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Whale Casting:
Remote mobile streaming
humpback whale vocalizations
to the world

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Over several days in early August 2021, while at sea in Chatham Strait, Southeast Alaska, aboard M/Y Blue Pearl, an online twitch.tv stream broadcast in real-time humpback whale vocalizations monitored via hydrophone. Dozens on mainland North American and around the planet listened in and chatted via the stream. The webcasts demonstrated a proof-of-concept: only relatively inexpensive commercial-off-the-shelf equipment is required for remote mobile streaming at sea. These notes document what was required and make recommendations for higher-quality and larger-scale deployments. One conclusion is that real-time, automated audio documenting whale acoustic behavior is readily accessible and, using the cloud, it can be directly integrated into behavioral databases—information sources that now often focus exclusively on nonreal-time visual-sighting narrative reports and photography.

Keywords: Megaptera novaeangliae, humpback whale, twitch, streaming, hydrophone

I. INTRODUCTION

Humpback whales (*Megaptera Novaeangliae*) are well-known for their extensive vocalizations, with dozens of short social calls believed to be used for group coordination and long, "melodic" songs from males believed to play a role in mate selection and competition [1]. The first broad appreciation of their vocal repertoire stemmed from hydrophone recordings made in the 1960s—captured on Roger Payne's 1970 LP record *Songs of the Humpback Whale* [2]. The LP sold 100,000s of copies and, eventually through increased human awareness, aided in the passage of international bans on whale hunting by the late 1970s.

Humpback whale ancestors—in the order *cetacea*—appeared in the planet's oceans some 56 Myrs ago, having evolved from ungulate land mammals—the ancestors of the modern-day hippopotamus. Their long evolution—exceeding that of human's by an order of magnitude—led to complex social organizations, tool-use (socially-coordinated bubble-net feeding), and hemisphere-spanning acoustic communication [3].

Though they must surface to breathe, their immediate experience largely occurs submerged. During their dives to feed and socially interact, ambient light rapidly dims at depths greater than 50 m. As a result, their world-experience—their *umwelt*—is predominantly acoustic. And, given the preponderance of time under the sea surface, out of sight from observers, they must be studied via hydrophone monitoring of their underwater vocalizations. The resulting technical and logistical challenges add to the mystery of their lives.

Much evidence, if anecdotal, has accumulated that points to their native intelligence. They exhibit advanced intentional behaviors and conscious awareness through their raw intelligence, song generation and sharing [4–6], communication and interactions with their own and other species [7, 8], and empathy (concern for other's well-being) [9].

How does such cognition manifest in humpback whale communicative acoustic interactions? Success in addressing this will both substantially enhance their conservation and advance our appreciation of co-existing, independent intelligent animals on the planet. The research challenge is daunting, however, as the principal observations come from hydrophone recordings occasionally supplemented with surface visual and acoustic observations made from ocean vessels in remote locations, sometimes far at sea. The animals are too large for study in captivity—a mode of research now deprecated for even smaller marine mammals.

Technological advances promise much improved understanding, though. Recently, for example, digital video-sound recording tags are being actively attached to swimming whales, providing acoustic, visual, and environmental data that can reveal new aspects of their undersea behaviors over tens of minutes to hours [10]. Recent, handsomely-funded efforts promise to deploy such technologies on a wholly new level of large-scale multi-modal monitoring and automated detection and data analysis [11].

One goal in all this is to infer the meaning content of humpback vocalizations. However the data is obtained, one approach to probe meaning is to correlate recorded

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vocalizations with observed social behavior. What kinds of social interaction might provide workable contexts in which to extract the semantics of vocalizations?

Humpbacks, especially in Southeast Alaska, are notable for their tool-use—socially-coordinated bubble-net feeding. In relatively small groups (half dozen to a dozen) they coordinate to improve their feeding. And, this is done, it appears, through much vocalization between group members as several in the group construct a cylindrical curtain of bubbles that localizes the prey (krill or herring). This culminates in a group member vocalizing a "feeding call" that initiates the lunge feeding of conspecifics waiting below who swim to the surface with mouths wide open to engulf a column of food. In this, humpbacks are an excellent study animal for correlating behavior and the function of social calls and so for extracting call semantics.

