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THE UNIVERSITY OF MICHIGAN

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HIGH ALTITUDE RADIATION MEASUREMENTS

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ABSTRACT

This report summarizes project activity during the period 1 January, 1966 to 31 March, 1966. Bi-directional reflectance data obtained with the 0.2-4.0 micron channel of the F-4 MRIR on the 10 March, 1965 balloon flight is presented and discussed. Some of the calibration data of the thermal channels of the F-4 MRIR are presented, illustrating differences between U. of M. and SBRC calibrations and variations in calibration data over a 14 month period.

The problems arising during the extensive preparation and calibration of the U. of M. IRIS interferometer for a balloon flight test are described.

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Introduction

This is the 13th quarterly progress report on Contract No. NASr-54(03) covering the period January 1, 1966 to March 31, 1966.

The project effort during this time period was divided among the following tasks.

1. Analysis of data from previous balloon flights.
2. Laboratory testing of the F-4 MRIR radiometer.
3. Development of an infra-red interferometer for spacecraft use.
4. Preparations for the next balloon flight.
5. Report writing.

1. Analysis of Data From Previous Balloon Flights

The study of reflectance data obtained on previous balloon flights has been continued. During this period data from the March 10, 1965 balloon flight has been carefully considered. The following discussion is taken from a technical report on earth reflectance which is being prepared for later publication.

The March 10, 1965 balloon flight was launched at 1210 G. M. T. (0610 C. S. T.) from Sioux Falls, S. D., and floated at an altitude of 107000 feet for about 7 hours above terrain which was 25-90% covered with wind blown snow. The altitude vs time curve and a trace of the balloon trajectory are shown in figures 1 and 2.

The F-4 MRIR radiometer which was flown on this balloon flight had only one channel (0.2-4.0 micron) for measurement of reflected and scattered solar radiation. Bi-directional reflectance patterns for this type of terrain and atmosphere were obtained at three different sun zenith angles, 72^{o}, 58^{o} and 50^{o}, at 0834, 0900 and 1110 C. S. T., respectively. When the sun was at zenith angles greater than 72^{o}, the balloon was not yet at altitude and so data was not obtained. During the rest of the flight, except at those times noted, data for reflectance patterns was not obtained because of insufficient gondola rotation or non-homogeneous fields of view (i. e. scattered clouds in the field of view).

The reflectance patterns obtained show the sum of reflected radiance from the snow covered terrain plus the scattered radiance from the atmosphere. The data is displayed in several ways for better understanding of its characteristics.

Figure 3 shows the coordinate system used for display of the entire bi-directional reflectance pattern in one diagram. The geometry is that of figure 4, as viewed from the zenith. The angle ψ, measured from the principal plane,runs from 0 to 360^{o} clockwise around the outside of the polar diagram. The concentric circles are curves of constant zenith angle, running from 0^{o} at the center to 100^{o} at the outside of the diagram. Solar radiation is incident from the azimuth direction $\psi = 180^{o}$. The orientation of the diagram on the earth's surface will depend on the sun's azimuth, i. e. the time of day; for example sometime in mid morning with the sun shining from the southeast, the direction E would lie at $\psi = 135^{o}$ on the diagram, with N at 45^{o} (i. e. $\psi = 45^{o}$). Note that the horizon will lie at a zenith angle of 95.9^{o} (i. e. the earth atmosphere interface as viewed from the balloon at 110000 feet).

The bi-directional reflectance diagram is shown on this coordinate system by a set of contours of constant reflectance.

Figure 5 is a bi-directional reflectance pattern that was obtained at 0832-0836 C. S. T., with the sun at a zenith angle of 72.2-71.5°. The balloon was still rising, and the pressure altitude varied from 20-16.5 during the data taking time interval. Note that the sun's position is not shown along the $\psi = 180^{\circ}$ line. Although calculations were made so that the diagram would have the sun at this value of ψ, the symmetry of the results obtained indicates that the sun's position should be along the $\psi = 172^{\circ}$ line, inside of the 70% reflectance contour (which represents the peak of the atmospheric backscattering). Large forward scattering is shown by the contours on the right hand side of the diagram. The maximum contour shown is 99%, the maximum value allowed in the data processing. A second pass through the data will yield higher values of reflectance in this region and thus show more detail on the peak of the forward scattering pattern. The reflectance pattern decreases symmetrically from the forward and backscattering peaks maintaining higher values near the horizon at all azimuths with the minimum value of reflectance of slightly less than 25% at the zenith. For geographical orientation note the E, S, W, and N directions of the figure.

Photographs of a 3 dimensional model of this reflectance pattern are shown in figures 6a and b. In 6a, the view is from N. E., showing the backscattering peak. The arrow indicates the direction of the incident radiation. In figure 6b the pattern is viewed from the S. W., showing that the forward scattering is a maximum very close to the horizon. The photographs show the generally diffuse but slightly non-homogeneous nature of the reflectance in directions approaching the zenith.

A third method of data display for the bi-directional reflectance pattern is to select a vertical slice of the pattern at some azimuth and to plot the resulting data as a function of zenith angle. Such a plot of the 0834 C. S. T. data in the principal plane is shown in figure 7, showing the forward and backward scattering with a rather uniform diffuse scattering toward the zenith.

The total directional reflectance for this pattern has been calculated by numerical intergration. A value of 35.0% was obtained. The integration was carried out over the upward hemisphere, neglecting the zenith angles between 90° and 95.9°, however the result would not be altered significantly by including this reflectance in the calculation.

The three different displays of the bi-directional reflectance pattern obtained at 0855-0909 C. S. T. on this balloon flight are shown in figures 8-10. The sun was approximately 5° higher, i. e. 68.3-66.0° zenith angle. Inspection of the figures shows a pattern similar to that obtained at the earlier time. However now the backscattering is less intense, but covers a slightly broader range of angles. The forward scattering is less intense and not as broad in angular range. In figure 10 it can be seen that the forward scattering has dropped to 73% at $\sigma = 90^{\circ}$ whereas at the earlier time, with the sun 5 degrees lower in the sky, the reflectance was still saturated at $\sigma = 90^{\circ}$. The directional reflectance, obtained by numerical integration of this data was 36.2% which is in agreement with the earlier value within the experimental error of the measurements.

Figures 11-13 show the bi-directional reflectance pattern with a much higher sun, i. e. a zenith angle of 50°. The pattern is significantly different from that obtained earlier in the day. The high intensity forward and backward scattering is not a feature at this high sun angle. There is a small peak at the proper angle for backscattering and a general maximum at almost all azimuths near the horizon. There is another peak at a zenith angle about 8^{o} greater than that for specular reflection. This is consistant with surface measurements of the mirror component of reflection from snow. The directional reflectance, obtained by numerical integration of this reflectance pattern, was found to be 30.1% about 5% lower than the values obtained earlier in the day.

2. Laboratory Testing of the F-4 MRIR Radiometer

The F-4 MRIR radiometer was returned to the U. of M. from the Santa Barbara Research Center (SBRC) after a complete set of calibrations had been made by SBRC personnel.

Another set of calibrations of the thermal channels was then made at the U. of M. Figures 14a shows a close up view of the calibration target (middle of photo) and the radiometer radiation cooling coil (top of photo). The data taking process is semi-automatic. Target temperature voltage readings are logged on a Dymec A-D system with data printer. Radiometer thermal channel data and housekeeping data are sent over the balloon flight telemetry system and recorded on magnetic tape. With this apparatus approximately 40 hours are required to take data at 9 scanner/electronics temperature combinations, varying target temperature from $-93^{o}C$ to $+40^{o}C$ for each combination. Data processing can be done by hand or by computer, after digitizing the analog thermal channel data. Total elapsed time by hand is two man weeks. Normal total elapsed time by computer has never approached this time in practice although one might expect that only one or two days would be required.

Although all of the data taken will not be discussed in detail here, it is informative to look at the data taken with both scanner and electronics package at 25^{o}c and to compare it with previous calibrations made under the same scanner/electronics temperature conditions. The data (tables 1-4) indicate significant differences between U. of M. and SBRC data and time variability in the results of both the U. of M. and SBRC data. This difference and time variability has not yet been satisfactorily explained.

