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CONCEALMENT DESIGN BY ENGINEERING METHODS

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June 1961

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FOREWORD

The material appearing on the pages which follow this foreword was written in 1957 to supplement presentations given to representatives of the Bureau of Ships, U. S. Navy. It was not issued as a Laboratory report because the results do not apply to any existing vessel or to any realistic viewing condition. There was an expectation on the part of the Laboratory, however, that engineering-type concealment design studies for Navy ships would become a part of fleet air defense activities, and that important reports modeled somewhat after the 1957 writings would result. Because this expectation was not borne out the following material has been lifted verbatim from the Laboratory files and issued as a report in the interest of completeness of record.

S. Q. Duntley
Director
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June 1961

PREFACE

Throughout two World Wars and many years of peace, the painting of naval vessels for concealment and deception has been evolved through the cumulative experience of the fleet, through skilled observations by artists, through the advice of naval scientists, and through trials at sea. Engineering methods for concealment design have not been available, however, and the trial-and-error evolution, while productive, has been slow, costly in dollars, and probably wasteful of ships and lives. At no time, including the present, has the Navy had assurance that optimum compromises have been reached and never has it been possible to assay the effectiveness of any concealment measure in terms of its effect on detection or recognition probability throughout a wide gamut of the conditions encountered at sea.

In recognition of this deficiency the Bureau of Ships has undertaken the long-range development of engineering procedures for the design of concealment measures and tactics and for comparing the effectiveness of different designs under various weather and viewing conditions. This program, presently symbolized by project number NS 714-100, has resulted in the creation of a new visual science and a new type of optical engineering.

Fruition of the new science in practical form has been so recent that its application to Navy problems has scarcely begun. A working arrangement has recently been established between the Visual Detection and Concealment Section of the U. S. Navy Electronics Laboratory and the Visibility Laboratory of the University of California under which current and proposed painting instructions and tactical doctrines can be subjected to a quantitative engineering analysis leading to an improved understanding of the effectiveness of present practice, and hopefully, to improved recommendations.

In the following paragraphs a simplified calculation will be used to illustrate one style of engineering approach and one form of result. This rudimentary study has provided an initial language of communication for the Navy problems to be studied and it has furthered the development of calculation techniques. No attempt should be made to draw general conclusions from the following calculation, for the only intent has been to produce a simplified illustration of one facet of the concealment engineering concept. To this end the technique of goniophotometric model photography, well established in the course of earlier work, was not used; instead, a ship has been simulated by a simple rectangular block floating on a calm sea. Much laboratory time was conserved thereby and the value of the example as a training exercise was not lessened. Readers are cautioned, however, that the numerical results do not apply to any actual ship; they serve merely to illustrate a concept. In this spirit, a simple but relatively uncommon environmental condition was selected; namely, a flat-calm sea under a clear, blue sky. The ship was assumed, moreover, to be at rest so that no wake or bow-wave was present. Neither of these unusual circumstances were a necessary choice, but their adoption lessened the work required. It goes without saying that highly accurate, complete, and realistic input data are to be used in all serious studies in order that valid conclusions concerning naval practice can be drawn.

Interest has been expressed in an account of the steps in a typical calculation, and the following description has been prepared by the Visibility Calculation Branch of the Visibility Laboratory in response to that interest. The reader is cautioned against the assumption that the procedures described herein represent a fixed pattern of approach, or define the existing state of the art.

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Director
Visibility Laboratory

SIO Ref. 61-16

CONCEALMENT DESIGN BY ENGINEERING METHODS

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INTRODUCTION

In the low-visibility type of camouflage and concealment, a useful criterion of the effectiveness of the measure taken is the sighting range of the target. This range is a function of the contrasts produced by the various surfaces of the target against its background. Minimization of these contrasts minimizes the sighting ranges and is, therefore, an essential first step in the design of concealment measures.

An engineering method has been developed by this Laboratory for minimizing the contrast of a Navy vessel under specified conditions. The purpose of this report is to describe the method and to illustrate the effectiveness of its use.

METHOD

The visual target selected to demonstrate the method was a destroyer. To facilitate the calculations, the form of the destroyer was simplified. A three dimensional model was employed approximating but reducing in complexity the general structure of the ship by retaining the actual side, top and front projected areas.

The conditions under which the contrasts were minimized were a stationary target oriented facing the sun and aerial observation. The background surface was calm, infinitely deep water. The lighting was provided by a sun at 45° zenith angle and a clear sky, symmetrical in luminance with respect to the meridian of the sun.

Although the standard Navy paint specifications for the target were selected by the Navy to provide camouflage under entirely different conditions than those selected for this demonstration, analysis of the contrasts of these paints can be used as an excellent reference point from which to compare other paints. Therefore, the first step was to paint the target model according to standard Navy paint specifications.

All horizontal surfaces were painted with a glossy dark deck paint of approximately 10% reflectance (No. 20 Gray Deck (Type A) Spec. 52P437). The remaining surfaces, hull, etc., were painted with dull light gray paint of approximately 27% reflectance (No. 27 Haze Gray (5-H) Spec. 52P45).

The contrast of a single target surface, such as the deck of the ship, varies with the gloss characteristics of the target surface and the background surface, the lighting level and geometry, and the angle of sight. In order to evaluate these complex variables, direct measurements of contrast were made under the appropriate conditions. These measurements were made with a goniophotometer, a photometer designed to measure luminances of surfaces from various angles of sight. The measurements of target and background luminances were made nearly simultaneously in order to assure equivalency of illumination.

A photograph of the instrument taken during the experiment is shown in Figure 1. The plaque represents the deck surface and is painted with standard

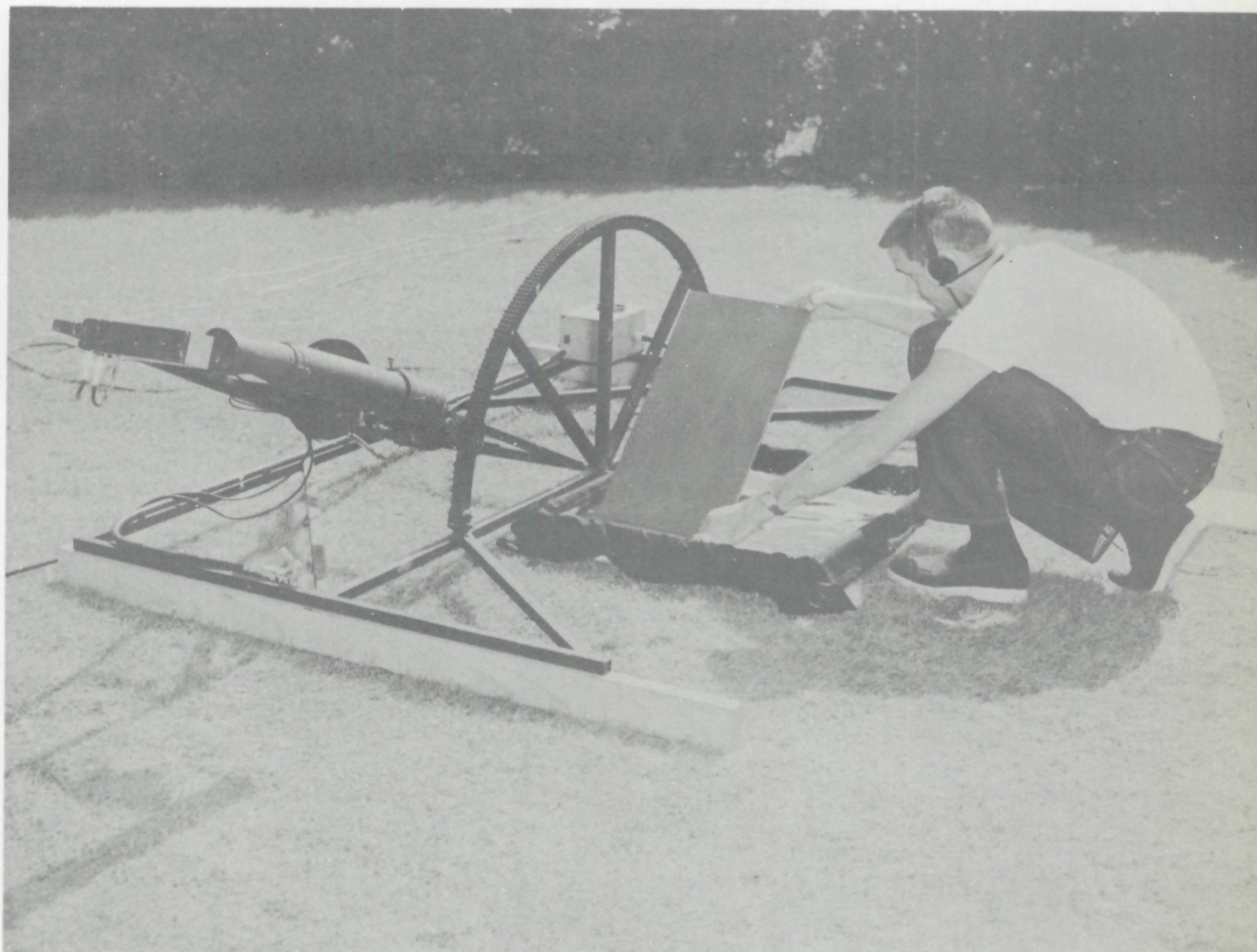


Figure 1

deck paint. Although held at a 45° angle in the picture, the only measurements used in this example were for the plaque in the horizontal position. The tray beneath has a black norzon cloth lining to prevent extraneous reflections from the sides. The bottom of the tray contains a second plaque appropriately painted to obtain a submerged reflectance equivalent to that of infinitely deep water.

The graph depicting the gloss characteristics of the infinitely deep water surface when viewed perpendicular to the azimuth of the sun is given in Figure 2. As can be seen, the luminance of this surface varies with angle of view, being highest at the lower angles. Figure 3 illustrates the luminance of the deck surfaces from the same angles of view. This particular target surface shows much less of a change with angle of view. Both curves have been plotted on a semi-logarithmic paper so that the luminance is essentially plotted linearly in log luminance. By placing Figure 2 over Figure 3, the interval between the two curves can be seen. This envelope is the logarithm of the ratio of the two luminances (log ${}_tB/{}_bB$) since by superimposing one curve on the other, the log of the background luminance (${}_bB$) has been graphically subtracted from the log of the target luminance (${}_tB$).

A replot of this envelope on a log luminance ratio scale is shown in Figure 4. Since contrast is a function of this ratio, it is now possible to relabel this scale (see the left hand margin in Figure 4) to read in contrast. This was done by subtracting one from each number on the luminance ratio scale on the right hand margin.

In actual practice, a log luminance ratio scale marked in contrast was used to generate the contrast plot from the target luminance graph and the

Path of Sight Perpendicular to Sun

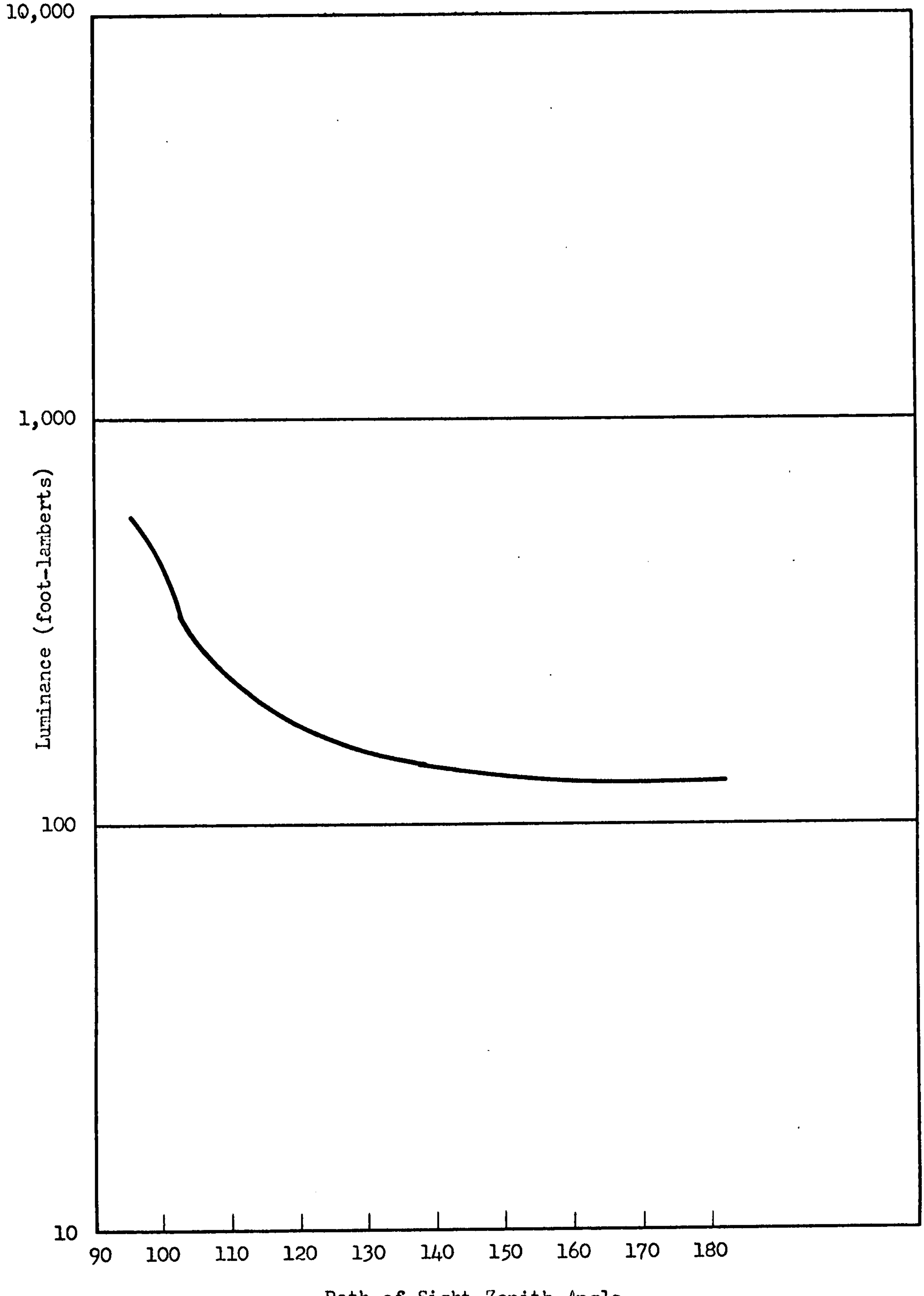


Figure 2

Path of Sight Perpendicular to Sun

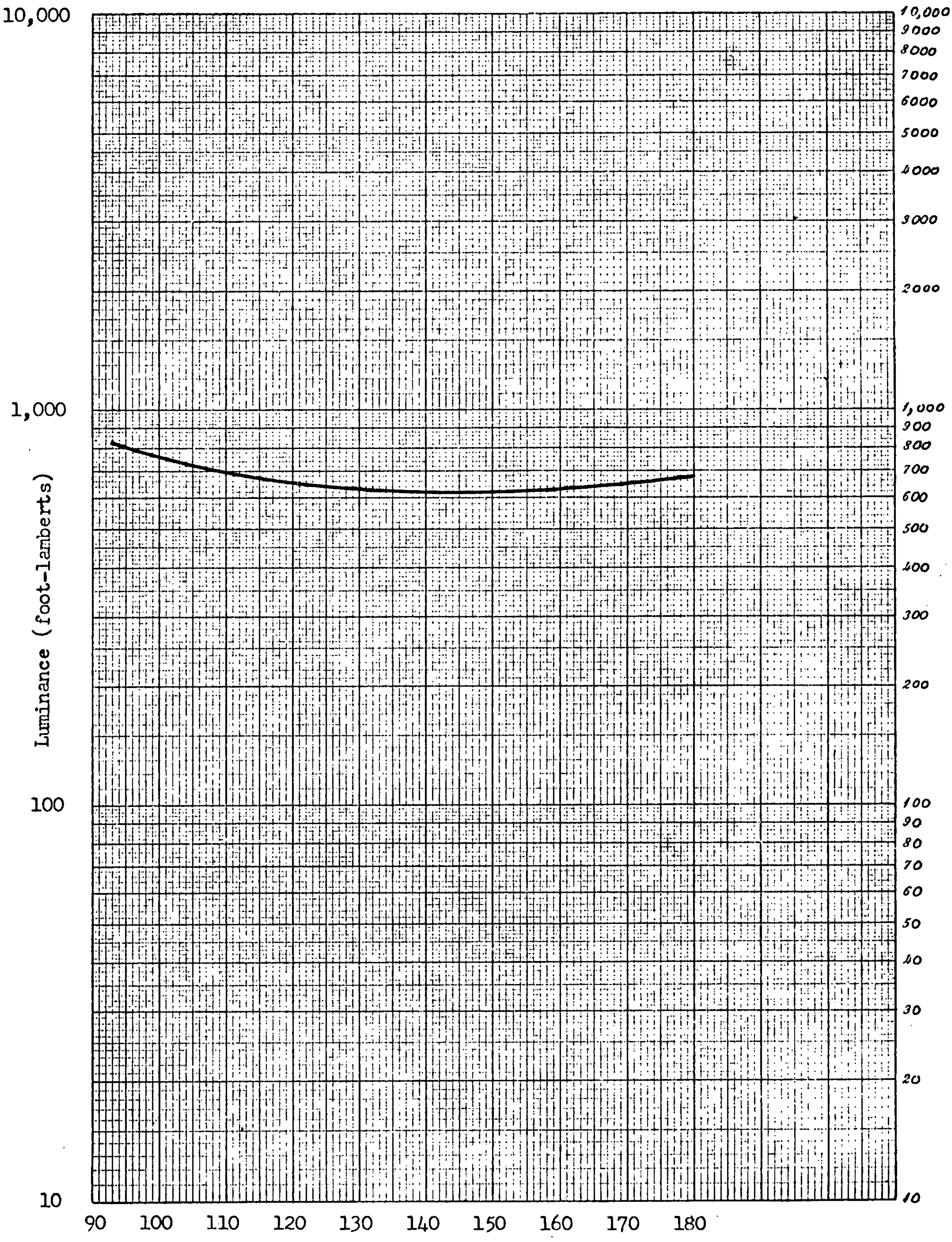


Figure 3

Background - Calm Water
Target Surface - 10% Reflectance Deck Paint

Path of Sight Perpendicular to the Sun

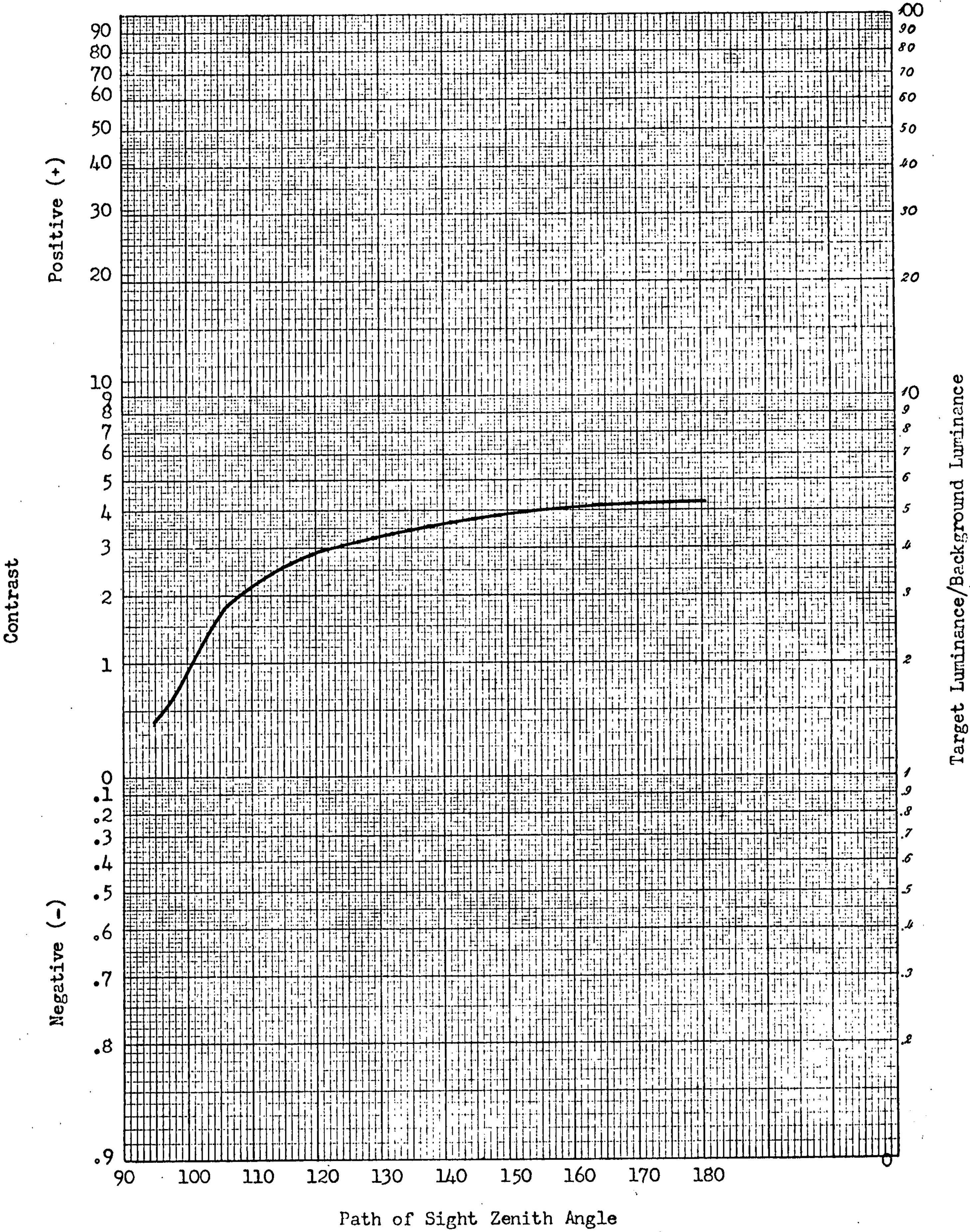


Figure 4

background overlay. Zero contrast was placed always on the background luminance curve and contrast read vertically above or below the background curve depending upon whether the contrast was positive or negative.

In this way a graph of the contrast of the deck surface from each of the orientations of view relative to the azimuth of the sun (toward, perpendicular and away) was generated from the goniophotometric data. This is presented in Figure 5. Since no surface other than the horizontal is painted with deck paint, this series of curves represents the entire contrast picture for this particular paint.

It would now be possible to compare this series of curves with similar curves of various other paints, and so select a paint which would minimize the contrast. This, however, would be expensive in time, requiring luminance data under each condition. Therefore, it is desirable to narrow the range of selection prior to taking more data.

To a first approximation it can be assumed that a paint can be found with approximately the same gloss characteristics as deck paint but with a higher or lower overall reflectance. A luminance curve of such a paint would have the same characteristics as shown in Figure 3 but be displaced above or below the deck paint curve depending on whether the reflectance has been raised or lowered. Therefore, the contrast curve in Figure 4 can be assumed to depict the contrast of the new paint but with curve displaced above or below the present curve. Instead of moving the curve, the zero contrast line can be moved with the same result. In Figure 5 the suggested change in the zero contrast line is shown as a dotted line.

