Smoothing Vegetation Index Profiles: An Alternative Method for Reducing Radiometric Disturbance in NOAA/AVHRR Data*

Albert van Dijk†
Cooperative Institute for Applied Meteorology, University of Missouri-Columbia, 701 Hitt Street, Columbia, MO 65211
Susan L. Callis and *Clarence M. Sakamoto*
NOAA National Environmental Satellite, Data, and Information Service/Assessment and Information Services Center, Federal Building, Room 200, 608 E. Cherry St., Columbia, MO 65201
Wayne L. Decker
Cooperative Institute for Applied Meteorology, University of Missouri-Columbia, 701 Hitt Street, Columbia, MO 65211

ABSTRACT: The NOAA satellites are becoming an increasingly important source of information for crop condition assessments. However, the data collected by sensors onboard the NOAA-N satellites are seriously disturbed radiometrically due to complex radiative interactions between atmosphere, sensor view angle, solar zenith angle, and vegetation canopy structure. Correction procedures for radiometric disturbances are still being developed and, as of yet, have not been quantified. Therefore, a method has been devised to reduce the effects of radiometric disturbances on remotely-sensed data without quantitative knowledge of the variable interactions that cause them. The method involves deriving composite weekly vegetation index values from the daily values for the area to be assessed followed by a "smoothing" of the weekly values over a selected period of time.

INTRODUCTION

SATELLITE REMOTE SENSING TECHNIQUES offer an alternative source of information on the key influences which are known to affect crop growth. Yield for a particular growing season can be predicted from knowledge of the level and types of stress the crop endures during its developmental stages (Hall, 1982; Henderson *et al.*, 1984). Accurate agrometeorological information at the time of stress is seldom available. A joint study by the University of Missouri Cooperative Institute for Applied Meteorology (CIAM) and the National Oceanic and Atmospheric Administration (NOAA) Assessment and Information Services Center (AISC) has applied vegetation indices derived from polar orbiting satellite data to crop condition and yield assessments.

One of the major advantages of using satellites for agricultural investigations is that multitemporal data can be economically acquired over large areas. Multitemporal data allow comparisons of spectral characteristics of vegetation through an entire growing season (Hall, 1982; Crist, 1984). However, because the data are collected on different days, they reflect differences in atmospheric conditions, positions of the sun, view angles of the sensor, and sensor calibration. These differences constitute the radiometric disturbances present in remotely sensed data and reduce the quality of the data. Any of these variables alone can cause significant day-to-day differences in sensor response, and a combination of the variables can cancel or reinforce the variability.

Calibration data have been used successfully to adjust for systematic and slowly changing radiometric variability of the sensor (Hall, 1982; Murphy *et al.*, 1985). However, the procedure to correct for differences in atmospheric conditions is very complex and requires information on solar zenith angle, background albedo, atmospheric vapor and aerosol content, and scattering and absorption thickness (Dave, 1981). It is not feasible to obtain this information on a routine basis. Investigators, therefore, have developed empirical procedures to correct for the influence of the atmosphere on radiance, without knowing exact atmospheric conditions, e.g., Atcor algorithm (Potter, 1977), X-star procedure (Lambeck, 1977), and using calibration data (dark level subtraction method (Brown *et al.*, 1982)). These procedures are only approximate and may, in some cases, incorrectly adjust the measured radiance (Dave, 1981; Kaufman and Fraser, 1984).

Information about the sensor view angle and the position of the sun is usually known. However, the reflectance interactions between the vegetation canopy and the sensor view angle and solar zenith angle are very complex. Canopies are non-isotropic diffuse reflectors; that is, they do not uniformly reflect light in all directions. Their bidirectional reflectance factors alter as their properties change during the growing season and as the view angle and solar angle change (Colwell, 1974; Egbert and Ulaby, 1972; Jackson *et al.*, 1979; Kimes, 1983; Vanderbilt *et al.*, 1981). Changes in the density, the optical properties, and the geometric structure of the vegetation during development as well as changes in geometric structure of the soil background reflected alter the radiance measured by satellite (Kimes, 1983; Kimes *et al.*, 1985). Research in this area is in progress but correction factors for these alterations have not yet been quantified (Ranson *et al.*, 1985). To better understand radiance interactions, different theoretical canopy reflectance models have been developed (Suits, 1972, 1983; Cooper *et al.*, 1982; Kimes and Kirchner, 1982). However, according to Shibayama and Wiegand (1985), the models are still incomplete and more experimental data are needed to validate and improve them.

The problem of radiometric disturbances and their impact on reflectance data still exists. This paper proposes a method to reduce the noise-to-signal ratio found in remotely sensed data without precise knowledge of the interactions which cause it.

MATERIALS AND METHODS

NOAA polar orbiter satellite data were selected by NOAA/AISC and CIAM over Landsat data for their large area crop condition and crop yield assessments. The reason for this choice is that the NOAA Advanced Very High Resolution Radiometer (AVHRR) satellite data exhibit features considered advantageous for operational crop condition and yield assessments. These are

- High temporal resolution. Daily coverage allows a greater chance for cloud-free images.
- Low spatial resolution.
- Ensured collection with world coverage.

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† Presently with DHV, P. O. Box 85, 3800 AB Amersfoort, The Netherlands.

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- Low cost.
- Real-time availability.

However, the data collected by AVHRR sensors onboard the NOAA-N satellites are more radiometrically disturbed than are the Landsat data. This is because the NOAA-N satellites have a greater scan angle (56°) either side of nadir than Landsat MSS (5.5°) and TM (7.5°).

A NOAA AVHRR product used for worldwide crop condition assessment is the Global Vegetation Index data set (Kidwell, 1983, 1985) which consists of Channel 1 (0.58 to 0.68 μm) and Channel 2 (0.73 to 1.10 μm) reflectance values for each picture element (pixel), as well as the Difference Vegetation Index $[DVI = (Ch_2 - Ch_1) + 100]$ and the Normalized Vegetation Index $[NVI = (Ch_2 - Ch_1/Ch_1 + Ch_2)]$ for each pixel. The Channel 1 and Channel 2 values were sampled from Global Area Coverage (GAC) data with a resolution cell of 4.5 km² which were collected daily for the entire world. Because of the sampling process, a pixel of the Global Vegetation Index data set, which has been geometrically corrected (SDSD, 1983; Kidwell, 1985), has a resolution cell of 4.5 km² but represents an area of 16 km².

