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Quick Spatial Assessment of Drought Information Derived from MODIS Imagery Using Amplitude Analysis

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***Abstract*—**The normalized difference vegetation index (NDVI) and normalized difference moisture index (NDMI) derived from the moderate resolution imaging spectroradiometer (MODIS) have been widely used to identify spatial information of drought condition. The relationship between NDVI and NDMI has been analyzed using Pearson correlation analysis and showed strong positive relationship. The drought indices have detected drought conditions and identified spatial extents of drought. A comparison between normal year and drought year demonstrates that the amplitude analysis considered both vegetation and moisture condition is an effective method to identify drought condition. We proposed the amplitude analysis is useful for quick spatial assessment of drought information at a regional scale.

***Keywords*—**NDVI, NDMI, Drought, remote sensing, spatial assessment.

I. Introduction

DROUGHT monitoring assessment using satellite data has been an important issue in environmental monitoring and assessment [1-4]. Food security and safety have also been critical issues under the increasing population of the whole world. Therefore, developing quick drought monitoring and assessment using remotely sensed imagery to identify regional impact of drought for cropping systems is important.

Satellite imagery was comprehensively applied to monitor and assess vegetation dynamics, drought condition, land surface moisture, cropping system, desertification [5-7]. For example, the moderate resolution imaging spectroradiometer (MODIS) were applied to monitor desertification in East Asia and found that the desert areas expanded from 2000 to 2002, shrunk in 2003, then expanded again from 2003 to 2005 [6]. The National Oceanic and Atmospheric Administration (NOAA)- Advanced Very High Resolution Radiometer (AVHRR) data have also been extensively used for drought monitoring and assessment.

Drought indices derived from satellite imagery have been widely used to identify spatial extents of drought [8-10]. For example, Kogan designed AVHRR-based indices to monitor drought and flood [10]. The indices are useful for detection and monitoring large area vegetation stress resulted from drought or soil oversaturation following flooding and excessive rains. Another study was designed to use NOAA-AVHRR imagery to compute normalized difference vegetation index (NDVI) and vegetation condition index (VCI) indices to correlate precipitation data in the northwest of Iran [11]. They concluded that NOAA-AVHRR derived NDVI well reflects precipitation fluctuations in the study area and is useful for drought risk management. The NOAA-AVHRR data were applied to compute satellite derived drought indices, including the NDVI, Anomaly of Normalized Difference Vegetation Index (NDVIA), Standardized Vegetation Index (SVI), Vegetation Condition Index (VCI), Land Surface Temperature (LST) and NDVI (LST/NDVI), the Vegetation Health Index (VH), and the Drought Severity Index (DSI) [8]. They found that the combination of drought indices can identify wider drought-occurred areas than the PDSI and the DAA maps. Therefore, drought indices derived from satellite imagery are helpful for detecting, monitoring, and assessing drought and its spatial information at a regional scale.

The objective of this study was to compare effectiveness of satellite derived drought indices applied to drought assessment in normal and drought years. The study was focused on quick drought assessment using satellite derived drought indices. The results should further our understanding of the relationship between vegetation- and moisture-based drought indices, and should improve remote sensing techniques used for drought assessment and identifying spatial information.

II. Study Area

The study was carried out in the western Liaoning, north-eastern China. The main land cover types are corn field and forest, which cover more than 73% of the study area's 27,536 km^2 (Fig. 1). Corn field is the dominant cropping system in the study area. The growing season of corn field is

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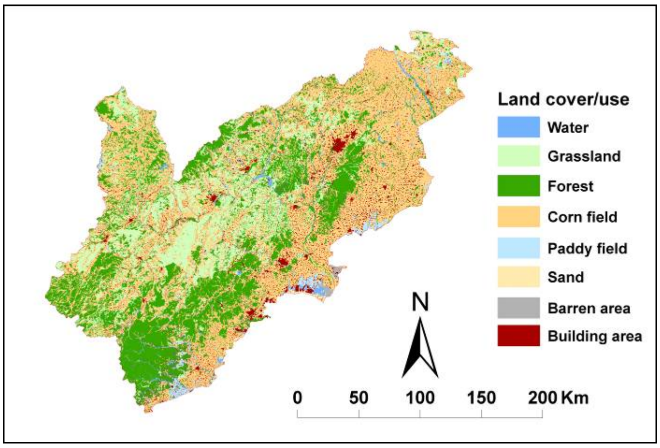

Fig. 1 Study area is restricted to the corn field and forest zones of western Liaoning, north-eastern China.

