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A method to incorporate phenology into land cover change analysis.

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ABSTRACT

Land cover change analysis is an important and common image processing technique. Normally, change analysis is performed between 2 images that have been matched by calendar date instead of using some form of environmental criterion. Under this scenario, detected changes may only reveal differences in phenology and not real differences in vegetative land cover trends.

Two primary factors influence the phenology of the environmental year. These are growing degree-days (GDD) and accumulated precipitation (AP). Other factors are important as well (e.g., humidity, wind, the rate and form of accumulated precipitation, and the precipitation regime from recent years), but growing degree-days and accumulated precipitation appear to be the best correlates with phenology. The potential errors and biases associated with this model are discussed.

The author developed a software program (Pheno-Calc) that allows the user to calculate GDD and AP, graph and view the data set, and perform match calculations. Match calculations allow the user to more strategically choose remotely sensed imagery for analysis of land cover change by providing the dates on which GDD and/or precipitation accumulation has been matched.

Keywords: remote sensing, GIS

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INTRODUCTION

Desertification, invasive plant species, and urban sprawl are topics confronting land managers each and every day. One means to quantify these changes on the landscape has been temporal land cover change assessment using remotely sensed imagery. This relatively common approach is often performed using Landsat or SPOT satellite imagery acquired on the same date from 2 different years (e.g., 1 June 1980 and 1 June 1990) (i.e., anniversary date (Lillesand and Kiefer 2000)). This type of synchronization is the norm and little consideration seems to have been given to the deliberate selection of imagery dates. Rather, a primary concern has been minimizing cloud contamination. While cloud contamination is still, and probably will always be a concern it should not be the sole consideration.

Climatic processes such as temperature and precipitation drive the phenology of a region. Other climatic variables like cloud cover, the form, duration, frequency, and timing of precipitation, as well as the timing of frosts also influence phenology. Precise modeling of a region's phenology is very difficult and perhaps impossible with the knowledge and technology available to researchers today. However, 2 variables (accumulated growing degree-days and accumulated precipitation) are believed to agree well with phenological events, and can be used as estimates or correlates of phenology (cf. Coupland 1950, Rauzi and Dubrenz 1970, French and Sauer 1974).

Compared to anniversary date synchronization, phenological synchronization of satellite imagery removes a variable and potential bias that otherwise influences the results of land cover change assessment (Lunetta et al. 1998). That is, the effect of phenological differences between the two years sampled. As an example, assume that imagery from 1 June 1980 was compared to imagery acquired on 1 June 1990. Further, assume that 1980 was a cool, wet year whereas 1990 was a hot, dry year. The results of this comparison will likely reveal significant changes in vegetative land cover. This result however, may not be reliable as much –if not all— the changes detected should be attributed to phenological variation between the years. Calendar dates reflect the relationship between the sun and the earth and do not control the earth's environment. Therefore they do not have any real influence on the landscape. Phenology ("the timing and sequence of natural events" (e.g., emergence, growth and senescence of vegetation (Craighead 1994)) or "the study of the timing of recurring biological events" (Lieth 1974)) and phenological variation between years can dramatically influence the appearance of a landscape over time. This difference in appearance refers to the landscape as it is perceived by the human eye and as it is recorded by a remote sensing device (McCloy, 1995).

Researchers since the 1970's (Weismiller et al. 1977, Yuan et al. 1998) have used change detection procedures. Regardless of the method used (raw image differencing (Weismiller et al. 1977, Miller et al. 1978, Williams and Stauffer 1978), change vector analysis (Malila 1980), image ratioing (Howarth and Wickware 1981, Howarth and Boasson 1983), or unsupervised classification change analysis (Pacific Meridian Resources 1996)), careful selection of imagery is critical (Lunetta 1998, Pacific Meridian Resources 1996). This paper describes the importance of considering phenology in the data selection/acquisition process.

Most research combining phenology and remote sensing deals with the estimation or modeling of crop phenology using remotely sensed satellite imagery (Eidenshink et al. 1991, Reed et al. 1994, Skinner and Majorowicz 1999, Morain 1974, Caprio et al. 1974). No other study known to the author has used phenological correlates to drive the selection of satellite imagery. However, the effect of phenology has been recognized as an important consideration in the selection of satellite imagery (Lillesand and Kiefer 2000).

METHODS

To perform a phenological synchronization of satellite imagery, daily weather data for the area to be analyzed are required. Suitable data sets can be obtained from National Weather Service offices or via the Internet by accessing sites such as Agrimet (http://mac1/pn/usbr.gov/agrimet/webarcread.html). To use these data in Pheno-Calc software (available from the author at http://giscenter.isu.edu/software) the raw data set containing date, daily precipitation, and daily minimum and maximum temperature is saved as a Microsoft Excel spreadsheet. Once this procedure has been accomplished, the data are ready to be used in Pheno-Calc software.

