

RELATIONSHIP OF DAILY FIRE ACTIVITY TO THE HAINES INDEX AND THE LAVDAS DISPERSION INDEX DURING 1998 FLORIDA WILDFIRES

By

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Abstract

The Haines Index is a common component in fire weather forecasts in the western part of the United States. The Haines Index provides an indication of the potential for large wildfires by examining the stability of the lower atmosphere and the dryness of upper levels of the atmosphere. In the eastern half of the country this index is not as widely used. Florida makes use of a different measure of atmospheric stability, the Atmospheric Dispersion Index (ADI). This index was designed to estimate the atmosphere's ability to disperse smoke from a prescribed fire. Experience among Florida's wildfire community indicates a strong relationship between high ADI values and fire control problems.

This study focuses on evaluating the predictive ability of these two indices with regard to the potential for large wildfires. Using data from the summer of 1998, when Florida experienced one of its most severe wildfire seasons on record, the relationship between both the Haines Index and the Atmospheric Dispersion Index to the occurrence of large wildfires was examined. The Haines Index performed well in predicting large wildfires during June of 1998. The ADI also performed well although the number of false alarms produced was much greater than for the Haines Index. Breaking out only the stability component of the ADI (i.e. neglecting transport winds) produced an index that performed comparably to the Haines Index.

Examination of the normalized ratio of the ADI stability component to the transport wind provided a further means of evaluating the atmosphere's ability to contribute to the rapid growth of wildfires. This ratio predicted all but two days of large wildfire growth and produced fewer false alarms than the other indices for 1998. For 1999, both the Haines index and the ADI performed poorly as indicators of large wildfire growth. The ratio of the stability component of the ADI to the transport wind again yielded better results. This ratio also indicated cases where the Haines index would work well (stability dominates) and when the ADI is most useful.

1.0 Introduction

During the spring and early summer of 1998 over 2,200 wildfires scorched nearly a half million acres of Florida. Many of these fires rapidly grew to large sizes and threatened and/or damaged private homes (126 were lost). During this period a strong ridge of high pressure developed over the region and persisted from late April through the

first week of July. High temperature records were continuously being set across Florida during the month of June, presenting severe fire weather conditions as these high temperatures combined with unusually low relative humidity. While these conditions persisted throughout the event, certain days exhibited very dramatic fire growth/activity that is likely to be strongly tied to atmospheric stability.

Simply stated, atmospheric stability is the resistance of the atmosphere to vertical motion and is generally related to the lapse rate. The Lower Atmospheric Stability Index (or Haines Index) was developed to predict the likelihood of large fire growth due to the stability and moisture content of the lower atmosphere (Haines 1988). Three variations of this index were developed for use in regions of different elevation (low, medium or high elevation). The index is a number between 2 and 6 that results from the addition of a moisture term and a lapse rate term. A Haines Index of 2 indicates a very low potential for large fire growth while a value of 6 predicts a strong probability of extreme fire behavior.

The Haines Index is not in widespread use in any of the southeastern states as many fire management personnel have come to the conclusion, or been told, that the low elevation of the Haines Index would not work on the Southern Coastal Plain. Conceptually there is generally no reason why this index would not work in the southeast.

The Atmospheric Dispersion Index (ADI), also called the Lavdas Index, was developed to estimate the atmosphere's capacity to disperse smoke from prescribed fires (Lavdas 1986). The dispersion of smoke is also strongly governed by atmospheric stability, mixing height and the transport winds. The mixing height marks the top of the layer of the atmosphere near the earth's surface that is well mixed due to turbulence. The transport wind is the average wind within this layer. The environmental factors used to calculate the ADI also help govern fire behavior. As the ADI increases smoke dispersion improves and combustion rate (reaction intensity) within the flame front will increase as turbulence helps to "fan the fire". Experienced burners tend to postpone burns when the ADI exceeds 70 as the benefits of good smoke dispersion begin to be overshadowed by the potential for problems in controlling the fire.

This study aims to examine the relationship between these two indices and fire activity, particularly the occurrence of dramatic fire growth. The period of interest for this study is Florida's 1998 fire season (May-June). This study focuses on answering the following questions: Is the Haines Index a useful tool in predicting potential for fire growth in Florida and does the Atmospheric Dispersion Index correlate well with fire activity and provide another means of predicting conditions conducive to the rapid growth of wildfires.

