

Visualizing the Effect of Interventions during the 2014–2015 West Africa Ebola Outbreak

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Introduction

During large scale epidemics, governments and NGOs try to minimize the spread of the disease. However, with some diseases, we do not know when patients became infected with the disease. This can be problematic in diseases like Ebola that have a long incubation period.

Alternatively, we can observe when patients begin showing symptoms. The symptom-onset curve is convolved, or distorted by the incubation period. This study seeks to find what filter works best to undo the distortion, or deconvolve the onset-of-symptoms curve into the unknown infection curve. This filter will be applied to the Ebola Outbreak so we can investigate the effect of certain interventions.

Objectives

- Build methods to deconvolve onset-of-symptoms dates to infection dates
- Test effectiveness of methods on simulated outbreaks
- Apply the most effective method to the Ebola Outbreak

Methods

- Simple Deconvolution:** This method is currently used for deconvolving infection curves. It moves the onset-of-symptoms dates back by the average incubation period.
- Random Deconvolution:** Each patients is randomly assigned an incubation period under the correct distribution to find when they were infected. They are shifted back this amount to find a possible infection curve. This process is repeated 100 times and the average is taken as the final infection curve.
- Ridge Regression:** This method minimizes $\|Ax - b\|^2 + \|\Gamma x\|^2$ with A , a matrix of incubation period probabilities, x , the infection curve, b , the observed symptom-onset-dates, and Γ , a multiple of the identity matrix. Increasing Γ introduces bias, reducing the MSE and avoiding overfitting.

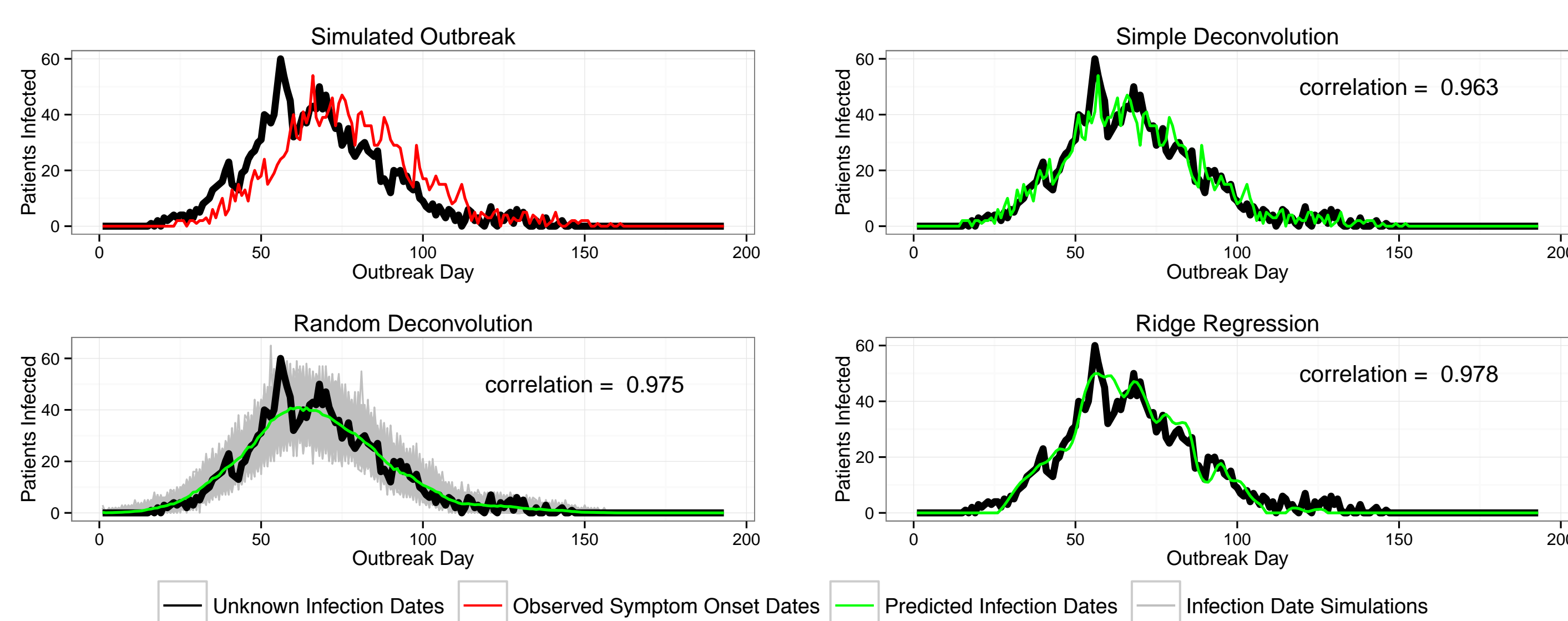


Figure 1: Each deconvolution method is tested on a simulated outbreak to see how well it matches the unobserved infection curve. Each of the methods does well at different aspects of deconvolution.

