ISTANBUL TECHNICAL UNIVERSITY ★ EURASIA INSTITUTE OF EARTH SCIENCES

A STUDY OF THE CHANGES IN THE FOREST PHENOLOGY IN TURKEY THROUGH MODIS SATELLITE DATA

M.Sc. THESIS

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Thesis Advisor: Prof. Dr. Nüzhet DALFES

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ISTANBUL TEKNİK ÜNİVERSİTESİ ★ AVRASYA YERBİLİMLERİ ENSTİTÜSÜ

TÜRKİYE ORMAN FENOLOJİSİNDEKİ DEĞİŞİKLİKLERİN MODIS UYDU VERİLERİ ARACILIĞIYLA İNCELENMESİ

YÜKSEK LİSANS TEZİ

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Tez Danışmanı: Prof. Dr. Nüzhet DALFES

HAZİRAN 2018

Yetkin İPEK, a M.Sc. student of İTU Graduate School of Eurasia Institute of Earth Sciences, student ID 601161006, successfully defended the thesis/dissertation entitled "A study of the changes in the forest phenology in Turkey through MODIS satellite data", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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Date of Submission : 14 May 2018
Date of Defense : 8 June 2018

To Muffin,

FOREWORD

First and foremost, I would like to thank Prof. Dr. Nüzhet Dalfes for giving me this opportunity to work with him; as well as helping me with this project. His guidance and contribution to my studies and his lectures I attended has been invaluable towards my knowledge and carreer during my time in the department.

To follow, for all the years I have had since the beginning of college, I would like to thank Barış Bekdaş, Çağıl Koçana, Dilşad Dağtekin, Ece Sönmezler, Emre Can Aksakal, and Özge Yetiş for their friendship and continuing support. I will always value every moment we spent together and will always appreciate them for pulling me through each and every hardship we faced. I can only hope to be as good as they are as a person and hope for the continuity of our friendship in our future days.

More importantly, I would like to thank my dearest Derya, for being with me and supporting me since the day we met. Without her selflessness and neverending belief in me, the writing of this thesis and the future of my career would be in jeopardy. My only hope is to be able to always have her presence by my side and keep returning her kindness in both better or worse days.

Last but most importantly, I would like to thank my family for their support. Although at times I could not fully express my appreciation towards their love, goodwill and the sacrifices they made for me; I will always be grateful to them for raising me to be the person I am today. All my current and future work will be always dedicated to them.

May 2018 Yetkin İPEK

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ABBREVIATIONS

SGS	**:** Start of Growing Season
EGS	**:** End of Growing Season
MODIS	**:** Moderate Resolution Imaging Spectroradiometer
GRVI	**:** Green-Red Vegetation Index
NDVI	**:** Normalized Difference Vegetation Index
ASTER	**:** Advanced Spaceborne Thermal Emission and Reflection Radiometer
DOY	**:** Day of Year
EMA	**:** Exponential Moving Average

SYMBOLS

ρ	**:** Reflectance
α	**:** Smoothing factor
Y_t	**:** Observed value at time = t
S_t	**:** EMA value at time = t

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A STUDY OF THE CHANGES IN THE FOREST PHENOLOGY IN TURKEY THROUGH MODIS SATELLITE DATA

SUMMARY

The Start of Growing Season (SGS) marks the time of year where a type of plant starts its growing season; therefore, forming green leaves. The End of Growing Season (EGS) is the opposite, where plants end their growing seasons and start defoliation. The difference in green leaf changes are much more dramatic in deciduous forests than coniferous forests, all plants show annual differences after SGS and EGS. As all plants undergo SGS and EGS, they look for environmental cues in order to keep up with their annual cycles. To detect variations in SGS and EGS, MODIS imagery was used. MODIS satellites have a polar orbit and capture images in 7 spectral bands daily. To detect the SGS and EGS from MODIS satellite data by comparing the surface reflectance in red versus green through the GRVI index was used. The threshold for the detection of SGS and EGS is set to GRVI = 0. If GRVI > 0, then it is currently the growing season; if GRVI < 0 then it is the senescence season. Yearly GRVI estimates are analyzed to detect the SGS and EGS by catching GRVI zero crossing. We tried to detect the yearly shifts of SGS and EGS using this GRVI estimates. For these measurements, daily MODIS Terra MOD09GA V006 products were downloaded for the period 2007-2017, then analyzed through an R script using RASTER package. Noise reduction was applied on the results using Exponential Moving Average and the GRVI=0 crossings were detected. Later, the refined data were compared annually and among regions with different vegetation to look for SGS and EGS shifts over time. Although in all plots there were obvious peaks during Growing Season, in some cases of mountain ranges and coniferous forests, GRVI method was unable to detect SGS or EGS; as there was no 0 crossing. In the regions where GRVI was successful, SGS shifted to an earlier DOY and EGS shifted to a later DOY on a scale of 11 years. Overall, the GRVI has been successful in showing seasonal patterns in a given region.

TÜRKİYE ORMAN FENOLOJİSİNDEKİ DEĞİŞİKLİKLERİN MODIS UYDU VERİLERİ ARACILIĞIYLA İNCELENMESİ

ÖZET

Büyüme Mevsimi Başlangıcı yıl içerisinde bitkilerin büyüme döneminin – yeşil yaprak oluşumunun başladığı dönem – başlangıcıdır. Büyüme Mevsimi Sonu ise tam tersidir; bu dönemde bitkiler büyüme mevsimini bitirerek yaprak dökmeye başlar. Yeşil yapraklardaki değişim iğne yapraklı ağaçlara göre yaprak döken ağaçlarda çok daha büyük olsa da, tüm bitkiler her yıl BMB ve BMS'den sonra farklılıklar gösterirler. Bütün bitkiler BMB ve BMS'ye girdiklerinden dolayı, yıllık döngülerine uyabilmek için bazı çevresel işaretler ararlar. BMB ve BMS'deki değişiklikleri tespit etmek için MODIS görüntüleme kullanılmıştır. MODIS uydularının kutupsal yörüngeleri vardır ve görüntüleri günlük 7 yansıma bandında yakalarlar. BMB ve BMS'yi MODIS uydu görüntülerinden yeşil ve kırmızı yansıma farkına bağlı olarak tespit edebilmek için GRVI endeksi kullanılmıştır. BMB ve BMS tespiti için eşik değer GRVI=0'dır. GRVI>0 ise büyüme mevsimidir; GRVI<0 ise yaprak dökümü mevsimidir. Yıllık GRVI tahminleri GRVI değerinin sıfırı geçtiği noktaları yakalayarak BMB ve BMS'yi tespitte kullanılmıştır. BMB ve BMS'deki yıllık kaymaları tespit edilmesinde yapılan GRVI hesaplamaları kullanılmıştır. Bu ölçümler için, günlük MODIS Terra MOD09GA V006 ürünleri 2007-2017 yılları aralığı için indirilmiş, sonra da bir R kodu ile RASTER paketi kullanılarak analiz edilmiştir. Sonuçlarda çeşitli sebeplerden dolayı ortaya çıkan kirlilik Üssel Hareketli Ortalama yöntemi kullanılarak giderilmiş, sonrasında ise GRVI=0 noktaları tespit edilmiştir. Sonrasında sadeleşen veriler BMB ve BMS'lerin zaman içerisindeki kaymalarının analizi için yıllık olarak ve bölgeler arası karşılaştırılmıştır. Çalışılan bütün bölgelerde Büyüme Mevsimi sırasında değerlerde artış görülse de, dağlık ve iğne yapraklı orman benzeri alanlarda GRVI yöntemi BMB ve BMS tespitinde yetersiz kalmıştır; çünkü değerlerde GRVI=0 noktaları bulunamamıştır. GRVI'ın başarılı olduğu bölgelerde ise, 11 senelik bir aralıkta BMB'nin daha erken bir tarihte, BMS'nin ise daha geç bir tarihte meydana geldiği gözlenmiştir. Genel olarak, GRVI ele alınan bir bölgede mevsimsel rutin değişikliklerin tespitinde başarılı olmuştur.

1. INTRODUCTION

The growing season in a part of the year which optimal conditions are met - such as photoperiod, temperature or rainfall – that allows plant growth. In plant phenology, all plants undergo a yearly cycle; where they start forming green leaves and flowering after these conditions are met. On the other hand, whenever these conditions fall below an optimal range of the plant, the plant starts senescence; as its leaf colors gradually turn yellow and red, before defoliation begins. While the phenological changes of some plants (i.e. deciduous forests) are much more visually apparent than others (such as evergreen coniferous forests), all plants undergo a yearly cycle [1].

On their yearly cycles, plants have specific dates of the year where environmental conditions become optimal for them to grow; and specific dates that environmental conditions fall below their optimal range that senescence starts. In phenology, these dates of the year are named as the Start of Growing Season (SGS) and the End of Growing Season (EGS). To keep up with these yearly cycles, all plants follow their environmental cues. The most important of these cues are photoperiod and temperature [2].

With the effect of climate change, monthly temperature means gradually increase between years. As a result, the temperature requirement for SGS is met at an earlier day of the year; for the overall temperature of a region is higher than a year before. The opposite can be said about the EGS – that it occurs at a later day of the year; for the temperature falls below the senescence threshold at a later date [3].

