# THE JOURNAL OF THE ALABAMA ACADEMY OF SCIENCE

**Volume 90 November 2019 No. 2**

**Cover Photograph**: Male brown anole (*anolis sagrei*) expanding its throat
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https://en.wikipedia.org/wiki/Brown_anole#/media/File:Brown_Anole_-_Anolis_Sagrei,_by_Fr%C3%A9d%C3%A9ric_Trudeau.jpg

**Editorial Comment**:
On behalf of the Alabama Academy of Science, I would like to express my gratitude and appreciation to the reviewers for their valuable contributions in reviewing the manuscripts of this issue.

Thanks!
*Brian Toone*
*Editor: Alabama Academy of Science Journal*

**THE JOURNAL OF THE**
**ALABAMA ACADEMY OF SCIENCE**
**AFFILIATED WITH THE**
**AMERICAN ASSOCIATION FOR THE**
**ADVANCEMENT OF SCIENCE**

VOLUME 90 NOVEMBER 2019 NO. 2



Publication and Subscription Policies:
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ISSN 002-4112

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### EXTRA

# NO PREFERENCE FOR MORE COLORFUL OR SHOWIER MALES AMONG FEMALE BROWN ANOLES

By John E. Steffen1, Ara Agato, Ibraheem Radhi, Vetta Stepanyan and Corey Bush.
Department of Biology, Shepherd University, Shepherdstown, WV, USA

[1]Correspondence: jsteffen@shepherd.edu

## ABSTRACT

Female choice is an important sexually selective agent shaping ornament evolution. We investigated brown anole female preferences by quantifying female temporal associations with tanks containing size-matched males that differed in dewlap color and behavioral display intensity during two reproductive seasons. We found that female temporal association with tanks was not associated with male's dewlap color or display intensity in either summer. We also found no evidence that females associate with empty tanks, in either summer, as might be expected if females avoid harassment.

## INTRODUCTION

'Pre-copulatory' female choice (coined by Anderson 1994 to distinguish from 'cryptic female choice' as described by Eberhard (1996) is an important selective mechanism that drives the evolution of sexual characters in a variety of animals (Andersson 1994). In pre-copulatory female choice, females use phenotypic trait variation among males to aid in mate choice decisions. This choice is apparent (and observable) because females spend time near males while they are making assessments of phenotypically varying males. Female choice has been shown to select for male size, territory size and quality, male reproductive behavior, tail length, call / song pitch, rate, duration and loudness, and ornament color in many animals (summarized by Andersson 1994).

Brown anoles (*Anolis sagrei*) are a Dactyloid lizard (*sensu* Nicholson et al. 2012) whose behavior exemplifies the polygynous territorial mating system. A dult males defend a space and/or access to several females (Tokarz 1998; Tokarz et. al. 2002) and mate with more than one female (Calsbeek and Manorcha 2006). Female home ranges often overlap one or more male's territories (Schoener and Schoener 1980; Tokarz 1998).

*Anolis* lizards are well known in the biological literature for their secondary sex characters, because adult males possess a colorful and extendable dewlap is displayed in intra- and inter-sexual contexts (Jenssen et al. 2000; Vanhooydonck et al. 2005; Jenssen 1970; Sigmund 1983). Furthermore, the ethological aspects of male displays are well understood (Jenssen 1977, McMann and Paterson 2003a, b; Paterson and McMann 2004). Head bob frequency, dewlap extension frequency and push-up frequency are important components of brown anole displays (Tokarz 1985; McMann and Paterson 2003a, b; Paterson and McMann 2004). Steffen and Guyer (2014) found that both dewlap color and display frequency (i.e. showiness) predicted contest success for territories as well as mates in brown anoles. These contests have yet to be fully understood, however, and because female home ranges overlap with several male's territories, speculation about the influence of female choice in Dactyloid evolution has dotted the literature (e.g., Sigmund 1983; Tokarz 1995, 1998).

Here, we perform behavioral observation trials during two consecutive reproductive seasons to investigate female temporal association with males who possess more colorful dewlaps or display more frequently. We predicted that if female choice was important to brown anole mating success, free-ranging females should move toward and spend more in front of a preferred male (i.e. a male that is more colorful or that displays more). We also considered the possibility that male dominance is intense and females avoid male's attentions to reduce harassment. We predicted that females would show temporal associations with empty tanks if male dominance was severe and females avoid harassment.

## MATERIALS AND METHODS

Male and female brown anoles were collected May 6-10, 2011, and May 20-22$^{nd}$, 2012 in Hillsborough County, FL, USA by Glades Herp employees, a reptile trade supplier. Lizards were shipped overnight to a lab at Penn State Behrend in Erie, PA., and cared for according to IACUC protocol (# 36766). Males and females were measured with a metal ruler to the nearest mm, and weighed to 0.001 grams using an electronic balance. Males larger than 39.0 mm and females larger than 34.0 mm were considered adults (see Licht, Gorman, 1970; Lee et al. 1989). Lizards were sprayed with water daily, fed crickets three times each week (3 per feeding) and meal worms ad libitum. All food items were dusted with Repta-vite vitamin powder (Zoo Med laboratories, San Luis Obispo, CA) before being offered to a lizard. Full spectrum fluorescent bulbs (Vitalite T8, 32 watt) were suspended 30.5 cm above each terrarium top. The laboratory was maintained at 32.2 °C, and relative humidity was maintained between 40-60%. No lizard was used in trials more than once.

We size-matched (nearest 0.5 mm) pairs of males and placed each individual male into two of 3 separate 37.9 liter ($50.8 \times 20.4 \times 30.5$ cm$^3$) terraria arranged next to a 208.2 L tank (91 x 45.72 x 45.72 cm$^3$) that contained an oviductal female (Figure 1). The outside walls of each tank were lined with green construction paper to facilitate visual detection of each male's red and yellow dewlap (Endler 1992). These individual green-walled tanks placed adjacent to each other prevented males from seeing each other and allowed us to study female mate choice without any chance of male-male competition affecting a female's preference. It also forces the focal female to seek out the male if she wishes to associate with him (Hill 2002; Burley et al 1982). All adult females were assumed to be reproductively active because females produce several single-egg clutches per month throughout the reproductive season (Andrews and Rand 1974; Lee et al. 1989). We measured the color of the dewlap in two distinct regions: the center (appears red to the unaided human eye) and the margin (appears yellow or white to the unaided human eye). Spectral measurements were taken with an Ocean Optics S2000 UV-visible spectrometer (OOIBase32 software) 1 day before initiation of the experiment (always starting at 10.00 h CST) on lizards that showed no signs of imminent shedding. All reflectance data were generated relative to a white reflectance standard and were taken in a dimly lit laboratory with no windows. We placed a small black rubber stopper on the tip of the reflectance probe, creating a 2-mm gap between the probe tip and the dewlap, ensuring a constant distance between probe and dewlap. To measure dewlaps with the spectrometer, we placed each lizard ventral side up on a flat black table and immobilized the animal with two pieces of athletic tape: one placed across its belly and the other across its mandible. The dewlap was maximally extended by grasping it with a small clamp and adjusting the height of the clamp via its attachment to a horizontal metal arm on a ring stand. We placed the spectrometer probe at a 90° angle, flush with the exposed skin of the dewlap. We measured spectral reflectance along the center and margin of the dewlap, taking six non-overlapping spectral measurements per dewlap region and averaging them for each lizard. Spectral measurements were gathered as percent reflectance at 1-nm wavelength increments from 300–700 nm (representing the lower range of photon absorption by UV-sensitive cones; Fleishman, Loew & Leal, 1993). Spectral measurements were smoothed using CLR, version 1.0 (Montgomerie copyright 2008). Each smoothed file was standardized (mean reflectance subtracted as described by Cuthill et al., 1999) and then reduced to the means of 20-nm bandwidths. Principal components analysis (PCA) was performed on these standardized spectral files and two PC's were found to be important in each dewlap regions spectral variation. The resulting PC coefficients were graphed against wavelength to describe spectral shape in the dewlap center and edge. Each spectral PC was interpreted using the following wavebands: short wavebands = 300-474 nm (which includes UV and blue spectra; medium wavebands = 475-599 nm (which includes green and yellow spectra); long wavebands = 600-700 nm (which includes orange and red spectra).

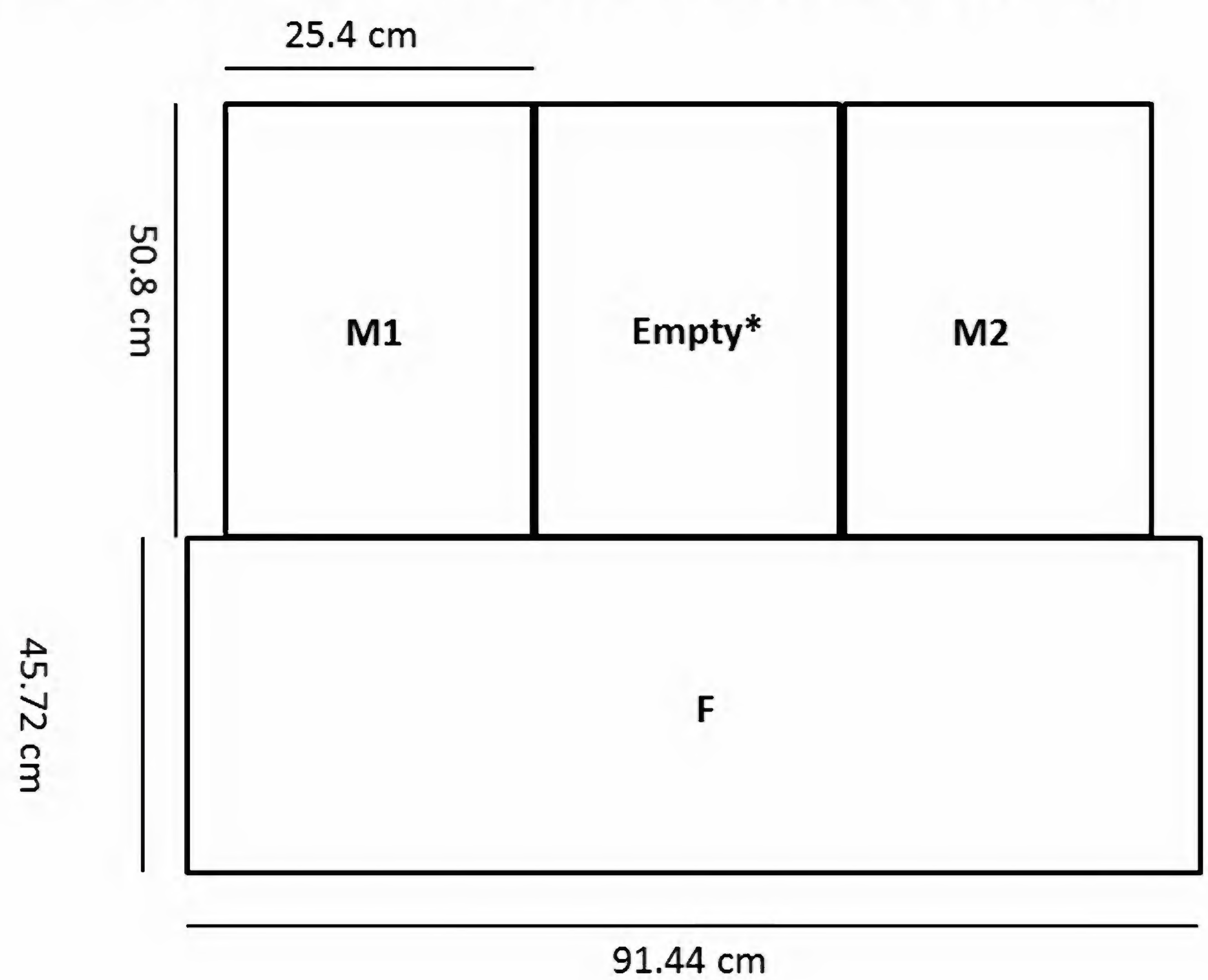


**Figure 1. Female movement and overt female choice tank schematic diagram., viewed from above. M1 = tank containing male number 1 in size-matched dyad, M2 = tank containing male number 2 in size-matched dyad. Empty * = tank with no lizard present. The distribution of size-matched males in each tank was randomized. F = tank containing a female whose movement across the tank was video recorded and ethologically quantified and analyzed.**

The lizards were video recorded (SONY Handycam DCRSX45), and observed at a later date. The frequency and duration of relevant male behaviors were quantified using an event-recorder program called Etholog (v. 2.2, 2006). Male behaviors such as dewlap extension frequency (# dewlap extensions per minute), head-bob frequency (# head-bobs per minute), and push-up frequency (# push-ups per minute) were quantified with Etholog.

Female preference was measured as female time associated with males of varying dewlap colors. We quantified the temporal association of females by summarizing the times spent in front of one of three 37.9 liter terraria (50.8 x 20.4 x 30.5 $cm^3$ (Figure 1). One of the 37.9 liter terraria was empty and its position was randomly assigned. The empty terraria served as a control tank to test if females preferred to spend a majority of time in front of a tank with no males, as a proxy for harassment avoidance. The other terraria contained males that differed in dewlap color and display frequency.

We used a k-ratios Chi-square test (Zar 1999) to determine if observed female tank associations (as measured via time spent in front of each tank) matched the tanks containing males who display the most or have the most colorful dewlap. We also used the k-ratios Chi-square test to determine if observed female tank associations matched empty tanks, to see if females avoided harassment.

## RESULTS

***Spectral analyses***—In 2011 dewlaps, 97.18 % of the center's variation was reduced to 3 PC's (**Figure 2 a & b**). PC1 represented low-to-medium wavelength reflectance (340-580 nm) relative to UV (300-340 nm) and long wavelength absorption (580-680 nm) and explained 74.83 % of the variation. PC2 represented medium-to long wavelength reflectance (520-700 nm) relative to short and medium wavelength absorbance (300-520 nm) and explained 15.91 % of the variation. PC3 represented short (300-420 nm) and long wavelength reflectance (600-680 nm) relative to medium-wavelength absorption (420-600 nm) and explained 6.44 % of the variation.

94.44% of the dewlap edge variation was reduced to two PC's. PC1 represented medium-to long wavelength reflectance (500-700 nm) relative to low-to-medium wavelength absorption (300-500 nm) and explained 89.38 % of the variation. PC 2 represented low-to-medium wavelength reflectance (300-540 nm) relative to medium-to-long wavelength absorption (540-700 nm) and explained 5.06 % of the variation.

In 2012 dewlaps, 92. 5% of the variation of the center was reduced to 2 PC's (**Figure 2 c&d)**. PC 1 represented low to medium wavelength reflectance (300-560 nm) relative to medium to long wavelength absorption (560-700 nm) and explained 80.02% of the variation. PC2 represented medium to long wavelength reflectance (~550-700 nm) relative to medium & low wavelength absorption (300 – 550 nm) and explained 12.35% of the variation of the dewlap spectra.

Spectral variation of the dewlap edge was reduced to two PC's that explained 93.43 % of the variation in 2012. PC1 of the dewlap center represented medium-to-long wavelength reflectance (500-700 nm) relative to medium to short wavelength absorbance (300-500 nm) and explained 87.33 % of the variation of the dewlap center. PC2 represented long wavelength absorbance (520-700 nm) relative to low to medium wavelength reflectance (300-520 nm) and explained 6.10 % of the spectral variation.

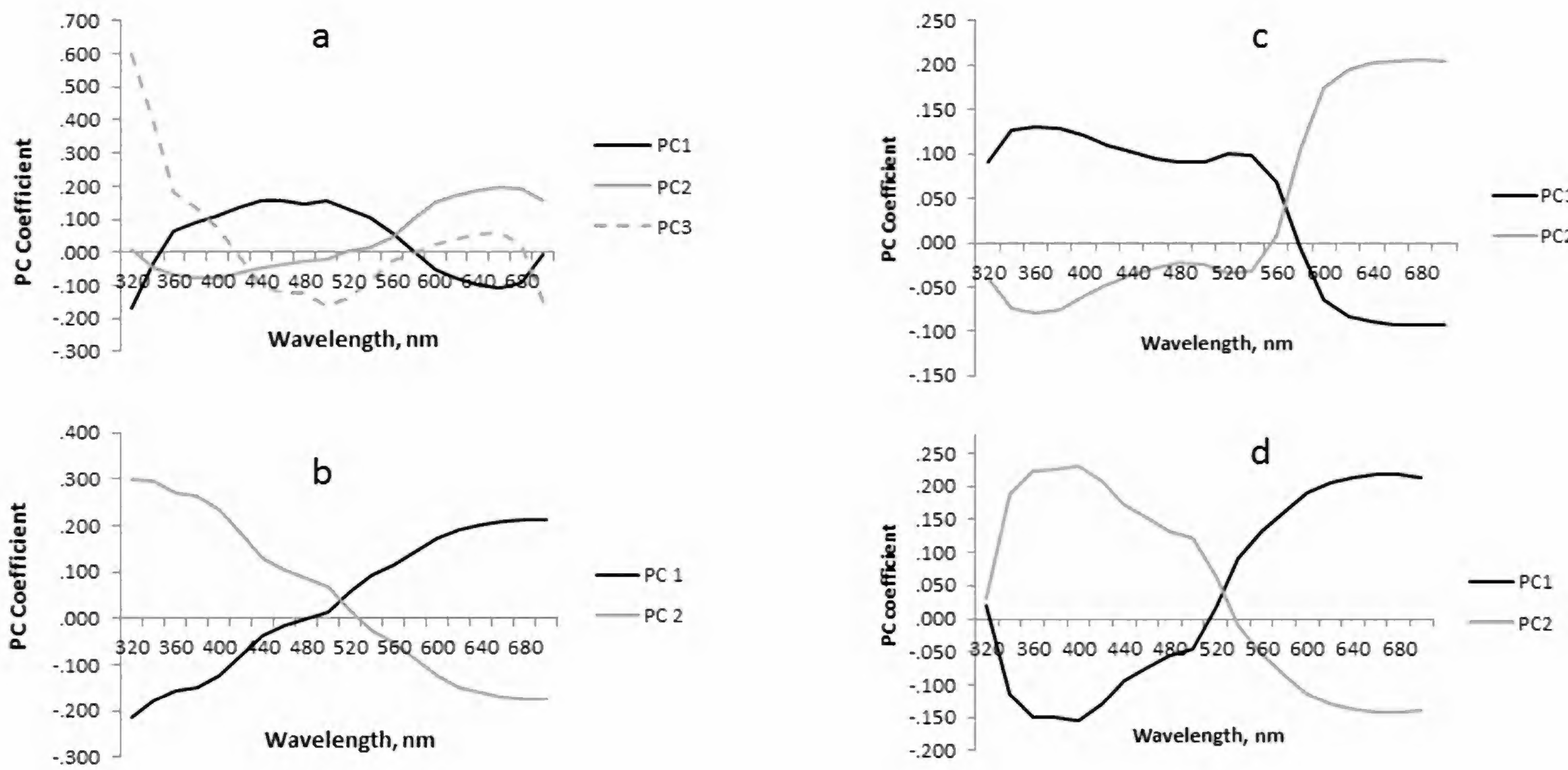


**Figure 2a-d. Spectral variation of male brown anole dewlaps in 2011 (a = center, b = edge), and 2012 (c = center, d = edge) transformed and expressed as PC coefficients. 2011 dewlap center PC1 represented 74.83 % , center PC2 represented 15.91 %, and center PC3 represented 6.44 % of the spectral variation. Dewlap edge PC 1 represented 89.38 % of the spectral variation and edge PC2 represented 5.06 % of the spectral variation. 2012 dewlap center PC1 represented 80.02 % and center PC2 represented 12.35 % of the spectral variation. Dewlap edge PC 1 represented 87.33 % of the spectral variation and edge PC2 represented 6.10 % of the spectral variation.**

***Female temporal association with males***—females showed variation in time spent in front of the right, center, and left tanks in each year, but that variation did not correlate with time spent in front of the male with the richer dewlap center (2011 PC 1 $X^2 = 0.553$, $P > 0.05$; PC 2 = 0.608, $P > 0.05$, PC 3 = 0.501; 2012 PC1 $X^2 = 0.569$, $P > 0.05$; PC 2 = 0.520, $P > 0.05$), or the dewlap edge (2011 PC 1 $X^2 = 0.569$, $P > 0.05$; PC 2 = 0.520, $P > 0.05$; 2012 PC1 $X^2 = 0.553$, $P > 0.05$; PC 2 = 0.608, $P > 0.05$) see Table 1.

The variation in time spent in in front of the right, center, and left tanks did not correlate with time spent in front of males that displayed more. (e.g. 2011 HB rate $X^2 = 0.498$, $P > 0.05$, 2012 HB rate $X^2 = 0.492$; 2011 DE rate $X^2 = 0.441$, $P > 0.05$ 2012 DE rate $X^2 = 0.469$, see Table 1) or tanks that contained no males (i.e. 2011 empty tank, $X^2 = 0.536$, $P > 0.05$; 2012 empty tank, $X^2 = 0.542$, $P > 0.05$) (Table 1).

| Year | Trait | Trait | L | C | R | $X^2$ | P |
|---|---|---|---|---|---|---|---|
| 2011 | Center spectra | Color PC 1 | 11(13) | 7(9) | 7(3) | 0.530 | > 0.05 |
| | | Color PC 2 | 11(13) | 7(9) | 7(3) | 0.530 | > 0.05 |
| | | Color PC3 | 10(13) | 8(9) | 7(3) | 0.501 | > 0.05 |
| | Edge spectra | Color PC 1 | 15(13) | 3(9) | 7(3) | 0.733 | > 0.05 |
| | | Color PC 2 | 6(13) | 8(9) | 11(3) | 0.536 | > 0.05 |
| | Behavior | Empty tank | 6(13) | 11(9) | 8(3) | 0.536 | > 0.05 |
| | | HB rate (# / min) | 17(7) | 9(12) | 6(8) | 0.498 | > 0.05 |
| | | DEW rate (# / min) | 16(7) | 9(12) | 8(8) | 0.441 | > 0.05 |
| 2012 | Center spectra | Color PC 1 | 7(15) | 13(8) | 7(4) | 0.569 | > 0.05 |
| | | Color PC 2 | 7(15) | 10(8) | 10(4) | 0.520 | > 0.05 |
| | Edge spectra | Color PC 1 | 6(15) | 12(8) | 9(4) | 0.553 | > 0.05 |
| | | Color PC 2 | 6(15) | 14(8) | 7(4) | 0.608 | > 0.05 |
| | Behavior | Empty tank | 11(15) | 6(8) | 10(4) | 0.542 | > 0.05 |
| | | HB rate (# / min) | 19(6) | 7(12) | 11(9) | 0.492 | > 0.05 |
| | | DEW rate (# / min) | 9(6) | 5(12) | 4(9) | 0.469 | > 0.05 |

**Table 1. Chi-square results demonstrating that female temporal associations with right, center, and left tanks containing size-matched males do not associate with tanks containing more colorful, showy Brown Anole males or tanks where no males are present (i.e. empty tanks). Numbers outside and inside parentheses = observed (expected). Numbers = numbers of trials. Edge = dewlap edge, Center = dewlap center, Empty tank = test for avoidance of males, Behavior, HB rate = tank containing male with greater head bob rate, number per minute; DEW rate = tank containing male with greater dewlap extension rate, number per minute.**

## DISCUSSION

Female brown anoles did not show preferences for more colorful males. Tanks that females spent the most time in front of did not correspond to tanks that contained the most colorful males. When females choose males, females should show longer durations of spatial association with males whom they prefer. For example, females affiliate with more colorful males in guppies, *Poecilia reticulate*, and this affiliation with a particular male is a reliable proxy of a male's ultimate reproductive success (Kodric-Brown 1993). In house finches females prefer the reddest males and they show this by spending the most time in front of the most colorful male's Plexigas compartment (Hill 1990).

Female brown anoles did not show preferences for males who displayed more. In contrast to our study, a recent field study of brown anoles showed that females associated with males who were more active, regardless of territory quality (Flanagan and Bevier 2014). However, in Flanagan and Bevier's study, males were not visually isolated from each other and females were not offered male-free space. Our analysis used glass tanks that had been visually modified to ensure that males were displaying to females, and not to nearby males. In addition, we offered females male-free space to investigate the possibility that male dominance is so intense that females avoid male harassment, and to test this possibility we always presented females with a randomly placed, male-free space. Female showed no temporal association with empty tanks in this study.

Very few lizards show female preference as the primary influence in male (or female) reproductive success. One notable exception to this infrequency is Broad-headed skinks (Cooper and Vitt 1988). In these lizards, females prefer larger males, and larger males defend mate access (Cooper and Vitt 1988). Lizards more commonly show male dominance. Male dominance has been found to be an important determinant of mate success in Wall lizards (Huyghe et al. 2005), Crotaphytine lizards (Husak et al. 2006), Phrynosomatids (Zucker 1994), Eublepharid geckos (Kratovich and Frynta 2002), and Agamid lizards (Whiting et al. 2006).

In at least two lizards (Iberian Rock Lizards, López et. al. 2002; Side-blotched lizards, Hews 1990), as well as several fish, frogs, and birds a combination of male dominance and female choice are determinants of reproductive success (summarized in Andersson 1994). Previous research on brown anoles had not eliminated this possibility because male brown anole lizards perform courtship displays in front of females, as well as rival males. Steffen and Guyer (2014) found that behavior and dewlap color were important predictors of copulation success (i.e. coitus) with females across years. The present findings, along with those of Steffen and Guyer (2014) suggest that pre-copulatory female mate choice is not a selective force in copulation and male reproductive success in brown anoles.

It remains possible that a female's choice becomes apparent over a longer time association scale, such that pre-copulatory preferences are not made until females have had repeated exposure with multiple males. It also remains possible that cryptic (post-copulatory) female choice may act as an intersexual selective mechanism that maintains armament / ornament size and color in brown anoles (as first suggested by Tokarz 1998; Tokarz et al. 2005). Female brown anoles can store sperm from up to 4 males (Calsbeek et al. 2007). Females show post-copulatory fertilization bias to determine hatchling sex and body size is used as a cue for sperm sex sorting (Calsbeek and Bonneaud 2008). Larger males are more dominant in social contests for territories (Tokarz 1985) but determining how sperm sex sorting might be related to social contests and sexual selection is an area for future research.

In summary, speculation about the influence of precopulatory female choice in Dactyloid ornament evolution has dotted the literature (e.g., Sigmund 1983; Tokarz 1995, 1998) because female home ranges often overlap one or more male's territories (Schoener and Schoener 1980; Tokarz 1998). Here we provide behavioral and observational evidence that females do not show temporal associations with males who are more colorful or who display more, as might be expected according to hypotheses about pre-copulatory female choice. We also show that females do not show associations with empty tanks, as might be expected if females avoid harassment due to intense male competition.

## ACKNOWLEDGMENTS

Lizards were euthanized and disposed of according to policies and procedures described Penn State University IACUC protocol # PRN 2006-096. I would like to thank would like to thank LDM and LS or comments on more recent drafts of the manuscript. I would like to thank Penn State Behrend Undergraduate Research Grants program for partial financial support of this research. I would like to thanks PW for all laboratory technical support.

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# PREDICTING THE SIZE AND TIMING OF THE NEXT SOLAR CYCLE: PAPER I, BASED ON SUNSPOT NUMBER

Robert M. Wilson
NASA Marshall Space Flight Center, NSSTC, Huntsville, Alabama

robert.m.wilson@nasa.gov

## ABSTRACT

This paper (Paper 1) provides estimates of the period (PER) for sunspot cycle (SC)24, the current ongoing solar cycle, and the timing and size of the next solar cycle, SC25. Presently, smoothed sunspot number *R* for SC24 continues to decrease with time, essentially being flat through 2018 into 2019 (measuring 6.0 in December 2018). The analyses presented herein strongly suggest that SC24, a slow-rising SC of small maximum amplitude, is also a cycle of long period (PER ≥ 135 months), inferring that the epoch of sunspot minimum (Em) for SC25 likely will occur on or later than March 2020. If true, then the epoch of sunspot maximum (EM) for SC25 likely will occur on or later than April 2024 and probably be of small maximum amplitude (RM < 184), but of greater maximum amplitude than was seen in SC24 (RM = 116.4), presuming that SC25 will not be a statistical outlier with respect to the even-odd cycle effect. The minimum interval for SC24/25 appears similar to that experienced during the preceding minimum interval of SC23/24, but possibly slightly longer.

## INTRODUCTION

Predicting the overall behavior (i.e., timing, size and duration) of a future SC is crucially important for forecasting solar cycle effects in the near-Earth and interplanetary space environment, solar irradiance, space weather, radio communications, power distribution systems, etc. (Withbroe 1989; Song, Singer, and Siscoe 2001; Clilverd et al. 2003; Hathaway, 2015). To accomplish this task, various techniques have been developed, including precursor methods, extrapolation methods, model-based methods, spectral methods, and neural networks (e.g., Hathaway, Wilson and Reichmann 1999; Hathaway 2008; Petrovay 2010; Pesnell 2012). In this paper, the expected duration of SC24, the present ongoing SC, and the size and timing of SC25 are investigated using specific SC parameters gleaned from the behavior of ongoing SC24. In a companion paper (Paper 2), the expected size and timing of SC25 will be examined using the strength of the *Aa* and *Ap* geomagnetic index values.

## METHODS AND MATERIALS

To perform this study, smoothed monthly mean sunspot number (*R*) has been taken from the Solar Influences Data Analysis Center (SIDC), available online at www.sidc.be/silso, using version 2.0, the newly revised sunspot number dataset (Clette et al. 2015; Wilson 2015). Smoothed monthly mean sunspot number is the 12-month moving average of monthly mean sunspot number (also called the 13-month running mean of monthly mean sunspot number). This investigation uses both linear regression analysis and nonparametric analyses (i.e., Fisher's exact test for $2 \times 2$ contingency tables and Kendall's $\tau$) (Everitt 1977; Gibbons 1993).

## RESULTS AND DISCUSSION

The dotted line in figure 1 displays *R*-values for the interval December 2005 through December 2018 (the last available *R* at the time of writing this paper), thereby covering the last three years of SC23 and the onset, ascent, maximum, and descent of SC24. As of December 2018, SC24 has persisted some 120 months based on *R*. Minimum smoothed monthly mean sunspot number (Rm) occurred in December 2008 (the epoch of cycle minimum, Em, identified by the unfilled triangle) and measured 2.2. SC24 attained its first maximum in March 2012, measuring 98.3, and its overall cyclic maximum (RM) in April 2014 (the epoch of cycle maximum, EM, identified by the filled triangle), measuring 116.4. Thus, SC24 had an ascent duration (ASC) of 64 months, the fifth longest on record (ASC has spanned 35–82 months, having a mean of 52.3 months and a standard deviation, *sd*, measuring 13.6 months). Since EM, SC24's *R*-values have decreased to $R = 6.0$ in December 2018, a value well within the range of previously observed Rm values for SC1–SC24, which spans 0.0–18.6, having a mean of 9.3 and $sd = 5.7$. Hence, Em for SC25, the next SC, is believed to be very near, probably occurring sometime between late 2019 and the end of 2021 (cf. Uzal, Piacentini, and Verdes 2012). Because of the large number of spotless days (Wilson 2017) now being seen, *R*-values are expected to continue to decrease falling below $R = 6.0$. Relative to previous cycles, SC24's RM is the fourth smallest SC on record (cf. Svalgaard, Cliver, and Kamide 2005). Likewise, the expected Rm value for SC25 will be among the lowest observed (0.0–5.9).

