Modeling vegetation phenology for the assessment of present and future fire hazard potential

JFSP Project Number: 03-1-1-08

Final Report

15 March 2007

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Executive Summary

Live fuels are an important component of the wildland fuel complex but no method exists to describe and quantify their seasonality across large areas. Existing methods that use satellite data are only useful for monitoring current live vegetation conditions and do not provide a means to estimate future conditions. This work is the first of its kind to develop a simple and general weather driven index to assess the condition of live vegetation across the landscape. We have developed a model that can be applied to any area of interest without regard to the existing vegetation of that location. It describes the seasonal constraint of water, temperature and light limits by a simple, easily interpreted index. Finally, we have used the model to predict the regional impacts of climate change on live fuel growing conditions. Climatic changes are expected to create novel growing conditions for live vegetation and may pose problems for future management.

Summary of Findings to Date

Existing methods of mapping live fuel moisture from satellite data are not adequate for fire management activities.

- Satellite-derived live fuel metrics are insufficient to provide useful guidance in determining live fuel conditions such as green-up and curing. Passive remote sensing of live fuel conditions is difficult due to problems with cloud cover, aerosols and other particulates which inhibit data collection. These problems are generally resolved through temporal compositing of the satellite data over days or weeks. We found that standard MODIS products were not sufficiently timely to provide metrics to decisions makers within a useful timeframe. We observed similar problems with AVHRR based indices where cloud cover over very large geographic areas were common and composite periods often had to be increased to three weeks to effectively reduce cloud cover problems. Our discussion with field users indicated that they desired a reliable product every two weeks or less. This drove many of our decisions throughout the rest of the project.

Simple metrics of live fuel conditions can be derived from weather data.

- Although we found that satellite data were insufficient to meet the needs of managers of the National Fire Danger Rating System, we were successful in developing a simple, weather driven model of live vegetation condition that can be run using both current weather data and future climate scenarios. This model can adequate predict plant seasonal cycles across the full range of ecosystems found throughout the world (Jolly et al. 2005b). The model was tested at site throughout the world (Figure 3) and it was able to adequately predict changes in leaf cover at these sites (Figure 4). This simple metrics is called the Growing Season Index (GSI) and it quantifies the cumulative effects of temperature, water and light limits on plant physiological processes. This model compares well with satellite-observed Normalized Difference Vegetation Index values and this thus be considered as a weather-driven surrogate of NDVI. We also used this model to map the influence of an extreme temperature event in the Swiss Alps and the model was able to mimic observed differences in tree growth across a large elevation gradient (Jolly et al. 2006) (Figure 1 and Figure 2).

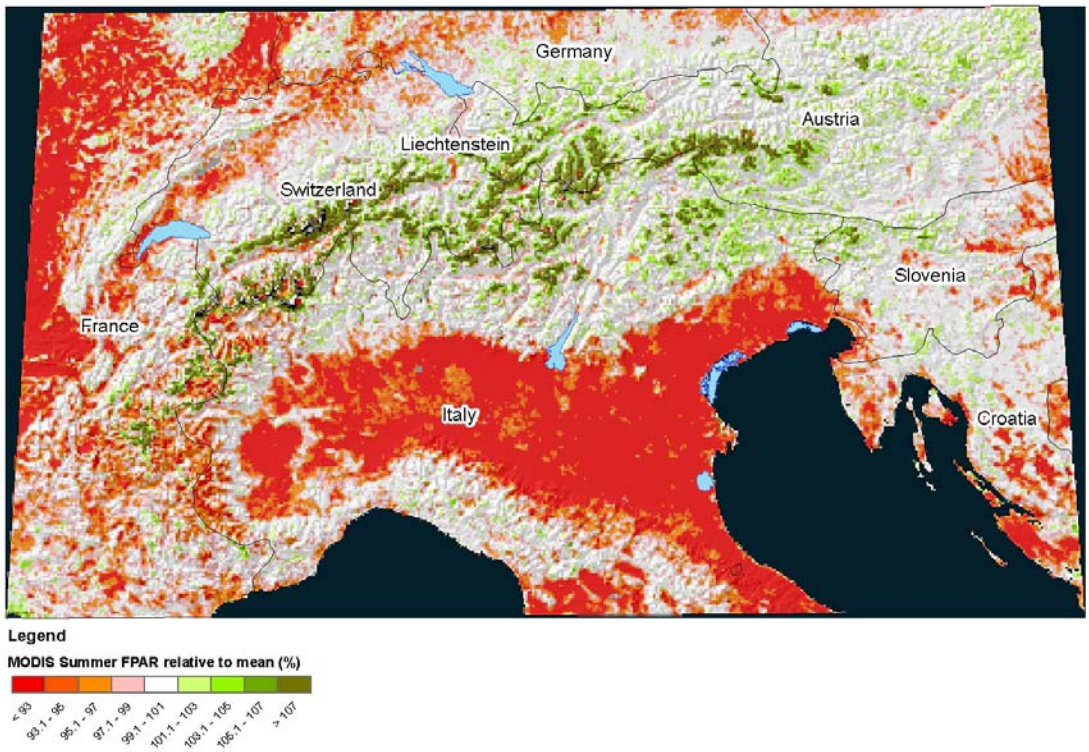

Figure 1 – Summer 2003 fraction of absorbed photosynthetically active radiation (FPAR) expressed as a proportion of the five year mean as calculated by NASA's Earth Observing System with data from the Terra/MODIS satellite. Red areas show where FPAR was less in 2003 as compared to 2002, green areas show where FPAR was higher in 2003 and white areas show places where values were little changed between the two years.

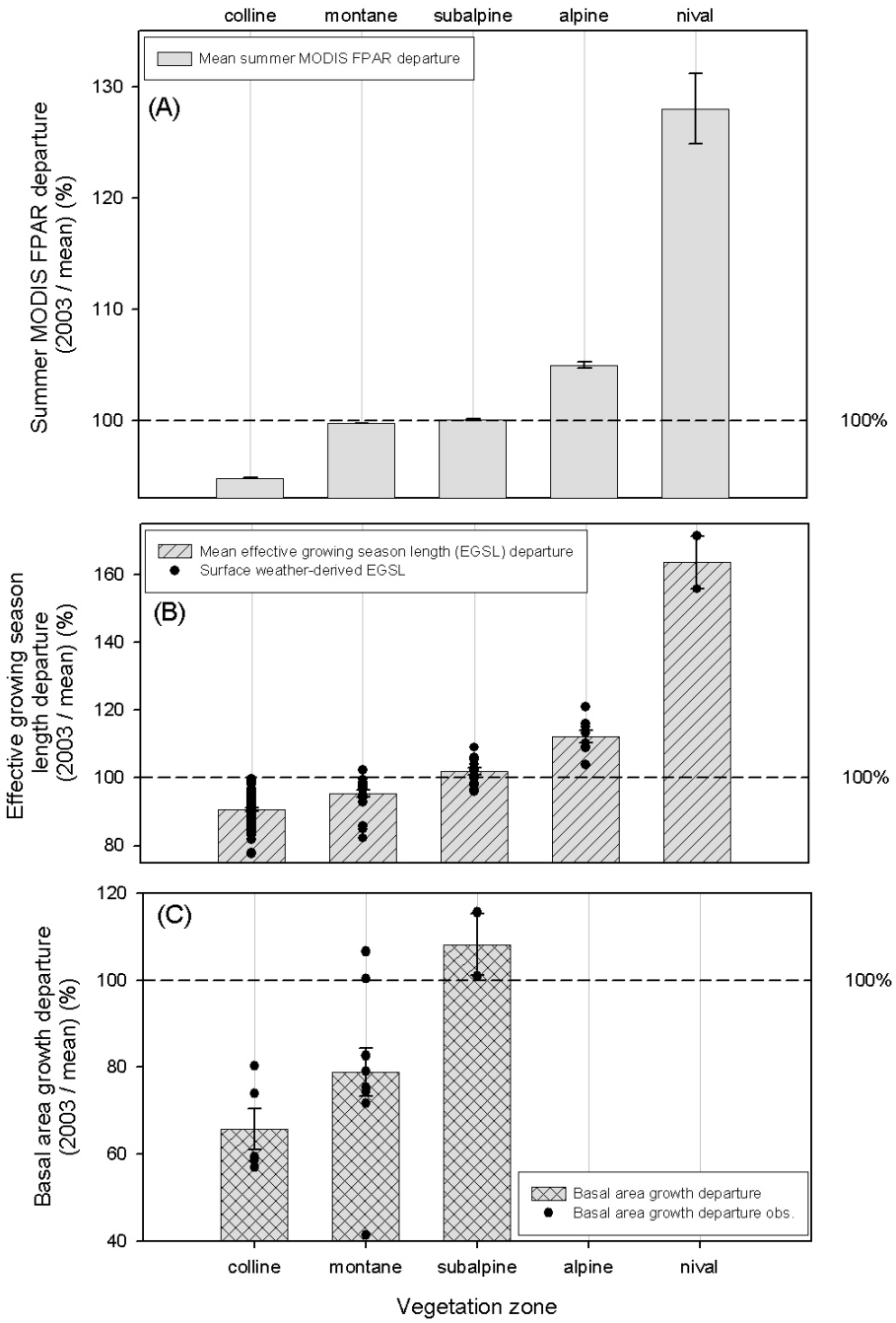

Figure 2 – (A) Mean and standard error of 2003 FPAR expressed as a percentage of the five year mean over the five Alpine vegetation zones. These values were calculated using a moderate resolution elevation map and the data shown in Figure 1.
(B) Zonal mean changes in effective growing season lengths (EGSL) between 2003 and the ten year mean estimated at 150 weather stations. Individual data values are plotted as closed circles along with the mean and standard error.
(C) Zonal mean basal area growth in 2003 expressed a percentage of the eight year mean for each species present at the fifteen forest monitoring sites. Individual data values are plotted as closed circles along with the mean and standard error. For all panels, values below 100% show areas where that quantity was reduced in 2003 relative to the mean, values near 100% signifies quantities where 2003 values were very close to the long-term mean and values above 100% indicates areas where those quantities were higher in 2003 relative to the mean.