III. MATERIALS AND METHODS

A. Satellite derived indices

In this study we use the 8-days MODIS surface reflectance product (Surface Reflectance 8-Day L3 Global 500m Product) for the image of Julian Day 225 to 232 from the year 2002 to 2009. The NDVI is a common measure of the condition of vegetation. The NDVI is comprehensively used in vegetation studies because of the ease of computation for most satellite spectral data available. Following data pre-processing, the NDVI for each 8-day image is calculated using Eq. (1)

$$NDVI = (\rho_{NIR} - \rho_{RED}) / (\rho_{NIR} + \rho_{RED}), \quad (1)$$

where ρ_{NIR} and ρ_{RED} are the surface reflectance in the visible (620-670 nm) and Near-Infrared (NIR) (841-876 nm) regions of the electromagnetic spectrum, respectively.

Recent studies suggest that there is a high correlation between the Normalized Difference Moisture Index (NDMI) and wetness [12]. The NDMI index was first proposed by Gao in 1996 who demonstrated it to be sensitive to changes in liquid water content in vegetation canopies [13]. The index has proven to be a promising technique for monitoring harvesting and other disturbances [14]. The NDMI has been demonstrated to be an improvement over the NDVI for the detection of changes in forest cover. Thus, here we adopt the NDMI to assess land surface dynamics of oasis vegetation. The NDMI is computed using equation (2) below, based on the contrast between mid-infrared (MIR) and near-infrared (NIR) reflectance which are sensitive to changes in vegetation leaf structure and water content [15-17]. The NIR and MIR bands are used to calculate the NDMI as follows:

$$NDMI = (\rho_{NIR} - \rho_{MIR}) / (\rho_{NIR} + \rho_{MIR}), \quad (2)$$

where ρ_{MIR} is the surface reflectance in the MIR (2105–2155 nm) region of the electromagnetic spectrum.

B. Drought indices

The Anomaly of Normalized Difference Vegetation Index (NDVIA) is a departure from the long-term average for a specific month indicating drought conditions as compared to the average range of time [8]-[18]. The NDVIA was computed as differences from multiyear 8-day composite image of Julian Day 225-232 using the 6-year record (2002 – 2008, except 2004), excluding cloud pixels. The mean 8-day NDVI and specific 8-day NDVI are used to calculate the NDVIA as follows:

$$NDVIA_{ijk} = \overline{NDVI_{ij}} - NDVI_{ijk}, \quad (3)$$

where $\overline{NDVI_{ij}}$ and $NDVI_{ijk}$ are the multiyear average NDVI for pixel *i* in 8-day *j*, and 8-day NDVI for pixel *i* in 8-day *j* for year *k*, respectively.

According to the formula of NDVIA, we propose a Anomaly of Normalized Difference Moisture Index (NDMIA) to measure the departure of land surface moisture condition in the study area. The NDMIA was computed as follows:

$$NDMIA_{ijk} = \overline{NDMI_{ij}} - NDMI_{ijk}, \quad (4)$$

Thus, the NDVIA and NDMIA identify vegetative and hydrologic drought conditions.

C. Amplitude analysis

The two indices of NDVIA and NDMIA are useful for identifying spatial extent of vegetative and hydrologic drought condition. Traditional drought assessment using remote sensing techniques is only adopted vegetative satellite derived indices, such as NDVI, NDVIA, VCI, SVI [1]-[8]-[11].

The amplitude image was computed as follows:

$$Amplitude_{ijk} = \sqrt{\left(\overline{NDVI_{ij}} - NDVI_{ijk}\right)^2 + \left(\overline{NDMI_{ij}} - NDMI_{ijk}\right)^2}, \quad (5)$$

IV. RESULTS AND DISCUSSIONS

A. Pearson correlation analysis between NDVI and NDMI

The Pearson correlation analysis was computed for the NDVI and NDMI. Because the relationship between vegetation and moisture varies within a growing season, especially a drought event, we analyzed the normal year and drought year separately.

Generally, strong positive correlations were found between NDVI and NDMI (Table 1). This reflects the fact that healthy vegetation condition implies a good moisture condition in the normal year ($r = 0.798$; $p<0.01$). However, the strength of this relationship was enhanced in the drought year ($r = 0.847$; $p<0.01$). The result indicates that vegetation condition is similar with moisture condition when a drought occurs.

TABLE I PEARSON CORRELATION COEFFICIENT (R) BETWEEN NDVI AND NDMI OF THE MODIS 8-DAY COMPOSITE IMAGE FOR THE NORMAL YEAR (2008) AND DROUGHT YEAR (2009)

	Pearson correlation coefficient (r)	Significance (p)
Normal year (2008)	0.798	$p < 0.01^*$
Drought year (2009)	0.847	$p < 0.01^*$

[*] Correlation is significant at the 0.01 level (2-tailed).

