System Velocity:

A new method for dimension reduction and ecological regime shift detection

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Ecological Regime Shifts

what? a persistent change in the structure or functioning of a system

how? loss of negative feedback(s) maintaining the system

goal? predict in time to prevent

Regime Shifts

Image credit: The Ocean Agency

Ecosystems are Complex

(and complicated)

- high dimensional

- many (∞ ?) interactions

- non-linear

- non-ergodic (open)

- dynamic

- difficult to model mathematically

(Too Many) Methods for Detecting Regime Shifts

> 70 (!) methods proposed in literature

10 suitable for multivariable data

few explicitly handle **noisy** data

few explicitly handle **irregular sampling**

Regime Shifts Detection Methods

Rising Variance/Critical Slowing Down

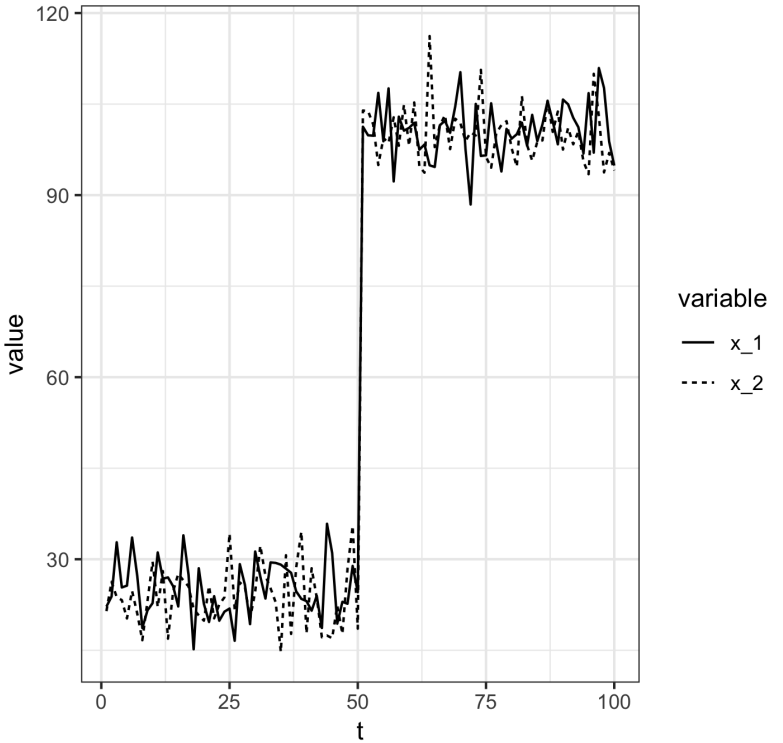
Variance Index (max eigenvalue of covariance matrix)