In selecting a new reference line it is desirable to minimize the average absolute value of the contrast, since the human eye responds equally

Background - Calm Water
Target Surface - Deck Paint
10% Reflectance

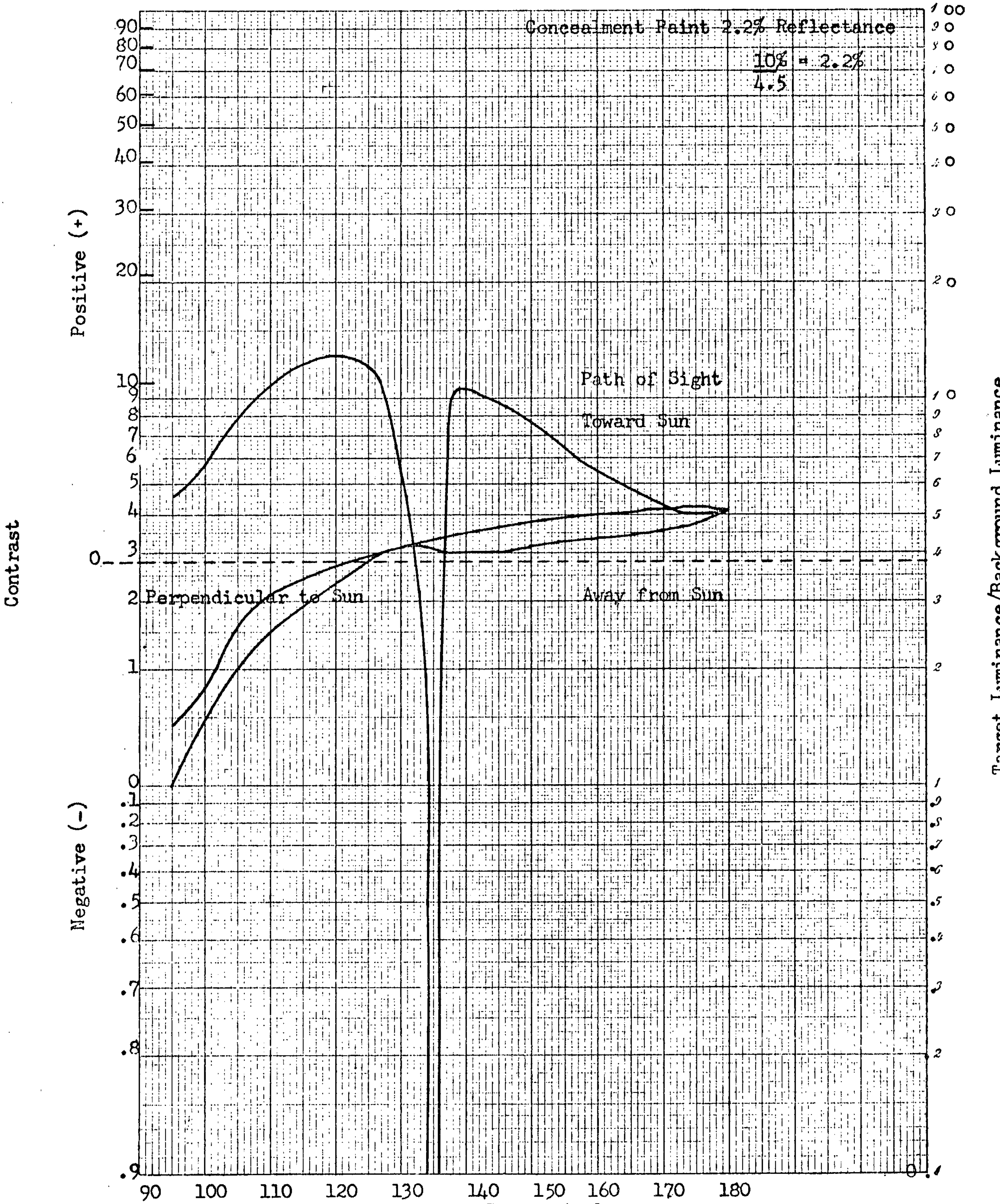


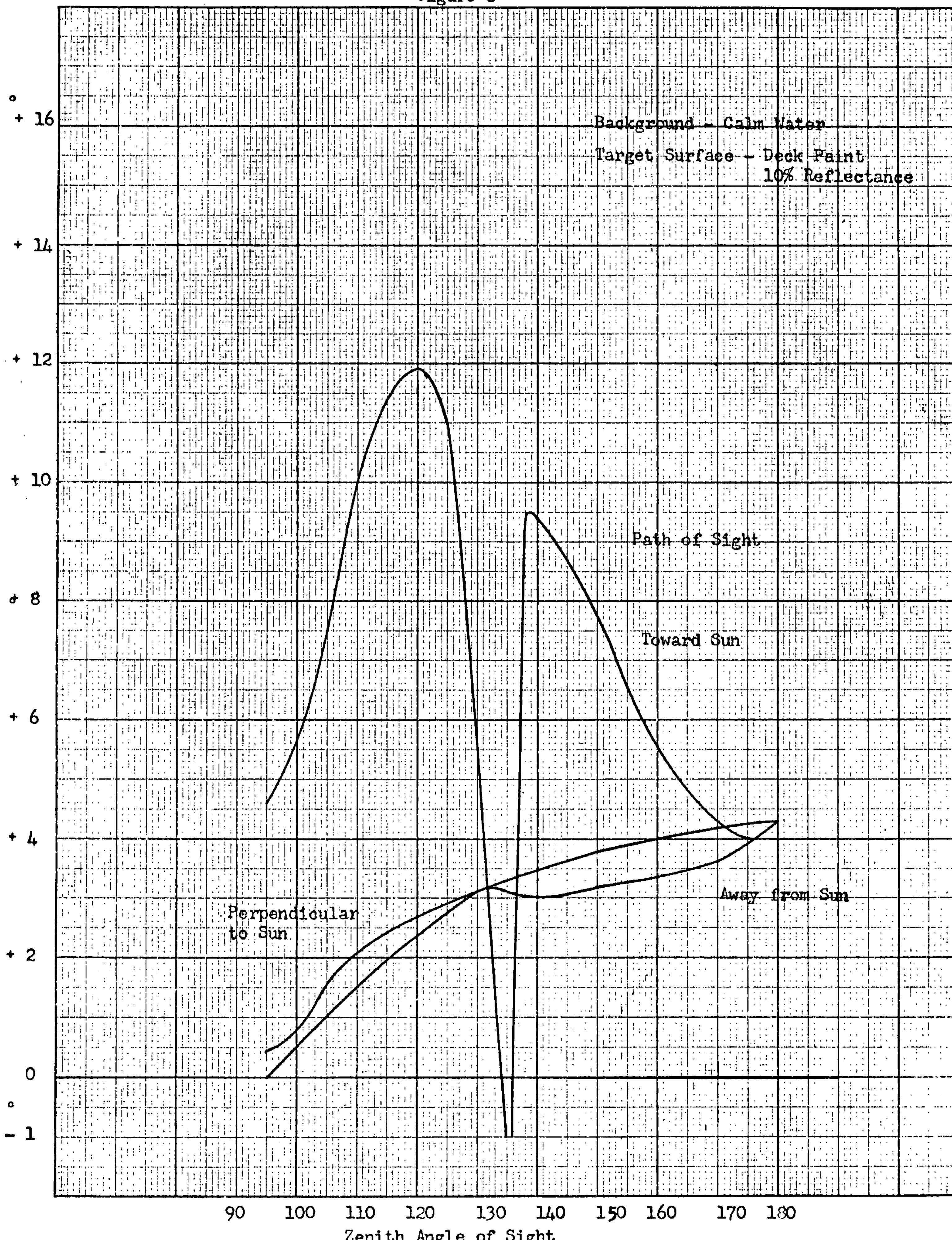
Figure 5

to positive and negative contrast of the same absolute value. The best reduction in absolute contrast can be achieved by a minimization of the area between the zero contrast line and the contrast curves when the curve is plotted on a linear contrast scale. One way to achieve this minimization is to have as large a portion of the contrast curve lie on or near zero contrast as possible. This would also usually mean that the area would be fairly equally divided between positive and negative contrast.

In achieving the above, several factors must be noted. First, the particular grid used for plotting the contrast curves gravely distorts the contrast picture. On this grid equal distances above and below the contrast line do not constitute equal absolute contrasts. The grid completely masks the fact that negative contrast has a maximum value of minus one, whereas positive contrast can be infinitely large. For this reason, in evaluating a change in reference line it is useful to use a moveable contrast scale to measure the new absolute values of contrast achieved. An illustration of contrast distortion by the logarithmic grid can be seen by comparison of Figures 5 and 6. Figure 6 gives the contrast curves for the standard Navy deck paint plotted on a linear contrast grid.

The second factor to be noted while minimizing the contrast is the relative importance of portions of the contrast curves. These must be evaluated in terms of the size of the projected area of the target which has this particular contrast. For instance, for the horizontal surface, the maximum area is seen when the line of view is normal to the surface, zenith angle of sight 180°. At 120° zenith angle the area has been reduced to 50% of its maximum. Therefore, for the deck paint the most important portion of the contrast curve lies on the right hand side of the graph, the contrasts for the more slanted paths of sight (zenith angle less than 120°) can be literally ignored.

Figure 6


Background - Calm Water
Target Surface - Deck Paint
10% Reflectance
Path of Sight
Toward Sun
Away from Sun
Perpendicular to Sun
+ 16
+ 14
+ 12
+ 10
+ 8
+ 6
+ 4
+ 2
0
- 1
90
100
110
120
130
140
150
160
170
180
Zenith Angle of Sight

The third factor is the achievability of a given paint reflectance which will produce the desired contrast change. There is a minimum reflectance achievable for black paint depending upon whether a dull or glossy finish is desired. Conversely there is also a maximum reflectance for dull or glossy paints.

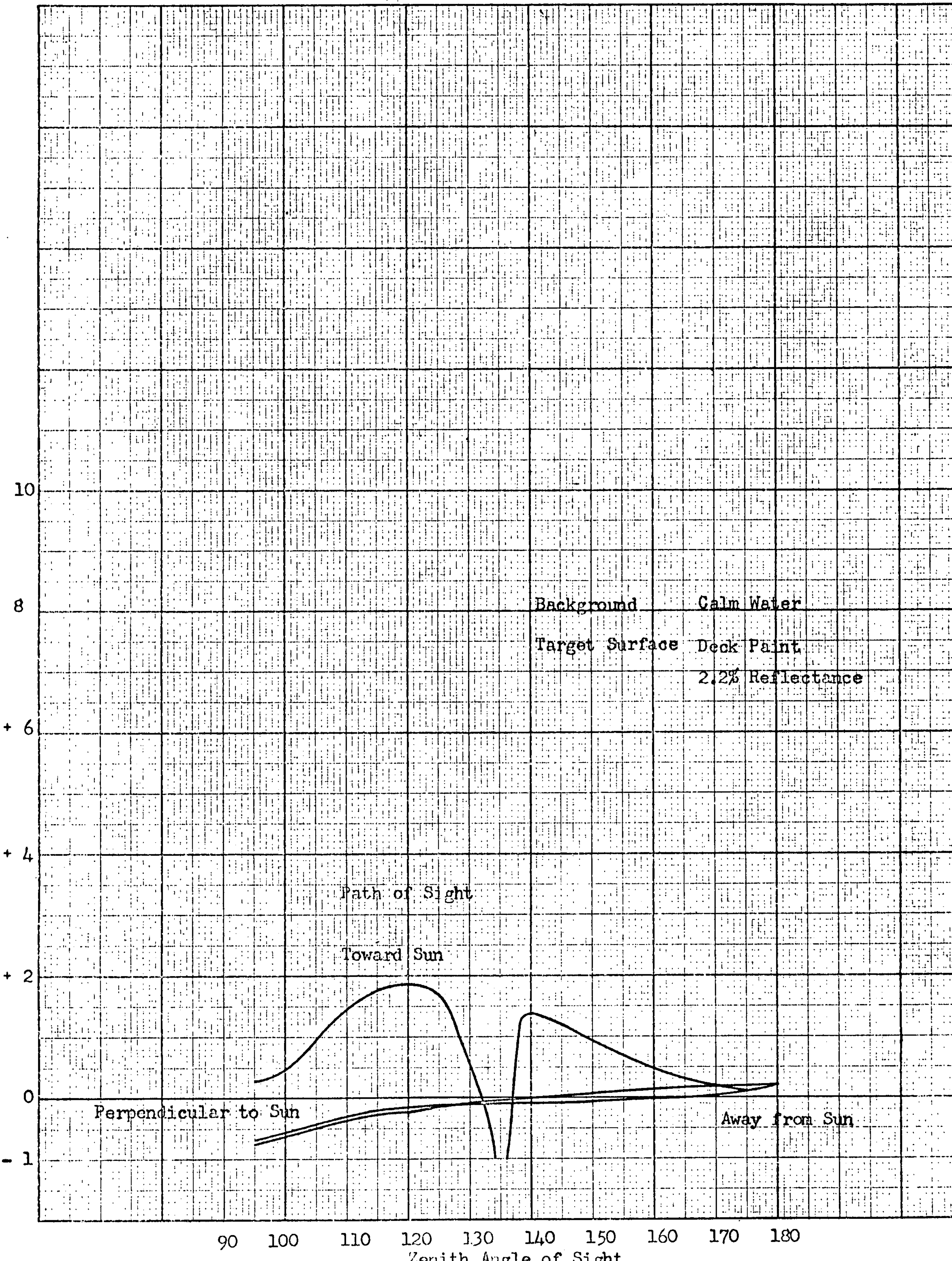
The dotted reference line depicted in Figure 5 was selected using the criteria outlined above. Figure 7 illustrates the effectiveness of this particular selection.

The reflectance of the paint which will produce this contrast was found by dividing the standard paint reflectance (10%) by the factor by which the zero reflectance line was raised (4.5). The specification for the concealment paint thus was 2.2%. This approximates the specification of a paint currently in use for submarines.

To complete the contrast reduction for the target under calm water, clear day condition, the contrast of the target surfaces which are painted with standard hull paint, 27% reflectance, were analyzed in a similar manner. Figure 8 illustrates the contrasts of the target surfaces and the change in the zero contrast reference line. In this instance the lower angles of sight were the most important in terms of the maximum projected area. The specification of reflectance for concealment paint on the hull surface was 7%.

The additional step necessary to complete the engineering procedure for contrast minimization of a target under the conditions defined above, would be to obtain contrast curves for paints approximating the above specifications by direct measurement under the appropriate conditions. This step has been omitted in this illustration. If several paints were found to approximate the desired gloss characteristics, the final criteria for selection would be the sighting ranges.

Figure 7


Background Calm Water
Target Surface Deck Paint
2.2% Reflectance
Path of Sight
Toward Sun
Perpendicular to Sun
Away from Sun
10
8
+ 6
+ 4
+ 2
0
- 1
90 100 110 120 130 140 150 160 170 180
Zenith Angle of Sight

Background - Calm Water
Target Surface - Hull Paint
27% Reflectance

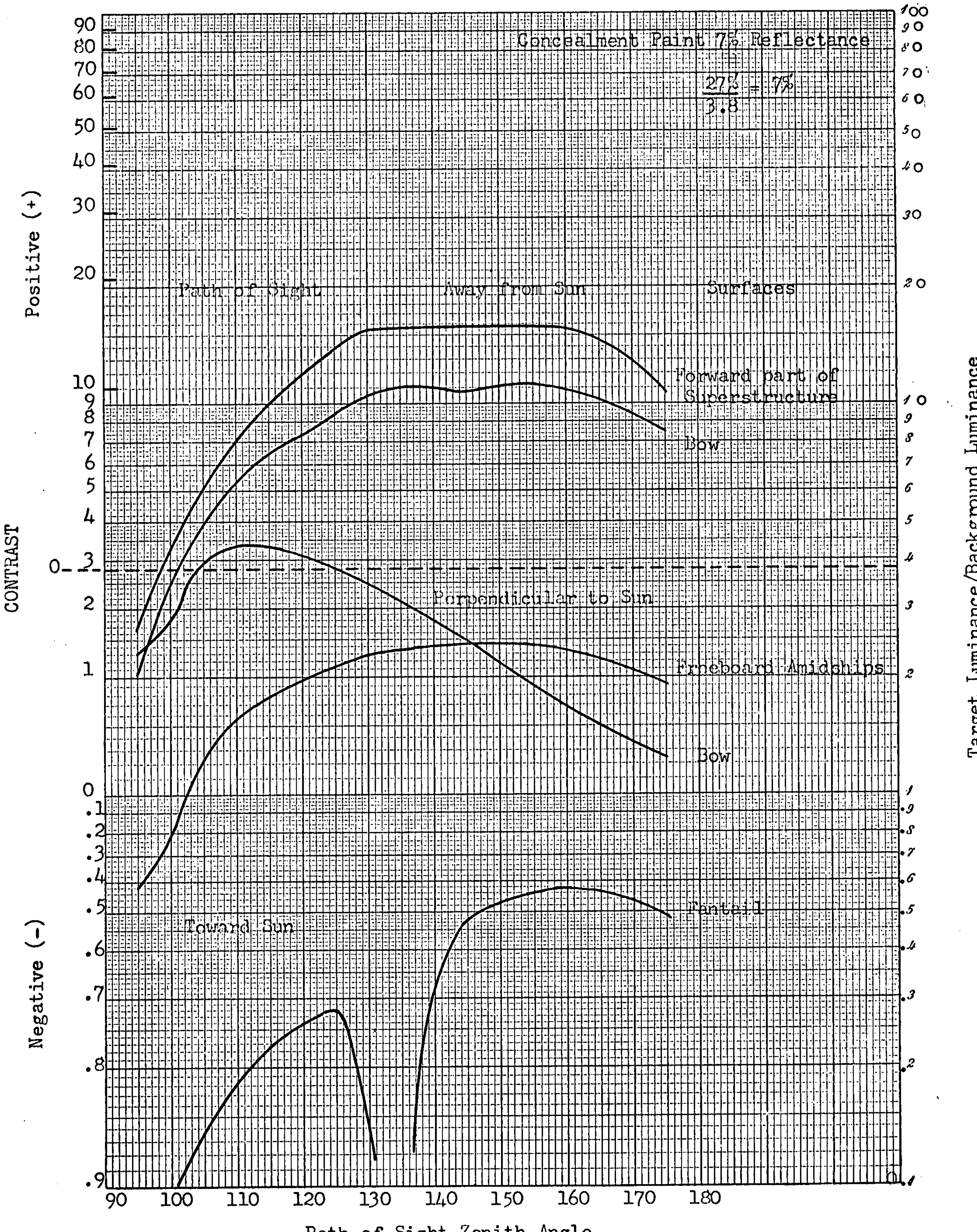


Figure 8

EFFECTIVENESS

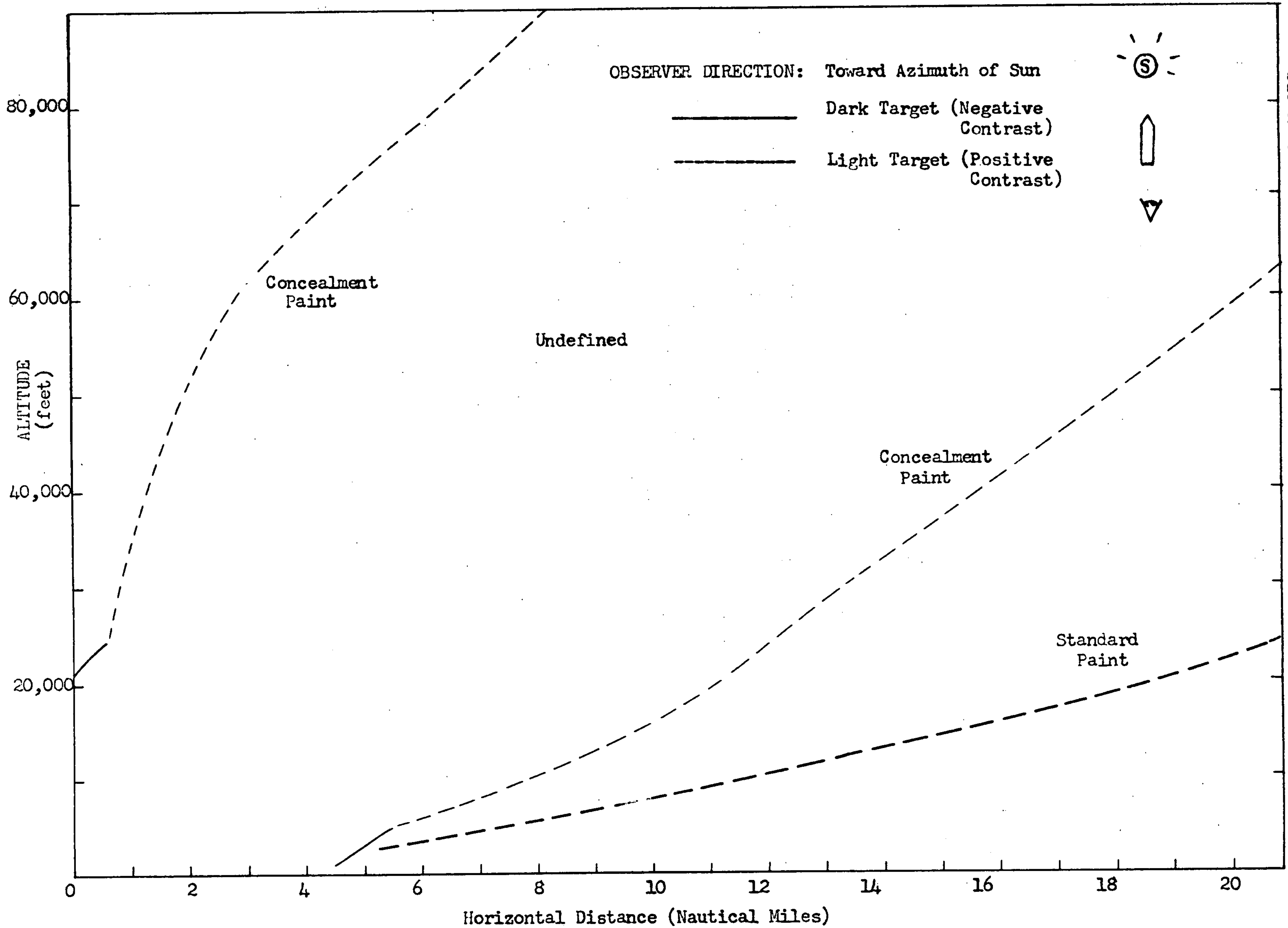
Although it is not the proper subject of this report to describe the method of calculating sighting ranges, it is perhaps appropriate to illustrate the effectiveness of the contrast minimization achieved in the above example, by a comparison of the visibility of the target when painted with the standard and the concealment paints.

For this example, the properties of the atmosphere were derived from data from the atmospheric optics program of this Laboratory. These data were taken on a clear day near Eglin Field, Florida, 28 February 1956. Data from this day can be considered typical of a clear day with the sun at 45° zenith angle.

The observer was assumed to be emmetropic and well-trained. He was flying at various altitudes a course which would take him directly over the target at a speed of 250 knots. The direction of his travel was toward the azimuth of the sun (Figure 9), perpendicular to the sun (Figure 10), and then away from the meridian of the sun (Figure 11).

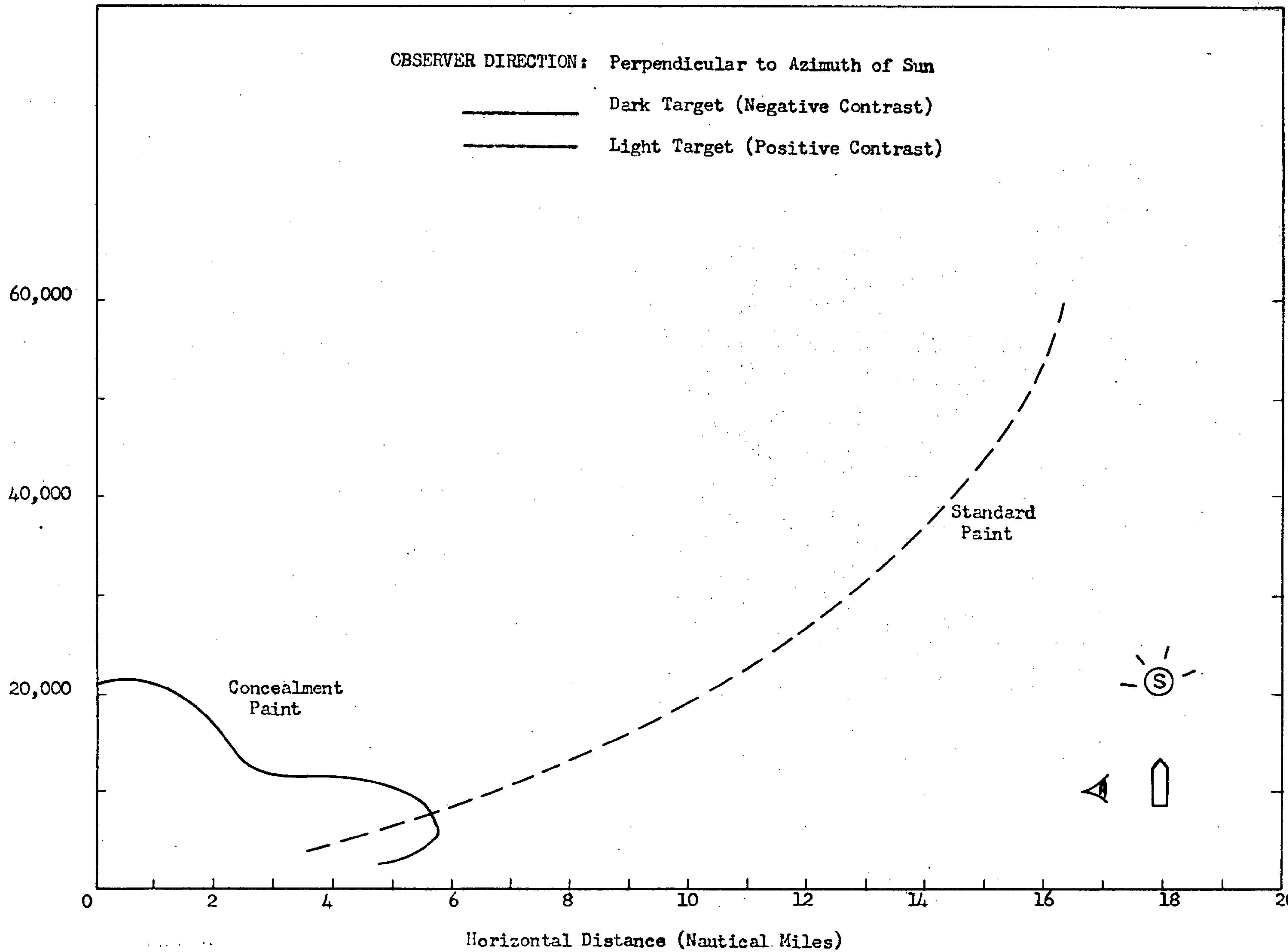
Detection ranges are given on the graphs. These are the maximum ranges that the presence of a target can be detected by an observer looking directly toward the target. In a search situation, these curves would represent zero percent probability of detection.

