Utrecht University

Graduate School of Natural Sciences
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Exploring Shifts in the Timing of the Growing Season

A Remote Sensing Analysis of Vegetation Dynamics in Val Grande National Park

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Abstract

This thesis investigates the potential shift in the timing of the end of the growing season by analyzing vegetation dynamics using remote sensing and the Normalized Difference Vegetation Index (NDVI). The study focuses on the Val Grande National Park in northern Italy as the study area. The Landsat 8 satellite imagery is used to assess NDVI trends over specific time intervals, including monthly trends and 16-day moving windows.

The results suggest potential shifts in the timing of the growing season based on the analysis of monthly and moving window trends. October exhibits pronounced changes, with vibrant green and red colors indicating increased NDVI values and improved vegetation health. These findings suggest a possible extension of the growing season into October. However, various factors, such as species composition and local environmental conditions, may contribute to these observed changes. Further research is needed to establish definitive trends and understand the underlying factors driving these shifts.

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Keywords

Growing season, Phenology, Remote sensing, NDVI (Normalized Difference Vegetation Index), Vegetation dynamics, Shift in timing, Plant growth, Temperature

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1 Introduction

1.1 Plants

Plants play a vital role in sustaining life on Earth, serving as essential components of our planet's ecosystem. Through photosynthesis, plants utilize sunlight, water, and carbon dioxide to create oxygen and energy in the form of sugar. They also contribute to the preservation of soil integrity, preventing erosion and promoting fertility by releasing nutrients. This restorative quality aids in the healing process after natural disasters. Besides, plants make up the basis of the food chain, which are consumed by both wildlife and humans alike. Many pharmaceuticals are produced from or based on substances found in plants. On top of that, plants also intercept pollutants through phytoremediation, which means that they can remove, detoxify, or stabilize contaminants in the soil, air, or water.

Many of these plant functions are influenced by temperature. As temperature rises till a certain point, plants functions such as photosynthesis, transpiration, and respiration increase. The transition from vegetative to reproductive growth is also affected by temperature. The impact of temperature can either speed up or slow down this transition, depending on the circumstance and the species of the plant. Therefore, it can be stated that temperature regulates the life cycle of plants.

According to Sparks and Menzel (2002), the warming of the Earth's temperature leads to delayed and shortened winters, accompanied by a decrease in the number of days with freezing temperatures. In contrast, spring arrives earlier, and the summer extends, resulting in an increase in heatwaves and the occurrence of more extreme weather events.

Due to these new circumstances, plants must adapt its growth pattern to survive. Consequently, with the onset of an earlier spring, plants experience earlier growing seasons, while the extension of summer leads to later endings of these seasons. This creates a potential timing conflict between pollinators and plants. Plants will also have more trouble dealing with pests and pathogens, as these are usually more active in warmer temperatures. This might increase pests' capacity to endanger the survival of their target species.

Furthermore, higher temperature at the beginning of fall can lead to many problems for plants. The timing of plant growth stages may be impacted by changes in temperature and precipitation patterns, which can have a big influence on ecosystems and agriculture. Additionally, unusual warmth in the late winter months can produce a "false spring" that causes plants to start growing prematurely and leave them vulnerable to any ensuing frosts.

1.2 Remote sensing and phenology monitoring

The duration of the growing season can vary depending on factors such as climate, geographical location, and specific plant species. In general, the growing season typically starts in the spring when temperatures rise, and conditions become favorable for plant growth. It continues through the summer months and often extends into the early fall until temperatures drop and conditions become less suitable for active plant growth. The specific start and end dates of the growing season can vary significantly based on regional and local factors, making it necessary to assess specific locations and plant types for more precise information.

Identifying the onset of growing seasons is straightforward, as it is commonly marked by the emergence of fresh shoots, buds, or leaves, which are easily observable and can be regularly monitored. On the contrary, the end of the season is often characterized by subtler changes. Instead of a sudden stop, plant growth and activity gradually decrease, making it difficult to pinpoint the exact moment when it concludes. Lastly, it is important to note that the conclusion of the growing season can vary both geographically and from year to year, further adding to the complexity of accurately defining this phenomenon.

Remote sensing has proven to be a valuable technique for investigating and monitoring vegetation changes across large geographical areas and extended timeframes. This approach enables the assessment of phenological changes by analyzing the spectral characteristics of vegetation captured by satellite sensors. By leveraging remote sensing, researchers can effectively study and track the dynamics of vegetation on broad scales (Mutanga et al., 2016).

The Normalized Difference Vegetation Index (NDVI) is a widely used vegetation index obtained from remote sensing data. It serves as a quantitative measure of the abundance of live green vegetation in a specific area. Calculated through analysis of satellite imagery, the NDVI finds broad applications in fields such as agriculture, forestry, and ecology, where it is employed to monitor and evaluate vegetation growth and overall health.