What experimental design and protocols support such studies? The challenge is to collect sufficient data of the animals' trajectories, vocalizations, and visual behavioral observations so that vocalizations can be placed within a context of functional behavior. To afford the appropriate statistical error analysis, the key here is sufficiency: long-term longitudinal data automatically collected over a spatial range large enough to appropriately cover humpback territory. The result would be an extremely large database. Initially, this would likely tax modern capabilities. Current trends, though, indicate that within several years automated analysis would be quite workable.

One overall strategy to achieve this is to deploy a whale "observatory" in grounds that are regularly visited. The observatory would consist of extensive sound recording and sound generating transducers along with autonomous airborne and undersea drones to visually monitor behaviors. The data flow to and from the transducers would be transmitted via high-speed Wifi radio links to land-based base-stations. The latter would then be connected via satellite link to the Internet.

This vision led to the 2019 proposal for SEAWHO—the SouthEast Alaska WHale Observatory; cf. the presentation N Whales from M Hydrophones. It should be noted that SEAWHO is, at present, modest compared to more recent efforts now ramping up. For example, there is the large and well-funded Project CETI that will study sperm whales in the Atlantic [11]. There is also interest in whale sanctuaries that provide safe environments for previously-captive marine mammals. The Whale Sanctuary Project comes immediately to mind.

The following addresses only a part of the technology SEAWHO requires: Internet streaming of humpback vocal behaviors from remote locations at sea. It starts describing an August 2021 voyage that implemented a very low-cost system. It then reviews issues related to the physics of the whale's water world and sound propagation. It recounts the technical details of live streaming and doing so remotely while at sea. Finally, it concludes listing resources and proposing directions for future efforts that take advantage of rapidly-advancing technologies to move closer to SEAWHO.

Note that real-time undersea sound is already available on the web. For some time, as an example, the Monterey Bay Aquarium Research Institute has supported a live link to acoustic signals deep in Monterey Bay, California, detected by an anchored hydrophone. The following report also concerns a live ocean-acoustic link, but with complementary motivations: the system is mobile, easily portable, deployed remotely, and inexpensive. This makes acoustic monitoring of whale vocalization widely available. In the context of open science, this could greatly accelerate our learning much more (and more quickly) about the lives of whales; at least, those that are vocal.

II. VOYAGE

The voyage departed Aurora Harbor, Juneau, Alaska, on 6 August 2021, on M/Y Blue Pearl, a Fleming 65 raised pilothouse motoryacht captained by Don and Denise Bermant. The voyage headed northwest to meet Chatham Strait and then headed south, anchoring in Funter Bay, Admiralty Island, (6 August) and at Hoonah (7 August) and Tenakee Springs (8 August) on Chicagoff Island. Few humpback whales were seen. From that point forward, however, motoring south through Chatham Strait the M/Y Blue Pearl encountered many, often performing their well-known socially-coordinated bubble-net feeding.

Due to the high number of whales actively feeding, the voyage spent several days on the western coast of Admiralty Island, first anchored at Killisnoo Island and then docked in Angoon Harbor. Day trips were taken out into Chatham Strait to observe the humpbacks, documenting their behaviors visually via vessel photography and aerial photography (drone), along with acoustically monitoring via hydrophone.

Vocalizations from the whale groups were particularly notable during bubble-net feeding: many minutes of a cacophony of diverse animal calls, apparently from many individuals, culminating in a distinctive frequency-upsweep "feeding call", seemingly from a single individual. Within just a minute or two of that call the feeding whales, that had been waiting below the bubble-net, breached the surface, mouths wide open to engulf the prey. Taking advantage of this activity, the voyage cruised the waters off Angoon over several days: Tuesday-Wednesday 9-11 August.

Having set up and tested the computing and recording equipment and software (described shortly), we streamed the underwater sounds picked up by hydrophone on August 10th and on August 11th. See Fig. 1 for the locations, at which the smartphone had line-of-sight connection to cell towers in the town of Angoon. Adapting to variable cell-signal quality, we streamed for several hours each day using twitch.tv on channel DrJPChaos.

