Investigating shallow seismic swarms between Askja and Herðubreið with QuakeMigrate: a new, open-source Python package for automatic earthquake detection and location

Tom Winder[1], Robert S. White[1] & Bryndís Brandsdóttir[2]

Abstract

Intense swarms of microearthquakes have been detected in the rift zone of Central Iceland since the 1970s, but the cause of their swarm-like nature remains enigmatic. We use the QuakeMigrate earthquake detection and location software[3] to produce a highly complete catalogue of microseismicity from 2007-2020, using data from a dense local seismic network.

Detecting and locating microearthquakes from continuous waveform records is the fundamental step in microseismic processing. Dense local networks and arrays have introduced the possibility to detect large numbers of far weaker events, but when viewed on seismic records from individual stations their waveforms are often obscured by noise. Furthermore, areas of interest for microseismic monitoring often feature extremely high event rates, highlighting the limitations of traditional techniques based on phase picking and association. QuakeMigrate is a new modular, open-source Python package providing a framework to efficiently and robustly detect and locate microseismicity. The user inputs continuous seismic data, a velocity model or pre-calculated look-up table and list of station locations. Instead of reducing the raw waveforms to discrete time picks, they are transformed (by amplitude, frequency and/or polarisation analysis) to continuous functions representing the probability of a particular phase arrival through time. These 'onset functions' from stations across the network are then migrated according to a travel-time look-up table and stacked to perform a grid-search for coherent sources of energy in the subsurface. This enables detection of earthquakes at close to or below the signal-to-noise ratio at individual stations, and implicitly associates phase arrivals even at very small inter-event times.

In this study automatic hypocentre locations are further refined by waveform cross-correlation and relative relocation, and combined with tightly constrained focal mechanisms obtained by manual analysis of a subset of events. The resulting high-resolution earthquake catalogue reveals a network of conjugate strike-slip faults, oriented to accommodate plate-boundary extension. Seismicity within individual swarms displays a systematic migration of hypocentres at velocities of ~ 1 km/day. Analysis of swarms within this fault network triggered by the 2014 Bárðarbunga-Holuhraun dike intrusion provides further constraint on the amplitude of the stress cycle. These exceptionally high-resolution observations provide an opportunity to probe the rheology of these faults, and the processes controlling their swarm-like behaviour.

1: Department of Earth Sciences, University of Cambridge, Cambridge, UK; tom.winder@esc.cam.ac.uk
2: Institute of Earth Sciences, University of Iceland, Reykjavík, Iceland
3: https://github.com/QuakeMigrate/QuakeMigrate Tom Winder, Conor Bacon, Jonathan D. Smith, Thomas S. Hudson, Julian Drew, & Robert S. White. (2021, January 15). QuakeMigrate v1.0.0 (Version v1.0.0). Zenodo. http://doi.org/10.5281/zenodo.4442749