IMPROVING SATELLITE ESTIMATES OF THE FRACTION OF ABSORBED PHOTOSYNTHETICALLY ACTIVE RADIATION THROUGH INTEGRATION

Xin Tao, Member, IEEE

Department of Geography, State University of New York at Buffalo, Buffalo, NY 14261, USA

IGARSS 2020 - 2020 IEEE International Geoscience and Remote Sensing Symposium | 978-1-7281-6374-1/20/$31.00 ©2020 IEEE | DOI: 10.1109/IGARSS39084.2020.9324638

ABSTRACT

The fraction of absorbed photosynthetically active radiation (FAPAR) is a critical input in many climate and ecological models. The targeted accuracy of FAPAR products is 10% or 0.05 for many applications. However, most current FAPAR products do not meet such requirements, and further improvements are still needed. In this study, a data fusion scheme based on the multiple resolution tree (MRT) approach is developed to integrate multiple satellite FAPAR estimates at site and regional scales. The fusion scheme removed the bias in FAPAR estimates and resulted in a 15% increase in the R^2 and 3% reduction in the root mean square error (RMSE) compared with the average of individual FAPAR estimates. The regional scale fusion filled in the missing values, and provided spatially consistent FAPAR distributions at different resolutions.

Index Terms— Data fusion, fraction of absorbed photosynthetically active radiation (FAPAR) integration, Moderate Resolution Imaging Spectroradiometer (MODIS), Multi-angle Imaging SpectroRadiometer (MISR), multiple resolution tree (MRT)

1. INTRODUCTION

The fraction of absorbed photosynthetically active radiation (FAPAR) is the fraction of incoming solar radiation absorbed by plants in the 400 nm to 700 nm spectral range. It is one of the fifty essential climate variables recognized by the UN Global Climate Observing System, and is a critical input parameter in biogeophysical and biogeochemical processes described in many climate and ecological models. FAPAR can be derived from field measurements at the point scale, but the monitoring network of in-situ measurements is insufficient for global coverage. Satellite sensors efficiently acquire land surface information at regional and global scales, providing new opportunities for monitoring biophysical parameters.

An accuracy of 10% or 0.05 in FAPAR is considered acceptable in agronomical and other applications. Some FAPAR products, such as those derived from MODIS and MISR, have accuracies approaching 0.1. Currently, none of these products meet the accuracy requirement of 0.05.

New sophisticated models could be developed to improve the accuracy of FAPAR estimates, but the temporal and spatial coverage of FAPAR from a single sensor is often limited by the availability of clear view observations. For example, Tao et al. [1] estimated FAPAR from Landsat with detailed spatial distribution information but estimates were limited by the few available clear images due to the long revisit time of Landsat. An alternative is to integrate multiple data products with different characteristics and accuracies. Data fusion could overcome the problems of a single satellite product, such as missing data when clouds contaminate the scene or when instruments malfunction. It combines the advantages of different data sources, and the fusion results provide continuous spatial and temporal coverage.

MRT consists of a multiscale Kalman filter and smoother over a Markov tree data structure that accommodates multiple observations with differing resolutions. At each node in the tree, the MRT method optimally blends the available observations with respect to the least mean squared error according to the Kalman gain and error characteristics of each sensor type. The original MRT fills the void regions with the nearest estimated values from a coarser scale, resulting in a blocky effect. In this study, an overlapping MRT method is utilized to interpolate values from a coarser scale to reduce the blocky effect. This study applies a data fusion method to FAPAR estimation at both the temporal and spatial domains.

2. DATA

The data used in this study include in-situ measured FAPAR and FAPAR estimates from satellite surface reflectance data. The in-situ measured FAPAR from four AmeriFlux sites, including one forest site and three crop sites, are collected to validate FAPAR estimates and integrations. We select surface reflectance data at different resolutions to estimate FAPAR, which serve as inputs in the MRT.

2.1. In-situ measured FAPAR

The AmeriFlux sites can be used for temporal validation of FAPAR estimates and integrations, due to their continuous FAPAR measurements. The land cover are crops for the three Mead sites: Mead Irrigated, Mead Irrigated Rotation, Mead Rainfed. The Bartlett site corresponds to deciduous broadleaf forests. The geolocation of the four AmeriFlux sites are (41.1651º N, 96.4766º W), (41.1649º N, 96.4701º W), (41.1797º N, 96.4396º W), (44.0646º N, 71.2881º W), respectively.

