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U.S. Department of the Interior

Natural Resource Stewardship and Science
Inventory and Monitoring Division

Northern Colorado Plateau Network
Southern Colorado Plateau Network



Satellite-based Vegetation Phenology, Condition and Snow Cover Extent Monitoring Standard Operating Procedures for the Park Units in the Northern and Southern Colorado Plateau Networks

David Thoma
National Park Service
Northern Colorado Plateau Network
2327 University Way, Suite 2
Bozeman, MT 59715

Jodi Norris, Paul Lauck
National Park Service
Southern Colorado Plateau Network
PO Box 5765
Northern Arizona University
Flagstaff, AZ 86011

Bradley Reed
U.S. Geological Survey
Reston, VA 20191

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Contents

Contents	ii
Figures	v
Tables.....	vii
Abbreviations	viii
1. SOP 1: Software Installation.....	1
1.1 MODIS Reprojection Tool (MRT)	1
1.1.1 MRT Installation Procedures:	1
1.2 MODIS Land Data Operational Product Evaluation (LDOPE).....	7
1.2.1 LDOPE Installation Procedures:	7
1.3 IDL Metrics Setup	12
1.3.1 IDL Metrics Setup Procedures:	12
2. SOP 2: Vegetation Index Processing and Smoothing	16
2.1 Processing Schedule	16
2.2 Data Acquisition Procedures	17
2.3 NDVI Processing.....	19
2.3.1 Mosaic, project and mask NDVI	19
2.4 Stacking, scaling and smoothing NDVI	21
2.4.1 Layer stacking	21
2.4.2 Link Windows and create corresponding Z-profiles.....	24
2.4.3 Data Smoothing	26
2.4.4 Prepare Data for Calculating Phenology Metrics	33
2.5 Quality Assurance/Quality Control and Validation	36
2.6 Literature Cited.....	37
3. SOP 3: Pixel-based Phenology Processing.....	38
3.1 Calculate and Process Phenology Metrics.....	38
3.1.1 Delete padded years of data from the Metrics files	40
3.1.2 Mask bad data values	41
3.1.3 Exporting from ENVI to ESRI GRID stack.....	41
3.2 Additional analysis options.....	41

4.	SOP 4 Snow Cover Extent.....	42
4.1	Data Acquisition Procedures	42
4.1.1	8-Day Snow Cover Processing	43
4.1.2	Data Visualization / Analysis.....	45
4.1.3	Layer Stacking and Z-Profiles of 8-day Data	46
4.2	Additional analysis options.....	50
5.	SOP 5: Creating aggregated analysis subsets.....	51
5.1	Pixel level analysis versus aggregated subsets.....	51
5.2	Streamlined area-averaged processing.....	51
5.2.1	Prepare Polygon for Clipping.....	52
5.2.2	(Place this text into a call out box)Tip: Convert Polygons to Rasters for Clipping	52
5.2.3	Clip Polygon Averaged NDVI Time-series	55
5.3	Customized area-averaged processing.....	55
5.3.1	Example using ecological sites.....	55
5.3.2	Map unit components and ecological sites.....	56
5.3.3	Grouping pre-processing steps.....	58
5.3.4	Processing options.....	59
5.4	Storage and documentation of processed data	60
5.4.1	Documentation.....	60
5.4.2	Data storage	61
5.4.3	Data input and retrieval	61
6.	SOP 6: Analysis scripts for graphics and tables NDVI, snow cover extent and weather stations.....	63
6.1	Required Software.....	63
6.2	NDVI Analysis.....	64
6.2.1	Clip Polygon NDVI.....	64
6.2.2	NDVI Excel module sequence	64
	(Place in a call out box)Tip: Enabling and Running Macros in Excel 2007 or Later	64
6.2.3	Description of NDVI Customized Excel Module Outputs	66
6.3	Snow Cover Extent Analysis	72
6.3.1	Clip Polygon Snow Cover	72
6.3.2	Snow Excel module sequence	72

6.3.3	Snow Module Outputs.....	72
6.4	Station Precipitation and Temperature Summary	77
6.4.1	Obtain raw weather station data	77
6.4.2	Weather station module sequence	78
6.5	Export to R Statistical Software	82
6.5.1	R input period.....	82
6.5.2	R code	83
6.6	Cheat sheet for processing steps	85
6.7	Monsoon anomaly map.....	86

Figures

	Page
Figure 1.1. Registration procedure for MODIS Reprojection Tool.	2
Figure 1.2. Login procedure for downloading MRT.....	3
Figure 1.3. Downloading MRT files.....	4
Figure 1.4. Enter the pathname of the Java bin directory.....	5
Figure 1.5. Message confirming successful installation of MRT.....	6
Figure 1.6. Text editor description of filenames to confirm proper naming conventions.	6
Figure 1.7. Initiating download for LDOPE software.	8
Figure 1.8. Download procedure for LDOPE software.	8
Figure 1.9. Accessing the system properties dialog box.	9
Figure 1.10. Accessing the Environmental Variables listing.	10
Figure 1.11. Assigning the ANCILLARY path to the ANCPATH variable.	10
Figure 1.12. Assigning \$PATH directory to allow the LDOPE executables to be run from any directory.....	11
Figure 1.13. Example of the location of the METRICS/idl/bin directory.	12
Figure 1.14. Setting the METRICS/idl/bin directory path in the IDL preferences.	13
Figure 1.15. Setting the METRICS/idl/bin directory path in the IDL preferences.	14
Figure 1.16. Setting the Working Directory.....	15
Figure 1.17. Select a path and folder.....	15
Figure 2.1 Navigating the LP DAAC Data Pool	18
Figure 2.2 Selection of image for file display	22
Figure 2.3. Listing of Input files for Layer Stacking procedure.	23
Figure 2.4. Temporal profile of a pixel.	24
Figure 2.5. Example NDVI profiles	26
Figure 2.6. Smoothed versus unsmoothed NDVI.	27
Figure 2.7. Results of smoothing operation on annual time-series.	27
Figure 2.8. Band Math expression to convert to byte.....	29
Figure 2.9. Three years of smoothed data.	32
Figure 2.10. Listing of bands in spectral subsetting process.	33

Figure 2.11. Band Math procedure to “fix” smoothed data prior to calculating phenology metrics.....	36
Figure 3.1. Placement of the IDL command line.	39
Figure 4.1. An example of the List_HDF dialog box.....	44
Figure 4.2. Display of an 8-day snow cover image	45
Figure 4.3. Display of an 8-day snow cover image	46
Figure 4.4. Layer stacking parameters box and list of input files for stacking.	47
Figure 4.5. Spectral profile of a single pixel from one year of stacked snow cover data.....	49
Figure 5.2 Example of curves created by NDVI analysis of targeted ecosites.....	60
Figure 5.3 Screenshot of database for storing metadata about analysis methods.....	61
Figure 5.4 Screenshot view of the data storage table.....	61
Figure 5.5 Screenshot of form used to import new datasets into the database.	62
Figure 5.6 Screenshot of form used to select data sets for further analysis, graphing and reporting.....	62
Figure 6.1. Long-term average NDVI versus recent year and differences.....	67
Figure 6.2. Time series charts of NDVI	68
Figure 6.3. Screenshot of Timesat curve fitting window.....	69
Figure 6.4. Time series of annual phenology metrics.....	71
Figure 6.5. Snow covered area box plots by day of year charted with most recent year snow cover by day of year. The above plots can be edited as needed for clarity.....	74
Figure 6.6. Variation, time-series and duration of snow cover. These plots can be edited in Excel as needed for clarity.....	75
Figure 6.7. Duration and area of snow cover for long-term average and recent year	76
Table 6.3. Snow phenology metrics, trends and significance of linear fit parameters computed with Excel module.	76
Figure 6.8. Snow phenology charts generated with Excel macro.	77
Figure 6.9. Growing degree days, cumulative precipitation, and NDVI time-series	80
Figure 6.10. Time-series of 16 day cumulative precipitation to match NDVI periods	81
Figure 6.11. Long-term 16 day cumulative precipitation versus recent year and cumulative exceedance frequency curves by period.....	82
Figure 6.12. Period of record box plot, monthly average time-series and long term time-series plots for NDVI.....	84
Figure 6.13. Monthly mean time-series, monthly box plots, period box plots for the entire period of record.....	84

Figure 6.14. Average growing degree days and precipitation by month.	85
Figure 6.15. Graphical display of lattice plot to help visualize results of Mann Kendall and Seasonal Mann Kendall tests.	85
Figure 6.16. Monsoon anomaly map for CP region comparing long-term average NDVI versus current year. Note the greener shades north and west of a line between Zion National park and Dinosaur National Monument. Compare this map to figure 1 in the introduction to gain an appreciation of the monsoon track and it's annual dynamics.	87
Figure 6.17. a) Monsoon anomaly map for BRCA comparing long-term average NDVI versus NDVI in 2009. Differences in greenness resulting from the 2009 Bridge Fire and 2008 Puma Fire are readily apparent as different shades of red. b) Difference between long term average precipitation (light blue line) and 2009 precipitation (dark blue line) for weather station at BRCA headquarters. c) The Bridge fire burned in 2009 when vegetation greenness for the entire park (dark green line) was well below average (light green line). Numbers above the box plots indicate the difference in NDVI between 2009 and long-term mean.....	89

Tables

	Page
Table 2.1 MODIS NDVI processing schedule.	16
Table 2.2. Required software for processing NDVI data.	17
Table 3.1. Listing of phenology metrics and their default filenames.	39
Table 4.1 MODIS Snow processing schedule.....	42
Table 4.2. Software required for processing MODIS Snow data.	42
Table 4.3. Classified pixel values for maximum snow extent products.....	44
Table 5.1 Example of exclusion conditions for ground-based and MODIS NDVI monitoring.	56
Table 5.2 Example of ecological sites for a SSURGO soil survey and their related mapunits, with an estimate of the percent of each ecological site within each mapunit. Rows shaded in gray indicate mapunits that would be excluded because they contain a low percent of that ecological site.	57
Table 5.3 Examples of cell grouping for MODIS NDVI aggregation.....	58
Table 6.1. Annual NDVI summary statistics.....	70
Table 6.2. Annual phenology metrics derived from Timesat with linear trend over time and significance.....	70
Table 6.3. Snow phenology metrics, trends and significance of linear fit parameters computed	76

Abbreviations

General abbreviations

AZ	Arizona
CO	Colorado
UT	Utah
WY	Wyoming
NPS	National Park Service
NACP	North American Carbon Project
SCPN	Northern Colorado Plateau Network
SOP	Standard Operating Procedure
USGS	U.S. Geological Survey

Remote Sensing Abbreviations

A-NDVI	Amplitude of annual NDVI curve
DMAX	Day of Year when maximum NDVI observed
DOY	Day of Year
EOS	Day of Year when Growing Season ends
EVI	Enhanced Vegetation Index
I-NDVI	Integrated area under the annual NDVI curve
LOS	Length of Season in days
MODIS	Moderate Resolution Imaging Spectrometer
NASA	National Aeronautics and Space Administration
NDSI	Normalized Difference Snow Index
NDVI	Normalized Difference Vegetation Index
SOS	Day of year when growing season starts

Park Units

Park

ARCH	Arches National Park
AZRU	Aztec Ruins National Monument
BAND	Bandelier National Monument
BLCA	Black Canyon of the Gunnison National Park
BRCA	Bryce Canyon National Park
CACH	Canyon de Chelly National Monument
CANY	Canyonlands National Park
CARE	Capitol Reef National Park
CEBR	Cedar Breaks National Monument
CHCU	Chaco Culture National Historical Park
COLM	Colorado National Monument
CURE	Curecanti National Recreation Area
DINO	Dinosaur National Monument
ELMA	El Malpais National Monument
ELMO	El Morro National Monument
FOBU	Fossil Butte National Monument
GLCA	Glen Canyon National Recreation Area
GOSP	Golden Spike National Monument
GRCA	Grand Canyon National Park
HOVE	Hovenweep National Monument
HUTR	Hubbell Trading Post National Historic Site

Network

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MEVE	Mesa Verde National Park	SCPN
NABR	Natural Bridges National Monument	NCPN
NAVA	Navajo National Monument	SCPN
NCPN	Northern Colorado Plateau Network	NCPN
PEFO	Petrified Forest National Park	SCPN
PETR	Petroglyph National Monument	SCPN
PISP	Pipe Springs National Monument	NCPN
RABR	Rainbow Bridge National Monument	SCPN
SAPU	Salinas Pueblo Missions National Monument	SCPN
SUCR	Sunset Crater Volcano National Monument	SCPN
TICA	Timpanogos Cave National Monument	NCPN
WACA	Walnut Canyon National Monument	SCPN
WUPA	Wupatki National Monument	SCPN
YUHO	Yucca House National Monument	SCPN
ZION	Zion National Park	

1. SOP 1: Software Installation

Colorado Plateau

Standard Operating Procedure (SOP) # 1

Software Installation

Revision History Log:

Previous Version #	Revision Date	Author	Changes Made	Reason for Change	New Version #

This Standard Operating Procedure outlines the installation instructions for software necessary to acquire, process, and reformat the standard MODIS image products described in this protocol. This SOP is intended for use on the Windows operating system. The software tools for processing raw MODIS tiles include

- **MODIS Reprojection Tool (MRT)**
- **MODIS Land Data Operational Product Evaluation (LDOPE) Tools**

This SOP also includes instructions for **IDL Metrics** setup in order to utilize the tools for deriving seasonal metrics from the NDVI time series. Separate procedures for installing each of these tools are outlined below.

The MODIS tools are freeware downloadable from the Land Processes Distributed Active Archive Center (LP DAAC) website: (<http://edcdaac.usgs.gov/datatools.asp>). The IDL Metrics tools will be provided to the CP networks for use in this protocol.

1.1 MODIS Reprojection Tool (MRT)

The MRT software tool enables users to read data files in HDF-EOS format (MODIS Level-2G, Level-3, Level-4 and Level-5 land data products), specify a geographic subset or specific science data sets as input to processing, perform geographic transformation to a different coordinate system/cartographic projection, write the output to file formats other than HDF-EOS, and are executable on Unix (Sun, SGI), Windows (9x, 2000, NT, XP), and Linux operating systems.

1.1.1 MRT Installation Procedures:

Register for access to the MODIS download page at the LP DAAC. From the MRT distribution page (https://lpdaac.usgs.gov/lpdaac/tools/modis_reprojection_tool), select Sign Up and receive a username and password that allows for downloading of binaries, source code, and documentation (Fig. 1.1). A username and password will be emailed to the address that you provide.

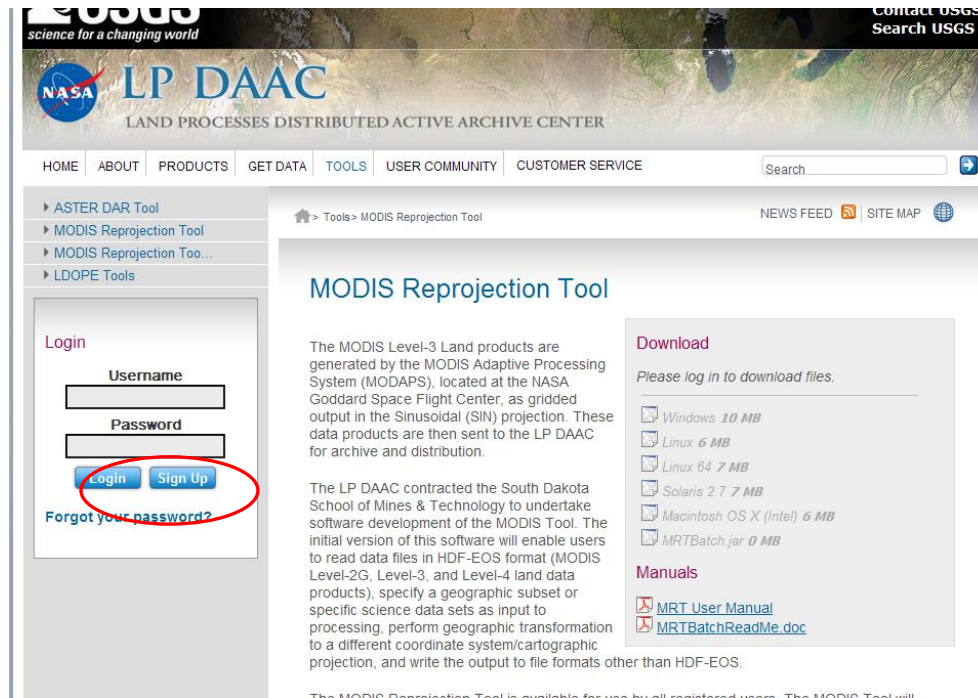


Figure 1.1. Registration procedure for MODIS Reprojection Tool.

If there are issues with the installation (e.g., if web sites change), you may want to try using the manual installation instructions or other troubleshooting steps provided in the MODIS Reprojection Tool overview and instructions for downloading and troubleshooting. This is currently located at:
http://lpdaac.usgs.gov/landdaac/tools/modis/info/MRT_Users_Manual.pdf.

1. This link provides access to the .pdf download. You may also log on to “Registered User Services” using your login information for access to Downloads (Fig. 1.2).



Figure 1.2. Login procedure for downloading MRT.

2. Successful login will activate the Download option on the right side of the page.
3. Create a MRT directory on the C drive (i.e. C:\MRT) of your local computer. Use 'right click', 'save target as' to copy the Windows platform file from the download page to the C:\MRT directory. Extract the *.zip file into the MRT directory.

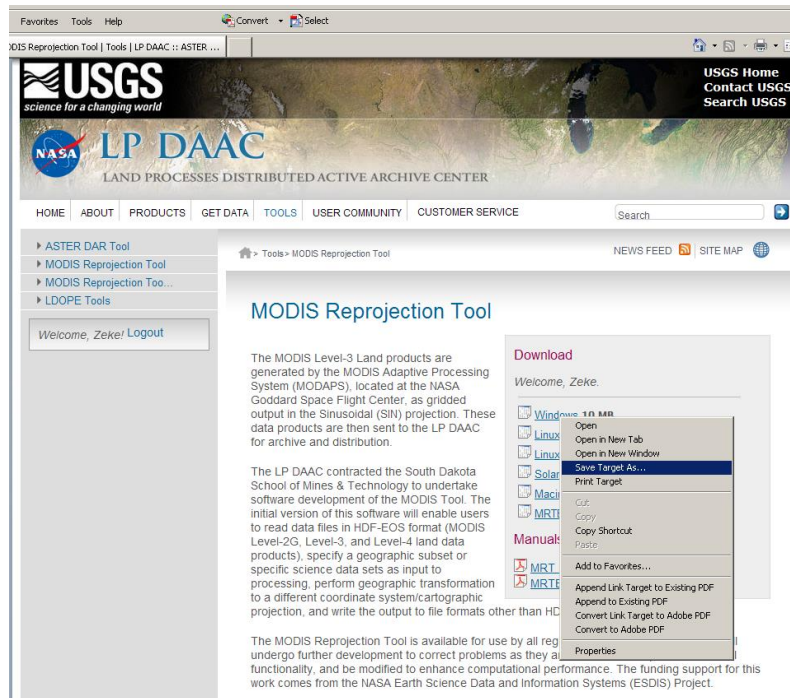
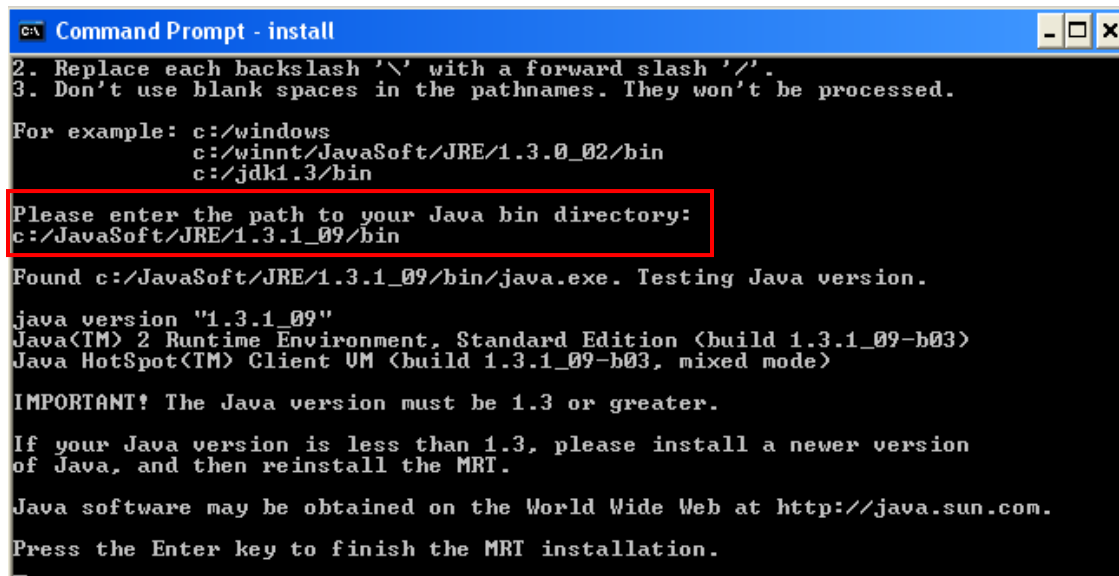


Figure 1.3. Downloading MRT files.

4. Open a navigation window by double-clicking the My Computer icon on your desktop. Navigate to the c:\MRT directory. To begin installation, double-click the install icon. Or open a command prompt window and navigate to the C:\MRT directory where the Windows files were saved. Type **install**. You will be given information necessary for continuing installation of the MRT and for obtaining necessary Java software if it is not already installed on your system. Java is used for the graphical user interface (GUI) version of the MRT. Issues related to Java software are discussed in procedure # 8. At this prompt, type **y** to continue with the installation . If this method does not work,
5. You will then be prompted to enter an MRT directory path. Since you've already created the C:\MRT directory, press **enter** to install to a MODIS sub-directory at this location. A second prompt will state that the MODIS sub-directory doesn't exist and ask if you want to create it. Type **y** to continue.
6. The installation will proceed to create a MODIS directory in the current location and extract a number of files/folders to the new directory. You will then be prompted to identify what version of Windows you are running. Type the **number** associated with your operating system and press **enter**.
7. You will be prompted to enter the path to the Java bin directory on your machine. Most PCs already have Java installed in C:\Program Files\Java\..., since the MRT does not process pathnames with spaces in them it will error if this path is given. You will need to make a copy of the Java directory and place directly under the C drive

(i.e. C:\Java\...etc.). The next step in installation is to **type the full path to the Java bin directory** and press **enter**. The install program will test the Java path and verify that it is an adequate version. If the version of Java does not meet the minimum requirements, a web location for downloading a newer version is provided (Fig. 1.4). In the event that your system does not contain a Java bin directory, you can access the latest version of Java at the following location: <http://java.sun.com/downloads/>. Select the most recent version from the Java Platform Standard Edition dropdown list.



```
c:\ Command Prompt - install
2. Replace each backslash '\' with a forward slash '/'.
3. Don't use blank spaces in the pathnames. They won't be processed.

For example: c:/windows
              c:/winnt/JavaSoft/JRE/1.3.0_02/bin
              c:/jdk1.3/bin

Please enter the path to your Java bin directory:
c:/JavaSoft/JRE/1.3.1_09/bin

Found c:/JavaSoft/JRE/1.3.1_09/bin/java.exe. Testing Java version.

java version "1.3.1_09"
Java(TM) 2 Runtime Environment, Standard Edition (build 1.3.1_09-b03)
Java HotSpot(TM) Client VM (build 1.3.1_09-b03, mixed mode)

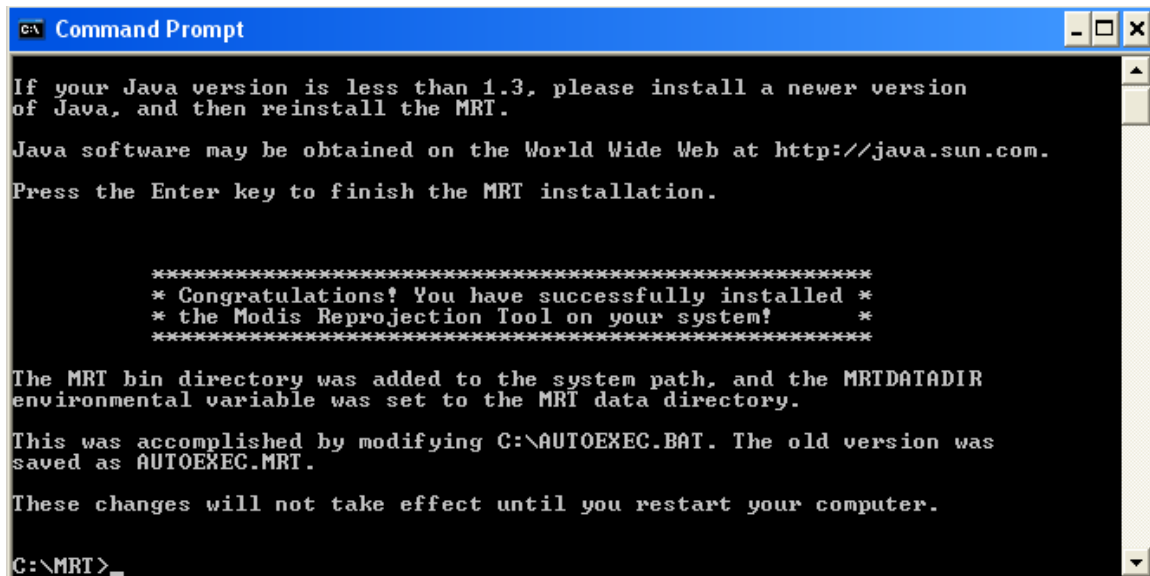
IMPORTANT! The Java version must be 1.3 or greater.

If your Java version is less than 1.3, please install a newer version
of Java, and then reinstall the MRT.

Java software may be obtained on the World Wide Web at http://java.sun.com.
Press the Enter key to finish the MRT installation.
```

Figure 1.4. Enter the pathname of the Java bin directory.

