

## **Physical and Biological Controls of Copepod Aggregation and Baleen Whale Distribution**

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### **LONG-TERM GOALS**

Our long-term goal is to develop a fundamental understanding of the physical and biological mechanisms that aggregate zooplankton on spatial scales of hundreds of meters to hundreds of kilometers. These aggregation processes have a profound effect on the distribution, movements, and behavior of top predators, including those that feed directly on zooplankton (e.g., basking sharks, manta rays, right whales). While all marine mammals rely on prey aggregation processes for their survival, baleen whales are perhaps most dependent upon these processes because of the enormous quantities of food they must consume daily. Therefore, we have chosen to focus our long-term research efforts on the interactions between baleen whales, zooplankton, and ocean physics to better understand the environmental factors influence marine mammal distribution.

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## OBJECTIVES

The objectives of this study are to

- Elucidate the mechanisms of copepod aggregation in the Great South Channel, a major springtime feeding area for right, sei, humpback, and fin whales in the southwestern Gulf of Maine
- Examine the relationship between these mechanisms and the distribution and abundance of baleen whales

## APPROACH

We are using field observations collected in 2005-2007 (hydrography, whale distribution, zooplankton distribution, and drifter tracks; Figure 1), the state-of-the-art FVCOM circulation model, and an individual-based particle tracking model to investigate copepod aggregation, and hence baleen whale distribution, in the Great South Channel. Our approach is as follows:

1. Validate FVCOM circulation fields
2. Conduct simulations with individual-based particle tracking model
3. Compare model results to in-situ observations
4. Characterize the physical-biological mechanisms that form and maintain copepod aggregations

We are comparing FVCOM hydrographic and circulation fields to in-situ observations (CTD and drifter data) to ensure the model is reasonably representing actual in-situ conditions, and then seeding the model with virtual copepods to track their advection through the study area. Copepods are represented in these simulations as Lagrangian particles that are either passive or exhibit diel vertical migration parameterized from in-situ observations of this migration behavior in the Great South Channel.

Our initial approach was to compare the particle-tracking model results to the distribution of both whales and zooplankton derived from the 2005-2007 survey data; however, we have found that the zooplankton sampling was too coarse for this kind of direct comparison (Figure 1). Moreover, we have found that diel vertical migration has a profound influence on advection and retention of copepods in the study area (see results below), and since this behavior is variable, we have found it difficult to compare model integrations with in-situ data. We have since changed our approach to focus more on process studies within the model framework to examine potential aggregation mechanisms at known locations of whale aggregations. The whale sighting survey data is now being examined to identify “hotspots,” and the physical/biological processes leading to copepod aggregations in these specific areas are being investigated.

## **WORK COMPLETED**

To date, we have compiled and processed all of the data for the 2005-2007 cruises, including all whale sighting data, NOAA surface drifter tracks, and in-situ profile data (CTD, fluorometer, VPR, OPC). FVCOM hydrographic and circulation fields from 2006 and 2007 have been acquired from the UMass Dartmouth archive. The model surface velocity fields have been compared to the surface drifter data to evaluate the model's ability to capture realistic circulation. Numerous numerical simulations have been conducted to test several hypotheses about aggregation mechanisms in the Great South Channel. Simulations consist of seeding the study area with Lagrangian particles to examine particular geographic areas or circulation features that may promote aggregation. Particle attributes, such as diel vertical migration behavior, turbulent diffusion (via random walk), and initial particle distribution, were varied in the simulations to examine their effect on aggregation behavior. We now plan to conduct simulations in areas occupied by zooplanktivorous whales to elucidate local aggregation processes.

## **RESULTS**

The FVCOM circulation fields were compared to surface drifters deployed in the northwest corner of the study area (the putative entrance for upstream flow into the Great South Channel). Lagrangian particle tracks originating at the drifter deployment sites did not agree perfectly with the drifter tracks, but this was likely due to the fact that the drifters were deployed in the strong jet located on the western side of the Channel where there is considerable cross-jet variability in velocity. To better compare the model to the drifters, several Lagrangian particles were released in the model across the jet, and the resulting tracks were used as an envelope of possible trajectories. This comparison yielded good agreement between the surface drifters and the model (Figure 2), particularly when a wind slip component was added to the Lagrangian particle trajectories (typical when comparing in-situ surface drifter tracks to model-derived particle tracks).

Numerical simulations have been conducted to determine if (1) particles tended to exit the Great South Channel in particular locations such that zooplanktivorous whales might aggregate to take advantage of higher abundances in these areas (the "exit door" or "funnel" hypothesis) and (2) diel vertical migration behavior (parameterized with in-situ observations from another study) retained particles in the study area for longer periods of time than if the particles remained at the surface. Particles tended to exit the Great South Channel along the western periphery regardless of whether they exhibited diel vertical migration behavior or not (Figure 3). The western margin of the channel, particularly the southwestern margin, is an area where right whales are often encountered, so we plan to examine the in-situ whale sighting data to test the "exit door" hypothesis. Simulations were also run to examine whether diel vertical migration behavior affected how long particles remained in the study area. We hypothesized that copepods that migrate near the sea floor during the day will be advected more slowly than copepods that remain near the surface 24 hours a day. The results of this simulation support this hypothesis: particles exhibiting diel vertical migration remained in the study area longer than particles that remained near the surface (Figure 4). This suggests that diel vertical migration may have a significant influence on aggregation processes in the Great South Channel.

