SnT 2025 8 SEPTEMBER ONLINE DAY 9 TO 12 SEPTEMBER AT HOFBURG PALACE, VIENNA & ONLINE
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

Two-step relocation of the seismicity of Oman

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INTRODUCTION AND MAIN RESULTS

We relocated 2,994 events in the Oman National Bulletin in two steps: first with the single-event locator iLoc, then with the multiple-event location algorithm, Bayesloc, using the reviewed iLoc locations as input.

The results demonstrate significant improvements in the view of seismicity and can help to identify anthropogenic events that represent the majority of onshore events in the region.

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Introduction

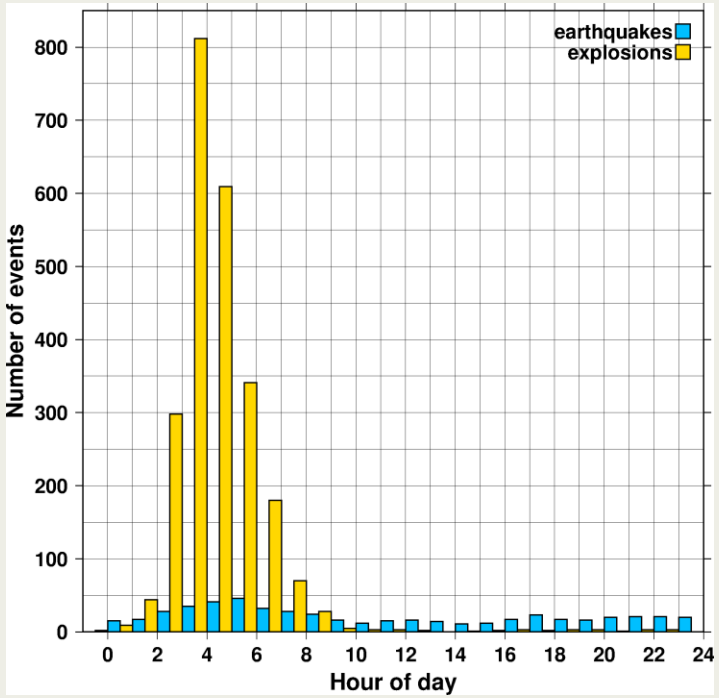
Oman is part of the Arabian Plate, surrounded by the Zagros fold and trust belt, the Makran subduction zone, and the Owen Fracture Zone. These major tectonic boundaries drive the seismicity of the Sultanate of Oman (Johnson, 1998, El-Hussain et al., 2012). There is also a significant anthropogenic activity in Oman that contributes to the onshore seismicity of Oman.

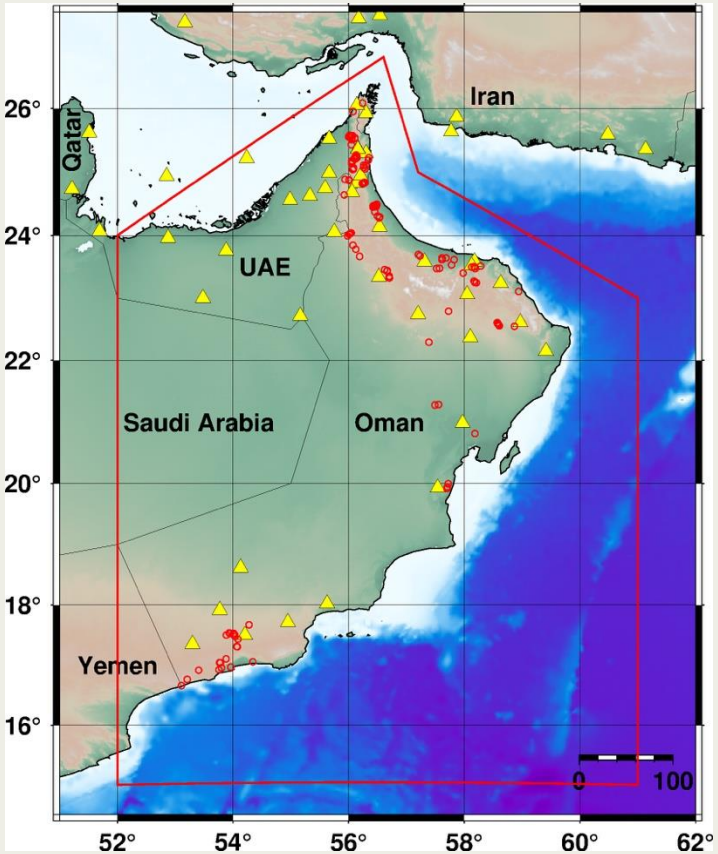
The cooperation in seismic research between the Earthquake Monitoring Center at Sultan Qaboos University (SQU) and the Lawrence Livermore National Laboratory (LLNL) has several decades long history.

