature, solar radiation, illumination, winds, cloud cover, and humidity parameters) become the cornerstone of the design process. By inputting environmental data into modern building-design software programs, computer simulations are generated which perform energy/cost trade-off studies.

NASA atmospheric science research has the capability to provide both advancements in industrial technologies and advanced design data for the globe that meet industry standards. This paper describes design of a data set, and an internet gateway, to provide architects and engineers specializing in the design of energy-efficient, “sustainable” buildings with a globally consistent and state-of-the-art satellite-based Surface Meteorology and Solar Energy Buildings (SSE-B) data set. The authors are building a pipeline drawing from the NASA Earth Science Enterprise (ESE) 20-year heritage in climate research and redirecting the results of these efforts to industry. And, in developing the first satellite-based climate data set for the building industry, the investigators are laying the foundation for influencing the way the building industry views, and utilizes, climate data in the future.

The long-term goal is to provide a 1 x 1-deg global data set that can be rapidly obtained for faster preliminary design and proposal activities for new buildings and similar structures. More specifically, this paper describes the type of information that is planned in a prototype web site now under development and recent results for several parameters. The authors are in the process of soliciting inputs from architects and builders for definition of additional parameters that may add to the value of the data set.

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2. APPROACH

The general approach is to utilize NASA ESE data to expand both the applicability and usefulness of existing building industry tools and procedures. Basis for the initial web site will be most parameters in the existing Solar Radiation Data Manual for Buildings (Marion and Wilcox, 1995) for 239 sites in the U.S. Additional information will include more detailed wind and humidity information as well as monthly average, diurnal-cycle trends for many parameters consistent with recent thinking concerning "sustainable" design needs. The data set is not aimed at any particular building-design software, but instead is intended for use by a wide range of both small and large organizations for preliminary design purposes. It is expected that user-supplied sophisticated design software and local data or estimates would be used for final design purposes within the 1-deg cell. The SSE-B data set will have some different parameters but will be consistent with the NASA SSE global data sets (Olson et al. 2000, Whitlock et al. 2000, and DiPasquale et al. 2002). SSE (http://eosweb.larc.nasa.gov/sse/) is often an input for power system and emissions analysis through Natural Resources Canada's RETScreen™ no-cost software (http://retscreen.gc.ca/ang/menu.html) which was developed in cooperation with the United Nations Environmental Program (UNEP). As a result, atmospheric inputs can be consistent between the building, energy, and emissions analysis industries. It is expected that both SSE and SSE-B web sites will be updated periodically as the need for new parameters becomes known or advanced data are available as part of the long-term NASA ESE activity.

3. ARCHITECTURAL/BUILDING PARAMETERS

A preliminary list of parameters has been selected after initial discussions with a few industry representatives. They are as follows:

3.1 Average, Maximum, and/or Minimum Monthly Parameters

a. Radiation on horizontal-, north-, east-, south-, and west-facing surfaces:

- All-sky and clear-sky total, diffuse, and direct Short Wave (SW) irradiance
- Incident illuminance for mostly-clear and mostly cloudy conditions
- All-sky and clear-sky clearness index*

* Clearness index = total SW irradiance on a horizontal surface / top-of-atmosphere SW irradiance

b. Temperatures:

- 10-m air temperature
- Heating and cooling degree days
- Earth skin temperature
- 10-m dew-point temperature

c. Wind

- 10-m* speed for various types of vegetation
- 50-m speed
- 50-m speed frequency of occurrence
- 50-m prevailing direction for various speeds

* All heights are above cell-average soil, water, or ice surfaces, not the "effective" surface near the top of vegetation canopies.

d. Miscellaneous

- 10-m air humidity ratio
- 10-m relative humidity
- Mostly-clear percent of daylight hours
- Number of frost days

3.2 Monthly-Average Diurnal Variation (3-hourly)

- Sun elevation and azimuth
- Incident illuminance on horizontal-, north-, east-, south-, and west-facing surfaces
- Temperature, humidity ratio, wind speed, and direction

These parameters are subject to change depending on future discussions with industry personnel as noted above.

