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USING NDVI TO DETERMINE GREEN-UP DATE FOR THE NATIONAL FIRE DANGER RATING SYSTEM

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1. INTRODUCTION

Across the United States, the National Fire Danger Rating System (NFDRS) is commonly used to define indexes of fire danger rating. These ratings are then used to support many strategic fire management decisions including agency staffing, readiness, and emergency funding; anticipating fire effects; initiating prescribed fire activity; public awareness; and activity restrictions or closures.

The NFDRS in use today was developed in the 1970s. Technologies of the 21st century are opening up new development opportunities for NFDRS. One opportunity is a change in spatial resolution of inputs and ratings from point to grid. To achieve this, the live fuel moisture model within NFDRS will need to be automated.

Two features of a live fuel moisture model for NFDRS in the 21st century are proposed. The first feature is an objective method to determine in "real time" the green-up date at 1-km spatial and 1-week temporal resolutions using Normalized Difference Vegetation Index (NDVI) from NOAA Advanced Very High Resolution Radar (AVHRR). The second feature is a process to determine historical green-up dates for historical analysis purposes.

The green-up date in NFDRS is a date that represents the time when a spring flush of growth is generally occurring in the rating area. This date corresponds to the time when "the annual and perennial herbaceous vegetation starts to grow or the leaves of deciduous shrubs begin to appear within the area represented by the fuel model" (NWCG 2002). Currently, green-up is determined with a visual survey of the area and initiated manually in the processor. The fire manager effectively "throws the switch" for the live fuel moisture model to begin to mimic the seasonal progression of herbaceous fuel moisture. This works well in some areas and is problematic in others. In either case, green-up is assumed to occur uniformly for each fuel model throughout a rating area and green-up dates have not been archived for future analysis opportunities. The intention here is to employ satellite imagery to provide the fire manager with a tool to objectively determine green-up through space and time within a rating area.

Satellite imagery, especially NDVI, has been extensively studied for its capability to monitor vegetation condition, generally in an historical context (e.g. Burgan and Hartford 1993, Senay and Elliot 2000, Schwartz et al. 2002). Here, the $NDVI_{ratio}$ technique described by White et al. (1997) is adapted to the problem of determining the timing of green-up operationally.

2. DATA

The primary source of data for this project is a January 1989 to August 2002 NDVI data set initially developed from spectral data by EROS Data Center (EDC) and then further processed into 1-week composites by the US Forest Service Intermountain Fire Sciences Lab in Missoula. The original (1989-2001) dataset (Burgan et al. 1999) was reconfigured during Summer 2002 to standardize the entire period of record.

This is a dataset of 1-week maximum composites for the contiguous 48 United States and portions of Canada and Mexico. There are 52 composite periods in each year, set up to enable inter-annual analysis of each period. The dataset has been corrected for atmospheric interference. The fractional values of NDVI have been transformed to values between 100 and 200 by the formula

$$NDVI_{transform} = \left(NDVI_{fraction} \times 100\right) + 100 . \quad (1)$$

In this way, NDVI expressed as 0.60 becomes 160. NDVI values less than 103 are considered non-vegetated and treated as missing. A time series for the period of record for the central pixel in each of three 3x3 pixel study areas is shown in Figures 1, 2, 3.

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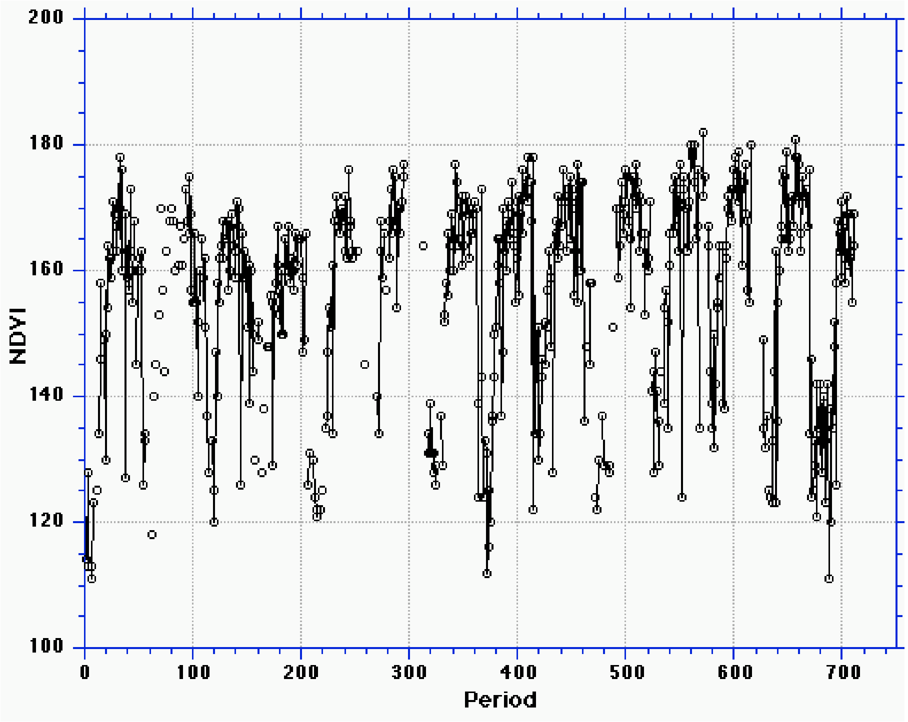

Figure 1. NDVI time series, period of record (January 1989 – August 2002), for central pixel of California study area.

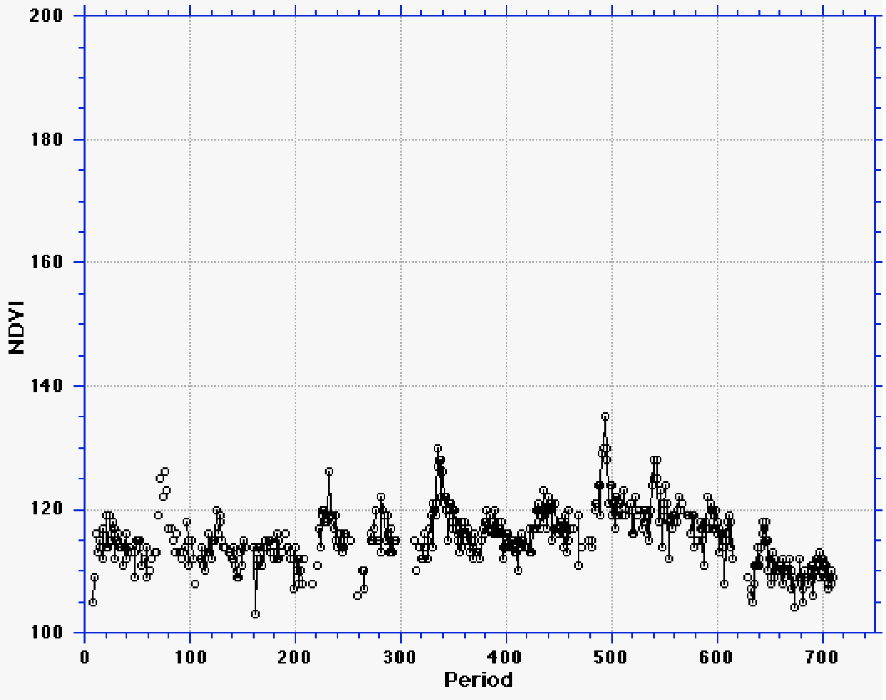

Figure 2. NDVI time series, period of record (January 1989 – August 2002), for central pixel of Nevada study area.