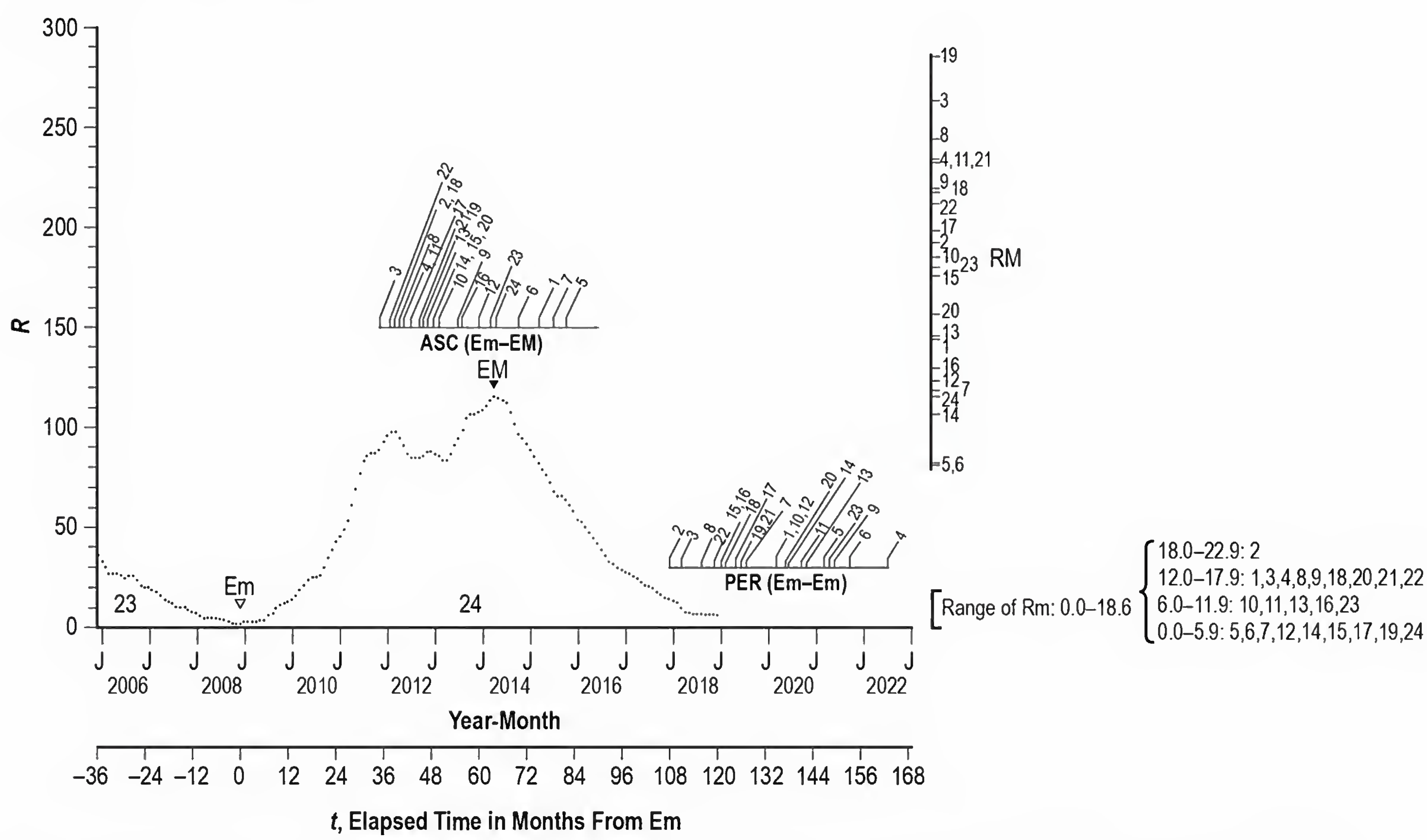


**Figure 1. Variation of smoothed sunspot number (*R*) December 2005–December 2018. The epochs of sunspot minimum (Em) and maximum (EM) are identified for sunspot cycle (SC)24. Also shown are the relative occurrences of the ascent (ASC) durations, maximum amplitudes (RM) and periods (PER) for SC1–SC24, as well as the range of minimum amplitudes for specific groupings. The individual numbers 1–24 refer to the individual SCs. *t* is the elapsed time in months from Em.**

Figure 2 shows the month-to-month change in *R*-values. SC24's greatest positive change in *R* (*gpΔR*) occurred in April 2011, measuring 8.2, some 3 years prior to EM. Its greatest negative change in *R* (*gnΔR*) occurred in August 2014, measuring –6.4, a mere 4 months following EM. Relative to previous cycles, SC24's *gpΔR* value is the ninth smallest, and its *gnΔR* value is the fifth smallest. In Figure 2, $t_1$ is the elapsed time in months from Em to *gpΔR* occurrence, $t_2$ is the elapsed time in months from *gpΔR* occurrence to EM, $t_3$ is the elapsed time in months from EM to *gnΔR* occurrence, and $t_4$ is the elapsed time in months from *gnΔR* occurrence to Em for SC (*n*+1). The *ΔR*-value signature (i.e., positive-negative-positive peaks) merely reflects the double-peaked nature of SC24. (For convenience, Tables 1 and 2 are included to give the reader specific information regarding parameters that will be discussed in the following charts.)

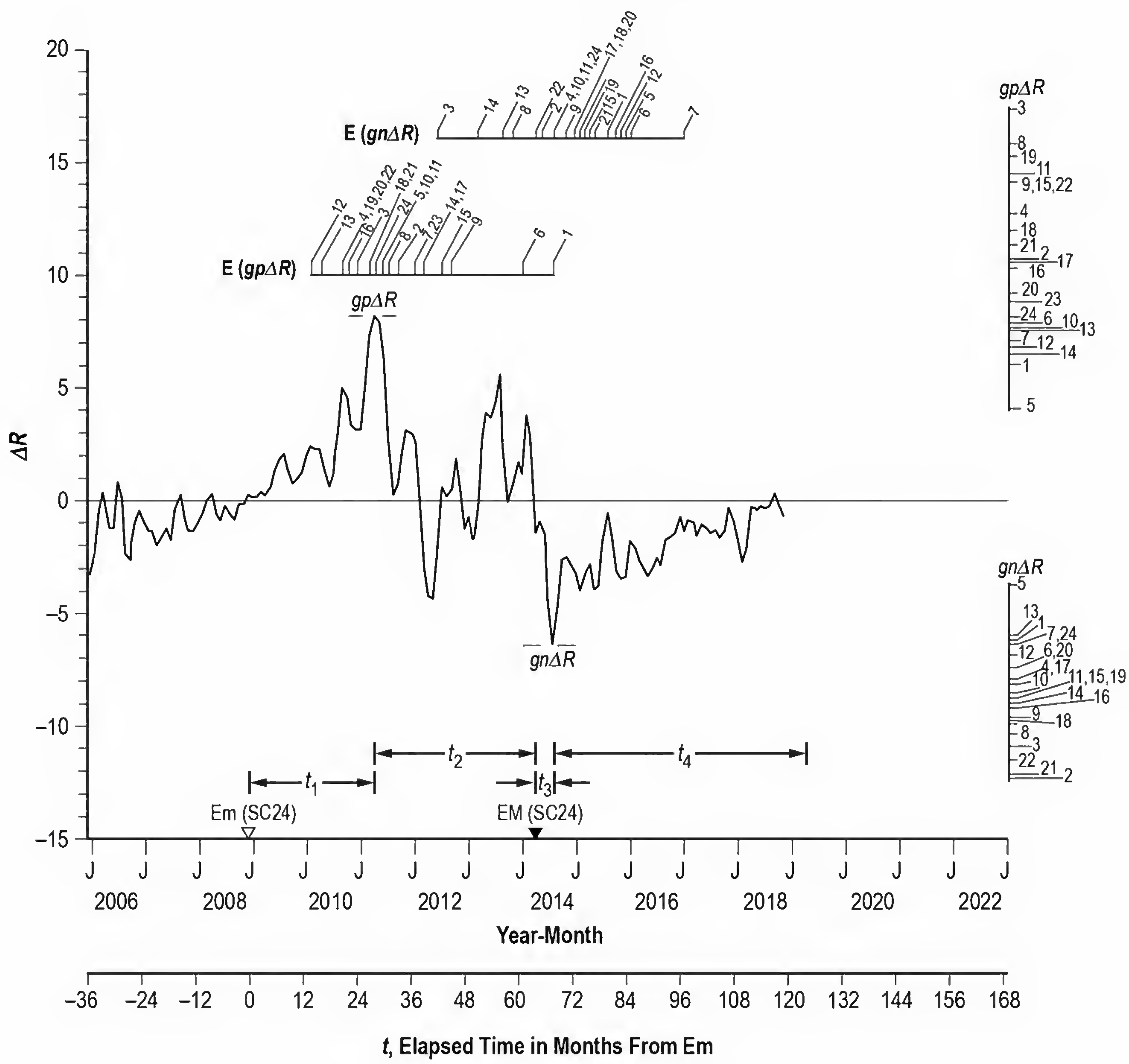


**Figure 2. Variation of the rate of change in *R* (*ΔR*) for the interval December 2005–November 2018. Also shown are the relative occurrences and amplitudes of the greatest positive (*gpΔR*) and greatest negative (*gnΔR*) rates of change in *R* for SC1–SC24. *t* is the elapsed time in months from Em.**

**Table 1. Parametric values for SC1–SC24.**

| SC | Em | EM | Rm | RM | ASC | DES | PER | SLOPE (ASC) | SLOPE (DES) | $gp\Delta R$ | $gn\Delta R$ | $t_1$ | $t_2$ | $t_3$ | $t_4$ | Class |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 | 1755-03 | 1761-06 | 14.0 | 144.1 | 75 | 60 | 135 | 1.7347 | –2.0917 | 6.0 | –6.2 | 68 | 7 | 5 | 55 | SL |
| 02 | 1766-06 | 1769-09 | 18.6 | 193.0 | 39 | 69 | 108 | 4.4718 | –2.6232 | 10.7 | –12.3 | 33 | 6 | 26 | 43 | FS |
| 03 | 1775-06 | 1778-05 | 12.0 | 264.3 | 35 | 76 | 111 | 7.2086 | –3.2684 | 17.4 | –10.9 | 24 | 11 | 7 | 69 | FS |
| 04 | 1784-09 | 1788-02 | 15.9 | 235.3 | 41 | 122 | 163 | 5.3512 | –1.8852 | 12.7 | –7.9 | 21 | 20 | 27 | 95 | FL |
| 05 | 1798-04 | 1805-02 | 5.3 | 82.0 | 82 | 65 | 147 | 0.9354 | –1.2615 | 4.1 | –3.7 | 30 | 52 | 2 | 63 | SL |
| 06 | 1810-07 | 1816-05 | 0.0 | 81.2 | 70 | 83 | 153 | 1.1600 | –0.9759 | 5.9 | –7.4 | 61 | 9 | 15 | 68 | SL |
| 07 | 1823-04 | 1829-11 | 0.2 | 119.2 | 79 | 48 | 127 | 1.5063 | –2.2292 | 5.1 | –6.3 | 37 | 42 | 18 | 30 | SS |
| 08 | 1833-11 | 1837-03 | 12.2 | 244.9 | 40 | 76 | 116 | 5.8175 | –2.9908 | 15.8 | –10.3 | 31 | 9 | 19 | 57 | FS |
| 09 | 1843-07 | 1848-02 | 17.6 | 219.9 | 55 | 94 | 149 | 3.6782 | –2.2755 | 14.1 | –9.6 | 45 | 10 | 16 | 78 | SL |
| 10 | 1855-12 | 1860-02 | 6.0 | 186.2 | 50 | 85 | 135 | 3.6040 | –2.0741 | 7.7 | –8.1 | 30 | 19 | 19 | 66 | SL |
| 11 | 1867-03 | 1870-08 | 9.9 | 234.0 | 41 | 100 | 141 | 5.4659 | –2.3030 | 15.5 | –8.7 | 30 | 11 | 27 | 73 | FL |
| 12 | 1878-12 | 1883-12 | 3.7 | 124.4 | 60 | 75 | 135 | 2.0117 | –1.5480 | 6.8 | –6.8 | 14 | 46 | 23 | 52 | SL |
| 13 | 1890-03 | 1894-01 | 8.3 | 146.5 | 46 | 96 | 142 | 3.0043 | –1.4792 | 7.6 | –6.0 | 16 | 30 | 11 | 85 | FL |
| 14 | 1902-01 | 1906-02 | 4.5 | 107.1 | 49 | 89 | 138 | 2.0939 | –1.1753 | 6.5# | –9.0 | 39 | 10 | 2 | 87 | SL |
| 15 | 1913-07 | 1917-08 | 2.5 | 175.7 | 49 | 72 | 121 | 3.5347 | –2.3097 | 14.2 | –8.8 | 43 | 6 | 27 | 45 | SS |
| 16 | 1923-08 | 1928-04 | 9.4 | 130.2 | 56 | 65 | 121 | 2.1571 | –1.9138 | 10.3 | –9.2 | 22 | 34 | 26 | 39 | SS |
| 17 | 1933-09 | 1937-04 | 5.8 | 198.6 | 43 | 82 | 125 | 4.4837 | –2.2646 | 10.6 | –7.9 | 39 | 4 | 30 | 52 | FS |
| 18 | 1944-02 | 1947-05 | 12.9 | 218.7 | 39 | 83 | 122 | 5.2769 | –2.5735 | 12.0 | –9.7 | 27 | 12 | 34 | 49 | FS |
| 19 | 1954-04 | 1958-03 | 5.1 | 285.0 | 47 | 79 | 126 | 5.9553 | –3.4266 | 15.3 | –8.8 | 22 | 25 | 28 | 51 | FS |
| 20 | 1964-10 | 1968-11 | 14.3 | 156.6 | 49 | 88 | 137 | 2.9041 | –1.5773 | 9.2 | –7.5 | 22 | 27 | 24 | 64 | SL |
| 21 | 1976-03 | 1979-12 | 17.8 | 232.9 | 45 | 81 | 126 | 4.7800 | –2.7086 | 11.4 | –12.1 | 27 | 18 | 32 | 49 | FS |
| 22 | 1986-09 | 1989-11 | 13.5 | 212.5 | 38 | 81 | 119 | 5.2368 | –2.4852 | 14.2 | –11.5 | 21 | 17 | 26 | 55 | FS |
| 23 | 1996-08 | 2001-11 | 11.2 | 180.3 | 63 | 85 | 148 | 2.6841 | –2.0953 | 8.8 | –7.9 | 37 | 26 | 11 | 74 | SL |
| 24 | 2008-12 | 2014-04 | 2.2 | 116.4 | 64 | – | – | 1.7844 | – | 8.2 | –6.4 | 28 | 36 | 4 | – | S? |
| | | mean | 9.3 | 178.7 | 52.3 | 80.6 | 132.4 | 3.6184 | –2.1537 | 10.4 | –8.5 | 32.0 | 20.3 | 19.1 | 60.8 | |
| | | *sd* | 5.7 | 57.8 | 13.6 | 15.0 | 14.1 | 1.7598 | 0.6359 | 3.8 | 2.1 | 12.9 | 13.7 | 9.9 | 16.3 | |

Note: SC24 DES >56, PER >120 (R values known thru December 2018)
SC means Sunspot Cycle
Em means Epoch of sunspot minimum (i.e., the occurrence of Rm)
EM means Epoch of sunspot maximum (i.e., the occurrence of RM)
Rm is the minimum value of the smoothed monthly mean sunspot number (i.e., the 12-month moving average of *R*)
RM is the maximum value of the smoothed monthly mean sunspot number (i.e., the 12-month moving average of *R*)
ASC is the elapsed time in months from Em to EM
DES is the elapsed time in months from RM ($n$) to Rm ($n + 1$)
PER is the Period or elapsed time in months from Em ($n$) to Em ($n + 1$) or ASC + DES or $t_1 + t_2 + t_3 + t_4$
SLOPE (ASC) = (RM – Rm)/ASC
SLOPE (DES) = (Rm ($n + 1$) – RM)/DES
$gp\Delta R$ is the greatest positive value in the difference of consecutive monthly smoothed *R* values during ASC

*gnΔR* is the greatest negative value in the difference of consecutive monthly smoothed *R* values during DES
# means a larger value (7.5) was observed after RM during SC14 decline
$t_1$ means time in months between Em and E (*gpΔR*)
$t_2$ means time in months between E (*gpΔR*) and RM
$t_3$ means time in months between RM and E (*gnΔR*)
$t_4$ means time in months between E (*gnΔR*) and Em ($n + 1$)
$t_1 + t_2$ = ASC
$t_3 + t_4$ = DES
$t_1 + t_2 + t_3 + t_4$ = ASC + DES = PER
FS means Fast ASC (ASC <49 months), Short PER (PER <135 months)
FL means Fast ASC, Long PER (Per ≥ 135 months)
SS means Slow ASC (ASC ≥ 49 months), Short PER
SL means Slow ASC, Long PER

**Table 2. Parametric means (standard deviations) for selected groupings of sunspot cycles.**

| Class | | RM | ASC | DES# | PER# |
|---|---|---|---|---|---|
| Fast Rise (11) | 12.0(4.5) | 224.2(37.2) | 41.3(3.7) | 78.0(27.1) | 127.2(16.0) |
| Slow Rise (13) | 7.0(5.8) | 147.3(43.4) | 61.6(11.8) | 75.8(14.0) | 137.2(10.6) |
| Short Period (11) | 10.0(6.0) | 206.8(51.5) | 46.4(12.4) | 73.8(10.3) | 120.2(6.3) |
| Long Period (12) | 9.2(5.5) | 158.1(54.4) | 58.4(15.4) | 86.8(16.3) | 143.6(8.7) |
| Even (12) | 9.4(6.0) | 167.2(55.0) | 49.6(10.9) | 83.3(14.9) | 131.5(16.4) |
| Odd (12) | 9.1(5.6) | 190.2(60.5) | 55.0(15.9) | 78.2(15.3) | 133.2(12.3) |
| FS (8) | 12.2(4.9) | 231.2(32.1) | 40.8(4.0) | 78.4(4.6) | 119.1(6.9) |
| FL (3) | 11.4(4.0) | 205.3(50.9) | 42.7(2.9) | 106.0(14.0) | 148.7(12.4) |
| SS (3) | 4.0(4.8) | 141.7(30.0) | 61.3(15.7) | 61.7(12.3) | 123.0(3.5) |
| SL (9) | 8.5(5.9) | 142.4(48.1) | 61.4(12.1) | 80.4(11.4) | 141.9(7.2) |

Note: # means DES and PER for SC24 remain unknown at present

Figure 3 displays the cyclic values of Rm, RM, ASC, DES (i.e., the descent duration), PER (i.e., the period or ASC + DES), SLOPE(ASC), SLOPE(DES), *gpΔR* and *gnΔR* for SC1–24. Similarly, Figure 4 depicts the cyclic values of $t_1$, $t_2$, $t_3$, and $t_4$ for SC1–SC24. Now, SLOPE(ASC) is simply computed as (RM – Rm)/ASC for cycle *n* and SLOPE(DES) is computed as (Rm (cycle $n + 1$) – RM (cycle *n*)) / DES (cycle *n*). Close inspection of ASC and DES for an SC reveals that, generally speaking, DES > ASC for an SC in 20 of 23 cycles. The only exceptions are the early-occurring, less-reliably determined cycles 1, 5, and 7. Hence, one expects SC24's DES >64 months, inferring that Em for SC25 should occur sometime after elapsed time $t = 128$ months (i.e., after August 2019). Since SC7, the smallest difference between ASC and DES is 9 months, suggesting that SC24's DES ≥73 months, inferring that Em for SC25 probably should not be expected until on or after May 2020. Based on the mean value of DES (80.6 ± 15 months), one does not expect SC25 Em to occur until about $t = 145 \pm 15$ months (i.e., on or after about October 2019). Also, because there is a noticeable gap in PER between 127 and 135 months, one really does not expect SC24's PER to fall within the gap, inferring that Em for SC25 should not be expected until on or after PER = 135 months (i.e., on or after March 2020), especially considering the previous findings. Based on the mean value of $t_4$ (= 60.8 months), one does not expect Em for SC25 until on or after August 2019.

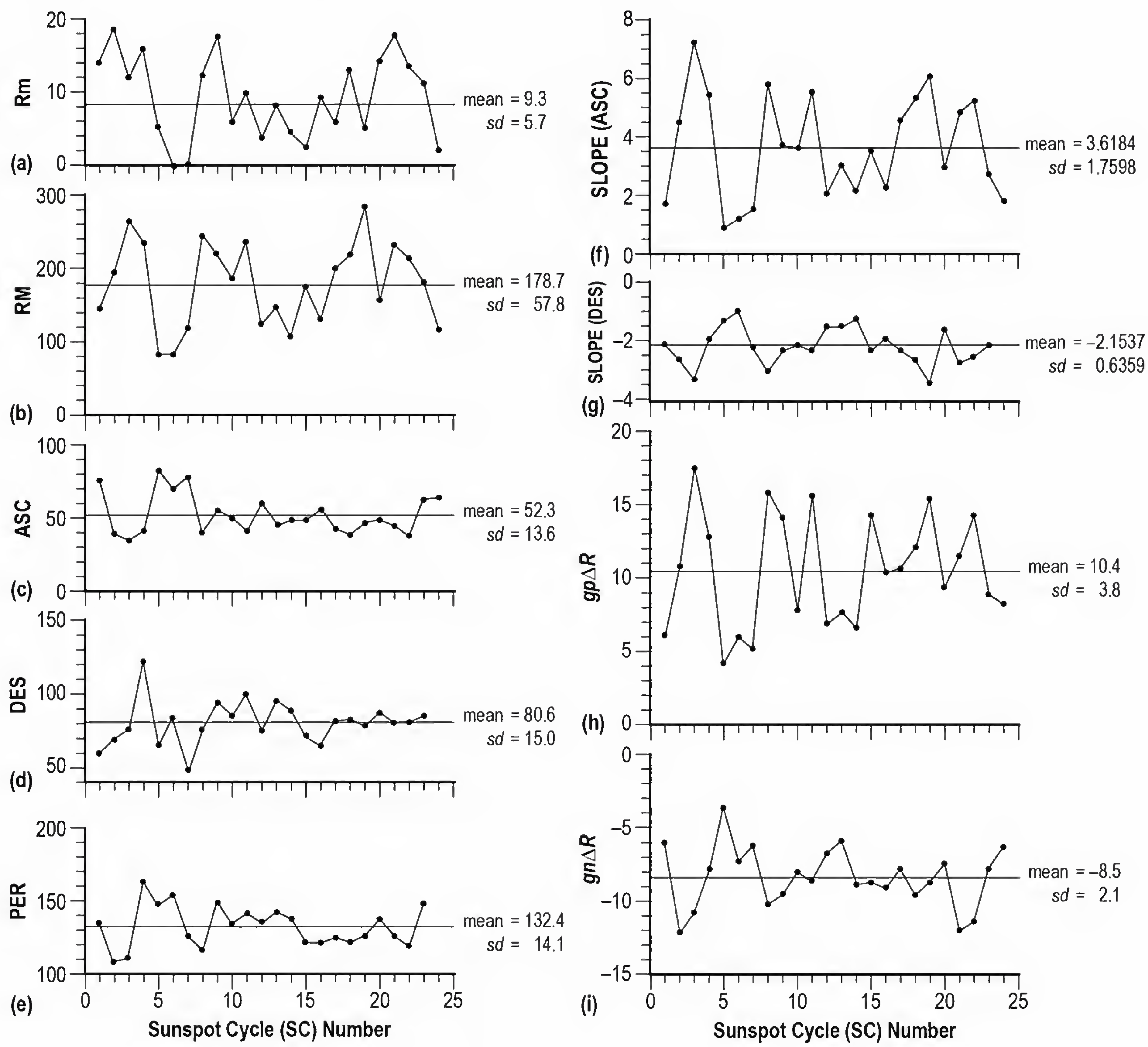


**Figure 3. Variation of cyclic values of (a) Rm, (b) RM, (c) ASC, (d) DES (i.e., the descent duration), (e) PER (i.e., the period or ASC + DES), (f) SLOPE (ASC), (g) SLOPE (DES), (h) *gpΔR* and (i) *gnΔR* for SC1–SC24. Also given are the parametric means and standard deviations (*sd*).**

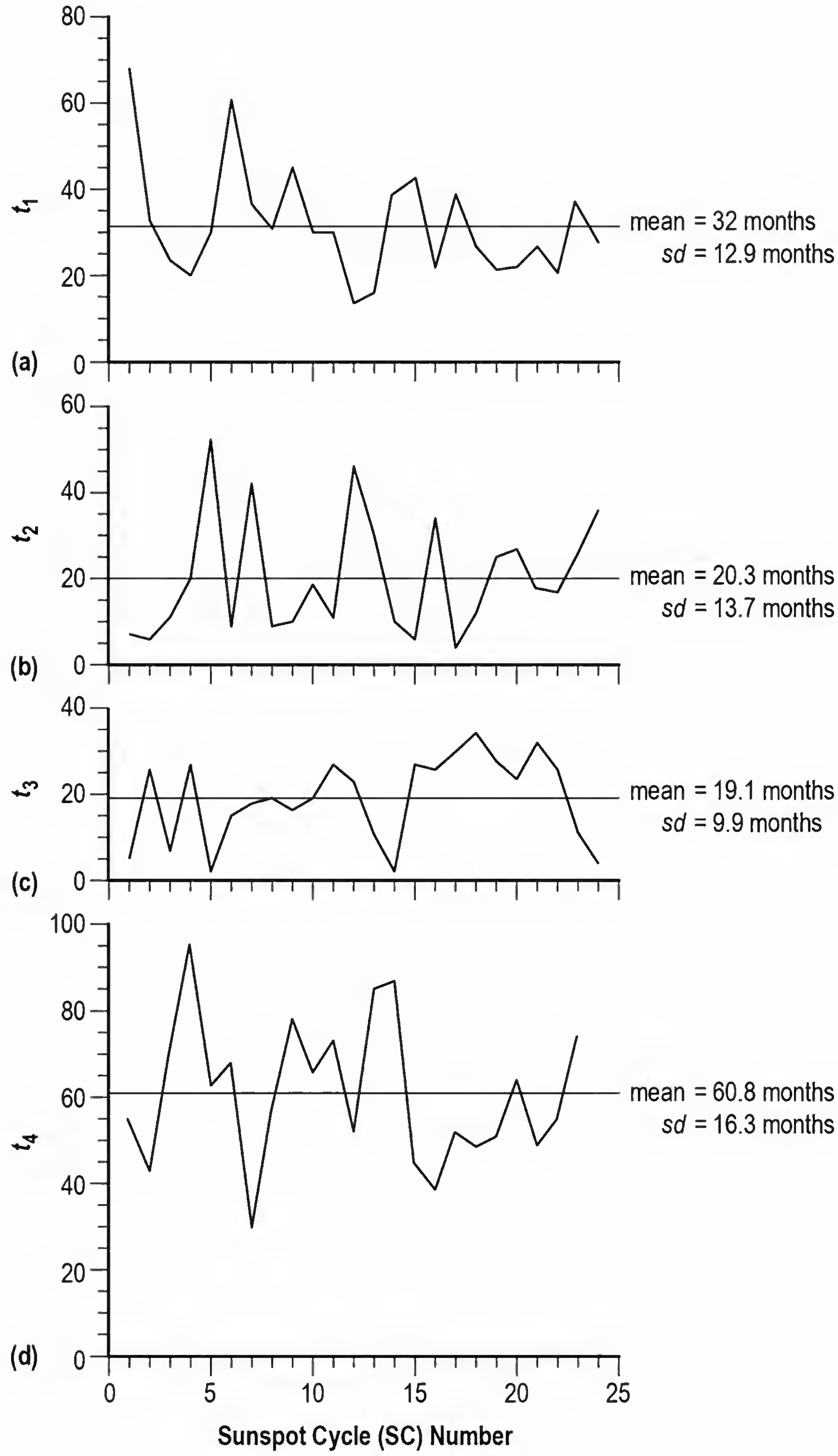


**Figure 4. Variation of (a) $t_1$, (b) $t_2$, (c) $t_3$, and (d) $t_4$ for SC1–SC24, where these parameters are defined in the note given in Table 1.**

Figure 5 depicts scatterplots of RM versus (a) *gpΔR* and (b) ASC for cycle *n*. Shown in both scatterplots are the results of linear regression analysis and nonparametric analyses. For RM versus *gpΔR*, the inferred regression equation is $y = 40.1234 + 13.2988x$, where $y$ is RM, and $x$ is *gpΔR*. The linear correlation coefficient is $r = 0.8842$ (inferring that the inferred regression can explain about 78% of the variance in RM). The standard error of estimate $S_{yx} = 31.0150$, and the *t*-statistic equals 7.8980, inferring a confidence level $cl$ >99.9%. The Kendall $\tau$ is computed to be $\tau_b = 0.7260$, and the *Z*-statistic is computed to be 4.9699 (inferring a probability $P$ <0.0002). The

Fisher's exact test for the observed $2 \times 2$ contingency table (determined by the parametric medians – the horizontal and vertical lines) is computed to be $P_o = 0.0001$ and the probability of obtaining the observed result—or one more suggestive of a departure from independence (chance)—is likewise $P = 0.0001$. For RM versus ASC, the inferred association also is determined to be statistically important, as well. Hence, if SC25 has a rapid growth (and shorter ASC), clearly it would be expected to be a larger amplitude cycle (RM ≥184). On the other hand, if SC25 is a slow growing cycle (of longer ASC), it would be expected to be a smaller amplitude cycle (RM <184). (Note that fast-rising cycles also tend to be cycles of shorter PER (8 of 11 cycles), while slow-rising cycles tend to be cycles of longer PER (9 of 12 cycles). The numbered filled-circles denote the SC.)

