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Seismic rate change as a tool to investigate remote triggering of the 2010-2011 Canterbury earthquake sequence, New Zealand

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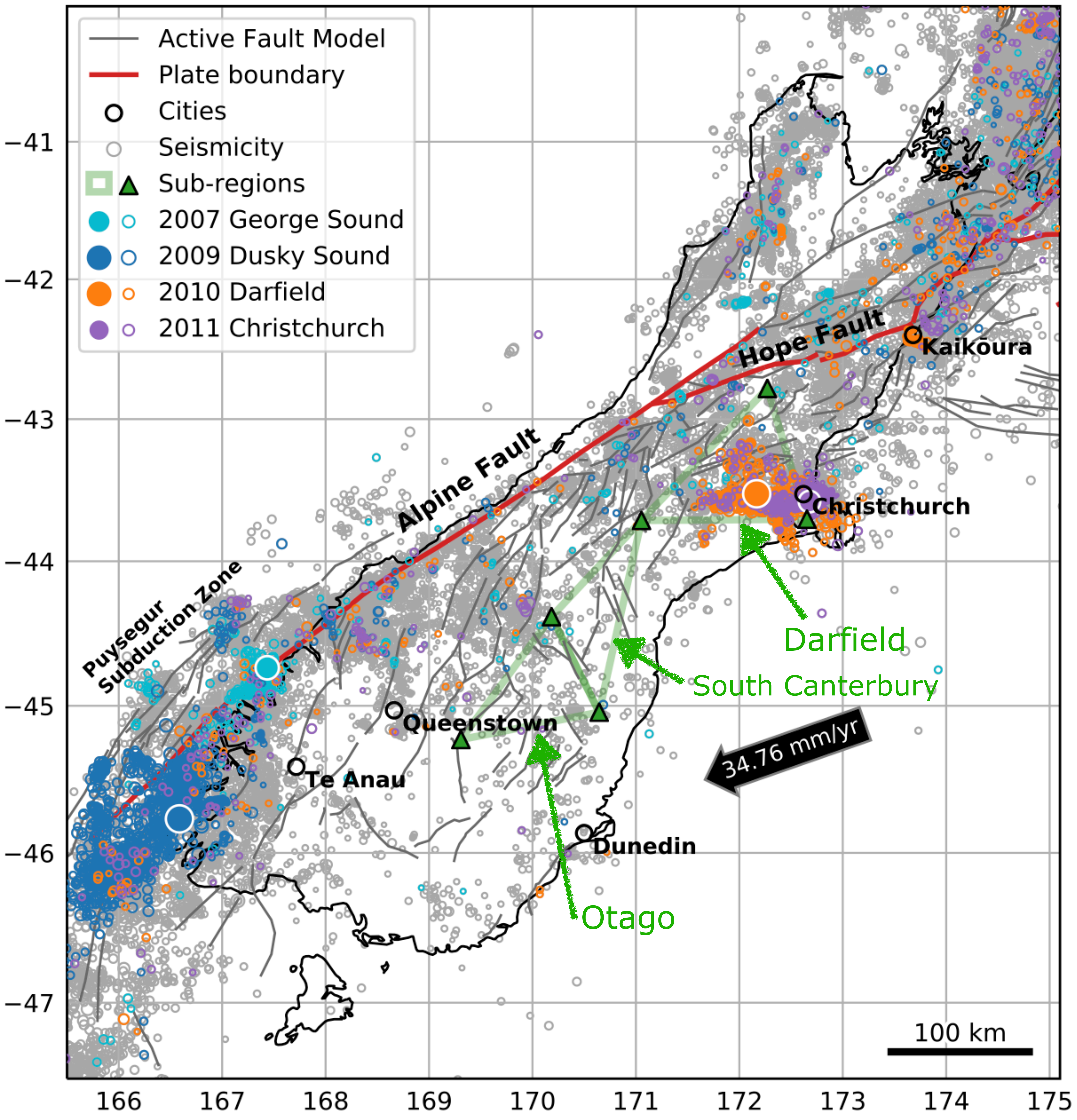

Figure 1. Seismicity of South Island, New Zealand from 2005-2012. Colored seismicity shows the main shocks and the seismicity one month after them. Green triangles are three sub region in this study.

