Assessing the Moment Distance Metric as an Indicator of Spring Green-up Using MODIS NBAR Data and Lilac/Honeysuckle Bloom Dates

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Abstract

We present a new metric called the Moment Distance (MD) that characterizes the shape of the reflectance curve in simple geometric operations. We compare lilac and honeysuckle phenophase sequences from 2008 then with 2007 with land surface phenologies described by NDVI and MD time series based on MODIS NBAR 0.05 degree data. The MD metric takes advantage of the seven bands available in the NBAR product and at each composite calculates the moment distances among the bands. Comparison between the NDVI and the MD reveals that MD can provide crisper identification of the timing of phenophase sequences. The disparity in spatial scale between the 0.05 degree MODIS data and the point observations is a source of potential error. However, if clonal plants are to be useful in sentinel networks, then the inference domain of the observations must extend beyond the immediate environmental neighborhood of the ground observations. Results also suggest that the onset of senescence may be clearly delimited due to the inclusion of both the visible and shortwave infrared bands in the MD calculation; however, we do not have ground observations of senescence at this point. We will be pursuing this analysis further with finer spatial resolution datasets.

Keywords: moment distance approach, distance matrix, MODIS NBAR, Lilac and Honeysuckle phenology

Introduction

Phenological data are often recorded as the start dates of phenology sequences that are measured in Julian days. For plants, these events often start at the leafing and flowering stages (Schwartz and Reiter, 2000).

There is too little information about the extent to which the end bloom phenology sequence of the lilac-honeysuckle. We monitored the timing of leaf emergence and blooming phases of lilac and honeysuckle that may provide insight into the species ecosystem responses to seasonal change. The Normalized Difference Vegetation Index (NDVI; Tucker, 1979) offers a way to look at the land surface phenologies using MODIS NBAR 0.05 degree data. We also use a new metric, Moment Distance, to provide include more spectral information toward detecting phenophase timing.

How does the MD compare against the NDVI in identifying phenophase timing? How sensitive are alternative formulations of the MD in detecting phenophase transitions? These questions led to our goals: (1) To compare lilac and honeysuckle spring phenophase sequences against the 2008 land surface phenologies described by NDVI and MD time series; and (2) To explore how the MD curve changes vis-à-vis the phenophase sequences when varying the number of MODIS bands input to the MD calculation.

Materials and Methods

MODIS NBAR 0.05 Degree Data

The MODIS NBAR data are 8-day maximum value composites within a 16-day window. The products are provided in global fields at a 0.05 degree resolution in geographic coordinates. MODIS product MCD43A4 provides 500-meter reflectance data adjusted using a bidirectional reflectance distribution function (BRDF) to model the values as if they were taken from nadir view. NBAR data are usually the primary input to MODIS land cover and phenology studies.

MODIS NBAR data includes 7 bands (Table 1) across the visible, near infrared, and shortwave infrared portions of the spectrum.

Table 1: MODIS bands and the corresponding wavelength locations. Each wavelength centers was utilized in this study.

Band	Bandwidth (nm)	Band Center (nm)
1	620 - 670	645
2	841 - 876	859
3	459 - 479	469
4	545 - 565	555
5	1230 - 1250	1240
6	1628 - 1652	1640
7	2105 - 2155	2130

Lilac and Honeysuckle Samples

We used 70 lilac and honeysuckle spring phenophase sequences collected in 2008 for the main investigation and utilized 57 samples from 2007 to verify trends (Table 2). Five phenophase sequences, representing two group events, leafing and flowering, were observed.

The phenophases consist of (1) First Leaf – the first emerging leaf, the date when lilac/honeysuckle leaves grow beyond their winter bud tips; (2) Leaf 95% – the date when growing leaf buds reach 95% growth; (3) First Bloom – when 50% of the flower clusters have at least one open fresh flower; (4) Full Bloom – the date when lilac/honeysuckle flowers reach maximum bloom development and no flower cluster remained unopened; and (5) End Bloom – when blossoms, around 95 to 100%, virtually have withered or dried up and the floral spectacle has ended. The five phases are described in number of days.