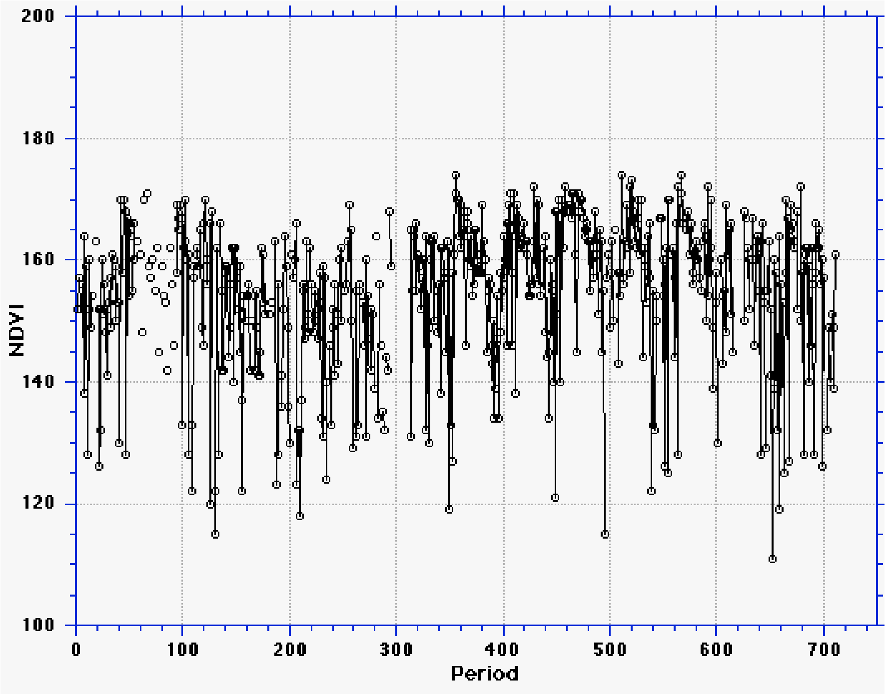

Figure 3. NDVI time series, period of record (January 1989 – August 2002), for central pixel of Florida study area.

A pixel classification of difference bins was developed (Figure 4) using WINDISP 4 (Pfirman et al. 1999). This classification scheme groups together in "difference bins" pixels whose climatological maximum and minimum NDVI differ by the same amount. For example, pixels whose climatological maximum is 128 and minimum is 120 are placed in difference bin 8. There is relatively small change throughout the year in NDVI signal at these pixels. Pixels with a maximum of 170 and a minimum of 110 are classified into difference bin 60. Pixels in this category experience relatively large intra-annual change in NDVI signal. This procedure allows pixels to be grouped according to the amplitude of their NDVI annual signal, rather than by a description of the vegetation or fuels on site. There are 45 even-numbered difference bins from 0-90 populated by pixel counts as shown in Figure 5. These bins are even-numbered because in WINDISP 4 the translation from pixel color value to NDVI value is

$$NDVI_{value} = \left(\left(Pixel_{value}\right) \square 2\right) \square 256 . \qquad (2)$$

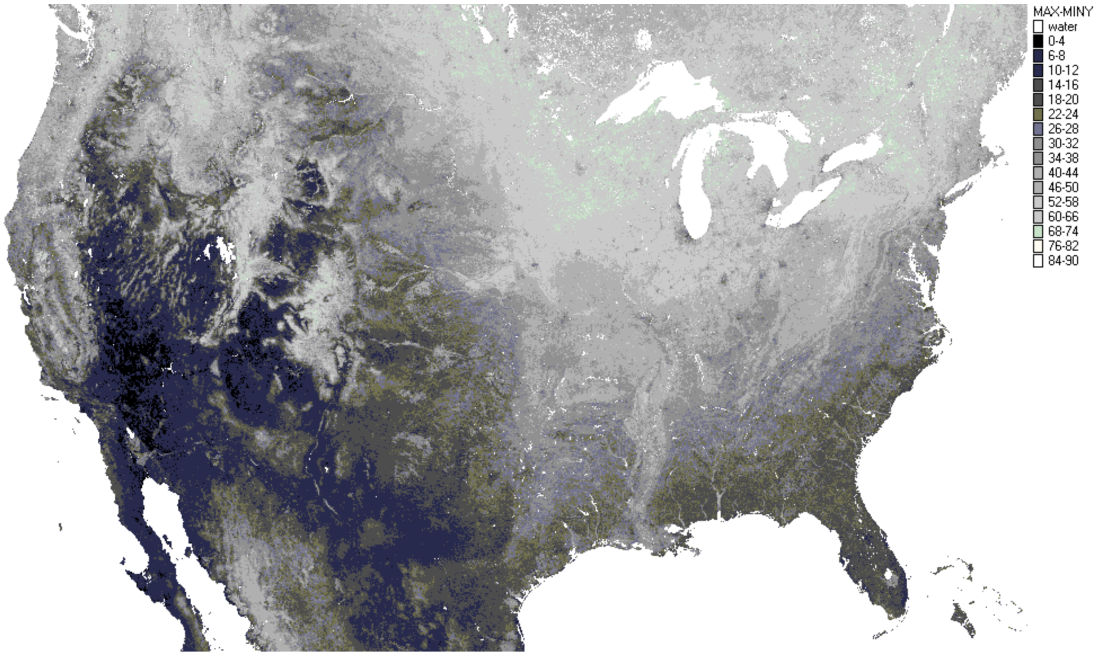

Figure 4. 1-km pixels classified by difference bin.

