

MODIS NDVI PRODUCTS AND METRICS USER MANUAL

Version 1.0

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1. Introduction

Moderate Resolution Imaging Spectroradiometer (MODIS) 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 in growing season length, lake ice formation and breakup, and snow season across Alaska. MODIS-derived true color imagery, Normalized Difference Vegetation Index (NDVI) and snow products (2000-present) are now being acquired, processed, and distributed by GINA. This user manual briefly introduces how to acquire the standardized MODIS products obtained from existing archives at the USGS-EROS Data Center as well as how to deliver the processed results. It describes in detail the data process algorithm and its usage.

This document updates the protocol by Reed et al. (2006) and indicates where changes in the processing stream have occurred.

2. NDVI product and Metrics

The U.S. Geological Survey's (USGS) Earth Resources Observation and Science (EROS) Center is generating one product called "eMODIS Alaska" (U.S. Geological Survey, 2012) based on Moderate Resolution Imaging Spectroradiometer (MODIS) data acquired by the National Aeronautics and Space Administration's (NASA) Earth Observing System (EOS). Historical surface reflectance and Normalized Difference Vegetation Index (NDVI) products over Alaska are composited in 7-day intervals on NAD83/Alaska Albers (EPSG3338) mapping grid in Geostationary Earth Orbit Tagged Image File Format (GeoTIFF). The spatial resolution of eMODIS Alaska data is 250 x250 square meters. eMODIS data is produced with improved cloud masking algorithm. The eMODIS Alaska expedited production stream delivers a 7-day rolling composite, created daily with the most recent 7 days of acquisition, to users monitoring real-time vegetation conditions. For trend analysis and comparative change, a historical record of 7-day intervals is generated. The eMODIS Alaska data are downloaded from the USGS-EROS Data Center eMODIS website (<http://dds.cr.usgs.gov/emodis/Alaska/historical/TERRA/>) to servers at GINA. The eMODIS Alaska data are now being used in place of the standard MODIS Vegetation Index (MOD13Q1) product described in Reed et al. (2006). MOD13Q1 data are available from the Land Processes Distributed Active Archive Center (LP DAAC). MODIS3Q1 data are 16-day composited at 250-meter spatial resolution as a gridded data in the Sinusoidal projection. For the purpose of evaluation of the NDVI metrics of Alaska region, the gridded data have to be mosaicked and re-mapped into Alaska Albers projection. On the other hand, eMODIS Alaska data are 7-day composited at 250-meter spatial resolution in Alaska Albers projection. Also, eMODIS Alaska data are processed with improved cloud mask algorithm. So, eMODIS data can be directly served in a web coverage service (WCS) to monitor the real-time vegetation condition and can be used to calculate NDVI metrics right way. Once transferred to GINA, the eMODIS Alaska data are distributed through the GINA WCS (<http://ndvi.gina.alaska.edu/year/modis>). Yearly 7-day composite NDVI data are stacked, interpolated, and smoothed, and then the yearly NDVI metrics are calculated. The yearly NDVI metrics product is also delivered through the WCS (<http://ndvi.gina.alaska.edu/metrics?>). Figure 2.1 describes the NDVI data processing and delivery procedure.

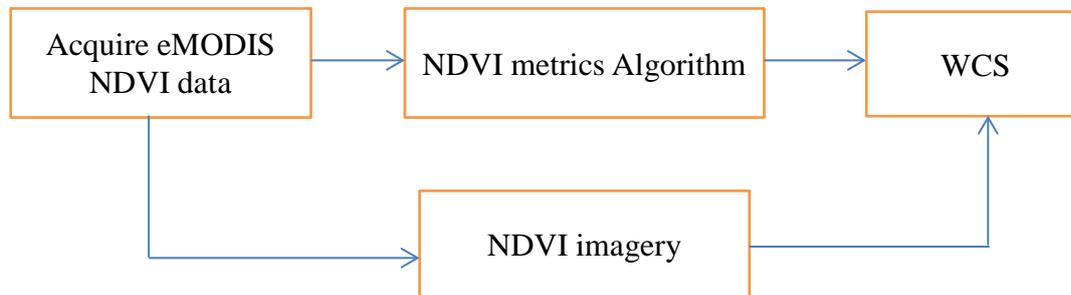


Figure 2.1. MODIS NDVI data automatic process scheme

2.1. Data Format of Input Data

One 7-day composite eMODIS dataset includes six files. They are: band 1-7 reflectance, NDVI, quality, acquisition image, acquisition table, and metadata. NDVI and quality data are used to calculate the NDVI metrics.

eMODIS NDVI data values range from -1999 to 10000, and -2000 is the fill value. Value "-1999" is assigned to any VI computation between "-1998" and "-10000". VI computations between "-1" and "-1997" are assigned face value. When surface reflectance input pixels contain negative fill values, the pixels will have a "-2,000" for NDVI and a corresponding "10" in the band quality layer. The scale factor is 0.0001. After applying the scale factor, NDVI values range from "-0.2" to "1.0", where valid NDVI range is from "0.0" to "1.0".

The quality layer includes flag values to indicate the quality of the corresponding NDVI values. The flag values are: 0—good, 1—cloudy, 2—bad data, 3—negative reflectance, 4—snow, and 10—fill value. Quality layer is critical for calculation of NDVI metrics pixels. In the time series of the pixels, only 'good' = 0 and 'snow' = 4 data are retained; all other values are interpolated or replaced (e.g., Figs. 2.5 and 2.6).

2.2 NDVI Metrics

The NDVI metrics algorithm was developed using the IDL programming language and ENVI software package (Both IDL and ENVI are products from Exelis Visual Information Systems, Boulder, Colorado, USA). The schema of the algorithm is illustrated in Figure 2.2.

