DEPARTMENT NEWS

CONGRATULATIONS TO BILL HINZE

Bill Hinze (Emeritus Professor) will be receiving the 2016 GSA Geophysics Division's Woollard Award, in recognition of his outstanding contributions to geology through the application of the principles and techniques of geophysics.

Sessions to be held at GSA, attached to this newsletter:

T65 - Session 7, Sun. 8:00-12:00
T65 - Session 37, Sun. 1:30-5:30
T66 - Session 130, Mon. 1:30-5:30
T65 - Session 243 (posters), Tues. 9:00-6:30

EAPS LIBRARY

Message from Terry Wade: “Fall semester 2016 is about to begin. I have received the textbook list from the office and put the books listed there on reserve here in the EAPS library. If you are teaching a class and have additional materials that you would like to put on reserve for your course please email me or stop in the library and let me know what those materials are...
My email address is twade2@purdue.edu and my phone number is 494-3264. Have a great semester. Thanks.

**PUBLICATIONS**


**UNDERGRAD/GRAD NEWS**

**CIMMS RESEARCH ASSOCIATE**

The Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) at The University of Oklahoma seeks to fill a research associate position to support verification efforts within the National Oceanic and Atmospheric Administration (NOAA) Office of Oceanic and Atmospheric Research (OAR) National Severe Storms Laboratory’s (NSSL) Warn on Forecast (WoF) Program.

Please see attached flyer for more detailed information about this position.

**10TH ANNUAL ECOLOGICAL SCIENCES AND ENGINEERING SYMPOSIUM**

**September 28 -29, 2016**
Discovery Park

More details to come: https://www.purdue.edu/gradschool/ese/symposium/index.html

**2016 BIG TEN GRADUATE SCHOOL EXPOSITION**

Sunday & Monday
Sept. 25-26, 2016

*Key networking opportunities
*Informational workshops
*Premier graduate school fair
*comprehensive information regarding graduate school education in:
   Engineering - Science - Science-related disciplines - Mathematics - Technology

Please see attached flyer.

**CAREER SERVICES CONSULTANT WITH PURDUE CCO**

Please plan to join Purdue CCO in learning about Purdue CCO services and how you can maximize your time in grad school.

Please see attached flyer for more details.

**August 29, 30, or 31**
6:00-7:00 pm
PGSC 105A

**PUPS**

**PURDUE UNIVERSITY PLANETARY SCIENCE**

There is a new student club called PUPS (Purdue University Planetary Science)–to provide a sense of community for students who are interested in planetary sciences, as well as, providing encouragement and information about the future of planetary science. The goal is to increase awareness of and the interdisciplinary nature of planetary sciences.

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http://www.eaps.purdue.edu/
OVERLEAF PRO

The Purdue University Graduate School is providing free Overleaf Pro accounts for all students, faculty and staff who would like to use a collaborative, online LaTeX editor for their projects, presentations and papers. Please see flyer for details.

PURDUE HOSTING WORKSHOP ON JETSTREAM, A CLOUD RESOURCE FOR SCIENCE AND ENGINEERING, AUG. 17

Purdue will host a workshop on Jetstream, a National Science Foundation cloud resource for science and engineering research, from 10-11:30 a.m. Aug. 17 for faculty, staff and students interested learning more about Jetstream and what it can offer, including easier access to national high-performance computing systems. More information: https://www.rcac.purdue.edu/news/860. Questions: rcac-help@purdue.edu.

HARRY S. TRUMAN FELLOWSHIP

Sandia National Laboratories is beginning its ad campaign to attract qualified candidates for its President Harry S. Truman Fellowship in National Security Science and Engineering. The deadline for proposal submission is November 1, 2016. Attached is a letter that was set from Marcey Hoover (a Purdue grad) to Dean Svensson and a flyer that I hope you will share with qualified individuals in your programs.

The flyer contains a link to the Sandia web site which explains the Truman Fellowship in more detail. If you need additional information, please contact Yolanda Moreno (ymoreno@sandia.gov).

See attached letter/flyer.

“SKILLS PERFORMANCE” TRAINING OPPORTUNITIES AVAILABLE FOR STAFF

Purdue University - Training offers a wide selection of extension courses for both personal and professional growth. Taught by experts in their fields, the courses provide practical, hands-on experience. And, best of all, anyone can afford them. Take a look through their online catalog for courses that interest you. Then, register for the courses you want right now using the web site below!

Please click here to sign up for upcoming classes: https://www.eventreg.purdue.edu/training/Home.aspx

COSINE

COSINE (College of Science Instructional Nightly Enrichment) is a free tutoring program to help students in first-year courses in Biology, Chemistry and Math. COSINE offers evening tutoring right in your own backyard. Our goal is to help you develop problem-solving skills needed to do your homework. Please visit their summer location for assistance. COSINE at Shreve Hall URSC (you may enter from the new dedicated entrance on 3rd street) from 6 – 9 pm on Tuesdays, Wednesdays, and Thursdays of summer school. Tutors will be available beginning June 14, 2016.

*** For optimal tutoring results, bring your textbook and class notes. ***

BIRTHDAYS

Terry West Aug 15

http://www.eaps.purdue.edu/
IMPORTANT NOTICE ABOUT THIS NEWSLETTER

This newsletter is used as the primary information source for current and upcoming events, announcements, awards, grant opportunities, and other happenings in our department and around campus. Active links to additional information will be provided as needed. Individual email announcements will no longer be sent unless the content is time-sensitive. We will continue to include our publications, presentations and other recent news items as well. Those using paper copies of the newsletter should go to our newsletter archive on the EAPS website at http://www.eaps.purdue.edu/news/newsletters.html and Click on News to access active links as needed. Material for inclusion in the newsletter should be submitted to Fallon McQuem (fmcquem@purdue.edu) by 5:00pm on Thursday of each week for inclusion in the Monday issue.

