Goldstone Solar Energy Instrumentation Project: Description, Instrumentation, and Preliminary Results

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A solar energy instrumentation project has been initiated at Goldstone in order to support the investigation of Goldstone as a possible site for a demonstration project by acquiring fundamental information about solar radiation characteristics at that location and by helping to build an adequate technological base for the engineering of solar-based energy systems suitable for Goldstone. The initial instrumentation and results for the first three months of operation are discussed and presented in tabular and graphical form.

I. Introduction

The Goldstone Space Communications Complex has several unique characteristics which make it appropriate for consideration as a solar energy demonstration project that could attain a high degree of energy self-sufficiency and possibly make a significant contribution to the achievement of a national goal of energy independence. This work supports the investigation of Goldstone as a possible site for a demonstration project by acquiring fundamental information about solar radiation characteristics and by helping to build an adequate technological base for the engineering of solar-based energy systems suitable for Goldstone.

The work unit is divided into two parts, which are of nearly equal importance and magnitude and have nearly concurrent schedules. Both parts require the acquisition of data over extended periods. Part A acquires solar radiation and meteorological data to improve the accuracy of probabilistic models essential to engineering design. Part B acquires performance data on measurement equipment placed at Goldstone for feedback to the technological base to improve the basic physical models used for system analysis and evaluation.

Solar collectors potentially suitable for a solar-electric-hydrogen fuel generation subsystem at Goldstone will be analyzed to determine what site-peculiar information is needed to specify, design, and evaluate them. The information falls into three classes: (1) insolation, both specular and diffuse; (2) meteorological, such as wind speed and direction, temperature, relative humidity, etc.;

and (3) environmental, such as dust and sand deposition and erosion. The information does not include characteristics that can be determined by measurement at places other than Goldstone, such as absorptivity and emissivity, or other properties of materials.

Raw data from measurements are not directly usable for the engineering of solar collectors or for the analysis of complete solar-hydrogen fuel subsystems; the probabilistic models must be fitted to the raw data. A probabilistic insolation model will be devised for the total insolation and for the specular component as a function of collector concentration, and a probabilistic meteorological model will be devised for wind speed and direction, temperature, relative humidity, etc. In all cases, the models will include probability density functions for the year and for each month. The insolation and meteorological models will be fitted to the data to improve their accuracy and to establish the degree of correlation among the random variables in the models. This correlation, however, will not be included in the early models.

As a result of examining potentially suitable solar collectors and probabilistic models, a set of measurements will be defined. Commercial instruments have been, and will continue to be, specified and procured to make as many of the measurements as possible. Where commercial instruments are not available, such as devices for measuring the specular component of insolation as a function of collector concentration, the necessary instruments will be designed and built.

Some of the measurements are already being made under other Office of Tracking and Data Acquisition (OTDA)-funded activities (Microwave Weather Project, Operational Meteorological Data System, Conscan Project). Whenever possible, common measurements will be made by instruments already incorporated into the other data-gathering equipments.

A complete program of measurements at other NASA tracking stations is not required at this time. However, an operational meteorological data system is being implemented at DSSs 14, 43, and 63, which will incorporate a single insolation instrument, a hemispherical pyranometer. The data from each of the systems will be delivered to this project for reduction and analysis. The reduced data from DSSs 43 and 63 will serve as the basis for preliminary insolation and meteorological models for those stations when needed. By correlating the data from the three stations, it will be possible to extend the Goldstone models to obtain preliminary models for the other complexes as needed. The extension technique will be useful in devising preliminary models for other NASA tracking stations and complexes.

Part B of the project is concerned with developing the technological base needed to analyze and evaluate an entire solar-hydrogen fuel subsystem for Goldstone, including its component parts. Particular attention will be paid to identifying the key parameters that would be needed in each case to specify devices and subsystems.

When sample collectors or other components are procured from industry (not by this project) or are supplied to JPL for evaluation, instrumentation will be developed or procured to measure actual performance. The performance data will be used to compare actual versus theoretical performance, and the information will be fed back to improve the technological base.

When a complete solar-hydrogen subsystem is installed at Goldstone (there may be more than one), instrumentation for the long-term evaluation of its performance will be developed or procured, installed, and transferred to the operations organization for maintenance and operation. Data acquisition will be monitored to assure the validity of the data. The actual performance data will be compared with the theoretical performance computed using data collected at the same time by the instruments provided under Part A.

The use of actual field test data will permit the economic feasibility of proposed modifications to the solar-hydrogen subsystem to be determined. The data will also permit an assessment of the economic factors relating to the possible installation of solar-hydrogen subsystems at other NASA tracking stations or complexes. The assessment will be facilitated through the use of preliminary insolation and meteorological models developed for the Spanish and Australian tracking complexes based on data from Part A.

II. Initial Instrumentation

A pyrheliometer was installed on the roof of the main control building at DSS 14 on June 19, 1974. A pyrheliometer is a commercial instrument which measures the total incident radiation, both specular and diffuse, over a hemisphere. Its orientation is horizontal to measure the total radiation from the sky.

This instrument is an Eppley-type pyranometer, which has a radial wire-wound differential thermopile as a detector. The hot junction receivers are blackened and the cold junction receivers are whitened. When exposed to solar radiation, the black and white surfaces develop a marked temperature difference, and the resulting voltage is proportional to the intensity of solar radiation. The instrument has a built-in temperature compensation circuit for a standard matching condition through the range −20 to +40°C. The thermopile unit is formed of 48 artificial junctions by copper-plated Constantan wire and mounted under a precision-ground optical quartz glass hemisphere. The wavelength response is maximized from 0.32 to 2.5 microns. Instrument linearity is ±1% over 0 to 2 langleys/min (0 to 1.3956 kW/m^2) and the temperature dependence is ±1.5% consistency over −20 to +40°C. Response time ($1/e$) is 3 to 4 seconds.