Research has explored the relationship between NDVI and leaf phenology, specifically the timing of leaf emergence and senescence. By leveraging NDVI, researchers successfully monitor vegetation phenology and identify changes in plant growth stages (Zuo et al., 2018). This demonstrates the effectiveness of NDVI in providing valuable insights into vegetation dynamics and phenological transitions.

1.3 Objectives

Evaluating the duration of a growing season is of utmost importance due to its significant implications across multiple domains. The primary objective of this study is to assess the temporal shift in the termination of growing seasons. This can be accomplished by employing remote sensing techniques and utilizing the NDVI. The NDVI serves as a quantitative measure of the vigor and vitality of plants, enabling the assessment of their greenness and overall health.

Through the analysis of temporal changes in NDVI, the shifting conclusion of growing seasons can be evaluated. A consistent pattern of persistently high NDVI values as the usual growing season approaches its end indicates an extended and delayed conclusion. To facilitate this analysis, remote sensing tools like Google Earth Engine can be utilized to gather and process NDVI data from satellite imagery.

1.4 Research question

The research question addressed in this study is: Is there a shift in the timing of the end of the growing season?

2 Study area

The study area chosen for this research is the Val Grande National Park (Parco Nazionale Val Grande). It is located in northern Italy, specifically in the region of Piedmont near the Swiss border. The park is surrounded by Lake Maggiore to the east, the Valle d'Ossola to the west, and the Valle Vigezzo to the north. It falls within the province of Verbano-Cusio-Ossola and encompasses ten municipalities. Known as "the largest wilderness in the Alps," the park is a protected area and is largely uninhabited.

The Val Grande Park boasts a rich and diverse vegetation, which is a major attraction of the area, thanks to the thermal influence of Lake Maggiore. In the lower Val Grande, mixed broadleaf forests are prevalent, with chestnut trees being the dominant species. Beech trees become more prevalent as the altitude rises into the upper Val Grande, especially on the moist, shady slopes as well as the southern slopes due to the region's heavy rainfall.

The park also features coniferous forests, mainly consisting of spruce and white fir, although their extent is limited. The presence of larch is scarce due to historical climate conditions and past logging activities. The gorges in the park are considered significant environments of European priority interest and are inhabited by badgers, alders, limes, and maples.

As the altitude ascends, shrubs replace the forests. On north-facing slopes, which tend to be more humid, vibrant green alders and a diverse understory of ferns and mosses are featured. Rhododendrons and blueberries thrive at higher elevations, often found along ridges, rocky outcrops, and sunny slopes.

At even higher altitudes, mountain pastures and rocky vegetation prevail. The park is home to rare plant species such as Alpine columbine, mountain arnica, great yellow gentian, and perforate bellflower. In the wetlands near Scaredi Alp, visitors can observe the Alpine tulip and the white blooms of cotton grass.

Given the richness and diversity of vegetation in the Val Grande National Park, combined with its unique geographical features and protected status, it provides an excellent setting for studying the phenological changes and NDVI patterns in relation to the park's varied landscapes and ecological factors.

It is worth noting that the study area has been clipped to ensure that the entire region of interest is taken into consideration. This approach allows for a comprehensive analysis of the vegetation dynamics and phenological changes within the designated area. This clipped area can be seen in Figure 1.

