Year-ahead prediction of US landfalling hurricane numbers: intense hurricanes

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Abstract

We continue with our program to derive simple practical methods that can be used to predict the number of US landfalling hurricanes a year in advance. We repeat an earlier study, but for a slightly different definition landfalling hurricanes, and for intense hurricanes only. We find that the averaging lengths needed for optimal predictions of numbers of intense hurricanes are longer than those needed for optimal predictions of numbers of hurricanes of all strengths.

1 Introduction

The reinsurance industry is interested in predictions of hurricane activity on all timescales, but is *most* interested in predictions that are available during the reinsurance contract renewal negotiations that typically take place towards the end of the calendar year. Such predictions can be used directly in the calculation of annual reinsurance premiums. Motivated by this, we are attempting to develop methods that give good predictions of annual hurricane numbers from November of the year prior to the year being predicted. Since this is a longer lead-time than produced in seasonal forecasts, and since next year's hurricane count is predicted as soon as we know this year's count, we call this the *year-ahead* prediction of hurricane numbers. Our approach is to start with the simplest possible statistical methods, and build up to more complex methods very gradually. Hopefully in this way we will develop a clear understanding of the advantages and disadvantages of different methods.

Our first attempt at year-ahead prediction of hurricane numbers was described in Khare and Jewson (2005). We used simple averages of numbers of historical hurricanes to predict future numbers. The single parameter in this approach is the length of the average used: we varied this parameter and performed out-of-sample backtests on the available historical record to see what averaging lengths would have worked well in the past. We found that shorter windows (from 6 to 28 years) worked better than longer windows, and this result was shown to be statistically significant. This purely empirical result corresponds well with physical theories for hurricane numbers that suggest that there is a multidecadal cycle of hurricane activity (Goldenberg et al., 2001), most probably governed by sea surface temperatures as part of a mode of variability known as the Atlantic Multidecadal Oscillation (AMO) (Sutton and Hodson, 2005).

The purpose of the current study is twofold. Firstly, we repeat the previous study, described in Khare and Jewson (2005), but using an alternative, and preferable, definition of landfalling hurricanes. We will see that the results are more or less the same as before. Secondly, we repeat the study for *intense* landfalling hurricanes only. Intense hurricanes cause the most physical damage and so the prediction of intense hurricanes is of the most interest to reinsurers.

2 Data

As in the Khare and Jewson (2005) study, the data we use is the HURDAT: the 'official' hurricane occurrence data set produced by the US National Hurricane Centre (Jarvinen et al., 1984). However, as discussed above, we now use a slightly different definition for landfalling hurricane. The previous study used the `XING` variable from HURDAT, while we now use the `SSS` variable. The `XING` variable counts a landfalling hurricane as a storm that is a hurricane at any point in its life, and that makes landfall. The

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weakness of this definition is that there are a certain number of hurricanes that weaken before landfall, and are no longer hurricanes at the moment of landfall. With the `XING` definition these are still classified as landfalling hurricanes. However, from the point of view of the on-shore insurance industry, and others who care about possible on-shore damage caused by hurricanes, such hurricanes are less interesting than hurricanes that are still hurricanes at the point of landfall. The `SSS` variable that we use instead defines 'landfalling hurricane' as 'a storm that is a hurricane at the point that it makes landfall'. The definition of 'intense landfalling hurricane' that we use is also derived from the value of the `SSS` variable.

The number of landfalling hurricanes per year defined using the `XING` variable is shown in figure 1 of Khare and Jewson (2005), while the number of landfalling hurricanes per year defined using the `SSS` variable is shown in figure 1 below. The difference between these two time series is shown in figure 2. In most years this difference is negative or zero, indicating that `XING` > `SSS` as expected. However in 1 year the difference is positive. This would seem to be an inconsistency in the HURDAT database. However, we use the data as is, as a project is underway elsewhere to reanalyse and correct such inconsistencies. It seems unlikely that these small inconsistencies will have any influence on our overall conclusions.

The number of intense landfalling hurricanes per year (based on the SSS variable) is shown in figure 8.

3 Method

For both all hurricanes and intense hurricanes we perform a backtesting study to determine what lengths of averaging window would have worked well for the year-ahead prediction of hurricane numbers in the past. The backtesting method used follows the method used in Khare and Jewson (2005) exactly. It consists of:

1. Using data from 1940 to 2004, a backtesting comparison to evaluate the use of different averaging windows. The skill of each prediction is measured using MSE, and the window length that gives the minimum MSE is described as the optimal window length.
2. A statistical test of the optimal window length, based on random reorderings of the observed hurricane number time series.
3. A repeat of the backtesting study using data for 1900 to 2004, as a sensitivity test. This gives a second optimal window length.
4. A repeat of the statistical test, now for the second optimal window length.
5. A repeat of the backtesting study, as a further sensitivity test, now using the 41 data series that start with each year from 1900 to 1940, and that all end with 2004.

4 Results

4.1 All landfalling hurricanes

The results from the backtesting analysis of all landfalling hurricanes are shown in figures 3 to 7.

In figure 3 we show the results for the backtesting analysis of data from 1940 to 2004, and we see that, as in Khare and Jewson (2005), shorter windows (from 6 to 25 years) work better than very short or very long windows. The effect is, however, slightly less strong than that seen previously: the minimum in MSE is broader and the 'kink' at 46 years is more pronounced. The lowest value of MSE occurs at 16 years, and the statistical test gives this a p-value of 3.35%. Figure 4 shows the distribution of optimal window lengths from the random reordering test.

In figure 5 we show the results for the backtesting analysis of data from 1900 to 2004. In this case, the curve looks very similar to the corresponding curve in Khare and Jewson (2005), with the minimum lying in a range from around 18 to 40 years. The precise minimum is at 20 years. The statistical test gives this a p-value of 2% (40 out of 2000 cases had shorter optimal windows). Figure 6 shows the distribution of optimal window lengths from the random reordering test, as before.

Finally figure 7 gives the distribution of optimal window lengths derived using start years from 1900 to 1941. The 41 optimal window lengths are distributed from 6 to 33 years, which is very similar to the distribution shown in Khare and Jewson (2005), figure 7, which was in the range 6 to 28 years.

Our conclusion at this point is that switching from the `XING` definition of landfalling to the `SSS` definition of landfalling does not make a material difference to the results given in Khare and Jewson (2005): the number of hurricanes is still best predicted using a short window with a length somewhere in the range 6 to 33 years.

4.2 Intense landfalling hurricanes

We now describe the results from the backtesting analysis of the numbers of *intense* landfalling hurricanes (where 'intense' is defined as Saffir-Simpson category 3-5). Intense landfalling hurricanes are the most important for many land-dwellers, because only for these hurricanes are the winds strong enough to cause severe damage to property.

