Attempt to estimate the underground resistivity structure of Kozushima using the electric field variation caused by the 2011 Tohoku tsunami

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Summary

Through the dynamo effect, tsunami propagation generates observable variations in the electric field as well as the magnetic field. On Kozushima, one of the Izu Islands in Japan, electric field variations were observed during the tsunami caused by the 2011 Tohoku earthquake, corresponding to changes in nearby tidal record data. A previous study suggests that tsunami-generated electric field variations observed on islands depend on underground resistivity. In this study, we attempted to estimate the resistivity structure of Kozushima that explains the electric field variations observed during the tsunami event. Three-dimensional simulations of tsunami electric fields were performed using structures with uniform resistivity and a structure with an L-shaped low-resistivity zone. The observed electric field variation was significant in the east-west direction. In the simulations, variation in the north-south direction was notable with the uniform structures, whereas variations in the east-west and north-south directions were comparable with the structure featuring the L-shaped low-resistivity zone. These results imply that the resistivity structure of Kozushima possibly exhibits a complex pattern that amplifies the electric field variations in the east-west direction.

Keywords: electric field, tsunami, resistivity structure, island, and simulation

Introduction

When a tsunami moves the electrically conductive seawater in the geomagnetic main field, observable electromagnetic (EM) field variations are generated. In the case of the tsunami caused by the 2011 Tohoku earthquake, numerous tsunami-generated EM (TGEM) field variations were observed on the seafloor and on land (e.g., Minami et al., 2017). On Kozushima, one of the Izu Islands in Japan, electric field variations were observed almost simultaneously with the peak time of a tidal gauge installed at the coast of Kozushima (Nakatani, 2015).

Shibahara (2022) performed numerical simulations of TGEM fields to investigate the dependence of TGEM variations observed at islands on the underground resistivity of the islands. While TGEM fields observed at the seafloor are minimally affected by the seafloor resistivity structure (Shimizu and Utada, 2015), Shibahara (2022) found that tsunami-generated electric (TGE) fields observed on islands are significantly influenced by the underground resistivity structure. It has been reported that the TGE variations observed on islands are larger when the underground resistivity is higher. In this study, we attempted to estimate the underground resistivity of Kozushima using the electric field variation data during the 2011 Tohoku tsunami event with the aid of simulations of the TGEM field.

Methods

Two long dipoles were placed at Kozushima, one in the southeast-northwest direction (2.382 km) and the other in the northeast-southwest direction (2.137 km), and data for two components of the electric potential difference were observed during the 2011 Tohoku tsunami. We converted the potential difference data into electric field data for the north-south and east-west components. Kozushima has a tide gauge on the western side of the island. Figure 1 shows the time series data of the two components of the electric field and the tide level. In this study, we attempted to reproduce the electric field variations using numerical simulation by testing several underground resistivity structures of Kozushima.

In the calculations of the electric field at Kozushima, the tsunami simulation code COMCOT (Wang and Liu, 2006) was used to create the tsunami seawater velocity field, which served as input for the EM field calculations using the time-domain finite element method TGEM simulation code TMTGEM (Minami et al., 2017). For the underground resistivity structure of Kozushima, TGEM field calculations were performed using homogeneous resistivity structures of 1000, 100, and 10 Ωm, as well as a resistivity structure with an L-shaped low resistivity zone (10 Ωm) in the southeastern part of the island. This is because the direction of electric field variation is dramatically changed by the existence of an L-shaped conductor (Ichihara and Mogi, 2009). To accurately compare the calculated electric fields with the observed data, pseudo-observation points were placed at equal intervals along the long dipoles of the potential difference observation. The calculated electric fields were integrated along the dipole to estimate the electric potentials for the dipole.

