1.2 MODELING FIRE GROWTH POTENTIAL BY EMPHASIZING SIGNIFICANT GROWTH EVENTS: CHARACTERIZING A CLIMATOLOGY OF FIRE GROWTH DAYS IN ALASKA'S BOREAL FOREST

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ABSTRACT

Current and future risks posed by wildfires are key elements in decisions about management of those fires. Carrying evaluations of that risk more than a few days into the future requires stochastic approaches that depend on the climatology of environmental conditions that favor or deter wildfire growth. Tools like the Fire Spread Probability (FSPro) simulator, and the Rare Event Risk Assessment Process (RERAP) before it, apply climatology in this way. This analysis identifies key environmental factors using spatial and temporal distributions of Moderate Resolution Imaging Spectroradiometer *(MODIS) fire detections. The Fine Fuel Moisture Code (FFMC) and Buildup Index (BUI) from the Canadian Forest Fire Danger Rating System (CFFDRS) define the critical climatology of conditions favorable for significant fire growth in Alaska's Boreal Interior. These conditions are used to inform the stochastic analyses and demonstrate the potential for effective and useful results.*

1. INTRODUCTION

Interior Alaska's boreal landscape has a rich history of significant wildfires over its modern history. The database of past fire perimeters and the fire scars on the landscape tell an important story of fire ecology and the human response to it. Figure 1 shows the strong relationship between the interior landscape and its affinity for fires.

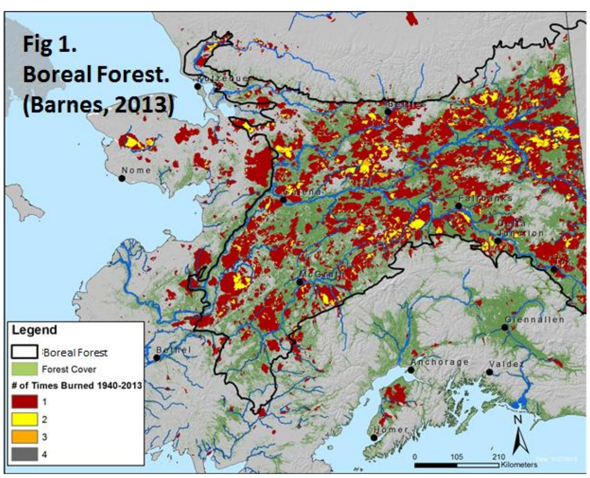

Figure 1. Alaska's Fire History, 1939 to present.

The increase in the occurrence and significance of large fires encountered in 2002, 2004, 2005, 2009, and 2013 has raised awareness and concern for management to protect the values of interest (life and health, property, and ecological services) at risk from even the most remote fires. The moving 10-year averages of annual area burned depicted in Figure 2 show a steep rise from generally less than 400,000 hectares per year to a new level over 700,000 hectares per year beginning in 2004.

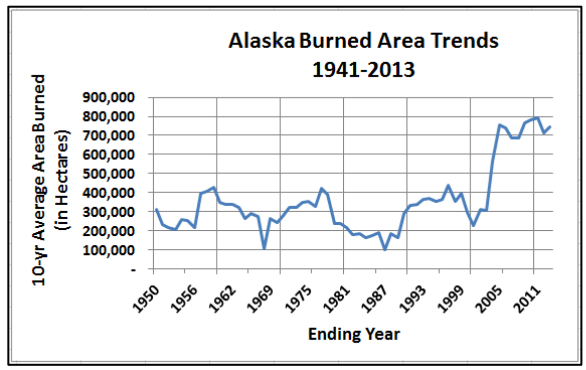

Figure 2. Alaska Burned Area Trends, represented as 10-year moving averages with the reporting year as the endpoint of that averaging. (AICCa, 2014)

Evaluating current and future risk to identified values is an important part of fire management decisions. Rating the potential for fire growth is a complex task for fire managers. It requires considerations of current and forecasted weather (temperature, humidity, cloud cover, precipitation, windspeed and direction) as well as the cumulative effect of past weather on fuelbed conditions. These environmental conditions overlay a complex of fuels and terrain that together determine the wildfire potential in any given point in time and space. Projecting that potential more than a day or two into the future demands the application of fire and weather history as well as forecasts and fire spread models. When the Fire Spread Probability (Finney and others, 2011) analysis tool became available for fire analysts in 2008, it held the promise to do just that. FSPro analyses use spatial depictions of terrain and fuels, as well as local climatology to estimate ranges for fuel moistures and wind inputs for the fire spread model. It uses climatological probabilities to differentiate growth potential among days that are expected to produce fire growth and to distinguish days when no growth is anticipated.

Alaska became an early evaluator and proponent of FSPro's utility for informing strategic decisions. However, even in that first year, differences among the analyst inputs highlighted the uncertainty about the

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FSPro results. Among those differences was the choice of fuel model to reflect the spread and flammability of the boreal spruce fuelbeds that dominate the landscape, burn aggressively, and signal large fire spread across Alaska's Interior. Over the last 5 years, individual FSPro fire spread probability depictions have variously been quickly exceeded by actual fire growth or posed exaggerations of fire growth potential as analysts have learned about the tool, the inputs, and the fire events on the landscape itself. Even when analyses produced useful projections to support decisions, doubts by managers due to the mixed history of results limited application.

The exploratory data analysis presented here demonstrates the utility of using significant thresholds found in the Canadian Forest Fire Weather Index (FWI) codes and indices (Figure 3: Van Wagner, 1987) to better predict when active fire spread events occur, and to assist in the evaluation of inputs and outcomes when predicting spread events for fires in this region. Alaskan fire managers have used the FWI system since 1992. With its three different moisture codes and three fire behavior indices, the FWI attempts to represent the current fire potential by integrating current and past weather in meaningful ways. Included are tools to assess fire ignition (Fine Fuel Moisture Code-FFMC), fuel availability and flammability (Duff Moisture Code-DMC, Drought Code-DC, Buildup Index-BUI), fire spread (Initial Spread Index-ISI), and fireline intensity as a measure of resistance to control (Fire Weather Index-FWI).

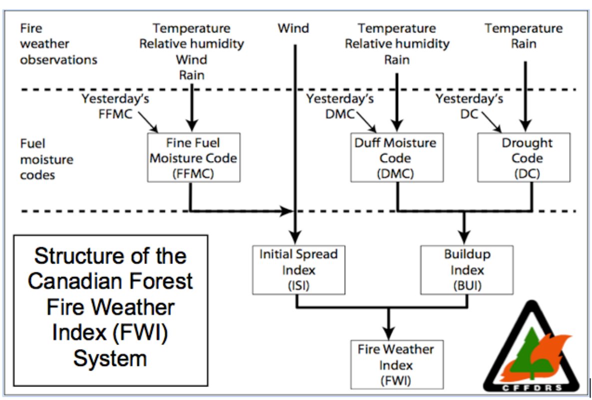

Figure 3. Canadian Forest Fire Weather Index (FWI) System structure, fire weather observations, the resulting fuel moisture codes, and overall fire behavior indices.

