HOW WELL DOES THE GROWING SEASON INDEX CORRESPOND TO THE START OF FIRE SEASON?

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1. ABSTRACT

In any given geographic region, expected fire season is often identified by specific calendar start and end days. In any given year, the actual start of the season - as determined by fire activity - typically differs from that calendar day due to the prevailing temperature, humidity, wind, vegetation and snow pack conditions. A reliable association between a climate-based annual index and actual fire occurrence would be of use for current as well as past and future climate estimates of fire season. We used the North American Regional Reanalysis historic data set, and historic dates of occurrence of the annual first large fire for the states of Washington and Oregon, to evaluate the potential use of the Growing Season Index in order to study the start of fire season. Results are presented using the Northwest Coordination Center's predictive service areas as the spatial unit of analysis.

2 INTRODUCTION

Currently, estimation of the start of fire season for a particular geographic region is based on an average of previous first fire start dates. For example, May 20th may be declared the start of the season because during the past few years fires began around this date. A downside to this method is that it does not take into account the changes in the weather. In this study, we seek an effective way to estimate the start of the fire season. We investigate whether a climate-based index could be a more reliable and precise gauge for the fire season than calendar day, which is essentially an astronomical index.

For this study, there are two qualities we consider desirable in an index to predict the start of fire season. First, it must obviously be consistent across time. From year to year, the value of the index at the start of fire season should be the constant. Second, it should be independent of location. Calendar day has some spatial coherence in the sense that broad regions of the United States have generally recognized fire seasons. Any alternative index would be more geographically robust if its critical value was independent of location.

The Growing Season Index (GSI), created by Jolly et al. (2005), reflects the state of vegetation and is based on temperature, moisture and length of daylight. It has been tested at widely dispersed locations around the world and shown to be a good indicator for phenological processes throughout the year. Because the GSI reflects vegetation state as well as temperature and humidity, it seemed a reasonable candidate as a climate based index of fire season start.

The GSI is the mathematical product of three sub indices: (1) a minimum temperature index, iT_{Min}, (2) a vapor pressure deficit index, $iVPD$ and (3) a photoperiod index, $iPhoto$. These indices, as well as the GSI, are bounded between 0 and 1, with 0 representing inactivity and 1 unconstrained vegetal growth. Each term and the combined GSI metric are calculated as indicated below. The minimum and maximum values used to derive each factor were selected by Jolly et al. (2005) based on pre-existing literature because they either limit or promote foliar development:

Minimum Temperature Index.

$$iT_{Min} = \begin{cases} 0, & \text{if } T_{Min} \leq T_{MMin}, \\ \dfrac{T_{Min} - T_{MMin}}{T_{MMax} - T_{MMin}}, & \text{if } T_{MMax} > T_{Min} > T_{MMIn}, \\ 1, & \text{if } T_{Min} \geq T_{MMax}, \end{cases} \tag{1}$$

where iT_{Min} is the daily indicator for minimum temperature, T_{Min} is the observed minimum temperature, T_{MMIn} = -2°C, and T_{MMax} = 5°C.

Vapor Pressure Deficit (VPD) Index.

$$iVPD = \begin{cases} 0, & \text{if } VPD \geq VPD_{Max}, \\ 1 - \frac{VPD - VPD_{Min}}{VPD_{Max} - VPD_{Min}}, & \text{if } VPD_{Max} > VPD > VPD_{Min}, \\ 1, & \text{if } VPD \leq VPD_{Min}, \end{cases} \tag{2}$$

where $iVPD$ is the daily indicator for the vapor pressure deficit index, VPD is the observed maximum VPD in Pascals, and VPD_{Min} = 900 Pa, and VPD_{Max} = 4100 Pa.

Photoperiod Index.

$$iPhoto = \begin{cases} 0, & \text{if } Photo \leq Photo_{Min,} \\ \frac{Photo - Photo_{Min}}{Photo_{Max} - Photo_{Min}}, & \text{if } Photo_{Max} > Photo > Photo_{Min}, \\ 1, & \text{if } Photo \geq Photo_{Max,} \end{cases} \tag{3}$$

where $iPhoto$ is the daily photoperiod indicator, $Photo$ is the observed daily photoperiod, and $Photo_{Min}$ = 10h, and $Photo_{Max,}$ = 11 h.

