

STATE OF THE OCEAN REPORT 2024



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A safe ocean where life and livelihoods are protected from ocean-related hazards

Trends and impacts of warning systems for ocean-related hazards: Outcome vs status

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Introduction

Ocean-related hazards, most notably tsunamis and storm surges, pose significant threats to coastal communities worldwide. These global threats, expected to intensify with climate change and rising sea level, can cause extensive damage to critical infrastructure and homes, disrupt economies and livelihoods, and lead to loss of life, especially with the current growth in coastal population and tourism worldwide. The UN Decade of Ocean Science for Sustainable Development (2021–2030) Outcome of a 'Safe Ocean' aims to build up coastal resilience from ocean hazards, necessitating the enhancement of multihazard early warning systems by utilizing recent advancements in technology, along with a growing emphasis on community preparedness and resilience.

Large tsunamis travel across entire ocean basins, striking coastlines with little or limited lead time. Nearly 90% of tsunamis have been generated by large earthquakes or landslides triggered by earthquakes.¹³ The 2004 Indian Ocean and 2011 Japan tsunamis generated by subduction zone megathrust-earthquakes are the most devastating natural disasters in history, claiming tens of thousands of lives with billions of dollars of damages. However, tsunamis produced by non-seismic sources, such as volcanic eruptions or meteorological disturbances, have proved to strike significantly more often than previously thought and have also resulted in severe loss of life and property – the most notable event being the recent Hunga Tonga–Hunga Ha'apai tsunami (Angove et al., 2021; Borrero et al., 2023; Lynett et al., 2022). All of these demand the implementation of emerging observational techniques in tsunami warning systems.

¹³ See National Geophysical Data Center/World Data Service: NCEI/WDS Global Historical Tsunami Database. NOAA National Centers for Environmental Information. doi:10.7289/V5PN93H7 (accessed 20 December 2023).

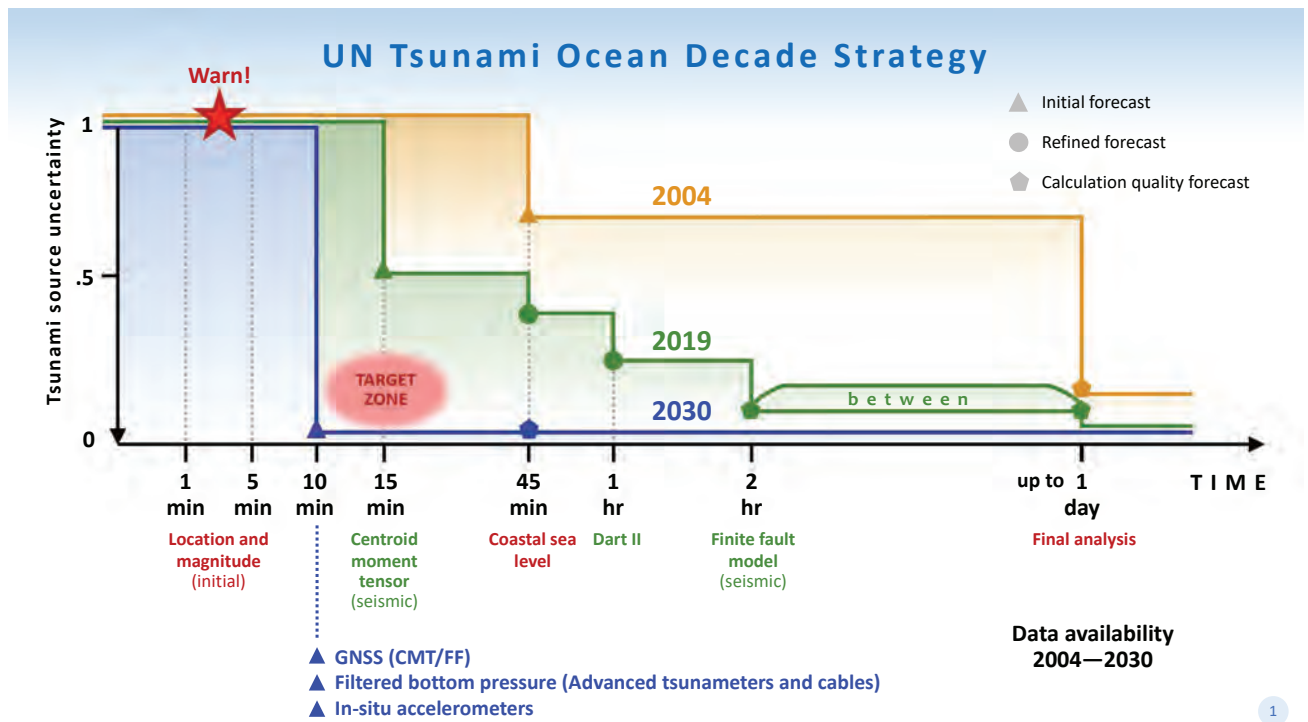


Figure 22. Generalized relationship between tsunami source uncertainty and time after earthquake origin for three different time frames. Notes: Orange line: tsunami source uncertainty levels prior to 2004; green line: tsunami source uncertainty levels at present (2019); blue line: tsunami source uncertainty levels achievable with the ocean sensing and analysis techniques. *Source:* Updated from Angove et al. (2019).