Pheno-Calc operates as a 5-page wizard (computer software containing 5 successive and related screens). The first page requires the user to load a spreadsheet and identify the appropriate fields containing date, precipitation, minimum temperature, and maximum temperature. Users cannot proceed to subsequent pages until all information required on page 1 has been entered. The second page allows the user to specify calculation parameters such as the base temperature for growing degree day (GDD) calculation and whether GDD is allowed to fall below 0 (absolute GDD routinely falls below zero during winter and normally does not rise above 0 until late spring). In addition, page 2 is used to identify the 2 years to be analyzed. The third page allows the user to load the data set into memory, perform all required calculations, and graph GDD and/or accumulated precipitation (AP). These graphs should be studied closely to understand the timing and character of the precipitation and temperature regime for the selected years. The fourth page allows the user to view the completed data set in spreadsheet format. The fifth and final page of the wizard allows the user to request output such as saving the completed data set or calculating phenological matches based on either accumulated GDD or AP. To use this 'match-maker' tool, a base value (in GDD or precipitation units) and a tolerance value (in percent) are also required.

Perhaps the most useful tools of Pheno-Calc are its graphing capabilities and the 'match-maker' tool. The graphing tool allows the user to interactively query the data set, view calculated values for the selected data point, and visually align the phenology (or surrogates of phenology) for the two selected years. The match-maker tool supplies the user with a temporal window within which the GDD or AP has been calculated to be within the thresholds prescribed by the user.

By using these tools, the user can identify the date in each year where both phenological surrogates (GDD and AP) were most similar. Once specific dates have been chosen and a temporal window (the range of dates satisfying the user's criteria) has been identified, acquisition of satellite imagery proceeds normally.

RESULTS

Case Study: The Upper Snake River

Because of the potential bias introduced with the use of anniversary date synchronized satellite imagery, Pheno-Calc software was used to identify a temporal window where phenology was effectively the same between 1987 and 1997. To describe the phenology of our study area (Fig. 1) historical weather data was acquired for Aberdeen and Rexburg, Idaho (42.95°N 112.83°W and 43.83°N 111.79°W respectively) and Afton, Wyoming (42.75°N 110.96°W). These sites were chosen because the data was readily available in digital format and because the location of the sites best approximated the centroid of the landsat scenes used in this study. Because data for Aberdeen, Idaho was not complete from 1987 through 1997 the temporal window was based on data from the Rexburg and Afton sites (Table 1 and 2).

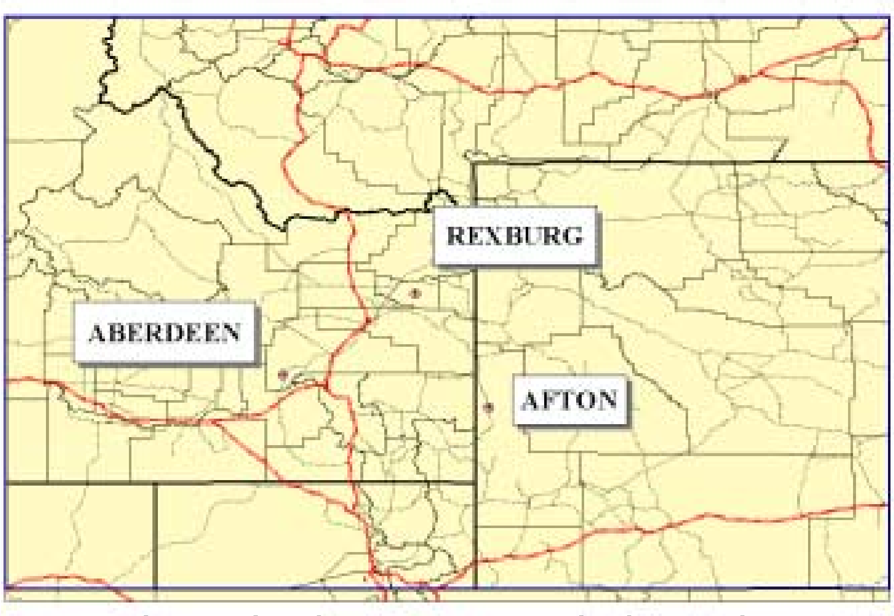

Table 1. Ideal imagery dates and temporal window (range of ideal dates) based on growing degree days (GDD) for the Rexburg (1) and Afton (2) sites (note: * indicates a phenological match based on GDD (e.g., using data for the Rexburg site (1) 24 June 1987 and 2 July 1997 were considered phenological matches)).