Growing Season Index.

$$iGSI = iT_{Min} \times iVPD \times iPhoto, \tag{4}$$

where $iGSI$ is the daily GSI indicator, iT_{Min} is the daily minimum temperature index, $iVPD$ is the daily vapor pressure deficit index, and $iPhoto$ is the daily photoperiod index. The daily GSI metric is a moving 21 day average of the $iGSI$ values. Jolly et al. (2005) used centered averages, but in this study we used a backward average, i.e., a given day's GSI value is a function of that day's weather and photoperiod and those for the preceding 20 days. This slight modification produces a GSI that can be calculated on a given day without the need to predict conditions 10 days into the future.

3. DATA AND METHOD

Evaluation of the GSI for fire season required meteorological data and fire data. To make this exploratory project tractable, we focused on the Pacific Northwest region of the United States, specifically the states of Washington and Oregon. If the GSI does not display the interannual and spatial consistency noted previously over this region, it necessarily cannot do so over a broader region.

We used the North American Regional Reanalysis (Parrish et al. 2006) to compute the GSI for the entire NARR domain for the time period in question. In order to calculate the Growing Season Index, we extracted all temperature and specific humidity information at 2 meters above ground level. We used the temperature recorded at 1200 UTC to approximate the daily minimum temperature, as this tends to be the coolest period of the day in the Pacific Northwest. To compute the observed vapor pressure deficit, we used specific humidity, pressure, and temperature measured at 0000 UTC, as this is frequently the driest time of day. The photoperiod length was calculated using solar geometry equations involving calendar day and latitude (Lowry and Lowry, 1989). To produce the GSI we multiplied the three indices.

Fire start dates were obtained from the Northwest Coordination Center's (NWCC) historic records. The NWCC management system divides Washington and Oregon into twelve climatically and topographically similar regions called Predictive Service Areas (PSA), as shown in Fig. 1. Areas 1 through 4 are hereinafter collectively the "Western" PSAs, 5 through 7 the "Central" PSAs and 8 through 12 the "Eastern" PSAs. Within each PSA, there are 4 to 9 "key" Remote Automated Weather Stations (RAWS) that NWCC staff use to represent that PSA. These RAWS' latitude and longitude coordinates were used to extract the nearest NARR grid points to use in calculation of an average GSI value for each PSA. In their operational work, NWCC defines a large fire as one in the 95^{th} percentile for a given PSA, but at least 100 acres. This threshold varies among the PSAs, as shown in Table 1. The NWCC has been keeping a record of the first large fire of the season in each PSA since 2002.

All analysis of the NARR data used C++ programs written for this project by the lead author. One program read in NARR data, calculated the Growing Season Index, and produced a new file containing the 21-day average GSI values for the entire NARR domain for every day of the year for the years 2002-2009 (Fig. 2). A second program read in RAWS geographic coordinates, and found the grid point closest to that point in the GSI file. The third program extracted the GSI values from the grid points closest to the RAWS locations, and wrote out a new file with PSA, year, calendar day, and RAWS location GSI values.

From this output, we calculated the average GSI for each PSA. We used scatter plots of calendar day (x-axis) versus GSI (y-axis) for each year and PSA to evaluate GSI as an indicator of fire season start. On these plots, if calendar day is a perfect predictor of fire season start, the points for the individual years will lie in a vertical line. If GSI is a perfect predictor, the points will lie in a horizontal line. If the scatter is close to horizontal (vertical) then GSI (calendar day) is a more constant predictor. Our second condition, locational independence, requires that the scatter not only be near-horizontal, but that it scatter around the same value of GSI regardless of the PSA.

