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Radiation Sensor Comparisons During the GATE International Sea Trials (GIST)

KIRBY J. HANSON

BOULDER, COLO.
APRIL 1974

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Preface

This report, on the results of the comparison of radiation sensors at sea during the GATE International Sea Trials (GIST), is based primarily on data which were exchanged at sea by small-boat operation. Similar data were received on the other three participating ships. A small amount of these data (about 1 day) was received from Mexico and the U.S.S.R. following the GIST.

The article, given by reprint here, was published in the Bulletin of the American Meteorological Society to make the information available before the GATE. Because that journal usually does not publish the rather extensive tabular data on which the article was based, we are combining the reprint article with the tables of data as appendices in this publication.

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Radiation Sensor Comparisons During the GATE International Sea Trials (GIST)*

Kirby J. Hanson

Sea-Air Interaction Laboratory, Atlantic Oceanographic and Meteorological Laboratories, NOAA, Miami, Fla. 33149

Abstract

Radiation sensors on two ships of the U.S.S.R., one of Mexico, and one of the U.S. were compared during the GATE International Sea Trials (GIST), 2–10 August 1973, near 20N, 60W.

Pyranometer comparison showed that two instruments disagreed by 23%, but the remaining four pyranometers disagreed by less than 6%. The data also suggest the Yanishevsky and Eppley pyranometers have dissimilar cosine response characteristics which causes them to disagree by 4 mW cm^{-2} or less at low sun elevation angles. Pyrheliometers on the four ships were in agreement to within 1.7%. Two pyrgeometers (an Anström type and Eppley type) differed by only 1.3%.

An analysis of the GIST data suggests that, if conditions during the main field experiment are the same as in GIST, the three-day comparison period should be sufficient to reduce random errors in pyranometer measurements to 0.8%. This will allow determination of systematic pyranometer errors to well within the 5% level specified by ISMG.

1. Background

The GARP Atlantic Tropical Experiment (GATE) is directed toward an improved understanding of the physical processes in the tropical atmosphere and ocean which play an important role in determining the main features of atmospheric circulation at all latitudes. The basis for achieving an improved understanding is the planned acquisition of a four-dimensional data set during the GATE, with highest density measurements in the tropical eastern Atlantic. Ships, aircraft, balloons, and satellites will be utilized as data collection platforms. Because many nations are participating with varied types of measuring instruments, it is vital that intercomparisons between measuring systems be obtained in order to assure internal consistency of the data set.

A pre-GATE intercomparison between four ships of three nations was planned by the International Scientific and Management Group (ISMG) for GATE and conducted 1–10 August 1973, at 20N, 60W. The intercomparison was called the GATE International Sea Trials (GIST), and included the ships *A. Korolov*, U.S.S.R.; *E. Krenkel*, U.S.S.R.; *Researcher*, U.S.A.; and *V. Uribe*, Mexico.

One of the primary purposes of the GIST was to test the adequacy of intercomparison methods planned for the GATE main field experiment. For example, such questions as how does ship spatial separation affect the comparison of sensors, and how much time is required to achieve an adequate comparison, had to be answered.

Tests of measuring systems included surface meteorology, atmospheric sounding, atmospheric boundary layer,

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surface oceanography, and oceanographic sounding. In addition, radio communications, ship positioning, data exchange at sea, and international coordination were conducted during the GIST to study the feasibility of these operations during the three intercomparisons planned for the GATE main field experiment—which includes a larger number of ships.

The International Coordinator of the GIST was Dr. Yuri Tarbeev (U.S.S.R.), Assistant Director of the ISMG. Dr. Verner Suomi (University of Wisconsin) was U.S. visiting scientist aboard the *A. Korolov.* The Chief Scientist of the *Researcher* was Dr. James Sparkman, NOAA. The Captain of the *Researcher* was Captain Lavon Posey, NOAA. The Radiation Subprogrammes were conducted on the ships by the following individuals: *A. Korolov,* Chief Meteorologist, V. V. Melnikov; *E. Krenkel,* Chief Meteorologist, T. F. Demechko, and special radiation consultant, E. I. Druzhinin; *Researcher,* the author and M. F. Poindexter; and *V. Uribe,* I. Galindo and A. Muhlia.

The GIST agreements specified data exchange at sea. For the Radiation Subprogramme, pyranometer and pyrheliometer data were exchanged daily when small boat operation was possible. A small amount of data was exchanged by mail after the GIST. In this way a complete radiation data set was made available to each of the four participating ships and to the ISMG. The study reported here is based on the radiation data set available from the *Researcher.* At this writing there has been no formal data publication of the Radiation Subprogramme data. The author plans to publish the data set as a Technical Report of ERL/NOAA (Hanson, 1974).

The period of GIST included three phases, as indicated in Table 1. Ship separation varied from 1–6 km during Phases I and III which were planned for intercomparisons. However, during Phase II ships simulated the GATE data acquisition mode and separation between ships was approximately 100 km. Although Phase I began on 1 August 1973, the beginning of the Radiation Subprogramme was delayed until 2 August 1973, because of the need for discussion, standardization of measurement schedules, and exchange of data forms.

TABLE 1. GIST schedule—radiation subprogramme.

Julian day	Date	GIST phase	Comments
214	2 August 1973	I	Phase I begins 0000 GMT
215	3	I	
216	4	I	
217	5	I	
218	6	I	Phase I ends 1800 GMT
219	7	II	Phaxe II begins 0000 GMT
220	8	II	Phase II ends 2359 GMT
221	9	III	Phase III begins 0600 GMT
222	10	III	
223	11	III	Phase III ends 1600 GMT

In evaluation of the results of the GIST Radiation Subprogramme it is necessary to consider the nature of differences between radiation measurements. In general, these differences can be attributd to three causes: 1) absolute calibration level and response characteristics of the sensors; 2) sampling errors due to the spatial separation of the sensors; and 3) recording systems and data processing and integration methods. Prior to the experiment it was hoped that random measurement differences due to spatial separation of the instruments and certain data processing errors would be sufficiently small that useful information could be obtained concerning systematic differences due to absolute calibration level and response characteristics of the sensors. This proved to be the case, and the results are discussed in this report. In addition, information is presented on the amount of time required for such an experiment to minimize the random errors due to spatial separation of the sensors and data processing to the extent that systematic errors can be determined to sufficient accuracy to meet specifications for GATE.

2. Description and installation of sensors

a. Pyranometers

Pyranometers have a 180° field-of-view, and when used in a horizontal position facing upward, they measure the total of the direct sun and diffuse sky components. They integrate solar radiation spectrally with approximate uniform sensitivity from 0.3 to 3 μm. This includes about 99% of the solar radiation at the earth's surface.

The upward facing pyranometer sensors on all four ships are described in Table 2 and the downward facing pyranometers are indicated in Table 3. Included in the test were six Yanishevsky pyranometers, four Eppley pyranometers, and one Moll Gorczynski type pyranometer. A unique feature of the comparison was the installation on the *Krenkel* of a Yanishevsky M-80 and Eppley model 2 on identical gimbal platforms separated by approximately 1.5 m and identical potentiometric recording. This installation is shown in Fig. 1.

The boom mounted pyranometers were installed 12 m forward of the bow on the *Korolov* and *Krenkel* and 10 m forward on the *Researcher.* Pyranometers were gimbal mounted on the *Korolov* and *Krenkel* but fixed relative to the ship in (average) horizontal position on the *Researcher* and *Uribe.*

b. Pyrheliometers

Pyrheliometers measure the component of direct solar radiation incident on a surface normal to the sun's rays. Measurements are possible only under conditions in which clouds are not in the field of view of the instrument.

The pyrheliometers of the four ships are indicated in Table 4. Measurements with these instruments were discontinuous. The planned observation frequency was 30 min; however, this varied because of cloudiness at some observation times. The Yanishevsky pyrheliometers, on

TABLE 2. Upward facing pyranometers.

