A mechanistic, weather-driven greenness model for the US National Fire Danger Rating System (NFDRS)

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Abstract

The US National Fire Danger Rating System generates daily estimates of fire potential throughout the United States. A key component of this system is the condition of live vegetation. Currently, there are no objective methods for determining vegetation condition. Inter-annual climatic variability causes the onset of spring green-up and fall leaf senescence to vary substantially from year-to-year. Therefore, methods used to assess live vegetation condition must be robust to these climatic changes. In addition, even adequate observations would not provide a means by which to project future changes in greenness as a result of climate change. We present a generalized model for determining live vegetation greenness that is driven by simple weather data and can adequately predict vegetation conditions over a wide range of climates. The model shows good agreement when compared to both field-observed and satellite-observed data. We show how the model can be coupled with daily, near real-time, gridded surface meteorology to continually assess the condition of live vegetation across a landscape. This model will allow us to both monitor current conditions and to assess changes in fire potential imposed by novel future climates.

Science and Technology Summary

The US National Fire Danger Rating System (NFDRS) assesses fire potential across the continental United States and Alaska. A key component of this system is the greenness condition of live vegetation (Deeming et al. 1977). The model assesses the moisture content of live vegetation with user-defined greenup and frost dates. Although the original system worked well in the west, it failed to adequately predict fire potential in the eastern US. In 1988, the system was revised to improve performance in the east and part of this revision was the addition of the 'greenness factor', a way for users to continuously modify the condition of live vegetation to better depict seasonal fire potential (Burgan 1988). Currently, both the 1978 and 1988 systems are used in various places throughout the US and both systems require user intervention to establish either the greenup date or greenness factor. There are no methods to mechanistically determine these conditions from prevailing weather conditions.

Here, we present a simple, weather-driven model that can be used to assess the greenness condition of live vegetation and we show that this metric can be used to derive greenup dates and greenness conditions from available data. The model uses variables that are key drivers of plant ecophysiological processes and are thus more meaningful than empirical, correlative models. There are three main environmental constraints of plant growth and they are: low temperatures, high evaporative demand (drought stress) and short daylengths. We chose three variables that represent these constraints and that are easily measurable with both standard weather observations and fire weather observations. We developed indicators for each of three variables that expressed the relative daily constraint of that variable on plant processes. The product of these three indicators forms a single metric that quantifies to aggregate limiting effect of low temperatures, high evaporative demand and short days on plant processes and is called the Growing Season Index (GSI) (Jolly et al. 2005).

We tested two components of the model that are comparable to the values that are needed by NFDRS. The first component is whether or not the model can adequately predict greenup dates from available weather data. To test this, we used phenological observations from Harvard Forest. Leaf onset dates were estimated across 33 native species for multiple years. This gives us the opportunity to examine the robustness of model predictions to inter-annual weather variability. We drove the model with data estimated using DAYMET (Thornton et al. 1997) for years where both phenological observations and weather data were available. Greenup date was determined as the date when GSI exceeded 0.5 during the beginning of the growing season. Model predictions and observations for greenup are given in Table 1 and predictions and observations for leaf senescence are given in Table 2. On average, the model predicted greenup date to within 3.38 days and leaf senescence date to within 2.29 days.

Observed Average Onset Date	Predicted Onset Date	Absolute Difference
4/28/1990	5/1/1990	3
4/16/1991	4/24/1991	8
5/1/1992	5/6/1992	5
4/24/1993	4/25/1993	1
4/28/1994	4/30/1994	2
5/3/1995	5/3/1995	0
4/25/1996	5/2/1996	7
5/5/1997	5/6/1997	1
	MAE (days)	3.38

Table 1 - Differences between model predicted and field observed average leaf onset dates for Harvard Forests from 1990 to 1997. The Mean Absolute Error (MAE) of the model predictions was 3.38 days. From Jolly et al. (2005).

