Phenology from space: an alternative to rainfall measurements for crop monitoring in West Africa?

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1. INTRODUCTION

Crop phenological dynamics should be essential to evaluating crop production [1], especially in the West African food-insecure regions where most of the cereals are rainfed. Vegetation conditions must be carefully monitored using early warning systems during the critical growth stages when estimating year-end crop yields in these regions.

Because vegetation phenology in arid and semiarid ecosystems is primarily controlled by water availability, a number of field studies have attempted to quantitatively link phenology to precipitation forcing. However, where weather stations are sparse and data access is difficult, GCM or satellite-derived rainfall data are not satisfactory to run agro-meteorological models due to aggregation issues [2]. Using interpolated ground data, the model output uncertainty can be high where rainfall displays strong spatial variability because agricultural production is also sensitive to rainfall levels and temporal distribution. Moreover, on a regional scale, vegetation phenology also depends on soil, micro-climates, regional climates, land use and management, for which complex spatio-temporal phenology patterns can be observed [3]. Thus, remotely sensed vegetation index data should include the main intra-seasonal vegetation dynamics and integrate both rainfall variability and land cover status. This is the reason why without field observations on a large scale, satellite-derived phenological indicators could be relevant for food security systems, which may indicate risky situations in the region due to delayed crop growth.

2. OBJECTIVES

The objective of this study was to test whether the phenometrics derived from the MCD12Q2 product express the spatial variability of crop phenological stages in Southern Mali. The few ground phenology and/or cropping practice observations on the local scale for several years prohibits data validation from the ground, and a deeper analysis of the phenology. However, a validated crop growth model for the sub-Saharan regions (SARRA-H, System for Regional Analysis of Agro-Climatic Risks) [4] provides precise agronomic information.

Thus, the methodology consisted in examining whether the satellite observations and crop phenology agro-simulations are consistent. Phenometrics derived from MODIS time series were compared to crop model simulations for sites in South Mali located near synoptic stations with available rainfall and climatic data.

3. DATA AND METHODS

We studied phenology over eight sites (10 km x 10 km) throughout South Mali during 2007 (Figure 1). For each site, the AGRHYMET Regional Center provided daily climatic data (rainfall, temperature, and insolation).

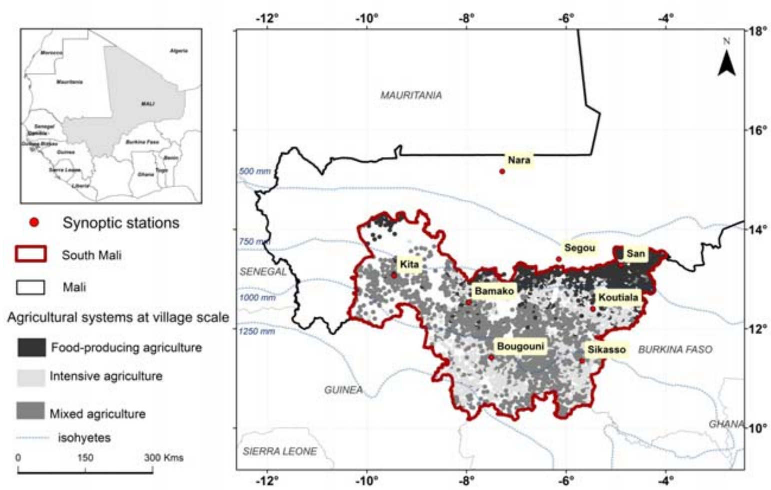

Figure 1. The eight synoptic station locations and a map of the crop production systems in South Mali [6]:

- Food-producing agriculture: area dedicated to millet and sorghum (> 50%) as well as cotton (< 10%);
- Intensive agriculture: area dedicated to maize and cotton (> 40%);
- Mixed agriculture: area dedicated to sorghum (> 20%) and cotton (between 5% and 40%).

The satellite data were yearly MODIS Land Cover Dynamics product (MCD12Q2), provided at 500 m spatial resolution, and including the phenological transition dates based on the 8-day EVI curvature-change rate : (1) green-up: the start-of-season (SOS); (2) maturity: the start-of-maximum (SMAX); (3) senescence: the end-of-maximum (EMAX); and (4) dormancy: the end-of-season (EOS) [5].

A cultivated domain map for Mali was produced at a 250 m spatial resolution, and a map of the agricultural systems was also produced for South Mali, in which each of the 4000 villages in the studied area were assigned to one of the three agricultural system classes (Figure 1; [6]).

The crop model SARRA-H v3.2 model simulates the biomass dynamics, for different varieties of the main cereal crops in West Africa: millet, maize and sorghum varieties. The model reproduces three major processes: evolution of the phenological stages for the varieties, carbon balance and water balance [4]. The model uses daily climate data (rainfall, global radiation, temperature and evapotranspiration), soil type, agricultural practices information, and crop variety. For each site, LAI time series were simulated using SARRA-H model, and fitted with the same algorithm that the one used for MODIS data, and model-phenological transition dates were produced.