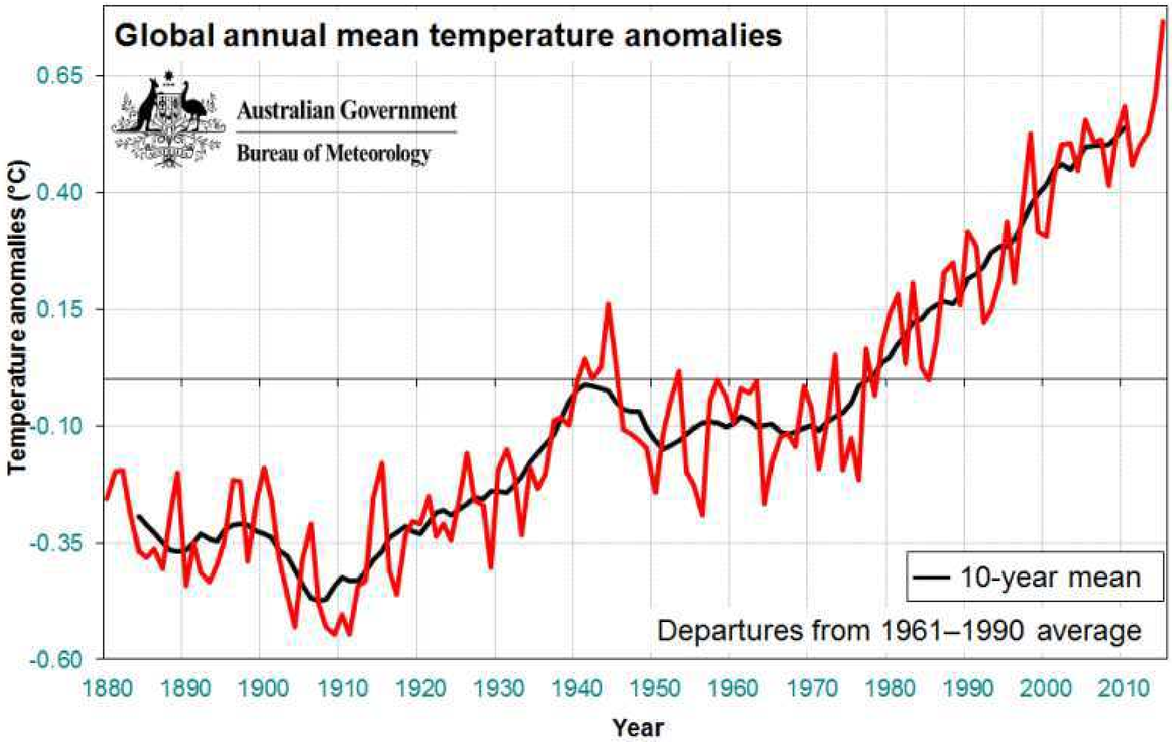

Figure 1: Global annual mean temperature measurements (the 0 value corresponds to 1961–1990 average) [4].

To detect the shifts of SGS and EGS dates, along with a correlation with climate change, a method that can be applied to multiple years is required. An easy way to measure changes in green leaf phenology and model these changes across multiple years is using remote sensing. The changes in leaf color can easily be detected across a color gradient using specific wavelength that these colors reflect to. Multiple methods can be used to obtain these measurements (such as fish-eye cameras or satellite imagery). On the other hand, an index that allows for the estimation of SGS and EGS from these measurements is also required. While there are many varying methods as the NDVI are already present, the most sensitive method to measure green-to-red changes is the GRVI index as in equation 1.1 [5].

$$GRVI = \frac{\rho_{green} - \rho_{red}}{\rho_{green} + \rho_{red}} \tag{1.1}$$

On this scale the threshold for the detection for SGS and EGS is GRVI = 0.

If GRVI > 0, then it is currently the growing season.

If GRVI < 0 then it is currently not the growing season.

As the reflectivity of green responds to 500-570 nm and the reflectivity of red responds to 620-700 nm, the responding ground cover types can be classified as:

- Green vegetation (conifers, deciduous trees, and grass): ρ_{green} is higher than ρ_{red}.
- Soils (brown sand, silt, and dry clay): ρ_{green} is lower than ρ_{red}.
- Water/snow: ρ_{green} and ρ_{red} are mostly the same [2,3,5].

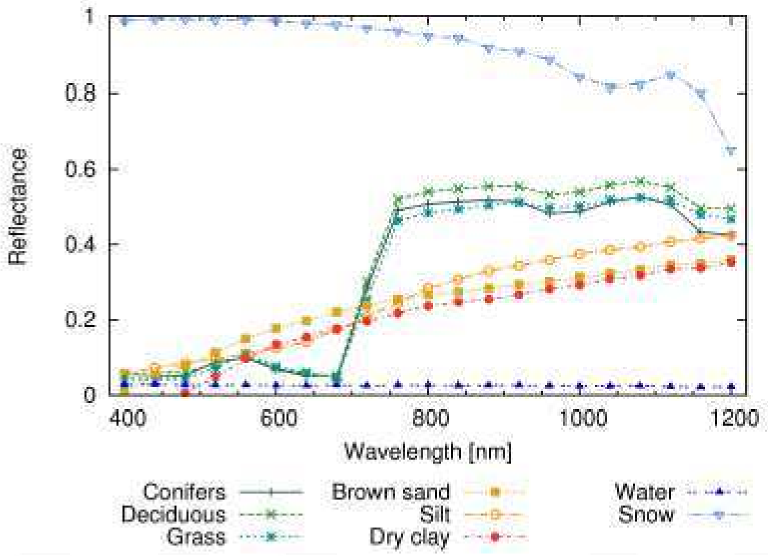

Figure 2: Reflectance of different vegetation types and ground cover. Original data had been retrieved from the ASTER library [5,6].

The Moderate Resolution Imaging Spectroradiometer (MODIS) is an instrument aboard the NASA Terra and Aqua satellites. The Terra and Aqua satellites have polar orbits and cross the equator in opposing directions; viewing the Earth's surface daily in 36 spectral bands [7]. With its daily imaging and recording, the instrument is vital to gain accurate data of Earth's surface. Ranging from the detection of snow cover to the detection of chlorophyll presence, the wavelength measurements allow for both qualitative and quantitative ground cover analyses [8].

The detection of the exact dates of the SGS and EGS can be performed by using MODIS reflectance data. If the green reflectance and the red reflectance imagery are used on the GRVI scale, the numerical average where GRVI = 0 gives the day of SGS/EGS [3].

2. MATERIALS AND METHODS

For these measurements, daily MODIS Terra MOD09GA V006 data was downloaded for a span of years 2007-2017. The data was requested in GEOTIFF format and without any changes in the projection method. It was also requested for the images to be cropped to only include Turkey region from granules h20v04, h20v05, h21v04 and h21v05. Only bands 1 and 4 were requested to include the green reflectance and red reflectance measurements (Appendix A). The sent data was then analyzed in R programming with the utilization of the RASTER package to utilize the data numerically (Figure 3).

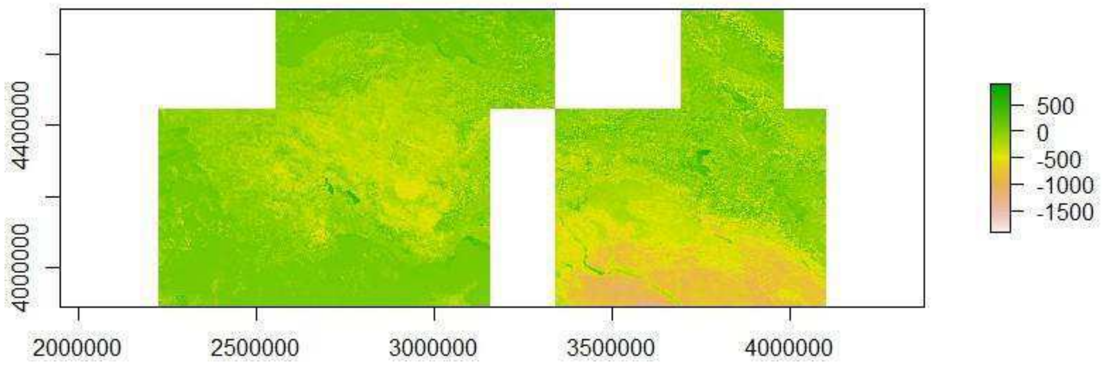

Figure 3: GRVI image of 31 December 2007, shown in RASTER.

From each RASTER image, 5 test areas were cropped to detect the average daily GRVI estimates (Table 1):

Table 1: Cropped region for each test area; based on the RASTER location index.

Region/Index	Aegean	Black Sea	Mediterranean	Central A.	Eastern A.
West	2400000	3000000	2700000	2900000	3500000
East	2500000	3300000	2900000	3000000	3600000
South	4300000	4500000	4100000	4300000	4300000
North	4400000	4550000	4160000	4400000	4400000

Yearly GRVI plots were drawn from the numerical data and for the detection of SGS and EGS. As it could interfere with the raw data, no maskings against cloud/snow covers were applied. As cloud cover interferes with reflection greatly, this resulted in a high noise in the data which made the detection of SGS and EGS highly difficult. However, despite the noise, the increases and decreases in the GRVI was still visible. To counter this problem, Exponential Moving Average method was applied. This filter takes into account a given period and applies a recurring average of said period. As the period can be between 0 and 1 (in this case, between 0 and 365); a higher value performs a better smoothing but tends to ignore small shifts in the data, while a small value does little smoothing and therefore does not clean up the noise [9].

$$S_t = \begin{cases} Y_1, & t = 1 \\ \alpha \cdot Y_t + (1-\alpha) \cdot S_{t-1}, & t > 1 \end{cases} \tag{2.1}$$

As seen on equation 2.1; α is the smoothing factor, Y_t is the observed value at time = t and S_t is the EMA value at time = t.

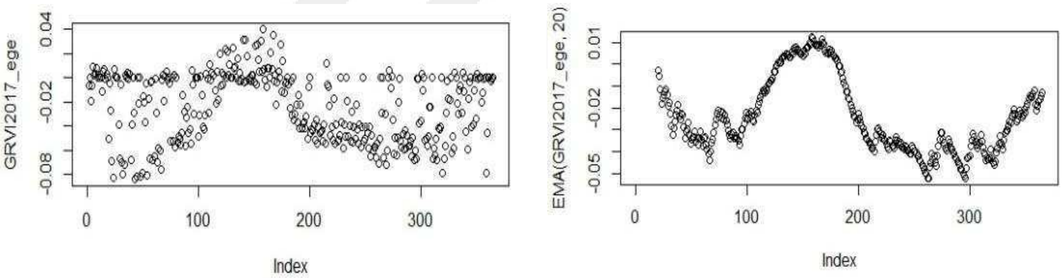

Figure 4: (a) GRVI2017 calculations of year 2017 (b) EMA results of GRVI from year 2017.