Daily difference vegetation index (DVI) values for one pixel covering the same location during one growing season are indicated in Figure 1 by a small dot (·). It can be seen in this figure that the daily vegetation index data is too erratic to use for interpretation of crop conditions. The selection of the greenest pixel within the week, indicated by a large dot (●) in the figure, corrects somewhat for the radiometric variation in the data. However, problems arise when a gray level (or a color) (see Figure 1 for a sample scale) is assigned to each weekly vegetation index value to produce an image. When two images produced six weeks apart are compared, the increase or decrease in the vegetation index due to the increase or decrease in vegetation (signal) will be greater than the radiometric disturbances (noise). The change of gray tone, then, can be interpreted as an increase in green biomass, and a statement can be made about the vegetation development in the area. On the other hand, when images for consecutive weeks are compared, the noise can be greater than the real increase or decrease in signal. The changes in gray scale, then, are more related to the radiometric disturbances than to the change in green biomass. This limits the use of the images for agricultural interpretations.

To delete some of the noise due to radiometric disturbances, weekly composites (Kidwell 1983, 1985) of each channel value and each index value of the Global Vegetation Index Product were derived for each pixel. Composites are derived by retaining the highest daily value for the week, thereby removing the maximum amount of clouds. Channel 1, Channel 2, and NVI values for all the pixels in the northwest crop reporting district (CRD) of the U.S. State of Illinois (CRD1) were each averaged and plotted in Figure 2. Eighty-eight percent of this CRD is planted in summer crops (i.e., 70 percent maize and 18 percent soybean). The development of vegetation (mainly summer crops) during the growing season is evident in the figure as increasing NVI values. It can also be seen that there is a great deal of week-to-week variation in Channel 1 and Channel 2 values due to radiometric disturbances. However, the variations in Channel 1 are strongly correlated with the variations in Channel 2. Although the NVI curve is smoother and seems to partially correct for radiometric disturbances, there are still large, unexplained week-to-week variations that need to be addressed.

A proposed way to reduce the effects of radiometric disturbances is to average the vegetation index over adjacent pixels, provided the terrain's spatial variability is not too great. The seven-day composite vegetation index (VI) values averaged over 36 pixels are represented in Figure 1 by "C" and a connecting line. Although using weekly instead of daily VI values and averaging over an area reduces the radiometric disturbances, the profile still exhibits high frequency noise variations.

It could be implied from Figure 1 that, by increasing the number of weeks (e.g., four to six weeks) for a composite, the noise could be reduced even further. These composite images, however, would include pixels representing vegetation conditions at moments four to six weeks apart. This means that, in any one image, the crops would be at completely different stages. The task of evaluating vegetation vigor at critical crop stages would be impracticable.

Techniques of curve fitting or filtering vegetation index profiles by eliminating selected fluctuations are available. They are based on the assumption that reflectance $X(t)$ is the sum of signal $S(t)$ and noise $N(t)$, where $S(t)$ and $N(t)$ are independent of each other (Parzen, 1967; Tukey, 1977). The noise $N(t)$ is known to consist of very high frequency components compared to the signal $S(t)$. Smoothing is an attempt to reduce the amount of noise and make the signal the main component of the curve. In the case of the vegetation index profile, the vegetation index, which reflects the green-up of vegetation during the growing season, and environmental conditions of interest such as agricultural drought have frequency waves of several weeks and can be regarded as signal components of the profile. View angles and atmospheric conditions such as haziness and cloudiness will change frequently and will add a high frequency component or noise to the signal.

The method proposed for reducing the noise found in re-

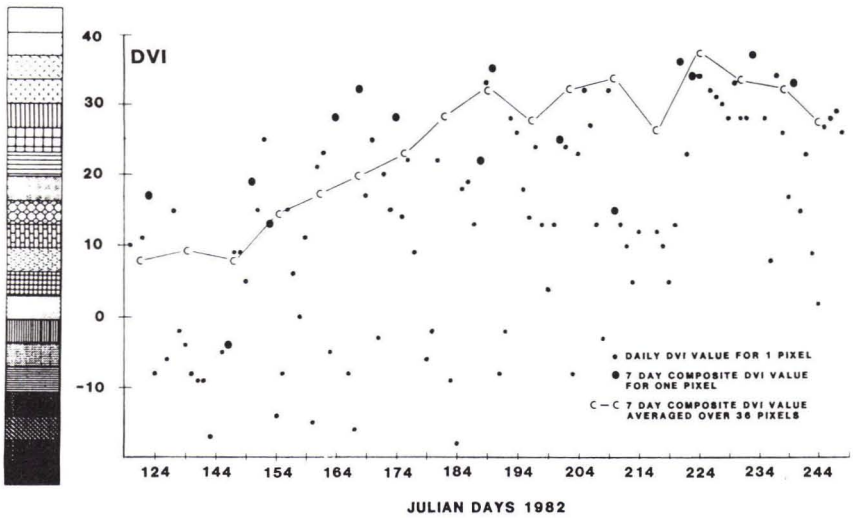

FIG. 1. Comparison of daily Difference Vegetation Index (DVI) and weekly composite DVI Data for 1982 of Meteorological Station Ft. Wayne, Indiana (van Dijk, 1986).

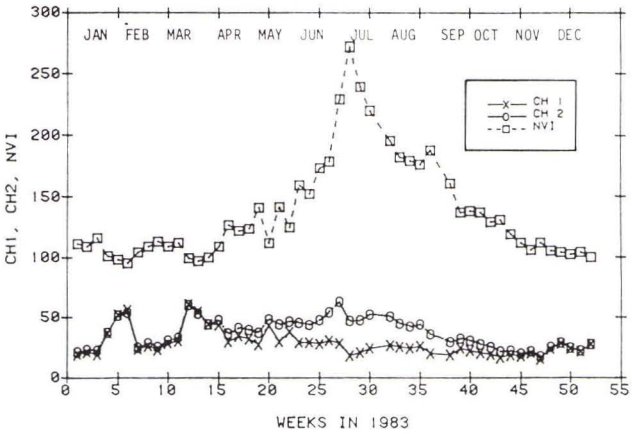

FIG. 2. Time-series of Channel 1, Channel 2, and NVI (× 100) of Illinois CRD1, 1983.