Figure 3 - Map of test sites of the Growing Season Index (GSI) foliar phenology model. Sites were selected to represent the full range of phenological strategies.

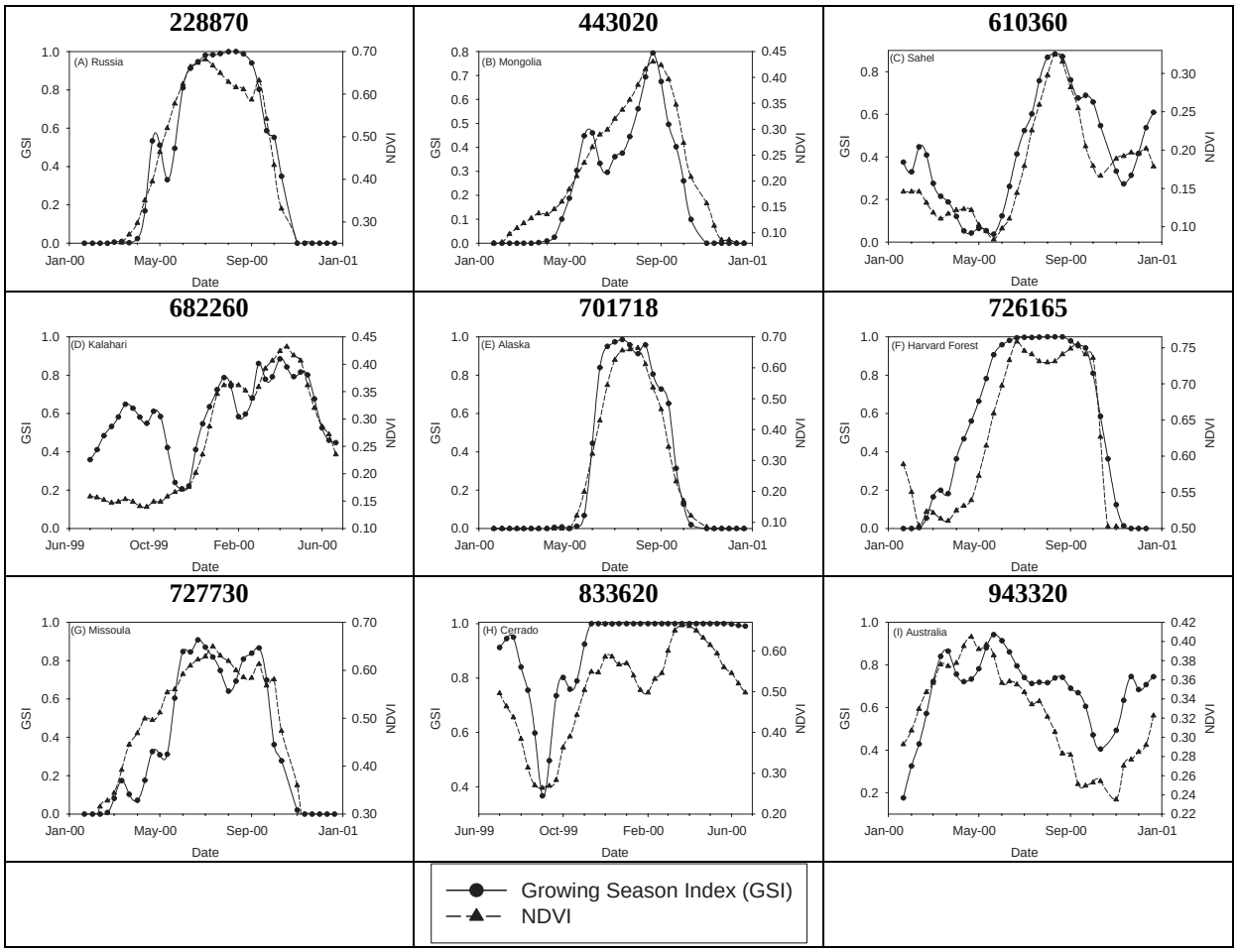

Figure 4 - Comparisons of the Growing Season Index (GSI) calculated from surface weather data to the satellite-derived Normalized Difference Vegetation Index (NDVI). The model is able to adequately reproduce the seasonality of vegetation across a large range of biome types.

The Growing Season Index can be used to derive green-up dates across the United States

- GSI values were compared to green-up dates from the Weather Information Management System (WIMS) across a range of sites throughout the Unites States including Alaska and Hawaii. We found that the index predicted the user-entered green-up dates within 10 days throughout the study area (Figure 5). We also tested the models ability to predict the interannual variability of leaf out and leaf senescence at the Harvard Experimental Forest and we found that it predicted greenup dates and senescence dates within 3 days and 2 days respectively.

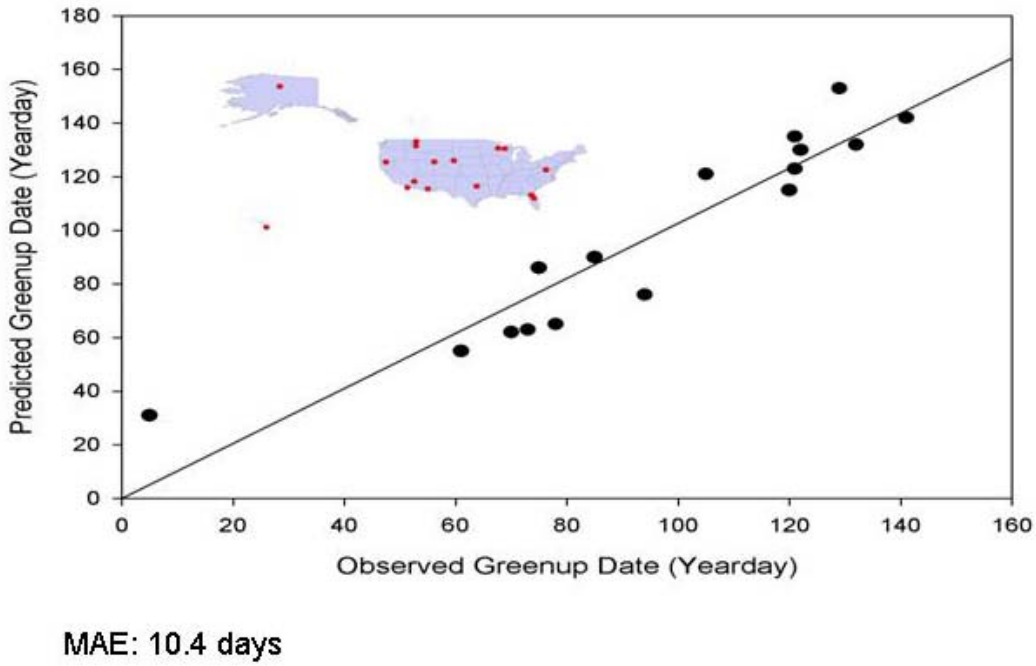

Figure 5 - Comparison of user-defined green-up dates from the Weather Information Management System (WIMS) and the Growing Season Index calculated at each location.

Weather data can be interpolated to map live fuel conditions across the landscape.

- Estimating live fuel conditions across the landscape is only possible if model inputs can be spatially interpolated with reasonable degrees of accuracy. We developed methods to take point-source surface weather observations from multiple sources and generate continuous surfaces of weather data which are suitable for running models spatially across large geographic areas (Jolly et al. 2005a) (Figure 6). This surface interpolation model can then be run in near real-time to provide inputs to the generalized phenology model (Figure 7). This gives managers the potential to assess live fuel conditions over their region of interest. The system was developed to be scalable to any resolution or region of interest. It generates estimates of maximum temperature, minimum temperature, vapor pressure deficit, daylength, precipitation amount and duration, minimum humidity and maximum humidity.