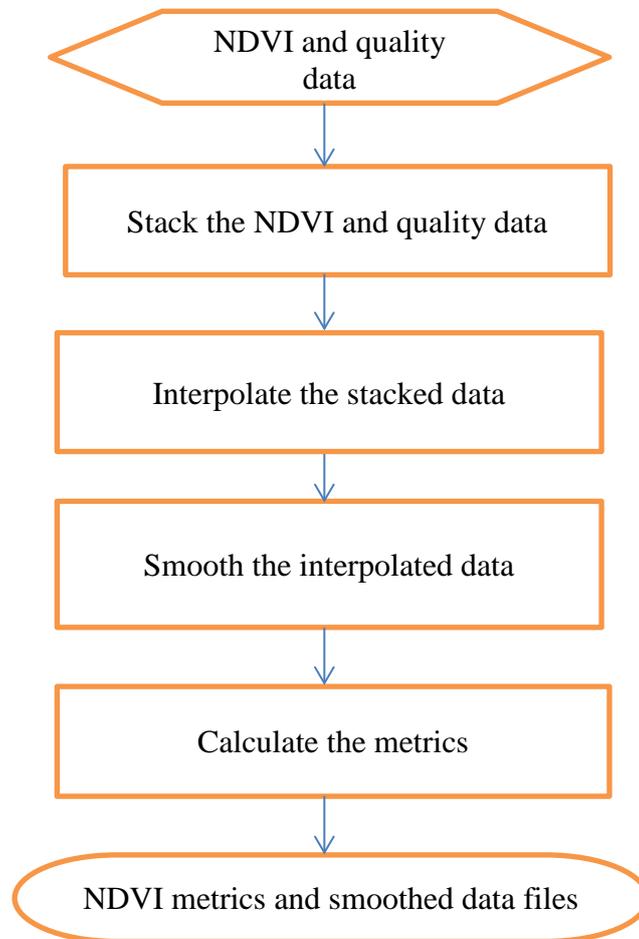


Figure 2.2. NDVI metrics algorithm schema

The yearly NDVI and quality data are inputs for the NDVI metrics algorithm. The algorithm stacks these data into a multiple-band data set, then interpolates and smooths the data. Finally, the algorithm calculates the NDVI metrics and provides those as output, as well as the smoothed NDVI data. The yearly NDVI metrics data include 12 metrics: day of onset of greenness (onp), NDVI value at onset day (onv), day of end of greenness (endp), NDVI value at the end day of greenness (endv), the duration of greenness season (durp), the day of the maximum NDVI value (maxp), maximum NDVI value (maxv), range of NDVI values (ranv), rate of green up (rtup), rate of senescence (rtdn), time-integrated NDVI (tindvi), NDVI metrics flag (mflg).

2.2.1 Installation, configuration, and execution of the MODIS NDVI metrics application

The algorithm codes were developed using the IDL programming language and ENVI software package. They work on both Linux and Windows operational environment with

IDL+ENVI installed. The instruction included here covers the installation, configuration, and execution of the algorithm codes in a Linux environment.

Installation of the application

- a. Download the algorithm zip file from

ftp://dds.gina.alaska.edu/public/modis_ndvi_metrics/modis_ndvi_metrics.zip

We will assume you download it to your home directory (\$HOME).

- b. Unzip the file, the expanded files will be stored in the “modis_ndvi_metrics” directory (\$HOME/modis_ndvi_metrics).

In the directory “modis_ndvi_metrics” you will find several subdirectories; 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 of the application

- a. Edit the startup_nps file and save to the \$HOME/modis_ndvi_metrics directory

The file “startup_nps” includes:

```
ENVI, /RESTORE_BASE_SAVE_FILES
PREF_SET, 'IDL_PATH',
'<IDL_DEFAULT>:+$HOME/modis_ndvi_metrics/bin', /COMMIT
```

- b. edit .bashrc and add the following lines:

```
export ndvihome=$HOME/modis_ndvi_metrics
export IDL_STARTUP=$HOME/modis_ndvi_metrics/startup_np
```

- c. edit 1yr_emodis_250_env.bash

```
export rawdata_dir=$HOME/emodis/distribution/Alaska/historical/TERRA
export work_dir=$HOME/modis_ndvi_metrics/work
export script_dir=$HOME/modis_ndvi_metrics/scripts
export idlprog_dir=$HOME/modis_ndvi_metrics/sav
export idl_dir=/usr/local/idl-7.1/bin
export result_dir=$HOME/results
```

Execution of the application

There are two options for running the application. 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/modis_ndvi_metrics/scripts
>./1yr_emodis_250_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

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

Step1. unzip the raw data files

```
>cd $rawdata_dir/yyyy  
>gunzip *.gz  
>ls $PWD/*NDVI*>yyyy_flist_ndvi  
>ls $PWD/*QUAL*>yyyy_flist_bq
```

Step2. create ndvi file list and quality file list.

```
>./1yr_emodis_250_flist.bash unzipped_data_file_dir, year
```

Step3. stack the one-year data

```
>./1yr_emodis_250_stack_v2.bash flist_ndvi,flist_bq, ul_lon, ul_lat, lr_lon, lr_lat
```

The flist_ndvi and flist_bq are file lists which include the full path of ndvi and quality file names, respectively. The ul_lon,ul_lat, lr_lon and lr_lat are upper left and low right location of the rectangular zone in longitude and latitude. They are used to subset the data. If one does not subset the data, one set the four location arguments as 0.

Step4. calculate ndvi metrics

```
>./1yr_emodis_250_calmetrics_v2.bash one_year_stacked_data_file
```

2.2.2 NDVI metrics algorithm Description

As described in Figure 2.2, NDVI metrics algorithm includes: stacking one year of NDVI data, interpolating the data, smoothing the data, and calculating the yearly metrics.

a) Stacking the NDVI and quality data

Figure 2.3 is the flowchart of the layer stacking process.