8. Once the installation is complete, you should see the successful installation Screen (Fig. 1.5). You can test the installation by navigating to C:\MRT\Modis\bin and double click on the ModisTool.bat file. If installed properly, this should launch the GUI interface for the MRT.



```
Command Prompt

If your Java version is less than 1.3, please install a newer version
of Java, and then reinstall the MRI.

Java software may be obtained on the World Wide Web at http://java.sun.com.
Press the Enter key to finish the MRT installation.

*****
* Congratulations! You have successfully installed *
* the Modis Reprojection Tool on your system! *
*****

The MRT bin directory was added to the system path, and the MRTDATADIR
environmental variable was set to the MRT data directory.

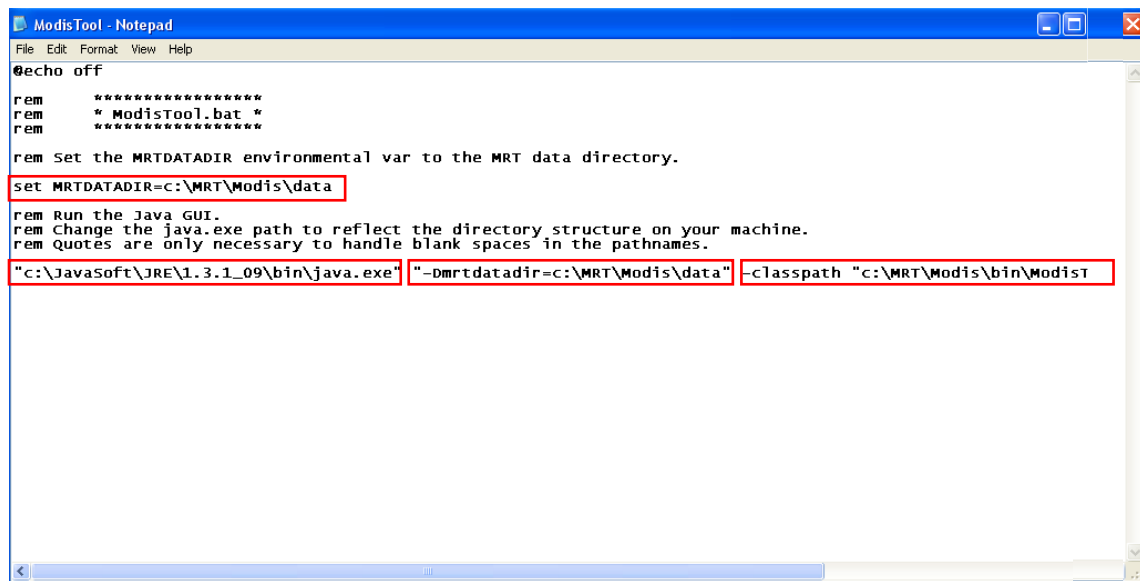
This was accomplished by modifying C:\AUTOEXEC.BAT. The old version was
saved as AUTOEXEC.MRT.

These changes will not take effect until you restart your computer.

C:\MRT>
```

Figure 1.5. Message confirming successful installation of MRT.

9. Installation problems with the MRT are almost exclusively related to directory paths. If you experience problems with the installation, the first place to troubleshoot would be the ModisTool batch file referred to in procedure 9. Using a text editor such as Notepad, open the batch file and confirm that the directory paths are accurate with regard to where files are located on your local computer. (Fig. 1.6). Correct paths as necessary, select File > Save, and test. **Note: The MRT will not work with any spaces in the path or file names.**



```
ModisTool - Notepad
File Edit Format View Help
@echo off

rem *****
rem * ModisTool.bat *
rem *****

rem Set the MRTDATADIR environmental var to the MRT data directory.
set MRTDATADIR=c:\MRT\Modis\data

rem Run the Java GUI.
rem Change the java.exe path to reflect the directory structure on your machine.
rem Quotes are only necessary to handle blank spaces in the pathnames.
"c:\JavaSoft\JRE\1.3.1_09\bin\java.exe" "-Dmrtdata=c:\MRT\Modis\data" -classpath "c:\MRT\Modis\bin\ModisT
```

Figure 1.6. Text editor description of filenames to confirm proper naming conventions.

10. If you are unable to troubleshoot the problem, please contact the LP DAAC User Services :

LP DAAC User Services

Phone : 605-594-6116

Toll Free: 866-573-3222

866-LPE-DAAC

Fax: 605-594-6963

Email: LPDAAC@eos.nasa.gov

Web: <http://LPDAAC.usgs.gov>

Hours: 8:00 a.m. – 4:00 p.m. (Central Time Zone)

1.2 MODIS Land Data Operational Product Evaluation (LDOPE)

The LDOPE software tools were developed to assist with the analysis and quality assessment of the MODIS Land (MODLAND) products. The tools have been developed with feedback from the MODLAND science team and incorporate the scientific knowledge, experience and insights gained during the substantial MODLAND product development period. These software tools are invoked as stand-alone executables from a command-line interface. The software is supported on Irix, Solaris, Linux, and Windows operating systems.

1.2.1 LDOPE Installation Procedures:

1. Since the LDOPE tools are also distributed through the LP DAAC, the same username/password established to download the MRT and MRT-Swath tools can be used for the LDOPE downloads (see MRT procedures 1 & 2 in SOP 1.1).
2. Log on to the MODIS LDOPE “registered user services” webpage, http://lpdaac.usgs.gov/lpdaac/tools/ldope_tools, using your login.
3. From the LDOPE tools page, select the file for your platform in the Download column. Right click, Save As, and, for the Windows operating system, download **Win_bin.zip** from the list and save it directly to the C drive. (Fig. 1.7).

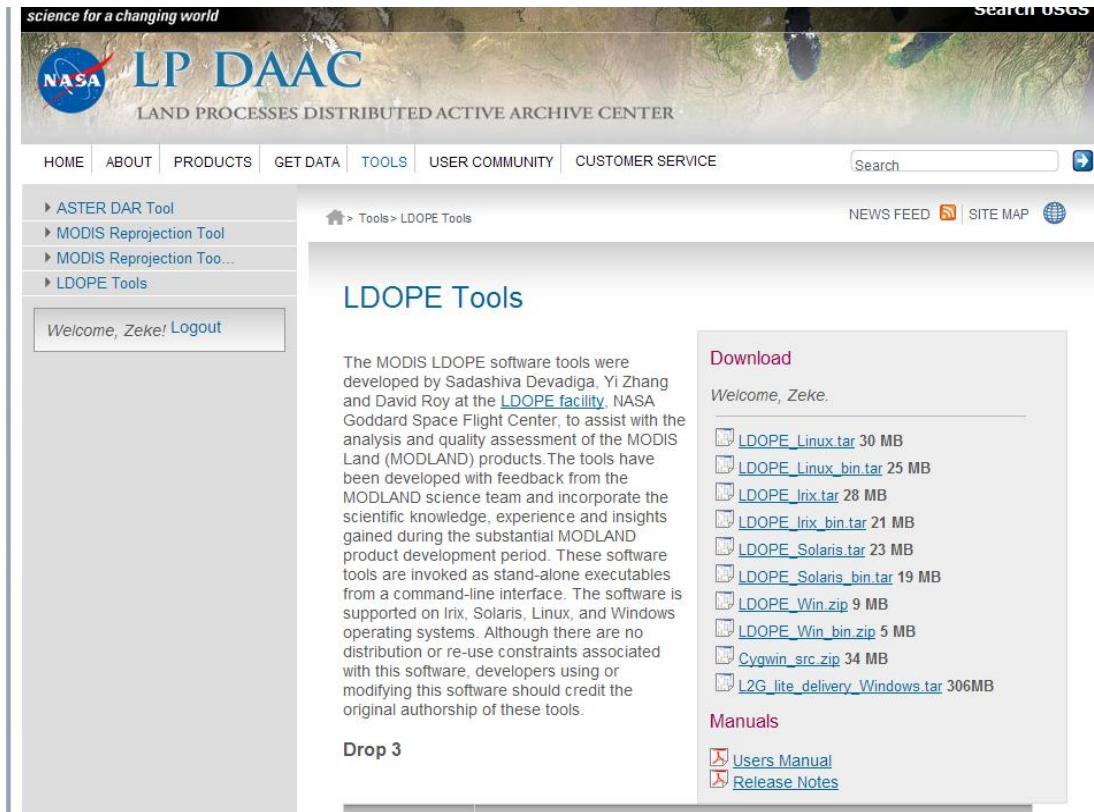


Figure 1.7. Initiating download for LDOPE software.

4. On the C drive, **right click** > **LDOPE_Win_bin.zip** file, and choose **extract to folder** (Fig. 1.8).

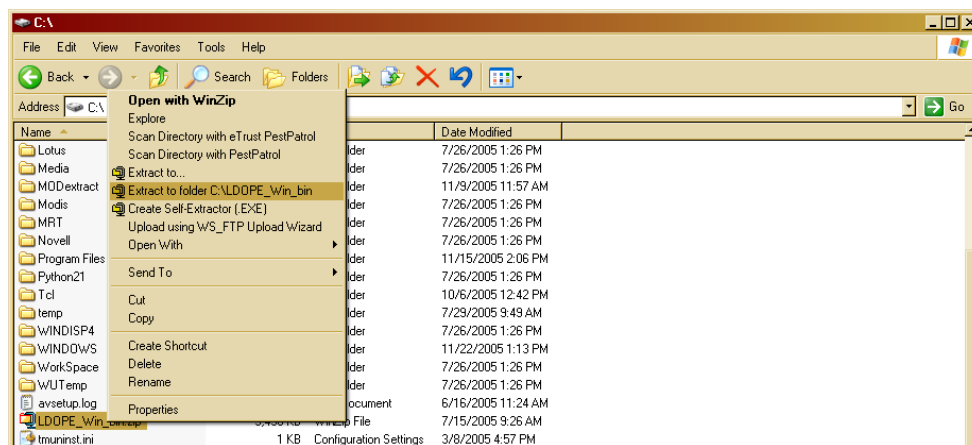


Figure 1.8. Download procedure for LDOPE software.

5. The directory LDOPE_Win_bin includes two subdirectories: **bin** and **ANCILLARY**. The 'bin' directory contains the LDOPE executable files and the 'ANCILLARY' directory contains the projection parameter files containing the

projection parameters for all land tiles in Sinusoidal and Integerized Sinusoidal projections .

- The next step is to set an environment variable (ANCPATH) that points to the ANCILLARY directory. Begin by clicking the Windows “start” > “settings” > “control panel”. Double click on the “system” icon. (Fig. 1.9)

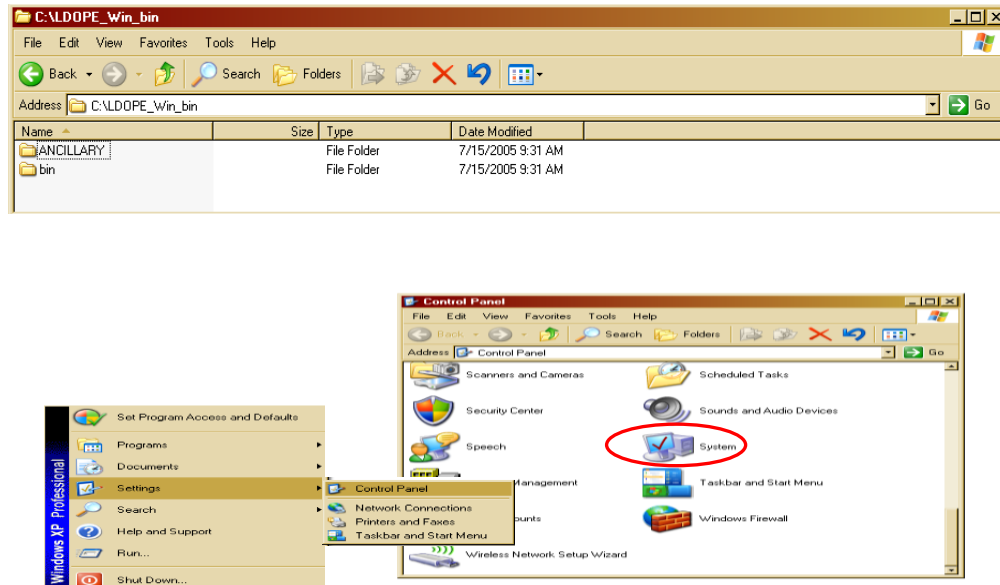


Figure 1.9. Accessing the system properties dialog box.

- From the system properties menu select the “advanced” tab and click on “environment variables” to open the environment variables listing (Fig. 1.10).

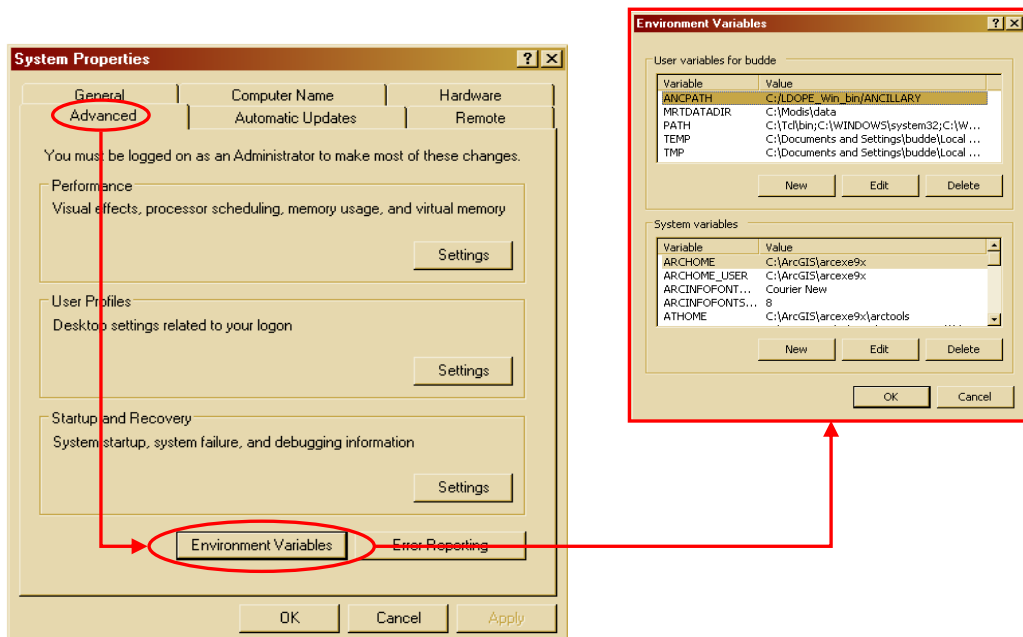


Figure 1.10. Accessing the Environmental Variables listing.

8. In the top panel labeled “**user variables ...**”, select new and put the following in the “new user variable” window: **Variable Name = ANCPATH** and **Variable Value = C:/LDOPE_Win_bin/ANCILLARY**. Click **Ok** (Fig. 1.11).

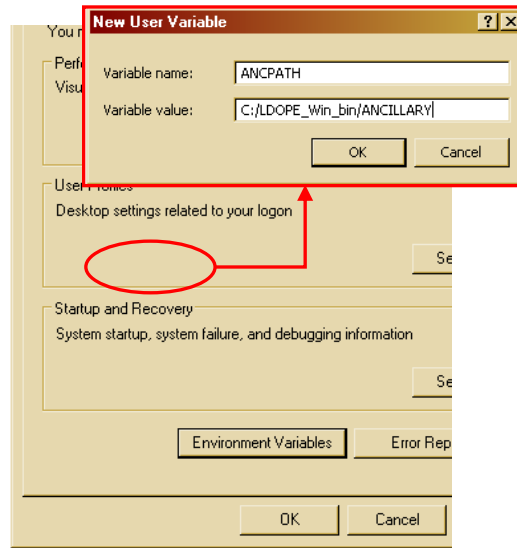


Figure 1.11. Assigning the ANCILLARY path to the ANCPATH variable.

9. An optional step, is to add the binary ('bin') directory path to the \$PATH variable to allow the LDOPE executables to be run from any directory on the local machine. Access the environmental variables window (procedure 7). Select the **PATH** variable from the list and click the **edit** button. Add the binary directory path (**c:\LDOPE_Win_bin\bin**) preceded by a semicolon (;) to the list of variable values. Click **ok** to apply changes (Fig. 1.12).

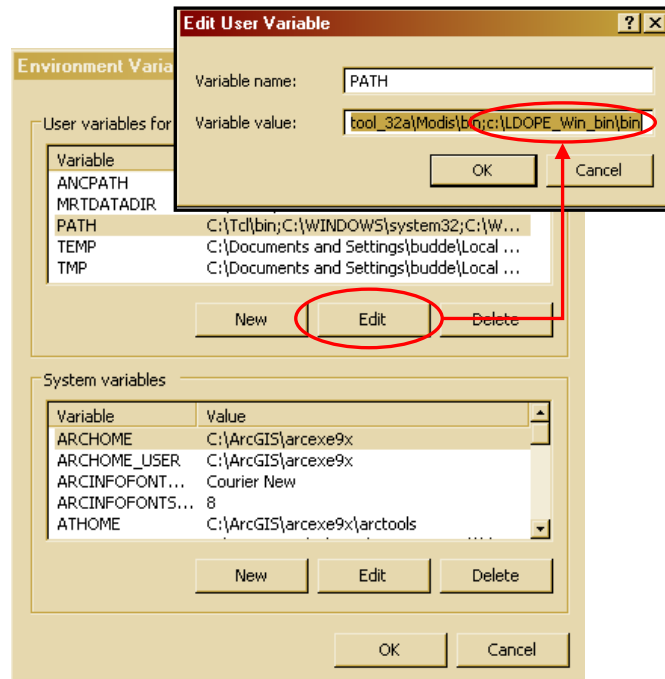


Figure 1.12. Assigning \$PATH directory to allow the LDOPE executables to be run from any directory.

You have completed installation of software tools for processing raw MODIS HDF-EOS files.

1.3 IDL Metrics Setup

The IDL tools are used for in SOP 4 for deriving pixel-based seasonal metrics (i.e. start of season, end of season, etc.) from the NDVI time series data. The program files for executing the tools must reside in a specific directory structure that must be referenced within the IDL preferences.

1.3.1 IDL Metrics Setup Procedures:

1. The METRICS/idl/bin directory must reside somewhere on the local machine (Fig. 1.13). The contents of this directory and sub-directories will be provided to the CP networks.

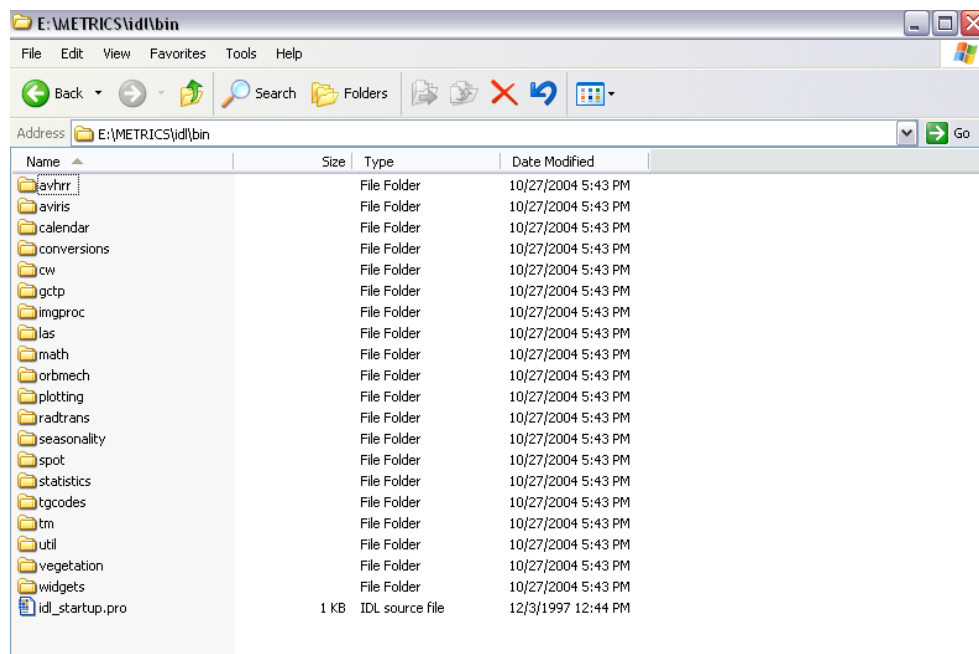


Figure 1.13. Example of the location of the METRICS/idl/bin directory.

2. Access IDL to add the directory path to the IDL preferences. Click **Start > Programs > RSI ENVI > IDL**.
3. From the IDL window, select **Window > Preferences**. Within the preferences dialog box, select the **IDL** tab, then the **paths** tab and use the **insert** button to navigate to the METRICS/idl/bin directory and select **ok**. This will add the directory path to the IDL preferences (Fig. 1.16).

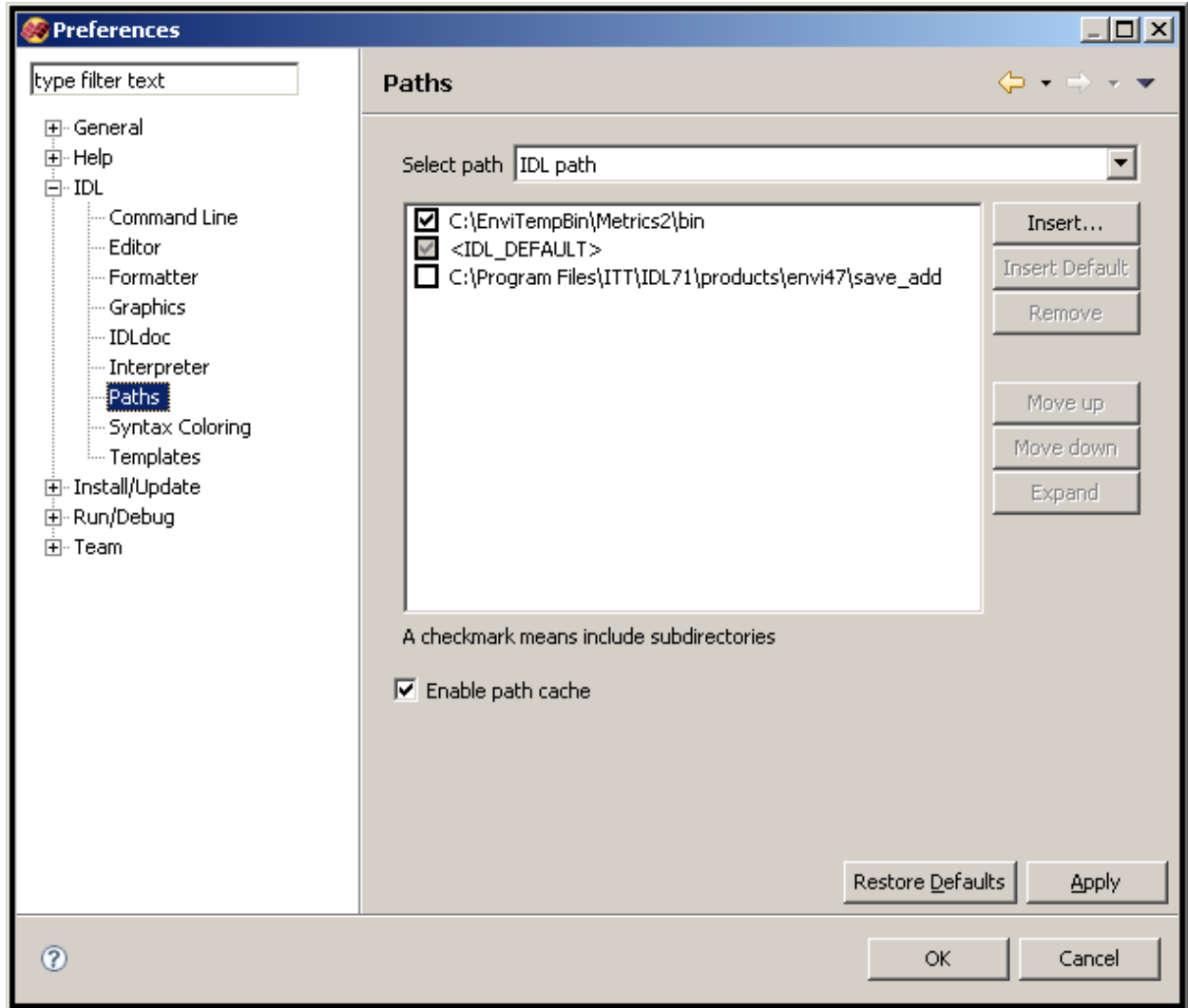


Figure 1.14. Setting the METRICS/idl/bin directory path in the IDL preferences.

From the IDL window, select **File > New > IDL Project**. Within the **New Project** dialog box select the **Project** tab and Browse to the METRICS/idl/bin directory and select **ok**. This will add the directory path to the IDL preferences (Fig. 1.14).

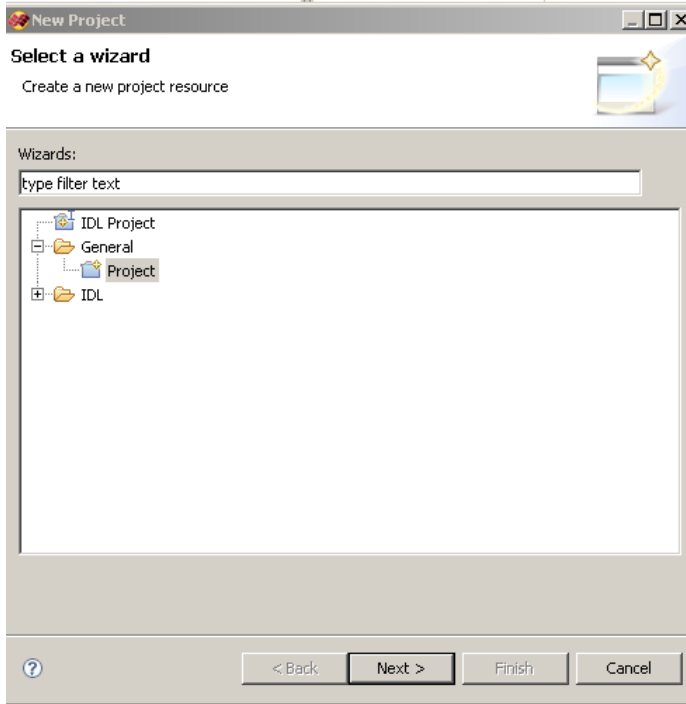


Figure 1.15. Setting the METRICS/idl/bin directory path in the IDL preferences.

4. The next step is to set the working directory where your data reside and where the output of the “imetricsoncube” program will be written. To do this select **File > Switch Workspace > Other**. (Fig. 1.16).

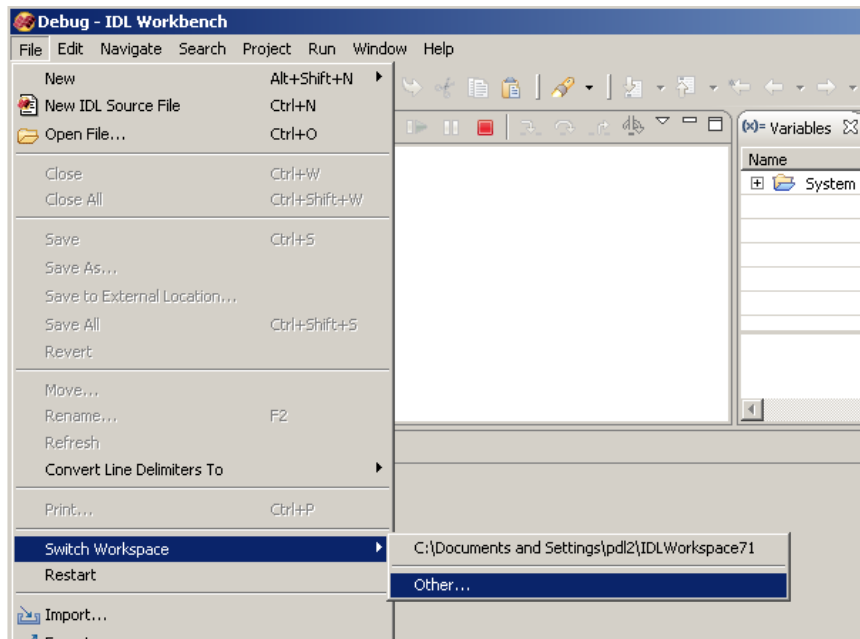


Figure 1.16. Setting the Working Directory.