In this study our objective was to produce the most accurate seismic catalogue to date that would provide input for probabilistic seismic hazard analyses, as well as a training set for seismic discrimination studies. To do this, we applied a two-step relocation procedure to improve the view of Oman's seismicity.

Data

We combined the SQU annual seismic bulletins between 2014 and 2024 with data from the International Seismological Centre (ISC) in order to supplement the SQU bulletins with further regional and teleseismic data. Our data set in our region of interest had 2,994 events, both natural and anthropogenic.





Top: Time-of-day distribution of earthquakes and anthropogenic events in the data set.
Right: Seismic stations (triangles) and known quarries (circles) in our region of interest around Oman.

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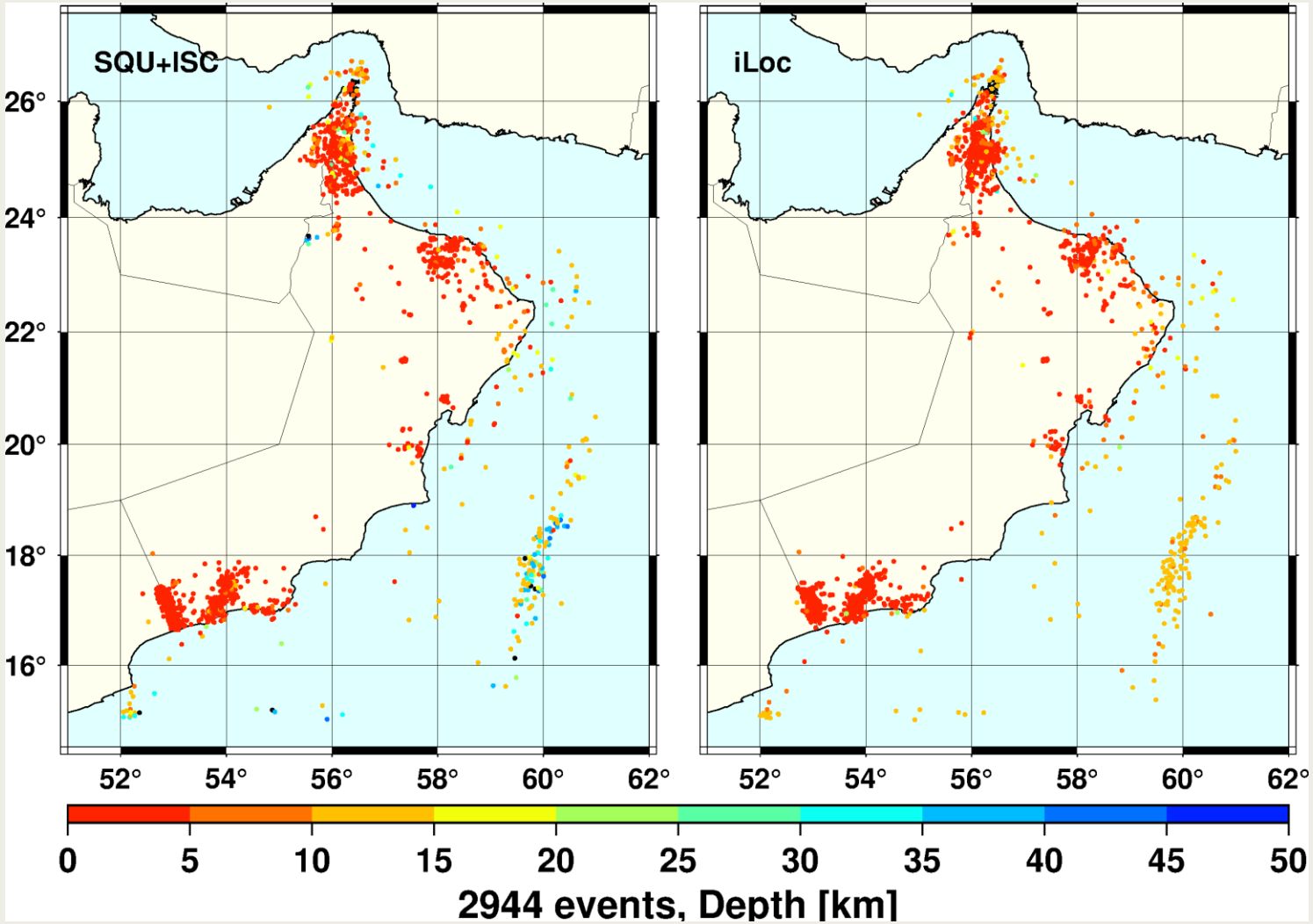
iLoc relocations

