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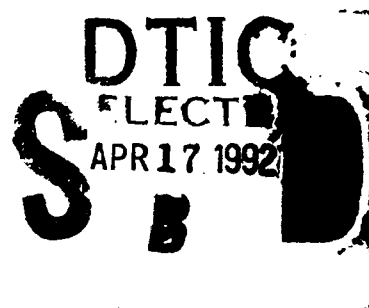
**OCEAN SUN GLINT IN THE 3 TO 5 MICRON
REGION AND ITS RADIANCE VARIATION
WITH OFF GLINT SUN ANGLE
AND SENSOR ELEVATION**

BY MONTE S. KaelBERER

RESEARCH AND TECHNOLOGY DEPARTMENT

9 MARCH 1990

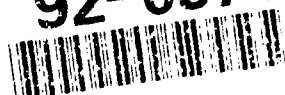
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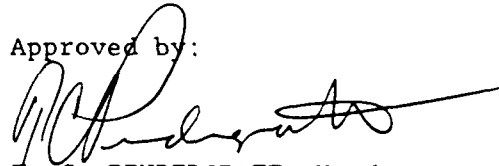
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FOREWORD

This report describes analyses of sun glint data collected with the Background Measurement and Analysis Program (BMAP) sensor during the mid 1980's. All available data taken with the BMAP infrared radiometric sensor operating in the 3 to 5 micron region was compiled and then searched for appropriate sun glint scenes. Average and standard deviation statistics were used to find the radiance variation due to different off glint axis angles, sensor elevations, and sun elevations.

This research analysis task was done while on a rotational assignment from the Electro-optics Branch, R42, to the Radar Engineering Branch, F43. The author would like to thank Mr. D. G. Kirkpatrick, F43, for his help and supervision throughout the rotation period.

Approved by:



T. C. PENDERGRAFT, Head
Electronics Systems Department

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INTRODUCTION

Infrared sensors operating in the 3 to 5 micron range are very sensitive to sun glint reflections from water surfaces. The Background Measurement and Analysis Program (BMAP) has a collection of sun glint scenes from field tests done in the period 1983-1986. The collection covers parameters affecting sun glint such as geographic location, off glitter axis angle, sensor elevation, and sun elevation. This report will compare different scenes in order to determine the average and standard deviation radiance variation with off glint axis angle, sensor elevation, and sun elevation.

Sun glint has many parameters that can affect its radiance and the size of its pattern. Some examples are sea slope, off glint angle, sun elevation, sensor height above the water, sensor depression angle, atmospheric absorption and scattering, wind speed, clouds, and water and air temperatures. Figure 1 is an illustration of the three parameters that will be examined in this report, i.e., off glint angle, sensor elevation, and sun elevation. The sea slope plays a major role in sun glint formation but, unfortunately, the sea states are not known for any of the tests. Wave rider information was available for data collected at Wallops Island, but it was not processed.

It is of interest to know at what rate sun glint intensity falls off as you move away from the glint axis and how it behaves as you decrease the elevation angle of the sensor. In order to quantify this behavior, four types of plots will be shown. The average radiance will be plotted against off glint angle and then sensor elevation. Also, the radiance standard deviation versus off glint angle and sensor elevation will be graphed.

DEFINITIONS

CHANNEL/DETECTOR: one of the 16 detectors in the focal plane array.

GLINT AXIS: axis formed by line between sensor and sun.

HORIZONTAL SCAN: normal scanning mode; scans along azimuth.

OFF GLINT ANGLE

OR GLINT ANGLE: angle measured at sensor from glint axis to sensor azimuth.

RUN: set of closely related scenes in which one parameter is incrementally changed, for example, sensor elevation.

SAMPLE: one value from one detector.

SCAN: image formed by one pass of the scanning mirror, usually a 16 by 371 array of points.

SCENE: collection of scans in which continuous data was taken.

SENSOR ELEVATION: angle sensor is above a perpendicular to its forward face when the sensor is level. Zero degrees is usually slightly above the horizon.

VERTICAL SCAN: scan in which sensor has been tipped on its side and scans along elevation.

FIELD SITES

Sun glint data was available from three different geographic locations. Most of the data available was taken at Wallops Island, Virginia. The duration of the test was from May 27 through June 5, 1986. The infrared sensor was placed on a rooftop at a height of 19 meters and 180 meters from the beach. The coordinates were 37 degrees 50 minutes north and 75 degrees 29 minutes west.

Fort Walton Beach, Florida, was another site at which some sun glint data was taken from May 29 through June 7, 1985. A fifth-floor condominium on the beach was rented, and the sensor was operated from the balcony. The coordinates were approximately 30 degrees 24 minutes north and 86 degrees 37 minutes west.

The BMAP sensor attended the NATO trials at Toulon, France, which were held from October 9 through October 16, 1985. The sensor was placed on a 45 meter cliff which faced in the direction of 240 degrees east of north and overlooked the Mediterranean.

RAYTHEON/BMAP SENSOR

The BMAP sensor is an infrared (IR) scanning radiometer built and owned by the Raytheon Corporation of Bedford, Massachusetts. It uses two, 16 detector focal plane arrays (FPA). One FPA is for midwave IR operation and the other for longwave. The 16 detectors, along with the scanning mirror, have a total field of view (TFOV) of 2.5 degrees in azimuth by 0.3 degrees in elevation. This TFOV includes the scanning of internal reference sources. Each detector has an instantaneous field of view (IFOV) of 0.3 milliradians in

azimuth and elevation. The noise equivalent irradiance (NEI) of the sensor is 1.5×10^{-14} watts cm^{-2} in the midwave and 2.0×10^{-13} watts cm^{-2} in the longwave.

The midwave filter had a full-width, half-maximum (FWHM) bandpass of 3.9 microns to 4.8 microns. The FWHM points for the longwave filter are 7.6 microns to 11.4 microns. Longwave data is not used in this report. During operation of the sensor, data can be collected only when the scanning mirror travels in one direction. No data is collected on the mirror's return. The mirror makes one scan and its return in 0.5 seconds (1 period). The most common mode of data collection records alternating scans of midwave and longwave data. Most of the scans in this report used the alternating mode of operation which made the midwave scans of a scene one second apart. The sampling rate of the detectors is such that an IFOV is sampled 3.4 times. In a typical scan there are 360 to 370 samples giving an image azimuth of about 2.0 degrees.

At Wallops Island the sensor was tipped on its side causing the scanning mirror to scan in elevation rather than azimuth. The TFOV is then 2.0 degrees in elevation and 0.3 degrees in azimuth. The sun glint average and standard deviation for this type of scene (vertical scan) will be plotted separately from the horizontal scenes.

DATA LIMITATIONS

Raw BMAP data was processed by the Naval Research Laboratory (NRL), Washington, DC. Their task was to calibrate the data, correct bit errors, flag dead detectors, add a NATO header onto each scan, and put the data onto 9-track computer tapes. The NRL correction algorithm works well on single-sample errors but is limited in its ability to correct multiple-sample errors. Of the three field sites, only Fort Walton Beach had single or multiple-sample errors, and each scan had, on average, 100 errors. Because there are approximately 5900 samples in a scan and because each point source is over-sampled 3.4 times, the errors should not seriously affect data statistics.

An unfortunate problem occurred at both Wallops Island and Toulon. Within 2 degrees off of the glint axis most of the data was saturated. Even at a 5-degree off glint angle, some samples were saturated. These saturated scenes were not used. Saturation radiance for the sensor in the midwave IR was approximately $4.2 \text{ W m}^{-2} \text{ sr}^{-1}$ (apparent temperature of 68 degrees Celsius). The scenes from Toulon, France, contained two dead detectors, numbers two and six, in the midwave FPA. In all calculations involving these scenes, the dead channels were not used. Some scenes had boats and other objects in them, in which case the statistics for those scenes were calculated by omitting those sections containing the objects.

Data points are stored on tape as 2-byte integers. The integers are converted to radiance by factors given in the NATO headers of each file. The factors in some of the Toulon data were recognized as incorrect. Since the header factors in the Toulon data that were not corrupted were equal to those

used for Fort Walton Beach and Wallops Island, they were also used for all the Toulon data. During the Wallops tests the time code signal used to mark the data sometimes became partially scrambled making some of the scans untraceable. Fortunately, the scenes used in this report had their time codes intact, and identification was not a problem. A factor shrinking the pool of available scenes was the limited amount of data that had been requested from NRL. While many different scenes of sun glint had been taken at each field site, only a fraction had been reduced to the 9-track tape format. Additional raw data of sun glint could not be acquired because NRL no longer reduces BMAP data.

REDUCTION METHOD

For horizontal scanning, the scan was divided into three sections of equal size. The section sizes were chosen to have an approximately square field of view of 0.3 degrees to a side. The average and standard deviation radiance was then found for each section. All sections used channels 1 to 16. The first section used samples 1 to 50, the second section, samples 155 to 205, and the third section, samples 310 to 360. Vertical scans were divided differently. Each section still used 16 channels but now the sample widths were 1 to 50, 51 to 100, 101 to 150, and so on. Figure 2 shows the partitioning of the sections for both horizontal and vertical scans.

Nineteen (19) different scenes were examined. Each scene had roughly 5 to 10 scans so a total of about 140 scans was processed. Many scenes were actually parts of runs. There were four runs in the compiled data, and all were at Wallops Island. The scenes from Toulon and Fort Walton Beach were not associated with any runs. Two runs were scenes with horizontal scanning, and two runs were scenes with vertical scanning. The first horizontal scanning run held the sensor at a 5-degree, off glint angle and then varied the sensor elevation from 0 to -3 degrees in 1-degree increments. The second horizontal run did the same but at an off glint angle of 10 degrees. Each vertical scanning run held the sensor elevation at 0 degrees. One of the vertical runs looked at off glint angles of 2, 5, 10, and 15 degrees while the other run looked at just 2, 5, and 10 degrees and at a different sun elevation than the first. As mentioned before, detector saturation occurred in some scenes so these runs cannot be shown in their entirety. Table 1 shows what scenes were used and their associated parameters.