The numbers of intense landfalling hurricanes per year are shown in figure 8, and the backtesting results are shown in figures 9 to 13. Using data from 1940 to 2004, the best hindcasts were for window lengths from around 15 to 30 years, with the actual minimum occuring at 16 years (see figure 9). This has a p-value of 3.4% (based on the random reordering results shown in figure 10, in which 67 out of 2000 cases had shorter optimal windows). Repeating the analysis for data from 1900 to 2004 gives a slightly different story, however. The best predictions occurred for window lengths of around 60 years, with the precise minimum at 56 years. This is noticeably longer than the optimal window lengths in our previous analyses. However, the distribution of the optimal window length derived from the random reordering is also noticeably different, with more mass at longer window lengths (see figure 12) and the value of 56 years still has a p-value of only 8.3%. In figure 13 we show the optimal window lengths obtained using data periods starting from 1900 to 1941, and we see values from 16 to 56.

From these results we conclude that the predictability properties of intense hurricanes are different from those of all hurricanes: longer averaging windows are needed.

4.3 Sources of forecast error variance

Figures 3, 5, 9 and 11 all show the decomposition of the MSE into bias (dotted line) and variance (solid line) terms. For short windows we see that the variance term completely dominates. This term can be decomposed further, into 'internal variability' and 'sampling error' terms. We show this decomposition for the four variance curves in these four figures in figure 14. What we see is that in all cases the reason that very short windows give poor predictions is mostly because of the high level of sampling error, as we might expect.

5 Conclusions

We are interested in predicting the number of landfalling hurricanes and the number of intense landfalling hurricanes, one year in advance. We are investigating using very simple time averages of historical hurricane numbers to make these predictions. Specifically, we have performed two studies:

- We have repeated the analysis of Khare and Jewson (2005), but for a more appropriate and more standard definition of 'landfalling hurricane'.
- We have repeated the analysis of Khare and Jewson (2005), but for intense landfalling hurricanes only.

The results are as follows. For all landfalling hurricanes, we find more or less the same results as we found in Khare and Jewson (2005), which are that:

- Short averaging windows, in the range from 6 years to 33 years, would have given the best predictions
- But there is a lot of uncertainty around any point estimate of the best window length

For intense landfalling hurricanes, the results are interestingly different from the results for all hurricanes. Again we found that short windows give the best predictions. But now the window lengths are longer: from 16 to 56 years. This suggests that the nature of the predictability of intense hurricanes is different from that of all hurricanes. It seems possible that there may be a purely statistical explanation for this: intense hurricanes are less common, and as a result the intense hurricane time series has a lower signal to noise ratio than the time series for all hurricanes. However whether this can really explain the differences that we see needs further, and more detailed, investigation.

Where does this leave us with respect to making practical forecasts of hurricane numbers (intense or otherwise) a year in advance? The biggest hurdle in making such predictions seems to be the problem of which window length to choose from within the wide ranges that emerge from our analysis. For all hurricanes, we could choose any number from 6 to 33 years. For intense hurricanes, we could choose any number from 16 to 56 years. These different choices would give very different results. How can we reduce this arbitrariness in a non-arbitrary way? Currently the most attractive answer seems to be to use weighting of each of these forecasts (or of forecasts using all possible window lengths), where the weighting is based on the likelihood scores achieved in the backtesting experiment. Testing this is one of our future priorities.

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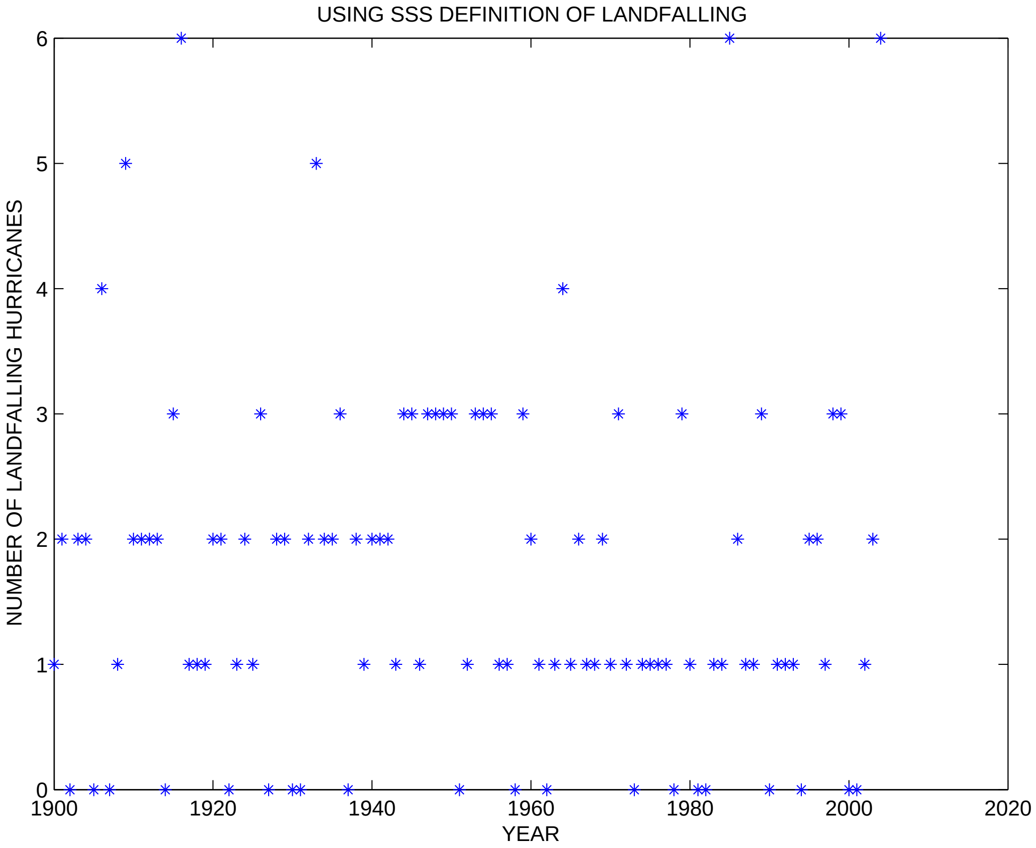


Figure 1: The observed number of US landfalling hurricanes for each year since 1900, using the SSS definition of landfalling from the HURDAT database.

