Solar Resource -Utility Load Matching Assessment

Project Report

Long term variability of solar radiation in the US
A preliminary utilization on NREL National Solar Radiation Data Base (NSRDB)

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DRAFT

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INTRODUCTION

The years 1987 and 1988 are used as test years for assessing the match between photovoltaic power production and the load of US electric utilities (see [1,2]). The aim of this study is to identify whether these two years are climatologically representative of the solar resource available throughout the United States.

Monthly-averaged daily global and direct irradiance data extracted from the new NREL Solar Radiation Data Base (NSRDB, [3]) covering a period of 30 years from 1961 to 1990 were analyzed. Only the sites where global irradiance was primarily measured over the period (as opposed to modeled) were considered. This represents a total of 54 sites in the lower continental United States. Data were analyzed both on a US-wide basis and on a regional basis corresponding to the service territories of utilities investigated in the load matching study [1].

US-WIDE RESULTS

Importance of Volcanic events

Figure 1 shows a timeline plot of all-year and summer mean daily global irradiances averaged over the 54 continental US sites; (note that the summer period is the most relevant for utility-PV load matching questions). Figure 2 shows a similar timeline plot for direct irradiance. The most striking feature of these plots is the impact of major stratospheric volcanic events over the period: (1) the El Chichon eruption in 1982 that compounded the smaller effects of

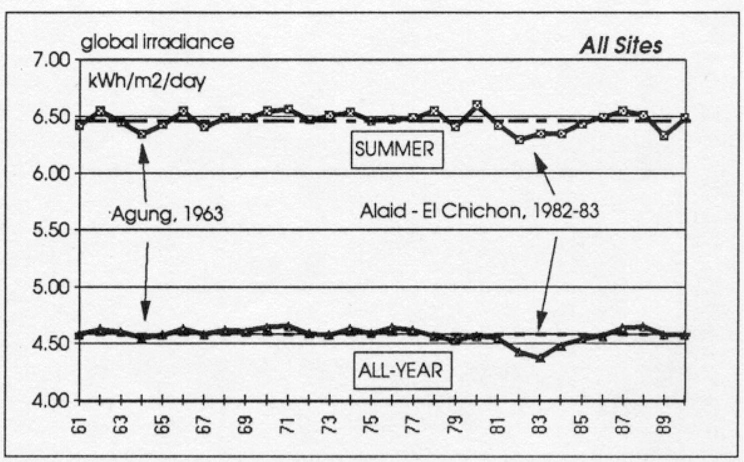

Figure 1: Global Irradiance US-wide

the Alaid eruption in 1981 (e.g., see [4]); and (2) the Agung eruption in 1963 [5]. As would be expected (e.g., see [6]), this effect is mostly apparent with direct irradiance but is clearly noticeable as well in the global irradiance stream.

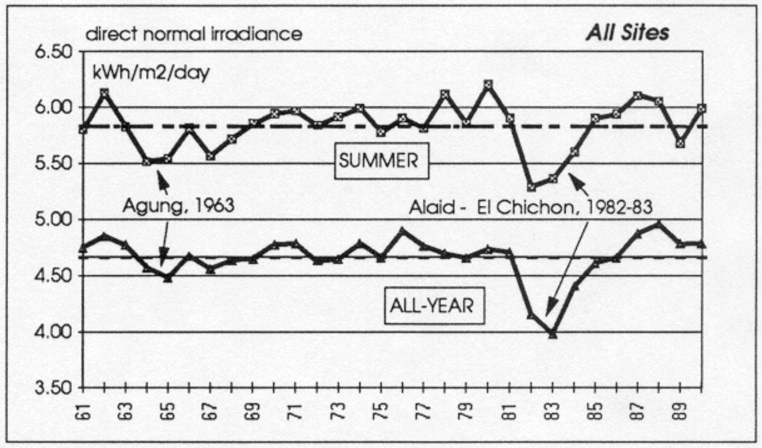

Figure 2: Direct irradiance US-wide

The 30-year relative standard deviation of yearly global irradiance is 1.4%, while that of summer-time global irradiance is 1.2%. For direct irradiance these numbers are respectively 4.3% and 3.8%. By comparison the largest volcanic troughs (El Chichon's) are of the order of -4.5% (all-year) and -2.7% (summer), for global irradiance and -15% (all-year) and -9% (summer) for direct irradiance. Note that the typical signature of stratospheric SO_2-releasing volcanic eruptions, showing maximum effect in winter and minimum in summer [4,6] is clearly apparent through the NSRDB , which speaks favorably for its overall quality.