As can be seen on Figure 4, the reduction of noise has allowed for the estimation of SGS and EGS dates, as DOY where GRVI=0 is now observable. The smoothing factor α was selected for a period of 20 days for optimal smoothing and retention of the increase and decrease in the data. From these estimations, SGS and EGS dates were recorded and shifts were analyzed.

3. RESULTS

As can be seen on figure 3, all data sent from NASA contained spatial losses around Thrace, Eastern Black Sea and South Central Anatolian regions. However, as GEOTIFF files contain geographical indexes inside, a mosaic of the requested regions did not cause any shifts, only losses in the data. For each day, the combined GEOTIFF images were cropped for different regions for testing, and GRVI plots were drawn for each region for each year (Appendix B). Appendix C contains the GRVI plots for each five selected regions (Aegean, Black Sea, Mediterranean, Central Anatolia and Eastern Anatolia), along with the plots after EMA filtering.

As seen on all the figures, the GRVI and EMA results show significant seasonal patterns. All figures show an increase in GRVI after around day 100 and a decrease after the Growing Season ends. There is also a loss of years 2009 and 2013 due to requested files being corrupt in format. Also, the year 2008 has a loss of data after day 137 and the year 2012 has a loss of data after day 180, because of the same reason. Another important result is, while the Mediterranean and Central Anatolian regions show clear seasonal increase in GRVI after day 100, the overall plot fails to ever exceed GRVI=0. Because of this, these 2 regions could not have been measured for SGS and EGS detection. The remaining 3 regions – Aegean, Black Sea and Eastern Anatolian – were checked after EMA filtering and the first days to exceed and fall below GRVI=0 were recorded as SGS and EGS, respectively (Table 2).

Table 2: SGS and EGS GRVI estimates of Aegean, Black Sea and Eastern Anatolian test regions, years 2007-2017.

SGS				EGS			
	Aegean	Black Sea	Eastern Anatolian		Aegean	Black Sea	Eastern Anatolian
2017	128	119	159	2017	182	236	160
2016	108	110	144	2016	149	244	168
2015	125	121	138	2015	193	310	165
2014	123	118	149	2014	158	234	152
2013	-	-	-	2013	-	-	-
2012	124	119	-	2012	173	-	-
2011	103	124	147	2011	179	313	182
2010	121	115	147	2010	133	291	155
2009	-	-	-	2009	-	-	-
2008	121	111	-	2008	-	-	-
2007	-	130	-	2007	-	300	-

Aside from the missing years, the Aegean region did not have an SGS or EGS point on year 2007 and has a missing EGS point on year 2008 (due to missing data). The Black Sea region has missing EGS points on years 2008 and 2012 (due to missing data). The Eastern Anatolian region did not have an SGS or EGS point on years 2007, 2008 and 2012 (due to missing data and low reflectance signal). The available SGS and EGS data were plotted (Figure 5):

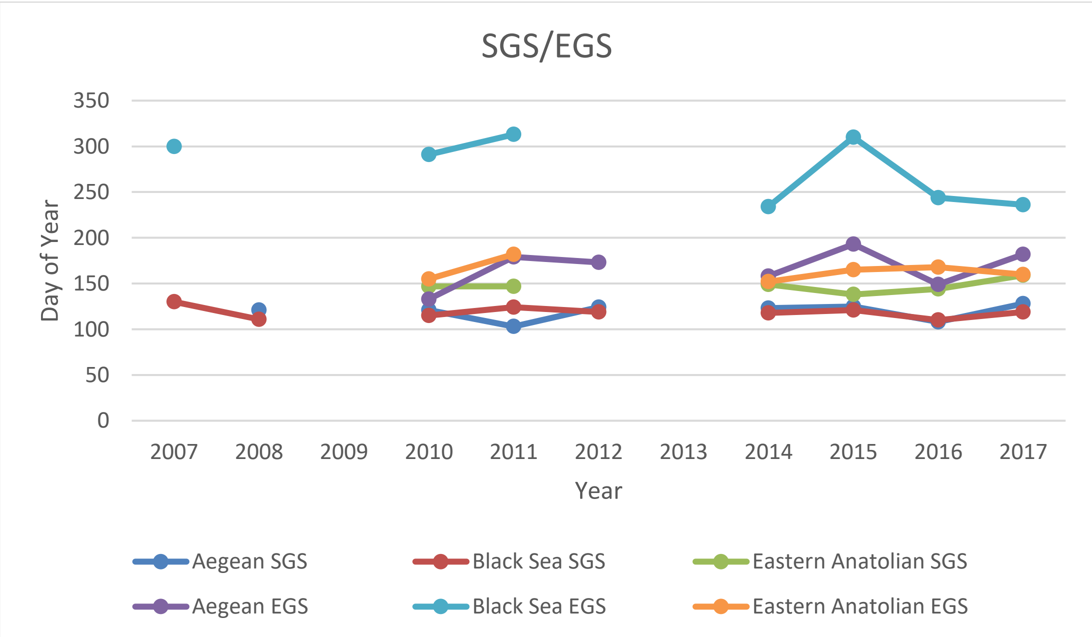

Figure 5: SGS and EGS estimates of Aegean, Black Sea and Eastern Anatolian regions, years 2007-2017.

4. DISCUSSION

GRVI is a method applicable for remote sensing equipment, which derives the start and the end of the growing season through the presence of green leaves. This presence, while under green reflectance wavelengths, gives positive numerical values. On the other hand, absence of greenness gives way to the appearance of red leaves, tree bark or the soil underneath; giving positive numerical outcomes under red reflectance wavelengths. So, in a manner, the GRVI index is dependent on the ratio of chlorophyll to the total area in a given region [5].

In this study, 5 test regions were selected. This selection was made depending on different climatic conditions, lattitudes and altitudes of characteristic regions of Turkey. The Aegean, Central Anatolian and Eastern Anatolian regions were selected to be on the same latitude; but to have a different effect of sea proximity and altitude. While the Aegean region is the closest to the sea, the Eastern Anatolian region has the highest altitude. On the other hand, the Mediterranean and the Black Sea regions have a greater proximity to water, but also have high sloped mountain ranges that altitude increases quickly [10,11].

The vegetation consists of maquis shrubs on the Aegean region, where mild rainy winters are followed by hot dry summers. Similar climatic conditions are also dominant on the Mediterranean region. However, due to high altitude on the mountain ranges, most of these areas are covered with pine species as opposed to the coastal region (Red Pine / Black Pine species). On the north, the Black Sea region is covered with deciduous forests (such as *Fagus orientalis*), and pine species at high altitudes; while having a wet rainy annual climate. The Central and Eastern Anatolian Regions are made up of steppes and dry forests; while having hot arid summers and cold snowy winters [12]. The selected regions were kept to a relatively medium-size; larger testing areas may have lost their regional characteristics while smaller testing areas may have had too much interference from cloud formation and seasonal variation.

All regions, under GRVI application, showed clear seasonal trends annualy. As snow cover reflectance results in approximately GRVI=0, all regions start the year with around GRVI=0. Between days 60-100, snow cover melts, revealing soil and reducing the GRVI value below 0. For each region, around after day 100, GRVI starts to increase as the green-up begins and vegetation slowly starts to form green leaves. (SGS is recorded during this incline). Around day 180, the GRVI reaches its peak, starting to decline after that point (EGS is recorded during this decline). After around day 300, GRVI slowly starts to rise back up to 0, as snow cover is formed again [3, 5].

As all regions show these trends, the Mediterranean and Central Anatolian regions have failed to ever reach, or rise above, GRVI=0. While a clear seasonal pattern was observed after the green-up, the green reflectance could not exceed the red reflectance. As the Mediterranean region has mostly needleleaf pine forests, a (mostly) rainless growing season, and high-altitude mountain ranges, it is possible to say that the green leaf reflectance signal cannot be enough for GRVI detection for SGS and EGS. The same occurrence can be observed in the Central Anatolian region, as savannah and dry forest fauna cannot give a strong reflectance signal; allowing for mostly red reflectance due to underlying soil [12].

The Aegean and the Black Sea regions give out strong GRVI values, along with SGS and EGS estimates. The Black sea region has the longest seasonal length spanning over 100 days because of the high annual rainfall. In comparison, the Aegean region has similar SGS dates but much earlier EGS dates because of the arid summer climate which causes leaves to dry out at an earlier day of the year. The Eastern Anatolian region has the shortest season length (around 20 days on the GRVI estimates), caused by long and harsh winter conditions followed by hot and arid summers. This results in later SGS but earlier EGS dates [10, 11, 12].

The recorded SGS and EGS dates have some observable shifts over time. As the final estimates of 2017 are similar to the initial estimates of 2007-2008, it is also recorded that the mean annual temperature of 2017 was much lower than its predecessors, 2016 and 2015 [13]. This has resulted in a later SGS and earlier EGS. With this knowledge, the estimated SGS shift for the Aegean region is 13 days between 2008-2016. For the Black Sea region, the SGS shift is 20 days between 2007-2016. And for the Eastern Anatolian region, the SGS shift is 3 days between 2010-2016. As all EGS shifts are towards an earlier date, the impact of climate chance can be considered for these results. On the other hand, the EGS shifts are also estimated. For the Aegean region, the EGS shift is 16 days between 2010-2016 and for the Eastern Anatolian Region, the EGS shift is 13 days between 2010-2016. The EGS data for the Black Sea has yielded no considerable results for a shift over time. As the season length is much longer than other regions, and there is much more annual cloud cover due to high precipitation, the data for an EGS estimation did not provide any meaningful results.