If it is in the newsletter, we assume you know about it and no other reminders are needed. For answers to common technology questions and the latest updates from the EAPS Technology Support staff, please visit: http://www.eaps.purdue.edu/resources/information_technology/index.htm

Also, as an additional resource for information about departmental events, seminars, etc., see our departmental calendar at http://www.EAPS.purdue.edu/events-calendar.html
WELCOME BACK PICNIC
EAPS Faculty, Staff, and Graduate Students

Thursday, August 18
4:30 - 7:00 P.M.
NEW LOCATION:
Cumberland Park, North Shelter

Dinner will be provided, but you are welcome to bring a dessert to share.

Families Welcome!
Spatial Redistribution of U.S. Tornado Activity between 1954 and 2013

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ABSTRACT
Climate change over the past several decades prompted this preliminary investigation into the possible effects of global warming on the climatological behavior of U.S. tornadoes for the domain bounded by 30°–50°N and 80°–105°W. On the basis of a warming trend over the past 30 years, the modern tornado record can be divided into a cold “Period I” from 1954 to 1983 and a subsequent 30-year warm “Period II” from 1984 to 2013. Tornado counts and days for (E)F1–(E)F5, significant, and the most violent tornadoes across a 2.5° × 2.5° gridded domain indicate a general decrease in tornado activity from Period I to Period II concentrated in Texas/Oklahoma and increases concentrated in Tennessee/Alabama. These changes show a new geographical distribution of tornado activity for Period II when compared with Period I. Statistical analysis that is based on field significance testing and the bootstrapping method provides proof for the observed decrease in annual tornado activity in the traditional “Tornado Alley” and the emergence of a new maximum center of tornado activity. Seasonal analyses of both counts and days for tornadoes and significant tornadoes show similar results in the spring, summer, and winter seasons, with a substantial decrease in the central plains during summer. The autumn season displays substantial increases in both tornado counts and significant-tornado counts in the region stretching from Mississippi into Indiana. Similar results are found from the seasonal analysis of both tornado days and significant-tornado days. This temporal change of spatial patterns in tornado activity for successive cold and warm periods may be suggestive of climate change effects yet warrants the climatological study of meteorological parameters responsible for tornado formation.

1. Introduction
The temporal change of spatial patterns in the U.S. “tornado climatology” is an increasingly important research area because of the potential effects of global warming on key meteorological fields of information that affect severe-thunderstorm and tornado development. Additional value in having such updated information is also evident in the study by Ashley and Strader (2016). Brooks et al. (2014a), as well as Agee and Chils (2014), have noted the various uncertainties in the tornado record that can potentially impede a determination of any climate change effects on tornado occurrences. Climate-model simulations (e.g., Trapp et al. 2007; Diffenbaugh et al. 2013) point to the possible effects due to increasing CAPE, yet these model predictions also show decreasing shear in the lower levels of the troposphere. These conflicting meteorological predictions in a warming climate introduce further uncertainty in detecting changes in severe-thunderstorm behavior that exceed the natural internal variability.

Dynamic downscaling of reanalysis data, as well as climate-model simulation, offers the opportunity to examine regional patterns of meteorological change

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that affect hazardous convective weather (HCW). Trapp et al. (2011) with downscaling of reanalysis data and Gensini and Mote (2015) through high-resolution dynamic downscaling of the CCSM3 (acronym definitions can be found at http://www.ametsoc.org/PubsAcronymList) show regions favored for increased HCW. Downscaling performed by Gensini and Mote (2015) to a 4-km grid spacing, using the Weather Research and Forecasting (WRF) Model, makes a comparison of severe-weather events east of the Continental Divide for the decade 1980–90 versus 2080–90. Their results show that the greatest increase of HCW is for the middle and lower Mississippi valley, Tennessee valley, and lower Ohio valley regions with decreased events to the north and the west of these areas. Results presented later support such findings.

From an observation perspective, there is growing interest in finding evidence of changes in tornado climatology associated with the possible effects of global warming in the U.S. tornado region for the past several decades. Elsner et al. (2015) present empirical evidence of changes in tornado climatology that are possibly related to climate change. Dixon et al. (2011) help to identify the emerging evidence of a “Dixie Alley,” which represents an eastward extension of the traditional “Tornado Alley” in the central plains. These efforts point to the need and opportunity to examine statistically the possible temporal and spatial changes in the tornado climatology (particularly since 1954, which is the accepted starting point of the modern tornado record).

A preliminary investigation of the modern tornado record encouraged this study by finding substantial differences in annual tornado counts for key tornado states such as Oklahoma (in the traditional Tornado Alley) and Tennessee (in Dixie Alley). This preliminary effort defined two successive 30-year periods—a cold “Period I” (1954–83) and a warm “Period II” (1984–2013)—on the basis of surface air temperature for the region 80°–105°W and 30°–50°N. State counts were compiled for each period (but not presented here). For example, in Oklahoma the tornado counts for tornadoes that are rated (E)F1–(E)F5 on the (enhanced) Fujita scale have decreased from 1096 in Period I to 713 in Period II for a loss of 383 (or a 35% decrease). Tennessee, however, increased from 275 in Period I to 457 in Period II for a gain of 182 (or a 66% increase).

Increasing population has historically accounted for a steady increase in annual tornado counts until recent years. Much of this increase is attributed to large increases in (E)F0 tornado counts (Verbout et al. 2006), and these events are not included in this study. Note also that shifts in rural population into expanding suburban areas may affect annual counts, especially for weaker tornadoes (but likely not for counts of strong and violent tornadoes).

Next, Student’s t tests on 2.5° × 2.5° grid boxes in the aforementioned domain (comparable to the resolution in the NCEP–NCAR reanalysis data) showed significant differences in the annual mean tornado counts for the four grid boxes with the most extreme change, which encompassed Oklahoma (maximum decrease) and Tennessee (maximum increase). Although these preliminary results were suggestive of two distinct populations, the t test is not the most effective statistical test to establish this spatial shift. Therefore, more rigorous statistical analysis, such as 1) field significance testing and 2) the comparison of individual grid boxes using the bootstrapping method of resampling, is required to establish acceptable spatial and temporal shifts in tornado activity. In essence, this is the nature of the analysis and the results presented below in this study.