5. In the "**Select a workspace**" window, browse to the path/folder where you want to store your project.

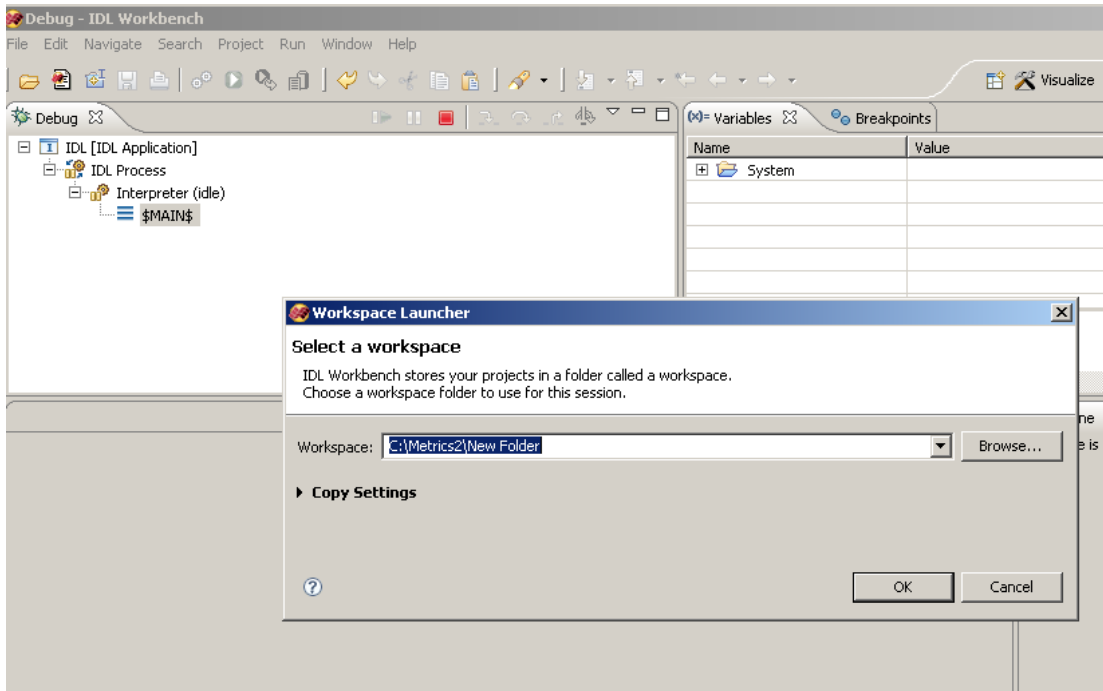


Figure 1.17. Select a path and folder.

This completes the process for the IDL Metrics setup. Procedures for executing these program commands are included in SOP 2.

2. SOP 2: Vegetation Index Processing and Smoothing

Vegetation Condition, Phenology and Snow Cover Extent
Colorado Plateau Networks

Standard Operating Procedure (SOP 2)

Revision History Log:

Previous Version #	Revision Date	Author	Changes Made	Reason for Change	New Version #

This Standard Operating Procedure outlines the procedures for acquisition and processing of the standard MODIS 250m 16-day Vegetation Index (MOD13Q1) product. This product is available from the Land Processes Distributed Active Archive Center (LP DAAC) Data Pool.

One of the intents of this protocol is to make the processing and analysis of these data more automated and therefore more standardized and user-friendly. The procedures outlined below represent those steps necessary to execute a set of scripts that have been provided to the CPNs in an effort to meet this intent.

2.1 Processing Schedule

The processing of MODIS NDVI products should be performed according to the processing schedule outlined in Table 2.1.

Table 2.1 MODIS NDVI processing schedule.

Action	Frequency
Data acquisition	Monthly
NDVI processing	Yearly
NDVI data exploration	Yearly
NDVI data smoothing	Yearly
Phenology Metrics	Yearly
Reporting	Yearly

The output from this set of SOPs will be georeferenced NDVI data at a 16-day compositing schedule for the CP region. From the NDVI data, phenology metrics (e.g., time of start of growing season, duration of season, etc) are computed and then statistically summarized for ecoregions within CP. The software and scripts that are required to run this set of SOPs are listed below in Table 2.2.

Table 2.2. Required software for processing NDVI data.

Software	Process
File transfer protocol (ftp)	File transfer
ListHDF_v2	List HDF file names
MRT	Process hdf files
ENVI	Image processing
Smooth	Smooth NDVI data
IDL	Calculate phenology metrics
IDLmetrics scripts	Calculate phenology metrics
VI Processing scripts	Process VI files
Excel (or other spreadsheet)	Reporting

Any use of the general “VI” term is in reference to the standard NASA-EOS MODIS Vegetation Index product which contains both a normalized difference vegetation index (NDVI) and an enhanced vegetation index (EVI) product. In this protocol, only the NDVI product is used.

2.2 Data Acquisition Procedures

Required software: none

The MOD13Q1 products are routinely placed into the LP DAAC Data Pool as soon as they are produced. The data policy at the time of this writing is to keep one year (the most recent year) of the VI product online at the Data Pool at any one time.

Each month, the data technician should navigate via a web browser to the Data Pool and download all new MOD13Q1 data to the local, operational computer. To access the data:

- Open an Internet browser of your choice.
- Navigate to the website for the Data Pool:

The most recent path (Jan 2010):

https://lpdaac.usgs.gov/data_access/data_pool

In the Access the DataPool window, select MODIS TERRA

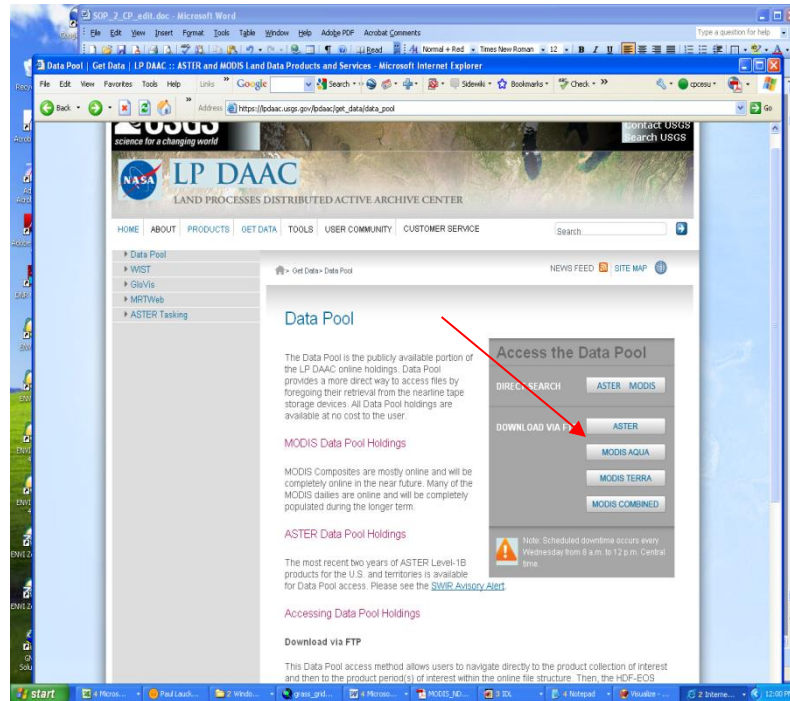


Figure 2.1 Navigating the LP DAAC Data Pool

This will take you to the ftp site. Open the Directory labeled MOD13Q1.005 (ftp://e4ftl01.cr.usgs.gov/MOLT/MOD13Q1.005/)

Inside this directory are folders for each date of MODIS NDVI data available. To download your desired tile(s), open the appropriately dated folder, select the tile image file and Copy to your local drive.

After confirming the appropriate pathing and file names (see next) you can download using your ftp Client for a batch download.

The MOD13Q1 files are listed in tile order. The tiles are sorted first by the horizontal tile number and next by vertical tile number. The first listed tile (using the 2006.09.14 folder) is:

MOD13Q1.A2007257.h00v08.2007280231445.hdf

The above file name is parsed according to the following:

MOD13Q1 – product name

A2006257 – Acquisition date; year 2006, day 257 (beginning of composite period)

h00v08 – horizontal and vertical tile numbers

2007280231445 – processing time; year 2007, day 280, hour 23,

minute 14, second 45

Note: Many MODIS files are named according to their Julian Date. Julian day is the sequential day number, starting from Jan 1 and running through Dec 31. In the example above, day 2007257 is Sept 14, 2007. Julian dates will change during leap years.

- Scroll downward until identifying the 4 tiles that comprise the CP and **highlight each of the files by left mouse-clicking** on the first file, then depressing the control key and clicking the left mouse button on the subsequent file names. It is only necessary to select the *.hdf files, not the *.hdf.xml. The files that should be selected are:

h08v05, h09v04, h09v05, h10v04

- Open the destination file folder (e.g. D:\CP\MODIS_VI_16day\2007).
- Drag and drop the selected files from the Data Pool into the file folder.

Notes:

Depending on the connection speed of the local network, the download may take some time. If a large number of 16-day periods are being acquired at one time, it is recommended that this acquisition step be run overnight.

Another caveat is that the LP DAAC has standard maintenance periods every Wednesday from 7a.m. to 11a.m. Central time and other unforeseen downtimes. CP personnel should avoid trying to acquire data during the scheduled downtime and should be aware that problems with the MODextract process may be due to server issues at the LP DAAC. These are listed on the Earth Observing System (EOS) Data Gateway welcome page (<http://edcimswww.cr.usgs.gov/pub/imswelcome/>). The user may need to scroll down the page to access the LPDAAC.

Earth Observing System Data Gateway (EDG) for Data Acquisition

If these data are no longer available in the respective data pools, the EOS Data Gateway provides an alternative method for searching and ordering any of the MODIS data sets from all DAAC locations.

2.3 NDVI Processing

2.3.1 Mosaic, project and mask NDVI

Required Software: MRT, VI processing scripts LDOPE

After a year's collection of MOD13Q1 HDF files (23 files that correspond to 23 time periods – the number of 16- day periods in a year) have been transferred to the local CP machine, the next step is to execute a program called **List_HDF_v2.exe**. This script will be provided to CP. List_HDF_v2 creates a text file of the file names that is used in the next SOP, where all the HDF files are processed.

- Double click on the **List_HDF_v2** executable to open a small dialog box. Using the dropdown file structure, point to the directory where the HDF files reside and will be processed and click ok.
- Navigate to the directory (e.g. D:\CP\MODIS_VI_16day\2007) and assure that a set of new files named **yyyyddd.txt** have been written. Each of these files contains the list of hdf file names that correspond to each of the 16-day composite periods

Execute the batch file **CP_vi_script_2007.bat** found in the annual directory where data are being processed (D:\CP\MODIS_NDVI_250m\2007 in this example). The batch file will process only those files for which text files (created above) and original HDF files exist. Note that the ASCII text files from which that *.bat files were created are also included in the directory for any unexpected editing that may be required (in case of MODIS version changes, path name changes, etc.).

- Execute the script by **double-clicking** on the filename.

The execution of this batch file will launch an MS-DOS window that shows the progress of the processing. The batch file uses command line MRT processes and LDOPE quality evaluation tools to process the vegetation index data.

- 1) The first step of this process creates a mosaic of the NVDI band (band 1).
- 2) The second step of the process creates a mask of poor quality data by accessing quality assurance information in the NDVI_Quality band (band 3). Poor quality data include pixels with high aerosol content, cloud contamination, or snow and ice cover.
- 3) The third step applies the quality mask to the NDVI mosaic
- 4) The fourth step executes the resample, subset, reproject, and reformat parameters to produce a single band NDVI image for analysis.
- 5) The final step of the process deletes temporary files that were created during the processing.

The output from this procedure is a set of 23 NDVI files (one for each 16-day composite period) in Geotiff format (with *.tif file extension) covering the CP region, in an Alaska Albers map projection.

- Navigate from the My Computer icon to the file folder where the data reside (in this example, it is D:\CP\MODIS_NDVI_250m\2007). Assure that the output files are present. Their filenames will be, for example:

NDVI_2007_001.250m_16_days_NDVI.tif (for composite period beginning with day 1 of the year)

2.4 Stacking, scaling and smoothing NDVI

This section describes one of several possible approaches for exploratory analysis and interpretation. The NDVI data interpretations require layer stacking of multiple NDVI images and comparing the images from one year (or multiple years) to another (e.g., an index year of historical extreme) or to the recent historical average. The following procedures assist the user to interpret the NDVI data sets:

- 1) Layer stacking
- 2) Link windows and create corresponding Z-profiles
- 3) Scaling NDVI

Data smoothing

2.4.1 Layer stacking

Required Software: ENVI

- Initiate ENVI by double-clicking on the ENVI icon on your desktop. In the main ENVI window, open the NDVI data files using the following procedure.
- **File > Open Image File**

Assure that you navigate to the proper file folder where the data that were processed in SOP 2.2 reside. The files have the filename structure:

NDVI_2007_001.250m_16_days_NDVI.tif

- Select (and open) all of the NDVI *.tif files that were output from the MODIS scripts for one year of observations. This will result in a total of 23 selected images for a single year. Scroll through the “Available Bands List” to assure that all of the images are present.
- View one (or more) of the images by highlighting the image name (for example, NDVI_2007_321.250m_16_days_NDVI.tif, by clicking the Band 1 listing under the filename, then clicking the Load Band button at the bottom of the window (Fig. 2.2).

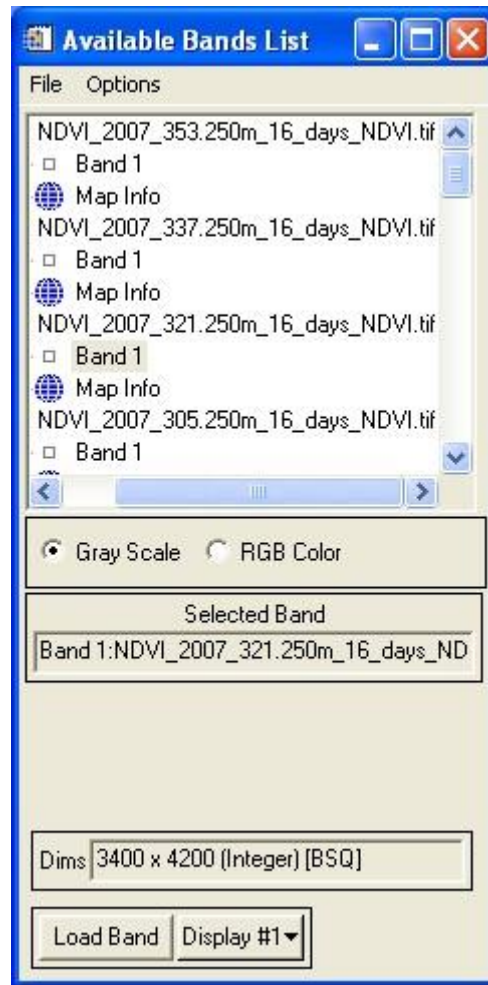


Figure 2.2 Selection of image for file display

Three display windows will pop up, displaying the image at three different levels of detail; the “scroll” window displaying the entire image at reduced resolution, the “image” window (largest of the display windows) displaying the image at 1/1 pixel resolution, and the “zoom” window at a default (but adjustable) zoom of 4x. To adjust the zoom power, you may click on the -/+ buttons at the bottom of the popup window.

In the next procedure, you will stack all of the images (layers) into one multi-band image in order to begin analysis of the data as a one-year data set.

- From the Main ENVI window, select **Basic Tools** > *Layer Stacking*
- Click the *Import File* button.
 - select all of the *.tif files as Input Files from the Available Files list. You may select all of the files at the same time, by using the

control or shift key on your computer while mouse-clicking. After all the files have been highlighted, Click OK.

In order to analyze the data in the proper temporal sequence, assure that the files are in the correct chronological order (image one corresponds to the Jan 1 observation, etc.). For example, Fig. 2.3 lists the data in reverse chronological order.

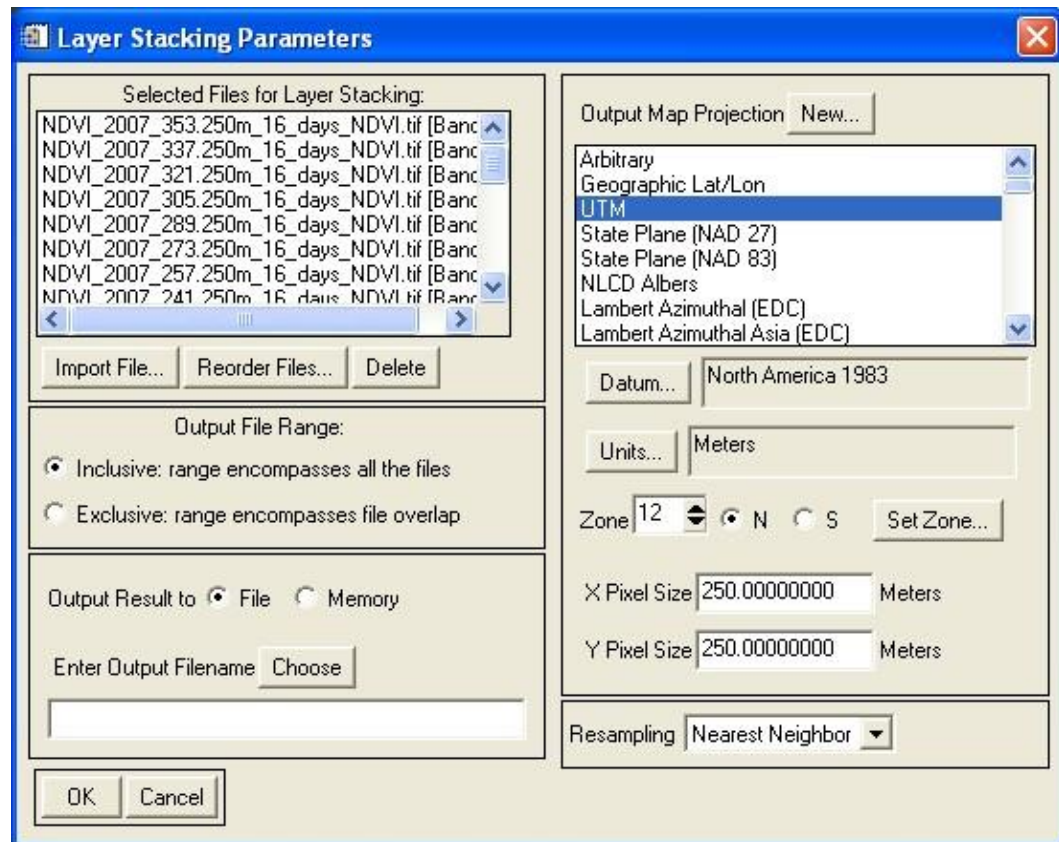


Figure 2.3. Listing of Input files for Layer Stacking procedure.

- Click the *Reorder Files* button – Note that the center mouse button reorders from bottom to top. Assure that the filenames are in the proper order:
NDVI_2005_001.250m_16_days_NDVI.tif
NDVI_2005_017.250m_16_days_NDVI.tif
NDVI_2005_033.250m_16_days_NDVI.tif
NDVI_2005_049.250m_16_days_NDVI.tif
- Enter Output Filename > CP-NDVI-2007.

Note: Assure that you have navigated to the proper destination file folder before clicking OK to initiate the process.

The newly created Layer Stack will now appear in the Available Bands List.

- Display the new file by highlighting one of the Layers in the CP-NDVI-2007 file and clicking the Load Band button in the Available Bands List
- To display the temporal sequence (profile) of the NDVI data, **right click** in one of the Display windows and select **Z profile (spectrum)**.

This displays a scaled NDVI value on the y-axis and band number (corresponding to time of year) on the x-axis (Fig. 2.4).

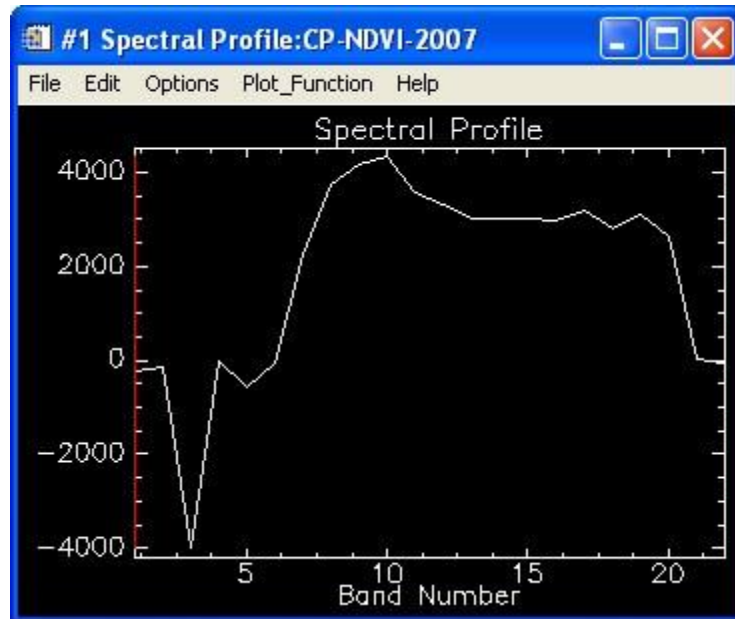


Figure 2.4. Temporal profile of a pixel.

You can observe an instance of snow and cloud contamination (-4000 values) that need to be addressed before phenology metrics may be calculated.

2.4.2 Link Windows and create corresponding Z-profiles **Required Software: ENVI**

The following methodology may be used to compare any set of time-series NDVI images. It is assumed that the layer stacking for individual years of VI has already been performed and are available for processing.

- Clear all images from the *Available Bands List* by clicking **File** in the Available Bands List window and selecting **Close All Files**. You will receive a warning that this will close all files. This is, indeed, what you wish to do, so select **OK**.

To compare two (or more) years of data, first open the image data and make sure they appear in the Available Bands List.

- In the Available Bands List window, click **File** and select **Open Image File**. Navigate first to the file folder containing a stacked data set, as prepared in the previous SOP. Select the stacked year (e.g., CP-NDVI-2007).
- Repeat the previous step and select a different year of stacked NDVI data (e.g., 2001).

Display the same band (say, Band 3) for each year in its own display window.

- First **highlight** one of the bands from 2001 (e.g. the 3rd listed layer), then click **Load Band** at the bottom of the *Available Bands List* window as in Fig. 2.3.
- Scroll down in the *Available Bands List* until you reach the 2007 data, and **highlight** the same band as you did for the 2001 data (e.g. the 3rd layer). At the bottom of the Available Bands List window, click the **Display # 1** button – select **New Display**. A blank display window will appear. Now click **Load Band** and the highlighted image band will be displayed.

In the next sequence, link the two display windows and display the temporal sequence for the same area (pixel) for the two separate years.

- Right click in one of the display windows and click **Link Displays**. A popup window will appear prompting for which displays should be linked. Leave the default values as are and click **OK**.
- To display the Z-profile (temporal sequence in this example), right click on the display window and select **Z-profile (Spectrum)**. Repeat for other display window(s). This creates a popup window with a temporal profile of the NDVI for each specified year.

You may now navigate through either of the images and left-click any place on the image and the Z-profiles for each year of data will update. To compare the individual years, it is important that the graphic scales be the same. The ENVI Z-profile function scales the y-axis depending on the data ranges.

- The y-axis scaling may be fixed by using the *Z-profile window* menu **Edit** > **Plot parameters**. Select Y-Axis and use a range of 0 to 4000 and click OK. Repeat the scaling for both Z-profile windows.

The resulting graphs may be compared side-by-side to identify differences in vegetation activity between years. For example, Fig. 2.5 illustrates NDVI differences between 2007 (left) and 2001 (right) for a single pixel.

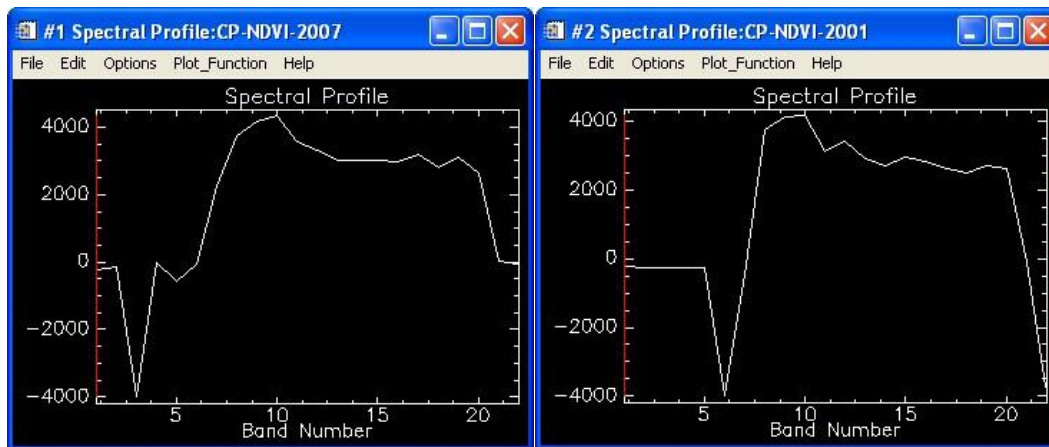


Figure 2.5. Example NDVI profiles for 2007 (left) and 2001 (right) for a pixel in CP

2.4.3 Data Smoothing

Required Software: *Smooth.exe, ENVI, Excel*

Many NDVI images exhibit areas with unsatisfactory values (masked out during the QA procedures) that were identified during SOP 2.2. A smoothing procedure can be performed on the NDVI imagery that eliminates the masked values by substituting temporally interpolated values. This results in a clean image that is appropriate for interannual analysis (Fig. 2.6).

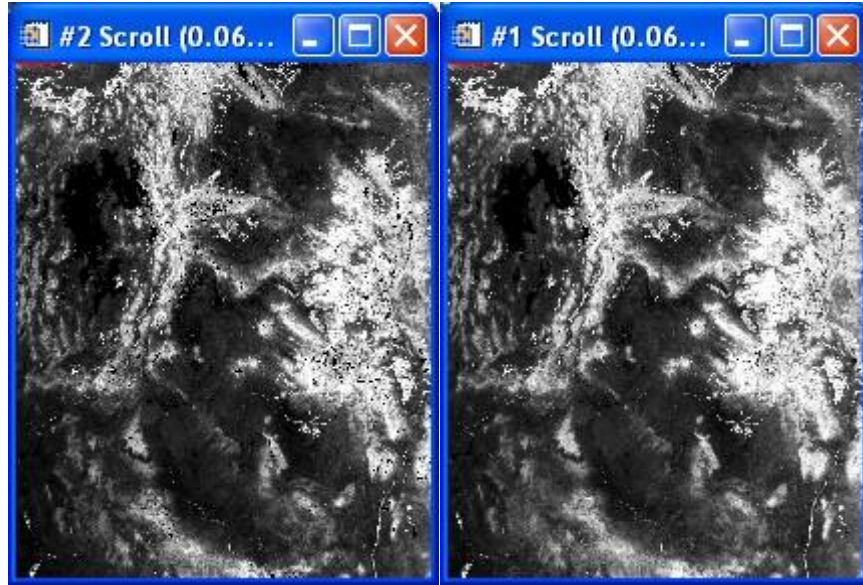


Figure 2.6. Smoothed versus unsmoothed NDVI. Before (left) and after (right) smoothing images of NDVI. Note the elimination of contaminated pixels (black areas) in the middle right portion of the image.

