Supplement

Text S1: Detailed Methods

Tag Deployment

The female porbeagle *Lamna nasus* was captured on July 6, 2008 using pelagic shark longline gear with J-hooks and fishing approximately 70 nautical miles off the Southern tip of Nova Scotia, on the continental shelf (66.5167° W/42.0833° N). The shark was brought onboard and morphological data (sex, length measurements) were recorded prior to tagging. The tag was attached externally by inserting a nylon umbrella tag anchor into the dorsal musculature of the shark (further details in Campana et al. 2010). While out of the water, the shark was kept moist and had continuous respiration with seawater over its gills by a saltwater hose positioned in the sharks mouth. The sea surface temperature at the time of release was approximately 16°C and the water depth was 86 m. The PAT MK10 tag popped off on the programmed date of April 15, 2009, approximately 300 nautical miles off the coast of Florida, USA in the Sargasso Sea (74.8580°W/28.3070°N). The tag successfully transmitted to the ARGOS system but was subsequently found on a beach in Florida and returned, allowing access to the entire dataset recorded in flash memory. This represented continuous measurements at 10 s intervals from July 6, 2008 to April 14, 2009. Relative to transmitted data, the recovered tag represents the most complete and accurate record that can be obtained from this technology.

Position Estimates

Maximum likelihood (ML) position estimates were generated from light-level readings using the state-space model in GPE3 software from Wildlife Computers (Users Guide v.201805; https://static.wildlifecomputers.com/Location-Processing-UserGuide.pdf). GPE3 uses a diffusion-based movement model to generate a gridded probability surface (0.25 degree resolution) and ML point estimates for the duration of deployment. Ancillary information on bathymetry and real-time SST relative to the depth and temperature information recorded by the tag are incorporated into the estimation process to improve positional accuracy (Aarestrup et al. 2009; Braun et al. 2018). This means that position estimates will never be in a location with water depth shallower than the recorded dive depth (e.g. closer to the coast or on land) and the ML point estimate of position gives the best correspondence between SST and light level, accounting for depth. While the shark was primarily on the continental shelf in the Gulf of Maine and Scotian Shelf (July 6, 2008 until February 26, 2009), the frequency with which it ascended to the surface helped improve positional accuracy from the light-level readings (Francis et al. 2015, Braun et al. 2018). The 95th percentile ellipse around each position estimate tended to encompass a 50-100 km radius. When the shark left the continental shelf and moved into the Gulf Stream (February 26th to April 14th, 2009), the 95th percentile radius tended to be in excess of 120 km because the shark remained at depth.

Oceanographic data

The GLORYS12V1 from Copernicus Marine Environment Monitoring Service (CMEMS) of the EU is an eddy-resolving global ocean product, which assimilates observational data (e.g. satellite sea surface temperature data, satellite altimeter data, temperature and salinity data from ARGO profilers and ship surveys). The GLORYS12V1 reanalysis product has a horizontal resolution of 1/12°, and 50 vertical levels (Fernandez & Lellouche 2018) and is considered to be one of the best available ocean data products. This study made use of the daily mean sea-surface temperature (SST), bottom temperature (BT), and salinity from GLORYS12V1 (http://marine.copernicus.eu/services-portfolio/access-to-products/?option=com_csw&view=details&product_id=GLOBAL_REANALYSIS_PHY_001_030) to investigate the responses of the shark to changing ocean conditions.

Data comparison

Since the GLORYS product only has daily averaged data available, the tag temperature data were averaged for each specified date to create a daily mean temperature profile from the tag. To partially account for the daily horizontal movements of the shark as well as any inaccuracies in estimated position, the GLORYS data were averaged by taking 9 grid points surrounding location estimates of the shark. This means the GLORYS data shown below are the area-averaged profiles, not those specific to the estimated shark positions. In some cases, it was not possible to ensure that the depths represented in the GLORYS data corresponded precisely to those recorded by the tag (middle panel, Figure S1). This was partially due to the fact that the vertical layers defined in GLORYS are at a coarser resolution than the information recorded by the tag.