A fundamental premise underlying this study has been to analyze two equal-length tornado records for the NCEP–NCAR gridded domain (80°–105°W, 30°–50°N) corresponding to two successive 30-year periods, 1954–83 and 1984–2013. It was noted a priori that changes in surface air temperature for the two periods selected also represented two successive multidecadal periods characterized by cold surface air temperature followed by a warmer period for the
continental United States (CONUS). This trend in temperature may have climate change implications for tornado behavior, but this possibility has not been investigated in this particular study.

2. Selection of data, time periods, and analysis

To identify temporal changes in spatial patterns of tornado activity it is appropriate to define a domain that encompasses the U.S. Tornado Alley, as well as appropriate time periods with homogenous data records. The domain selected (30°–50°N, 80°–105°W) covers the principal region of U.S. tornado activity and is divided into a 2.5° × 2.5° gridbox array, corresponding to the NCEP–NCAR reanalysis data record. The modern tornado record for climatological studies begins with 1954, and in this study the period chosen is from 1954 to 2013. The objective was to use the longest possible data record for each period and that these two periods have equal length, which happened to correspond to successive cold and warm periods. Surface air temperature for the tornado data record helps to define the above-mentioned cold Period I (1954–83) and warm Period II (1984–2013). Figure 1 shows the two trend lines of the average annual surface air temperature for CONUS that correspond to the cold [0.35°F (0.19°C) decrease] and warm [1.19°F (0.66°C) increase] periods. The trend lines of the average annual surface air temperature for the domain of this study are comparable to the trend lines for CONUS (in Fig. 1), but CONUS provides a slightly larger larger region over which surface air temperature trends can be examined because it encompasses the domain of this study as well as the surrounding area in which storm systems that affect the chosen domain may form.

a. Tornado counts and tornado days: Period I versus Period II

As can be noted in the previous studies that were referenced earlier, the recognized tornado record for climatological studies consists of the (E)F1–(E)F5 tornado events. Tornado counts for each grid box are determined on the basis of the following: 1) tornado starts in the grid box and ends elsewhere, 2) tornado starts elsewhere and ends in the grid box, 3) tornado starts...
and ends in the grid box, or 4) tornado starts elsewhere and ends elsewhere but the straight-line path crosses though the grid box. It is noted at this point that the gridbox numbers for all figures that follow are not presented but rather are simply referenced and represented by the contour plots. Figures 2a–i present the respective (E)F1–(E)F5, (E)F2–(E)F5, and (E)F3–(E)F5 tornado counts for Period I (Figs. 2a–c), Period II (Figs. 2d–f), and Period II minus Period I (Figs. 2g–i). Figures 2a, 2d, and 2g show the (E)F1–(E)F5 tornado counts across the domain. The grid box (2.5° × 2.5°) with the maximum (E)F1–(E)F5 count in Period I, as shown in Fig. 2a, was in southeastern Oklahoma and northeastern Texas (with 477 events). For Period II the (E)F1–(E)F5 count for this grid box decreased to 260 events, as shown in Fig. 2d, for a reduction of 217 (or a decrease of 45%). For Period II, the grid box with the maximum tornado count is now located in northern Alabama (also 477 events). For Period I the count for this grid box was 323 events, which represents an increase of 48% from Period I to Period II. These contour plots that are based on data for each grid box show strong evidence of a possible major shift in the geographical location of the most tornado activity (as well as for the most significant tornadoes, shown in Figs. 2b, 2e, and 2h). It is proposed that the new “heart of Tornado Alley” as based on annual totals (and not on any particular season) is now located in central Tennessee/ northern Alabama and not in eastern Oklahoma. The findings in Figs. 2a, 2d, and 2g (and the additional results to follow) are also very supportive of the shift in the traditional Tornado Alley, as well as the targeted region for the Verification of the Origins of Rotation in Tornadoes Experiment-Southeast (VORTEX-SE) field program scheduled for 2016. Next, as shown in Figs. 2b, 2e, and 2h, for the significant tornadoes (E)F2–(E)F5 similar results are found, and the new maximum number (185) is located in northern Alabama while the greatest decrease (~159) is located in southeastern Oklahoma/ northeastern Texas. The maximum significant-tornado grid box for Period I was in eastern Oklahoma (271 events), which decreased to 123 events in Period II (for a reduction of 55%). Although the maximum gridbox count for Period II was located in northern Alabama and was comparable to Period I, the adjacent northern grid box in central Tennessee had a maximum increase in counts of nearly 100% (from 84 to 166). Also, it is evident in Fig. 2h that the significant tornadoes in northeastern Texas and eastern Oklahoma
decreased by counts of 159 and 148, respectively (equivalent to reductions of 62% and 55%). Furthermore, these results are similar to the collective count of the strong-to-violent (E)F3–(E)F5 tornadoes, as shown in Figs. 2c, 2f, and 2i. On the basis of the results shown in Figs. 2a–i, from central Tennessee to northern Alabama is presented as the modern-day center for annual tornado activity, replacing Oklahoma, the previous heart of Tornado Alley from 1954 to 1983, which has also experienced a substantial decline in tornado activity. Statistical support for this statement is presented later.

Although these figures and percentages of change are noteworthy, a new paradigm for U.S. tornado activity can be further defended by additional analysis. The question can be raised, for example, as to whether...
FIG. 5. As in Fig. 4, but for spring (MAM).

