Applications of VEGETATION data to resource management in arid and semi-arid rangelands

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1 Context and objective

Arid and semi-arid rangelands with low vegetation coverage show rapid changes due to climate and human activities. Unfortunately, empirical or physical methods to estimate vegetation parameters as biomass or coverage by satellite are difficult to use due to external parameters as atmosphere, view and solar angles, structural parameters of vegetation, soil effects and land use.

The objective of this contribution to the VEGETATION Preparatory Programme is to assess the feasability of using VEGETATION data to improve rangeland management in arid regions, using in-situ ground measurements and rangeland information databases.

This project is quite ambitious as it tends to obtain, not only scientific understanding of how remote sensing products like VEGETATION imagery could be used in an innovative way of inferring physical properties of rangelands, but also improved understanding the needs of end users (rangeland managers, local institutions …), and their insights of what remote sensing products should be.

In this paper, we first show results on the validation of VEGETATION based surface reflectance and vegetation indices by comparing ground or model based ones. Then, the ability of VEGETATION based reflectance and Vegetation Index to track vegetation biophysical parameters is assessed. Finally, we investigate the best strategy for using VEGETATION data to assess improved information on vegetation and soil and for helping in the future regional management decisions. At this end, an example of evaluation of the VEGETATION products by potential users is presented.

2 Study sites and measurements

For this study, two contrasted grassland sites were identified. One is the grassland plateau of southwest United States and northern Mexico (San Pedro Basin) mainly composed of perennial plants. This basin was the study area of the SALSA experiment (Goodrich et al., 2000). The other site is the Sahelian part of Niger, composed of annual species.

In Niger, biomass sampling was made according to a methodology adopted since 1987 by the Ministère de l'Elevage. It consisted in 60 estimated quadrats (visual estimation) of 0.5m², of which about 10 were clipped and measured (dry biomass and species composition), sampled along a random pattern assigned permanently for each 3km per 3km ground truth sites. The Ministère de l'Elevage proceeds to these measurements once (at the peak of biomass) or twice a year on 40 ground truth sites in the pastoral zone of Niger. For this VEGETATION project, we add to the protocol 6 ground truth sites located on the Ekrafane ranch (15°15' N; 3°50'E). These additional sites were measured 3 times throughout the 1997, 1998 and 1999 rainy seasons.

Vegetation characteristics (green and dead biomass, leaf area-index, floristic composition, density of clumps, total vegetation cover etc.) have been taken during the monsoon season of 1998 (dry year) and 1999 (wet

year) on Mexican sites in Sonora (Mexico) and on American sites in Arizona. The experimental protocol, which was similar both sides of the US-Mexico border, consisted of sampling 10 plots of 1m² each along a transect of about 1 km. This protocol was repeated 3 or 4 times during the monsoon seasons (one during each stage of the vegetation growth).
In 1998 and 1999, ground based BRF data were collected over Zapata site (110°15'49''W, 31°14'09''N, 1435 m of altitude) once a week throughout the growing season. We used a field radiometer (EXOTECH with 15° field of view) equipped with the TM bands (no SWIR band was available in 1998) measuring the radiance of the same spot at several view angles (namely from -45° antisolar to +45° forward scatter), at different sun angles for each day. In 1998, ground BRF data provides a large sample of view-sun angle configurations, it lacks appropriate representation of the spatial variability. In 1999, ground BRF data were collected over 10 plots along the same 1 km transect of the vegetation sampling using a radiometer equipped with VEGETATION filters.

3 Validation of VEGETATION data

We first validate VEGETATION based surface reflectance in RED, NIR, SWIR and vegetation indices (NDVI, and VI integrating SWIR band) by comparing them to ground or model based ones.

Daily VEGETATION data acquired from April 1998 to November 1999 was processed at CESBIO in the framework of Dedieu's project. A VEGETATION dedicated version of SMAC (Berthelot and Dedieu, unpublished) was used to apply atmospheric correction. Water vapour fields at 1x1° resolution were derived from atmospheric analysis of the French weather forecast operational model available every 6 hours. This procedure for atmospheric correction is the same being now used for the operational processing of VEGETATION data. View and sun effects on VEGETATION based data were normalised following the approach described in Wu et al. (1995). Finally, green and dry leaf area index, spectral properties of the soil and the vegetation were used in conjunction with SAIL model simulated surface reflectance in RED, NIR and SWIR as "seen" by VEGETATION sensor during the 1998 and 1999 seasons (Cayrol et al., 2000).

