Quantifying the performance of spatial and temporal early warning signals of disease elimination

Dominic G. Gray[1,2] and John M. Drake[2]

[1] College of Science, Engineering and Technology, Norfolk State University, Norfolk, VA 23504
[2] Odum School of Ecology, University of Georgia, Athens, GA 30602

Odum School of Ecology
The University of Georgia

Population Biology of Infectious Diseases
REU site @ UGA

Introduction and Background

- Many dynamical systems including coral reefs, financial markets, and physiological regulatory systems undergo critical transitions in which the system passes a tipping point into an alternative stable state. These tipping points occur at bifurcations of their mean field dynamics.

- Dynamical systems approaching such bifurcations often show "near critical" phenomena such as flickering (where the system alternates between two states) or critical slowing down (where a system's recovery from small changes slows down as it approaches the bifurcation).

- Early warning signals are statistical probes for studying the approach to bifurcations in time series data. So called "temporal early warning signals" may predict bifurcations, but omit spatial information.

- We sought to determine how additional information contained in the spatial configuration of cases improves early warning signals applied to an open SIR compartmental model in a spatially homogeneous environment.
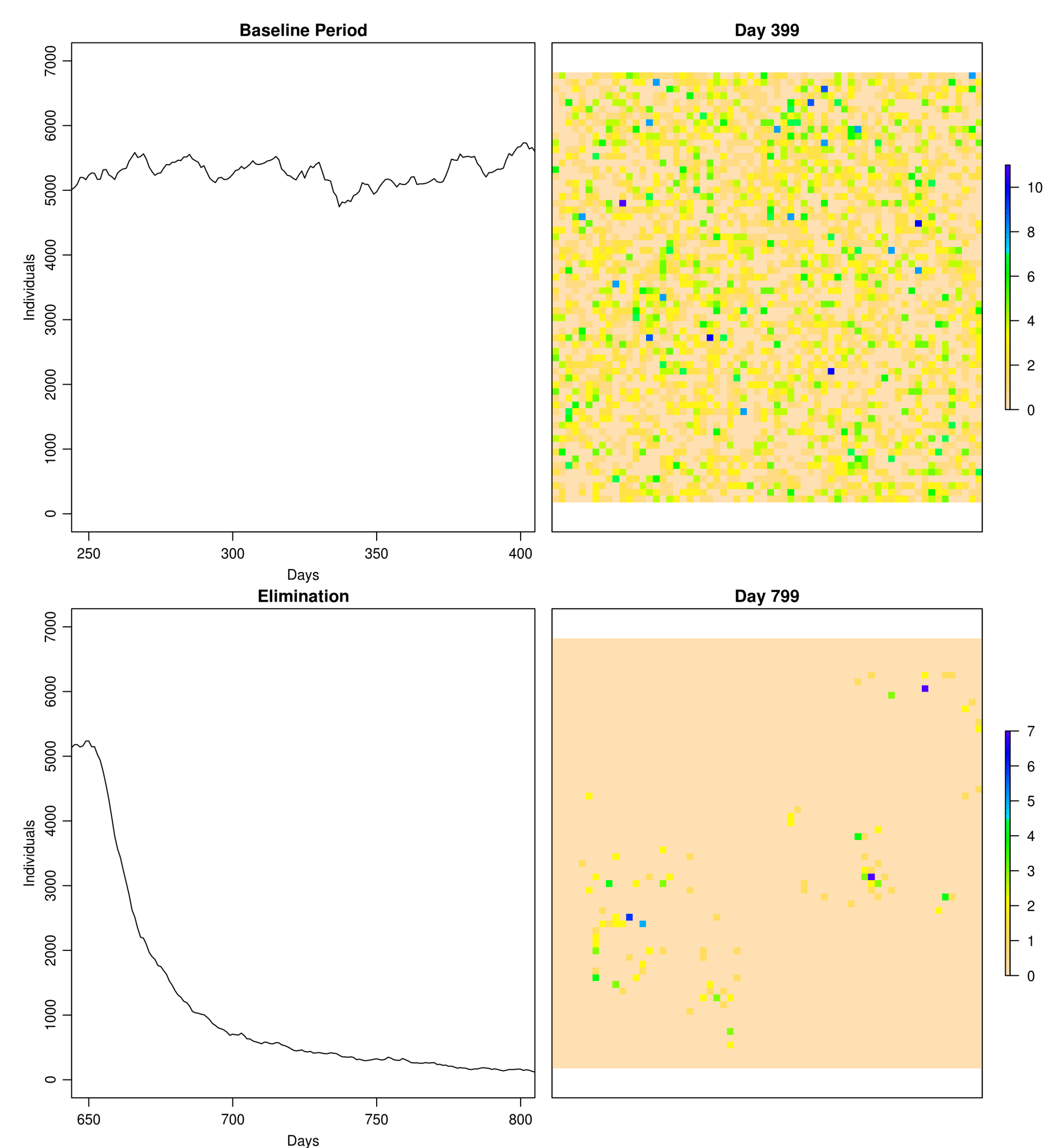

Figure 1: Time series (left) and spatial data (right) for a baseline period (top), where there is no approaching bifurcation, and elimination period (bottom), where the infection is approaching the bifurcation.. The spatial data are snapshots of the end of the baseline period of study at day 399 and the elimination period of study at day 799.