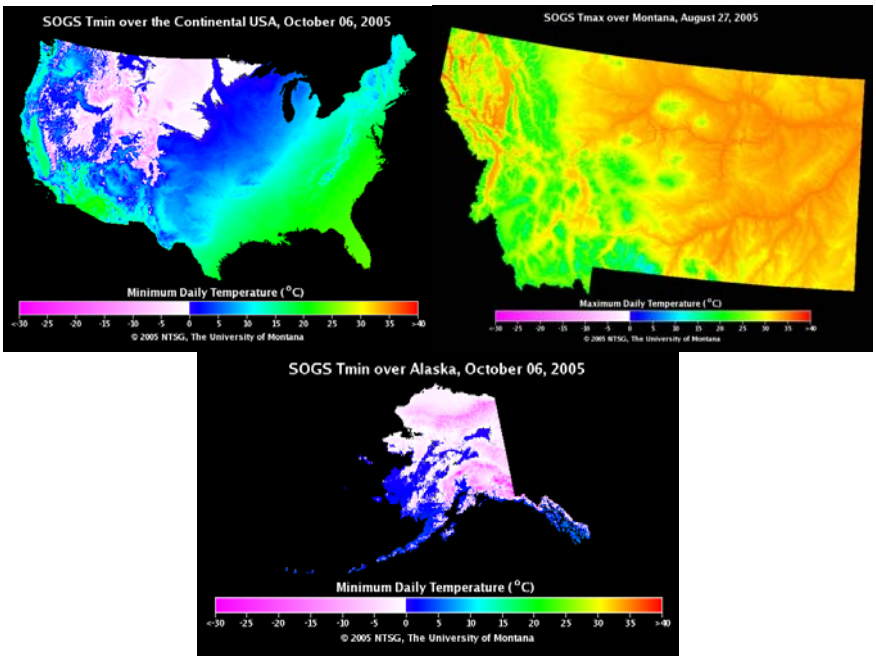

Figure 6 - Example outputs from the surface weather interpolation system.

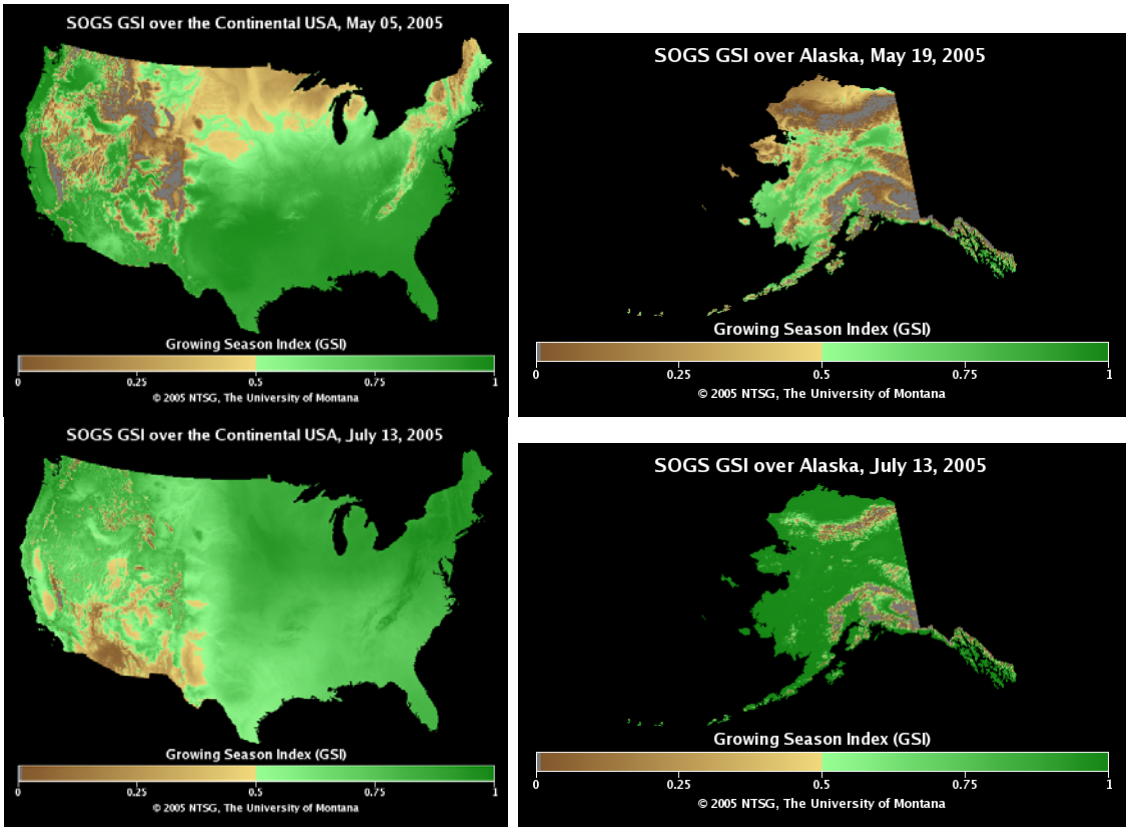

Figure 7 - Example outputs from the weather-driven phenology model for a typical spring and summer for the continental United States and Alaska. Green areas show locations where green-up has already occured and brown areas show indicate either pre-greenup conditions or curing as a function of water stress

The Growing Season Index can be used to map local and regional climate constraints on foliar phenology.

- We used our simple phenology model to graphically display the seasonal constraints of weather on plant processes (Figure 8). These graphs show areas were constraints are interactive during certain times of the year and it also display the importance of considering temperature, water and light limits concurrently to increase our understanding of the link between climate and phenology .We were able to use the simple, bioclimatic index to create the first ever global map of the regional constraints of climate on foliar phenology (Figure 9). This map is useful in understanding the potential impacts of climate change on plant processes.

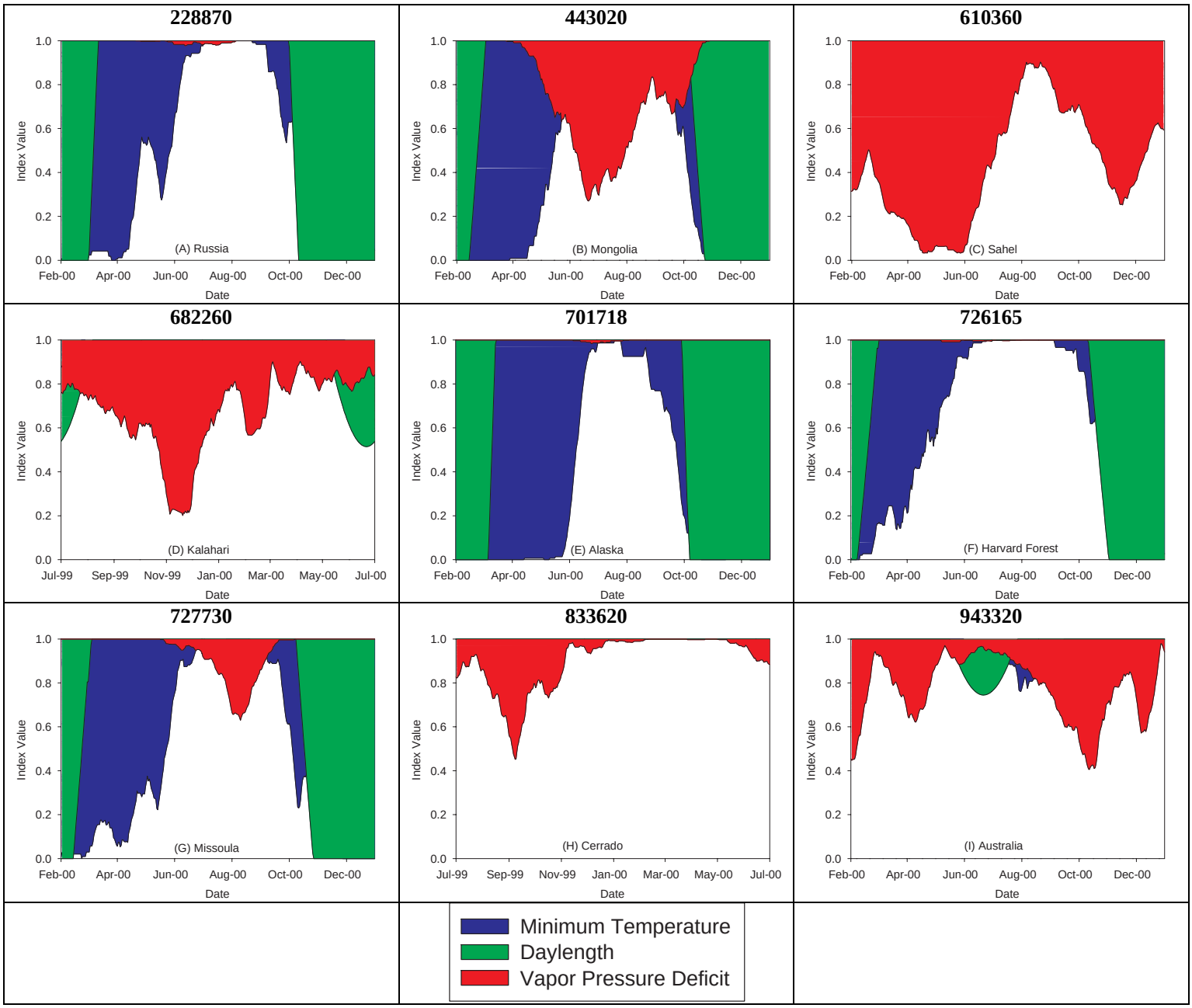

Figure 8 - Seasonal phenological climatic limits of each of the nine test sites. Areas in red show times of the year where water limits plant processes, areas in blue show times when temperatures limit activity and green areas indicate light limits.