Representativeness of 1987 and 1988

The year 1987 was slightly above average in terms of global irradiance (+1.3%) and in terms of direct irradiance (+4.5%). The year 1988 was also slightly above average with +1.6% for global and +6% for direct. However, one must keep in mind that the 30 year average is lowered by the volcanic events of the period. When comparing 1987 and 1988 to the "non-volcanic" background, the departures become +0.7% and +1% for global and +2% and 4% for direct irradiance, that is well within the 30-year standard deviation.

On a US-wide basis, the years 1987-1988 may thus be considered as representative of normal (i.e., non-volcanic) insolation conditions. The remaining above-normal departure is indeed a very small effect in light of instrumentation precision, instrumentation changes, data acquisition changes and gap-filling models over the period.

REGIONAL RESULTS

Selected NSRDB sites were grouped regionally in an attempt to represent insolation conditions for the twenty utilities investigated in Phase 1 of the PV Load-Matching study.

A total of 12 distinct regions are considered. These are listed in Table 1 along with their corresponding NSRDB sites and electric utility companies.

For this regional study, attention is focused on global irradiance, (especially summer-time global), because this quantity is the most pertinent for the flat plate PV configurations considered in the load matching study (e.g., see discussions in [1]).

Figures 3 to 14 contain 30-year timeline plots of global irradiance for each of the considered regions. Although they are understandably more noisy, the general features of the regional plot do not depart substantially from the US average.

Table 1
Regional Analysis

REGION	NSRDB SITES	CORRESPONDING UTILITIES
Colorado	Boulder, CO, Grand Junction, CO, Alamosa	Colorado Public Service Company
Central US	Omaha, NE, Columbia, MO, Dodge City, KS	Kansas City Power and Light, Lincoln Electric System, St. Joseph Light and Power Company, Omaha Public Power District
South Mid-Atlantic	Sterling, VA, Cape Hatteras, NC	Delmarva Power and Atlantic Electric
South/East Florida	Miami, Fl and Daytona Beach, Fl	Florida Power and Light and Gainsville regional Utility
Eastern Great Lakes	Burlington Vt., Pittsburgh, PA, Albany, NY	Niagara Mohawk Power Corporation
East/North Great Plains	Madison, WI	Northern State Power, Wisconsin Public Service Corporation
North Mid-Atlantic	New York, NY, Boston, MA	Consolidated Edison, Long Island Lighting Company and New York Power Authority
Central California	Fresno, CA, Daggett, CA	Pacific Gas and Electric
South East	Atlanta, GA, Montgomery, AL, Savannah, GA	Southern Electric System
South Central Arizona	Phoenix, AZ	Salt River Project
Idaho	Boise, ID	Idaho Power Corporation
Central Texas	San Antonio, TX	City of Austin Power and Light

Colorado Region (Figure 3)

Summer global irradiance was slightly above average in 1987 and slightly below in 1988. Yearly values are very close to the 30-year mean. Local utility load matching differences between 1987 and 1988 are small but are consistent with insolation differences: the effective load carrying capability (ELCC) of PV was found to be 5% higher in 1987 than in 1988 for the Public Service Company of Colorado.

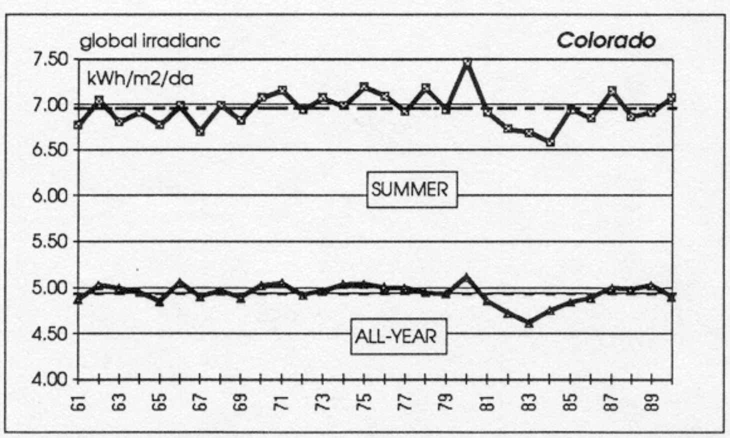

Figure 3: Colorado Region

Central US Region (Figure 4)

Summer values are right on the 30-year mean in 1987, and slightly above in 1988. All-year values are very close to the 30-year mean (and are right on the "non-volcanic" mean). Unlike above, however, the load matching tendency is opposite to the insolation tendency for the four considered central US utilities, where ELCCs were found to be marginally higher in 1987 than in 1988.

