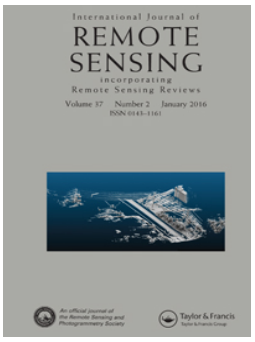


International Journal of Remote Sensing

ISSN: 0143-1161 (Print) 1366-5901 (Online) Journal homepage: http://www.tandfonline.com/loi/tres20

Investigating collection 4 versus collection 5 MODIS 250 m NDVI time-series data for crop separability in Kansas, USA

Eunmok Lee, Jude H. Kastens & Stephen L. Egbert

To cite this article: Eunmok Lee, Jude H. Kastens & Stephen L. Egbert (2016) Investigating collection 4 versus collection 5 MODIS 250 m NDVI time-series data for crop separability in Kansas, USA, International Journal of Remote Sensing, 37:2, 341-355, DOI: 10.1080/01431161.2015.1125556

To link to this article: http://dx.doi.org/10.1080/01431161.2015.1125556

Published online: 12 Jan 2016.

INTERNATIONAL JOURNAL OF REMOTE SENSING, 2016
VOL. 37, NO. 2, 341–355
http://dx.doi.org/10.1080/01431161.2015.1125556

Taylor & Francis
Taylor & Francis Group

Investigating collection 4 versus collection 5 MODIS 250 m NDVI time-series data for crop separability in Kansas, USA

Eunmok Lee[a], Jude H. Kastens[b] and Stephen L. Egbert[b,c]

[a]Department of Geography, Miami University, Oxford, OH, USA; [b]Department of Geography, Kansas Applied Remote Sensing, Lawrence, KS, USA; [c]Department of Geography, University of Kansas, Lawrence, KS, USA

ABSTRACT
The primary objective of this research was to analyse collection 5 versus collection 4 time-series normalized difference vegetation index (NDVI) data from the Moderate Resolution Imaging Spectroradiometer (MODIS) 250 m for the purpose of separating crop types. Using extensive ground reference data from the state of Kansas in the central USA, NDVI value profiles were extracted from different collection versions for 2001 (collections 4 and 5) and 2005 (collection 5 only). Phenological curves for all crops and all data sets were created and visually inspected. Jeffries–Matusita (J-M) distance statistical analysis was performed to assess crop separability. Contrary to expectations, collection 5 time-series MODIS 250 m NDVI data were found to be inferior to collection 4 with respect to crop separability. Specifically, collection 4 data exhibited a greater dynamic range across the growing seasons of the various crop types, and this discriminatory advantage was supported by J-M distance analysis. Though the analysis did not suggest reasons for the outcome, it corroborates the conclusion of the only other similar study in the literature comparing data from collections 4 and 5. Considering the pervasive use of these data for land-cover mapping, it is recommended that MODIS NDVI data from collection 4 should be used where possible for crop type mapping in agricultural regions with climate, geography, and crops similar to Kansas.

ARTICLE HISTORY
Received 18 July 2015
Accepted 14 November 2015

1. Introduction

Since the first Moderate Resolution Imaging Spectroradiometer (MODIS) data were acquired in February 2000, MODIS standard products have experienced several updates based on evolving processing priorities (Justice et al. 2002). Reprocessing refers to employing the latest version of the 'scientific algorithm' to process the data and applying the best available calibration and geolocation information, among other treatments (Didan and Huete 2006). Reprocessing of the entire MODIS inventory has been carried out four times and has included important changes such as employing improved calibration algorithms, geolocation information, cloud masking, applying techniques for

CONTACT Eunmok Lee leee5@miamioh.edu Department of Geography, Miami University, 229 Culler Hall, 620 E. Spring Street, Oxford, OH 45056, USA

reducing spatial normalized difference vegetation index (NDVI) discontinuity or 'patchiness', and updated atmospheric profiles. Each reprocessed data set is referred to as a 'collection' or 'version', and the most recent data set available at the time of this research was collection 5. The underlying expectation of the reprocessing performed by the MODIS Science Team is that the new data will have improved spatial and temporal characteristics. Updating the MODIS products to the latest version also directly affects the quality of the vegetation index (VI) products, as the process is related to improvements in VI compositing methods, sub-pixel cloud handling, and aerosol filtering. (MODIS Vegetation Index Product Series 2006).

When collection 5 was introduced with eight new refinements to the MODIS Land Surface Temperature and Emissivity (LST&E) product, Hulley and Hook (2009) analysed the temporal and spatial variations of the MOD11B1 LST&E product for collections 4, 4.1, and 5 to understand the impact of version changes on their studies. Although the refinements to the latest version were designed to improve spatial coverage, stability, and accuracy of the LST&E product, they concluded that users should consider using the older versions (collection 4 or 4.1) instead of the latest version (collection 5) for arid and semi-arid areas because version 5 degraded the accuracy of the derived emissivity over arid areas (Hulley and Hook 2009).

In designing the refinements for collection 5 of the MODIS vegetation index products, emphasis was placed on the constrained view-angle maximum value composite (CV-MVC) compositing algorithm, as well as improved handling of sub-pixel and mislabelled clouds, aerosol filtering, and inland water bodies, and phased production for improved temporal frequency (MODIS Vegetation Index Product Series 2006). All these are important aspects that potentially can affect product quality in terms of spatial and temporal characteristics. In this study we analysed temporal-spectral variations in the time-series MODIS 250 m NDVI vegetation index data from collections 4 and 5.

1.1. *Problem statement*

The objective of this study was to investigate differences in the MODIS 250 m NDVI time-series from collections 4 and 5 with respect to their use for crop differentiation. Specifically we analysed the ability of these data sets to distinguish five major crops grown in the state of Kansas in the central USA (alfalfa, *Medicago sativa*; corn, *Zea mays*; sorghum, *Sorghum bicolor*; soybean, *Glycine max*; and winter wheat, *Triticum aestivum*). NDVI data from 2001 and 2005 were used since ground reference data of good quality are available for these years at the Kansas Applied Remote Sensing Program (KARS).

Two primary research questions were examined. First, are there meaningful differences between NDVI crop profiles from the two collections? Second, does collection 5 of the time-series MODIS 250 m data set have better ability to discriminate the study area's major crop types (alfalfa, corn, sorghum, soybean, and winter wheat) compared to collection 4?

2. Study area

The research area for this study is the state of Kansas (Figure 1) where there is a strong east-west precipitation gradient in a mid-continental temperate climate.

