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CRITICALITY OF OCEAN FRONTS
TO ASW OPERATIONS.

by

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R. W. James
Naval Oceanographic Office
Washington, D. C. 20390

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CRITICALITY OF OCEAN FRONTS TO ASW OPERATIONS1. INTRODUCTION

Basic to the disposition of ASW forces and choice of specific search tactics is knowledge of the sonar conditions. Range prediction information is presently transmitted to surface units from shore stations through the Ship, Helicopter Acoustic Range Prediction System (SHARPS) as described by NAVWEASERVCOM (1971). SHARPS provides computerized prediction of the 50 percent probability range for predetermined acoustical regimes. These acoustical regimes have been selected to represent, as far as possible, areas of conservative sonic conditions. On this basis the daily message providing periscope depth range (PDR) and best depth range (BDR) information for varying sonars and ship speeds is considered valid for the entire domain for 24 hours.

Since some of the regimes are quite large, and transient changes are possible, on-scene modification of the forecast may be required. This is accomplished by subjectively comparing observed thermal conditions to those predicted in the SHARPS message and making appropriate adjustments to the ranges. A specific problem arises in areas of oceanic fronts or eddies where complex and rapidly varying sonic conditions are thought to exist and simple corrections are not always possible.

The objective of this paper is to describe anomalous thermal features, illustrate the degree to which they may affect ASW ship operations and suggest the need for experimentation to identify acoustic behavior in the vicinity of fronts.

II. OCEAN FRONTS

An ocean front separates waters of different physical characteristics such as temperature and salinity, but often the color, clarity, surface turbulence and other less noticeable properties change across the front as well. Figure 1 (Gotthardt-1970) shows two fronts observed on a ship transit from New York to Bermuda; the well known Gulf Stream North Wall, and the lesser known Slope Front. The surface positions of the fronts are marked by strong horizontal temperature gradients but more important to ASW is the dramatic changes in layer depth, vertical temperature gradients and sound channels. Not apparent from the bathythermograms are changes in biological activity that occur across fronts which may lead to variations in ambient noise and reverberation. In addition, sea surface roughness often varies in the vicinity of fronts due to either changes in the wind speed or to currents and waves acting in opposition.

Unlike fronts in the atmosphere, major ocean fronts do not move rapidly but tend to remain within a fairly well defined zone. Variability about this mean position, however, may be extreme and occurs in the forms of meanders, overrunning, and through the formation of cold and warm eddies. Minor fronts may disappear at times, reforming at a later time in a slightly different location in the same general area.

Since water masses react uniquely to varying atmospheric conditions, the change of thermal properties across a front

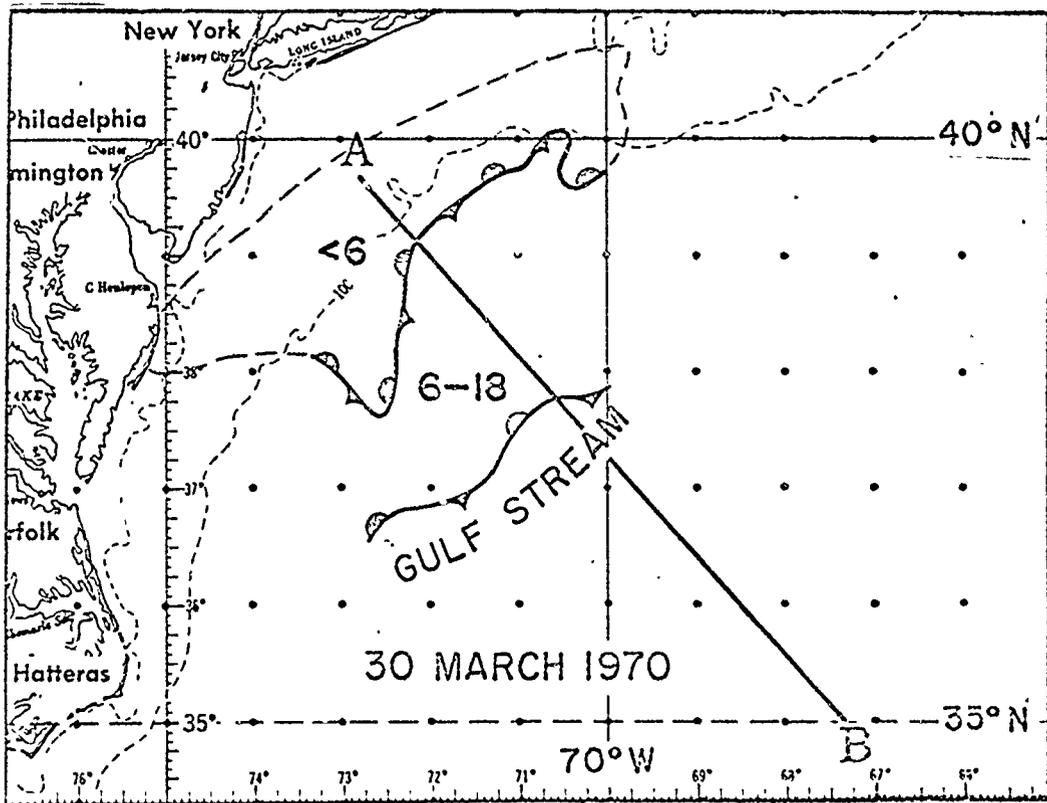
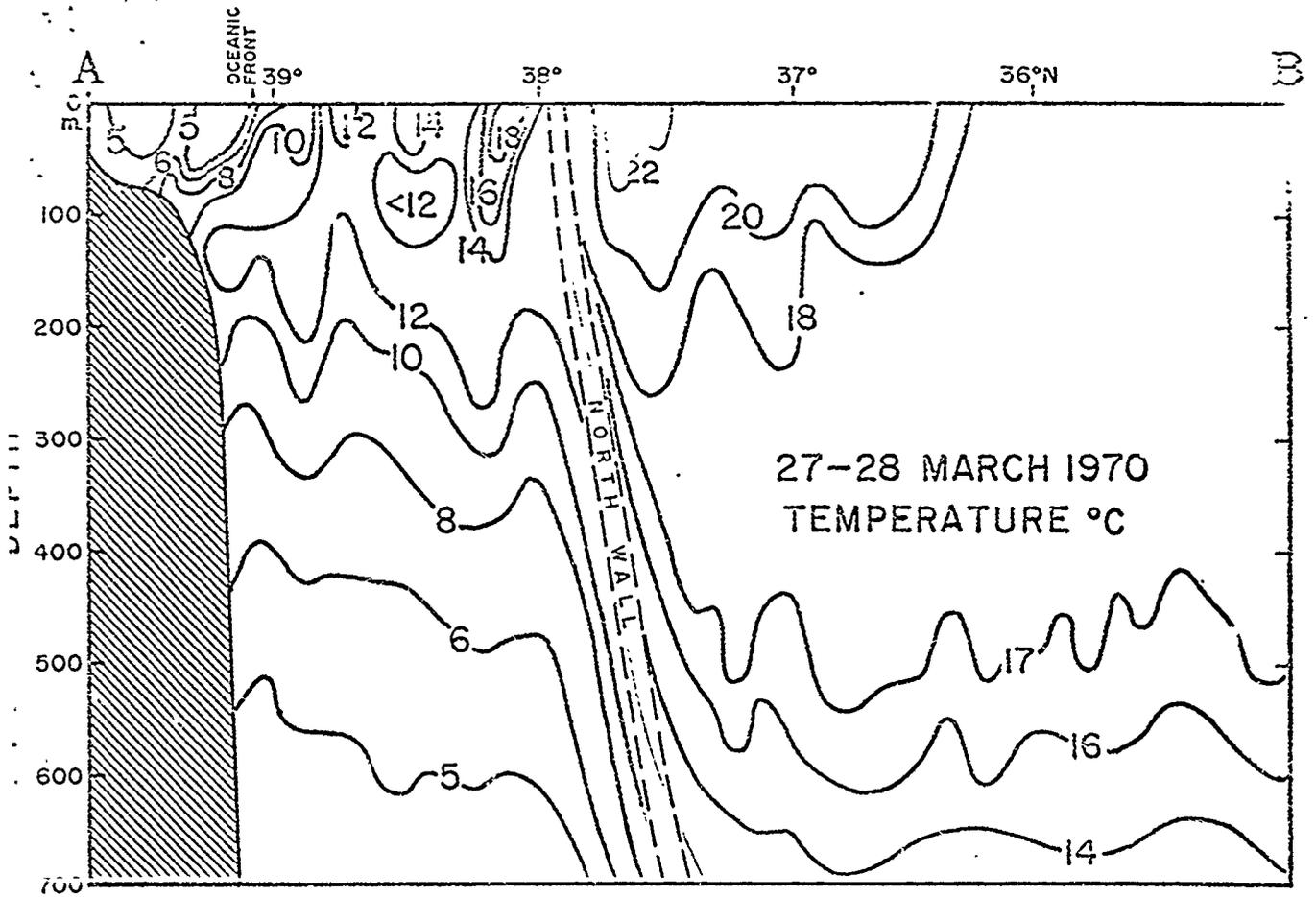