The clear day data from this instrument will be useful for determining or verifying a theoretical clear day insolation model for Goldstone. Data for cloudy days will be useful for determining or verifying a probabilistic model of Goldstone insolation. This report presents the data from this instrument for the period June 19 through September 30, 1974.

Other instruments that were operating at Goldstone (DSS 14) during this period were meteorological instruments. These included temperature, barometric pressure, dew point, wind speed and direction, and rainfall. The data that are presented in this report are temperature, barometric pressure, and absolute humidity in terms of grams of equivalent water per cubic meter of air.

An automatic data acquisition assembly has been procured and is presently being commissioned. It consists of a central recording station which has the capability of interfacing with up to 10 remote stations. The remote stations will interface with transducers in a given instrument, or set of associated instruments, and condition the signals for transmission to the central station. The various signals will be time-multiplexed for transmission under the control of the central station. The central station will control the multiplexing of the remote stations so that the signals from all of them are interlaced. The station will condition the signals and record them on a magnetic tape that is computer-readable. The recording will be time-tagged.

III. The Results

The pyranometer output is a voltage which is calibrated in terms of langleys per minute (kW/m^2) of solar flux. The data system recorded one data point per minute. When these data are plotted on a daily basis, the result is a curve of langleys per minute (kW/m^2) versus time. Figures 1 through 5 show samples of these daily graphs which cover the range of weather conditions experienced at Goldstone since the start of this project. Figure 1 is a clear day. Figure 2 shows some noon haze in an otherwise clear day. Figure 3 is the graph of a day with clouds in the afternoon. Figure 4 shows a day with fast moving clouds, and Fig. 5 is the graph of a heavily clouded day. It must be noted that the peaks in Figs. 4 and 5 are higher than would be expected from a clear day. This is due to reflection off large white clouds not in the direct sun-line.

Computer integration of the area under these curves yields the total energy received for the day. The units are kW/m^2, sometimes quoted as langleys, where 1 langley = 1.1630×10^{-2} kWh/m^2.

Table 1 is a listing of the pyranometer data by day number and date for the period June 19 through September 30, 1974. The table lists peak energy for the day in kW/m^2 and total received energy for the day in kWh/m^2. These two columns list measured data only, and only those days have been included when data were recorded continuously throughout the sunrise-to-sunset period. The next column lists total energy for the day in kW/m^2 as determined by a theoretical clear day model. This model is the JPL theoretical clear day model for Goldstone based on the ASHRAE formula (Ref. 1). The next column in the table lists the dimensionless ratio of measured total daily radiation to total daily radiation by the clear day model.

One of the first objectives of this project is to determine a clear day model of solar insolation at Goldstone from which a probabilistic model of cloudy day insolation can be built. On those days with light or moderate clouds the graph of langleys per minute (kW/m^2) versus time was curve-fitted to remove the effects of the clouds and thus simulate a clear day. This was possible on a number of days when the langleys per minute (kW/m^2) curve could be filled in with reasonable certainty. The curve with cloud effects removed was integrated to yield a corrected clear day total energy. The last column in the table lists these data.

Figure 6 is a plot of the daily measured peak energy as a function of time for the period June 19 through September 30, 1974. Figure 7 is a plot of daily total energy together with a curve of the JPL clear day model for Goldstone. Figure 8 shows daily total energy for all clear days, both real and corrected, for the period June 19 to September 30 above. The standard deviation of these data from the clear day model is 0.316 kWh/m^2 or about 4%. Some data points, however, are above the model and this is under investigation. Figure 9 is a graph of the ratio of measured data to clear day model. The data are total daily energies and the horizontal line indicates measured data equal to the clear day model.

Figures 10 through 13 show certain meteorological parameters measured at DSS 14 for the same period as the solar figures. Ambient temperature and daily maximums, minimums, and means are plotted in Figs. 10 and 11; Fig. 12 is barometric pressure. Figure 13 shows absolute humidity in terms of grams of equivalent water per cubic meter of air calculated from measured dew point and ambient temperature.

IV. Conclusion

Preliminary data have been obtained and reduced. The results demonstrate the clear requirement for more data and more consistent data acquisition. Other measuring instruments will be added when they are built or procured and more efficient data analysis techniques will be investigated and implemented.

Reference

1. *ASHRAE Handbook of Fundamentals*, American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Inc., New York, 1972.

Table 1. Solar insolation data, specular and diffuse, for Goldstone for the period June 19 through September 30, 1974

