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Supporting Information for

Anomalous foreshock activity in southern California is associated with zones of high heat flow

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Introduction

The supporting information contains additional information about the ETAS model used for the analyses and its verification.
It also reports the results using alternative methods to infer and select anomalous foreshock sequences (e.g., the spatiotemporal windows (STW) method to identify mainshocks and their foreshocks, using a significance level of 95%, using an alternative analysis of TEST1, and using an independent dataset).

Text S1. ETAS model

We used the stochastic ETAS aftershock simulator program developed by K. Felzer (see Felzer et al., 2002, Data Availability Statement, and Table S1) with parameters provided by Hardebeck et al., 2008, see Table S2). The program simulates background events, and triggered earthquakes in time and space. It makes use of Monte Carlo methods and empirical aftershock relationships following the ETAS model of Ogata (1988).

Text S2. Verifying the reliability of ETAS model

To verify the reliability of ETAS model, we adopt a Turing-style test (Page & van der Elst, 2018), comparing the number of earthquakes in the real catalog with the number of simulated events in the synthetic catalogs (Figure S1). We also apply the same kind of analysis to different earthquake magnitude classes C_M = {3.0 ≤ M < 4.0, 4.0 ≤ M < 5.0, 5.0 ≤ M < 6.0, M ≥ 6.0} (Figure S2). In all cases, the real observation (solid vertical line) is within the 95% confidence interval (vertical dashed lines), indicating that the ETAS model is reliable and the synthetic catalogs consistent with the observation.

Text S3. Results for a significance level of 95%

Figures S6 shows the results of TEST1 using a significance level of 95%. Of a total of 152 foreshock sequences, we found 65 (43%) anomalous foreshock sequences using the NN method. Figure S7 shows the results for TEST2: we found 51 of 152 (36%) foreshock sequences to be anomalous using the NN method.

Table S1. Parameters used in K. Felzer's ETAS simulator.

Start date of simulation	1-1-1981
Start date of synthetic catalogs	1-1-1983
End date of synthetic catalogs	31-12-2019
Lower magnitude limit of active earthquakes, M_o	2.5
Lower magnitude limit in synthetic catalog	2.5
Lower magnitude limit for modelling planar sources	6.5
Upper magnitude limit	7.9
Minimum aftershock distance from parent event	0.001 (km)
Maximum aftershock distance from parent event	500 (km)

Table S2. Used ETAS parameters as given by Hardebeck et al., 2008 for M_o = 2.5. μ is the background rate; *K*, *c*, and *p* are parameters of Omori's law; *n* is the aftershock decay with distance (exponent in r^{-n}); α is the productivity law exponent (productivity scaling with magnitude); and β is the scaled b-value, β = *b* * ln(10), of the Gutenberg-Richter relation (describing the magnitude distribution).

μ	*K*	*c*	*p*	*n*	α, β
spatially variable	**0.008**	**0.095**	**1.34**	**1.37**	**ln(10) ≈ 2.30**

References

Felzer, K. R., Becker, T. W., Abercrombie, R. E., Ekstrom, G., & Rice, J.R. (2002). Triggering of the 1999 MW 7.1 Hector Mine earthquake by aftershocks of the 1992 MW 7.3 Landers earthquake, *Journal of Geophysical Research*: *Solid Earth*, *107*(B9), ESE 6-1–ESE 6-13. doi: 10.1029/2001JB000911.

Hardebeck, J. L., Felzer, K. R., and Michael, A. J. (2008), Improved tests reveal that the accelerating moment release hypothesis is statistically insignificant, *Journal of Geophysical Research*, *113*(B8). doi: 10.1029/2007JB005410.

Page, M. T., & van der Elst, N. J. (2018). Turing-Style Tests for UCERF3 Synthetic Catalogs, *Bulletin of the Seismological Society of America*, *108*(2), 729–741. doi: 10.1785/0120170223.

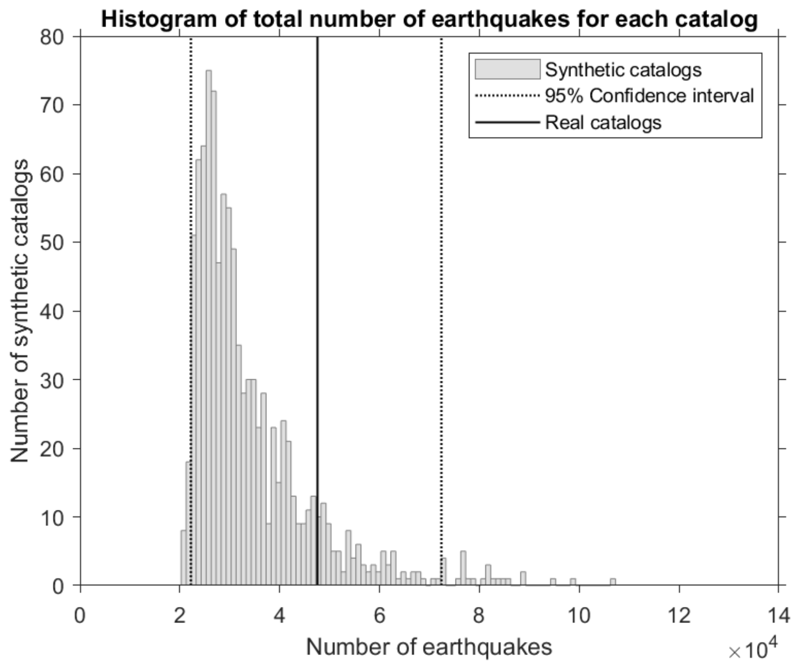

Figure S1. Total number of events in the synthetic catalogs (distribution) and the real catalog (solid vertical line). The dashed vertical lines refer to the 95% confidence interval (i.e., the 2.5th – 97.5th percentile range of the distribution). For more information, see Text S2.