1. Ship name	*Korolov*	*Krenkel*	*Krenkel*	*Krenkel*	*Researcher*	*Uribe*	*Uribe*
2. Sensor							
a. Position on ship	Bow boom	Bow	Bow boom	Bow	Bow boom	Bridge	Bridge
b. Type and model	Yanish. M-80	Yanish. M-80	Yanish. M-80	Eppley 2	Eppley 2	Eppley (bulb)	Moll-Gor.
c. Identification no.	43	2	5373	11539	12159	3192	683224
d. Assumed sensitivity for data processing (mV cal^{-1} cm^2 min^1)	9.60	10.7	8.18	7.17	7.00	8.23	8.00
e. Temp. compensation	No	No	No	Yes	Yes	No	No
3. Sampling rate (per hour)	30	45	50	45	Cont.	Cont.	Cont.
4. Integration method							
a. Electro/mechanical							
b. Visual	X	X	X	X	X	X	X

TABLE 3. Downward facing pyranometers.

1. Ship name	*Korolov*	*Krenkel*	*Researcher*	*Uribe*
Sensor				
a. Position on ship	Bow boom	Bow boom	Bow boom	Boom
b. Type and model	Yanish. M-80	Yanish. M-80	Eppley 8-48	Yanish.
c. Identification no.	9	290	11990	1711
d. Assumed sensitivity for data processing (mV cal^{-1} cm^2 min^1)	11.10	8.56	8.13	7.06
e. Temp. compensation	No	No	Yes	No
3. Sampling rate (per hour)	30	50	Cont.	Cont.
4. Integration method				
a. Electro/mechanical				
b. Visual	X	X	X	X

the *Korolov* and *Krenkel,* having a 10° field-of-view, were placed on a stationary platform to obtain measurements. The roll of those ships was sufficiently small that the sun remained in the pyrheliometer's field of view in spite of ship roll. On the *Researcher,* an adjustable tripod mount was used to manually direct the pyrheliometer (5° field-of-view) at the sun. On the *Uribe,* pyrheliometer (No. 54585) was gimbaled on 8 August. On previous days, stationary or hand-held measurements were attempted. These attempts did not produce satisfactory data, and they are not reported here.

c. Pyrgeometers

Pyrgeometers were used to measure the IR radiation from sky and clouds incident on a horizontal surface. Only two pyrgeometers were present during the GIST; one on the *Researcher* and one on the *Krenkel.* These instruments were compared only once for a period of four hours and 15 min on the night of 5–6 August 1973 on the bow of the *Krenkel.* The sensors are described in Table 5.

The instrument on the *Krenkel* was an Ångström compensation pyrgeometer as developed by Ångström (1905) and described by the *Comite Special de l'Annee Geophysique Internationale* (1958). The instrument on the *Researcher* was an Eppley pyrgeometer which employs a KRS-5 hemisphere with interference filter on its inner surface (Eppley Lab, 1971). The composite transmission of the pyrgeometer hemispheric window is 4–50 μm.

3. Pyranometer comparison

Measurements with pyranometers were obtained during the period 2–10 August 1973. The resulting hourly and daily integrated radiation values for both upfacing and downfacing pyranometers were exchanged at sea

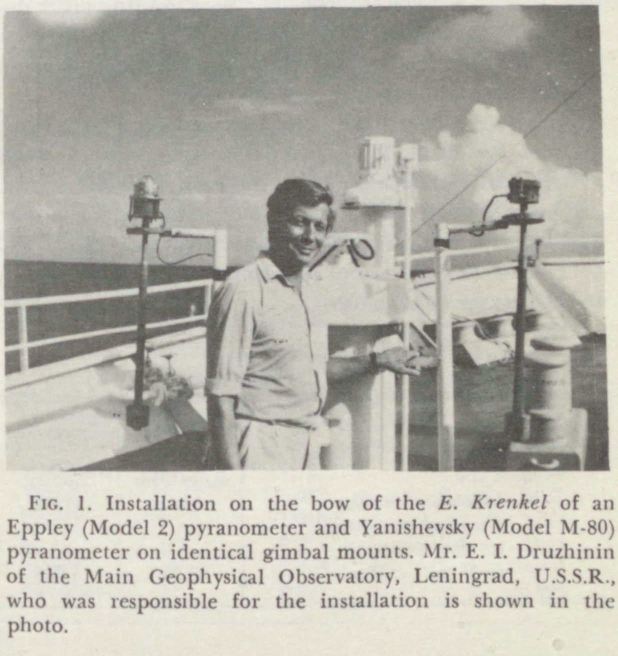

FIG. 1. Installation on the bow of the *E. Krenkel* of an Eppley (Model 2) pyranometer and Yanishevsky (Model M-80) pyranometer on identical gimbal mounts. Mr. E. I. Druzhinin of the Main Geophysical Observatory, Leningrad, U.S.S.R., who was responsible for the installation is shown in the photo.

TABLE 4. Pyrheliometers.

	Korolov	*Krenkel*	*Researcher*	*Uribe*	*Uribe*
1. Ship name	*Korolov*	*Krenkel*	*Researcher*	*Uribe*	*Uribe*
2. Sensor					
a. Position on ship	Mid-ship	Mid-ship	Bow	Bridge	Bridge
b. Type and model	Yanish. AT-50	Yanish. AT-50	Eppley NIP	Yanish.	Yanish.
c. Identification No.	6632	247	11946	797	54585
d. Assumed sensitivity for data processing (mV cal^{-1} cm^{-2} min^{-1})	6.35	6.32	5.62	5.90	6.69
e. Temp. compensation	No	No	Yes	No	No

and serve as the basis for this report. The data will be published by Hanson (1974).

a. Time averages

In order to compare the pyranometers on days when the ships were in close location (Phases I and III), the data for 2, 3, 4, 5, 6, and 9 August have been averaged. August 10th was not used in the average because the *Uribe* was not present on that date. During this averaging period continuous measurements are available from all pyranometers except Nos. 3192 and 1711 on the *Uribe*. For this reason these two sensors are not included in the Phase I and III average.

Hourly solar radiation averages were calculated for each sensor for the Phase I and III period. The results are given in Table 6. Plotted in Fig. 2 are hourly radiation values from four of the sensors which include the upper and lower range of measurements. From Fig. 2 it is clear that there exists systematic differences between sensors and these differences are consistent from hour to hour.

The average daily radiation measurement from each upfacing pyranometer and for each day during the period 2–9 August 1973 is plotted as a time series in Fig. 3. Again, it is apparent that the significant differences between the sensors are maintained from day to day. In Fig. 3 it can be seen that the sampling error due to spatial separation of the sensors is sufficiently small (even in Phase II) that the systematic differences between sensor measurements are not obscured.

Finally, the data have been averaged for Phase I and III and for Phase I, II, and III to determine a single average daily radiation value for each instrument during both of these two time periods. The resulting averages are shown in Fig. 4 as average irradiance values and in Table 7 as the ratio of the individual sensor response to the average of all sensors.

TABLE 5. Pyrgeometers.

	Krenkel	*Researcher*
1. Ship name	*Krenkel*	*Researcher*
2. Sensor		
a. Type	Ångström	Eppley
b. Identification No.	6	11540
c. Assumed sensitivity for data processing (mV cal^{-1} cm^{2} min^{1})	2.22	4.965

From this information, it is clear that regardless of whether the data from only Phase I and III are used or whether all three Phases are included, the same relative response of each sensor is obtained. The largest departures from the average of all sensors are by pyranometer No. 43 on the *Korlov* (+12.5%) and pyranometer No. 2 on the *Krenkel* (−10.7%); and the difference between these two sensors is 23%. The other four pyranometers present in the intercomparison are within 2–4% of the average of all sensors.

Subsequent to the field comparison, Galindo (Mexico) has advised that the radiation values for pyranometer No. 683224 should be increased by 5% due to a record-

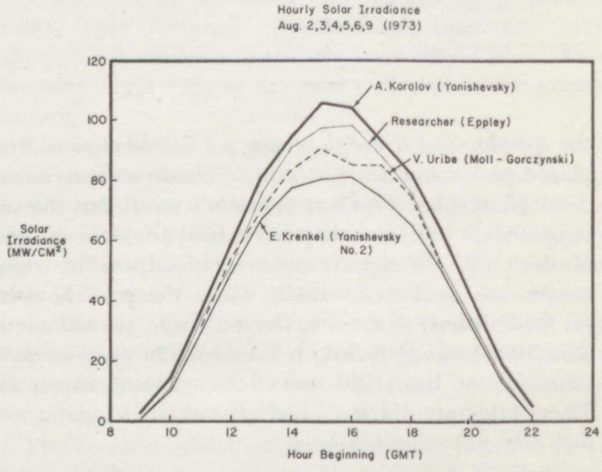

FIG. 2. Average hourly pyranometer values during Phases I and III. The data indicate the widest range of pyranometer responses. Data from other pyranometers not included here (for convenience of illustration) are given in Table 6.