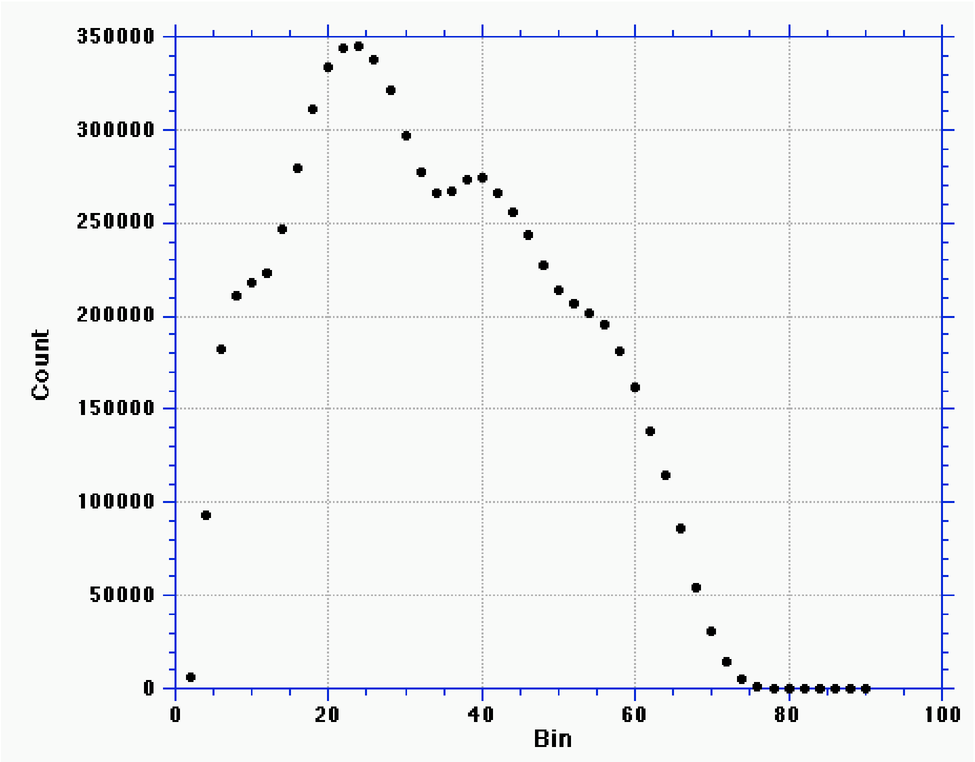

Figure 5. Distribution of difference bin counts for pixels in Figure 4.

Three study areas were selected to demonstrate the application of the methods. Each location consists of 9 pixels in a 3x3 grid. The sites were chosen to represent the two peaks in the frequency distribution for the difference bins (20 and 40) (Figure 5) and one difference bin (10) typical of sparsely vegetated areas. Study area 1 is located in California on the El Dorado National Forest at 1500 meters. Its central pixel is located at Longitude -120.43/Latitude 38.89, west of Union Valley Reservoir. It is representative of the mixed conifer forests of the western slopes of the Sierra Nevada range. Study Area 2 is located in Nevada on the Carson City District, Bureau of Land Management, at Longitude -118.32/Latitude 39.05, south of Big Kosock Mountain, near State Route 839. It is representative of pinyon-juniper woodland. Study Area 3 is located in Florida on the Ocala National Forest at Longitude -81.70/Latitude 29.16. It is representative of southern rough or pine stands with palmetto/gallberry understory. The fuel model and difference bin classifications of all 9 pixels at each location are shown in Table 1.

3. METHODS

White et al. (1997) used the maximum and minimum NDVI values for a single year to determine onset of greenness for that year. Operationally, the annual maximum is not yet known and green-up must be declared before the NDVI maximum occurs each year. The comparison of the current growing season trend of NDVI to the climatology for NDVI-derived green-up is here proposed by computing the integral of smoothed NDVI values.

The first step is to compute the climatological NDVI values for each of the 52 annual periods (weeks) of the year. Next, a smoother is fit to the climatological NDVI values as shown in Figures 6, 7, and 8 for the central pixel in each study area. White et al. (1997) observed that the spring NDVI value equaling 50% of its annual maximum ($NDVI_{0.5}$) occurred during the period of most rapid growth in grasslands and deciduous forests of the US. For this method, the area under the curve bounded by the period of the minimum NDVI ($Period_{min}$) and the period when $NDVI_{0.5}$ is achieved ($Period_{0.5}$) on the abscissa and by the $NDVI_{min}$ and $NDVI_{0.5}$ on the ordinate (see Figures 9, 10, and 11) is computed. This becomes the target area for achieving green-up in each individual year.

Table 1. Fuel model and difference bins for each pixel at 3 study areas.

California			**Nevada**			**Florida**		
G 40	G 40	G 42	C 10	C 10	C 10	D 24	O 22	O 22
G 36	G 40	G 40	C 10	C 12	C 10	D 22	D 20	D 20
H 36	G 36	F 42	C 10	C 10	C 10	D 22	D 20	D 18

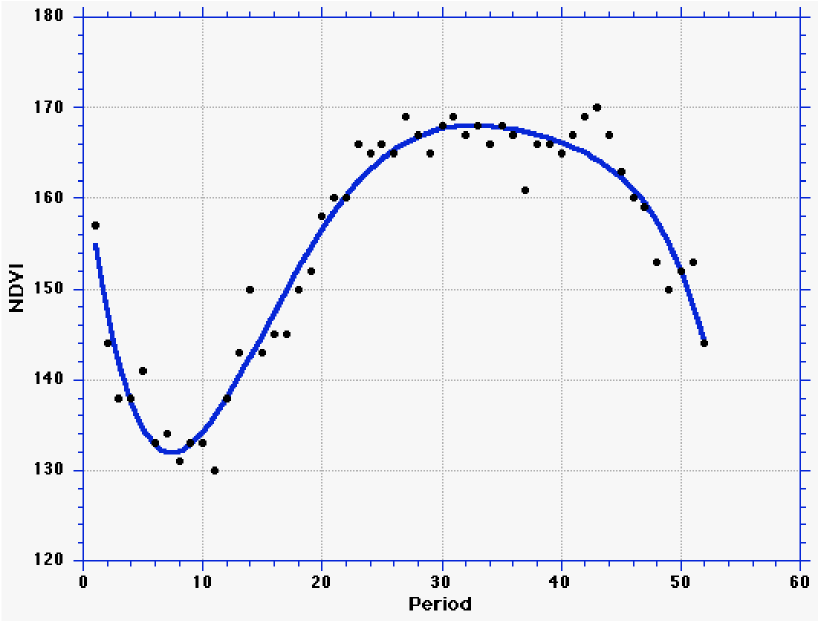

Figure 6. Fit of the polynomial smoother to the 1-52 week (period) climatology for NDVI at the central pixel of the California study area.

