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Multi-Sensor & Temporal Data Fusion for Cloud-Free Vegetation Index Composites

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1. Introduction

Remotely sensed data from satellite sensors such as Moderate Resolution Imaging Spectroradiometer (MODIS) and Advanced Very High Resolution Radiometer (AVHRR) provide almost daily global coverage. Satellite sensor data are used to create scientific data products that include surface reflectance, land surface temperature, sea-surface temperature and many others, as well as ancillary metadata like satellite viewing angle and data quality information. Vegetation indices, like Normalized Difference Vegetation Index (NDVI) (Jensen, 2000), derived from reflectance products of satellite sensors, are generally used as indicators of relative abundance and activity of green vegetation, often including leaf-area index, percentage green cover, chlorophyll content, green biomass, and absorbed photo-synthetically active radiation.

Frequently reflectance data products needed to create vegetation indices include undesired cloud, water vapour, aerosols, or other poor quality pixels. Continuous monitoring of occurrences such as droughts, frosts, floods, major fires, forest stress, or natural disasters are just a few of the circumstances when daily cloud-free vegetation index composites data are of high utility. The traditional approach to creating a single synthetic cloud-free image that includes ideal values selected from a temporal set of possibly cloudy satellite images collected over a continuous time period of interest is called multi-temporal compositing (MTC). MTC compositing is generally used to create vegetation indices images from data products with high temporal and low spatial resolution such as those produced by the National Oceanic and Atmospheric Administration's (NOAA) AVHRR sensor or NASA's MODIS (Justice, 1998). Various methods of MTC have been utilized to produce scientific data products including Maximum Value Compositing (MVC), Constrained View Maximum Value Compositing (CV-MVC) (Cihlar et. al., 1994, Heute et. al., 1999), and CV-MVC which incorporates sensor data quality information.

The motivation for investigating multi-sensor and temporal fusion for creating high-temporal frequency composites is to overcome the limitations of single-sensor MTC methods and deliver continuous monitoring capabilities that exceed the temporal frequency of currently available 8-day, 10-day, 14-day, and 16-day composite vegetation index data products. Currently available composite products do not provide sufficient frequency and temporal detail to capture and quantify important events, do not deliver data for continuous environmental monitoring, and provide temporally sparse inputs precluding effective agricultural productivity modelling.

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In this chapter, new approaches are presented for creating high-temporal resolution vegetation index data products by multi-sensor and temporal fusion (MSTF) (Shrestha et. al., 2006). MSTF methods are detailed that employ rule-based image fusion methods to combine data streams from similar sensors to deliver almost daily cloud-free high-temporal resolution vegetation index composites. Results of daily MSTF cloud-free vegetation index compositing are presented to illustrate their significance and potential operational utility for 1) providing regional vegetation and ecosystem condition monitoring as applied to a disaster event such as Hurricane Katrina, and 2) providing bioproductivity monitoring and crop modelling insight for an agricultural study area of interest with large crop production fields that include a plurality of pixels. In the earlier case, daily data sets are shown as well as cross-platform fused products providing visible indication of decreasing greenness, whereas in the latter case, the MSTF approach is implemented, products are demonstrated, phonological growth stages of crops are examined using daily data products, and results are compared to traditional standard scientific data product produced by MTC methods.

1.1 NDVI

Vegetation indices are conventionally used as a representative of vegetation that characterizes the vegetation vigor (Rouse et al., 1974). Vegetation indices are defined as dimensionless, radiometric measures that function as indicators of relative abundance and activity of green vegetation, often including leaf-area index, percentage green cover, chlorophyll content, green biomass, and absorbed photo-synthetically active radiation (Jensen, 2000). In this study, we have used Normalized Difference Vegetation Index (NDVI); the most widely used form of VI, which was introduced by Deering (Deering, 1978) and Tucker (Tucker, 1979). The principle underlying NDVI is the strong reflectance of healthy, chlorophyll-based vegetation at near-infrared wavelengths and its relatively weak reflectance in the visible red. NDVI is simply defined as the ratio of the difference between these reflectance normalized by their sum as shown by the equation 1. This yields a dimensionless quantity ranging in theory from -1 to 1, but in practice the lowest value seldom falls below -0.25. The value increases from -1 to +1 with the increase in vegetation. The clouds are in the lower end of the NDVI value range.

$$\mathrm{NDVI} = \frac{\mathrm{NearIR} - \mathrm{R}}{\mathrm{NearIR} + \mathrm{R}} \qquad (1)$$

The NDVI is calculated using equation 1, where NearIR represents near infra-red reflectance and R represents red reflectance. Unfortunately, these images frequently include undesired cloud and water cover. Areas of cloud or water cover preclude analysis and interpretation of terrestrial land cover, vegetation vigor, and/ or analysis of change. Figure 1 shows NDVI images of Mississippi and Arkansas, US, created using reflectance data from AVHRR (a) and Terra MODIS (b) on May 7, 2004.

This chapter presents multi-sensor and temporal fusion (MSTF) of NDVI datasets from the MODIS sensor, a key NASA sensor system aboard two satellites, the Terra (EOS AM) and Aqua (EOS PM). Terra and Aqua MODIS collect image data for the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths. The spatial resolution of MODIS images varies from 250m x 250 m to 1000m x 1000 m.

