MULTITEMPORAL FUSION OF LANDSAT AND MERIS IMAGES

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ABSTRACT

Monitoring Earth dynamics from current and future observation satellites is one of the most important objectives for the remote sensing community. In this regard, the exploitation of image time series from sensors with different characteristics provides an opportunity to increase the knowledge about environmental changes, which are needed in many operational applications, such as monitoring vegetation dynamics and land cover/use changes. Many studies in the literature have proven that high spatial resolution sensors like Landsat are very useful for monitoring land cover changes. However, the cloud cover probability of many areas and the 15-days temporal resolution restrict its use to monitor rapid variation phenomena. On the contrary, sensors with coarser spatial resolution like MERIS acquire images every 1-3 days.

In this paper, Landsat/TM and ENVISAT/MERIS sensors are combined in a synergistic manner to enhance image time series at high spatial resolution using the temporal information provided by the MERIS sensor. The capabilities of the proposed methodology are illustrated using a temporal image series of both sensors acquired over Albacete (Spain) in 2004. Additionally, the temporal profile of the NDVI is selected as demonstrative application of agricultural monitoring.

Index Terms— Multi-resolution, data fusion, spatial unmixing, sub-pixel, Landsat TM, MERIS

1. INTRODUCTION

Nowadays, Earth observation satellites provide a huge amount of images at different spatial, temporal and spectral resolutions. However, users usually demand images with high spatial and also high temporal resolutions, which cannot be provided by a single instrument due to technical constraints. Besides, it is worth noting that clouds hamper the operational use of satellite time series with low revisit time ($8-16$ days) but higher spatial resolutions, such as Landsat, ASTER or SPOT-XS ($10-30$ m). On the contrary, sensors like MERIS or MODIS provide higher spectral resolution and global coverage with a revisit time of $1-3$ days, but the spatial resolution varies from 250 m to 1.2 km. In this context, the main objective of this work is to use image fusion techniques in order to combine relevant information from multiple images captured by different sensors in order to yield a composite image that ideally contains the best features from each of the original images. In particular, medium (ENVISAT/MERIS FR) and high (Landsat/TM) spatial resolution data are combined in a synergistic manner to enhance image time series at high spatial resolution using the temporal information provided by the MERIS sensor.

The fusion algorithm is based on the previous work in [1, 2, 3], but has been conveniently modified to accommodate some important characteristics of the particular problem. In this paper, we extend the use of the image fusion method recently presented in [4] to the multitemporal setting. The goal is to increase the number of time series images thus allowing a closer agricultural and phenological phenomena monitoring. Time series at higher spatial resolution and with enough temporal sampling are the key to obtain operational applications that require monitoring rapidly varying phenomena, such as precision agriculture, irrigation advisory services, near-real time change detection, and updating of cartography. Unlike previous image fusion methods [1, 3], the algorithm in [4] makes use of a soft clustering that provides land cover class proportions (or membership) at Landsat resolution, i.e. Landsat pixels are considered as mixed pixels rather than as pure land covers. This characteristic proves very effective in modeling spatio-spectral image features and thus yields a more robust way to estimate multitemporal changes. The multitemporal fusion approach is illustrated using a time series of Landsat/TM and ENVISAT/MERIS images acquired over Albacete (Spain) in 2004.

2. METHODOLOGY

The spatial unmixing method is based on the one proposed in [1], which was initially used to increase the spatial resolution of the LANDSAT/TM thermal band. Subsequent studies using this methodology have shown good results in land applications to fuse Landsat with MERIS [3, 5] and ASTER [6] images. In this method, the linear mixing model is applied

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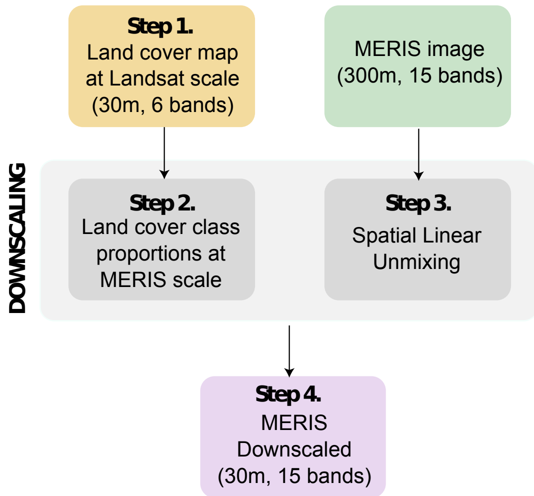

Fig. 1. Scheme for MERIS and Landsat image fusion.

to unmix or disaggregate the coarser resolution image using the information about their pixel composition provided by the Landsat images in a sliding-window. The method is summarized in Fig.1 and is based on the following steps.