major tornado outbreaks affecting the “Dixie” states, such as 3–4 April 1974 and 27–28 April 2011, can bias the results. By examining tornado days [defined as a day with at least one (E)F1+ tornado], major outbreaks are counted as one or two days rather than a large quantity of tornadoes, thus eliminating the bias. The results of this tornado-day analysis further support the tentative conclusion presented in this study. Figures 3a–i are presented for tornado days with the same format of data presentation as Figs. 2a–i. These results, especially for the significant-tornado days, support the same general conclusion as deduced from tornado counts; that is, the candidate new heart of Tornado Alley. Figure 3a shows the most tornado days (246) from south-central Oklahoma to north-central Texas in Period I, but the new maximum in Period II (shown in Fig. 3d) is 208 in southern Mississippi. These regions
experienced decreases of 48% and 5%, respectively, while central Tennessee increased by 29 tornado days. Figures 3b, 3e, and 3h for the significant-tornado days show a maximum gridbox count of 151 in Period I, which decreases to 56 in Period II, with the greatest increase seen in central Tennessee of 25 significant-tornado days. Also, from Period I to Period II there is a general decline in significant-tornado days for almost the entire domain, with the maximum decrease occurring in the traditional Tornado Alley. Figures 3c, 3f, and 3i show the counts of tornado days for (E)F3–(E)F5, with two pronounced maxima: one in the traditional Tornado Alley and the second one in the Dixie Alley. It is also noted that Period II shows an overall weaker tornado-day signal than does Period I, but the new maximum is now located in northern
Alabama. Central Tennessee shows the greatest increase of 100% (from 14 to 28 days) for the most-violent tornadoes.

b. Seasonal changes (counts and days): Period I versus Period II

The changes noted above can be further examined for seasonality, beginning with the winter season (DJF) for Period I, Period II, and their difference for both the (E)F1–(E)F5 tornadoes, as shown in Figs. 4a, 4c, and 4e, and the significant tornadoes, as shown in Figs. 4b, 4d, and 4f. Period II has seen a substantial increase in (E)F1–(E)F5 tornado counts from Tennessee to the lower Mississippi valley. Similar results are shown in Figs. 4b, 4d, and 4f for the significant tornadoes; there are decreases near the Gulf Coast for Period II but an
increase in central and western Tennessee from Period I to Period II. The spring season (MAM), shown in Figs. 5a and 5b, identifies the traditional center of expected springtime tornado activity in Oklahoma for Period I. For Period II, however, two distinct maxima are apparent, as shown in Figs. 5c and 5d: one in central Oklahoma and one in northern Alabama. Central Tennessee had a maximum increase of 105 from Period I to Period II, while north-central Texas and southwestern Oklahoma had a maximum decrease of 172. Figures 5b, 5d, and 5f show similar results for the significant tornadoes, and values have continued to decline from Period I to Period II in the traditional Tornado Alley (with a maximum gridbox decrease of 105). Central Tennessee shows an increase in significant tornadoes of 55% (going from 65 in Period I to 101 in Period II), however. Figures 6a–d show the expected northward movement of tornado activity for the
summer (JJA) season, but Fig. 6e shows a substantial decrease in EF1–EF5 tornadoes of 80% (from 101 down to 20 tornadoes) in central Oklahoma for Period II minus Period I; this summertime decrease was also noted by Brooks et al. (2014b). Western Minnesota shows gridbox increases of 37 and 40, and eastern Colorado has an increase of 48. Figures 6b, 6d, and 6f present results similar to those for Figs. 6a, 6c, and 6e, but for the significant tornadoes. There are substantial decreases over much of the domain, as seen in Fig. 6f, except for the increase in southern Minnesota. The maximum gridbox decrease in east-central Oklahoma is 44 counts (Fig. 6f). Figures 7a–d show increases for counts and significant tornadoes from Period I to Period II. In particular, Fig. 7e shows a 68% increase in tornado counts (from 74 to 124) in southern Mississippi.
for SON, with the maximum increase in western Tennessee of 350% (from 18 to 81). Figures 7b, 7d, and 7f show the counts and differences for the significant tornadoes for the autumn season with noted increases from Georgia up through the Tennessee and Ohio valleys into northern Indiana and notable decreases west of the Mississippi River. These results are supported in part by the downscaling results shown in Gensini and Mote (2015, their Fig. 4).

Winter-season counts for (E)F1–(E)F5 tornado days and significant-tornado days are presented in Figs. 8a–f for Period I, Period II, and Period II minus Period I. For DJF the counts are largely confined to the Dixie Alley states for both periods, with a notable decrease along the
Gulf Coast. Figures 9a–f show a general spring-season decrease in tornado days and significant-tornado days for Period II minus Period I, with the largest MAM decreases in Oklahoma and north-central Texas. Figures 10a–f for JJA show the continued decline of both tornado days and significant-tornado days. Figures 11a–f for SON show an increase in tornado days for the southern tier of states as well as in portions of the Midwest and the Ohio valley, with continued evidence of decreases west of the Mississippi River (for both tornado days and significant-tornado days). In general, it is noted that the autumn season makes the greatest contribution to the annual increase in Tennessee/Alabama and that the summer contributes the greatest decrease
across Oklahoma and north-central Texas, which has implications for seasonal prediction and climate change projections. These results also show agreement with Gensini and Mote (2015).

3. Field significance and bootstrapping (annual counts): Period I versus Period II

As large as the spatial changes seem to be from Period I to Period II, suggesting a new center of maximum annual tornado counts (as well as significant tornadoes), additional analysis is required. The approach used now to further solidify these results is to apply a field significance test, which addresses any high spatial correlation present in the data, as well as the classical bootstrapping method through resampling (10000 times) to examine the corresponding probability density functions (PDF) and confidence intervals that can be determined (Diciccio and Romano 1988).

The field significance test performed in this study follows the method proposed by Elmore et al. (2006). First, a block bootstrap that resamples 10000 times with a block size of five values is used to test the significance of Period II minus Period I for all grid boxes in the domain at $\alpha = 0.05$. The proportion of statistically significant grid boxes $N$ is recorded and stored for later use. Next, a Monte Carlo process with 10000 trials calculates the correlation coefficient between the annual means of Period II minus the annual means of Period I and a series of values randomly selected from a standard normal distribution, and then it determines the proportion of correlation coefficients that are statistically significant at $\alpha = 0.05$. If the proportion of statistically significant grid boxes is greater than the proportion of statistically significant correlation coefficients, then the domain is “field significant.” For the (E)F1–(E)F5 tornado counts, $N$ is calculated to be 27.5% and the threshold is 8.75%.
Because $N$ exceeds the threshold, the (E)F1–(E)F5 tornado counts are field significant at the 95% confidence level. In a similar way, the (E)F2–(E)F5 tornado counts are found to be field significant at the 95% confidence level with an $N$ of 37.5% and a threshold of 8.75%.