3. Development of an Infrared Interferometer for Spacecraft Use

This was a period of intensive effort in preparation for the next balloon flight test.

Mechanical details worked on were:

a.) A shroud (container) for the interferometer was designed and constructed.

b.) A cold black body for use in calibrations on the balloon flight was designed and constructed and a method of cooling it was devised.

c.) An instrument door, transparent to thermal radiation was designed and constructed.

d.) A nitrogen purging system was developed.

e.) A mobile test cart for use in field operations was designed and constructed.

f.) The vacuum system was made ready for calibration work.

TABLE 1. F-4 MRIR CALIBRATION DATA

6.7 Micron Channel

Scanner 25°/Electronics 25°

	S. B.	S. B.	U. M.	S. B.	U. M.	S. B.	S. B.	U. M.
°C	10/2/64	10/12/64	2/65	4/8/65	9/65	12/20/65	12/29/65	2/1/66
-93	5.20	5.25	--	4.70	4.95	4.70	4.70	5.15
-83	5.15	5.15	--	4.60	4.85	4.65	4.65	5.00
-73	5.00	5.10	--	4.40	4.65	4.55	4.55	4.84
-63	4.80	4.90	4.20	4.25	4.40	4.30	4.30	4.56
-53	4.50	4.55	3.95	3.95	4.05	4.10	4.10	4.25
-43	4.05	4.05	3.55	3.45	3.60	3.60	3.60	3.75
-33	3.40	3.40	2.90	2.80	3.05	3.00	3.00	3.10
-23	2.55	2.60	2.05	2.10	2.20	2.10	2.10	2.26
-13	1.50	1.50	1.00	1.05	1.10	1.10	1.10	1.15
-3	--	--	--	--	--	--	--	--

TABLE 2. F-4 MRIR CALIBRATION DATA
10-11 Micron Channel
Scanner 25°/Electronics 25°

	S. B.	S. B.	U. M.	S. B.	U. M.	S. B.	S. B.	U. M.
°C	10/2/64	10/12/64	2/65	4/8/65	9/65	12/20/65	12/29/65	2/1/66
-93	6.30	6.25	--	6.10	6.10	6.10	6.05	--
-83	6.20	6.15	--	6.00	6.05	6.00	5.95	6.14
-73	6.00	6.05	--	5.90	5.90	5.85	5.80	5.96
-63	5.85	5.85	5.60	5.65	5.70	5.65	5.65	5.75
-53	5.65	5.60	5.40	5.45	5.45	5.45	5.40	5.50
-43	5.35	5.30	5.15	5.15	5.15	5.15	5.10	5.19
-33	5.00	5.00	4.80	4.85	4.80	4.85	4.85	4.85
-23	4.60	4.55	4.40	4.40	4.40	4.45	4.35	4.45
-13	4.05	4.10	3.90	4.00	3.95	3.95	3.90	3.99
-3	3.55	3.50	3.40	3.50	3.45	3.50	3.40	3.45
7	3.00	3.20	2.85	2.90	2.90	2.90	2.85	2.85
17	2.30	2.25	2.20	2.25	2.25	2.25	2.20	2.20
27	1.50	1.50	1.50	1.50	1.55	1.55	1.50	1.50
37	0.65	0.70	--	0.70	0.75	0.75	0.70	0.70
47	--	--	--	--	--	--	--	--

TABLE 3. F-4 MRIR CALIBRATION DATA
14-16 Micron Channel
Scanner 25°/Electronics 25°

°C	S. B. 10/2/64	S. B. 10/12/64	U. M. 2/65	S. B. 4/8/65	U. M. 9/65	S. B. 12/20/65	S. B. 12/29/65	U. M. 2/1/66
-93°	5.00	5.00	--	4.80	4.75	4.75	4.75	4.94
-83°	4.70	4.70	--	4.40	4.55	4.40	4.40	4.63
-73°	4.35	4.35	--	4.10	4.15	4.00	4.10	4.25
-63°	3.85	3.90	3.45	3.75	3.70	3.50	3.60	3.77
-53°	3.40	3.35	3.05	3.25	3.20	3.05	3.10	3.30
-43°	2.75	2.75	2.55	2.60	2.65	2.50	2.55	2.75
-33°	2.30	2.15	1.95	2.00	2.00	1.85	1.90	--
-23°	1.55	1.50	1.25	1.35	1.35	1.20	1.25	--
-13°	0.80	0.75	0.45	0.60	0.55	0.50	0.50	--
-5.5°	-0.20	-0.15	--	0.00	+0.05	+0.05	+0.05	--

TABLE 4. F-4 MRIR CALIBRATION DATA
5-30 Micron Channel
Scanner 25°/Electronics 25°

	S. B.	S. B.	U. M.	S. B.	U. M.	S. B.	S. B.	U. M.
°C	10/2/64	10/12/64	2/65	4/8/65	9/65	12/20/65	12/29/65	2/1/66
-93	5.80	5.80	--	5.70	5.80	5.65	5.70	5.98
-83	5.60	5.65	--	5.50	5.70	5.50	5.50	5.80
-73	5.40	5.50	--	5.35	5.55	5.35	5.35	5.60
-63	5.25	5.25	5.30	5.10	5.30	5.15	5.10	5.35
-53	5.00	5.00	5.10	4.85	5.00	4.85	4.85	5.05
-43	4.65	4.70	4.80	4.60	4.70	4.55	4.55	4.75
-33	4.30	4.35	4.40	4.25	4.30	4.20	4.25	4.40
-23	3.95	3.90	3.95	3.90	3.90	3.80	3.80	4.00
-13	3.50	3.50	3.50	3.40	3.45	3.40	3.40	3.50
-3	3.00	3.00	2.95	2.95	3.00	2.90	2.90	3.00
7	2.40	2.40	2.40	2.40	2.45	2.40	2.35	2.45
17	1.80	1.80	1.80	1.85	1.80	1.75	1.75	1.82
27	1.15	1.10	1.15	1.15	1.15	1.15	1.15	1.10
37	0.40	0.50	0.35	0.40	0.35	0.35	0.35	0.35
47	--	--	--	--	--	--	--	--

Electronic problems worked on included:

a.) An A-D inhibit circuit was designed and constructed.

b.) Noise interference from the power supply converter was eliminated.

c.) The problem of poor contacts on electronic plug in boards was corrected.

d.) The drive amplifier was completed.

e.) Wiring was completed for the recording of housekeeping data.

f.) A voice amplifier for the instrumentation recorder was designed and constructed.

g.) The program sequencing motor was wired.

h.) The Ampex FR-1300 tape recorder was adjusted for interferometer data recording. Defects in the instrument were corrected by the factory service man.

Most of this mechanical and electronics work was completed by 31 January and the first test interferograms were made. They were not very satisfactory. After a considerable effort, the cause of unsatisfactory operation was found to be the new drive amplifier. It was replaced by the original amplifier with improved results.

Ground loop noise and cross coupling interference was then eliminated and by 14 February a long series of calibration tests had been started. Five calibrations were carried out in our laboratory and seven were conducted in environmental test chambers at Bendix Systems Division and at the Chrysler Missile Division.

Minor problems solved during this testing and calibration period included:

a.) Elimination of noise from the DC to DC converter which triggered the neon lamp signal.

b.) Elimination of program motor noise from the interferogram.

c.) Elimination of leaks from the shroud.

d.) Re-design of the liquid nitrogen supply system for cooling the black body.

e.) Design of vibration isolation devices for use in mounting the interferometer on the balloon gondola.

f.) Elimination of false shifts of the reference voltage by the divide by ten circuit.

g.) Re-location of the calibration black body so that it would completely fill the interferometer field of view.

Major failures during the test and calibration period were those of the interferometer detectors and battery power supplies.

A considerable effort was devoted to improvement of computer programs for analysis of the interferometer data.

The calibration tests were still being carried out at the end of this work period.

