Monitoring Phenology and Vegetation Productivity in Parks with the Terrestrial Observation and Prediction System

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Background & Objectives

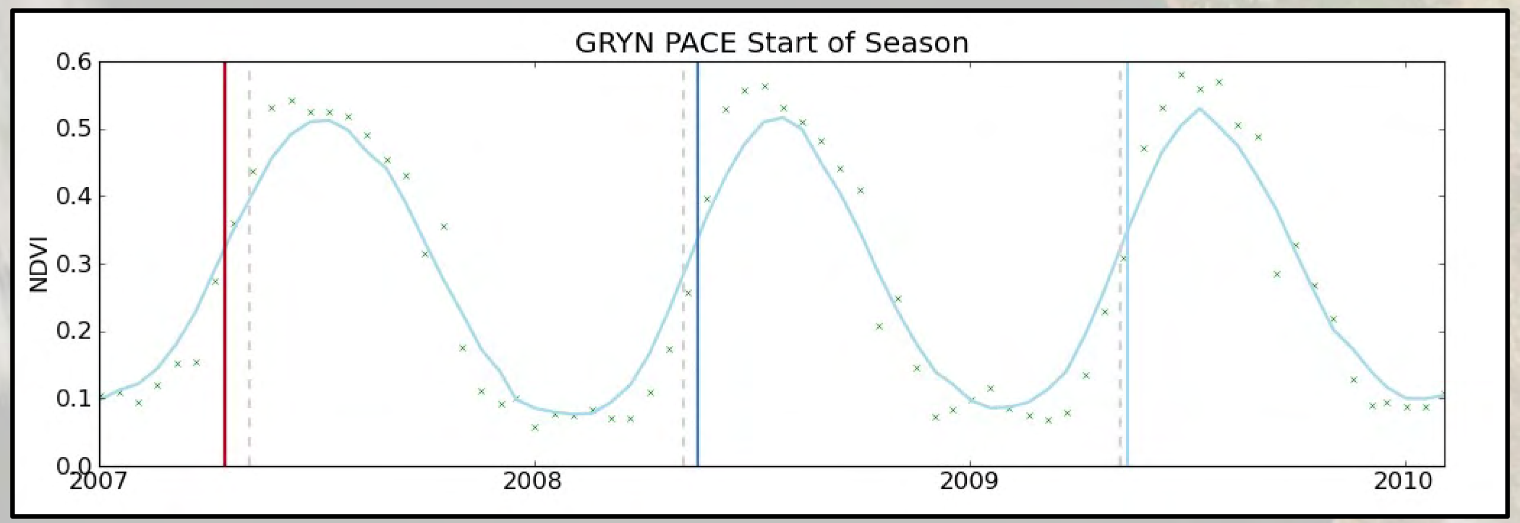
Future climate change is predicted to impact vegetation phenology and productivity for ecosystems within many parks and protected lands. Monitoring these parameters over large areas can be challenging, however, making it difficult to implement cost effective monitoring protocols to detect emerging trends. Satellite data and ecosystem models can supplement other measurements and observations to derive indicators of interannual changes in these parameters over large areas.

The Terrestrial Observation and Prediction System (TOPS), developed and maintained by the Ecological Forecasting Lab at NASA Ames Research Center, is a modeling framework that integrates operational satellite data, microclimate mapping, and ecosystem simulation models to characterize ecosystem status and trends[1]. Through the NASA-NPS PALMS project[2,3], and in partnerships with four NPS I&M Networks, we applied TOPS to provide indicators of phenology and vegetation productivity, and to characterize interannual variability and evaluate patterns in these indicators from 2000-2010.

Approach

Phenology

Measures of vegetation phenology can be estimated using satellite remote sensing data products to produce spatially continuous indicators characterizing the onset of greenness, or start of season (SOS), as well as other phenological indicators. By observing time-series of Normalized Difference Vegetation Index (NDVI) data from the MODIS satellite data record, we are able to estimate each year's SOS for each 1km x 1km pixel in the study areas using a modified Midpoint-XL algorithm[4]. TOPS provides a flexible framework and supports implementation of multiple phenology algorithms.



An NDVI time-series from the GRYN PACE showing the estimated SOS dates for 2008-2010. The green points indicate the satellite-derived NDVI, and the blue curve represents the smoothed time-series. The dotted horizontal lines indicate the average SOS value from the 10-year record, and the solid horizontal lines represent the modeled SOS date for each year.

