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MONITORING CROP PROGRESS USING NOAA AVHRR DATA ADJUSTED FOR SEASONAL CLIMATIC VARIATION

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ABSTRACT

The assessment of changes in agricultural crop condition during the cropping season is an important function for the U.S. Department of Agriculture (USDA). The National Agricultural Statistical Service (NASS) of the U.S. Department of Agriculture currently produces a biweekly difference image map product using NOAA AVHRR images. This product is based on the difference and ratio of the normalized difference vegetation index (NDVI) for the current year and previous year for the same biweekly period. The objective of this research is to develop an improved difference image map product that accounts for the lag or acceleration of weather related conditions during the current crop season. The State of Illinois was selected for the development and evaluation of this new product. A growing degree day (GDD) parameter computed from daily air temperature is used to derive an average biweekly image data base (1989-92). The final map product describes areas in the corn belt as either above or below normal conditions. Comparing these images with USDA reports, suggests that this technique provides a good spatial and temporal assessment of crop condition for operational assessment.

INTRODUCTION

The progress in crop development and condition from sowing to harvest is of great importance to the U.S. Department of Agriculture (USDA). The National Agricultural Statistical Service (NASS) monitors the progress and condition of agricultural crops through survey reports from county agents to produce a biweekly report that is published by each State such as the Illinois Weather & Crop Report (USDA/Illinois Department of Agriculture, 1995). Crop progress is reported regarding the date of sowing and subsequent stages of crop development through maturity and harvest. The report also provides an interpretation of regional soil moisture and crop condition during the crop season in response to weather conditions. The NASS report attempts to provide a spatial understanding of the changing conditions.

Parameters derived from remotely sensed data can be used to monitor changes in the vegetation dynamics throughout the crop growing season. The Advanced Very High

Resolution Radiometer (AVHRR) on board the National Oceanic and Atmospheric Administration (NOAA) polar orbiting satellites provide daily coverage of remotely sensed data at a spatial resolution of 1.1 km. The normalized difference vegetation index (NDVI) derived from the visible and near-infrared reflectance of the AVHRR meteorological satellite have been successfully used to monitor vegetation changes at regional scales (Tucker et al.,1983). Temporal changes in the NDVI have also been correlated with net primary production (Prince et al., 1986, Malingreau et al., 1986, and Goward et al., 1987).

The dynamics of seasonal changes in vegetation conditions has been used to characterize the land cover of the conterminous U.S. using the 1.1 Km resolution NOAA AVHRR data (Loveland et al., 1991; Brown et al., 1993). Temporal change in NDVI is an indicator of changes in crop condition as well as the vegetation dynamics that follow progress. The magnitude of the NDVI parameter is between -1.0 and +1.0. The NDVI values greater than about 0.2, generally indicate a greater amount of vegetative biomass. The temporal and spatial differences in crop condition, can be attributed to the phenological development as well as to crop responses to changes in the soil-plant water relations. These influencing factors as well as major climatic events such as flooding can be assessed by monitoring changes in NDVI (Doraiswamy et al., 1994). Small scale problems such as weeds, pest and diseases cannot normally be detected at low resolutions unless the events are over extended areas.

There is a rapid increase in the magnitude of NDVI during the vegetative growth, early in the season under normal conditions. A slow rate of an increase in NDVI can be influenced by deficit in soil moisture conditions, a cold spring when growth is slow, a delay in sowing due to excess moisture conditions in the fields and a combination of these factors. Later in the season during the grain-fill period, there is a decline in green leaf area due to leaf senescence. A soil moisture deficit condition during this period would hasten the rate of senescence. The above two indicators may play a significant role in determining the final crop yields. A deviation from normal detected by a difference image product may provide very useful indicators of crop condition.

A biweekly map product is ideal for operational monitoring of crop condition in the United States. The NDVI parameter is an excellent tool for operational assessment of changes in crop condition and development. This paper will explore the accuracy of a difference image product that compares the current year with the average condition from images over several years. The difference image product should minimize the effects of crop progress by comparing images that represent the same stage of crop development. An image product developed by Kogan (1995) uses the AVHRR Global Area Coverage (GAC) time series composite. A comparison of the current image with the maximum and minimum NDVI values was an effective method to measure the current condition of the vegetation. This paper demonstrates an improvement in the NDVI difference image map product, by normalizing the images based on crop phenology.