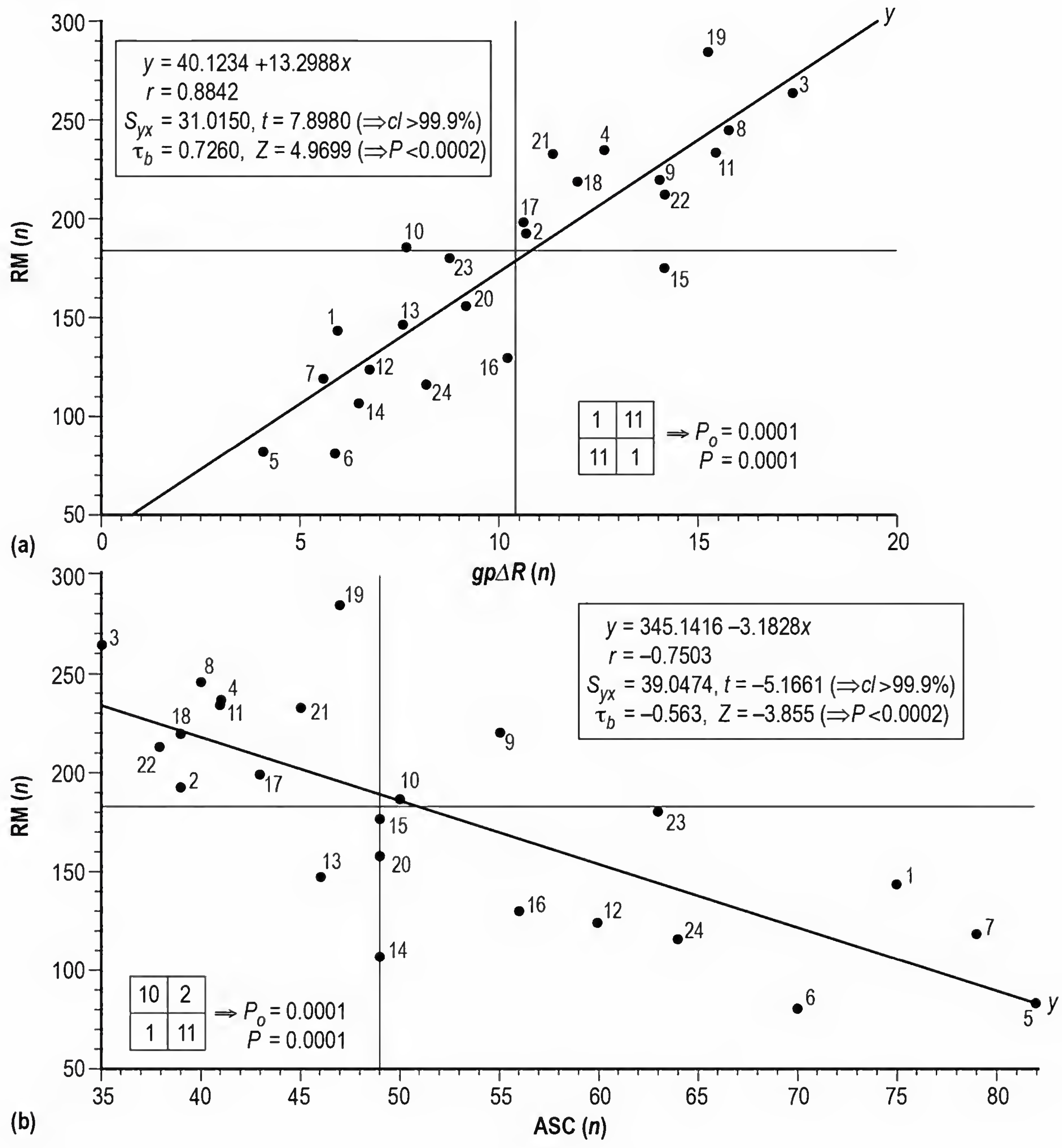


**Figure 5. Scatterplots of RM (cycle *n*) versus (a) *gpΔR* (cycle *n*) and (b) ASC (cycle *n*).**

Figure 6 displays scatterplots of PER versus (a) *gnΔR* and (b) RM for cycle *n*. As in Figure 5, the results of linear regression analysis and nonparametric analyses are given. The more statistically important association is that of PER versus *gnΔR*. Based on the observed value for SC24 (denoted by the arrow along the x-axis), one predicts using the inferred linear regression that PER = 141.1 ± 11.7 months for SC24, inferring that Em for SC25 should not be expected until on or after September 2019, probably near September 2020. Certainly, based on the observed 2 × 2 contingency table, one expects PER ≥135 months for SC24 (meaning Em for SC25 should not be expected until on or after March 2020).

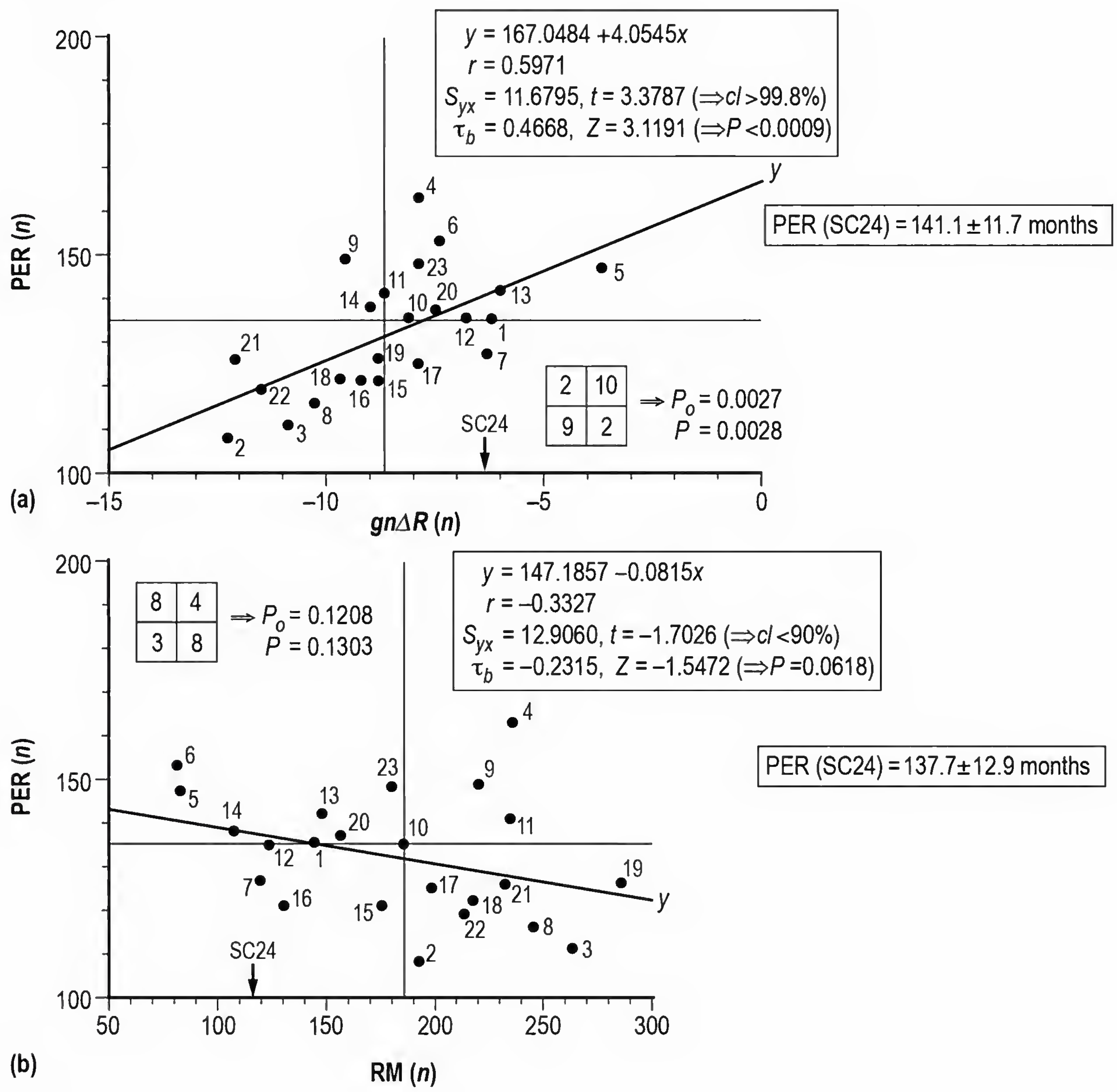


**Figure 6. Scatterplots of PER (cycle *n*) versus (a) *gnΔR* (cycle *n*) and (b) RM (cycle *n*).**

Figure 7 shows the scatterplot of SLOPE (DES) versus SLOPE (ASC). Based on the observed SLOPE (ASC) for SC24, one predicts that SLOPE (DES) = –1.5903 ± 0.3789 for SC24 using the inferred linear regression. Assuming SLOPE (DES) = –1.5903 for SC24 and that Rm = 0 for SC25, then one determines that DES = 73 months for SC24, yielding PER = 137 months for SC24 and that SC25's Em would be May 2020. Of course, the actual value for SLOPE (DES) will not be known until Rm for SC25 is known. (*R* = 6.0 in December 2018 and the trend is towards smaller *R*-values.)

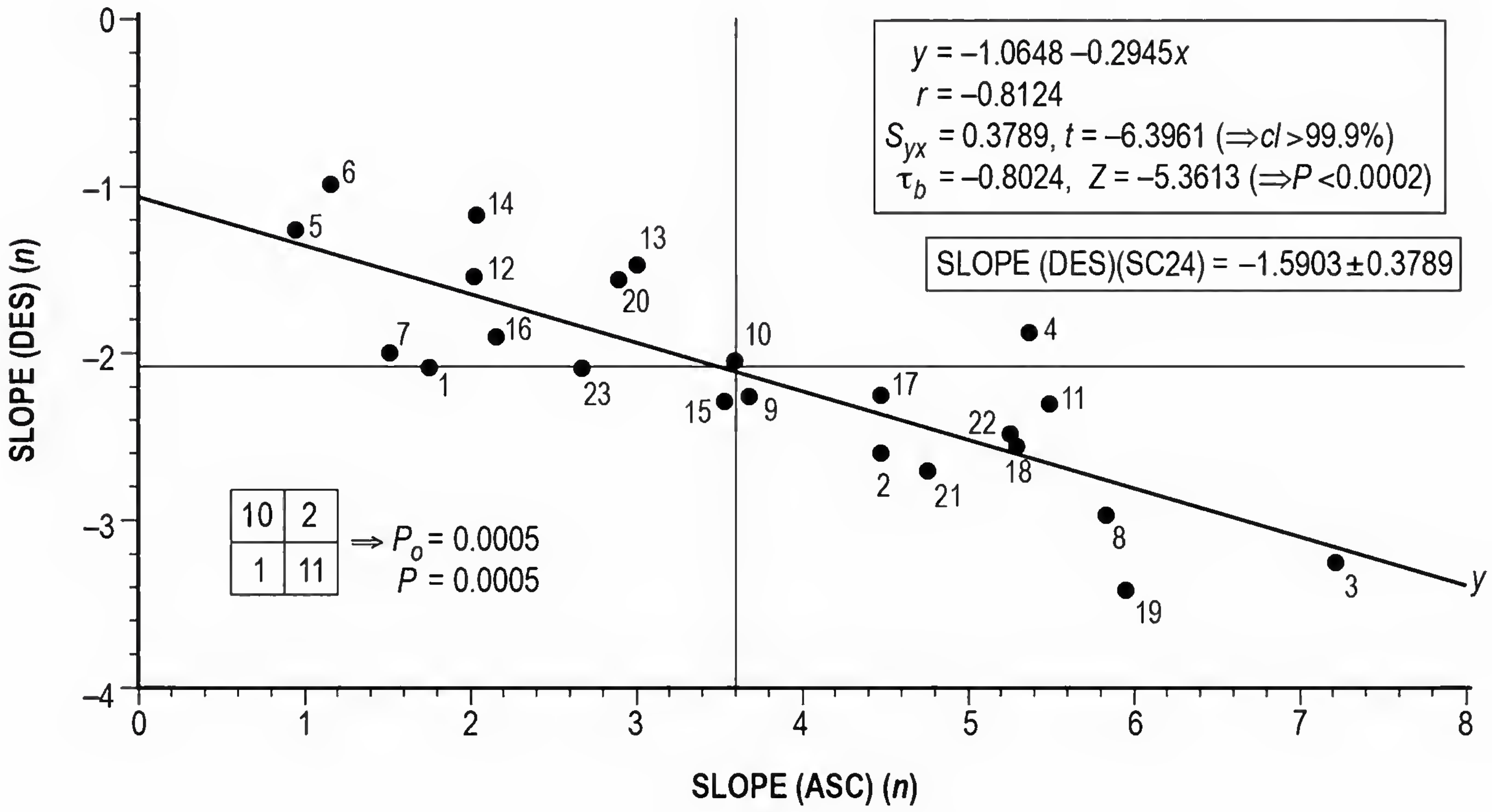


**Figure 7. Scatterplot of SLOPE (DES) (cycle *n*) versus SLOPE (ASC) (cycle *n*).**

Figure 8 displays (a) the scatterplot of Rm ($n + 1$) versus PER ($n$) and (b) the variation of $R$ from May 2017 through December 2018. Regarding the scatterplot, both the linear regression analysis and nonparametric analyses indicate that the inferred association is statistically important. The $R$-value for December 2018 (= 6.0), which is elapsed time $t = 120$ months, is well below the median value of Rm ($n + 1$) = 9.4. For $t = 120$ months, one expects Rm (25) = 12.1 ± 4.7 based upon the inferred linear regression. Presuming SC24/25 is not a statistical outlier, an Rm value of 6.0 or below suggests that PER (24) likely will be ≥135 months, suggesting Em for SC25 on or after March 2020. If this is true, then the minimum interval for SC24/25 will be uncharacteristically long, as was the minimum interval between SC23/24 (cf. Russell, Luhmann and Jian 2010; Nandy, Muñoz-Jaramillo and Martens 2011). Using $R = 10.0$ as an arbitrary level for indicating the beginning and ending of a sunspot minimum interval, one finds that 10 of the intervals never dipped below the arbitrary threshold. These included cycle minimum intervals SC1/2, SC2/3, SC3/4, SC7/8, SC8/9, SC17/18, SC19/20, SC20/21, SC21/22, and SC22/23. Thirteen intervals, however, did cross below the threshold. These include SC4/5 (16 months), SC5/6 (44 months), SC6/7 (19 months), SC9/10 (11 months), SC10/11 (1 month), S11/12 (16 months), SC12/13 (11 months), SC13/14 (21 months), SC14/15 (34 months), SC15/16 (4 months), SC16/17 (7 months), SC18/19 (7 months) and SC23/24 (26 months). The time in months from crossing below the threshold to Em ($n + 1$) has spanned 1–26 months, averaging 10.2 ± 7.4 months. SC24 dipped below the threshold in March 2018, indicating that the duration of this arbitrary minimum interval will be ≥9 months. If the time between crossing below the threshold to Em (25) is similar to that of SC23/24 (= 17 months), then Em (25) would be expected about August 2019. However, if the time between crossing below the threshold and the Em is more like that for SC14/15 (= 26 months), then Em (25) should not be expected until May 2020. (SC24 has been compared to that of SC14; Wilson 2017.)

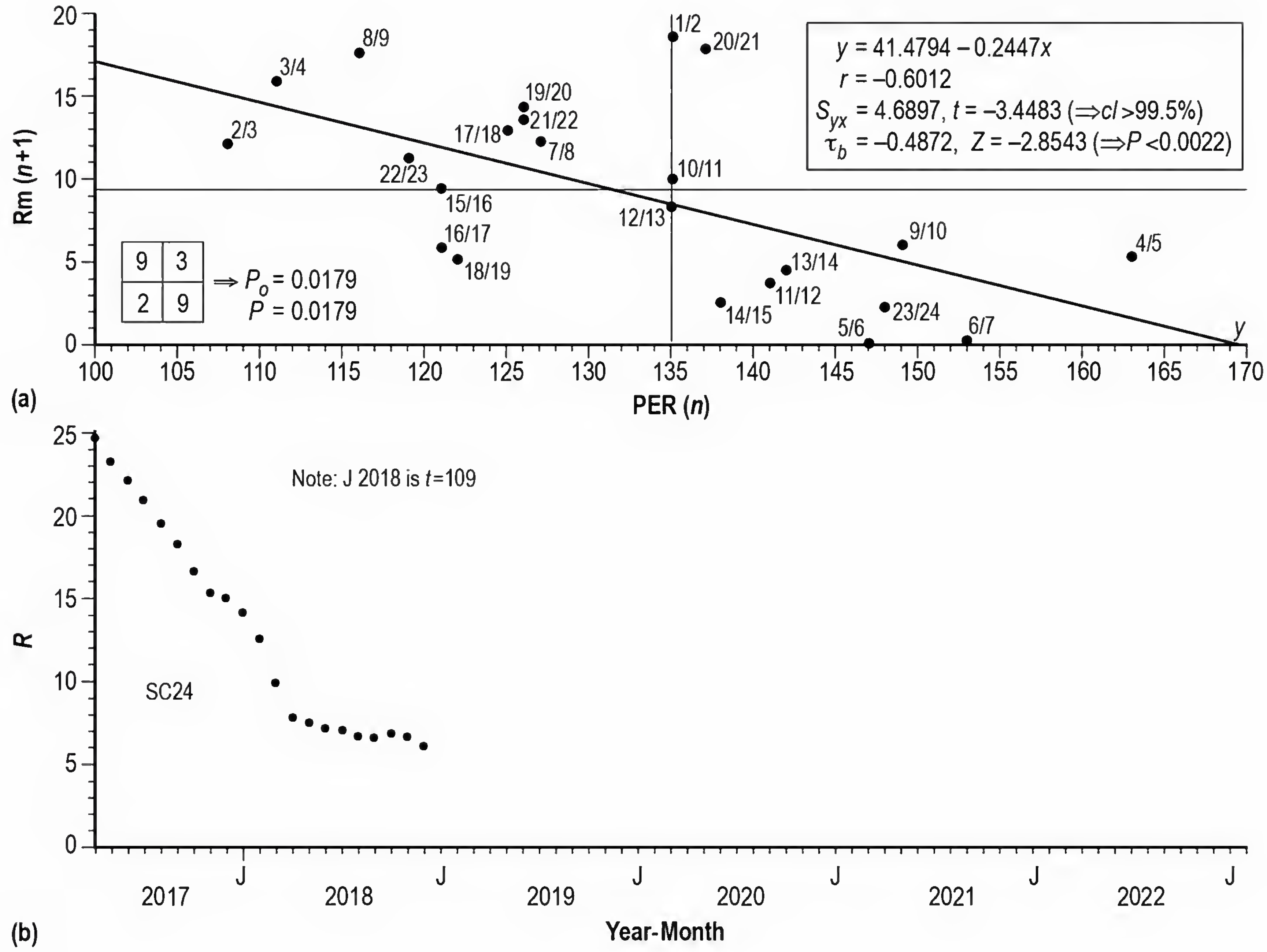


**Figure 8. (a) Scatterplot Rm (cycle *n* + 1) versus PER (cycle *n*) and (b) variation of *R* for April 2017 through December 2018.**

Figure 9 shows scatterplots of (a) RM ($n + 1$) versus PER ($n$) and (b) ASC ($n + 1$) versus PER ($n$). Of the two scatterplots, the former one is the more statistically important. In the scatterplot, notice the PER gap between PER = 127–135 months. Of the 23 SC of known PER that have been recorded, none have had a PER falling within this gap. Eleven have had PER = 108–127 months and 12 have had PER = 135–163 months. Hence, one suspects that PER (24) will be either ≤127 months or ≥135 months. Although $R$-values are known only through December 2018 ($t = 120$ months), monthly mean values of sunspot number are known through June 2019 ($t = 126$ months), with the first 6 months of 2019 having monthly mean sunspot number values of 7.7, 0.8, 9.4, 9.1, 10.1 and 1.2 (January–June). For July 2019, there have been only 2 days reported with nonzero daily sunspot number (July 7 (12) and July 22 (13)). Hence, a preliminary monthly mean value of 0.8 is estimated for July 2019, inferring $R = 5.4$ for January 2019, a decrease of 0.6 units of sunspot number from December 2018. Hence, it appears very likely that SC24 will have PER ≥ 135 months, suggesting Em for SC25 on or after March 2020, unless SC24 is a statistical outlier and becomes the first cycle to have a PER that falls within the gap. Presuming SC24 is indeed a longer-period cycle, one expects SC25 to be of smaller amplitude, with the SC24/25 dot falling in the lower right quadrant of Figure 9(a). Also, one would expect SC25 to be a slow rising cycle with ASC ≥49 months, with the SC24/25 dot falling in the upper right quadrant of Figure 9(b), meaning that EM for SC25 should occur on or after April 2024.

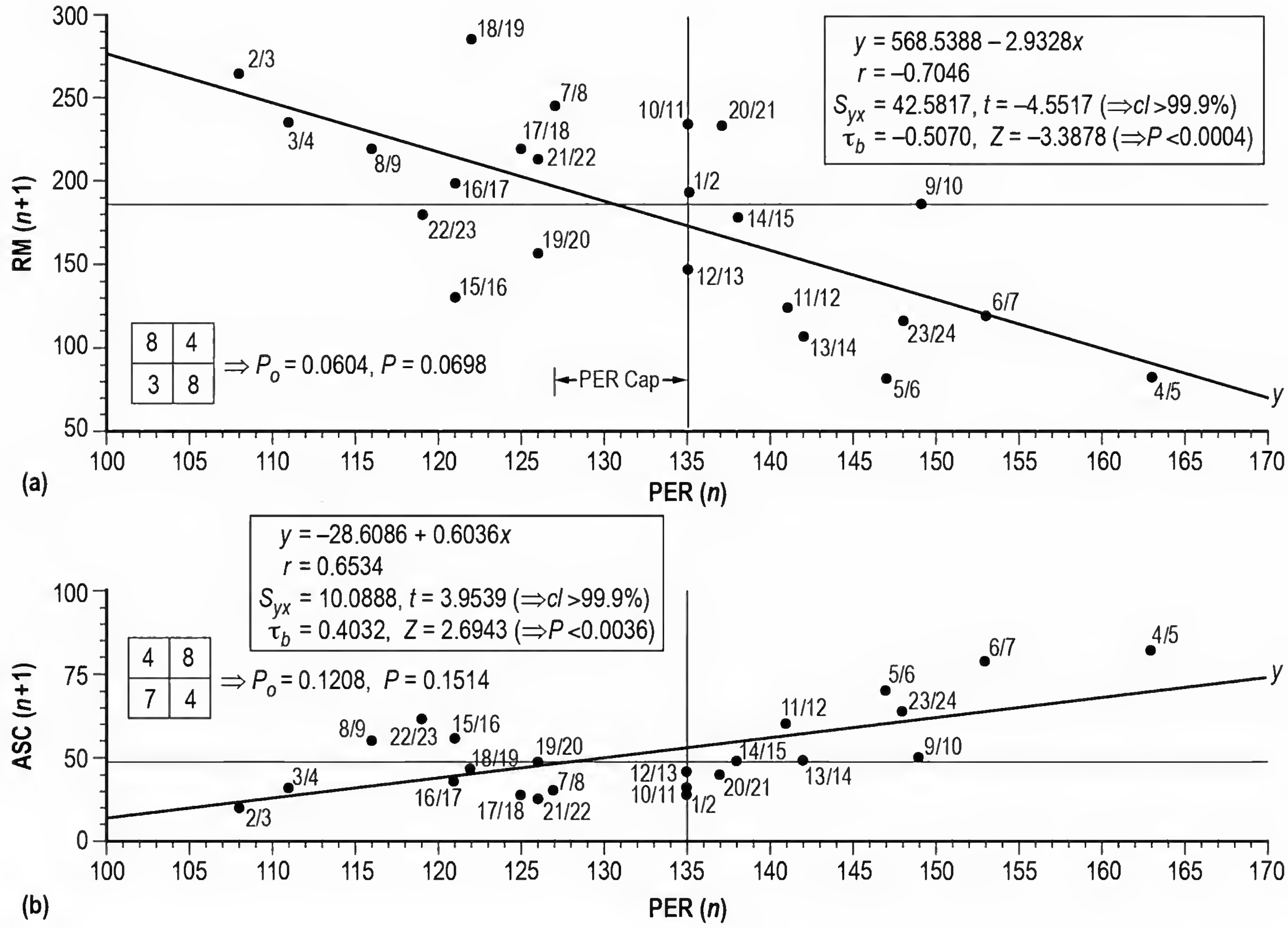


**Figure 9. Scatterplots of (a) RM (cycle $n$ + 1) versus PER (cycle $n$) and (b) ASC (cycle $n$ + 1) versus PER (cycle $n$).**

Figure 10 displays (a) the undifferentiated latitudinal (LAT) location of the spot groups on the Sun and (b) the number of spotless days (NSD) for the interval January 2018–June 2019. The lone dot at 32° is region 12694, observed January 9–11, 2018 (actually located at LAT = –32°), which was a magnetically simple old-cycle (i.e., SC24) spot of corrected small area (10 millionths of the solar hemisphere). Plainly, through June 2019, no high-latitude (i.e., ≥30°) new-cycle (SC25) spots have been observed, where new-cycle spots have positive leading magnetic field in the northern hemisphere and negative-leading magnetic field in the southern hemisphere in odd–numbered solar cycles. Typically, when the number of high-latitude new-cycle spots become more prevalent, Em for the new cycle is very close (cf. Harvey and White 1999). Hence, Em for SC25 remains in the future, probably occurring in 2020 or later. Regarding NSD, there were 208 spotless days in 2018 and 107 for the first half of 2019 (136 through July 2019). (NSD peaks in the year of sunspot minimum based on annual sunspot number; Wilson 2017.)

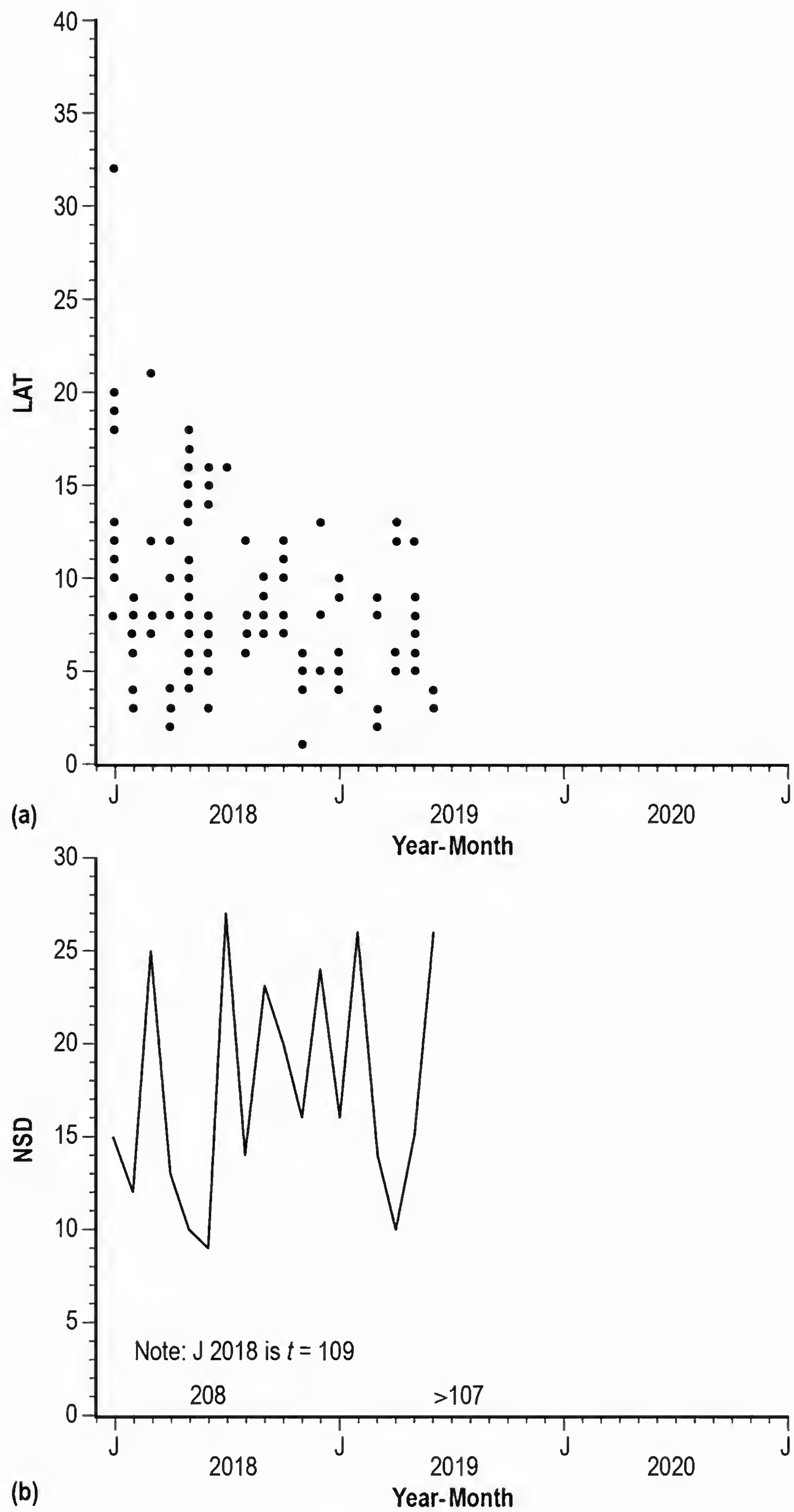


**Figure 10. (a) Variation of undifferentiated spot latitude (LAT) for January 2018 through June 2019 and (b) variation of number of spotless days (NSD) for January 2018 through June 2019.**

In conclusion, Em for SC25 is close but not really expected until probably March 2020 or later. Hence, the relatively low *R*-values experienced throughout 2018 likely will continue through 2019 and into 2020. This portends another uncharacteristically long minimum interval for SC24/25 like that experienced for SC23/24. Therefore, SC24 is projected to be a cycle of longer PER (≥135 months), meaning that Em for SC25 should not be expected until March 2020 or later. If true, then one expects SC25 to be a cycle of smaller amplitude (RM < 184) and a slow riser (ASC ≥ 49 months), inferring EM for SC25 in 2024 or later. Also, assuming SC25 is not a statistical outlier, its RM should be larger than 116.4 (the RM for SC24), based on the even-odd effect (i.e., odd-numbered SCs typically have been the larger cycle in even-odd SC pairs, true for 8 of 12 cycle pairs for SC0–SC23; cf. Wilson 2018).

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# PREDICTING THE SIZE AND TIMING OF THE NEXT SOLAR CYCLE: PAPER II, BASED ON GEOMAGNETIC VALUES

Robert M. Wilson
NASA Marshall Space Flight Center, NSSTC, Huntsville, Alabama

robert.m.wilson@nasa.gov

## ABSTRACT

This is the second paper in a two-part study of predicting the size and timing of the next sunspot cycle (SC)25. Paper I examined the behavior of sunspot number (*R*) as a predictor, based on specific markers as gleaned from SC24. This paper (Paper II) examines the *Aa* and *Ap* geomagnetic indices, as well as the number of disturbed days (NDD), to effect the prediction for the size and timing of SC25. Presently (as of September 2019), SC24 is in the midst of what appears to be an extended solar minimum, with *R*, *Aa*, *Ap*, and NDD all of extremely low value and the nonoccurrence of any new cycle high latitude sunspots. Paper II describes methods for estimating the size of an SC and sets upper limits to the size of SC25. A definitive prediction cannot be made at this time but can be made when the minimum values of *Aa*, *Ap*, and NDD actually become available—probably in 2020 or more likely 2021.

## INTRODUCTION

In Paper I (Wilson 2019b), estimates for the length of sunspot cycle (SC)24 and the timing and size of SC25 were determined based on specific SC parameters gleaned from the behavior of the present ongoing SC24. In this paper (Paper II), the behaviors of the *Aa* and *Ap* geomagnetic indices (annual values) and the number of disturbed days (NDD)—where a disturbed day is one having an index value ≥25 nT—are examined in relation to the annual variation of sunspot number (*R*).

Geomagnetic indices, in particular, the *Aa*-index (Mayaud 1972, 1980), have been used for many years to forecast the size of the just beginning SC, typically, 2–4 years in advance of cycle maximum (e.g.,Ohl 1966, 1976; Kane 1978, 1987, 1997; Sargent 1978; Wilson 1990; Thompson 1993; Wilson and Hathaway 2006, 2008). Geomagnetic indices have generally proven to provide the most accurate prediction for the expected size of an SC in advance of its maximum occurrence.