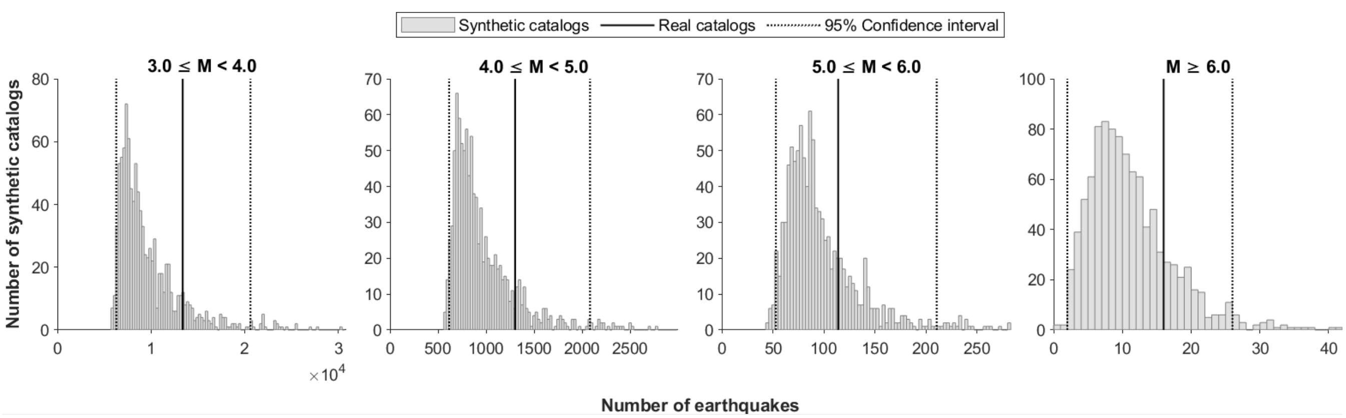

Figure S2. Like Figure S1 but for different magnitude classes.

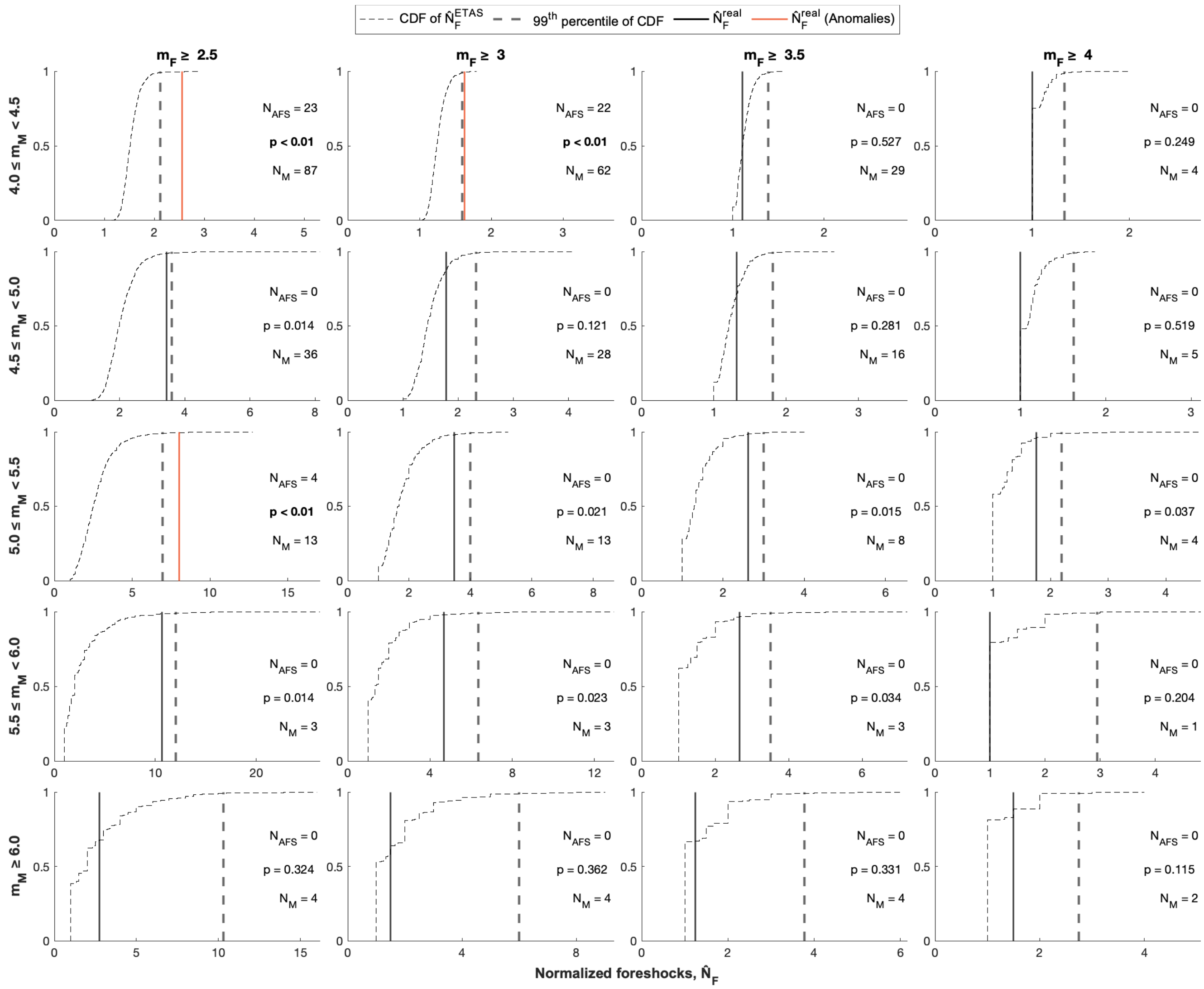

Figure S3. Like Figure 1 in the main paper (TEST1) but using the STW method.

