Friday, 3 May 2024—Oral Sessions

Presenting author is indicated in bold.

Time	*Tikahtnu Ballroom C*
	The 2024 Magnitude 7.5 Earthquake and the Associated Earthquake Swarm Beneath the Noto Peninsula, Central Japan
8:00 AM	Rupture Process and Consequences of the 2024 Noto Peninsula Earthquake. **Koketsu, K.**, Diao, H., Si, H.
8:15 AM	INVITED: Geodetically Estimated Ground Displacement and Fault Motions of the 2024 Noto Peninsula Earthquake. **Kobayashi, T.**, Munekane, H., Suito, H., Kuwahara, M., Ishimoto, M., *et al.*
8:30 AM	Noto Peninsula, Japan, Earthquake, January 1, 2024: Implications of Inconsistent Seismic Energy Estimates From Teleseismic and Strong Ground Motion Observations. **Anderson, J. G.**, Brune, J. N.
8:45 AM	Strong Motion Characteristics and Structural Damage in Noto Peninsula During the 2024 Noto Hanto Earthquke. **Kawase, H.**, Ito, E., Baoyintu, B.
9:00 AM	Infrasound Signals and Their Implications From the 2024 M7.5 Noto Earthquake in Japan. **Park, J.**, Arrowsmith, S., Che, I., Hayward, C., Stump, B.
9:15–10:30 AM	Poster Break
10:30 AM	Human Behavioral Response in the M7.5 Noto Hanto Japan Earthquake of January 1, 2024: Did Receiving an Earthquake Early Warning Affect Response? **Goltz, J. D.**
10:45 AM	Deformation of the 2020-2024 Noto Peninsula Earthquake Sequence Revealed by Combined Analysis of Multiple GNSS Observation Networks in Central Japan. **Nishimura, T.**, Hiramatsu, Y., Ohta, Y.
11:00 AM	INVITED: The 2024 Mw 7.5 Noto Peninsula Earthquake Initiated in a Fluid-Driven Swarm. **Yoshida, K.**
11:15 AM	The Evolution Process Between the Earthquake Swarm Beneath the Noto Peninsula, Central Japan and the 2024 M 7.5 Noto Hanto Earthquake. **Peng, Z.**, Lei, X., Wang, Q., Wang, D., Mach, P., *et al.*
11:30 AM	
11:45 AM–2:00 PM	Lunch Break

Poster Sessions

The 2024 Magnitude 7.5 Earthquake and the Associated Earthquake Swarm Beneath the Noto Peninsula, Central Japan

180. STUDENT: Comparison of Multiple Methods to Identify Remotely Triggered Tremor and Their Application in Japan Following the 2024 M 7.5 Noto Earthquake. **Ding, C.**, Peng, Z., Yao, D., Obara, K., Enescu, B.
181. Mechanisms of Early Postseismic Deformation Following the 2024 Noto Hanto Earthquake Inferred from GNSS Data. **Kim, J.**, Pollitz, F., Schmidt, D. A.
182. Preliminary Analysis of the 2024 Noto Peninsula Earthquake, Perspective From LANL's Geophysical Explosion Monitoring (GEM) Team. **Kintner, J. A.**, Alfaro-Diaz, R. A., Begnaud, M., Bishop, J., Blom, P. S., *et al.*
183. Seismic Dynamics in Advance and After the January 1, 2024 MJMA 7.6 Noto Peninsula Earthquake. Kossobokov, V. G., Nekrasova, A. K., **Rabinovich, A. B.**
184. Adaptive Wavelet Thresholding and Grouping Approach for Repetitive Seismic Swarm Detection: Application to the Noto Peninsula Earthquake Swarm. **Zhang, J.**, Yang, H.

The 2024 Magnitude 7.5 Earthquake and the Associated Earthquake Swarm Beneath the Noto Peninsula, Central Japan

Oral Session • Friday 3 May • 08:00 AM Pacific

Conveners: Dara Goldberg, U.S. Geological Survey (degoldberg@usgs.gov); Sarah Minson, U.S. Geological Survey (sminson@usgs.gov); Takuya Nishimura, Disaster Prevention Research Institute, Kyoto University (nishimura.takuya.4s@kyoto-u.ac.jp); Zhigang Peng, Georgia Institute of Technology (zpeng@gatech.edu); Dun Wang, Chinese University of Geosciences (wangdun@cug.edu.cn); Suguru Yabe, Geological Survey of Japan (s.yabe@aist.go.jp)

