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Quality Assurance of Global Vegetation Index Compositing Algorithms Using AVHRR Data

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Abstract -- In this study the quality control aspects of the vegetation index produced by the MODIS (MODerate resolution Imaging Spectroradiometer) algorithm were evaluated and compared with the results of the currently used maximum value composite (MVC), which chooses the highest NDVI (normalized difference vegetation index) over a certain time interval. The composite scenarios were evaluated with respect to: 1) quality flags related to data integrity, cloud cover and composite method, 2) temporal evolution of the VI for different continents and vegetation cover types, and 3) accuracy of the standardization of reflectance values to standard view angles (nadir). On a continental scale the composited NDVI results from the MODIS algorithm were 1 to 24% lower than the off-nadir NDVI results based on the MVC criteria. A simple BRDF (Bidirectional Reflectance Distribution Function) model was adequate to produce nadir equivalent reflectance values from which the NDVI could be computed. The temporal evolution of the NDVI derived with the MODIS algorithm was similar to or smoother than the NDVI derived from the MVC algorithm. The composite method applied in the MODIS algorithm, was dependent on the global position and season, e.g. the BRDF interpolation was most frequently applied in arid and semi-arid regions and during the dry season over tropical rain forests. Examples of a global NDVI and quality flags were displayed using a pseudo color bit mapping scheme.

INTRODUCTION

A vegetation index composite scenario was developed for the MODIS sensor in the MODIS (Moderate resolution imaging spectroradiometer) framework to minimize effects of cloud cover, atmosphere, bidirectional reflectance factors (BRF) and spatial distortions, while maintaining the finest spatial resolution [1].

MODIS Compositing Objectives

- Provide accurate and cloud-free vegetation index (VI) imagery over set temporal intervals.
- Maximize global and temporal land coverage at the finest spatial and temporal resolutions possible.
- Standardize variable sensor view and sun angles.
- Ensure the quality and consistency of the composited data.
- Depict and reconstruct phenological variations.

MODIS Angular Considerations

- Sensor view angles vary +/- 55° cross track.
- Solar zenith angles may vary up to 20° across an image.
- Solar zenith angles vary with latitude and day of year.
- The NDVI tends to increase with both larger view and larger solar zenith angles.
- The pixel size is increasing with view angle (whiskbroom).

Current AVHRR Maximum Value Composite (MVC) Approach and MODIS Considerations

The MVC selects maximum NDVI values on a per pixel basis over set compositing periods and is designed to minimize atmospheric effects, including residual clouds. However, the MVC becomes inconsistent and unpredictable over anisotropic vegetated canopies. Pixel selection is biased toward large view angles in the forward scatter (shaded) view direction and large solar zenith angles. The MVC becomes even less appropriate with atmospherically-corrected data sets.

Therefore, the MODIS compositing criteria need to be weighted more toward angular considerations. This is done by incorporating a BRDF compositing approach, which has the goal to standardize the VI to nadir view and constant solar angles. The purpose of the nadir view approach is to achieve the finest spatial resolution and detail. It also has the most accurate atmospheric correction. Furthermore, validation of VI - biophysical relationships will generally be coupled to nadir view in the field and nadir Landsat-7 observations. Finally, VI - saturation problems decrease for nadir view angle observations.

MODIS VI COMPOSITING ALGORITHM

Daily, global 8 km Pathfinder AVHRR (Advanced very high resolution radiometer) data were processed to prototype the MODIS and MVC vegetation index algorithms for the MODIS era. The version 1 (V1) MODIS algorithm selects the reflectance data for a 16-day period, based on data integrity and cloud flags, and applies a BRDF (bidirectional reflectance distribution function) model to the individual band data (if more than 4 data points are of good quality) to standardize the reflectances to nadir view angles. The accuracy of the BRDF algorithm was evaluated through temporal NDVI profiles. Nadir interpolated values were rejected when the resulting NDVI was higher than the MVC based NDVI. Since not all pixels had more than 4 cloud-free data points during a 16-day period, a back-up algorithm was used which selected the highest NDVI for two, cloud-free, view angles closest to nadir. If all data during a 16-day period was affected by clouds, based on the cloud flags, the MVC criterion was applied. The empirical Walthall BRDF model is [2]:

$$\rho(\theta_v,\phi_s,\phi_v)=a\theta_v^2+b\theta_v\cos(\phi_v-\phi_s)+c \quad (1)$$