The spatial footprint of AmeriFlux sites is about 1 km^2. Total FAPAR measurements are used as the main validation data in this study, considering its spatial and temporal continuity. Green FAPAR is calculated by multiplying total FAPAR with the ratio between green LAI and total LAI, and is used as supplemental validation data.

2.2. Surface reflectance data

MISR, MODIS, Landsat Thematic Mapper (TM), and Enhanced Thematic Mapper Plus (ETM+) reflectance data are used to estimate FAPAR based on the algorithm presented and validated in Tao et al. [1]. The satellite FAPAR estimates correspond to instantaneous FAPAR around 10:15 am local time, considering both direct and diffuse radiation absorbed by the green components. Spatial resolutions of satellite FAPAR estimates are 1000 m for MISR, 500 m and 250 m for MODIS, and 30 m for TM and ETM+. The temporal resolutions vary from 8 days (MISR and MODIS) to 16 days (TM and ETM+).

3. METHOD

3.1. Overview of the MRT

We assume the data at different spatial resolutions are autoregressive and can be organized in a tree structure (Fig. 1). The MRT algorithm involves two steps: Kalman filtering from leaves to root and Kalman smoothing from root to leaves. One assumption in the MRT algorithm is that the tree structure follows a Markov chain process, which implies that the state variable is only related to its instant child and parent nodes. The first step is filtering from high to low resolution. The major purpose of this step is to fill the data gaps at coarser resolutions with information from high-resolution data. The second step is smoothing from low to high resolution to update the state variable with information at a coarser resolution. The overlapping tree structure is designed to apply the Kalman smoothing process to generate smooth estimates. The values for the overlapping child nodes are the average of the neighboring nodes from coarser resolution. After the Kalman smoothing step, the datasets at different scales become smooth and consistent. More details of the two steps are available in Tao et al. [2].

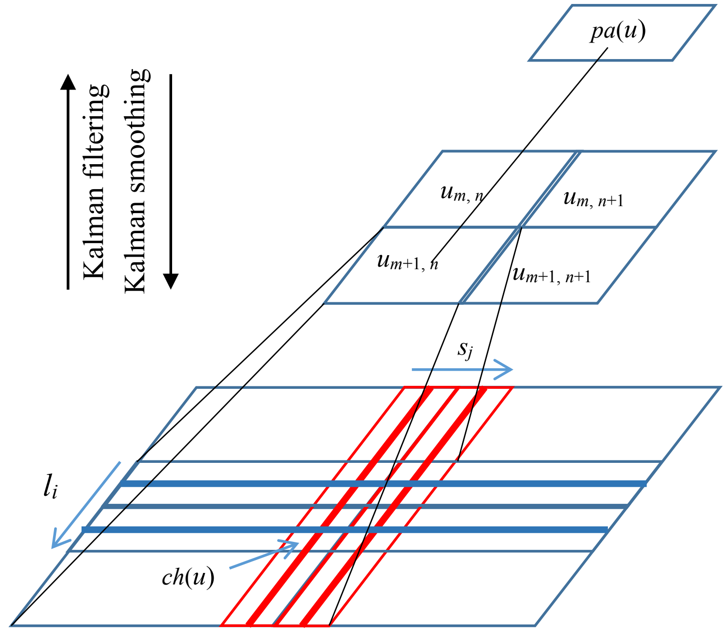


Fig. 1. The overlapping MRT algorithm. The root node is at the top and the leaves nodes are at the bottom. Coarse resolution data serve as root and fine resolution data serve as leaves. There are two steps to implement the algorithm: Kalman filtering from leaves to root and Kalman smoothing from root to leaves. The overlapping tree structure in the Kalman smoothing process is designed to mitigate the blocky effect in the data. $ch(u)$ denotes child node and $pa(u)$ denotes parent node.

3.2. Satellite based FAPAR

The surface reflectance images were converted to FAPAR by inverting a radiative transfer model, which assumes that vegetation is continuous and horizontally homogeneous. The full approach is described in Tao et al. [1]. It consists of four steps: high quality image selection, atmospheric correction, land cover classification, and FAPAR estimation. The FAPAR uncertainty is 0.1 when validating with total FAPAR measurements, and 0.08 when validating with green FAPAR measurements.