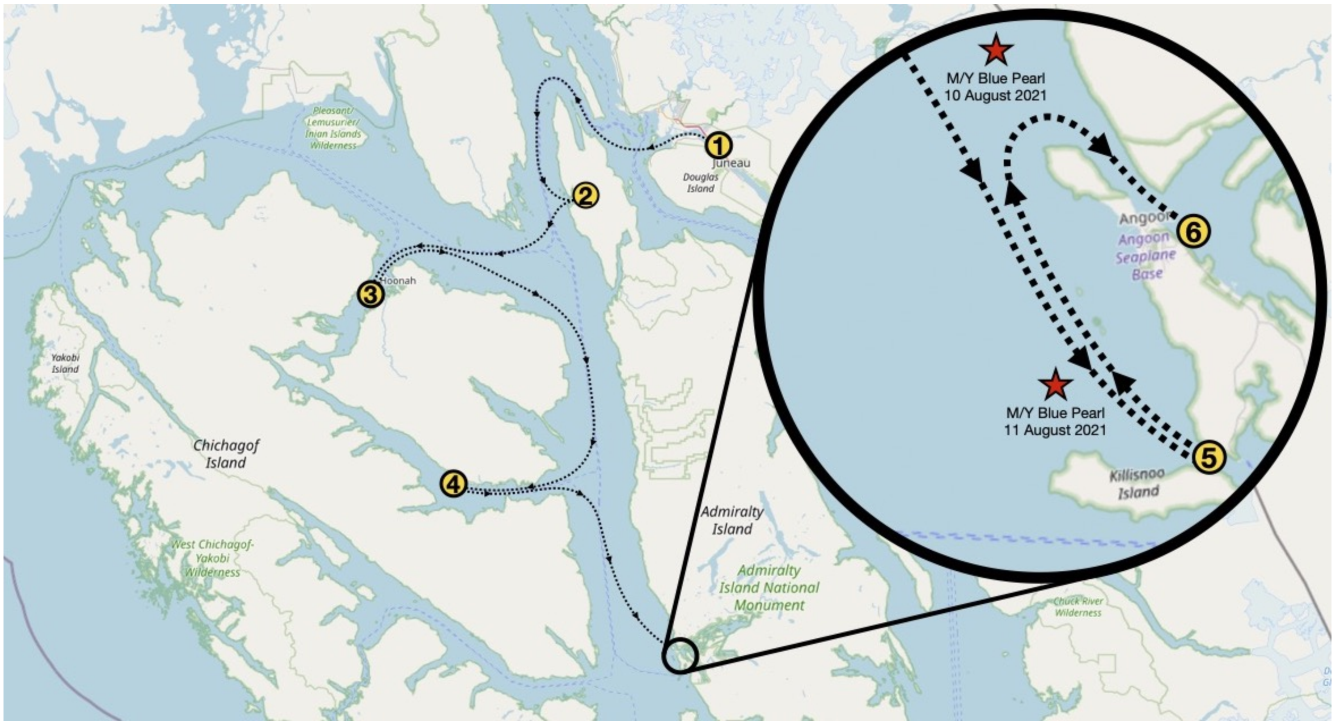

FIG. 1: Streaming humpback whale vocalizations in Chatham Strait, anchored off Angoon, Alaska. The red stars denote the location of M/Y Blue Pearl on the two successive streaming days, 10 and 11 August 2021. OpenStreetMap CC BY-SA 2.0.

III. OCEAN ACOUSTIPHYSICS

Sound propagation in water differs markedly and in key ways from propagation in air. Given human's innate sense and experience of sound in air, the differences need to be taken into account when interpreting the signals that hydrophones pick up.

First, the speed of sound in water is five times that in air: $1,500$ meters per second compared to 340 meters per second, respectively, owing to the water medium being markedly denser than air. Practically, this leads to, for example, echos as sounds bounce off the seabed. Since density increases with depth, water depth is important and, of course, changes when changing anchorages. This also means that sounds from distant sources can be detected. For example, one is often surprised by the degree to which vessel noise is heard and in some cases dominates the undersea soundscape, even if vessels are not in sight. Commercial cruise liners are notable contributors to ocean noise given their immense displacement (key to waves generated by their passing) and massive engines.

Second, the precise nature of propagation in water is complicated by the fact that sound velocity increases with water pressure (and so depth) and decreases with water temperature and salinity.

Third, unlike sound in air, underwater sound at different frequencies propagates at different speeds—this is referred to as frequency dispersion. Thus, a distinct sound pulse detected at some distance loses its sharpness and blurs out over a time period much longer than the original pulse.