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where the reflectance ρ is a function of the view zenith angle (θ_v), and sun (ϕ_s) and view (ϕ_v) azimuth angles. a, b and c are coefficients obtained using a least squares curve fitting procedure, "c" is equal to the reflectance at nadir. The BRDF model was inverted, after which nadir-equivalent reflectance and NDVI values were derived using forward modeling. Back-up algorithms were: 1) the constraint view angle MVC (CV-MVC; MVC based on two cloud-free observations with the view angles closest to nadir) and 2) the MVC algorithm (MVC; MVC will choose the maximum NDVI value based on all observations without considering the quality).

The current quality control (QC) flags for a global NDVI composite using a BRDF approach include 8 flags/bits related to: data integrity (1); land/water mask (2); the composite approach applied (3-5) (BRDF, CV-MVC, MVC); and the cloud mask (6-8) (cloudy, mixed cloudy/clear, shadow).

RESULTS AND DISCUSSION

Figs. 1 and 2 are prototypes of the global MODIS NDVI and QC product. Notice that the BRDF correction is limited to the semi-arid/arid regions. An increased number of BRDF corrections might be obtained using longer time steps and spatially aggregated observations, while taking into account the land cover type. Fig. 3 shows seasonal profiles of the current version 1 (V1) MODIS-NDVI and the MVC-NDVI for each

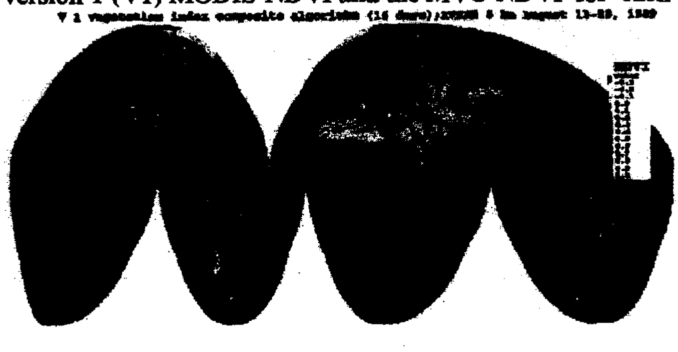

Fig. 1, Global NDVI image (pseudo color) using the MODIS VI composite algorithm (BRDF/ CV-MVC/ MVC approach).

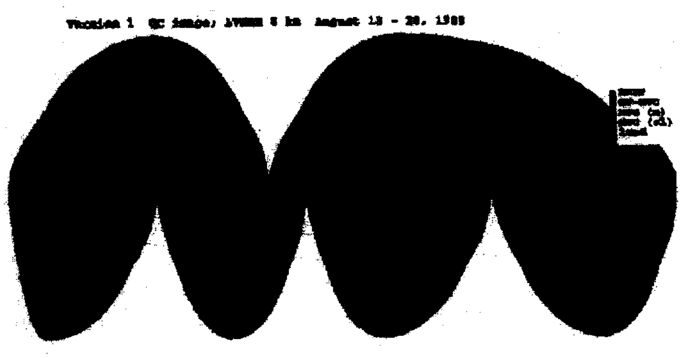

Fig. 2, Color coded quality control flags for a Global NDVI composite using a BRDF approach (MODIS V1); red=BRDF composite method applied; green=CV-MVC; blue =MVC; (m) mixed cloud/clear, (cl)=cloudy pixels; gray=land; black=water.

continent. Fig. 4 indicates the relative difference (ranging between 1 and 24 %) between the MVC derived NDVI and the MODIS derived NDVI for each continent and all 16-day composite periods during the 1989 AVHRR observations. An example of the quality of the NDVI product is illustrated in Fig. 5, where the fractions of pixels for which the NDVI was derived from either BRDF, CV-MVC or MVC part of the MODIS algorithm were given as function of time/season. In Fig. 6, the temporal profiles of the MODIS-NDVI and MVC-NDVI are compared. NDVI estimates from the MVC approach are always higher or equal to the MODIS approach. The peak of the growing season is also different for the examples in Fig. 6. The view angle distribution for the MVC algorithm is more biased towards the forward scatter direction than for the MODIS algorithm (Fig. 7). Notice the strong peak at nadir view angles due to the BRDF standardization of the reflectance factors to nadir. Future research will address more effective ways of standardizing reflectance observations with BRDF models to increase the spatial representation on a global scale.