The GRVI index has been useful in terms of seasonal estimates. Before and after the utilization of the EMA filter, the seasonal increases and decreases are easy to see on the graphs. However, more experimentation is required to optimize the applicability of the GRVI index to all regions of Turkey. Firstly, there is a lot of noise in the data, as cloud contamination results in different reflectance values while simultaneously covering the soil below. In future experiments, it can be considered to apply a cloud filter before analyzing the data. However, any filtering of this sort can also interfere with the raw data, as the ground cover values may also be changed during filtering. Secondly, as MODIS data accumulates, measurements over longer periods can be performed, resulting in more statistically accurate estimates for longer time spans. This study was performed over a span of 11 years, and with the missing data from the request, it is difficult to perform a statistical analysis on SGS and EGS shifts. Finally, the problem of "GRVI not exceeding 0" can be resolved by analyzing more specific regions of broadleaf forests, or by cross-examination with other indexing methods such as the NDVI. As red reflectance from the soil keeps the overall GRVI value under 0, this particular indexing method may be inefficient in the analysis of coniferous, savannah or dry forest flora types.

5. CONCLUSION

This study has been conducted in order to see the applicability of the GRVI index on determining the season start and end dates; as well as season length and variation of greenness between regions. To detect the GRVI signals from regions, MODIS satellite bands 1 and 4 were used in order to compare red versus green, respectively. The study was performed to check for the applicability of the GRVI rather than to find specific estimates for SGS and EGS dates. While GRVI plots showed clear seasonal trends, cross checks with specific species distributions and other methods for SGS and EGS detection still need to be performed.

Climate change has a dramatic impact on the environment; changing annual cycles and altering ecological processes. One of the most important effects of climate change is its effect on phenology. As yearly cycles start to shift, all the ecosystem tries to – and may fail to – adapt to the new conditions. On plant phenology, the most important effect of the climate change is the changes in the beginning and the end of plants' growing seasons. As utilized in this study, the Green-Red Vegetation Index (GRVI) is a clear way to observe annual cycles and the changes in these cycles over time, through a variety of remote sensing instruments. In future studies, the GRVI methodology can be improved by using more accurate filtering methods, using larger data over longer year spans and by employing other indexing methods as control groups.

REFERENCES

[1] **Growing Season** (n.d.). *National Geographic Encyclopedia.* Retrieved from: https://www.nationalgeographic.org/encyclopedia/growing-season/

[2] **Kobayashi et. al.** (2015). Latitudinal gradient of spruce forest understory and tundra phenology in Alaska as observed from satellite and ground-based data. Remote Sensing of Environment. p. 177 (2016) 160–170

[3] **Nagai S., Saitoh T.M., Nasahara K.N., Suzuki R.,** (2014). Spatio-temporal distribution of the timing of start and end of growing season along vertical and horizontal gradients in Japan. DOI: 10.1007/s00484-014-0822-8

[4] **Annual Climate Statement 2015,** (2016). *Australian Government Bureau of Meteorology.* Retrieved from: http://www.bom.gov.au/climate/current/annual/aus/2015/

[5] **Motohka T., Nasahara K.N., Oguma H., Tsuchida S.,** (2010). Applicability of Green-Red Vegetation Index for remote sensing of vegetation phenology. *Remote Sensing.* DOI: 10.3390/rs2102369

[6] **Spectral Library,** (n.d.). *NASA California Institute of Technology, Jet Propulsion Laboratory.* Retrieved from: https://speclib.jpl.nasa.gov/library

[7] **Moderate Resolution Imaging Spectroradiometer - About** (n.d.). *National Aeronautics and Space Administration Website.* Retrieved from: https://modis.gsfc.nasa.gov/about.php

[8] **Moderate Resolution Imaging Spectroradiometer** (n.d.). *NASA Terra Website.* Retrieved from: https://terra.nasa.gov/about/terra-instruments/modis

[9] **Dealing with Measurement Noise: Exponentially Weighted Moving Average Filter** (n.d.). *Newcastle University, School of Chemical Engineering and Advanced Materials.* Retrieved from: http://lorien.ncl.ac.uk/ming/filter/filewma.htm

[10] **Turkey** (n.d.). *Weather Online Website.* Retrieved from: https://www.weatheronline.co.uk/reports/climate/Turkey.htm

[11] **Seasons and Weather, Climate in Turkey** (2014). *National Parks of Turkey.* Retrieved from: http://nationalparksofturkey.com/seasons-and-climate-in-turkey/

[12] **Atalay I.,** (1986). Vegetation formations of Turkey. *Travaux de l'Institut de Géographie de Reims.* 65-66. pp. 17-30

[13] **2017 Yılı İklim Değerlendirmesi** (2018). *T.C. Orman ve Su İşleri Bakanliği Meteoroloji Genel Müdürlüğü.*

APPENDICES

APPENDIX A: MODIS spectral bands

APPENDIX B: R code utilized for GRVI index

APPENDIX C: Yearly R plots of GRVI for 5 regions of Turkey, 2007-2017

APPENDIX A:

Table A.1: MODIS spectral bands on wavelength and usage.

Primary Use	Band	Bandwidth	Primary Use	Band	Bandwidth
Land/Cloud/Aerosols Boundaries	1	620 - 670	**Surface/Cloud Temperature**	20	3.660 - 3.840
	2	841 - 876		21	3.929 - 3.989
Land/Cloud/Aerosols Properties	3	459 - 479		22	3.929 - 3.989
	4	545 - 565		23	4.020 - 4.080
	5	1230 - 1250	**Atmospheric Temperature**	24	4.433 - 4.498
	6	1628 - 1652		25	4.482 - 4.549
	7	2105 - 2155	**Cirrus Clouds Water Vapor**	26	1.360 - 1.390
Ocean Color/ Phytoplankton/ Biogeochemistry	8	405 - 420		27	6.535 - 6.895
	9	438 - 448		28	7.175 - 7.475
	10	483 - 493	**Cloud Properties**	29	8.400 - 8.700
	11	526 - 536	**Ozone**	30	9.580 - 9.880
	12	546 - 556	**Surface/Cloud Temperature**	31	10.780 - 11.280
	13	662 - 672		32	11.770 - 12.270
	14	673 - 683	**Cloud Top Altitude**	33	13.185 - 13.485
	15	743 - 753		34	13.485 - 13.785
	16	862 - 877		35	13.785 - 14.085
Atmospheric Water Vapor	17	890 - 920		36	14.085 - 14.385
	18	931 - 941			
	19	915 - 965			

APPENDIX B:

```
library(raster)
library(TTR)

path <- "D:/Documents/Phenology/TIF FILES/2007/"

i <- 1
year <- "2007"
GRVI2007_karadeniz=c()
GRVI2007_akdeniz=c()
GRVI2007_ege=c()
GRVI2007_içana=c()
GRVI2007_doguana=c()

repeat {

  i <- as.character(i)

  red1 <- paste(path,year,"_red1_ (",i,").tif",sep="")
  red2 <- paste(path,year,"_red2_ (",i,").tif",sep="")
  red3 <- paste(path,year,"_red3_ (",i,").tif",sep="")
  red4 <- paste(path,year,"_red4_ (",i,").tif",sep="")

  r1 <- raster(red1)
  r2 <- raster(red2)
  r3 <- raster(red3)
  r4 <- raster(red4)

  green1 <- paste(path,year,"_green1_ (",i,").tif",sep="")
  green2 <- paste(path,year,"_green2_ (",i,").tif",sep="")
  green3 <- paste(path,year,"_green3_ (",i,").tif",sep="")
  green4 <- paste(path,year,"_green4_ (",i,").tif",sep="")

  g1 <- raster(green1)
  g2 <- raster(green2)
  g3 <- raster(green3)
  g4 <- raster(green4)

  finalred <- mosaic(r1,r2,r3,r4,fun=mean)
  finalgreen <- mosaic(g1,g2,g3,g4,fun=mean)

  GRVI <- ((overlay(finalred,finalgreen,fun=function(y1,y2){return(y2-
y1)}))/(overlay(finalred,finalgreen,fun=function(y1,y2){return(y2+y1)})))

  #karadeniz
  e <- as(extent(3000000, 3300000, 4500000, 4550000), 'SpatialPolygons')
  GRVI1 <- crop(GRVI, e)
```

```
  GRVI_mean <- cellStats(GRVI1,stat='mean',na.rm=TRUE)

  GRVI2007_karadeniz[i] <- GRVI_mean

  #akdeniz
  e <- as(extent(2700000, 2900000, 4100000, 4160000), 'SpatialPolygons')
  GRVI1 <- crop(GRVI, e)

  GRVI_mean <- cellStats(GRVI1,stat='mean',na.rm=TRUE)

  GRVI2007_akdeniz[i] <- GRVI_mean

  #ege
  e <- as(extent(2400000, 2500000, 4300000, 4400000), 'SpatialPolygons')
  GRVI1 <- crop(GRVI, e)

  GRVI_mean <- cellStats(GRVI1,stat='mean',na.rm=TRUE)

  GRVI2007_ege[i] <- GRVI_mean

  #iç anadolu
  e <- as(extent(2900000, 3000000, 4300000, 4400000), 'SpatialPolygons')
  GRVI1 <- crop(GRVI, e)

  GRVI_mean <- cellStats(GRVI1,stat='mean',na.rm=TRUE)

  GRVI2007_içana[i] <- GRVI_mean

  #dogu anadolu
  e <- as(extent(3500000, 3600000, 4300000, 4400000), 'SpatialPolygons')
  GRVI1 <- crop(GRVI, e)

  GRVI_mean <- cellStats(GRVI1,stat='mean',na.rm=TRUE)

  GRVI2007_doguana[i] <- GRVI_mean

  i <- as.numeric(i)
  i = i+1

  if (i==366) break
}

#EMA
plot(GRVI2007_içana)
plot(EMA(GRVI2007_içana,20))
test <- (EMA(GRVI2007_doguana,20))
test
```

