

MODISrsp: A tool for automatic preprocessing of MODIS time series

Lorenzo Busetto (busetto.l@irea.cnr.it), Luigi Ranghetti (ranghetti.l@irea.cnr.it)

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1 Introduction

MODIS_{tsp} is a novel “R” package allowing to automatize the creation of time series of rasters derived from MODIS Land Products data. It allows to perform several preprocessing steps on MODIS data available within a given time period.

Development of MODIS_{tsp} started from modifications of the ModisDownload “R” script by Thomas Hengl (2010), and successive adaptations by Babak Naimi (2014). The basic functionalities for download and preprocessing of MODIS datasets provided by these scripts were gradually incremented with the aim of:

- Developing a standalone application allowing to perform several preprocessing steps (e.g., download, mosaicking, reprojection and resize) on all available MODIS land products by exploiting a powerful and user-friendly GUI front-end;
- Allowing the creation of time series of both MODIS original layers and additional Quality Indicators (e.g., data acquisition quality, cloud/snow presence, algorithm used for data production, etc.) extracted from the aggregated bit-field QA layers
- Allowing the automatic calculation and creation of time series of several additional Spectral Indexes starting from MODIS surface reflectance products

All processing parameters can be easily set with a user-friendly GUI, although non-interactive execution exploiting a previously created Options File is possible. Stand-alone execution outside an “R” environment is also possible, allowing to use scheduled execution of MODIS_{tsp} to automatically update time series related to a MODIS product and extent whenever a new image is available.

Required MODIS HDF files are automatically downloaded from NASA servers and resized, reprojected, resampled and processed according to user’s choices. For each desired output layer, outputs are saved as single-band rasters corresponding to each acquisition date available for the selected MODIS product within the specified time period. “R” *RasterStack* objects with temporal information as well as Virtual raster files (GDAL vrt and ENVI META files) facilitating access to the entire time series can be also created.

2 Installation

MODIS_{tsp} was developed completely in the “R” Language and Environment for Statistical Computing (R Development Core Team 2014) v. 3.1.3 and is distributed as open source software under the GNU-GPL 3.0 License. Source code can be downloaded at the GITHUB repository [https://github.com/lbusett/MODIS_{tsp}](https://github.com/lbusett/MODIS_tsp).

IMPORTANT: *MODIS_{tsp}* requires GDAL (Geospatial Data Abstraction Library) v >1.2 To be installed in your system. Brief instructions for installing GDAL can be found [HERE](#)

2.1 On Windows

1) Install MODIS_{tsp} package from GitHub. (You’ll need to have the “devtools” package installed and loaded)

```
install.packages("devtools", repos = "http://cran.us.r-project.org")
library(devtools)
install_github("lbusett/MODIS_tsp")
```

2) Finalize the installation of the *gWidgetsRGtk2* library:

```
library(gWidgetsRGtk2)
```

“R” will probably throw a Warning:

```
## Warning: Failed to load RGtk2 dynamic library, attempting to install it
```

and an error window will appear. **Don't worry !** This is just signaling that *libatk-1.0-0.dll* is missing from your system. This is due to the fact that library “GTK+” is not yet installed on your system and needs to be installed. To do so, press “OK”. A new window dialog window will appear, asking if you want to install “GTK+”. Select “Install GTK+” and then “OK”. Windows will download and install the GTK+ library. When it finishes, the RSession will be restarted and you should be ready to go !¹

2.2 On Linux

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2.3 Dependencies

MODIS_{tsp} exploits functionalities of several additional “R” packages. A complete list of required packages is shown in the following table.

Table I: List of “R” package dependencies for the MODIS_{tsp} tool.