2.0 Data

2.1 Soundings

The Haines Index (HI) was calculated using the 00 UTC and 12 UTC soundings for Tallahassee, Jacksonville, Melbourne and Tampa. These stations surround the area of Florida that experienced the majority of the fire activity during the summer of 1998. Data

for May and June of 1998 were used. For each day the maximum HI from the four stations were compared to fire activity.

For the atmospheric dispersion index (ADI), values were collected from the fire weather forecasts produced by the Tampa office of the National Weather Service. In Florida, the fire weather forecasts are produced by 7:30 am local time which during the summer is prior to the 00 UTC sounding. Thus, ADI forecasts rely upon the 12 UTC soundings.

2.2 Fire Activity Data

Information on fire activity was collected from the daily reports made by the Florida Division of Forestry districts. This information includes the number of fires and the number of acres burned on each day. This study focused on statewide fire activity as opposed to particular incidents as the weather data is not necessarily applicable to a specific site but is amenable to a more general view. The main use of the HI is to predict large fire growth; therefore, the primary fire statistic examined was acres per fire.

3.0 Methods

3.1 Haines Index

The Haines Index is calculated by simply adding a temperature term to a moisture term. The temperature term is the lapse rate, or temperature difference, between two pressure levels in the atmosphere, while the moisture term is the dewpoint depression for the upper pressure level. For this study the low elevation form of the Haines Index is used which examines temperature and moisture at 950 mb and 850 mb. Both the temperature and moisture terms are classified into 1 of 3 categories. The definitions of each category depend upon whether the low, mid or high elevation version of the index is used (Table 1). Once the temperature and moisture term have been classified, the category numbers are added to yield a number between 2 and 6, this number is the Haines Index. Low values of the Haines index indicate a low potential for large fire growth while high values indicate a strong potential for large fire growth.

Table 1: Classification of temperature and moisture terms for the low elevation Haines Index.

CLASS VALUE	950 mb T – 850 mb T	850 mb T – 850 mb T _D
1	< 4 °C	< 6 °C
2	4 °C to 8 °C	6 °C to 10 °C
3	≥ 8 °C	≥ 10 °C

In the western United States, Haines (1988) found that roughly 6% of all fire season days had a Haines Index of 6 while 62% of the days had a Haines Index of 2 or 3. A more recent study by Werth and Werth (1998) revealed considerable variability in the percentage of class 6 days in the west. The percentage ranged from 0% up to 53%. This variability was between different locations as well as different months.

3.2 Dispersion Index

In contrast to the simple calculations to arrive at the Haines Index, the Atmospheric Dispersion Index (ADI) calculation is much more involved. The inputs for determining the ADI are the stability class (Pasquill-Gifford-Turner classification), mixing height and transport wind speed. The graphical method for determination of the ADI is outlined here (Figure 1) and the reader is referred to the original work of Lavdas (1986) for a more complete description of the index and its calculation.

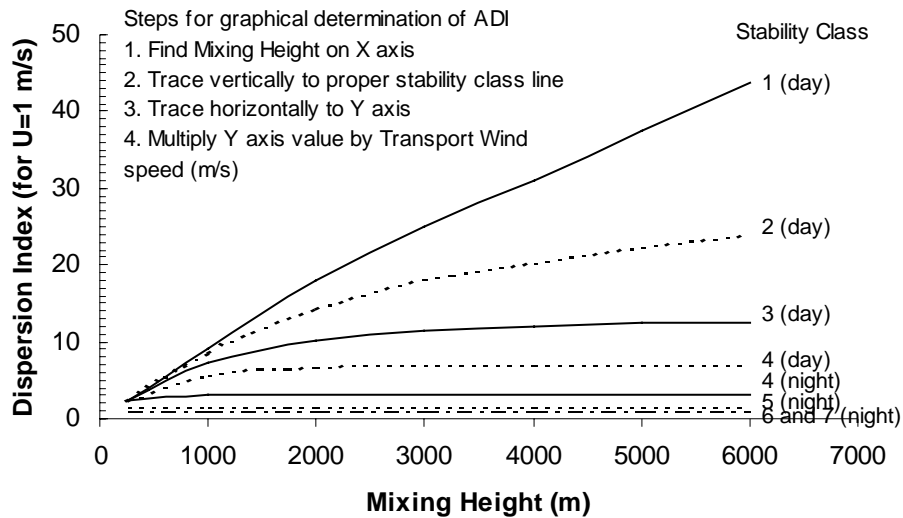


Figure 1: Response of dispersion index to mixing height by stability class (adapted from Figure 3 of Lavdas, 1986).

