J9.4 **THE SOUTHWEST MONSOON AND THE RELATION TO FIRE OCCURRENCE**

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1. INTRODUCTION

In southeastern Arizona, a decline in climatological fire starts occurs in early July. This pattern is not as characteristically precipitous elsewhere in the southwestern United States (U.S.). The decline coincides with the arrival of the Southwest Monsoon, a seasonal climate feature impacting a large area of the southwestern U.S. Changes in atmospheric conditions resulting in conjunction with the monsoon could be some of the key mitigating factors. However, determining the extent of the monsoon's role in fire occurrence has not been well quantified or documented in either the climate or fire communities. In addition to the complicated characteristics of the monsoon, one of the chief problematic issues in investigating the fire-monsoon relationship is the interannual variability of both fire occurrence and the monsoon itself.

The monsoon attributes of onset, strength and duration are not yet at a high degree of reliable predictability, in part because the monsoon's mechanisms are not fully understood (e.g., Mitchell et al 2002). The 'official' definition of the onset from the Phoenix National Weather Service Forecast Office (NWSFO) in Phoenix, Arizona is a dew point of 55 degrees or higher for 3 consecutive days (http://www.wrh.noaa.gov/Phoenix/general/55degree/index.html). There are other definitions, though unofficial, using atmospheric and non-atmospheric variables. Higgins et al. (1997) developed a gridded precipitation index for most of Arizona and western New Mexico using +0.5 mm precipitation per day for 3 consecutive days as the onset. A recent study by Mitchell et al. (2002) has quantitatively related sea-surface temperatures in the Gulf of California to the onset, amount, and regional extent of monsoonal rainfall.

A non-disputable outcome of a well-developed monsoon is an increase in atmospheric moisture for most areas of the southwestern U.S. Given the topographical and elevational differences, the degree of increase will vary from one area to the next. The climatological increase in atmospheric moisture for southeastern Arizona is graphically displayed in the time series shown in Figure 1. Superimposed with the dew point climatology is the corresponding fire start (both human and lightning caused) time series. The curves imply an inverse relationship between dew point and fire occurrence starting around July 7th. This date is the average onset as defined by Phoenix NWSFO. These intriguing curves lead to the question: Is there a relationship between decreasing fires and increasing moisture associated with the onset of the Southwest Monsoon? A superficial glance at these synchronized climatologies would certainly suggest this could be true, but individual years' fire and dew point patterns often reveal an inconsistency to this climatological pattern. Undoubtedly, the interannual variability of these two variables will complicate the comprehensive picture.

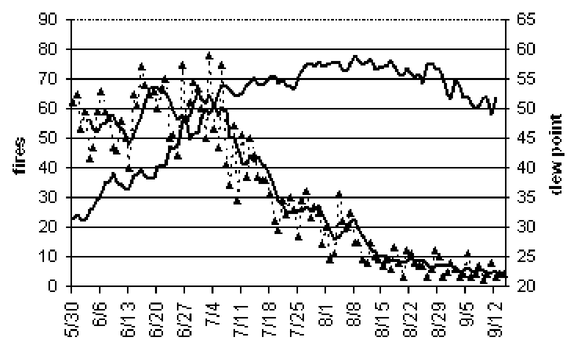

Figure 1. Dew point (solid line), and all fire (triangles with 5 day running mean applied) climatology for SE Arizona, 1980-2002.

In this study, applicability of the 'official' definition of the onset of the monsoon using a 55-degree or greater dew point for 3 days or more in the context of fire occurrence is discussed. In response to the findings, additional dew point analyses are performed to expose other unknown values that could have an impact. The dew point is used for two primary reasons: 1) It is the defining variable in the 'official' and accepted definition of the onset and 2) It is reasonably representative of atmospheric moisture content and is generally more consistent diurnally in comparison to other daily moisture variables such as relative humidity.

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The results of this research should provide an improved understanding of the 'firesoon', a suggested term referring to the impact on fire start activity due to the change in climate elements resulting from the Southwest Monsoon. This study also serves as a background for continuing research pertaining to meteorological and fire relationships in concert with other relevant fire weather variables such as fuel moisture.

