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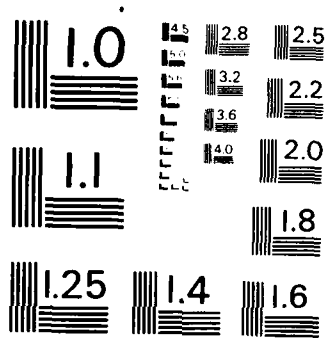

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THESIS

COUPLED MIXED LAYER-ACOUSTIC MODEL

by

John J. McManus

September 1985

Thesis Advisor: R.W. Garwood

for 20 days. This was then compared with actual bathythermograph data taken 20 days later. Three cases were examined: initial, model, and final data as input to the RAYMODE acoustic model. The acoustic performance for the three cases was measured median detection range (MDR) and convergence zone range (CZR). In the absence of strong horizontal advection, over a 20 day period the OBL can predict surface temperature to within an average of 0.5°C. Therefore the coupled models can be used effectively to help predict MDR and CZR in a tactical situation.

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Coupled Mixed Layer-Acoustic Model

by

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OCEANOGRAPHY

from the

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ABSTRACT

A coupled ocean mixed layer-acoustic model is evaluated in two dimensions at a line of stations in the northeast Pacific Ocean. The Oceanic Boundary Layer Model (OBL) is initialized using bathythermograph data acquired during the 1980 Storm Transfer and Response Experiment (STREX). The OBL model was used to predict a new thermal profile after integrating in time for 20 days. This output was then compared with actual bathythermograph data taken 20 days later. Three cases were examined: initial, model, and final data as input to the RAYMODE acoustic model. The acoustic performance for the three cases was measured using median detection range (MDR) and convergence zone range (CZR). In the absence of strong horizontal advection, over a 20 day period the OBL can predict surface temperature to within an average of 0.5°C. Therefore the coupled models can be used effectively to help predict MDR and CZR in a tactical situation.

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I. INTRODUCTION

The coupling of a mixed layer model with an ocean acoustic model is an opportunity to make acoustic predictions from earlier BT information and meteorological analyses and forecasts. The thermodynamic model is initialized with an observed temperature profile, and it makes use of meteorological information that is currently available such as wind speed and solar radiation. The thermodynamic forecasts are then input into an acoustic model. In the past, similar studies have concentrated on one particular acoustic or thermal model. R. H. Fisher (1981) investigated the variability and sensitivity of a coupled model system. He found that a one dimensional thermal model integrated in time at a single point (Ocean Station Papa 50°N 145°W) predicted mixed layer structure better than did the Expanded Ocean Thermal Structure (EOTS) system which was currently in use at the Fleet Numerical Oceanography Center (FNOC).

The working hypothesis for this research is that it is possible to make accurate acoustic forecasts using recent BT information to initialize an ocean mixed layer model driven by atmospheric forcing. The atmospheric forcing is readily available from atmospheric analysis and predictions by FNOC. The Garwood model is a proven mixed layer model which employs a mathematical model for turbulent entrainment (Martin, 1985). The results from the Garwood model are input into the RAYMODE Passive Propagation Loss Computer Program which uses the RAYMODE propagation loss model, producing an acoustic forecast. The RAYMODE model uses aspects of both ray and normal mode theory to calculate acoustic pressure. Using this system, the acoustic forecaster would not be constrained to making predictions based on climatological data alone.

The purpose of this thesis is to test the working hypothesis by expanding the originally one dimensional scope of this research to include a line of data points, making the acoustic analysis two dimensional. Also proposed is a change in the method Fisher used to merge upper layer thermodynamic model output with deeper ocean historical information. The thermodynamic model being used provides an output of temperature every 5 m down to 200 m. The original approach (Fisher, 1981) was to connect the final output point at 200 m to historical data available at FNOC. In almost every case, there was a large and unrealistic discontinuity in the resulting thermal profile. This manifested itself in a large sound velocity gradient when input into the acoustic model, and this anomaly tended to dominate the acoustic model output.

The data used in this research was acquired in support of the joint U.S.-Canadian Storm Transfer and Response Experiment (STREX) which was held in the fall of 1980. The general objectives of STREX were to understand the physical processes of the boundary layers of the atmosphere and ocean in mid-latitude storms, the interactions of the two boundary layers, and the interactions with larger-scale phenomena (Miyake, 1980). Observations were made in the vicinity of Ocean Station PAPA as storms passed during the fall of 1980. The acoustic portion of the experiment was called ASTREX and was designed to supplement STREX with acoustic measurements relating to the study of the effects of winter storms (Dunlap and Andersen, 1985). The data used in this research consisted of airborne expendable bathythermograph (AXBT) information acquired from a series of six P-3 flights between 15 November and 5 December 1980. These flights were carried out as a part of the Naval Postgraduate School's research effort during STREX. Each of the nine hour missions flew northwestward from Cape Mendocino, California outbound along the center track (Fig. 1.1). The spacing between the stations was 55.6 kilometers (30 nm).

The complete set of navigation equipment on the P-3C was used in calculating the position of each of the deployed AXBTs and the cumulative error of the inertial navigation system was checked and

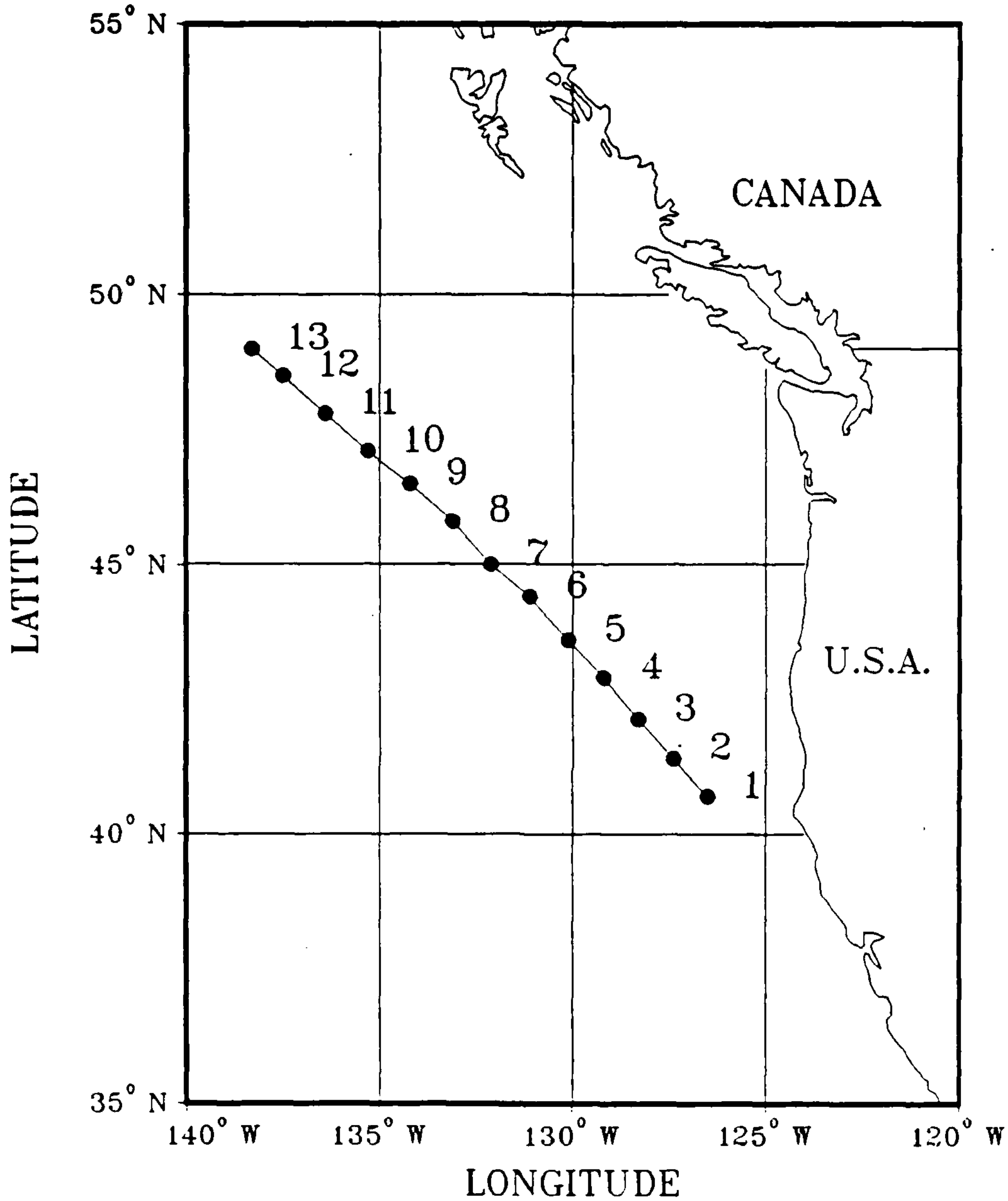

Figure 1.1 ASTREX center track AXBT stations.

recorded. This error was less than 4 nautical miles for the flights selected for this research (Lundell, 1981). This data is very suitable for thermal-acoustic model analysis because it allows for comparison between thermal model output and actual AXBT observations made at the same time. Also, because the stations are in a straight line and are equally spaced, the transition from one dimension to two dimensions is easily accomplished.

II. OCEANIC CHARACTERISTICS OF THE PROJECT AREA

The region chosen for the Naval Postgraduate School's portion of the STREX project was that portion of the northeast Pacific Ocean between latitudes 40°N and 50°N and 126°W and 139°W. The area is located between the Pacific Subarctic Water Mass and the Pacific Equatorial Water Mass (Tabata, 1965). The North Pacific Current flows eastward at about 45°N and splits into the Alaska Current and the California Current as it approaches the eastern coastal boundary of the Pacific Ocean. This divergence of the current varies seasonally and has been demonstrated by satellite-tracked drogue buoys. In the winter, more of the buoys turn southward, and in the summer more of the buoys turn northward (Picard and Emery, 1982).

The AXBT observations from the northwest portion of the project area would be expected to show characteristics of the Subarctic Water Mass. Those observations from the southeast portion should be influenced by the colder offshore waters of the California Current. Both the North Pacific Current and the California Current have surface speeds of less than one knot. As a result, the water in the project area is subject to constant climactic conditions and has time to adjust to seasonal variations. During the late-fall time period of this experiment, the ocean experiences a net loss of heat. This heat loss drives the winter convective mixing process and is the major influence on the area's vertical thermal structure.

The physical structure of the ocean depends on both temperature and salinity. The principal salinity feature in the north Pacific is a permanent halocline found at about 100 m depth. Above this level, the water is nearly isohaline and is of relatively low salinity. The low salinity water of this region is caused by an excess of precipitation over evaporation. Between 100 and 200 m depth, the salinity rises about one ppt.

The winter cooling season runs from about mid-September to about mid-April. Surface cooling and strong wind mixing cause the MLD to deepen. If the winter cooling is severe, the residue of the decaying seasonal thermocline can descend into the halocline early in the season. The water in the mixed layer above continues to cool, and the result is a temperature inversion in the upper portion of the halocline. This structure is hydrostatically stable because of the relative domination of salinity over temperature in controlling the pycnocline (Tully and Giovando, 1963). If the winter cooling is not severe, the residue of the mixed layer will not reach the halocline during the cooling season. In this case, the halocline would remain intact and there would be no temperature inversion at depth.

