An objective change point analysis of *landfalling* historical Atlantic hurricane numbers

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Abstract

In previous work we have analysed the Atlantic basin hurricane number time-series to identify decadal time-scale change points. We now repeat the analysis but for US *landfalling* hurricanes. The results are very different.

1 Introduction

In previous work (Jewson and Penzer, 2006) we have attempted to identify change points in the Atlantic hurricane number time-series. We used a brute-force search through all possibilities to find the change points defined by the global minimum in an out-of-sample mean squared error (MSE) cost function. When we allowed gaps between change points as short as 2 years we were unable to find the global minimum because of the vast number of possible combinations of change points relative to currently available computer power. However, when we increased the minimum gap between change points to 10 years we were able to find the global minimum of the cost function. This global minimum corresponded to 4 change points, occurring in 1931/1932, 1947/1948, 1969/1970 and 1994/1995. We also applied the method to intense storms only, and found change-points in the years 1914/1915, 1947/1948, 1964/1965 and 1994/1995. The most recent two change-points we identify in the intense series correspond exactly with the most recent two change-points identified in the earlier work of Elsner et al. (2000, 2004), using a very different detection algorithm.

We now repeat our change-point analysis for US landfalling hurricanes only. This is a much more difficult time series to work with, since the number of landfalling hurricanes is much lower than the total number of Atlantic hurricanes, and there are many years with no landfalling hurricanes at all. We can thus anticipate that it might be more difficult to identify change points in this time-series. Elsner et al. (2004) has previously analysed the same time series using a Markov Chain Monte Carlo method. In section 5 we compare our results with those from this earlier study.

2 Methods

Our method is the same as that used in Jewson and Penzer (2006), except that we now consider US landfalling hurricane numbers rather than basin hurricane numbers. We also only use a 10 year minimum gap between change points, whereas in Jewson and Penzer (2006) we performed a preliminary study using a 2 year minimum gap.

We create our landfalling hurricane number time series directly from the current version of the HURDAT database (Jarvinen et al., 1984), and define a landfalling hurricane as one which is a hurricane at the point of landfall. We exclude hurricanes that weaken to non-hurricane status before landfall. The resulting time series of hurricane numbers is shown in figure 1.

3 Results

Tables 1, 2 and 3 show the change points detected in the landfalling hurricane number time-series, the out-of-sample RMSE scores for these change points, and the number of combinations tested to find them.

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respectively. Starting with the RMSE scores in table 2, we see a big difference between these results and the results in Jewson and Penzer (2006). In that study, the RMSE reduced monotonically as we increased the number of levels, down to a minimum at 5 levels, after which it started to increase again. The minimum RMSE achieved was highly statistically significant i.e. it is very unlikely that it could have occurred unless the hurricane number time series has real temporal structure. In the landfalling case, however, there is no clear monotonic decrease. In fact the best two level model is slightly worse than the one level model. The best of the models with more than 2 change-points beat the score for the one level model, but only very slightly. We cannot, therefore, identify any change-points at all in this time series, and a model which considers the landfalling rate to be constant in time performs as well as any other. We could, at this point, stop this study, since we haven’t found any statistical evidence for change points in the landfalling hurricane time-series. We will, however, press on, since we have strong physical reasons to think that change points do actually exist. The total number of hurricanes shows clear change points, and landfalling hurricanes are closely related, both physically and statistically, to the total number of hurricanes. We now ask: even though we can’t detect any benefit from the modelling of change points in the landfalling time-series, what indications are there that there might be change points in this time series? If we had to choose some change points, what would they be? And do the change points we find show any resemblance to those in the total number of hurricanes? Figure 2 and subsequent figures show the locations of change points for the optimum models with 1 to 4 change points. The one change point results show a reduction in the number of hurricanes in 1956. The two change point results show a brief reduction in activity in the 1970s and 1980s, which is perhaps similar to the reduction in activity from 1970 to 1994 seen in the total number results (see figure 9 in Jewson and Penzer (2006)). The three change point results show a brief increase in the 1950s, which again is perhaps similar to something seen in the total number results. The four change points results show reductions in the 1920s and the 1960s-1970s. Overall, however, we have to conclude that the change points we identify don’t really match closely with the change points for the basin, although with the eye of a believer one can perhaps see some similarities. Considering the stability of our optimal change points, relative to the top 30 results in each case, we see that the results are distinctly less stable than the equivalent results for basin numbers.