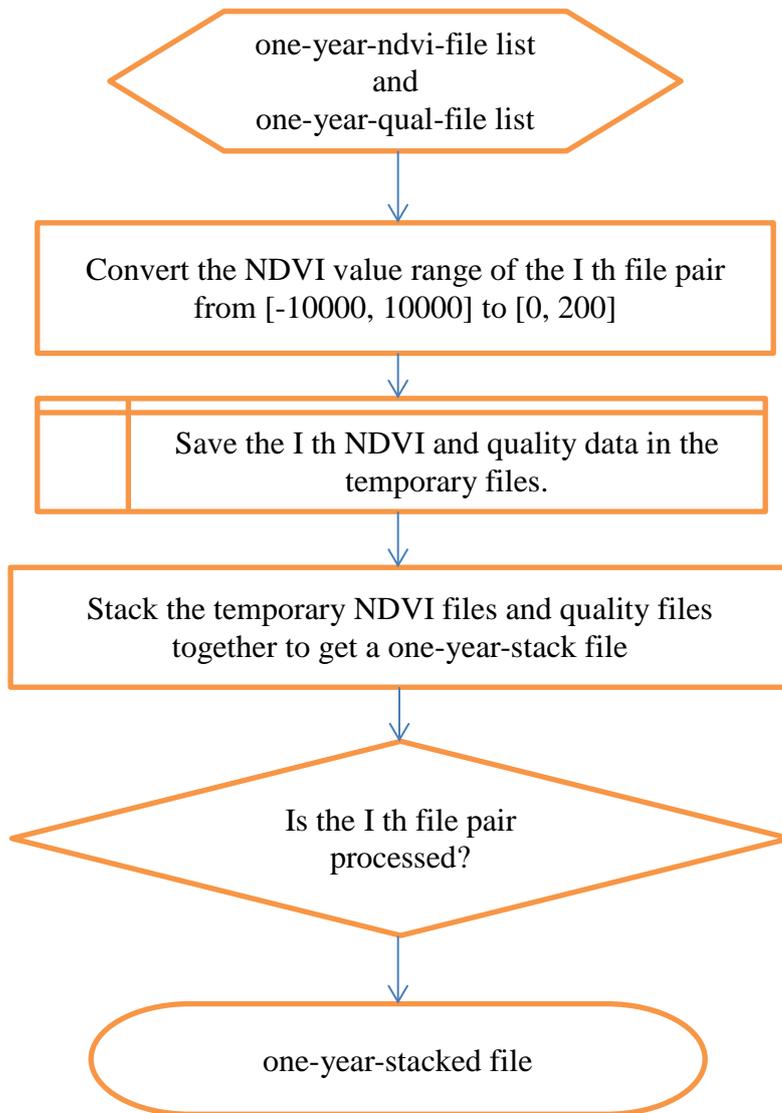


Figure 2.3. Flowchart of stacking processing

The one-year-ndvi-file list and the one-year-qual-file list include the full-path formatted NDVI and quality data file names, respectively. Each NDVI file has a corresponding quality file. The stacking program goes through each pair of files and reads them into a temporary memory space, converts the raw NDVI data from $[-10000, 10000]$ to $[0, 200]$, and stacks these data together. Finally, it outputs the stacked data.

b) Interpolate the stacked-data time series (interpol_noextention_1y_verctor_ver9.pro)

The algorithm goes through each pixel and its corresponding time series. Figure 2.4 describes the interpolation process for the time series.

