

ON CURRENT COMPOSITING ALGORITHMS

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ABSTRACT:

Several techniques exist for compositing the multitemporal Advanced Very High Resolution Radiometer (AVHRR) data for vegetation studies. The major pixel selection criteria of these techniques rely on the characteristics of the NDVI: appearance of clouds, poor atmospheric conditions, and off-nadir viewing geometries would depress the NDVI values. Consequently, selecting the pixels with the maximum value of NDVI would presumably eliminate these external perturbing effects. However, the maximum NDVI does not always correspond to these ideal conditions. In fact, the NDVI varies with these external factors in an unpredictable way. There was an indication that the maximum NDVI tended to favor the off-nadir view in the forward direction. The resultant composite product would be consequently affected. To improve the multitemporal data via compositing, therefore, both the pixel selection criteria and the classifier NDVI need to be modified or corrected for external factors. In this study, the current compositing algorithms were reviewed, and alternatives were proposed to use the combinations of the red and near-infrared channels and biological characteristics of vegetation as second criteria in pixel selections. In addition, the traditional classifier NDVI was replaced with different vegetation indices. The new approach was applied to an AVHRR data set over Hapex study site in Niger in 1992. The results showed that the new approach improved the AVHRR time series quality and was promising towards the development of an efficient compositing algorithm. The new approaches will be presented and limitations will be further discussed.

KEY WORDS: Composite, AVHRR, Vegetation Index, Remote Sensing, Satellite

INTRODUCTION

The advanced very high resolution radiometer (AVHRR) on the National Oceanographic and Atmospheric Administration (NOAA) satellite series has been the major sensor that provides scientists with continuous remote sensing data at regional and global scales over much of the Earth's surfaces for global change studies. The major constraints of the AVHRR data have been both generic and external problems. The generic problems include the radiometric calibrations of the sensors, especially the first two spectral channels for which no on-board calibration is available. The external problems are caused by cloud masking, atmospheric contamination, geometric registration, and sensor viewing angle variations. Consequently, the observed AVHRR data contain substantial uncertainties, preventing scientists from making a quantitative analysis of the Earth's vegetation dynamics (Gutman, 1991).

Compositing techniques have been used to reduce uncertainties due to external factors, especially due to clouds masking. These techniques involve choosing a subset of data that are cloud-free and have least atmospheric contaminations from a large data set. Several techniques exist for compositing. The most popular one is the maximum value compositing (MVC) algorithm proposed by Holben (1986). This algorithm first defines a compositing period within which the normalized difference vegetation index (NDVI) classifier is assumed to change little. Within each compositing period, the pixel with the maximum value of NDVI is selected. The rationale behind this is that clouds or poor atmospheric conditions or larger off-nadir view angles depresses NDVI value. Selecting the maximum value of NDVI presumably reduces the chances of obtaining cloud-masked, atmosphere-contaminated, and off-nadir viewing angle data. Because this technique employs a single pixel selection criterion (maximum NDVI), the quality of the composited data relies on the characteristics of the NDVI.

Although major noises, especially the cloud-masking, can be reduced substantially, problems remain because of the nature of the NDVI classifier and because of the lack of precise pixel selection criteria. The NDVI is vulnerable to soil background variations (Huete, 1989) and atmospheric conditions (Kaufman, 1989; Goward et al. 1990). The maximum NDVI favors off-nadir viewing angles in the forward directions (D'Iorio et al., 1990 and 1991). Subsequent selection of highest NDVI may, therefore, be biased toward larger off-nadir view angles. In addition, the atmosphere and the view angle effects are coupled (Qi et al., 1994a). Reduction in one noise may be offset by an increase in another type of noise.

The pixel selection criteria of current compositing algorithms are not specific enough to eliminate all of these external factor-related noises as only a single criterion is employed. Besides, selecting one pixel with each compositing period may ignore the real variations of NDVI due to vegetation changes such as anomalies. Consequently, pixel selection based solely on the highest NDVI may not ensure high data quality and the MVC procedure may also result in losses of valuable data. To improve composited data quality and restore data losses by MVC, current compositing algorithms and the classifier need to be revised. The objective of this study is to give a general review of existing compositing algorithms together with their classifiers and propose alternatives for compositing multitemporal remote sensing data sets.

