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Fully automated drought analysis from the products of the moderate resolution imaging spectroradiometer (MODIS)

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ABSTRACT

Remote sensing data have become one of the important data sources to monitor and analyze drought. However, how to access, retrieve, process, and analyze Earth observation data, and discover drought from them in an automated manner is a big challenge to researchers. In this study, one of the most common drought monitoring and analysis methods was implemented to streamline and automate the process of accessing to and downloading from the data server, pre-processing the data, calculating drought indices, and producing the drought maps following the well-known hierarchical concept: Data, Information, and Knowledge. All developed modules can act as independent components. They can also be seamlessly integrated into the process or reused by other researchers. Several open-source libraries in Python such as Geospatial Data Abstraction Library (GDAL) and Numerical Python (NumPy) were extensively exploited in the implementation. With the help of these libraries, one of the satellite data-derived vegetation indices named the Vegetation Health Index was calculated.

1. Introduction

In the recent two decades, monitoring drought using remote sensing data has gained too much attention because remote sensors onboard satellites acquire earth observation data continuously across the globe once a day, and they collect observations about all parts of the world in great spatial detail. These advantages in spatial and temporal resolution make satellite data become a common and popular source to monitor territorial vegetation conditions.

Drought monitoring methodology based on vegetation was first introduced by (Tucker and Choudhury 1987) that reduced photosynthetic activity can result from drought and such declines in photosynthetic capacity of terrestrial Earth surface can be detected by satellite remote sensing. The normalized difference vegetation index (NDVI) was found to be associated with green leaf area (Tucker 1979) and vegetation abundance (Price 1992). Therefore, It was proposed to quantify photosynthetically active biomass (Tucker 1979). Furthermore, the NDVI has been used extensively in global and regional drought monitoring applications (Kogan 1993; Yagci, Di, and Deng 2013; Deng et al. 2013; Yagci, Di, and Deng 2015).

Vegetation condition index (VCI) was calculated from NDVI which were obtained from NOAA's the Advanced Very High Resolution Radiometer (AVHRR) sensor in order to highlight weather impacts on vegetation (Kogan 1993). Later, two new indices were introduced by (Kogan 1995), Temperature Condition Index (TCI) and Vegetation Health Index (VHI). These indices have been very helpful and useful to detect important historical droughts, so they have been utilized for this purpose by many scientists (Quiring and Ganesh 2010; Singh, Roy, and Kogan 2003; Liu and Kogan 1996). NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) sensors are currently available in space and have been acquiring Earth observation data since 2000. Originally, aforementioned indices were calculated from AVHRR data, in this study, datasets from the MODIS sensors will be used because of their better radiometric accuracy, and higher spatial and temporal resolution than the AVHRR data.

In brief, the drought methodology was built on the premise that vegetation health dynamics are good indicators of weather impacts on natural and cultivated vegetation such that unhealthy vegetation likely occur as a result of adverse weather.

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2. Data & methods

2.1. Satellite data

Each MOD09Q1 file in Hierarchal Data Format (hdf) contains two tiled surface reflectance layers, Red-Visible (Red) band and Near Infrared Band (NIR), and one corresponding quality layer regarding the first two bands in 250m spatial resolution. Each product is collected by the MODIS sensor flown on NASA's Terra satellite. The first three letters of the product name indicate which satellite is MODIS instrument mounted and the last three letters after the dot denote the collection number. In this case, "MOD" means the MODIS instrument on Terra satellite, while "005" indicates 5th collection. Moreover, reflectance values in Red bands are collected at 620-670 nm channel, while surface reflectance values in NIR bands are acquired at 841-876 nm portion of the Electromagnetic spectrum. Each MOD09Q1 tile with the size of 4800 by 4800 is projected onto the sinusoidal projection. This product is essentially 8-day composite product, meaning that each pixel represents a period of 8-day. The best possible observation whose characteristic features are cloud/cloud shadow-free, aerosol-free and low view angle, from 8-day interval is assigned to the final composite product (Vermote, Kotchenova, and J. P. Ray 2011).

The MOD11A2 is a Land surface Temperature (LST) & Emissivity product derived from the MODIS sensor onboard NASA's Terra satellite. It is an 8-day composite product in 1km (1000m) spatial resolution. Each pixel is comprised of an average of clear sky observations in 8-day period unlike the MOD09Q1.005 products. Each tile with 1200 by 1200 dimension is projected onto the sinusoidal like the MOD09Q1.005 product. In total, each MOD11A2 hdf file contains 12 different layers. However, the daytime LST layer and its corresponding quality layer are needed for this application. All LST products have been validated with ground-truth (Wan 2007).

The MOD44W is a Land-water mask in 250m resolution derived from several sources such as the Shuttle Radar Topography Mission's (SRTM) Water Body Dataset (SWBD) and the MODIS dataset from NASA's terra satellite. There is only one version of this dataset projected onto sinusoidal projection in 250m spatial resolution for each MODIS tile. This product is an improved version of land-water mask products derived from spectral data alone because the RADAR offers cloud-penetrating capability unlike the MODIS to detect terrestrial water bodies (Carroll et al. 2009).

