The Influence of Oceanographic and Biological Processes on the Distribution of Cetaceans on the West Florida Shelf: A Synoptic Study Based on Underwater and Space-Based Remote Sensing

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LONG-TERM GOALS

Studies employing visual surveys for cetaceans typically suffer from high levels of spatial and temporal aliasing due to limitations in the number of vessels and the amount of survey time. We will use autonomous acoustic data recorders to monitor cetaceans over a large spatial and temporal scale, overcoming some of the limitations of studies based on visual surveys alone. These data will be complemented by visual survey data within the acoustic survey area during recorder deployment and retrieval. With *in-situ* and satellite remote sensing oceanographic data, relationships between the distribution of cetaceans and such factors as sea surface temperature, chlorophyll levels and background noise levels will be investigated on appropriate temporal and spatial scales. Results from existing numerical circulation models of the Gulf of Mexico will help understand underlying oceanographic processes.

WORK COMPLETED

This project began in August 2007. Below we describe the achievements of the project during this past fiscal year. The main achievements were the development and successful deployment of the DSG recorder, measurements of cetacean whistles with a towed hydrophone array, analysis of archived satellite data for probability of front presence, incorporation of the DSG recorder into the Bottom-stationed Ocean Profiler (BSOP), and development of a data analysis suite based in MATLAB.

APPROACH AND WORK PLAN

OBJECTIVES

1. Determine the spatial and temporal distribution of cetaceans and noise on the central West Florida Shelf (WFS) through autonomous passive acoustic monitoring
2. Determine source levels of common cetacean species on West Florida Shelf and model sound propagation
3. Detect and quantify biological and physical oceanographic features present on the central WFS with satellite imagery, *in-situ* measurements, and modeling
4. Develop a library of sounds produced by common cetaceans from the Gulf of Mexico
5. Characterize the relationships between cetacean distribution, oceanographic variables and ambient noise levels

Key Individuals and their roles:

Dr. David Mann is PI overseeing the project and is responsible for acoustic recorder development

Peter Simard and Carrie Wall are Ph.D. student swith Dr. Mann who is responsible for managing the field deployments and analyzing the acoustic data in concert with the physical and satellite data.

Dr. Adam Frankel of Marine Acoustics, Inc. is in charge of towed array recordings to determine dolphin whistle source levels and also for modeling acoustic propagation to determine recorder active space.

Dr. Robert Weisberg is in charge of the COMPS buoy system and 3-D physical oceanographic modeling data which will feed into the sound propagation model and into analyses of variability in dolphin distribution in response to physical events.

Dr. Frank Muller-Karger is in charge of satellite oceanography operations at USF along with Dr. Chuanmin Hu who is preparing and QA/QC'ing satellite imagery data.

In the upcoming year we will:

1. Deploy the full array of 72 DSG recorders on the West Florida Shelf. These will be in place for one year.

2. Deploy the BSOP's with onboard DSG recorders to add to the acoustic and physical oceanographic data from the full array.
3. Analyze the acoustic data from the three month deployment and produce maps of dolphin distributions and correlate them with oceanographic variability.
4. Collect additional towed hydrophone array measurements of dolphin source levels.

RESULTS

SUMMARY OF MAJOR DEVELOPMENTS AND FINDINGS

- Towed array recordings showed that the majority of whistle source levels was approximately 150 dB re 1 mPa.
- The detection range based on these source level estimates and acoustic propagation modeling is about 4 km
- The DSG acoustic recorder was developed and successfully tested and a preliminary deployment was made. This recorder was also integrated into the Bottom-Stationed Ocean Profiler (BSOP)
- Analysis of offshore bottlenose dolphin versus onshore bottlenose dolphin echolocation click trains showed that on average dolphins living in shallower water tended to click at higher rates than dolphins living in deeper water.

More detailed information about these developments and findings is presented below.

TOWED HYDROPOHONE ARRAY RECORDINGS

We performed towed array recordings in April 2008 in the Gulf of Mexico with Marine Acoustics Inc (MAI) led by Dr. Adam Frankel on the West Florida shelf to obtain cetacean source level estimates (Figure 1). The array was the 8-channel Cornell University squid array. The data were hand-browsed using the XBAT browser tool. When high SNR whistles were detected on more than one channel, they were "boxed" using the selection tool. The parameters of the box were stored as an XBAT log for later use in batch analysis.

