Mathematical Modelling of Sunspot Cycles: A SDE Perspective

Muhammad Ilyas*
Department of Mathematics, GC University, Hyderabad, Pakistan.

ABSTRACT

The Sun's activity follows an approximate 11-year cycle, characterized by fluctuations in sunspot numbers. Although this cycle is well recognized, its exact timing, magnitude, and variability remain uncertain., We propose a stochastic differential equations (SDE) model that incorporates both the cyclic behavior and the randomness of sunspot activity. By fitting a Gamma distribution to estimate model parameters. The Solar Cycles 22nd to 24th data are obtained. Our results suggest that sunspot activity reverts to a long-term average of about 11.56, with random jumps scaled by a factor of 7.13. Analysing the cycles individually revealed a significant trend: the mean activity level and volatility decreased from Cycle 22 ($\mu = 13.94, \sigma = 7.02$) to Cycle 24 ($\mu = 7.92, \sigma = 3.81$), indicating a considerable recent weakening of solar activity. The model is statistically robust, confirmed by an excellent goodness-of-fit (KS test p-value = 0.967). Overall, the proposed SDE framework provides a statistically robust and conceptually simple tool for describing and forecasting sunspot variability, offering valuable insights into both historical and future patterns of solar cycles.

Keywords: Stochastic Differential Equation (SDE) Model, Stochastic Model, Sunspots, Solar Cycle, Gamma Distribution.