Though fuel moisture values are critical considerations in evaluating whether fires can grow at all, the fire spread models widely implemented in the Canadian and US fire danger and fire behavior systems are much more responsive to variations in windspeed, wind direction, fuel type, and slope inputs (Bishop, 2007). As a consequence, outputs from these models are regarded as projections of active fires, with much less sensitivity to effective measures of cumulative drought and their influence on the fire environment. In Alaska's Boreal Forest, this seems especially true. Transitions between limited spread and crown fire behavior are observed across a narrow set of environmental conditions, even in the most flammable fuels.

Others have concluded that trying to model the potential for fire growth across the entire range of possible environmental conditions tends to either underestimate the potential for growth or overestimate the acres burned using the current spatial tools. Podur and Wotton (2011) identified fire "spread event" days in verification analyses using the deterministic CFFDRS Prometheus (Tymstra and others, 2010) spatial fire modeling tool. We explore whether such an approach can be applied to probabilistic (FSPro) as well as deterministic fire analyses. Limiting the number of burn days, those that support significant fire spread, over an analysis period (much like limiting the number of burn hours in a day) can significantly improve agreement between modeled growth and actual fire perimeters in deterministic analyses, and hopefully outputs from probabilistic analyses as well.

Using Alaska's rich history of significant fire growth events occurring with only limited suppression intervention, FWI codes and indices are linked to both fire growth days and individual events signaled by MODIS Active Fire Detections to define the fire growth potential thresholds. These relationships are then used to define and distinguish *Predicted Fire Growth Days* where the vast majority of acres burn. This definition of fire growth events is used to produce climatology of fire growth potential in Alaska that can be used in a variety of contexts, including fire behavior and growth analysis. The climatology associated with these significant fire events applied to models that predict potential fire size and shape better captures the range of variation in fire growth events and promote greater confidence in analysis results among decision-makers.

2. DATA AND METHODS

Under the Alaska Statewide Annual Operating Plan, the Bureau of Land Management Alaska Fire Service (AFS) maintains an extensive database of fire management information (AICCb, 2014) to support fire managers across the state. One of the datasets maintained is a history of weather observations for a surface observation network that has grown to over 120 locations around the state. With those weather observations, the database contains daily estimates of the FWI codes and indices to characterize the fire potential for the entire weather observation network.

Though AFS also maintains a database of burned area perimeters (AICCa, 2014), even dated "progression" perimeters in some cases, identifying the date that any location burned from this dataset remains problematic. In many cases, the date of fire growth events are unknown by the time they are mapped on subsequent days. Even if temporal assignments were possible, some perimeters are sufficiently large that they may have been under the influence of a range of environmental conditions over the area burned for a given fire event.

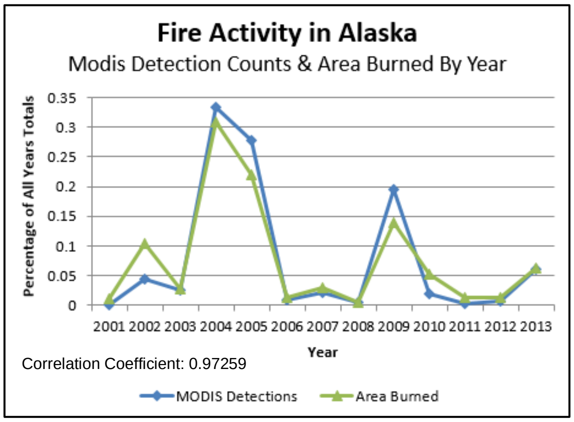

Figure 4.Distribution of MODIS fire detections and total area burned by year for Alaska; 2001-2013.

Since 2001 (MODIS) data has been used to detect active fires in the US and Canada. These MODIS fire detections (*MODIS detects*) are collected twice daily in the mid to high latitudes (one daytime and one nighttime observation) by sensors on two satellites at 1,000-meter spatial resolution. They represent individual reports of the locations of active portions of ongoing wildfires as they are occurring. The USDA Forest Service Remote Sensing Application Center (RSAC) maintains a database of these fire detections available for download and use (USDA, 2014). The nearly 180,000 *MODIS detects* occurring in Alaska over the 13-year period are better identified both spatially and temporally than other data sets. As shown in Figure 4, the distribution of *MODIS detects* by year is highly correlated with acres burned by year.

A further analysis of these *MODIS detect*s demonstrates their co-location with corresponding fire perimeters from the AFS database. Over this 13 year period, 97% of the total *MODIS detects* fell within final fire perimeter polygons from the corresponding year. The conclusion drawn here is that *MODIS detects* provide a reasonable depiction of when and where significant acreages burned, helping to identify days and locations with demonstrated significant fire growth. Parks (2014) found that [MODIS derived] day-of-burning maps generated with the best performing interpolation technique showed reasonably high quantitative and qualitative agreement with [observed] fire progression. With this background, the frequency of *MODIS detects* in a given area, based on the associated weather station, is used as a scale for general fire growth potential for both those locations and aggregated areas.

Approximately 89% of all the *MODIS detects* within Alaska occur within the following Alaska Interagency Coordination Center (AICC) Predictive Service Areas (PSA) that include the interior boreal ecoregion (AK01E, AK01W, AK02, AK03N, AK03S, AK04, AK05, AK07, AK09) comprising the study area in Interior Alaska (Figure 5).

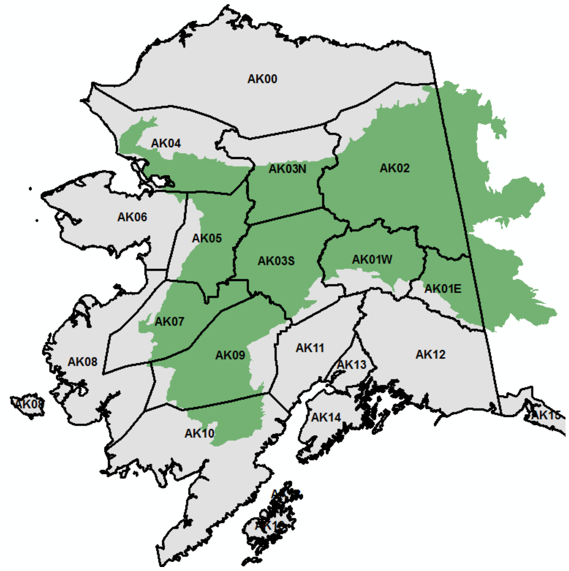

Figure 5. Alaska's Interior Boreal Eco-Region and the Alaska Interagency Coordination Center's Climate based Predictive Service Areas (PSA) that comprise the area of interest for this study of weather and climate, fuel availability, and fire growth potential.