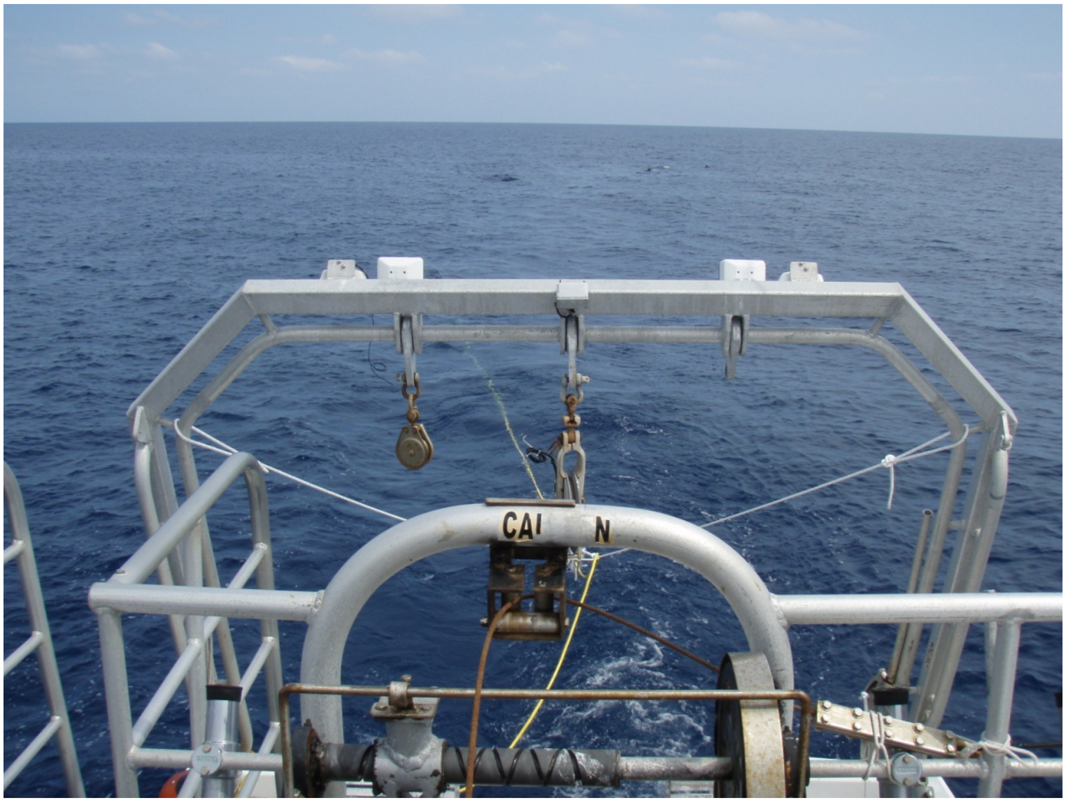


Figure 1. Towed hydrophone array recordings in the Gulf of Mexico. The yellow cable is the hydrophone array. A group of Atlantic spotted dolphins (*Stenella frontalis*) can be seen in the background near the array.

Acoustic Location Analysis

The CSE locator tool in XBAT was used to batch locate all of the selected whistles (Figure 2). The maximum range allowed in the location analysis was 4 km. Any values that had a range approaching 4 km were presumed to be the result of a bad location attempt and discarded. This condition could be caused by the array being curved at that moment, so the real relative positions of the hydrophone elements did not correspond to the measured potions in the array file within the software.

