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341-6-6

USNEL REPORT NO. 12

BUSHIPS PROBLEM NO. D1.8C

DATE: 10 JUNE 1947

Observations of Radar Propagation and Influencing Meteorological Factors during the 1946-47 Antarctic Expedition.

Final Report

OBSERVATIONS OF RADAR PROPAGATION AND INFLUENCING METEOROLOGICAL FACTORS DURING THE 1946-47 ANTARCTIC EXPEDITION

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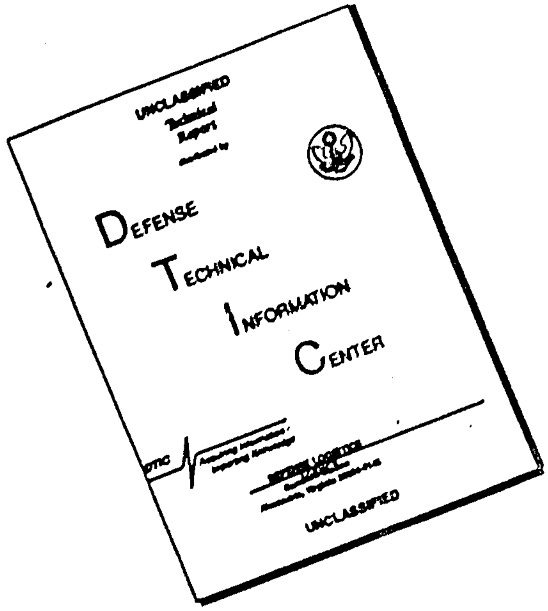

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preface

This report is based primarily on information obtained by NEL scientists who were assigned to the Western Task Group of the U. S. Navy 1946-47 Antarctic Expedition. A study was made of meteorological conditions affecting SG and SK radar propagation.

Appreciation is expressed for the numerous courtesies extended to the NEL representatives by Captain C. H. Bond, Task Group Commodore, and Captain J. E. Clark, Commander of the USS CURRITUCK. Lt. Comdr. L. C. Clarke, Aerological Officer of the Task Group, was exceedingly helpful in making available meteorological information obtained by ship's personnel, and particular thanks are extended him for his cooperation.

Mr. Lloyd Anderson of NEL worked closely with the authors in laying the plans for the meteorological investigation.

table of contents

introduction

Admiral Byrd's antarctic expedition of 1946-47 offered an excellent opportunity to study radar wave propagation and low-level meteorological conditions which exist about the Antarctic Continent. Although a great deal has been reported concerning the general meteorology of the antarctic, the conditions which affect the ranges of radar have never been stressed due to the relatively recent development of radar and use of the radio frequencies concerned. This report deals with the radar and meteorological measurements that were made during the cruise of the Western Task Group of Operation HIGHJUMP.

Most of the measurements reported were made aboard the seaplane tender USS CURRITUCK. This tender made available the convenient use of PBM and helicopter aircraft. The antarctic portion of the cruise was made