CURRENT COMPOSITING ALGORITHMS

Several algorithms exist for compositing multitemporal remote sensing data sets. Besides the MVC algorithm as discussed above, other techniques have also been practiced by adding secondary pixel selection criteria such as minimum channel 1 (Min Ch1), or maximum channel 4 (Max Ch4) of the AVHRR data (D'Iorio et al., 1990; Goward et al., 1990). These techniques involve two-step pixel selections. The first stage of pixel selection retains a range (10 percent) of maximum NDVI values within each composite period. Then, a second stage pixel selection is performed using a secondary criterion.

The Min Ch1 secondary criterion selects the pixel with the minimum value in channel 1 from the AVHRR pixels retained after the first stage of pixel selection. This technique is based on the reflectance characteristics of clouds. Clouds have much higher reflectance values in channel 1 than do other terrestrial surfaces. Selecting the pixels of minimum channel 1 could further reduce the chances of choosing cloudy pixels. The remaining problem, however, is the shadowing caused by clouds. The use of Min Ch1 as an additional criterion would choose those shaded pixels.

The Max Ch4 secondary criterion selects the pixel with the maximum value in channel 4 from the AVHRR pixels retained after the first stage of pixel selection. This technique is based on the thermal properties of clouds. When clouds or cloud-created shadows are present in a pixel, the thermal channel response of the AVHRR will be low. Selecting the pixels exhibiting the maximum thermal channel within a range of NDVI would prevent the cloud and shadow-affected pixels from being selected when better choices are available. Another approach is to set a threshold on the temperature derived from channels 4 and 5 as the pixel selection criteria, which is not discussed further here.

Viovy et al. (1992) proposed a best index slope extraction (BISE) algorithm that uses vegetation growth pattern as its secondary pixel selection criteria. The BISE examines each pixel and selects pixels according to whether the pixel value matches the vegetation growth pattern. In a time series, the BISE searches forward and accepts the following day pixel if the NDVI is larger than that of the previous one. A sudden drop in NDVI will be accepted, however, only if there is no pixel, within a predefined period, that has an NDVI larger than 20 percent of the difference between previous high and previous low values. If such a pixel exists, then the previous low value will be ignored; otherwise, the low value will be selected. The rationale behind this is that the compositing classifier (NDVI) should follow the vegetation pattern (steady growth followed by senescence). If any anomaly occurs, vegetation recovers slowly. Therefore, sudden decreases in the NDVI classifier should be regarded as due to external effects unless there is a gradual increase in the next few days. The BISE has advantages over the simple MVC because it retains more valuable data but does not ignore sudden changes caused by anomalies. The disadvantages, however, are that this algorithm may select severely cloud-contaminated data when clouds occur suddenly but disappear slowly.

ALTERNATIVES

Alternatives for Compositing

Noise in composited products was not only from using the NDVI, but also from the compositing algorithms used. Therefore, alternative algorithms should be investigated to obtain reliable data products. The following ones are listed as alternatives:

Average (AVG). In the first attempt, the maximum value, and down to 10 percent of the maxima, were averaged within each compositing period. This algorithm uses a group value of vegetation index (VI) instead of using a single maximum value. This is similar to a moving window average in that it uses mathematical averages, but it differs in that it only averages those pixels whose values are within a certain range. These remaining pixels (10 percent) were presumably not affected by clouds or poor atmosphere. Another underlying assumption is that the chances of large view angles are equal to those of small view angles. The extremes induced by large view angles extremes would be averaged with other pixels of small view angles. Consequently, the spikes due to view angle variation will be smoothed out, resulting in a smoother temporal profile.

Minimum View Angle. Selecting surfaces. Selecting angles are preferable could be minimized keeps the maximum From these remaining variations among the conditions. Consequently, Because of the bidding than the MVC.

