ENHANCING THE GEOGRAPHICAL AND TIME RESOLUTION OF NASA SSE TIME SERIES USING MICROSTRUCTURE PATTERNING

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ABSTRACT

In this paper, we present and test a methodology to augment the time and geographical density of NASA SSE 3-hourly time series going back to 1983 by using a few recent years of high resolution GOES-derived solar resource data as a microstructuring template.

1. BACKGROUND

The National Renewable Energy Laboratory is producing an update to the National Solar Resource Data Base (NSRDB, e.g., Wilcox et al, 2005). High resolution GOES-derived hourly irradiances, hereafter SUNY-model data (Perez et al., 2004), are being produced as part of this effort for the most recent years (1998-2005). Another source of input to the NSRDB is the NASA Surface Meteorology and Solar Energy data set (SSE, Stackhouse et al, 2004) derived from the ISCCP cloud cover data (ISCCP, 1983-). The SSE data extend back to 1983; the time resolution is 3-hourly and the geographical resolution is 1^{o} latitude by 1o longitude.

The recent years (1998-2005) are common to both the SUNY and SSE data sets. This time period can be used to observe the relationship between the two and to develop and test a methodology to extract high resolution from low resolution data. Pending success with this approach, the NSRDB could include high resolution time series spanning 1983 through 2005.

Our initial study (Perez et al., 2006) showed that the proof of concept has merit. Indeed, the relative distribution of irradiance within a one degree cell (representing the SSE data footprint) was found to be very stable from year to year, both on annual and on monthly basis. This is understandable because irradiance variability due to weather is captured by the low-resolution SSE data, whereas microclimatic enhancements, orographic or coastal in nature, tend to be more stable in relative terms. Perez et al., 2006, show that the overall relative distribution of irradiance within an SSE cell is stable from year to year and that the year-to-year variability of this pattern is considerably smaller than the range of values within that cell. This was shown to be true for a wide range of climatic conditions.

In this article, we go one step further by evaluating the validity of high resolution hourly GHI time series extracted from low resolution 3-hourly SSE time series.

2. METHODOLOGY

The approach to generate high resolution time series from the SSE input includes the following steps.

(1) Extrapolating hourly time series from the 3-hourly SSE data using constant clearness index.
(2) Deriving a relative microstructure pattern within the footprint of an SSE cell quantified in terms of monthly clearness index difference between any high resolution pixel within a cell and the cell's average. The microstructure patterns are derived from seven years of high resolution satellite data.
(3) Assessing the systematic bias between the SSE and SUNY data by comparing cell-wide monthly averages for the SUNY and SSE data, and quantifying this bias in terms of clearness index difference. The estimation of this bias is currently based on one year -- 1999 -- of data for which we have access to the SSE data. In an

operational mode, the bias will be based on all the years coincident to SSE and SUNY data.

(4) Applying the Time-Series-Generator (TSG, Perez, 2000) to modify the time series from step (1) so that its average monthly clearness index is increased/decreased by an amount equal to the sum of the clearness index differences from step (2) and (3).

The result of this procedure yields 100 hourly time series per SSE cell that retain the basic day-to-day timeline of the SSE data, but that are adjusted to account for the relative GHI intensity distribution within the cell and any systematic bias in the SSE data.

The methodology is assessed by comparing the input SSE, the benchmark SUNY, and the microstructured SSE (step 4 above) time series against high quality irradiance measurements at six climatically distinct locations for the year 1999. The stations are listed in Table 1 along with their main climatic characteristics.

3. RESULTS

3.1 SUNY and SSE time series vs. ground measurements

Continuing on the initial model evaluation undertaken last year [6], we compared hourly time series from the SUNY data (closest pixel) and time-extrapolated SSE data (closest cell) to ground measurements for each of the six stations. The scatter-plots in Figures 1 and 2 illustrate this comparison. Yearly RMSEs and MBEs are reported in Figure 3.