2. DATA

2.1 Fire occurrence

Fires and dew point data were collected within the geographical boundaries of latitude 31.35 to 33.5 and longitude –109.05 to –111.45. Fire datasets were obtained from the U.S. Forest Service and Department of Interior (includes Bureau of Land Management (BLM), Bureau of Indian Affairs (BIA), National Park Service (NPS), and Fish and Wildlife Service (FWS)). State agency fires were not used due to the absence of cause codes and the limited availability of data from Arizona. Because of potentially serious data quality issues, all fires were subjected to a coarse assessment (Brown et al., 2002) to ensure the location, date of occurrence, type of fire, cause of fire, agency, and size were available and accurate. The 1km Current Cover Type (version 2000) fuel model map (http://www.fs.fed.us/fire/fuelman/) was used to estimate the vegetative fuel associated with the start location of each fire. Only fires assigned as a timber or shrub vegetative type were used for purposes of this study.

2.2 RAWS

A cluster of Remote Automatic Weather Stations (RAWS) in southeastern Arizona collectively characterizes the region's climatology. Specific criterion was used in the selection of these RAWS. A minimum of 11 years of weather data including temperature and relative humidity values during the time period of 1980-2002 from an individual RAWS site was compulsory. Non-existing or insufficient fire data preceding 1980 precluded the use of earlier years. If an available year had weather data, no more than 30 missing values could be present during the time period from June 1st to September 15th. The final number of RAWS was reduced to 7 from a possible 21 due to data deficiencies. For example, there are not only large data gaps during the year, but some years were missing altogether. Indeed, instances of missing data are too common and remain one of the biggest hindrances of this research. The relatively small sample size of fire occurrence in this region necessitated the grouping of RAWS rather than using analysis from individual sites. From the 7 usable RAWS, the median daily dew point value was determined for each year of the study period using the 1300 observations.

The fire climatology (Figure 1) is daily total number of fire starts for the 23-year period. The dew point climatology (Figure 1) is derived from the average median value from each year for each day in the series. The seasonal time period of reference for both series is from June 1st to September 15th.

3. ANALYSIS

The following analyses were conducted to explore the concept of increasing atmospheric moisture resulting from the Southwest Monsoon impacting fire occurrence in southeastern Arizona. The applicability of the 'official' definition of the onset (i.e., 55 dew point or higher for 3 consecutive days) and other potential dew point thresholds to fire occurrence is addressed. The first part examines each daily dew point (June 1st to September 15th) that occurred for the years 1980-2002 and the fire count for that dew point without consideration of an onset date, and then with an onset date. The objective for the 1st part is to find a dew point that exhibits a signal in decreasing fire occurrence for the cases of no onset and with an onset. For the second part, a 1, 2 and 3 consecutive day condition is not only used to define the time period of the Southwest Monsoon but also to calculate percentages of fire counts for each time this condition was met or exceeded during the defined monsoon season. This is to investigate the relevance of multiple days not only as an onset definition but also as a possible threshold for decreasing fire occurrence during the actual monsoon season.

3.1 Results – Part 1

A description of the two fundamental plots illustrating how the results quantitatively link fire occurrence to dew point is given below:

1) *Histogram plot* – Individual years' fire starts are totaled for the dew point value observed on the same day as the fire. For example, if on July 3rd, there were 10 fires that occurred and the 1300 dew point observation was 53 degrees then 10 is added to

current sum of fire counts that had a dew point of 53 degrees during the specified time period of analysis.

2) *Standardization curves* – To allow for direct comparison between the fire occurrence and dew point values, the frequency of fire counts and total number of days of each 1 degree dew point range (from X degree to Y degree) are standardized and plotted as well as the difference between these two curves. This is done to analyze the frequency of fire starts at each 1 degree dew point range relative to how many days occurred of that dew point.