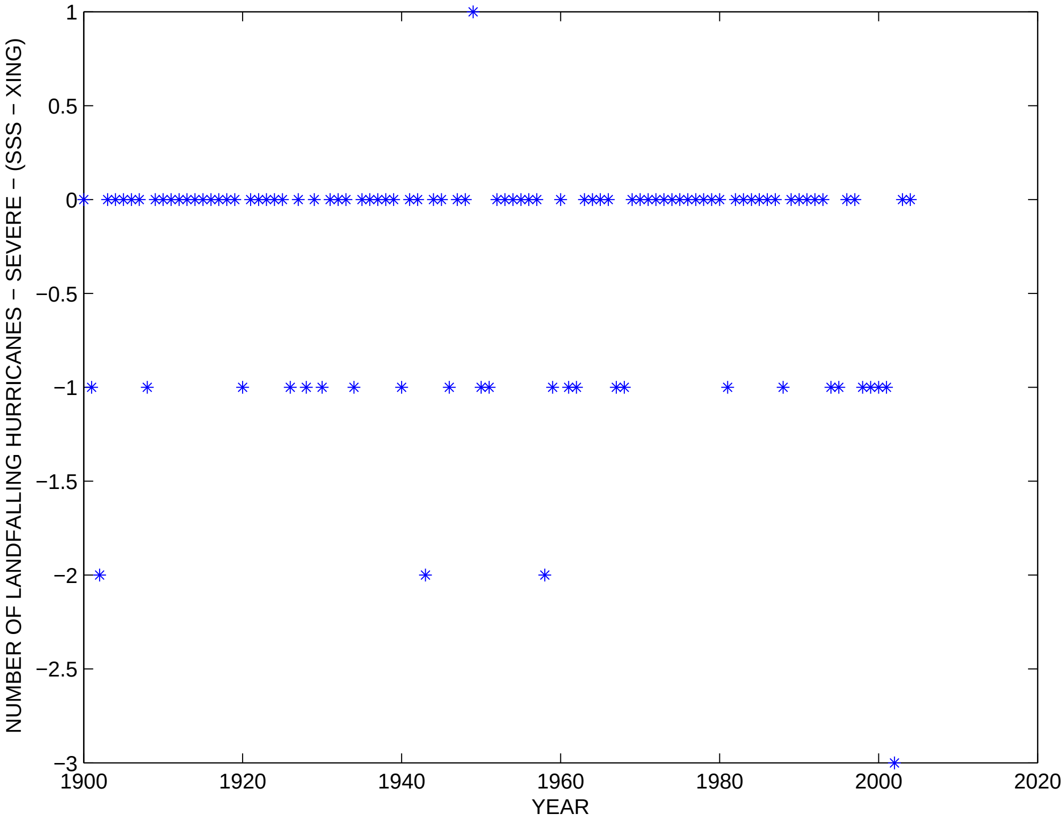


Figure 2: The difference between the number of US landfalling hurricanes calculated using the SSS definition and the XING definition.

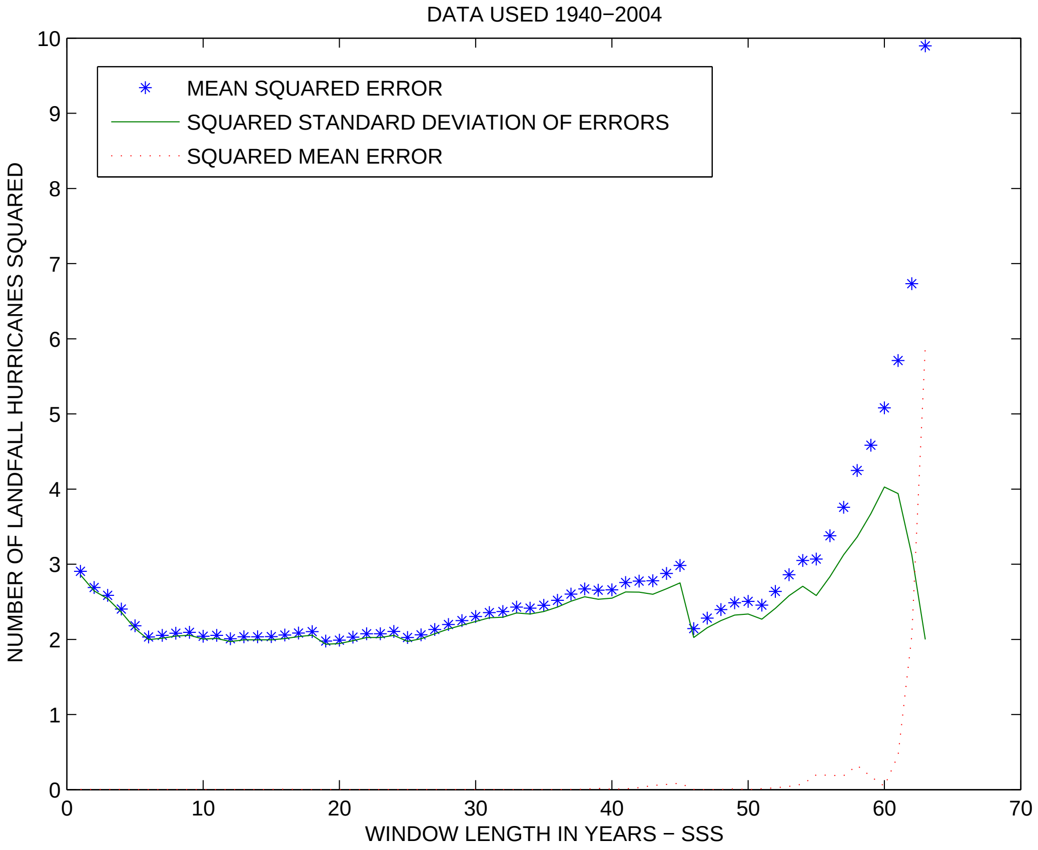


Figure 3: The results from a backtesting study of the ability of averages of length n years to predict the time series of numbers of US landfalling hurricanes.