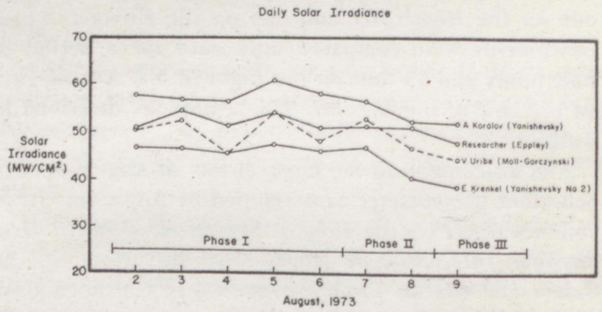

FIG. 3. Average daily pyranometer values, indicating the widest range of pyranometer responses.

TABLE 6. Phase (I and III) pyranometer data (mW cm^{-2}). Average for 2, 3, 4, 5, 6, and 9 August 1973.

Ship	AK	EK	AK	EK	EK	RES	RES	VU	VU	EK
Measurement	H↓	H↑	H↑	H↓	H↓	H↓	H↑	H↓	H↓	H↓
Sensor type	Yan.	Yan.	Yan.	Yan.	Epp.	Epp.	Epp.	MG	Epp.	Yan.
Sensor ident.	43	290	9	2	11539	12159	11990	683224	3192	5373
Hour beginning (GMT)	Sensor No.									
	1	2	3	4	5	6	7	8	9	10
9	2.72	0.00	0.70	0.87	1.40	0.48	0.10	1.70		0.20
10	14.28	2.83	2.22	10.62	10.03	11.00	1.68	12.42		12.10
11	35.57	3.80	3.54	29.30	31.05	34.15	2.88	31.80		31.43
12	58.67	3.85	4.10	49.22	52.43	51.47	2.55	54.60		52.43
13	80.87	3.62	4.25	67.43	71.90	75.73	2.55	70.23		72.70
14	94.78	3.92	4.25	77.92	87.45	90.97	2.65	83.27		89.15
15	105.70	4.12	4.47	80.50	89.68	97.42	2.62	90.67	Not	91.37
16	104.07	3.86	4.43	81.08	89.92	98.10	2.68	85.05	included	95.18
17	92.72	3.72	4.32	74.83	80.78	88.13	2.38	85.40		87.77
18	82.13	3.67	4.24	65.50	71.08	75.88	2.05	75.12		77.47
19	63.90	3.80	4.18	50.13	53.73	52.17	1.48	51.38		59.87
20	41.33	3.93	4.48	32.92	33.97	34.18	1.47	33.63		40.73
21	19.07	2.72	3.33	13.77	12.48	14.15	1.12	14.88		18.27
22	5.03	0.93	1.12	1.52	0.87	1.42	0.10	1.36		2.33
Daily average	57.17	3.07	3.27	45.38	48.95	51.80	1.87	49.38	—	52.20

ing error which was detected after the experiment. This suggested correction has not been applied in the present report but should be considered applicable in any future use of this comparison.

b. Sensor characteristics

In evaluating the data, it was noted that the Yanishevsky M-80 pyranometer appeared to give relatively higher values than the Eppley Model 2 at low sun elevation angles and the opposite for large sun elevation angles. To quantify this, the hourly data of three Yanishevsky pyranometers (Nos. 43, 2, and 5373) and two Eppley pyranometers (Nos. 11539 and 12159) were averaged for the period 2–9 August 1973. The results in Fig. 5 show the response of each of these two instrument types relative to the average of all instruments, and in Fig. 6 the radiation differences are shown. From these two figures it appears that there are relatively high percentage differences between these two instrument types at low sun elevation angles, although the energy differences at these angles is less than 4 mW cm^{-2}.

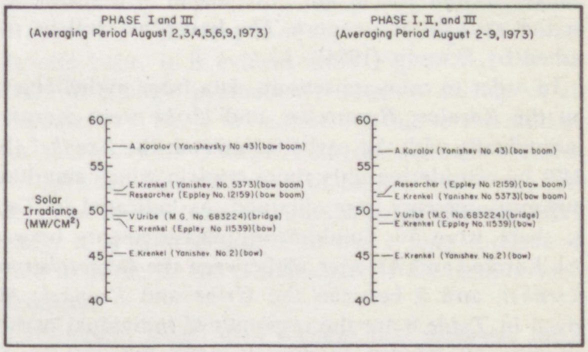

FIG. 4. Individual pyranometer averages for two different averaging periods. During Phases I and III the ships were separated by only a few kilometers, but during Phase II were separated by approximately 100 km.

4. Pyrheliometer comparison

Measurements with pyrheliometers were obtained on each day during the period 2–10 August 1973. Not all ships obtained measurements each day, but a sufficient

TABLE 7.

Ship	Measurement			Sensor response relative to average of all sensors	
	Sensor No.	Position sensor	Type sensor	Averaging period 2, 3, 4, 5, 6, and 9 August 1973	Averaging period 2–9 August 1973
A. Korolov	43	bow boom	Yanishev.	1.125	1.120
E. Krenkel	5373	bow boom	Yanishev.	1.027	1.021
Researcher	12159	bow boom	Eppley	1.019	1.024
V. Uribe	683224	bridge	M. G.	0.972	0.981
E. Krenkel	11539	bow	Eppley	0.963	0.961
E. Krenkel	2	bow	Yanishev.	0.893	0.891

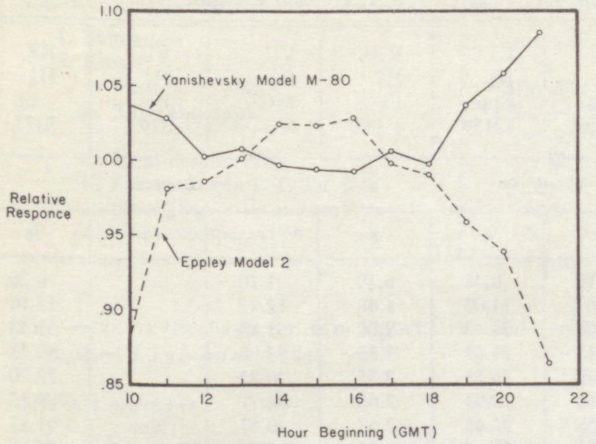

FIG. 5. Relative response of a group of Yanishevsky pyranometers (Nos. 43, 2, and 5373) and a pair of Eppley pyranometers (Nos. 11539 and 12159) during the period 2–9 August 1973, showing the variation in response due to sun elevation angle.

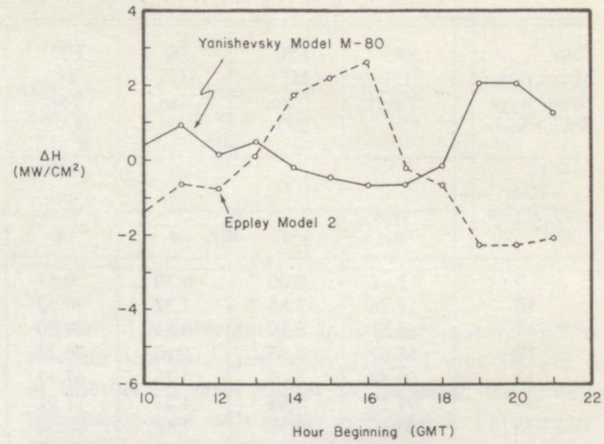

FIG. 6. Difference in radiation measured by the pyranometer groups of Fig. 5.

number were obtained during the period to provide a useful comparison. Measurements were obtained once each 30 min when cloud conditions allowed. The pyrheliometer measurements were exchanged at sea and serve as the basis for this report. The basic data will be published by Hanson (1974).

