LandsatLinkr 0.1.6 User Guide

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LandsatLinkr: An automated system for processing Landsat imagery and building long spectrally consistent chronologies across MSS and TM/ETM+ sensors.

LandsatLinkr was developed by the Laboratory for Applications of Remote Sensing in Ecology at Oregon State University, Department of Forest Ecosystems and Society with funding from USDA Forest Service and USGS.

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Guide Version	Changes	Date
0.1.0a	Initial release	1/7/15
0.1.4a	Changes to how LLR is installed	3/5/15
0.1.6a	Changes to interface selection and description for new DEM and spatial resolution handling	4/7/15

Contents

Introduction

About LandsatLinkr

LandsatLinkr (LLR) is an automated Landsat image processing system designed to spatially and spectrally link MSS, TM, and ETM+ images through time. It efficiently processes hundreds of images to produce annual cloud-free image composites from which to build 42+ year spectral chronologies (Figure 1). The resulting spectrally consistent composite images can be used individually as inputs to mapping or modeling projects, to investigate simple image-to-image change, or as inputs to complex change detection algorithms such as LandTrendr.

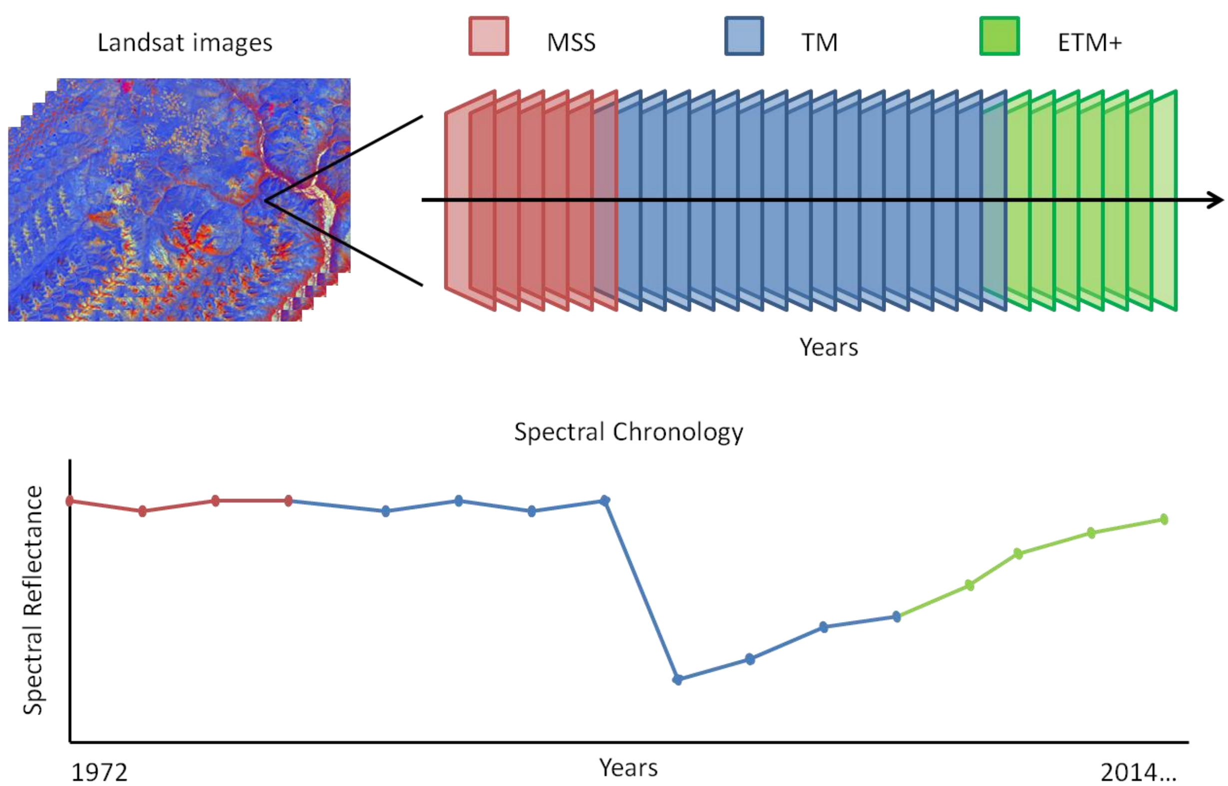


Figure 1 Conceptual representation of LandsatLinkr

LLR takes hundreds of images and automatically completes the following steps:

1) Decompresses
2) Resamples
3) Reprojects
4) Stacks image bands
5) Creates cloud masks
6) Improves georegistration accuracy
7) Applies atmospheric correction
8) Spectrally calibrates MSS data to TM/ETM+ data
9) Creates annual cloud-free image composites and stacks

Each step produces outputs which are independently useful (Table 1), so even if you only need a couple of images processed to surface reflectance and do not care about annual composites or time series stacks, LLR is still relevant, though the true benefit is in large volume processing.

MSS data

4-band DN raster stacks
4-band radiance raster stacks
4-band atmospherically corrected surface reflectance raster stacks
3-band calibrated tasseled cap raster stacks
1-band calibrated tasseled cap angle rasters
1-band cloud and shadow mask rasters

TM/ETM+ data

6-band atmospherically corrected surface reflectance (LEDAPS) raster stacks
3-band tasseled cap raster stacks
1-band cloud and shadow mask rasters

Composite data

1-band annual tasseled cap brightness rasters
1-band annual tasseled cap greenness rasters
1-band annual tasseled cap wetness rasters
1-band annual tasseled cap angle rasters
Multi-band tasseled cap brightness time series raster stack
Multi-band tasseled cap greenness time series raster stack
Multi-band tasseled cap wetness time series raster stack
Multi-band tasseled cap angle time series raster stack

Table 1. LandsatLinkr output data list.

LandsatLinkr is written in the R programming language and distributed as an R package. The system features an interactive interface for simple operation with no R experience needed, but can also be run with customary function calls. It provides an option to run the system in parallel using 2 cores to reduce standard processing time by half.

It was developed for landscape change research as a way to easily incorporate the entire Landsat archive (still working on adding OLI) into spatially and spectrally consistent 42+ year time series stacks. As such, it is constantly changing to meet new needs and is not considered end-point software. However, the outputs are generically useful for nearly all applications of Landsat time series data, so we provide it freely, encourage its use, and welcome any feedback regarding bugs and suggested improvements.

LandsatLinkr workflow

MSS and TM/ETM+ sensors produce somewhat different data. Though part of the same Landsat family, with similar mission objectives, technology enhancements over time have led to a divergence in image attributes between sensors (Table 2). LLR bridges the difference between sensors by spatially and spectrally aligning the data through georegistration improvement, resampling, and spectral index modeling and calibration. The processing procedures are based on established methods and executed with a high degree of automation and standardization. A brief description of the LLR workflow follows. Step-by-step instructions for setup and executing are presented in the *Setup* and *Running LandsatLinkr* sections.

Attribute	MSS	TM	ETM+	OLI
Spectral reflectance (µm)				
Ultra-Blue	-	-	-	0.43 - 0.45
Blue	-	0.45-0.52	0.45-0.52	0.45 - 0.51
Green	0.50-0.60	0.52-0.60	0.52-0.60	0.53 - 0.59
Red	0.60-0.70	0.63-0.69	0.63-0.69	0.64 - 0.67
NIR	0.70-0.80 0.80-1.10	0.76-0.90	0.77-0.90	0.85 - 0.88
SWIR 1	-	1.55-1.75	1.55-1.75	1.57 - 1.65
SWIR 2	-	2.08-2.35	2.09-2.35	2.11 - 2.29
Cirrus	-	-	-	1.36 - 1.38
Radiometric Resolution (bit)	8*	8	8	12
Spatial resolution (m)	60**	30	30	30
Temporal resolution (days)	18 & 16	16	16	16
Years of operation	1972-1992	1982-2012	1999-…	2013…

Table 2 Select Landsat sensor characteristics. *Scaled from 6-bit to 8-bit. **Resampled from 68 m x 83 m to 60 m.

LandsatLinkr has four major processing steps (Figure 2):

1. Preparing MSS imagery
2. Preparing TM/ETM+ imagery
3. Calibrating MSS to TM/ETM+ imagery
4. Annual cloud-free image compositing.

The inputs include:

1. A temporal series of LPGS MSS images for a given Landsat scene
2. An MSS scene-corresponding digital elevation model (DEM)
3. A temporal series of LEDAPS TM/ETM+ images for a given Landsat scene