4. <u>Preparations for the Next Balloon Flight</u>

Arrangements have been made to have the next balloon flight launching at the NCAR Scientific Balloon Flight Station at Palestine, Texas.

There will be two complete balloon flights during the one field operation. On the first flight the U. of M. IRIS instrument, the GSFC filter wheel spectrometer and the F-4 MRIR will be flown. The second flight, a joint operation with J. P. L., will test two JPL instruments; the infrared scanning spectrometer (IRSS), the infrared multidetector spectrometer (IRMS) and the F-4 MRIR.

Two gondolas are available for these flights, the second one having been procurred by J. P. L. The same gondola instrumentation will be used on both flights.

The balloon flight system was made ready for the U. of M. - GSFC flight early in this work period. Integration of the IRIS and filter wedge instruments with the gondola was completed with only a few last minute problems. The most serious of these was the problem of shock mounts for the IRIS instrument. At the end of this work period, all equipment was ready for this flight and we were waiting for the completion of the IRIS calibrations, before carrying out an environmental test at Chrysler Missile Division.

An environmental test of the U. of M. - JPL flight configuration was carried out on 4 March, with a failure of the JPL, IMRS instrument due to a cold solder joint, a failure of an electronic tube in a tape recorder and the discovery that the heat insulation of the F-4 MRIR was not adequate to maintain the instrument temperature in the desired range under nighttime flight conditions. This insulation problem was corrected.

At the end of this work period the balloon flight preparations were waiting for IRIS calibrations to be completed.

5. <u>Report Writing</u>

A technical report "The Calibration of and Interpretation of Data From the 0.55-0.85 Micron and 0.2-4.0 Micron Channels of the F-1 and F-4

MRIR Radiometers," by F. L. Bartman, University of Michigan, College of Engineering Report #05863-9-T under Contract No. NASr-54(03), February, 1966, was completed and distributed.

6. Future Work

During the next three months the primary project effort will be to complete the IRIS calibrations and to carry out the two balloon flights at Palestine, Texas.

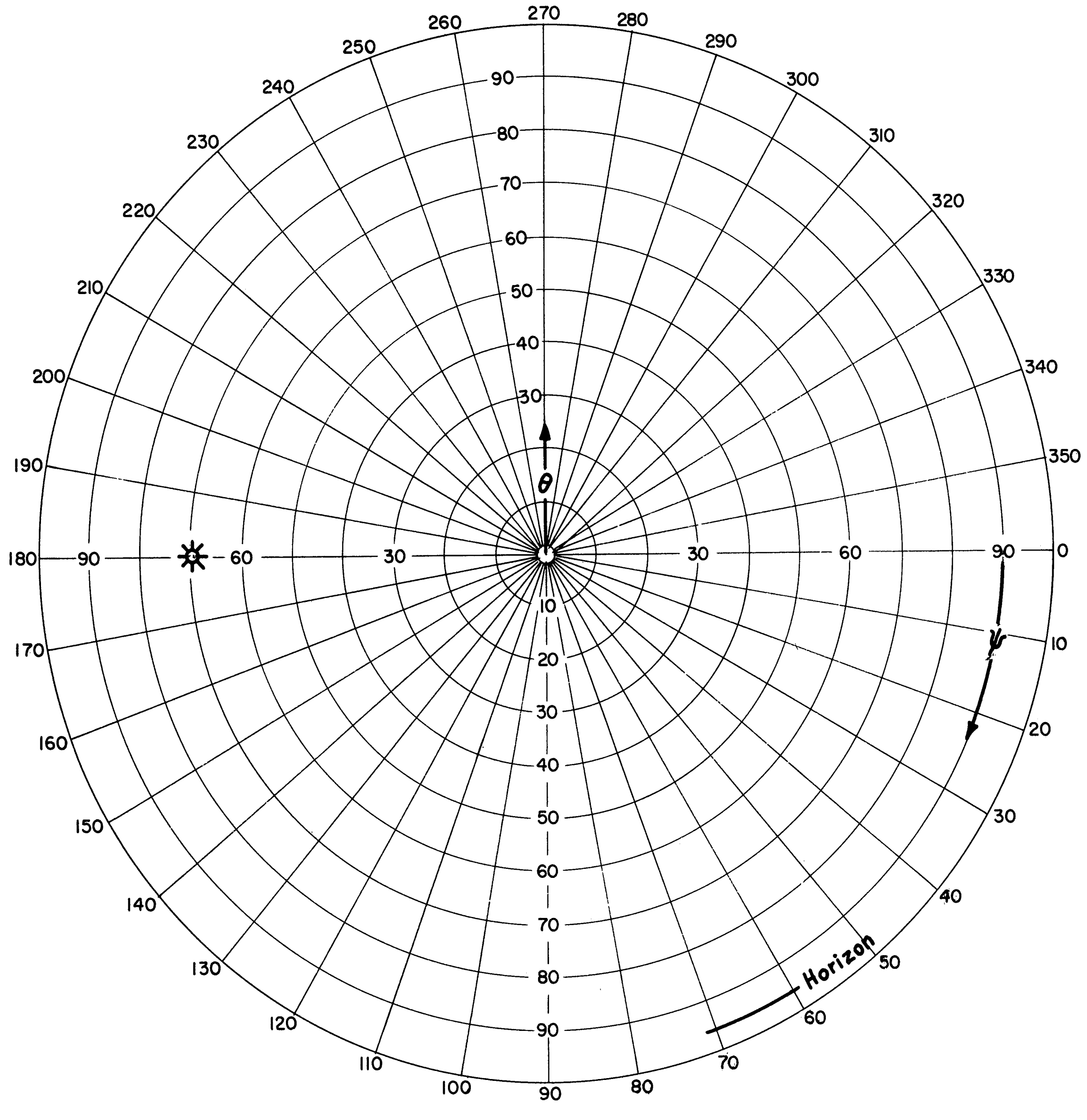


Figure 3. Polar coordinate system for bi-reflectance diagrams.

