P2.30 IS THERE A WEEKLY CYCLE OF WARM SEASON PRECIPITATION?

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1. INTRODUCTION

In many populated continental regions a weekly cycle of anthropogenic air pollution aerosols has been observed with a minimum in concentrations on weekends and a maximum on weekdays. Several studies of the past decade have investigated if there is also a corresponding weekly cycle of precipitation. Results have been mixed and the influence of anthropogenic aerosols on precipitation remains controversial.

Studies finding a weekly cycle of precipitation include Cerveny and Balling (1998) where a weekly cycle of precipitation was observed off the northeast coast of the U.S. using satellite data. They observed more rainfall on weekends than on weekdays and attributed the increase to air pollution aerosols advecting off the heavily populated Northeast Coastal region. Bell et al. (2008) used 8 years of TRMM data over the U.S. and found a weekly cycle of rainfall in the Southeast having a Tuesday/Wednesday maximum and weekend minimum.

Other studies, however, have refuted the presence of a weekly precipitation cycle. DeLisi and Cope (2001) examined 20 years of precipitation from 7 coastal cities in northeastern U.S. and did not find a significant weekly cycle at the 95% confidence level. Schultz et al. (2007) examined 42 years of precipitation records in the U.S. (219 stations) and also found no significant dependency on day of week.

Given the inconclusive results to date additional studies are needed to determine what role, if any, anthropogenic aerosols have in precipitation climatology. Here we examine data from a U.S. national composited radar data set for a weekly cycle of precipitation during the warm season (June-August).

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2. DATA SOURCE AND METHODOLOGY

The data source for this study is a U.S. national WSR-88D radar composite having spatial and temporal resolutions of 2 km and 15 min, respectively. The reflectivity values are converted to a rainfall rate using a standard Z-R relation and then integrated over 24 h to obtain estimates of daily rainfall at each grid point. The rainfall values are then sorted by day of week and standard statistical values are calculated. Statistical significance is determined using the Wilcoxon rank-sum and bootstrap methods. Twelve years (1996-2007) of radar data during the warm season are examined. There are approximately 13 weeks each warm season, hence each gird point has about 150 samples for each day of the week.

3. RESULTS

Since Bell et al. (2008) found a Tuesday/ Wednesday rainfall maximum and a weekend minimum, we first examine the 12-year averaged Tuesday and Saturday rainfall maps and their differences (Fig. 1). In the Tue-Sat difference plot (Fig. 1c) it can be seen that many locations have positive differences of order 0.07-0.15 mm h^{-1} (30-50%) particularly east of the Mississippi River and in the Central Plains. Furthermore the anomalies are of large scale and intuition would probably lead one to conclude that they are significant. A few smaller areas of negative differences can be noted in Florida and central Texas.

To test the significance of the differences the Wilcoxon rank-sum test is used. At each grid point the ~150 Tuesday and Saturday daily rainfall values are ranked from highest to lowest and the difference between each ranked pair is found. Figure 2 shows two examples of the ranked data at individual grid points. One plot is from a region of positive Tue-Sat difference (northern Illinois) and the other from northern Florida where a negative difference is evident. It is clear from Fig. 2 that nearly all of the ranked differences (blue