In order to compare sensors, data from pyrheliometers on the *Korolov, Researcher,* and *Uribe* were compared individually with the pyrheliometer on the *Krenkel* (No. 247) by considering only those cases in which simultaneous measurements were obtained. As indicated in Table 8, there were 76 simultaneous measurements between the *Korolov* and *Krenkel,* 63 between the *Researcher* and *Krenkel,* and 9 between the *Uribe* and *Krenkel.* Also given in Table 8 are the responses of individual pyrheliometers, all relative to pyrheliometer No. 247 on the *Krenkel.* The results show that all four pyrheliometers are within 2% and that three of the four are within 1%.

The pyrheliometer on the *Researcher* has traceability to the International Pyrheliometric Scale, 1956, as do the pyrheliometers on the *Korolov* and *Krenkel;* these three instruments differ at most by 1.7%. The pyrheliometer on the *Uribe* (No. 54585) was calibrated at sea against Yanishevsky control pyrheliometer No. 209 on board the *Krenkel.* This accounts for the close agreement (Table 8) between pyheliometers on the *Krenkel* and *Uribe.*

TABLE 8. Comparison of pyrheliometers.

Ship	Type sensor	Sensor serial No.	Number samples simultaneous with *Krenkel*	Sensor response relative to *Krenkel* pyrheliometer
A. Korolov	Yanishev.	6632	76	0.993
E. Krenkel	Yanishev.	247	—	1.000
Researcher	Eppley	11946	63	0.983
V. Uribe	Yanishev.	54585	9	1.002

In comparing pyrheliometer measurements between two ships, it was found that the average standard deviation of the two measurements was from 1.5 to 2.0 mW cm^{-2}. Since the error in sampling is probably random, the 1.5–2.0 mW cm^{-2} uncertainty associated with a single comparison will decrease (by $1/\sqrt{n}$) as the number of samples is increased. Thus, the uncertainty associated with the comparison of pyrheliometers on the *Korolov* and *Krenkel* (in which 76 simultaneous measurements are available) is probably about 0.2 mW cm^{-2} or near 0.4% of the measurement value.

5. Pyrgeometer comparison

A comparison of two pyrgeometers was carried out on the *Krenkel* from 0200–0615 GMT, 6 August 1973. The pyrgeometer types and their sensitivities are given in Table 5.

A total of 35 simultaneous pyrgeometer measurements were obtained. The cloudiness varied from 1/10 to 4/10 cumulus during the comparison, and the temperature of the radiating surface of the Ångström pyrgeometer varied from 26.0–26.9C. The measurements were exchanged at sea and will be published by Hanson (1974).

The average atmospheric downward IR radiation was 39.84 mW cm^{-2} measured by the *Krenkel* pyrgeometer and 40.38 mW cm^{-2} measured by the *Researcher* pyrgeometer; the averages differ 0.54 mW cm^{-2} or 1.3%.

6. Implications about radiation sensor comparisons during the GATE main field experiment

One of the primary purposes of GIST was to learn about the uncertainties involved in intercomparisons at sea and to determine the length of time required during comparisons in order to standardize the instruments to suitable accuracy. In this sense GIST was undertaken to learn how to conduct comparisons during the main field phases of the GATE.

As indicated in the first section of this report, differences between *pyranometers* in comparisons at sea (in which instruments are separated by a few kilometers) can be attributed to three sources: 1) absolute calibration level and response characteristics of sensors; 2) sampling errors due to spatial separation of sensors; and 3) recording systems and data integration methods.

In the first case, the error in instrument response is mainly systematic but to a small extent could be random, if, for example, instrument characteristics differed and therefore instrument response would depend on cloudiness which is random. In the second case, the error in instrument response is mainly random because of the random nature of cloudiness and the physical separation of instruments by a few kilometers. In the third case, the error in measurement could be systematic from recording errors and also random due to visual integration methods which are usually employed in data processing.

With these error sources in mind, it is of interest to examine the GIST data in order to compute these errors and the time series needed to minimize random errors to a point where systematic differences between instruments can be resolved.

The GIST pyranometer data given in Section 3 of this report show there were large systematic differences between the measurement level of some pyranometers. The largest systematic difference between two pyranometers was 11.8 mW cm^{-2} or 23% of the daily integrated solar radiation. However, for the other four pyranometers, differences between sensors were less than 6% and for some sensor pairs were less than 2%. The ISMG has asked that pyranometers in GATE be standardized to within 5% (Kraus, 1973).

As previously indicated, the random differences between sensors is due to two sources: 1) spatial sampling, and 2) visual integration. We have evaluated the sum of these two sources as a function of the time period over which the data are integrated. The curve shown in Fig. 7 represents sensor departure from the average of all sensors after a systematic difference component has been removed. It is clear that for longer integrating time periods the sensor departure (from the average of all sensors) will decrease due to the random nature of cloudiness and visual integration errors.

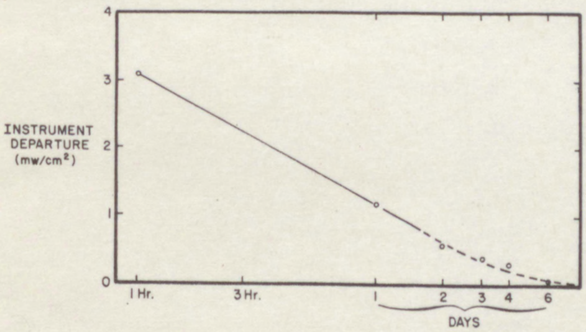

FIG. 7. Departure of pyranometer sensor due to random errors in measurement. Time indicates the period over which the data are integrated.

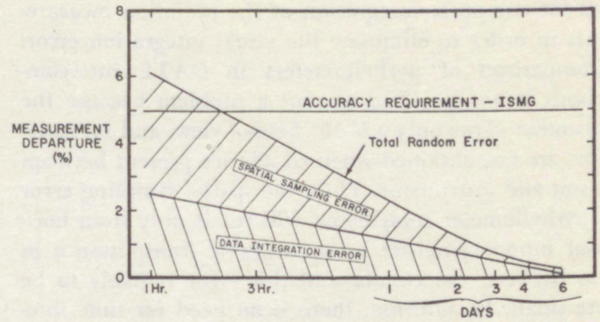

FIG. 8. Departure of pyranometer sensor due to random errors of (1) spatial sampling and (2) data integration. Time indicates the period over which the data are averaged.

By using the data from the *Krenkel* on which three pyranometers were located, we have evaluated the error due to visual integration alone. In this way it was possible to separate the total random error (Fig. 7) into the two components as shown in Fig. 8, and to examine how they varied as a function of integration time.

The information in Fig. 8 is useful in illustrating the relationship between the accuracy required for GATE measurements (5%) and the random errors of spatial sampling and data integration; it also shows how this relationship depends on the period of integration. For example, if the length of the intercomparison were only one hour, it is evident from Fig. 8 that the departure of a single pyranometer from the average of all pyranometers is likely to be near 6% due to the random error sources. This is larger than the accuracy requirement specified by ISMG and, of course, would not provide an adequate basis for standardizing pyranometers. Clearly, it is most desirable to use a long integration period to minimize the random part of the measurement differences.

The present ISMG plan suggests that three-day intercomparisons will be conducted at sea during the main field phases with approximately the same ship spacing as in GIST. The estimates in Fig. 8 suggest that if the pyranometer data are integrated for a three-day period, the uncertainty in individual sensor measurement due to random sources will be about 0.8%, of which about 2/3 is due to visual integration error and 1/3 is due to spatial sampling error. If two sensors are compared, the uncertainty due to random sources would double, amounting to nearly 1.6%. This means that in such comparisons systematic differences between instruments can be removed with a residual uncertainty of 1.6%. This is well within the 5% accuracy required by ISMG for pyranometer measurements in GATE.

Whether these GIST results are realized in the GATE intercomparisons will depend on whether cloud conditions and integration methods in GIST are duplicated. Certainly, emphasis in pre-GATE training should be placed on optimizing integration methods through the use of electrical, mechanical, or computer integration. In the U.S., pre-GATE planning and training is stressing the need for computer integration of the radiation measurements in order to eliminate the visual integration error.