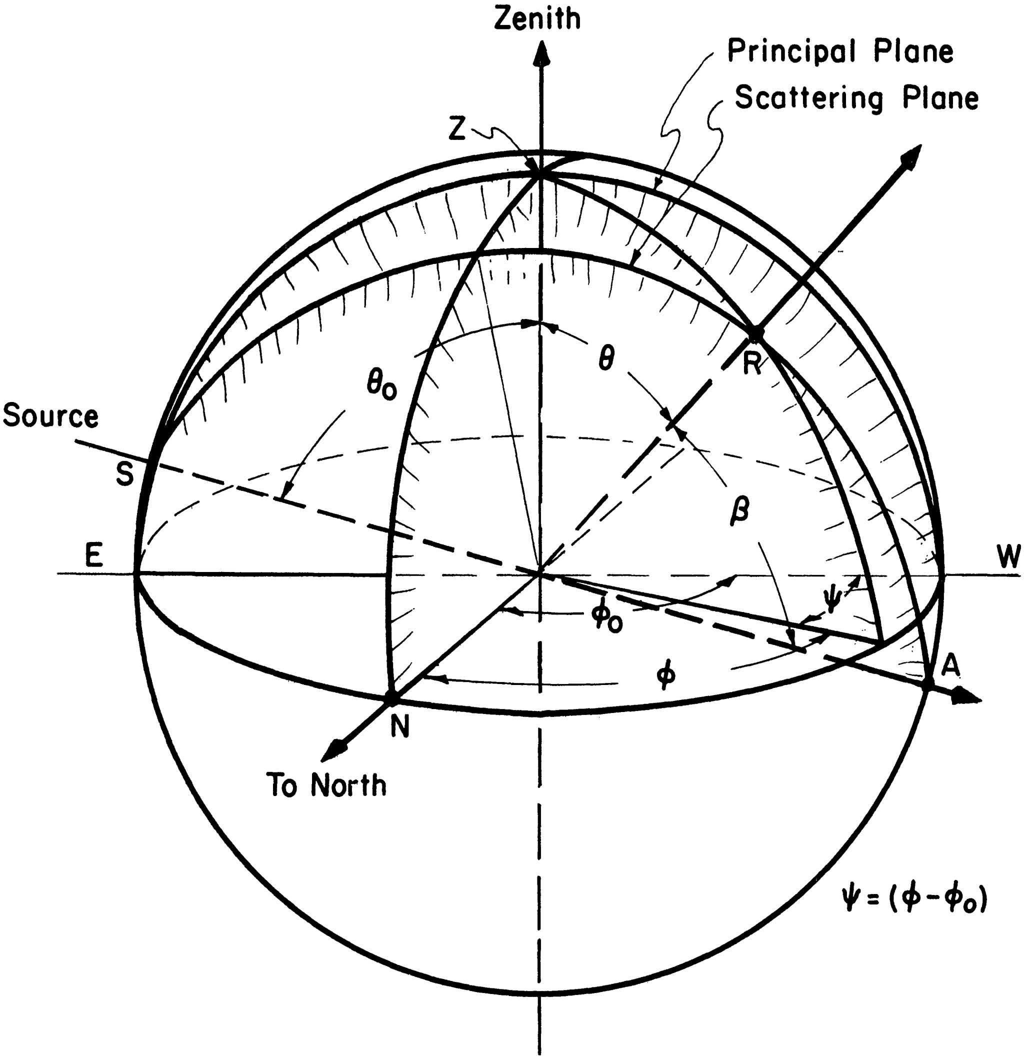


Figure 4. Geometry of reflection and scattering.

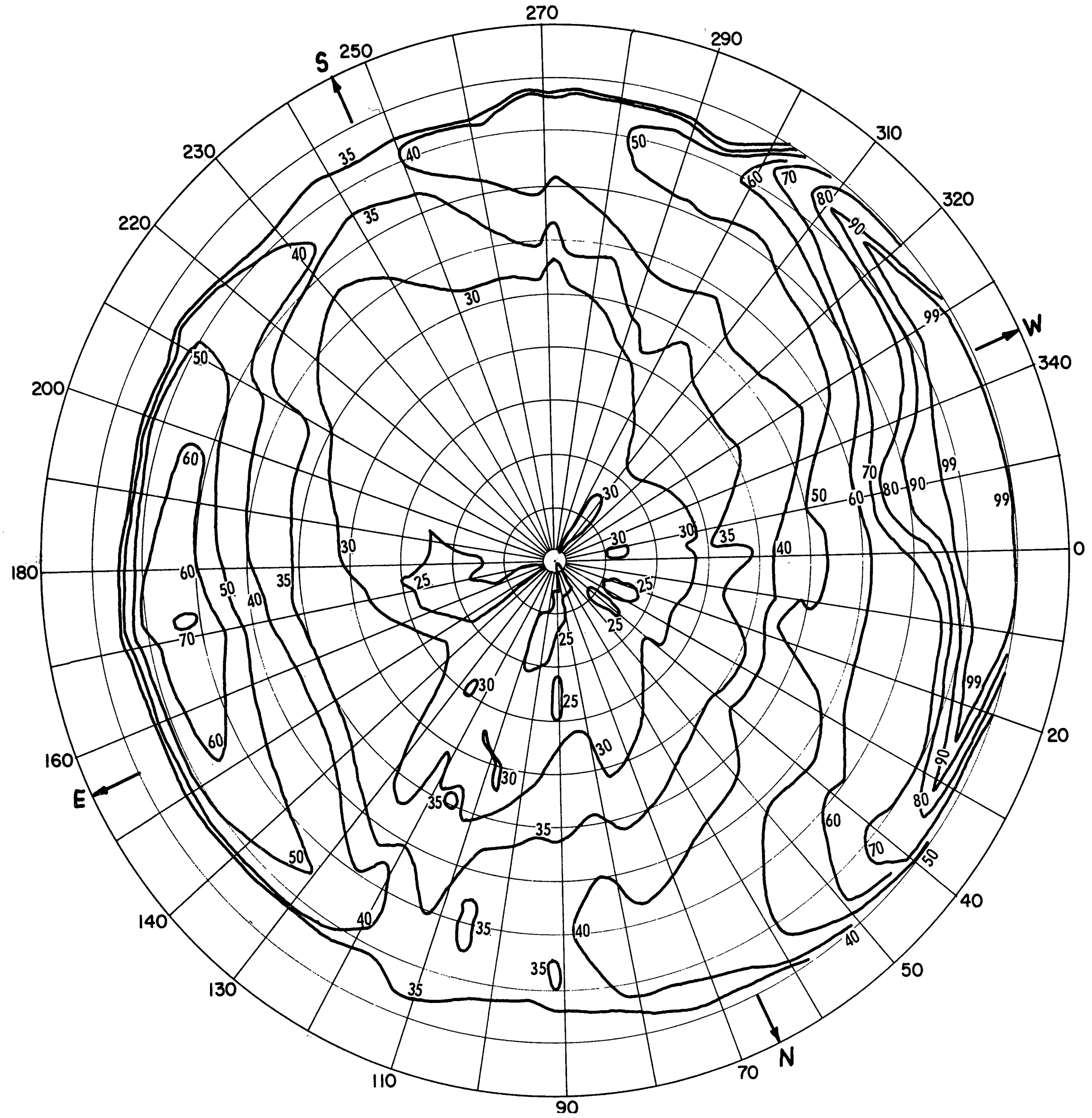
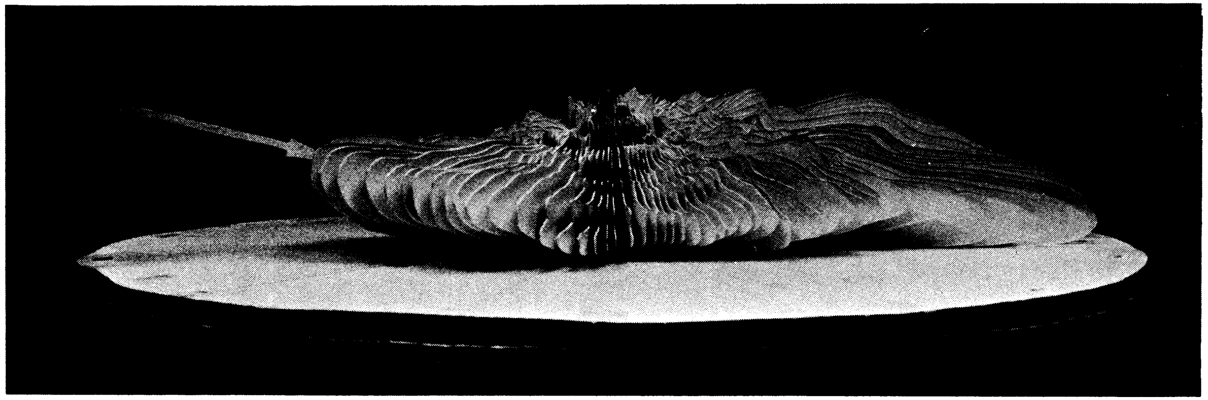
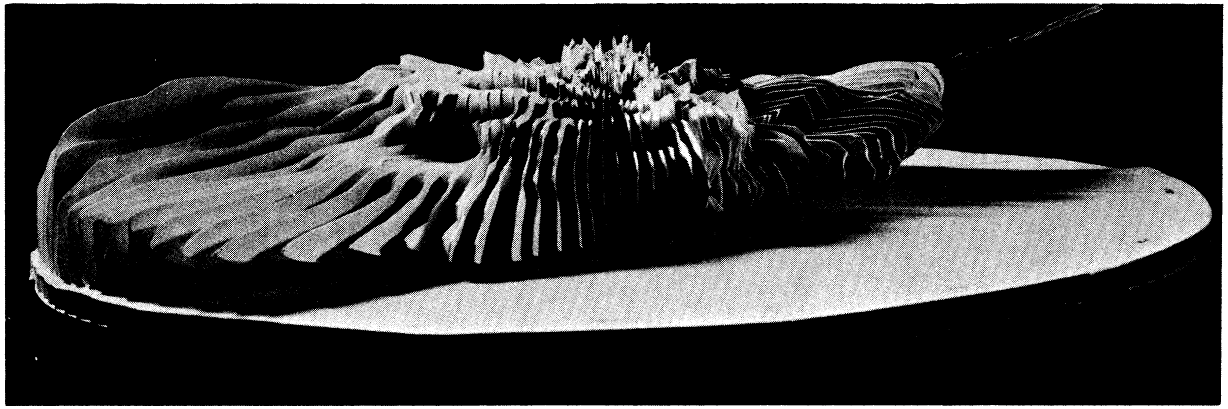


Figure 5. Bi-directional reflectance diagram obtained at 0832-0836 C.S.T. on March 10, 1965 balloon flight, θ_0 = 72.2 - 71.5°, pressure altitude, 20-16.5 mb.