3.3. Application of MRT to integrate FAPAR

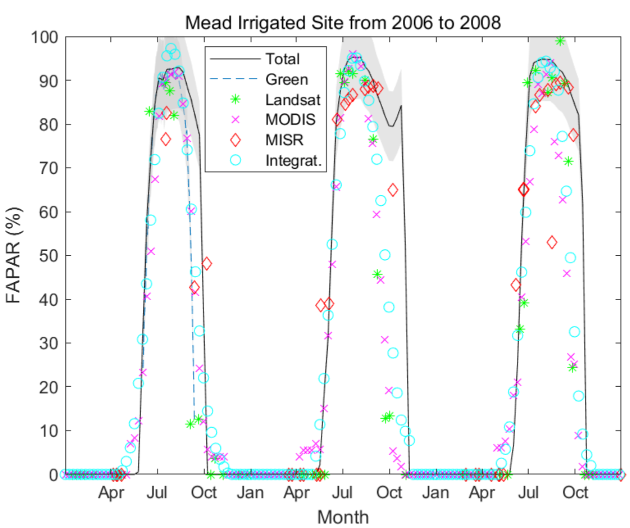
The MISR data were resampled to a spatial resolution of 960 m, and the MODIS 500 m and 250 m data were resampled to 480 m and 240 m, respectively, to construct a multi-scale tree-structured model. In this case, one 960-m pixel corresponds to 2 × 2 480-m, 4 × 4 240-m, and 32 × 32 30-m pixels. The FAPAR estimates in this study have the same definition and hierarchical spatial resolutions, so they can be directly used for integration.

FAPAR estimates were integrated at both site and regional scales. The MRT was applied at the site scale for three consecutive years for the MISR, MODIS, and Landsat data. To make the temporal values continuous, we interpolated the satellite estimates of FAPAR at the temporal scale before integration. The temporal resolution was set to 8 days so that there were 138 records of satellite FAPAR estimates in the 3-year period. Two study regions covering the four AmeriFlux sites are selected for application at the regional scale. The imaging dates of the products differed within 4 days. The vegetation likely remained relatively stable within this short period and therefore, the integration of FAPAR from these different sensors is reliable.

4. RESULTS

4.1. Site-scale validation

The comparisons of the time series curves of the integrated FAPAR and in-situ measurements at the four sites are shown in Fig. 2. The time series curves demonstrate crop or forest seasonality profiles and are smooth over a certain period. The RMSE reduces to an average of 0.109 and standard deviation of 0.024 for all four sites. For comparison, the average RMSE are 0.126, 0.128, and 0.186 and the standard deviations are 0.041, 0.016, and 0.043 for the MISR, MODIS, and Landsat FAPAR, respectively. The biases reduce to an average of −0.039, and the R^2 improves to around 0.874 for the four sites. The integrated FAPAR has higher accuracy than the Landsat FAPAR estimates at the four sites. The integrated FAPAR has better accuracy than the MISR and MODIS FAPAR estimates at three sites, and its accuracy is comparable to the MISR and MODIS FAPAR estimates at the Mead Rainfed site.