Comparison of pyrheliometers in GATE intercomparisons is not likely to present a problem because the instrument views only a 5–10° field-of-view, and measurements are not obtained when clouds are present between the sun and instrument. Thus, the spatial sampling error for pyrheliometer comparison will result only from horizontal inhomogeneities in atmospheric transmittance in areas between the clouds, and this error is likely to be quite small. In addition, there is no need for time integration with pyrheliometer measurements. As discussed in Section 4, it is likely that a single simultaneous measurement by two pyrheliometers on separate ships will have an uncertainty of 1.5–2.0 mW cm^{-2} or about 3–4% of the measurement value. However, this uncertainty will decrease as the number of measurements is increased. If, for example, 16 simultaneous measurements are obtained during the 3-day intercomparisons, the uncertainty will be reduced to 1% or less. In the U.S., pre-GATE training is specifying the need for at least this number of measurements during each of the GATE intercomparisons.

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Appendix A. Pyranometer data

PYRANOMETER DATA

August 2, 1973

Ship	AK	EK	AK	EK	EK	RES	RES	VU	VU	EK	VU
Measurement	H↓	H↑	H↑	H↓	H↓	H↓	H↑	H↓	H↓	H↓	H↑
Sensor type	Yan.	Yan.	Yan.	Yan.	Epp.	Epp.	Epp.	MG	Epp.	Yan.	Yan.
Sensor ident#	43	290	9	2	11539	12159	11990	683224	3192	5373	1711

Sensor no. (mw/cm^2)

Hour beginning (GMT)	1	2	3	4	5	6	7	8	9	10	11
9	1.8	.0	.0	.0	.0	.9	.1	2.2	Missing	.0	Missing
10	11.6	2.8	1.8	9.8	9.8	10.9	1.6	13.5		10.2	
11	39.6	3.6	4.3	32.1	34.2	34.2	3.6	36.0		30.8	
12	61.9	3.6	4.2	48.2	53.0	55.2	2.9	53.4		52.8	
13	82.2	3.9	4.3	69.6	73.3	74.0	2.8	70.6		70.8	
14	93.2	4.2	4.1	76.8	85.8	83.8	2.6	70.8		87.4	
15	105.2	4.6	4.2	84.5	94.9	93.8	2.7	108.1		92.6	
16	106.2	3.8	4.6	85.2	95.5	92.4	2.9	77.0		93.8	
17	89.7	3.6	4.3	78.9	86.8	83.9	2.8	89.3		84.1	
18	84.6	3.6	4.3	67.1	72.6	75.2	2.6	74.8		75.4	
19	68.9	3.6	4.3	52.4	55.1	57.3	2.2	58.8		59.4	
20	42.1	3.6	4.1	33.5	34.9	36.4	2.2	36.8		36.3	
21	16.7	2.0	1.8	15.4	14.7	12.8	1.1	13.1		15.4	
22	5.4	.0	.7	1.4	.0	1.5	.0	1.3		1.4	
Daily average (14 hour)	57.79	3.06	3.36	46.78	50.76	50.88	2.15	50.41		50.74	

PYRANOMETER DATA

August 3, 1973

Ship	AK	EK	AK	EK	EK	RES	RES	VU	VU	EK	VU
Measurement	H↓	H↑	H↑	H↓	H↓	H↓	H↑	H↓	H↓	H↓	H↑
Sensor type	Yan.	Yan.	Yan.	Yan.	Epp.	Epp.	Epp.	MG	Epp.	Yan.	Yan.
Sensor ident#	43	290	9	2	11539	12159	11990	633224	3192	5373	1711

Sensor no. (mw/cm^2)

Hour beginning (GMT)	1	2	3	4	5	6	7	8	9	10	11
9	.0	.0	.0	.0	.0	.5	.1	[2.2]	Missing	.0	Missing
10	17.2	2.6	2.6	11.2	10.5	12.8	2.2	[12.8]		11.9	
11	37.7	4.0	4.0	29.3	30.7	33.2	3.2	30.7		30.8	
12	64.3	4.6	4.6	48.9	49.6	58.7	3.1	58.4		55.4	
13	74.6	4.0	4.0	64.2	64.9	80.6	2.9	68.5		73.4	
14	89.7	4.1	4.1	69.8	85.8	93.6	3.0	88.1		92.1	
15	94.1	4.5	4.5	87.9	92.1	102.9	3.2	87.7		97.4	
16	103.1	4.6	4.6	87.2	92.1	100.7	2.9	95.4		99.8	
17	101.5	4.5	4.5	81.0	79.6	93.6	2.5	95.7		94.5	
18	72.1	3.9	3.9	66.3	68.4	68.2	1.7	71.0		75.4	
19	69.2	4.4	4.4	55.1	59.3	62.5	2.1	53.9		64.4	
20	49.2	4.5	4.5	34.2	36.3	37.8	2.5	43.5		45.5	
21	19.8	4.1	4.1	16.8	15.4	17.7	2.1	24.6		22.2	
22	4.8	1.8	1.8	2.1	1.4	1.7	.1	2.6		3.6	
Daily average (14 hour)	56.95	3.69	3.69	46.71	49.01	54.61	2.26	52.51		54.74	

PYRANOMETER DATA

August 4, 1973

Ship	AK	EK	AK	EK	EK	RES	RES	VU	VU	EK	VU
Measurement	H↓	H↑	H↑	H↓	H↓	H↓	H↑	H↓	H↓	H↓	H↑
Sensor type	Yan.	Yan.	Yan.	Yan.	Epp.	Epp.	Epp.	MG	Epp.	Yan.	Yan.
Sensor ident#	43	290	9	2	11539	12159	11990	683224	3192	5373	1711

Hour beginning (GMT)	Sensor no. (mw/cm^2) 1	2	3	4	5	6	7	8	9	10	11
9	1.7	.0	.0	1.4	1.4	.5	.1	2.2	.0	.0	Missing
10	15.3	3.5	.0	11.2	8.4	10.7	1.8	9.7	10.0	13.3	
11	39.1	3.5	.0	31.4	30.0	37.8	3.0	32.1	31.9	33.9	
12	48.2	3.5	3.9	51.6	58.6	45.2	2.3	58.1	50.0	52.6	
13	80.5	3.5	4.1	67.7	75.4	71.6	2.2	69.4	71.9	72.0	
14	89.2	3.5	3.9	78.2	87.9	95.0	2.5	84.9	94.9	90.3	
15	113.8	3.5	4.5	89.3	101.9	100.3	2.3	86.4	88.2	96.9	
16	115.4	3.5	4.5	76.1	85.2	101.4	2.4	83.2	92.2	93.2	
17	88.9	3.5	4.2	85.2	94.9	94.7	2.2	78.4	92.6	96.1	
18	85.3	3.5	4.5	61.4	65.6	78.1	2.2	81.1	82.8	73.2	
19	50.3	3.5	3.6	39.1	41.2	37.5	1.0	27.3	26.1	47.9	
20	37.7	3.5	4.2	32.1	33.5	29.6	.9	24.1	29.7	38.5	
21	20.3	3.5	4.2	15.4	14.0	17.2	.8	2.8	23.7	20.4	
22	5.6	.7	1.4	1.4	.7	1.1	.1	.0	.0	1.7	
Daily average (14 hour)	56.52	3.05	3.07	45.82	49.91	51.48	1.70	45.69	49.57	52.14	

PYRANOMETER DATA

August 5, 1973

Ship	AK	EK	AK	EK	EK	RES	RES	VU	VU	EK	VU
Measurement	H↓	H↑	H↑	H↓	H↓	H↓	H↑	H↓	H↓	H↓	H↑
Sensor type	Yan.	Yan.	Yan.	Yan.	Epp.	Epp.	Epp.	MG	Epp.	Yan.	Yan.
Sensor ident#	43	290	9	2	11539	12159	11990	633224	3192	5373	1711