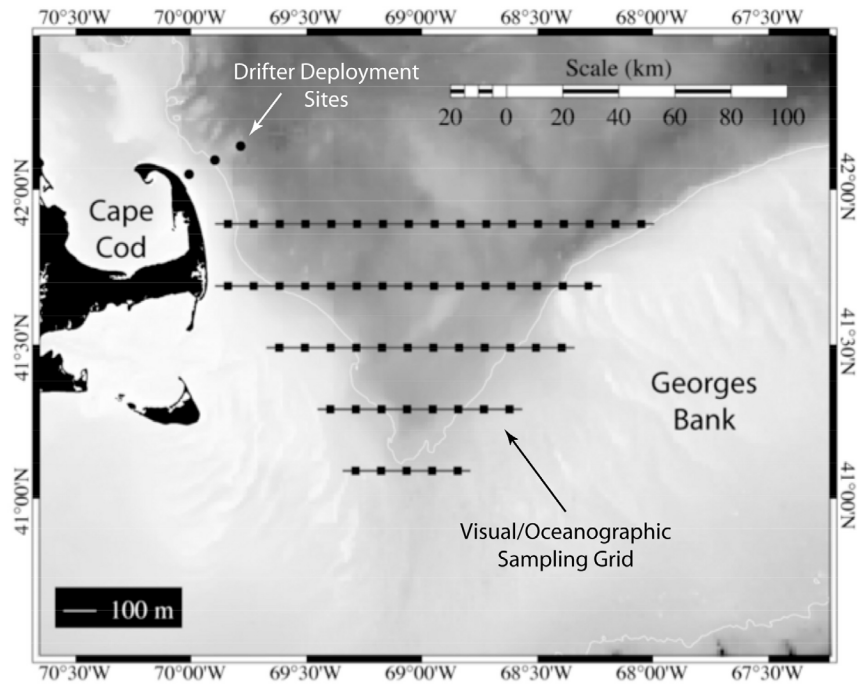
## **IMPACT/APPLICATIONS**

By understanding aggregation mechanisms, critical marine mammal habitats can be better identified, studied, and ultimately protected. Risk managers need to account for the environmental factors that

make particular areas attractive to marine mammals so that both human activities (e.g., fishing, shipping, Naval exercises) and marine mammals can coexist with minimal impact to each other. Research on the underlying processes that aggregate prey will ultimately inform our efforts to predict when and where interactions between human activities and marine mammals will occur.

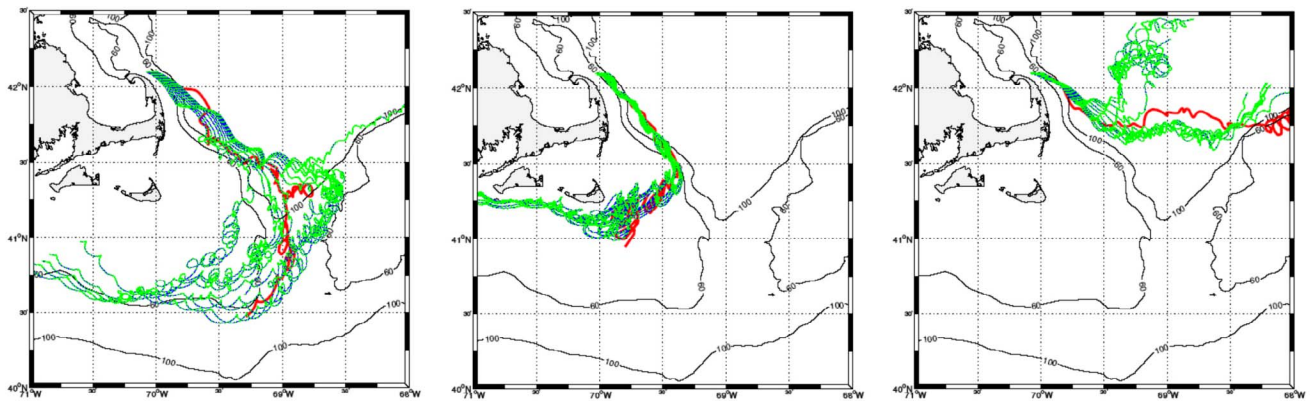
## **RELATED PROJECTS**

The project entitled “Right Whale Diving and Foraging Behavior in the Southwestern Gulf of Maine” (award number N000140910545, PI Mark Baumgartner) is closely linked to this project, as it is directly examining the response of North Atlantic right whales to the aggregation processes being investigated in this project.



