Statistical Evidence for a Shift in Average Daily Sunspot Group Counts

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Study Questions

1. Sunspot group count
   Did a statistically significant shift in sunspot group count occur midway in the study period?

2. Observer
   Is there evidence of a change in observer reporting behavior?

3. Relative sunspot number
   Is the relative sunspot number affected by changes in the sunspot group count?

Concepts

- Sunspots are observed both individually and in groups
- The sunspot number is formed from sunspot group counts and individual sunspot counts
- Study period is August 1, 2011 through August 31, 2012
- The study period midpoint is February 14, 2012
- Use modern statistical methods

Methods

The Statistical Methods

- Time series plots
  Shows counts through time
- Box plots
  Visual representation of differences
- t-test
  Statistical test for differences in means between two samples
- Generalized linear mixed modeling (glmm)
  Model for counts-specific data

GLMM

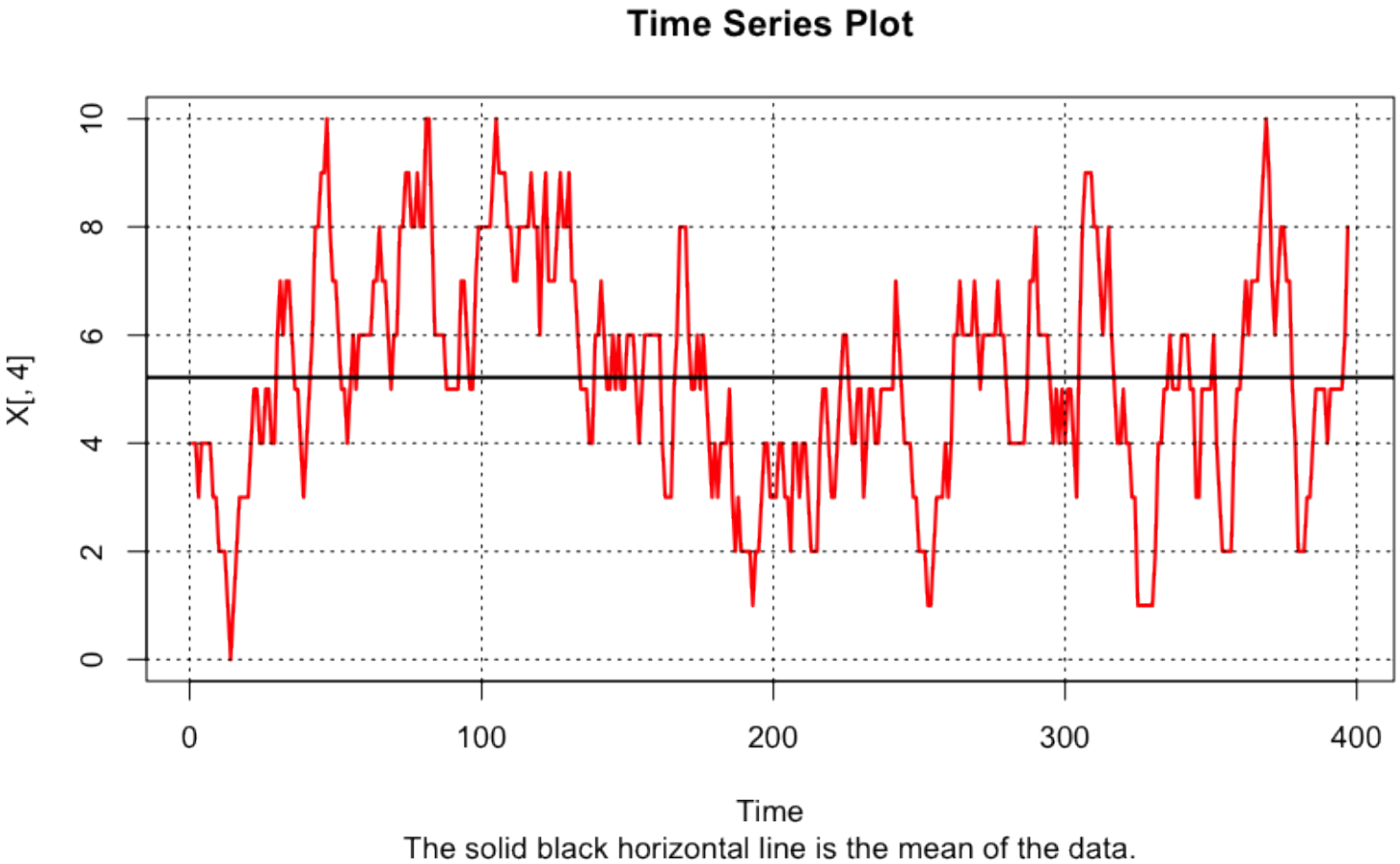
- GLMM models sunspot group or relative sunspot number effects (2 models)
- Multiple observers (~ 60) worldwide provide counts
- Study period
  - First half Aug 1, 2011 - Feb 14, 2012 (sample 1)
  - Second half: February 15 - 31 Aug 2012 (sample 2)
- Filters out variability due to observer, observer experience, seeing conditions
- Model 1: sunspot group counts
- Model 2: relative sunspot number