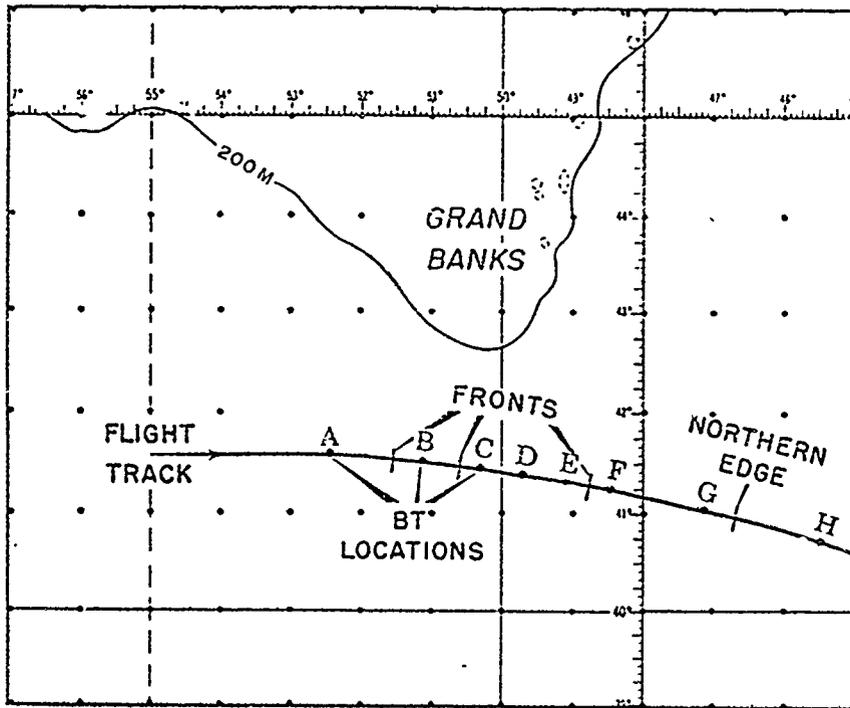
FIGURE 1 OCEAN FRONT THERMAL PATTERN

exhibit seasonal variability. For instance the layer depth may deepen from a value of 80 m in the Gulf Stream to over 300 m in Sargasso Water in the winter but decrease from 30 m to zero on the same transit in the summer.

Figure 2 illustrates how quickly, and to what degree, the thermal structure can change in the vicinity of ocean fronts. These bathythermograms are based on an aerial survey but assuming a Task Force was following the same track they would encounter seven distinct and significant changes in the thermal structure within 24 hours. Surface temperature varied by 12°C in less than 2 km, layer depth varied from zero to 300 m over the length of the track, and vertical gradients changed in both magnitude and direction of slope.

The extent to which fronts occur in the oceans is not always appreciated. As shown by Laevastu and LaFond (1970) one can trace the Atlantic Polar Front from Florida to south of Iceland, a strong front exists between Iceland and the Faeroe Islands and a weaker front between Iceland and Greenland. Several fronts have been located in the Greenland and Norwegian Seas, and along the 50th parallel in the eastern North Atlantic.

Numerous small fronts have been found in the supposedly uniform Sargasso Sea and reported by Voorhis and Hersey (1964), and Voorhis (1967). These fronts vary in location but usually a discontinuity can be found between 25° and 33° North latitudes. Although weaker than the major fronts the Sargasso fronts exhibit