These results are entirely consistent with our initial evaluation of the two models (Perez and Kmiecik, 2005) stating that both perform adequately, but in almost all instances, the dispersion and bias of the SUNY is smaller than that of the NASA-SSE -- one of the reason for the higher SSE dispersion stems from the lower spatial and temporal resolution of the latter. The negative bias of the SSE data, particularly for the arid locations, had also been reported, and is consistent with recent evaluations of both

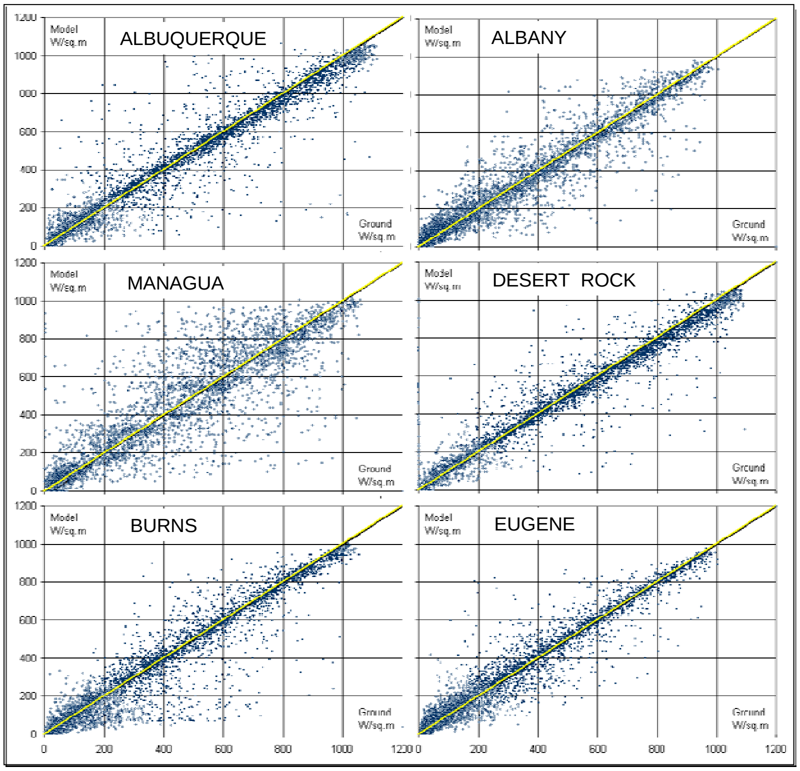

Figure 1 : SUNY model GHI (Y axis) vs. ground measurements (X-axis)

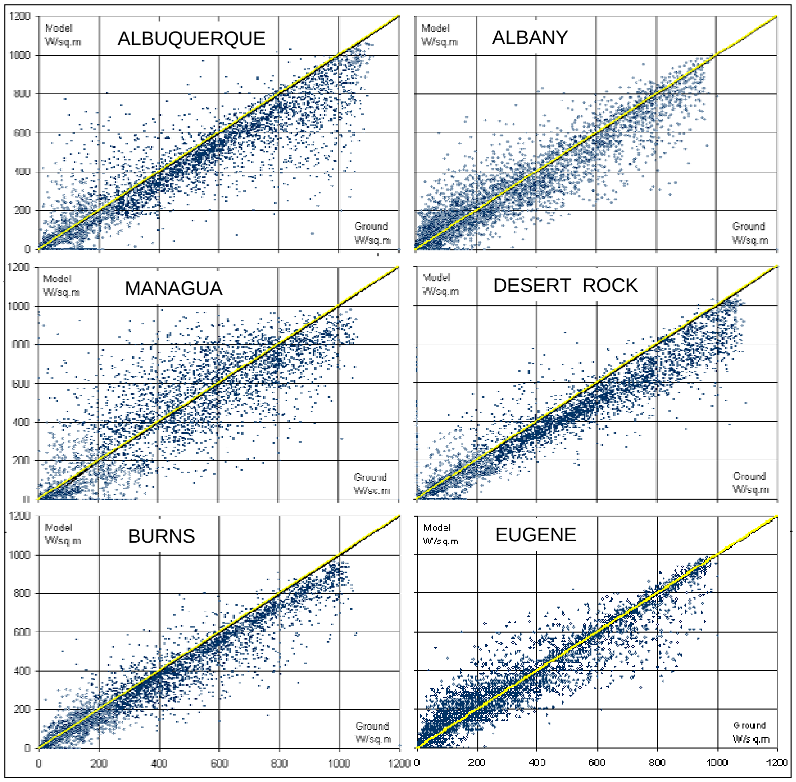

Figure 2: NASA-SSE (Y-axis) vs. ground measurements (X-axis)

TABLE 1 METHODOLOGY VALIDATION SITES

	CLIMATE	LAT	LON	ELEV (meters)	SOURCE
ALBUQUERQUE, NM	Arid	35.08	-106.65	1516	Sandia Natl. Labs.
BURNS, OR	Semi-arid	43.52	-119.02	1267	U. Oregon
EUGENE, OR	Maritime temperate	44.05	-123.05	125	U. Oregon
ALBANY, NY	Continental humid	42.65	-73.85	90	U. Albany
DESERT ROCK, NV	Arid	36.62	-116.02	1372	Surfrad Network
MANAGUA, NICARAGUA	Tropical	12.15	-86.25	132	U. Centroamericana