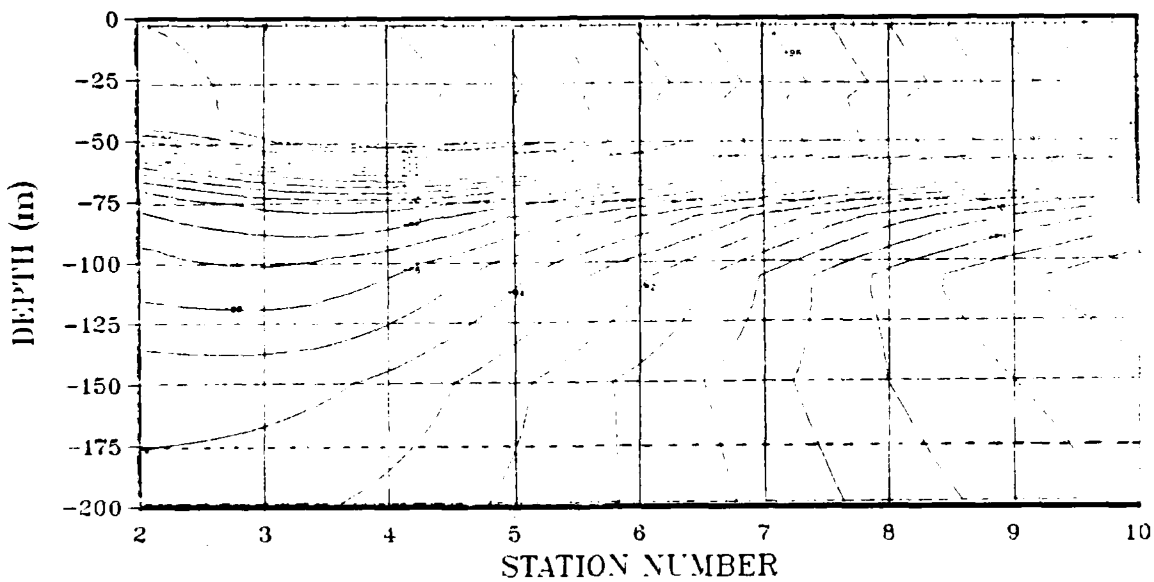

Figure 2.1 Sound velocity contours spaced at 1 m/s showing shallow sound channel (after Dunlap et al., 1985).

The existence of a temperature inversion at depth will result in the formation of an acoustic shallow sound channel (SSC). The sound channel intensity or magnitude is measured in units of sound velocity and is the difference between the sound velocity at the axis and that occurring at the lower boundary (Dunlap, 1982). A sample set of sound velocity contours is plotted using EOTS data for the ASTREX region (Fig. 2.1). The existence of an SSC can be seen as the transect extends seaward, from station 8 to 10 at about 110 m depth.

III. MODEL THEORY

A. OCEAN THERMODYNAMIC MODEL

The ocean thermodynamic model used in this coupled system is the Oceanic Boundary Layer Model (OBL) which was developed by Garwood (1977). It is a one dimensional, second order turbulence closure, vertically integrated (bulk) model of the ocean surface turbulent boundary layer. The model employs the Navier-Stokes equation of motion without the geostrophic component, the continuity equation for an incompressible fluid, the heat equation from the first law of thermodynamics, an analytical equation of state, and a two-component vertically integrated turbulent kinetic energy (TKE) budget.

The rate of deepening or shallowing of the mixed layer is determined by the dynamics of the entrainment process. The TKE in the mixed layer erodes the stable water mass found below the mixed layer. The entrainment hypothesis is based on the TKE budget. Closure for the system of equations is achieved by using the bulk buoyancy and momentum equations along with the mean turbulent field modeling of the vertically integrated equations for the individual TKE components (Rosner, 1985).

The OBL model differs from earlier models in the following ways. First, the amount of wind generated TKE to be used in mixing is a function of the ratio of the mixed layer depth (MLD) to the Obukhov mixing length. Second, viscous dissipation is dependent on a local Rossby number and separate vertical and horizontal equations for TKE are used (Garwood, 1977).

The energy for vertical mixing is provided by both buoyancy flux and shear production. However, buoyancy flux is a more efficient energy source because of its direct contribution to the vertical component of TKE. The buoyancy equation is derived from a linearized equation of state along with the conservation of heat and salinity equations:

$$\rho = \rho o\{1 - \alpha(\theta - \theta o) - \beta(S - So) \qquad (3.1)$$

Buoyancy is defined by:

$$b = g(\rho o - \rho)/\rho o \qquad (3.2)$$

where:

θ = temperature

S = salinity

g = gravity

ρ = density

α = thermal expansion coefficient

β = density coefficient for salinity

In most open ocean regions in low or mid-latitudes, salinity does not have much effect, and temperature is the dominant factor contributing to density structure (Miller, 1976). However, by using buoyancy instead of temperature, the model is able to allow for processes such as precipitation and evaporation which may significantly affect surface buoyancy flux.

The OBL uses several profiles for initialization:

1. mixed layer temperature;
2. mixed layer salinity; and
3. wind-driven horizontal current.

The lack of initial salinity and wind-driven current profiles is not a significant problem because the model will evolve its own profiles within the first diurnal cycle. These profiles are not available when the input is from AXBTs. However, the model results are not sensitive to initial salinity and current profiles (Davidson and Garwood, 1984).

The time step used in OBL is one hour and there are two ways of inputing hourly information into the model. The first method, and the one used in this research, is to supply the heat fluxes directly from FNOC. The second method is to calculate these heat fluxes each hour using the following boundary conditions:

1. net upward turbulent heat flux at the sea surface;
2. incident solar radiation;
3. absorption factor for short wave radiation in the top meter of the sea;
4. wind speed and wind direction;
5. cloud cover;
6. sea surface temperature (SST);
7. dry bulb air temperature;
8. dew-point; and
9. precipitation.

Several other physical and model constants are input including:

1. extinction coefficient;
2. Coriolis parameter;
3. critical Richardson number for stability adjustment below the mixed layer;
4. expansion coefficient for temperature; and
5. density coefficient for salt.

The upward heat flux, Qu, can be calculated by summing the turbulent flux of latent heat, Qe, the turbulent flux of sensible heat, Qh, and the net back radiation, Qb:

$$Qu = Qe + Qh + Qb \tag{3.3}$$

The Qe term is calculated using:

$$Qe = Cd(.98Es - Ea)U^{(10)} \tag{3.4}$$

where:

Cd = coefficient of drag

Es = air vapor pressure of marine air

Ea = air vapor pressure based on dew point temperature

$U^{(10)}$ = wind speed at 10 meters

The Qh term is calculated using:

$$Qh = Cd(Ts - Ta)U^{(10)} \qquad (3.5)$$

where:

Ta = air temperature in degrees Kelvin

Ts = sea surface temperature in degrees Kelvin

The Qb term is estimated using an empirical equation (Husby and Seckel, 1978):

$$Qb = 1.14 \times 10^{-7} (Ts)^4 (.39 - .5Ea^{1/2})(1 - .6C^2) \qquad (3.6)$$

where:

C = cloud cover

The net radiation is not just the simple difference between the upward and downward heat fluxes because the shortwave radiation is absorbed throughout the mixed layer (Swaykos, 1985). Approximately 50% of the energy is absorbed in the top meter and the rest is absorbed below that. Very little energy penetrates below the mixed layer because the underlying stable thermocline has very low thermal conductivity. The percentage absorbed in the top meter (Rf) varies from region to region and is most dependent on the amount of suspended particulate matter. Knowledge of this absorption factor allows calculation of the net heat flux, Qn, at the surface:

$$Qn = Qe + (Rf)Qs - Qs \qquad (3.7)$$

The surface fluxes of momentum and buoyancy can be calculated when Qn is known. Mixed layer temperature, salinity, velocity and buoyancy fluxes can be computed using four equations and four unknowns. These fluxes determine mixed layer shallowing or deepening by entrainment.

The boundary layer will always deepen if there is a positive (upward) surface buoyancy flux. The entrainment heat flux is determined from the entrainment model (Garwood, 1977), and it determines the rate of mixed layer deepening. This deepening rate is used to compute a new temperature profile each time step. The boundary layer will shallow if the surface buoyancy flux is negative and there is not enough wind mixing and resultant vertical TKE to transport heat down to the bottom of the earlier-established mixed layer. A new mixed layer will be created at the depth where the vertical flux approaches zero. When there is no entrainment and the boundary layer shallows, there will be a unique solution for the depth of the mixed layer which allows for conservation of heat.

B. OCEAN ACOUSTIC MODEL

The ocean acoustic model used in the second part of this coupled system is the RAYMODE passive propagation loss model developed by G. A. Leibiger at Naval Underwater Systems Center, New London Laboratory (Leibiger, 1971). This model is contained in the RAYMODE Passive Propagation Loss Computer Program and the version used in this research was written in 1982. The term RAYMODE represents a technique of combining aspects of ray theory and normal mode theory to calculate acoustic pressure. Normal mode theory allows calculations with more accuracy and detail than does ray theory and avoids the ambiguities when rays cross and create false caustics. The use of ray theory simplifies some of the normal mode calculations because it uses the usual geometrical interpretations of ray paths.

The RAYMODE program uses the sound speed profile (SSP) to partition the corresponding wavenumber domain into regions which relate to the different propagation paths. The acoustic pressure field is calculated by a numerical integration of the normal modes for each path. By summing over all of the different propagation paths, the total field is obtained. The components of this pressure field are used to form coherent and random phase summations which give the total pressure field at each desired range. The difference between coherent and random propagation losses is that the coherent losses result from the contribution of each ray path assuming the actual phase between the rays, while the random losses are summed assuming a random phase distribution (Medeiros, 1982).

RAYMODE has several advantages that make it a good program for the at-sea acoustic forecaster who requires sonar performance predictions (Yarger, 1982):

1. This version can be run on small machines such as the HP 9845 or Tektronix 4051 desktop computers;
2. It considers and sums together ducted, convergence zone, bottom bounce, and other propagation paths;
3. It handles a large range of sonar frequencies;
4. It accommodates any type of sound velocity profile; and
5. It produces valid results for deep or shallow water.

There are some drawbacks for this 1982 version of RAYMODE (T.B. Gabrielson, personal communication, 1985):

1. It does not allow for change of any environmental parameters along the propagation track even if these changes are known;
2. The leakage from the surface duct is ignored for frequencies less than 100 Hz;
3. The integral approximations can be poor for frequencies less than 100 Hz;
4. The smoothing in the incoherent mode is excessive; and
5. Too few bottom bounce rays are used.

It is possible that the problem of not being able to input changing environmental parameters could be corrected if a range-dependent program is developed in the future.

The original approach (Fisher, 1981) to combining thermodynamic and acoustic models used the Fast Asymptotic Coherent Transmission Loss model (FACT) for acoustic prediction. Fisher stated that the FACT model had several known problems:

1. Low frequency problems caused by large scale cancellations of caustics due to the inability of ray theory to deal with the resulting intensities;
2. Half channel cases historically presented a problem due to surface interference. This problem has been addressed in recent updates to the FACT model; however, the the existing routine available at the Naval Postgraduate School is FACT-9H, and it has not been modified for half channel cases; and
3. The propagation in the surface duct is virtually unaffected by wind speed and wave height. For some low frequencies, unrealistic duct thicknesses are required.

A comparison between RAYMODE-X, FACT-9H, and two ray tracing models was carried out (Hall and Holt, 1981). The basic physics behind the models was discussed and all models were run using identical inputs. At low frequencies (below 1 kHz), RAYMODE encountered the fewest problems with a surface duct. This is because it employs a combination of both normal mode and ray tracing inside the duct. The other three ray tracing models are forced to perform special calculations for duct propagation. The FACT model characterizes gross features of duct propagation using the Clay-Tatro equations. These equations use conservation of energy along with range-related leakage and scattering losses to calculate intensity when both the source and receiver are located in the surface duct. For cases when only the source or the receiver is in the duct, the intensity is reduced by 10 dB. The use of these different equations causes inconsistent results in propagation loss for velocity profiles that contain a surface duct.

The RAYMODE model was chosen for this research because the combination of normal mode and ray tracing should, in theory, work better for low frequencies and surface duct cases. The OBL predicts temperature profiles for the upper layer of the ocean, and it has very little effect in the short term on temperature below 150 m. In coupling the OBL to an acoustic model, the most important results will be those obtained for shallow receivers and shallow sources where the variation of MLD has the greatest effect.

