EFFECT OF HURRICANE MICHAEL ON THE UNDERWATER ACOUSTIC ENVIRONMENT OF THE SCOTIAN SHELF

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In October 2000 DRDC Atlantic carried out a detailed characterization of the shallow water environment in a 150 by 170 km area of the Scotian Shelf. The study area was centered at 44 deg. N, 61 deg. W and had an average water depth of 70 m. In addition to oceanographic moorings, two rapid environmental assessment surveys of water temperature profiles were made from Canadian maritime patrol aircraft which dropped 72 air-expendable baththermographs (AXBTs) in an 8 by 9 grid with 16 km nominal spacing. Between the AXBT surveys on Oct. 14 and 21, hurricane Michael passed over the study area. The AXBT surveys and satellite-derived sea surface temperature imagery show that passage of the hurricane cooled surface waters and changed the thickness of the mixed layer by up to 10 m. The effect of the environmental change on acoustical propagation in the 20 Hz to 10 kHz band was estimated by calculating broadband transmission loss with the PROLOS normal modes model using sound speed profiles measured before and after the hurricane and using climatological profiles.

1 Introduction

The complexity of continental shelf ocean processes and the spatial variability of seabed characteristics, results in an environment in which it is difficult to predict acoustic propagation. The increased military interest in littoral zones in recent years has led to a requirement to understand and model this environment. As a first step, we have begun development of a high-resolution oceanographic model of the Scotian Shelf. The model, based on the Princeton Ocean Model, will eventually assimilate remotely sensed sea surface temperature data [1]. Work is also underway to examine other types of remote sensing data such as ocean color and radar backscatter, for their potential to provide information about the underwater acoustical environment [2].

This paper describes ocean data obtained during cruise Q255 of DRDC’s research vessel CFAV Quest on the Scotian Shelf in Oct. 2000. The goal of the cruise was to obtain in situ oceanographic data and remotely sensed sea surface data which would be used to test the ocean model. It happened that the most powerful hurricane of the Canadian 2000 season, Michael, passed over our study area providing a rare opportunity to study the impact of such a disturbance on shelf oceanography. Although underwater acoustical propagation measurements were not made during the trial, the measured water temperature profiles are interpreted here in terms of modelled acoustical propagation. It was found that the passage of hurricane Michael caused mixing of the water column,
reducing the temperature of the mixed layer by 1°C and affected the depth of the thermocline by nearly 10 m.

2 Scotian Shelf environment

Figure 1 shows the continental shelf area southeast of Nova Scotia, known as the Scotian Shelf. Bounded to the northeast by the Laurentian Channel and in the southwest by the Gulf of Maine, the Scotian Shelf has a range of seabed types with clay in basins and sand or gravel on the shallow banks. An overview of the geoacoustic and oceanographic environment of the Scotian Shelf is given by Osler [3]. The average depth in the Q255 study area, shown in Fig. 1, is 70 m and much of the seabed in the southern half of the area is composed of Sable Island Sand.

3 Environmental characterization

The locations of oceanographic moorings (sites s1 to s4) are shown in Fig. 1 with the instruments listed in Table 1. Self-locating Datum Marker Buoys (SLDMB) which drift with the surface current were used to measure currents during the course of the trial. Results from the SLDMB measurements can be found in Hutt et al. [4]. The Minimet buoy is a weather station equipped with standard meteorological sensors. For the purposes of this paper, discussion of ocean data is limited to the two rapid environmental assessment (REA) surveys that took place on Oct. 14 and 21, 2000. During each survey, maritime patrol aircraft (MPA) deployed 72 AXBTs (aircraft-deployed expendable bathy-thermographs) in an 8 by 9 grid with 16 km nominal spacing which covered the entire test area shown in Fig. 1.
Table 1. Measurement sites for Q255, Oct. 2000.

<table>
<thead>
<tr>
<th>Site</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Depth (m)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>44°05.0 N</td>
<td>61°10.0 W</td>
<td>70</td>
<td>Geoacoustic experiments</td>
</tr>
<tr>
<td>2</td>
<td>43°40.0 N</td>
<td>61°00.0 W</td>
<td>60</td>
<td>S4 current meters SLDMBs (Oct. 14)</td>
</tr>
<tr>
<td>3</td>
<td>44°24.0 N</td>
<td>61°37.0 W</td>
<td>180</td>
<td>S4 current meters SLDMBs (Oct. 21)</td>
</tr>
<tr>
<td>4</td>
<td>44°10.0 N</td>
<td>61°10.0 W</td>
<td>65</td>
<td>ADCP S4 Current meter Minimet buoy Triaxys wave buoy SLDMBs (Oct. 14 and 21)</td>
</tr>
</tbody>
</table>