A 'signal' in a particular dew point range is manifested by an increasing or unchanged frequency in dew point occurrence and a corresponding decrease in fires for that specific dew point. If the frequency of days with particular dew points and fires are decreasing concurrently, statistical rather than physical or atmospheric influences could be the reason for the decrease in fire occurrence.

Using all fires, Figure 2 shows dew point values and their corresponding number of fires for the season June 1st to September 15th and the frequency of days with the dew point value. As the dew point approaches 57-60 degrees, the number of fires increases. At these values, the frequency of fires drops from 142 to 87 fires. The frequency of days with 60 degree dew points actually increases slightly and does not decrease until 62 degrees.

The results from Figure 2 are re-expressed using standardized anomalies (Figure 3). A moderate to large negative difference between standardized fire counts and dew point day frequency would demonstrate more validity in the 60-degree signal as opposed to the 'official' 55 degree definition. When the dew point day frequency exceeds the fire counts (ideal case), a negative difference is produced. The opposite (non-ideal case) would display a positive difference. Figure 3 shows at 56 degrees, there is a noted difference of –1.0 standard deviation but the number of fires is still quite high for this value. From 60 to 63 degrees, the difference is –1.0 to -1.3 standard deviations. This could be considered a moderate difference and it is conceivable that the decrease in fires is physically related to these higher dew points. After 63 degrees, the number of days of dew point occurrence significantly decreases along with the frequency of fire starts.

The lack of consideration of an onset date could distort the standardized anomaly results by allowing fires that occurred before the actual monsoon onset to be included in the mean term of the standardized anomaly equation. For this next discussion, the 'official' definition of the onset is used to find a yearly onset date. The time period of analysis (monsoon season) becomes shorter if the onset of the monsoon is defined by a dew point threshold rather than June 1st with each season varying in length due to the interannual variability of the onset. The season ending date is arbitrarily determined to be the last day that 55 degrees occurs plus 4 additional days or September 15th, whichever comes first. This newly defined time period likely reduces the frequency of dew point occurrence especially at lower dew points. The drop in fire counts (figure not shown) at 60 degrees is similar to Figure 3 (no onset). But, the difference in the standardized curves with an onset is not even –1.0 standard deviation (Figure 4). When the time period is confined to a window of days after a pre-determined onset, it is clear that 60 degrees is not as strong of a signal. This is statistically explained since the average of these two variables are no longer including days outside the bounds of the monsoon season.

Cloud-to-ground lightning data were provided by Vaisala-GAI. Lightning strikes for the region and time of interest were summed by the dew point value in the same manner as fire occurrence. Though not shown, there are a considerable number of lightning strikes that remain high until a dew point value of 64 degrees. After this value, the number declines sharply. Based on the lightning climatology for this region, strikes (i.e., the ignition source for natural fires) continue until the beginning of September indicating potential of natural ignition sources all through the monsoon season. Lightning will obviously impact the natural fire trends, but not the non-natural fires, which encompass a range of causes such as campfire, smoking and railroad sparks. Figure 5 is a plot of the natural and non-natural fire climatology for southeastern Arizona. The time series are smoothed using a 5-day running mean. Interestingly, a sharp decline in non-natural fires begins around July 6th, but natural fires continue to increase until the 3rd week of July – almost two weeks after the 'official' climatological onset date of the Southwest Monsoon. After this time, they decrease moderately, but do not reach the level of non-natural fire occurrence for the remainder of the season. The dramatic dissimilarities in the two fire climatologies warrant separate analyses applying the same methodology as above. The 'official' definition of onset is again used to define the time period annually for natural and non-natural fires.

