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A kinematically-distorted flux-rope model for magnetic clouds

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Constant-alpha force-free magnetic flux-rope models have proven to be a valuable first step toward understanding the global context of in situ observations of magnetic clouds. However, cylindrical symmetry is necessarily assumed when using such models, and it is apparent from both observations and modelling that magnetic clouds have highly non-circular cross-sections. A number of approaches have been adopted to relax the circular cross-section approximation: frequently the cross-sectional shape is allowed to take an arbitrarily chosen shape (usually an ellipse), increasing the number of free parameters that are fit between data and model. Whilst a better "fit" may be achieved in terms of reducing the mean square error between the model and observed magnetic field time series, it is not always clear that this translates to a more accurate reconstruction of the global structure of the magnetic cloud. We develop a new, non-circular cross-section flux-rope model that is constrained by observations of CMEs/ICMEs and knowledge of the physical processes acting on the magnetic cloud: The magnetic cloud is assumed to initially take the form of a force-free flux-rope in the low corona, but to be subsequently deformed by a combination of axis-centred self-expansion and heliocentric radial expansion. The resulting analytical solution is validated by fitting to artificial time series produced by numerical MHD simulations of magnetic clouds, and shown to accurately reproduce the global structure.