Optical Senescence in Vermont and New York

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I. Introduction

The changing of leaf color in temperate hardwood forests during autumn months a phenomenon called senescence, which is tied to forest productivity, climate change, and tourism, among other fields (Rozenstein and Adamowski, 2017). Zhu et al. (2016) discovered an overall lengthening growing season in North America due to delayed dormancy, but around three times more research has been conducted on springtime phenological phenomenon than those in autumn. A shift in vegetation phenology could be an indication of climate change (Zhu et al. 2016). Previous studies (Hatfield and Prueger 2010, Zhang and Goldberg 2011) have attempted to monitor senescence with satellite imagery over larger ranges using several vegetation indices (Figure 1), such as Normalized Difference Vegetation Index (NDVI), Plant Senescence Reflectance Index (PSRI), Chlorophyll index – green (CIgreen), and Brownness Index, but have not overlapped with the this study region of Vermont and New York. This project will examine the relationship of senescence with certain variables.

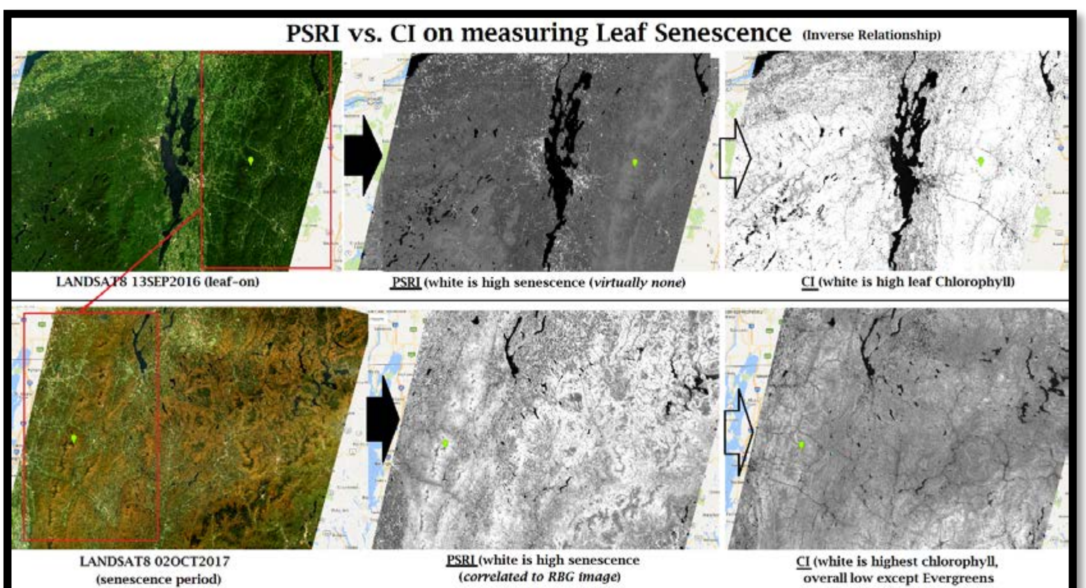

Figure 1. Initial exploration of relationship between PSRI and CIgreen.

2. NDVI Analysis

Since PSRI, CIgreen, or Brownness indexes were not able to map successfully across the image collection (see Appendix for script link), NDVI was used as the sole metric for assessing change in chlorophyll content throughout the year. NDVI could also be calculated interannually from 2000 to 2018 for the months of September through December (inclusive), as well as for each of those months separately, in order to assess any change in senescence timing onset (Figure 2). No significant trends in changed to peak timing could be identified.