To determine the ADI, the user first estimates the stability class based on environmental factors such as wind speed, cloud cover and incoming solar radiation. The stability class determines which curve in Figure 1 is to be used to determine the ADI. The next step is finding the mixing height (in meters) along the x-axis and then finding the Dispersion Index value that corresponds to that combination of stability class and mixing height. This number is then multiplied by the transport wind speed (m s^{-1}).

4.0 Results

May of 1998 began with modest fire activity that increased toward the end of the month (Figure 2a). By May 22 the state was experiencing around 40 fires per day, however activity dropped off at the very end of the month to less than 10 fires per day. During June, fire activity began gradually increasing until the middle of June when lightning activity caused the number of fires to rocket to over 100 fires per day. The number of acres burned shows a similar dramatic increase in activity during mid June (Figure 2b). A similar trend is seen in the number of acres burned on a per fire basis (Figure 2c). May saw a few days where fires averaged over 50 acres per fire. During June fires grew to an average size of over 400 acres on several occasions with 2 days having average fire sizes in excess of 1000 acres.

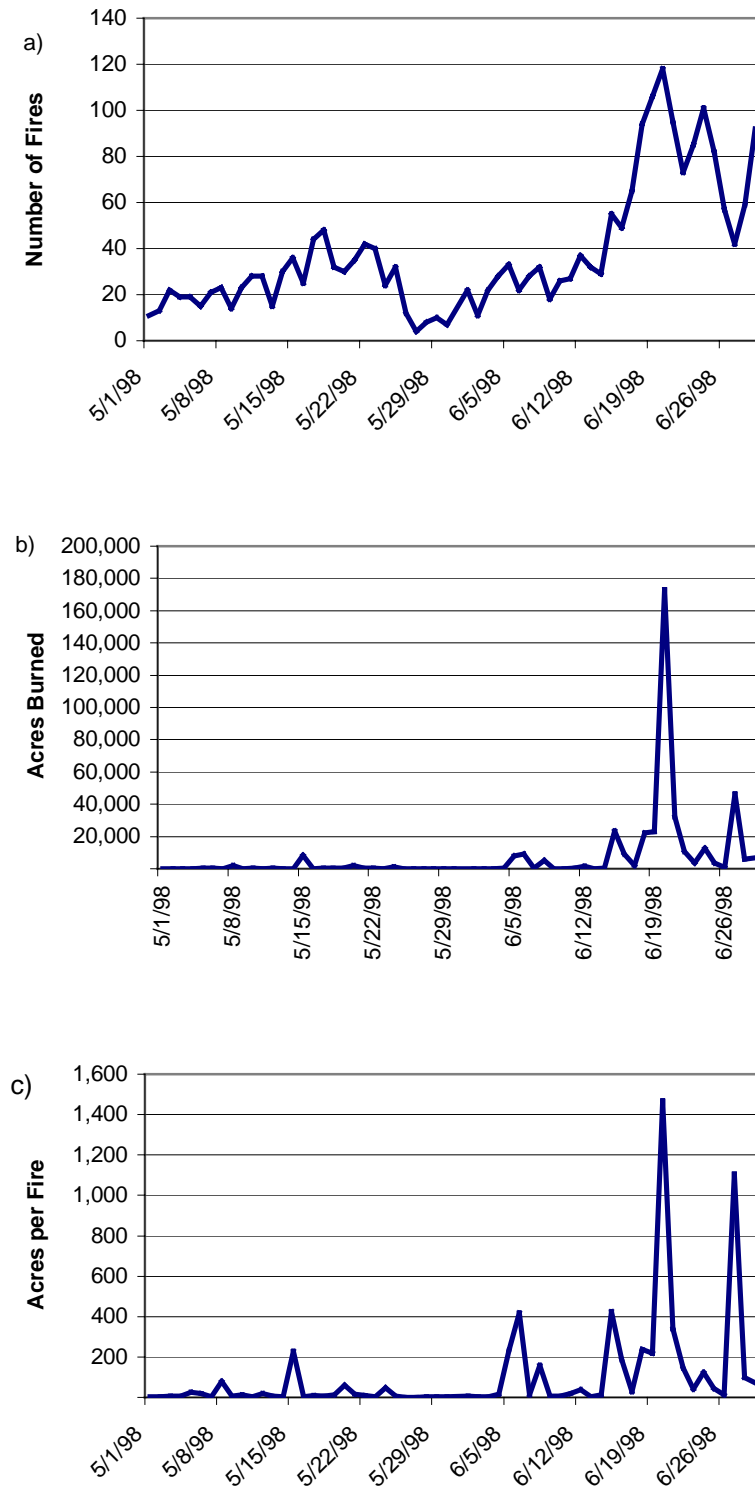


Figure 2: Number of fires (a), the number of acres burned by these fires (b) and the average size of the fires (c) during May and June of 1998 in Florida.