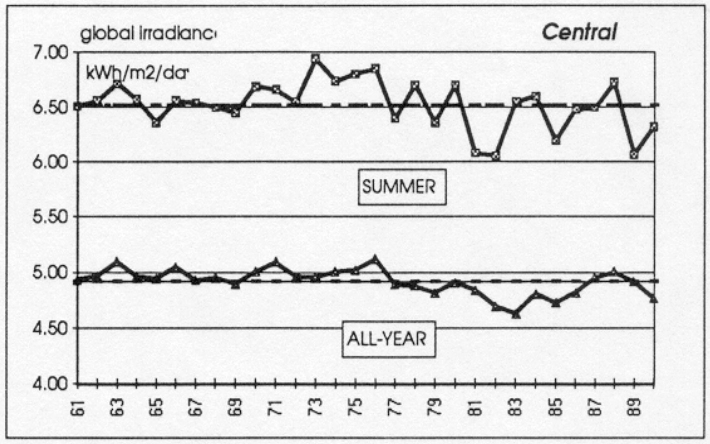

Figure 4: Central US region

South Mid-Atlantic Region (Figure 5)

Both 1987 and 1988 are above average in summer, although 1987 remains well within the 30-year standard deviation for the region. Yearly values are very close to the 30-year mean. Note that the effective load carrying capability (ELCC) observed in 1988 for Atlantic Electric is marginally higher than in 1987, but that this is not the case for Delmarva Power.

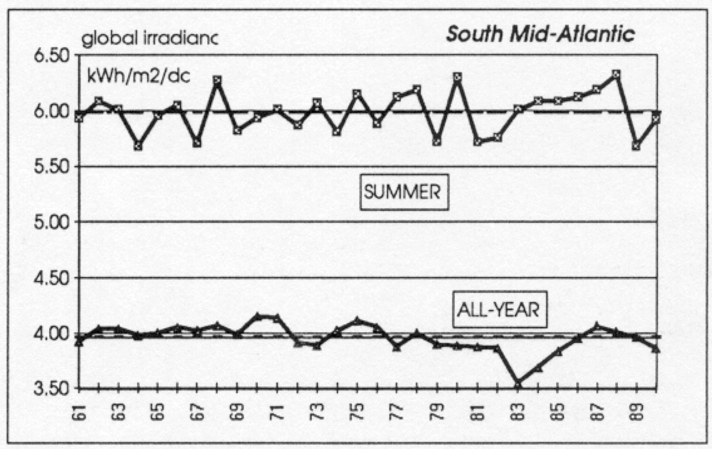

Figure 5: South mid-Atlantic region

South East Florida Region (Figure 6)

Yearly means are very close to the 30-year average for both 1987 and 1988. Summer irradiances are also very close to the average in 1988, but are noticeably above the average in 1988. It is interesting to note that the relative ELCC for Florida Power and Light and Gainsville Regional Utility are respectively 7% and 5% higher in 1987 than in 1988, in agreement with the summer insolation's differences.

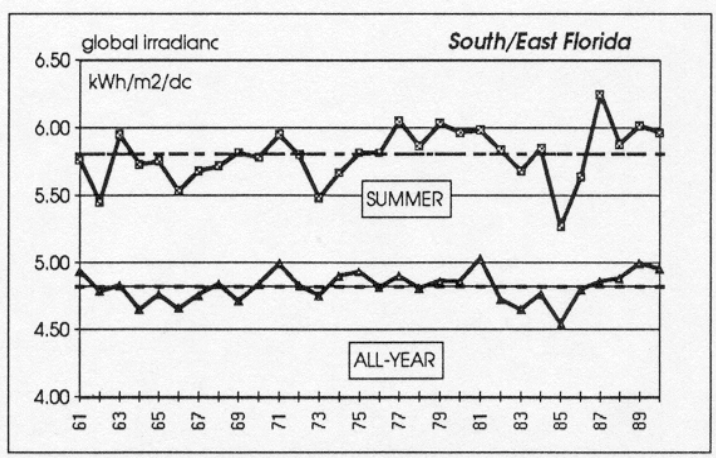

Figure 6: South-east Florida region

Eastern Great Lakes Region (Figure 7)

The years 1987 and 1988 are slightly above the 30-year average for both year-around and summer time frames. However departures remain within long term standard deviation.

