Use and Analysis of Temporal Map Algebra for Vegetation Index Compositing

Preeti Mali, Charles O' Hara, Bijay Shrestha and Veeraraghavan Vijayaraj
GeoResources Institute, Mississippi State University
Mississippi State, MS 39762

Abstract— **Temporal image cubes are created using co-registered temporal image data sets as ordered stacks of bands within a multi-band image. These may be manipulated and analyzed using new temporal map algebra (TMA) functions that extend normal raster map algebra from operating on a single raster band to operating on one, many, or all bands within the temporal image cube. Temporal image cubes can be constructed to encode attribute information such as image quality, scan angle, or other attribute per each pixel. Multiple cubes may be utilized to manipulate image data and generate model-specific results. Low resolution imagery such as NOAA-AVHRR and MODIS require the use maximum value compositing (MVC) that consider local pixel values in time series multi-temporal NDVI image cube. Using temporal map algebra multiple criteria may be imposed on attribute cubes to create masks cubes that can select from temporal image cubes only those specific pixels that meet scan angle, quality, or other user-defined criteria. After reducing the image data to only the desired pixels, local and focal functions may be employed to create custom composites for specific temporal intervals.**

Index Terms— **Map Algebra, Temporal image cube, Temporal Map Algebra, Vegetation Index Compositing**

I. Introduction

Compositing can be described as a process in which a multi-temporal set of image datasets are used to obtain a single representative image dataset for a given time period. It is especially useful for vegetation monitoring as vegetation studies do not require daily monitoring. Therefore, composite image representing weekly, bi-weekly or monthly vegetation activity is usually sufficient.

The compositing process is generally used for vegetation index images with high temporal and low spatial resolution such as Advanced Very High Resolution Radiometer (AVHRR), Moderate Resolution Imaging Spectroradiometer (MODIS) etc. The images from these satellites usually have cloud cover due to wide area coverage. Therefore such satellite images require a compositing process to obtain a cloud free image representative of a given time period. Vegetation index such as normalized difference vegetation index (NDVI) have low values for cloud pixels and by selecting pixels with high NDVI values, the compositing process is able to omit the cloud pixels and cloudless composites can be obtained. The process of selecting pixel with high NDVI value for compositing purposes is known as maximum value compositing (MVC).

For performing MVC over a temporal range, usually a map algebra function called 'local maximum' is used. Tomlin has defined map algebra as an approach to raster data handling which treats spatial data layers as variables which may be combined using mathematical operators [1]. 'Local maximum' uses a local map algebra function in which the value of cells in an output image is represented by the maximum value among the cells in the corresponding element position of the multi-temporal set of images. This method has been used effectively in vegetation index compositing processes [2, 3].

In contrast to traditional map algebra where map algebra functions are usually applied in two dimensions, temporal map algebra (TMA) allows the map algebra functions to be applied in three dimensions. Therefore, it has also been termed as 3-dimensional map algebra or multi-dimensional map algebra [4]. The main difference between the conventional map algebra and the temporal map algebra is the dimensions in which mathematical or statistical functions can be operated. Hence, temporal map algebra provides more analysis capability for multi-temporal images by extending the space so that spatial and temporal analysis can be performed together.

Temporal map algebra has been used previously for multi-temporal analysis. Mennis and Viger used temporal map algebra for determining the El Niño/Southern Oscillation (ENSO) effect on southern African vegetation intensity over different land cover types [4]. The temporal map algebra function assisted in effectively obtaining the ENSO effects over various land cover from a time series NDVI datasets using a zonal function for a given multi-temporal dataset. The study concluded that the use of "cube function approach" assisted in implementation of temporal map algebra functions.

In this research temporal map algebra has been used for vegetation index compositing of AVHRR and MODIS datasets. The results from temporal map algebra compositing have been compared with traditional compositing results. The main objective of using temporal map algebra for vegetation index compositing is to obtain improved capabilities to perform compositing process on a multi-temporal datasets such as a time-series NDVI and extract the required information effectively.