“R” package	Version	Authors
bitops	>= 1.9.6	(Dutky and Maechler 2013)
data.table	>= 1.9.6	(Dowle et al. 2015)
gdalUtils	>= 2.0.1.7	(Greenberg and Mattiuzzi 2014)
gWidgetsRGtk2	>= 0.0-54	(Lawrence and Verzani 2013)
hash	>= 2.2.6	(Brown 2013)
plyr	>= 1.8.3	(Wickham 2012)
raster	>= 2.5-2	(Hijmans 2014)
RCurl	>= 1.95-4.8	(Lang 2013a)
rgdal	>= 1.1-8	(Bivand, Keitt, and Rowlingson 2014)
rgeos	>= 0.3-8	(Bivand and Rundel 2014)
xts	>= 1.0-10	(Ryan and Ulrich 2015)
sp	>= 1.2-2	(Pebesma and Bivand 2005)
stringr	>= 1.0.0	(Wickham 2012)
XML	>= 3.98-1.1	(Lang 2013b)

Additionally, MODIS_{tsp} requires availability of the **GDAL - Geospatial Data Abstraction Library v. >1.10**, with support for **HDF4** raster format.

3 Running the tool

3.1 Interactive mode

To run the tool in interactive mode, load the package and launch the MODIS_{tsp} function, with no parameters

```
library(MODIStsp)
MODIStsp()
```

¹If you encounter problems installing the gWidgetsRgtk2 library, please signal it in the issues GitHub page of MODIS_{tsp} and we'll try to help you !

This opens a GUI from which processing options can be specified and eventually saved (or loaded). A description of the different processing parameters to be selected is reported in the “Selection of Processing parameters” subsection.

3.2 Non-Interactive mode (Using a previously saved options file)

MODIS_{tsp} can be also launched in non-interactive mode by setting the optional “GUI” parameter to FALSE, and the “Options_File” parameter to the path of a previously saved Options file. This allows to exploit MODIS_{tsp} functionalities within generic “R” processing scripts

```
library(MODIStsp)
# --> Specify the path to a valid options file saved in advance
options_file = "X:/yourpath/youroptions.RData"    from the GUI
MODIStsp(gui = FALSE, options_File = options_file)
```

Specifying also the “spatial_file_path” parameter overrides the output extent of the selected Options File. This allows to perform the same preprocessing on different extents using a single Options File, by looping on an array of spatial files representing the desired output extents.

For example:

```
# Create a character array containing a list of shapefiles (or other spatial files)
extent_list = list.files("X:/path/containing/some/shapefiles/", "\\*.shp$")

# loop on the list of spatial files and run MODIStsp using each of them to automatically
# define the output extent (A separate output folder is created for each input spatial file).

for (single_shape in extent_list) {
  MODIStsp(gui = FALSE, options_File = "X:/yourpath/youroptions.RData",
    spatial_file_path = single_shape )
}
```

4 Selection of processing parameters through the GUI

When running MODIS_{tsp} in Interactive Mode, a user-friendly GUI allows selection of all processing options required for the creation of the desired MODIS time series. The main available processing options are described briefly in the following.

4.1 MODIS Product, Satellites and Layers

Allows to select the MODIS product of interest from a drop-down menu. The user can also select which MODIS sensors should be considered for download and creation of the time series (“Terra”, “Aqua” or both). After selecting the product, pushing the “Select Layers” button opens the “Select Processing Layers” GUI panel (Figure 2), from which the user **must** select which MODIS original and/or derived QI and SI layers should be processed:

1. The left-hand frame allows to select which original MODIS layers should be processed
2. The central frame allows to select which Quality Indicators should be extracted from the original MODIS Quality Assurance layers.

Select Main Processing Options

MODIS Product, Satellites and Layers selection

Product	Platform	Processing Layers
Vegetation Indexes_16Days_250m (M*D13Q1)	Both	Click To Select

Processing Period

Starting Date (yyyy-mm-dd): 2015-01-01 Ending Date (yyyy-mm-dd): 2015-01-01

Spatial Extent

Output Extent:

Horizontal Tiles: Start: 18 End: 18 Required MODIS Tiles

Vertical Tiles: Start: 4 End: 4

Bounding Box for output images (IN OUTPUT PROJECTION !)