The two curves in Figure 9 are actually not defined near 135° zenith angle of sight. Both targets are highly visible near that angle of sight due to the high positive contrast of the deck paints against the dark water surface. For a couple of degrees before and after 135°, however, the image of the sun



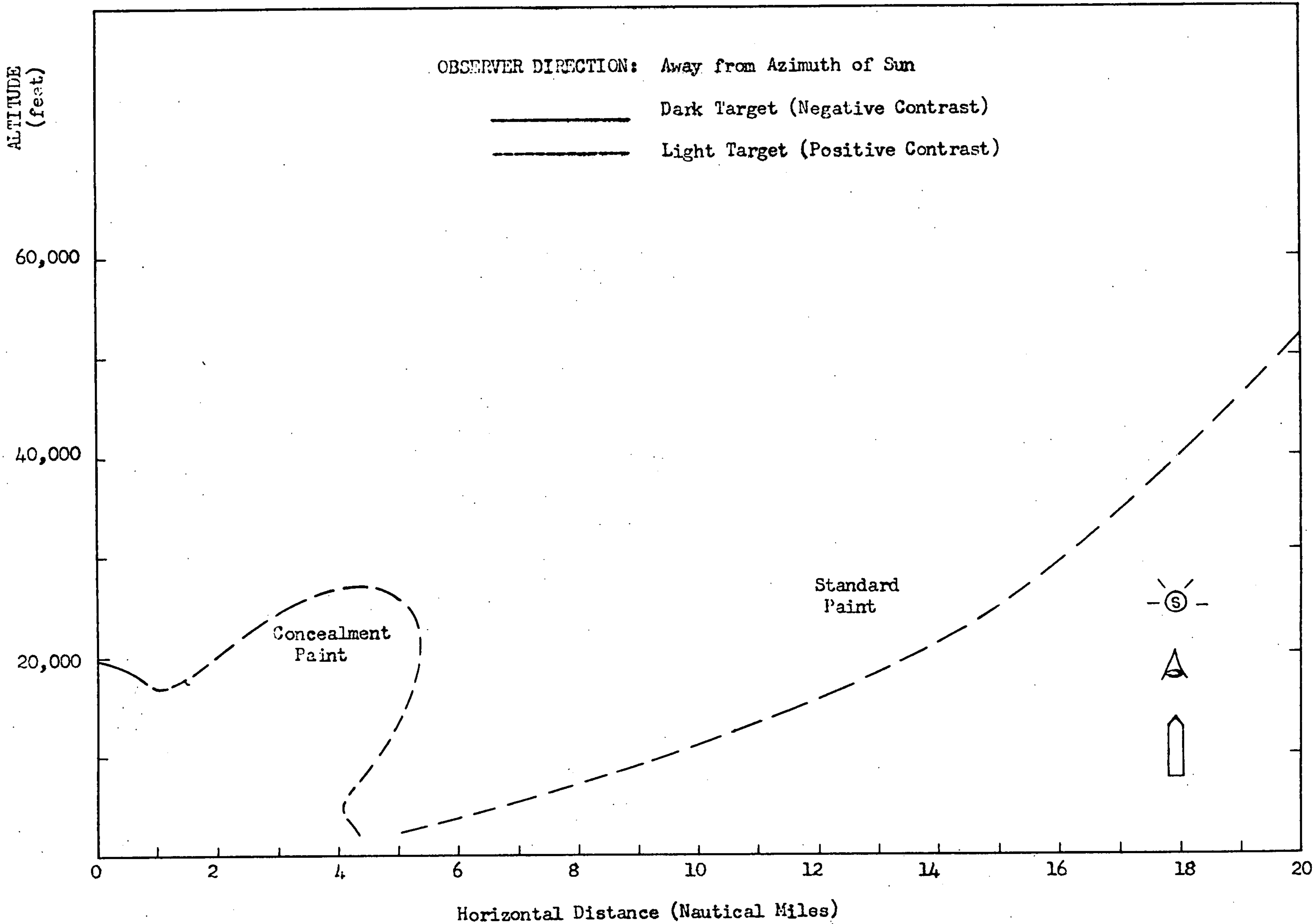
OBSERVER DIRECTION: Toward Azimuth of Sun
Dark Target (Negative Contrast)
Light Target (Positive Contrast)
S
Concealment Paint
Undefined
Concealment Paint
Standard Paint
ALTITUDE (feet)
80,000
60,000
40,000
20,000
0
2
4
6
8
10
12
14
16
18
20
Horizontal Distance (Nautical Miles)

SIO Ref. 61-16



OBSERVER DIRECTION: Perpendicular to Azimuth of Sun
Dark Target (Negative Contrast)
Light Target (Positive Contrast)
60,000
40,000
20,000
Standard Paint
Concealment Paint
S
0
2
4
6
8
10
12
14
16
18
20
Horizontal Distance (Nautical Miles)

Figure 10



OBSERVER DIRECTION: Away from Azimuth of Sun
Dark Target (Negative Contrast)
Light Target (Positive Contrast)
ALTITUDE (feet)
60,000
40,000
20,000
Concealment Paint
Standard Paint
S
0
2
4
6
8
10
12
14
16
18
20
Horizontal Distance (Nautical Miles)

is reflected in the comparatively calm water, and the targets are negative in contrast or silhouettes. Since the change from positive to negative contrast in this portion of the curve is extremely sudden, and the glare from the direct sun image in the water makes that angle difficult from the observer's standpoint, that portion of the curve has been left undefined.

For this particular set of conditions, calm sea, etc., the contrast could have been further minimized for an aerial observer by increasing the gloss in the deck paint. It is believed that the gloss in the present deck paint (and in the concealment paint) is more suitable for higher sea states where the image of the sun is smeared over a larger angle of sight.

Figure 12 is a picture showing the appearance of the two ships when the observer looks 20° from the vertical (zenith angle of view of 160°) and away from the meridian of the sun (the sun is at the back of the observer). Both targets are lighter than the background but the standard deck paint is very high in contrast, comparatively.

In any given problem of contrast minimization for a Navy vessel, it is conceivable that there might be a single condition in which it is paramount to have contrast minimized or a series or conditions of equal or varying importance. The initial contrast analysis would, in the latter case, include all of these conditions and the selection of the contrast reference line would involve a compromise with what is best for each separate situation.

To illustrate the necessity for compromise when several conditions become important, sighting ranges were also computed for the situation for which the standard Navy paints were originally selected. The standard paints were selected to minimize the visibility of the ship from submarines and other surface ships. Figure 13 shows the comparison of the two destroyers when

Figure 12

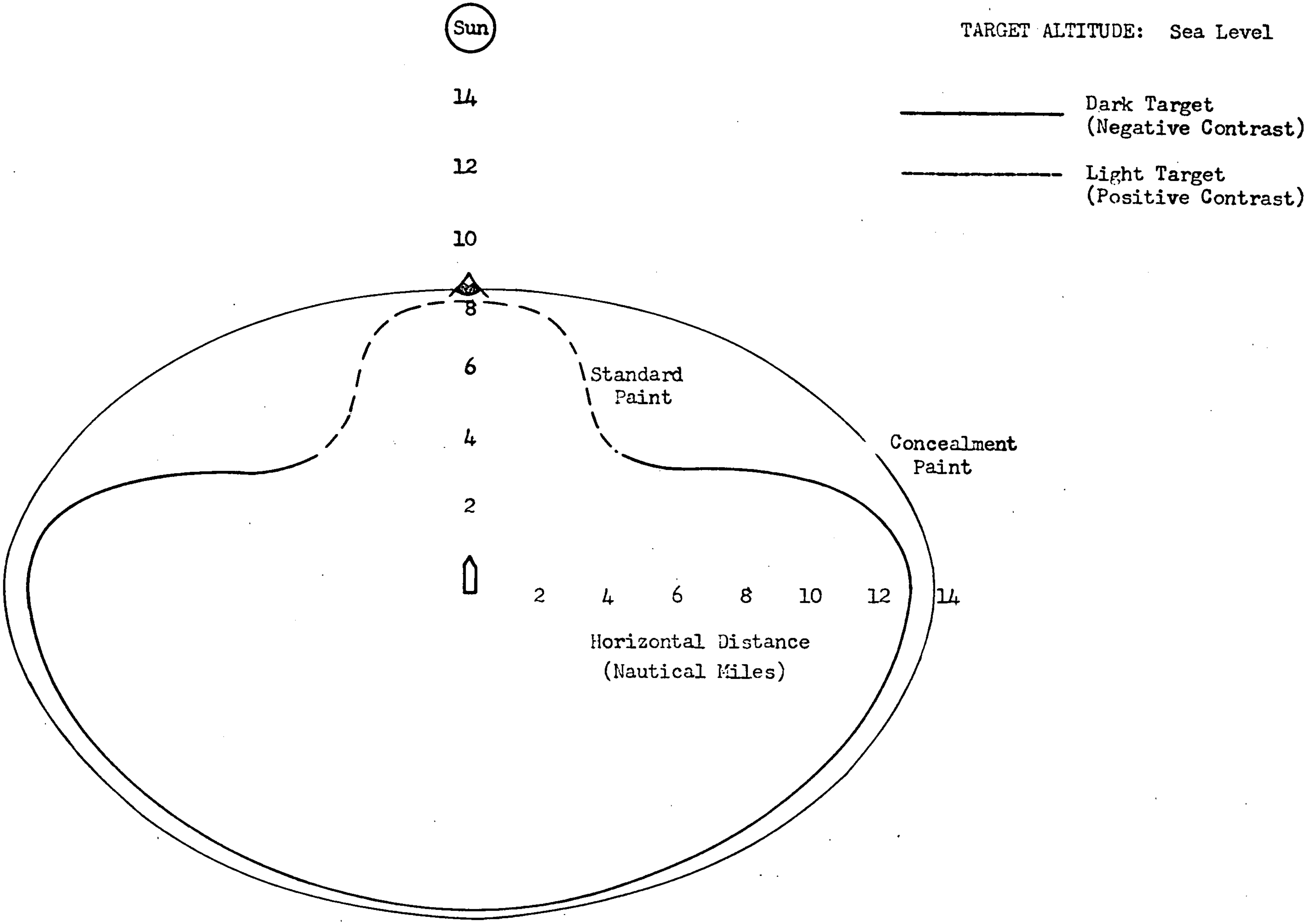
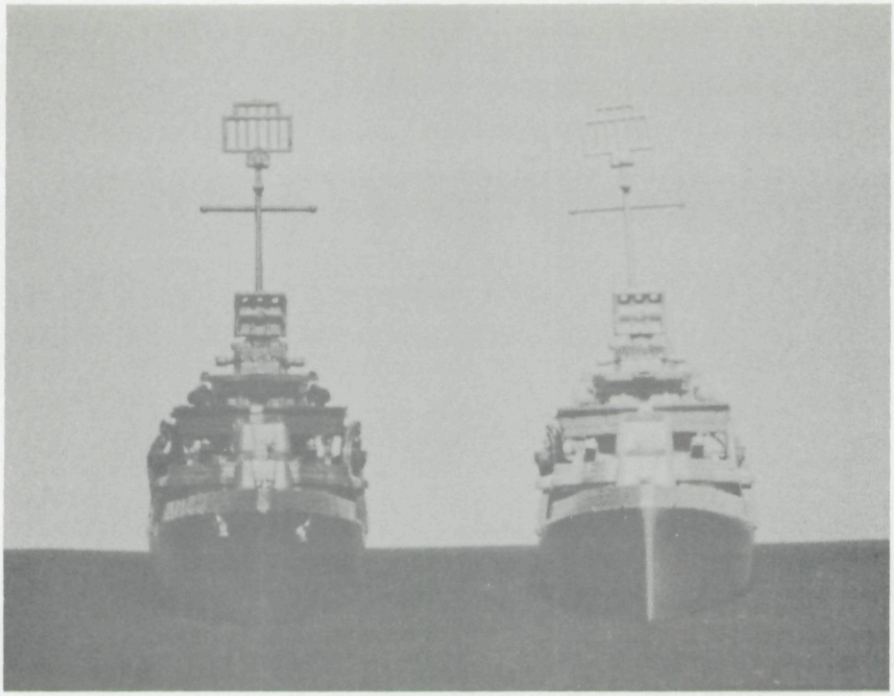

TARGET ALTITUDE: Sea Level
Dark Target
(Negative Contrast)
Light Target
(Positive Contrast)
Sun
14
12
10
8
6
4
2
Standard
Paint
Concealment
Paint
2
4
6
8
10
12
14
Horizontal Distance
(Nautical Miles)

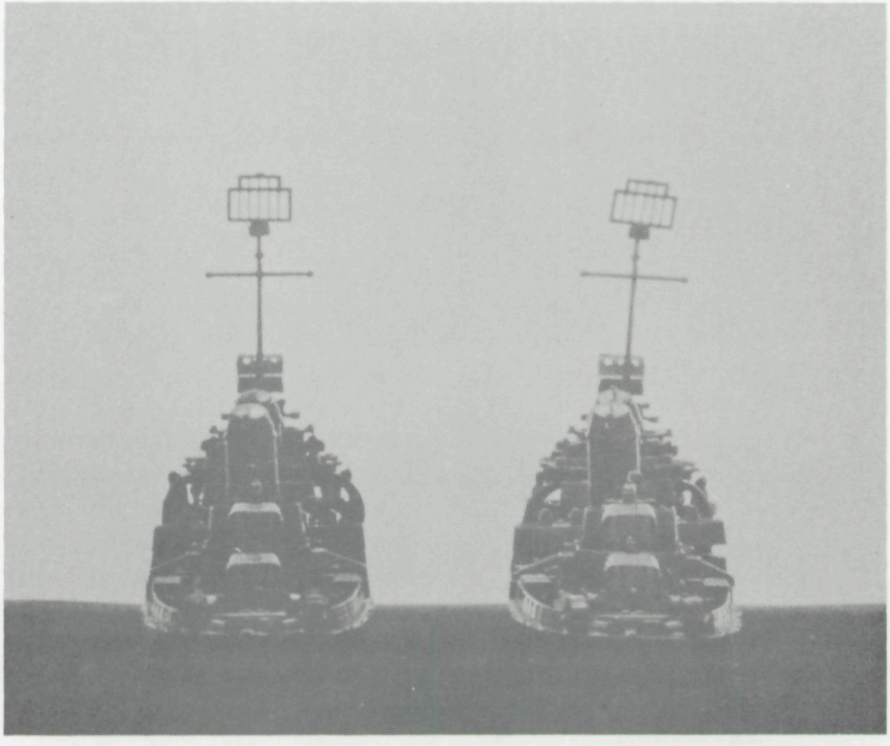
Figure 13

viewed horizontally. As can be seen, although the sighting ranges of an aerial observer were minimized by the concealment paints, the sighting ranges of an observer at sea level are greater than for the same ship painted with standard Navy paint.

Figure 14 illustrates the appearance of the two ships when viewed against the horizon sky from the front and from the rear. In the first case the lighter paint on the standard vessel has made it lighter than the background whereas the concealment paint makes it appear as a dark target. From the rear both are seen in the shadow and are dark targets, with the standard vessel slightly less visible.



Concealment Paint Standard Paint



Concealment Paint Standard Paint

Figure 14

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SEASONAL SURVEY OF AVERAGE CLOUDINESS CONDITIONS OVER THE ATLANTIC AND PACIFIC OCEANS

Catharine R. Penn

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Seibert Q. Duntley

Seibert Q. Duntley, Director
Visibility Laboratory

62-19

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SEASONAL SURVEY OF AVERAGE CLOUDINESS CONDITIONS OVER THE ATLANTIC AND PACIFIC OCEANS

1. INTRODUCTION

Charts providing information on percentage frequencies of cloudiness over the oceans are available on a monthly basis in the U. S. Navy Marine Climatic Atlases of the World[1,2,3,4]. Seasonal summaries of this material are required as input data for problems on which the Visibility Laboratory is working. This was accomplished by graphically averaging the contours for each season. Separate charts were made for percentage frequency of total cloud cover less than 2/10 and for percentage frequency of low cloud amounts more than 6/10. They are presented seasonally by ocean.

Data for total cloud cover 8/10 or more are contained in a more recent publication[5]. Similar seasonal analyses have been made of these data and it is planned to continue the analyses as additional volumes become available. They are not included in this report.

In the original data there is an overlapping of areas but since the volumes were issued separately and presumably analyzed independently by ocean, the isolines at the overlap are not coincidental. No attempt has been made to make the overlap continuous at this time.

As in the original publications, broken lines are used in areas where marine data are sparse or non-existent.