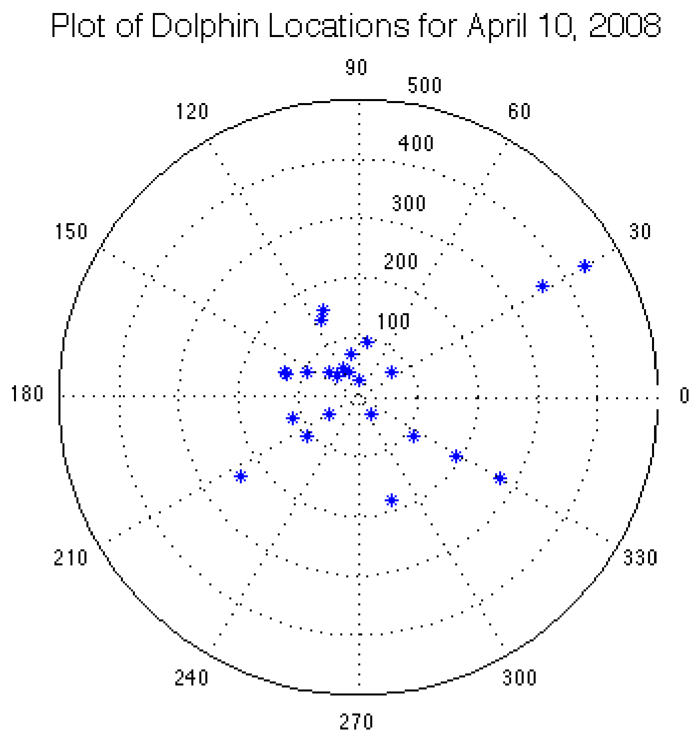


Figure 2. Localization of dolphin vocalizations with the towed array.

Received Level Analysis

After the location analysis was completed, each selected whistle was automatically clipped out to a separate wav file for analysis. A MATLAB script was written that would read the wav file and

1) Convert the scaled .wav values to voltages

2) Using the calibrated hydrophone sensitivity, convert the voltages to received pressure values (μPa).

3) High-pass filter the data at 5 kHz to remove the contribution from boat noise.

4) Calculate a spectrogram, and find the spectral slice with the maximum energy. (FFT size = 1024, overlap = 512 pts, Sampling Rate = 64kHz).

5) Extract the spectral slice with maximal energy and report the loudest level in any frequency bin. With the given sampling rate and FFT size, each frequency bin has a bandwidth of 62.5 Hz, approximating the bandwidth of a dolphin whistle. This value was reported as the received level.

6) During the analysis, the spectra were examined by eye to determine an approximate noise level for range analysis. (to be replaced by a better effort, later).

Transmission Loss Analysis

An Acoustic Integration Model © (AIM) run was created for a sample location at 27.2° N and 83° W. The transmission loss was estimated using the Bellhop transmission loss model. The simulation had a dolphin animat at 5 meters depth and a receiver animat that moved one kilometer south, recording the received level every few meters. The April sound velocity profile was used. Bathymetry was from the USGS Coastal Relief Model at a three-second resolution. A surface wind speed of 10 knots was specified to inform the surface loss module and the default MGS coastal regime of 2 was specified for bottom loss.

The resulting data were plotted and a logarithmic curve was fit to the data and shown in Figure 3. The data corresponded well to a curve fit of 20.45 * $\log_{10}$(range). This approximates spherical spreading with an absorption term.