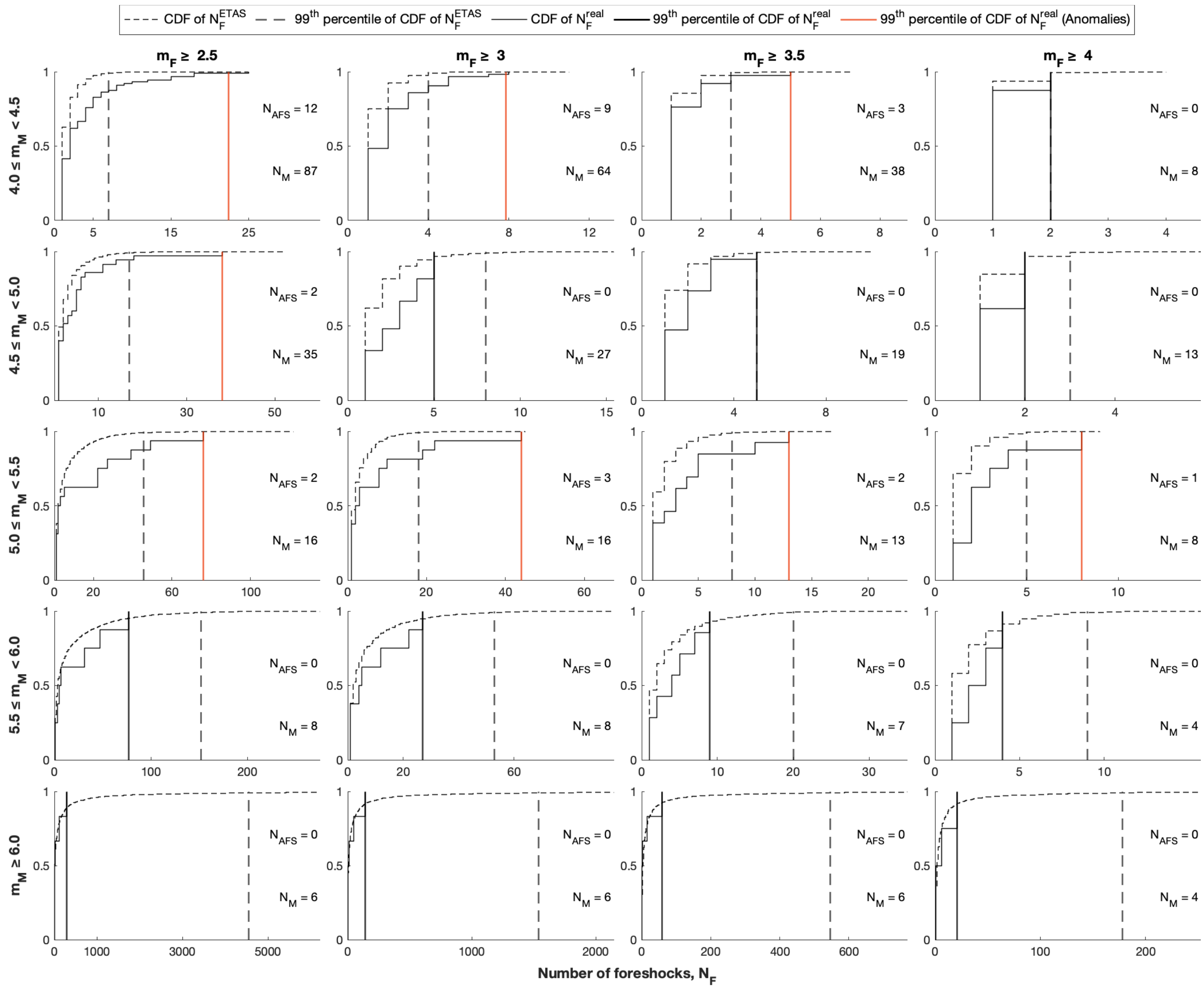

Figure S4 Like Figure 1 in the main paper (TEST1, NN method) but using the individual number of foreshocks, N_F. In this way, the empirical Cumulative Distribution Function (eCDF) of N_F can be constructed for both the real catalog (solid curve) and all 1000 synthetic catalogs combined (dashed curve); vertical lines show their corresponding 99th percentile (real catalog: solid; synthetic catalogs: dashed). If the former is above the latter, the solid vertical line becomes red, indicating more anomalous foreshock sequences than expected. Each subplot also reports the number of anomalous foreshock sequences, N_{AFS}, and the number of mainshocks, N_M.