The smoothing operation permits a more realistic depiction of the vegetation conditions throughout the year when cloud cover obscures view of ground target (Fig. 2.7).

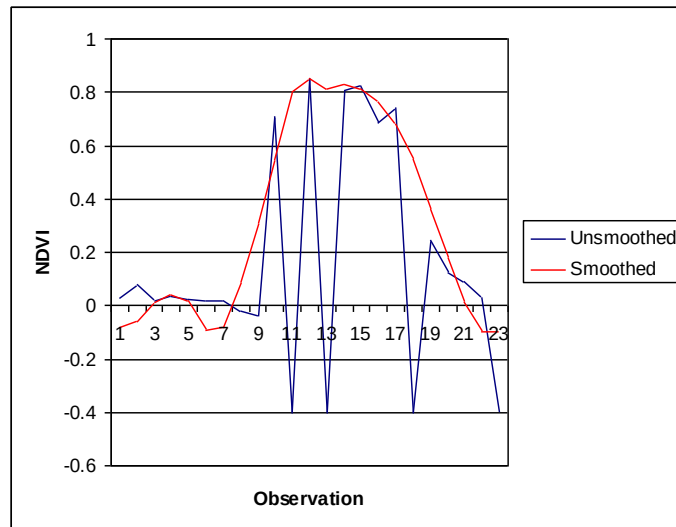


Figure 2.7. Results of smoothing operation on annual time-series.

To perform the smoothing operation, you first convert the data to byte range, then combine multiple years for assuring that the temporal smoother has data both before and after the dates of analysis for its operation (it operates using a temporally moving window), then execute the smoothing operation.

2.4.3.1 Convert the data to byte data range

Required Software: ENVI

The smoothing procedure operates on a stacked data set. The first step in this process is to convert the previously stacked data to byte range - this reduces the data volume, while retaining the temporal characteristics of the data that are required for the time-series phenology analysis.

To convert to byte:

- **ENVI > Basic Tools > Band Math**
 - Within the Band Math window, ***Enter an expression:***

byte((b1/100)+100)

This expression has been supplied to the CP in a restorable file. You may restore this expression by clicking the *Restore* button and navigating to where the file is stored: (D:\CP\ENVI_Expressions\BandMath-byte). Assure that the expression is highlighted and click **OK**.

- A new window will open **Variables to Bands Pairings > Map Variable to Input File >**
 - Select the stacked image created earlier: CP-NDVI-2007
 - *Enter Output Filename:* Navigate to proper file folder and enter CP-NDVI-2007-byte (Fig. 2.8)

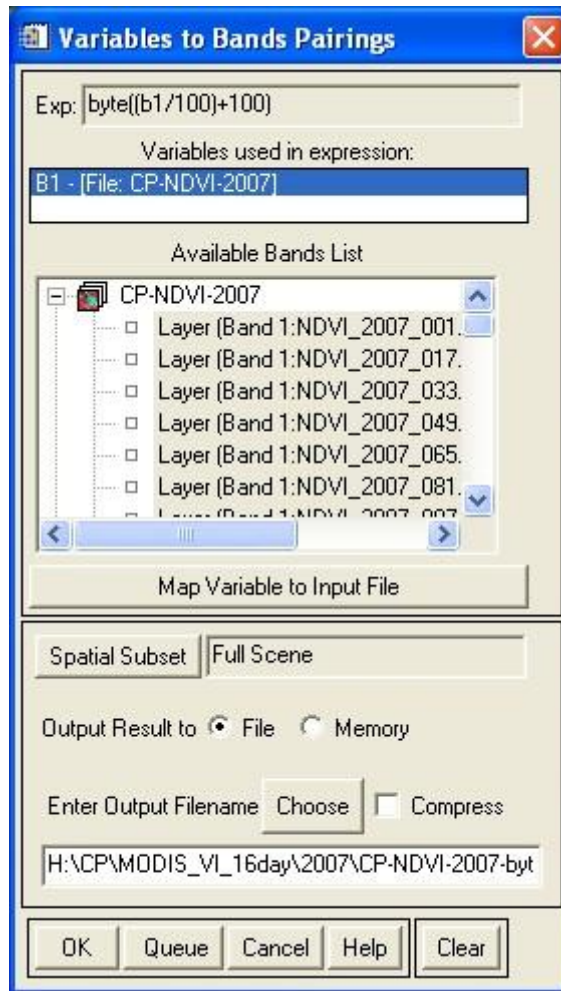


Figure 2.8. Band Math expression to convert to byte

This step converts the VI data from a scaling of 1/10,000 to the 0-200 data range. In this new scaling, the data may range from 0-200, where a NDVI value of -1 corresponds to 0, an NDVI of 0 = 100, and an NDVI of 1 = 200.

The data are now ready to be prepared for temporal smoothing to eliminate the snow, cloud, and aerosol contamination.

Note: If there is ever a need to convert to “true” NDVI values (such as reporting values for a publication), use the equation: $NDVI = (Scaled\ NDVI - 100) / 100$

Example in ENVI: $(float\ b1 - 100) / 100$

A complete example for scaling and unscaling a single pixel follows:
Using this HDF image as an example:
MOD13Q1.A2006017.h10v04.005.2008067144143

From the NDVI layer zero in the raw HDF file
NDVI layer = MOD13Q1.A2006017.h10v04.005.2008067144143.hdf:0

A given pixel value = 3043
Scaled NDVI value is
 $(3043/100)+100= 130.43$

Convert to NDVI unscaled
 $(130.43-100)/100 = 0.3043$

2.4.3.2 Prepare multiple-year data stack for smoothing

Required Software: ENVI

Since the smoothing process uses a temporal moving window (Swets et al, 1999) it requires that data be present both before and after the data that are to be smoothed. Therefore, the next step is to “pad” the data that are to be smoothed (2007) with one year of data before (2006) and one year of data after. In many cases, such as this example, we repeat the final year of the series (in this example, 2007, again) when the collection for the following year (2008) has not yet been completed. Assuming that no data sets are open and in the **Available Bands List**, begin ENVI and:

- **Open Image File** > Open the 2007 stacked, byte data.
- **Open Image File** > Open the 2006 stacked, byte data.
- **Basic Tools** > *Layer Stack*
*Import File...*import stacked 2006 data
*Import File...*import stacked 2007 data
*Import File...*import stacked 2007 data again
- Assure that the files are in the proper order: 2006, then 2007, then 2007 again. If not, initiate the **Reorder Files** function. Choose an output filename (CP-NDVI-060707-byte), press **OK**. This will result in a 69-band file that is ready to be smoothed.

2.4.3.3 Run Smoother

Required Software: Smooth.exe, ENVI

The data are now ready to be temporally smoothed using techniques described by Swets and colleagues (1999).

NOTE: This only seems to work in Run As:Administrator mode, and all files used – smooth.exe, smoothparams20xx.txt and the stacked ‘byte’ images - must be located in the same folder

- Begin a command prompt window (**Start > Programs > Accessories > Command Prompt**) and change directories to the location of the smoother program, first by switching to the appropriate drive (**e.g. > d:**), then changing directories to the appropriate path (**d:\> cd CP\Smother**).

This file folder contains the correct parameter file for executing the smoother for each year (e.g., smoothparams2007.txt).

- Initiate the smoothing algorithm from the command prompt:
d:\CP\smother> smooth smoothparams2007.txt

Note: the input and output paths in the smoothparams200.txt file may need to be changed (using a text editor) to correspond to the source and destination file folder locations.*

The smoother will then begin operation and will update the operator by displaying each line that is being processed. The estimated operating time for this operation is 20-30 minutes, depending on computer speed, other processes that are running, etc.

The results may then be displayed in ENVI from either the main ENVI window or the **Available Bands List** by the following procedure.

- **Open Image File** > navigate to where the new smoothed image resides and select it > CP-NDVI-060707_sm

Since the image was created outside of ENVI, it does not yet have valid header information (file description, projection information, etc.) so a popup window will appear and request information about the file.

- *Select Input Header Info From > Other File* and select the previous byte image (CP-NDVI-060707-byte).

In ENVI 4.7, using any file OTHER than the stacked/byte object file to attribute the hdr will not work. You must use the 69 band file.

Note: this file (CP-NDVI-060707-byte) must be in the Available Bands List – if not, open the image using procedures described earlier.

This will assign the proper header information to the file.

- Display the file using procedures described earlier

- Right click within one of the image windows and select **Z-profile (Spectrum)** to view the new, smoothed temporal profile of the NDVI imagery. Note that the new graph displays 3 years of data, due to the stacking of multiple years (Fig. 2.9).

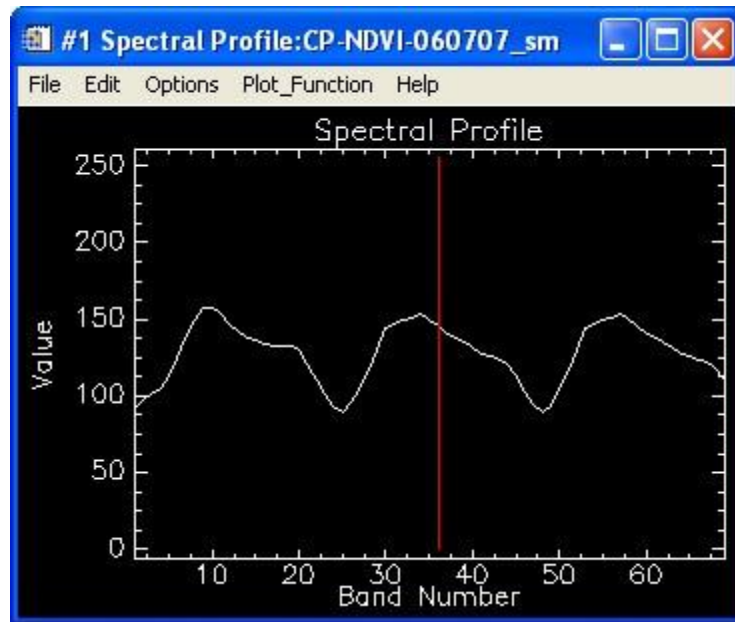


Figure 2.9. Three years of smoothed data.

2.4.3.4 Subset image into one, smoothed year of data

Required Software: ENVI

Now that the year of concern (2007 in the example) has been smoothed, it needs to be taken from the 3 year stack, so it can stand alone and be used for other applications.

From the ENVI Main Menu, select:

- **Basic Tools** > *Resize Data* (Spatial/Spectral). This will popup a window prompting the user to *Select Input File*. Select the file that has been smoothed and with the header information added (CP-NDVI-060707_sm, in this example).

The window will then activate fields for *Spatial Subset* and for *Spectral Subset*.

- Click *Spectral Subset*. This will popup a new window called File Spectral Subset that lists all the individual date images (bands) that comprise the stacked image in chronological order. Scroll down the window until you

reach the first band of the year that you are trying to isolate (Fig. 2.10). Highlight this band and all other bands (using the shift or control key) for the year of data that you are subsetting (for a 3-year stack, you will highlight bands 24-46). Click **OK**.

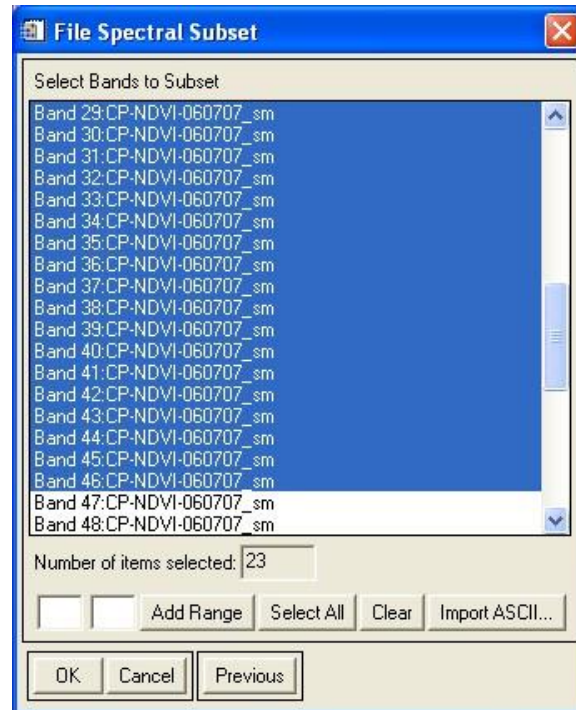


Figure 2.10. Listing of bands in spectral subsetting process.

This will return you to the Resize Data Parameters window. Do not change any other file parameters.

- Enter Output Filename (e.g., CP_NDVI_2005_sm). Click **OK**.

2.4.4 Prepare Data for Calculating Phenology Metrics **Required Software: ENVI**

The calculation of phenology metrics is described in SOP 3 and 6, but additional preprocessing as described below is necessary before metrics can be derived. To derive phenology metrics for one year, three years of smoothed NDVI data are required. This is because the algorithm operates by examining data both before and after the time of analysis to identify trend shifts. When examining the most recent year of observation (a typical analysis scenario), there is not yet any data after the time of observation. In this instance, we repeat the current (most recent) year of observation. Therefore, the first step in this procedure is to create a layer stack of smoothed data.

- Assure that the *Available Bands List* is empty. On the *Available Bands List* window, click **File** > **Close All Files**.
- Open the required files. On the *Available Bands List* window, click **File** > **Open Image File**, open the smoothed files for 2006 and 2007.
- Stack these data using the same procedures as used in SOP 2.3.1. Stack them in the order, 2006, 2007, and then 2007 again. Note that if a complete year of smoothed 2008 data were available, those data would be used instead of repeating 2007. Assure that the data are in chronological order before clicking OK. **Enter Output Name:** *CP-NDVI-060707_sm*. The result is a 69-band file.

Before the phenology metrics can be calculated, two data preparation steps must be performed. Some of the calculations in the metrics algorithm require the slope of the NDVI value through time as an input variable. When there is an extended period of time where the NDVI value is identical (such as masked values over snow, cloud, aerosol or water), the slope becomes zero. This slope value is later used as a divisor in part of the metrics algorithm and crashes the program as it currently operates. Therefore, a workaround is to search for and alter these values. We have constructed an ENVI image that can be used as part of an ENVI Math Expression to identify and eliminate these constant values.

2.4.4.1 Eliminate the extended snow, cloud, or aerosol pixels

Required Software: ENVI

During the original MODIS processing of NDVI (SOP 2.2) snow, clouds, and high aerosols were flagged and written as a value of -4000, which during the transfer to byte data range and the smoothing process becomes a value of 90. Water values in the image also need to be masked in order to avoid nonsensical phenology metrics. Water values can vary, but generally have an NDVI value of 0 (DN of 100) or less. This procedure involves identifying values of less than or equal to 100 in the data set and recoding them to values that are near a value of 100 (ranging from 100-102) – values that are in the realistic range of NDVI values.

A 69-band image, corresponding to 3 years of MODIS 16-day data, has been prepared containing these values in alternating bands to eliminate the constant value issue discussed above. Before starting the next procedure, assure that the **NDVI_69band_fill_3** image has been opened and is in the Available Bands List. This file consists of 69 stacked bands, the first 23 containing only DN 100 values, the second 23 containing only DN 101 values and the last 23 bands containing only DN 102 values.

- On the *Available Bands List* window, click **File** > **Open Image File**, open D:\CP\ENVI Expressions\69band-fill

- Under **Basic Tools** > *Band Math* when the Band Math popup window opens, select,
 - *Restore* (this function will restore an existing Band Math expression). A popup window for a filename will open. Navigate to D:\CP\ENVI Expressions and select the file BandMath-fill. This will insert the following expression into the Band Math window:
 - $\text{byte}((B1 \leq 100) * B2) + \text{byte}((B1 > 100) * B1)$

This expression states that if B1 (input smoothed image) is less than or equal to 100 (previously masked data values), assign the value of B2 (the fill image containing the 100-102 values). If greater than 100, B1 retains the original values of B1. The byte portion of the expression assures that the data remain in byte range, rather than the default floating point data type.

After clicking **OK**, a new window will popup that prompts the user to assign variables to the expression (Fig. 2.13).

- Make sure that B1 – [undefined] is highlighted, and then press the button *Map Variable to Input File*. This spawns a new window containing the possible input files – select the newly stacked, smoothed image (CP-NDVI-060707_sm).
- Next, highlight the next variable B2 – [undefined] and map that variable to the fill file (69-band-fill).
- Choose an output name (CP-NDVI-060707-fix). Press **OK**.

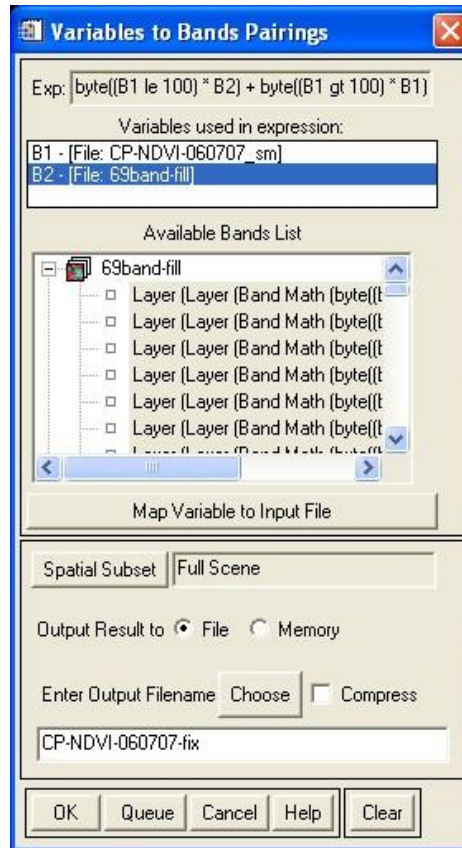


Figure 2.11. Band Math procedure to “fix” smoothed data prior to calculating phenology metrics.

Note: If you are going to process the phenology metrics using a program other than ENVI, such as TimeSAT, continue, beginning again at SOP 5.

2.5 Quality Assurance/Quality Control and Validation

Quality assurance and control is a major element of the original MODIS product development (before the Landscape Processes Protocol is implemented). For a summary of the types of processing QA/QC that have been implemented, see an overview of the Land Data Operational Product Evaluation (http://landweb.nascom.nasa.gov/cgi-bin/QA_WWW/newPage.cgi). Similarly, many of the standard MODIS products have undergone validation experiments. The MODIS Land Processes Validation web site summarizes many of these efforts (<http://landval.gsfc.nasa.gov/index.php>).

While the quality of the MODIS data is evaluated using the QA information outlined above, validation of data analysis and interpretation, in terms of actual CP landscape processes, requires a much more intensive effort. The issue of validating satellite derived measures of these various processes is beyond the scope of this protocol and will need to be addressed by CP I & M staff as further investigations are undertaken. It may be

possible to identify a small localized area that could be evaluated as a test validation site for each of the standard MODIS products – possibly in conjunction with the National Phenology Network. The feasibility of such a validation site should be evaluated by CP personnel during the initial protocol implementation. Therefore, no formalized procedures for validation of data analysis and interpretation are included in this protocol.

2.6 Literature Cited

- Badhwar, G.D., Use of Landsat-derived profile features for spring small-grains classification, *International Journal of Remote Sensing*, 5(5), 783-797, 1984.
- Lloyd, D. A phenology classification of terrestrial vegetation cover using shortwave vegetation index imagery, *International Journal of Remote Sensing*, 11, 2269-2279, 1990.
- Reed, B.C., J.F. Brown, D. VanderZee, T.R. Loveland, J.W. Merchant, and D.O. Ohlen, Measuring phenology variability from satellite imagery, *Journal of Vegetation Science*, 5, 703-714, 1994.
- Reed, B.C., M. White, and J.F. Brown, 2003. Remote Sensing Phenology. Chapter 5 in *Phenology: An Integrative Environmental Science*, Kluwer Publishing, pp. 365-382.
- Swets, D.L., B.C. Reed, J.R. Rowland, S.E. Marko, 1999. A weighted least-squares approach to temporal smoothing of NDVI. In 1999 ASPRS Annual Conference, From Image to Information, Portland, Oregon, May 17-21, 1999, Proceedings: Bethesda, Maryland, American Society for Photogrammetry and Remote Sensing, CD-ROM, 1 disc.
- White, M.A., P.E. Thornton, and S.W. Running, 1997. A continental phenology model for monitoring vegetation responses to interannual climatic variability, *Global Biogeochemical Cycles*, 11, 217-234.
- Zhang, X, M.A. Friedl, C. B.Schaaf, A.H. Strahler, J.C. F. Hodges, F. Gao, B.C. Reed, and A. Huete, 2002. Monitoring vegetation phenology using MODIS Remote Sensing of Environment, Vol. 84, No.3, pp. 471-475

3. SOP 3: Pixel-based Phenology Processing

Vegetation Condition, Phenology and Snow Cover Extent
Colorado Plateau Networks

Standard Operating Procedure (SOP 3)

Revision History Log:

Previous Version #	Revision Date	Author	Changes Made	Reason for Change	New Version #

3.1 Calculate and Process Phenology Metrics

Required Software: IDL, ENVI

- Initiate IDL by clicking on the IDL icon on your desktop
- Assure that the IDL data directory points to the proper path. From the toolbar at the top of the IDL window: **Files > New > Project**. Using the Project Wizard, Select **General > Project** and **Next**. Create a project name and navigate to the location of the smoothed, fixed data created in SOP *.*). Click **Finish**.

NOTE: *If you are not the Administrator on your machine, the imetricsoncube script may not work as described. One solution is to put the object file (in this case CP-NDVI-060707-fix) into your personal folder under C:\Documents and Settings\my_folder.*

- Navigate to the MODIS_software directory. Double-click the metrics.txt file for the appropriate year (2007 in this example – metrics2007.txt). The text file will contain the following expression:

```
imetricsoncube,'CP-NDVI-060707-fix',3200,4200,69,3,22,20,23,1
```

or for a constructed grid using averages:

```
imetricsoncube, 'C:\Modis\ReverseHdf\CFAP000102.hdf', 2, 2, 69,  
3, 22, 20, 23, 1, ISS = 2, ISL = 2
```

- Cut and paste the command into the IDL command line (Fig. 2.14). Press the Enter key on your keyboard.

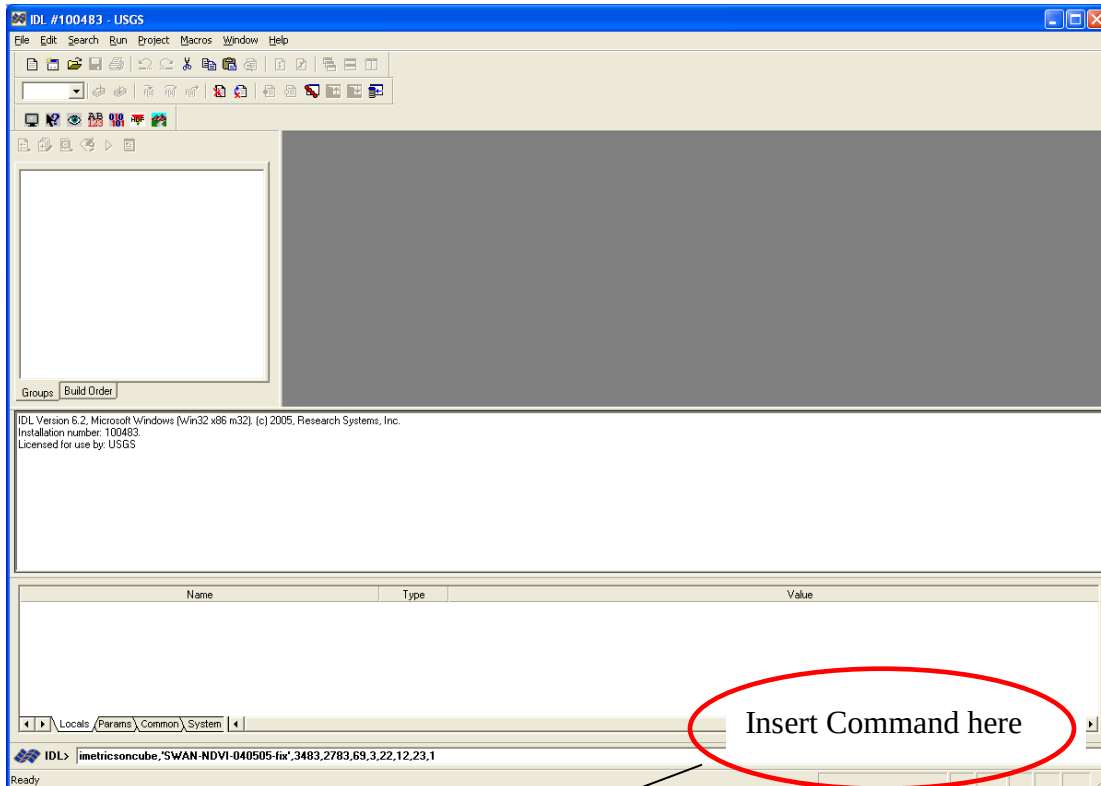


Figure 3.1. Placement of the IDL command line.

The process takes approximately 3 hours, depending on computer speed and other processes that may be running on the computer.

This program outputs 12 files, only a few of which will be used for analysis of the CP (Table 3.1).

Table 3.1. Listing of phenology metrics and their default filenames.

Metrics Filename	Phenology metric
CP-NDVI-040505-fix.eosn	End of season NDVI value
CP-NDVI-040505-fix.eost (EOST)	End of season time
CP-NDVI-040505-fix.maxn (MAXN)	Maximum NDVI value
CP-NDVI-040505-fix.maxt (MAXT)	Time of maximum NDVI
CP-NDVI-040505-fix.ndvitodate	Accumulated NDVI at last

	observation
CP-NDVI-040505-fix.rangen	Range of NDVI values
CP-NDVI-040505-fix.ranget (RANGET)	Duration of growing season
CP-NDVI-040505-fix.slopedn	Rate of NDVI decrease to EOS
CP-NDVI-040505-fix.slopeup	Rate of NDVI increase from SOS
CP-NDVI-040505-fix.sosn	Start of season NDVI value
CP-NDVI-040505-fix.sost (SOST)	Start of season time
CP-NDVI-040505-fix.totalndvi (TOTALNDVI)	Seasonally integrated NDVI

The following phenology metrics are being used for CP monitoring: EOST, MAXN, MAXT, RANGET, SOST, and TOTALNDVI.

- Navigate to the file folder containing the phenology metrics and **delete** the files with the following suffix: **eosn, ndvitodate, rangen, slopedn, slopeup, sosn.**

Note: If, for whatever reason, you rerun this step using the same file names, you must delete the previously created files first. Imetricsoncube does not overwrite files.