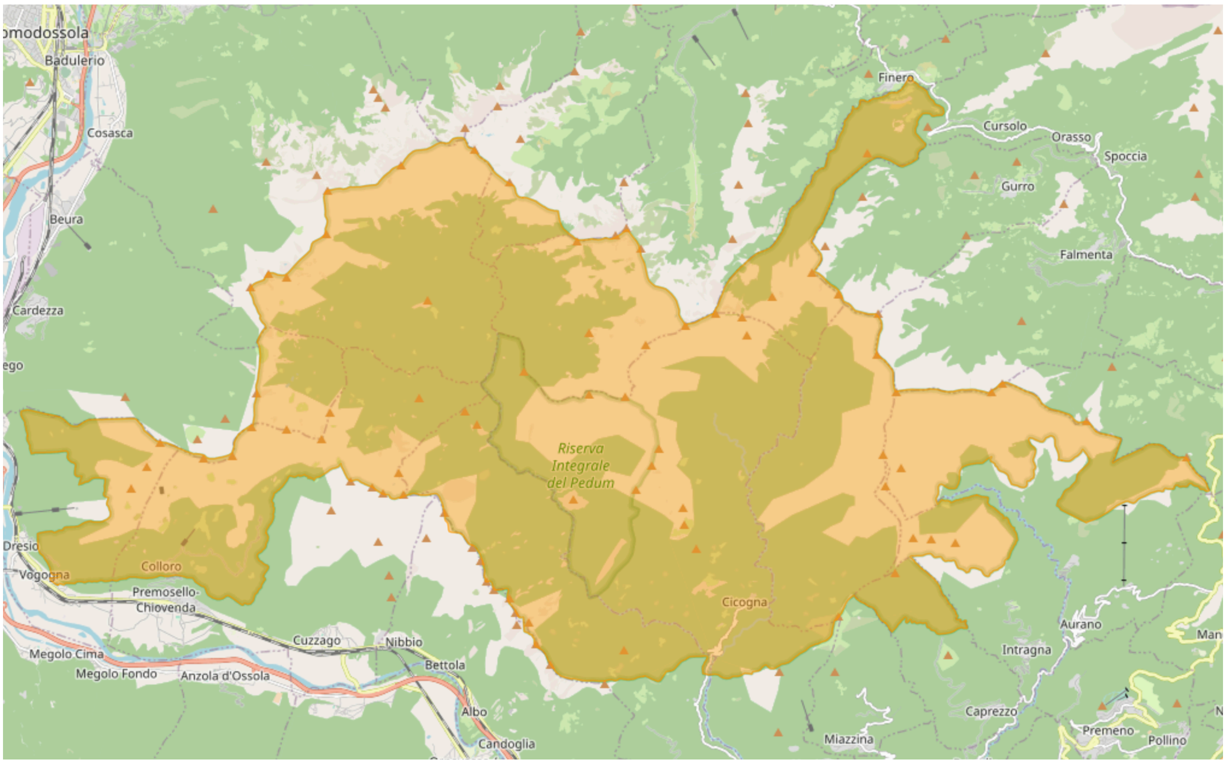

Figure 1 – Map of Val Grande National Park
[Source: Parco Nazionale Val Grande website, https://www.parcovalgrande.it/]

3 Data

3.1 Landsdat 8

The research will utilize datasets consisting of imagery and information obtained from the Landsat 8 satellite. The Landsat 8 satellite is an integral component of the NASA and U.S. Geological Survey (USGS) Landsat program. It was launched on February 11, 2013, from Vandenberg Air Force Base in California and is still operating regularly. Equipped with two scientific instruments—the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS)—the Landsat 8 satellite provides valuable data for the study.

The OLI sensor captures imagery in nine spectral bands, including visible, near-infrared, and shortwave infrared bands. This multispectral data provides information about land cover, vegetation health, water quality, and various other applications. The OLI sensor also has improved radiometric and spatial resolution compared to its predecessors, enabling more detailed and accurate analysis.

The TIRS sensor on Landsat 8 measures thermal infrared radiation to assess land surface temperature. This information is crucial for monitoring heat signatures, analyzing urban heat islands, identifying active fires, and understanding the energy balance of the Earth's surface.

Data from Landsat 8 is freely available to the public through the USGS Earth Explorer and other online platforms. Researchers, scientists, and other users can access and download

Landsat 8 imagery and data for their specific applications, such as land cover mapping, change detection, environmental monitoring, and scientific research.

3.2 Data correction

Landsat 8 data is not atmospherically corrected in its raw form. The raw data acquired by Landsat 8 satellite contains atmospheric effects such as scattering and absorption of light, which can distort the spectral information captured by the sensor. To account for these atmospheric effects and obtain more accurate surface reflectance values, atmospheric correction is typically performed on Landsat 8 imagery.

The USGS provides a product called Landsat Surface Reflectance (SR) data, which offers atmospherically corrected imagery for Landsat 8 and other Landsat missions. The Landsat SR data undergoes a rigorous atmospheric correction process using various algorithms and atmospheric models. By utilizing this corrected dataset, researchers can conduct precise quantitative analysis, including tasks such as land cover classification, change detection, and vegetation monitoring. Therefore, the Landsat SR data will serve as the primary dataset for this research.

3.3 Data preparation

The Landsat 8 data was processed to remove cloud, cloud shadow, and other undesirable pixels using a custom cloud masking algorithm. By applying the cloud mask to the original image, the cloudy areas can be effectively masked or removed, while the clear areas remain intact. This process allows for better visualization and analysis of the land surface features and phenomena of interest.

3.4 Data exploration

In this study, the time series of NDVI values will be examined for every pixel in the designated area to comprehend the fluctuations in vegetation activity over time. The NDVI values were calculated for each pixel using the formula (NIR - Red) / (NIR + Red), with NIR denoting the near-infrared band and Red representing the red band of the imagery.

The time series analysis reveals interesting patterns in the NDVI values for each pixel over the study period. Figure 2 displays the line plots of NDVI for a representative sample of pixels in the study area.

Due to the cloud masking process, a significant amount of data is omitted, particularly during winter periods. The prevalence of cloud cover during winter seasons leads to a greater number of masked pixels in the final dataset. Consequently, the availability of information is somewhat limited during these periods.

