Concurrent Measurements of Beaked Whale Clicks, Physical Oceanography, and Prey Fields in the Tongue of the Ocean
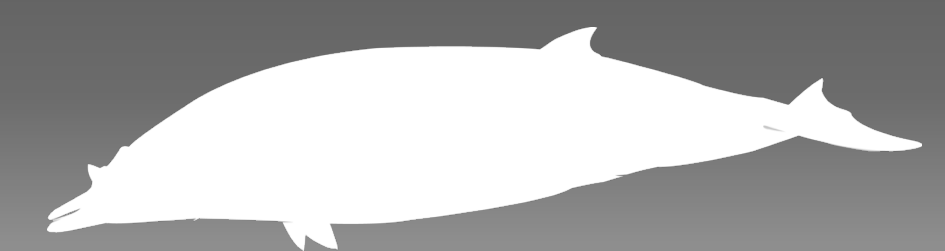
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ABSTRACT: Assessments of the potential risks of noise exposure to beaked whales have historically occurred in the absence of information about the physical and biological environments in which these animals are distributed. Understanding the habitat utilization of these whales will increase our understanding of beaked whale behavior and the effectiveness of future risk assessments. Beaked whales, specifically Blainville's (*Mesoplodon densirostris*) and Cuvier's beaked whales (*Ziphius cavirostris*), are known to feed in the tongue of the ocean, Bahamas. These whales can be reliably detected and often localized within the Atlantic Undersea Test and Evaluation Center (AUTEC) acoustic sensor system. The AUTEC range is outfitted with regularly spaced bottom mounted hydrophones over 350 nm[2] providing a valuable network to record anthropogenic noise and marine mammal vocalizations. From 9/12-10/2 of 2008 we used a downward looking 38 kHz SIMRAD EK60 echosounder to measure prey scattering layers concurrent with fine scale turbulence measurements from an autonomous microstructure profiler (MP). Using an 8km, 4-leaf clover sampling pattern, we completed a total of 7.5 repeat surveys with 3 MP casts to concurrently measure the physical and biological oceanography so as to examine the spatiotemporal scale relationship in the microstructure and scattering layer. We found a strong correlation between increased prey density relative to increased click densities. These results open the door for future analyses examining the specific scale structure of prey patches and ultimately broad scale models of beaked whale foraging habitat.

SAMPLING METHODS:
Transects were designed in the shape of a four leaf clover extending 8 km E-W and N-S to sample around potential beaked whale detections from September 12th – October 2nd, 2008 aboard the 84m R/V Revelle. Additional transects were sampled while transiting between clovers and across the basin. Acoustic data were primarily collected at night (87%) with one clover sampled during the day.

ACOUSTICS:
Acoustic data were collected using a SIMRAD EK-60 with a 38-DD transducer mounted through the moon pool of the R/V Revelle. Density was summarized using Sv a logarithmic relative density of acoustic scatterers (db) and NASC a linear measure of acoustic density ($m^2 \cdot nmi^{-2}$).

MICROSTRUCTURE PROFILER:
An autonomous microstructure profiler was released three times per clover to measure diffusivity and water column environmental data. Sensors on the profiler included a standard CTD, as well as dual airfoil probes from the measurement of microstructure shear, and an FP07 fast thermistor for the measurement of temperature. Below is an echogram (depth axis on the left) showing the DSL primarily between 400-600 meters in depth with blue showing scattering targets. The inset plot below shows a single plot of mean dissipation (W/kg) binned according to density with depth. Density (σ_θ) using potential temperature is shown in purple to blue.
