A New Hybrid Method for Remote Sensing VI Time Series Reconstruction

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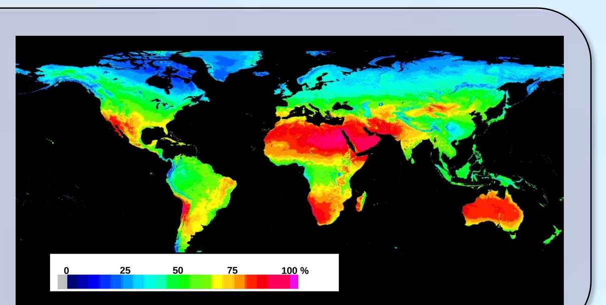
Introduction

Vegetation indices (VI) are useful proxies for studying vegetation states and dynamics. Three decades of daily global satellite images are currently available, however, the presence of clouds, aerosols, variable viewing geometry and inefficient processing algorithms render most of this daily data of little value to change studies (as much as 80% of the data are either missing or of marginal usefulness, Figure 1). In order to improve the temporal frequency and coverage of these data various gap filling techniques were proposed. Most of these methods are based on the use of smoothing techniques, like Fourier Transform Functions, Gaussian models, or multi-day compositing techniques.

Here, we're proposing a new technique that aims at producing consistently high quality VI data, while preserving adequate temporal resolution to support accurate land surface vegetation change research. The method is based on finding the seasonally variable per-pixel optimum composite period and then applying a simple interpolation technique to address the remaining gaps. The method is constrained by a moving window long term average to address biases that may result from data outliers.

Figure 1: A 30-year combined AVHRR and MODIS measure of the VI record reliability. This global map illustrates the 'probability' of finding useful remote sensing data in the 30-year record of Earth Observing by AVHRR &MODIS. Most vegetated biomes reveal a considerable lack of reliable data, in particular the Boreal and Tropical Forests (due to cloud, biomass burning, and snow, etc…).



Objectives

1. To develop a gap filling technique that improves the temporal characterization of the land surface and preserves the integrity of data in support of accurate change studies.

2. To evaluate the performance and reliability of this gap filling method.

Data and Methodology

We used the daily global 0.05° resolution MODerate Resolution Imaging Spectroradiometer (MODIS) Terra collection 5.0 data record (starting March 2000). MODIS provides daily data surface reflectance and quality information about clouds, shadow, presence of ice and snow, and aerosol loads. We computed a daily NDVI and estimated the long term average and standard deviation from the highest quality data in the record using the reliability index developed for MODIS VI product suite (Didan & Huete, 2006).

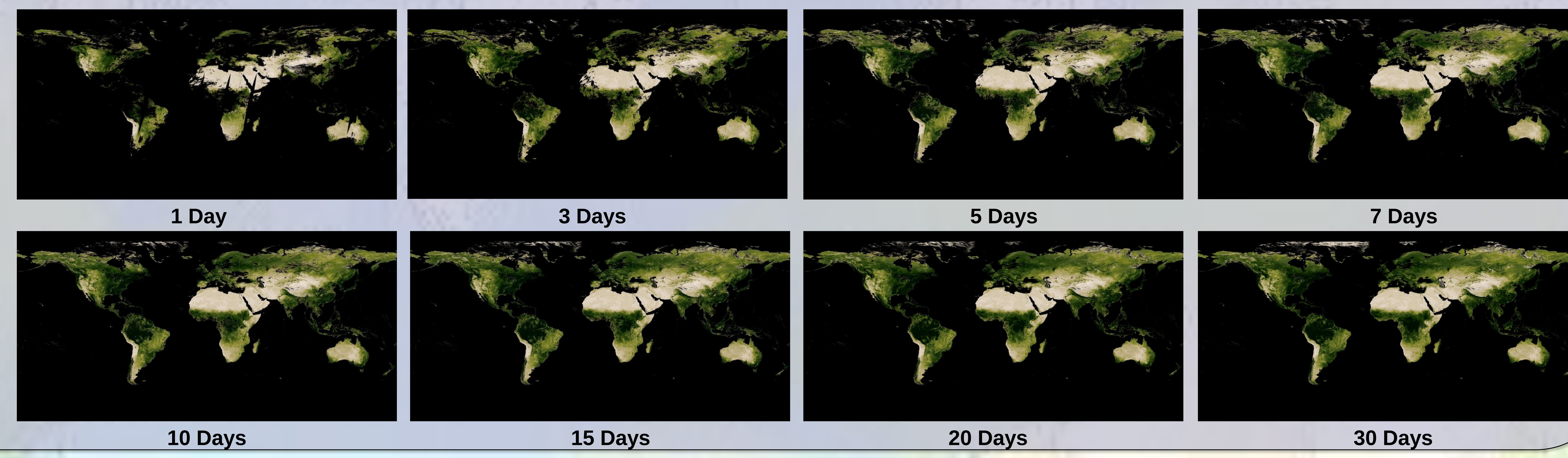
We then constructed several multiday data records using the *maximum-value composite (MVC)* technique (Holben 1986) with different composite intervals to determine the optimum compositing period length. For each day added to the compositing period, the percent of pixels with high quality data increased. An ad hoc fuzzy logic function was used to describe the positive impact of adding more days to the composite period versus the negative impact of missing change that happens over shorter periods of time. A longer period guarantees high quality data but less frequency, versus shorter period lack of good data but better frequency.

