Real-Time Climate Monitoring Using an AVHRR-Based Vegetation Index

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Abstract: A normalized difference vegetation index (NDVI) has been produced and archived on a 1° latitude by 1° longitude grid between 55°S and 75°N. The many sources of data errors in the NDVI include cloud contamination, scan angle biases, changes in solar zenith angle, and sensor degradation. Week-to-week variability, primarily caused by cloud contamination and scan angle biases, can be minimized by temporally filtering the data. Orbital drift and sensor degradation introduces interannual variability into the dataset. These trends make the usefulness of a long-term climatology uncertain and limit the usefulness of the NDVI. Elimination of these problems should produce an index that can be used for climate monitoring.

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Introduction

A normalized difference vegetation index (NDVI), based on weekly digital data provided by the Advanced Very High Resolution Radiometer (AVHRR) on the NOAA operational polar orbiting satellites, has been produced from 1985 through 1990. The digital data are Global Area Coverage at a resolution of 4 km, which is then sampled to 16 km. These data are combined into a 1° latitude by 1° longitude grid. The dataset produced at the Climate Analysis Center consists of the mean, median, standard deviation, number of observations, and a 7-class histogram for each 1° by 1° grid square. Data are archived between 55°S and 75°N.

Computational Problems

The NDVI is the ratio of the difference to the sum of the values from the near infrared channel and the visible channel. Although this calculation is simple, several problems are associated with it. Since the calibration coefficients are determined from linear regressions, low solar zenith angles or illumination can cause channel radiances to appear negative. Therefore, the individual channel data were examined and negative values were removed. Pixels with negative vegetation index values were also eliminated, because a negative NDVI indicates greater reflectance in the visible than in the near IR (which is not what is expected from surface vegetation).

The NDVI has other sources of data contamination. Data errors are known to be caused by cloud contamination, scan angle biases, changes in solar zenith angle, and sensor degradation. Cloud contamination and

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noise due to changes in viewing geometry introduce week-to-week variability into the dataset, and sensor degradation and changes in illumination due to orbital drift result in interannual variability. For the vegetation index to have utility for climate monitoring, these problems must be minimized.

Short-Term Variability

Week-to-week scatter of the NDVI is primarily due to cloud contamination, even though the digital data are cloud screened by retaining the largest NDVI value for a given week. The AVHRR infrared window channel is used to further screen for clouds by eliminating pixels whose temperature values are less than a specified value. The current procedure uses a temperature of 10°C during the warm season and a value of -5°C during the cold season. Data inconsistencies also arise from the viewing geometry associated with different scan angles. The AVHRR has scan angles ranging from 55.4° to -55.4° relative to nadir. The NDVI calculated from the back-scatter direction is often lower than values obtained from either nadir or the forward direction. This can be seen in Figure 1, which shows the distribution of vegetation index values stratified by scan angle for an area in the midwestern United States during two adjacent weeks in the summer of 1988. The majority of pixels during early July (Figure 1a) have scan angles from the large back-scatter direction. During the following week (Figure 1b) only four pixels were obtained from these angles, although these four pixels did have low NDVI values. This shift in distribution of pixels results in large week-to-week variability, which in this case is manifested as the spike in the time series shown in Figure 2a.

Due to scan angle biases and cloud contamination, temporal filtering is used to smooth the data. Figure 2a presents an unfiltered time series for 1988 over a 5° latitude by 5° longitude area of the midwestern United States; the data in Figure 2b are filtered with a 3-week median filter. Both are compared to the 4-year mean NDVI. The unfiltered time series shows the large week-to-week variations; the median filtered time series is much smoother and is consistent with the drought during summer 1988.

Interannual Variability

In addition to the week-to-week variations due to cloud contamination and scan angle biases, trends exist in the dataset. These trends are introduced as a result of orbital drift and sensor degradation. Higher vegetation indices occur with larger solar zenith angles relative to nadir over desert areas. Figure 3 shows a weekly time series of the NDVI over a 10° latitude by 10° longitude area of the Sahara Desert. The apparent annual cycle in vegetation over this region is a result of changing solar zenith angles throughout the year, with lower NDVI values occurring with lower angles. Due to orbital drift, the equator crossing time becomes later throughout the life of the satellite. As this occurs, the solar zenith angle for any given week becomes greater, as does the NDVI for each year. The trend is especially obvious during the winter months, where each peak is higher than the maximum value reached during the previous year. There is an abrupt decrease in NDVI toward the end of 1988 that is associated with the change of satellite from NOAA 9 to NOAA 11. The equator crossing time of NOAA 11 was much earlier than NOAA 9, which resulted in much smaller solar zenith angles. Research is underway to determine if the effects of changing sun angle are as pronounced over vegetated surfaces as over deserts.