Observed Average Offset Date	Predicted Offset Date	Absolute Difference
10/23/1991	10/25/1991	2
10/23/1992	10/20/1992	3
10/18/1993	10/19/1993	1
10/21/1994	10/20/1994	1
10/24/1995	10/28/1995	4
10/21/1996	10/22/1996	1
10/28/1997	10/24/1997	4
	MAE (days)	2.29

Table 2 - Differences between model predicted and field observed average leaf offset dates for Harvard Forests from 1991 to 1997. The Mean Absolute Error (MAE) of the model predictions was 2.29 days. From Jolly et al. (2005).

We then tested the models ability to predict intra-annual variation in greenness conditions by comparing daily model results to a satellite-derived vegetation index. Satellite data are unique because they provide observed greenness conditions continuously throughout the year rather than a single, discrete greenup date. Thus, it represents the continuous response of vegetation to changing weather conditions, similar to the greenness factor in the 1988 NFDRS. Nine global sites were selected to represent a range of phenologically-different biomes. At least one site was selected per continent, excluding Antarctica, with additional sites selected to provide a range of biome types.

Figure 1 - Location of test sites, designated by the weather station identification provided by the World Meteorological Office (WMO).

Meteorological Data

We retrieved daily average temperature, minimum temperature and dewpoint temperature from the National Climate Data Center Global Summary of the Day for each site. Daily vapor pressure deficits were estimated for each site as the difference between saturation vapor pressure and actual vapor pressure estimated using average temperature and dewpoint temperature respectively with a standard relationship between temperature and vapor pressure. The daily photoperiod was estimated using site latitude and yearday.

Satellite Data

Normalized Difference Vegetation Indices (NDVI) were extracted from the NOAA/NASA Pathfinder AVHRR Land (PAL) global, 10-day, eight-kilometer resolution composite dataset. We selected the raster value closest to each site, based on latitude and longitude, and extracted an NDVI corresponding to the meterological dataset. PAL NDVI values were spatially-averaged to 0.25° and temporally filtered with a five composite period moving average to remove spurious increases and decreases in NDVI caused by atmospheric contamination.

Model Comparisons to Satellite-Derived NDVI

The correlations between model-predicted GSI values and satellite-derived NDVI values are shown in Table 3. Using the same model and the same parameters we were able to adequately predict the intra-annual dynamics of the vegetation canopy at all sites regardless of the dominant or co-dominant climatic controls at that site. There was a slight, but not marked, bias towards better predictions at temperate sites. The highest correlations were found in the high latitude forests, presumably because they are more purely temperature limited than other sites. However, correlations at the hydroperiodic sites were still very high, suggesting that the vapor pressure deficit control adequately depicts the intra-annual canopy dynamics in these regions.

Results of model comparison to NDVI and estimated Growing Season Index

WMOID	Location	Correlation Between GSI and NDVI
228870	Russia	0.939
443020	Mongolia	0.903
610360	Sahel	0.896
682260	Kalahari	0.742
701718	Alaska	0.986
726165	Harvard Forest	0.870
727730	Missoula	0.839
833620	Cerrado	0.868
943320	Australia	0.571

Table 3 - Correlations between composite period NDVI values and modeled GSI values averaged over the composite period for each of the nine test sites. All correlations were significant ($p < 0.01$).

We have presented a simple, meteorological data-based greenness model that can adequately predict the intra-annual dynamics of plant canopies at sites throughout the world using the same model logic and parameters with no *a priori* knowledge of the local vegetation or climate. The model is robust to interannual climatic variability and can provide both greenup dates and greenness conditions that are suitable for use in the US National Fire Danger Rating System. We have demonstrated that this model is flexible enough to predict greenness regardless of the factors that control phenology regionally. The model presented is simple and independent of any particular modeling framework and thus should be suitable for many global change applications.

References

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Biography

William M. Jolly received a Bachelor of Arts in Environmental Science from the University of Virginia in 2000 and a Doctorate of Philosophy from the University of Montana in 2004. He currently works as an Ecologist in the Fire Behavior Research Work Unit of the USDA Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory in Missoula, MT.

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