Summary of Session 5.1:
General session for earthquake forecasting and hazard quantification

D. Jackson[1], X.C. Yin [2], A. Yoshida [3]

(1) Department of Earth and Space Sciences, UCLA, Los Angeles, CA 90095-1567, USA (e-mail: djackson@ucla.edu; phone: 310-825-1885; fax: 310-825-2779).

(2) Centre for Analysis and Prediction (CAP), China Seismological Bureau (CSB), 63 Fuxing Road, Beijing 100036, China (e-mail:yinxc@sun.ihep.ac.cn; fax: +86-10-6252-8760; fax: +86-10-6256-1284).

(3) Earthquake Prediction Information Division, Japan Meteorological Agency, 1-3-4, Ote-machi, Chiyoda-ku, Tokyo 100-8122, Japan (e-mail: akio.yoshida-a@hq.kishou.go.jp; phone: +81-3-3212-8341; fax: +81-3-3212-2807).

Accurate and specific predictions of individual large earthquakes may be impossible in the foreseeable future, but many other types of prediction, in the broader sense, would have practical benefits and would help to advance our understanding of earthquake science. Such "predictions" include probabilistic forecasts of future earthquake activity, recognition of statistical patterns that may signal anomalously high earthquake potential, predictions of the maximum size of earthquakes that may occur in a given time-space region, and ground motion that would result from hypothetical future earthquakes. The session addressed questions related to the predictability of features of the earthquake system and the use of computer models to aid in constructing and testing such predictions, and the expectations that can rightly be placed on earthquake analogs such as laboratory and computer models.

Earthquake potential was defined as the probability of earthquakes as a function of location, magnitude, and time. Earthquake forecasting includes estimation of the long-term earthquake potential (averaging over any temporal variations on the scale of decades), and temporal variations of earthquake probability. Earthquake prediction is a limiting case of earthquake hazard estimation, when the earthquake potential is much higher than normal, and high enough to justify extraordinary protective measures.

Three approaches were discussed for estimating earthquake potential. The first, discussed both by Jackson and Kagan, and Minster and Williams, is based entirely on past earthquake data. While it may include statistical models of clustering, it is basically an attempt to quantify the present state of seismicity, and describe its evolution into the future in statistical terms. Such models serve primarily as "null hypotheses" against which other models can be measured. While the concept is simple, the details are important; an adequate statistical model must deal with earthquake clustering (including aftershocks) both in time and space.

A second approach to forecasting earthquakes is based on recognizing anomalous behavior signaling that the conditions are ripe for large earthquakes. Several such approaches were described in this session. For example, Li et al. considered six different functions derived from a catalog of earthquakes in China, and derived nonlinear relationships between these functions and the size of the maximum earthquake expected in each of 19 regions in Southern and Northwestern China. The six functions were:

1. The elapsed time covered by the last 100 events,
2. the b-value,
3. the mean square deviation about the regression based on the Gutenberg-Richter relationship,
4. the mean magnitude of the last 100 events,
5. the magnitude difference between the largest event in the last 100 and that expected from the Gutenberg-Richter relationship, and
6. the rate of strain release in the calculating window.

The relation between the six indicators and the maximum magnitude of subsequent earthquakes within a certain period were analyzed by the method of categorical data analysis using a genetic algorithm-neural network model. The model was tested on both a five-year training period and a one-year prospective test period. While it forecast significantly better than random in some regions, it did less well in other regions, and the null hypothesis was not fully developed. Another approach was based on the loading/unloading response ratio, which is related to the ratio of strain release during times when tidal stresses increase or decrease the regional Coulomb stress according to a simple model. This approach was applied by Yin and others to China and California and by Yoshida and Hosono in Japan. In retrospective application it is easy to find regions in which significant earthquakes are preceded by large values of the loading/unloading response ratio, and there are some examples of apparently successful prospective application. However, it has not been shown that the method can outperform a null hypothesis based on past seismicity. Yoshida and Hosono also noted that seismic quiescence, relative to the historical seismicity rate, often precedes earthquakes in Japan and they suggested that it might serve as an indicator of the state of stress in the crust. However, they also noted that some earthquakes are not preceded by quiescence, and that some periods of quiescence are not followed by significant earthquakes. Minster and Williams used the "receiver operating characteristic" curve to test the "M8" algorithm for forecasting large global earthquakes. The M8 algorithm is based on several indices of seismic behavior. Minster and Williams found that the M8 algorithm appears statistically significant when measured against space-time in the region in the active seismic zones in which the algorithm is operable. However, a null hypothesis based on past seismic behavior cannot be rejected. All of the above studies illustrate the importance of making earthquake forecasts very specific, testing them prospectively against independent data, and constructing adequate null hypotheses.

A third approach to earthquake forecasting is to construct detailed models of stress accumulation and release using detailed physical models. While models that include the full complexity of earthquake behavior are still reserved for the future, many investigators have shown that computer models can simulate some proposed precursory observations. For example, Mora and Place showed that in a 2-D physically-based lattice model, small earthquakes tend to develop a long-range correlation that is destroyed by very large earthquakes. Such behavior resembles the log-periodic energy release observed before some earthquakes, and if it occurred regularly in the crust it might indicate that self-organized criticality might actually be a clue that earthquake potential is high, rather than evidence of non-predictability. However, the gap between computer simulations and real earthquakes is still formidable, and the achievable probability gain over purely statistical models is yet to be determined. Even if the probability gain is not yet known, a general consensus was reached that simulations will provide complementary information to the purely statistical approaches, and hence, offer an outstanding opportunity for advancement.

Papers presented in this symposium:

- David D. Jackson and Yan Kagan, *Global Earthquake Potential, 1999*
- Zhou Shengkui, Wang Chengmin and Ma Li, *Application of Artificial Intelligence in Earthquake Forecasting*
- Ma Li, Zhu Lieyuan and Shi Yaolin, *Attempts at using seismicity indicators for the prediction of large earthquakes by genetic algorithm-neural network method*
- Jean-Bernard Minster and Nadya Williams, *Systematic Global Testing of Intermediate-Term Earthquake Prediction Algorithms*
- Akio Yoshida and Kohji Hosono, *Evaluation of spatio-temporal seismicity change*
- XiangChu Yin, XueZhong Cheng, YuCang Wang, HaiTao Wang, KeYin Peng, Yongxian Zhang, and JianCang Zhuang, *Development of A New Approach for Earthquake Prediction: Load/Unload Response Ratio*
- Peter Mora and David Place, *Accelerating energy release prior to large events in simulated earthquake cycles: implications for earthquake forecasting*
- Michael Winter, Steven Jaume and Russell Cuthbertson, *Determination of site response and attenuation in Brisbane, Australia*