Droughts of the Late 1980s in the United States as Derived from NOAA Polar-Orbiting Satellite Data

Abstract

Drought is one of the most adverse and powerful weather-related disasters that occur every year across a portion of the United States. The consequences of droughts quite often can be devastating. To mitigate these consequences, droughts require careful monitoring. Recently, NOAA's National Environmental Satellite Data and Information Service developed a new Advanced Very High Resolution Radiometer-based vegetation condition index (VCI) that showed good results when it was used for drought detection and tracking. The VCI is a vegetation index with reduced noise and is adjusted for land climate, ecology, and weather conditions. This index provides a quantitative estimate of weather impact on vegetation and also measures vegetation conditions. Several large-area experiments showed that the VCI had excellent ability to detect drought and to measure the time of its onset and its intensity, duration, and impact on vegetation. The VCI provides accurate drought information not only for the cases with well-defined, prolonged, widespread, and very strong droughts, but also for very localized, short-term, and ill-defined droughts. The advantages of this index compared to conventional ground data are in providing more comprehensive, timely, and accurate drought information. This paper describes the methodology and technical principles used to derive the vegetation condition index, explores data processing, and gives many examples of VCI application for drought monitoring in the United States during 1985–90. The spatial and temporal patterns of VCI-derived drought were in a very good agreement with the identical patterns identified from precipitation and yield anomalies.

1. Introduction

Drought is a typical phenomenon of the North American climate. Nearly 80% of the United States is located in the climatic zone where the annual consumption of water, estimated from the potential evapotranspiration, is greater than the annual amount of precipitation (Golitsberg 1972). Droughts occur almost every year across a portion of the nation. Over the past century many events of major droughts and dry spells were recorded in the United States that have had significant economic, social, and environmental impacts. The famous drought of the 1930s dust bowl period affected the American economy for several years (Rosenberg 1980). Fifty-five years later, economic impact of the 1988 U.S. drought was estimated at $39 billion. The greatest losses occurred in the agricultural sector. Yields of agricultural crops decreased so sharply that grain production fell below domestic consumption, probably for the first time in history. The federal government spent $3.9 billion on drought relief programs and $2.5 billion on farm credit programs (Riebsame et al. 1990). Damage to the economy, human health, environment, and wildlife ranks the 1988 drought as one of the nation’s greatest disasters of the twentieth century (NOAA 1988). The drought significantly reduced natural water resources. This severely hampered navigation and limited water and hydropower use. The drought caused disastrous forest fires and critically disturbed wildlife of the forests, rivers, reservoirs, wetlands, and other species habitats.

In order to reduce drought consequences, the main components of a drought preparedness plan should include drought monitoring/early warning, assessment of impacts, and response (Wilhite 1993). The first step toward drought mitigation is drought monitoring that includes timely information about the onset of drought and its extent, intensity, duration, and impacts. Early drought warning is also highlighted as an important goal of the United Nations’ International Decade for Natural Disaster Reduction (Castells 1991).

Weather data are normally used for drought monitoring in the areas with a well-developed weather network. For example, the weather-based Palmer drought severity index (PDSI) is used for assessment of long-term drought conditions in the United States (USDC/USDA 1988). Unfortunately, the PDSI did not find much application outside the North American continent. The drought-watch system in other countries is mostly based on analysis of weather anomalies or domestic indexes (Sastri 1993; White et al. 1993;
The absence of a universal drought-watch system makes it difficult to compare droughts in different ecosystems and to estimate their impacts on a country's economy. In addition, some large areas in Africa and Central and South America have insufficient density of weather stations to assess regional drought and its impact. The lack of weather information becomes especially acute in the areas with marginal climatic resources, economic problems, and/or political conflicts. In addition, weather data are quite often incomplete and/or they are not available in real time to the international institutions responsible for global weather analysis and impact assessments.

Vegetation indexes derived from satellite data have been studied since the early 1980s because they provide frequent observations and describe global and regional vegetation distribution and condition better than weather and climate parameters (Gray and McCarry 1981; Tucker et al. 1982; Tucker and Sellers 1986; Tarely et al. 1984; Justice et al. 1985; Kogan 1987). Moreover, observations from satellites provide more timely and much better spatial coverage information. Recently, the National Oceanic and Atmospheric Administration (NOAA) has designed a new Advanced Very High Resolution Radiometer (AVHRR)–based vegetation condition index (VCI) that has shown success when applied to drought detection and tracking in many countries of the world (Kogan 1987, 1990). This paper presents the results of using the VCI for monitoring the late 1980s droughts in the United States. These droughts were the most interesting for analysis and validation because they were different in the size of affected area, duration, intensity, time of occurrence, and damage to agriculture.