Summary

The South Island of New Zealand is prone to destructive earthquakes. However, all but one of them happens along the fast-moving plate boundary (red lines). The Canterbury earthquake sequence (seismicity marked in orange and purple) occurred in a quiet region prior to the first event in 2010, the Darfield Earthquake. Most certainly, the Canterbury Plain undergoes the tectonic stress that also drives the nucleations of M7.8 Dusky Sound Earthquake and M7.8 Kaikōura Earthquake. But there lacks the geophysical evidence pointing to the disaster. We revisit the regional seismicity prior to the Canterbury sequence using matched-filter technique, refined with a simple supervised learning classifier. With the enriched catalog, we see that the seismic rate in Canterbury region is sensitive to the Puysegur subduction zone events. Specifically, the internal deformation cause by the 2009 Dusky Sound Earthquake after -slip confirm the deformation is concentrated in the vicinity of Darfield ruptures and matches the stress field of the Darfield CMT.

Template-matching with a twist

Before the Canterbury sequence, established seismic stations are few and far between. The amount of events is not enough to support a robust rate change analysis. To overcome this, we use the popular template-matching technique (Chamberlain et al., 2018) to enrich the catalog. We perform matching using three groups of three stations to balance between efficiency and resolution (see pale green triangles in fig 1.) An example of detections and their quality metrics are shown in figure 2. To remove false detection, we have an experienced earthquake analyst ranking 168 out of 3’947 detections and assign the valid/rejected tag to them. Fig. 2 demonstrate how good and bad detections look like and where they fall on the selective metrics. These and other metrics from the 168 labelled detections trains a support vector machine classifier that further classify the rest of detections. By enforcing this strict selection, we are not able to lower the M_C in the study region. However, we are confident in the stability of the rate estimation.

