Accessing the atmospheric role on different vegetation indexes and how it affects the forest cover calculation over Taiwan using SPOT 4 Vegetation data

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Abstract

As mankind's technological advancements continue at a surprisingly fast rate, the computer models and tools that atmospheric scientists use to analyze and forecast our climate and weather have improved significantly. With the data collecting tools becoming increasingly sophisticated, the data obtained are becoming more and more accurate. In addition, more input data can now be fed into the models to obtain better simulations. One piece of input data that cannot be ignored is information regarding the land cover. The type and distribution of the land cover can seriously affect the climate and weather patterns of the Earth, such as regulating the amount of solar radiation that reenters the atmosphere. The land cover is usually measured through vegetation indexes such as the commonly used normalized difference vegetation index (NDVI). However, due to the fact that the NDVI index is susceptible to various outside influences---most notably the atmospheric disturbance, additional indexes have been developed to counter these effects. This paper explores two such indexes---- the Aerosol Free Vegetation Index (AFRI) and the Atmospherically Resistant Vegetation Index (ARVI). Comparisons are made with the NDVI index to see if they indeed performed better. In addition, actual applications are performed in calculating the percentage of the forest cover over Taiwan with the three indexes. In general, the results showed that the AFRI and ARVI (using a gamma value of one) did indeed perform better than their NDVI counterpart.

Keyword: Land cover、vegetation index

1. Introduction

Simply put, the vegetation index is used to access the amount of vegetation biomass covering the surface. Through the index we may further retrieve information regarding the leaf area index (LAI), vegetation fractional cover, (French, Schmugge, & Kustas, 1997), chlorophyll concentration (Buschmann & Nagel, 1993), global CO^2 concentration (Tucker, Fung, Keeling,& Gammon, 1986) and so forth. All of this data are considered important information that may help us understand the world's weather, energy, and climate patterns. In addition, the vegetation indexes also help us constantly monitor changes in the world's vegetation. The NDVI index is one of the most widely used indexes in assessing the amount of vegetation biomass. The formulation of the index is based upon the different behaviors exhibited by the vegetation toward different wavelengths of the EM spectrum. As the solar radiation strikes the Earth's surface, the chlorophyll inside the vegetation absorbs the energy within the red wavelengths, while the mesophyll reflects back the infrared segment.

By tuning to these specific wavelengths, the sensors onboard satellites or aircrafts can measure the amount of reflectance from the surface, and calculate the value of the NDVI index. The formula produces a scale from -1 to +1. Different value represents different land cover. The closer it is to the value of 1, the larger the amount of vegetation biomass there will be. Its mathematical expression is as follows:

$$NDVI=(\rho NIR-\rho RED)/(\rho NIR+\rho RED)$$

where ρ NIR refers to the Near infrared reflectance and ρ RED refers to the Red band reflectance.

Unfortunately, the NDVI index is susceptible to atmospheric scattering from aerosols. If the AOD of the atmosphere is high, it may cause the NDVI index to produce inaccurate values. This is why different indexes such as the AFRI and ARVI were conceived in attempting to counteract the atmospheric effects. •

The AFRI index stands for the Aerosol Free Vegetation index (Karnieli, Kaufman, Remer, & Wald 2001). The index takes advantage of the longer short-wave infrared wavelength (SWIR) to penetrate the atmospheric haze. It mostly uses channels situated at 1.6μm or 2.1μm. The SWIR has the advantage of being sensitive to vegetation while also having the capability to circumvent the suspended particles (mainly because of its longer wavelength). The AFRI index seeks to replace or in another sense, simulate the reflectance of the red band with the SWIR wavelength. Therefore, Kaufman et.al., 2001 sought to derive the mathematical relationship between the red band and SWIR under clear sky conditions, where the red band can be substitute with the SWIR.

$$AFRI_{2.1}=(\rho NIR-0.5\rho_{2.1})/(\rho NIR+0.5\rho_{2.1})$$

$$AFRI_{1.6}=(\rho NIR-0.66\rho_{1.6})/(\rho NIR+0.66\rho_{1.6})$$

The index again produces a similar scale ranging between –1 and 1. Due to the fact that the Spot 4 Vegetation data contains only 1.6μm data, we can test only the 1.6μm channel.