2. Satellite data

The drought-monitoring algorithm was developed and tested during 1985–1993 in several large areas of the world with different environmental and economic resources (the United States, the former Soviet Union, China, central and southern Africa). In this study, the algorithm was applied to the global vegetation index (GVI) dataset, which is the NOAA product described in Tarely et al. (1984) and Kidwell (1990). The GVI is produced by sampling and mapping the 4-km daily radiances, measured onboard NOAA polar-orbiting satellites, to a 16-km map. Radiance measured in the visible [0.58–0.68 μm (CH1)] and near-infrared [0.725–1.10 μm (CH2)] wavelengths are used to calculate the normalized difference vegetation index (NDVI):

\[
\text{NVDI} = (\text{CH2} - \text{CH1})/(\text{CH2} + \text{CH1}).
\]

The NDVI is a quantity that measures greenness and vigor of vegetation (Tarely et al. 1984). The daily maps of GVI parameters (radiance, NDVI, and satellites and sun angles) are composited over a seven-day period by saving those values that have the largest difference between radiances for near-infrared and visible wave bands during the seven days for each map cell. This procedure has the effect of minimizing cloud contamination in the weekly composite. The weekly GVI data from April 1985 through 1990 were used in the development of the U.S. drought-watch system (Kogan 1991).

3. Algorithm for drought monitoring

An algorithm was designed to reduce noise and to enhance the weather-related component in the time series of NDVI data. The largest sources of noise in the calibrated NDVI are the residual clouds, fluctuating transparency of the atmosphere, varying sun/target/sensor geometry, and satellite orbital drift (Gutman 1991; Goward et al. 1991). Other noise is related to data sampling, processing, observation and communication errors, or simple random noise. As a result, the annual curve of weekly NDVI is always noisy (Fig. 1). These fluctuations must be removed before the NDVI is used for drought monitoring. The scientific literature provides some algorithms for identifying clouds and for correcting satellite data for sensor degradation and satellite change (Gutman 1991; Rao and Chen 1993). There has also been some research on atmospheric and angular corrections (Kaufman and Sendra 1989; Popp 1993; Flasse et al. 1993). However, complete physically based corrections for all effects and for various land surfaces are not available. Therefore, temporal fluctuations were removed by smoothing the weekly NDVI time series with a compound median filter (Velleman and

![Fig. 1. Weekly normalized difference vegetation index: smoothed (solid line) and unsmoothed (dotted line) for one 16 km x 16 km pixel (lat 39.14°, long -80.86°) in 1987.](image-url)
Hoaglin 1981). This technique was superior to others in eliminating outliers, emphasizing the annual vegetation cycle and weather-related NDVI fluctuations (van Dijk et al. 1987; Kogan 1987, 1990). The smoothed curve in Fig. 1 illustrates that.

After smoothing, year-to-year differences caused by weather variations in NDVI became more apparent (Fig. 2). The largest midseason NDVI was during 1986 in Illinois (Fig. 2a) and during 1990 in North Dakota (Fig. 2b), because summer months of these years were mild and wet. The 1988 midseason NDVI was the lowest on record in both locations due to the extremely dry and hot summer (NOAA 1988). Meanwhile, Fig. 2 also shows that the same NDVI values should be interpreted differently in various locations due to dissimilarity in the productivity of their ecosystems. The highest NDVI of 0.39 in Fig. 2b would suggest excellent vegetation conditions in a less productive North Dakota ecosystem and poor conditions in a more productive Illinois ecosystem (Fig. 2a), where the NDVI of around 0.39 was the lowest on record.

In sum, Fig. 2 shows that the NDVI quantifies both spatial differences between productivity of ecosystems (ecosystem component) and year-to-year variations in each ecosystem due to weather fluctuations (weather component). The ecosystem component is mainly controlled by such slow-changing environmental factors as climate, soil, topography, and vegetation type, which determine the amount and distribution of vegetation on the earth. The weather component of NDVI is controlled by weather parameters (rainfall, temperature, wind, etc.) that determine vegetation state and greenness in the annual cycle.

