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Resilient Timekeeping Underwater in Extreme GNSS Denied Conditions

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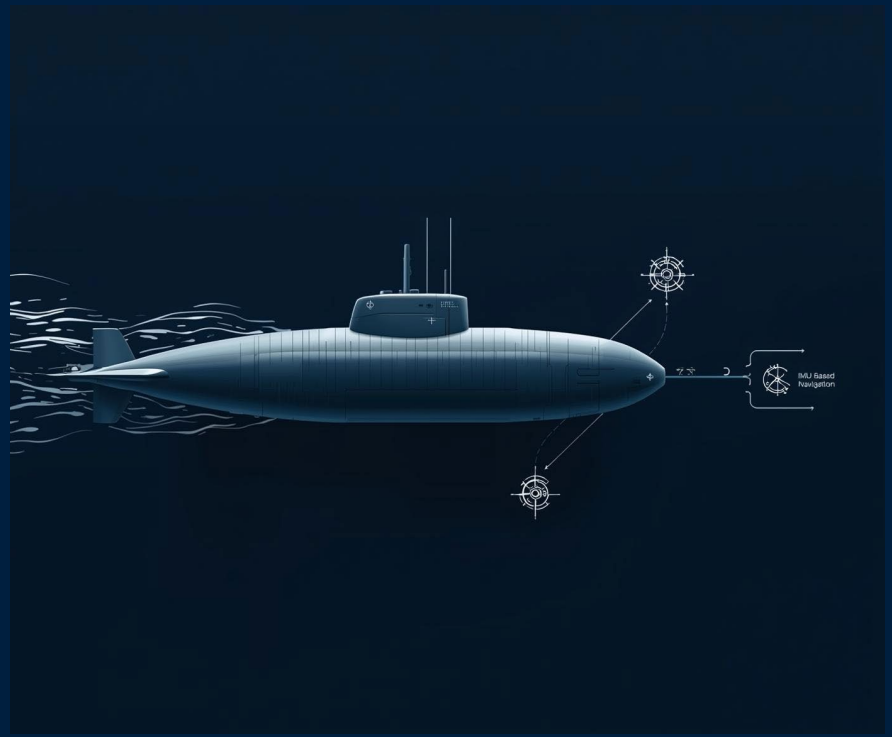
Why Timing without GNSS is Required

- Submarines operate long periods without GNSS
- Accurate Sync is needed for:
  - Communications
  - Internal Synchronization
  - Ranging & Sensing Systems
  - GNSS-less Location and Navigation (IMU / INS)



Growing Interest in Ultra-Accurate Timing Underwater

ROYAL NAVY NEWS / EQUIPMENT AND TECH / TECHNOLOGY

QUANTUM TECHNOLOGY TRIALLED ON ROYAL NAVY UNCREWED SUBMARINE XV EXCALIBUR

"This experiment was a first critical step towards understanding how quantum clocks can be deployed on underwater platforms to enable precision navigation and timing (PNT) in support of prolonged operations."

nature

Optical clocks at sea

Jonathan D. Roslund, Arman Cingöz, William D. Lunden, Guthrie B. Partridge, Abijith S. Kowligy, Frank Roller, Daniel B. Sheredy, Gunnar E. Skulason, Joe P. Song, Jamil R. Abo-Shaeer & Martin M. Boyd

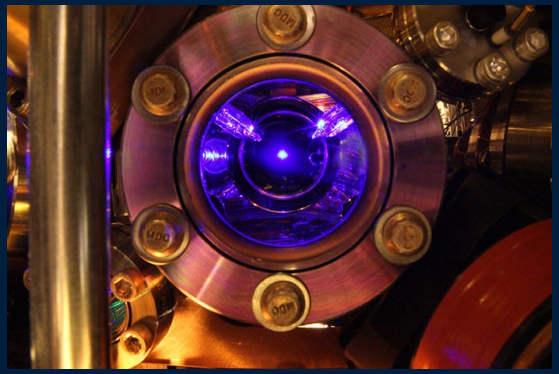
Nature **628**, 736–740 (2024) | Cite this article

"Deployed optical clocks will improve positioning for navigational autonomy"

"Three of these clocks operated continuously aboard a naval ship in the Pacific Ocean for 20 days while accruing timing errors below 300 ps per day"