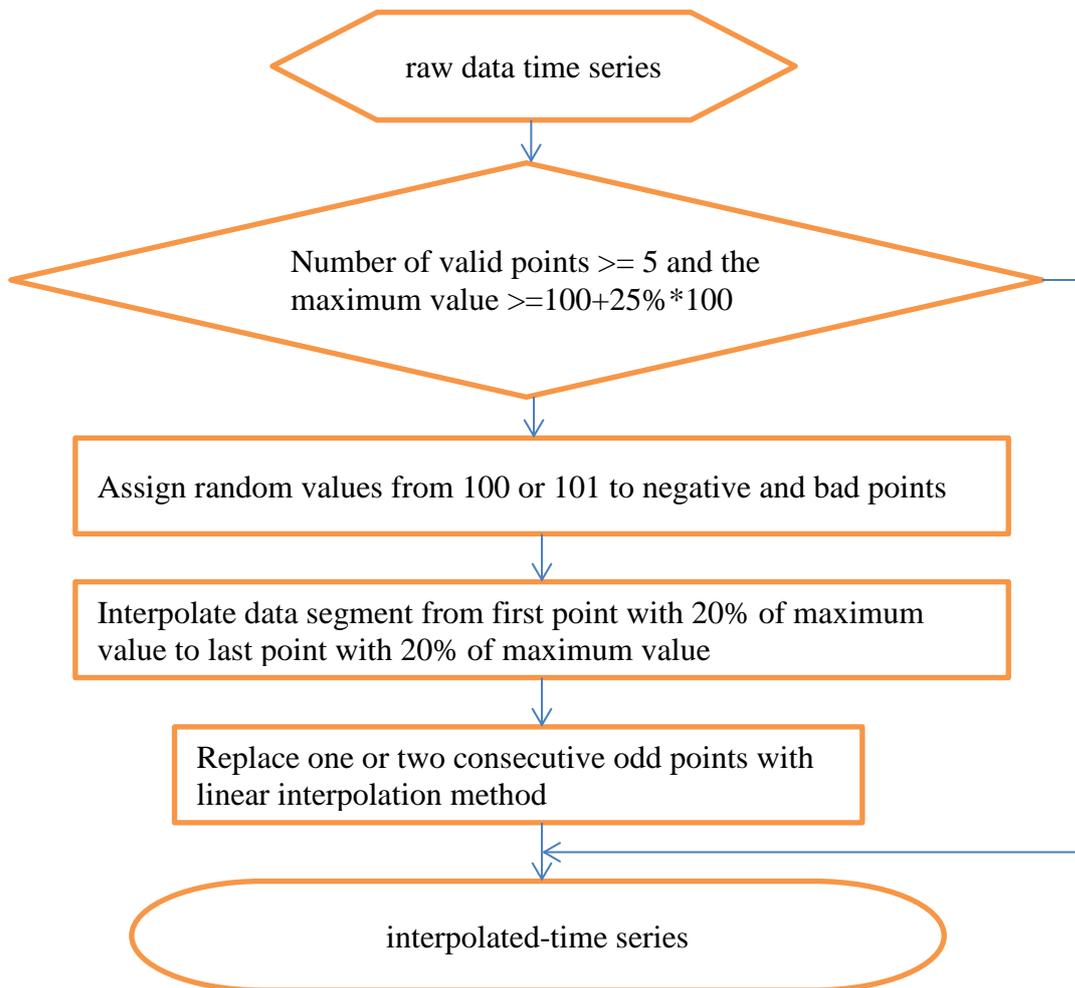


Figure 2.4. Flowchart of interpolation of time series

A raw-data time series for a pixel includes 42 weekly composite data points, starting with the 5th week of the year (~early February), and ending with 46th week (~early December). The value range of NDVI in the raw-data time series is [0, 200], where the valid data range is [100,200], and fill value=80. The raw data are classified into 6 types: good, cloud, bad, negative reflectance, snow, and fill. Figure 2.5 gives an example of a time series. As you can see, there are two fill-value points (80) in the time series, and some no valid points with values in the range (80,100). The interpolation process targets these ‘fill’ and ‘not valid’ points.

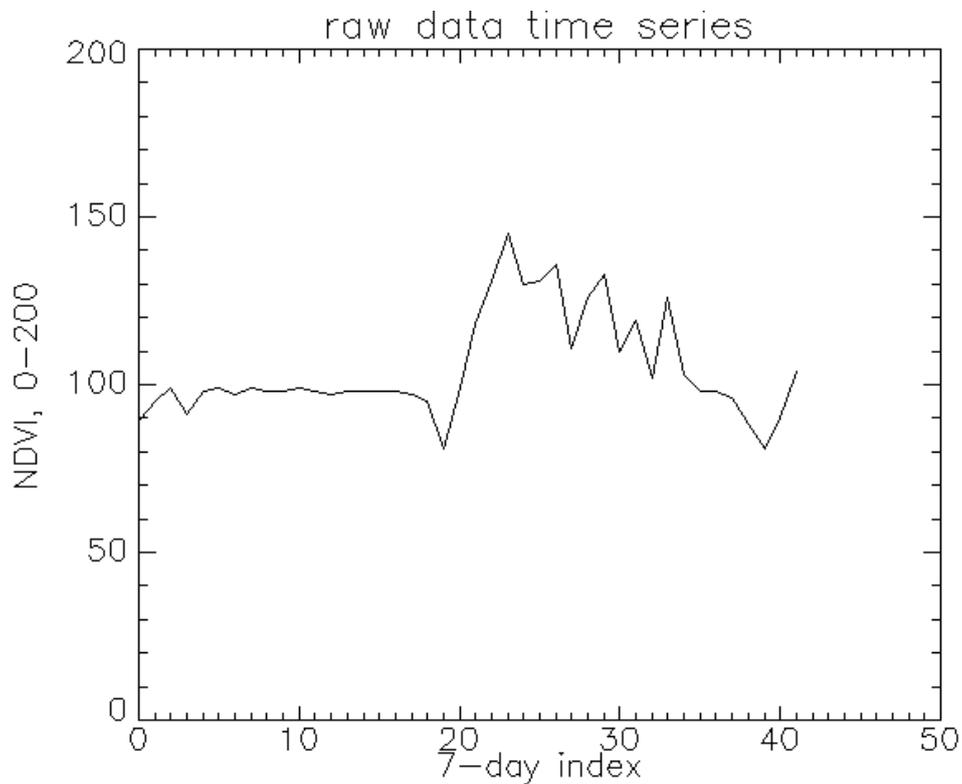


Figure 2.5. A raw-data time series

First a time series is checked to determine if it can be used in the NDVI metrics calculation. Two conditions are applied to determine a time series' validity: a) the time series has more than 5 valid points, or b) the maximum value of the time series must be greater than 25% of the valid raw data range of [100,200]. That is to say, the maximum value must be greater than 125. If the time series does not meet either of the conditions, the program stops. Otherwise, the program continues to process the time series. Only good and snow data points are kept; other points are either interpolated linearly or replaced randomly with 100 or 101. Negative NDVI value or band points are randomly assigned a 100 or 101 value to avoid false crossovers for start of season and end of season detection. Linear interpolation is applied to the segment from the first to last points with greater than or equal to 20% of the maximum NDVI value of the time series; this 20% threshold is subsequently used to estimate start and end of season dates (Figures 2.8 and 2.9). A check is run to determine if the time series 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.