The ARVI index on the other hand, stands for Atmospheric Resistant Vegetation index (Kaufman, Tanre, 1992). The index employs the blue band in conducting atmospheric corrections on the red band. Compared with the red band, the blue band is much more easily scattered by the atmosphere. It's a self-correcting process, which "utilizes the difference in the radiance between the blue and red channels to cancel out and correct the radiance in the red channel." (Kaufman, Tanre, 1992). Mathematically,

$$ARVI=(\rho NIR-\rho_{rb})/(\rho NIR+\rho_{rb})$$

ρ_{rb} equals $\rho_r-\gamma(\rho_b-\rho_r)$, γ is like a weighting function that depends on the aerosol type. It serves as a weighting function for the difference obtained between the reflectance of the two bands. Various numbers can be chosen for γ, which depends on the type of aerosol size, but according to Kaufaman et al., 1992, it is best to select a gamma value of 1 "when information on the aerosol type is not available." The index again produces a similar scale ranging between –1 and 1.

2.DATA and Methodology

The data used in this paper is obtained from the Spot 4 Vegetation sensor. The Spot 4 satellite (see figure 1), one of the newest additions in the series of Spot satellites, was lofted into a sun-synchronous orbit onboard an Arian 4 launch vehicle on March 24, 1998 and is operated by Spot Imaging of France.

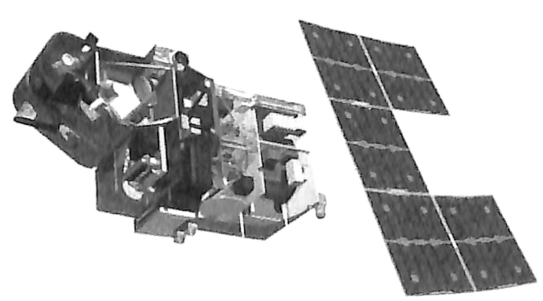


Fig.1 Image of the Spot 4 satellite

The Vegetation sensor's primary mission is in the environmental monitoring of the

Earth's surface. Its total field of view is 50.5°, where it has a swath width of 2,250 km. The spatial resolution is 1km across the entire field of view or FOV. The sensor provides data in four separate channels— 1) Blue: 0.43~0.47 μm 2) Red: 0.61~0.68 μm 3) Near infrared: 0.78~0.89 μm 4) Short-wave infrared: 1.58~1.75 μm. The satellite scans the Earth through linear array detectors, and orbits the planet 14 times a day, where its equatorial crossing time is 10:30 a.m. A special feature of the sensor is its short-wave infrared channel, which in addition to the usual visible and near infrared channels provided onboard satellite sensors, can be used as an alternative in analyzing the Earth's surface. The Spot 4 data is downloaded through a satellite-receiving dish located on top of one of the buildings at the Center for Space and Remote Sensing Research at the National Central University in Chungli, Taiwan. The downloaded data is first processed by the Meteorological Satellite Laboratory through a series of software designed for the sensor, where it is then distributed to potential users. The center began receiving data from the sensor on Sep 1, 2001. The data representing the respective reflectance of the spectral channels composing each vegetation index is thrown into a program where it constructs a grayscale image representing the index. The digital count that each pixel exhibits, represents a value of the vegetation index (see fig.2 for example), where it ranges between 0 and 255. However, the digital count must be recalculated through a simple mathematical relationship in order to obtain the true value of the respective vegetation index. Therefore, this paper sets to compare the three vegetation indexes, and in addition to the gamma value of 1, the values of 0.7, and 1.3 are also tested. According to the paper of Ramon et al. (2001), it concluded that γ =1.3 was deemed more suitable over their test area located in France. As a result, it may be possible that a different gamma value may also be more suitable over the Asian area. Here we test γ =0.7.