The Lilac and Honeysuckle datasets are part of the "Plant Phenology Programs" of the developing USA-National Phenology Network (www.usanpn.org) and will soon be available through that site. Data prior to 2004 are now available online through the USA National Climatic Data Center. Schwartz and Caprio (2003) discussed more details of the North American First Leaf and First Bloom Lilac phenology data.

Table 2: *Statistics of the Lilac and Honeysuckle datasets from 2008 and 2007.*

Phenophase Sequences	2008 (n = 70)			2007 (n = 57)		
	Mean	Max	Min	Mean	Max	Min
First Leaf (FL)	106.33	135	60	101.61	121	65
Leaf 95% (95%)	115.20	146	72	112.00	130	68
First Bloom (FTB)	132.47	161	100	126.36	145	79
Full Bloom (FLB)	139.33	173	103	133.10	149	89
End Bloom (EDB)	151.91	180	114	143.86	161	107

Normalized Difference Vegetation Index

The Normalized Difference Vegetation Index (NDVI) was used by Tucker (1979) to estimate leaf physiological variables for grasses. The index (eq. 5) uses Red and NIR bands to exploit the photosynthetic process occurring in leaves.

$$NDVI = \frac{(NIR - red)}{(NIR + red)} \quad (1)$$

Tapping the two most important bands in vegetation studies, plus the simplicity of the index, NDVI is one of the vegetation indices most successful in tracking vegetation phenologies. The start of the vegetation growing season, end of season, and length of growing season – are few metrics that could be roughly extracted from a time-series NDVI data (Reed et al., 1994; Myneni et al., 1997; Zhou et al., 2001) – regardless whether they are ground-based or satellite-based (Myneni et al., 1997; Schwartz, 1997; Ricotta and Avena, 2000; Schwartz et al., 2002).

Moment Distance Metric

The new Moment Distance (MD) was developed by Salas and Henebry (2xxx) that exploits a strategy based on refereed distance. The basic idea of the approach is simple and realistic: headlining the curve structure to analyze behavioral patterns. It detects the shape of the reflectance curve, despite sameness of features visually. The robustness in defining the curve is instituted by computing the refereed distances from two point locations designated as shorter and longer wavelength pivots (Fig. 1).

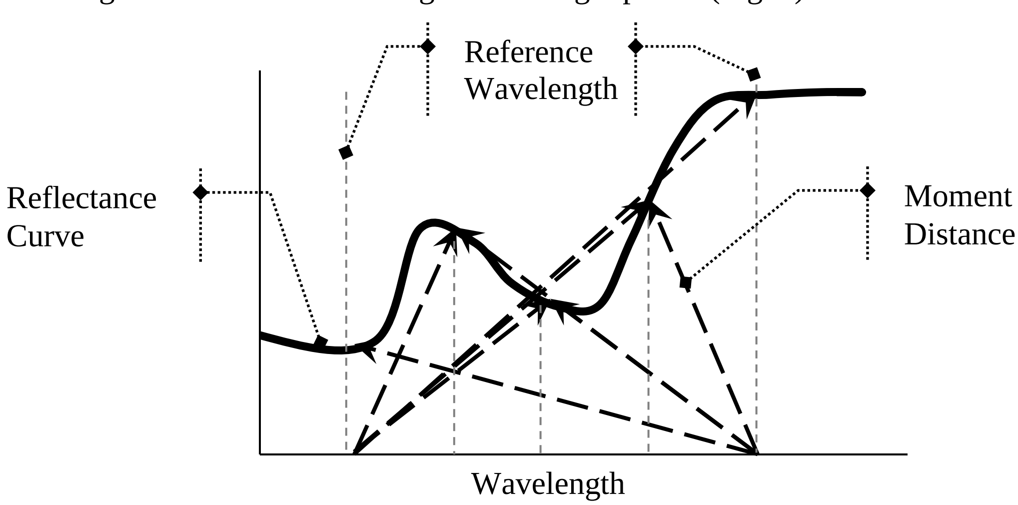

Figure 1: The concept of the Moment Distance metric involving diagonal lengths from the abscissa of a reference wavelength to a point on the reflectance curve.