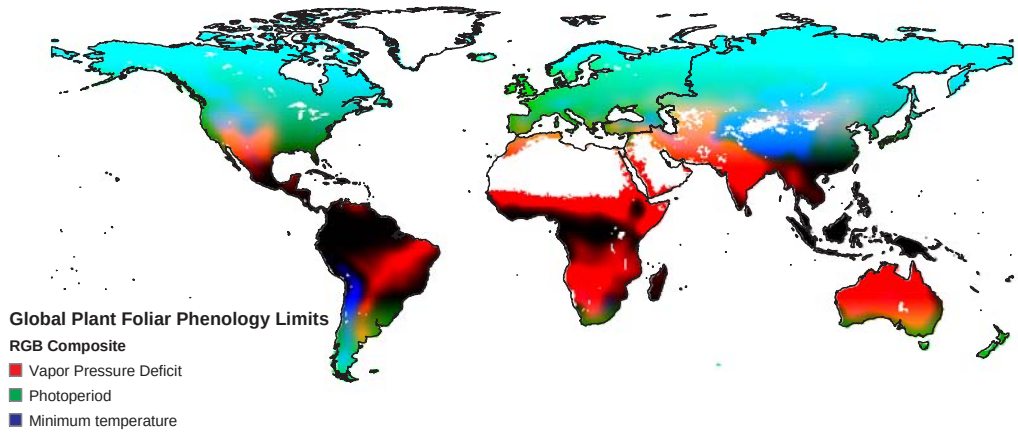

Figure 9 - Regional constraints of climate on foliar phenology.

The Growing Season Index can be used to derive greenness factors for the 1988 version of the National Fire Danger Rating System

- One of the benefits of a model like the Growing Season Index is that is quantifies the changes in live fuel conditions throughout the year, rather than at discrete points such as the time of leaf out and leaf senescence. This allows us to examine the seasonal changes of live fuels and to quantify these numbers into greenness factors that can be used in the 1988 version of the National Fire Danger Rating System (Figure 10).

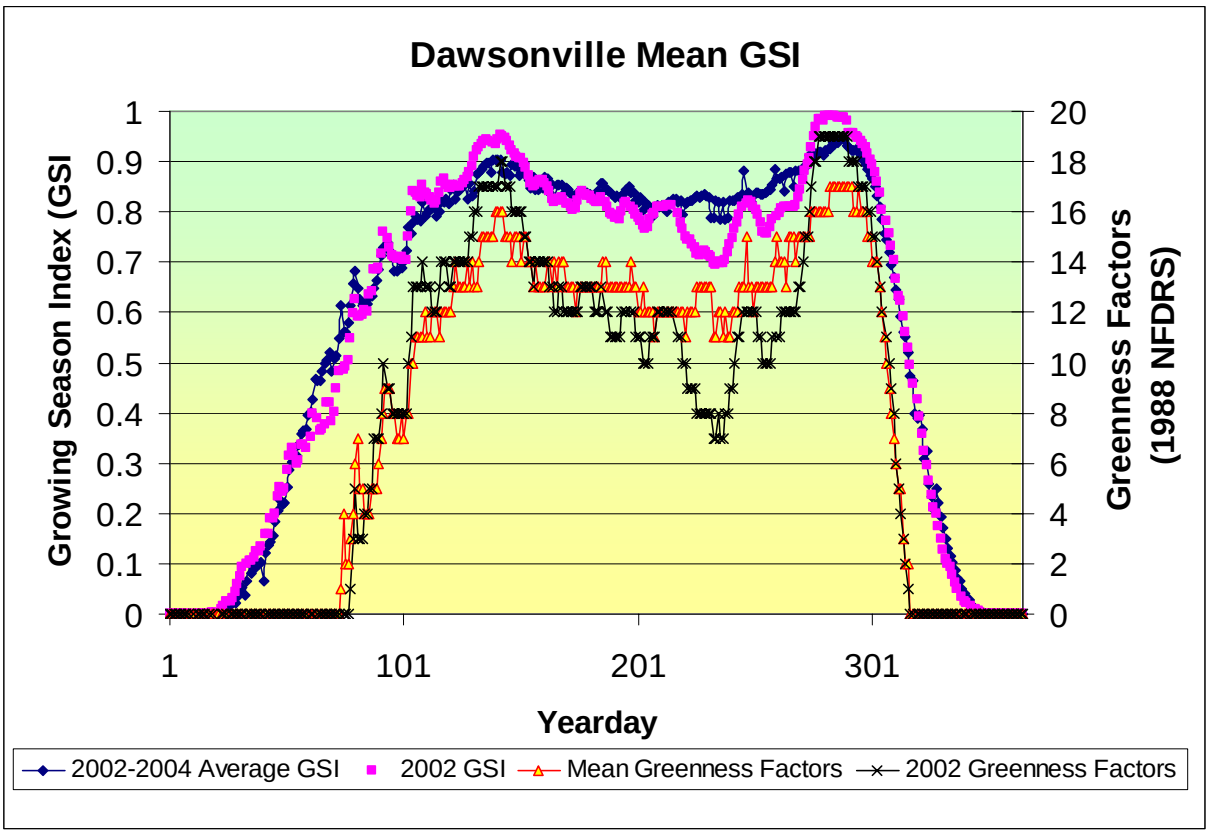

Figure 10 - Example of deriving greenness factors for the 1988 version of the National Fire Danger Rating System for a weather station in Georgia.

Climatic changes will create novel growing conditions for live fuels.

- We used our phenology model to assess the impacts of climatic changes on live fuel growing conditions and we found that there future climatic may promote novel growing conditions for plants throughout the United States. Much of the current research in foliar phenology has focused on the changes in plant leaf display periods and they have shown that these leaf display periods have increased across much of the Northern hemisphere. However, they do not attempt to incorporate the effects of changes in evaporative demand that are likely to occur concurrently with changes in temperature. We utilized the outputs from four general circulation models that used both the A2 and B2 emissions scenarios to assess future climates through the year 2100 (Figure 11 and Figure 12). We found that although the temperature limited growing season increased as expected, concurrent water limitations either mitigated the benefits of these growing season length changes or they actually shortened the growing season where bioclimatic conditions were adequate. These results were summarized by geographic area to provide regions with a general expectation of future plant growing conditions (Figure 14 and Figure 15). Some geographic areas, particularly the Southern Area, show expected temperature-limited growing season increases but large declines in effective growing season length when temperature and water limits are considered concurrently. This indicates that climate change is expected to increase summertime aridity. Under these drier conditions, the possibility for more summertime fire in the East

