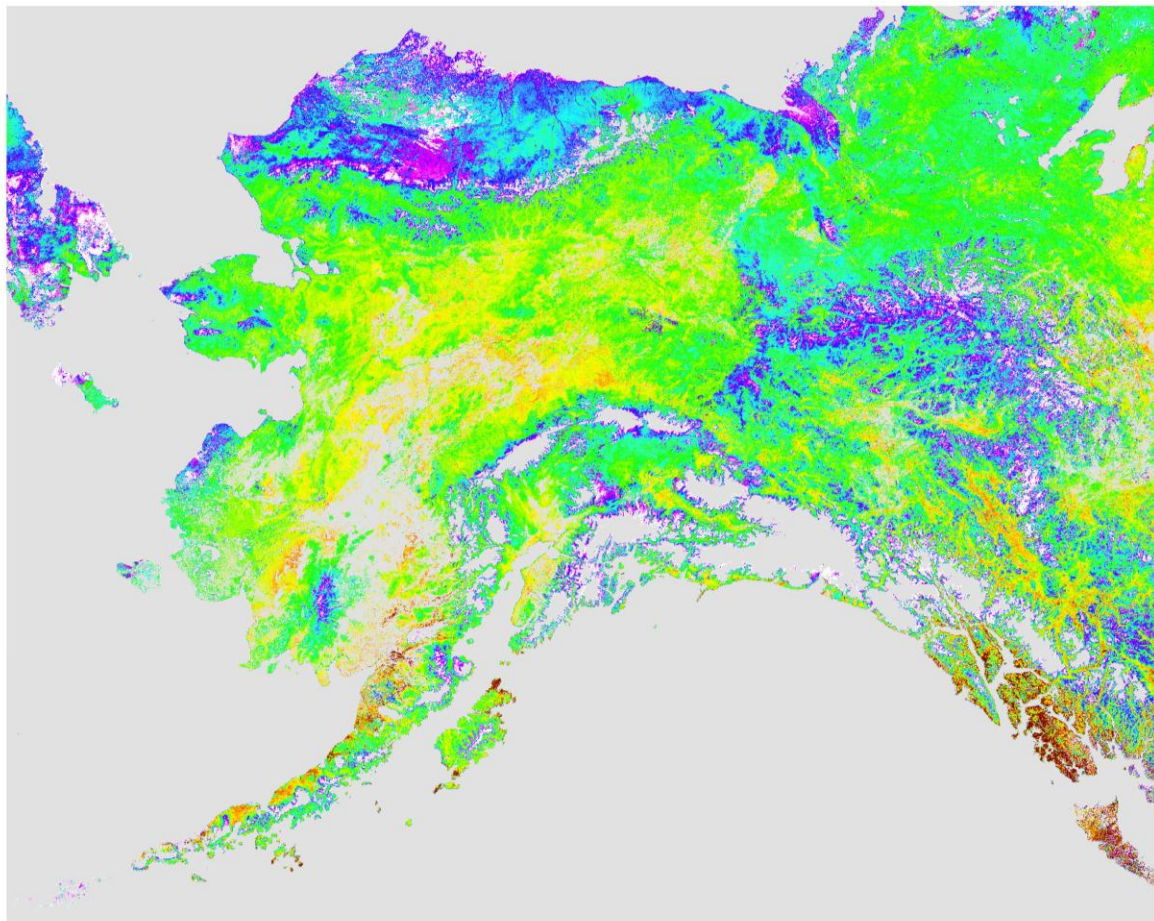




AVHRR-derived NDVI Metrics Product Development

Version 1.0

Natural Resource Data Series NPS/AKRO/NRDS—2015/788



ON THE COVER

The total number of greenness days during 2013 is illustrated using a color ramp from pink to brown, where pink represents 90 days and brown represents 150 days, respectively. Image produced by Jiang Zhu.

AVHRR-derived NDVI Metrics Product Development

Version 1.0

Natural Resource Data Series NPS/AKRO/NRDS—2015/788

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National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Data Series is intended for the timely release of basic data sets and data summaries. Care has been taken to assure accuracy of raw data values, but a thorough analysis and interpretation of the data has not been completed. Consequently, the initial analyses of data in this report are provisional and subject to change.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

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Earth Resources Observation and Science ([EROS](#)) Center

Introduction

Advanced Very High Resolution Radiometer (AVHRR) data are being used by the National Park Service (NPS), Alaska Region Inventory & Monitoring (I&M) Program and the University of Alaska-Geographic Information Network of Alaska (GINA) to monitor and study the interannual variability of vegetation across Alaska. GINA acquires standardized AVHRR-derived Normalized Difference Vegetation Index (NDVI) data, derives NDVI metrics, and distributes the NDVI data and NDVI metrics data. This document briefly introduces how to acquire the standardized AVHRR products from existing archives at the USGS-EROS Data Center, as well as how to deliver the processed results. It also describes the NDVI metrics algorithm and its usage.

Data and Methods

The U.S. Geological Survey's (USGS) Earth Resources Observation and Science (EROS) Center acquires afternoon AVHRR 1-km resolution daily observations to produce a 7-day composite Normalized Difference Vegetation Index (NDVI) dataset for Alaska. The dataset generally includes twenty-eight weekly composites for the period April through October, including each year since 1995. The dataset is projected into the WGS84/Albers Conical Equal Area mapping grid and is distributed as Geostationary Earth Orbit Tagged Image File Format (GeoTIFF) files. The spatial resolution of the dataset is 1km x 1km. The dataset is produced by means of several data processing steps: scene selection, correction for satellite and solar viewing geometry, radiometric calibration, atmospheric correction, scaling of the reflectance and temperature data, calculating NDVI, geometric registration, compositing, and cloud screening. We did not choose to calculate NDVI by ourselves for two reasons: 1) the data process is complicated and the 7-day composite NDVI dataset from USGS-EROS is widely used for vegetation monitoring and analysis among various communities; and 2) the dataset can be directly served in a web coverage service (WCS) to monitor the vegetation condition and can be used to calculate NDVI metrics directly from the source files. Once transferred to GINA and processed, the data are distributed through the GINA WCS (<http://ndvi.gina.alaska.edu/year/avhrr>). Yearly 7-day composite NDVI data files are stacked into a 28-band tiff file, missing values in the time series of pixels are interpolated, the time series are smoothed, and finally the yearly NDVI metrics are calculated. The yearly NDVI metrics product is also delivered through the WCS (<http://ndvi.gina.alaska.edu/metrics?>). Figure 1 describes the generalized NDVI data processing and delivery workflow.

Figure 1. AVHRR NDVI data processing workflow.

Source and Format of Input Data

The AVHRR 7-day composite NDVI dataset for Alaska generally includes twenty-eight weekly composites for April through October of each year. Each composite file has a naming convention of satID_regionIDyy_dddddd_tif.tar, where satID represents the source satellite, regionID represents the region of coverage, yy represents the acquisition year, ddddd represents composite-day range from start ordinal day of year to end ordinal day of year, tif identifies the file is in geotiff file format. For example, the filename n18_ak11_088094_tif.tar indicates that the 7-day composite data were

collected on board the NOAA-18 satellite for the Alaska region, and it consists of data from 2011 for days 088 to 094 of that year. Each 7-day composite tar file includes 14 geotiff files, with each geotiff representing a single band. Table 1 describes the bands in a composite file.

Table 1. Band description of a composite file.

Band	Description	Notice
1	Top of atmosphere Channel 1 reflectance	
2	Top of atmosphere Channel 2 reflectance	
3	Radiance	
4	Temperature	
5	Temperature	
6	NDVI value	0-99=cloud, snow, or water; 100-200=valid NDVI
7	Satellite zenith	
8	Solar zenith	
9	Relative Azimuth	
10	Atmospheric corrected Channel 1 surface reflectance	
11	Atmospheric corrected Channel 2 surface reflectance	
12	QA/QC	
13	Date index	
14	Cloud mask	0-99=clear; 100-200=cloudy

The input datasets are available at earthexplorer.usgs.gov. NDVI 7-day composite data from 1995 to 2012 were downloaded for the NDVI metrics calculations completed by UAF-GINA. Each file of the dataset includes 28 7-day composite tar files per year, for all but two years. The 2006 dataset does not include two 7-day composite data collections (4/5-4/11, 4/12-4/18) and the 2007 dataset has one 7-day composite data gap (10/2-10/8).

