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Science Report: Phenology

Identification of Optimal Satellite Compositing Length Using GLOBE Budburst Measurements

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Abstract

Phenology, the study of recurring biological cycles and their connection to climate, is a critical and growing field of global change research. In particular, scientists now recognize that regular satellite monitoring of the timing and length of the terrestrial growing season is a valuable metric of biospheric responses to short- and long-term climate variability. While many methodologies exist with which to detect growing season dynamics, most have a poorly understood relationship to actual ground vegetation conditions. GLOBE schools, through participation in the budburst protocols, are helping to bridge this gap between satellite observations and ground conditions. In this research we show how GLOBE budburst data can be used to select the optimal satellite compositing length (a technique used to reduce cloud, snow, and atmospheric contamination). One- and two-week compositing lengths produced similar results, both of which were superior to monthly compositing. The longer compositing length, contrary to popular remote sensing lore, tended to predict an earlier initiation of growth due to removal of inflection points in the satellite greenness time series. Overall, the GLOBE budburst data were extremely useful but also contained several troubling artifacts probably relating to infrequent observation, errors in date reporting, and use of exotic species.

Introduction

Scientists investigating the short- and long-term variability of the land biosphere are increasingly recognizing that the study of the timing and length of the terrestrial growing season and its connection to climate is a crucial field of global change research (Menzel and Fabian, 1999; Myneni et al., 1997; Schwartz, 1998). In order to consistently monitor growing season dynamics over large areas, satellites must be used. Since the 1980s (Goward et al., 1985), this practice has grown rapidly and the field now includes many different methodologies, each slightly different and best suited to a particular research topic (Moulin et al., 1997; Reed et al., 1994; White et al., 1997). Regardless of which methodology is used, researchers need to know how the particular satellite algorithm corresponds to actual ground vegetation conditions. Failure to do so might, for example, results in the prediction of a photosynthetically active canopy when in fact none existed. This field of research, termed vegetation phenology, has an exceptionally long field measurement record in some areas, especially Japan and Europe (e.g. Sparks and Carey, 1995), but spatially extensive and consistently measured field datasets are rare.

To address this need, the GLOBE budburst protocols were developed in early 1998. In the protocols, students use a consistent methodology to measure the dates of budburst (initial leaf expansion) for dominant native tree species in their region. Early results from this research showed that the satellite methodology of White et al. (1997) corresponded well to the dates of budburst of the dominant overstory species as measured by the participating GLOBE schools (White et al., 1999).

In addition to understanding how satellite predictions of the growing season relate to ground conditions, it is also important to understand the impact that satellite processing itself has on prediction accuracy. One such processing feature is compositing (Holben, 1986), in which for a given period of time, the date with the highest recorded greenness (often measured by the normalized difference vegetation index, NDVI) signal is retained. The date of maximum greenness is assumed to represent the ground condition with minimal cloud, snow, and atmospheric contamination. Shorter compositing lengths increase the number of data points and the probability of residual cloud cover while longer compositing lengths reduce cloud cover and the ability to distinguish phenological events occurring over short time periods. For the purposes of satellite remote sensing of vegetation phenology, the ideal compositing length is that which produces the minimal difference between satellite predictions and ground observations. Here, our goal is to identify the ideal compositing length by comparing 1999-2000 data from the GLOBE budburst observation network with predicted onset of greenness computed from three commonly used compositing lengths.

Methods

We obtained weekly NDVI composit data from the Advanced Very High Resolution Radiometer for 1999 and 2000. The data were initially screened to remove obvious cloud cover and then reprocessed to biweekly and monthly composits. Thus, for any given pixel, three different time series were available for analysis. For each of these time series, we used the modified method of White et al. (1997) used in White et al. (1999) to predict the onset of greenness, a metric of the start of ecosystem level photosynthetic activity. To summarize, onset is predicted at the date on which the NDVI time series exceeds a site-specific NDVI threshold determined by a historical analysis. We then obtained data from the GLOBE budburst protocols. As of May 2001, over 800 budburst measurements concentrated in Western Europe and the eastern United States (Figure 1a) were available. Data showed patterns such as a later budburst at higher latitudes (Figure 1b) that were consistent with know phenological patterns. From the full dataset, we extracted 1999 and 2000 values. Excluded were 1998 due to low data availability (Figure 1c) and 2001 because, as of this writing, budburst was not complete. If more than one measurement existed, we used the average value for that site.