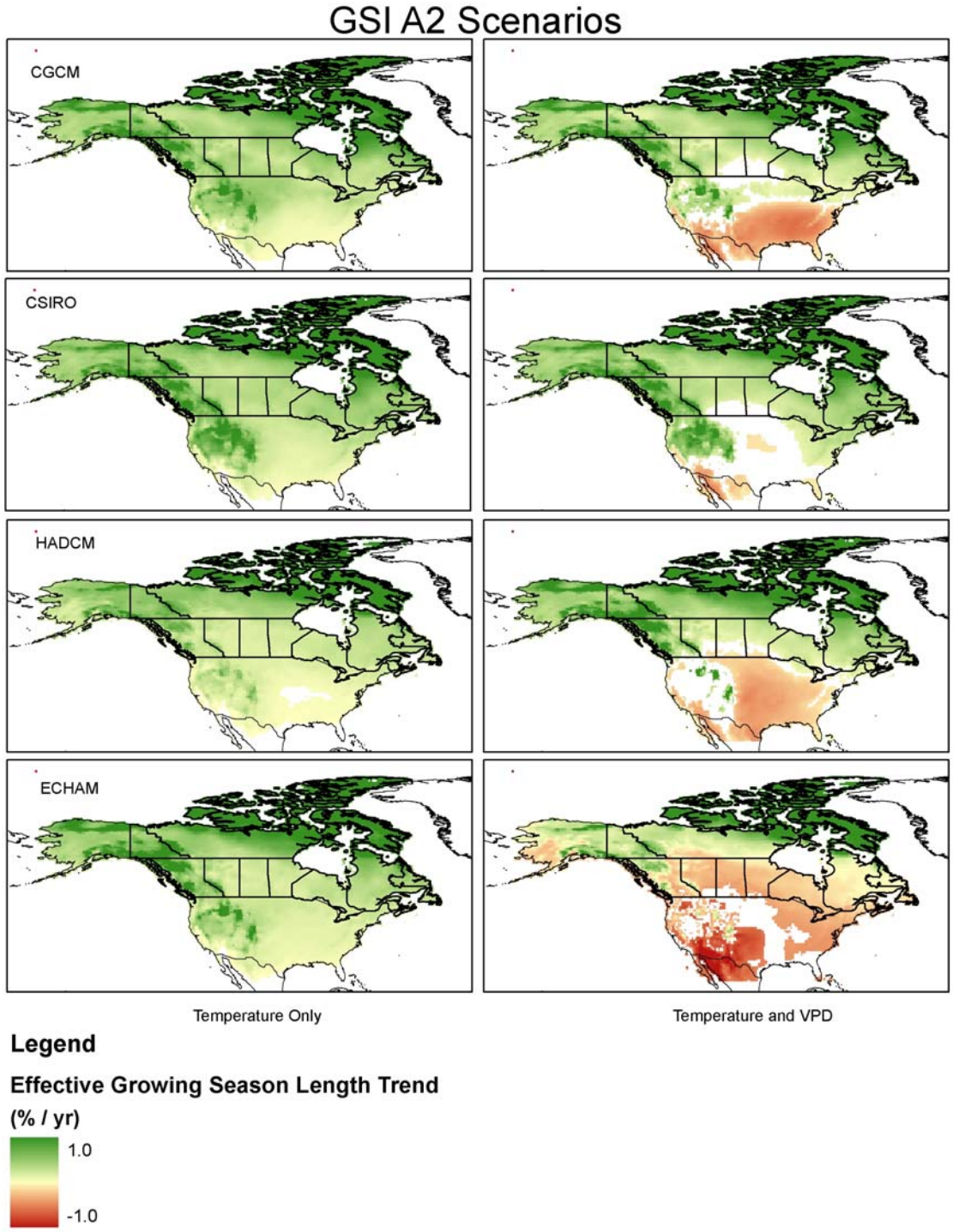

Figure 11 - Climate change scenarios for four climate change models using the A2 emissions scenario. Panels on the left show the change in growing season length when only temperature is considered and panels on the right show both temperature and water limits combined. Green areas indicate increases in the effective growing season length and red areas show declines in effective growing season length.

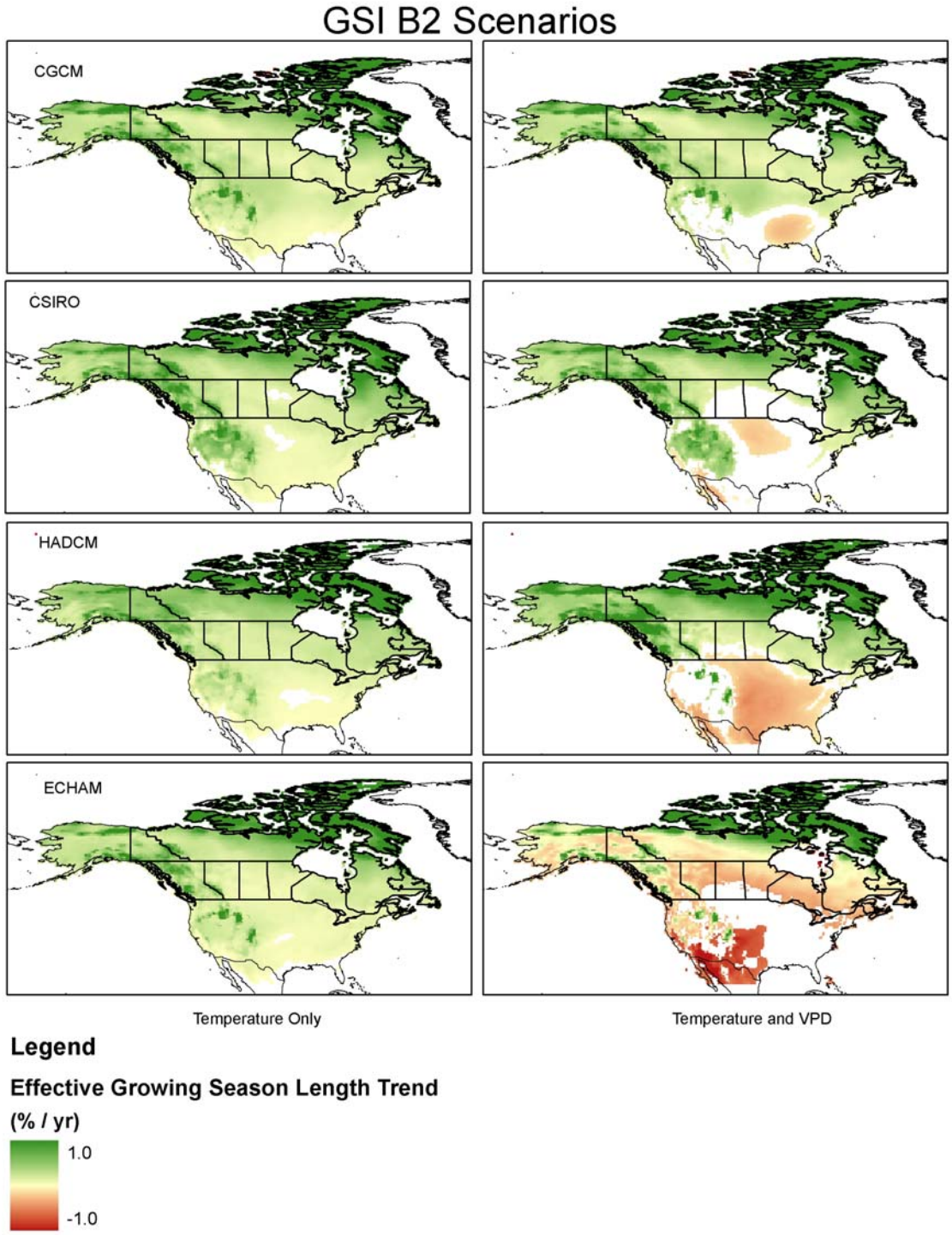

Figure 12 - Climate change scenarios for four climate change models using the B2 emissions scenario. Panels on the left show the change in growing season length when only temperature is considered and panels on the right show both temperature and water limits combined. Green areas indicate increases in the effective growing season length and red areas show declines in effective growing season length.