Next, the classical bootstrapping method of resampling is performed to show the statistical significance of the difference between the two regions of most extreme change for each time period. Figure 12 shows the method for bootstrapping used to calculate the PDF for the difference between two grid boxes in a single period. First, two values are randomly selected with replacement, one from the set of annual mean counts for the eastern region and one from the set of annual mean counts for the western region. After the difference (eastern region minus western region) of the values is calculated, two more values are randomly selected in the same manner; this process is repeated until a set of 30 difference values is obtained. Then the mean of the 30 difference values is calculated. This entire process of sampling and calculating the mean is repeated 10000 times to obtain a set of 10000 mean difference values. From this set of mean difference values, a PDF is created that can then be used to test the significance of the counts at the 99% confidence level for a given period.

The bootstrapping method described above is done for the annual tornado counts and the annual significant-tornado counts with a focus on the regions of extreme change. Figure 13 highlights two of the most extreme regions of change, consisting of four grid boxes each and labeled as box $\alpha$ (decrease) and box $\beta$ (increase), that are prime targets for bootstrap analysis. Within these two regions, the individual west and east grid boxes with the greatest change are identified as GW (decrease) and GE (increase), respectively. Figure 14a shows the resampling results for the annual tornado counts over box $\beta$ minus box $\alpha$. Inspection of the accompanying table shows that the two regions are mutually exclusive at the 99% confidence level. Figure 14b is similar to Fig. 14a but is for grid box GE minus grid box GW. The comparison of these PDFs from resampling also shows 99% confidence level for the differences. Results for the significant tornadoes for grid box GE minus grid box GW are presented in Fig. 14c, which also supports, at the 99% confidence level, the different PDFs for the observational data versus the resampled data.

On the basis of all of the results presented in Fig. 14, there is statistical support for major temporal changes in the spatial climatology of U.S. tornadoes in the annual counts both for (E)F1–(E)F5 tornadoes and for significant tornadoes (E)F2–(E)F5. Furthermore, these shifts show a new region of maximum annual tornado (and significant tornado) occurrence for 1984–2013 identified by box $\beta$ (located in the Dixie Alley) and not by box $\alpha$ (located in the Period-I traditional Tornado Alley region).

4. Summary and conclusions

A statistical assessment of changes in the U.S. tornado climatology for two consecutive 30-year time periods over the domain bounded by 30°–50°N, and 80°–105°W has been completed. These two time periods of equal length were characterized by changes in the mean surface air temperature from cold in Period I (1954–83) to warm in Period II (1984–2013). The years 1950–53 are not considered to be a homogeneous part of the modern-day tornado record. Further, 2014 is not included because doing so would have resulted in time periods of unequal length. The chosen domain was divided into grid boxes that were 2.5° × 2.5°, which corresponds to the resolution of the NCEP–NCAR reanalysis data. Tornado counts for each grid box were made for all (E)F1–(E)F5 tornadoes, including various subsets of these data for significant, strong, and violent tornadoes. The gridbox counts were made for each event according to the following criteria: 1) tornado starts in the grid box and ends elsewhere, 2) tornado starts elsewhere and ends in the grid box, 3) tornado starts and ends in the grid box, or 4) tornado starts elsewhere and ends elsewhere but the straight-line path crosses the grid box. Similar considerations were given to tornado days, as well as seasonal partitions for all data. Tornado days are defined as a day with at least one (E)F1+ tornado. Statistical field significance testing, along with classical bootstrap resampling of selected datasets, has been introduced to support
FIG. 14. The difference in (a) (E)F1–(E)F5 tornado counts for box $\beta$ minus box $\alpha$ and the difference in (b) (E)F1–(E)F5 and (c) (E)F2–(E)F5 tornado counts for grid box GE minus grid box GW. All PDFs are derived from 10 000 times of resampling, and all of the PDFs are mutually exclusive at the 99% confidence level.
conclusions regarding spatial changes in tornado climatology between the two periods.

Tornado counts for Period I captured the classical, well-known center of Tornado Alley with a gridbox maximum of 477 located in southeastern Oklahoma and northeastern Texas. In Period II the new maximum gridbox value (also 477) is now located in northern Alabama. Differences in counts from Period I to Period II show respective changes of –217 and +154 for these grid boxes. Similar compilations for significant tornadoes again show the maximum count (271) in Oklahoma for Period I, but the new maximum in Period II (185) is located in northern Alabama. Equally important is the overall decline in significant tornadoes, with the largest decrease (–159) located in southeastern Oklahoma and northeastern Texas. Similar results have also been shown for the (E)F3–(E)F5 tornado counts. The field sampling test and the bootstrapping method of resampling (10000 times) for both the tornado counts and the significant-tornado counts support this geographical shift in the relocation of the center of U.S. tornado activity at the 95% confidence level and the 99% confidence level, respectively. Although several studies have shown evidence of the Dixie Alley of tornado events, the results here reveal that there is a temporal shift of maximum activity away from the traditional Tornado Alley.

Equally important in this study has been the examination of the number of tornado days, since it can be argued that the statistics are dominated by a few big outbreak events. The maximum number of tornado days in Period I (246) is located in southeastern Oklahoma and northeastern Texas, but in Period II the new maximum (208) is located in southwestern Mississippi and eastern Louisiana. The greatest decrease (137) is located in southwestern Oklahoma and north-central Texas, with the greatest increase (29) in central Tennessee. Similar results are noted for the significant and violent tornado days with a general overall decline in numbers.