A "Spatial Join" query available in ArcGIS (ESRI, 2011) was used to link each *MODIS detect* within the study area with the nearest weather station location. The resulting MODIS-Weather Station attribute table provided a date and time for each *MODIS detect*, the identifier for the nearest Weather Station, and it's associated PSA. Linking these *MODIS detects* with the daily FWI codes and indices for the nearest weather station based on date and time allows for correlation between the two data sets. Because *MODIS detect* observations are recorded in the morning and evening, those observations prior to 1700 GMT (0700 AKDT) were associated with the previous day's FWI record to best capture existing fuel moisture conditions at the time of the detection.

Predicting fire growth potential based on thresholds for weather and fuel moisture conditions required a climatological analysis of the conditions occurring throughout the interior Boreal ecoregion, and required analysis of the conditional frequency of the fire events (represented by *MODIS detects*) that occur under the range of weather and fuel moisture conditions found in the climatology. To do this, three different frequency distributions were prepared for each of the FWI codes and indices:

1) Frequency distributions for *All Days* that includes all of the daily FWI records (weather observations and the associated FWI codes and indices) collected at fire weather observing locations in the Interior PSAs from 2001 to 2013. This data set includes 91,857 observations in all. Though this period is shorter than the typical "30-year climatological" dataset, when combined with fire event data, a wide range

of weather conditions are captured that effectively represents the range of conditions that have supported fire growth events encountered in recent history for Interior Alaska.

2) Daily FWI records that were associated with *MODIS detects* in the Interior PSAs are called *MODIS days,* or days that *at least one MODIS detect* occurred. Frequency distributions for these *MODIS days* were developed, using the weather and FWI elements of this data subset. It includes less than 5% of all daily weather observations identified in 1) above.

3) Daily FWI records were associated with each of the MODIS fire detections (*Modis detects*) that occur within the PSAs of Interior Alaska and are individually called *MODIS detects*. The resulting dataset includes 158,607 individual records, or approximately 99% of all *MODIS detects* in the Interior PSAs of interest. Missing weather observations at the nearest RAWS locations were responsible for the omission of 1751 observations for many comparisons. Frequency distributions for these *MODIS detects* were similarly based on the weather and FWI elements from the associated FWI records

Each of these frequency distributions can be depicted independently. However, considering the distribution of *MODIS days* and *MODIS detects* as conditional to the overall climatology in the study area by relating them to the distribution of all FWI observations allows the analysis to better evaluate the probability or likelihood of their occurrence, based on a given set of associated weather/FWI conditions.

To identify these distributions of conditional (or likelihood) frequencies*,* counts of *MODIS days,* from 2) and counts of *MODIS detects,* from 3), encountered in given ranges of individual weather and FWI elements are divided by *All Days* counts, defined in 1) above, in the same ranges to produce transformed frequencies. These conditional frequency distributions were examined for trends and correlations that suggest a given weather/FWI element range will predispose the occurrence of *MODIS days* and/or individual *MODIS detects.*

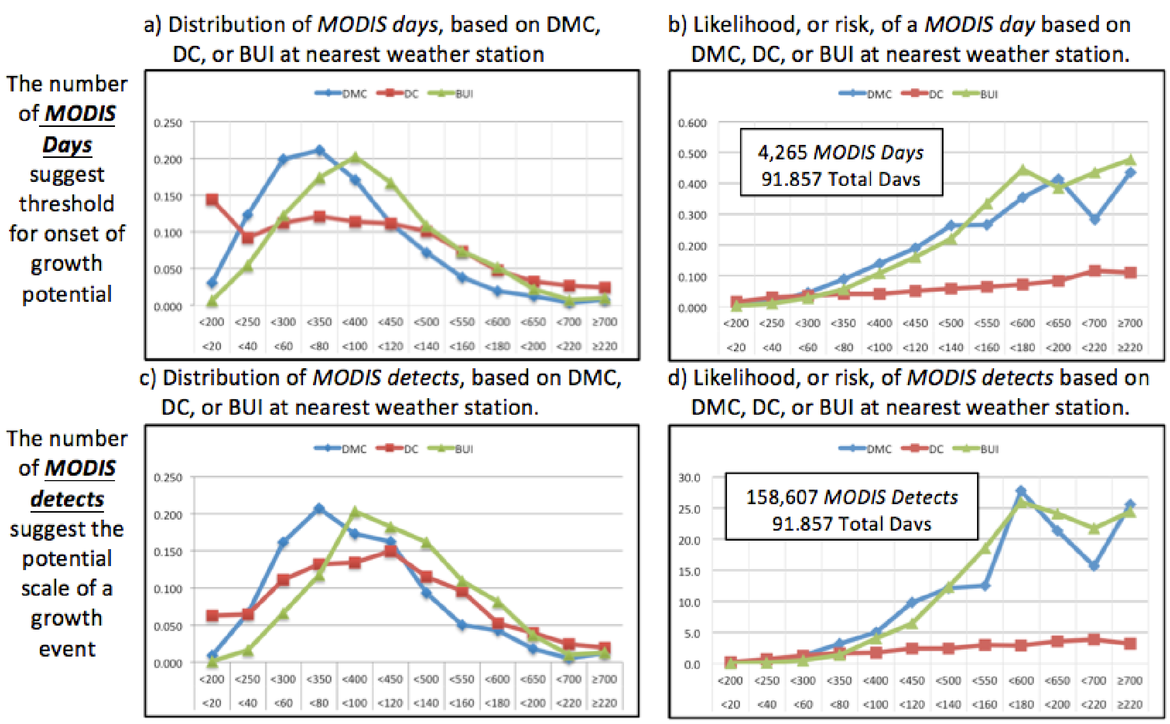

Figure 6. Frequency distributions of *MODIS days* and *MODIS detects* based on cumulative drying indicators. a) And c) represent simple frequency distributions for DMC, DC, and BUI. b) and d) represent conditional frequencies for DMC, DC, and BUI.

The Duff Moisture Code (DMC), with a timelag of 15 days, Drought Code (DC) with a timelag of 52 days, and Buildup Index (BUI) that integrates these two moisture codes were considered for their utility in characterizing the antecedent fuel moisture conditions that develop over weeks and months through the fire season to influence growth potential. If, as understood intuitively, fire potential increases as precipitation deficits grow and drought develops, the resulting increases in at least one of these values should produce corresponding increases in likelihood and frequency of *MODIS detects*. In fact, all three show positive correlations with *MODIS detects*, with BUI and DMC showing much stronger relationships (Figure 6).