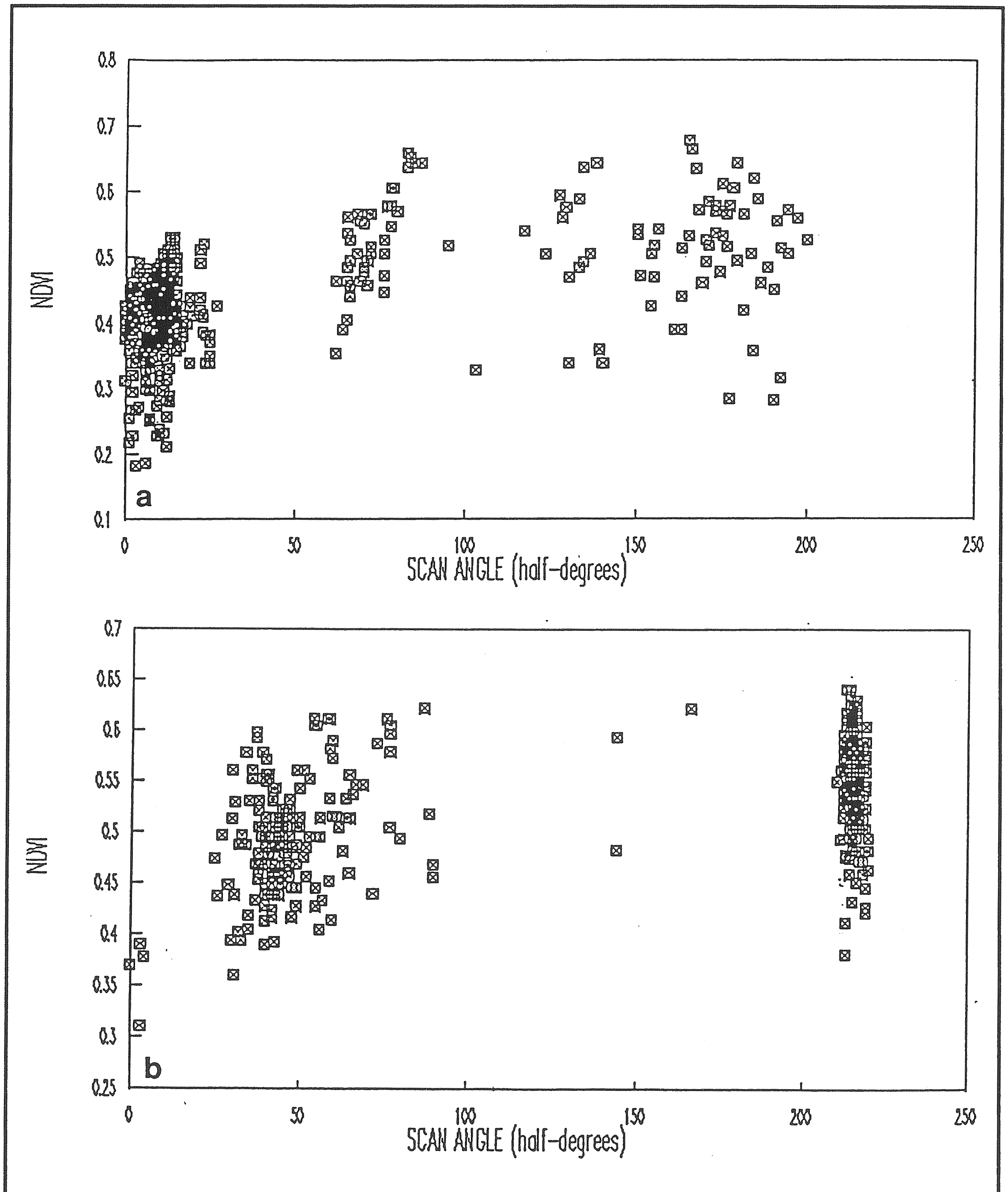

Figure 1. Scatter plots of the NDVI versus scan angle in half degrees for Week 30 (a) and Week 31 (b) of 1988 for an area in the midwestern United States. Scan angles between 0 and 110 represent the back-scatter direction; angles between 110 and 220 are from the forward-scatter direction.