Seasonal considerations of tornado counts and tornado days have been made that show interesting results that affect the annual totals discussed above. The winter season (DJF) shows substantial increases in tornado counts from Period I to Period II, with the maximum increase (56) in central Tennessee. Significant-tornado counts were largely unchanged except for decreases along the Gulf Coast and increases across Tennessee and western Kentucky. The spring season (MAM) shows a bifurcation in maximum counts from a single center in central Oklahoma (308) for Period I to two centers in Period II located in northern Alabama (283) and central Oklahoma (263). The greatest increase (105) is in central Tennessee, and the greatest decrease (172) is located in north-central Texas and southwestern Oklahoma. Similar results are noted for the significant-tornado counts. The summer season (JJA) shows the expected shift northward for both Period I and Period II, with the greatest decrease (81) located in western Oklahoma. Similar results are shown for the significant-tornado counts. The autumn season (SON) shows increases in tornado counts from Period I to Period II for the Dixie Alley states extending into northern Indiana, with a maximum gridbox value (63) located in western Tennessee. Similar results are shown for the significant tornadoes, with a new value of maximum change (22) located in western Tennessee, western Kentucky, and southern Illinois. Seasonal tornado days have also been determined for both tornadoes and significant tornadoes, and results are consistent and supportive of the findings for the seasonal tornado counts. Changes in seasonal tornado activity from Period I to Period II have accounted in part for the relocation of the center of annual maximum tornado activity.

Although this study has shown a temporal change in spatial patterns of tornado activity, no results have been presented to relate this to climate change. It is noteworthy, however, that the two periods studied are characterized by differences in surface air temperature that may be related to parameters that can influence tornado activity. Climate-model predictions of increasing CAPE and weaker shear raise interesting questions regarding the role of climate change in current and future U.S. tornado climatology. Considerably more investigation into the meteorological parameters responsible for the patterns of change in the new tornado climatology is warranted, with particular attention given to the agreement (or lack thereof) with climate-model simulations.

Acknowledgments. The authors are grateful to Purdue University doctoral candidate Kimberly Hoogewind for assistance with the gridbox tornado counts and their accuracy. Purdue University professor Michael Baldwin is recognized for suggesting use of the classical bootstrapping method and for assistance in implementing the field significance test. The reviewers are also recognized for their many valuable comments and constructive suggestions that have allowed the authors to improve the manuscript.

REFERENCES
Agee, E., and S. Childs, 2014: Adjustments in tornado counts, F-scale intensity, and path width for assessing significant


Research Associate

The Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) at The University of Oklahoma is currently seeking a Research Associate to collaborate with scientists and instructors at the National Weather Service (NWS) Warning Decision Training Division (WDTD) in Norman, OK, on training for severe weather warning decision making.

The duties of this position are:

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3) Develop technical expertise with AWIPS-2, WSR-88D products and applications, and the warning decision-making process.
4) Acquire skills in operation of Linux and Windows workstations to support development of simulations and other tools for warning decision-making training.
5) Participate in experimental warning/forecast exercises and WDTD training workshops.
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7) Review technical/professional publications and attend seminars to stay abreast of current developments in meteorological applications.
8) Perform related duties as assigned.

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T65. PRECAMBRIAN EVOLUTION AND MINERAL RESOURCES OF THE MIDCONTINENT RIFT REGION (POSTERS): IN HONOR OF WILLIAM J. HINZE
GSA Geophysics Division; Society of Economic Geologists; GSA Mineralogy, Geochemistry, Petrology, and Volcanology Division; GSA Sedimentary Geology Division; SEPM (Society for Sedimentary Geology)
Authors will be present from 4:30 to 6:30 PM.

243-1 145 LITHOSPHERIC STRUCTURES IDENTIFIED BY THE CIWEN ARRAY REVEAL INSIGHTS INTO THE EVOLUTION OF THE MIDCONTENT
GILBERT, Hersh1, CHEN, Chen1, YANG, Xiaotao2, PALVIS, Gary L.2, HAMBERGER, Michael W.2, MARSHAK, Stephen3 and LARSON, Timothy H.4, (1)Department of Earth, Atmospheric, and Planetary Sciences, Purdue University, West Lafayette, IN 47907, (2)Department of Geological Sciences, Indiana University, Bloomington, IN 47405, (3)Dept. of Geology, University of Illinois, 605 E. Springfield, Champaign, IL 61820, (4)Illinois State Geological Survey, Prairie Research Institute, 615 E Peabody Drive, Champaign, IL 61820, hersh@purdue.edu

243-2 146 NEW AIRBORNE GEOPHYSICAL DATA FOR THE LAKE SUPERIOR REGION OF NORTHWESTERN ONTARIO: A NEW TOOL FOR THE IDENTIFICATION OF NEOARCHEAN TO MESOPROTEROZOIC STRUCTURES AND ASSOCIATED MAFIC-ULTRAMAFIC INTRUSIONS
PUUMALA, Mark1, EASTON, R. Michael2, CUNDARI, Robert1, CAMPBELL, Dorothy1, RANSFORD, Desmond R.B.2 and METSERANTA, Riku2, (1)Resident Geologist Program, Ontario Geologic Survey, Suite B002, 435 James St. South, Thunder Bay, ON P7E 6S7, Canada, (2)Department of Geology, Lakehead University, 955 Oliver Rd, Thunder Bay, ON P7B 5E1, Canada, mike.easton@ontario.ca

243-3 147 GEOCHEMISTRY OF THE LOGAN IGNEOUS SUITE AND IMPLICATIONS FOR THE MAGMATIC EVOLUTION OF THE NORTHERN PART OF THE MIDCONTINENT RIFT
CUNDARI, Robert1, HOLLINGS, Pete2 and SMYK, Mark1, (1)Resident Geologist Program, Ontario Geological Survey, Suite B002, 435 James St. South, Thunder Bay, ON P7E 6S7, Canada, (2)Department of Geology, Lakehead University, 955 Oliver Rd, Thunder Bay, ON P7B 5E1, Canada, pnhollin@lakeheadu.ca

243-4 148 BUILDING A DIGITAL DATABASE FOR THE MIDCONTINENT RIFT SYSTEM
DICKEN, Connie L., Dept of Interior, U.S. Geological Survey, 12201 Sunrise Valley Dr, MS 954, Reston, VA 20192 and NICHOLSON, Suzanne W., U.S. Geological Survey, 954 National Center, 12201 Sunrise Valley Dr, Reston, VA 20192, cdicken@usgs.gov

