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Reconstructing 3D reentrant cardiac electrical wave dynamics using data assimilation

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For many years, reentrant scroll waves have been predicted and studied as an underlying mechanism for cardiac arrhythmias using numerical techniques, and high-resolution mapping studies using fluorescence recordings from the surfaces of cardiac tissue preparations have confirmed the presence of visible spiral waves. However, assessing the three-dimensional dynamics of these reentrant waves using experimental techniques has been limited to verifying stable scroll-wave dynamics in relatively thin preparations. We propose a different approach to recovering the three-dimensional dynamics of reentrant waves in the heart. By applying techniques commonly used in weather forecasting, we combine dual-surface observations from a particular experiment with predictions from a numerical model to reconstruct the full three-dimensional time series of the experiment. Here, we use model-generated surrogate observations from a numerical experiment to evaluate the performance of the ensemble Kalman filter in reconstructing such time series for a discordant alternans state in one spatial dimension and for scroll waves in three dimensions. We show that our approach is able to recover time series of both observed and unobserved variables matching the truth. Where nearby observations are available, the error is reduced below the synthetic observation error, with a smaller reduction with increased distance from observations. Our findings demonstrate that state reconstruction for spatiotemporally complex cardiac electrical dynamics is possible and will lead naturally to applications using real experimental data.