Three months of data from September to November (2001) were processed to construct the various vegetation index images. Six days were chosen randomly (09/14, 11/09, 11/10, 11/20, 11/21, and 11/26) to compare the respective vegetation indexes with the NDVI index. 30 random points were chosen around the image including the island of Taiwan for each date. The digital counts selected were recalculated into their respective index values. Scatter plots of each index with the NDVI index were then drawn to analyze their relationship. Theoretically, when the correlation is higher, it indicates that the AOD is lower, allowing the vegetation indexes to behave more similarly. On the other hand, if the correlation is lower, it should indicate that the NDVI has been affected by a higher AOD.Results indicate that the AFRI and ARVI index (when γ =1) seemed to be the most capable in reducing the effects from the atmosphere. When γ =1.3, the correlation plummetssignificantly. This may be attributed by an "over-correction" of the index, causing the ARVI values to rise too highly. By contrast, when γ = 0.7, the correlation soars significantly, which on the other hand may be causedby an "under-correction", rendering the ARVI value to behave too similarly with the NDVI index.

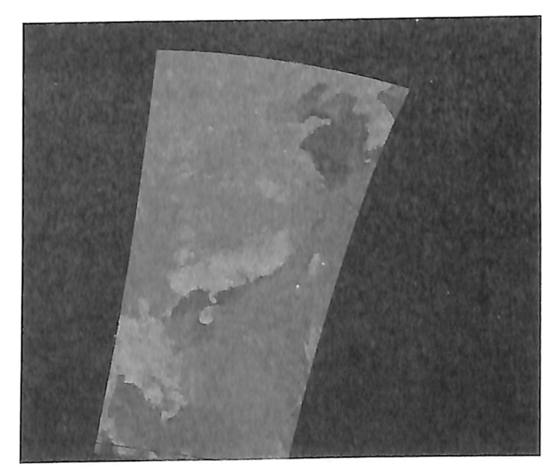
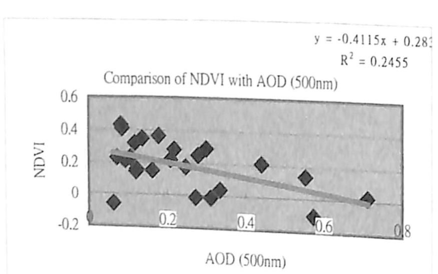
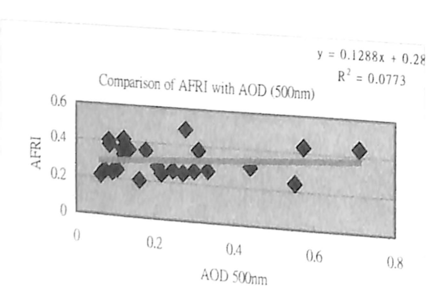


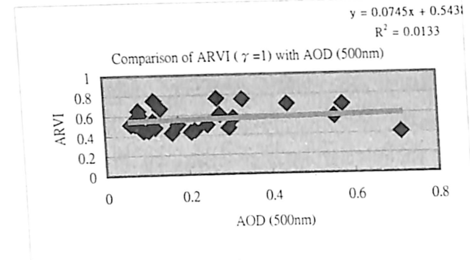
Fig.2 Image example of the processed Spot 4 data (NDVI image 2001/11/10)

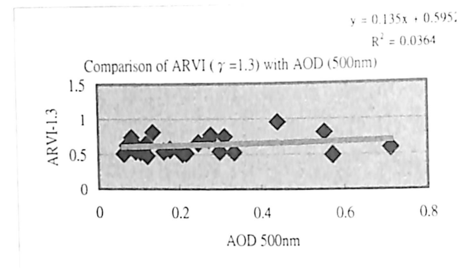
Originally, the same dates that were used to compare the vegetation indexes were intended to be selected in analyzing their relations with the AOD or aerosol optical depth by utilizing several stations from the Aeronet that were near the thirty points chosen previously from the vegetation index images. Aeronet is a vast network comprised of stations scattered across the world that are used in the monitoring of the AOD. However, due to availability of data from each station and exclusion of clouds, analysis of the AOD with the vegetation index had to be conducted based primarily on the Anmyon station located near South Korea.Twenty-four separate days were chosen over the three-month long period to conduct analysis of the relationship of the AOD with the vegetation indexes. The twenty-four dates were again chosen based upon data availability, and exclusion of clouds. Furthermore, image acquisition time from the Vegetation sensor also had to coincide or at least be near the time of the AOD measurement.

