UNOOSA 2022 Space4Youth Essay Competition:
"Space as a tool to accelerate change in sustainable water resources management, hydrology and the protection of aquatic ecosystems"

Climate risks and capability sharing in the Asia-Pacific region: Exploring a future GNSS-based early warning system for tsunami

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Abstract

Climate change effects are set to increase the risks associated with tsunami events. For nations vulnerable to tsunami, a sea level rise of only 0.5m presents a dramatically heightened risk factor for tsunami frequency. Inequitable global investment in disaster-resilient infrastructure and monitoring leads to a further uneven risk factor for poorer nations vulnerable to coastal hazards. New research from Japan shows that tsunami prediction using GPS satellites is technically feasible. This essay presents a case for developing this research into a space-based tsunami early warning system, encouraging GNSS capability-sharing beyond Japan for the benefit of the wider Asia-Pacific community.

Explosive emergence; relentless power; cataclysmic destruction. With velocities up to 800 kilometres an hour and crests as high as 30 metres above sea level (NOAA, 2018), tsunamis are the catastrophic flooding of the ocean onto coastal communities. Tsunami waves have claimed more lives in the last century than any other natural hazard; over the last 100 years, 58 known events led to a total loss of more than 260,000 lives (UNESCO, 2022).

The effects of climate change are expected to increase the impact of tsunami (Sepúlveda, 2021). While most tsunami are caused by earthquakes ("*seismic*" tsunami), up to 15% are caused by other sources, including volcanic eruptions and ice sheet collapse (Cunneen, 2022). Studies have found that climate change is likely to increase the number of volcanic eruptions (Swindles, 2017) and heighten the tsunami risks associated with rising sea levels (Alhamid, 2022). For example, one recent case study has found that a sea-level rise of only half a metre would double the tsunami hazard in the low-lying coastal city of Macau (Li, 2018).

This increasing threat of tsunami charts across a map of vulnerable nations. Coastal areas are more densely populated than inner lands, with higher rates of population growth and urbanisation (Neumann, 2015). At the same time, an uneven global poverty distribution has 15 developing countries containing over 90% of the world's coastal low-elevation poor (Barbier, 2015). This combination of high coastal human density and poverty presents a 'perfect storm' for future high-casualty tsunami disasters in these countries, as higher population and lesser investment leads to poorer outcomes for evacuation (Makinoshima, 2020).

Efforts to mitigate losses from tsunami focus on maximising rapid tsunami warning systems (*TWS*). However, the current systems used will not be sufficient for effectively warning the most vulnerable communities about varied future tsunami types.

Current tsunami warning systems broadly fall under two categories: seismic warnings and direct observations. Seismic warnings form the basis of major warning systems (e.g. UNESCO's Pacific Ocean TWS [1], Japan's TWS [2]), where data from earthquake sensors is extrapolated to predict the chances of a triggered tsunami. This system provides a reliable indication that a tsunami is coming, if the tsunami is triggered by a seismic event. Tsunami from other causes, however, are not necessarily detected. Even then, since only the initial earthquake is measured, tsunami height, severity, and location predictions are unreliable by this method alone (Kanai, 2022). It also cannot directly provide predictions about secondary and later tsunami waves, which can be larger and more deadly than the initial tsunami (Geist, 2022).

Direct tsunami observations are therefore needed to supplement seismic monitoring. Current systems include water buoys and sea floor pressure sensors. A large number of these are needed for comprehensive coverage, and the cost (~US$ 3M/buoy) (Mulia, 2020) may prove prohibitive for some developing nations. Buoys also have a short lifespan of 1-2 years (Gonzalez, 2005) and require continual investment, presenting similar problems; Indonesia's

[1] https://www.tsunami.gov
[2] https://www.data.jma.go.jp/svd/eqev/data/en/tsunami/tsunami_warning.html

entirely buoy-based TWS is considered to have failed in the case of the 2018 tsunami due to a lack of maintenance (Titov, 2021). A more reliable and accessible method of tsunami warning is therefore urgently needed for emerging tsunami risk areas.

A satellite-based tsunami early warning system

A space-based tsunami early warning system presents a low-cost, low-maintenance, and high coverage solution to the global tsunami monitoring problem. Recent research from Japan shows that such a system may be possible through observations of tsunami ionospheric holes (*TIH*), which are depressions in atmospheric electron rates detectable through simple GPS satellite observations (Kamogawa, 2016). This is a physical phenomenon where rising waves in water disturb and suppress ion production in the atmosphere above (Shinagawa, 2013). GPS signals propagate differently through these ‘holes’ compared to the normal atmosphere, and so they can be detected by standard GPS receivers, as illustrated in Figure 1 (Kanai, 2022).