(a) View from N.E.



(b) View from S.W.

Figure 6. Photos of model of 0832-0836 C.S.T. bi-directional reflectance pattern. Solar zenith angle θ_o = 72.2-71.5°.

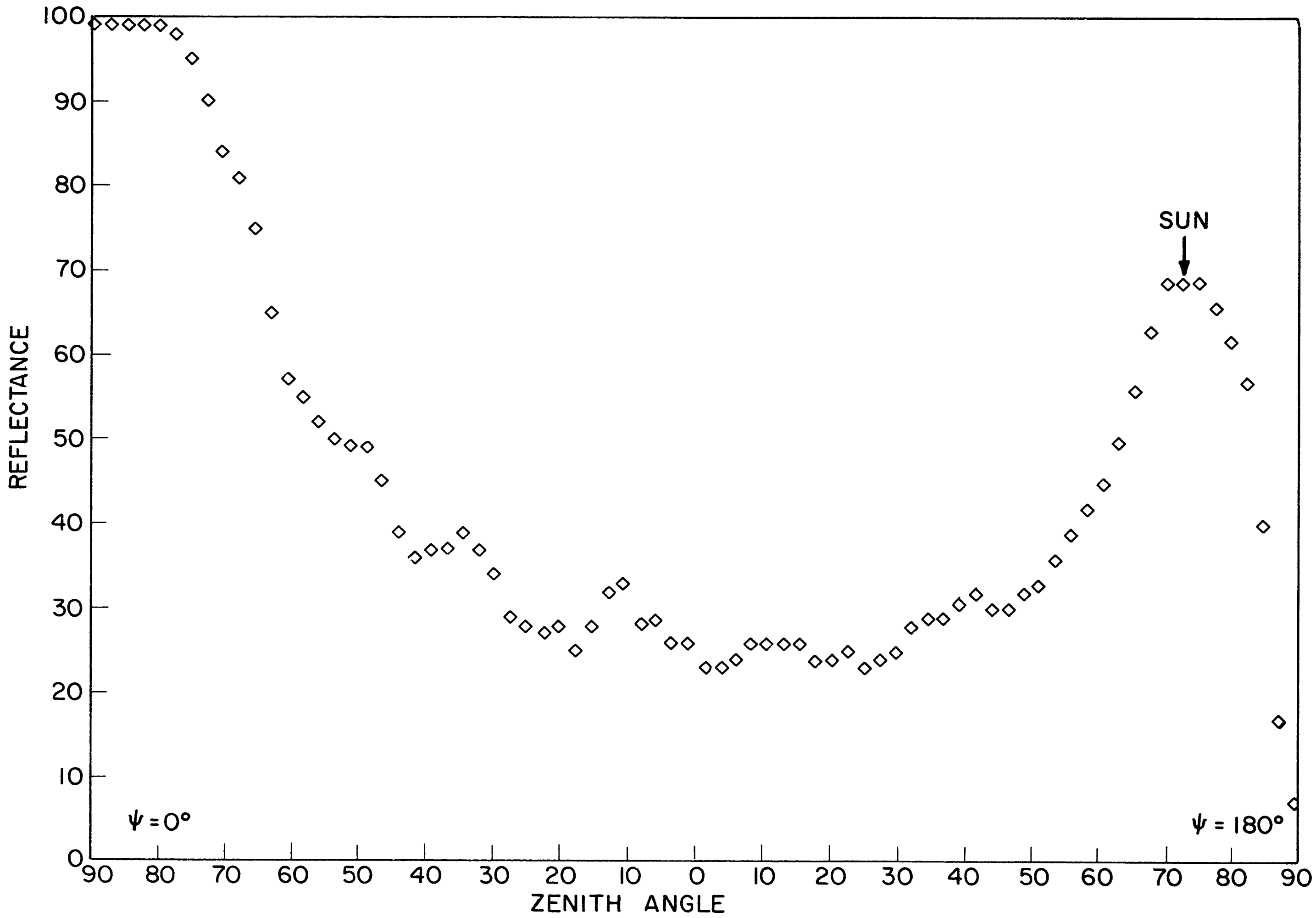


Figure 7. Bi-directional reflectance of snow covered earth and atmosphere in principal plane, March 10, 1965 balloon flight, solar zenith angle 72.2-71.5°.