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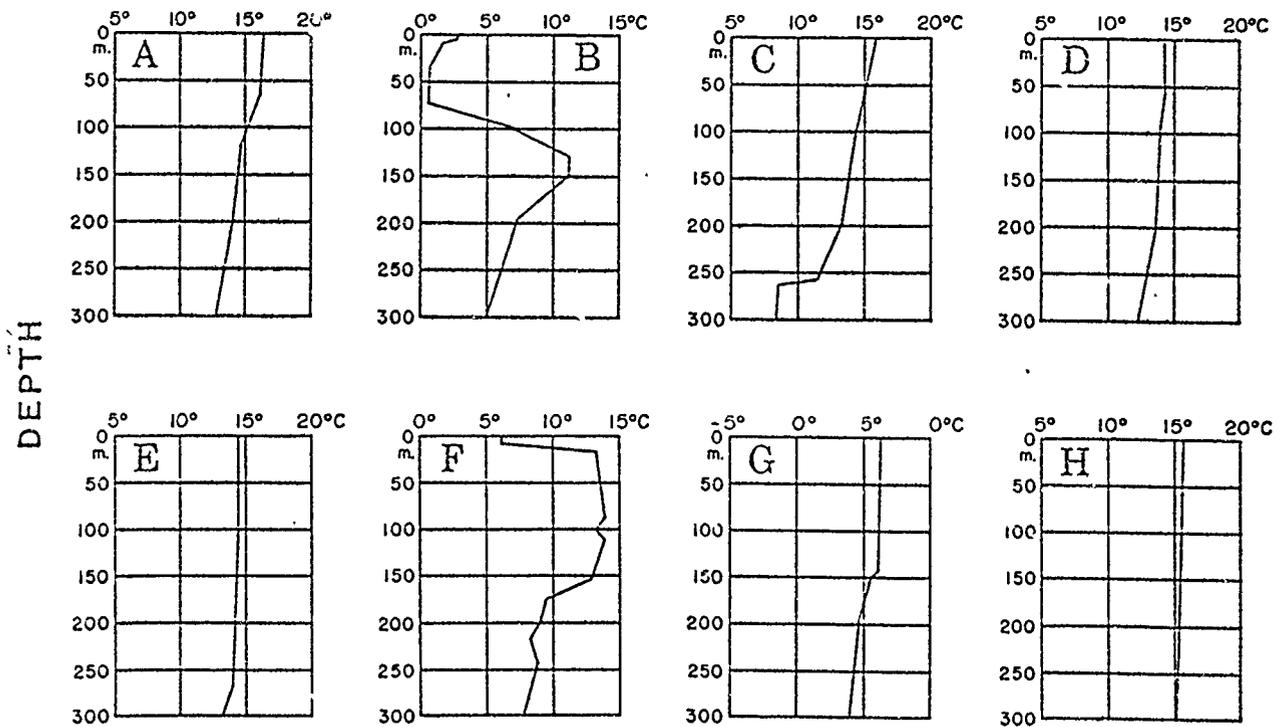


FIGURE 1 VARIABILITY OF BATHYTHERMOGRAMS ALONG OCEAN FRONT

the same characteristic patterns in currents, surface temperatures, layer depths and vertical temperature gradients. Aerial surveys of the Sargasso Sea over a period of time, as reported by Bratnick and Gemmill (1970), indicate that a system of fronts may exist, with the surface temperature generally increasing in a step-like manner toward the south. Some of the fronts they tracked extended for over 500 km and exhibited significant changes in temperature.

Semipermanent fronts exist in the Mediterranean (Johannessen et al.-1971) and in many areas of the North Pacific in a distribution similar to those of the Atlantic. A Mediterranean front extends from Sicily some 70 km to the south-southeast and exhibits extreme changes in vertical thermal gradients, sound channel characteristics and layer depth.

III. EDDIES

When the meanderings of a major front reach a certain stage of amplitude and curvature, pools of warm or cold water break off as shown in Figure 3. The anticyclonic flow around the warm meander (W) eventually closes the loop and Gulf Water ceases to pump further heat into the meander. Eventually the warm water pool breaks loose and after some random drift appears to follow a westward trajectory until rejoining the Gulf Stream off the coast. Cold water (C) is trapped in a similar fashion when the Gulf Stream Water breaks across the narrow neck and no further

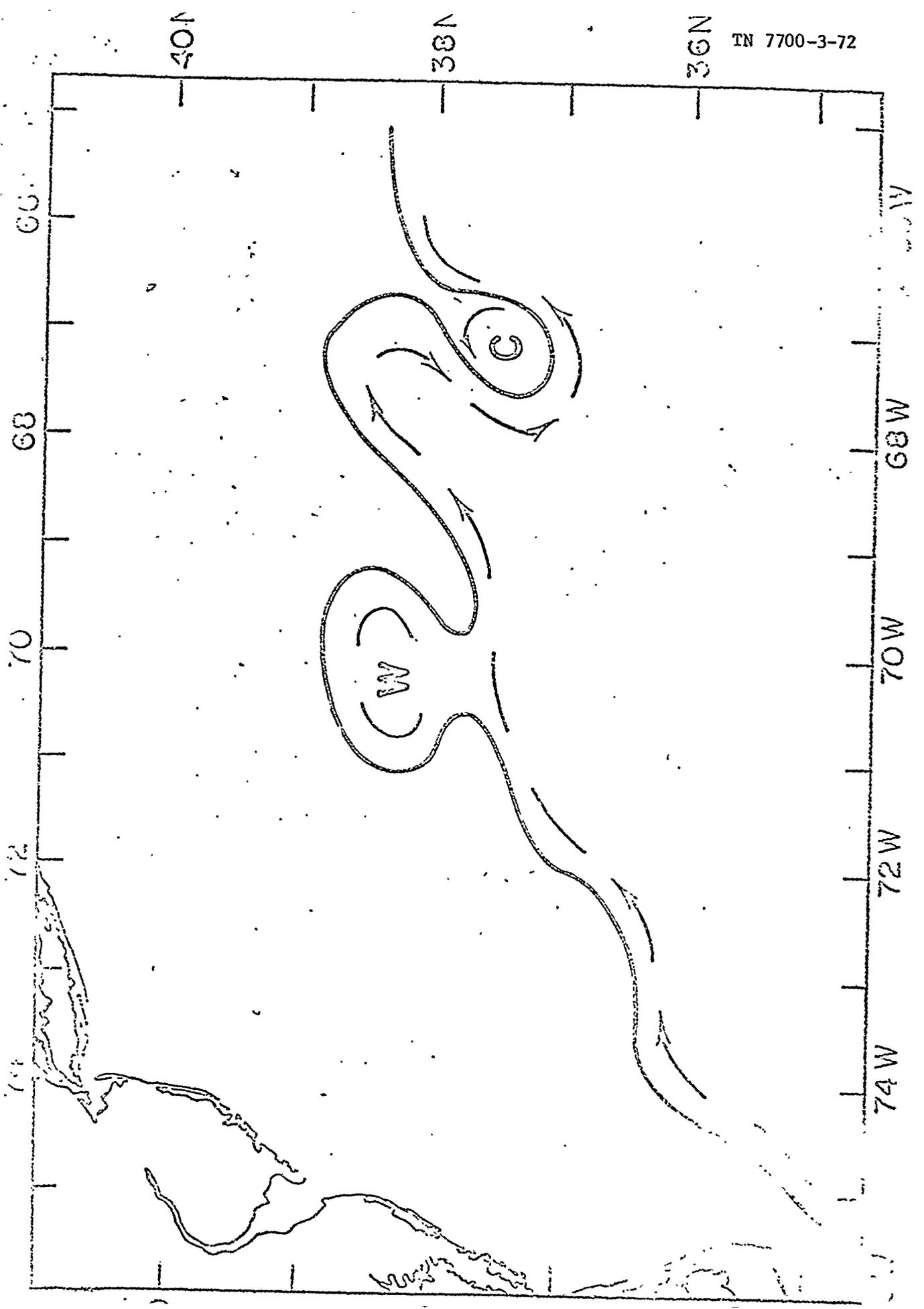


FIGURE 3 FORMATION OF WARM AND COLD EDDIES

connection to the main current remains. These features are called eddies, and they exhibit the same complex thermal structure associated with fronts; that is, strong horizontal temperature changes, and variation in layer depth and in-layer gradients. These eddies are large (60-90 km), extend to over 500 m in depth, and may persist for months. Essentially, transiting an eddy is similar to crossing a front twice with the added complication that the direction of the physical changes are reversed the second time, so that the feature acts as an acoustic lens. Survey of the western North Atlantic over the past several years indicates that the formation of eddies is a fairly common occurrence and one warm and two cold eddies are generally present at the same time.