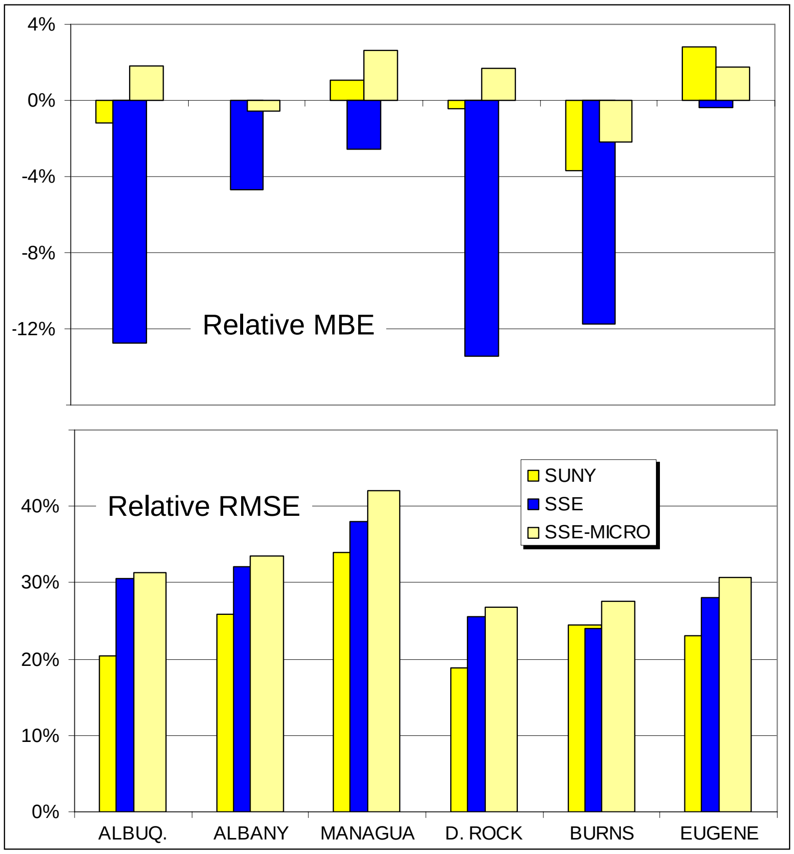

Figure 3 : Relative mean bias, root mean square errors for the SUNY model, the SSE data and the microstructured SSE data

approaches for Afghanistan and Pakistan (Perez et al., 2007)

3.2 Microstructured SSE data.

The TSG program requires three pieces of information:

- An input hourly time series and location,
- An output location,
- Monthly clearness index differences (Δkt') between the input and output time series.

The input time series is the "hourlized" SSE data set from step (1) above.

The output locations are all pixel locations within an SSE cell (100 possible locations at present)

Each monthly Δkt' is the sum of two terms:

1. The monthly microstructuring Δkt' between the SSE cell's center and any location within the cell, and
2. The monthly difference between cell-wide SUNY and SSE values.

The yearly microstructures of all investigated SSE cells are shown in Figure 4, while the monthly Δkt' corresponding to the test station locations are listed in Table 2. Also listed in Table 2 are the monthly Δkt' values resulting from cell-wide SUNY and SSE differences – these values largely reflect the bias noted above (Fig. 3) and implicitly assume that the SUNY data have less bias than SSE.

The hourly data generated using the TSG program are compared to the test location measurements in Fig. 5. Annual RMSEs and MBE are shown in Fig. 3.

Results show that the new data are largely bias free. Bias removal is achieved at the cost of a slight increase in RMSE – this is to be expected because the TSG process is randomized and short term site-time-specific information is not a known input. However the scatter plots are quite symmetrical and provide a qualitative indication that the microstructured SSE data are physically representative. A measure of this assertion is to compare the frequency distributions for the SSE, SUNY, ground and micro-structured SSE data and to quantify these distributions in terms of the distributions third and fourth moments: skewness and kurtosis (measuring respectively the distributions' asymmetry and peakedness). The distributions are shown in Fig. 6; their skewness and kurtosis are reported in Fig. 7. In all cases the microstructured data shows considerable improvement over the SSE data, even scoring better than the SUNY data for these benchmarks.