Correlation of the 00 UTC and 12 UTC HI's with fire activity reveals that the 00 UTC HI relates better to large fire growth than the 12 UTC HI while the reverse is true when looking at the number of fires (Table 2). The ADI does not show any significant correlation to fire activity, although there is a modest correlation (0.41) to the 00 UTC HI. This correlation is not unexpected as both indices are measures of atmospheric stability. Since fire growth is the primary area of concern in this study, the 12 UTC HI was not considered further due to its weak correlation to large fires.

Table 2: Correlation of stability indices to fire activity.

STABILITY INDEX	CORRELATION TO NUMBER OF FIRES	CORRELATION TO ACRES PER FIRE
00 UTC Haines Index	0.15	0.31
12 UTC Haines Index	0.41	0.14
Dispersion Index	0.06	0.21

Examination of the standardized anomalies for the HI and ADI show no dramatic difference between May and June of 1998 (Figure 3). The period of reduced fire activity in late May/early June is evident by the below normal values for these indicators of atmospheric stability. May experienced many days where both the 00 UTC HI (hereafter referred to simply as the HI) and ADI were above the normal, yet fires were generally small. This is likely the result of effective suppression activity. Later in the study period, suppression personnel were becoming overwhelmed by the sheer number of new starts and severe fire weather conditions. To minimize the impact of suppression activity, June was the focus of this study. Limiting the scope of the study to June significantly improves the correlation between acres per fire and the HI (Table 3).

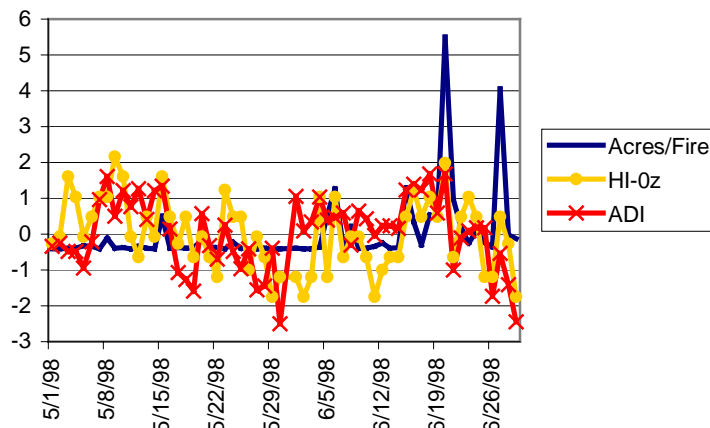


Figure 3: Standardized anomalies for acres per fire, Haines index at 0Z (HI) and the atmospheric dispersion index (ADI).

Table 3: Correlation of stability indices to fire activity for June 1998.

STABILITY INDEX	CORRELATION TO NUMBER OF FIRES	CORRELATION TO ACRES PER FIRE
00 UTC Haines Index	0.40	0.53
12 UTC Haines Index	0.49	0.15
Dispersion Index	-0.17	0.19

For each day of June, fire activity, the HI and the ADI are grouped into 4 classifications (extreme, high, moderate and low). The breakpoints for each classification are presented in Table 4. This information was used to classify each day such that the frequency of occurrence of each class (Figure 4). Low fire activity occurred on 41% of the days in June, but both the HI and ADI were classified as high on 69% and 45% of the days. The distribution of the two stability indices is very similar, but both are very different from the distribution of the number of acres burned per fire. Despite the superior correlation to acres per fire, the HI does not show a frequency distribution that is in better agreement with that of the acres burned per fire than the ADI.

