

Sound Travels Far Because It Does Not Travel Straight

— the speed of sound in the sea has a minimum of **1482.7386** m/s at **1000** m, bracketed by **1521.5200** at the surface and **1530.7386** at the bottom — a ray leaving at **10** degrees turns at **2429.6** m and never reaches the seabed — make the water isothermal and the trapping disappears — [Paper 395]

Yuuki YAMAGISHI (山岸 勇輝)

Yamagishi Complexity Torus Lab, Japan

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— *From thinking to syncing.* —

Abstract

One would think sound fails to travel far because it is attenuated along the way. This paper shows that bending is not a loss but the mechanism of trapping——travel straight and it is lost sooner. No new theorem or law is claimed. First, the speed of sound is set by both temperature and depth, and the two act in opposite senses (Section 1). Second, so it reaches a minimum of **1482.7386 m/s at a depth of **1000** m (Section 2). Third, and this is the core of the paper. The speed is higher on both sides of that minimum, so rays bend toward it and are trapped (Section 3). Fourth, a ray leaving at **10** degrees turns at **2429.6** m and never reaches the **4000** m seabed (Section 3). Fifth, make the water isothermal and the speed rises monotonically, and the trapping disappears (Section 4). Sixth, the separator is whether the sound-speed profile has a minimum or is monotone (Section 5).**

Scope of this paper (scope note): No new theorem or law is claimed—the sound-speed equation for sea water, the SOFAR channel and ray bending by Snell’s law are all known in ocean acoustics. No acoustic instrument is designed—sonar and underwater communication are not the subject. Only the profile and the turning points are examined. Attenuation is not treated—losses by absorption and scattering are not the subject. Only geometrical acoustics. No claim is made about a real sea—the temperature profile is a model; it varies greatly with season and latitude. Only sameness of shape is asserted. Wave effects are not treated—normal-mode theory and diffraction are not the subject. Only the ray approximation is used. No range is claimed—how many kilometres the sound reaches is set by attenuation and noise, outside this paper. Relation to earlier papers: Paper 384 showed that the frequency term of free-space loss comes from the receiving side—here what looks like a loss is a trapping. Paper 393 showed that a sum of two monotone terms has an interior minimum—here too the sound speed has an interior minimum. Paper 390 showed that the cap is decided by the heading—here the range is decided by the launch angle. Paper 300 showed that same-root and different-root can be decided—the temperature effect and the pressure effect are different-root by that criterion. What is added is putting numbers on the sound speed at nine depths, locating the minimum, obtaining turning depths for two launch angles, showing by a control that an isothermal ocean loses the trapping, and placing the separator at “is there a minimum”.

1. Notation and the Question

Setting: write the speed of sound in sea water as a function of temperature T , depth z and salinity S .

$$c = 1449.2 + 4.6T - 0.055T^2 + 0.00029T^3 + (1.34 - 0.010T)(S - 35) + 0.016z$$

Take $S = 35$, with the temperature falling linearly from 20 degrees at the surface to 4 degrees at 1000 m and constant at 4 below.

Observation 1.1

the temperature term is positive and so is the depth term. Raise either and the speed rises—but in the sea, going deeper lowers the temperature.

Observation 1.2

so depth acts twice. Directly as $+0.016z$, and negatively through the temperature—temperature wins in the shallows, pressure wins in the deep.

Observation 1.3

where the winner changes, the speed has a minimum. The shape of Paper 393—a sum of two monotone effects with an interior extremum.

Question: why does sound carry thousands of kilometres through the sea?

2. The Minimum Sits at a Depth of 1000 m

Computation 2.1: temperature and sound speed against depth (computed in this paper).

Depth [m]	Temperature [deg]	Sound speed [m/s]
0	20.00	1521.5200
200	16.80	1515.5319
500	12.00	1504.9811
800	7.20	1492.3770
1000	4.00	1482.7386
1500	4.00	1490.7386
2000	4.00	1498.7386
3000	4.00	1514.7386
4000	4.00	1530.7386

Observation 2.2

the minimum is bracketed from above and below. 1521.5200 at the surface, 1530.7386 at the bottom, 1482.7386 between—a valley.

Observation 2.3

the valley walls differ in height. 38.78 m/s to the surface, 48.00 m/s to the bottom——asymmetric, but closed on both sides.

Observation 2.4

below 1000 m the temperature does not change. Constant at 4 degrees——everything beyond that is the pressure term $0.016z$.

Observation 2.5

above 1000 m the temperature term wins. From 20 degrees to 4——the fall it produces exceeds the 16 m/s from $0.016z$.

3. A Ray at Ten Degrees Never Reaches the Seabed

Computation 3.1: turning points by Snell's law (computed in this paper). A ray leaving the axis at angle θ_0 turns where the speed reaches $c_{\min}/\cos\theta_0$.

Launch angle [deg]	Speed at turning [m/s]	Turning depth [m]
5	1488.4024	1354.0
10	1505.6122	2429.6
(seabed)	1530.7386	4000

Observation 3.2

this is the core of the paper. Neither ray reaches the seabed——they turn at 1354.0 m and 2429.6 m and never touch 4000 m.

Observation 3.3

not touching means not being lost.Striking the bottom costs scattering and absorption——bending avoids that loss.

Observation 3.4

a steeper ray dives deeper before turning.1354.0 m at 5 degrees, 2429.6 m at 10——past some angle the ray reaches the bottom and the trapping fails.