GPP

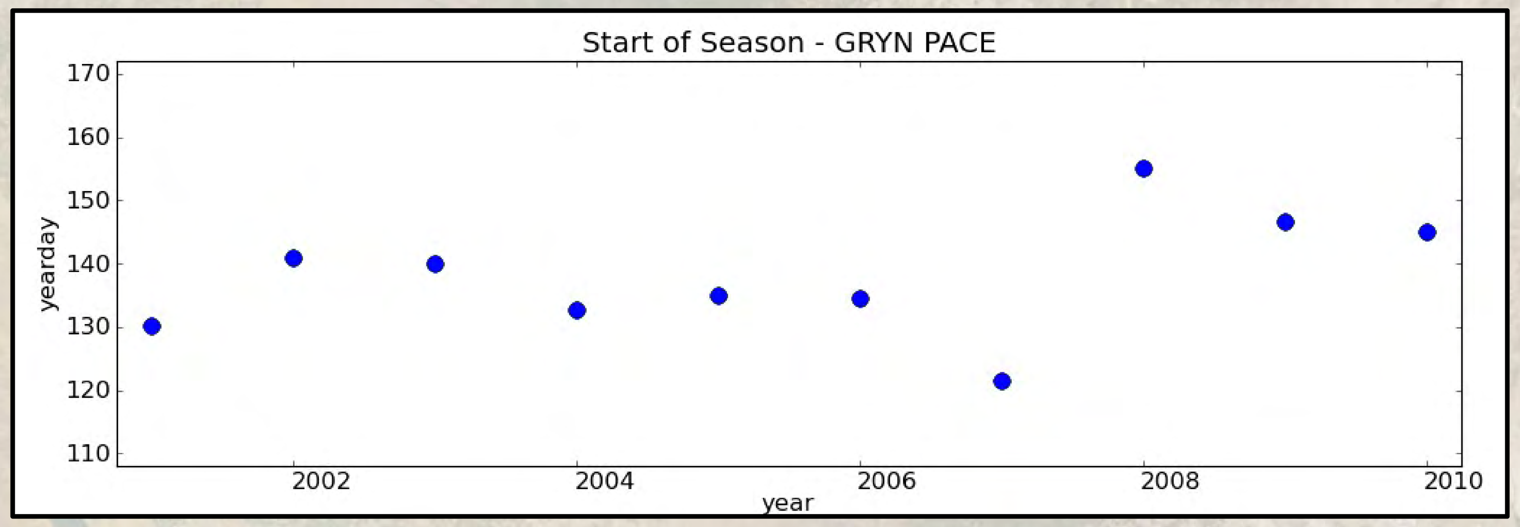
Gross primary productivity (GPP) is the rate at which plants and other producers in an ecosystem capture and store energy as biomass via photosynthesis. Some fraction of this energy is used to maintain existing tissues or is lost through plant respiration, and net primary production (NPP) is the remaining amount that is 'fixed' or stored by an ecosystem. As indicators of ecosystem productivity, GPP and NPP provide an integrative measure of ecosystem condition that incorporates seasonal climatic influences and satellite measures of vegetation condition, as well as information on topography, soils and water availability.

To characterize ecosystem productivity for each of the partner I&M Networks, we followed the general approach employed by the MODIS algorithms[5] and applied a modified version of the BIOME-BGC ecosystem model[6] within TOPS. Relative to standard MODIS GPP/NPP products, TOPS uses gridded climate data at a much finer spatial resolution (1 km) to account for heterogeneous terrain in many of our partner I&M Networks and parks. TOPS uses satellite-derived estimates of leaf area to estimate various water (evaporation, transpiration, stream flows, and soil water), carbon (net photosynthesis, plant growth) and nutrient flux (uptake and mineralization) processes on a daily time step. The model requires as inputs spatially continuous data layers to describe the land cover, soil texture and depth, daily meteorology, and elevation across the land surface[1].