B. Mapping with drought indices

The spatial information of normal and drought condition using NDVIA and NDMIA provides useful geographic representation visually and digitally (Fig. 2 and 3). The MODIS 8-day surface reflectance composites of Julian Day 225 to 232 have been collected for the year 2008 and 2009. NDVIA and NDMIA have been used to quantify the vegetative drought in the normal year (2008) and drought year (2009). The NDVIA and NDMIA maps have been generated by plotting pixel values of NDVIA having a 500m spatial resolution, and have been classified to represent various drought intensities (Extreme, Severe, Moderate, Mild, Slight, and No Drought).

The drought situation, the worst drought condition during the period from 1950 to 2009, was encountered during the growing season of corn field of the year 2009 in western Liaoning. The comparison between the normal year and drought year indicates the effectiveness of satellite derived drought indices for quick drought monitoring and assessment. The map of NDVIA and NDMIA of the year 2008 appear no or slight drought conditions in the western Liaoning, north-eastern China. The drought conditions mainly appear over the central part of the study area.

C. Amplitude Analysis

The amplitude image computed from NDVIA and NDMIA had a similar spatial pattern with NDVIA and NDMIA maps. The vector length of the amplitude image was longer than the NDVIA and NDMIA images, as shown in Fig. 4. The spatial information of drought condition showed in Fig. 4 is clearer than the other images. Thus, Fig. 4 demonstrates the amplitude analysis using both vegetation and moisture conditions to identify spatial extent of drought is quite well.

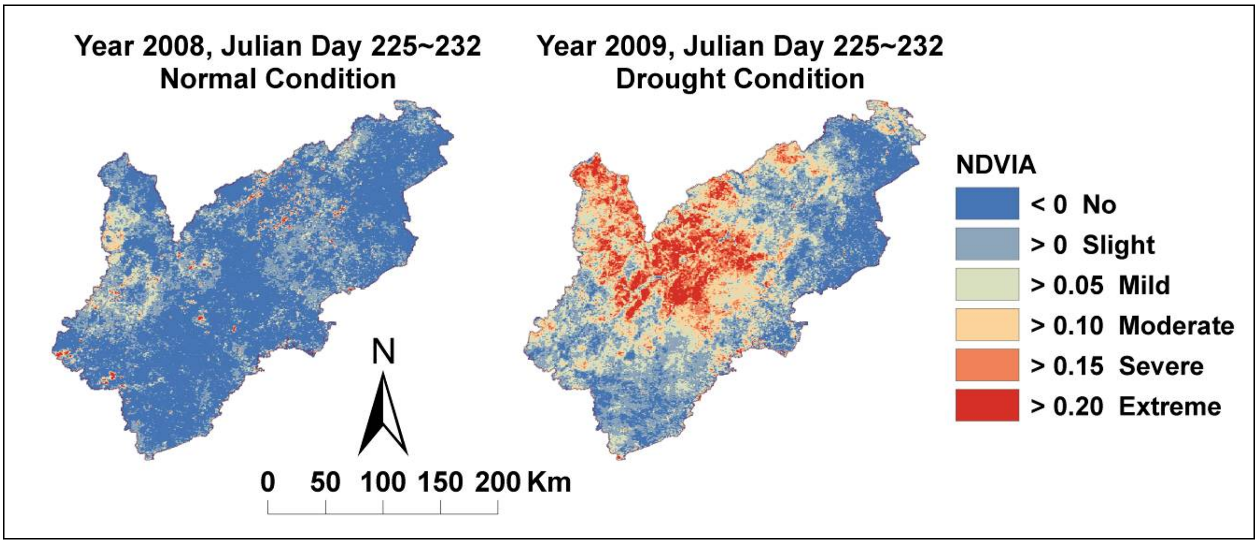

Fig. 2 NDVIA values for the composite image of Julian Day 225~232 in the year 2008 and 2009.

