Biologically detailed spiking network models increasingly reproduce local response statistics, yet it remains unclear whether they capture the multiscale dynamical organization of cortical circuits. Here, we address this question using a data-driven model of mouse primary visual cortex (V1) and lateromedial visual area (LM), extending a previously validated V1/LGN framework with an LM cortical column and reciprocal interareal connectivity to enable mechanistic analysis of feedforward–feedback interactions. We test whether commonly used descriptors—intrinsic timescale, distance to criticality, dynamic range, and spatial correlations—reflect independent properties or coupled signatures of a shared dynamical regime. By linking specific circuit components to measurable dynamical signatures across single neurons, cell types, layers, and population-wide activity, we show that temporal memory, response gain, critical propagation, and spatial coordination co-vary systematically. These results indicate that multiscale dynamical markers are best understood as complementary readouts of an underlying organizing principle, rather than isolated features. More broadly, our findings establish this model as a principled test bed for probing how feedforward and feedback interactions in the visual system shape cortical dynamical states.