Slide Window (SW). pixel selections. Station one and will accept both that pixel and While searching for there is a pixel with there are no pixels value, within the slide and the marked low values, the marked from the date of the date. The advantages reduces the chance than the length of time

Choice of Classifier

Sensitivity analysis studies. For compositing selected the following

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- 2) Soil adj
- 3) Modified
- 4) Global

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RESULTS AND CONCLUSIONS

Data Set Description

The data set used in this study was collected at Hapex Sahel station and tiger bushes. At November. The data NDVI profiles of the showed no significant extremely high reflectance were due to line-draw values for these pixels

Minimum View Angle (Min View). The NDVI tends to favor off-nadir in the forward direction for natural terrestrial surfaces. Selecting the maximum NDVI, therefore, creates a bias toward large view angles. In practice, nadir view angles are preferable because of reduced atmospheric path and bidirectional effects. Consequently, the view angle effect could be minimized by selecting the pixels with view angles nearest to the nadir. To implement this goal, the algorithm keeps the maximum and down to 10 percent of the maxima in each composite period (same as in AVG algorithm). From these remaining pixels, the one with the smallest view angle will be chosen. Again, the assumption is that variations among the remaining pixels are due to the view angles rather than due to the clouds or the atmospheric conditions. Consequently, the view angle effects will be minimized, and cloud-affected pixels will not be selected. Because of the bidirectional effects, this algorithm would, in general, tend to result in a lower vegetation index profile than the MVC.

Slide Window (SW). Instead of using either the BISE or the MVC criteria alone, this algorithm combines the two in pixel selections. Starting from the first date, the algorithm searches forward. It compares the next pixel with the previous one and will accept it if greater than the previous one. When a vegetation index suddenly decreases, the algorithm marks both that pixel and the previous one. It then continues to search forward for a maximum of n days (slide window). While searching forward, it compares each pixel with the previously marked high pixel value. It will stop searching if there is a pixel with a value higher than the previously marked high pixel. Then a new search starts from that date. If there are no pixels with a value higher than the previously marked high pixel, the algorithm will compare the maximum value, within the slide window period, with the previously marked low pixel. If the difference between the maximum and the marked low value is greater than 20 percent of the difference between the previously marked high and low values, the marked low value pixel will be ignored and the maximum will be selected. A new search will then continue from the date of the maximum. Otherwise, the marked low pixel will be selected, and a new search started from that date. The advantages of this algorithm are that it (1) keeps more valuable data than the MVC, (2) detects anomalies, (3) reduces the chance of selecting cloudy pixels, as in BISE, and (4) selects the cleanest pixels if clouds persist for more than the length of the slide window period.

Choice of Classifier

Sensitivity analysis (Qi et al., 1994a) indicated that the choice of vegetation indices is dependent upon the purpose of studies. For compositing satellite data at regional and global scales for arid and semiarid land surface studies, we selected the following vegetation indices:

- 1) Normalized difference vegetation index (NDVI):

$$NDVI = (\rho_{NIR} - \rho_{red}) / (\rho_{NIR} + \rho_{red}); \quad (1)$$

- 2) Soil adjusted vegetation index (SAVI) of Huete (1988):

$$SAVI = (\rho_{NIR} - \rho_{red}) / (\rho_{NIR} + \rho_{red} + L) (1 + L); \quad (2)$$

- 3) Modified soil adjusted vegetation index (MSAVI) of Qi et al. (1994b):

$$MSAVI = \{ [2 \rho_{NIR} + 1 - \sqrt{(2 \rho_{NIR} + 1)^2 - 8 (\rho_{NIR} - \rho_{red})}] \} / 2; \quad (3)$$

and

- 4) Global environmental monitoring index (GEMI) of Pinty and Verstraete (1992):

$$GEMI = \eta (1 - 0.25 \eta) - (\rho_{red} - 0.125) / (1 - \rho_{red}), \quad (4)$$

where

$$\eta = [2 (\rho_{NIR}^2 - \rho_{red}^2) + 1.5 \rho_{NIR} + 0.5 \rho_{red}] / (\rho_{NIR} + \rho_{red}). \quad (5)$$

RESULTS AND COMPARISONS

Data Set Descriptions

The data set used in this study consisted of daily AVHRR data acquired during 1992 of four different vegetation types at Hapex Sahel study site (Table 1) near Niamey Niger. The vegetation types included fallow, degraded fallow, millet, and tiger bushes. All possible 1.1 km resolution AVHRR data were acquired since early April till the beginning of November. The data were geometrically, but not atmospherically corrected. The temporal reflectances in red, NIR, and NDVI profiles of these four study sites are presented in Figure 1. Although differed in vegetation types, these four sites showed no significant difference in reflectance before compositing algorithms were applied. The cloud-induced noises, extremely high reflectances in both red and NIR spectral regions, can be easily identified and those zero reflectances were due to line-drops. These noises can be reduced by compositing since the resultant NDVI classifier had very low values for these pixels.