This fuzzy logic function assumes the following:

1. Besides sudden disturbance, there should be minimal to no change in vegetation in a period of one to three days. So composite periods 3 days or less are scored the highest.
2. With periods longer than sixteen days (16 days was conveniently selected because it represents MODIS revisit period) change detection becomes discrete and inaccurate. With longer periods, the vegetation phenology characteristics start to be biased (MVC tends to select the later days of the period during the start of season and the earlier days during the senescence period). Longer composite periods are then scored low.
3. A linear function is used to score composite periods in between high and low scores.

Optimal Compositing Period

Figure 2: We composited the NDVI using periods ranging from 2 to 50 days with one day increment. Within 5 to 7 days a reasonably full global coverage is achieved. Any additional days tend to contribute very little, because clouds and other problems persist over particular areas for very long periods of time (cloudy season for example in the tropics). Even after 50 days there was still spatial gaps.



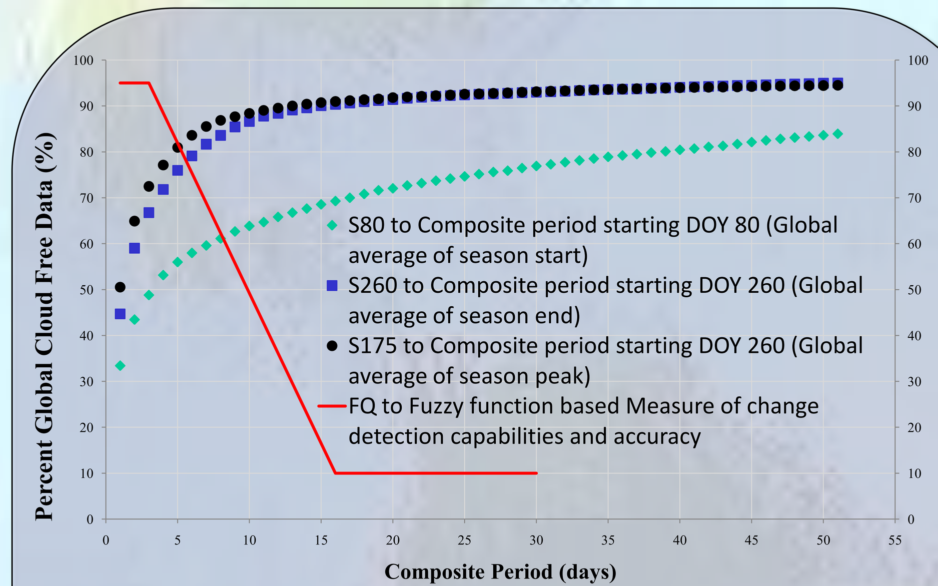


Figure 3. Optimum compositing period length corresponds to the intersection between the % cloud free data curve and the Fuzzy score function (FQ).