Hour beginning (GMT)	Sensor no. (mw/cm^2) 1	2	3	4	5	6	7	8	9	10	11
9	3.4	.0	.7	.7	.0	.5	.1	2.2	0.0	.0	Missing
10	17.1	3.5	2.9	12.6	14.0	13.1	2.2	16.4	16.0	13.6	
11	40.1	4.9	3.9	27.2	34.2	36.4	2.9	32.4	30.9	33.0	
12	67.5	4.2	4.5	51.7	57.2	54.8	2.7	59.2	60.2	54.5	
13	90.5	3.5	4.5	70.5	75.4	75.7	2.4	75.3	78.6	73.9	
14	102.3	4.2	4.6	87.7	91.4	90.9	2.5	89.1	88.2	91.5	
15	113.2	4.2	4.6	65.6	77.5	94.2	2.7	91.8	89.0	74.8	
16	104.6	.0	4.5	89.3	101.9	100.7	2.5	98.8	100.4	99.0	
17	94.6	.0	4.2	83.8	94.2	95.2	2.3	94.3	95.4	89.8	
18	76.9	3.5	4.1	69.8	77.5	84.6	2.0	80.8	74.0	86.5	
19	71.0	3.5	4.6	54.4	60.0	61.5	1.1	58.0	57.6	65.7	
20	45.0	4.2	5.4	36.3	37.0	38.7	.7	43.1	40.0	45.1	
21	22.4	4.2	4.0	16.8	15.4	13.3	.6	18.8	13.6	22.3	
22	6.0	.0	1.0	1.4	.7	.7	.0	1.1	1.0	2.7	
Daily average (14 hour)	61.04	2.85	3.82	47.70	52.60	54.31	1.76	54.38	53.21	53.74	

PYRANOMETER DATA

August 6, 1973

Ship	AK	EK	AK	EK	EK	RES	RES	VU	VU	EK	VU
Measurement	H↓	H↑	H↑	H↓	H↓	H↓	H↑	H↓	H↓	H↓	H↑
Sensor type	Yan.	Yan.	Yan.	Yan.	Epp.	Epp.	Epp.	MG	Epp.	Yan.	Yan.
Sensor ident#	43	290	9	2	11539	12159	11990	683224	3192	5373	1711

Sensor no. (mw/cm^2)

Hour beginning (GMT)	1	2	3	4	5	6	7	8	9	10	11
9	3.4	.0	.0	.7	.0	.1	.0	.7	.0	.0	Missing
10	16.2	3.1	2.8	10.5	9.8	10.2	1.5	12.5	11.0	13.6	
11	41.0	4.2	4.5	32.1	32.8	37.2	2.9	35.4	35.1	34.7	
12	55.3	4.1	4.2	55.1	54.3	48.4	2.2	48.0	47.5	54.5	
13	82.1	3.4	4.4	70.5	76.1	79.3	2.4	72.0	74.9	74.4	
14	101.8	3.4	4.4	83.8	94.2	93.3	2.5	92.1	91.0	87.9	
15	105.0	4.1	4.5	79.6	90.0	99.8	2.6	87.7	95.8	97.8	
16	94.4	4.1	4.1	78.9	85.9	101.9	2.7	79.5	84.3	102.2	
17	104.2	3.6	4.6	76.1	82.4	91.0	2.3	80.1	87.2	97.4	
18	91.3	4.1	4.4	64.2	71.9	74.1	1.7	72.2	70.2	86.0	
19	61.9	4.2	4.0	54.4	57.2	37.8	.7	57.0	49.6	67.3	
20	37.4	4.7	4.2	34.9	34.2	29.3	.5	23.7	22.4	47.7	
21	19.6	2.0	4.0	7.7	6.3	12.3	.6	17.5	11.9	17.0	
22	4.1	.3	.0	2.1	.7	2.5	.0	.7	.0	4.1	
Daily average (14 hour)	58.41	3.24	3.58	46.47	49.70	51.23	1.61	48.51	48.64	56.04	

PYRANOMETER DATA

August 7, 1973

Ship	AK	EK	AK	EK	EK	RES	RES	VU	VU	EK	VU
Measurement	H↓	H↑	H↑	H↓	H↓	H↓	H↑	H↓	H↓	H↓	H↑
Sensor type	Yan.	Yan.	Yan.	Yan.	Epp.	Epp.	Epp.	MG	Epp.	Yan.	Yan.
Sensor ident#	43	290	9	2	11539	12159	11990	683224	3192	5373	1711

Sensor no.
(mw/cm^2)

Hour beginning (GMT)	1	2	3	4	5	6	7	8	9	10	11
9	3.3	.0	.0	.0	.0	.2	.0	1.0	.0	.0	Missing
10	14.0	.3	3.4	9.8	6.3	8.7	1.3	16.7	14.7	7.0	
11	39.4	3.6	4.8	30.7	32.1	23.3	1.9	23.5	21.5	32.4	
12	53.9	3.4	3.8	49.6	53.0	59.4	2.8	52.2	51.1	54.2	
13	79.5	3.1	4.5	64.2	72.6	53.6	2.2	76.2	73.7	73.8	
14	97.3	3.1	4.8	81.7	90.7	93.8	2.8	88.2	85.7	89.4	
15	104.7	3.1	5.0	87.2	97.7	97.8	2.7	90.7	94.1	93.7	
16	73.5	3.2	3.8	87.9	97.0	99.9	2.8	96.5	102.1	97.6	
17	95.2	3.3	4.6	83.8	90.7	93.0	2.7	90.6	96.9	91.8	
18	89.1	2.3	4.7	64.2	74.7	82.2	2.7	81.8	80.6	75.3	
19	73.8	2.4	4.6	52.4	55.8	55.6	2.4	63.6	64.9	61.8	
20	45.7	3.4	5.3	32.8	33.5	37.4	2.8	40.5	36.4	43.4	
21	22.0	1.6	4.7	14.7	14.0	16.9	1.9	20.9	14.5	15.0	
22	4.8	.2	1.1	1.4	.7	1.6	.1	1.9	1.1	1.9	
Daily average (14 hour)	56.87	2.36	3.94	47.17	51.34	51.67	2.08	53.16	52.66	52.66	

PYRANOMETER DATA

August 8, 1973

Ship	AK	EK	AK	EK	EK	RES	RES	VU	VU	EK	VU
Measurement	H↓	H↑	H↑	H↓	H↓	H↓	H↑	H↓	H↓	H↓	H↑
Sensor type	Yan.	Yan.	Yan.	Yan.	Epp.	Epp.	Epp.	MG	Epp.	Yan.	Yan.
Sensor ident#	43	290	9	2	11539	12159	11990	633224	3192	5373	1711

Hour beginning (GMT)	Sensor no. (mw/cm^2) 1	2	3	4	5	6	7	8	9	10	11
9	1.8	.0	.0	.7	.0	.2	.0	.5	.0	.0	Missing
10	7.5	2.3	.7	9.8	8.4	10.7	1.2	11.7	9.0	12.4	
11	58.2	3.1	3.8	25.8	26.5	32.4	2.8	30.2	29.7	31.0	
12	61.3	2.9	4.3	47.5	49.6	55.2	2.7	55.0	49.3	55.0	
13	57.9	3.3	3.5	57.2	60.0	72.5	2.6	59.7	73.1	68.1	
14	84.2	2.9	4.6	76.1	83.1	82.9	2.6	84.2	83.6	84.1	
15	74.5	3.1	4.0	82.4	93.5	97.7	3.2	78.5	82.8	92.0	
16	81.2	3.8	4.3	70.5	78.9	97.1	3.3	95.5	98.3	79.7	
17	106.0	3.1	5.0	80.3	84.5	90.7	2.8	72.8	78.5	90.1	
18	81.7	2.9	4.5	48.2	53.0	76.8	2.2	71.7	77.3	56.0	
19	63.3	2.3	4.5	32.1	32.8	58.2	3.0	51.1	53.9	34.1	
20	41.7	2.9	4.3	28.6	28.6	34.4	2.1	33.0	34.1	36.3	
21	14.9	2.0	1.2	11.2	9.8	11.6	.9	14.6	12.4	15.7	
22	2.8	.5	.3	.7	.0	1.2	.1	1.4	1.7	2.2	
Daily average (14 hour)	52.64	2.51	3.21	40.79	43.48	51.54	2.11	47.14	48.84	46.91	

PYRANOMETER DATA

August 9, 1973

Ship	AK	EK	AK	EK	EK	RES	RES	VU	VU	EK	VU
Measurement	H↓	H↑	H↑	H↓	H↓	H↓	H↑	H↓	H↓	H↓	H↑
Sensor type	Yan.	Yan.	Yan.	Yan.	Epp.	Epp.	Epp.	MG	Epp.	Yan.	Yan.
Sensor ident#	43	290	9	2	11539	12159	11990	683224	3192	5373	1711