APPENDIX C:

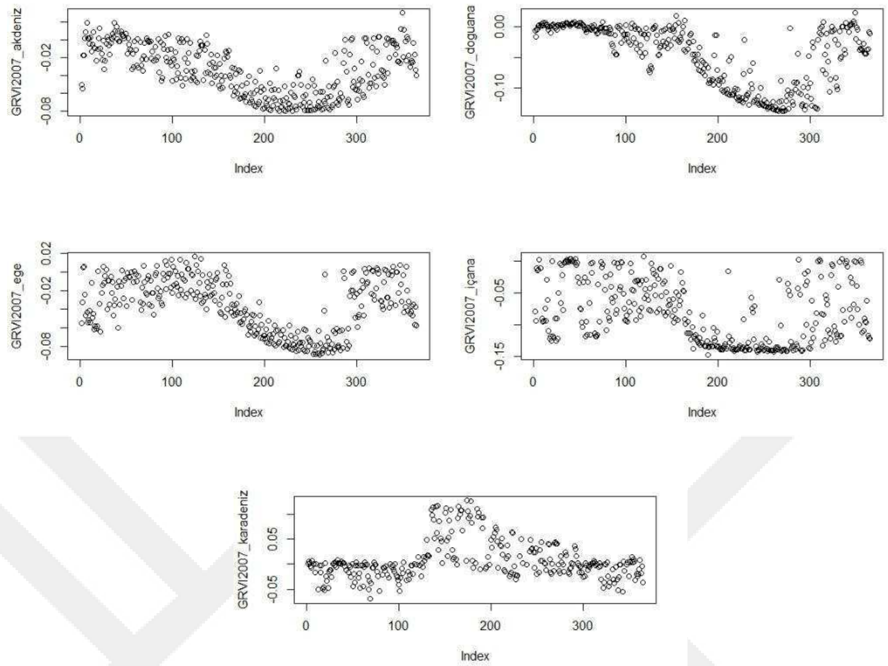

Figure A.1: GRVI plots for regions of Turkey for the year 2007.

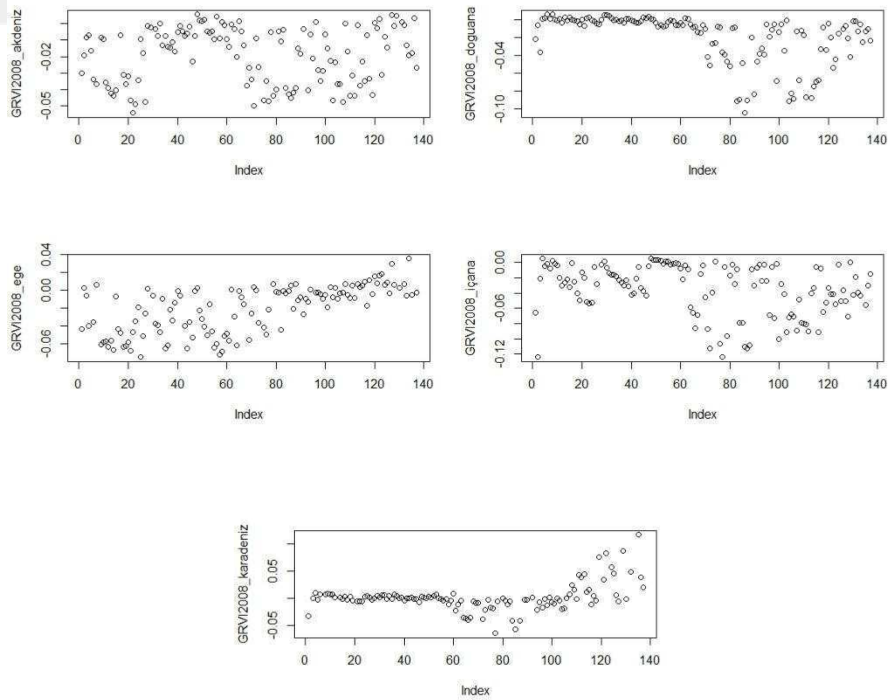

Figure A.2: GRVI plots for regions of Turkey for the year 2008.

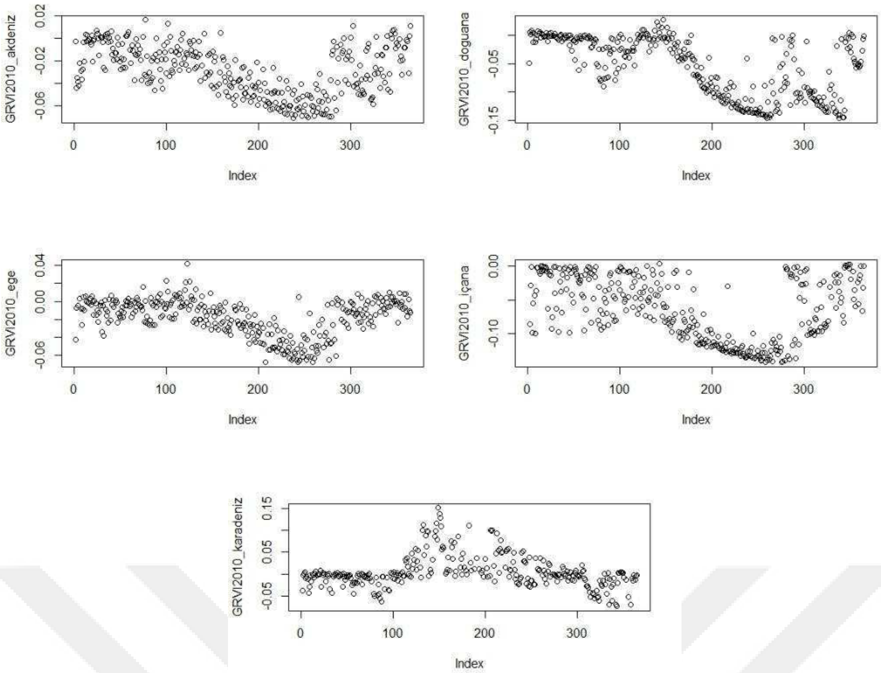

Figure A.3: GRVI plots for regions of Turkey for the year 2010.

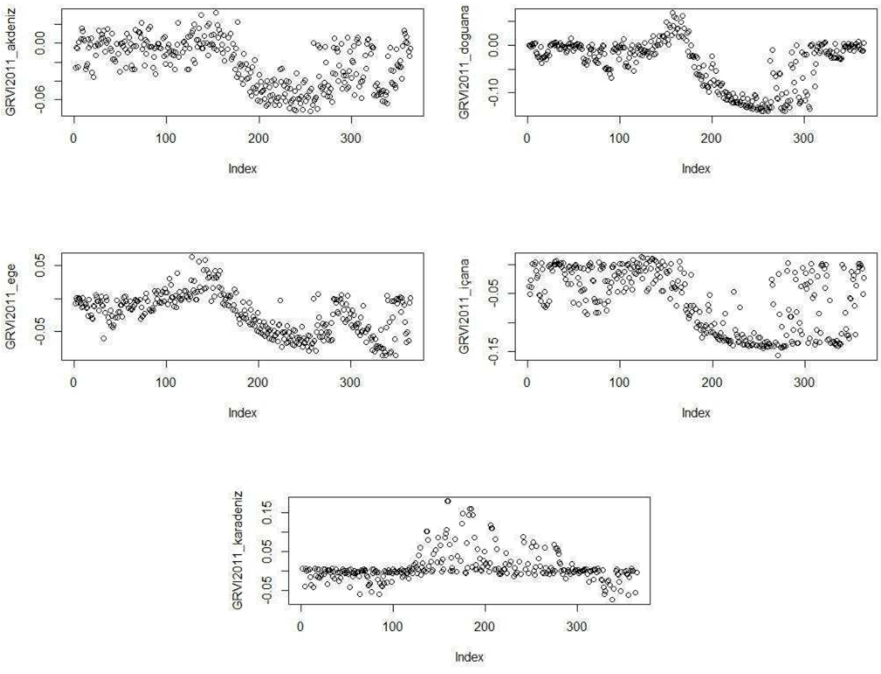

Figure A.4: GRVI plots for regions of Turkey for the year 2011.

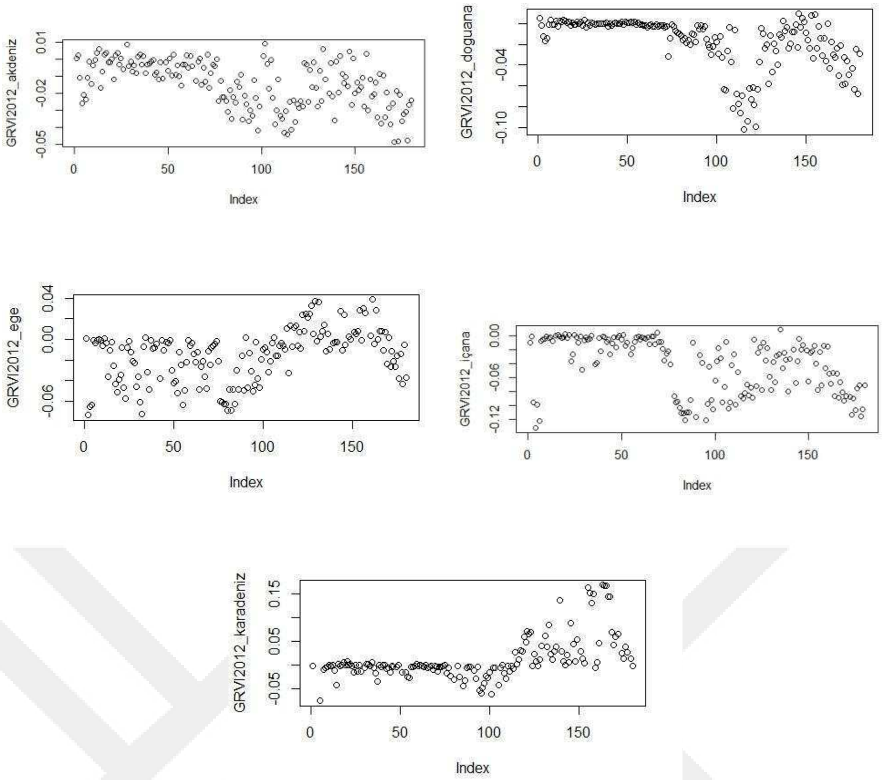

Figure A.5: GRVI plots for regions of Turkey for the year 2012.