Rupture Process and Consequences of the 2024 Noto Peninsula Earthquake

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The Noto Peninsula earthquake occurred in the northern part of the Noto Peninsula at 16:10:10 (local time, UTC+9) on January 1, 2024, causing extensive and severe damage. To construct a rupture process model for this earthquake, we first built a fault model, which consists of northeastern (NE) and southwestern (SW) segments, based on the known active fault traces, aftershock distribution and reported focal mechanisms. The hypocenter (rupture initiation point) was located on the NE segment, whose strike and dip are consistent with the focal mechanism of the mainshock. The strike and dip of the SW segment were mainly determined according to the aftershock distribution. We next performed a joint source inversion using teleseismic waveforms from the Global Seismographic Network and strong motion waveforms recorded by K-NET and KiK-net. The results showed that the mainshock ruptured with a duration of about 50 s, releasing a total seismic moment of 2.4×10^{20} Nm, which corresponds to an M_w of 7.5. The rupture began with small slips on the NE segment in the first 10 s. It then propagated northeastward and the SW segment began to rupture. These two beginnings would correspond to two events determined at 16:10:10 and 16:10:23 by the JMA. Large slip zones (asperities) with maximum slips of 5 and 6 meters were formed in the shallow parts of both NE and SW segments. The SW asperity roughly covers the northern part of the peninsula and is responsible for the strong ground motion and resulting damage there. It is also responsible for the large uplift of the northern coast of the peninsula. On the other hand, since the NE asperity is under the sea, it is responsible for large tsunamis and resulting damage on the northeastern coast.

Geodetically Estimated Ground Displacement and Fault Motions of the 2024 Noto Peninsula Earthquake

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An intense seismic swarm and transient crustal deformation have started in the Noto Peninsula, central Japan since the end of 2020, followed by a magnitude 7.5 earthquake occurred on January 1, 2024. Here we report on GNSS- and SAR-detected ground deformation and the geodetically estimated fault model. The GNSS data show that the northern part of the peninsula which is distributed in the east-west orientation uniformly moves westward with ~2 m at most. Large uplifts with ~ 1 m are observed at stations deployed in the northern coast of the peninsula. SAR-derived deformation map estimated by InSAR and pixel offset methods unveils the detailed spatial distribution of the displacement field. Large uplift is distributed along the northern coast with two main areas: The maximum uplift reaches ~4 m in the northwestern tip of the peninsula, and the second largest uplift, reaching ~2 m, is located in the west of the epicenter. GNSS data also detect significant post-seismic deformation. Northwestward displacements with ~1-2 cm are widely observed not only in the peninsula but also in areas 50-100 km away from the source region. Subsidence and upheaval are observed within and outside the peninsula, respectively.

Our fault model for the coseismic deformation consists of three fault segments with almost pure reverse motions: The westernmost fault extending a north-northeast orientation has a slip amount of ~10 m which produces the uplift of ~4 m on the ground. The fault next to the east extends in almost east-west orientation along the coast, and includes a right-lateral slip motion. The easternmost fault segment changes direction to the northeast on the west side of the epicenter, and has a large slip off the east coast of the tip of the peninsula. The post-seismic deformation can be explained by a slip off the east coast of the tip of the peninsula on the easternmost segment.

Acknowledgements: ALOS-2 data were provided from the Earthquake Working Group under a cooperative research contract with JAXA (Japan Aerospace Exploration Agency). The ownership of ALOS-2 data belongs to JAXA.

Noto Peninsula, Japan, Earthquake, January 1, 2024: Implications of Inconsistent Seismic Energy Estimates From Teleseismic and Strong Ground Motion Observations

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The excellent network of strong motion accelerographs on the Noto Penninsula enables comparison of the radiated seismic energy (E_S) from the earthquake of January 1, 2024, as observed locally and at teleseismic distances. At teleseismic distances, IRIS estimates that the radiated energy in the broadband frequency range was 2.32 e+15 J. Considering alternative fault geometries, the strong motion stations on the hanging wall yield estimates in the range 8.8-20.2 e+15 J, i.e about 4-9 times greater. These results can be compared with other earthquakes using the scaled energy (E_S/M_0), log scaled energy (θ), or apparent stress ($\tau_a=\mu E_S/M_0$). For the Noto Penninsula earthquake, the teleseismic data imply τ_a=0.44 MPa, while local estimates give 1.6-3.8 MPa. Differences in the observed frequency bands are ruled out as a cause for the discrepancy between the teleseismic and local estimates. For perspective, the teleseismic study of Convers and Newman (2011) reports average values of θ for reverse, strike slip, and normal faulting that convert to values of τ_a of 0.7, 1.6, and 1.2 MPa, respectively.