Using a selected wavelength range bounded by the reference points, calculation of the Moment Distance metric follows equation 2:

$$MD_{x_1 x_2} = \sum_{x_1 \to x_2} MD - \sum_{x_2 \to x_1} MD \qquad (2)$$

where: x_1 = first reference wavelength point, x_2 = second reference wavelength point. The selected range represents could characterize vegetation biophysical or biochemical property or a behavior of vegetation development. As a distance-based approach to band analysis, MD could become an effective tool for enhancement and partitioning of minute but often significant differences in spectral reflectance that are not detected when using two-band or ratio-based indices.

Analysis

Using equation 2, we calculated MD values from the MODIS NBAR data to every sample from both years. We exploited the possibility of varying the number of MODIS bands used within the MD range to verify sensitivity of the new approach to the phenophase transitions. This is one of the advantages seen using the MD – its capability to supplement the loss or absence of an important band and still obtain satisfactory relationships. Thus, we tested its curve shape detection potential via deletion of bands, one or two at a time. Equivalent NDVI values were also calculated and plotted to track vegetation growing season. These parameters may not necessarily correspond directly to conventional, ground-based phenological episodes, but do afford clues of ecosystem dynamics. We put side by side the two measures and located the occurrence of the Lilac and Honeysuckle phenophase sequences along the curves. Slopes of both curves were also monitored within and outside the phenophases to understand correspondence, through r^2, between the two measures – where and why they diverge.

Results

MD vs. NDVI for Detecting Phenophase Timing

Using samples from the 2008 MODIS data, NDVI showed increasing values starting from around the 100th day and then peaked around the 200th day. MD had a fashion to flatten during the early days before it started to spike around the 140th day. We divided the samples based on the location of the phenophase and the timing of the curve peaks of the MD. The first group (70% of the samples) had EDB near or at the foot of the peak and the second group (30% of the samples) had EDB on the slope of the peak (Fig. 2).

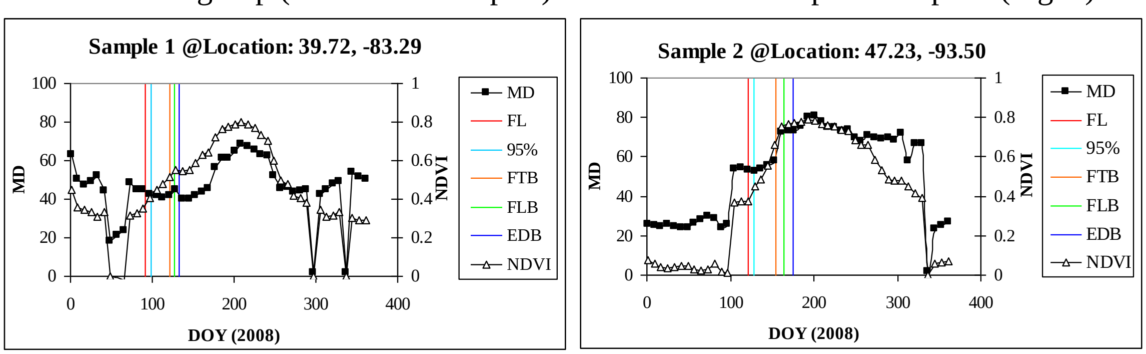

Figure 2: MODIS 2008 representative samples from two groups showing the MD and NDVI curves. Left – First group with EDB near or at the foot of the peak. Right – Second group with EDB on the slope of the peak. Colored vertical lines represent the five phenophase sequences. Note: MD uses 7 MODIS bands.

For the first group, the moment the EDB is reached, the MD curve begins to peak. The average EDB for the samples of the first group is 148 days. MD values during the blooming period range between the 40-60. The average EDB for samples in the second group is 161 days with MD curve flattening at the phenophase transitions less evident. At lower NDVI, MD is observed to flatten out (data not shown).

MD curves from the MODIS 2007 samples exhibit the same flattening of the MD around the phenophase range (Fig. 3). The average EDB for samples falling in the first group (55% of the samples) is 137 days, while for samples in the second group (45% of the samples) is 150 days.