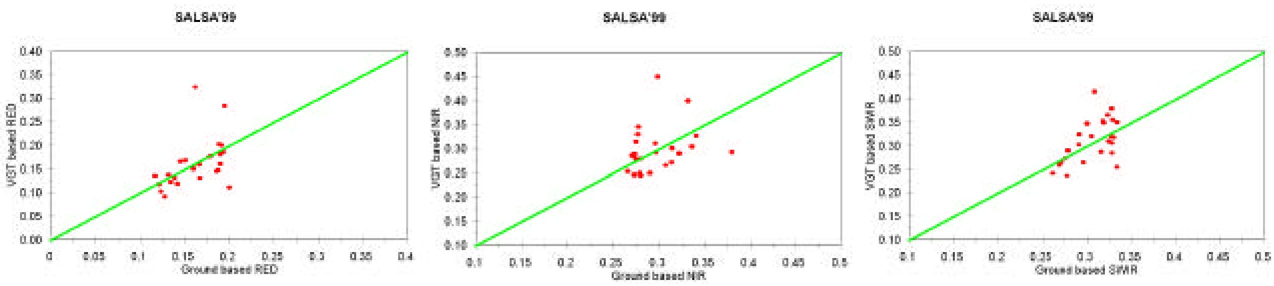


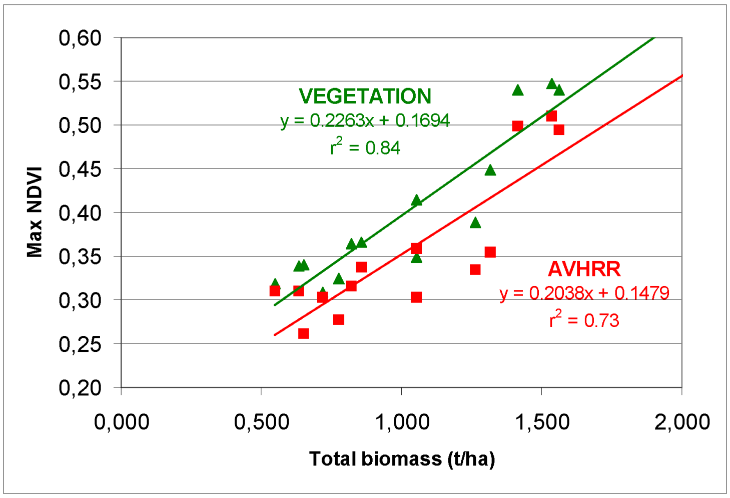
Figure 1 : Comparison between ground based and VEGETATION based reflectances corrected for atmosphere, view and sun angle effects.

Figure 1 presents, for the 1999 season, a validation of the corrected VEGETATION data. One can say that beside the limitation associated with input data for atmospheric correction and that inherent to any "parametric" directional model, VEGETATION data compared fairly well with observations.

4 Estimation of surface biophysical parameters

4.1 VEGETATION derived products

An empirical relationship between integrated NDVI from MVC on decades with AVHRR and total dry biomass is usually applied to produce biomass maps on Sahelian region. Different NDVI indicators were tested: maximum of NDVI, integrated NDVI up to maximum, integrated NDVI up to maximum plus one decade to two decades more, from vegetation started date, integrated minus minimum.



The same protocol was applied to VEGETATION data during the rainy season in 1999. The best indicator was the maximum of NDVI, but small differences only exist between these indicators. With the same set of ground data, the r² indicate an improvement with VEGETATION compared to AVHRR data (Figure 2). Using this relationship, a biomass map was derived from VEGETATION data (Figure 8).

Figure 2 : Comparison of biomass estimation using NOAA-AVHRR and VEGETATION data (Niger sites, 1999).

The difference between AVHRR and VEGETATION data comes mainly from resolution and registration quality. Figure 3 presents a multitemporal classification using AVHRR and VEGETATION data during the rainy season in Niger, on vegetated dunes landscape in the north of Niamey. Pattern is better identified with VEGETATION data and more vegetation classes are discriminated.