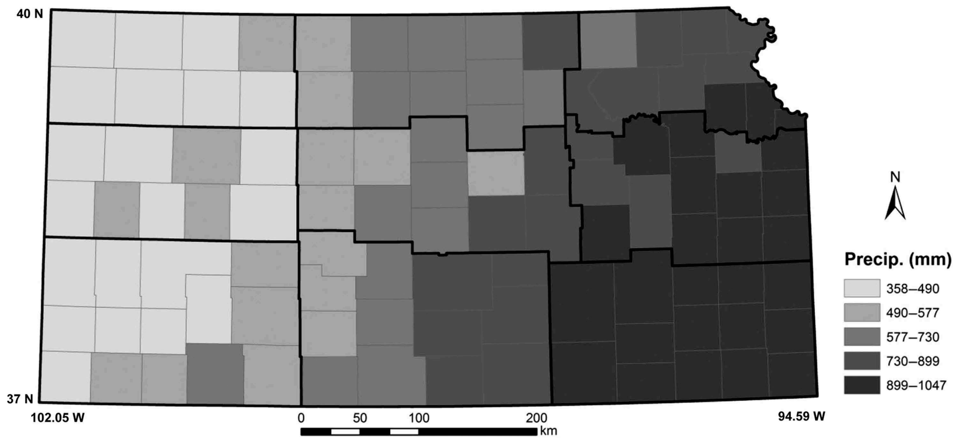


Figure 1. Five-year (2001–2005) mean annual precipitation (Precip.) across Kansas, by county. Also visible are the nine agricultural statistics districts that partition the state and follow county boundaries. [Weather Data Library, K-State Research and Extension].

Most rainfall occurs during the growing season from April through September with average annual precipitation of 460–510 mm for western Kansas, 580–870 mm for central areas, and 890–1020 mm for eastern parts of the state. The temperature gradient, which increases from the northwest (mean annual temperature <11 °C, with relatively high seasonal variability) to the southeast (mean annual temperature >15 °C, with relatively low seasonal variability), also affects temporal and spatial patterns of crop growth that in turn are reflected in NDVI values in the study area (Wang, Price, and Rich 2001; Wardlow, Egbert, and Kastens 2007). The diverse range of climatic conditions across the state affects local decisions regarding a range of crop management practices.

3. Data description and processing

3.1. *MODIS vegetation index 16-day composite 250 m data*

MOD13Q1 is the 16-day 250 m vegetation index product that gathers information from the MODIS Terra platform on a per-pixel basis through multiple observations over a 16-day period. For this study, collections 4 and 5 images from the NDVI product were downloaded from the Land Process Distributed Active Archive Center (LPDAAC, https://lpdaac.usgs.gov/data_access/data_pool) for 2001.

Using the MODIS Reprojection Tool (version 4.0), all the downloaded images were processed, reprojected to the Albers Equal Area Conic projection, and saved in GeoTiff format. The converted images were mosaicked to cover the Kansas state area (three tiles are required to cover the state: h09v05, h10v05, and h10v04). From these data, two 12-month time-series (one for each collection) consisting of 23 periods of 16-day MODIS 250 m NDVI spanning the period January to December for 2001 were created. NDVI data for 2005 acquired and processed in the same fashion were also used for statistical analysis. Table 1 summarizes the imagery used in this study.

Table 1. Summary of 16-day time-series MODIS 250 m NDVI data.

Product name	MOD13Q1		
Spatial resolution/Composite period	250 m/16-day		
Year	2001		2005
	Collection 4	Collection 5	Collection 5
Number of dates/Number of scenes[1]	23/69	23/69	23/69

[1] Three scenes (h09v05, h10v05, and h10v04) are needed to cover Kansas.

3.2. *Field site database*

For this research, we used the same ground reference data used by Wardlow, Egbert, and Kastens (2007) in their research for 2001. To assemble this data set, Wardlow *et al*. acquired and geocoded the information from annotated aerial photos that were provided by the United States Department of Agriculture (USDA) Farm Service Agency (FSA). This was then used to create a database of field site locations with known crop types and irrigation status (i.e. irrigated or non-irrigated). The data set consists of a large number of widely distributed field sites for each crop class. The minimum field size was 32.4 ha, which covers approximately five MODIS pixels at 250 m resolution so that each site would be represented by multiple pixels (Wardlow, Egbert, and Kastens 2007). Field site locations used in this research are shown in Figure 2.

The ground reference data for 2005 were acquired in the same way as for 2001, but the field site locations were different from those of 2001. To minimize any spatial gaps between the data sets, sites nearest to those in the 2001 data set were selected by using a proximity analysis function in ArcGIS tools. The function finds the nearest field site by calculating the distance from each point in the input layer (2001 field sites) to the nearest point in the second layer (i.e. the 2005 field sites). Table 2 shows the number of field sites for each data set and the selected nearest sites. Figure 2 illustrates the geographic locations of each data set and selected nearest points.

4. Methods

4.1. *NDVI profiles*

Disregarding the minor variations between the collection-specific compositing algorithms, for the most part each NDVI value in the analysed data set was obtained through the MVC procedure on a pixel-by-pixel basis to secure only the highest NDVI value for each pixel location (Holben 1986). The mean multi-temporal NDVI profiles for each of the five major crops for collections 4 and 5 were calculated by averaging them at the state level, and these NDVI profiles were first visually compared to their crop calendars. The NDVI profiles also were visually compared for irrigated and non-irrigated crops to detect possible separability between these two crop management practices based on spectral-temporal differences during the year. The two different collections of MODIS 250 m data sets were compared to analyse the potential causes of differences detected.