Upper Left Easting (xmin): 610877.8 Lower Right Easting (xmax): 916200.9

Lower Right Northing (ymin): 4959994.3 Upper Left Northing (ymax): 5090185.2

Reprojection and Resize Options

Output Projection: PROJ4 String: +proj=sinu +lon_0=0 +x_0=0 +y_0=0 +a=6371007.181 +b=6371007.181 +units=m

Output Resolution: Pixel Size: m

Resampling Method:

Processing Options

Output Files Format: GTiff Compression:

Virtual Rasters: RasterStacks: ☒ Yes ☐ No Change NODATA values ☐ Yes ☒ No

Main Output Folder for Time Series storage

 ReProcess Existing Data ☐ Yes ☒ No

Output Folder for Original HDF files download

 Delete original HDF files ☐ Yes ☒ No

Start Processing Quit Program Load Options Save Options

Figure 1: The MODISTsp main GUI

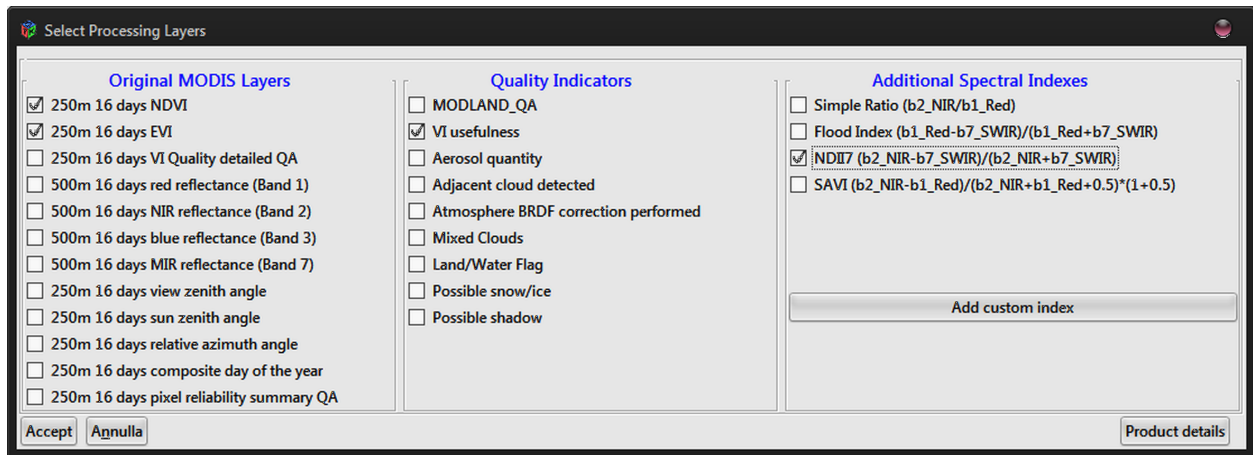


Figure 2: The “Select Processing Layers” GUI

3. For MODIS products containing surface reflectance data, the right-hand frame allows to select which additional Spectral Indexes should be computed.²

Some of the most commonly used Spectral Indexes are available for computation by default (Table II).

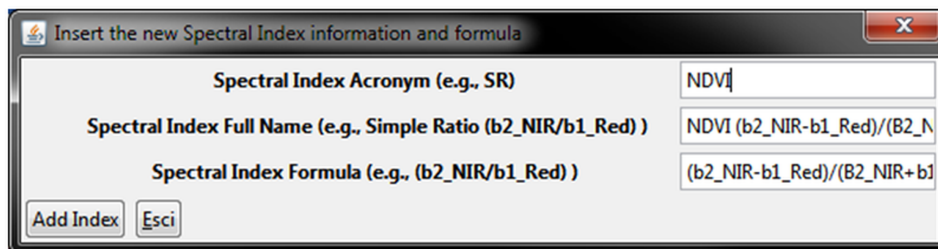
Table II: List of default Spectral Indexes available in MODISTsp

Index Acronym	Index name and reference
NDVI	Normalized Difference Vegetation Index (Rouse et al. 1973)
EVI	Enhanced Vegetation Index (Huete et al. 2002)
SR	Simple Ratio(Tucker 1979)
NDFI	Normalized Difference Flood Index (Boschetti et al. 2014)
NDII7 (NDWI)	Normalized Difference Infrared Index - Band 7 (Hunt and Rock 1989)
SAVI	Soil Adjusted Vegetation Index (Huete 1988)
NDSI	Normalized Difference Snow Index (Hall et al. 2002)
NDII6	Normalized Difference Infrared Index - band 6 (Hunt and Rock 1989)
GNDVI	Green Normalized Difference Vegetation Index (Gitelson and Merzlyak 1998)
RGRI	Red Green Ration index (Gamon and Surfus 1999)
GRVI	Green-red ratio vegetation index (Tucker 1979)

Users can however **specify other SIs to be computed without modifying MODISTsp source code** by clicking on the “**Add Custom Index**” button, which allow to provide info related to the new desired SI using a simple GUI (Figure 3) interface.