For a typical annual VI phenology curve, the rising and descending limbs represent the faster changing phenological periods, therefore our interest is to be able to find the composite period that guarantees enough data points to describe these vegetative phases. The composite period analysis was limited to looking at days around day of year 80 (Average global start of growing season), day of year 260 (Average global end of growing season), and day of year 175 (Average global peak of growing season). Figure 3, shows the performance of the different composite periods, suggesting optimal results are achieved when using 5 to 7 days.

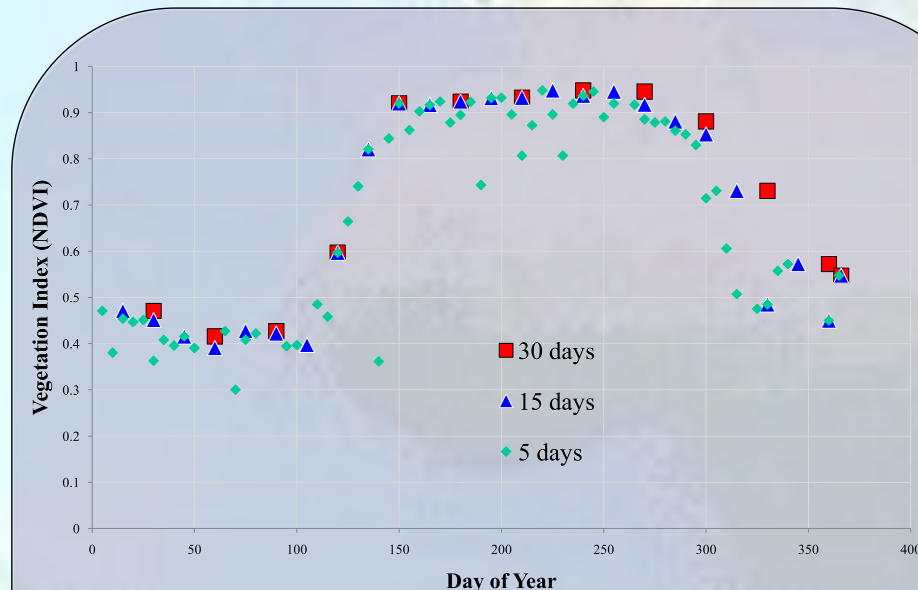


Figure 4: Impact of compositing period length on growing season characterization. Longer compositing period tend to shift the phenology curve and consequently changes the start, end and other growing season parameters.

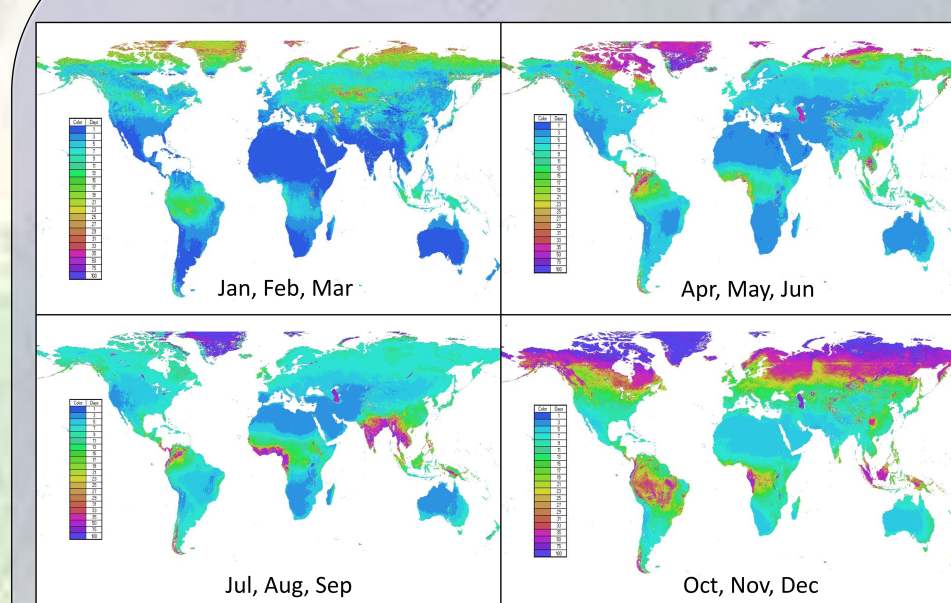


Figure 5: Seasonal mean of the number of days between useful observations based on the analysis of Terra MODIS 10-year record of daily observations. This indicates that even very long composite periods are unable to address gaps over certain areas.