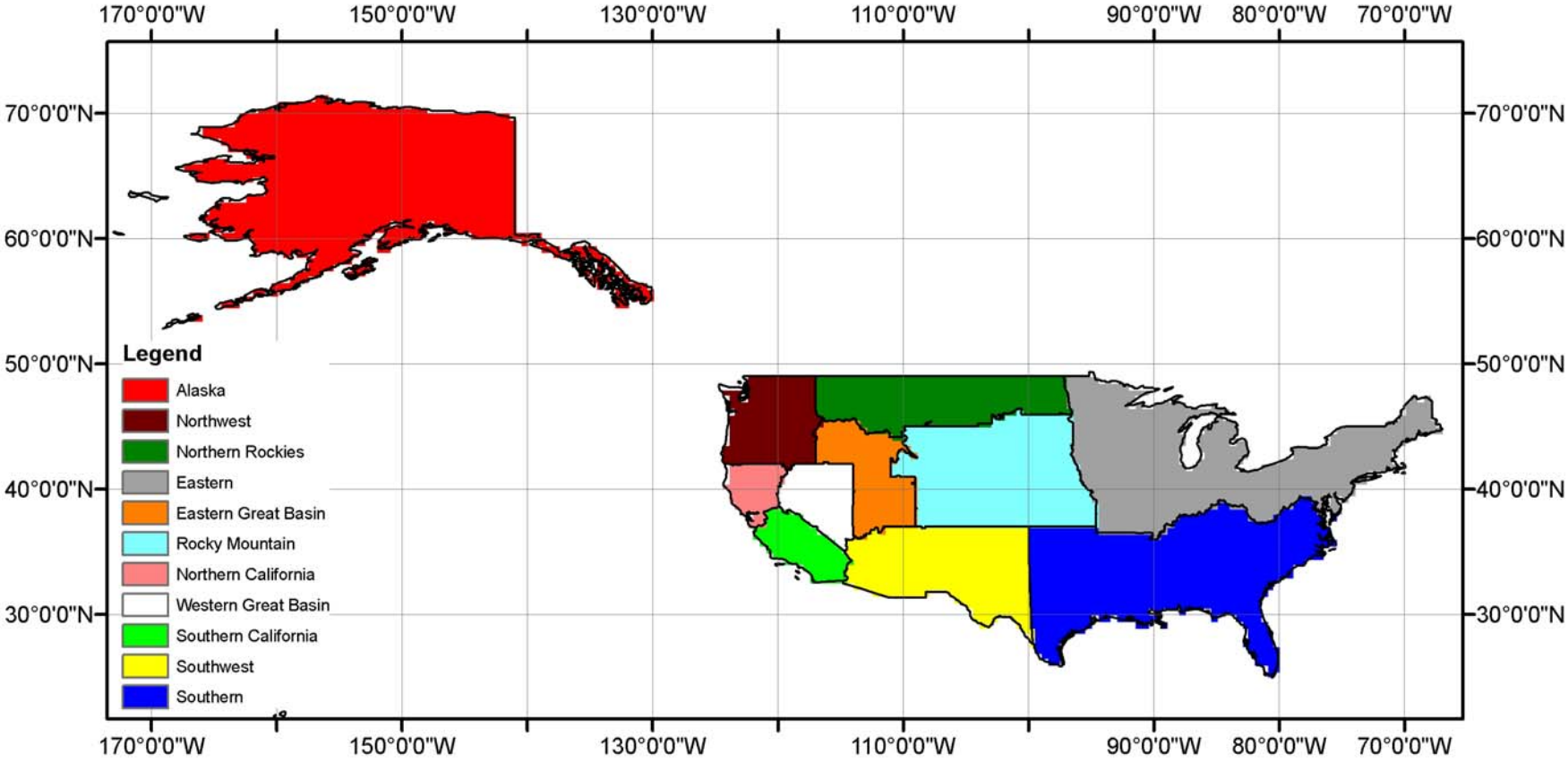

Figure 13 - Climate change zonal analysis map.

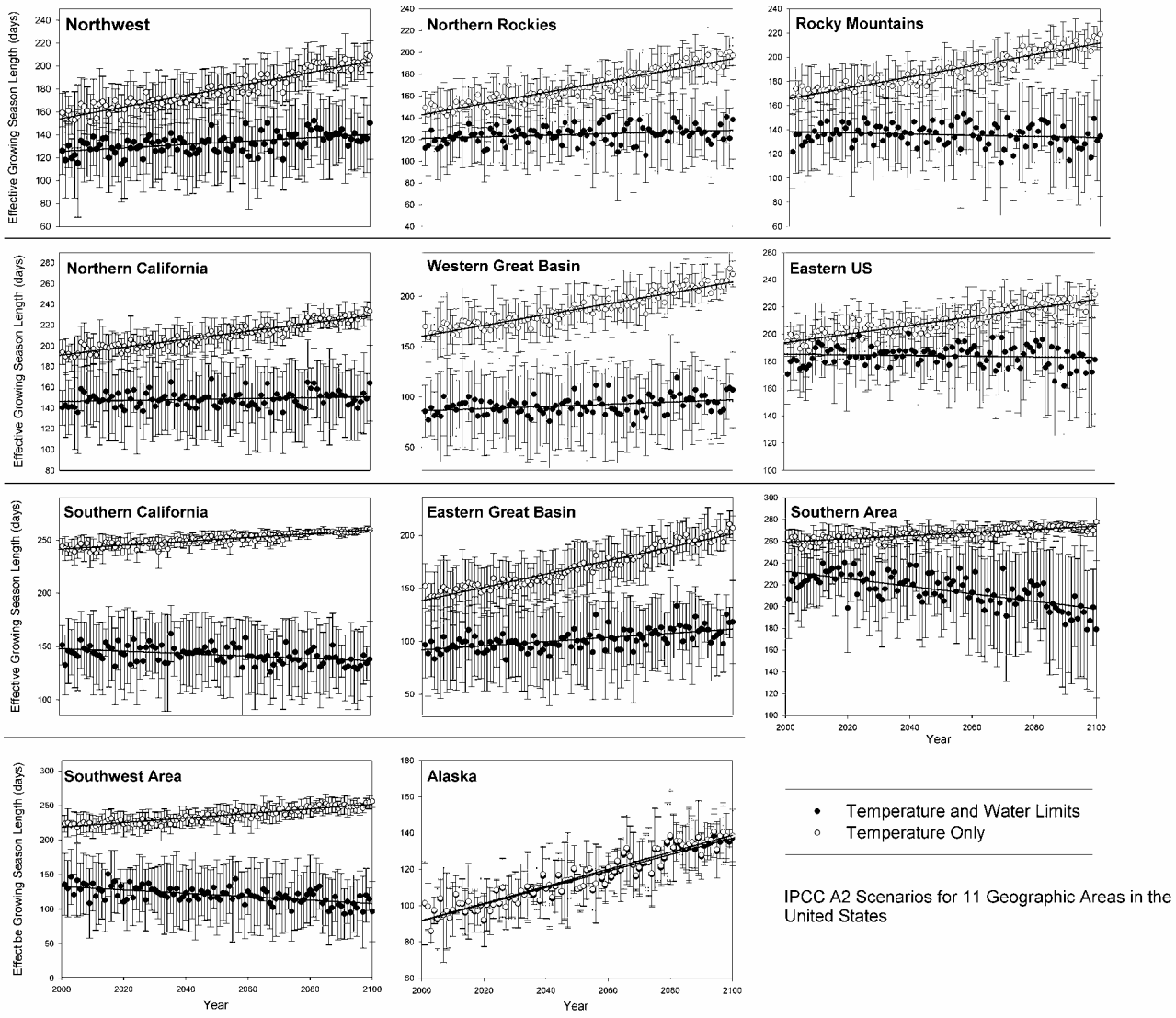

Figure 14 - Climate change summaries for each of the 11 Geographic Areas of the Unites States for the A2 emissions scenario. Open circles show the temperature-only changes in effective growing season length and close circles show the combined impact of temperature and evaporative demand limit on live fuels.

