School of Mathematical Sciences | Lancaster University

Detection of spatiotemporal changepoints in air quality – a generalised additive model approach

Rebecca Killick
Joint work with Mike Hollaway (UK Centre for Ecology & Hydrology)
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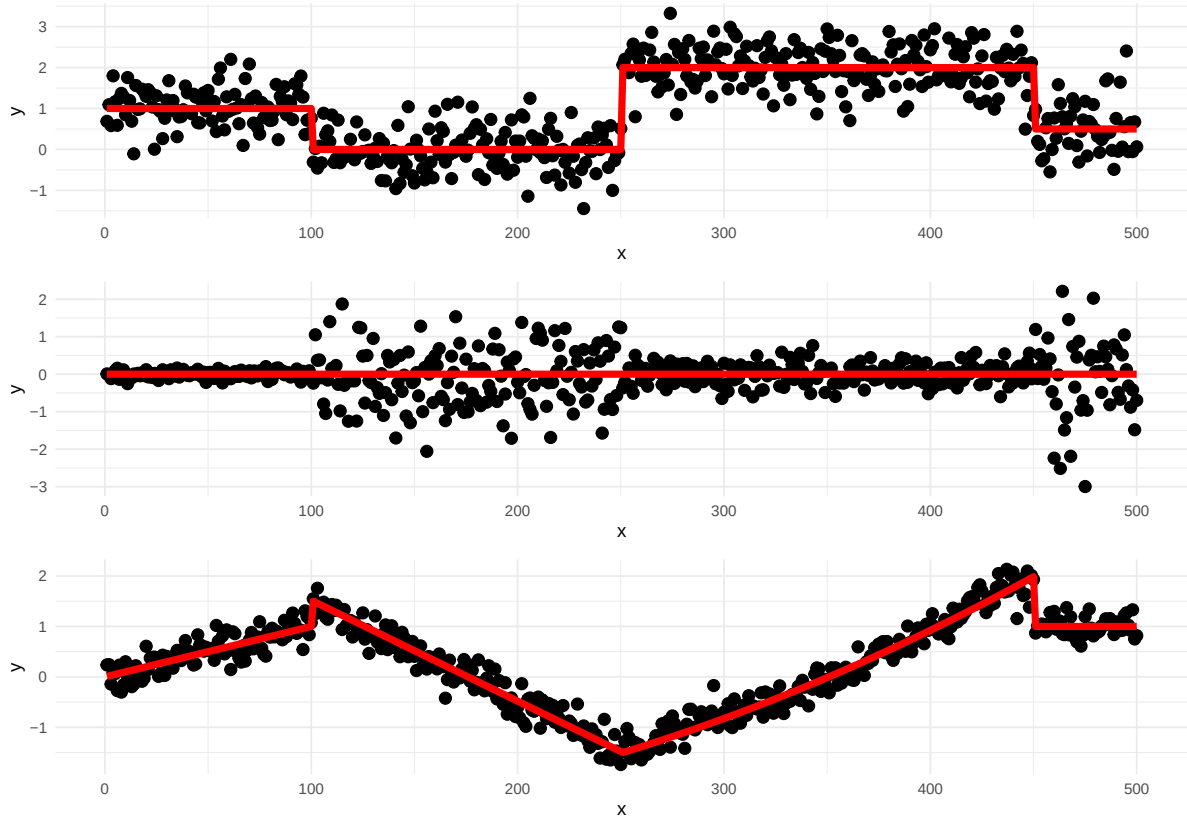
Overview

- What are changepoints?
- Fitting multiple changepoint models
- Spatiotemporal changes
- Application to Air Quality