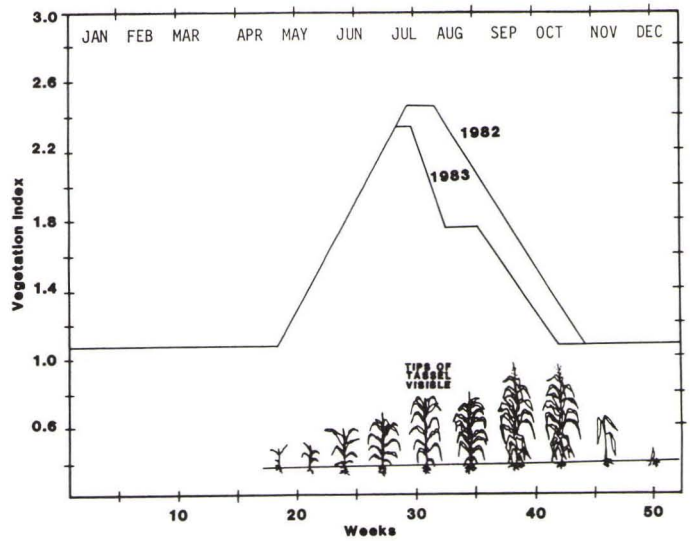

FIG. 3. Schematic representation of Vegetation Index of IA060 for 1982 and 1983.

motely sensed data involves four steps. First, as can be seen in Figure 2, the high frequency waves in the visible channel are strongly related to the high frequency waves in the near infrared channel. A vegetation index (Rouse *et al.*, 1973) is selected which is either a ratio or the difference between the visible and near infrared reflectance. In addition to the NVI and DVI already defined, the Ratio (RVI) is another commonly used vegetation index and is defined as CH_2/Ch_1. A vegetation index partially corrects the data for radiometric variations. Second, weekly composite vegetation index values are derived for each picture element from the daily values using the highest value (least amount of clouds) for the week. Third, vegetation index values of several pixels are averaged to derive a value for a selected area. Fourth, a smoothing technique is applied to a vegetation index time-series for the area.

Six different smoothers, (1) polynomial, (2) Fourier, (3) mean, (4) median, (5) "4253H, twice," and (6) "3RSSH, twice" (which will subsequently be described) were applied to vegetation index profiles for two areas: one area is a crop reporting district in Iowa (IA060), and the other is an area in West Central Thailand (described later). The selection of a preferred smoothing method is an exploratory process and depends upon user requirements, among other things. The requirements in this study are that the smoothing method selected eliminate atmospheric and view angle effects and that the smoothed profile represent the vegetation development of an area.

Beginning and endpoints in a time series cannot be smoothed because data do not proceed or follow them. Profiles of Chad and Niger are used to illustrate a proposed method to improve unrealistic beginning and endpoints.

EXAMPLES, ANALYSES, AND RESULTS

IOWA EXAMPLE

In IA060 the main vegetation type is corn; it occupies about 30 percent of the land surface. The shapes of the vegetation index profiles for IA060 for 1982 and 1983 reflect the growing conditions for corn during those years. Schematic 1982 and 1983 profiles for IA060 are provided in Figure 3. The end of July and the beginning of August 1983 were very hot and dry. The weekly Crop Moisture Indices (CMI) (Palmer, 1965) cited by the *Weekly Weather and Crop Bulletin* (1983) were below −3 during this period, indicating that potential yields would be severely reduced by drought. Crop conditions improved somewhat during the last week of August and the first week of September (weeks 35 and 36) and the CMI rose to around −2.5. After that, crop conditions again worsened and the CMI again fell below −3. The unfavorable crop growing conditions in 1983 resulted in a yield decrease of about 35 percent for corn compared to 1982. In 1982, the same crop area experienced little stress and the smoothed vegetation index profile was bell-shaped with one peak at the time of maximum greenness, that is, when the tips of the tassels were first visible. According to the *Weekly Weather and Crop Bulletin* (1982), tasseling occurred around July 22 or week 30 (beginning from January 1). The 1983 profile had a different shape due to the stress the crop experienced. The peak of the 1983 profile was lower and earlier than that of the 1982 profile. Furthermore, the rate of decrease after the peak was greater in 1983 than in 1982. There was a lower rate of decrease in the 1983 profile around week 35 due to the improved crop conditions at that time.

The following curve fitting and filtering techniques were applied to the vegetation index profile of IA060 for 1983.

Curve Fitting. Curve fitting is one way to smooth a high frequency or noisy curve. It is one approach to detect hidden periodicities based on the theory that a "fitted" curve does not pass exactly through all data points (James *et al.*, 1977). The curve fitting techniques discussed in this study are based on polynomials and Fourier series.

Polynomials may be linear ($y=ax$) or of a higher order relationship, e.g., quadratic ($y=ax^2$), cubic ($y=ax^3$), etc. As an example, in Figure 4 the profile of IA060 was fitted with a fifth degree polynomial. A polynomial of a higher order could also have been used to fit the curve to even more datum points. In

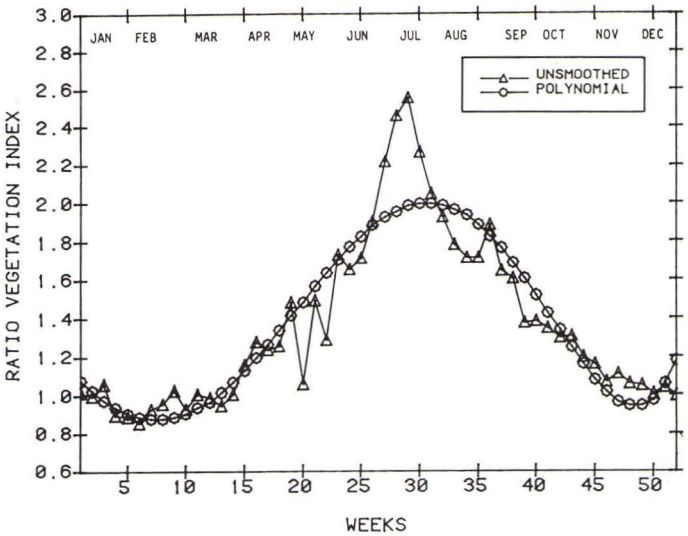

FIG. 4. RVI smoothed with polynomial curve fitting for IA060, 1983.