(a) (b)

Fig. 1. Color coded NDVI for states of Mississippi and Arkansas, US from AVHRR (a) and Terra MODIS (b) sensors for 7 May 2004 (Mali et al., 2005).

2. Compositing

To more effectively monitor the dynamics of changing conditions on the surface of our planet, removing the frequent and extensive cloud cover that obscures daily observations over many parts of Earth's is the primary motivating reason for developing methods for producing spatially and temporally continuous and consistent NDVI images. The traditional approach of creating a single synthetic cloud-free image that includes ideal values selected from a temporal set of possibly cloudy satellite images collected over a continuous time period of interest is called multi-temporal compositing (MTC). There are several MTC methods that are generally based on the temporal NDVI values, satellite view angle, and also the quality flags for the pixel.

The MTC process of selecting pixels with highest NDVI value for each individual pixel across a set of temporal collection for compositing purposes is known as Maximum Value Compositing (MVC). MVC is the procedure used to generate composited AVHRR-NDVI product (Holben, 1986). Presence of a high concentration of water vapour lowers the near infrared channel response and thereby lowers the derived NDVI value. Therefore, the highest NDVI value, also referred to as the greenest pixel, is presumed to select the observation under conditions when the atmosphere contained the least amount of water vapour. The shortest path length for reflected radiation occurs at nadir, and it is least affected by water vapour concentration (USGS). Furthermore, pixel size increases with view angle; therefore nadir-view pixels are considered optimal because they possess minimal spatial distortions (Gao et al., 2003). In addition, high-angle views enable the relative altitude of vegetation above the ground to present more leaf area and less soil cover to the observing system sensor. For all of these reasons, MVC processing approaches have been refined to include constraints that remove such bias by employing a scan angle or zenith angle constraint. In this refined approach to MVC, the selection criteria allows the use of pixels observed at angles near nadir during the compositing process and discards pixels observed at angles far from nadir. MODIS-VI compositing algorithm uses either reflectance based BRDF or constraint view maximum value compositing (CV-MVC) algorithm over a period of 16 days (Huete et al., 1999).

The presence of clouds in the daily data products precludes the use of NDVI for continuous vegetation monitoring using satellite observation. Additionally, the traditional MVC is a representative NDVI (highest value) for a given temporal range is selected for 8/ 10/ 16 days and up to 30 days period. For example, the NASA standard scientific data product, MOD13 (LPDAAC, 2008) is a comprehensive standard vegetation index product that includes NDVI composited over 16 day period. These standard cloud-free composites of NDVI have high utility/ usefulness for many applications where regular continuous vegetation monitoring may not be required. However, in certain cases where regular vegetation monitoring is required, an 8/ 10/ 16 day or longer temporal range may not be sufficient. For example, in the case of crop monitoring, changes in NDVI values can provide significant insight to crop vigor and provide information for identifying changes from one stage of vegetation growth to other. Therefore, there is a need for cloud-free NDVI products that provide high temporal resolution. Multi-sensor and temporal fusion (MSTF) provides methods needed to generate daily cloud-free NDVI products with broad areas of useful application.

3. Multi-Sensor and Temporal Fusion (MSTF)

The MODIS sensor system is onboard two satellites Aqua and Terra and has high temporal resolution providing almost daily revisitis around the globe. Therefore, using the MODIS sensors onboard the two satellites, NDVI images created from MODIS land surface reflectance datasets (MOD09) provide an ideal opportunity for multi-sensor fusion. In addition to observation reflectance data, the LPDAAC also provides additional metadata associated with the datasets for Global Geolocation Angles (MODMGGAD) and Quality Assurance (MODGST). The fusion algorithm uses the associated MODIS geolocation angles and MODIS quality assurance (QA) metadata (extracted from MODGST) to differentiates between land, water, cloud, and snow observation.

The principles behind the presented rule-based algorithm for multi-sensor and temporal fusion are a) that observations selected for the day of interest are preferred, but values may be considered that persist from observations made over previous days; b) that pixels with lower view angles contain less noise; and c) that associated MODIS QA metadata may be used to select land observations. After the preprocessing steps to extract NDVI, zenith angle, and quality data, a stepwise temporal selection process is followed to identify observation pixels, from both Aqua and Terra, which fulfill the necessary criteria for fusion. The criteria that are enforced are for i) a zenith angle for the pixel less than 48°, and ii) a quality code for the underlying pixel indicating classification as a clear land observation. Thereby, pixels classified as water, cloud, snow, and no data values are exempted from consideration for fusion. The zenith angle threshold (MAX_ANGLE) of 48° is used, such that only pixels with associated zenith angles less that 48° are selected. The zenith angle threshold was chosen to reduce striping effects that were observed in the composites created using higher zenith angles (Mali et al., 2005). Given the view angles and quality metadata for each pixel of the images from different satellites, the following pseudo code illustrates the rule-based fusion (O'Hara et al., 2008, Shrestha et al., 2005).

```
For day from 0 to MAX_DAY
if (angle is less than MAX_ANGLE) AND (mask is MASK_LAND)
        select pixel, zenith angle, mask
        compute confidence
else
```

get next pixel
If no pixel selected
select pixel with highest NDVI, zenith angle, mask
assign least confidence

In both the cases that are presented in this chapter, a six day temporal window (MAX_DAY), 48^{o} zenith angle (MAX_ANGLE), and the quality mask observation classified clear observation of land (MASK_LAND) are used. When both of the observations for a day meet the required constraints, either the observation with lower zenith angle or the observation with higher NDVI can be selected for fusion. In this case, we have chosen observation with higher NDVI.

