On the Possible Influence of the Material Medium on Local Time:

A Methodological Critique of the Vacuum-Isolated Clock Experiment, the Unresolved GPS Correction Problem, and a Proposal for a Three-Depth Empirical Investigation

Miguel Ángel Percudani
Independent Researcher, Puan, Buenos Aires, Argentina
miguel_percudani@yahoo.com.ar

ORCID: 0009-0007-1748-3212

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Abstract

We examine the standard interpretation of the submerged atomic clock experiment —in which a clock at depth and one at the surface are compared and found to differ as predicted by General Relativity (GR)— and argue that this result does not constitute a proof that the material environment has no influence on local time. Both clocks confine their timing photons to ultra-high vacuum chambers, thereby excluding the surrounding medium from the measurement. We note that the Global Positioning System requires continuous clock corrections beyond those expected from pre-launch relativistic calibration, suggesting that environmental factors may play a role in timekeeping that is not yet fully understood. To investigate whether the medium itself contributes to time dilation beyond GR, we propose a three-depth experiment in which the timing photon is deliberately passed through the water column, and we provide quantitative estimates of the expected signal magnitude under a phenomenological saturation model. The proposed measurement is falsifiable with current optical clock technology and does not require new hardware. We make no claim as to the underlying physical mechanism; the experiment is designed to determine whether an unmodeled residual exists at all.

1 Introduction

The question of whether the material environment influences the rate at which time flows locally has received little direct experimental attention. The prevailing view —that only gravity, as described by General Relativity (GR), affects time dilation— draws support from experiments in which atomic clocks are placed at different ocean depths and their timekeeping compared. The measured difference matches the GR prediction for the gravitational potential difference, and this is widely taken as evidence that the surrounding medium is irrelevant.

We suggest that this conclusion may be premature. The experiment, as currently designed, does not test the medium. It tests GR in a vacuum-isolated system.

2 The Submerged Clock: A Methodological Observation

2.1 The Architecture of an Atomic Clock

Atomic clocks achieve their precision by measuring the frequency of photons required to induce electronic transitions in isolated atoms. To minimize perturbations, the atoms and the interrogating laser are housed in an **ultra-high vacuum (UHV) chamber** at pressures below 10^{-10} mbar.

The timing photon does not traverse the ocean. It travels through an artificial vacuum inside the chamber. The atoms are not in contact with seawater. The clock is, by design, an **environmentally isolated system**.

2.2 An Instructive Analogy

Consider the following hypothetical:

> *A thermometer, encased in a perfectly insulating Dewar flask, is submerged at 3000 meters. A second, identically insulated thermometer is placed at the surface. Both read 23.0°C — the laboratory temperature where they were calibrated. The experimenter concludes that the deep ocean has no temperature.*

The reader will immediately recognize the flaw. The instrument was designed to exclude the very quantity it purports to measure. The experiment reveals nothing about the ocean; it reveals only that the insulation is effective.

We suggest that the submerged atomic clock experiment, as currently interpreted, may suffer from a similar limitation. The agreement between the vacuum-isolated clock and GR demonstrates that **GR correctly describes isolated systems in vacuum**. It does not demonstrate that a photon traversing seawater would experience no additional delay beyond GR.

2.3 What Remains Untested

GR predicts:

$$\Delta t_{\mathrm{GR}} = t_{\mathrm{obs}} \cdot \sqrt{1 - \frac{2GM}{c^2}\left(\frac{1}{r_{\mathrm{deep}}} - \frac{1}{r_{\mathrm{surface}}}\right)} \tag{1}$$

This is a prediction about the metric tensor $g_{\mu\nu}$, determined by the mass-energy distribution. The metric is not sensitive to the refractive index, density, or viscosity of the intervening medium. Whether the medium itself contributes an additional delay —distinct from both GR and classical refraction— is a separate question, and one that the vacuum-isolated experiment does not address.