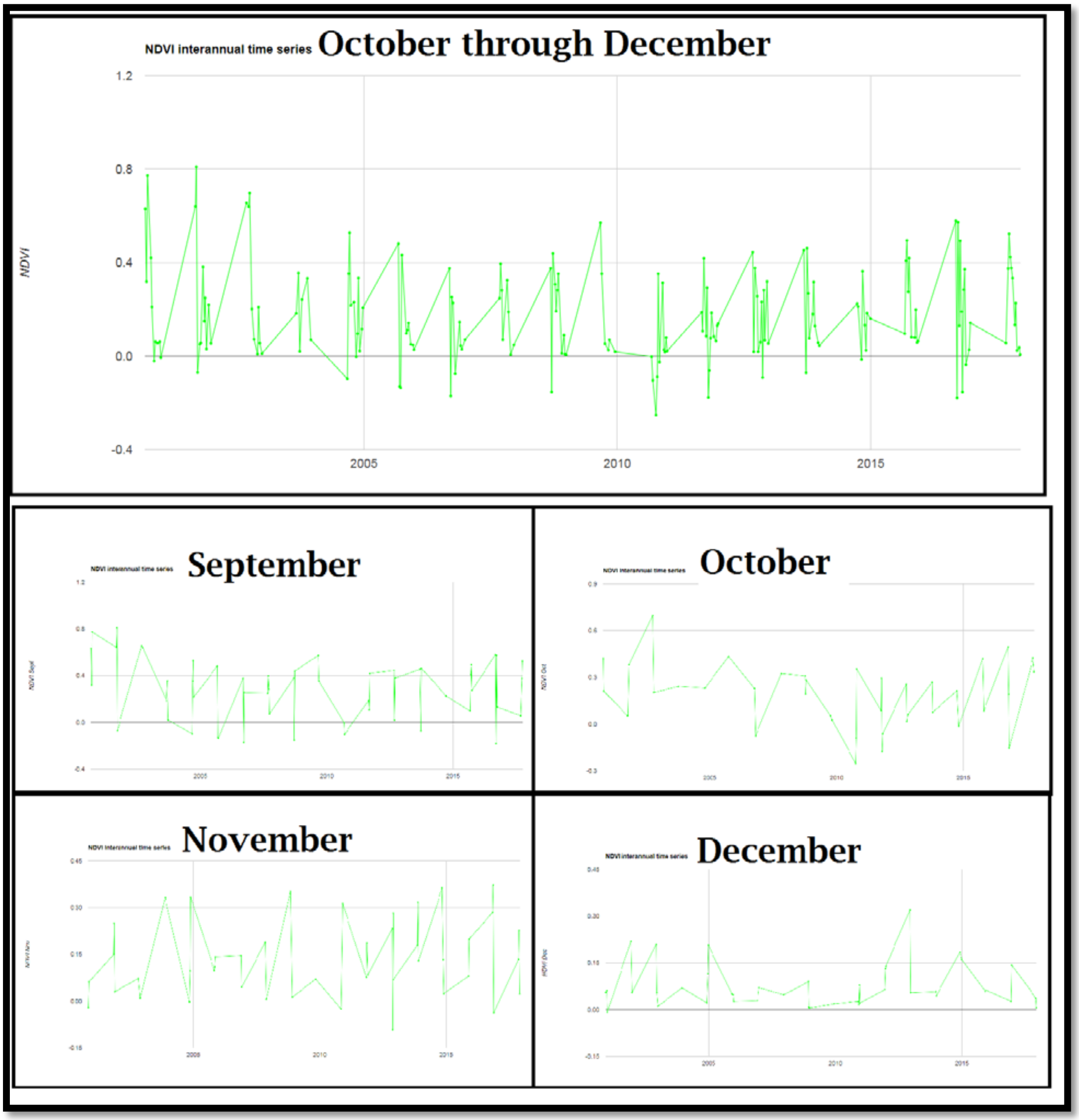

Figure 2. Interannual time-series analysis of NDVI during autumn, total, and by month.

An image collection of the MODIS Combined 16-Day NDVI data was used to compile average NDVI values per day of the year ranging from August to December, 2000-2016. The chart shows conformance until around November 2, when values diverged greatly.

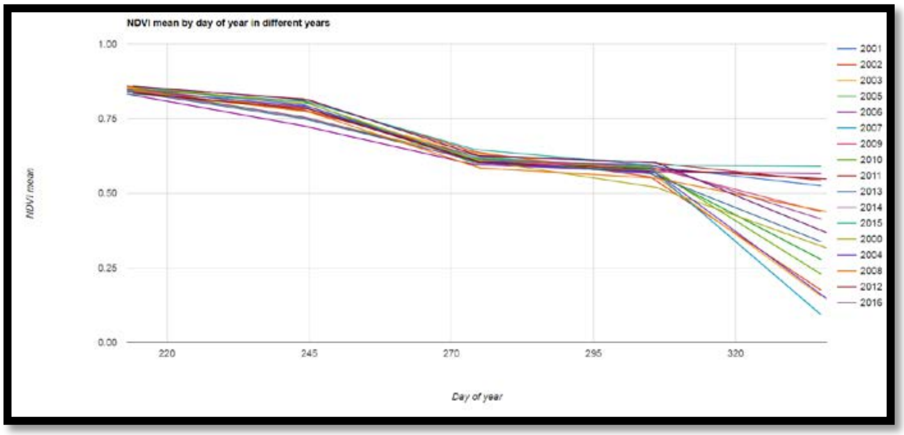

Figure 3. MODIS Combined 16-Day NDVI means, per year, from September to December.

Although this made apparent the significant deviation from year to year in the rate of declining leaf productivity, the repeated onset occurrence date seen was likely attributable to data pre-processing of the MODIS collection (rather than natural phenomenon). NDVI decline was therefore graphed again using Landsat 7 imagery over the same months, as well as independently from 2000-2005, 2006-2011, and 2012-2017.