Hour beginning (GMT)	Sensor no. (mw/cm^2) 1	2	3	4	5	6	7	8	9	10	11
9	3.3	.0	.0	.7	.0	.4	.0	.7	.9	.2	.2
10	8.3	1.5	1.0	8.4	7.7	8.3	.8	9.6	9.5	10.0	1.5
11	15.9	2.6	1.0	23.7	24.4	26.1	1.7	24.2	24.7	25.4	2.4
12	54.8	3.1	3.2	39.8	41.9	46.5	2.1	50.5	45.2	44.8	3.0
13	75.3	3.4	4.2	62.1	66.3	73.2	2.6	65.6	68.1	71.7	3.6
14	92.5	4.1	4.4	71.2	79.6	89.2	2.8	74.6	79.7	85.7	3.5
15	[102.9	3.8	4.5	76.1	81.7	93.5	2.2	82.3	91.8	88.7	3.6
16	100.7	3.3	4.3	69.8	78.9	91.5	2.7	76.4	88.2	83.1	3.2
17	77.4	3.4	4.1	44.0	46.8	70.4	2.2	74.6	72.5	64.7	3.2
18	82.6	3.4	.0	64.2	70.5	75.1	2.1	70.8	71.6	68.3	3.5
19	62.1	3.6	.0	45.4	49.6	56.4	1.8	53.3	51.7	54.5	3.6
20	36.6]	3.1	.0	26.5	27.9	33.3	2.0	30.6	31.2	31.3	2.7
21	15.6	.5	1.9	10.5	9.1	11.6	1.5	12.5	10.5	12.3	1.8
22	4.3	.0	.7	.7	.0	1.0	.0	1.1	1.1	.5	.5
Daily average (14 hour)	52.31	2.56	2.09	38.79	41.74	48.32	1.75	44.77	46.19	45.80	2.59

PYRANOMETER DATA

August 10, 1973

Ship	AK	EK	AK	EK	EK	RES	RES	VU	VU	EK	VU
Measurement	H↓	H↑	H↑	H↓	H↓	H↓	H↑	H↓	H↓	H↓	H↑
Sensor type	Yan.	Yan.	Yan.	Yan.	Epp.	Epp.	Epp.	MG	Epp.	Yan.	Yan.
Sensor ident#	43	290	9	2	11539	12159	11990	683224	3192	5373	1711

Sensor no. (mw/cm^2)

Hour beginning (GMT)	1	2	3	4	5	6	7	8	9	10	11
9	3.5	.0	.0	1.4	.7	.4	.0	Missing	Missing	1.4	Missing
10	13.6	2.1	1.5	9.8	8.4	9.8	1.5			11.2	
11	36.1	4.2	3.7	28.6	31.4	30.1	2.4			32.2	
12	60.8	3.5	4.1	46.1	49.6	49.6	2.5			54.4	
13	81.2	4.2	4.3	68.4	72.6	75.0	2.4			74.7	
14	98.0	4.9	4.6	64.9	70.5	87.8	2.6			74.0	
15	105.6	4.2	4.7	64.9	69.8	93.2	2.8			61.4	
16	109.8	4.2	4.7	78.9	86.6	96.1	2.9			90.0	
17	62.1	3.5	3.7	69.8	71.2	70.7	1.7			81.7	
18	53.6	3.5	3.4	41.9	44.0	48.8	1.7			51.0	
19	67.1	3.5	4.4	45.4	48.9	58.8	2.0			55.8	
20	36.5	3.5	4.4	23.7	26.5	30.2	1.5			25.8	
21	18.2	.7	2.6	7.0	6.3	13.7	1.2			8.4	
22	5.0	.0	.3	1.4	.7	1.4	.0			2.1	
Daily average (14 hour)	53.65	3.00	3.31	39.44	41.94	47.54	1.80			44.58	

Appendix B. Pyrheliometer data

PYRHELIOMETER DATA

August 2, 1973

HOUR	DAY	MNTH	YEAR	INTENSITY (MW/CM SQ) AK	EK	RES	VU
1130	2	8	73	51.9	.0	.0	.0
1200	2	8	73	58.0	60.0	57.7	.0
1230	2	8	73	63.1	64.1	62.2	.0
1300	2	8	73	66.7	67.0	66.0	.0
1330	2	8	73	69.2	70.5	67.0	.0
1400	2	8	73	70.4	70.5	.0	.0
1430	2	8	73	70.4	70.5	68.6	.0
1500	2	8	73	72.2	73.3	.0	.0
1530	2	8	73	70.6	71.2	68.7	.0
1600	2	8	73	70.6	.0	.0	.0
1630	2	8	73	70.6	71.2	.0	.0
1700	2	8	73	69.4	.0	68.3	.0
1730	2	8	73	.0	.0	.0	.0
1800	2	8	73	63.4	65.6	61.9	.0
1830	2	8	73	60.5	59.3	57.5	.0
1900	2	8	73	55.6	55.1	52.7	.0
1930	2	8	73	.0	53.8	50.1	.0
2000	2	8	73	46.8	47.5	44.4	.0
2030	2	8	73	37.8	36.3	.0	.0
2100	2	8	73	28.2	27.9	.0	.0
2130	2	8	73	15.6	.0	.0	.0

PYRHELIOMETER DATA

August 3, 1973

HOUR	DAY	MNTH	YEAR	INTENSITY (MW/CM SQ) AK	FK	RES	VU
1100	3	8	73	.0	57.9	.0	.0
1130	3	8	73	59.4	.0	.0	.0
1200	3	8	73	70.0	69.8	68.8	.0
1230	3	8	73	73.8	76.8	.0	.0
1300	3	8	73	76.9	78.9	75.3	.0
1330	3	8	73	80.3	82.4	.0	.0
1400	3	8	73	81.4	85.2	82.5	.0
1430	3	8	73	84.8	83.8	83.0	.0
1500	3	8	73	86.8	84.5	85.8	.0
1530	3	8	73	86.1	86.6	85.3	.0
1600	3	8	73	84.6	85.9	84.1	.0
1630	3	8	73	.0	87.2	.0	.0
1700	3	8	73	83.6	87.2	85.1	.0
1730	3	8	73	83.5	84.4	84.1	.0
1800	3	8	73	83.6	.0	82.4	.0
1830	3	8	73	.0	.0	.0	.0
1900	3	8	73	.0	83.8	81.6	.0
1930	3	8	73	76.2	77.5	75.9	.0
2000	3	8	73	73.5	73.3	.0	.0
2030	3	8	73	67.0	62.1	63.9	.0
2100	3	8	73	61.3	60.0	57.3	.0
2130	3	8	73	47.1	48.2	.0	.0
2200	3	8	73	24.8	27.9	26.6	.0

PYRHELIOMETER DATA

August 4, 1973

HOUR	DAY	MNTH	YEAR	INTENSITY (MW/CM SQ) AK	EK	RES	VU
1200	4	8	73	75.3	74.0	74.1	.0
1230	4	8	73	.0	.0	.0	.0
1300	4	8	73	.0	.0	.0	.0
1330	4	8	73	85.5	85.2	84.6	.0
1400	4	8	73	87.6	87.2	86.3	.0
1430	4	8	73	.0	87.2	86.2	.0
1500	4	8	73	.0	86.6	.0	.0
1530	4	8	73	.0	88.6	.0	.0
1600	4	8	73	88.4	.0	.0	.0
1630	4	8	73	88.2	88.6	86.1	.0
1700	4	8	73	86.1	83.8	86.8	.0
1730	4	8	73	85.8	86.6	85.7	.0
1800	4	8	73	85.5	85.8	84.2	.0
1830	4	8	73	81.8	82.4	81.4	.0
1900	4	8	73	81.6	81.7	79.5	.0
1930	4	8	73	.0	.0	.0	.0
2000	4	8	73	.0	.0	70.4	.0
2030	4	8	73	.0	.0	60.5	.0
2100	4	8	73	58.1	61.4	.0	.0
2130	4	8	73	47.0	46.8	.0	.0