In order to produce a homogeneous bulletin from the combined SQU – ISC bulletin, we first relocated the events with iLoc, a state-of-the art single-event location algorithm (Bondár and McLaughlin, 2009; Bondár and Storchak, 2011).

Among the most important features of iLoc are that it accounts for correlated travel-time prediction errors that may arise from unmodeled 3D velocity structures, and it uses RSTT, a 3D global tomographic model to obtain travel-time predictions for crustal and mantle phases (Myers et al., 2010, Begnaud et al., 2021a, 2021b). iLoc also uses the neighboorhood algorithm search (Sambridge, 1999; Sambridge and Kennett, 2001) to obtain an initial guess for the linearized inversion.

For a final quality control, we manually reviewed every single event to provide the best possible input for Bayesloc.

iLoc rectifies the unrealistically deep events in the combined SQU+ISC bulletin in the Owen Fracture Zone and makes the anthropogenic event clusters around quarries tighter.



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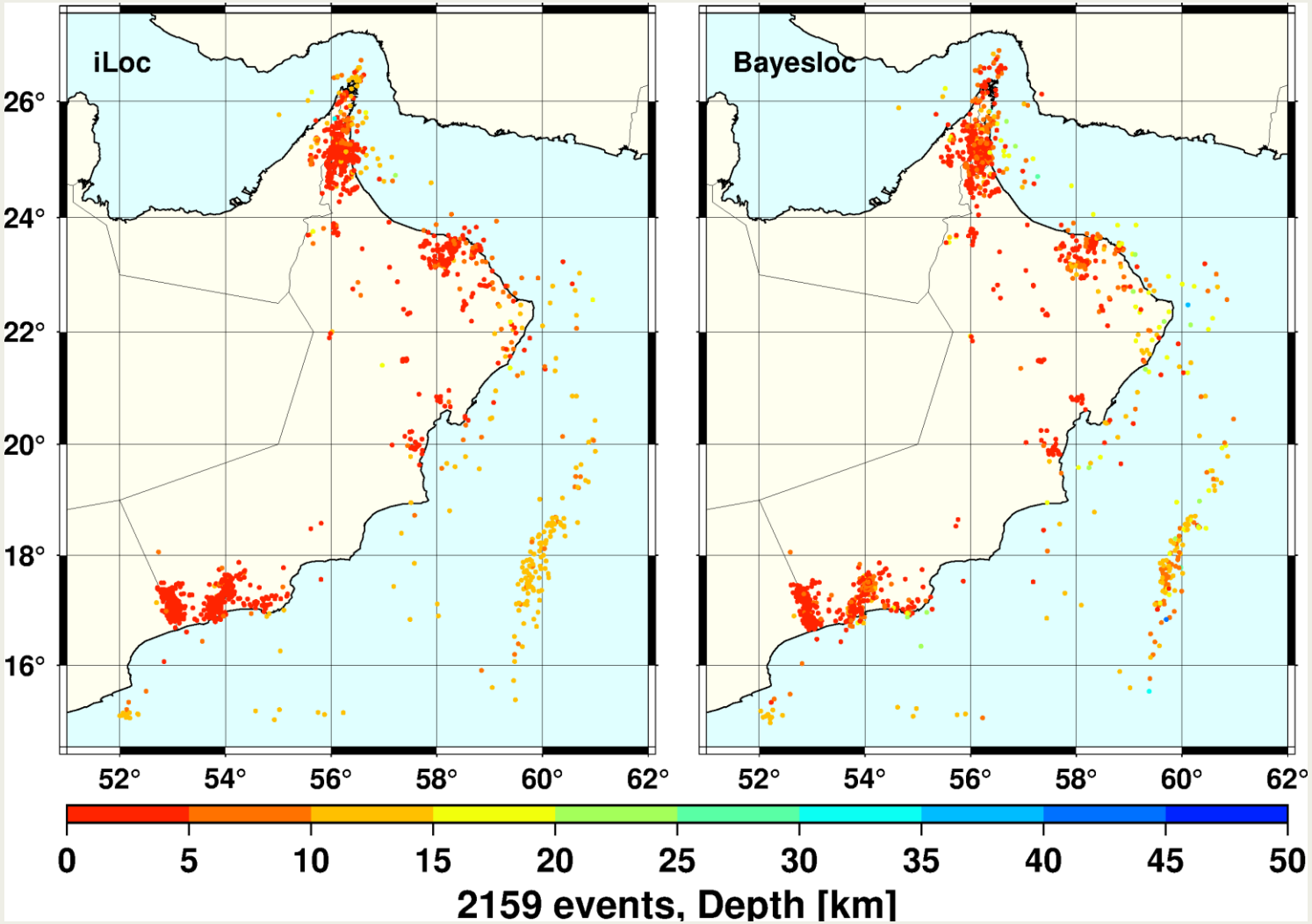
Bayesloc relocations

The reviewed iLoc locations served as input for Bayesloc, a non-linear, multiple-event location algorithm (Myers et al., 2007, 2009). To solve the multiple-event location problem, Bayesloc applies Markov Chain Monte Carlo simulation to sample the joint a posteriori probability distribution postulated by Bayes' theorem.

We only used those events from the reviewed iLoc bulletin that were recorded by at least 3 stations, had more than 4 time-defining phases, and the semi-major axis of their error ellipse was less than 500 km. 2,928 iLoc locations passed this quality control step.

Even with the above selection, a large number of events suffered from large azimuthal gaps. Therefore, we ran Bayesloc with a large number of iterations (80,000) on 10 Markov chains to make sure that Bayesloc reaches convergence for most of the events. Bayesloc converged for 2,159 events.

Bayesloc improves the offshore locations in the Owen Fracture Zone and tightens the clusters of anthropogenic events.