4. Results and analysis

Using the technique for multi-sensor and temporal fusion described in earlier section, experiments were conducted to illustrate use cases for vegetation and ecosystem condition monitoring for a disaster event and for agricultural crop bioproductivity monitoring and modelling. The locations for the use cases considered two sites – 1) the Mississippi Delta, USA and 2) the Pampas of Argentina. Use case results are presented in the following sections.

4.1 Mississippi delta, USA

The texts and results in this section are extracted from (O'Hara et al., 2008). This section illustrates the use case for MSTF fused NDVI created of Mississippi Delta region in Unites States during the time frame of Hurricane Katrina. For this use case, the objective was to utilize MSTF to demonstrate temporal compositing methods with significant implications for monitoring continuous vegetation status. To accomplish this objective, it was decided that a major meteorological event would provide unique insight as to whether the application would enable status tracking, identification, and potentially quantification of pre-event conditions, event-related stress, and post-event recovery of greenness. To accomplish this, an area within Mississippi was selected above the coast, but within the areas impacted by Hurricane Katrina. The ability to remove clouds and characterize the daily vegetation conditions before and after a major hurricane was deemed to be a good application for testing the ability to remove heavy or complete cloud cover for a desired geographic area and a temporal interval of interest (O'Hara et al., 2008).

For a thirty-two (32) day period from August 20 to September 20, during a time frame covering the temporal period prior to as well as after Hurricane Katrina (August 29th, 2005), MODIS – Aqua and Terra datasets were downloaded for the Area of Interest (AOI). The AOI is focused in the Mississippi Delta region, and corresponds to MODIS grid H10V5. These daily data were downloaded, pre-processed to NDVI and associated metadata of zenith angle and quality, and were used to compute fused daily NDVI. The daily MODIS reflectance, geolocation angle, and quality assurance datasets were downloaded from the NASA LPDAAC.

Figures 2 and 3 represent the color coded daily NDVI images computed from Aqua and Terra MODIS land surface reflectance datasets for August 20, 2005 to September 20, 2005. Figure 4 represents the fused dataset created using multi-sensor and temporal fusion for the same time period.

