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A simplified data assimilation method for reconstructing time-series MODIS NDVI data

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Abstract

The Normalized Difference Vegetation Index (NDVI) is an important vegetation index, widely applied in research on global environmental and climatic change. However, noise induced by cloud contamination and atmospheric variability impedes the analysis and application of NDVI data. In this work, a simplified data assimilation method is proposed to reconstruct high-quality time-series MODIS NDVI data. We extracted 16-Day L3 Global 1 km SIN Grid NDVI data sets for western China from MODIS vegetation index (VI) products (MOD13A2) for the period 2003–2006. NDVI data in the first three years (2003–2005) were used to generate the background field of NDVI based on a simple three-point smoothing technique, which captures annual features of vegetation change. NDVI data for 2006 were used to test our method. For every time step, the quality assurance (QA) flags of the MODIS VI products were adopted to empirically determine the weight between the background field and NDVI observations. Ultimately, more reliable NDVI data can be produced. The results indicate that the newly developed method is robust and effective in reconstructing high-quality MODIS NDVI time-series.

Keywords: Data assimilation; Reconstruction; MODIS NDVI; Time-series data

1. Introduction

The Normalized Difference Vegetation Index (NDVI) is widely used vegetation index due to its simplicity, ease of application, and wide-spread familiarity. Time-series NDVI products, derived from multiple satellite sensors such as the NOAA/AVHRR (Advanced Very High Resolution Radiometer), MODIS (Moderate Resolution Imaging Spectroradiometer), Landsat TM (Thematic Mapper), ETM+ (Enhanced Thematic Mapper Plus), and SPOT/VEGETATION, have proven powerful tools for learning from past events, monitoring current natural-resource conditions and long-term land-use/cover changes, and extracting canopy biophysical parameters and phenological information. Forecasting the trends of terrestrial ecosystems on global, continental, and regional scales (Tucker, 1979; Sellers et al., 1994; Field et al., 1998; Van Leeuwen et al., 1999; Fang et al., 2001) is also performed with these tools. However, the current NDVI product is still spatio-temporally discontinuous due to cloud cover, seasonal snow, atmospheric variability, bi-directional effects and instrument problems (Gutman, 1991; Huete and Liu, 1994; Xiao et al., 2003; Moody et al., 2005). These biases limit the application of NDVI in vegetation dynamics monitoring and global change research.

The most common compositing criterion used to produce NDVI composite data is the Maximum Value Composite (MVC) algorithm, which is applied to obtain a higher percentage of clear-sky data. Nevertheless, significant residual effects remain (Holben, 1986). Moreover, in recent years a number of mathematical filters have been applied to reduce noise and to reconstruct high-quality time-series of NDVI data for further analysis and application. These filters are generally grouped into two types:

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(1) noise reduction in the frequency domain such as Fourier-based fitting methods (Sellers et al.,1994; Verhoef et al., 1996; Roerink et al., 2000);
(2) noise reduction in the temporal domain with approaches such as the best index slope extraction algorithm (BISE) (Viovy et al., 1992); weighed least-squares linear regression (Swets et al., 1999); modified BISE filtering (Lovell and Graetz, 2001); asymmetric Gaussian function-fitting approach (Jonsson and Eklundh, 2002); polynomial least squares operation (PoLeS) approach (Jose et al., 2002); Savitzky–Golay filtering (Chen et al., 2004); and the mean-value iteration filter (Ma and Veroustraete, 2006).