Another indication of the increasing NDVI values over desert areas and the relationship to solar zenith angle is the decrease in total land surface that has NDVI values less than 0.1 (Figure 4). Land area with low NDVI values ranges from more than 50% during the Northern Hemisphere winter to less than 25% during the summer. The summer percentages are derived mainly from indices over the deserts, although low sun illumination in southern South America probably accounts for some of the total land area. During the summer months, the amount decreases from about

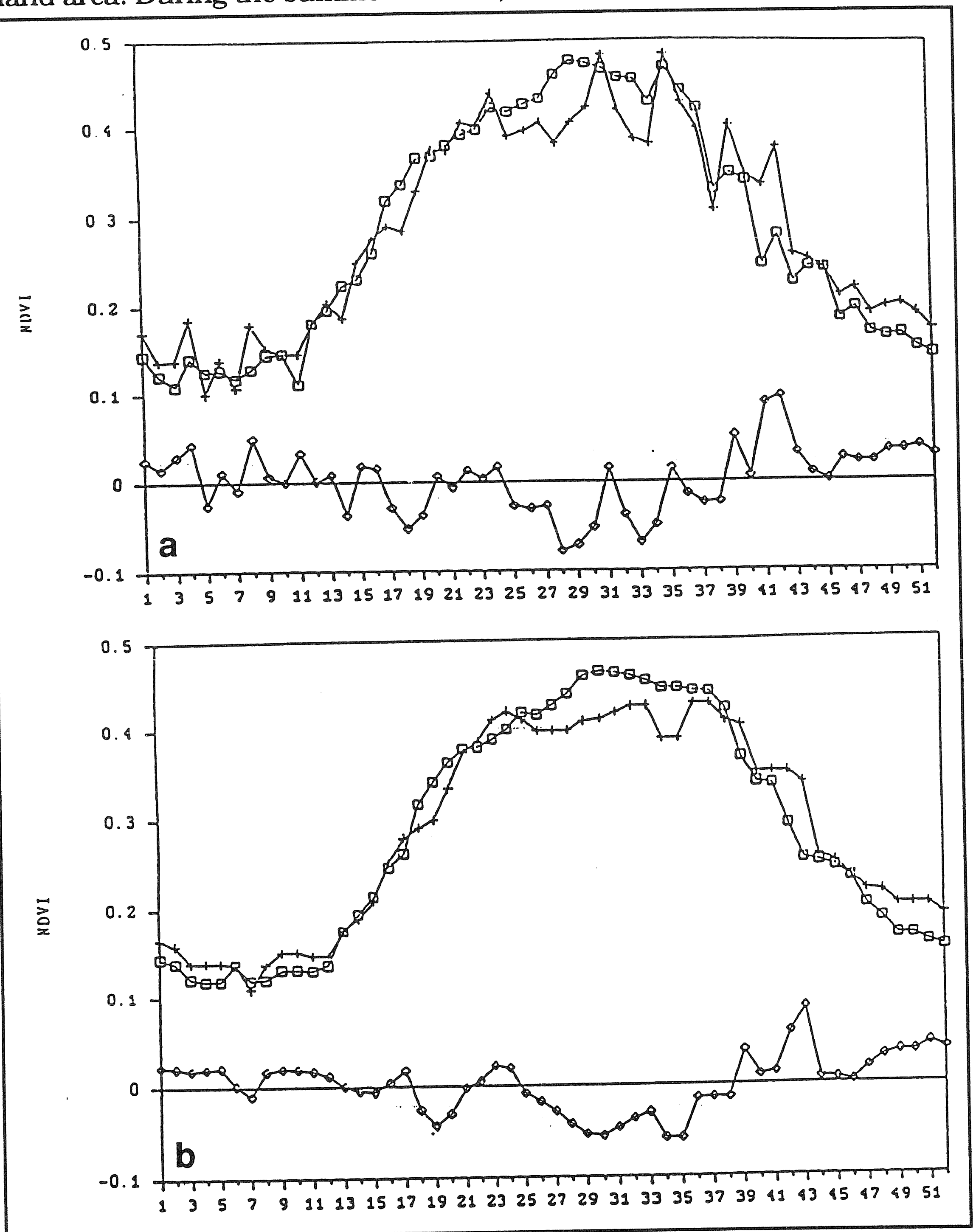

Figure 2. Weekly time series of the 1985-1988 mean (open boxes), 1988 total (plus symbols), and the 1988 anomalies (open diamonds) of the NDVI unfiltered (a) and 3-week median filtered (b). Data are averaged over an area from 38°N-43°N and from 90 °W-95°W.