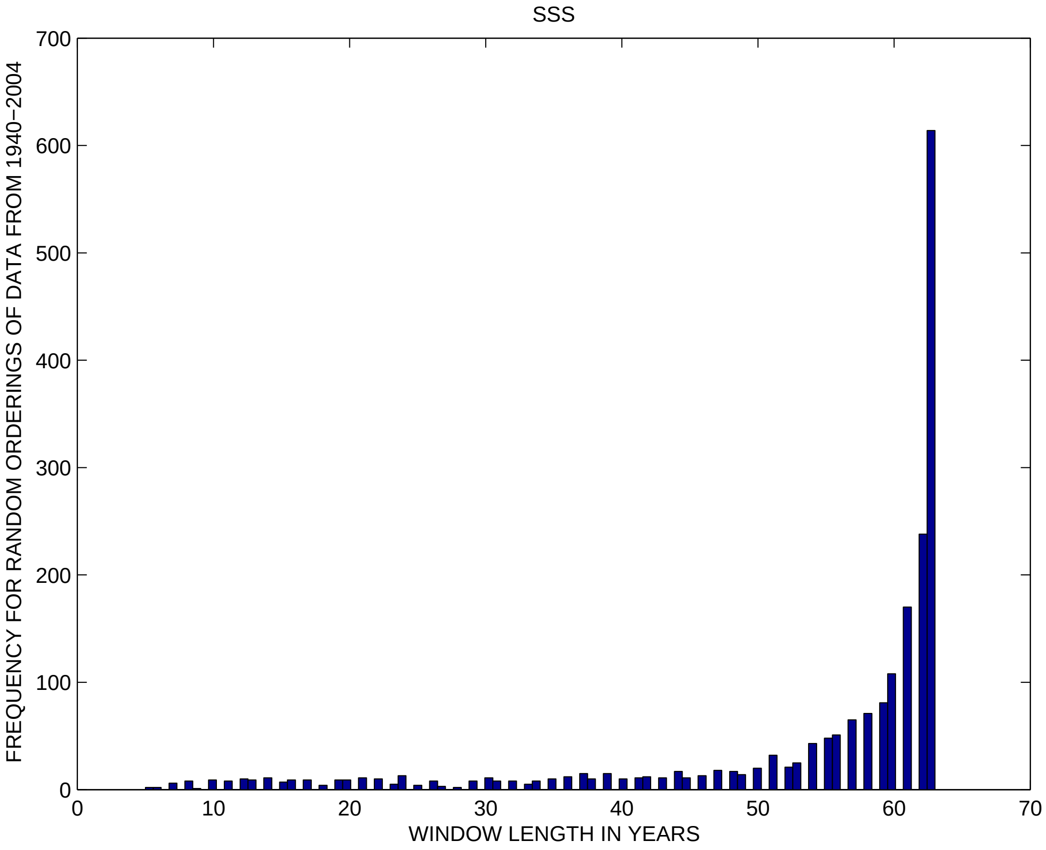


Figure 4: The results from a statistical test of the minimum in figure 3. In 2000 random reorderings of the hurricane number time series, 67 fall below 16 years, giving a p-value of 3.35%.

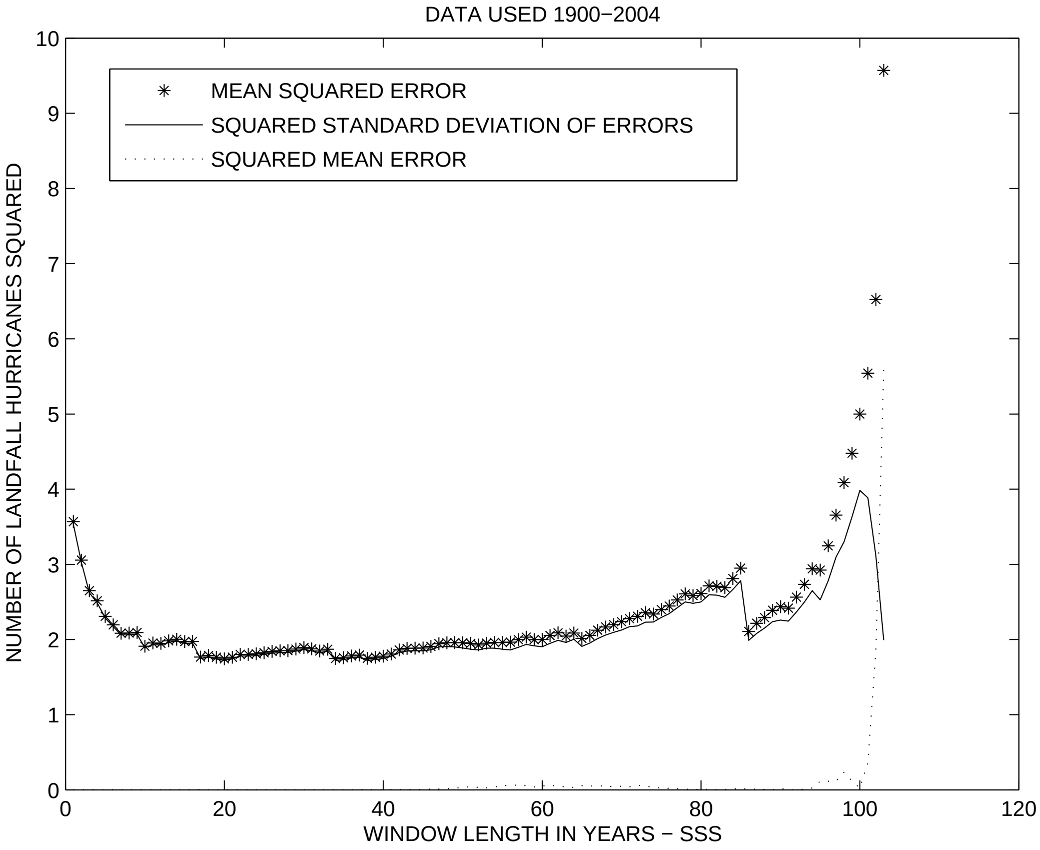


Figure 5: As figure 3, but now using data from 1900 to 2004.

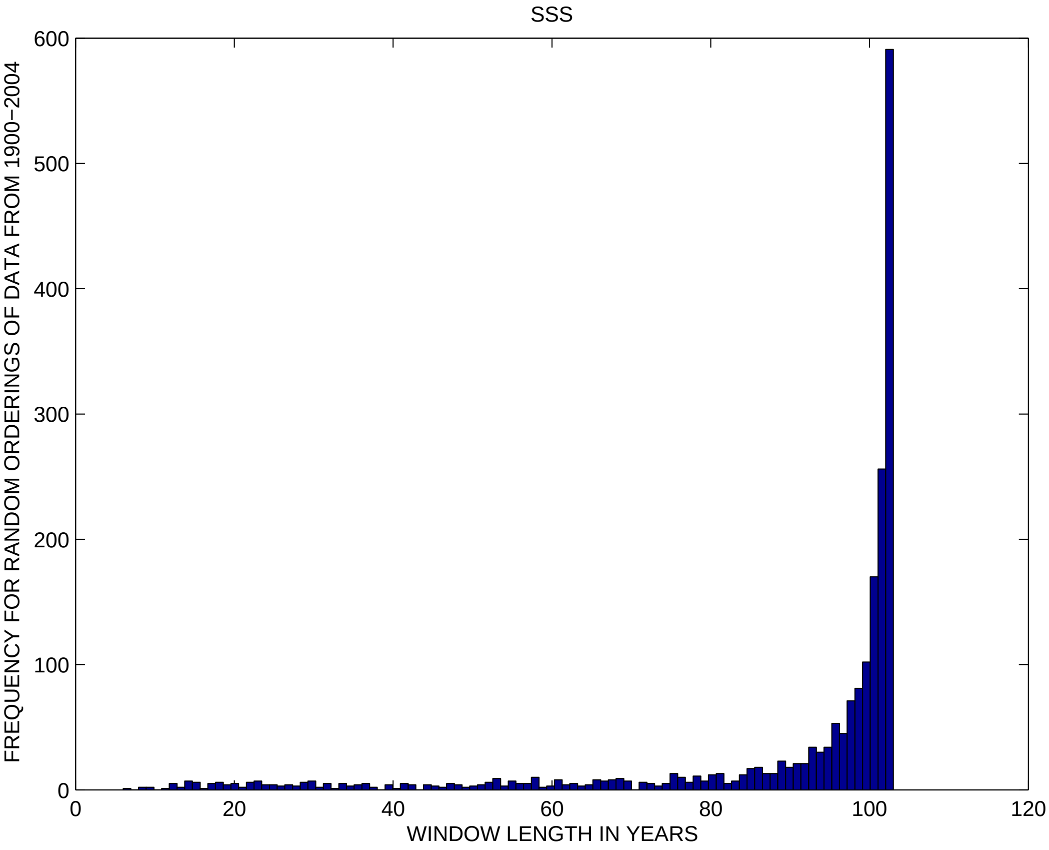


Figure 6: As figure 4, but now using data from 1900 to 2004.