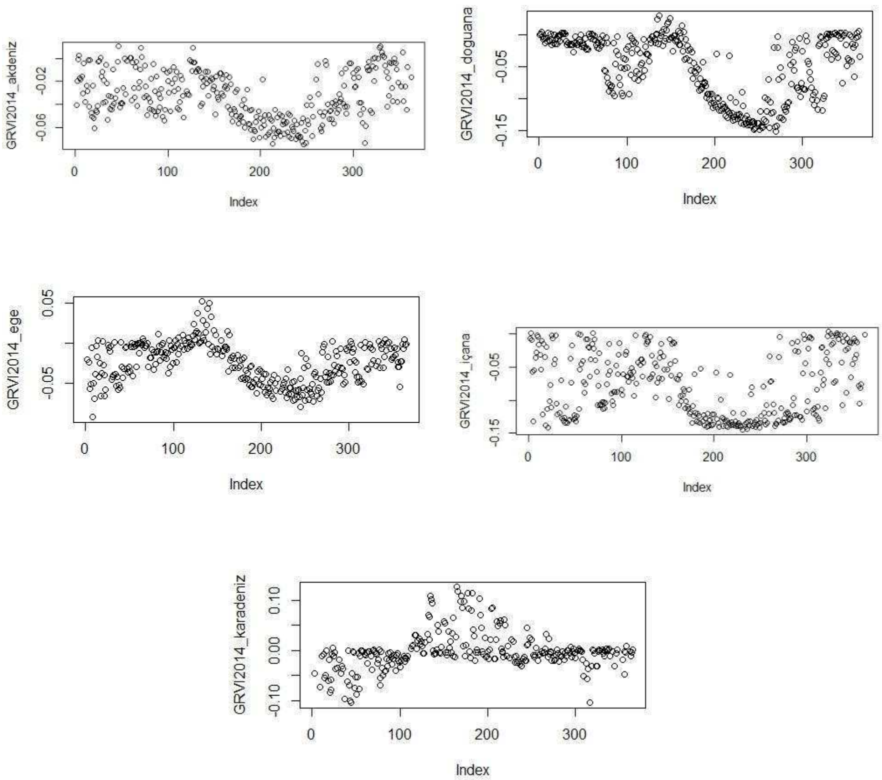

Figure A.6: GRVI plots for regions of Turkey for the year 2014.

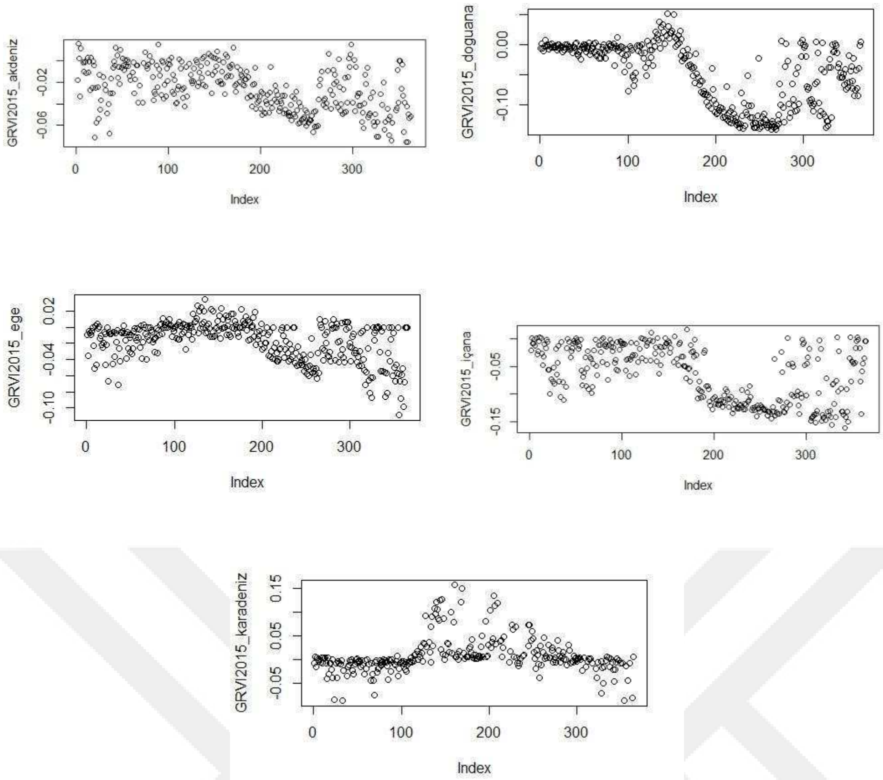

Figure A.7: GRVI plots for regions of Turkey for the year 2015.

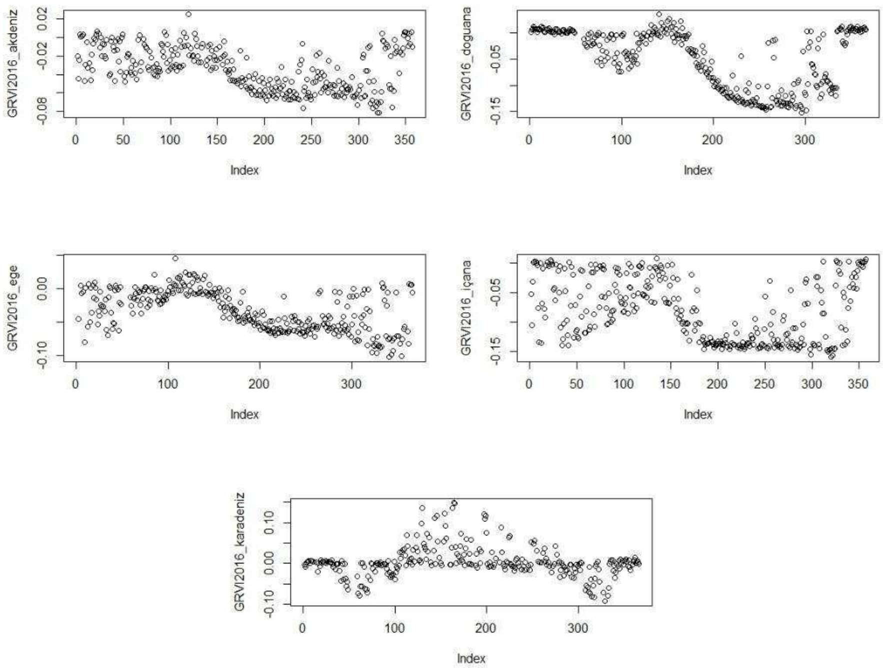

Figure A.8: GRVI plots for regions of Turkey for the year 2016.

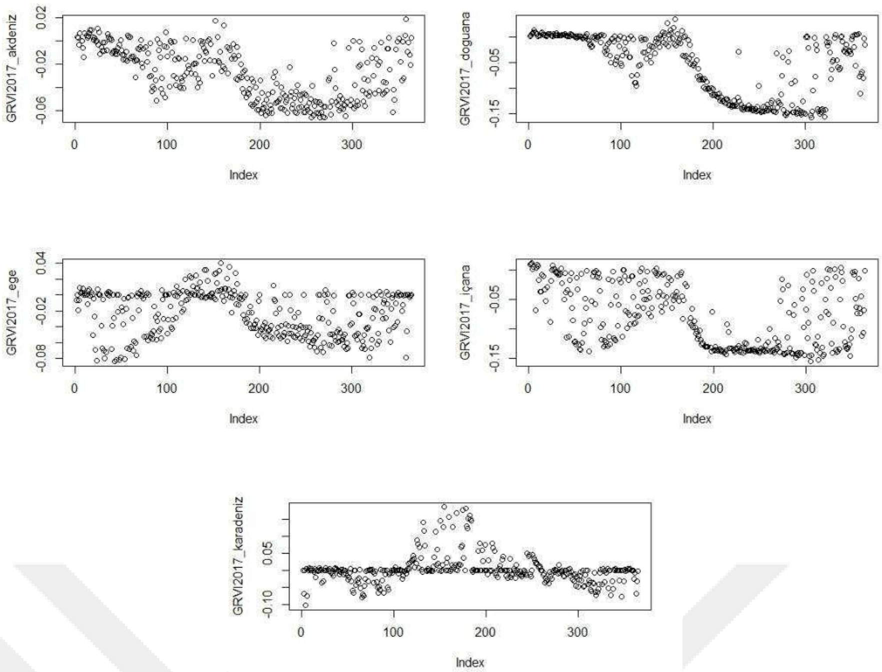

Figure A.9: GRVI plots for regions of Turkey for the year 2017.