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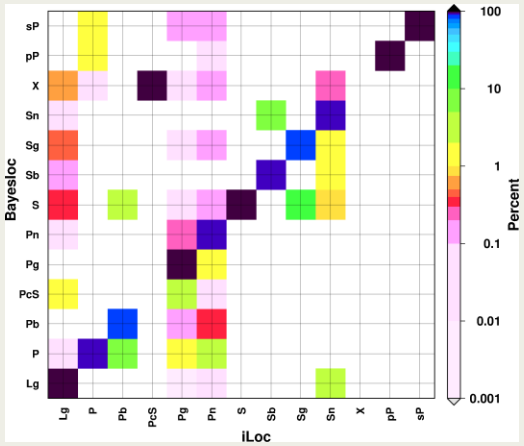
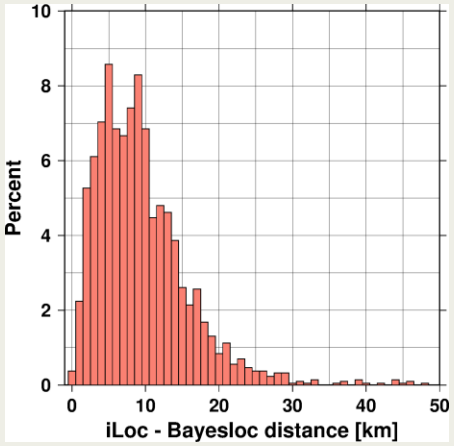