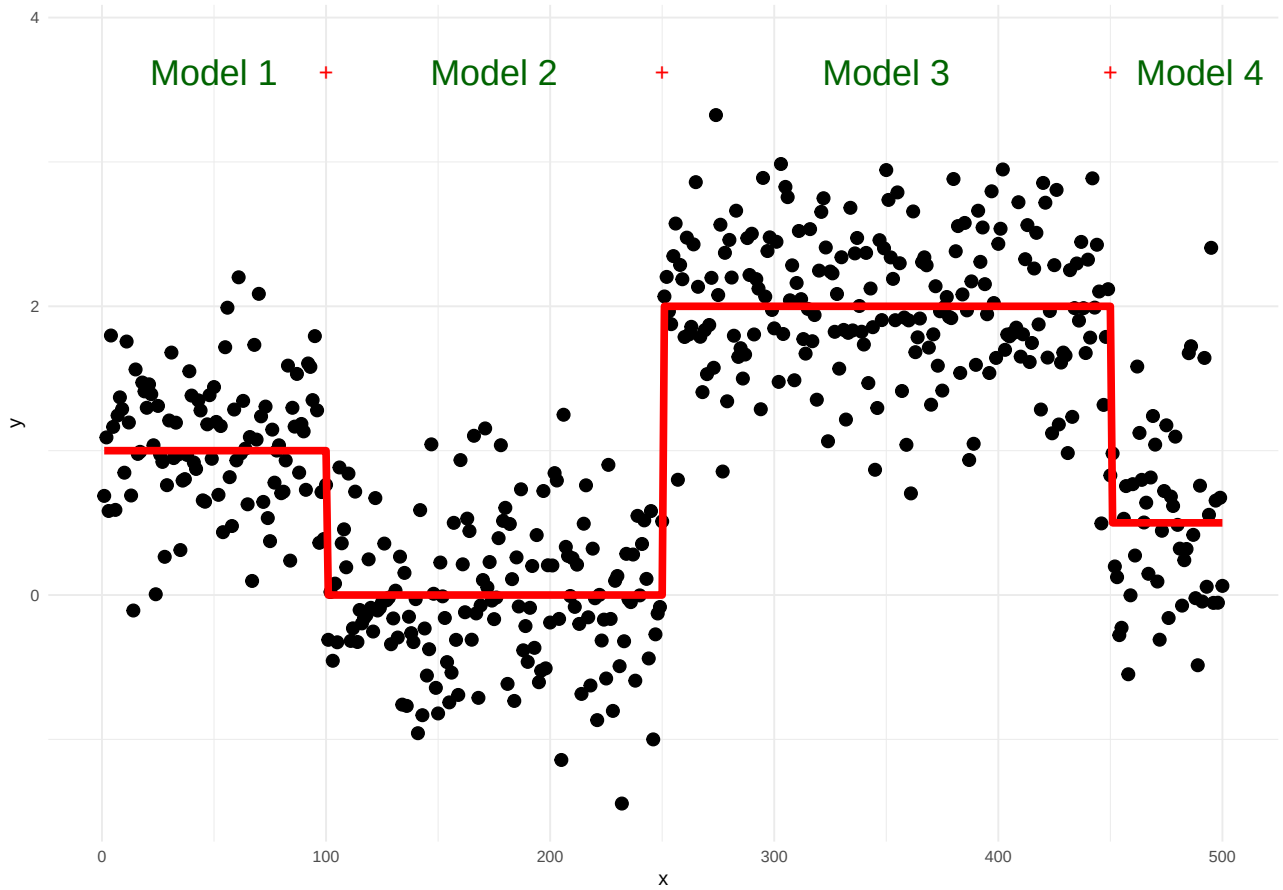
What are changepoints?

For data $y_1, \ldots, y_n$, if a changepoint exists at τ, then $y_1, \ldots, y_\tau$ differ from $y_{\tau+1}, \ldots, y_n$ in some way.

There are many different types of change.



