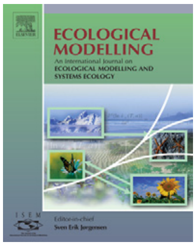
ECOLOGICAL MODELLING 201 (2007) 144–156

available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/ecolmodel



On the use of the advanced very high resolution radiometer for development of prognostic land surface phenology models

Naven Kathuroju[a], Michael A. White[a,*], Jürgen Symanzik[b], Mark D. Schwartz[c], James A. Powell[b], Ramakrishna R. Nemani[d]

[a] Department of Watershed Sciences, Utah State University, Logan, UT, USA
[b] Department of Mathematics and Statistics, Utah State University, Logan, UT, USA
[c] Department of Geography, University of Wisconsin-Milwaukee, Milwaukee, WI, USA
[d] NASA Ames Research Center, Moffett Field, CA, USA

ARTICLE INFO

Article history:
Received 24 November 2005
Received in revised form
17 August 2006
Accepted 5 September 2006
Published on line 18 October 2006

Keywords:
Budburst
Climate change
Senescence
Leaf out
Growing season
Interannual variability
Spring
Fall
Canopy duration
Carbon
GCM

ABSTRACT

Regulation of interannual phenological variability is an important component of climate and ecological models. Prior phenological efforts using the advanced very high resolution radiometer (AVHRR) as a proxy of vegetation dynamics have often simulated spring events only or failed to simulate interannual variability. Our aim is to address these shortcomings and to use the AVHRR to develop prognostic models for interannual land surface phenology and, critically, to test whether or not the developed models are superior to use of climatological phenology values from the AVHRR. Using datasets for the conterminous United States, we first filtered data to select regions and plant functional types for which the best-possible remotely sensed signal could be obtained. We then used a generalized linear model approach to model the relationship between an integrative productivity index and estimates of the start of season (SOS) and end of season (EOS) derived from the AVHRR, yielding models capable of prognostically predicting SOS/EOS events independently of satellite data. Mean absolute errors between the model-predicted and AVHRR-observed SOS/EOS ranged from 5.1 to 20.3 days. SOS errors were uniformly lower than EOS errors. SOS models for the deciduous broadleaf forest and grassland plant functional types produced lower errors than use of the climatological SOS values while all other models produced errors higher than those obtained from the climatological dates. Based on this criterion for success, we suggest that the AVHRR may not be appropriate for further development of prognostic land surface phenology models. However, an intercomparison of phenological dates from an independent spring index model, our model predictions, and the AVHRR observations indicated that interannual predictions from our models may be superior to the satellite data upon which they are based, implying that a further comparison between models based on the AVHRR and newer, superior sensors, should be conducted.

---

[*] *Corresponding author.*
E-mail address: mikew@cc.usu.edu (M.A. White).

doi:10.1016/j.ecolmodel.2006.09.011

1. Introduction

Phenology, the study of the timing of recurring biological cycles and their connection to climate, is a critical field in global change science (Penuelas and Filella, 2001; Menzel, 2002). For terrestrial ecosystem and climate models, vegetation phenology is important in at least three central areas. First, although interannual variation in canopy duration is not a primary determinant of annual carbon fluxes (White and Nemani, 2003), failure to incorporate realistic phenological subroutines will induce serious errors in simulated carbon fluxes (up to 20% errors across the normal range of phenological variability; White et al., 1999). Second, energy balance calculations, as influenced by the partitioning of net radiation into latent and sensible heat, are strongly influenced by phenological variability in climate models (Levis and Bonan, 2004). Third, for the emerging field of hydrologic forecasting (e.g. http://ecocast.arc.nasa.gov/), accurate prediction of phenological variability is especially important for areas characterized by low levels of canopy cover (White and Nemani, 2004). Phenology is also a crucial component of land–atmosphere interactions (Schwartz, 1992; Fitzjarrald et al., 2001), evapotranspiration (Guillevic et al., 2002), patterns of soil organic matter (Epstein et al., 1999), and the seasonality of carbon fluxes (Baldocchi et al., 2001). The importance and utility of phenology, while widely recognized in a broad modeling community (e.g. Lu and Shuttleworth, 2002), has not led to extensive efforts to develop prognostic phenology models compatible with coarse resolution ecological and climate models. Indeed, this shortcoming has been identified specifically as a major need for future modeling efforts (Kucharik et al., 2006). Here, we attempt to address this need by expanding on prior attempts to develop prognostic phenology models.

