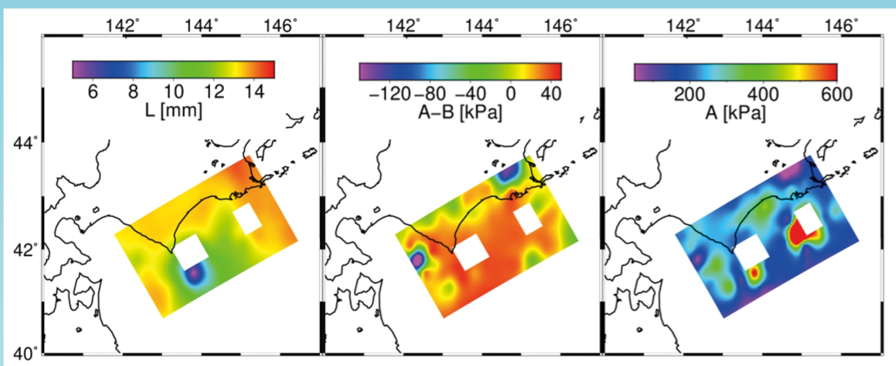
Earth, Planets and Space

Kurile Arc Subduction Zone: View of Great Earthquake Generation and Disaster Mitigation of Related Phenomena



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Earth, Planets and Space

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PREFACE

Open Access

Special issue, "Kurile arc subduction zone: View of great earthquake generation and disaster mitigation of related phenomena"

Yuichiro Tanioka[1*], Naoki Uchida[2], Aditya Riadi Gusman[3], Masanobu Shishikura[4] and Takuya Nishimura[5]

Various great earthquakes have occurred in the past along the Kurile subduction zone where the Pacific plate subducts along the Kurile Trench. The Headquarters for Earthquake Research Promotion, Japan, published a long-term evaluation report on the occurrence of large subduction earthquakes along the Kurile Trench (Headquarters of Earthquake Research Promotion 2018). They reported that the probability of a giant earthquake with a magnitude exceeding M_w 8.8 along the Kurile trench in 30 years is between 7 and 40%, as of 2021. Mitigation of disasters due to the giant earthquake along the Kurile arc subduction zone has become one of urgent challenges in Japan. This special issue covers various researches concerning earthquake generation and postseismic processes, seismic wave attenuation, forecast of seismic activities, and mitigation of tsunami disasters in and around the subduction zone.

First, precise hypocenter estimation of micro-earthquakes along the Kurile subduction zone is a key to understand seismic activity and the stress field. Ichiyanagi et al. (2020) presented that the estimation error of hypocenter along the Kurile trench was significantly reduced using both Japanese and Russian data. In addition, Shiina et al. (2021) indicated that high-attenuation zones in the backarc mantle wedge controlled propagations of high-frequency S-wave later phases in addition to the scatterers in the forearc region.

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Next, using precise micro-earthquake data, the stress field due to the Kurile subduction can be studied. Maeda et al. (2020) studied the spatiotemporal variation in stress from eastern Aomori to Tsugaru Strait using those data. Their results indicated that those variations reflected the effects of the upper-plate bending and the 2011 Tohoku-Oki earthquake, and that the compressional stress caused by the Pacific plate was relatively weak. Using aftershock data of the 2018 Eastern Iburi earthquake, Susukida et al. (2018) studied the stress field in the aftershock area in the western boundary of the Hidaka Collision Zone. Their results showed that the reverse-fault-type stress field was predominant in this area.

Finally, forecast of future earthquake activities and precise tsunami forecast are challenges for disaster mitigation. Katsumata and Nakatani (2021) tested the seismic quiescence hypothesis through retrospective trials of alarm-based earthquake prediction in the Kurile–Japan subduction zone. Their conclusion is that there is a reasonable chance that their tested quiescence will pass the cross-validation test when more target earthquakes become available in the near future. Kano et al. (2020) developed an adjoint method assimilating GNSS time series data to optimize the frictional parameters that control the slip behavior on the fault. They applied the method to the observed GNSS time series for the first 15 days following the 2003 Tokachi-oki earthquake and found that the optimized frictional parameters quantitatively predicted the postseismic GNSS time series. Therefore, their data assimilation method is an effective evaluation method for assessing risks of subsequent earthquakes and for monitoring the recovery process of megathrust earthquakes. As a near-field tsunami forecasting method, Tanioka (2020) developed a method assimilating ocean-bottom pressure sensor network (S-net) without any information of earthquakes. The method was numerically tested for two large underthrust fault models, a giant earthquake (M_w8.8) and the Nemuro-oki earthquake (M_w8.0) models along the Kurile arc subduction zone. The results indicated that the method was applicable to the data at the S-net stations.