With horizontal scanning a sensor elevation of 0 degrees has the horizon present in the upper channels. The averages and standard deviations for these sections were found using channels 13 through 16 which were always below the horizon. Vertical scans always contained the horizon, in which case only the sections below the horizon were used.

Tables 2 and 3 are summaries of each scene's statistics. The average and standard deviation radiance for each section in a scan was calculated and compared with the other scans from that scene. Then the minimum and maximum statistic was found for each section within the scene. The range (maximum minus the minimum) within a section was typically very small as is clear in

Tables 2 and 3. The midrange $((\text{maximum} + \text{minimum})/2)$ rather than the scene section average was used because the range was small and it saved a large amount of computation time. For example, the Wallops scene with a glint angle of 5 degrees and sensor elevation of -1 degrees had five scans with radiance averages for section one of 1.38, 1.38, 1.36, 1.33, and 1.31 $\text{W m}^{-2} \text{sr}^{-1}$. For this scene the midrange and the average of the section averages are the same, 1.35 $\text{W m}^{-2} \text{sr}^{-1}$.

Note that horizontal scans have 3 sections. Because the FOV is approximately 2 degrees, the middle section is taken to be the off glint angle of the scene, and the right and left sections will be one plus and minus the off glint angle respectively. The actual offset is closer to plus and minus 0.83 degrees but will be shown as 1 degree in the figures. The sensor elevation for a vertical scan was determined by letting the section with the horizon be at 0 degrees and the sensor elevation for each lower section be decreased by 0.33 degrees.

ANALYSIS

Figures 3 through 10 plot the average radiance and standard deviation radiance against the off glint angle and the sensor elevation. The legend in each figure shows the relation between a point and its associated scene parameters such as location and sun elevation. The average and standard deviation radiance were taken from the midrange values of Tables 2 and 3. Table 4 is a temperature to radiance conversion chart and shows the radiance needed between 3.8 to 4.9 microns to produce the equivalent blackbody temperature. The table was calculated by numerically integrating Planck's radiation law between the appropriate limits. Table 4 can be used along with Figures 3, 5, 7, and 9 to convert the average radiance values to apparent temperature. Table 5 gives the radiance needed to produce a 1 Celsius degree change in temperature for several different temperatures and was calculated by numerically integrating the partial temperature derivative of Planck's radiation law between 3.8 and 4.9 microns. Table 5 can be used with Figures 4, 6, 8, and 10 to get a rough estimate of the standard deviation radiance in terms of Celsius degrees.

Figure 3 plots the average radiance of the horizontal scanning scenes against the off glint angle. Notice the decrease of the radiance between off glint angles of 4 to 6 degrees while at off glint angles of 9 to 11 degrees there is little or no decrease. Because of the saturation of the data at Wallops, there are no points from Wallops at a 2-degree off glint angle, but as mentioned earlier in this report, the saturation occurred at about 4.2 $\text{W m}^{-2} \text{sr}^{-1}$ which would show a steep decline in the radiance in going from a 2 degree to a 5 degree off glint angle. Also notice that the radiance increases with decreasing sensor elevation for Wallops data at 4, 5, and 6 degrees off glint angles. The Toulon points (diamond and x symbols) stand out because they do not have a radiance as high as the saturated data at Wallops for similar off glint angles, and their radiance does not decrease with an increasing off glint angle. This could be caused by the much greater sensor height at Toulon as compared to the other sites, or it might be caused

by different sea states, meteorological conditions, or the higher sun elevation. The Fort Walton Beach points with symbol "2" also stand out because their radiance is different from Wallops data. The most likely explanation is that the ambient temperature at Fort Walton Beach, or even the water temperature, was higher than at Wallops and therefore raised the radiance level above that of the Wallops data.

Figure 4 plots the average radiance of the vertical scanning scenes against the off glint angle. The x and y axis scales have been kept the same as in Figure 3 so that comparisons between figures can be made easily. As in Figure 3, there are points excluded at an off glint angle of 2 degrees because of saturation, and there is a noticeable decrease in the radiance with increasing off glint angle. If points of the same symbol are connected by an imaginary line, the slope of the line would be positively increasing from a negative value towards zero.

Figure 5 is a plot of the standard deviation radiance versus the off glint angle for horizontal scanning scenes. As was the case for the average radiance, the standard deviation radiance decreases with increasing off glint angle up to an off glint angle of 9 degrees at which point the decrease stops. The Wallops data between off glint angles of 4 and 6 degrees shows a decreasing standard deviation with decreasing elevation angle. The Toulon points (diamond and x symbols) have a very low standard deviation which indicates that there was either very little glint or a large patch of constant glint. Because of the subdued radiance values of the Toulon points in Figure 3, there was probably very little glint present in the scene. As before, the saturated data could not be shown.

Figure 6 is a plot of the standard deviation radiance versus the off glint angle for vertical scanning scenes and has the same x and y scales as Figure 5. The standard deviation again decreases with increasing off glint angle. Notice that the data for a sun elevation of 33 degrees (triangle, diamond, and x symbols) has a lower standard deviation than data with a 20 degree sun elevation, and that the 33 degree sun elevation data is quite linear across off glint angles of 2 to 15 degrees.

Figure 7 plots the average radiance against the sensor elevation for horizontal scanning scenes. The spread of the data in this figure can be attributed to the different off glint angles of the points. For example, the plus symbol radiance (off glint angle of 10 degrees) does not seem to change with sensor elevation. However, Figure 3 made it clear that at an off glint angle of 10 degrees there was little glint in the scene. Likewise, the "1" symbols at each sensor elevation come from different off glint angles which explains the spread of the symbols at each of the sensor elevations. The "1" symbols do show a decreasing radiance for an increasing sensor elevation which means the glint pattern was more intense at lower sensor elevations.

Figure 8 plots the average radiance against the sensor elevation for vertical scanning scenes. The y axis but not the x axis has been kept the same as in Figure 7. The separation of the data into two major areas is caused by the different off glint angles of the higher radiance data (less than a 6 degree off glint angle) and the lower radiance data (greater than a 6 degree off glint angle). No decrease in the radiance with increasing sensor

elevation was expected in the 10 degree off glint angle data because there is little glint at this angle, but even for data at the 5 degree off glint angle the radiance change is small. As seen in Figure 7, because the radiance decreases more slowly at higher elevation angles, the small change in radiance is caused by the relatively high elevation angle of 1 degree and the narrow range of the elevation (-0.33 to -1.33 degrees).

Figure 9 plots the standard deviation radiance against the sensor elevation for horizontal scanning scenes. Only the Wallops data at off glint angles around 5 degrees show any decrease in the standard deviation with increasing sensor elevation. The rest of the data has low standard deviation values because there was little or no glint in the scenes. In Figure 10, where the standard deviation radiance has been plotted against the sensor elevation for vertical scanning scenes, the standard deviation decreases with increasing sensor elevation for all the data except the "x" and box symbols. It is not known why there is a dip in the "x" symbol standard deviation at a -1.3 sensor elevation. It might have been caused by a cloud shadow or a change in the water structure. Note that the y axis has the same scale as Figure 9.

Other statistics such as skewness, kurtosis, histograms, and distribution fits were also calculated. In brief, the skewness for all scenes ranged from 0.1 to 10 and was always positive or skewed to the right. Figure 11 is a histogram of a Wallops Island scene at a 5 degree off glint angle, minus 3 degree sensor elevation, and 25 degree sun elevation. The skewness was large, but the actual calculated value was only 1.2 because the 6 or 7 large spikes at the higher radiances significantly affected the average radiance. For this scene the average radiance was $1.84 \text{ W m}^{-2} \text{ sr}^{-1}$ and the standard deviation was $0.72 \text{ W m}^{-2} \text{ sr}^{-1}$. The histogram is not gaussian because the distribution is essentially bimodal. The water radiance dominates the lower radiances while the sun glint contributes to the upper radiances. A total of 5776 samples is represented in the histogram, and of that total 38 samples had values above $4.2 \text{ W m}^{-2} \text{ sr}^{-1}$ and could be the result of saturation of the sensor.

Figure 12 is a histogram of a Toulon scene with a 2-degree off glint angle, -5 degree sensor elevation, and 33-degree sun elevation. In contrast to Figure 11, the skewness, 0.5, average radiance, $1.72 \text{ W m}^{-2} \text{ sr}^{-1}$, and standard deviation, $0.036 \text{ W m}^{-2} \text{ sr}^{-1}$, for this scene were much lower. A Gaussian curve has been fit to the data to emphasize the skewness. The mean and standard deviation Gaussian parameters of $1.71 \text{ W m}^{-2} \text{ sr}^{-1}$ and $0.022 \text{ W m}^{-2} \text{ sr}^{-1}$ respectively were chosen to match the left side (lower radiances) of the IR data. Both curves are normalized so the area under the Gaussian curve equals one and the sum of the y axis values for the IR data equals one. Kurtosis values among all the scenes were typically -1 to +1.

CONCLUSIONS AND RECOMMENDATIONS

As seen by looking at sun glint with the eye, the glint intensity falls off as you move away from the glint axis. For the scenes used in this report,

the average and standard deviation IR radiances are also highly dependent on the off glint angle and are quite subdued for an off glint angle of 10 degrees or more. There are, however, large differences between different locations having similar sun and sensor elevations. Parameters, such as sensor height and sea slope, are assumed to cause much of the discrepancy. The average radiance showed a weak dependence on the sensor elevation while the standard deviation radiance usually increased with lower elevation angles and showed a strong dependence. Exceptions to this are, again, probably caused by different meteorological conditions and different sensor parameters such as sensor height. Most importantly, this report has provided a summary of the available sun glint which can be stored as part of a database and be compared with future data.