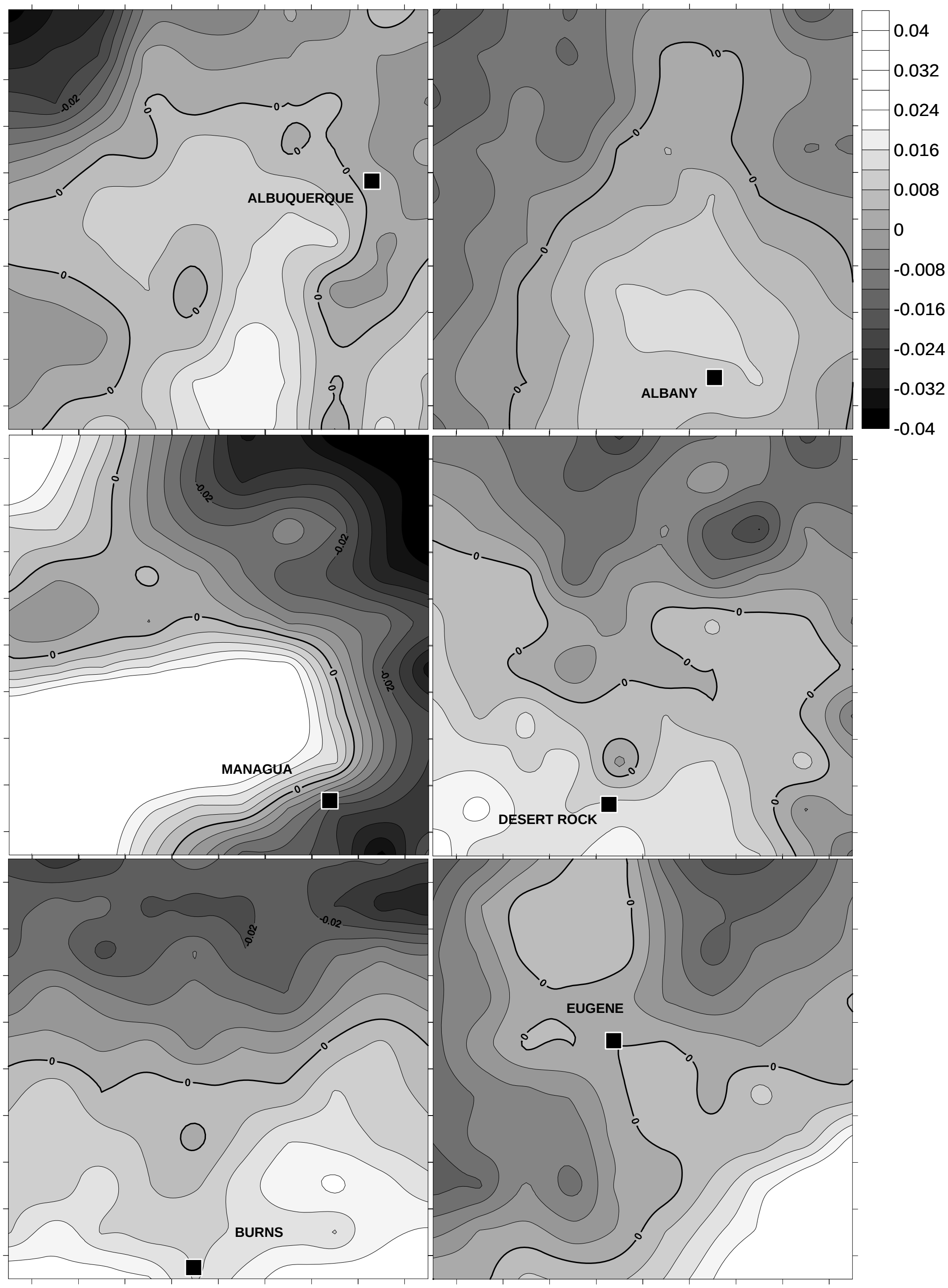

Figure 4: microstructure of the six 1o SSE cells surrounding the selected validation locations, quantified in terms of clearness index difference from cell average

4. CONCLUSIONS

The evidence presented and evaluated in this report shows that the proposed microstructuring methodology could be reliably used to enhance the time and space resolution of SSE data.

- We had previously shown microclimatic solar resource distribution within SSE cells is stable in relative terms.
- We show here that the application of the TSG algorithm generates output time series that are largely bias free and that have representative statistical distributions.