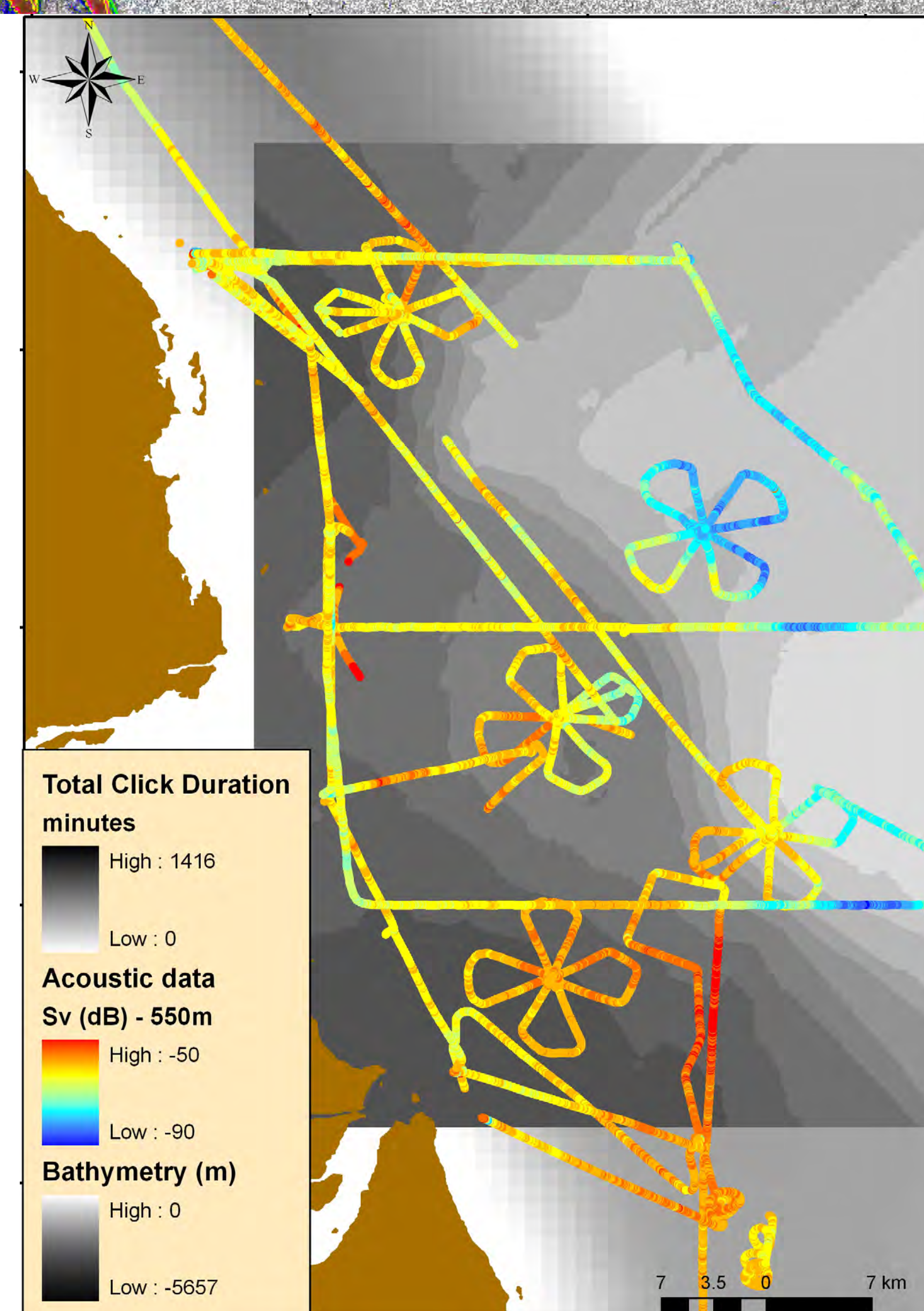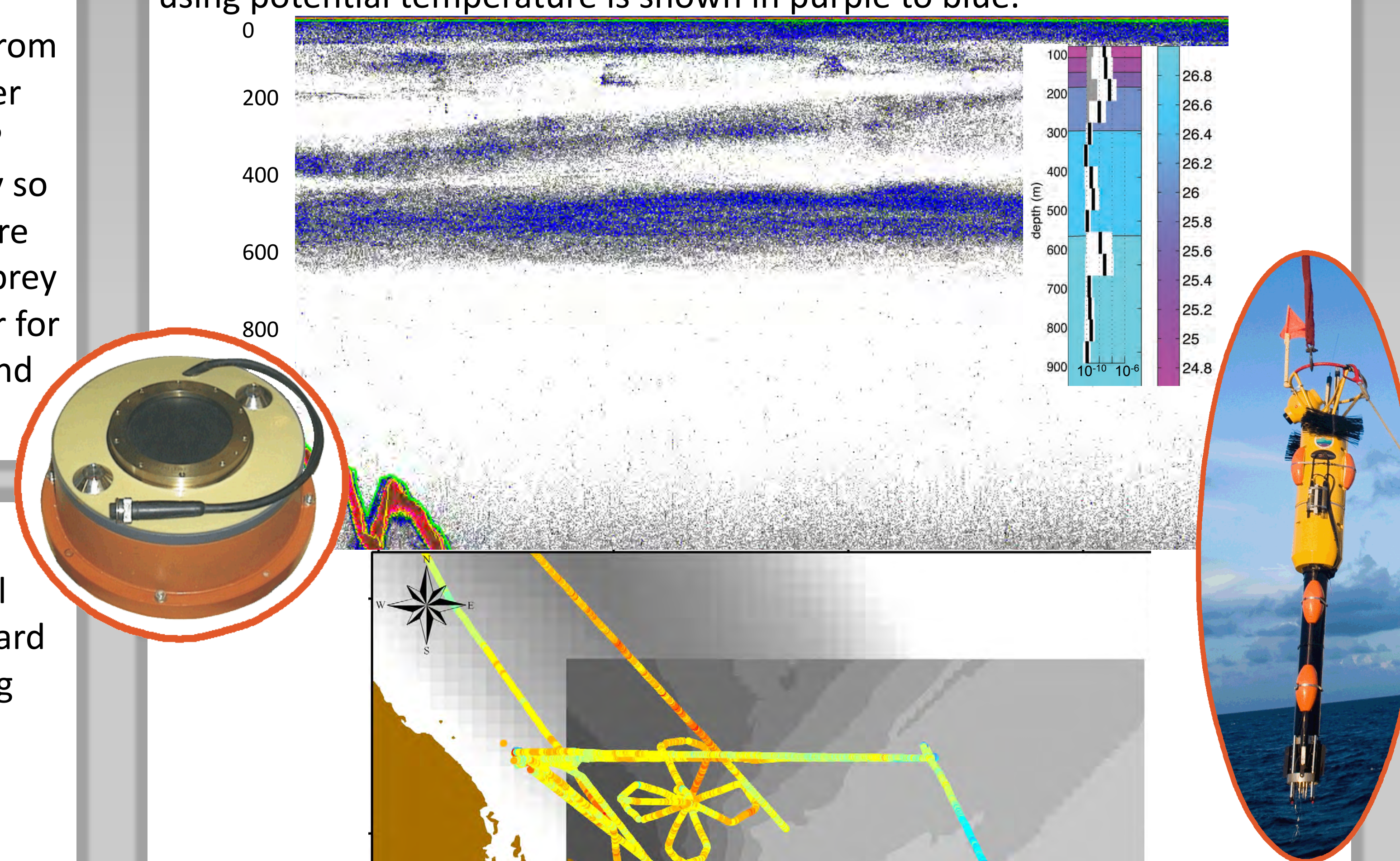
BEAKED WHALE CLICKS:
Audio data from the 82 bottom mounted hydrophones of the AUTEC tracking range were simultaneously recorded digitally at a 96 kHz sampling rate. A multi-stage FFT based energy detector has been successfully used for detection of clicks from a variety of echo-locating odontocetes including Blainville's beaked whales (Moretti et al. 2006). We used the automatic click detector to identify Blainville's beaked whale clicks which were subsequently manually scrutinized.

ANALYSIS METHODS:
By summing the total number of hours of recorded click trains during our survey at each hydrophone, we were able to create a relative measure of foraging intensity. Variograms of prey density were used to identify the key spatial scales horizontally and vertically as an input for the geostatistical analysis. Each data type was interpolated into a surface using a universal kriging function to identify hotspots and coldspots. Each hydrophone location was used to sample the acoustic surface, bottom depth, and microstructure diffusivity as inputs for the linear model (LM) of click density as a function of prey and environment.

RESULTS:
Click duration was well correlated spatially with prey biomass measured at 550m. A higher total click duration was found on the west side of the basin and matches observed patterns in DSL density.
