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Evaluation of Earth Observation based global long term vegetation trends — Comparing GIMMS and MODIS global NDVI time series

Rasmus Fensholt *, Simon R. Proud

Department of Geography and Geology, University of Copenhagen, Øster Voldgade 10, DK-1350 Copenhagen, Denmark

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ABSTRACT

A new and updated version of the AVHRR (Advanced Very High Resolution Radiometer) based GIMMS (Global Inventory Modelling and Mapping Studies) NDVI (Normalized Difference Vegetation Index) dataset is now available covering 1981 to 2010 (GIMMS3g). Earlier versions of this global coverage 15-day composite dataset have been used for numerous local to global scale vegetation time series studies during recent years. However, several aspects of the AVHRR sensor design and data processing potentially introduce substantial noise into the NDVI dataset if not corrected for. The more recent NDVI dataset from Terra MODIS (Moderate Resolution Imaging Spectroradiometer) is considered an improvement over AVHRR data and with the release of GIMMS3g an overlapping period of 11 years now provides a possibility to perform a robust evaluation of the accuracy of GIMMS3g data and derived trends. In this study the accuracy is evaluated by comparison with the global Terra MODIS NDVI (MOD13C2 Collection 5) data using linear regression trend analysis. The trends of GIMMS NDVI were found to be in overall acceptable agreement with MODIS NDVI data. A significant trend in NDVI ($\alpha = 0.05$) was found for 11.8% of the MODIS NDVI pixels on a global scale (5.4% characterised by positive trends and 6.3 with negative trends) whereas GIMMS NDVI analysis produced a total of 10.5% significant pixels (4.9% positive, 5.6% negative). However, larger differences were found for the Southern Hemisphere land masses (South America and Australia) and the high northern latitude Arctic regions. From a linear regression analysis the correlation coefficient between the two datasets was found to be highly significant for areas with a distinct phenological cycle. Discrepancies between the GIMMS and MODIS datasets were found in equatorial areas (broadleaved, evergreen forest), Arctic areas (sparse herbaceous or sparse shrub cover) and arid areas (herbaceous cover, closed–open). Linear regression of QA filtered Terra and Aqua MODIS NDVI (2003–2010) revealed similar inconsistencies for Arctic and equatorial areas suggesting that robust long-term NDVI trend estimates in these areas are difficult to obtain from both GIMMS and MODIS data. Additionally, GIMMS based NDVI trend analysis in arid areas of limited photosynthetic activity should be interpreted with caution. The regression coefficient (slope value) ($p<0.01$) was found to be close to 1 for most land cover types on a global scale (global land cover class average slope = 1.00) suggesting overall compatibility between MODIS and GIMMS NDVI, but with land cover class specific variations (within class and between classes).

1. Introduction

Our understanding of variations in vegetation resources from a local to global scale has improved by quantifying inter-annual trends in vegetation from time series of Advanced Very High Resolution Radiometer (AVHRR) data covering the last three decades (from 1981 to present). AVHRR NDVI has been widely used for regional to global scale vegetation trend analysis (Anyamba & Tucker, 2005; de Jong et al., 2011; Eklundh & Olsson, 2003; Hellden & Tottrup, 2008; Jeyaseelan et al., 2007; Myneni et al., 1998; Olsson et al., 2005; Slayback et al., 2003; Tucker et al., 2001) and changes in vegetation phenology (Heumann et al., 2007; Myneni et al., 1997; Stockli & Vidale, 2004). Other studies of AVHRR NDVI time series have examined the response of vegetation vigour to climatic variations of variables like rainfall and air temperature to understand causes of observed changes in vegetation greenness (Fensholt & Rasmussen, 2011; Herrmann et al., 2005; Zeng et al., 2005). AVHRR NDVI has also been used as input for terrestrial NPP (Net Primary Production) estimates (Hickler et al., 2005; Prince & Goward, 1995; Ruimy et al., 1994) with Nemani et al. (2003) using two different AVHRR NDVI global coverage products as input for NPP modelling to analyse climate driven changes in global terrestrial NPP.