Experimental Design

Each method may be better at deconvoluting different types of outbreaks. To test this, we generated 1,000 outbreaks at 3 difficulty levels and added normal noise. One onset-of-symptoms curve was simulated for each outbreak.

Easy: Quadratic. **Medium:** 10th-degree polynomial.

Hard: Quadratic plus a sine wave.

The three methods were tested on how well each deconvolved curve correlated with the original outbreak.

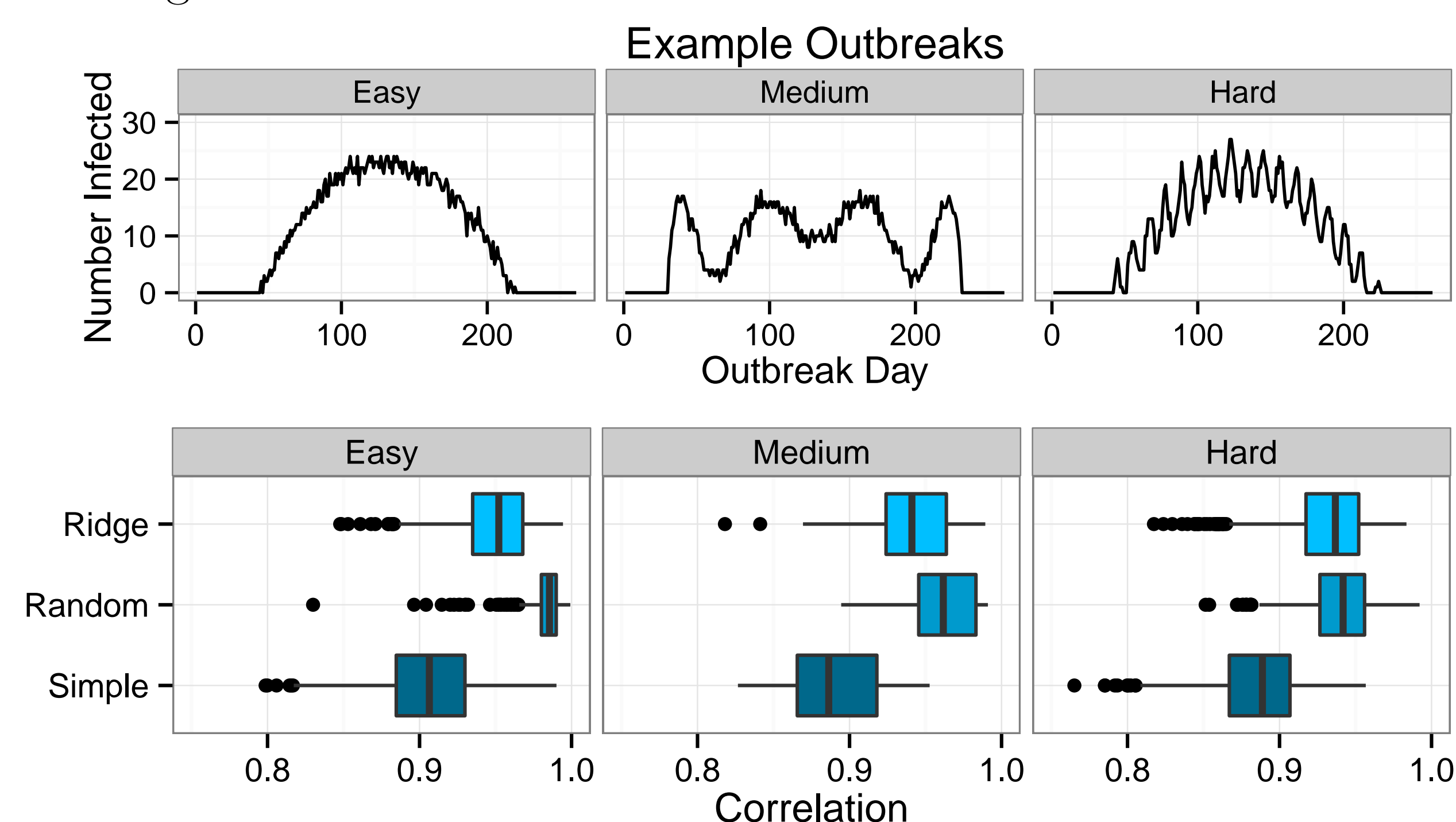


Figure 2: The Random Deconvolution method performed significantly better on all difficulty levels.

