EVALUATING THE SENTINEL-2A SATELLITE DATA FOR FUEL MOISTURE CONTENT RETRIEVAL

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ABSTRACT

Fuel moisture content (FMC) of vegetation canopy is a critical variable in affecting wildfire behavior. Methodologies based on multiple sources of remote sensing data have shown a prominent advantage for spatial and temporal FMC mapping. However, there is no study focused on FMC retrieval using the Sentinel-2A satellite data to date. This study is to evaluate the performance of this data for FMC retrieval under the framework of the multiple coupled radiative transfer models. Due to the limited field measurements and discontinuous satellite data, only 15 field measurements from USA, South Africa, Australia and France were available for the validation of the retrieved FMC. Results show that the retrieved FMCs were promising with R^2 = 0.64 and RMSE = 47.16%, which demonstrated the potential usage of the Sentinel-2A data for FMC mapping and further applications for early-warning of wildfire risk.

Index Terms— Fuel moisture content (FMC), Sentinel-2A, Multiple radiative transfer models (RTMs), Wildfire

1. INTRODUCTION

Wildfire causes serious ecological damage and economic losses, which suffers a large number of countries and regions worldwide. Many countries including China, the United States and Australia have taken the risk assessment and early-warning of wildfire as an important policy for forest and grassland management. Fuel moisture content (FMC), defined as the proportion of water content over dry mass, is a critical variable in assessing wildfire risk and fire spread rate [1, 2]. Developing a comprehensive description of the FMC distribution map worldwide would be useful for understanding the fire potential risk distribution and also could aid fire early-warning management [3, 4]. Due to the high temporal and spatial resolution of the remotely sensed image of large landscape observation, remote sensing technique used to quantitatively infer FMC over large areas, has been a major application within the remote sensing domain area since last two decades [5-7].

To date, numerous studies have focused on utilizing optical remote sensing data for monitoring FMC [7]. The first studies were conducted in 1980s and 1990s, and were based on the positive relationships between FMC and AVHRR-derived normalized different vegetation index (NDVI) found for herbaceous species using the [8, 9]. However, weaker correlations were found for shrubs and forests due to the fact that the chlorophyll absorption in the red band and the pick in the NIR reflectance do not correlate as strongly as for FMC of grasses [10]. Since the launch of Terra and Aqua satellites by NASA in 1999 and 2002, the MODIS data have attracted much more attention for FMC estimation [11-13]. Medium spatial resolution sensors such as Landsat Thematic Mapper (TM), Enhanced Thematic Mapper (ETM+) and Operational Land Imager (OLI) have also been used to estimated FMC [2, 3, 14] after then.

To date, however, no study to date using Sentinel-2A satellite for FMC retrieval. This satellite data has a high spatial resolution and unique "red-edge" bands, which has the potential value for providing a new prospect for extracting and analyzing the FMC information at regional to global scale.

2. MATERIALS AND METHODS

2.1. FMC measurements

A large number of field grass and shrub FMC measurements sampled during 2001 to 2017 was received (Yebra et al., In preparation). However, only limited field measurements in forest, shrub and grass were used for the validation purpose since the Sentinel-2A satellite data was only available online after 2015 (Table 1).

2.2 Remote Sensing Data

2.2.1 Sentinel-2A satellite data

The Sentinel-2A satellite successfully launched on June 23,

Table 1 The information of FMC field measurements used in this study for validation of retrieved FMC.