3.1.1 Delete padded years of data from the Metrics files

Required software: ENVI

- Initiate ENVI by clicking on the ENVI icon on your desktop
- Open the file that was used to derive the metrics (e.g., CP_NDVI_040505-fix), **File > Open Image File**
- From the main ENVI window, **File > Open Image File >** Select one of the phenology files (e.g. CP-NDVI-060707-fix.eost). Because these files were created outside of ENVI, header information is required. A popup window will appear with blank spaces for Samples, Lines, Band, etc.
- Click the button “*Input Header Info From*”, click “*Other File...*”, select “CP_NDVI_060707-fix”. Click **OK**.
- Edit some of the entries in this window. The Samples (3483) and Lines (2783) are correct. However, you must change Band from **69** to **3**. Also, the Data Type should be changed from **Byte** to **Integer**. Click **OK**. You may now use this file (CP_NDVI_060707-fix.eost) as an “Input Header Info From” for the other phenology metrics files.
- From the main ENVI menu, **Basic Tools > Resize Data (Spatial/Spectral)** From the popup window, *Select Input File >* Highlight 3-band metrics file (e.g. CP-NDVI-060707-fix-eost) and click *Spectral Subset* button. Highlight only Band 2. Click OK. For the Output Filename, Choose:

D:\CP\MODIS_VI_16day\2007\Phenology\EOST-2007

Repeat the process for the other phenology metrics.

3.1.2 Mask bad data values

Required software: ENVI

In this step, we remove bad data values (due to a poorly defined NDVI “season”) where phenology metrics were not satisfactorily identified, so these values do not affect subsequent statistical analysis. The bad values are assigned a value of 0, which will not be considered in subsequent steps. An ENVI Band Math Expression has been created for each of the phenology metrics for cleanup.

- Open image file of phenology metric, whose bad data values will be fixed
- Band Math > Restore >
 - Navigate to ENVI Expressions file folder and select EOST-fix (or the appropriate metric “fix” expression).
- Highlight expression in Band Math window, click OK
- Assign B1 variable to the Phenology metric file
- Enter Output Filename (be sure to navigate to proper output file folder):

A reminder: You may want to convert to “true” NDVI values at this point. Refer back to SOP 2.3.3.1 for the ‘SCALED’ BandMath equation used for this process.

D:\CP\MODIS_VI_16day\2007\Phenology\EOST-2007-fix

3.1.3 Exporting from ENVI to ESRI GRID stack

- From the Main ENVI menu bar, go to Save File As > ESRI GRID. In the new window, select the file you wish to export.

3.2 Additional analysis options

A package of Excel macros and R code is provided in SOP 6 for deriving summary statistics and charts of NDVI data that automates most of the steps outlined above.

4. SOP 4 Snow Cover Extent

Vegetation Condition, Phenology and Snow Cover Extent
Colorado Plateau Networks

Standard Operating Procedure (SOP 4)

Revision History Log:

Previous Version #	Revision Date	Author	Changes Made	Reason for Change	New Version #

4.1 Data Acquisition Procedures

Required Software: FTP client

The processing of MODIS Snow products should be performed according to the processing schedule outlined in Table 4.1 using the scripts listed in Table 4.2.

Table 4.1 MODIS Snow processing schedule.

Action	Frequency
Data Acquisition	Yearly
8-day Snow processing	Yearly
Data Visualization /Analysis	Yearly
Summarizing / Reporting	Yearly

Table 4.2. Software required for processing MODIS Snow data.

Software	Process
File transfer protocol (ftp)	File transfer
List_HDF	List of HDF file names (.txt)
MRT	Process HDF files
Snow Processing Scripts	Process Snow Files
ENVI	Image Visualization/Analysis
Excel (or other spreadsheet)	Reporting

Acquisition of MODIS 8-day data from the National Snow and Ice Data Center (NSIDC) DAAC (<http://nsidc.org/daac/>) utilizes the NSIDC “data pool” which allows users to download files via FTP.

- Using either a command line prompt or an FTP client, access the NSIDC data pool at the following location:

ftphost:	n4ftl01u.ecs.nasa.gov
username:	anonymous
password:	your email address
ftp directory:	nsidc.org/data/data_pool/ftp (8-day collection 5)

- After accessing the ftp site, Select the **MOST Directory**
- Navigate to the 8-day directory from which you want to download data, the MOD10A2.xxx directory. The 8-day directories are named using the following format: yyyy.mm.dd, where yyyy equals a four digit year, mm equals a two digit month, and dd equals the two digit calendar day.
- Download only the HDF files necessary for coverage of the Colorado Plateau parks (i.e. h08v05, h09v04, h09v05, h10v04) to the 8-day MODIS Snow directory. The filenames begin with MOD10A2.A2007293 (this example using day 293 of 2007 - four digit year and 3 digit Julian day), followed by the horizontal and vertical tile locations. An example of a complete filename is shown below.

MOD10A2.A2006293.h09v04.005.2007309235918.hdf

4.1.1 8-Day Snow Cover Processing

Required Software: List_HDF, MRT, 8-Day Snow Processing Scripts

- Once the MOD10A2 HDF files have been retrieved from the NSIDC FTP site and reside on the local CP machine, run the **List_HDFv2.exe** script provided in the MODIS software directory (e.g. N:\CP\MODIS_software). **Double click** on the executable file to open a small dialog box.

Using the dropdown file structure, **point to the directory where the HDF files are located and click ok** (Fig. 3.1). This will create a text file named with the four digit year and three digit Julian day of the HDF files (i.e. 2007293.txt).

Note: Many MODIS files are named according to their Julian Date. Julian day is the sequential day number, starting from Jan 1 and running through Dec 31. Julian dates will change during leap years.



Figure 4.1. An example of the List_HDF dialog box.

- Execute the batch file CP_8-day_maxsnow_script.bat found in the annual directory where data is being processed (e.g., N:\CP\MODIS_SNOW_8-day\2007 in this example). The batch file will process only those files for which text files (created using List_HDF) and raw HDF files exist.

The execution of this batch file will launch an MS-DOS window that shows the progress of the processing. Since the batch file is written to process a complete year, it will flash a number of error screens for dates that have already been processed or are not yet available. It uses command line MRT processes to extract the maximum snow extent data set (data set [or band] 1) from the daily MODIS snow product, mosaic the individual tiles, and apply the predefined projection parameters for the CP region to the output image.

- The result is a set of GeoTIFF images (one for each 8-day period) with the following

Table 4.3. Classified pixel values for maximum snow extent products.

Value	Classification
0	Missing
1	No Decision
3	Scan Angle Limit Exceeded
4	Erroneous Data
11	Night
25	Snow-Free Land
37	Lake or Inland Water
39	Open Water (ocean)

50	Cloud Obscured
100	Snow-Covered Lake Ice
200	Snow

4.1.2 Data Visualization / Analysis

Required Software: ENVI

The visualization and analysis of the MODIS snow cover products is largely exploratory. In addition to viewing the classified snow cover images and assessing the spatial extent of snow cover on an 8-day time step, we have also established some basic methods for analysis. The following procedures will be used:

- 1) Visualization of the 8-day composite data.
- 2) Layer stacking and Z-profiles of 8-day data.
- 3) Quantification of 8-day extent by ecoregion.

4.1.2.1 Snow cover Data Visualization

- Start ENVI by double clicking the desktop icon
- Select **File > Open Image File** and navigate to the 8-day snow directories where the GeoTIFF outputs were written for a given year (SOP 3.2) and select a .tif file from a winter time period. The selected file will be displayed in the available bands list.
- Select **Band 1 > Load Band** with the grayscale button selected. A black and white classified image (Fig. 4.2) will be displayed.

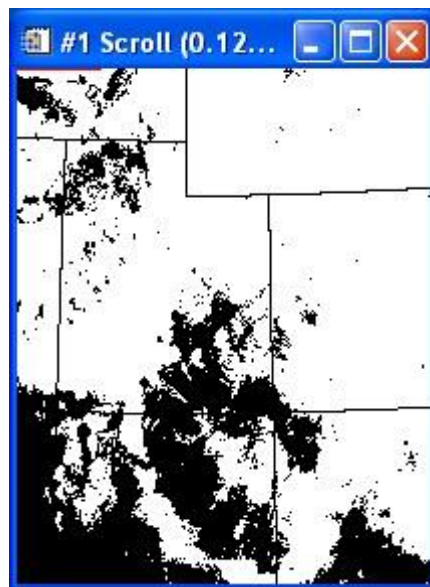


Figure 4.2. Display of an 8-day snow cover image (with state boundaries added).

- Since the black and white classified image isn't very meaningful, apply a color map to the image so individual classes can be distinguished. From the large display window select **Tools > Color Mapping > Density Slice**, select **Band 1**.
- From the density slice dialog box select **File > Restore Ranges** and navigate to the 8-day snow cover directories and select the **CP_maxsnow.dsr** file and click **Apply**.
- The .dsr file contains color assignments for each of the classification values in the image (Table 4.3). The values will generally be in the range from 25 – 200 as seen in Fig. 4.3, where green is snow free land (25), light blue is inland water (37), dark blue is ocean (39), gray is cloud (50), aquamarine is snow-covered lake ice (100), and white is snow (200). Not all classes are represented in each image.

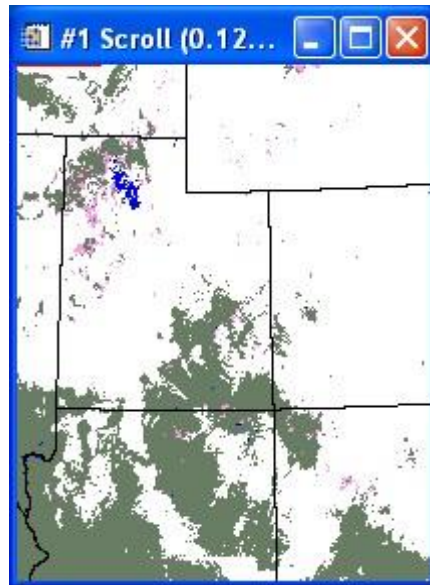


Figure 4.3. Display of an 8-day snow cover image with the color map (.dsr) file applied.

- If you are uncertain of a pixel value or want to explore the image in more detail, you can use the **Cursor Location/Value** option under the **Tools** menu of the large display window and navigate with your cursor to view the latitude/longitude and classification values of individual pixels.

4.1.3 Layer Stacking and Z-Profiles of 8-day Data

As a means of utilizing the high temporal frequency of the daily snow cover data it may be useful to stack an entire year of data into an annual stacked image. These can then be

assessed using the Z-profile tools on a per pixel basis to identify specific dates of snow on/off times, snow persistence, cloud persistence, etc.

The procedures for layer stacking and producing Z-profiles are outlined below.

- Start ENVI if necessary
- Select **File > Open Image File** and navigate to the file folder where the imagery is located. Select all .tif images that you want to stack using the shift key to select multiple images. The available bands list will include all the images selected (this could take a little while to populate if you're doing a complete year of 46 images).
- From the **Basic Tools** menu select **Layer Stacking** to launch the layer stacking parameters window. Select the **Import File** button and select the list of files that you loaded into the available bands list (Fig. 4.4), again using the shift key to select multiple images and click **ok**.

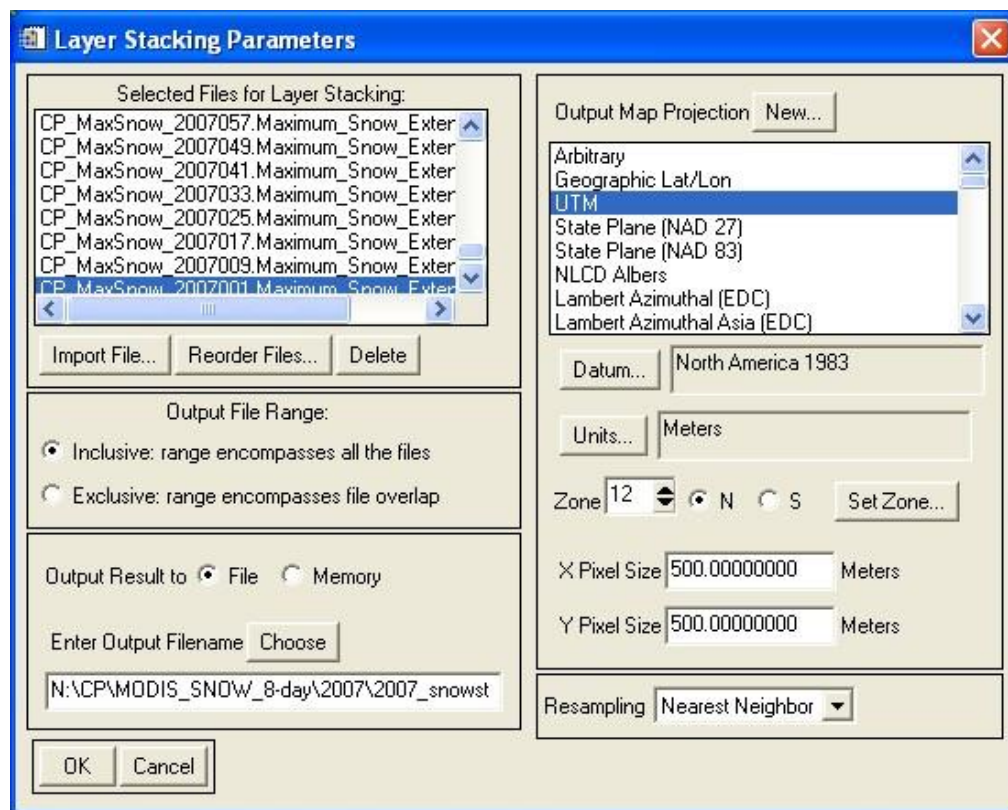


Figure 4.4. Layer stacking parameters box and list of input files for stacking.

- After the files have been loaded into the selected files listing, select the **Reorder Files** button to show the temporal (chronological) order in which the images will be stacked. The default will list the files in descending order with day 361 as the first file, day 353 as the second and so on. Reverse the order of the images to be chronological by **holding the cursor over the file names** and **clicking the center mouse button**. The files will now be in order. Click **ok**.
- **Enter an output filename > 2007_snowstack > click ok.**
- The layer stack image will display in the available bands listing when completed. Display one band of the image by **selecting a band** and clicking **load band**. Apply the colormap (.dsr) file to assign color to the image if desired.
- You are now displaying one band of a 46-band image. To view the Z-profile of the snow cover time series select **Tools > Profiles > Z-profile (spectrum)**.

The spectral profile displays for the single pixel where the cursor is located (Fig 4.5). As you move the mouse over the image, the profile changes for each pixel selected. It should be noted that the Z-profile for the classified snow cover image is quite different from a more continuous measure such as NDVI. The profile of the classified image varies greatly from day to day as a single pixel may be classified cloud then snow then cloud all in the span of a few days.

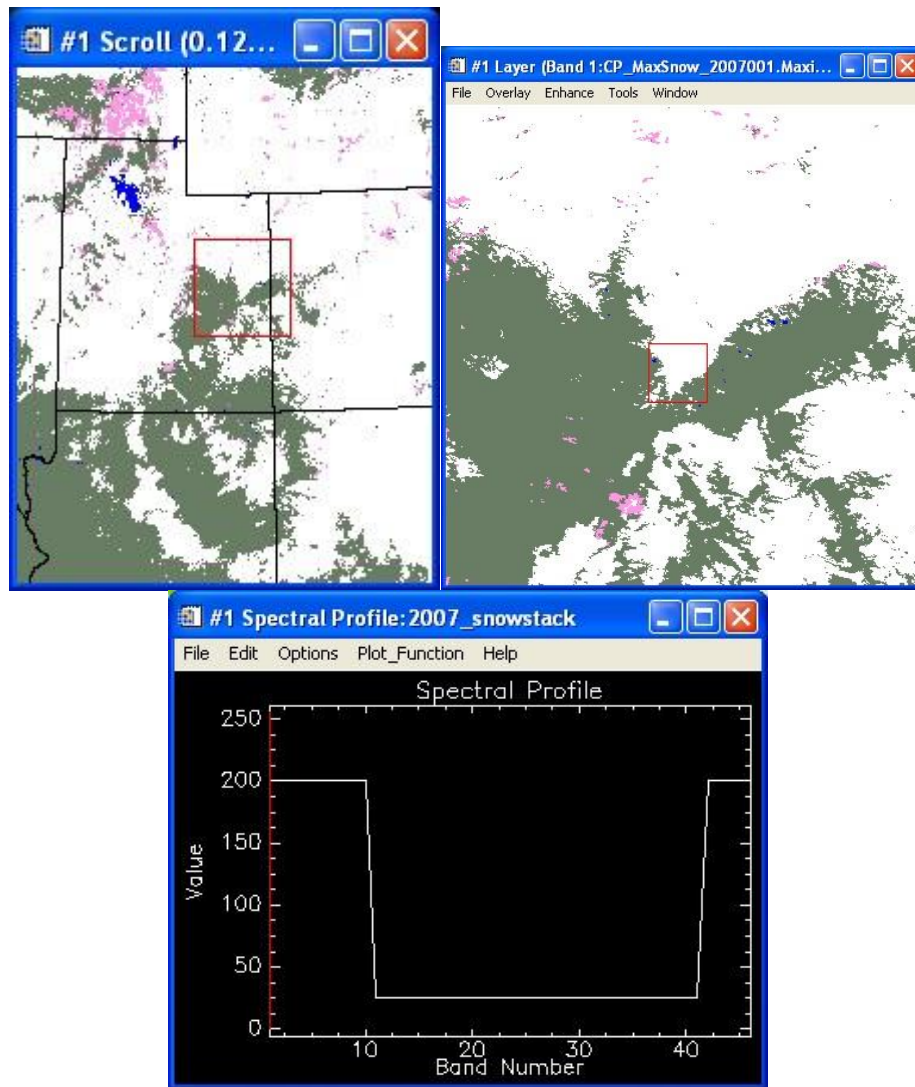


Figure 4.5. Spectral profile of a single pixel from one year of stacked snow cover data.

The example in Fig. 4.5 for 2007 shows that this pixel was largely snow covered (values of 200) until approximately 8-day period 10 (~ 21 March). The pixel was cloud or snow-free land (values of 25) through 8-day period 41 (~ 24 November).

Layer stacking and the Z-profile tools allow a quick per pixel assessment of the snow cover time series.

- The values that make up the profile can be easily saved to a text format for importation to a spreadsheet by selecting **File > Save Plot As > ASCII** from the profile window.

4.2 Additional analysis options

A package of Excel macros is provided in SOP 6 for deriving summary statistics and charts of snow extent data.

5. SOP 5: Creating aggregated analysis subsets

Vegetation Condition, Phenology and Snow Cover Extent
Colorado Plateau Networks

Standard Operating Procedure (SOP 5) ***Target-area analysis of NDVI***

Revision History Log:

Previous Version #	Revision Date	Author	Changes Made	Reason for Change	New Version #

5.1 Pixel level analysis versus aggregated subsets

This SOP addresses steps in processing MODIS data to obtain aggregate signals for target areas of interest. Two general methods of aggregation are presented. The first is a streamlined approach that takes a shapefile containing target polygons of a single vegetation type or area of interest and calculates aggregated annual NDVI curves for that area using software defaults to select individual MODIS cells. The second approach allows the user some additional controls including:

- Having multiple target areas as the input (such as a park vegetation map), which outputs to multiple aggregated annual NDVI curves based on a user defined grouping field.
- Allowing the user to set minimum threshold limits for the percent of the target area that must be present within a MODIS pixel for that pixel to be included in the aggregated calculations for the target.
- Letting the user specify a threshold for a minimum number of pixels for aggregation.

Both methods create as their output a text file containing one value per period for aggregated NDVI over the time period of interest. Refer to SOP #X for methods of processing and graphing these data.

5.2 Streamlined area-averaged processing

Follow SOP #2 for NDVI as far as 2.3.4. At this point the NDVI analysis diverges to spatially average pixel values by area before computing phenology metrics. We developed this line of analysis specifically to account for areas of low productivity where the vegetation signal was weak and combining the signal from multiple pixels increased sample size. The following steps evaluate NDVI time-series by year and day of year and

allow users to import results to TimeSat software for computing phenology metrics. Additionally the data summaries are importable to other statistical software for trend analysis of seasonal data such as the Seasonal Kendal non-parametric trend test.

5.2.1 Prepare Polygon for Clipping

You will typically get polygons in shapefile format from park staff that need to be converted to raster format before they can be used to extract NDVI values from MODIS imagery. If you do not have shapefiles provided by park staff you can download park boundary files from the Lands Program at: <http://nrddata.nps.gov/Programs/Lands/>

5.2.2 (Place this text into a call out box)Tip: Convert Polygons to Rasters for Clipping

Do this in ArcGIS by opening the shapefiles in a map view. Click the toolbox icon  > conversion tools > To Raster > Feature to Raster then enter the shape file name to convert, the name and location to save the rasterized version of the shape file and be sure to set the grid size for the output to 250m, the image resolution of the MODIS NDVI imagery.

Open the newly created raster and display with the shape file to ensure they represent roughly the same geographic area excepting some mismatch due to raster pixel scale and original shapefile boundaries. The number of 250m pixels (ie pixel count) can be determined by double clicking the newly created raster name in the layers list then symbology>unique values> then look under “count”.

Tip: How to Subset Polygons from Complex Layers

To create a smaller subset polygon of larger multi-polygon file using the selection method:

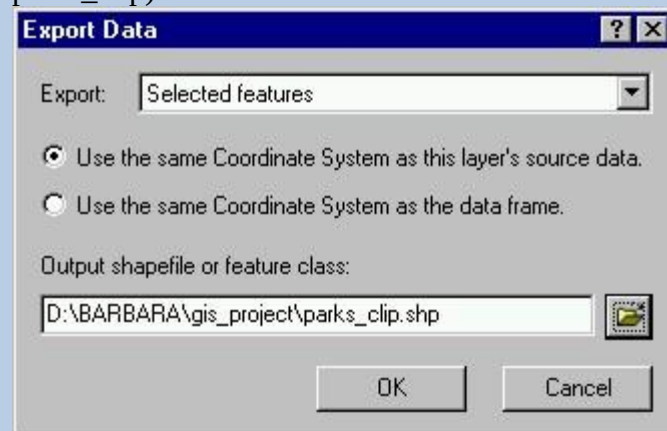
From http://soa.utexas.edu/crp/gis/arcgis_tips/subset.html

In the selection method, you first select features from a larger data set, then export those selected features to a data file.

- In ArcMap, add all the data sets for which you want to create subsets
- Check to make sure that all these data sets are selectable by choosing **Selection-Set Selectable Layers**. Checkmark all the datasets for which you want subsets. Press *Close*.
- Find the *Tools* toolbar - depending on how the last session ended, this may be in different places on the screen. If it is not visible, choose **View-Toolbars-Tools**



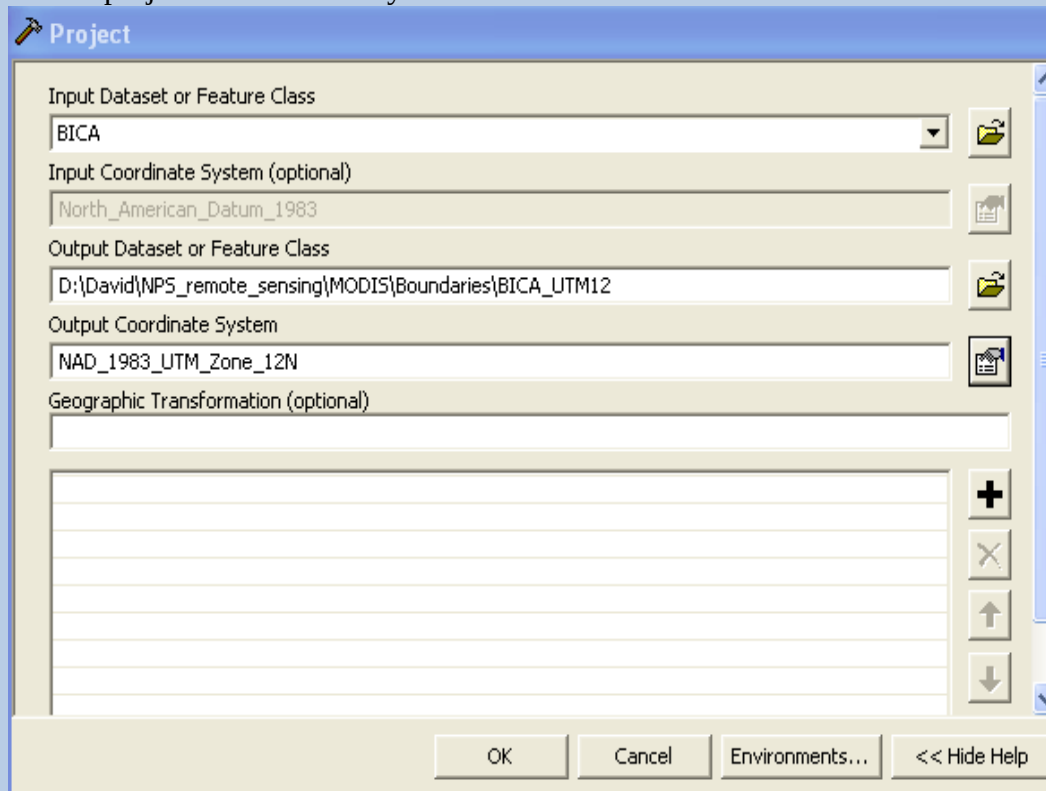
- Press the *Select Features* icon ()
- The easiest method for selecting is simply making a box to mark the project area (click and hold the mouse key in the upper left corner of the area, drag down to the lower right corner and release, just like making a zoom-in box). Alternatively, you can point and click at a feature. To add more features to the selection, press the Shift key and point to another feature. To delete a feature from a selected set, you can press the Shift key and click on that feature. Basically, keeping the Shift key pressed allows you to add or delete features to a selected set. There are a number of ways to select features in a map - to find out more, in ArcMap, choose *Help-ArcGIS Desktop Help*, click on the *Contents* tab, and go to *ArcMap-Querying Maps*, and look at the different entries about *selecting*.
- Once you have the features selected that you want in the new subset data file, you can start the exporting process. You must export data for each data layer. To do this, *right-click the data layer* containing selected features and choose **Data-Export**
- For *Export*, make sure that *Selected Features* is the specified option.
- Specify how you want a coordinate system defined for this new data file (probably same as the source-original data).
- Navigate to your personal project folder and give this data set a new name (e.g., parks_clip)



- This will create a new shape file with only the selected features.
- Repeat this process for every data layer for which you want a smaller subset.
- When finished, make sure that all your new data sets are working and viewable in ArcMap.

Reproject Subset Polygons

If you follow the instructions above for selecting and saving a NPS unit from the National NPS units shape file which is in geographic coordinates you must “reproject” your saved sub-unit. Do this by opening ArcToolbox > Data Management Tools > Projections and Transformations > Feature>project, then select your park unit and assign to it from the projected coordinate system > UTM/NAD83/Zone 12.



Now you should be able to convert your file to a raster image that can be used to clip NDVI imagery.

5.2.3 Clip Polygon Averaged NDVI Time-series

Open and modify the Arc Macro Language (AML) script **extract_ndvi_park.aml** in a text editor

Edit the

- workspace directory path
- input polygon file name
- smoothed imagery data path
- number of years for analysis
- output path and file name.