Objective

Compare performance of spatial and temporal early warning systems for disease elimination.

The Model

Figure 2: The prevalence of infection (solid line) and the vaccination coverage (dotted line) as the vaccine campaign rolls out.
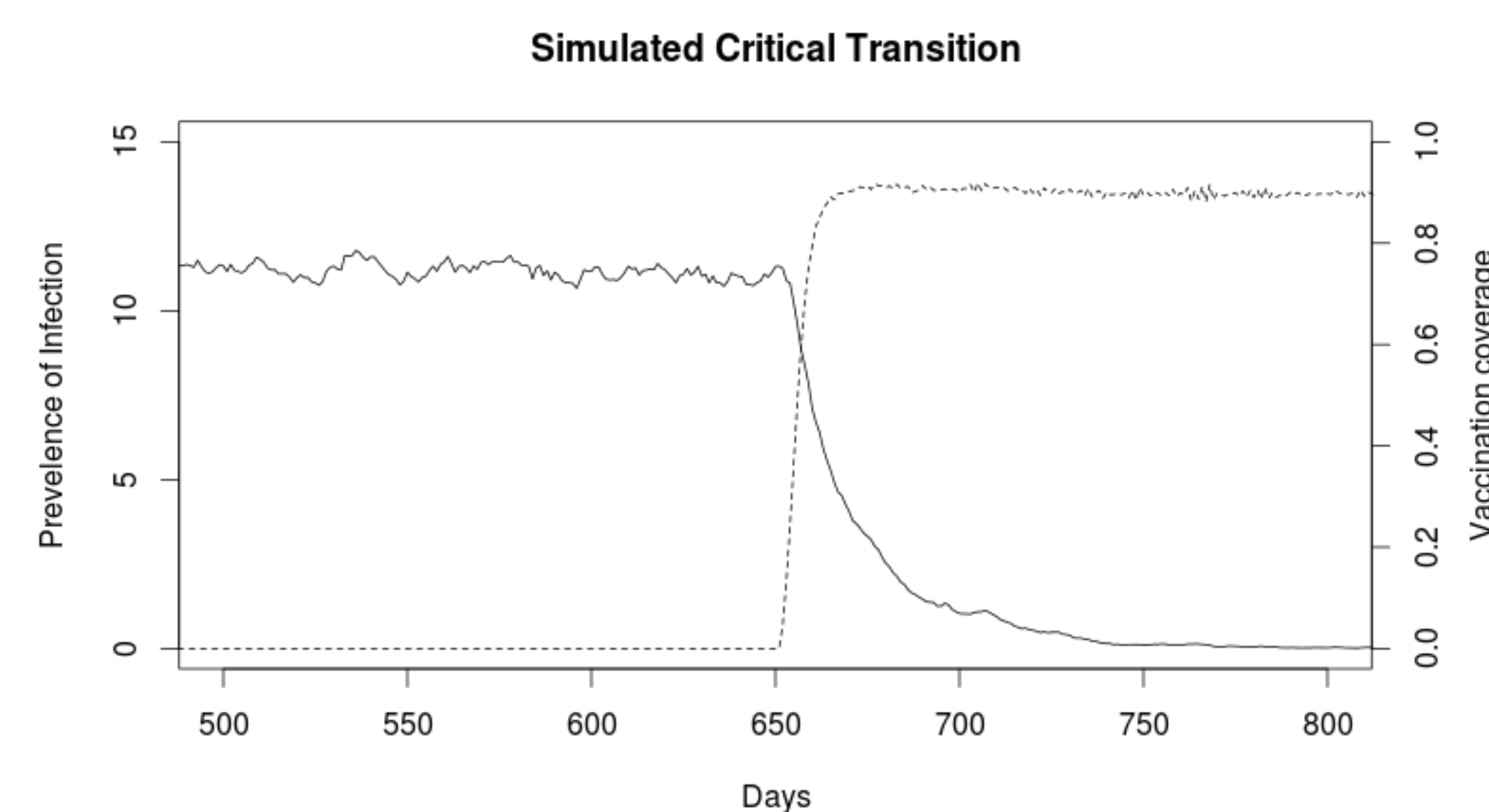
Methods

❶ We modified a simulation platform previously developed in the Drake lab to study the stochastic dynamics of SIR epidemics in spatial environments. Our modifications included addition of host population demography and time-dependent vaccination.

❷ For this study, we introduced vaccination on day 650 with a maximum coverage of 0.96. This vaccination campaign resulted in extinction of infection in most simulations.

❸ We simulated 50 replicates of our model in a population of 40,960 individuals distributed on a 64 x 64 lattice.

❹ We computed spatial and temporal early warning signals using the earlywarnings and spatialwarnings libraries. Consistency with theory was checked by estimating Kendall's tau correlation coefficient.