However, despite the masking, the seasonal variations of the NDVI can still be observed. The study area experiences a pronounced increase in NDVI during the spring and summer months, indicating vigorous vegetation growth. Conversely, NDVI values decline dramatically during the fall and winter, reflecting vegetation senescence and dormancy.

When examining the NDVI values with the naked eye, it becomes apparent that visually detecting trends in the data is challenging. Therefore, it is necessary to conduct a more rigorous analysis to ascertain the presence of any underlying trends.

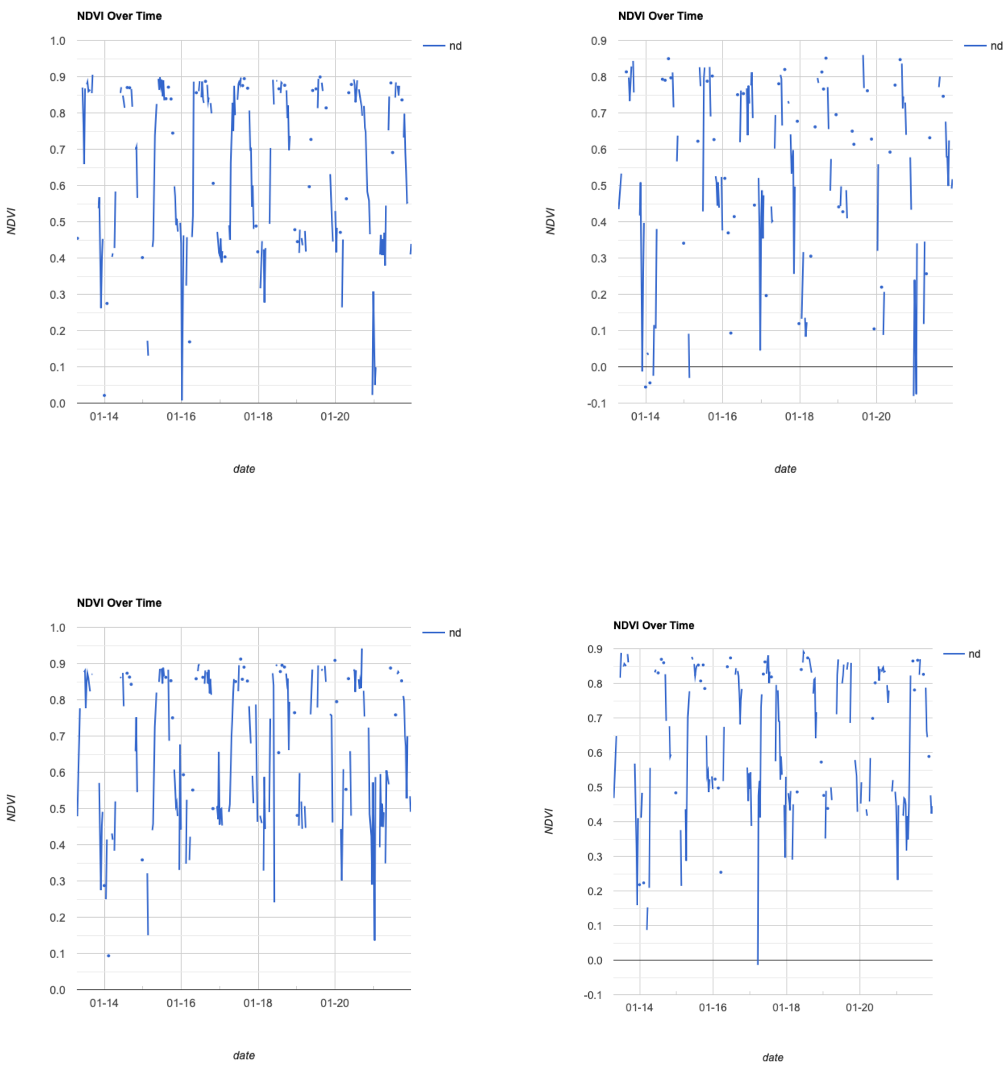

Figure 2: Line plots of NDVI time series for selected pixels.

4 Methods

The exploration of the time series of NDVI in the study area per pixel provides valuable insights into vegetation dynamics over time. The analysis reveals seasonal pattern, as the study area exhibits a clear seasonal trend in vegetation activity, with peak NDVI values during spring and summer, and lower values during fall and winter.

Apart from examining seasonal variations, it is crucial to investigate the presence of a discernible long-term trend in the NDVI data. This analysis allows for the identification of potential shifts occurring at the conclusion of the growing season. Linear regression is an effective statistical technique employed to detect, measure, and evaluate trends in NDVI data. By estimating the slope, linear regression offers valuable insights into the direction and magnitude of the trend.

4.1 Monthly trends

To examine the monthly trends of NDVI data, a linear regression was employed. The objective was to quantify the trends in NDVI values for each specific month over the years. This analytical approach facilitated the assessment of long-term patterns and changes in NDVI.