Table of Contents

	Page
1. INTRODUCTION	1
2. NORTH ATLANTIC OCEAN	
Chart 1 Dec., Jan., Feb., Total Cloud 2/10 or less	2
Chart 2 Dec., Jan., Feb., Low Cloud 6/10 or more	3
Chart 3 Mar., Apr., May, Total Cloud 2/10 or less	4
Chart 4 Mar., Apr., May, Low Cloud 6/10 or more	5
Chart 5 Jun., Jul., Aug., Total Cloud 2/10 or less	6
Chart 6 Jun., Jul., Aug., Low Cloud 6/10 or more	7
Chart 7 Sep., Oct., Nov., Total Cloud 2/10 or less	8
Chart 8 Sep., Oct., Nov., Low Cloud 6/10 or more	9
3. SOUTH ATLANTIC OCEAN	
Chart 9 Dec., Jan., Feb., Total Cloud 2/10 or less	10
Chart 10 Dec., Jan., Feb., Low Cloud 6/10 or more	11
Chart 11 Mar., Apr., May, Total Cloud 2/10 or less	12
Chart 12 Mar., Apr., May, Low Cloud 6/10 or more	13
Chart 13 Jun., Jul., Aug., Total Cloud 2/10 or less	14
Chart 14 Jun., Jul., Aug., Low Cloud 6/10 or more	15
Chart 15 Sep., Oct., Nov., Total Cloud 2/10 or less	16
Chart 16 Sep., Oct., Nov., Low Cloud 6/10 or more	17
4. NORTH PACIFIC OCEAN	
Chart 17 Dec., Jan., Feb., Total Cloud 2/10 or less	18
Chart 18 Dec., Jan., Feb., Low Cloud 6/10 or more	19
Chart 19 Mar., Apr., May, Total Cloud 2/10 or less	20
Chart 20 Mar., Apr., May, Low Cloud 6/10 or more	21
Chart 21 Jun., Jul., Aug., Total Cloud 2/10 or less	22
Chart 22 Jun., Jul., Aug., Low Cloud 6/10 or more	23
Chart 23 Sep., Oct., Nov., Total Cloud 2/10 or less	24
Chart 24 Sep., Oct., Nov., Low Cloud 6/10 or more	25
5. SOUTH PACIFIC OCEAN	
Chart 25 Dec., Jan., Feb., Total Cloud 2/10 or less	26
Chart 26 Dec., Jan., Feb., Low Cloud 6/10 or more	27
Chart 27 Mar., Apr., May, Total Cloud 2/10 or less	28
Chart 28 Mar., Apr., May, Low Cloud 6/10 or more	29
Chart 29 Jun., Jul., Aug., Total Cloud 2/10 or less	30
Chart 30 Jun., Jul., Aug., Low Cloud 6/10 or more .	[illegible]
Chart 31 Sep., Oct., Nov., Total Cloud [illegible]	
Chart 32 Sep., Oct., Nov., Low Cloud [illegible]	
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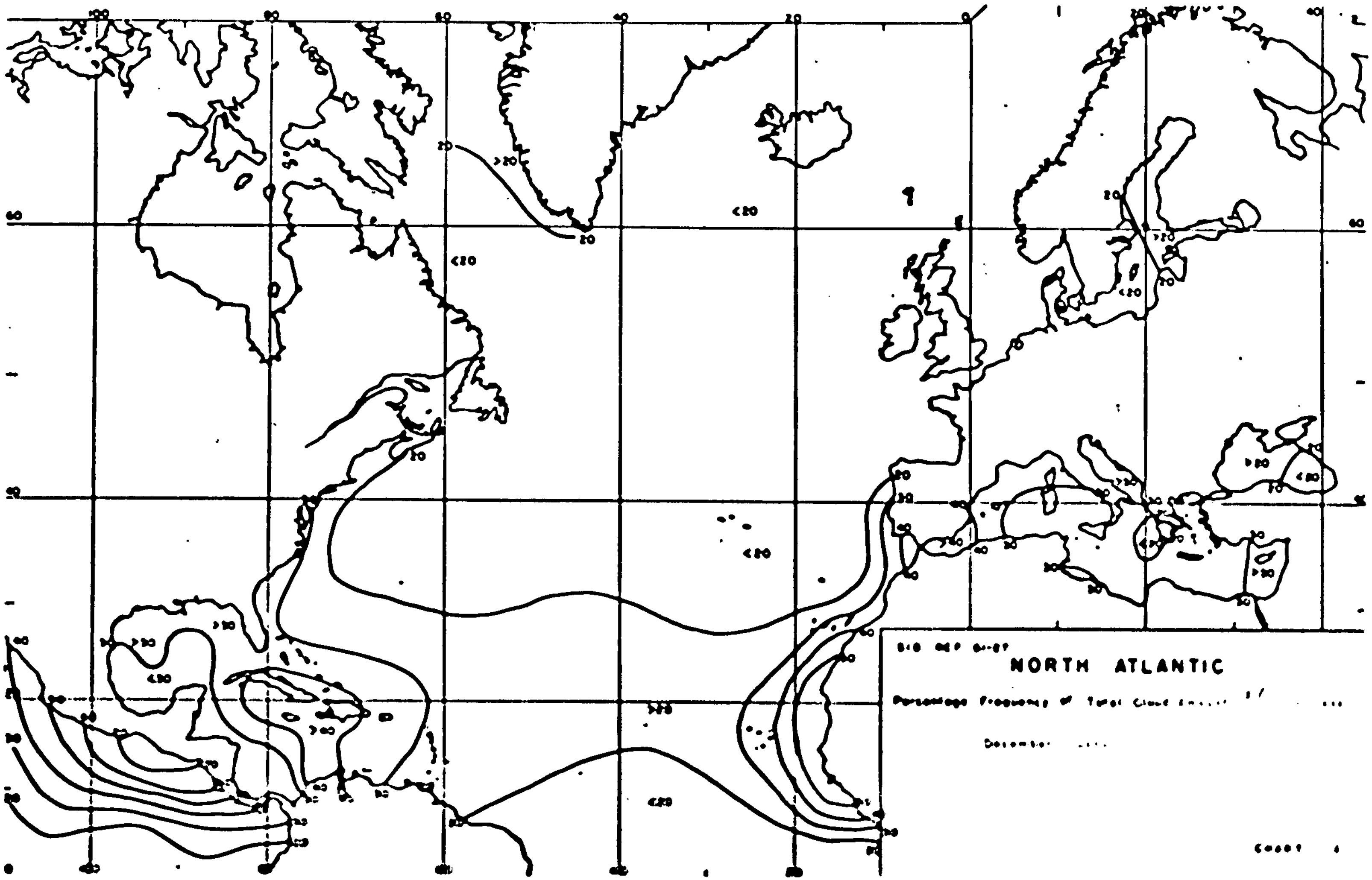
NORTH ATLANTIC
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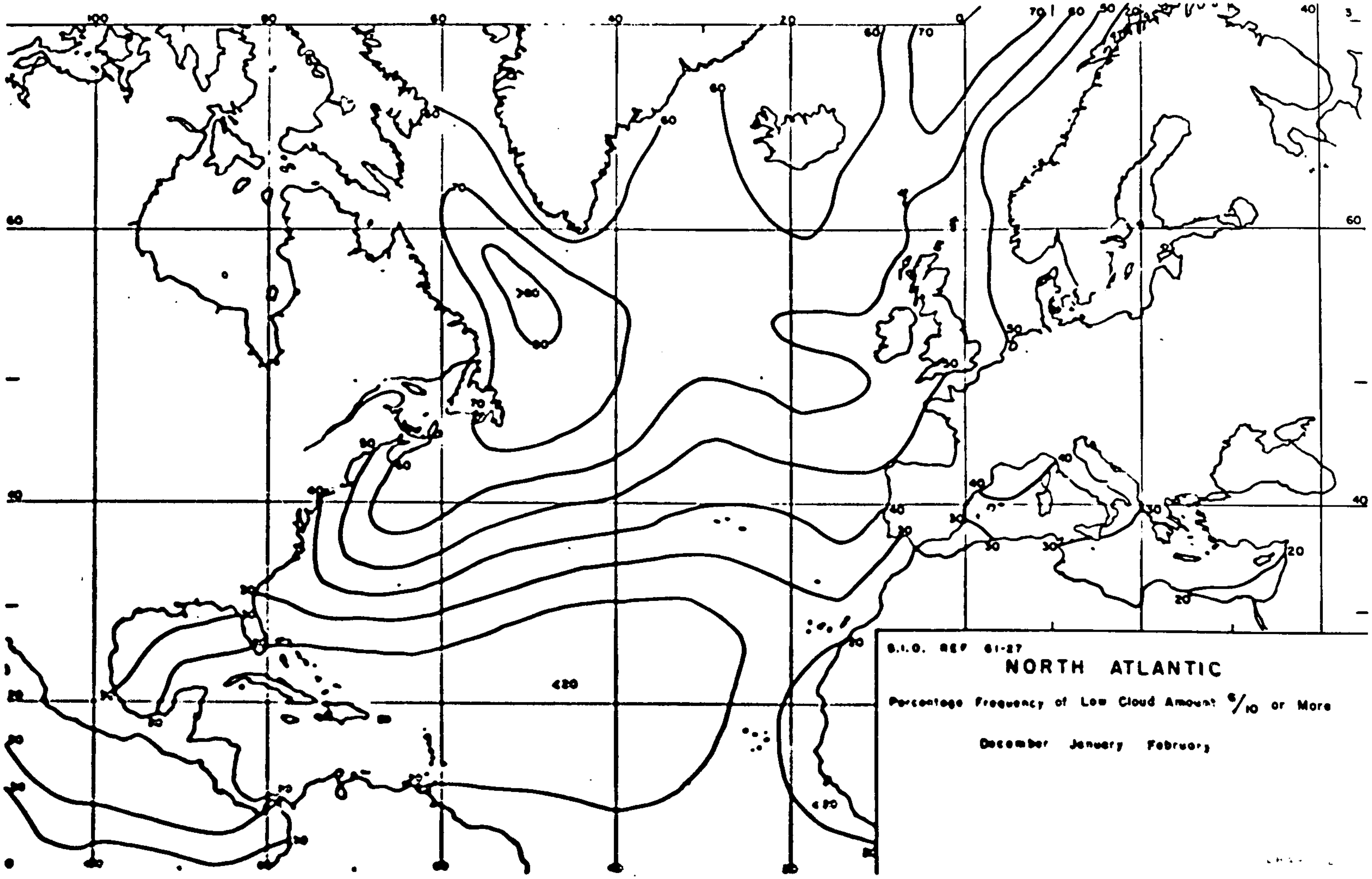
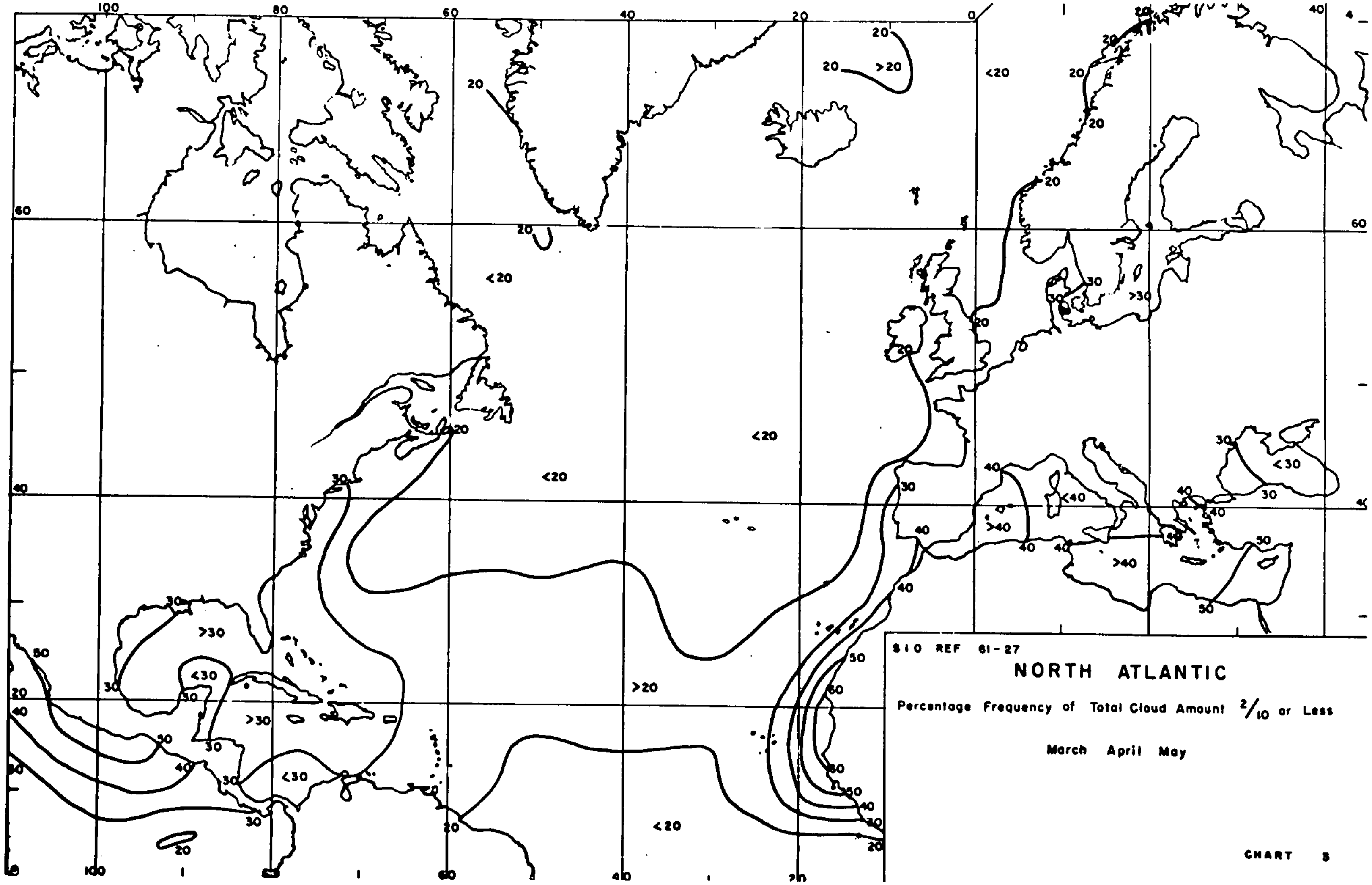

S.I.O. REF 61-27
NORTH ATLANTIC
Percentage Frequency of Low Cloud Amount 6/10 or More
December January February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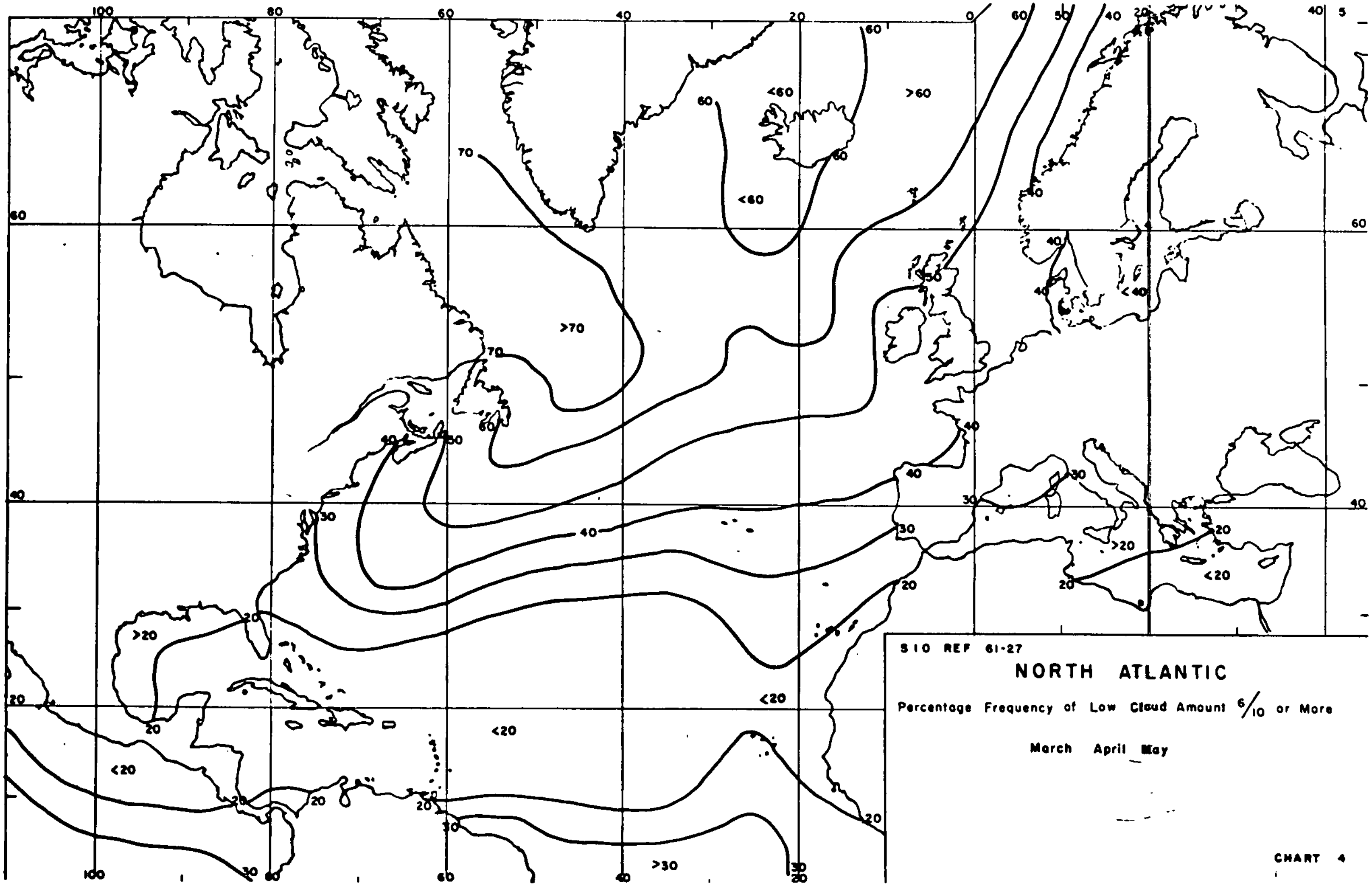
NORTH ATLANTIC
Percentage Frequency of Total Cloud Amount 2/10 or Less
March April May
CHART 3



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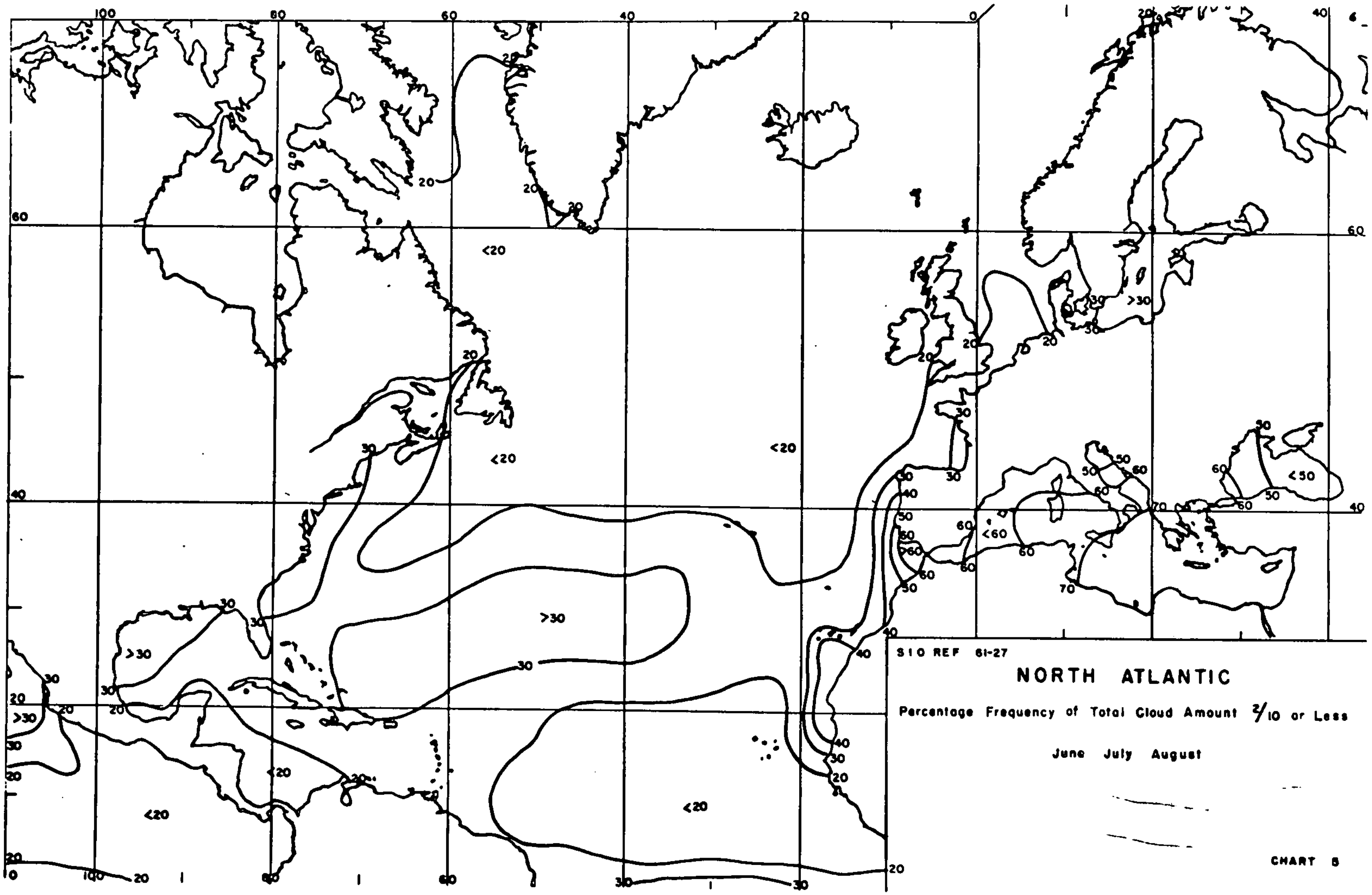
NORTH ATLANTIC