An eddy may also act like a giant net, retaining the biological activity of the parent water mass within its walls because of the tendency of many organisms to remain within a narrow temperature range. While studying false sonar targets C. Levenson (Naval Oceanographic Office) observed that in transits from Slope Water to either Shelf or Gulf Stream Water (thus crossing the Slope Front or North Wall respectively), the intensity of scattering is greatly increased at the fronts and rapidly diminishes thereafter. This pattern of scattering was found when crossing a warm eddy; the echogram showed a marked increase in scattering at the approach to the boundary of the eddy, followed by an abrupt weakening within the warm core.

Figure 4 shows typical locations of anomalous thermal features in the western North Atlantic Ocean based on numerous surveys. Although Figure 4 is patterned after spring the same number of features could be found anytime of the year. Considering the size, number and thermal variability represented by these features it appears essential that fronts and eddies should be considered in ASW planning and tactics.

Salinity also varies across fronts and eddies, of course, and in some cases undergoes considerable variation. Owing to the strong dependence of sound velocity on temperature, however, the thermal profile is the controlling factor in most ASW considerations. Another consideration is that in operational applications a ship would not have salinity data available but would have to depend on bathythermograms.

Table 1 summarizes the magnitude of changes in thermal characteristics a ship may encounter in crossing fronts. The values given are relative variations and thus indicate the change across a front may be as little as the first value or as big as the second. Sea surface temperature, for instance, typically increases 1°C across small fronts but may jump 12°C for a major front. Although the degree to which a property changes across a front does generally reflect the strength of the front, extremes are not given in Table 1. Thus, on occasion much greater changes may be found; surface temperature has been observed to change 16°C within a few kilometers.

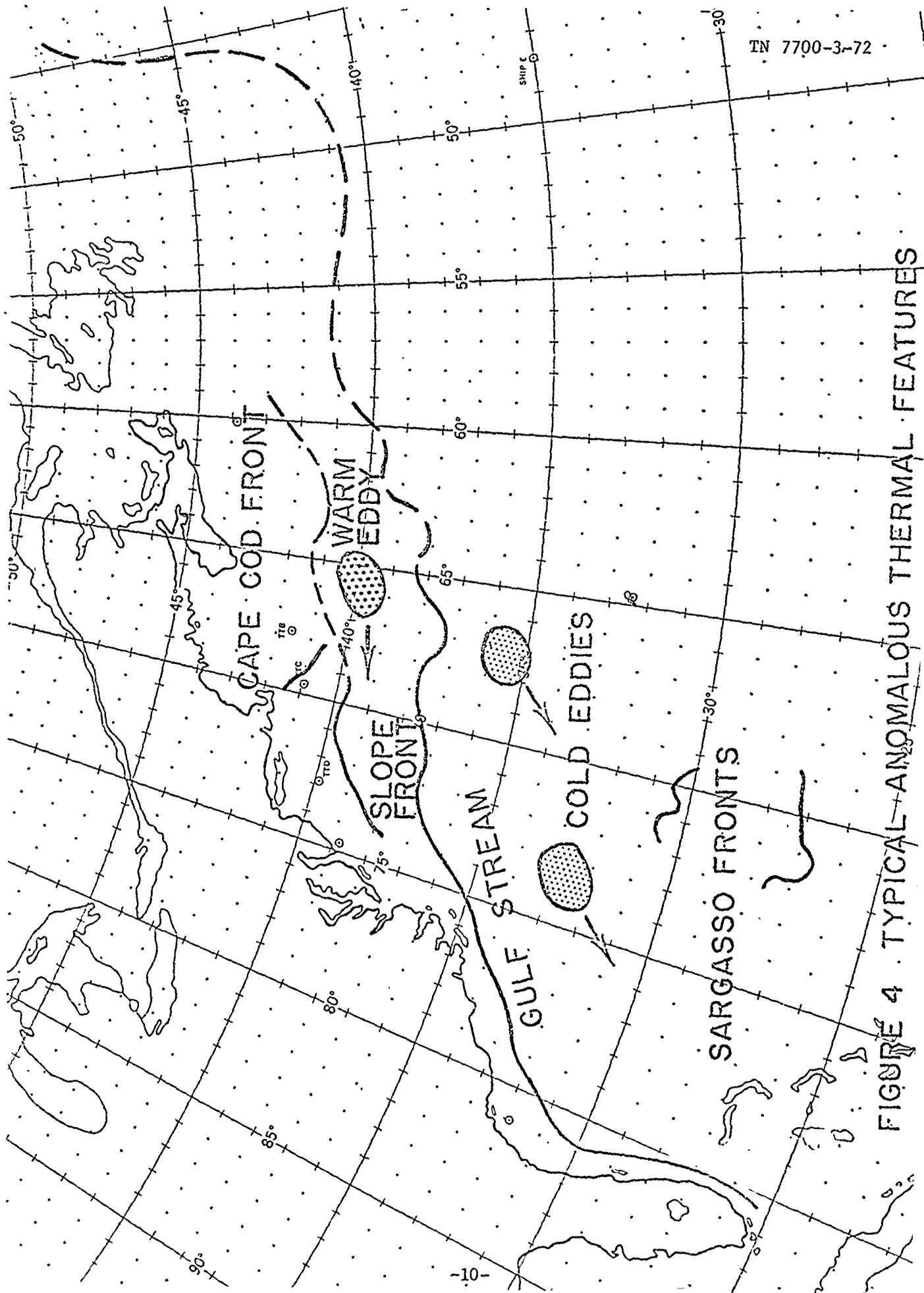


FIGURE 4 TYPICAL ANOMALOUS THERMAL FEATURES

TABLE I CHANGE IN THERMAL CHARACTERISTICS
ACROSS FRONTS AND EDDIES

<u>Property</u>	<u>Change in 10 KM</u>
Sea Surface Temperature, °C	1 to 12
Layer Depth, M	0 to 200
In-Layer Gradient °C/10 M	0 to \pm 10
Below-Layer Gradient, °C/100 M	1 to 7

IV. IMPACT ON SONAR CONDITIONS

The impact of these anomalous thermal features on ASW is two-fold. First, through the disruption of optimum detection capabilities as the sonic conditions fluctuate in and near the front. Second, through the effect of the front itself when the target is on one side and the ASW ship on the other. In the first case the Task Force may assume sonar ranges are greater than they really are, and thus the ship deployment is ineffective. Or the ship may assume a range which is maintained but fail to realize that owing to the rapidly changing conditions the range could be materially increased by a change in mode or tow depth.