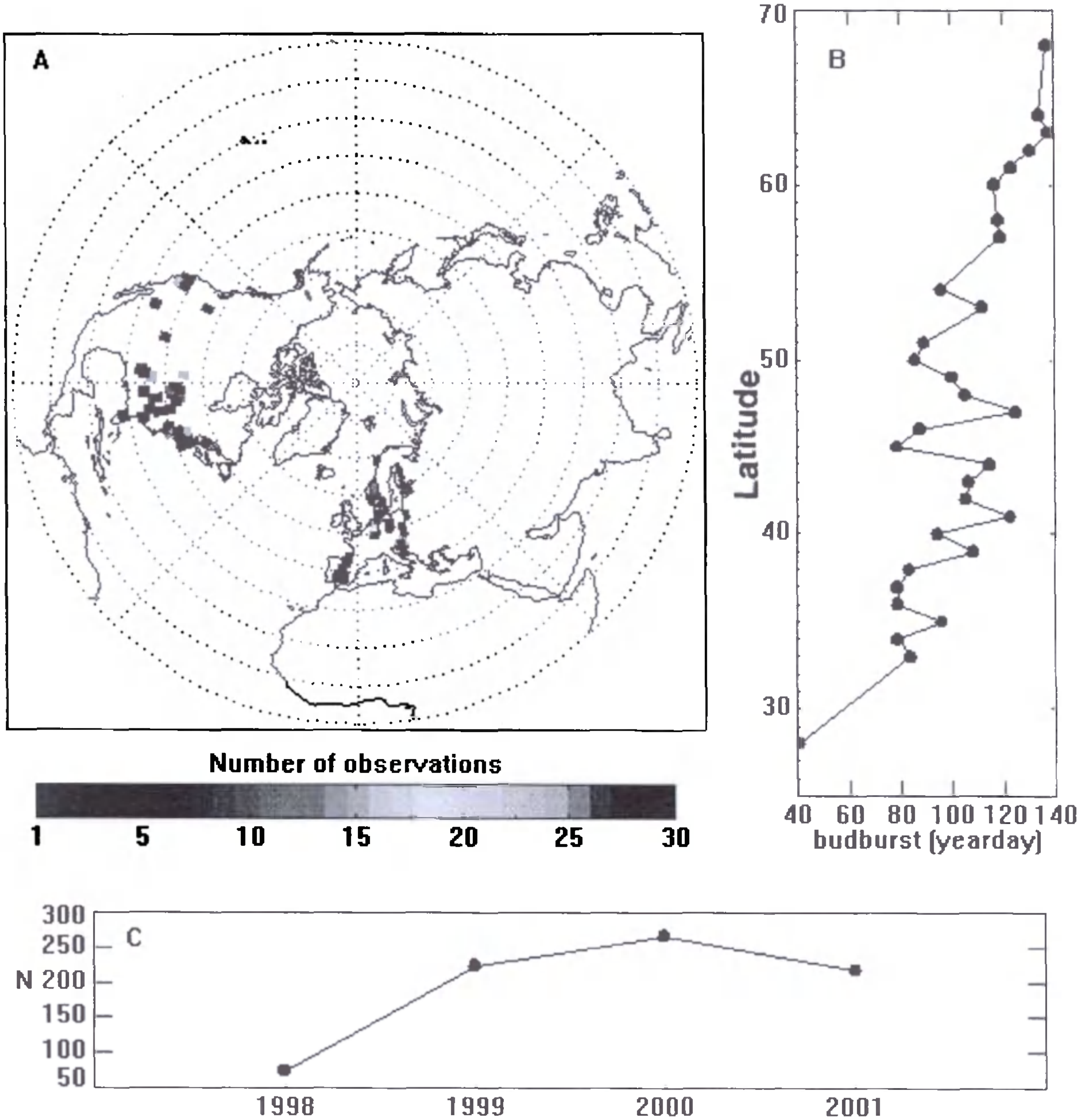

Figure 1

Following this initial data extraction, we screened the dataset in three ways. First, for both years, satellite data was unavailable in early composit periods and we removed any budburst observations that occurred before the date of first satellite availability. Second, we removed data points if the first NDVI value was greater than the threshold NDVI, indicating that onset occurred before the earliest available satellite data. Note that in order for our comparison to function, this second check had to be valid for all three composit lengths. As a comparison of the phenologies of different land covers in the same area will lead to large prediction errors, we lastly used the land cover map of Hansen et al. (2000) to remove all pixel coded as agricultural or grassland.

Results and Discussion

From the initial pool of budburst and satellite observations, seventeen cases remained with valid couplings of satellite predictions and budburst observations. Table 1 shows that weekly and biweekly compositing produced approximately similar mean absolute error results, both of which were superior to results from monthly compositing (bi-weekly slightly better). Median absolute error was also lowest for bi-weekly compositing, but highest for weekly. All median and mean absolute error values were less than the standard deviation of budburst (12.4 days), a prerequisite for any monitoring technique. Mean and median of satellite-predicted onset of greenness generally decreased with compositing length, contradicting the generally held precept that a generally increasing NDVI signal leading to selection of dates from later in the compositing period will cause prediction of late onset of greenness.

Table 1. Effects of compositing length. First two data columns show the difference between the satellite predictions of the onset of greenness and GLOBE budburst measurement. Last two columns show the effect on compositing length purely on satellite predictions.

	Mean absolute error	Median absolute error	Mean onset	Median onset
Weekly	**8.9**	**10**	**113.4**	**114**
Bi-weekly	**8.2**	**7**	**113.8**	**115**
Monthly	**11.2**	**9**	**105.8**	**106**

Figure 2 shows an illustration of the different composit lengths and their effect on prediction accuracy. In Figure 2a, the weekly composit data still retains considerable jaggedness in the NDVI time series and one data point at about yearday 216 with apparent cloud contamination that escaped both the compositing and cloud-screening processes. Figure 2b shows that by expanding the compositing length to two weeks, a much smoother NDVI time series results with, in this case, a slight improvement in detection accuracy. At a monthly time step, the NDVI curve is fairly straight and lacks the inflection point seen in Figure 2b. This linearization of the NDVI time series and the removal of the curved portion of the curve at about the time of onset is the main cause for the earlier onset seen at monthly compositing lengths.