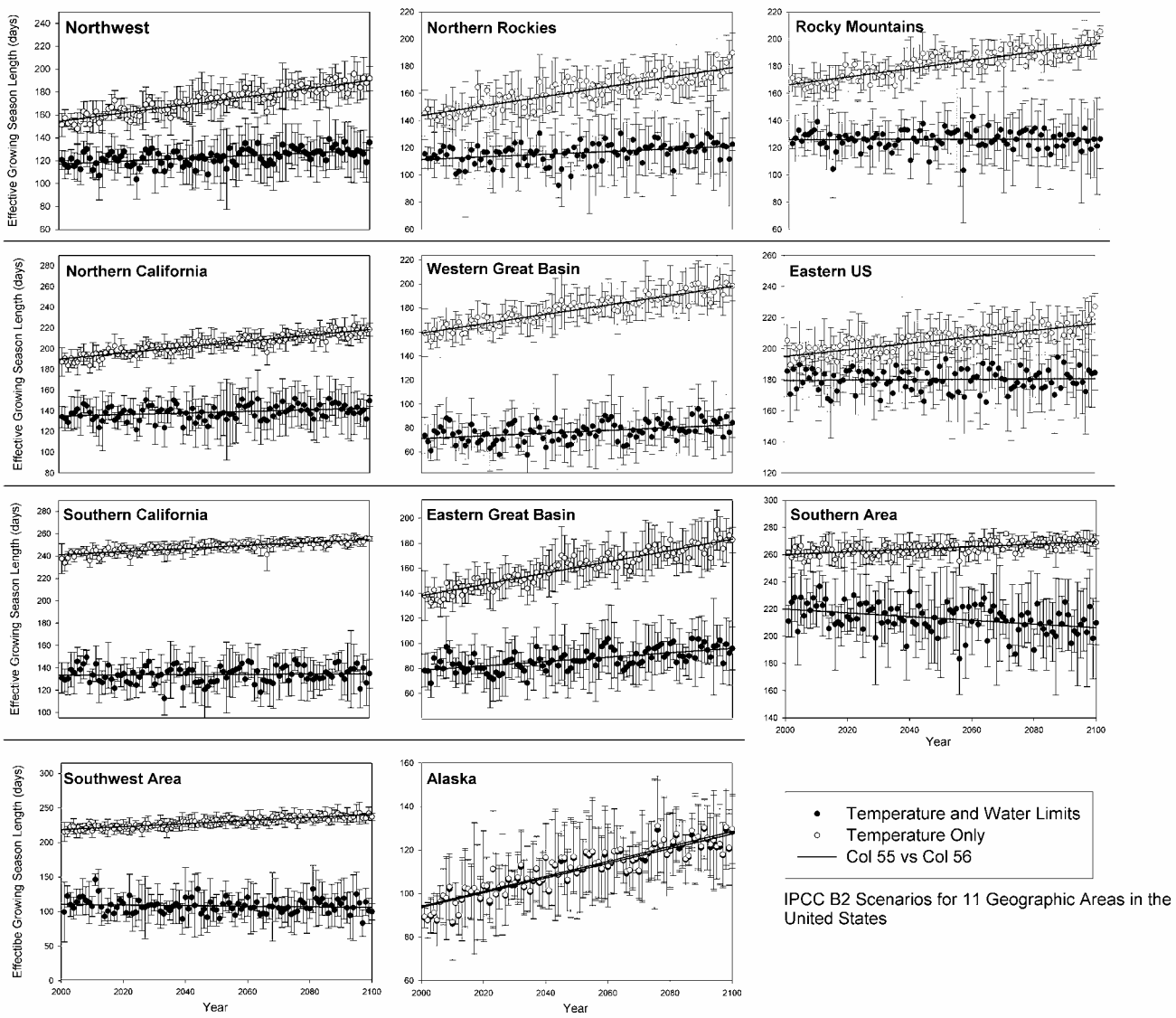

Figure 15 - Climate change summaries for each of the 11 Geographic Areas of the Unites States for the A2 emissions scenario. Open circles show the temperature-only changes in effective growing season length and close circles show the combined impact of temperature and evaporative demand limit on live fuels.

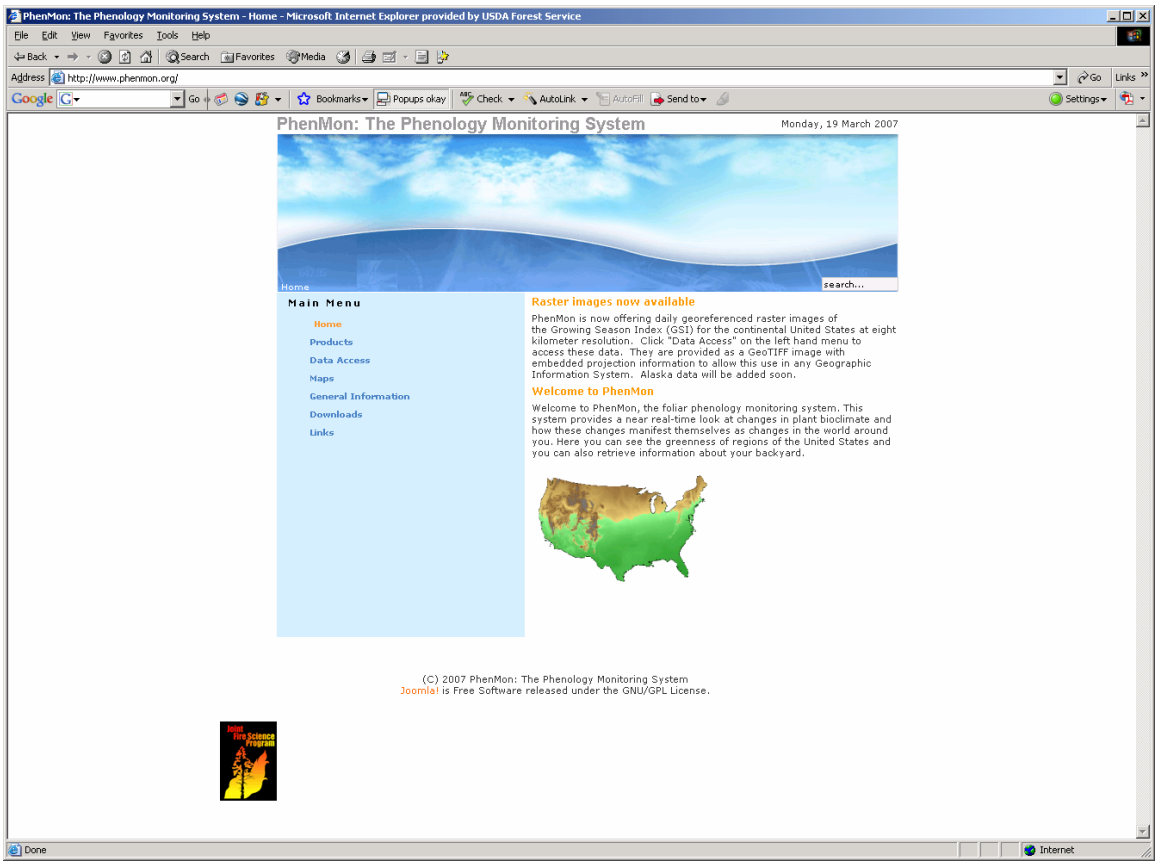

Figure 16 - Homepage of the Phenology Monitoring System (PhenMon) (http://www.phenmon.org).

Technology transfer efforts are the key to success.

- We undertook extensive technology transfer efforts to describe our findings to managers in the field and to make the results of our efforts regularly available to decisions makers across the country. As such, the Growing Season Index has become a well-established metric of live fuel conditions across the country. We worked closely with fire danger experts in nearly every geographic area of the United States to develop an understanding of the utility of this metric to their fire business. As such, this tool is now used regularly in several of these geographic areas to quantify the state of live fuels seasonally. We constructed long-term climatologies of the Growing Season Index for many of the Geographic Area Coordindation Centers and we worked closely with them to help them interpret these values for their area. We also developed an Excel-based software tool to simplify the calculation of this index for fire weather stations. Finally, we created a website that provides daily access to the Growing Season Index across the continental United States and Alaska (Figure 16). It also provides access to regional subsets of the Growing Season Index across each of the Geographic Areas (Figure 17). This website integrates web mapping technology to allow users to define their region of interest (Figure 18).

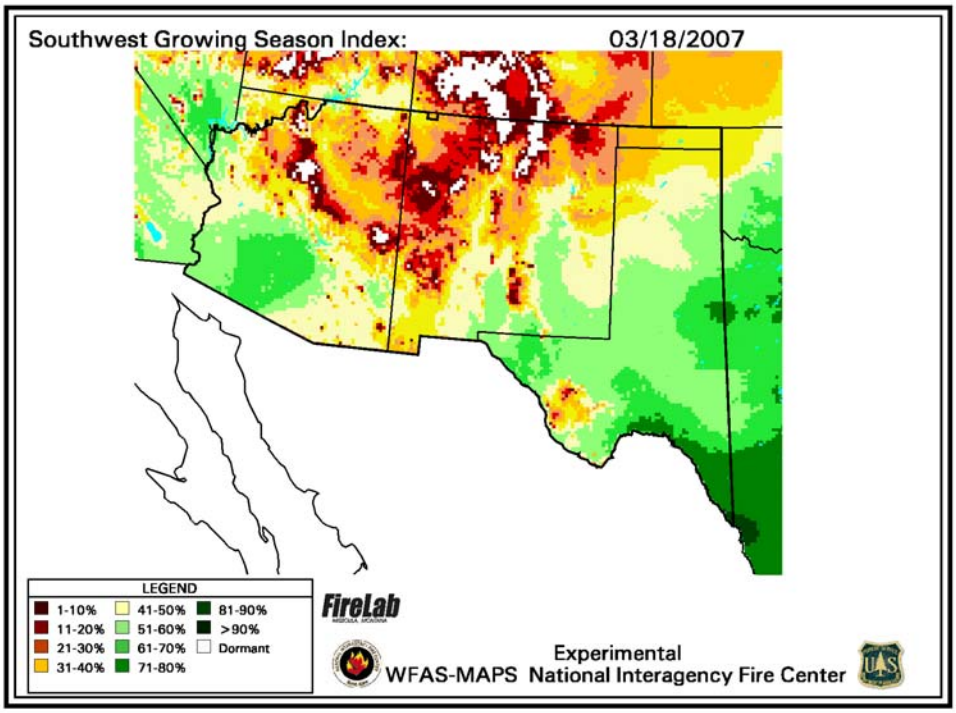

Figure 17 - Example regional subset of the Growing Season Index for the Southwest Area Coordination Center domain.