243-5 149 DISTRIBUTION OF RADIOACTIVITY AND RADIOGENIC HEAT PRODUCTION ACROSS THE SEDIMENTARY BASIN IN NEBRASKA, CENTRAL UNITED STATES
YOUNG, Dylan W. and GOSNOLD, William D., Geology and Geological Engineering, University of North Dakota, 81 Cornell, Stop 8358, Grand Forks, ND 58202, dylan.young@my.und.edu
Session: Precambrian Evolution and Mineral Resources of the Midcontinent...
7-10  10:55 AM  PASSIVE RIFTING – TIME TO RETHINK THE PLUME PARADIGM FOR THE MIDCONTINENT RIFT  
LEVANDOWSKI, Will, U.S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025, william.levandowski@usgs.gov

7-11  11:10 AM  MAKING IT AND BREAKING IT IN THE UPPER MIDWEST: CONSTRAINTS ON CONTINENTAL ASSEMBLY AND RIFTING FROM EARTHSCOPE  
BEDROSIAN, Paul A., U.S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025, paul.a.bedrosian@usgs.gov

7-12  11:25 AM  LITHOSPHERIC BLOCKS AND RIFTING IN CENTRAL NORTH AMERICA: STRUCTURE, TECTONICS, AND GLOBAL ANALOGS  
KELLER, G. Randy, School of Geology and Geophysics, University of Oklahoma, Norman, OK 73019, grkeller@ou.edu

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Session No. 37

Sunday, 25 September 2016: 1:30 PM-5:30 PM
Room 407 (Colorado Convention Center)

T65. PRECAMBRIAN EVOLUTION AND MINERAL RESOURCES OF THE MIDCONTINENT RIFT REGION II: IN HONOR OF WILLIAM J. HINZE

GSA Geophysics Division; Society of Economic Geologists; GSA Mineralogy, Geochemistry, Petrology, and Volcanology Division; GSA Sedimentary Geology Division; SEPM (Society for Sedimentary Geology); GSA Annual Meeting in Denver, Colorado, USA - 2016

Session No. 37

1:30 PM METALLOGENY OF THE 1.1 GA MIDCONTINENT RIFT (Invited Presentation)

1:50 PM SULFUR ISOTOPE CHARACTERISTICS OF SULFIDE MINERALS IN THE ARCHEAN AND PALEOPROTEROZOIC BASEMENT ROCKS ASSOCIATED WITH THE MIDCONTINENT RIFT
THAKURTA, Joyashish and HINKS, Benjamin D., Department of Geosciences, Western Michigan University, 1903 W. Michigan Ave, Kalamazoo, MI 49008-5241, joyashish.thakurta@wmich.edu

2:05 PM S. OS AND CU ISOPE VARIATIONS BETWEEN SHEET- AND CONDUIT-STYLE NI-CU-PGE MINERALIZATION IN THE MIDCONTINENT RIFT SYSTEM USA
SMITH, Joshua M.1, RIPLEY, Edward M.2, LI, Chusi3, WERNETTE, Benjamin1 and TARANOVIĆ, Vjekoslav2, (1)Department of Geological Sciences, Indiana University, Bloomington, IN 47405, (2)Geology, Wayne State University, Detroit, MI 48202, jms44@umail.iu.edu

2:20 PM THE DISCOVERY OF EAGLE EAST: AN EXAMPLE OF MODEL-DRIVEN EXPLORATION
MAHIN, Robert and BEACH, Steve, Lundin Mining Corp., Eagle Mine, 4547 C.R. 601, Champion, MI 49814, bob.mahin@lundinmining.com

2:35 PM STRATIGRAPHIC AND STRUCTURAL CONTROLS ON KUPFERSCHIEFER-TYPE COPPER MINERALIZATION, WHITE PINE, MICHIGAN
ROWELL, William F.1, HRIVI, Daniel A2 and SHEPECK, Eric S.2, (1)Consultant, Lake Forest, IL 60045, (2)Highland Copper Company Inc., PO Box 338, White Pine, MI 49971, billrowell@comcast.net

3:05 PM S, OS AND CU ISOPE VARIATIONS BETWEEN SHEET- AND CONDUIT-STYLE NI-CU-PGE MINERALIZATION IN THE MIDCONTINENT RIFT SYSTEM USA

3:20 PM METALLOGENY OF THE 1.1 GA MIDCONTINENT RIFT (Invited Presentation)

3:35 PM THE MIDCONTINENT RIFT SYSTEM IN IOWA

3:50 PM THE MIDCONTINENT RIFT SYSTEM IN THE WESTERN LAKE SUPERIOR REGION, WISCONSIN, MINNESOTA, AND MICHIGAN

4:05 PM PRELIMINARY 3D MODEL OF THE MIDCONTINENT RIFT SYSTEM IN THE WESTERN LAKE SUPERIOR REGION, WISCONSIN, MINNESOTA, AND MICHIGAN

4:20 PM THE MIDCONTINENT RIFT SYSTEM IN IOWA

4:35 PM THE NORTHEAST IOWA INTRUSIVE COMPLEX: A MAJOR UNWRITTEN CHAPTER IN THE STORY OF THE MIDCONTINENT RIFT SYSTEM

See more of: Technical Sessions
Session: Structure and Tectonics of the South-Central United States: Craton to Gulf of Mexico and the Annual George P. Woollard Award Presentation

GSA Geophysics Division

Jay Pulliam, Harold Gurrola, Kevin L. Mickus, Gregory Dumond, Melanie A. Barnes and G.R. Keller, Advocates

130-1 1:30 PM AN OVERVIEW OF THE STRUCTURAL EVOLUTION OF THE GULF COAST REGION OF TEXAS AND LOUISIANA

MICKUS, Kevin L., Dept. of Geosciences, Missouri State University, Springfield, MO 65897, KELLER, G. Randy, School of Geology and Geophysics, University of Oklahoma, 100 East Boyd, Norman, OK 73019, PULLIAM, Jay, Geosciences, Baylor University, One Bear Place #97354, Waco, TX 76798 and GURROLA, Harold, Dept. of Geosciences, Texas Tech University, MS 1023, Science Building, Room 125, Lubbock, TX 79409-1053, kevinmickus@missouristate.edu