Table 1. Locations and vegetation types of Hapex Sahel study sites selected in this study.

Station_name	Latitude	Longitude	Location
Millet Site - H2SIS Team	13.538833	2.513917	Central West
Fallow site - H2SIS Team	13.542333	2.513333	Central West
Degraded Fallow site - H2SIS Team	13.553167	2.568	Central West
Tiger Bush Site - H2SIS Team	13.502167	2.578667	Central West

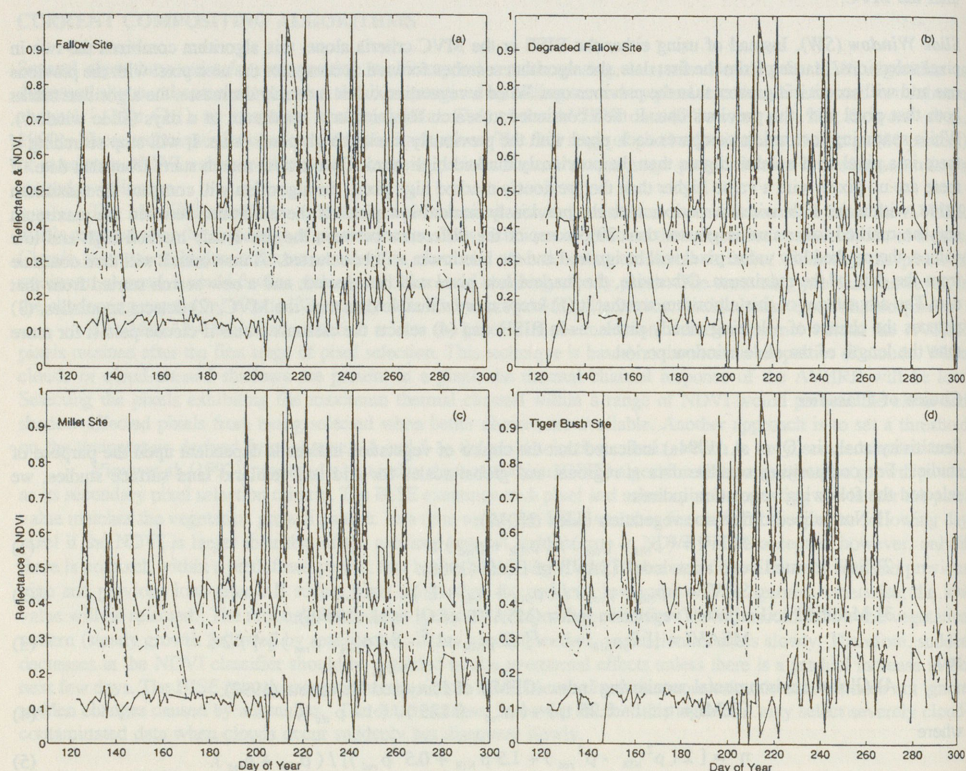


Figure 1. Temporal Red (dotted line) and NIR (solid) reflectance profiles and corresponding NDVI (solid with dots) for Fallow (a), Degraded Fallow (b), Millet (c), and Tiger Bush (d) study sites.

Comparison of Different Algorithms

The AVG, Min View are compared with the MVC, Min Ch1, and Max CH4 because of the similarities in the numbers of retained pixels, and the SW was compared with the BISE because of their similarities in the following analysis.