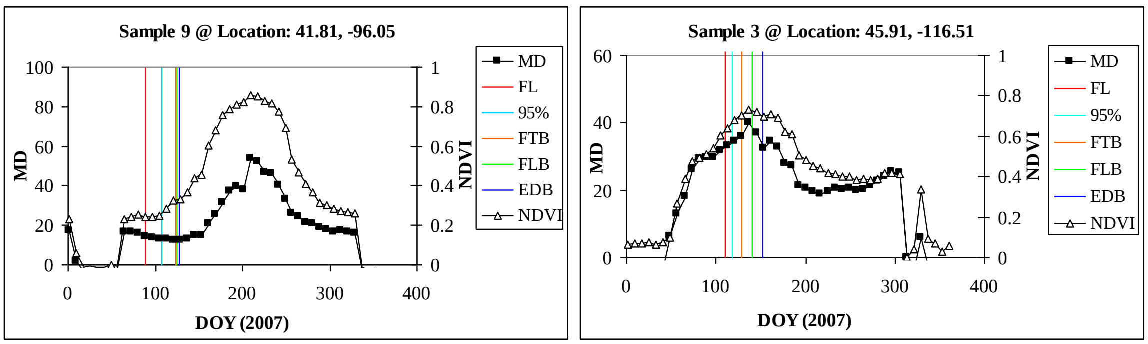

Figure 3: MODIS 2007 representative samples from two groups showing the MD and NDVI curves. Left – First group with EDB near or at the foot of the peak. Right – Second group with EDB on the slope of the peak. Colored vertical lines represent the five phenophase sequences.

Moment Distance has a lesser average correlation against the NDVI in the range 97 to 153 days, which covers the phenophase sequence, for both years, when compared to the average on later days of vegetation development (Fig. 4A for 2008 and Fig. 4C for 2007).

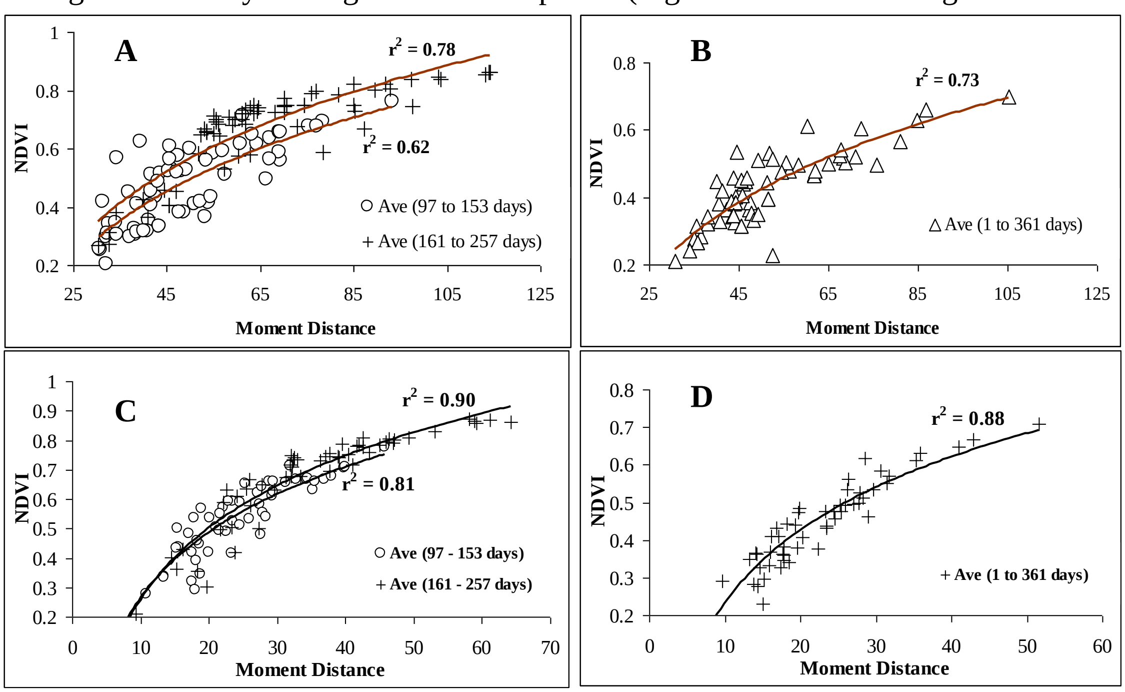

Figure 4: Relationships between MD and NDVI at different phenophase range days. Figures A and B were from the 2008 MODIS; Figures C and D were from 2007 MODIS.