The local - teleseismic discrepancy here may be typical of reverse faulting events, as the free surface boundary for the upper wedge allows it to move more than the rock below the fault. If this discrepancy is general, a teleseismic estimate of τ_a would not be reliable for local hazard estimates. Also, the average apparent stress in reverse faulting events may not be smaller than normal and strike-slip events. One might expect that some energy radiated into the wedge is reflected to teleseismic distances and contributes to the teleseismic estimate, but even if this is true, the large discrepancy remains. Perhaps that is because the fault not transparent while it ruptures. One possible mechanism is separation of the hanging wall from the foot wall, (e.g. Brune, 2001; Gabuchian et al., 2017). Non-linearity in the upper wedge, in the bedrock as well as in soils, would also absorb energy before it can be reflected to teleseismic distances.

Strong Motion Characteristics and Structural Damage in Noto Peninsula During the 2024 Noto Hanto Earthquke

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During the 2024 Noto Hanto earthquake, we have observed strong ground motions at about 20 sites in the region of the seismogneic fault in the Noto Peninsula, primarily by the network of NIED (K-NET and KiK-net) and JMA (Shindo-kei network). We also measured microtremors at some of these strong motion sites as well as the sites in the middle of the devastating damage in Suzu City, Wajima City, and Anamizu Town several days after the mainshock. The occurrence of aftershocks were continued at that time and so what we measured should be considered as small aftershocks. Before the mainshock we have been analysing the site effects of all the strong motion network sites in Japan and found that conspicuous strong site amplifications were observed at the strong motion sites in these cities and towns inside the Noto Peninsula. There is a strong concern what is the primary source of the observed heavy damage in these three cities and towns. To that end we used a structural damage prediction models developed by the damage statistics during the 1995 Kobe earthquake (Nagato and Kawase, 2000) in which we can calculate structural damage probabilities by using a set of structures with different seismic capacities for each category of buildings and houses. When we applied the model for 2-storied wooden houses, we hound that at the sites in the middle of the heavily damaged zones the calculated damage probabilities reach to about 30 %. This level of damage ratios corresponds to the observed damage ratios around the strong motion sites performed by a team of Profs. Nakazawa and Sakai as an immediate survey in the field (Nakazawa et al., 2024). Considering the limited area of the damage concentration in Suzu City, Wajima City, and Anamizu Town, there is no space for doubt where the site effects played a significant role for the structural damage distributions in these cities and towns. However, we should emphasize that this correlation with site conditions should not be interpreted as a consequence of amplification above the engineering badrock, because the amplification is high in the intermediate frequency around 1 Hz and lower.

Infrasound Signals and Their Implications From the 2024 M7.5 Noto Earthquake in Japan

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Earthquakes can generate infrasound, low-frequency (< 20 Hz) acoustic waves that propagate through the atmosphere as a result of surface ground motions near the epicenter. The study of earthquake-generated infrasound using remote sensor array data can provide constraints on the coupling mechanism between ground motion and the atmosphere, the level of strong ground motion around the source, as well as the propagation path effects through the atmosphere. The earthquake (M7.5, 1 January 2024) occurred on the west coast of Japan on the Noto Peninsula produced infrasound signals that were observed by at least 14 remote infrasound arrays to distances as great as 3489 km. This data set includes signals at six seismo-acoustic arrays operated cooperatively by Southern Methodist University and Korea Institute of Geoscience and Mineral Resources (KIGAM), three infrasound arrays operated by KIGAM, and five International Monitoring System infrasound stations in Japan, Russia, Mongolia, and US, designed to monitor the Comprehensive Nuclear-Test-Ban Treaty. In this study, we focus on the assessments of infrasound signal characteristics and constraints of propagation effects to reconstruct the earthquake source region that generated these waves. Infrasound signals from the main earthquake and aftershocks are identified based on the F-K analysis using array data. Multiple infrasound arrivals of coherent waves with long time durations (15 minutes to 1 hour) are linked to epicentral and diffracted infrasound sources with backazimuths changing in time, corresponding to the source location and the topography of the surrounding area. The atmospheric model predicts a two-directional stratospheric duct at the time of the earthquake associated with a sudden stratospheric warming event. Infrasound backprojections are produced using the backazimuths and arrival times at each array to image source locations. This event illustrates how infrasound observations accompanying earthquakes can be utilized to constrain strong ground motions near the source and the subsequent interactions of the coupled infrasound waves with the atmosphere.

