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A self-adaptive approach for producing clear-sky composites from VIIRS surface reflectance datasets

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ABSTRACT

With the launch of the Joint Polar Satellite System (JPSS)/Soumi National Polar-orbiting Partnership (S-NPP) satellite in October 2011, the need for the operational monitoring of terrestrial processes at the regional and global scales led to the expansion of terrestrial remote sensing products (*e.g.*, the clear-sky composited surface reflectance products) generated from the Moderate Resolution Imaging Spectroradiometer (MODIS) into the JPSS/S-NPP mission using the new Visible Infrared Imaging Radiometer Suite (VIIRS) data. Seamless cloud composites are usually generated using a single criterion without an explicit consideration of phenological variations among different surface types. However, because the spectral signals of many surface types change dramatically due to seasonal variations, the single-criterion compositing methods are only effective for specific surface cover conditions. This study proposed a new self-adaptive compositing approach (SA-Comp) to produce global terrestrial clear-sky VIIRS surface reflectance composites. The proposed approach employs contextual spectral and temporal information to determine the surface cover conditions within a pre-defined temporal window, and adaptively selects the most suitable criterion. A comprehensive evaluation of the SA-Comp approach was conducted by comparing it with the maximum NDVI (MaxNDVI), minimum Red (MinRed) and maximum ratio (MaxRatio) compositing schemes, and with the MODIS and VIIRS composited surface reflectance products. The results, including visual representations and temporal profiles, revealed that the SA-Comp approach outperformed all of the other methods. The results also highlighted that the SA-Comp approach is more feasible and effective at compositing global VIIRS data and has great potential for regional, national and even global terrestrial monitoring.

1. Introduction

The launch of the Joint Polar Satellite System (JPSS)/Suomi National Polar-orbiting Partnership (S-NPP) mission in October 2011 marked a new generation of operational polar-orbiting spacecraft (Justice et al., 2013). It is well known that the Moderate Resolution Imaging Spectroradiometer (MODIS) instruments on board the Terra and Aqua satellites have far exceeded their initial design life (Cao et al., 2013). Consequently, the goal of the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument on board the S-NPP is to improve upon the operational Advanced Very High Resolution Radiometer (AVHRR) and provide continuity with MODIS to provide global environmental measurements. The VIIRS instrument has a medium spatial resolution (375 and 750 m at nadir) and multispectral (22 bands) capabilities as well as visible capabilities for nighttime imaging using the day/night band (DNB) (Zhang et al., 2017). Subsequent to the VIIRS first-light images acquired in November 2011, a suite of operational products (Niclòs et al., 2018), including environmental data records (EDRs), has been developed by scientists from the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA).

The VIIRS sensor has a 3040-km-wide swath. Consequently, the images obtained by VIIRS provide complete coverage of the Earth's surface without the spatial gaps between adjacent orbits in MODIS or AVHRR global mosaicked images (Hillger et al., 2013). However, due to the presence of cloud cover, sensor limitations and suboptimal imaging conditions, the time series images and EDR parameters extracted from VIIRS data still suffer from spatial and temporal discontinuity problems that have seriously restricted the application of VIIRS data to land surface process simulation, climate modeling and global climate change

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studies.

Based on different user-defined rules, image compositing can be employed to select the highest-quality observation over the same geographical region from multi-temporal images in a certain period to provide cloud-free and seamless images over large areas (Bian et al., 2015; Griffiths et al., 2013; Roy et al., 2010; Vermote and Vermeulen, 1999). Numerous compositing methods have been proposed to date for different applications, although each was designed with the purpose of optimally eliminating the influences of cloud cover, aerosols and various other factors (Bian et al., 2017; Dennison et al., 2007; Luo et al., 2008). The maximum value composite (MVC) method was first proposed by Holben (1986) and applied to the maximum normalized difference vegetation index (NDVI) for the compositing of multi-temporal AVHRR data. While it remains the most commonly utilized compositing algorithm, the MVC technique tends to select pixels from forward-scattering view geometries and does not work over water bodies (Luo et al., 2008). To avoid some of the problems associated with the MVC, several other methods that rely on low reflectance values in the visible wavelengths to discriminate clear pixels from cloud-contaminated pixels has been proposed (Chuvieco et al., 2005; Vermote and Vermeulen, 1999). These include methods that utilize minimum values in the blue or red band. Since these minimum reflectance methods may select cloud shadow pixels, some scholars suggested using the third-lowest value in the time series based on the assumed low likelihood of a cloud shadow occurring within a given pixel more than twice (Cabral et al., 2003). Image compositing for wide swath data must also consider large spectral distortions introduced by the bidirectional reflectance distribution function (BRDF). To mitigate this problem, some techniques employ view angle constraints to reduce the likelihood of selecting observations with extremely high view angles (Huete et al., 2002).