Climate and coarse resolution ecosystem models typically simulate plant functional types, not individual species. Species-specific phenology models, which may or may not be representative of general landscape phenology, are therefore inappropriate. For large-area modeling efforts, satellite remote sensing observations of land surface phenology are in practice the only proxy of vegetation seasonality obtained at an appropriate level of aggregation. The satellite signal, representing the phenological integration of the entire pixel, is termed land surface phenology (de Beurs and Henebry, 2004a) and includes the usually undesirable confounding effects of soil, snow, and atmospheric variability.

For late 20th century and current periods, satellite datasets may be used directly to monitor land surface phenology (Justice et al., 1985; Lloyd, 1990; Reed et al., 1994; Myneni et al., 1997a; Duchemin et al., 1999; Chen et al., 2000; Zhang et al., 2004) and to force directly vegetation seasonality in climate and/or ecological models. However, many modeling applications involve simulations for periods prior to the satellite record and/or for future climate scenarios. In these cases, remote sensing cannot be used to regulate vegetation seasonality: prognostic land surface phenology models are necessary.

Such models, in which the timing of a specific event such as the start of season (SOS) or end of season (EOS) is predicted, are comparatively rare. Botta et al. (2000) extrapolated land surface phenology models valid over a regional scale to a global scale and developed models to determine the time of leaf onset. White et al. (1997) developed land surface phenology models to determine the SOS and EOS for grassland and deciduous broad leaf forest (DBF) plant functional types in the conterminous United States. Kaduk and Heimann (1996) used simulations of net primary production and climate dependent plant physiological rules to simulate land surface phenology.

These and other studies often contain one or more limitations: (1) regions with mixed plant functional types are used, introducing multiple phenological signals that may respond differently to interannual climate variability; (2) mean land surface phenology events are predicted, not interannual phenological variability (Botta et al., 2000; Arora and Boer, 2005); (3) satellite data are not screened to remove less than ideal conditions; (4) *a priori* assumptions are made about the environmental factors controlling the timing of land surface phenology events; (5) only spring models are developed; (6) a single arbitrary stage of canopy development is selected as a phenological event; (7) model prediction errors are not compared to use of the mean (climatological) phenological date as the prediction.

Here, our goal was to address all seven limitations and to test whether or not the advanced very high resolution radiometer (AVHRR), the sensor with longest continuous record of high frequency global observations of land surface phenology, can be used to develop rigorous prognostic land surface phenology models for use in ecological and/or climate models. To our knowledge, no similar effort has investigated whether or not such models can predict interannual phenological variability with errors lower than those obtained when simply using climatological phenology.

2. Data

We conducted our analysis for the conterminous United States from 1990 to 1997 (1994 excepted due to satellite failure). Model development required meteorology and remote sensing datasets. All data were produced at or resampled and reprojected to a 1 km resolution in the Lambert's Azimuthal Equal Area projection.

2.1. *Meteorology*

We obtained 1990–1997 one-kilometer daily meteorology for the conterminous United States from the DAYMET dataset (Thornton et al., 1997). The data, interpolated from weather station records, include maximum temperature, minimum temperature, precipitation, shortwave radiation, and vapor pressure deficit.

2.2. *Remote sensing*

We obtained three remotely sensed datasets. First, we obtained 14-day composited (Holben, 1986) 1 km AVHRR normalized difference vegetation index (NDVI) data from the Earth Resources Observations & Science Data Center (EDC). We then calculated leaf area index (LAI) using NDVI and the algorithms in Myneni et al. (1997b). We retained the EDC-assigned