The weather component of NDVI is superimposed on the ecosystem component. Maximum vegetation is developed in years with optimal weather since such weather stimulates efficient use of ecosystem resources (for example, an increase in the rate of soil nutrition uptake). In contrast, minimum vegetation is developed in years with extremely unfavorable weather (mostly dry), which suppresses vegetation growth both directly and through a reduction in the rate of ecosystem resources use. For example, lack of water in drought years reduces considerably the amount of soil nutrition uptake. The absolute maximum and minimum of NDVI calculated from several years of data that contain the extreme weather events can be used as criteria for quantifying these extreme conditions.

Therefore, we calculated the largest and the lowest NDVI values during 1985–90 for each of the 52 weeks of the year and for each pixel. The resulting maximum and minimum NDVI were used as the criteria for estimating the upper (favorable weather) and the lower (unfavorable weather) limits of the ecosystem resources. These limits characterize the "carrying capacity" (Reining 1974) of an ecosystem. In the examples shown in Fig. 2, the minimum curves for the

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Fig. 2. Smoothed weekly NDVI during 1985–1990 for one pixel in (a) Illinois and (b) North Dakota.
middle of the growing season should be composited from the lowest 1988 weekly NDVI values. The maximum curves should be composited from several years’ weekly NDVI: in Fig. 2a from the years 1990, 1986, and 1985 for early, mid, and late season, respectively, and in Fig. 2b mostly from 1990. Since the minimum and
maximum NDVI curves delineate the contribution of the ecosystem component into NDVI value for the cases with the most extreme weather, the area between these curves approximates primarily the weather-driven component of the NDVI.

Figure 3a shows the weekly maximum and minimum NDVI curves for selected ecosystems (one pixel for the ecosystem) typical for the United States. Each ecosystem has its own NDVI signature in terms of NDVI value, shape of the curve, rate of NDVI change during leaf appearance and senescence, and partitioning of NDVI value into weather and ecosystem components. The eastern and western states (curves 1, 2, 6, 7, 11, and 12 in Fig. 3a) have the highest NDVI values with clearly defined seasonal dynamics and smaller total area of weather (blue envelope) versus ecosystem components (green area). This type of seasonal dynamics is typical for forest ecosystems with some differences between deciduous and coniferous forests. The west-central states have the lowest NDVI values without distinctive seasonal dynamics and almost equal contribution of weather and ecosystem components into the integrated area under the maximum curve (curve 8). This type represents a desert ecosystem. Moving to the east, the NDVI increases again and shows a seasonal cycle that is more pronounced in prairies and broadleaf forest (curves 4 and 5) than in the steppe ecosystems (curves 3 and 10). The portion of weather component (blue envelope) gradually decreases to the east.

Figure 3b shows stratification of the whole United States area (for each 16 x 16 km grid) based on the maximum and minimum NDVI averaged for the middle of the growing season (May through August). It should be noted that six years of data hardly satisfy statistical requirements to formulate reliable conclusions. However, the concept of the minimum NDVI suggests the existence of only one year in the study period with drought (1988). For the near-optimal weather, several years of data were used. Verification showed that even for such a small sample there is a very good correspondence between spatial distribution of NDVI-derived zones in Fig. 3b and spatial distribution of vegetation and climate zones based on in situ data (Hammond 1991).

For vegetated regions the integrated area of the weather-related NDVI component is smaller than the ecosystem one. Consequently, the weather impacts on vegetation are not easily detectable from NDVI data. When the NDVI was used for assessment of these impacts and drought detection, the weather component of the NDVI was enhanced by separating it from the ecosystem component (Kogan 1987, 1990). Therefore, the weather-related NDVI envelope (blue area in Fig. 3a) was linearly scaled from zero, minimum NDVI to 100, maximum NDVI, for each grid cell and week. The resulting parameter was named the vegetation condition index (VCI), defined by the following expression:

\[ VCI = 100 \frac{(NDVI - NDVI_{\text{min}})}{(NDVI_{\text{max}} - NDVI_{\text{min}})} \]

where NDVI, NDVI_{max}, and NDVI_{min} are the smoothed weekly normalized difference vegetation index, its multiyear maximum, and its multiyear minimum, respectively, calculated for each pixel.

