面向地震预测的科学框架与发展路线图

海城倡议

Haicheng Initiative

海城地震 1975.2.4
Haicheng Earthquake

海城地震50周年地震预测国际学术研讨会讨论通过

2025年7月8-11日 沈阳

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自地震预测被纳入国家和全球地震科学事业发展的议程以来，已过去了四分之三个世纪，然而，地震预测至今仍是一道亟待攻克的世界性科学难题。尽管如此，在向地震预测进军的征程中，仍然取得了一些显著成就，其中最为突出的就是 1975 年 2 月 4 日海城 7.3 级地震的成功预报。这次预报是历史上第一次达成减灾实效的强震预报案例，它表明面对地震灾害的威胁，科学技术可以在降低灾害损失方面发挥建设性作用、作出实质性贡献。

半个世纪以来，地震可预测性及其在灾害风险减轻中的应用研究取得了显著进展。同时，地震监测、建模以及不同时空尺度的地震灾害评估方面的新技术展现出潜在的应用价值。地震预测研究和实践展现出明显的跨学科、跨机构以及国际特性。基于过去半个世纪的经验教训，面向以下目标:

1.强化中长期地震预测与地震危险性评估的物理基础

2.力争短临预测有所突破

3.提升地震预测在减轻灾害风险中的实效

即“中长期预测更加科学、短临预测有所突破、地震预报更有实效”，需要讨论未来五十年的大陆地震预测科学框架和发展路线图。

大陆地震对人类生命财产安全构成最直接的、严峻的威胁。近年来开展的交叉学科研究，为评估大陆地震的可预测性提供了科学依据。

为纪念海城地震成功预报50周年，攀登地震预测科学高峰，地震预测国际学术研讨会于2025年7月8日至10日在沈阳召开。来自38个国家/地区的约300名代表，经过交流、讨论与辩论，达成如下共识，倡导合作开展科技攻关。

1. 推动地震可预测性研究及其在灾害风险减轻中的应用

1.1 深化对地震构造的理解

越来越多的大陆地震表明，大陆地区的大地震主要发生在活动地块边界带上。了解这些构造带的变形和断层运动，是识别地震复发模式的重要基础。随着现代技术的应用，大地测量、地球物理调查和年代学方法的精度和分辨率得到显著提高，为研究构造带变形和断层运动提供了更可靠的信息和新的视角。

1.2 推进地震地球物理与地震大地测量研究

针对强震震源区的深部结构研究，亟待促进新兴跨学科数据和研究成果的共享，以帮助阐明板内强震的深部结构、机制和过程，包括但不限于地质学、地球物理学、大地测量学和地球动力学等领域。

1.3 发展地震动力学

近年来，随着密集台网、深井观测和光纤传感等新型观测技术的发展和理论的发展，科学家以更多的数据支持和新的视角，加深了对强震孕育发生过程的理解，逐步揭示了地震起始与破裂模式的多样性，如地震预滑与级联、亚剪切与超剪切破裂等。同时，随着大数据的应用和显著地震的科考与震例总结，基于物理的震源模型不断发展，能够为地震震级和地震概率提供合理的估计。

2. 应用新技术于地震监测、建模及多尺度地震危险性评估

2.1 推进人工智能手段赋能地震预测

人工智能的发展为地震研究带来了革命性的变化。聚焦大数据和人工智能在地震监测预报中的应用，以及方法测试，将极大地促进地震监测与预测领域的科技创新，为地震预报和灾害减轻提供更高效的技术手段。但同时也必须强调，若缺乏针对实际震例的广泛的检验，人工智能也可能为地震预测领域带来误导性的解译、结论及对策建议。

2.2 应用空间技术于地震预测

地震孕育、发生的全过程对岩石圈、大气层与电离层产生显著影响。空间技术的突破性进展为研究地震的多圈层耦合响应、优化监测体系和追踪能力提供了新的机遇。

2.3 推进现场地震科学考察

显著地震发生后迅速启动科考，对于理解地震复发和地震可预测性具有重要意义。地震科考相关的科学问题的系统探讨需重点关注:

（1）多学科协同机制与国际合作;

（2）新技术方法的系统应用;

（3）基于实测物理量、科学准则及行业规范的严格验证;

（4）地震观测数据共享政策的优化实施。

2.4 创新地震预测实验场与原位实验

地震科学实验场的设计、建设、运营、评估和优化，特别是地震预测领域的原位地震实验、人类活动诱发／触发地震、地球介质变化的检测、实验场作为“大科学”基础设施的可持续性、实验场的比较研究和标准化、基于遥感和数值模拟的“虚拟”实验场，以及其他相关的创新工作，是地震预测领域的重要科学问题。

3. 不断改进地震预测实践

3.1 发展中长期地震预测

准确的地震风险评估是地震灾害防御的基础，这需要

对强震进行定量的和精细的预测。随着地震观测与探测的理论与技术的发展，震源物理模型逐渐完备，破裂传播机制更加清晰，地震破裂动力学过程的数值模拟技术愈加成熟。中长期概率地震预测与数值预测在理论基础、计算资源及观测数据支撑方面已具备良好基础，但其预测效能仍需通过实际震例严格验证。

3.2 坚持短临地震预测探索

中国和其他国家／地区近50年的地震预测实践表明，一些强震前确实存在地震前兆异常。然而，地震前兆异常的识别仍是复杂的。在地震前兆异常的检测和识别中，首先需要排除各种影响观测的非构造因素；同时，观测数据的异常需要通过相关的映震过程来进行解释。地震短临预测的突破将建立在对前兆异常的深入研究的基础上。

3.3 推动地震预测相关的科技成果转化

基于对地震的新认识和地震监测与建模的新技术，总结过去半个世纪的经验教训，显著提高可操作地震预测和地震危险性评估（包括经验方法、统计方法、物理方法和数值方法）的“技术就绪水平”，使地震预测和地震危险性评估在灾害风险减轻方面更有实效，目前已具备较成熟的条件。

3.4 通过灾害情景构建提升地震预测的针对性

地震发生前预知潜在地震动至关重要。通过构建满足

预警触发条件的地震灾害情景获取此类信息，通过潜在地震的最大震级和安全系数得到预期地震动的理论峰值上限。

除地震动直接效应外，灾害链还威胁经济社会发展及人民生命财产安全。因此，亟需深化地震灾害链成灾机理研究，实施精准化风险评估，并制定科学减灾应急预案以筑牢安全防线。

3.5 探讨地震预测的社会问题

地震预测是一个实践导向型的跨学科难题，涉及自然科学、工程学及社会科学。这一特性已在海城地震的地震社会学与震前备灾体系得到充分体现。未来发展关键在于区域-国家-全球尺度的地震预测系统规划与具有关键作用的信息传递机制。各国家和地区在此领域积累的宝贵经验与教训亟待系统整合提炼。

地震序列具有非随机性特征，尽管其成因的理解尚不完备，但某些地震序列是可以预测的，1975 年海城地震的成功预报即为其早期实践证明。

我们呼吁国际同行，凝聚智慧、联合行动，共同推进地震预测研究，助力社会可持续发展。

A Roadmap Towards Earthquake Forecasting

The Haicheng Initiative

Discussed and endorsed at the

International Symposium on Earthquake Forecasting, 8-10 July 2025

It has been over three quarters of a century since earthquake prediction was put on the agenda of national and global endeavor of earthquake science. Yet earthquake prediction remains a grand scientific challenge. However, in the long march to earthquake prediction, there were some remarkable achievements. The successful prediction of the 4 February 1975, Haicheng, Liaoning Province, China, *M*s7.3 earthquake was one of them. This was the first prediction of a major earthquake which played an important role in the mitigation of earthquake disasters. The prediction itself had shown that, facing the threat of earthquake disaster, science and technology can at least do something constructive and contribute to the reduction of earthquake disaster.