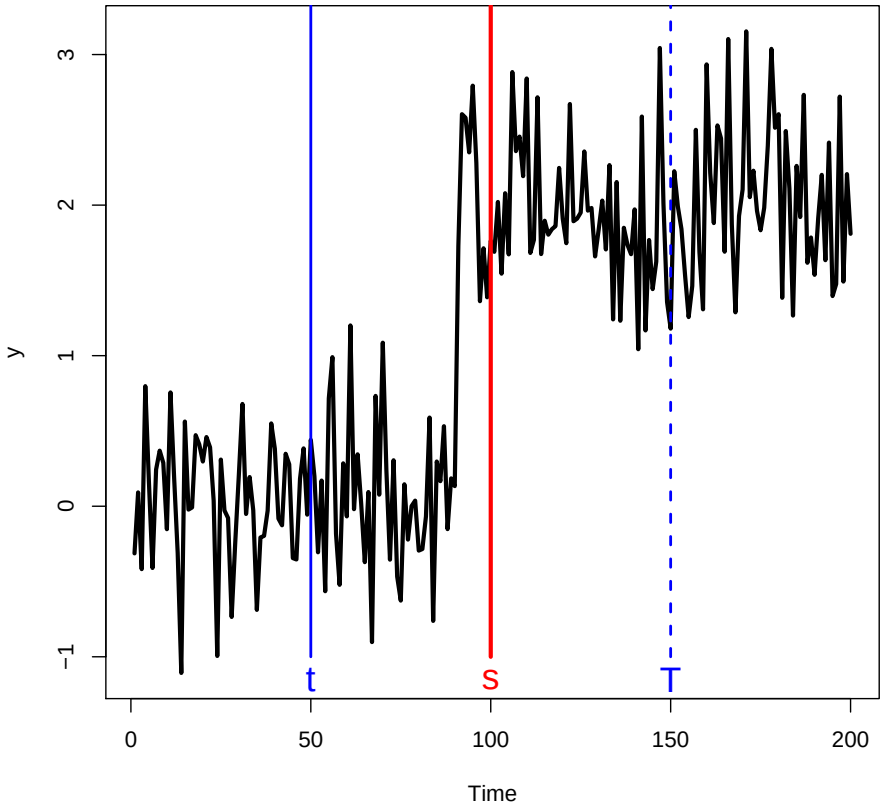
Problem



- How many changes?
- Where are the changes? 2^{n-1} possible solutions!

PELT in a nutshell

- Dynamic programming allows us to only worry about the location of the *last* change.
- Pruning means that as we go through the data we are smart about which locations are potential last change locations.