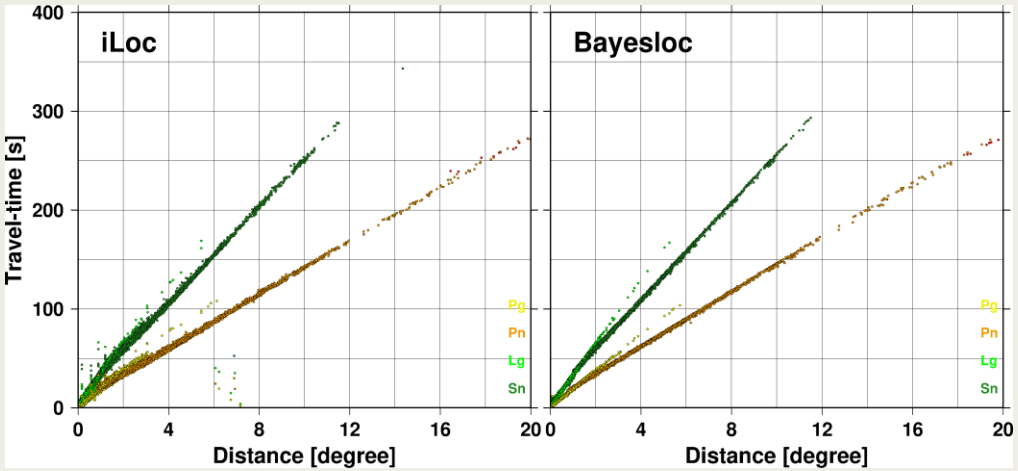
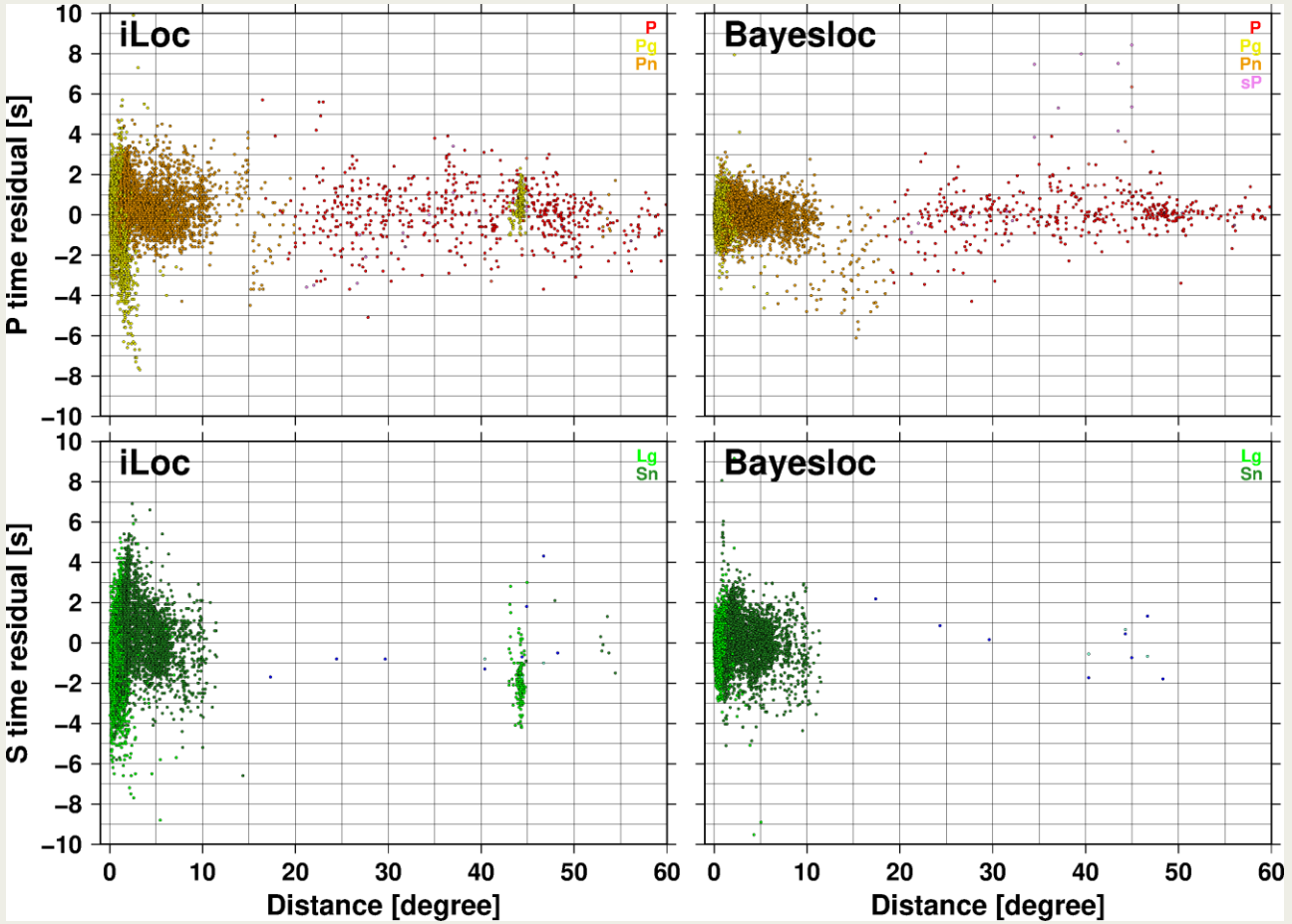
iLoc vs Bayesloc