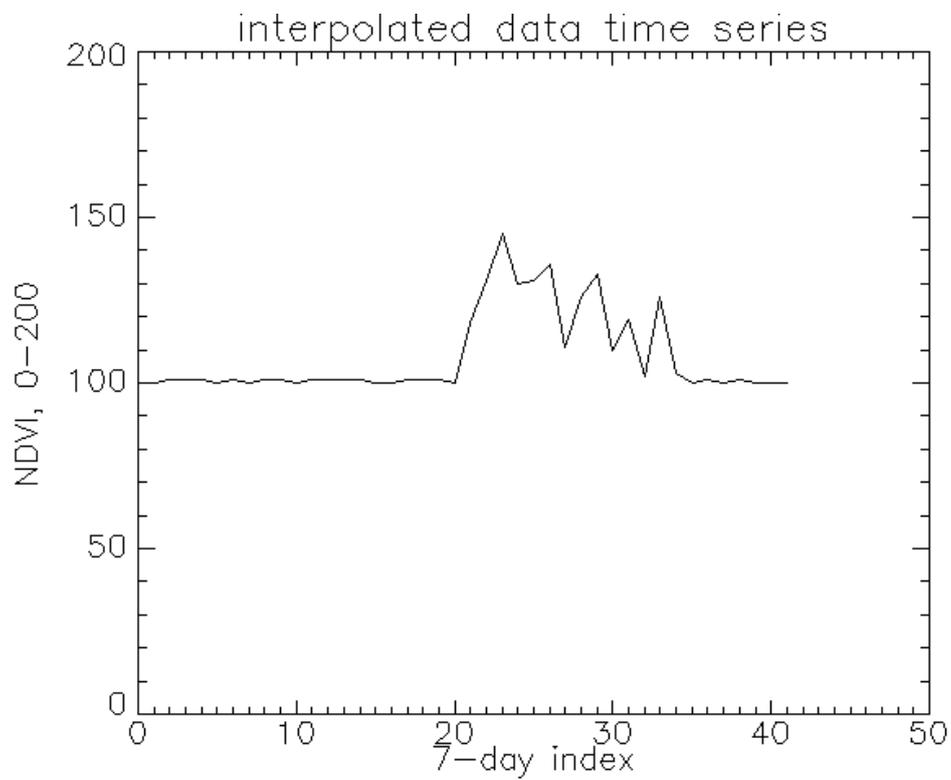


Figure 2.6. Interpolated-data time series

c) Smoothing the interpolated data time series

A weighted-least-square smooth algorithm is applied to the interpolated time series. The algorithm is based on methods described by Swets (2001). Figure 2.7 shows an example of a smoothed time series, in which the 31st point of the line is increased.

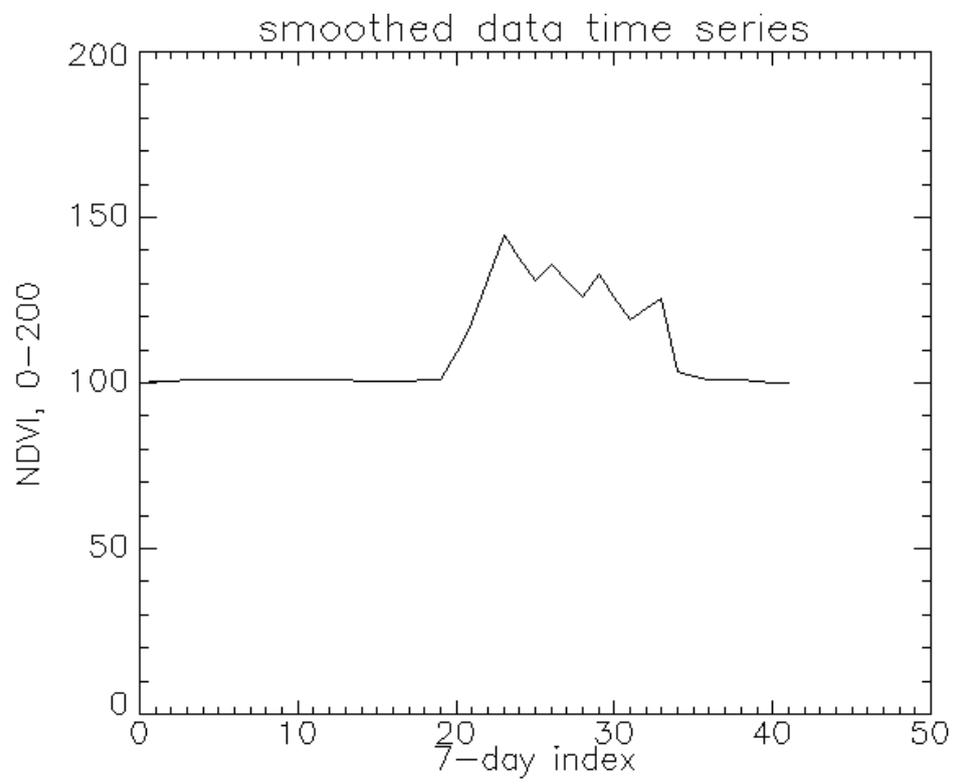


Figure 2.7. Smoothed-data time series

d) Calculating the smoothed-data time series

The NDVI metrics calculation method combines the delayed moving window method (Reed *et al.*, 1994) and the threshold method. Figure 2.8 describes the process of calculating the NDVI metrics from the time series.

