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Study of Heliospheric Particle Populations far from Thermal Equilibrium during Three Solar Cycles, Periodicities and q-index

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Heliospheric energetic particle populations of energies higher than 1 MeV are studied using a 33 year long data record composed of hourly measurements, as extracted from the NASA Goddard Space Flight Center's OMNI data set. Their periodicities are examined by means least-squares spectral analysis and wavelet analysis and found to be in good agreement with periodicities seen in sunspot numbers, which are well-known indicators of variations in solar activity. Hence, the source of this energetic and positively charged gas is mainly the Sun but part of it should be cosmic rays. As derived from the analyses of suprathermal "heavy" tails of the probability distribution, we assume that the gas kinetics is described by a deformed Maxwell-Boltzmann distribution, namely, the *kappa* distribution. The q-index analogue to the κ-index is computed for every hour in the data record and used to investigate how far away the gas is from being in classical thermal equilibrium ($q = 1$). We compare the q-index time series with that of sunspot numbers and conclude that the gas is in continously variable states away ($q > 1$) from the almost always assumed thermal equilibrium. During the first ~15 years, the q-indices somewhat exceed the theoretically predicted limit but follow a pattern which is very homogeneous. However, just before 1990, the q-indices begin to fluctuate in a periodic manner, creating maxima and minima, as they continuously increase until they peak about 1996–1997, while after these years, they decrease following a similar pattern. As a result, we assume that after 1990, for a period that lasted at least 10 years, something changed in the Sun's behaviour. A higher number of solar bursts could easily affect the gas but further research, for instance an analysis of solar flare timeseries from the same period, is required to draw a more robust conclusion of what may have caused the observed anomaly.