Taken altogether, the effects of these dependencies have on propagation are unlike those of our experience of sound in air. They often result in unusual and counterintuitive sound phenomena. The physics underlying these effects are nicely recounted in Ref. [12].

For example, the dependencies lead to a fascinating phenomenon of extremely long-ranged detection of sound signals in the ocean. This is the *Sofar channel*. Due to the competing effects of pressure and temperature on sound speed, there is a horizontal "channel" that conducts sounds like a waveguide: signals within a certain frequency band bounce between a shallow "ceiling" (perhaps 10s of meters in depth) and a "floor" (100s meters or more in depth). The net result is that sound signals in the Sofar channel can propagate very long distances—easily tens of kilometers or, depending on conditions, to hundreds or thousands of kilometers.

Given the undersea is their environment and given their evolution over millions of years, whales have accounted for and take advantage of these ocean-acoustic properties. These features affect what they can perceive, how they generate sound underwater, and how they communicate and socialize. Undoubtedly, many aspects of their vocalizations are naturally adapted.

Finally, these properties affect the acoustic signals

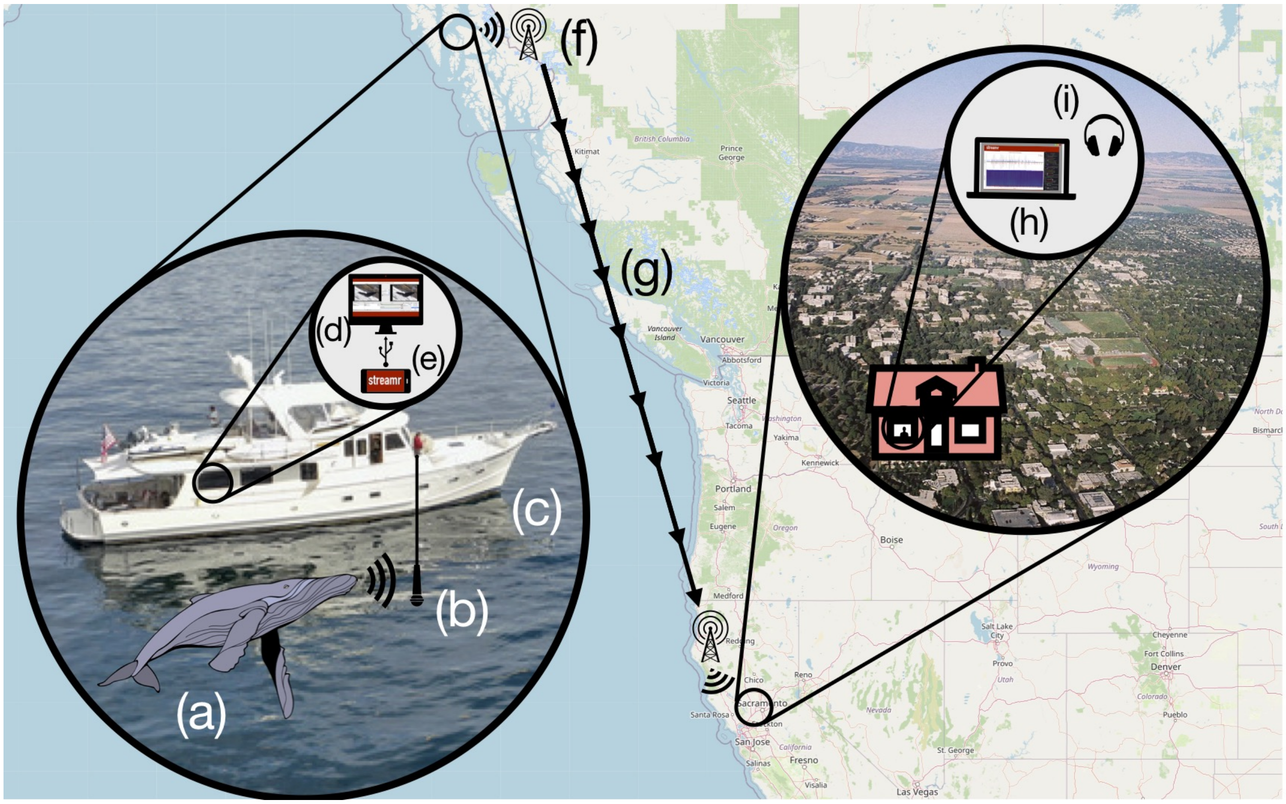

FIG. 2: Remote mobile whale streaming: Humpback whales (*Megaptera Novaeangliae*) (a) vocalizing and hydrophone (CT54, Cetacean Research Technologies) (b) submerged $15' - 30'$ beneath vessel (M/Y Blue Pearl, Vancouver, Canada) (c) converts underwater acoustic waves to electronic signal linked via secured cable to MacBook Pro 15" computer (d) on the Blue Pearl's flying bridge that recorded the hydrophone signal. The computer (d) was tethered to an iPhone 5s smartphone (e) connected line-of-sight to a land-based cell tower (f) on the Internet (g). In this way, the system webcast the humpback vocalization twitch stream through the cloud to a laptop computer (h) somewhere in the world that is being listened to on headphones (i).