APPROACH

A map product describing the spatial changes in crop condition by comparing the current year with an average condition of the crop during the same stage of crop development can be achieved by normalizing each image to the same scale of crop development. Current crop yield models that are used for predicting yields at field and regional scales use the summation of daily average temperature to determine the phenological stage of crop development (Amir et al., 1991; Maas, 1993; Williams, et al., 1984). The summation of the daily air temperature subtracted by a base temperature is called the growing degree days (GDD). The base temperature is specific to a crop and is the temperature below which there is minimal activity related to crop growth. In this study, a base temperature of 50°F is used for areas in the U.S. corn belt.

The State of Illinois where corn and soybeans are the principal crops were selected to develop and evaluate this improved algorithm. There is a significant range of a seasonal temperature and rainfall pattern from the northern to the southern part of the State and results in a range of growing conditions. The study period selected to evaluate this improved procedure was for the 1995 growing season. The AVHRR imagery for a period of four years (1989-1992) was used to compute the average crop condition.

Selection and adjustment of the biweekly images.

The phenological development of the corn crop was the standard used to select the appropriate NOAA AVHRR imagery. The GDD computation was made for each of the NOAA climate stations throughout the State. There was an average of 112 operating climate stations in the State of Illinois during the study period. The GDD computations were from the beginning of each year. The NOAA AVHRR data used in these analyses were obtained from EROS Data Center, U.S. Geological Survey, Sioux Fall, SD. The data is a biweekly maximum NDVI composite image at the 1.1 km resolution.

The difference image product can be developed in an operational mode at a frequency of 14 days. However, this algorithm was tested for three periods during the crop season to correspond approximately to the meeting dates of the NASS Agricultural Statistics Board that takes place after the first week of each month during the crop season. The three dates selected to develop the difference image (DI) map product for the 1995 crop season was, day of the year (DOY) 175, 203 and 231. These dates generally corresponded to the mid-vegetative, reproductive (silking) and grain-fill (denting) stages respectively, for the corn crop in Illinois. The spectral characteristics during these stages of development are quite distinct and represent critical periods that influence the final crop yields (Doraiswamy et al., 1995).

Figure 1. describes the procedure for the development of a four-year average base image that is used to produce the final difference image map product. The average image is developed by selecting the appropriate image in each year to represent the same stage of crop development as the 1995 image. The selection process involves identifying the date

(D) in each year that corresponds to the equivalent GDD. This date (D) is then used to select the biweekly period (P) in which it falls. The calculated date (D) for each year may fall closer to the start or end of the biweekly period and may not be truly represented by the maximum biweekly value for that period. A further adjustment to the image is made by taking the image from the previous (P-1) and the following period (P+1). The adjustment is done by weighting the NDVI values from two periods based on where the date (D) falls in the biweekly.

When the NDVI difference image is created, the pixel resolution is still maintained at 1.1 km. Smoothing the final image product to obtain a spatial average is achieved by conducting a 9 x 9 km pixel moving average across the image. This averaging window size was selected to be the optimum for smoothing the image without compromising the spatial integrity of the difference image map product.

RESULTS AND DISCUSSIONS

The NDVI difference images shown in Figures 2, 3 and 4 represent approximately the mid-vegetative, silking and denting stages of corn development. The image on the left side in each figure is the DI for the biweekly period ending on DOY 175 (1995) compared with the four-year average image adjusted for GDD. The image on the right is the DI for 1995 and the four-year average based on biweekly periods. The scaling of the DI product is consistent within each method. There are five ranges which categorize the DI values. The ranges are based on the spread in the magnitude of the DI values over the season. In this study the three dates (DOY 175, 203 and 231) were used to develop the ranges based on a statistical method. The DI mean for the three dates provided the middle scale for the no difference. The range for the scale of no difference category was set to ± one standard deviation (STD) of the mean value. The next scale was set to a range between one and two STDs on either side of the mean value. The positive values represent crop conditions that are better in the 1995 crop season compared to the four-year average and the negative values represent below average crop conditions. The final scale was set to a range between two and three STDs below and above the mean, respectively representing extremely poor and very good crop conditions.