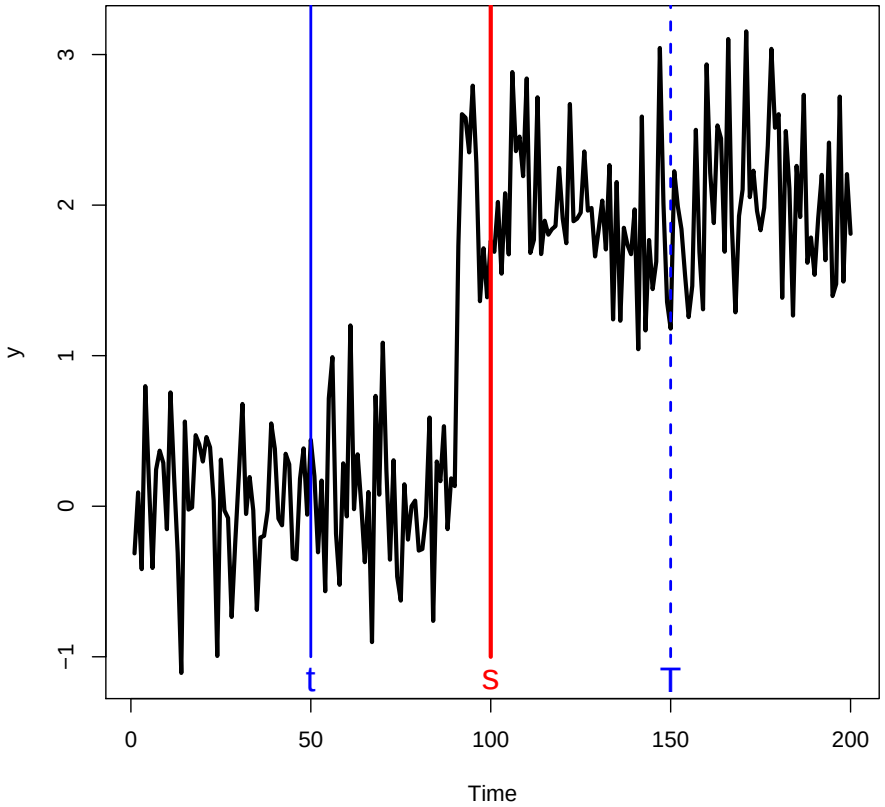


PELT: Pruning

Let $0 < t < s < T$, if

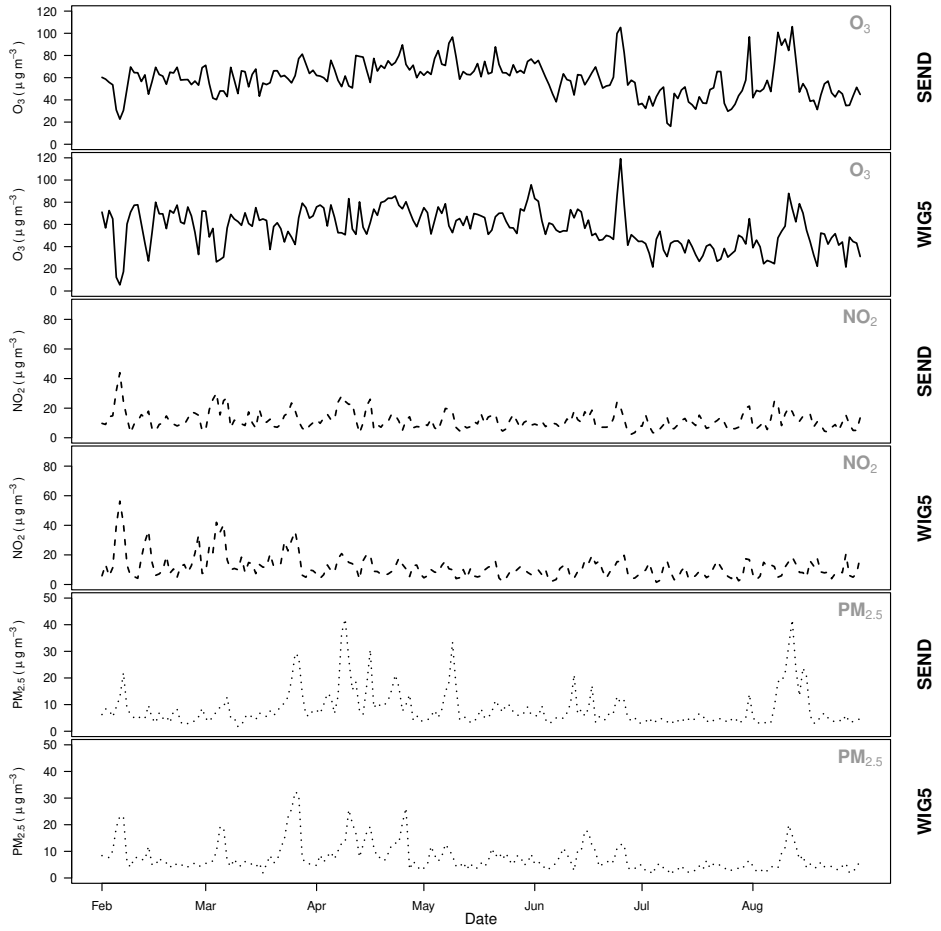
$$F(t) + \mathcal{C}(y_{(t+1):s}) < F(s)$$

then at any future time $T > s$, t can never be the optimal last changepoint prior to T.
We can prove that, under certain regularity conditions, the expected computational complexity will be $\mathcal{O}(n)$.



