

# Statistical Evidence for a Change 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 ( $\sim 60$ ) 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

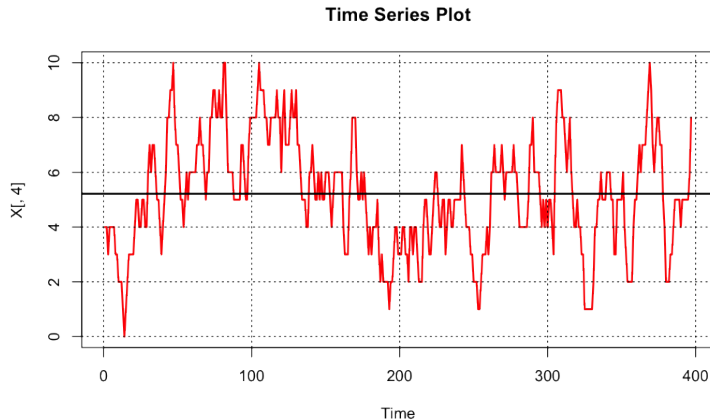
## Study Results

# Sunspot Group Count

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



# Sunspot Group



The solid black horizontal line is the mean of the data.

# Sunspot Group Count

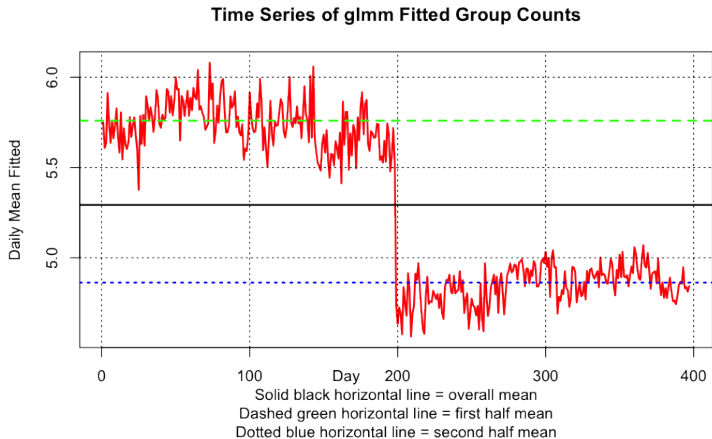
Time series plot after removing all but group count variability

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

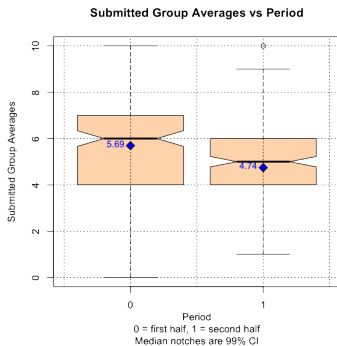
$t = 4.6849$ ,  $df = 387.451$ ,  $p\text{-value} = 3.883e-06$   
 indicates significant difference (see box plot)

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

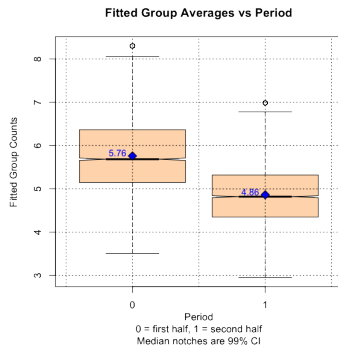
**Table:** Sunspot Group Count by Period Statistics

Statistic	1 <sup>st</sup> half	2 <sup>nd</sup> 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



The solid black horizontal line is the mean of the data.

# 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