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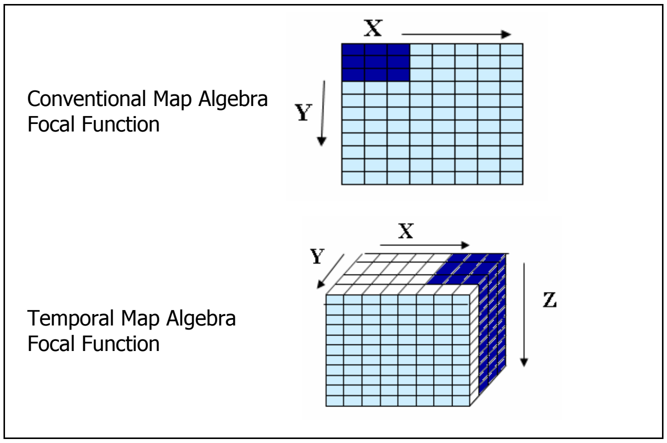

Fig.1. In the conventional map algebra-focal function, the center pixel value is the result of neighboring pixels; in Temporal Map Algebra, the focal function can compute the value of center pixel based on any number of time step (z). A multi-temporal or time series dataset can be represented as a 3-dimensional image cube in which X, Y and Z represent image rows, image columns, and time respectively.

II. Datasets Used

NOAA-17 AVHRR level 1B datasets were downloaded from NOAA-NESDIS website. Level 1B dataset are packed raw datasets with full resolution (approx 1km) in which calibration coefficients and earth location information are included but not applied in the datasets [5].

Similarly, MODIS AQUA level 2G datasets with 250 meter resolution were downloaded from Land Processes – Distributed Active Archive Center (LP-DAAC) website for our study area. Along with the image datasets quality datasets, sensor and solar angles datasets related with images for each day were also obtained. The study area chosen for our research are the states of Mississippi and Arkansas.

III. Preprocessing

The MODIS Level 2G images downloaded from LP DAAC were already radiometrically, atmospherically and geometrically corrected. The projection for the images was changed from World Sinusoidal to Universal Transverse Mercator (UTM) projection, Zone 15, WGS 84 Datum. The projected images were then subsetted to the boundaries of Mississippi and Arkansas.

In the case of AVHRR, the images were not pre-processed; therefore the level 1B images were unpacked and processed. The images were radiometrically calibrated in which the visible channels were converted into top of the atmosphere reflectance and thermal channels were converted to brightness temperature [6]. The atmospheric correction was done using Simplified Method for Atmospheric Corrections (SMAC) model which corrected for aerosol optical thickness, ozone content, water vapor, surface pressure [6, 7]. The bidirectional reflectance factor (BRDF) is corrected for the images using model for crop surface type [6, 8]. The atmospherically corrected images were then geometrically corrected using the GCP provided in the datasets. The corrected images were projected to UTM projection, Zone 15, WGS 84 Datum. And similar to MODIS datasets, the pre-processed AVHRR datasets were also subsetted to the boundaries of Mississippi and Arkansas.

IV. Methodology

The preprocessed AVHRR and MODIS images were converted to normalized difference vegetation index (NDVI) images. The NDVI was calculated using the following relation:

$$NDVI = \frac{NearIR - \mathrm{Re}\,d}{NearIR + \mathrm{Re}\,d} \qquad (1)$$

The NDVI value ranges from -1 to +1; the value increases from -1 to +1 with the increase in vegetation. The clouds are in the lower end of the NDVI value range. Therefore, vegetation index compositing using NDVI is effective for cloud removal when maximum NDVI condition is applied in the time series NDVI.