The AVG, Min View, Min Ch1, and Max Ch4 are compared with the MVC algorithm in Figure 2 for the four study sites, with the NDVI as the classifier. In general, the composited results of the four algorithms are similar in temporal variations and in that they showed some variations among the study sites. For the Tiger Bush site, there are little differences among these algorithms, while for Millet and Degraded Fallow sites the AVG resulted in a lower profiles than other algorithms. The similar results from different compositing algorithms may have been due to several reasons. First, although the pixel selection criteria (highest NDVI, minimal view, maximum Channel 4, or minimum Channel 1) were different, they all corresponded the same condition where NDVI is maximum. Second, the choice of pixels within each compositing period is limited by the available number of candidate pixels. In some periods, there

was only one or two selected by these algorithms, unable to pick anomalies for AVG, resulted in

The results profiles in Figure 3 for the SW and the solid lines and the variations of the NDVI both SW and BISE resulted in apparently due to the and Tiger Bush sites can be described as not result in sharp at the BISE, but never.

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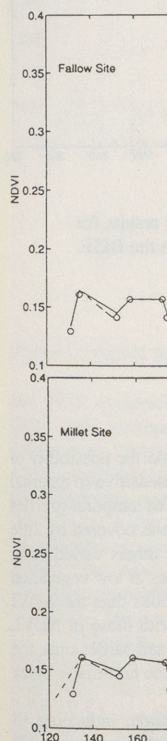


Figure 2. (line), Min (a) Fallow

was only one or two available pixels, restricting the alternatives for pixel selections. Third, only one pixel was to be selected by these algorithms with each compositing period, the detailed variation within each period may have been lost, unable to pick anomalies occurred within compositing period. Consequently, all of these compositing algorithms, except for AVG, resulted in the similar temporal profiles of NDVI of the four study sites.

The results from SW algorithm is compared with that from BISE algorithm and the raw NDVI temporal profiles in Figure 3 for the four selected study sites. The dotted lines are the NDVI temporal profile before compositing, and the solid lines are that of BISE, while the dashed line is that of SW algorithm. One can see some detailed variations of the NDVI evolutions were retained for the four study sites, even within each composite period. Apparently, both SW and BISE retained more valuable pixels than that of MVC, or Min Ch1, or Max Ch4, or Min View, or AVG. The BISE resulted in a profile that capped the NDVI in general. However, it sometimes also selected pixels that were apparently due to the appearance of clouds such as the sharp and deep valleys at day of year (DOY) of 248 at Millet and Tiger Bush sites and at DOYs 254 and 256 for the Tiger Bush site (Figure 3). The general pattern of the BISE can be described as if the BISE 'walked' on the top of the NDVI, skipping most valleys. In comparison, the SW did not result in sharp and deep valleys, and it can be said that the SW 'walked' on the top of the NDVI profile, as did the BISE, but never fell into the valleys.

Both the SW and the BISE, in general, reduced the high frequency noises as seen in the NDVI profiles caused by external factors but retained more valuable pixels than MVC and other algorithms. One unique feature of both the SW and the BISE temporal profiles was that the deep valleys almost always corresponded to a temporal discontinuity. Some compositing periods had a limited number of pixels, sometimes only one or two. Because the small number of pixels limited the choice for pixel selections, the noise (if any) after compositing probably would most likely be resulted from the lack of data. Because of the discontinuity of the data sets, the BISE and the SW selected lower value pixels. This shortcoming of the BISE and SW can be overcome by increasing the slide window (or compositing period). However, increasing the slide window period will result in the loss of valuable data.