Scatter plots of each respective vegetation index with the AOD were drawn for analysis (see fig 3). From the slope, we see that the NDVI index value goes down steeply with an increasing AOD. For the other indexes they do not go up or down so abruptly, where the AFRI and ARVI (γ = 1.0) is the least influenced by the AOD.









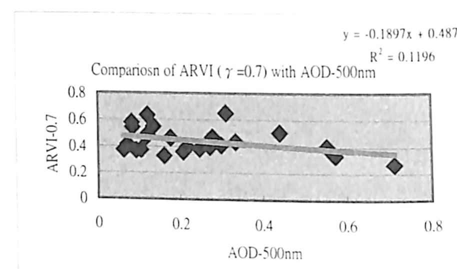


Fig 3. Scatter plots of the respective vegetation index with the AOD.

3. Forest cover calculation over Taiwan

As the AFRI and ARVI index using a gamma value of one apparently are more capable of withstanding the atmospheric influence, they were put to test along with the NDVI vegetation index in calculating the forest cover percentage over Taiwan. The calculated results were compared with ground surveys conducted by the Taiwan Forestry Bureau. Two composite images, one from November, and the other from the first three days in December, were constructed for each index for analysis (fig.4, 5, and 6). Using the forest cover image from the Taiwan Forestry Bureau as a reference, a simple supervised classification process was conducted in delineating the forest areas and non-forest areas over the composite images of Taiwan. Green areas indicate forests, while the yellow portions represent non-forest areas. According to the Taiwan Forestry Bureau's

third survey, the forest cover percentage over Taiwan was roughly around 58%. The various calculated forest cover percentage values of the three vegetation indexes were as follows: 1.) NDVI**:** 55.1% in November and 54% in December. 2.) ARVI (γ=1)**:** 55.1% in November and 54% in December 3.) AFRI**:** 54.9% in November and 55.1% in December. Although the forest cover percentage for each index did not differ much with the Taiwan Forestry Bureau survey, the more important aspect was that the variation of the NDVI index was larger than the other two. The fluctuations of the AFRI and ARVI (γ =1) were not as high, which further justifies that the two indexes are not as easily affected by the atmospheric influence. An obvious example is the area encircled in red from the Dec NDVI composite image, where it has a yellow color. From the NDVI image in November, and from the other two index images both in November and December, the area is instead delineated in a green color. This is consistent with the map from the Taiwan Forestry Bureau. Therefore, it was very likely that the AOD was higher over that certain area, causing the NDVI value to drop.

4. Conclusions

From the comparisons, the AFRI and ARVI index (γ =1) seem to be the most capable in reducing the effects from the atmosphere, which can be seen by the scatter plots produced from the Anmyon station. When γ =1.3, an over-correction seems to occur, and when γ =0.7, an under-correction seems to occur.However, more research should be made regarding the value of gamma. Although both indexes attempt to decrease the effect caused by atmospheric aerosols, I am personally fonder of the former one. The theoretical basis of the ARVI index is complex and not direct enough. I believe eventually the AFRI index will attain a more important role in future studies. Its physical interpretations are clear and more direct. In addition, with the scheduled launch of the Spot 5 spacecraft in May this year, which will carry onboard the second-generation Vegetation instrument, more precise measurements can also be made of our home planet's surface.

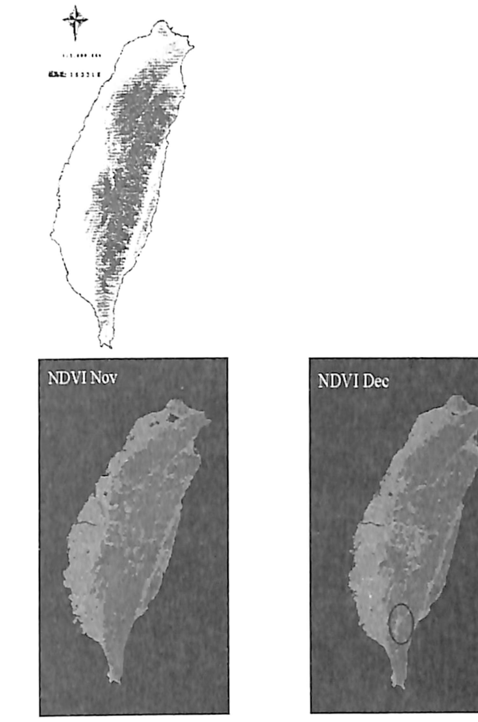


Fig.4 Forest cover of Taiwan calculated through the NDVI index. Green areas indicate forests, and the yellow portions represent non-forest areas. The forest cover percentage is 55.1% for November, and 54% in December.

