

# Temporal seismic velocity changes during the 2020 rapid inflation at Mt. Thorbjorn-Svartsengi, Iceland, using ambient seismic noise

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## Introduction

Seismic ambient noise allows us to quantify relative velocity variations (0.01%) in the medium, thus it has a great potential to be used for real-time volcano monitoring. The large amount of high quality seismic data and frequent volcanic activity provide a unique opportunity to investigate temporal changes in seismic velocity during pre-eruptive and eruptive phases. Our study presents temporal seismic wave velocity variations (dv/v, in percent) based on ambient noise seismic interferometry using continuous three-component waveforms collected by IMO, (<http://www.vedur.is>) for the period from April 2018 to November 2020. We focus our interest to repeated periods of inflation-deflation (January-November 2020) in the vicinity of the Mt. Thorbjorn-Svartsengi, which is situated on the Reykjanes Peninsula (RP, SW-Iceland). In January 2020, deformation (GPS and InSAR) studies revealed an uplift located ~2 km west of Mt. Thorbjorn, indicating magmatic inflation (Geirsson et al., 2020). The seismic station (GRV) closest to the inflation source center (~1 km) showed the largest velocity drop (~1%). The 2020 unrest period is followed by an effusive eruption on 19 March 2021 in Geldingadalir, ~10 km E-NE of Mt. Thorbjorn. This is the first time in Iceland that seismic velocity variations (dv/v, %) are monitored in near real-time during volcanic unrest.

## Seismicity and Deformation

The seismicity rate in the RP has substantially increased (Figure 1a) due to repeated magmatic intrusions in the Reykjanes-Svartsengi volcanic system. GPS and InSAR observations confirmed surface deformation centered near Mt. Thorbjorn (Figure 1b), and approximately ~14,000 earthquakes ( $2 \leq M \leq 4.9$ ) were reported by IMO during January-July 2020.

