Title:

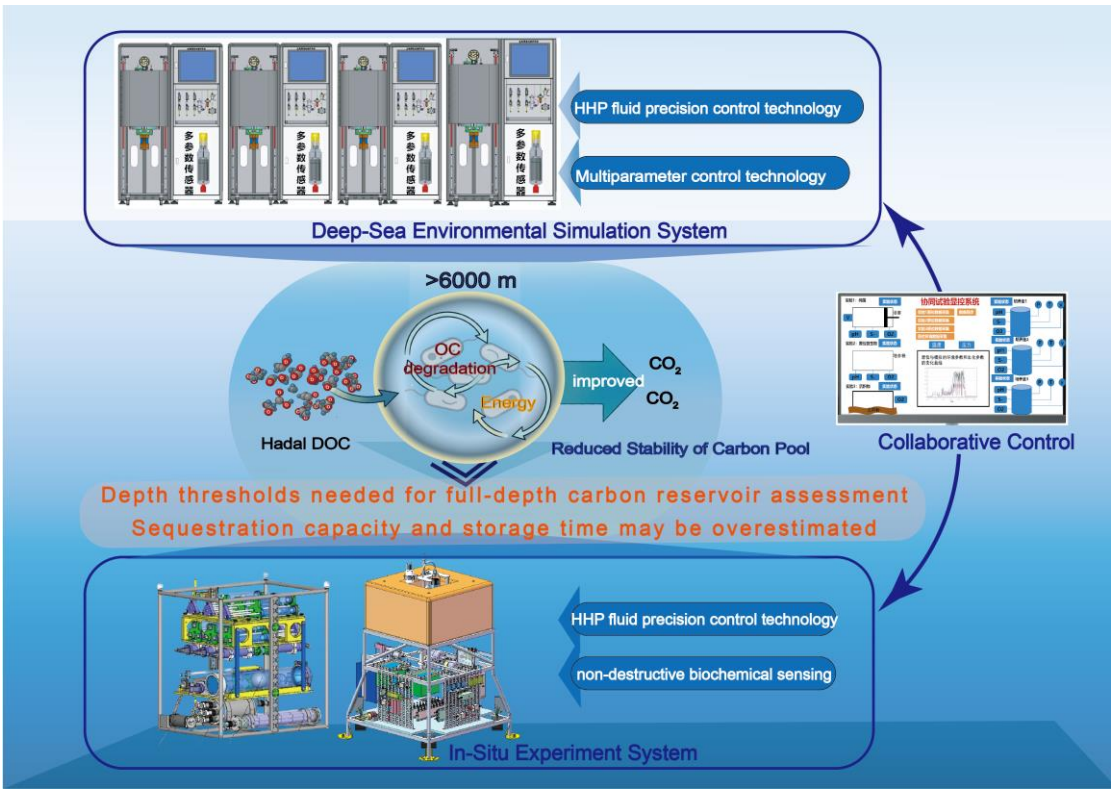
Intelligent Connected Technologies for Exploring Carbon Cycling in the Hadal Ocean

Abstract:

The hadal ocean, extending from approximately 6,000 to 11,000 m, represents one of Earth's least explored frontiers and a hotspot of carbon cycling in the deep ocean. Trench topography promotes the transport and accumulation of organic matter, while extreme hydrostatic pressure strongly regulates microbial activity and carbon transformation. Yet hadal environments are highly heterogeneous in space and time, and conventional sampling often captures only isolated snapshots. Understanding how carbon is transported, transformed, remineralized, and preserved in the deepest ocean therefore requires new technologies capable of observing processes across multiple scales and under realistic environmental conditions.

To meet this challenge, we have developed an intelligent connected observation framework linking surface-based high-pressure simulation, deep-sea in situ experimentation, and collaborative control. A series of key technologies have been advanced, including full-ocean-depth high-hydrostatic-pressure fluid precision control, multiparameter environmental regulation, non-destructive biochemical sensing, autonomous in situ experimentation, intelligent sensing, and collaborative control. Together with multidimensional data analysis and artificial intelligence algorithms, these technologies enable high-fidelity investigation of hadal environments and biological processes, moving deep-sea research from sample collection toward process-oriented observation and experimentation.

These technological advances are also opening new windows for scientific discovery. Our studies indicate that hydrostatic pressure can substantially reshape microbial carbon utilization and metabolic allocation, altering the balance between organic carbon transformation, biomass production, and remineralization. Such pressure-dependent responses suggest that the stability and storage potential of deep-ocean carbon pools may vary across depth regimes, highlighting the need to explicitly consider pressure and depth thresholds when assessing carbon sequestration in the full-depth ocean. By connecting technological innovation with scientific questions, we aim not only to reach and measure the hadal ocean, but ultimately to understand how life and carbon cycling operate at Earth's deepest frontier.


HHP fluid precision control technology
Multiparameter control technology
Deep-Sea Environmental Simulation System
>6000 m
OC degradation
Energy
improved
CO_2
CO_2
Hadal DOC
Reduced Stability of Carbon Pool
Collaborative Control
Depth thresholds needed for full-depth carbon reservoir assessment
Sequestration capacity and storage time may be overestimated
HHP fluid precision control technology
non-destructive biochemical sensing
In-Situ Experiment System