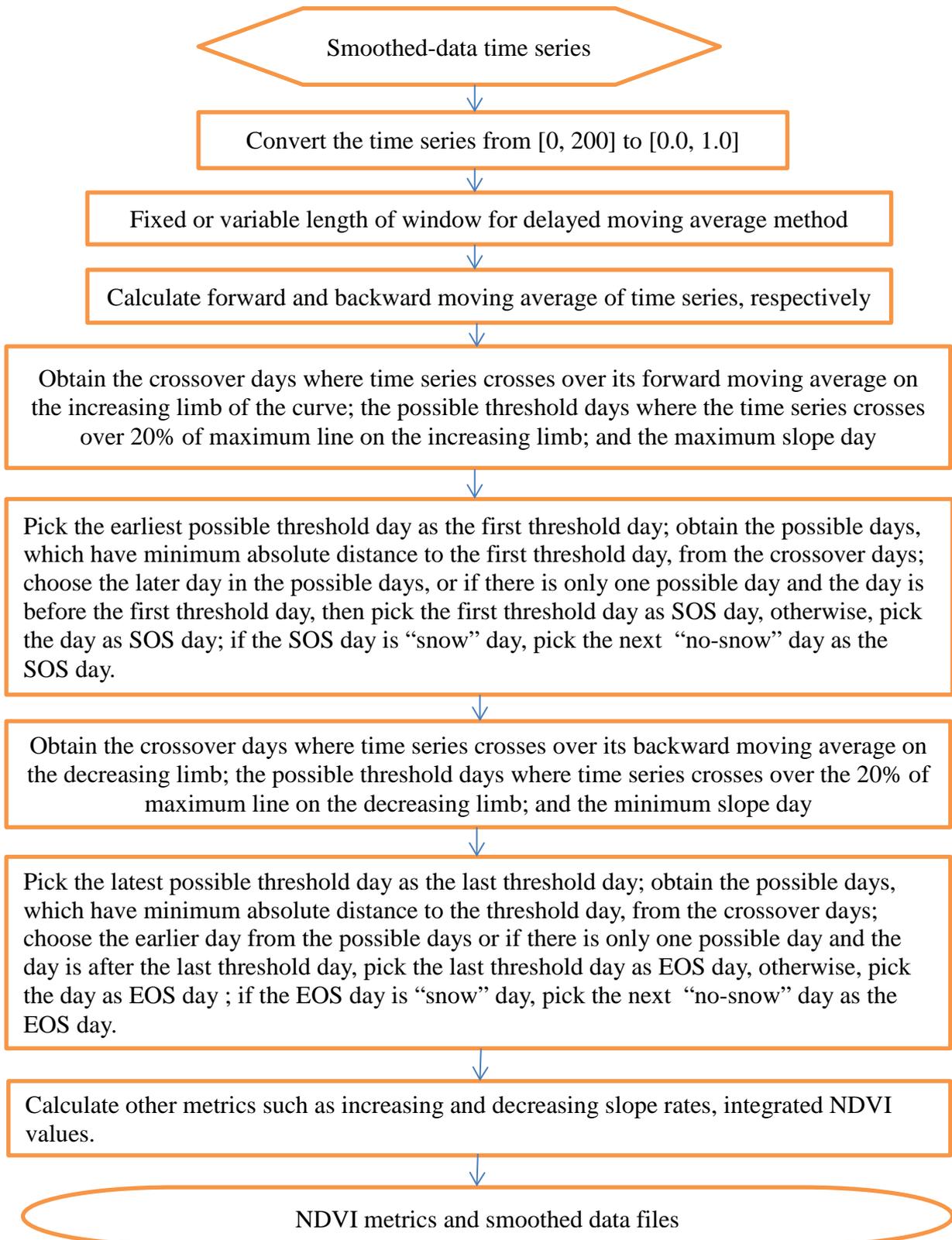


Figure 2.8. Flowchart of calculation of NDVI metrics

The calculation of 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, it uses a fixed or variable window length and delayed moving average method. Using a fixed-length moving window for the delayed moving average is beneficial when comparing multiple years of NDVI metrics data. The algorithm uses a fixed length window as a default. The algorithm also provides a method to determine dynamically the moving window length according to the possible greenness season length (described in the next section). 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 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 day which is the most closest to the first threshold day as the possible start of season (SOS). It then picks the later day between the possible SOS and first threshold day, and if the SOS day is a “snow” day, it chooses the next “no-snow” day as the SOS day.

Figure 2.9 describes how to determine the SOS day. The solid line is the smoothed time series, the dotted line is the forward moving average of the time series, the star is a possible crossover, the triangle is the first threshold day, and the square is the maximum slope day. In this case, the SOS day is equal to the first threshold day, since the crossover day that occurs one day before the first threshold day does not have a value of $\geq 20\%$ maximum NDVI.

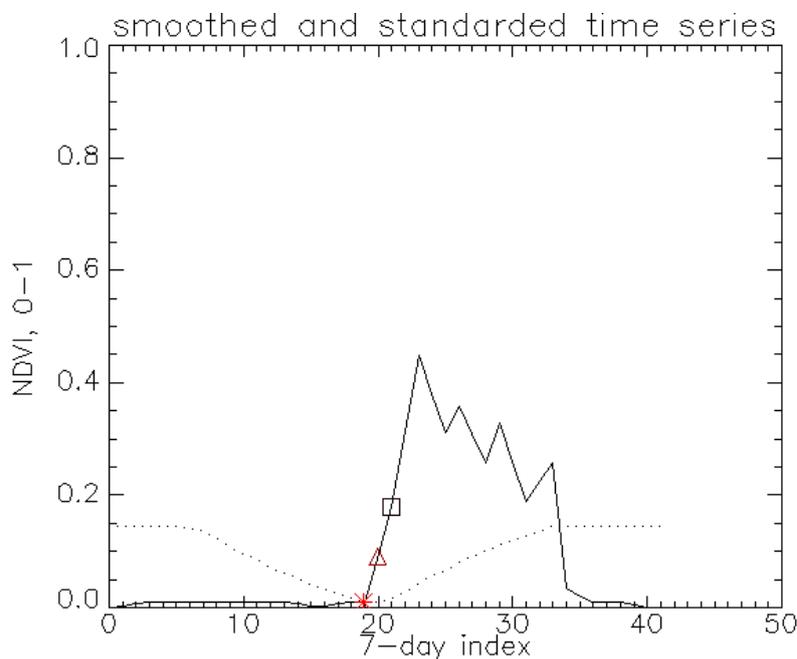


Figure 2.9 Determination of SOS day

Steps 6 and 7 determine the EOS day. They follow the similar logic as in steps 4 and 5. Figure 2.10 illustrates the process of determining the EOS day. In this case, the EOS day is equal to last threshold day, again because the crossover day, which occurs approximately two days later than the threshold day, does not have a NDVI value of $\geq 20\%$ maximum NDVI.

