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# From Local Hubs to Global Effects: A Multilayer Network Approach to Earthquake Dynamics

*Keywords: earthquakes; multilayer networks; temporal multiplex networks; network topology*

## Extended Abstract

In this work, we investigated the topological properties of multilayer earthquake networks, using a similar approach as the authors applied in [1] for California and Iran, but now considering global seismic events. Shallow earthquakes (depth of up to 70 km) and deep events (depth greater than 70 km) were investigated separately. The networks created are temporal multiplex, each layer representing one year of seismic activity from 2000 to 2019. The links between the nodes in each layer were given by the successive model [2]. This approach allowed us to identify spatial and temporal patterns that are not observed in aggregated networks. In the shallow earthquake networks, regions such as Japan, Sumatra, Tonga and Chile stood out, with the formation of hubs consistent with the known high seismic activity in these areas. In particular, we observed that the Great Sumatra earthquake (2004) was preceded by an increase in local connections and was followed by interactions with distant regions, revealing global effects (Figure 1). For deep earthquakes, the networks showed a more stable distribution over time, with vertices concentrated in subduction zones, especially in the Tonga region. This highlights the distinct dynamics of deep events, with less temporal variability. The strength distributions of the networks follow a power law with an exponential cutoff, suggesting a structural limitation for high values [3]. An optimal number of layers (3 for shallow events and 5 for deep ones) was identified that maximizes the power law regime, demonstrating an advantage of the multilayer approach over the single-layer approach. The global clustering coefficient, $C$, decreases with the number of layers for shallow earthquakes, following a power law, indicating time-scale invariance. This pattern was not observed in the deep-seismic data, whose values resemble random networks, suggesting limitations of the current model for certain aspects of these events. The average shortest path length, $\ell$, increased linearly with the number of layers in both cases, a behavior similar to that observed in spatial variations of single-layer networks. Although $\ell$ scales with the logarithm of the number of vertices, the values of $C$ were not high enough to characterize the networks as small-world. Future studies will include the application of more robust edge construction methodologies (such as the Visibility Graph Model [4] and the Time Window Model [5]), with the aim of exploring the presence of properties such as scale-free and small-worldness in global seismic networks.

## References

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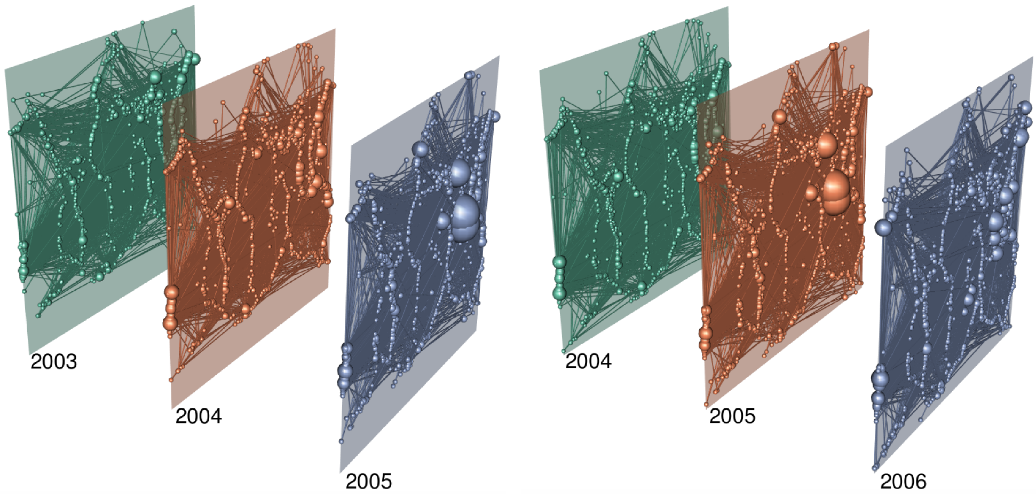
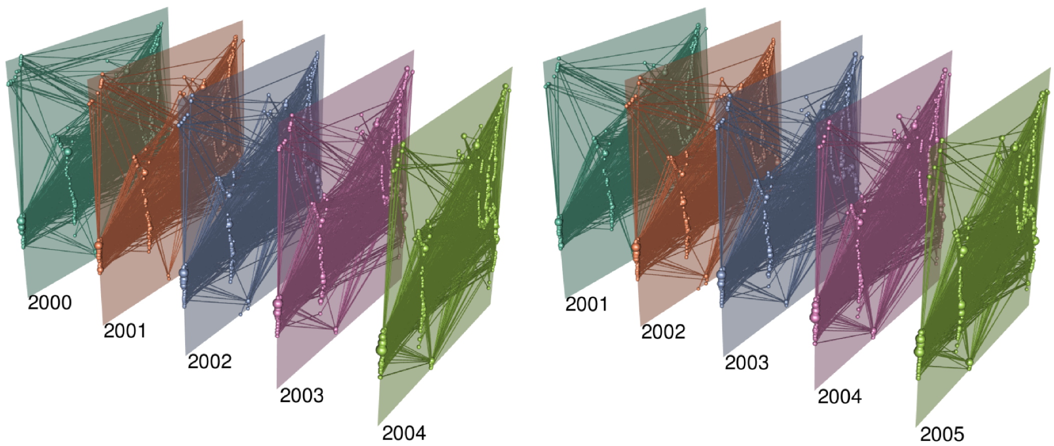



(a)




(b)

Figure 1: Multiplex Networks of global earthquakes for (a) Shallow earthquakes, showing the evolution of connections around the world in the period between 2003 and 2006. For these data, the number of layers considered was 3. Between 2003 and 2004, there is an increase of the seismic activity close to Sumatra, culminating in the high-magnitude earthquake. The repercussions of this seismic event were especially notable in the following year, 2005, where enormous hubs of this network were located in Sumatra and its surroundings. Moreover, more activity was observed not only in nearby regions, but also in China and Iceland, which are locations where other network hubs were located 2005. (b) Deep earthquakes, for the period from 2000 to 2005, using 5 layers. There were no significant changes in the appearance of the networks from one year to the next. The hubs are often located in the Fiji Islands, Argentina, and Colombia. For better visualization, interlayer links are not presented.