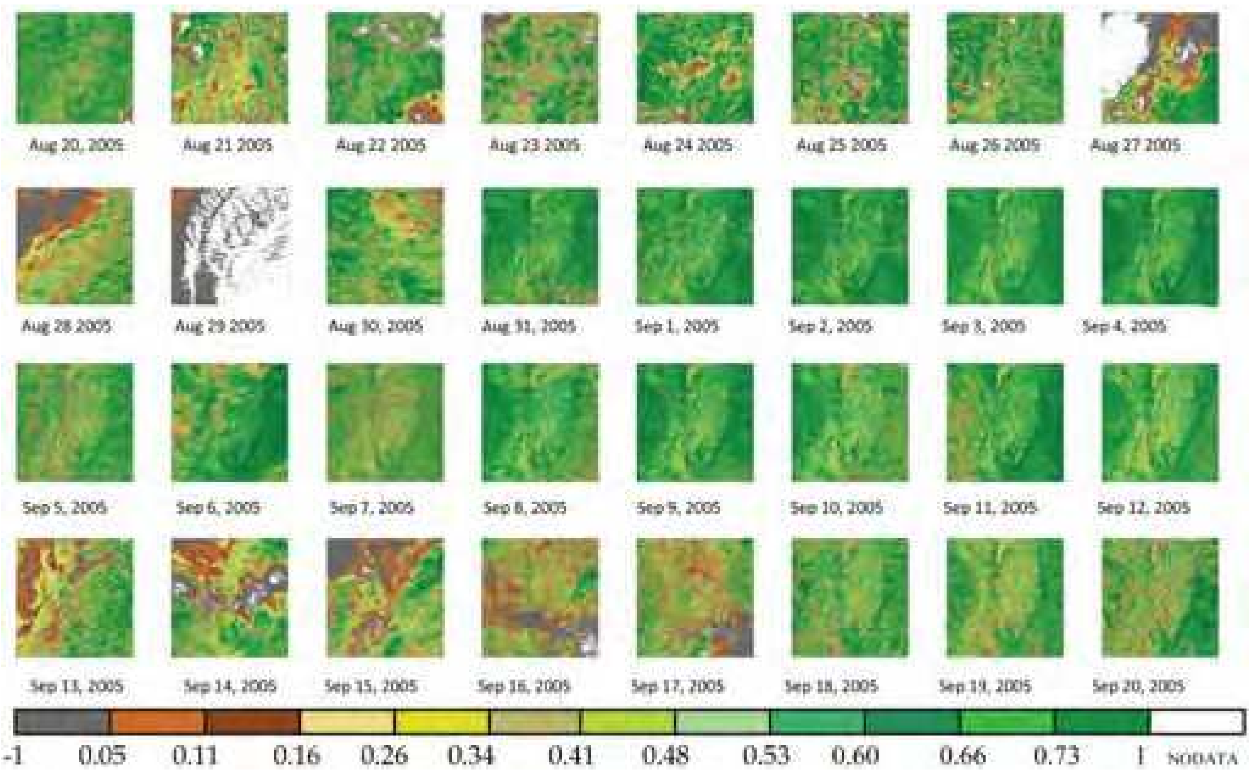


Fig. 2. Color coded Aqua NDVI Data for 32 days (Aug 20 – Sep 20, 2005). Here Grey color shows cloud cover, the low NDVI values are in orange and yellow colors, the increase in NDVI is shown by increase in darkness of green color, and the white color represent the 'No Data' values; and are related to the NDVI values represented in the color bar (O'Hara et al., 2008).

Fig. 3. Color coded Terra NDVI data for 32 days (Aug 20- Sep 20, 2005). The color mapping is the same as employed in Figure 2 (O'Hara et al., 2008).

Through visual inspection of daily Aqua, Terra, and fused NDVI images, from Figures 2, 3, and 4, initial indications of cleanness, completeness, and continuity of data coverage as well as general trends in greenness are observed in the fused images compared to the cloud obscured and noisy appearance of NDVI products created from daily reflectance data. Here, visual representations of the regional NDVI datasets are provided. Detailed field level zonal analyses of fused datasets with respect to daily and composited standard single sensor MODIS datasets will be published in upcoming publication (O'Hara et al., 2008). Visual inspection of MSTF results show a clear trend, when viewing along a diagonal from top-left to lower right (earliest date to latest date), of general decrease in greenness and increase in yellow content. This clearly illustrates the usefulness of the products to provide improved understanding of the significant decreases in vegetation vigor due to loss of leaves, downed trees, and general vegetation stress as a result of Hurricane Katrina event.
In the next section, the use of MSTF fused NDVI for crop productivity and continuous vegetation monitoring of large agricultural fields in Argentina is presented.

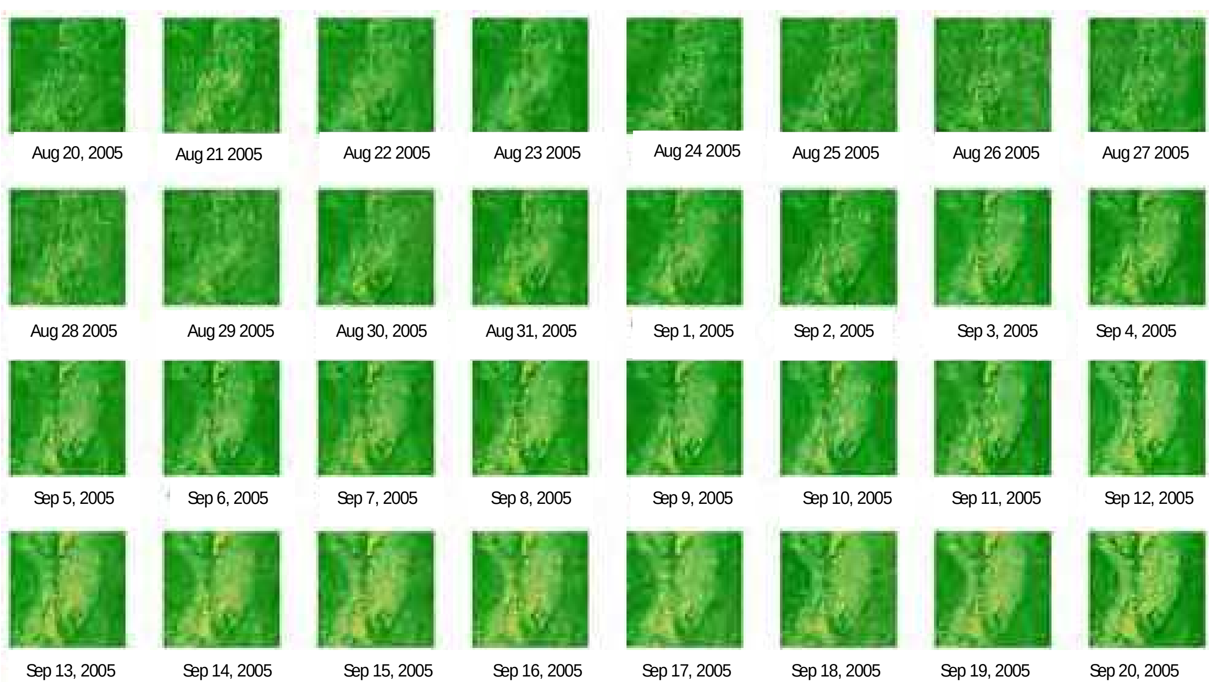


Fig. 4. Color coded fused output NDVI data for 32 days (Aug 20- Sep 20, 2005). The color mapping is the same as employed in Figure 2 (O'Hara et al., 2008).

