Monitoring Drought and its Impacts on Vegetation from Space

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Abstract

With nearly 30 years of the accumulated AVHRR data which were collected from NOAA operational polar-orbiting environmental satellites, the area of their applications expanded in the direction of monitoring vegetation condition, modeling agricultural production, analysis of climate and global change, resource management, and early and more efficient monitoring of the droughts on economy and society. This becomes possible due to the development of Vegetation Health indices (VHI). This paper discusses utility of AVHRR-based VHI focusing on monitoring vegetation with the emphasis on early drought warning and estimation of losses in agricultural production.

Introduction

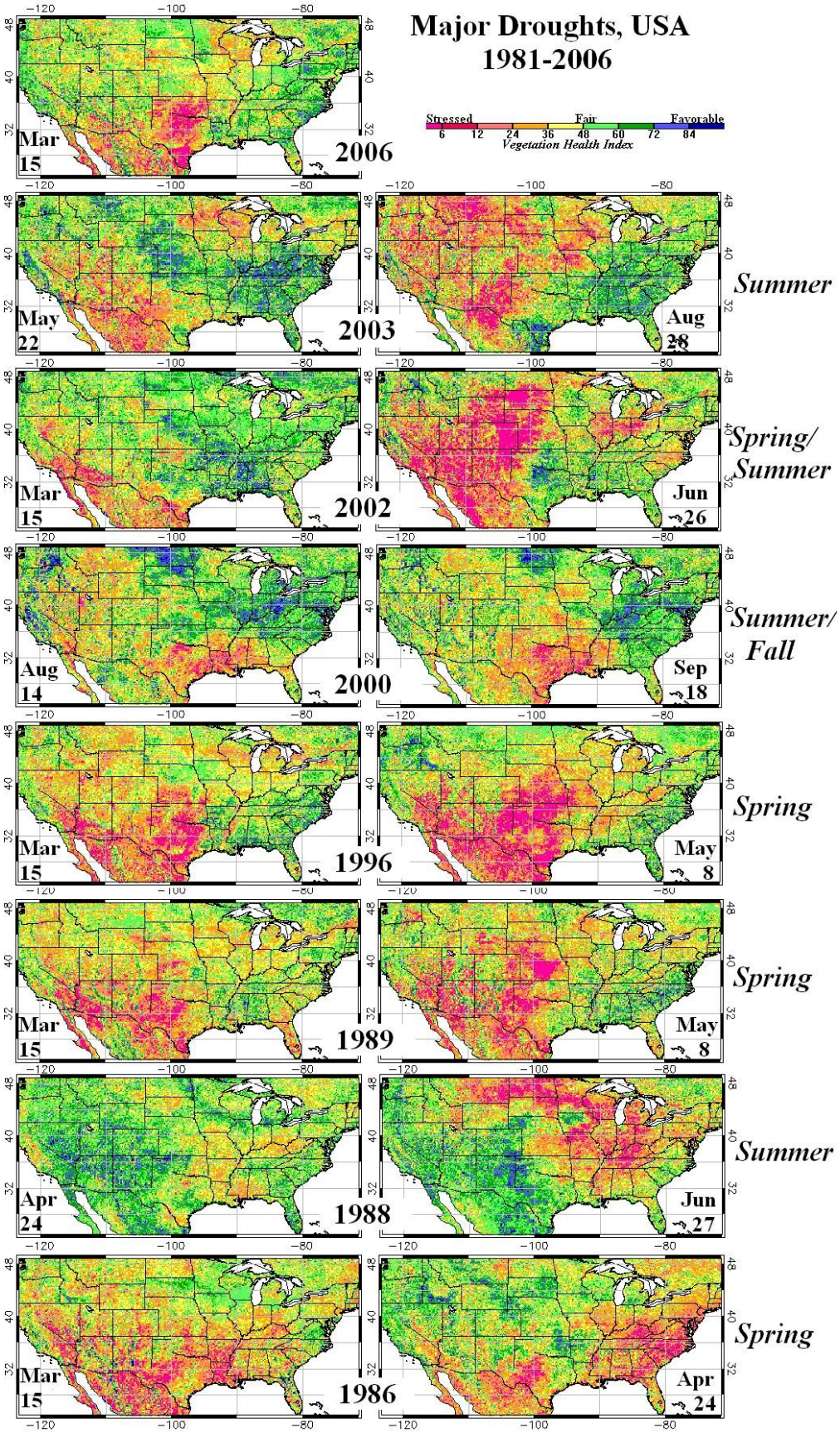
Drought is a typical phenomenon of the US climate. Drought losses in agricultural production are staggering and account on the average around $6 billion annually. In extreme drought years such as the 1988, the losses might be 5-8 times larger. This paper discusses satellite-based land-surface observing system, developed from the Vegetation health indices (VHI). The VHI were derived from the Earth observations by the Advanced Very High Resolution Radiometer (AVHRR) flown on NOAA afternoon operational polar-orbiting satellites. The focus here is VHI application for early drought warning, assessment of vegetation condition and estimation of losses in agricultural production. Unlike other remote sensing techniques, the new method uses three-channel AVHRR reflectances and the main ecosystem's laws for analysis of vegetation health in response to weather changes (Kogan 1990, 1997).