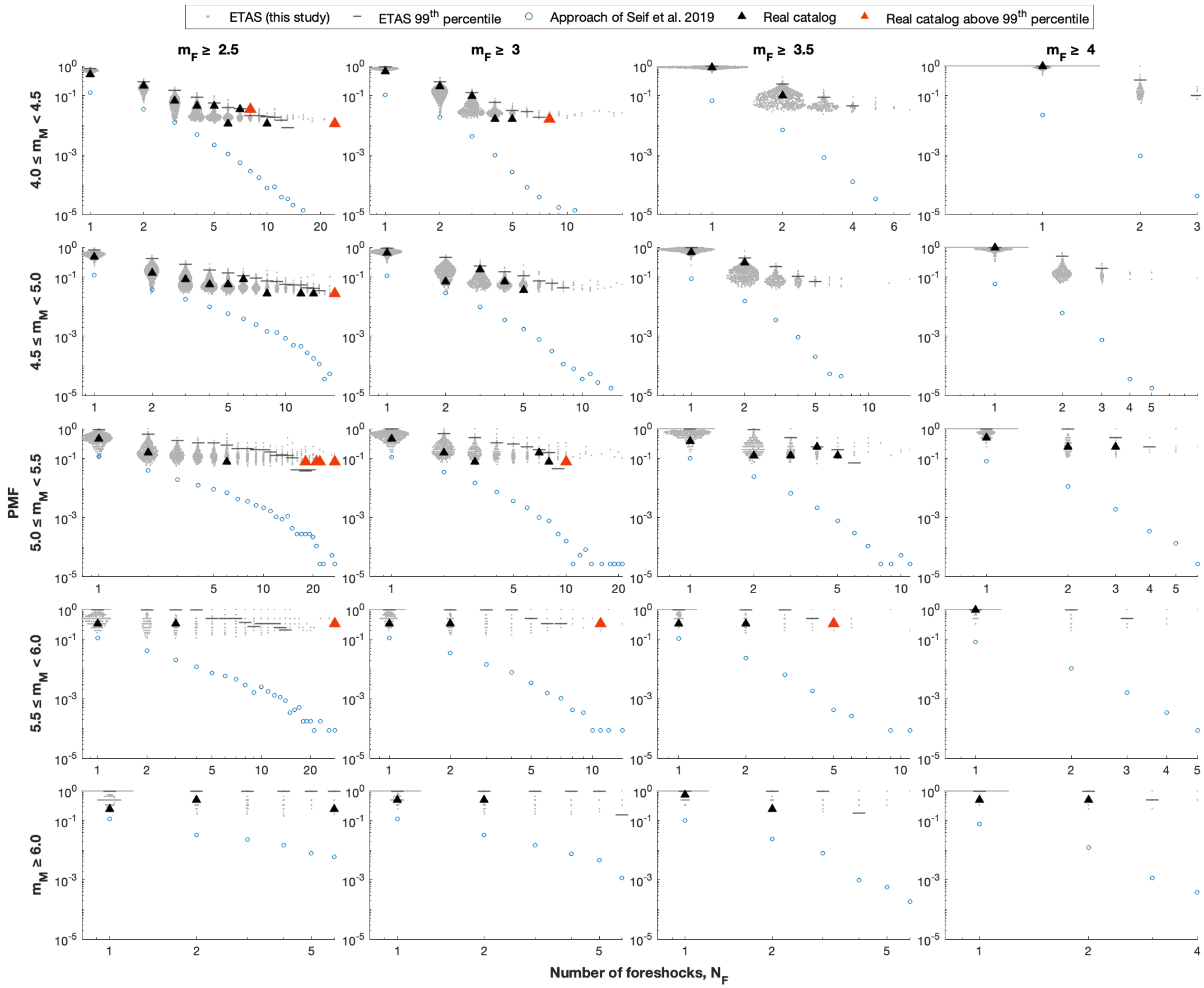

Figure S5. Like Figure 2 in the main paper (TEST2) but using the STW method.

