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Dildora Aralova, Kristina Toderich, Ben Jarihani, Dilshod Gafurov, Liliya Gismatulina

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Monitoring of vegetation condition using the NDVI/ENSO anomalies in Central Asia and their relationships with ONI (very strong) phases

Dildora Aralova^{a*}, Kristina Toderich^b, Ben Jarihani^c, Dilshod Gafurov^d & Liliya Gismatulina^e

^{a*} Dresden University of Technology (TU-Dresden), Institute of Photogrammetry and Remote Sensing, Dresden, Germany & Samarkand State University, Laboratory "Environmental Problems", Uzbekistan. E-mail: dildora.aralova@tu-dresden.de ; aralovad@daad-alumni.de

^b International Center of Biosaline Agriculture, ICBA-Dubai, Tashkent office & Samarkand State University, Uzbekistan; E-mail: k.toderich@cgiar.org

^c University of Sunshine Coast – CSIRO, Australia; Locked Bag 4, Maroochydore DC QLD 4558, Australia; E-mail: bjarihan@usc.edu.au

^d Research Institute for cotton breeding, seeding and cultivation agro-technologies, Kibray, Uzbekistan ;

^e Samarkand State University, Laboratory "Environmental Problems", Uzbekistan. E-mail: lfulton@gmail.com

Abstract

An investigation of temporal dynamics of El Niño–Southern Oscillation (ENSO) and spatial patterns of dryness/wetness period over arid and semi-arid zones of Central Asia and their relationship with Normalized Difference Vegetation Index (NDVI) values (1982-2011) have explored in this article. For identifying periodical oscillations and their relationship with NDVI values have selected El Nino 3.4 index and thirty years of new generation bi-weekly NDVI 3g acquired by the Advanced Very High Resolution Radiometer (AVHRR) satellites time-series data. Based on identification ONI (Oceanic Nino Index) is a very strong El Nino (warm) anomalies observed during 1982-1983, 1997-1998 and very strong La Nino (cool) period events have observed 1988-1989 years. For correlation these two factors and seeking positive and negative trends it has extracted from NDVI time series data as "low productivity period" following years: 1982-1983, 1997 -1998; and as "high productivity period" following years: 1988 -1989. Linear regression observed warm events as moderate phase period selected between moderate El Nino (ME) and NDVI with following periods:1986-1987; 1987-1988; 1991-1992; 2002-2003; 2009-2010; and moderate La Niña (ML) periods and NDVI (1998-1999; 1999-2000; 2007-2008) which has investigated a spatial patterns of wetness conditions.

The results indicated that an inverse relationship between very strong El Nino and NDVI, decreased vegetation response with larger positive ONI value; and direct relationship between very strong La Niña and NDVI, increased vegetation response with smaller negative ONI value. Results assumed that significant impact of these anomalies influenced on vegetation productivity.

These results will be a beneficial for efficient rangeland/grassland management and to propose drought periods for assessment and reducing quantity of flocks' due to a lack of fodder biomass for surviving livestock flocks on upcoming years in rangelands. Also results demonstrate that a non-anthropogenic drivers of variability effected to land surface vegetation signals, understanding of which will be beneficial for efficient rangeland and agriculture management and establish ecosystem services in precipitation-driven drylands of Central Asia.

Keywords: ENSO, Central Asia, vegetation, degradation, NDVI, ONI

Introduction

The irregular patterns of precipitation and drought anomalies are affecting Central Asian (CA) drylands and our preliminary studies have shown (very strong phase) that ENSO anomalies phases directly linked to vegetation responses in CA ecosystems. CA countries (Tajikistan, Kazakhstan, Uzbekistan, Kyrgyzstan and Turkmenistan) have a sharp continental climate (*i.e.*, located in the middle of Asia) and ENSO phases have been demonstrated and reported to be linked to land surface responses in CA [5; 3; 12]. The rising occurrence of drought events and following soil salinization are serious threats that have major impacts on land-use and land-cover (LULC) patterns in agricultural regions of CA. These abiotic (anthropogenic influence) factors are well reported by researchers, especially after desiccation Aral Sea Basin coupled with the USSR collapse have caused increased population migration and