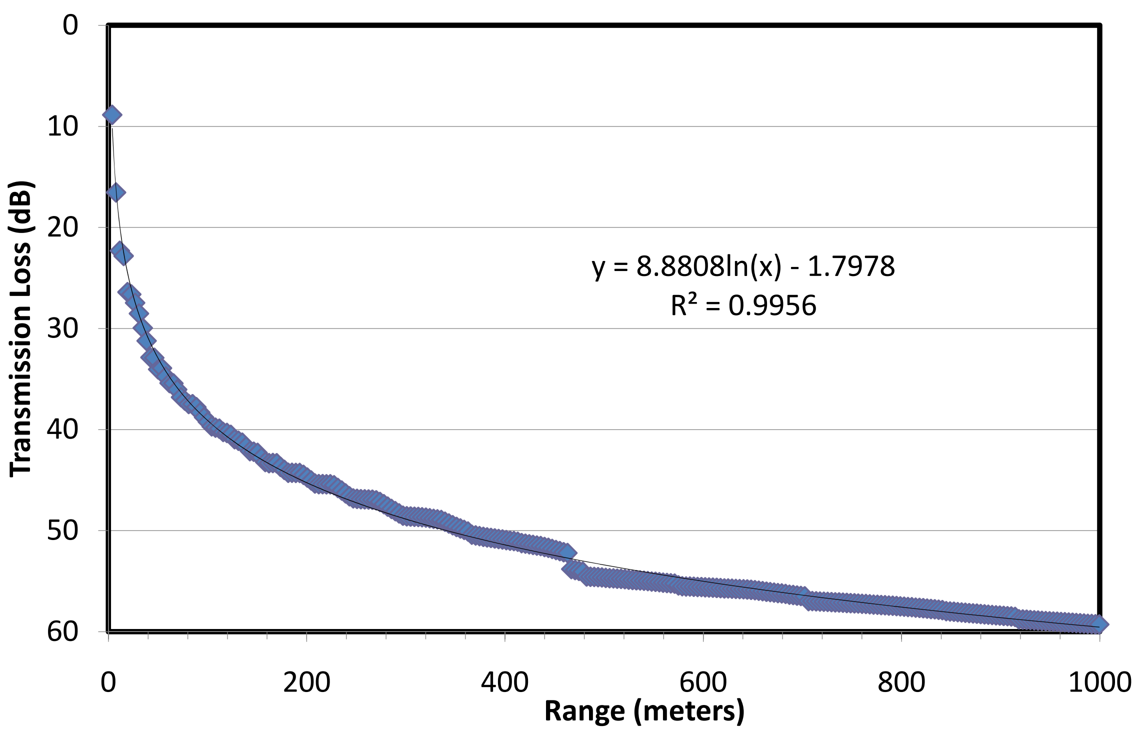


Figure 3: Modeled transmission loss data from Bellhop with a logarithmic curve fit to the data.

RESULTS

A total of 1,843 whistles were clipped out and analyzed. To date, only 39 whistles had both a range estimate and a source level estimate > 100 dB re 1 μPa at 1 m. The median of those source levels was 142.5 dB re 1 μPa at 1 m. The distribution of SL estimates is shown in Figure 4.

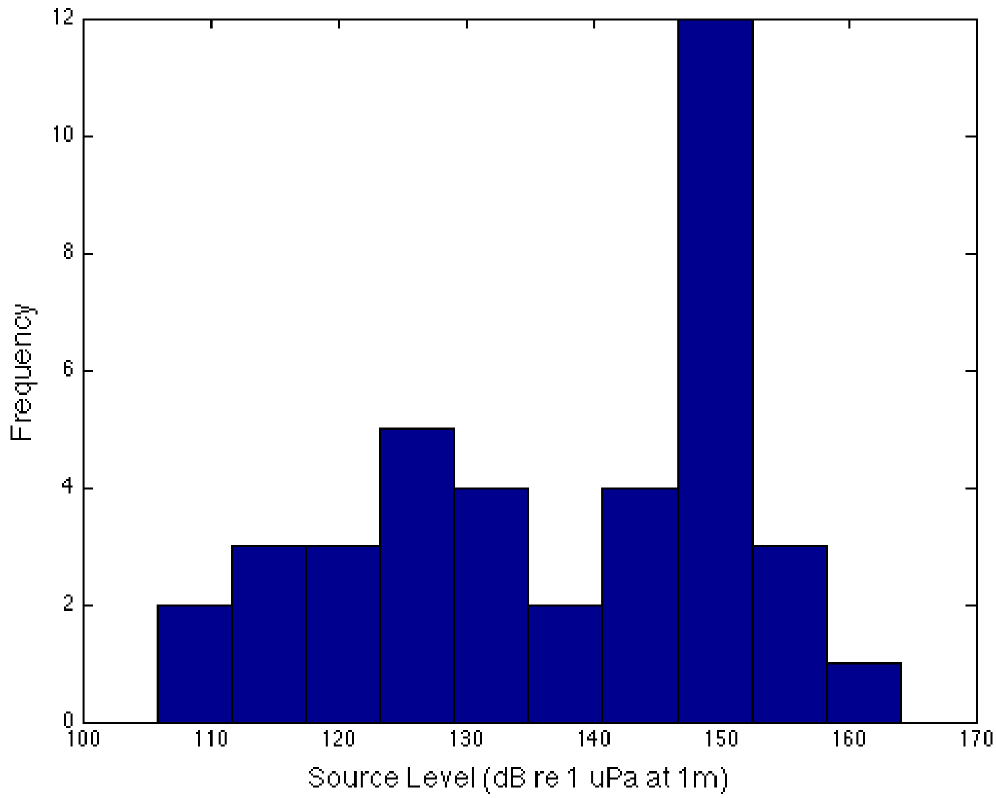


Figure 4: The distribution of dolphin source level estimates.