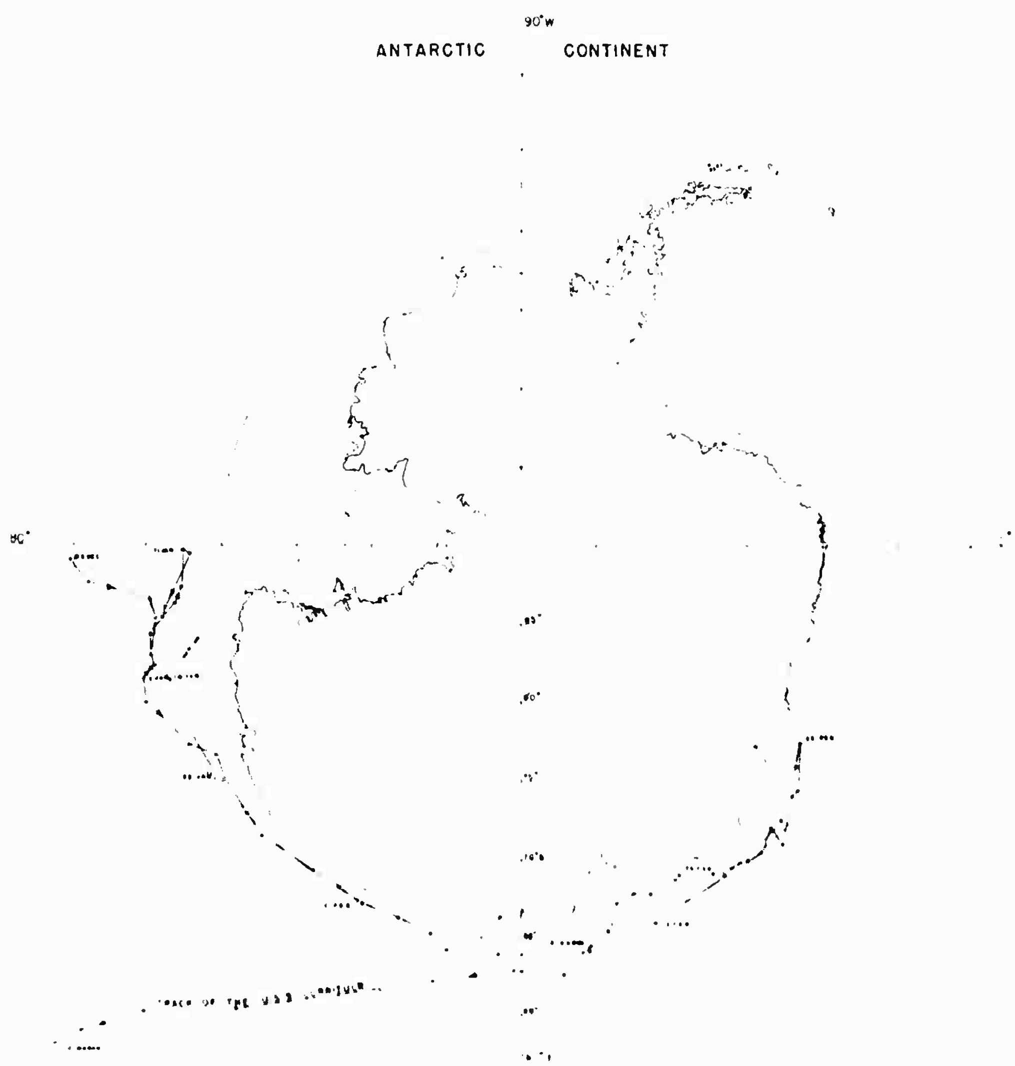

FIGURE 1. Course followed by the USS CURRITUCK in antarctic waters.

during the antarctic summer months, between 22 December 1946 and 4 March 1947. The ship kept a close proximity at all times to the continental ice pack which extends about 50 to 150 miles from the continent in most regions. The area covered lay between 180 degrees east longitude and 34 degrees east longitude during the above-mentioned period. A track of the ship showing the dates of position is shown in figure 1.

radio measurements

When the task group approached the antarctic area, radar logs were issued to the ships' radar operators. These logs were designed to check the maximum ranges detected by the ships' radars and were kept by each of the three ships. Readings were taken each watch and operators were urged to record anything of an unusual nature, such as extended ranges or noise phenomena. Radar performance was checked regularly on the CURRITUCK using echo box technique and observations of ring time. Competent technicians aboard the CURRITUCK kept the radars in good condition after 10 January. Targets were generally icebergs of unknown size.

A second type of measurement was made by tracking of the PBM aircraft by the SK radar. During each flight the planes were tracked to the limit of detection by this method and were guided home as soon as they were detected on the return trip. This gave valuable information on the limit of detection each day that aircraft operations were made. As there were usually two planes flying each day of operations, there was always a check against the operators' ability. Data were obtained for both signal echoes and IFF echoes. The IFF allowed tracking to greater ranges.

The third type of measurement consisted of receiving the 3300 Mc. propagation from the plane's radar and recording it on an Esterline-Angus recorder. A 12-inch parabolic reflector antenna was mounted in the clear in front of the ship's bridge and connected through RG-8U cable to the receiver. The antenna was oriented using plane bearings that were obtained from the SK radar. The small "dish" was used to minimize misadjustments of alignment. A modified Boonton 215C signal generator was used to calibrate the receiver. The receiver used was of the peak pulse recording type with a peak reading circuit having a time constant sufficiently long to minimize the effect of the radar scanning. Best results with this system were obtained with the radar on sector scan. The track of the aircraft was plotted from data which had been obtained from the SK radar positions, and used to assign ranges to the recorded field strength values.

Radar facilities aboard the USS CURRITUCK consisted of an SK 200 Mc. radar, with antenna center at 120 feet elevation; an SG 3000 Mc. radar, with antenna center at 130 feet elevation, and APS-2F, 3300 Mc. radar, in each PBM aircraft. A 3300 Mc. receiver was taken to record the field strength of the PBM's APS-2F radar transmission. Equivalent 200 Mc. and 3000 Mc. radars were carried by the other ships of the task group, the USS HENDERSON, DD-785, and the USS CACAPON, AO-52.

meteorological measurements

Several methods of measuring the temperature and humidity of the lower atmospheric levels were used. The first method only considered values from the surface to 105 feet and consisted of a blower aerated unit containing a Friez humidity strip and a ceramic temperature element which could be raised from the surface of the water to the ship's yardarm. Multiple-conductor cable transmitted the readings to a recording temperature meter and a standard NEL wired sonde meter from which humidity was read. It was hoped that these measurements would present a micrometeorological picture at low levels that could be used in correlation with the surface search propagation data, but it was found that convection currents set up about the highly heated ship (the interior of the ship was maintained at 70 degrees F) distorted the picture to such an extent that this system was eventually abandoned.