2.1. Multitemporal soft clustering of the high spatial resolution images

The high resolution image is segmented into K clusters by using an unsupervised clustering method. Among the several methods available, self-organizing maps (SOM) showed better results [7]. In the multitemporal setting, each MERIS image in the temporal series is downscaled or fused selecting the closest Landsat images to the MERIS date in order to preserve the temporal consistency on the image fusion procedure. For each MERIS image, the Landsat images acquired before and after of the MERIS date are used to classify the high resolution image. Furthermore, a change detection map between both images is also calculated using the Spectral Angle Mapper (SAM) and Mahalanobis distances in order to stress land cover changes. The Landsat spectral bands together with the SAM and Mahalanobis temporal distances are used as the input data in the clustering. Next, the membership of each pixel of the high resolution image to the clusters is also calculated [8].

2.2. Land cover class proportions at MERIS scale

The posterior probabilities at Landsat resolution are used to get the class abundances or proportions for each MERIS pixel. In this study, these MERIS pixels abundances are estimated by projecting each MERIS point spread function (PSF) onto the membership class image at Landsat resolution. This PSF also takes into account the effective pixel size in the along and across track directions due to the panoramic

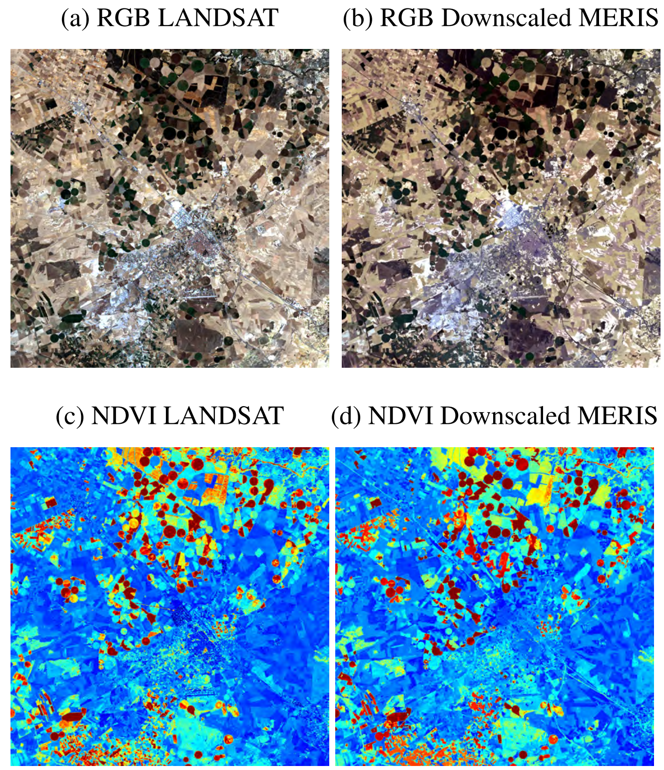

Fig. 2. RGB composition and NDVI for the original Landsat acquisition on 01/07/2004 and the fused image.

distortion including the Earth curvature, which causes greater distortions for observations away from nadir and in spaceborne imaging systems with large swaths, such us MERIS.

2.3. Sliding-window spatial unmixing of the low spatial resolution image

The MERIS image is processed using a sliding-window in order to use the contextual information of the MERIS neighboring pixels to estimate the MERIS endmembers for each class present in this window. Each MERIS pixel is unmixed in the window by the inversion of a system of linear mixture equations. Furthermore, a regularization term is added to the cost function to limit large deviations of the unmixed pixels from natural spectral prototypes for each class. See more details in [4].