If one were to look only at the 4,265 daily FWI observations that had *MODIS detects* associated with them in Figure 6a or the distribution of *MODIS detects* themselves in Figure 6c, the distribution appears counter-intuitive with intermediate fuel moisture conditions represented frequently. But recognizing that these *MODIS days* and *MODIS detects* are associated with less than 5% of all daily FWI observations, relating the two distributions by dividing *MODIS days* and *MODIS detects* by *All Days* in each index range produces a telling transformation. Figure 6b shows that, in fact, as fuels dry, the risk of a day with at least 1 MODIS detect increases steadily. Figure 6d shows that the frequency of *MODIS detects* is similarly related to increasing fuel moisture codes, rising sharply with increasing DMC and BUI. In this manner, weather elements and FWI values were related to *MODIS days* and *MODIS detects*, both individually and in combination, for the entire study area and for individual PSAs to evaluate their efficacy as predictors of fire growth potential across this large ecological and climatological region.

Additionally, high ambient temperature, low atmospheric moisture, and/or high winds among current weather conditions can increase current fire potential in concert with high levels or in spite of lower levels for these seasonal indicators. If the current conditions include low temperatures, high atmospheric moisture, and/or low windspeeds, fire potential may be mitigated even under extreme drought conditions. The FWI system includes 3 elements (FFMC, ISI, and FWI) as indicators of current conditions that may either mitigate or exacerbate the seasonal potential.

FFMC integrates its value from yesterday with current ambient temperature, rainfall, relative humidity and wind speed to produce a current FFMC value that defines how readily fine dead fuels ahead of the fire will ignite and promote fire spread. ISI integrates current FFMC and wind speed to further evaluate initial spread potential. FWI combines the influences of ISI and BUI to produce a seasonally adjusted overall fire potential. Air Temperature during the burn period was also considered as a factor that may work independently, potentially exacerbating otherwise intermediate fuel moistures. Conditional frequency distributions were similarly developed for *MODIS days* and *MODIS detects* based on these four indicators of current fire potential to determine the most representative and effective predictors of fire growth potential.

3. RESULTS AND DISCUSSION

Considering first the cumulative drying that influences the overall flammability of the fuelbed, both BUI and DMC show similarly predictive distributions. DC also shows a positive correlation, though barely so. BUI is preferred as the indicator of cumulative severity due to its more consistently increasing trend line (Figure 6). Further, seasonal drought as manifest in the DC, influences and increases BUI over DMC later in the season when curing of live fuels becomes a bigger contributor. Figure 7 shows average DMC and BUI trends for the Upper Yukon Valley, highlights this difference. While the earlier peak is generally associated with long burn periods and very dry current conditions, the later peak in early August reflects the effect of cumulative drying on green, growing season fuelbeds; where additional fuels become available due to the premature curing that occurs with drought.

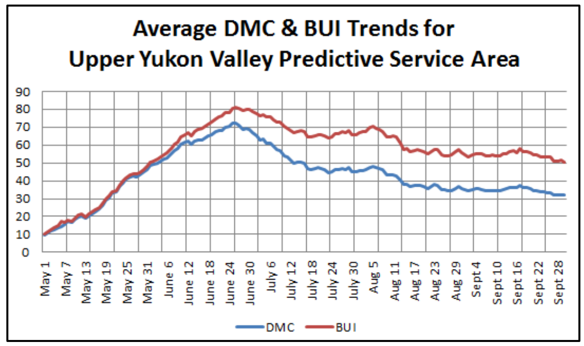

Figure 7. Daily average DMC and BUI trends for all weather observations in the Upper Yukon Valley Predictive Service Area (PSA) for years 1994-2014

Based on the conclusion that BUI effectively reflects the influence of cumulative drying on fuel flammability, each of the short-term fire potential factors (FFMC, ISI, FWI, and ambient temperature) were integrated with BUI using Microsoft (2010) Access cross-tab queries. These produced distributions of *All Days*, *MODIS days*, and *MODIS detects* as in Figure 6. The two-way distributions for *MODIS days* and *MODIS detects* were similarly divided by the corresponding *All Days* distribution to produce conditional frequency distributions as before to evaluate the predictive efficacy of each combination of cumulative drying (BUI) and current weather factor (ambient temperature, FFMC, ISI, and FWI) indicators. Figure 8 depicts the responsiveness of MODIS days and *MODIS detects* to each combination of BUI and current weather factor.

Among the current conditions evaluated, combining FFMC with BUI proved to be the strongest and most consistent predictor of overall fire growth potential, as measured by the conditional frequency distribution produced by dividing the classified *MODIS detect* counts by the *All Days* counts. Figure 8a shows little MODIS activity below the FFMC threshold of 88, and a steepening curves above that based on BUI levels.