Provided information (e.g., correct bandnames, computable formula, etc...) is automatically checked, and the new index added in the list of available ones for all products allowing its computation at the next MODISTsp execution.

²The lists of original MODIS layers, QIs and Sis available for the selected product are automatically retrieved from the “MODISTsp_Products_Opts” XML file distributed with the package in /ExtData subfolder.



4.2 Processing Period

Allows to specify the starting and ending dates (dd/mm/yyyy) to be considered for the creation of the time series.

4.3 Spatial Extent

Allows to define the area of interest for the processing. Two main options are possible: .

1. *Full Tiles Extent*: the user must specify which MODIS tiles he would like to process using the “Start” and “End” horizontal and vertical sliders in the “Required MODIS Tiles” frame. During processing, data from the different tiles is mosaiced, and a single file covering the total area is produced for each acquisition date (Note: pressing the “show map” button, a representation of the MODIS tiles grid is shown to facilitate the selection).
2. *Resized*: the user can specify the spatial extent of the desired outputs either;
 - a. **Manually inserting** the coordinates of the Upper Left and Lower Right corners of the area of interest in the “Bounding Box” frame. *Coordinates of the corners must be provided in the coordinate system of the selected output projection.*
 - b. **pressing the “Load Extent from a Spatial File” and selecting a raster or vector spatial file.** In this case, the bounding box of the selected file is retrieved, converted in the selected output projection, and shown in the “Bounding Box” frame. Required input MODIS tiles are also automatically retrieved from the output extent, and the tiles selection sliders modified accordingly.

4.4 Reprojection and Resize

Allows to specify the options to be used for reprojecting and resizing the MODIS images. In particular:

1. The “**Output Projection**” menu allows to either select one of the pre-defined output projections or specify a user-defined one by selecting “User Defined” and then inserting a valid “Proj4” string in the pop-up window. Validity of the Proj4 string is automatically checked, and error messages issued if the check fails.
2. The “**Output Resolution**”, “**Pixel Size**” and “**Reprojection Method**” menus allow to specify whether output images should inherit their spatial resolution from the original MODIS files, or be resampled to a user-defined resolution. In the latter case, output spatial resolution must be specified in the measure units of the selected output projection. At the moment, the resampling method can

instead be chosen among “Nearest Neighbour” and “Mode” (Useful for downsampling purposes). Other resampling methods (e.g., bilinear, cubic) are not currently supported since i) they cannot be used for resampling of categorical variables such as the QA and QI layers, and ii) using them on continuous variable (e.g., reflectance, VI values) without performing an a-priori data cleanind would risk to contaminate the values of high-quality observations with those of low-quality ones.

4.5 Processing Options

Allows first of all to specify the **format desired for the output images**. Two of the most commonly formats used in remote sensing applications are available at the moment: ENVI binary and GeoTiff. If GeoTiff is selected, the type of file compression can be also specified among “None”, “PACKBITS”, “LZW” and “DEFLATE”.

The user can then specify if **virtual multitemporal files** should be created. These virtual files allow access to the entire time series of images as a single file without the need of creating large multitemporal raster images. Available virtual files formats are ENVI metafiles and GDAL “vrt” files. Additionally, the user can select if he desires to save the time series also as “R” *rasterStack* objects (with temporal information added through the “setZ” method of the *raster* package). This may be useful in order to easily access the preprocessed MODIS data within “R” scripts.

Finally, users can select if the **NoData values** of MODIS layers should be kept at their original values, or changed to those specified within the “MODISsp_Products_Opts” XML file. By selecting “Yes” in the “Change Original NODATA values” checkbox, NoData of outputs are set to the largest integer value possible for the data type of the processed layer (e.g., for 8-bit unsigned integer layers, NoData is set always to 255, for 16-bit signed integer layers to 32767, and for 16-bit unsigned integer layers to 65535). Information about the new NoData values is stored both in the output rasters, and in the XML files associated with them.