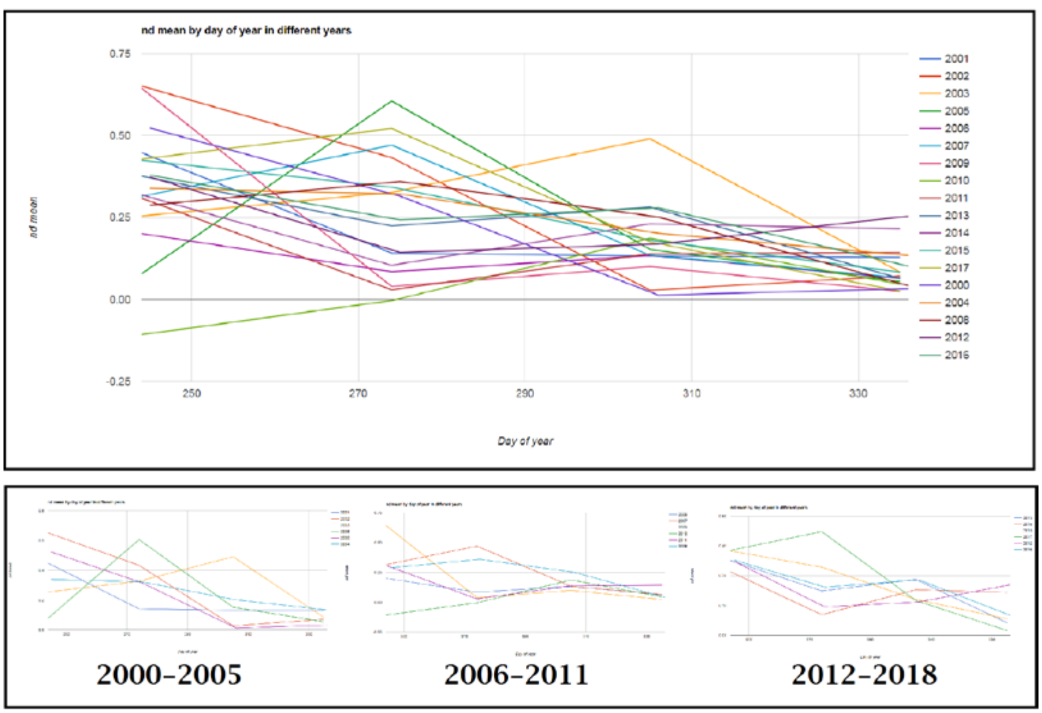

Figure 4. Landsat 7 NDVI means, per year, from September to December (top), as well as per 5-6 years (bottom)

Further exploring NDVI, the median and quality (highest-value) mosaics of NDVI were created for all images from 2000-2016, by month, from September to December (Figure 5).

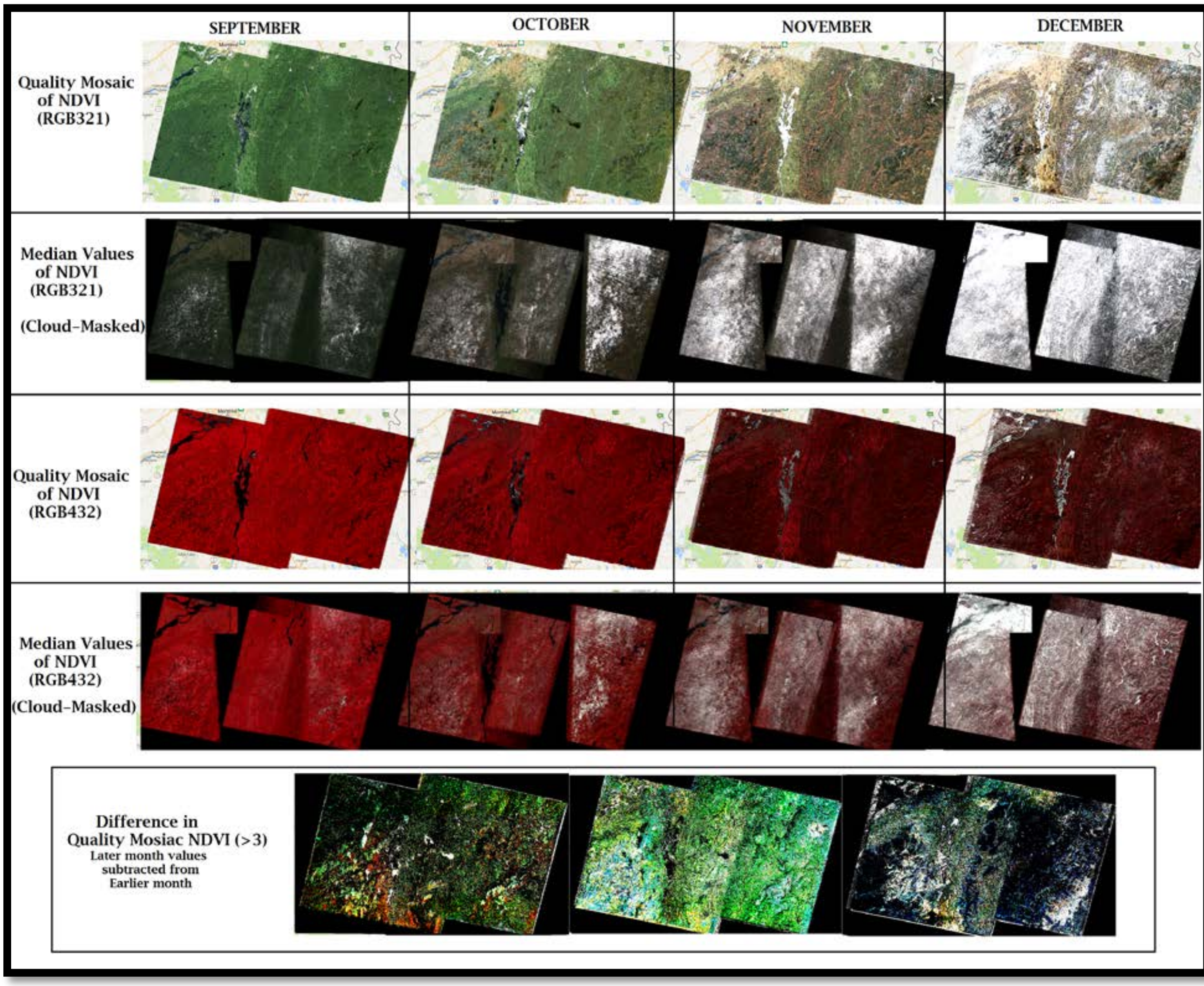

Figure 5. Quality and Median mosaics for all images, 2000-2016, by month, shown in true color R-G-B and false color NIR-R-G, along with changes in highest NDVI between months (bottom).