Bayesloc, being a multiple-event location algorithm, is less sensitive to outliers. It also allows for renaming the phases based on their prior probability that they are correctly identified (90% in our case). The median distance between the iloc and Bayesloc location is 8.4 km, indicating that the iLoc locations were good to start with. Even though the locations did not change much, that was enough to considerably reduce the time residuals and tighten the seismicity.









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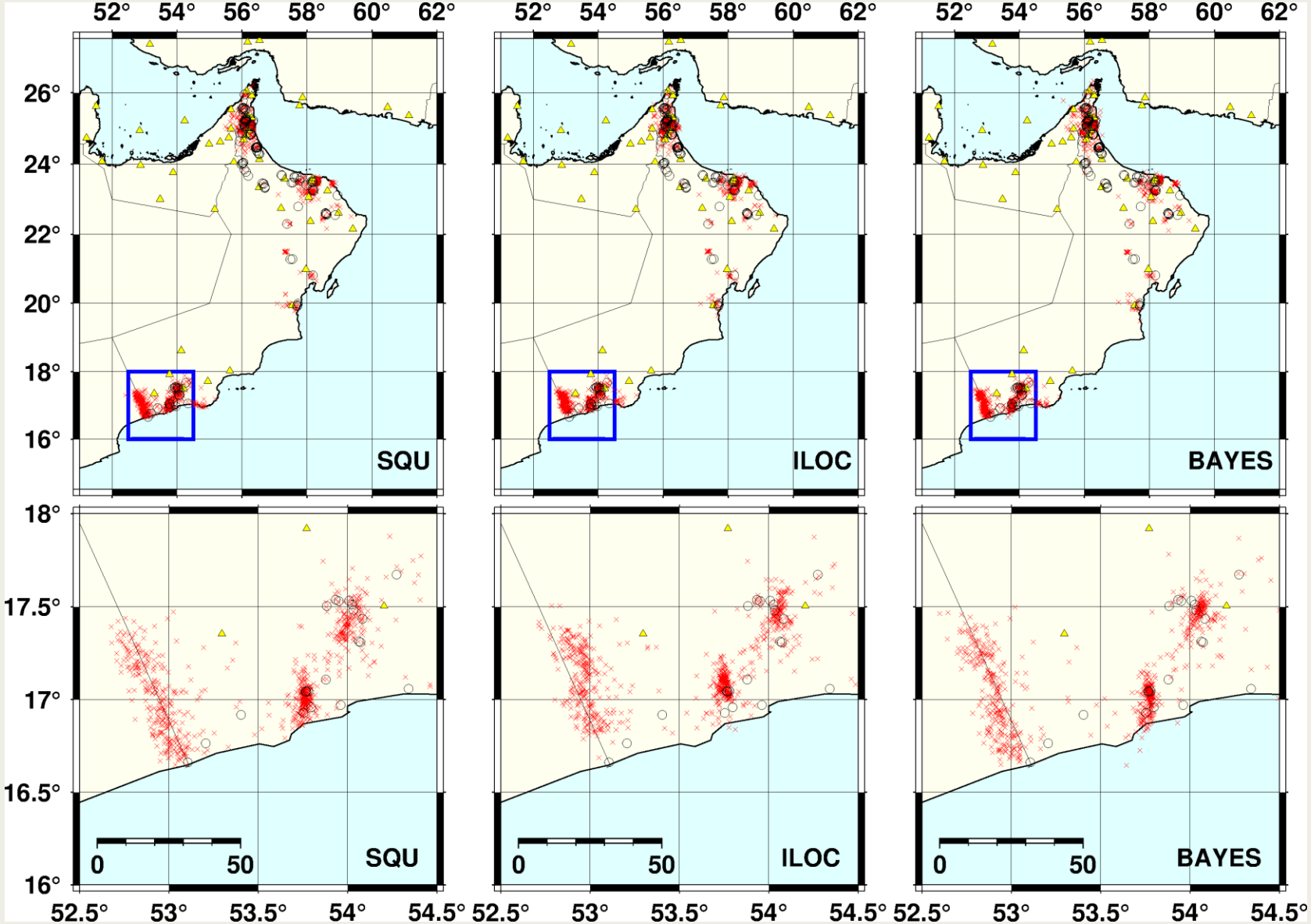

Anthropogenic events

The majority of the seismicity in Oman is due to anthropogenic activity, quarry blasts, mining and roadworks. The figure shows the distribution of suspected man-made events (black circles) in the combined SQU+ISC, the reviewed iLoc, and the final Bayesloc bulletin. The blue rectangles indicate the Southern region of Oman with activities from both roadworks and quarries.

The bottom figures show an enlarged map of this region. Bayesloc, by taking advantage of the multiple event-to-station ray paths, is able to cluster better the event locations around the quarries as well as the roadworks along the Oman-Yemen border. The improved event locations allowed for the better separation of anthropogenic and tectonic seismicity.

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Conclusions

We used a two-step process that has already been successfully applied to that Caucasus region (Bondár et al., 2023) to relocate the past 10 years of seismicity in Oman. Using iLoc we produced an improved, homogenous bulletin from the combined Oman and ISC bulletin, that served as input for Bayesloc. Bayesloc further improved the locations by achieving better clustering of both natural (Owen Fracture Zone) and anthropogenic (quarry blasts and roadworks) events. The results enhanced the quality of the Oman National Bulletin and will be used in refining seismic hazard models in the region. Our results will also provide a valuable training set for seismic discrimination studies.