3 The GPS Anomaly: An Open Question

3.1 Pre-Launch Calibration

GPS satellites carry atomic clocks that are intentionally detuned before launch to compensate for the net relativistic effect:

- Special Relativity (orbital velocity ~3.9 km/s): ~ -7 μs/day.
- General Relativity (altitude ~20,200 km): $\sim +45$ μs/day.
- Net correction applied before launch: $+38$ μs/day.

3.2 Operational Reality

If GR accounted for all timekeeping effects, this single pre-launch calibration would suffice. In practice, **GPS clocks require continuous correction**. Master Control Stations upload updated clock parameters multiple times per day. The residual fluctuations correlate with:

- Ionospheric electron density (solar activity, diurnal cycles).

- Tropospheric water vapor content (weather, humidity).
- Satellite thermal variations.

3.3 Two Interpretations

The standard model treats these as "signal propagation errors" —well-understood electromagnetic effects that delay the radio signal but do not affect the clock itself. They are modeled empirically and subtracted.

An alternative perspective notes that the *need* for such continuous correction, despite exhaustive pre-launch relativistic calibration, indicates that **timekeeping in real environments involves factors beyond those captured by GR alone**. Whether these factors are exclusively electromagnetic (as the standard model holds) or include additional physics remains an open empirical question.

We do not claim that GPS proves the existence of new physics. We observe only that the system's behavior is **consistent with** the hypothesis that environmental parameters affect timekeeping in ways not fully captured by current models. This warrants direct experimental investigation.

4 Proposal: A Three-Depth Experiment

4.1 Motivation

The submerged clock experiment, as noted, isolates the photon from the medium. We propose a simple modification: **allow the timing photon to traverse the water column**. If the medium contributes nothing beyond GR and classical refraction, the total delay between clocks at different depths should be fully accounted for by:

$$\Delta t_{\text{total}} = \Delta t_{\text{GR}} + \Delta t_{\text{refraction}} \tag{2}$$

If a residual remains after subtracting both components, it would indicate an unmodeled effect.

4.2 Experimental Design

1. **Clock A (Surface):** Reference clock at sea level (0 m).
2. **Clock B (Mid-depth):** At $d_1 = 1000$ m. Timing signal transmitted through water to surface.
3. **Clock C (Deep):** At $d_2 = 3000$ m. Timing signal transmitted through longer water column.

The key departure from existing experiments is that the timing photons **explicitly traverse the water medium**.

4.3 Phenomenological Model for an Unexplained Residual

We do not assert a specific physical mechanism for any residual that may be found. However, to provide a quantitative benchmark for the experiment's sensitivity, we adopt a phenomenological model motivated by the UAT framework [4, 5]. This model proposes that if the medium exerts a "viscous" resistance to the flow of information, the resulting delay should not grow linearly with density but should saturate —otherwise it would already have been detected in submarine fiber optic networks.

The saturation-corrected estimate is:

$$\Delta t_{\text{residual}} = \kappa \cdot L \cdot \left(1 - e^{-\kappa_{\text{crit}}/\rho}\right) \cdot k_{\text{early}} \tag{3}$$

where:

- $\kappa = 2.791 \times 10^{-10}$ s/m (empirically motivated by atmospheric water vapor analysis).
- $\kappa_{\text{crit}} = 4.978$ (saturation threshold parameter).
- $k_{\text{early}} = 0.967$ (dimensionless damping parameter).
- $\rho =$ medium density (kg/m^3).
- $L = 2 \times$ depth (round-trip optical path).

We emphasize that these parameters are **not fitted to the experiment** —they are derived from independent considerations within the UAT framework— and that the model serves only as a **benchmark for the expected sensitivity** of the proposed measurement.

4.4 Estimated Signal Magnitudes

Table 1 presents the calculated delays, assuming 1 hour of observation per depth. The full calculation is provided in the supplementary Python script.