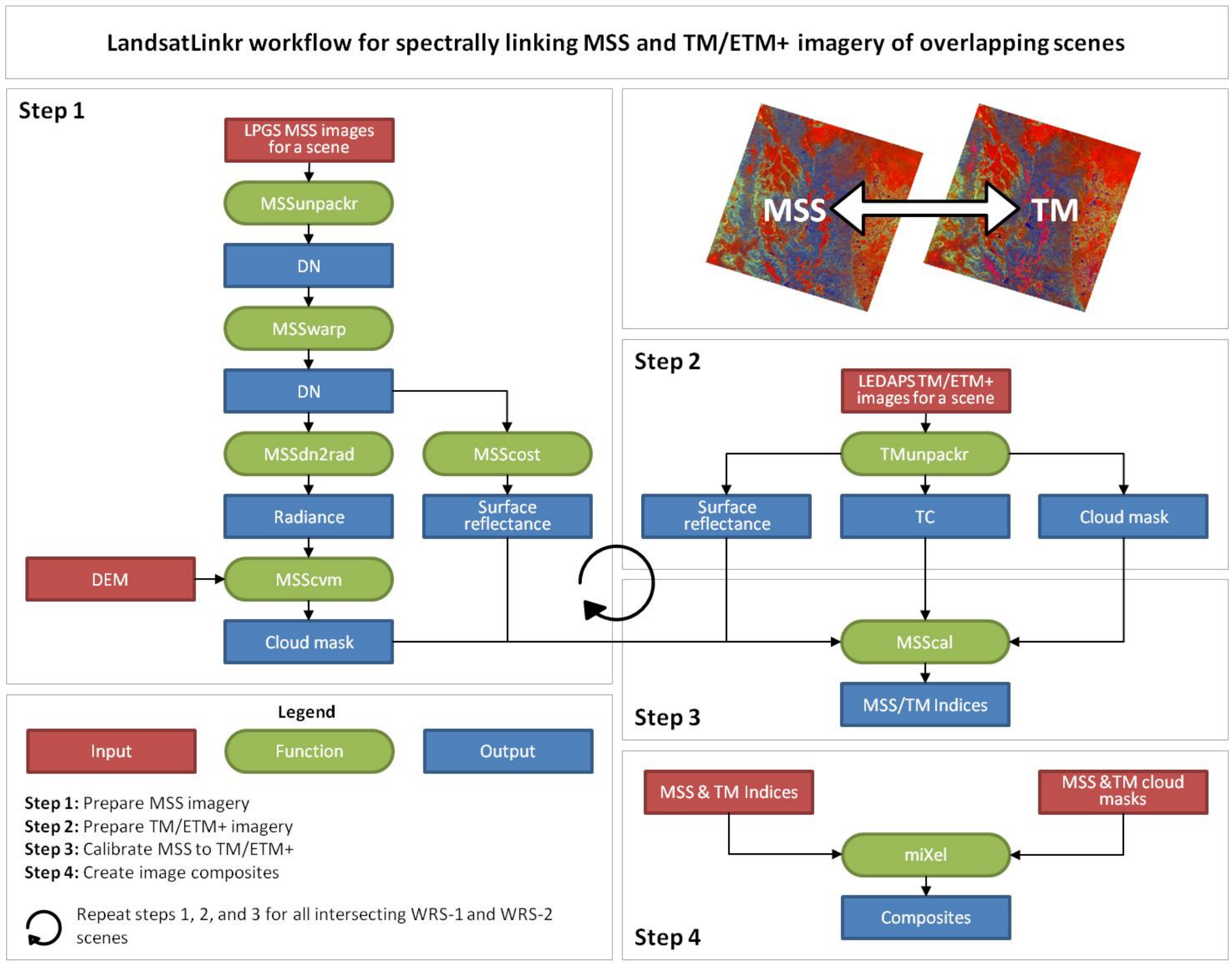


Figure 2. LandsatLinkr workflow.

Step 1:

Every MSS image for a particular Landsat scene is decompressed, stacked, optionally resampled and reprojected, renamed, and organized into a defined directory structure (*MSSunpackr*). Georegistration accuracy is assessed from image metadata and enhanced using an image-to-image tie point search and warp procedure (*MSSwarp*) if scene-level RMSE ≥ 0.75. All images are then converted to units of top-of-atmosphere radiance (MSSdn2rad) and surface reflectance (*MSScost*). The radiance images along with a scene-corresponding DEM are then used in a cloud masking procedure (*MSScvm*) to create raster images that identify clear-view and obscured pixels for later use in cloud-free compositing.

Step 2:

Every TM/ETM+ image for an intersecting MSS scene processed in *Step 1* will be decompressed, stacked, and optionally resampled and reprojected. From the included surface reflectance image stack, a 3-band Tasseled Cap transformation raster stack is created. Finally, the included Fmask cloud mask is aggregated to identify clear-view and obscured pixels with the same designation as the MSS masks created in *Step 1*. All image data are renamed and organized into a defined directory structure. The *TMunpackr* function is responsible for procedures in Step 2.

Step 3:

The *MSScal* function develops models to predict TM/ETM+ spectral indices from MSS surface reflectance bands based on the relationship between coincident MSS and TM dates for years 1982-1992. Specifically, models are created for Tasseled Cap Brightness, Greenness, Wetness, and Angle. The models are then applied to all MSS images in the model reference scene.

Note: steps 1-3 are repeated as necessary for all intersecting scenes in a project study area. This is particularly relevant for including the multiple Landsat 1-3 WRS-1 scenes that intersect Landsat 4-8 WRS-2 scenes. See section Setup processing directories for more details on the World Reference System version difference.

Step 4:

Step 4 produces annual cloud-free image composites for all spatially intersecting images in a given region of interest. The *miXel* function searches provided directories for images to composite and sorts them into groups by year. For all images in each year group, cloud masks are applied to set obscured pixels to the background (NA) value and then the year composite is calculated from the per-cell mean value of overlapping images.

For more detailed information on each function listed in the LLR function descriptions.

Each LLR processing steps is run with R commands, which can be initiated in multiple ways (only one way at the moment). The simplest is a single command for all steps with an interactive interface to select running options and provide function arguments. Each step of the process is run independently and must be completed in order.

System requirements

Computer

LandsatLinkr was developed and tested on computers running Windows 7 64-bit OS with ≥ 8 GB of RAM. Performance on other operating systems and less RAM is unknown (testing in progress).

Data storage

2 TB of data storage is recommended for processing a single WRS-2 scene project with ~250 images.

Software

GDAL
R
RStudio

Setup

Install software

LLR requires R, RStudio, and GDAL programs be installed on your computer. R is a free computer programming language for statistical computing and graphics. RStudio provides a convenient frontend interface to the R environment. GDAL is a program for reading, writing, and manipulating geospatial data.

If you don't already have a current version of these programs you'll need to download and install them to your computer.

GDAL

1. Go to http://www.gisinternals.com/sdk/

2. Scroll to the "GDAL and MapServer latest release versions:" and select the download for MSVC2010 (Win64) – you'll be linked to a new page

3. Download the "Generic installer for the GDAL core components"

4. Run the installer

5. Include GDAL in your system's environmental variable "PATH".
    a. Open Windows "Control Panel" and select "System"
    b. Click on "Advanced system settings"
    c. Click the "Environmental Variables…" button
    d. Under System variables, scroll down to "Path" variable and click on it to highlight it
    e. Click the "edit" button
    f. Get your curser to the end of the line, add a semi-colon (;) and add the path to the GDAL installation location. Example: C:\GDAL

R

Follow the install directions from their website http://www.r-project.org/

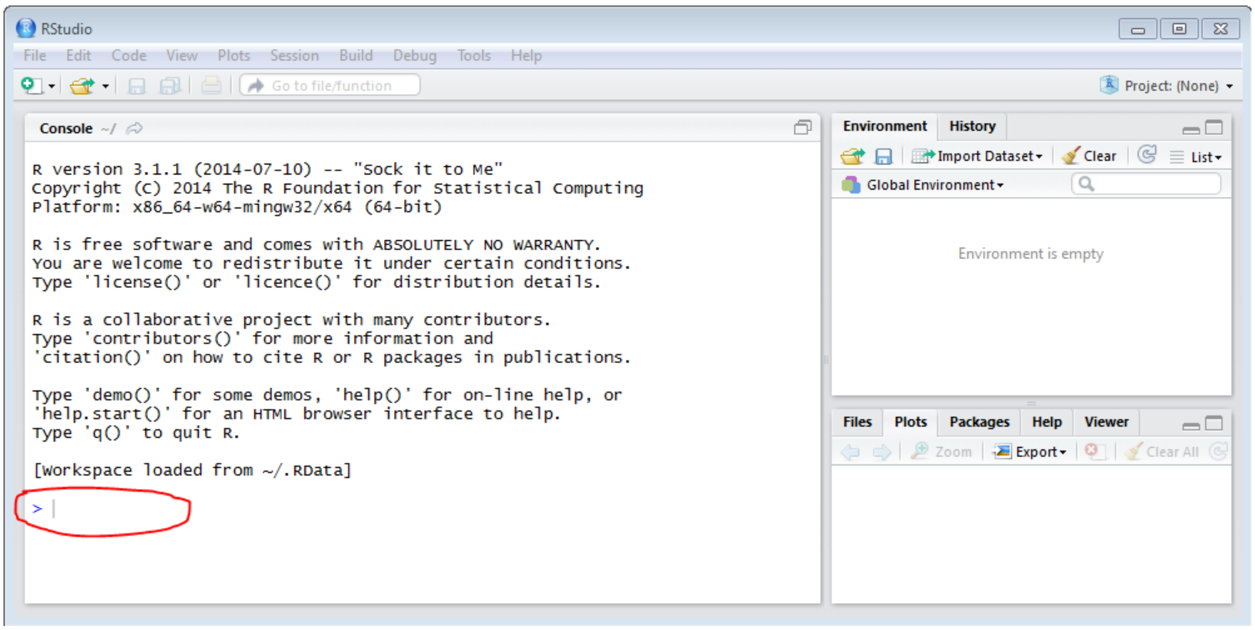
RStudio

Follow the install directions from their website http://www.rstudio.com/

Install LandsatLinkr

LandsatLinkr is written in the R programming language and its commands are entered and run through RStudio. R has many user-developed packages to handle most data concerns. LandsatLinkr is one such package and it relies on several other useful packages that are automatically downloaded and installed upon running LandsatLinkr. Once R and RStudio are set up you'll need to install the LandsatLinkr package.

1. Open RStudio and find the console command prompt



This is where you will be entering function calls and their arguments - example:

this_function(argument1 = input, argument2 = NULL)

Upon pressing enter the function will execute – not in this case – this is a mock example.

2. Install the LandsatLinkr package. To install the package from the GitHub repository, copy and paste the following code lines into the RStudio command prompt and press enter. Alternatively, use the commands provided on the LLR website download page: http://landsatlinkr.weebly.com/download.html

```
download.file("https://github.com/jdbcode/LandsatLinkr/releases/download/0.1.4-
beta/LandsatLinkr_0.1.4.zip", "LandsatLinkr")
install.packages("LandsatLinkr", repos=NULL)
install.packages(c("raster","SDMTools","doParallel","foreach","ggplot2","MASS","gridExtra","zoo","segmented
","plyr","ecp","gdalUtils","rgdal"))
```

3. Once the package has been installed it must be loaded into the current R session. Loading the package allows R to access the installed code. This procedure must be done each time a new session is started. The first time that the LLR package is loaded it will automatically prompt R to download and install several dependent packages. To load the LLR package, type or copy the following line into the command prompt and press enter.

```
library(LandsatLinkr)
```

LandsatLinkr is now ready to run on your machine.