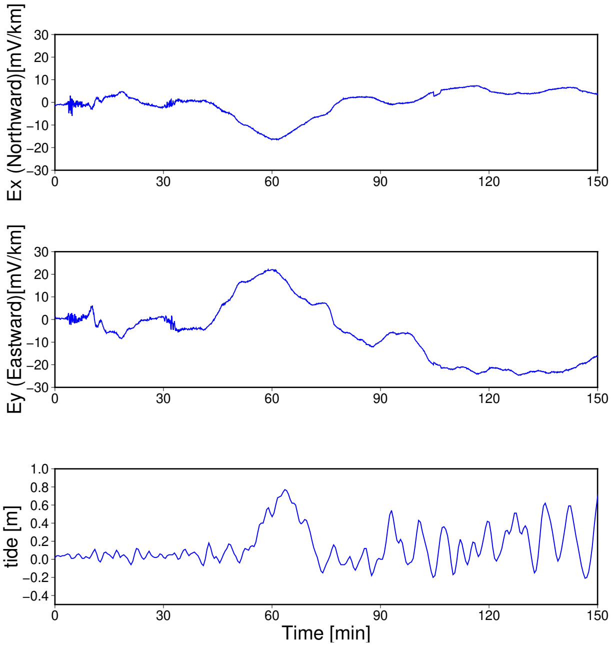

Figure 1. Time series data showing electric field variations and tide gauge record at Kozushima. Time is measured relative to the occurrence of the earthquake .

Result

The time series of the observed data and calculated results are shown in Figure 2. In the numerical simulations, the peak of the electric field variation was obtained at about the same time as the maximum variation of the tide level. The observation data exhibit significant variation in the east-west direction. For the homogeneous resistivity structures, there are almost no variations in the east-west direction, and variations in the north-south direction are dominant.

In the case of the structure with the L-shaped zone, the east-west and north-south variations exist in equal proportions. Since the observed data is dominated by the east-west variation, our results imply that a structure that enhances the east-west electric field variation possibly exists on Kozushima.

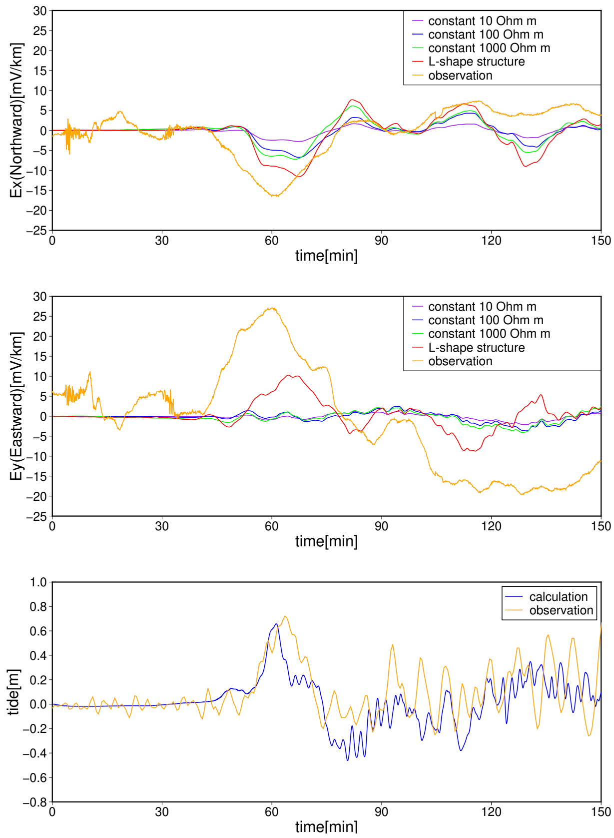

Figure 2. Comparison of observed and simulated electric field and tide level at Kozushima. The yellow line represents the observations, while the other colored lines depict the simulated data: magenta, blue, and green correspond to homogeneous resistivity structures of 10, 100, and 1000 Ω m, respectively; red represents the resistivity structure featuring an L-shaped low-resistivity zone. Time is measured relative to the earthquake occurrence.

Conclusions

On Kozushima, electric field variations corresponding to changes in the tide level were observed during the 2011 Tohoku earthquake tsunami event. We attempted to reproduce the observed TGE variations by numerical simulations with a plausible resistivity structure of Kozushima. However, the direction of the electric field variation observed was predominantly in the east-west direction, whereas with the uniform resisitivty structures, the variation was predominantly in the north-south direction. On the other hand, the resistivity structure featuring an L-shaped low-resistivity zone provides comparable amplitudes of TGE variation in both the east-west and north-south directions. Our results imply that the resistivity structure of Kozushima possibly has a complex pattern that amplifies the electric field in the east-west direction.

Acknowledgements

The electric field data used in the analysis was recorded as part of the then Science and Technology Agency's "International Frontier Research on Earthquakes" (project leader: Seiya Ueda, Professor Emeritus, University of Tokyo), and we would like to thank Dr. Yoshiaki Orihara and Yoichi Noda who actually conducted the observations. We would also like to take this opportunity to thank Dr. Toshiyasu Nagao for providing the Kozushima electric field data and Dr. Makoto Uyeshima for providing the ASCII data expansion program.

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