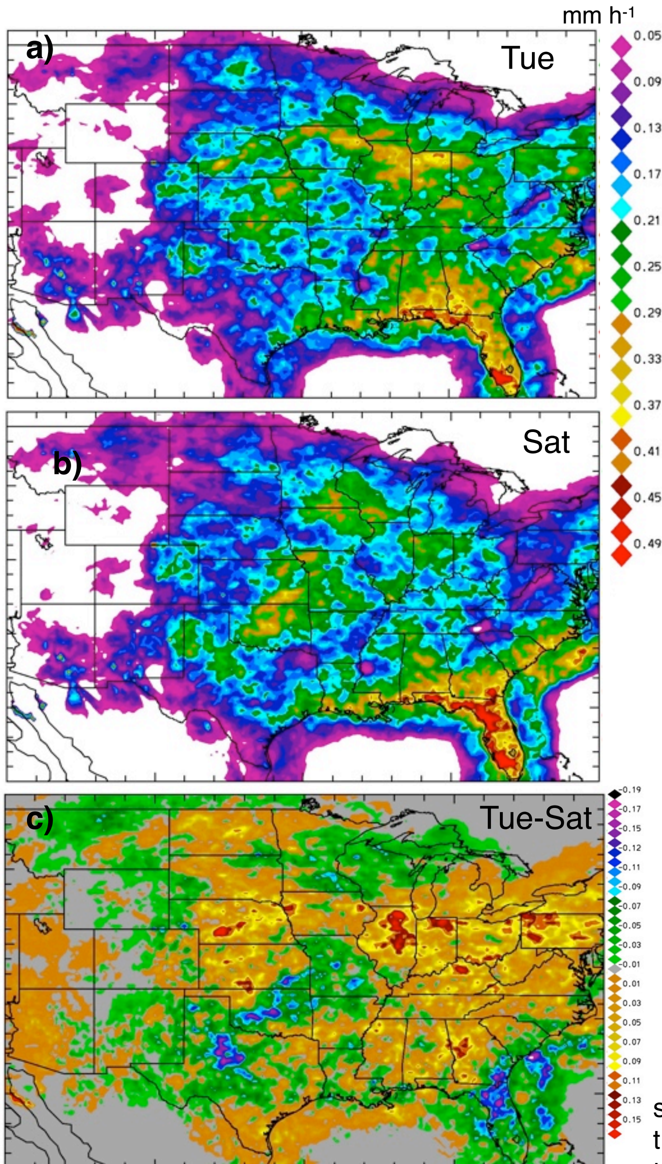

Fig. 1. Twelve-year average of radar derived rainfall for Tuesday, Saturday and the Tue-Sat difference.

curve) are positive (negative) for the Illinois (Florida) gird point.

Figure 3a shows a map of the percentage of ranked pairs that have a positive difference. Again it shows that large regions east of the Mississippi River and the Central Plains have all or nearly all of the Tue-Sat ranked pair differences as positive. It is somewhat astounding that there are such large areas of nearly all positive differences. The Wilcoxon rank-sum test is applied to these data to determine if they are indeed significant. Figure 3b shows the results of Fig. 3a but only those locations which are significant at the 1% level are

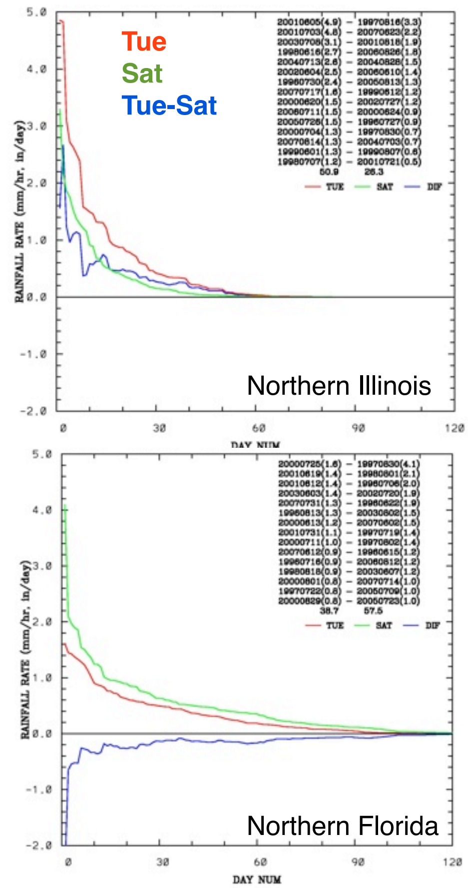

Fig. 2. Plots of ranked daily rainfall values for Tue (red), Sat (green) and the Tue-Sat difference (blue) at the indicated location.

shown. As one would expect many of the areas in the eastern U.S. and Central Plains would appear to have significant Tue-Sat differences. However, as will be shown shortly there are valid reasons to suspect these results.

Figure 1c shows large areas of positive Tue-Sat differences that would appear to be significant using a standard statistical test. One way to help assess the significance of these patterns is to perform random draws of the data without regard to the day of week, i.e., virtual Tuesday and Saturday samples are created by drawing from all days. The process is done so that the sample sizes are kept the same as the true Tuesday and Saturday populations.