4.6 Main Output Folder for Time Series Storage

Allows to specify the main folder where the pre-processed time series data will be saved stored. The **“Reprocess Existing Data”** checkbox allows to specify if images already available should be reprocessed if a new run of MODISsp is launched with the same output folder. If set to “No”, MODISsp skips dates for which output files following the MODISsp naming conventions are already present in the output folder. This allows to incrementally extend MODIS time series without reprocessing already available dates.

4.7 Output Folder for Original HDF Storage

Allows to specify the folder where downloaded **original MODIS HDF files** are stored. The **“delete original HDF files”** checkbox allows to specify if the downloaded images should be deleted from the file system at the end of the processing. To avoid accidental file deletion, this is always set to “No” by default, and a warning is issued before execution whenever the selection is changed to “Yes”.

5 Processing

Upon pressing the “Start” button, the main processing routine is launched (MODISsp_process). This routine performs the following main tasks:

1. Retrieve the processing options from the GUI (or the saved RData file in case of non-interactive execution)

2. Connect to the lpdaac http MODIS distribution archive, and retrieve the list of HDF images of the selected MODIS product available for the time period selected by the user, for each tile required to cover the selected study area.
3. For each identified date of acquisition;
 - Download all required hdf images.
 - For each original hdf layer i) selected by the user, or ii) required to compute a selected QI or SI layer, extract the data from the original MODIS images and resize and reproject it to the selected output projection, extent and resolution. If more than one tile is needed to cover the output extent, all required tiles are automatically mosaicked before resizing (gdalbuildvrt functionalities are used to avoid creating large temporary raster files). All the main spatial processing tasks are performed using standard GDAL routines, exploiting the wrappers for “R” provided in the “gdalUtils” package (Greenberg and Mattiuzzi 2014). Results are saved as raster GeoTiff or ENVI files using MODISstsp naming conventions (See Section 5).
 - Starting from files created at point b), compute required QI and/or SI layers and save the results as GeoTiff or ENVI files. Quality Indicators are computed from original QA layers using bitwise operators available in the “bitOps” package (Dutky and Maechler 2013), using a generalization of the “modis.qc.R” script by Yann Chemin (Chemin 2008). Computation of SI layers exploits on-the-fly parsing of the indexes’ formulae to identify the required input raster files and perform the computation.
 - Delete raster files created at point b) used to compute the QI or SI layers but that correspond to original HDF layers not originally selected for processing.
4. When all dates have been processed, create the virtual time series files if required.

6 Output format and naming conventions

Output raster files are saved in specific subfolders of the main output folder. A separate subfolder is created for each processed original MODIS layer, Quality Indicator or Spectral Index. Each subfolder contains one image for each processed date, created according to the following naming conventions:

“ProdCode”_“Layer”_“YYYY”_“DOY”_“ext” (e.g., *MOD13Q1_NDVI_2000_065.dat*)

ProdCode is the code name of the MODIS product from which the image was derived (e.g., MOD13Q1), **Layer** is a short name describing the dataset (e.g., b1_Red, NDII, UI), **YYYY** and **DOY** corresponds to the year and DOY (Day of the Year) of acquisition of the original MODIS image, and ext is the file extension (.tif for GTiff outputs, or .dat for ENVI outputs).

ENVI and/or GDAL virtual time series files and *RasterStack* RData objects are instead stored in the “Time_Series” subfolder if required.

Naming convention for these files is as follow:

“ProdCode”_“Layer”_“StartDOY”_“StartYear”_“EndDOY”_“EndYear2”_“suffix”.ext”
(*MOD13Q1_NDVI_49_2000_17_2015_RData.dat*)

where *suffix* indicates the type of virtual file (ENVI, GDAL or RData), while *StartDOY*, *StartYear*, *EndDOY* and *EndYear* indicate the temporal extent of the time serie created.

7 Standalone execution and scheduled processing

MODISTsp can be executed as a standalone application using the MODISTsp.bat (for Windows) or MODISTsp.sh (for Linux) batch execution scripts available in the “MODISTsp/ExtData/launcher” subfolder of the package installation. Double-clicking the files or launching them from a shell without parameters launches MODISTsp in interactive mode.