Half century has passed, there have been significant advances in both the study on the predictability of earthquakes and its application

for disaster risk reduction (DRR), and new technologies have developed which are potentially useful for the monitoring and modeling of earthquakes and the assessment of seismic hazards at different spatio-temporal scales. Earthquake forecasting itself has shown its interdisciplinary, inter-institutional, and international characteristics. Based on the experiences and lessons of the past half century, and aiming at the goals of

1. More physics in long-and-intermediate-term earthquake forecast and seismic hazard assessment;

2. More insights in short-and-imminent-term earthquake forecast;

3. More and better application of earthquake forecast and seismic hazard assessment for disaster risk reduction

abbreviated as M^3, it is time to discuss the vision of earthquake forecast and priorities of science and technology, towards the next half century.

Continental earthquakes pose the most direct and serious threat to people's lives and property. In recent years, interdisciplinary research on continental earthquakes has been conducted, providing scientific basis for assessing the predictability of earthquakes.

Commemorating the 50th anniversary of the successful prediction of

the Haicheng earthquake, and promoting to address the scientific challenges of earthquake forecast, the International Symposium on Earthquake Forecasting was held from 8 to 10 July 2025, with about 300 participants from 38 countries/regions, which reached the following consensus on the agenda of developments based on the exchange, discussion, and debate, advocating the joint actions in science and technology.

1. Promoting the study on the predictability of earthquakes and its application for disaster risk reduction (DRR)

1.1 Improving the understandings of seismotectonics

An increasing number of continental earthquakes indicate that major earthquakes primarily occur along tectonic boundary zones. Therefore, understanding the deformation of these tectonic zones and fault movements is an important foundation for recognizing the patterns of earthquake generation. With the application of modern technologies, the precision and resolution of data from topographic surveys, geophysical investigations, and dating methods have significantly improved, providing more reliable information and new perspectives for studying tectonic zone deformation and fault movements.

1.2 Advancing the understandings of deep processes and seismogenesis

Study of seismogenic structure of large earthquakes needs to promote the sharing of new interdisciplinary data and results to help elucidate the deep structure, mechanisms and processes of destructive earthquakes within plate interior, including, but not limited to, geology, geophysics, geodesy and geodynamics.

1.3 Developing earthquake dynamics modeling

With the progress of new observation techniques and theories, such as high-density network, deep drilling observation and optical fiber sensing, scientists have more data support and new perspectives on the understanding of the occurrence process of large earthquakes. The research revealed the diversity of earthquake nucleation and rupture modes, such as pre-slip versus cascade phenomena, and subshear versus supershear rupture. Meanwhile, with big data and lessons learnt from recent earthquakes, there is an ongoing progress of physics-based earthquake source modeling, providing reasonable estimates of the magnitude and likelihood of earthquake rupture.

2. Applying new technologies which are potentially useful for the monitoring and modeling of earthquakes and the assessment of

seismic hazards at different spatio-temporal scales

2.1 Applying artificial intelligence to earthquake forecast

The development and application of artificial intelligence (AI) have brought about revolutionary changes to earthquake research, providing more scientific basis and more efficient technical means for earthquake forecasting. On the other hand, without extensive testing against observed seismicity, AI may provide broad avenues for deceptive interpretations/conclusions/ recommendations.

2.2 Applying space technology to earthquake forecast

Earthquakes have a strong impact on the lithosphere, atmosphere, and ionosphere during their preparation, occurrence, and aftermath stage. The development of space technology provides opportunities for studying the multi-layer response to earthquakes and improving monitoring system and tracking capabilities.

2.3 Encouraging comprehensive field investigation of earthquakes

Rapid initiation of comprehensive field investigations after large earthquakes plays an important role in understanding earthquake occurrence and earthquake predictability. To systematically explore related scientific issues, the following aspects are to be stressed in

comprehensive investigations of significant earthquakes:

a) Multi-disciplinary synergies and international collaborations in earthquake investigations;

b) Application of new technologies;

c) Rigorous testing against registered observables, scientific guidelines, standards;

d) Data-sharing policies of earthquake monitoring agencies.