Further investigation of sun glint should include the 8 to 12 micron range of the IR spectrum of which there is available BMAP data. There is also data from the Infrared Analysis, Measurement, and Modeling Program (IRAMMP) that contains sun glint in both the 3 to 5 micron and 8 to 12 micron range with a higher resolution. The characterization of the sun glint distribution functions could be compared with the log normal or Weibull distributions to check for skewness, and curve fits showing the rate of intensity decrease could be done using sliding averages. In any future analysis, it would be very desirable to have more of the meteorological parameters known and compared.

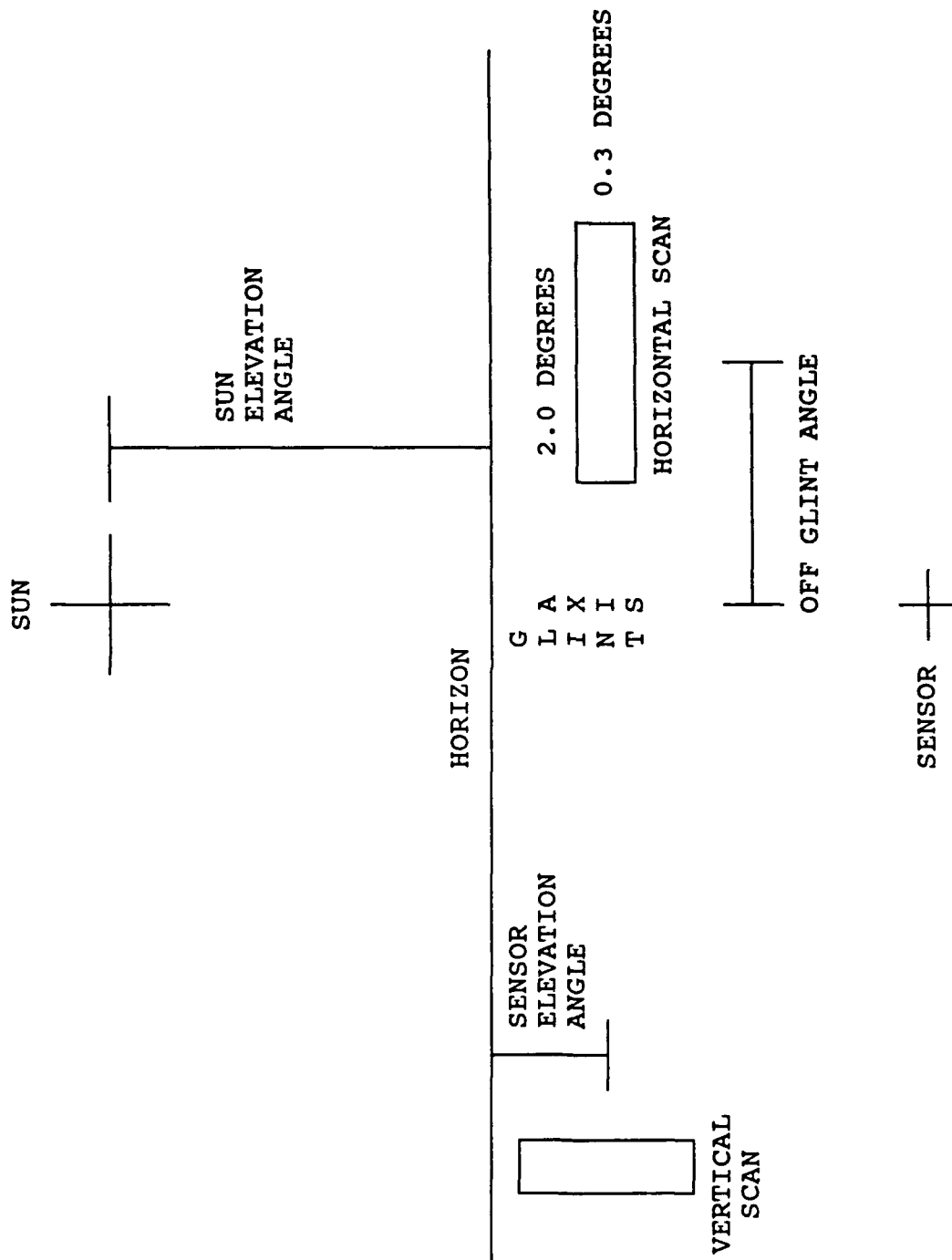


FIGURE 1. SCENE DESCRIPTION

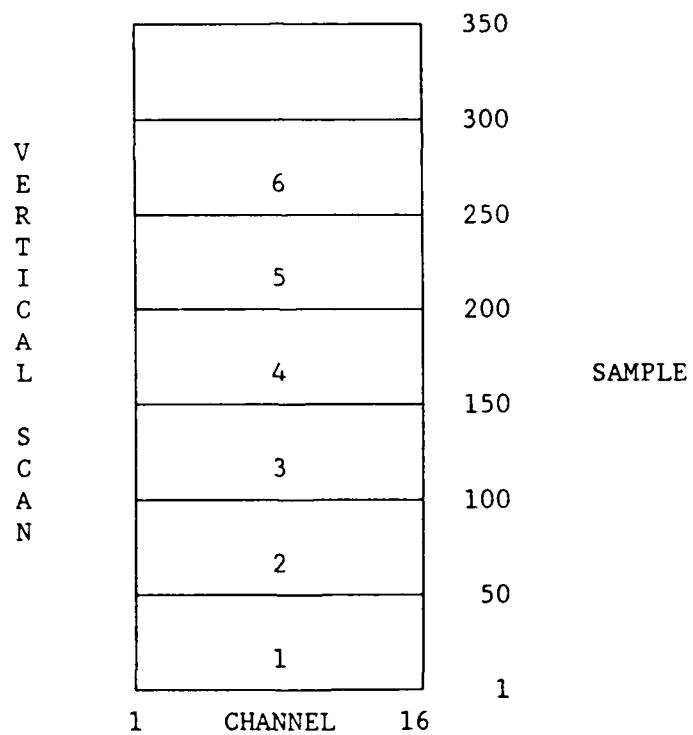
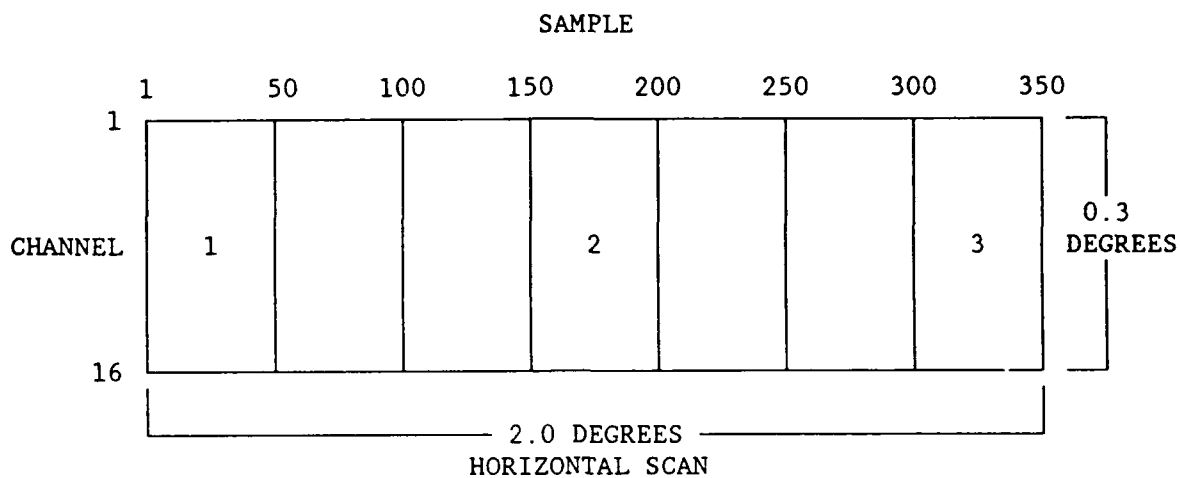
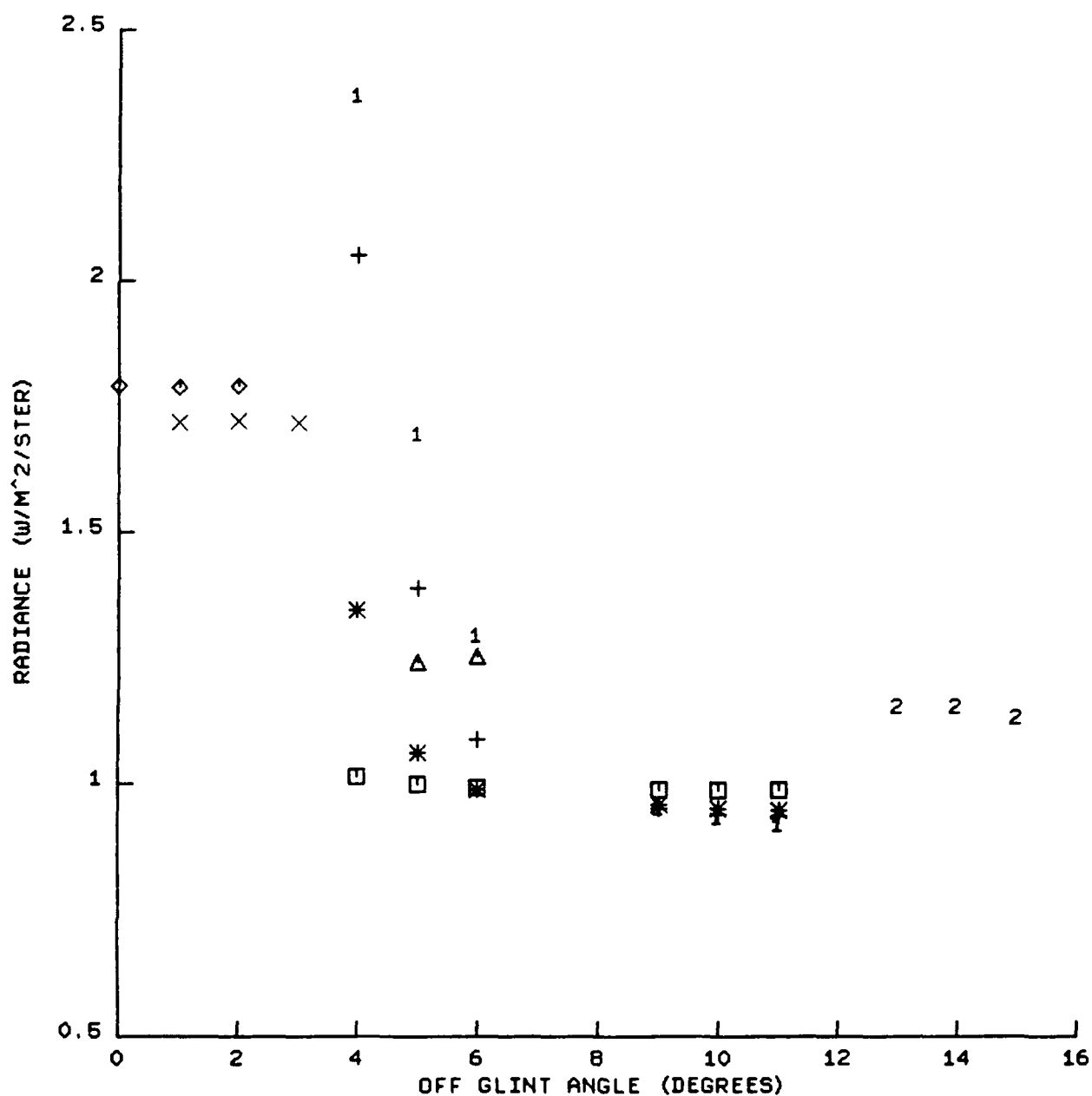
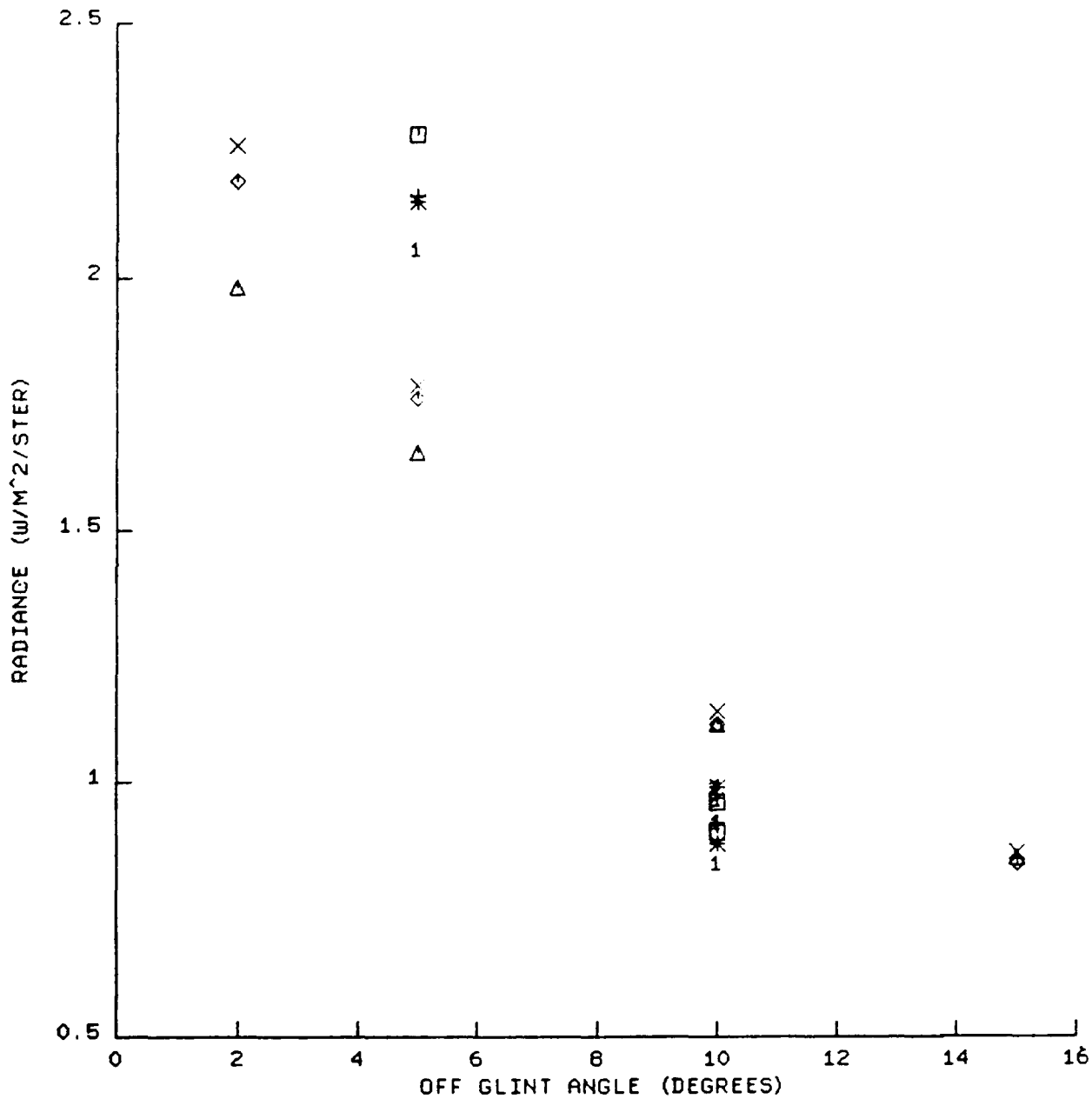


FIGURE 2. HORIZONTAL AND VERTICAL SCAN SECTIONS



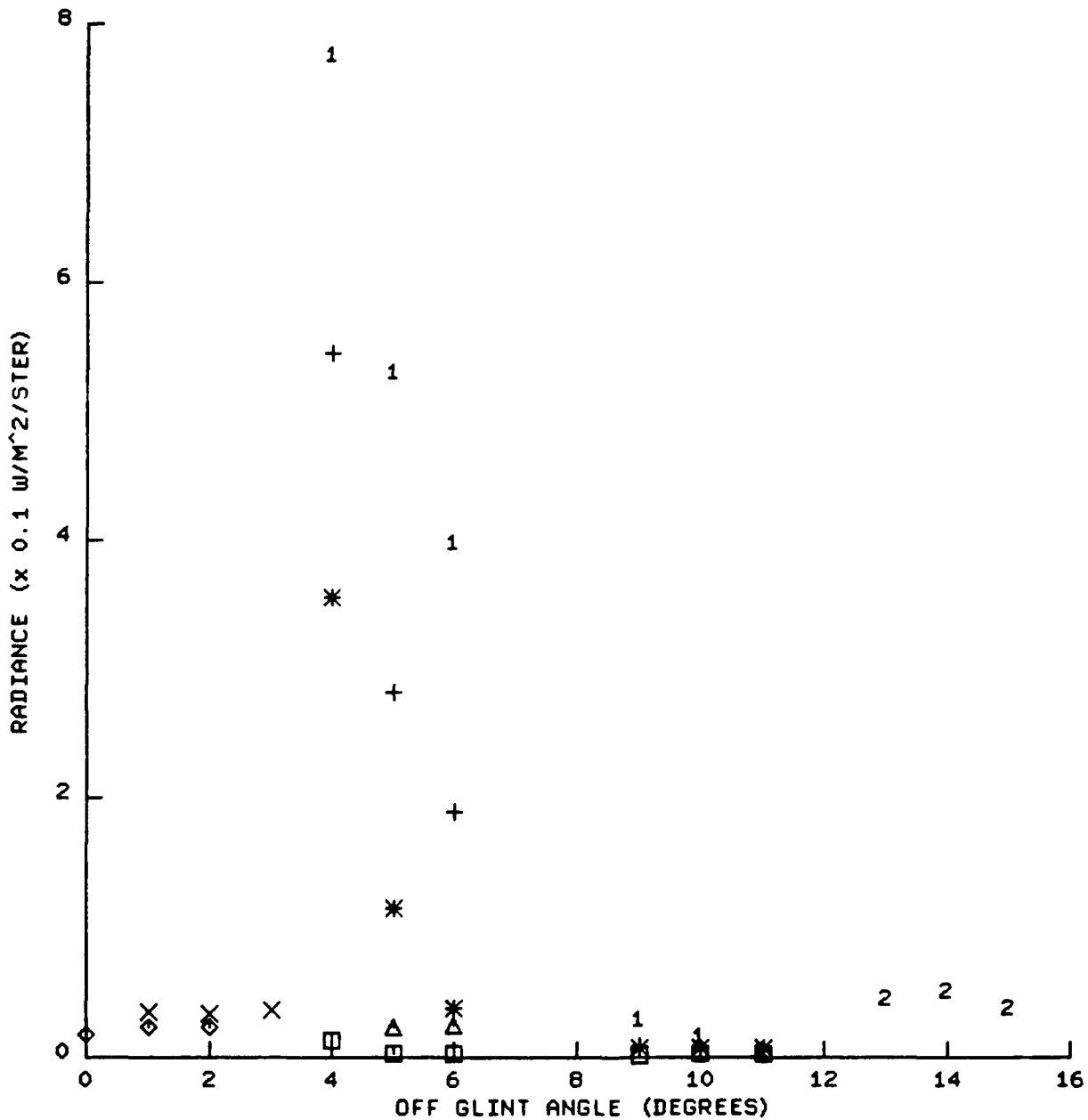
LEGEND: (SYMBOL, LOCATION, SENSOR ELEVATION, SUN ELEVATION)
 1-----WALLOPS, -3, 25; PLUS-----WALLOPS, -2, 24
 ASTERISK-WALLOPS, -1, 22; BOX-----WALLOPS, 0, 21
 X-----TOULON, -5, 33; TRIANGLE-FORT WALTON BEACH, -2, 58
 DIAMOND--TOULON, -2, 30; 2-----FORT WALTON BEACH, -1, 61