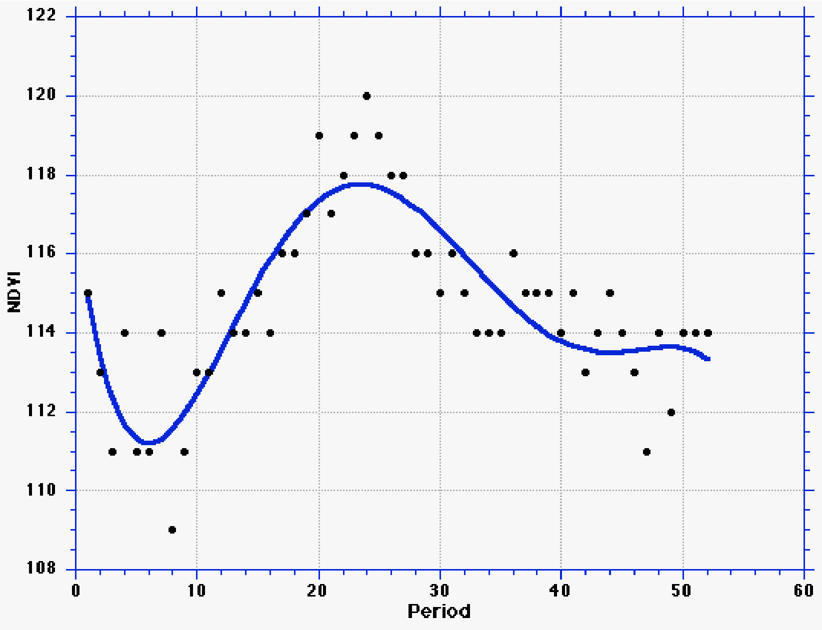

Figure 7. Fit of the polynomial smoother to the 1-52 week (period) climatology for NDVI at the central pixel of the Nevada study area.

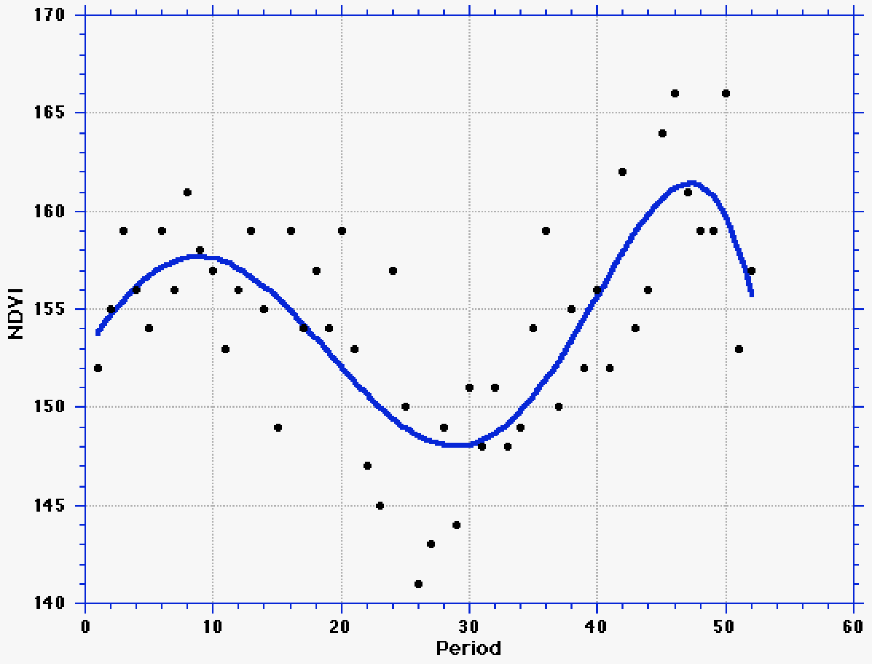

Figure 8. Fit of the polynomial smoother to the 1-52 week (period) climatology for NDVI at the central pixel of the Florida study area.

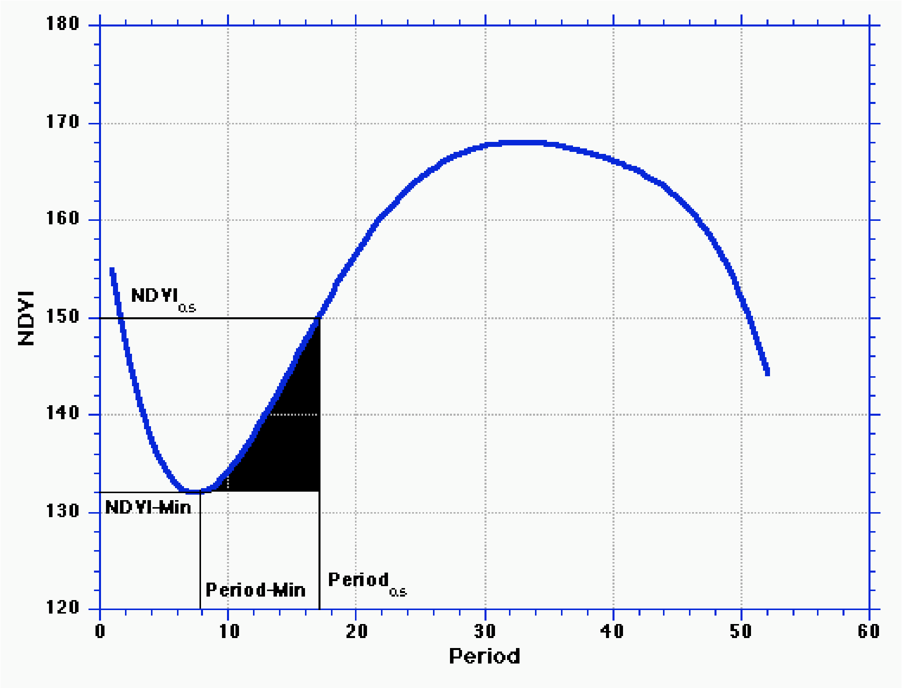

Figure 9. The target area (shaded) for the central pixel of the California study area, bounded by the period of the minimum ($\text{Period}_{\text{min}}$) and the period when $\text{NDVI}_{0.5}$ is achieved ($\text{Period}_{0.5}$) on the abscissa and by the NDVI_{min} and $\text{NDVI}_{0.5}$ on the ordinate.