Human Behavioral Response in the M7.5 Noto Hanto Japan Earthquake of January 1, 2024: Did Receiving an Earthquake Early Warning Affect Response?

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The January 1, 2024 earthquake located in the Noto Hanto peninsula area of Ishikawa Prefecture measured M7.5 at a depth of 10 km. The earthquake occurred at 4:10 PM local time and generated a maximum intensity of 7 on the Japanese Shindo scale. As of February 9, the Japanese Red Cross reported 241 fatalities, 1,291 injuries, 45,231 residential buildings collapsed or damaged and a sheltered population of 13,469 in 522 evacuation shelters https://www.jrc.or.jp/english/relief/2024NotoPeninsulaEarthquake.html. A total of 393 people completed the USGS 'Did you feel it?' (DYFI) questionnaire reporting their experience of the earthquake and 67 responded to the new earthquake early warning (EEW) supplemental questionnaire implemented in February 2022. The earthquake in Japan is the largest event to date to include data on receipt of an EEW within the larger context of the DYFI system. Though the number of respondents was not large, there were some trends in the data that may be suggestive of response to other large earthquakes in countries with EEW systems. The data include whether an EEW was received before, during or after shaking was experienced; the length of the alert in seconds; where the respondent was located when the alert was received; who he/she was with; and most important, how the respondent responded to the EEW received. There are additional questions on respondent perceptions of the usefulness of the EEW and preferences for future alerts. The EEW questionnaire also includes demographic data on age, gender and educational attainment. Preliminary review of the data suggests that those who received an EEW were more likely than those who did not to actively (vs. passively) respond and to respond according to the recommended drop, cover and hold on procedure. Other findings based on the DYFI supplemental EEW questionnaire suggest that users find the EEW system in Japan useful and that early alerts will likely promote adaptive behavioral response in future earthquakes.

Deformation of the 2020-2024 Noto Peninsula Earthquake Sequence Revealed by Combined Analysis of Multiple GNSS Observation Networks in Central Japan

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Since November 30, 2020, an intense earthquake swarm and transient deformation have been continuously observed in the Noto Peninsula, central Japan, which is a non-volcanic/geothermal area far from major plate boundaries. During the earthquake sequence, M_w6.2 and M_w7.5 earthquakes occurred on May 5, 2023, and January 1, 2024, respectively. We report the transient and coseismic deformation based on a combined analysis of multiple Global Navigation Satellite System (GNSS) observation networks, including one operated by SoftBank Corp., relocated earthquake hypocenters, and tectonic settings. The start of the transient deformation coincides with a burst-type activity of small earthquakes in late 2020. A total displacement pattern in the first two years shows horizontal inflation and uplift of up to ~60 mm around the source of the earthquake swarm. The coseismic horizontal and vertical displacements of the M_w7.5 earthquake reached ~2 m westward motion and uplift along the northern coast. The postseismic displacement for the first month shows horizontal displacement directed toward the source area and the differences between co- and post-seismic displacements are a gentle spatial decay of horizontal displacement from the source area and subsidence in and around the source area during the postseismic period. Based on the observation, we suggest that fluid with a few 10^7 m^3 of volumetric increase was upwelled to mid crust, and that the fluid spread at a depth of ~16 km through an existing shallow-dipping permeable fault zone. Then it diffused into the fault zone, triggering a long-lasting aseismic slip below the seismogenic depth. The aseismic slip further triggered intense earthquake swarms including the M_w7.5 earthquakes at the updip.

Acknowledgments: The SoftBank's GNSS observation data used in this study was provided by SoftBank Corp. and ALES Corp. through the framework of the "Consortium to utilize the SoftBank original reference sites for Earth and Space Science". We are also grateful to GSI for providing us with GNSS data.