Percentage Frequency of Low Cloud Amount $^{6}/_{10}$ or More

March April May

CHART 4

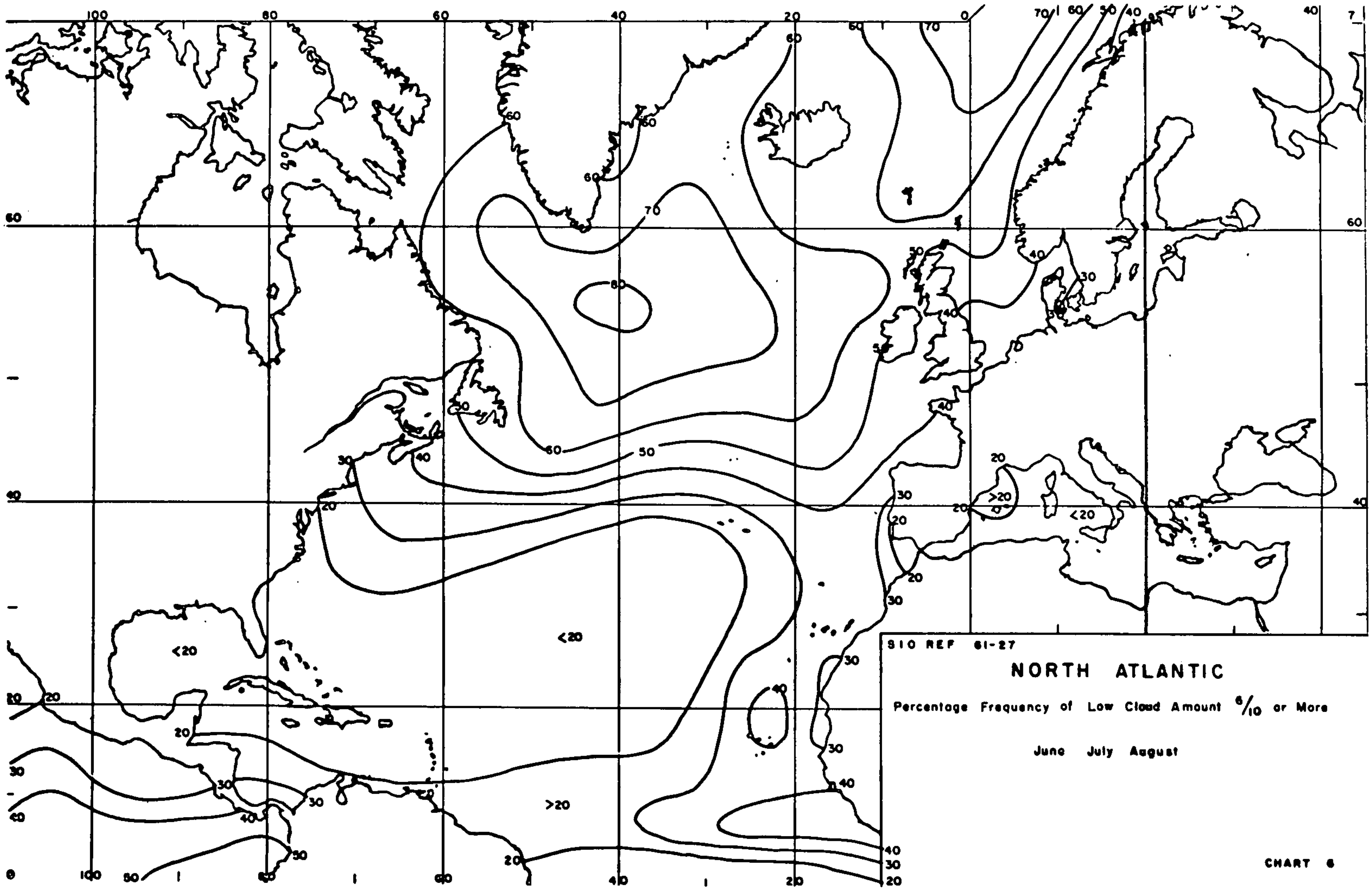


NORTH ATLANTIC

Percentage Frequency of Total Cloud Amount 2/10 or Less

June July August

CHART 8



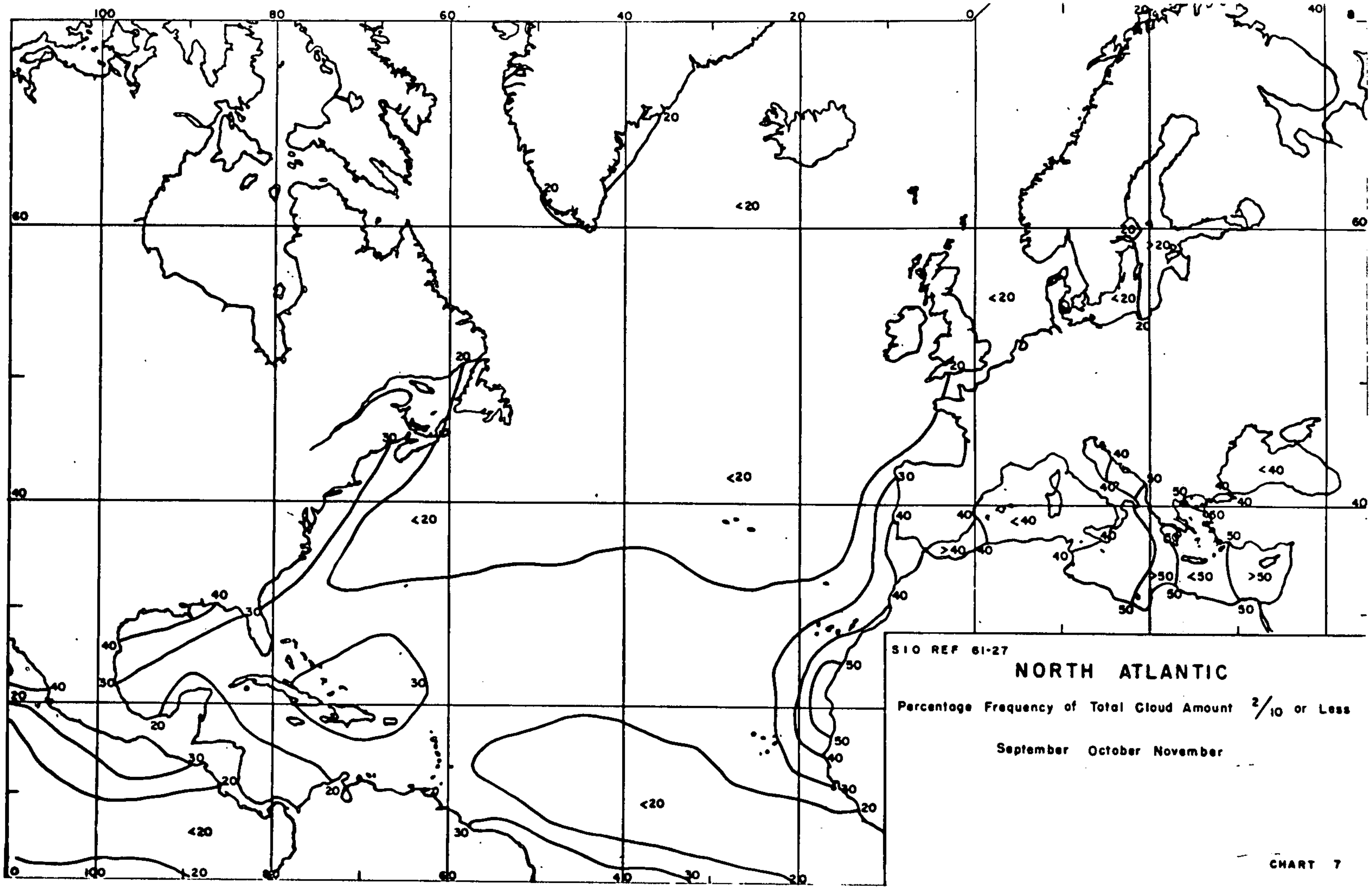
SIO REF 61-27

NORTH ATLANTIC

Percentage Frequency of Low Cloud Amount $^{6}/_{10}$ or More

June July August

CHART 6



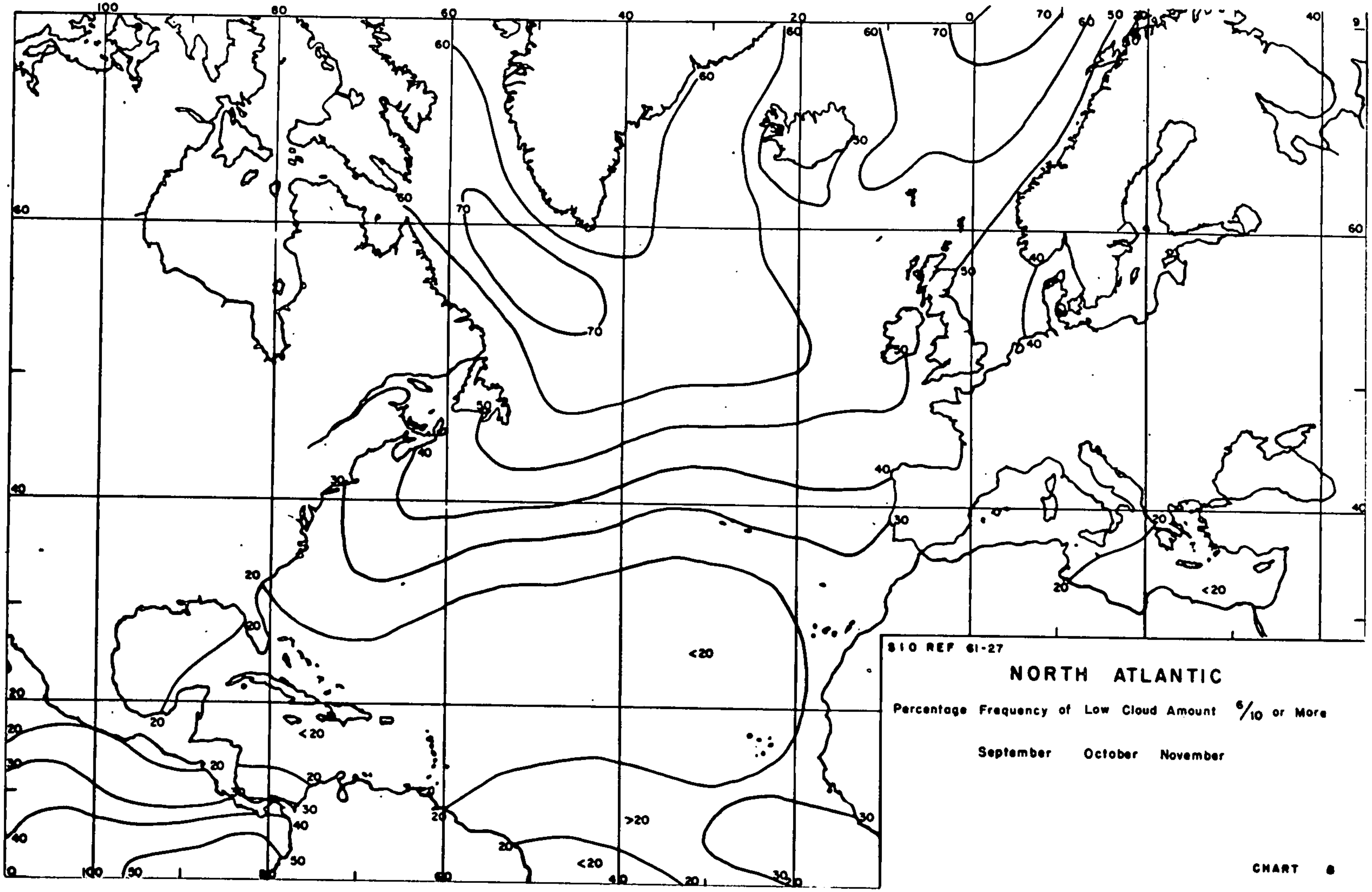
SIO REF 61-27

NORTH ATLANTIC

Percentage Frequency of Total Cloud Amount $^2/_{10}$ or Less

September October November

CHART 7



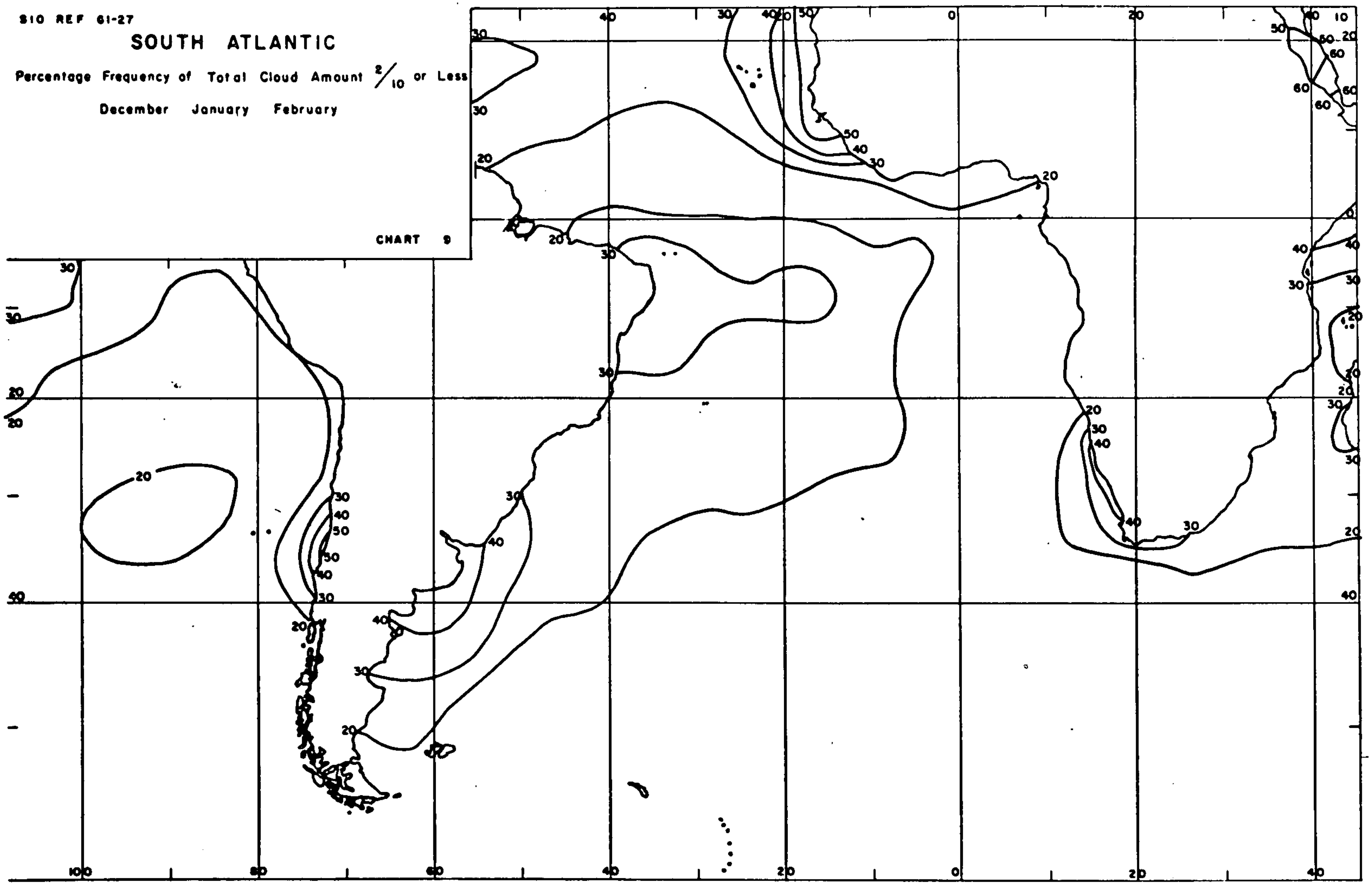
SIO REF 61-27

NORTH ATLANTIC

Percentage Frequency of Low Cloud Amount $^{6}/_{10}$ or More

September October November

CHART 8


SIO REF 61-27
SOUTH ATLANTIC
Percentage Frequency of Total Cloud Amount 2/10 or Less
December January February
CHART 9

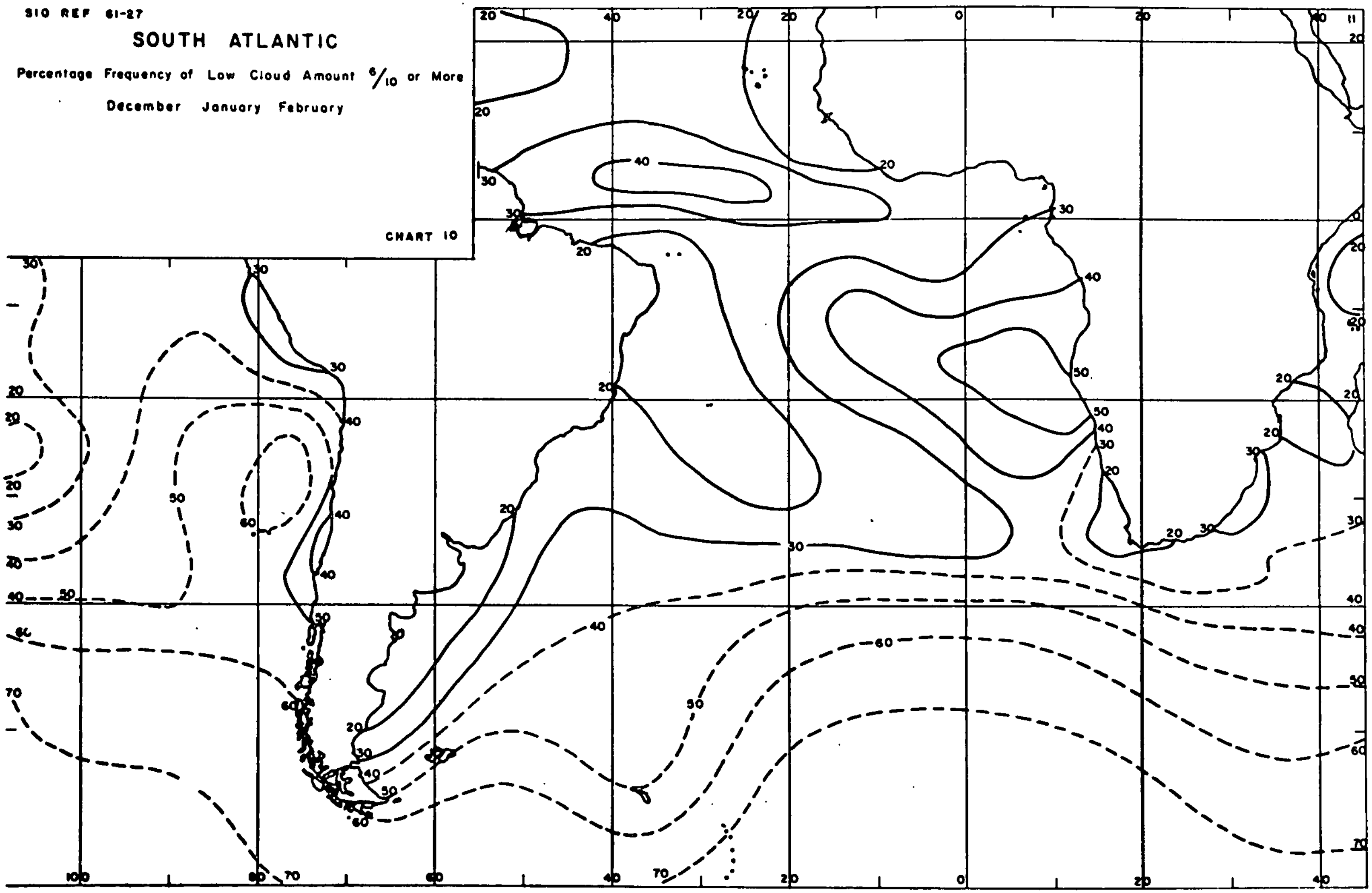
SIO REF 61-27

SOUTH ATLANTIC

Percentage Frequency of Low Cloud Amount 6/10 or More

December January February

CHART 10

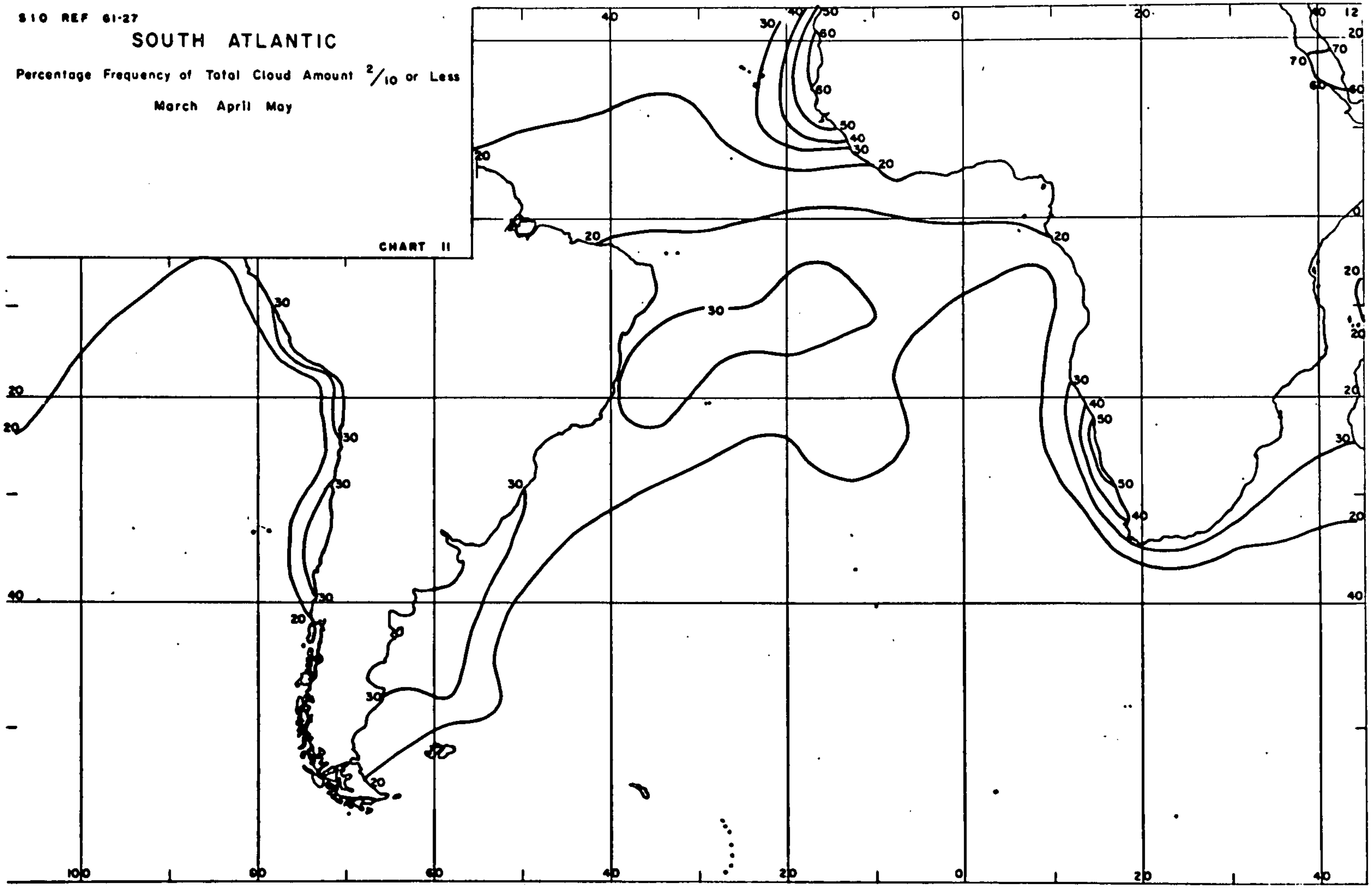


SIO REF 61-27

SOUTH ATLANTIC

Percentage Frequency of Total Cloud Amount 2/10 or Less

March April May



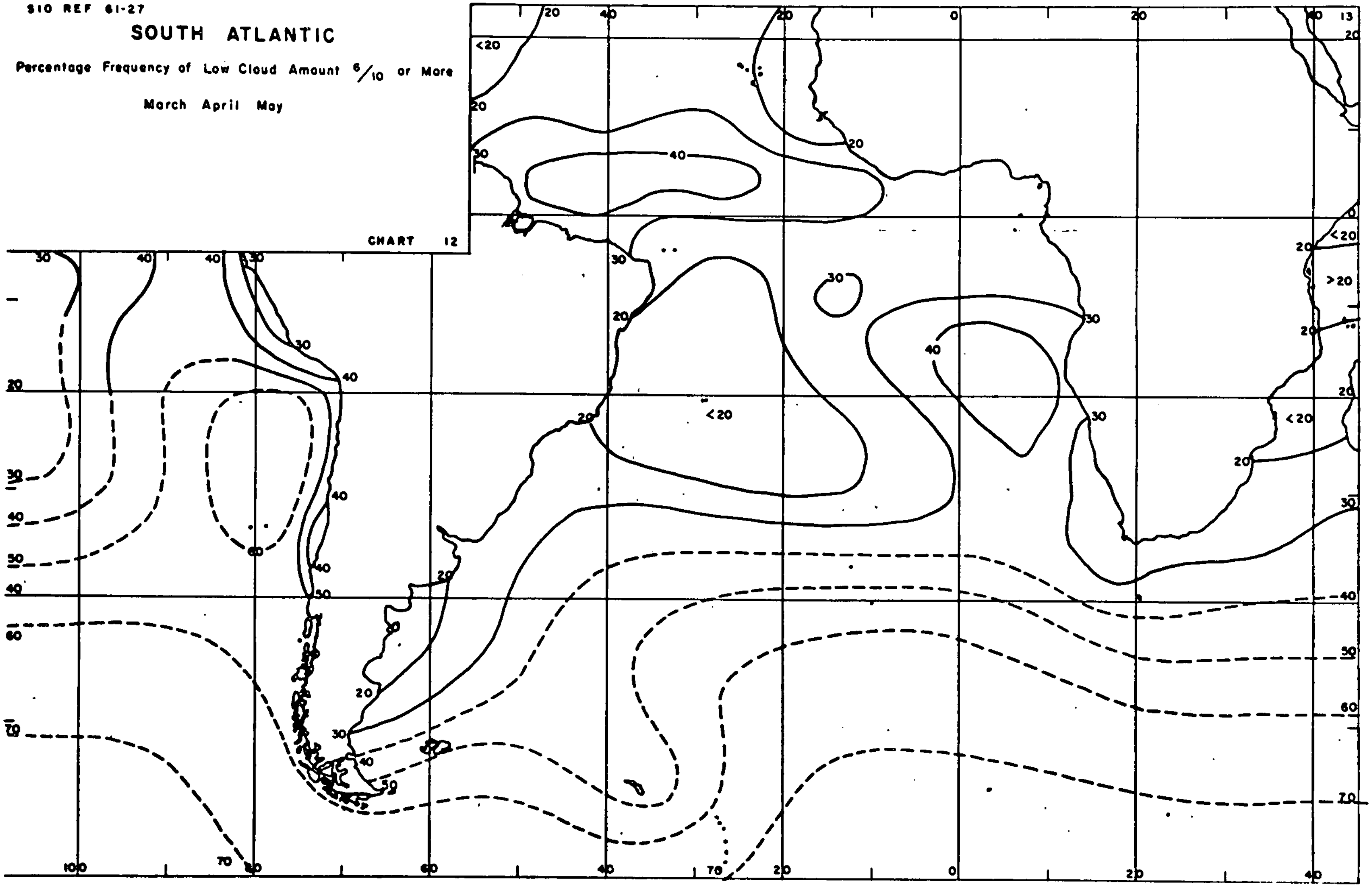
SIO REF 61-27

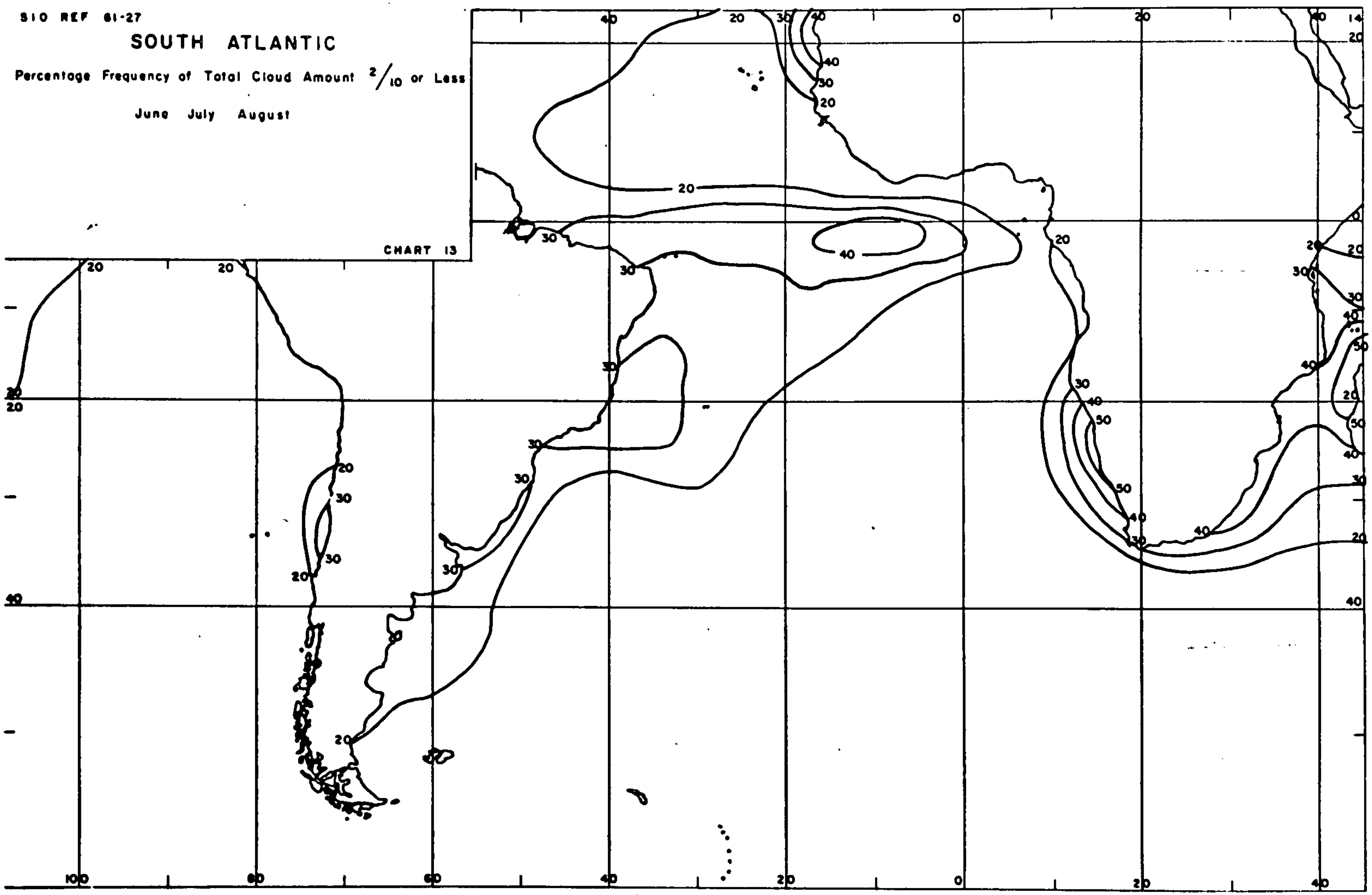
SOUTH ATLANTIC

Percentage Frequency of Low Cloud Amount 6/10 or More

March April May

CHART 12




SIO REF 61-27
SOUTH ATLANTIC
Percentage Frequency of Total Cloud Amount 2/10 or Less
June July August
CHART 13