## METHODS AND MATERIALS

Annual values of *R* were taken from <http://sidc.oma.be/silo/datafiles>, and annual values of the geomagnetic indices *Aa* and *Ap* were computed from their monthly mean values taken from <http://www.geomag.bgs.ac.uk/data_service/data/magnetic_indices/aaindex.html> and <http://www.geomag.bgs.ac.uk/data_service/data/magnetic_indices/apindex.html>. The NDD for both *Aa* and *Ap* (i.e., NDD(*Aa*) and NDD(*Ap*)) were determined from the daily values given in each monthly summary. Linear regression and bivariate regression analyses, as well as Fisher's exact test for $2 \times 2$ contingency tables, were employed in this investigation.

## RESULTS AND DISCUSSION

Table 1 provides a tabular summary of the solar and geomagnetic index yearly values and counts that form the basis for this study. In Table 1, the occurrences of the parametric minimum (min) and maximum (max) for each of the parameters are given in the Comments column. Table 2 gives cyclic values for each of the parameters and the parametric means and standard deviations (*sd*) for each of the parameters for SC11–SC24.

**Table 1. Annual values of *R*, *Aa* and *Ap* and yearly counts of NDD(*Aa*) and NDD(*Ap*).**

| Year | *R* | *Aa* | *Ap* | NSD(*Aa*) | NSD(*Ap*) | Comments |
|---|---|---|---|---|---|---|
| SC11 | | | | | | |
| 1867 | 13.9 | – | – | – | – | $R_{min}$ |
| 1868 | 62.8 | 18.4 | – | 86 | – | $Aa_{min}$? |
| 1869 | 123.6 | 21.0 | – | 116 | – | |
| 1870 | 232.0 | 22.4 | – | 101 | – | $R_{max}$ |
| 1871 | 185.3 | 21.5 | – | 101 | – | |
| 1872 | 169.2 | 23.8 | – | 125 | – | $Aa_{max}$, NDD($Aa$)$_{max}$ |
| 1873 | 110.1 | 20.3 | – | 107 | – | |
| 1874 | 74.5 | 14.8 | – | 58 | – | |
| 1875 | 28.3 | 11.4 | – | 32 | – | |
| 1876 | 18.9 | 9.7 | – | 21 | – | |
| 1877 | 20.7 | 9.1 | – | 19 | – | |
| SC12 | | | | | | |
| 1878 | 5.7 | 7.4 | – | 10 | – | $R_{min}$ |
| 1879 | 10.0 | 7.1 | – | 5 | – | $Aa_{min}$, NDD($Aa$)$_{min}$ |
| 1880 | 53.7 | 11.6 | – | 32 | – | |
| 1881 | 90.5 | 13.7 | – | 52 | – | |
| 1882 | 99.0 | 23.1 | – | 92 | – | $Aa_{max}$ |
| 1883 | 106.1 | 17.8 | – | 78 | – | $R_{max}$ |
| 1884 | 105.8 | 14.3 | – | 55 | – | |
| 1885 | 86.3 | 15.6 | – | 55 | – | |
| 1886 | 42.4 | 20.7 | – | 114 | – | NDD($Aa$)$_{max}$ |
| 1887 | 21.8 | 16.6 | – | 80 | – | |
| 1888 | 11.2 | 15.6 | – | 75 | – | |
| SC13 | | | | | | |
| 1889 | 10.4 | 12.6 | – | 39 | – | $R_{min}$ |
| 1890 | 11.8 | 10.8 | – | 24 | – | $Aa_{min}$, NDD($Aa$)$_{min}$ |
| 1891 | 59.5 | 17.2 | – | 78 | – | |
| 1892 | 121.7 | 24.3 | – | 115 | – | $Aa_{max}$, NDD($Aa$)$_{max}$ |
| 1893 | 142.0 | 17.1 | – | 81 | – | $R_{max}$ |
| 1894 | 130.0 | 20.9 | – | 91 | – | |
| 1895 | 106.6 | 18.2 | – | 86 | – | |
| 1896 | 69.4 | 18.1 | – | 89 | – | |
| 1897 | 43.8 | 13.7 | – | 46 | – | |
| 1898 | 44.4 | 15.2 | – | 59 | – | |
| 1899 | 20.2 | 13.3 | – | 42 | – | |
| 1900 | 15.7 | 7.6 | – | 13 | – | |
| SC14 | | | | | | |
| 1901 | 4.6 | 6.2 | – | 9 | – | $R_{min}$, $Aa_{min}$ |
| 1902 | 8.5 | 6.6 | – | 8 | – | NDD($Aa$)$_{min}$ |
| 1903 | 40.8 | 12.0 | – | 30 | – | |
| 1904 | 70.1 | 11.8 | – | 36 | – | |
| 1905 | 105.5 | 15.1 | – | 56 | – | $R_{max}$ |
| 1906 | 90.1 | 12.6 | – | 42 | – | |
| 1907 | 102.8 | 16.2 | – | 59 | – | |

| Year | *R* | *Aa* | *Ap* | NSD(*Aa*) | NSD(*Ap*) | Comments |
|---|---|---|---|---|---|---|
| 1908 | 80.9 | 17.2 | – | 79 | – | $NDD(Aa)_{max}$ |
| 1909 | 73.2 | 17.3 | – | 65 | – | |
| 1910 | 30.9 | 17.6 | – | 77 | – | $Aa_{max}$ |
| 1911 | 9.5 | 16.0 | – | 76 | – | |
| 1912 | 6.0 | 9.0 | – | 17 | – | |
| SC15 | | | | | | |
| 1913 | 2.4 | 8.7 | – | 15 | – | $R_{min}$, $Aa_{min}$, $NDD(Aa)_{min}$ |
| 1914 | 16.1 | 10.1 | – | 27 | – | |
| 1915 | 79.0 | 15.7 | – | 72 | – | |
| 1916 | 95.0 | 19.9 | – | 111 | – | |
| 1917 | 173.6 | 18.3 | – | 82 | – | $R_{max}$ |
| 1918 | 134.6 | 21.7 | – | 127 | – | $NDD(Aa)_{max}$ |
| 1919 | 105.7 | 22.6 | – | 125 | – | $Aa_{max}$ |
| 1920 | 62.7 | 17.7 | – | 81 | – | |
| 1921 | 43.5 | 16.6 | – | 55 | – | |
| 1922 | 23.7 | 18.8 | – | 102 | – | |
| SC16 | | | | | | |
| 1923 | 9.7 | 10.4 | – | 30 | – | $R_{min}$ |
| 1924 | 27.9 | 9.3 | – | 29 | – | $Aa_{min}$, $NDD(Aa)_{min}$ |
| 1925 | 74.0 | 13.1 | – | 47 | – | |
| 1926 | 106.5 | 20.0 | – | 96 | – | |
| 1927 | 114.7 | 16.7 | – | 70 | – | |
| 1928 | 129.7 | 17.8 | – | 78 | – | $R_{max}$ |
| 1929 | 108.2 | 19.5 | – | 99 | – | |
| 1930 | 59.4 | 28.7 | – | 181 | – | $Aa_{max}$, $NDD(Aa)_{max}$ |
| 1931 | 35.1 | 16.9 | – | 85 | – | |
| 1932 | 18.6 | 19.1 | 11.5 | 111 | 39 | |
| SC17 | | | | | | |
| 1933 | 9.2 | 16.4 | 10.1 | 82 | 24 | $R_{min}$ |
| 1934 | 14.6 | 13.5 | 7.2 | 54 | 9 | $Aa_{min}$, $Ap_{min}$, $NDD(Aa)_{min}$, $NDD(Ap)_{min}$ |
| 1935 | 60.2 | 15.7 | 8.9 | 65 | 22 | |
| 1936 | 132.8 | 15.4 | 9.1 | 70 | 25 | |
| 1937 | 190.6 | 19.1 | 12.4 | 91 | 40 | $R_{max}$ |
| 1938 | 182.6 | 23.6 | 15.2 | 116 | 63 | |
| 1939 | 148.0 | 23.3 | 16.5 | 115 | 66 | |
| 1940 | 113.0 | 23.6 | 16.0 | 118 | 52 | |
| 1941 | 79.2 | 25.0 | 16.9 | 123 | 58 | |
| 1942 | 50.8 | 21.8 | 13.8 | 127 | 56 | |
| 1943 | 27.1 | 25.9 | 16.9 | 161 | 84 | $Aa_{max}$, $Ap_{max}$, $NDD(Aa)_{max}$, $NDD(Ap)_{max}$ |
| SC18 | | | | | | |
| 1944 | 16.1 | 17.9 | 10.8 | 83 | 36 | $R_{min}$ |
| 1945 | 55.3 | 16.4 | 10.4 | 63 | 25 | $Aa_{min}$, $Ap_{min}$, $NDD(Aa)_{min}$, $NDD(Ap)_{min}$ |
| 1946 | 154.3 | 25.4 | 18.7 | 113 | 65 | |
| 1947 | 214.7 | 25.3 | 18.8 | 129 | 75 | $R_{max}$ |
| 1948 | 193.0 | 22.6 | 15.4 | 120 | 51 | |
| 1949 | 190.7 | 21.3 | 15.4 | 99 | 52 | |
| 1950 | 118.9 | 25.3 | 18.0 | 138 | 80 | |
| 1951 | 98.3 | 28.8 | 22.3 | 162 | 113 | $Aa_{max}$, $Ap_{max}$ |
| 1952 | 45.0 | 28.0 | 21.2 | 168 | 114 | $NDD(Aa)_{max}$, $NDD(Ap)_{max}$ |
| 1953 | 20.1 | 22.3 | 15.6 | 121 | 93 | |
| SC19 | | | | | | |
| 1954 | 6.6 | 17.3 | 11.0 | 71 | 26 | $R_{min}$, $Aa_{min}$, $Ap_{min}$, $NDD(Aa)_{min}$ |
| 1955 | 54.2 | 17.7 | 11.3 | 83 | 24 | $NDD(Ap)_{min}$ |
| 1956 | 200.7 | 24.8 | 18.1 | 144 | 67 | |
| 1957 | 269.3 | 29,4 | 20.2 | 157 | 83 | $R_{max}$ |
| 1958 | 261.7 | 28.6 | 19.3 | 163 | 81 | |
| 1959 | 225.1 | 30.3 | 21.4 | 166 | 92 | |
| 1960 | 159.0 | 32.9 | 23.7 | 186 | 100 | $Aa_{max}$, $Ap_{max}$, $NDD(Aa)_{max}$, $NDD(Ap)_{max}$ |

| Year | *R* | *Aa* | *Ap* | NSD(*Aa*) | NSD(*Ap*) | Comments |
|---|---|---|---|---|---|---|
| 1961 | 76.4 | 22.5 | 14.4 | 114 | 52 | |
| 1962 | 53.4 | 21.6 | 12.3 | 112 | 40 | |
| 1963 | 39.9 | 21.4 | 12.6 | 121 | 44 | |
| SC20 | | | | | | |
| 1964 | 15.0 | 17.3 | 10.0 | 81 | 26 | $R_{min}$ |
| 1965 | 22.0 | 14.1 | 7.8 | 51 | 10 | $Aa_{min}$, $Ap_{min}$, NDD($Aa$)$_{min}$, NDD($Ap$)$_{min}$ |
| 1966 | 66.8 | 17.4 | 10.3 | 86 | 21 | |
| 1967 | 132.9 | 19.9 | 12.0 | 83 | 34 | |
| 1968 | 150.0 | 22.6 | 13.5 | 121 | 41 | $R_{max}$ |
| 1969 | 149.4 | 20.1 | 11.4 | 90 | 24 | |
| 1970 | 148.0 | 20.0 | 11.9 | 95 | 31 | |
| 1971 | 94.4 | 20.2 | 11.3 | 97 | 35 | |
| 1972 | 97.6 | 20.7 | 12.6 | 90 | 32 | |
| 1973 | 54.1 | 26.9 | 17.1 | 163 | 82 | |
| 1974 | 49.2 | 30.4 | 19.5 | 212 | 94 | $Aa_{max}$, $Ap_{max}$, NDD($Aa$)$_{max}$, NDD($Ap$)$_{max}$ |
| 1975 | 22.5 | 23.9 | 14.0 | 140 | 62 | |
| SC21 | | | | | | |
| 1976 | 18.4 | 22.3 | 12.9 | 121 | 40 | $R_{min}$ |
| 1977 | 39.3 | 20.3& | 11.9& | 97 | 31 | NDD($Aa$)$_{min}$, NDD($Ap$)$_{min}$ |
| 1978 | 131.0 | 25.7 | 16.9 | 143 | 65 | |
| 1979 | 220.1 | 22.6 | 14.5 | 117 | 43 | $R_{max}$ |
| 1980 | 218.9 | 16.7 | 11.1 | 86 | 27 | $Aa_{min}$, $Ap_{min}$ |
| 1981 | 198.9 | 24.8 | 16.3 | 134 | 61 | |
| 1982 | 162.4 | 34.1 | 22.5 | 210 | 107 | $Aa_{max}$, $Ap_{max}$, NDD($Aa$)$_{max}$, NDD($Ap$)$_{max}$ |
| 1983 | 91.0 | 29.7 | 18.6 | 186 | 89 | |
| 1984 | 60.5 | 27.0 | 18.8 | 184 | 84 | |
| 1985 | 20.6 | 22.7 | 13.7 | 121 | 42 | |
| SC22 | | | | | | |
| 1986 | 14.8 | 21.2 | 12.6 | 102 | 34 | $R_{min}$ |
| 1987 | 33.9 | 19.1 | 10.9 | 83 | 30 | $Aa_{max}$, $Ap_{min}$, NDD($Aa$)$_{min}$, NDD($Ap$)$_{min}$ |
| 1988 | 123.0 | 22.6 | 12.7 | 114 | 35 | |
| 1989 | 211.1 | 31.1 | 19.4 | 177 | 85 | $R_{max}$ |
| 1990 | 191.8 | 26.6 | 16.3 | 154 | 65 | |
| 1991 | 203.3 | 34.3 | 23.4 | 198 | 108 | $Aa_{max}$, $Ap_{max}$, NDD($Aa$)$_{max}$, NDD($Ap$)$_{max}$ |
| 1992 | 133.0 | 27.4 | 16.6 | 160 | 62 | |
| 1993 | 76.1 | 25.5 | 14.6 | 151 | 62 | |
| 1994 | 44.9 | 29.4 | 18.2 | 180 | 89 | |
| 1995 | 25.1 | 21.9 | 12.7 | 128 | 57 | |
| SC23 | | | | | | |
| 1996 | 11.6 | 18.6 | 9.3 | 78 | 22 | $R_{min}$ |
| 1997 | 28.9 | 16.1 | 8.4 | 68 | 14 | $Aa_{min}$, $Ap_{min}$, NDD($Aa$)$_{min}$, NDD($Ap$)$_{min}$ |
| 1998 | 88.3 | 21.2 | 12.0 | 96 | 33 | |
| 1999 | 136.3 | 22.3 | 12.5 | 119 | 48 | |
| 2000 | 173.9 | 25.4 | 15.1 | 135 | 53 | $R_{max}$ |
| 2001 | 170.4 | 22.4 | 12.9 | 103 | 36 | |
| 2002 | 163.6 | 22.7 | 13.1 | 133 | 39 | |
| 2003 | 99.3 | 36.2 | 21.7 | 243 | 114 | $Aa_{max}$, $Ap_{max}$, NDD($Aa$)$_{max}$, NDD($Ap$) $_{max}$ |
| 2004 | 65.3 | 23.1 | 13.4 | 128 | 32 | |
| 2005 | 45.8 | 23.2 | 13.5 | 123 | 44 | |
| 2006 | 24.7 | 16.2 | 8.5 | 73 | 17 | |
| 2007 | 12.6 | 15.0 | 7.5 | 71 | 7 | |
| SC24 | | | | | | |
| 2008 | 4.2 | 14.2 | 6.9 | 58 | 6 | $R_{min}$ |
| 2009 | 4.8 | 8.7 | 3.9 | 10 | 0 | $Aa_{min}$, $Ap_{min}$, NDD($Aa$)$_{min}$, NDD($Ap$)$_{min}$ |
| 2010 | 24.9 | 12.3 | 6.0 | 33 | 7 | |
| 2011 | 80.8 | 14.8 | 7.5 | 52 | 17 | |
| 2012 | 84.5 | 17.0 | 9.1 | 71 | 23 | |
| 2013 | 94.0 | 14.8 | 7.6 | 62 | 15 | |

| Year | *R* | *Aa* | *Ap* | NSD(*Aa*) | NSD(*Ap*) | Comments |
|---|---|---|---|---|---|---|
| 2014 | 113.3 | 15.7 | 7.8 | 61 | 5 | $R_{max}$ |
| 2015 | 69.8 | 22.3 | 12.2 | 116 | 38 | $Aa_{max}$, $Ap_{max}$, NDD($Aa$)$_{max}$, NDD($Ap$)$_{max}$ |
| 2016 | 39.8 | 20.0 | 10.5 | 102 | 26 | |
| 2017 | 21.7 | 19.4 | 10.3 | 94 | 29 | |
| 2018 | 7.0 | 13.9 | 6.9 | 45 | 7 | |
| 2019 | – | – | – | (21) | (3) | |
| 2020 | | | | | | |

Note:
NDD means number of disturbed days, taken to be *Aa* = 25 or greater
*Ap* = 25 or greater
& means, the lowest value in the vicinity of $R_{min}$

**Table 2. Solar and geomagnetic parametric values based on annual counts/averages for SC11-24.**

| Cycle | $R_{min}$ | $R_{max}$ | $Aa_{min}$ | $Aa_{max}$ | $Ap_{min}$ | $Ap_{max}$ | <*R*> | <*Aa*> | <*Ap*> | NDD (*Aa*) | NDD (*Ap*) | NDD (*Aa*) min | NDD (*Ap*) min | NDD (*Aa*) max | NDD (*Ap*) max |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | 13.9 | 232.0 | 18.4? | 23.8 | – | – | 94.5 | 17.2 | – | 849 | – | – | – | 125 | – |
| 12 | 5.7 | 106.1 | 7.1 | 23.1 | – | – | 57.5 | 14.9 | – | 648 | – | 5 | – | 114 | – |
| 13 | 10.4 | 142.0 | 10.8 | 24.3 | – | – | 64.6 | 15.8 | – | 763 | – | 24 | – | 115 | – |
| 14 | 4.6 | 105.5 | 6.2 | 17.6 | – | – | 51.9 | 13.1 | – | 554 | – | 8 | – | 79 | – |
| 15 | 2.4 | 173.6 | 8.7 | 22.6 | – | – | 73.6 | 17.0 | – | 797 | – | 15 | – | 127 | – |
| 16 | 9.7 | 129.7 | 9.3 | 28.7 | – | – | 68.4 | 17.2 | – | 826 | – | 29 | – | 181 | – |
| 17 | 9.2 | 190.6 | 13.5 | 25.9 | 7.2 | 16.9 | 91.6 | 20.3 | 13.0 | 1,122 | 499 | 54 | 9 | 161 | 84 |
| 18 | 16.1 | 214.7 | 16.4 | 28.8 | 10.4 | 22.3 | 110.6 | 23.3 | 16.7 | 1,196 | 704 | 63 | 25 | 168 | 114 |
| 19 | 6.6 | 269.3 | 17.3 | 32.9 | 11.0 | 23.7 | 134.6 | 24.7 | 16.4 | 1,317 | 609 | 71 | 24 | 186 | 100 |
| 20 | 15.0 | 150.0 | 14.1 | 30.4 | 7.8 | 19.5 | 83.5 | 21.1 | 12.6 | 1,309 | 492 | 51 | 10 | 212 | 94 |
| 21 | 18.4 | 220.1 | 20.3& | 34.1 | 11.9& | 22.5 | 116.1 | 24.6 | 15.7 | 1,409 | 589 | 97& | 31& | 210 | 107 |
| 22 | 14.8 | 211.1 | 19.1 | 34.3 | 10.9 | 23.4 | 105.7 | 25.9 | 15.7 | 1,447 | 627 | 83 | 30 | 198 | 108 |
| 23 | 11.6 | 173.9 | 16.1 | 36.2 | 8.4 | 21.7 | 85.1 | 21.9 | 12.3 | 1,370 | 459 | 68 | 14 | 243 | 114 |
| 24 | 4.2 | 113.3 | 8.7 | 22.3? | 3.9 | 12.2? | 49.5* | 15.7* | 8.1* | (726)* | (175)* | 10 | 0 | 116 | 38 |
| mean | 10.2 | 173.7 | 13.3 | 25.6 | 8.9 | 20.3 | 84.8 | 19.5 | 13.8 | 1,002.8 | 519.4 | 44.5 | 17.9 | 159.6 | 94.9 |
| *sd* | 5.0 | 51.5 | 4.8 | 8.4 | 2.6 | 4.0 | 25.7 | 4.2 | 2.9 | 315.5 | 160.9 | 31.1 | 11.2 | 47.8 | 25.2 |

Note: * means incomplete
& means lowest value in vicinity of $R_{min}$
? means unsure

Figure 1 displays (a) the annual variation of *R* spanning 1867–2018, (b) the annual variation of the *Aa*-geomagnetic index spanning 1868–2018, and (c) the annual variation of the *Ap*-geomagnetic index spanning 1932–2018. In each frame, the occurrences of sunspot minimum ($R_{min}$) and maximum ($R_{max}$) are identified using unfilled and filled triangles, respectively. The numbers 11–24 identify specific SC. The circled numbers 1–5 correspond to times when changes occurred in the location of the magnetic observatories used for measuring the *Aa*-index values (see Legend).

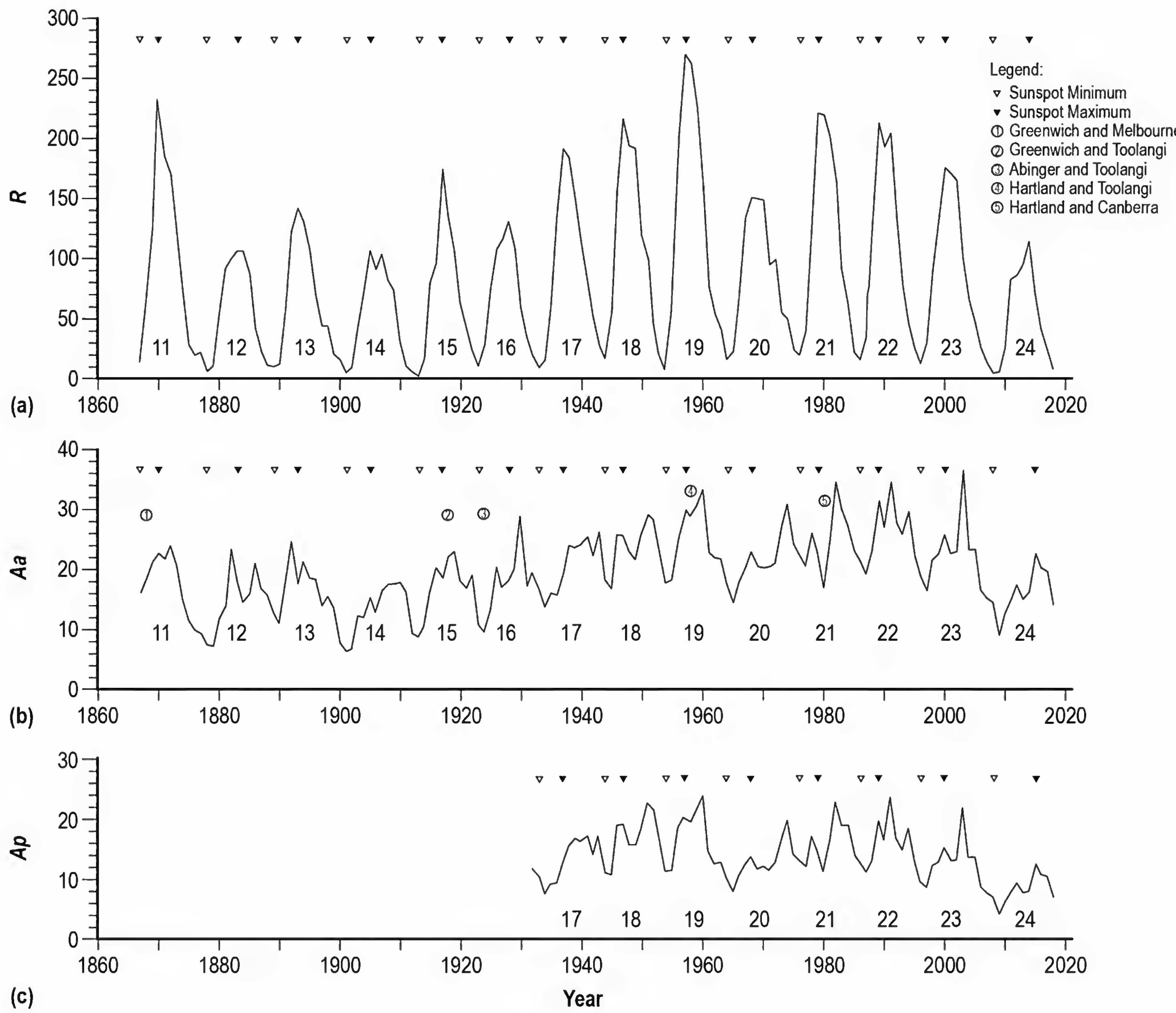


**Figure 1. Annual variation of (a) *R* spanning 1867-2018, (b) *Aa* spanning 1868–2018, and (c) *Ap* spanning 1932–2018.**

Recall that the *Aa*-geomagnetic index is a simple global measure of the geomagnetic fluctuations of the Earth's magnetic field due to changing conditions in the solar wind at Earth. The daily 3-hr *aa*-index (having units of nT, as does the ap index) is derived from the K indices (Patel 1977) from two nearly antipodal magnetic observatories. The resultant daily *Aa*-index is the rounded average of the eight 3-hr *aa*-index values, the monthly *Aa*-index is the rounded average of the daily *Aa*-index values, and the yearly *Aa*-index is the rounded average of the monthly *Aa*-index values. Currently (since 1980), the two observatories used in the computation of the *Aa*-index are Hartland in the United Kingdom and Canberra in Australia. Nevanlinna and Kataja (1993) have generated an extension to the *Aa*-index going back to 1844 based on magnetic observations made at the Helsinki magnetic observatory, but this extension has not been used in this analysis (except for the possible determination of $Aa_{min}$ for SC11). The planetary *Ap*-index values are similarly calculated to that of the *Aa*-index but are based on a larger number of worldwide magnetic observatories (Rostoker 1972).

Figure 1 shows that $R$ increased in strength (i.e., amplitude) from about SC12 to a peak in SC19 and then decreased in strength from SC19 through SC24. Coupled with this rise and fall in $R$ has been a similar rise and fall in the geomagnetic index values, albeit with subtle differences. For example, the peak associated with geomagnetic indices is not really the occurrence of a single SC, but rather it is found to span a broader interval over several SC (i.e., SC17–SC23), with $Aa_{max}$ for SC21–SC23 being larger than that found for SC19. Two other differences are that (1) $Aa_{min}$ and $Ap_{min}$ generally occur after $R_{min}$ (i.e., usually in the year following $R_{min}$, true for 10 of 13 SCs, excluding SC11), and (2) $Aa_{max}$ and $Ap_{max}$ generally occur after $R_{max}$ (true for 12 of 14 SCs; SC12 and SC13 had $Aa_{max}$ the year before $R_{max}$). Additionally, $Aa_{min}$ has occurred concurrently with $R_{min}$ for only SC14, SC15, and SC19, and $Aa_{min}$ and $Aa_{max}$ have always occurred concurrently with $Ap_{min}$ and $Ap_{max}$, respectively, for all cycles. (Based on Nevanlinna and Kataja 1993, $Aa_{min}$ for SC11 appears to have occurred concurrently with $R_{min}$ rather than in the year following $R_{min}$, having a value of about 16.0 ± 1.0 nT.)

Figure 2 displays the annual behavior of (a) NDD($Aa$) and (b) NDD($Ap$). The occurrences of $R_{min}$ and $R_{max}$ are again shown, as before, using unfilled and filled triangles, respectively. NDD($Aa$)$_{min}$ generally is found to follow $R_{min}$ by 1 year (with the exception for SC15 and SC19 and probably SC11) and NDD($Aa$)$_{max}$ generally is found to follow $R_{max}$ (the lone exception being SC13, in which it is found to precede $R_{max}$ by 1 year). NDD($Ap$)$_{min}$ is found to have occurred concurrently with NDD($Aa$)$_{min}$, except for SC19 and SC24, where it is found to have followed NDD($Aa$)$_{min}$ by 1 year. NDD($Ap$)$_{max}$ is found to have always been concurrent with NDD($Aa$)$_{max}$. As with $R$ and $Aa$, NDD($Aa$) is found to have risen from SC12 to a broad peak spanning SC17–SC23 but then to have fallen very sharply in SC24. NDD($Aa$) was greatest (243) in 2003 (SC23), while NDD($Ap$) was greatest (114) in 1952 (SC18) and 2003 (SC23).

