radiating outwards from the older mechanized agricultural areas to the periphery with time (Fig. 7).

4. Discussion

A major frontier croplands is found in the state of Mato Grosso, Brazil where natural ecosystems of Amazon rainforest and *cerrado* (savanna) are giving way to some of the largest contiguous row-crop plantations in the world. Agricultural census provides detailed information on cultivated area and crop yields, but is not spatially explicit beyond the level of *municipio* nor does it tell us the sequence and duration of crops. Census data is compiled annually, but does not elucidate the number of crops grown per parcel, or other land-use practices that impact local biogeochemistry. Remote sensing tools allow us to detect agricultural phenology and derive parameters from which we can construct timeline of land-use and land-management on a per pixel basis. These results have many possible future applications such as for understanding changes in carbon and nitrogen cycling, important from both agricultural and environmental sustainability perspectives, or for estimating crop production rates for economic analysis.

Our application of the wavelet transform to an EVI time series (WFCP) captures crop phenological behavior with low error. This was a test of the WFCP methodology under new environmental conditions, namely climate which creates high frequency noise from clouds, and different agricultural phenology than the areas the model was created and validated (Sakamoto et al., 2005, 2006). Occasionally, the wavelet transform exaggerates small phenology peaks from weedy growth or creates a false peak due to wavelet resonance. Small peaks such as these should be classified with double crops. Although the classification of false maximums or weedy growth as double crops is troublesome from a curve-fitting perspective, it is acceptable for the purposes of detecting cropping patterns. Using the 90% power wavelet, many of these false maximums actually fall below the detection threshold for maximums of 0.4 EVI and are not counted, contributing to our high overall accuracy.

We have observed distinct spatial patterns in the wavelet-smoothed time-series results. New areas of croplands are nucleated around existing areas of croplands (Fig. 7). Small areas of *cerrado* between large areas of croplands are often filled in with croplands. We observe areas of single crops becoming areas of double crops over time, as seen in Fig. 7. This intensification appears spatially constrained to the center of the zones of agriculture and likely reflects the evolution of farming practices with cropland age. Our knowledge of agricultural practices supports this—often, in the first years of cultivation, a single soybean crop is grown. After two to three years, double cropping practices emerge, where there may be two soybean crops grown, soybean and secondary cash crop such as corn, or soybean and a soil-conditioning crop such as millet. Increases in crops in the 2002–2004 time period may be related to economic factors, such as the high global market price (Morton et al., 2006). These results show an increase of crops grown per area across the entire study area, either as the development of new croplands or as the intensification of existing lands from a single crop system to a double crop system.

5. Conclusions

The goal of this study was to apply time-series analysis to detect rapid changes in land-cover and land-use choices (single and double cropping patterns). The challenge of this study was to detect crop patterns within croplands. We have tested the wavelet transform to filter noisy EVI time-series data. First, we detect the areas of row crops by applying an annual standard deviation threshold to discriminate row crops from other land-cover types. This threshold was selected annually from the local minimum in a bimodal histogram of standard deviation. Identifying areas of row crops on a year-to-year basis allows us to analyze cropping patterns for a pixel only after it has been converted to row crops, thereby reducing processing time. After selecting areas in row crops, we then created wavelet-smoothed time series with the 90% power wavelet. Local maximums, or phenological peaks, were counted as a crop if the time series exceeded 0.4 EVI; this threshold was a means of removing false peaks sometimes created in the wavelet-smoothed time series.

We selected this study area to test this model in an area of rapid development of row crops. During the five-year study period, we found an increase in croplands of 3281 km^2, an area larger than the state of Rhode Island. Intensification of row crops is also evident, with increases in row crops coming first in single crops and, subsequently, in double crops, such as in 2003 and 2004. We expected this pattern where there is an extensification in row crops that would typically be grown in a single crop pattern for the first growing season. In subsequent years agricultural intensification, or a shift from growing one crop to two crops, could explain the increase in double crops. Spatially, the extensification of row crops is on the edges of existing areas of agriculture and intensification occurs within the existing areas of croplands.

These results show that there is a large increase in cropland in our study area and it is important to understand how this drastic change in land cover will (and does) impact carbon and nitrogen cycling. Distinguishing crop types, such as soybean and corn, is important as different crops have different implications for carbon and nitrogen cycling. Soybean plants fix nitrogen, but most of the fixed nitrogen leaves the system at harvest. Without proper management, over time, the loss of carbon and nitrogen decreases the soil fertility and may have other implications for land-use sustainability and management. Secondary crops, such as corn, may require large inputs of nitrogen fertilizers that increase nitrous oxide emissions. Addition of nitrogen fertilizers also impact local water quality. Knowing the number and type of crops being used allows us to proceed with spatially explicit models of biogeochemical changes associated with this agricultural development and intensification.

In this study we demonstrate the stability of the wavelet approach over many years of an EVI time series. Thereby we can apply the WFCP methodology to a wider study region to study regional development patterns of row crops. One future