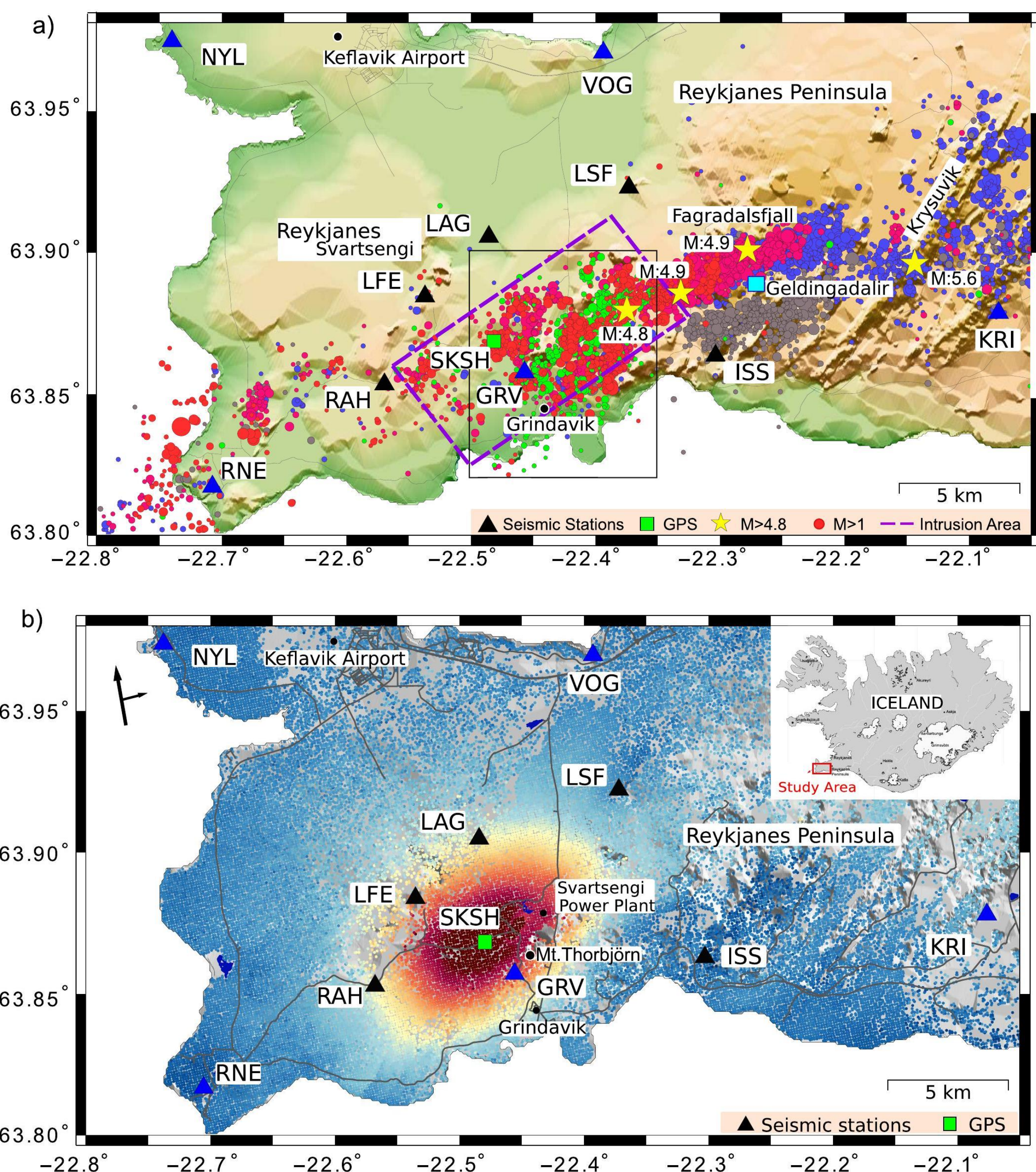


**Figure 1.** a) The earthquake activity in the period of August 2019–November 2020 ( $M > 1$ ). Black triangles mark seismic stations with an analysis period spanning from February to November 2020 (provided by the Czech Academy of Sciences and Iceland Geosurvey), while blue triangles indicate permanent seismic stations. The green square shows the location of the cGPS station SKSH. The purple box approximates the area affected by intrusions. Events related with the 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> intrusion periods are shown with green, red and pink circles, respectively. Gray and purple colors indicate earthquakes that occurred before 20 January and after 23 July, 2020. The seismicity compared to the dv/v curve of GRV is confined to the black box. b) InSAR map showing deformation in the RP, the red colors indicate inflation.

## Method

Seismic data processing for this study is managed using the MSNoise software package (<http://www.msnoise.org>) for calculating cross-correlations of seismic ambient noise. We consider different frequency bands (e.g., 0.1–1 Hz, 0.5–1 Hz, 1–2 Hz, 0.4–0.8 Hz) while applying the correlation techniques to continuous recordings of seismic ambient noise. Resulting correlograms are stacked for 10-days in order to enhance coherency. We considered travel-time changes of the scattered waves for time lags between 5 to 25s in the cross-correlation coda. We implemented the Stretching Method (SM, Sens-Schönfelder and Wegler, 2006) to measure relative velocity changes. Our analysis covers the period between April 2018 to November 2020.