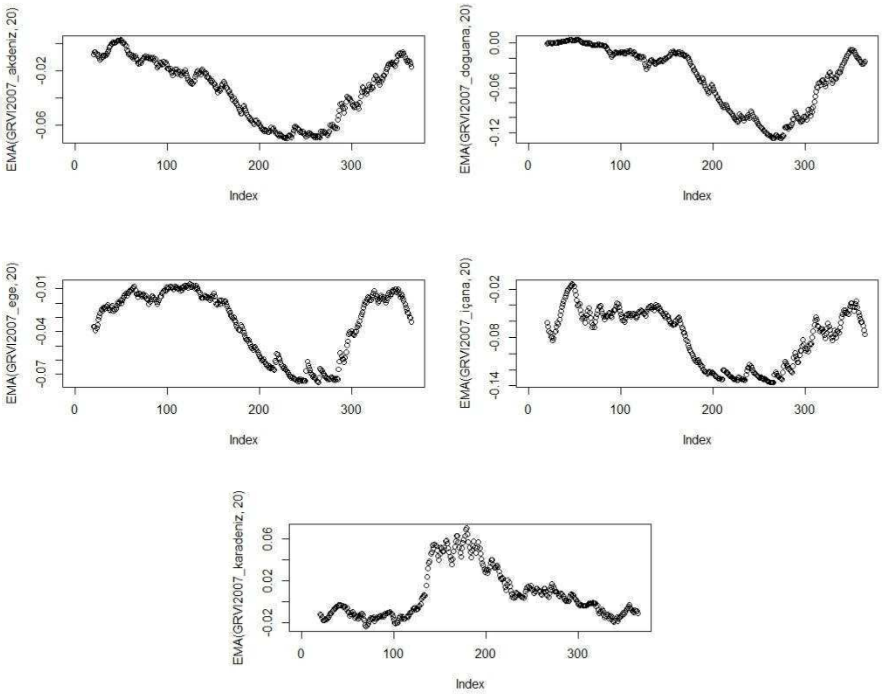

Figure A.10: EMA plots for regions of Turkey for the year 2007.

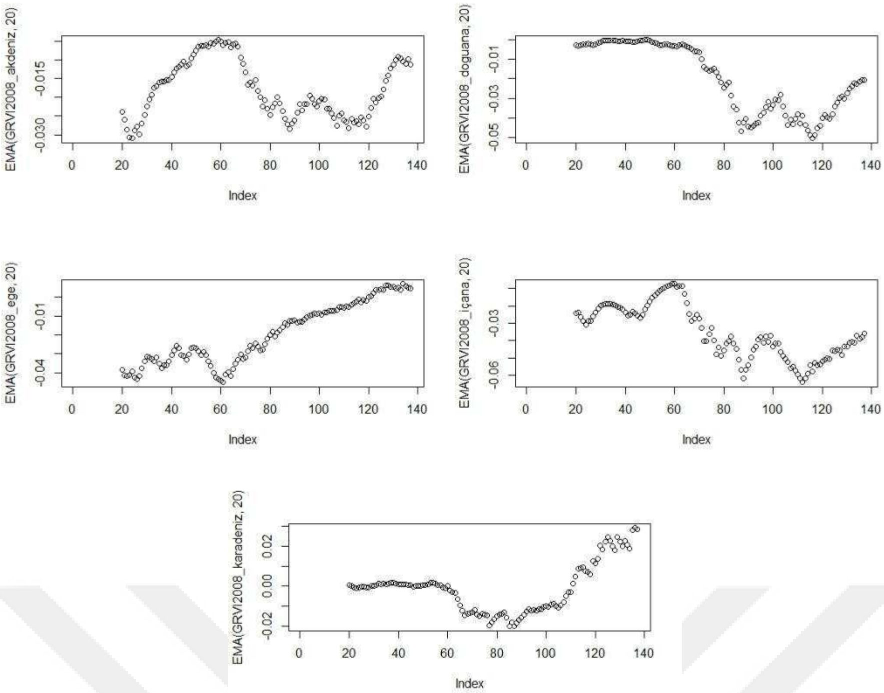

Figure A.11: EMA plots for regions of Turkey for the year 2008.

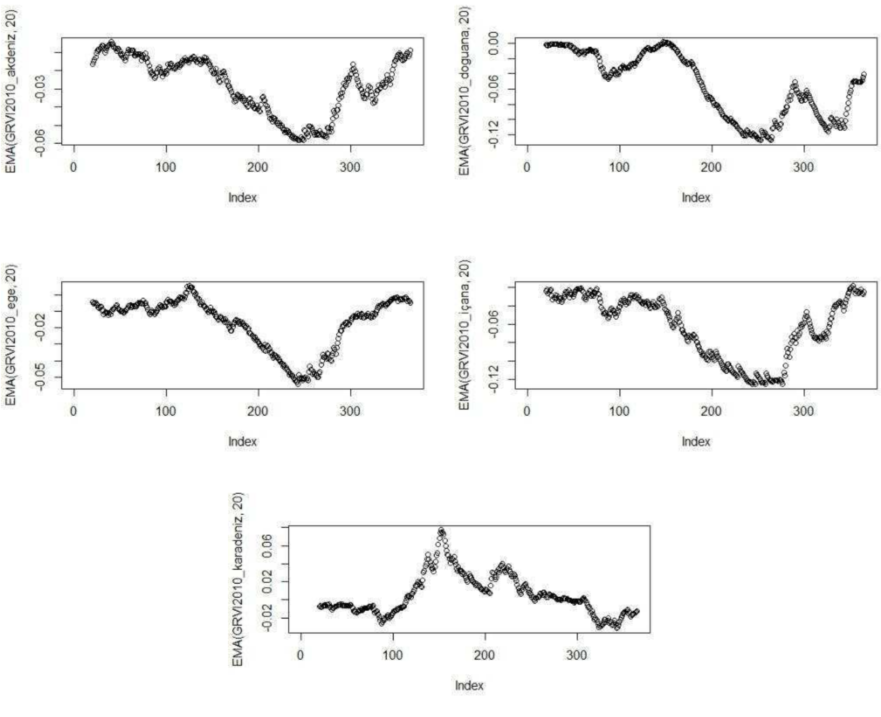

Figure A.12: EMA plots for regions of Turkey for the year 2010.

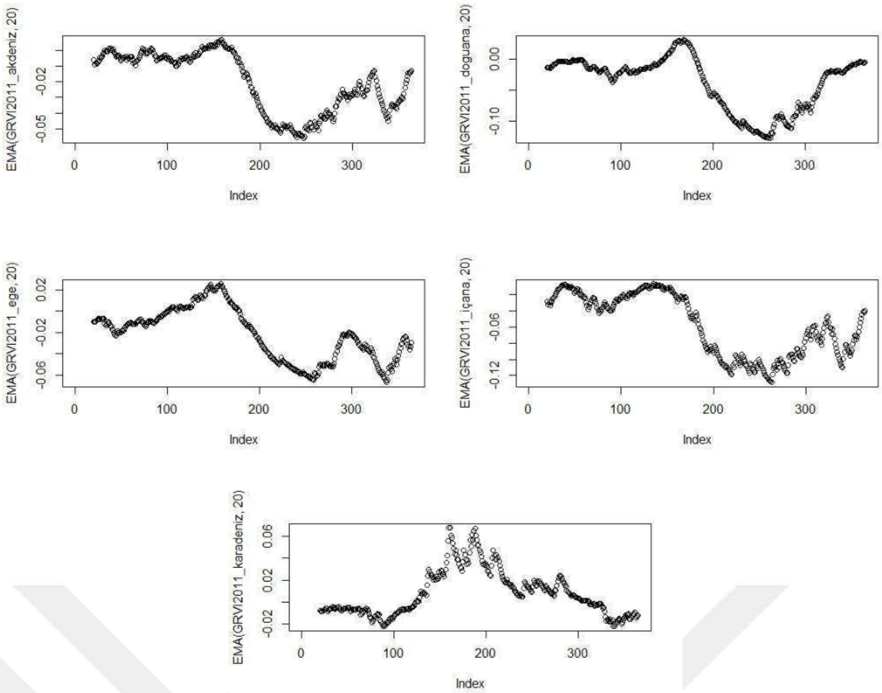

Figure A.13: EMA plots for regions of Turkey for the year 2011.

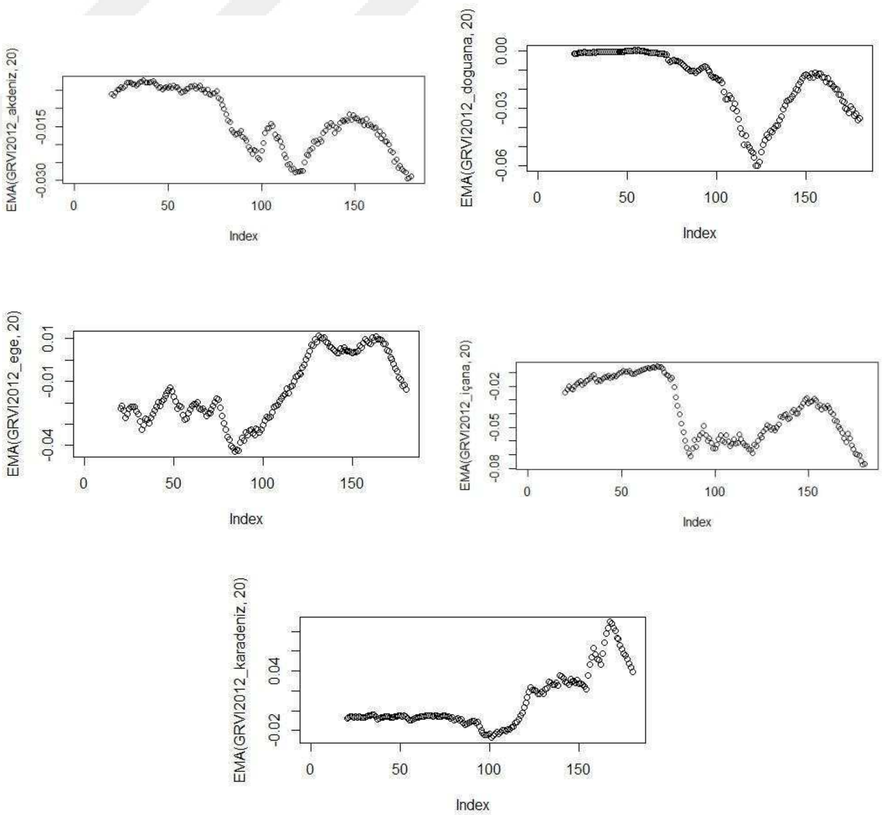

Figure A.14: EMA plots for regions of Turkey for the year 2012.