The data processing commences with the division of the original dataset into twelve distinct image collection. These collections contain imagery corresponding to each month throughout the dataset's time span. Within each monthly collection, the average NDVI values for each year were calculated for every pixel. In order to enhance data precision, values below 0.05 are adjusted to 0. This step ensures that the resulting images contain NDVI values that are strictly above the set threshold, thereby filtering out lower values.

Subsequently, a linear regression analysis was conducted to examine the trend of NDVI values for each pixel. The outcome of this analysis is an image collection in which each image represents the linear fit trend of NDVI values over the years for a specific month at every pixel. Furthermore, the "month" property is assigned to each image using the corresponding month number. This facilitates convenient identification and retrieval of the trend images for specific months during subsequent analysis or visualization processes.

4.2 Moving window trends

When looking at a monthly trend, one can argue that it can provide a general overview of the trends within each month. However, moving windows offer a finer temporal resolution. Monthly ranges treat each month as a homogeneous unit, assuming that vegetation conditions remain constant throughout the entire month. Nonetheless, vegetation dynamics can vary significantly within a month. By using moving windows, it is possible to capture more nuanced variations in vegetation patterns and responses, providing a more precise and granular analysis of the data.

The methodology for implementing this approach closely resembles that of creating the monthly trend. However, there is a key difference in how the data is organized and analyzed. Instead of dividing the dataset into monthly collections, it is partitioned into moving window ranges, each covering a span of 16 days.

4.3 Code implementation

The detailed process and implementation of the methods presented in this thesis can be found in the accompanying code. The code, written in JavaScript, provides a comprehensive framework for data processing, trend analysis, and visualization. It includes functions and algorithms for retrieving and preprocessing Landsat 8 imagery, calculating NDVI values, conducting linear regression analysis, and generating visualizations. The code, along with relevant documentation and instructions, is available at GitHub. Researchers and interested parties can refer to the code for a deeper understanding of the methodology and to replicate the study.

5 Results

5.1 Monthly trends

Considering that this study specifically investigates the potential shift of the end of growing seasons, it is logical to examine the results pertaining to the months of September and October. These months are of particular interest as they are indicative of the late stages of the growing season and can provide insights into any potential lengthening or changes in vegetation patterns during this critical period.

In Figure 3, the trends for the month of September are visualized using a color-coded representation. The trends represent the changes observed in NDVI over the years. The color scale employed in the visualization ranges from negative values (-0.05) to positive values (0.05). Negative trends, indicating a decrease in NDVI, are assigned a distinct red color. Conversely, positive trends, signifying an increase in NDVI, are represented by a vibrant green color. Regions with relatively stable or insignificant trends are portrayed using a neutral white color.

The trends observed in September are predominantly insignificant. This conclusion is supported by the extensive presence of white color across the displayed areas, indicating a trend value of near zero. The prevalence of white color signifies that the NDVI values remain relatively stable and unvarying during September, without notable fluctuations or discernible patterns. This suggests that the vegetation health and greenness, as measured by NDVI, experience little to no significant alterations within the month of September over the annual cycle.

While there are instances of red and green colors scattered across the visualization, their limited prevalence and subdued intensity indicate that any trends present in the NDVI during September are not substantial or highly noticeable. The small-scale patches of color suggest localized areas where minor changes may occur but do not reflect widespread or prominent trends.

Figure 4 presents a visualization of the trends for the month of October, following a similar approach as that used for September. Notably, the color green and red are more prevalent and dominant in October compared to September. This heightened presence of colors indicates a greater occurrence of changes in the NDVI during the month of October.

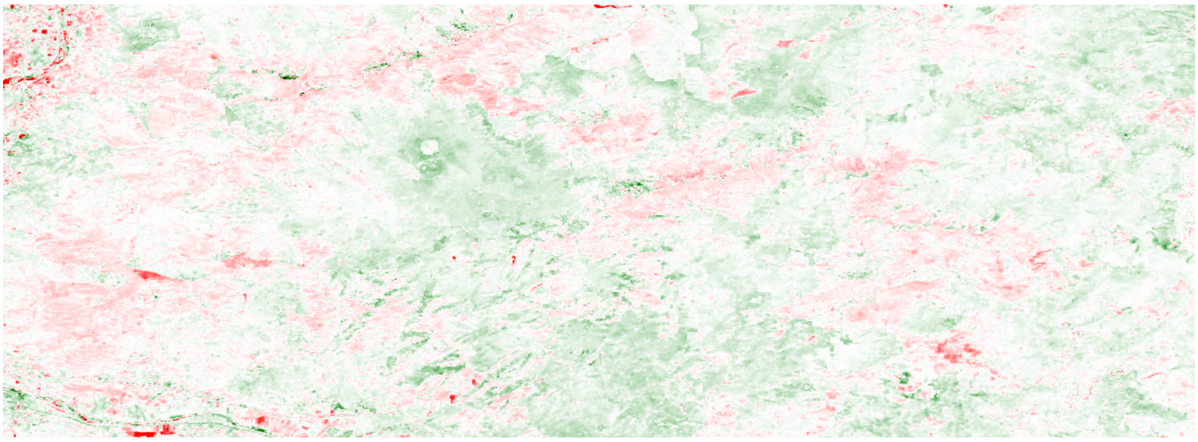

Figure 3 – NDVI trends in September (2014-2022)