Day number	Date	Peak, kW/m^2	Measured total energy, kWh/m^2	Clear day model, kWh/m^2	Ratio data/model	Clear and corrected total energy, kWh/m^2
171	Jun 20	0.973	8.300	9.176	0.905	8.392
172	Jun 21	1.004	8.503	9.173	0.927	8.605
173	Jun 22	1.000	8.454	9.171	0.922	8.536
174	Jun 23	0.999	8.464	9.169	0.923	8.554
175	Jun 24	0.991	8.182	9.166	0.893	8.278
176	Jun 25	0.969	8.232	9.162	0.898	8.302
177	Jun 26	1.008	8.551	9.157	0.934	8.638
178	Jun 27	1.027	8.824	9.151	0.964	8.906
179	Jun 28	1.026	8.738	9.145	0.955	8.822
180	Jun 29	0.995	8.471	9.138	0.927	8.540
181	Jun 30	0.988	8.373	9.131	0.917	8.373
196	Jul 15	1.157	6.349	8.932	0.711	
197	Jul 16	0.985	8.172	8.913	0.917	8.172
199	Jul 18	1.017	8.260	8.873	0.931	8.495
200	Jul 19	1.098	4.140	8.853	0.468	
201	Jul 20	1.060	7.669	8.831	0.868	
202	Jul 21	0.968	7.994	8.809	0.907	8.163
203	Jul 22	1.046	7.137	8.790	0.812	
204	Jul 23	1.173	6.501	8.770	0.741	
212	Aug 1	0.932	6.823	8.587	0.795	7.994
213	Aug 2	1.034	4.966	8.561	0.580	
225	Aug 13	0.991	7.895	8.197	0.963	8.013
226	Aug 14	0.972	7.861	8.162	0.963	7.929
227	Aug 15	1.007	8.140	8.127	1.002	8.181
228	Aug 16	1.018	8.200	8.091	1.013	8.262
229	Aug 17	1.020	8.183	8.055	1.016	8.219
230	Aug 18	1.069	7.848	8.018	0.979	
231	Aug 19	0.997	7.942	7.981	0.995	8.059
232	Aug 20	1.008	7.707	7.924	0.973	8.083
233	Aug 21	1.005	7.981	7.904	1.010	7.981
234	Aug 22	1.000	7.914	7.870	1.006	7.914
235	Aug 23	1.015	7.991	7.836	1.020	7.991
236	Aug 24	0.992	7.808	7.802	1.001	7.808
239	Aug 27	1.014	7.976	7.694	1.037	7.993
240	Aug 28	0.975	7.363	7.657	0.962	7.520
241	Aug 29	0.946	7.357	7.619	0.966	7.502
242	Aug 30	1.028	7.623	7.581	1.006	
247	Sept 4	0.923	6.510	7.377	0.882	
248	Sept 5	0.927	6.921	7.336	0.943	7.141
249	Sept 6	0.873	6.618	7.294	0.907	6.639
250	Sept 7	0.873	6.513	7.251	0.898	6.545
251	Sept 8	0.849	6.441	7.209	0.893	6.494
252	Sept 9	0.858	6.510	7.165	0.909	6.517
253	Sept 10	0.859	6.553	7.122	0.920	6.565
254	Sept 11	0.855	6.444	7.077	0.911	6.444
256	Sept 13	0.851	6.433	6.988	0.921	6.448
257	Sept 14	0.861	6.502	6.942	0.937	6.520
258	Sept 15	0.858	6.509	6.896	0.944	6.541
259	Sept 16	0.858	6.447	6.850	0.941	6.468

Table 1 (contd)

Day number	Date	Peak, kW/m²	Measured total energy, kWh/m²	Clear day model, kWh/m²	Ratio data/model	Clear and corrected total energy, kWh/m²
260	Sept 17	0.855	6.421	6.803	0.944	6.436
261	Sept 18	0.853	5.752	6.756	0.851	
264	Sept 21	0.822	6.094	6.613	0.922	6.117
265	Sept 22	0.822	6.066	6.565	0.924	6.066
271	Sept 28	0.860	6.173	6.276	0.984	6.204
272	Sept 29	0.849	6.029	6.227	0.968	
273	Sept 30	0.863	5.873	6.178	0.951	6.360

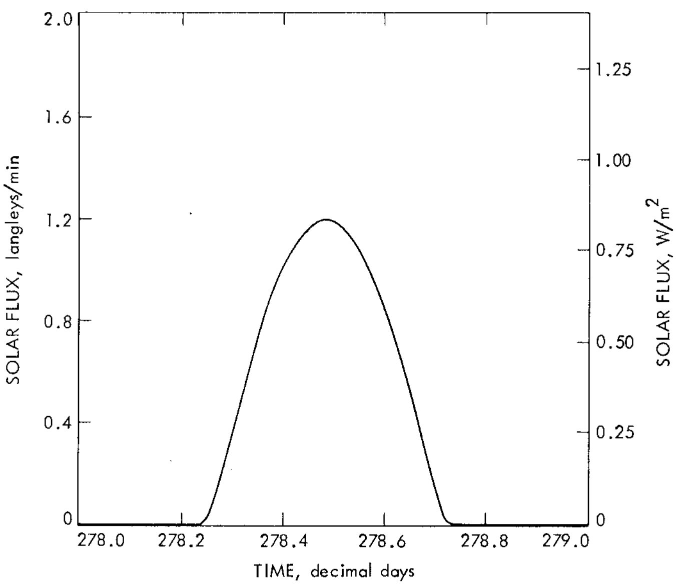

Fig. 1. Plot of pyranometer output versus time for day number 278, October 5, 1974

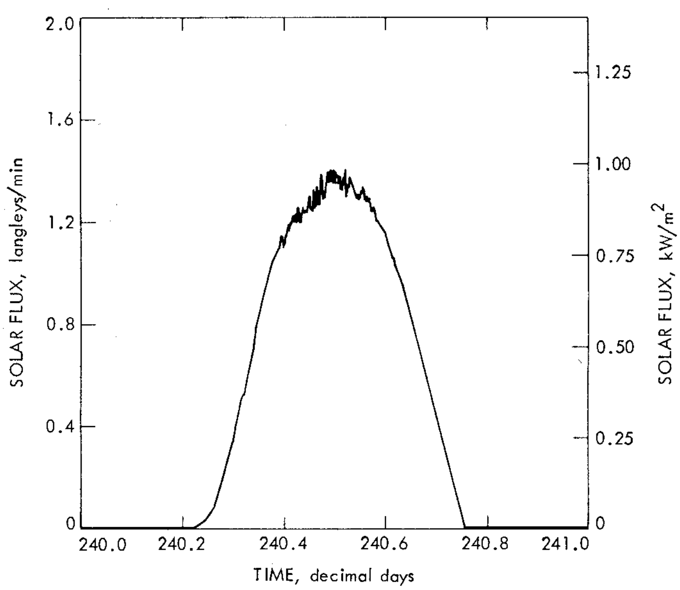

Fig. 2. Plot of pyranometer output versus time for day number 240, August 28, 1974