Study Results

Sunspot Group Count

Time series plot suggests a difference in counts before day 198 and from day 199 going forward

Sunspot Group



Sunspot Group Count

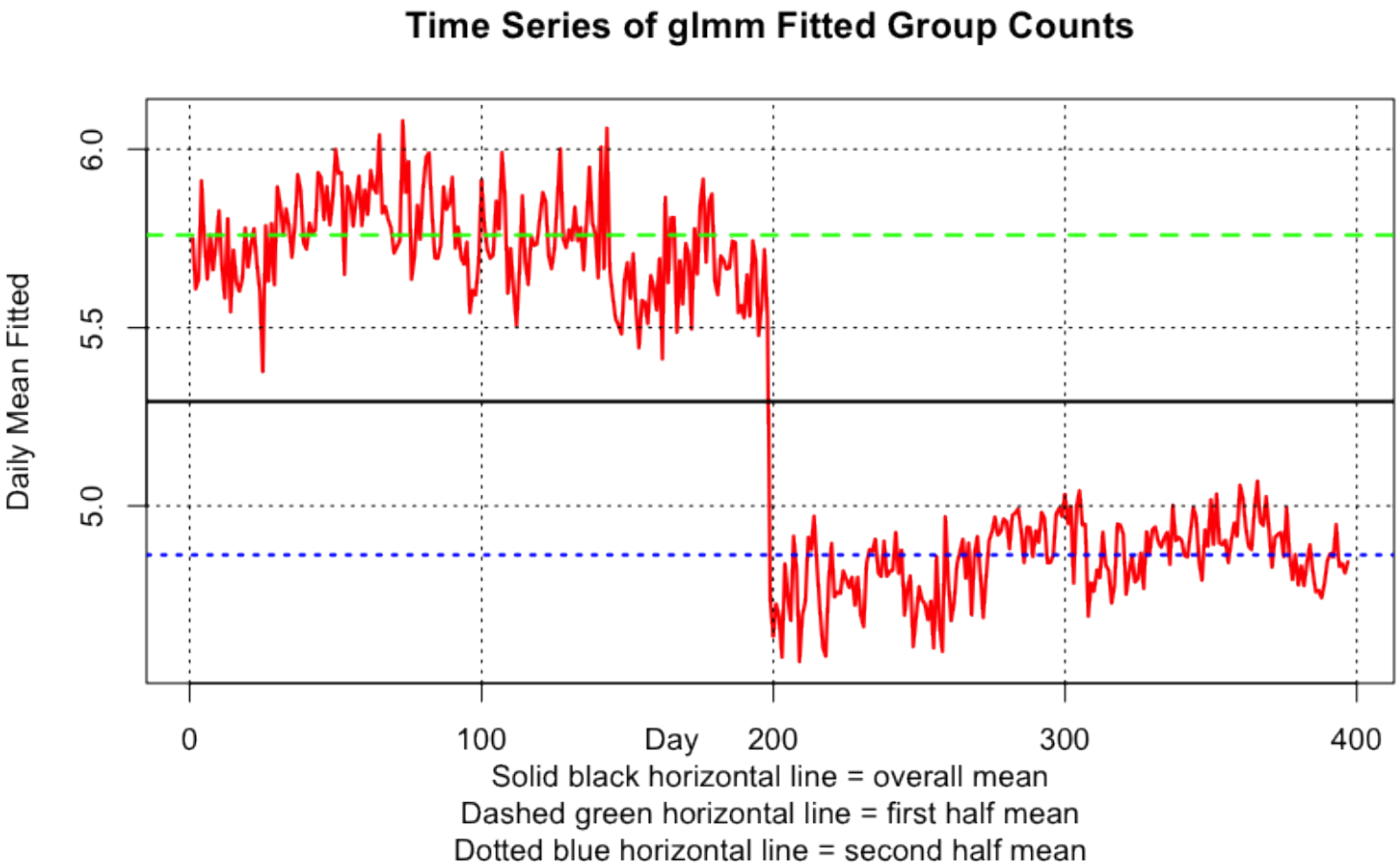
Time series plot after removing all but group count variability