The 2024 Mw 7.5 Noto Peninsula Earthquake Initiated in a Fluid-Driven Swarm

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On 1 January 2024, an Mw 7.5 earthquake rupture occurred along the northern coast of the Noto Peninsula, Ishikawa Prefecture, and its eastern extension. The northeastern tip of the Peninsula, near the Mw7.5 hypocenter, has seen a rapid increase in seismicity since the end of 2020, attracting much attention. This talk will present the characteristics and implications of the spatio-temporal distribution of earthquakes before and after the Mw 7.5 earthquake, revealed from regional seismic data.

During the earthquake swarm before the mainshock, small earthquakes systematically moved to the shallow side via a complex fault network (Yoshida et al., 2023, JGR). Seismicity was initiated in a locally deep cluster, with a distinct S-wave reflector and seismic low-velocity zone below. Unusual crustal deformations, the magnitude of which was much larger than that of the swarm earthquakes, were observed around the hypocenter (Nishimura et al., 2023). The 2023 Mw 6.2 earthquake occurred near the upper end of one of a fault zone, propagating in the updip direction, with aftershocks occurring further shallow on the same fault (Yoshida et al., 2023, GRL). The Mw7.5 mainshock started near the fault zones of the swarm and eventually ruptured both the east and west sides. Aftershocks occur within a range of 150 km but are basically concentrated on the north-northeast dipping plane to the west and the south-southeast dipping plane to the east.

Upward migration of fluids likely triggered the swarm activity and aseismic deformations before the mainshock. The present observation indicates that Mw7.5 earthquakes can be initiated by fluid-driven swarm activity. Presumably, considerable strain energies may have accumulated in the main rupture regions before the mainshock, where the properties (e.g., temperature and heterogeneity) may differ from those in the swarm region. In the source region of the prior swarm earthquakes, earthquakes started to occur at a shallower plane than before, and this plane may coincide with a known active fault. Upward migration of fluids may still be ongoing there.

The Evolution Process Between the Earthquake Swarm Beneath the Noto Peninsula, Central Japan and the 2024 M 7.5 Noto Hanto Earthquake

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Understanding the nucleation process of large earthquakes is crucial for forecasting damaging earthquakes and seismic hazard mitigation. While the nucleation process has been identified in the laboratory settings and numerical simulations, it is difficult to observe them directly in the field. Foreshocks may be considered as a by-product of such nucleation process. While many large earthquakes have foreshocks, it is challenging to effectively distinguish foreshocks from background earthquake sequences. Several physical mechanisms of foreshocks, such as pre-slip, cascade triggering, migratory aseismic slip, and fluid-driven models, have been proposed. However, it is still not clear which model(s) play the most important role in driving the foreshocks and mainshock nucleation for a specific sequence. In this study, we focus on the relationship between an intensive earthquake swarm that started beneath the Noto Peninsula in Central Japan since November 2020 and the nucleation of the 2024 M7.5 Noto Hanto earthquake. We perform back-projection of high-frequency teleseismic P waves of the M7.5 mainshock to better understand the rupture initiation and propagation. In addition, we relocate earthquakes listed in the standard Japan Meteorological Agency (JMA) catalog with the double-different relocation method, and compute Coulomb stress changes from the M 5.5 and 4.6 foreshocks that occurred about 4 and 2 minutes before the M7.5 mainshock. Our back-projection results show a prolonged initial rupture process near the mainshock hypocenter lasting for ~25 sec, before propagating bi-laterally outward. In addition, the Coulomb stress changes from the M5.5 foreshock were negative at the hypocenter of the M7.5 mainshock, inconsistent with the cascade triggering model. Our results suggest a complex nucleation process of the M7.5 mainshock, which cannot be simply explained by either of the aforementioned physical models. Instead, we propose that a combination of fluid migration, aseismic slip and elastic stress triggering, likely work in concert to drive both the prolonged earthquake swarm and the nucleation of the M7.5 mainshock.