Setup processing directories

Keeping data organized with standard directory structures and file naming conventions is important to automation and data management. Before beginning a project you must create three directories for:

1. MSS WRS-1 images
2. MSS WRS-2 images
3. TM/ETM+ WRS-2 images

The image sensor (MSS and TM/ETM+) is an obvious distinction for keeping Landsat data organized, but WRS-1 and WRS-2 scene grid designations are equally as important. WRS refers to the World Reference System. It is a standard path/row grid that defines the spatial extent of each Landsat scene footprint on Earth's surface. Unfortunately, the two grid systems do not have the same path/row alignment or numbering scheme because of differences in satellite obits. This means that including the full temporal archive for a single WRS-2 scene requires that multiple WRS-1 scenes are processed and included in calibration and compositing. Landsat 1-3 (MSS only) use WRS-1 and Landsat 4-8 (MSS 4-5, TM, ETM+, and OLI) use WRS-2. Figure 3 shows an example of the mismatch in the alignment and path/row numbering for a single WRS-2 scene of interest. For more information on the World Reference Systems please visit this site: http://landsat.gsfc.nasa.gov/?p=3231

Determining which scenes are needed to process a region of interest for the full 42+ year history is the first step in setting up a processing directory structure. This can be accomplished several ways. USGS provides ArcGIS shapefiles for both WRS-1 and WRS-2 grids that can be used to identify which scenes are needed to cover your region of interest. The files can be downloaded here. Alternatively, the Earth Science Data Viewer provided by the Global Land Cover Facility can also be used to figure this out using the following steps:

1. Go to the Science Data Viewer page and use "Map Search" to zoom into your region of interest
2. Click on the "Map Layers" tab at the top of the viewer and highlight WRS-2 and click "Update Map"
3. Determine which WRS-2 path/row covers your region of interest
4. Click on the "Path/Row" tab at the top of the viewer and type in the path and row for the WRS-2 scene of interest (start and end as the same) and click "Update Map"
5. Go back to the "Map Layers" tab and highlight WRS-1 and click "Update Map" and then note which WRS-1 scenes intersect the outlined WRS-2 scene.

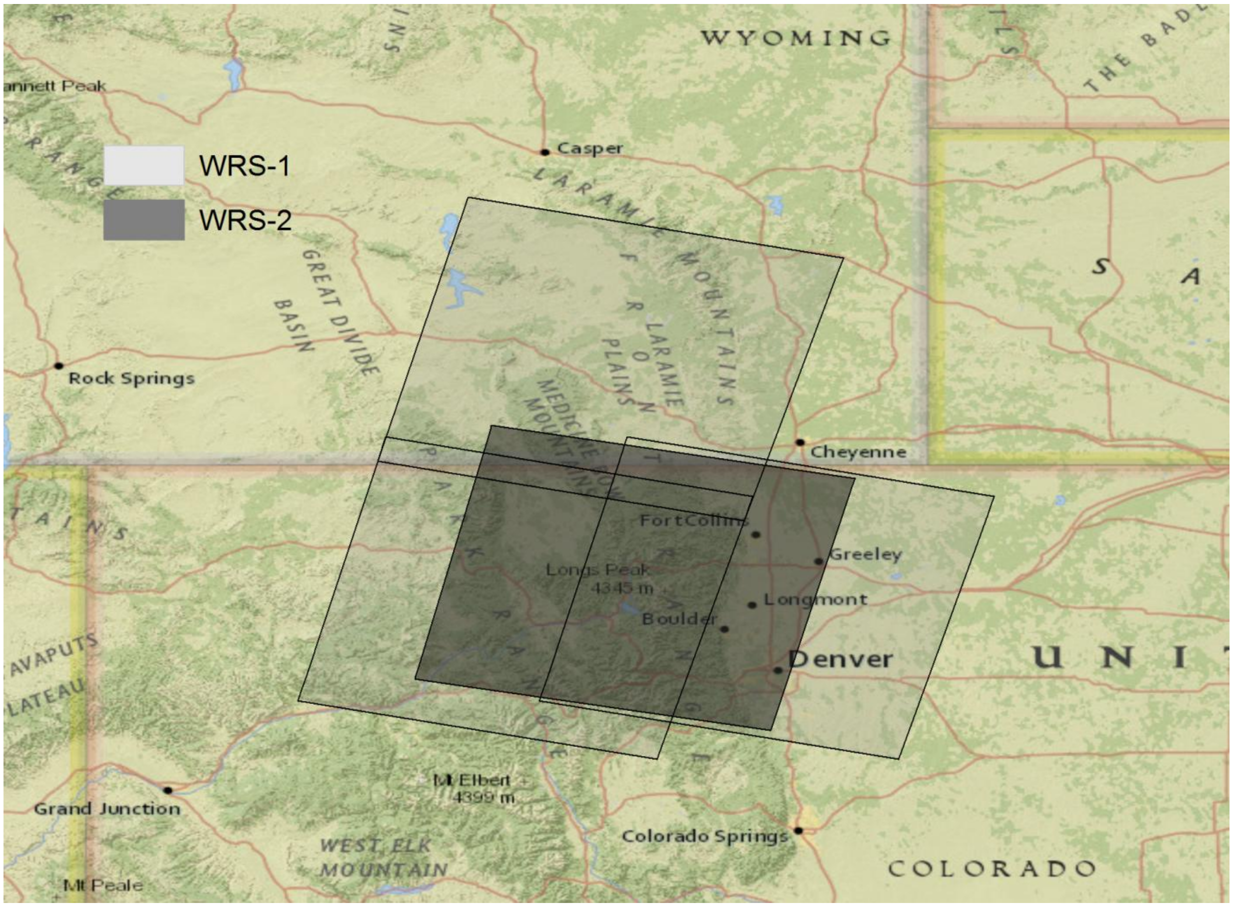


Figure 3. Example of disparity between WRS-1 and WRS-2 Landsat scenes. Generally three WRS-1 scenes are needed to provide full overlap with a WRS-2 scene.

Once you know what scenes you'll need, you can create the LandsatLinkr base directory structure (Figure 4).

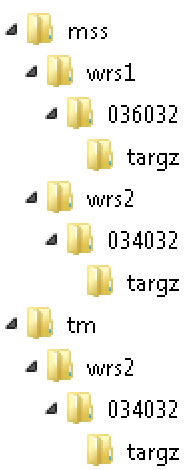


Figure 4. Example LandsatLinkr base directory structure.

Each scene should have the following directory path that first defines what sensor it comes from, then which WRS system (1 or 2) the data is from, followed by the 6 digit path/row label, and finally a folder to place the downloaded images in (targz):

<drive><…><sensor>< wrs><ppprrr><targz>

Where:

drive = the drive letter for the disk you are writing to
… = any other designation you want (optional)
sensor = what sensor collected the data (“mss” or “tm” – TM is used for both TM and ETM+)
wrs = what WRS grid system delineates the scene (“wrs1” or “wrs2”)
ppprrr = what is the 6-digit scene code (example: “036034”)
targz = a folder called “targz” where the downloaded images are to be placed

Example: L:/landsat/mss/wrs1/036032/targz

There are three main directories defined by all combinations of sensor and WRS grid type:

*/mss/wrs1
*/mss/wrs2
*/tm/wrs2

Within each of these main directories you may have several scene directories, each with their own targz folder.

For all the scenes identified intersecting your region of interest, create directories for them following the LLR directory structure.

Download Landsat images

All images are downloaded from the USGS Earth Explorer website. MSS images should be of the LPGS product type and TM/ETM+ of the Landsat CDR (LEDAPS) type. For Landsat MSS 1-3 (WRS-1), MSS 4-5 (WRS-2), TM and ETM+ you will select images to include in separate processing orders. You will need an Earth Explorer user account to download images. You can register for one on the home page, if you don’t already have an account.

Currently, LLR is designed to work with summer images from July – August. Using this short time window during the summer reduces the ephemeral spectral inter- and intra-annual variability due to phenology, snow cover, and sun angle. We are working on ways to allow more flexibly in date range, but for now it is advisable to use only images from July and August.

MSS images

1. At the Earth Explorer homepage, within the “Search Criteria” tab and under the “Data Range” tab select only months July and August from the “Search months” drop down menu.
2. Under the “Results Options” tab increase the “Number of records to return” to 1,000 (ensures that the image list is not truncated) and then press the “Data Sets” button

3. Expand the “Landsat Archive” menu and check the “L1-5 MSS” box and click the “Additional Criteria” tab.
4. Scroll down to the “WRS Type” menu and select the WRS type that corresponds to the scene you intend to download. “WRS for Landsat 1, 2, & 3” (WRS-1) or “WRS for Landsat 4 & 5” (WRS-2).
5. Under the “WRS Path” and “WRS Row” fields enter the associated path and row number for the scene of interest.
6. Scroll down to the “Data Type Level 1” menu and select “MSS L1T” and then click the “Results” button
7. For each image in the list that is not completely clouded select either the “Add to Bulk Download” button or “Add to Cart” button and then press the “View Item Basket”
8. Review your selected images to ensure that you have images for only the intended scene from July and August for years 1972 -1982 (WRS-1) or 1982 - 1992 (WRS-2) (may be some missing years for lack of data) and then press the “Proceed to Checkout” button.
9. Press the “Submit Order” button.
10. You will receive an order confirmation email. If the order includes images added as “Bulk Download” they are immediately available. Follow the instructions in the email to download them. If there are images that were added to the cart for processing, then you will be instructed to wait for a second email indicating that processing is complete.

Repeat these steps for all MSS scenes (WRS-1 and WRS-2), adjusting the WRS type and path/row entries as needed in steps 4 and 5.

Once images have been downloaded move them to the “targz” folder for the appropriate sensor, WRS type, and path/row identification.

TM/ETM+ images

Downloading TM/ETM+ images requires the same steps as downloading MSS images, but with a different data set selection.

1. At the [Earth Explorer homepage](), within the “Search Criteria” tab and under the “Data Range” tab select only months July and August from the “Search months” drop down menu.
2. Under the “Results Options” tab increase the “Number of records to return” to 1,000 (ensures that the image list is not truncated) and then press the “Data Sets” button
3. Expand the “Landsat CDR menu and check the “Land Surface Reflectance” box for “L4-5 TM” and click the “Additional Criteria” tab.
4. Under the “WRS Path” and “WRS Row” fields enter the associated path and row number for the scene of interest.
5. Scroll down to the “Data Type Level 1” menu and select “TM L1T” and then click the “Results” button
6. For each image in the list that is not completely clouded select either the “Add to Bulk Download” button or “Add to Cart” button and then press the “View Item Basket”

7. Review your selected images to ensure that you have images for only the intended scene from July and August for years 1982 - 2011 (TM) or 1999 - present (ETM+) (may be some missing years for lack of data) and then press the "Proceed to Checkout" button.
8. Press the "Submit Order" button.
9. You will receive an order confirmation email. If the order includes images added as "Bulk Download" they are immediately available. Follow the instructions in the email to download them. If there are images that were added to the cart for processing, then you will be instructed to wait for a second email indicating that processing is complete. When processing is complete follow instructions for downloading. If the email does not indicate the option to bulk download the files you can use a third party downloading utility such as DownThemAll for the Mozilla Firefox browser to efficiently retrieve all hyperlinked files on the image download list page.