A clear statistical difference is apparent

Table: Sunspot Group Count GLMM Parameter Estimates

	Estimate	Std. Error	z value	Pr(>|z|)
Period	-0.1725	0.0089	-19.4614	0.0000

Sunspot Group Count



Sunspot Group Count

Two Sample t-test (Welch) of sunspot group mean by period
Another way to see model results

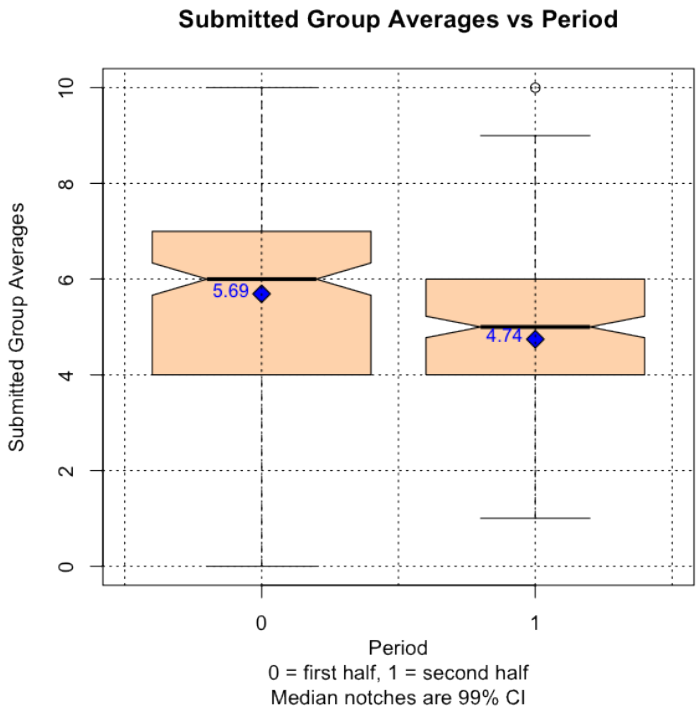
t = 4.6849, df = 387.451, p-value = 3.883e-06
indicates significant difference (see box plot)

95 percent confidence interval around the difference of the means:
(0.5422303, 1.3264565)

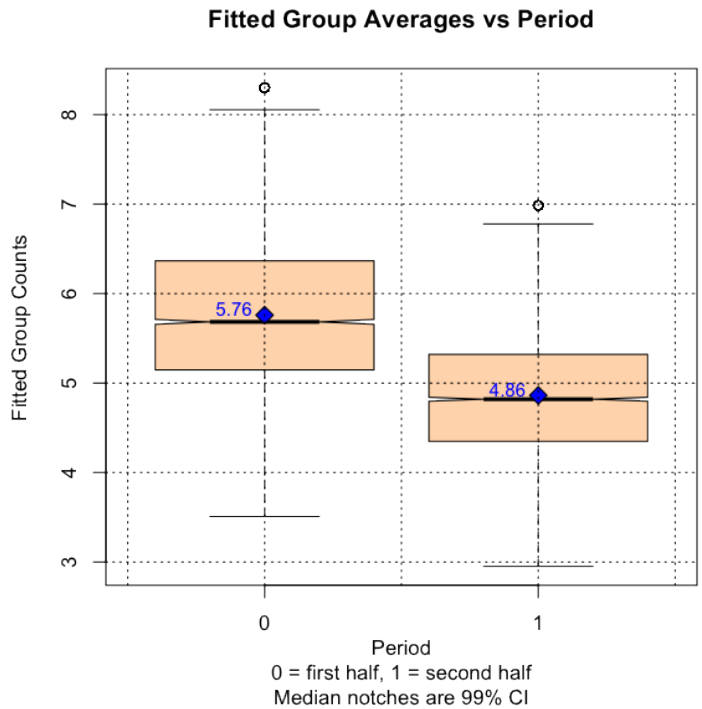
Table: Sunspot Group Count by Period Statistics

Statistic	1^{st} half	2^{nd} half
Mean	5.686869	4.752525
Std Dev	2.109425	1.85088