4 Intense landfalling hurricanes

We now repeat our change-point analysis for intense landfalling hurricanes. In the basin data the change points for the intense hurricanes are more visually striking than those for the total number of hurricanes, and so one might imagine that it might be possible to detect change points in the intense number of landfalls even if it is not possible to detect them in the total number of landfalls. Figure 10 shows the time-series of the number of intense landfalling hurricanes. By eye, it is hard to see any marked changes in this time series. Tables 4 and 5 show the change points identified, with the scores. At least the score now decreases as we move from 0 change points (1 level) to 2 change points (3 levels), suggesting that perhaps there might be two real change points in this data. However, as we saw in the statistical tests in Jewson and Penzer (2006), the presence of a minimum in this score is actually no indication of statistical significance: what matters is the value at the minimum. Running the same set of statistical tests we ran in Jewson and Penzer (2006), we find that the minimum achieved for the intense landfalling data is not significant at all. Of our 100 random reorderings of the data, the mean of the best RMSE values achieved was 0.822, which is actually lower than the 0.840 achieved by the optimal RMSE value on the real data.

5 Discussion

We have performed an objective change point analysis on data for the number of hurricanes making landfall annually on the US coastline. We did not find any evidence for the existence of change points in this time-series. The change points that our algorithm does detect do not correspond very closely to the change points that we have found previously in the total number of hurricanes, and are not particularly stable. These results are consistent with the earlier findings of Elsner and Jagger (2004), who ran a very similar analysis but using a very different algorithm based on Monte Carlo Markov Chains rather than brute-force searching. An interesting avenue of future work would be to examine regionalization, and apply our change point analysis to the Florida, East Coast and Gulf Coast landfalling hurricane number time series separately.
Elsner and Jagger (2004) found that the only detectable change points were in the Florida time series. In conclusion: the average number of landfalling hurricanes may change over time, but there is little evidence for such changes in the landfalling hurricane data considered here. This could either be because such changes don’t exist, or, perhaps more likely, because there is not enough data to distinguish the changes from the noise.

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Figure 1: US landfalling hurricane numbers for the period 1900 to 2005.
Table 1: The change points identified in the landfalling hurricane number time series, versus the number of model levels.

| model | cp1 | cp2 | cp3 | cp4 | cp5 | cp6 |
|-------|-----|-----|-----|-----|-----|-----|
| 1     | 56  |     |     |     |     |     |
| 2     | 72  | 85  |     |     |     |     |
| 3     | 44  | 56  | 85  |     |     |     |
| 4     | 17  | 32  | 56  | 85  |     |     |
| 5     | 17  | 32  | 56  | 72  | 85  |     |
| 6     | 17  | 32  | 44  | 56  | 72  | 85  |
| 7     | 17  | 32  | 44  | 56  | 72  | 85  |

Table 2: The predictive RMSE scores for the different models.

| model | predictive RMSE |
|-------|-----------------|
| 1     | 1.412481        |
| 2     | 1.413486        |
| 3     | 1.399329        |
| 4     | 1.401652        |
| 5     | 1.396658        |
| 6     | 1.392119        |
| 7     | 1.398182        |

Table 3: The number of combinations tested for each model.

| model | number of combinations tested |
|-------|------------------------------|
| 1     | 1.00E+00                     |
| 2     | 8.70E+01                     |
| 3     | 5.93E+03                     |
| 4     | 3.01E+05                     |
| 5     | 1.06E+07                     |
| 6     | 2.29E+08                     |
| 7     | 2.57E+09                     |
Figure 2: The best 2 level model.

Figure 3: The change points for the top 30 two level models considered.
Figure 4: The best 3 level model.

Figure 5: The change points for the top 30 three level models.
Figure 6: The best 4 level model.

Figure 7: The change points for the top 30 four level models.
Figure 8: The best 5 level model.

Figure 9: The change points for the top 30 five level models.
Figure 10: US landfalling hurricane numbers for the period 1900 to 2005.
Table 4: The change points identified in the landfalling *intense* hurricane number time series, versus the number of model levels.

| model | cp1 | cp2 | cp3 | cp4 | cp5 | cp6 |
|-------|-----|-----|-----|-----|-----|-----|
| 1     | 15  |     |     |     |     |     |
| 2     | 15  |   56|     |     |     |     |
| 3     | 15  | 62  | 79  |     |     |     |
| 4     | 15  | 56  | 71  | 83  |     |     |
| 5     | 15  | 32  | 56  | 71  | 83  |     |
| 6     | 15  | 34  | 44  | 56  | 71  | 83  |
| 7     | 15  |     |     |     |     |     |

Table 5: The predictive RMSE scores for the different models.

| model | predictive RMSE |
|-------|-----------------|
| 1     | 0.8439727       |
| 2     | 0.8417796       |
| 3     | 0.8401334       |
| 4     | 0.8433204       |
| 5     | 0.8456246       |
| 6     | 0.8500992       |
| 7     | 0.8541917       |
Figure 11: The best 3 level model.

Figure 12: The change points for the top 30 three level models.