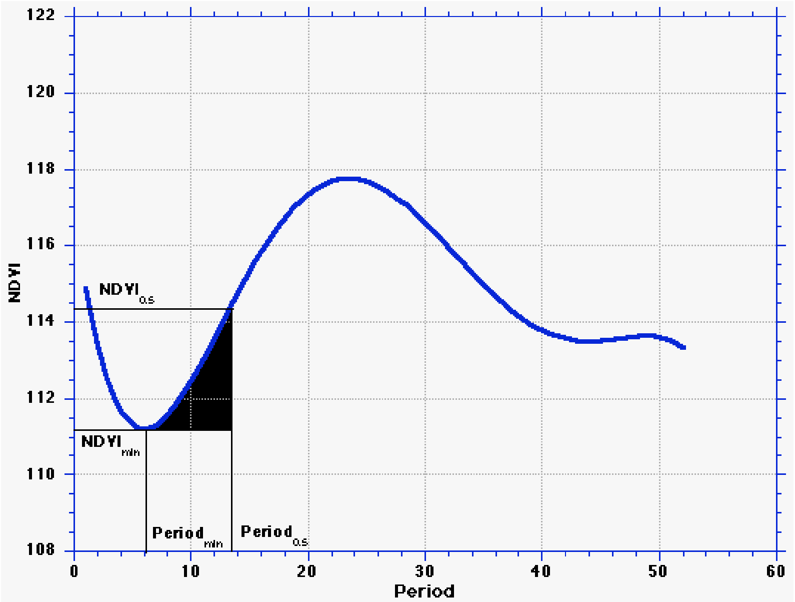

Figure 10. The target area (shaded) for the central pixel of the Nevada study area, bounded by the period of the minimum ($\text{Period}_{\text{min}}$) and the period when $\text{NDVI}_{0.5}$ is achieved ($\text{Period}_{0.5}$) on the abscissa and by the NDVI_{min} and $\text{NDVI}_{0.5}$ on the ordinate.

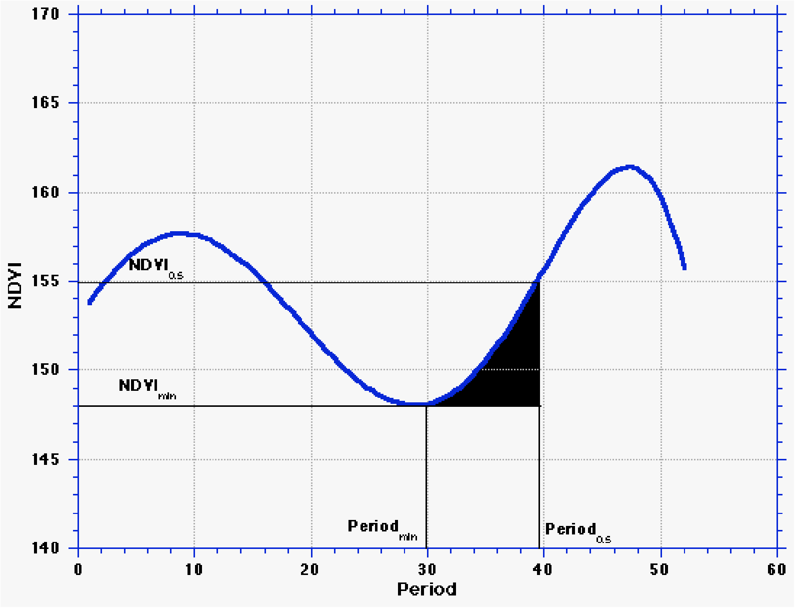

Figure 111. The target area (shaded) for the central pixel of the Florida study area, bounded by the period of the minimum (Period$_{min}$) and the period when NDVI$_{0.5}$ is achieved (Period$_{0.5}$) on the abscissa and by the NDVI$_{min}$ and NDVI$_{0.5}$ on the ordinate.

To determine green-up dates for each year in the period of record, the next step is to compute the integral after each minimum in the smoothed data set. This is done on the leading edge of the 104-period sequence as if it were a real time calculation as shown in Figure 12. The 104-period sequence is moved forward one period at a time until the target area is achieved. At each step forward, the polynomial smoother is fit to the data. The slope of the smoother from periods 103 to 104 is computed. If the slope is negative, as in the upper left plot of Figure 12, the smoother is assumed to be declining from a maximum. This condition is necessary before an integral is computed. At the first step forward with a positive slope from periods 103 to 104, the smoother is assumed to be rising, and the most recent minimum prior to period 104 is determined. The integral from the minimum to period 104 is computed and compared to the target area. If the integral is less than the target area, as in the upper right plot of Figure 12, the process continues. At the first step forward to equal or exceed the target area, the period-of-record period number (1-728) corresponding to analysis period 104 is declared the green-up date. For example, if the target area were achieved at period 645, as in the lower plot in Figure 12, this is translated to the calendar period (1-52) of 21 and the calendar date based on the EDC/FS data set of May 24, 2001. This process begins at the beginning of the record and continues until green-up dates are identified for as much of the dataset as possible.