The intensified green and red colors signify distinct trends in NDVI, reflecting notable alterations in vegetation conditions. The variation in colors suggests that different areas within the depicted region exhibit diverse patterns of vegetation growth and change. Some areas lean towards green, indicating an increase in NDVI and a likely improvement in vegetation health. Conversely, other parts lean towards red, indicating a decrease in NDVI and potentially a decline in vegetation health.

This observed spatial variability in trends can be attributed to different factors, such as variations in species composition or local environmental conditions. Different plant species may have unique growth patterns or respond differently to seasonal changes, leading to varying NDVI trends. Additionally, variations in local environmental factors such as soil moisture, temperature, or land use practices can also influence the observed differences in vegetation growth and NDVI trends.

It is important to note that even though the colors green and red are more prevalent and dominant in October compared to September, the overall presence of white color is still evident. While the intensified green and red colors signify notable changes in vegetation conditions, the widespread white color suggests that there are areas where the trends in NDVI are relatively stable.

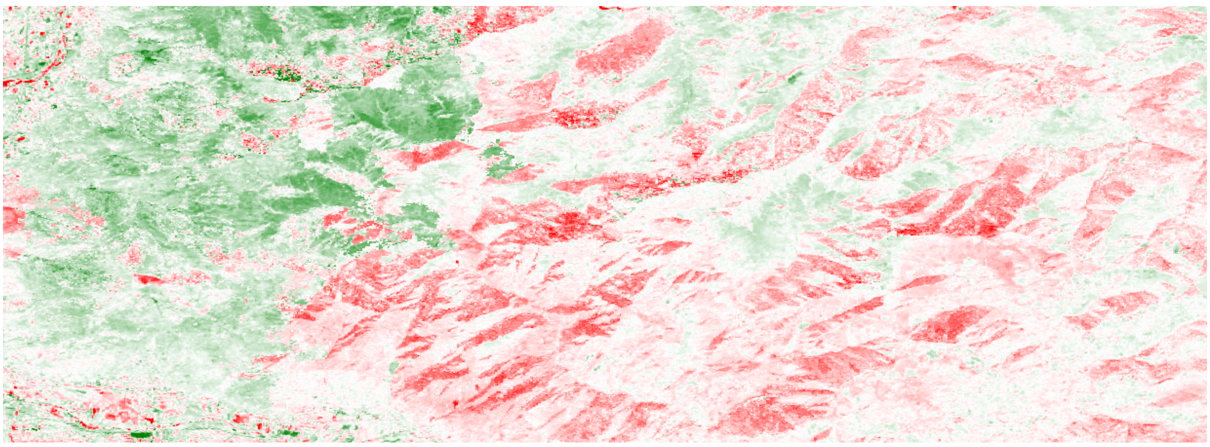

Figure 4 – NDVI trends in October (2014-2022)

In conclusion, the analysis suggests that there may be a shift in the timing of the end of growing seasons. While September generally exhibits insignificant trends with minimal color variations, the more pronounced changes observed in October, with a mix of green and red colors indicating diverse vegetation responses, indicate potential alterations in the timing of the end of growing seasons. These findings imply that the growing season in some part of the study area may be extending into October, indicating a potential delay in its conclusion. However, further investigation and analysis of long-term data are required to establish a definitive trend in the timing of the end of growing seasons.

5.2 Moving window trends

It is important to acknowledge that focusing solely on monthly trends may not provide a comprehensive understanding of vegetation dynamics. Seasonal changes in vegetation can exhibit significant variations within a given month, and examining a specific range of days within that month can yield more comprehensive insights. By analyzing vegetation trends over specific time intervals throughout the years, a more accurate identification of patterns and potential shift of the conclusion of growing seasons can be achieved, facilitating a deeper understanding of vegetation dynamics.

Figure 5 showcases the visualization of NDVI trends, focusing on the last two weeks of September. The selected date range spans from day 240 to day 256, allowing for an observation of vegetation trends and changes specifically within the 16-day period from September 15th to October 1st. This visualization provides valuable insights into the dynamics of vegetation during this critical timeframe.