The ship's helicopter was also used, since this aircraft was making regular flights. Soundings were taken employing a blower aerated unit suspended below the craft by a short multiconductor cable. Readings were made on the standard NEL wired sonde meter. As this aircraft has the ability to hover at any altitude, it was possible to maintain any certain position long enough to allow the elements to reach equilibrium. An unfortunate accident to the helicopter terminated its use at too early a date to exploit fully its possibilities.

After termination of the above system, soundings were made from the surface to a height of 1100 feet using standard wired sonde technique. These soundings could only be made from the ship when the relative wind was under 16 knots. Standard NEL equipment consisting of NH-4 neoprene balloons, a blower aerated unit, NEL wired sonde meter, and 3-strand, nylon insulated, aluminum wire cable was used. These soundings gave very good results, but were limited in number by high winds and the fact that the ship was underway most of the time. It was found that ordinary precautions such as heating the balloons before inflating and inflating them inside the ship were adequate to obtain satisfactory performance at the temperatures encountered. Occasionally balloons were inflated outside, although the casualty rate was high.

Radiosonde ascents were conducted by the ship's personnel twice daily. It was hoped that the data from this source would be sufficiently accurate for a rough correlation with radar ranges on aircraft. The ascents gave better than average results because the balloons were carefully inflated to give slow ascension rates. At best, however, these rates were of the order of 500 feet per minute, too fast for accurate measurement of humidity because of the lag of the humidity strip. However, the large humidity lapse rates that often occurred at heights of 2000 to 6000 feet were readily detected.

Ship's personnel made hourly observations of water temperature, precipitation, clouds, fog, wind, ice conditions, and other weather conditions commonly reported by surface and shipboard weather stations.

The atmospheric variables, temperature, humidity and pressure, were used to calculate the index of refraction of the air as represented in "B" units. The equation for "B" differs from the familiar "M" only by the constant employed in the height function of the equation. This constant is chosen for the "B" equation* such that if "B" is constant with height, atmospheric conditions are standard. If a negative slope is evidenced, superrefraction should be expected; if positive, substandard ranges. The factors of height, thickness, and intensity of superrefraction layers are considered in correlation with radar ranges.

meteorological conditions

The general meteorological conditions found along the coastline of Antarctica are chiefly governed by:

1. A permanent high-pressure area over the continent.
2. A permanent low-pressure belt surrounding the continent, the mean low-pressure line lying very near the 60-degree parallel.
3. Permanent "lows" existing in areas of the Ross Sea, Weddel Sea, and the area west of the Palmer peninsula.
4. Low-pressure eddies emanating from the low-pressure areas listed in "3" above, and circulating around the continent in a clockwise direction, in a path roughly following the mean low-pressure line.

These conditions consistently result in off-shore winds, southeasterlies for an east-west coastline, southwesterlies for a north-south coastline such as that of the western side of Ross Sea, etc. Thus the factors to be considered in a study of an air mass at the outer edge of the ice pack could be evaluated by assuming the trajectory for the air mass to have been seaward from the continent over the ice pack moving at an angle of approximately 45 degrees with the trend of the coastline.

Now, considering an air mass over the continent, there will be a surface inversion of a magnitude of 5 to 10 degrees C and extending perhaps to a height of 2000 to 5000 feet dependent on mixing, as shown in figure 6. As this air mass moves seaward, the lower layers are heated from the warmer ice pack, and a dry adiabatic lapse rate is established near the surface washing out the lower part of the surface inversion and intensifying the upper section because of mixing and adiabatic cooling resulting from convection. This tends to form an elevated temperature inversion at heights varying from 2000 to 7000 feet as the air mass reaches the outer edge of the ice pack. This inversion should not be confused with the usually

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$$^{*}B = \frac{79.0}{T} P + \frac{4800.e}{T} + .0022h,$$

where

T = temperature in degrees Kelvin

P = total pressure in millibars

and

e = vapor pressure in millibars

h = altitude in feet.

present subsidence inversion, which was found occurring between 8000 and 15,000 feet.

Considering meteorological conditions in the light of their effect on radar propagation, two characteristics of an air mass are important:

1. The refractive index vs. height will influence the ranges acquired.

2. Suspended or falling water, snow, or ice particles will attenuate the waves by scattering and absorption. In the area in which the Western Task Group operated during the period from 22 December 1946 to 1 March 1947, only nineteen days (averaging eight days a month) were encountered during which a propagation analysis could be made in terms only of the index of refraction or "B" values vs. height.