Projected Detection Range

Given the parameters derived to date, and a 10 dB detection threshold, the preliminary estimate of detection range is 4.2 kilometers, based on a noise level (in the signal band of 62.5 Hz width) of 60 dB re 1μPa. If noise level were to drop to 54 dB re 1 μPa, then the detection range would increase to 8.4 km. Likewise, an increase in the noise level would reduce detection range to 2.1 km.

The disappointing number of successful locations suggests that the location analysis should be repeated. Options include alteration of the location parameters and/or implementation of another location algorithm. It also reinforces the necessity to minimize course changes during recording. It also suggests that a second data collection effort is warranted in 2009.

Given the variable detection ranges based upon variable noise levels, it will clearly be necessary to produce a noise floor metric from the acoustic data from the recorders to dynamically predict the acoustic space of the recorders.

DEVELOPMENT AND SUCCESSFUL DEPLOYMENT OF DSG RECORDER

The DSG Recorder is a new long-term, low-power recorder of acoustic signals that was developed for this project. DSG is capable of sampling at 80 kHz continuously and up to 400 kHz in burst mode. The

DSG records based on a schedule file system that allows arbitrary record times and durations. DSG stands for 'digital spectrogram' because one of its record modes allows creation of spectrograms from stuttered recordings. This is useful for 'lossy' data compression of high frequency signals, such as those produced by dolphins and bats, in which the main goal is to detect the presence of the animal. The recorders were deployed in the configuration shown in Figure 6, and are currently being retrieved.

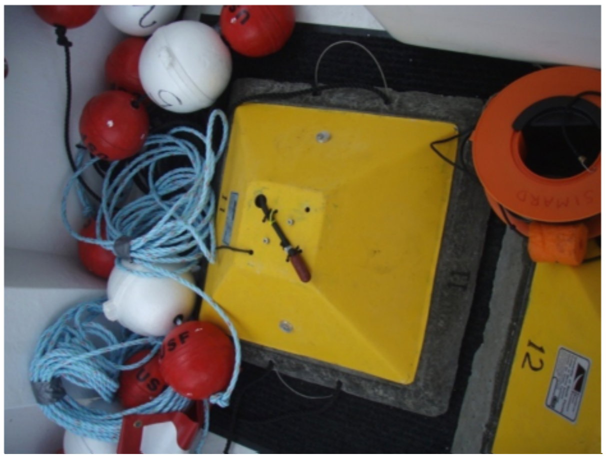
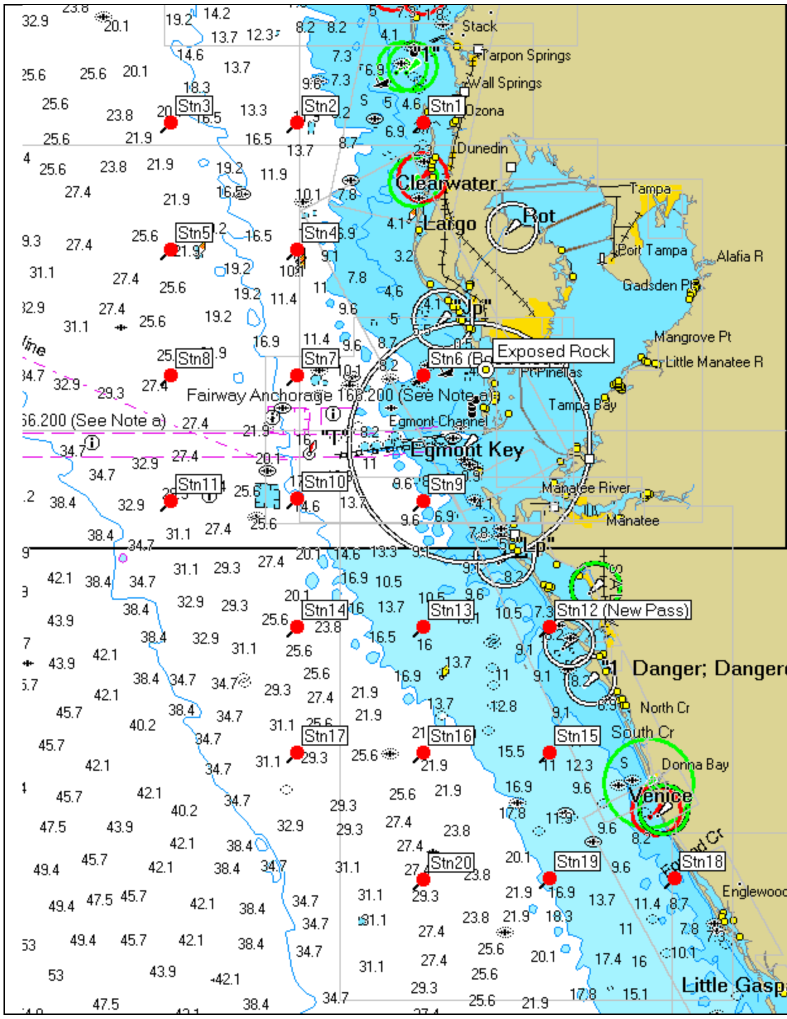