AVHRR-derived NDVI metrics algorithm

The AVHRR-derived NDVI metrics algorithm was developed using the IDL and ENVI software packages (Exelis Visual Information Systems, Boulder, Colorado, USA). The schema of the algorithm is illustrated in Figure 2.

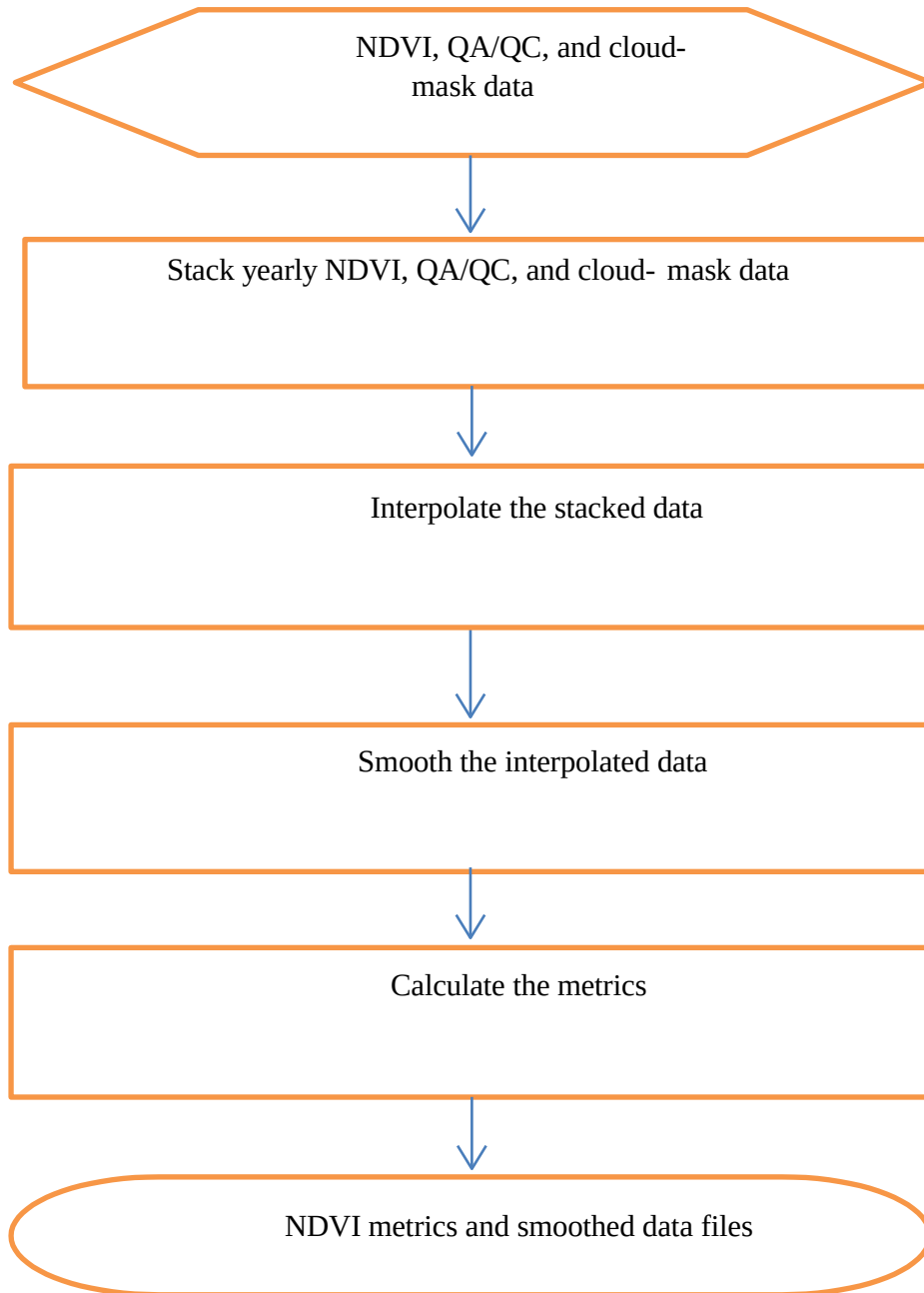


Figure 2. Schema of AVHRR-derived NDVI metrics algorithm.

The yearly NDVI, QA/QC, and cloud-mask data are inputs for the NDVI metrics algorithm. The algorithm is divided into two parts. Part 1 stacks yearly NDVI, QA/QC, and cloud-mask data into multiple-band data sets, respectively. Part 2 interpolates and smooths the NDVI data using information from the QA/QC and cloud-mask data, and calculates the NDVI metrics. The outputs of

the algorithm are NDVI metrics and the smoothed NDVI data. The NDVI metrics data include 12 metrics which are stored into a 12-band geotiff file. Table 2 lists the metrics name and value range. The days in bands 1, 3, and 6 are ordinal days of the year.

Table 2. Band description of a metrics file

Band No.	Description	Value Range
1	Day of onset of greenness (onp)	1-366
2	NDVI value at onset day (onv)	0.0-1.0
3	Day of end of greenness (endp)	1-366
4	NDVI value at the end day of greenness (endv)	0.0-1.0
5	The duration of greenness season (durp)	0-366
6	The day of the maximum NDVI value (maxp)	1-366
7	Maximum NDVI value (maxv)	0.0-1.0
8	Range of NDVI values (ranv)	0.0-1.0
9	Rate of green up (rtup)	
10	Rate of senescence (rtdn)	
11	Time-integrated NDVI (tindvi)	
12	NDVI metrics flag	0-not valid data, 1-good data

In Table 2, the rate of green up (rtup) is the slope value calculated using NDVI values at the day of onset of greenness (onp) and the day of the maximum NDVI value (maxp). The rate of senescence (rtdn) is defined as the absolute value of the slope determined by NDVI values at the day of maximum NDVI value (maxp) and the day of end of greenness (endp). The time-integrated NDVI (tindvi) is the integration of NDVI values within the time range, from the day of onset of greenness (onp) to the day of end of greenness (endp). It should be noted that the algorithm does not accurately estimate the timing for end of greenness for parts of southern Alaska. This is because the last 7-day AVHRR NDVI composite of the year provided by the USGS generally includes data from late September to early October, and during this time of year it is still possible for areas in southern Alaska to have pixels recording greenness.

A. Stack yearly NDVI, quality, and cloud-mask data

Figure 3 shows the data stacking program (avhrr_stack_oneyear_data.pro). The stacking program takes three file lists as inputs. The three lists are the one-year-ndvi-file list, the one-year-bq-file list, and the one-year-cloud-mask-file list which includes the absolute directory path and file names of NDVI, quality (bq), and cloud-mask files, respectively. The program goes through each triple group (the I^{th} group) of files and reads them into a temporary memory space. It stacks a year of data together, and produces three stacked data files per year, one for each file type (ndvi, bq, cloudmask).

