2017 — 2018 年对地震预测研究具有潜在意义的科技进展

相关进展由“我是地震学家”微信群、中国地震局地震预测重点实验室学术委员会提名，由中国地震局地震预测研究所科学技术委员会投票确定。

入选的十大科技进展

1. 明确数值地震预测路线图

石耀霖，孙云强，罗纲，董培育，张怀. 2018. 关于我国地震数值预报路线图的设想——汶川地震十周年反思. *科学通报*, 63, 1865-1881. https://doi.org/10.1360/N972018-00335

2. 人工智能在地震预测方面得到新的应用

Rouet-Leduc, B., Hulbert, C., Lubbers, N., Barros, K., Humphreys, C. J. and Johnson, P. A. 2017. Machine learning predicts laboratory earthquakes. *Geophysical Research Letters*, 44, 9276-9282. https://doi.org/10.1002/2017GL074677

Rouet-Leduc, B., Hulbert, C., Bolton, D. C., Ren, C. X., Riviere, J., Marone, C., Guyer, R. A. and Johnson, P. A. 2018. Estimating fault friction from seismic signals in the laboratory. *Geophysical Research Letters*, 45, 1321-1329. https://doi.org/10.1002/2017GL076708

DeVries, P. M., Viégas, F., Wattenberg, M. and Meade, B. J. 2018. Deep learning of aftershock patterns following large earthquakes. *Nature*, 560, 632. https://doi.org/10.1038/s41586-018-0438-y

Beroza, G. C. 2018. Machine learning improves forecasts of aftershock locations. *Nature*, 560, 556-557. https://doi.org/10.1038/d41586-018-06030-y

3. 光缆用于地震监测

Hand, E. 2018. Seafloor fiber optic cables can listen for earthquakes. *Science*, 360, 1160-1160. https://doi.org/10.1126/science.360.6394.1160

Marra, G., Clivati, C., Luckett, R., Tampellini, A., Kronjäger, J., Wright, L., Mura, A., Levi, F., Robinson, S., Xuereb, A. and Baptie, B. 2018. Ultrastable laser interferometry for earthquake detection with terrestrial and submarine cables. *Science*, 361, 486-490. https://doi.org/10.1126/science.aat4458

Jousset, P., Reinsch, T., Ryberg, T., Blanck, H., Clarke, A., Aghayev, R., Hersir, G. P., Henninges, J., Weber,

M. and Krawczyk, C. M. 2018. Dynamic strain determination using fibre-optic cables allows imaging of seismological and structural features. *Nature Communications*, 9, 2509. https://doi.org/10.1038/s41467-018-04860-y

4. “断层模型 + 统计地震学模型”应用于长期地震危险性分析

Field, E. H., Milner, K. R., Hardebeck, J. L., Page, M. T., Van der Elst, N., Jordan, T. H., Michael, A. J., Shaw, B. E. and Werner, M. J. 2017. A spatiotemporal clustering model for the third Uniform California Earthquake Rupture Forecast (UCERF3-ETAS): Toward an operational earthquake forecast. *Bulletin of the Seismological Society of America*, 107, 1049-1081. https://doi.org/10.1785/0120160173

Jia, K., Zhou, S., Zhuang, J., Jiang, C., Guo, Y., Gao, Z. and Gao, S. 2018. Did the 2008 Mw 7.9 Wenchuan earthquake trigger the occurrence of the 2017 Mw 6.5 Jiuzhaigou earthquake in Sichuan, China? *Journal of Geophysical Research: Solid Earth*, 123, 2965-2983. https://doi.org/10.1002/2017JB015165

Huang, Y., Wang, Q., Hao, M. and Zhou, S. 2018. Fault slip rates and seismic moment deficits on major faults in Ordos constrained by GPS observation. *Scientific Reports*, 8, 16192. https://doi.org/10.1038/s41598-018-34586-2

5. 在 SCEC4 向 SCEC5 发展的过程中 CSEP1.0 向 CSEP2.0 发展

SCEC. 2016. *Southern California Center: Research program in earthquake system sciences, 2017-2022*. Proposal to the National Sciences Foundation and U. S. Geological Survey.

Schorlemmer, D., Werner, M. J., Marzocchi, W., Jordan, T. H., Ogata, Y., Jackson, D. D., Mak, S., Rhoades, D. A., Gerstenberger, M. C., Hirata, N. and Liukis, M. 2018. The Collaboratory for the Study of Earthquake Predictability: Achievements and priorities. *Seismological Research Letters*, 89, 1305-1313. https://doi.org/10.1785/0220180053

6. “低频地震”形成较系统的目录

Shelly, D. R. 2017. A 15 year catalog of more than 1 million low-frequency earthquakes: Tracking tremor and slip along the deep San Andreas Fault. *Journal of Geophysical Research: Solid Earth*, 122, 3739-3753. https://doi.org/10.1002/2017JB014047

7. 证实断层结构变化可影响和控制发震与破裂传播行为

Guo, H., Zhang, H. and Froment, B. 2018. Structural control on earthquake behaviors revealed by high-resolution Vp/Vs imaging along the Gofar transform fault, East Pacific Rise. *Earth and Planetary Science Letters*, 499, 243-255. https://doi.org/10.1016/j.epsl.2018.07.037