On days when the wind velocities were low (high barometer), a sharp moisture lapse was noted between 100 and 1000 feet, extending over three or four hundred feet. This was probably due to insufficient turbulence along the trajectory to furnish moisture to higher levels. Superrefraction was in evidence on days when this occurred. When interpreted in terms of a "B" curve, propagation under these conditions is much like that encountered around San Diego during the summertime.

Meteorological data which have been introduced into the analysis for correlation with propagation data must not be accepted as representative of the lower air conditions all along the transmission path, but since all of the aircraft propagation data had a transmission path from inland-seaward, the meteorological data may be accepted as an index to, or a product of, the conditions along the transmission path.

results of investigations

RADAR SURFACE RANGES

Ranges obtained on the SG radar were limited principally by the influence of precipitation on atmospheric conditions. Snowfall and sleet were encountered frequently as well as heavy fog and sea spray whipped up by winds. Figure 2 shows the relation between meteorological conditions and the ranges obtained by the SG radars aboard the USS CURRITUCK and USS HENDERSON. From these graphs it is evident that superrefraction cannot occur on days when any considerable precipitation is evidenced. The low ranges on the USS CURRITUCK prior to 10 January were due to defective radar equipment. When the radars were operating at peak efficiency the average range of the CURRITUCK's radar was 25 miles and that of the HENDERSON about 18 miles. Correlation of the HENDERSON's ranges with percipitation is modified by the consideration that it generally operated about 100 miles west of the CURRITUCK.

Extended ranges occurred on the 30th of January, and the 2nd, 7th, 8th and 25th of February. On these days weather conditions were very stable (high barometer and low cloud coverage). Such conditions were necessary to allow the building up of the moisture lapse responsible for near-surface superrefraction.