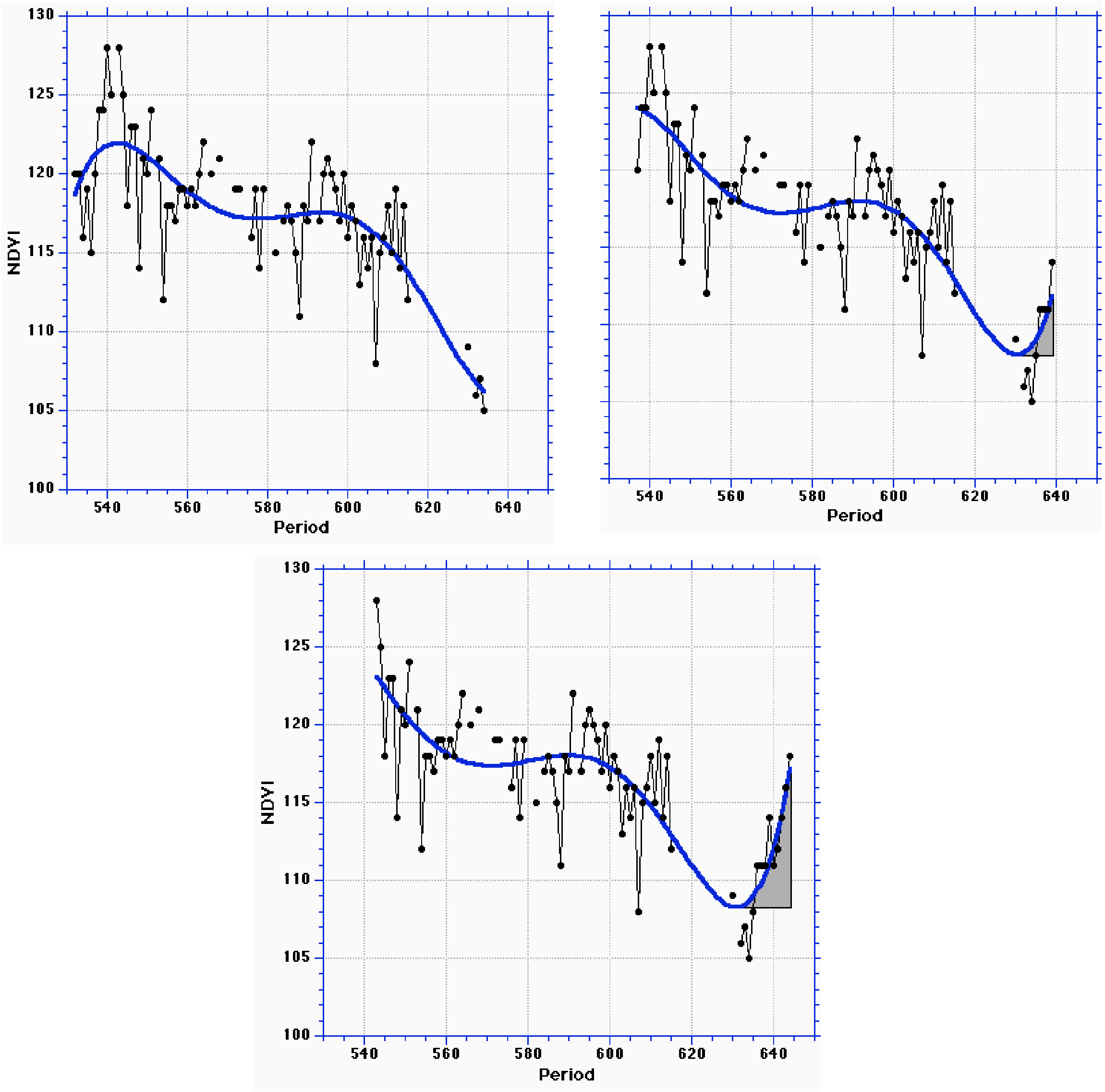

Figure 12. Example of 104-period smoothed NDVI and computation of the integral under the curve at the leading edge. Green-up is declared when this integral reaches the target area.

4. RESULTS

4.1 *California*

At each pixel of the California site, the integral method identified one green-up date during the spring of each year between 1991-2002. This is the set of years that can be analyzed using 104 periods at each step. There were no years with multiple green-up dates, such as one in spring and fall. The median green-up date (late May – early June), range (late April – early July), and variation (2-3 weeks about the median), as measured by the pseudosigma (Hoaglin et al. 1983), are reasonable dates for this location based on the climate of the area (Table 2). The median date is nearly centered on the spread from earliest to latest dates. The consistency of the median and spread between neighboring pixels relative to the Nevada and Florida sites suggests a more consistent spring season at this location. The variation between neighboring pixels is most likely due to influences of aspect, and slope upon vegetation condition.

Green-up dates used by local fire managers on nearby NFDRS weather stations in 2003 were May 15 at Bald Mountain station sited at 1400 meters elevation and June 3 at Hell Hole station sited at 1600 meters elevation. Traces are plotted in Figure 13 for herbaceous fuel moisture (FmH) and energy release component (ERC) at Hell Hole station in 1996 using the median (June 7) and agency (June 3) green-up dates. Records of the 1996 green-up date for this station are not available, as previously explained. Use of the current (2003) or other green-up date, while not necessarily historically accurate, is the same procedure that is used by fire managers who conduct historical analysis with existing software packages. The increase in FmH associated with green-up is delayed and slightly suppressed with the June 7 date, but this is of minimal significance to reported fire danger. The ERC trace is the same either way, thus the integral method is capable of providing green-up dates that produce outputs identical to those of the current system at this location.

The ERC trace in Figure 13 declines from about 55 to 0 in less than two weeks during the middle of May. Any drop of this magnitude for the ERC is the result of precipitation duration significant enough to increase fuel moisture of large fuels. Such a precipitation event, coupled with its impact on vegetation moisture may be an appropriate time to declare green-up at this location. Indeed, the actual green-up estimates for 1996 by the integral method ranged from May 2 to May 16. This demonstrates that the integral method can identify green-up dates that match those suggested through the processing of NFDRS historical weather records.

Table 2. Green-up date statistics (median, pseudosigma, and range) for 9 pixels in the California study area using the integral method.

Median (period number, start date)			**Pseudosigma (periods)**		
23 (Jun 7)	21 (May 24)	23 (Jun 7)	3	1	2
23 (Jun 7)	23 (Jun 7)	22 (May 31)	2	3	3
23 (Jun 7)	22 (May 31)	22 (May 31)	2	2	2
Minimum (period number, start date)			**Maximum (period number, start date)**		
20 (May 17)	19 (May 10)	19 (May 10)	27 (Jul 5)	25 (Jun 21)	25 (Jun 21)
19 (May 10)	19 (May 10)	19 (May 10)	25 (Jun 21)	25 (Jun 21)	25 (Jun 21)
17 (Apr 27)	17 (Apr 27)	19 (May 10)	27 (Jul 5)	25 (Jun 21)	27 (Jul 5)