Principal Coordinates Analysis

Fisher Information

Velocity, v

Toy System

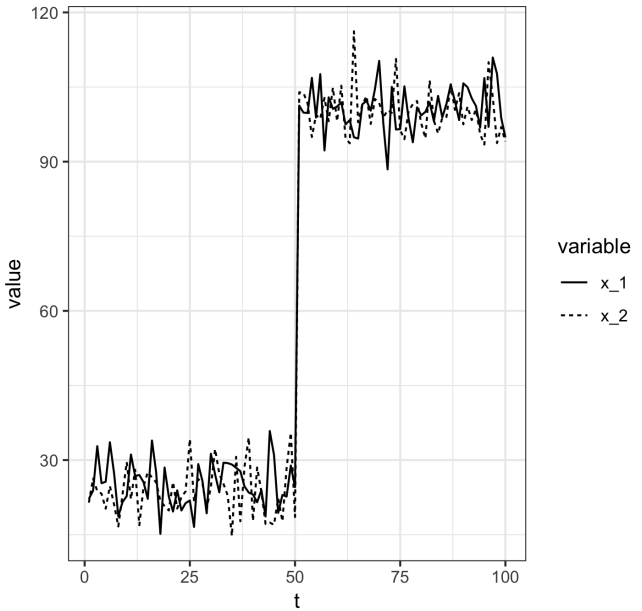


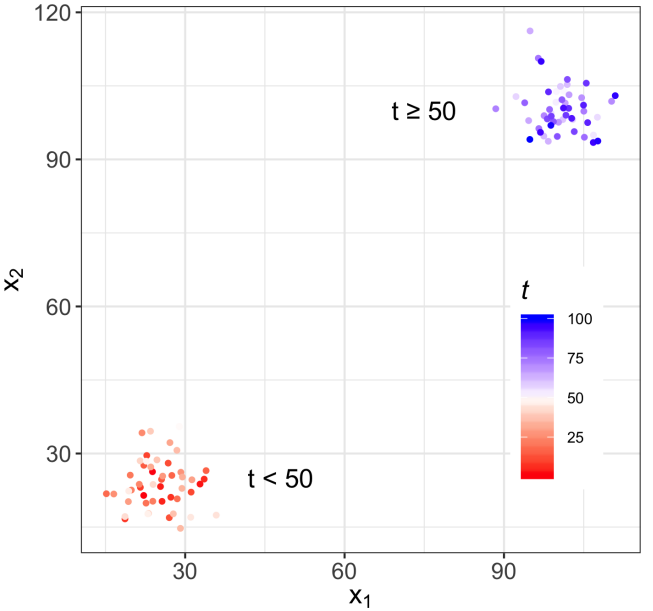
$$x\ normal(\mu = 25, \sigma = 5) \text{ for t } < 50$$

$$x\ normal(\mu = 100, \sigma = 5) \text{ for t } \geq 50$$

Velocity, $v = \frac{\Delta s}{\Delta t}$

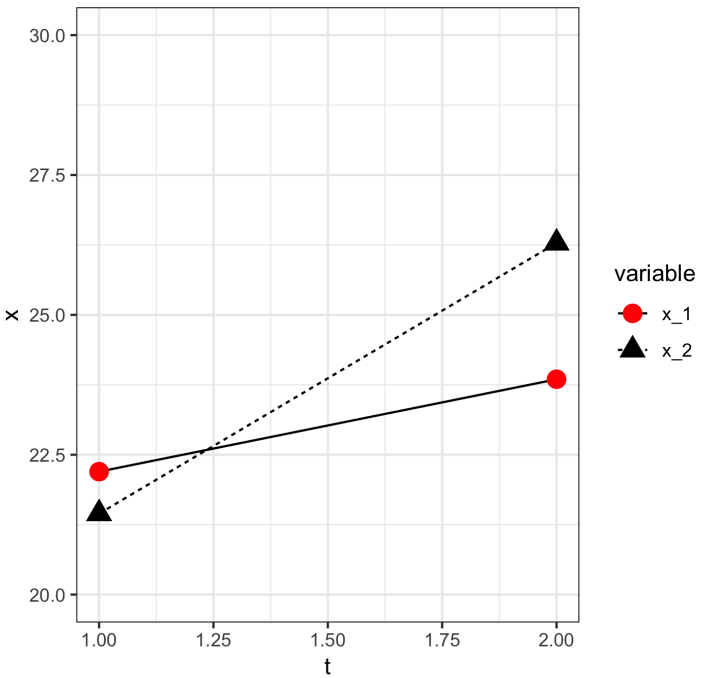
the linear speed of a system's trajectory (e.g., in phase space)





Step 1: Calculate Δx_i

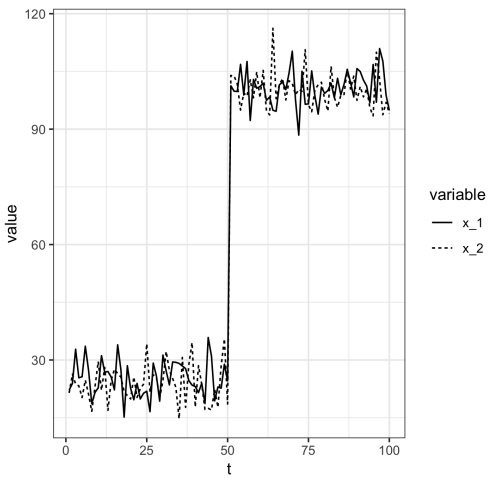
$$\Delta x_i = (x_{i,j} - x_{i-1,j})^2$$