The GDD adjusted, DI image has less than average vegetative growth at the biweekly period ending June 24 for 1995. The majority of the areas in the central and southern parts of the State, approximately 60% of the area, have vegetation that is below normal or average conditions. About 36% of the area had average conditions. The image on the right in figure 2 represents the NDVI difference image between 1995 and the four-year average image, based on the corresponding biweekly periods. This DI shows that 50% of the State appears to be in average condition, while 10% of the areas in the central and southern edge of the State doing extremely well. Only parts (30%) of north central Illinois have conditions that are below average (30%). The NASS crop report for Illinois confirms that although the corn crop in the State was completely planted, delayed planting resulted in corn to be 15 inches tall where as the 5-year average height is 29 inches by June 26. The GDD adjusted, DI showed the true conditions on the ground.

Figure 3 shows the DI during the silking period for the 1995 season. The images generated by the two methods appear to be closer in the proportions of similar conditions, although the spatial coincidence is not evident except for an eight-county area in the south. About 50% of the area in both images is closer to the average with a small proportion of the area below average. The NASS reports suggest that although the vegetative growth was near completion, only 46% of the corn crop in the State had reached the silking stage compared to 73% over a 5-year average. Figure 4 shows clearly a significant difference between the two methods when the corn crop was at the dented stage. The GDD adjusted, DI map product suggests that greater than 65% of the State is above average vegetation condition compared to only 30% for the other method. The NASS report on crop progress shows that 17% of the corn crop in 1995 was at the dented stage compare to the 34% for a 5-year average. The GDD adjusted method clearly shows that the crops were still behind in the development and the NDVI was above the average. However, the biweekly based DI image does not reflect the same condition and most of the areas in the image(66%) are at average condition. The latter method does not correctly represent the prevailing conditions and can misrepresent the spatial as well as the temporal changes in crop condition.

A method for comparing the NDVI of the current year with average NDVI values averaged over several years is proposed in this paper. This method is a useful tool for real-time monitoring of crop condition during the crop growing season. The images are compared by taking the difference between the current year and the average of several years. The comparisons are made when the crops represent in each of the images are at the same stage of phenological development by selecting the images based in GDD.

The examples provided in this paper are for three days (DOY 175,203 and 231) during the 1995 season for the crop areas in the State of Illinois. The results are compared with a commonly used method where the difference image is created by taking the NDVI images of the current year and the average of the NDVI images of several years for approximately the same biweekly period. Since biweekly periods represent only calender dates, air temperature and soil moisture conditions may shift the start of the crop season. When changes in weather related conditions are not used in the development of the image product, false alarms may occur.

The conclusion from this evaluation is that the difference image adjusted for GDD followed the condition and progress of the crop reported by NASS. At mid-season when NDVI values have reached a maximum, the differences in the two methods are minimized for a short period. But the greatest departure occurs in the vegetative and post reproductive stages of crop development. Further evaluation of this method will continue with the additional spatial information on soil moisture conditions derived from models.

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Figure 1. Procedure for the Development of a Difference Image Product.