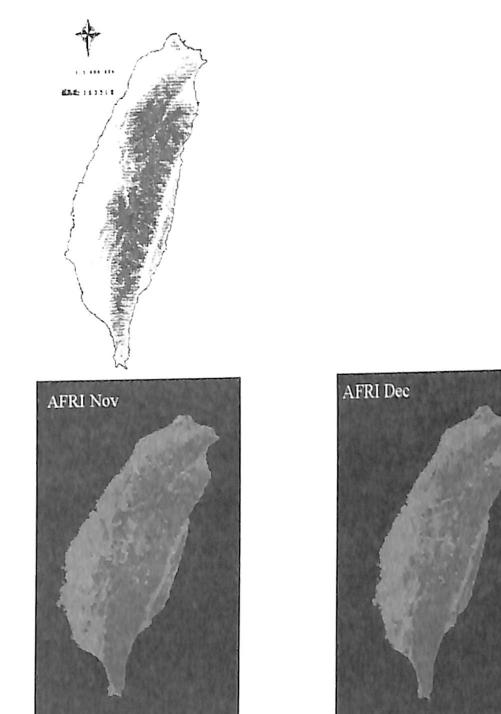


Fig.5 Forest cover of Taiwan calculated through the AFRI index. Green areas indicate forests, and the yellow portions represent non-forest areas. The forest cover percentage is 54.9% for November, and 55.1% in December.

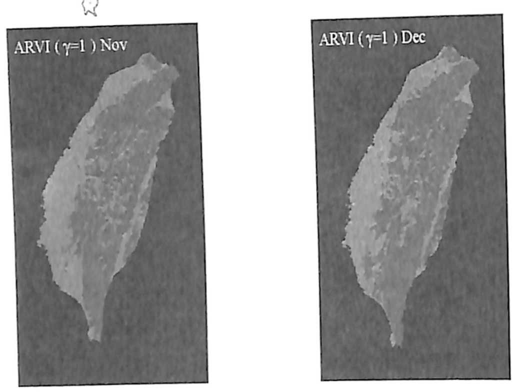


Fig.6 Forest cover of Taiwan calculated through the ARVI index (γ =1). Green areas indicate forests, and the yellow portions represent non-forest areas. The forest cover percentage is 55.1% for November, and 55.5% in December.

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不同植被對大氣及對台灣森林覆蓋量計算之影響

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摘　要

隨著人類科技不斷的快速進步，許多研究學者用來分析天氣的儀器和模式也跟著不斷的提升。而由於儀器的改進與提升，使得獲取的資料更具準確性。再加上模式不斷的改進和升級，我們可以將越來越多獲取的資料丟入模式中，已取得更佳的模擬結果。在這些資料中，有一種不可以忽略的是關於地球表面的覆蓋情形。這是由於不同的地表覆蓋物型態與分佈情況會對於地球上的大氣與氣候狀況產生顯著的影響，譬如調節留在地球內的太陽輻射量等。一般來說，植被指數是通常被用來衡量地表覆蓋物的多寡與分佈情況，而 NDVI 是目前最常被使用的指數。但由於 NDVI 較容易受到大氣的影響，所以一些研究學者就發展出受大氣影響較小的植被指數。故在本篇中，主要在探討兩種較不受大氣影響的植被指數----AFRI 和 ARVI，並將此兩種植被指數與 NDVI 作比較。此外，也將三種植被指數實際應用在估算台灣地區森林面積的比率並且作比對。大致上來說，AFRI 和 ARVI（當 gamma 值＝1 時）所顯示的結果的確表現的比 NDVI 好。