Repeat these steps to place an order for ETM+ images with exceptions for step 3 and 5 where you will select the ETM+ sensor options instead of TM.

Once images have been downloaded move them to the "targz" folder for the appropriate sensor, WRS type, and path/row identification.

Note that there are multiple ways to get the image data, the method above is just one example. As long as the MSS data are LPGS compressed .tar.gz files and the TM/ETM+ images are LEDAPS CDR .tar.gz compressed files then LLR should ingest them just fine.

Image information

Please see the hyperlinked USGS product guides for more information regarding image processing of LPGS MSS and CDR TM/ETM+ Surface Reflectance data.

Downloaded images are named with a unique identity that contains basic information on each image. All components of the image ID, except for ground station and version, are maintained throughout the production of derived data in the LLR process (more on this in Outputs section).

Landsat Image Identifier: LXSPPPRRRYYYYDDDGSIVV

Where:
L = Landsat
X = Sensor (M = MSS, T = TM(4-5) or TIRS(8), E = ETM, O = OLI(8), C = OLI_TIRS(8))
S = Satellite
PPP = WRS Path
RRR = WRS Row
YYYY = Year of Acquisition
DDD = Day of Acquisition Year
GSI = Ground Station Identifier
VV = Version

Digital elevation model

A digital elevation model is needed for processing both MSS WRS-1 and MSS WRS-2 scenes. It is used during the cloud masking procedure to correct for topographic illumination and identifying water. The extent of the DEM should be larger than its corresponding scene. So depending on what DEM product you use, you may need to mosaic several together. The DEM should be between 30 and 90 meter resolution. The program will ask you for its location and then it will automatically resample, reproject, and crop it to match a given scene. A good source for DEMs is the Global Landcover Facility site, which distributes SRTM data as Landsat WRS-2 footprints. Use the Filled Finished-B product at 1 arc second (30 meter) where possible and the Filled Finished-B product at 3 arc seconds (90 meter) elsewhere. You can use other data sources, but SRTM has the advantage of being a global product with standard processing and void filling. The program-prepared DEM files will be written to a new directory called "topo" inside of the scene folder.

Running LandsatLinkr

With images downloaded and archived in their appropriate directory structures, and all required programs installed, LLR is ready to run. The following instructions walk through the process of running LLR with instruction descriptions as plain text, R commands to be typed or copied/pasted into the R command prompt outlined in grey boxes, printouts from the R council outlined in red boxes, and specific references to "R text" in blue font.

*Before running any functions, ensure that LLR is loaded in your current R session. Type the following command into the console and press enter.

```
library(LandsatLinkr)
```

Running LLR Step 1 – Prepare MSS images

1. Call the LandsatLinkr program - open RStudio and type the following command into the console and press enter.

```
run_landsatlinkr()
```

2. Select a process to run - within the console you will be presented with a list of options for which process to run.

```
Select a process to run

1: Prepare MSS
2: Prepare TM/ETM+
3: Calibrate MSS to TM/ETM+
4: Composite imagery
5: Fit neat lines

Selection:
```

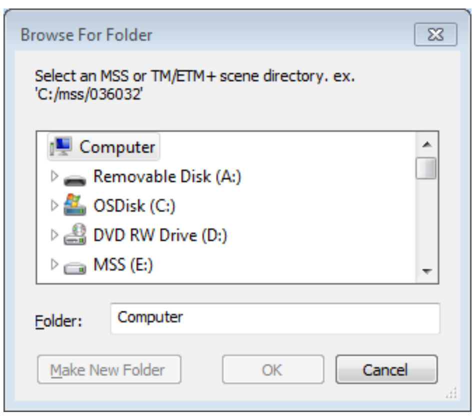
Place your cursor after Selection: and type 1 and press enter to run `Prepare MSS`.

3. Choose how many cores to process imagery with - within the console you will be presented with a choice of processing in parallel with two cores or not.

```
Process in parallel using 2 cores?

1: No
2: Yes

Selection:
```

Place your cursor after Selection: and type 1 (do not process in parallel) or 2 (process in parallel) and press enter to commit the selection. Note: processing is limited to a maximum of 2 cores for I/O reasons.

4. Select an MSS scene directory to process imagery from - a Windows directory browser pop-up will prompt you to interactively choose a folder. Navigate to an MSS scene directory. Be sure to select the scene head folder designated by a 6 digit WRS identifier (example: 034032). Note: the browser pop-up will not always come up as the active window so the icon must be clicked on in the Windows application menu bar.

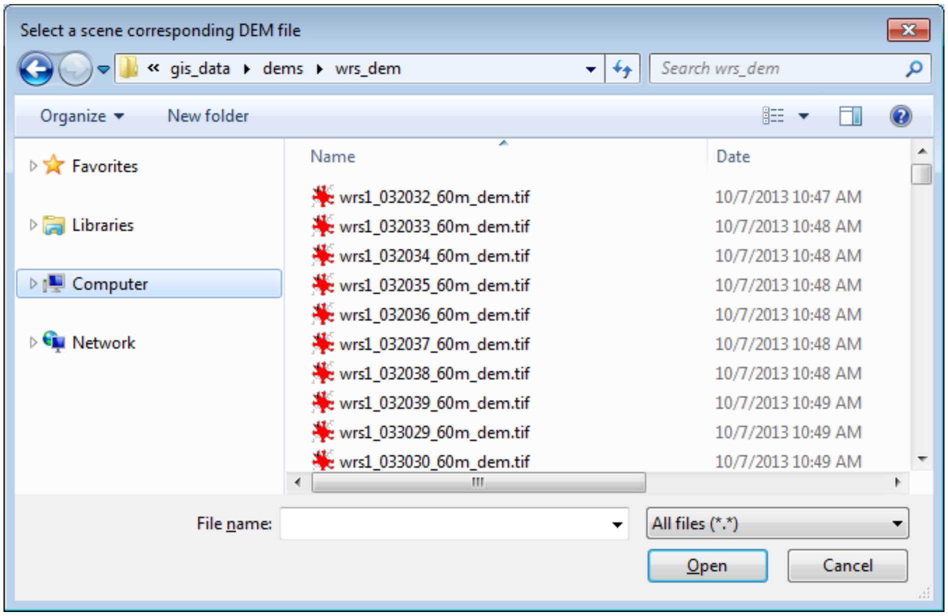


5. Select a map projection to use - within the console you will be presented with a choice of using the native NAD83 UTM projection or USGS North American Albers.

```
Select a map projection to use

1: Native NAD83 UTM
2: USGS North American Albers

Selection:
```

Place your cursor after Selection: and type 1 or 2 and press enter to commit the selection. Note: it is recommended that you use USGS North American Albers so that there is consistency across scene boundaries. Also, we are working on allowing users to provide their own PROJ.4 projection definition.

6. Select a scene corresponding DEM - a Windows directory browser pop-up will prompt you to interactively choose a file. Navigate to a DEM file that has full overlap (plus some buffer) with the MSS scene you selected in Step 4. Note: the browser pop-up will not always come up as the active window so the icon must be clicked on in the Windows application menu bar.



The run_landsatlinkr() will take the information supplied and run through all procedures in Step 1: Prepare MSS described in Fig. 2 for each image in the selected scene directory. The process can take 12 hours.

*Repeat all of these steps for all MSS WRS-1 or MSS WRS-2 scenes that intersect your region of interest.

Running LLR Step 2 – Prepare TM/ETM+ images

Repeat the same steps as “Running LLR Step 1 – Prepare MSS images”, except select 2 (Prepare TM/ETM+) when prompted to `“Select a function to run”.` Also, be sure to select a TM/ETM+ scene directory when prompted with the Windows directory browser. Note: you will not be asked to select a scene corresponding DEM file.

Running LLR Step 3 – MSS to TM/ETM+ calibration

1. Call the LandsatLinkr program - open RStudio and type the following command into the console and press enter.

```
run_landsatlinkr()
```

2. Select a process to run - within the console you will be presented with a list of options for which process to run.

```
Select a process to run

1: Prepare MSS
2: Prepare TM/ETM+
3: Calibrate MSS to TM/ETM+
4: Composite imagery

Selection:
```

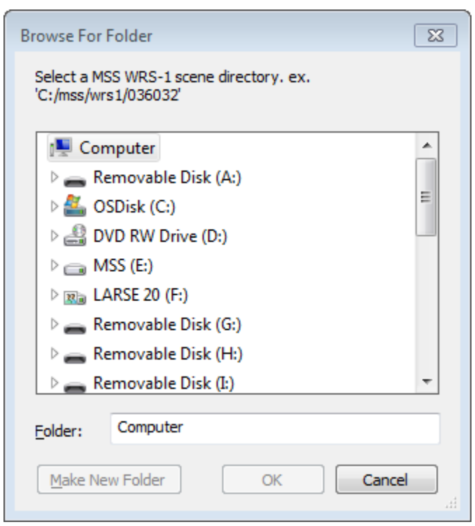
Place your cursor after Selection: and type 3 and press enter to run `Calibrate MSS to TM/ETM+`.

3. Choose how many cores to process imagery with - within the console you will be presented with a choice of processing in parallel with two cores or not.

```
Process in parallel using 2 cores?

1: No
2: Yes

Selection:
```

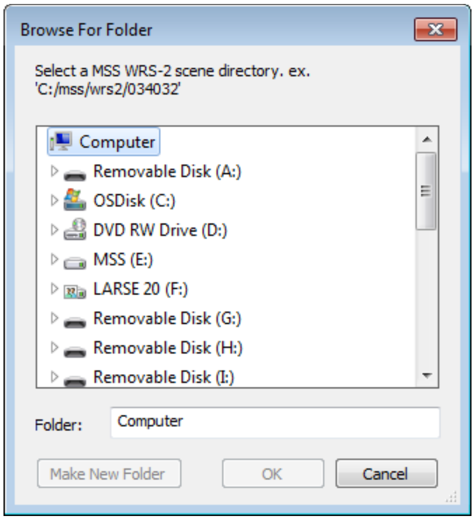
Place your cursor after Selection: and type 1 or 2 and press enter to commit the selection. Note: processing is limited to a maximum of 2 cores for I/O reasons.