Open an Arc Info DOS window Start>All Programs> ArcGIS > ArcInfo Workstation>ARC

Set your workspace to D:\...\aml_scripts

Then at the arc prompt type **&run extract_ndvi_park.aml** to run the script

The output **ndvi_results_park.txt** from the above script is a long list of polygon averaged NDVI values, one for each period in each year.

5.3 Customized area-averaged processing

5.3.1 Example using ecological sites

The SCPN is matching its MODIS NDVI grouping methods with the methods the network is currently using for ground-based monitoring of upland vegetation and upland bird communities. For each of these, the primary ecosystem grouping is based on the system of "ecological site" designations that are maintained by the Natural Resources Conservation Service. An ecological site is defined as a distinctive kind of land with specific physical characteristics that differs from other kinds of land in its ability to produce a distinctive kind and amount of vegetation (USDA 1997). Individual ecological sites may comprise multiple mapunits from multiple surveys. Ecological sites have associated state and transition models, providing a conceptual framework for interpreting change. These have an advantage of not being limited by political or land management boundaries while still being mapped as part SSURGO, which is the finest scale soil mapping program in the United States.

When grouping, consideration is given to factors that could violate assumptions of similarity within the ecological site. These include substantial differences in dominant vegetation, geology, slope and aspect, disturbance history, and current and past land management differences (eg cattle grazing, forest thinning, exotic species removal). These factors can affect both single pixel calculations if there is high variability within a single pixel, as well as multi-pixel aggregations.

For both MODIS and ground-based monitoring, the mapped ecological site areas are adjusted to either remove or separately group areas that are expected to be substantially different (Table 5.1, 5.2). Somewhat looser restrictions are placed on the MODIS data because of the larger scale of MODIS pixels (250x250m) compared to ground-based plots (70x70m).

There are not sufficient resources to support ground-based upland vegetation and bird monitoring for all ecological sites in all park units. Instead, park resource managers and I&M network staff worked together to prioritize ecological sites for ground based monitoring. For each ecological site chosen for ground-based monitoring, the networks have established a spatially distributed set of long term monitoring plots within individual park units. At this time 2-4 years of monitoring data are available, and plot information will continue to be collected either on an annual or rotating basis. All data from these efforts are entered into long term databases, quality control checked, and annual report summaries are provided for major metrics including species-specific estimates of cover class at the time of sampling.

5.3.2 Map unit components and ecological sites

Ecological sites are not explicitly mapped in NRCS soil surveys. Instead, ecological sites are associated with specific map unit components; those in turn are associated with 'map units', which are the finest spatially defined features. Each map unit may be composed of multiple map unit components, and the soil survey includes an estimate of the proportion of each component (and therefore ecological site) within a map unit. Consequently, when summarizing data from MODIS pixels, it is necessary to select and group the mapunits by dominant ecological site. To reduce the potential for mixing vegetation NDVI signals, the CPNs typically only analyze those map units composed of $\geq 70\%$ of an individual ecological site.

Table 5.1 Example of exclusion conditions for ground-based and MODIS NDVI monitoring.

Removal condition	Typical ground-based removal conditions	MODIS analysis conditions
Ecological site is not dominant within mapunit	Mapunit is typically retained if a target ecological site comprises $\geq 80\%$ of the mapunit	Mapunit is typically retained if a target ecological site comprises $\geq 70\%$ of the mapunit
Ecological site boundary	50 m	Variable threshold, generally retaining only grid cells where $>90\%$ of the cell falls within the target mapunit
Roads or other infrastructure (developed areas, ruins, buildings, structures)	200 m for interstate highways, 100 m for all other features.	Because of relatively small size of road features, we are only removing interstate road areas
Slope: retained $\leq 20\%$ in unforested ecological sites and shrubland, and $\leq 30\%$ in forested ecological sites	50 m (40 m at WUPA)	Ecological sites with steep slopes generally excluded because of problems with variable reflectance, and variable vegetation related to aspect.
Aspect –	Not stratified in advance, however aspect may be considered during analysis	Initially not grouping by aspect. Will consider this option in the future.
Fires (forest and pinyon-juniper ecological sites only)	100 m removed moderate to high severity categories, in consultation with park staff	Removing moderate to high severity categories.
Fuels treatments	50 m variable by park and treatment plan	Generally not separated
Research Plots	50 m Consultation with park staff	Not applicable
Accessibility	retain areas within ~ 2 hrs one-way walking distance	Not applicable

Because of NRCS efforts to standardize and match both data content and data formatting across SSURGO soil surveys, it is possible to use ecological site information among multiple surveys covering a larger area, and to use the same scripts and queries to select the data (Figure 5.1).

Table 5.2 Example of ecological sites for a SSURGO soil survey and their related mapunits, with an estimate of the percent of each ecological site within each mapunit. Rows shaded in gray indicate mapunits that would be excluded because they contain a low percent of that ecological site.

QryPercentOfEcositeInEachMapunit				
Ecological Site Name	Ecological Site ID	Number of contributing components of this ecosite	Ecosite as a percent of mapunit	Mapunit
BOTTOMLAND 8 - 10 "	R042XA057NM	2	95	GH
BOTTOMLAND 8 - 10 "	R042XA057NM	3	92	Af
BOTTOMLAND 8 - 10 "	R042XA057NM	3	92	Br
BOTTOMLAND 8 - 10 "	R042XA057NM	2	91	Ag
BOTTOMLAND 8 - 10 "	R042XA057NM	2	91	Ao
BOTTOMLAND 8 - 10 "	R042XA057NM	2	91	Gb
CLAYEY	R036XB128NM	1	85	KbB
DEEP SAND 8 - 10 "	R042XA054NM	1	100	Bb
DEEP SAND 8 - 10 "	R042XA054NM	1	90	BcA
DEEP SAND 8 - 10 "	R042XA054NM	1	85	BCC
DEEP SAND 8 - 10 "	R042XA054NM	1	50	BKD
GRAVELLY SAND 8 - 10 "	R042XA053NM	1	85	KOE
GRAVELLY SAND 8 - 10 "	R042XA053NM	1	75	KR
GRAVELLY SAND 8 - 10 "	R042XA053NM	1	40	BKD

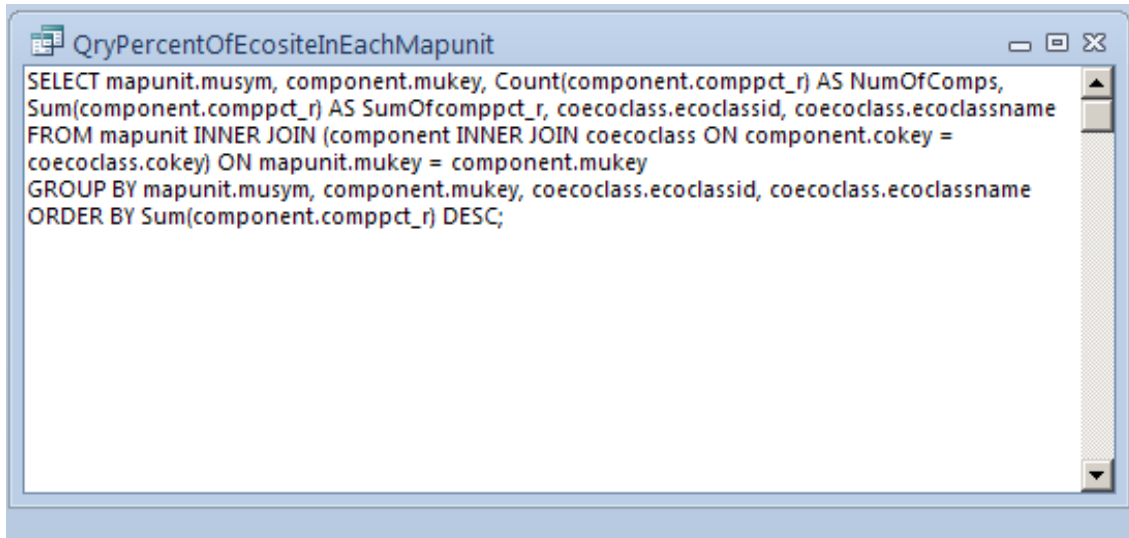


Figure 5.1 Example of the SQL query used to create Table 5.1 in the standard SSURGO database

5.3.2.1 Additional grouping conditions

In addition to soil-based ecological sites, it may be appropriate to group or exclude areas based on geography, disturbance history, and current or past land management practices (Table 5.3)

Table 5.3 Examples of cell grouping for MODIS NDVI aggregation.

Park	Primary group	Additional grouping 1	Additional grouping 2
PEFO	Ecological site: Sandy Loam	Area with different land management history: park area added in 2000	
GLCA	Ecological site: Desert sand	Geography: park extends for more than 200km, compare geographic precipitation correlations and group by major areas	Grazing history within and adjacent to GLCA
GRCA	Ecological site: Mixed Conifer	Adjacent area with different land management practices: Kaibab National Forest	Fire history, group burned areas separately

5.3.3 **Grouping pre-processing steps**

SCPN has created scripts to accommodate grouping similar to those described in section 5.2; however the input and processing options differ. Using the ecological sites as an example, the appropriate preprocessing steps are

- 1) Download most current SSURGO geospatial and tabular datasets for all areas of interest.
- 2) Add an empty user-defined grouping field to the Ssurgo shapefile(s) as a text field with a length of 4 characters that will be used to identify each group, this will be used to name individual masks. The 4-character limit is to accommodate file name limits.

- 3) Identify and screen target ecological sites within the SSURGO using the methods (SQL statements and slope limitations) described earlier. This should result in a one-to-many table of ecological sites and their associated map units. It is usually preferable to include an additional field of what percent of the ecological site is estimated to be within each mapunit for future reference and adjustment.
- 4) Identify additional groups (Table 5.x). Typically, this will be done using a grouping shapefile such as a fire perimeter, grazing allotment boundary, or parkunit boundary. Ensure that each grouping shapefile has a field that can be used to identify for later grouping, often this will just be a positive condition field such as "WithinPark" or "RecentFire" in which all values are filled with "yes" and all other areas are assumed to be no.
- 5) Use appropriate analysis tools to merge this information, typically this will be mean intersecting the ssurgo dataset with the other datasets.
- 6) Populate the user-defined grouping field,

The NPS MODIS analysis effort also compares within-park conditions to areas of the same ecological site outside the park, as well and includes subdivisions of areas where appropriate based on major differences in land management or disturbance history.

5.3.4 Processing options

Now that the input shapefile has been created, the processing script may be run. The script is written in a combination of Python and ArcInfo AML. There are multiple ways of accomplishing this task using scripts, we describe here the inputs and generic steps. Updated scripts are maintained by the CPNs.

Important user defined variables in the script are:

- Name of the input shapefile containing grouping polygons
- Name of the grouping field within that file
- Location of the MODIS data
- Minimum percent of a cell required to retain for processing (Default is 0.9 = 90%)
- Minimum number of cells within a group to retain for processing (default is 6)
- Start year
- End year

The processing script will break out MODIS pixels data by target grouping site code, aggregate the smoothed pixel data into a single response, and provide 16-day averaged NDVI data for each combination of target management unit and ecological site (Figure 5.2). The output format from this script is essentially identical to that provided by the "streamlined" version and may be manipulated, graphed, and analyzed using the same output scripts. A modified python addition to this script writes the information to table form and includes run properties as separate fields, including cell percent threshold, minimum number of cells, number of cells within the aggregation, start year and end year.

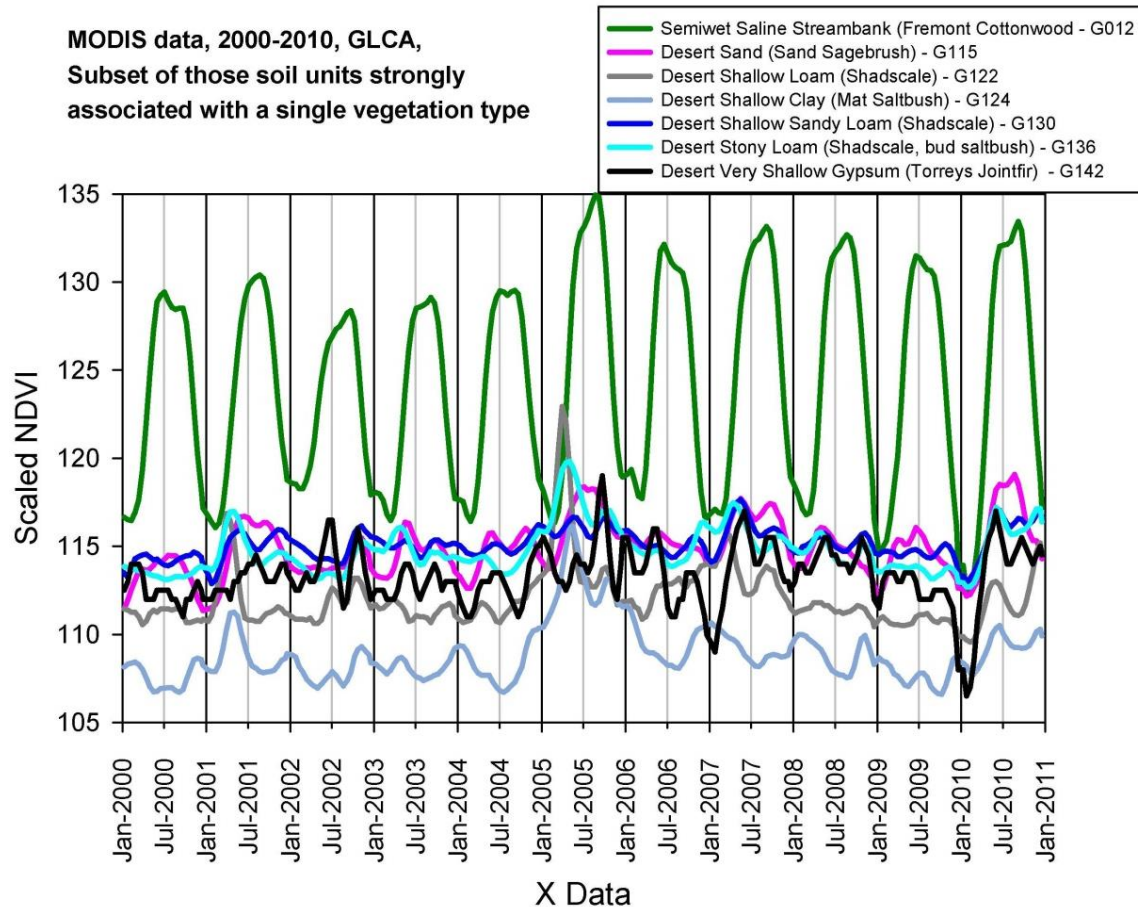


Figure 5.2 Example of curves created by NDVI analysis of targeted ecosites

5.4 Storage and documentation of processed data

Because of the many possible ways to subset and process the data, it will be important to document the methods used and any changes in these methods, as well as provide a stable data storage location for the processed data. One alternative for this is a data documentation and storage database described here that accomplishes these tasks. The example shown here is of a documentation and storage database developed for SCPN MODIS data.

5.4.1 Documentation

The documentation table (Figure 5.4) within the database stores the properties set for individual runs, including

- Description and location of the input shapefiles
- Grouping variable used
- Ecological Site threshold percent
- Masking percent threshold
- date of run,
- source of MODIS data used
- smoothing method used

- band interval
- spatial coverage (single park unit or list of units),
- ecological sites coverage (all ecosites or list of specific ecological site)

Additional lookup tables describe individual values for some fields, such as the smoothing method, which provides references or links to documentation (Figure 5.3).

Runid	Park	IndexType	SourceProcess	BandPerYr	Description
Cach20002010ReedNdvi01	CACH	NDVI	Reed	23	From new veg map, 3 basemap classes: barren wash, Rio Grande Cotton
Cach20002010ReedNdvi02	CACH	NDVI	Reed	23	From new veg map, 3 basemap classes: barren wash, Rio Grande Cotton
Glca20002010ReedNdvi01	GLCA	NDVI	Reed	23	selected all ecosites with > 79% estimated component content, dissolve
Glca20002010ReedNdvi02	GLCA	NDVI	Reed	23	breaking up the Desert Sand ecosite by the three possible sample areas
Pefo20002010ReedNdvi01	PEFO	NDVI	Reed	23	slop sandy loam, old park only

Figure 5.3 Screenshot of database for storing metadata about analysis methods

5.4.2 Data storage

The data storage table (Figure 5.4) provides access to the actual data values derived from the calculations, with a link to the RUNID so that the user has complete documentation of the methods used and can store data from multiple methods, either as an archive of older reported data, or to compare results from different methods

Runid	YearM	Band	Statistic	ValueM	Category	EcositeShort
Pefo20002011ReedNdvi01	2003	22	MAX	118 AP	SL	
Pefo20002011ReedNdvi01	2003	22	MIN	112 AP	SL	
Pefo20002011ReedNdvi01	2003	22	STD	0.8854204 AP	SL	
Pefo20002011ReedNdvi01	2003	22	AVG	114.04057 AP	SL	
Pefo20002011ReedNdvi01	2003	23	AVG	114.16781 AP	SL	
Pefo20002011ReedNdvi01	2003	23	MAX	118 AP	SL	
Pefo20002011ReedNdvi01	2003	23	MIN	111 AP	SL	
Pefo20002011ReedNdvi01	2003	23	STD	0.9217703 AP	SL	
Pefo20002011ReedNdvi01	2004	1	MAX	119 AP	SL	
Pefo20002011ReedNdvi01	2004	1	MIN	111 AP	SL	
Pefo20002011ReedNdvi01	2004	1	AVG	114.209313 AP	SL	
Pefo20002011ReedNdvi01	2004	1	STD	0.95035163 AP	SL	

Figure 5.4 Screenshot view of the data storage table

5.4.3 Data input and retrieval

Simple forms have been created to facilitate importing new data (Figure 5.5) and running queries to create output (Figure 5.6) that can then be used for analysis and reporting.

The screenshot shows a software window titled "ImportAndAssignData". Inside the window, there is a blue button labeled "Import data" and a text input field labeled "File name". Below these, there is a blue button labeled "update RunID" next to a text input field. The "update RunID" button and its adjacent input field are highlighted with a dashed orange border. At the bottom of the window, there is a status bar with the text "Record: 1 of 1", navigation icons, a "No Filter" button, and a "Search" input field.

Figure 5.5 Screenshot of form used to import new datasets into the database.

The screenshot shows a software window titled "FrmGetDataForPlotting". Inside the window, there are two dropdown menus. The first is labeled "Park" and has "PEFO" selected. The second is labeled "RunId" and has "Pefo20002010R" selected. At the bottom of the window, there is a status bar with the text "Record: 1 of 1", navigation icons, a "No Filter" button, and a "Search" input field.

Figure 5.6 Screenshot of form used to select data sets for further analysis, graphing and reporting

6. SOP 6: Analysis scripts for graphics and tables NDVI, snow cover extent and weather stations

Vegetation Condition, Phenology and Snow Cover Extent
Colorado Plateau Networks

Standard Operating Procedure (SOP 6)

Revision History Log:

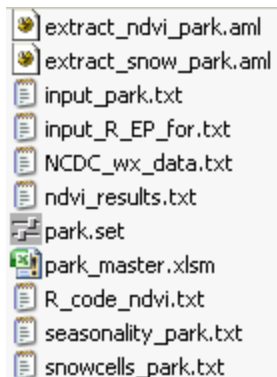
Previous Version #	Revision Date	Author	Changes Made	Reason for Change	New Version #

This SOP describes methods developed to automate calculation of phenology metrics and to create graphs and tables that can be used in a report with minimal additional formatting. The following sequence of analysis steps relies on ArcInfo aml scripts and customized Excel macros and requires that macros be enabled. The macros have been “soft coded” in order to handle new years in the analysis as the MODIS record grows. An R script is also provided that does some of the same analysis as the Excel macros plus more complex time-series and correlation analysis.

6.1 Required Software

- ArcInfo
- Excel 2007 or later with macros enabled
- Timesat
- R

The following example scripts and files were used to generate figures and tables discussed below. They are available in digital format.



6.2 NDVI Analysis

6.2.1 Clip Polygon NDVI

- Before running any of the Excel NDVI modules execute all steps in NDVI SOP 2 for preprocessing the NDVI image stack.
- Edit the file path names in the ArcInfo aml script `extract_ndvi_park.aml` .
- For each polygon you plan to clip for time-series analysis. Edit the
 - workspace directory path
 - input polygon file name
 - ndvi imagery data path
 - number of years for analysis
 - output file name
- Run the aml script `extract_ndvi_park.aml`.
 - Open an Arc Info DOS window Start>All Programs> ArcGIS > ArcInfo Workstation>ARC
 - Set your workspace to D:\...\aml_scripts
 - Then at the arc prompt type **&run extract_ndvi_park.aml** to run the script
 - The output **ndvi_results_park.txt** from the above script is a long list of polygon averaged NDVI values, one for each period in each year.

6.2.2 NDVI Excel module sequence

Open the polygon averaged output file **ndvi_results.txt** in a text editor
Select all, then copy and paste into file **park_master.xlsx** spreadsheet page called “**results**”. Immediately save and rename this spreadsheet to reflect the park being analyzed, for instance D:\...**BRCA_master** .xlsx. Renaming will preserve an original unmodified copy.

A description of each module and its output is provided below.

(Place in a call out box)Tip: Enabling and Running Macros in Excel 2007 or Later

From <http://office.microsoft.com/en-us/excel-help/enable-or-disable-macros-in-office-documents-HA010031071.aspx#BM12>

Change macro security settings:

You can change macro security settings in the Trust Center, unless a system administrator in your organization has changed the default settings to prevent you from changing the settings. On the Developer tab, in the Code group, click Macro Security.

TIP If the Developer tab is not displayed, click the Microsoft Office Button  , click Excel Options, and then in the Popular category, under Top options for working with Excel, click Show Developer

tab in the Ribbon *or* in Excel 2010, click the Microsoft Office Button  , click Excel Options, and then in the Customize Ribbon category, under Main Tabs choose the Developer checkbox. In the Macro Settings category, under Macro Settings, click the option that you want.

NOTE Any changes that you make in the Macro Settings category in Excel apply only to Excel and do not affect any other Microsoft Office program.

TIP You can also access the Trust Center in the Excel Options dialog box. Click the Microsoft Office

Button , and then click Excel Options. In the Trust Center category, click Trust Center Settings, and then click the Macro Settings category.

Run a macro

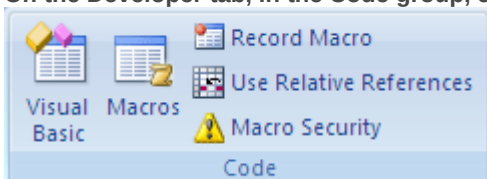
If the Developer tab is not available, do the following to display it:

Click the Microsoft Office Button , and then click Excel Options. In the Popular category, under Top options for working with Excel, select the Show Developer tab in

the Ribbon check box, and then click OK. or in Excel 2010, click the Microsoft Office Button , click Excel Options, and then in the Customize Ribbon category, under Main Tabs choose the Developer checkbox.

To set the security level temporarily to enable all macros, do the following:

On the Developer tab, in the Code group, click Macro Security.



In the Macro Settings category, under Macro Settings, click Enable all macros (not recommended, potentially dangerous code can run), and then click OK.

NOTE To help prevent potentially dangerous code from running, we recommend that you return to any one of the settings that disable all macros after you finish working with macros. For more information about how to change the settings, see [Change macro security settings in Excel](#).

Open the workbook that contains the macro.

On the Developer tab, in the Code group, click Macros.

In the Macro name box, click the macro that you want to run.

Do the following:

To run a macro from a Microsoft Visual Basic module, click Edit.

This opens the macro in a window that allows you to edit settings

Make any needed changes to the macro

then on the Run menu, click Run Sub/UserForm , or press F5.

#####

#####

Tip: Editing Axis Ranges in Modules

Depending on the geographic area you are analyzing you may need to adjust y-axis ranges in charts. This can be done directly on Excel charts by clicking and editing axis ranges, or changes can be made directly to the module code. To make changes to module code

Click the tab called Developer>Visual Basic>View>Project Explorer>scroll down to the module you want to edit and double click it. Click on the  icon and search for “axisymax” then edit the y-axis values and re-run the module.

#####

Run the Excel modules contained in spreadsheet Park_master.xlsm in the following order

- NDVI_data_handler
- NDVI_doy
- NDVI_year
- Create_TimeSat_input
- Run TimeSat (this is done outside of Excel using Timesat software)
- NDVI_Season_stats
- Process_TimeSat_output1 for unimodal precipitation pattern
- Process_TimeSat_output2 for bimodal or monsoon precipitation pattern
- Build_ndvi_stats_table
- Order_sheets (can be run at any time)

6.2.3 Description of NDVI Customized Excel Module Outputs

6.2.3.1 NDVI_data_handler

Formats ArcInfo output to run with analysis scripts

Converts this..

```
BD 24
OURPATH
D:\David\NPS_remote_sensing\MODIS\Imagery\ucbn_gryn\NDVI\smoothed
NDVIMEAN2009_19 154.5974499089
NDVIMEAN2008_19 163.2695810565
NDVIMEAN2009_18 155.6029143898
NDVIMEAN2007_19 162.8652094718
NDVIMEAN2008_18 160.8615664845
NDVIMEAN2009_17 158.0236794171
```

To...

Year	16d	NDVIMEAN	DOY	holder	Date
2000	1	161.730419	16	1/1/2000	1/16/2000
2000	2	161.375228	32	1/1/2000	2/1/2000
2000	3	159.930783	48	1/1/2000	2/17/2000
2000	4	159.752277	64	1/1/2000	3/4/2000
2000	5	160.209472	80	1/1/2000	3/20/2000
2000	6	160.808743	96	1/1/2000	4/5/2000

6.2.3.2 NDVI_doy

On sheet **graphs_doy** a chart is generated that compares the recent year NDVI time series (dark green) with the long-term average NDVI time-series (light green) for each period (Figure 6.1). The box plots represent the range in variability of NDVI in the historic record. The numbers above the box plots are the difference between the recent year NDVI and the long-term average NDVI for each period.

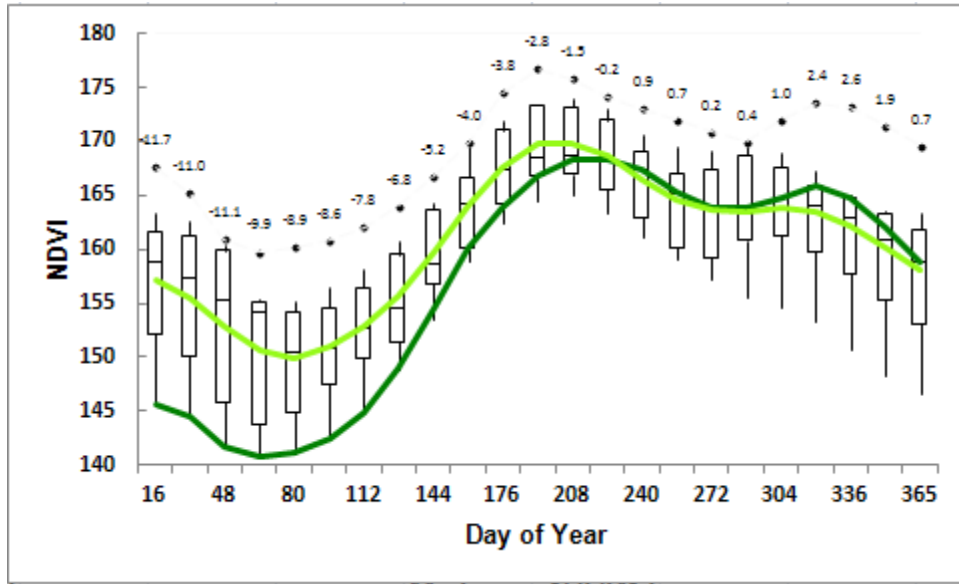


Figure 6.1. Long-term average NDVI versus recent year and differences.