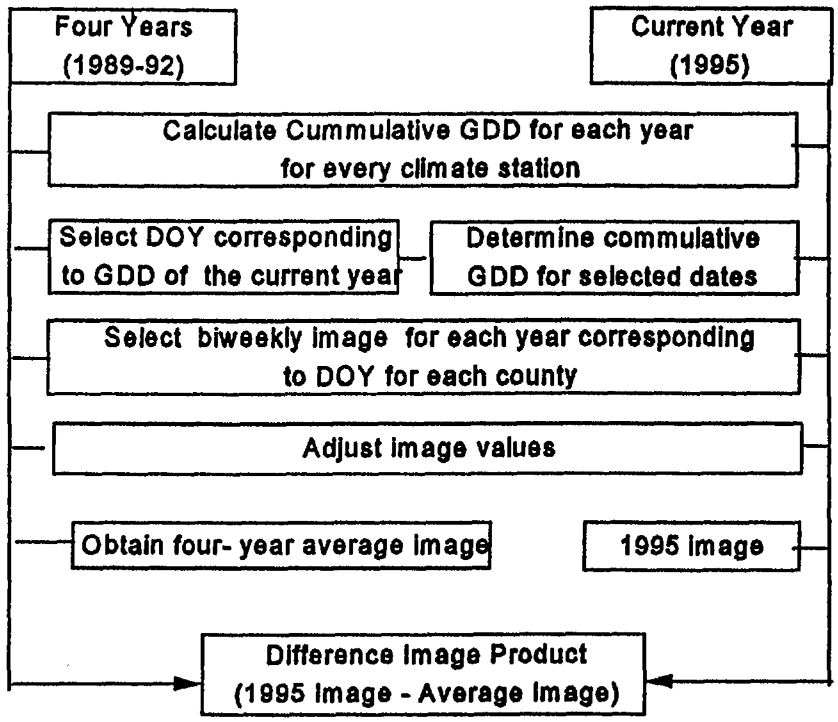
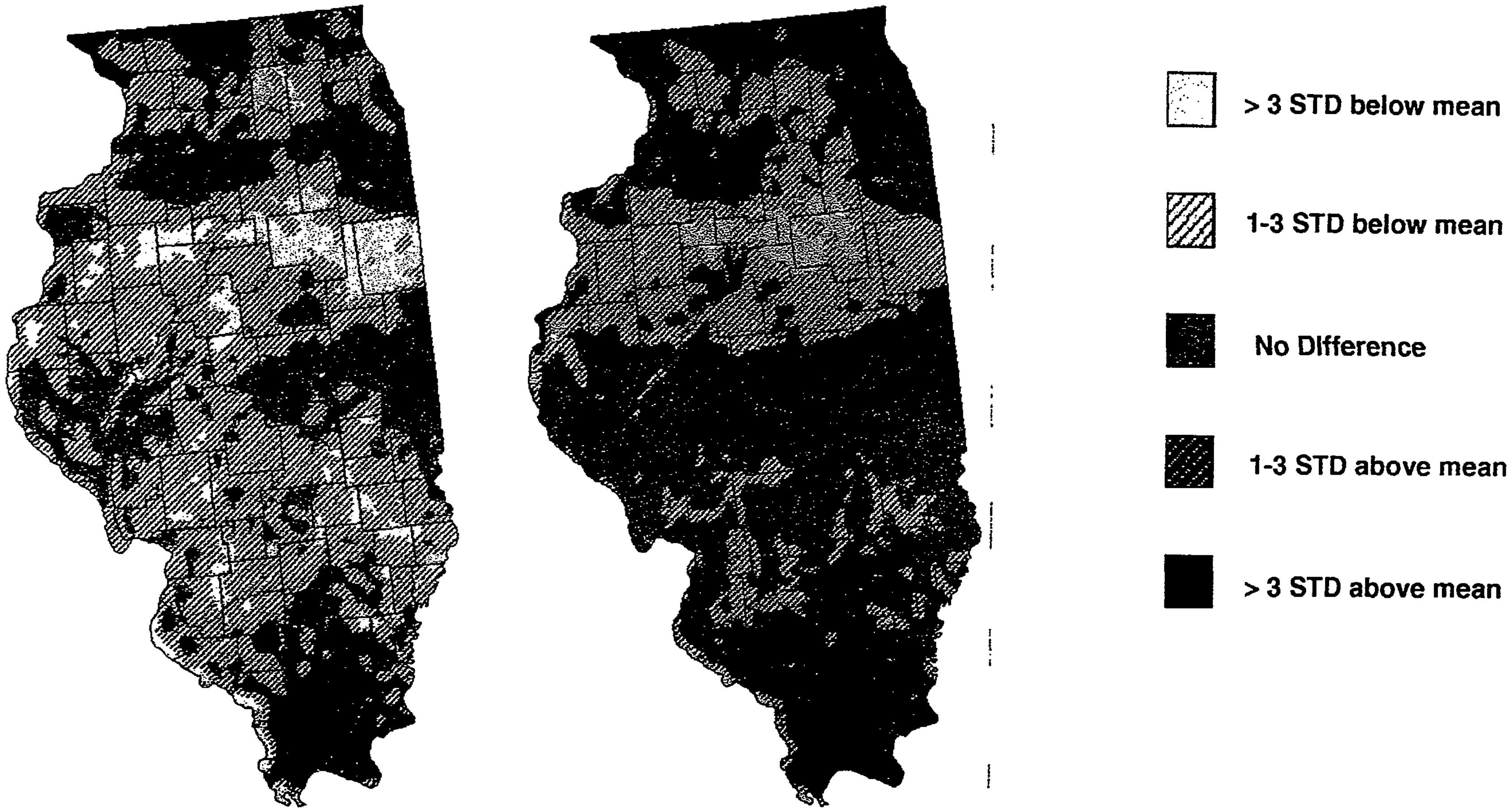