4. PROGRESS

Most of the temperature and humidity parameters are expected to be easily obtainable from Goddard Earth Observing System (GEOS) reanalysis data. In fact, a few have already been validated and are included as part of the SSE web site, Release 4. More challenging are some of the wind and radiation parameters.

4.1 Wind Parameters

Wind speed and direction information are desired for various vegetation types such that building orientation landscaping, daylighting, and the Heating, Ventilation, and Air Conditioning (HVAC) diurnal duty cycle can be optimized for season. For example, it may be desirable to select vegetation or wall landscaping for wind blockage in the winter and ventilation in warmer months while maintaining maximum daylighting in winter and reduced solar heating in the summer. Optimized ventilation, dehumidification, and air conditioning diurnal duty cycles are especially important for "sustainable" design in many parts of the world.

SSE winds will be based on Version 1 GEOS reanalysis data set (Takacs, Molod, and Wang, 1994) with some adjustments based on science information from Dorman and Sellers, 1989, and recent vegetation maps developed by the International Geosphere and Biosphere Project (IGBP). New 50-m height velocities were developed and converted to 10-m values airport-type terrains based on procedures in Gipe, 1999. Ten-year average maps of both 50-m and 10-m "airport" speeds are shown in Fig. 1 for January. Note that SSE heights are above the soil, water, or ice surface and not above the "effective" surface in the upper portion of vegetation canopies.

10-m "airport" estimates were compared with several different airport data sets over the globe. In general, bias values varied between $\pm$0.2 m/s and RMS (including bias) values ranged between 0.82 and 1.2 m/s. This represents a 20 to 25 percent level of uncertainty relative to mean monthly values. That is about the same level of uncertainty quoted by Schwartz (1999). Gipe (1999) notes that operational wind measurements are sometimes inaccurate for a variety of reasons. SSE 10-m "airport" winds tend to be higher than airport measurements in remote desert regions in some foreign countries. SSE values are usually lower than measurements in mountain regions where localized accelerated flow may occur at passes, ridgelines or mountain peaks. One-degree resolution wind data is not an accurate predictor of local conditions in regions with significant topography variation or complex water/land boundaries.

An architect or builder is interested in winds relative to the prospective building site that may be below vegetation canopies in either some or all directions. Trees and shrub-type vegetation with various heights and canopy-area ratios reduce near-surface velocities by different amounts. GEOS-1 calculates 10-m velocities for a number of different vegetation types. Values are calculated by parameterizations developed from a number of "within-vegetation" experiments in Canada, Scandinavia, Africa, and South America (see Dorman and Sellers, 1989 for leads back to these data sets). The ratio of 10-m to 50-m velocities (V10/V50) for 17 vegetation types is provided in the table. All values were taken from GEOS-1 calculations except for the "airport": flat rough grass category that was taken from Gipe (1999).

An architect or builder may estimate localized 10-m winds in different directions for his site by first picking the vegetation type closest to each directional from the table. Given 50-m prevailing wind speeds and direction for each month, he may approximate the magnitude and direction of prevailing 10-m wind at his