Satellite Data

Satellite data were collected from the AVHRR-based Global Area Coverage (GAC) data set. The GAC is produced by sampling and mapping the AVHRR 1-km daily reflectance in the visible (VIS, Ch1, 0.58-068 (µm), near infrared (NIR, Ch2, 0.72-1.1 (µm), and two infrared bands (IR, Ch4, 10.3-11.3 and Ch5, 11.5-12.5 µm) to a 4-km map. The VIS and NIR reflectance were pre- and post-launch calibrated and the Normalized difference vegetation index (NDVI) was calculated as (NIR-VIS)/(NIR+VIS). The IR emission was converted to brightness temperature (BT), which was corrected for non-linear behavior of the AVHRR sensor. Daily NDVI and BT were composited over a 7-day period by saving those values that have the largest NDVI for each map cell. The 1981-2007 NDVI and BT weekly time series were processed to remove high frequency noise, identify seasonal cycle and to calculate climatology.

Vegetation Health Indices

A new method is based on estimation of green canopy stress/no stress from AVHRR-derived indices, characterizing moisture, thermal conditions and total vegetation health (Kogan 1990, 1997). Unlike the two spectral channel approach (NDVI-based) routinely applied for vegetation monitoring, the new numerical method in addition to NDVI, uses also 10.3-11.3 µm IR channel, which estimate the hotness of the vegetation canopy. In dry years, high temperatures, at the background of insufficient water supply, lead to overheating the canopy, which intensifies negative effects of lack of moisture impact on vegetation. The three-channel algorithm consists of


Major Droughts, USA
1981-2006
Stressed
Fair
Favorable
6 12 24 36 48 60 72 84
Vegetation Health Index
Mar 15
2006
May 22
2003
Aug 28
Summer
Mar 15
2002
Jun 26
Spring/ Summer
Aug 14
2000
Sep 18
Summer/ Fall
Mar 15
1996
May 8
Spring
Mar 15
1989
May 8
Spring
Apr 24
1988
Jun 27
Summer
Mar 15
1986
Apr 24
Spring

comprehensive processing of NDVI and BT annual time series, which includes complete removal of high-frequency noise, enhancing seasonal cycle, calculation of climatology and single out medium-to-low frequency fluctuations associated with weather impacts on vegetation (Kogan 1995, 1997). This procedure was formalized by equations 1-3, where climatology was represented by the difference between 22-year absolute maximum and minimum NDVI and BT values for each pixel and week.

$$VCI = 100*(NDVI - NDVI_{min}) / (NDVI_{max} - NDVI_{min} \quad (1)$$
$$TCI = 100*(BT_{max} - BT) / (BT_{max} - BT_{min}) \quad (2)$$
$$VHI = a*VCI + b*TCI \quad (3)$$

where NDVI, $NDVI_{max}$, and $NDVI_{min}$ are the smoothed weekly NDVI, its multi-year absolute maximum and minimum, respectively; BT, BT_{max}, and BT_{min} are similar values for BT; *a* and *b* are coefficients quantifying a share of VCI and TCI contribution in the total vegetation health. The VCI (Vegetation Condition Index), TCI (Temperature Condition Index) and VHI (Vegetation Health Index) are indices estimating cumulative moisture, temperature and total vegetation health conditions, respectively on a scale from zero (extreme stress) to 100 (favorable condition) with 50 corresponding to average condition.

