Humpback whale migration affected by internal wave surfing and mixing?

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In their fascinating paper, Garrigue et al. (2015) [1] document observations of South Pacific humpback whale migration halted near seamounts. The authors suggest seamounts may be used by the whales as navigational cue, resting stop or for additional foraging. In this comment, an oversight is noted in their description: they missed the key physics process and in particular the breaking of large internal waves that may draw the whale's attention.

A century ago, V. Bjerknes reported strange sailing behaviour by mysterious underwater motions. The physical oceanography of these 'internal waves' was first explained by his student Ekman [**2**]. Internal waves are supported by the stable density stratification in the ocean. In contrast with surface waves, they can propagate in three dimensions and attain large amplitudes [**3-5**], even exceeding 100 m in the vertical. Yet, they are hardly detectable at the sea surface.

Because of these particular properties, internal waves can be generated at any underwater topography, including sills, continental slopes and seamounts. Tides and the Earth rotation are important for their generation. After crossing a basin, with multiple reflections at surface and bottom, internal waves may beach at distant slopes. Before doing so, they steepen like surface waves breaking at a shore. However, at the slopes [**5,6**] and over the top [**3,4,7**] of mounts one can observe several tens of meters high slowly rolling breakers: ideal surfing spots of Hawaiian proportions.

With the recent advent of high-resolution moored temperature sensors, details have been revealed of the overturning and turbulence generation by large internal waves over deep-ocean topography

[**5,6**], see also the example in Figure 1. Moreover, as temperature can be used as a proxy for density variations in particular ocean areas, the turbulence is quantified with the same detail. Overall, the level of turbulent mixing over steep topography is found thus energetic that, when extrapolated over all seamounts, it is sufficient to maintain the entire ocean stratified. This confirmed previous estimates for the importance of internal wave induced mechanical mixing for the deep ocean [**8,9**].

The consequences of these physical processes for ocean life are immense. Not only is the density stratification preserved by mixing heat down from the sea surface, whereby the ocean interior is saved from being a stagnant pool of cold water. The turbulent mixing by the wave breaking also supplies food to benthic organisms like cold water corals [**7**] and resuspends materials previously deposited at the sea floor and whirls them up tens of meters high like in a desert dust storm, as was experienced by submarine crew as reported in [**10**]. During the breaking, vertical speeds exceed 0.1 m s^{-1}. Replenished nutrients become available in the water phase for phytoplankton growth, when brought into the photic zone. These attract zooplankton and, in a later phase, whales as well. Although, if I were a young humpback whale, I might just opt for an exciting surf ride…

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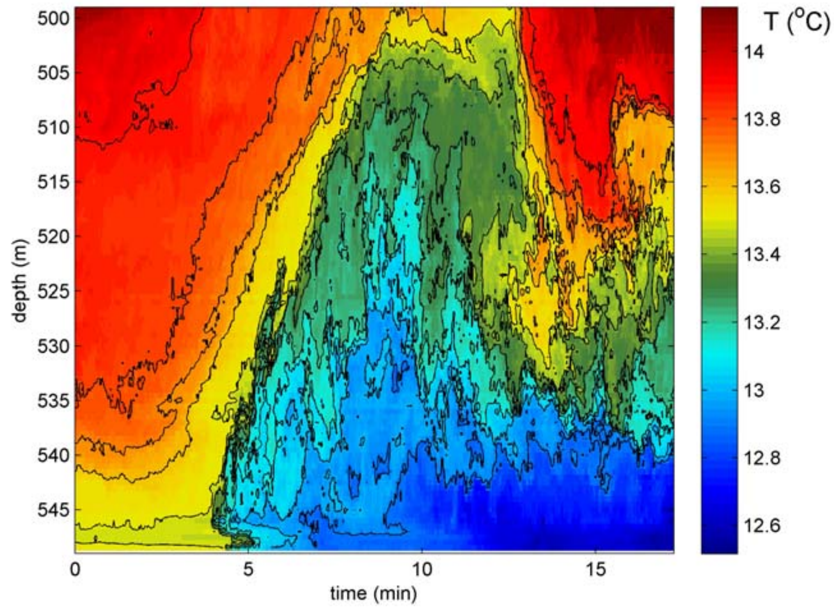

Figure 1. Example of a deep-ocean breaking wave. Sixteen min time-50 m depth range consisting of observations made using 101 independent temperature sensors (one every 0.5 m) sampling at a rate of 1 Hz. Data obtained about 250 m below the top of Great Meteor Seamount, NE Atlantic Ocean, see also [**6**].