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Interpreting the power spectrum of Dansgaard-Oeschger events via stochastic dynamical systems

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Dansgaard-Oeschger (DO) events are abrupt climate shifts, which are particularly pronounced in the North Atlantic region during glacial periods [Dansgaard et al. 1993]. The signals are most clearly found in δ^{18}O or log [Ca^{2+}] records of Greenland ice cores. The power spectrum $S(f)$ of DO events has attracted attention over two decades with debates on the apparent 1.5-kyr periodicity [Grootes & Stuiver 1997; Schultz et al. 2002; Ditlevsen et al. 2007] and scaling property over several time scales [Schmitt, Lovejoy, & Schertzer 1995; Rypdal & Rypdal 2016]. The scaling property is written most simply as $S(f) \sim f^{-\beta}$, $\beta \approx$1.4. However, physical as well as underlying dynamics of the periodicity and the scaling property are still not clear. Pioneering works for modelling the spectrum of DO events are done by Cessi (1994) and Ditlevsen (1999), but their model-data comparisons of the spectra are rather qualitative. Here, we show that simple stochastic dynamical systems can generate power spectra statistically consistent with the observed spectra over a wide range of frequency from orbital to the Nyquist frequency (=1/40 yr^{-1}). We characterize the scaling property of the spectrum by defining a local scaling exponent β_{loc}. For the NGRIP log [Ca^{2+}] record, the local scaling exponent β_{loc} increases from $\sim$1 to $\sim$2 as the frequency increases from $\sim$1/5000 yr^{-1} to $\sim$1/500 yr^{-1}, and β_{loc} decreases toward zero as the frequency increases from $\sim$1/500 yr^{-1} to the Nyquist frequency. For the δ^{18}O record, the local scaling exponent β_{loc} increases from $\sim$1 to $\sim$1.5 as the frequency increases from $\sim$1/5000 yr^{-1} to $\sim$1/1000 yr^{-1}, and β_{loc} decreases toward zero as the frequency increases from $\sim$1/1000 yr^{-1} to the Nyquist frequency. This systematic breaking of a single scaling is reproduced by the simple stochastic models. Especially, the models suggest that the flattening of the spectra starting from multi-centennial scale and ending at the Nyquist frequency results from both non-dynamical (or non-system) noise and 20-yr binning of the ice core records. The modelling part of this research is partially based on the following work:

Takahito Mitsui and Michel Crucifix, Influence of external forcings on abrupt millennial-scale climate changes: a statistical modelling study, Climate Dynamics (first online). doi:10.1007/s00382-016-3235-z