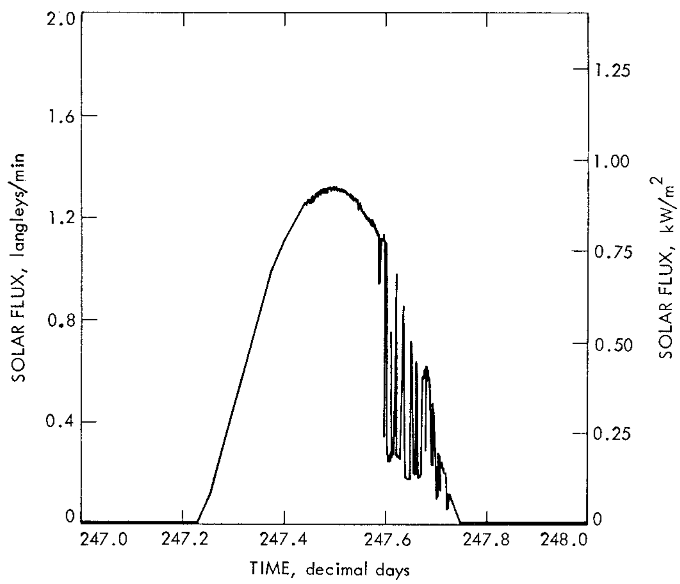

Fig. 3. Plot of pyranometer output versus time for day number 247, September 4, 1974