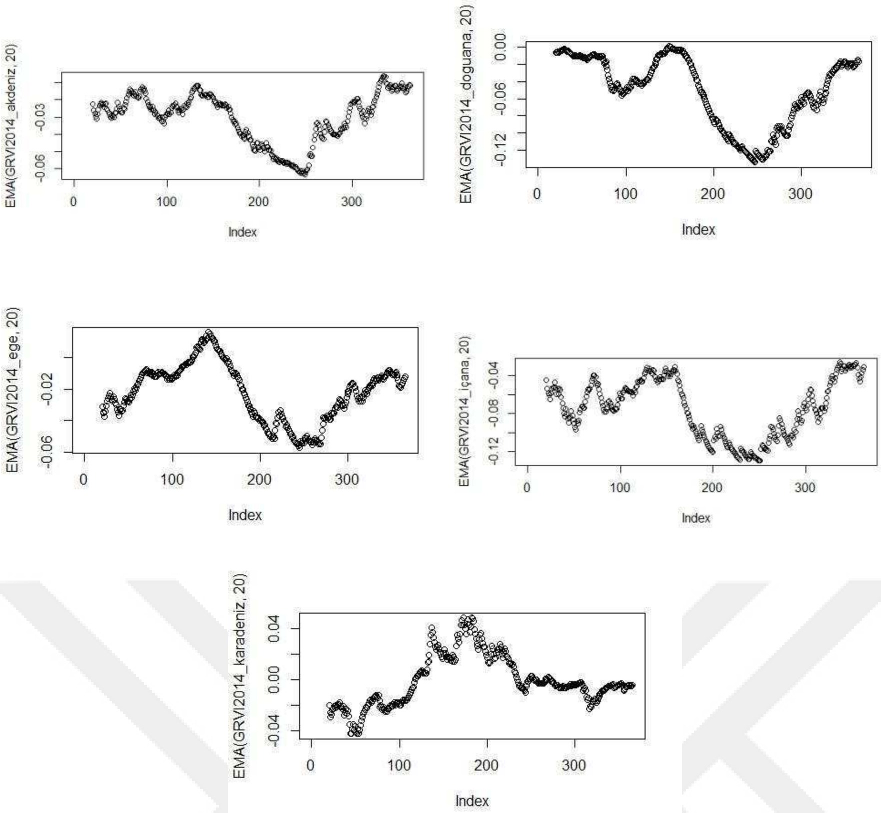

Figure A.15: EMA plots for regions of Turkey for the year 2014.

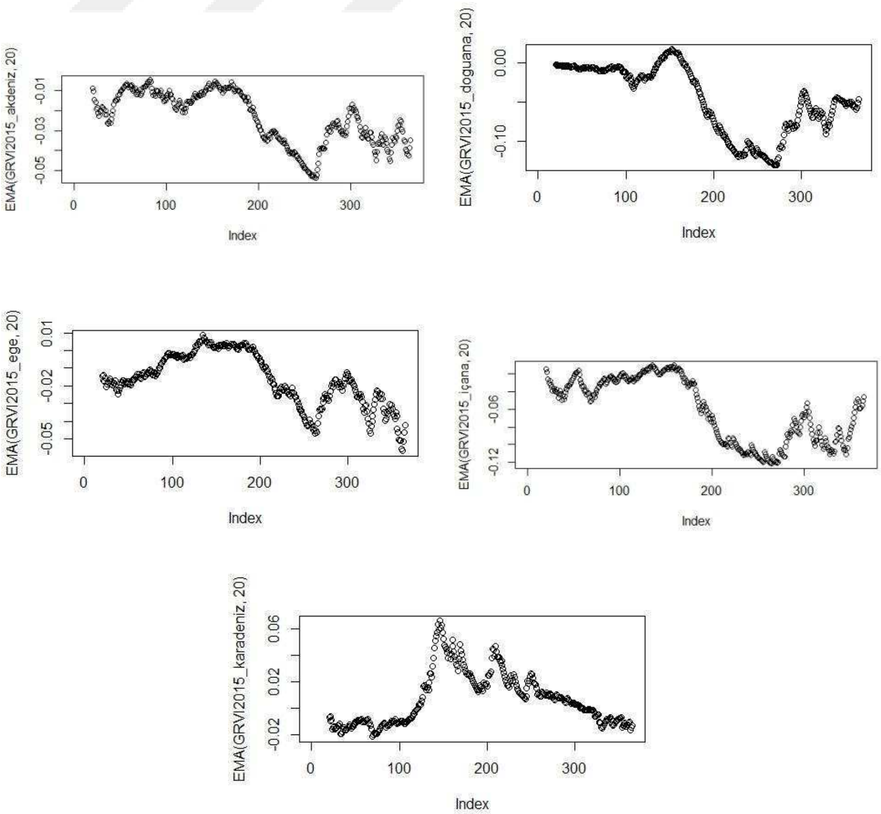

Figure A.16: EMA plots for regions of Turkey for the year 2015.

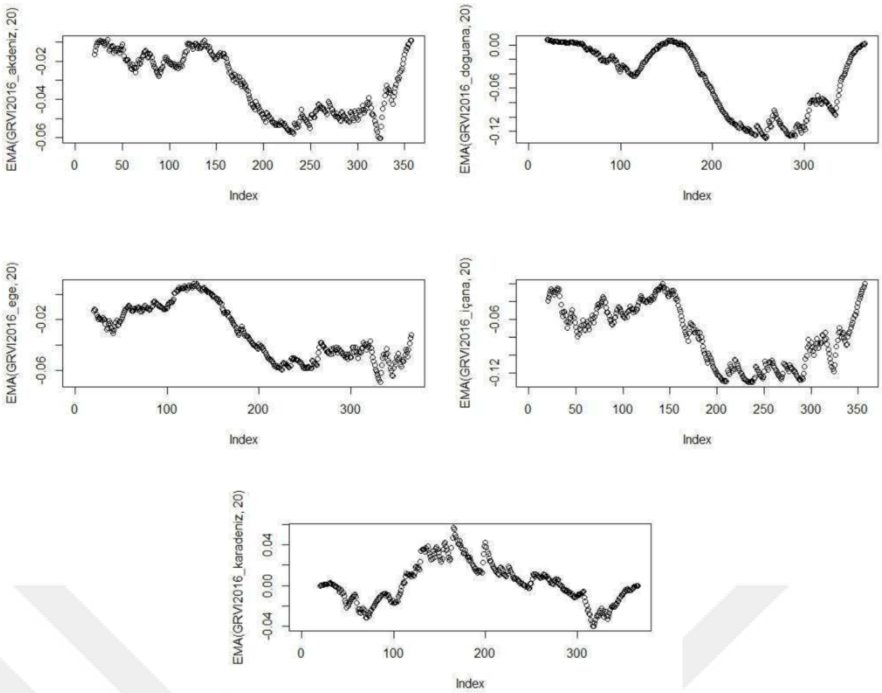

Figure A.17: EMA plots for regions of Turkey for the year 2016.

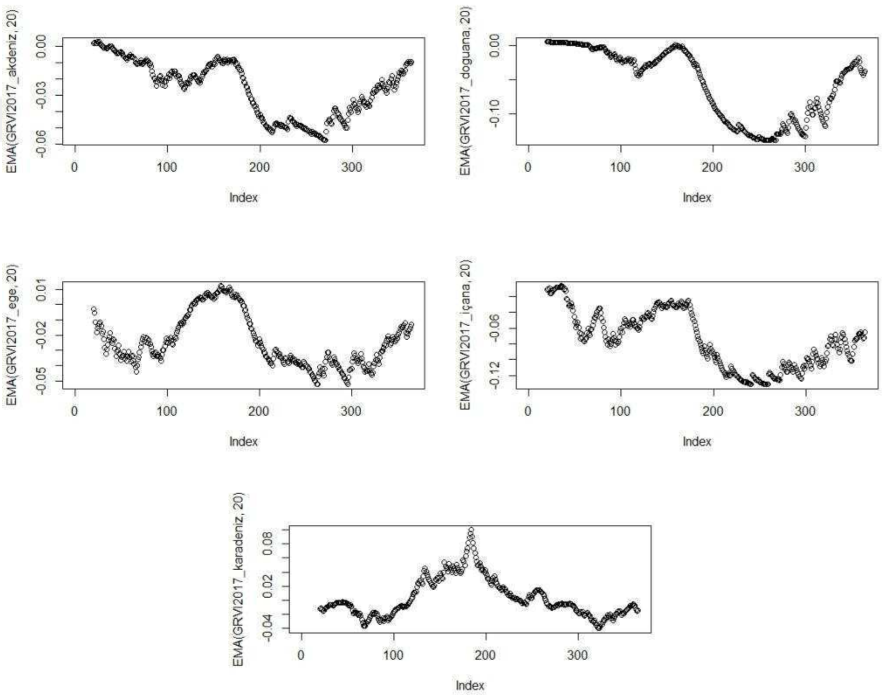

Figure A.18: EMA plots for regions of Turkey for the year 2017.

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- **Turanlı-Yıldız B., Yetiş Ö., İpek Y.** 2016: Evolutionary Engineering of Resistance to Phenolic Compounds in Saccharomyces cerevisiae (Poster - PYFF6 - 6th Conference on Physiology of Yeasts and Filamentous Fungi / July 11-14, 2016, Lisbon, Portugal)