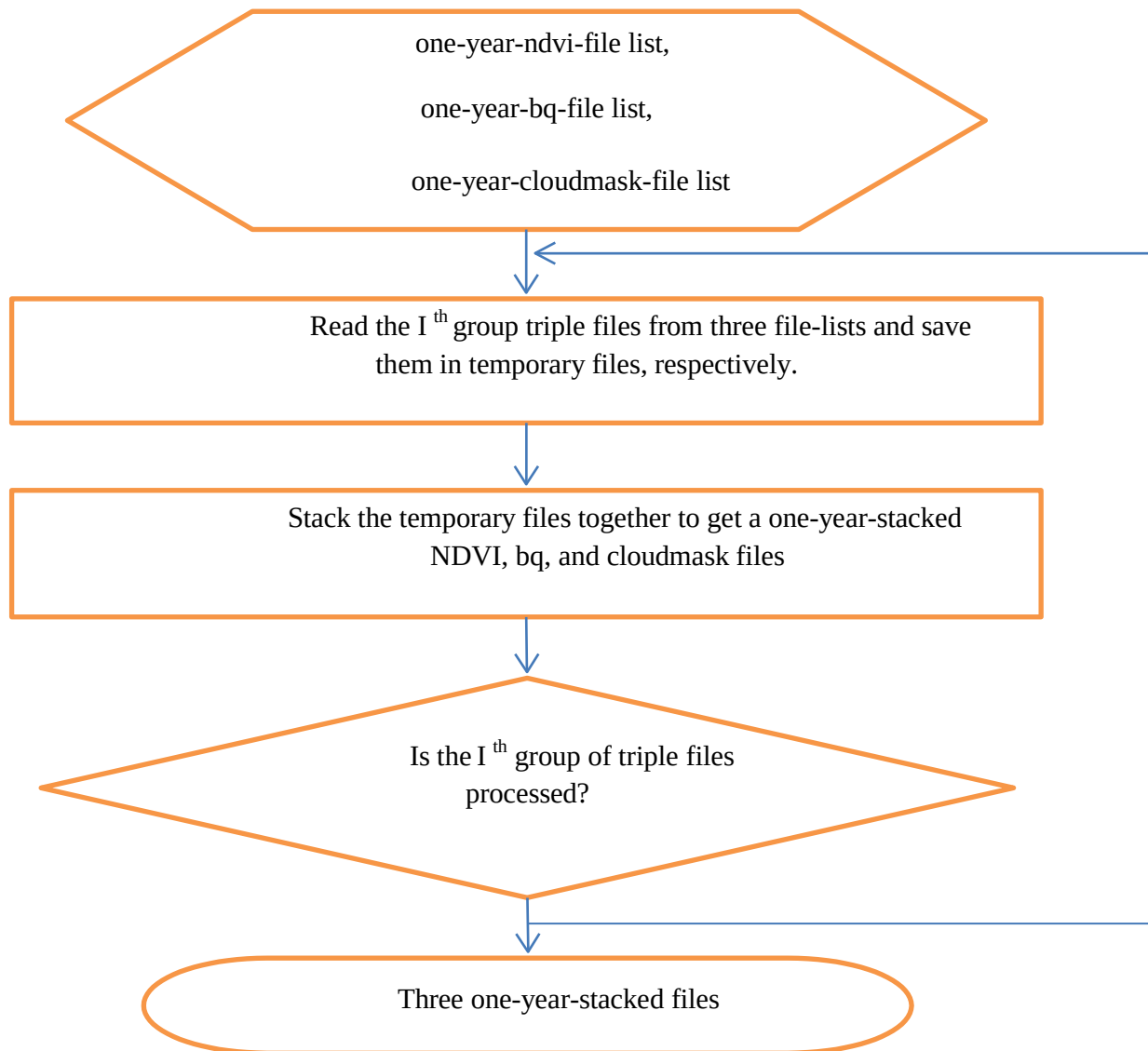


Figure 3. Flowchart of Part 1 of the algorithm - stacking process.

B. Interpolate the data

The second part of the algorithm includes interpolation, smoothing, and calculation of NDVI metrics. Figure 4 shows the flowchart of Part 2 of the algorithm (avhrr_calculate_ndvi_metrics_tile.pro). The program inputs three stacked files: stacked_ndvi_file, stacked_bq_file, and stacked_cldmsk_file. It goes through each pixel (J^{th}) to interpolate and smooth the NDVI time series and calculate the NDVI metrics.

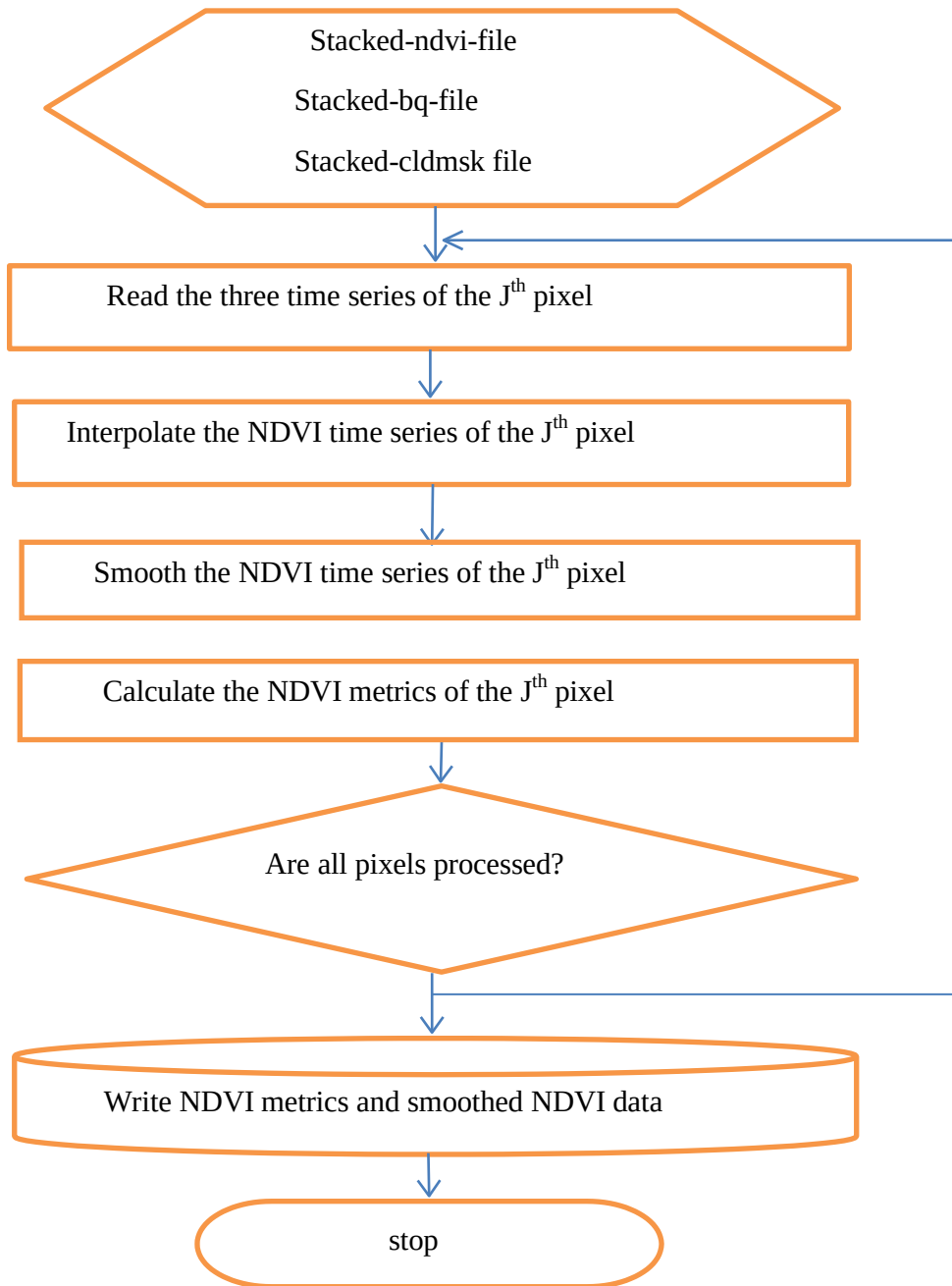


Figure 4. Scheme of Part 2 of the NDVI metrics calculation algorithm.

The interpolation subroutine (avhrr_interpol_extension_1yr.pro) is shown in Figure 5.