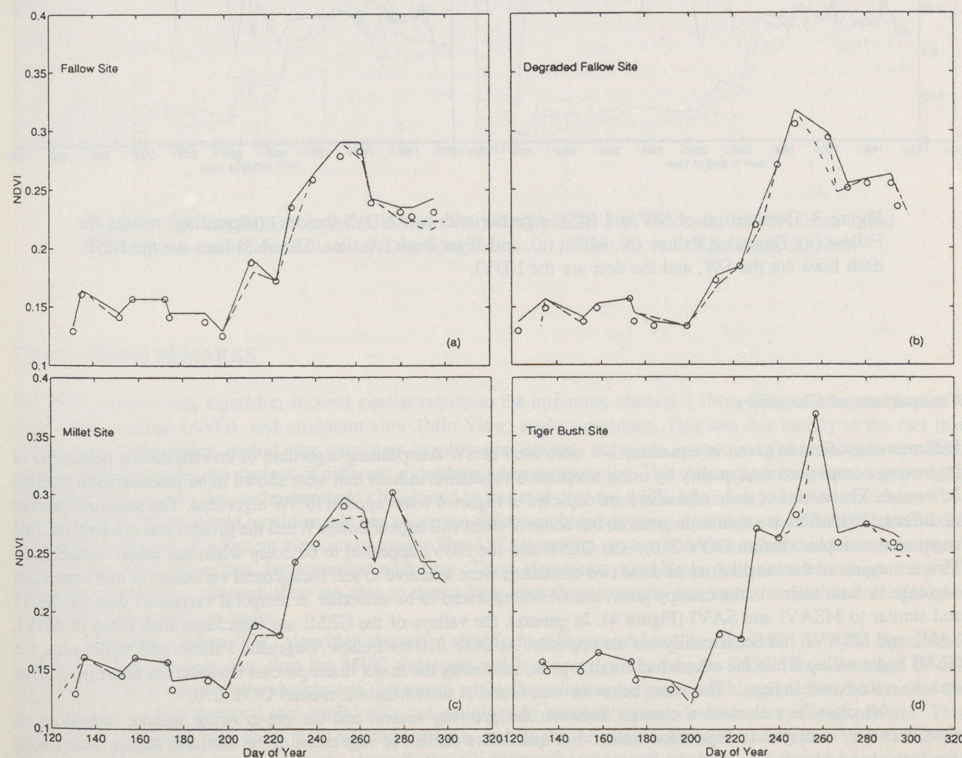


Figure 2. Compositing results of the four selected sites using MVC (solid lines), Min View (dotted line), Min Ch1(dash lines), Max Ch4 (long dashed line), and AVG (circles) compositing algorithms. (a) Fallow sites, (b) Degraded Fallow site, (c) Millet site, and (d) Tiger Bush site.