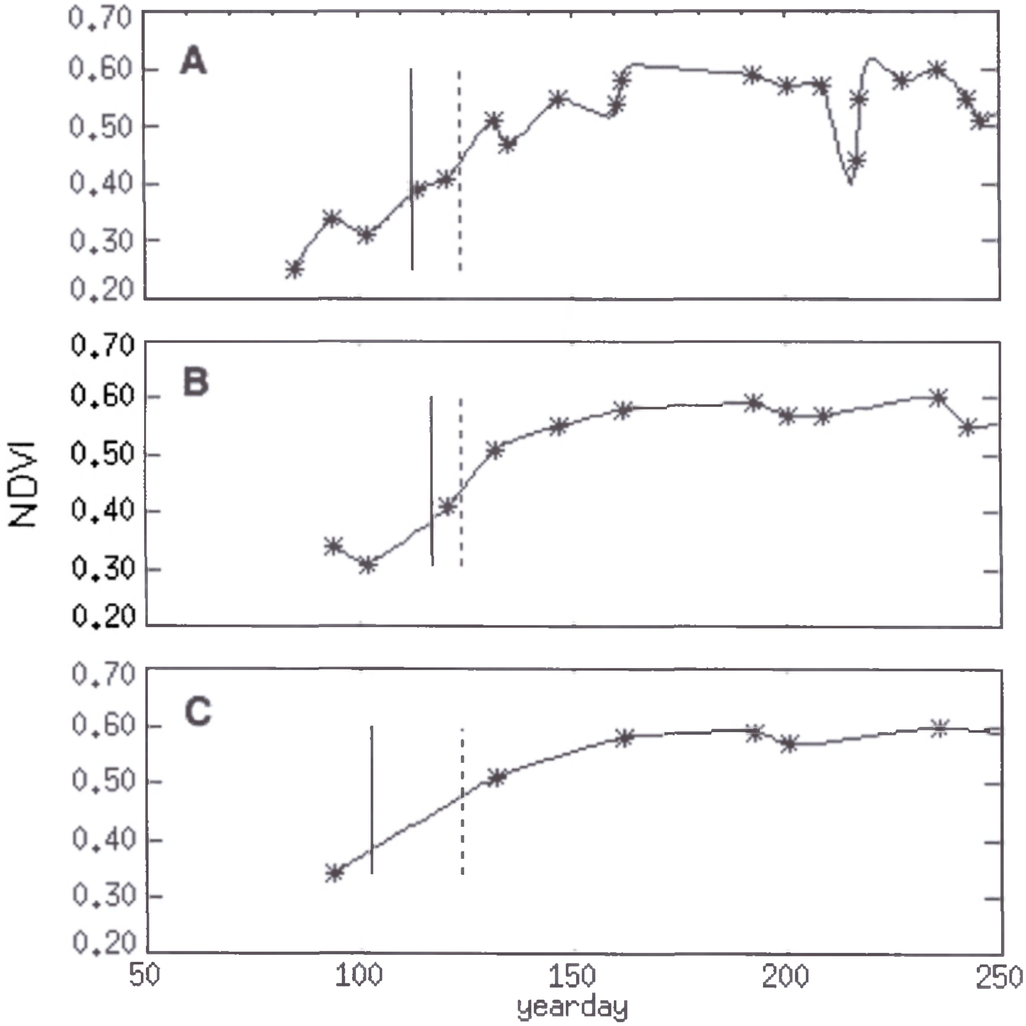

Figure 2

Although Table 1 shows apparent accuracy differences given different compositing lengths, the Kruskal-Wallis H-test showed no significant differences between the three sets of predicted-observed differences. A t-test between the bi-weekly and monthly differences produced a P-value of 0.056, still not significant by most standards. We suspect, however, that given a larger dataset, differences would indeed be statistically significant. Although not provable with the current results, our data suggest that a two-week compositing period is most appropriate for phenological studies of the land biosphere.

Our results showed that the GLOBE budburst dataset could be used to assess the effects of compositing length on the accuracy of phenological detection. However, several issues with the budburst data advocated a cautionary approach. First, many schools reported the identical budburst date not only for several individuals of the same species, but also for different species. This is a highly unlikely occurrence and probably means that the students were unable to visit the observations trees with sufficient regularity. Most likely, on the date they actually did visit the site, all trees had experienced budburst and this date was recorded for all individuals. Second, in one site reporting different species, maples had budburst one month earlier than oaks in one year and two months earlier in another. It is common for maples to initiate growth earlier than oaks, but the offset should be approximately constant. Reported exotic species, such as Siberian Elm, are often quite phenologically different than the satellite time series and may produce larger errors than if native species alone had been used. These and other issues imply that (1) the schedule of requested daily visits for the budburst protocol may be overly optimistic, (2) reporting errors, as in reporting of dates, may exist, and (3) students and teachers should be encouraged to choose widely representative native species for the protocol.

Figure Captions

Figure 1. GLOBE budburst data. A) distribution of schools participating in the GLOBE protocols. Colors indicate the number of observations individual schools have recorded from 1998-2001. B) Budburst observations within each 1° latitude band averaged from 1998-2001. C) Number of budburst observations from 1998-2001.

Figure 2. Impact of compositing length on budburst detection accuracy. A) weekly, B) bi-weekly, and C) monthly. Solid vertical lines show the onset of greenness yearday predicted from the satellite algorithm. Dashed vertical lines show the yearday of budburst. Budburst data are for *Quercus rubra* from Henniker Community School in New Hampshire.

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