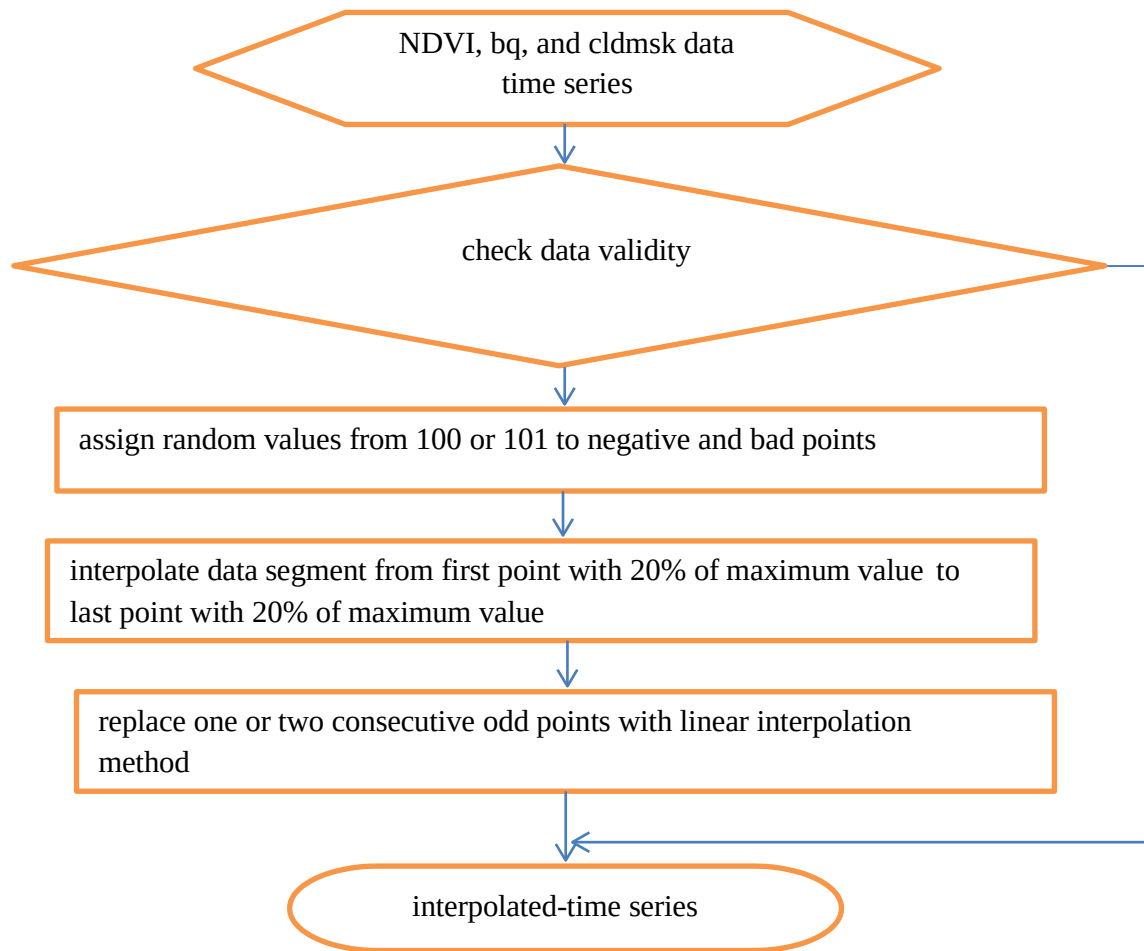


Figure 5. Flowchart of data interpolation for a NDVI time series.

The raw NDVI time series for a pixel includes 28 weekly composite data points, starting with late March and ending with early October. The value range of the raw NDVI time series is $[0, 200]$, where the valid data range is $[100, 200]$, and data within the range of $[0, 100]$ are called non-valid data and indicate cloud, snow or water. There are also odd data whose values are unexpectedly low compared to their neighbors. Two conditions are applied to determine the validity of a time series: a) the time series must have at least 3 clear-sky points with an NDVI value equal or greater than 25% of the valid raw data range of $[100, 200]$; i.e., NDVI values must be greater than 125; b) the time series must have a normal distribution, in which the maximum NDVI value point must be located between the first 20% of the maximum value point and the last 20% of the maximum value point. If the time series does not meet both conditions, interpolation of the time series cannot be completed, the flag of the time series is set as no data (-1) and the subroutine returns to the calling program. The calling program starts to process the time series of the next pixel. If the time series is valid, the subroutine continues to process the time series. Good points with values equal to or greater than 100 are kept. Other points are randomly assigned a value of 100 or 101 to avoid false crossovers for start of season and end of season detection. The time series is divided into three segments. The first segment is

defined from the first point of the time series to the point right before the first 20% of the maximum value point. The second segment is from the first to the last point of 20% of the maximum value point. The last segment is defined from the point right after the last 20% of the maximum value point to the last point of the time series. The linear interpolation method is applied to the second segment by keeping clear-sky points with valid NDVI values and interpolating the non-valid points. Then the time series is checked to determine if it includes one or two consecutive odd points which are significantly smaller than their adjacent points, and if so, these odd points are replaced with values determined by the linear interpolation method. Figure 6 gives an example of such a raw NDVI time series. As shown in Figure 6, three non-valid points (points 4, 7, and 25) and several odd points (points 10, 17, 18, 20, 21, and 22) need to be interpolated before the data can be used to calculate metrics. The interpolation process targets these non-valid and odd points.

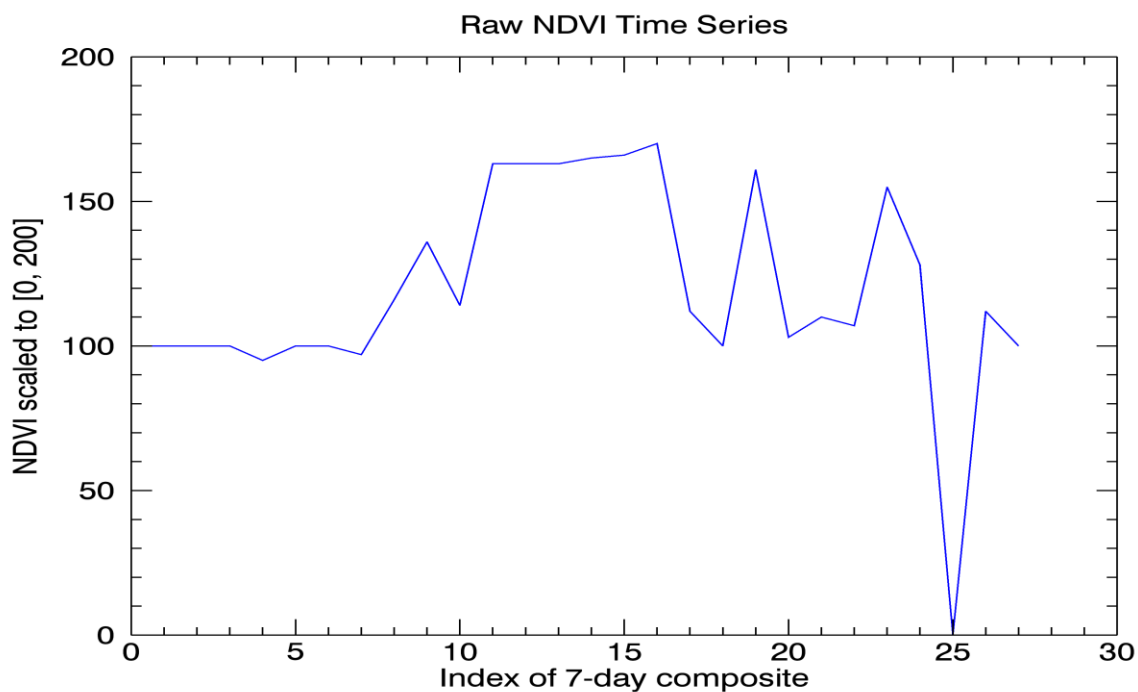


Figure 6. A raw NDVI time series.

Figure 7 shows the interpolated time series. As shown, both non-valid and odd points from Figure 6 are linearly interpolated.

