IX. IMPACT OF AEROSOLS FROM THE ERUPTION OF EL CHICHÓN ON BEAM RADIATION IN THE PACIFIC NORTHWEST

The eruptions of the Mexican volcano El Chichón over the period of March 28 to April 4, 1982 ejected an amount of ash comparable to that spewed forth from Mount St. Helens in May of 1980. While the volume of ash ejected by the two eruptions was comparable, the stratospheric cloud created by the eruption of El Chichón was over 140 times denser. Utilizing the scattering of laser light by the material in the atmosphere, scientists at the National Aeronautics and Space Administration's Langley Research Center determined that the dense stratospheric cloud was about 2.5 kilometers wide and was situated at an altitude of 25 kilometers [1]. The effect of this dense cloud upon the atmosphere and climate in the Northern Hemisphere is the largest since the eruption of the Indonesian volcano Krakatau in 1883.

It is now known that the amount of fine ash and dust released in a volcanic eruption is not a good measure of the final effect upon the climate. It appears that most of the particulate matter settles out of the atmosphere in the relatively short time of a few months [1]. The composition of the long-lived stratospheric cloud is mostly an aerosol of sulfuric acid droplets. Thus, a prime factor for the long-term severity of atmospheric effects is the amount of sulfur emission from the volcanic eruption. It is estimated that over 20 million tons of sulfur gases were emitted by the El Chichón event. The composition of these gases was most likely sulfur dioxide and hydrogen sulfide [2].

The stratospheric cloud quickly spread out, encircling the globe in about three week's time. After the first circuit of the globe the cloud extended over a 25-degree swath around the earth from 5 degrees to about 30 degrees north latitude. The cloud has had an effect upon temperature as well as solar radiation [3]. One analysis suggests that a maximum drop of 0.2ºC was obtained within two months of the eruption. It has even been suggested that the El Chichón event may have triggered the onset of El Niño. Optical phenomena such as those following the eruptions of Krakatau and Mount Agung in 1963 have also been reported. This type of atmospheric disturbance is generally associated with high level stratospheric turbidity [4].

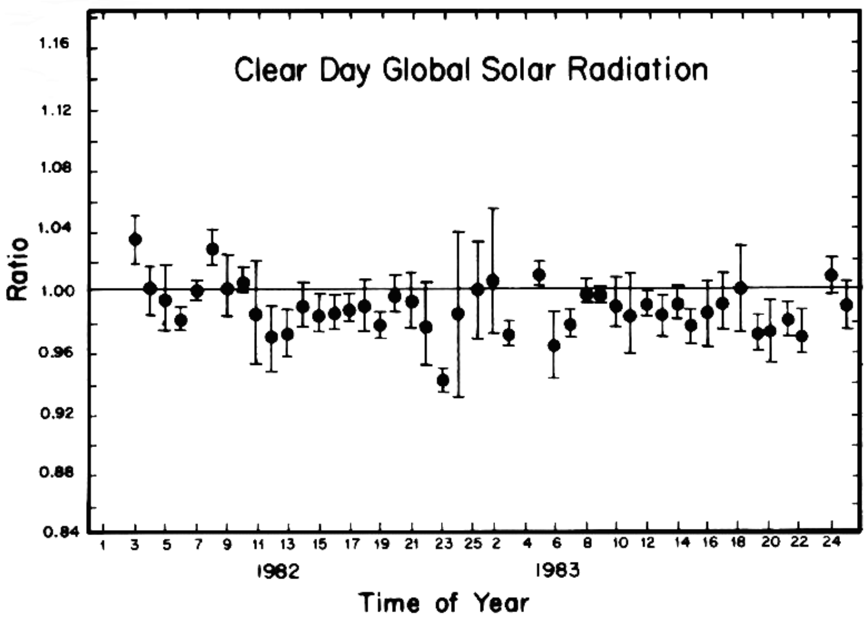
In this section we discuss the changes observed in clear day transmission values of beam and global solar radiation from several different sites in the Pacific Northwest due to the effects of the stratospheric cloud from El Chichón. By looking at quantities measured on clear days the effects of normal climatic differences are avoided. Solar radiation data taken over the past 24 months are compared with similar information obtained over several previous years.