IV. MODEL RESULTS

A. THERMODYNAMIC MODEL RESULTS

1. General

The thermodynamic model (OBL) was initialized using the AXBT data acquired 15 November 1980 during the STREX field phase. The stations used were 2, 3, 4, 5, 6, 7, and 8 (see Fig. 1.1) because they were located on the center track, and that track was the outbound leg on all P-3 flights. No data were available for station 1 as the 15 November AXBT did not deploy properly. The OBL was run for 20 days and the model output was compared with final AXBT data acquired 5 December 1980 at these same stations.

The model used atmospheric forcing which had been obtained from FNOC and placed in mass storage files. A correction factor was applied to the supplied heat fluxes to account for known bias in the forcing (Gallacher, 1979). The program interpolated to the closest two degrees of latitude and five degrees of longitude to obtain wind speed, solar radiation, and heat flux. An example of this atmospheric forcing which was interpolated for station 2 is plotted for the 20 days (Fig. 4.1). The model used a time step of one hour and integrated for 20 days. Each station will be discussed independently and then the stations will be considered together for a two dimensional analysis.

2. Station 2

The OBL was initialized at station 2 with AXBT data that indicated a MLD of 32 m and a surface temperature of 13.8°C (Fig. 4.2). After integrating for 20 days, it predicted that due to increased TKE, the MLD would deepen to 58 m, and the surface temperature would cool 2.6°C to 11.2°C. The final AXBT taken 20

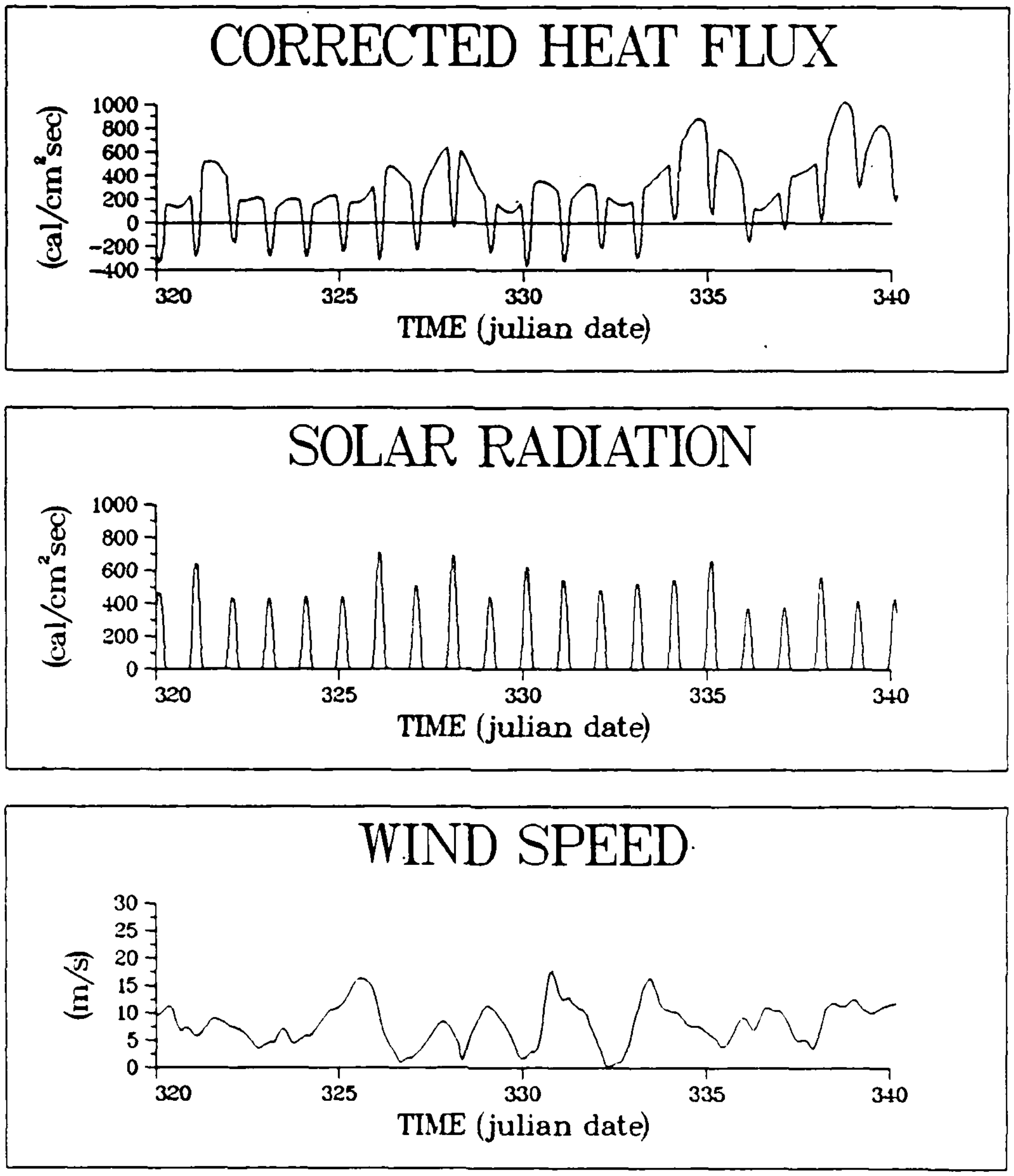

Figure 4.1 Interpolated atmospheric forcing for Station 2.

days later showed a MLD of 57 m. However, the surface temperature cooled only 0.7°C to 13.1°C. Of the seven stations studied, this was by far the smallest amount of surface cooling and was the only station to show a local temperature maximum at 125 m. A local temperature maximum at this depth could be caused by

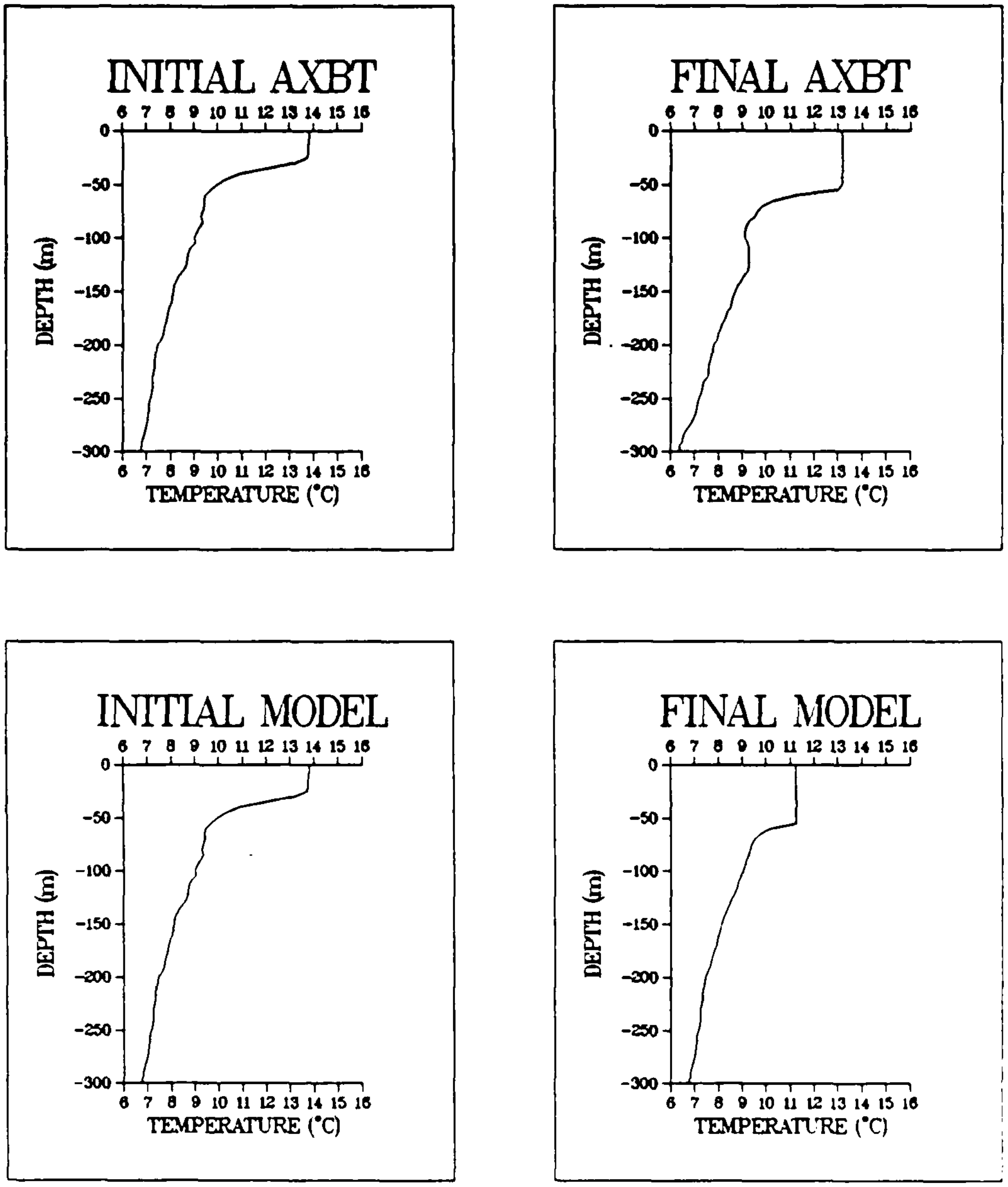

Figure 4.2 Comparison between AXBT and OBL at Station 2.

horizontal advection or by a deep mixed layer earlier in the year. Since there was no evidence of this feature in the AXBT taken 20 days before, the results suggest that this station was either affected by horizontal advection or influenced by a mesoscale feature which had been missed (navigational error) by the previous AXBT observation. The one dimensional OBL initialized with AXBT data is not able to resolve either of these situations.