These methods are commonly used to restore NDVI multi-temporal profiles, but they suffer from several drawbacks that limit their use (Jonsson and Eklundh, 2002; Chen et al., 2004). For instance, the BISE algorithm requires the definition of a sliding period and a threshold for acceptable percentage increase in NDVI for re-growth during a sliding period based on an empirical strategy. That strategy is usually subjective and depends on the skills and experience of the analyst (Viovy et al., 1992; Lovell and Graetz, 2001). The remaining noise after application of the BISE algorithm may make the extracted temporal information unreliable (Ma and Veroustraete, 2006). Fourier-based fitting methods may generate spurious oscillations when applied to asymmetric NDVI time-series since they depend critically on symmetric sine and cosine functions (Roerink et al., 2000; Chen et al., 2004). The asymmetric Gaussian function-fitting approach is more flexible and effective in obtaining high-quality NDVI time-series, but it fails to identify a reasonable and consistent set of maxima and minima to which the local functions can be fitted, especially for noisy data or for data from areas where there is no clear seasonality (Jonsson and Eklundh, 2002). With respect to the Savitzky–Golay filter approach, it can reduce the noise of NDVI time-series effectively, but it also requires empirical analysis to determine the width of the smoothing window and the degree of the smoothing polynomial (Chen et al., 2004). Many rank order-based filters, such as the mean-value iteration filter method (Ma and Veroustraete, 2006), are efficient at removing additive impulsive noise, while linear filters succeed in suppressing Gaussian noise. However, most suffer from trade-offs, e.g., removing noise yet preserving details of the NDVI temporal dynamics.

In fact, smoothing filter design in signal processing basically depends on different types of noise. Moreover, as the type and the amount of noise are mixed differently, noise removal continues to provide a challenge for smoothing filter designers (He, 2007). Due to this issue, more information is required to improve the quality of multi-temporal NDVI data. This process is data assimilation, which has been widely used to initialize numerical weather prediction models (Daley, 1991) and to improve estimations of soil moisture or soil temperature profiles in the vertical direction by assimilating remote sensing data or in situ observations of recent years (Li et al., 2004; Huang et al., 2008a, b). During the last 2 years, data assimilation methods have been used to dynamically reconstruct remote sensing data. Gu et al. (2006) adopted the optimal interpolation method to generate multi-temporal MODIS LAI data. He (2007) performed an experiment based on the gradient inverse weighted filter and performed an objective analysis to improve the estimation of multi-temporal series of MODIS LAI data products. However, until now, only limited research has focused on multi-temporal NDVI time-series.

In this paper, a simplified data assimilation method is developed using NDVI quality assurance (QA) data sets to reconstruct multi-temporal time-series of MODIS NDVI products. The method was tested and evaluated by MODIS 16-Day L3 Global 1 km SIN Grid VI data sets (MOD13A2). The remainder of this paper is organized as follows. In Section 2 the data analysis strategy for reconstructing MODIS NDVI is introduced. The results are analyzed in Section 3, and conclusions are presented in the last section.

2. Data analysis strategy

The data assimilation method is used to integrate all information available to improve state estimation, which is widely applied to atmospheric and oceanic numerical predictions. In this study, a simplified data assimilation scheme is used to improve the quality of time-series MODIS NDVI data. A flowchart for reconstructing MODIS NDVI multi-temporal data is shown in Fig. 1.

(1) Historical multi-year NDVI data, extracted from MODIS VI products (i.e., MOD13A2), are used to produce a background field of NDVI based on a three-point smoothing method. The smoothing results describe the general features of the mean NDVI for every pixel occurring during the past years.

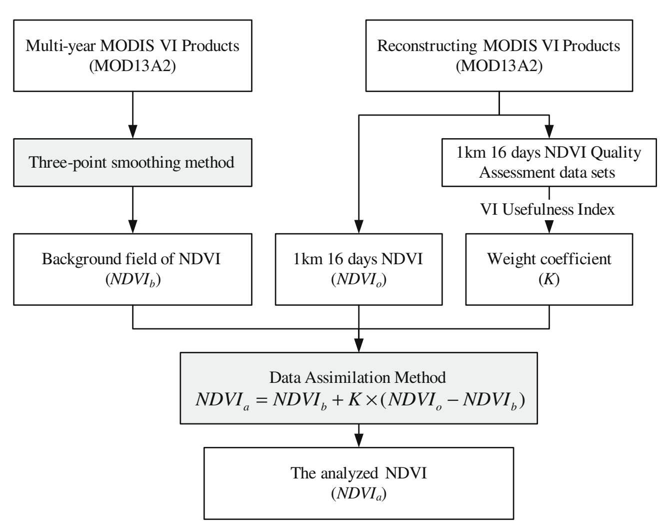

Fig. 1. A flowchart outlining the reconstruction process of MODIS NDVI data.