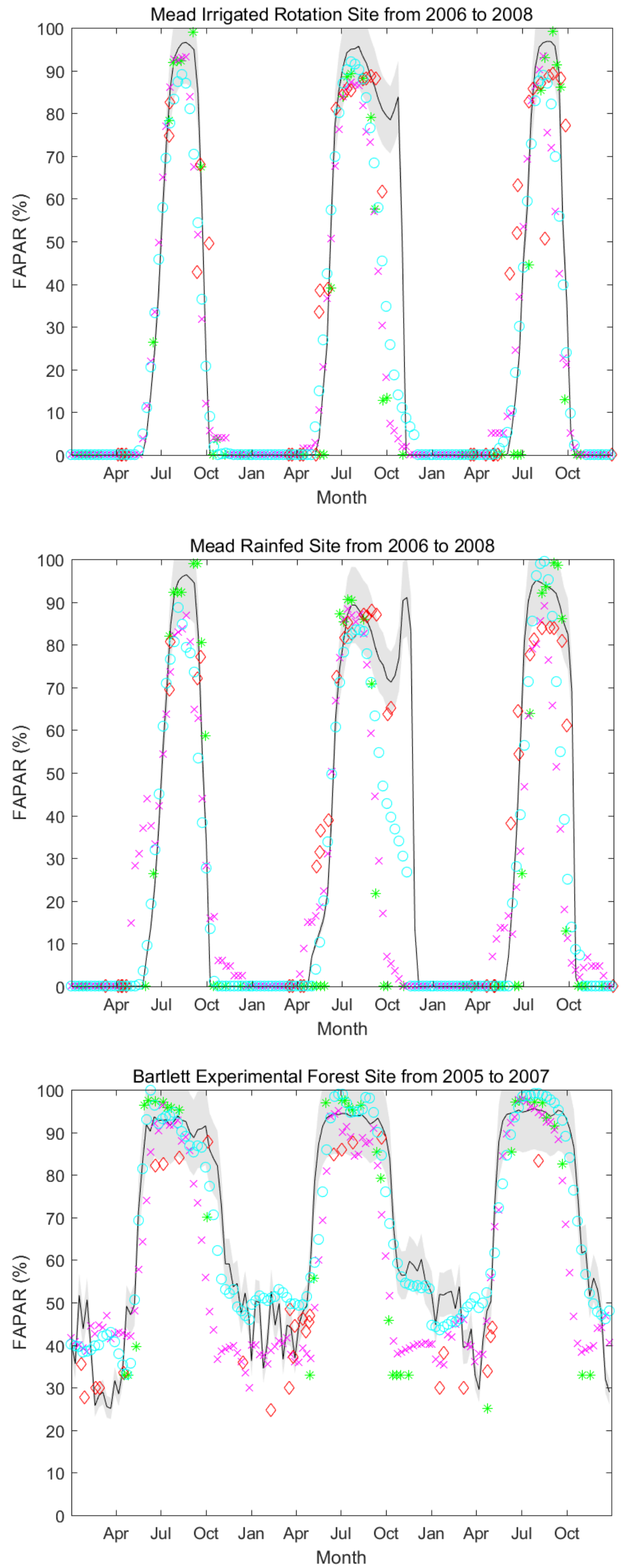


Fig. 2. The time series of in-situ FAPAR measurements and satellite FAPAR estimates at four AmeriFlux sites. Green FAPAR measurements are depicted in blue dashed line in the first panel, and total FAPAR measurements are depicted in black line in all

panels. The shaded area is the 10% accuracy requirement. The Landsat, MODIS, MISR FAPAR estimates, and FAPAR integrations are depicted in asterisks, crosses, diamonds, and circles, respectively.

4.2. Application of MRT at the regional scale

The FAPAR estimates are consistent across different scales in the MISR, MODIS, TM, and ETM+ images for the two study regions (The first row of Fig. 3 and Fig. 4, respectively). The values have similar distribution patterns across scales, in which the highest values are observed in evergreen forests, followed by deciduous forests, and crops. Rivers and central urban areas have FAPAR estimates close to zero.

The MRT method fills the gaps in the original FAPAR estimates in the MISR data, as shown in the second row of Fig. 3 and Fig. 4. Therefore, image quality is greatly improved in terms of spatial continuity. The FAPAR distributions become more homogeneous and continuous after data fusion, which is desirable in terms of continuity among multiple-scale data. Some pixels with low values of FAPAR, less than 0.1, exist along the boundary between the vegetation and non-vegetation regions in the map after applying MRT. They are caused by the sparse vegetation observed near the river or urban area at a higher resolution. The differences become much smaller after applying the MRT method across scales for the study region.

