A Regional Phenology Model for Detecting Onset of Greenness in Temperate Mixed Forests, Korea: An Application of MODIS Leaf Area Index (LAI)

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Introduction

Leaf Area Index (LAI) (projected, m^2 m^{-2}), a surrogate measure of the amount of canopy vegetation per unit area, is widely used as an important input/output variable of ecosystem models that relate solar radiation to terrestrial carbon and hydrologic cycles (Running and Coughlan, 1988; Band *et al*., 1993; Landsberg and Waring, 1997). LAI is an aggregate variable for canopy status in terms of radiation and thermal physics, which is applied with satellite data to estimate spatial and temporal patterns of LAI (Spanner *et al.*, 1990; Settle and Drake, 1993; Sellers *et al.*, 1994; Chen and Chilar, 1996; Myneni *et al.*, 1997a; White *et al.*, 1997; Turner *et al.*, 1999) and the timing of leaf onset or offset (Goward *et al.*, 1985; Bradley *et al.*, 1994; White *et al.*, 1997). Vegetation phenology, that is seasonality of LAI driven by environmental factors, controls seasonal variability in photosynthesis and evapotranspiration for a deciduous biome which is broadly distributed mid-latitude countries in the northern hemisphere. Together with maximum LAI, timings of leaf onset and offset are special concerns of vegetation phenology models, since those have considerable influences on spatial and interannual variability of terrestrial carbon cycles (Hanninen *et al.*, 1990; White *et al.*, 1997; Menzel and Fabian, 1999; White *et al.*, 1999).

In recent years, vegetation phenology has found new relevance within global climate change research, with increasing data obtained by satellites (White *et al.*, 1997) and by regional phenology networks (Kramer, 1994; Schwartz, 1998; Menzel and Fabian, 1999; Chuine *et al.*, 2000a). Together with meteorological data, surface-based phenology data have been used for developing several species-specific leaf onset and/or leaf offset models. The timing of leaf onset has been successfully modeled using cumulative thermal summation with or without consideration of chilling requirement (Cannell and Smith, 1983; Valentine, 1983; Marray *et al.*, 1989; Hanninen *et al.*, 1990; Hanninen, 1994; Kramer, 1994; Chuine and Cour, 1999; Chuine *et al.*, 1999; Chuine, 2000). Chuine *et al.* (2000) implemented a successful pilot study to scale phenology from the local to the regional level using species-specific phenological models. Regional or global carbon cycling models, however, consider mean phenological change within each pixel of a study area where diverse vegetations are aggregated. Large-scale carbon cycling models require regional or global-scale phenology models to capture aerial-mean phenological change related to average environmental conditions for each grid pixel. In this context, satellite data provides a means for monitoring regional or global-scale phenology (Running *et al.*, 1994; Moulin *et al.*, 1997; Myneni *et al.*, 1997a, 1997b). Notably, satellite spectroscopic reflectance from NOAA-AVHRR has been used to estimate the timing of leaf onset or offset because of its high temporal frequency, which can capture day-to-day variations in canopy status (Goward *et al.*, 1985; Bradley *et al.*, 1994; Liidele *et al.*, 1996; White *et al.*, 1997). White *et al.* (1997) used the normalized difference vegetation index (NDVI) from AVHRR to develop a continental phenology model for deciduous broadleaf and grass biomes in United States.

The current study aims to develop a regional phenology model for detecting leaf onset in temperate mixed forests using MODIS 8-day composite LAI product (MOD15A2). In contrast to its predecessors including AVHRR, MODIS incorporates enhanced atmospheric correction, improved geo-referencing, and the enhanced ability to monitor vegetation. In addition, MODIS provides further necessary information on landcover and cloud contamination for developing the phenology model. We also suggest an objective approach for model parameterization for general application to other regions, and validated the developed phenology model with field observed leaf onset in Korea.

SCIENCE TEAM ACTIVITIES:

John Kimball, Faith Ann Heinsch, Alana Oakins

Meetings attended:

July 2002:	MODIS Vegetation Workshop, Missoula MT.
July 2002:	IARC Research Development Workshop, Fairbanks AK.
August 2002:	Western Arctic Linkages Experiment Workshop, Polson MT.
August 2002:	ChEAS Workshop, Woodruff, WI.