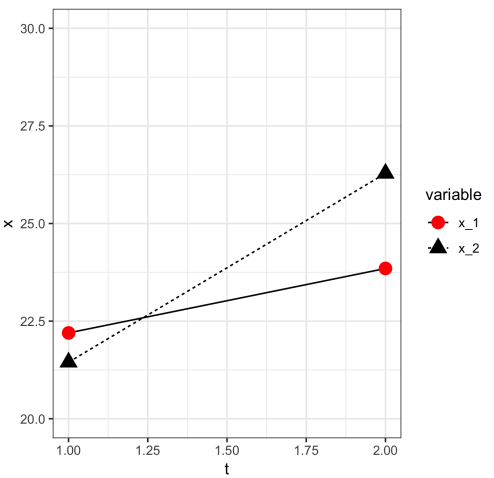


github: trashbirdecology/regimeDetectionMeasures

Step 2: Calculate Δs , 'distance travelled'

$$\Delta s_i = \sqrt{\sum_{j=1}^{n} (x_{i,j} - x_{i-1,j})^2}$$





github: trashbirdecology/regimeDetectionMeasures

Step 3: Calculate s , **cumulative** distance travelled

$$\Delta s_i = \sqrt{\sum_{j=1}^{n} (x_{i,j} - x_{i-1,j})^2}$$

$$s_k = \sum_{i=2}^{k} \Delta s_i$$

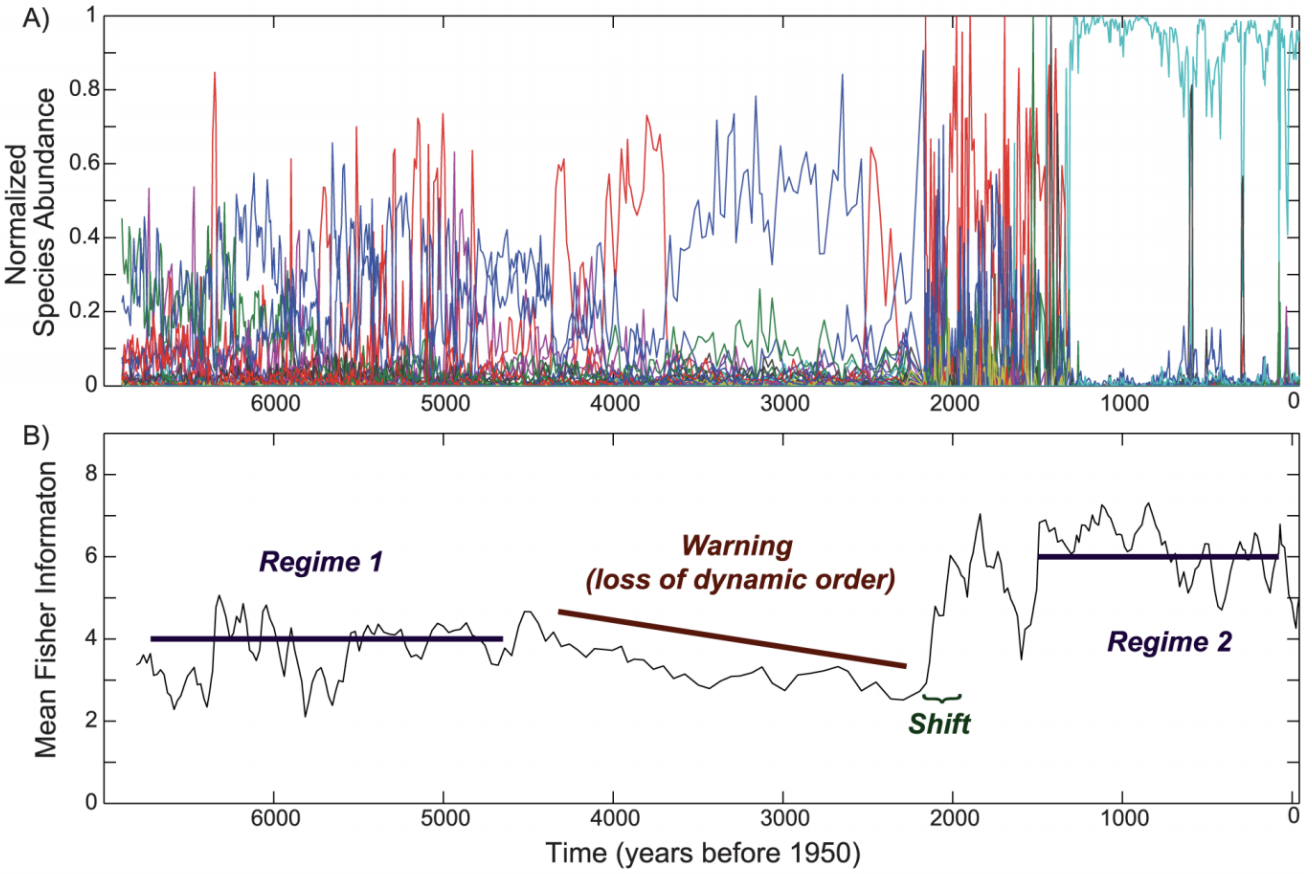
$$2 \leq k \leq n$$

github: trashbirdecology/regimeDetectionMeasures

Step 4: Calculate v , the linear speed of s

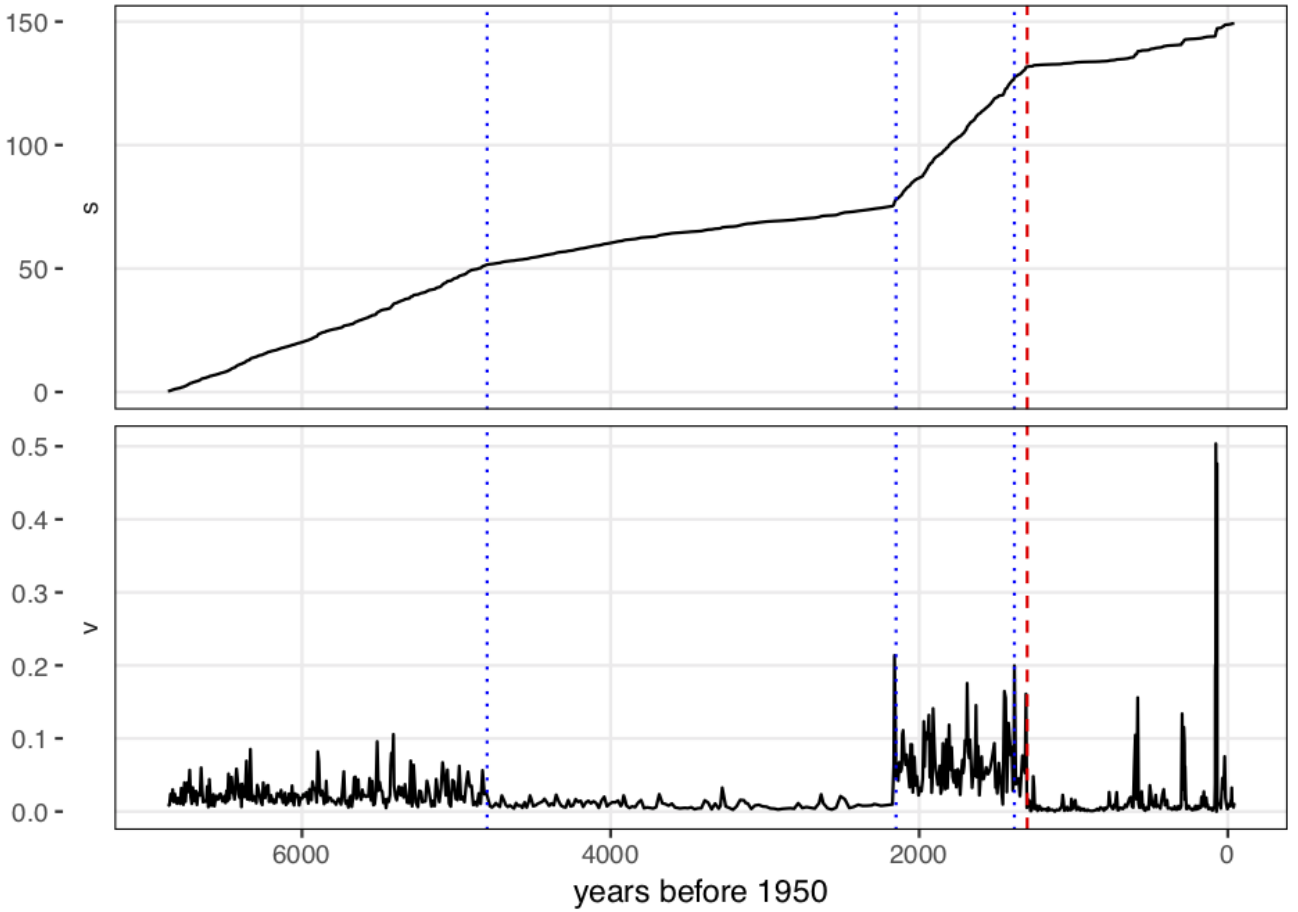
