An optimization of parameter settings in HANTS for global NDVI time series reconstruction

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AN OPTIMIZATION OF PARAMETER SETTINGS IN HANTS FOR GLOBAL NDVI TIME SERIES RECONSTRUCTION

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ABSTRACT

The applications of Multi-temporal Normalized Difference Vegetation Index (NDVI), a critical proxy for analysing vegetation dynamics, have been long hindered by prevalent noise. The Harmonic ANalysis of Time Series (HANTS) has been widely applied to reconstruct noise- and cloud-free NDVI time series data set from regional to global scales. The reconstruction performance of HANTS is severely dependent on the inherent parameter settings in HANTS. However, most applications set the parameters of HANTS based on users' experience. This study analysed the sensitivity of the reconstruction performance to several critical parameters and weighting scheme of HANTS. The results document the optimized parameter settings for global NDVI time series reconstruction.

Index Terms — HANTS, parameter setting, NDVI, sensitivity analysis

1. INTRODUCTION

Global long-term Normalized Difference Vegetation Index (NDVI) archives have been widely used to analyse vegetation dynamics or the response and feedback of global vegetation under climate change scenarios [1]. However the discontinuity problem in NDVI time series caused by cloud contamination or ill observation geometry hampered the way to derive accurate information on spatio – temporal variability from the NDVI dataset [2]. The Harmonic ANalysis of Time Series (HANTS), derived from the Fourier transformation theory, was extensively applied to eliminate the clouds and noise contaminated observations in the NDVI time series [3-5]. Appropriate parameter settings in HANTS are very critical for reliable reconstruction of global NDVI time series [5].Users usually set up the values of parameters in HANTS based on practical experience. This study will analyse the sensitivity of several critical parameters and the weighting scheme in HANTS on the reconstruction performance globally, and suggest optimized parameter settings for global NDVI reconstruction.

2. METHODOLOGY

2.1. Evaluation procedure

The evaluation of reconstruction performance of HANTS is based on the comparison of noise added time series mimicking cloud contamination with a cloud-free reference NDVI series [6]. In this study, 14 years (from 2001 to 2014) 250 m daily land surface reflectance data from MODIS on board TERRA (MOD09GA) were used to simulate pixel-wise 16-day yearly reference NDVI series and noise added NDVI time series respectively for 445 BELMANIP2 (BEnchmark Land Multisite Analysis and Intercomparison of Products) sites. The BELMANIP2 sites were carefully selected to represent the global vegetation dynamics [7]. The yearly 16-day reference series, simulated based on 14 years daily observations, was used to represent pixel-wise real annual NDVI time series and can be treated as cloud free series [8]. The detail procedure to simulate the reference series and noise added series was given in [8]. Briefly, the yearly reference series and 100 yearly noise-added series were simulated for each site (pixel), where each yearly series had 23 samples corresponding to 16-day composites. Then HANTS was applied to reconstruct all reference series and noise added series with different parameter settings (corresponding to different cases given in section 2.2). Finally the Overall Reconstruction Error (ORE), defined as the RMSE between reference series and HANTS reconstructed noise added series [5], was calculated for each site. The sensitivity of the reconstruction to different parameters can be evaluated by comparing the ORE under different parameter setting cases.

2.2. Sensitivity analysis design

All parameters of HANTS and the corresponding classical settings were given in Table 1. For a detail explanation of these parameters, one can refer to [4]. The global reconstruction performance under the classical parameter settings was evaluated in [5]. As harmonic components (i.e. number of frequency and base period) and Fit Error tolerance (FET) are the most influential parameters in HNATS method, the sensitivity of the reconstruction to these parameters were analysed in this study.

The HANTS reconstruction of all 445 BELMANIP2 sites with different parameter settings and their corresponding ORE were compared with the reconstruction result of HANTS with mostly used parameter settings given in Table 1. The sensitivity of harmonic components (number of frequency and base period) and FET were analysed separately.

Table 1 The parameters and their mostly used settings in HANTS to reconstruct NDVI time series. The parameters were set for 16-day NDVI time series reconstruction in this table.

Parameters	**Setting**
High (high range of parameter)	1
Low (low range of parameter)	-0.2
High/Low Flag	Low
Degree of overdeterminedness (DOD)	5
Number of frequencies (NF)*	3
Base period*	365 days
Fit error tolerance (FET)*	0.05
Regularization factor (Delta)	0.5

Note: The sensitivity of parameters denoted by asterisk (*) was analysed in this study.