4. Select a MSS WRS-1 scene directory to be calibrated and included in compositing - a Windows directory browser pop-up will prompt you to interactively choose a folder. Navigate to an MSS WRS-1 scene directory. Be sure to select the scene head folder designated by a 6 digit WRS identifier (example: 034032). Note: the browser pop-up will not always come up as the active window so the icon must be clicked on in the Windows application menu bar.

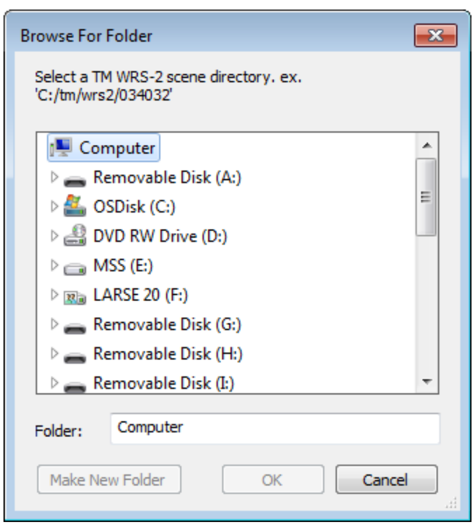


5. Select a MSS WRS-2 scene directory to be calibrated and included in compositing - a Windows directory browser pop-up will prompt you to interactively choose a folder. Navigate to an MSS WRS-2 scene directory. Be sure to select the scene head folder designated by a 6 digit WRS identifier (example:

034032). Note: the browser pop-up will not always come up as the active window so the icon must be clicked on in the Windows application menu bar.



6. Select a TM WRS-2 scene directory to be calibrated and included in compositing - a Windows directory browser pop-up will prompt you to interactively choose a folder. Navigate to an TM WRS-2 scene directory. Be sure to select the scene head folder designated by a 6 digit WRS identifier (example: 034032). Note: the browser pop-up will not always come up as the active window so the icon must be clicked on in the Windows application menu bar.



Running LLR Step 4 – Compositing

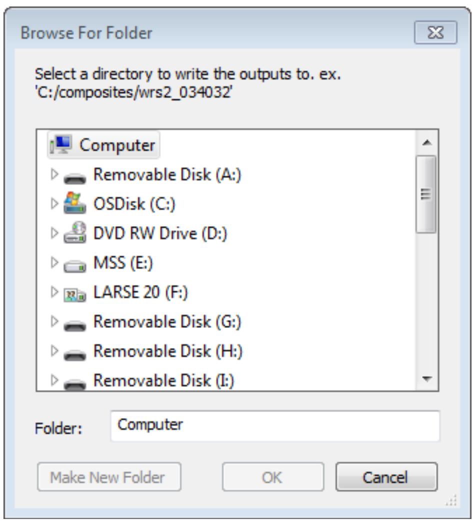
Repeat the same steps as “Running LLR Step 3 – MSS to TM/ETM+ calibration”, except select 4 (`Composite imagery`) when prompted to “`Select a function to run`”. Additionally, after selecting a directory for MSS WRS-1, MSS WRS-2, and TM WRS-2 image sets you will be asked if there are any other directories you want to add. This allows you to create composites that straddle multiple scenes.

```
Is there another MSS WRS-1 scene directory to add?

1: Yes
2: No

Selection:
```

Place your cursor after Selection: and type 1 or 2 and press enter to commit the selection. This process of adding directories will continue for each sensor/WRS type until you select No.

Once you've selected all directories to include in compositing, complete the following steps.

7. Select a composite output directory where composite image files are to be written - a Windows directory browser pop-up will prompt you to interactively choose a folder. Navigate to a directory you have created ahead of time or create one using the browser. Note: the browser pop-up will not always come up as the active window so the icon must be clicked on in the Windows application menu bar.



8. Select a spectral index to create composites for - within the console you will be presented with a choice of tasseled cap: angle, brightness, greenness, and wetness.

```
Select an index to create composites for

1: Tasseled cap angle
2: Tasseled cap brightness
3: Tasseled cap greenness
4: Tasseled cap wetness

Selection:
```

Place your cursor after Selection: and type 1 (Tasseled cap angle), 2 (Tasseled cap brightness), 3 (Tasseled cap greenness) or 4 (Tasseled cap wetness) and press enter to commit the selection. Note: working on an option to create composites for multiple indices without re-running this step.

8. Provide a unique name for the composite image data - within the console you will be prompted to type in a name for the composite.

```
Provide a unique name for the composite series. ex. project1:
```

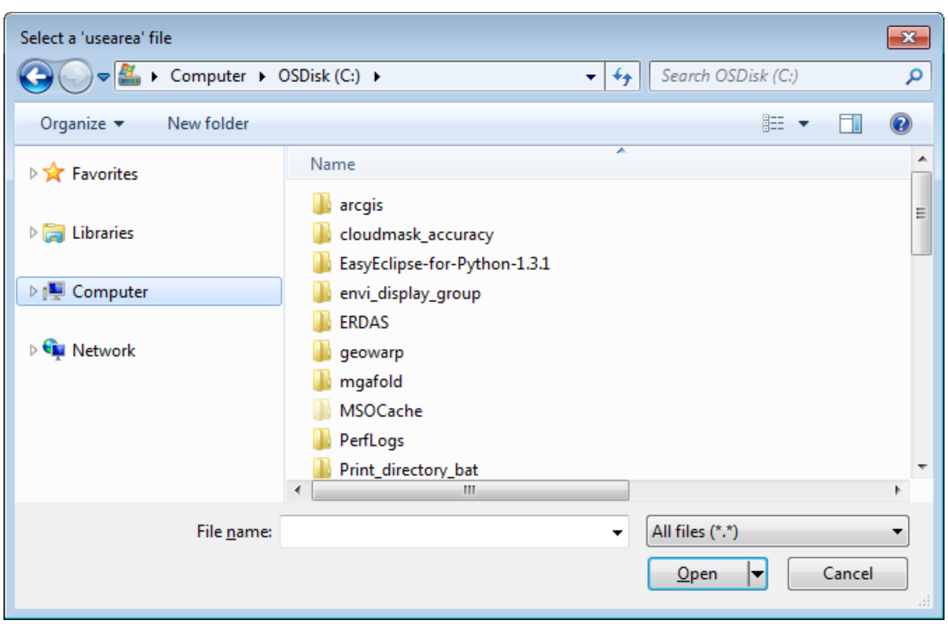
Place your cursor after ex. project1: and type a name or unique identifier without quotations. The name can contain any character allowed in a file path. The name will automatically be inserted into the series of composite output file names.

9. Select a geographic region to create composites for - within the console you will be prompted to select an option for defining a region of interest to create composites for.

```
What area do you want to create composites for?

1: From file

Selection:
```

Place your cursor after Selection: and type 1 (From file) Note: working on an option to create composites for area of intersection of MSS WRS-1, MSS WRS-2, and TM WRS-2 for a WRS-2 scene of interest.

If you are defining the region of interest for compositing from a file a Windows directory browser pop-up will prompt you to interactively choose a file. Select a geographically coincident usearea that geographically corresponds to the extent of your image data. Ensure that the usearea file contains only values 0 and 1, where 0 indicates areas to ignore in compositing, and 1 where compositing is to be preformed. Note: the browser pop-up will not always come up as the active window so the icon must be clicked on in the Windows application menu bar.



Outputs

LandsatLinkr produces many new files including directories, raster files, text files, comma delimitated files, and graphic files. Each adheres to a consistent naming convention and is placed in a defined directory structure. Image outputs are divided into three categories: individual, calibration, and composite. The following sections describe the files in each category.

Individual image outputs

During the preparation of MSS and TM/ETM+ images for a given scene, a new directory called “images” is created with subdirectories for each year of imagery (Figure 5).

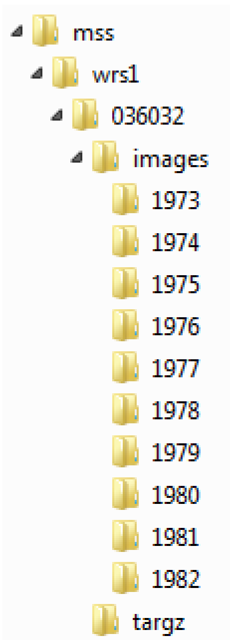


Figure 5. Example directory structure for individual files.

Within the individual year folders, a series of image and ancillary files are produced for each date in that year. Filenames contain the Landsat image ID code and a unique descriptor. Each MSS image has 13 associated files (Figure 6) and TM/ETM+ images have 5 (Figure 7). Table 3 (MSS) and 4 (TM/ETM+) describe what each file is and what LLR function (see Figure 2 and appendices) creates it.

LM10360321973191_archv.tif
LM10360321973191_archv_drkobjv.png
LM10360321973191_cloud_rmse.csv
LM10360321973191_cloudmask.tif
LM10360321973191_dos_sr.tif
LM10360321973191_GCP.txt
LM10360321973191_MTL.txt
LM10360321973191_proj.txt
LM10360321973191_radiance.tif
LM10360321973191_tc.tif
LM10360321973191_tca.tif
LM10360321973191_VER.jpg
LM10360321973191_VER.txt

Figure 6. Example LLR filenames for an MSS image.

LT50340321984181_cloudmask.tif
LT50340321984181_ledaps.tif
LT50340321984181_proj.txt
LT50340321984181_tc.tif
LT50340321984181_tca.tif

Figure 7. Example LLR filenames for TM/ETM+ images.

File	Description	Function
archv.tif	4-band MSS DN image	MSSunpackr (LPGS L1T MSS image)
archv_drkobjv.png	Histogram-based dark object selection assessment aid	MSScost
cloud_rmse.csv	Percent cloud cover and georegistration RMSE information	MSSunpackr
cloudmask.tif	1-band cloud/shadow mask image. 0=clouds/shadow, 1=clear-view	MSScvm
dos_sr.tif	4-band MSS surface reflectance image	MSScost
GCP.txt	Ground control points used in USGS LPGS processing	MSSunpackr
MTL.txt	Image metadata	MSSunpackr (from LPGS processing)
proj.txt	PROJ.4 image projection definition	MSSunpackr
radiance.tif	4-band MSS radiance image	MSSdn2rad
tc.tif	3-band MSS tasseled cap image (brightness, greenness, wetness)	MSScal
tca.tif	1-band MSS tasseled cap angle image	MSScal
VER.jpg	Verify Image Product from USGS LPGS processing (georegistration information)	MSSunpackr (from LPGS processing)
VER.txt	Verify Image Product from USGS LPGS processing (georegistration information)	MSSunpackr (from LPGS processing)

Table 3. Description of MSS files associated with each MSS image.