4. RESULTS

Figure 3(a-c) shows the results, separated into the Western, Central and Eastern groups. In the Western set, PSAs 2, 3, and 4 displayed several GSI values at the maximum value of 1 while PSA 1 showed a pattern at a GSI value of about 0.95 with one data point at 0.5. The three Central PSAs had nearly all GSI values at the upper limit. Only PSA 5 had one data point that was not at the maximum value. In the Eastern region, PSAs 8, 9 and 10 presented a varied distribution of GSI values between 0.3 and 1. All the points in PSA 12 and most of the data points in PSA 11 saturated at the upper threshold. For all the PSAs, the calendar day was spread over a range of about 150 days.

5. MODIFIED GSI

Upon examining the initial results and discussing them with our colleagues, we decided to make a few modifications to the GSI and repeat our calculations. We removed the upper and lower thresholds on the GSI, allowing them to fall below 0 or above 1, in order to reveal any broader pattern that may be present, a variant we called the open GSI. We also inverted the $iVPD$ term so that a higher metric corresponded to drier conditions (the dry GSI). We ran the test for each of these changes as well as a combined open-dry GSI.

6. MODIFIED GSI RESULTS

Figures 4 through 6 show the results for the open, dry, and open-dry variants, respectively. No variant showed the same relationship to start day for all 12 PSAs. Some appear to have positive slope, some negative, and some appear to have maxima or minima. The dry GSI variant was almost always at or near zero, simply inverting the problem seen in the original GSI. While only one slope (zero, a horizontal line) would actually indicate the variant qualifies as a good indicator of fire season start, the variations in scatter across

PSAs suggest that no simple transformation or adjustment of these variants will yield a formula that produces horizontal scatter for all PSAs, let alone scatter at approximately the same value of GSI-variant across PSAs.

7. CONCLUSION

The objective of this research project was to determine whether a climate-based index could be an effective means of indicating the start of the fire season. To do this, the index had to have the same or a similar value from year to year on the day the first large fire started, and that value had to be independent of geographic region. The index we tested, the Growing Season Index developed by Jolly et al. (2005), did not satisfy these conditions. In most of the areas considered, the GSI had saturated at a value of 1 and thus failed to provide useful information. Variants of the GSI, including an unbounded GSI (open), a GSI with an inverted $iVPD$ term (dry), and an open and dry GSI, were tested as well. None of these variants showed a consistent relationship between GSI and fire occurrence. From these results we conclude that the GSI in its present and slightly modified forms is not a viable indicator for the start of large fire season in the Pacific Northwest PSAs. It therefore cannot be a viable indicator for any broader region that includes the Pacific Northwest.

Clearly there are many reasons the GSI might not serve as a robust indicator of the start of fire season. These include some that are relatively obvious, such as the absence of wind, precipitation or snowpack in its computation. Others are less obvious, including the varying threshold sizes across the PSAs. It is possible that using a common size, or allowing the threshold in PSAs where the 95th percentile is smaller than 100 acres to equal the percentile value, would modify the results shown here. Inclusion of other factors or use of a modified threshold size might provide more usable results, but go beyond the evaluation of an existing index in the current operational context.

8. REFERENCES

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Parrish, D., D. Jović, E. Rogers, E.H. Berbery, E. Kalnay, G. Manikin`, H. Li, J. Woollen, K. Mitchell, M.B. Ek, P.C. Shafran, R. Grumbine, W. Higgins, W. Shi, W. Ebisuzaki, Y. Lin, Y. Fan, F. Mesinger, G. Dimego, 2006: North American regional reanalysis. *Bulletin of the American Meteorological Society*, **87**, 343-360, 10.1175/BAMS-87-3-343.

Table 1. Lower threshold for "large" fire size as used by the Northwest Coordination Center for Predictive Service Areas.