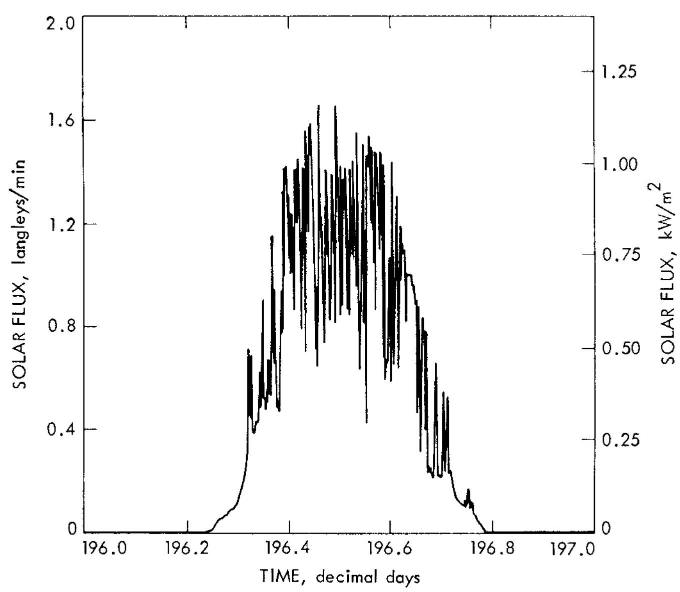

Fig. 4. Plot of pyranometer output versus time for day number 196, July 15, 1974

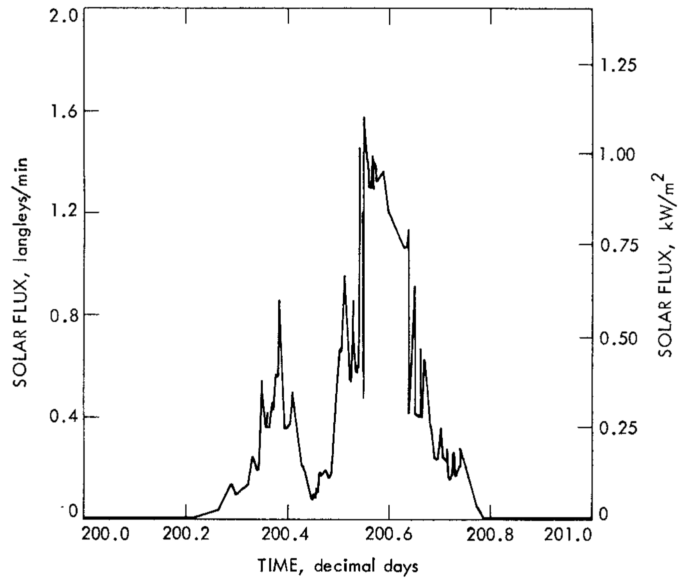

Fig. 5. Plot of pyranometer output versus time for day number 200, July 19, 1974

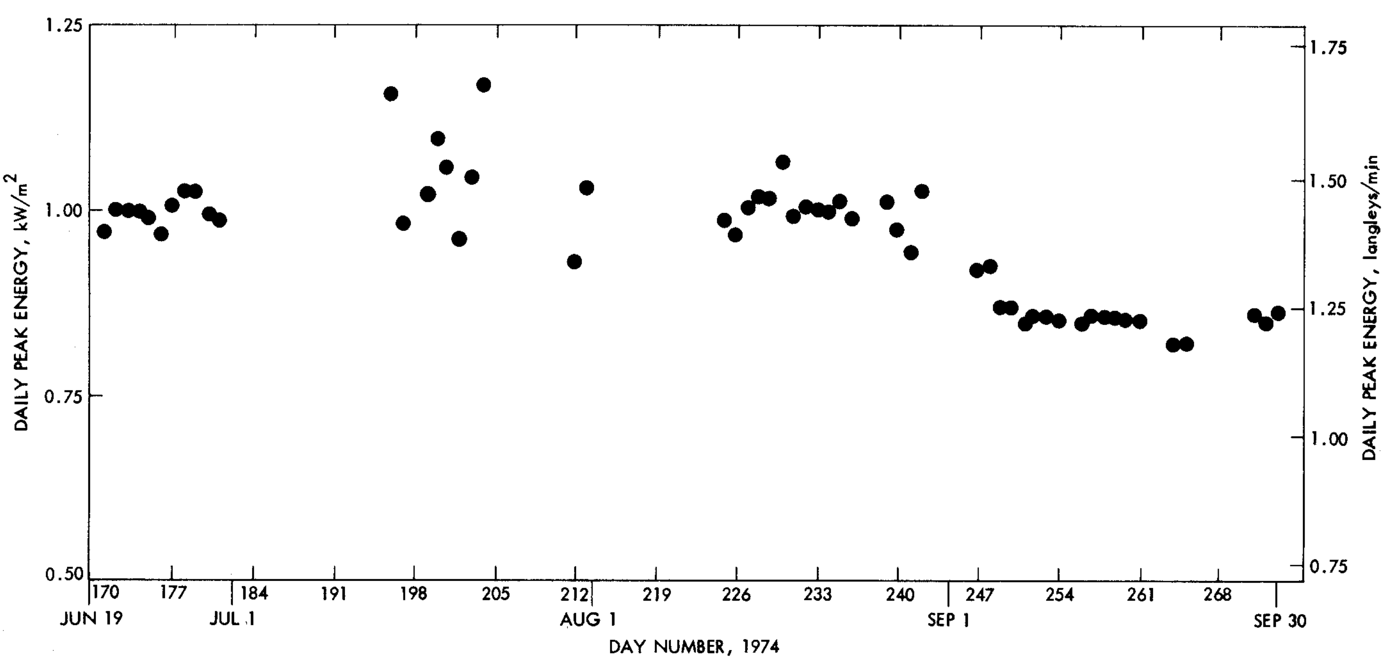

Fig. 6. Daily Peak Solar Insolation for Goldstone for the Period June 19 through September 30, 1974

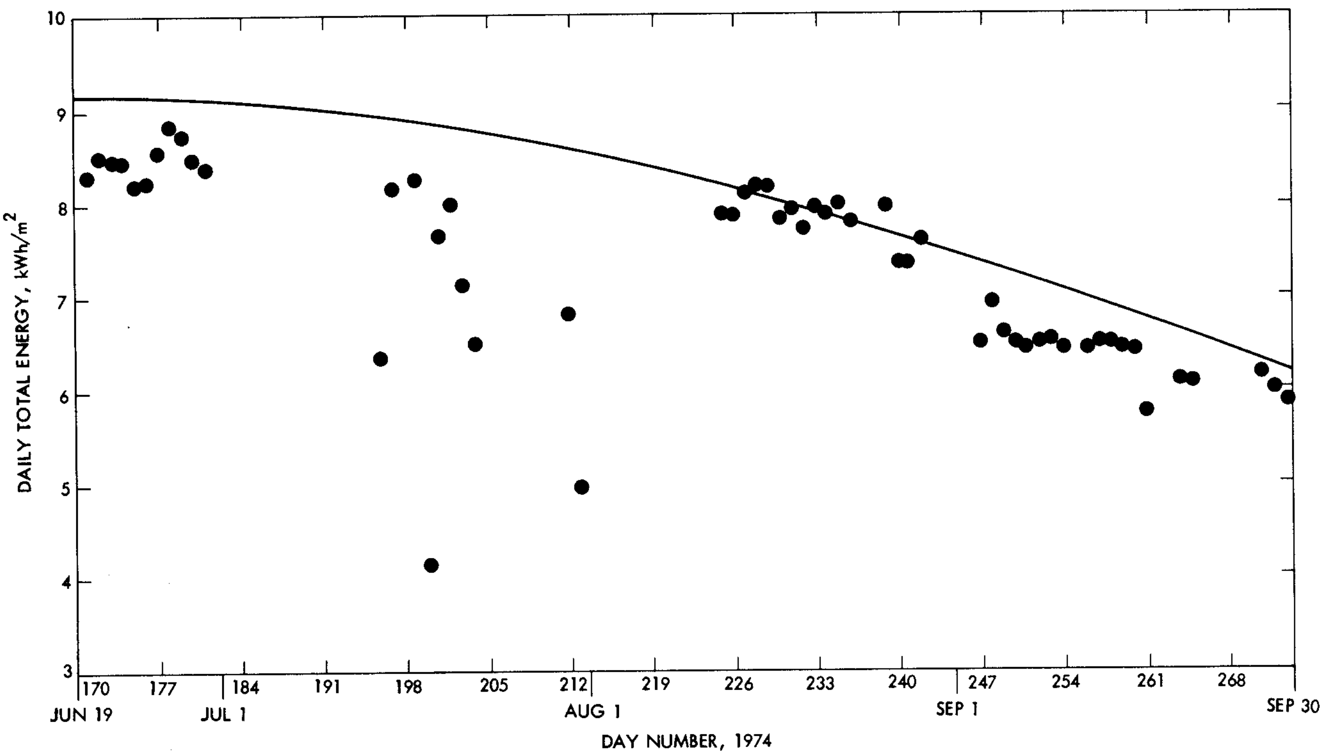

Fig. 7. Daily total energy as a function of time for the period June 19 through September 30, 1974