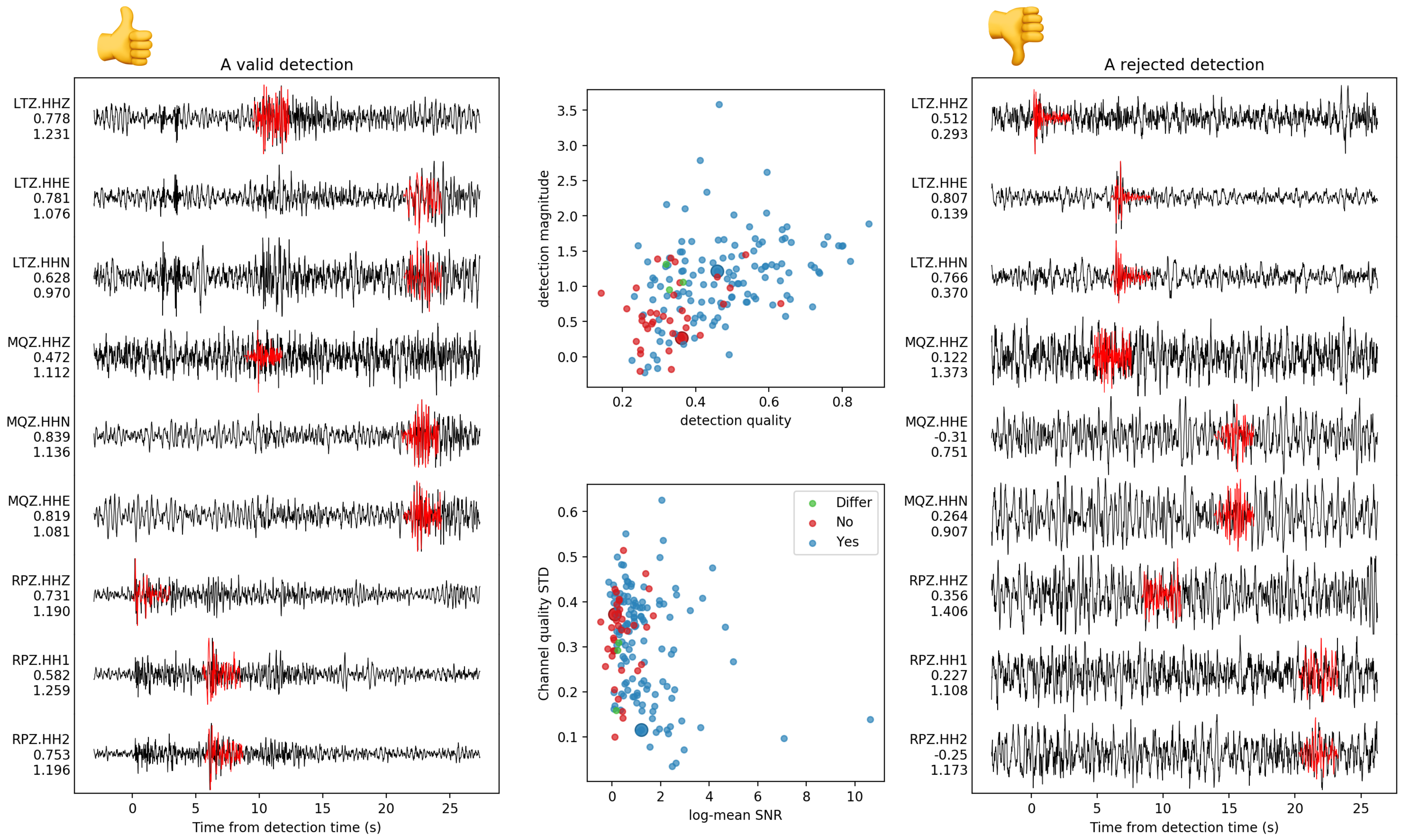

Figure 2. A valid detection (A) and a rejected detection (B) and their metrics comparing with other analyst-labelled detections in (C) and (D).

Visualize rate change in time with Z-statistic

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With the detection, we look into how seismic rate change with resect to major events, the 2007 George Sound Earthquake and 2009 Dusky Sound Earthquake in this case. Z-statistics (Wiemer, 2001) help us determine if the seismicity in two time period is significantly different. We see from the cumulative curves of the three sub-region that although they are all intra-plate region, they behave differently. The Z statistic in the lower panel helps marking out the time when rate changes are significant before and after the time. First, we see in South Canterbury the seismicity is too scarce to make meaningful rate change estimation. In Otago, the seismic rate is stable over two subduction zone events with a slight increase mid-2008. In Darfield, the seismicity not only fluctuate more, but the trends of catalog events and detections are different. It might suggest the stress regime induced by the two events are different. One excite smaller events (detections) and one does not.