130-2 1:45 PM SEISMIC ANISOTROPY BENEATH THE CONTIGUOUS UNITED STATES FROM SHEAR WAVE SPLITTING ANALYSIS UTILIZING ALL THE USARRAY AND OTHER STATIONS

LIU, Kelly H., YANG, Bin B., LIU, Yunhua and GAO, Stephen S., Geology and Geophysics Program, Missouri University of Science and Technology, Rolla, MO 65409, kliu@msst.edu

130-3 2:00 PM NEW INSIGHT INTO THE LITHOSPHERE OF THE SOUTHERN MARGIN OF NORTH AMERICA FROM EARTHSCOPE SEISMIC DATA

GURROLA, Harold, Dept. of Geosciences, Texas Tech University, MS 1053, Science Building, Room 125, Lubbock, TX 79409-1053, PULLIAM, Jay, Geosciences, Baylor University, One Bear Place #97354, Waco, TX 76798, MICKUS, Kevin L., Dept. of Geosciences, Missouri State University, Springfield, MO 65897 and KELLER, G. Randy, School of Geology and Geophysics, University of Oklahoma, 100 East Boyd, Norman, OK 73019, harold.gurrola@ttu.edu

130-4 2:15 PM CRUSTAL SEISMIC VELOCITY MODELS OF TEXAS

BORGFELDT, Taylor M., WALTER, Jake and FROHLICH, Cliff, University of Texas Institute of Geophysics, University of Texas at Austin, 10100 Burnet Road, Austin, TX 78758, taylor.borgfeldt@utexas.edu

130-5 2:30 PM SEISMIC CONSTRAINTS ON LITHOSPHERIC REMOVAL ASSOCIATED WITH THE TRANSITION FROM THE BASIN AND RANGE TO THE GREAT PLANS AT THE SOUTHERN RIO GRANDE RIFT

PULLIAM, Jay, Geosciences, Baylor University, One Bear Place #97354, Waco, TX 76798, Jay.Pulliam@baylor.edu

130-6 2:45 PM STRUCTURAL AND PETROLOGICAL INSIGHTS AND CONTRASTS BETWEEN THE WICHITA AND ARUBBLE SEGMENTS OF THE SOUTHERN OKLAHOMA AULACOGEN AS REVEALED BY DEEP DRILLING INTO RIFT-RELATED ROCKS

PUCKETT, Robert E., 12700 Arrowhead Lane, Oklahoma City, OK 73120, HANSON, R., Geology Dept, Texas Christian University, Fort Worth, TX 76129, BRUESEKE, Mathew E., Department of Geology, Kansas State University, 108 Thompson Hall, Manhattan, KS 66506, PRICE, Jonathan D., Kimbell School of Geosciences, Midwestern State University, 3410 Taft Blvd., Wichita Falls, TX 76308, KELLER, G. Randy, School of Geology and Geophysics, University of Oklahoma, 100 E. Boyd, Norman, OK 73019, BULEN, Casey L., Department of Geology/Geography, Northwest Missouri State University, 800 University Drive, Maryville, MO 64468, ESCHBERGER, Amy M., Division of Reclamation, Mining and Safety, Colorado Department of Natural Resources, Denver, CO 80203, HOBBS, Jasper M., Geology, Kansas State University, Manhattan, KS 66502 and MERTZMAN, Karen M., (1)Department of Geology, University of Georgia, 210 Field Blvd., Athens, GA 30602, (2)Department of Geological Sciences, Brown University, Providence, RI 02912, (3)Department of Terrestrial Magnetism, Carnegie Institution for Science, 5241 Broad Branch Road NW, Washington, DC 20015, pbrockett@priceedwards.com

130-7 3:00 PM PRECAMBRIAN BASEMENT OF WEST TEXAS AND EASTERN NEW MEXICO: THE STORY FROM CORE AND CUTTINGS

BARNES, Melanie A., Department of Geosciences, Texas Tech University, Lubbock, TX 79409 and DENISON, Tim, Department of Geosciences, The Univ of Texas at Dallas, 2601 North Floyd Road, P.O. Box 830688, MS FO21, Richardson, TX 75083-0688, melanie.barnes@ttu.edu

130-8 3:15 PM A PROPAGATING RIFT MODEL FOR SEAFLOOR SPREADING IN THE GULF OF MEXICO BETWEEN 169-150 MA

HARRY, Dennis L. and JHA, Sumant, Department of Geosciences, Colorado State University, Fort Collins, CO 80523, Dennis.Harry@colostate.edu

130-9 3:30 PM INVESTIGATION OF P-WAVE REFLECTIVITY BENEATH THE SOUTHERN APPALACHIANS USING THE SESAME BROADBAND ARRAY

VERELLEN, Devon N., ALBERTS, Erik C., PARKER, E. Henry, HAWMAN, Robert B., FISCHER, Karen M.2 and WAGNER, Lara S., (1)Department of Geology, University of Georgia, 210 Field St, Athens, GA 30602, (2)Department of Geological Sciences, Brown University, Providence, RI 02912, (3)Department of Terrestrial Magnetism, Carnegie Institution for Science, 5241 Broad Branch Road NW, Washington, DC 20015, devon@sesamearray.org

130-10 3:45 PM ECENZOCIC FAULTING AND STRESS: TIPTON COUNTY, TN, WITH IMPLICATIONS FOR CENozoic Stress Field Rotation

VANDERLIP, Christopher, Department of Earth Sciences, University of Memphis, 109 Johnson Hall, The University of Memphis, Memphis, TN 38152 and COX, Randel T., Earth Sciences, University of Memphis, 109 Johnson Hall, Memphis, TN 38152, cvndrlip@memphis.edu

4:00 PM Break
HINZE, William J., Earth, Atmospheric, and Planetary Sciences, Purdue University, West Lafayette, IN 47906, wjh730@comcast.net

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