Fuel class	Date	Latitude	Longitude	FMC
Shrub	20160509	43.91334	-117.178	215
Shrub	20170503	43.91334	-117.178	233
Shrub	20160621	43.91334	-117.178	104
Shrub	20170728	43.91334	-117.178	108
Shrub	20160620	44.53	-117.419	135
Shrub	20160608	44.53	-117.419	153
Shrub	20170903	-33.9364	22.52273	106
Shrub	20171005	-33.9364	22.52273	107
Grass	20151125	-35.2787	149.0559	183
Grass	20160413	-35.2787	149.0559	45
Grass	20160604	-35.2787	149.0559	77
Forest	20160412	-35.5979	148.8165	130
Forest	20160906	43.74139	3.595833	51
Forest	20160831	43.74139	3.595833	59

2015. It carried the multi-spectral imager (MSI), which can effectively distinguish 13 bands of visible light (VIS), near infrared (NIR) and short-wave infrared (SWIR) with an imaging width of 290 km[8]. The Sentinel-2A data has three kinds of spatial resolution (10 m, 20 m and 60 m) and update every 10 days. Especially, the unique 'red-edge' spectral band parameters of the Sentinel-2A data provide great convenience in retrieving various vegetation indices.

2.2.2 Data Collection

According to the time and location of measured FMC data, the data were screened and downloaded from the sentinel open access hub (https://scihub.copernicus.eu/dhus/#/home). In order to ensure the consistency with the space-time conditions of field observations as much as possible, three criteria are followed in data selection:

1. The location of the observation site must be included in the image data range.
2. The difference between the imaging time of image data and the measured time is less than 7 days.
3. The image quality is good, and the observing site is not covered by cloud.

Finally, a total of 15 images were used in this study based on the above rules.

2.2.3 Atmospheric Correction

The Sentinel-2A data downloaded from the sentinel open access hub are Level-1C data, which are Top-of-Atmosphere (TOA) reflectance images with geographic correction. In order to eliminate the effects of the atmosphere, the Level-1C TOA data need convert to the Level-2A Bottom-of-Atmosphere (BOA) reflectance data through the Sen2Cor Tool (version 2.4.0) (European Space Agency (ESA) official atmosphere correction plugin). In this study, all resolution data were corrected and unified to 20 m for retrieving the FMC.

2.2.4 Pixel Extraction

SNAP (Version 6.0) (http://step.esa.int/main/toolboxes/snap/) is a remote sensing image processing software issued by the European Space Agency (ESA), which can handle Sentinel-2A data with convenience. Pin manager tool can extract the pixel values of each band in a certain latitude and longitude. In order to make the pixel values more accurate, according to the relative position between the actual observation site and adjacent pixels, the extraction strategy can be divided into the following four cases.

1. For sites close to the center of the pixel, the pixel value of the pixel is taken directly.
2. For a site near the pixel vertex, the average value of the nearest four pixels is taken.
3. In other cases, the average of the pixel values of the nearest nine pixels is taken.
4. If there are any adjacent pixels that differ greatly from the pixel values of the remaining pixels, the pixel is removed and replaced by the average of the pixel values of the remaining pixels.

2.2. The RTMs for FMC retrieval

Three models, the PROSPECT, SAIL and GeoSAIL models were coupled to retrieve FMC for grassland (PROSPECT + SAIL), shrubland (PROSPECT + SAIL) and forest (PROSPECT + GeoSAIL). PROSPECT model [9] was used to obtain the reflectance and transmittance spectra in grass and tree leaves and was linked to the SAIL and GeoSAIL models for the description of the canopy reflectance at scene level, respectively. The calculated reflectance and transmittance using this model are expressed as a function of several scattering and absorption components: leaf structure parameter (N), Cab, DMC, EWT, leaf brown pigment (Cbp) and carotenoid content (Car).

The SAIL model [10] was used to simulate the spectra of the grass canopy for its generally homogeneous assumption, and requires a few numbers of parameters: two leaf inclination distribution function (LIDF) parameters, LIDFa, which controls the average leaf slope, and LIDFb, which controls the bimodality of distribution; LAI; hot spot factor, hspot; the Sun zenith angle, tts; observer zenith angle, tto; relative azimuth angle, psi; leaf hemispheric reflectance, LR; and leaf transmittance, LT.