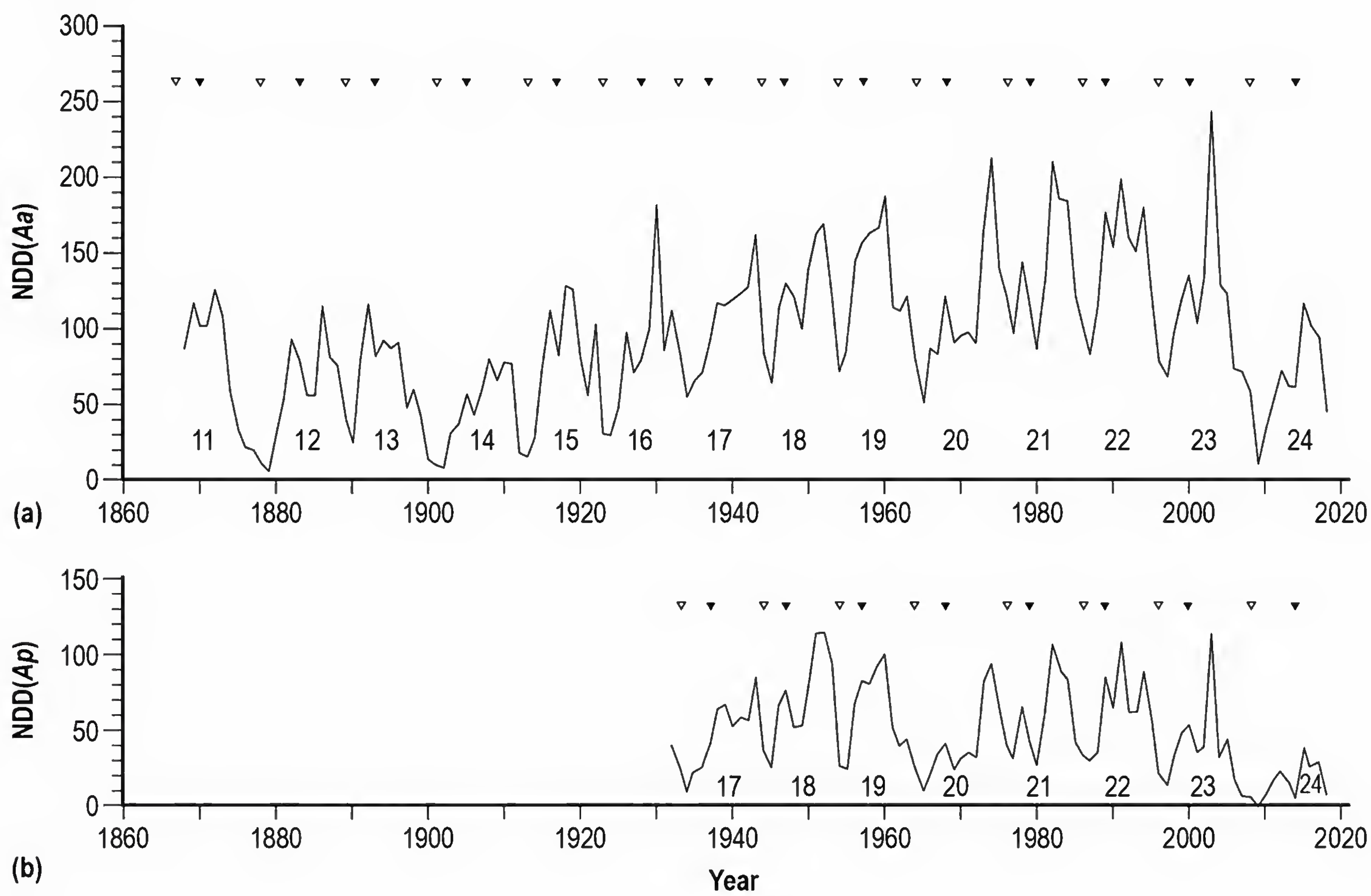


**Figure 2. Annual behavior of (a) NDD(*Aa*) spanning 1868-2018 and (b) NDD(*Ap*) spanning 1932–2018.**

Figure 3 depicts cyclic values of min, max, and mean for (a) $R$, (b) $Aa$, (c) $Ap$, and cyclic counts for (d) NDD($Aa$) and NDD($Ap$). For all parameters, SC24 appears to mark a return to lower values not seen since SC12–SC16. (The arrows denote that subtle changes might have to be made in the values since $Aa_{min}$ is not exactly known for SC11 and the end of SC24 has yet to occur.)

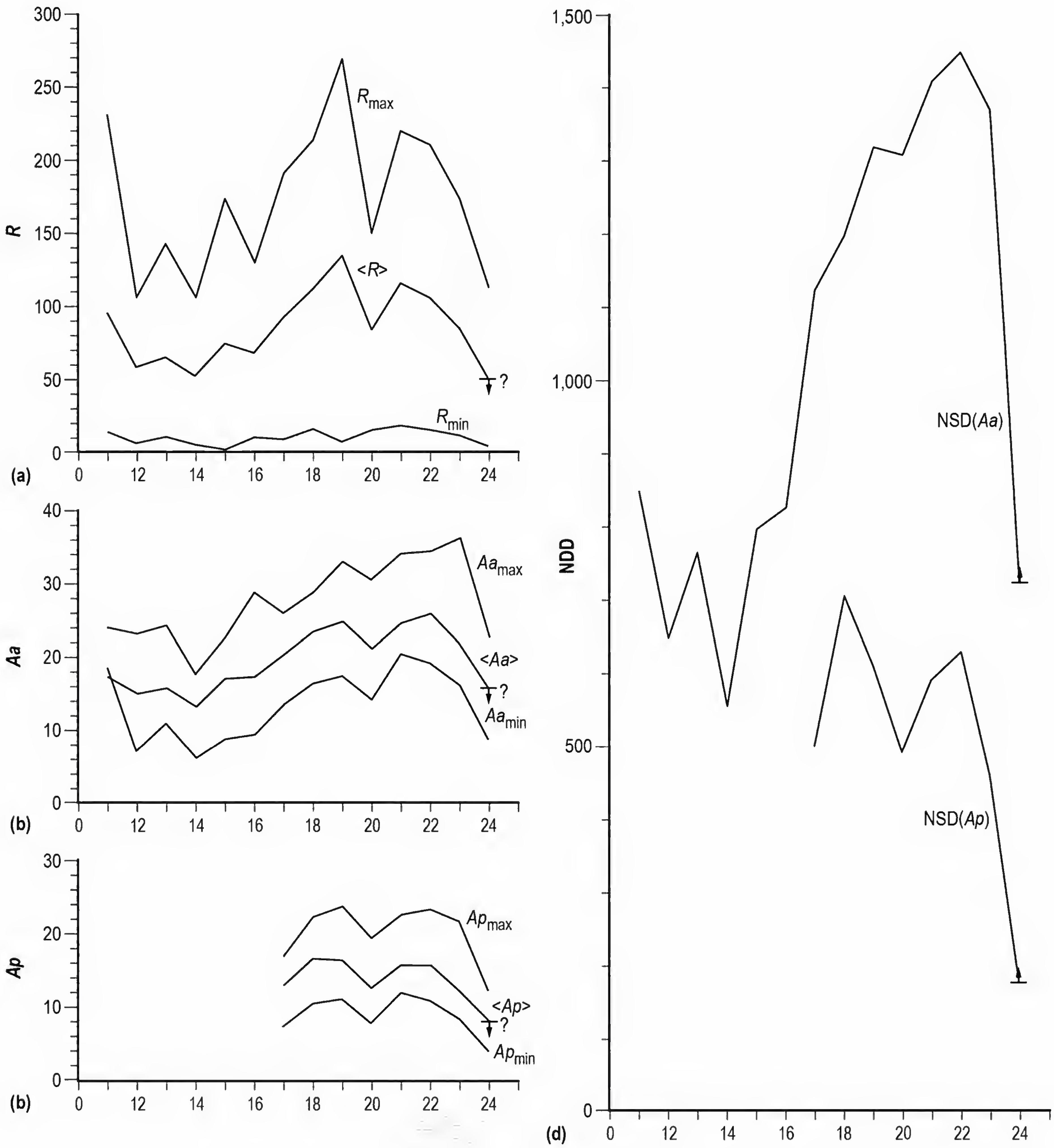


**Figure 3. Cyclic values of min, max, and mean for (a) *R*, (b) *Aa*, (c) *Ap*, and cyclic counts for (d) NDD(*Aa*) and NDD(*Ap*).**

Figure 4 shows the scatterplots of the maximum versus minimum values for (a) *Aa* and (b) *Ap*. Both scatterplots are inferred to be highly statistically important. Given in each frame is the inferred linear regression equation ($y$), the linear correlation coefficient ($r$), the standard error of estimate ($S_{yx}$), the $t$-statistic, and the confidence level ($cl$) for the inferred regression. The numbers 11–24 are the individual SCs. The result of Fisher's exact test for the $2 \times 2$ contingency tables (determined by the vertical and horizontal medians) are shown giving the probability of obtaining the observed result, or one more suggestive of a departure from independence, $P$. Plainly, the observed $Aa_{min}$ and $Ap_{min}$ provide early estimates for the later occurring $Aa_{max}$ and $Ap_{max}$ values. ($P_o$ is the probability of obtaining the observed result only.)

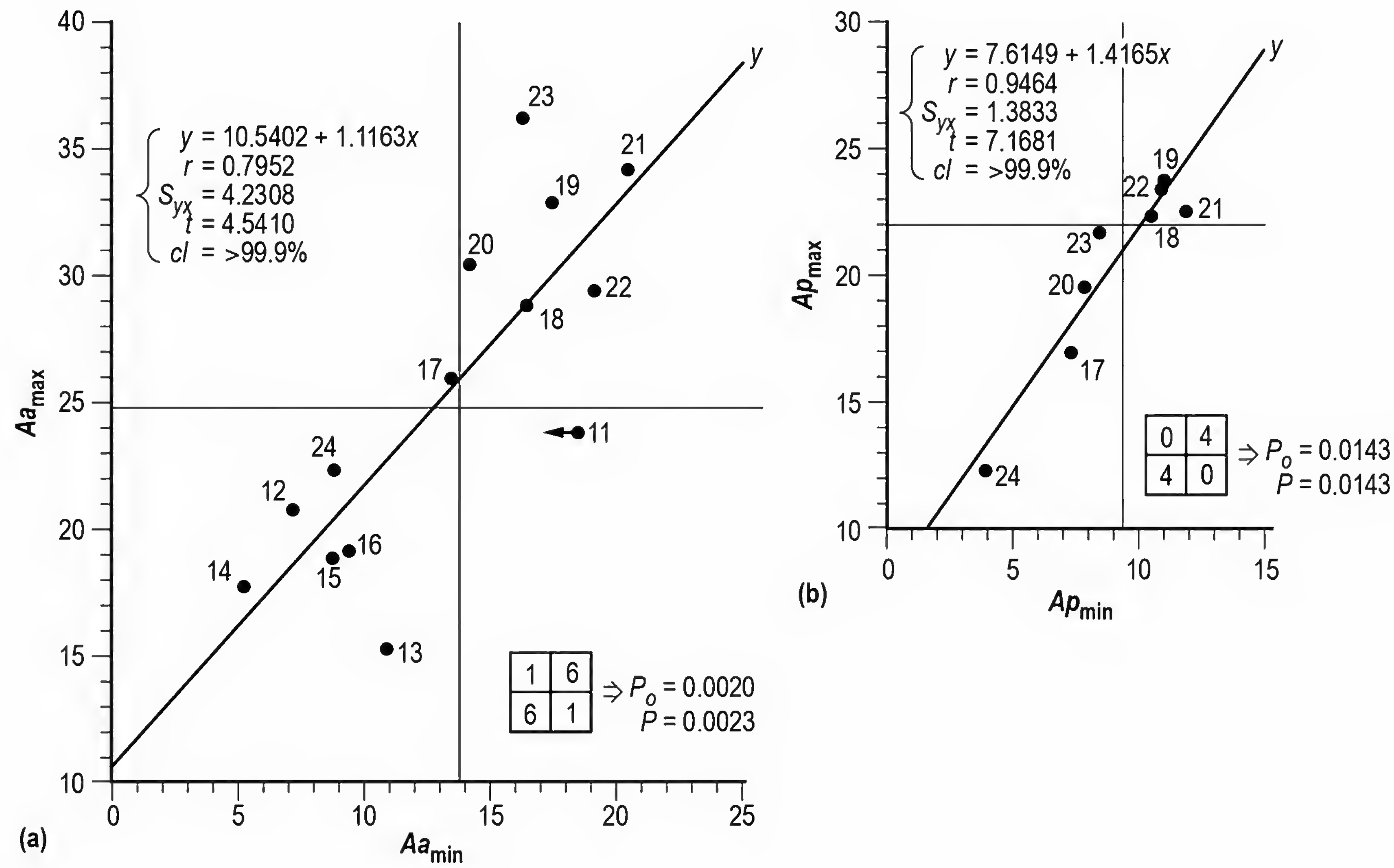


**Figure 4. Scatterplots of the maximum versus minimum values for (a) *Aa* and (b) *Ap*.**

Figure 5 shows scatterplots of $R_{max}$ versus (a) $R_{min}$, (b) $Aa_{min}$, and (c) $Ap_{min}$. The results of linear regression analysis and Fisher's exact test for $2 \times 2$ contingency tables are also given. Noticeable is that all three scatterplots suggest a positive correlation to exist between the minimum values and the later occurring $R_{max}$ values. The weakest inferred correlation is the one between $R_{max}$ and $R_{min}$, having $r = 0.4788$, suggesting that the inferred correlation can explain only about 23% of the variance in $R_{max}$ (i.e., $r^2 = 0.2292$). The inferred correlation has $S_{yx} = 47.0248$ and $t = 1.8892$, meaning that the inferred correlation is statistically significant at $cl$ >90%. Based on Fisher's exact test for $2 \times 2$ contingency tables, the probability of obtaining the observed result, or one more suggestive of a departure from independence, is $P = 0.1431$, not particularly strong. As an example, assuming $R_{min} = 2$, one estimates $R_{max} = 133.2 \pm 47.0$ (i.e., the $\pm 1$ standard error of estimate prediction interval) using the inferred correlation and possibly $R_{max}$ <174 based on the $2 \times 2$ contingency table (i.e., the estimated value of $R_{max}$ would be expected to fall in the lower-left quadrant of Figure 5(a)).

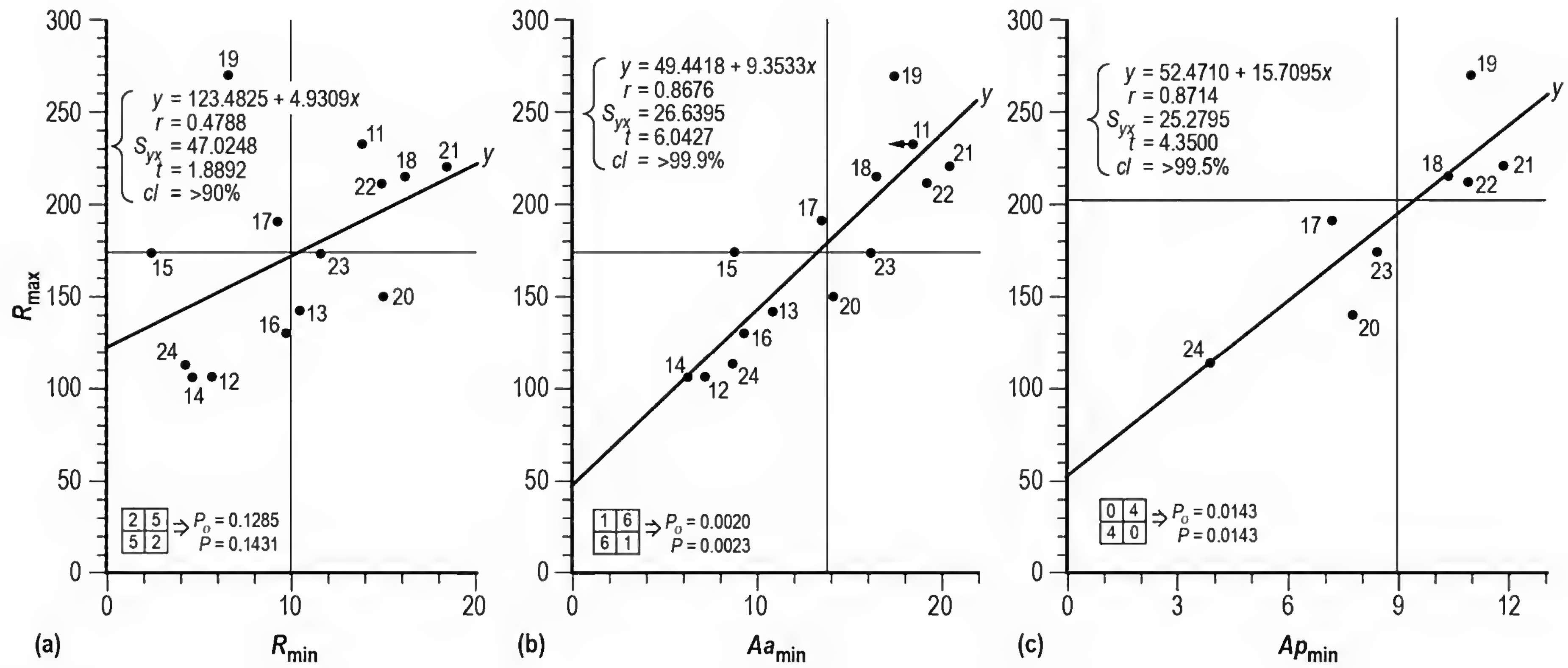


**Figure 5. Scatterplots of $R_{max}$ versus (a) $R_{min}$, (b) $Aa_{min}$, and (c) $Ap_{min}$.**

The stronger correlations are those based on the geomagnetic indices. For $R_{max}$ versus $Aa_{min}$, the inferred regression equation, $y = 49.4418 + 9.3533x$, has $r = 0.8676$, suggesting that the inferred correlation can explain about 75% of the variance in $R_{max}$ (i.e., $r^2 = 0.7527$). The inferred correlation has $S_{yx} = 26.6395$ and $t = 6.0427$, meaning that the inferred correlation is statistically significant at $cl$ >99.9%. Based on Fisher's exact test for 2×2 contingency tables, the probability of obtaining the observed result, or one more suggestive of a departure from independence, is $P = 0.0023$. As an example, assuming $Aa_{min} = 10$, one estimates $R_{max} = 143 \pm 26.6$ and very probably $R_{max} < 174$ (i.e., the value of $R_{max}$ would be expected to fall within the lower-left quadrant of Figure 5(b)). For $R_{max}$ versus $Ap_{min}$, one finds $r = 0.8714$, $r^2 = 0.7593$, $S_{yx} = 25.2795$, $t = 4.35$, $cl$ >99.5%, and $P = 0.0143$. Assuming $Ap_{min} = 5$, one estimates $R_{max} = 131 \pm 25.3$ and very probably $R_{max} < 201$, again having a value of $R_{max}$ in the lower-left quadrant of Figure 5(c).

The estimates of $R_{max}$ are greatly improved using a bivariate fit, one combining the effects of $R_{min}$ and either $Aa_{min}$ or $Ap_{min}$ (i.e., $R_{max}$ versus $y'$). Figure 6 displays the scatterplots of $R_{max}$ versus (a) $R_{min}$ and $Aa_{min}$ and (b) $R_{min}$ and $Ap_{min}$. Both inferred correlations are highly statistically significant. As an example, assuming $R_{min} = 2$ and $Aa_{min} = 10$ nT, one computes $y' = 175.5861$ and $R_{max} = 175.6 \pm 9.2$. Assuming $R_{min} = 2$ and $Ap_{min} = 5$ nT, one computes $y' = 159.1707$ and $R_{max} = 159.2 \pm 12.1$. The overlap in the two estimates is $R_{max} = 166.4$–$171.3$. Such a value, if true, suggests that the hypothetical SC would be comparable in size to that of SC23 and larger than that of SC24. (The main driver in the bivariate fits is $Aa_{min}$ and $Ap_{min}$; therefore, a smaller $Aa_{min}$ or $Ap_{min}$ yields a smaller $R_{max}$, while a larger $Aa_{min}$ or $Ap_{min}$ yield larger $R_{max}$.)

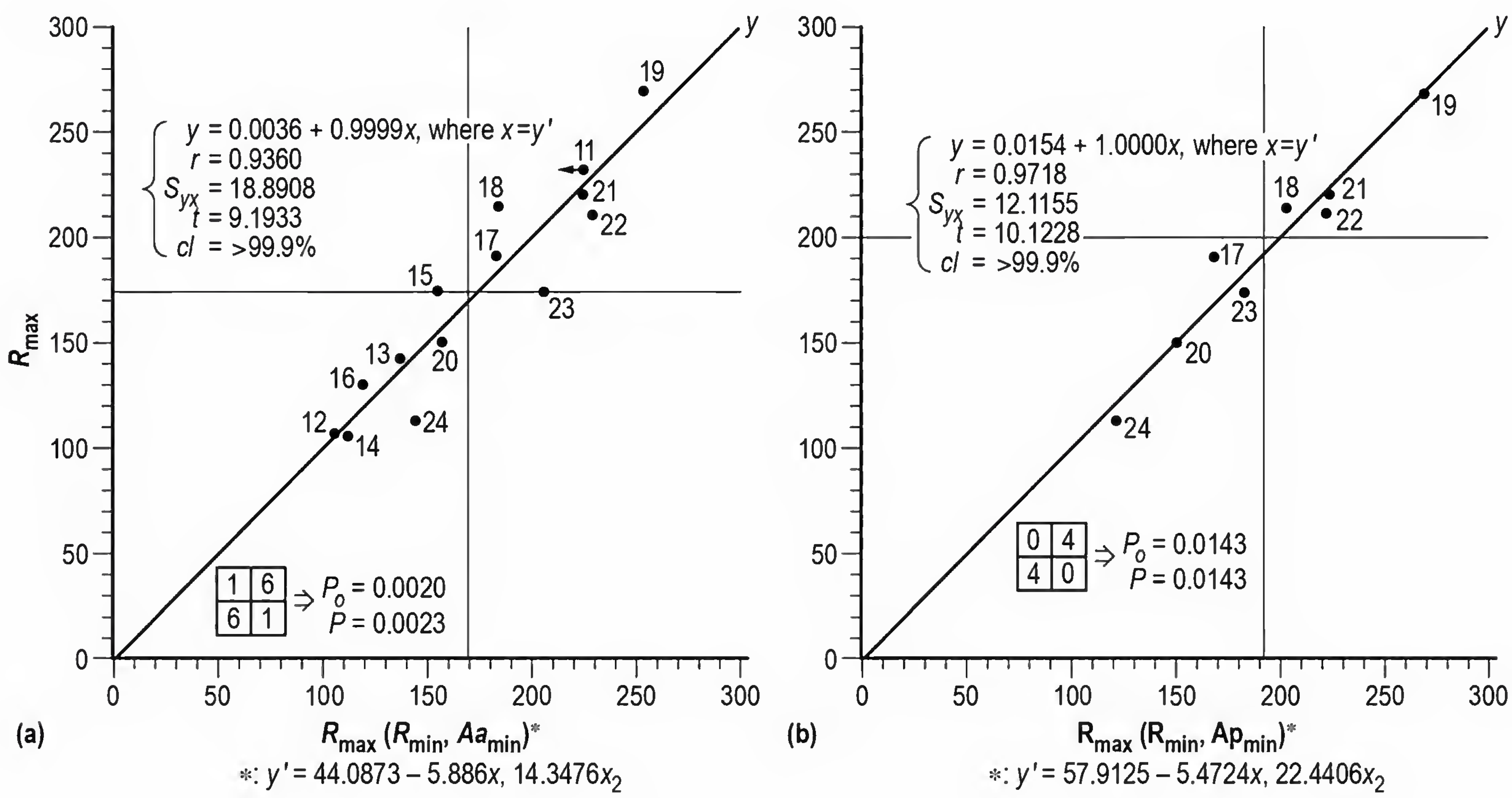


**Figure 6. Scatterplots of $R_{max}$ versus (a) $R_{min}$ and $Aa_{min}$, and (b) $R_{min}$ and $Ap_{min}$.**

Figure 7 displays scatterplots of maximum amplitude for *R* and NDD, respectively, versus (a) and (b) NDD($Aa_{min}$), and (c) and (d) NDD($Ap_{min}$). All scatterplots are inferred to be statistically important, especially, those for $R_{max}$ versus NDD($Aa_{min}$) and $R_{max}$ versus NDD($Ap_{min}$).

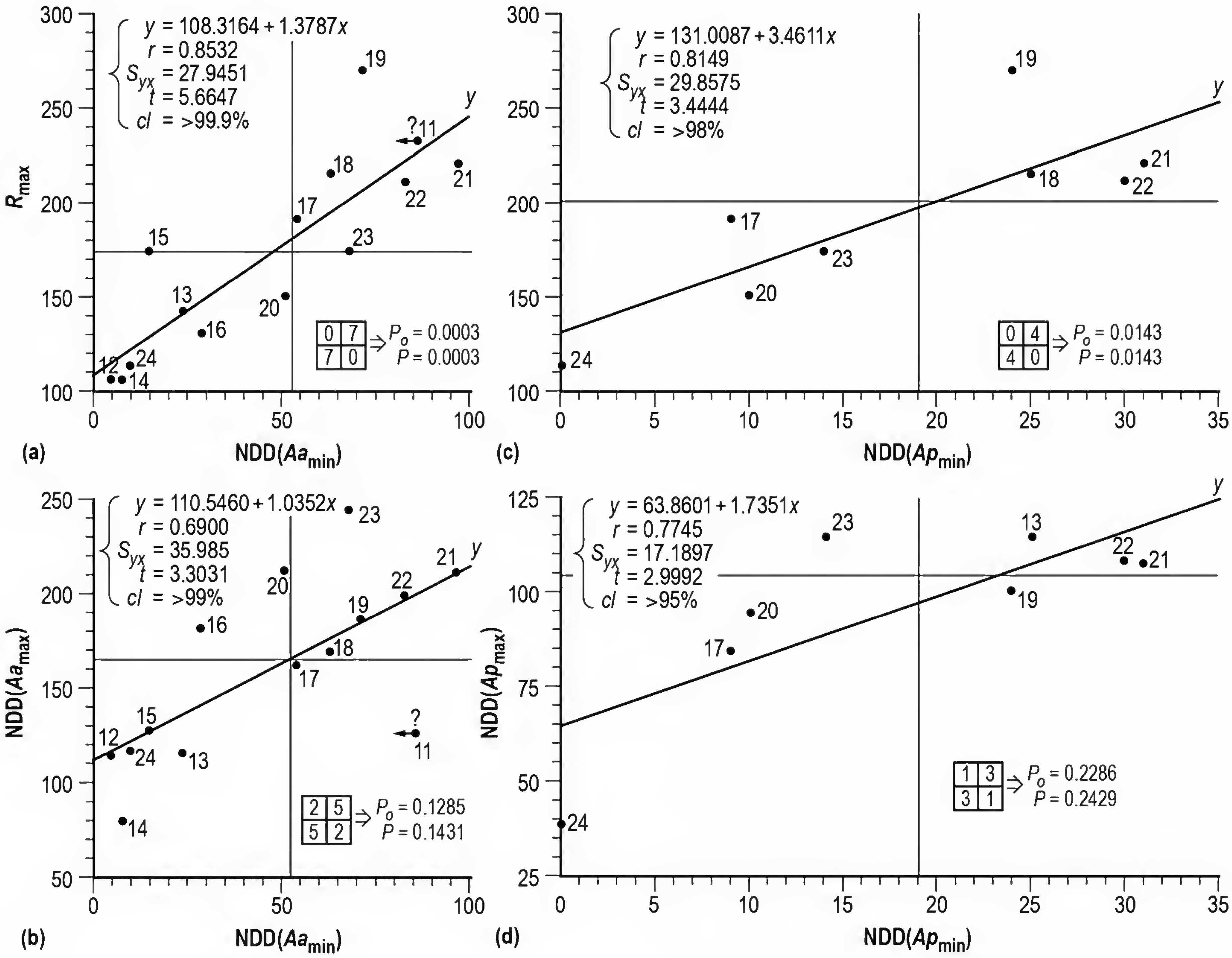


**Figure 7. Scatterplots of maximum amplitude for *R* and NDD, respectively, versus (a) and (b) NDD($Aa_{min}$), and (c) and (d) NDD($Ap_{min}$).**

Figure 8 shows the monthly variations of (a) *R*, (b) *Aa*, (c) *Ap*, (d) NDD(*Aa*), and (e) NDD(*Ap*) for the interval January 2018–August 2019 and shows previous minimum values for SC11–SC24. The trend is obviously downward for all parameters. For January–December 2018, $R = 7$, $Aa = 13.9$ nT, $Ap = 6.9$ nT, NDD(*Aa*) = 45, and NDD(*Ap*) = 7. For the interval January–August 2019, $R = 5.0$, $Aa = 10.7$ nT, $Ap = 6.1$ nT, NDD(*Aa*) = 21, and NDD(*Ap*) = 3. Therefore, one anticipates that all parameters will continue to decrease in value through 2019 into 2020, with sunspot minimum expected in 2020 or later (Wilson 2016, 2017, 2019a, b). For *R*, *Aa* and *Ap*, the observed minimum values for previous SC are identified. Values for 2019 suggest that the minimum values for SC25 will be comparable to the lowest values found for previous cycles. For NDD(*Aa*), the count for 2019 (=21, thus far) is below all previous SC, except SC12 (5), SC14 (8), SC15 (15), and SC24 (10). For NDD($Ap_{min}$), the count for 2019 (3, thus far) is below all previous SC, except SC24 (0).

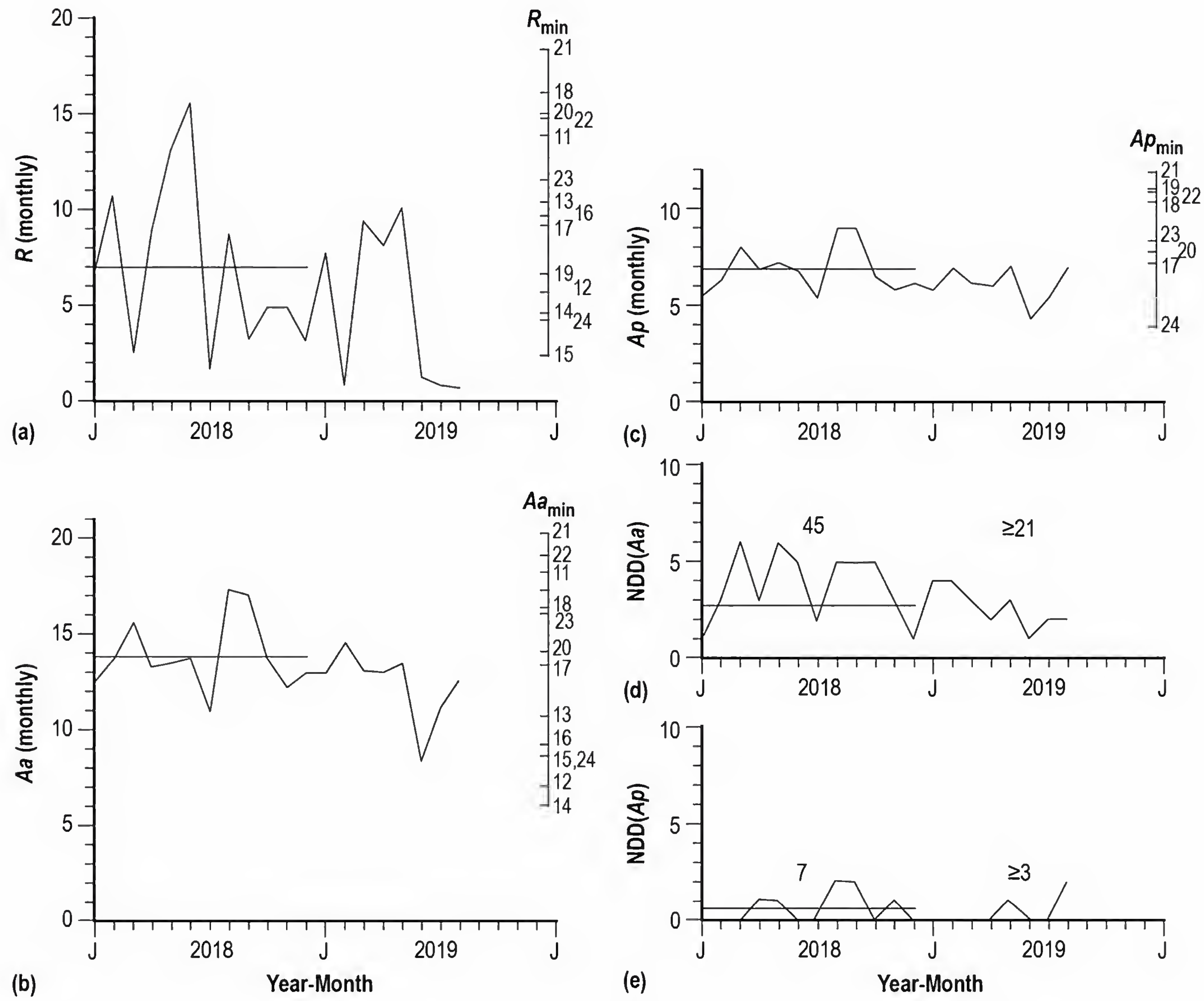


**Figure 8. Monthly variations of (a) *R*, (b) *Aa*, (c) *Ap*, (d) NDD(*Aa*), and (e) NDD(*Ap*) for the interval January 2018–August 2019 and previous minimum values for SC11–SC24.**

Now, Thompson (1993) noted that the NDD in the current SC ($N_c$, following his nomenclature) can be used to estimate $R_{max}$ in the next SC ($R_n$). In particular, he compared the sum of two consecutive SC amplitudes (i.e., $R_c+R_n$) against $N_c$ using the *Ap* index. In order to extend the *Ap* index backwards in time (i.e., to include SC11–SC16), the *Aa*-index was used to derive *Ap* equivalents. In the analysis here, the combined sum of two consecutive SC amplitudes ($R_c+R_n$) is compared separately against $N_c$ (*Aa*) and $N_c$ (*Ap*).