one records via a hydrophone and so, too, how one interprets what one is hearing.

IV. DESIGN FOR WHALECASTING

To capture humpback vocalizations in real-time we deployed a "dip" hydrophone (Model C54, Cetacean Research Technology, Seattle, WA) suspended at a depth of approximately $5 - 10$ m ($15' - 30'$) below the vessel. On occasion, though, strong local currents varied this depth considerably due to the wind-blown vessel dragging the hydrophone. Note that the currents in Southeast Alaska are powerful—largely driven by substantial 6 m ($15' - 20'$) tides and constrained by the complex seabed and island shoreline topography.

Via physically-secured, long audio cables, the hydrophone signal was recorded by a laptop (Macintosh MacBook Pro 15") on the M/Y Blue Pearl's flying bridge. This above-water-line vantage point was extremely helpful in sighting and following whales. For vessel and equipment safety, the hydrophone was never deployed while the vessel's engine was operating. Recording sample rates were set at 44.1 kHz with 16 bits per sample.

To prepare, edit, and monitor audio files we used both Audacity (v. 3.0.2) and Raven Pro (v. 1.6). They provide waveform and spectrogram views of audio signals, but each has complementary user interfaces that are convenient in different real-time operation settings.

Figure 2 presents a schematic of the overall setup.. High quality and sound-isolating headphones were essential, given ambient sounds and often subtle ocean sounds coming in from the hydrophone.

For video recording and live streaming we used open source software Open Broadcast Software OBS Studio 27.0.1. It merges images and audio and video signals and makes the connection to the twitch streaming engine in the cloud. Figure 3 presents a screenshot of OBS Studio operating on the laptop.