Figure 4 shows virtual Tue-Sat differences for the first and tenth random draws. During the random draw process each grid point is assigned the same day on each draw. **The key point of Fig. 4 is that random draws produce anomalies**

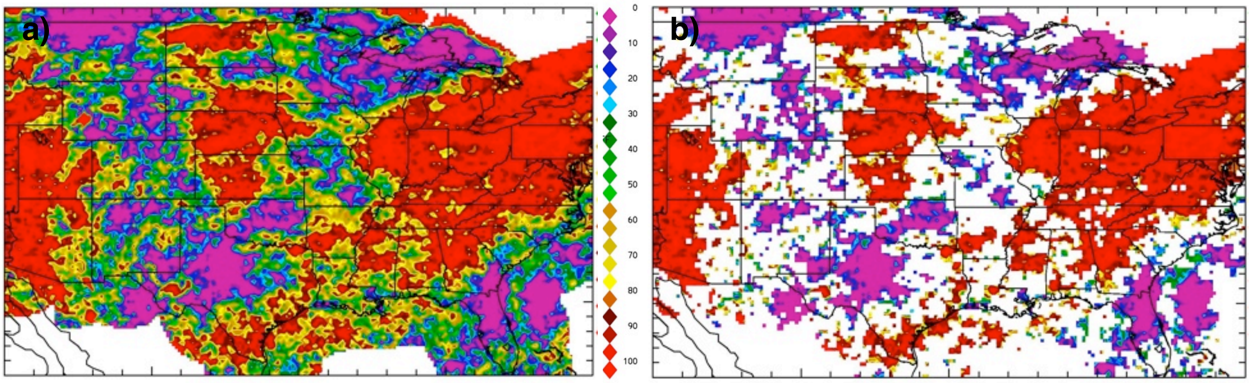

Fig.3. Plots of a) the percentage of Tue-Sat ranked pairs that have a positive difference and b) those locations that are significant at the 1% level using the Wilcoxon rank-sum test.

that are comparable in scale and magnitude to the actual Tue-Sat difference (Fig. 1c)! This raises a red flag that the data need to be examine more closely and of course begs the question of why do random draws produce anomalies of such large scale. It should be noted that an average of the random draws tends towards zero as more draws are included.

Figure 5 shows a random draw done in the same manner as Fig. 4 except that data values are chosen independently at each grid point, i.e., grid points do not share the same set of randomly chosen dates. This is a subtle but important difference. **Doing the draws in this manner eliminates the large spatial coherence that is inherent in rainfall events. It is this spatial coherence that leads to the large, but fictitious perturbations seen in the random draws of Fig. 4 and raises serious questions about the validity of the results in Fig. 1c.** Note that the magnitudes of the perturbations of Figs 4 and 5 are comparable. Thus while the process used in Fig. 5 eliminates the spatial coherence of rainfall events the temporal variance is retained.

There are several aspects of the rainfall data that make it challenging to analyze and use for testing. First ~40-50% of the days have zero (no rain) values. Secondly In most locations only 10-15 days contribute to 50% or more of the total 12-year rainfall. Thus while at first it may seem that the population is sufficiently large, it really isn't and is highly skewed. As already noted above the large spatial coherence of rainfall events can lead to misleading large-scale perturbations.

In data situations such as we have here the standard statistical tests (t-test, Wilcoxon rank-sum) may give misleading results and more

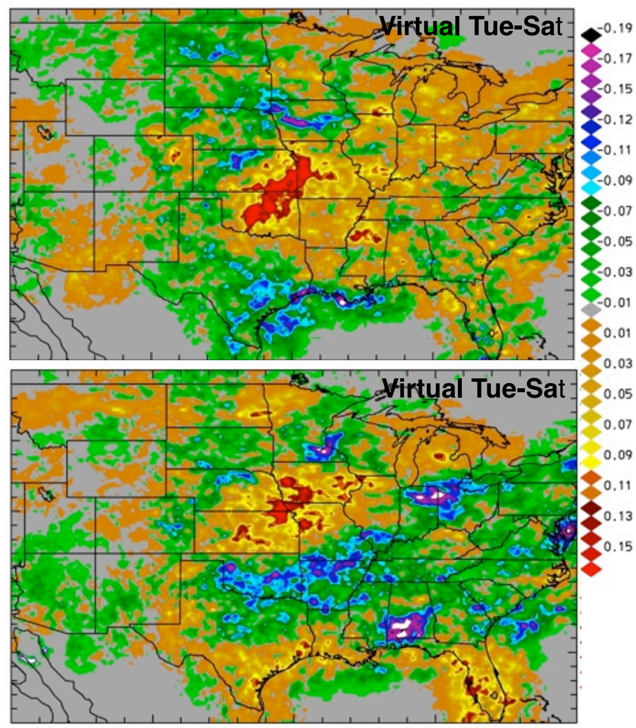

Fig. 4. Two examples of virtual Tue-Sat differences resulting from random draws of the data