Sunspot Group Count



(a) Before GLMM

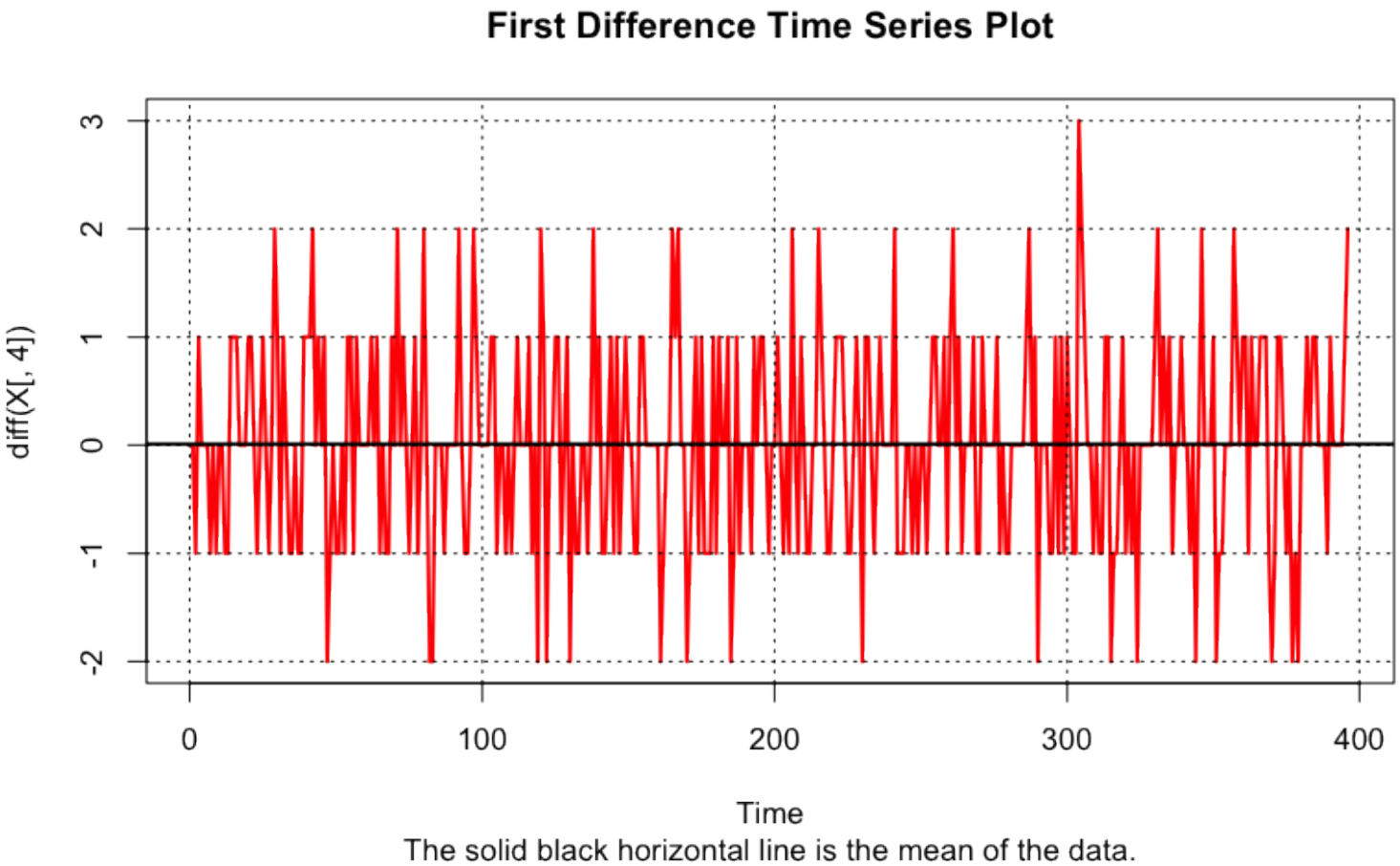


(b) After GLMM

Observer Reporting Behavior

- Is sunspot group count due to observer inconsistency?
- Obtain the daily sunspot group count rate of change
- If reporting behavior changes, it may be seen in the reporting rate
- Time series plot suggests no difference in counts reporting before day 198 and from day 199 going forward

Observer Reporting Behavior



Relative Sunspot Number

$$R_a = 10g + s$$

GLMM R_a vs *Period*

A clear statistical difference is apparent

A significant change in group count implies a change in the relative sunspot number

Table: Relative Sunspot Number GLMM Parameter Estimates

	Estimate	Std. Error	z value	Pr(>|z|)
Period	-0.1630	0.0022	-74.4568	0.0000

Conclusions

Conclusions

1. Sunspot group count
   A statistically significant shift exists between August 1, 2011 and August 31, 2012

2. Observer
   There is no clear change in reporting behavior

3. Relative sunspot number
   For these data, the statistically significant shift in sunspot group count has statistically significantly affected the relative sunspot number