Here we selected three dates representing P1 (23rd of September, 2008) , P2 (18th of December, 2008) and P3 (28th of March, 2009) to compare temperature profiles over depth from GLORYS and the shark tag (Figure S1). On these three dates, the estimated locations of the shark were 64.425^{o}W/43.475^{o}N, 66.55^{o}W/41.375^{o}N, and 74.925^{o}W/34.25^{o}N, respectively. Although there were slight discrepancies between the data from the two independent sources, the patterns that they show are in agreement. In the top panel of Figure S1, the GLORYS data shows that the mixed layer is in the top 10 m of the water column and then temperature declines consistently with depth until reaching a minimum of ~7.4 ^{o}C at 150 m. The shark data shows a similar trend, with temperature declining until around 150 m. Even though the temperature ranges are slightly different, it is possible to conclude that the shark remained below the mixed layer while diving. In the middle panel of Figure S1, the tag data shows a consistent temperature of ~8.6°C in the top 90 m of the water column, while the GLORYS data indicates that the well mixed layer is in the top 40 m. We think the GLORYS probably underestimates vertical mixing in the cold water season, which leads to this discrepancy. However, the behavior exhibited by the shark is clear; the shark inhabited the well-mixed waters. In the bottom panel of Figure S1, the variations of temperature with depth from these two datasets are similar and demonstrate that the shark largely avoided the top of the water column, which had the highest temperatures. Strong eddying activities of the Gulf Stream challenge any ocean model, which makes it difficult for the model to capture small-scale eddy events.

References

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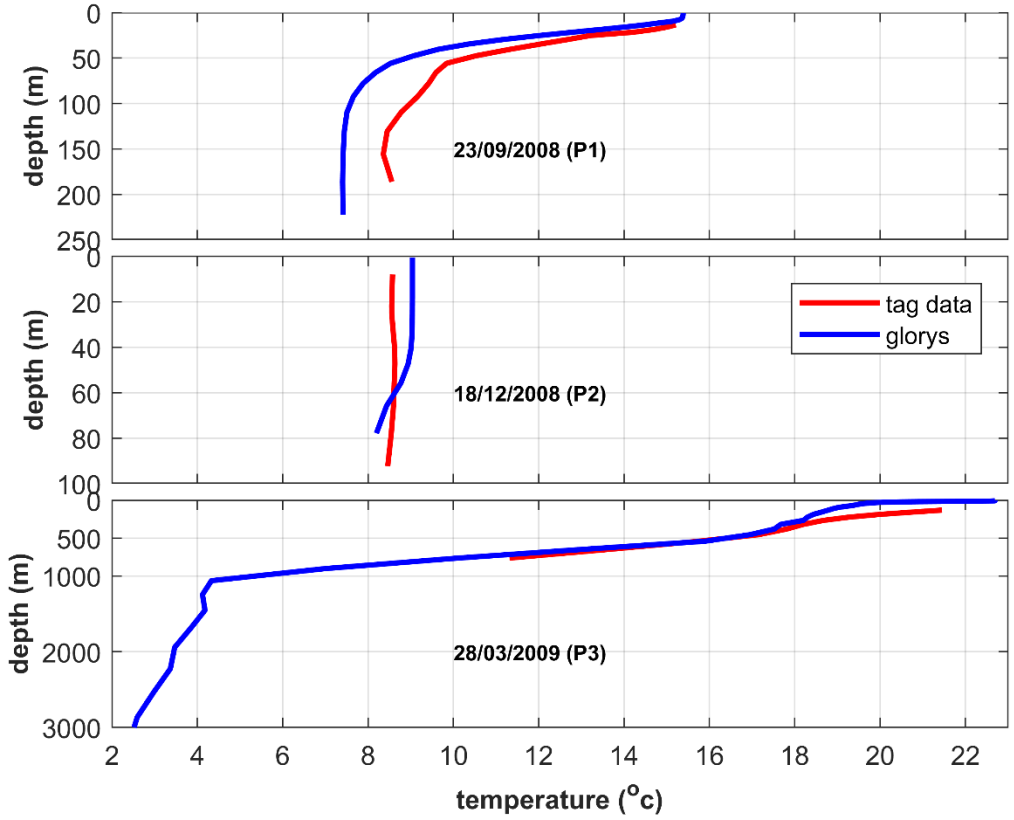

Figure S1. Daily mean profiles of the temperature from tag data (red) and area-averaged GLORYS product (blue) for 23rd of September, 2008 (P1; top panel), 18th of December, 2008 (P2; middle panel) and 28th of March, 2009 (P3; bottom panel). Note the differences in scale on the y-axes.