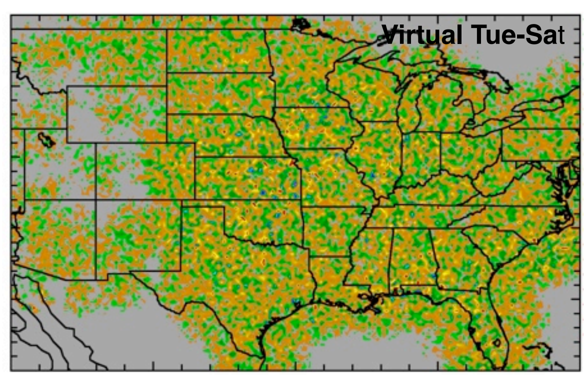

Fig. 5. Same as Fig. 4 except that random data values at each grid point are chosen independently of the other grid points.

robust tests should be used (Delucchi and Bostrom, 2004). One of the most robust tests that can be applied to a broad class of problems is the bootstrap. In the bootstrap, random resampling is done with the Tuesday and Saturday samples being drawn (with replacement) from the actual Tuesday and Saturday populations, respectively. The sample sizes are kept equal to the original samples and because of the replacement procedure any one bootstrap sample may contain two or more of the same observation, but none of other observations. As in other statistical tests the null hypothesis is that there is no difference between the Tuesday and Saturday populations. The null hypothesis is rejected if from a large number of bootstrap samples there is less than a 1% or 5% chance of zero being a member of the population.

Figure 6 shows the distributions of average Tue-Sat differences from 5000 bootstrap samples at two locations. The black and red dashed lines indicate zero difference and actual Tue-Sat difference, respectively. From the western Pennsylvania probability distribution there is 99.5% confidence that the Tue-Sat difference is different from zero and the null hypothesis can be rejected. In the southern Indiana location there is only 67% confidence and the null hypothesis cannot be rejected.

Figure 7 shows a map of the significance level determined from 5000 bootstrap samples. Areas of significant negative Tue-Sat difference at the 1% and 5% levels are enclosed by the purple and dark blue contours respectively. Areas of significant positive difference are denoted by the dark red (95%) and red (99%) contours. Note that the areas of significant Tue-Sat differences determined from the bootstrap method are much reduced compared to the Wilcoxon test of Fig. 3b and are only local in scale. The main area of significance remaining is in western Pennsylvania.

The overall significance level was calculated for region B of the Bell et al. (2008) study (white dashed box in Fig. 7) and was found to have a value of 59%. Thus on the regional scale of the Bell et al. (2008) study a significant Tue-Sat difference is not observable in the radar data.

Thus far only the Tue-Sat difference has been examined and it has been found that with the more robust bootstrap testing only limited, local areas of Tue-Sat differences are significant. Figure 8 shows how the area of significance changes as a function of the day of week, i.e., the “day of week”-Sat and “day of week”-Sun differences. Blue and