Description of findings, trends, status

Presently, the Global Tsunami Warning and Mitigation Systems, coordinated by IOC-UNESCO, covers the world's major ocean basins: the Pacific (PTWS), the Indian Ocean (IOTWMS), the Northeastern Atlantic, Mediterranean and connected seas (NEAMTWS), and the Caribbean and Adjacent Regions (CARIBE-EWS). Approximately 150 countries and territories are contributing to the global efforts in tsunami hazards resilience. The status of warnings for tsunamis has seen considerable advancement in the past decade, but the aspiration is to further improve (Figure 22; Angove et al., 2019). The estimation of earthquake forcing mechanisms can be obtained between 2–3 hours, and sometimes much sooner (~15 min). An increasing network of state-of-the-art monitoring infrastructure, including tens of thousands of seismometers, 74 deep-ocean tsunami buoys, about 1,234 active sea level stations shared through the UNESCO Sea Level Station Monitoring Facility tide gauges (in 2022 1,043 sea level stations were in place) and several submarine cable observatories are now available to detect and measure large tsunamis with sufficient lead time to alert distant coastlines (Figure 23). The expansion of the Deep-Ocean Assessment and Reporting of Tsunamis (DARTs) network, in particular New Zealand's new deployments, played a vital role in assessing the tsunami threats of the Tonga volcanic eruption (GNS Science, 2022). Moreover, advancements

in satellite-based remote sensing technologies, such as the Global Navigation Satellite System (GNSS) and ionospheric-disturbance detection (Martire et al., 2023), will further enhance the capability of tsunami detection and early warning system with increased precision. The UN initiative on Science Monitoring and Reliable Telecommunications (SMART) subsea cables (Howe et al., 2019 and 2022) has facilitated the installation of the SMART Wet Demonstration system off the coast of Italy. Two contracted SMART systems, one connecting Vanuatu and New Caledonia and the other off Portugal, will be ready for service in 2026. Support for these come from the European Union (Digital Connectivity) and respective governments, development banks, foundations and companies. Equipped with sensors measuring pressure, seismicity and temperature, SMART cables aim for direct *in situ* early detection of earthquakes and tsunamis for regions not covered by the sparse distribution of tsunami buoys. The rapidly growing field of optical fibre sensing in submarine cables, including distributed acoustic sensing (DAS), is showing potential for detecting tsunamis (Xiao et al., 2024). Algorithms relying on underwater earthquake-derived acoustic signals are also emerging for rapid source determination of tsunamis (Gomez and Kadri, 2023) and undersea acoustic communication methods are being used to transfer near-shore bottom pressure data to land (Comfort and Rahayu, 2023).