Hopkin's Law of Bioclimatics suggests that temperature is the main driving factor of senescence (Rozenstein and Adamowski 2017); to test that theory, the difference in NDVI between the first half and second half of each month was analyzed, using two different years that were identified in Figures 3-4 to have drastically different rates of declining leaf productivity. Temperature reports were collected from Weather Underground and ACIS Northeast Regional Climate Center were synthesized to see how changes in temperature affect leaf coloration (or, at least NDVI; PSRI and CIgreen could also be telling, but were not examined). 2002 was selected as a year with very rapid decline in NDVI, and had an average fall temperature in Lamoille County of 44.45ºF; 2012 was selected as the year with relatively low decline in NDVI; average fall temperature was 45.6ºF. These years were not of the most extreme rates, but were the most NDVI-disparate years where Landsat 7 imagery was obtainable in both halves of the month.

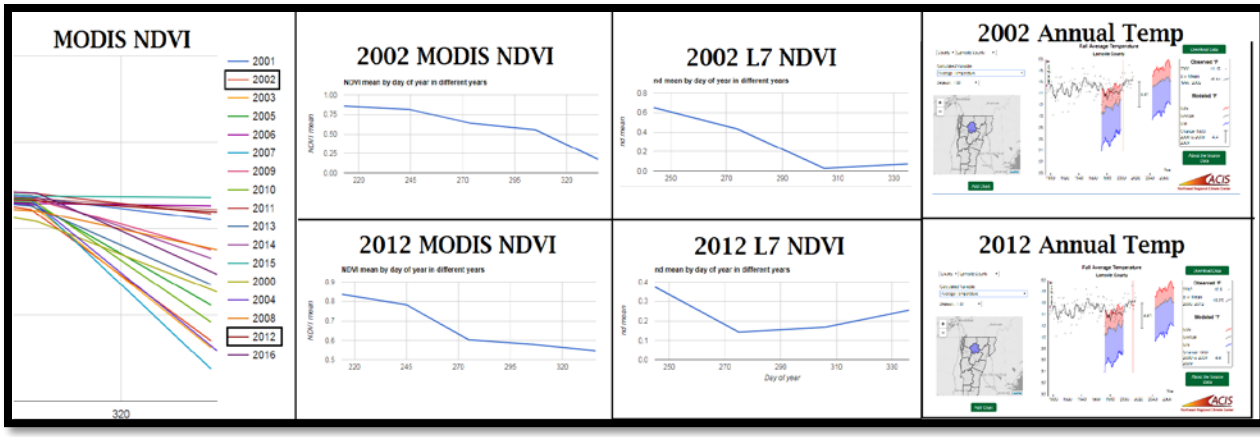

Figure 6. NDVI for 2002 and 2012, measured by MODIS and Landsat 7 (L7), as well as ACIS annual temperature.

Month-by-month temperature readings are shown in Figure 7, beneath images showing differences in NDVI from the start to end of the month (i.e., image NDVI values from days 1-15 minus NDVI values from days 16-31). While images show drastic differences in NDVI between different months, temperature does not seem to the driving factor.