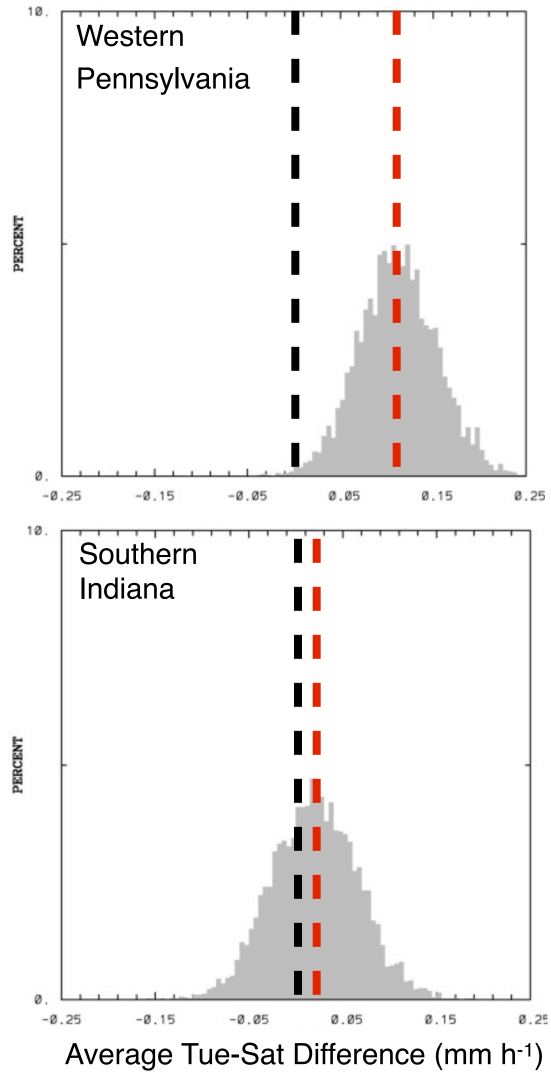

Fig. 6. The distribution of average Tue-Sat differences from 5000 bootstrap samples at the indicated locations. The red and black dashed lines indicate zero and actual Tue-Sat differences, respectively.

green curves are for the day-Sat and day-Sun differences, respectively. There is an increase in the area of positive difference from the weekend into Monday before leveling off and remaining near constant Tue through Fri. Note that only local areas exhibit a possible weekly cycle. A weekly cycle is not observed on the larger regional scale.

4. SUMMARY

Twelve years of warm season radar data were examine for a weekly cycle of precipitation. Initial results of simple statistics showed large areas of apparently significant (at the 1% level) positive Tue-Sat differences over large portions of the eastern U.S. Random resamplings of the data (drawing from all days), however, produced anomalies comparable in scale and magnitude to the actual Tue-Sat anomalies leading to a questioning of the validity of the initial results. It was demonstrated that the large anomalies from the random draws were due solely to the large spatial coherence inherent in precipitation events.

The standard statistical tests (t test, Wilcoxon rank-sum) probably produce misleading results because of the nature of rainfall distributions to have many zero events and to be highly skewed. The more robust bootstrap method was applied resulting in a large reduction of the area of significant differences and only localized regions remained. It is concluded that a large regional-scale weekly cycle of precipitation is not observable in the radar data. It is certainly possible that local areas of significant differences are present (most notably in western Pennsylvania) and these are worthy of further investigation.

5. REFERENCES

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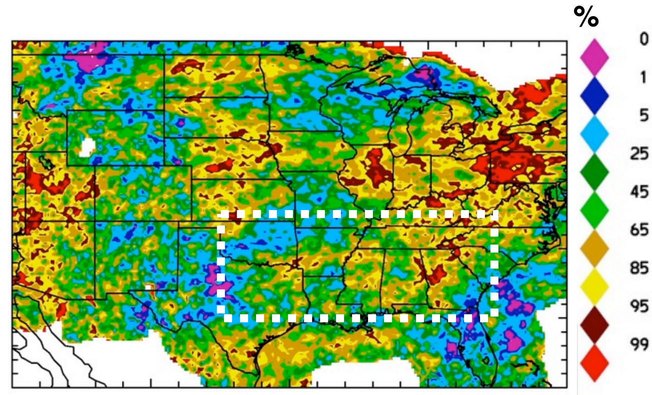

Fig. 7. Map of the significance level determined from 5000 bootstrap samples. White dashed box denotes area B of the Bell et al. (2008) study.

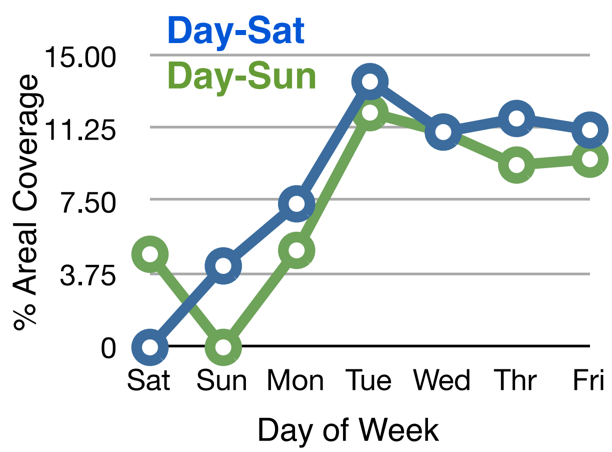

Fig. 8. Percentage of area having a significant positive difference over the eastern 2/3 of the U.S. as a function of day of week,i.e., percentage of areal coverage by the dark red contour in Fig. 7.