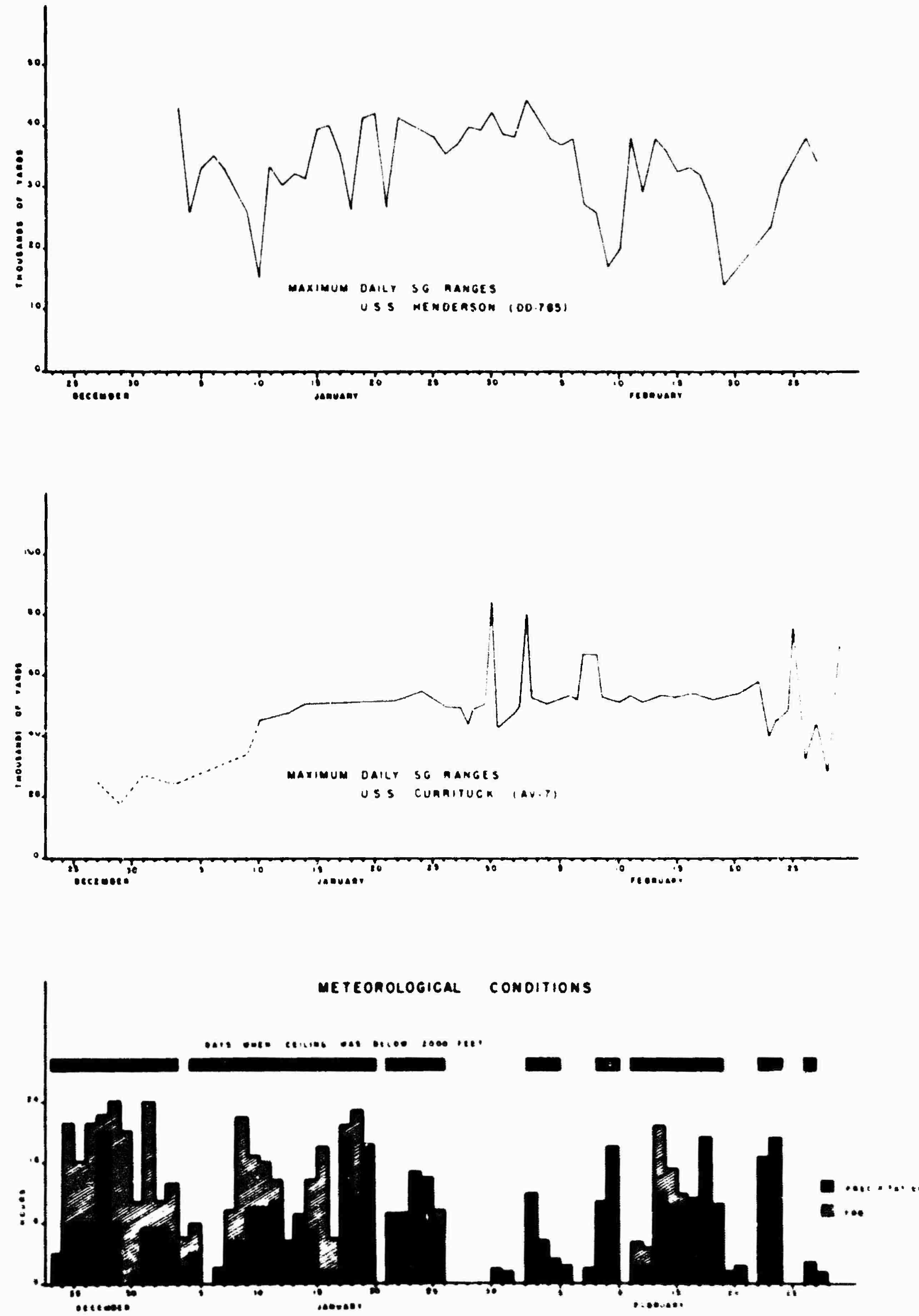


FIGURE 2. Daily meteorological and SG radar observations.

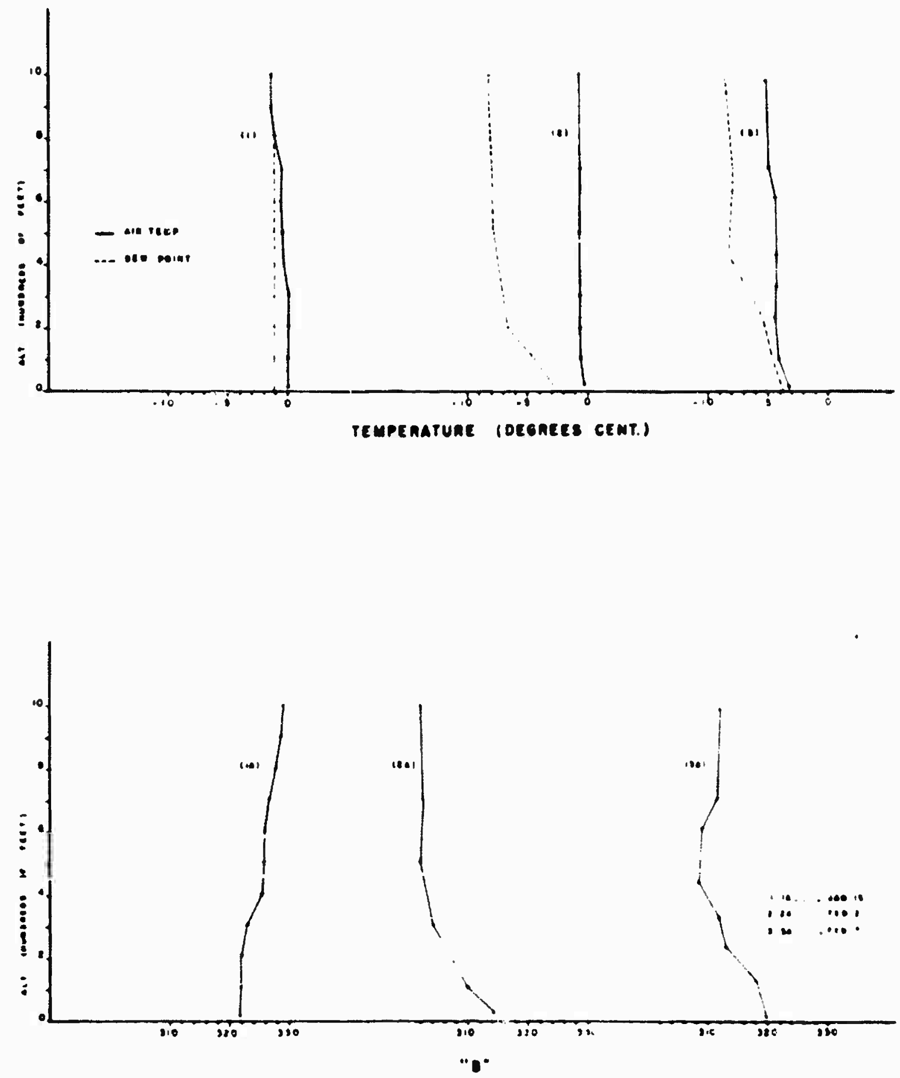


FIGURE 3. Low level meteorological soundings with calculated "B" curves for an average day (15 January) and for two days (2 February, 7 February) on which superrefraction was observed.

Figure 3 shows three meteorological soundings along with representative "B" curves. One is for an average day with 1500-foot ceiling (15 January) and the other two, 2 February and 7 February, were days when superrefraction was indicated by extended radar ranges.