$$v = \frac{\Delta s}{\Delta t}$$

Empirical System: Paleodiatom Community



data: Spanbauer *et al.* 2014 PlosOne

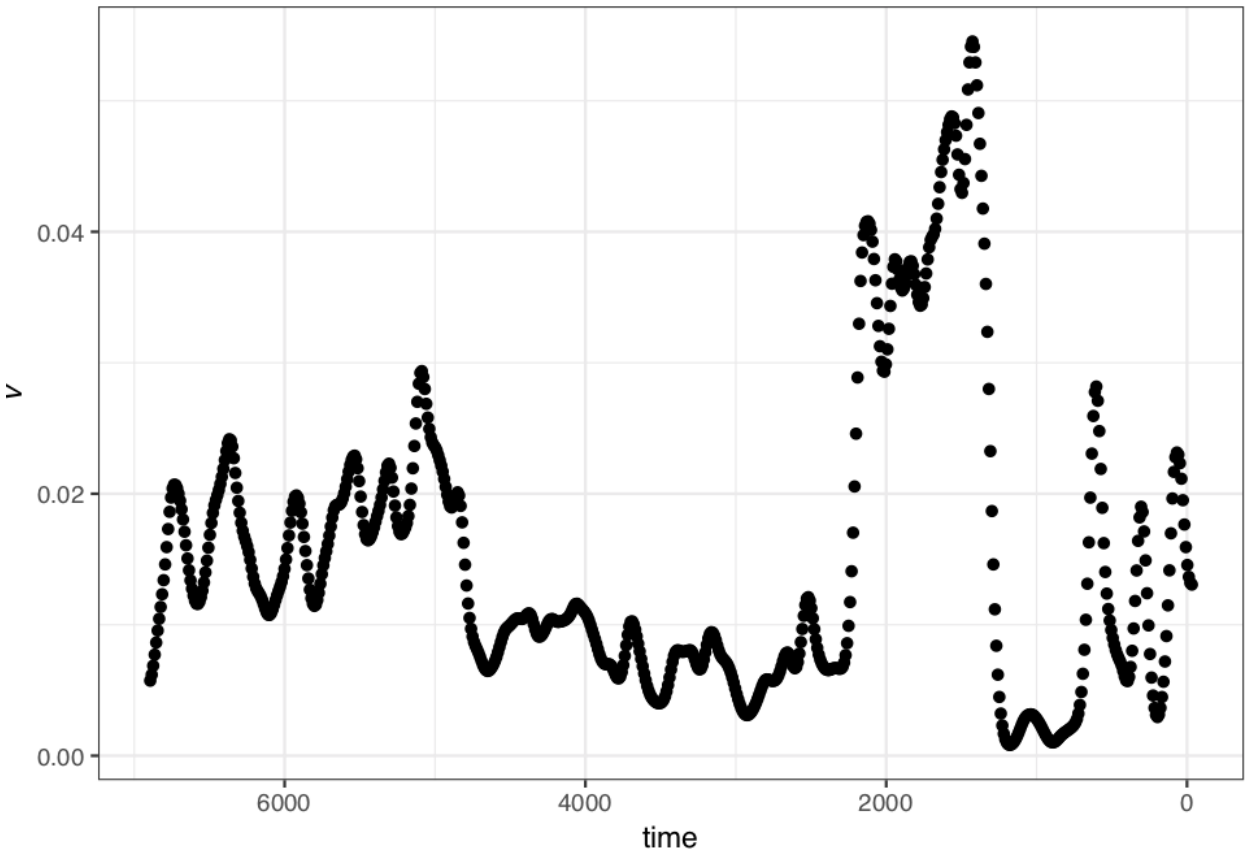
Empirical System: Paleodiatom Community



Dotted blue lines = **our** shift points
Dashed red line = Spanbauer *et al.* shift point