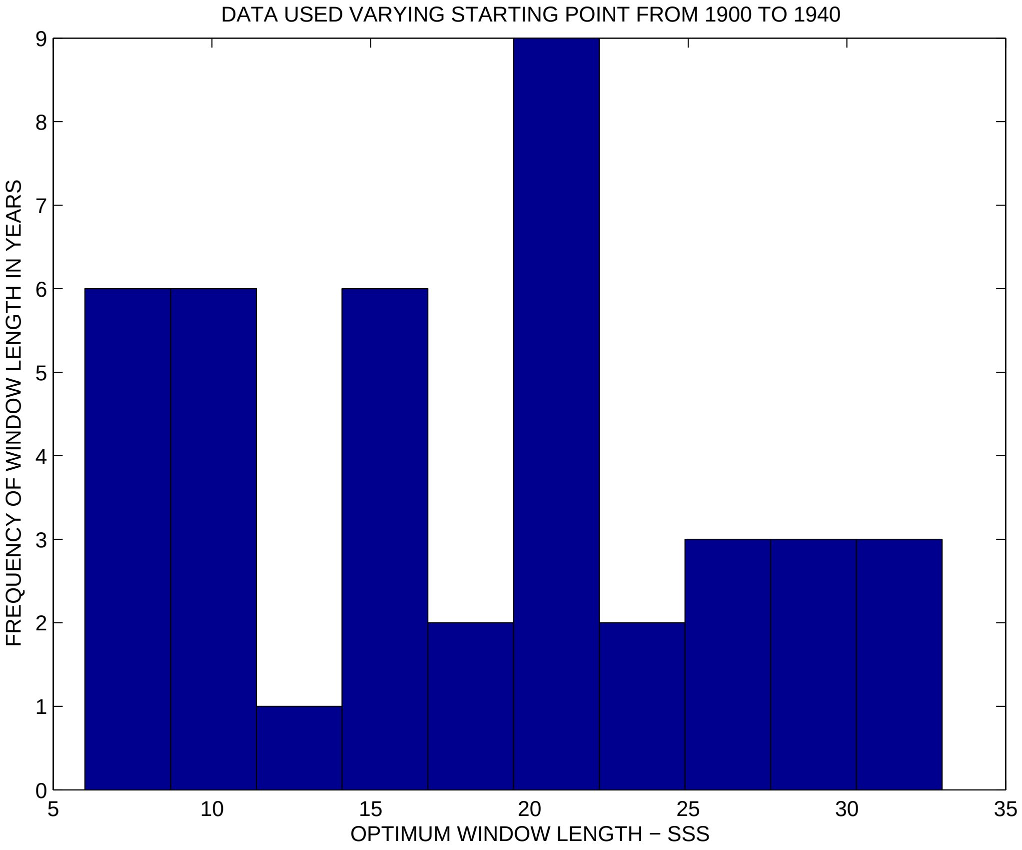


Figure 7: The distribution of optimal window lengths from our backtesting comparison of methods for prediction of the number of landfalling hurricanes. The shortest optimal window length is 6 years and the longest is 33 years.

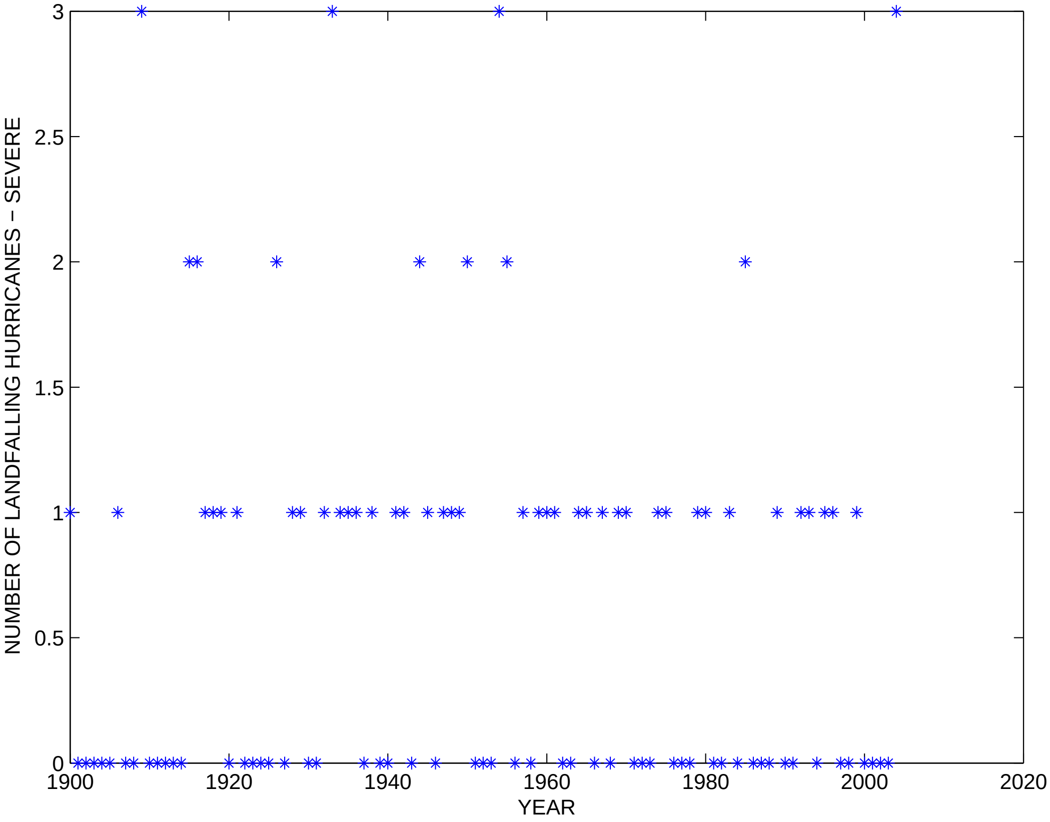


Figure 8: The observed number of *intense* US landfalling hurricanes for each year since 1900, using the SSS definition of landfalling from the HURDAT database.