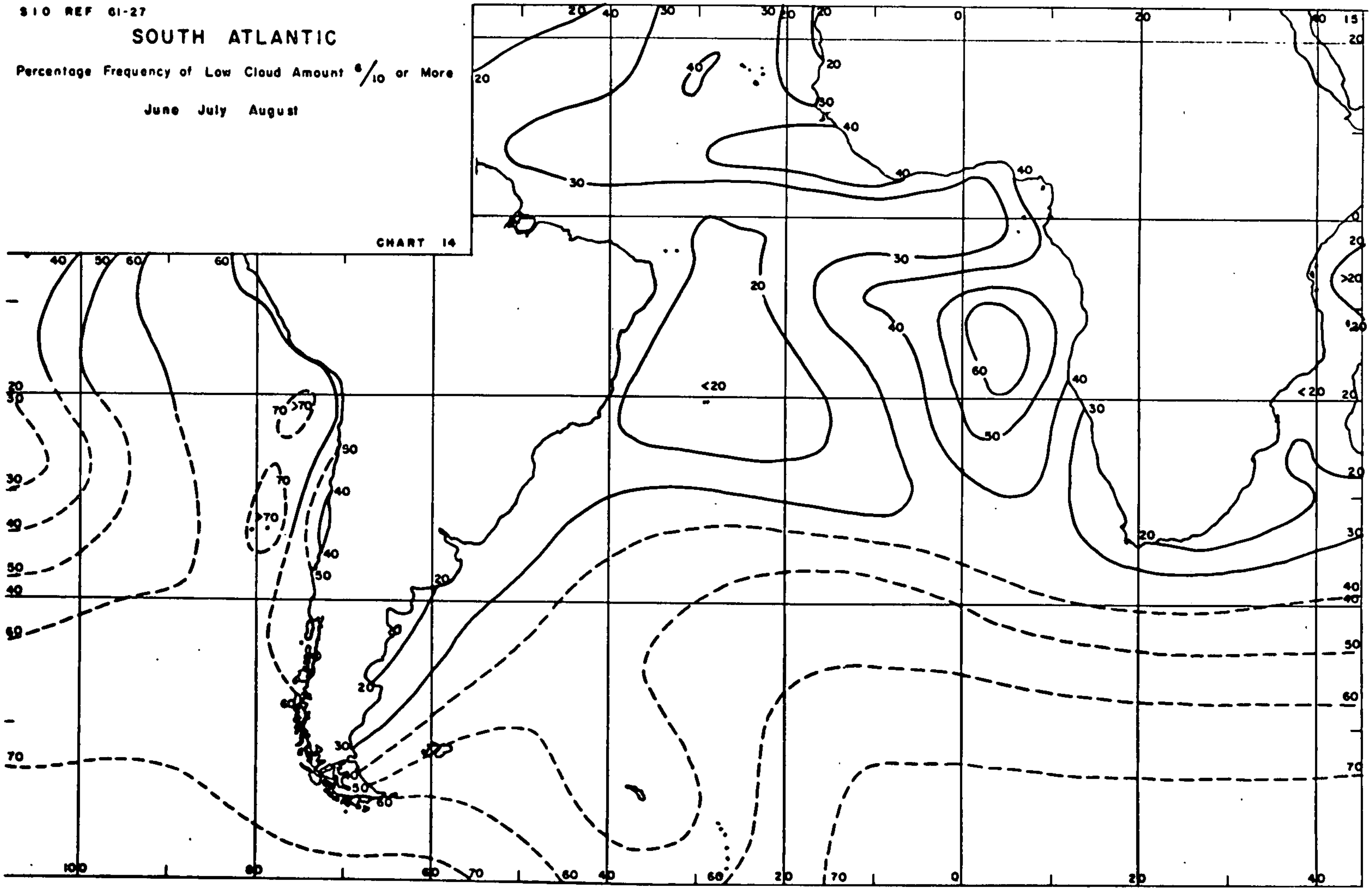
SIO REF 61-27

SOUTH ATLANTIC

Percentage Frequency of Low Cloud Amount 6/10 or More

June July August

CHART 14



SIO REF 61-27

SOUTH ATLANTIC

Percentage Frequency of Total Cloud Amount $^{2}/_{10}$ or Less

September October November

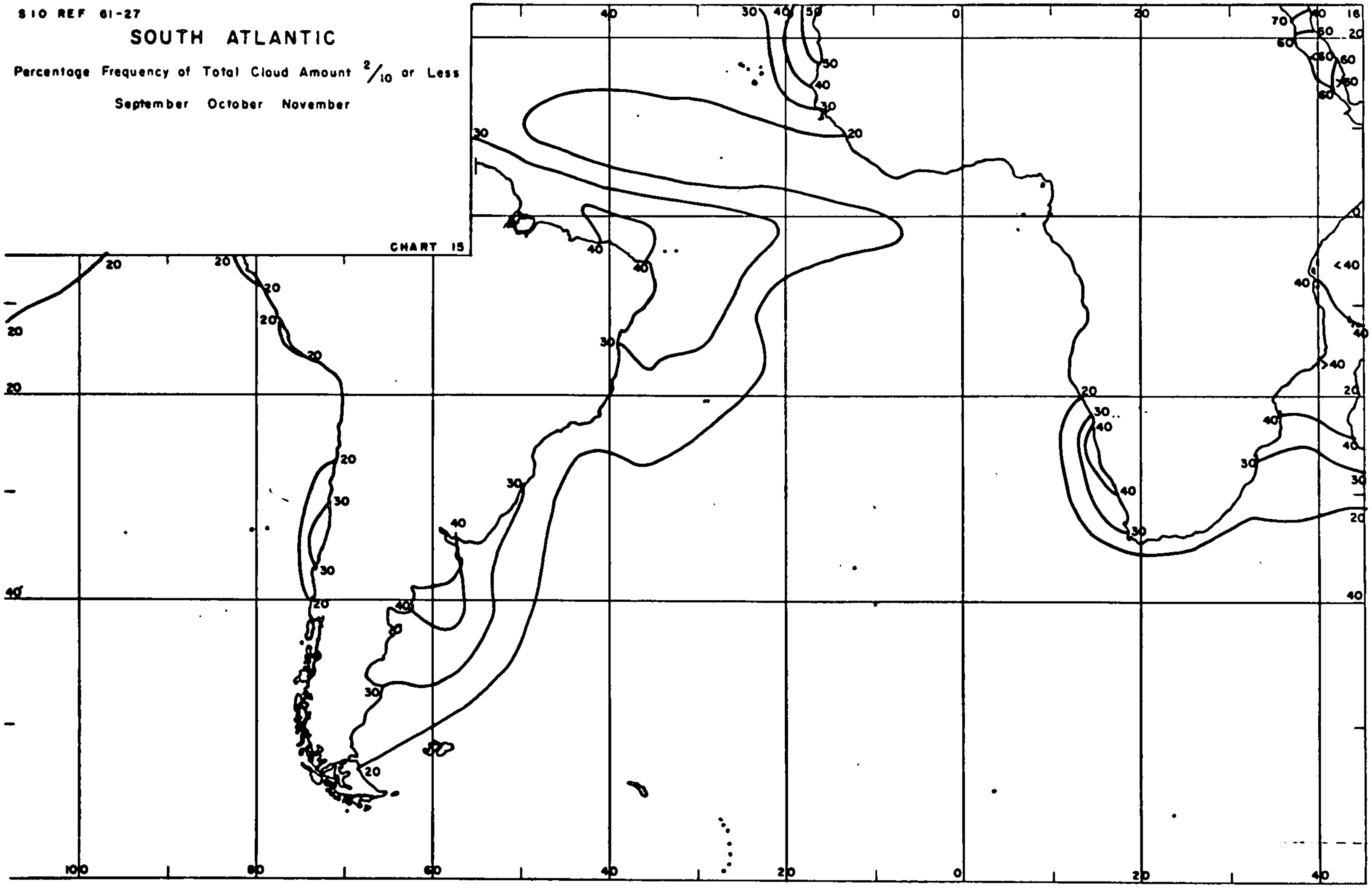


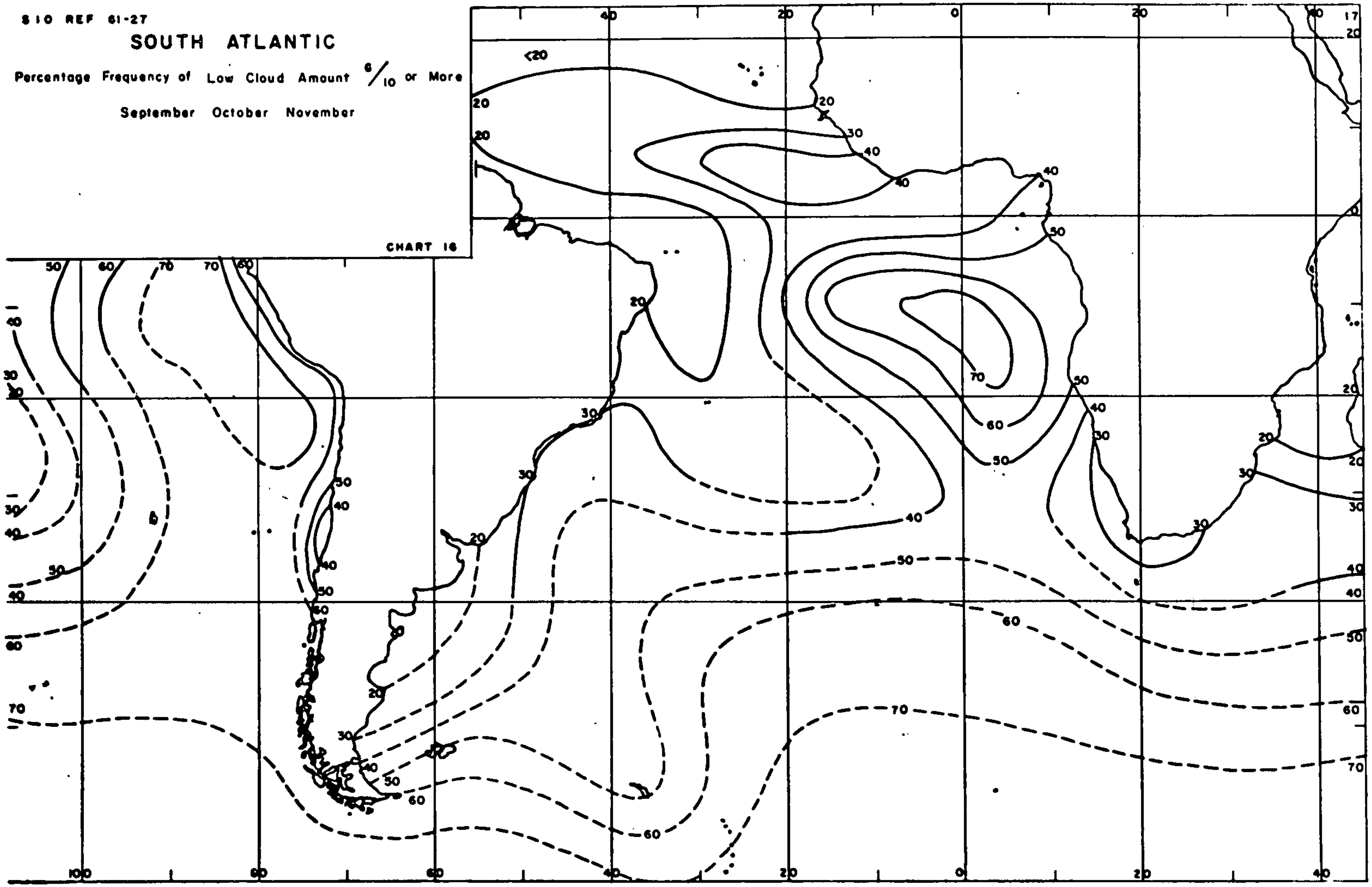
CHART 15

SIO REF 61-27

SOUTH ATLANTIC

Percentage Frequency of Low Cloud Amount $^6/_{10}$ or More

September October November



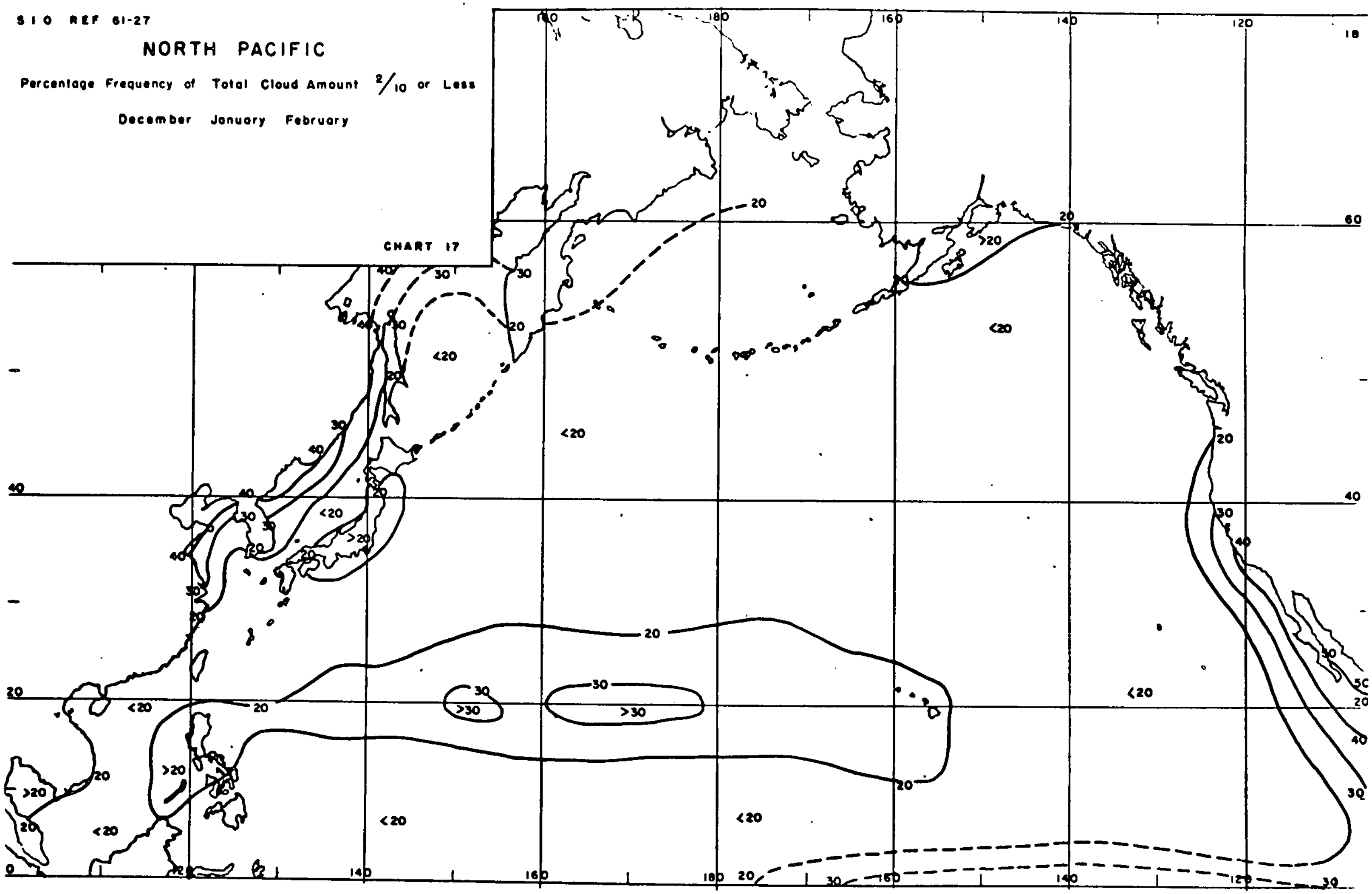
SIO REF 61-27

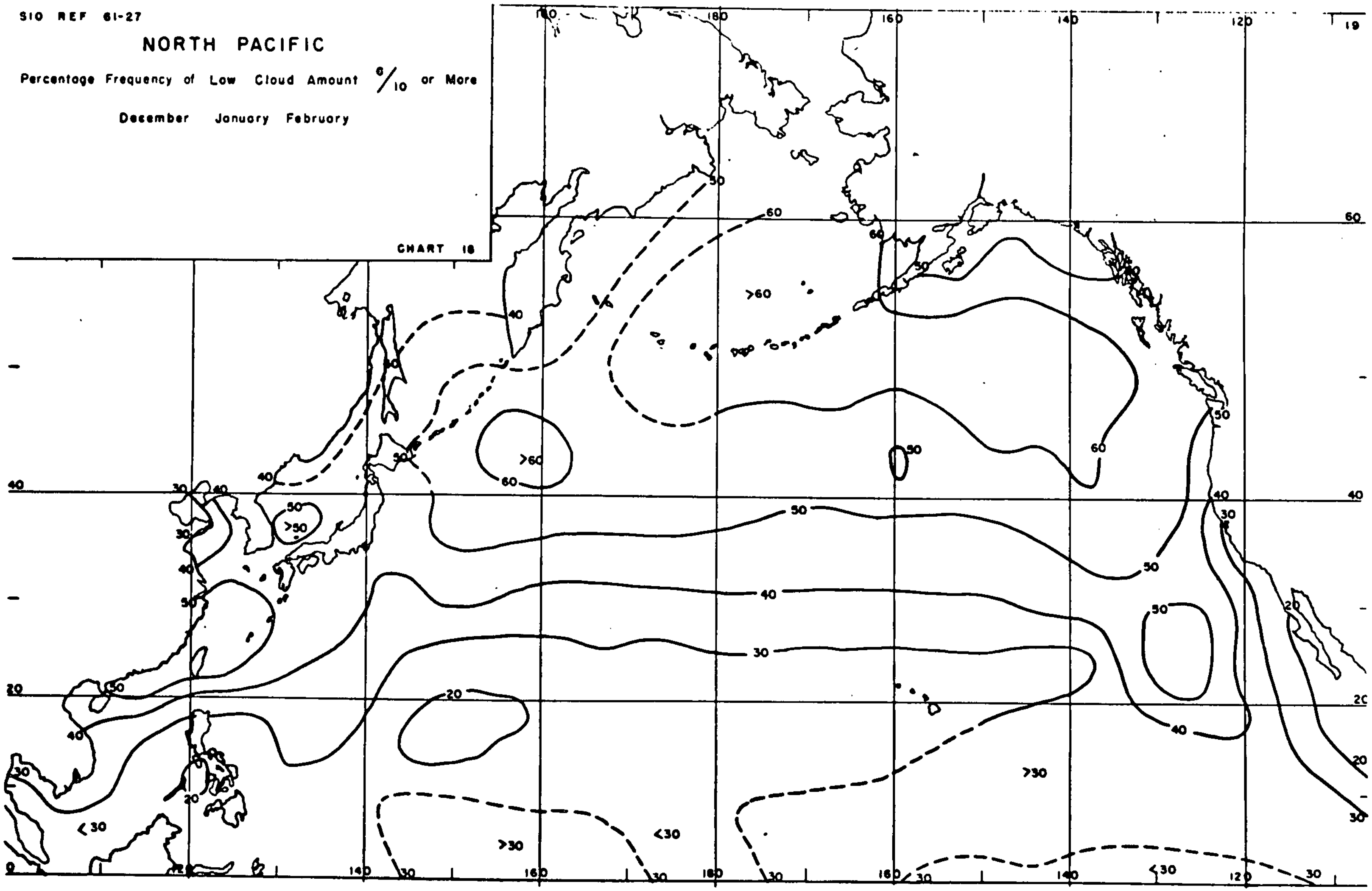
NORTH PACIFIC

Percentage Frequency of Total Cloud Amount $^2/_{10}$ or Less

December January February

CHART 17




SIO REF 61-27
NORTH PACIFIC
Percentage Frequency of Low Cloud Amount 6/10 or More
December January February
CHART 18