❺ Performance of each early warning signal was measured using the Receiver Operator Characteristic (ROC) for spatial and temporal early warning signals calculated for approach to elimination versus baseline.
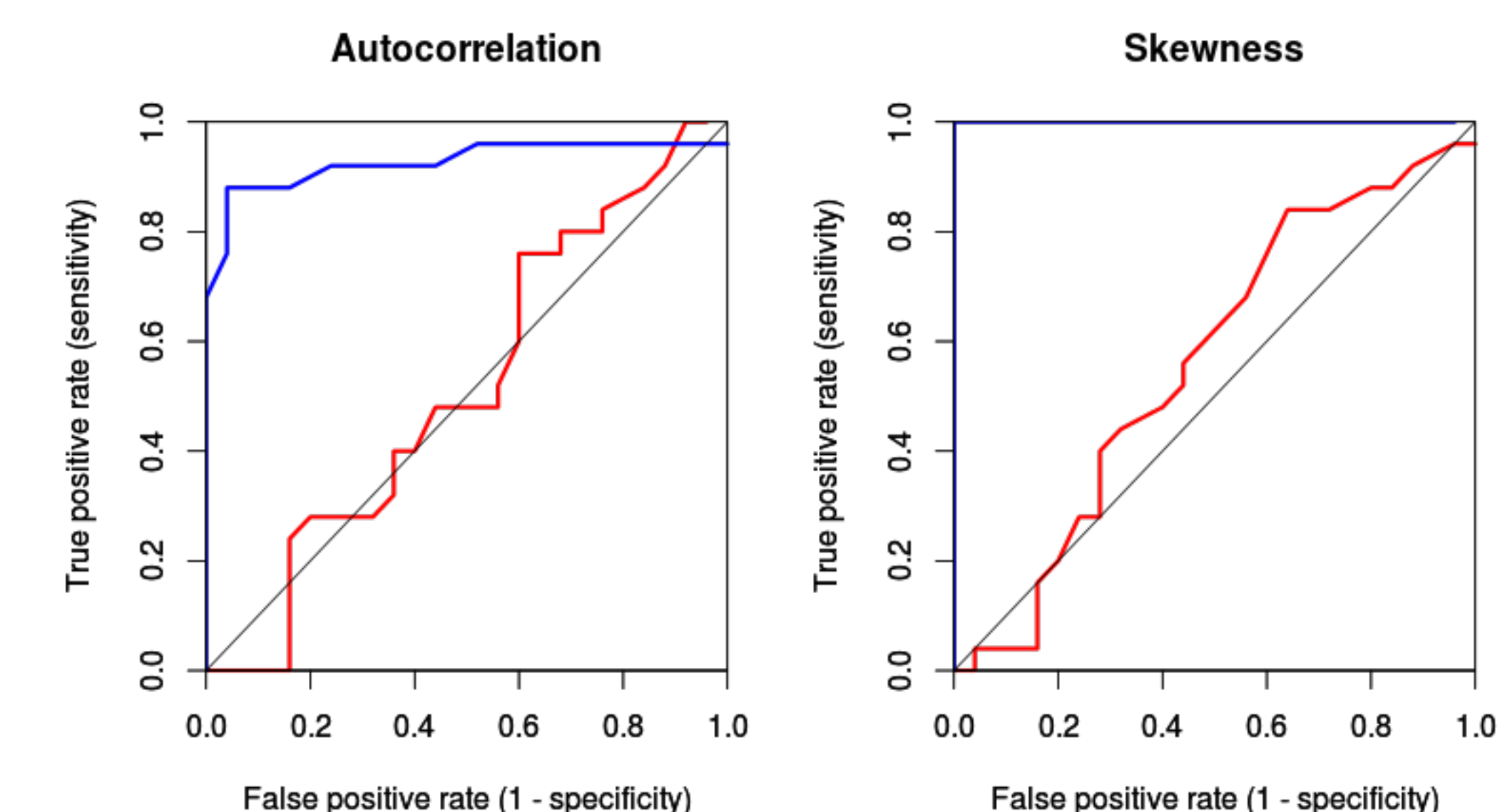
Results

Figure 3: ROC plots of spatial (blue) and temporal (red) autocorrelation and skewness. The spacial indicators outperform the temporal indicators in both tests.

- From our ROC plots, the AUC value for autocorrelation was 0.49 (not different from Random); AUC for spatial autocorrelation was 0.93. AUC for temporal skewness was 0.57; AUC for spatial skewness was 0.96.

- These data suggest that spatial early warning signals considerably outperform temporal early warning signals at a key practical forecasting task.

Discussion

In conclusion, newer (spatial) methods are found to be more statistically efficient and reliable than temporal methods previously proposed. Next steps include determining if spatial early warning systems may be calculated for intrinsically heterogeneous systems (where the intrinsic heterogeneity is predicted to disrupt the signature of critical slowing down) and under conditions of realistic data collection, including under-reporting.

Acknowledgements

email: d.g.gray@spartans.nsu.edu