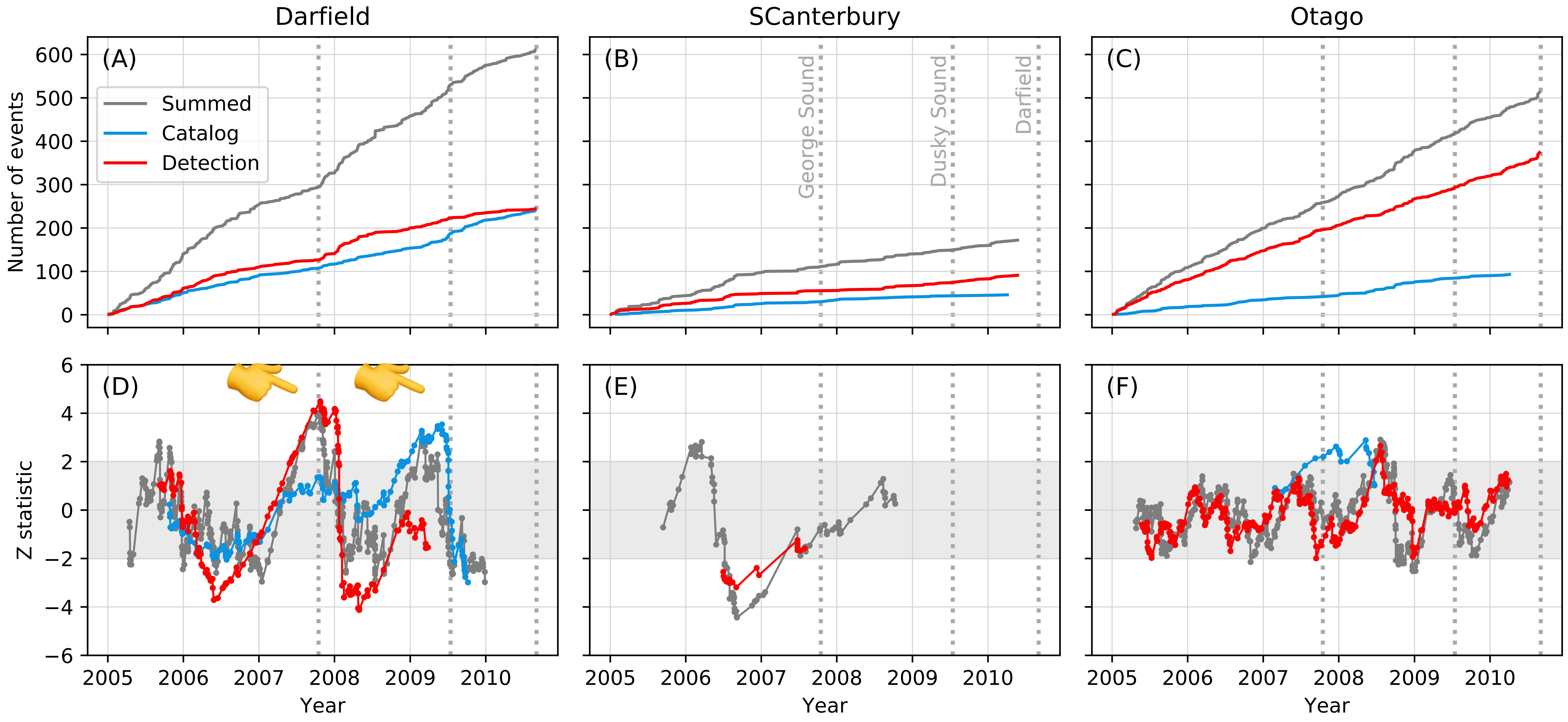

Figure 3. (A-C) The cumulative number of events of the three sub-region (D-F) The Z statistic calculated using a fixed-event number sliding window of 36 events.