This special issue presents promising results for mitigation of disaster due to giant earthquakes along the Kurile arc subduction zone although some of researches are still primitive and also challenging. Continuation of studies is necessary to mitigate disaster due to future giant earthquakes. Most of researches presented in this special issue were supported by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan, under "The Second Earthquake and Volcano Hazards Observation and Research Program".

Authors' contributions
YT, NU, AG, MS, and TN served as guest editors for this special issue. All authors read and approved the final manuscript.

Competing interests
The authors declare that they have no competing interests.

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Tanioka Y (2020) Improvement of near-field tsunami forecasting method using ocean-bottom pressure sensor network (S-net). Earth Planets Space 72:132. https://doi.org/10.1186/s40623-020-01268-1

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FULL PAPER **Open Access**

Improvement of near-field tsunami forecasting method using ocean-bottom pressure sensor network (S-net)

Yuichiro Tanioka

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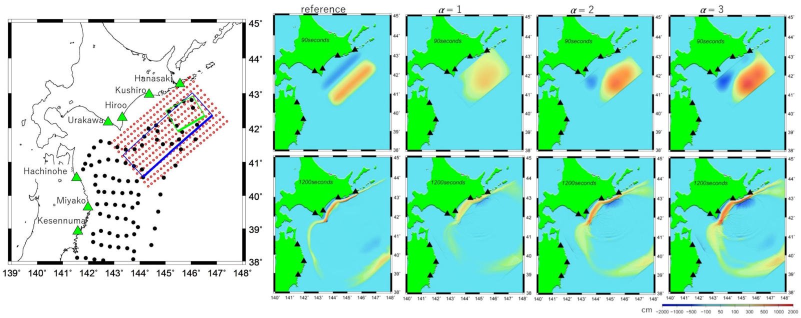
Abstract

Since the installation of a dense cabled observation network around the Japan Trench (S-net) by the Japanese government that includes 150 sensors, several tsunami forecasting methods that use the data collected from the ocean floor sensors were developed. One of such methods is the tsunami forecasting method which assimilates the data without any information of earthquakes. The tsunami forecasting method based on the assimilation of the ocean-bottom pressure data near the source area was developed by Tanioka in 2018. However, the method is too simple to be used for an actual station distribution of S-net. To overcome its limitation, we developed an interpolation method to generate the appropriate data at the equally spaced positions for the assimilation from the data observed at sensors in S-net. The method was numerically tested for two large underthrust fault models, a giant earthquake (Mw8.8) and the Nemuro-oki earthquake (Mw8.0) models. Those fault models off Hokkaido in Japan are expected to be ruptured in the future. The weighted interpolation method, in which weights of data are inversely proportional to the square of the distance, showed good results for the tsunami forecast method with the data assimilation. Furthermore, results indicated that the method is applicable to the actual observed data at the S-net stations. The only limitation of the weighted interpolation method is that the computed tsunami wavelengths tend to be longer than the actual tsunamis wavelength.

Keywords: Tsunami forecasting method, Data assimilation, Tsunami numerical simulation, Kurile subduction zone



Graphical abstract

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FULL PAPER **Open Access**

Adjoint-based direct data assimilation of GNSS time series for optimizing frictional parameters and predicting postseismic deformation following the 2003 Tokachi-oki earthquake

Masayuki Kano*, Shin'ichi Miyazaki, Yoichi Ishikawa and Kazuro Hirahara

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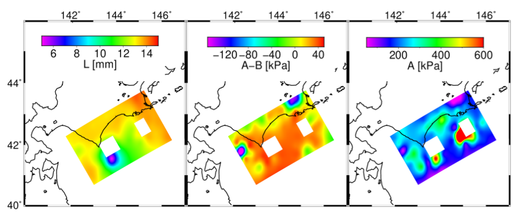
Abstract