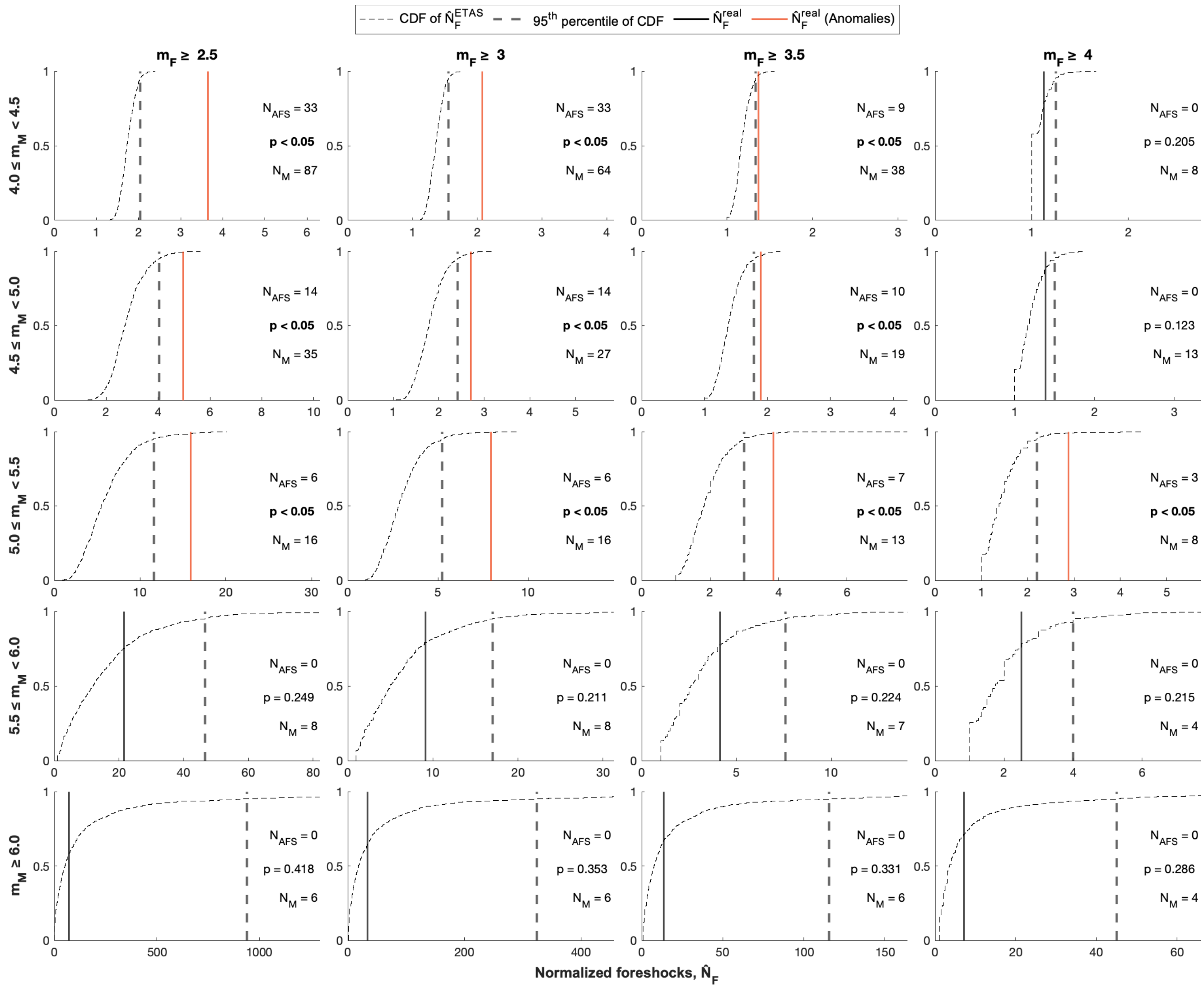

Figure S6. Like Figure 1 in the main paper (TEST1, NN method) but using a significance level of 95%.

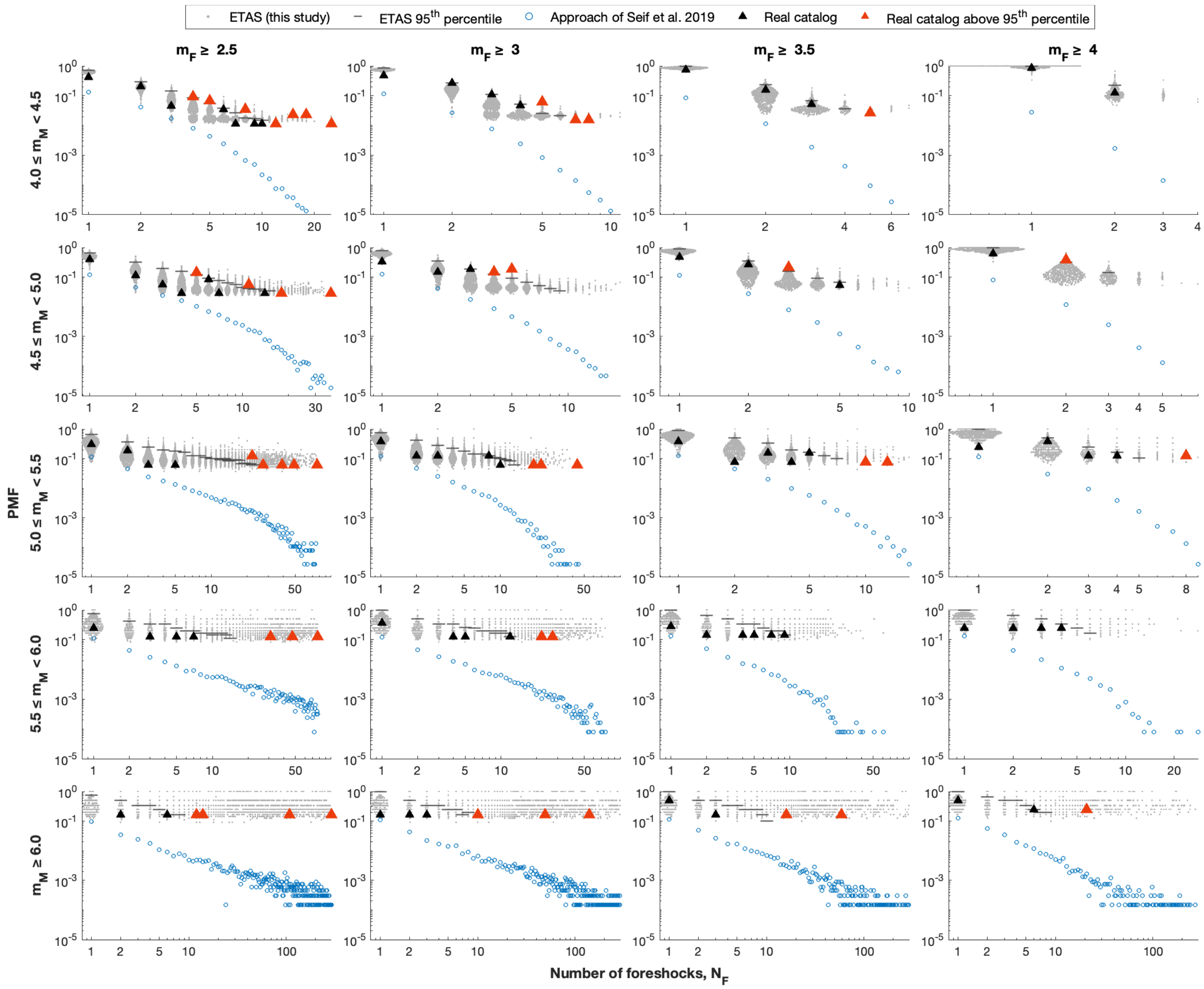

Figure S7. Like Figure 2 in the main paper (TEST2, NN method) but using a significance level of 95%.