CONCLUDING REMARKS

- A simple BRDF model and few observations (≥ 5) per pixel were needed the standardize the NDVI to nadir view angles (VIs behave anisotropic).
- The Walthall BRDF model was successfully used in global AVHRR/NDVI composite scenarios.
- Backup composite algorithms were needed for the pixels with limited number of observations (BRDF model can not be inverted with limited observations).
- On a continental scale, the composited MVC-based off-nadir NDVI results were 1 to 24 % overestimated compared to the NDVI results from the MODIS algorithm.
- A BRDF approach is more representative of vegetation changes over a 16-day period than the MVC approach.
- A BRDF scenario automatically extrapolates to finer spatial resolutions.
- The MODIS- BRDF approach had few spatial discontinuities (AVHRR, 8 km).

ACKNOWLEDGMENTS

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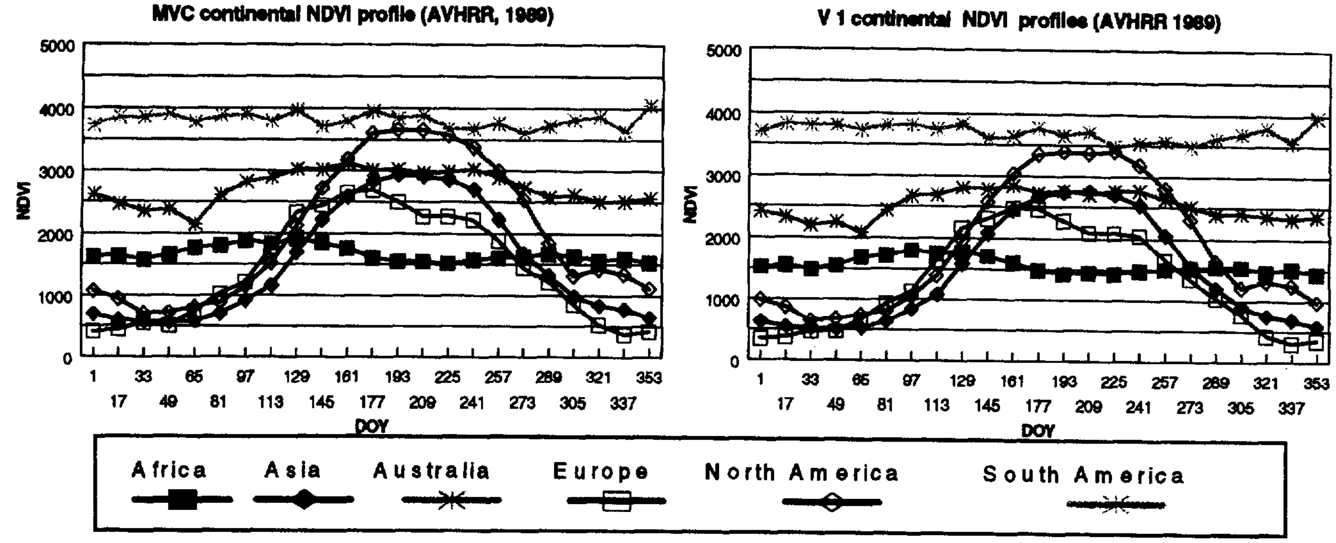

Fig. 3, Continental NDVI profiles for the current (V1) MODIS composite algorithm and MVC algorithm; AVHRR (8km).