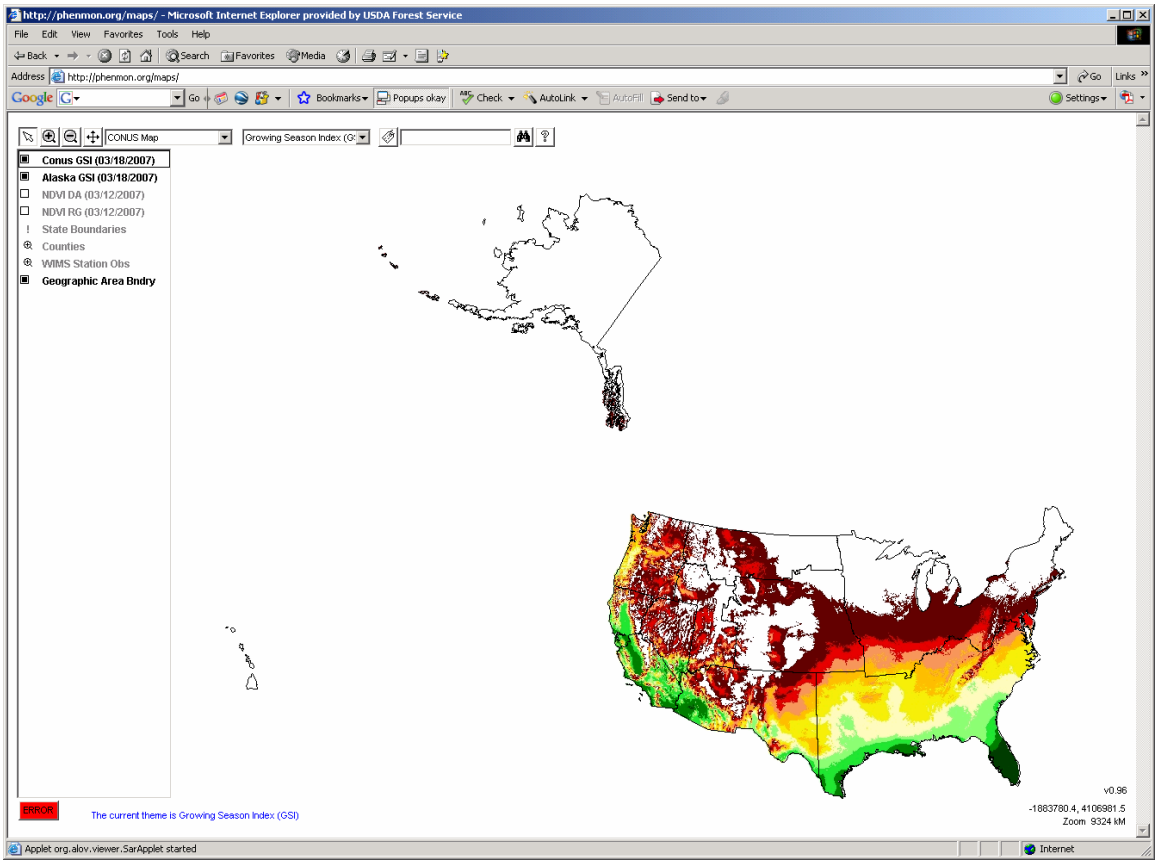

Figure 18 - Screen capture of the PhenMon web mapping system. Users can pan and zoom to a region of interest for both Growing Season Index and NDVI-based metrics of live fuel conditions.

Original Proposed Deliverables	Accomplished / Status
1. A suitable greenness model that can be used with the NFDRS. This model will be based on the use of MODIS satellite data for the derivation of the vegetative greenness conditions. **2. A mechanistic model that can predict the effects of climate change on vegetation greenness and its subsequent effects on fire potential. This model will be a derivative of the BIOME-BGC ecosystem process model and will contain the National Fire Danger Rating System calculations.** **3. A publication that details the logic used in deriving the greenness state of live vegetation from MODIS data and the incorporation of these data into the NFDRS.**	**Publications detailing the weather-driven phenology model and its implementation as a web-based monitoring system:** • Jolly, William M. (2004). A near realtime system for monitoring the foliar phenology of the terrestrial biosphere. PhD Dissertation, College of Forestry and Conservation, University of Montana. • Jolly, W. M., et al. (2005), A flexible, integrated system for generating meteorological surfaces derived from point sources across multiple geographic scales, *Environmental Modelling & Software*, 20, 873-882. *i. Selected as the Enviormental Modelling and Software paper of the year for 2005* • Jolly, W. M., et al. (2005), A generalized, bioclimatic index to predict foliar phenology in response to climate, *Global Change Biology*, *11*, 619-632. • Jolly, W. M., et al. (2006), Divergent vegetation growth responses to the 2003 heat wave in the Swiss Alps, *Geophysical Research Letters,32:18, L18409* • Jolly, W. M. (2005), A mechanistic, weather-driven greenness model for the US National Fire Danger Rating System (NFDRS). EastFire Conference proceedings. **Symposium, seminars and conference related presentations** ***Oral Presentations*** • Jolly, William M. (2004). A generalized bioclimatic index to predict foliar phenology in response to climate. Swiss Federal Research Institute for Forest, Snow and Landscape Research, Birmensdorf, Switzerland. • Jolly, William M. (2004). A generalized, bioclimatic index to predict foliar phenology in response to climate. American Geophysical Union, Fall Meeting. • Jolly, William M. (2005). A mechanistic, weather-driven greenness model for the US National Fire Danger Rating System (NFDRS). EastFire Conference.

- Jolly, William M. (2005). A generalized bioclimatic index to predict foliar phenology in response to climate. EROS Data Center seminar.
- Jolly, William M. (2006). A remote sensing primer. Western Seasonal Assessment Workshop.

Poster Presentations

- Jolly, William M. (2003). A mechanistic, weather-driven greenup model for the National Fire Danger Rating System. American Meteorological Society, Fire and Forest Meteorology Meeting.
- Jolly, William M. et. Al. (2005). The Wildland Fire Assessment System (WFAS): A web-based resource for decision support. EastFire Conference. Fairfax, VA.

Training and Related Informational Talks

- Jolly, William M. (2004). A mechanistic, weather-driven greenup model for the National Fire Danger Rating System. Geographic Area Predictive Services Annual Meeting.
- Jolly, William M. (2004). A mechanistic, weather-driven greenup model for the National Fire Danger Rating System. Southern Area Fire Danger / Fire Weather Working Team.
- Jolly, William M. (2005). A mechanistic, weather-driven greenup model for the National Fire Danger Rating System. National Predictive Services Groups (NPSG) Bi-annual meeting.
- Jolly, William M. (2006). Northern Rockies Fire Behavior Workshop. Missoula, MT.
- Jolly, William M. (2006). Advanced National Fire Danger Rating. National Advanced Fire and Resources Institute (NAFRI).
- S-491 Intermediate National Fire Danger Rating Presentations.
    - (2005) Southern Area / Mississippi Forestry Commission. Pearl, MS.
    - (2006) (2006) Eastern Area / Wisconsin Department of Natural Resources. Rhinlander, WI.
    - (2006) US Forest Service, Region 8. Atlanta, GA.

4. An analysis of the effects of climate change on fire potential using the mechanistic phenology model coupled with the outputs from a General Circulation Model. **5. Maps showing the areas where climate change has the highest impact on fire potential.**	• This analysis was performed with four separate general circulation models that predicted future climate to the year 2100. Each model used both the Intergovernmental Panel on Climate Change's A2 and B2 emission scenarios. We estimated the Growing Season Index (GSI) for these future scenarios. Maps of the impact of climate change on live vegetation are shown in Figure 11 and Figure 12. • Climate change effects on live vegetation were also summarized by each of the 11 Geographic Area Coordination Centers (Figure 14 and Figure 15). • Preliminary results were presented at the Geographic Area Predictive Services annual meeting in November, 2006.
6. A publication detailing the vegetation greenness model and the results from the climate change analysis.	• This publication is in preparation and will be submitted for peer review within the next two months. • Results will be presented at the 2nd Fire Behavior Conference, Destin, FL.

Technology Transfer Efforts	**Website, updated daily, that contains point and spatial summaries of the Growing Season Index across the continental United States and Alaska.**
	• http://www.phenmon.org
	
	Daily point summaries at RAWS sites for specific geographic areas
	• Southwest Coordination Center (SWCC)
	  o http://www.phenmon.org/cgi-bin/gsi-swgacc_new.pl
	• Southern Area Coordination Center (SACC)
	  o http://www.phenmon.org/cgi-bin/gsi-sagacc_new.pl
	
	Subsets of the Growing Season Index for each of the continental Unites States Geographic Area Coordination Centers
	• http://www.phenmon.org/index.php?option=com_content&task=view&id=23&Itemid=31
	
	Software Tools
	• Excel-based Toolkit for calculating the Growing Season Index
	  o ftp://ftp.ntsg.umt.edu/pub/models/gsi/GSI_Toolkit.xls

References

Jolly, W. M., M. Dobbertin, M. Reichstein, and N. Zimmermann. 2006. Divergent vegetation growth responses to the 2003 heat wave in the Swiss Alps. Geophysical Research Letters 109:doi: 10.1029/2004JD004959.

Jolly, W. M., J. M. Graham, A. Michaelis, R. Nemani, and S. W. Running. 2005a. A flexible, integrated system for generating meteorological surfaces derived from point sources across multiple geographic scales. Environmental Modelling & Software 20:873-882.

Jolly, W. M., R. R. Nemani, and S. W. Running. 2005b. A generalized, bioclimatic index to predict foliar phenology in response to climate. Global Change Biology 11:619-632.