4 Hurricane Michael

4.1 Synoptic Overview of Hurricane Michael

Hurricanes which travel northward along the east coast of North America are a common occurrence in late summer and autumn. Their energy is sustained by circulation of the warm humid air over the Gulf Stream. Hurricanes typically lose energy quickly once they pass north of the Gulf Stream where they are affected by cooler water. However, in some cases hurricanes may reintensify due to acceleration by mid-latitude winds. Hurricane Michael, which passed over the Scotian Shelf on Oct. 19, 2000 was an example of such a “baroclinically enhanced” extra-tropical hurricane.

Formed in response to an upper-level low moving over a stationary surface front north of the Bahamas on Oct. 12, Michael attained hurricane status on Oct. 17. It began to move north on Oct. 18 and experienced significant intensification on Oct. 19 as it passed over the Scotian Shelf. It reached the south coast of Newfoundland late on Oct. 19 with its tropical core still intact. With maximum sustained winds of 140 km/h and barometric pressure of 966 mb at its center, Michael was the most intense hurricane to pass eastern Canada in 2000. The rapid passage of Michael across the Scotian Shelf is shown in the sequence of GOES East images in Fig. 2. Between 08:15 and 19:15 UTC on Oct. 19, 2000, Michael travelled about 1000 km with an average speed of 90 km/hr.

Figure 2. Progression of hurricane Michael across Scotian on Oct. 19, 2000.
4.2 Effect of Hurricane Michael on Test Area

The GOES imagery show that the closest the center of the hurricane was to the Minimet buoy, moored at site 4, was 75–100 km to the southeast at approximately 16:00 UTC on Oct. 19. Figure 3 shows times series of several of the meteorological parameters measured by Minimet sensors. The passage of the eye of the hurricane is easily seen in the figure as a deep trough of pressure late on Oct. 19. The characteristic lull in wind speed and reversal of wind direction as the center of the hurricane passes the buoy is also evident.

Figure 3. Sea surface meteorology during passage of hurricane Michael.

Although hurricane Michael passed over the Scotian Shelf in less than six hours, it was intense enough to effect changes in the shelf oceanography. Images of sea surface temperature (SST) from the NOAA-14 AVHRR sensor before and after the hurricane indicate that the surface of the water was cooled by an average of 1.2 °C (std. dev. 0.2 °C) in the study area. Figure 4 shows the SST images of Oct. 14 and 22, 2000 which were the last clear day before and the first clear day after passage of the hurricane.

Figure 4. Sea surface temperature from NOAA-14 AVHRR imagery on Oct. 14, 2000, left (before hurricane) and on Oct. 22, 2000, right (after passage of hurricane).
Data from the REA surveys on Oct. 14 and Oct. 21 show a similar 1°C drop in surface temperature caused by the hurricane. The uppermost temperature measurement of the AXBTs, made at a depth of 1.5 m, are shown as temperature contour plots in Fig. 5. The water column temperature structure before and after Michael is shown in transects from west to east through the middle of the two REA surveys in Fig. 6. The 1°C drop in surface temperature between the surveys can be seen to extend throughout the mixed layer. In the deeper west side of the transect, there was a slight warming of water below the thermocline after the hurricane which is evidence that mixing occurred throughout the entire water column. Before Michael, the thermocline was at a constant depth of 32 m across the entire transect. After the hurricane, there is much more variability in the depth of the thermocline. Near AXBTs 20 and 21, the thermocline is 8 m lower after the hurricane and near AXBTs 22 and 23 a new thermocline has appeared at approximately 20 m whereas before Michael the entire water column was isothermal in that area.
5 Acoustical modelling

5.1 Broadband Transmission Loss Modelling with PROLOS

To examine the effect of the environmental changes caused by hurricane Michael on broadband propagation, incoherent transmission loss (TL) was calculated from 20 to 10000 Hz at discrete frequencies in one-octave increments. The propagation model employed, PROLOS [5,6], is based upon normal modes acoustic propagation theory. PROLOS is a research model that has been incorporated into the allied environmental support system (AESS). It can model propagation with range-dependent sound speed profiles, bathymetry, and sediment geoacoustic parameters and includes losses due to seabed and sea surface roughness. The results in this paper were calculated using a geoacoustic model for Sable Island Bank [3] with 50 m of sand, overlying 50 m of glacial till, and then a sedimentary rock half space. The roughness of the seabed and surface were specified as 0.01 and 0.3 m rms respectively.