25% in 1985 to less than 20% by 1988. The 1988 curve continues to indicate less land with NDVI values below 0.1 (compared to previous years) until November, when the percentage jumps to about the same percentage found during 1985. This jump is coincident with the change in satellites, which greatly changed the viewing time and, hence, the solar zenith angle.

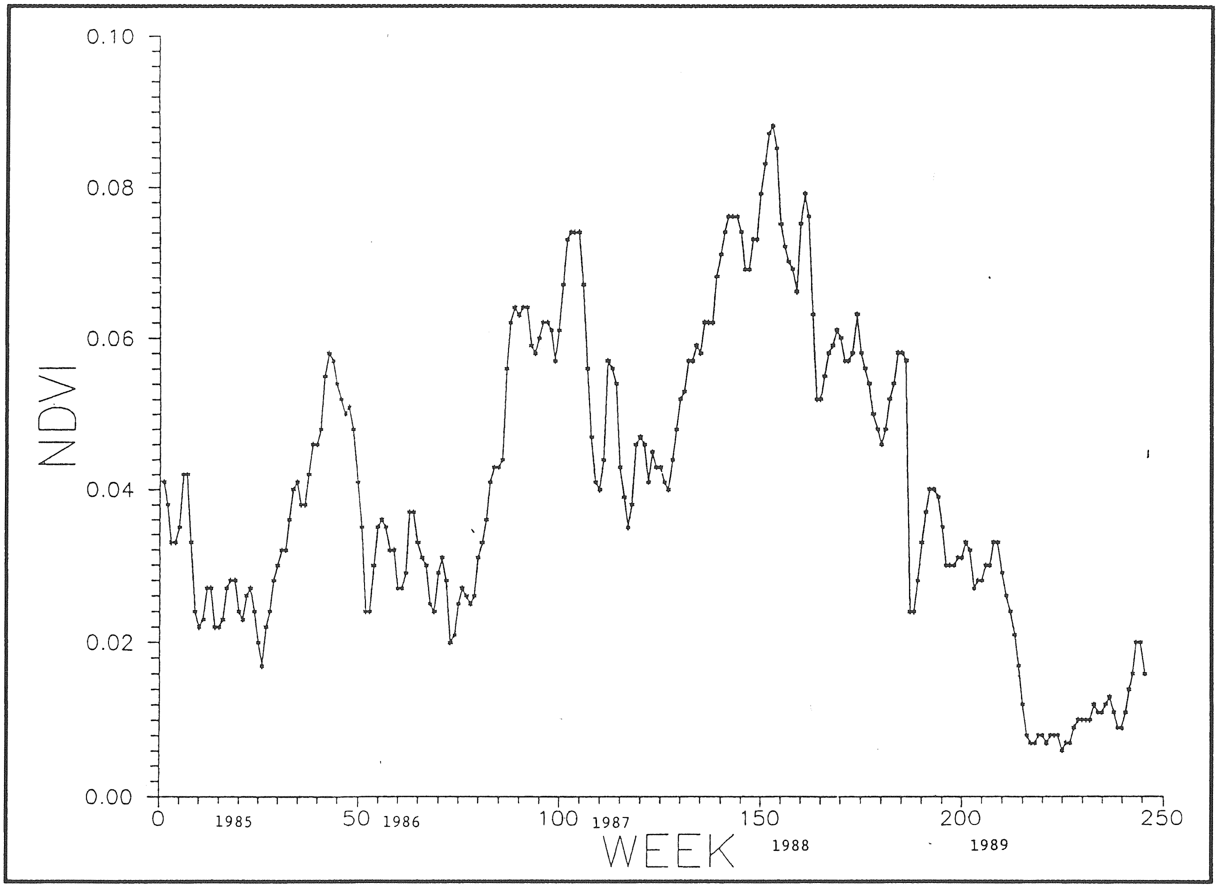

Figure 3. Weekly time series of the NDVI for a 10° latitude by 10° longitude area in the Sahara. The time series begins in April 1985 and runs through December 1989.

Conclusion

Biases introduced into the NDVI as a result of orbital drift and sensor degradation make the usefulness of a long-term climatology uncertain. For this reason, we have not computed anomalies from a prescribed base period for climate monitoring but, instead, make year-to-year comparisons of the vegetation index. Comparisons of July 1987 with the severe drought of July 1988 for the United States indicate mean NDVI values during 1988 were 20 to 30% smaller than in 1987 throughout the Midwest.