Air Quality

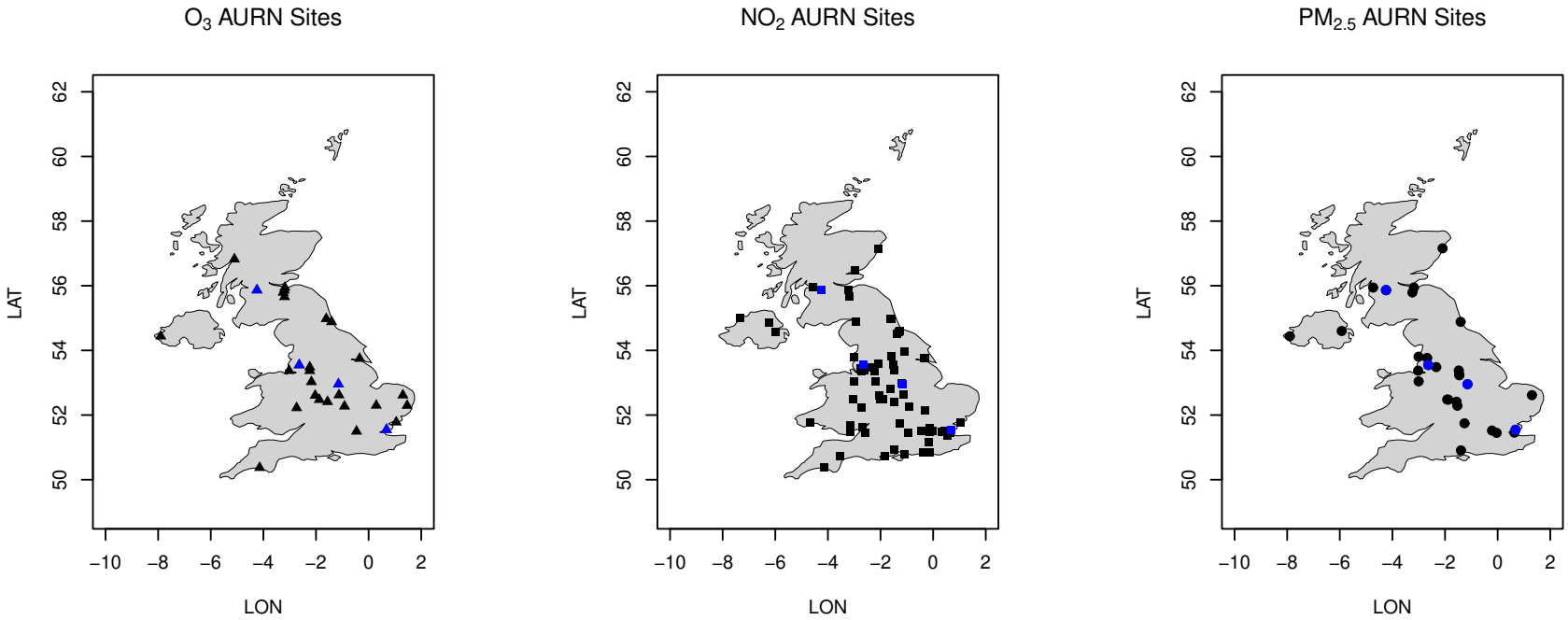
UK Defra Air Quality Expert group requested scientific evidence around COVID lockdown effects on air quality across the UK.



Data

175 AURN active stations, 1st Feb - 31 Aug 2020 (213 days).

O_3 - 30 stations, NO_2 - 74 stations, $PM_{2.5}$ - 30 stations.



`OpenAir` R package.