determining the order of the polynomial, some predetermined knowledge of the characteristics of the data (including environmental conditions under which they were collected and the types of crops involved) should be known. The fitted curve is a measure of the trend (gradual change with time) and residuals (original data minus trend) that reflect local conditions (Chatfield, 1975). The question should be asked: Are the fitted fluctuations reasonable in light of what is known about the crop calendar and environmental conditions? As seen in Figure 4, a fifth-order polynomial disregards too many high and low RVI values and smoothes the data too much. In general, polynomials only work well when the profile is nearly straight or when there is some principle that points to the use of a particular kind of polynomial (Tukey, 1977). This means that the polynomial fit, including the degree, will vary unpredictably from year to year and can only be used when all the data points of a year are available. Therefore, polynomials are not suitable for smoothing when effects of environmental conditions on a profile are being studied and are eliminated in a real-time operational environment.

Fourier series analysis is based on the mathematical principle that a function given at every point in an interval can be represented by an infinite series of sine and cosine functions. The variation of a profile with 52 data points ($M=52$) can be explained completely by 52 sines and cosines (degree $N=52$). The curves using N degree sines and cosines are called harmonic polynomials or $F_N(t)$. When degrees N decreases, $F_N(t)$ becomes a stronger smoother and the fitted curve passes through a decreasing number of data points. Therefore, N determines the degree of smoothing (Panofsky *et al.*, 1968). In Figures 5 and 6, $N=M/2=26$ and $N=M/4=13$, respectively. The degree of smoothing used will depend upon the intended application of the smoothed profile. A harmonic polynomial of degree $M/4$ is sufficient for general profile study. A polynomial of degree $M/2$ is required for a more detailed profile study (Panofsky *et al.*, 1968).

A shortcoming of a polynomial and a Fourier series smoother of degree $M/2$ is that they can only determine the general shape of the spectral curve; they do not pinpoint particular cycles. In a profile study, the particular cycles are the features of interest. Furthermore, Fourier methods are inappropriate without considerable modification when applied to the analysis of particularly noisy data and are not recommended in such cases (Parzen, 1967). Figure 7 illustrates what will happen when particularly noisy data are smoothed by a Fourier series. It can be seen that the harmonic polynomial $F_{N(t)}$, $N=M/2$, was influenced by the two extreme outlying points.

Another shortcoming of the Fourier series smoother is found in operational use when new data points are acquired every week. The result is that the M and the N will change weekly, causing the shape of the curve to change weekly. Therefore, there is no consistency for crop assessment purposes during the growing season.

Filtering. Filters are designed to emphasize frequencies of interest or to deemphasize undesirable frequencies. A low-pass filter reduces the amount of high frequencies and barely affects low frequencies. A high-pass filter has the opposite effect; it filters out low frequencies, leaving the higher frequency waves in the data series. A band-pass filter removes both high and low frequencies outside a particular range (Panofsky *et al.*, 1968).

Two filtering methods used in this study to reduce high frequency noise in vegetation index profiles are "running weighted means" and "running medians." One variation of the first method uses a progressive weighting system on each value and the value before and after it in the time-series (e.g., 0.25, 0.50, and 0.25). The result is a smoothed curve in which the high frequency waves are reduced in amplitude and the noise is averaged. The disadvantage is that the spectrum of the original series is altered as in Figure 8, weeks 21, 22, and 23, where local maxima are turned into local minima and vice versa.

The second method of filtering is based on a running median of a certain span. The term "span" refers to the number of successive data values included in the determination of a median. A running median with a span of four ignores the largest and the smallest value in each group of four values and averages the two middle-sized values. A running median with a span of two averages the two data values. With a span of three, five, or any higher odd number, the middle-sized value is used in the filtering (Velleman and Hoaglin, 1981). The span size selected for a running median depends upon the minimum duration of the discontinuities which the user wishes to preserve. For example, because atmospheric conditions and view angle change frequently, it is possible to have two outlying data points right next to each other. A running median of span four will ignore the two outliers and average the two remaining points (see Figure 9, week 20). Although the median of span four reduces the extremely high-frequency noise, it inadequately filters out the broad band noise.

Rabiner *et al.* (1975) discussed the properties of running medians which make them good smoothers. These are

- Median $[\alpha x(n)] = \alpha \text{median } [x(n)]$. This means that scaling the input data leads to scaling of the smoothed output data.
- Medians will not smooth discontinuities in the data as long as the duration of the discontinuity exceeds some critical length. By varying the span of the median, the user can decide the duration of the discontinuity he wishes to smooth out or preserve.
- Medians will approximately follow polynomials. This means that the general quadratic shape of a vegetation index profile with minimal noise will be preserved.

Compound Smoothers. Very often smoothing is accomplished by using two methods of filtering. Tukey (1974) proposed a combination of running medians and linear filtering. Rabiner *et al.* (1975) applied this combination to process voice levels and found it sufficiently smoothed the noise component of the input data but kept the important sudden changes in amplitude.

Velleman and Hoaglin (1981) developed the "compound smoothers" "4253H, twice" and "3RSSH, twice." The number in the names of these smoothers indicates the spans used. The 4253H compound smoother first filters the data using a running median of span four, then two, then five and three. The "H" stands for "hanning." The hanning (or weighting system) used by Velleman consisted of the weights 0.25, 0.50, and 0.25. After filtering the data four times using the running median method with the various spans, the data are filtered using the running weighted mean method with the above weights. The first and the last value of the time series cannot be smoothed in the same manner as the other values because they are not surrounded by other values. Velleman and Hoaglin proposed that the beginning and endpoints be interpolated linearly from the smoothed values. Generally, running median filtering smooths a data sequence too much and removes patterns of interest. Velleman and Hoaglin overcame this problem by smoothing the residuals and adding the results to the smoothed data sequence. This process is called reroughing and is known to be included in the "4253H, twice" compound smoother because of the term "twice."