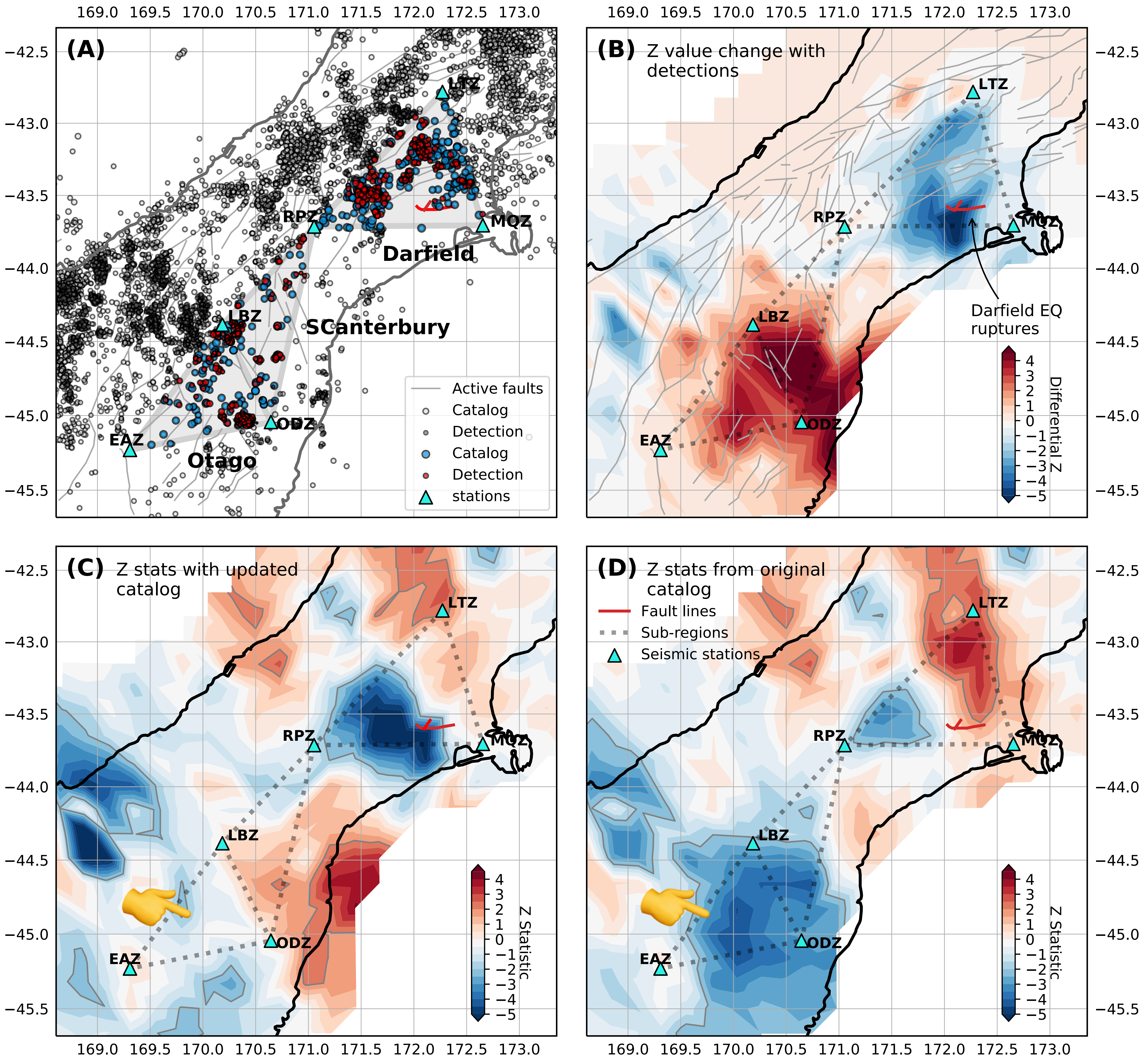

Figure 4. A valid detection (A) and a rejected detection (B) and their metrics comparing with other analyst-labelled detections in (C) and (D).

Visualize rate change in space with Z-statistic

We can also calculate the significance of seismic rate change in space. Here we compare two inter seismic periods before and after the M7.8 Dusky Sound Earthquake: 2007-11 to 2009-07 and 2009-08 to 2010-09. Z-statistics beyond ±2 means the rate change is statistically significant. We see in figure 3C, region west to the Darfield ruptures (red lines) has a significant dip in seismic rate after Dusky Sound Earthquake. To the north and west, the rate increase along the plate-boundary faults. We also see clear changes in patterns with added micro-seismicity (fig. 4C) and without (fig. 4D). The Otago triangle which has lowered seismicity rate turns to insignificant when we add detected events back. How come region closer to epicenter has little response to a subduction-zone events?