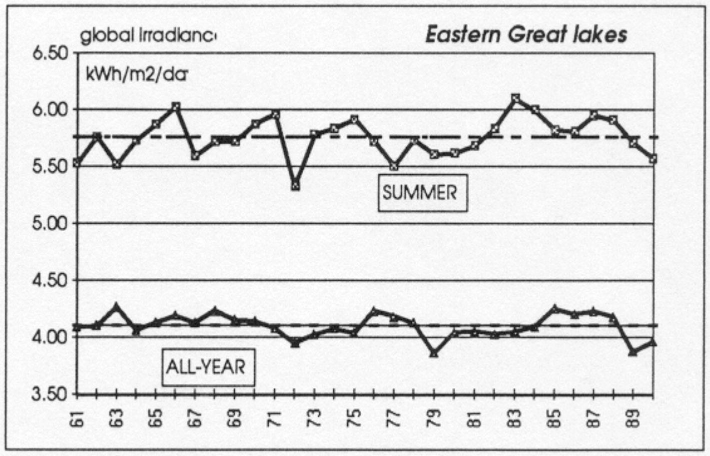

Figure 7: Eastern Great Lakes region

East/North Great Plains Region (Figure 8)

The year 1987 is right on the 30-year average (hence below the non-volcanic background average), while the year 1988 exhibits the highest irradiance over the period, both year-around and in summer. This notable insolation difference has a small impact on ELCC: This is slightly higher in 1988 both for Northern State Power (+2.5%) and for Wisconsin Public Service (+4%).

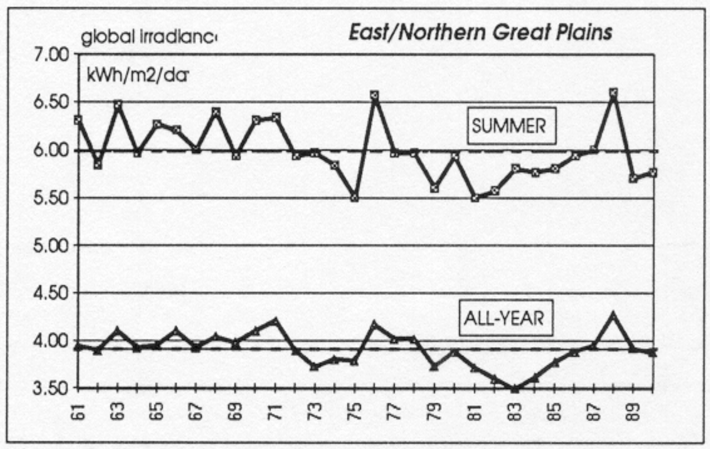

Figure 8: East/north Great Plains region

North Mid-Atlantic Region (Figure 9)

Both 1987 and 1988 are very close to the long term average for this region in summer as well as year- around. Here again, note that the slight edge of 1988's summer insolation over 1987 translates into a slightly higher (+0.5%) ELCC in 1988 for ConEdison , Long Island Lighting Company and the New York Power Authority.

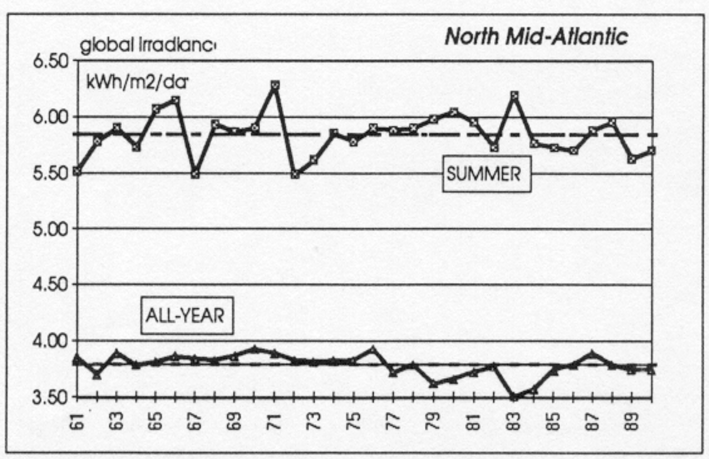

Figure 9: North mid-Atlantic region

Central California Region (Figure 10)

Both 1987 and 1988 are right on the 30-year line, with a slight edge for 1987 in summer. However, the ELCC of PGE was found to be 10% higher in 1988 than in 1987, going against the insolation tendency.