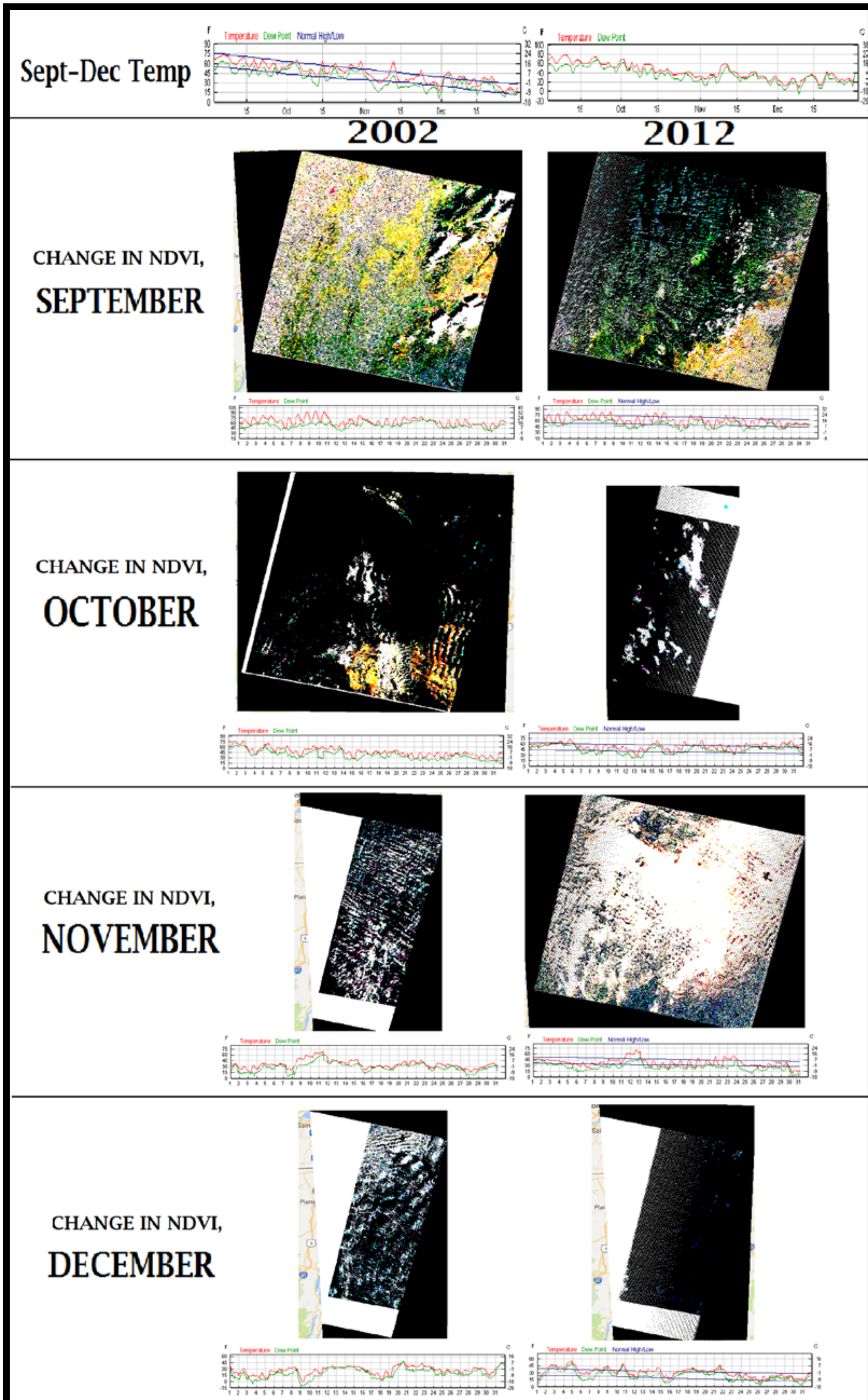

Figure 7. Intra-month NDVI difference, compared to WU temperature data.

As a final attempt to explore the relationships between NDVI, PSRI, and CIgreen, a manual image-by-image time-series was conducted to visually compare images from September through December for 5 years between 2000-2016 (using the single most cloud-free image per month), and displayed with corresponding histogram values for the respective indices (see Appendix). Although some images have heavy clouds, it is possible to interpret an inverse relationship between PSRI and CIgreen between months of each year. PSRI is particularly interesting, as it increases up to November, then decreases in December (easiest recognized in 2016 imagery). It appears the PSRI is in fact the most appropriate metric to utilize when attempting to capture the autumn color flush.

3. Classification Performance

The best cloud-free image from summer (June-August, 2000-2018) and autumn (September-December, 2000-2018) were each classified using the Weka K-means unsupervised classification algorithm. This test was performed to determine whether the accuracy and performance of the classification algorithm would vary depending on whether image inputs were used from leaf-out vs. senescence (peak images were visually estimated). Both images were classified using the same input parameters (15 classes, 5000 training pixels, 50 max. Iterations, 17 seed value, 30m image scale).