FIGURE 3. AVERAGE RADIANCE VERSUS GLINT ANGLE FOR HORIZONTAL SCANS



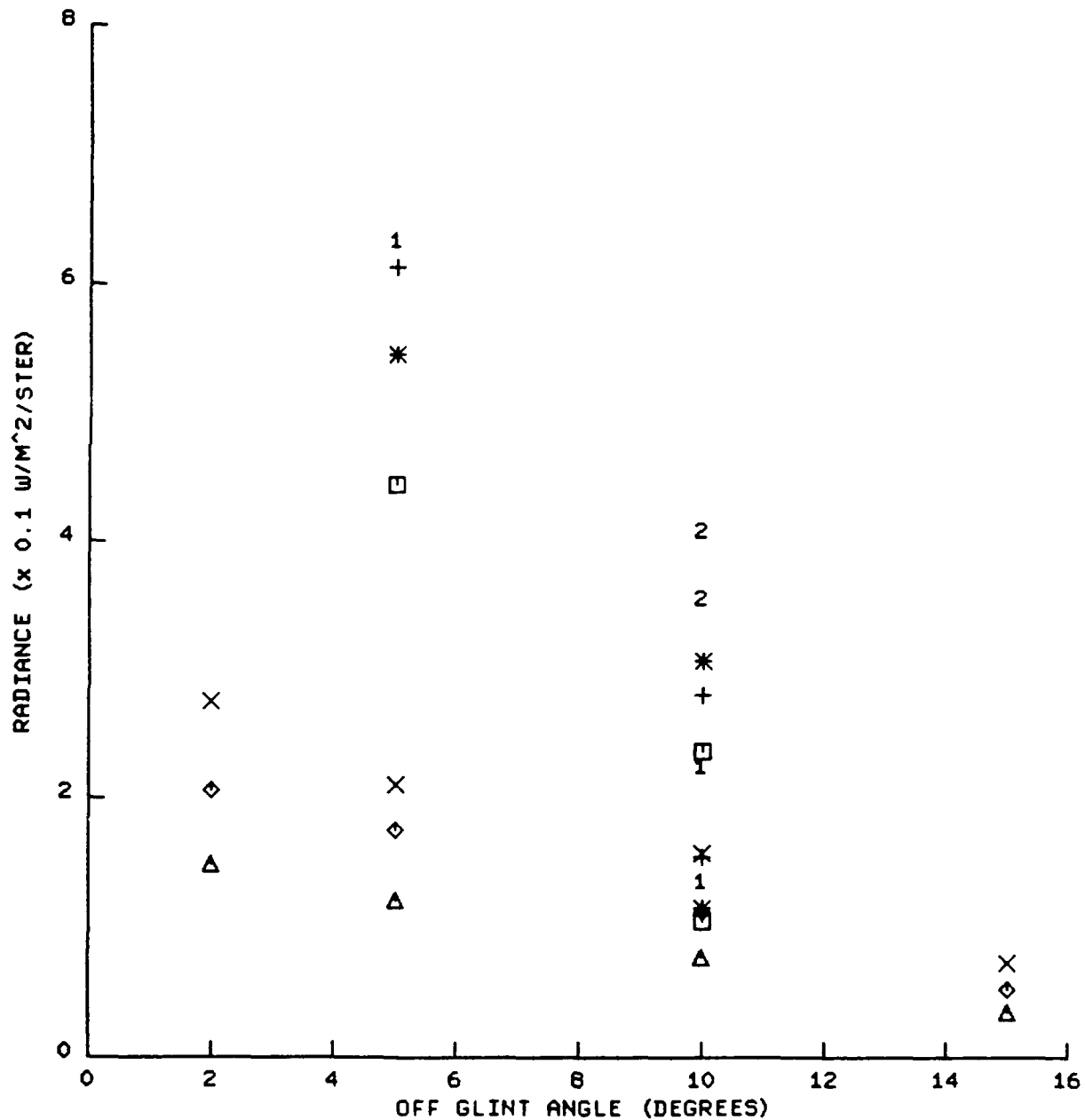
LEGEND: (SYMBOL, LOCATION, SENSOR ELEVATION, SUN ELEVATION)
 1-----WALLOPS, -1.3, 20; PLUS-----WALLOPS, -1.0, 20
 ASTERICK-WALLOPS, -0.66, 20; BOX-----WALLOPS, -0.33, 20
 X-----WALLOPS, -1.0, 33; DIAMOND-WALLOPS, -0.66, 33
 TRIANGLE-WALLOPS, -0.33, 33; 2-----WALLOPS, <-1.33, 20

FIGURE 4. AVERAGE RADIANCE VERSUS GLINT ANGLE FOR VERTICAL SCANS



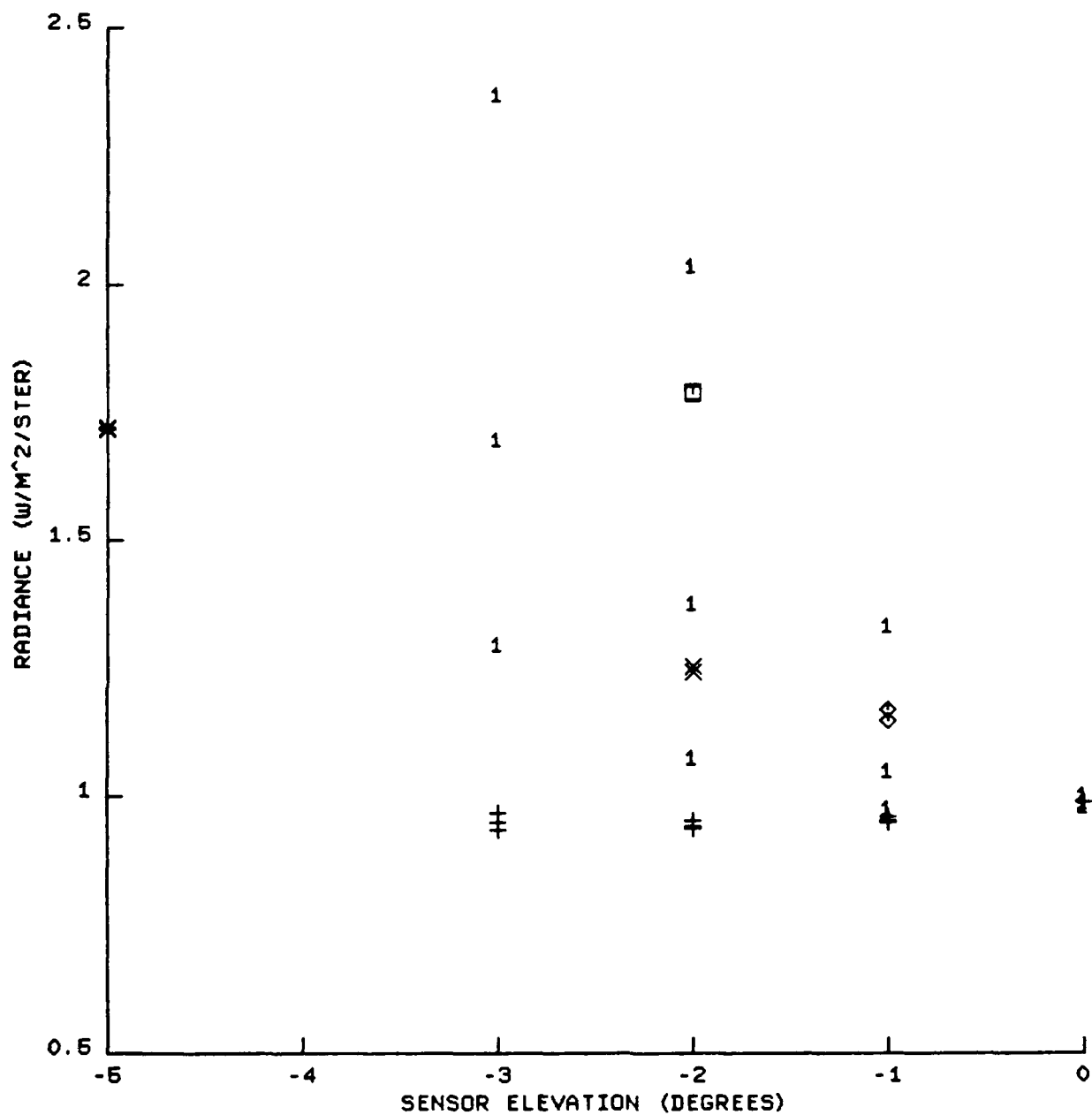
LEGEND: (SYMBOL, LOCATION, SENSOR ELEVATION, SUN ELEVATION)
 1-----WALLOPS, -3, 25; PLUS-----WALLOPS, -2, 24
 ASTERISK-WALLOPS, -1, 22; BOX-----WALLOPS, 0, 21
 X-----TOULON, -5, 33; TRIANGLE-FORT WALTON BEACH, -2, 58
 DIAMOND--TOULON, -2, 30; 2-----FORT WALTON BEACH, -1, 61