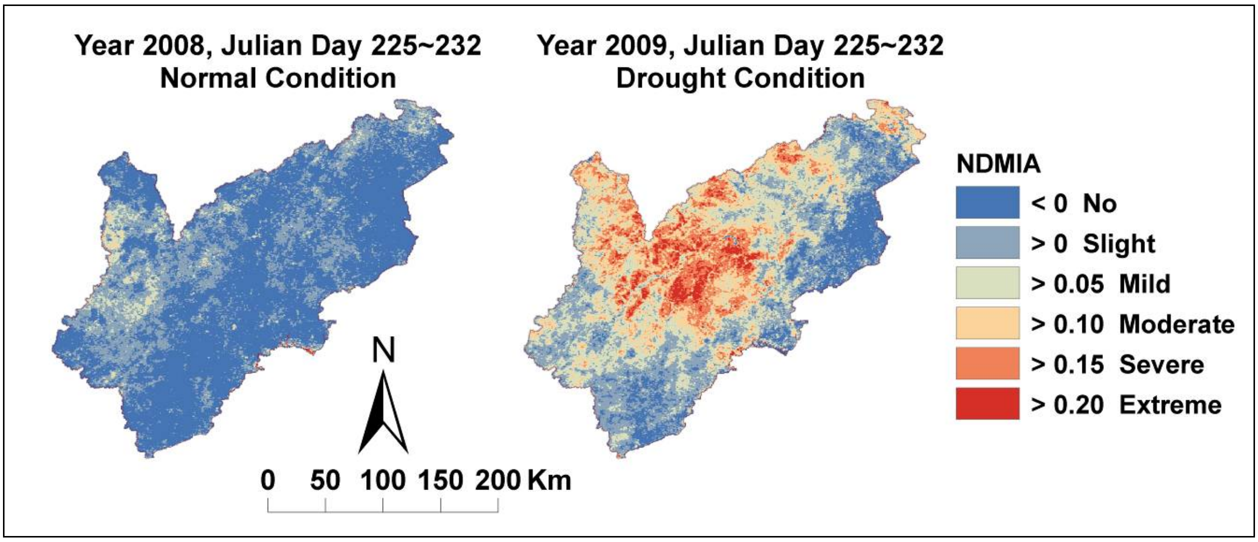

Fig. 3 NDMIA values for the composite image of Julian Day 225~232 in the year 2008 and 2009.

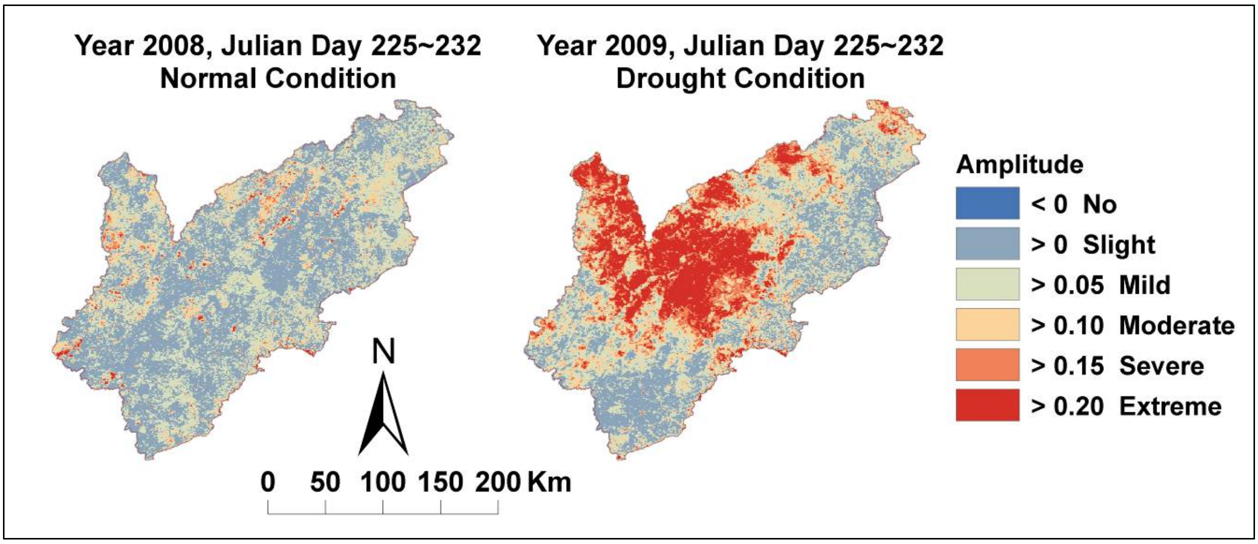

Fig. 4 Amplitude values for the composite image of Julian Day 225~232 in the year 2008 and 2009.

V. CONCLUSION

It is concluded that the drought condition of the year 2009 has been assessed and identified the spatial extent and drought magnitude using satellite imagery. The NDVI and NDMI are useful satellite derived indices to detect the land surface dynamics of vegetation and moisture condition. In this study, we have demonstrated that the NDVIA and NDMIA are useful for monitoring and assessing drought condition in the vegetation and moisture aspects. Furthermore, the amplitude analysis using the NDVIA and NDMIA has also demonstrated its effectiveness to identify the spatial extent of drought condition. The amplitude analysis considered both vegetation and moisture condition in a drought event improves the traditional drought assessment methods, which only considers vegetation condition.

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