The 2024 Magnitude 7.5 Earthquake and the Associated Earthquake Swarm Beneath the Noto Peninsula, Central Japan [Poster Session]

Poster Session • Friday 3 May

Conveners: Dara Goldberg, U.S. Geological Survey (degoldberg@usgs.gov); Sarah Minson, U.S. Geological Survey (sminson@usgs.gov); Takuya Nishimura, Disaster Prevention Research Institute, Kyoto University (nishimura.takuya.4s@kyoto-u.ac.jp); Zhigang Peng, Georgia Institute of Technology (zpeng@gatech.edu); Dun Wang, Chinese University of Geosciences (wangdun@cug.edu.cn); Suguru Yabe, Geological Survey of Japan (s.yabe@aist.go.jp)

POSTER 180

Comparison of Multiple Methods to Identify Remotely Triggered Tremor and Their Application in Japan Following the 2024 M 7.5 Noto Earthquake

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Deep tectonic tremor belongs to seismically observed slow earthquakes. It is found beneath the seismogenic zone along major plate boundary faults. While most tremor occurs spontaneously or is driven by aseismic slow-slip events (ambient tremor), tremor can be dynamically triggered during long-period surface waves of large distant earthquakes (triggered tremor). The most common way to identify triggered tremor is through a visual inspection of spectrograms or high-frequency waveforms modulated by the surface waves, which is time-consuming and subjective. Recently several automatic methods like cross-correlation of long-period seismic waves and high-frequency envelope function for ambient tremor detection (Masuda and Ide, 2023), or energy ratios between the triggering and preceding windows for dynamic triggering (Yun et al., 2021), have been developed. In this study, we compared the performance of these automatic methods with the results from the visual inspection. We utilized continuous waveforms recorded by Hi-net and F-net stations in Japan (epicentral distance > 200 km) following the 2024 M7.5 Noto Hanto earthquake. Our visual inspection found triggered tremor in Shikoku and Kyushu regions, consistent with previous findings (Chao and Obara, 2016). In addition, we found a prolonged increase of low-frequency earthquakes in the Kii Peninsula, likely driven by a slow-slip event delay triggered by the Noto mainshock. Next, we computed the cross-correlation coefficients (CCCs) between high-frequency envelope functions and long-period surface waves, using them as metrics to quantify the triggering relationship. While the CCCs show relatively high values at stations where triggered tremor is visually identified, we also found high values at stations with strong clipping or triggered earthquakes/aftershock signals. Our next step is to combine the CCCs values with other parameters to come up with a robust automatic way to identify triggered tremors following large distant earthquakes. We will also combine with other geodetic observations to understand candidate mechanisms for increasing low-frequency earthquakes.

POSTER 181

Mechanisms of Early Postseismic Deformation Following the 2024 Noto Hanto Earthquake Inferred from GNSS Data

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The 2024 M_w 7.5 Noto earthquake provides an opportunity to investigate postseismic mechanisms in regions on and surrounding the Noto Peninsula, Japan. Here, we present our model for the early stage postseismic crustal deformation inferred from GNSS data. We consider the effects from both the viscoelastic (VE) relaxation and afterslip. We produce a postseismic velocity field up to the present (~ 2 months) by fitting each component of GNSS daily position time series with a secular velocity, amplitudes of annual and seasonal variations, steps, and a quadratic function starting from January 2nd, 2024. A calibrated VE relaxation model alone adequately explains far-field postseismic velocities but fails to predict velocities in the vicinity of the earthquake source. Another endmember model of only afterslip, derived by inverting for an optimal slip distribution on the coseismic rupture plane, tends to overpredict near-field and underpredict far-field signals, respectively. Since neither process can solely account for the data, we examine integrated VE relaxation and afterslip models. Preliminary models suggest that the postseismic velocity field can be effectively represented by a combination of afterslip and VE relaxation on a vertically layered model with a 30-40 km thick elastic layer, representing the crust and mantle lithosphere, underlain by a mantle asthenosphere with transient viscosity ~10^{18} Pa s. Afterslip appears to persist several 10s of km to the northeast of the Noto Peninsula, complementing the coseismic slip that appears to be restricted to the peninsula (e.g., the USGS Finite fault model). Our longer-term goals are to characterize the evolving postseismic deformation with a more comprehensive model, which may include lateral variations in viscoelastic properties, and explore the implications for postseismic stress transfer. This study provides insights into the early postseismic deformation processes following the 2024 M_w 7.5 Noto earthquake, underscoring the need to integrate both afterslip and VE relaxation to accurately capture the earthquake-induced transient deformation.