File	Description	Function

cloudmask.tif	1-band cloud/shadow mask image. 0=clouds/shadow, 1=clear-view	TMunpackr (FMask)
ledaps.tif	6-band TM/ETM+ surface reflectance image from LEDAPS	TMunpackr (LEDAPS image)
proj.txt	PROJ.4 image projection definition	TMunpackr
tc.tif	3-band TM/ETM+ tasseled cap image (brightness, greenness, wetness)	TMunpackr
tca.tif	1-band TM tasseled cap angle image	TMunpackr

Table 4. Description of TM/ETM+ files associated with each TM/ETM+ image.

Calibration outputs

MSS WRS-2 images spectrally tie all intersecting MSS images to the TM/ETM+ images for a given scene. Landsat satellites 4 and 5 carried both MSS and TM sensors and from 1982 to 1992 collected images coincidently. These coincident image pairs provide an excellent dataset to calibrate the MSS data to TM/ETM+ data. Currently, linear models for each coincident pair are developed, as well as an aggregated model that combines a sample of pixels from each pair together in one model. The single models are compared against the aggregated model for evaluation purposes, but in the end only the aggregated model is used to calibrate MSS images to TM/ETM+ images. Until we are confident in these methods, a large number of diagnostic files are produced and placed in a directory structure in the MSS WRS-2 scene folders under "calibration" (Figure 8).

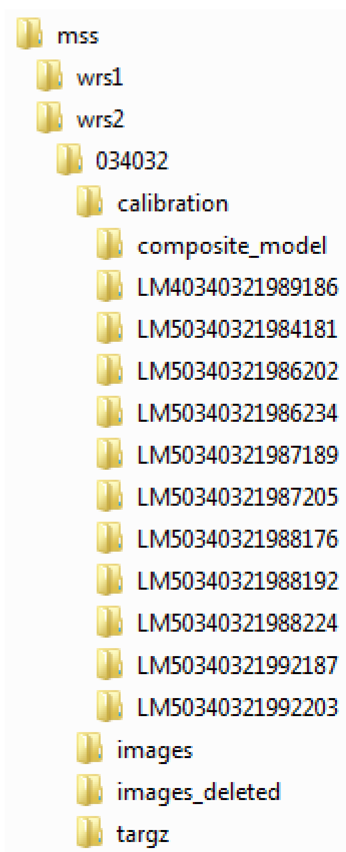


Figure 8. Example directory structure demonstrating the "calibration" folder

Within the calibration folder there are a number of Landsat image ID folders that contain files specific to each MSS/TM pair-wise model. Figure 9 and Table 5 respectively show and describe the files.

LM40340321989186_tc_cal_planes.png
LM40340321989186_tca_cal_coef.csv
LM40340321989186_tca_cal_plot.png
LM40340321989186_tca_cal_samp.csv
LM40340321989186_tcb_cal_coef.csv
LM40340321989186_tcb_cal_plot.png
LM40340321989186_tcb_cal_samp.csv
LM40340321989186_tcg_cal_coef.csv
LM40340321989186_tcg_cal_plot.png
LM40340321989186_tcg_cal_samp.csv
LM40340321989186_tcw_cal_coef.csv
LM40340321989186_tcw_cal_plot.png
LM40340321989186_tcw_cal_samp.csv

Figure 9. Example LLR filenames for individual MSS/TM image pair models.

File	Description
tc_cal_planes.png	Graphic displaying the comparison of MSS and TM based tasseled cap planes
***cal_coef.csv**	Linear model coefficients for deriving TM index from MSS bands
***cal_plot.png**	Scatterplot showing relationship between MSS-modeled index and TM index
***cal_samp.csv**	Table of sample values from MSS and TM used to develop linear model

Table 5. Description of MSS individual image-pair model calibration files. *Files exist for each Tasseled cap index: brightness (tcb), greenness (tcg), wetness (tcw), and angle (tca).

Besides the individual image-pair model folders there is a “composite_model” folder that contains diagnostic files related to the aggregate models (Figure 10).

composite_cal_tc_planes_comparison.png
tca_cal_combined_coef.csv
tca_cal_composite_coef.csv
tca_cal_composite_sample.csv
tca_composite_mean_dif.png
tca_composite_regression.png
tca_single_mean_dif.png
tca_single_regression.png

Figure 10. Example files for the composite model.

File	Description
composite_cal_tc_planes_comparison.png	Graphic displaying the comparison of MSS and TM based tasseled cap planes
***cal_combined_coef.csv**	List of all individual image-pair linear model coefficients for deriving TM index from MSS bands
***cal_composite_coef.csv**	Aggregated image-pair linear model coefficients for deriving TM index from MSS bands
***composite_sample.csv**	Table of aggregated image-pair sample values from MSS and TM used to develop linear model
***composite_mean_dif.png**	Table of sample values from MSS and TM used to develop linear model
***composite_regression.png**	Scatterplot showing relationship between MSS aggregated model based index values and corresponding TM index values.
***single_mean_dif.png**	Graphic displaying the mean difference between actual TM values and corresponding MSS aggregated model based values
***single_regression.png**	Graphic displaying the mean difference between actual TM values and corresponding MSS individual image-pair model based values

Table 6. Description of MSS aggregated model calibration files. *Files exist for each Tasseled cap index: brightness (tcb), greenness (tcg), wetness (tcw), and angle (tca).

Composite outputs

The final step of LLR creates annual cloud free composites by applying image cloud masks and merging multiple overlapping images from the same year into a single image using the mean. It produces a set of files for each index selected as individual year composite images and also as a temporal stack. The output directory is specified by the user along with a unique composite identification string that is included all file names for a given study area composite set. A subset example of the output files are showing figure XX and Table XX describes what each file is. All file names adhere to the following naming convention:

<year>_<unique ID>_<spectral index>_<descriptor>.<extension>
Example: 2013_test_tca_composite.bsq
year = the year of the image composite
unique ID = the user-provided name of the composite series requested upon running the Step 4 of LLR
spectral index = the spectral index of the composite series
descriptor = a string describing the file
extension = file extension

2013_test_tca_composite.bsq
2013_test_tca_composite.bsq.aux.xml
2013_test_tca_composite.hdr
2013_test_tca_composite_img_list.csv
2014_test_tca_composite.bsq
2014_test_tca_composite.bsq.aux.xml
2014_test_tca_composite.hdr
2014_test_tca_composite_img_list.csv
test_tca_composite.bsq
test_tca_composite.bsq.aux.xml
test_tca_composite.hdr

Figure 11. Example composite image files.

File	Description
<year>_<id>_<index>_composite.bsq	Image composite for a given year – ENVI file type
<year>_<id>_<index>_composite.bsq.aux.xml	Metadata for the corresponding composite image produced by default when writing ENVI files
<year>_<id>_<index>_composite.hdr	ENVI header file – needs to always accompany the corresponding .bsq image file
<year>_<id>_<index>_composite_img_list.csv	A list of individual images that went into creating the composite for a given year
<id>_<index>_composite.bsq	Annual image composite stack with as many bands as there are years. The bands are in acceding order of years ie low band number = early year and high band number = late year
<id>_<index>_composite.bsq.aux.xml	Metadata for the corresponding composite image produced by default when writing ENVI files
<id>_<index>_composite.hdr	ENVI header file – needs to always accompany the corresponding .bsq image file

Table 7. Description of composite image files.

LandsatLinkr function descriptions

MSSunpackr

MSSunpacker automatically assesses image quality, decompress, resamples, stacks, reprojects, and fixes image edge error. It locates the targz folder in the user-provided scene directory path and for each compressed image file creates a new temporary folder where compressed images in the targz folder are decompressed to. It reviews the image metadata to determine if it is an L1G or L1T processed file. If the image is only processed to L1G all files associated with the image are deleted and a record is made in the scene sub-folder *images_deleted*. If the image is L1T, then a 4-band raster stack file is created from the 4 individual MSS band files. Pixels with values of 0 or 1 in any band are then set to background as background (value 0) – if a pixel is background in 1 band all corresponding pixels in the other bands are set to background as well. This procedure cleans bad data apparent along the edge of images when overlapping scenes are mosiaced. Images that are composed of greater than 75% of these bad pixels EW deleted along with all associated files and recorded as a note in the *images_deleted* folder. An estimate of the percent cloud cover is made by finding the proportion of pixels in MSS band 1(4) greater than 130. This value along with the scene georegistration RMSE are recorded in a file.

MSSwarp

MSSwarp automatically checks georegistration accuracy of MSS images and attempts to improve images with poor positional RMSE. It looks at image metadata on georegistration found in the **VER.*txt file accompanying each MSS LPGS to determine georegistration accuracy. If the overall scene RMSE is > 0.75, the image is selected for improvement. An image-to-image tie-point search and warping procedure based on Kennedy & Cohen (2003) is conducted. More specifically, a geometric reference image is selected automatically by identifying an MSS image with the lowest percent cloud cover and lowest scene RMSE. The procedure then creates a series of spatially corresponding image subsets for both the geometric reference image and the image being adjusted (Figure 12). For each image subset, the dependent image chip is offset from its original position and slide over the reference image chip in single pixel increments. At each adjusted position the cross correlation coefficient for the overlapping area of the image subsets are calculated (Figure 13). The correlation coefficient matrices are evaluated as surfaces where the best matching position between reference and depended image subsets is the apex of a cone representing radially increasing correlation (Figure 14). The cross correlation surfaces are filtered for noise and prominence of the apex to ensure proper fitting. Further, the x and y coordinates of acceptable surfaces are evaluated for their individual contribution to overall RMSE of all position offsets. Points that disproportionately contribute to overall error are removed. This process iterates until either no points exceed the threshold for acceptable error contribution or until the minimum number of points for the warp model is reached. The remaining points are used in a 2nd order polynomial function (*gdalwarp* – see *System requirements* section) to spatially warp the dependent image to more closely align with reference image.