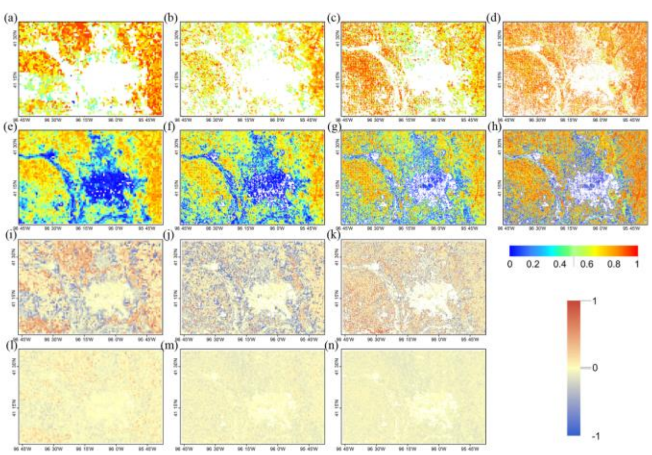


Fig. 3 The FAPAR maps derived from the MISR, MODIS, and TM scenes around Mead crop sites. The first row show the MISR, MODIS 480 m, MODIS 240 m, and TM FAPAR estimates before fusion. The second row show the FAPAR after fusion. The lighter areas in the map refer to non-vegetation or sparse vegetation with FAPAR values smaller than 0.01. The third row show the differences of the MISR, MODIS 480 m, and MODIS 240 m FAPAR to the TM FAPAR before fusion. The last row show the differences after fusion.

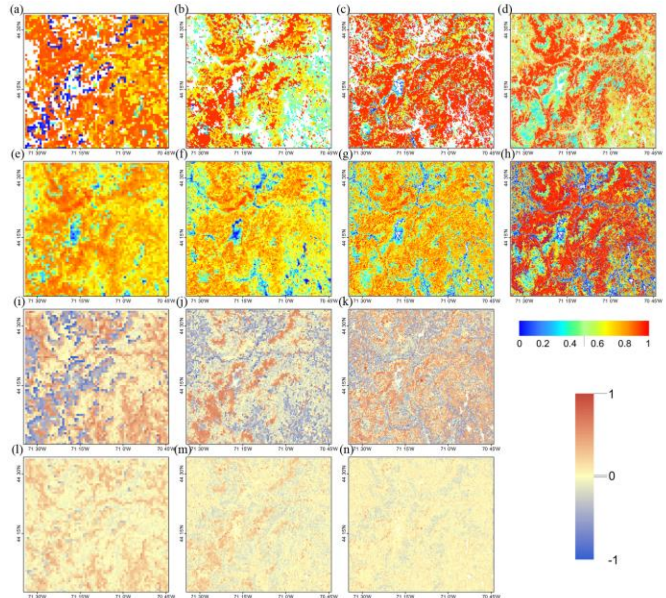


Fig. 4. The FAPAR maps derived from the MISR, MODIS, and ETM+ scenes around Bartlett forest site. The first row show the MISR, MODIS 480 m, MODIS 240 m, and ETM+ FAPAR estimates before fusion. The second row show the FAPAR after fusion. The lighter areas in the map refer to non-vegetation or sparse vegetation with FAPAR values smaller than 0.01. The third row show the differences of the MISR, MODIS 480 m, and MODIS 240 m FAPAR to the ETM+ FAPAR before fusion. The last row show the differences after fusion.

5. CONCLUSION

This study integrated satellite FAPAR values using the MRT data fusion scheme at site and regional scales. The overlapping MRT improves FAPAR data accuracy, resolution, and continuity. It actively integrates high-resolution Landsat FAPAR products to provide unprecedented continuous FAPAR values at the 30-m scale, which can facilitate applications requiring higher spatial resolution, such as crop growth monitoring and precision agriculture. The integrated FAPAR reduced the biases. The R^2 was improved to around 0.87, a 15% increase over the average R^2 of the individual FAPAR estimates. The integrated FAPAR values became continuous and more consistent at multiple resolutions with improved quality.

6. REFERENCES

[1] X. Tao, S. L. Liang, T. He, and H. R. Jin, "Estimation of fraction of absorbed photosynthetically active radiation from multiple satellite data: Model development and validation," *Remote Sensing of Environment*, vol. 184, pp. 539-557, Oct 2016.

[2] X. Tao, S. L. Liang, D. D. Wang, T. He, and C. Q. Huang, "Improving Satellite Estimates of the Fraction of Absorbed Photosynthetically Active Radiation Through Data Integration: Methodology and Validation,", *Ieee Transactions on Geoscience and Remote Sensing*, vol. 56, no. 4, pp. 2107-2118, Apr 2018.