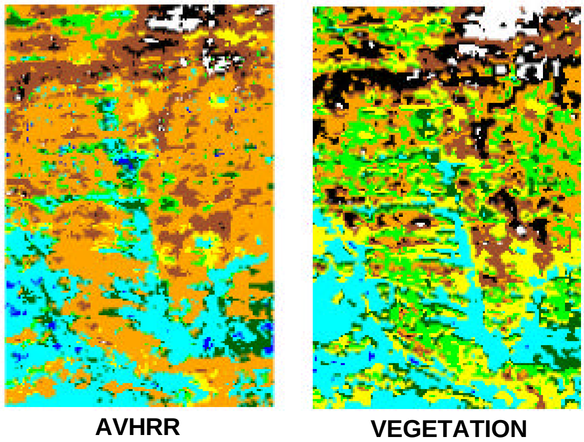


Figure 3 : Comparison of multitemporal classification using NOAA-AVHRR and VEGETATION data (1999).

Figure 4 shows NDVI decade profiles classes obtained from the previous multitemporal classification. The profiles are more regular, with larger range values, a better sensitivity for low NDVI and a noisiness in dry season (bare soils and dry biomass).

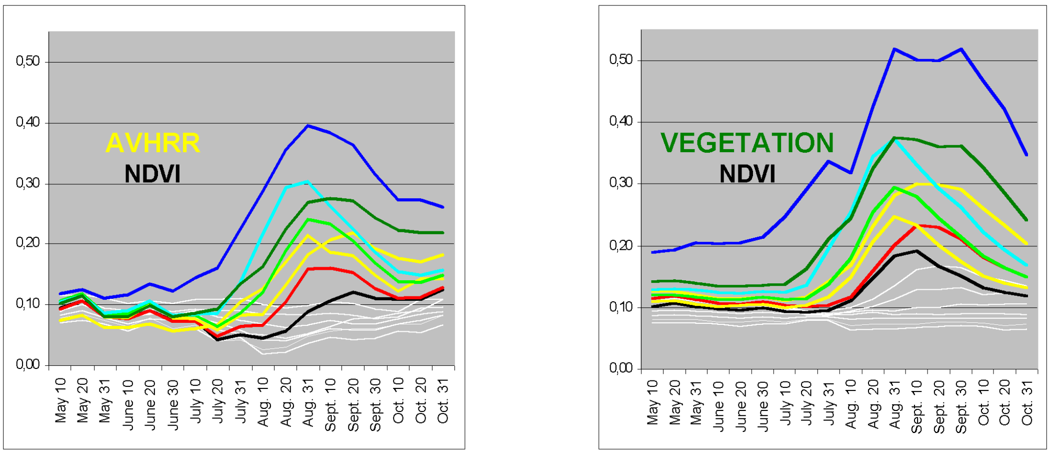
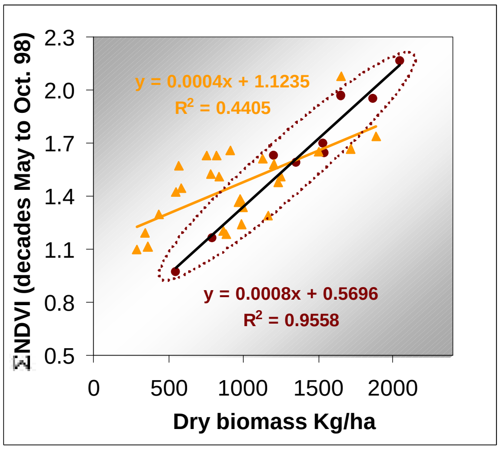


Figure 4 : Comparison of profiles from multitemporal classification of NDVI (MVC on decade) using NOAA-AVHRR and VEGETATION data from May to October 1999.

In the following sections, we explored three different ways of improving biomass estimations using empirical relationships with VEGETATION data.

4.2 Stratification from soil indices and landscapes types

NDVI is a good integrator of vegetation activity and is widely used. New vegetation indices are not usually applied to large areas as the entire Sahel region due to problems of homogeneous acquisition conditions (atmosphere, view and sun angles).
Another way consists to adapt empirical relationships between biomass and vegetation indicators for every homogeneous landscape units. Thus, we have similar soil surface conditions at 1km resolution and high possibilities to observed similar vegetation development according to rainfall.