Australia Completes First-Ever Sea Trial of Portable Optical Clock

Published 22 April, 2026



"Such devices could provide precision support to navigation systems without the need for global satellite positioning networks."

ePRTC: Stable Time Reference for Weeks

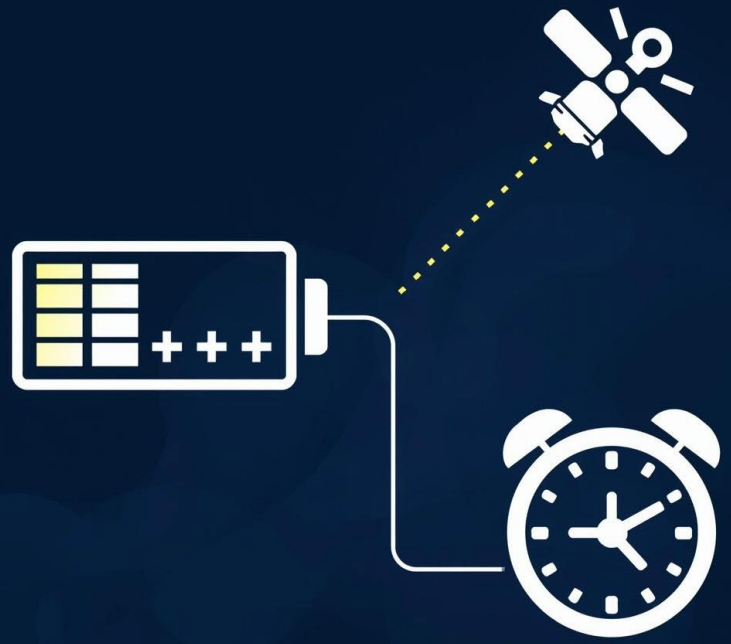
- The ePRTC system ensures precise time synchronization by integrating stable clock (Atomic Clock) with Phase and Time signals (such as GNSS)
- Achieving accuracy within 100 nanoseconds for reliable operations in critical environments

The Gap is Short Surfacing Periods

- In real operations, submarines may surface briefly but not long enough to “recharge” holdover fully
- After a short surfacing, ePRTC in fact requires restart the learning period