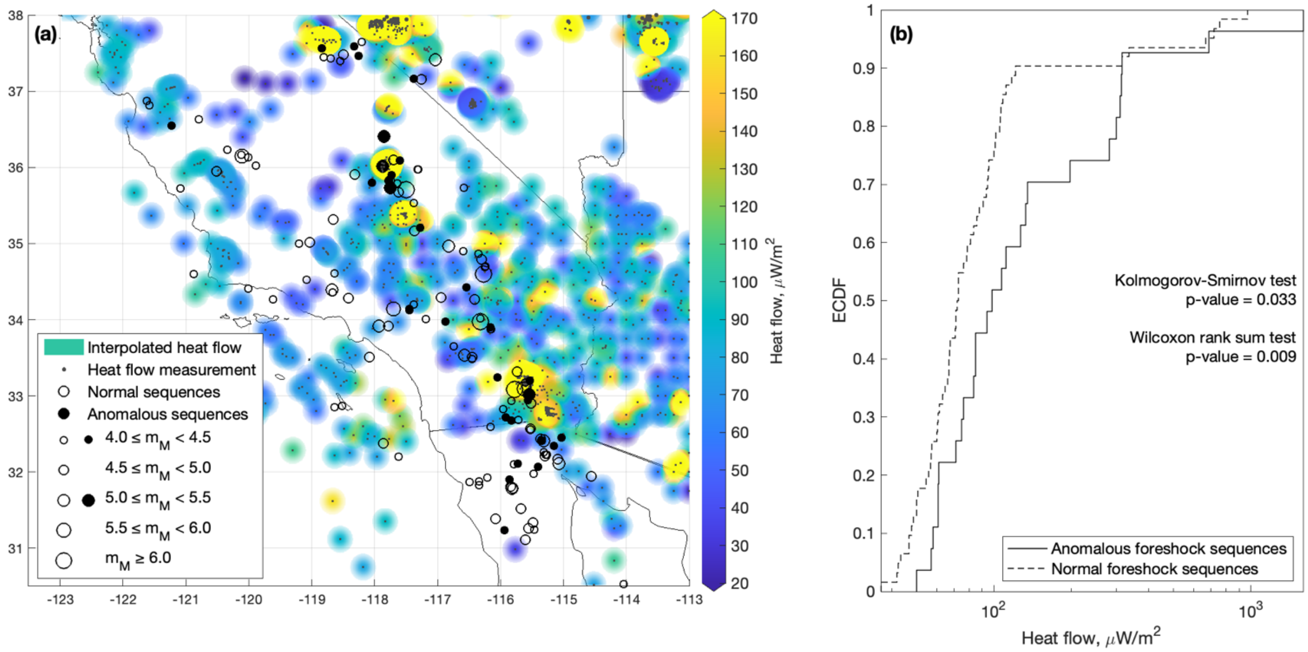

Figure S8. Like Figure 3 in the main paper (TEST1) but using the STW method.

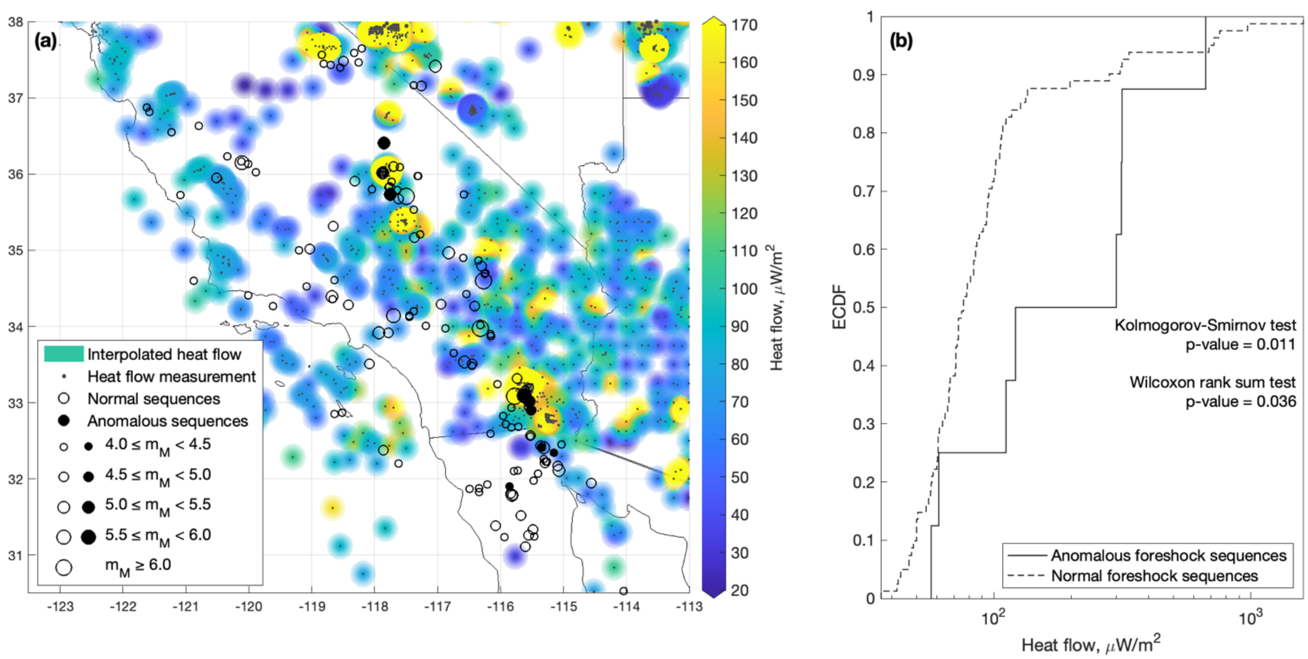

Figure S9. Like Figure 4 in the main paper (TEST2) but using the STW method.