Acknowledgements

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.
Both iLoc and Bayesloc are open-source software, they can be downloaded from https://github.com/IstvanBondar/iLoc and from https://gs.llnl.gov/nuclear-threatreduction/nuclear-explosionmonitoring/bayesloc, respectively.

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References

Begnaud, M.L., S.C. Myers, B. Young, J.R. Hipp, D. Dodge. W.S. Phillips (2021a). Updates to the Regional Seismic Travel Time (RSTT) Model: 1. Tomography, *Pure Appl. Geophys.*, **178**, 2475–2498, https://doi.org/10.1007/s00024-020-02619-5.

Begnaud, M.L., D.N. Anderson, S.C. Myers, B. Young, J.R. Hipp, W.S. Phillips (2021b). Updates to the Regional Seismic Travel Time (RSTT) Model: 2. Path-dependent travel-time uncertainty, *Pure Appl. Geophys.,* **178**, 313-339, https://doi.org/10.1007/s00024-021-02657-7.

Bondár, I. and K. McLaughlin (2009a). Seismic location bias and uncertainty in the presence of correlated and non-Gaussian travel-time errors, *Bull. Seism. Soc. Am.,* **99**, 172-193, https://doi.org/10.1785/0120080922.

Bondár, I., and D. Storchak (2011). Improved location procedures at the International Seismological Centre, *Geophys. J. Int.,* **186**, 1220-1244, https://doi.org/10.1111/j.1365-246X.2011.05107.x.

Bondár, I., T. Godoladze, E. Cowgill, G. Yetirmishli, S.C. Myers, I. Gunia, A. Buzaladze, B. Czecze, T. Onur, R. Gök, A. Chiang (2023). Relocation of the Seismicity of the Caucasus Region, *Bull. Seism. Soc. Am.*, **114**, 873-881, https://doi.org/10.1785/0120230155.

El-Hussain I., A. Deif, K. Al-Jabri, N. Toksoz, S. El-Hady, S. Al-Hashmi, K. Al-Toubi, Y. Al-Shijbi, M. Al-Saifi, S. Kuleli, (2012) Probabilistic seismic hazard maps for Sultanate of Oman, Natural Hazards, **64**, 173-210, https://doi.org/10.1007/s11069-012-0232-3.

Johnson, P.R., (1998) Tectonic map of Saudi Arabia and adjacent areas, Deputy Ministry for Mineral Resources, Jiddah, Saudi Arabia, *Technical Report USGS TR-98-3*.

Myers, S.C., G. Johannesson, W. Hanley, (2007) A Bayesian hierarchical method for multiple-event seismic location, *Geophys. J. Int.,* **171**, 1049-1063, https://doi.org/10.1111/j.1365-246X.2007.03555.x.

Myers, S.C., G. Johannesson, W. Hanley, (2009) Incorporation of probabilistic seismic phase labels into a Bayesian multiple-event seismic locator, *Geophys. J. Int.,* **177**, 193–204. https://doi.org/10.1111/j.1365-246X.2008.04070.x.

Myers, S.C., M.L. Begnaud, S. Ballard, M.E. Pasyanos, W.S. Phillips, A.L. Ramirez, M.S. Antolik, K.D. Hutchenson, J.J. Dwyer, C.A. Rowe, and G.S. Wagner (2010). A crust and upper-mantle model for Eurasia and North Africa for Pn travel-time calculation, *Bull. Seismol. Soc. Am.,* **100**, 640–656, https://doi.org/10.1785/0120090198.

Sambridge, M., (1999). Geophysical inversion with a neighbourhood algorithm. I. Searching the parameter space, *Geophys. J. Int.,* **138**, 479–494, https://doi.org/10.1046/j.1365-246X.1999.00876.x.

Sambridge, M., B.L.N. Kennett (2001). Seismic event location: non-linear inversion using a neighbourhood algorithm, *Pure appl. Geophys.*, **158**, 241–257, https://doi.org/10.1007/PL00001158.