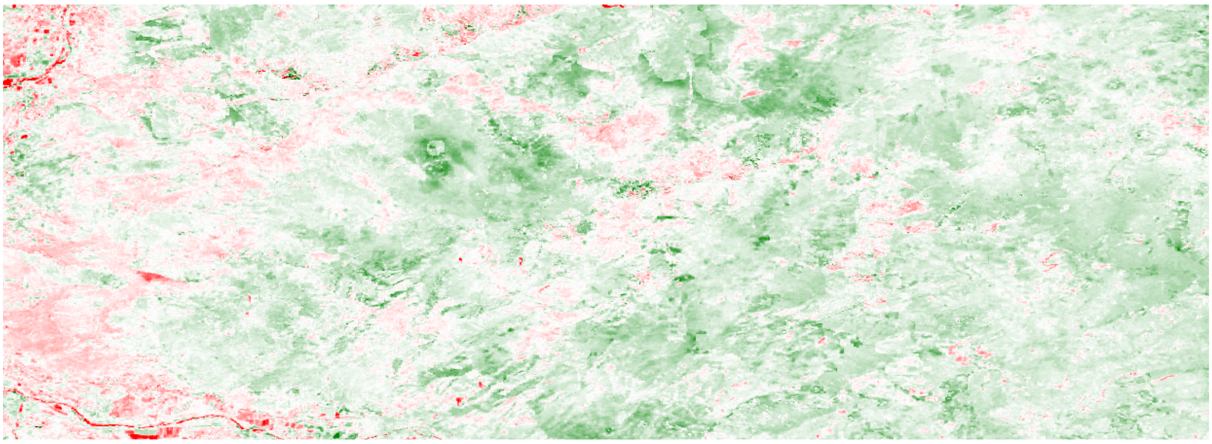

Figure 5 – NDVI trends between day 240 and 270 (2013-2022)

In contrast to the overall monthly trends observed in September, a distinct pattern emerges when examining the last two weeks of the month. A substantial portion of the area exhibits a green hue, suggesting significant changes and a general upward trend in NDVI values during this timeframe. The prevalence of green color signifies enhanced vegetation health and an overall increase in greenness.

These positive shifts in vegetation health and greenness can be attributed to a variety of factors, including favorable environmental conditions, extended growing seasons, or heightened vegetation activity specifically towards the end of September. Collectively, these findings indicate a positive trend in vegetation dynamics during the end of the summer.

By selecting a specific day range between day 256 and 274, corresponding to the period from October 1st to October 15th, a parallel pattern emerges, similar to the observations made for the entire month of October as discussed earlier. Figure 6 visually represents this phenomenon, where the colors green and red become more prominent and dominant. The heightened presence of these colors signifies a greater occurrence of changes in the NDVI values during the first two weeks of October.

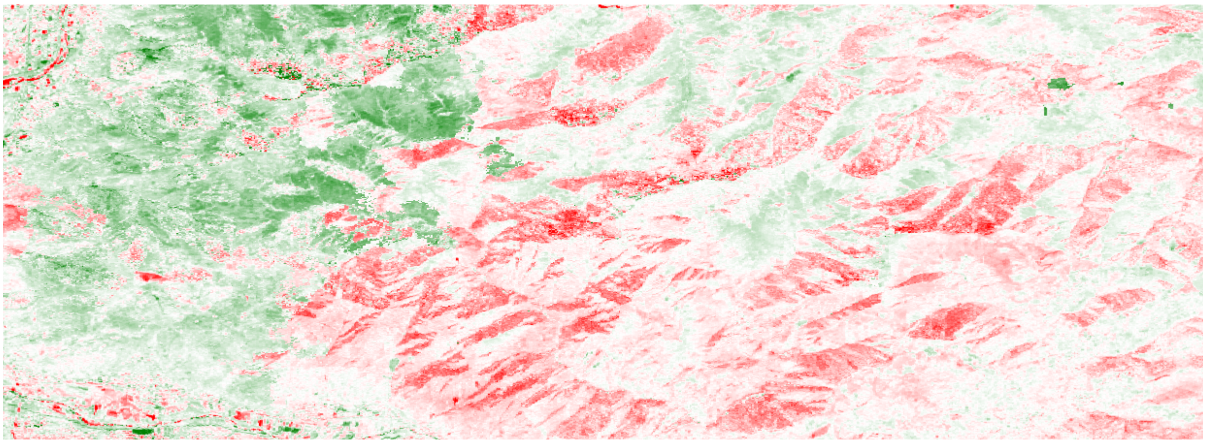

Figure 6 – NDVI trends between day 256 and 274 (2013-2022)

The spatial variability in observed trends can be ascribed to various factors, including variations in species composition and local environmental conditions. Distinct plant species may exhibit unique growth patterns and respond differently to seasonal changes, resulting in diverse NDVI trends.