Postseismic Global Navigation Satellite System (GNSS) time series followed by megathrust earthquakes can be interpreted as a result of afterslip on the plate interface, especially in its early phase. Afterslip is a stress release process accumulated by adjacent coseismic slip and can be considered a recovery process for future events during earthquake cycles. Spatio-temporal evolution of afterslip often triggers subsequent earthquakes through stress perturbation. Therefore, it is important to quantitatively capture the spatio-temporal evolution of afterslip and related postseismic crustal deformation and to predict their future evolution with a physics-based simulation. We developed an adjoint data assimilation method, which directly assimilates GNSS time series into a physics-based model to optimize the frictional parameters that control the slip behavior on the fault. The developed method was validated with synthetic data. Through the optimization of frictional parameters, the spatial distributions of afterslip could roughly (but not in detail) be reproduced if the observation noise was included. The optimization of frictional parameters reproduced not only the postseismic displacements used for the assimilation, but also improved the prediction skill of the following time series. Then, we applied the developed method to the observed GNSS time series for the first 15 days following the 2003 Tokachi-oki earthquake. The frictional parameters in the afterslip regions were optimized to $A–B \sim O(10\ \mathrm{kPa})$, $A \sim O(100\ \mathrm{kPa})$, and $L \sim O(10\ \mathrm{mm})$. A large afterslip is inferred on the shallower side of the coseismic slip area. The optimized frictional parameters quantitatively predicted the postseismic GNSS time series for the following 15 days. These characteristics can also be detected if the simulation variables can be simultaneously optimized. The developed data assimilation method, which can be directly applied to GNSS time series following megathrust earthquakes, is an effective quantitative evaluation method for assessing risks of subsequent earthquakes and for monitoring the recovery process of megathrust earthquakes.

Keywords: Data assimilation, Afterslip, The 2003 Tokachi-oki earthquake, GNSS, Frictional parameters, Postseismic deformation prediction



Graphical abstract

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FULL PAPER **Open Access**

Focal mechanisms and the stress field in the aftershock area of the 2018 Hokkaido Eastern Iburi earthquake ($M_{JMA}=6.7$)

Yuki Susukida, Kei Katsumata*, Masayoshi Ichiyanagi, Mako Ohzono, Hiroshi Aoyama, Ryo Tanaka, Masamitsu Takada, Teruhiro Yamaguchi, Kazumi Okada, Hiroaki Takahashi, Shin'ichi Sakai, Satoshi Matsumoto, Tomomi Okada, Toru Matsuzawa, Hiroki Miyamachi, Shuichiro Hirano, Yoshiko Yamanaka, Shinichiro Horikawa, Masahiro Kosuga, Hiroshi Katao, Yoshihisa Iio, Airi Nagaoka, Noriko Tsumura, Tomotake Ueno and The Group for the Aftershock Observations of the 2018 Hokkaido Eastern Iburi Earthquake

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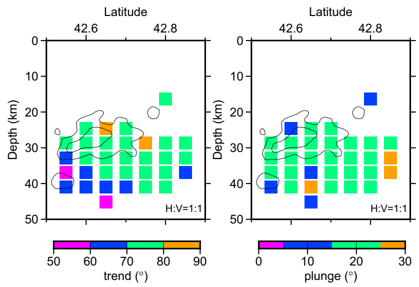
Abstract

The tectonic stress field was investigated in and around the aftershock area of the Hokkaido Eastern Iburi earthquake ($M_{JMA}=6.7$) occurred on 6 September 2018. We deployed 26 temporary seismic stations in the aftershock area for approximately 2 months and located 1785 aftershocks precisely. Among these aftershocks, 894 focal mechanism solutions were determined using the first-motion polarity of P wave from the temporary observation and the permanent seismic networks of Hokkaido University, Japan Meteorological Agency (JMA), and High Sensitivity Seismograph Network Japan (Hi-net). We found that (1) the reverse faulting and the strike-slip faulting are dominant in the aftershock area, (2) the average trend of P- and T-axes is 78°±33° and 352°±51°, respectively, and (3) the average plunge of P- and T-axes is 25°±16° and 44°±20°, respectively: the P-axis is close to be horizontal and the T-axis is more vertical than the average of the P-axes. We applied a stress inversion method to the focal mechanism solutions to estimate a stress field in the aftershock area. As a result, we found that the reverse fault type stress field is dominant in the aftershock area. An axis of the maximum principal stress (σ_1) has the trend of 72°±7° and the dipping eastward of 19°±4° and an axis of the intermediate principal stress (σ_2) has the trend of 131°±73° and the dipping southward of 10°±9°, indicating that both of σ_1- and σ_2-axes are close to be horizontal. An axis of the minimum principal stress (σ_3) has the dipping westward of 67°±6° that is close to be vertical. The results strongly suggest that the reverse-fault-type stress field is predominant as an average over the aftershock area which is in the western boundary of the Hidaka Collision Zone. The average of the stress ratio $R=(\sigma_1-\sigma_2)/(\sigma_1-\sigma_3)$ is 0.61±0.13 in the whole aftershock area. Although not statistically significant, we suggest that R decreases systematically as the depth is getting deep, which is modeled by a quadratic polynomial of depth.