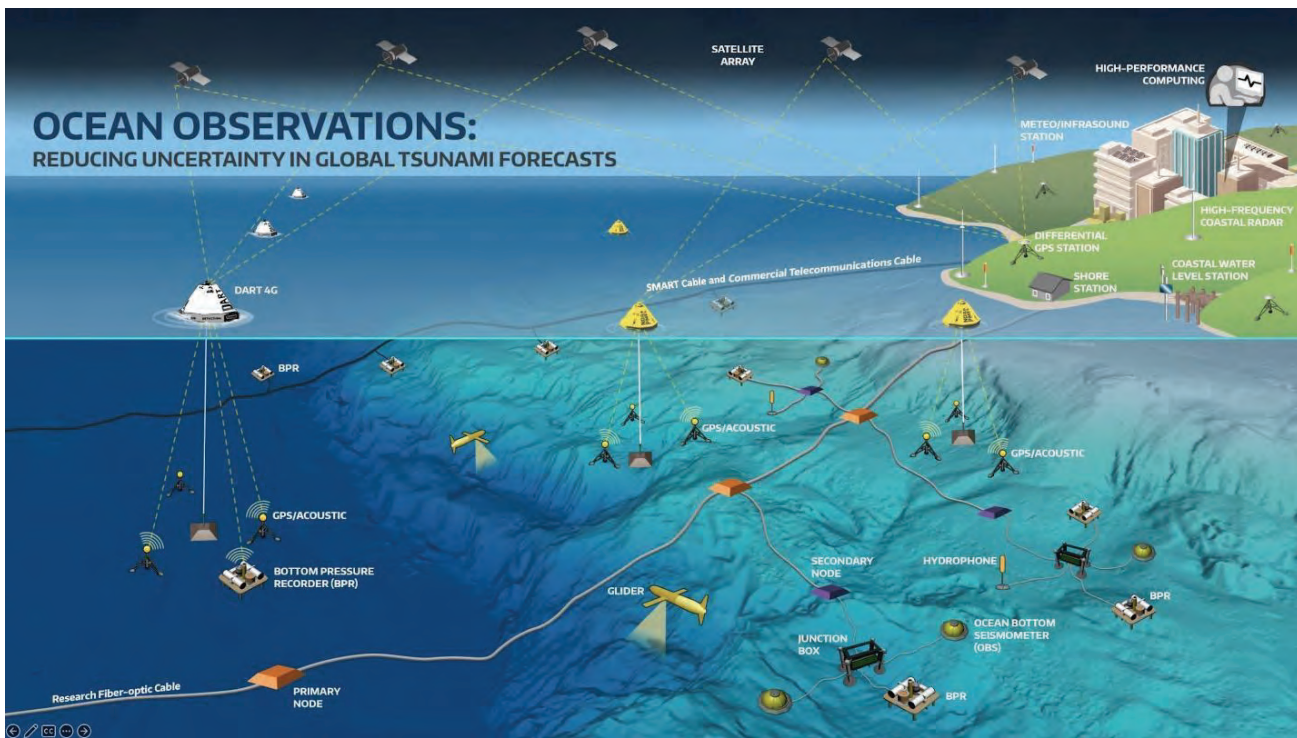


Figure 23. Existing and emerging ocean observational technologies for global tsunami forecasts. *Source:* Pacific Marine Environmental Laboratory, National Oceanic and Atmospheric Administration, USA.

Monitoring and predicting storm surges is crucial to provide valuable information for early warning of severe weather events and emergency response efforts. Tropical cyclones and storm surges are monitored by a variety of meteorological services and warning centres. Ten of these warning centres worldwide are designated as either a Regional Specialized Meteorological Centre or a Tropical Cyclone Warning Centre by the World Meteorological Organization (WMO). Aircraft, satellites, drones and unmanned aerial vehicles (UAVs) are now commonly used technologies in hurricane tracking, with data from them being used as real-time input for the model forecast system. The storm surge level is usually monitored by a range of tools, including tide gauges, coastal radar systems, satellite remote sensing and ocean buoys.

One notable trend in response systems for ocean-related hazards is the integration of real-time data from various observational sources into advanced and unified model simulation platforms, which are moving to the next generation, featured by global coverage, probabilistic ensembles and three-dimensional realizations, as well as impact-based forecasting. In the USA, the National Oceanic and Atmospheric Administration (NOAA) is currently implementing this integration to enable more accurate and timely predictions of extreme flooding impacts, encouraging early action and empowering decision-makers to implement targeted evacuation orders and emergency response plans. In hazard-prone

regions, another prominent trend is the growing emphasis on constructing resilient infrastructure and enforcing hazard-resistant building codes for critical facilities such as hospitals, schools and emergency shelters, as well as power plants, airports and ports. The new chapter 'Tsunami Loads and Effects' incorporated in the American Society of Civil Engineers (ASCE) Standard (ASCE, 2017), *Minimum Design Loads and Associated Criteria for Building and Other Structures*, is the first national, consensus-based standard for tsunami-resilient building design in the US. This standard was also included in the requirement of the 2018 International Building Code (IBC).

The inclusion of community preparedness in warning systems has led to improved public awareness and education regarding ocean-related hazards, in an end-to-end and people-centred early warning system. After extensive piloting, in 2022 the UNESCO Tsunami Ready Program was established. As of early 2024, 48 communities across 23 countries in the Caribbean, Pacific, Indian Ocean and North East Atlantic and Mediterranean regions were recognized for achieving the established indicators. The goal is that by 2030, 100% of tsunami at-risk communities are prepared and resilient to tsunamis through efforts like Tsunami Ready. This will foster a culture of resilience, empowering individuals and communities to take proactive measures to protect themselves and their surroundings during hazardous events, not only tsunamis.

Conclusions and next steps

Enhancing global resilience of ocean-related hazards is currently challenged by limited resources and capacity, urbanization and population growth, and abrupt climate change and sea level rise. The UN Decade of Ocean Science (2021–2030) with an emphasis on a ‘Safe Ocean’ is an opportunity to apply science, technology and innovation and the best available knowledge to develop conventional and innovative solutions for effective preparedness and response.

The Ocean Decade Tsunami Programme is one such initiative under the UN Ocean Decade that provides a framework for collaboration among all relevant stakeholders to enhance resilience to tsunami and other ocean hazards (IOC-UNESCO, 2023).

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