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Tectonic "quakes", scaling and the turbulence of solids

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Over thirty years ago, Y. Kagan proposed that seismicity is "the turbulence of solids". Indeed, fluid turbulence and seismicity have many common features: they are both highly nonlinear with huge numbers of degrees of freedom. Beyond that, Kagan recognized that they are both riddled with scaling laws in space and in time as well as displaying power law extreme variability and – we could add – multifractal statistics.

Kagan was referring to seismicity as usually conceived, as a sudden rupture process occurring over very short time periods. We argue that even at million year time scales, that the movement of tectonic plates is "quake-like" and is quantitatively close to seismicity, yet caused by relatively smooth mantle convection fluid.

To demonstrate this, we analyse the GPlates data base of 1000 point trajectories over the last 200 Myrs, analyzing the statistics of the dynamically important vector velocity differences where D*r* is the great circle distance between two points and D*t* is the corresponding time lag. The longitudinal and transverse velocity components are analysed separately. The longitudinal scaling of the mean longitudinal difference follows the scaling law <Dv(Dr)> ≈ Dr^H with *H* close to the theoretically predicted value *H* = 1. This high value implies that mean fluctuations vary relatively smoothly with distance. Yet at the same time, the intermittency exponent C_1 is extremely high (C_1 ≈ 0.5) implying that from time to time there are enormous "jumps" in velocity. For comparison, laminar (nonturbulent) flow has *H* = 1 and is not intermittent (C_1 = 0), fully developed isotropic fluid turbulence has the (less smooth) value *H* = 1/3 (Kolmolgorov) but with non-negligible intermittency C_1 ≈ 0.07 and seismicity has very large C_1 ≈ 1.3. Our study thus quantitatively shows how smooth fluid-like behaviour can co-exist with highly intermittent quake-like behaviour.

We find that the outer spatial scale is near the size of the Earth (≈15000km) whereas the outer time scale is ≈60Myrs. We show that the statistics are multifractal with a very large intermittency parameter that is close to that of seismicity determined at sub-decadal time scales. The transverse scale function is the 2/3 power of the longitudinal scale function, the transverse intermittency exponent (C_1) is reduced by this factor. The temporal scaling of the mean fluctuations of both the longitudinal and transverse components is close to a ½ power of the time lag: Dr≈Dt^(1/2). However since the spatial scaling of the longitudinal and transverse components are different, we obtain two somewhat different space-time diagrams. We link the parameter

estimates to fundamental mantle convection parameters, and we make corresponding multifractal simulations.

Finally, we discuss the implications for the megaclimate regime, including macro-evolution. Both megaclimate and macroevolution of global diversity are scaling processes with $H>0$ characterized by intermittent — climate “events”, such as P-Tr hyperthermal, in the case of former, and mass extinctions and originations in the case of latter. The tectonic scaling, and the extreme multifractal behavior grounds both—the long-term climate, and the biological evolution on the first principles of scaling in macroscopic physical systems.