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Non-extensive energy release in fracturing sea ice

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Various power law distributions that characterize the dynamics of fundamental processes in geophysics, hydrology, and atmosphere science are strictly empirical expressions. They cannot be derived from conventional statistical mechanics which issues from the exponential decay of the event probability with the energy increase. The classical Boltzmann-Gibbs energy distribution emerges from the main principle of equilibrium thermodynamics, which states that all events occurring along the space-time trajectory of a statistical system produce an additive contribution to the integral physical process.

The power law distributions that inherent in non-equilibrium, open systems are due to the presence of long-range and long-term correlations between individual events; in this case the principle of additivity of events becomes violated, and the system exhibits non-extensive (non-additive) dynamics. The discrepancy between the Boltzmann-Gibbs statistics and observed power law distributions was resolved by Tsallis [1] who developed a generalized statistical mechanics that covers both equilibrium and non-equilibrium processes.

In this work, the fracture-induced oscillations in the Arctic sea ice were detected by seismic tiltmeters prior to and during the formation of a "fault" consisting of highly fragmented ice floes. The analysis of the energy distribution in a series of oscillations showed that the Tsallis parameter q, which could serve as a measure of non-additivity, decreases from $\sim$ 1.4 to $\sim$ 1.0 in periods of intensive sea ice fracturing caused by irregular wind forcing. In terms of the Tsallis statistics, $q > 1$ evidences the non-extensive dynamics of the process, while $q = 1$ means the additivity of fracture events in highly fragmented sea ice where long-range correlations cannot be physically established. Thus, the non-extensive statistical mechanics provides an adequate description of processes both under equilibrium and not-equilibrium conditions in the framework of a common approach.

[1] Tsallis C., J. Stat. Phys., 1988, 52, 479-487.