PSA	Threshold Size (acres)
1	100
2	100
3	100
4	100
5	700
6	1,200
7	100
8	2,200
9	100
10	700
11	1,200
12	10,000

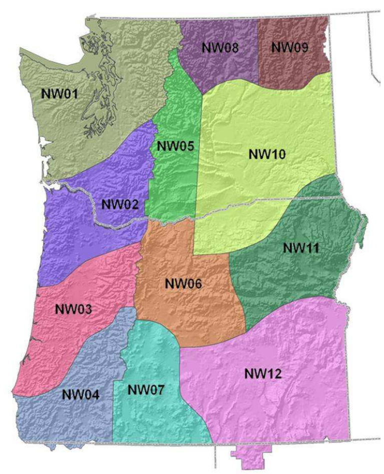

Figure 1. Predictive Service Areas (PSAs) used by the Northwest Coordination Center and in this study.

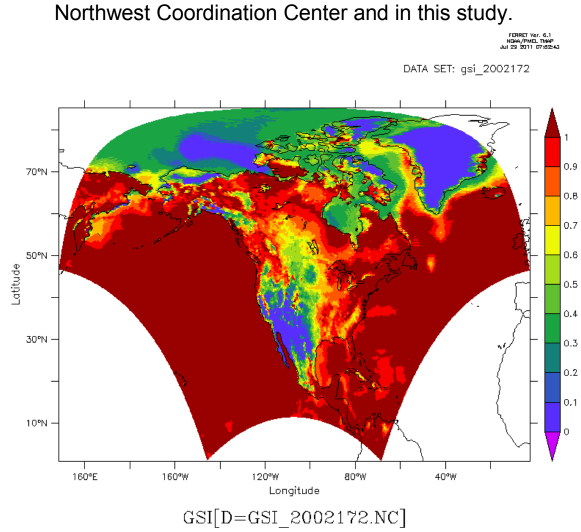

Figure 2. Example showing GSI values for the entire NARR domain for calendar day 172 (June 21) of 2002.

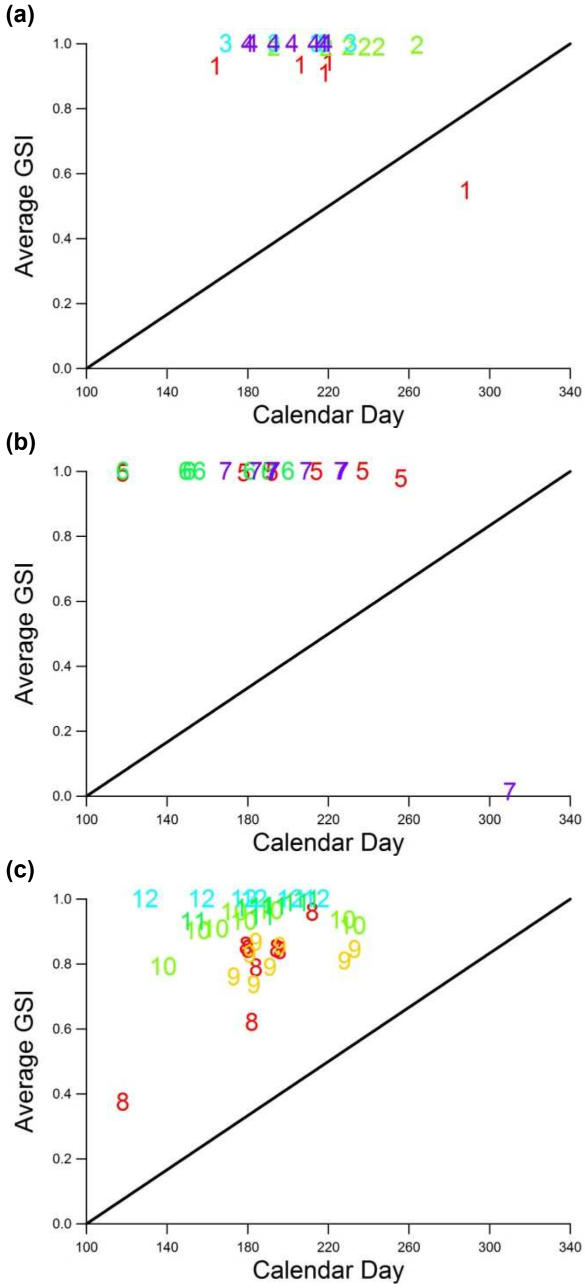

Figure 3. Scatter plots of GSI and calendar day for Western (a), Central (b) and Eastern (c) PSAs for 2002 through 2009. PSA numbers correspond to Fig. 1. If GSI (calendar day) is a strong indicator of the start of fire season, points for a PSA will lie on a horizontal (vertical) line.