4. RESULTS

Figure 2 shows the four MCD12Q2 product phenometrics calculated for each synoptic station in 2007. The north-south gradient for the start-of-season (SOS) metric was confirmed with a growing season that began in April in Sikasso, May in Bougouni, the end of June in Koutiala and Bamako, and the first half of July in San, Segou and Kita, except for Nara, wherein the season began surprisingly earlier (June 27th). The start-of-maximum (SMAX) was concentrated in the second half of August, while the end-of-maximum (EMAX) was concentrated in the second half of September, and the end-of-season (EOS) occurred between mid-November and mid-December.

The satellite- and model-derived phenometrics of the eight stations were regressed against each other and compared. The relationships between the satellite- and model-derived SOS, SMAX and EOS are consistent among the stations (R = 0.92, 0.74 and 0.65, respectively; p-value < 0.05). The SOS phenometrics yielded the best results; in contrast, the results were unsatisfactory for EMAX, especially for the Nara station.

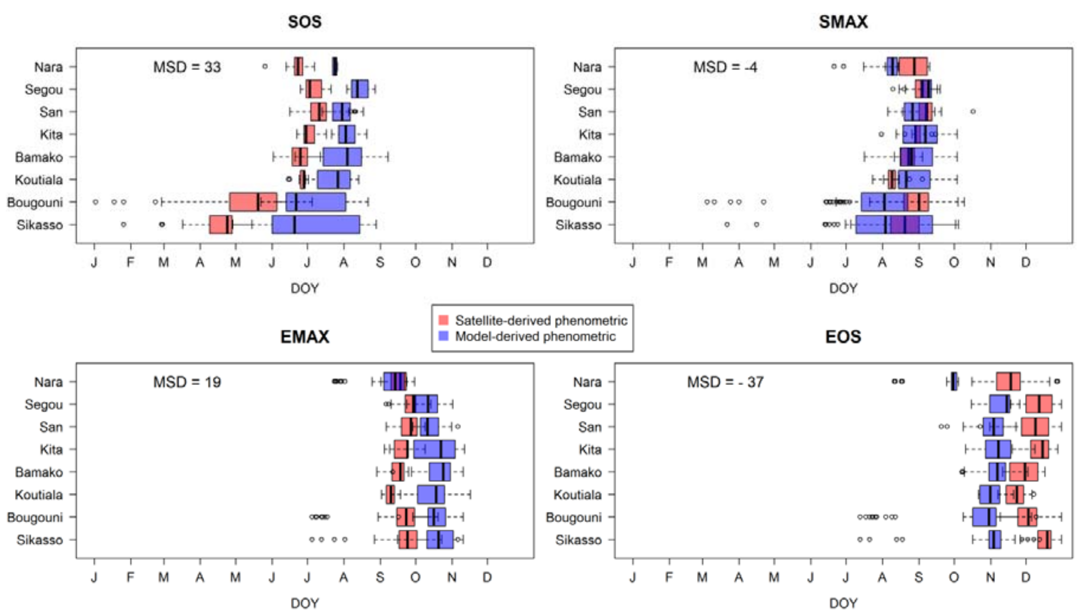

Figure 2. Satellite- (pink) and model-derived (violet) phenometrics boxplots were calculated for 8 synoptic stations, ranged from north (top) to south (bottom), in 2007. For the satellite-derived phenometrics, the variability is due to the area of the station (20 x 20 pixels), and for the model-derived phenometrics, the variability is due to

the number of simulations performed for each station. The mean signed difference (MSD) is the difference between the model- and satellite-derived phenometric values in days.

5. DISCUSSION AND CONCLUSION

The results obtained in this study reinforce our conviction that our method is relevant in countries where ground observations are scarce or difficult to collect. This study documents the simultaneous use of remotely sensed indicators and a crop growth model to provide a better estimate of vegetation phenological changes in the data-scarce West African countries with food insecurity and a monsoonal ecosystem. We observed that the phenological indicators from the MODIS Land Cover Dynamics Yearly product reproduce the spatial variability of crop phenological stages in Southern Mali. Where the satellite observations are not contaminated by clouds and are well distributed over the transition phase, the start-of-season indicator could be recalculated from the EVI time series and used as complementary information with the crop model. Food security systems could benefit from such remotely sensed indicators, which provide spatially continuous information and vegetation phenological change information that integrates rainfall variability, land cover diversity and farmer practices.

In the future, crop phenology monitoring should also benefit from ESA's upcoming satellite Sentinel-2, which will provide high spatial-, spectral- and temporal-resolution images of Earth on national and global scales.

6. REFERENCES

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