Droughts, Vegetation Stress and Crop Losses

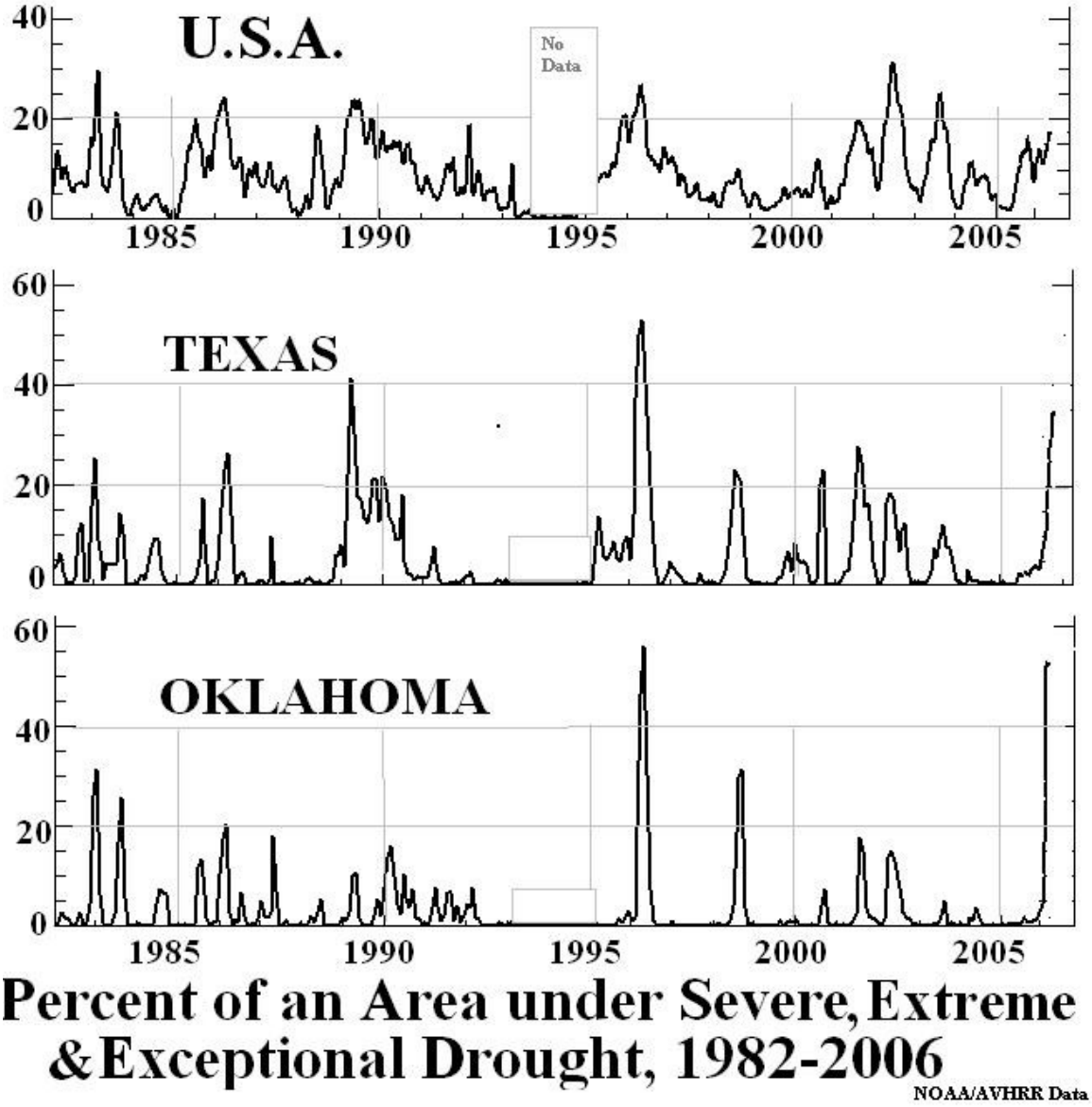
In the last 15 years, the VHI have been used successfully for detection of drought-related vegetation stress and estimation of crop losses in the USA. The data showed that large-area drought can be detected up to two months in advance of other techniques, outlined more accurately and the impact on grain reduction can be diagnosed long in advance of harvest (Kogan 1995. 2001)

Figure above shows VHI-derived major US droughts. As it is seen, all droughts are different in coverage, timing and intensity although some of them can be found identical. For example, among early season droughts, 1989 and 1996 started at the beginning of spring and affected the primary winter wheat areas; in later spring (May) vegetation was stressed affecting summer crops production in the central US. Luckily, vegetation was stressed only in a few states of the central and northern Great Plains. Therefore, the total US spring crop production did not shrink much in 1989 (one-two percent from the 1985-1990 mean, Kogan 1995).Droughts of 2002 and 2003 devastated summer vegetation in the western US triggering enormous forest fires.