Non-interactive mode is triggered by adding the “-g” argument to the call, and specifying the path to a valid Options File as “-s” argument

- **In Linux:** `yourpath_to_MODISTsp_sh/MODISTsp.sh -g -s "/yourpath/youroptions.RData"`

(launch `yourpath_to_MODISTsp_sh/MODISTsp.sh -h` for details).

- **In Windows:** `yourpath_to_MODISTsp_bat\MODISTsp.bat -g -s "X:/yourpath/youroptions.RData"`

(launch `yourpath_to_MODISTsp_bat\MODISTsp.bat -h` for details).

Standalone non-interactive execution easily allows to automatically update the time series of a selected product over a given study area whenever a new MODIS image is available. To do that, the user must simply:

1. Open the MODISTsp GUI, define the parameters of the processing specifying a date in the future as the “Ending Date” and save the processing options. Then quit the program
2. Schedule non-interactive execution of MODISTsp.bat (or MODISTsp.sh) as windows scheduled task (or linux “cron” job) according to a specified time schedule, specifying the path of a previously saved Options file as additional argument:

- **In Linux:** edit your crontab by opening a terminal and typing

```
bash    crontab -e
```

Then add an entry for the MODISTsp.bsh For example, if you want to run the tool every day at 23.00, add the following row:

```
bash    0 23 * * * /bin/bash /yourpath_to_MODISTsp_sh/MODISTsp.sh -g -s "/yourpath/youroptions.RData"
```

- **In Windows:** create a Task following these instructions; add the path of the MODISTsp.bat launcher as Action (point 6), and specify `-g -s "X:/yourpath/youroptions.RData"` as argument.

7.1 Adding links to desktop/Start menu for standalone execution

Links to the MODISTsp.bat or MODISTsp.sh standalone launchers can be created automatically launching from R the function `MODISTsp_install_launcher()`

- **In Linux:** this creates a desktop entry (accessible from the menu in the sections “Science” and “Geography”), and a symbolic link in a known path (default: `/usr/bin/MODISTsp`). If the path of the symbolic link is included in the user PATH variable, the standalone execution can be done simply calling `MODISTsp -g -s "/yourpath/youroptions.RData"`.
- **In Windows:** this creates a link in the Start Menu and optionally a desktop shortcut.

See `?install_MODISTsp_launcher` for details and path customisations.

8 Installing GDAL

8.1 On Windows

The easiest way to install GDAL on Windows is from the OSGeo4W Website

1. Open the OSGeo4W Website
 2. In the **Quick Start for OSGeo4W Users** section, select the download of 32bit or 64bit of OSGeo4W network installer
 3. Run the installer
- *Easiest Option:* +Select **Express Desktop Install**, then proceed with the installation. This will install GDAL and also other useful Spatial Processing softwares like QGIS and GRASS GIS
 - *Advanced Option:*
 - Select **Advanced Install**, then click on “Next” a few times until you reach the “Select Packages” screen.
 - Click on “Commandline Utilities”, and on the list look for “_gdal: The GDAL/OGR library...” entry
 - Click on “Skip”: the word “skip” will be replaced by the current GDAL version number
 - Click on “Next” a few times to install GDAL