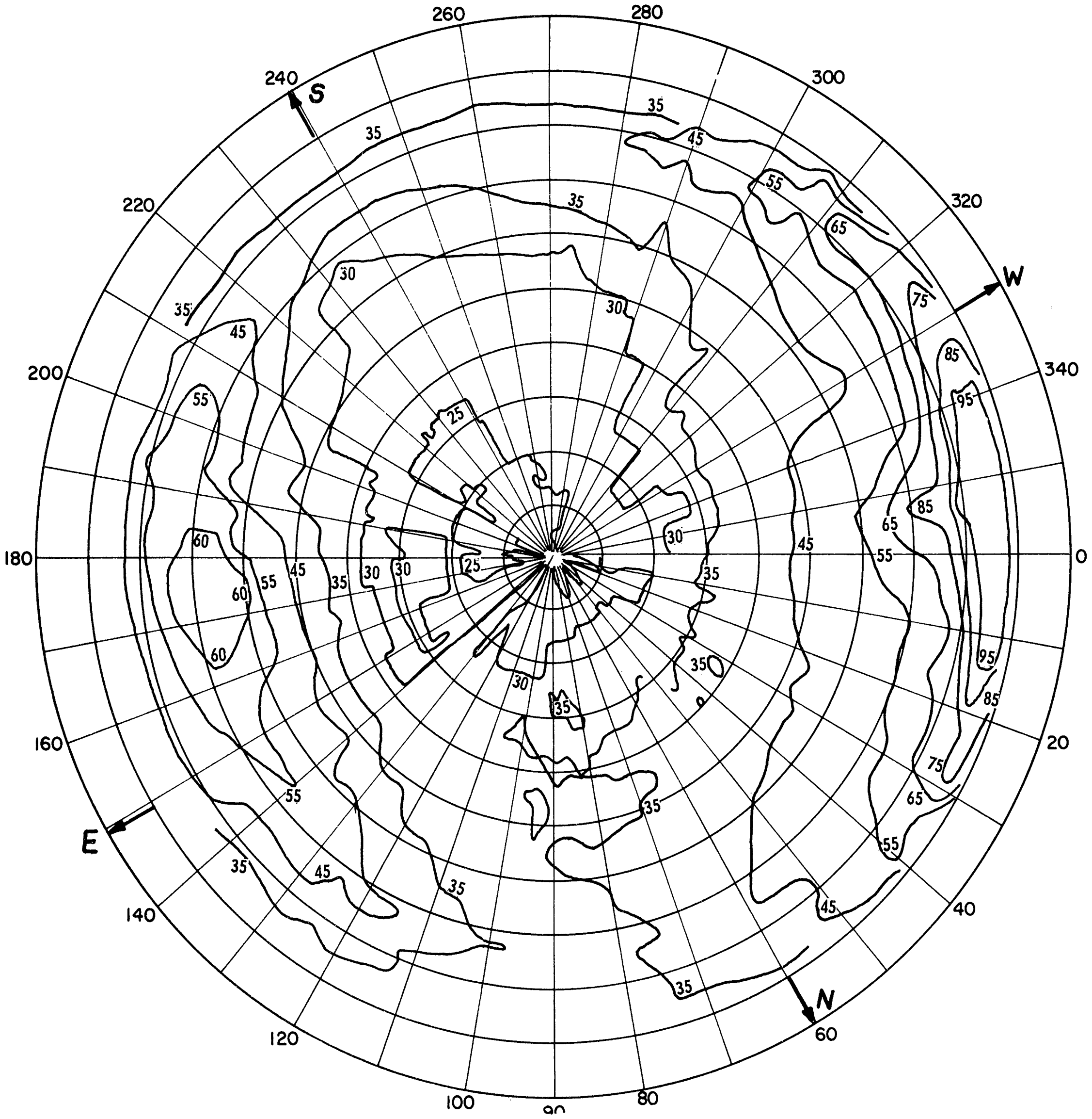
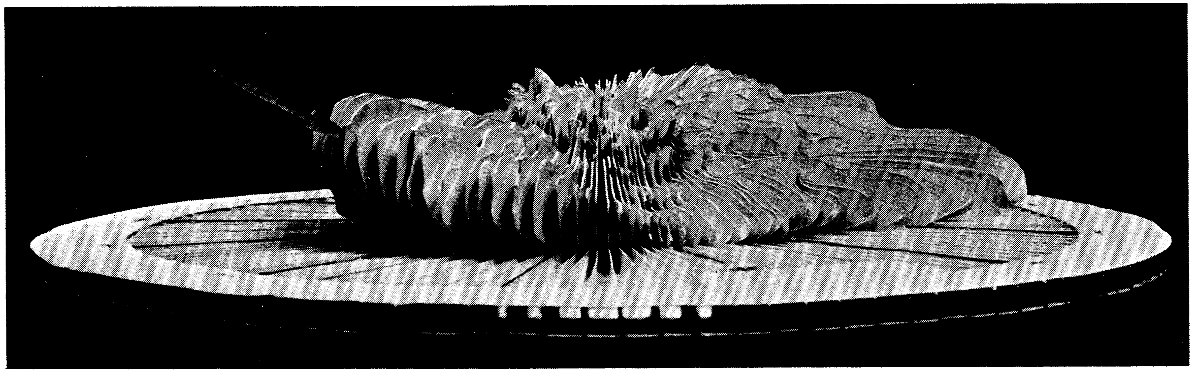
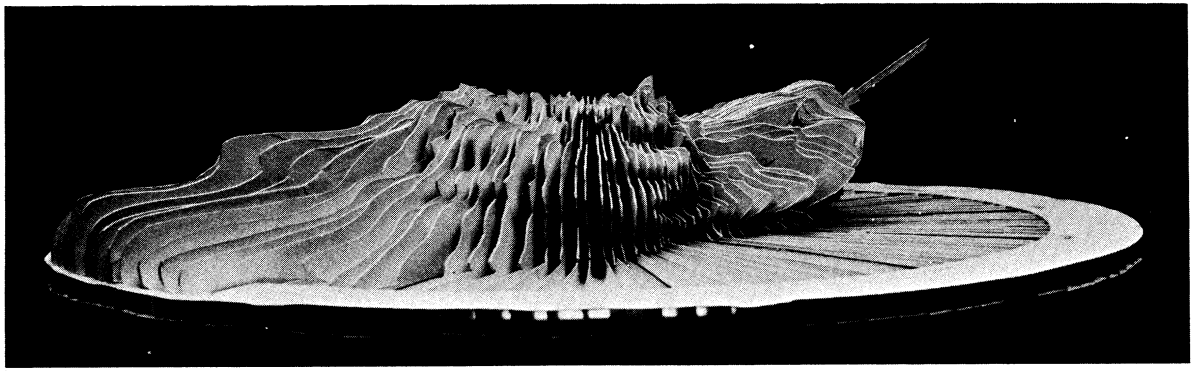


Figure 8. Bi-directional reflectance diagram obtained at 0855-0909 C.S.T. on March 10, 1965 balloon flight. θ_o = 68.3-66.0°, balloon pressure altitude = 9.0-8.5 mb.



(a) View from E.-N.E.



(b) View from S.-S.W.

Figure 9. Photos of model of 0855-0909 C.S.T. bi-directional reflectance pattern. Solar zenith angle θ_o = 68.3-66.0°.

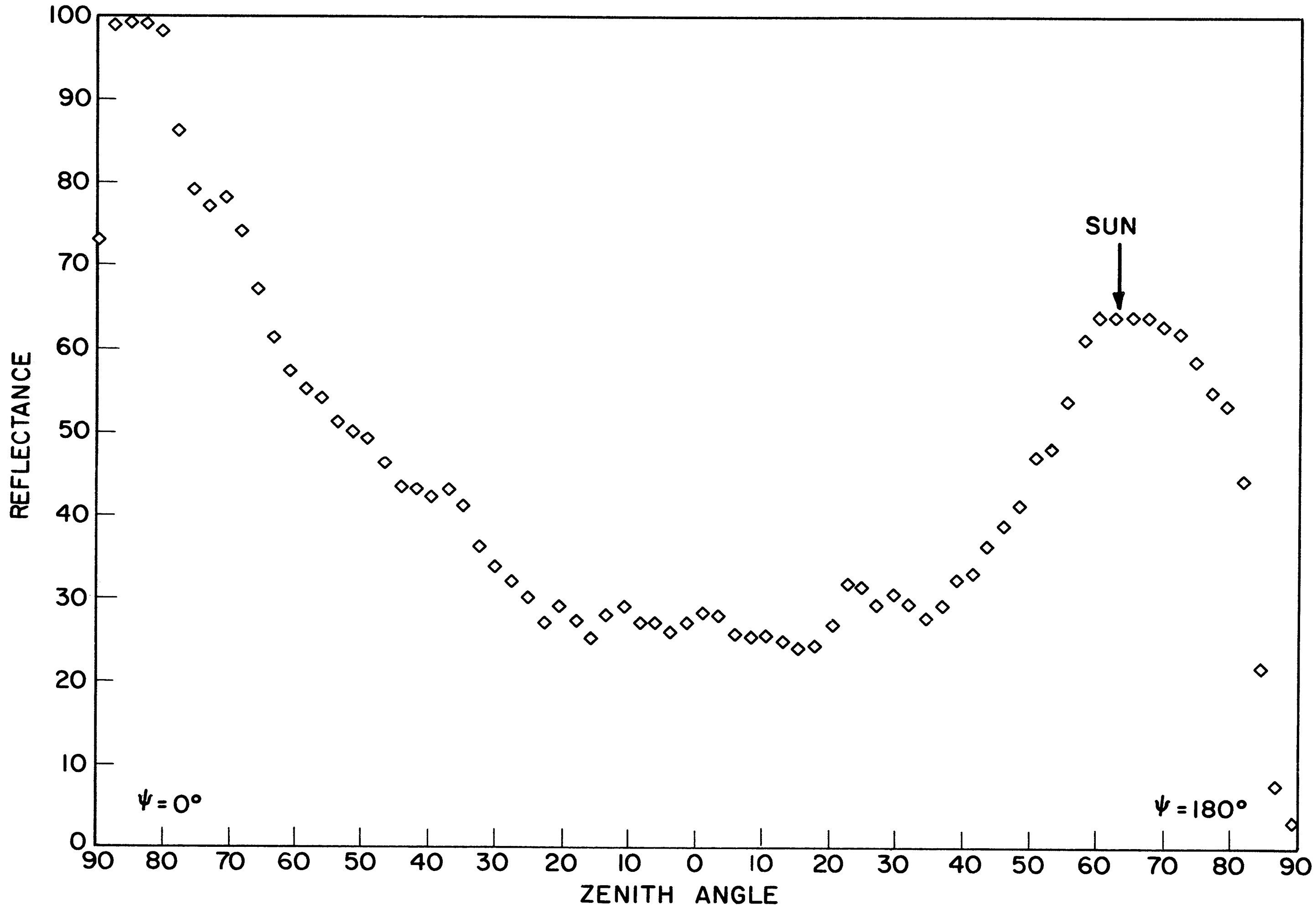


Figure 10. Bi-directional reflectance of snow covered earth and atmosphere in principal plane, March 10, 1965 balloon flight, solar zenith angle 68.3-66.0°.