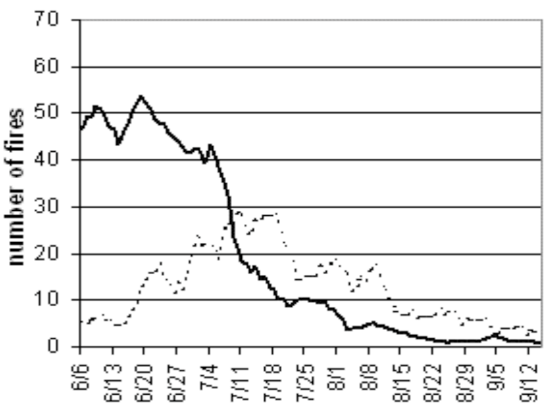

Figure 5. Natural (dashed line) and non-natural (solid line) fire climatology for SE Arizona, 1980-2002.

For natural fires (figure not shown), the drop in fire counts at a 60 degree dew point is still prevalent with the number of times for dew point occurrence unchanged. The standardized curves show a standard deviation difference close to –1.0 starting at 60 degrees (figure not shown). This finding is consistent with the results from using all combined cause fires (shown in Figure 1). Unlike natural fires, non-natural fires do not appear to exhibit any signal in the dew point values. The decline in fire counts is gradual rather than abrupt after 58 degrees and the standardized curves of the frequency of dew point occurrence and fire counts correspond closely indicating the decrease in fires is resulting from the limited frequency of the dew points (figures not shown).

The 'official' definition of the onset has been shown to be sufficient to elicit some signal in 60 degrees as a possible threshold in fire occurrence for natural and all causes combined fires. The 3-day period can still be applied but the next analysis uses 60 degrees as the defining value instead of 55 degrees. The monsoon season time frame with a higher dew point for the onset will be curtailed further thus restricting the frequency of dew point occurrence and the number of fires occurring within this time period. However, there remains a sufficient amount of data for analysis.

The standardized curves for 3 days at 60 degrees for the natural fire counts and dew point frequency reveal a standard deviation difference around –1.2 at 60 degrees, slightly greater than the difference found with using the 'official' onset (figure not shown). The rising dew point frequency that occurs between 58 and 61 degrees is not seen in the previous analyses. For non-natural fires (figure not shown), there are no sharp or notable changes in fire counts for any dew point value.

Thus far, these analyses have examined fire counts and dew point frequency for any dew point that occurred within the annually varying monsoon time period as defined by 3 consecutive days of 60 or 55 degrees. Perhaps using 1 day at 60 degrees to define the time period would yield similar results. Indeed, it is shown in Figure 6**,** that natural fires using this onset exhibits the same signal at 60 degrees as noted in other analyses. Non-natural fire analyses do not elicit a signal for any dew point using 1 day at 60 degrees for the onset (Figure 7).

3.2 Results – Part 2

Even though 60 degrees repeatedly appears as a possible 'signal' in combined and naturally caused fires for 1 and 3 consecutive days, the same methodology can be applied quantitatively to a range of dew point values. From 45 to 65 degrees at 1, 2, or 3 consecutive days as a condition, percentages were calculated by dividing the number of fires and dew point days above this condition by the total number of fires and dew point days for the monsoon season. The monsoon season is defined by the first date the condition is met and the end is defined by the last time the condition is met plus 4 additional days. An example will assist in clarification of this methodology. Suppose the condition is 58 degrees at 2 consecutive days. For each year from 1980-2002, starting at June 1st, the first date this condition is met defines the onset of the monsoon season for that year. Without applying this condition again during the season, the number of fires and the number of frequency of dew point days are totaled ('total' fire counts, and 'total' dew point days). These 'totals' are then combined from all 23 monsoon seasons. Subsequently, fires occurring during these same defined monsoon seasons when the condition of 58 degrees or higher for 2 consecutive days is met, are counted in the 'above' fire counts. The number of days 58 degrees or higher for 2 consecutive days is observed during the monsoon seasons is counted in the 'above' dew point days. The 'total' numbers are divided by the 'above' numbers to calculate the percentage of fires and dew point days occurring above this specific condition. This process was applied for each dew point from 45 to 65 degrees at 1, 2 and 3 consecutive days. These are the percentages plotted in Figures 8, 9, & 10.