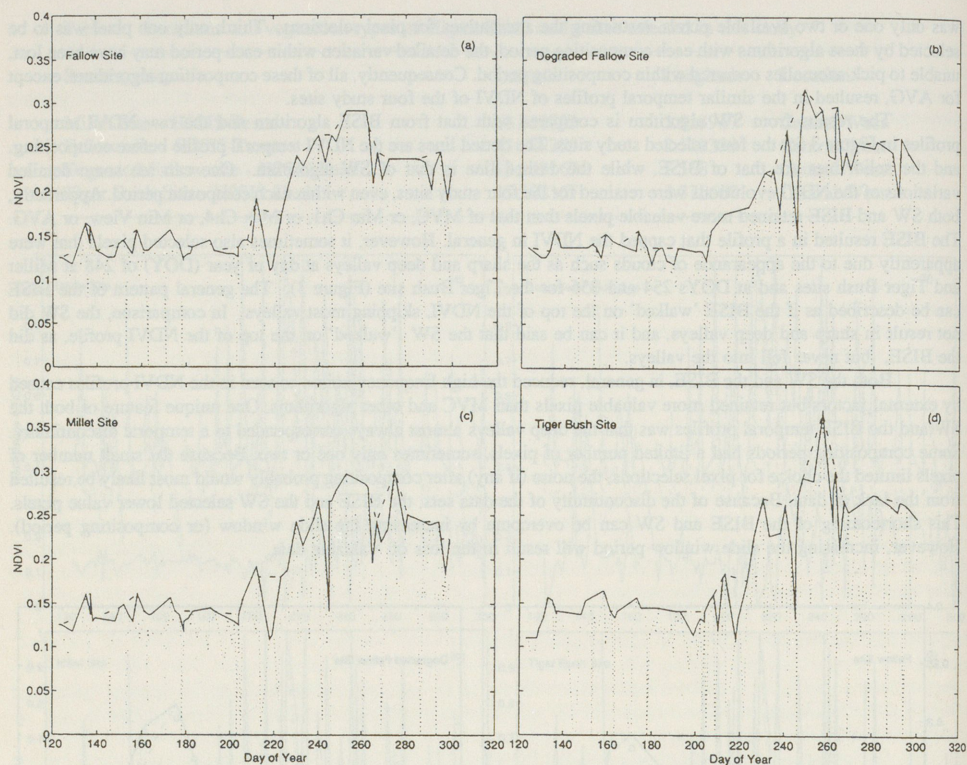


Figure 3. Comparison of SW and BISE together with raw NDVI (before compositing) results for Fallow (a), Degraded Fallow (b), Millet (c), and Tiger Bush (d) sites. The solid lines are the BISE, dash lines are the SW, and the dots are the NDVI.

Comparison of Classifiers

Different classifiers as given in equations 1-4 were used in SW compositing algorithm to investigate the possibility of improving composited data quality by using alternative vegetation indices that were shown to be insensitive to external influences. The results of these classifiers are depicted in Figure 4 when applied to SW algorithm. The temporal profiles of different classifiers are similar in general, but some of them still appear noisy. When the ground was covered by little vegetation canopies (before DOY 210), the GEMI and the NDVI appeared to be noisy while the others varied little. This is because of the sensitivities of these two classifiers were sensitive to soil background variations at low vegetation coverage or bare soils. As the canopy grew, the GEMI appeared to be smoother in temporal variations than the NDVI and similar to MSAVI and SAVI (Figure 4). In general, the valleys of the GEMI are coincident with those of NDVI, SAVI, and MSAVI, but occasionally are the opposite. At DOY 210 for Fallow, Degraded Fallow, and Millet sites, the GEMI had a valley while the others had small a peak, indicating the major discrepancies between the non-linear index and the ratio-based indices. The same behavior was found at the Millet site around DOY 270.

All classifiers showed a contrast between the growing season and the pre-growing season, indicating all classifiers were sensitive to vegetation status. For qualitative studies of vegetation in the semiarid region, where soils dominate the remote sensing spectral signatures, the MSAVI and SAVI appeared to be better as they were less sensitive to soils, and therefore, were smoother in temporal profiles. However, for quantitative studies, the noises occurred in the temporal profiles of all classifiers tested need to be further quantified since all classifiers appeared to be noisy, although differed in degree.

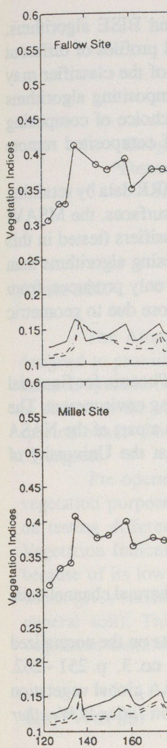


Figure 4. Comparison of GEMI and NDVI results for Fallow (a), Degraded Fallow (b), Millet (c), and Tiger Bush (d) sites. The solid lines are the GEMI, and the dots are the NDVI.

CONCLUDING R

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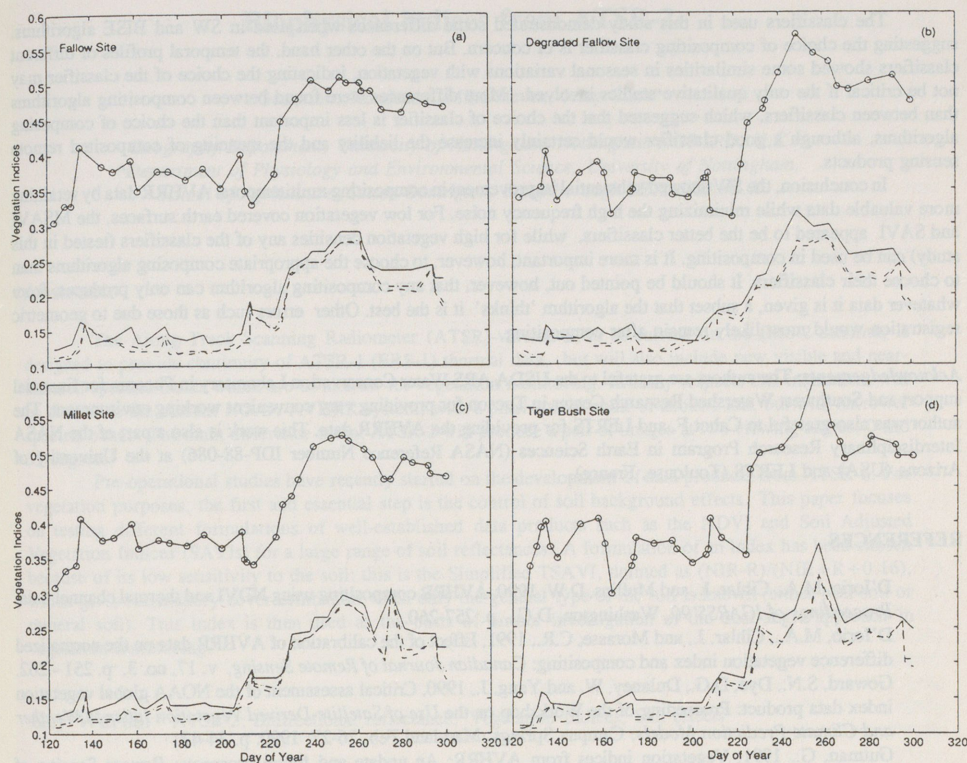