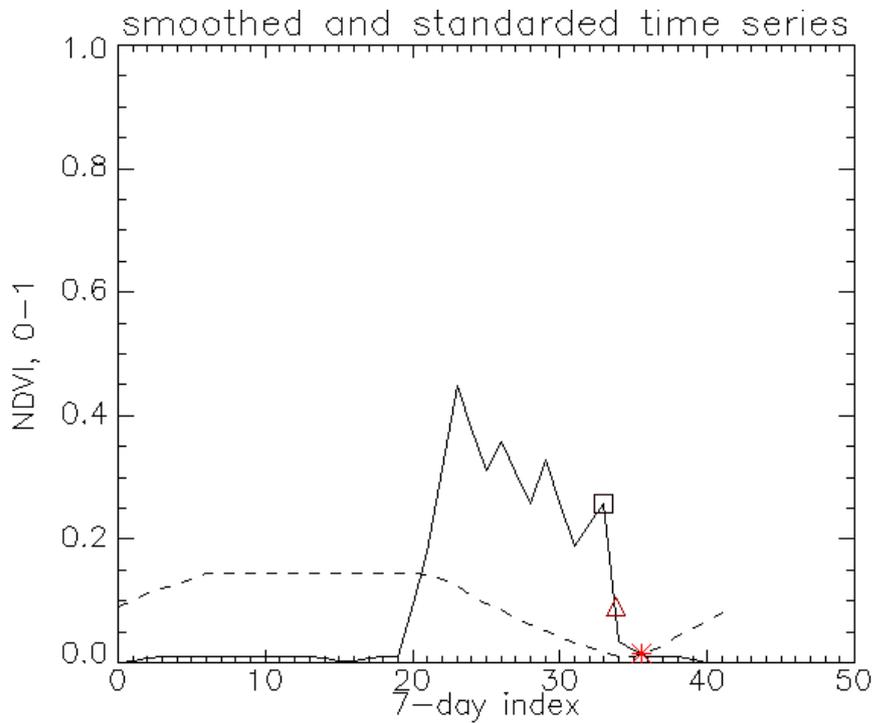


Figure 2.10. Determination of EOS day

Once the SOS day and EOS day are determined, it is easy to calculate the other metrics such as the maximum NDVI day and its NDVI value, up and down slope rates, and the integrated NDVI-day value.

Since Alaska covers such a large area, the window width in the delayed moving average method is critical in the NDVI metrics algorithm. Using a fixed window width will over or under estimate the SOS and EOS days depending on how long or short the growing season is at a given pixel (e.g., growing season length is shorter at higher latitudes and elevations). Dynamically determining the window width is more suitable for estimating the SOS and EOS days by the delayed moving average method. Figure 2.11 shows the process of determining the window width by using a percentage of maximum NDVI recorded during the greater growing season (April 1-September 30). Step 1, determine the index (idx_max) and the value ($maxv20$) of the maximum NDVI in the time series. Step 2, get the index (idx_sosmin) and value ($sosmin$) of the minimum NDVI between the first index and the idx_max in the time series and the index (idx_eosmin) and value ($eosmin$) of the minimum NDVI from the idx_max to the last index of the time series. Step 3, obtain the index (idx_sosv20) whose value is equal to 20% of ($maxv20 - sosmin$) and the index (idx_eosv20) whose value is equal to 20% of ($maxv20 - eosmin$). Step 4, the length of the window is equal to ($(\text{the length of the time series} - idx_eosv20 + idx_sosv20)$). Figure 2.12 gives an example of how to calculate the variable length of the window.