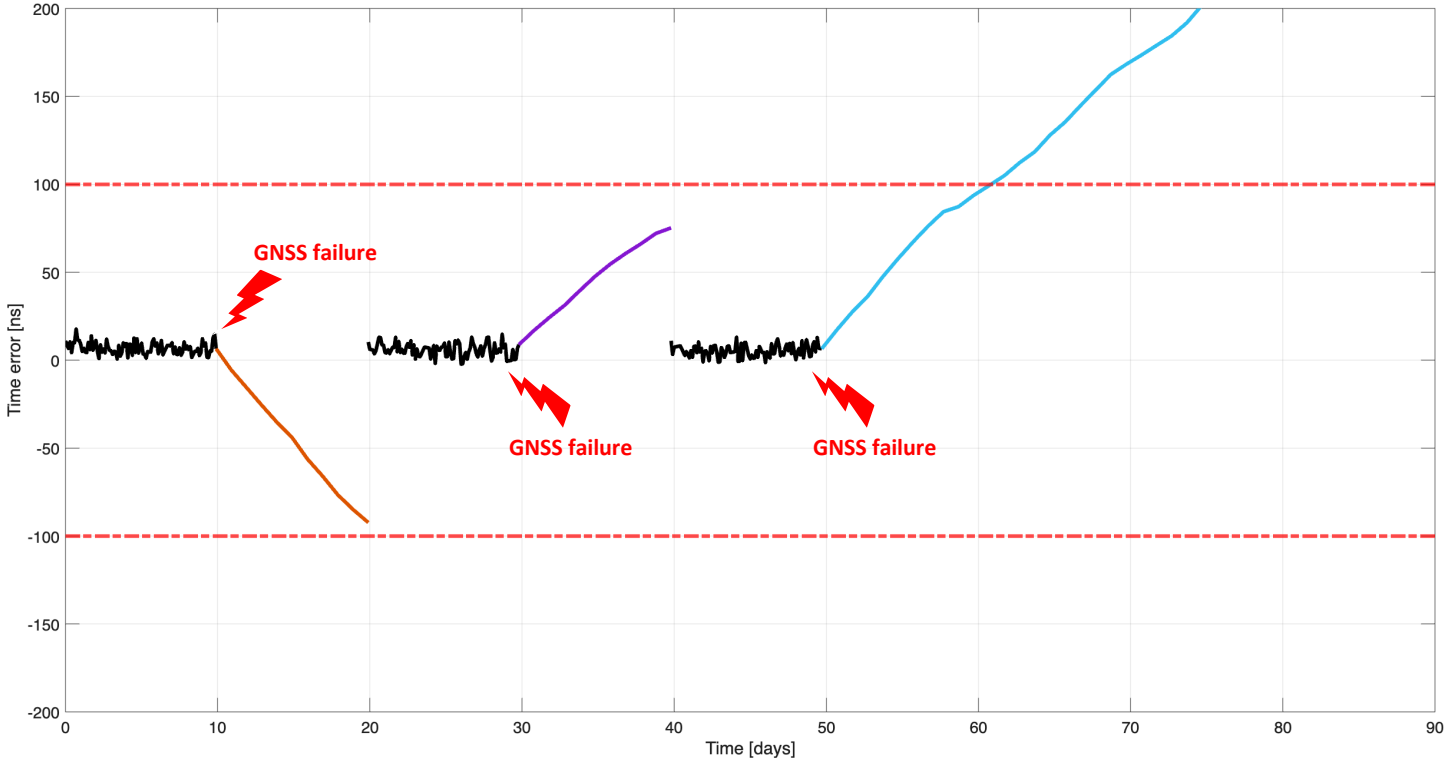
The Timing TOP UP Approach

- Instead of requiring long learning periods, we treat holdover like a battery
- Even short GNSS windows incrementally “top up” the holdover reserve
- This allows more flexibility: brief surfacing still extends your timing stability underwater. A once in a while have small window of GNSS reception