The vegetation index compositing using maximum value condition is usually coupled with scan angle or zenith angle constraint. The view angles are used in MVC to select pixels near nadir during the compositing process. The maximum value compositing process tends to select off nadir pixels during compositing process [9]. Therefore removing the pixels with large angle values is required. The view zenith angle was available with the obtained dataset. The scan angle was calculated using the view zenith angle dataset [10]. The following relation was used to calculate the scan angles:

$$\text{Scan angle} = \arcsin[\sin\lambda(\frac{R_e}{R_e + S_h})] \qquad (2)$$

λ = Satellite Zenith angle, R_e = Radius of the earth (~6378 km), S_h = Satellite Height (850km for NOAA AVHRR)

Similarly, the compositing process also requires attention to pixels with solar zenith angle greater than 80 degrees. The AVHRR data pixels with large solar zenith angle are considered to have value errors [9]. The solar zenith dataset was searched for pixels with solar zenith values greater than 80 so that those pixels can be removed.

In the traditional approach, a local maximum function is used in a multi-temporal dataset. Instead of using just the local maximum, the temporal map algebra is able to extend the maximum value search from a single pixel based temporal search to a focal window based three dimensional searches to obtain the resultant composite image [See Fig. 1.]. The time steps can be any number depending upon the composting period selected.

The temporal map algebra algorithm used in this research uses a time-series NDVI that can be considered as an NDVI cube dataset. Similarly, a view angle for each image of NDVI cube is used forming a view angle cube.

For AVHRR, the algorithm masks out the NDVI values that have scan angle of greater than 42 degrees in the scan angle cube; hence, the masked NDVI cube consists of only those NDVI values that have less than 42 degrees of scan angle.

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In the case of MODIS, the difference from the compositing method used in AVHRR is the addition of surface reflectance quality cube, and the use of view zenith angle cube instead of scan angle cube. The NDVI values with view zenith angle greater than ± 55 were masked out from the NDVI cube [11]. The surface reflectance quality cube has been derived from the quality image datasets obtained from LP-DAAC. The information content from the original quality dataset was recoded to represent various cover types which are cloud, land (good data), water, snow and no data values. Only land or good data values were used for NDVI compositing process.

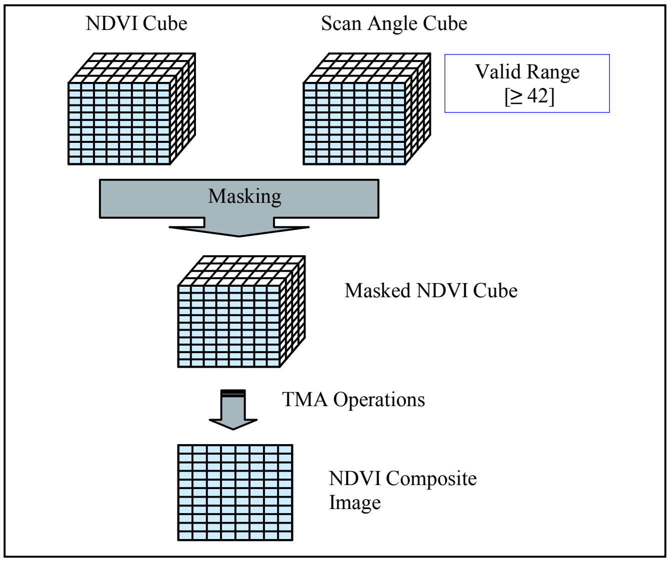

Fig. 2. Schematic Representation of Multi-temporal compositing process for AVHRR.

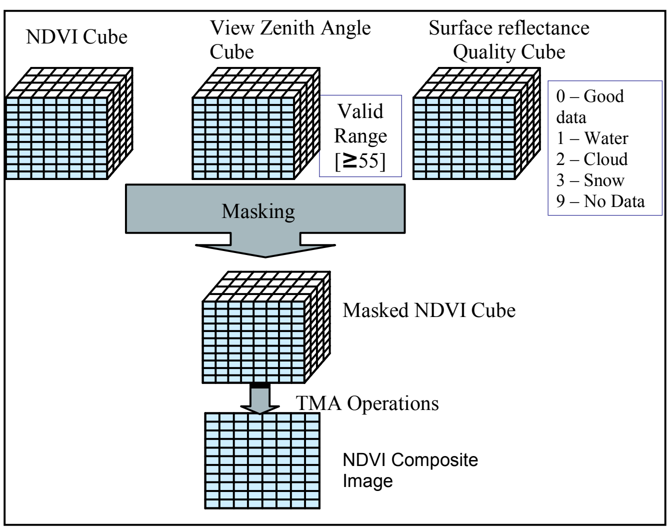

Fig. 3. Schematic Representation of Multi-temporal compositing process for MODIS.

