

Multi-scale animal movement modelling using state-switching varying-coefficient stochastic differential equations

Stochastic differential equations (SDEs) are popular tools for uncovering mechanistic relationships underlying time series data. By modelling the parameters of the process of interest as potentially smooth functions of a given set of covariates, varying-coefficient SDEs provide an extension of basic SDEs that allows us to capture more detailed, non-stationary features of the data-generating process. However, in practice, these parameters often vary at multiple time scales, which will be illustrated using dive data of Baird's beaked whales: while changes in pitch, roll, and heading exhibited within some dives can be described by some varying-coefficient SDE, other dives can be better characterised by other varying-coefficient SDEs; a pattern that is not readily accommodated for by the existing approach. To account for such state-switching patterns between dives while simultaneously allowing to make inference on the underlying behavioural processes that occur within dives, we propose a Markov chain operating at the between-dives scale that selects among a finite set of varying-coefficient SDEs to model the behaviour at the within-dive scale. The resulting class of state-switching varying-coefficient SDEs thus allows us to simultaneously model time series data at multiple time scales in a joint modelling framework.