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Reply to Wu "Comment on Regional level Forecasting of Seismic energy release by Kavitha and Raghukanth"

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Abstract Kavitha and Raghukanth (doi:10.1007/s40328-015-0131-7, 2015) have developed an algorithm to forecast earthquake energy for a given seismogenic zone. The forecasting strategy is based on empirical mode decomposition and nonlinear regression analysis. The proposed algorithm has been validated with independent subset of seismicity data. Wu (Acta Geod Geophys 2015) has raised concern about the uncertainties and the input seismicity data used to develop the model. This article discusses the problems associated with the modelling of the seismic energy at regional level.

Keywords Earthquake forecasting · Seismic energy release · Tectonic zones

Kavitha and Raghukanth (2015) have compiled a global earthquake catalogue from various sources in literature and used a well defined procedure to forecast earthquake energy in 41 tectonic regions. The seismic energy time series is first decomposed into two statistically uncorrelated models using the empirical mode decomposition (EMD) technique of Huang et al. (1998). The forecasting strategy is based on nonlinear regression analysis (Iyengar and Raghukanth 2005). The developed model is verified by comparing with independent subset of data. Wu (2015) has raised concern about the procedure and the earthquake catalogue used to develop the model. Wu's objections to the methodology is based on his theoretical interpretation. The proposed algorithm can be made time dependent by updating the coefficients in the artificial neural network (ANN) every year. In our article the model parameters are held constant throughout the forecasting period which represents conditions more stringent than necessary. The main assumption in our empirical model is

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that the annual earthquake energy time series of any seismogenic zone has the influences of all the causes within the time series itself. The future seismic energy release depends on the previous year values. The large uncertainties in some zones can be attributed to the complexities in the data.

1. The delineation of seismogenic zones can be handled in different ways. The whole Earth can be considered as a single seismogenic zone and the entire catalogue can be used for the analysis. However, forecasting on such a large spatial scale is not desirable. On the other hand, different segments of all the tectonic plate boundaries as suggested by Wu (2015) can be considered as different seismogenic zones. By considering all the segments in plate boundaries separately will increase the number of seismogenic zones. Even the seismicity data in each zone can be separated into shallow and deep events. The challenge with these small spatial scales is that there will not be sufficient past seismicity data in each zone. The smaller segments with very few past earthquakes will result in insufficient datasets. The seismic energy time series for these small spatial regions will have zeroes for some years. The number of unknown parameters and the uncertainties increases with these small spatial regions. To circumvent these difficulties intersection between any two tectonic plates is considered as the 'seismogenic zone'. The tectonic plates with very small area and the tectonic plates with very low seismic activity in the past are merged with the neighboring seismogenic zones.
2. Several algorithms are available in the literature to estimate magnitude of completeness for a given catalogue. One can obtain different results with these algorithms. For our study, we have used the procedure suggested by Wiemer and Wyss (2000). The maximum curvature method is used to determine M_c from the frequency magnitude distribution. The magnitude of completeness is taken as the magnitude when the negative slope trend of the data stabilizes to approximate a straight line. We have estimated energy time series for each seismogenic zone by including the events above M_c. We agree with Wu (2015) that Mc may change with time. However it does not alter the final results since the small magnitude events have very small contributions to the total seismic energy release.
3. Principal component analysis (PCA) is widely used in multivariate data analysis for reducing the dimensionality of the data. Wu (2015) suggests that each seismogenic zone will have its own unique tectonic setting and hence indicates to develop separate models for these 41 zones. To identify these unique zones, PCA is carried out on the energy time series data. The energy time series of the 41 zones are highly correlated among themselves which is revealed by PCA. The obtained periods of the IMF's of all the 41 zones also indicates similarities in the energy time series. The periodicities of the IMF_3 and IMF_4 of all the 41 zones indicates the influence of the sunspot and lunar standstill cycle on the earthquake occurrences in these zones. These correlations are also brought out by PCA. Based on PCA, the 41 seismogenic zones have been arranged into 16 groups. There are also some 7 zones which does not belong to any group. As pointed out by Wu (2015) these seven seismogenic zones have their own unique tectonic setting and heterogeneities. These zones have been modeled individually to forecast the earthquake energies. The time series data of all the seismogenic zones in a particular group has been used for forecasting instead of individual zone data. The correlation among the zonal energy time series will enhance the signal in the data and improves the predictability of the model. The obtained root

mean square error, correlation coefficient and percentage variance explained in both the modeling and forecasting period indicates that the model is capable of capturing the signal in the data.

The favorable comparison of the estimated energies with the data indicates that the model is reliable and can be used to forecast seismic energies in tectonic zones. The spatial and temporal variability of the seismic energy time series has been brought out in the article. The ANN does not account for all the variability in the seismic energy time series. The interannual variability only has been incorporated in the forecasting model. However the proposed algorithm is general and predictability can be enhanced by including antecedent geophysical parameters as inputs in the ANN. There are some limitations in the algorithm and further improvements can be made as more data becomes available.

References

Huang NE et al (1998) The empirical mode decomposition and the hilbert spectrum for nonlinear and non stationary time series analysis. Proc R Soc Lond A 454(903):995

Iyengar RN, Raghukanth STG (2005) Intrinsic mode functions and strategy for forecasting Indian monsoon rainfall. Meteorol Atmos Phys 90:17–36

Kavitha B, Raghukanth STG (2015) Regional level forecasting of seismic energy release. Acta Geod Geophys. doi:10.1007/s40328-015-0131-7

Wiemer S, Wyss M (2000) Minimum magnitude of complete reporting in earthquake catalogs: examples from Alaska, the Western United States, and Japan. Bull Seismol Soc Am 90:859–869

Wu WN (2015) Comment on the paper by Kavitha and Raghukanth “Regional level forecasting of seismic energy release”. Acta Geod Geophys. doi:10.1007/s40328-015-0157-x