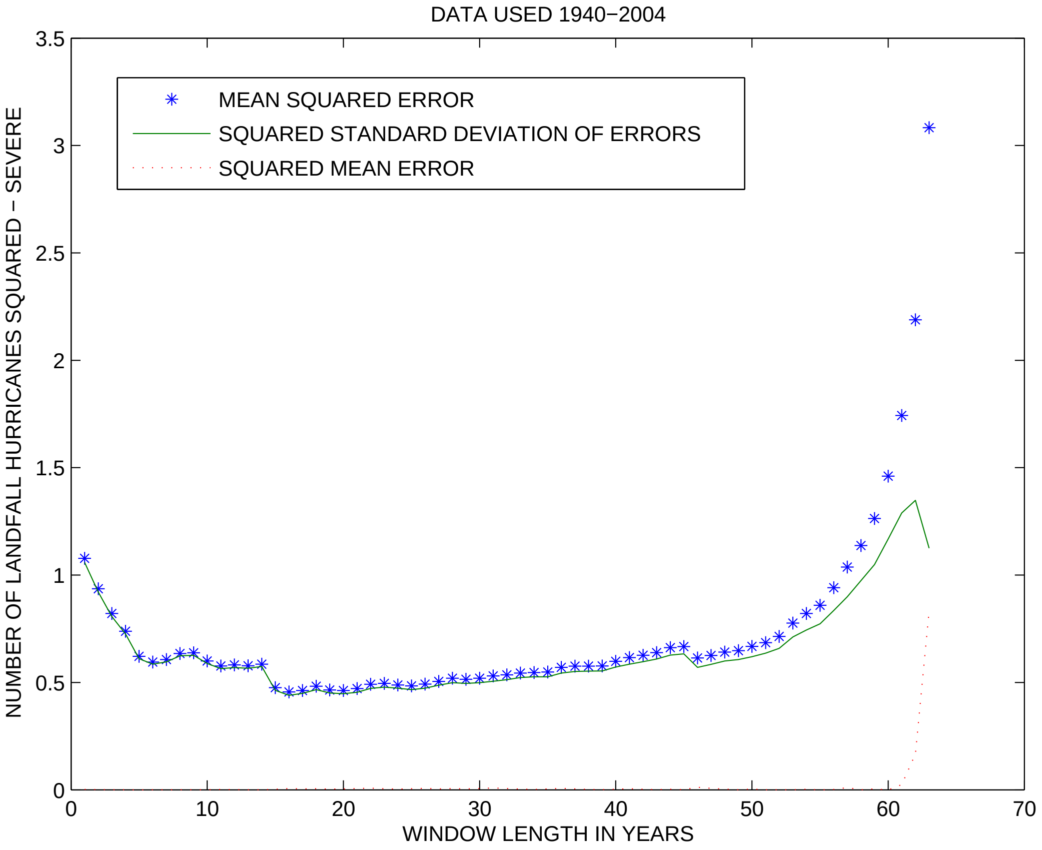


Figure 9: As figure 3, but now for intense hurricanes.

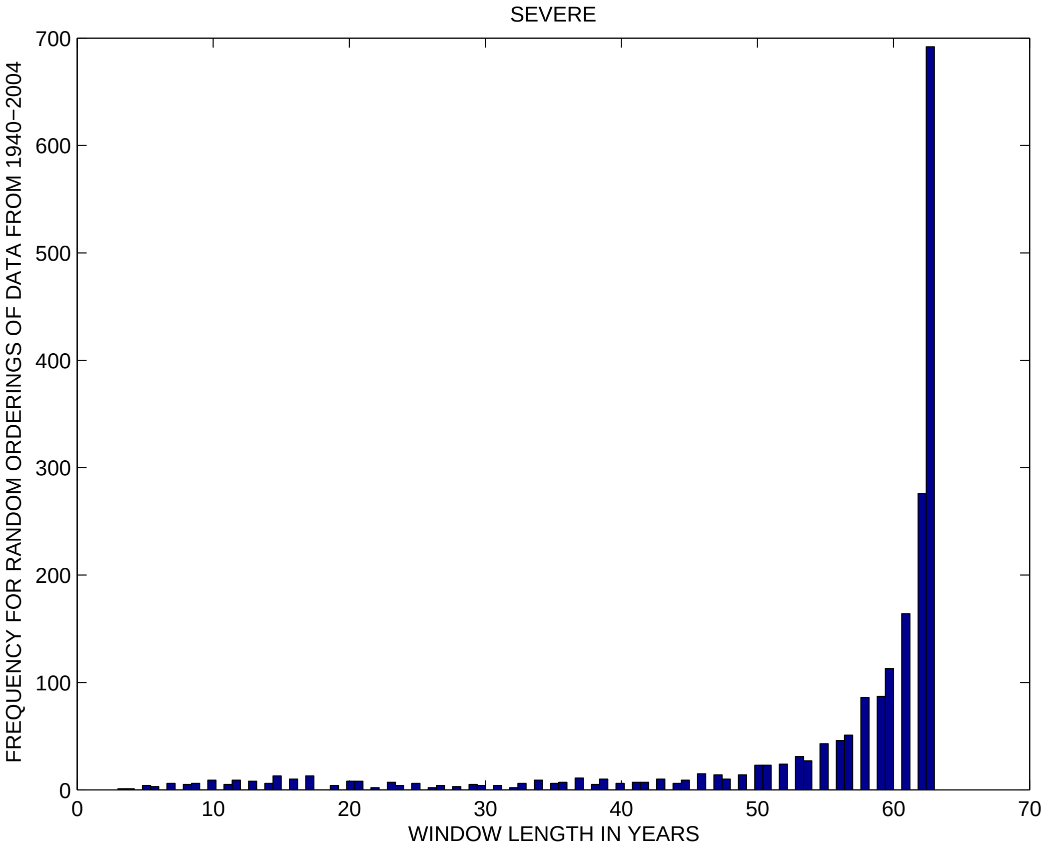


Figure 10: As figure 4, but now for intense hurricanes.