The vegetation index profile for IA060 in Figure 10 was smoothed with "4253H, twice." It is clear that the two extreme outliers had no effect on the shape of the smoothed profile. The smoothed profile of Figure 10 has approximately the same shape as the schematic profile of Figure 3.

The "3RSSH, twice" compound smoother first filters the data using a running median of span three and then resmooths repeatedly until further smoothing no longer changes the data. The "R" in the name of the compound smoother refers to "resmooth." A running median filter of span three tends to reduce peaks and valleys to two-point flat segments. Velleman developed an operation that splits (hence the "S" in the name) the data into three parts, the two-point flat segment and two smoothed data sequences (one to the left and one to the right of the flat segment). A linear interpolation is then applied to

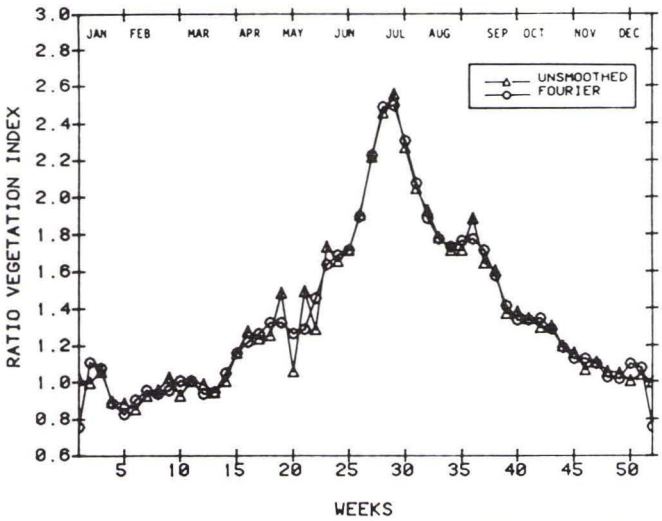

FIG. 5. RVI smoothed with Fourier series for IA060, 1983, N = 26.

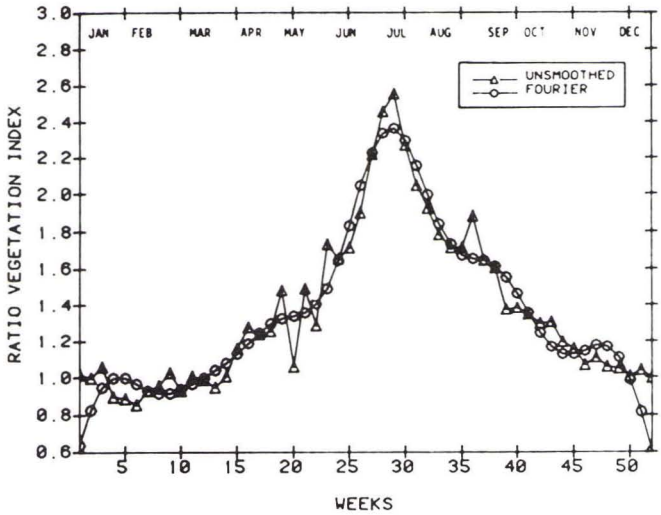

FIG. 6. RVI smoothed with Fourier series for IA060, 1983, N = 13.

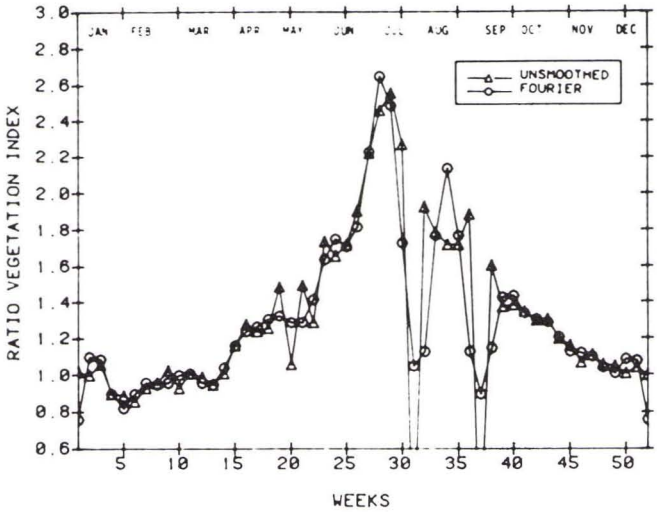

FIG. 7. RVI smoothed with Fourier series for IA060, 1983 (same data as Figure 6 with two outliers included).

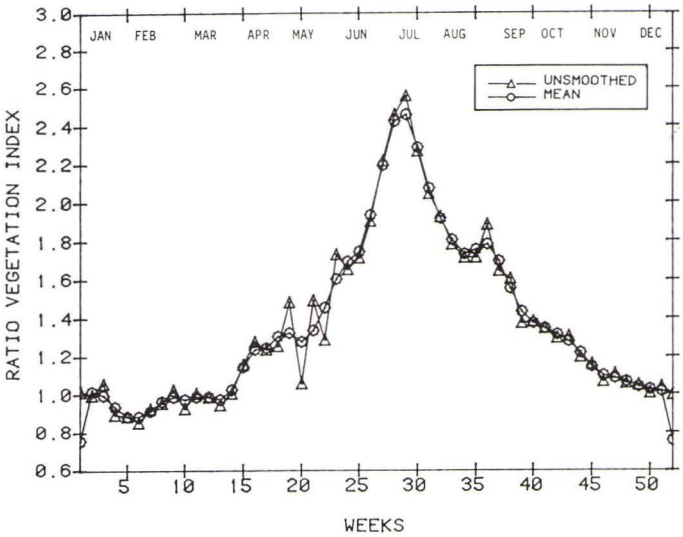

FIG. 8. RVI smoothed with running mean for IA060, 1983.