Ideally, any dew point within 45-65 degrees showing *less* than half of the fires occurring above the condition but *more* than half of the days at that dew point or above would be an ideal case. The results (Figures 8, 9, & 10) for natural fires at 1, 2 and 3 consecutive days are slightly different from each other but all show the same characteristics. The fire count percentages exceed the dew point day percentage from 45 to 58 degrees for all day periods. In addition, the percentage curves both follow an exponential decrease. After 58 degrees, the ratios of the percentages are close to 1:1 for 1 and 2 days. However, for the 3 day period the percentage curves approach but never intersect meaning the fire counts at or above this condition were always greater than the times the condition occurred meteorologically at any dew point. This is consistent with earlier findings and stems from the physical limitations in the atmosphere with each day added to the condition. From the previous results, a notable change in the fire count percentage without appreciable changes in the dew point day percentage at 60 degrees would have been expected. But as demonstrated, only for the 1-day period does the dew point day percentage exceed the fire count percentage and this is only slightly. With the condition of 55 degrees or higher at 3 consecutive days (i.e., 'official' onset of the monsoon), 77% of natural fires still occurred at and above this condition during the monsoon season. This percentage is *not* incorporating fires that occurred before the defined monsoon season. It does not appear that dew point is a limiting factor in human fire starts. Even for natural fires, because of increased lightning, the fire counts stay elevated at relatively high dew points.

4. SUMMARY/CONCLUSIONS

The combination of fire counts and specific dew points at which they occurred was examined to reveal a potential relationship between these two variables. Constraining the time period of analysis using the 'official' definition revealed a dew point signal at 60 degrees. The ample number of lightning strikes occurring climatologically into September necessitated plotting natural fires and non-natural fires separately. Applying an onset of 1 or 3 consecutive days of 60 degrees or more to natural fires demonstrated the recurring signal of 60 degrees giving further credence to the notion that dew point is possibly a mitigating factor in natural fire occurrence.

The decline in natural fires after 60 degrees associated with an unchanged dew point frequency and large number of lightning strikes up to 64 degrees suggest increasingly wet thunderstorms with higher dew points. The observed signal for 60+ degrees at 1 day for natural fires allude to the idea of 1 day localized precipitation events as significant enough to inhibit fire occurrence as opposed to multiple days of a dew point less than 60 degrees with or without precipitation. Further analysis is required to explore this concept more fully.

None of the results showed 55 degrees at 3 consecutive days (the 'official' definition of the onset) as a key indicator of decreasing fire occurrence after the onset has occurred. The final test using a range of dew points showed that a little over three-fourths of natural fires still occurred after this specific condition was met or exceeded. Moreover, no dew point from 45 to 65 degrees appeared to be largely influential in the fire decrease for any cause fire.

The strongest signal and most surprising result is the sharp and early decline in human-caused fires around the time of the average onset. The reasons for this finding are unclear, as no dew point emerged as a signal in any of the results. This convincingly illustrates that dew point is not a limiting factor for non-natural fires unlike natural fires. When all fires were combined, the natural fire trends were obscured by this decline in human fires. As was shown, the natural fires do drop off around the 3rd week of July but not as sharp and not to the level of human fire occurrence.

4.1 Future work

The possibility of precipitation rather than or in addition to increasing moisture as the cause of decreasing fire occurrence warrants further research into this association. However, the limited availability of high temporal and spatial resolution precipitation datasets for this region and for the time period of interest are largely the reasons for not incorporating this variable thus far.

Fuel moistures for different vegetation types, should be explored to a greater extent. Minimum relative humidity was briefly examined with fire occurrence using all fires and for the complete summer season. Initial results suggested a lack of relationship, but more detailed analysis by fire cause and size would be of interest.