Where a ship is pinging through a front the effect may be to produce anomalous behavior of the sound rays, such as trapping of the near surface rays or through bearing errors.

Some of the changes in ASW capabilities that may occur when operating near, or through a front are discussed in the following sections. At this time it is not possible to define the variability in a quantitative sense, or even to specify the degree to which they occur world wide. One fact is certain, however, the enemy submariners know the sea and will utilize its anomalous characteristics to their advantage. In order to maintain equality the ASW forces must understand what happens to sonic conditions in frontal areas and develop tactics to cope with these changes.

(1) Variation in Surface Duct Ranges (PDR)

On the basis of the sonar doctrine developed for the SQS-23 by Chapman et al. (1971) periscope depth ranges (50 percent detection) were computed for a destroyer following the track of Figure 2. Average source level, ship noise and ambient noise values were selected in accordance with the above publication and ranges calculated for bathythermograms A through H. The results are shown in Figure 5 where to avoid classification, the variability in range is shown as a percent of the ideal range. This would be the range for a layer depth of 500 feet or greater, sea surface temperature of 60°F or over and wind 10 knots or less for the same figure of merit. As the ship transits the are predicted PDR varies four times, with an average change of 80 percent in range for each occurrence.

Variations in temperature are of the utmost importance in regard to the surface duct since only slight changes in the in-

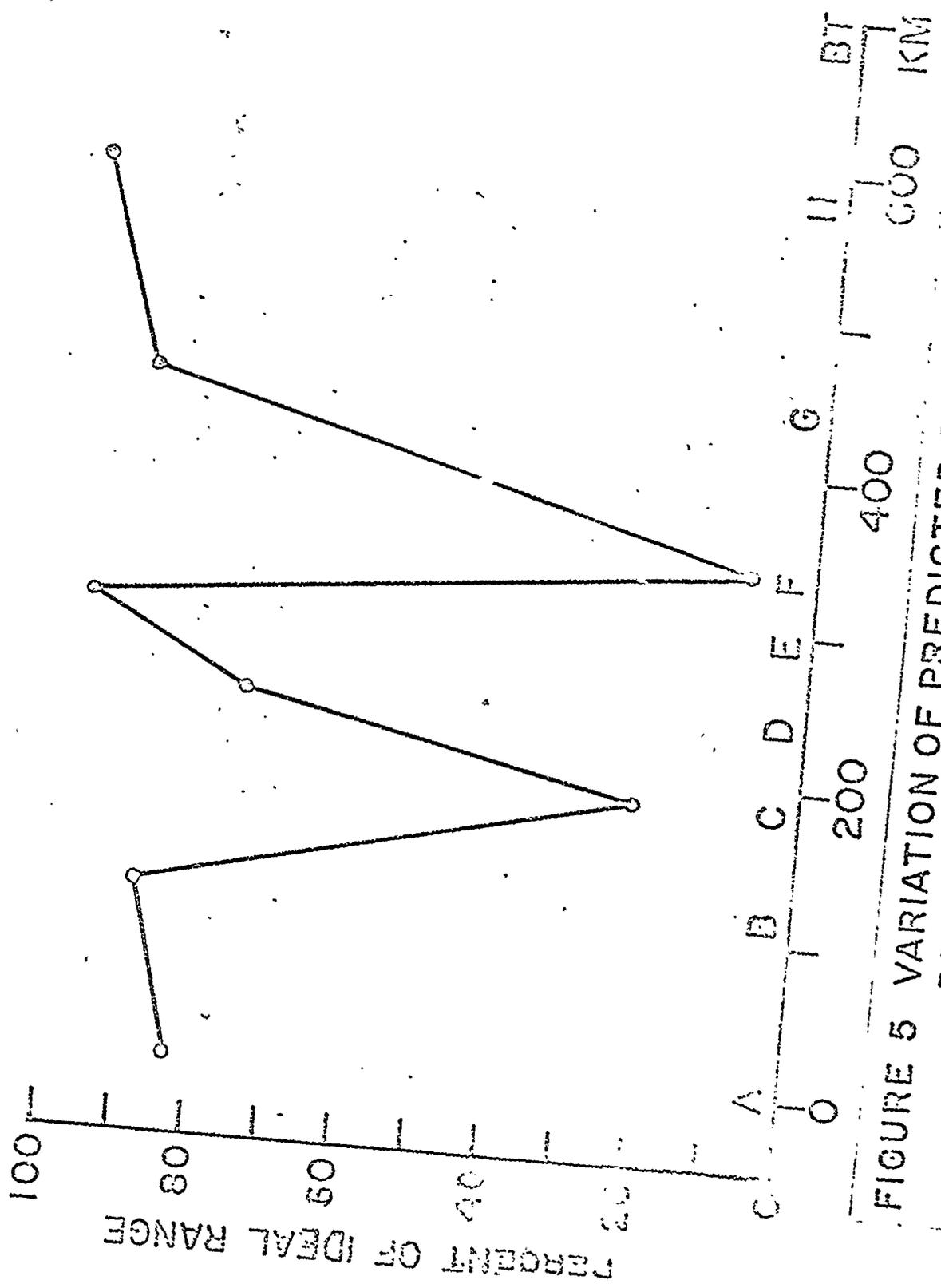


FIGURE 5 VARIATION OF PREDICTED SQS-23 PERISCOPE DEPTH RANGE IN FRONTAL AREA

layer gradient can mark the difference between an excellent duct and none at all. The periscope depth range varies similarly in other frontal areas although perhaps not as drastically. Examination of all types of fronts (major, weak, deep, shallow) and computation of the sonic variability from both a theoretical and experimental basis should provide valuable information concerning the best tactics to utilize in frontal areas.

(2) Convergence Zone Feasibility

Convergence zone propagation depends upon a velocity excess, where a portion of the deep sound velocity trace exceeds the surface value. In order for sufficient rays to be trapped to provide a high probability of detection this excess should be on the order of 10 m/s.

