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Interactive comment on "Interplay between linear, dissipative and permanently critical mechanical processes in Arctic sea ice" *by* A. Chmel et al.

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Dear Editor,

The main goal of our work is the demonstration of the energy- and time invariance of spontaneous fracturing process in drifting sea ice. This finding confirms instrumentally the non-equilibrium nature of mechanical processes in the Arctic ice pack concluded previously from, mainly, the analysis of fractal pattern of leads and cracks seen in satellite images. To our best knowledge, there are no reported results in literature, which are identical or similar to those presented in the manuscript (MS).

The experimental data are preceded by a brief overview of well known facts in the field of sea ice mechanics, including a classical work of Marco and Thompson (1977) who explained the regular crack-and-leads pattern in the framework of conventional mechanics, and a pioneering work of Rothrock and Thorndike (1984) who showed that some quantitative relations between the number and dimensions of sea ice fragments cannot be explained by means of equilibrium statistical mechanics. The latter result evidenced that the Arctic sea ice cover is the non-equilibrium, critical system whose behavior could be considered in terms of the concept of self-organized criticality (SOC).

Of course, this short introduction to the problem "adds nothing to the current state of the art" (Referee); however, we supposed that it would facilitate the understanding of the problem for readers who are not specialists in non-linear statistical mechanics. A review of "a vast amount of recent literature . . . about Coulombing faulting" seems to be excessive in this context.

We agree that a few words said in the MS about "non-equilibrium systems", "criticality", etc. is apparently insufficient for recognizing the sense of our result by a reader who meets these terms in the first time. In such cases, some extra information would be necessary. There is a vast of geophysical literature where these terms are explained and discussed in detail; as regards the cryosphere, a good starting point could be a comprehensive review "Scaling fracture and faulting of ice on Earth" by J. Weiss (Surv. Geophys., 24, 185-227, 2003). The absence of this reference in the original MS is our significant omission.

Once again, a detailed review of literature on the role of elastic waves in ice "going back to the 60's" would be hardly compatible with a reduced format of this communication. Figure 3 (taken from a book "Dynamic processes in sea ice" by V. Smirnov, 1996) seems to be sufficient for understanding the opportunities given by seismic devices for elastic wave detecting if a potential reader works in an adjacent area.

Experiment. Signals from two differently oriented tiltmeters were recorded continuously during a few months. Figure 4 shows a typical portion from one tiltmeter. Of course, this portion does not reflect all peculiarities of the long-term field observations. However, it reflects adequately the energy- and time invariance of the process (see Figures 5 and 6, respectively) – the main results of this study. More detailed analysis is in progress.

Wind forcing. The fracture process in ice pack is determined predominantly by wind forcing (irregular wind forcing ïĆő non-uniform sea ice drift ïĆő stresses ïĆő fracturing). Other factors (Coriolis inertia, tidal activity, atmospheric pressure etc.) affect the flow of mechanical processes but these are of secondary significance. Thus, the wind forcing (and its intermittency) is, really, the primary cause of mechanical perturbations accompanying with the emission of elastic waves.

Thermodynamics. Referee's question: "Where is "thermodynamics" in the data discussed here?" Authors' response: The dependence (4), which is observed in experiments (as well as in many other experiments in seismology, since Eq. (4) is an analogue of the Gutenberg-Richter law), cannot be derived analytically from primary principles: the Boltzmann-Gibbs statistics implies the exponential decay of natural processes while our experiment gives a power law. The power law dependence of the energy release in fracturing process means that the given system does not go to a full disorder – fractality is a kind of order; correspondingly, the entropy does not go to infinity, and remains limited by a certain value. This takes play because mechanical interactions in such geophysical objects as ice pack and tectonic formations are long-range correlated, while the Boltzmann-Gibbs statistics is based on essentially local, weakly correlated events (see C. Tsallis, Possible generalization of Boltzmann-Gibbs statistics, J. Stat. Phys., 52, 479-487, 1988). This problem is highly debated in geophysics.

There is a few points in the Referee's report where the using of specific terms is put in doubt. Some of these remarks are justified, and the text should be corrected, while other ones concern commonly accepted terms ("tuning parameter", "semi-brittle", etc.); in addition, some used terms are cited out of the context: for example, a term "thermodynamically profitable attractor" transformed into an ambiguous "profitable attractor".

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