Clear Day Global Radiation

The effect of El Chichón upon the solar radiation is best studied by looking at quantities measured on clear days. For global radiation the effect is best seen by utilizing the ratio of the clear day solar noon transmission values measured in 1982 or 1983 divided by the equivalent quantity averaged over previous years. A typical plot of clear day solar noon transmission values over a period of a year has a significant seasonal variation superimposed on the average transmission [5,8]. By using ratios the systematic fluctuation due to the seasonal variation are minimized.

The result of following this procedure for the clear day solar noon global radiation is shown in Fig. 21. The data shown in this figure are the combined results from all of our sites that

Fig. 21: *Plot of the ratio of the 1982 and 1983 clear day solar noon global values to the corresponding global data averaged over the years 1979-1981. Each year has been divided into 25 intervals and each point represents averaged clear solar noon data in one of the 15-day intervals.*

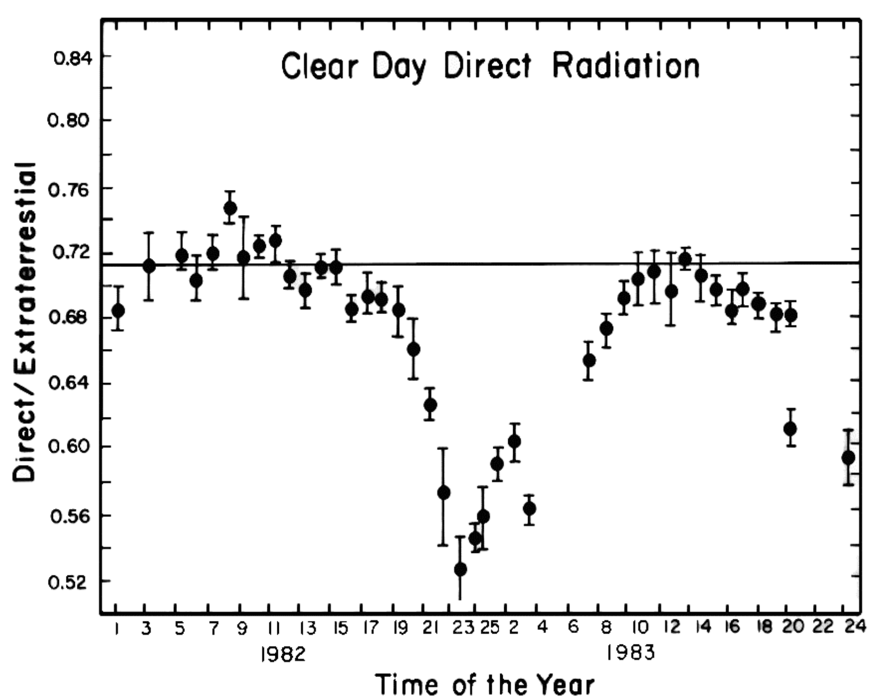


monitor both beam and global solar radiation except Coeur d'Alene and Hood River that were not part of the solar monitoring network during the beginning of this event. From this figure it appears that there is possibly a very small decrease during the latter part of 1982 and the first half of 1983. This point is covered further at the end of this section. However, the possible decrease in the global radiation is a small effect when compared to the dramatic reduction in intensity of the clear day beam solar radiation.

Clear Day Direct Normal Beam Radiation

In Fig. 22 the ratio of the beam radiation to the extraterrestrial value (the solar constant corrected for the varying distance to the sun) is plotted as a function of time of year for 1982 and 1983. The data are from our sites at Burns, Whitehorse Ranch, and Kimberly, all

Fig. 22: Clear day solar noon beam radiation divided by the extraterrestrial radiation is plotted as a function of the time of year for 1982 and 1983. Each point corresponds to a time interval of 15 days.