When a ship is operating in frontal zones the near surface temperatures may rise 5 to 10°C over a short distance. Assuming a salinity of 35 ‰ the surface sound velocity thereby increases 20-40 m/s, sufficient in many cases to reduce, or eliminate, the velocity excess and convergence zone propagation. As a ship proceeds from Point A to H in Figure 2 for instance the feasibility of convergence zone varies from good to bad several times. Over much of the track the depths are over 3000 m and the critical sound velocity for convergence zone would be 1505 mps. Surface sound velocities below that value permit convergence zone while those above do not, and a sound velocity below 1495 at the sur-

face permits enough rays to be trapped to ensure good detection capability. Table II shows an example of the variability in convergence zone feasibility a ship would encounter operating south of the Grand Banks.

TABLE II CONVERGENCE ZONE FEASIBILITY IN FRONTAL ZONE

<u>Point</u>	<u>SV (m/s)</u>	<u>CZ Feasibility</u>
A	1513	No
B	1460	Too Shallow
C	1511	Too Shallow
D	1504	Too Shallow
E	1504	Poor
F	1479	Good
G	1476	Good
H	1511	No

Another aspect to be considered is that the strength of the convergence zone signal also fluctuates as a function of layer depth so that abrupt changes in this parameter may produce detection problems.

(3) Ambient Noise

Ambient noise is a function principally of ship traffic, wind (sea state) and biological activity. At the frequencies of the SQS-23 and 26 sea surface turbulence is the most important cause of ambient noise. An increase in wind speed from 10 to 20 knots for instance, can theoretically decrease a sonar range by ten percent or more due to the increase in ambient noise.

Several phenomena occur at ocean fronts that affect the nature of sea surface turbulence and should lead to significant changes in ambient noise. Specific measurements are required to support this theory but under the following conditions ambient noise may change significantly as one proceeds from cold to warm water:

(A) When current set in the frontal zone is in opposition to the wave direction. In the Gulf Stream off Cape Hatteras a current shear exists with strong currents setting easterly in the warm water and weaker currents flowing to the west in the cold water. With moderate northeast winds the seas are relatively smooth and uniform in the cold water but chaotic and turbulent in the warm. Opposing currents steepen the waves, produce white caps, surging water and considerably more noise. One can observe the edge of the Gulf Stream from the air by the change in its appearance due to surface turbulence alone when the above conditions occur. A change in sea state by 1 category can increase ambient noise by 5 db, and since all fronts have current shear to some degree a significant variation in noise is possible across fronts due to wave turbulence.

(B) When cold air passes over a front from the cold to the warm water side. It has been observed that surface winds are more gusty and turbulent when the air near the ground is unstable. Cold air passing off the coast and over warm water has been observed to increase its wind velocity by a factor of three. Similarly, across sharp ocean fronts the increased con-

vective turbulence due to surface heating can double the wind speed and for cases of moderate to strong winds increase the ambient noise by 5 to 10 db.

(4) Tow depth for Variable Depth Sonar

Variable Depth Sonar has extreme sensitivity to the thermal structure so that continuous monitoring of the environment is desirable if optimum use of the sensor is to be obtained. A ship transiting frontal areas will find the best tow depth to be highly variable.

As an example the operating doctrine specified for the SQS-35 VDS (Genung et al. 1972) was used to compute best tow depth for the frontal area shown in Figure 2. These depths are shown in Figure 6 as a percent of total tow depth capability. The variability is extreme, with the best tow depth fluctuating from zero to full depth and changing by significant depths four times in the total 600 km distance. Computations of ranges for the AN/SQS-35 VDS for the same track as above show useful ranges about 60 percent of the track, where useful means the range for below-layer targets is significantly better than the hull-mounted BDR.

(5) Volume Reverberation

As discussed earlier there is evidence that the intensity of scattering varies as one transits the Gulf Stream, the Slope Front and eddies. Whether this is a common occurrence across all fronts is unknown, however, it is known that nutrients are more plentiful in up-welling areas such as occur at fronts. where