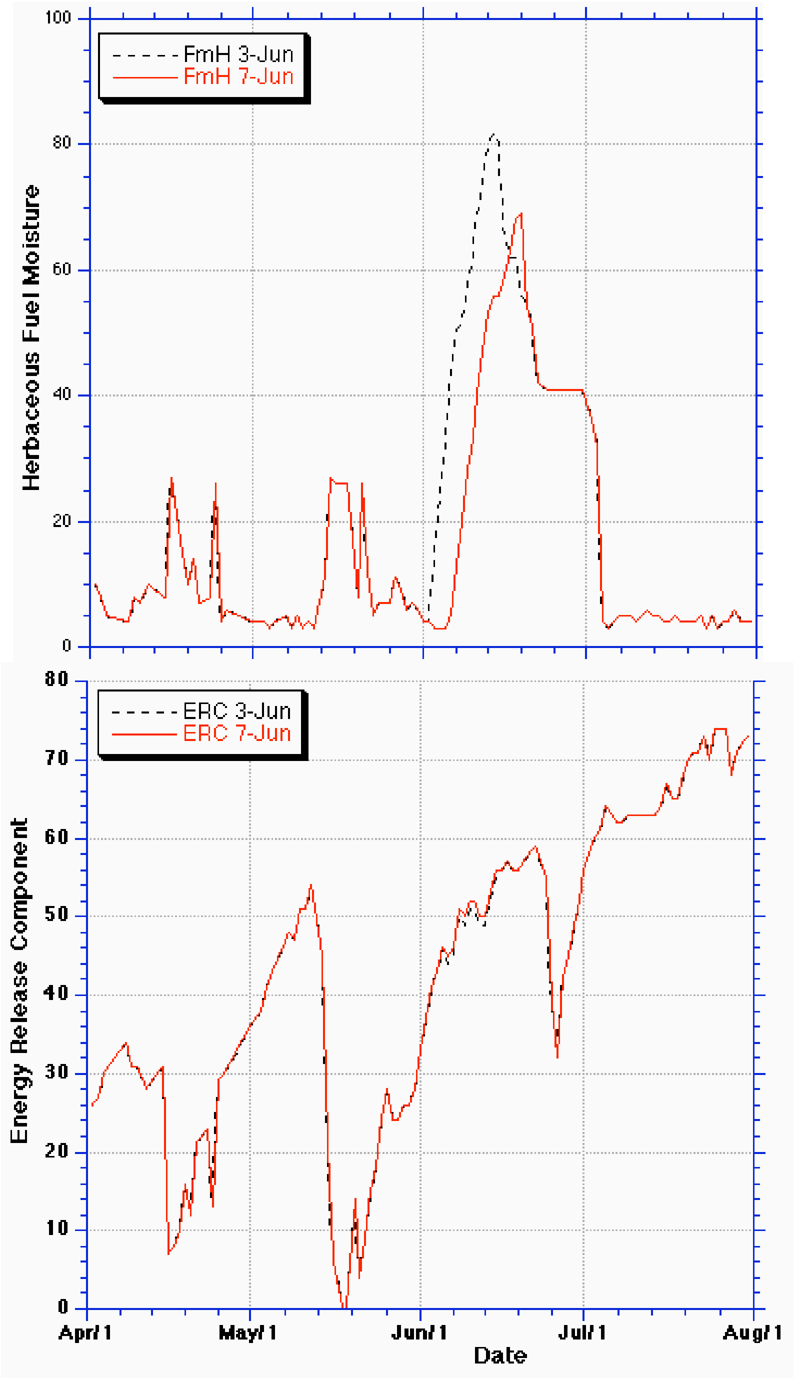

Figure 13. Comparison of traces for herbaceous fuel moisture and energy release component based on median integral method-derived green-up and agency green-up date entry for 1996 weather data from Hell Hole station.

4.2 *Nevada*

At the Nevada site, one spring green-up date per year was identified (1991-2002). There were no green-up dates declared at other times of the year. The median green-up date (late to mid April), spread (early March – mid June), and variation (2-5 weeks around the median) are reasonable dates for this location given its arid climate (Table 3).

Pixel 3 (upper right) was not included because the climatological minimum occurred at period 52, the last week of the year, which resulted in no target area being determined. In the other 8 pixels, the minimum occurred in period 5-7, followed by 7-8 periods before the integral-method green-up estimate. The reason the pixel 3 minimum occurred at period 52 is most likely because of the strict use of a 1-52 period analysis sequence, the proximity of the climatological minimum to the beginning or end of the sequence, and smoother end-point issues. This situation could be resolved by shifting the set of 52 periods used to develop climatology for this location to begin and end in the fall, for example at periods 43 and 42, respectively. This would place the late-winter – early-spring minimum NDVI signal in the middle, rather than the beginning or end, of the data sequence.

Green-up dates used by local fire managers on nearby NFDRS weather stations in 2003 were April 15 at Fish Springs station and May 16 at Desatoya station. Traces are plotted in Figure 14 for FmH and burning index (BI) at Desatoya station in 2000 using the agency (May 16) green-up date and the date suggested by the integral-method for 2000 (March 16). Declaring green-up as late as May 16 that year would have had no apparent impact on fire danger and would have kept the BI relatively high during April. Declaring green-up on March 16 produced a spike in FmH and a depression of the BI, as is generally expected when the green-up declaration approximates actual conditions. These results demonstrate that the integral method is capable of identifying appropriate green-up dates in this sparsely vegetated study area.

The median date is nearly centered on the spread from earliest to latest dates and the expected variation is longer than at the California site. This range of early to late green-up dates is most likely due to the interannual variability of springtime precipitation at this arid site. The variation in median and spread values between neighboring pixels suggests the influences of soil reflectance, aspect, slope, and locally variable precipitation on vegetation condition. This level of precision for green-up is not possible with today's ocular estimate of a rating area.

Table 3. Green-up date statistics (median, pseudosigma, and range) for 8 pixels in the Nevada study area using the integral method.

Median (period number, start date)			**Pseudosigma (periods)**		
14 (Apr 5)	14 (Apr 5)		3	2	
16 (Apr 19)	14 (Apr 5)	14 (Apr 5)	5	4	2
16 (Apr 19)	14 (Apr 5)	14 (Apr 5)	3	4	4
Minimum (period number, start date)			**Maximum (period number, start date)**		
11 (Mar 15)	9 (Mar 1)		20 (May 17)	17 (Apr 26)	
9 (Mar 2)	10 (Mar 8)	10 (Mar 8)	24 (Jun 14)	23 (Jun 7)	17 (Apr 26)
11 (Mar 15)	9 (Mar 1)	9 (Mar 1)	21 (May 24)	21 (May 24)	24 (Jun 14)