4.2 The pampas of Argentina

The second use case demonstrates the use of fused daily NDVI data to create data products that deliver greatly enhanced capabilities to analyze current conditions and long-term crop signatures. These signatures as shown as greeness curves that depict representative vegetation conditions characterized by NDVI and enable improved understanding of crop phenological growth states. As studies have shown in the past, multi-temporal observation data may be analyzed to detect phenological changes useful for crop classification (Haralick, at al., 1980) as well as to provide signature curves of crop growth which utilize NDVI to model crop growth, phenological growth stages, and crop maturity. This approach is presented in terms that illustrate utility for delivering enhanced understanding of specific crop types as well as development and vigor over time during a crop season as well as over multiple seasons to provide insight about crop rotation, management practices, double cropping, and timing of planting and maturity of crops.

This use case demonstrates the use of fused NDVI Data products derived from satellite observations of Aqua and Terra MODIS to provide a major observational source of field level vegetation data.

South America is considered as the major soybean growing region of the world. For that reason, Argentina was chosen as the main area of interest for this experiment. The study area lies in the *Pampas*, which includes the Cordoba region and other nearby areas, is a major soybean farming region within Argentina. Figure 5 shows the eight field sites in Argentina. The field sites were chosen with the help of a local expert such that the MODIS tile with grid ID H12V12 contained all the field sites. For each field site, large soybean fields were chosen, and the field boundaries were decided and validated. By using large crop production fields it was insured that the fields included a plurality of pixels in coarse-resolution (250m x 250m) MODIS reflectance datasets. Most of the fields selected are more than 50 hectares in area to comply with coarse resolution of MODIS datasets. For this chapter, we show the results from one of the sites in Marco Juarez. Figure 6 shows the three field boundaries at Marco Juarez in a) high resolution AWiFS image and b) low resolution fused MODIS image.

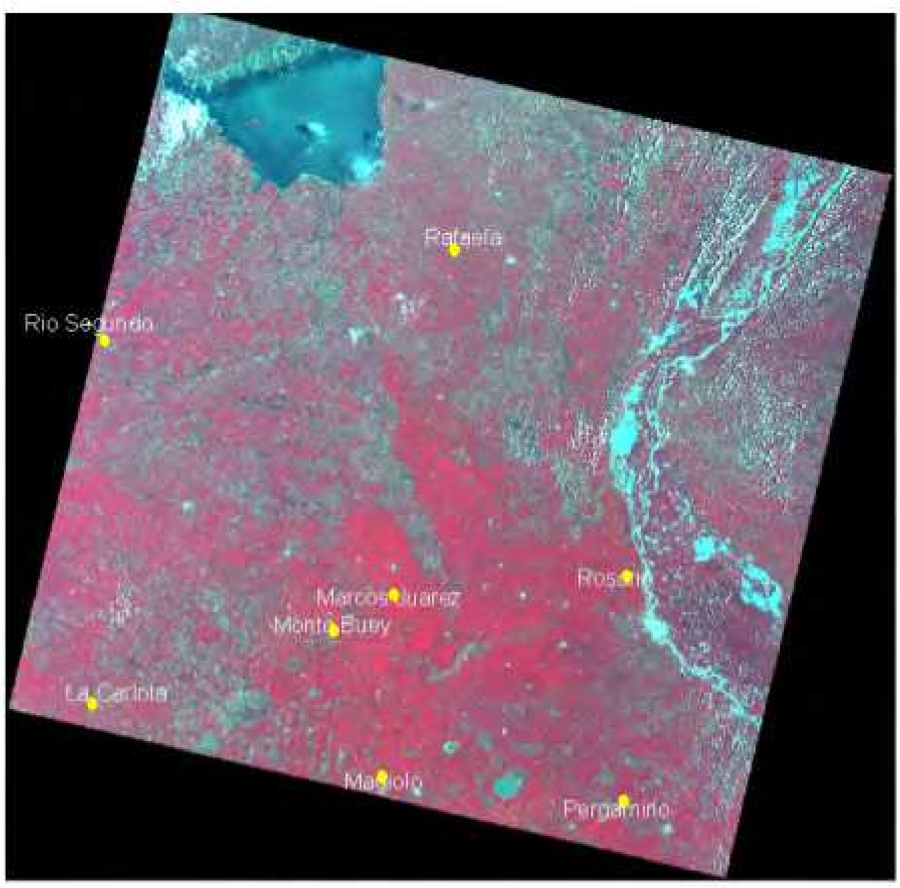
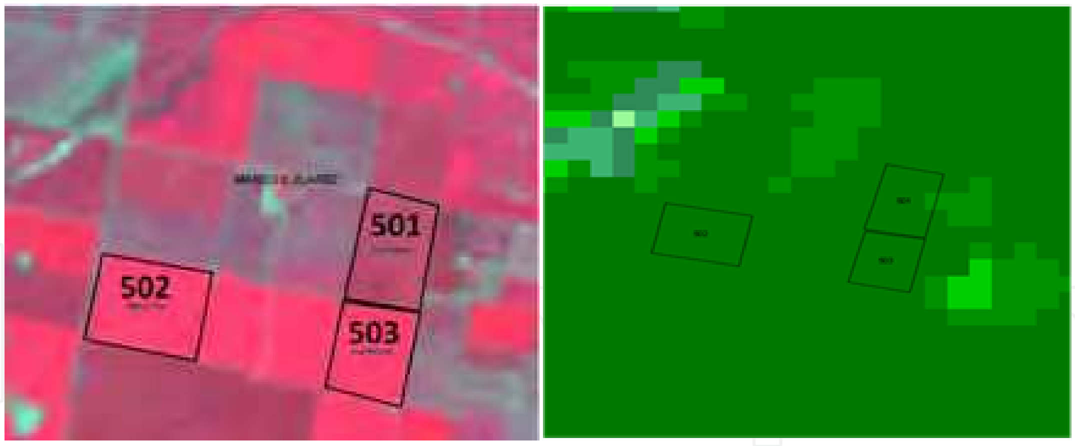