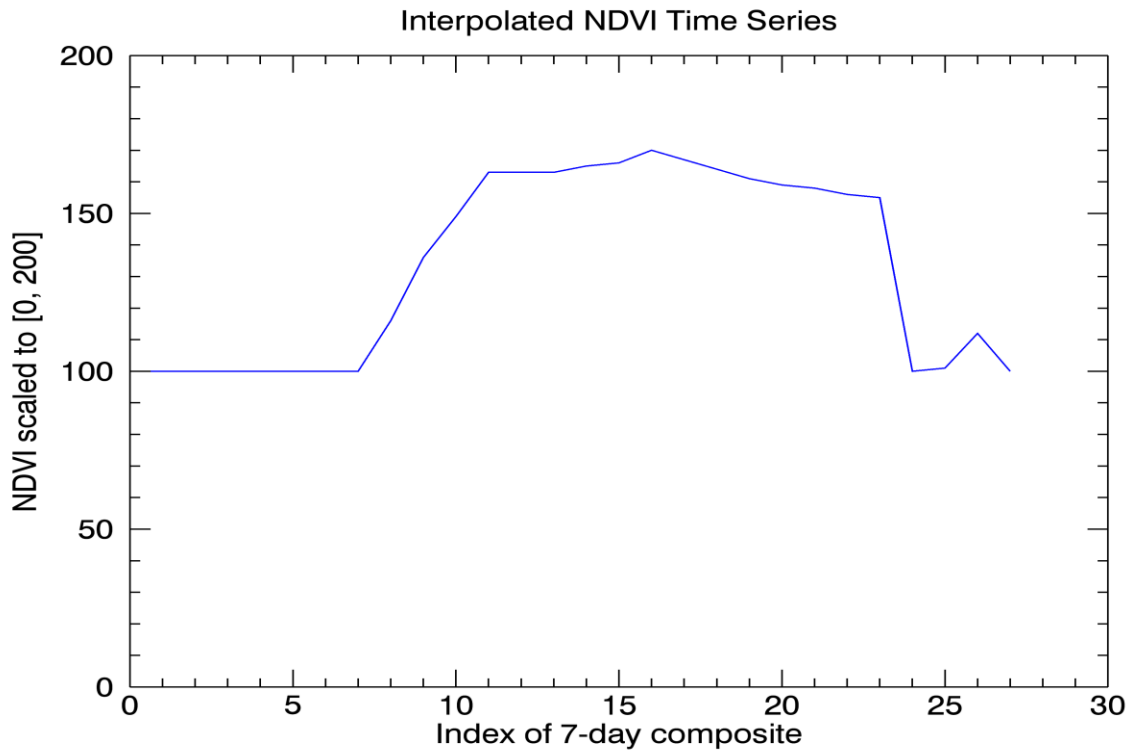


Figure 7. Interpolated-data time series.

C. Smooth the interpolated data

A weighted-least-squared smoothing algorithm is applied to the interpolated time series. The algorithm is based on methods described by Swets et al. (1999). Figure 8 shows the smoothed time series (`wls_smooth.pro`). Notice that the value of the 24th point of the time series is increased to simulate a more realistic profile.

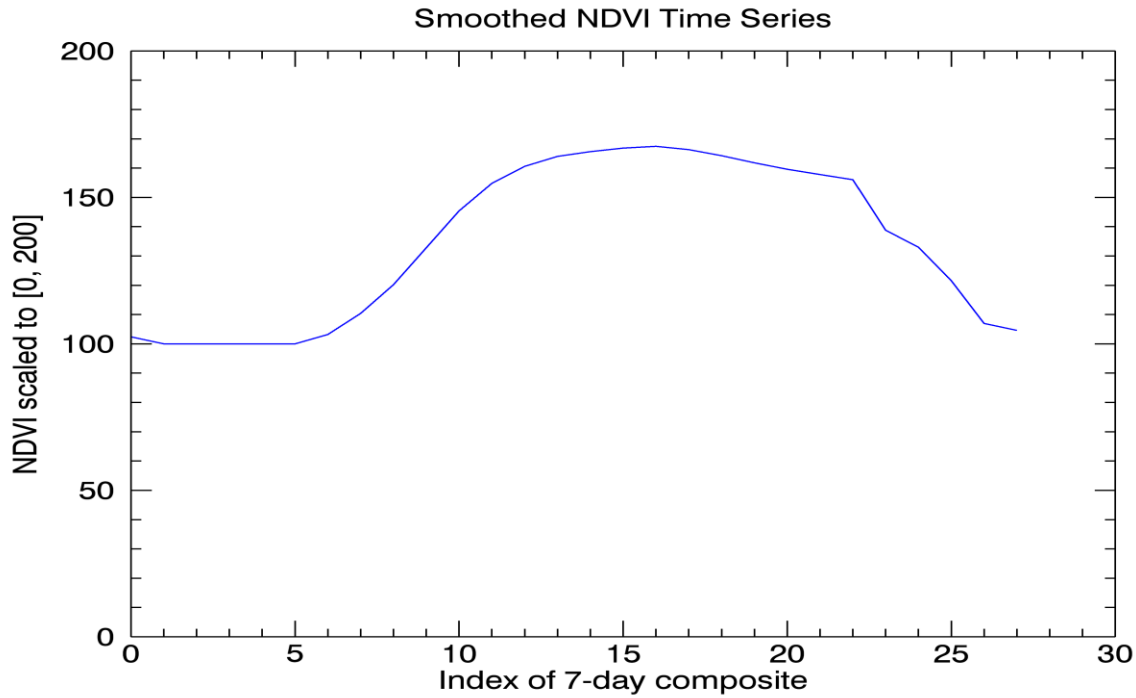


Figure 8. Smoothed-data time series.

D. Calculate NDVI metrics for the smoothed-data

The NDVI metrics calculation method combines the delayed moving average method (Reed et al., 1994) and the threshold method (Jönsson and Eklundh, 2002). Figure 9 describes the process of calculating the NDVI metrics from the time series. Application of the NDVI metrics algorithm takes a smoothed-data time series as the input. In step 1, it converts the time series from $[0, 200]$ to $[0.0, 1.0]$. In step 2, the subroutine calculates both the forward and backward delayed moving average of the time series. The fixed window length for the delayed moving average method is chosen in the algorithm, and the default value of the window length is 16. Because one point in the time series represents 7 days, a 16-point window length represents 112 days. Using a fixed-length moving window for the delayed moving average is beneficial when comparing multiple years of NDVI metrics data. Step 3 calculates the forward and backward moving averages of the time series. Step 4 obtains the crossover days, possible threshold days, and maximum slope days in the time series. A threshold value of 20% of the maximum NDVI is used to identify possible threshold days. Step 5 chooses the earliest day from the possible threshold days as the first threshold day, and chooses the crossover day which is the closest to the first threshold day as the possible start of season (SOS) day. It then picks the later day between the possible SOS days and first threshold day.