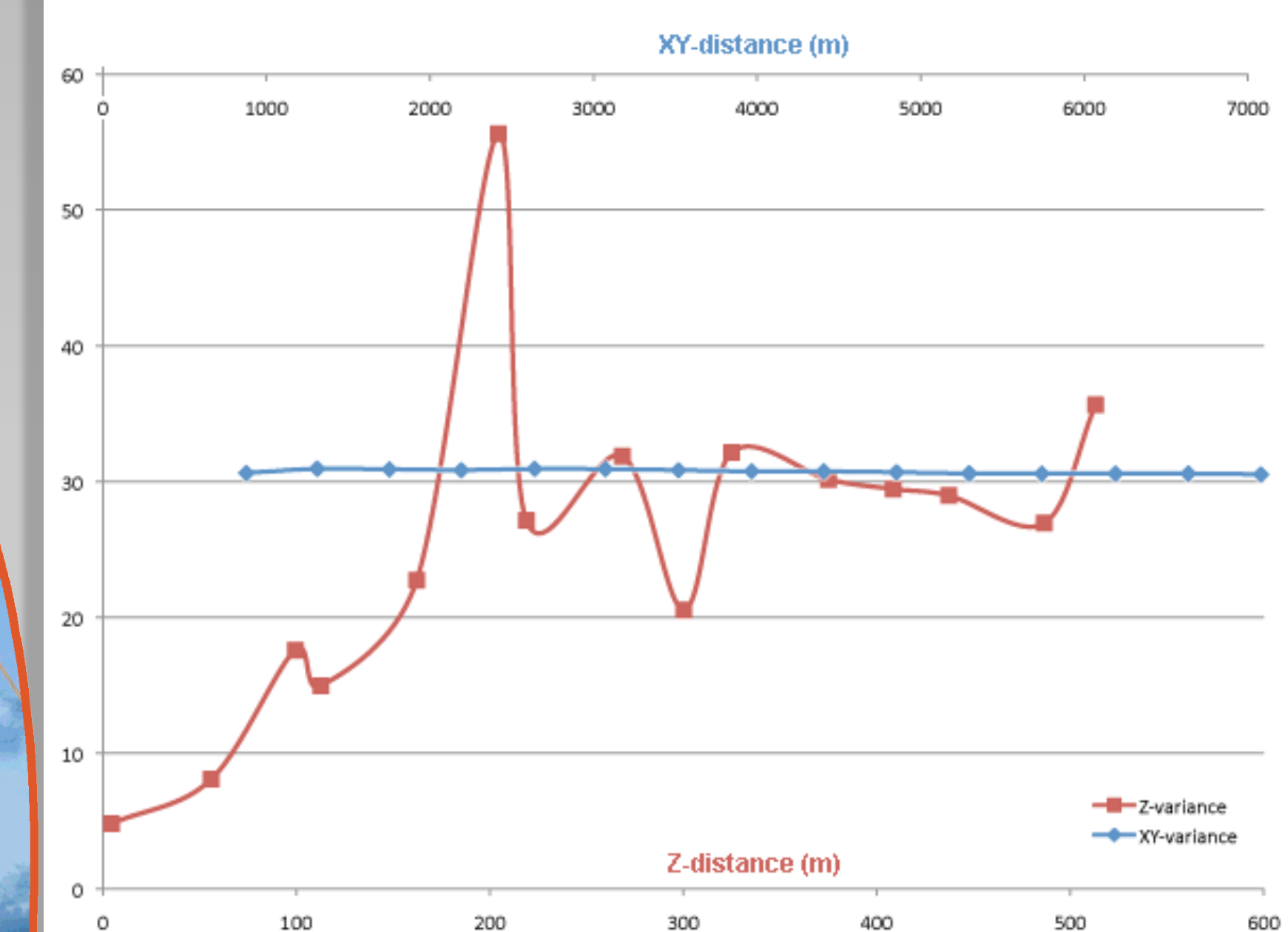
Horizontal scales of prey patchiness were greater than the length of the clovers (>7 km) suggesting large patch sizes or even layers in the X-Y dimension. Vertical scales of prey patchiness had a sill of 200m which was the approximate Z-thickness of the DSL.

Linear models showed:
1) A significant positive relationship (p < 0.001) between linear backscatter and click duration
2) A significant negative relationship (p < 0.02) between depth and click duration
3) A non-significant relationship (p > 0.05) between diffusivity and click duration.