Table 4: Breakpoints for classifications

	EXTREME	HIGH	MODERATE	LOW
Acres per Fire	> 750	749-300	299-20	≤19
Haines Index	6	5	4	≤3
Dispersion Index	>76	75-61	60-31	≤30

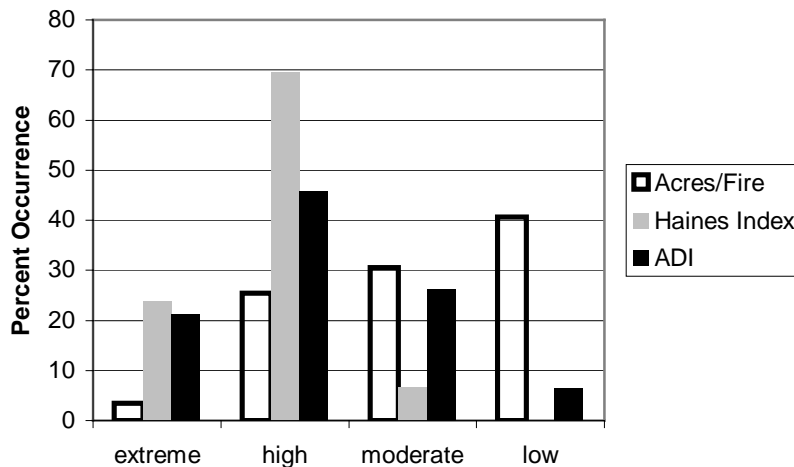


Figure 4: Frequency of occurrence for different classes of fire activity (Acres/Fire), Haines index and atmospheric dispersion index (ADI) for June of 1998.

The distribution of large fire growth (high acres per fire) is similar to what Haines (1988) described for the distribution of the Haines Index in the west (low frequency of the severe events). However, our distribution for the Haines Index is strongly skewed toward the more severe events, which is consistent with the findings of Werth and Werth (1998) for some locations. These locations were at higher elevations, allowing the mixed

layer at these sites to extend up to at least the lower of the two pressure levels used in calculating the Haines Index. During the afternoon, convectively driven thermals transport heat from the surface throughout the mixed layer, warming the lower level used for the Index and increasing the temperature difference.

Both the Haines Index and the Atmospheric Dispersion Index are measures of the stability of the atmosphere. However, the ADI also contains information regarding the transport winds, a factor not included in the Haines Index. The peak transport winds from the four stations ranged from a low of 7 mph up to 21 mph (Figure 5). The mean transport wind speed during June of 1998 was 12 mph. During late June when the largest fire growth was observed, the transport wind speeds were generally at or below the mean value. Since the ADI is directly proportional to the transport wind speed, these low values may be hiding some information regarding the degree of instability in the atmosphere. Removing the transport wind speed from the ADI calculation and comparing the standardized anomalies to those for acres per fire reveals a stronger agreement than when the wind information is included, correlation of 0.50 for June 1998 (Figure 6). The stability component of the ADI does a better job of capturing the two large peaks in fire activity than either the HI or ADI.

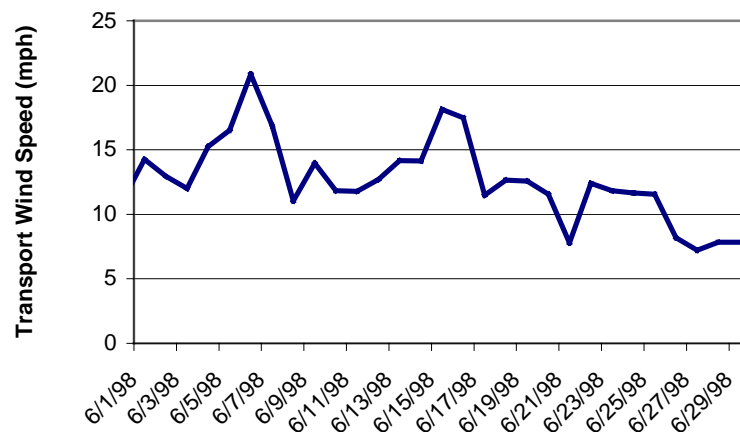


Figure 5: Average daily transport wind speed for June 1998.

Examination of the more moderate events reveals that none of the indices are perfect (Figure 7). During June 1998, eleven cases of large fire growth (standardized values > 0) were observed. The HI predicted 8 correctly while the ADI and the stability component of the ADI correctly predicted 7 and 6 of the events respectively. While correct predictions are one measure of successful forecasts, a low number of false alarms is also desirable. The HI produced false alarms in 3 of 17 cases, the stability component of the ADI in 6 of 17 cases and the ADI produced false alarms in 13 of 17 cases. These cases represented false alarms in the sense that the average fire size that day was not above average; fire danger may have still been very high but effective suppression activity may have limited the size of the fires.