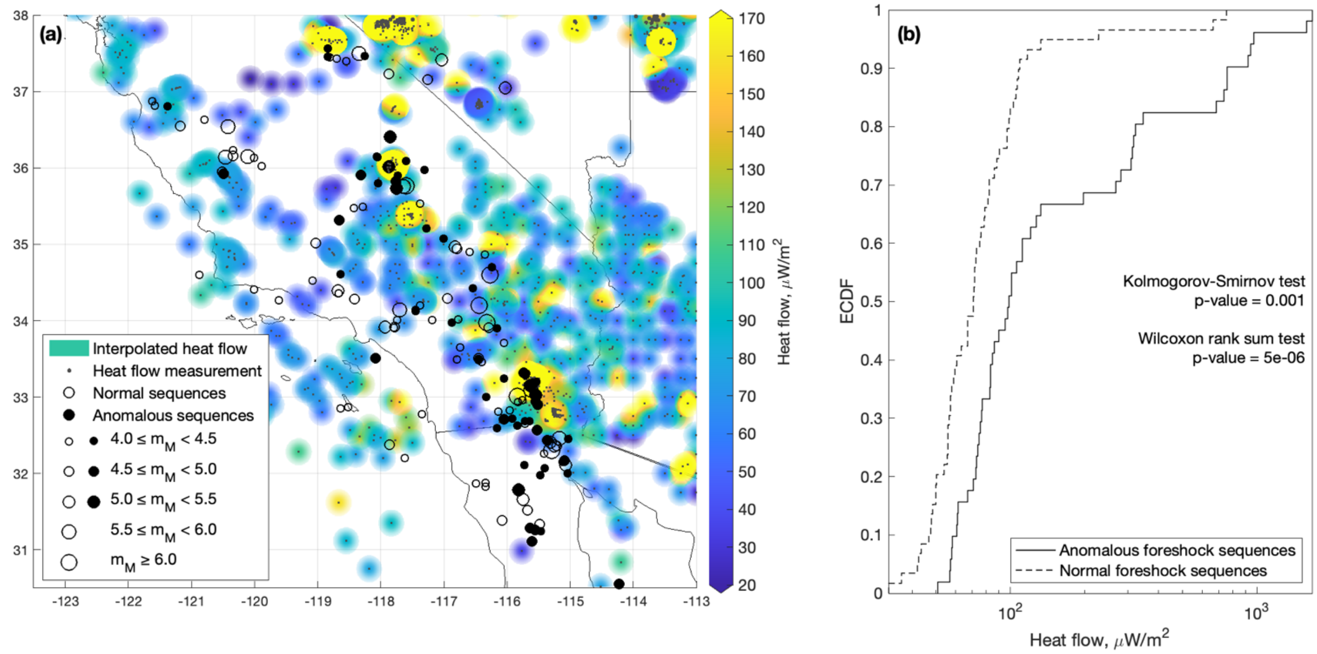

Figure S10. Like Figure 3 in the main paper (TEST1, NN method) but using a significance level of 95%.

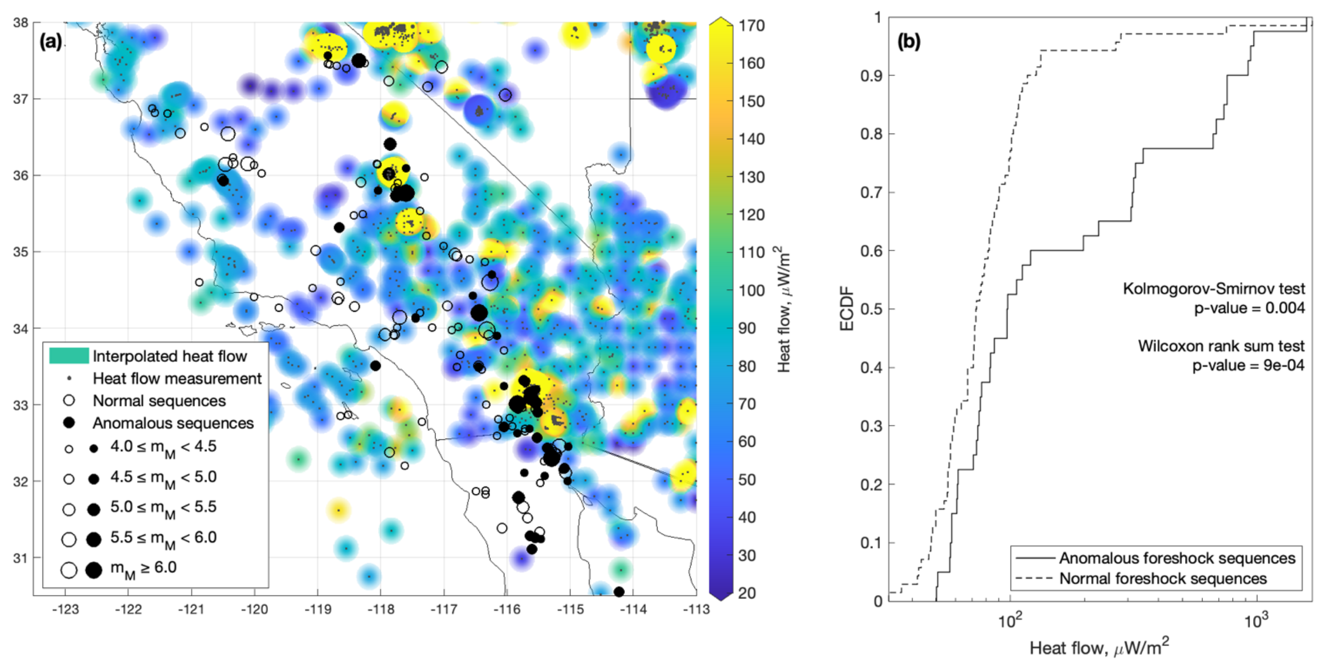

Figure S11. Like Figure 4 in the main paper (TEST2, NN method) but using a significance level of 95%.