NDVI values for September 1990 and 1989 were also compared over the African Sahel. Vegetation index values were greater during 1989, indicating better growing conditions, which is in agreement with precipitation data for this area. However, NDVI values over the Sahel were greater during 1987 than during 1989 even though precipitation amounts indi-

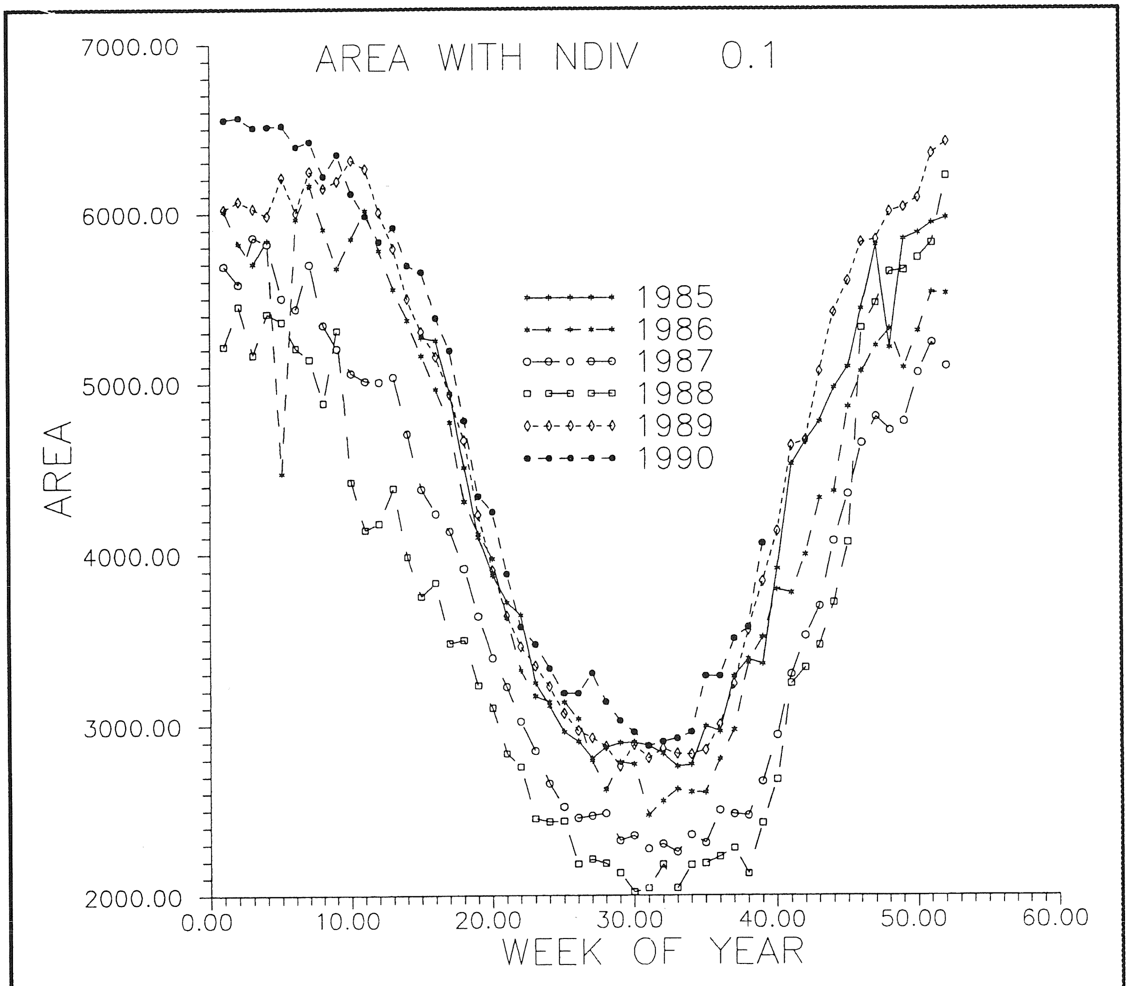

Figure 4. Weekly time series of the percent total land area with NDVI less than 0.1 for 1985-1990.

cate the reverse should have been true. This discrepancy arises from the change in satellite during 1988 and limits the flexibility and usefulness of these yearly comparisons because any year-to-year comparisons must be made between neighboring years, and the data must come from the same satellite.

A weekly vegetation index dataset from 1985 through the present has been produced on a 1° latitude by 1° longitude grid. Despite continuing uncertainties with cloud contamination and scan angle differences, large-scale climate parameters have been identified. The index is not yet stable enough to produce a climatology because of interannual variability associated with sensor degradation and orbital drift. Elimination of these problems should produce an index that can be used for global climate monitoring as well as the diagnostic study of climate variations.