uncontrolled grazing, which lead to salinization and further deterioration of rangeland ecosystems in the region. But another biotic factor is also simulated to effect well on solid earth's ecosystems of CA. For most regions of the world, a greening (increasing)–browning (decreasing)–greening (G-B-G) trend is observed over the periods 1982–2004, 1995–2004, and 2005–2012, respectively AVHRR satellites time-series data [8]. Warm ENSO phases have been shown to result in an intensified precipitation signal, while cold ENSO phases result in drier conditions in the region [11; 13; 12]. Same time, core synoptic systems to influence climate and NDVI anomalies especially singularities of zonal circulations on winter period, as a less precipitation and warm temperature anomaly over arid zones have affected negatively for whole seasonal year. An increase and decrease of vegetation productivity with warm and cold ENSO phases respectively affected in non-agricultural areas of Turkmenistan [9]. Regarding on this research suggestions, our objective was an assessment ENSO impacts to the vegetation patterns and their relationships between drought persistent and NDVI anomalies in CA. The goal was two-fold: an assessment of ENSO impacts to vegetation growth patterns (1); and characterize their relationships with NDVI anomalies (2) in CA. The changing characteristics of winter and spring rainfall and their teleconnections with large-scale climate through the dominant time scales of variability related with ENSO anomalies. Teleconnections with global sea surface temperature and atmospheric circulation anomalies are established, but are different for each time scale [1]. This kind of research is a few examines due to less attention on this ecosystem and target zone is far away from any oceans (**fig.1**). According results of Colditz [4] limited precipitation during El Niño has diminished plant productivity in southern Africa, while eastern Africa has shown an increase in biomass production. The results of CA are also indicated and observed similarity as southern part African research [10]. Determination of NDVI anomalies are clearly described that at decadal time scales of greenness intensity is a various and not related on agricultural intensifications. The relationship between temporal dynamics of ENSO events and NDVI have relationships and according results it was defined a minimum five threshold under over-lapping seasons. Results of de Beurs [2] described that Arctic Oscillation index is significantly correlated with the peak timing of the growing seasons and since 2000 the negative NDVI changes altered to positive changes (25.3% versus 7.3%) based on all land area above 60°N. In particular, a positive precipitation anomaly is typically found in correspondence of the positive North Atlantic Oscillation (NAO) phase and warm ENSO phase over a sub-region encompassing northern Pakistan, Afghanistan, Tajikistan and southern Uzbekistan [3]. The both the NAO and ENSO affect climate over the region [5].

Target zone

The area covered lies between $34^{\circ}57'30''N$ and $55^{\circ}47'30''N$ and $46^{\circ}12'29''E$ and $87^{\circ}52'29''E$. Vegetation trends in this area are mostly driven by precipitation and temperature dynamics. Kazakhstan is the largest country ($2,727,000\text{ km}^2$) and Tajikistan is the smallest ($142,000\text{ km}^2$) [6]. Precipitation and temperature patterns are most important for dryland ecosystems that are strongly dependent on these two factors. Dryland zones in CA (**fig.1**) are mostly in a temperate continental arid climate: very hot (dry) summer and cold winter, total precipitation ranges from 0-200 mm, a vast majority of the land in the area is low lying <200 m but there are peaks of >5000 m. Elevation increases to the east, from the coast of Caspian Sea in western Turkmenistan and Kazakhstan to the mountainous terrain in eastern Kazakhstan and Uzbekistan and across Kyrgyzstan and Tajikistan [6]. The vast area of the territory is located on desert and semi-desert zones. The deserts include sparse vegetation and closed to open shrublands. The growing season of vegetation in most of the study area lasts from April to October as winter temperature controls vegetation growth [7]

Figure 1. Targeted zones are located far away from any oceans and mostly occurred with drought anomalies due to a less precipitation and high evapotranspiration ratings. Climate datasets are modified from CRU-TS 2.3 and Land Use and Land Cover Change map modified GlobCov2009 (MODIS datasets).

Materials and Methods

Using observational and re-analysis datasets for NDVI and ENSO anomalies this aspect is analyzed systematically in terms of better estimate relationships and quantify the probability of their occurrence when sea surface temperatures are abnormal (dry and wet) periods.