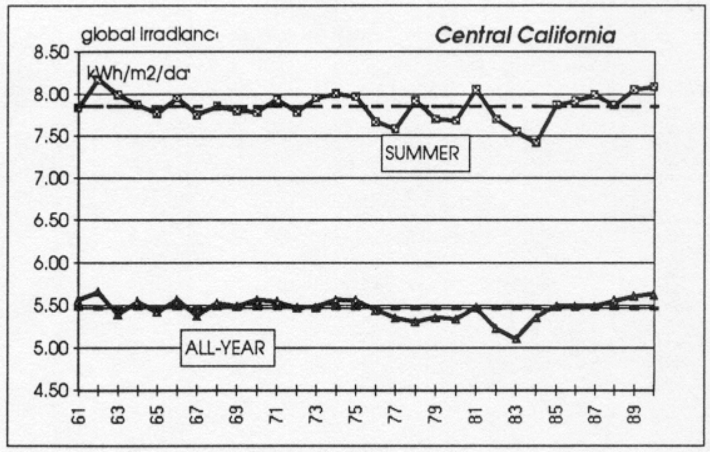

Figure 10: Central California region

South East Region (Figure 11)

Both 1987 and 1988 are above average, especially in summer. However 1988 is well within the 30-year standard deviation. The difference in summer insolation between 1987 and 1988 (2.5%) corresponds to a marginal difference in ELCC for Southern Electric System (0.3%) between the two years.

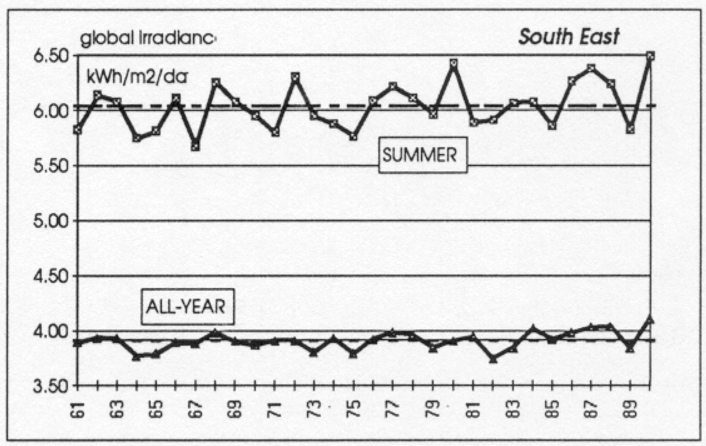

Figure 11: South East US region

South Central Arizona Region (Figure 12)

The years 1987 and 1988 are very close to the 30-year average. The summer insolation tendency between 1987 and 1988 is opposite to the ELCC tendency for the considered regional utility, Salt River Project (+3% in 1988).

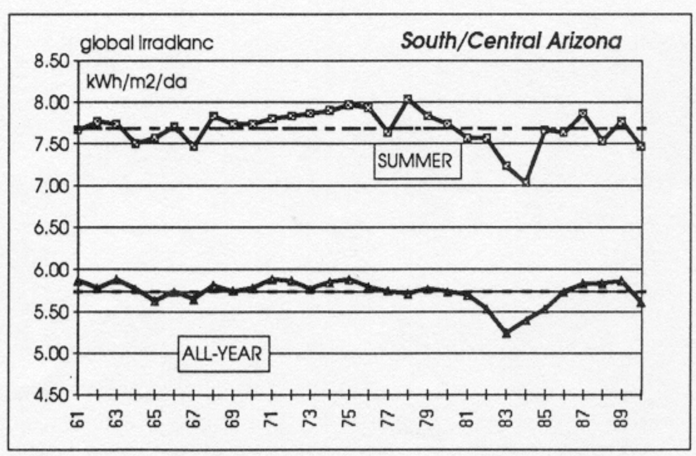

Figure 12: South/central Arizona region

Idaho Region (Figure 13)

Summer insolation is slightly below the 30 year line in 1987 and above the line in 1988. Both summer values are within the 30-year standard deviation. Year around insolation is above average for both 1987 and 1988. The ELCC difference for Idaho Power Corporation (+6% in 1988) goes in the direction of the summer insolation tendency.

