From Taiwan to Tibet: Expanding the Real-time Landquake Monitoring System (RLAMS) for Glacier Collapse Events

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Abstract: The Real-time Landquake Monitoring System (RLAMS) has been operated in Taiwan since 2015, was developed to automatically detect, locate, and characterize large-scale (volume exceeding 10^6 m3) landquakes (landslide, rock avalanche, glacier collapse) using real-time seismic signals. Integrating full seismic waveform inversion and location approach, RLAMS provides near-real-time estimation of source location, magnitude, and sliding force dynamics. This system has been successfully implemented for monitoring recent landquake events in Taiwan, where intense rainfall and seismic activity frequently trigger catastrophic slope failures. In particular, RLAMS was directly applied to the 2025 Matai'an landslide in eastern Taiwan, which formed a large landslide dam. The subsequent dam-break flood caused severe downstream devastation, resulting in 19 fatalities, 5 missing people, and 157 injuries. The seismic inversion approach adopted in RLAMS has also been applied to analyze the 2016 twin Aru Glacier collapses on the Tibetan Plateau and the 2022 Bukadaban East Glacier collapse (Xinqingfeng Ice Cap), unraveling source failure mechanisms for these catastrophic ice–mass movements. Based on above applications, this study proposes the new development of an RLAMS network in the Tibet region (Tibet-RLAMS), which will enable real-time detection and monitoring of future glacier collapses and other large gravitational mass-wasting processes across the plateau utilizing seismic waveform data provided by the Incorporated Research Institutions for Seismology Data Management Center (IRIS-DMC).

Keywords: ***RLAMS, Landquakes, Seismic waveform inversion, Glacier collapse.***

Introduction

Rapid detection and quantitative characterization of large-scale gravitational mass movements—referred to as landquakes—are critical for hazard mitigation and emergency response (Cook et al., 2021). RLAMS has been operated in Taiwan since 2015 to automatically detect, locate, and characterize large-scale landquakes (volumes exceeding 10^6 m³) using continuous seismic waveform inversion.

As summarized in Table 1, RLAMS has been successfully applied to a total of 13 recent events that occurred between 2014 and 2025, including both global and Taiwan cases. These events cover a wide range of source volumes—from as small as 0.02 × 10^6 m³ (local slope failures) to as large as 80 × 10^6 m³ (Aru Glacier collapse, Tibet)—demonstrating RLAMS's capability to resolve dynamic source parameters across several orders of magnitude. Among these, the 2025 Mataian landslide in eastern Taiwan represents a typical case in which RLAMS enabled near-real-time identification of a catastrophic slope failure that generated a landslide dam and a subsequent dam-break flood, resulting in 19 fatalities, 5 missing persons, and 157 injuries.

Matai'an Landslide

On July 21 2025, a deep-seated landslide occurred in Wanrong Township village, Hualien County, Taiwan, which has been detected by the RLAMS system, as to be single-force (SF) event corresponding to landslide source type at about 05:53:55 pm (local time with format: hour, minute, second) resulted a force magnitude of 1.417×10^{12} N with the sliding direction of 137.4° (Figure 1a). After 80 seconds, the RLAMS was triggered by another landslide event, with a magnitude about 0.2 times that of the previous event and a sliding direction of 163.7° (Figure 1b). Image-based analysis estimated the landslide volume to be 200×10^6 m³ and that approximately 138×10^6 m³ of collapsed mass reached the Matai'an River and formed a landslide dam. The centroid location (121.293°E; 23.720°N) of landslide was estimated from satellite images. Overall, the force directions derived by the RLAMS are roughly consistent with field observations and satellite- and aerial-images. However, the large location error that existed in results of the RLAMS (star shown in Figure 1) leads the uncertainties in the estimation of landslide source parameters, which pose significant challenge to comprehensively understand the landslide failure mechanisms.

Development of RLAMS for Tibet

Based on previous implementations of RLAMS techniques in regions such as Tibet, Greenland, Iceland, and Oso–Steelhead, our main goal in this study is to establish a RLAMS for the Tibetan Plateau (RLAMS-Tibet) by utilizing continuous broadband seismic data from the IRIS-DMC seismic network (Figure 2 and Table 1). The grid-based single-force inversion (gSF) method was employed to estimate the source characteristics of potential landslides, including the force history, direction, and equivalent area, based on low-frequency seismic signals. This approach, originally implemented in the RLAMS proposed by Chao et al. (2017) In this study, the inversion was conducted using a frequency band of 0.02–0.05 Hz, a source depth of 1 km, and spatial grid spacings of 0.2° (~20 km). A one-second time window shift was adopted to enhance temporal resolution compared with the seven-second step used in the real-time system. The optimal results were selected when the fitness value exceeded 95% of the maximum fitness, and the mean and standard deviation of the corresponding parameters were then computed.

Table 1, Global and Taiwan Landslide Events Summary (2014-2025).