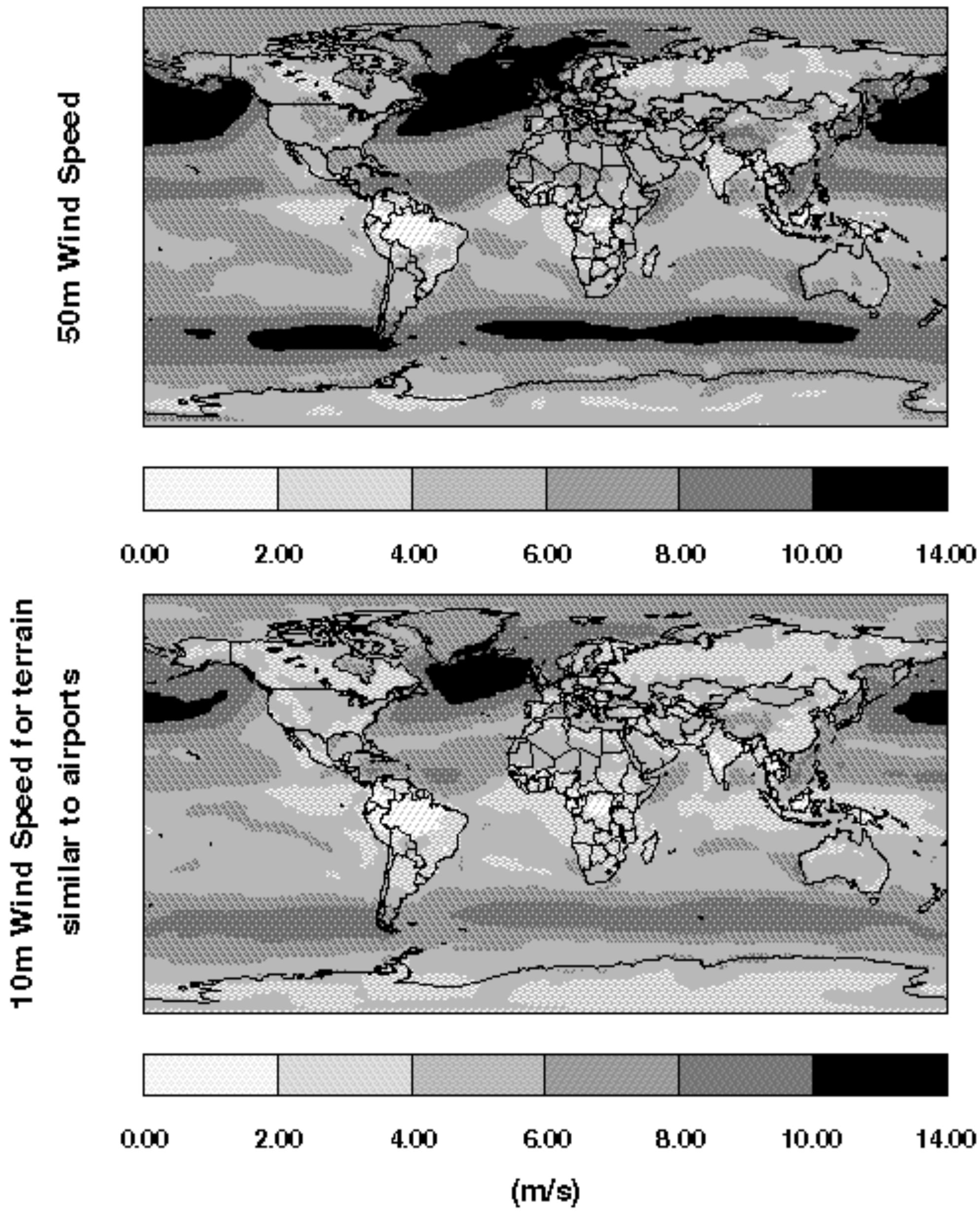

Fig. 1. Average January wind speeds for 2 heights above either soil, water, or ice surfaces for the period July 1983 through June 1993. Heights above the "effective" surface near the top of vegetation canopies will be lower depending on vegetation height.

site. In flat country, he could use SSE 50-m speed and direction data. Alternatively, he could obtain 10-m data from a local airport and multiply it by the inverse of the "airport": flat rough grass ratio [(1/0.79 = 1.266)] to obtain an estimate of 50-m velocity over the airport. Assuming 50-m values over the airport and building site to be the same, he may estimate prevailing 10-m velocities and direction for each month at his site. Outdoor or ventilated living /working spaces may be more accurately orientated and designed. Wind blocks may be more accurately located also.

Table. V10/V50 velocity ratios for various surface types.