2.4 Revolutionizing test sites and in-situ experiments for earthquake forecast and prediction

The design, construction, operation, evaluation, and optimization of the test sites for earthquake forecast, especially recent developments of in-situ experiments, monitoring of the variation of Earth media, sustainability of the test sites as 'big science' infrastructures, networking of testing areas as a unified system, and virtual test sites based on remote sensing and numerical simulation are the important issues in earthquake forecast and prediction.

3. Improving the practice of earthquake forecast and prediction

3.1 Improving long-to-intermediate term earthquake forecast

Accurate earthquake risk assessment is the foundation for the

effectiveness of operational earthquake defensive measures, which demands quantitative and refined forecast of large earthquakes. With the development of earthquake observation and exploration, theory and technology, the physical model of earthquake source has progressively improved, the mechanism of strong earthquake propagation became clearer, and numerical simulation technology of the dynamic process of strong earthquake propagation has gradually matured. The long- and intermediate-term probabilistic earthquake forecast and numerical forecast have good foundations in theoretical, computational and observational resources. The forecast must pass through extensive testing against observed seismicity.

3.2 Keeping exploring short-to-imminent term earthquake forecast

The nearly 50 years of earthquake forecast practice in China as well as other countries/regions has shown that precursors were observed before certain earthquakes. However, identifying earthquake precursors is still difficult; most of so-called well-known “significant earthquake precursors” still require durable testing against seismic reality for reliable operational forecasting. In the detection of earthquake precursors, all of the non-tectonic factors affecting the observation need to be excluded. Meanwhile, the observed anomalies need to be explained by the related seismogenic processes.

Breakthrough of short-to-imminent-term earthquake forecast relies on the study of the precursors.

3.3 Facilitating the transition of earthquake forecast from science to application

Based on the new understandings of earthquakes and new technologies of the monitoring and modeling for earthquake forecast, and summarizing the experiences and lessons over the past half century, it has been possible to significantly enhance the technical readiness level (TRL) of the existing methods of operational earthquake forecast (OEF) and seismic hazard assessment (SHA) - the empirical, the statistical, the physics-based, and the numerical, making earthquake forecast and SHA applicable to the society for disaster risk reduction (DRR).

Effective forecasting requires a holistic, step-by-step approach—progressively narrowing magnitude, location, and time within physical and data limits. OEF must be reliable, testable, supported by evidence, but not necessarily perfect. Evaluating OEF requires tracking both successes and failures. Rigorous, prospective testing is needed, properly compared with the results of random guesses to assess error rates and optimized parameters through

user-specific cost-benefit analyses. A shared theoretical framework is essential for evaluating forecasting tools consistently.

3.4 Making earthquake forecast useful through disaster scenario simulation

It is essential to know the expected ground shaking before the earthquake occurrence. Such information can be attained by modelling a wide set of possible scenarios for earthquakes that satisfy the alert conditions. An upper bound for the expected ground shaking can also be determined by considering the maximum magnitude for the impending earthquakes plus an additional safety term.

In addition to ground motion, earthquakes may lead to cascading disasters and pose serious threats to social and economic development, people's life and property. Therefore, it is very important to explore the formation mechanism of earthquake related disasters, accurately assess their risks, and formulate the mitigation and emergency plan to ensure the safety of people's life and property.

3.5 Investigating the social aspects of earthquake forecast

Earthquake forecast is a practice-oriented problem crossing the border of natural science, engineering, and social sciences. This

character was much reflected during the occurrence of Haicheng earthquake by the disciplines of seismo-sociology and preparedness for earthquakes. Systematic planning and communication of earthquake forecasts at the regional, national, and global scales play important roles for future developments. In this regard different countries/regions have accumulated rich experiences and lessons which need to be addressed comprehensively.

Earthquake sequences are not random, but rather lack comprehensive geneses: the successful prediction of the 1975 Haicheng earthquake is an early proof.

We call for the international wisdom and joint action towards earthquake forecasting, for the sustainability of the society.