The different testing cases for harmonic components were given in Table 2. In the C1-NF case, the base period and the number of frequency were 12-month (365 days) and 3 respectively, thus it was exactly the setting in Table 1. There exist some trends within annual time series, which cannot be described very well by 12 months base period derived harmonic components. Actually this phenomenon is caused by Picket Fence Effect in the Discrete Fourier Transform (DFT) theory, which means there are some frequency components between harmonics for real signals (Vijay Madisetti, 2009). This study checked if the harmonics group generated with extended base period can address this problem (C2-NF). Also polynomial components were used to account interannual trends in NDVI time series [9]. The effectiveness of polynomial components was evaluated by C6-NF, and C7-NF. On the other hand, Although using harmonic components with higher frequencies in HANTS can capture more detail variation of time series, more fake variation of noise will also be preserved. In contrast, HANTS using only low frequency harmonics is robust to noise but may lose some important detail variation. Thus it is necessary to pursue a balance between robustness and fidelity by selecting harmonics with appropriate frequencies. C4-NF, C5-NF, and C6-NF were design to investigate the impact of harmonics with different frequencies on reconstruction performance.

Table 2 Testing cases for harmonic components (. number of frequency and base period) in HANTS method. In different cases, only the base period or the number of frequency of HANTS were changed, but all other parameters settings keep the same as in Table 1.

Cases	**Base period (month)**	**NF**	**Harmonic components (month)**
C1-NF	12	3	12-, 6-, 4-month
C2-NF	24	5	24-, 12-, 8- ,6-, 4-month
C3-NF	12	5	12-, 6-, 4-, 3-, 2-month
C4-NF	12	4	12-, 6-, 4-, 3-month
C5-NF	12	2	12-, 6-month
C6-NF	12	3	12-, 6-, 4-month, and 1st order polynomial
C7-NF	12	3	12-, 6-, 4-month , and up to 2^{nd} order polynomial

As shown in Table 3, seven cases with different settings for FET were designed to analyze the sensitivity of HANTS to FET. Settings for all other parameters of HANTS are same as the value listed in Table 1. In the first five cases, a constant value was applied to global sites, which is the canonical design of HANTS. However, the real dynamic range of NDVI for some areas may be very small and a large FET setting is not enough to identify contaminated observations. Thus two cases with dynamic FET setting was set in C6-FET and C7-FET, in which the FET is dependent of the real dynamic range of NDVI signal (yr is the resultant series during each iteration).

Table 3 Testing cases for FET. The “yr” in the C6-FET and C7-FET cases is the resultant series of harmonics fitting during each iteration. In these two cases, the FET varies with the real range of NDVI temporal signals in the pixel. In different cases, only FET of HANTS was changed, but all other parameters settings keep the same as in Table 1.

Cases	**FET**
C1-FET	0.05
C2-FET	0.02
C3-FET	0.08
C4-FET	0.10
C5-FET	0.15
C6-FET	0.05*(Max(yr)-Min(yr))+0.01
C7-FET	0.10*(Max(yr)-Min(yr))+0.01

The observations identified as outliers by the FET threshold were usually assigned zero weight directly in classical HANTS. However, the FET was set based on users' experience and the erroneous identification was unavoidable. To avoid using the rigid weighting scheme in the classical HANTS, we investigated to use a dynamic weighting scheme to improve the performance of HANTS. For the dynamic weighting scheme, practically, the initial weight is set to 1.0 for each observation, and the weight is updated on the basis of the smoothing result according to Equation (1) during the k-th iteration:

$$w_k = w_{k-1} + \frac{yr_k - yr_{k-1}}{(\max(yr_k) - \min(yr_k))} \quad (1)$$

where w_k and yr_k are the weights vector and the harmonics fitting result in the k-th iteration respectively [8].

3. RESULTS

Results from all cases listed in Table 2 showed large difference in the overall reconstruction performance as described by ORE when compared with the results from the often used harmonic settings (case C1-NF) (Fig.1). The harmonic case with 24 months as base period (C2-NF, Fig.1a) gave improved reconstruction performance over many sites, especially for sites with high reconstruction error (Fig. 1). By including the 2-month (C3-NF (Fig.1b)) and 3-month (C4-NF (Fig.1c)) harmonics, the ORE over most sites decreased extensively while a slight increase remained apparent for some sites. Using HANTS with only two harmonics (C5-NF, Fig.1d) the performance is one of the worst as the ORE is higher than the results from the often used harmonic settings over most sites. Incorporating polynomial components (C6-NF， Fig.1e and C7-NF, Fig.1f) can improve the reconstruction performance for many sites.