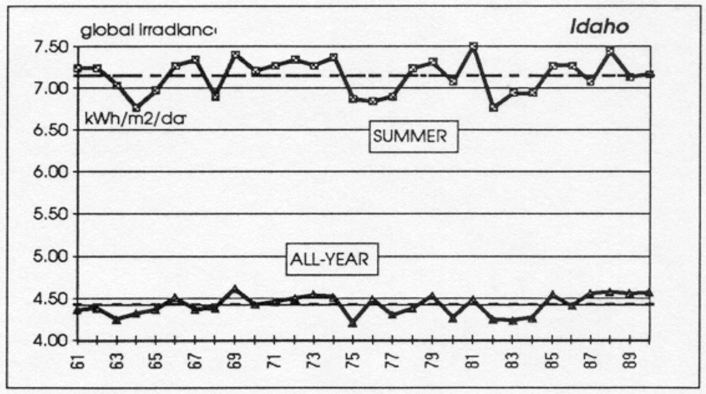

Figure 13: Idaho region

Central Texas Region (Figure 14)

The summer of 1987 was noticeably below average while 1988 was right on the average. Yearly values are very close to the 30 year line. No sizable ELCC difference was found for the City of Austin utility.

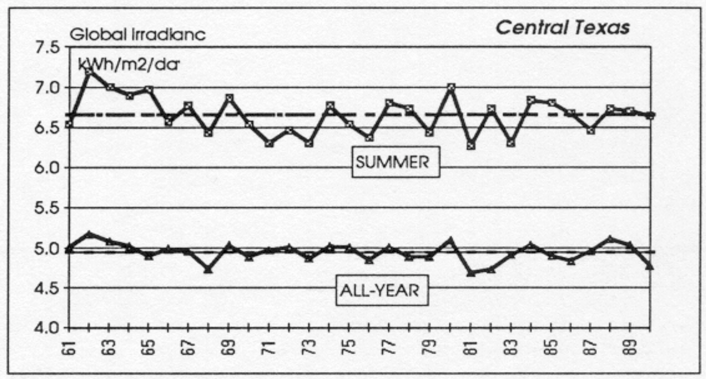

Figure 14: Central Texas region

CONCLUSION

This analysis has shown that 1987 and 1988 are slightly above average for most, but not all regions. Much of the departure may be traceable to the volcanic events having marked the period, by lowering the 30-year average; 1987 and 1988 may therefore be considered as climatologically representative years for clean stratospheric conditions. With a few exceptions, local departures from the norm are well within the 30-year standard deviation.

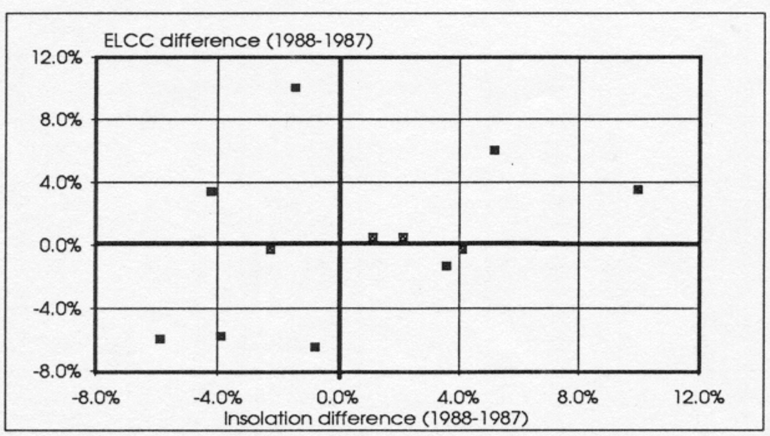

Figure 15: ELCC vs. insolation change for the 12 considered regions

The effect of insolation variations on PV load matching capability was found to be marginal: out of twenty utilities, seven were found to exhibit a higher PV ELCC in the year with less insolation, while eleven followed the insolation tendency. This weak relationship is illustrated in Figure 15, where the difference in ELCC between 1988 and 1987 has been plotted against the summer global insolation difference for the two years.

This tends to confirm the broad statements made on this matter in [1], asserting that overall insolation levels are not determinant factors for utility load matching , but that insolation timing, and utility load characteristics are considerably more relevant factors.

In conclusion, the years 1987 and 1988 are not thought to be a climatological cause of concern for the validity of the load matching study.

ACKNOWLEDGMENT

Thanks to Joe Michalsky (ASRC) for his insight on volcanic history.

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