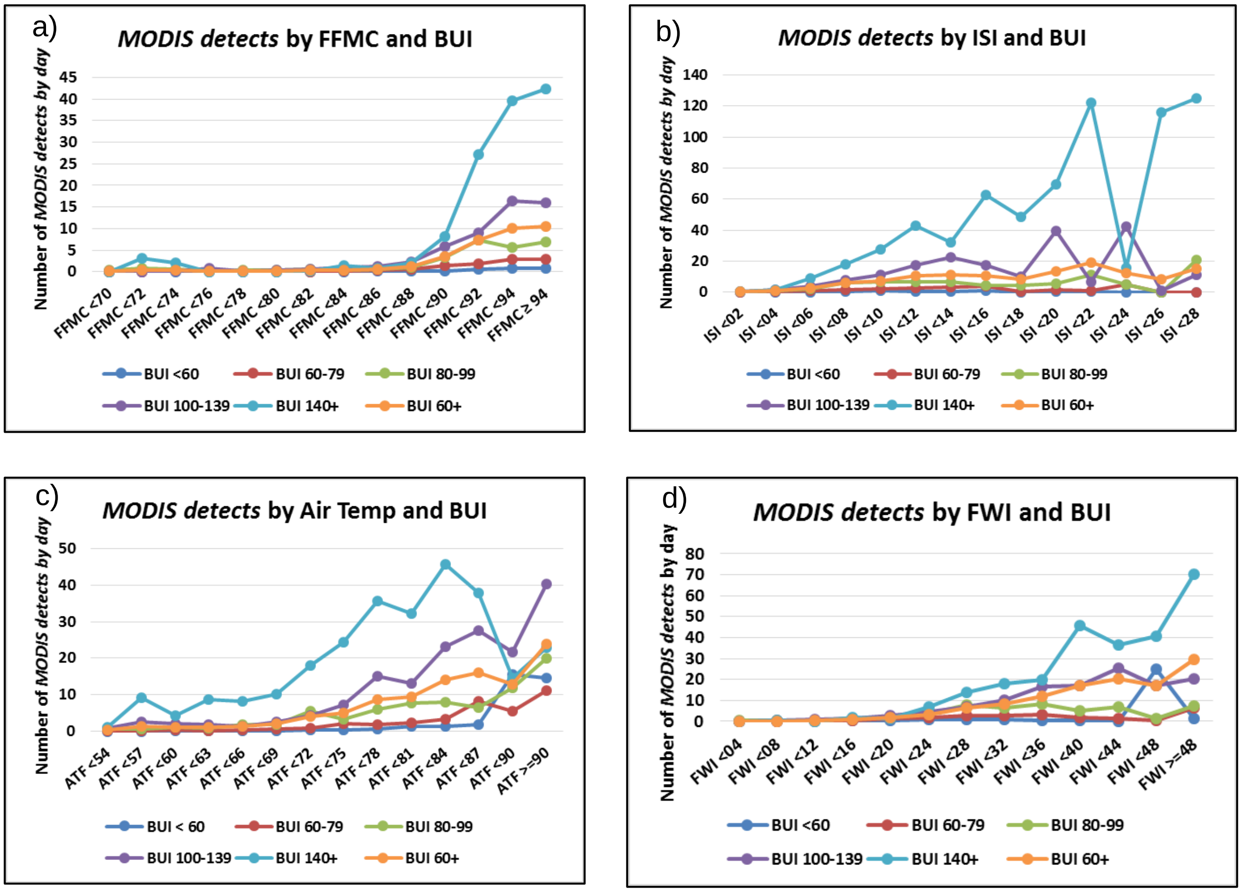

Figure 8. Comparison of Conditional Frequency Distributions for *MODIS Detects* based on several current condition indicators (FFMC-a, ISI-b, Air Temperature-c, and FWI-d) in combination with BUI as the indicator of cumulative drying.

Windspeed, known to be a critical factor in assessing fire growth potential and events, was found to be related to the onset of significant fire growth (*MODIS day* probability) and the size of these fire growth events (*MODIS detect* frequency) in the analysis. However, the relationships were less consistent than found for FFMC. There are a number of contributing factors.

- Windspeed is a highly variable factor over both time and space, and observations from a sparse network of surface observations may not effectively represent conditions influencing fire behavior at the *MODIS detect* locations. With only approximately 125 observing locations, sensors are representing winds for 2,500 square miles or more.
- Using windspeeds from only a single solar noon observation generally under-represents sustained windspeeds later in the day during the peak of the burn period. Wind observations from many automated sensors under-represent forecast, modeled values and onsite reports due to the surrounding vegetation, terrain, height of sensor, and measurement protocols.
- Additionally, wind without sufficiently dry fuels does not support significant fire spread in most cases while fire spread events are frequently noted with low windspeeds when dry fuels are present.

As a result, windspeed and the wind sensitive indices (ISI and FWI) reported in the single daily observations were not used in the fire growth criteria established here. Instead, this analysis recognizes that wind inputs are considered independently as inputs to fire spread models.

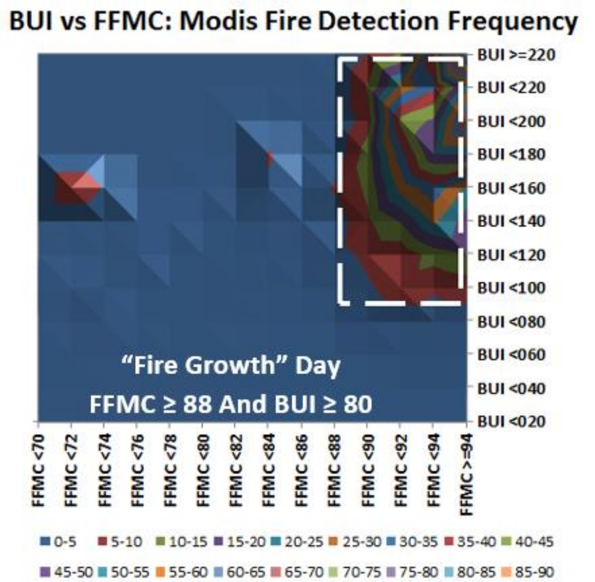

Figure 9. Conditional Frequency of *MODIS detects*, classified by FFMC (representing current conditions) and BUI (indicator of cumulative drying).

The combined frequency distribution for FFMC and BUI provide a distinct threshold for what becomes a consistent increase in *MODIS detect* frequency. As shown in Figure 9, conditional frequencies remains very low until reaching thresholds of 88 for FFMC and 80 for BUI. Further, as FFMC and BUI values increase in combination beyond those thresholds, the frequency of *MODIS detects* continues to rise sharply. One conclusion is that BUI and FFMC, as strong predictors of the relative “size” of fire growth events across the interior, can inform inputs to fire growth models as they predict area burned and fuel consumed, suggest potential smoke production, as well as thresholds for critical prohibitions for wildland activities.

The combined thresholds of 88 for FFMC and 80 for BUI were further evaluated to determine if they can be used as criteria to define a *Predicted Fire Growth Day*, whether they produced a *MODIS detect* or not. With that definition, all daily FWI records for the interior PSAs were classified as either *Predicted Fire Growth Day*, or non-growth days. Independent distributions of the 4,418 *MODIS days* and of the 11,595 *Predicted Fire Growth Days* were sorted by week and year and summarized for the study area. Groupings of records for the peak year (2004) alone, four large burned area years (2004, 2005, 2009, 2013), and all 13 years (2001-2013) were produced to evaluate the overall fit. Distributions for each of these groupings were then scaled by dividing the number of observations in each week by their respective distribution totals, with the resulting percentages plotted against each other.

Comparing the actual distributions for the *Predicted Fire Growth Days* and *MODIS days* in Figure 10 demonstrates the effectiveness of the *Predicted Fire Growth Day* criteria in forecasting *MODIS days* and the fire growth events they infer. Considering that general indicators of fuelbed flammability are only pre-disposing factors in assessing the potential for fire growth events, the strength in the relationship between the predictions and the actual events during years of significant active fire growth is excellent.