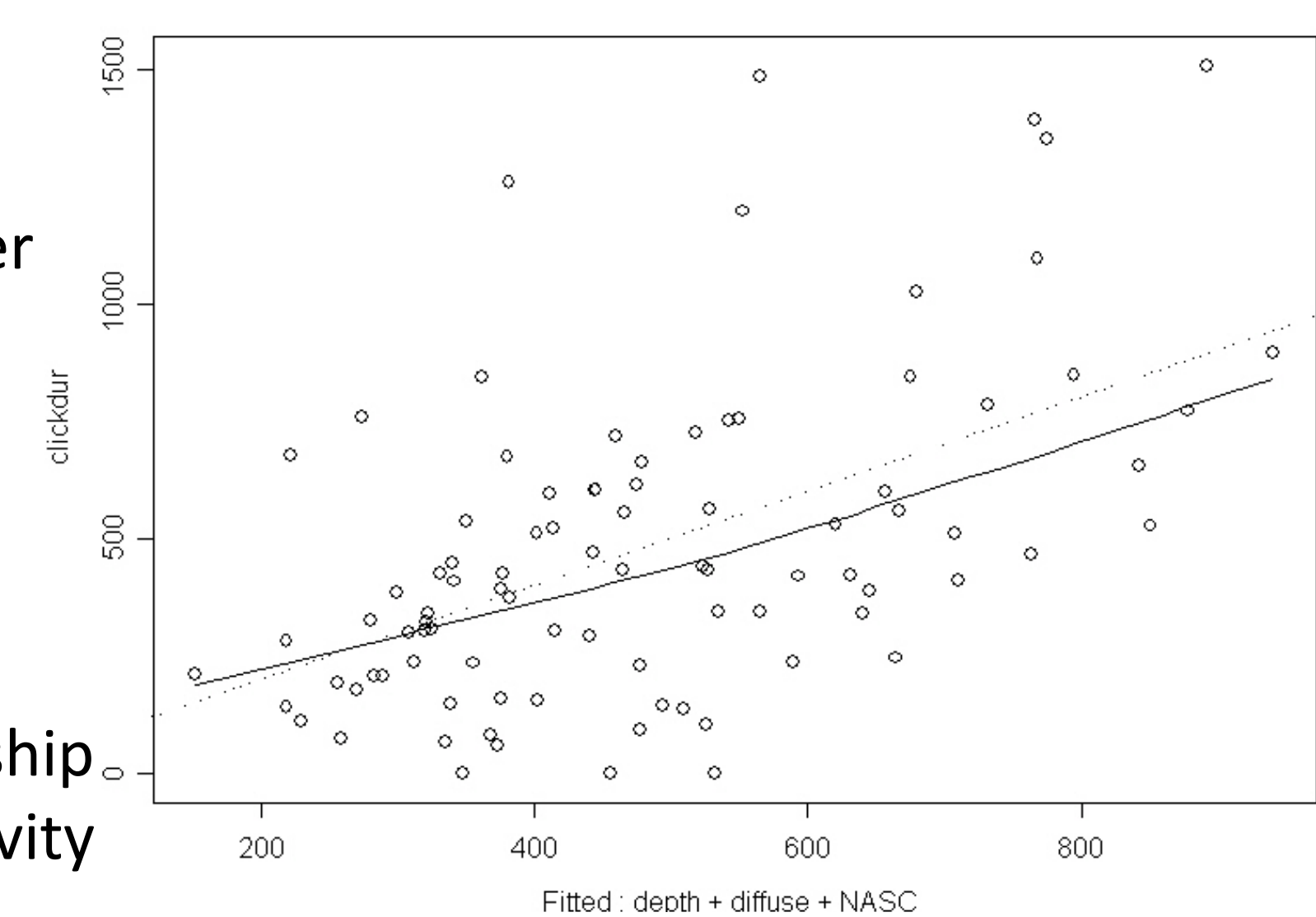
CONCLUSIONS:
- The scale of prey distribution was broad in the horizontal (Xy-sill > 8000 m) but much finer in the vertical dimension (Z-sill = 250 m) suggesting broad scale surveys in the Tongue of the Ocean should be sufficient for measuring DSL distribution.
- The relative foraging duration at each hydrophone was significantly related to the density of the DSL. While beaked whales often forage on squid in or below the deep scattering layer, the DSL density itself may serve as a valuable tool in predicting beaked whale distribution. Diffusivity at the same layer was less valuable as a predictor but this may be due in part to the lower sampling resolution compared to prey data.
- Further analysis of temporal scale and examination of individual targets at multiple depth bins could further elucidate the relationship between Beaked whales and their prey in the Tongue of the Ocean. Adding additional physical variables may strengthen our understanding of how these elusive predators interact with their environment.