Model

Generalised Additive Model

$$y_{s,t} = f_1(x_s) + f_2(x_t) + f_3(x_s, x_t) + \epsilon_{s,t}$$

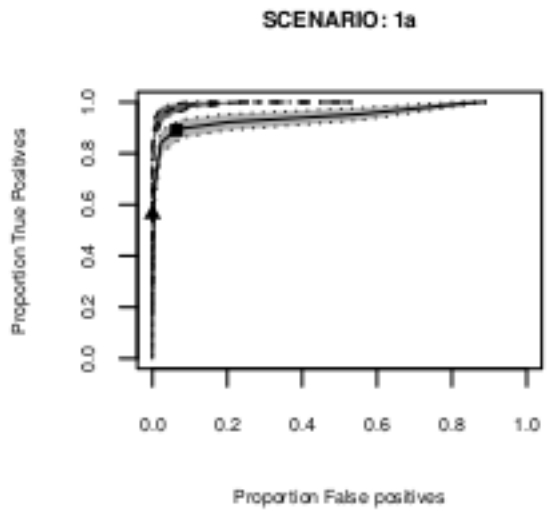
- f_1 is a 2D thin plate spline over space
- f_2 is a cubic regression spline over time
- f_3 is a tensor product for space-time interactions

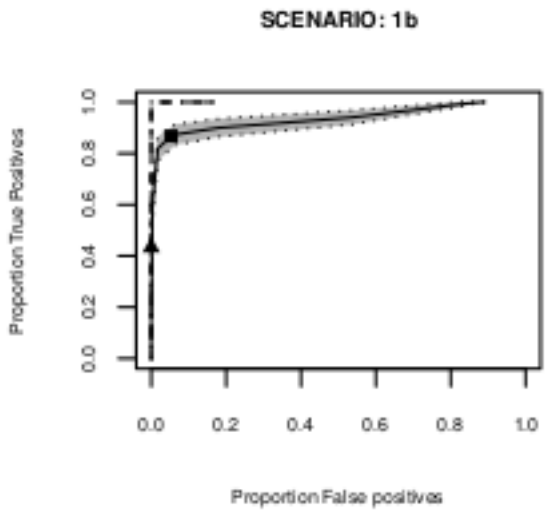
Use `mgcv` in `R` or `GLMgam` in `Python` for GAM fit and likelihood.