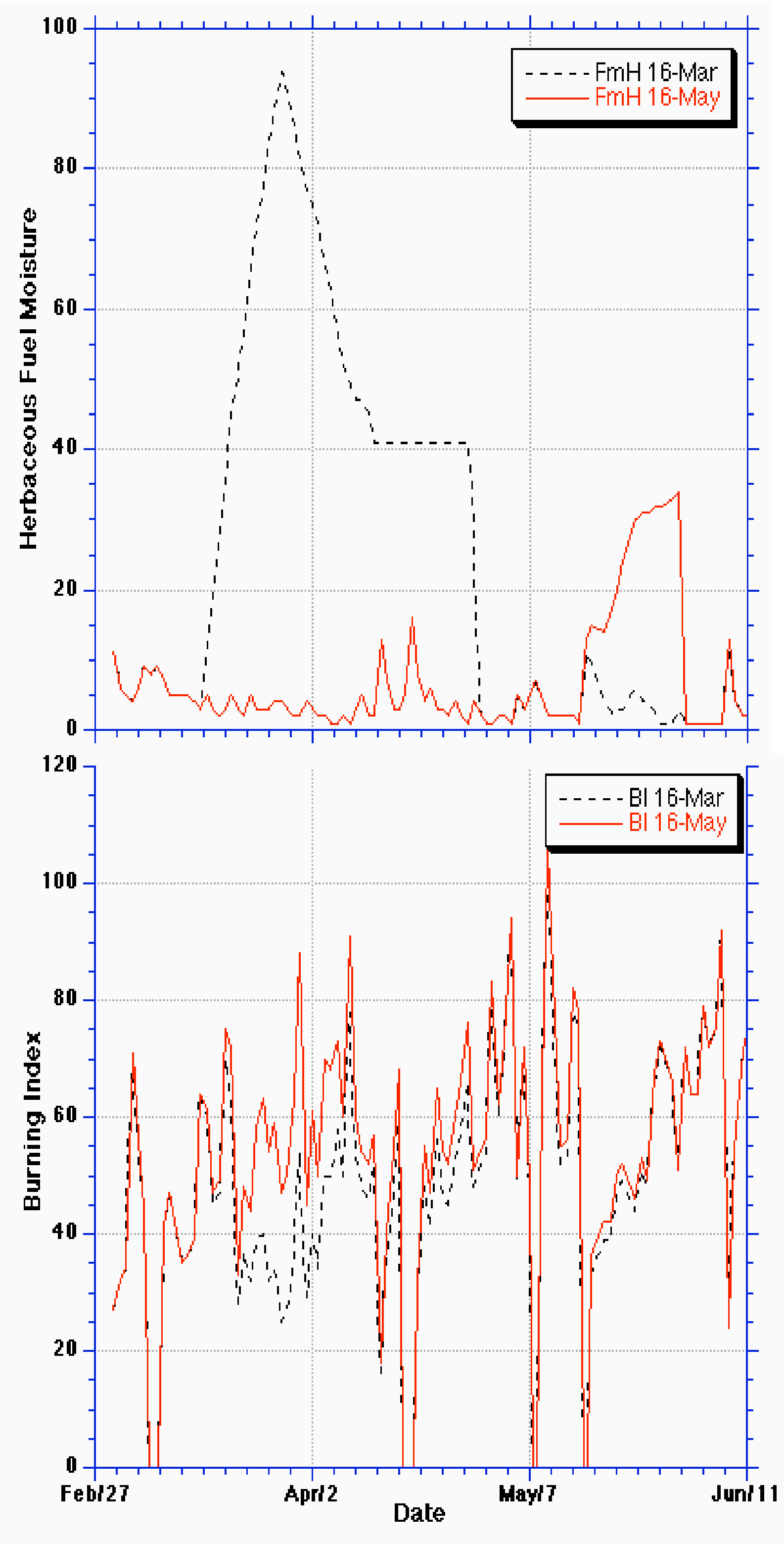

Figure 14. Comparison of traces for herbaceous fuel moisture and burning index based on integral method-derived 2000 green-up date and available (2003) agency green-up date applied to 2000 weather data from Desatoya station.

Table 4. Green-up date statistics (median, pseudosigma, and range) for 9 pixels in the Florida study area using the integral method.

Median (period number, start date)			**Pseudosigma (weeks)**		
38 (Sep 20)	44 (Nov 1)	41 (Oct 11)	4	3	3
42 (Oct 18)	41 (Oct 11)	42 (Oct 18)	3	3	3
42 (Oct 18)	41 (Oct 11)	40 (Oct 4)	3	2	3
Minimum (period number, start date)			**Maximum (period number, start date)**		
34 (Aug 23)	39 (Sep 27)	35 (Aug 30)	52 (Dec 27)	52 (Dec 27)	50 (Dec 13)
33 (Aug 16)	35 (Aug 30)	36 (Sep 6)	52 (Dec 27)	52 (Dec 27)	52 (Dec 27)
33 (Aug 16)	38 (Sep 20)	35 (Aug 30)	52 (Dec 27)	52 (Dec 27)	52 (Dec 27)

4.3 *Florida*

At the Florida site, the integral method identified at least one green-up date in every year. Fall green-up occurred in each year having fall data (1990-2001) and a spring green-up was identified for some pixels during 1991-1996 and 2001. For this analysis, green-up dates from August to December were considered fall green-up dates; spring dates occurred from January to June. The median fall green-up date (late September – early November), spread (mid-August – late December), and variation (3 weeks around the median) are reasonable dates for this location based on the climate of the area. Green-up dates or season codes used by local fire managers on nearby NFDRS weather stations were not available from WIMS for comparison.

5. DISCUSSION

The method appears to have several desirable qualities. First, it is independent of interannual variability, capturing variation in NDVI signal sufficient to discern similarities and differences in green-up between neighboring pixels. Second, the method performs as it would in an operational setting, without knowledge of the annual NDVI maximum. Third, the method can reproduce green-up dates determined by the current system, thereby producing the same fire danger ratings to which fire managers are accustomed. Historical green-up dates, as suggested by fire danger ratings computed from historical weather records, can be identified. Fourth, the method identifies green-up dates at various times of the year and one or more times in the same year according to the NDVI signal.

Limitations of the method exist, but should not prevent its application. It assumes the measures of NDVI for each new year fall within the climatology of NDVI used to develop the green-up threshold. More years of data will alleviate this limitation to some extent, but anomalous years that deviate from average values are always possible. The approach described here assumed a week-1 to week-52 climatology was appropriate for determining the climatological green-up threshold, but results suggest that analysis of some areas needs to start and end in the fall rather than the winter. The performance of the smoother at the edge of the data series led to erroneous green-up designations in some cases. While the integral method is independent of the choice of smoother, the smoother is an important contributor to the methods results. Further exploration of smoothers appropriate to this method is recommended.

6. CONCLUSION

A new method has been developed that uses NDVI to derive green-up dates for the National Fire Danger Rating System. With some further work, this method could be utilized in the operational, day-to-day processing of fire danger ratings, both in the short and long term evolutions of NFDRS. This work primarily involves integrating the method into the planning and operational processes that are necessary to compute fire danger at the local level.

This new method is also capable of generating historical green-up dates for fire weather stations, which will allow for the first time an objectively produced data set of green-up dates for all years for any pixel location. More work is necessary to handle the data computational processing and connect the results to desired analysis tools, but a basic method is now available.

7. ACKNOWLEDGEMENTS

This project would not have been possible without the support of the BLM National Office of

Fire and Aviation, Dr. Paul Tueller, Kevin Hull, Bob Abbey, Roberta Bartlette, and Ron Dunton.

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