The VCI approximates the weather-related component in the NDVI value. It changes from 0 to 100, corresponding to the changes in vegetation conditions from extremely unfavorable to optimal. In order to use the VCI as a tool for assessment of vegetation conditions, it should be calibrated against some weather-dependent characteristics of vegetation, such as vegetation height, biomass, and yield of agricultural crops. From all indicated parameters we had U.S. yield estimates from the U.S. Department of Agriculture. Since these estimates are regional, they require the matching VCI dataset aggregated over the same regions. We have initiated this work.

The scatter diagram in Fig. 4 shows the results of correlation between crop-reporting district’s (CRD) average yield anomaly and CRD’s average VCI for two different ecosystems: Prairie in Illinois (Fig. 3, type 4) and steppe in North Dakota (Fig. 3, type 3). Moreover, crops were also different: corn and spring wheat, respectively. In spite of these differences, yields of both crops and in both states were significantly re-
duced after the VCI falls below 35, which occurred during the 1988 drought. These results suggest that the VCI can be used effectively for regional analysis of drought. Therefore, the detection of drought and its temporal and spatial development was performed only for those cases when VCI values fall below 35. This analysis included outlining the areas and time of the growing season when the VCI values matched with corn yield reduction below 90% of the 1985–88 mean.

However, in concluding this section we should indicate that the results shown in Fig. 4 are preliminary and require further exploration. The research should include stratification of the VCI by its severity in the range between 0 and 35. In addition, the correlation for VCI values above 35 and yield anomalies near and above mean value should be investigated further for various ecosystems and, more importantly, for the critical periods of different crops.

4. Drought types

Drought is the most complex but least understood of all natural disasters. Therefore, a universally accepted definition of drought does not exist (Wilhite 1993). The major cause of drought is lack of precipitation. However, the same precipitation deficit could have different impacts depending on other meteorological elements, type of ecosystem, and economic activities. The many definitions of drought reflect these impacts (Wilhite and Glantz 1985). They might also identify specific climatic conditions, regional differences, physiological characteristics, economic development, and even traditions. Currently, scientific literature classifies drought into four types: meteorological, agricultural, hydrological, and socioeconomic (WMO 1975; Wilhite and Glantz 1985). Because the vegetation index is commonly used as a tool for drought monitoring, the first two types of drought will be further discussed.

Meteorological droughts measure the degree of dryness expressed as a deviation of precipitation and temperature from a mean value for the area. Agricultural drought characterizes a disproportion between available water from precipitation plus water stored in the soil and the water demand by a plant community during a critical crop stage. These demands can be expressed in the form of physical parameters (potential evapotranspiration, soil moisture, energy balance) and indexes (Palmer drought severity index, soil moisture index), and/or as parameters that characterize vegetation directly (vegetation state, development, coverage, productivity, losses).

Droughts have some specific features that distinguish them from other natural hazards and make them difficult to identify (Wilhite 1993). Drought development is cumulative and builds up slowly over a period of time. The impacts of drought on the environment and/or economic activity are also cumulative. Therefore, the losses from drought are not immediately detectable; that is, there is a time lag. In addition, the absence of a distinctive criterion for drought creates difficulties in identifying drought, assessing its onset, duration, areal extent, and severity. Drought spreads over a large area, which makes its impacts difficult to identify. In sum, drought is not easily identifiable, especially at the very beginning, even if the appropriate weather observations are available.

5. Large-area U.S. droughts

During the 1985–90 period, droughts in the United States were observed every year. However, they differed in areal coverage, time of occurrence, intensity, duration, and impact. Yield of agricultural crops serves as a good indicator of agricultural drought and its impact. For example, the impact of the 1988 drought is clearly seen even from the average for the entire U.S. yield of agricultural crops (Table 1). The 1988 yields were 20%–25% below the 1985–90 mean. Such a large reduction resulted from a severe, large-scale drought that affected the principal agricultural areas. In other years, the average yield was near and above normal. However, another year with large-areal drought was 1985, although that drought was less intense and did not cover main crop areas. The following discussion covers the most interesting features of the 1985...
and 1988 droughts as identified by the vegetation condition index and validated by in situ data.

a. Highlights of the 1985 drought

The 1985 large-area drought covered areas not considered principal agricultural regions in the western United States. As seen in Fig. 5, this drought started around mid-May (week 20) with a clearly identified pattern of stressed vegetation (red) in the northern United States. In the following four to six weeks, drought expanded to the southern and western United States. By the beginning of July (week 26) the area of stressed vegetation was the largest. This period of drought continued for four weeks, until week 30 (beginning of August); there was some reduction of the drought area after that.