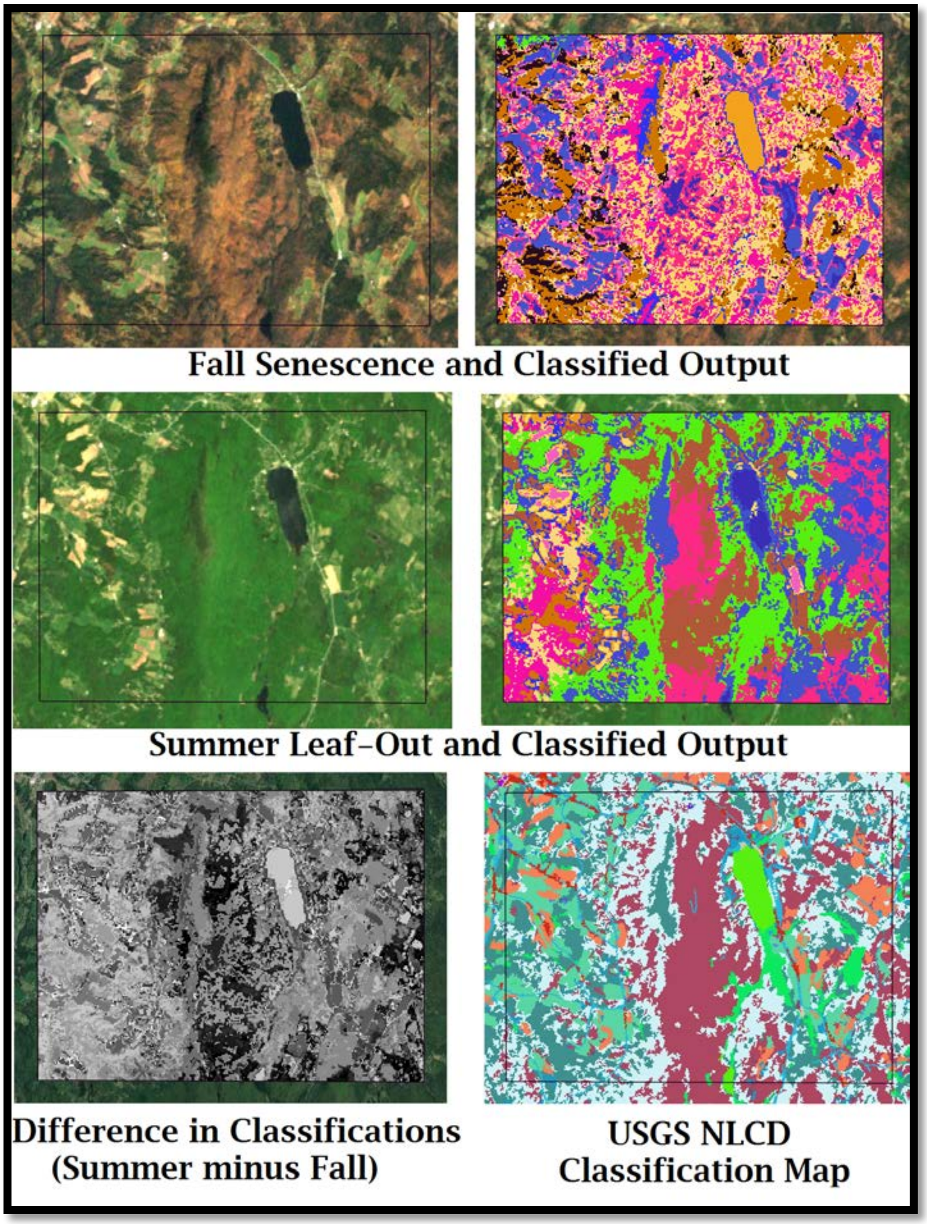

Figure 8. K-means unsupervised classification using leaf-out vs. senescence inputs.

The results showed an overall better performance by the autumn senescence input image at separating water and land, distinct agricultural plots, and evergreen forests (dark green on NLCD map), while the summer leaf-out input image was a better input for teasing apart deciduous and mixed forest types (maroon and white, respectively, on NLCD map). It seemed that the image from autumn could do very well with separating features with high contrast in RBG (such as water and yellow vegetation), but failed at distinguishing within colors (i.e. distinguishing vegetation cover types within the same color). The summer image was not as good at classifying the contrasting features, but performed very well within the same color (i.e. teasing apart vegetation classes all spectrally similar in RGB). This difference in performance is presumably related to the algorithm using all bands in its class separation, and in summer there is much more reflectance of NIR compared to other bands – a relationship that fades in contrast in to the fall as the leaves lose their ability to photosynthesize.

4. Discussion and Further Investigation

This paper assessed rates of senescence in the northeastern US. While temperature was not discovered to be correlated to the timing of changes in NDVI between the first and second half of each month, change in NDVI does not necessarily reflect optical coloration of leaves. This comparison of temperature data to pixel change could be better with PSRI or CIgreen indices. Moreover, senescence has been shown to correlate highly with longitude, and Landsat imagery did not always cover the exact same longitudinal range. Some issues with clouds could also be attributed to poor image products.

References

Cho, Moses A, et al. "Response of Land Surface Phenology to Variation in Tree Cover during Green-Up and Senescence Periods in the Semi-Arid Savanna of Southern Africa." *Remote Sensing*, vol. 9, no. 7, ser. 689, July 2017, pp. 1–19. *689*, doi:10.3390/rs9070689.

Hatfield, Jerry L., and John H. Prueger. "Value of Using Different Vegetative Indices to Quantify Agricultural Crop Characteristics at Different Growth Stages under Varying Management Practices." *Remote Sensing*, vol. 2, no. 12, 23 Feb. 2010, pp. 562–578., doi:10.3390/rs2020562.

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APPENDIX

https://code.earthengine.google.com/93a437a3811986adbb181c381cf06dff

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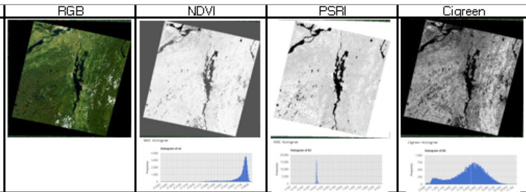
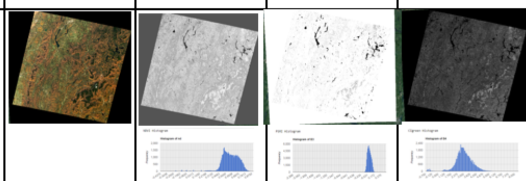
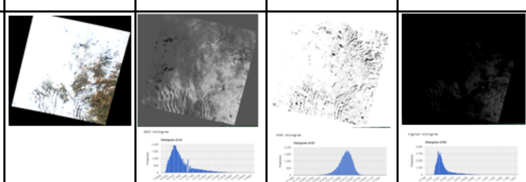
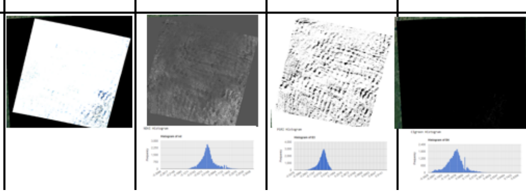
9/25/2000				
10/20/2000				
11/21/2000				
12/23/2000				