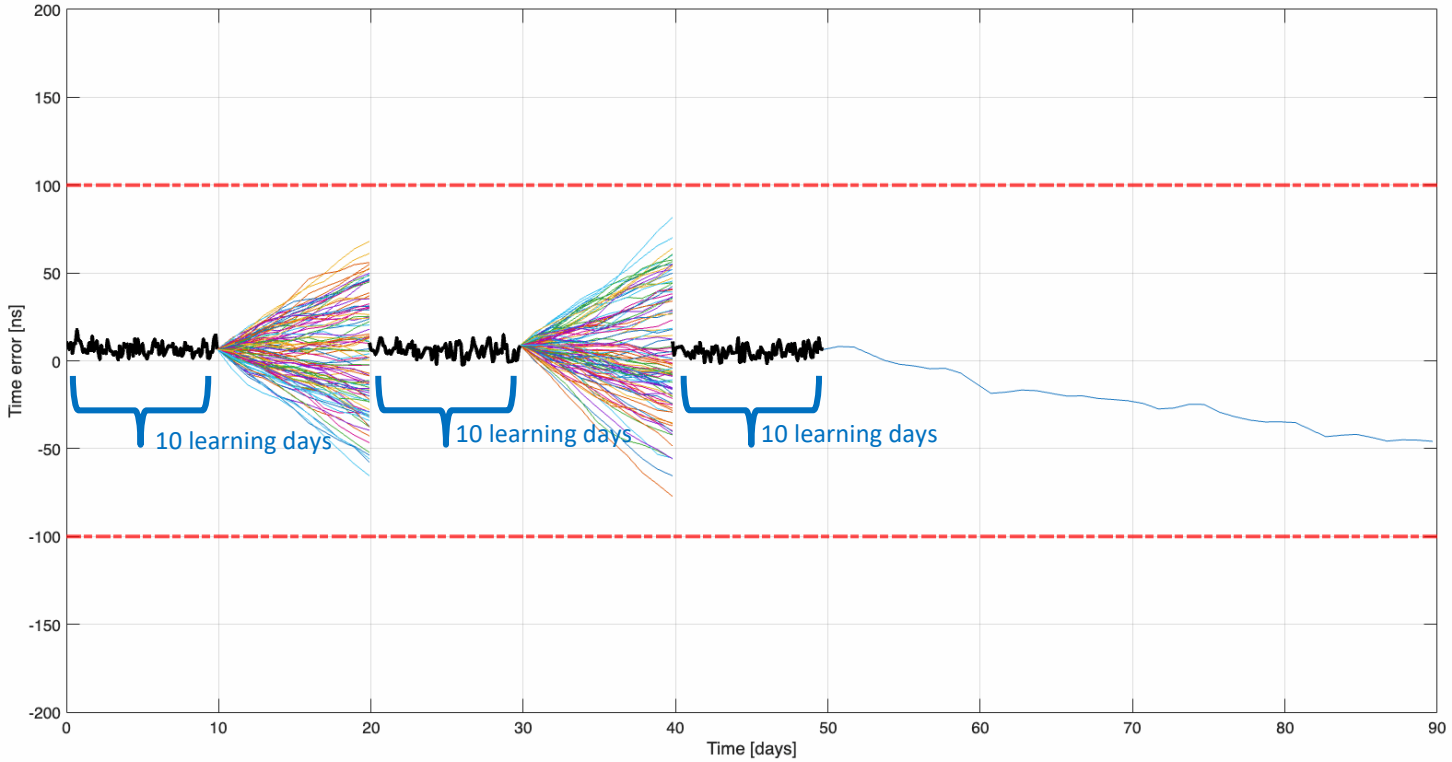


The Timing Battery Affect on Holdover Period

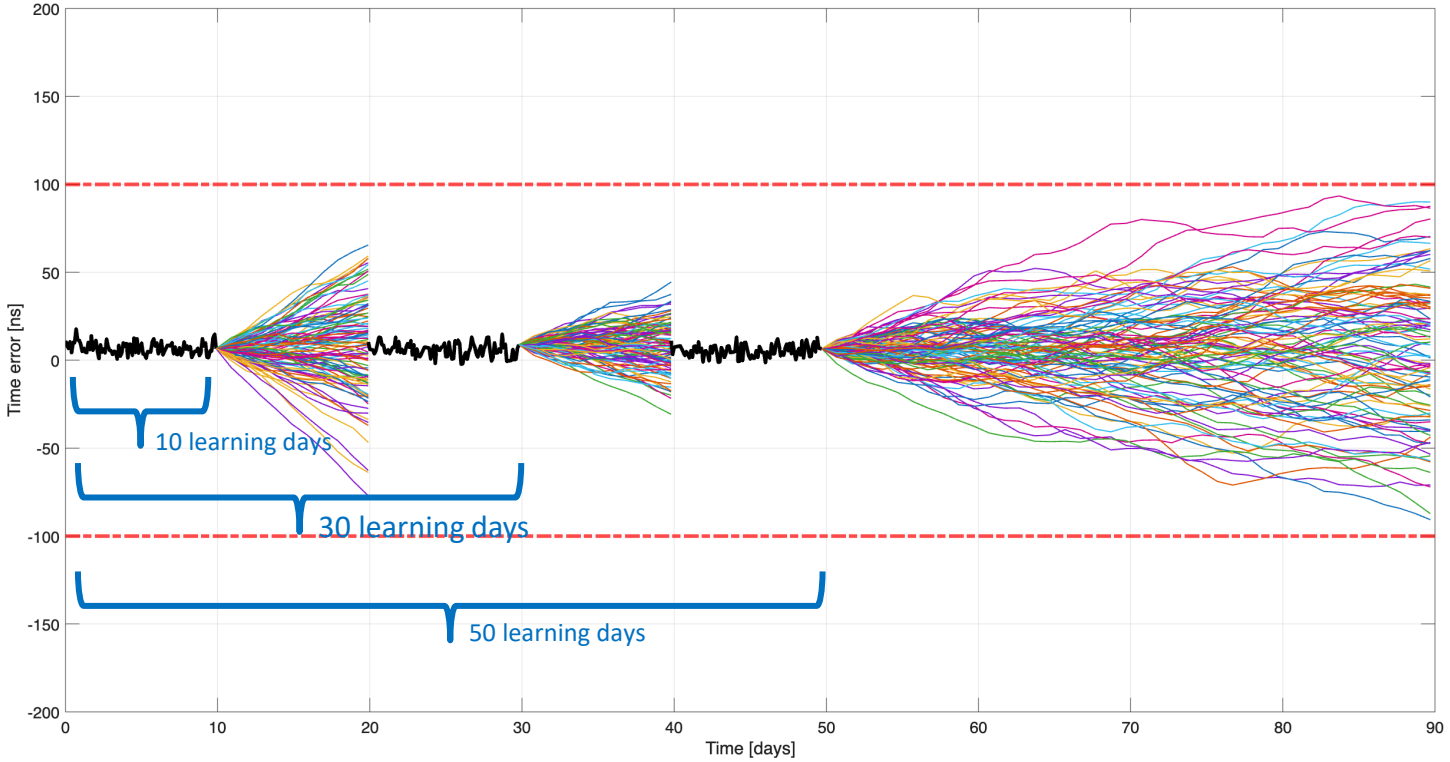
Holdover Performance Depends on Locked Mode Duration