FIGURE 5. STANDARD DEVIATION RADIANCE VERSUS GLINT ANGLE FOR HORIZONTAL SCANS



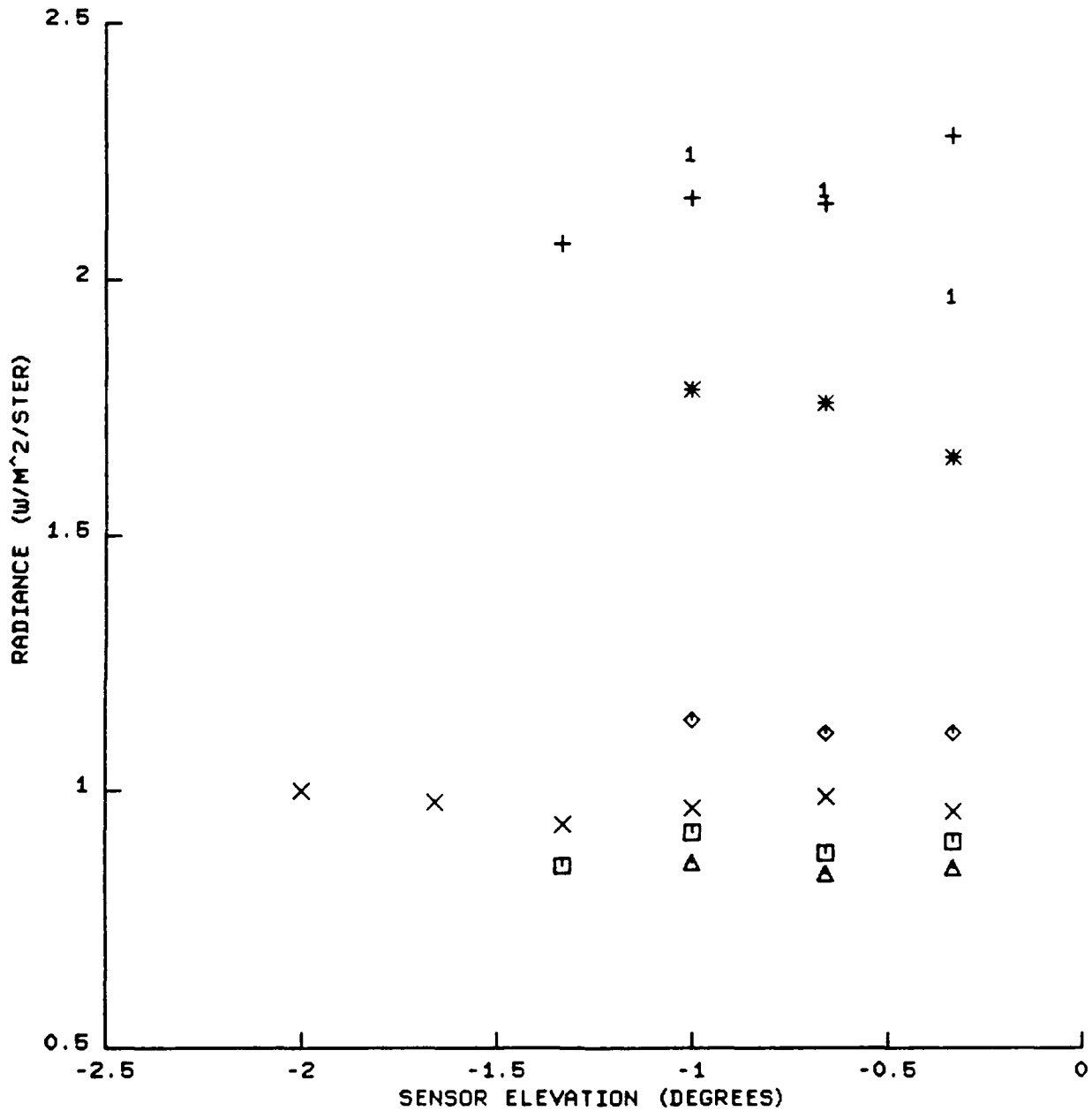
LEGEND: (SYMBOL, LOCATION, SENSOR ELEVATION, SUN ELEVATION)
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 ASTERICK-WALLOPS, -0.66, 20; BOX-----WALLOPS, -0.33, 20
 X-----WALLOPS, -1.0, 33; DIAMOND-WALLOPS, -0.66, 33
 TRIANGLE-WALLOPS, -0.33, 33; 2-----WALLOPS, <-1.33, 20

FIGURE 6. STANDARD DEVIATION RADIANCE VERSUS GLINT ANGLE FOR VERTICAL SCANS



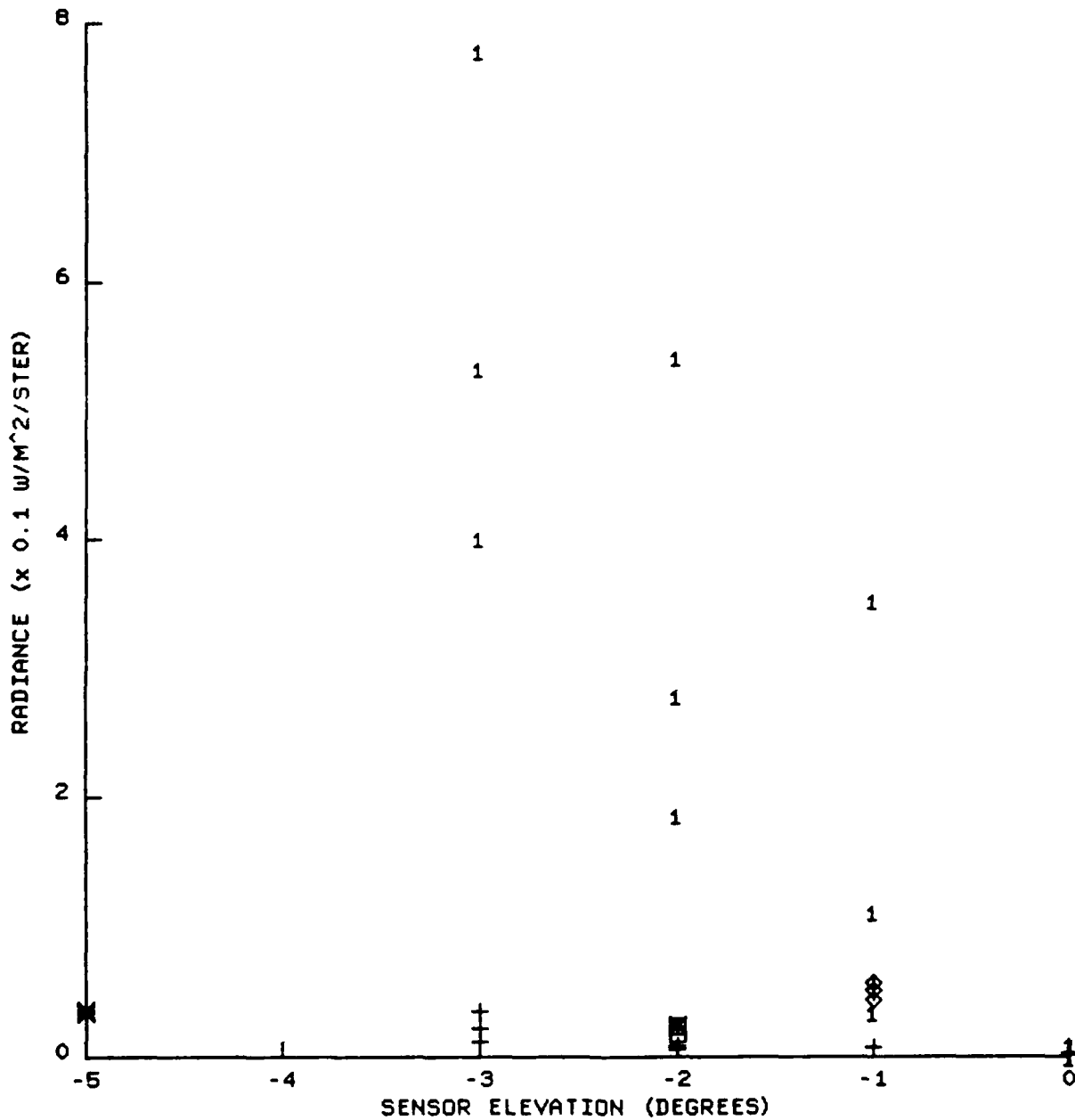
LEGEND: (SYMBOL, LOCATION, OFF GLINT ANGLE, SUN ELEVATION)
 1-----WALLOPS, 5, 20-25; PLUS-----WALLOPS, 10, 22-26
 ASTERISK-TOULON, 2, 33; X-----FORT WALTON BEACH, 6, 58
 BOX-----TOULON, 1, 30; DIAMOND-FORT WALTON BEACH, 14, 61