Figure 5. DSG in trawl resistant housing showing hydrophone coming out of the top. The base is made of cement that nestles inside of the pyramidal mount.



Recorder stations		
Stn	Lat	Long
1	28 03.196	82 50.109
2	28 03.196	83 02.255
3	28 03.196	83 14.400
4	27 52.397	83 02.255
5	27 52.397	83 14.400
6	27 41.598	82 50.109
7	27 41.598	83 02.255
8	27 41.598	83 14.400
9	27 30.799	82 50.109
10	27 30.977	83 02.255
11	27 30.799	83 14.400
12	27 20.000	82 38.000
13	27 20.000	82 50.109
14	27 20.000	83 02.255
15	27 09.201	82 38.000
16	27 09.201	82 50.109
17	27 09.201	83 02.255
18	26 58.409	82 25.922
19	26 58.409	82 38.000
20	26 58.392	82 50.094

Figure 6. Chart showing locations of DSG recorders for three-month deployment.

Analysis of Echolocation Patterns

A major goal of this project is to distinguish between different species of dolphins based on the sounds they produce. However, reports of molecular, morphological and ecological differences between inshore and offshore populations of bottlenose dolphins (*Tursiops truncatus*) in the Gulf of Mexico have also lead us to investigate if differences exist in the sounds produced within this species. From recordings conducted on cruises in June through September 2008, the spectral and temporal qualities of echolocation clicks from bottlenose dolphins in inshore and offshore locations have been investigated. Both the pulse rate and energy spectrum between 20 kHz and 48 kHz of bottlenose echolocation clicks change significantly with water depth (Figures 7 & 8; Simard et al. in prep).

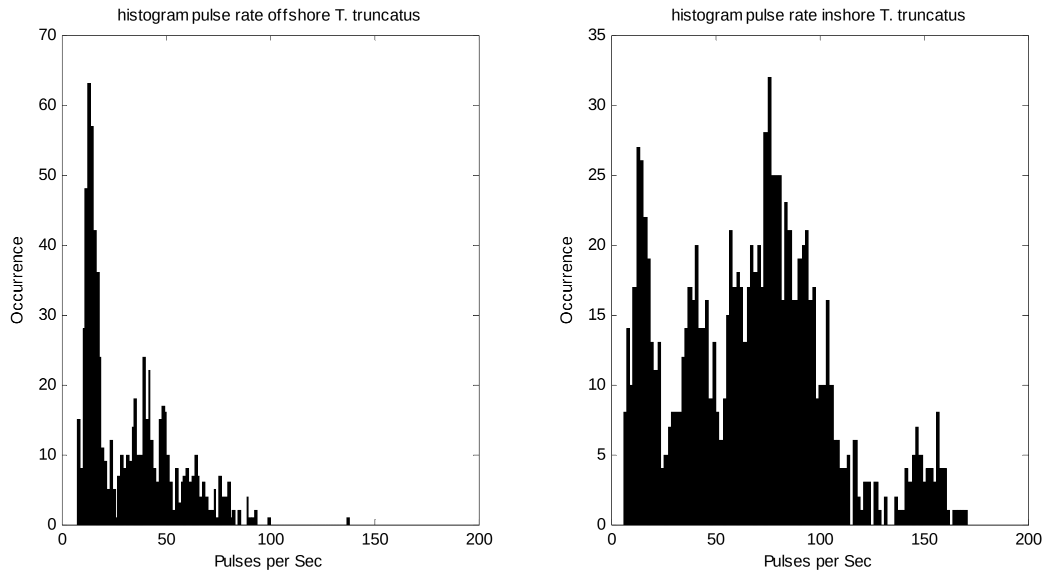


Figure7: Histograms showing the occurrence of echolocation pulse rates for offshore (left) and inshore (right) bottlenose dolphins. The mean pulse rates for these groups are 32.7 pulses per second and 66.8 pulses per second, respectively.