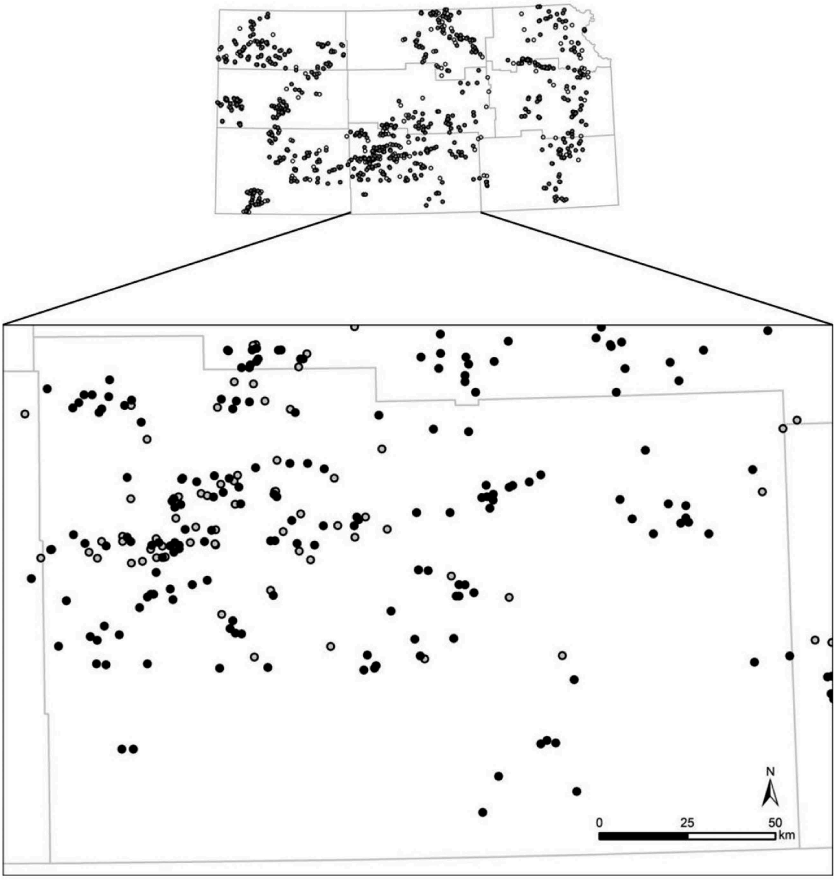


Figure 2. Field site locations of corn for 2001 (black circle) and 2005 (white circle) data sets across Kansas and zoomed in to the South Central Agricultural Statistics District.

Table 2. Number of field sites for each crop.

Crop type	2001	2005[1] (before refinement)
Alfalfa	243	109 (out of 528)
Corn	609	349 (out of 3,524)
Sorghum	354	239 (out of 4,393)
Soybean	454	217 (out of 2,581)
Winter wheat	446	356 (out of 20,481)
Total	2,106	1,270 (out of 31,507)

[1] The number of the selected sites for 2005

4.2. *J-M distance*

The J-M distance statistic, which has been found to provide a useful separability measure by several researchers (Richards and Jia 1999; Van Niel, McVicar, and Datt 2005; Wardlow, Egbert, and Kastens 2007), was employed in this study to investigate separability within each crop class in the time-series NDVI data between the two collection versions. The J-M distance between a pair of class-specific probability functions is defined as

$$J_{i,j} = \int \left[\sqrt{p_i(x)} - \sqrt{p_j(x)} \right]^2 \mathrm{d}x. \tag{1}$$

Subscripts i and j each specify a class, and $p_i(x)$ and $p_j(x)$ are two class-specific probability density functions. When classes are normally distributed, Equation (1) reduces to

$$J_{i,j} = 2\left(1 - \mathrm{e}^{-B}\right), \tag{2}$$

where

$$B = \frac{1}{8}D^2 + \frac{1}{2}\ln\left(\left| \frac{\sum_i \sum_j}{2} \right| \Big/ \sqrt{\left|\sum_i\right|\left|\sum_j\right|} \right) \tag{3}$$

and

$$D^2 = \left(\mu_i - \mu_j\right)^{\mathrm{T}} \left(\frac{\sum_i + \sum_j}{2} \right)^{-1} \left(\mu_i - \mu_j\right). \tag{4}$$

In Equation (4), μ_i indicates the mean value of the ith class and $\sum^i$indicates the covariance of the same class. The J-M distance provides a measure of distributional distinction between two classes that accounts for both differences in class means as well as the individual class spreads.

As defined, J-M distance values range from 0 to 2. A J-M distance of 2 between a pair of crop classes implies that the two crops are completely distinguishable from each other within the data sets used. A J-M distance of 0, on the other hand, implies that the two crops are completely indistinguishable. Values lying between 0 and 2 indicate different degrees of distributional distinction between the two classes.

5. Results and discussion

5.1. *Alfalfa*

The mean NDVI profiles shown in Figure 3 compare not only different MODIS collection versions for alfalfa in 2001 but also different crop management practices. Non-irrigated data are illustrated in Figure 3(a) and irrigated data in Figure 3(b). The major phenological pattern of alfalfa consists of multiple 'growth and cut' cycles, as the crop is normally harvested three or four times per year in Kansas (Shroyer, St. Amand, and Thompson 1998). The growth-and-cut cycles are evident to some degree in Figure 3(a) and (b).

As previous researchers have discussed (Wardlow and Egbert 2008; Wardlow, Egbert, and Kastens 2007), distinctive NDVI patterns were observed for non-irrigated versus irrigated alfalfa in the time-series MODIS data. As would be expected, slightly higher NDVI values were observed in the irrigated sites during the summer. Data from collection 4 generally had higher NDVI values than collection 5, especially for irrigated sites.

5.2. *Summer crops*

Although all three summer crops (corn, sorghum, and soybean) show similar phenological curves, unique spectral-temporal responses representing subtle differences in their growth cycles are reflected in their individual NDVI profiles (Wardlow, Egbert, and