The methodology could be applied to extend the time coverage of high resolution data for the NSRDB, but could also be applied elsewhere in the world, where high resolution data are available for short but sufficient period to define micro-climatic patterns and be used as an input to generate operational high resolution time series from SSE data. Another possible application could be an improvement of the SUNY model when the ground is covered with snow and when the model has a difficult time distinguishing between the two: the SUNY model could automatically switch to a microstructured SSE mode during these periods (assuming that snow cover is better handled through the ISCIP cloud detection procedure).

5. ACKNOWLEDGEMENT

This task was undertaken in parallel with a task from NREL prototyping the production of microstructured time series in the vicinity of Eugene. Four hundred time series, representing four NASA cells were generated for the year 1999 as part of this work (NREL-Subcontract #AEV66639201) in view of their eventual incorporation into the NSRDB.

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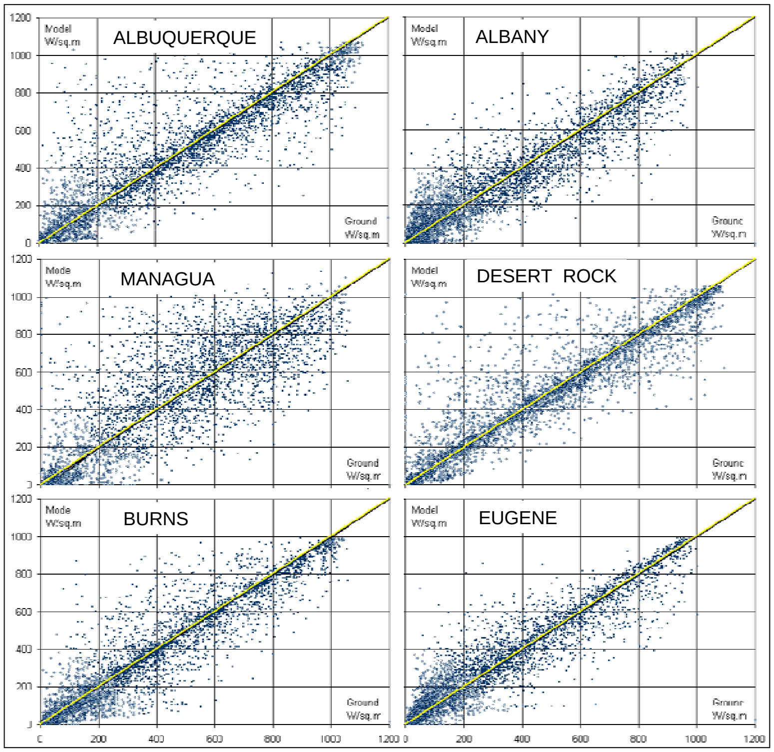

Figure 5 : Comparing hourly GHI values obtained via microstructuring of SSE data (Y axis) to ground measurements (X axis)