2.4. Spectral assignment

Finally, the enhanced-MERIS or fused image is obtained by assigning the estimated spectra to the corresponding Landsat pixels, which are estimated from the MERIS endmembers of each land cover weighted by the Landsat posterior class (land-cover) probabilities. The use of these posteriors from the Landsat image guarantees the spectral variability of the land cover classes within each MERIS pixel footprint in the fused image [4].

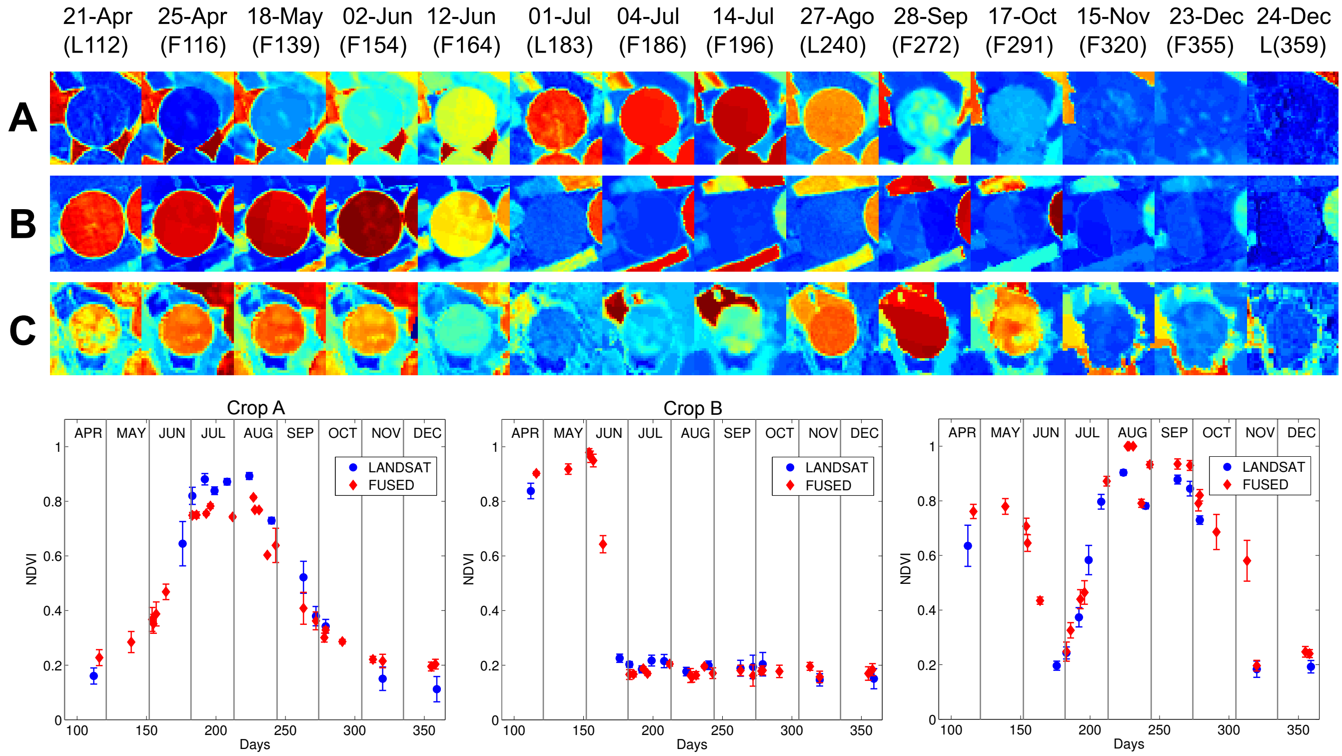

Fig. 3. Time series of NDVI (mean and standard deviations) derived from the Landsat-5 TM and the downscaled MERIS images for three different crop fields.

3. RESULTS

A temporal series of Landsat TM and MERIS acquired over Albacete (Spain) in 2004 are used to illustrate the capabilities of the proposed multitemporal image fusion approach. The study area (30 $\times$ 30km) was selected in the overlap area between adjacent Landsat images. This procedure gives an additional image between two nominal Landsat acquisitions (16 days), which is very useful to better assess phenology changes and is also used for validation purposes. In this study, 13 Landsat and 25 MERIS images from April to December were used, which cover an urban area and also an irrigated agricultural area.