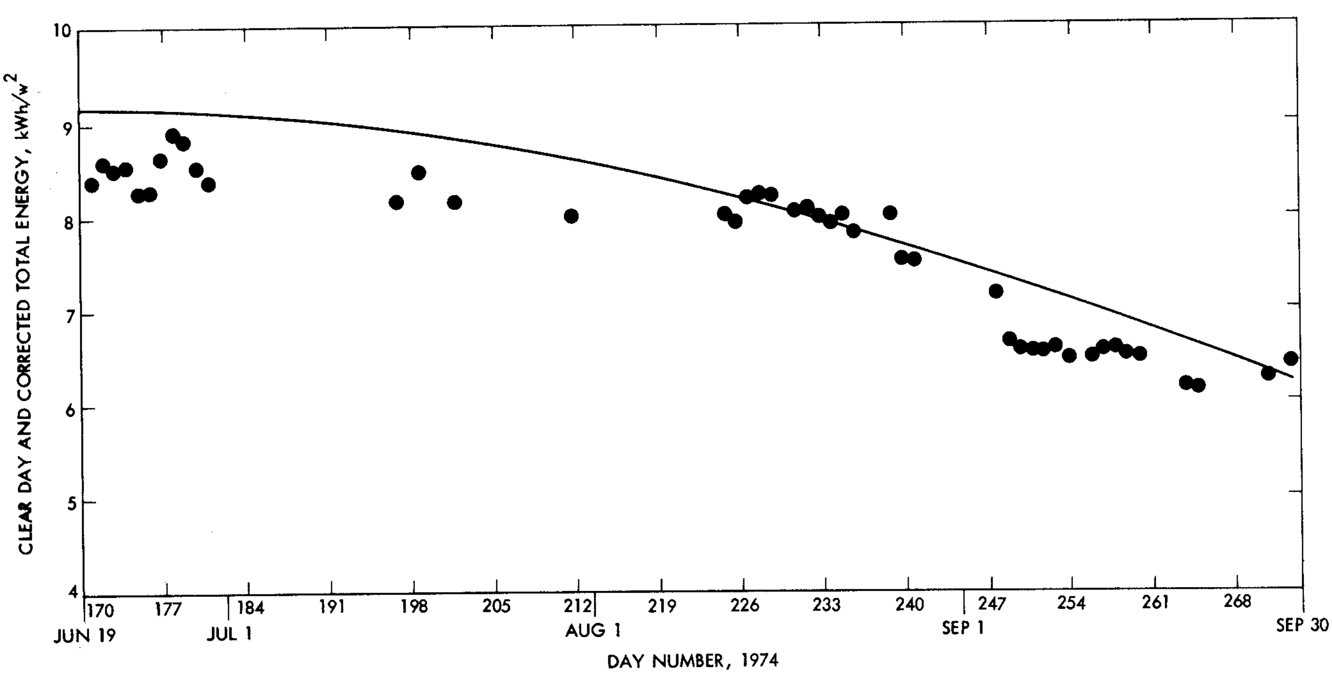

Fig. 8. Clear day total energy, actual and corrected, for the period June 19 through September 30, 1974

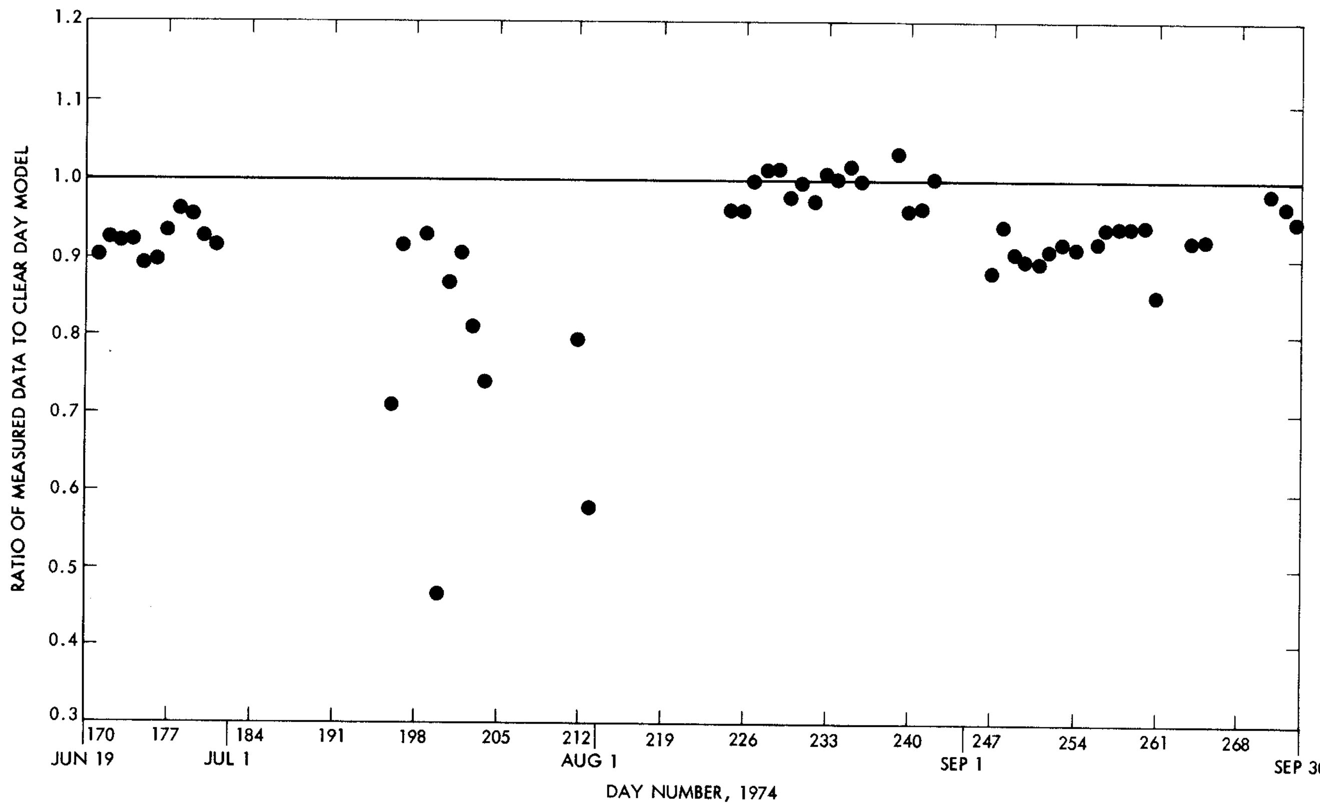

Fig. 9. Ratios of measured data to clear day model, for the period June 19 through September 30, 1974