V. ANALYSIS

The MODIS and AVHRR composites for the month of May 2004 were analyzed. Three compositing periods of 14 days each were selected within the month of May. The compositing periods are May 05 to May 18, May 12 to May 25, and May 19 to June 1. The following compositing methods were computed for both MODIS and AVHRR:

1. MVC using Angle Constraint for AVHRR: Traditional Local max and TMA based Focal Max

2. MVC using Angle Constraint for MODIS: Traditional Local max and TMA based Focal Max

The obtained compositing results were then compared with reference image. A reference image is a cloudless image during the compositing period. For the whole month of May only one cloudless image was available on the date of May 7, 2004 for AVHRR and only for two dates (May 5, 2004 and May 6, 2004) for MODIS. Therefore, the results could be compared for only one compositing period of May 05-May 18 for both MODIS and AVHRR.

For the compositing period in which the reference image was available, Mean Square Error (MSE), Root Mean Square Error (RMSE), Correlation Coefficient, Mean Difference (%) along with general statistics (mean, standard deviation) was calculated. The result obtained from the comparison is shown in the tables below.

VI. RESULTS AND DISCUSSION

Visual inspection as well as mean statistics (comparing with reference image) showed some saturating effect on focal max based composites with values on the higher ranges of NDVI relative to the values in local max composites. Some amount of averaging affect due to the use of focal window was also observed. In the MODIS composites, some striping effect could be seen, which seem to be due to the zenith angle constraint. Further studies on the angle constraint are being performed to remove such striping. The statistical results from the analysis of the reference and the composite images show that the MSE, RMSE and Correlation Coefficient values do not differ substantially between the focal and local max composite methods.

TABLE I
MSE, RMSE AND CORRELATION COEFFICIENT VALUES BETWEEN COMPOSITE AND REFERENCE IMAGE.

AVHRR May 05 – May 18	**MSE**	**RMSE**	**Correlation Coefficient**
Local max	0.0201	0.1417	0.9621
Focal max-TMA	0.0215	0.1466	0.9723
MODIS May 05 – May 18	**MSE**	**RMSE**	**Correlation Coefficient**
Local max	0.008	0.0894	0.9906
Focal max-TMA	0.0299	0.173	0.9722