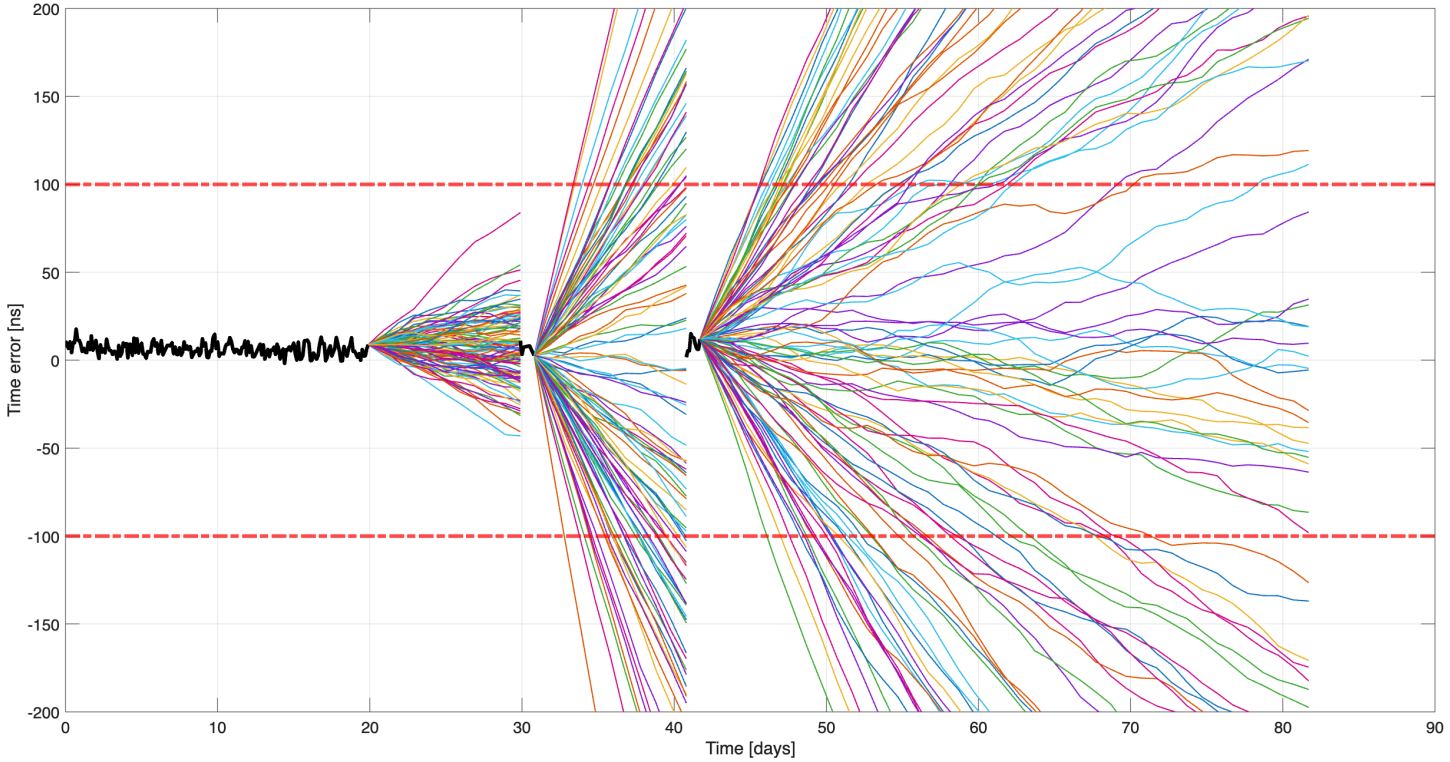
No Holdover Improvement with Relearning After Each GNSS Lock