In addition to these single-criterion methods, multi-criteria methods have also been proposed (Chuvieco et al., 2005; Frantz et al., 2017; Griffiths et al., 2013; Luo et al., 2008; Roy et al., 2010). For example, the criteria matrix scheme was proposed to combine multiple criteria to produce MODIS clear-sky composites (Luo et al., 2008). Multi-criteria methods consider the spectral characteristics of the land surface and clouds in different wavelengths. Consequently, they are more effective than single-criterion methods in many cases (Chuvieco et al., 2005; Luo et al., 2008). However, multi-criteria methods often rely on cloud mask products (Frantz et al., 2017; Griffiths et al., 2013), which typically have errors and hence may lead to erroneous compositing results. In addition, although multi-criteria methods can utilize the multispectral properties of clouds and land surfaces, the phenological variations in the land surface are still not fully considered. When the surface of a target area changes dramatically within a single year, the temporal variation will result in drastic spectral changes, leading to failure in some compositing cases. For instance, multi-criteria methods using only spectral information may fail for annual herbaceous vegetation or open water at high latitudes in the wintertime when the ground is covered by snow or ice over long periods of time.

The main goal of this work is to propose a new approach that can address the above problems in creating global clear view composites using VIIRS observations. The proposed approach employs temporal and spectral information using a two-level, self-adapted technique to determine the surface cover condition of each pixel during a specific time period, which is then used to select an appropriate compositing method for identifying a clear-sky observation during that time period. The approach was evaluated via a comprehensive comparison with three existing compositing methods, namely, the maximum NDVI (MaxNDVI) (Holben, 1986), minimum Red (MinRed) (Chuvieco et al., 2005) and maximum Ratio (MaxRatio) (Luo et al., 2008) methods, and with the MODIS MYD09A1 Collection 6 (Vermote et al., 2015) and VIIRS (Roger et al., 2016) VNP09A1 composited surface reflectance products at the regional and global scales. The global VIIRS compositing results were finally composited using the proposed approach.

Table 1
List of the VIIRS M-bands. The ones used in this study are highlighted in bold face*.

Band	Central Wavelength (μm)	Bandwidth (μm)	Wavelength Range (μm)	Band Explanation
M1*	0.412	0.02	0.402–0.422	Visible/Reflective
M2*	0.445	0.018	0.436–0.454	
M3*	0.488	0.02	0.478–0.488	
M4*	0.555	0.02	0.545–0.565	
M5*	0.672	0.02	0.662–0.682	
M6	0.746	0.015	0.739–0.754	Near IR
M7*	0.865	0.039	0.846–0.885	
M8*	1.24	0.020	1.23–1.25	Shortwave IR
M9	1.38	0.015	1.371–1.386	
M10*	1.61	0.06	1.58–1.64	
M11*	2.25	0.05	2.23–2.28	
M12	3.7	0.18	3.61–3.79	Mediumwave IR
M13	4.05	0.155	3.97–4.13	
M14	8.55	0.3	8.4–8.7	Longwave IR
M15	10.76	1.0	10.26–11.26	
M16	12.01	0.95	11.54–12.49	

2. Data and processing

The VIIRS instrument is a critical payload onboard the S-NPP satellite. VIIRS has three types of bands: five high-resolution imagery bands (I-bands, with a nadir resolution of 375 m), 16 moderate resolution bands (M-bands, with a nadir resolution of 750 m), and the DNB (750-m resolution, near constant across scan). The M-bands are listed in Table 1.

The VIIRS surface reflectance intermediate product (IP) for 2015 from bands M1 to M11 (excluding M6 and M9) were obtained from the NOAA's Comprehensive Large Array-Data Stewardship System (CLASS) (NOAA, 2016). The standard VIIRS surface reflectance IP product is processed in NOAA's Interface Data Processing System and produced in swath-based format (NOAA, 2014). The swath data were then reprojected into a sinusoidal projection and mosaicked into global daily data following the method described in Zhang et al. (2017). The dimensions of the global mosaicked images are 43,200 columns × 21,600 rows, and the spatial resolution is 926.65 m. The NDVI, normalized difference water index (NDWI) and normalized difference snow index (NDSI) were calculated from the equations provided in Table 2. These indices were useful for enhancing specific surface type signals in previous studies.

3. Methodology

3.1. Existing single-criterion compositing methods

Many existing single-criterion clear-sky compositing methods utilize minimum or maximum rules, such as the MaxNDVI (Holben, 1986), MinRed (Chuvieco et al., 2005), median values (Flood, 2013) or some other single-threshold criterion to select clear-sky observations. These approaches are designed to screen clouds automatically because they often prefer clear-sky pixels over cloudy ones. For vegetated surfaces,

Table 2
Spectral indices used in conjunction with the VIIRS bands during the compositing.

Spectral index	Formula	Reference
NDVI	$(\rho_{M7}-\rho_{M5})/(\rho_{M7}+\rho_{M5})$	Tucker (1979)
NDWI	$(\rho_{M5}-\rho_{M10})/(\rho_{M5}+\rho_{M10})$	Gao (1996)
NDSI	$(\rho_{M4}-\rho_{M10})/(\rho_{M4}+\rho_{M10})$	Hall et al. (1995)