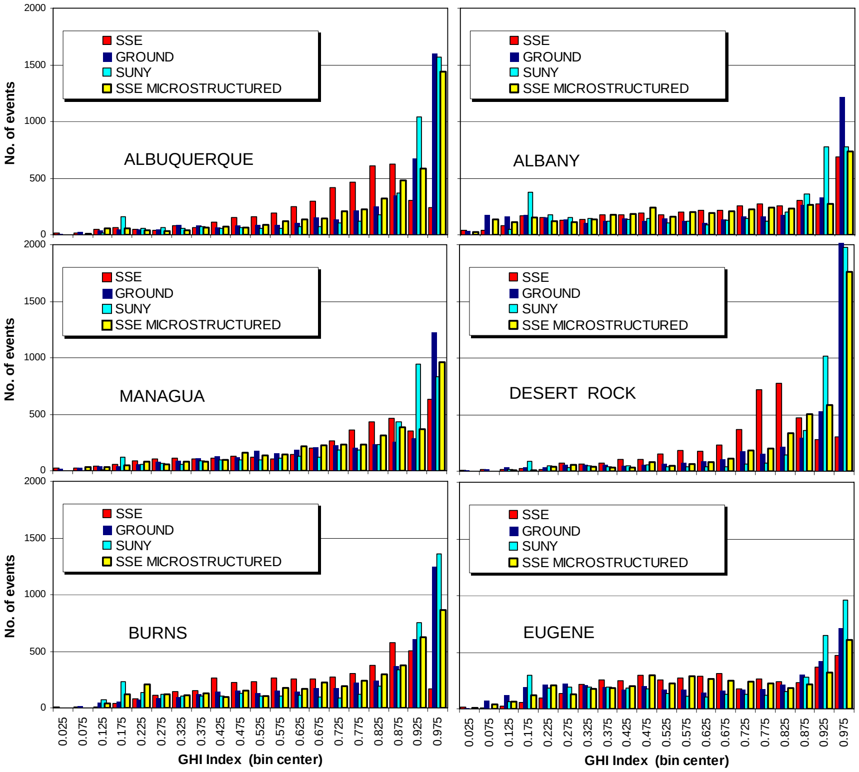

Figure 9: Distribution of measured, SSE, SUNY and microstructured SSE GHI index (i.e., ratio of GHI to GHI clear)

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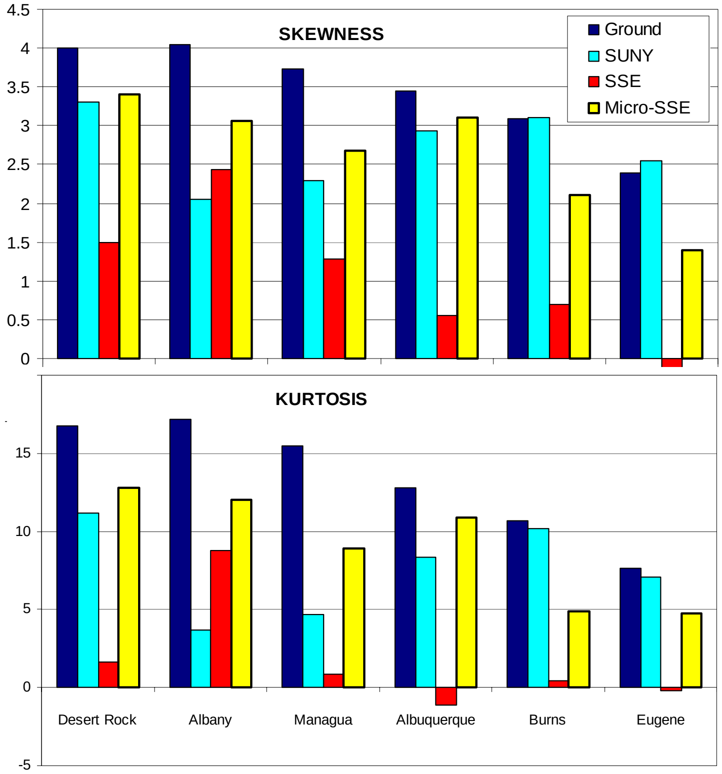

Figure 10 : Skewness and kurtosis of the distributions presented in figure 9

TABLE II
Monthly Δkt' from cell microstructure and from SUNY-SSE difference
Used as input to the time series generator.

Microstructure Delta-Kt'												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Albuquerque	0.01	-0.01	-0.02	0	0.01	0.01	0.01	0.01	0.02	-0.01	-0.01	0.01
Albany	0.01	0.01	0.01	0	0	0	0.01	0.01	0.02	0	0	0.01
Managua	-0.03	-0.03	-0.02	-0.01	0	-0.03	-0.04	-0.03	-0.02	-0.01	-0.02	-0.02
Desert Rock	0.01	0.01	0.02	0.02	0.02	0.02	0	0.01	0.01	0.01	0	0
Burns	-0.05	0.02	0.02	0.01	0.01	0.02	0.01	0.02	0.03	0.02	0	-0.02
Eugene	0	0.01	0.02	0.01	0.02	0	-0.01	0.01	0.01	-0.02	-0.02	-0.03
SUNY-SSE Delta-Kt'												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Albuquerque	0.08	0.09	0.05	0.04	0.08	0.09	0.17	0.13	0.12	0.07	0.13	0.11
Albany	-0.03	0.01	0	0.07	0.05	0.03	0.01	0.01	-0.01	-0.02	0	0.05
Managua	0.06	0.04	0.07	0.05	0.01	-0.01	0.04	0.03	0.07	0.08	0.07	-0.02
Desert Rock	0.12	0.07	0.1	0.05	0.07	0.11	0.09	0.13	0.12	0.12	0.14	0.15
Burns	-0.03	-0.07	0.08	0.09	0.07	0.03	0.06	0.06	0.07	0.08	0.01	-0.09
Eugene	-0.02	-0.03	0	-0.02	0.03	0	0.04	0.05	0.04	0.02	-0.12	-0.03