Most of the radar ranges were obtained from iceberg echoes except those shown for the 25th of February, which were echoes from mountains on the coast. In addition to extended SG ranges on this day there were strong echoes observed on the SK 200-megacycle radar to ranges of 163 miles. This day was also marked by mirages and looming of distant icebergs and mountains. In this case it was quite evident that inversions existing over the continent were much stronger than those over the sea.

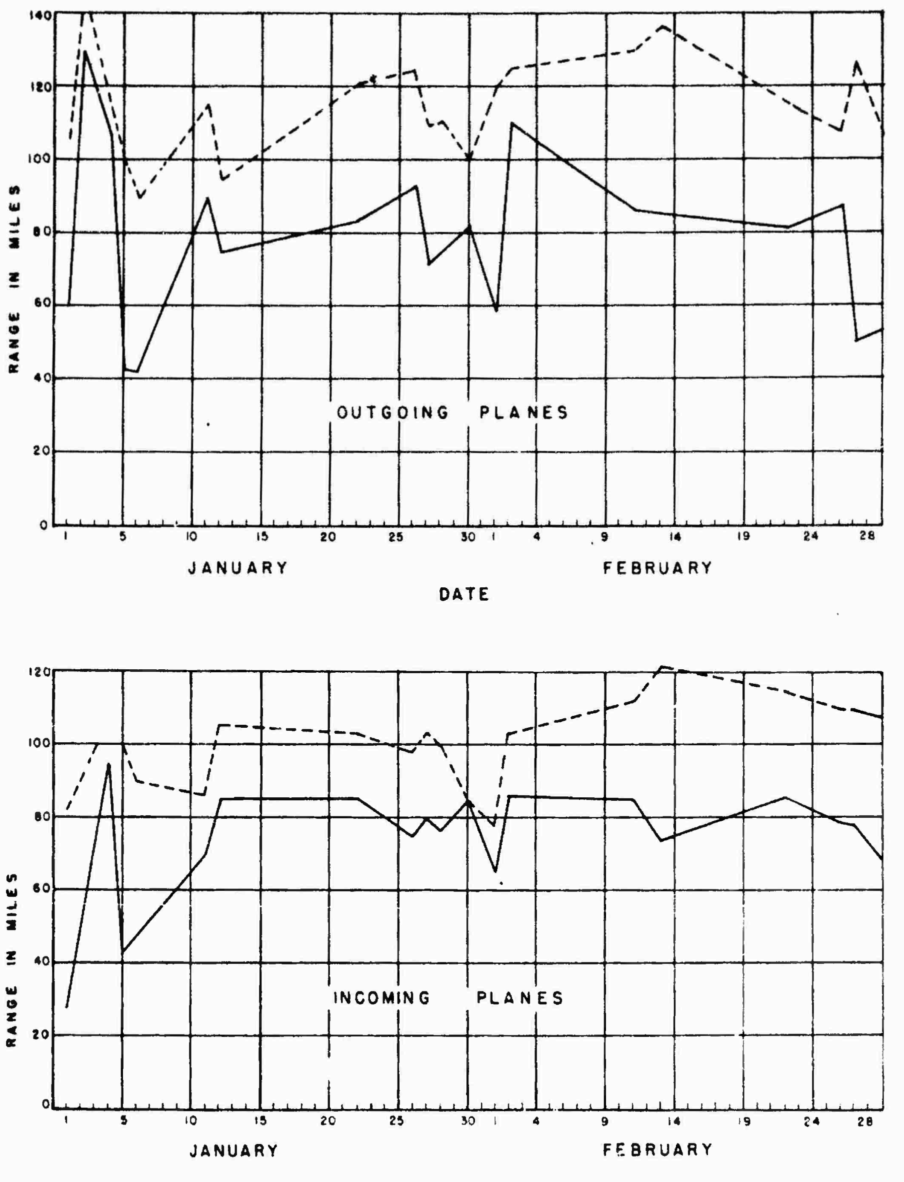
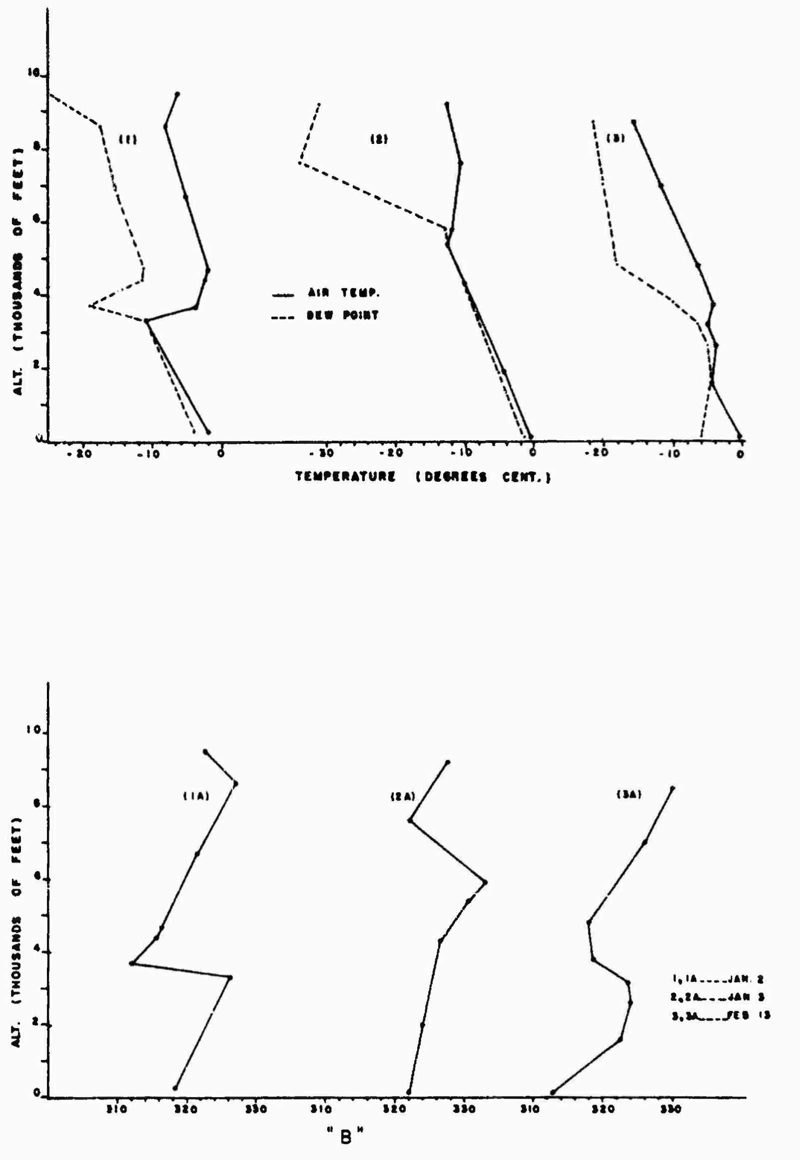