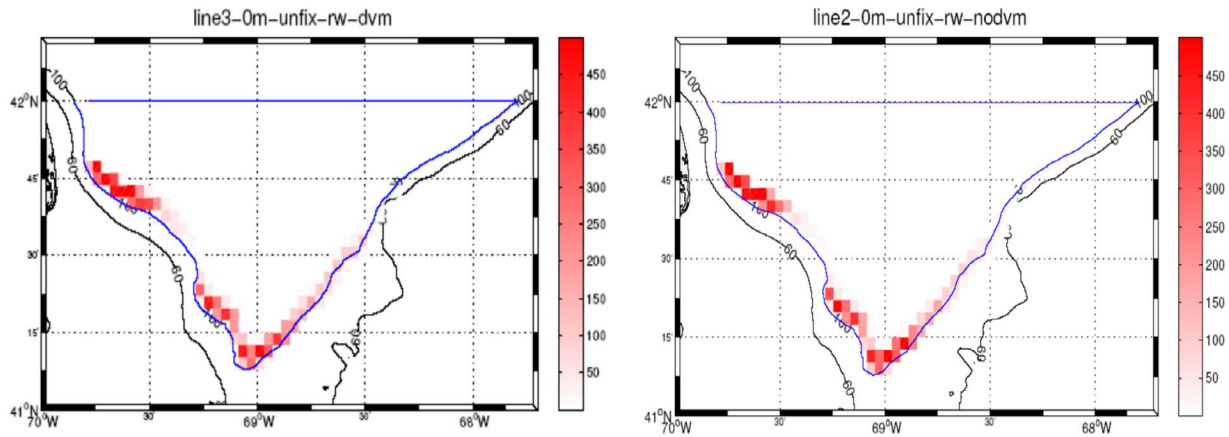
**Figure 1. Visual and oceanographic station grid in the Great South Channel. Surface drifter deployment sites also shown.**

**[Map of oceanographic station grid in the Great South Channel between Cape Cod, Massachusetts and Georges Bank]**



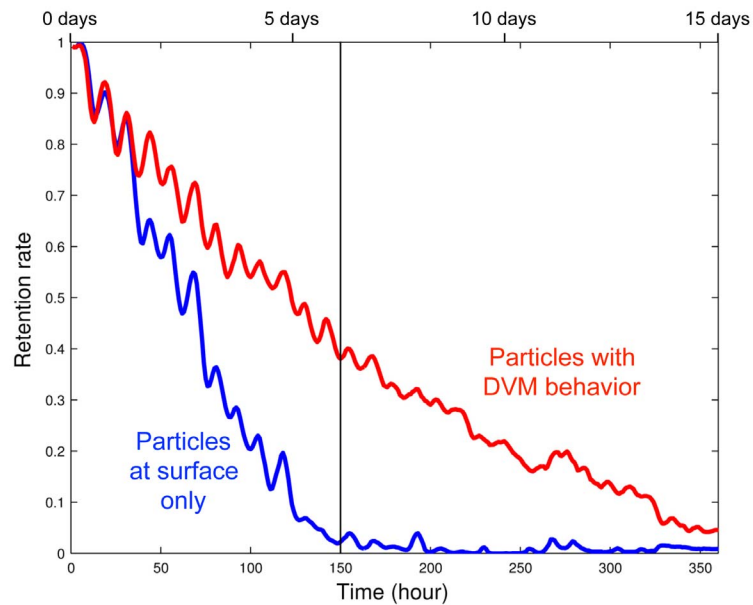
**Figure 2. Surface drifter trajectories (red) and Lagrangian particle trajectories for particles deployed across the western jet near the surface drifter deployment site (green) for 2005 (left) and 2006 (middle, right).**

**[Maps of drifter and particle tracks in the Great South Channel between Cape Cod, Massachusetts and Georges Bank showing agreement between in-situ observations and circulation model]**



**Figure 3. Examining the “exit door” or “funnel” hypothesis that certain geographic areas are attractive to whales because most particles exit the Great South Channel there. Red shading indicates regions where high abundances of particles with (left) and without (right) diel vertical migration behavior exit the Great South Channel (particles initially inserted into model circulation at the blue line at 42 °N).**

*[Maps of the Great South Channel showing the western and southern peripheries as areas where particles entering the model domain from the north typically leave the Channel]*



**Figure 4. Retention rate of particles with (red) and without (blue) diel vertical migration behavior (DVM). The model was seeded with particles throughout the Great South Channel. After 6.25 days (150 hours), particles exhibiting no DVM behavior have left the study area, whereas 40% of the particles with DVM behavior are retained.**

*[Graph showing decreasing retention rate over time for both particles with and without DVM behavior, but a much faster rate of decline for particles without DVM behavior]*