Keywords: The Hokkaido Eastern Iburi earthquake, Reverse fault, Aftershock distribution, Focal mechanism solution, Temporary seismic network, Stress inversion



Graphical abstract

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FULL PAPER **Open Access**

Attenuation contrast in mantle wedge across the volcanic front of northeastern Japan that controls propagations of high-frequency S-wave later phases

Takahiro Shiina*, Kei Katsumata, Kiyoshi Yomogida and Aitaro Kato

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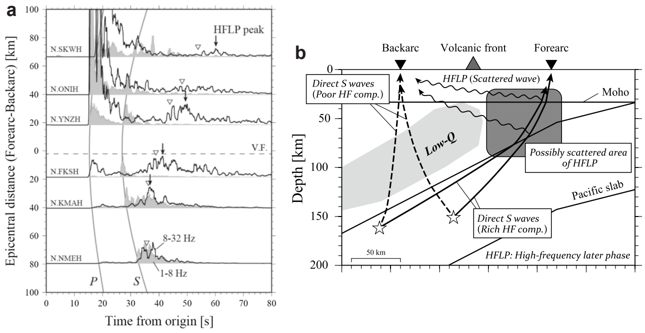
Abstract

Distinct later phases of waves with rich high-frequency (>8 Hz) components were observed for intraslab earthquakes that occurred at intermediate depths, particularly at depths exceeding 100 km, in the northeastern (NE) Japan subduction zone. These high-frequency later phases (HFLPs) showed anomalously large peak-amplitude delays, up to ~50 s after direct S-wave arrivals at stations in the backarc region. Using a source-scanning algorithm, we investigated the locations of passing points affecting the propagation of HFLPs. The passing points were estimated to be in the forearc region in the entire NE Japan, indicating that HFLPs are scattered waves that pass through the forearc region. The propagating HFLPs seem to bypass the backarc mantle wedge, as a consequence of the distinct attenuation contrast in the mantle wedge across the volcanic front in NE Japan. These HFLP observations suggest that the high-attenuation zone in the backarc mantle wedge controls propagations of the high-frequency waves of intraslab earthquakes, in addition to the scatterers possibly locate in the forearc region.

Keywords: High-frequency later phase, Intraslab earthquake, Seismic wave scattering, S-wave attenuation



Graphical abstract

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FULL PAPER **Open Access**

Testing the seismic quiescence hypothesis through retrospective trials of alarm-based earthquake prediction in the Kurile–Japan subduction zone

Kei Katsumata* and Masao Nakatani

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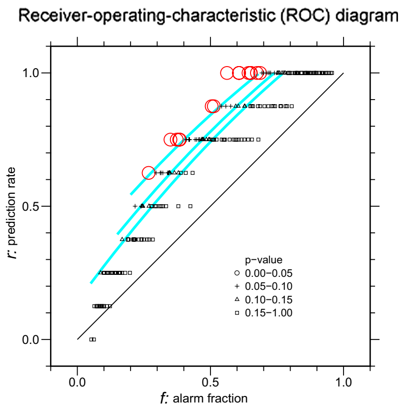
Abstract

We make trial binary forecasts for the Kurile–Japan subduction zone for the period 1988–2014 by hypothesizing that seismic quiescence (i.e., the absence of earthquakes of $M \geq 5$ for a minimum period of T_q) is a precursor of a large ($7.5 \leq M_w < 8.5$) earthquake in the coming period T_a within a radius R of the quiescence. We evaluate the receiver-operating-characteristic diagram constructed using a range of forecast models specified by (T_q, R, T_a). A forecast experiment targeting eight large earthquakes in the studied spacetime suggests that the risk of a large earthquake is modestly (probability gain $G \sim 2$) but significantly (p-value less than 5%) heightened for several years following a long quiescent period of $T_q \geq 9$ years, within several tens of kilometers of the quiescence. We then attempt cross-validation, where we use half the data for training [i.e., optimization of (T_q, R, T_a)] and the remaining half for evaluation. With only four target earthquakes available for evaluation of the forecasts in each of the learning and evaluation periods, our forecast scheme did not pass the cross-validation test (with a criterion that the p-value is less than 5%). Hence, we cannot formally deny the possibility that our positive results for the overall period are a ghost arising from over-fitting. However, through detailed comparison of optimal models in the overall test with those in the cross-validation tests, we argue that severe over-fitting is unlikely involved for the modest G of ~ 2 obtained in the overall test. There is thus a reasonable chance that the presently tested type of quiescence will pass the cross-validation test when more target earthquakes become available in the near future. In the meantime, we find that G improves to ~ 5 when target earthquakes are limited to $8 \leq M_w < 8.5$, though we cannot say anything about the possible involvement of over-fitting because we have only three such very large target earthquakes.