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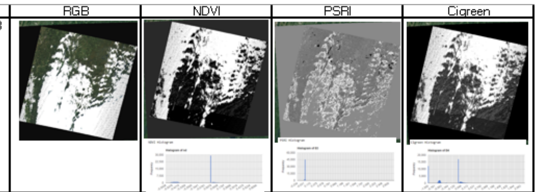
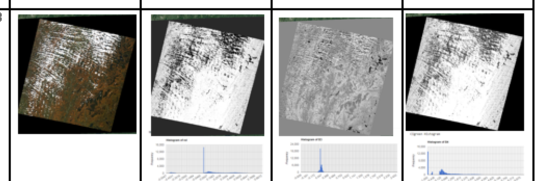
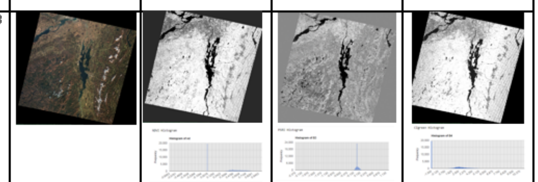
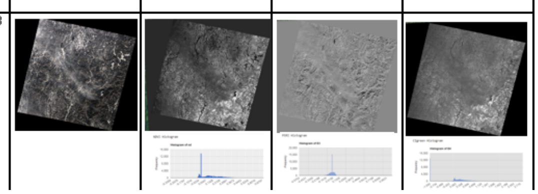
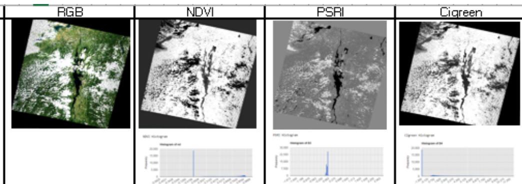
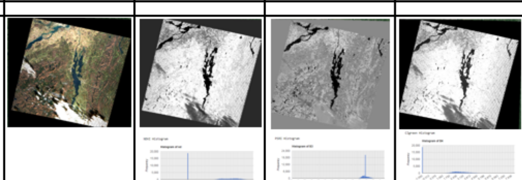
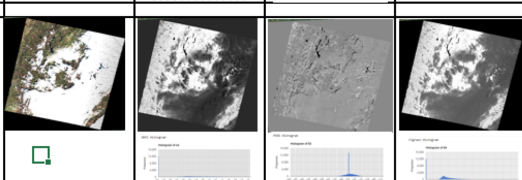
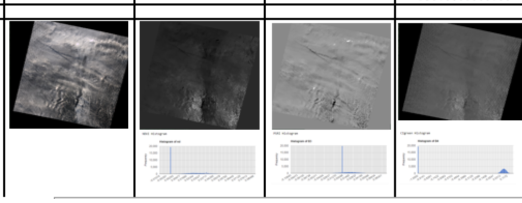
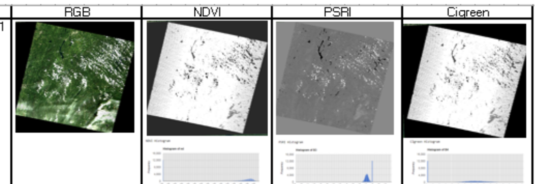
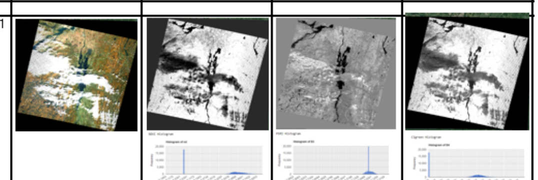
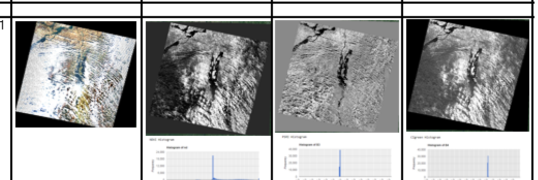
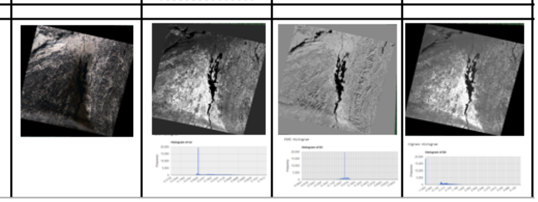
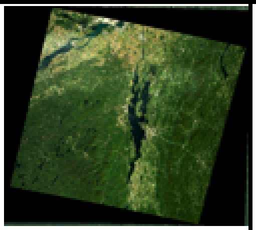
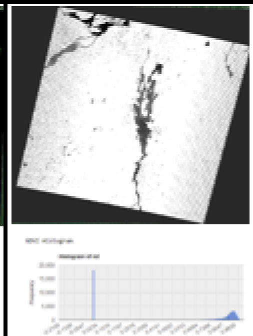
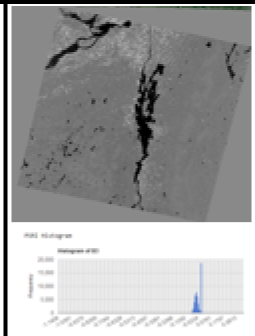
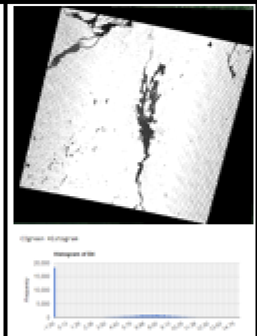
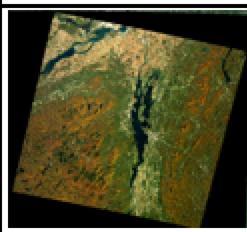
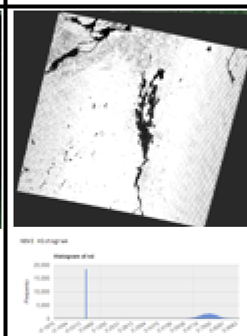
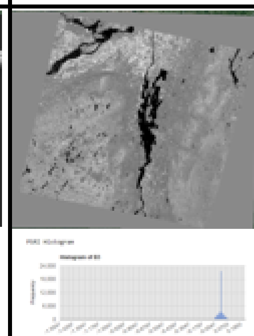