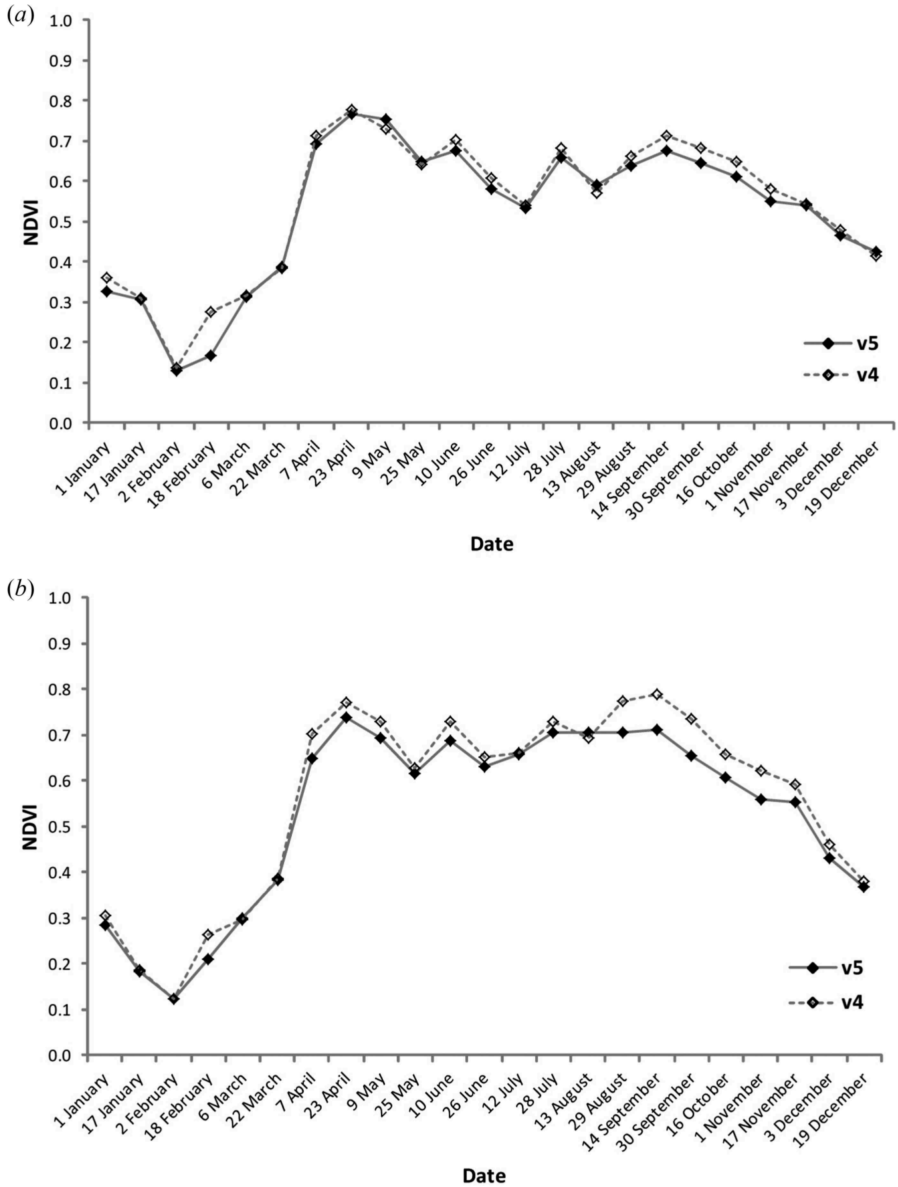


Figure 3. Alfalfa NDVI profile comparisons (a) v4 versus v5, non-irrigated, (b) v4 versus v5, irrigated.

Kastens 2007) (Figure 4). Corn typically is the earliest planted summer crop in Kansas (April to mid-May), followed by soybean (mid-May to mid-June) and sorghum (late May to late June) (Shroyer et al. 1996). Figure 4 shows the same mean NDVI profile data for corn that were shown for alfalfa in Figure 3.

As expected, irrigated corn (Figure 4(b)) had higher NDVI values than non-irrigated corn (Figure 4(a)) during the peak greenness period (12 July) and the senescence phase (28 July–14 September). Collection 4 had higher NDVI values only during the peak greenness period. At most other times during the growth cycle (green-up and

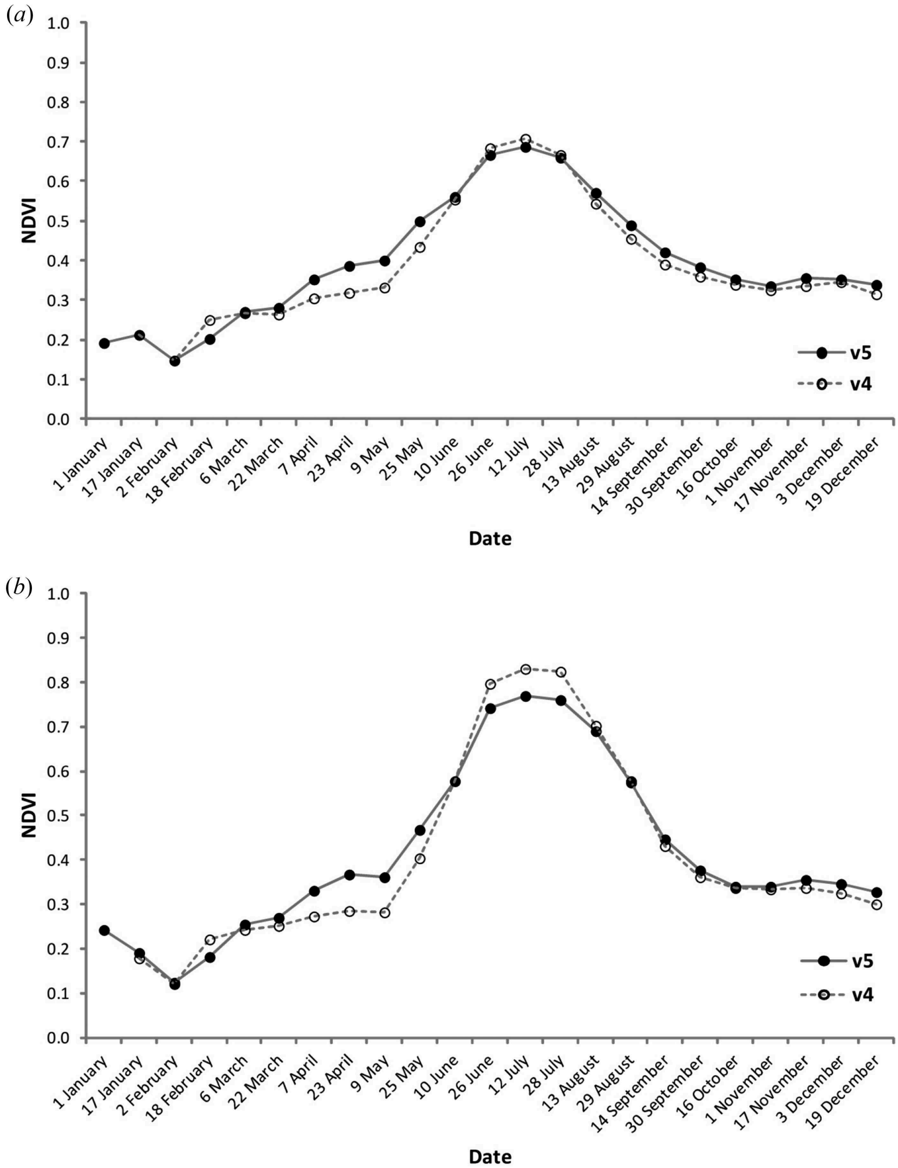


Figure 4. Corn NDVI profile comparisons (a) v4 versus v5, non-irrigated, (b) v4 versus v5, irrigated.

senescence), the values for collection 5 NDVI were higher. In other words, the range of NDVI values (lowest to highest) was greater for collection 4 than for collection 5, a pattern repeated for all the summer crops. This suggests that collection 4 may have a greater dynamic range of summer crop NDVI values across the growing season than collection 5.