Event	Date (UTC)	Location	Coordinates (WGS84)	Volume (10^6 m^3)	Reference / Note
Oso-steelhead landslide	2014-03-22	Washington, USA	48.27°N / 121.87°W	8	Chao et al. (2016, SciRep)
Aru-1 Glacier collapse	2016-07-17	Western Tibet	34.082°N / 82.826°E	68	Kääb et al. (2018, Nature Geoscience)
Aru-2 Glacier collapse	2016-09-21	Western Tibet	34.045°N / 82.840°E	83	Kääb et al. (2018, Nature Geoscience)
Tibet Glacier	2022-11-01	Tibet	35.969°N / 90.869°E	40	Kääb et al. (2025, The Cryosphere)
Karrat Fjord / Nuugaatsiaq	2017-06-17	Greenland	71.643°N / 52.336°W	35–58	Chao et al. (2018, SRL)
Askja caldera landslide	2014-07-21 23:39	Iceland (Öskjuvatn)	65.020°N / 16.720°W	35–80	Schöpa et al. (2018, ESD)
Kukuan landslide	2020-06-12 09:09	Taichung, Taiwan	121.154°E / 24.25°N	0.023	Weng et al. (2021, Landslides)
Danan landslide	2021-02-04 14:19	Taitung, Taiwan	120.9526°E / 22.7244°N	0.09	Yang et al. (2022, Landslides)
Silabaku landslide	2021-08-07 01:17	Kaohsiung i, Taiwan	120.8406°E / 23.17°N	12.0	Yang et al. (2022)
Cilan landslide	2022-10-16 08:10	Yilan, Taiwan	121.5178°E / 24.60°N	0.66	Chang et al. (2015, NHESS)
Chiaolin landslide	2025-07-08 09:45	Yunlin, Taiwan	120.6724°E / 23.5803°N	2.15	NYCU CoLLab (2025)
Mataian landslide	2025-07-21 09:54	Hualien, Taiwan	121.2950°E / 23.7716°N	287	NYCU CoLLab (2025)
Baolia landslide	2025-04-31 22:26	Kaohsiung, Taiwan	120.78°E / 23.1314°N	2.14	NYCU CoLLab (2025)
Taroko landslide	2025-10-17 20:58	Hualien, Taiwan	121.5589°E / 24.173°N	0.20	NYCU CoLLab (2025)
Mataian (subevent)	2025-10-20 18:57	Hualien, Taiwan	121.2950°E / 23.7716°N	0.56	NYCU CoLLab (2025)

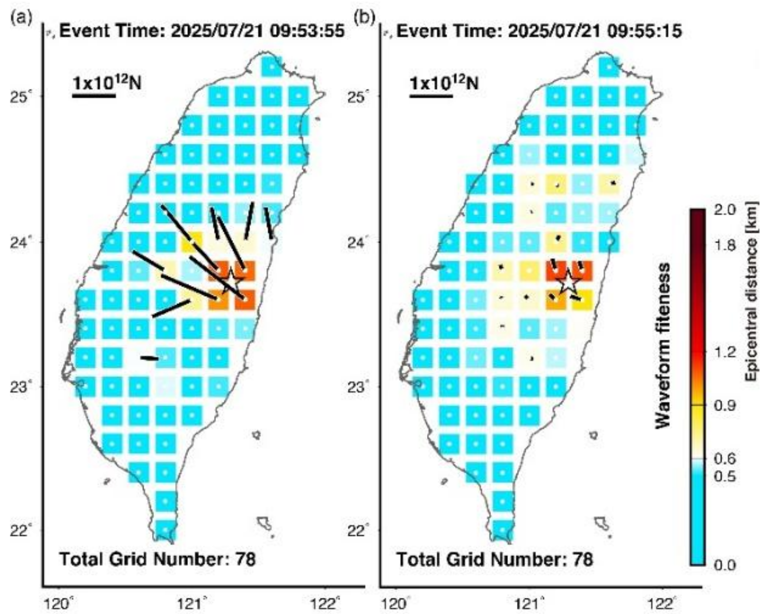

Figure 1, Inversion results of RLAMS for (a) first- and (b) second- triggered event reports. Color scale on the map represents the waveform fitness, with the open star indicating the centroid location of landslide mapped from satellite images. Bars indicate the directions of force axes. White dots are distributions of grid points used in the inversion.

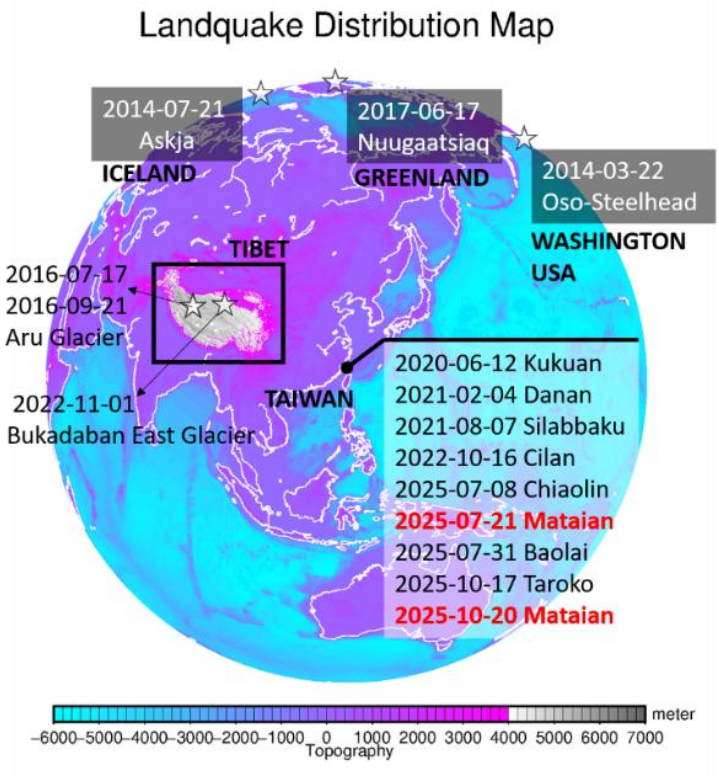

Figure 2, Global distribution of major landquake and landslide events analyzed using RLAMS.

RLAMS-Tibet aims to deliver rapid situational awareness for high-altitude basins prone to glacier collapse and glacier-lake outbursts—offering a powerful tool for safeguarding communities, infrastructure, and hydropower facilities in this tectonically and climatically sensitive region.

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