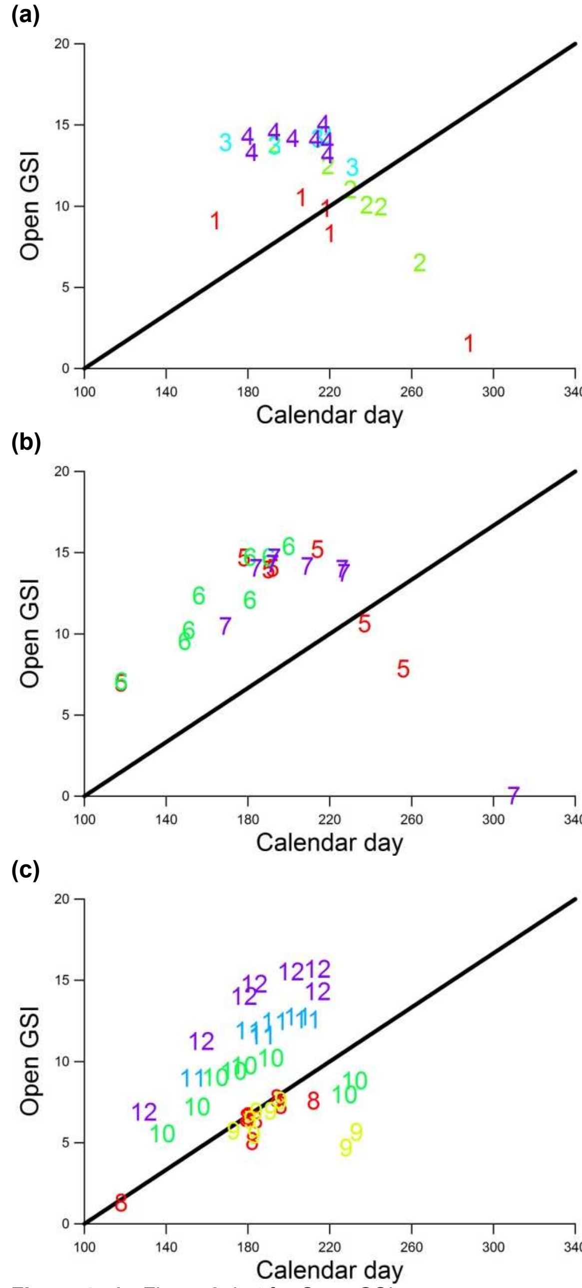

Figure 4. As Figure 3, but for Open GSI.