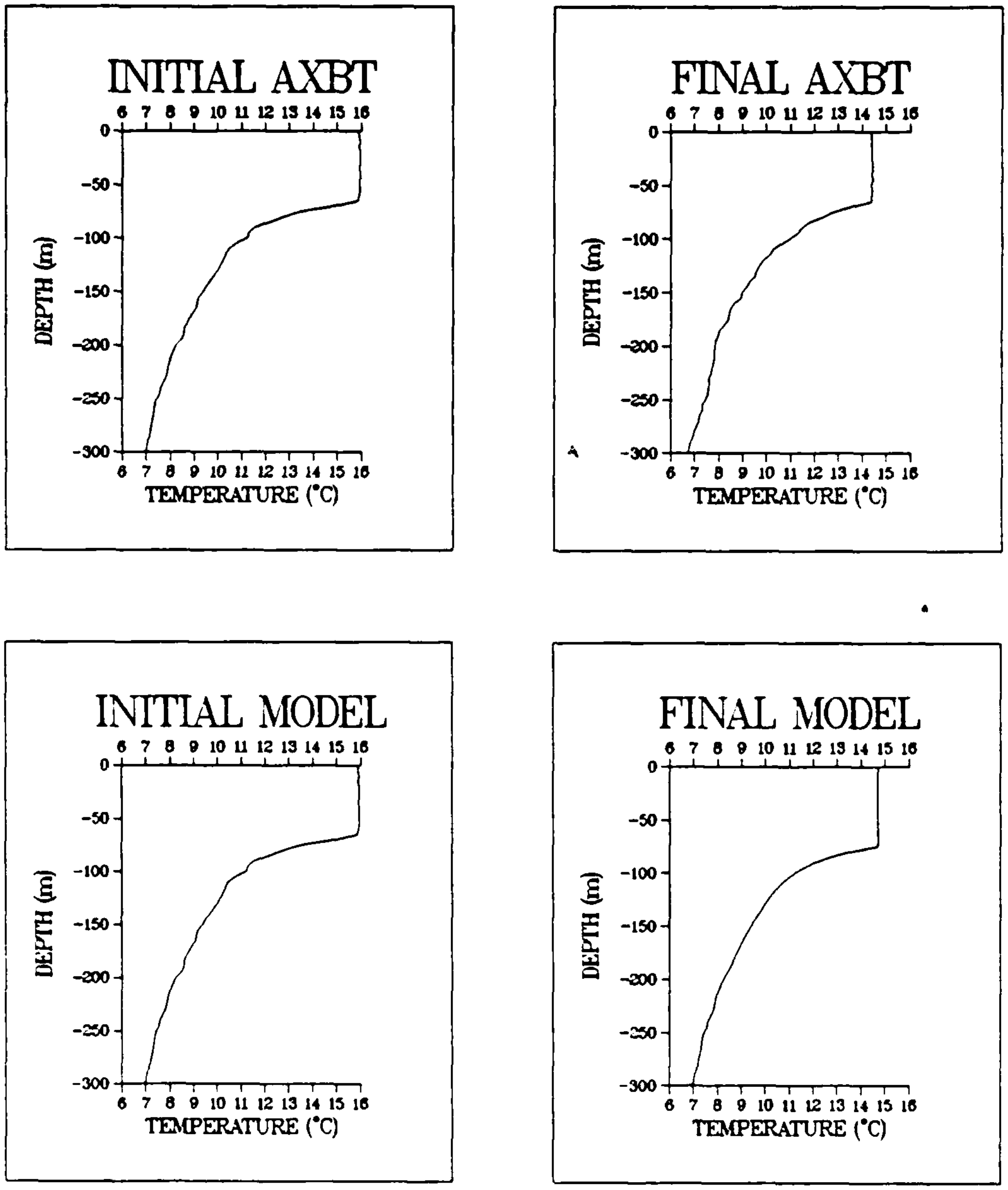

Figure 4.3 Comparison between AXBT and OBL at Station 3.

3. Station 3

The OBL at station 3 was initialized using AXBT data which had a MLD of 66 m and a surface temperature of 15.9°C (Fig. 4.3). The model was integrated for 20 days and predicted a MLD of 77 m with a surface temperature of 14.7°C. The final AXBT 20 days later showed a surface temperature of 14.4°C and a MLD that only deepened very slightly to 68 m. At this station, it is possible that the model calculated more TKE than actually existed. The shape of the temperature profile below the layer shows a very good correlation between the model output and the final AXBT information, with the exception that the model output tends to be smoother. This smoothness is to be expected as the model employs a weak below-layer diffusion and does not account for the small-scale horizontal currents and internal wave motion that influence the actual temperature profile.

4. Station 4

The OBL at station 4 was initialized with AXBT data that had a MLD of 52 m and a surface temperature of 14.9°C (Fig. 4.4). The model was integrated for 20 days and predicted a MLD of 67 m with a surface temperature of 13.5°C. The final AXBT data from 20 days later showed a surface temperature of 13.8°C down to the MLD of 72 m. The profile shapes of the model output and the final AXBT information look very similar with the major difference again being that the model profile is much smoother. An interesting feature of the initial AXBT conditions was that the cooling of the top part of the mixed layer appeared to have already started. The cooler water at the surface at this station is unstable because the salinity is well mixed in the mixed layer. This initial trace clearly shows the cooling source of the TKE for mixed layer deepening.

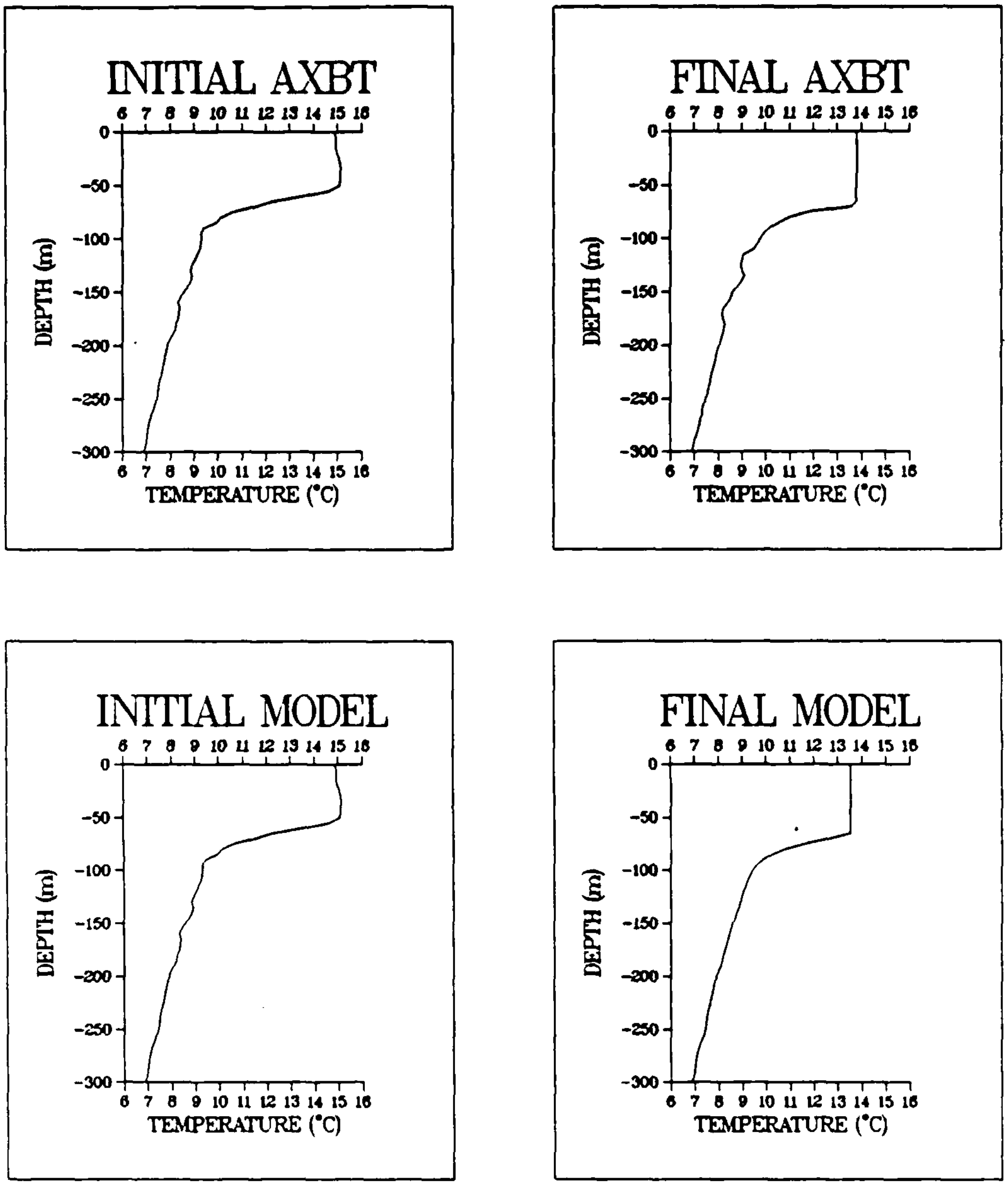

Figure 4.4 Comparison between AXBT and OBL at Station 4.

5. <u>Station 5</u>

The OBL at station 5 was initialized with AXBT data that showed a surface temperature of 14.4°C down to a MLD of 42 m (Fig. 4.5). The model was integrated for 20 days and predicted

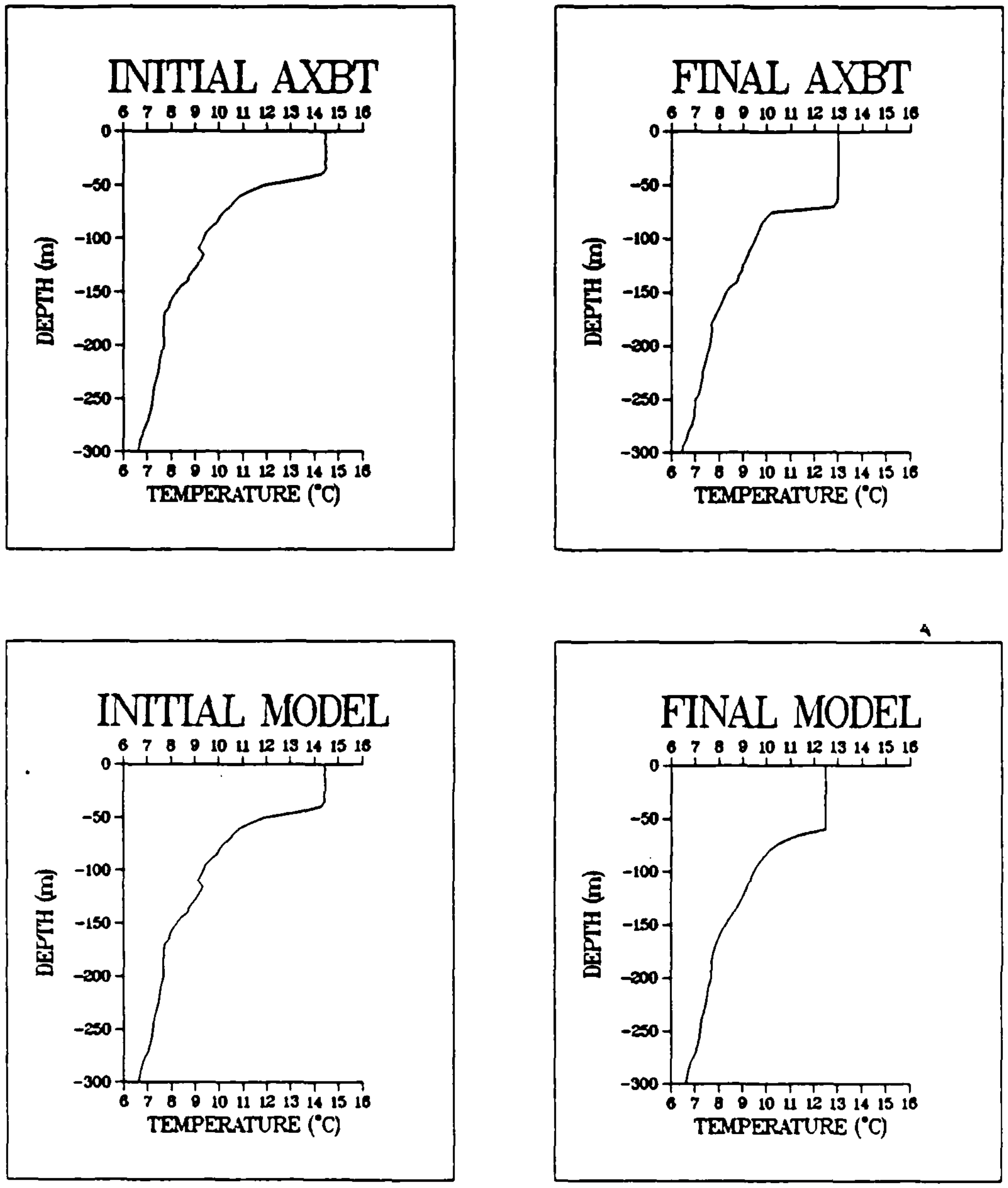

Figure 4.5 Comparison between AXBT and OBL at Station 5.

a surface temperature of 12.5°C down to a MLD of 64 m. The final AXBT taken 20 days later showed a surface temperature of 13.0°C down to a MLD of 68 m. This AXBT taken 5 December was never properly digitized and was not part of the STREX data.

This trace was recovered from the original aircraft files and read using a metric AXBT grid overlay. The profile could only be resolved to about 0.2°C and to about 3 m in depth. Even with this resolution, the AXBT data confirmed that the model deepened to approximately the correct depth, but showed that the model surface temperature was too cold by 0.5°C. This could be due to inaccuracies in the heat fluxes provided by FNOC or the flux field not being resolved closely enough for the particular station. The difference could also be due to surface currents which would result in horizontal advection and a relative warming of the mixed layer.