The AVHRR sensors were not originally intended for vegetation study (Cracknell, 2001) using indices like NDVI (Rouse et al., 1973). When the potential and shortcomings of AVHRR for vegetation studies became a subject of research (Holben, 1986; Tucker et al., 1983)

* Corresponding author. Fax: +45 35322501.
E-mail address: rf@geo.ku.dk (R. Fensholt).

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modifications to optimise the sensor for vegetation studies were not prioritised due to data continuity considerations. Consequently, there are several aspects of AVHRR sensor design that are not ideal for vegetation trend studies (Steven et al., 2003; Teillet et al., 1997; van Leeuwen et al., 1999), such as post-launch degradation in sensor calibrations and drift in the satellite overpass times. The seasonal variations in sun-sensor viewing geometry (as defined by the Bidirectional Reflectance Distribution Function, BRDF) combined with sensor drift over time has a large effect on time series of observed NDVI for a given location (Pinzon et al., 2005; Tucker et al., 2005). If not corrected for, historical sensor replacements – including shifts in the satellite overpass time – will influence observed NDVI trends and thereby undermine the usefulness of the dataset for long-term trend analysis. Additionally, the spectral configuration of the AVHRR sensors (number of bands, wavelengths covered and the specific band Spectral Response Functions (SRF)) does not permit an accurate atmospheric correction scheme to be applied and absorption and scattering by atmospheric components such as water vapour (Tanré et al., 1992) and aerosols (Nagol et al., 2009) are a source of error in AVHRR estimates of surface NDVI. The AVHRR channel 2 (near-infrared band) covers wavelengths in which there is considerable absorption by water vapour in the atmosphere, influencing observed NDVI (Cihlar et al., 2001; Holben, 1986). The data reduction methodology used for transforming the 1 km resolution local coverage pixels LAC AVHRR data into global coverage pixels (GAC) and finally into an 8 km resolution grid of AVHRR NDVI also has an impact on the quality of the data (James & Kalluri, 1994).

Several studies have evaluated NDVI continuity as a function of the red and near-infrared satellite band SRF's and have proposed inter-sensor translation methods amongst the different AVHRR instruments as well as the general compatibility between AVHRR instruments and newer sensors, including the Systèm Pour l'Observation de la Terre (SPOT) VEGETATION, the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), the MODIS and the MEdium Resolution Imaging Spectrometer (MERIS) (Beck et al., 2011; Brown et al., 2006; Fensholt & Sandholt, 2005; Fensholt et al., 2006b; Pedelty et al., 2007; Swinnen & Veroustraete, 2008; Tucker et al., 2005). It remains a challenge to produce a long-term, consistent, NDVI time series across the sequence of multiple sensor systems with their different spectral responses, spatial resolutions, swath width and orbiting geometry. However, 3 global NDVI data products (Pathfinder AVHRR Land (PAL)) (James & Kalluri, 1994), the Fourier-Adjustment, Solar zenith angle corrected, Interpolated Reconstructed (FASIR) (adopted from PAL; Los et al., 2000) and NASA Global Inventory, Monitoring, and Modelling Studies (GIMMS) (Tucker et al., 2005) have been created from the spatially and temporally comprehensive AVHRR GAC dataset and are important for detection of global scale long-term trends in land degradation and vegetation productivity. Currently the NASA-funded Land Long Term Data Record (LTDR) are developing daily reflectance data from 1981 to 2000 that includes an improved atmospheric correction scheme and BRDF corrections (Pedelty et al., 2007). Two recent studies (Alcaraz-Segura et al., 2010a and Beck et al., 2011) conducted an intercomparison of these four AVHRR based NDVI dataset for the overlapping period 1982–1999 for the Iberian Peninsula and on a global scale respectively.