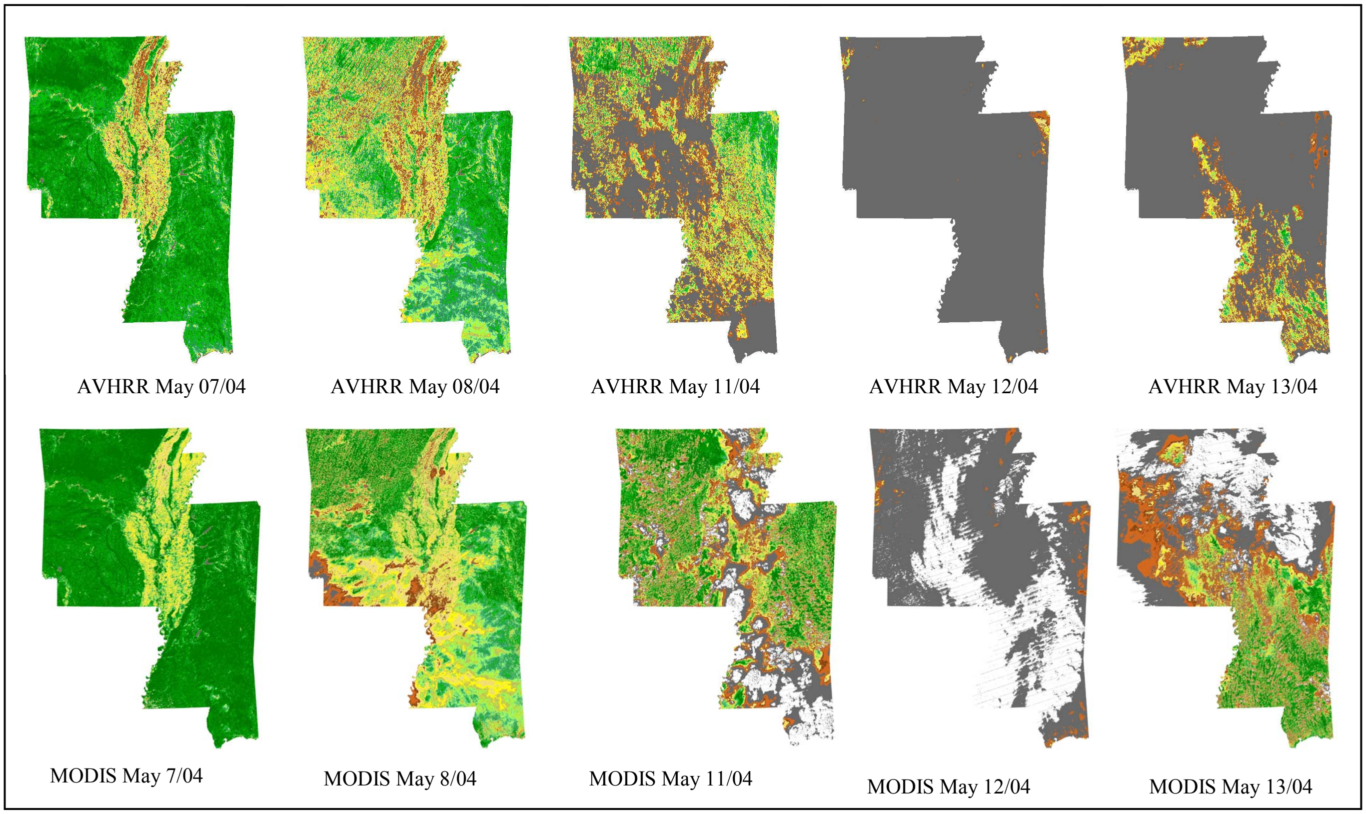

Fig. 4. Some examples of cloud covered daily dataset for AVHRR (1km) and MODIS (250m) within the temporal range of May 05- May 18. Grey Color shows cloud cover, the low NDVI values are in orange and yellow colors, the increase in NDVI is shown by increase in darkness of green color. In MODIS datasets the white color represent the 'No Data' values.