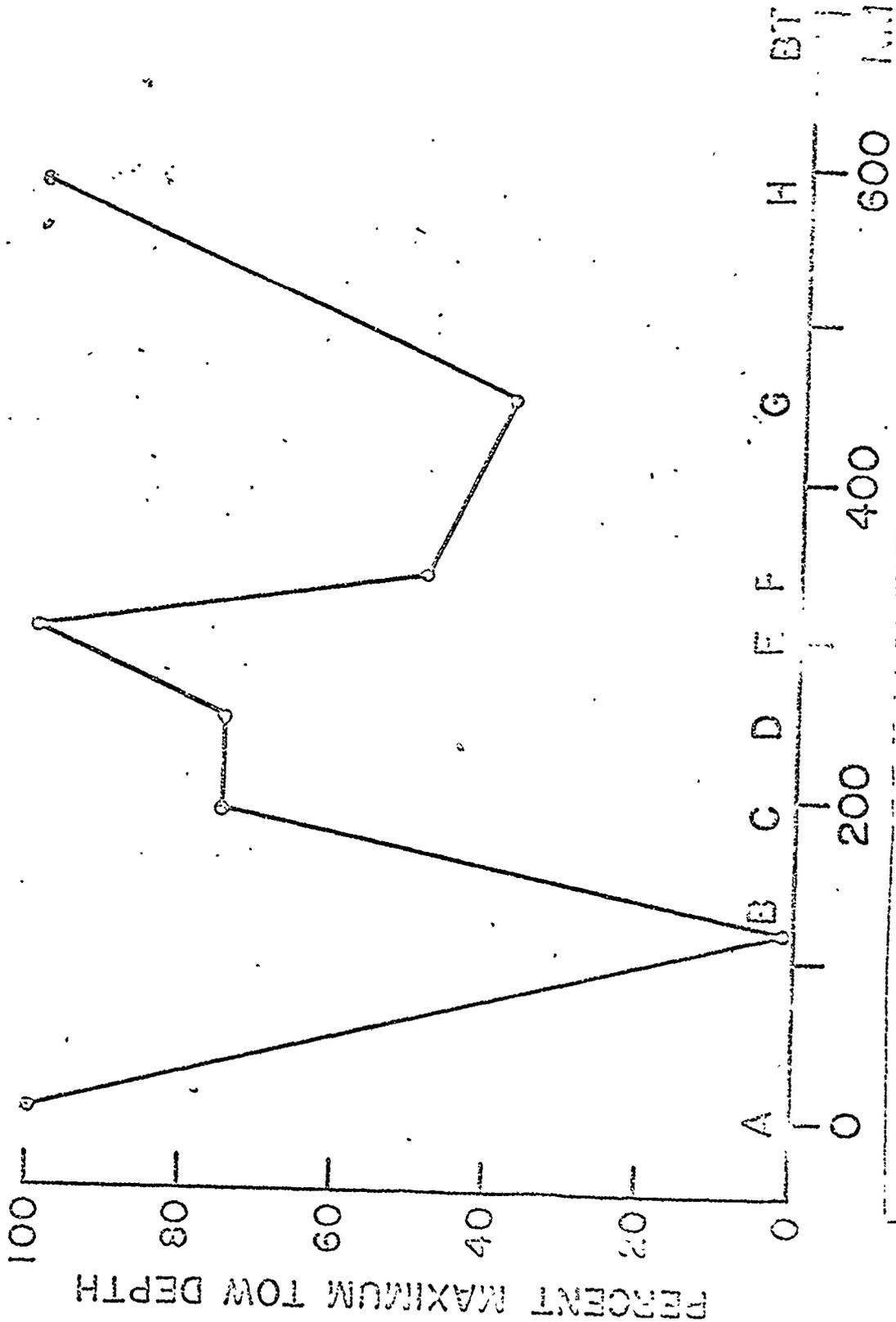


FIGURE 6 VARIATION IN PREDICTED VDS TOW DEPTH IN FRONTAL AREA

there are nutrients one is likely to find the small fish and other biological organisms that are responsible for volume reverberation. Existence of a deep scattering layer (DSL) for instance may increase reverberation by up to 10 db over that for no DSL present.

Experiments with the Bureau of Commercial Fisheries to correlate frontal zones with fish catch have shown positive results. Forecasts of areas of frontal activity were made for the East Coast of the U.S. and fishing ships directed to locations where fish catches were substantially increased. It may also be possible to find a relationship between the thermal structure and the existence of sound scatterers. An important aspect of any frontal acoustic model would be the variation of volume reverberation across fronts.

(6) Best Depth Ranges

Best depth ranges for the submarine to avoid detection (BDR), vary in a frontal area similarly to PDR, with the added problem that BDR ranges are generally poor. PDR in frontal areas varies from bad to good, but BDR often is restricted to a narrow range of bad to fair. This is due to the high probability of warm water overriding cold water in frontal zones so that a shallow layer depth is produced over a sharp negative gradient. The result of this thermal profile is sharp downward refraction of rays that have vertexed close in, and consequently poor BDR.

Figure 7 shows two-way propagation loss curves for bathy-

thermograms A, B, and C of Figure 2. This is for active sonar at a depth of 6 meters pinging on a target at its best depth to avoid detection appropriate to the above thermal profiles. Obviously, during the time the ship is in the vicinity of Point B, its detection capability is very poor. These curves were prepared on the NOVA computer utilized by the Integrated Carrier Acoustic Prediction System (ICAPS).

(7) Sound Propagation through a Front

The above discussions have considered the variations encountered in sound conditions as a ship proceeded from one side of a front to the other. A different problem arises in the propagation of sound through a frontal zone.

Laevastu et al. (1971) made calculations of the effect of a front on sound rays. They showed three cases of sound propagating from warm to cold and vice versa, where the distance across the front varied from 10 km to 6 km. Only two bathythermograms were used, however, to represent thermal conditions in each of two adjacent water masses respectively. They found significant modifications in the sound ray pattern across all fronts. D. Barron of the Naval Oceanographic Office has calculated propagation loss and ray paths across the Gulf Stream based on a thermal cross-section consisting of sixty bathythermograms and found anomalous behavior of the sound ray paths.

If a destroyer takes one bathythermograph in the Gulf Stream and uses it as representative of the general area how much

SURFACE DUCT
SOURCE: 6 M
TARGET: BEST DEPTH
TO AVOID
DETECTION

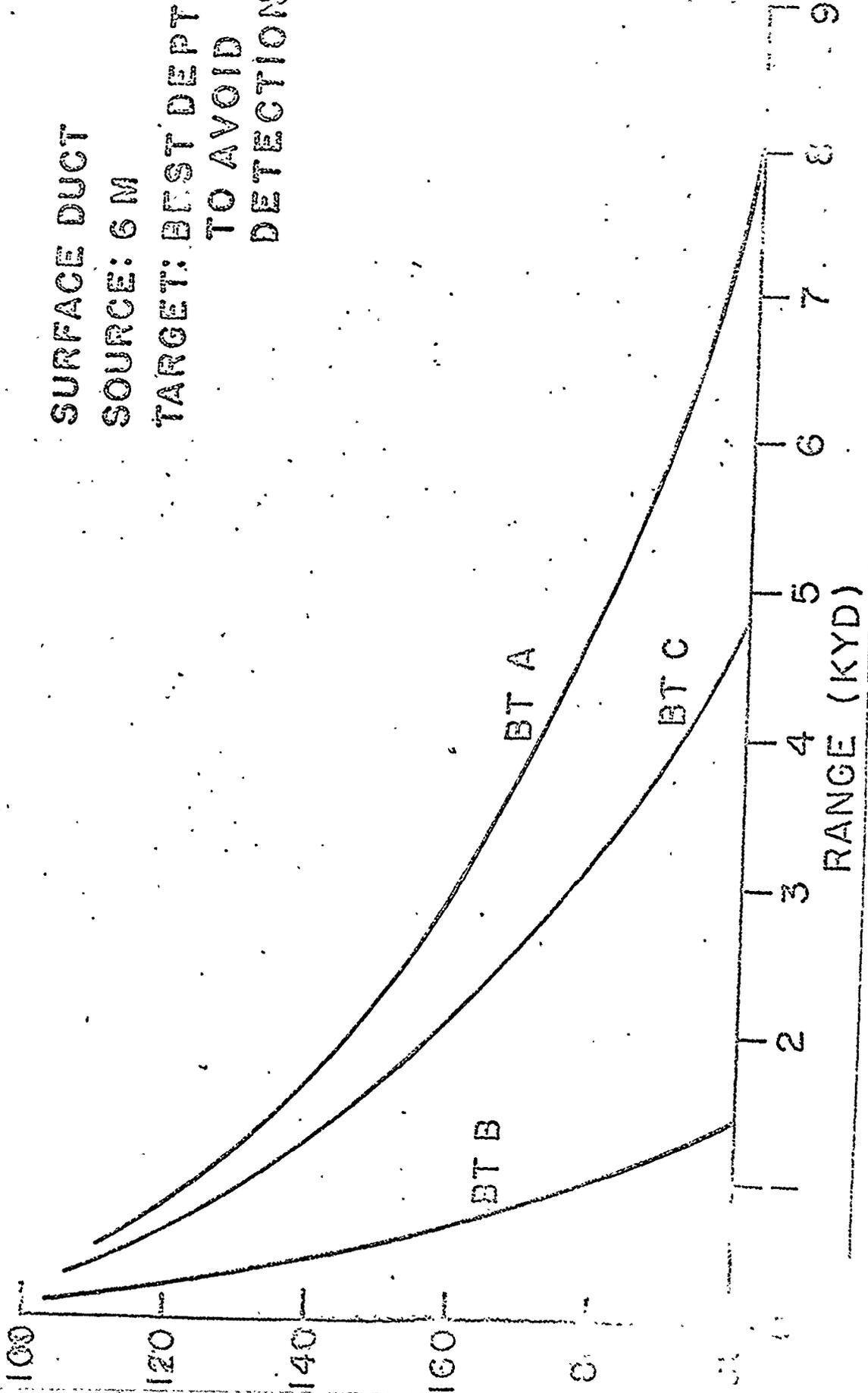


FIGURE 7 TWO-WAY PROPAGATION LOSS IN FRONTAL AREA

difference does it make to the propagation loss? The difference is shown for a passive case in Figure 8, where the lower curve is based on one bathythermogram and the upper curve on thirteen bathythermograms. For the multi-profile curve the sound rays are trapped in the surface duct for some distance and then refracted by the front in concentrated bundles toward the bottom. Bottom bounce propagation then accounts for the remaining sharp ridges and troughs. With the single thermal profile, the sound rays are refracted to the bottom in a more dispersed pattern so that the sound intensity is reduced at the receiver and no sharp peaks of sound energy are found.