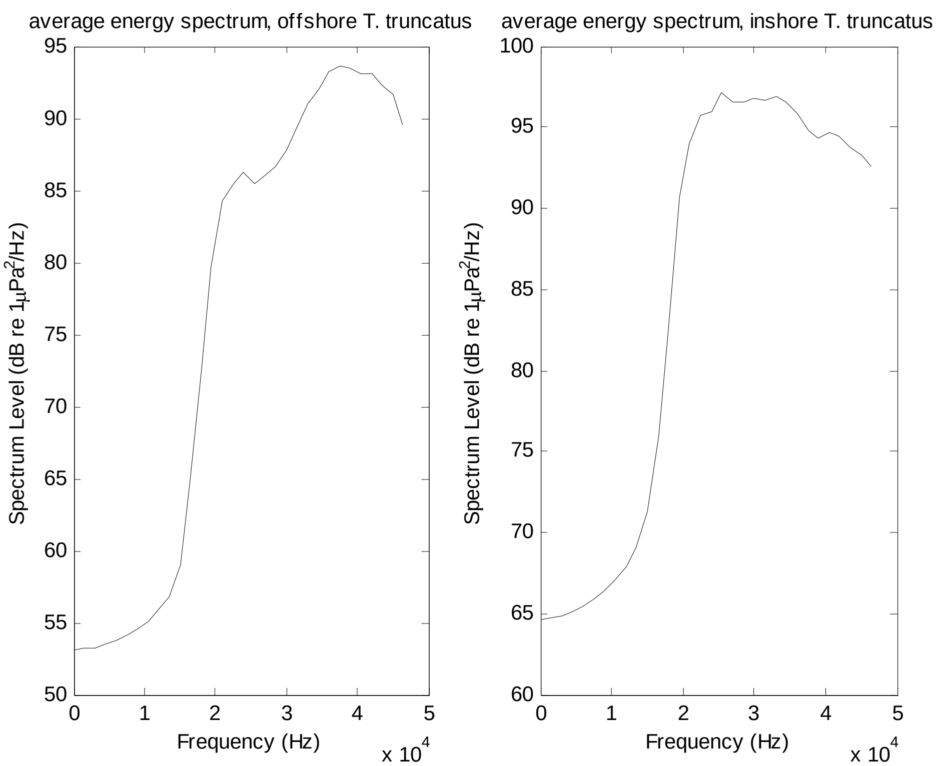


Figure 8: Plots of the energy spectrum between 20 kHz and 48 kHz for offshore (left) and inshore (right) bottlenose dolphins. The mean peak frequencies for these groups are 38.1 kHz and 31.6 kHz, respectively. Note data were high-pass filtered at 20 kHz for the analysis.

Bottom-Stationed Ocean Profiler (BSOP) Development

As part of this project we are integrating the DSG recorder into the BSOP, which is a profiling buoy that measures salinity and temperature and relays those data via satellite. The DSG recorder has been integrated into the BSOP and now

Satellite Oceanography Data

Dr. Muller-Karger's team performed an analysis on typical locations of front development on the West Florida Shelf. This analysis was used to fine-tune the locations of the deployment of the DSG recorders in the test deployment. High resolution, 1 km x 1 km sea surface temperature measured from NOAA's Advanced Very High Resolution Radiometer (AVHRR) polar orbiting satellites collected between Jan 1, 1998 to Dec 31, 2007 and NASA's Moderate Resolution Imaging Spectroradiometer Aqua/Terra satellite sensors collected between 2004 to Dec 31, 2007 were used to create weekly composite SST images for the eastern Gulf of Mexico. A front detection algorithm (Wall 2006) was then applied to the weekly mean images. The frequency of a front occurring on a given pixel within the image for the ten-year time span was then calculated (Figure 9). From these images we see that bathymetry plays a role in the set up, stability and strength of the sea surface temperature fronts in this region, with areas of high frontal strength corresponding to areas where fronts frequently form.