POSTER 182

Preliminary Analysis of the 2024 Noto Peninsula Earthquake, Perspective From LANL's Geophysical Explosion Monitoring (GEM) Team

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The magnitude 7.5 (Mw) earthquake that struck beneath Japan's Noto Peninsula on January 1, 2024 provided an opportunity to test Los Alamos National Laboratory's rapid analysis capability and ongoing R&D in a setting relevant to both nuclear safety and explosion monitoring. Our approach involved characterizing infrasound observations and utilizing numerical modeling to identify, associate, and localize the event's acoustic signatures with corresponding uncertainties. Our seismological analysis provided an opportunity to evaluate event relocation algorithms, automate picking of local to regional phases, investigate remote triggering in areas of interest, and analyze the non-linear soil response during strong ground motions. We also analyzed long-period (<0.05 Hz) seismological signals to estimate source time functions and conduct source inversion. Notably, data from a recent Science Monitoring and Reliable Telecommunications (SMART) cable deployment offshore of Sicily, featuring novel sensor types and data sources, captured strong signals from the event. By integrating these findings, we assessed the reliability of our geophysical data acquisition and storage systems, tested infrasound processing and modeling software, and evaluated seismological source characterization methods.

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Seismic Dynamics in Advance and After the January 1, 2024 Mjma 7.6 Noto Peninsula Earthquake

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Earthquakes are critical transitions in self-organized system of blocks-and-faults of the Earth lithosphere. We continue characterizing foreshock, main shock, and aftershock earthquake sequences in terms of their magnitude-space-time variability and scaling properties, including the time-dependent control parameter of the Unified Scaling Law for Earthquakes, which value $\eta = \tau \times 10B\times(3.5\text{-}M) \times L^C$, in essence, controls distribution of inter-event times between earthquakes at a given site (here τ is the time between the two successive earthquakes, M is the magnitude of the second one, L is the distance between the two, B is analogous to b-value of the classical Gutenberg–Richter relationship, and C estimates fractal dimension of the epicenter loci). A systematic statistical analysis of the recent 2024 Noto Peninsula earthquake discloses that seismic activity at angular distances of 1° and 2.5° from its epicenter resided at steady levels of η before a dramatic change after origination of the seismic swarm marked with escalating maximum of earthquake magnitude: M5.1 on 2021/09/15, M5.4 on 2022/06/19, and M6.5 on 2023/05/05. The M2.5+ aftershocks of the later strong shock followed exponential decay and eventually terminated with the M2.7 quake on 2023/12/04, i.e. 15 days in advance the immediate M5.7 foreshock 4 minutes in advance at 3 km from the epicenter of the major strike. A large rupture 160 km long occurred on the Noto Peninsula, causing tsunami. The aftershocks of the M7.6 shock follow a power decay from 96 M2.5+ events on the first day to about 1-3 a week by the end of February.

Our results of systematic analyses of foreshock, main shock, and aftershock sequences in Central Italy, New Zealand, Southern Alaska, and Japan (i) do not support presence of a unique universality in seismic energy release, however, (ii) provide fundamental constraints on modelling realistic earthquake sequences, (iii) give a new insight into better understanding of regional seismic dynamics, and (iv) can be used to improve seismic and tsunami hazard assessments, including forecast/predictions at different space-time scales.

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Adaptive Wavelet Thresholding and Grouping Approach for Repetitive Seismic Swarm Detection: Application to the Noto Peninsula Earthquake Swarm

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Repetitive seismic swarms serve as good indicators of fluid movement and aseismic deformation in the crust and may alert the imminence of devastating earthquakes. Before the occurrence of the 2024 Mw7.5 Noto Peninsula, Japan earthquake, intense seismic swarms involved with an upward fluid migration are continuously reported in the northeastern Noto Peninsula since December, 2020. However, most of earthquakes during the ~3-year swarm activity have small magnitudes and are hardly detectable. In this study, we develop an adaptive wavelet approach to identify earthquake swarms buried in noisy data recordings. By characterizing seismic waveforms in the frequency and time domain using wavelets, a short-term/long-term average magnitude (STA/LTA) algorithm is firstly performed to adaptively divide the whole trace into different wave segments. Noise is removed though soft-thresholding approach and then the signals having compatible characteristics after normalization are identified as repeating earthquake swarms and classified into different groups based on scalogram similarity. We apply the technique for continuous time series data using Hi-net stations in the Noto Peninsula. The result for a daily recording of September 28, 2023 show that tens of small-magnitude (<=Mb 4) earthquake swarms missing in the catalog can be clearly identified with improved SNR. The wavelet method provides a computationally efficient way for real-time, rapid detection of repetitive earthquake swarms, which can further improve existing earthquake catalogs, enabling a detailed investigation of swarm activity and implications of fluid migration.

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