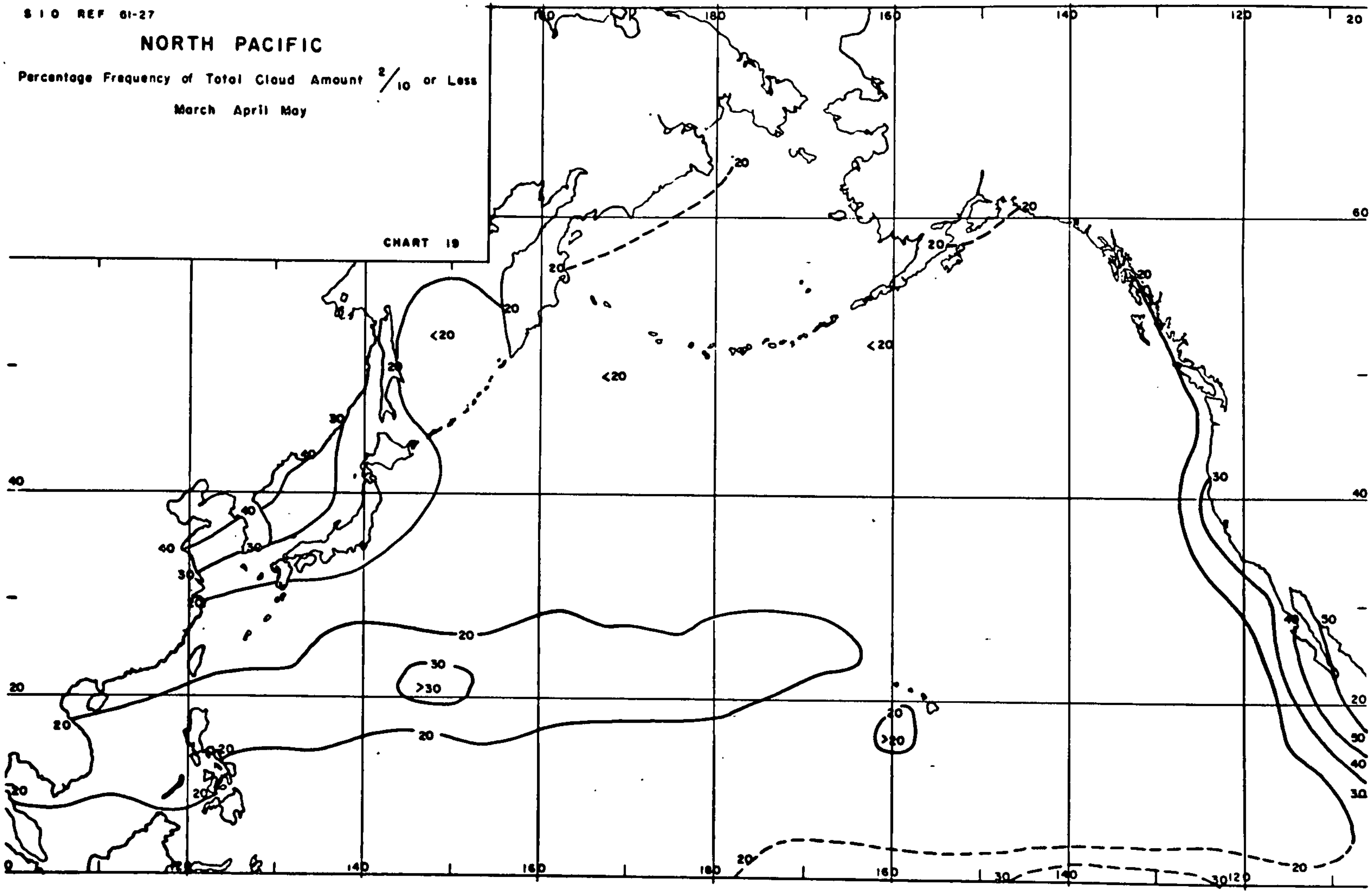
S I O REF 61-27

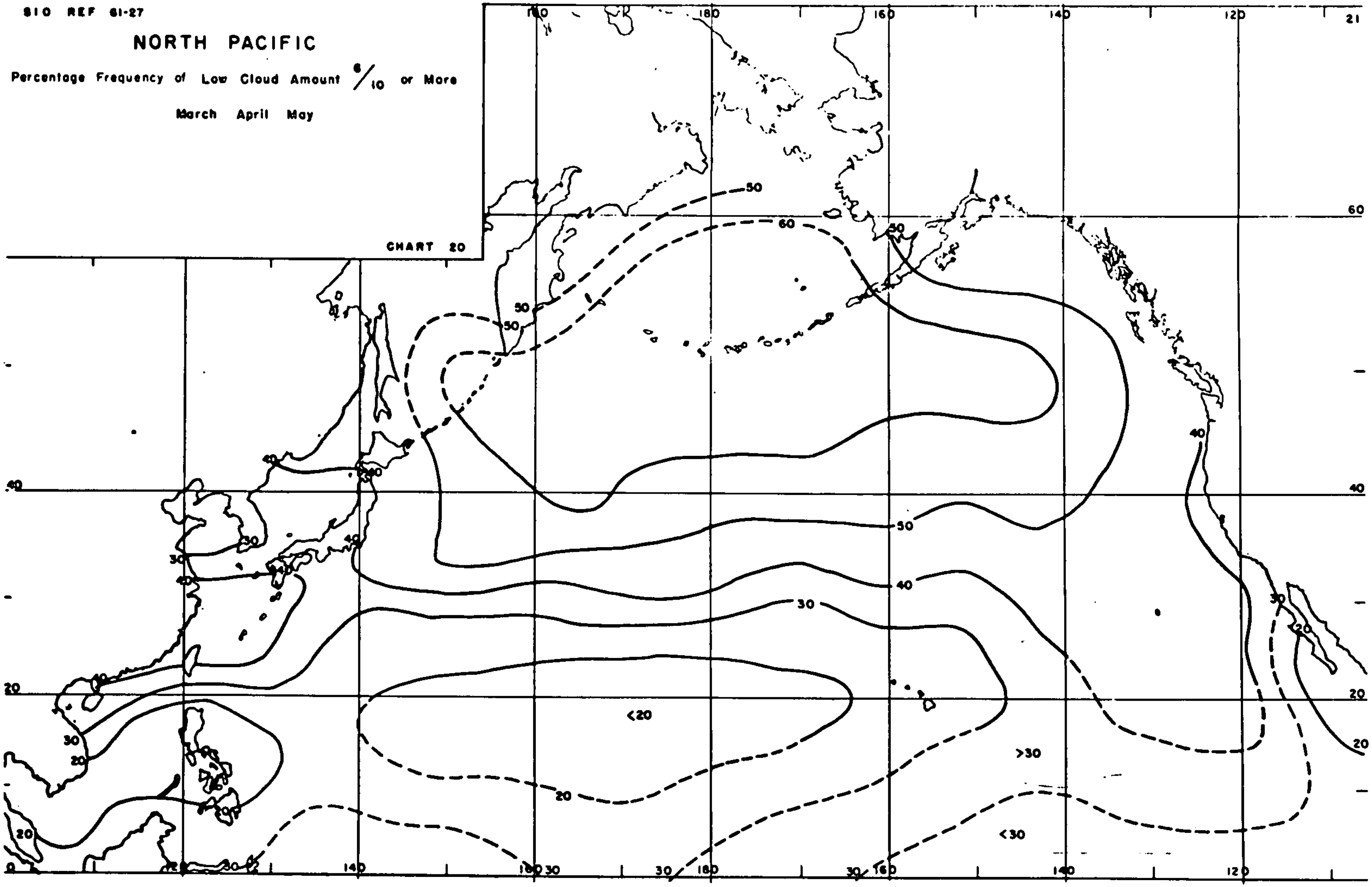
NORTH PACIFIC

Percentage Frequency of Total Cloud Amount $^{2}/_{10}$ or Less

March April May

CHART 19





SIO REF 61-27
NORTH PACIFIC
Percentage Frequency of Low Cloud Amount 6/10 or More
March April May
CHART 20
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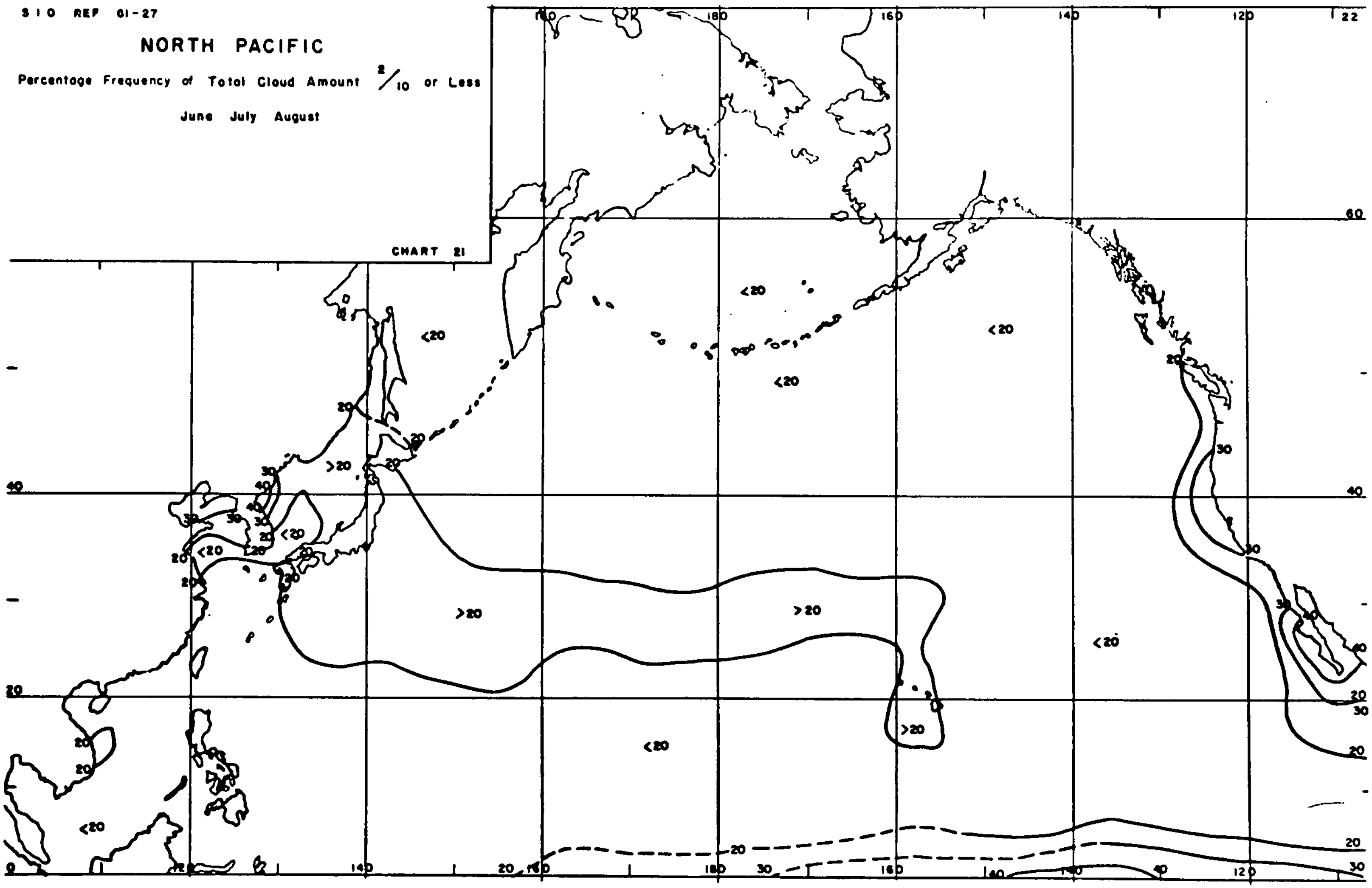
>30
<30

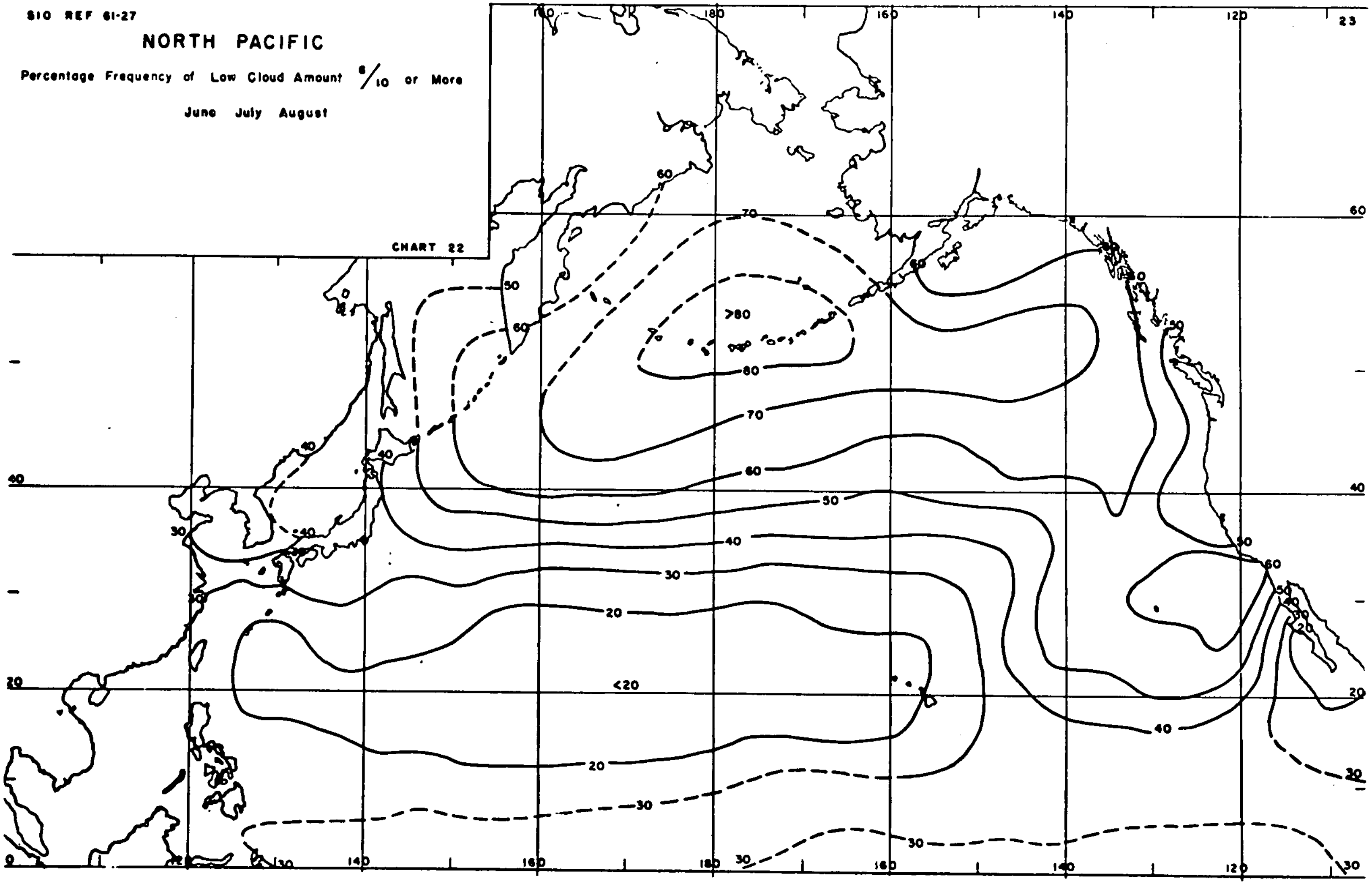

SIO REF 61-27
NORTH PACIFIC
Percentage Frequency of Total Cloud Amount 2/10 or Less
June July August
CHART 21

SIO REF 61-27

NORTH PACIFIC

Percentage Frequency of Low Cloud Amount $^{6}/_{10}$ or More

June July August

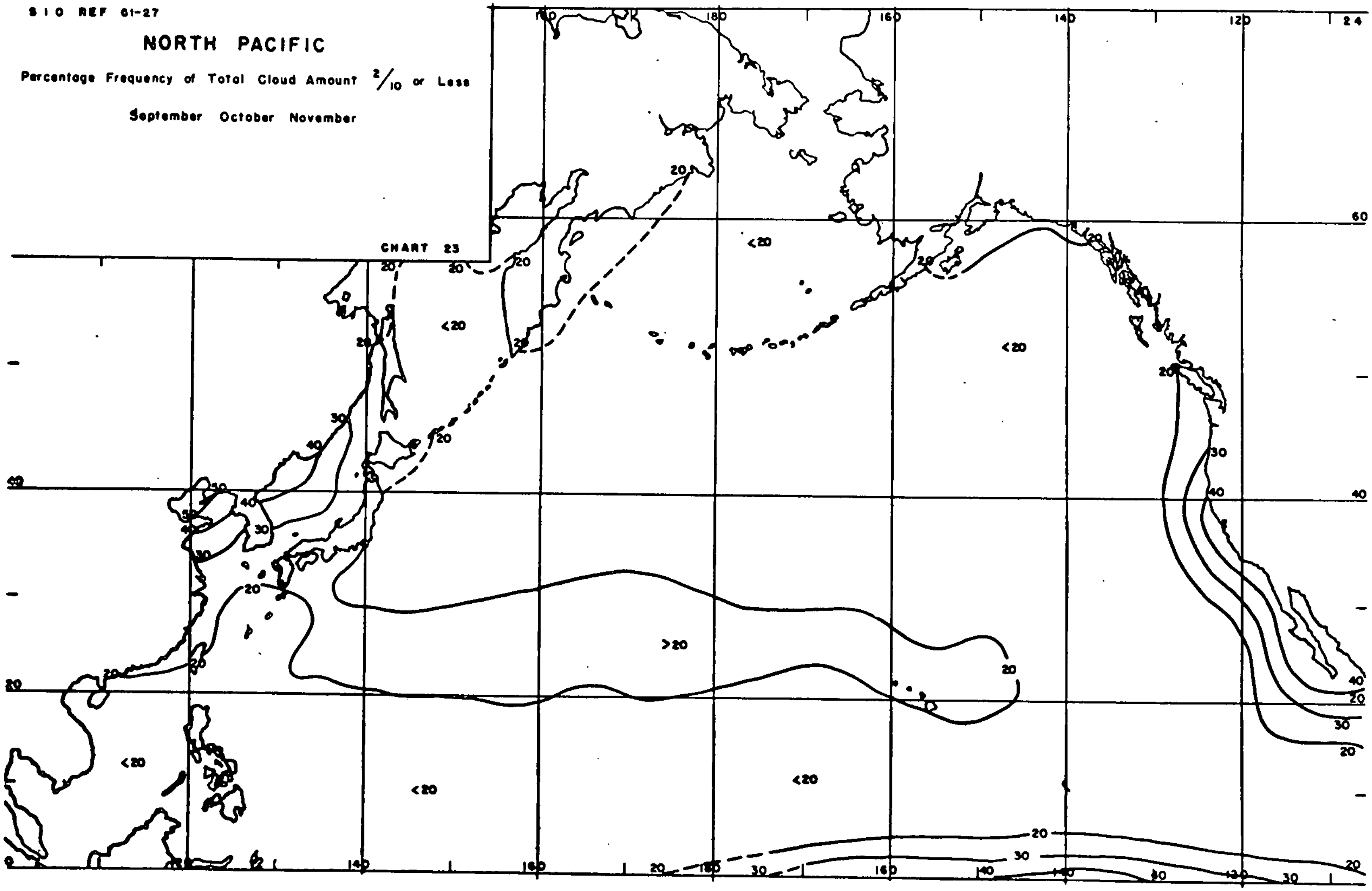


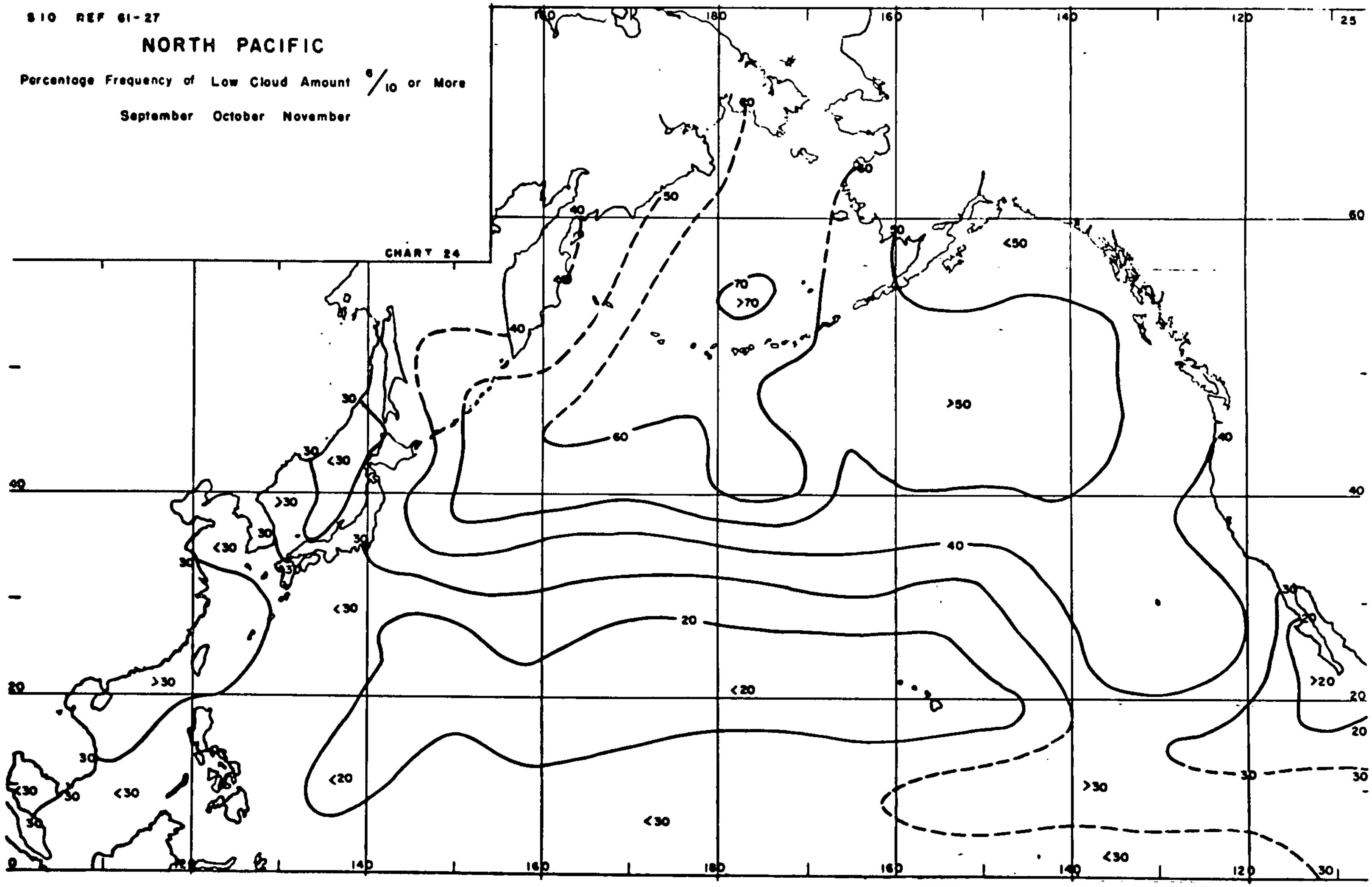
S I O REF 61-27

NORTH PACIFIC

Percentage Frequency of Total Cloud Amount 2/10 or Less

September October November




SIO REF 61-27
NORTH PACIFIC
Percentage Frequency of Low Cloud Amount 6/10 or More
September October November
CHART 24
70
>70
<50
>50
60
50
40
30
<30
>30
20
<20
>20