Human-caused fires could be examined from the sociological perspective by using historical statistics of human activity in this area. The goals of this particular study would be directed toward discovering the anthropogenic or non-anthropogenic reasons for the sharp decline after July 4th. Enhanced knowledge of other potential fire mitigating variables may assist in the explanation of this trend.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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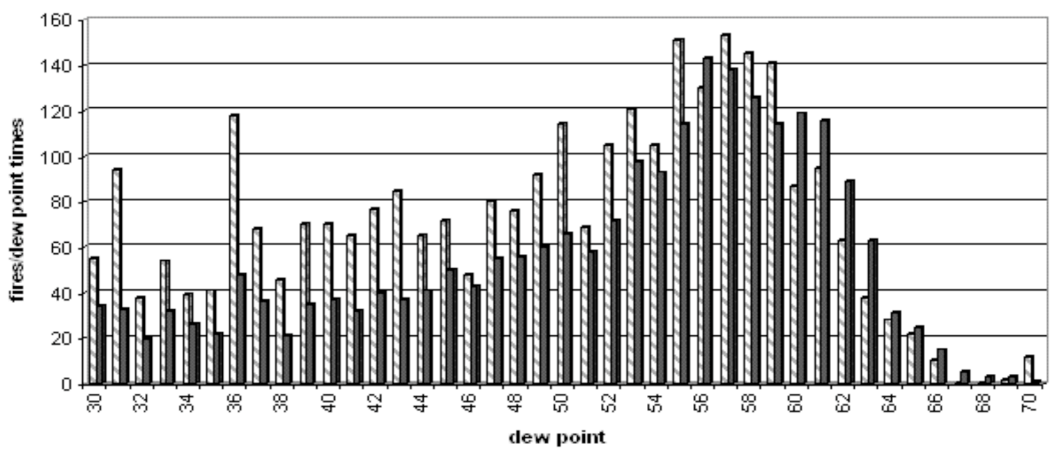

Figure 2. Histogram of dew point day frequency (solid bars) and all cause fire counts (striped bars) with no defined onset for SE Arizona, 1980-2002.

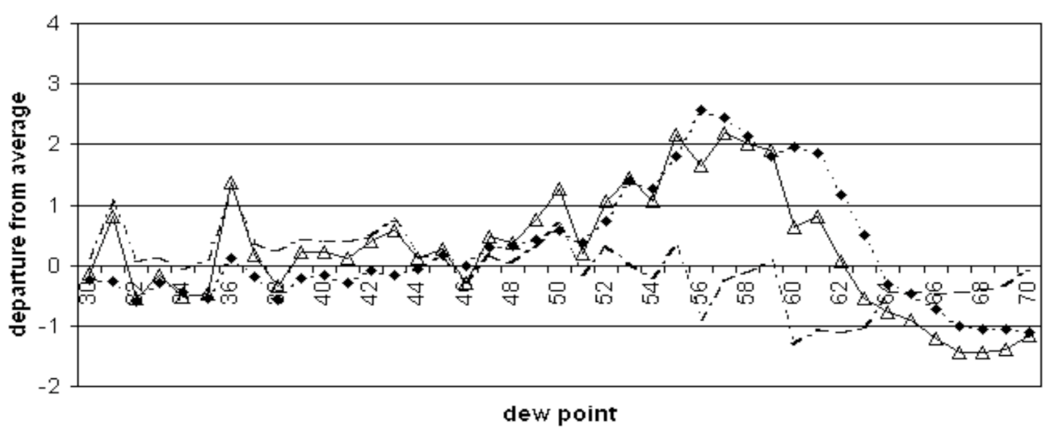

Figure 3. Standardized anomalies with no defined onset of dew point day frequency (diamonds), and all cause fire counts (triangles) from the above histogram (figure 2). The dashed line represents the difference of these curves.