For the ENSO and NDVI analyses, departures or anomalies were calculated by subtracting the base period of monthly average data for periods 1981-2010. Such as updated version of ENSO till 2010. Updated version is available: http://www.cpc.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml. Therefore, the most recent ONI values should be considered an estimate. Warm and cold episodes were calculated based on a threshold of $\pm 0.5^{\circ}\text{C}$ using the ONI index based on 30-year base periods with every five years updates. Datasets for ONI anomalies are available on following link: <http://ggweather.com/enso/oni.htm>. Flowchart described (**fig.2.**) the combination of three parameters and complex inter-linkages between them. For historical purposes, cold and warm episodes were defined when the threshold was met for a minimum of five consecutive over-lapping seasons. The threshold was further broken down into strong (1.5 to 1.9) and very strong (≥ 2.0) events. For NDVI data analyses, we calculated departures or anomalies by subtracting the base period of monthly means for data available from 1981-2011. Bi-weekly NDVI 3g time-series data were used to calculate three-month average vegetation value to match the temporal resolution of ONI index. We used the El Niño 3.4 Sea Surface Temperature (SST) Indices to identify periodical oscillations of ONI.

Figure 2. Workflow for the processing of time series from (NDVI 3g), Nino 3.4 sea surface temperature (SST) and Oceanic Nino Index (ONI) with threshold is broken down into strong (1.5-1.9) and very strong (≥ 2.0) events

Results and Discussions

These results demonstrate that understanding of non-anthropogenic drivers of variability in land surface vegetation signals is beneficial for efficient rangeland/grassland management in precipitation-driven ecosystems of Central Asian rangelands. We have also calculated standard deviation, minimum, and maximum values for all those months over the reference period. The outcomes from our study demonstrated an inverse relationship between El Niño and NDVI, where vegetation response decreased with larger positive ONI value; and a direct relationship between La Niña and NDVI, where vegetation response increased with smaller negative ONI value (**fig. 3**). Furthermore, there was an inverse relationship between El Niño and NDVI with decreased vegetation response with larger positive ONI value (orange colored bars); and direct relationship between La Niña and NDVI (blue bars) with increased vegetation response with lower negative ONI value.

MAXIMUM NDVI

MINIMUM NDVI

Accumulation of NDVI trends (max & min) with 3-month running mean in CA on the phase of ENSO very strong anomalies: 1982-1983 (El Niño); 1988-1989 (La Niña) & 1997-1998 (El Niño)

Figure 3. Robust understanding of biotic factors and their effects on NDVI anomalies, trends of ENSO phases detected inverse relationship between El Niño and NDVI, decreased vegetation response with larger positive ONI value; and direct relationship between La Niña and NDVI, and increased vegetation response with smaller negative ONI value.

Bi-weekly NDVI 3g time-series data for CA countries and their annually average of greenness index (legends multiplied *10000)

Trends of ENSO phases detected anomalous patterns of precipitation and drought conditions with following years: 1982-1983; 1997-1998 (VSE) & 1988-1989 (SL) phases among five countries of CA. Vegetation productivity with warm and cool ENSO phases and their intensities with running 3-month mean ONI values. Legends described with beginning of the month with following composition of last three month (*e.g.*, JFM-January, February, March).

NDVI changes (from negative to positive) are predominantly driven by minimum temperature changes [2]. We reveal that ONI values are correlated with maximum NDVI compare than minimum NDVI. As described, on the La Niña period (blue bar) maximum NDVI accumulated well, but on minimum is more a less equivalent with drought prone periods. High accumulation of NDVI on the phase La Niña (max.NDVI) indicated in the autumn and winter periods, mostly it has been observed on permanent forest zones and rangelands. Developing observational and modelling tools for agricultural and land use systems (ecosystem service) is a main issue currently on these ecosystems and it will assist water –food nexus objectives in further. For the CA regions, longstanding land use practices and water management challenges are unique and do not align well.

Figure 4. For 3-month NDVI anomalies we averaged the values over the six months in question, and then normalized them by using the mean value.

Figure 4a. NDVI trends expressed as a histogram with composition of a three-month running mean for ENSO phases. Histograms have been developed to define how temporal greenness values fitted under the curve and represented a value between the minimum and maximum values with the three month cycles for various ENSO episodes.

This study demonstrates potential applications of the large-scaled datasets to assess and measure relationships between global database patterns and regional scale vegetation responses to support land and water use efficiency and management this drought-prone regions with establish ecosystem services. Also results demonstrate that a non-anthropogenic drivers of variability effected to land surface vegetation signals, understanding of which will be beneficial (strong, moderate or weakness effects) for efficient rangeland and agriculture management and in precipitation-driven drylands of Central Asia. Generally, it is a good agreement between globally observed and simulated NDVI index to apply and develop details on further drought and vegetation anomalies with detecting trend changes.

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