The disparity is caused by the presence or absence of the flattening. MD vs. average NDVI considering all days (Figs. 4B for 2008 and 4D for 2007) still give strong relationships (r^2=0.73 and r^2=0.88, respectively). These results use 7 MODIS NBAR bands for 2008 and 6 MODIS NBAR bands for 2007.

MD Sensitivity in Varying Number of MODIS Bands

Figure 5 shows the behavior of the MD curve at various MODIS band combinations. Figure 5A used 6 bands, while 5B used combinations of 5 bands. The elimination of the red (645 nm) affected tremendously the shape of the curve to a point that the peak vanished and flattened from start to end of the vegetation season. Figure 5B showed the importance of red and NIR for vegetation studies, with leveling observed on the MD curve as well. Flattening within the phenophase sequences are clear at several band trials with the END unscathed near the foot of the peak.

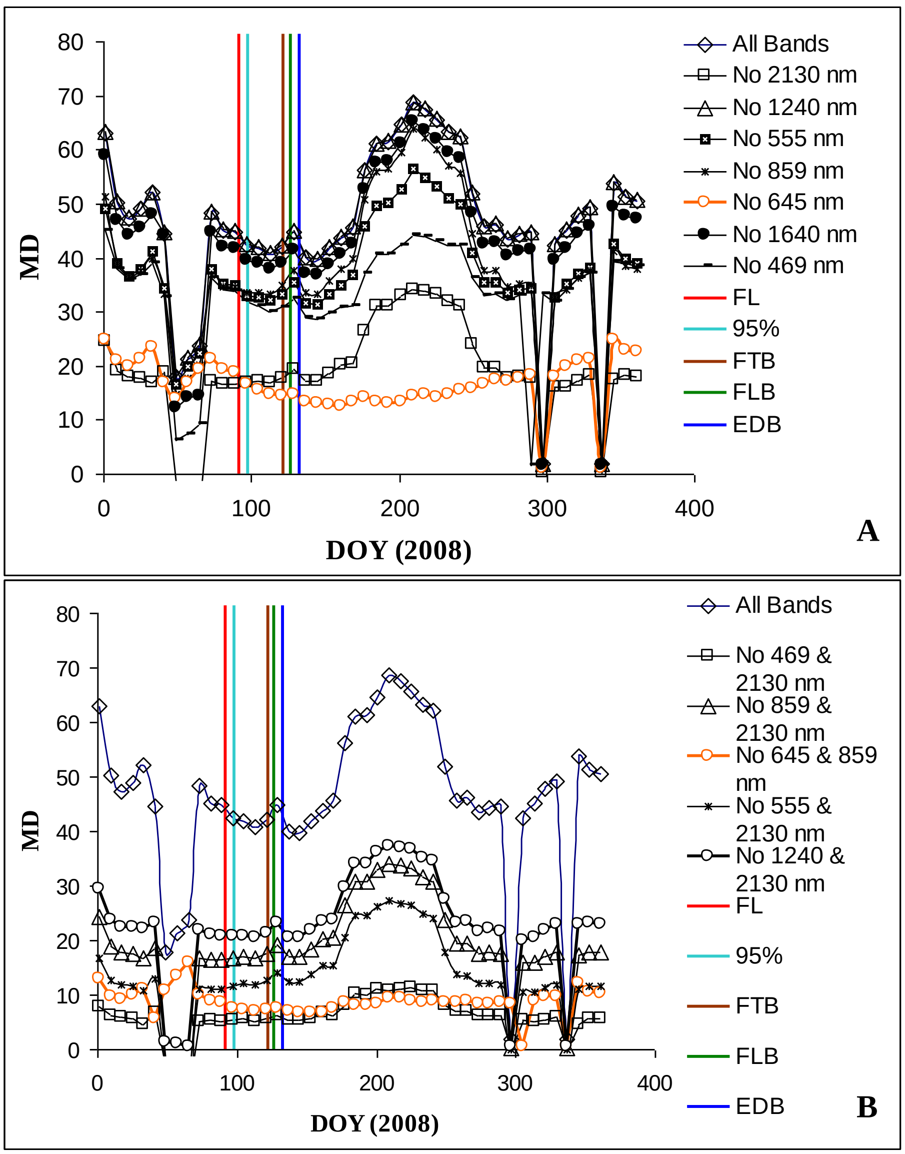

Figure 5: Moment Distance behavioral curves from various combinations of MODIS bands: (A) exploits the 6 band groupings, while (B) utilizes 5 bands one at a time.