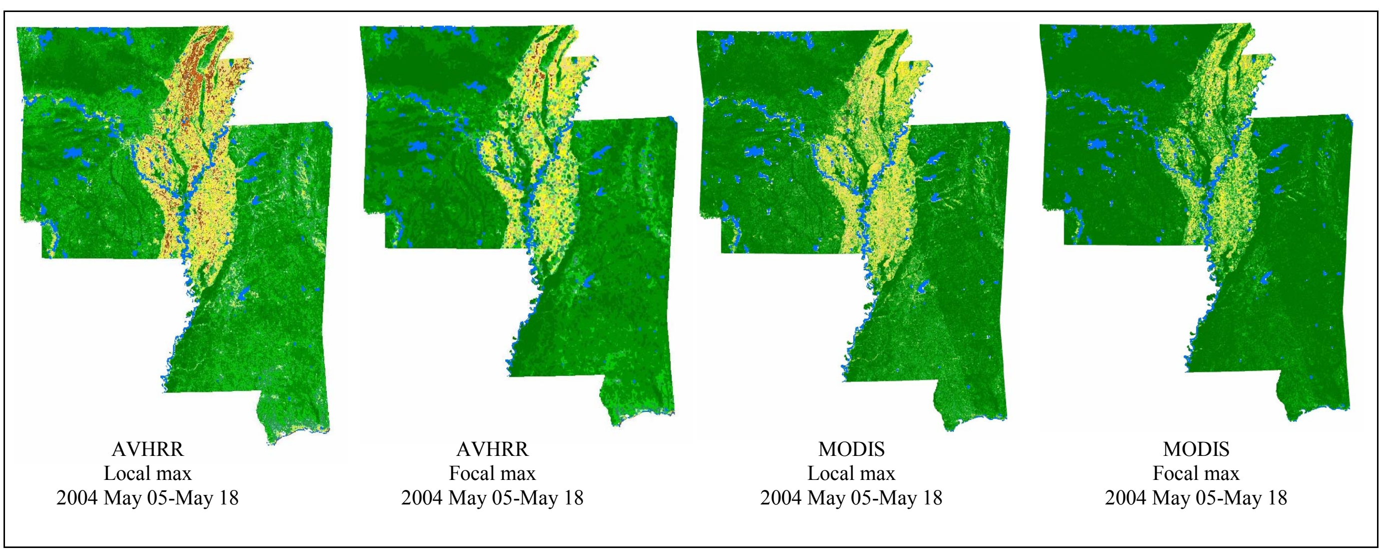

Fig. 5. Biweekly AVHRR and MODIS Composites for Mississippi Arkansas Study Region for period of May 05-May18, 2004. The color mapping is similar as in Fig.4.

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Even though the differences are not substantially conspicuous, on comparison of the correlation coefficient in AVHRR, the focal max (TMA based) had higher correlation with the reference image than the local max. In the case of MODIS, the results were different. The local max method had high correlation than TMA based focal max method in MODIS. The contrast between the MODIS and AVHRR could be due to lack of good geometric accuracy in the GCP's related with the AVHRR dataset. The MODIS dataset had more geometric accuracy than AVHRR hence the lack of geometric accuracy in AVHRR could have resulted in the higher correlation coefficient in the focal max composites.

TABLE II
GENERAL STATISTICS AND MEAN DIFFERENCE % VALUES BETWEEN COMPOSITE AND REFERENCE IMAGE

AVHRR May 05–May 18	**Max**	**Min**	**Mean**	**Std. Dev**	**Mean-Difference%**
Local max	0.919192	-0.136283	0.658762	0.203524	1.92063718
Focal max-TMA	0.919192	-0.124752	0.738559	0.16341	14.26646327
MODIS May 05–May 18	**Max**	**Min**	**Mean**	**Std. Dev**	**Mean-Difference%**
Local max	0.999687	-0.826866	0.737394	0.193814	7.626919501
Focal max-TMA	0.999687	-0.59309	0.807974	0.158367	17.92847875

On comparing the RMSE and MSE calculated between composite and reference images, in both MODIS and AVHRR, local max composites had lower values than focal max. Similarly in the case of mean difference (%), the local max composites had lower percentage difference from reference image than TMA based focal max composites for both MODIS and AVHRR.

TABLE III
REFERENCE IMAGE STATISTICS FOR MODIS AND AVHRR

REFERENCE IMAGE	**Max**	**Min**	**Mean**	**Std. Dev**
AVHRR May 07, 2004	0.919192	-0.571429	0.646348	0.218813
MODIS MAY 06, 2004	0.998975	-0.890756	0.685139	0.205631

VII. CONCLUSIONS

After analyzing the results, we can conclude that the TMA based focal max compositing process is able to produce cloud free composites. Even though the comparison results did not show large difference in values, local max seemed to perform consistently better than focal max. However, due to the low difference in values obtained in MSE, RMSE and Correlation Coefficient, further analysis need to be performed before reaching into substantial conclusions. The results presented in this paper shows that even though the results from focal max compositing (TMA based) are not significantly substantial, the obtained results can be leveraged with the conventional and established local max process. Further analysis and refinements are planned for the temporal map algebra based compositing process.

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