

# Temporal variability of tsunami detection distance revealed by virtual tsunami observation experiments using HF radar

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We statistically examined the tsunami detection distance based on virtual tsunami observation experiments by using receiving signals of the Nagano Japan Radio Co., Ltd. (NJRC) HF radar during February 2014 installed on the Mihama coast, Japan and numerically simulated velocities induced by a  $M_w$  9.0 Nankai Trough earthquake (Japan Cabinet Office's fault model case 3). In the experiments, the Doppler frequencies associated with the simulated tsunami velocities were superimposed on the receiving signals of the radar by the method developed by Gurgel et al. (2011), and the radial velocities were calculated from the synthesized signals by the fast Fourier transform. Tsunami arrival was then detected based on the temporal change in the cross correlation of the radial velocities, before and after tsunami arrival, between two range cells 3 km apart along beam 04. Combinations of HF radar systems and tsunami detection methods should be assessed as the onshore-offshore distribution of tsunami detection probability, because the detectability of tsunami wave will be affected by the signal-to-noise ratio and the tsunami magnitude in addition to the radar system specifications. We found that the detectability with a combination of NJRC radar system and our detection method primarily depends on the kinetic energy ratio between tsunami- and shorter-period background current- (BGC) velocities. In the onshore-offshore direction, the monthly average detection probability is over 90% when the energy ratio exceeds 5 (offshore distance: 9 km  $L$  36 km and water depth: 50 m  $< h <$  600 m) and is about 50% when the energy ratio is approximately 1 ( $L = 42$  km,  $h = 1,200$  m). The probability reduced over the continental shelf slope with decreasing tsunami-induced velocities. For a certain range cell on the radar beam, the energy ratio temporally varied in accordance with the variations of ocean surface wave height, ionospheric electron density and also with the shorter-period BGC physics. The energy ratio significantly decreased when the extremely large wave height exceeded 5 m and/or the ionospheric electron density became greater. From statistical analyses of the Wakayama-Nanseioki GPS wave gauge, significant wave heights are smaller from spring to summer, that is to say, the receiving signals would be more intense in this season. Meanwhile, the ionospheric electron density of the F2 layer generally becomes greater in the season, which would lead to greater receiving noise in the daytime. In addition, the energy ratio also varies depending on the tsunami magnitude. When a weaker (greater) tsunami occurs, the energy ratio becomes small (large) and the maximum detection distance is thus expected to become shorter (longer). In the experiments, the tsunami detection distance found to be dependent on the energy ratio between tsunami- and shorter-period BGC velocities and sea surface state as well as receiving noise. This demonstrates that the virtual tsunami observation experiments for other seasons and/or for another coastal regions with varying tsunami magnitude are required to understand the tsunami detection performance of HF radars comprehensively. This study is the first step towards a comprehensive understanding of variability of the maximum tsunami detection distance and development of real-time detection methods.

Keywords: HF radar, Tsunami arrival detection, Detection probability, Virtual tsunami observation experiment, Energy ratio, Signal-to-noise ratio