For sorghum (Figure 5), peak greenness occurs during the 28 July period and the crop has the lowest NDVI values among the summer crops. Similar to corn, the greatest differences between non-irrigated (Figure 5(a)) and irrigated (Figure 5(b)) sorghum are found during mid- to late summer, with irrigated sorghum having slightly higher NDVI

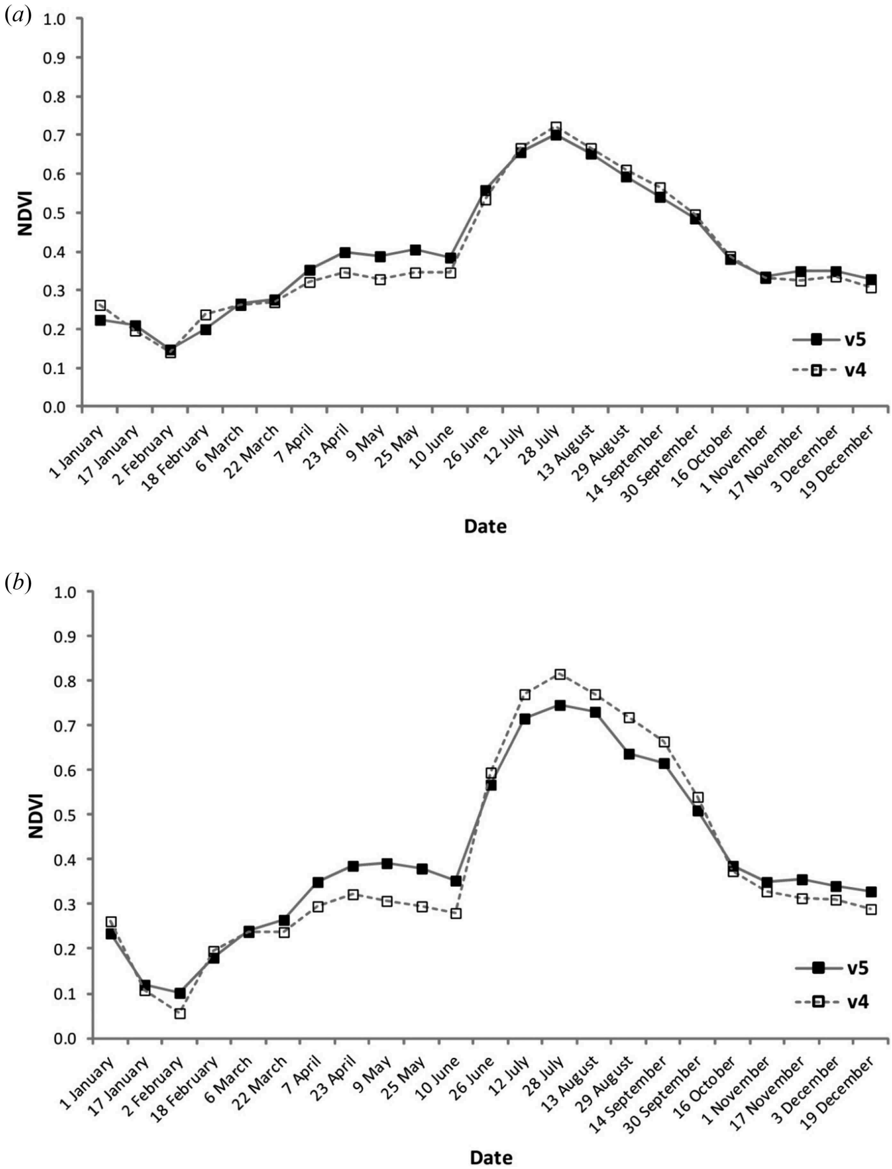


Figure 5. Sorghum NDVI profile comparisons (a) v4 versus v5, non-irrigated, (b) v4 versus v5, irrigated.

values than non-irrigated sorghum especially during the peak greenness phase. Collection 4 shows higher NDVI values from around peak greenness through senescence (from 26 June to 16 October periods) than collection 5. The difference is larger in the irrigated field sites.

Soybean (Figure 6) exhibits the highest NDVI values among the crops examined in this study, with a rapid drop in NDVI values during the 14 September period. Similar to corn and sorghum, differences between non-irrigated (Figure 6(a)) and irrigated (Figure 6(b)) soybean are found during the senescence period in mid- to late