Tables 3 and 4 provide the relationships of the MD against the NDVI at different range of days and at different bands combinations.

*Table 3: The 6-band combinations for MODIS-MD based on the MD average within the range considered: *Best combination; **'Very low' to 'No relationship' was evident for most of the range.*

No. of Bands	**r^2 (97-153 Days)**	**r^2 (161-257 Days)**	**r^2 (1-361 Days)**	**r^2 (97-257 Days)**	**Slope (97-157 Days)**	**Remarks**
7	0.62	0.78	0.73	0.76	0.60	All Bands
*6	0.86	0.92	0.92	0.89	0.76	No 2130 nm
6	0.72	0.83	0.81	0.75	0.65	No 1240 nm
6	0.73	0.83	0.80	0.76	0.57	No 555 nm
6	0.80	0.88	0.84	0.82	0.63	No 859 nm
6	0.71	0.84	0.81	0.77	0.67	No 1640 nm
6	0.72	0.77	0.75	0.76	0.70	No 469 nm
**6	NA	NA	0.31	NA	NA	No 645 nm

*Table 4: The 5-band combinations for MODIS-MD based on the MD average within the range considered: *Best combination; **Not advisable to omit the Red and NIR at the same time.*

No. of Bands	**r^2 (97-153 Days)**	**r^2 (161-257 Days)**	**r^2 (1-361 Days)**	**r^2 (97-257 Days)**	**Slope (97-157 Days)**	**Remarks**
7	0.62	0.78	0.73	0.76	0.60	All Bands
5	0.82	0.90	0.89	0.88	0.75	No 645 and 2130 nm
*5	0.86	0.92	0.92	0.89	0.76	No 859 and 2130 nm
**5	0.26	0.30	0.35	0.24	-0.13	No 645 and 859 nm
5	0.87	0.92	0.85	0.90	0.69	No 555 and 2130 nm
5	0.83	0.90	0.90	0.89	0.75	No 1240 and 2130 nm

Omission of band 7 (2130 nm) gave high values of r^2 for both 6-band and 5-band combinations and in all range of days. Deletion of the NIR band (859 nm) alone still gave a good correspondence with $r^2 \geq 0.80$. The absence of 859 nm and 645 nm in the computation of the MD, significantly affected the association with NDVI in all scales, especially at the phenophase time period ($r^2 = 0.26$). High r^2 were observed even without 1240 and 2130 nm.

The slope was positive in all trials except when omission of the Red was involved. No significant findings were seen for the 6-band combination, while an $r^2 = -0.13$ was seen when the Red and NIR were both deleted at the same time.

Figure 6 shows the different behavior of the MD in the absence of the 645 nm only or both 859 nm and 645 nm wavelengths. The r^2 for slopes at the phenophase sequence (97 to 153 days) for 99% of the samples in the 2008 dataset had low negative values, either with a 6-band combination (Fig. 6A) or a 5-band combination (Fig. 6B).

Discussion

The lilac and honeysuckle end bloom (EDB) phenophase shows a promise of remote detection with trends of the MODIS-derived MD flattening towards the beginning of the sequence, and then afterwards shooting to a peak after the onset of the EDB. The timing of the EDB phenophase vis-à-vis to the shape of the moment distance curve is shown to be happening in 70% of the 2008 samples and 55% of the 2007 samples (we labeled them as first group samples where EDB fell near or at foot of the MD peak). The second group, which contains 30% of the 2008 samples and 45% of the 2007 samples, was still observed to manifest flatness at the phenophase stages, however, at short span.

Playing on the number of MODIS bands to use for the MD calculation has revealed essential gauges in deciding the best band combination to monitor peaks and phase stages. Whether the option is to choose a 6-band or 5-band combination, the leveling found at the phenophase sequence was sustained, although at varying degrees. Varying the bands used also proved the importance of some bands in lilac and honeysuckle studies or for vegetation studies, in general.