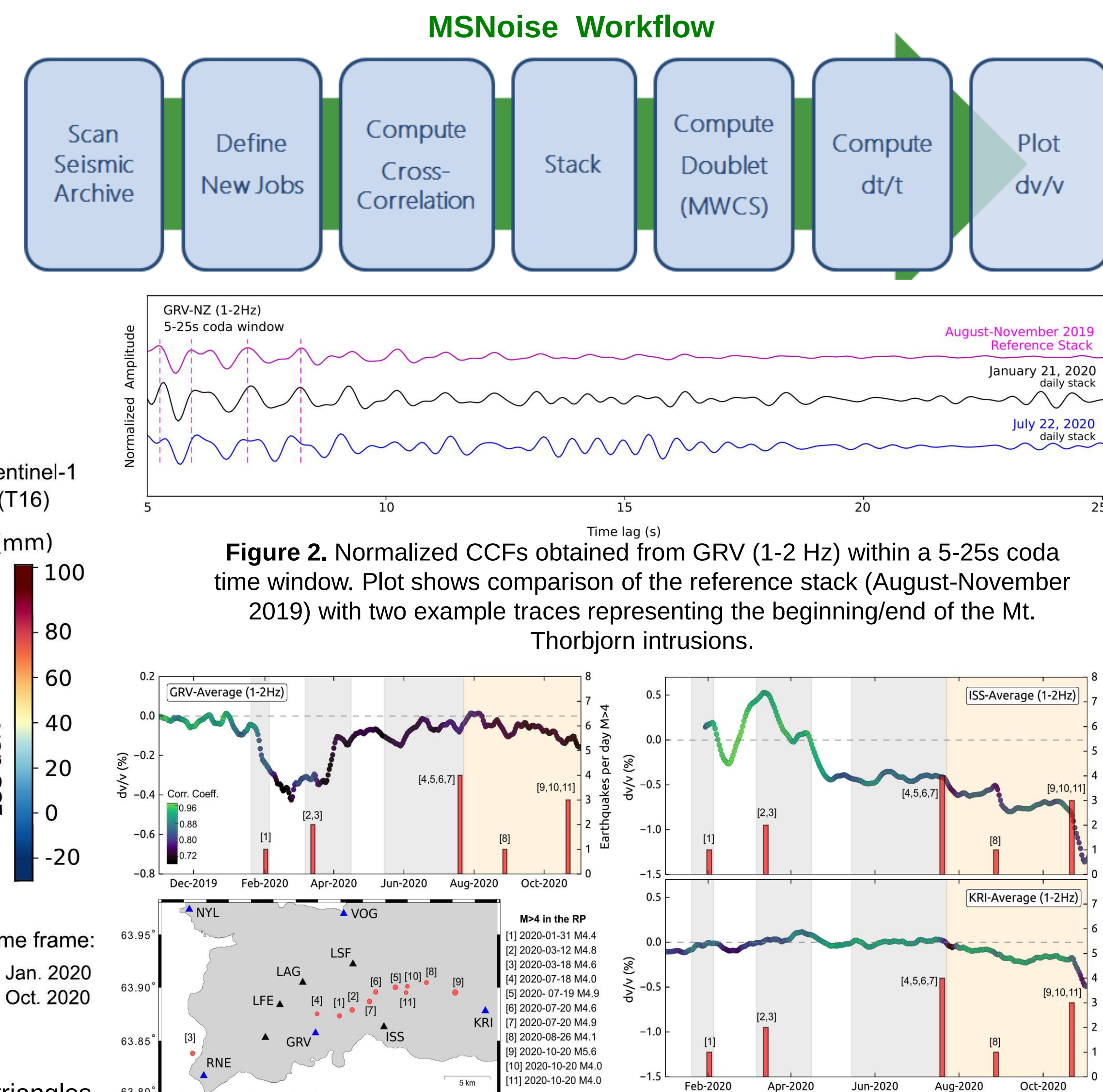


**Figure 2.** Normalized CCFs obtained from GRV (1–2 Hz) within a 5–25s coda time window. Plot shows comparison of the reference stack (August–November 2019) with two example traces representing the beginning/end of the Mt. Thorbjorn intrusions.