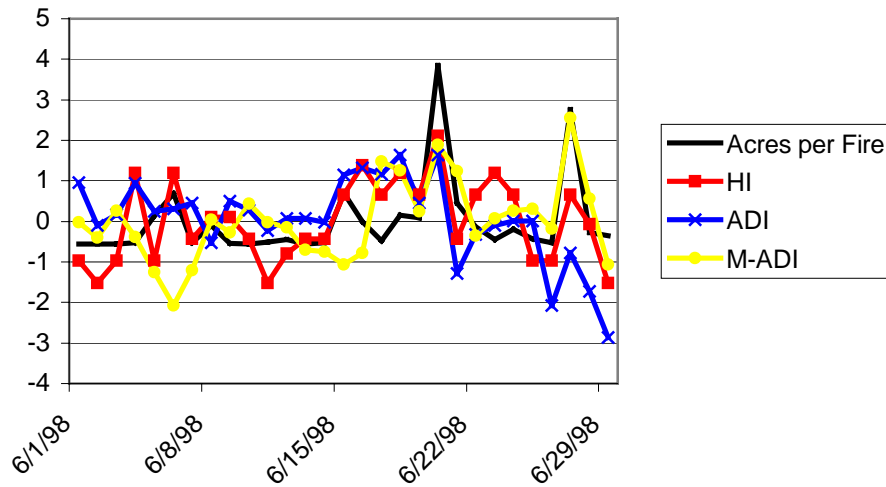


Figure 6: Comparison of standardized anomalies of acres per fire, Haines index (HI), atmospheric dispersion index (ADI) and the stability component of the atmospheric dispersion index (M-ADI).

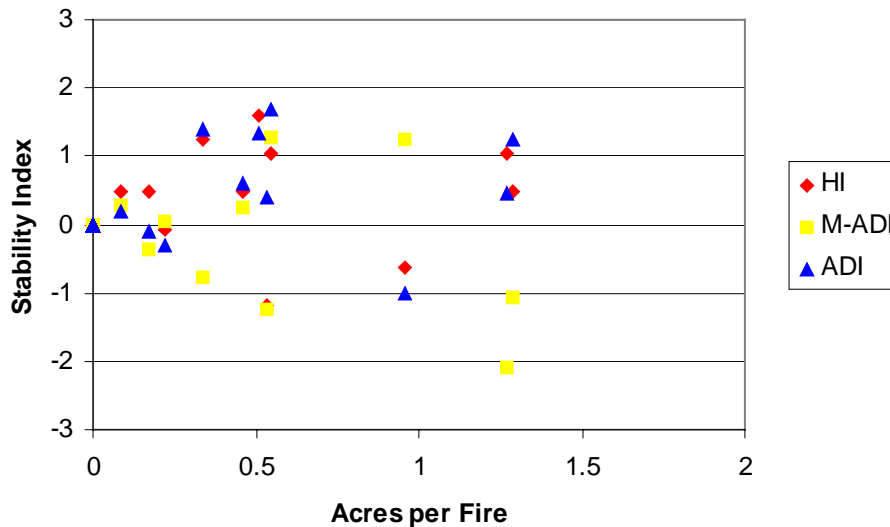


Figure 7: Scatter plot showing the relationship between the various stability indices (HI, ADI, M-ADI) and fire activity (acres per fire). All values are normalized.

5.0 Discussion

The Haines Index and the Atmospheric Dispersion Index both display considerable skill in predicting conditions that favor large fire growth. This ability is related to these indices being based, at least in part, on atmospheric stability. Unstable atmospheric conditions are related to more active fire behavior. However, there were some cases of large fire growth that were not predicted by either index. This raises the question of whether another factor aside from stability added to the severe fire conditions.

The differences between the predictive ability of the full ADI and just its stability component indicate that transport wind may be an additional factor that influences large fire growth.