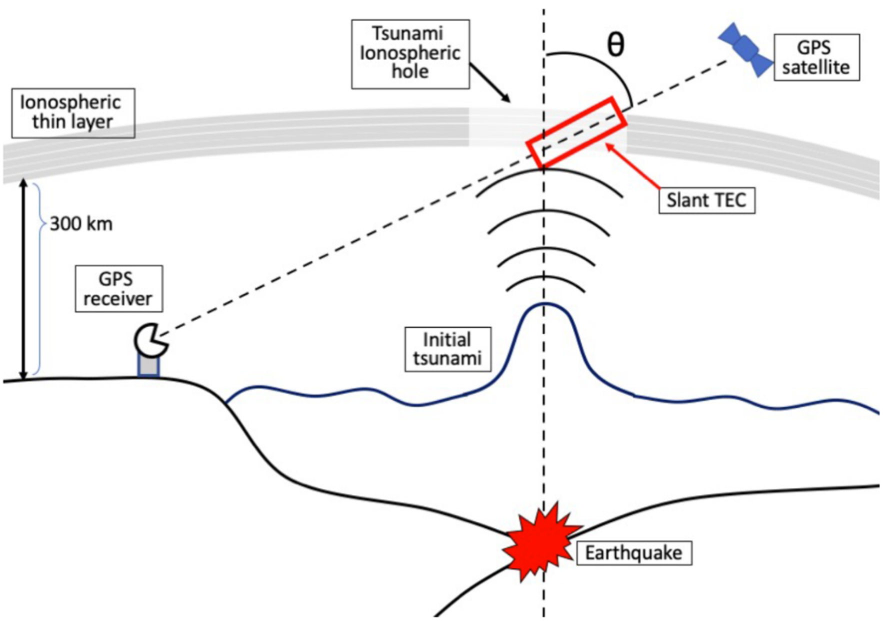

Figure 1: Formation and GPS detection of a tsunami ionospheric hole (Kanai, 2022)

New research from Kanai et al (2021) has demonstrated that by building a statistical system, GPS measurement of TIHs can now be used to accurately estimate the dimensions of a tsunami with up to 10 minutes' notice, completely independently of any other resources. Crucially, this model can be used even with a very small number of available GPS receivers, and so is equally applicable globally and with no additional infrastructure. What this means is a technically feasible, space-based system for tsunami warnings; a system that is low-cost, low-maintenance, and high-coverage.

Three forms of support would be needed to bring this new space application to full potential. Firstly, further research is needed to build a practically implemented system. Secondly, while the number of GPS points needed for the system to work is now very small, the reliability is improved with a greater number of data points. Increasing access to GNSS in target areas could therefore improve the efficacy of the system. Japan in particular has extensive expertise in the use and maintenance of GNSS systems for tsunami monitoring and response, and is therefore encouraged to engage in capability-sharing and investment across the Asia-Pacific region in light of the increasing regional threat from tsunami in the future.

Finally, the United Nations has already established a seismic network for tsunami early warning in the Pacific Ocean [3], and is establishing one in the Indian Ocean [4]. The United Nations could look to include space-based tsunami warnings as part of a future unified tsunami warning system, ideally through coordination between UNOOSA and UNESCO. Such a system could include automated multi-source warnings and capability-building for interpretation and response in developing countries.

As tsunami threats grow with the effects of climate change, so does the vulnerability of the world's poorer low-lying coastal regions. With investment, research, and integration, a new GPS-based space system for international tsunami warning and response may be a new tool to bring life-saving space benefits to people on Earth. Low-cost, low-maintenance, and high-coverage, this system could be the right solution for tsunami disaster prevention in our most threatened communities.

[3] https://www.tsunami.gov
[4] https://iotic.ioc-unesco.org/what-is-iotws/

References

Alhamid, Abdul Kadir, Mitsuyoshi Akiyama, Hiroki Ishibashi, Koki Aoki, Shunichi Koshimura, and Dan M. Frangopol. "Framework for Probabilistic Tsunami Hazard Assessment Considering the Effects of Sea-Level Rise Due to Climate Change." *Structural Safety* 94 (2022): 102152. https://doi.org/10.1016/j.strusafe.2021.102152.

Barbier, Edward B. "Climate Change Impacts on Rural Poverty in Low-Elevation Coastal Zones." *Estuarine, Coastal and Shelf Science* 165 (2015). https://doi.org/10.1016/j.ecss.2015.05.035.

Carrivick. "Climatic Control on Icelandic Volcanic Activity during the Mid-Holocene." *Geology* 46, no. 1 (2017): 47–50. https://doi.org/10.1130/g39633.1.

Cunneen, Jane. "5 Ways That Climate Change Increases the Risk of Tsunamis." World Economic Forum. The Conversion, January 26, 2022. https://www.weforum.org/agenda/2022/01/climate-change-tsunmai-earthquake-volcano-sea-levels/.