Figure 9 displays scatterplots of ($R_c+R_n$) versus (a) $N_c$ (*Ap*) and (b) $N_c$ (*Aa*). Both inferred correlations are found to be statistically significant at $cl > 95\%$. The inferred correlation between ($R_c+R_n$) and $N_c$ (*Ap*) has the higher $R = 0.7890$ as compared to the correlation between ($R_c + R_n$) and $N_c$ (*Aa*), which has $r = 0.6896$, and it also has the smaller $S_{yx} = 41.5123$. On the other hand, based on Fisher's exact test for $2 \times 2$ contingency tables, the stronger association is the one between ($R_c + R_n$) and $N_c$ (*Aa*), having $P = 0.0251$ (due primarily to more data entries). SC24 has had far fewer $N_c$ than any other SC on the basis of using *Ap*; however, it has slightly more $N_c$ than

SC12 and SC14 on the basis of using *Aa*. Through August 2019, $N_c$ (*Aa*) has totaled about 726 days, and $N_c$ (*Ap*) has totaled about 175 days. Plainly, $N_c$ (*Aa*) and $N_c$ (*Ap*) for SC24 will fall within the lower-left quadrant of the scatterplots. On the basis of the inferred linear regressions, one estimates $(R_c + R_n) > 183.1 \pm 41.5$ using $N_c$ (*Ap*) and $(R_c + R_n) > 295.6 \pm 73.4$ using $N_c$ (*Aa*). Since, $R_c = 113.3$ for SC24, one estimates $R_n > 69 \pm 41.5$ from $N_c$ (*Ap*) and $R_n > 182.3 \pm 73.4$ from $N_c$ (*Aa*) for SC25, yielding an overlap of 108.9–111.3, inferring that SC25 might be of similar amplitude to SC24. (The overlap would be greater using larger prediction intervals. The ±1 standard error of estimate prediction interval suggests a probability of occurrence of only about 68.3%.)

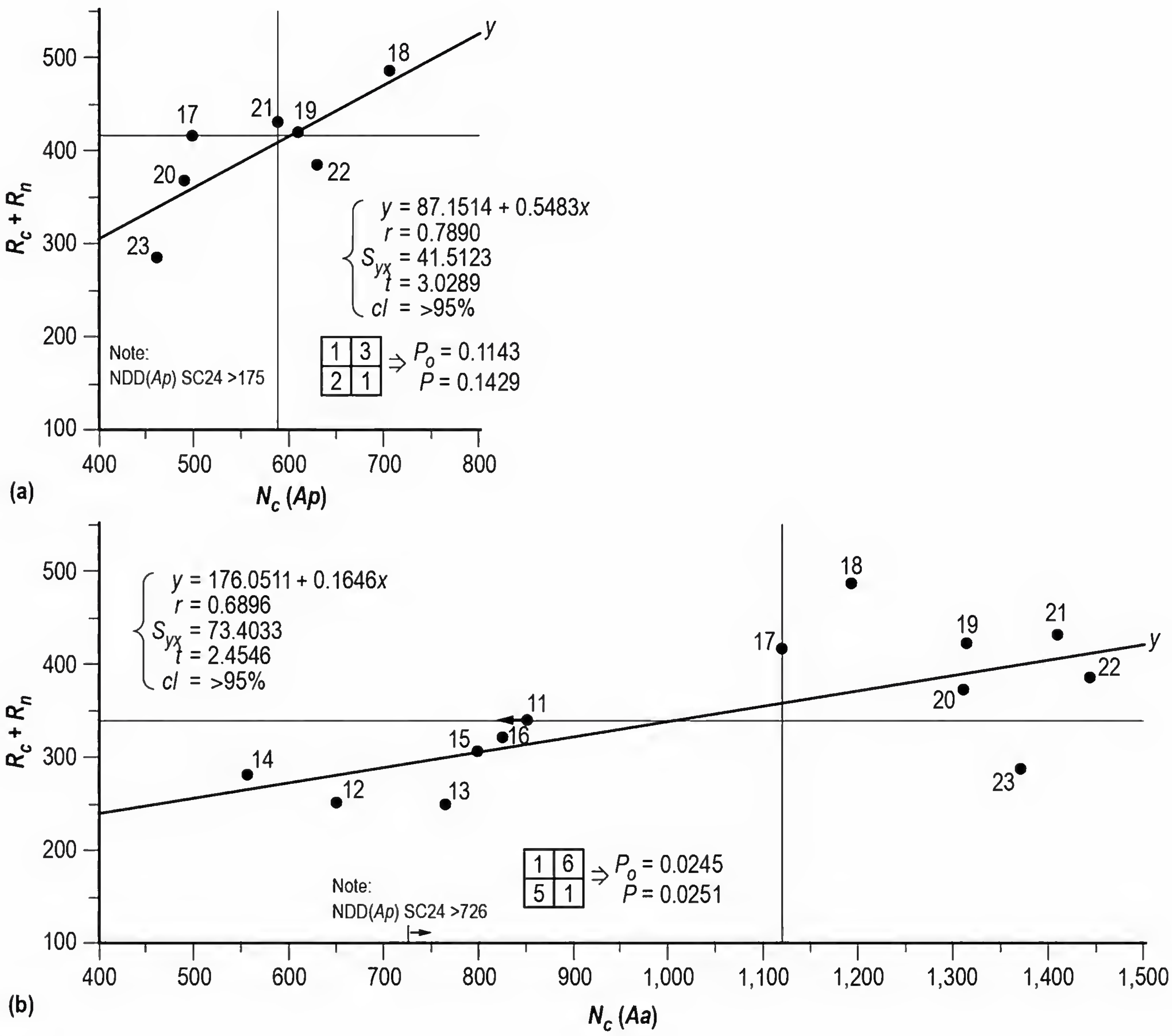


**Figure 9. Scatterplots of ($R_c + R_n$) versus (a) $N_c$ (*Ap*) and (b) $N_c$ (*Aa*).**

Previously, Wilson (2019a) showed that if the even-odd cycle amplitude effect is operative for this current even-odd cycle pair (i.e., SC24/25 is not a statistical outlier as was SC22/23), then $R_{max} = 170.4 \pm 13.7$ for SC25 (compared to SC24 = 113.3). Similarly, based on the belief that the highest latitude spot minimum (HLSmin) occurred in 2017 and measured 19°, $R_{max} = 136.2 \pm 14.8$ for SC25, with both predictions being ±1 standard error prediction intervals. The 90%-prediction intervals for these two estimates are 170.4±24.4 and 136.2±26.4, yielding an overlap of about 146.0–162.6.

In the companion paper to the present paper (Paper I, Wilson 2019b), it was noted that smoothed monthly mean sunspot number maximum *RM* averages about 224.2 ± 37.2 for fast-rising SC (i.e., SC having ascent duration ASC <49 months) and only 147.3 ± 43.4 for slow-rising SC (i.e., SC having ASC ≥49 months). SC24 had ASC = 64 months (and *RM* = 116.4), one month longer than SC23, inferring that SC24 is a slow-rising SC. Slow-rising SC also tend to be SC of long duration (i.e., minimum-to-minimum period PER ≥135 months), true for 9 of 12 slow-rising SC. Hence, SC24 is expected to be a long-period SC ending sometime in 2020 or later (certainly on or after March 2020 based on smoothed monthly mean sunspot number). Through September 2019, there has yet to occur any new cycle sunspots at higher latitude (i.e., ≥30°) and smoothed monthly mean sunspot number continues to decline, measuring 4.6 in March 2019. Wilson (2019b) also showed that the greatest negative change in smoothed monthly mean sunspot number (i.e., $gn\Delta R$) during the decline of SC24 measured –6.4, a value suggesting that SC24's PER = 141.1 ± 11.7 months, with 10 of 12 SC having $gn\Delta R$ = –8.7 or smaller being of long period (PER ≥135 months).

In this paper (Paper II), it has been shown that the long-term cyclic behavior of *R* is coupled with the cyclic behavior of geomagnetic indices, in particular *Aa*, *Ap*, and NDD. For all parameters, it appears that SC24 marks a return to smaller parametric values not seen since SC12–SC16, suggesting that SC25, and perhaps following SC, might well be of smaller amplitude. It has also been shown that the minimum value in the geomagnetic indices provides a reliable estimate some 2–4 years in advance for the size ($R_{max}$) of the ongoing SC, with minimum values in the geomagnetic indices nearly always occurring in the year following $R_{min}$. Linear regression correlations between $R_{max}$ and $Aa_{min}$ or $Ap_{min}$ measure $r = 0.87$, while bivariate correlations between $R_{max}$ and $R_{min}$ and $Aa_{min}$ or $R_{min}$ and $Ap_{min}$ measure $r = 0.94$ and 0.97, respectively. It is important to note that, at present, minimum amplitudes of *R*, *Aa*, *Ap*, and NDD have not yet occurred. However, based on present values of *R*, *Aa*, *Ap*, and NDD, one can estimate, as an upper limit, $R_{max}$. For 2019 (January–August) one computes the means for *R*, *Aa* and *Ap* to be 5.0, 12.4 nT, and 6.1 nT, respectively. Therefore, based on the inferred linear regression fits, one predicts $R_{max} = 150.1 \pm 47.0$ (based on *R*), $R_{max} = 165.4 \pm 26.6$ (based on *Aa*), and $R_{max} = 148.3 \pm 25.3$ (based on *Ap*), all ±1 standard error of estimate prediction intervals. For the bivariate fits, one predicts $R_{max} = 192.0 \pm 18.9$ ($R_{max}$ versus $R_{min}$ and $Aa_{min}$) and $R_{max} = 167.4 \pm 12.1$ ($R_{max}$ versus $R_{min}$ and $Ap_{min}$). Actual estimates will be smaller because minimum values have not yet occurred. Figure 10 is included to show the relationship between (a) *Rm* and $R_{min}$ and (b) *RM* and $R_{max}$. (*Rm* is always ≤ $R_{min}$ and *RM* is always ≥ $R_{max}$.)

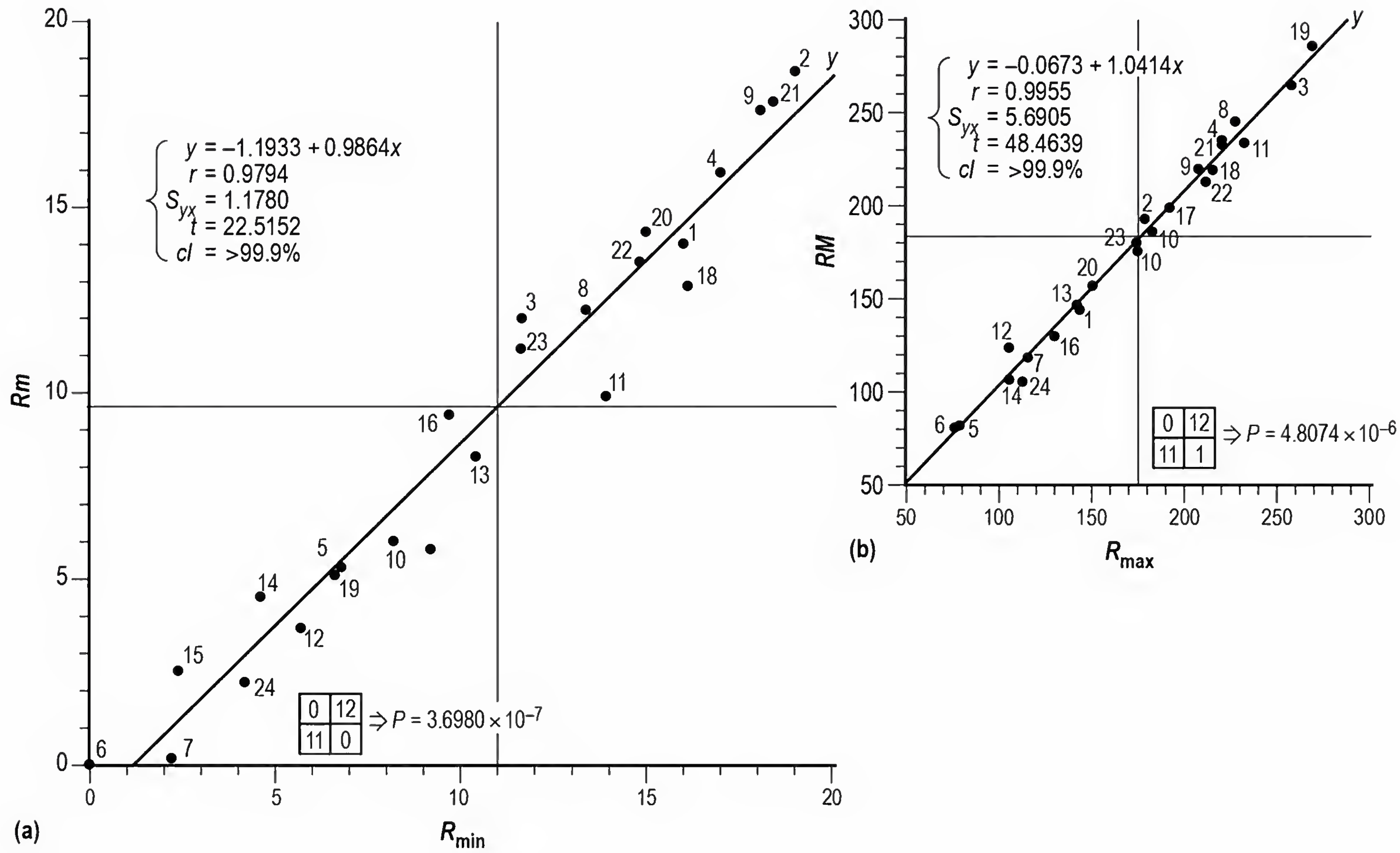


**Figure 10. Scatterplots of (a) *Rm* versus $R_{\min}$ and (b) *RM* versus $R_{\max}$.**

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# SUMMER HEAT CLIMATOLOGY FOR URBAN ALABAMA, 1958-2017

Stephen G. Tsikalas, Ph.D.
Assistant Professor of Geography, Department of Geography and Anthropology, 103 Isle Hall
Eastern Washington University, Cheney, WA 99004

stsikalas@ewu.edu

## ABSTRACT

In this study, we focus our attention on urban regions in the State of Alabama to create a better understanding of changing summer heat trends. Rising summer temperatures, prolonged heat waves, and high heat index values are cause for public health concerns. Additionally, an increase in summer heat poses a stress on energy demands, costs to consumers, and health risks to the most vulnerable populations. Alabama is within the "warming hole" of the twentieth century warming trend in the U.S.; however, we hypothesize that summer urban temperatures have been on the rise over the past 60 years. To test our hypothesis, we analyze daily maximum and minimum temperatures for the months of June, July, and August between two, thirty-year time periods: 1958 to 1987 and 1988 to 2017. We also calculate cumulative summer cooling degree days (CDD) for each year, June 1st through August 31st. Statistical comparisons suggest a rising maximum and minimum temperature and CDD for 80 percent of the cities in this study ($\alpha$ = 0.05).

**Keywords**
Applied climatology, climate change, temperature extremes, urban heat

## INTRODUCTION

### *Purpose*

This paper addresses summer heating trends in Alabama cities over a 60-year time frame, 1958 to 2017. We investigate whether there have been any statistically significant shifts in daily summer maximum temperature, minimum temperature, and cumulative cooling degree days (CDD). We define summer as June 1st through August 31st (JJA). Throughout Alabama, these months are the hottest of the year. We chose summer over annual temperature and CDD patterns for the purpose of understanding potential health and energy concerns. Although Alabama has not shown to have an average annual temperature increase from 1901 to 2015 (NOAA 2016), there has been a steady warming since the 1970s (Runkle *et al.* 2017). Specifically, our intent is to better understand summer heating trends for urban areas, a spatial and temporal scale not currently well represented in the academic literature.

### *Heat-related Illnesses and fatalities*

Interest in this research arises from concern for urban Alabama populations exposed to heat stress and increased energy demands. Common heat-related illnesses vary from heat rash, sunburn, and heat cramps to the more severe heat exhaustion and heat stroke (CDC 2017; Mørch, Andersen, and Bestle 2017). Heat exhaustion and heat stroke can lead to nausea, vomiting, and fainting. Heat stroke is considered to be a medical emergency and may cause death. The most vulnerable to heat-related illnesses include: infants, children, adults 65 years of age and older, people with chronic medical conditions, outdoor workers, and people in low-income households (CDC 2018). People living without adequate shelter, particularly urban homeless populations, also have a higher risk of exposure (Nicolay 2016).

From 1900 to 2017, there have been 4,801 fatalities resulting from heat extreme temperatures (CRED 2018). Heat waves ranked 4$^{th}$ in all U.S. natural hazard deaths behind tropical cyclones (16,297), convective storms (7,699), and storms (no subtype; 6,408). When considering our years of study, there were 1,870 deaths in the U.S. resulting from heat waves between 1958 and 1987, compared to 1,587 deaths in the more recent time period, 1988 and 2017. Although fatalities have dropped, the number of heat waves has risen from eight to thirteen between these two thirty-year periods (CRED 2018). Work with global coupled climate models suggest that areas in North America and Europe that have been experiencing strong heat waves (e.g., the U.S. Southeast) will see more intense heat waves in the near future (Meehl and Tebaldi 2004).

An in-depth study conducted by the Center for Disease Control (Choudhary and Vaidyanathan 2014) tracked and analyzed heat stress illness (HSI) hospitalizations across the U.S. between 2001 and 2010. Of the 20 states involved in the study (not including Alabama), 28,133 HIS hospitalizations were documented. Florida, the only bordering state with Alabama in the study, experienced a significant increase of HSI hospitalizations. All 20 states of the study had a positive statistical correlation between monthly average number of HIS hospitalizations and average monthly maximum temperature. Furthermore, the South and Midwest regions were found to have the highest rate of HSI hospitalizations, 2001 to 2010 (Choudhary and Vaidyanathan 2014).

### *Heat and energy consumption*

Rising summer temperatures also contributes to urban energy demand. Increasing the amount of energy needed to cool buildings results in higher costs and potentially impacts how well buildings can be kept at reasonable temperatures (Santamouris 2014). In order to address these energy concerns, we compare the cumulation of summer CDD. CDD are calculated as how many degrees higher a day's average mean temperature is above 65° F and are commonly used as a way to measure the potential energy requirements to cool a building (NOAA 2009). Heating degree days (HDD) are a similar measurement, differing in that they cumulate degrees below 65° F during cooler months.

CDD are a practical way to study temperature patterns because 65° F is commonly the temperature at which buildings are switched from heating to air conditioning (Santamouris 2014). In national surveys studied by the U.S. Climate Change Science Program, energy requirements were set to increase by 5% to 20% per every 1° C (1.8° F) rise in temperature. These estimates fluctuated based on differences in locality and energy type (Scott and Huang 2007). Degree day projection models suggest large scale increases in CDD values in the Southeast, with cities such as Memphis and Atlanta predicted to increase by over 1,000 CDD by the end of the 2000s (Petri and Caldeira 2015).

Other economic impacts of increased CDD include influences on the weather derivative market. CDD directly affect temperature derivatives, which are purchased and traded by individuals and companies facing significant temperature related risks (e.g., farmers and utility companies) (Erhardt 2014). Degree days are a standard measurement in the formulas used to calculate payments for these derivatives. For example, for each CDD above the marked 1,000 in June, an additional payment of $150 would be charged.

$$P = 150 \cdot \max\left(\sum_{d \,\epsilon\, July} max(T_d - 65{,}0) - 1000, 0\right)$$

The potential impact on prices and contingent contracts could greatly influence the weather derivative market, estimated at $11.8 billion as of 2011 (Erhardt 2014).

CDD are predicted to rise faster than HDD in the Southern U.S. Energy providers will likely be impacted by the change in demand (Petri and Caldeira 2015). These demands have raised concerns over energy availability, as well as the environmental impact of electricity generation from fossil fuels. The U.S. Southeast is heavily reliant on fossil fuels, which are not sustainable from an environmental or economic standpoint.

### *A "warm hole" over Alabama*

An overall global warming trend in recent decades is well established (Stocker *et al.* 2013). Within the U.S., annual average temperatures have risen for most of the contiguous states over the past century. An interesting exception is the U.S. Southeast with nearly the entire state of Alabama experiencing a cooling trend from 1901 to 2015 (NOAA 2016). This phenomenon has been referred to as the "warming hole" and has received substantial academic attention (Robinson, Reudy, and Hansen 2002; Trenberth *et al.* 2007; Portmann *et al.* 2009; Leibensperger *et al.* 2012; Yu *et al.* 2014; Maleski and Martinez 2017; Partridge 2018).

In Alabama, temperatures were at their hottest during the 1920s and 1930s and began to cool approximately 2° F into the 1960s and 1970s (Runkle *et al.* 2017 and references therein). A warming of 1.5° F has been documented since then. There is supporting evidence that the cooling period may have been driven by an increase in aerosols and sulfates by means of unregulated industry into the regional atmosphere. The end of the cooling period aligns well with the timing of the Clean Air Act of 1970 (amended in 1977 and 1990) (Leibensperger *et al.* 2012). Another recent explanation of the warming hole indicates possible influences of jet stream shifts in the late 1950s, bringing cooler air to the U.S. Southeast (Partridge 2018).

In recent decades, the number of hot summer days (maximum temperatures exceeding 95° F) has been much less across Alabama when compared to the 1930s and early 1950s (Runkle *et al.* 2017). There has also been a drop in the number of very warm nights (minimum temperatures above 75° F) in recent decades; although these have been on the rise in the last several years.

## METHODS

### *Study Area*

Alabama, the Yellowhammer State, is home to 4.9 million people (U.S. Census 2017). Positioned in the U.S. Southeast, the humid subtropical climate is similar to that of the region. Alabama experiences year-round precipitation, moderate winters (monthly averages above freezing), and hot, humid summers. Thunderstorms and tropical cyclones are common during the late spring and summer months. Tornadoes and severe weather are common across the state. Between 1988 to 2017, Alabama experienced 1,354 tornadoes, averaging 46 per year (NWS 2018). There are two severe weather seasons, one in the spring and another, shorter season in the fall; however, tornadoes and severe weather may occur during any time of year (NWS 2018).

Interested in urban heat, we decided to study the five most populated cities in Alabama: Birmingham, Montgomery, Huntsville, Mobile, and Tuscaloosa (Figure 1). Each city has a population near or above 100,000 and together compose approximately 18 percent of Alabama's population (Figure 2) (U.S. Census 2010).

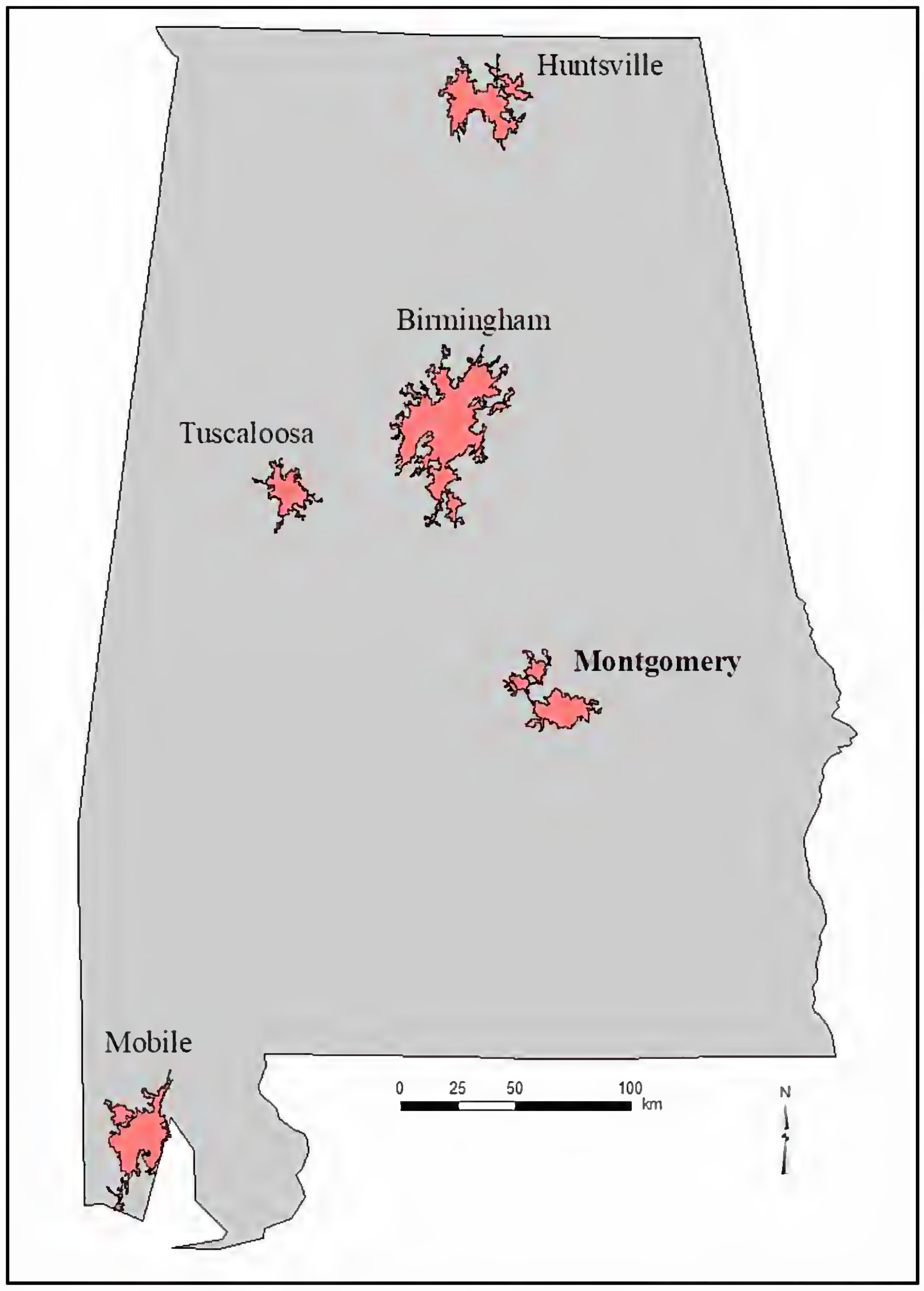



**Figure 1. A map of Alabama highlighting the urban areas in this study. Montgomery, the state capital, is in boldface.**

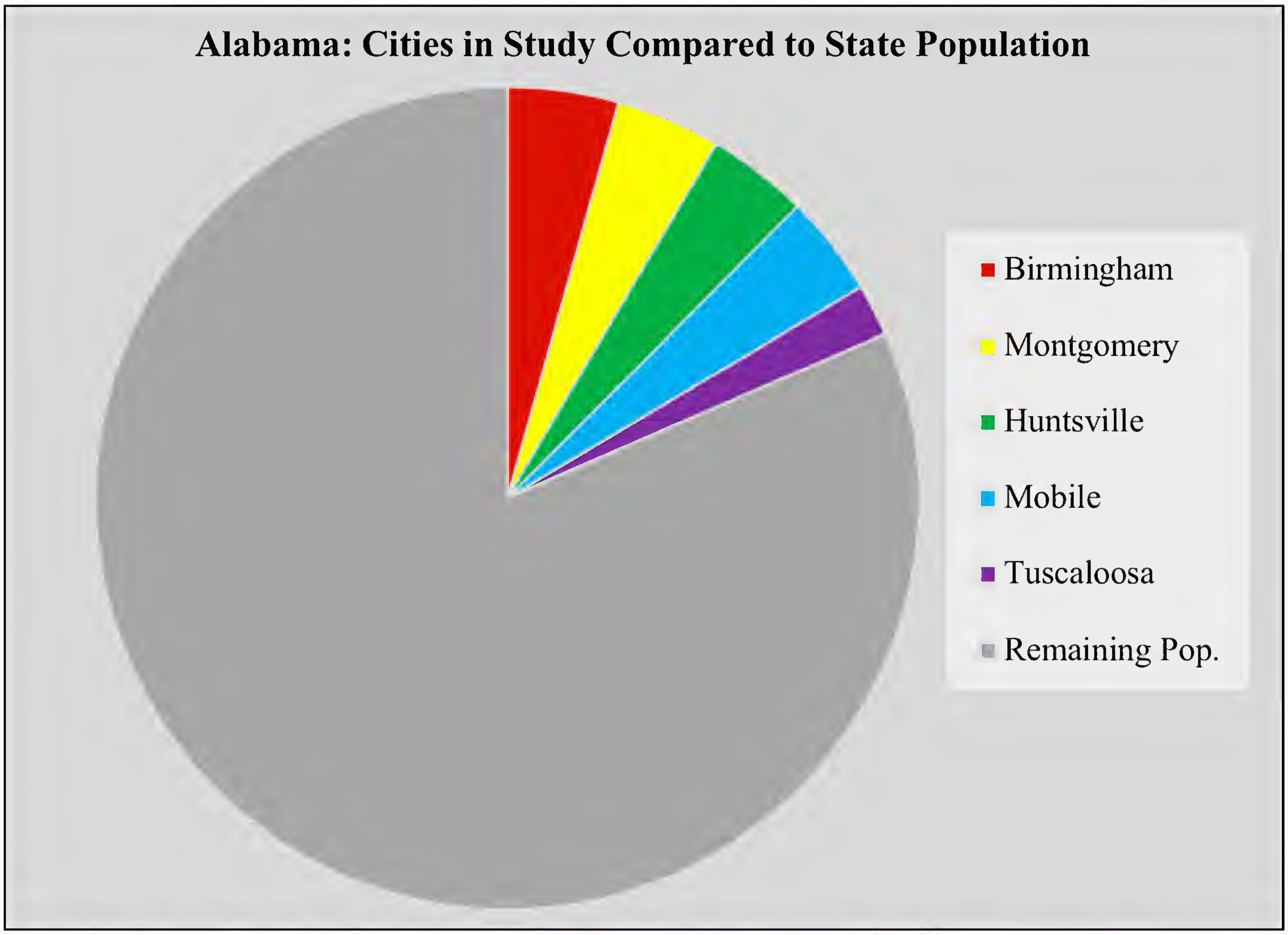



**Figure 2. Population of Alabama cities in this study compared to the state population.**

***Temperature dataset***

Data for daily maximum and minimum temperatures were accessed via the National Centers for Environmental Information (NCEI), formally known as the National Climatic Data Center (NCDC), for each of the five cities in the study for the years 1958 to 2017. Although each of the cities have a variety of weather stations to choose data from, very few began continuous recording of maximum and minimum temperature as early as 1958. As is typical across the U.S., the longest and most complete weather stations were those associated with a city airport. Each city in our study had an airport weather station to select data from in the NCEI database.