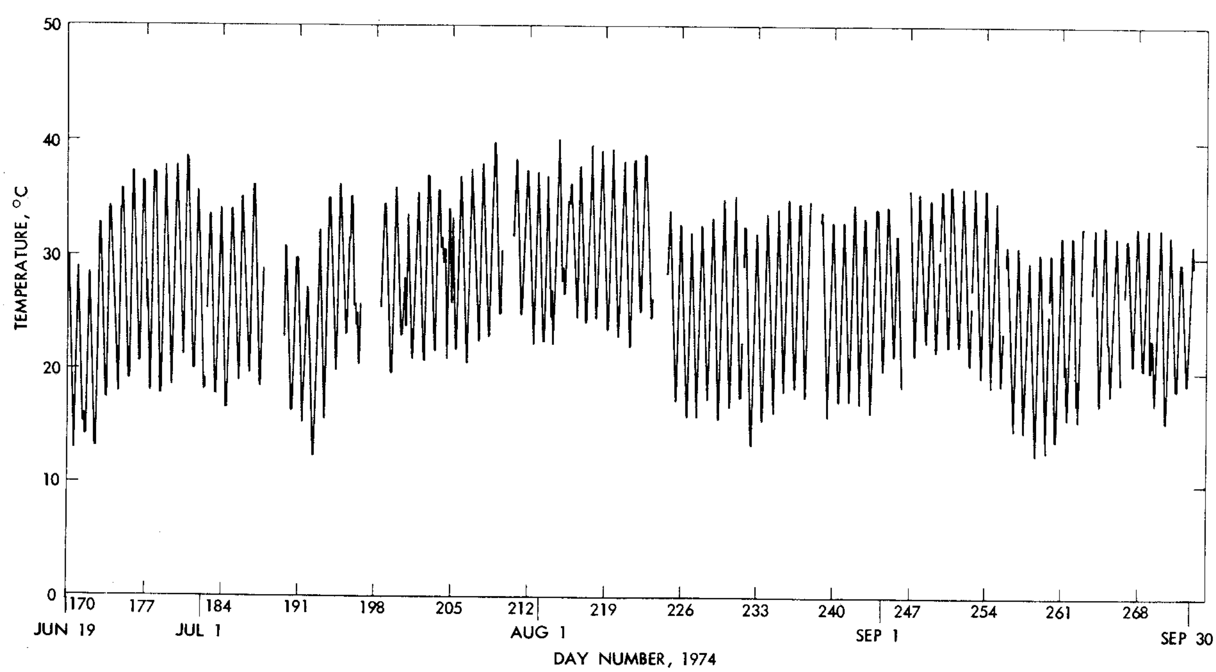

Fig. 10. Ambient temperature at Goldstone, DSS 14, for the period June 19 through September 30, 1974

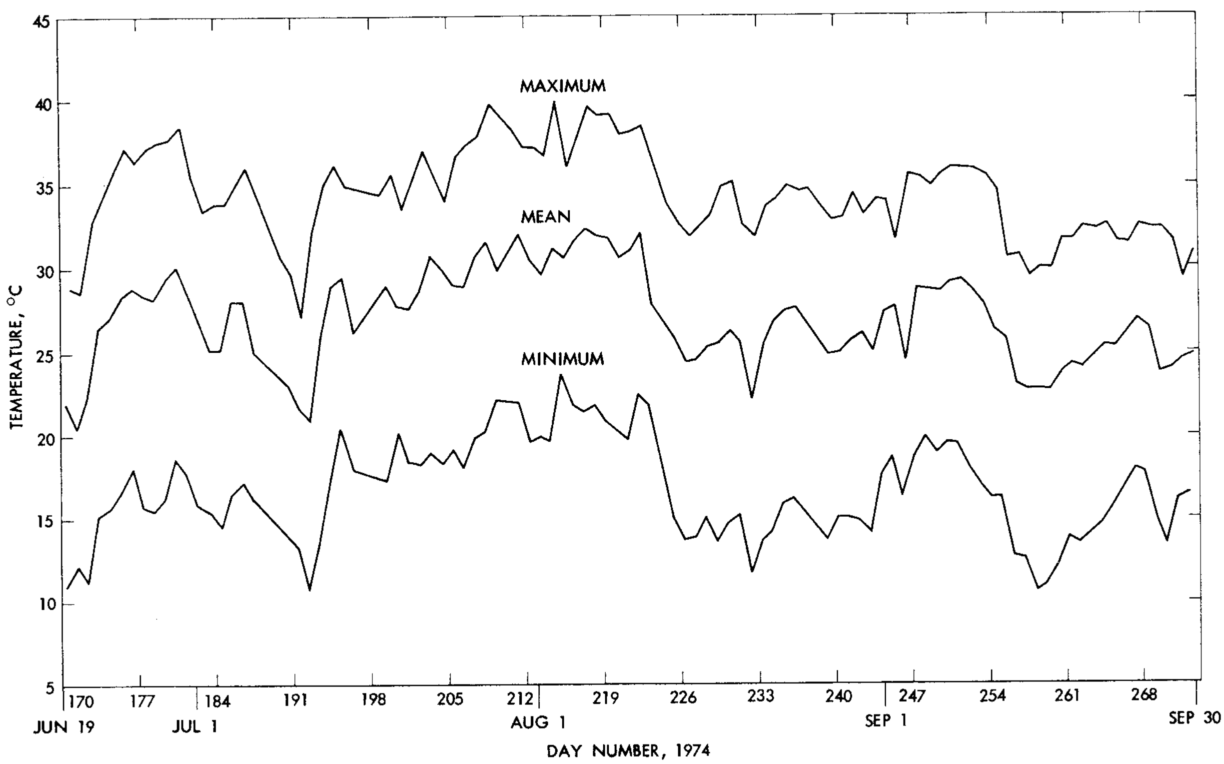

Fig. 11. Daily maximum, minimum, and mean temperatures for Goldstone for the period June 19 through September 30, 1974