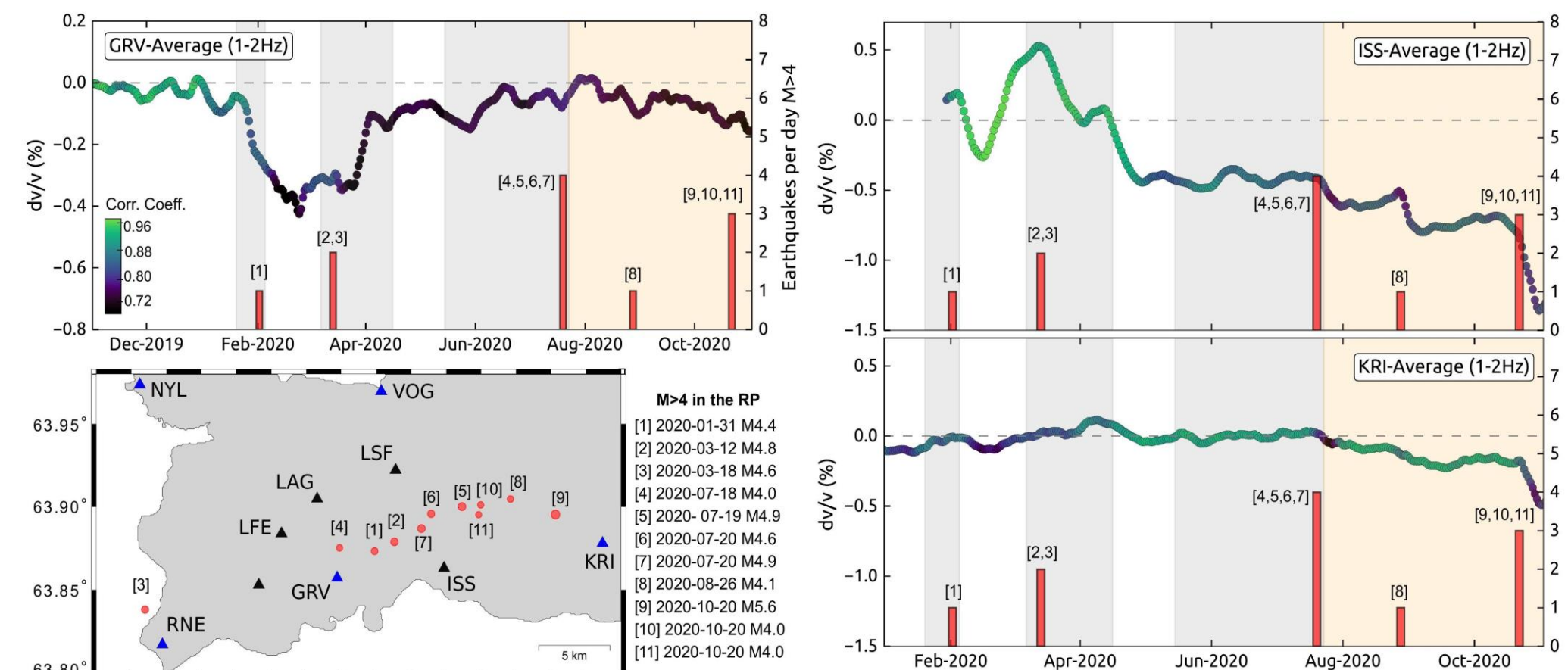


**Figure 3.** Comparison of the average dv/v variations with the daily number of  $M > 4$  earthquakes in the RP. Events are numbered according to their origin time on the map and labeled on top of each bar graph. The gray shaded boxes show three intrusion periods. Plot indicates that we do not observe systematic dv/v changes coinciding with earthquakes ( $M < 5$ ), and the velocity changes are mostly related with the magmatic intrusions. We only observe a clear co-seismic velocity drop (0.4%) for the October, 2020  $Mw=5.6$  earthquake in Krysuvik (KRI, ISS).