After-slip create uneven internal deformation

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Beavan et al. (2010) noticed that the Dusky Sound Earthquake rupture slips persistently after the event. This is Sean in fig. 4A. The minus displacement shows the westward movements increased since the Dusky Sound Earthquake. We visualize the areal dilatation caused by after-slip using the Delaunay triangular mesh. Not surprisingly, The north-west and south-east subduction zones show large compression. In addition, the strain concentrate in the triangle immediate north of the Darfield ruptures , while Otago undergo next-to-none deformation (fig. 4B) even if it is closer. The triangle where the Darfield ruptures located undergoes minor extension with a NNE-SSW trending. The max and mean strain axis is very close to that calculated from focal mechanisms by Sibson et al. (2011). The after-slip likely promote the Darfield Earthquake and subsequent events.

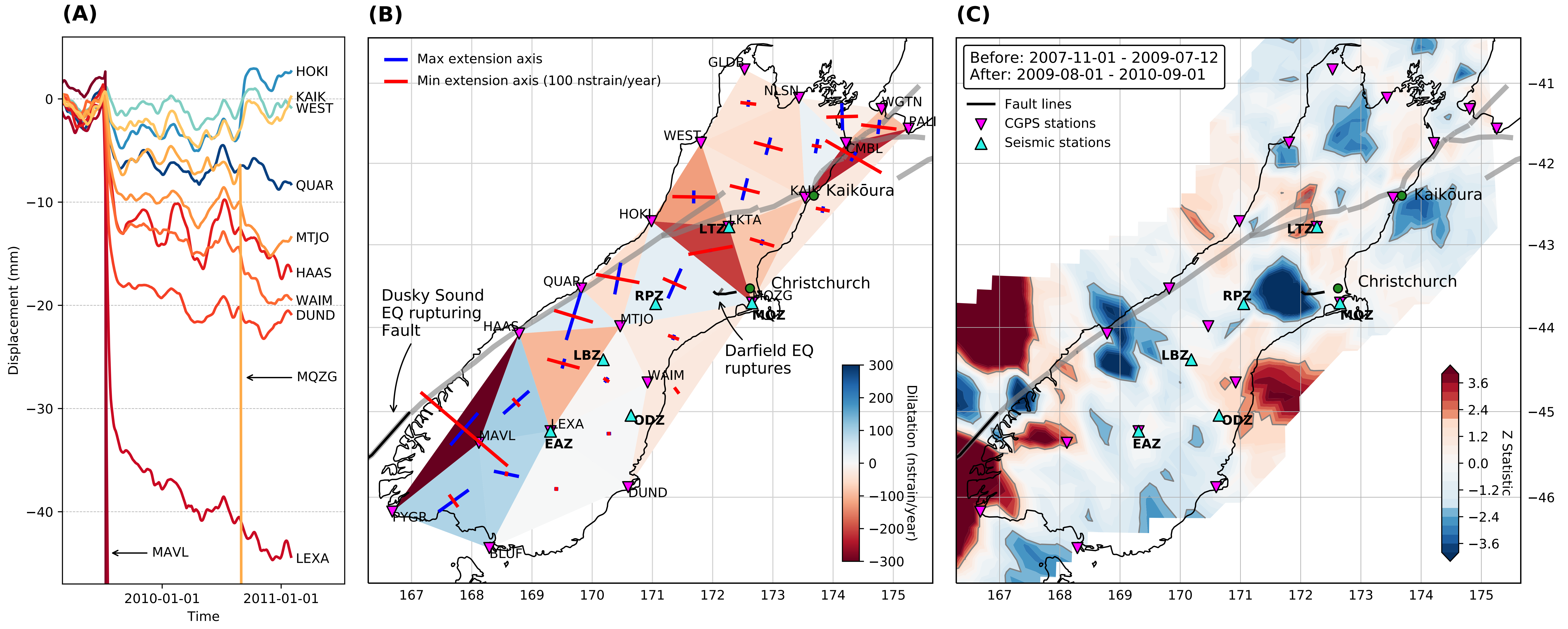

Figure 5. (A) East-west detrended GPS displacement. (B) Areal dilatation after Dusky Sound Earthquake (C) Z statistic same as fig 4C with insignificant region toned out. The thick pale grey lines shows the fast-moving plate-boundary faults (Litchfield et al., 2014)