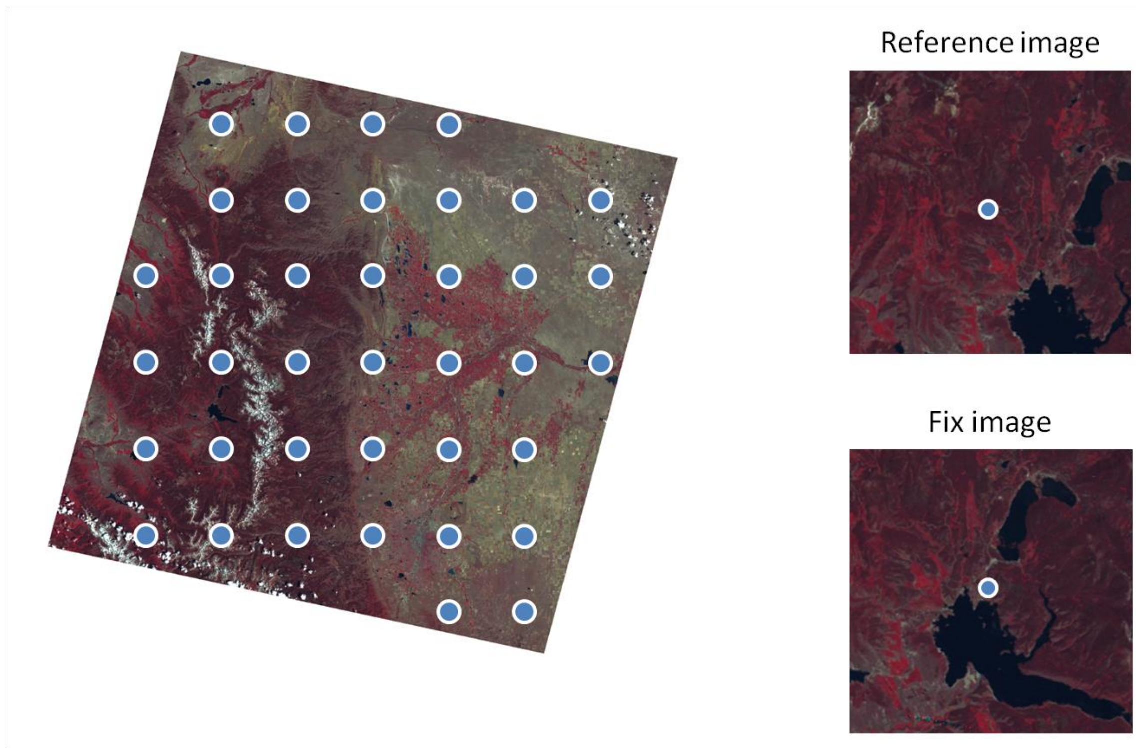


Figure 12. Representation of MSSwarp image sampling and image subsets. Note the spatial difference between the reference and fix image subset for the same geographic center. MSSwarp attempts to automatically determine the x and y coordinate offsets and spatially shift/warp the fix image to align with the reference image.

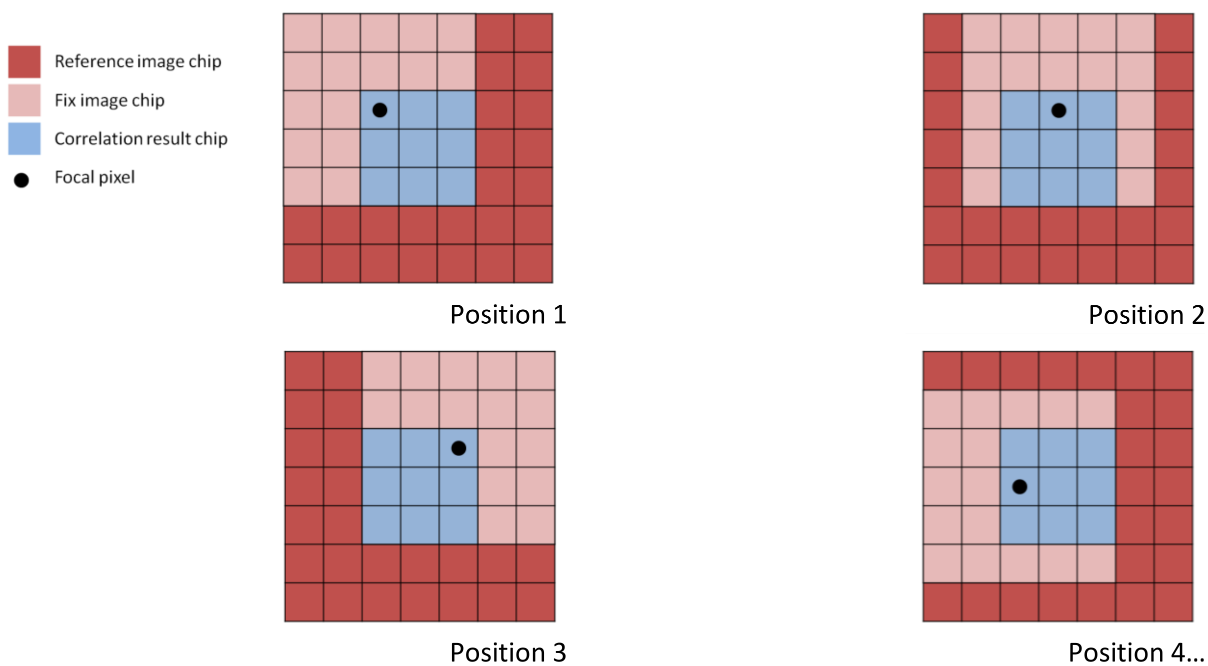


Figure 13. Example of the MSSwarp moving window cross correlation analysis for determining the x and y offset between the reference and fix image subset surrounding a sample point. For each position of the fix image chip the cross correlation between the overlapping area of the reference chip and the fix image chip is assigned to the focal pixel in the correlation result chip.

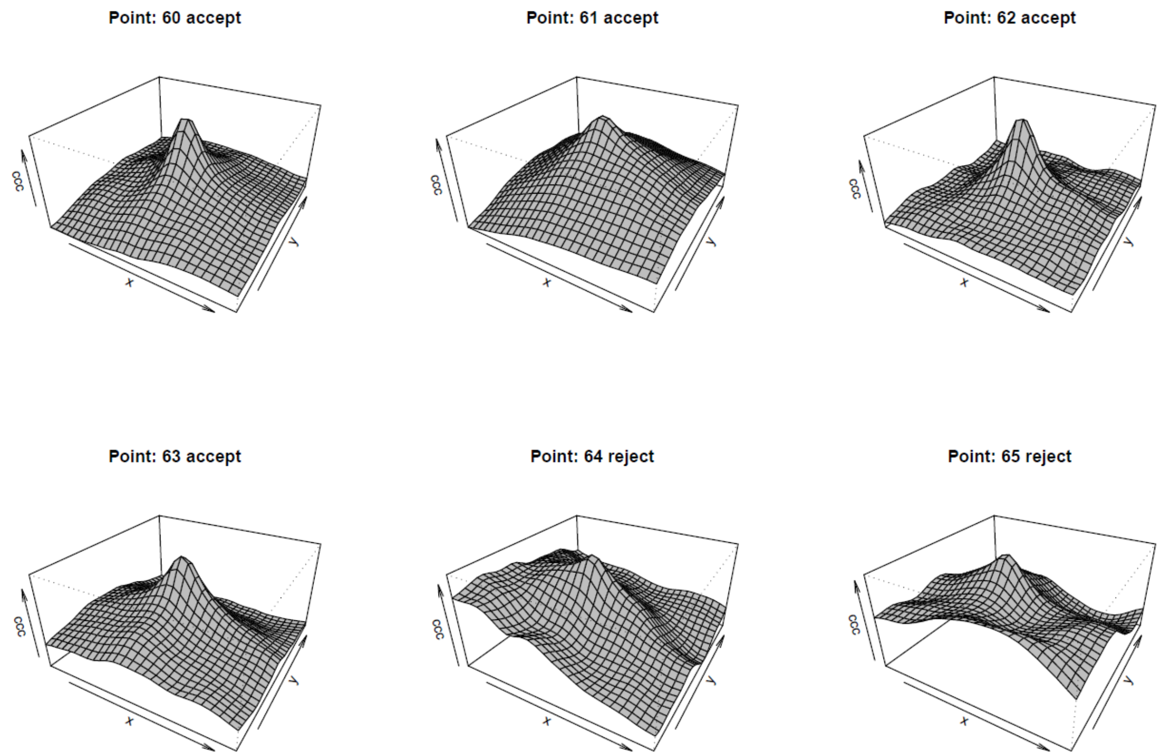


Figure 14. Example cross correlation coefficient surfaces from the MSSwarp moving window analysis. The x-y position of the cone apex represents the x-y offset needed to align a given fix image subset to its reference subset, with the center of the matrix equal to 0, 0. Note the filtering decision on whether to use the point in the warping equation or not – only prominent, well defined peaks are included in the warp model.

MSSdn2rad

MSS images with scaled digital number units are converted to units of top-of-atmosphere radiance by the equation:

L_λ = "gain" * QCAL + "bias"

As directed by USGS using parameters from LPGS L1T image metadata.
http://landsat.usgs.gov/how_is_radiance_calculated.php

MSScost

MSS images with units of scaled digital numbers are converted to units of surface reflectance using the COST method (Chavez, 1996). The “Lhaze” parameter or dark object value per band is estimated by the histogram method (Chavez, 1988) using an automated algorithm (Figure 15). The DN image and the estimated DN-based dark object values are converted to radiance using the equation described in the previous *MSSdn2rad* function. The dark object values are then subtracted from each band and then the conversion to surface reflectance is made using Equation 1.