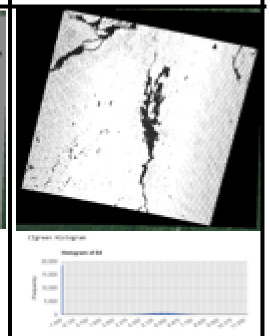
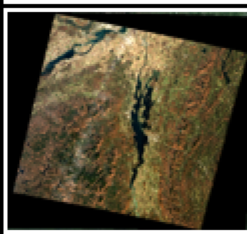
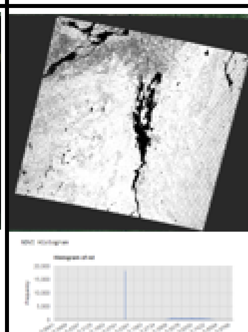
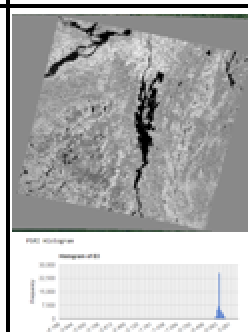
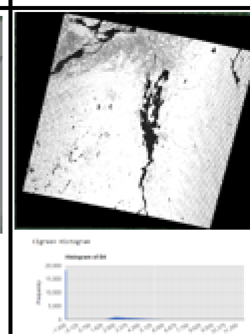
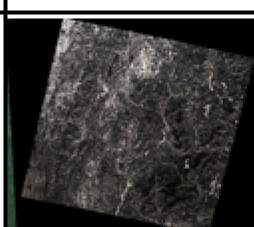
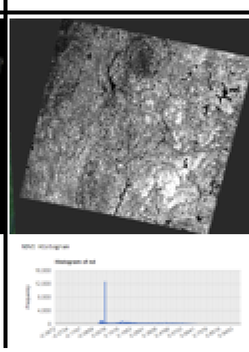
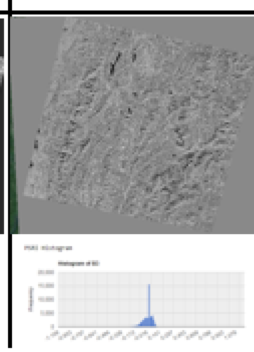
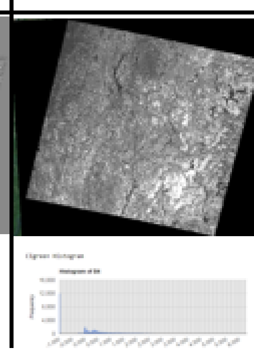
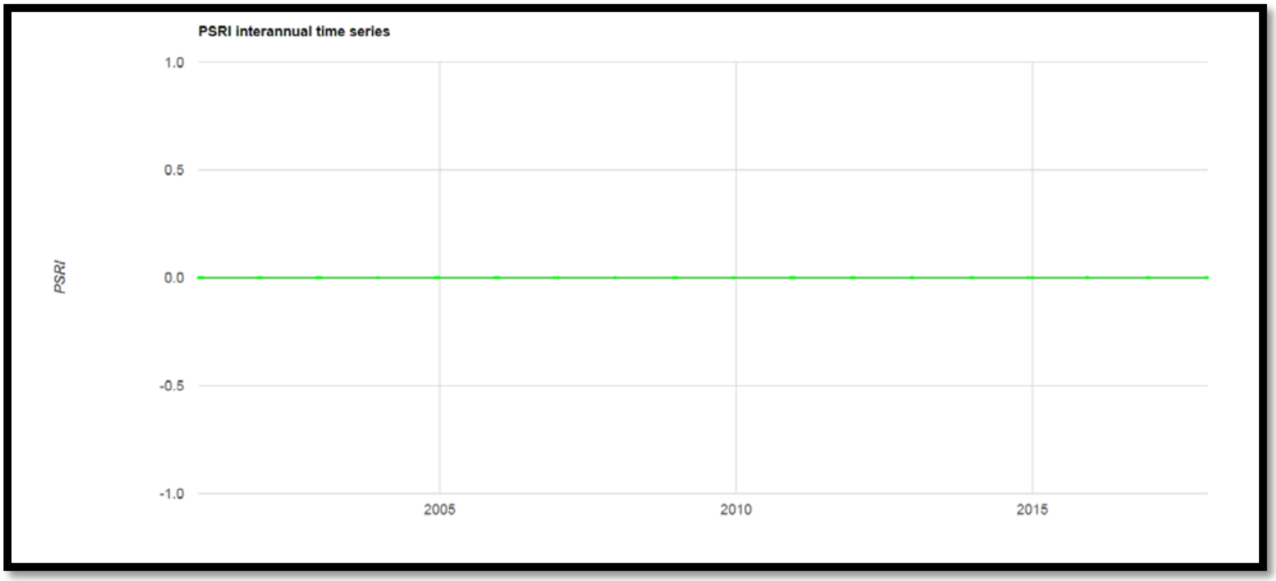
9/27/2003				
10/13/2003				
11/21/2003				
12/16/2003				

DATE	RGB	NDVI	PSRI	Cigreen
9/13/2007				
10/31/2007				
11/9/2007				
12/18/2007				

DATE	RGB	NDVI	PSRI	Cigreen
9/17/2011				
10/10/2011				
11/11/2011				
				

DATE	RGB	NDVI	PSRI	CIgreen
9/21/2016				
10/7/2016				
11/8/2016				
12/19/2016				



Attempted PSRI time series analysis. Could not map PSRI or CIgreen functions across image collection, as was performed with NDVI.