At column EX on sheet **graphs_doy** a table is created for period summary statistics min, max, mean, median, percentiles and standard deviation for each period for the duration of the MODIS record. Those data can be reported or used to compute the annual percent relative difference between the recent year and the long term average in cell FZ4.

6.2.3.3 NDVI_year

On sheet **graphs_yr** the upper left graph is the NDVI time-series for the entire record. The upper right graph is the annual NDVI time-series stacked for direct year-to-year comparison. The bottom left graph shows annual box plots which represent the range and central tendencies in NDVI. The bottom right figure is a cumulative exceedance frequency curve for NDVI (Figure 6.2). It indicates the amount of time NDVI was above a given NDVI value. It provides a way of evaluating the relative magnitude and duration of the annual NDVI values. Curves shifted further up and right are generally greener longer than curves shifted down and left.

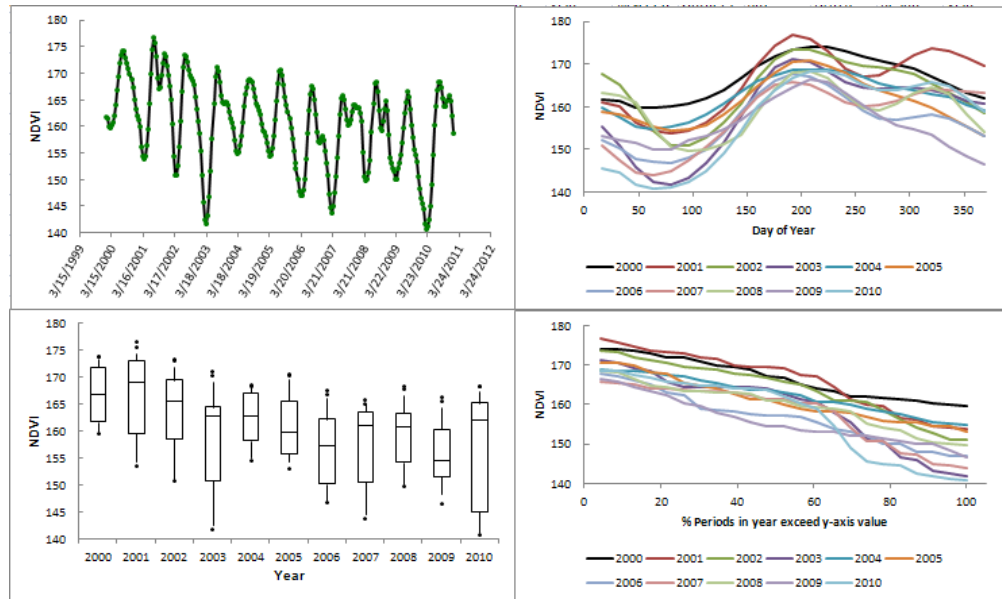


Figure 6.2. Time series charts of NDVI

At column CD on sheet **graphs_yr** a table is generated for annual summary statistics mean, median, percentiles and standard deviation for each year for the duration of the MODIS record. Those data can be reported or used in other ways to demonstrate differences on an annual basis.

6.2.3.4 Create TimeSat_input

This module formats NDVI data for import to Timesat which computes phenology metrics. Copy and paste results on “TimeSat_input” sheet into UltraEdit or text editor, then save as **input_park.txt**

The file should look like this...

```
11      23      1
161.7304189  161.3752277  159.9307832.....
```

6.2.3.5 TimeSat

Timesat is free software that allows users to compute phenology metrics by pixel or from polygon-averaged time-series. It is available on request with user manuals at:

<http://www.nateko.lu.se/TIMESAT/timesat.asp>

Start TimeSat software ver. 3.0 then in the TimeSat menu system window click “File” then “preferences” then select the directory where you stored the file **input_park.txt**.

This will also be the location where results from TimeSat analysis will be written as a file called **seasonality.txt**

In the TimeSat menu system window click “TSM_GUI”. Once the GUI opens click “File” then “open ASCII data file”. Browse to the file called **input_park.txt**, then click “load data”. Your time series is now loaded and ready for analysis.

The default analysis for NCPN has been to select the “points”, “Savitsky-Golay”, and “Season start/stop” check boxes. “Season start” and “Season stop” are set to 0.1. This defines the start and end of season as 10% of the annual amplitude (Figure X).

The “Seasonal par.” should initially be set to 0.5, unless the data are noisy as in very low productivity landscapes such as ARCH. If the above selections do not define all seasons change the “Seasonal par” to 0 which attempts to fit 2 seasons. Typically this will identify seasons for every year of the data record. If seasons cannot be defined for some years this is okay. It complicates temporal trend analysis later, but is nonetheless an indication of an extremely low productivity year. There is no known work around that allows users to “force” seasons in Timesat if the algorithm is unsuccessful at identifying seasons for every year.

There are separate processing modules in Excel for handling results for unimodal or bimodal seasonality.

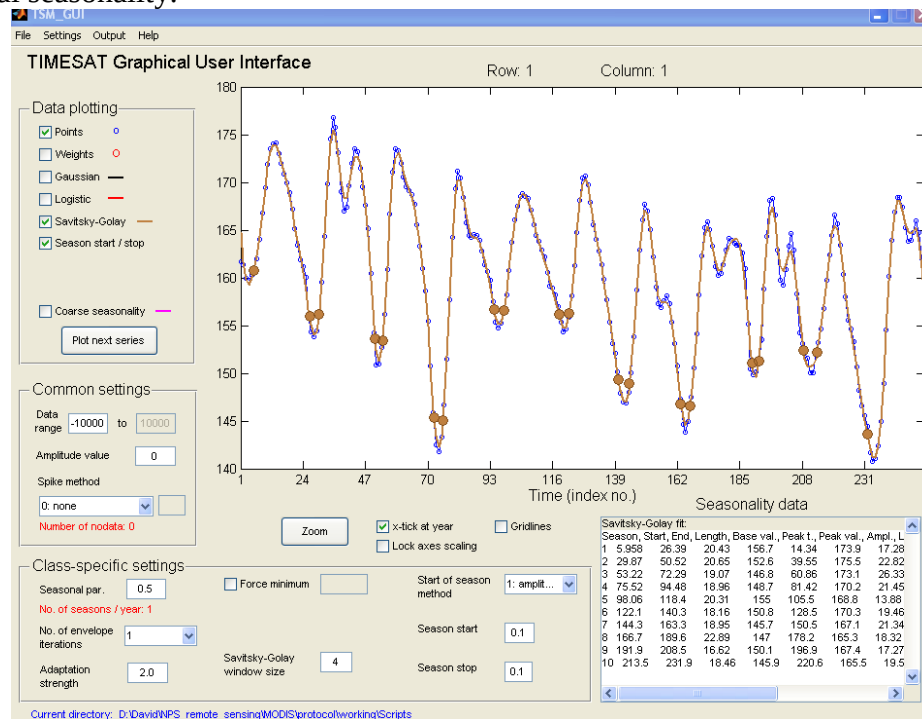


Figure 6.3. Screenshot of Timesat curve fitting window.

Save settings file

It is extremely important to save the settings file so that the exact analysis can be recreated if needed. Save this file by clicking in the GUI “Settings”, then “Save to settings file”. This opens a settings tool. In this tool change the job name to “park”, then click “File”, then “save settings file as” **park.set**. Close the settings tool window.

Create seasonality file

The seasonality file contains the phenology metrics. In the TSM_GUI save this file by clicking “Output”, then “Write Seasonality data to file”. This creates a new file in your working directory called “**seasonality.txt**”. **Seasonality.txt** is an autogenerated file name that will be overwritten, so rename this file immediately to “**seasonality_park.txt**”.

6.2.3.6 NDVI Season Stats

Run the NDVI_Season_Stats module to generate the following annual summary table of statistics at cell A37 on page “ndvi_stats”

Table 6.1. Annual NDVI summary statistics

Year	Scaled NDVI					
	Mean	Median	Max	Min	Range	Sum
2000	166.60	166.79	174.12	159.75	14.37	3831.81
2001	166.22	169.07	176.77	153.79	22.97	3823.14
2002	163.90	165.60	173.51	150.89	22.62	3769.72
2003	158.77	162.83	171.16	141.77	29.39	3651.60
2004	162.39	162.91	168.79	154.79	14.00	3734.99
2005	161.09	159.81	170.71	153.07	17.64	3704.99
2006	156.54	157.28	167.70	146.92	20.78	3600.45
2007	157.60	161.17	165.90	143.83	22.07	3624.81
2008	159.56	160.86	168.35	149.82	18.54	3669.80
2009	155.80	154.60	166.59	146.62	19.97	3583.36
2010	156.90	161.95	168.38	140.76	27.63	3608.80

6.2.3.7 Process TimeSat Output

Open the file **seasonality_park.txt** in UltraEdit, or a text editor, select all, copy and paste into cell A1 on spreadsheet page “paste_TimeSat_output_here”. Then run the module called “Process_TimeSat_export1” if you are working with unimodal phenology, or “Process_TimeSat_export2” if you are working with bimodal phenology. Results are output to cell R49 on spreadsheet page “ndvi_stats”. These modules create summary tables and charts describing phenology metrics and simple statistical analysis using linear regression. Statistically significant trends are denoted in bold when p-value is < 0.10.

Table 6.2. Annual phenology metrics derived from Timesat with linear trend over time and significance.

Year	Start (DOY)	End (DOY)	Length (Days)	Peak (DOY)	Integral (NDVI)	Ampl (NDVI)
2000	95	422	327	229	3821	17.28
2001	110	440	330	265	3837	22.82
2002	116	421	305	238	3415	26.33
2003	104	408	303	199	3387	21.45
2004	97	422	325	216	3581	13.88

2005	114	405	291	216	3216	19.46
2006	101	405	303	200	3299	21.34
2007	91	458	366	275	3980	18.32
2008	126	392	266	206	3032	17.27
2009	104	398	295	218	3115	19.59
correlation	0.13	-0.55	0.95	0.77	0.78	-0.07
slope	0.47	-1.04	1.29	0.74	9.69	0.00
p-val slope	0.71	0.31	0.38	0.53	0.10	0.43
intercept	-840.42	526.78	-226.76	-2.78	1276.44	22.25
p-val						
intercept	0.74	0.27	0.36	0.50	0.09	0.42

The seasonality metrics in the above table are plotted in the following graph to provide some indication of temporal pattern. Sometimes statistically significant trends will be noted that may result from steps in the data that could be caused by abrupt disturbance like fire. The chart helps identify such patterns in the temporal data to aid interpretations.

6.2.3.8 Build ndvi stats table

On page “stat_tables” a rather large and unwieldy table is generated beginning at cell A1 that summarizes NDVI on a period basis, whereas other tables summarize NDVI on annual basis. This table may have applications for questions centered in differences by period, although all of this data is summarized graphically in earlier modules.

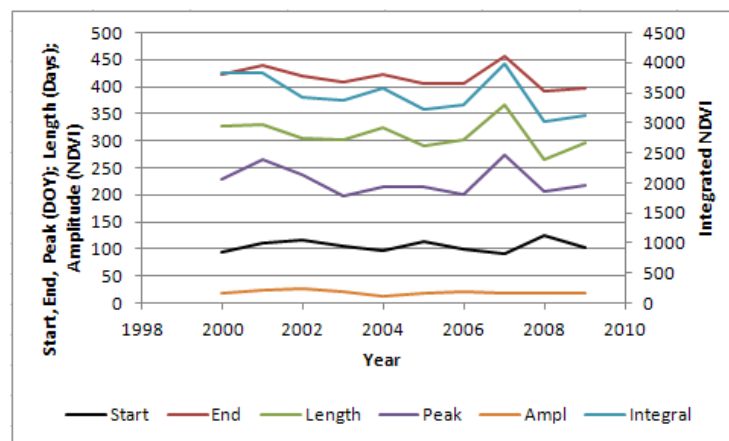


Figure 6.4. Time series of annual phenology metrics

6.2.3.9 Order sheets

This module organizes the many spreadsheets that result from running the modules. Experience indicates a user will grow accustomed to looking for analysis outputs in a sequence or particular order. Order_sheets tidies up the work environment to make report writing and interpretations easier.

6.3 Snow Cover Extent Analysis

6.3.1 Clip Polygon Snow Cover

- Before running any of the Excel snow modules execute all steps in snow cover SOP 3 for preprocessing the snow extent image stack.
- Open and modify the Arc Macro Language (AML) script **extract_snow_park.aml** in a text editor. For each polygon you plan to clip for time-series analysis. Edit the
 - workspace directory path
 - input polygon file name
 - snow imagery data path
 - number of years for analysis
 - output file name.
- Run the aml script **extract_snow_park.aml**.
 - Open an Arc Info DOS window Start>All Programs> ArcGIS > ArcInfo Workstation>ARC
 - Set your workspace to D:\...\aml_scripts
 - Then at the arc prompt type **&run extract_snow_park.aml** to run the script
 - The output **snowcells_park.txt** from the above script is a long list of polygon averaged snow cover values, one for each period in each year.
 - Copy and paste results into spreadsheet page “snowcells” in spreadsheet **park_master.xlsm**.

6.3.2 Snow Excel module sequence

Run the modules contained in spreadsheet Park_master.xlsm in this order

- Snow_data_handler2
- Snow_doy
- Snow_year
- Snow_pctile
- Snow_melt_freeze
- Order_sheets (can be run at any time)

6.3.3 Snow Module Outputs

6.3.3.1 Snow_data_handler2

This module formats the ArcInfo output for further analysis. Formatted results get written to pages snow_results and snowcells_fmt.

The module snow_data_handler2 converts this..

SNOWDATE	2000	1
	200	26
SNOWDATE	2000	2
	-9999	5
	200	21

SNOWDATE	2000	3
	200	26
SNOWDATE	2000	4

To...

year	period	pct snow	doy	holder	date
2000	1		8	1/1/2000	1/8/2000
2000	2		16	1/1/2000	1/16/2000
2000	3		24	1/1/2000	1/24/2000
2000	4		32	1/1/2000	2/1/2000
2000	5		40	1/1/2000	2/9/2000
2000	6		48	1/1/2000	2/17/2000
2000	7		56	1/1/2000	2/25/2000
2000	8	100	64	1/1/2000	3/4/2000
2000	9	80.76923	72	1/1/2000	3/12/2000
2000	10	100	80	1/1/2000	3/20/2000
2000	11	100	88	1/1/2000	3/28/2000
2000	12	100	96	1/1/2000	4/5/2000
2000	13	100	104	1/1/2000	4/13/2000

If analysts need to model snowcover to minimize cloud interference it is best to do so on page snowcells_fmt. A linear interpolation equation that checks for inflections in the time-series and then interpolates across inflections can be implemented with the following equation.

$$=IF(AND(C16>C17,C18>C17),(C16+C18)/2,C17)$$

This particular cell reference works if the equation is in cell M17 on page snowcells_fmt.

Note: Results from this equation are not hard coded into the charts made in subsequent steps. If the interpolated snow cover is the desired cover for analysis and reporting then analysts need to make sure charts refer to the data in the column containing the interpolated results.

6.3.3.2 Snow_doy

This module computes summary stats for snow cover by period for the MODIS record then on page snow_graphs_doy, charts boxplots for each period with the most recent year's data superimposed as a line (Figure 6.5). A graph of cumulative exceedance frequency by period is also generated, but line colors are difficult to differentiate for 43 periods. To be useful this chart would likely require manual removal of some of the data series in order to highlight years of interest. Snow cover summary statistics by period begin at column KF on page snow_graphs_doy.

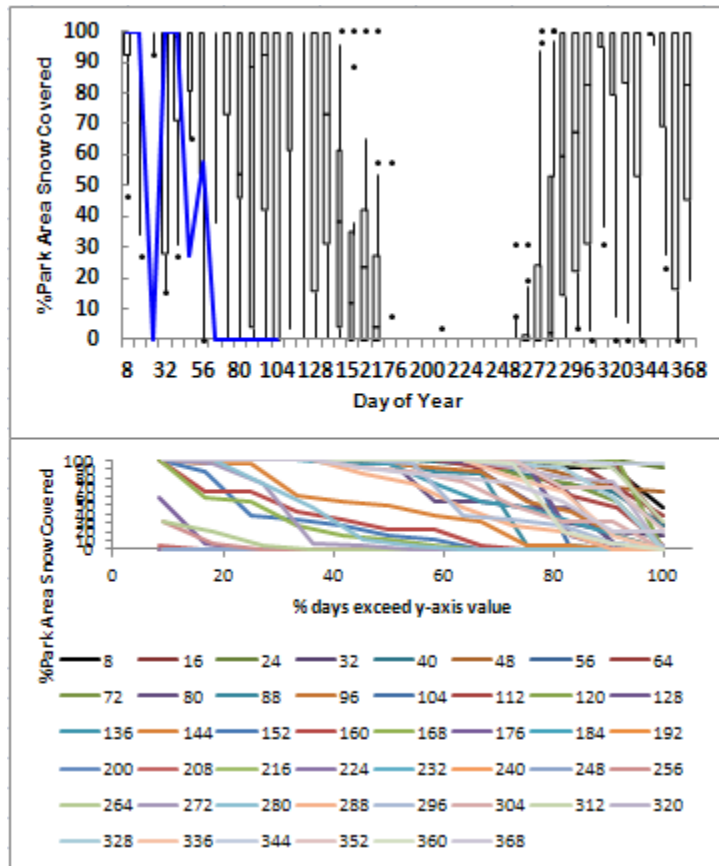


Figure 6.5. Snow covered area box plots by day of year charted with most recent year snow cover by day of year. The above plots can be edited as needed for clarity.

6.3.3.3 Snow_year

This module computes summary statistics for snow cover by year for the MODIS record. The statistics are computed for calendar year presently. For example that means snow cover for 2007 is snow cover from January 2007 through December 2007. It is recognized that snow cover reporting by water year is preferable for hydrology applications and improvements will be made to the macros to incorporate this capability in the future. The top figure is a boxplot of snowcover variation. The middle figure is the time-series of snow cover. The bottom figure is the cumulative exceedance frequency that indicates both the extent and duration of snow cover by year (Figure 6.6).

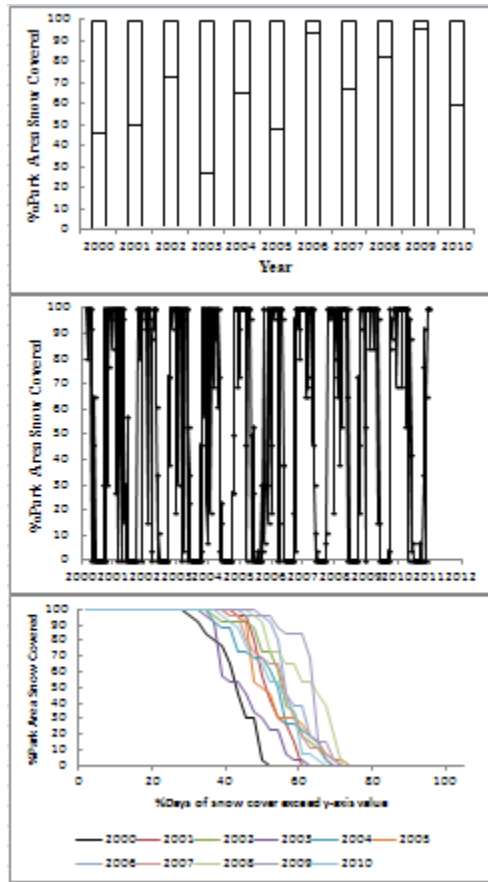


Figure 6.6. Variation, time-series and duration of snow cover. These plots can be edited in Excel as needed for clarity.

A table of summary statistics is generated at column CD on sheet **snow_graphs_yr** that includes min, max, mean, median, percentiles and standard deviation for each year for the duration of the MODIS record. Those data can be reported or used in other ways to demonstrate differences on an annual basis.

6.3.3.4 Snow doy_pctile

This module generates a chart on page snow_doy_pctile that illustrates the long-term average percent snow cover by period for the MODIS record with snow cover for the most recent year for comparison. Prominent dips in the blue line are likely due to persistent cloud cover that lasted longer than the 8 day composite period. Those dips can be mitigated with the linear interpolation equation,

$$=IF(AND(C16>C17,C18>C17),(C16+C18)/2,C17),$$

where column C contains the percentage of snow covered area at each time step.

Analysts can experiment with the width of the smoothing window in this equation to determine the appropriate degree of smoothing that minimizes cloud cover issues. An alternative not provided for in these scripts is to use the quality layer, or cloud pixel

symbology in the snow product layer to identify the percentage cloud cover that could then be used in smoothing decisions.

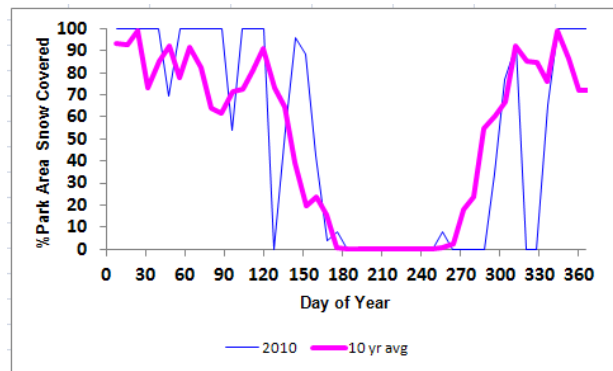


Figure 6.7. Duration and area of snow cover for long-term average and recent year

6.3.3.5 Snow melt freeze

This module computes the snow cover phenology metrics and does linear regression trend assessment on those metrics. The summary table is generated at cell I2.

Statistically significant ($p\text{-value} < 0.10$) are indicated in bold. A chart of the phenology metrics is generated as well as a stacked annual time-series of snow cover curves.

Table 6.3. Snow phenology metrics, trends and significance of linear fit parameters computed

Year	Snow off	Snow on	DOY <6.4% cover	DOY >6.4% cover	Days snow free	Days snow covered
2000	6/16/2000	9/12/2000	168	256	88	277
2001	6/25/2001	10/7/2001	176	280	104	261
2002	6/26/2002	9/30/2002	176	272	96	269
2003	6/19/2003	10/9/2003	168	280	112	253
2004	6/27/2004	10/9/2004	176	280	104	261
2005	6/28/2005	9/8/2005	176	248	72	293
2006	6/13/2006	9/17/2006	160	256	96	269
2007	6/14/2007	9/26/2007	160	264	104	261
2008	6/30/2008	9/26/2008	176	264	88	277
2009	6/15/2009	10/5/2009	160	272	112	253
2010	7/10/2010	9/12/2010	184	248	64	301
correlation			-0.06	-0.37	-0.26	0.26
slope			-0.15	-1.38	-1.24	1.24
intercept			463	3036	2573	-2208
p-val slope			0.86	0.26	0.43	0.43
p-val intercept			0.79	0.22	0.42	0.48

with Excel module.

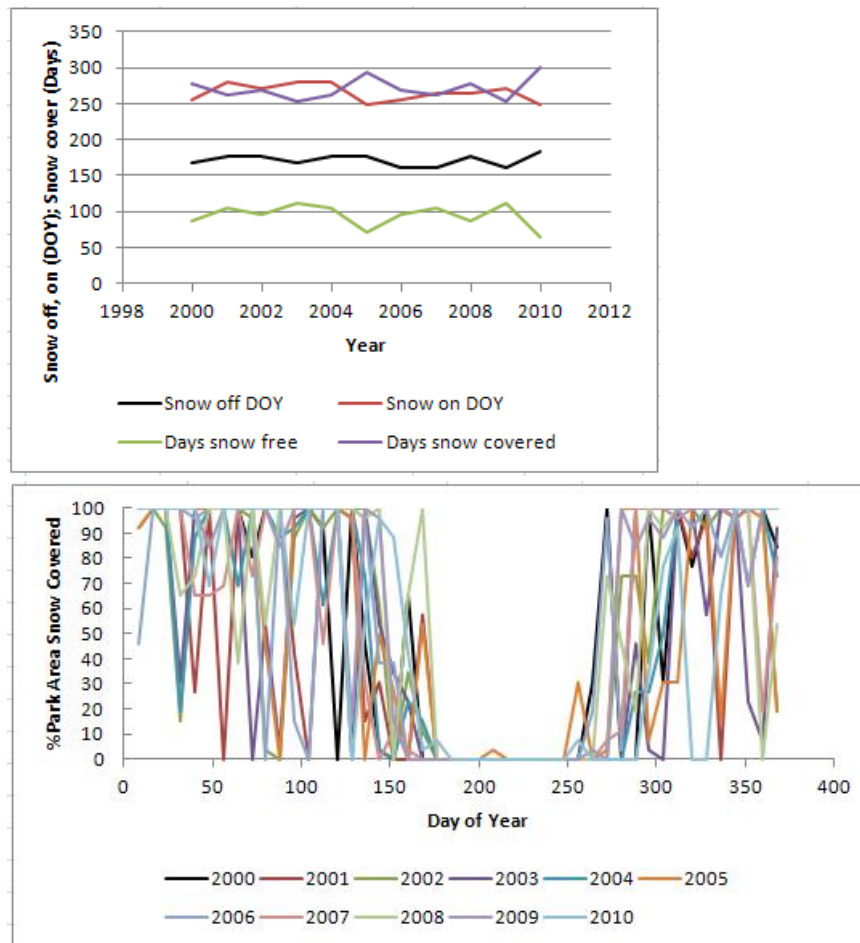


Figure 6.8. Snow phenology charts generated with Excel macro.

6.4 Station Precipitation and Temperature Summary

- Obtain raw weather station data

6.4.1 *Obtain raw weather station data*

Navigate to the National Climatic Data Center website <http://www.ncdc.noaa.gov/oa/climate/stationlocator.html> and follow instructions for locating a station of interest.

- click "DATA" then scroll down to "Digital ASCII Files"
- select "SOD - Daily Surface Data.."
- click "continue with SIMPLIFIED Options"
- select date range of interest then click "Continue", provide an e-mail address then submit
- after receiving an automated e-mail reply
- click on the link to the ASCII data file

- "... - SOD - Surface Data, Daily - US - ASCII Form (xxxx bytes)"
- after it opens in a web page click "select all" then "copy"
- paste the file into the workbook page tab called "paste_raw_wx_data_here"

This code assumes weather data are not delimited automatically when they are pasted into Excel.