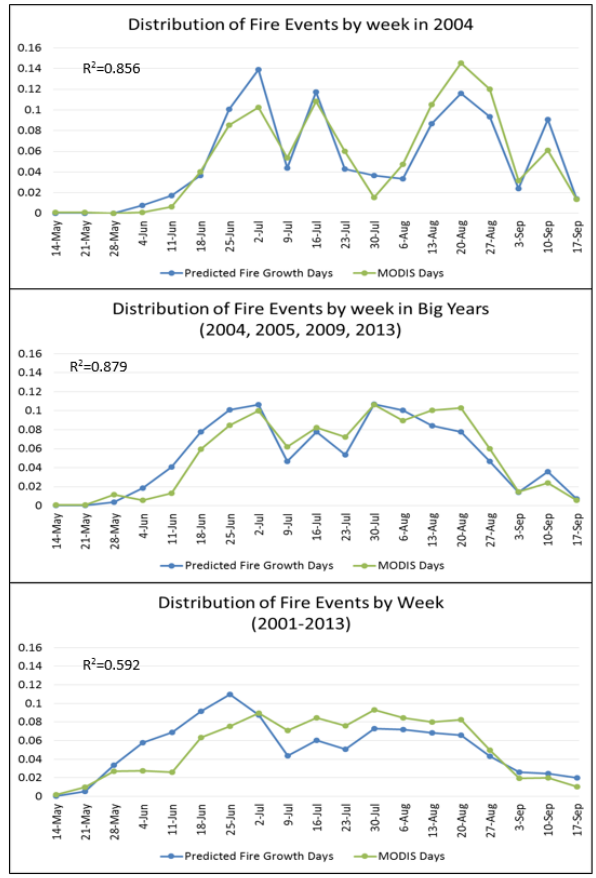

Figure 10. Comparison of *MODIS days* and *Predicted Fire Growth Days* (based on FFMC and BUI thresholds)

Defining the expected frequency of the occurrence of significant fire growth events within fire seasons in climatologic/ecologic regions in Alaska can inform probabilistic models and long term decisions, especially when outlooks suggest above normal potential in the weeks and months ahead. The 13-year distributions were used to develop probability distributions of *Predicted fire growth days*. In this case, dividing the weekly total number of *Predicted Fire Growth Days* by weekly totals for daily FWI observations and then multiplying by 7 provides the average *of Predicted Fire Growth Days* per week across individual PSAs and the Interior as a whole. Recognizing the typical number of growth days each week is important when making fire assessments that extend beyond the forecast period.

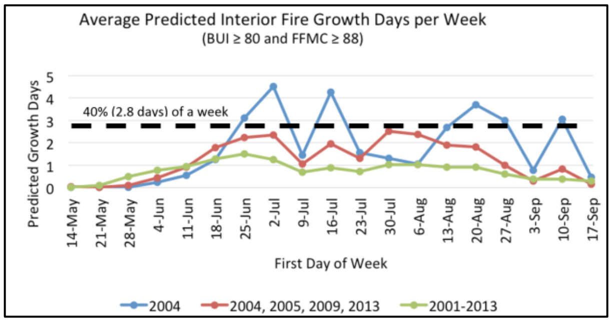

Figure 11. Historic trends of *Predicted Fire Growth Days* for Interior Alaska

This "climatology" of *Predicted Fire Growth Days* shown in Figure 11 represents the typical number of days each week with potential for significant fire growth for the average fire weather observing location using three different combinations of years. It suggests that large fire growth potential begins to rise at the end of May and in significant years, becomes pronounced by mid-June. In these 13 years, there seems to be a dip in the number of growth days in the middle of July due to higher precipitation (Alaska Climate Research Center, 2015) and a rebound at the beginning of August as seasonal curing begins.

For the entire 13 year history, the overall average number of *Predicted Fire Growth Days* per Week peaks between 1 and 2 days, or about 20% of the days in a week. In 2004, when burned area exceeded all expectations, this criteria predicted average peak weeks of nearly 5 days (70%) in July and 3-4 days (40-50%) in mid August. Using the 4 years (2004, 2005, 2009, and 2013) of multiple significant summertime growth events in the interior as representative of active summer seasons, the average number of predicted growth days peaks at between 2 and 3 days per week, or 40% of those days.

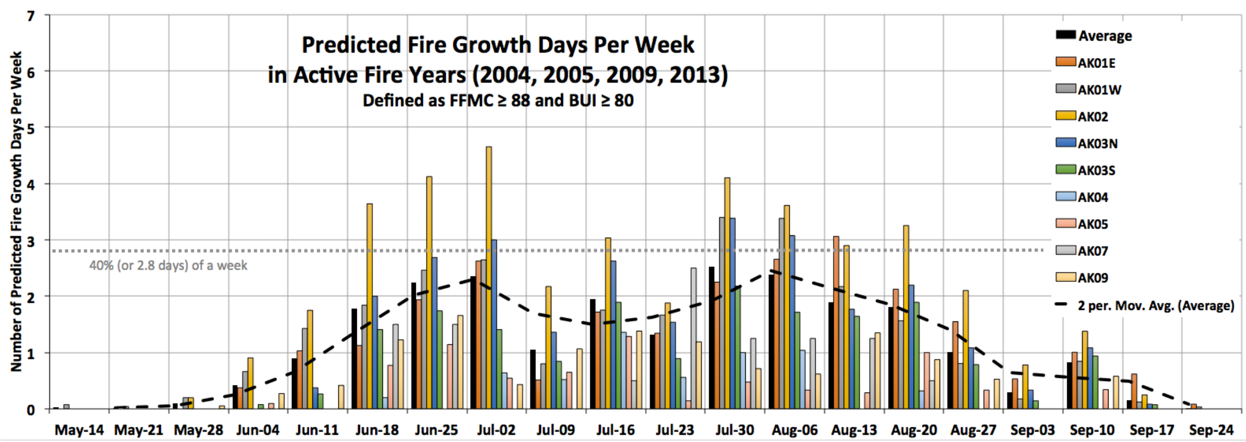

Figure 12. Distribution of the average number of *Predicted Fire Growth Days* by week and Predictive Service Area (PSA) for active fire years.

How does this climatology vary from PSA to PSA? The variability among Interior PSAs is shown in Figure 12. The Upper Yukon PSA (AK02) has the highest frequency of days with significant fire growth, peaking at between 4 and 5 days. The western PSAs (AK04, AK05, AK07, and AK09) are represented with lower frequencies of both *Predicted Fire Growth Days* and *MODIS days* throughout the fire season. These spatially defined variations in growth event frequency may offer important insights when evaluating potential for specific incidents.

At the beginning of this analysis, individual growth events (days) were identified for 8 large fires in 2013. Over the periods of significant activity for those fires, often 2 weeks or more, counts of these events and their resulting frequencies were determined. This 40% frequency seems to fit well with the anecdotal frequency of growth days reported for these significant fires. This average peak frequency of 40% should be useful for predicting the number of growth events in typically encountered in dry periods for much of the interior.