Key Findings

- The current method for finding infection dates is good, but can be greatly improved by applying a filter.
- The deconvolution method that should be applied does not depend on the behavior of an outbreak.

Discussion

Simulations exposed inherent problems with each method:

- Simple deconvolution preserves large spikes, but has a high probability of misplacing them.
- Random Deconvolution captures the general trend, but misses the sudden increases and decreases in infection rate.
- Ridge Regression captures the high points, but under steady rates of infection it overestimates small portions and negates many of the intervening segments.

After deconvolving the data, we investigated the curve around certain dates. We can only say that there is a significant change in the curve surrounding the event in question. A large number of unknown factors may cause an unexpected increase or decrease in the infection rate, and the event in question may be uncorrelated with such a change.

Results

The following figures were produced with the Random Deconvolution method. Since data was recorded by week, we randomly assigned each person a day of the week on which they arrived at the hospital. The transmission rate on day x_i , with the serial interval distribution S ,

$$T(x_i) = \sum_j \frac{x_i}{P(S = j)x_{i-j}}$$

We investigated the transmission rate surrounding five events in the three affected countries. Two of these are shown below:

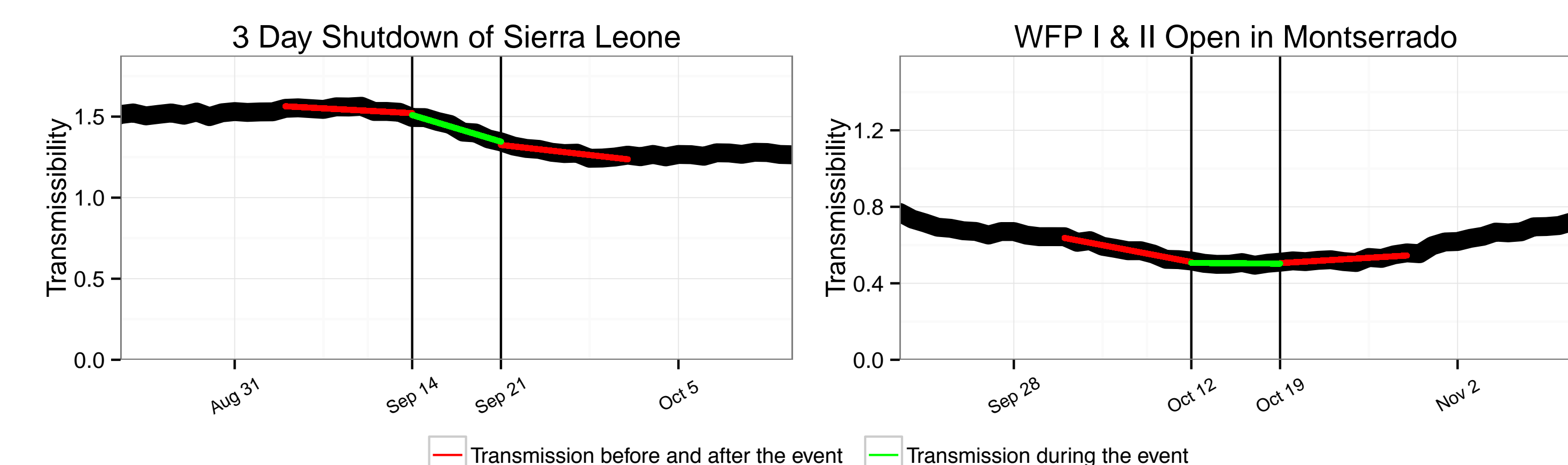


Figure 3: From September 19–21, 2014, the entire country of Sierra Leone was shut down. No one was allowed out of their homes. This was an attempt to decrease the transmission, which it clearly did. This made citizens more aware, and decreased transmission for the next few weeks.

Figure 4: On October 18, 2014, two Ebola Treatment Units (ETUs) opened in Montserrado, Liberia. Combined, they provided 200 beds to take infected patients out of the susceptible population. It is possible that this increased the reporting rate, which would be seen as an increase in transmission.

Future Work

- The Richardson-Lucy Maximum Likelihood method, which has been used in the past, was not explored in this study. Does it perform better than the methods presented here?
- Random deconvolution works best, but should fewer simulations be averaged to achieve a better fit?
- Do combinations of methods perform better than each method by itself?
- Does the length of an epidemic affect how well each method performs?

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