Posters and Presentations:

Modeling the role of high latitude terrestrial ecosystems in the Arctic. Presentation for WALE Workshop, August 2002, Polson MT.

Using MODIS to estimate GPP/NPP on a global scale. Presentation for IARC Research Development Workshop, July 2002.

Biome-BGC and estimations of tower fluxes. Presentation for ChEAS 2002 Workshop, August 2002.

Science activities:

MODIS Science activities to date have been directed toward evaluating MODIS LAI, GPP and PSN products through intercomparisons with site network measurements and ecosystem process model simulations at tower eddy flux measurement sites from FLUXNET and other biophysical monitoring networks. Current activities include the assembly of tower site meteorology and water and CO2 flux data at half-hourly time steps. We have developed protocols for estimating and filling in missing tower data at half-hourly time steps in order to aggregate these data to complete daily time steps. Daily tower meteorological data are being used as inputs for stand level ecosystem process model (BIOME-BGC) and MODIS GPP and NPP algorithm (MOD-16/17) based simulations at each study site. Site-specific ecophysiological parameterization files have been developed for each study site, which are being used to generate BIOME-BGC daily model simulations for intercomparison with MODIS based products. Intercomparison studies involve direct comparisons of relative magnitudes and seasonal behavior between MODIS, Tower and BIOME-BGC results. Sensitivity analyses are also being conducted using alternate meteorological inputs derived from tower measurements and NCEP and DAO forecast model outputs. Protocols are also being developed to uncouple tower eddy flux net CO2 exchange measurements into GPP and respiration components to enable more direct comparison to MODIS and BIOME-BGC outputs.

To date, most of our analyses have occurred within the continental US. We have also conducted similar studies to evaluate MODIS LAI, GPP and NPP products for boreal and arctic sites in Alaska and Canada. Initial results indicate that the behavior of the MODIS algorithms at high latitudes is different than results show for other regions. MODIS LAI/FPAR data were found to exhibit a high degree of seasonality relative to ground based results even over predominantly evergreen coniferous forests. However, comparisons of annual maximum LAI between MODIS and site results showed a high level of agreement. Impacts of the strong seasonality of MODIS LAI/FPAR results on resulting GPP and NPP estimates was apparent but somewhat mitigated to a large degree because of other environmental controls on the seasonal behavior of these results such as light availability and temperature.

Integrating MODIS-derived Net Primary Production into scientific and management applications of Switzerland

Members of the EOS Training Center, working as part of an international research collaboration with the Swiss Federal Research Institute for Forest, Snow and Landscape Research, designed and implemented a research plan to facilitate the integration of MODIS-based Net Primary Production (NPP) data into scientific and management applications in Switzerland. The research plan was designed as a nested spatial and temporal scale application of several models and remote sensing-based tools in conjunction with field collected data to establish a long-term time-series of NPP for the country as well as to establish methods by which researchers could monitor changes in the domestic carbon budget.

The first phase of the research plan was to establish a long-term time series of NPP using the ecosystem process model BIOME-BGC. To accomplish this, researchers collected ancillary data on gas exchange and leaf characteristics of the dominant tree species throughout Switzerland. These data complement an already extensive set of data collected as part of Long Term Forest Ecological Research (LTFER) program. They will be used to parameterize BIOME-BGC for the sites within the LTFER network where we will generate estimates of NPP for at least 70 years. Within these sites, long-term validation data sets will be compiled from tree ring density chronologies to allow researchers to validate the NPP estimates.

After completion of the retrospective analysis, the second phase of the research plan is designed as a crossover from the BIOME-BGC NPP estimates to MODIS-derived estimates of NPP. To accomplish this, we will use a combination of the long-term dataset of LAI and FPAR derived from Pathfinder AVHRR data in conjunction with the at-launch MODIS NPP algorithm to generate an NPP time-series in the locale of the LTFER sites from 1982 to 2000 that will overlap the time-series of NPP generated from BIOME-BGC. This step is crucial to show that the dynamics of the of the more parsimonious remote sensing derived data tracks closely with the more rigorously estimated NPP values from BIOME-BGC. We will then use the MODIS NPP to continue the record from 2000 to present to establish the full time series as well as the means by which to monitor future changes.