Figure 4. SW and BISE composited results with NDVI (solid), SAVI (dotted), MSAVI (dash), and GEMI (with circles) for Fallow (a), Degraded Fallow (b), Millet (c), and Tiger Bush (d) sites.

CONCLUDING REMARKS

The MVC compositing algorithm showed similar results to the minimum channel 1 (Min Ch1), maximum channel 4 (Max Ch4), average (AVG), and minimum view (Min View) angle algorithms. This was due mainly to the fact that within each compositing period, the candidate pixels were limited, only one or two available in some periods, consequently restricting the choices of different algorithms when compositing. This similarity among these compositing algorithms may also be due to the threshold (20%) used in this study for the AVG, Min View, Min Ch1, and Max Ch4. The increase in the threshold would enable one to see the difference between these algorithms and the MVC, but would also increase the risk of selecting more noisy pixels. The AVG algorithm appeared to have resulted in a lower temporal profiles than other algorithms, but smoother with time. These algorithms most likely omit short-term (high temporal frequency) anomalies, although they are able to detect long term (low temporal frequency) anomalies such drought, which may last months to years.

The slide window (SW) algorithm showed a significant difference from either the BISE or MVC algorithms. It retained more valuable data than the MVC and contained less noisy pixels than the BISE. The advantage of this algorithm is that it retained all valuable data (no waste) while discarding noisy pixels, enabling scientists to monitor the earth surface in a fine temporal step confidently, not omitting any anomaly occurred within compositing periods. This algorithm is dependent both on its pixel selection criteria, such as the threshold (20% in this study) and on its classifier used. A good classifier would certainly increase the reliability of composited products. It should be pointed out, however, all of compositing algorithms did not take geometric registration into account. Uncertainty in geometric registration may be up to several pixels and, therefore, causes problems since all existing compositing algorithms are on "pixel-to-pixel" bases.

The classifiers used in this study demonstrated some differences when used in SW and BISE algorithms, suggesting the choice of compositing classifier is of concern. But on the other hand, the temporal profiles of different classifiers showed some similarities in seasonal variations with vegetation, indicating the choice of the classifier may not be critical if the only qualitative studies involved. More differences were found between compositing algorithms than between classifiers, which suggested that the choice of classifier is less important than the choice of compositing algorithms, although a good classifier would certainly increase the liability and the meaning of composited remote sensing products.

In conclusion, the SW showed substantial improvement in compositing multitemporal AVHRR data by retaining more valuable data while minimizing the high frequency noise. For low vegetation covered earth surfaces, the MSAVI and SAVI appeared to be the better classifiers, while for high vegetation densities any of the classifiers (tested in this study) can be used in compositing. It is more important, however, to choose the appropriate compositing algorithms than to choose their classifiers. It should be pointed out, however, that any compositing algorithm can only produce, from whatever data it is given, a subset that the algorithm 'thinks' it is the best. Other errors such as those due to geometric registration would most likely remain after compositing.

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