Table 1. Independent testing of Yield/VHI models in Kansas (Salazar et al 2006)

REGION	Mean Absolute Error	Root MSE	Systematic Error	Non-Systematic Error	R^2 Between Simulated (S) and Observed (O) Yield
Kansas	2.095	2.541	0.00	2.387	0.84
CRD 10	1.667	2.135	0.01	2.006	0.89
CRD 20	2.347	3.074	0.00	2.888	0.85
CRD 30	2.126	3.293	0.00	3.105	0.82
CRD 40	2.936	3.921	0.01	3.683	0.81
CRD 50	2.545	3.338	0.00	3.135	0.87
CRD 60	1.829	2.309	0.01	2.169	0.91
CRD 70	3.539	4.707	0.01	4.421	0.82
CRD 80	2.624	3.696	0.00	3.458	0.76
CRD 90	2.427	3.514	0.03	3.287	0.81

Among the droughts of the last 30 years, the 1988 drought was the most devastating to the US economy, human health, environment, and wildlife (Riebsame et al 1990, Kogan 1995). Agriculture suffered in many states from north to south (the US “grain basket” of the Great Plains) since vegetation was stressed during the critical period of crop growth (with the worst combination of both moisture and thermal stress).



Compared to 1988, the 2006 drought in US affected only two states Texas and Oklahoma which are the major producers of winter wheat. Oklahoma was the most severely affected. VHI estimates indicated that fifty five percent of the entire state experienced extreme and exceptional drought (every 10-year occurrence). Prior to 2006 similar phenomenon was observed in 1996 (see Fig. above).

Crop and pasture losses occur every year somewhere in the North American because of droughts. The VHI was used in the USA as a predictor for assessment of winter wheat yield in Kansas which produces nearly one-fifth of all USA winter wheat volume and ranks number one in export. Weekly Vegetation Condition Index (VCI) during the critical time (one week before and after

heading) of winter wheat growth in spring was used as an independent variable to characterize moisture condition and productivity of this crop. Models relating variations in winter wheat related weather with VCI were developed for the entire Kansas state and for the nine crop reporting districts (CRD). Table 1, showing an independent testing of models, indicates that R-square is very high (0.76-0.91) and systematic errors is near zero confirming high performance of the selected predictors (Salazar et al 2007).

Conclusions

The new Vegetation health indices, characterizing moisture and thermal conditions and the entire vegetation health, have been used successfully for early drought detection and estimation of losses in crop and pasture production for winter wheat in the USA. Unlike other remote sensing techniques, the new method is based on the three ecosystem's laws applied for analysis of vegetation health in response to environmental changes. One of the important advantages of this method is using combination of NDVI and 10.3-11.3 µm IR channel. This method was tested and validated against ground data in all major agricultural countries of the world and in different climate environment. The fifteen-year tests showed that with the introduction of the new method, drought can be detected 4-8 weeks earlier than before in any corner of the globe, outlined more accurately and the impact on grain reduction can be diagnosed long in advance of harvest. The NOAA/NESDIS web site (http://www.orbit.nesdis.noaa.gov/smcd/emb/vci/VH) contains operational VHI data sets and products which are updated every Tuesday during 2008. Table 2 describes main features of the GVI-x data set and products

Table 2. GVI-x Product Description

Item	Description
Products	NDVI, BT, SMN, SMT, VCI, TCI, VHI, NDmax, NDmin, BTmax, BTmin
Availability	Operational, in 2008 on Tuesday
Coverage	From 75º N to 55º S
Resolution	Temporal – weekly; Spatial – 4 km²
Period	1981-present
Gaps	Sep 1994-Feb 1995
File format	HDF, 16-bit integer, scaled (see documentation)
Data problems to address	Correction for Mt. Pinatubo aerosols; Orbit degradation in 1993, 1994 and 2000

NDVI, SMN, NDmax, NDmin - Normalized difference vegetation index: raw, smoothed, multi-year maximum and minimum data, respectively; BT, SMT, BTmax, BTmin – Brightness temperature: raw, smoothed, multi-year maximum and minimum data, respectively; VCI,TCI,VHI – indices: Vegetation condition, Temperature condition and Vegetation health

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