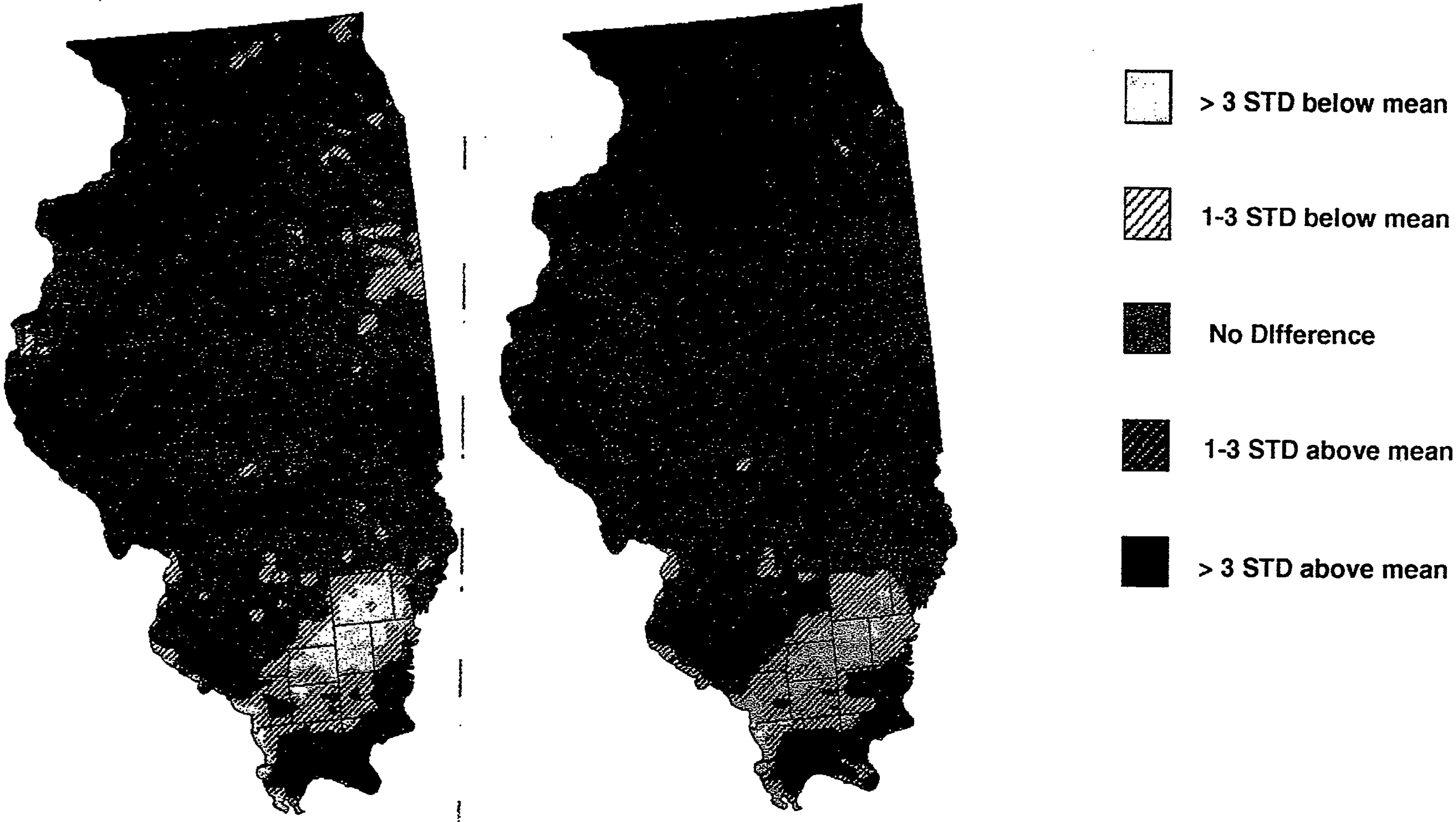
Figure 2. NDVI Difference image between 1995 and 4 year mean (1989-1992) for biweekly period ending June 24



Adjusted to Growing Degree Day

Adjusted to Bi-weekly Period

Figure 3. NDVI Difference image between 1995 and 4 year mean (1989-1992) for biweekly period ending July 22



Adjusted to Growing Degree Day

Adjusted to Bi-weekly Period

Figure 4. NDVI Difference image between 1995 and 4 year mean (1989-1992) for biweekly period ending August 19

Adjusted to Growing Degree Day

Adjusted to Bi-weekly Period