Northern hemisphere month	1	2	3	4	5	6	7	8	9	10	11	12
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
20-m broadleaf-deciduous trees (75% coverage)	0.58	0.57	0.56	0.55	0.53	0.51	0.49	0.51	0.53	0.55	0.56	0.57
20-m broadleaf and needleleaf trees (75% coverage)	0.44	0.47	0.50	0.52	0.53	0.54	0.54	0.52	0.50	0.48	0.46	0.45
17-m needleleaf-evergreen trees (75% coverage)	0.50	0.53	0.56	0.58	0.57	0.56	0.55	0.55	0.55	0.54	0.53	0.52
14-m needleleaf-deciduous trees (50% coverage)	0.52	0.53	0.55	0.57	0.57	0.58	0.58	0.54	0.51	0.49	0.49	0.50
Savanna:18-m broadleaf trees (30%) & groundcover	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52
0.6-m perennial groundcover (100%)	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
0.5-m broadleaf shrubs (variable %) & groundcover	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
0.5-m broadleaf shrubs (10%) with bare soil	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
Tundra: 0.6-m trees/shrubs (variable %) & groundcover	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
Rough bare soil	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Crop: 20-m broadleaf-deciduous trees (10%) & wheat	0.64	0.62	0.69	0.57	0.57	0.57	0.57	0.57	0.57	0.59	0.61	0.63
Rough glacial snow/ice	0.57	0.59	0.62	0.64	0.64	0.64	0.64	0.64	0.62	0.59	0.58	0.57
Smooth sea ice	0.75	0.78	0.83	0.86	0.86	0.86	0.86	0.82	0.78	0.74	0.74	0.74
Open water	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
"Airport": flat ice/snow	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
"Airport": flat rough grass	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79

Note: 10-m and 50-m heights are above either soil, water, or ice surfaces, not above the "effective" surface near the tops of vegetation.

4.2 Radiation Parameters

Total SW irradiance will be the same or an advanced version of that used in the SSE web site. At the time of this manuscript, the authors are in the final stages of developing and validating an approach for estimating both diffuse and direct beam irradiances from satellite-derived total SW irradiance.

Satellite data has measurement frequency characteristics that do not allow most methods used with hourly ground site data. Based on results from Brunger and Thevenard (1999), the method of Page (1961) was selected to estimate monthly diffuse irradiance from monthly total irradiance. The original Page method employed only 10 reference ground sites in its procedure. The authors are in the process of expanding the number of reference sites to include locations over a wider range of atmospheric climate types. At the time of this manuscript, we have located prospective sites in 12 of the 13 global climates defined in Wilber, Smith, and Stackhouse (1999), and Smith, et al. (2002). When finished, we expect to utilize approximately 70 reference ground sites in many regions of the globe. We are carefully testing our diffuse results with data from over 400 sites. Applicability of the method is expected to expand to from 90^{o}N to 90^{o}S. Direct beam on a horizontal surface is obtained by subtracting diffuse irradiance from the value for total. A solar angle correction is made when direct normal irradiance is desired.

A preliminary estimate of 10-yr average values for January is shown in Fig. 2. These particular diffuse and direct beam calculations were made with 30 reference sites. Calculations have been limited to latitudes between $\pm$ 53^{o} in this particular case.