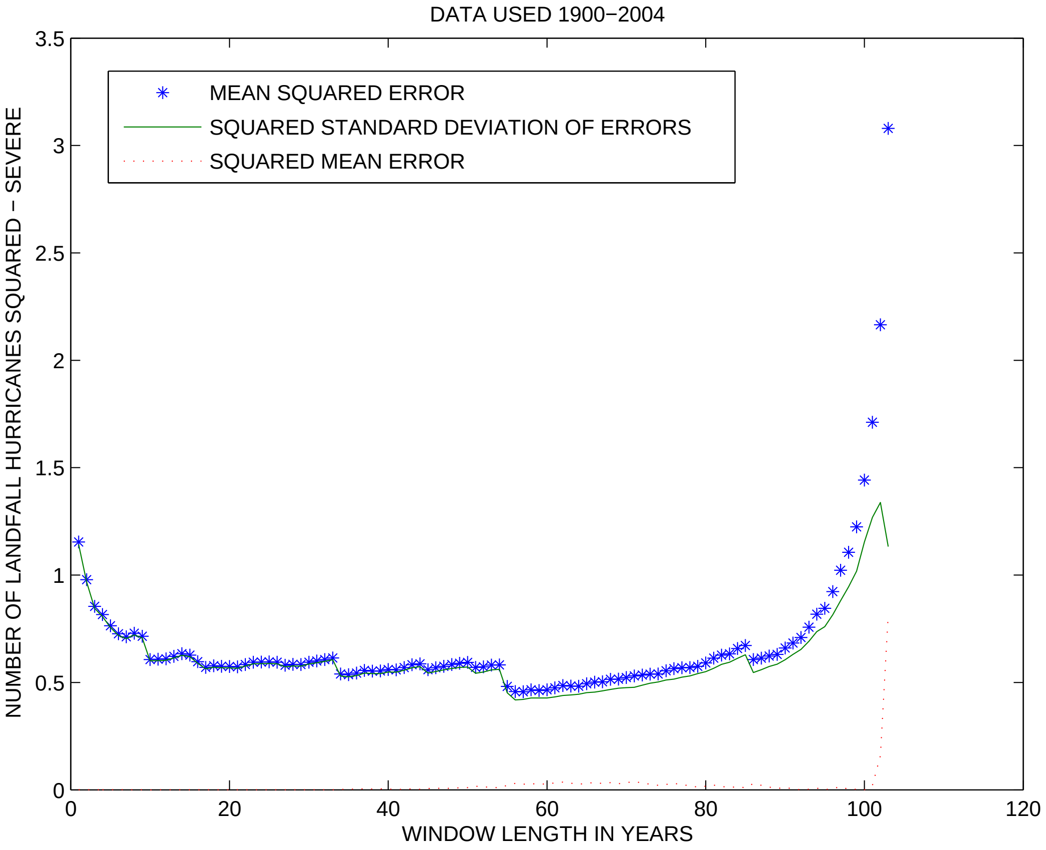


Figure 11: As figure 5, but now for intense hurricanes.

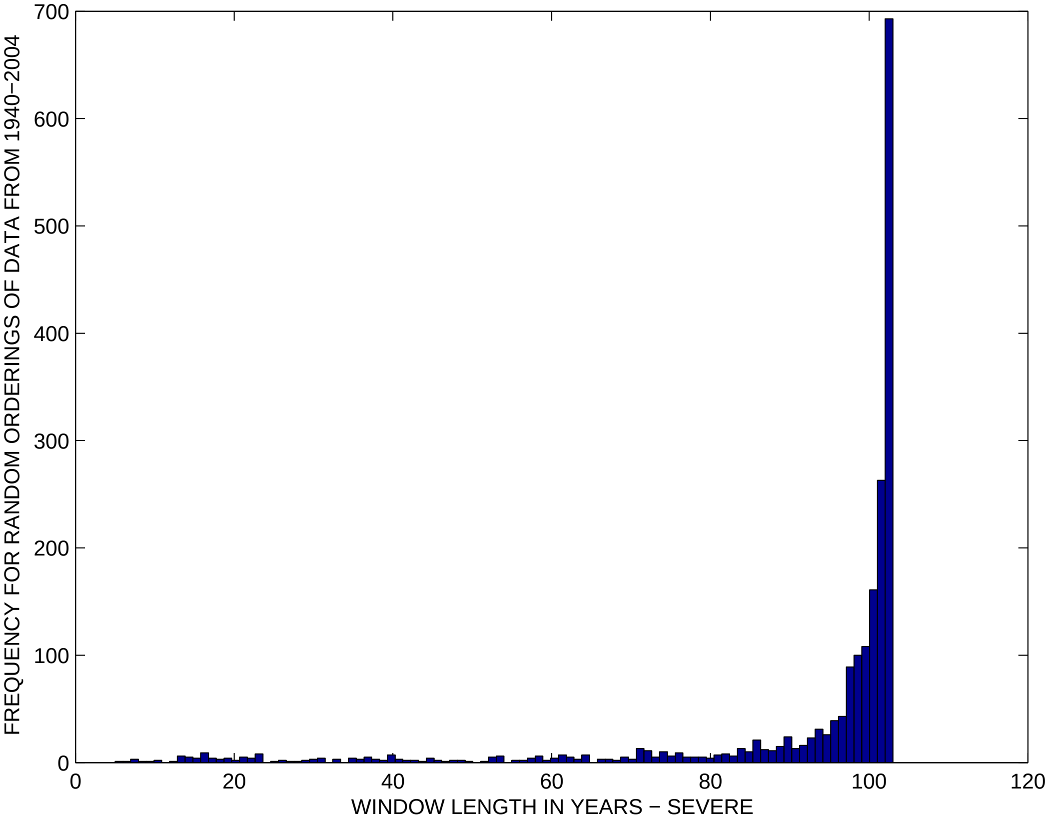


Figure 12: As figure 6, but now for intense hurricanes.

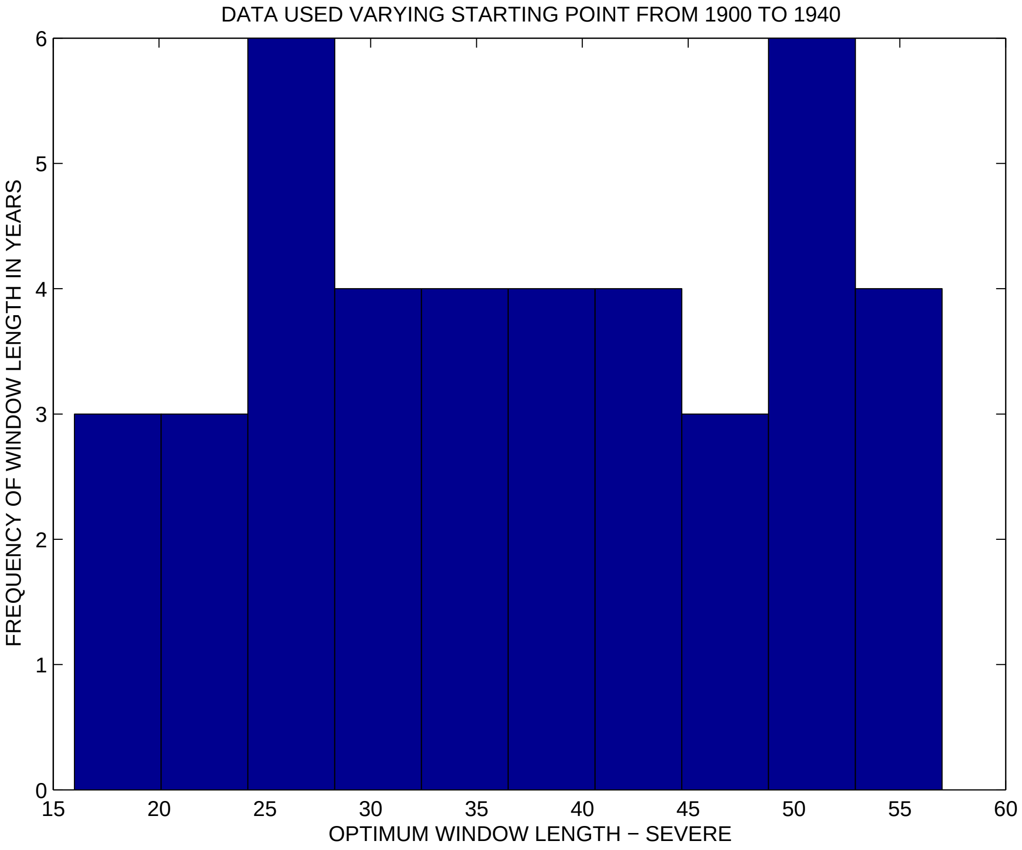


Figure 13: As figure 7, but now for intense hurricanes.