For example, the improved fitted regression in black on Figure 5 represents the set of ground data with a low brightness index value calculated in dry season just before starting of vegetation. Colour indices are also used to differentiate landscape and soil units and the associated vegetation. It is also an interesting way in arid lands to improve inaccurate geomorphological maps or to map high changes of soil surface features (erosion...). The improvement of these relationships by using soil corrected vegetation classes was not obvious due to various atmospheric conditions and surface moisture changing. This approach must be tested in the future and seems interesting to vegetation models.

Figure 5 : Empirical relationship between integrated VEGETATION NDVI and total biomass in Niger in 1998. The fitted regression drawn in black corresponds to dark soils (clay) situated on plains and valleys.

4.3 New vegetation indices suitable for rangeland applications

To provide timely estimates of biomass during the whole year, we have begun development of an algorithm to estimate a vegetation index that is also sensitive to senescent vegetation. The rationale for developing an indicator suitable for senescent vegetation was that most rangelands are a mixture of dry and green vegetation (or remain dry for a long period of time for the perennial grasses). When investigating vegetation densities with multispectral remote sensing imagery, the primary component is senescent and often cannot be picked up by most vegetation indices such as the NDVI. An algorithm to use the shortwave infrared band has been proposed and reported that this spectral band can enhance the senescent vegetation signals while maintaining the green component. In collaboration with Qi's and Dedieu's projects, different vegetation indices which make use of the SWIR band have being tested (Qi et al., 2000).

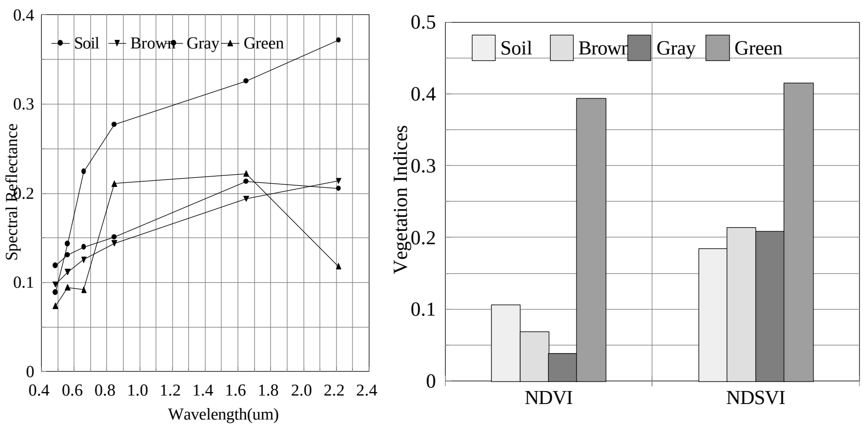


Figure 6 : Spectral responses and vegetation indices of soil, green, senescent, and gray vegetation.

- The SWVI which consists of replacing RED by SWIR in NDVI formulation. This index, conceived to enhance the effect of scattering in NIR and the sensitivity of vegetation water content in SWIR, is less sensitive to aerosol than the NDVI. The results concerning biomass and LAI estimations using this index are shown in Dedieu's paper (Belgirate Proceedings).
- The SNDVI, which consists of replacing NIR by SWIR in NDVI formulation improves substantially the estimation accuracy of senescent vegetation (Qi et al., 2000).

To obtain a clear evaluation of RED, NIR and SWIR information contents in terms of dry, green and total biomass estimations (Figure 6), other band combinations are being investigated.

4.4 VEGETATION data compositing

A recent method of compositing presented by Duchemin et al. (Belgirate Proceedings) has been tested on VEGETATION data in Niger. Figure 7 presents a NDVI temporal profile obtained on a typical grassland site which produced 640 and 860 kg/ha in 1998 and 1999 respectively. The MVC method is not able to detect the change in biomass production between 98 and 99, while the "BRDF compositing" method indicates an increase of biomass production as observed.