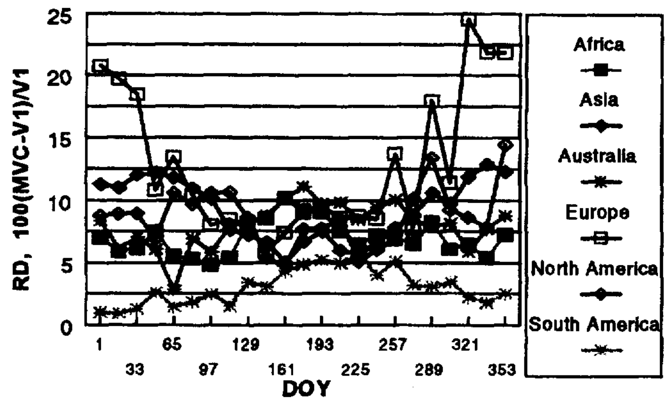

Fig. 4, Percent relative difference between MVC and V1 MODIS derived NDVI for 16-day composite periods (1989).

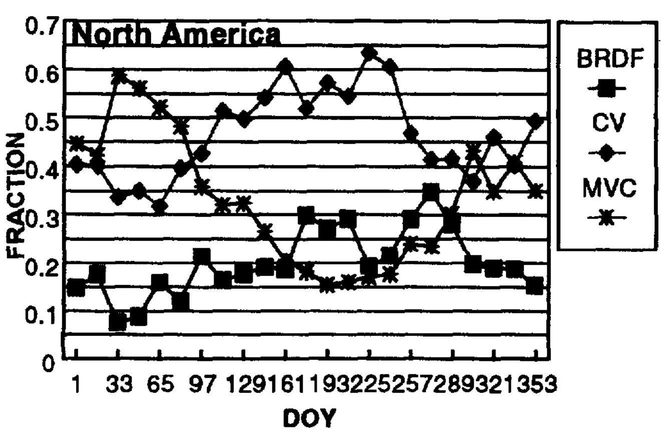

Fig. 5, Temporal profile of the fractions of pixels (North American continent) where the BRDF, CV-MVC or MVC was used as part of the MODIS composite algorithm.

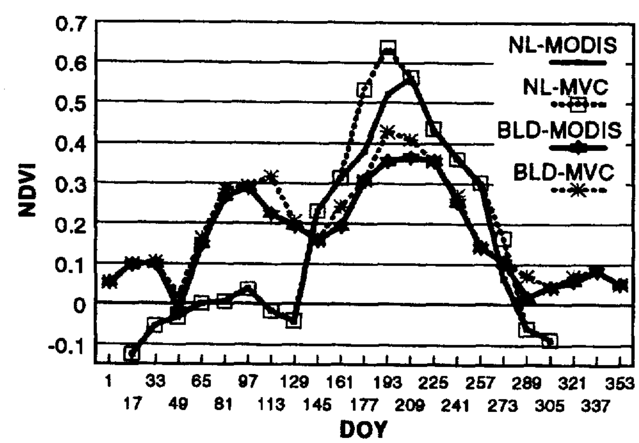

Fig. 6, Temporal profile of NDVI for needleleaf (NL; Lat. 63.2°N, Long. 92.7°E) and broadleaf deciduous (BLD; Lat. 32.0°N, Long. 115.5°E) forest for the MODIS V1 and the MVC composite approaches.

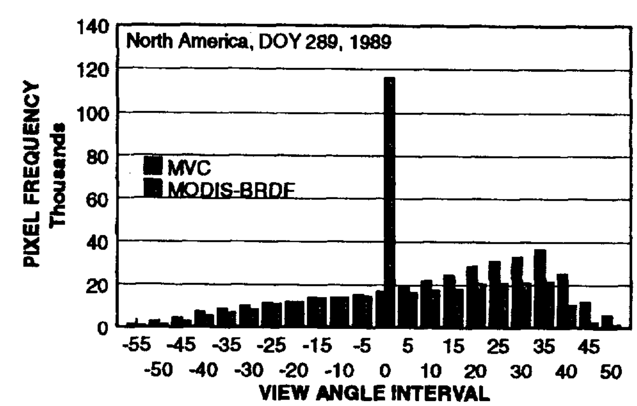

Fig. 7, View angle distribution for North America for a 16-day composite period for the MODIS V1 and MVC algorithms.