Keywords: Earthquake prediction, Seismic quiescence, Cross-validation, Kurile–Japan subduction zone



Graphical abstract

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EXPRESS LETTER **Open Access**

Spatiotemporal variations in the stress field in the northeasternmost part of the NE Japan arc: constraints from microearthquakes

Sumire Maeda*, Toru Matsuzawa, Tomomi Okada, Hiroshi Katao, Takeyoshi Yoshida, Masahiro Kosuga and Makoto Otsubo

Earth, Planets and Space 2020, **72**:117 10.1186/s40623-020-01245-8
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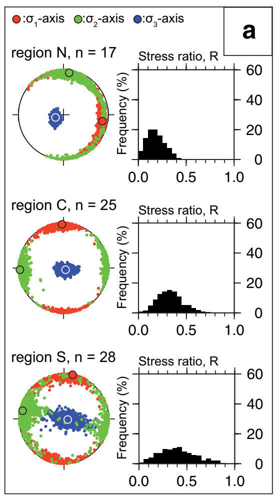
Abstract

We determined focal mechanism solutions of microearthquakes and examined the stress field in the low-seismicity region from southern Hokkaido to eastern Aomori, NE Japan. The stress fields determined in this study comprise (1) a reverse faulting stress regime in southern Hokkaido with the axis of maximum compressional stress (σ_1) being sub-horizontal and trending WNW–ESE, and (2) a stress regime in eastern Aomori to Tsugaru Strait that shows temporal variations and differential stress of less than tens of MPa. The spatiotemporal variation in stress from eastern Aomori to Tsugaru Strait might reflect the effects of the upper-plate bending and the 2011 M_w 9.0 Tohoku-Oki earthquake. It also indicates that the compressional stress caused by the descending Pacific plate is relatively weak, which is similar to other areas in eastern parts of the NE Japan arc.

Keywords: Focal mechanism, Stress field, Low-seismicity area, Microseismicity, Forearc, Northeastern Japan, Pacific plate subduction, Kurile arc



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TECHNICAL REPORT Open Access

Evaluation for hypocenter estimation error in the southwestern Kuril trench using Japan and Russia joint seismic data

Masayoshi Ichiyanagi, Valentin Mikhaylov, Dmitry Kostylev, Yuri Levin and Hiroaki Takahashi*

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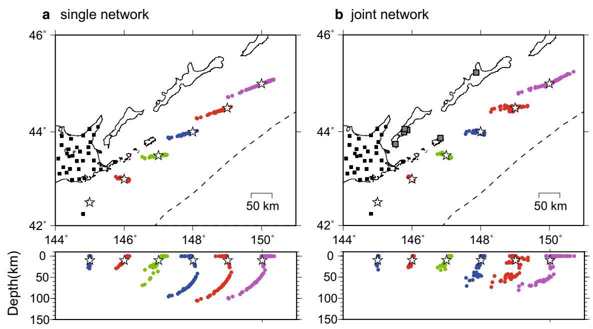
Abstract

The southwestern Kuril trench is seismically active due to the subduction of the Pacific plate. Great earthquakes in this zone have frequently induced fatal disasters. Seismic monitoring and hypocenter catalogs provide fundamental information on earthquake occurrence and disaster mitigation. Real-time hypocenter and magnitude estimates are extremely crucial data for tsunami warning systems. However, this region is located in the international border zone between Japan and Russia. The Japan Meteorological Agency and Russian Academy of Sciences have routinely determined hypocenters and issued earthquake information independently. Waveform data have not yet been exchanged internationally in real time. Here, we evaluated how a hypothetical Japan–Russia joint seismic network could potentially improve the hypocenter estimation accuracy. Experiments using numerical and observed data indicated that the joint network extended the distance over which hypocenters can be accurately determined over 100 km eastward compared to the Japan network only. This fact suggests that joint seismic data have the potential to improve the hypocenter accuracy in this region, which would provide improved performance in gathering disaster information at the moment of a tsunami warning.

Keywords: The southwestern Kuril trench, Hypocenter determination, Japan and Russia joint seismic network, Great subduction earthquakes, Tsunami warning



Graphical abstract

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