FIGURE 4. Maximum SK ranges on PBM aircraft.

SK RANGES ON AIRCRAFT

Twenty flights were made by the PBM aircraft of the USS CURRITUCK. The maximum ranges at which it was possible to detect the planes with the SK radar are shown on the graphs in figure 4. The top graph is for outgoing planes and the bottom graph is for incoming planes. The dashed curves in each set represent the maximum ranges using IFF and the solid curves are the maximum echo ranges. The IFF curves are more precise indications of maximum range than the echo curves because tracking was often switched to IFF while the echo was in a fade zone. The aircraft operated at a standard altitude of 10,000 feet during the



FIG'URE 5. Radiosonde observations showing the elevated inversion with calculated "B" curves for a day when substandard aircraft ranges were observed (5 *January*), *and for two days when superrefraction was in evidence.*

tracks and variations from this were generally less than 10 per cent. With standard atmospheric conditions the maximum value of the first interference lobe occurs at approximately 93 miles, and this is used as the average range.

In order to obtain a qualitative correlation of the radar ranges with atmospheric conditions, the "B" curves for three flying days are shown in figure 5. These curves were taken from radiosonde observations and should be considered only as a rough indication of actual conditions. However, useful information such as the height of the elevated inversion, its approximate strength, and an indication of the moisture lapse in this region was gained from a study of these soundings.