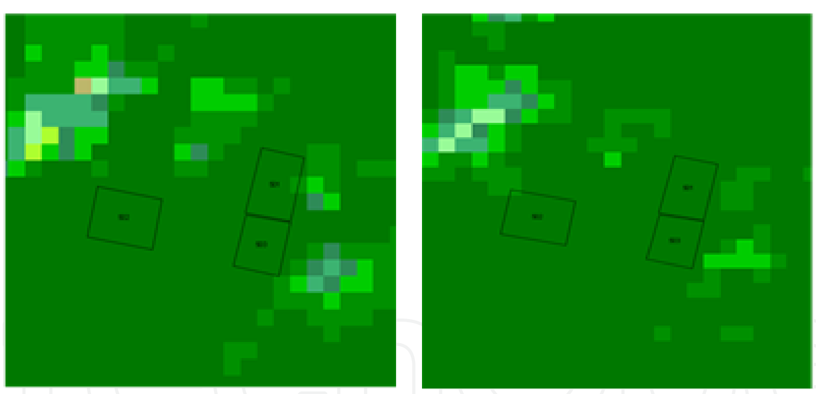
Fig. 5. The eight field sites in Argentina shown overlaying AWIFS imagery (56m resolution).



(a) (b)

Fig. 6. (a) Three digitized field boundaries shown for Marcos Juarez overlaying high resolution AWIFS false color composite. The fields are numbered 501, 502, and 503 for identification purposes (b) Fields in Marco Juarez shown in lower resolution (250m x 250m) color coded fused MODIS imagery for February 1, 2007.

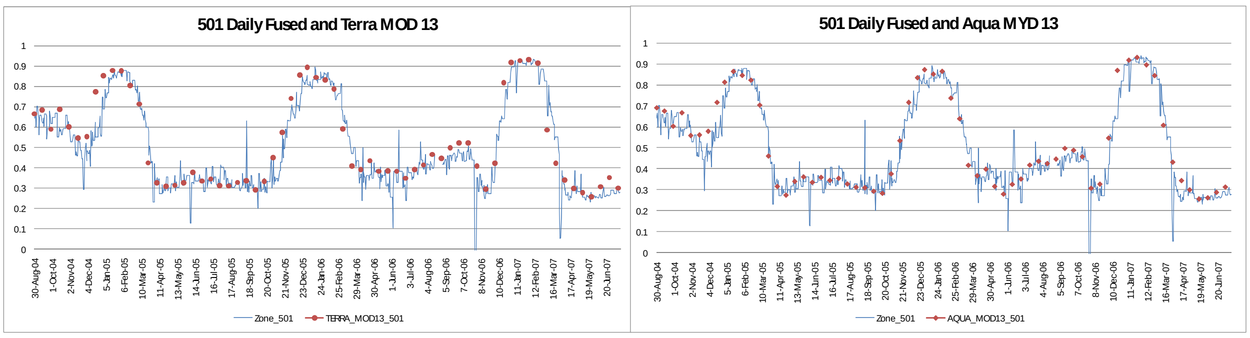
Daily MODIS reflectance (MOD09), Geolocation Angle (MODMGGAD), and Quality Assurance (MODGST) data for the H12V12 tile were acquired for Aqua and Terra MODIS for three years (August 2004-August 2007). These daily Aqua and Terra MODIS datasets were pre-processed to NDVI and associated metadata for quality assurance were computed. The pre-processed daily datasets were then used to compute fused daily NDVI using the multi-sensor and temporal fusion (MSTF). Figure 6 b) shows the fused NDVI product for February 1, 2007 for Marco Juarez with the overlay of three fields in the region.



(a) (b)

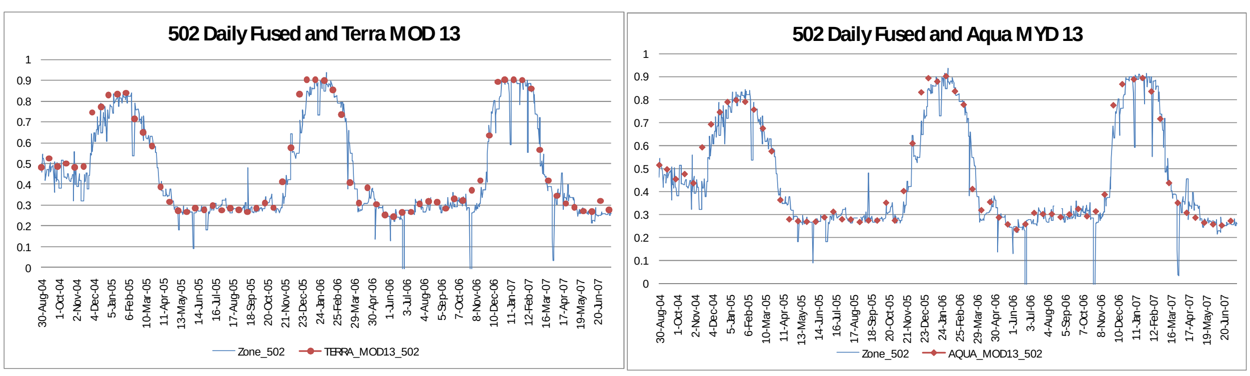
Fig. 7. (a) Color coded Aqua 16-day composite MYD13 NDVI for January 25- February 10, 2007 (b) Color coded Terra 16 day-composite MOD13 NDVI for January 17- February 2, 2007 showing the fields in Marco Juarez. The color mapping is the same as employed in Figure 2.