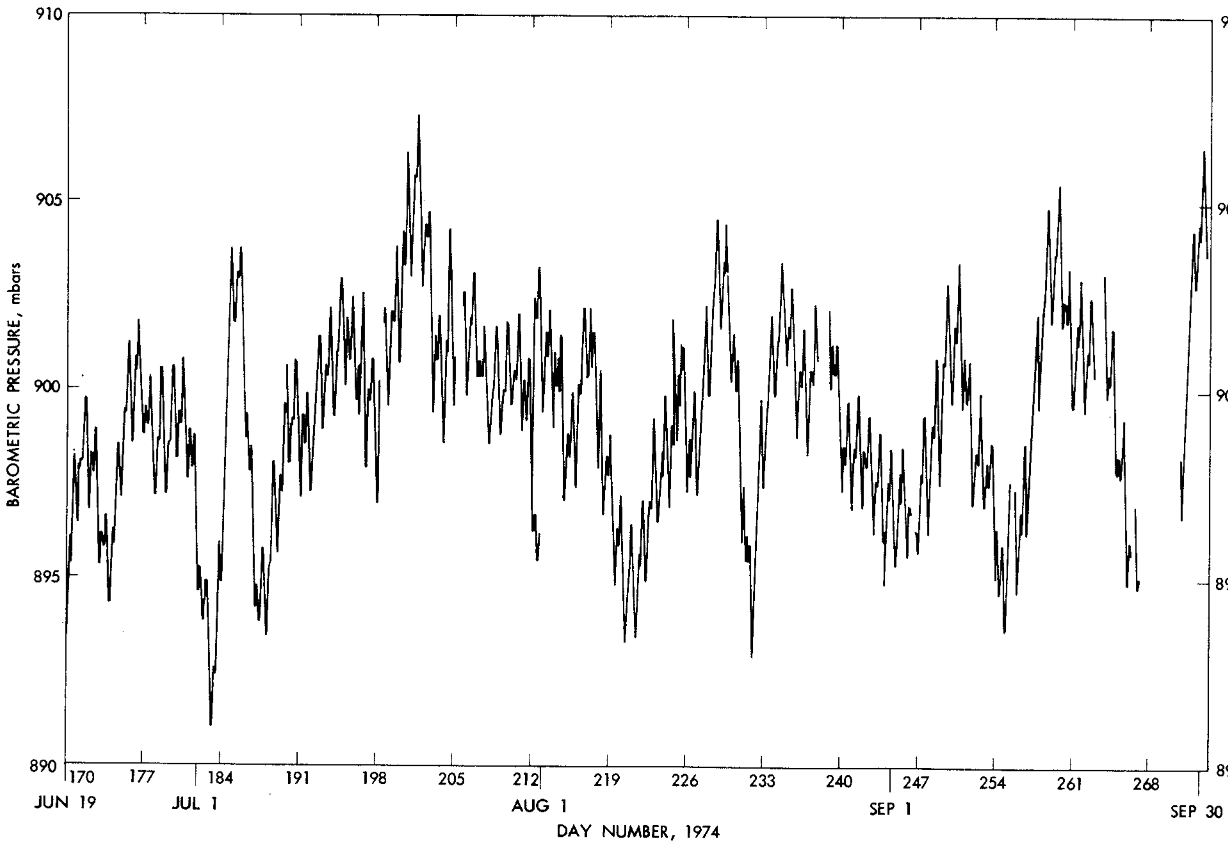

Fig. 12. Goldstone barometric pressure for the period June 19 through September 30, 1974

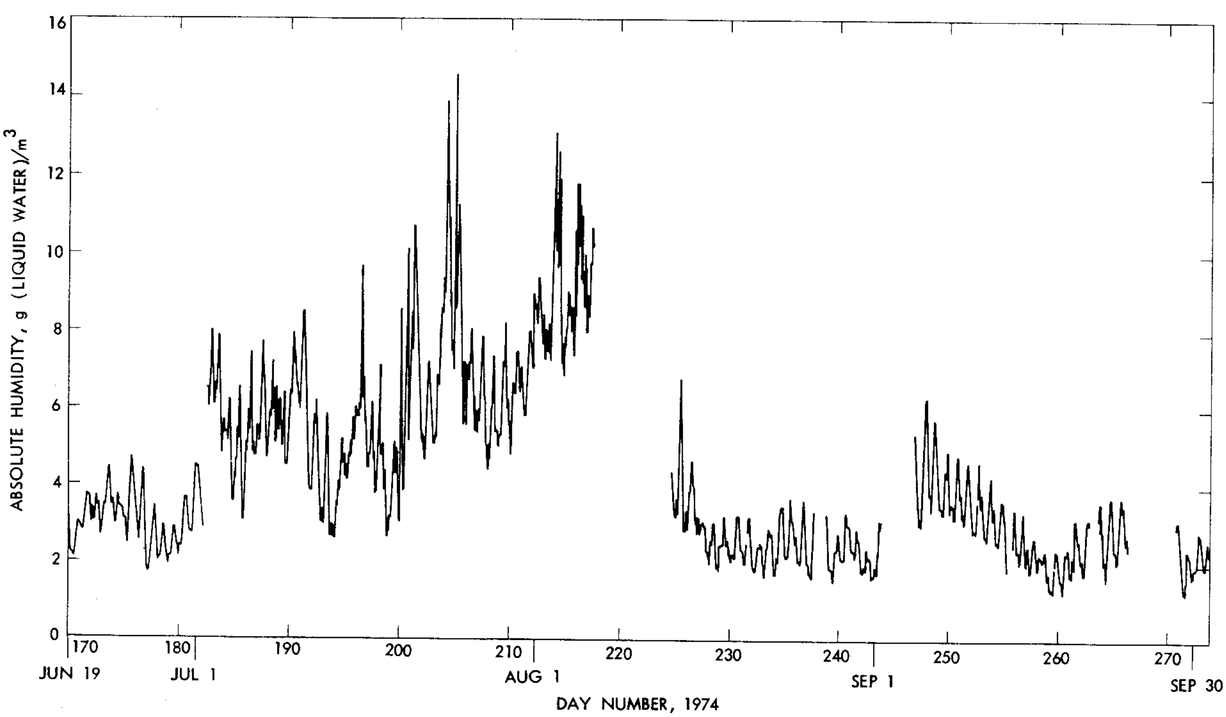

Fig. 13. Absolute humidity at Goldstone, DSS 14, for the period June 19 through September 30, 1974