FIGURE 7. AVERAGE RADIANCE VERSUS ELEVATION ANGLE FOR HORIZONTAL SCANS



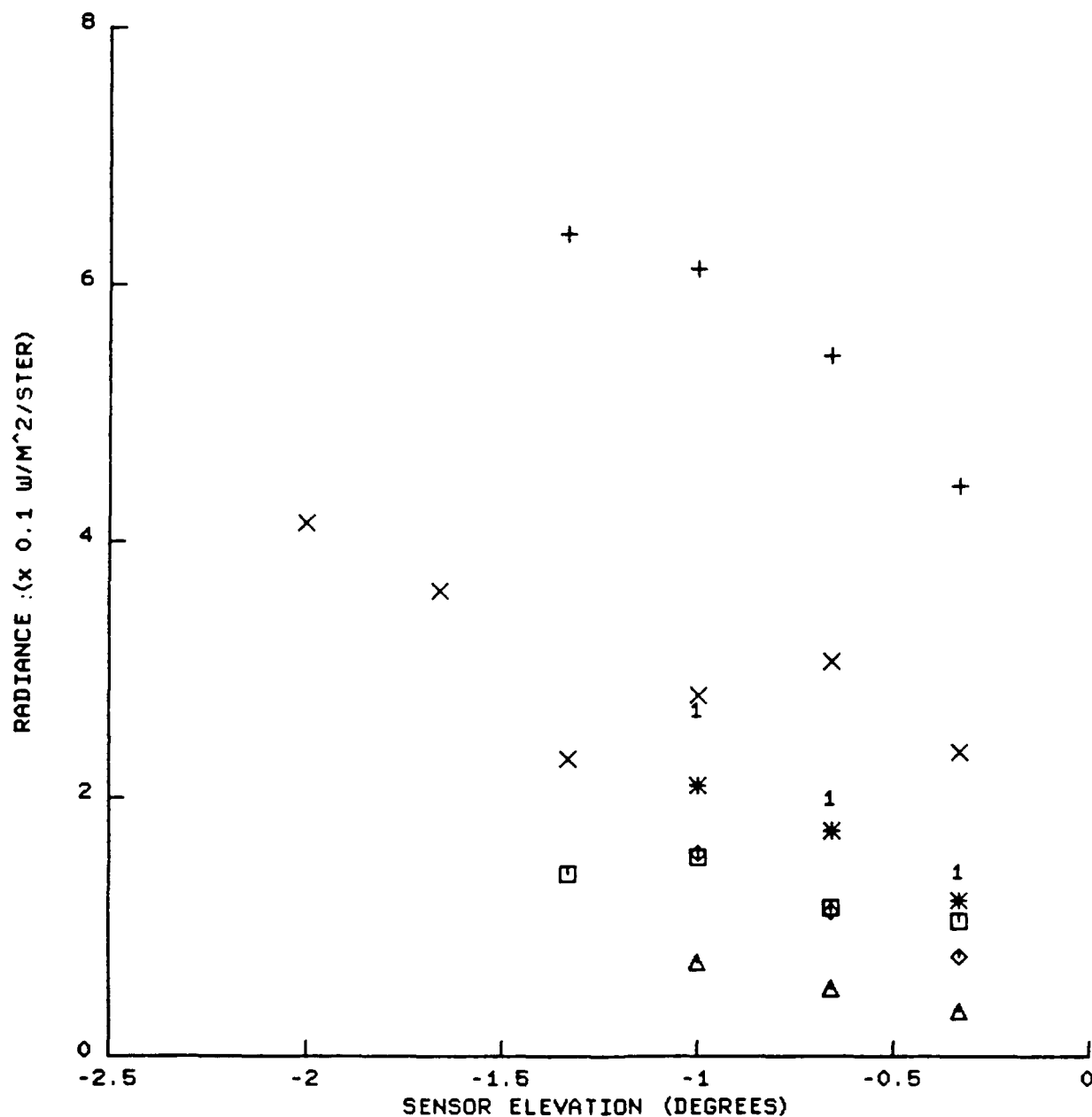
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 ASTERISK-WALLOPS, 5, 33; BOX-----WALLOPS, 10, 20
 X-----WALLOPS, 10, 21; DIAMOND-WALLOPS, 10, 33
 TRIANGLE-WALLOPS, 15, 34

FIGURE 8. AVERAGE RADIANCE VERSUS ELEVATION ANGLE FOR VERTICAL SCANS



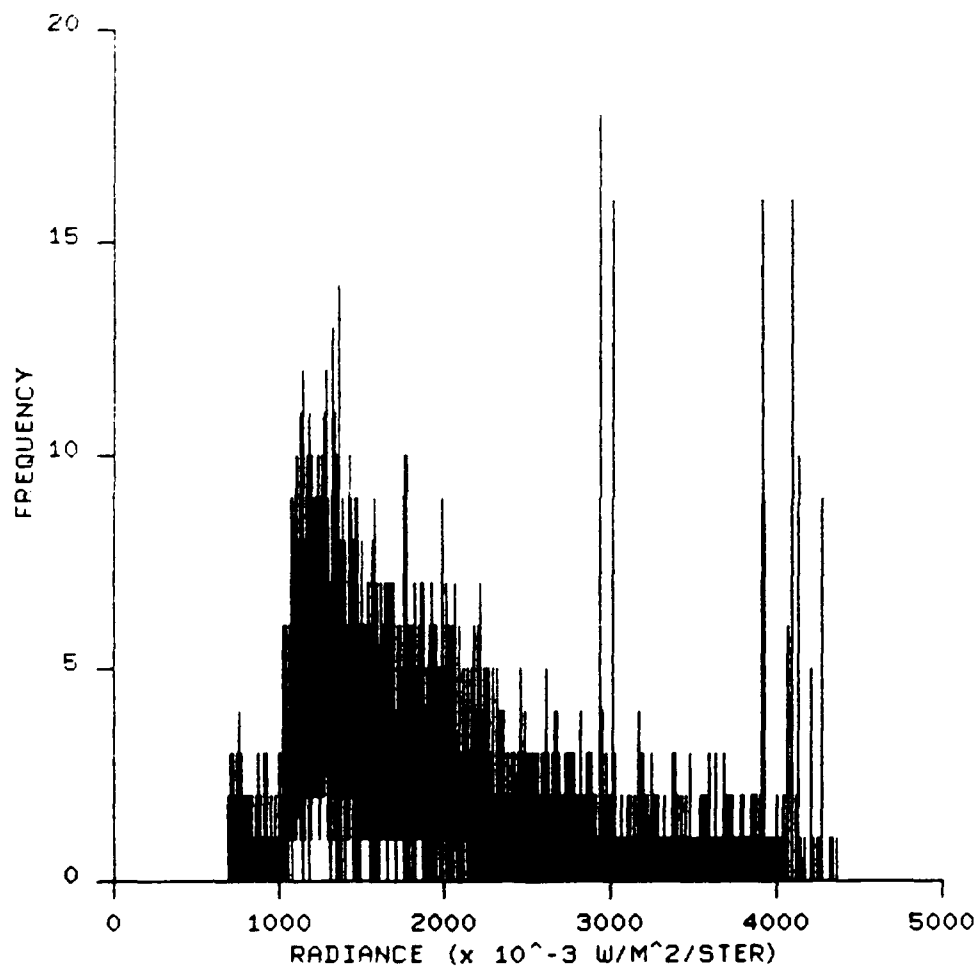
LEGEND: (SYMBOL, LOCATION, OFF GLINT ANGLE, SUN ELEVATION)
 1-----WALLOPS, 5, 20-25; PLUS----WALLOPS, 10, 22-26
 ASTERISK--TOULON, 2, 33; X-----FORT WALTON BEACH, 6, 58
 BOX-----TOULON, 1, 30; DIAMOND--FORT WALTON BEACH, 14, 61

FIGURE 9. STANDARD DEVIATION RADIANCE VERSUS ELEVATION ANGLE FOR HORIZONTAL SCANS



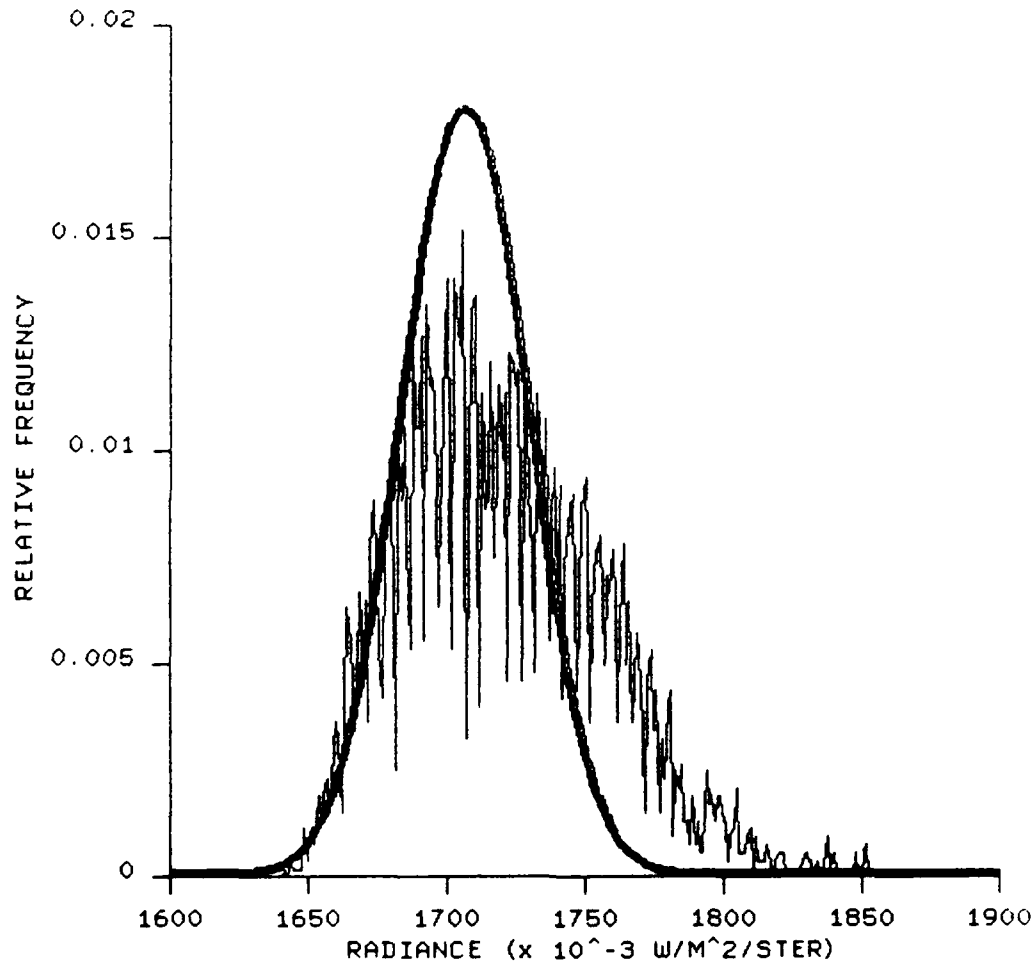
LEGEND: (SYMBOL, LOCATION, OFF GLINT ANGLE, SUN ELEVATION)
 1-----WALLOPS, 2, 33; PLUS----WALLOPS, 5, 20
 ASTERISK-WALLOPS, 5, 33; BOX----WALLOPS, 10, 20
 X-----WALLOPS, 10, 21; DIAMOND-WALLOPS, 10, 33
 TRIANGLE-WALLOPS, 15, 34