8.2 On Linux

References

- Bivand, R., and C. Rundel. 2014. “geos: Interface to Geometry Engine - Open Source (GEOS). R package version 0.3-8.” <http://cran.r-project.org/package=rgeos>.
- Bivand, R., T. Keitt, and B. Rowlingson. 2014. “rgdal: Bindings for the Geospatial Data Abstraction Library. R package version 0.8-16.” <http://cran.r-project.org/package=rgdal>.
- Boschetti, M., F. Nutini, G. Manfron, P. A. Brivio, and A. Nelson. 2014. “Comparative analysis of normalised difference spectral indices derived from MODIS for detecting surface water in flooded rice cropping systems.” *PLoS ONE* 9 (2). doi:10.1371/journal.pone.0088741.
- Brown, C. 2013. “Hash: Full Feature Implementation of Hash/associated Arrays/dictionaries. R Package Version 2.2.6.” <http://cran.r-project.org/package=hash>.
- Chemin, Y. 2008. *modis.qc.R “R” script*.
- Dowle, M, A Srinivasan, T Short, S Lianoglou with contributions from R Saporta, and E Antonyan. 2015. *Data.table: Extension of Data.frame*. <http://CRAN.R-project.org/package=data.table>.
- Dutky, S., and M. Maechler. 2013. “bitops: Bitwise Operations. R package version 1.0-6.” <http://cran.r-project.org/package=bitops>.
- Gamon, J.A., and J.S. Surfus. 1999. “Assessing leaf pigment content and activity with a reflectometer.” *New Phytologist* 143 (1): 105–17.
- Gitelson, A.A., and M.N. Merzlyak. 1998. “Remote sensing of chlorophyll concentration in higher plant leaves.” *Advances in Space Research* 22 (5): 689–92. doi:10.1016/S0273-1177(97)01133-2.
- Greenberg, J.A., and M. Mattiuzzi. 2014. “gdalUtils: Wrappers for the Geospatial Data Abstraction Library (GDAL) R package version 0.3.1.” <http://cran.r-project.org/package=gdalUtils>.
- Hall, Dorothy K, George A Riggs, Vincent V Salomonson, Nicolo E DiGirolamo, and Klaus J Bayr. 2002.

- “MODIS snow-cover products.” *Remote Sensing of Environment* 83 (1-2): 181–94. doi:10.1016/S0034-4257(02)00095-0.
- Hengl, T. 2010. “Download and resampling of MODIS images.” <http://es>.
- Hijmans, R.J. 2014. “raster: raster: Geographic data analysis and modeling. R package version 2.3-0.” <http://cran.r-project.org/package=raster>.
- Huete, A., K. Didan, T. Miura, E.P. Rodriguez, X. Gao, and L.G. Ferreira. 2002. “Overview of the radiometric and biophysical performance of the MODIS vegetation indices.” *Remote Sensing of Environment* 83 (1-2): 195–213. doi:10.1016/S0034-4257(02)00096-2.
- Huete, A.R. 1988. “A soil-adjusted vegetation index (SAVI).” *Remote Sensing of Environment* 25 (3): 295–309. doi:10.1016/0034-4257(88)90106-X.
- Hunt, J.R., and B. Rock. 1989. “Detection of changes in leaf water content using Near- and Middle-Infrared reflectances.” *Remote Sensing of Environment* 30 (1): 43–54. doi:10.1016/0034-4257(89)90046-1.
- Lang, D.T. 2013a. “RCurl: General network (HTTP/FTP/...) client interface for R. R package version 1.95-4.1.” <http://cran.r-project.org/package=RCurl>.
- . 2013b. “XML: Tools for parsing and generating XML within R and S-Plus. R package version 3.98-1.1.” <http://cran.r-project.org/package=XML>.
- Lawrence, M., and J. Verzani. 2013. “gWidgetsRGtk2: Toolkit implementation of gWidgets for RGtk2. R package version 0.0-82.” <http://cran.r-project.org/package=gWidgetsRGtk2>.
- Naimi, B. 2014. “ModisDownload: an R function to download, mosaic, and reproject the MODIS images.” <http://r-gis.net/?q=ModisDownload>.
- Pebesma, Edzer J., and Roger S. Bivand. 2005. “Classes and Methods for Spatial Data in R.” *R News* 5 (2): 9–13. <http://CRAN.R-project.org/doc/Rnews/>.
- Rouse, J.W.J., R.H. Haas, J.A. Schell, and D.W. Deering. 1973. “Monitoring vegetation systems in the Great Plains with ERTS. Third ERTS Symposium, NASA SP-351. U.S. Gov. Printing office.” Edited by S.C. Freden, E.P. Mercanti, and M.A. Becker. NASA.
- Ryan, Jeffrey A., and Joshua M. Ulrich. 2015. *Xts: EXtensible Time Series*. <https://R-Forge.R-project.org/projects/xts/>.
- Tucker, C.J. 1979. “Red and photographic infrared linear combinations for monitoring vegetation.” *Remote Sensing of Environment* 8 (2): 127–50. doi:10.1016/0034-4257(79)90013-0.
- Wickham, H. 2012. “stringr: Make it easier to work with strings.. R package version 0.6.2.” <http://cran.r-project.org/package=stringr>.