Short-Term Precursors, Why do I care? (Opening Remark/Lecture)

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"S*pecial* physical preparation processes whereby a *big* earthquake nucleates." Do such things exist? A somewhat weaker version, "*special* physical conditions where a *big* earthquake is about/ready to occur" are also of my concern.

Like small kids all over the world, I am very curious about this, which is the reason why I am so interested in short-term precursors. They would provide unique constraints to the seismogenesis scenario. Of course, short-term precursors might help improve earthquake forecasting. However, to my knowledge, none of the claimed precursors has demonstrated so high a probability gain (*PG*) to allow a strong, obviously useful forecast such as "> ~30 % chance of M7+, in one week, in this 100 km diameter," even if we accept occasional false alarms and also the overlooking of many of M7+ events [Nakatani, 2017]. I dare to say practical merits are of secondary importance. Although this symposium emphasizes statistical assessment by trial forecasting, it is only to confirm if the claimed precursors are worth studying. Note that it is practically very difficult to judge if a certain anomaly was a precursor of a certain earthquake. Hence, we need trial forecasting based on your anomalies, as a tool to find anomalies some fraction of which must have been precursors [e.g., Zechar and Jordan, 2008]. As a side effect, more soundly motivated people can learn the extent of earthquake predictability.

The rest of this Abstract is my lecture to prepare you for the symposium's bit convoluted discussions regarding seismogenesis. *The real formidable part is the role in seismogenesis*, rather than specific mechanism such as slow slip, fluid-infiltration, microfractures, piezo-electric, streaming current, p-holes, charged gas emanation, etc. Note that I'm never satisfied with a naive level of thinking. Theories need a clicking feel to be published.

By recalling Reid's earthquake cycle, where shear stress on the fault increases slowly with time to finally reach the strength of the fault, it is fine for a big earthquake to occur without being preceded by any precursors. However, any mechanical failure under slow loading is a delayed failure, where the material starts deteriorating as the stress comes close to the instantaneous failure strength. Such deterioration necessarily involves physical damage or breakage of atomic bonds, which would emit various signs. This robust notion was adopted to explain many claimed short-term precursors in the 60's and 70's [e.g., Scholz, 1973], and people believed that short-term forecasting was a no-brainer. They were wrong. M7 is a rupturing over a 30 km of the fault, and there's no reason to expect that stress reaches the alarming level over a comparably broad region in such good sync suitable for short-term precursors. In short, their notion of *precursors as a sign of ~+0 strength excess* was too naive, though they certainly clicked at their time.

In the 80's, a more thoughtful successor came up: the preslip-nucleation [e.g., Tse and Rice, 1986]. It invokes slow slip localized in a small portion of the faulting area of the big earthquake to come. Griffith energy balance guarantees finite slow preslip until the slipping patch and displacement there reach a threshold value, so this is a necessary process. Furthermore, the preslip is self-accelerating as the slip is a deterioration process and the growth of preslip increases the driving force at their front. So, rapid acceleration signifies the sufficient condition met. In short, this is the unskippable slow beginning of a dynamic rupture, seemingly a perfect *special* physical process. However, no case of accelerating slow slip continuing to grow into an earthquake has been observed yet (some indirect observation have bee reported, though). What was wrong? There is no reason to expect that the size of slow nucleation (proportional to the local frictional fracture energy) has to correlate with the size of the earthquake rupture that is determined by when the dynamic rupture stops. A hierarchical heterogeneity hypothesis by Ide and Aochi [2005] addresses these problems quite well.

Thus, these deterministic theories of seismogenesis bear demonstrated weakness, though I still have not given up entirely [Noda et al., 2013]. On the other hand, when we look at the statistical performance of precursor-based forecasting, many short-term precursors bring a low (< ~10), but significant *PG* > 1. It is true that their performance is perhaps severely hampered by external noises not related to tectonic activities. However, this excuse does not work for the far-below-perfect anomaly appearance rate (*AAR*), usually < 30%. This fact implies that those precursors derive from underground processes that are not required for the earthquake occurrence, while they certainly encourage the occurrence given the often significant (10-20%) net *AAR* (≅ gross *AAR* - alarm fraction). Dependence of precursor on the earthquake size would be another key to infer the role in seismogenesis. My other talk will offer an interesting example along this line.

Lastly, I would like to call your attention to *apparent precursors* that increase the probability of the occurrence of a big earthquake while not involving any *special physical conditions/processes*. Foreshocks make an educational example. Before, most everybody believed foreshock activities derive from special physical preparation processes like preslip or micro-fracturing, while it was well known that many large earthquakes occur without foreshocks. However, Helmstetter et al. [2003] have shockingly pointed out the foreshock phenomenology can be explained just by aftershock mechanism. They synthesized a catalog assuming earthquakes occur randomly except that occurrence probability is raised for a short-while following each earthquake (the Omori-law [1908]), to the extent dependent on the magnitude of the triggering earthquake (ETAS model [Ogata, 1988]) while the magnitude of each occurring earthquake is assigned by drawing from the Gutenberg-Richter pot. Then, they made trial forecasting on this synthetic catalog, where they turned on M6+ alarm when seismicity exceeds a certain level. Their forecast got a *PG* of 129! The lesson learned is that a good *PG* is achieved just by the fact that when seismicity is high, it will remain high for some time coming due to the aftershock effect (= delayed triggering from stress transfer [Dieterich, 1994]), and some fixed percentage of earthquakes are expected to be M6+. If mainshocks are merely conditional aftershocks of foreshocks, foreshocks are not *real* precursors signifying a special physical process/condition I am seeking, while they nevertheless do improve forecasts very much. Ironically, the currently highest *PG* of *O*(1E4) has been attained from heightened seismicity [e.g., Lippiello et al., 2012]. While *foreshock-recognition* techniques, including theirs, often utilize features not ascribable to ETAS, their intermediate product solely based on ETAS already exhibited a *PG* of ~*O*(1E3) when converted to binary alarm by setting an empirical threshold on the ETAS probability. Thus, meticulous treatment is necessary to elucidate the role of foreshocks in seismogenesis scenario.

In conclusion, short-term precursors are not no-brainers at all, unfortunately. Above-average intelligence is needed, I guess.