6.4.2 Weather station module sequence

This code formats ascii daily weather data from the NCDC web site

Instructions for obtaining raw station data

- navigate to: <http://www.ncdc.noaa.gov/oa/climate/stationlocator.html>
- follow instructions for locating a station of interest
- click "DATA" then scroll down to "Digital ASCII Files"
- select "SOD - Daily Surface Data.."
- click "continue with SIMPLIFIED Options"
- select date range of interest then click "Continue", provide an e-mail address then submit
- click on the link to the ASCII data file
- "... - SOD - Surface Data, Daily - US - ASCII Form (xxxx bytes)"
- after it opens in a web page click "select all" then "copy" paste the file into the workbook page tab called "paste_raw_wx_data_here"
- Once pasted into excel if data are in one column, then use text to columns in the data tab to get data into cols
- include raw data header row and only rows of data that include complete records for an entire year.
- some code was included here to screen out years that don't start on January 1, but don't rely on that alone for screening
- as some years have missing months and there are likely other inconsistencies in the raw data that will invalidate the
- The code does the following computations after screening for missing data which are "included" by adding blank rows.
 - compute the sum of precipitation

- compute the sum of snow fall
- compute the average snow depth
- compute average max temp
- compute the average min temp
- compute growing degree days (GDD) base X
- Specifics of GDD calculations
 - Compute growing degree days (GDD) base 40 as
 - Base = 40 'deg F which = 4.44 degC
 - $GDD = ((T_{max} + T_{min})/2) \text{ minus base}$
 - where T_{max} is daily max temp
 - T_{min} is daily min temp
 - $T_{base} = 40$ = temperature below which growth essentially ceases
 - Then $T_{max} - T_{min} / 2$ is the daily average temperature
 - so if daily average is less than T_{base} no growth occurs
 - if result < 0 then set = 0

Run the modules contained in spreadsheet Park_master.xlsm in the following order

- Precip_summary_16d_NCDC_ascii
- Precip_year_NCDC_ascii
- Precip_doy_NCDC_ascii

6.4.2.1 Precip_summary_16d_NCDC_ascii

This module scans weather station data for missing values and enters place holder rows where daily values are missing. It then computes 16 day cumulative precipitation and 16 day cumulative growing degree days that can be used to interpret 16 day NDVI. The 16 day cumulative precipitation and GDD values are charted with 16 day NDVI on spreadsheet page "wx_graphs" (Figure 6.9).

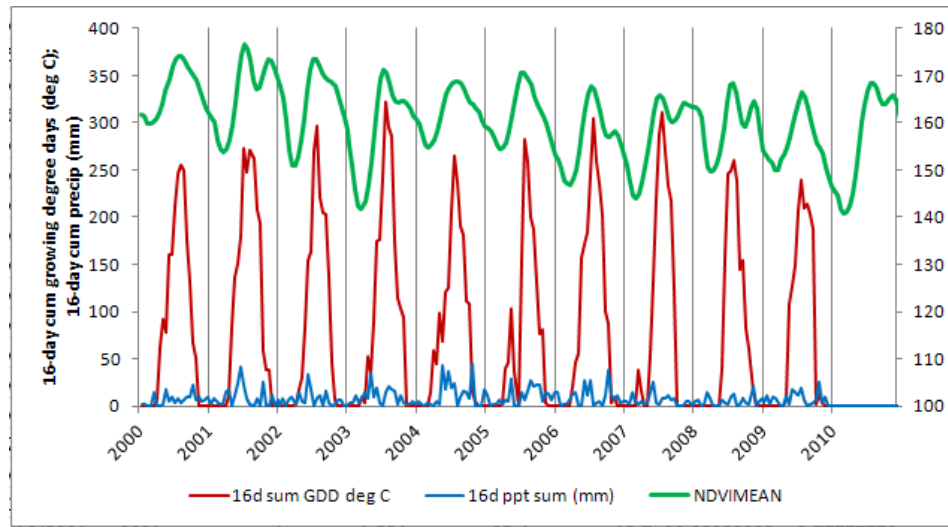


Figure 6.9. Growing degree days, cumulative precipitation, and NDVI time-series

The program sifts through the data to find missing days of data, a common occurrence with COOP station data. Where it finds missing days it adds a place holder row that contains only the date. It accounts for the expected number of days in each month, leap years and leap days.

Years that don't start on January 1 are eliminated from the analysis so that only full years are included in statistical summaries. Sixteen day periods missing more than two records are flagged in columns L, M, N on spreadsheet page "wx_graphs". It is not possible to know a priori all the potential errors that may be found in station data, so there may be other inconsistencies in the raw data that will invalidate the results of this program code so be careful with interpretations.

The code as written deletes all records prior to year 2000 in the output table to correspond with the period of record for MODIS imagery. The original raw NCDC data file pasted into page "paste_wx_data_here" is not altered.

6.4.2.2 Precip_year NCDC ascii

On sheet **wx_graphs_yr** the upper graph is the 16 day cumulative precipitation curve for each year stacked for direct comparison. The middle graph is the annual cumulative precipitation for each year as a blue line plotted over annual box plots of precipitation which represent the range and central tendencies in precipitation abundance. The bottom figure is a cumulative exceedance frequency curve for precipitation (Figure 6.10). It indicates the amount of time precipitation for a 16 day period was above a given 16 day period value. It provides a way of evaluating the relative magnitude and duration of the annual precipitation. Curves shifted further up and right are generally wetter for longer than curves

shifted down and left. Summary statistics table for mean, stdev, median and percentiles begins at cell CD1.

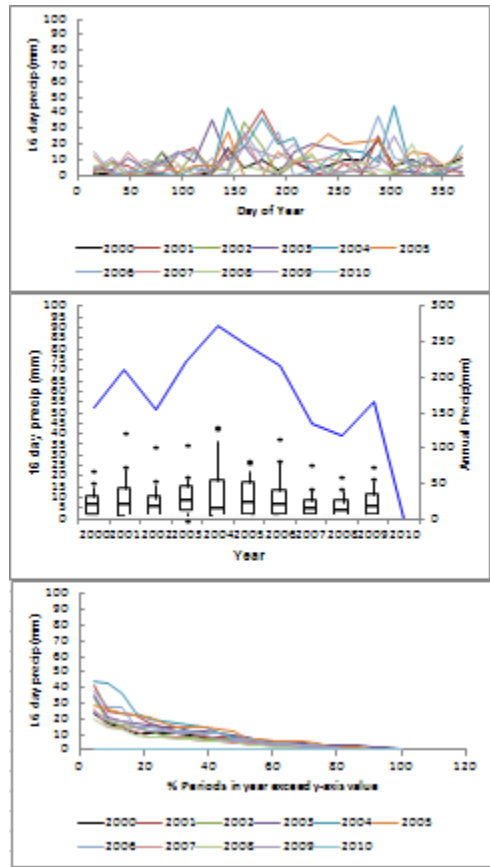


Figure 6.10. Time-series of 16 day cumulative precipitation to match NDVI periods

6.4.2.3 Precip_doy_NCDC_ascii

On sheet **wx_graphs_doy** a chart is generated that compares the recent year 16 day cumulative precipitation values (dark blue) with the long-term average 16 day precipitation values (light blue) for each period. The box plots represent the range in variability of 16 day precipitation in the historic record. The numbers above the box plots are the difference between the recent year 16 day precipitation sum and the long-term average 16 day precipitation sum for each period. This figure is directly comparable to the NDVI figure created in the module graphs_doy.

The bottom figure is a cumulative exceedance frequency curve for precipitation. It indicates the amount of time precipitation for a 16 day period was above a given 16 day period value. It provides a way of evaluating the relative magnitude and duration of the annual precipitation. Curves shifted further up and right are generally wetter longer than curves shifted down and left. Summary statistics table for mean, stdev, median and percentiles begins at cell CD1.

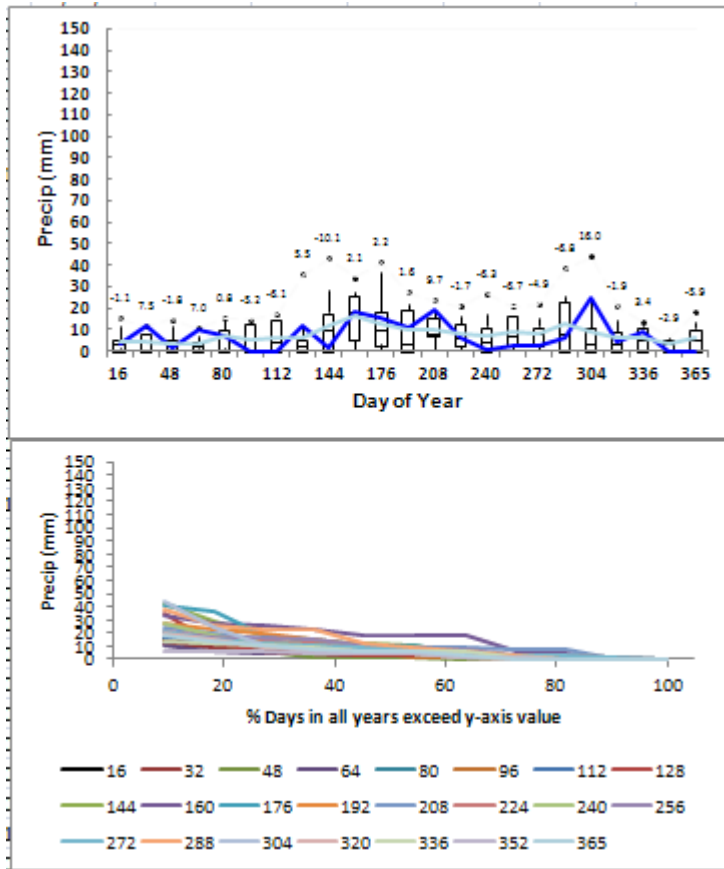


Figure 6.11. Long-term 16 day cumulative precipitation versus recent year and cumulative exceedance frequency curves by period.

6.5 Export to R Statistical Software

A macro was written to format 16 day NDVI, precipitation and temperature so that it could be read by the statistical software R.

- R input period –Excel macro
- R code – text file for statistical analysis in the R environment

6.5.1 R input period

Run the macro “R input period” in Excel to produce a table that is readable by R (Table 6.4).

Table 6.4. Output from Excel macro used to format NDVI and weather data for import to R.

year	period	ndvi	day	date	julian	pptmm1(gddc16d	site	month
2000	1	161.730419	16	1/16/2000	00016	1.27	0 ep_for	1
2000	2	161.375228	32	2/1/2000	00032	1.27	0 ep_for	2
2000	3	159.930783	48	2/17/2000	00048	0	0 ep_for	2
2000	4	159.752277	64	3/4/2000	00064	0	0 ep_for	3
2000	5	160.209472	80	3/20/2000	00080	15.24	0 ep_for	3
2000	6	160.808743	96	4/5/2000	00096	0 7.222222	ep_for	4

The R code that accompanies this protocol uses site name as the analysis unit. This allows multiple sites to be analyzed together when tables like the above are stitched together for multiple sites (do so by appending in Excel or text editor). This enables comparative analysis by site. Thus the macro “R_input_period” asks what name will be used to associate these data with a geographic location. Once the analyst provides a site name in the pop-up window the table is generated. This file should be saved as a tab delimited *.txt file.

File > save as> Save as type dropdown > Text (Tabdelimited)(*.txt)

6.5.2 R code

- Note: the R code development is being updated and expanded in an on-going basis. Contact protocol authors for latest versions.
- Open the file “R_code_park.txt” in a text editor
- Change the working directory to point to the path containing the input data created in the previous step.
- Change the read.table line to include the name of the input data file created earlier
- Save the “R_code_park.txt” file with a new name that is descriptive of the project
- Start R
- Copy and paste chunks of the R code from the text editor window into the R console window
- Outputs

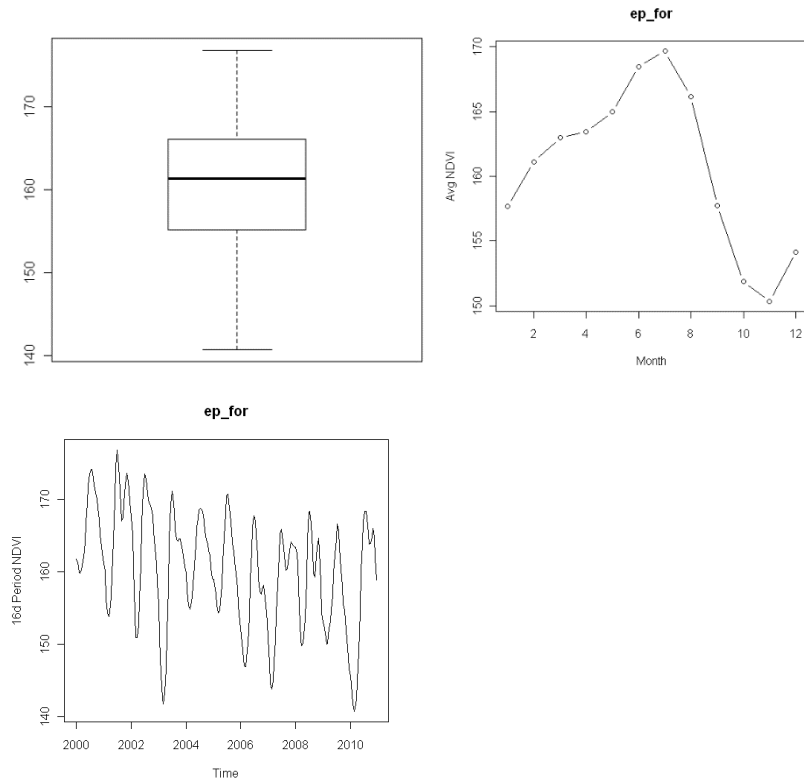


Figure 6.12. Period of record box plot, monthly average time-series and long term time-series plots for NDVI

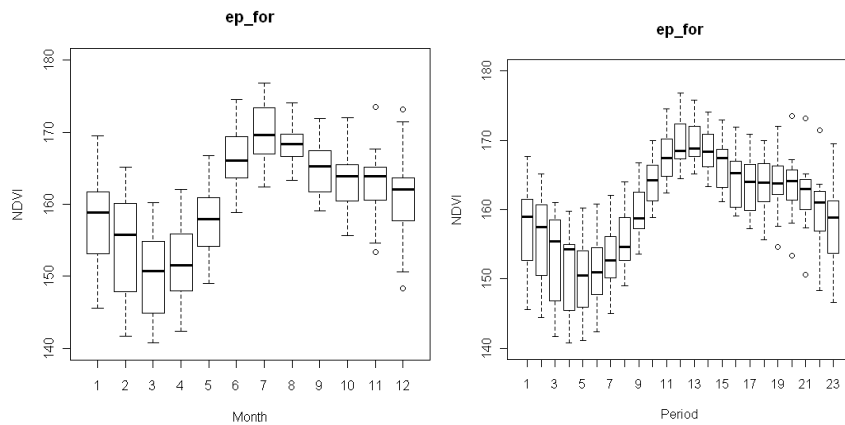


Figure 6.13. Monthly mean time-series, monthly box plots, period box plots for the entire period of record

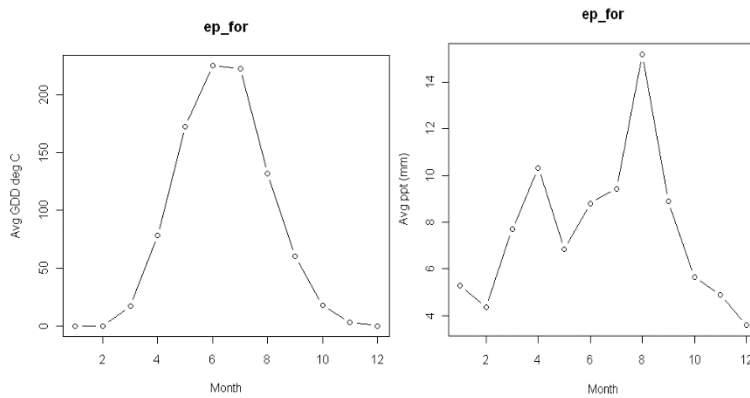


Figure 6.14. Average growing degree days and precipitation by month.

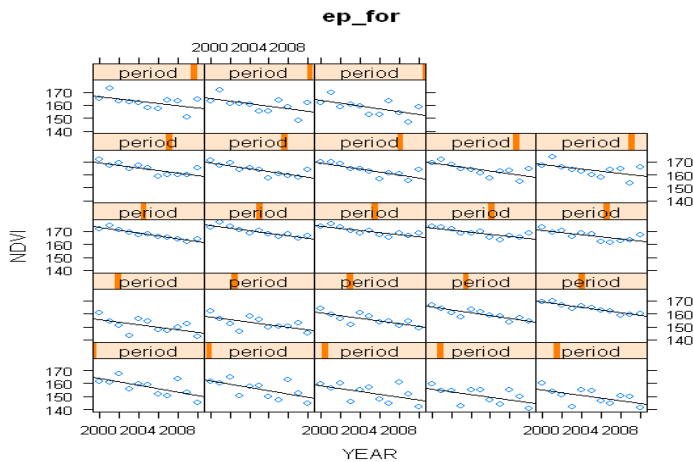


Figure 6.15. Graphical display of lattice plot to help visualize results of Mann Kendall and Seasonal Mann Kendall tests.

6.6 Cheat sheet for processing steps

Run modules in the following order.

- 1) Convert area of interest shape files to raster for clipping in ArcInfo
- 2) Run extract_ndvi.aml
- 3) Run extract_snow.aml
- 4) Format_raw_ndvi_data
- 5) NDVI_year
- 6) NDVI_doy
- 7) Create_Timesat_input then copy to text editor and save as XXX_input.txt
 - a. Run Timesat on XXX_input.txt> save output XXX_seasonality.txt then paste into spreadsheet page "paste_timesat_output_here"
 - b. Save settings file created in Timesat
- 8) NDVI_season_stats

- 9) Process_Timesat_output1 or 2 depending on user selected seasonality in Timesat analysis for unimodal or bimodal precipitation regimes.
- 10) Build_NDVI_stats_table
- 11) Download NCDC weather station data
- 12) Copy raw weather station data into "paste_raw_wx_data_here"
- 13) Precip_summary_16d_NCDC_ascii
- 14) Precip_year_NCDC_ascii
- 15) Precip_doy_NCDC_ascii
- 16) Snow_data_handler
- 17) Snow_doy
- 18) Snow_year
- 19) Snow_doy_pctile
- 20) Snow_melt_freeze
- 21) R_input_period
- 22) Run R code

6.7 Monsoon anomaly map

Anomaly maps show the magnitude and spatial pattern of change in vegetation condition that provides intuitive insight to the process of interest. Intuitive is used intentionally here to describe the response of managers to this particular product. It is perhaps the most compelling product for sharing with park staff.

The following ArcGIS map algebra calculations for year 2009 NDVI anomaly are based on the maximum smoothed monsoon value for each year. This can be done with the following grid or map algebra commands on the smoothed grid stacks in ArcGIS:

For each year determine the max monsoon (periods 14-20) NDVI value.

MAX00 = max(N00B14, N00B15, N00B16, N00B17, N00B18, N00B19, N00B20)

MAX01 = max(N01B14, N01B15, N01B16, N01B17, N01B18, N01B19, N01B20)

MAX02 = max(N02B14, N02B15, N02B16, N02B17, N02B18, N02B19, N02B20)

Etc

Determine the long-term average maximum monsoon value from the max from each year.

MMEAN = mean(MAX00, MAX01, MAX02, MAX03, MAX04, MAX05, MAX06, MAX07)

Determine the difference between year 2009 max monsoon value and long-term max.

ANOM_09 = MAX09 – MMEAN

ANOM_09I = int(ANOM_09 + 0.5)

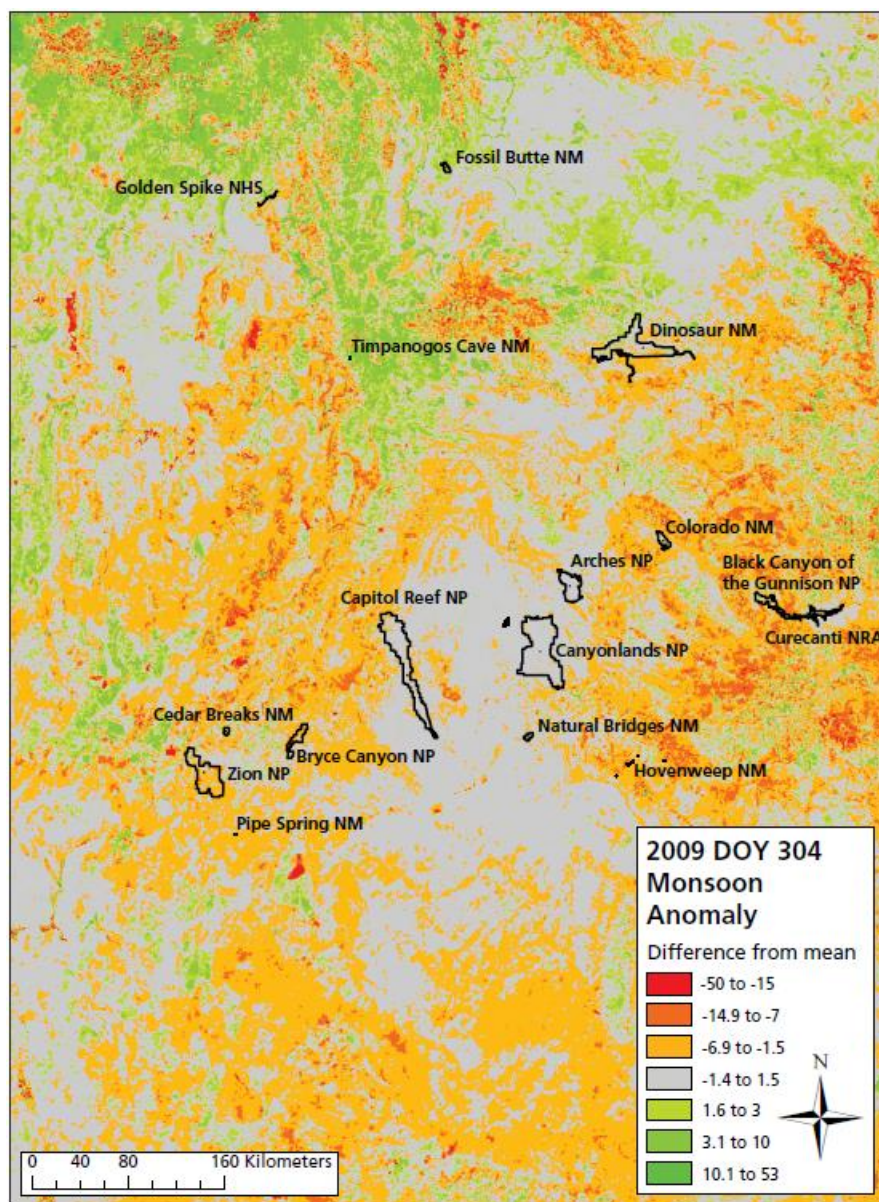


Figure 6.16. Monsoon anomaly map for CP region comparing long-term average NDVI versus current year. Note the greener shades north and west of a line between Zion National park and Dinosaur National Monument. Compare this map to figure 1 in the introduction to gain an appreciation of the monsoon track and it's annual dynamics.

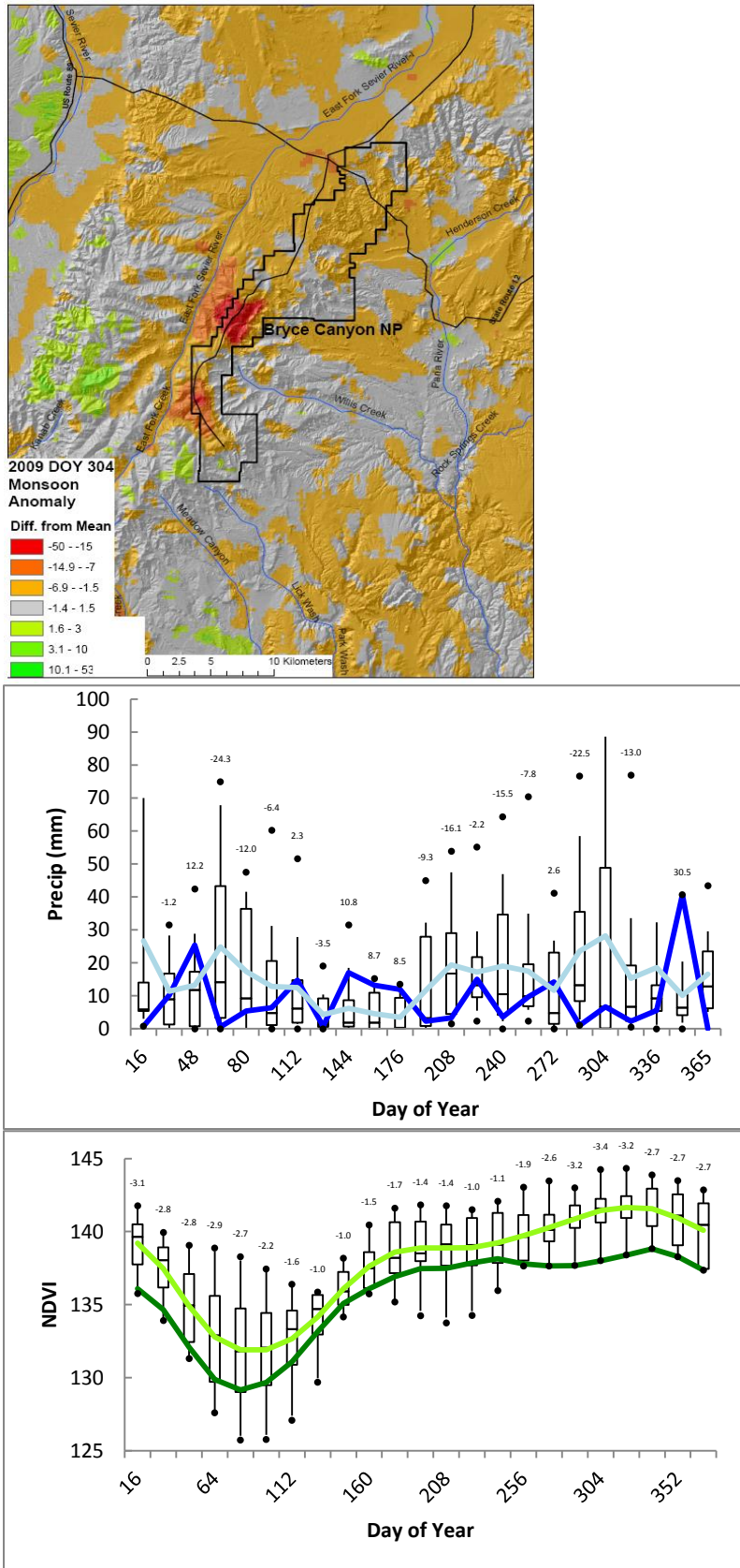


Figure 6.17. a) Monsoon anomaly map for BRCA comparing long-term average NDVI versus NDVI in 2009. Differences in greenness resulting from the 2009 Bridge Fire and 2008 Puma Fire are readily apparent as different shades of red. b) Difference between long term average precipitation (light blue line) and 2009 precipitation (dark blue line) for weather station at BRCA headquarters. c) The Bridge fire burned in 2009 when vegetation greenness for the entire park (dark green line) was well below average (light green line). Numbers above the box plots indicate the difference in NDVI between 2009 and long-term mean.