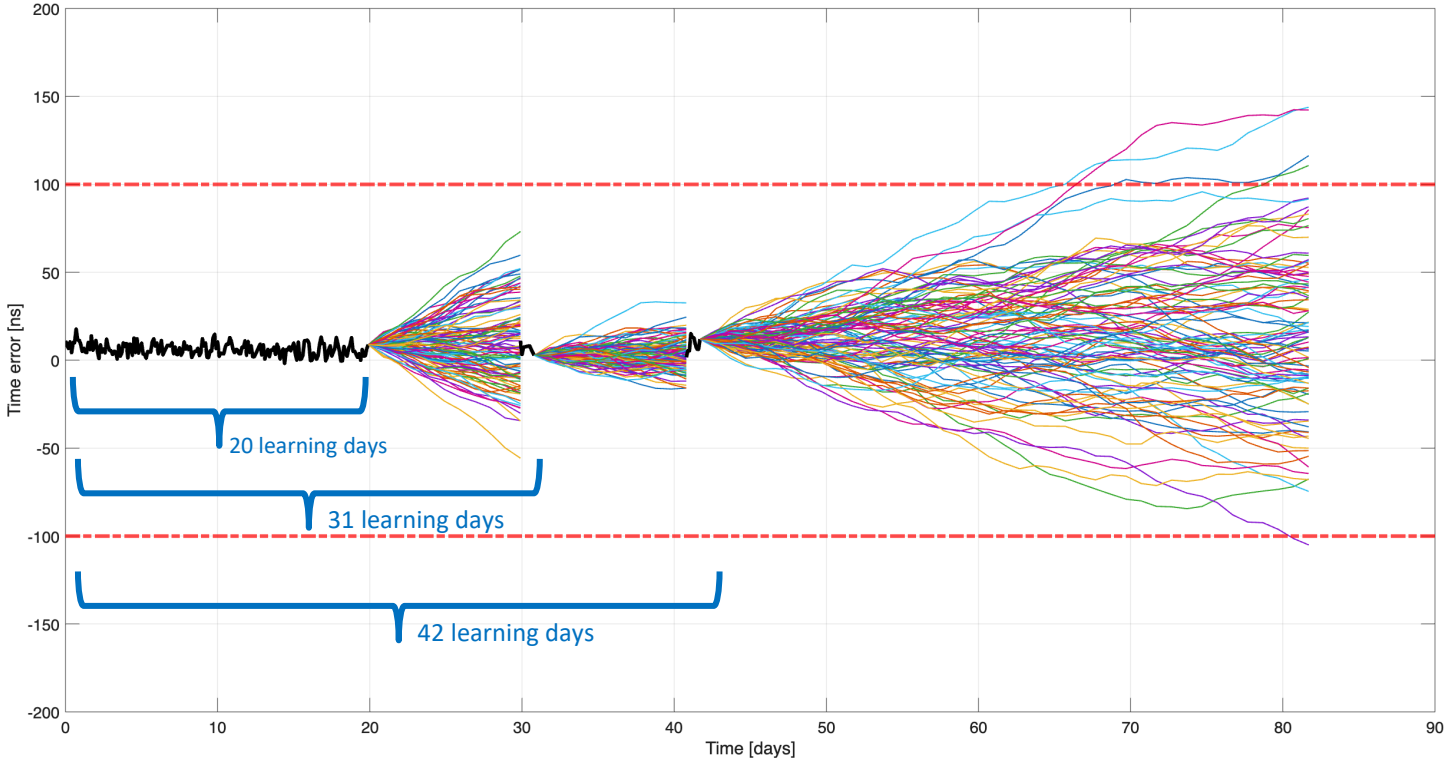
Learning Beyond Lock: Using Holdover as Training Time



Poor Holdover Readiness When Having short Window of GNSS Reception



Be Ready for Extended Under-Water Mission with Short Windows of GNSS Reception



Takeaways

- Submarines operate long periods without GNSS
- Accurate timing is needed
- Enabling accurate positioning and navigation autonomy, supporting integration with next-generation quantum-based IMUs
- Be ready for extended under-water mission with excellent holdover performance
- Use short GNSS availability period to “charge” holdover readiness instantly

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Thank you

Please contact me in case you have any comments or questions:

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