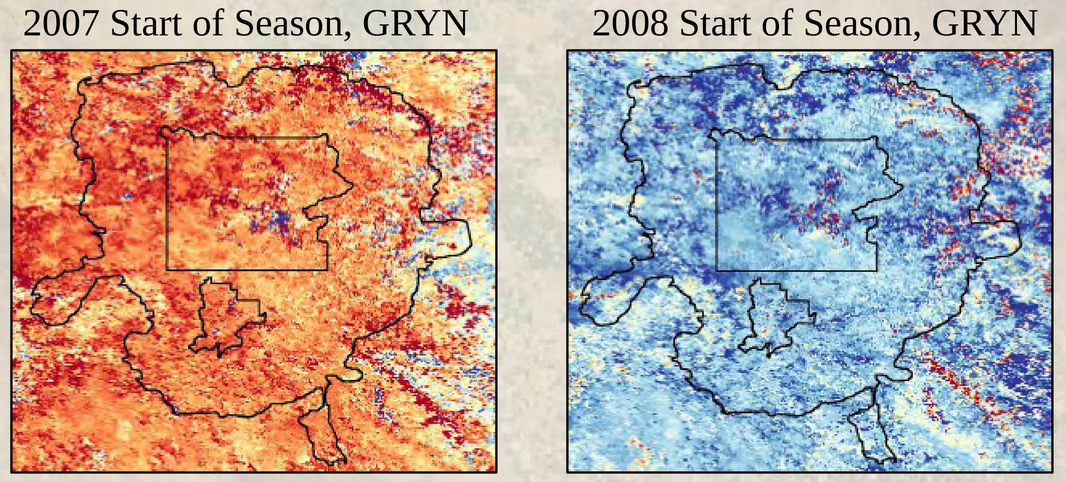
Sample Indicators and Results

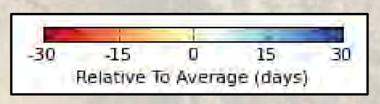
To evaluate spatial and temporal patterns in phenology and GPP, maps were produced for the region surrounding each of the focal parks for the period from 2001-2010. Based on input from I&M collaborators, daily and weekly data products were aggregated into seasonal and annual summaries of GPP and SOS dates by park, Protected Area-Centered Ecosystem (PACE), and major ecosystem type, and evaluated to characterize baseline conditions for future monitoring and to identify any emerging trends over the past decade. SOPs were prepared for the vegetation productivity and phenology data products[7], and the summary products were distributed via the web interface described below.

The SOS indicators calculated for each partner I&M Network captured the interannual variability in SOS, and provided data to characterize baseline conditions for the period from 2001-2010 for use in evaluating future trends in phenology. An example is provided for the Greater Yellowstone Network (GRYN), establishing a typical range in SOS dates from DOY 130-145, though the full range observed spanned DOY 121-155. Current work is focused on extending the analysis to include calculation of end of season dates and measures of growing season length.



Estimated SOS dates from the GRYN PACE showing the interannual variability in phenology.