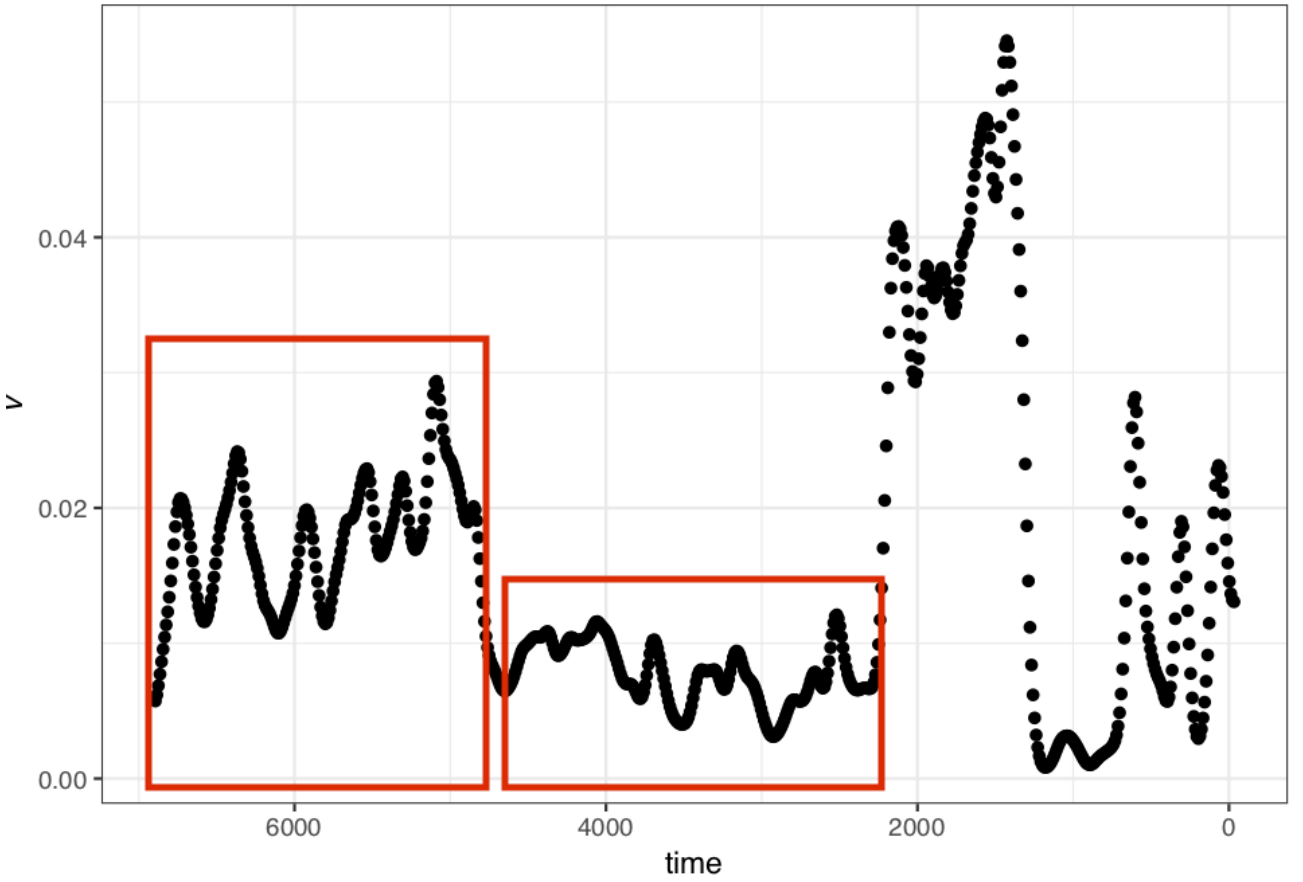
Getting the Derivatives of Noisy Data

Total Variation Regularized Numerical Differentiation to smooth the original data