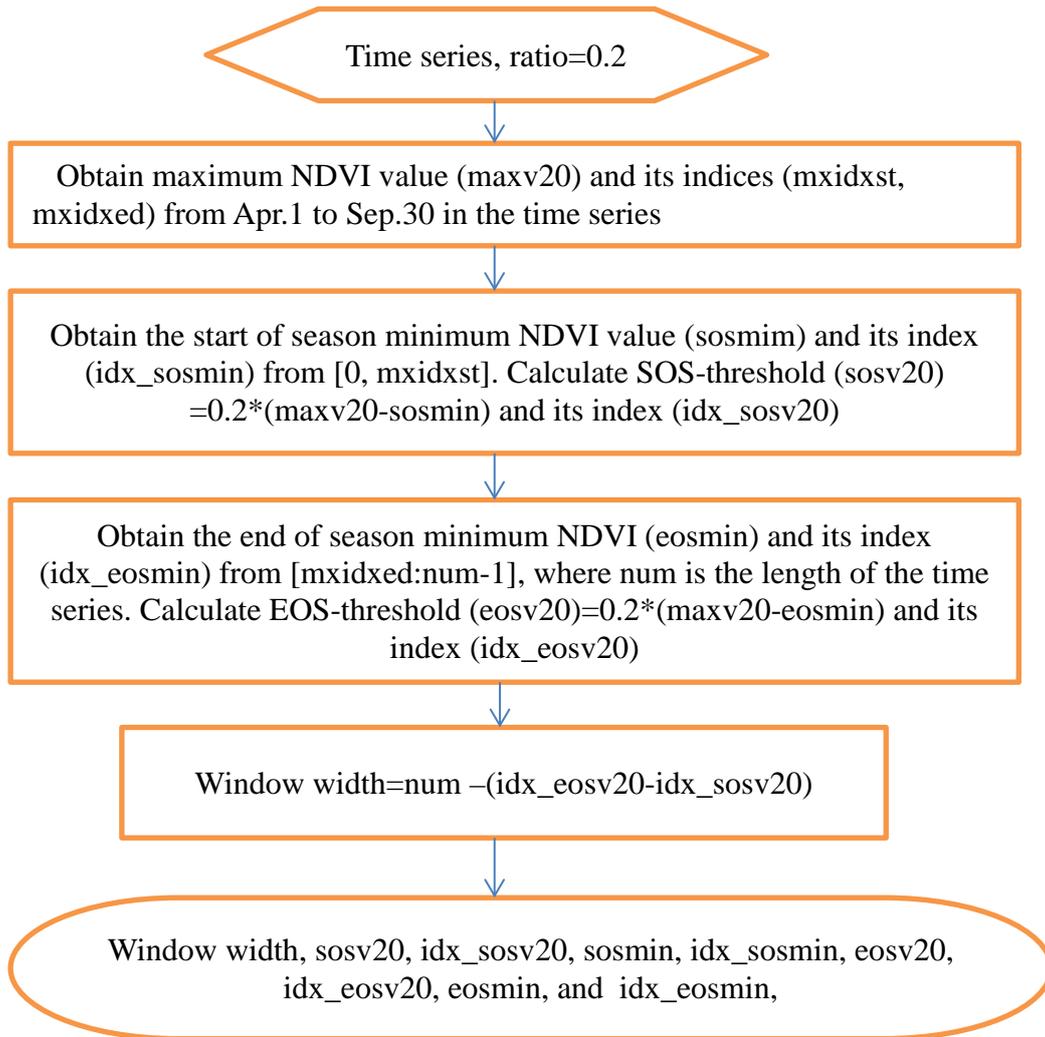


Figure 2.11. Flowchart of dynamic determination of window width

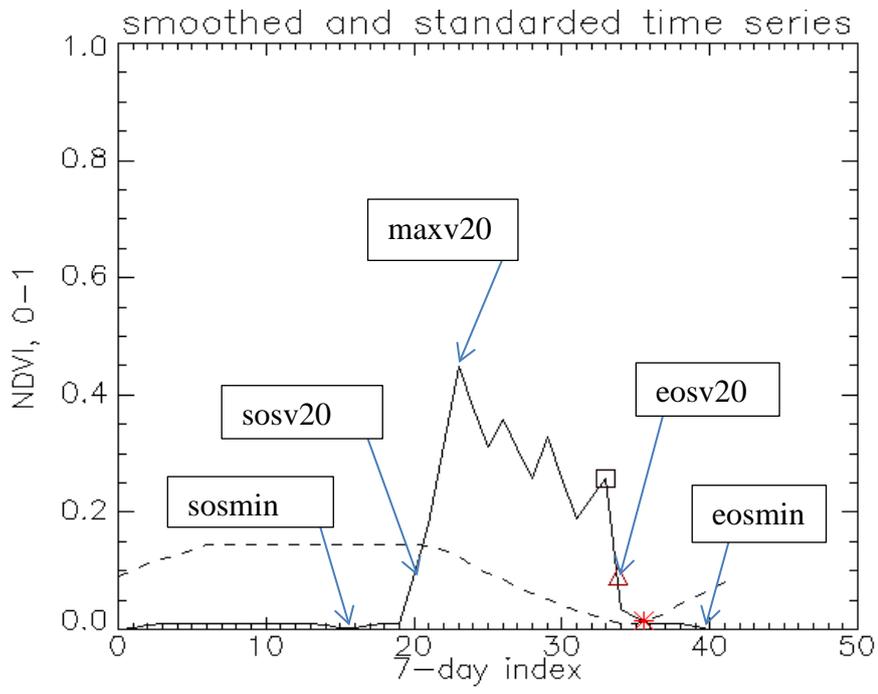


Figure 2.12. Example of variable length of window

Appendix A. Program List for NDVI metrics Algorithm

- 1, smooth_calculate_metrics_tile.pro
 - 1.1, start_batch.pro
 - 1.2, time_series_process_nps_oneyear.pro
 - 1.2.1, interpol_noextension_1y_vector.pro
 - 1.2.1.1 cutoff_interp.pro
 - 1.2.1.1.1 filter_2odd.pro
 - 1.2.2, wls_smooth.pro
 - 1.2.3, user_metrics_nps_by1yr.pro
 - 1.2.3.1, ComputeMetrics_by1yr.pro
 - 1.2.3.1.1 GetForwardMA.pro
 - 1.2.3.1.2 GetBackwardMA.pro
 - 1.2.3.1.3 GetCrossOver_percentage_extremeslope.pro
 - 1.2.3.1.4 GetSOS.pro
 - 1.2.3.1.5 GetEOS.pro
 - 1.2.3.1.6 GetMaxNDVI.pro
 - 1.2.3.1.7 GetTotNDVI.pro
 - 1.2.3.1.8 GetNDVItoDate.pro
 - 1.2.3.1.9 GetSlope.pro
 - 1.2.3.1.10 GetRange.pro
 - 1.2.3.2, findday.pro
- 2, oneyear_data_layer_subset_good.pro
 - 2.1, start_batch.pro
 - 2.2, read_ndvi.pro
 - 2.2.1, subset.pro

Literature Cited

U.S. Geological Survey, 2012, eMODIS Alaska Product Guide, <http://dds.cr.usgs.gov/emodis/Alaska/> (last accessed November 30, 2012)

Reed B., M. Budde, P. Spencer, and A. Miller. 2006. Satellite-Derived Measures of Landscape Processes: Draft Monitoring Protocol for the Southwest Alaska I&M Network, ver. 1.0. National Park Service, Inventory & Monitoring Program, Southwest Alaska Network, Anchorage, Alaska. 30 pp.

Daniel L. Swets, Bradley C. Reed, James D. Rowland, and Shaun E. Marko. 1999. A weighted Least-Squares Approach to Temporal NDVI Smoothing. Proceedings of the 1999 ASPRS Annual Conference, Portland, Oregon, pp. 526-536.