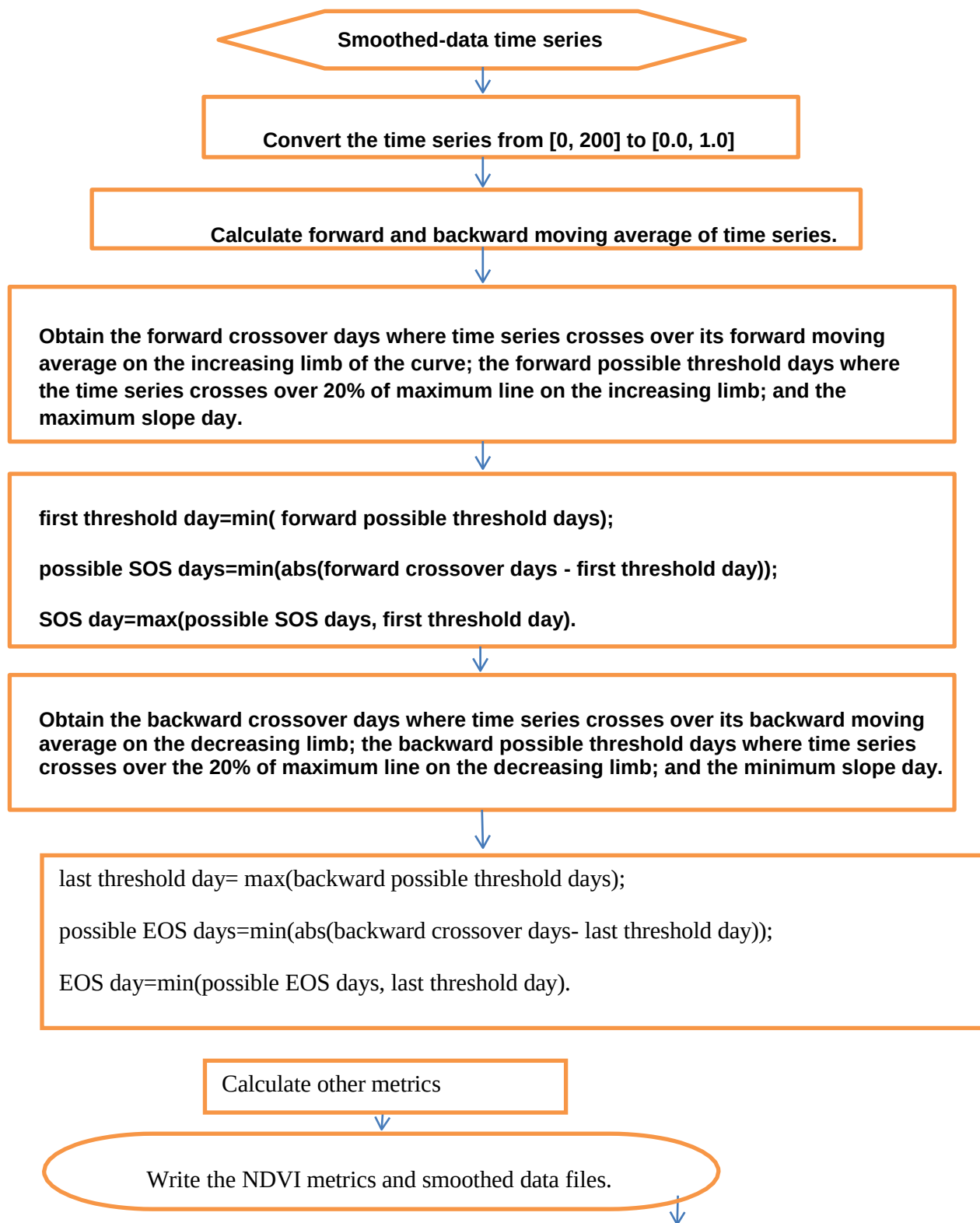


Figure 9. Flowchart of calculation of NDVI metrics

Figure 10 illustrates how the SOS day is determined. The solid line in the graph is the smoothed time series and the dotted line is the forward delayed moving average of the time series. The star is a forward crossover day and the triangle is the first threshold day. According to the logic of the algorithm, the SOS day is equal to the crossover day, since the threshold day occurs before the crossover day.

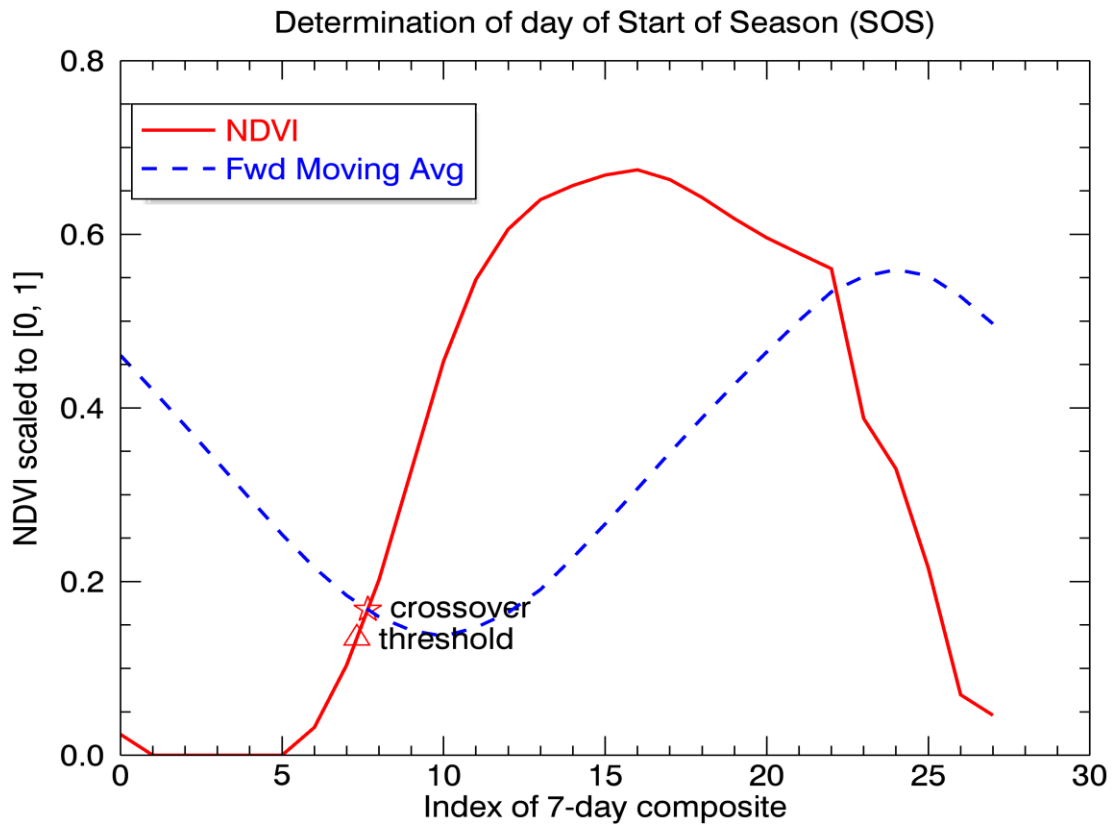


Figure 10. Determination of SOS day.

Steps 6 and 7 determine the end of season (EOS) day. They follow similar logic as in steps 4 and 5. Figure 11 illustrates the process of determining the EOS day. In this case, the EOS day is equal to the crossover day, because the threshold day is later than crossover day.

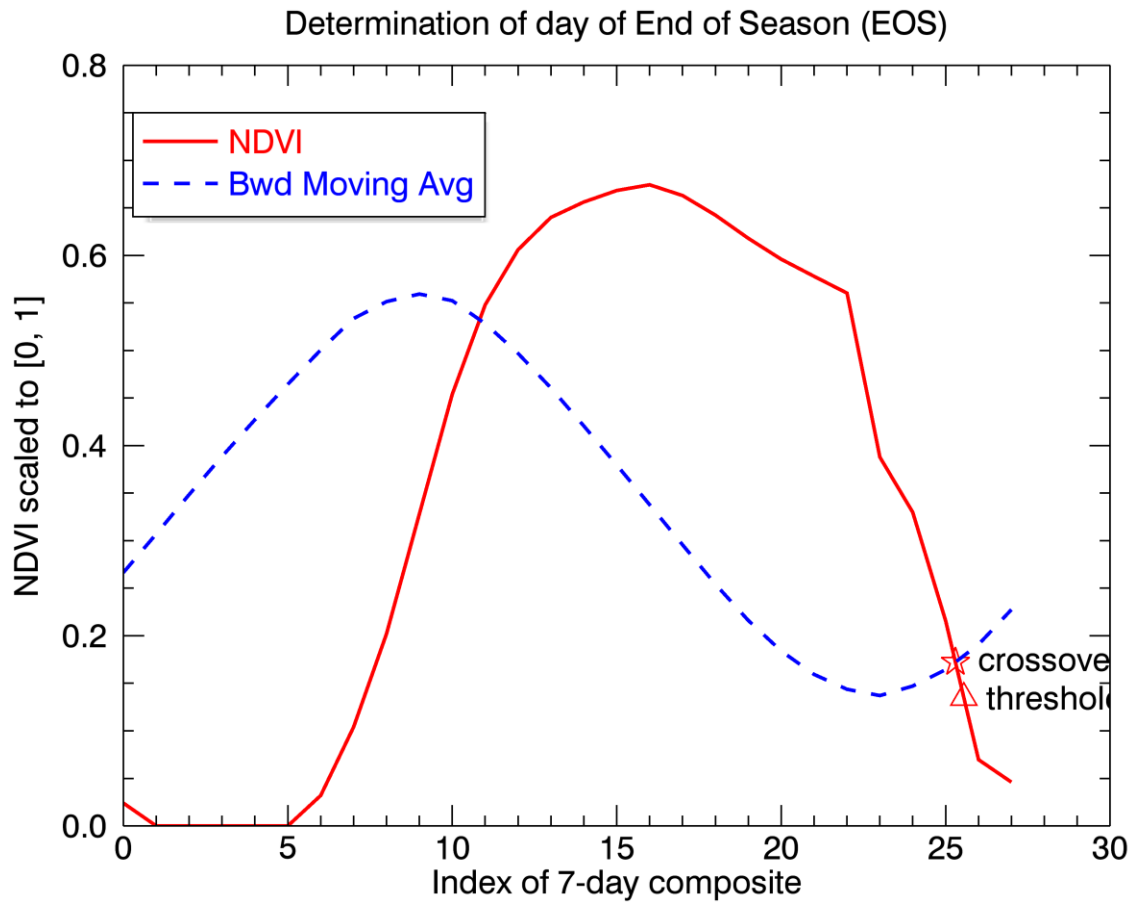


Figure 11. Determination of EOS day.