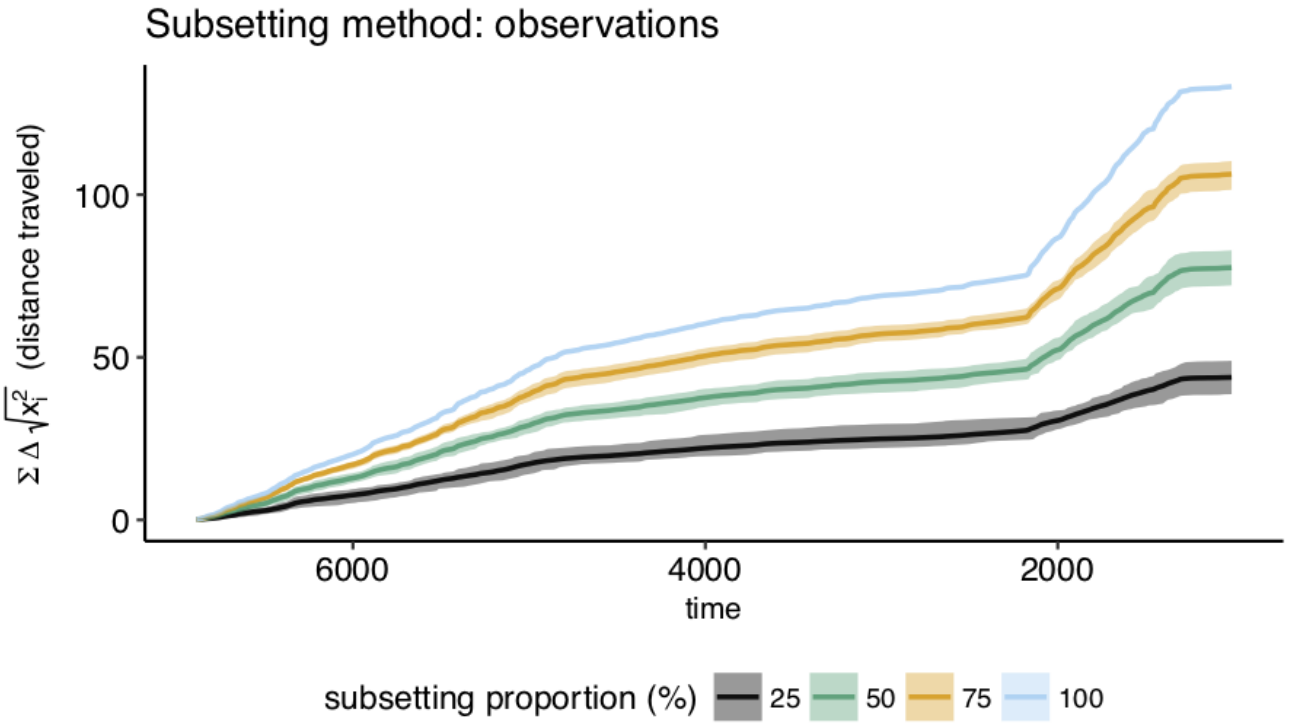


github: natbprice/tvdiff

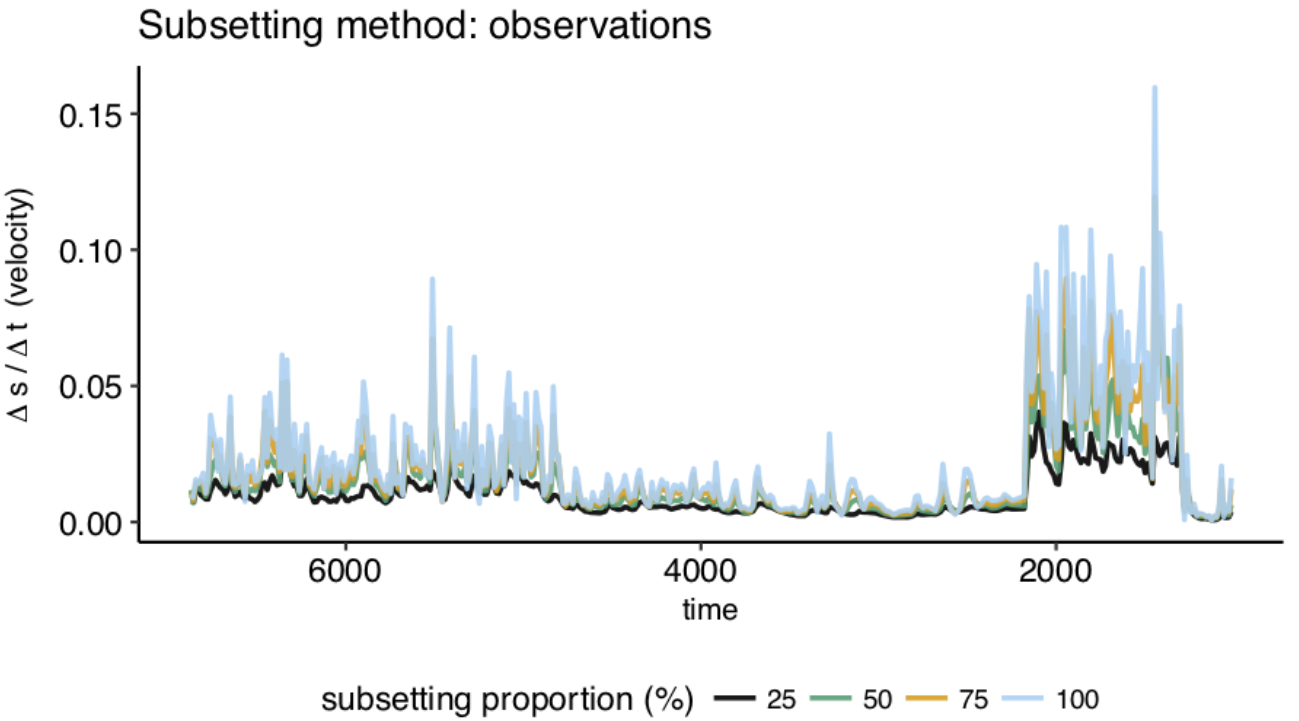
Velocity (v) Identifies Previously Unknown Periodicities



s and v Robust to Data Quality & Quantity Issues



s and v Robust to Data Quality & Quantity Issues



Conclusions

Simply calculation, relative to other regime detection methods

Handles noisy and sparse data

Less sensitive to data quality issues common in ecology

Velocity is best when mean > variance

Next Steps

Numerical identification of exact change points

Compare to distance-based metrics

Compare to ordination techniques

Identify out-of-sample predictive capacity

Relevant R Packages:

- `distanceTravelled` calculate velocity
- `regimeDetectionMeasures` calculate various metrics
- `bbsRDM` application to Breeding Bird Survey
- `tvdiff` regularized differentation noisy data

More Information

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Analysis & Presentation

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