The different settings of FET have evident impacts on the reconstruction performance (Fig. 2). Specifically, worse performance were found in most sites when FET is 0.02 (C2-FET, Fig.2a) compared to the often used FET value (0.05). For C3-FET (Fig.2b), C4-FET (Fig.2c), in which FET are larger than 0.05, the reconstruction performance improved over many sites. When the FET is 0.15 (C5-FET (Fig.2d)), the performance is largely degraded over many sites. As for the dynamic FET setting scheme (C6-FET, Fig.2e and C7-FET, Fig.2f), the C7-FET is one of the best performed reconstruction parameter settings as the ORE is both low and compact.

As presented in Fig. 3, the dynamic weighting scheme led to smaller ORE over many sites and kept the same ORE over the other sites. Thus the dynamic weighting scheme is a promising method to improve the global reconstruction performance.

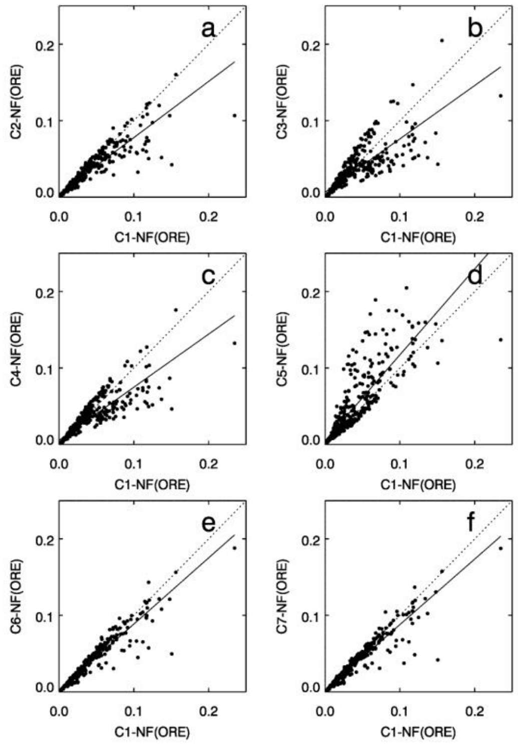

Figure 1. The ORE of HANTS under different harmonic settings (C2-NF ~ C7-NF) for 445 BELMANIP2 sites compared to the often used harmonic settings (C1-NF). The detail settings of all cases are referred to Table 2.

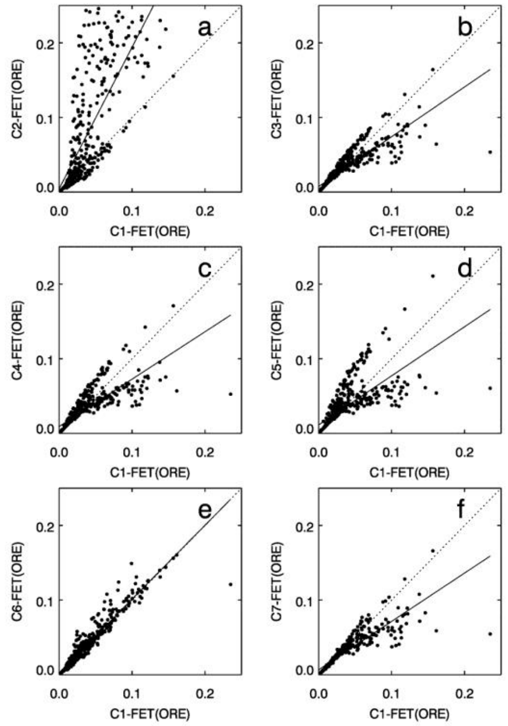

Figure 2. The ORE of HANTS under different FET settings (C2-FET ~ C7-FET) for 445 BELMANIP2 sites compared to the often used FET settings (C1-FET). The detail settings of all cases are referred to Table 3.