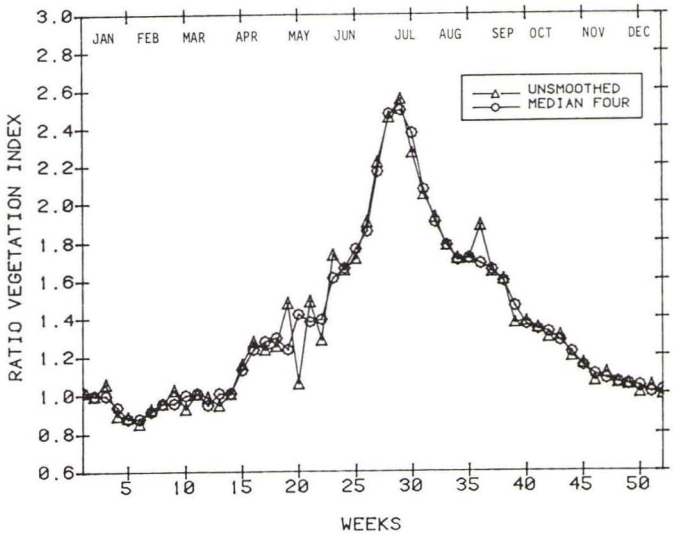

FIG. 9. RVI smoothed with median span four for IA060, 1983.

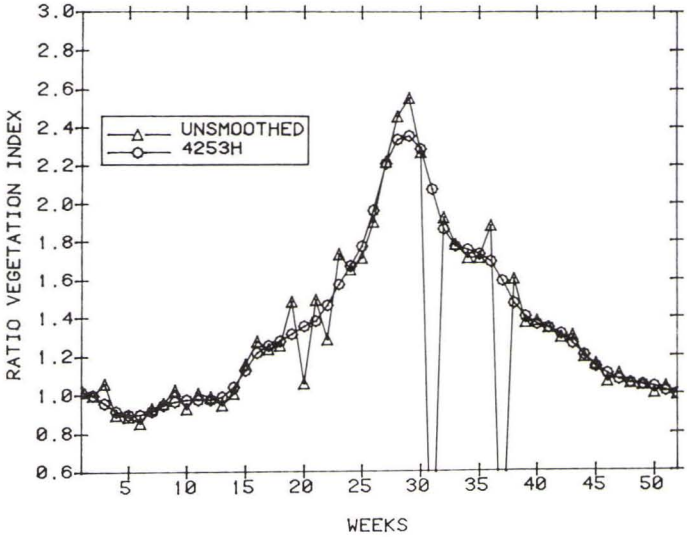

FIG. 10. RVI smoothed with "4253H, twice" for IA060, 1983.

the twice-smoothed data sequences to re-estimate the values of the endpoints of the flat segment (because the original points were a result of too rigid smoothing). The combination of smoothing with a running median of span three and splitting is repeated (hence the second "S" in the name). Finally, the hanning and reroughing processes are performed. The profiles in Figure 11 were smoothed by the compound smoothers "4253H, twice" and "3RSSH, twice," respectively. The general shapes of both curves in Figure 11 are very similar. This is presumably due to the reroughing process.

Of the two compound smoothers discussed above, "4253H, twice" is preferred by the authors. This is because, when two data extremes fall right next to each other, a running median of span four will ignore the two outliers and retain the signal. A running median of span three will select one of the outliers and ignore the signal.

Thailand Example

The selection of the ideal smoother for a profile of West Central Thailand is based upon comparisons of the smoothed vegetation index profile with the crop calendar in Table 1. The main crops grown in this area are rice and corn. The area in Thailand is characterized by denser and more frequent cloud cover than the area in the U.S. Therefore, the profile for the area in Thailand is expected to be "noisier" than the profile for the area in the U.S.

The test case on the area in West Central Thailand shows how various smoothers perform on very noisy profiles. In Figure 12, the vegetation index profile for the Thailand area was smoothed with a fifth-order polynomial. It can be seen that polynomial curve-fitting is an extremely rigid smoother. The profiles in Figures 13 and 14 were smoothed with the Fourier series of $N=M/2$ and $N=M/4$, respectively. The single-point outliers had a major influence on the shape of the harmonic polynomials. The profile in Figure 15 was smoothed with a running mean. In this case, also, the outliers had a major effect on the shape of the smoothed curve. In Figure 16, the compound smoother "4253H, twice" was applied to the profile and the outliers were disregarded.

The shape of the smoother profile can be explained using the crop calendar information in Table 1. The peak around week 10

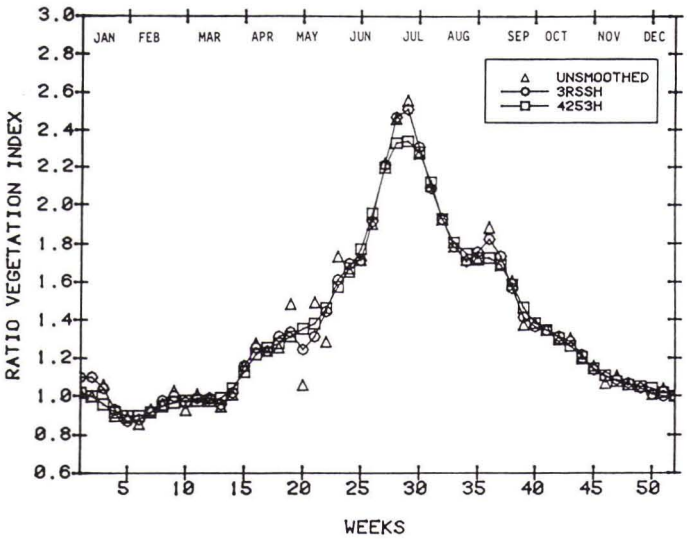

FIG. 11. RVI smoothed with 3RSSH and 4253H for IA060, 1983.

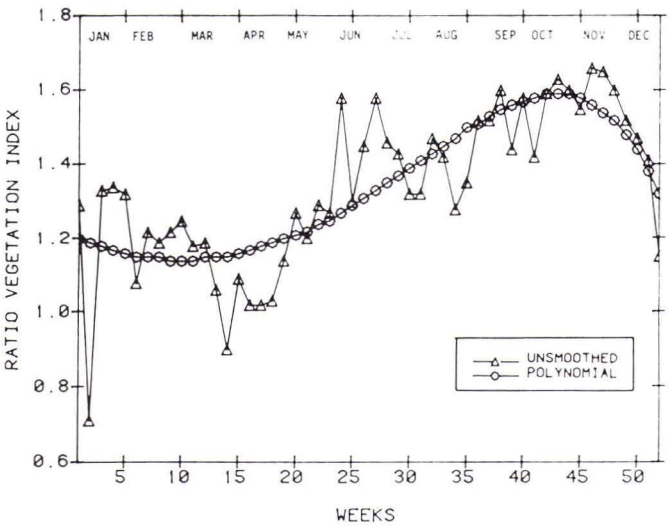

FIG. 12. RVI smoothed with polynomial curve-fitting for Thailand, 1983.