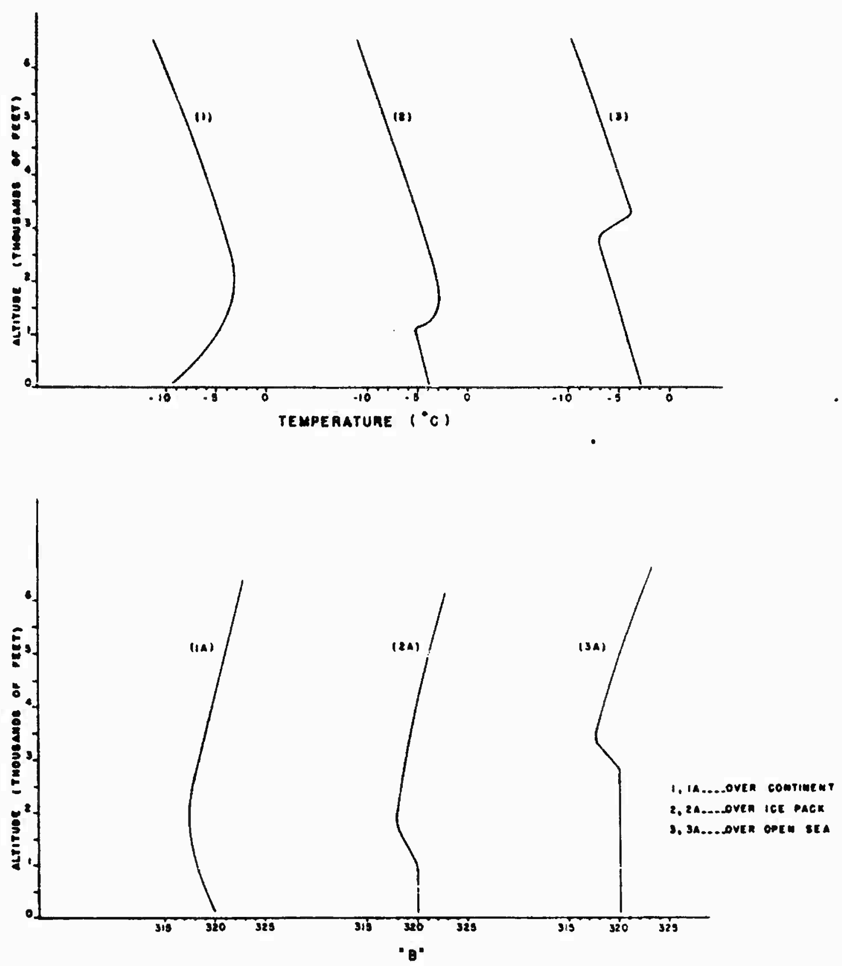


FIGURE 6. The progressive formation of an elevated inversion in a continental air mass moving seaward, and representative "B" curves for each stage of development.

Quite frequently superrefraction was in evidence and was usually accompanied by a low elevated inversion along with a sharp moisture lapse. It was found if the inversion occurred above 4000 feet (at sea) it has little affect on propagation. However, the inversion height all along the transmission path must be considered (figure 6). On 2 January this inversion was very low and had a marked effect on the outgoing ranges (figures 4 and 5). Also on 13 February a low inversion was coincident with extended ranges. In contrast, the inversion on 5 January was much higher and ranges were greatly reduced. The atmosphere was found to have a substandard lapse rate from 2000 to 7000 feet except for the region where the inversions occurred. This would account for the substandard ranges that were often obtained, and place increased importance on the presence of a low inversion.

No marked monthly variations in propagation were noted by SG or SK observations, variations being due to frontal passages and local weather conditions. Because of the intense surface inversions over the continent in the winter, however, better ranges should occur at that time.

APS-2F FIELD STRENGTH RECORDINGS

A number of recordings were made of the field strength of the PBM's APS-2F radar propagation received at the ship. These measurements were all made on days of average weather conditions and the recordings indicate little variation from the standard case. The radar signals were received to the distance where the signal was attenuated to approximately 45 db below the maxima of the first lobe of the interference pattern. This generally occurred about 140 miles from the ship.

The most significant fact gathered from the field strength recordings is that the nulls of the interference pattern were depressed 20 to 40 db below the maxima, depending on the range of the plane, indicating that the reflection coefficient over the broken ice pack is nearly unity for high angles and gradually decreasing for low angles, roughly corresponding to the theoretical variation over sea water. As the ship was very close to the ice pack during aircraft operations the point of reflection was always located in the ice pack.

summary

Although surface ranges, as shown in figure 2, show few deviations from the standard case (except for the aforementioned days when superrefraction occurred) there were many factors limiting the use of SG radar for navigational purposes. Chief among these were frequent heavy sea returns and the fact that small icebergs, or "bergy-bits" which, although large enough to be a navigational hazard, did not always present a large enough cross section above the water to provide a good target. These aspects, however, will be covered in reports to be published by NRL.

Superrefraction was encountered frequently with the SK radar in tracking planes over the continent. This was expected, for, in preliminary letters from NEL to BuShips, predictions were made from existing meteorological data that, in general, standard to substandard index of refraction lapse rates were to be expected on the ocean near the coast, with propagation improving inland. Since the propagation path of the SK radars was from seaward inland, SK data may be taken as an index to inland conditions. It is believed that the inversions causing this superrefraction would be intensified during the winter months and would, perhaps, enable shipboard operators to maintain radar tracks on aircraft for great distances. The effect of these strong winter inversions has been observed in the past by antarctic mariners through resulting superior mirages. These mirages have led to errors of several hundred miles in the calculation of antarctic distances. It is also quite probable that surface search ranges would be improved in this season due to the greater temperature differential which would be encountered during the seaward movement of an air mass resulting in the drying of the higher levels.

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