The ADI is directly proportional to the transport wind speed. This relationship may mask the role of the winds in assessing fire growth potential from the ADI as the same ADI value can be obtained from different combinations of the transport wind speed and the stability component. Stable atmospheric conditions (low stability component value) along with strong transport winds can produce the same value as less stable conditions (higher stability component value) with weaker transport winds. To assess the relative roles of transport winds and atmospheric stability in contributing to an environment conducive to large fire growth, a ratio of the contribution of stability to that of transport wind speed is constructed.

$$R = \frac{\frac{S}{\bar{S}}}{\frac{W}{\bar{W}}} \quad (1)$$

In equation 1, S is the stability component of the ADI and W is the transport wind speed; the overbars indicate the mean value of each quantity for the month of June (5.26 and 12.71 respectively). Values of R above 1 indicate that the importance of the stability term over the contribution from the transport winds, while values below 1 highlight the importance of the transport wind. Examination of the cases of large fire growth using R reveals two regimes associated with large fire growth during this period. The first is when the atmosphere is more unstable than average and the transport winds are weak ($R > 1.2$) and the second regime is when the transport winds are a dominant factor ($R < 0.7$) (Figure 8). Using these break points R predicts all but 2 cases of above average numbers of acres per fire. The transport wind term dominated the stability term on five occasions that coincided with the three days that the HI failed to predict large fire growth.

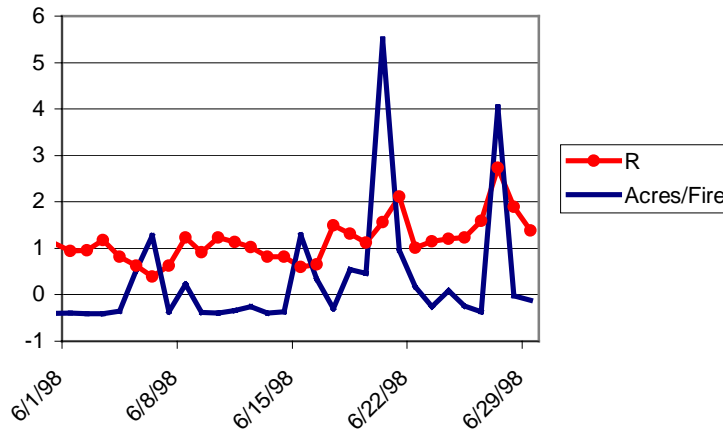


Figure 8: Comparison between fire activity and the ratio of stability component to transport wind.

On eight days during June of 1998 the number of acres per fire exceeded 200. Table 5 presents a comparison of the HI, ADI and *R* for these days along with the transport wind (in mph). The potential value of *R* is evident from examining June 5 and June 27. On June 5, the HI indicated moderate conditions while the ADI predicted more severe fire conditions. Examination of *R* revealed the dominance of the transport wind term over the stability ($R < 0.7$), which implies that the ADI may be the more useful index on that day. For June 27, the ADI is predicting moderate conditions while the HI is showing higher fire potential. Again *R* provides some insight into the relative value of each index on this day. An *R* value greater than 1.2 shows increased importance of the stability term indicating that the HI may be a more reliable indicator of fire potential.

Table 5: Comparison of fire activity and stability indices for days where more than 200 acres per fire burned.

DATE	ACRES PER FIRE	HAINES INDEX	ADI	<i>R</i>	TRANSPORT WIND SPEED
6/5/98	235	4	71	0.62	17
6/6/98	418	5	71	0.40	21
6/15/98	426	5	81	0.60	18
6/18/98	238	5	87	1.31	13
6/19/98	217	5	73	1.19	13
6/20/98	1466	6	72	1.29	11
6/21/98	340	5	53	2.12	8
6/27/98	1106	5	59	2.74	7

The capability of these stability indicators to predict the potential for the rapid growth of wildfires was further tested by examining weather and wildfire data from April and May of 1999. This year produced above normal fire activity (over 3,900 fires burned over 285,000 acres), however the fire weather conditions were not as extreme as in 1998 when temperature records were broken on a daily basis. Correlations between the Haines index or dispersion index and the number acres burned per fire were significantly lower in 1999 than in 1998 (Haines index dropped from 0.53 to -0.048 while the ADI dropped from 0.19 to -0.141). This 61-day period produced 22 days of above average values for acres per fire although only one day was classified as extreme or high by the scheme presented in Table 4 (Figure 9).