Filtering and Gap Filling

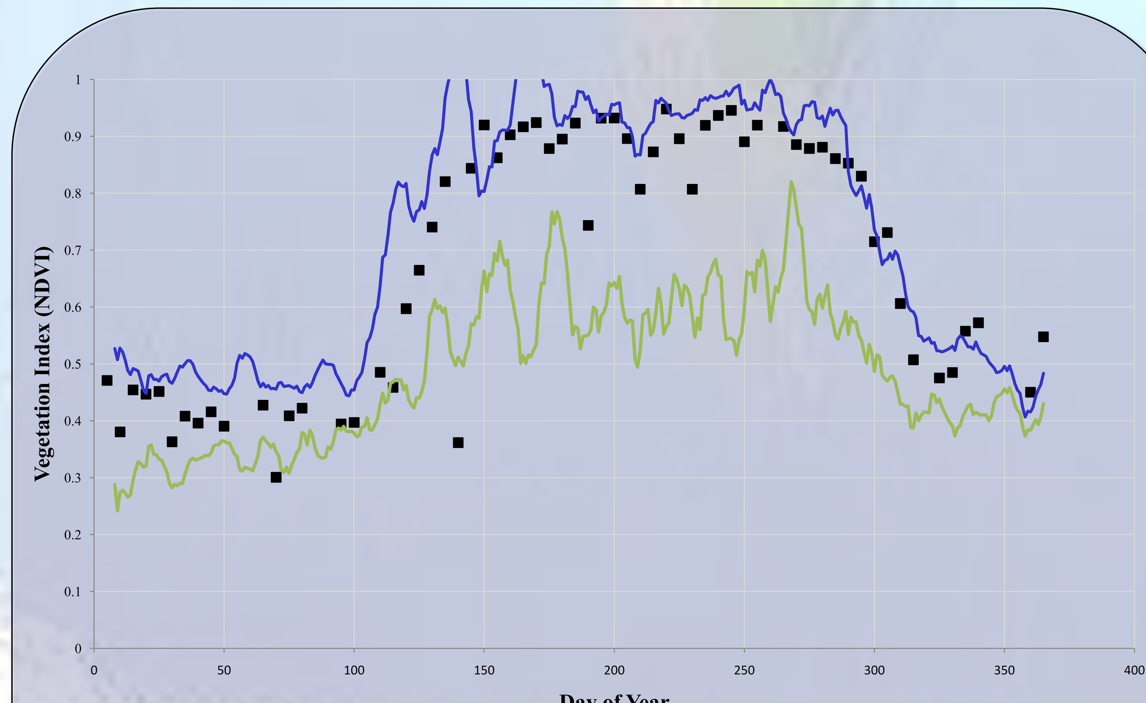


Figure 6: MODIS Terra 5-day NDVI Time Series (black squares) for the year 2008 (US East coast) constrained by the long term average (blue and green lines are long term average ±σ).