Furthermore, fluctuations in local environmental factors, such as soil moisture, temperature, or land use practices, can also contribute to the observed differences in vegetation growth and NDVI trends. These combined factors underscore the complexity of vegetation dynamics and highlight the significance of considering multiple influences when interpreting spatial variations in NDVI trends.

Overall, it can be inferred that certain locations within the study area may exhibit a positive shift in the conclusion of the growing season, indicating a later end. However, it is important to note that negative shifts are also observed, suggesting an earlier end in some areas. These variations in the timing of the growing season's conclusion can be attributed to a multitude of factors, including local environmental conditions, species composition, and other influencing variables. The complex interplay of these factors underscores the need for further investigation to comprehensively understand the diverse responses and determine the underlying causes of the observed shifts in the growing season's end.

6 Conclusion

6.1 Main findings

Based on the analysis of both monthly and moving window trends, there are indications of potential shifts in the timing of the end of growing seasons.

When examining the monthly trends, specifically focusing on September and October, interesting patterns emerge. In September, the trends are predominantly insignificant, with the presence of white color indicating relatively stable NDVI values throughout the month. This suggests that vegetation health and greenness experience little to no significant alterations within September over the annual cycle.

However, in October, the trends show a greater occurrence of changes in NDVI values. The intensified green and red colors signify distinct alterations in vegetation conditions, indicating potential shifts in the timing of the end of growing seasons. The variation in colors suggests different areas within the study region exhibit diverse patterns of vegetation growth and change, with some areas showing an increase in NDVI and likely improvement in vegetation health, while others exhibit a decrease in NDVI and potentially a decline in vegetation health.

To gain a more comprehensive understanding of vegetation dynamics, the moving window trend analysis focused on specific time intervals within September and October. During the last two weeks of September, a substantial portion of the study area exhibited a green hue, indicating significant changes and an overall upward trend in NDVI values. This suggests enhanced vegetation health and increased greenness during that timeframe.

Similarly, during the first two weeks of October, a parallel pattern emerges, with the colors green and red becoming more prominent. This indicates a greater occurrence of changes in NDVI values, further suggesting potential alterations in the timing of the end of growing seasons.

It is important to consider multiple influences when interpreting these spatial variations in NDVI trends, such as species composition and local environmental factors like soil moisture, temperature, and land use practices. These factors contribute to the complexity of vegetation dynamics and can explain the observed differences in vegetation growth and NDVI trends.

6.2 Domain implications

The potential extension of the growing season has significant implications across various domains. In ecology and biodiversity, changes in the timing of the growing season can disrupt plant-pollinator interactions, leading to mismatches between flowering plants and their pollinators. This disruption can have cascading effects on ecosystem dynamics and biodiversity. To address these shifts, conservation efforts should consider the changing timing of the growing season and take proactive measures to mitigate any potential negative consequences.

Furthermore, the findings of this study contribute to climate change adaptation strategies. The observed shifts in the timing of the growing season align with broader climate change trends, such as delayed and shortened winters, earlier springs, and extended summers. These changes have implications for the overall climate system, impacting weather patterns and the occurrence of extreme events. Monitoring and understanding the timing of the growing season is crucial for assessing the impacts of climate change and developing effective strategies to mitigate risks and optimize outcomes.

6.3 Limitations

While this study provides valuable insights into the potential shift in the timing of the end of the growing season, there are several limitations that should be acknowledged.

First, the study focused on a specific region, namely the Val Grande National Park in northern Italy. The findings may not be directly applicable to other regions with different climate and ecological characteristics. It is essential to conduct similar studies in diverse geographical locations to obtain a more comprehensive understanding of the global patterns and variability in the timing of the growing season.

Another limitation is the temporal coverage of the data. The study utilized data from a limited time period, ranging from 2013 to 2022. While this timeframe allows for the assessment of trends and patterns, longer-term data would provide a more robust understanding of the long-term changes in the timing of the growing season. It is essential to continue monitoring vegetation dynamics over extended periods to identify persistent trends and validate the observed shifts.

Furthermore, the study focused on the analysis of NDVI trends and did not consider other factors that can influence the timing of the growing season, such as temperature, precipitation, and local environmental conditions. Incorporating these additional variables in future research would provide a more comprehensive understanding of the complex interactions and drivers of vegetation dynamics.

Lastly, the study utilized linear regression analysis to assess trends in NDVI values. While linear regression is a commonly used statistical technique, it assumes a linear relationship between variables, which may not always capture the complexity of vegetation dynamics. Exploring alternative analytical approaches, such as non-linear models or machine learning algorithms, could provide further insights into the shifts in the timing of the growing season.

Overall, these limitations highlight the need for further research and the consideration of multiple factors in understanding the timing of the growing season. Addressing these limitations would enhance the accuracy and generalizability of the findings, contributing to a more comprehensive understanding of the impacts of climate change on vegetation dynamics.

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