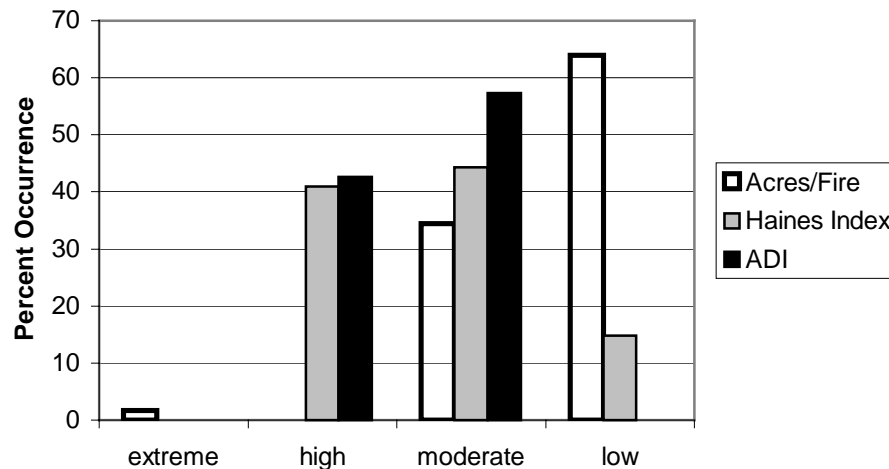


Figure 9: Frequency of occurrence for different classes of fire activity (acres/fire), Haines index and atmospheric dispersion index (ADI) for April-May of 1999.

The Haines index and the ADI were generally in the moderate to high range during this period. Selecting the high classification as a predictor for days with large fire growth, the Haines index correctly predicted 8 of the 22 above average fire days while the ADI predicted 9. The ratio R from (1) correctly identified 13 of the 22 above average fire days. Six of the twenty-two days of above average acres per fire are presented in Table 6. The first 3 day period saw over 75,000 acres burned by 103 fires across the state. While the Haines index indicated low to moderate fire potential, the ADI was indicating moderate to high potential. The values of R indicate the dominance of the strong transport winds present during this period, which created the moderate to high ADI values despite the stable conditions indicated by the Haines index. The second period had 66 fires for 3,452 acres, and is characterized by higher Haines index values and relatively unchanged values for the ADI. The value of R indicates that the unstable conditions are more dominant than the transport winds for this three-day period. Of the 9 cases not identified by R , 6 were wind dominated and three were stability dominated. Adjusting the break points used with R could decrease the number of cases not identified, but would also increase the number of incorrect predictions.

The main use of the ratio R is to identify the relative importance of the stability and transport wind terms. The 1999 data produced a number of cases where R was close to 1, but still exhibited large fire growth. In this case neither term dominated the ratio, both terms were above average. High values of R appear to indicate conditions for which the Haines index would be useful/appropriate. Breaking the ADI value into a stability component (ADI divided by transport winds) and a wind component can provide a more complete view of the weather conditions that may potentially impact a fire.

Table 6: Comparison of fire activity and stability indices

DATE	ACRES PER FIRE	HAINES INDEX	ADI	R	TRANSPORT WIND SPEED
4/15/99	59	4	74	0.26	26
4/16/99	73	3	52	0.47	16
4/17/99	3190	4	48	0.41	17
5/21/99	42	4	50	1.97	7
5/22/99	6	4	50	1.63	8
5/23/99	62	5	51	1.38	9

6.0 Summary

Both the Haines Index and the Atmospheric Dispersion Index have shown good utility in predicting the occurrence of large fire growth in Florida during the fires of 1998; however, this utility was diminished somewhat during a more "typical" fire season (1999). Stability obviously plays a vital role in determining whether conditions are favorable for the rapid growth of wildfires, but on some days, other factors, such as transport winds, become more important. Slightly unstable conditions when coupled with strong transport winds can lead to large fire growth as the transport winds help increase the spotting distance in advance of the flaming front. Under more unstable conditions with light transport winds, increased lofting of burning embers/debris can enhance spotting in all directions, producing rapid fire growth. While the ADI does include the transport wind in its calculation, the nature of its direct proportionality can mask the relative importance of the stability and wind information.

The quantitative role of atmospheric instability in fire behavior still requires much study. The Haines index is widely used in the western United States, but its usefulness in the southeast is still questionable. Perhaps a reevaluation of the low elevation Haines index's definition and breakpoints may lead to a more applicable index for the southeast, but the lack of wind information in the Haines index appears to be a serious limitation as it relies solely on convective mixing to transport dry air aloft to the surface and ignores shear induced mixing. The atmospheric dispersion index developed by Lavdas for prescribed burning applications does show some favorable relationships to wildfire activity, although this information is not readily obvious just by looking at the numeric value. Examination of the ratio of the stability component to the transport wind component can provide some insight into the applicability of either the Haines index or the ADI.

References

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