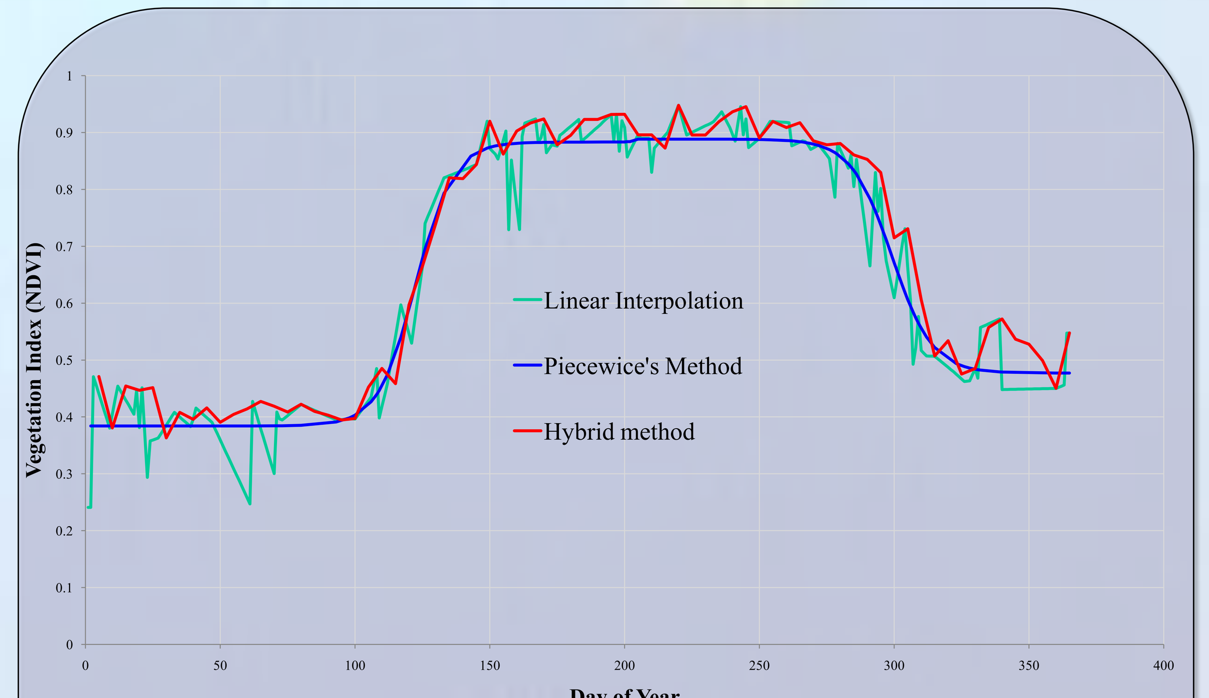


Figure 7: New Hybrid method versus simple Linear interpolation and the Piecewise logistic method (Zhang et al., 2003)

Two different data gap filling techniques were applied to the 2008 MODIS Terra NDVI Time Series (US East coast). Our new Hybrid method (Inverse Distance Weighting (IDW) method) in comparison to the Piecewise and linear interpolation methods. Although all methods were similar, our method minimized the noise/error associated with the linear interpolation and avoided the excessive smoothing of the piecewise logistic or similar methods.

Inverse Distance Weighting Method

Once the data is properly composited to retain the highest quality data only, the resulting gaps are filled using the Inverse Distance Weighting (IDW) method. This method estimates the missing data by using a moving window. The IDW method is based on the assumption that the interpolation should be influenced most by the nearby points and less by the more distant points. The following equation describes this method:

$$VI_j = \frac{\sum_i \frac{VI_i}{d_{ij}^n}}{\sum_i \frac{1}{d_{ij}^n}}$$

Where:

VI_i is the vegetation index value of the known points

d_{ij} is the distance to the known point

VI_j is the vegetation index value of the unknown point

n is a user defined power parameter (often 1, 2 or 3)

Gaps are filled with IDW method using a 10-day moving window.

Conclusions

Our analysis shows that the global composite period length should be close to 5-7 days. This insures a balance between the need for a short composite period to detect small change and high quality data. The remaining gaps are then filled using the IDW method.

This new hybrid method has several advantages:

1) It is simpler and less computer intensive,
2) It is superior to other methods since it only looked at the data around the temporal gap which helps eliminate the biases that may result from methods that simultaneously need the full annual cycle, and
3) It kept a balance between providing higher frequency and higher quality data without the noise associated with daily data while avoiding the excessive smoothing of other methods.

This new method did however show sensitivity to residual noise in the composited data and more advanced filtering techniques are needed to alleviate this issue.

This method is currently being implemented as a package to support the estimation of global phenology and to generate high quality long term Earth System Data Records of Vegetation Index from multiple sensors.

References

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