Ray plots show that sound propagating through fronts is significantly affected by the thermal discontinuities. Sound channels are discontinued and the rays directed downward. Sharp near-surface thermal gradients force the sound rays into the deep channel thereby reducing PDR and BDR if a convergence zone is impossible. In general, the sound rays tend to bend beneath warm water when propagating from cold water side of the front.

Another problem that arises in frontal areas but has not yet been measured is bearing error. The strong horizontal thermal gradient may be capable of producing significant bearing errors depending on the angle of approach of a ship and the type sonar involved.

V. CONCLUSIONS

It has been shown that ASW capabilities may be significantly

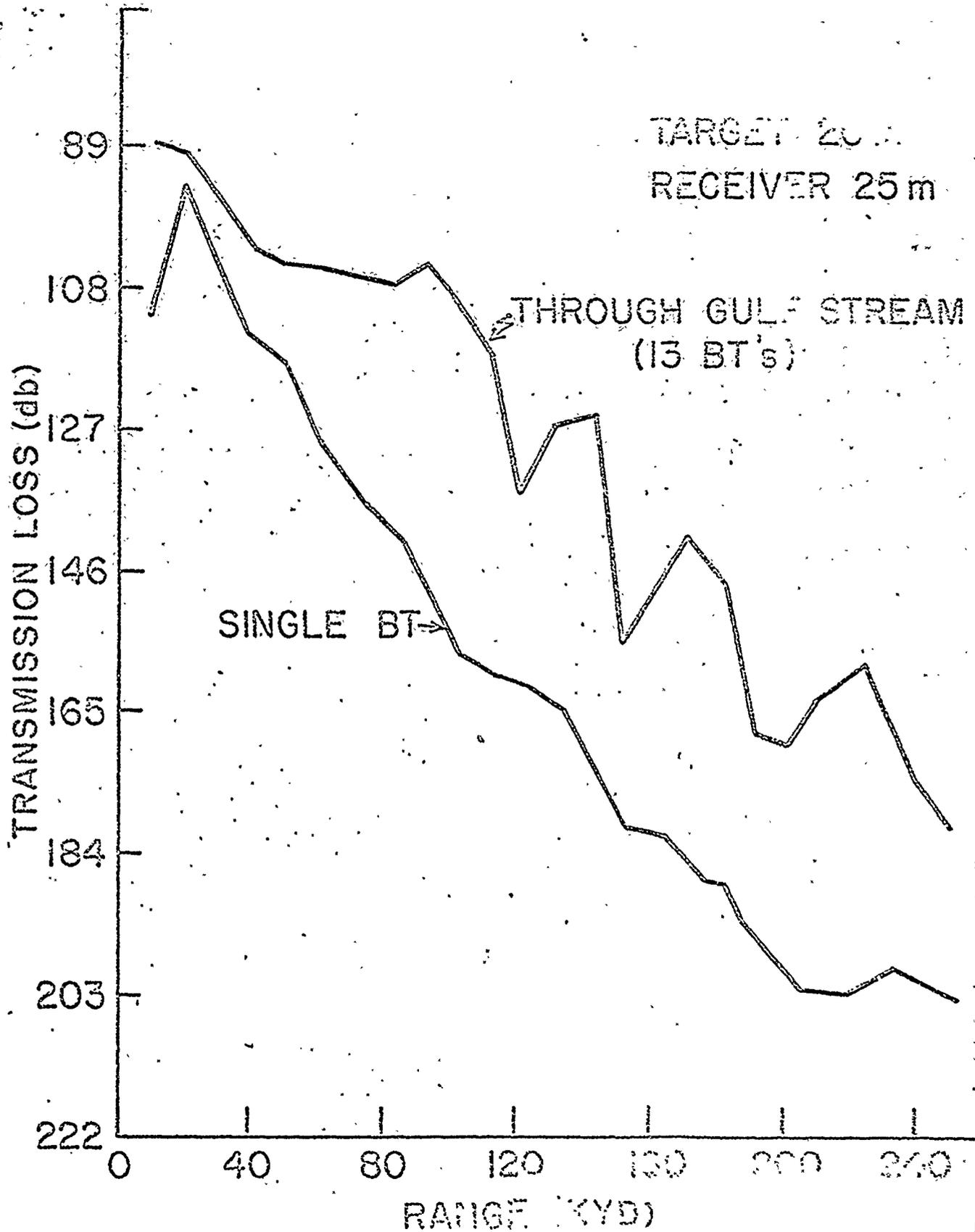


FIGURE 8 PROPAGATION LOSS THROUGH GULF STREAM WHEN THERMAL CONDITIONS ARE REPRESENTED BY ONE OR THIRTEEN BATHYTHERMOGRAMS.

affected in the vicinity of fronts. At the present time there is no established tactic for dealing with these complications. Continuous monitoring of the entire upper 300 m of the ocean is not practical at the present time and although the sea surface temperature could be recorded continuously, it is not always a reliable indicator of the thermal profile below. A towed device at 100 m in conjunction with the surface temperature could provide a good indication of the entire thermal profile, but this may not be feasible from an operational viewpoint.

The best solution may be to measure thermal structure, ambient noise, and volume reverberation across various fronts in order to establish a model simplifying the complexities to manageable levels but still providing a more realistic approach than now followed. It would not be too difficult to characterize all fronts by some classification system and provide the model on magnetic tape. Upon approaching a particular frontal zone, a ship could utilize the appropriate tape to display on a cathode ray tube (CRT) information concerning thermal characteristics, optimum modes, range information and sonar settings, as well as recommended tactics. Present work on automated shipboard prediction systems, such as ICAPS, will provide the means for realizing this approach.

In addition to the above approach there is a need to measure propagation loss through fronts under various bearings and ranges in order to establish the effect of fronts on all detection systems.

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TECHNICAL NOTE *

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