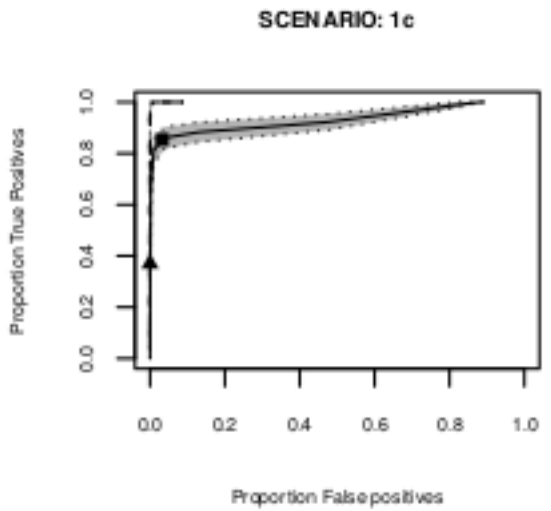
Time Change Sims

Spatial: Constant, Random, Correlated

GAM-PELT: Dashed, Marginal: Solid



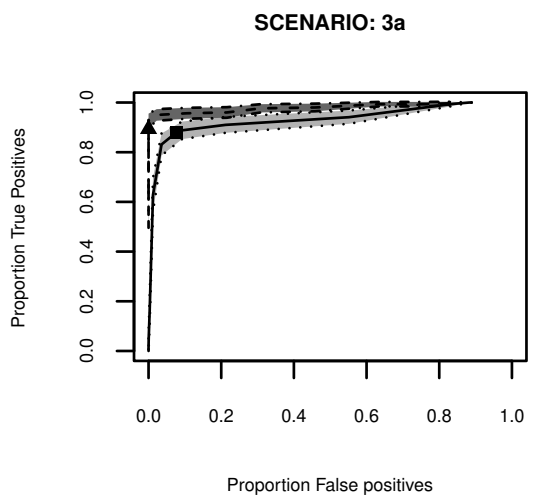


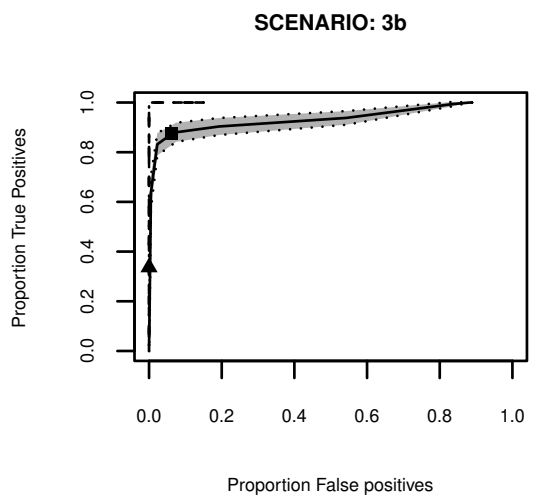


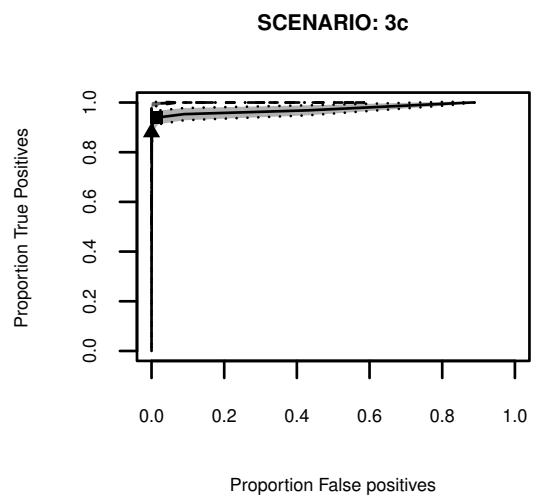
Space Change Sims

Spatial: Constant, Random, Correlated

GAM-PELT: Dashed, Marginal: Solid



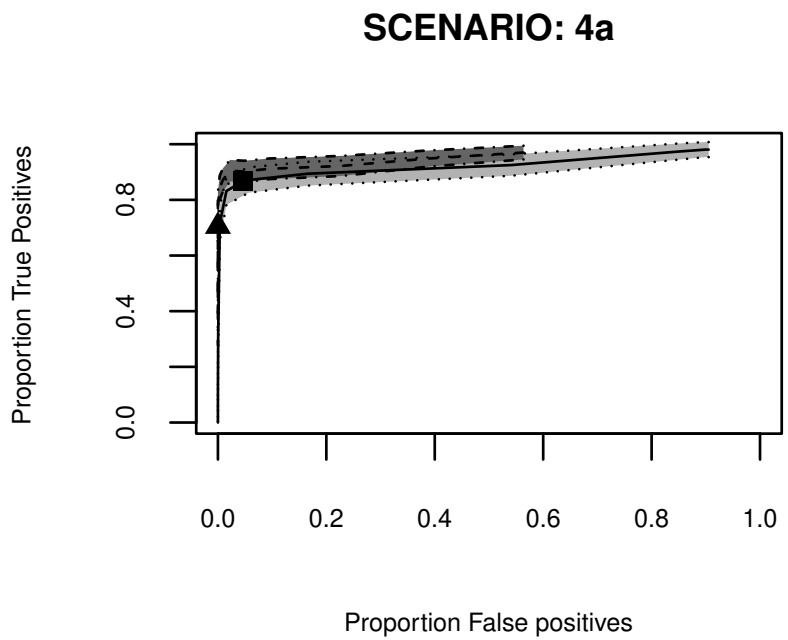


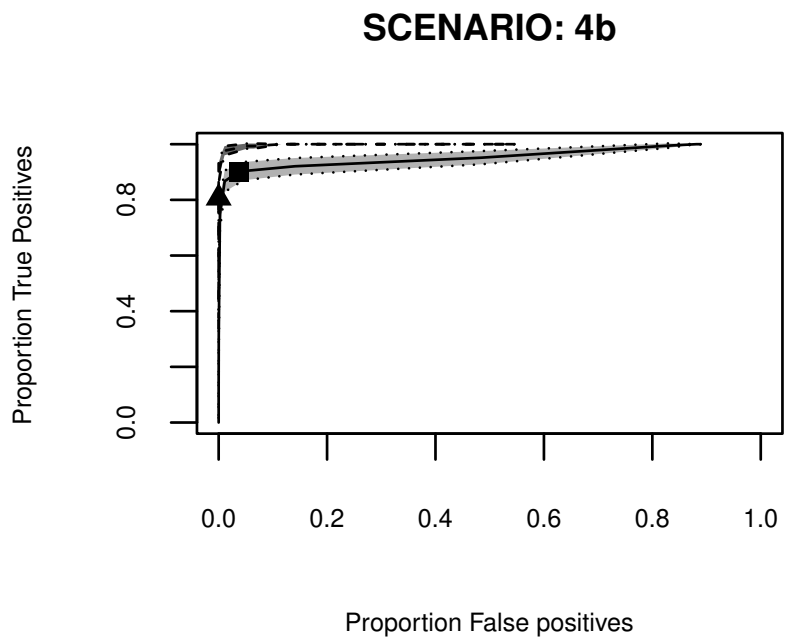


Space-Time Change

Random change in all. Left includes No change option.

GAM-PELT: Dashed, Marginal: Solid





AURN analysis

Changepoint at 21st March 2020

$PM_{2.5}$ (pre–lockdown)

$PM_{2.5}$ (lockdown)

AURN analysis

Changepoint at 26th March 2020

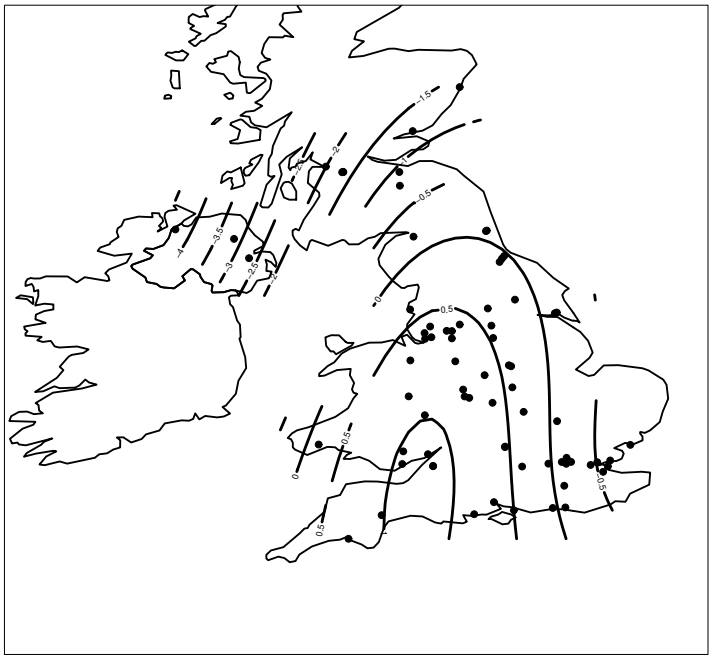
O_3 (pre−lockdown)

O_3 (lockdown)

AURN analysis

Changepoint at 27th March 2020

NO_2 (pre–lockdown)



NO_2 (lockdown)

Insights

- The GAM model is flexible enough to capture spatio-temporal patterns in air quality
- The addition of the PELT step for changepoint detection provides an easy-to-use extension to the model
- Early change for $PM_{2.5}$ correlates with early work from home in cities
- The decrease in O_3 and increase in NO_2 aligns with expectations from science around pollution dissipation
- Changepoints for phased return for schools in June are also seen.

Summary

- Introduced the PELT algorithm for identifying multiple changepoints optimally in a computationally efficient way
- Developed an approach to identify changepoints in spatiotemporal data with an application in air quality
- These and other extensions are useful for identify changes in a host of climatology applications