The Landsat images were previously geometrically and atmospherically corrected, and the MERIS image was also corrected atmospherically [9] and geometrically using the AMORGOS software provided by the European Space Agency (ESA). The free parameters of the fusion algorithm were selected taking into account the results obtained in previous work [4]: number of clusters $K = 15$, spread of the clusters $m = 1.1$, window size $w = 11$, and regularization parameter $\alpha = 0.1$.

In this paper, the quality assessment of the proposed fusion approach is performed by visual inspection and the analysis of the NDVI temporal profiles. In Fig. 2, a Landsat image acquired on July 1st is compared with the fused image for two typical user products: the RGB composite and the Normalized Difference Vegetation Index (NDVI). We can observe that both images are visually very similar and that the use of the Landsat probabilities to reconstruct the fused image increases the class spectral variability in the final fused image, avoiding also that some discontinuities between spectra appear from one window to the next.

Agricultural monitoring is selected as a demonstrative application of the methodology potential, and the multitemporal coverage during the vegetation period should provide essential information for an accurate determination of the crop type and phenology. Three different fields with central pivot irrigation (crops A, B and C) were selected to show the temporal profile of NDVI (Fig. 3), which are found to be consistent with the phenological cycles of different vegetation classes. Crop A corresponds to a summer cereal crop, which cycle is characterized by a growth and development stages in spring followed by a drying phase. An early-spring crop that was harvested in June is shown in crop B. Note that it presents a sudden change in the temporal NDVI profile which date can not be estimated properly using only the Landsat temporal serie. Finally, crop C shows a double-cropped and irrigated field, in which a second crop is planted after the first has been harvested. As noted in the previous crop, a more accurate temporal NDVI profile is obtained when the downscaled MERIS images are used.

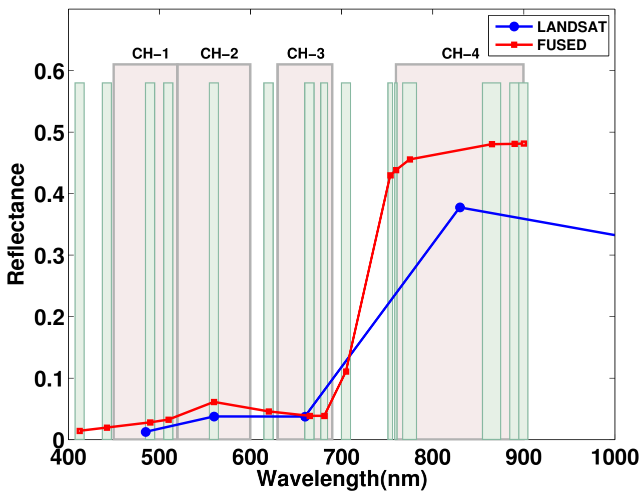

Fig. 4. Mean spectra obtained from the Landsat-5 TM and the downscaled MERIS images for the crop A acquired on July 1th. The bandwidth of the first 4 Landsat-5 TM and the 15 MERIS bands are also shown in pink and green colors, respectively.

Finally, note that a fused image is obtained at Landsat resolution (30 m) from each MERIS image with the spectral features of the MERIS image (15 bands), providing a richer spectral information (Fig. 4) that can be exploited for further studies [10]. For instance, the MERIS spectrum allows to estimate accurately several biophysical parameters, such as chlorophyll content, leaf area index, fractional cover or water content.

4. CONCLUSIONS

The paper presented a multitemporal image fusion method for combining MERIS and Landsat sensors in a synergetic way. The method gives a set of images with both the Landsat spatial and MERIS spectral resolutions, and also allows to increase the temporal resolution. The exploitation of image time series is a key objective for studying and monitoring the Earth environment, which provides knowledge about the vegetation seasonal dynamics and land cover/use changes at local and national scales. The preliminary results presented confirm the validity of the processing scheme, both in terms of fusion subjective quality assessment and the NDVI multitemporal product derived. Future studies will focus in the evaluation of the processing chain robustness and the quantitative analysis between the fused and control images.

Furthermore, the proposed methodology is also general enough to be applied to similar sensors, such as the multispectral instruments which will fly on board the ESA GMES (Global Monitoring for Environment and Security) Sentinel-2 and Sentinel-3 upcoming satellite series.

5. REFERENCES

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