5.2 Impact of Hurricane Michael on Acoustical Propagation

The incoherent transmission loss for range independent propagation was compared for in situ sound speed profiles before and after the passage of hurricane Michael and for a climatological profile for the month of October. The in situ sound speed profiles were derived from the AXBT temperature profiles at drop site 21 shown in Figs. 5 and 6. The climatology profile, prepared as part of the ocean model project [1], is a simple depth average of a compilation of historical data. This approach yields a thermocline that is much less pronounced than the in-situ profiles but is typical of climatology-based sound speed profiles often used operationally for sonar performance prediction. The sound speed profiles used for the TL calculations are shown in Fig. 7.

Figure 7. Sound speed profiles from AXBT site 21 before and after hurricane Michael, and sound speed profile from climatology.

Results of the PROLOS propagation modelling are shown in Figs. 8 and 9 as TL as a function of frequency and range for two different cases. In the first case (Fig. 8), the source and receiver are both located below the thermocline at a depth of 50 m. The result is that most of the energy is trapped between the thermocline and the seabed. There are higher losses above 1 kHz due to surface scatter and below 200 Hz due to penetration into the seabed. This gives rise to an optimal propagation frequency of approximately
500 Hz. The TL predicted using the climatological sound speed profile is in reasonable agreement with the TL calculated using both of the measured profiles. Thus, below the thermocline, hurricane Michael had negligible effect on the propagation.

For the second case (Fig. 9), the source is below the thermocline at a depth of 50 m but the receiver is above the thermocline at a depth of 30 m. Here, the effects of hurricane Michael and inadequacies in the climatology become evident. After the hurricane, losses are higher for the \textit{in situ} profile, but they are restricted to frequencies above 500 Hz. The hurricane has not had a dramatic effect because the basic character of the profiles has been retained, that is a well mixed surface layer, a sharp thermocline, and a downward refracting sound speed profile between the thermocline and the seabed. There are however significant differences in TL for frequencies above 200 Hz when the predictions using the climatology are examined. The weaker thermocline in the climatology allows considerably more energy to reach the receiver whereas the TL for the \textit{in situ} profiles is much higher.

The inadequacy of the climatology in this case underscores the requirement for a more suitable method of representing the structure of the sound speed profile in climatology and the requirement for nowcast and forecast capabilities of an ocean model on the Scotian Shelf.

![Figure 8](image1.png) Figure 8. Broad-band transmission loss with source and receiver both at 50 m (below thermocline). a) before hurricane, b) after hurricane, c) climatology.

![Figure 9](image2.png) Figure 9. Broad-band transmission loss with source at 50 m (below thermocline) and receiver at 30 m (above thermocline), a) before hurricane, b) after hurricane, c) climatology.
6 Summary

We presented results of an environmental survey of part of the Scotian Shelf carried out in Oct. 2000. During the trial, hurricane Michael passed over the study area, affording a unique opportunity to observe the effect of an intense storm on shelf oceanography and on the acoustical propagation environment. The passage of the hurricane across the Scotian Shelf took only 6 h but it was intense enough to lower the temperature of the mixed layer by more than 1°C and to disturb the level of the thermocline by nearly 10m.

To estimate the effect the hurricane had on acoustical propagation, measured water temperature profiles from one location were use to calculate broadband TL in the 20 Hz to 10 kHz band with the PROLOS normal modes model. It was found that with the source and receiver both located below the thermocline, most of the energy remained trapped between the thermocline and the seabed with an optimal propagation frequency near 500 Hz. TL calculations for the same source-receiver geometry but using a sound speed profile based on climatology gave similar results. The conclusion was that the hurricane had little or no impact on the propagation environment below the thermocline and that use of a sound speed profile based on climatology was adequate for that case.

A second case was then examined with the source below the thermocline but with the receiver above. Here, it was found that although propagation losses were somewhat greater after the hurricane, the effect was not dramatic because the basic shape of the profiles was not altered by the hurricane. However, there were significant differences between TL calculated with the measured SSPs and with the climatological profile. The weaker thermocline in the climatology allows considerably more energy to reach the receiver whereas the TL for the in-situ profiles is much higher, particularly for frequencies above 200 Hz. This result shows that climatology can be a poor substitute for accurate, timely SSPs for some situations, particularly for propagation above or across the thermocline.

Acknowledgements

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References