However, as represented for PSA AK02 in Figure 12 and as demonstrated in 2004, landscape factors, pre-green conditions or extreme drought and frequent lightning can alter the frequency of fire growth events.

4. POTENTIAL APPLICATION

BUI and FFMC represent only generalized fuel flammability conditions for a given area and ignore important factors such as fuelbed composition that varies locally from spruce to hardwood and tundra across the interior and terrain that ranges from flat to 20% slope or more. There is little in this definition of a *Predicted Fire Growth Days* (or in the frequency distribution of *MODIS detects*) that suggests when or where a fire will start. Analysis of factors that influence the number of lightning strikes and the ability to predict that continue. The vagaries in human behaviors that cause wildfires suggests that people act without thinking every day, with the significant day-to-day changes coming primarily in weather and fuel moisture.

Understanding these limitations, this analysis demonstrates the utility of BUI and FFMC in predicting the potential for and frequency of fire growth events throughout the Interior, and suggesting their scale and impact when and where they do occur over this huge fire-prone landscape. Almost as important is the ease with which they can be forecasted. These two indices require only a small set of once-per-day weather inputs that are readily available in typical weather forecasts.

As Podur and Wotton (2011) suggest, identifying informed weather parameters as criteria to select specific days where significant growth is anticipated may significantly improve predictions of fire growth for individual events and for analysis over extended periods. The concept of a *Predicted Fire Growth Day* climatology recognizes the episodic nature of significant fire growth events and focuses fire spread analyses that span extended periods on these anticipated days and events.

Fire Spread Probability (FSPro) analysis in the Wildland Fire Decision Support System (WFDSS) is used widely to evaluate potential fire growth over one to several weeks for ongoing fires using local climatology. It projects independent fire growth projections for each of the specified number of "completed fires" and then determines the burn probability for each pixel based on the intersection of the resulting burned areas. It uses Energy Release Component (ERC) from the National Fire Danger Rating System (NFDRS) to track both antecedent fuel moisture conditions and model day-to-day variability for each "completed fire" during the analysis period. FSPro actually tracks and reports a summary total of the number of Burnable (or fire growth) days" within the user-defined analysis period (number of days with a starting date), modeling growth only for each of those burnable days.

There have been many calls to replace ERC with BUI in these FSPro analyses in Alaska, with little prospect for that change. Instead, this analysis of fire growth potential demonstrates that locally defined thresholds for significant fire growth, such as the *Predicted Fire Growth Day* criteria, can influence the ERC settings in the analysis that determine the number of burnable days and the range of fuelbed flammability inputs on those burnable days. Further, local forecasts of fire growth potential as scaled by these thresholds can help the analyst adjust the ERC forecasts within FSPro to best represent forecasted conditions and growth expectations.

Within the analysis period, defined by a start date and duration in days, FSPro produces unique modeled streams of day-by-day ERC values for each of the user-selected number of "fires" using its initial ERC value, recent past ERC values, and a selected reference ERC climatology. In many cases, the analyst may include one or more days of forecasted ERC values at the beginning of each stream. Those ERC streams classify each day as "burnable" or "non-burnable" and models the day to day variation in fuelbed flammability among those burnable days for each "fire".

The controlling inputs can all be found in the ERC Classes table (Figure 13), among the input tabs:

- The number of "burnable days" for the analysis period is defined by the analysis start date, the number of days in the analysis period, the date filter, and the number of ERC classes (rows) in ERC Classes table. It is also influenced by the current and recent ERC trends, as well as the ERC stream forecasts and modeled streams for each "completed fire." As a result, a scoping analysis is required to determine the "burnable days" proportion in each class. Based on that result, the user can increase the number of "burnable days" by adding rows to the ERC Classes table or decrease the number of "burnable days" by deleting rows in it.

  Using the ERC Class Distribution in Figure 13, with 6 rows in the ERC Classes table, 87% of all days are classified as "burnable days" for which the analysis models growth.

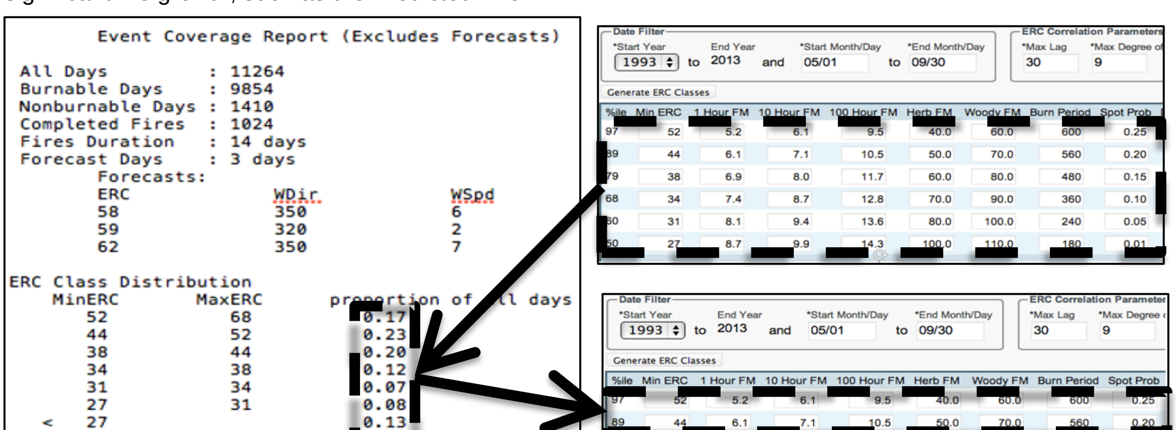

Figure 13. Example Event Coverage Report from FSPro analysis showing "burnable days" frequency both before and after modification in the ERC table.

- Based on the *Predicted Fire Growth Days* climatology developed, there is little reason to accept that 87% of analysis days are receptive to significant fire growth. Subsequently editing the table by retaining only the top 2 rows would reduce this percentage to 40% of all days (0.17 + 0.23), in line with the *Predicted Fire Growth Days* frequency.
- The day-to-day variability in modeled fuelbed flammability is based on the fuel moistures, burn period, spot probability, and delay inputs found in each row of the ERC Classes Table. These inputs are selected from the appropriate row based on the ERC identified for that day in the ERC stream for that fire. It may be appropriate to use the *Predicted Fire Growth Day* distribution to adjust inputs and scale growth potential for each ERC class in the table. In FSPro, these inputs are combined with day-to-day variability in windspeed/direction based on a separate representative climatological distribution and the fuelbed/terrain features encountered each day based on the current modeled perimeter, the defined landscape characteristics that surround it, and resulting modeled growth rates for each location as the fire grows during "burnable days".