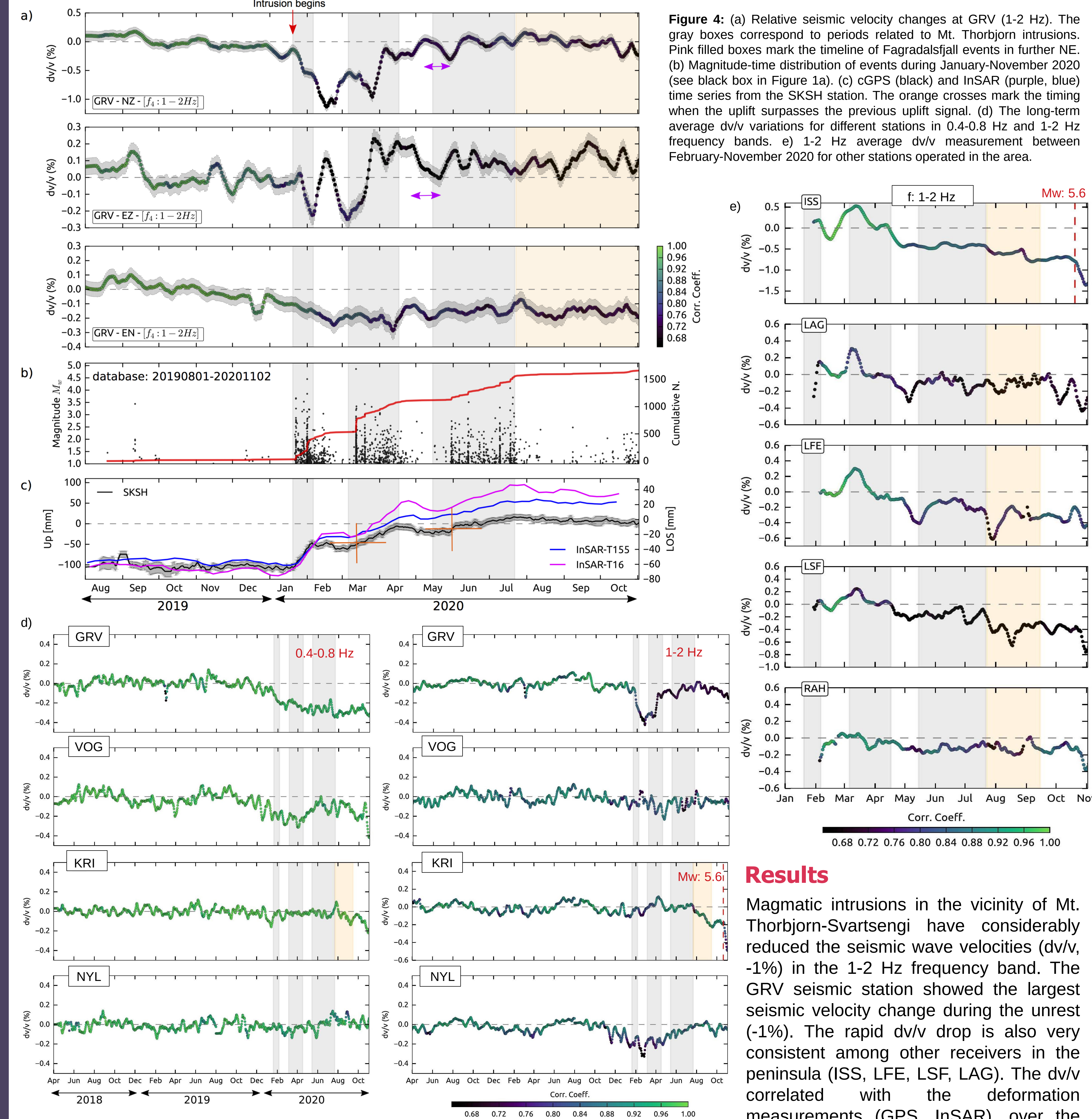


**Figure 4:** (a) Relative seismic velocity changes at GRV (1–2 Hz). The gray boxes correspond to periods related to Mt. Thorbjorn intrusions. Pink filled boxes mark the timeline of Fagradalsfjall events in further NE. (b) Magnitude-time distribution of events during January–November 2020 (see black box in Figure 1a). (c) cGPS (black) and InSAR (purple, blue) time series from the SKSH station. The orange crosses mark the timing when the uplift surpasses the previous uplift signal. (d) The long-term average dv/v variations for different stations in 0.4–0.8 Hz and 1–2 Hz frequency bands. (e) 1–2 Hz average dv/v measurement between February–November 2020 for other stations operated in the area.

## Results

Magmatic intrusions in the vicinity of Mt. Thorbjorn-Svartsengi have considerably reduced the seismic wave velocities (dv/v, -1%) in the 1–2 Hz frequency band. The GRV seismic station showed the largest seismic velocity change during the unrest (-1%). The rapid dv/v drop is also very consistent among other receivers in the peninsula (ISS, LFE, LSF, LAG). The dv/v correlated with the deformation measurements (GPS, InSAR), over the unrest period. We interpret the relative seismic velocity decrease to be caused by crack opening induced by intrusive magmatic activity. Our analysis was used in near-real time to assist the Iceland Civil Protection Science Board with the joint interpretation of different datasets during the volcanic unrest.

## References

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