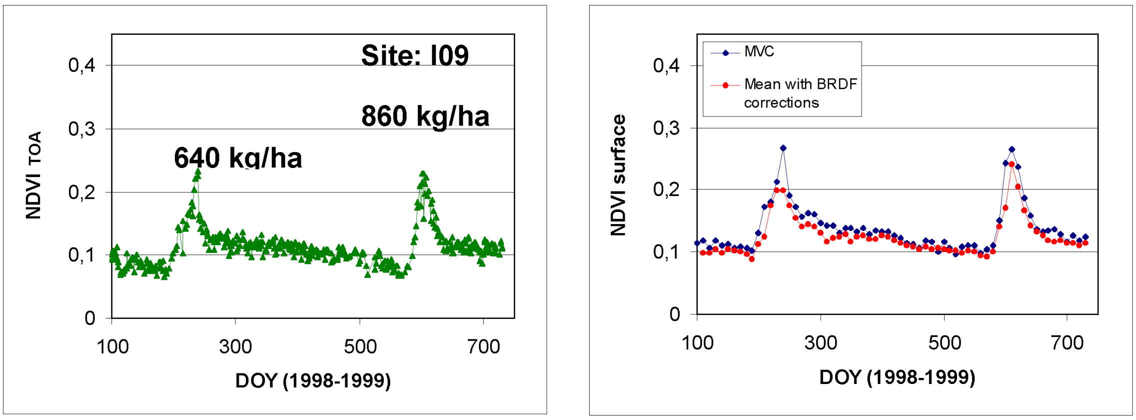
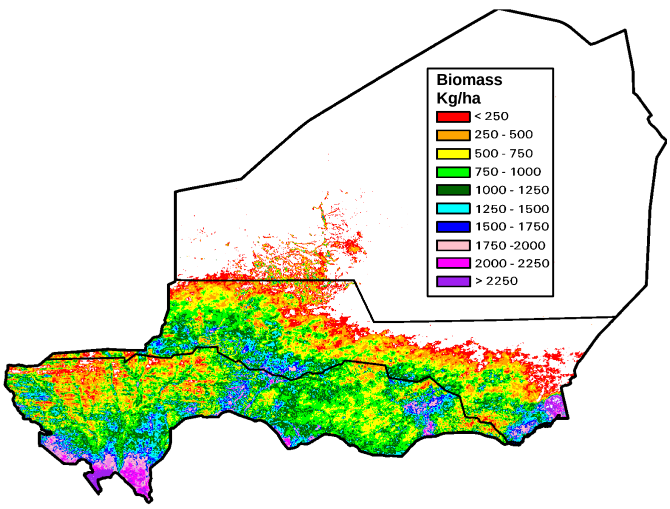


Figure 7 : Daily and decade temporal profile with VEGETATION data in 1998 and 1999 and differences observed between two methods of compositing MVC and mean with BRDF and atmospherical corrections.

5 Towards an operational procedure for using VEGETATION data in rangeland management



An interactive method was developed in the "Centre Régional AGRHYMET" in Niamey (Niger), combining ground biomass measurements and NDVI indicators (MVC method on decades). The different methodology improvements shown in this study should be implemented in the future. AGRHYMET receives S10 products from JRC (Ispra) by email or ftp transfers. Pre-processed VEGETATION data facilitates distribution and thematic using.

Figure 8 : Niger VEGETATION biomass map (kg/ha) derived from NDVI, May to October 1999.

The capacity of VEGETATION data to detect low vegetation coverage will extent the use of these data in very arid lands and using in Early Warning Systems. Other products derived from VEGETATION data as soil colour in relationships with surface texture and erosion intensity could help to actualise data in Environmental Information Systems of the CILSS countries.

In the US, a major research activity was initiated in 1999 to develop efficient ways of interacting with rangeland managers to evaluate VEGETATION products (Qi et al., 2000). A protocol was developed and presented at the user workshop held from March 2-4, 2000 for user's evaluation.
At this workshop, several rangeland managers, representatives of the Bureau of Land Management, the US Forest Service and the Natural Resources Conservation Service were shown 6 monthly estimates of NDVI values in the VEGETATION scene that covers Arizona. The design was made to fit the major research objectives of this project, which is to provide users timely information to be provided by VEGETATION sensor, so that they 1) assess the value of the VEGETATION imagery products and 2) use the information for making sound management decisions. The preliminary web design (Figure 9) is available at http://bsrsi.msu.edu/~qi/projects/vgt_range/vgt_range_prj.html site.