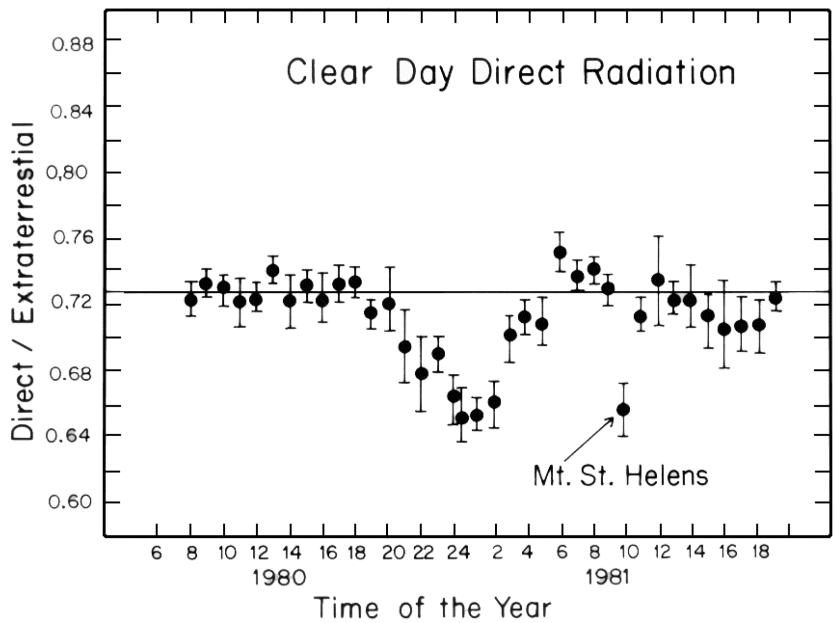


Fig. 23: The clear day solar noon beam radiation divided by the extraterrestrial radiation is plotted as a function of the time of year for 1980 and most of 1981. Each point corresponds to a time interval of 15 days.

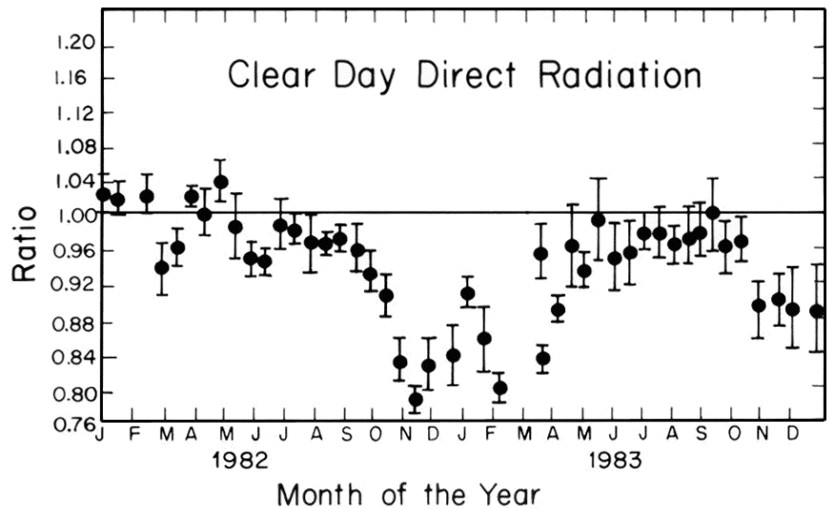
of which experience similar climatic behavior. From Fig. 22 it is seen that the ratio of beam to extraterrestrial radiation started to decrease dramatically about October 1, 1982. It decreased to a value of about 0.54 by December 15, which is about 24% below the average summer value. This ratio then started to increase and returned to normal by June 1983. It appears that the beam solar radiation has suffered a systematic decrease for a period of about 8 months starting around October 1, 1982. Also, the decrease in clear day beam solar radiation seems to occur again in October 1983 that is roughly one year after the first wave of atmospheric turbidity started.

Unfortunately, the ratio of beam to extraterrestrial plotted in Fig. 22 is not as accurate an estimator of the effect of the aerosols from El Chichón as one might at first expect. This is because there is also a pronounced seasonal variation for beam radiation, just as was the case for the global radiation [5]. This seasonal variation is demonstrated graphically in Fig. 23 that shows the plot similar to Fig. 22, but for the years of 1980 and 1981, prior to the eruption of El Chichón. The seasonal variation is evident, becoming quite pronounced during the winter. A maximum seasonal drop of about 7-8% occurs in December. Of particular note is the sudden and dramatic drop due to the particulate matter, etc. ejected into the atmosphere from an eruption of Mount St. Helens.