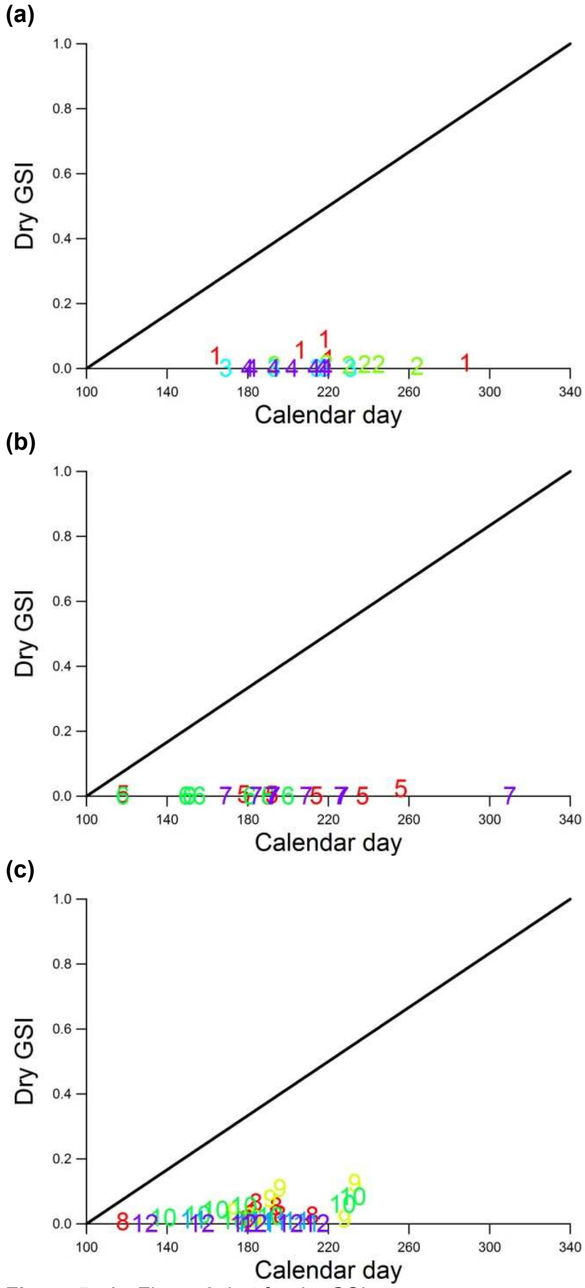

Figure 5. As Figure 3, but for dry GSI.

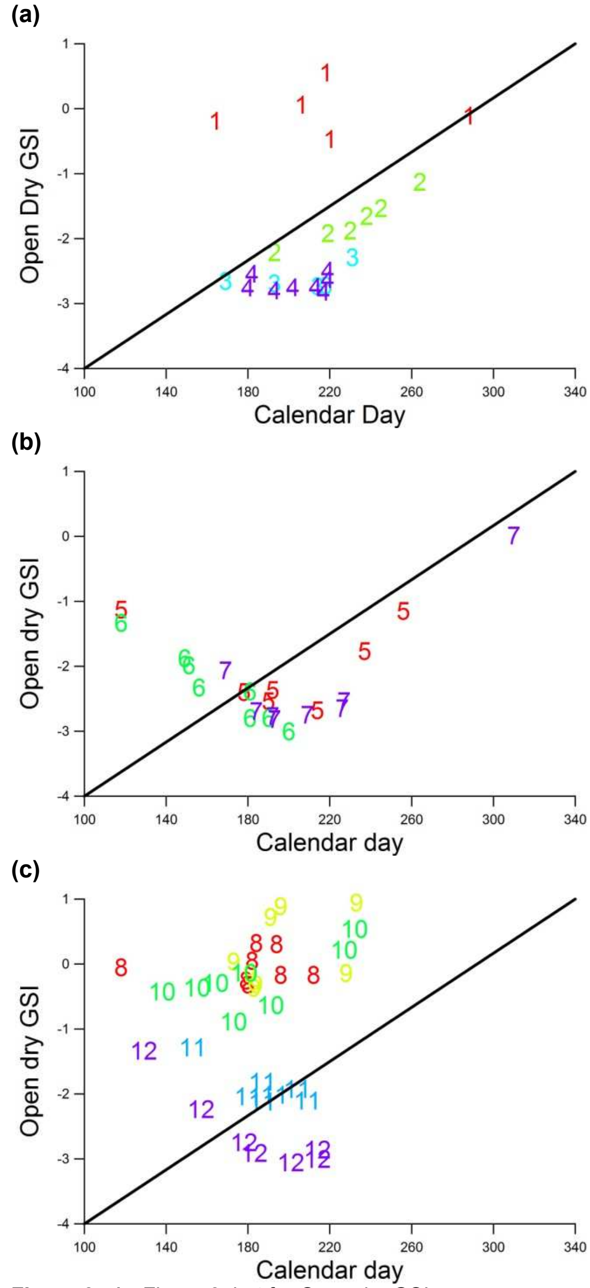

Figure 6. As Figure 3, but for Open dry GSI.