Red and NIR, for instance, had to be incorporated at all times to avoid losing information crucial for the detection of plant development. Moment distance approach has shown the sensitivity of the curve to the Red wavelength most especially. Despite the importance of the NIR band, the Red has come out to be the chief mover of the form of the reflectance curve, where MD is based from. Leaving out the 645 nm band resulted into a massive curve deformation to a point of annihilation of the peak, as shown in Fig. 5.

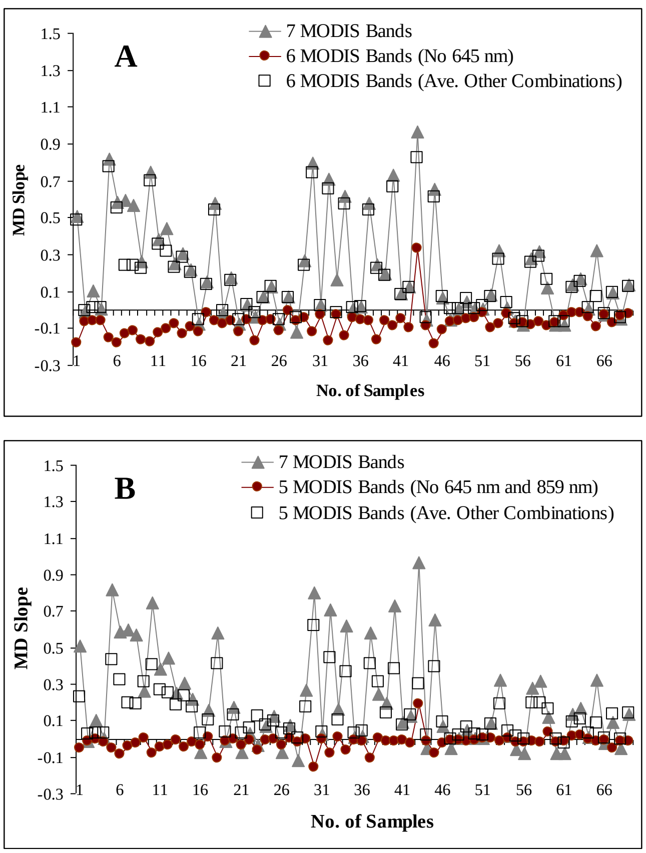

Figure 6: Analysis of the slopes at the phenophase sequence (97 to 153 days) when one band is deleted (A) and when two bands are deleted (B).

Observations with the omission of the 859 nm have indicated that, even in its absence, a useful MD curve was still attainable. Neighboring NIR bands (1240 nm and 1640 nm) showed almost identical results for all range of days, which could mean that either one could substitute for the other and emerge with conclusive results, nonetheless. Bands 859 nm, 1240 nm and 1640 nm tended to complement each other and compensate for the other’s absence.

Strong seasonal correspondence between MD and NDVI has been observed when days were divided into shorter range to isolate the phenophase sequence. Our results showed that MD is much more related to NDVI beyond the phase stages rather than the phase sequence itself. We have shown that the disparity has been generated by the opposing curve trends when NDVI was increasing compared to the flattening MD during the early days within the sequence. While NDVI missed to provide information at the stages of lilac and honeysuckle leafing and flowering phenology, MD showed positive indications of wider dynamic range in the late blooming season, despite the spatial limitations forced by the MODIS datasets. The timing of the phenophase sequence and the curve behavior of the MD suggested a close functional link between the two, which may not be observed with a broader NDVI.

Conclusions

With the promise of an advanced spaceborne imaging spectrometer as envisioned for the Decadal Survey mission HYSPIRE, the time is ripe to explore alternative approaches to summarizing spectra data into effective metrics. Results from this exploratory look at the use of MD for land surface phenology studies, suggests further investigation of MD is warranted. MD exhibits a wider dynamic range than NDVI later in the season, but it is unclear if this confers an advantage to detecting senescent phenophases.

The refereed-distance MD has the advantage over the two-band NDVI in defining the shape of the curve that could result to a more detailed spectral behavior. Also, MD takes credit in compensating missing bands with another neighboring comparable band. This edge makes the approach a stand-out in multi-spectral analysis, especially in cases when a wavelength that is needed to compute other two-band indices, are rendered useless.

Our results highlight the MD as an alternative approach to better understand land surface phenology in a simple, back-to-basic spectral analysis.

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