6. Station 6

The OBL at station 6 was initialized with AXBT data that showed a surface temperature of 14.3°C down to a MLD of 63 m (Fig. 4.6). The model was integrated for 20 days and predicted a surface temperature of 12.7°C down to a MLD of 78 m. The final AXBT taken 20 days later showed a surface temperature of 12.6°C down to a MLD of 77 m. The OBL predictions made at this station were very accurate. Almost every point on the profile down to 200 m was verified within 0.1°C. Perhaps this station was not affected by any significant mesoscale activity during the 20 days.

7. Station 7

The OBL at station 7 was initialized with AXBT data that showed a surface temperature of 13.4°C down to a MLD of 49 m (Fig. 4.7). The model was integrated for 20 days and predicted a surface temperature of 11.3°C down to a MLD of 72 m. The final AXBT taken 20 days later showed a surface temperature of 11.8°C down to a MLD of 72 m. The OBL again predicted the new MLD within a meter but showed 0.5°C too much surface cooling. The final AXBT profile below the layer looked very similar to the OBL profile with the exception of a small region between 150 and 170 m. The AXBT profile showed a very slight positive gradient

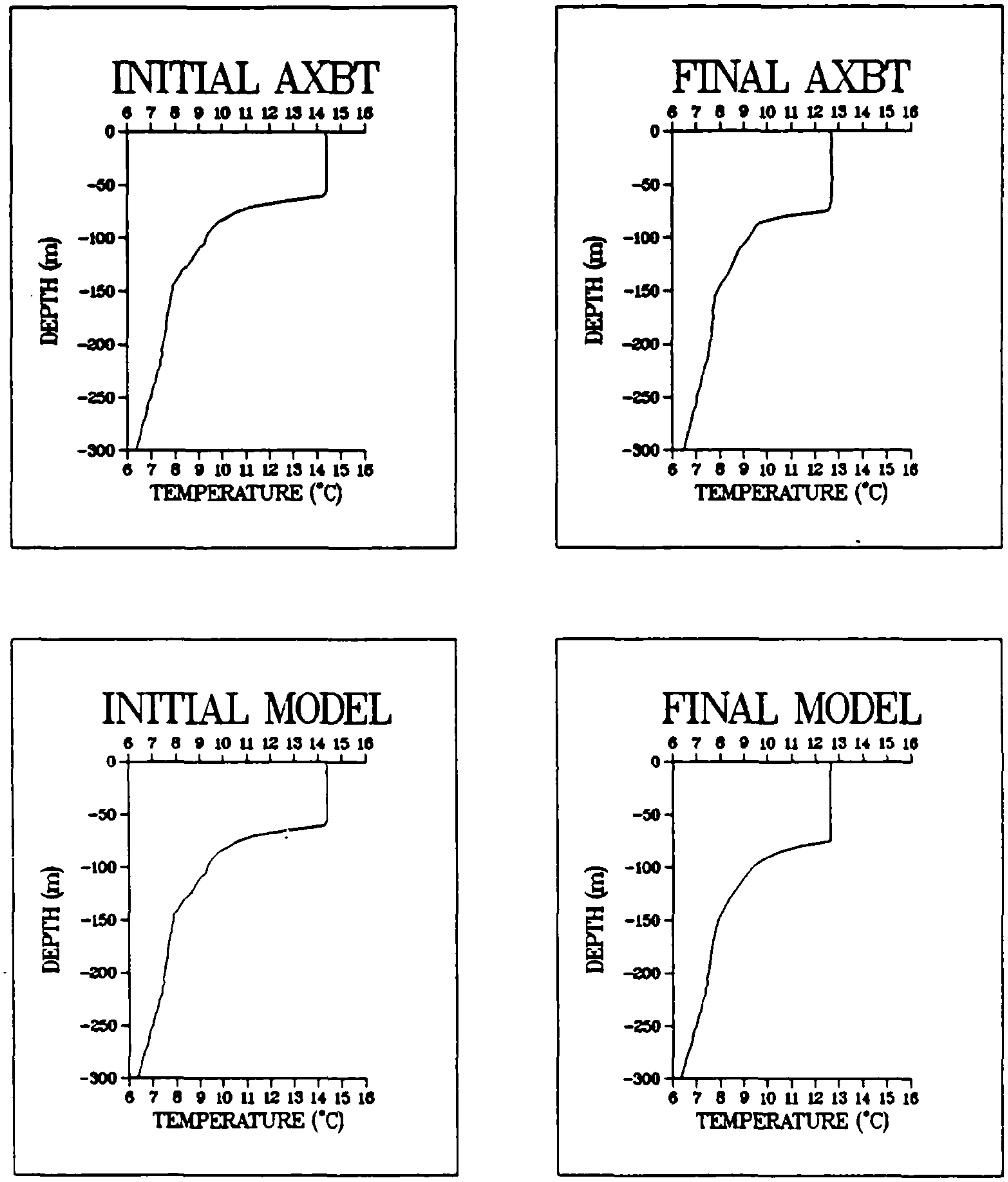

Figure 4.6 Comparison between AXBT and OBL at Station 6.

at 200 m depth that did not exist 20 days before and could not be developed by the model. This must be due to horizontal advection, internal vertical motion of the water column, or movement of a sub-surface mesoscale feature with respect to the station position.

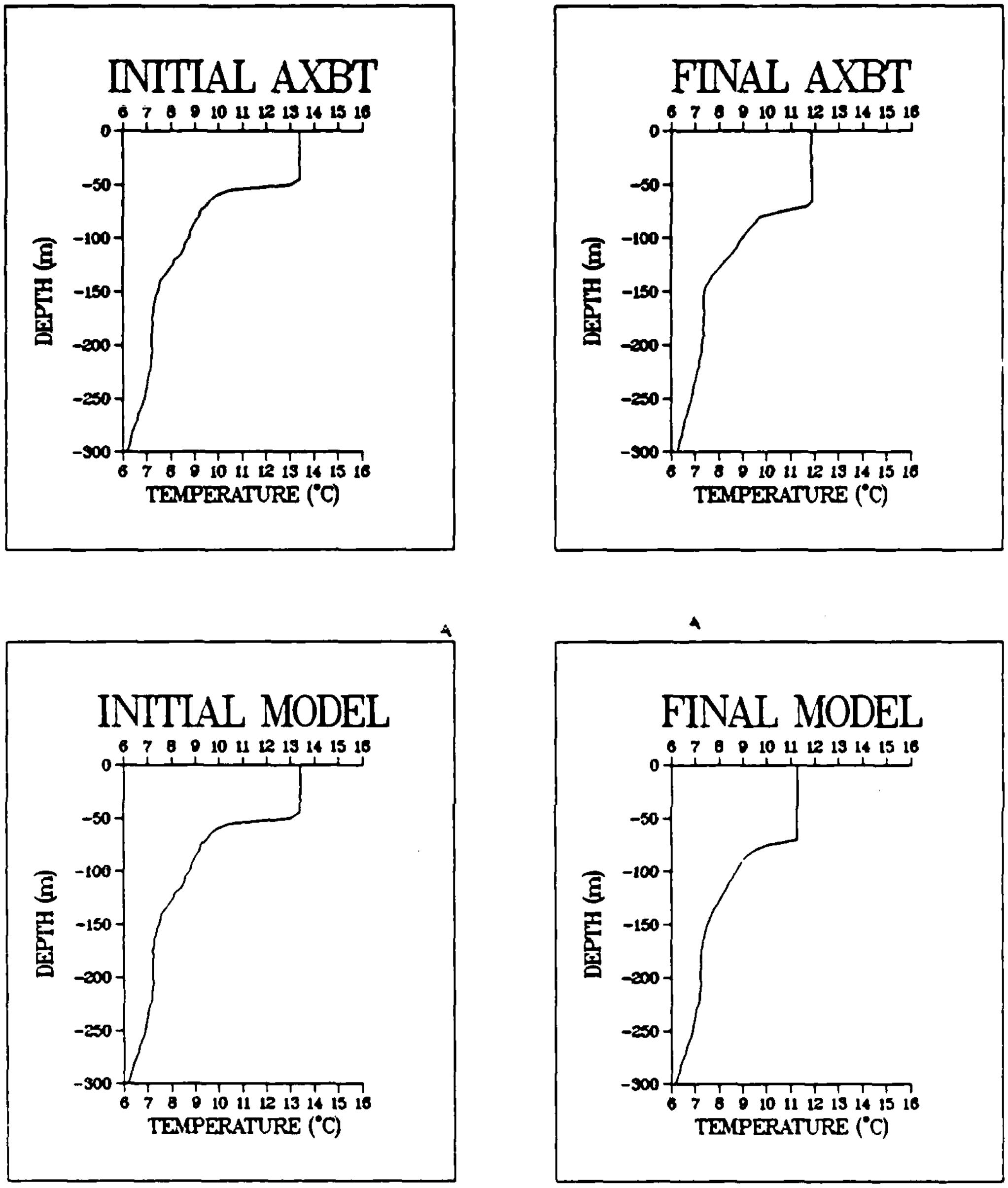

Figure 4.7 Comparison between AXBT and OBL at Station 7.

Another possibility is that the AXBT observations 20 days apart were not in the same position.

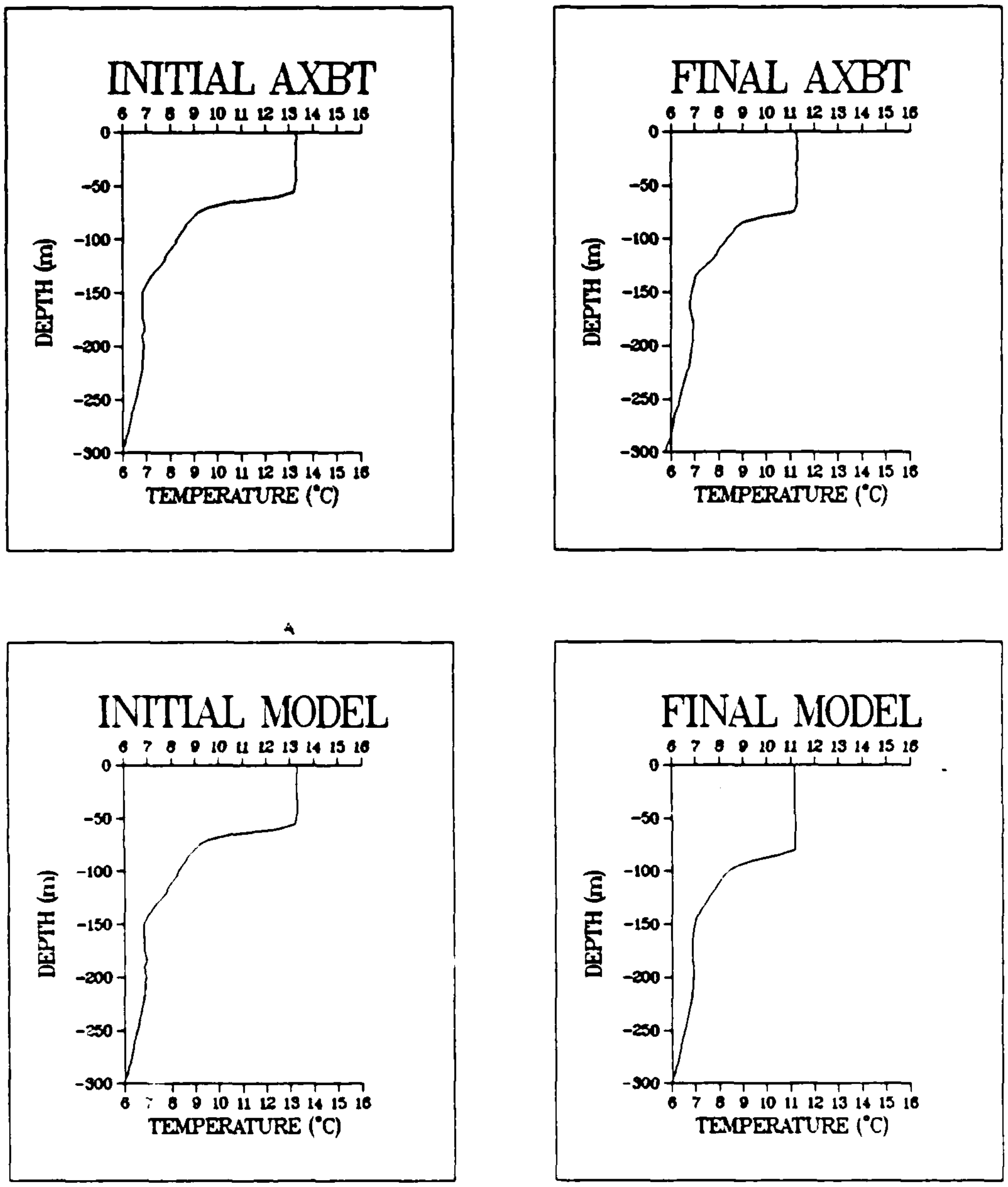

Figure 4.8 Comparison between AXBT and OBL at Station 8.