Month	Day	1987GDD	1997GDD	Site
6	24	231.54	339.89*	1
7	2	340.78*	406.31	1
7	3	315.19*	269.97	2
7	8	364.97	316.84*	2

Table 2. Ideal imagery dates and temporal window based on accumulated precipitation (AP) for the Rexburg (1) and Afton (2) sites sites (note: * indicates a phenological match based on AP (e.g., using data for the Rexburg site (1) 27 July 1987 and 4 April 1997 were considered phenological matches)).

Month	Day	1987 AP	1997 AP	Site
4	29	2.04	2.62*	1
6	9	10.99*	9.60	2
7	1	11.56	11.00*	2
7	27	2.63*	4.74	1

The temporal window based on GDD was 24 June - 8 July while the temporal window based on precipitation was 29 April - 27 July. Once the temporal window was defined we began to search for available Landsat thematic mapper data for our study area (http://edc.usgs.gov/webglis/). Ideally, all scenes for a given year would have been acquired on the same day, however this is not possible as a study area of this size (requiring 9 scenes over 3 paths) cannot be acquired on one day by Landsat thematic mapper. In addition, cloud contamination was a major impediment to the acquisition of satellite imagery.

The imagery selected for this research (Table 3) was recorded on dates that were within the previously identified temporal window but did not yield the perfect phenological matches as those dates identified in Tables 1 and 2.

Table 3. Growing degree days (GDD) and accumulated precipitation (AP) for the acquired imagery (note that while the dates of the acquired imagery do not match the ideal dates given in tables 1 and 2, they do fall within the identified temporal window).

Scene	‘87 GDD	‘97 GDD	‘87 AP	‘97 AP	‘87 Date	‘97 Date
Path 38- rows 29-31	460.85	379.96	13.52	12.68	20 July	15 July
Path 39- rows 29-31	223.96	197.30	11.12	10.95	25 June	20 June
Path 40- rows 29-31	303.43	395.89	11.56	12.68	2 July	16 July

DISCUSSION

Once a temporal window was specified, cloud contamination was a major concern in the selection of Landsat satellite imagery. Most of the acquired imagery contained little to no cloud cover. However some portions of the imagery were obscured by cloud cover requiring ancillary data sets (e.g., digitized cloud perimeters) to remove the cloud-contaminated areas from the imagery.

The temporal resolution of Landsat imagery (16 days) posed another problem in the selection process. Based strictly on GDD, our temporal window was only 15 days. That meant that in some areas no satellite imagery would be acquired during that time. Fortunately, we chose our temporal window to include the acquisition date of 1 set of imagery. Due to availability problems (i.e., EROS data center did not have access to some of the imagery) and cloud contamination concerns, the temporal window identified using GDD was not sufficient. Therefore, we were required to broaden the temporal window. The temporal window of the imagery we acquired ranged from 20 June - 20 July. These dates fell within the temporal window identified using AP. However, all but 2 of the imagery dates fell outside the temporal window identified using GDD. Under most circumstances, the user will need to identify a relatively broad temporal window in order for this selection technique to be successful.

The fact that the temporal window based on both GDD and AP ranged from 29 April - 27 July raises another concern. If satellite imagery were compared between these extremes the solar incident angle would vary substantially and thereby introduce an undesirable effect into the change classification due to bidirectional reflectance (cf., BDRF, Schott 1977, Lillesand and Kiefer 2000). For this reason, imagery was selected to reduce or minimize this potential bias. The solar incident angle and azimuth for the acquired imagery is given in Table 4. The range in elevation (3.89°) and azimuth (8.50°) among the acquired imagery is considered minimal.

Table 4. The solar incident angle and azimuth for acquired imagery (in degrees).

	Elevation	Azimuth
Mean	59.53	123.80
Standard deviation	1.14	2.30
Range	3.89	8.50
Minimum	57.35	120.46
Maximum	61.24	128.96

In some environments (e.g., short grass prairie (French and Sauer 1974, Rauzi and Dubrenz 1970)), precipitation influences vegetative growth more so than temperature (i.e., GDD). In these areas, defining the temporal window using AP may be more important than using GDD.

This study used an environmental calculation (GDD) and measurement (AP) as surrogates or correlates of phenology. It is important to understand that this technique cannot model phenology perfectly as many other variables are involved in determining the timing and rate of growth and senescence of plants. However, the author believes these variables are some of the most important and perhaps the primary variables driving a region's phenology. One variable that has not been taken into account however, is the precipitation and temperature regime from recent years (e.g., an 'average' rainfall year following previous 'average' rainfall years will not produce the same response in vegetation as an 'average' rainfall year that follows 3 years of drought). Another variable that should be addressed is the timing of precipitation. This can be accomplished by closely examining the graph of accumulated precipitation produced by Pheno-Calc (page 3 of the 5-page wizard). These variables should be investigated by the user and included in the decision making process.

While a comparison of change detection results using traditional anniversary date synchronization versus phenological synchronization is yet to be completed, the technique of using surrogates of phenology to select satellite imagery seems to be a valid one.

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