The best way to demonstrate the effect of the sulfuric acid aerosols from the eruption of El Chichón upon the beam solar radiation is to plot the ratio of the clear day solar noon beam radiation measured over a given 15-day time period in 1982 and 1983 to the radiation received during the equivalent time period averaged over the three previous years of 1979-1981. This is done in Fig. 24. The ratio starts to drop around the first of October 1982 and returns to normal again in June 1983. The maximum drop in December is about 18% below the prevailing average of the three previous years.

The best value for the maximum drop in beam solar intensity is obtained by looking at the information plotted in Fig. 24. A maximum decrease in intensity of about 18% is observed. The phasing of the start and stop of the change in beam radiation due to the influence of the material from El Chichón obtained

Fig. 24: Plot of the ratio of the 1982 and 1983 clear day solar noon beam values to the corresponding beam data averaged over the three years from 1979 through 1981. Each point represents a time interval of 15 days. Data are from our sites at Burns, Whitehorse Ranch, Kimberly, Eugene, Portland, and Hermiston.



from Fig. 24 agrees well with that deduced from Fig. 22.

Discussion

To summarize, the above results show that the stratospheric cloud of aerosols from the eruption of El Chichón had a dramatic effect upon the clear day solar noon beam radiation at our monitoring sites. It is found that the best way to study the decrease in beam intensity due to the aerosol cloud is to plot the ratio of the clear day solar noon beam values for 1982 and 1983 to the corresponding values from earlier years prior to the eruption. In this way a maximum decrease in the clear day solar noon value of 18% was determined. The beam intensity started to decrease about October 1, 1982, and returned to normal in June 1983. A new wave of aerosols appeared in October 1983. This may imply that the upper atmosphere aerosol cloud tends to disperse and then reappear with a period of one year, perhaps due to a movement towards lower or higher latitudes. Looking at the clear day solar noon data, the estimated half life of the aerosol cloud is about 1 year.

There was a small decrease in the global solar radiation on clear days during the period of time that the sulfuric acid aerosol cloud from El Chichón was at its peak. The data in Fig. 21 tend to indicate a drop of a few percent. On the other hand a recent study [6] for Corvallis, Oregon indicated an overall decrease of about 14% for the months of November and December 1982. To obtain a more quantitative relation, we have determined k_t the ratio of global to extraterrestrial, for our clear day solar noon values during the months of December 1982 and January 1983. These months correspond to the largest observed decrease in the direct beam solar radiation. Our results are summarized in Table 10. From these results we would conclude that a maximum decrease of 4±1% in the global is observed. Since these are results obtained at solar noon, the expected decrease in the daily global radiation would be larger. As shown below, one would expect a daily decrease of about 6%. Our value of k_t of 0.649±0.101 for Eugene compares well with the Corvallis value [6] of 0.644±0.005.

The above analysis pertains to clear day solar noon values. It is of interest to look at the observed attenuation away from solar noon. The increased path length through the stratospheric cloud will result in a larger attenuation of the direct beam. In order to evaluate this effect in a preliminary fashion, we have utilized a clear day model [7] to compare the calculated beam radiation over the day with measured values for January 12, 1983 and January 12, 1981. Both were very clear days.

Table 10. Evaluation of Clear Day Solar Noon Global Radiation During the Months of December, 1982 and January 1983.

Site	k_t(82-83)	k_t(79-81)	r=k_t(82-83)/k_t(79-81)
Whitehorse Ranch	0.704±0.003	0.714±0.006	0.986±0.009
Burns	0.706±0.009	0.744±0.012	0.940±0.019
Kimberly	0.724±0.005	0.750±0.011	0.965±0.016
Eugene	0.649±0.010	0.678±0.009	0.957±0.020
Hermiston	0.654±0.003	0.700±0.009	0.934±0.013
Average			**0.958±0.009**

The water vapor content was assumed to be identical for both days, while the turbidity coefficient for January 12, 1983 was almost 50% higher than that used for the comparable clear day in 1981. These coefficients resulted in matching the solar noon values to about 0.9%, and resulted in daily totals about 2.5% larger than observed. This is an excellent match between the model and the data. Therefore, the observed fall off during the day away from solar noon can be reasonably well accounted for within the framework of a conventional clear day model.