Once the SOS day and EOS day are determined, the remaining NDVI metrics are calculated.

Installation, configuration, and use

The algorithm routines were developed using the IDL programming language and ENVI software package. They work on both Linux and Windows operational environments with IDL plus ENVI installed. The instructions included here cover the installation, configuration, and use of the algorithm code in a Linux environment.

Installation

Download the algorithm zip file named avhrr-ndvi-metrics-master.zip from the URL link: <https://github.com/gina-alaska/avhrr-ndvi-metrics> to your home directory (\$HOME), and rename the zip file into “avhrr-ndvi-metrics-master.zip”.

Unzip the zip file. Files will be extracted into the “avhrr_ndvi_metrics” directory (\$HOME/avhrr-ndvi-metrics-master). In this directory, there will be one file (startup_nps) and several sub-directories: docs, bin, sav, codes, and scripts. The “doc” directory includes the documentation; the “~/bin” stores IDL library codes; the “~/codes” includes the IDL source codes; the “~/sav” stores the compiled IDL binary file; and the “~/scripts” includes script files used to execute the application in batch mode.

Configuration

Edit the startup_nps file and save it to the \$HOME/avhrr-ndvi-metrics directory. The file “startup_nps” should include:

```
ENVI, /RESTORE_BASE_SAVE_FILES

PREF_SET, 'IDL_PATH', '<IDL_DEFAULT>:+$HOME/avhrr-ndvi-metrics/bin',
/COMMIT
```

edit .bashrc by adding the following lines:

```
export ndvi_home=$HOME/avhrr-ndvi-metrics

export IDL_STARTUP=$HOME/avhrr-ndvi-metrics/startup_np

edit 1yr_avhrr_env.bash by adding following lines:

export rawdata_dir="avhrr_raw_data_main_directory"

export work_dir=$HOME/avhrr-ndvi-metrics/work

export script_dir=$HOME/avhrr-ndvi-metrics/scripts

export idlprog_dir=$HOME/avhrr-ndvi-metrics/sav

export idl_dir="home directory of installed IDL"

export result_dir=$HOME/results
```

AVHRR raw data are stored in the “avhrr_raw_data_main_directory”. Under the main directory, there are subdirectories to store different years of data. For example, year 2009 data are stored in the 2009 subdirectory.

Use

There are two options for running the application, which are described below. The first is to run it in batch mode, and the second is to run the application step by step.

a. Run the application in batch mode:

```
>cd $HOME/avhrr_ndvi_metrics/scripts  
>./1yr_avhrr_main_v2.bash yyyy
```

The parameter yyyy is the year that you want to process, such as 2007. It will automatically complete all steps to produce the NDVI metrics data file and smoothed data file in the \$result_dir.

b. Run the application step by step

Assuming the AVHRR raw data are stored in the \$rawdata_dir/YYYY, where YYYY represents year (such as 2007).

Step1. Produce ndvi, quality, and cloud mask file lists.

```
>./1yr_avhrr_flist.bash avhrr_raw_data_main_dir, year
```

This script produces three files. The yyyy_flist_ndvi, yyyy_flist_bq, and yyyy_flist_cldm. They include file names of ndvi, quality, and cloud mask files, respectively. For example, 2009_flist_ndvi, 2009_flist_bq, and 2009_flist_cldm.

Step2. Stack the one-year data

```
>./1yr_avhrr_stack_v2.bash flist_ndvi, flist_bq, flist_cldmsk, ul_lon,  
ul_lat, lr_lon, lr_lat
```

The flist_ndvi, flist_bq, and flist_cldmsk are file lists which include the full path of ndvi, quality, and cloud mask file names, respectively. The ul_lon, ul_lat, lr_lon and lr_lat are upper left and lower right location of the rectangular zone in longitude and latitude. They are used to subset the data. If one does not subset the data, all four location arguments are set as 0. This script produces three stacked files - yyyy_stacked_ndvi, yyyy_stacked_bq, and yyyy_stacked_cldm. For example, 2009_stacked_ndvi, 2009_stacked_bq, and 2009_stacked_cldm.

Step3. Calculate NDVI metrics

```
>./1yr_avhrr_calmetrics.bash stacked_ndvi_file, stacked_qa_file,  
stacked_cldmsk_file, ver_flag
```

This script accepts three stacked_file names, and user can choose ver_flg, for example, 'ver5'. It produces a yearly metrics file and a yearly smoothed 7-day composite NDVI data file.

Products

AVHRR-derived metrics dataset was produced for the years 1995 to 2013. GINA maintains and updates the dataset. The dataset can be accessed through http server at URL: http://dds.gina.alaska.edu/public/public/public/NPS_products/AVHRR_NDVI/AVHRR_derived_NDVI_metrics/. The same datasets are also provided through WCS server at the following URL: <http://ndvi.gina.alaska.edu/metrics/avhrr>.

The yearly NDVI metrics data are stored in a 12-band geotiff file. In order to illustrate the metrics data included in the file, the 2013 day of start of greenness season, day of end of greenness season, and days of greenness season are plotted in Figures 12 through 14.

2013 Day of Year for Start of Greenness Season (SOS)

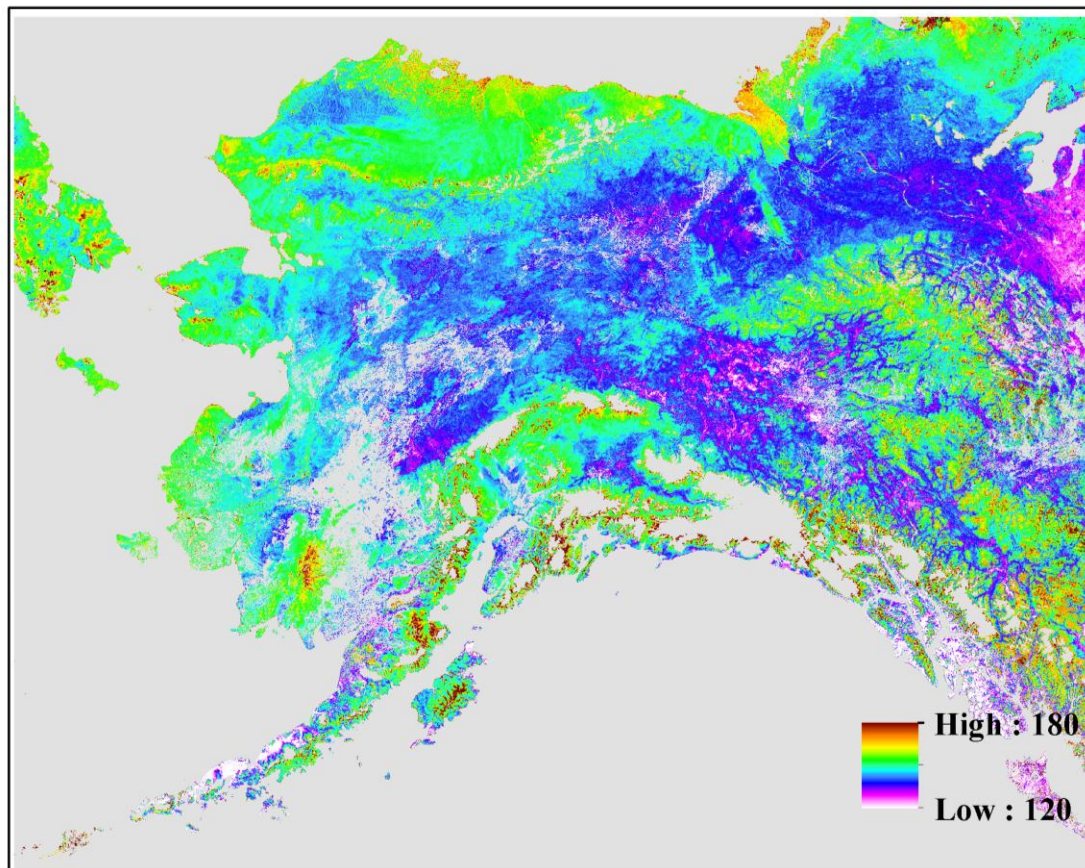


Figure 12. 2013 day of year for start of greenness season.