8. <u>Station 8</u>

The OBL at station 8 was initialized with AXBT data that showed a surface temperature of 13.3°C down to a MLD of 57 m (Fig. 4.8). The model was integrated for 20 days and predicted a surface temperature of 11.2°C down to a MLD of 83 m. The final AXBT taken 20 days later showed a surface temperature of 11.2°C down to a MLD of 77 m. The OBL and AXBT profiles appeared very similar at this station with the only exception being the smoothness of the OBL profile. The predicted MLD was 6 m too deep, but the temperatures in the upper 200 m were almost all verified within 0.2°C. Both profiles had isothermal regions between 150 and 180 m, and that feature was also apparent in the initial AXBT.

9. Two Dimensional Analysis

The main reason that this ASTREX AXBT information was selected for analysis was that the one dimensional model could be run at several equally spaced points along a track. This enabled an easy transition from one dimension to two dimensions. The initial AXBT information was plotted from station 2 to station 8 and contoured for temperature down to 300 m (Fig. 4.9). These contours provided a view of the synoptic features which were not readily apparent from the individual AXBT traces. Each station is separated by about 50 km and the track heads northwestward from the Californian coastline.

The cool coastal currents are apparent as the surface waters just off the coast are initially cool and become warmer between stations 2 and 3. The MLD is deepest (67 m) at station 3 and every isotherm in the transect is at its deepest point here.

After the OBL has integrated for 20 days (Fig. 4.10), the predicted temperature contours are plotted for station 2 to station 8. The MLD has deepened at all stations, and the temperature in the layer has cooled an average of 1.9°C. The surface cooling was the greatest where the mixed layer was the shallowest, because the colder water below was entrained into the mixed layer as the TKE increased due to surface cooling and wind stress.

The final AXBT contours are plotted for the same stations (Fig. 4.11). The MLD deepened as predicted and is well defined

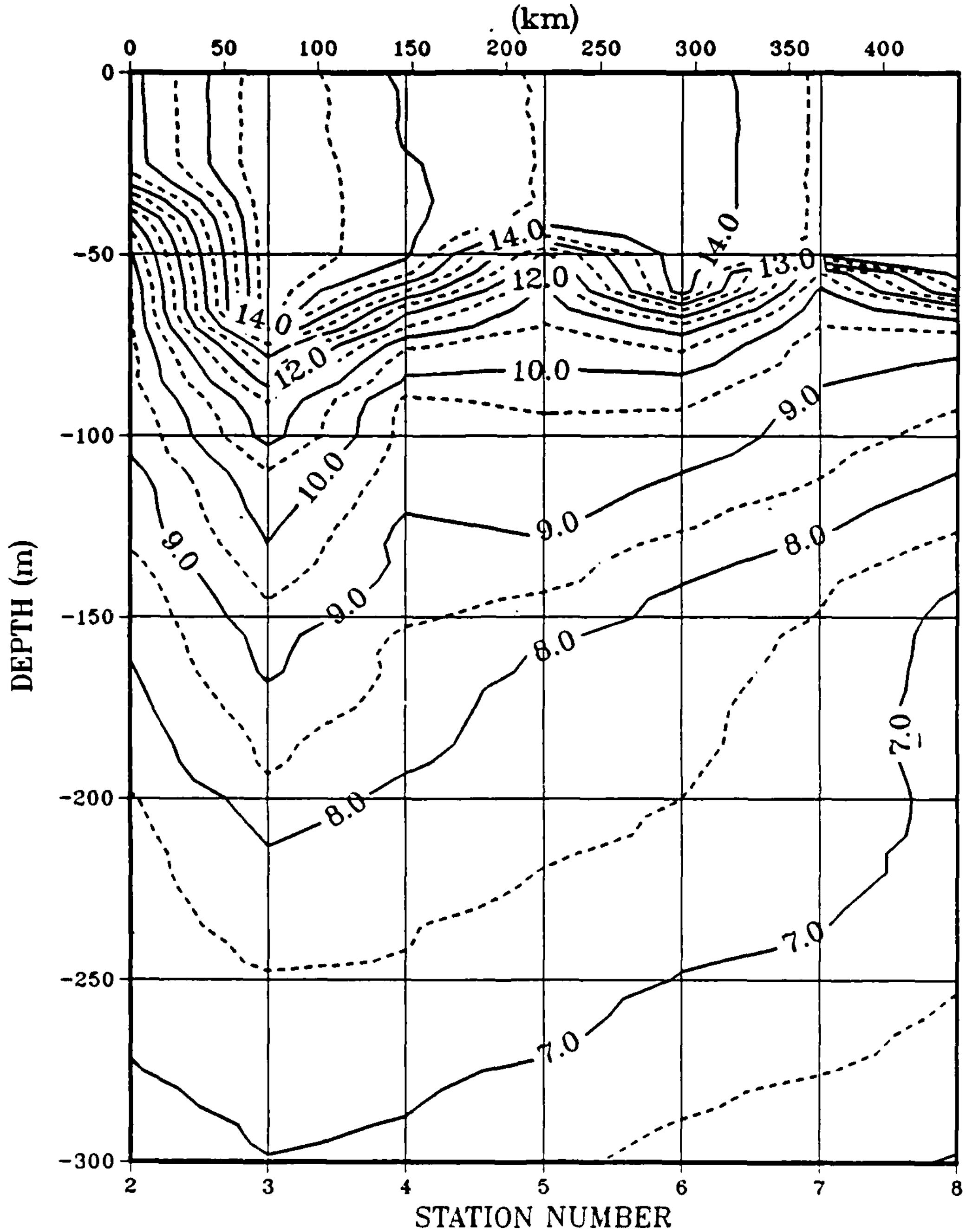

Figure 4.9 Initial AXBT contours of temperature versus depth 15 November 1980.

in this transect. The surface layer cooled an average of 1.4°C, or 0.5°C less than was predicted. This difference in surface

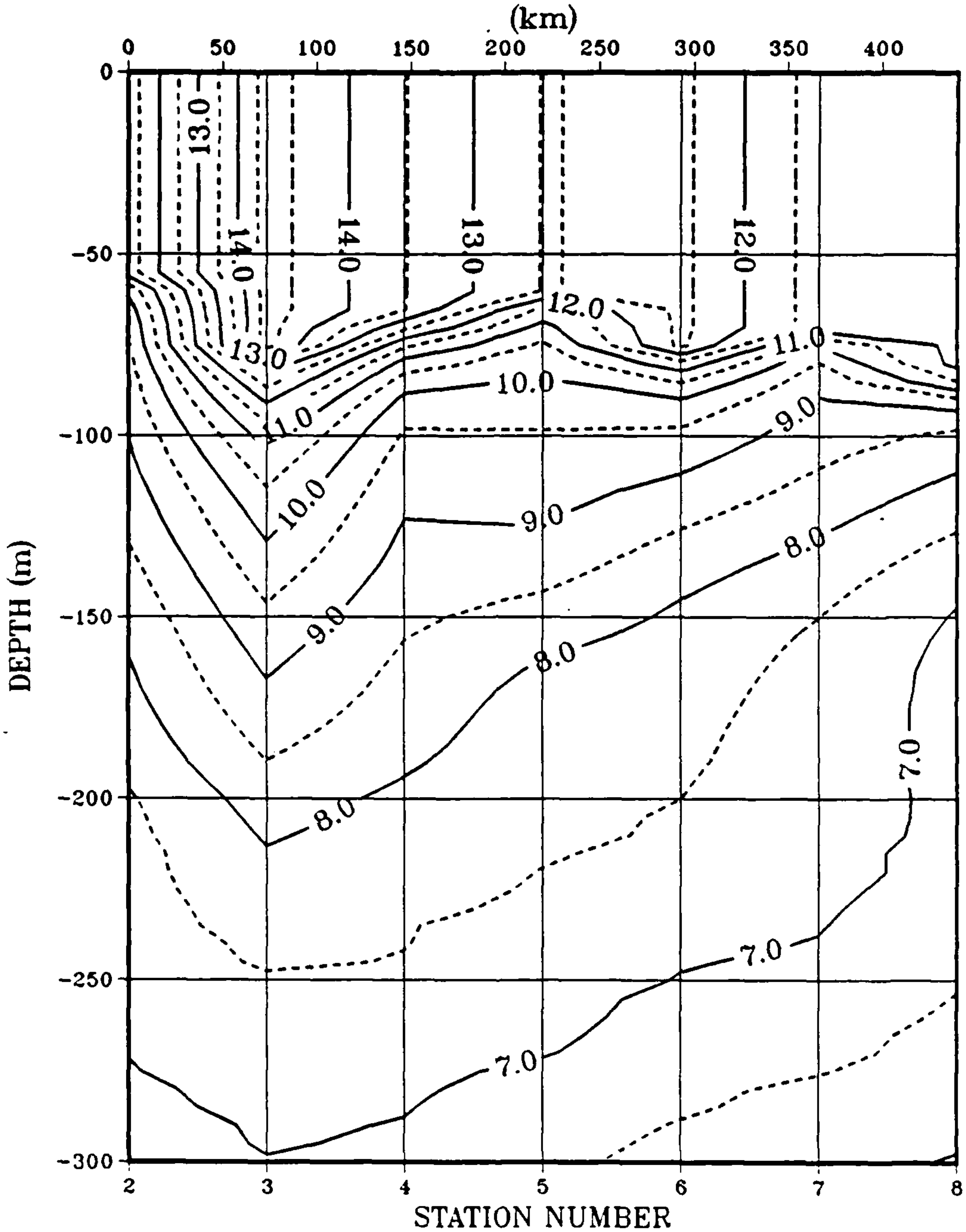

Figure 4.10 Predicted contours of temperature versus depth 5 December 1980.

temperature was seen in the analysis at the individual stations and may have been as a result of the heat fluxes supplied by FNOC.