Geist, Eric. "Tsunami and Earthquake Research | U.S. Geological Survey." Life of a Tsunami, 2022. https://www.usgs.gov/centers/pcmsc/science/tsunami-and-earthquake-research.

Gonzalez, Frank I., Eddie N. Bernard, Christian Meinig, Marie C. Eble, Harold O. Mofjeld, and Scott Stalin. "The NTHMP Tsunameter Network." *Natural Hazards* 35, no. 1 (2005): 25–39. https://doi.org/10.1007/s11069-004-2402-4.

Kamogawa, Masashi, Yoshiaki Orihara, Chiaki Tsurudome, Yuto Tomida, Tatsuya Kanaya, Daiki Ikeda, Aditya Riadi Gusman, Yoshihiro Kakinami, Jann-Yenq Liu, and Atsushi Toyoda. "A Possible Space-Based Tsunami Early Warning System Using Observations of the Tsunami Ionospheric Hole." *Scientific Reports* 6, no. 1 (2016). https://doi.org/10.1038/srep37989.

Kanai, Ryuichi, Masashi Kamogawa, Toshiyasu Nagao, Alan Smith, and Serge Guillas. “Robust Uncertainty Quantification of the Volume of Tsunami Ionospheric Holes for the 2011 Tohoku-Oki Earthquake: towards Low-Cost Satellite-Based Tsunami Warning Systems.” *Natural Hazards and Earth System Sciences* 22, no. 3 (2022): 849–68. https://doi.org/10.5194/nhess-22-849-2022.

Li, Linlin, Adam D. Switzer, Yu Wang, Chung-Han Chan, Qiang Qiu, and Robert Weiss. “A Modest 0.5-m Rise in Sea Level Will Double the Tsunami Hazard in Macau.” *Science Advances* 4, no. 8 (2018). https://doi.org/10.1126/sciadv.aat1180.

Makinoshima, Fumiyasu, Fumihiko Imamura, and Yusuke Oishi. “Tsunami Evacuation Processes Based on Human Behaviour in Past Earthquakes and Tsunamis: A Literature Review.” *Progress in Disaster Science* 7 (2020): 100113. https://doi.org/10.1016/j.pdisas.2020.100113.

Mulia, Iyan E., and Kenji Satake. “Developments of Tsunami Observing Systems in Japan.” *Frontiers in Earth Science* 8 (2020). https://doi.org/10.3389/feart.2020.00145.

Neumann, Barbara, Athanasios T. Vafeidis, Juliane Zimmermann, and Robert J. Nicholls. “Future Coastal Population Growth and Exposure to Sea-Level Rise and Coastal Flooding - a Global Assessment.” *PLOS ONE* 10, no. 3 (2015). https://doi.org/10.1371/journal.pone.0118571.

Sepúlveda, Ignacio, Jennifer S. Haase, Philip L.-F. Liu, Mircea Grigoriu, and Patricio Winckler. “Non-Stationary Probabilistic Tsunami Hazard Assessments Incorporating Climate-Change-Driven Sea Level Rise.” *Earth's Future*9, no. 6 (2021). https://doi.org/10.1029/2021ef002007.

Shinagawa, H., T. Tsugawa, M. Matsumura, T. Iyemori, A. Saito, T. Maruyama, H. Jin, M. Nishioka, and Y. Otsuka. “Two-Dimensional Simulation of Ionospheric Variations in the Vicinity of the Epicenter of the Tohoku-Oki Earthquake on 11 March 2011.” *Geophysical Research Letters* 40, no. 19 (2013): 5009–13. https://doi.org/10.1002/2013gl057627.

Swindles, Graeme T., Elizabeth J. Watson, Ivan P. Savov, Ian T. Lawson, Anja Schmidt, Andrew Hooper, Claire L. Cooper, Charles B. Connor, Manuel Gloor, and Jonathan L.

Titov, Vasily V. "Hard Lessons of the 2018 Indonesian Tsunamis." *Pure and Applied Geophysics* 178, no. 4 (2021): 1121–33. https://doi.org/10.1007/s00024-021-02731-0.

"Tsunamis." National Oceanic and Atmospheric Administration. NOAA, 2018. https://www.noaa.gov/education/resource-collections/ocean-coasts/tsunamis.

"Tsunami Warning System: Preparing for the Unpredictable." UNESCO.org. UNESCO, December 20, 2022. https://www.unesco.org/en/tsunami-warning-system-preparing-unpredictable?TSPD_101_R0=080713870fab2000e27a5bdc7aa47bd30dac5145eb042382c16006be6a2c7eb1a5aef88aa57c8fdf08d6c21cd114300016c96009a1ab21b86d778d859d2ee1bef2eb046fe5778f46cc45c245f8068d264522c6e8267a2d1aa8803baa1e9e4308.