To quantify the vegetation vigor of a field that is represented by multiple NDVI pixels, an average of all the NDVI pixel values within the area of the field boundary is calculated. After the fusion of the datasets using MSFT, daily average NDVI value for each field was calculated from the fused daily datasets. Using the daily average NDVI values for the field, temporal NDVI signatures were created for each field. The temporal NDVI signatures for three fields in Marco Juarez (fig. 6) are shown in figures 8, 9, and 10. The temporal NDVI signatures represent the phenology curves for the changing vegetation on the field. To make comparisons with standard datasets, average NDVI value were also calculated from 16-day MOD13 standard composites from Aqua and Terra. Figure 7 a) and b) show the MOD13 composites for Aqua and Terra that contain the February 1, 2007 respectively.



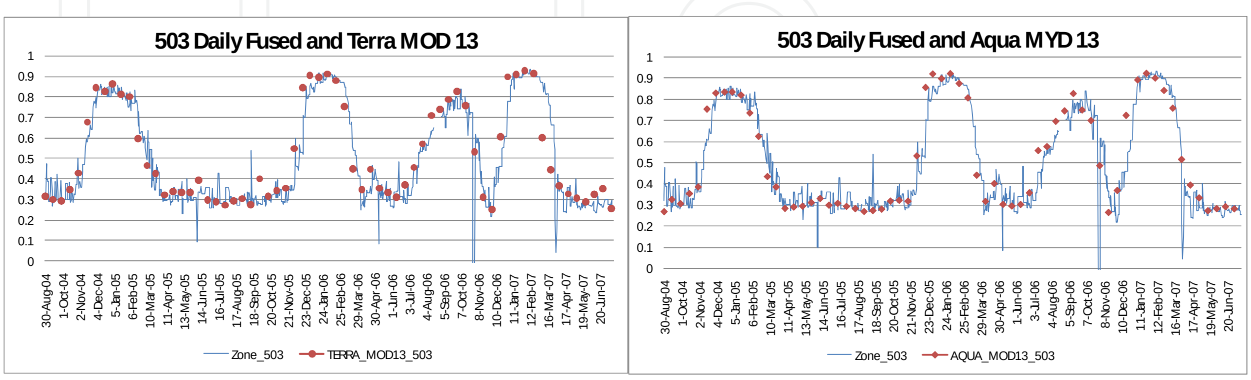
(a) (b)

Fig. 8. Temporal signatures created using fused NDVI for field 501 at Marco Juarez. The red circles on (a) represent mean NDVI for the field from 16 day MOD13 composites from Terra and red squares on (b) represent mean NDVI from 16 day MOD13 composites from Aqua.



(a) (b)

Fig. 9. Temporal signatures created using fused NDVI for a field 502 at Marco Juarez. The red circles on (a) represent mean NDVI for the field from 16 day MOD13 composites from Terra and red squares on (b) represent mean NDVI from 16 day MOD13 composites from Aqua.



(a) (b)

Fig. 10. Temporal signatures created using fused NDVI for a field 503 at Marco Juarez. The red circles on (a) represent mean NDVI for the field from 16 day MOD13 composites from Terra and red squares on (b) represent mean NDVI from 16 day MOD13 composites from Aqua.

In figures 8, 9 and 10, the NDVI temporal signatures using mean NDVI for three different fields in Marco Juarez are presented for August 2004 - July 2007. Also presented are the Aqua and Terra 16 day MOD13 average NDVI values for the fields using the red circles and red squares respectively. In periods outside the crop season, low NDVI values represent fallow conditions when there is little or no greenness or vegetation within the field boundary. At the beginning of the crop season, seeds are planted, crops emerge, leaf area accumulates, and vegetation growth may be monitored by tracking changes and increases in NDVI values. As the crop matures, NDVI values increase, and with higher crop vigor, NDVI values continue to increase up to the maturation stage for the plants at which point leaf growth terminates and observed greenness starts to decrease. Crop harvesting and fallow periods (for out of seasons) are part of the typical cycle for agricultural regions and this phenomena is well represented in 8,9, and 10. The NDVI values for all the fields in the figures exhibit fallow periods between the crop seasons during which vegetation growth can be readily observed for the three (3) year period presented. It can also be seen from the figures that the fused NDVI follows the trend demonstrated by the 16 day MOD13 NDVI composite values. The fused daily NDVI, however, provide a much greater detail of change in NDVI than the 16-day composites.