We recognize that a single station is not the most effective representation for the entire city, but we were constrained by the lack of weather stations encompassing our timeframe. Another concern is that the airports are located on the fringe of the urban regions, which may not accurately reflect the temperature of the more central locations of the cities. While these concerns are viewed as weaknesses to the study, the temperature data do serve as a basis for comparison both spatially and temporally. It is also important to note that the NCEI data from the Tuscaloosa Airport have a five-year gap (1994 to 1998). Since a nearby weather station in Tuscaloosa had temperature data available for most of this timeframe (with the exception of 1995), the gap years were filled in from the alternative station.

Once obtained, the data were organized into a database and filtered to show daily maximum and minimum temperature values for the months of June, July, and August (JJA) for the time period of 1958 to 1987 and 1988 to 2017. These months compose meteorological summer and are the warmest months of the year in Alabama. Cooling degree days (CDD) were calculated by the following formula: $C_d = T_{da} - 65°F$, where $C_d$ is the daily CDD value, $T_{da}$ is the daily average temperature (calculated as the average between the daily maximum and minimum temperature), and 65°F is used as the standard reference in a CDD calculation (NWS 2005). We then took the daily CDD from June 1st to August 31st and summed them for a cumulative CDD value for each year in the study. This variable is unique in that we do not start the cumulation from the first calendar day to exceed 65° F but rather start with a value of zero and adding the CDD solely for JJA.

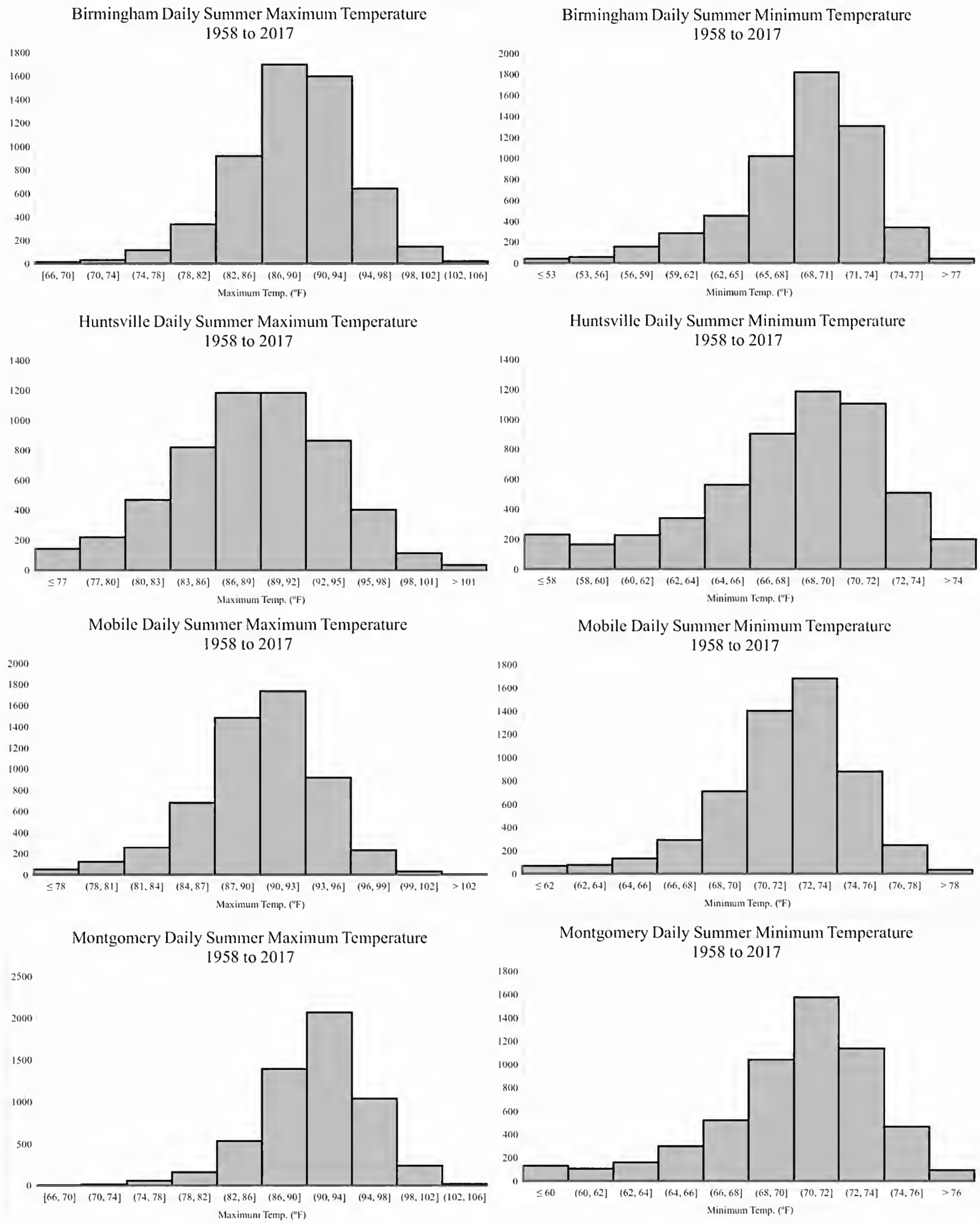
### *Hypothesis and statistical testing*

The first step in our hypothesis and statistical testing was to determine the distribution of our variables: maximum temperature, minimum temperature, and cumulative CDD. Our datasets contain very large samples for each of the three variables (Table 1). It is important to note that the n-values for maximum and minimum temperature are much higher than the CDD for each city. This is because CDD is one value per year, the cumulative CDD for June 1st through August 31st, while the n-values for maximum and minimum temperature datasets are the daily value, so there are a maximum of ninety-two values per summer (thirty days of June plus thirty-one days in July and August).

| | Max. Temp. | Min. Temp. | CDD |
|---|---|---|---|
| **Birmingham** | 5520 | 5520 | 60 |
| **Huntsville** | 5428 | 5428 | 59 |
| **Mobile** | 5520 | 5520 | 60 |
| **Montgomery** | 5519 | 5519 | 60 |
| **Tuscaloosa** | 5408 | 5408 | 59 |

**Table 1. N-values for test variables. Gaps exist in several weather station records and are reflected in the inconsistency in n values. The maximum possible n value for daily summer maximum temperature (max. temp.) and minimum temperature (min. temp.) is 5520 (the ninety-two days of one year's summer multiplied by the sixty years in the study) and 60 for CDD (one value of cumulative CDD per year).**

Using R Studio to construct histograms (Figures 3 and 4), q-q plots, and box plots, we interpreted non-Gaussian distributions for all three variables in all five cities. We confirmed non-normal distributions with a Shapiro-Wilk Test of Normality for each dataset using R Studio. Maximum and minimum values for each city had to be broken into the two, thirty-year time periods before running the Shapiro-Wilk test due to R's cap on the sample size. The software is capable of handling larger samples; however, the Shapiro Wilk test has limited power when values in the sample exceed five thousand. According to the Central Limit Theory, one can use parametric mean comparisons given a non-normal distribution if the sample size exceeds 40 (Elliot and Woodward 2007; Ghasemi and Zahediasl 2012). We, however, decided to use non-parametric testing for the following reasons: the non-Gaussian distributions of the data, the notable number of outliers (possibly influencing the means of our datasets), and interest in a more conservative testing. Comparisons made with the non-parametric, two-sample Mann-Whitney U test considers the sum of ranks and median values within the two, thirty-year time periods, rather than the individual sample and mean values. This test is more conservative than a parametric two-sample, unpaired t-test in that it does not make assumptions about the parameters of the datasets (Nahm 2016). In other words, we are less likely to reject the null hypothesis running a Mann-Whitney U rather the parametric equivalent.



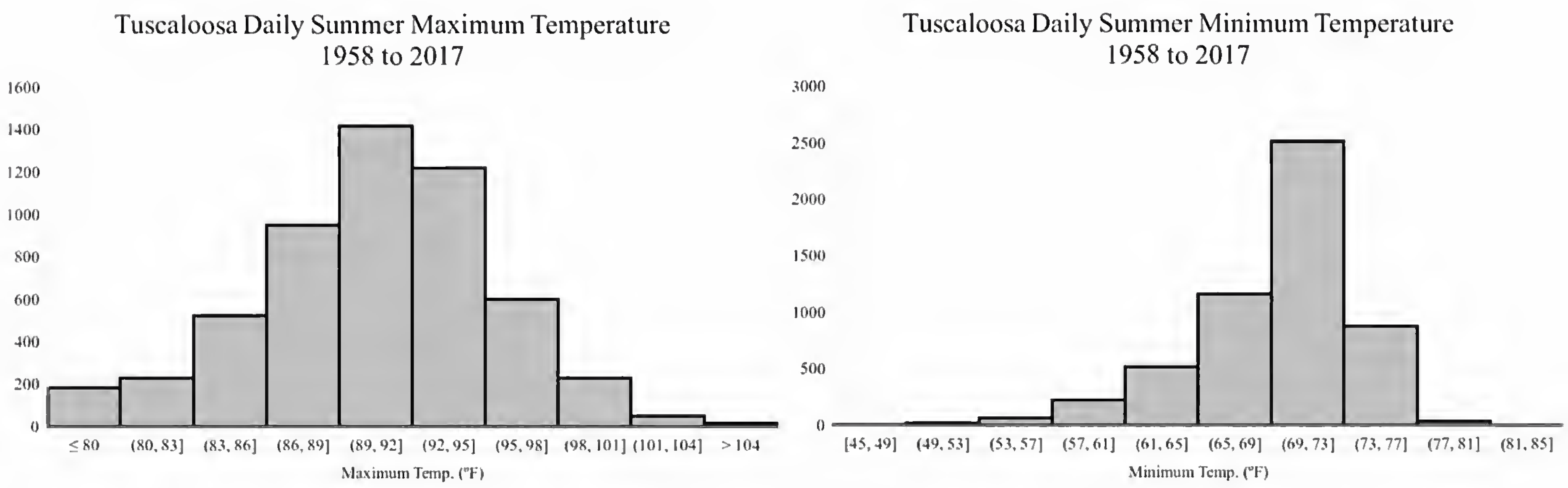



Figure 3. Histograms for maximum and minimum temperature for select cities in Alabama, 1958 to 2017.

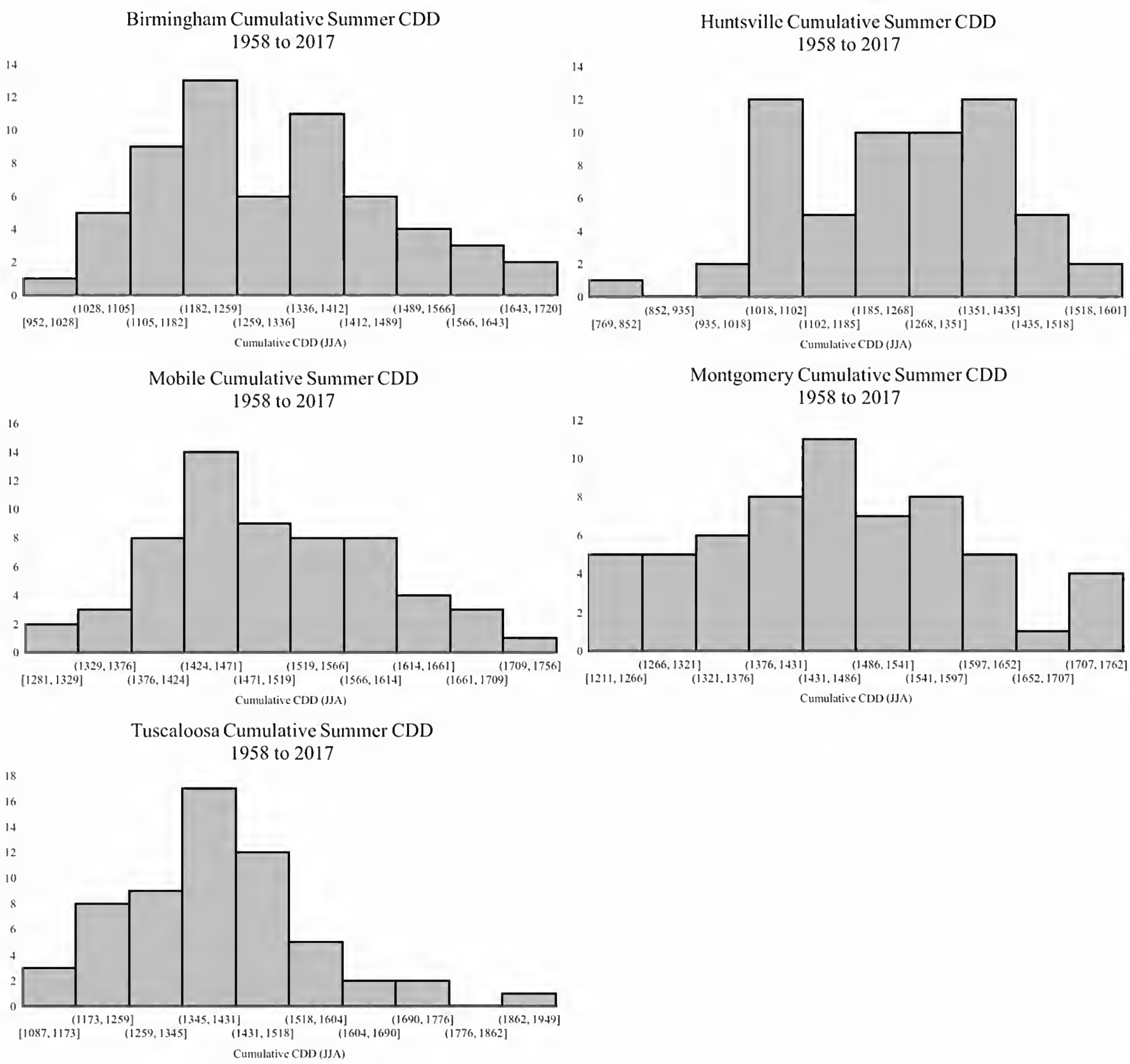



**Figure 4. Histograms for cumulative summer CDD for select cities in Alabama, 1958 to 2017.**

Interested in determining directionality of any shifts in distributions determined by the Mann-Whitney U test, we analyzed trend lines for each city's summer maximum temperature, minimum temperature, and cumulative CDD. For maximum and minimum temperature, this meant simplifying our dataset from ninety-two values per year to one value per year; otherwise, the graphs were too overcrowded with the large sample sizes. The yearly value was calculated by the mean summer maximum (minimum) temperature for JJA. A line chart was created using Microsoft Excel to show yearly summer variations from the prior thirty-year period (1958 to 1987) summer mean maximum (minimum) temperature. This reference temperature was calculated by finding the mean average of each year's (1958 to 1987) summer mean maximum (minimum) temperatures ($n = 30$). We constructed similar charts for summer cumulative CDD, but this did not require any additional steps since the CDD datasets already contained one value per summer. As in the maximum and minimum trend line analysis, we compared the yearly summer cumulative CDD with the 1958 to 1987 mean average ($n = 30$) CDD value.

## RESULTS

Finding our data to be non-normally distributed, we determined the best means of comparison between time periods for our variables should be made using a non-parametric test, the Wilcox Rank Sum test, also known as the Mann-Whitney U test. This test was used to compare the sum of ranks between the two time periods of 1958 to 1987 and 1988 to 2017 for 1) maximum temperature values and 2) minimum temperature values, and 3) cumulative summer CDD. To determine if temperatures have been on the rise, cooling, or staying the same over the past sixty years, the following hypotheses were tested for each of the five cities in the study:

H0: The sum of ranks for daily summer maximum temperature (minimum temperature; summer cumulative CDD) for the period 1958 to 1987 is the same as the sum of ranks for daily summer maximum temperature (minimum temperature; summer cumulative CDD) for the period 1988 to 2017.

H1: The sum of ranks between the two time periods are significantly different.

We rejected the null hypothesis for all three questions in four of the five cities in our study (Birmingham, Huntsville, Montgomery, and Tuscaloosa) (Table 2). This suggests these cities have experienced a different maximum temperature, minimum temperature, and cumulative summer CDD in the more recent thirty-year period (1988 to 2017) when compared to the data from the previous 30 years (1958 to 1987).

We failed to reject our null hypothesis for all three variables for the city of Mobile, suggesting that there has been no significant shift in summer maximum temperature, minimum temperature, or cumulative CDD (Table 2).

| | n1 | M1 | n2 | M2 | U | p value |
|---|---|---|---|---|---|---|
| Birmingham | 2760 | 89 | 2760 | 90 | 3364900 | $p < 0.001$ |
| Huntsville | 2668 | 89 | 2760 | 90 | 3273400 | $p < 0.001$ |
| Mobile | 2760 | 91 | 2760 | 91 | 3782200 | $p = 0.652$ |
| Montgomery | 2760 | 91 | 2759 | 92 | 3052100 | $p < 0.001$ |
| Tuscaloosa | 2757 | 91 | 2651 | 92 | 3086700 | $p < 0.001$ |

Daily summer minimum temperature.

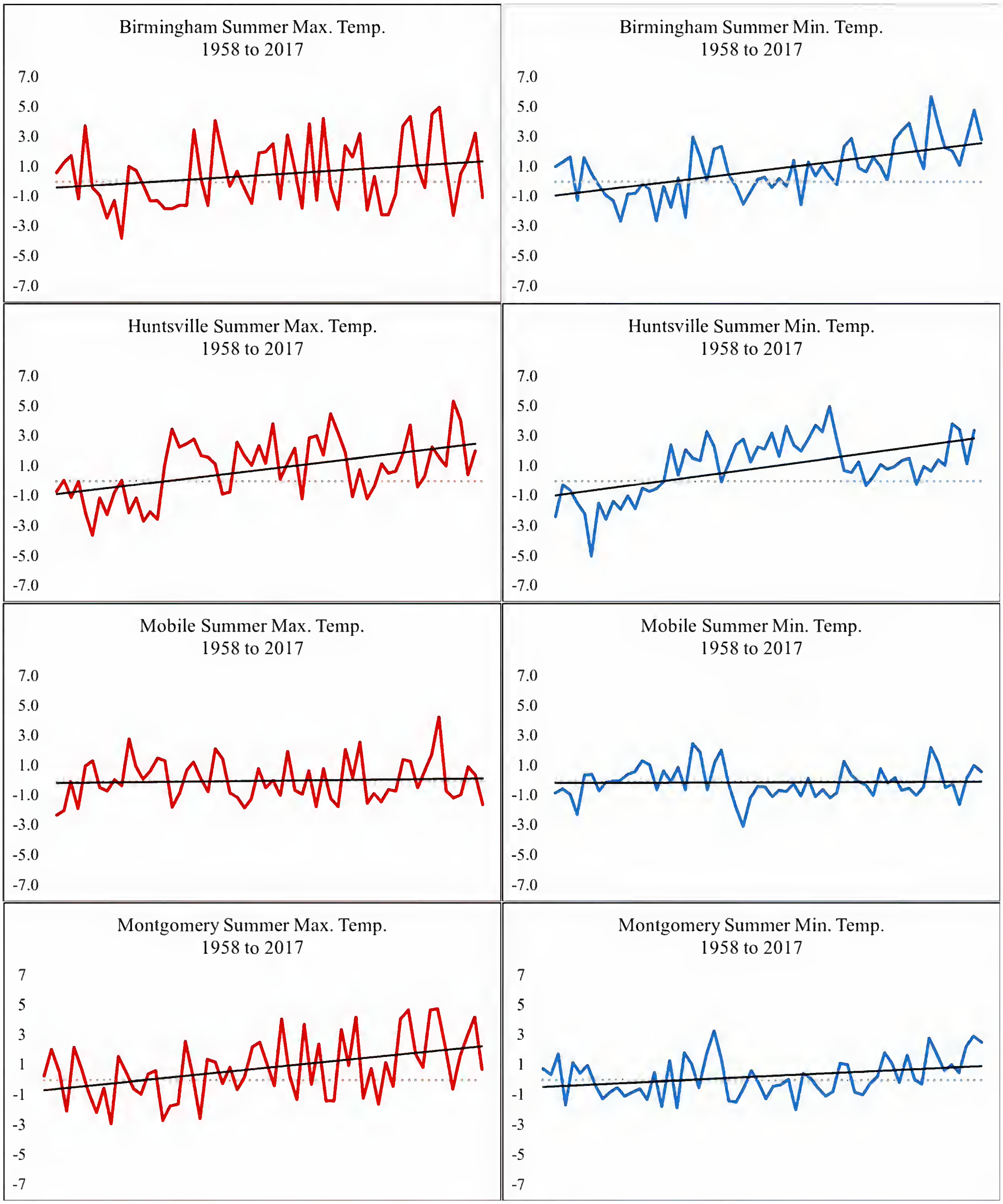
| | n1 | M1 | n2 | M2 | U | p value |
|---|---|---|---|---|---|---|
| Birmingham | 2760 | 69 | 2760 | 71 | 2902200 | $p < 0.001$ |
| Huntsville | 2668 | 68 | 2760 | 70 | 2783600 | $p < 0.001$ |
| Mobile | 2760 | 71 | 2760 | 71 | 3920700 | $p = 0.057$ |
| Montgomery | 2760 | 71 | 2759 | 71 | 3552200 | $p < 0.001$ |
| Tuscaloosa | 2757 | 70 | 2651 | 71 | 3225500 | $p < 0.001$ |

Summer cumulative CDD.

| | n1 | M1 | n2 | M2 | U | p value |
|---|---|---|---|---|---|---|
| Birmingham | 30 | 1236 | 30 | 1349 | 255 | $p = 0.004$ |
| Huntsville | 30 | 1123 | 29 | 1302 | 211 | $p < 0.001$ |
| Mobile | 30 | 1507 | 30 | 1474 | 485 | $p = 0.615$ |
| Montgomery | 30 | 1413 | 30 | 1507 | 291 | $p = 0.019$ |
| Tuscaloosa | 30 | 1367 | 29 | 1428 | 287 | $p = 0.025$ |

**Table 2. Results of Mann-Whitney U tests, where n1 = sample size for 1958 to 1987; n2 = sample size for 1988 to 2017; M1 = median value for 1958 to 1987; M2 = median value for 1988 to 2017; U = Mann-Whitney U test statistic; p value is the calculated probability. Daily summer maximum temperature.**

The Mann-Whitney U tests were run as two-tailed, which does not indicate directionality. To resolve whether there has been a warming or a cooling trend in the four cities for which we rejected the null hypothesis, we compared the medians between groups (1958 to 1987 and 1988 to 2017) for each city and analyzed trend lines across the entire sixty-years (Table 2, Figure 5, and Figure 6). Comparing the medians between the two, thirty-year periods for Birmingham, Huntsville, Montgomery, and Tuscaloosa, we conclude that the directionality has been an increase in maximum temperature, minimum temperature, and summer cumulative CDD in all scenarios, with one exception. The exception being the daily summer minimum temperature medians between the two periods for Montgomery, which was the same median value for both periods, 71° F. Examining the trend line for the sixty-year study period shows increasing temperatures and cumulative CDD for all cities except for Mobile (no trends for any variable), which agrees with our Mann-Whitney U results. Although Montgomery's minimum temperature had the same median for both time periods, the trend line shows an increase in minimum temperature over the sixty years.


Birmingham Summer Max. Temp.
1958 to 2017
Birmingham Summer Min. Temp.
1958 to 2017
Huntsville Summer Max. Temp.
1958 to 2017
Huntsville Summer Min. Temp.
1958 to 2017
Mobile Summer Max. Temp.
1958 to 2017
Mobile Summer Min. Temp.
1958 to 2017
Montgomery Summer Max. Temp.
1958 to 2017
Montgomery Summer Min. Temp.
1958 to 2017
7.0
5.0
3.0
1.0
-1.0
-3.0
-5.0
-7.0
7
5
3
1
-1
-3
-5
-7

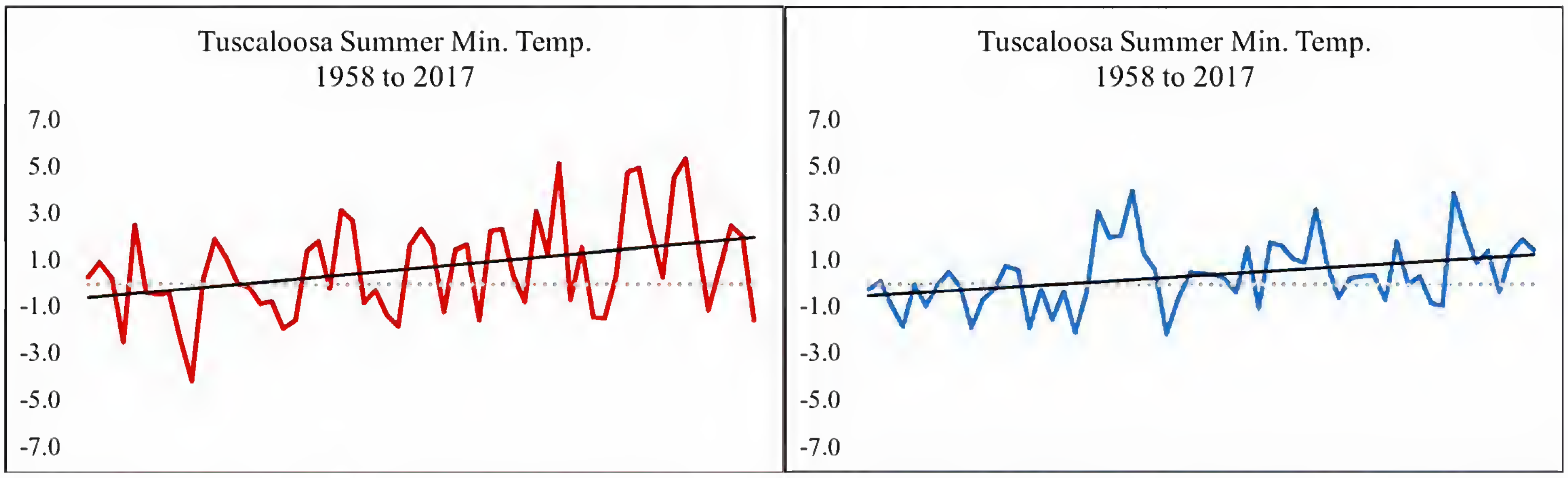



**Figure 5. Trend line for summer maximum and minimum temperatures in select Alabama cities, 1958 to 2017.**

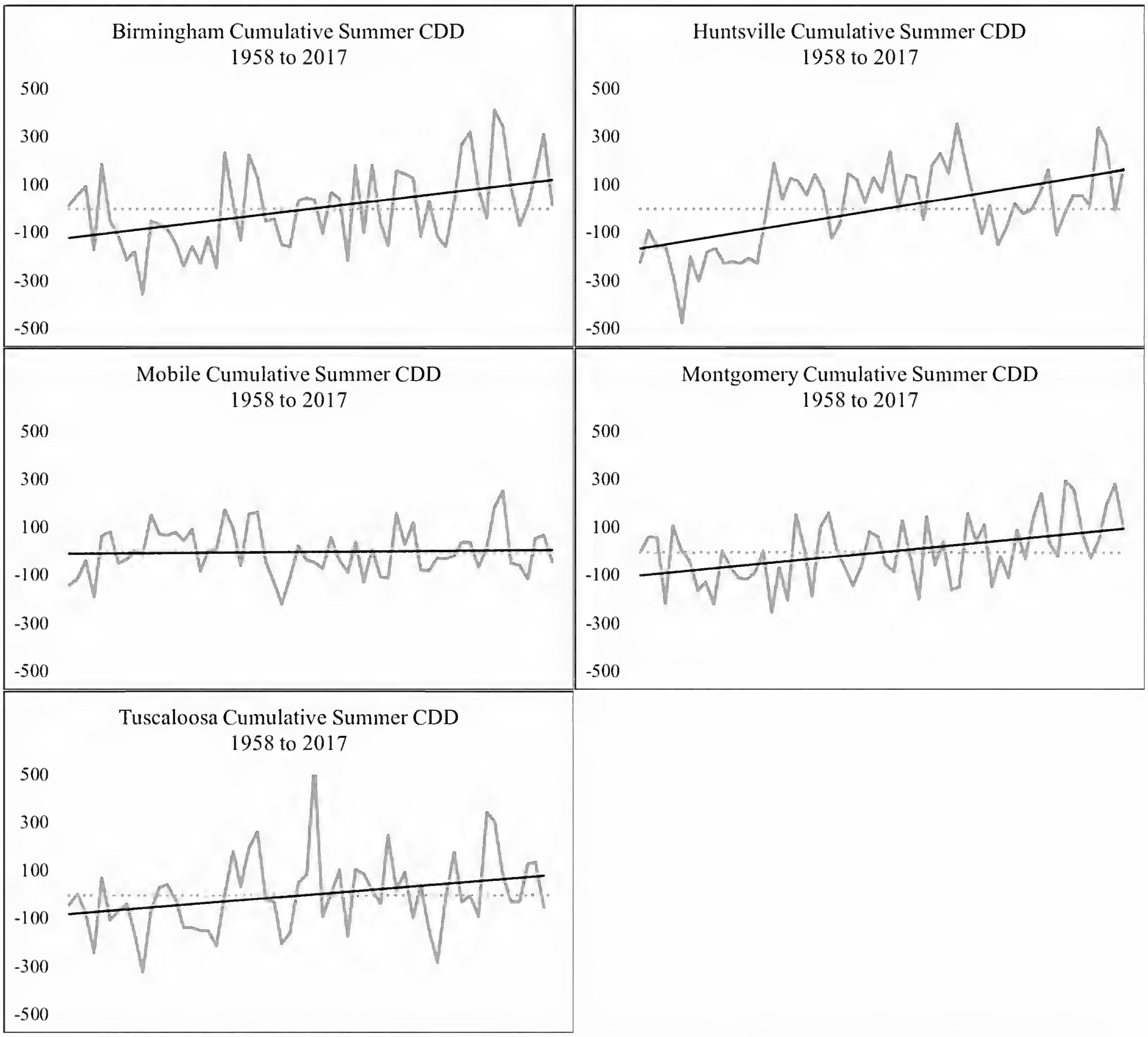



**Figure 6. Trend line for summer cumulative CDD in select Alabama cities, 1958 to 2017.**

## DISCUSSION

Alabama experienced an overall cooling during the twentieth century, with temperatures at their warmest during the 1920s and 1930s. Average annual temperatures across the state cooled by nearly 2° F going into the 1960s and 1970s. The proceeding decades have seen a return of the warmth with an increase of 1.5° F, nearing the temperatures of the warmest time period of the 1900s (Runkle *et al.* 2017).

Our study focuses on summer heat rather average temperatures and specifically on the major urban locations of Alabama rather the entire state. Further distinction of our study is the time frame of the previous sixty years rather stretching back to 1900. With these distinctions, we were able to highlight the increase of three heat-indicating variables across 80 percent of our study region (four out of five cities). Birmingham, Huntsville, Montgomery, and Tuscaloosa have all experienced a significant shift in their daily summer (JJA) maximum temperatures, minimum temperatures, and cumulative summer CDD.