GeoSAIL model [11] was selected to simulate the spectra of the tree canopy since it can provide an approximately realistic description of the canopy reflectance of discontinuous and heterogeneous vegetation types with low computational cost. This model requires the parameterization of 8 model inputs: LIDF; leaf-level spectral reflectance and transmission for each waveband; LAI; spectral reflectance of the background; solar zenith angle; the shape of the crowns (either cylinder or cone); height to width ratio of the crown (CHW); ccov. For how these RTMs coupled and parametrized, please refers to [2, 12-15].

2.3. LUT-based inversion strategy

An indispensable step for accurate and robust retrieval of FMC is the way to inverse the RTMs. Different inversion algorithms and strategies were developed to search the optimal single one or multiple solutions of variables and alleviate the ill-posed inversion problem. These algorithms include the numerical optimizations, look-up table (LUT), Bayesian network, artificial neural network (ANN) and support vector regression. Compared with other algorithms, the LUT is a global optimal algorithm that avoiding local minima as numerical optimizations and is easy to implement with known accuracy and computational efficiency, and therefore it was widely used for canopy variables (including FMC) retrievals. LUT-based FMC inversion generally includes three steps, the selections of spectra or vegetation indices (VIs) for building the LUT, cost functions that used to search for the best fit between the observed bands or VIs from remotely sensed data with the modelled ones, and the ways for dealing with the searched spectra and characterizing the associate uncertainty. In the inversion process, The Spectral Angle (SA) [16] was used as the merit function in this study to search the matched spectra with the simulated spectra by the PROSAIL RTM. SA is a pixel-based supervised classification technique that measures the similarity between spectra. This angle is independent of the length of vector, so it is insensitive to differences in illumination effect or albedo. The SA is defined as,

$$SA\left(\vec{v},\vec{w}\right) = \cos^{-1}\left(\frac{\vec{v}\times\vec{w}}{\left\|\vec{v}\right\|\times\left\|\vec{w}\right\|}\right) \quad (1)$$

where v and w are the observed (satellite image) and the simulated spectra, respectively. Traditionally, the solution is regarded as the combination of free parameters corresponding to the simulated values which provide the smallest SA. However, due to the ill-posed inverse feature in the physically model-based methods, the solution was not always unique. To enhance the consistency of the retrieved values, the mean value of 30 best fitted values in the LUT was regarded as the final retrieved value [17].

3. RESULTS

Fig. 1 shows scatter plots of measured FMC compared with the retrieved FMC using the Sentinel-2A data. In general, the retrieved FMC vs. measured FMC is evenly distributed around the range from 50 to 250. Results show that the retrieved FMCs were strong positive correlated with the retrieved FMC with R^2 = 0.64 and RMSE = 47.16%, which demonstrated the potential usage of the Sentinel-2A data for FMC mapping and further applications for wildfire risk early-warning. However, retrieved FMC at most stations is slightly higher than the measured value, which may be caused by the local precipitation, soil moisture, field measurement uncertainty, etc.

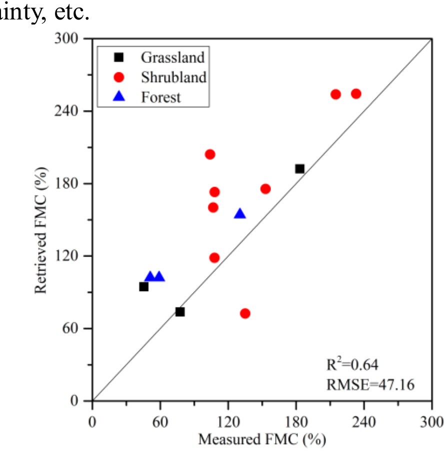

Fig. 1 Scatter plots of measured FMC and retrieved FMC.

4. CONCLUSION

Based on the combining usage of Sentinel-2A data and coupled RTMs, the practicability and reliability of retrieved FMC are illustrated. Results show that the retrieved FMCs were promising compared with the measurements, which demonstrated the potential performance of the Sentinel-2A data for FMC mapping and further applications for wildfire risk early-warning. Next work will be focused on the further evaluate the performance of multiple types of remotely sensed data for FMC retrieval, towards the way for a near real-time and high spatial mapping the FMC at regional to global scale.

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