For field 503 shown in figure 10, for the planting season for 2006-2007, two discreet crop signatures are present as evidenced by the significant and separate increases in NDVI during that crop season. The two readily observed “humps” represent double cropping, which means that two crops were planted during the same season. Typical of management practices in the region, double cropping is usually conducted wherein an early planting of wheat is followed by a late planting of soybean. For the rest of the fields (501 and 502), single cropping practices may be observed across the three years presented.

This use case presents results indicating that MSTF provides unique and previously unavailable capabilities to continuously monitor and analyze crop conditions, development, management practices, maturity, and overall productivity for fields, farms, and regions of agricultural interest. The method of MSTF presented is intended to demonstrate robust results that can be obtained by a simple rule-based implementation of cross-platform fusion. The method presented in no way alters, modifies, or changes observation values. Therefore, for any observation system, there will be noise present that accompanies the desired “signal” portion of the results. The degree of agreement between the MSTF results and standard NASA MOD13 products is remarkable and clearly illustrates the powerful capabilities that MSTF delivers for continuous temporal monitoring of vegetation conditions. Clearly, there are significant opportunities to improve on these results, and this can be readily accomplished by implementing approaches to noise removal. It can be seen from the figures that even on the relatively cleaner fused datasets, there is some noise present in the NDVI temporal signatures. Further research and implementation testing may be conducted to evaluate different filtering methodologies to denoise the temporal NDVI signatures. Approaches that may be readily implemented include simple median filtering, moving-average, or wavelet based denoising (Bruce et al., 2006) or using Savitzky-Golay Filtering (Chen et al., 2004). Regardless of the noise component, the MSTF results presented in this use case clearly illustrate the useful nature of daily products and the utility of this method to deliver needed products for agricultural applications.

5. Conclusion

Vegetation indices, like Normalized Difference Vegetation Index (NDVI), derived from reflectance products of satellite sensors with high temporal resolution (e.g. MODIS) are very useful resource for vegetation monitoring. However, these images frequently include undesired cloud and water cover. Such areas of cloud or water cover preclude analysis and interpretation of terrestrial land cover, vegetation vigor, and/ or analysis of change. Multi-sensor and temporal fusion (MSTF) is a useful tool to perform fusion to remove clouds from NDVI datasets originating from multiple sensors that collect observations at slightly different times of each day across a geographic area of interest (and may be selected for a temporal window of interest). MSTF is performed by using both the reflectance observation data as well as the available ancillary metadata for the available reflectance datasets. The cloud-free daily NDVI composite data products obtained using the MSTF datasets provide an advantage for a wide variety of applications, such as disaster monitoring, vegetation stress monitoring, crop health monitoring, and regional or global bio-productivity modelling that would benefit greatly by the availability of higher temporal resolution NDVI data.

In this chapter, two use case examples were presented clearly showing the utility of MSTF for the fusion of NDVI datasets from Aqua and Terra MODIS. In the first use case, fusion based NDVI products were created and illustrated the usefulness of the process to provide cloud-free image datasets during the time frame of Hurricane Katrina. This use case clearly shows that MSTF provides capabilities of value to vegetation and ecosystem monitoring and change analysis. In the second use case, fusion based NDVI products were used for remote vegetation observation for appropriately sized agricultural fields in Argentina to model and quantify crop growth and development. MODIS NDVI products and field boundaries were employed to extract data that were presented in the form of crop growth phenology curves which are evidence of the ability to show in high temporal detail the stage of growth and maturity of crops. This approach has obvious application to detecting the onset of greenness that may be used to refine estimations of planting date, crop growth status, and maturity. In both of the presented use cases, a 6 day maximum temporal window was chosen. The presented temporal compositing period is provides daily data and can be observed to be highly complementary to standard NASA data sources such as 16 day MOD13 composites. It is also observed that the fused products exhibit the trend of NDVI change the MOD13 composites and provide a greater detail of change in NDVI than the 16-day composites. Here, we have used datasets from Aqua and Terra MODIS which have the same spatial resolution and have same spectral characteristics.

Further studies may be conducted to consider refinements to the MSTF process. The easiest pathway to improved products lies in considering and evaluating methods to remove noise and enhance the signal component of MSTF products. More challenging improvements may be considered aimed at increasing the richness of MSTF products by evaluating how best to include in MSTF processing data streams from additional sensors with different spectral, spatial, and temporal characteristics. In all MSTF provides a new set of capabilities for improving capabilities to observe the dynamic and changing conditions of the earth's surface. This data fusion approach offer major opportunities for extensible and highly transferable application as well as operational implementations to meet a broad variety of earth science and societal needs.

6. Acknowledgements

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Data fusion is a research area that is growing rapidly due to the fact that it provides means for combining pieces of information coming from different sources/sensors, resulting in ameliorated overall system performance (improved decision making, increased detection capabilities, diminished number of false alarms, improved reliability in various situations at hand) with respect to separate sensors/sources. Different data fusion methods have been developed in order to optimize the overall system output in a variety of applications for which data fusion might be useful: security (humanitarian, military), medical diagnosis, environmental monitoring, remote sensing, robotics, etc.

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