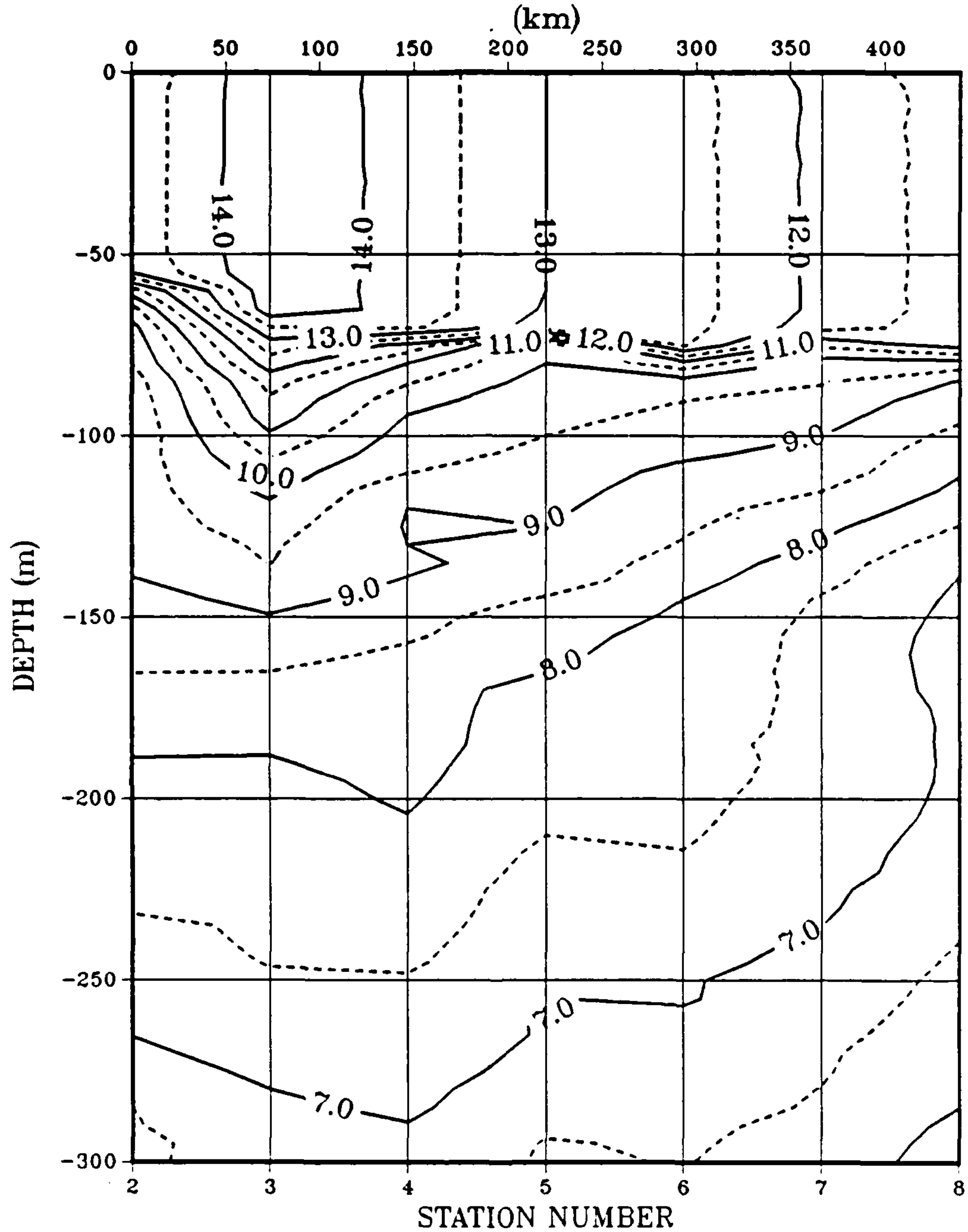

Figure 4.11 Final AXBT contours of temperature versus depth 5 December 1980.

Although these fluxes included a correction factor (Gallacher, 1979), it is possible that a more accurate flux field could be calculated for this portion of the Pacific.

The warmest mixed layer water is found at station 3. The warm synoptic feature predicted for this station down to 250 m was verified, but only down to 150 m. A temperature inversion can be seen at station 4, and the final AXBT data contain other inversions but they are not large and are not resolved by the contours of Fig. 4.11. The 10°C isotherm in both transects is found at the bottom of the steep temperature gradient found immediately below the mixed layer. It appears in almost the same place in both the predicted and observed transects. Both sets of contours show a convergence of isotherms just below the MLD as the transect extends seaward in the northwestward direction. Overall, these transects demonstrate that the OBL, if initialized properly and forced by the atmosphere, posseses a significant predictive capability.

B. ACOUSTIC MODEL RESULTS

1. General

The RAYMODE model was run three times at each of the seven stations. The first run was made using the initial AXBT information taken 15 November 1980. The second run was made using the thermal structure calculated for 5 December 1980 after the model was integrated for 20 days. A final run was made using the AXBT information available for these stations on 5 December. No changes were made to any of the RAYMODE parameters or inputs except for the temperature profile. The RAYMODE program uses salinity and depth to calculate a velocity for each point that a temperature is input. In all three runs, a standard historical salinity profile was used at all stations and was not changed for the 20 days. Neglect of salinity variations has a negligible effect on sound speed calculations in this region of the Pacific Ocean. The major effect of salinity variations is that changes in the salinity profile permit temperature inversions.

The user has the choice whether to use coherent or random propagation loss information. The coherent output is theoretical and shows large fluctuations every tenth of a kilometer which is not realistic for the operational user. In this research, the random output is used for both the MDR and the CZR calculations. The random output has been smoothed for the user. However, the amount of smoothing carried out is high and this is a recognized problem with the RAYMODE program.

The acoustic results were based on one frequency (300 Hz), one wind speed (5 kts), one receiver depth (20 m), and one source depth (60 m). It is recognized that all of these variables could be changed and studied with each of the temperature inputs, but a sensitivity analysis of the RAYMODE model is beyond the scope of this research. The shallow source and receiver were selected because the OBL models the upper 200 m of the ocean and finds the most variability in the upper 80 m. The 20 m receiver depth was selected because it was very close to the standard shallow sonobuoy depth of 60 .feet. The 60 m source depth was selected because it is of interest to model a scenario where the submarine is acoustically hiding just below the mixed layer. The frequency of 300 Hz was chosen because it was high enough to avoid the low frequency problems experienced by the RAYMODE model and low enough to allow good passive acoustic information to be obtained. The arbitrary wind speed of 5 knots was selected because that low wind speed causes very little interference in the surface duct and at 5 knots, the RAYMODE Program will not experience any problems as the wind speed approaches zero.

Two measures of acoustic performance were used in this evaluation of acoustic output. The first was median detection range (MDR). This was calculated from the propagation loss curve at figures-of-merit (FOM) of 75, 80, and 85 decibels (dB). Operationally, a user in the fleet enters a propagation loss plot with an FOM and extracts the MDR from the intersection of the curve and the FOM. Three values of FOM were used to lend

TABLE I

RAYMODE Output for MDR and CZR in Kilometers

Station 2

FOM (dB)	INITIAL MDR	INITIAL CZR	MODEL MDR	MODEL CZR	AXBT MDR	AXBT CZR
75	2.0	-	2.5	-	2.8	-
80	3.3	-	3.4	32.3	3.8	35.8
85	5.1	35.7	4.7	30.8	5.4	34.6

Station 3

FOM (dB)	INITIAL MDR	INITIAL CZR	MODEL MDR	MODEL CZR	AXBT MDR	AXBT CZR
75	2.5	-	2.4	-	2.6	-
80	3.4	-	3.3	38.6	3.4	37.7
85	4.5	39.1	4.3	37.2	4.6	36.2

Station 4

FOM (dB)	INITIAL MDR	INITIAL CZR	MODEL MDR	MODEL CZR	AXBT MDR	AXBT CZR
75	2.5	-	2.6	-	2.7	-
80	3.2	37.9	3.5	35.6	3.6	36.1
85	4.5	36.9	4.9	34.4	5.1	34.2

Station 5

FOM (dB)	INITIAL MDR	INITIAL CZR	MODEL MDR	MODEL CZR	AXBT MDR	AXBT CZR
75	2.3	-	2.5	-	2.6	-
80	3.1	-	3.4	37.9	3.5	36.1
85	4.3	37.3	4.8	33.6	4.8	34.3

Station 6

FOM (dB)	INITIAL MDR	INITIAL CZR	MODEL MDR	MODEL CZR	AXBT MDR	AXBT CZR
75	2.5	-	2.2	-	2.4	-
80	3.4	37.9	3.0	35.4	3.3	35.6
85	4.6	36.1	4.2	33.6	4.3	33.7

Station 7

FOM (dB)	INITIAL MDR	INITIAL CZR	MODEL MDR	MODEL CZR	AXBT MDR	AXBT CZR
75	2.3	-	2.4	-	2.4	-
80	3.1	-	3.2	33.2	3.2	34.4
85	4.1	36.0	4.4	31.9	4.4	33.2

Station 8

FOM (dB)	INITIAL MDR	INITIAL CZR	MODEL MDR	MODEL CZR	AXBT MDR	AXBT CZR
75	2.5	-	2.4	-	2.4	-
80	3.4	37.5	3.1	34.3	3.1	34.2
85	4.6	35.2	4.4	32.6	4.3	33.0

insight to trend analysis. The MDR is an important acoustic model output because it is used by ASW fleet units such as patrol aircraft, helicopters, and towed array ships for sonobuoy spacing and for tactical planning.

The second measure of acoustic effectiveness used was convergence zone range (CZR). A fleet user obtains CZR from the same propagation loss plot and continues further along the FOM line until there is an intersection again with the propagation loss curve. The CZR is also an important acoustic model output because knowledge of the expected CZR allows for faster resolution between direct path and convergence zone paths from passive acoustic receivers. The lack of, or change in expected CZR can have important tactical implications on the deployment of sonobuoys and ASW aircraft. The bottom depth along the track ranged from 3000 to 4000 m as the stations extended seaward with the deep sound channel between 250 and 300 m. There was more than sufficient depth excess at all stations to insure CZ propagation. There is not a convergence zone in all cases, and in this particular analysis, the 75 dB FOM did not give a CZR at any of the stations. The MDR and CZR outputs have been tabulated (Table I) for the RAYMODE runs.

2. <u>Median Detection Range</u>

The MDR is plotted at all stations for the three different FOM cases studied (Fig. 4.12). As would be expected, the MDR increases in both range and variability with increasing FOM. The amount of MDR variability between the three runs at each station is low, but it is clear from the plot that the model predicts the MDR well.

At an FOM of 75 dB, the effect of a shallow MLD and a steep gradient below the layer is clearly seen at station 2. After the MLD has deepened, the MDR is more consistent with the results at the other stations. With an FOM of 80 dB, there is more variation over the 20 day time period, and again the model predicts