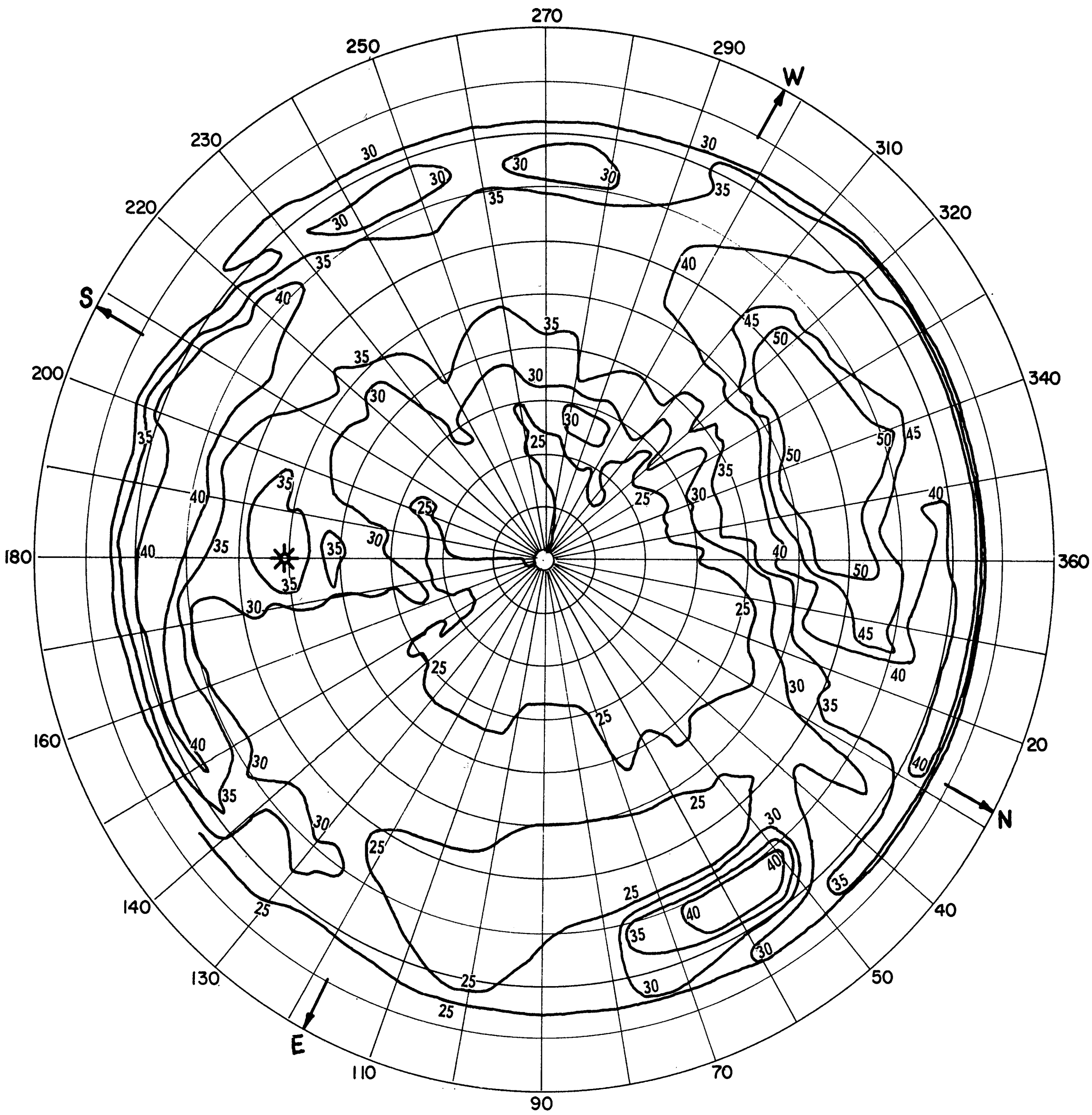
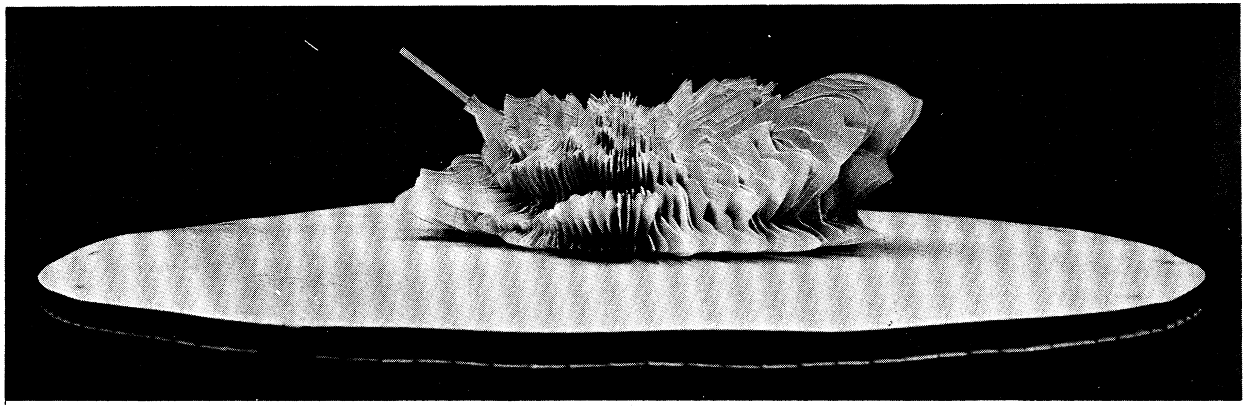
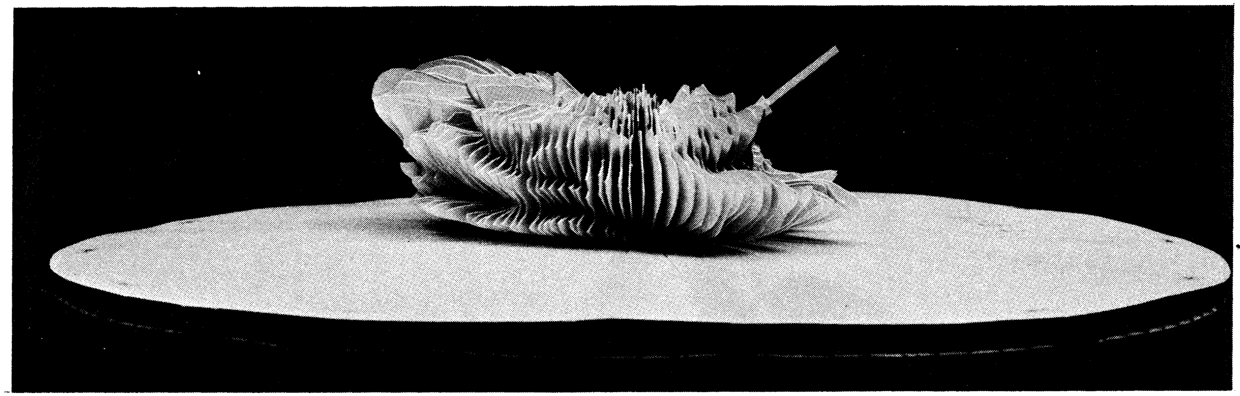


Figure 11. Bi-directional reflectance diagram at 1109-1116 C.S.T. on March 10, 1965 balloon flight, θ_0 = 50.5-50.0°, balloon pressure altitude = 8.5-8.3 mb.



(a) View from N.E.



(b) View from South.

Figure 12. Photos of model of 1109-1116 C.S.T. bi-directional reflectance pattern. Solar zenith angle, θ_o = 50.5-50.0°.