The only updated global coverage AVHRR dataset, covering the full period from 1981 to present, is the GIMMS. A release of the global coverage GIMMS data (1981–2006) (GIMMSg) was made available in 2007 and recently an updated GIMMS NDVI dataset (GIMMS3g; covering from 1981 to 2010) has been processed and made available by the GIMMS research group. The GIMMS correction scheme (Empirical Mode Decomposition (EMD) transformation method) (Pinzon et al., 2005) implies that the GIMMS dataset is dynamic by nature and must be re-calculated every time more recent years of data are added.

The possibilities of testing the quality and reliability of GIMMS NDVI time series trend analyses on a global scale have been limited by the lack of an appropriate time series of data from other moderate/coarse resolution satellite sensors of adequate quality. Only since late '90s have other instruments, with improved sensor attributes like Terra MODIS, started to make NDVI time-series measurements. The processing of MODIS NDVI is based on spectral bands that are specifically designed for vegetation monitoring and include state-of-the-art navigation, atmospheric correction, reduced geometric distortions and improved radiometric sensitivity (Huete et al., 2002). MODIS NDVI is therefore considered to be an improvement over the NDVI product derived from the AVHRR sensors (Huete et al., 2002; Justice et al., 1998). With the current availability of 11 years of Terra MODIS NDVI (March 2000–present) an evaluation of the reliability of GIMMS NDVI trends for this time-span can be performed. This time period includes the operational use of four different AVHRR sensors; NOAA-14, NOAA-16, NOAA-17 and NOAA-18, each having a different Equator passing time (morning and afternoon satellites are combined) and varying degrees of orbital drift (Pinzon et al., 2007). The combined effect on the sun-sensor geometry (as expressed by the BRDF) will influence the observed NDVI if not corrected for and 2000–2010 therefore serves as a well suited period for studying the successfulness of the GIMMS NDVI correction method.

In this study the quality of the GIMMS3g NDVI data will be evaluated against MODIS NDVI using pixel wise linear regression analysis. Trend analyses of 11 years of overlapping monthly and annually integrated global scale NDVI data (2000–2010) from the two different sensor systems are intercompared on a continental scale and as a function of land cover classes. Direct per-pixel comparisons between GIMMS and MODIS NDVI are conducted and studied at the continental, regional and land cover class scale using pixel wise linear regression between Terra and Aqua MODIS NDVI (2003–2010) as a reference.

2. Data and methods

2.1. GIMMS 15-day composite NDVI product (GIMMS3g)

The series of AVHRR instruments have a 110° across-track field of view allowing for near-daily global coverage. The GIMMS NDVI dataset is based on the GAC 1B product (Goward et al., 1993). GAC data were derived by onboard averaging and sampling of the 1.1 km full resolution data LAC to a 4 km resolution (Townshend, 1994). For a given scan line the first four pixels out of five are averaged and only every third scan line is processed resulting in a nadir cell-size of 1.1 km × 4 km with a gap of 2.2 km across the scan lines (Kidwell, 1991). The channel 1 and 2 data used for the GIMMS data are calibrated as suggested by Vermote and Kaufman (1995), and the derived NDVI is further adjusted using the technique of Los (1998). The cloud detection algorithm is based on reflectance and brightness temperature values (Stowe et al., 1991; Tucker et al., 2005). No atmospheric correction is applied to the GIMMS data except for volcanic stratospheric aerosol periods (1982–1984 and 1991–1994) (Tucker et al., 2005). A satellite orbital drift correction is performed using an empirical mode decomposition/reconstruction (EMD) method of Pinzon et al. (2005) minimising effects of orbital drift by removing common trends between time series of Solar Zenith Angle (SZA) and NDVI. The GIMMS3g NDVI data is provided in 1/12-degree resolution and is processed to match the range of SPOT Vegetation and MODIS (Tucker et al., 2005) enabling the advantages of the MODIS NDVI and VGT NDVI data to be used in conjunction with the historical information provided by the GIMMS dataset. NDVI quality flags are embedded in the 15-day maximum value compositing (Holben, 1986) data files, providing information on per-pixel NDVI status identical to earlier versions of the GIMMS data. NDVI that are flagged as influenced by clouds or snow cover (flag = 1–5) are retrieved from either spline interpolation or average seasonal profiles whereas flag = 0