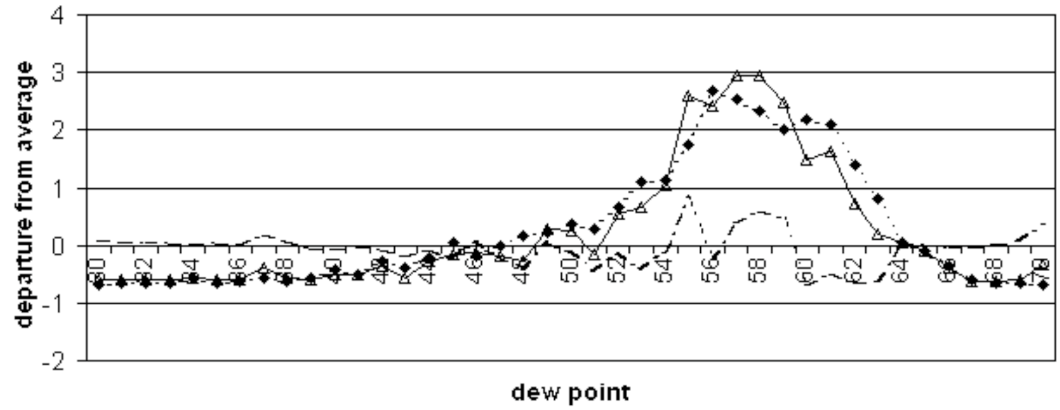

Figure 4. Standardized anomalies of dew point day frequency (diamonds), and all cause fire counts (triangles) using 'official' onset. The dashed line represents the difference of these curves.

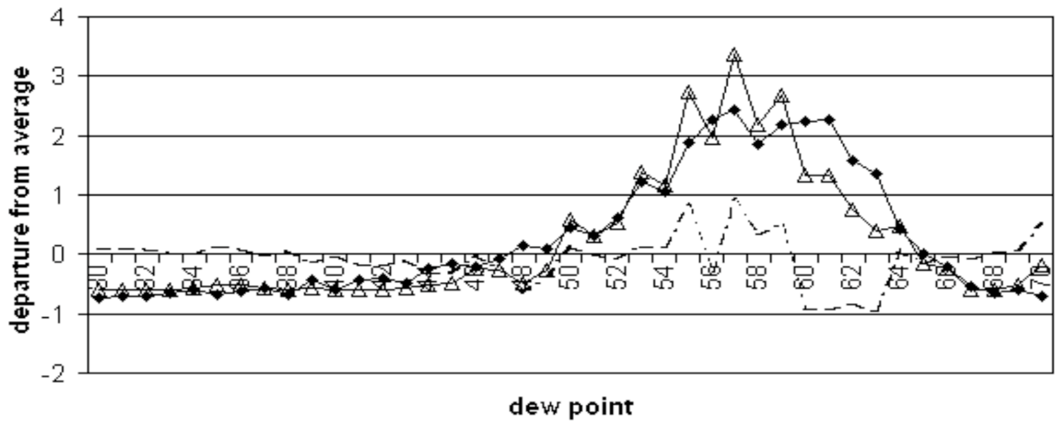

Figure 6. Standardized anomalies using onset of 1 day at 60 degree dew point of dew point day frequency (diamonds), and *natural* fire counts (triangles). The dashed line represents the difference of these two curves.

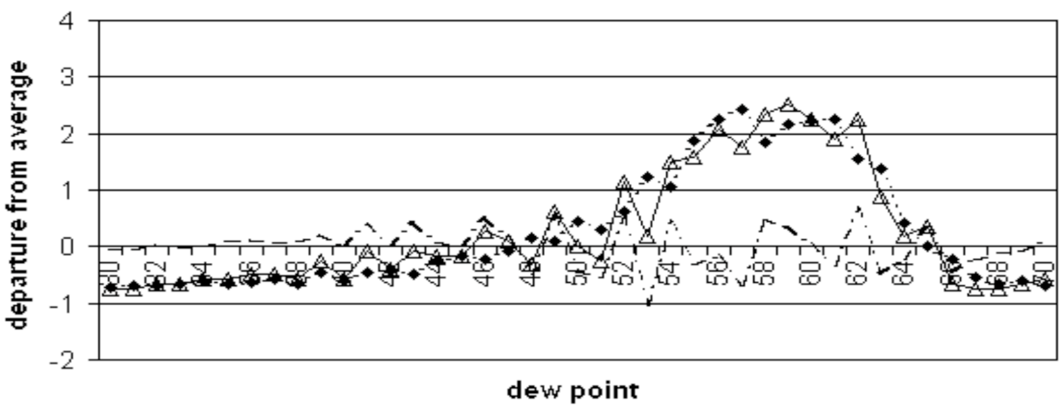

Figure 7. Standardized anomalies using onset of 1 day at 60 degree dew point of dew point day frequency (diamonds), and *non-natural* fire counts (triangles). The dashed line represents the difference of these two curves