An increase in daily maximum temperature means that summer days have been hotter between 1988 and 2017 than they were between 1958 and 1987. At the same time, an increase in nighttime low temperatures in the more recent time period is made evident by a significant shift in daily summer minimum temperatures. The combination of hotter days and warmer nights can lead to an increase in heat-waves (see Kent *et al.* 2014 for thorough comparison of heat wave measurements and correlation with heat-related illnesses in Alabama).

Measuring CDD is typically done throughout the year. We decided to analyze a cumulation for just the JJA period to use as an indicator of summer heat and energy demand. Rather having 92 values per year (days in JJA) as in our daily maximum and minimum temperature datasets, we calculated one value per year, the cumulation of CDD from June 1$^{st}$ through August 31$^{st}$. A significant increase in CDD suggests demands of summer energy consumption will likely be needed. Huntsville experienced the greatest shift in the median, 179 CDD, followed by Birmingham (113 CDD), Montgomery (94 CDD), and Tuscaloosa (61 CDD). Mobile's median dropped 33 CDD; however, this was not statistically significant, so we report no change over the sixty years.

We can only speculate as to why Mobile was the only city not to have increasing heating trends over the past sixty years. Mobile is the only coastal city in our study, located along the Gulf of Mexico at the Mobile Bay. The maritime location may be the most governing factor in its distinction from the warming pattern exhibited by the other four cities. Mobile is also the furthest south, which may place it outside of the range of an influencing atmospheric circulation or other contributing factor.

## CONCLUSION

In recent decades, average annual temperatures throughout Alabama are still below where they were in the 1920s and 1930s; however, there has been a state-wide warming trend since the 1970s. It is likely that, in the coming decades, Alabamians will be facing daily highs and nighttime lows exceeding the averages of the past one hundred years.

Excessive summer heat poses health risks and creates a stress on energy demands required to cool buildings and houses. Our study of heat trends in urban Alabama over the past sixty years compared distributions of daily summer maximum and minimum temperatures and cumulative summer CDD for the five largest cities in the state. The results indicate there has been a significant warming shift for each of these variables in four of the five cities, or 80 percent of our study area. Alabamians living in Birmingham, Huntsville, Montgomery, and Tuscaloosa have been experiencing hotter summer days, warmer summer nights, and an increase in cumulative summer CDD. Mobile, AL has not experienced a similar shift in summer heat. The reason or which is outside the scope of this paper but may be attributed to the maritime influences of their coastal location.

The importance of adaptation, mitigation, and preparation for heat-related hazards should be a priority for city planners, government officials, emergency response, and other related organizations in the likely-hood of Alabama facing hotter summers in the coming decades. Rising summer heat should also be the concern of individuals living in urban locations throughout the state. Properly educating the public on the recent warming trends, heat-related illnesses, and budgeting for energy costs of summertime cooling is recommended.

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# RESISTANCE TO BROWN V. BOARD OF EDUCATION – THE GARDENDALE EXPERIENCE

By William E. Kelly
Department of Political Science, Auburn University, Auburn, AL, USA

[1]Correspondence: kellywe@auburn.edu

## ABSTRACT

This article reflects on how the effects of *Brown v. Board of Education (1954)* have been avoided in the state of Alabama. It is a case study involving legal maneuvering which many have interpreted as being motivated by race to maintain school segregation in a changing environment. Yet, it is also an explanation of how other states have avoided compliance with the *Brown* case with the effect being that the American educational system is becoming more segregated than it has been in the past. It also shows that careful analysis of our educational system needs to be maintained by our judicial system if we are to prevent the factor of race from damaging our educational system which is the foundation of a better way of life for all Americans.

## INTRODUCTION

The landmark case of *Brown v. Board of Education* in 1954 has brought many favorable changes to American society especially in the area of equality. The case itself focused primarily on bringing educational equality to our citizens which had been absent primarily as a result of racial factors. Although resistance in the South to its implementation was very strong and lasted a long time, southern schools eventually progressed to a time when noticeable integration was characteristic. A source notes "… desegregation in the 1960s and 1970s led to improvements in educational attainment by black students and possibly greater achievement'' (Levine, Daniel S.). Since 1971 federal courts have continued an oversight of school districts in reference to some of their policies. Many of these school districts have remained under a federal desegregation order until they have achieved "unitary status"--achieving the goals of becoming non-segregated. However, one source notes that in a series of decisions in the early 1990s, "….starting with Board of Education of Oklahoma City v. Dowell, the U.S. Supreme Court ruled that desegregation orders were intended to be temporary and eased the criteria required for release from court oversight'' (Levine, Daniel S.). According to one study, however, "the average district released from a federal court order saw segregation levels grow faster than 90 percent of other school districts'' (Levine, Daniel S.). This could demonstrate that a lack of federal monitoring lessens the chance of a more integrated American educational system.

In the South and in other parts of the United States educational statistics have indicated a return to a segregated system in our schools. This return to segregation seems to be due to a number of factors. One being that blacks have begun to dominate one part of a city or county with fewer Caucasians living there. Hence, the schools in these parts are becoming overwhelmingly black in student enrollment. Another factor is that some small cities with a large Caucasian population have been allowed under federal guidelines to leave a county wide school system and form their own school district. This particular article deals with the latter reason; namely, a city leaving a large county school system with the intention of establishing its own educational district. In a very strong sense it is about a return to a segregated school system counter to the decision of the *Brown* case.

## EDUCATION QUALITY IN ALABAMA

Alabama is a poor state and a high percent of its citizens experience poverty. In addition, property taxes are very low in this state and this has resulted in Alabama's educational system having difficulties. As of 2019 new teachers start out at about $41,000. Unfortunately, race and social class also determine the quality of education received by a student. A 2019 Alabama Failing School List indicated 76 schools are failing which is a similar rating to the years 2017 and 2018. In Montgomery, ten schools were on the failing list (Alabama Failing List, 2019). Perhaps this is just one reason why so many Caucasians are moving from Montgomery to a nearby suburb or to Auburn, Alabama which has a reputation for having a commendable school system. Auburn has what one would expect when explaining the success of its school system—a high percent of educated and affluent citizens. In addition, it has a nationally acclaimed university which probably has a major effect on the quality of education in its public schools. It is also a primarily Caucasian community. Other areas of the state which do not have these characteristics will probably not be able to match Auburn or some other Alabama communities in providing comparable educational opportunities.

## CHARACTERISTICS OF GARDENDALE

Gardendale is mostly a white suburb near Birmingham, Alabama which has one of the most heavily black populations in the country. Gardendale is quite different in terms of race which has a white population of about 88 percent whereas the black population of Birmingham, Alabama is about 75 percent. The conditions in each political entity are quite different not only in relation to race, but to income and housing conditions. They are also different in terms of who is attending public schools in each city. As expected the percentage of black students in Birmingham is quite high; the percentage of white students in Gardendale is also quite high. In reality the schools are segregated as a result of what is called de facto segregation which comes about because a majority of one race lives in one area and a majority of another race lives in another area. This is common throughout the United States and is not just limited to the South. It is a particular type of segregation that is not in violation of the Brown case. "That ruling specifically related to finding segregation of schools unconstitutional when it results from state action – when state government or agencies require or enforce school segregation. It did not, however, find segregation unconstitutional if it results from people deciding to live in segregated communities by choice" (Levine, Daniel S.).

Yet, Gardendale provides an opportunity to explain the presence of a resurgence of segregated schools in this country. In addition, its legal ramifications provide an interesting commentary about how our society is reacting to a more pluralistic society. As a city it had requested federal approval to set up its own school district and separate itself from the Jefferson County School System which has a large black student enrollment of about 44 percent. The reality that could come about is a new school district which is heavily white in population separated from a county system which is heavily black.

## LEGAL APPROVAL IN FEDERAL DISTRCIT COURT

When Gardendale attempted to secede from the Jefferson County School District some might have thought that it was a "done deal." Perhaps it could have been viewed as another attempt to improve educational quality for students in that entity. One source notes:

> This process of breaking off is known as secession, and school secessions have become fairly common. Laws in 30 states explicitly allow communities to form their own public-school systems, and since 2000, at least 71 communities across the country, most of them white and wealthy, have sought to break away from their public-school districts to form smaller, more exclusive ones, according to a recent study released by EdBuild, a nonpartisan organization focused on improving the way states fund public education (Jones, Nikole-Hannah).

Yet there was opposition to the separation of Gardendale from the Jefferson County School System and this resulted in the attempt being disputed in federal district court with representatives of both sides presenting their case. Federal district court Judge Madeline Haikala, an appointee of President Obama, presided over the case and would have to decide if indeed it was permissible for the white suburb to secede from the county school district since Jefferson County was still under a federal court desegregation order.

A view of the secessionists was presented by a number of sources. One noted:

> There will be no credible evidence in this trial of racial animus motivating the Gardendale Board of Education, … 'What the evidence will show is that the citizens of Gardendale cared so much about the education of their children that they raised their own taxes to enable their city to operate the schools their kids attend, and that is all that Gardendale is asking the court for today, to be allowed to operate its own school system for the sake of their children's education (Jones, Nikole-Hannah).

Basically, the secessionist view arguing for separation was that race was not a factor but that a desire to improve educational experiences was the major reason for their request as well as local control. A source notes:

> Those who wanted to break off had some legitimate complaints about their schools — in some cases, children attended classes in trailers because of overcrowding, roofs sometimes leaked, textbooks could be in short supply and technology was too often outdated and broken. But the organizers also acknowledged in court testimony that they were satisfied with their children's teachers and that they had never complained to the district about conditions and were, in fact, pretty happy with how their children were performing (Jones, Nikole-Hannah).

Not everyone agreed that race was not a factor. One source described it this way:

> The people organizing Gardendale's secession effort were too obvious about their reasons. They cited how their schools "looked" different from their local churches

> and community events. A flyer even asked locals if they would "rather live in an affluent white city or a formerly white city that now is well-integrated or predominantly black." That flyer, featuring a white little girl in a backpack, listed four integrated cities and four mostly white cities in the area and asked Gardendale residents "which path" they would choose (Green, Sara).

What is so interesting about the case is the finding by United States District Judge Haikala and what she did. Even though Judge Haikala found that: "Gardendale's motives were based on the idea that the school's district's black students were inferior; even though she noted that it would set back the county's desegregation efforts to make schools equal; and even though it would negatively impact the black students who already attend Gardendale schools, she allowed Gardendale to move forward anyway" (Harriot). It would seem that the finding of racial motivation would be enough to deny the request for secession. In addition, one should remember what the Supreme Court noted in the *Brown* case:

> Such segregation of white and black children in public schools has a detrimental effect upon the black children, an impact that is greater when it has the status of law. It "generates a feeling of inferiority as to their status in the community that may affect their hearts and minds in a way ever to be undone…. We conclude that in the field of public education the doctrine of 'separate but equal' has no place. Separate educational facilities are inherently unequal (Brown v. Board of Education).

However, Judge Haikala added some stipulations to her allowance of secession. For example, she required the appointment of an African-American to serve on the schoolboard, meet requirements set out by the court, and abide by a desegregation plan formulated by the Justice Department for the new school district (Palma, Bethania). Perhaps this was a balancing act on her part which might be viewed as some sort of a compromise. On the one hand it satisfied the secessionists and on the other hand the requirement of a desegregation plan approved by the Justice Department might suggest that the new school district would not be a segregated one. Yet the reality of the situation would be the continuation of a segregated school system at least temporarily since the overwhelming majority of citizens living in Gardendale are white. In its simplest form—this is called "de facto" segregation—segregation that comes about because a majority of one race resides in a particular area of a city or county.

Even though the secessionists were successful on the district court level there were expressions of disappointment. One reason for the disappointment was the belief that the media had used the idea of race to project a negative picture of Gardendale residents. For example, one person felt that: "The media has twisted and turned this issue to make everyone think this is about race." "The people who live in this community and love this community know that nothing is further from the truth. But the fact is that damage has been done" (Felton, Emmanuel).

However, U.W. Clemon who represented in court those opposed to secession noted that the decision set back 50 years of integration effort. A number of his quotes reflect some interesting views: "If you can create a school system with racially inspired motivations, there is nothing stopping the return of segregation." "We've always had problems with Gardendale. It was a sundown town-blacks didn't even buy gas there," (Felton, Emmanuel).

At this time Mr. Clemon was a retired black federal district judge from Birmingham, Alabama with extensive first-hand experience with segregation resulting from his background in Jefferson County, Alabama. As an impressive undergraduate at Miles College he was not allowed to enter the University Of Alabama School Of Law but later graduated from Columbia University's prominent law school. He then returned to Alabama and became a successful attorney and prominent jurist. He was a representative of opposition to the secession of Gardendale from the Jefferson County School District.

It is also possible that the ruling could have drastically reduced funding for the Jefferson County School system since it would lose some taxes paid by the Gardendale citizens regarding education. Of course, funding affects the quality and quantity of educational resources. Shortly after Judge Haikala made her decision a number of published commentaries which were critical of it came about. For example one source had the headline: "Did Alabama Just Bring Back School Segregation?" (Palma Bethana). Another headline read: "Judge Allows White Ala. Town to Return to Segregation."(Harriot, Michael) Monique Lin-Luse, an assistant counsel of the NAACP Legal Defense and Educational Fund who represented the black plaintiffs in the Gardendale secession case also said: "it's a real question of fairness and equity, and it really leaves some students behind by virtue of where they live,"(Camera, Lauren). However, Judge Haikala's decision was appealed to the United States 11th Circuit Court for a review.

## THE VIEW OF THE 11th CIRCUIT COURT

This time there was a different result. This court did not approve of the secession. The opinion was written by Judge William Pryor, a former Alabama Attorney General, who cited a number of cases to justify this court's different conclusion. The general perception of racial motivation on the part of Gardendale seemed to be the main reason for the reversal by the 11th Circuit Court.

> The district court (Haikala) found that the Gardendale Board acted with a discriminatory purpose to exclude black children from the proposed school system and, alternatively, that the secession of the Gardendale Board would impede the efforts of the Jefferson County Board to fulfill its desegregation obligations," "Despite these findings, the district court devised and permitted a partial secession that neither party requested. ….
>
> We conclude that the district court committed no clear error in its findings of a discriminatory purpose and of impeding the desegregation of the Jefferson County schools, but that it abused its discretion when it sua sponte (own her own) allowed a partial secession. We affirm in part, reverse in part, and remand with instructions (to Haikala) to deny the motion to secede''(Gardendale Will Cease Efforts To Create New School System).

Apparently, one factor influencing the 11th Circuit Court was the content of certain social media posters from which one might imply a racial motivation. Judge Pryor noted that the intent of social media posters was clear. Such posters pointed out the advantages of having a new school district as opposed to what could happen to students who had to remain out of it. A message that might have been implied in the posters was that those students who remained in the

Jefferson County School District would be primarily black and those who attended the new Gardendale School District would be primarily white. The 11th Circuit Court noted that the comments in some of the posters shed light on the motivation behind the creation of a new school district in Gardendale. The appeals court concurred with the district court, which found, “The Gardendale Board not only failed to disavow those messages of inferiority but instead reinforced them”(Court Blocks Predominantly White Alabama City from Creating Its Own School System). Yet, Judge Pryor did leave open the possibility that in the future Gardendale might be able to secede from the Jefferson County School System:

> If the Gardendale Board, for permissible purposes in the future, satisfies its burden to develop a secession plan that will not impede the desegregation efforts of the Jefferson County Board, then the district court may not prohibit the secession," according to the ruling. ‘We do not belittle the 'need that is strongly felt in our society' to have '[d]irect control over decisions vitally affecting the education of one's children,’ according to the ruling that cites a previous case. ‘Indeed, the ‘local autonomy of school districts is a vital national tradition,’.’We hold only that the desire for local autonomy must yield when a constitutional violation is found and remains unremedied,’ (Court Rules Gardendale Can’t Form School System…).

What these comments simply seem to mean is that secession could occur unless there is a violation of a constitutional right or protection. Hence, future movements comparable to Gardendale’s attempt to become an independent district must be careful about conforming to federal guidelines. This is where the Justice Department can play an important role by overseeing such a movement to determine its legality or compliance with federal law. In addition, the comments also recognize the value at times of local control over certain educational policies.

## GARDENDALE’S REACTION TO THE 11th CIRCUIT COURT

The advocates of secession for Gardendale initially did not give up after the 11th Circuit Court’s opinion by Judge Pryor came out. The question could possibly been brought before the United States Supreme Court for a final decision. They had some interesting views of the 11th Circuit Court’s opinion. One source reflected their views:

> We know the heart and intent of this board and of the residents of Gardendale as a welcoming community, and we believe our actions reflect just that, “This is not the result we deserve, and the fight is not over.” “A decision that blames Gardendale for the comments of private citizens on social media is both contrary to the Constitution and a fundamental miscarriage of justice-and is one we will continue to appeal,’’ (McLaughlin, Elliot G.)

Yet the advocates of a new Gardendale School District did not appeal to the United States Supreme Court. Apparently, there were multiple factors affecting this decision. Gardendale Mayor Stan Hogeland cited some of them such as a belief that the circuit court was their best chance, the chances of winning on an appeal to the Supreme Court were low, and many citizens of Gardendale were ready for this to be over with.”(Gardendale Will Cease Efforts to Create New School System).

## POSSIBLE FUTURE EDUCATIONAL RAMIFICATIONS

Unfortunately, however, for the advocates of school integration the future may not be optimistic. One source notes: "With Trump in office, it's probably only a matter of time before the number of desegregation orders drops again, possibly to zero. Trump's team is opposed to using consent decrees to keep the pressures on school district and make sure they've fulfilled their promise to erase the legacy of Jim Crow, arguing that the court and the Justice Department need to get out of these local matters.''(Felton, Emmanuel).

Hence, the future does not look good for minorities in terms having an integrated educational experience in the United States and in Alabama. One source notes that "the number of students of color in segregated schools in Alabama has grown significantly since the mid-'90s, when the formation of white school districts gained momentum. Southern schools are more segregated today than they were 40 years ago."(Felton, Emmanuel). Yet, Alabama is not alone in having a segregated school system. Other states are not that impressive in terms having an educated school system. For example, New York State has the most segregated school system in the country. (New York State Singled Out for Most Segregated Schools).

However, "Today the percentage of black students in intensely segregated schools in the South is on the rise. More than one in three (35.8 percent) now attend such schools. But Southern school segregation no longer concerns just black and white students. Latino enrollment is at 27 percent, while black enrollment is at 24 percent.''(Kirk, Mimi). As the percent of Latinos increase in our society there will be an increase in segregated schools in terms of race. Of course, American society in the future will look quite different in terms of race and ethnicity. Most studies indicate that by the year 2042 Caucasians will be a minority in the country. The majority of citizens will be different in terms of race. It will be comprised primarily of African-Americans, Hispanics, and Asians.

## CONCLUSION

The attempt by Gardendale to secede and institute its own school district is nothing new in American society. It has been going on since the Brown case and probably will continue to be present in American society. Unfortunately, it will be just one factor inhibiting the integration of our educational system. Perhaps what we learn from their attempt is that race is an important factor in the American educational system, and that it should be taken more seriously when considering the establishment of a new school district. We also learn from the Gardendale attempt that it will be necessary for our federal court system to closely monitor movements which concern the establishment of new districts and to focus on the reason why such a movement is advocated and what the possible effects would be. Specifically, if the motivation is racial and the effect is educationally detrimental to one group of students, the judicial system must not allow it to take place. It is also interesting to note how the presence of social media even when it is used by private individuals or especially those who have some connection to a school board can affect a school policy because it seems that both Judge Haikala and Judge Pryor used some of their content to believe it showed race as a motive for Gardendale's request for secession (Richter, Jeremy W.).

Yet, let's be realistic. Economic conditions of citizens have always affected educational opportunities in this country. The wealthy can afford to live in those parts of an environment which have the better schools and resources. Too often the poor are forced by economic conditions to remain in areas where educational benefits are few and less rewarding to children. Until minorities have the economic means to leave a poor part of a city or a county and move to a different part where the schools are more advantageous for students we will be faced with a segregated educational system.

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# MINUTES OF THE
# ALABAMA ACADEMY OF SCIENCE
## Executive Committee Meeting
## Samford University
## Room 033, William Propst Hall
## October 19, 2019

Meeting was called to order at 8:39 am by President, Drew Hataway. Those in attendance were:

Sarah Adkins
Ellen Buckner
Donna Cleveland
Matthew Edwards
Ravi Gallapalli
Mary Anne Garner
Cameron Gren
Drew Hataway
Susan Herring
Ron Hunsinger
Mark Jones
Bryan Kennedy
Larry Krannich
Akshaya Kumar
Adriane Ludwick
Ken Marion
Ken Marion
Donna Perigyn
Jack Shelley-Tremblay
Chris Stopera
Brian Toone

Ken Marion moved to approve the minutes and Jack Shelley-Tremblay seconded. Minutes were approved.
The following is an update of the Action Items from the Spring Executive Committee meeting was done.

**Table 1: Action Items for October 19, 2019 Executive Committee Meeting**

| Action Item | Person Responsible | Due Date | Outcome | New Action Items |
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| **Send JAAS Issues to members with optin** | Larry Krannich | Will do when JAAS issues are available; Fall 2019 | Hard copies have not been mailed out | 1. Hard copies will be printed and sent in Fall |

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| **hardcopy instructions** | | | but the electronic issues have been posted to the website. Hard copies will be printed and sent in Fall 2019. Links for back issues will be emailed to membership by November 1, 2019 | 2019 by an associate editor<br>2. Links for back issues will be emailed to membership by November 1, 2019 |
| **Develop a list of duties & responsibilities of associate editors.** | Brian Toone | Fall 2019 | By Spring 2020 | |
| **Schedule a working meeting of editor, associate editors, and interested individuals for noon, Thursday, March 19, 2020.** | Brian Toone | Spring 2020 | Meeting has been scheduled for Spring 2020. A phone call or webex will be scheduled before December 2019. Printing and mailing of journal is now the responsibility of an associate editor and this will be discussed in the fall 2019 phone or webex conversation. | 3. Working meeting for all Journal parties has been scheduled for Spring 2020.<br>4. A phone call or webex will be scheduled for journal editors and interested parties before December 2019. |
| **Review and approve** | Jack Shelley-Tremblay, Executive | Fall 2019 | Motion to approve the new website | |

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| **new AAS website. [C-18]** | Committee | | was advanced by Matthew Edwards, which was seconded by Bryan Kennedy. The motion was approved | |
| **Vote on appointment of Jack Shelley-Tremblay as Associate Executive Director with an honorarium. [Old Business]** | Executive Committee | Fall 2019 | Duties as defined by Executive Director. Drew Hataway suggested a future amendment that the Executive Director and Associate Executive director not hold other positions within the Academy. Matthew Edwards moved to vote on this appointment, and Ellen Buckner seconded the motion. Discussion clarified the parameters of the position. The motion passed. | |
| **Approve Registration Form/Fees for AAS 2020 Annual Meeting [B-13,** | Executive Committee | Fall 2019 | Jack Shelley-Tremblay moved to accept the fees as | |

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| **Appendix A]** | | | proposed. Cameron Gren seconded the motion. Discussion addresses the costs of the Executive Committee dinner. The Academy covers those costs, and has for the past two years. The motion passed. | |
| **Approve Call for Papers for 2020 Annual Meeting [B-13, Appendix B]** | Executive Committee | Fall 2019 | Ellen Buckner moved to accept the fees as proposed. Susan Herring seconded the motion. The motion passed. Online submission will go live December 1, 2019. | |
| **Discuss/Action on Video Proposal for See It Productions [C-17, New Business]** | Executive Committee | Fall 2019 | Mark Jones and Ellen Buckner will fund the next video, which will be about the senior Academy. This was approved by a vote in Spring 2019. Jack | |

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| | | | Shelley-Tremblay proposed that We consult with Mr. Bara at See It productions to produce 20-30 second video or audio ads for advertising on TV, radio, or online. Discussion proposed creating multiple short 30 second – 1 minute videos instead of a single 4 minute video. | |
| **Discuss/Action on Alabama Science Trail Proposal [C-18, New Business]** | Executive Committee | Fall 2019 | Ellen Buckner has identified a series of science-related sites in Alabama and put the information into Google Maps. Larry Krannich suggested involving the Junior Academy in a task force for further development of this resource. They could improve the | Susan Herring, Ellen Buckner, Mark Jones, Cameron Gren, and Dr Harmon from the Alabama Tourism Department will form an ad-hoc task force to develop this concept. |

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| | | | utility of this resource for K-12 science educators and homeschoolers. Susan Herring, Ellen Buckner, Mark Jones, Cameron Gren, and Dr Harmon from the Alabama Tourism Department will form an ad-hoc task force to develop this concept. | |

President Hataway then proceeded to go through the Committee reports.

- B-1: Ken Marion presented the Board of Trustees report. He commented on the passing of Larry Boots, longtime member. Drew Hataway reported that Ketia Shumaker is stepping off of the Board of Trustees. A replacement will be voted on at the spring 2020 meeting.
- B-6: The Treasurer's report was approved.
- C-2: The Budget and Finance Committee Report was reviewed.
- B-8: Counselor to the Alabama Junior Academy of Science Report was discussed. The NSTA assumed the hosting of the national competition this year and things went smoothly. The program was audited successfully this year. Grant funding for the coming year has been secured.
- Ellen Buckner proposed that Mary Lou Ewald receive some support from the Academy, as a representative on the Governor's Task Force for Excellence in STEM. Jack Shelley-Tremblay explained that the members of the task force were assigned specific tasks by the governor's cabinet. He proposed that the Academy help to inform the governor's cabinet about appropriate tasks and questions for the task force. Proposed topic: increasing participation in high school science fairs state-wide.
- B-12, 7: STEM-ED has been discussing creating a calendar. The new Associate Executive Director will be supporting this process. He will be investigating national academy merchandise and potential for producing Alabama Academy merchandise for the 2021 spring meeting.
- STEM-ED has also proposed creating short video or podcasts to share info about Alabama Academy members and science with education and outreach.

• Action Item: The STEM-Ed Section will conduct a business meeting at the spring 2020 meeting to discuss this calendar proposal.
• Jack Shelley-Tremblay proposed individual sites for each section on the website. It would provide a venue to announce new initiatives. The concern is that there may not be enough content updates to keep these sites fresh. The more appropriate venue may be the main website.
• Ellen Buckner proposed Mark Jones creating podcasts to help students get started with the AJAS or Science Fair process. He proposed having the students going to nationals in April create these.
• Action Item: Spring 2020 meeting STEM education committee and Mark Jones will have a meeting about creating short videos or podcasts. Potential time: Thursday, late afternoon.
• C-1: Local Arrangements Committee presented a report on the plans for the 2020 meeting at Albama A&M. Jack Shelley-Tremblay suggested that Academy members meet with deans and chairs to encourage submissions from those entities and students. Suggestions were made that he STEM-Ed committee reach out to the space and rocket center and their new planetarium director to bring in for the meeting in spring 2020.
• Mary Lou Ewald is on the STEM Exploration and Discovery Committee of the Governor's Task Force.
• Action Item: Place and Date of Meeting Committee will begin to identify hosts for 2024 and 2025. Birmingham Southern and Auburn were proposed as a possibility.
• Action Item: Need to elect a full Place and Date of Meeting Committee.
• Action Item: Need to clearly articulate on the website how members may update contact information
• Alabama Science Trail: Drew Hataway moved to create an ad hoc task force to support this effort, and Brian Toone seconded the motion. The motion passed. The task force will consist of Susan Herring, Ellen Buckner, Mark Jones, Cameron Gren, and Dr Harmon from the Alabama Tourism Department and will meet at the spring 2020 meetings.
• A motion was made by Drew Hataway and seconded by Cameron Gren to schedule committee and business meetings for Spring 2020 meetings so that they do not overlap, with the aid of Matthew Edwards and Larry Krannich. The motion passed.
• New business: Jack Shelley-Tremblay has been engaged in a dialog with the director of the Exploreum in Mobile. Alabama has 5 science centers. There is some interest in adding a meeting between these science center directors at the annual meeting of the Alabama Academy of Science Meeting. A motion was made by Drew Hataway and seconded by Larry Krannich to move forward with contacting relevant science center representatives. Jack also proposes to set up an interactive exhibit near the lobby or posters to use Oculus Rift equipment to provide activities for the AJAS participants.

**Action Items for Spring 2020 Executive Committee Meeting:**

| Action Item | Person Responsible | Due Date |
|---|---|---|
| **Hard copies will be printed and sent in Fall 2019 by an associate editor** | Jack Shelley-Tremblay | Fall 2019 |
| **Links for back issues will be emailed to membership by November 1, 2019** | Brian Toone | Fall 2019 |
| **Schedule a working meeting of editor, associate editors, and interested individuals for noon, Thursday, March 19, 2020.** | Brian Toone | Spring 2020 |
| **A phone call or webex will be scheduled for journal editors and interested parties before December 2019.** | Brian Toone and Jack Shelley-Tremblay | Fall 2019 |
| **The STEM-Ed Section will conduct a business meeting at the spring 2020 meeting to discuss this calendar proposal.** | Sarah Adkins | Spring 2020 |
| **Spring 2020 meeting STEM education committee and Mark Jones will have a meeting about creating short videos or podcasts. Potential time: Thursday, late afternoon.** | Mark Jones | Spring 2020 |
| **Place and Date of Meeting Committee will begin to identify** | Larry Krannich | Spring 2020 |

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|---|---|---|
| **hosts for 2024 and 2025.** | | |
| **Elect a full roster for the Place and Date of Meeting Committee** | Jack Shelley-Tremblay | Spring 2020 |
| **Identify a replacement for a trustee position** | Jack Shelley-Tremblay | Spring 2020 |
| **Clearly articulate on the website how members may update contact information** | Jack Shelley-Tremblay and Brian Toone | Spring 2020 |
| **Investigate advertising the meeting through public media** | Jack Shelley-Tremblay | Spring 2020 |
| **Hold a meeting of the ad-hoc task force to discuss the Alabama Science Trail** | Ellen Buckner | Spring 2020 |
| **Schedule committee and business meetings for Spring 2020 meetings so that they do not overlap** | Matthew Edwards, Drew Hataway, Larry Krannich | Fall 2019 |

# Alabama Academy of Science Journal

**Scope of the Journal:**

The Alabama Academy of Science publishes significant, innovative research of interest to a wide audience of scientists in all areas. Papers should have a broad appeal, and particularly welcome will be studies that break new ground or advance our scientific understanding.

**Information for the Authors:**

- Manuscript layout should follow the specific guidelines of the journal.
- The authors are encouraged to contact the editor (E-mail: brtoone@samford.edu) prior to paper submission to obtain the guidelines for the author.
- At least one author must be a member of the *Alabama Academy of Science* (except for Special Papers).
- The author(s) should provide the names and addresses of at least two potential reviewers.
- Assemble the manuscript in the following order: Title Page, Abstract Page, Text, Brief acknowledgments (if needed), Literature Cited, Figure Legends, Tables, Figures.

**Review Procedure and Policy:**

Manuscripts will be reviewed by experts in the research area. Manuscripts receiving favorable reviews will be tentatively accepted. Copies of the reviewers' comments (and reviewer-annotated files of the manuscript, if any) will be returned to the correspondent author for any necessary revisions. The final revision and electronic copy are then submitted to the *Alabama Academy of Science Journal* Editor. The author is required to pay $100 for partial coverage of printing costs of the article.