2.2. The vegetation indices

Several vegetation indices from NDVI and LST were utilized in our study. They are NDVI, VCI, TCI and VHI. The NDVI is reliable and accurate measure of vegetation vigor or greenness (Kogan 1993).

The VCI is used to extract the weather impacts on vegetation in the NDVI. Low VCI values indicate bad vegetation health due to adverse weather conditions, whereas high VCI values indicate healthy vegetation due to favorable weather conditions (Kogan 1993). It can be calculated by the following equation:

$$VCI_{ij} = \frac{(\mathrm{NDVI}_{ij} - \mathrm{NDVI}_{min})}{(\mathrm{NDVI}_{max} - \mathrm{NDVI}_{min})}\ x\ sf \qquad 1$$

where NDVI_{max} and NDVI_{min} are multi-year maximum and minimum NDVI values for a pixel, respectively. NDVI_{ij} is the NDVI value collected on the date of interest in yyyyddd (eg. 2011177 or 06/26/2011) format, year with trailing Julian day. For example, for the date of 2011177, the $\mathrm{NDVI}_{i=2011,j=177}$ value should be inserted into (2) and the VCI will take this form $\mathrm{VCI}_{i=2011,j=177}$. Finally, the sf, scale factor, can be any positive number. The suggested scale factor is 100, but 250 is used in this study to get more precision. Another index, TCI was designed to compensate the situation when both the NDVI and the VCI is depressed as a result of excessive soil wetness. In this case, small VCI value is interpreted as drought mistakenly. The TCI helps solve this shortcoming of VCI (Kogan 1995). The TCI can be computed by this formula to assess drought conditions;

$$TCI_{ij} = \frac{(\mathrm{LST}_{max} - \mathrm{LST}_{ij})}{(\mathrm{LST}_{max} - \mathrm{LST}_{min})}\ x\ sf \qquad 2$$

where LST_{max} and LST_{min} are multi-year maximum and minimum LSTs for a pixel, respectively. The date numbering of LST_{ij} and TCI_{ij} are exactly similar to the VCI's date numbering explained in the previous paragraph. The sf, scale factor, is exactly same with the scale factor utilized in the (1). It is important to note that high LST indicates low vegetation water content (Choudhury and Tucker 1987) as opposed to the premise that high NDVI signals healthy vegetation. In other words, negative relationship between NDVI and LST exists during warm months (Sun and Kafatos 2007). For this reason, this negative relationship is reflected in the TCI equation by subtracting the current value from maximum instead of subtracting minimum from the current value than so that both low values of TCI and VCI identify bad vegetation due to adverse weather. The VHI as a final index is designed to combine the reports from both VCI and TCI. It is an additive combination of the VCI and TCI as depicted by the following equation;

$$VHI_{ij} = a\ x\ VCI_{ij} + (1 - a)\ TCI_{ij} \qquad 3$$

where α is the empirical constant that defines contributions from two indices. The recommended constant for α in (3) is 0.5 (Bhuiyan, Singh, and Kogan 2006).

3. Implementation

In this section, implementations of the automated drought monitoring and analysis from MODIS data will be described. The open-source python modules and libraries are used in the development. Users who are familiar with the ESRI's ArcGIS can consider a Python module as a tool like tools in the ArcGIS toolbox.

3.1. Data download

The data download module is implemented, and users can use their functions to download the MODIS data of interest by calling the function named *dailyDownload*. This function needs three arguments including the link of FTP server of MODIS data with the specified date, the full target path on the local machine, and the name of the MODIS tiles. The *dailyDownload* function will resolve the server's address, the folder on the server where the MODIS data are stored and the date of the MODIS data from the given ftp address. Then, the function will go into the folder and search the requested tiles. Finally, the requested tile for the specified date will be retrieved and saved into the given directory on user's local machine. To download multi-date MODIS data, a simple for loop is adequate by feeding the parameter of the ftp address with new dates.

3.2. The calculation of vegetation indices

Vegetation indices such as NDVI, VCI, TCI and VHI were implemented as separate generic functions or tools. The implemented python function can be regarded a tool that takes arguments from users and works with any type of data derived from different sensors. The NDVI tool takes RED and NIR band parameters along with land/water mask and output file parameters. In the end, water bodies are masked out and only land is preserved after the NDVI computation. Furthermore, the land/water mask parameter is designed to be an optional parameter. Like the NDVI function, the VCI tool takes a list of input files and their corresponding output files. Another implemented vegetation index function is the TCI function which takes a list of LST files and their corresponding output files that indicate where the TCI results will be saved into. The last function is the VHI. This function takes one VCI file and one TCI file. Obviously, both files must be acquired on the same date. These VI functions implemented based on the MODIS sensor data are generic functions so they will be able to work with Earth observation data from other Remote Sensing instrument (e.g., AVHRR).