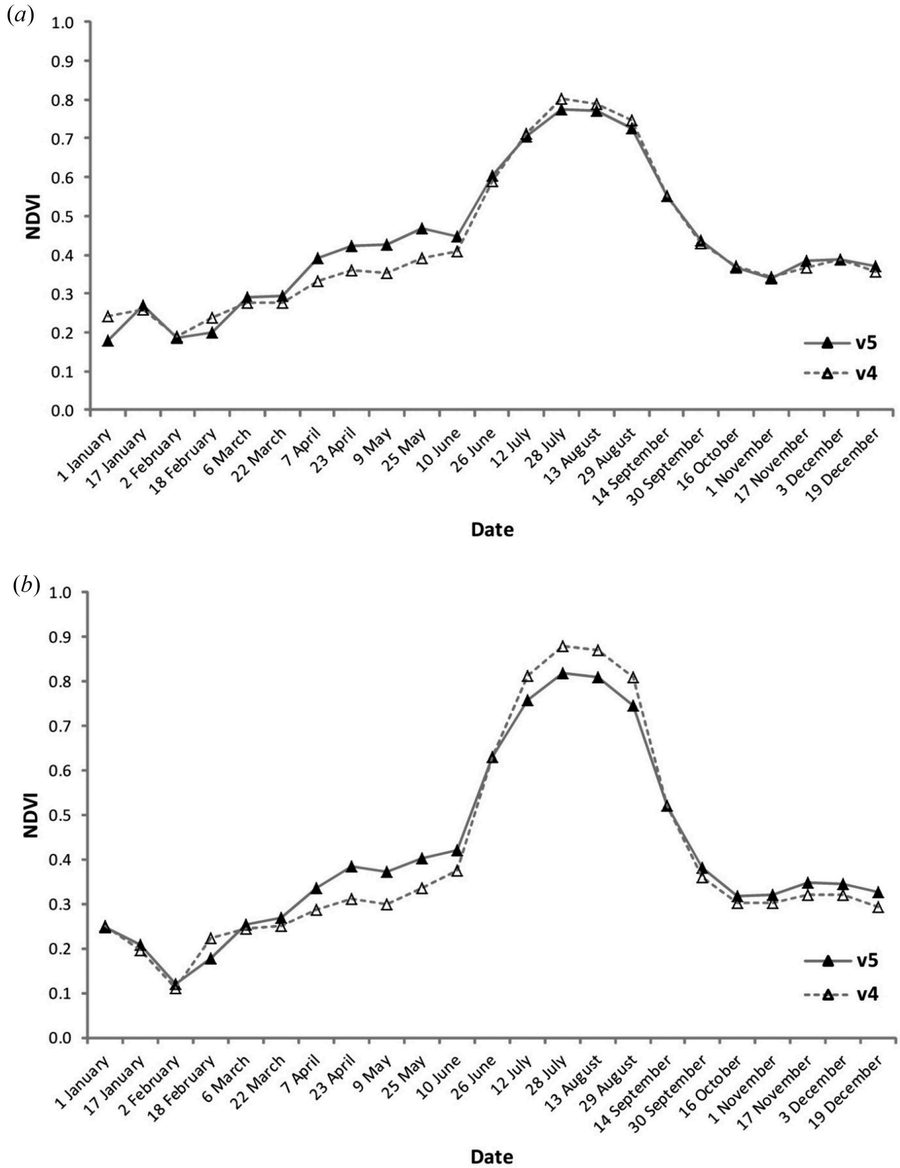
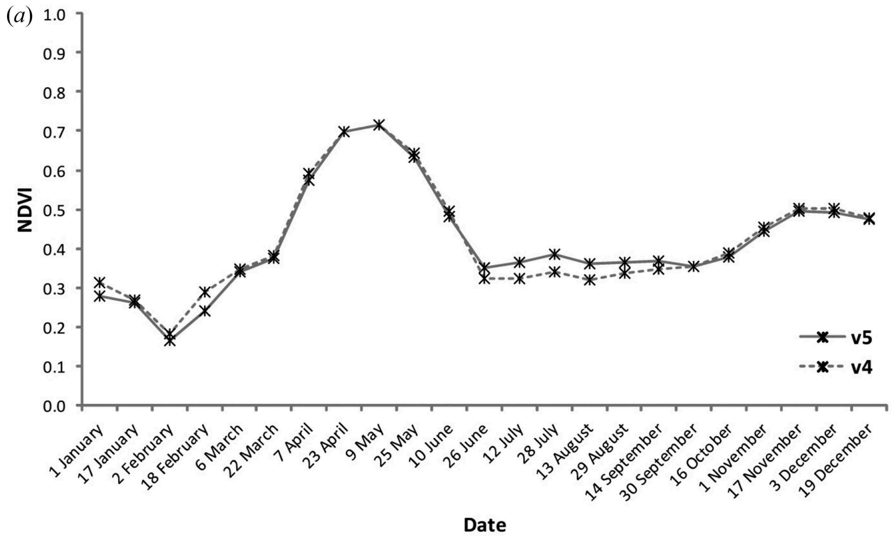


Figure 6. Soybean NDVI profile comparisons (a) v4 versus v5, non-irrigated, (b) v4 versus v5, irrigated.

summer. Collection 4 shows higher NDVI values than collection 5 around peak greenness (from 26 June to 14 September periods), a difference that is larger for the irrigated field sites.

5.3. *Winter wheat*

Figure 7 shows the mean NDVI profile data for winter wheat. Winter wheat phenology is characterized by planting and emergence in the late autumn before winter



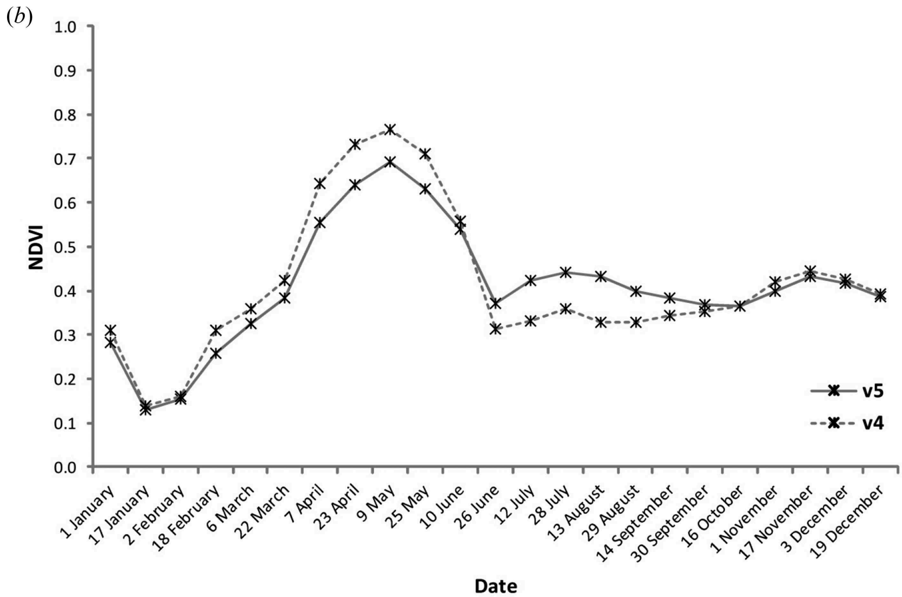


Figure 7. Winter wheat NDVI profiles (a) v4 versus v5, non-irrigated, (b) v4 versus v5, irrigated.

dormancy and resumption of growth in the early spring (Paulsen et al. 1997). In Kansas, harvest of winter wheat typically is completed by mid-year (late June or early July). It is difficult to observe any differences between the collection 4 and 5 data in the non-irrigated field data, but differences are apparent in the irrigated field data (Figure 7(b); namely, collection 4 NDVI values generally are higher than collection 5 during the spring and early summer growing season and lower during the months immediately following harvest).

5.4. *Inter-class comparison of crop VI profiles*

Figure 8 shows mean NDVI profiles for all five crops in the study area during 2001. Figure 8(a) displays collection 4 data and Figure 8(b) shows collection 5. First, alfalfa and winter wheat are clearly distinguishable from summer crops in the spring for both collection versions. Though alfalfa becomes undistinguishable in early summer as the summer crops' NDVI values increase, winter wheat remains distinguishable throughout most of the growing season due to its unique phenology. While summer crop profiles demonstrate a high degree of overlap, there are still a few composite periods where these crops show distinctive patterns during the green-up and senescence phases.