8. 震级预测技术得到发展（最大事件的贝叶斯预测和下一次地震震级）

Shcherbakov, R., Zhuang, J. and Ogata, Y. 2017. Constraining the magnitude of the largest event in a foreshock–mainshock–aftershock sequence. *Geophysical Journal International*, 212, 1-13. https://doi.org/10.1093/gji/ggx407

Ogata, Y., Katsura, K., Tsuruoka, H. and Hirata, N. 2018. Exploring magnitude forecasting of the next earthquake. *Seismological Research Letters*, 89, 1298-1304. https://doi.org/10.1785/0220180034

9. 刻画地震成核过程中断层亚失稳阶段的特征

Ren, Y., Ma, J., Liu, P. and Chen, S. 2018. Experimental study of thermal field evolution in the short-impending stage before earthquakes. *Pure and Applied Geophysics*, 175, 2527-2539. https://doi.org/10.1007/s00024-017-1626-7

Zhuo, Y. Q., Liu, P., Chen, S., Guo, Y. and Ma, J. 2018. Laboratory observations of tremor-like events generated during preslip. *Geophysical Research Letters*, 45, 6926-6934. https://doi.org/10.1029/2018GL079201

Zhuo, Y. Q., Guo, Y., Chen, S., Ji, Y. and Ma, J. 2018.

Laboratory observations of linkage of preslip zones prior to stick-slip Instability. *Entropy*, 20, 629. https://doi.org/10.3390/e20090629

10. 提出应力闭锁区的微震事件对小应力扰动存在敏感性

Wang, C., Liang, C., Deng, K., Huang, Y. and Zhou, L. 2018. Spatiotemporal distribution of microearthquakes and omplications around the seismic gap between the Wenchuan and Lushan earthquakes. *Tectonics*, 37, 2695-2709. https://doi.org/10.1029/2018TC005000

获得提名的科技进展

利用地表观测数据确定发震断层的摩擦参数

Weng, H. and Yang, H. 2018. Constraining frictional properties on fault by dynamic rupture simulations and near-field observations. *Journal of Geophysical Research: Solid Earth*, 123, 6658-6670. https://doi.org/10.1029/2017JB015414

提出可对人工诱发地震进行预测的模型

Petersen, M. D., Mueller, C. S., Moschetti, M. P., Hoover, S. M., Shumway, A. M., McNamara, D. E., Williams, R. A., Llenos, A. L., Ellsworth, W. L., Michael, A. J. and Rubinstein, J. L. 2017. 2017 one-year seismic-hazard forecast for the central and eastern United States from induced and natural earthquakes. *Seismological Research Letters*, 88, 772-783. https://doi.org/10.1785/0220170005

Norbeck, J. H. and Rubinstein, J. L. 2018. Hydromechanical earthquake nucleation model forecasts onset, peak, and falling rates of induced seismicity in Oklahoma and Kansas. *Geophysical Research Letters*, 45, 2963-2975. https://doi.org/10.1002/2017GL076562

Barbour, A. J., Norbeck, J. H. and Rubinstein, J. L. 2017. The effects of varying injection rates in Osage County, Oklahoma, on the 2016 *Mw* 5.8 Pawnee earthquake. *Seismological Research Letters*, 88, 1040-1053. https://doi.org/10.1785/0220170003

Pei, S., Peng, Z. and Chen, X. 2018. Locations of injection-induced earthquakes in Oklahoma controlled by crustal structures. *Journal of Geophysical Research: Solid Earth*, 123, 2332-2344. https://doi.org/10.1002/2017JB014983

提出可对震颤事件进行预测的隐马尔可夫模型

Wang, T., Zhuang, J., Obara, K. and Tsuruoka, H. 2017. Hidden Markov modelling of sparse time series from non-volcanic tremor observations. *Journal of the Royal Statistical Society: Series C (Applied Statistics)*, 66, 691-715. https://doi.org/10.1111/rssc.12194

提出考虑三维震源和各向异性的精化的余震预测模型

Guo, Y., Zhuang, J., Hirata, N. and Zhou, S. 2017. Heterogeneity of direct aftershock productivity of the main shock rupture. *Journal of Geophysical Research: Solid Earth*, 122, 5288-5305. https://doi.org/10.1002/2017JB014064

提出新的地震预测方法“*Nowcasting*”（“即时预测”）

Rundle, J. B., Luginbuhl, M., Giguere, A. and Turcotte, D. L. 2018. Natural time, nowcasting and the physics of earthquakes: Estimation of seismic risk to global megacities. *Pure and Applied Geophysics*, 175, 647-660. https://doi.org/10.1007/s00024-017-1720-x

改进加卸载响应比方法（量纲分析）

Liu, Y. and Yin, X. C. 2018. A dimensional analysis method for improved load–unload response ratio. *Pure and Applied Geophysics*, 175, 633-645. https://doi.org/10.1007/s00024-017-1716-6