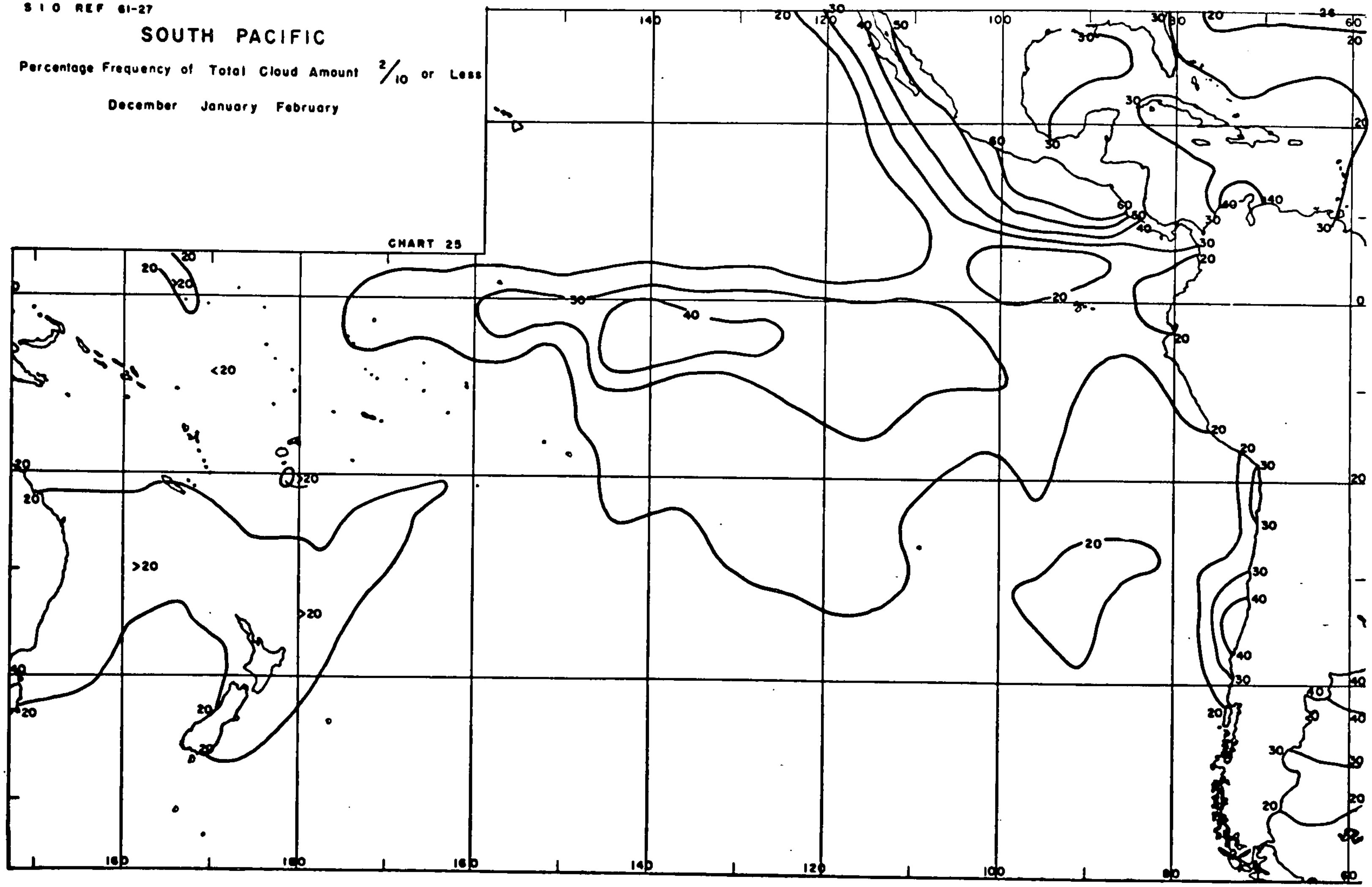
S I O REF 61-27

SOUTH PACIFIC

Percentage Frequency of Total Cloud Amount $^{2}/_{10}$ or Less

December January February

CHART 25



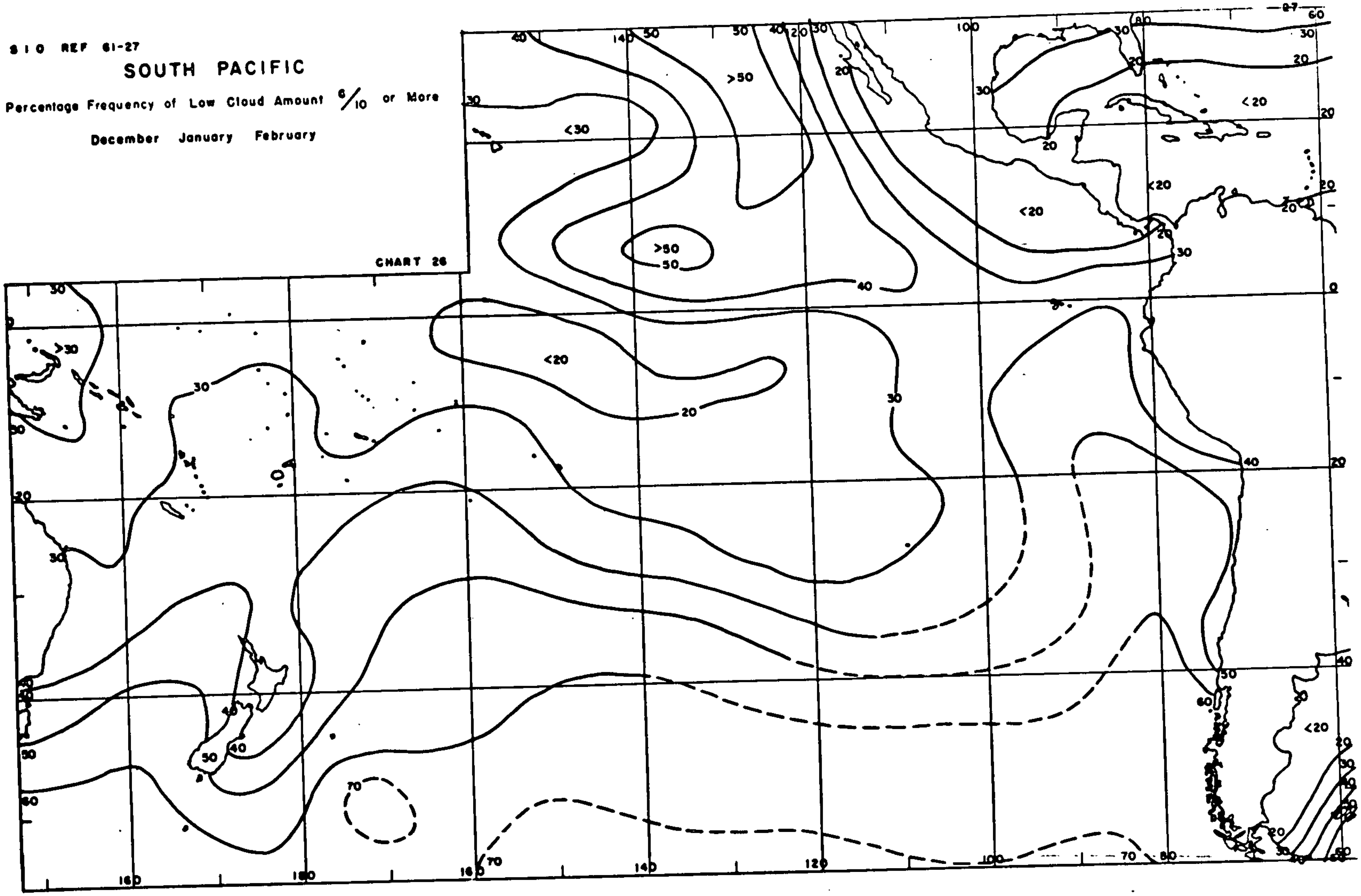
SIO REF 61-27

SOUTH PACIFIC

Percentage Frequency of Low Cloud Amount 6/10 or More

December January February

CHART 26

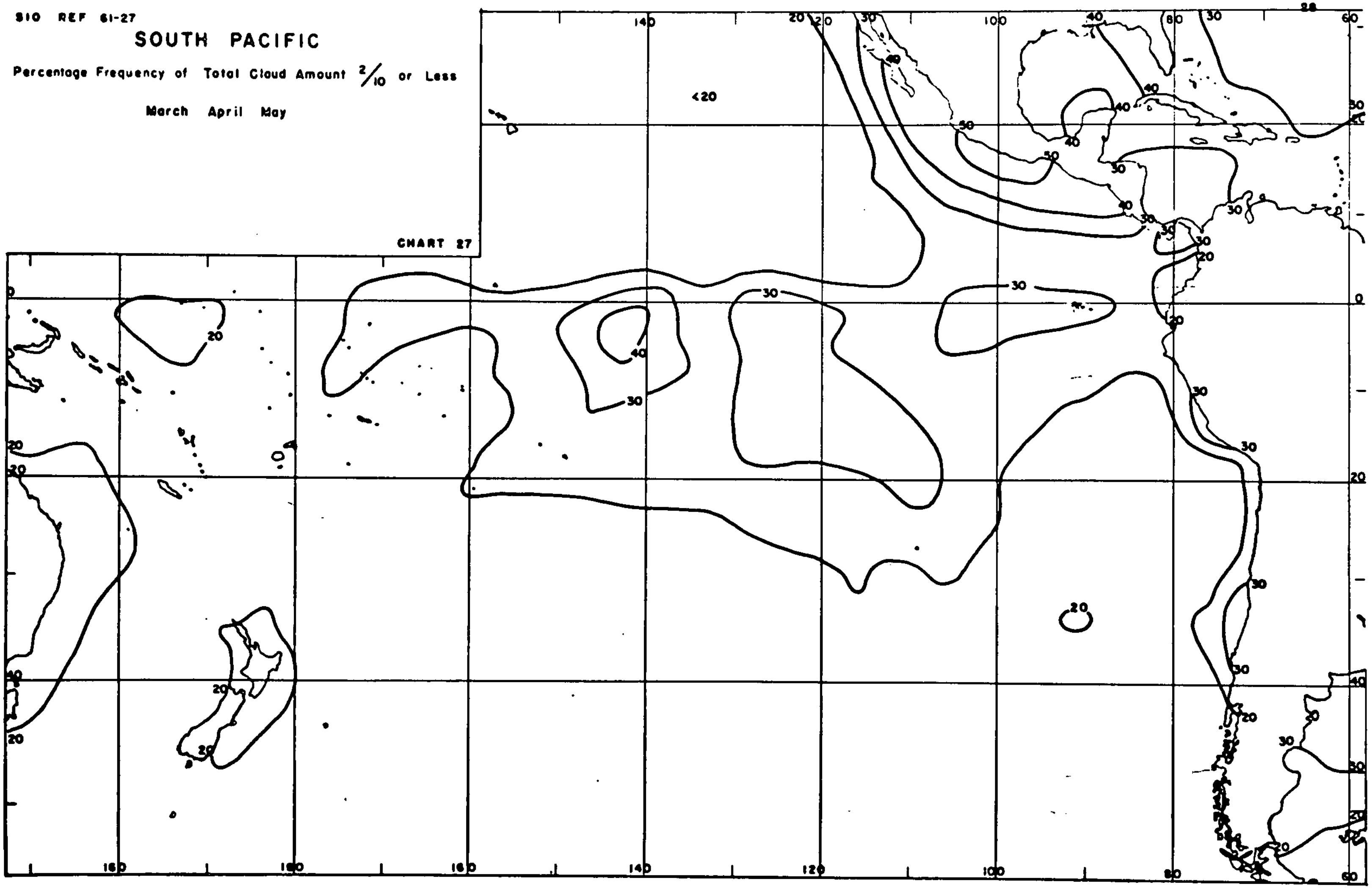


SIO REF 61-27

SOUTH PACIFIC

Percentage Frequency of Total Cloud Amount 2/10 or Less

March April May

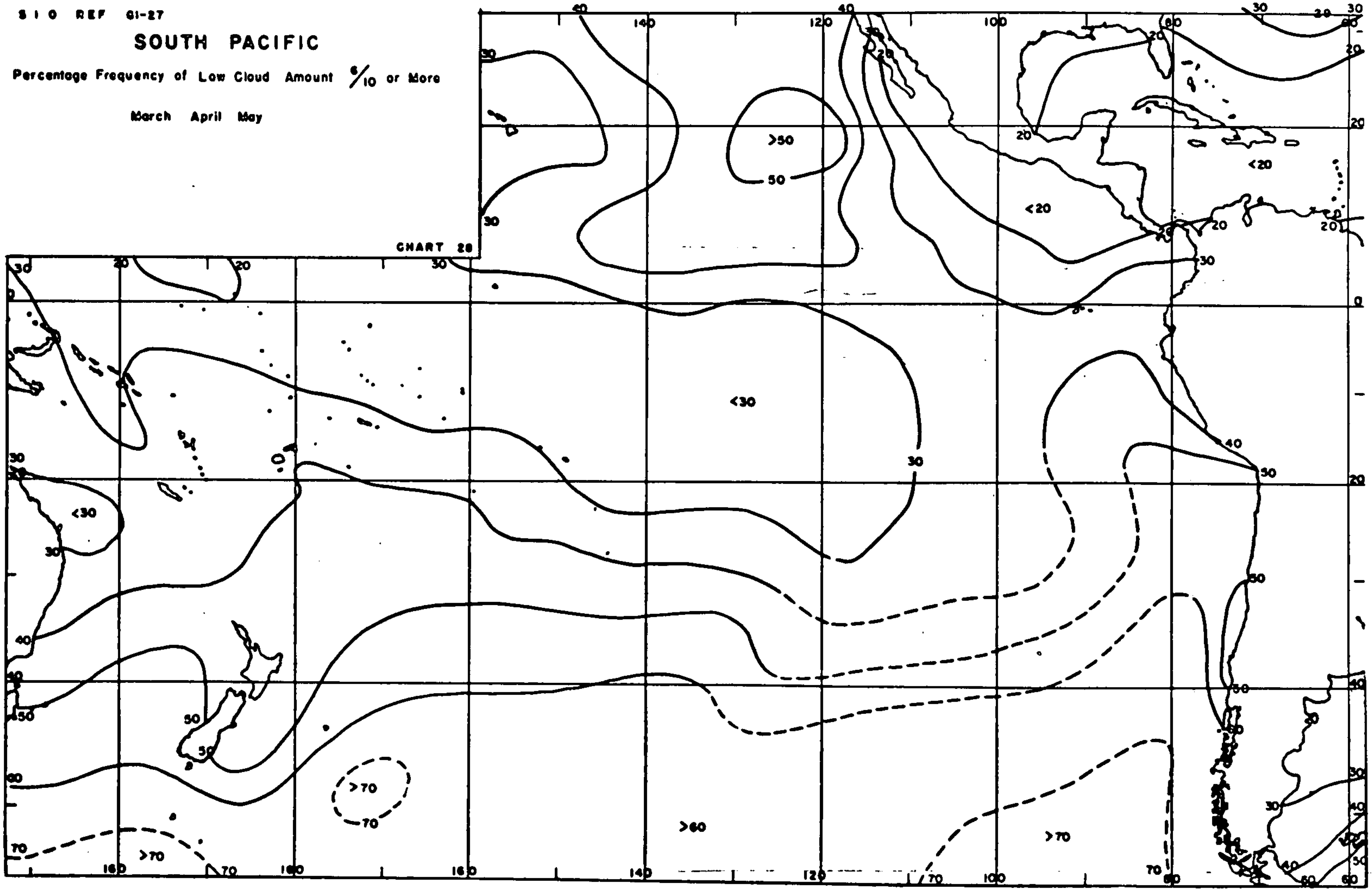


S I O REF 61-27

SOUTH PACIFIC

Percentage Frequency of Low Cloud Amount $^{6}/_{10}$ or More

March April May

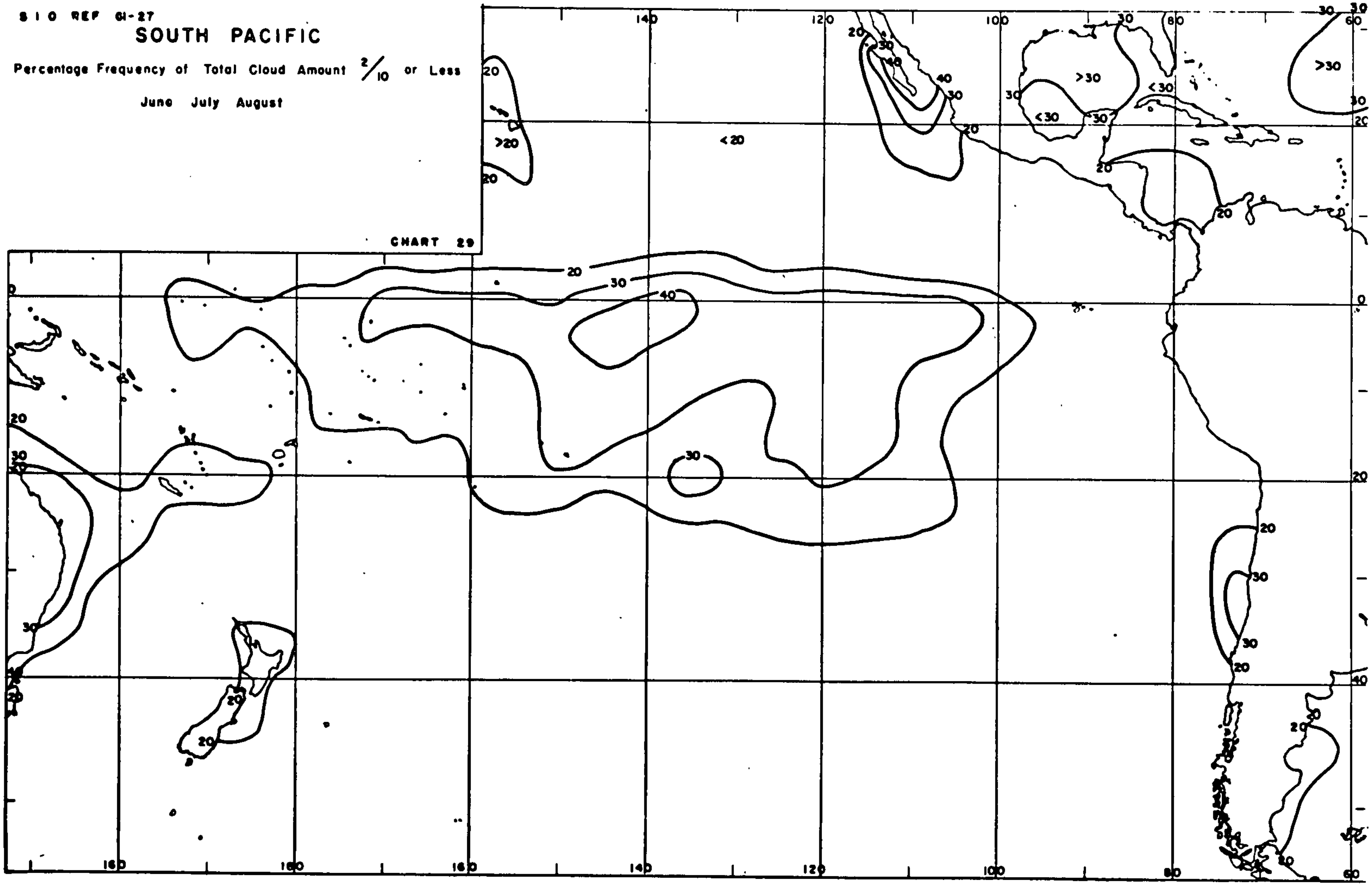


S I O REF 61-27

SOUTH PACIFIC

Percentage Frequency of Total Cloud Amount 2/10 or Less

June July August



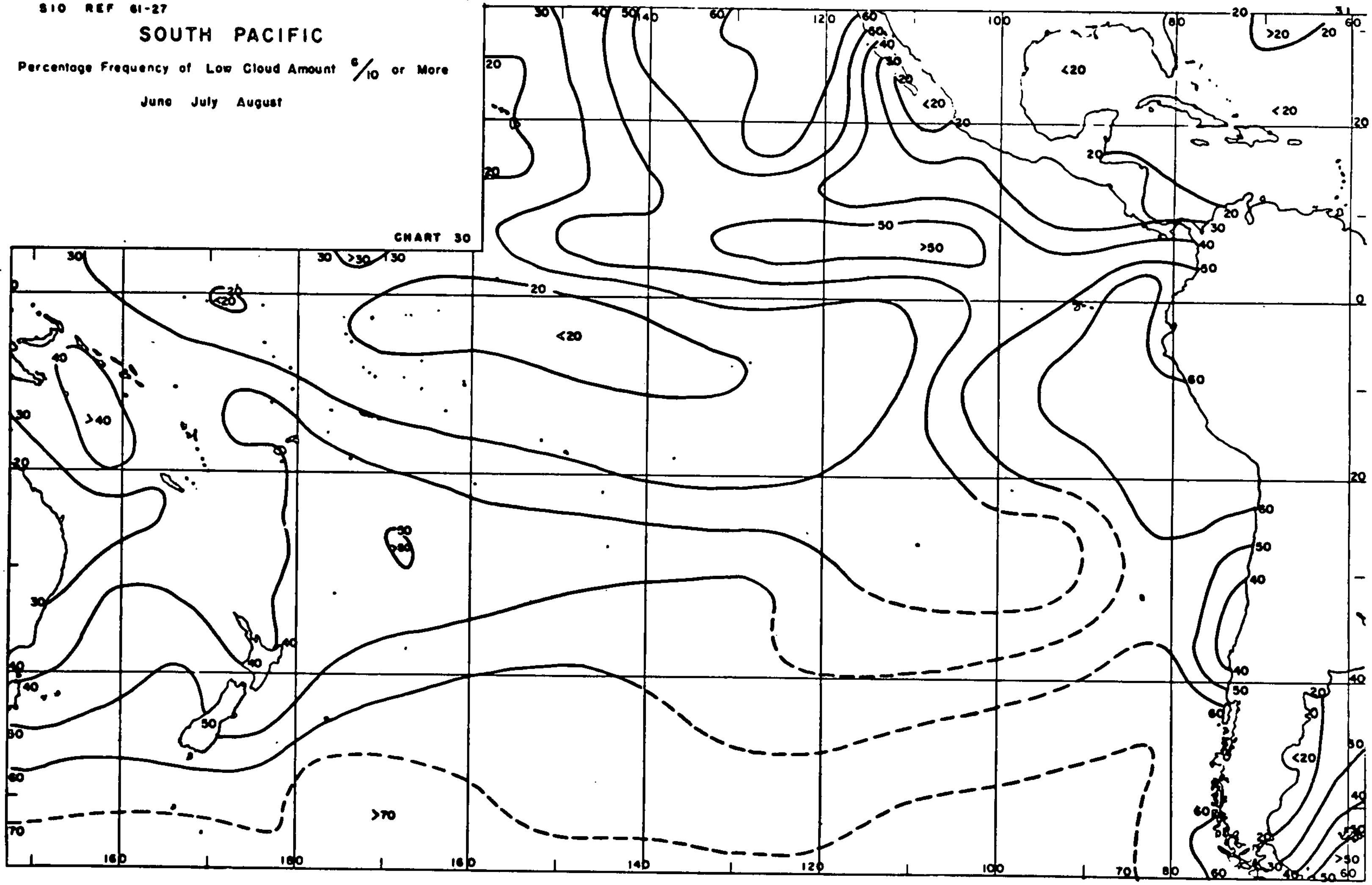
SIO REF 61-27

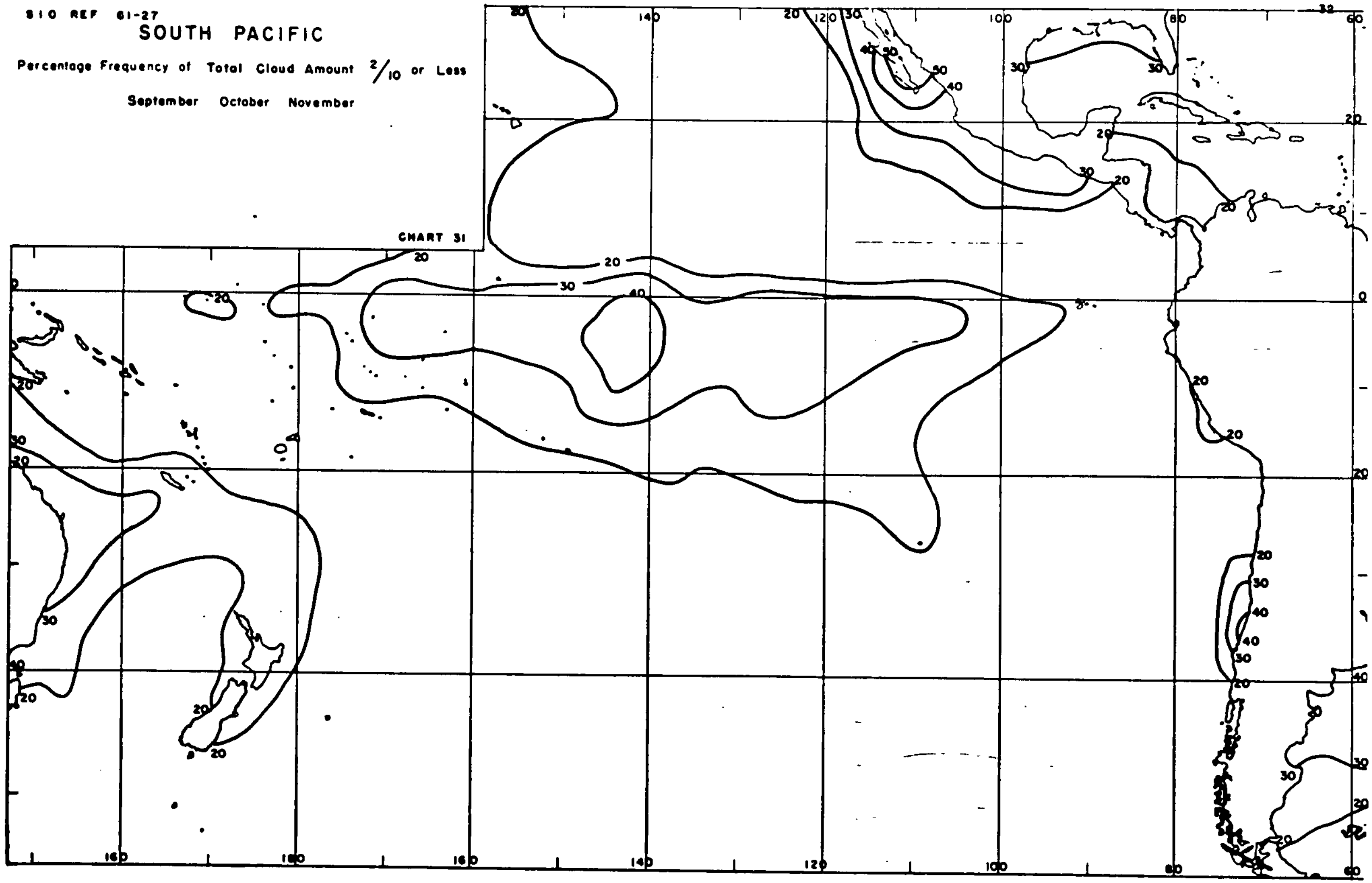
SOUTH PACIFIC

Percentage Frequency of Low Cloud Amount $^{6}/_{10}$ or More

June July August

CHART 30



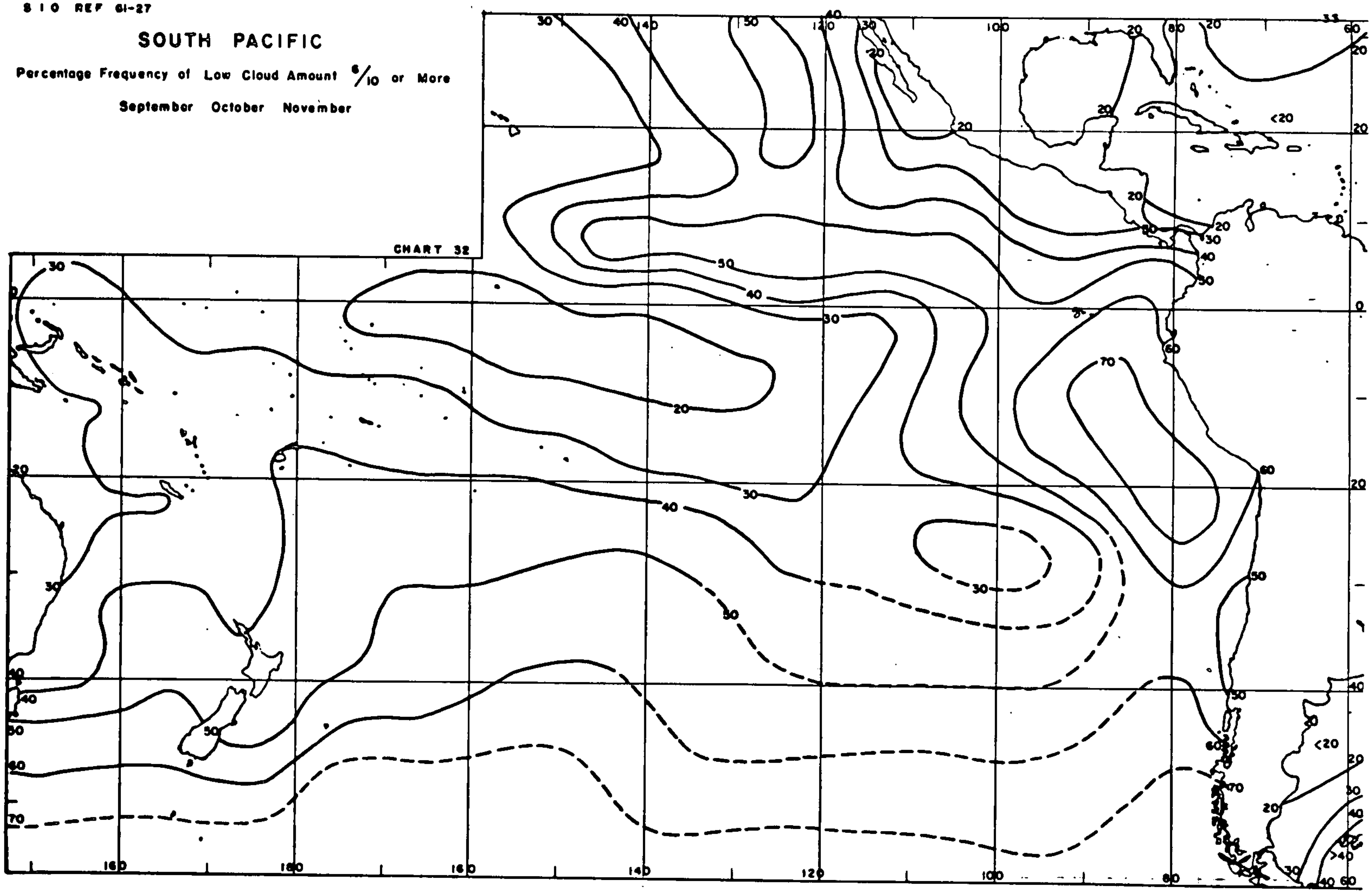

SIO REF 61-27
SOUTH PACIFIC
Percentage Frequency of Total Cloud Amount 2/10 or Less
September October November
CHART 31

S I O REF 61-27

SOUTH PACIFIC

Percentage Frequency of Low Cloud Amount 6/10 or More

September October November



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   Volume 1, North Atlantic Ocean, NAVAER 50-1C-528
   Published by Direction of Chief of Naval Operations,
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