Observation 3.5

the same happens upward.The valley is not symmetric but both sides are higher——surface reflection is avoided too.

Observation 3.6

the shape is that of Paper 384.There a “loss” was not a loss——here “bending” is not a loss. In both, a word that sounds unfavourable is doing something else.

4. Make the Water Isothermal and the Trapping Disappears

Computation 4.1: control (computed in this paper). Fix the temperature at 4 degrees at all depths.

Observation 4.2

the sound speed then rises monotonically with depth.Only 0.016z remains——the minimum is gone.

Observation 4.3

with no minimum, rays keep bending downward.No valley——they strike the bottom and are lost.

Observation 4.4

so the trapping is made by the temperature profile. Pressure alone is not enough—the Sun warming the surface is what builds the deep sound channel.

Observation 4.5

they are different-root by the criterion of Paper 300. The temperature effect is set by sunlight and mixing, the pressure effect by gravity—one quantity, the sound speed, carries two different roots.

Observation 4.6

at high latitudes the valley rises to the surface. The upper layer is cold—the depth of the sound channel varies with latitude.

5. Separator: Does the Profile Have a Minimum, or Is It Monotone

Observation 5.1

separator—is there a valley in the sound speed with depth, or none.

Profile	Rays	Strike a boundary	Range
Has a minimum	bend toward it	no	long
Monotone (isothermal)	bend one way	yes	short

Observation 5.2

the difference comes from geometry, not attenuation. The absorption coefficient is the same—all that differs is whether a boundary is struck.

Observation 5.3

so “it carries well” is not a property of the medium. The same sea water—the shape of the profile decides.

Observation 5.4

the separator can be moved. Change the surface temperature with the season and both the depth of the valley and the strength of the trapping move—the same sea transmits differently in different seasons.

Observation 5.5

to be honest—both 1482.7386 m/s and 2429.6 m come from a model with a linear temperature profile. Real profiles are more complicated—what does not move is that temperature and pressure act in opposite senses, and that this puts a minimum at an interior depth.

Observation 5.6

one last thing—straight is the shortest path and not the best one. Sound that travels straight strikes a boundary and is lost—only the sound that bends survives to a distance.

6. Roll Call and Closing

1. Temperature and pressure act oppositely (Observation 1.2): **depth acts twice.**
2. Minimum 1482.7386 m/s at 1000 m (Computation 2.1): **a valley.**
3. Surface 1521.5200, bottom 1530.7386 (Computation 2.1): **bracketed both sides.**
4. Asymmetric walls (Observation 2.3): **38.78 and 48.00 m/s.**
5. Five degrees turns at 1354.0 m (Computation 3.1): **it never reaches the bottom.**
6. Ten degrees turns at 2429.6 m (Computation 3.1): **nor does this one.**
7. Steeper dives deeper (Observation 3.4): **past some angle it fails.**
8. Isothermal is monotone (Observation 4.2): **the trapping disappears.**
9. The temperature profile builds the channel (Observation 4.4): **pressure alone is not enough.**

10. Straight is not best (Observation 5.6): only the bent sound survives.

Closing: one would think sound fails to travel far because it is attenuated along the way—but in the sea, bending is not a loss; it is the mechanism of trapping. The speed of sound rises with both temperature and depth, and in the sea going deeper lowers the temperature—so depth acts twice: temperature wins in the shallows and the pressure term $+0.016z$ wins in the deep. Where the winner changes, the speed has a minimum. As in Paper 393, a sum of two monotone effects has an interior extremum. The minimum is **1482.7386** m/s at a depth of 1000 m—a valley bracketed by 1521.5200 m/s at the surface and 1530.7386 m/s at the 4000 m bottom, with walls of 38.78 m/s and 48.00 m/s—asymmetric, but closed on both sides. Below 1000 m the temperature is constant at 4 degrees, so everything beyond is the pressure term. And rays bend toward the minimum and never reach the boundaries—a ray leaving the axis at θ_0 turns where the speed reaches $c_{\min}/\cos\theta_0$, so 5 degrees turns at **1354.0** m and 10 degrees at **2429.6** m, neither touching the 4000 m seabed. Not touching means not being lost: striking the bottom would cost scattering and absorption, and bending avoids that. A steeper ray dives deeper, and past some angle it reaches the bottom and the trapping fails. As in Paper 384, where a “loss” was not a loss, a word that sounds unfavourable is doing something else. Make the water isothermal and the trapping disappears—fix the temperature at 4 degrees everywhere and only $0.016z$ remains, so the speed rises monotonically and the minimum is gone. With no minimum, rays keep bending downward, strike the bottom and are lost. So the trapping is made by the temperature profile, not by pressure—the Sun warming the surface is what builds the deep sound channel. By the criterion of Paper 300 they are different-root: sunlight and mixing on one side, gravity on the other. One thing does the separating—is there a valley in the sound speed with depth, or none. The difference comes from geometry, not attenuation: the absorption coefficient is the same and all that differs is whether a boundary is struck. So “it carries well” is not a property of the medium—the same sea water, with the shape of the profile deciding. Change the surface temperature with the season and the same sea transmits differently. To be honest—both 1482.7386 m/s and 2429.6 m come from a model with a linear temperature profile, and real profiles are more complicated. What does not move is that temperature and pressure act in opposite senses, and that this puts a minimum at an interior depth. One last thing—straight is the shortest path and not the best one. Sound that travels straight strikes a boundary and is lost. Only the sound that bends survives to a distance.

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Yuuki YAMAGISHI (山岸 勇輝)

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