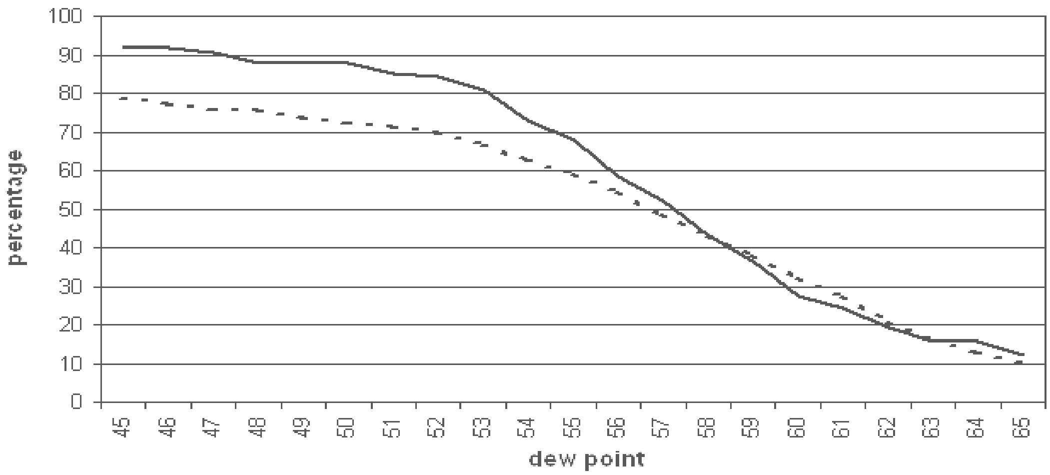

Figure 8. Dew point day frequency % (dashed line), and fire count % (solid line), for 1 day condition.

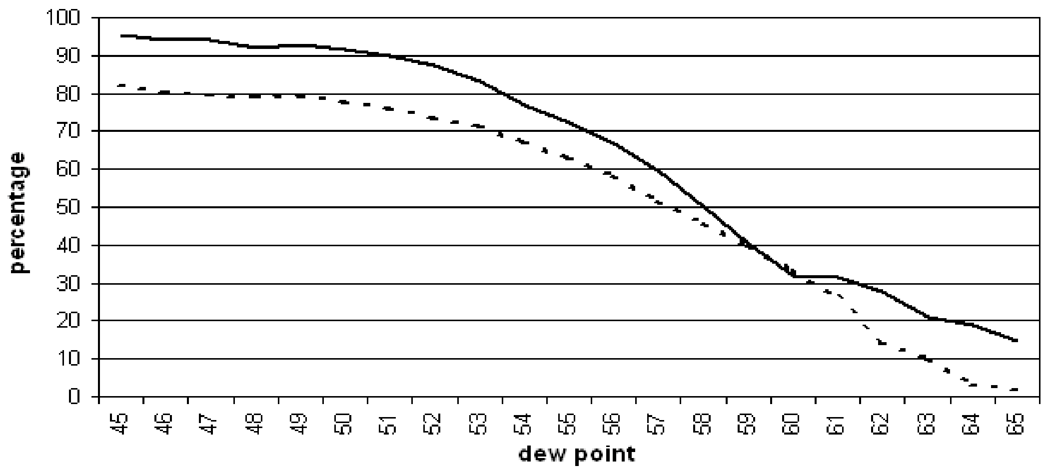

Figure 9. Dew point day frequency % (dashed line), and fire count % (solid line), for 2 day condition

Figure 10. Dew point day frequency % (dashed line), and fire count % (solid line), for 3 day condition.