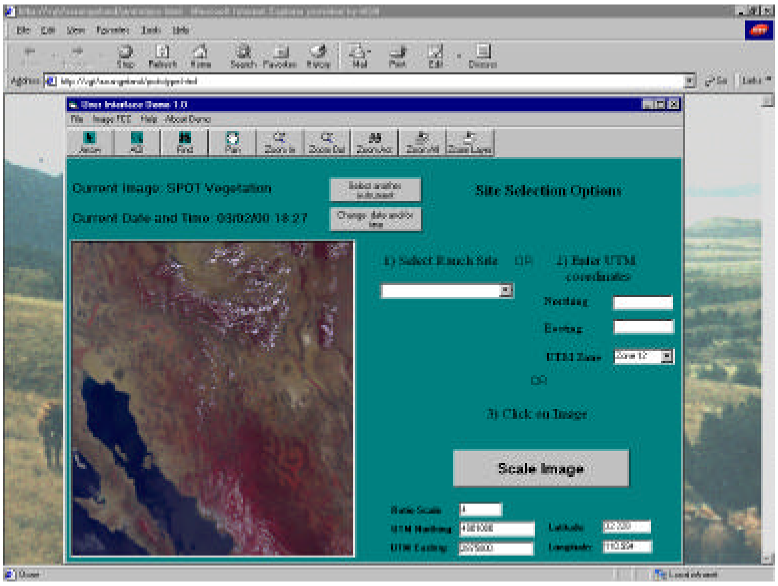


Figure 9 : Preliminary design of a web interface for end-users.

Based on discussions with public land managers in Arizona, perhaps the largest obstacle to the widespread application of remote sensing technology for rangeland management is institutional rather than technological. Although most of the rangeland is publicly owned, some is owned by the State of Arizona and the rest by the Federal government. Within the Federal holdings there are many agencies that manage land with different objectives and very little coordination. It is unlikely that any one agency could economically process images for the small portion of the land managed by that one agency, and they don't work together enough to share. Another institutional problem is that the remote sensing and geospatial expertise in the large land management agencies is centralised, so it is difficult to coordinate the development of data products that address local needs of field offices other than for specific, short term projects. If these institutional barriers could be surmounted, data products from VEGETATION imagery would be much more likely to be used on rangelands.
Anyway, the development of the Web interface for user-interaction is continuing and it is expected to be operational by the end of 2000. Two years of VEGETATION products developed through this project will be online for end user evaluation. The effort initiated by the VEGETATION project in developing data products to improve management of grasslands. will continue through a NASA-funded project '*Prototyping Value-Added EOS Data for Rangeland Management and Assessment*' .
(http://bsrsi.msu.edu/~qi/projects/nasa_usda/nasa_usda.html).

6 Conclusions and future developments

A series of results obtained in this project (VEGETATION validation, use of SWIR in the vegetation indices, new BRDF compositing method, combination of satellite data and external maps) illustrate how the radiometric and geometric quality of VEGETATION data allows to better estimate biomass in arid and semi-arid lands and to improve annual indicators for the future. However future work is required to reach the general objective of this project. To go further in the investigation, we now plan to work on the particular following points :

- Empirical data analysis : band combinations investigations to get more accurate estimation of total amount of biomass.
- A new modeling research axis : Analyses of temporal profiles of vegetation indices over Sahelian sites using coupled grassland functioning and canopy reflectance models. The vegetation functioning model developed for grasslands of semi-arid regions had been used before for perennials in Mexico (Nouvellon et al, 2000) and for annuals in the Sahel. VEGETATION data analysis through canopy modeling (Mougenot et al., 2001) and assimilation of these data in the model is in test.
- User transfer : In Arizona, set-up of an operational web-interface for end-users in Arizona, training of the potential end-users in the interpretation of data products for their management concerns, and data production to meet their needs. In Niger, similar developments will improve capabilities to inform and to offer a better way to manage rangelands at regional and local scales.

7 Acknowledgements

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