2013 Day of Year for End of Greenness Season (EOS)

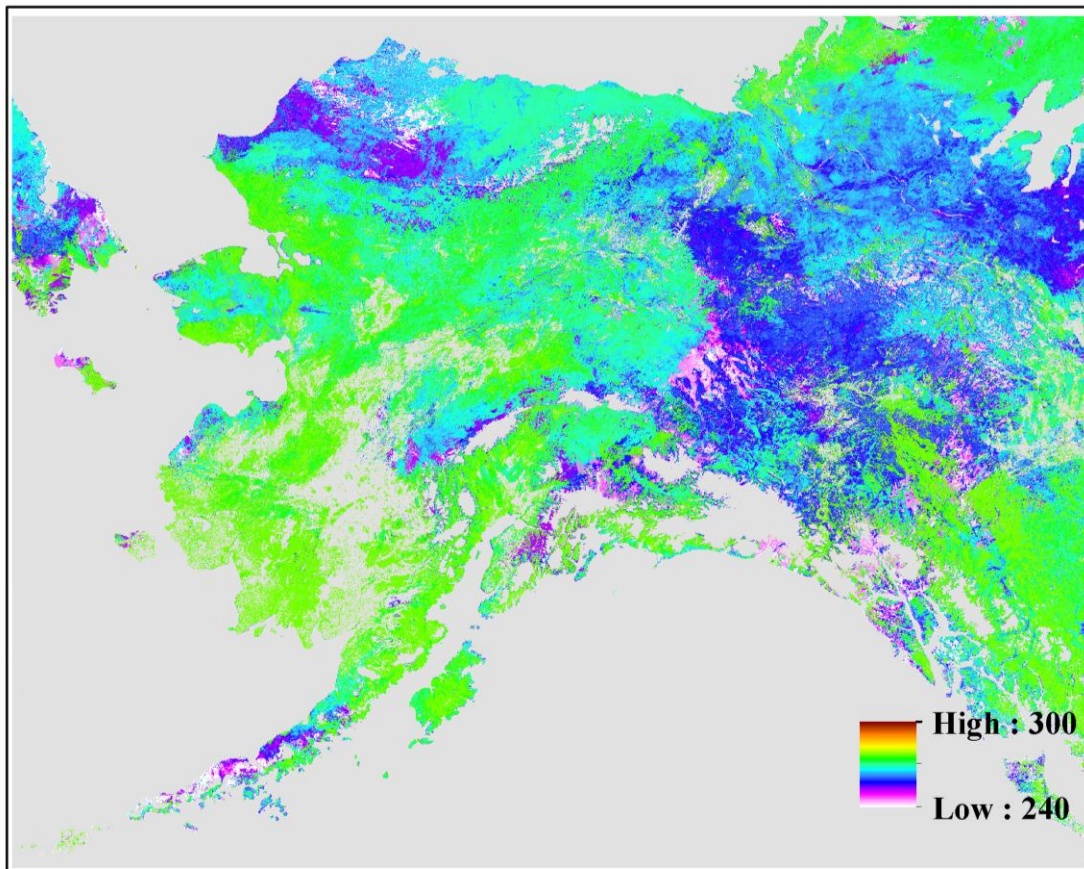


Figure 13. 2013 day of year of end of greenness season.

2013 Duration of Greenness Season (days)

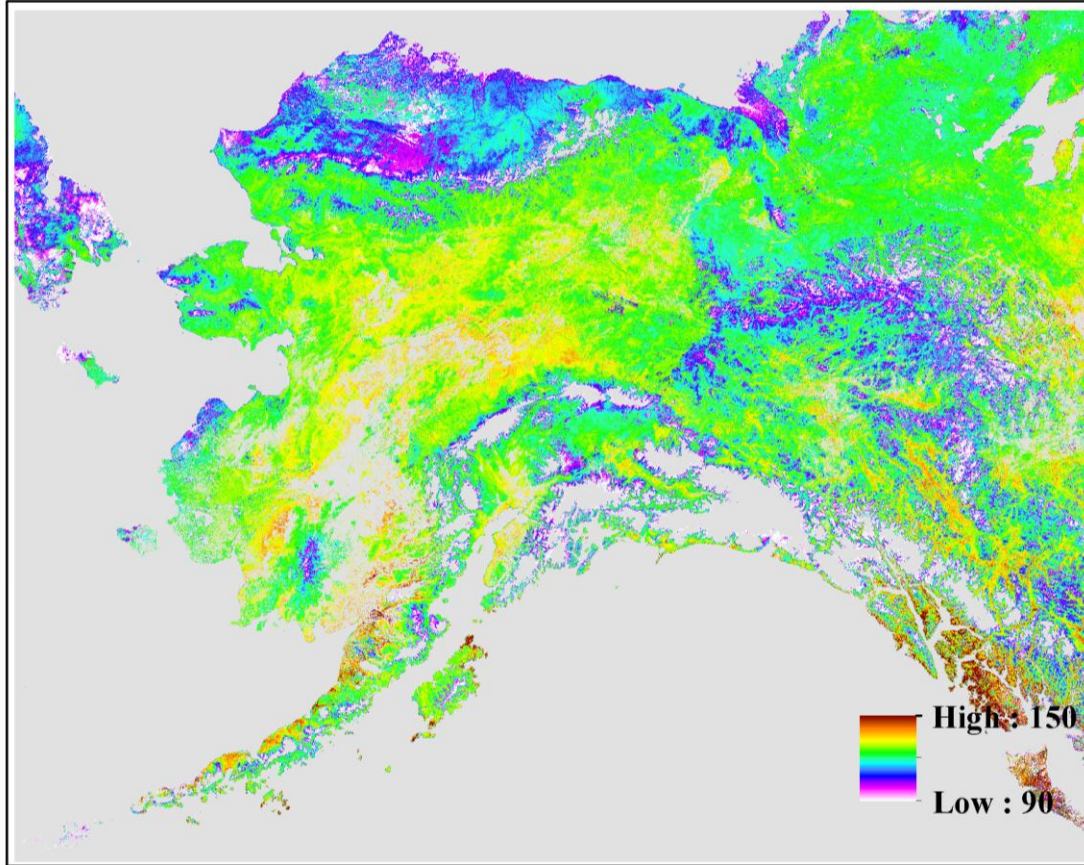


Figure 14. 2013 duration of greenness season (day)

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- Jönsson, P. and Eklundh, L. (2002). Seasonality extraction by function fitting to time-series of satellite sensor data. IEEE Transactions on Geoscience and Remote Sensing 40 (8), 1824-1832.

Appendix A List of program names of the Algorithm

1, avhrr_stack_oneyear_data.pro

1.1 start_batch.pro

1.2 read_ndvi.pro

1.2.1 subset.pro

2, avhrr_calculate_ndvi_metrics_tile.pro

2.1, start_batch.pro

2.2, avhrr_time_series_process.pro

2.2.1, avhrr_interpol_extension_1yr.pro

2.2.1.1 cutoff_interp.pro

2.2.1.1.1 interpol_line100b.pro

2.2.1.1.2 filter_2odd.pro

2.2.2 wls_smooth.pro

2.2.3 avhrr_user_metrics_by1yr.pro

2.2.3.1 ComputeMetrics_by1yr.pro

2.2.3.1.1 GetForwardMA.pro

2.2.3.1.2 GetBackwardMA.pro

2.2.3.1.3 GetCrossOver_percentage_extremeslope.pro

2.2.3.1.4 GetSOS.pro

2.2.3.1.5 GetEOS.pro

2.2.3.1.6 GetMaxNDVI.pro

2.2.3.1.7 GetTotNDVI.pro

2.2.3.1.8 GetNDVItoDate.pro

2.2.3.1.9 GetSlope.pro

2.2.3.1.10 GetRange.pro

2.2.3.2 findday.pro

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 953/128482, April 2015

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