In return for assistance with the technical and staffing aspects of such a project, the Swiss researchers are providing a data set for use in validation of MODIS NPP data products. Swiss researchers are developing methods to reconstruct NPP from stand measurements of leaf area index and biomass increments collected at all 17 sites within the LTFER network. This will provide Montana researchers with an excellent dataset to validate their NPP data products.

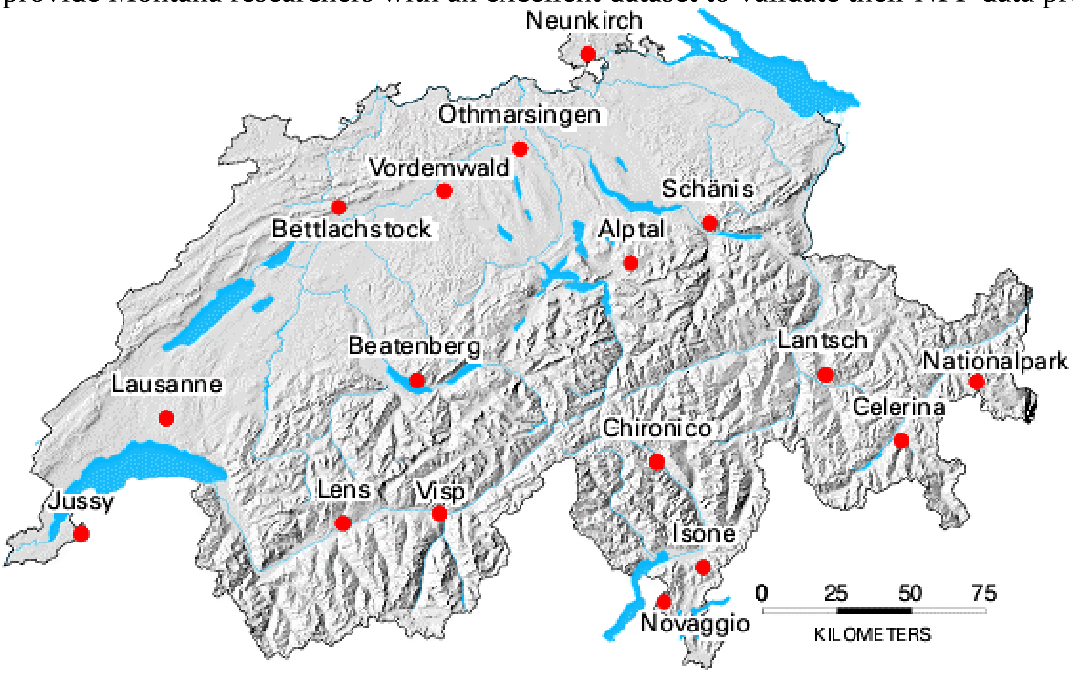

Figure 1 - Swiss carbon budget pilot study sites.

The effects of moisture status on the intra-annual dynamics of leaf area in the semi-arid regions of the Kalahari

We examined the effects of precipitation and soil moisture status on the dynamics of leaf area in semi-arid, drought-deciduous ecosystems in the Kalahari region of South Africa. We postulated that the onset of greenness in these vegetation types was controlled by a large significant precipitation event and the offset was a dynamic feedback between leaf area, soil water potential and net primary production. Leaf onset dates were estimated as the first day where a rainfall event exceeded that day's estimate of potential evapotranspiration after a defined dry season. Leaf senescence was determined by dynamically modeling the effects of downward trends in soil water potential on leaf area in relation to negative trends in net primary production (NPP) in the ecosystem process model BIOME-BGC. The results of predictions of leaf area index (LAI) were then compared to satellite-derived Normalized Difference Vegetation Indices (NDVI) to determine whether or not the modeled dynamics of the system supported our hypothesis. Mean absolute error (MAE) for the prediction of the onset date compared to onset dates derived from the NDVI times were 12.3 days for the Maun site and 27.5 days for the Tshane sites. Peak leaf timing and leaf fall dynamics were adequately predicted using the dynamic soil water controls on leaf area (Figure 2). In general, the results suggest that water moisture status cannot be ignored as a dynamic control on leaf area in these semi-arid, drought-deciduous ecosystems.