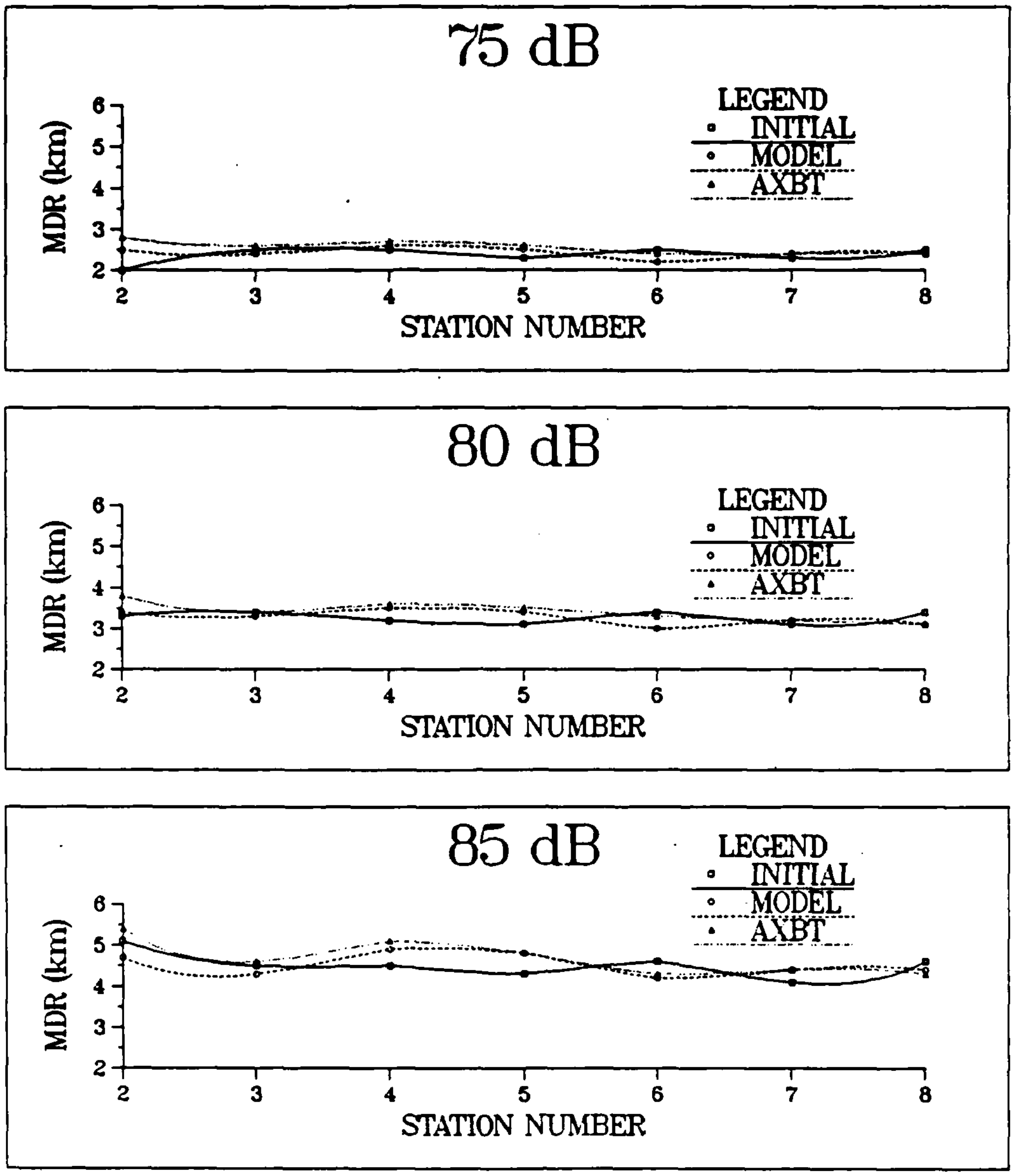

Figure 4.12 RAYMODE MDR for FOM of 75, 80, and 85 dB..

MDR very well. The case of an FOM of 85 dB shows the most variability over the 20 days, and the model predicts the MDR well except at station 2. This may be due to the fact that the OBL was off by nearly two degrees in the layer temperature and missed the below layer temperature maximum.

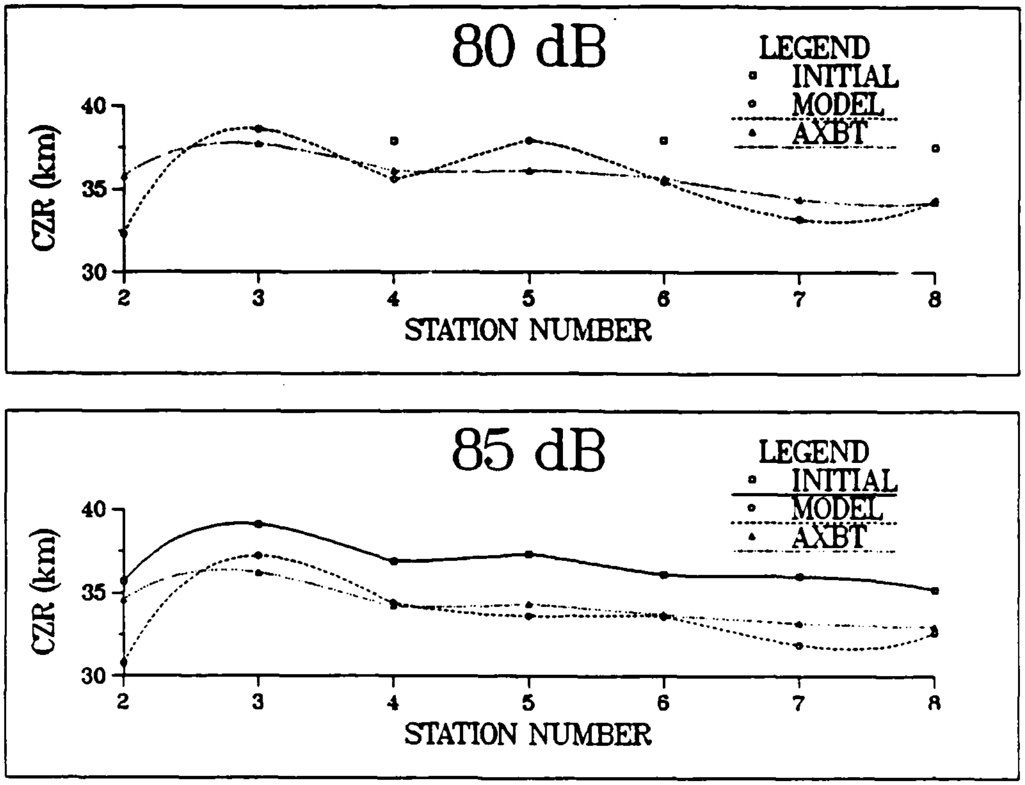

Figure 4.13 RAYMODE CZR for FOM of 80 and 85 dB..

3. Convergence Zone Range

The CZR is plotted at all the stations for the two different FOM cases studied. There was no convergence zone (CZ) below 77 dB at any of the stations in any run using the random propagation loss output. There is clearly much more variability in CZR than in MDR. This variability is to be expected because small changes in surface temperature are amplified by the deep convergence zone rays.

At an FOM of 80 dB, the initial conditions showed a CZ only at stations 4, 6, and 8. The model output predicted a CZ at all the stations as did the computations using the AXBT data. The variability associated with the model run at station 2 and the warm synoptic feature at station 3 is evident. At an FOM of 85 dB, this variability at station 2 is also evident as is a clearly defined maximum CZR at station 3. The range where the CZ is first detected is well predicted by the model and, at all stations, is less than the range given by the *initial conditions*. *This is due to* surface cooling where both the source and receiver are located, and the fact that the deep ocean characteristics remain unchanged.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The coupled mixed layer-acoustic model was subject to analysis at a line of stations in the northeast Pacific Ocean. Since no real-time acoustic data were available for verification, the OBL thermodynamic model output was compared to final AXBT data after both cases were run through the RAYMODE acoustic model. Thermal and acoustic analysis of the data led to several important conclusions:

1. The OBL model, after integrating for 20 days, accurately predicts the magnitude of the deepening of the mixed layer;
2. The coupled model accurately predicts trends in MDR and CZR by determining MLD and surface temperature using the physics of entrainment;
3. The variability of MDR during the 20 days was very low and demonstrates how slowly the thermal structure changes during the late fall period and how important it is to initialize acoustic models with actual data from the exact location being studied; and
4. The OBL, and hence the coupled system, produces better results when the station at which it is run is not influenced by near-shore currents or by horizontal advection of any kind.

B. RECOMMENDATIONS

This coupled model could be used operationally in the fleet and would be an excellent aid to the on-board tactical commander. The situation that presently exists in the fleet calls for the user to rely on historical BT profiles generated for arbitrary grid squares when a current profile is not available. Even if a fairly recent profile is available, historical data bases currently in use at FNOC such as the Expanded Ocean Thermal Structure (EOTS) model discard actual BT information after an arbitrary time. Many situations arise where a fairly recent profile may be obtained, but no method is available to advantageously apply that information because surface conditions such as temperature and MLD may have changed. The following recommendations are made to enable the coupled model to be used operationally:

1. The OBL and RAYMODE programs could be combined so that both models can be run using the output of one as the input for the other;
2. This coupled program should be adapted for use on the small computers presently employed for acoustic prediction at sea;
3. A method should be found to allow the fleet user easy access to the atmospheric forcing files available from FNOC; and
4. Further acoustic analysis of the coupled model output should be carried out. The OBL has been throughly tested and is fairly reliable. However, its interaction with an acoustic model needs to be studied for different acoustic and thermodynamic scenarios.

This coupled model has much potential for the tactical commander in the fleet. It offers a predictive capability that does not exist now on shore or at sea. Adapted for use at sea, this system would produce reliable short term acoustic forecasts in a stand-alone mode. The task force then would be able to make use of AXBT information for a specific area even if that information was several days or weeks old.

LIST OF REFERENCES

Davidson, K. L., and R. W. Garwood Jr., 1984: Coupled oceanic and atmospheric mixed layer model. **Dynamics of Atmospheres and Oceans**, 8, 283-296.

Dunlap, C.R., 1982: Shallow water sound channels in ASW. Environmental Systems Division Newsletter, Naval Oceanographic Office, Vol. 4, No. 1, 1-2.

Dunlap, C.R., and K. Andersen, 1985: Presentation of acoustic measurements of ambient sea noise during ocean storm conditions in the Northeast Pacific. IAMAP/IAPSO Joint Assembly, Honolulu, Hawaii, Aug. 5-16.

Fisher, R.H., 1981: Variability and sensitivity of coupled mixed layer-acoustic systems. M.S. Thesis, Naval Postgraduate School, Monterey, Ca., 123 pp.

Gallacher, P.C., 1979: Preparation of ocean model forcing parameters from FNOC atmospheric analysis and model predictions. Technical Report, Naval Postgraduate School, Monterey, Ca., 24 pp.

Garwood, R.W., Jr., 1977: An ocean mixed layer model capable of simulating cyclic states. **J. Phys. Oceanogr.**, 7, 455-468.

Hall, R.L., and R.M. Holt, 1981: Model comparison FACT-9H, RAYMODE-X, NISSM-II, SHARPS-III. Ocean Data Systems Inc., Rockville, Maryland. 349 pp.

Husby, D.M., and G.R. Sekel, 1978: Large scale air-sea interactions at ocean station V. **NOAA Tech. Rep. NMFS SSRF-696**, 44 pp.

Leibiger, G.A., 1971: A combined ray theory-normal mode approach to long range propagation loss prediction. Naval Underwater Systems Center Technical Memorandum No. PA3-0109-71, 253 pp.

Lundell, G.W., 1981: Rapid oceanographic data gathering: some problems in using remote sensing to determine the horizontal and vertical thermal distributions in the northeast Pacific Ocean. M.S. Thesis, Naval Postgraduate School, Monterey, Ca., 188 pp.

Martin, P.J., 1985: Simulation of the mixed layer at OWS November and Papa with several methods. **J. Geophys. Res.**, 90, 903-916.

Medeiros, R.C., 1982: RAYMODE passive propagation loss program performance specification. NUSC TD 8502 Naval Underwater Systems Center, New London, 313 pp.

Miller, J.R., 1976: The salinity effects in a mixed layer ocean model. **J. Phys. Oceanogr.**, 6, 29-35.

Miyake, M., 1980: Storm Transfer and Response Experiment operational plan. International Strex Office, PMEL, NOAA, Seattle, Washington, 87 pp.

Picard, G.L., and W.J. Emery, 1982: **Descriptive Physical Oceanography**, Fourth ed., Pergamon Press, 249 pp.

Rosner, H.S., 1985: Evaluation of surface exchange coefficients from MILDEX ocean/atmosphere mixed layer data. M.S. Thesis, Naval Postgraduate School, Monterey, Ca., 74 pp.

Swaykos, J.W., 1984: Simulation of the coupled atmospheric and oceanic boundary layer model during MILDEX. M.S. Thesis, Naval Postgraduate School, Monterey, Ca., 67 pp.

Tabata, S. 1965: Variability of the oceanographic conditions at Ocean Station 'P' in the Northeast Pacific. Trans. Roy. Soc. Can. Sect. III, 3(4), 367-418.

Tully, J. P., and L.F. Giovando, 1963: Seasonal temperature structure in the eastern Subarctic Pacific Ocean. Roy. Soc. Can. Sp. Pub., 5, 10-36.

Yarger, D.F., 1982: The user's guide for the RAYMODE Propagation Loss Program. Technical Memorandum, Naval Underwater Systems Center, New London Laboratory, New London Connecticut, 103 pp.

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