The ground-truth data show a pattern very similar to that derived from the 1985 VCI data. This drought was triggered by below-normal rains (Fig. 6a) and elevated air temperature (2°–4° F) during spring and summer 1985. The area of VCI-derived 1985 drought coincides with the area of corn yield reduction in 1985 (Fig. 7). The PDSI also showed drought in the western United States (Fig. 6b). However, since the PDSI is used for analysis of prolonged dryness, the intensity of the PDSI-derived drought is different compared to rainfall, yield, and vegetation index data.

b. Highlights of the 1988 drought

The 1988 drought was unique due to its occurrence early in the season, rapid development, expansion, and unusual severity, especially in the main agricultural areas. This drought devastated crops, pastures, and natural resources and brought considerable damage to the U.S. economy (NOAA 1988; Johnson et al. 1993). Figure 8 shows biweekly VCI-derived drought dynamics (red) from the first week in May (week 18) through the end of October (week 44). The VCI detected stressed vegetation in the northern Great Plains, the East, some western states, and in southern Texas.
at the beginning of May (week 18). This drought pattern was persistent until mid-June (week 24), when the VCI showed rapid expansion of the area of stressed vegetation to the central and southern United States. By the end of June (week 26), the drought area expanded to its maximum intensity and covered the main agricultural regions. The first weather-based drought advisories report in 1988 was issued only on 21 June (NOAA 1988), even though a stable drought pattern was detected on satellite images four to six weeks earlier. The cessation of the 1988 drought started in July (weeks 28, 30) following the arrival of rains. During July and August VCI data showed a slow recovery of vegetation. By the end of August (week 36) the drought area was reduced considerably.

Similar assessment of drought onset and development was obtained from rainfall analysis (NOAA 1988). There is a good agreement in location and time of occurrence of the VCI-derived (Fig. 8, weeks 26 and 36) and rainfall-derived (Figs. 9a,b) drought patterns. Unfortunately, VCI data compression (averaging over area) conceals many details necessary for regional drought analysis. Figure 10 shows these details for each 16 x 16 km pixel for the week ending 1 August

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Fig. 7. Corn yield (percent of the 1985–90 average yield) calculated from USDA’s estimates (USDA 1991); 1) 80%–90%; 2) below 80%. For the states North Dakota, Montana, Wyoming, Oregon, and Nevada wheat data were used; for Arkansas sorghum data were used.
6. Regional U.S. droughts

The years 1986, 1987, 1989, and 1990 are known as the years with regional droughts (Karl and Young 1987; Kogan 1990). Similar to the large-area drought years, these four years were different in drought intensity, area coverage, duration, and time of occurrence. These droughts did not have considerable impact on the average yield of crops in the whole United States (Table 1). However, in some states during these years yield was reduced considerably (Fig. 7). We will discuss the 1987 and 1989 droughts because they covered different ecosystems that range from forest/arable lands with a wet climate in 1987 to arable lands with a dry climate in 1989.

a. Highlights of the 1987 drought

The 1987 weather was favorable for vegetation growth, and U.S. mean crop yield was mostly above the 1985–90 average (Table 1). However, several regional droughts were observed during the 1987 growing season. Virginia and North Carolina were the most severely affected by drought, resulting in 20%–25% reduction in corn yield (USDA 1991). Average corn yield in Pennsylvania was reduced by only 8% because the drought affected only the southern and eastern regions. Figure 11 shows VCI images at the end of May, June, and July. The states indicated above show a stable pattern of stressed vegetation during these months. In Pennsylvania, VCI-derived stressed vegetation occurred only in June and
Fig. 9. (a) Area with the 1988 rainfall deficit below 3 in. (pattern 1) and 3–6 in. (pattern 2) during April–June; (b) below 2 in. (pattern 1) and 2–4 in. (pattern 2) during July and August (NOAA 1988).

Fig. 10. Vegetation condition index for the week 26 July–1 August 1988 for each 16 x 16 km pixel.

July. Therefore, reduction in average corn yield was less pronounced then in the other drought-affected states.

The area of VCI-derived drought in the east-central United States also coincides with the area and timing of greater than 25% rainfall reduction during summer.
January–July was above normal (Heim 1990). Meanwhile, spring and early summer dryness hurt vegetation in the central and southern plains. Fortunately, the area affected by the dry spell was relatively small, although the drought was intensive. This drought affected early- and midseason crops mostly in the Midwest. Kansas had the lowest wheat yield since 1967 (LeComte 1990). Because the 1989 drought was regional, the average U.S. wheat yield was reduced by only 8%. Late-season crops (corn, soybeans) withstood early dryness and produced near-normal yield (USDA 1991).