We found that the decrease in daily totals was about 50% larger than the corresponding decrease for solar noon values in going from 1981 to 1983. This implies that a maximum decrease of 18% for the clear day solar noon beam values would correspond to a reduction of about 27% for the daily totals. Similarly, a 4% decrease in clear day solar noon global values may correspond to a 6% reduction in the daily totals.

We finish by comparing the total annual beam solar radiation at our stations in 1983 as compared to the average over previous years. This will allow us to estimate the combined effect of El Chichón and El Niño. The comparison is summarized in Table 11. The average ratio of the 1983 values to the previous average radiation is 12.9±1.7%, where the uncertainty of 1.7% is the standard deviation of the mean.

Now, suppose that we try to estimate crudely the effect of El Chichón upon this overall decrease. From Fig. 21, we estimate an average decrease of at least 12% for the clear day solar noon direct radiation over a period of 6 months. Multiply this by 1.5 to correct to daily totals given a decrease of 18% over 6 months. Averaged over 12 months; this amounts to an average decrease of the annual direct radiation by about 9%. At most, the effects of El Niño reduced the beam radiation by 4%. Apparently, most of the decrease is due to the stratospheric cloud from El Chichón.

Table 11. Comparison of Direct Beam Solar radiation Received in 1983 with the Average for the Station

Station	1983 Beam†	Average Beam†	Period Covered for Average	% 1983 Value / Average
Burns	4.33	4.96	1979-1983	-12.5%
Eugene	2.68	3.26	1978-1983	-17.8%
Hermiston	4.15	4.48	1979-1983	- 7.3%
Kimberly	4.48	5.09	1980-1983	-11.9%
Portland	2.43	2.70	1980-1983	-10.1%
Whitehorse Ranch	4.29	5.20	1979-1983	-17.5%

†Beam solar radiation in kiloWatt hrs/m^2-Day

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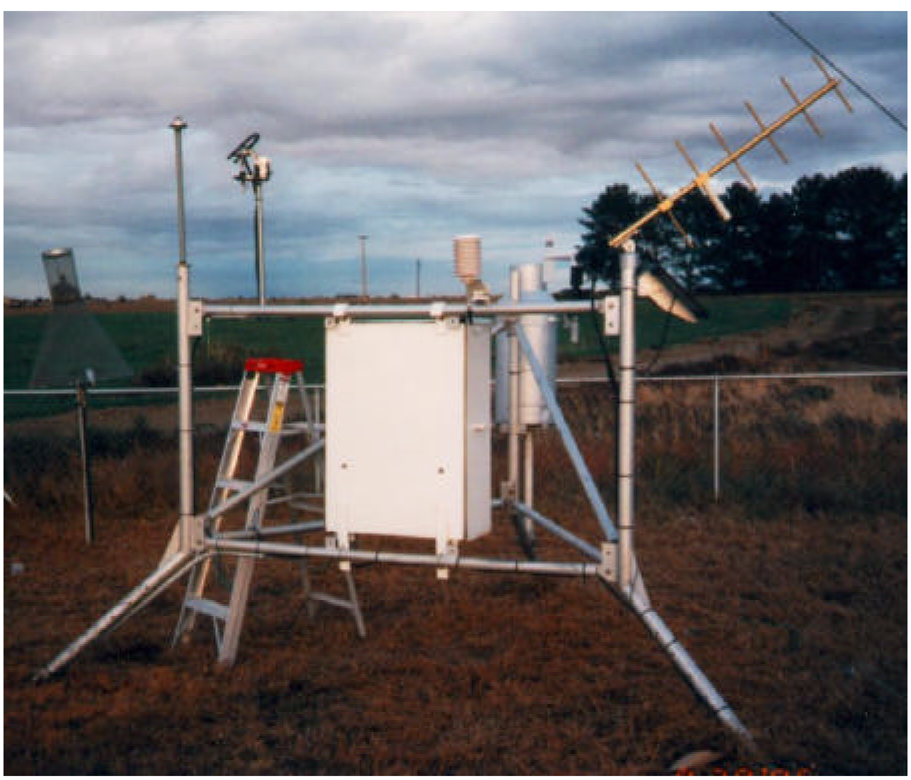

AgriMet Station at Hermiston