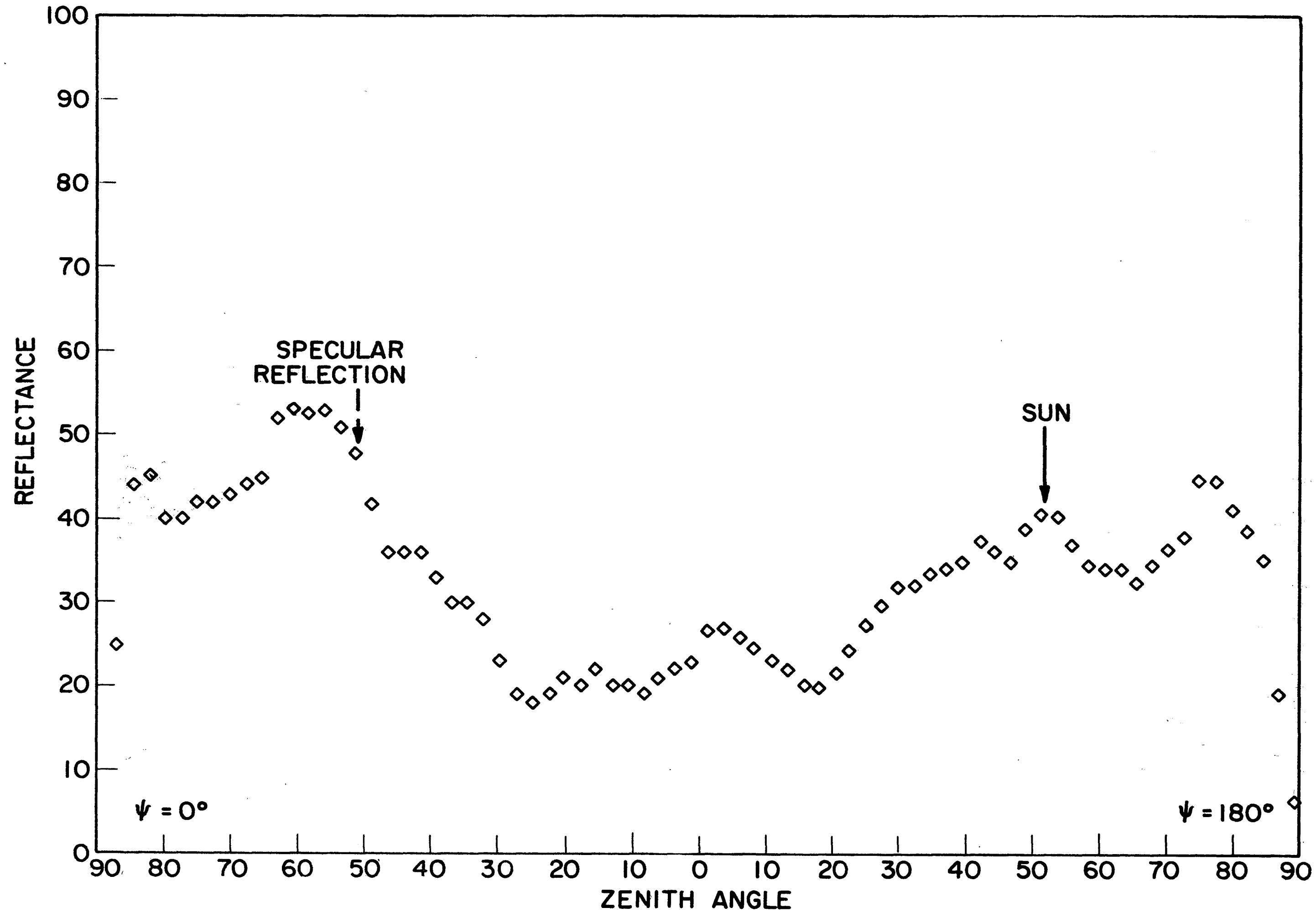
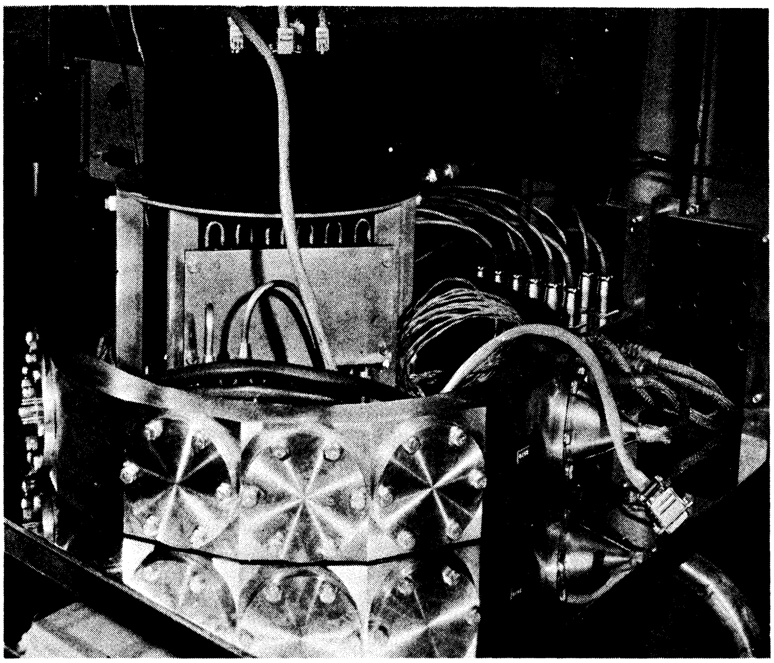
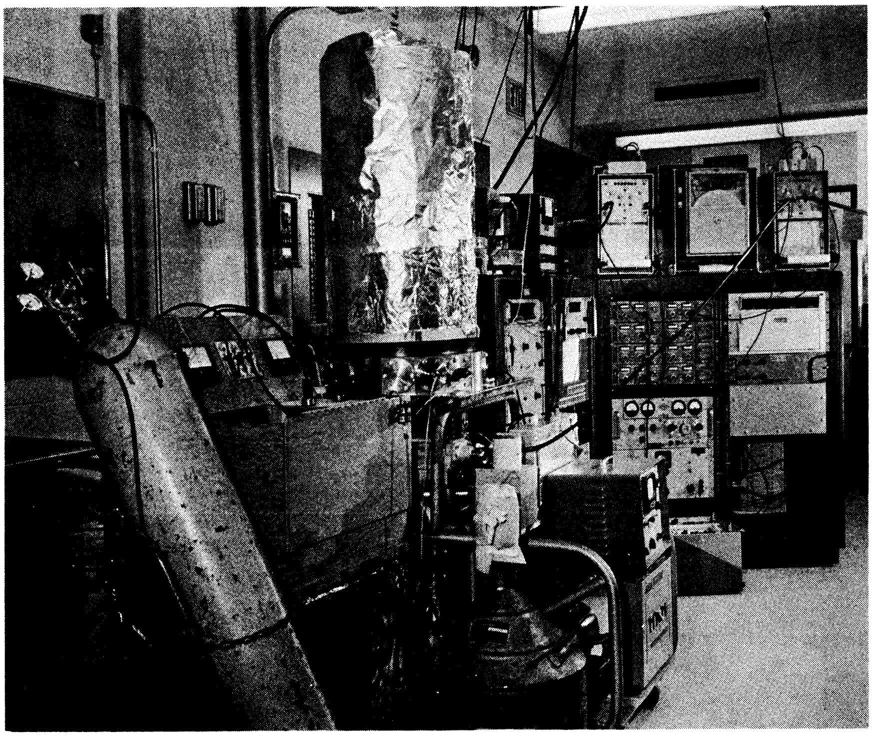


Figure 13. Bi-directional reflectance of snow covered earth and atmosphere in principal plane, March 10, 1965 balloon flight, solar zenith angle θ_0 = 50.5-50.0°.



(a)



(b)

Figure 14. U. of M. thermal channel calibration apparatus for MRIR radiometer.