3.3. Utility functions

The spatial resolutions of MOD11A2 and MOD09Q1 products are different. All bands such as Red band and NIR band in MOD11A2 product are in 250m resolution, whereas all bands in MOD09Q1 product are in 1000m (1km) spatial resolution. Therefore, each VCI result derived from MOD11A2 products has 4800*4800 pixels, while each TCI result derived from MOD09Q1 products has 1200*1200 pixels. Resampling function was implemented to resolve the dimension mismatch between VCI and TCI products prior. Moreover, another utility function, named *gdalMerge*, was developed from Geospatial Data Abstraction Library's (GDAL) gdal_merge.py program to mosaic tiled-based VHI results tiles into one. In addition, a utility function, named *extractbyshp*, was implemented to extract the VHI data for the specified administrative district from the large VHI files.

3.4. Drought classification

The threshold value to classify drought were recommended by (Kogan 2002). However, the threshold in the drought classification scheme were modified because the data range of the VHI-based drought maps is between 0 and 250 as opposed to recommended VHI's data range between 0 and 100 by (Kogan 2002). Moreover, the drought severity classes are adopted from the classification scheme of the US Drought Monitor (USDM).

4. Results

All implemented tools were imported and integrated into a "py" file, so that the whole process can run in an automated manner after the required parameters are fed. Here, the state of Texas, United States (US) was chosen to test the automated code for a specific Julian day, 177.

Firstly, the code begins to download satellite data from NASA's server and saved them into separate directories whose names are MOD09Q1, MOD11A2 and MOD44W.Next, all files with their full paths in the MOD09Q1 and MOD44W directories are written into different lists and then the NDVI function loops through the lists and calculates one NDVI image for each MOD09Q1 product and its corresponding water mask extracted from MOD44W products. For the TCI function, all LST files with the same pattern are noted in a list and fed to the TCI function, while all NDVI files with the same pattern are entered to the VCI function. After all VCI and TCI data are computed, all results in TCI and VCI directories with their full paths are written into separate lists. The VHI function loops through these two lists and calculates VHI results. After completion of VHI calculation, merge operation takes place by mosaicking five tiles in the study area. Later, extraction of Texas by state's administrative GIS shape file from mosaicked large VHI results one by one is completed. Consequently, drought classification scheme is applied to each VHI results. The flow of the drought model is well illustrated in Figure 1. One example VHI map is given in Figure 2.

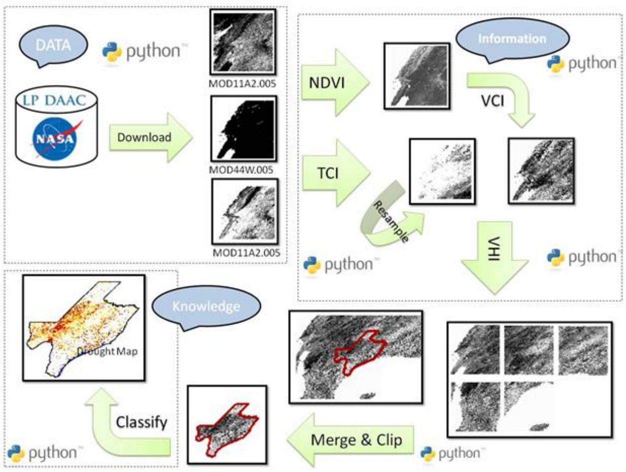

Figure 1. Flow chart of the study

5. Conclusion

In this study, satellite data-based drought indices calculation to detect droughts was successfully automated from data download through final drought products. The whole process is streamlined in the Python modules. An example of drought monitoring and analysis for the state of Texas is given to demonstrate this method. The most prominent feature of the Python programming language is that programmer doesn't necessarily implement every function from scratch. Freely available packages implemented by other programmers in Python such as NumPy, SciPy (Scientific tools for Python) and GDAL can be downloaded from the internet. Later, users can integrate or reuse desired functions in these packages into their own programs. This integration is so intuitive and seamless that only a single line, importing user-desired function from the package, is adequate. Besides freely available open-source libraries, built-in methods in Python allow to list files in directories, search for a specific pattern in filenames and record filenames that match the pattern in lists very quickly and easily.

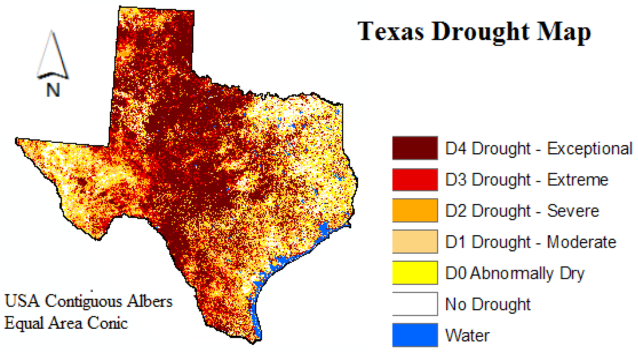

Figure 2. Resulting Drought Map

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