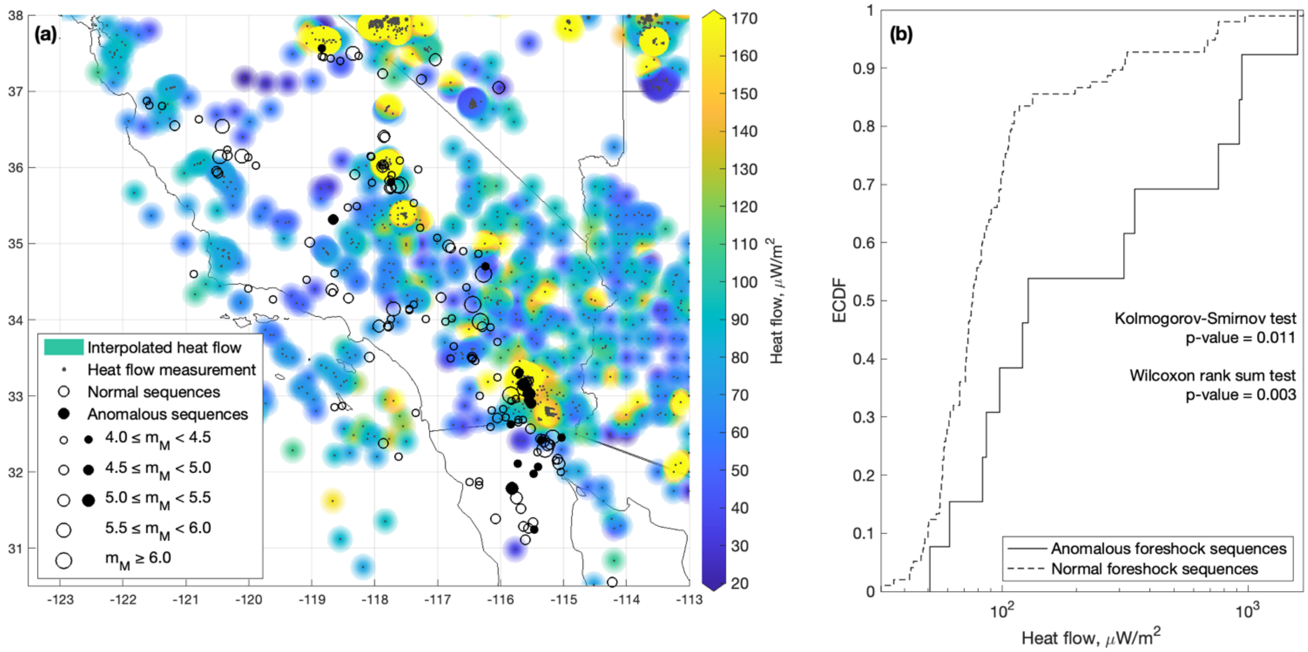

Figure S12. Like Figure 3 in the main paper (TEST1, NN method, 99th percentile) but with anomalous sequences identified using an alternative analysis that uses the distributions of the individual number of foreshocks (not the average, see Figure S4).

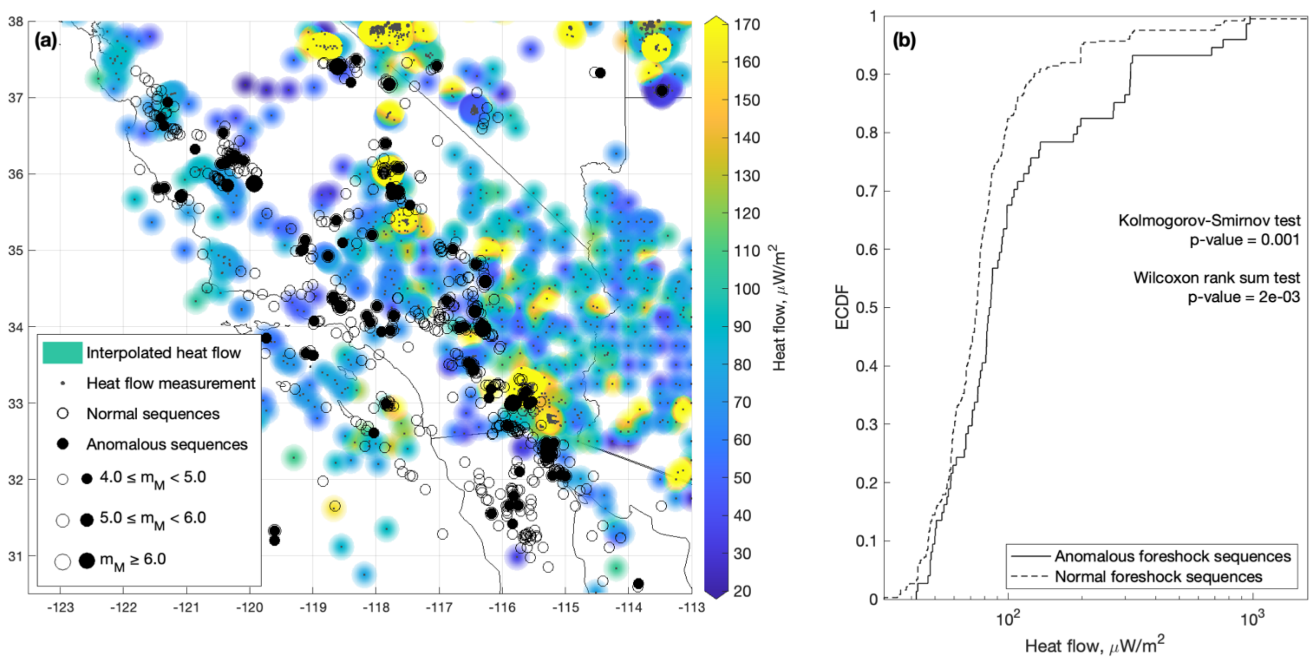

Figure S13. Like Figure 3 in the main paper but with the locations of normal and anomalous foreshock sequences identified by Petrillo & Lippiello (2021).