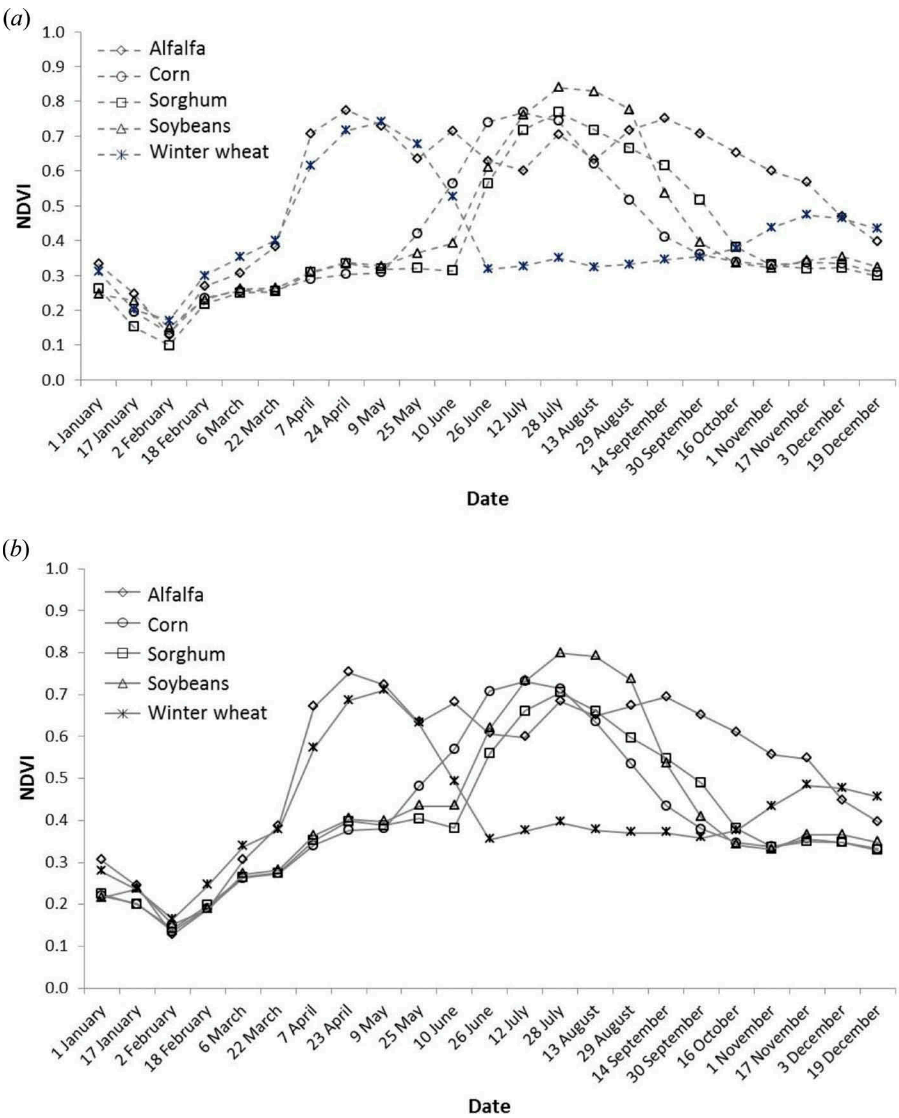


Figure 8. Inter-class comparisons with NDVI profiles for 2001: (a) collection 4, (b) collection 5.

Despite the obvious similarities between the crop profile sets from collections 4 and 5, it appears that the NDVI value range for collection 5 phenology curves generally is smaller than that of collection 4. For example, during the time between green-up start and peak greenness (10 June–28 July), the NDVI values of soybean increase from 0.39 to 0.84 (range = 0.45) for collection 4, while those for collection 5 increase from 0.43 to 0.80 (range = 0.37). Once again, this difference suggests that collection 4 may have a wider dynamic range of NDVI values than collection 5 for the purpose of crop type classification in the study area. This observation potentially implies greater separability between crop classes if intra-class variability among collection 4 profiles does not offset this advantage. The J-M distance statistic, which considers both intra-class variability as well as differences between inter-class means, was used to further investigate the apparent differences between the collections.

5.5. *J-M distance analysis*

Table 3 represents J-M distance results for all pair-wise crop comparisons to examine potential class separability differences between collections 4 and 5. Following Wardlow, Egbert, and Kastens (2007), the growing season defined for this analysis spans the period 22 March–1 November because it covers most of the crops' growth periods.

Table 3(a) illustrates J-M distances calculated for collection 4 for 2001 (adapted from Wardlow, Egbert, and Kastens 2007). The average J-M distance for all crops is 1.89. Due to similar crop calendars and growth profiles, J-M distances for summer crop comparisons are lower than those between either alfalfa or wheat and the summer crops; the average J-M distance for summer crops only is 1.63. Table 3(b) shows J-M distances for collection 5 for 2001. Overall J-M distances for collection 5 are lower than those for collection 4 (Table 3(a)) and, in particular, the decreased J-M distances for summer crops are substantial. The average J-M distance for all crops is 1.58 and the average for summer crops only is 1.09 (Table 3(b)). Table 3(c) also shows J-M distances for collection 5, but uses ground reference samples from 2005 (collection 4 data are not available for 2005). As would be expected, when compared to the preceding tables (Table 3(a) and

Table 3. J-M distance values for all pair-wise crop comparisons.

Crop type	Corn	Sorghum	Soybean	Winter wheat
(*a*) J-M distance values for 2001 collection version 4, 16-day time-series MODIS 250 m data				
Alfalfa	2.00	2.00	2.00	1.99
Corn	-	1.66	1.63	2.00
Sorghum	-	-	1.61	2.00
Soybean	-	-	-	2.00
(*b*) J-M distance values for 2001 collection version 5, 16-day time-series MODIS 250 m data				
Alfalfa	1.84	1.81	1.84	1.78
Corn	-	1.05	1.05	1.78
Sorghum	-	-	1.16	1.75
Soybean	-	-	-	1.76
(*c*) J-M distance values for 2005 collection version 5, 16-day time-series MODIS 250 m data				
Alfalfa	1.89	1.84	1.86	1.74
Corn	-	1.31	1.23	1.63
Sorghum	-	-	1.01	1.50
Soybean	-	-	-	1.60

(b)), Table 3(c) shows a similar pattern to Table 3(b). The average J-M distance for all crops in Table 3(c) is 1.56 and the average for summer crops only is 1.18.