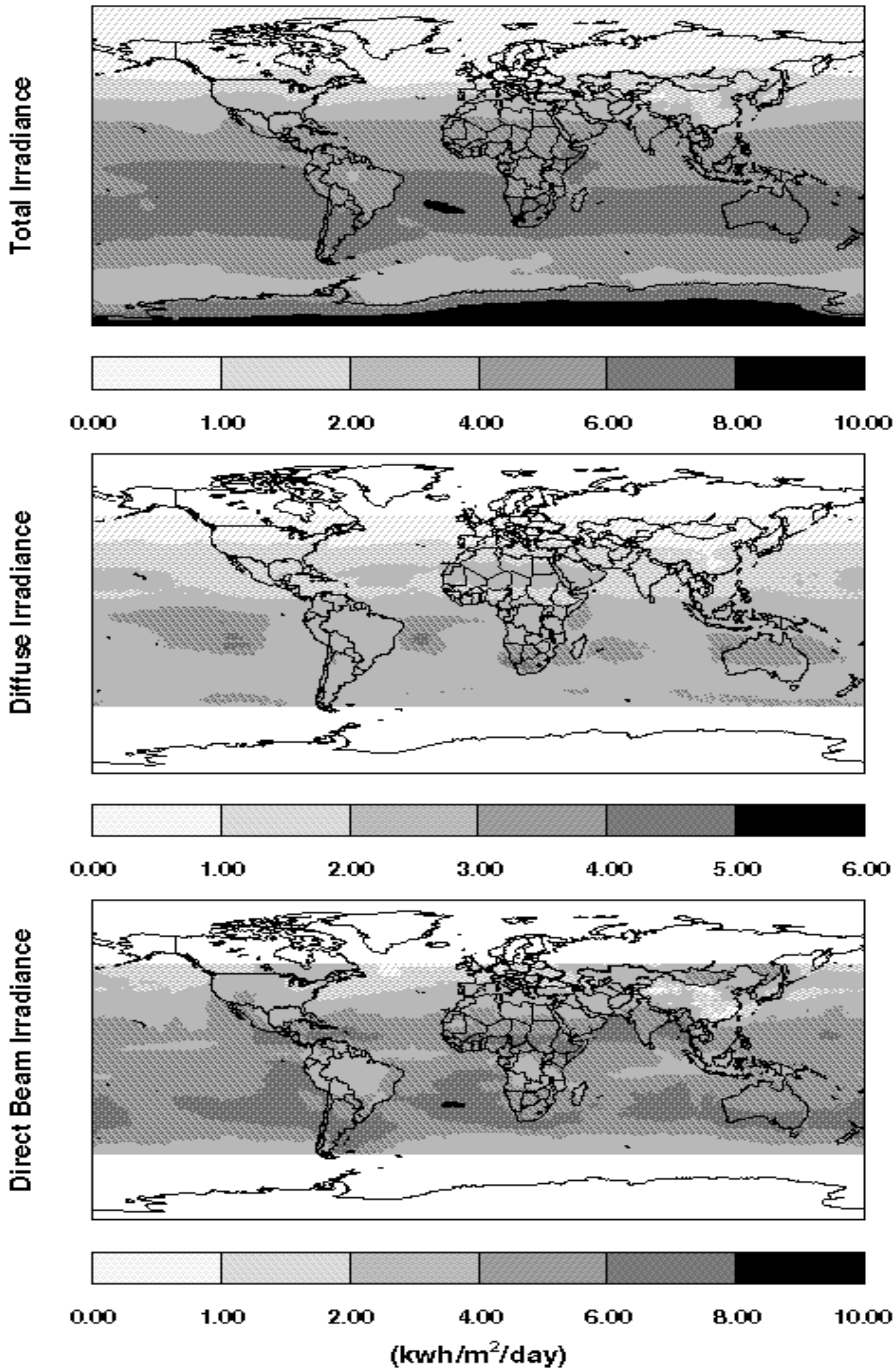

Fig. 2. Preliminary estimates of average January total, diffuse, and direct beam surface solar irradiance for the period July 1983 through June 1993.

5. OUTLOOK TO THE FUTURE

Extensive validation of the SSE-B data set will be performed prior to data distribution. An innovative web site will then be developed. The data distribution web site will allow for data browsing and download capabilities for various parameters, in a range of digital formats, for any region of the world. Two and three dimensional plotting capabilities and tabular data formats will be featured for the online display. A comprehensive downloadable user manual that educates users on satellite-based parameters, a frequently-ask-questions guide, and links to other web sites that pertain to energy-efficient building design is planned.

The authors believe that energy-efficient building designs will continue to grow in importance as we become internationally aware of climate and climate change. Consequently, statistics from climate models that predict the future weather conditions may be of significant value to architects and engineers for buildings, and potentially urban development.

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