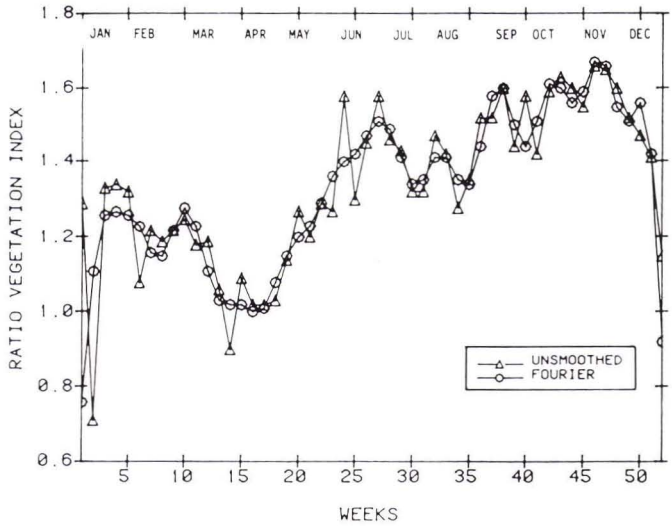

FIG. 13. RVI smoothed with Fourier series for Thailand, 1983, N=M/2=26.

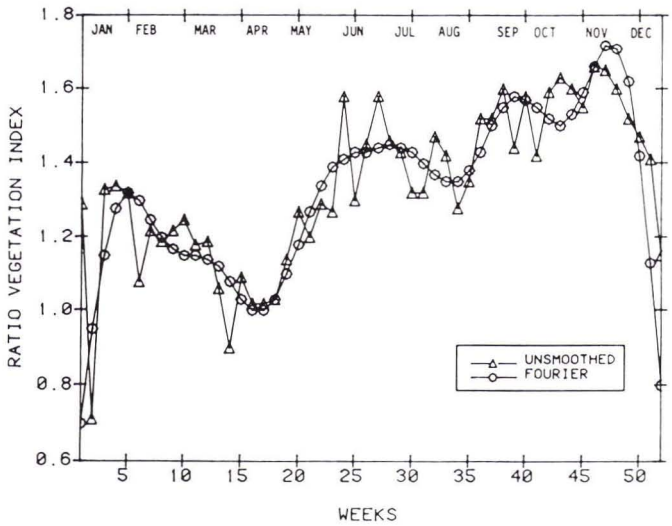

FIG. 14. RVI smoothed with Fourier series for Thailand, 1983, N=M/4=13.

TABLE 1. NORMAL CROP CALENDAR FOR WEST-CENTRAL THAILAND (RASMIDATTA *ET AL.*, 1981)

/// = planting, 000 = harvesting, ——— = transplanting

	Month	J	F	M	A	M	J	J	A	S	O	N	D
	Week	1 5	9	14	18	22	27	31	36	40	44	48	52
Crop	Season												
Maize	Main					////	//		0000	00			
Rice	Broadcast	000				////	////	//					0000
	Main	000				////	////	//					0000
	Secondary	////	////			0000	0000						

is a result of the maximum greenness of the secondary rice crop. The smoothed profile shows a minimum around weeks 15, 16, and 17 in April. This period coincides with inundations of the rice fields before the planting of the rice crops and the harvest of the secondary rice crop. Another local maximum occurs during weeks 26, 27, and 28 in July. At that time, the maize is at maximum greenness. The profile has a second minimum during week 31 in August. During this period the maize is harvested. There is a third and highest maximum in November (week 46). This is when the rice crop has a maximum amount of green biomass. The profile declines during week 50 in December when the rice is harvested. In both test cases, one with little cloud cover and one with dense and frequent cloud cover, smoothing a profile with "4253 H, twice" facilitates interpretation of the NOAA/AVHRR vegetation index data.

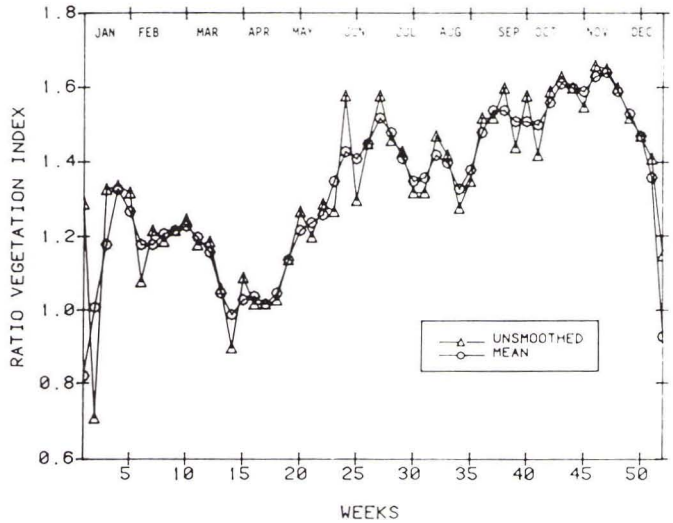

FIG. 15. RVI smoothed with running mean for Thailand, 1983.

DISCUSSION AND CONCLUSIONS

Although the smoother "4253H, twice" has been determined to be the best smoother in the two study cases, it must be adapted for use in operational crop condition assessments. For example, when making real-time crop condition assessments, the most recently gathered data points in a vegetation index time series may be critical for decision making.