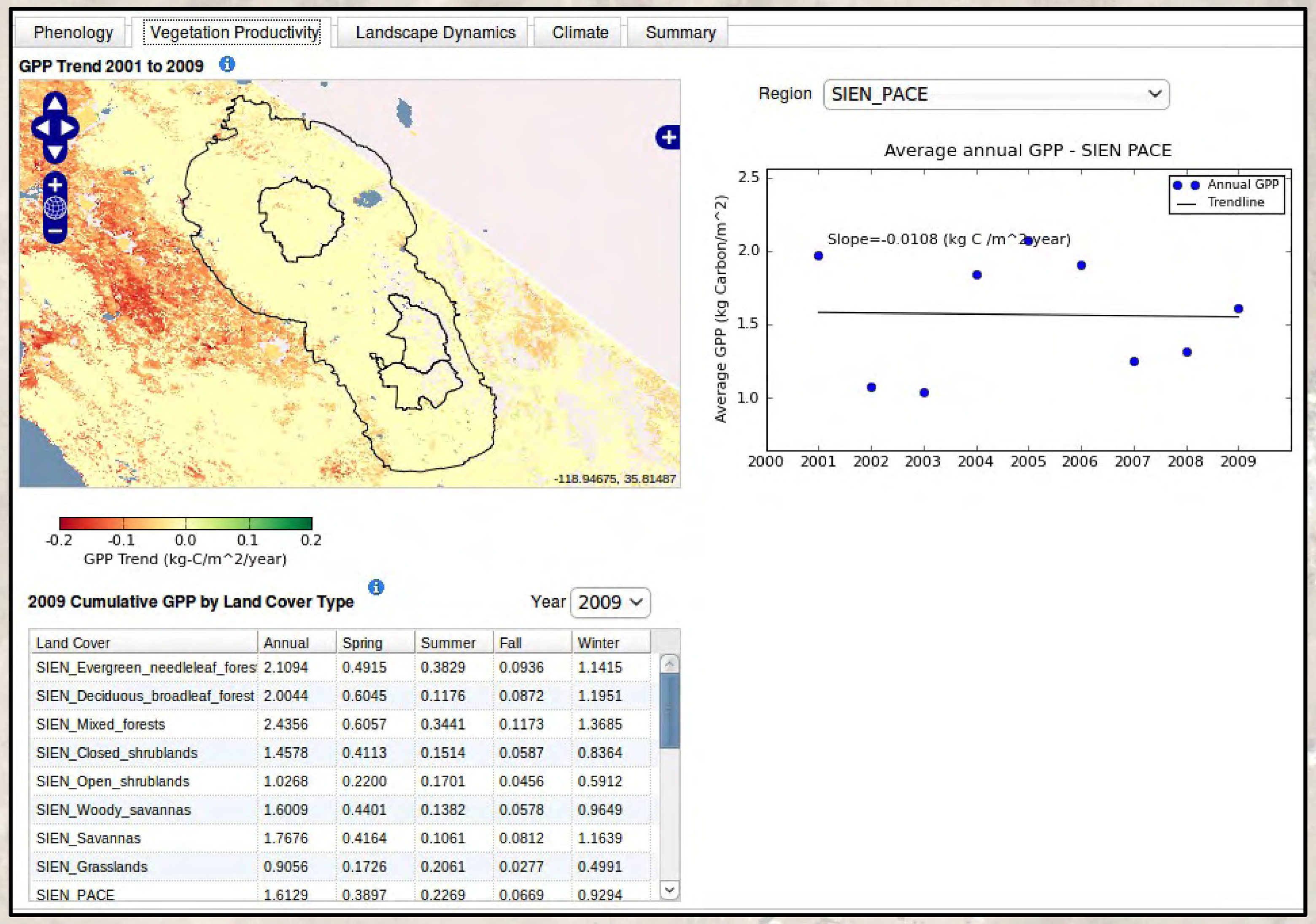


Start of Season anomaly maps for the Greater Yellowstone Network (GRYN). Yellowstone NP, Grand Teton NP, and the Protected Area-Centered Ecosystem boundaries are shown.

Patterns in GPP also varied by park, region, and ecosystem type. For example, in the Sierra Nevada parks, the indicator captured the significant interannual variability in productivity driven by year to year variations in the timing of snow accumulation and melt. In contrast, parks in the Eastern Rivers and Mountains I&M Network showed sustained declines in GPP over the past decade, which may be due in part to increasing tree mortality resulting from infestations of the hemlock wooly adelgid (Adelges tsugae) throughout the region. While a ten-year data record is too short to definitively identify long term trends, the indicator was shown to capture the impact of climate variation and disturbance events on ecosystem condition.

Data Access

Satellite data analysis and ecosystem modeling are specialized fields, and park managers may be unfamiliar with satellite-derived indices and model parameters (e.g., NDVI, leaf area index, GPP, NPP), presenting a barrier to their adoption and use in park monitoring. To address this challenge, we developed a dynamic web application to present visual examples to NPS collaborators and to demonstrate how indicators derived from satellites and ecosystem models could be applied to characterize spatial and temporal patterns in park ecosystem conditions. This web interface utilizes open source software to serve dynamic web maps to characterize spatial patterns, as well as graphs and charts to summarize temporal patterns in the satellite- and model-derived indicators.



Land Cover	Annual	Spring	Summer	Fall	Winter
SIEN_Evergreen_needleleaf_fores	2.1094	0.4915	0.3829	0.0936	1.1415
SIEN_Deciduous_broadleaf_forest	2.0044	0.6045	0.1176	0.0872	1.1951
SIEN_Mixed_forests	2.4356	0.6057	0.3441	0.1173	1.3685
SIEN_Closed_shrublands	1.4578	0.4113	0.1514	0.0587	0.8364
SIEN_Open_shrublands	1.0268	0.2200	0.1701	0.0456	0.5912
SIEN_Woody_savannas	1.6009	0.4401	0.1382	0.0578	0.9649
SIEN_Savannas	1.7676	0.4164	0.1061	0.0812	1.1639
SIEN_Grasslands	0.9056	0.1726	0.2061	0.0277	0.4991
SIEN_PACE	1.6129	0.3897	0.2269	0.0669	0.9294

An example of the TOPS data gateway for indicators of vegetation productivity in the Sierra Nevada parks.

The data underlying the web maps shown above are also accessible via an OPeNDAP[8] server which provides both a web browser-based interface as well as programmatic access, enabling the download and analysis of user-defined subsets of data. Ongoing efforts are developing web interfaces and software tools for retrieving and processing data from the TOPS OPeNDAP interface[9] to assist NPS I&M networks in utilizing data from NASA satellites and ecosystem models in park monitoring, enabling them to maintain and customize summaries directly from the satellite data and model outputs. (e.g., for examples of recently developed tools, see http://www.coasterdata.net; http://www.edc.uri.edu/ATMT-DSS/).

Future Directions

Through a NASA supported project focused on monitoring conditions along the Appalachian Trail, led by Dr. YQ Wang, we are currently working to expand the TOPS OPeNDAP interface to provide support for ArcGIS software tools and clients, in collaboration with the Univ. of Rhode Island, NPS, USFS, and USGS. NPS and other resource management agencies rely on ArcGIS software (ESRI, Redlands, CA; http://www.esri.com) for many geospatial analyses, and integration of TOPS data services with ArcGIS tools is anticipated to further streamline access to data from NASA satellites and models. Integration with ArcGIS is also expected to increase the ability of NPS I&M Networks to more easily tailor data processing and analysis steps to address issues of specific concern to individual parks and networks.

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