Table 1: Estimated signal components at each depth. The "residual" row corresponds to the saturation model and serves as a sensitivity benchmark, not a claimed prediction of a specific physical effect.

Component	**1000 m**	**3000 m**	**Differential (C − B)**
GR dilation	0.39 ns	1.18 ns	0.79 ns (cancels in test)
Classical refraction	2.27 μs	6.80 μs	4.53 μs (modelable)
Residual (saturation model)	2.61 ns	7.77 ns	5.16 ns

4.5 Isolating Any Unexplained Residual

The differential measurement is constructed as:

$$R = (\Delta t_{A-C} - \Delta t_{A-B}) - [\Delta t_{\text{GR}}(d_2) - \Delta t_{\text{GR}}(d_1)] - [\Delta t_{\text{ref}}(d_2) - \Delta t_{\text{ref}}(d_1)] \tag{4}$$

The GR term is known analytically. The refractive term is modelable with established optical oceanography. Any non-zero R would indicate an effect beyond current models.

With an optical clock precision of $\sim 3.6 \times 10^{-15}$ s over 1 hour, a residual of ~ 5 ns —if present— would be detectable with an SNR of $\sim 10^6$. The measurement is therefore **feasible with existing technology**, regardless of whether a residual actually exists.

4.6 Interpretation of Possible Outcomes

- $R = 0$ **within error:** The standard interpretation is supported. An upper bound is placed on any medium-induced delay. The parameters κ and κ_{crit} would be constrained.
- $R > 0$ **with statistical significance:** An unmodeled effect is detected. Its dependence on depth, density, and temperature could then be characterized to infer the underlying mechanism.

5 Discussion

5.1 Why Has This Not Been Measured?

Three reasons may explain the absence of prior detection:

1. **Vacuum isolation:** All existing deep-clock experiments confine photons to vacuum.
2. **Fiber optic constraints:** At the per-meter level of the saturation model (~ 2.6 ps/m), the effect is undetectable by commercial submarine cables, which operate with nanosecond-scale timing margins and much larger thermal fluctuations.
3. **No differential measurement:** No prior experiment has compared multiple depths with photons traversing the medium.

5.2 What This Experiment Would and Would Not Show

A positive detection would not, by itself, identify the physical mechanism. It would indicate that **something beyond GR and classical optics** contributes to time delay in material media. Determining whether that something is causal friction, a modification of the metric by the medium, or an entirely different effect would require further investigation.

A null result would place meaningful constraints on a class of models —including the UAT framework— that predict environmental influences on timekeeping.

6 Conclusion

We have made the following observations:

1. The submerged atomic clock experiment, as currently designed, isolates the photon from the medium and thus does not test whether the medium affects local time.
2. The GPS system's continuous correction requirements suggest that environmental factors influence timekeeping beyond pre-launch GR calibration, though the standard model attributes these to electromagnetic propagation effects.
3. A three-depth experiment in which timing photons traverse the water column would, for the first time, directly test whether an unmodeled residual exists beyond GR and classical refraction.
4. A phenomenological saturation model provides a benchmark sensitivity estimate of ~ 5 ns differential signal, which is readily detectable with current optical clock technology.

We make no claim as to the physical origin of any residual that may be found. The experiment is proposed as a **model-independent empirical investigation**: does the material medium contribute to time delay beyond General Relativity and classical optics? The answer —whatever it may be— would advance our understanding of the relationship between time and the environment in which it is measured.

$$\boxed{\text{The question is not whether the medium affects time.}}$$

$$\boxed{\text{The question is: has anyone ever measured it?}}$$

Data and Code Availability

The analytical script (`saturation_causal_friction.py`) containing the full calculation of the estimates in Table 1 is provided as supplementary material. It uses only standard Python libraries (NumPy, Matplotlib) and reproduces all reported values.

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This document does not claim the discovery of new physics.
It proposes an experiment to determine whether an unmodeled effect exists.

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