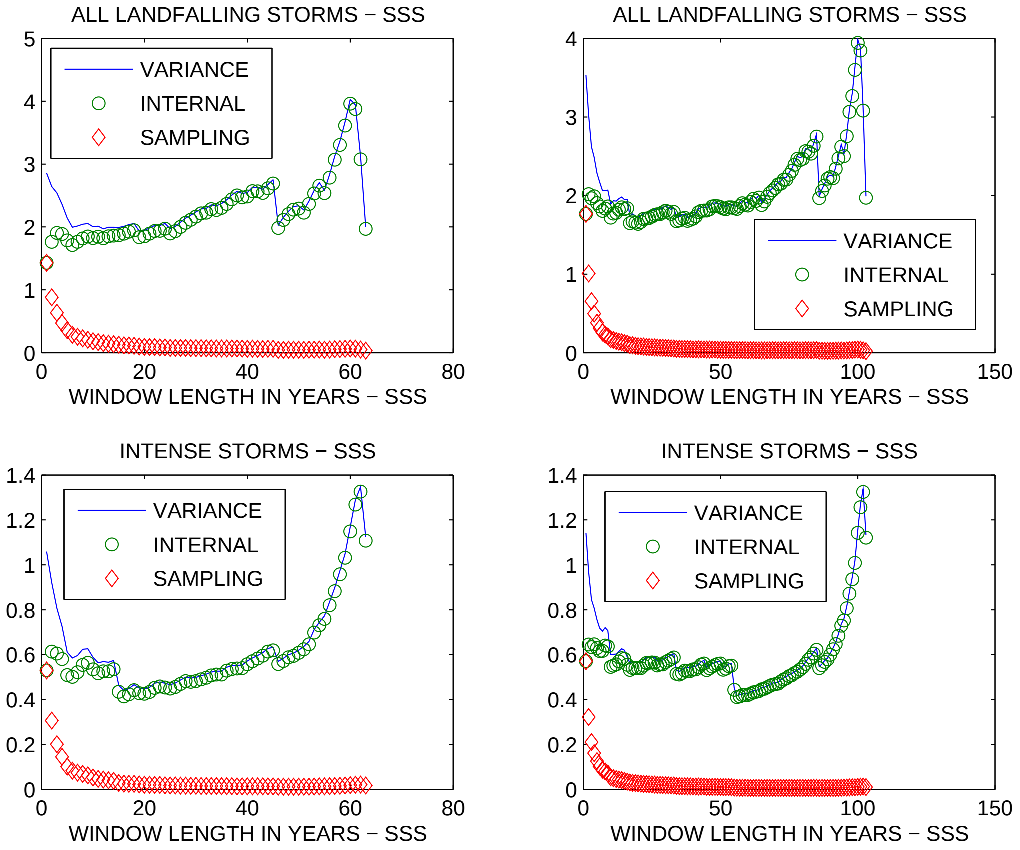
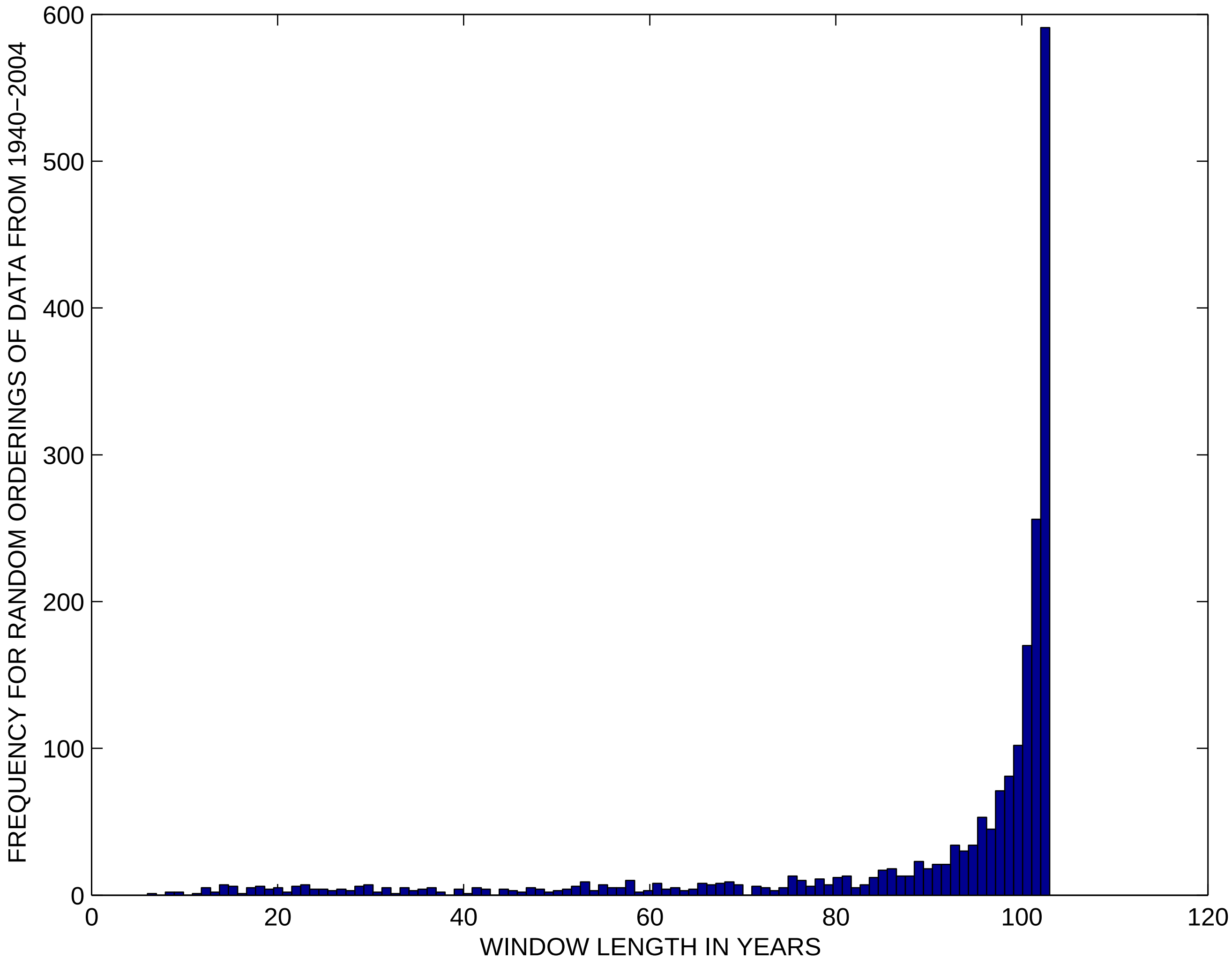


Figure 14: The decomposition of the variance curves shown in figures 3, 5, 9 and 11 into internal variability variance and sampling error variance.


FREQUENCY FOR RANDOM ORDERINGS OF DATA FROM 1940−2004
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WINDOW LENGTH IN YEARS