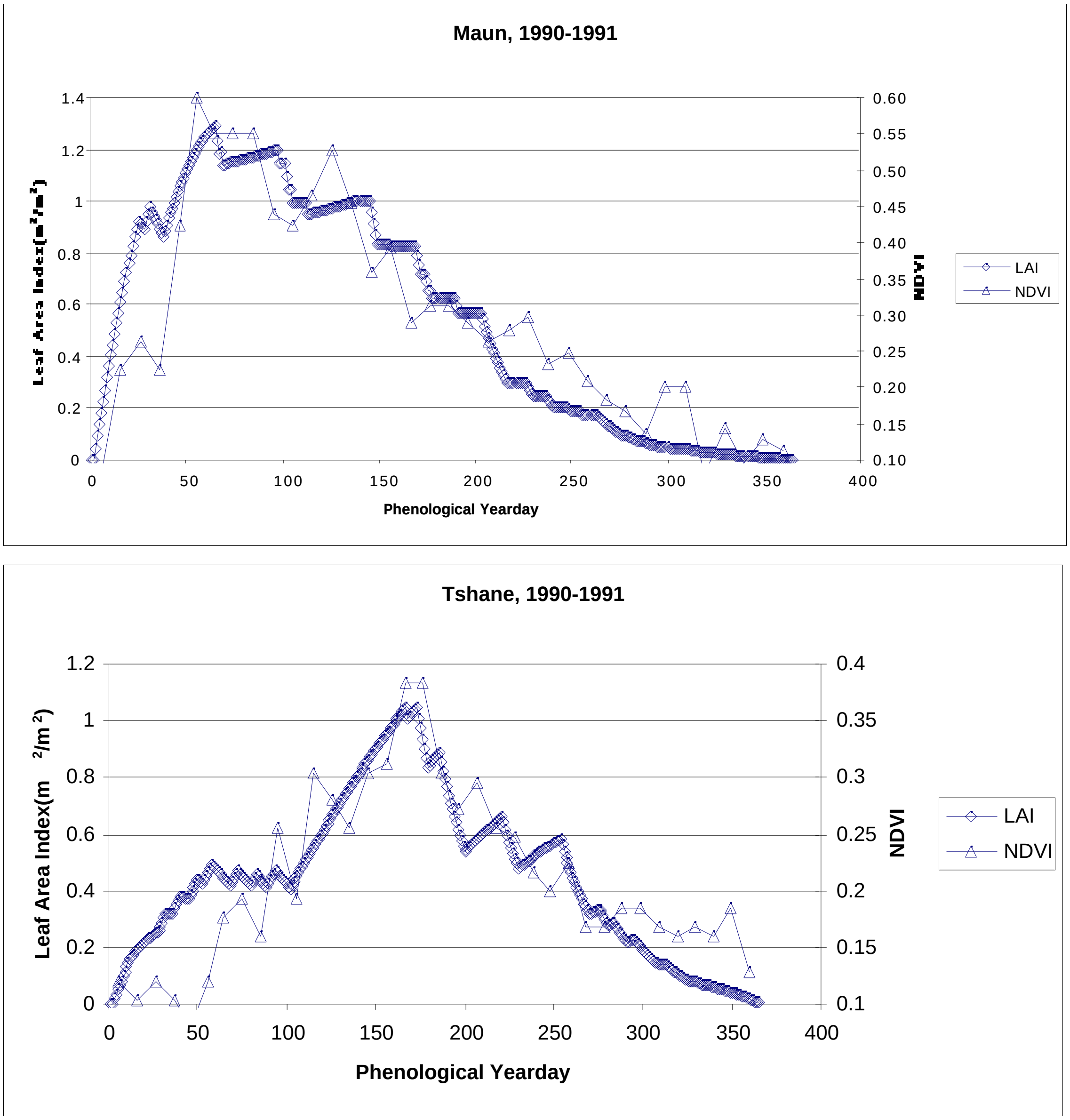

Figure 2 - Examples of model derived leaf area index compared to Pathfinder NDVI data for two sites within the Kalahari Transect.

Development of the Surface Observations Gridding System (SOGS)

The Surface Observations Gridding System (SOGS) is a near real-time system designed to interpolate surface meteorological data onto a user-defined grid. These data can then be used as inputs to ecological process models or hybrid models incorporating remote-sensed data with surface-based data. The system was developed to operate in near real-time by injesting surface observations from a multitude of internet-based data sources and incorporating those data into an SQL database which serves as the heart of the system. The point data can then be interpolated into surfaces of data using a user-selectable algorithm, Ordinary Kriging for temperature data and a truncated gaussian filter for precipitation by default. Upon completion, the system will be able to generate surfaces maximum and minimum temperature, precipitation, dewpoint temperature, vapor pressure deficit and solar radiation.