As already mentioned, the endpoints of a profile cannot be smoothed. Velleman and Hoaglin (1981) proposed that the beginning and endpoints of a profile be interpolated linearly from the smoothed values. Linearly interpolated endpoints use the unchanged gradient of the smoothed points preceding them and disregard the change in gradient which may be indicated by the unsmoothed endpoints. However, this procedure can produce unrealistic results at times. For example, in Figure 17 the last points in profiles A and B for Chad and C and D for Niger were interpolated. The profiles in A and C cover the period up to week 33 (August) of 1985 and were used for the August 1985 crop condition assessment of the Sahel and Horn

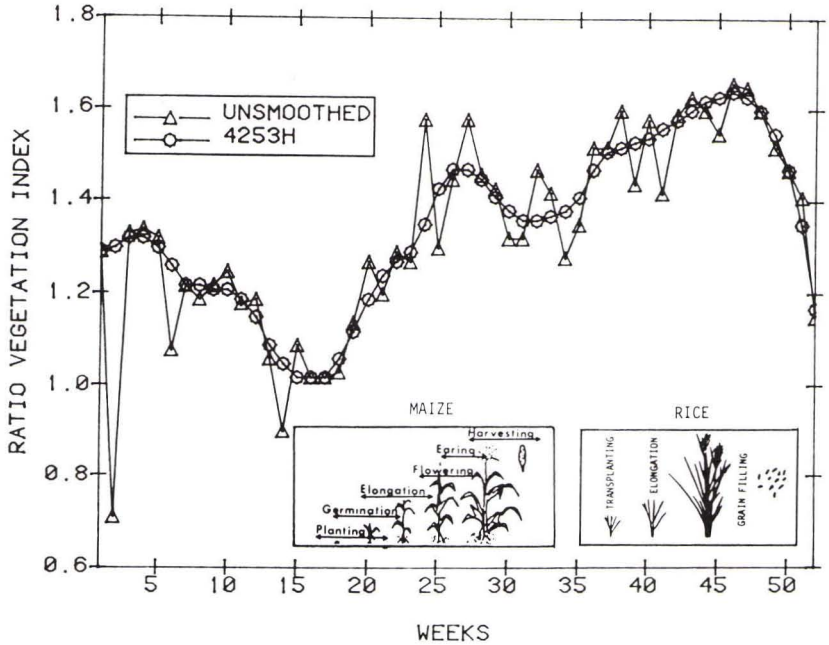

FIG. 16. RVI smoothed with "4253H, twice" for Thailand, 1983.

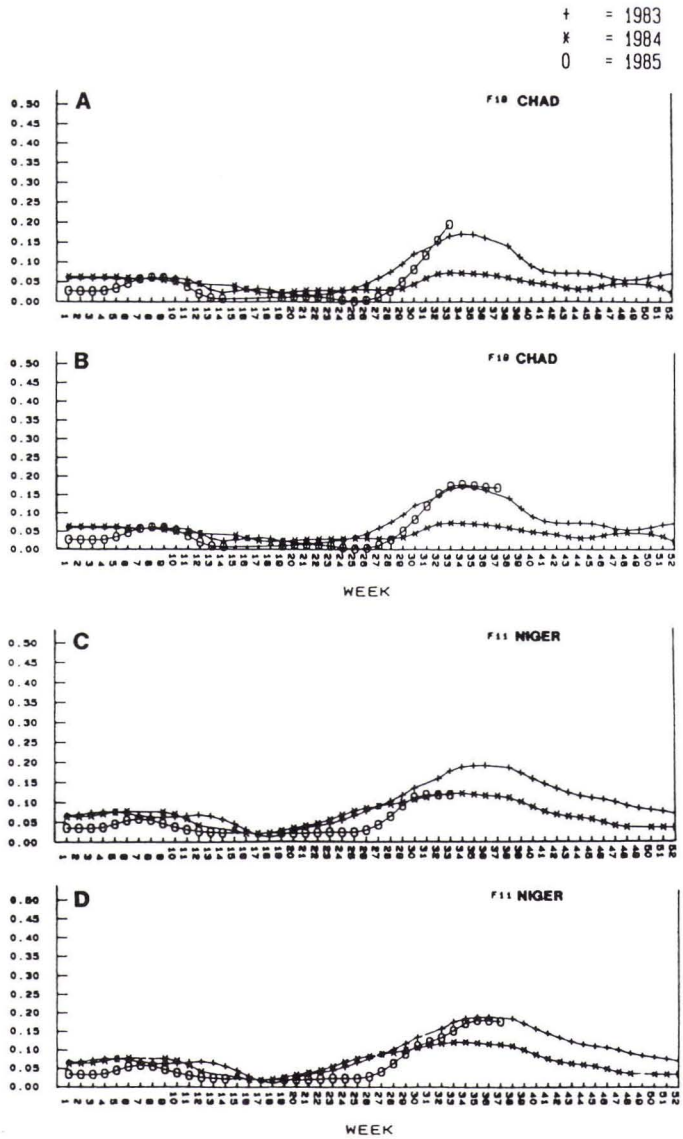

FIG. 17. Effect of linear interpolation on endpoints.

countries of Africa. The profiles in B and D include later data for the period up to week 37 of 1985 and were used for the September 1985 assessment. A comparison of the profiles in A and B shows that the interpolated point at week 33 in profile A was overestimated. Also, a comparison of C and D shows that the point at week 33 in profile C was underestimated.

An unrealistic endpoint occurs when that endpoint is a point of inflection. In this study they occurred relatively infrequently (about 3 percent in 340 profiles) in the examples studied. The alternative, retaining the raw, unsmoothed values for the endpoints, is not a viable solution because linear interpolation provides satisfactory results 97 percent of the time. When profiles are smoothed and endpoints are interpolated, the final two or three datum points resulting from the smoothed algorithm must be used with caution. Knowledge of the crop calendar for the area being assessed can aid in determining the reliability of the last few datum points. Another useful technique when working with vegetation index profiles for several consecutive years is to combine the profiles to form one continuous profile, thereby reducing the number of endpoints to be interpolated. For example, the number of beginning and endpoints for a set of three profiles (as in A of Figure 17) can be reduced from six to two when the three profiles are combined and considered as one continuous time-series profile to be smoothed. The values at the beginning and the end of the long profile are obtained by averaging the unsmoothed values and the linearly interpolated values. The resulting profile is then divided into three separate years again.

At the present time, the proposed method of reducing the disturbing effects of atmosphere, sun angle, and look angle based on time and space averaging provides satisfactory results. However, when quantifiable relationships for radiometric corrections become available in the future, they will be tested against this proposed method.

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