Simply reducing the number of "burnable days" for analyses already calibrated to overall acreage burned would likely result in serious underestimates of probability or acreage burned. Ziel (2008) found that, in fact, tu4 (dwarf conifer) did not perform as well as sh5 (High Load, Dry Climate Shrub) in modeling individual fire growth events using FLAMMAP (Finney, 2006), often underestimating the size of individual growth events. Combining the more aggressive fuel model (sh5) selection for the very flammable black spruce fuels with the reduced number of burnable days more accurately reflects observed episodic growth patterns for fires in Interior Alaska.

The example in Figure 14 from the Stuart Creek #2 Fire near Fairbanks in 2013, demonstrates the opportunities posed by applying the *Predicted Fire Growth Day* climatology to the FSPro analysis process. These two 14-day analyses were initiated from conditions on June 30th, when the fire was poised to begin large fire growth.

In the first version a), conventional inputs to the ERC Classes table are applied over 6 rows that allowed growth to be modeled over 84% of all days in the analysis period. In the second version b), the ERC Classes table was shortened to include only 3 rows, which included only 48% of all days in the analysis period. This reduction in the number of "fire growth" days allowed the analysis to calibrate inputs to the significant growth events by selecting a more flammable fuel model, sh5, instead of the conventional choice, tu4.

On first look, these two analyses appear very similar, with the entire probability cloud out to and including the <0.2% contour covering similar areas. However, looking more closely there are several important differences attributed to the differing approaches.

- First, and most noticeable are the differing sizes in the highest (80-100%) probability band, where the fewer burnable days in b) will tend to limit its size. The forecast inputs that are applied to the beginning of the analysis period in each of the ERC streams should have a large influence on the size and shape of the 80-100% contour. In this case, the 3 day forecast for June 30-July 2 was aligned with actual weather and wind conditions on those days. The resulting 80-100% contour in b) provides a fair fit to the day 3 perimeter while the one in a) exceeds it significantly.

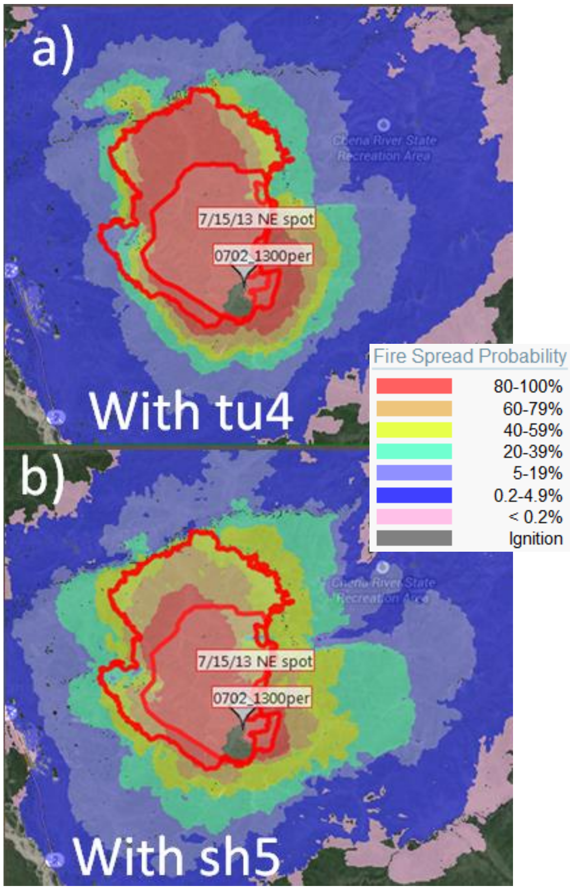

Figure 14. 14-day Fire Spread Probability (FSPro) results from June 30th for the Stuart Creek 2 Fire of 2013. Probabilities are represented in a) using classical analyses with tu4 for spruce fuelbeds and b) using the reduced frequency of growth events and the more flammable sh5 fuel type

One might intuitively think that analysis depicted in a) produced an accurate result because the 80-100% contour closely matched the final perimeter. But a final perimeter from actual growth over the analysis period that matched the 80-100% contour actually reflects much less than average growth given the starting point of the analysis and the climatology for the area because 80% of all analysis runs burned that area.

If the 80-100% band can be effectively related to the forecasted first few days and represent the truly high probability area for all likely climate scenarios, it may be an important temporal as well as spatial prioritization tool for strategic decisions early in an incident or analysis period.

- The successive probability bands in b) are significantly larger than in a), again related to the lower number of burnable days cumulating more of the overall growth potential on fewer days that emphasize large fire growth. These more significant middle probability bands may also be useful in prioritizing management actions as well.
- Notice also the stronger tendency of analysis b) to indicate an increased likelihood of the fire to move to the northeast in each of the probability contours based on the input wind climatology that emphasizes SW and West winds. The effect is much less pronounced in a) because there are more burn days applied across the entire distribution of wind directions.

Applying this informed fire growth event climatology to probabilistic modeling of fire spread and spread potential demands an informed interpretation of the probability cloud. If the analyst expects the eventual pattern of fire growth to exceed the expected number of growth days based on forecasts and outlooks, the briefing should emphasize potential for growth into the lower probability bands . If, on the other hand, expected weather during the analysis period will discourage spread, the message should emphasize the reduced potential for the rare event scenario.

5. CONCLUSION

Predicting fire growth requires considerable judgement when using widely available modeling systems such as the WFDSS spatial analysis tools or the CFFDRS Fire Behavior Prediction (FBP) system. In situations where actual fuelbed flammability is persistent over an analysis period valid variations in inputs for wind, fuels, and terrain allow the models to work very effectively. However, when these fuelbed flammability conditions change significantly from day to day and the associated growth events are episodic in nature, calibrating the models to one situation (significant growth versus moderated or little growth) produces inconsistent results when applied to the other.

Recognizing that nearly all of the total acres burned in Alaska have come during these episodic fire growth events, historical frequency for these events should be considered when conducting spatial growth analyses. An overall level of 40% for a given location, which translates to about 3 days out of 7, is a representative frequency in Alaska's interior during active fire seasons. Though not attempted here, the linkage between these FWI indicators and MODIS detection frequency suggests the potential for predicting the potential size of significant growth events themselves.

The methodology outlined here addresses the episodic nature of large fire growth on certain days heavily weighted to weather factors that influence fuelbed flammability. Fire growth analysis still needs accurate fuelbed descriptions and wind vectors as inputs to any analysis. Understanding the nature of fire growth events in a given analysis area, be they relentless daily spread in cured surface fuels or episodic events under extreme conditions in green fuelbeds, provides the basis for calibrating the most basic element in any fire growth prediction.

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