According to the analysed J-M distances, the differences in J-M distance values between the different collection versions (Table 3(a) vs. Table 3(b)) are notably larger than those between the two years of collection 5 data (Table 3(b) vs. Table 3(c)). This observation provides some support for the assumption that the substantial differences in J-M distance results from the two collections in 2001 are not simply an artefact ascribable to that particular year's growing season characteristics.

6. Conclusions

The objective of this research was to investigate differences in crop type separability in Kansas using MODIS 250 m NDVI data from collections 4 and 5. Using an extensive ground reference data set containing samples from five major crop types (alfalfa, corn, sorghum, soybean, and winter wheat), NDVI profiles were extracted from the two different collection versions for 2001 and 2005 (collection 5 only).

Mean NDVI profiles from the different crops and collections in 2001 were analysed visually, and collection 4 data generally were found to exhibit a wider dynamic range of NDVI values than collection 5. Furthermore, J-M distance statistics were calculated to provide a more complete examination of statistical separability tendencies of the two collections. Collection 4 data consistently demonstrated a greater propensity for pair-wise crop separation than collection 5. To examine the robustness of this single-year assessment, J-M distance values from a different ground reference data set in the study area were computed using 2005 NDVI data from collection 5, and were found to be similar to the collection 5 J-M distance values observed in the 2001 analysis.

Just as Hulley and Hook (2009) concluded that collection 4 of the MODIS LST&E product was superior for deriving accurate emissivity values for arid and semi-arid areas as compared to collection 5, we found the collection 4 data for the MODIS13Q1 16-day composite NDVI product to have better crop discrimination capability than collection 5 among the major crop types in Kansas. Unfortunately, the reasons for these outcomes are not clear, as the science algorithm underlying collection 5 was specifically designed to improve a number of different aspects of the data. While it would certainly be possible to perform additional research to evaluate data from the two collections for the purpose of crop type classification, it is less clear how a research project could be designed to identify which aspects of the algorithm are responsible for any observed differences such as those found in this study.

The underlying hypothesis for this research was that the then-latest version (collection 5) of MODIS 250 m time-series data might be more useful for distinguishing five major crops grown in Kansas. The observed and analysed results failed to support that assumption. Observations of the ranges between low and high NDVI values over the growing season showed that collection 4 consistently had greater ranges for all crops compared with collection 5. Furthermore, a J-M distance statistical separability analysis suggested that the older version (collection 4) has a greater capacity to distinguish crop types than collection 5. Further studies would be useful for better understanding of how the different MODIS collection algorithms impact LULC classification.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Didan, K., and A. R. Huete, 2006. MODIS Vegetation Index Product Series Collection 5 Change Summary. MODIS Land Data Discipline Team webpage. http://landweb.nascom.nasa.gov/QA_WWW/forPage/MOD13_VI_C5_Changes_Document_06_28_06.pdf.

Holben, B. N. 1986. "Characteristics of Maximum-Value Composite Images from Temporal AVHRR Data." *International Journal of Remote Sensing* 7 (11): 1417–1434. doi:10.1080/01431168608948945.

Hulley, G. C., and S. J. Hook. 2009. "Intercomparison of Versions 4, 4.1 and 5 of the MODIS Land Surface Temperature and Emissivity Products and Validation with Laboratory Measurements of Sand Samples from the Namib Desert, Namibia." *Remote Sensing of Environment* 113: 1313–1318. doi:10.1016/j.rse.2009.02.018.

Justice, C. O., J. R. G. Townshend, E. F. Vermote, E. Masuoka, R. E. Wolfe, N. Saleous, D. P. Roy, and J. T. Morisette. 2002. "An Overview of MODIS Land Data Processing and Product Status." *Remote Sensing of Environment* 83: 3–15. doi:10.1016/S0034-4257(02)00084-6.

MODIS Vegetation Index Product Series. 2006. *Collection 5 Change Summary*. MODIS Land Data Discipline Team webpage. http://landweb.nascom.nasa.gov/QA_WWW/forPage/MOD13_VI_C5_Changes_Document_06_28_06.pdf

Paulsen, G. M., J. P. Shroyer, J. Kok, and C. R. Thompson, 1997. *Wheat Production Handbook*. K-State Research and Extension webpage. http://www.ksre.ksu.edu/bookstore/pubs/c529.pdf.

Richards, J. A., and X. Jia. 1999. *Remote Sensing Digital Image Analysis*, 273–274. 3rd ed. Berlin: Springer-Verlag.

Shroyer, J. P., P. C. St. Amand, and C. Thompson, 1998. *Alfalfa Production Handbook*. K-State Research and Extension webpage. http://www.ksre.ksu.edu/bookstore/pubs/c683.pdf.

Shroyer, J. P., C. Thompson, R. Brown, P. D. Ohlenbach, D. L. Fjell, S. Staggenborg, S. Duncan, and G. L. Kilgore. 1996. "Kansas Crop Planting Guide." K-State Reserach and Extension webpage. https://gostarseed.com/files/photos/KSU_Kansas_Crop_Planting_Guide.pdf

Van Niel, T. G., T. R. McVicar, and B. Datt. 2005. "On the Relationship between Training Sample Size and Data Dimensionality: Monte Carlo Analysis of Broadband Multi-Temporal Classification." *Remote Sensing of Environment* 98: 468–480.

Wang, J., K. P. Price, and P. M. Rich. 2001. "Spatial Patterns of NDVI in Response to Precipitation and Temperature in the Central Great Plains." *International Journal of Remote Sensing* 22 (18): 3827–3844. doi:10.1080/01431160010007033.

Wardlow, B. D., and S. L. Egbert. 2008. "Large-Area Crop Mapping Using Time-Series MODIS 250 M NDVI Data: An Assessment for the U.S. Central Great Plains." *Remote Sensing of Environment* 112: 1096–1116. doi:10.1016/j.rse.2007.07.019.

Wardlow, B. D., S. L. Egbert, and J. H. Kastens. 2007. "Analysis of Time-Series MODIS 250 M Vegetation Index Data for Crop Classification in the US Central Great Plains." *Remote Sensing of Environment* 108: 290–310. doi:10.1016/j.rse.2006.11.021.