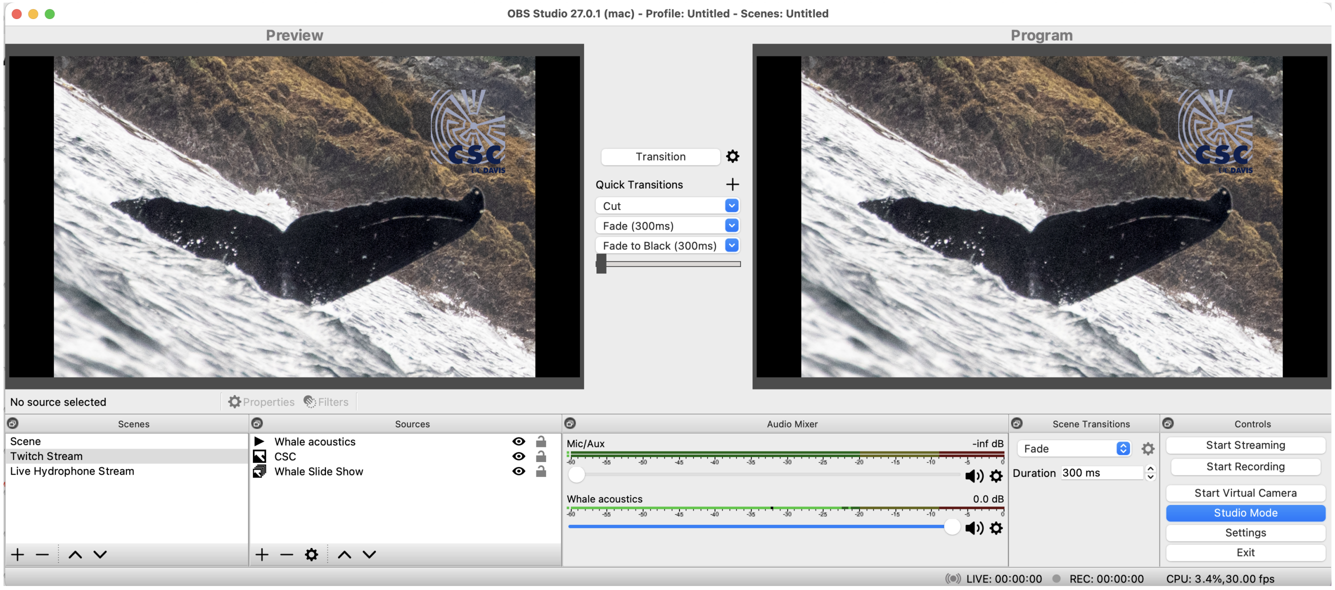

FIG. 3: OBS Studio: Screenshot of running the twitch stream on board M/Y Blue Pearl anchored off Angoon, Alaska. The left window (Preview) allows the user to see and compose the stream components: live or recorded video, labels, images, and the like. Meanwhile, the live stream appears in the right window (Program). Below the two windows, the audio mixer shows the current status of one or several audio clips, either prerecorded or real-time. The available stream components are listed to the left. Due to limited bandwidth for streaming, only static images were used as visual background, not live video.

V. CLOUD ACCESS

A medium- to high-speed link to the Internet was essential for access to twitch.com and smooth streaming. This was helped in large measure by finding a line-of-sight connection to a land-based cell tower in Angoon. This limited the flexibility of choosing our anchorages. This combined with the humpback's rapid movements—at the surface they often cruise around 10 kph—complicated planning and determining when to webcast.

There is good online documentation for configuring streaming parameters and using twitch itself and for setting up and running OBS Studio (OBS Studio Quickstart). Needless to say, configuring and testing the software and online performance were extensively explored prior to the voyage. This was key to establishing a number features necessary for smooth streaming and for minimizing dropping and restarting the connection.

For the functionality reported here the free version of twitch.com was adequate; that is, no subscription was required. The initial impression of twitch, though, is dominated by its strong push to monetize one's channel. Fortunately, this and its heavy merchandising can be avoided once a channel is configured and running. Twitch's content has a bias towards gaming and a very young demographic.

The DrJPChaos channel was featured on our research websites: Voices of the Deep and World Wide Whale. The whale casting page is hosted on the latter.

VI. CONCLUSION

Times and technology have changed immeasurably since Roger Payne's LP recording. The challenge now is how to actively shape our future understanding of whale communication in the wild. The results suggest a coming era of citizen marine social science. Whale casting—remote mobile streaming of whale vocalizations—gives a practical and relatively inexpensive path to it.

This report outlined a very modest, but accessible implementation using inexpensive commercial-of-the-shelf (COTS) hardware and software. The net functionality allowed for real-time streaming of humpback whale vocalizations from remote locations on a mobile at-sea platform. The main constraint, as noted, was the need to find in these locations line-of-sight connections to cell towers. Nonetheless, the report outlined a path that moves us closer to SEAWHO and improved appreciation of the lives of humpback whales.

The successful proof-of-concept suggests substantial improvements. So, one can look forward to future implementations that provide higher quality and multichannel sound and video streaming and larger-scale implementations that support multiple hydrophones and video monitoring and real-time monitoring, recording, and analysis in the cloud.

Perhaps most critical to achieving these is the recent emergence of high-speed mobile links to satellite Internet. For example, In-Motion Starlink recently arrived to support mobile webcasting, which requires high-speed, low-latency internet access. Notably, this just became an option for the tests recounted here as southeast Alaska become an area rated for “high capacity” coverage.

Specifically, Flat High Performance Starlink promises to provide high-speed, low-latency internet communication while in-motion. Given the new system’s wide field of view and enhanced GPS, it connects to broader range of satellites for consistent connectivity while moving. There are as yet no reports of shipboard deployments, though. Given the antenna’s design, deployments will likely require calm seas or, more elaborately, motion compensation to stabilize antenna and so reception.

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