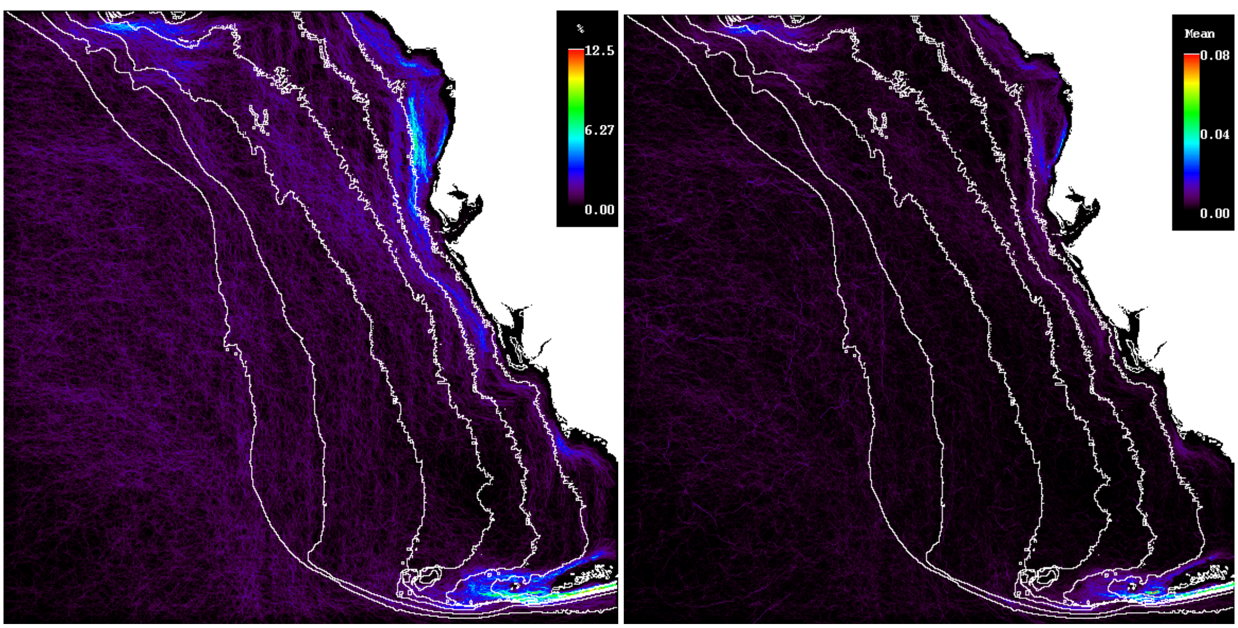


Figure 9. (LEFT) Front frequency over a ten year time span. This shows a higher frequency of fronts occurring alongshore, namely following the contours of the 10 and 20 m isobaths.
(RIGHT) The gradient surrounding the front was calculated for each frontal image and then averaged over the ten year time span. This shows the strongest fronts occurred mainly along the coast, contouring the bathymetry, where depth is shallow. Areas of higher frontal strength largely coincide with areas of higher frontal frequency. White lines represent 10, 20, 30 50, 100, 200 m isobaths.

IMPACT AND APPLICATIONS

National Security

The acoustic array that is being deployed on the West Florida Shelf, and integrated into the bottom-stationed ocean profiler has the ability to record the movement of boats and also the development of this technology could serve as the basis of a boat detection system.

Economic Development

In a few sentences, what is the potential future impact on Economic Development, e.g., new product lines, businesses, practices, increased efficiency, new manufacturing techniques, etc?

Quality of Life

We expect this technology to become an integral part of coastal observing systems for monitoring marine ecosystems. The results from this project will allow us to determine patterns of cetacean distributions in relationship to physical and biological oceanographic features. It will establish baseline data for understanding future potential impacts, such as the effect of seismic air-gun exposures on the behavior and distribution of whales and dolphins. This is important information for the oil and gas industry.

Science Education and Communication

The results from this study will result in tools for science education for integrating many disciplines including physics and biology. Because the project involves distributions of dolphins and whales, it is of inherent interest to the general public and thus readily communicated.

TRANSITIONS

Economic Development

The DSG recorders have been made available to other researchers and they are being used internationally in cetacean research projects including studies in the Bahamas and Denmark.