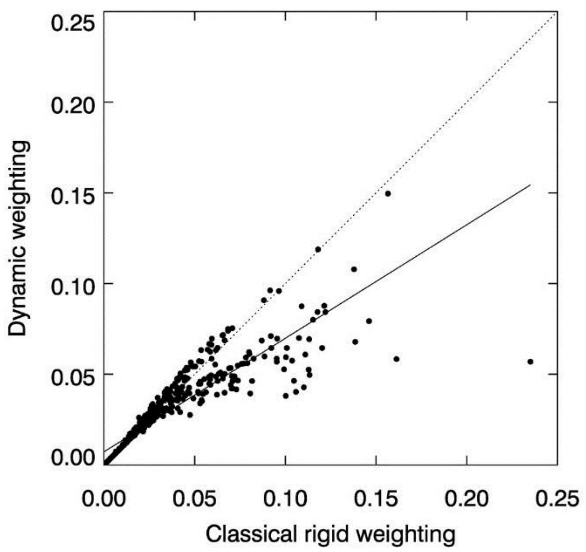

Figure. 3. The ORE of HANTS with dynamic weighting scheme for 445 BELMANIP2 sites compared to the often used rigid weighting.

4. CONCLUSION

The sensitivity of the settings for harmonic components, FET, and weighting scheme on the global reconstruction performance of HANTS was analysed based on the systematic evaluation framework developed in [8]. We can conclude that the harmonics group with 24 months as the base period, the dynamic FET scheme (C7-FET), and the dynamic weighting scheme can improve the global reconstruction performance compared to the most often used parameter settings (Table 1),. Only two harmonics (C5-NF) is not adequate to improve reconstruction performance. Only harmonics with period no shorter than 3-month are suggested to be used as higher frequency harmonics may bring more noise and leads to deviation from the main periodical signals.

Although the optimization of parameter settings were conducted in this study based on 16-day NDVI data set, the conclusion also apply to HANTS for global reconstruction of other land surface parameters like Fractional Vegetation Cover (FVC), Leaf Area Index (LAI), Fraction of Photosynthetically Active Radiation (FPAR), or Land Surface Temperature (LST). In addition, with shorter sample rate like 8-day or daily in original time series, harmonics with higher frequencies can be included in HANTS.

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REFERENCE

[1] S. Piao, H. Nan, C.Huntingford, P.Ciais, P. Friedlingstein, S. Sitch, S. Peng, A. Ahlström, JG. Canadell, N. Cong, and S. Levis, "Evidence for a weakening relationship between interannual temperature variability and northern vegetation activity," *Nature communications*, 5, Oct 16, 2014.

[2] G. Gutman, , and A. Ignatov, "Global land monitoring from AVHRR: potential and limitations," International Journal of Remote Sensing, vol. 16, no. 13, pp. 2301-2309, 1995.

[3] M. Menenti, S. Azzali, W. Verhoef, and R. van Swol, "Mapping agroecological zones and time lag in vegetation growth by means of fourier analysis of time series of NDVI images," Advances in Space Research, vol. 13, no. 5, pp. 233–237, 1993.

[4] G. J. Roerink, M. Menenti, and W. Verhoef. "Reconstructing cloudfree NDVI composites using Fourier analysis of time series". International Journal of Remote Sensing, vol. 21, no. 9, pp. 1911–1917, 2000.

[5] J. Zhou, L. Jia, & M. Menenti, "Reconstruction of global MODIS NDVI time series: Performance of Harmonic ANalysis of Time Series (HANTS)," Remote Sensing of Environment, vol. 163, pp. 217–228, Jun 2015.

[6] S. Kandasamy, F. Baret, A. Verger, P. Neveux, and M. Weiss, "A comparison of methods for smoothing and gap filling time series of remote sensing observations - application to MODIS LAI products, " Biogeosciences, vol. 10, no. 6, pp. 4055–4071, 2013.

[7] F. Baret, J. T. Morissette, R. A. Fernandes, J. L. Champeaux, R. B. Myneni, J. Chen, S. Plummer, M. Weiss, C. Bacour, S. Garrigues, and J. E. Nickeson, "Evaluation of the representativeness of networks of sites for the global validation and intercomparison of land biophysical products: Proposition of the CEOS-BELMANIP," IEEE Transactions on Geoscience and Remote Sensing, vol. 44, no. 7, pp. 1794–1803, 2006

[8] J. Zhou, L. Jia, and M. Menenti, "On the performance of remote sensing time series reconstruction methods – a spatial comparison," Remote Sensing of Environment, Under review, 2016.

[9] P. Jönsson, and L. Eklundh, "TIMESAT—a program for analyzing time-series of satellite sensor data," *Computers & Geosciences*, vol. 30, no. 8, pp: 833-845, 2004.