In the spring of 1989, VCI data identified stressed vegetation in the central, southern, and northeastern United States (Fig. 13, week 19). Such early dryness resulted from a lack of precipitation (except Colorado) during October 1988–April 1989 (Fig. 14a). The patterns of VCI-derived drought and precipitation deficit have good agreement in areal coverage and timeliness. Further development of the 1989 drought was quite different across the United States. During May and June the VCI showed a reduction of drought area. In the northeastern United States, where some measures to mitigate drought had been already initiated (LeComte 1990), this reduction occurred very quickly (compare weeks 19 and 23, Fig. 13) following heavy showers in the first 15 days of May (Fig. 14b). In the central United States, VCI data showed the continuation of drought throughout the midsummer, although the area of drought diminished gradually and moved to the north (compare the VCI pattern of stressed vegetation for weeks 19, 23, and 30; Fig. 13).

Because the 1989 drought occurred early in the season, it hit winter wheat in the central states the hardest. The area with below-average yield (Fig. 7) matched with the area of stressed vegetation outlined by the VCI in mid-May (week 19, Fig. 13). The largest reduction in winter wheat yield (nearly 30%) was

Fig. 11. Vegetation condition index in 1987 for each 16 × 16 km pixel.

1987 (Fig. 12). Another large area of VCI-derived stressed vegetation in Fig. 11 that coincides with rainfall deficit is central and southern California. In the southern United States, stressed vegetation was observed only during May 1987 (Fig. 11). However, the drought ended after above-normal rains fell in June, bringing total summer rainfall to near and above average (Fig. 12).

b. Highlights of the 1989 drought

The 1989 weather was favorable for vegetation growth. Across the nation precipitation during

Fig. 12. Rainfall (50%–75% of normal) during summer 1987.
shorter than in 1988, the vegetation condition index highlighted accurately the area of its extent, timeliness, and intensity.

7. Conclusions

Nearly 50% of the world’s agricultural areas, especially the semiarid and subhumid regions, are susceptible to drought (Goltsberg 1972). Drought affects both the economy and the environment unfavorably. Several years of data presented in this paper illustrated that the droughts identified from satellite data with the vegetation condition index corresponded to those droughts outlined from ground observations of precipitation and yield anomalies. This index showed an excellent ability to detect drought and to measure time of its onset, intensity, duration, dynamics, and impacts on vegetation. The VCI detects and traces drought not only for the cases with well-defined, prolonged, widespread, and very strong droughts (1988) but also for localized, short-term, and ill-defined droughts (1987, 1989).

Drought tests and validations are also in progress for the early 1990s in the United States using not only NDVI but also brightness temperature. This temperature helps us to identify persistent clouds and/or flooded areas. Preliminary results show that the vegetation condition index and a temperature index perform quite well. Moreover, validation results are also obtained for other areas of the world. Good agreement between the VCI and in situ data in identifying area and time of the 1990 drought in sub-Saharan Africa, 1991 droughts in southern Africa and southeastern China, and 1986 and 1988 droughts in the former Soviet Union.

The validation results presented in this paper clearly show that satellite data can be used as a source of drought information if weather observations are not available. However, it would be beneficial to combine satellite and weather data and use them as the major components of the comprehensive drought-watch system. The vegetation condition index was also useful for near-real-time assessments and diagnosis of vegetation condition and weather impacts on vegetation as well as for drought estimates.

It should be pointed out that the VCI might have multiple uses. The VCI below 35 can be definitely used as a drought indicator during the growing season of perennial vegetation. Assessment of crop yield and soil moisture and parameterization of biospheric models are other possible applications of this index. Further research should be directed to stratify the VCI by its severity in the range between 0 and 35. For VCI values above 35, yield/ VCI correlation should be studied in relation to critical periods of crops. The VCI might

Fig. 13. Vegetation condition index in 1989 for each 16 x 16 km pixel.

observed in Kansas and Nebraska (LeComte 1990). This agreed with VCI estimates of drought extent and time of its impacts. The 1989 drought also reduced corn yield. However, in Kansas, where the VCI-derived drought ended in mid-June, corn yield was near nor-

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also have other applications considering the users' contribution in VCI calibration.

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References