PYRHELIOMETER DATA

August 5, 1973

HOUR	DAY	MNTH	YEAR	INTENSITY (MW/CM SQ) AK	EK	RES	VU
1200	5	8	73	.0	.0	74.9	.0
1230	5	8	73	.0	83.1	.0	.0
1300	5	8	73	82.9	83.8	.0	.0
1330	5	8	73	86.8	86.6	85.7	.0
1400	5	8	73	87.4	87.9	86.6	.0
1430	5	8	73	87.6	.0	86.7	.0
1500	5	8	73	88.0	.0	.0	.0
1530	5	8	73	88.7	.0	87.7	.0
1600	5	8	73	88.9	.0	.0	.0
1630	5	8	73	.0	87.9	88.4	.0
1700	5	8	73	88.7	88.6	86.9	.0
1730	5	8	73	87.4	86.6	85.0	.0
1800	5	8	73	.0	85.6	.0	.0
1830	5	8	73	.0	.0	.0	.0
1900	5	8	73	82.9	83.1	81.1	.0
1930	5	8	73	77.1	78.2	77.9	.0
2000	5	8	73	73.5	79.0	73.3	.0
2030	5	8	73	68.5	69.1	67.9	.0
2100	5	8	73	61.6	62.1	60.4	.0

PYRHELIOMETER DATA August 6, 1973

HOUR	DAY	MNTH	YEAR	INTENSITY (MW/CM SQ) AK	EK	RES	VU
1100	6	8	73	.0	.0	57.6	.0
1130	6	8	73	.0	.0	.0	.0
1200	6	8	73	.0	73.3	74.1	.0
1230	6	8	73	77.1	78.1	75.5	.0
1300	6	8	73	78.9	80.1	.0	.0
1330	6	8	73	82.2	85.1	82.3	.0
1400	6	8	73	84.9	86.9	84.7	.0
1430	6	8	73	86.1	87.1	85.4	.0
1500	6	8	73	87.9	88.7	86.8	.0
1530	6	8	73	87.9	.0	86.9	.0
1600	6	8	73	88.7	89.1	86.9	.0
1630	6	8	73	88.3	.0	87.1	.0
1700	6	8	73	88.0	88.0	87.4	.0
1730	6	8	73	87.5	85.4	85.3	.0
1800	6	8	73	86.1	83.0	84.7	.0
1830	6	8	73	83.9	76.5	.0	.0
1900	6	8	73	80.9	.0	.0	.0
1930	6	8	73	78.0	75.2	.0	.0
2000	6	8	73	.0	74.6	.0	.0
2030	6	8	73	.0	79.8	.0	.0
2100	6	8	73	60.5	59.1	.0	.0
2132	6	8	73	49.6	.0	.0	.0
2203	6	8	73	.0	25.6	.0	.0

PYRHELIOMETER DATA August 7, 1973

HOUR	DAY	MNTH	YEAR	INTENSITY (MW/CM SQ) AK	EK	RES	VU
1200	7	8	73	75.1	.0	.0	.0
1230	7	8	73	75.8	.0	.0	.0
1300	7	8	73	80.9	.0	.0	.0
1330	7	8	73	83.8	84.5	.0	.0
1400	7	8	73	.0	.0	84.2	86.6
1430	7	8	73	.0	87.6	86.6	87.6
1500	7	8	73	.0	.0	.0	.0
1530	7	8	73	.0	90.2	.0	.0
1600	7	8	73	.0	89.1	.0	90.2
1630	7	8	73	.0	90.0	88.8	88.6
1700	7	8	73	.0	89.8	88.2	88.6
1730	7	8	73	.0	88.4	87.2	.0
1800	7	8	73	.0	85.6	86.9	.0
1830	7	8	73	.0	82.5	83.5	85.5
1900	7	8	73	.0	81.6	81.4	.0
1930	7	8	73	.0	80.7	78.0	82.4
2000	7	8	73	73.8	77.2	.0	76.6
2030	7	8	73	.0	69.3	.0	.0
2100	7	8	73	62.2	63.7	.0	.0
2135	7	8	73	46.3	.0	.0	.0
2200	7	8	73	.0	36.6	.0	.0

PYRHELIOMETER DATA

August 8, 1973

HOUR	DAY	MNTH	YEAR	INTENSITY (MW/CM SQ) AK	EK	RES	VU
1130	8	8	73	.0	56.9	.0	.0
1200	8	8	73	51.8	58.0	.0	.0
1230	8	8	73	58.2	62.0	.0	.0
1300	8	8	73	.0	.0	64.1	.0
1330	8	8	73	.0	66.2	.0	.0
1400	8	8	73	.0	70.0	.0	71.4
1430	8	8	73	.0	.0	.0	70.4
1500	8	8	73	.0	77.0	.0	.0
1530	8	8	73	.0	77.0	.0	.0
1600	8	8	73	75.8	77.9	.0	.0
1630	8	8	73	.0	.0	.0	.0
1700	8	8	73	.0	79.8	.0	77.9
1730	8	8	73		79.6	.0	.0
1800	8	8	73		74.1	.0	.0
1830	8	8	73	.0	.0	.0	.0
1900	8	8	73	.0	74.8	.0	.0
1930	8	8	73		.0	.0	.0
2000	8	8	73		45.9	.0	.0
2030	8	8	73	.0	34.6	.0	.0
2100	8	8	73	.0	21.6	.0	.0

PYRHELIOMETER DATA

August 9, 1973

				INTENSITY (MW/CM SQ)			
HOUR	DAY	MNTH	YEAR	AK	EK	RES	VU
1400	9	8	73	56.8	.0	.0	.0
1530	9	8	73	60.5	.0	.0	.0
1600	9	8	73	59.9	.0	.0	.0
1830	9	8	73	.0	52.5	.0	.0
1930	9	8	73	.0	45.2	.0	.0
2030	9	8	73	.0	28.7	.0	.0
2130	9	8	73	.0	31.1	.0	.0

PYRHELIOMETER DATA

August 10, 1973

				INTENSITY (MW/CM SQ)			
HOUR	DAY	MNTH	YEAR	AK	EK	RES	VU
1100	10	8	73	.0	29.8	.0	.0
1130	10	8	73	.0	.0	.0	.0
1200	10	8	73	48.0	48.7	.0	.0
1230	10	8	73	51.9	52.4	.0	.0
1300	10	8	73	56.8	59.0	.0	.0
1330	10	8	73	61.8	63.9	.0	.0
1400	10	8	73	65.3	.0	.0	.0
1430	10	8	73	69.2	.0	61.9	.0
1500	10	8	73	68.5	.0	.0	.0
1900	10	8	73	63.1	.0	.0	.0
1930	10	8	73	59.6	.0	.0	.0
2030	10	8	73	25.4	.0	.0	.0

Appendix C. Pyrgeometer data

PYRGEOMETER DATA August 6, 1973

Ship	KRENKEL		RESEARCHER
Sensor no.	6		11540
	L↓ (mw/cm^2)	T (°C)	L↓ (mw/cm^2)
0200	39.8	26.6	40.3
0205	39.6	26.7	40.1
0210	39.8	26.7	40.1
0215	39.9	26.5	40.4
0220	40.6	26.4	41.2
0225	39.9	26.4	40.5
0230	39.9	26.4	40.2
0235	40.1	26.4	40.6
0240	39.9	26.4	40.4
0245	39.8	26.2	40.4
0250	39.9	26.3	40.2
0255	39.9	26.2	40.5
0300	39.9	26.3	40.6
0305	40.2	26.5	40.8
0310	40.0	26.8	40.3
0315	40.3	26.9	41.1
0320	40.4	26.5	41.1
0325	40.3	26.6	40.7
0330	40.8	26.5	41.5
0500	39.2	26.2	40.0
0505	39.4	26.4	40.0
0510	39.0	26.1	39.9
0515	38.9	26.2	39.8
0520	39.3	26.4	40.0
0525	39.6	26.3	39.9
0530	39.6	26.0	40.3
0535	39.7	26.0	40.5
0540	40.0	26.2	40.4
0545	39.9	26.2	40.4
0550	39.8	26.2	40.1
0555	39.8	26.2	40.1
0600	39.4	26.0	40.1
0605	39.9	26.3	40.3
0610	39.7	26.1	40.1
0615	40.1	26.2	40.5

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