FIGURE 10. STANDARD DEVIATION RADIANCE VERSUS ELEVATION ANGLE FOR VERTICAL SCANS



WALLOPS ISLAND, VA
OFF GLINT ANGLE IS 5 DEGREES
SENSOR ELEVATION IS -3 DEGREES
SUN ELEVATION IS 26 DEGREES

FIGURE 11. HISTOGRAM, HIGH SKEWNESS



TOULON, FRANCE
 OFF GLINT ANGLE IS 2 DEGREES
 SENSOR ELEVATION IS -5 DEGREES
 SUN ELEVATION IS 33 DEGREES

FIGURE 12. HISTOGRAM, LOW SKEWNESS

TABLE 1. PARAMETERS FOR EACH SCENE

<u>LOCATION</u>	<u>OFF GLINT ANGLE (DEGREES)</u>	<u>SENSOR ELEVATION (DEGREES)</u>	<u>SUN ELEVATION (DEGREES)</u>	<u>HORIZONTAL SCANNING</u>
TOULON	2	-5	33	YES
TOULON	1	-2	30	YES
WALTON	6	-2	58	YES
WALLOPS	5	0	21	YES
WALLOPS	5	-1	22	YES
WALLOPS	5	-2	24	YES
WALLOPS	5	-3	25	YES
WALLOPS	10	0	22	YES
WALLOPS	10	-1	23	YES
WALLOPS	10	-2	24	YES
WALLOPS	10	-3	26	YES
WALTON	14	-1	61	YES
WALLOPS	2	0	33	NO
WALLOPS	5	0	20	NO
WALLOPS	5	0	33	NO
WALLOPS	10	0	20	NO
WALLOPS	10	-1	21	NO
WALLOPS	10	0	33	NO
WALLOPS	15	0	34	NO

TABLE 2. AVERAGE AND STANDARD DEVIATION RADIANCE BY SCENE SECTION (HORIZONTAL SCANS)

LOCATION AND PARAMETERS*	SECTION	MINIMUM, MIDRANGE, AND MAXIMUM AVERAGE RADIANCES ($\text{W m}^{-2} \text{sr}^{-1}$)	MINIMUM, MIDRANGE, AND MAXIMUM STANDARD DEVIATION ($\times 10^{-2} \text{W m}^{-2} \text{sr}^{-1}$)
TOULON 2, -5, 33	1	1.71, 1.72, 1.72	0.31, 0.35, 0.38
	2	1.72, 1.72, 1.73	0.29, 0.33, 0.37
	3	1.71, 1.72, 1.72	0.33, 0.37, 0.41
TOULON 1, -2, 30	1	1.79, 1.79, 1.79	0.17, 0.17, 0.17
	2	1.79, 1.79, 1.79	0.20, 0.23, 0.26
	3	1.79, 1.79, 1.79	0.23, 0.23, 0.23
WALTON 6, -2, 58	1	1.24, 1.25, 1.25	0.20, 0.23, 0.26
	2	1.25, 1.26, 1.26	0.22, 0.25, 0.27
WALLOPS 5, 0, 21	**	1.01, 1.02, 1.02	0.04, 0.12, 0.20
	**	1.00, 1.00, 1.00	0.02, 0.02, 0.03
	**	0.99, 0.99, 0.99	0.02, 0.02, 0.03
WALLOPS 5, -1, 22	1	1.31, 1.35, 1.38	2.61, 3.56, 4.50
	2	1.06, 1.07, 1.07	0.96, 1.16, 1.35
	3	0.98, 0.99, 1.00	0.17, 0.37, 0.57
WALLOPS 5, -2, 24	1	1.95, 2.05, 2.15	4.61, 5.46, 6.31
	2	1.34, 1.39, 1.44	2.22, 2.83, 3.43
	3	1.03, 1.09, 1.15	1.62, 1.90, 2.18

* Parameters are off glint angle, sensor elevation, and sun elevation respectively.

** Section composed only of channels below horizon.

TABLE 2. (CONT.)

LOCATION AND PARAMETERS*	SECTION	MINIMUM, MIDRANGE, AND MAXIMUM AVERAGE RADIANCES ($\text{W m}^{-2} \text{sr}^{-1}$)	MINIMUM, MIDRANGE, AND MAXIMUM STANDARD DEVIATION ($\times 1 \text{ W m}^{-2} \text{sr}^{-1}$)
WALLOPS	1	2.25, 2.39, 2.52	7.11, 7.83, 8.55
5, -3, 25	2	1.57, 1.71, 1.85	4.35, 5.36, 6.37
	3	1.16, 1.31, 1.46	3.03, 4.05, 5.07
WALLOPS	**	0.99, 0.99, 0.99	0.01, 0.02, 0.02
10, 0, 22	**	0.99, 0.99, 0.99	0.02, 0.02, 0.02
	**	0.99, 0.99, 0.99	0.02, 0.02, 0.02
WALLOPS	1	0.96, 0.96, 0.96	0.07, 0.07, 0.07
10, -1, 23	2	0.95, 0.96, 0.96	0.07, 0.07, 0.08
	3	0.95, 0.95, 0.95	0.07, 0.07, 0.07
WALLOPS	1	0.95, 0.95, 0.95	0.06, 0.09, 0.12
10, -2, 24	2	0.94, 0.94, 0.94	0.05, 0.05, 0.06
	3	0.94, 0.94, 0.94	0.06, 0.06, 0.07
WALLOPS	1	0.96, 0.97, 0.98	0.18, 0.34, 0.51
10, -3, 26	2	0.95, 0.95, 0.95	0.18, 0.21, 0.25
	3	0.93, 0.94, 0.94	0.06, 0.11, 0.15
WALTON	1	1.16, 1.17, 1.18	0.42, 0.51, 0.59
14, -1, 61	2	1.16, 1.17, 1.18	0.48, 0.57, 0.66
	3	1.14, 1.15, 1.16	0.35, 0.44, 0.52

* Parameters are off glint angle, sensor elevation, and sun elevation respectively.

** Section composed only of channels below horizon.

TABLE 3. AVERAGE AND STANDARD DEVIATION RADIANCE BY SCENE SECTION (VERTICAL SCANS)

LOCATION AND PARAMETERS*	SECTION	MINIMUM, MIDRANGE, AND MAXIMUM AVERAGE RADIANCES ($\text{W m}^{-2} \text{sr}^{-1}$)	MINIMUM, MIDRANGE, AND MAXIMUM STANDARD DEVIATION ($\times 10^{-1} \text{W m}^{-2} \text{sr}^{-1}$)
WALLOPS 2, 0, 33	1	2.20, 2.26, 2.32	2.26, 2.75, 3.24
	2	2.11, 2.19, 2.27	1.60, 2.06, 2.51
	3	1.95, 1.98, 2.01	1.45, 1.49, 1.52
WALLOPS 5, 0, 20	1	1.89, 2.07, 2.25	5.56, 6.39, 7.22
	2	2.02, 2.16, 2.30	5.17, 6.13, 7.09
	3	2.07, 2.15, 2.23	4.79, 5.45, 6.10
	4	2.20, 2.28, 2.36	3.85, 4.44, 5.02
WALLOPS 5, 0, 33	1	1.73, 1.79, 1.84	1.73, 2.11, 2.49
	2	1.72, 1.76, 1.80	1.58, 1.76, 1.93
	3	1.63, 1.66, 1.68	1.11, 1.21, 1.30
WALLOPS 10, 0, 20	1	0.81, 0.85, 0.89	0.91, 1.42, 1.93
	2	0.89, 0.92, 0.95	1.12, 1.55, 1.97
	3	0.86, 0.88, 0.90	0.94, 1.16, 1.38
	4	0.89, 0.90, 0.92	0.92, 1.06, 1.20
WALLOPS 10, -1, 21	1	0.80, 1.00, 1.20	0.54, 4.15, 7.77
	2	0.87, 0.98, 1.09	1.66, 3.62, 5.57
	3	0.84, 0.94, 1.03	0.96, 2.31, 3.66
	4	0.89, 0.97, 1.05	1.68, 2.82, 3.96
	5	0.90, 0.99, 1.08	1.82, 3.08, 4.33
	6	0.90, 0.96, 1.03	1.77, 2.37, 2.97
WALLOPS 10, 0, 33	1	1.09, 1.14, 1.19	1.42, 1.58, 1.73
	2	1.09, 1.12, 1.14	0.96, 1.13, 1.30
	3	1.10, 1.12, 1.13	0.66, 0.78, 0.91
WALLOPS 15, 0, 34	1	0.86, 0.86, 0.87	0.66, 0.73, 0.80
	2	0.83, 0.84, 0.85	0.41, 0.53, 0.65
	3	0.84, 0.85, 0.86	0.30, 0.35, 0.41

* Parameters are off glint angle, sensor elevation, and sun elevation respectively.

TABLE 4. CONVERSION OF RADIANCE TO APPARENT TEMPERATURE

<u>TEMP(C)</u>	<u>RADIANCE</u> <u>(W m⁻² sr⁻¹)</u>	<u>TEMP(C)</u>	<u>RADIANCE</u> <u>(W m⁻² sr⁻¹)</u>
15	0.74	33	1.44
16	0.77	34	1.49
17	0.80	35	1.54
18	0.83	36	1.59
19	0.86	37	1.65
20	0.89	38	1.70
21	0.93	39	1.76
22	0.96	40	1.82
23	1.00	41	1.88
24	1.04	42	1.95
25	1.08	43	2.01
26	1.12	44	2.08
27	1.16	45	2.15
28	1.20	46	2.22
29	1.25	47	2.29
30	1.29	48	2.36
31	1.34	49	2.44
32	1.39	50	2.52

TABLE 5. RADIANCE NEEDED FOR A ONE-DEGREE CHANGE IN TEMPERATURE

<u>TEMPERATURE</u> <u>(C)</u>	<u>1 DEGREE RADIANCE CHANGE</u> <u>(W m⁻² sr⁻¹ C⁻¹)</u>
15	0.029
30	0.046
50	0.078

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