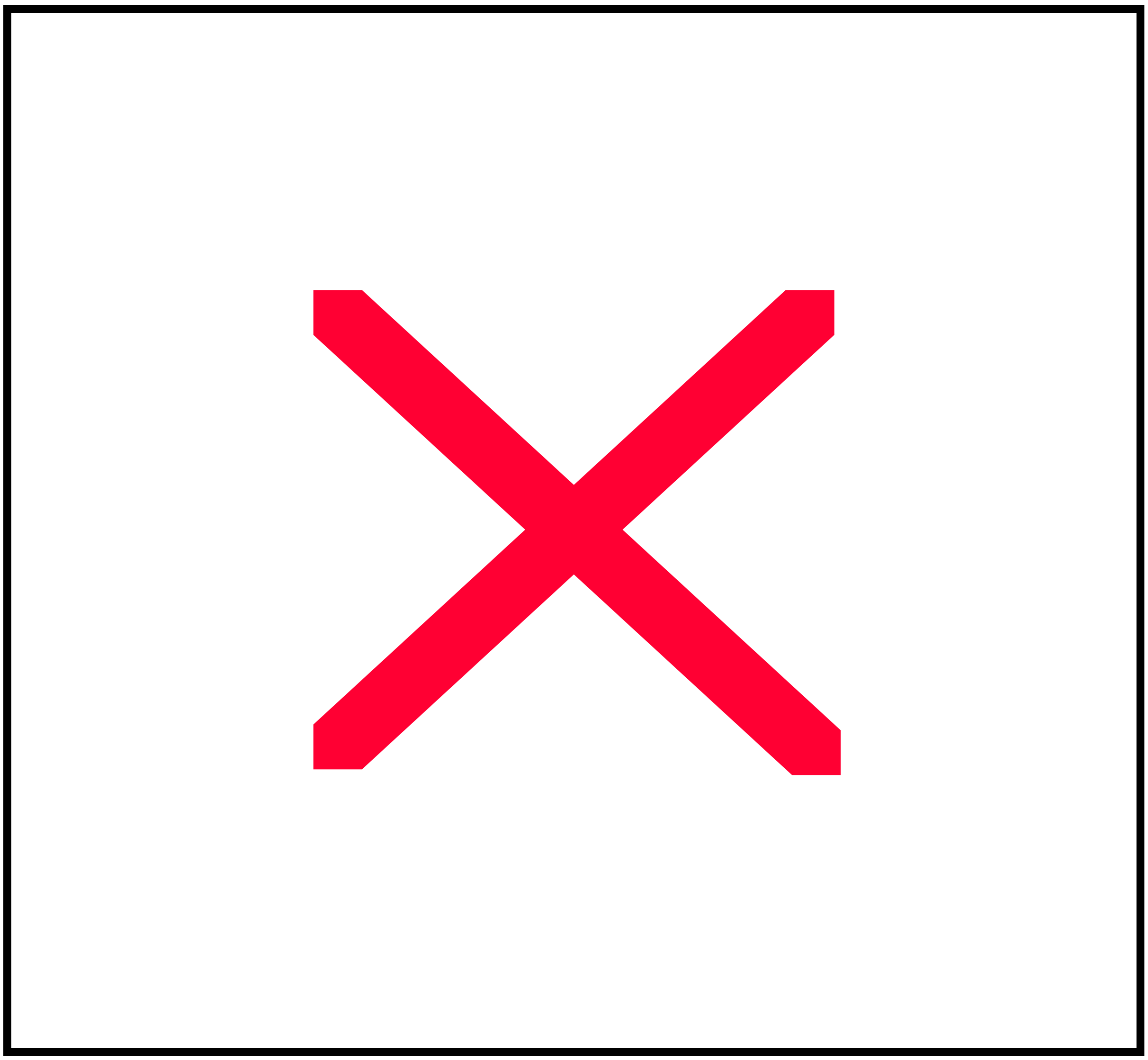

Figure 3 - System flow diagram of the Surface Observations Gridding System (SOGS).