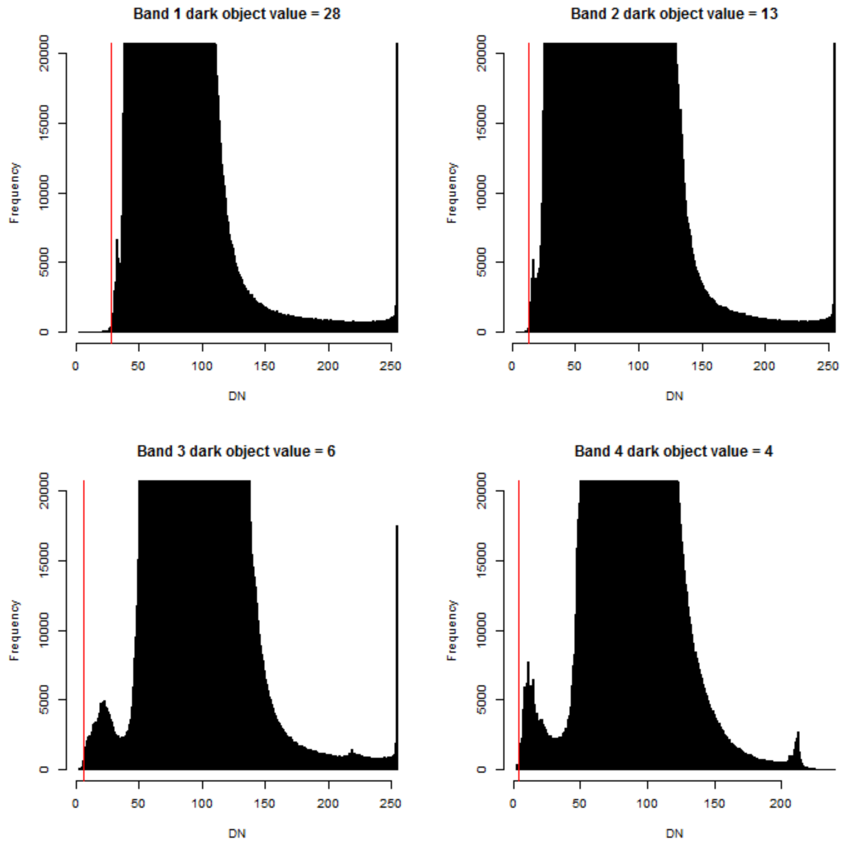


Figure 15. Demonstration of the automated histogram-based dark object value estimation. The red line indicates the estimated dark object value per band.

$$\rho_p = \frac{\pi \cdot L_\lambda \cdot d^2}{ESUN_\lambda \cdot cos\theta_s}$$

ρ_p = Unitless planetary reflectance
L_λ = Spectral radiance at the sensor's aperture
d = Earth-sun distance in astronomical units
$ESUN_\lambda$ = Mean solar exoatmospheric irradiances
θ_s = Solar zenith angle in degrees

Equation 1. Conversion from top-of-atmosphere radiance to surface reflectance

MSScvm

MSScvm (MSS clear-view-mask) is an automated cloud and cloud shadow identification algorithm for MSS imagery. The algorithm is specific to the unique spectral characteristics of MSS data, relying on a simple rule-based approach. Clouds are identified based on green band brightness and the normalized difference between the green and red bands, while shadows are identified by near infrared band darkness and exclusion of topographic shadows and water though illumination correction and a separate water identification module. Based on an accuracy assessment of 1,800 stratified random interpretation points representing twelve images with variation in land cover and cloud cover, MSScvm achieved an overall accuracy of 77.4%. Accuracy was highly dependent on land cover and cloud type, performing best for clouds and shadows over vegetative cover and for thick opaque clouds. Error in the assessment was mostly due to cloud shadow commission error and thin cloud omission error. Figure 16 provides a demonstration of the algorithm performance. The method is currently under revision for the journal Remote Sensing of Environment.

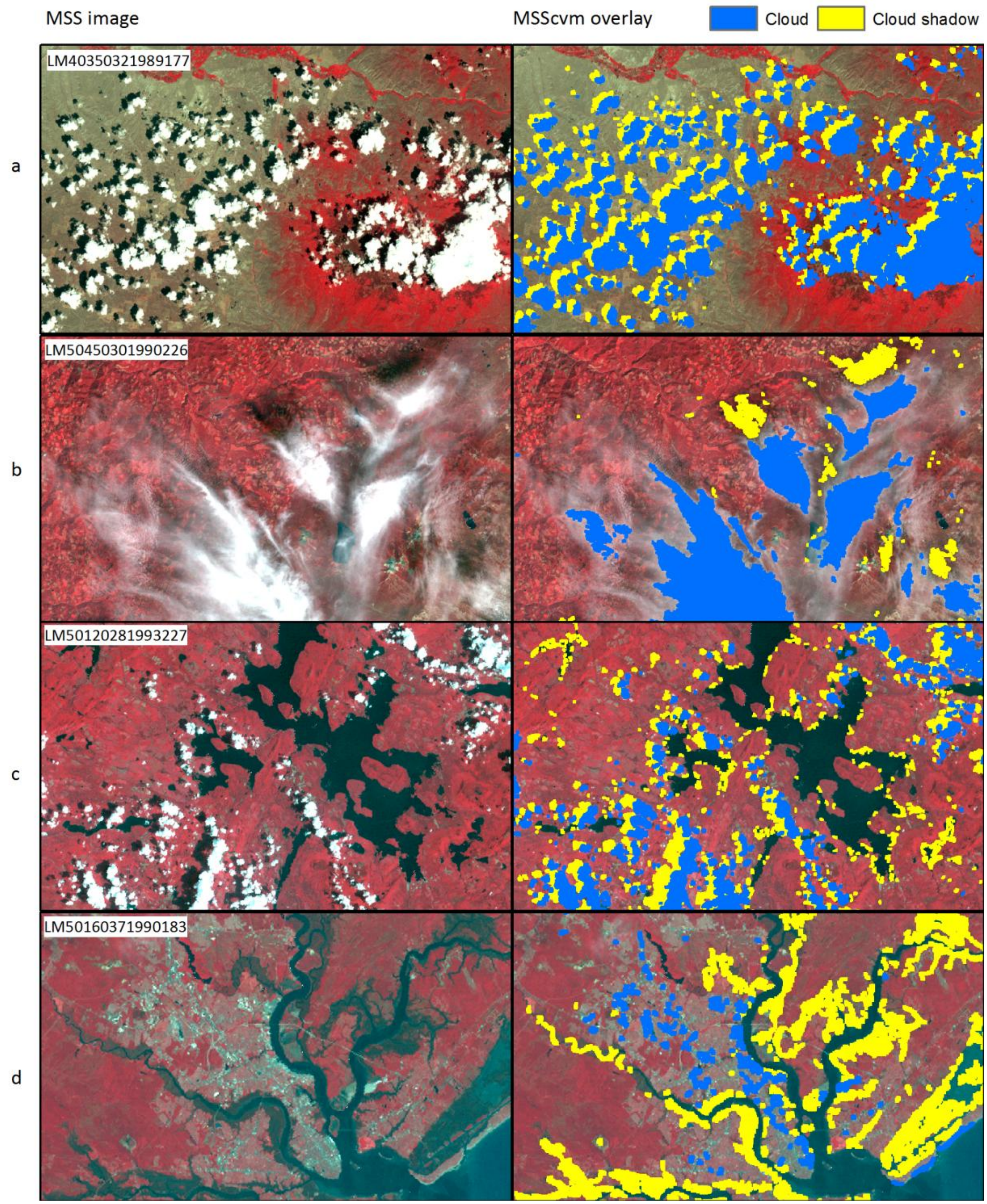


Figure 16. Examples of MSScvm algorithm performance for a sample of cloud, shadow, and land cover types. Thick, opaque clouds and their dark shadows are well identified in barren and forested cover (a). Thin, semi-transparent clouds and their diffusely illuminated shadows are often mislabeled as clear, causing a combination of commission and omission error (b). Though dark surfaces are sometimes confused for cloud shadows, water is largely unaffected, except at the shoreline (c). Very bright impervious surfaces, such as high density urban environments are occasionally identified as clouds, and dark wetland cover as shadow (d).

TMunpackr

TMunpacker automatically decompress, resamples, stacks, reprojects, produces tasseled cap transformations, and derives a cloud mask. It requires USGS CRD TM and ETM+ image products downloaded from USGS Earth Explorer as input. It locates these files in targz folder in the user-provided scene directory path. For each compressed image file it creates a new temporary folder where compressed images in the targz folder are decompressed to. The compressed CDR product includes LEDAPS surface reflectance image bands and cloud masks. TMunpackr decompresses the CDR product, stacks image bands 1-5 and 7 and optionally resamples and reprojects the image stack. The included Fmask cloud mask is reclassified to include on values 0 and 1 representing obscured and clear-view pixel designations. This mean that original values for cloud, cloud shadow, snow, and no observation are all assigned the value 0 while clear land and clear water are assigned the value 1. FMask reclassication is done to match the MSS cloud mask produced by MSScvm and to allow efficient mask application during the composting process (*miXel*). The cloud mask is resampled and reprojected in the same way as the corresponding image stack. Finally, the tasseled cap transformation is applied the surface reflectance image stack to produce tasseled cap brightness, greenness, and wetness spectral indices.

MSScal

MSScal calibrates MSS images to TM/ETM+ images through modeling of TM/ETM+ spectral indices from the 4 MSS bands. A set of coincident images are used to define the model (Landsat satellites 4 and 5 carried both MSS and TM sensors collecting images simultaneously). MSScal identified MSS/TM image pairs from directories provided by the user. A spatially coincident sample of pixel values are drawn from each image pair and placed in a large database (Figure 17). A separate database is created for each TM/ETM+ tasseled cap index (brightness, greenness, wetness, and angle). The MSS sample includes values from all 4 bands and the TM sample values represent a single spectral index. Multiple linear regression is applied to the predict the TM/ETM+ spectral index from the four MSS bands. Since the model incorporates variance introduced by multiple individual MSS/TM relationships, it represents a mean model which can be applied to all MSS images in an LLR project (Figure 18). To showcase the results of the calibration, three figures are provided. Figure 19 provides a visual comparison of standard tasseled cap planes for MSS (top row) and TM (bottom row) for a sample of pixel values from a coincident image pair. The shape and density of the scatter plots are very similar, particularly for tasseled cap brightness and greenness, with some disparity for wetness. In a similar example, Figure 20 shows an MSS/TM image pair as tasseled cap brightness, greenness, wetness displayed to the red, green, and blue color guns with the same scaling. Notice the close similarity in visual appearance. Finally, Figure 21 displays a time series of calibrated pixel values at a given coordinate for all images included for an example LLR project. Note the smooth blended transition between sensors at their overlap.

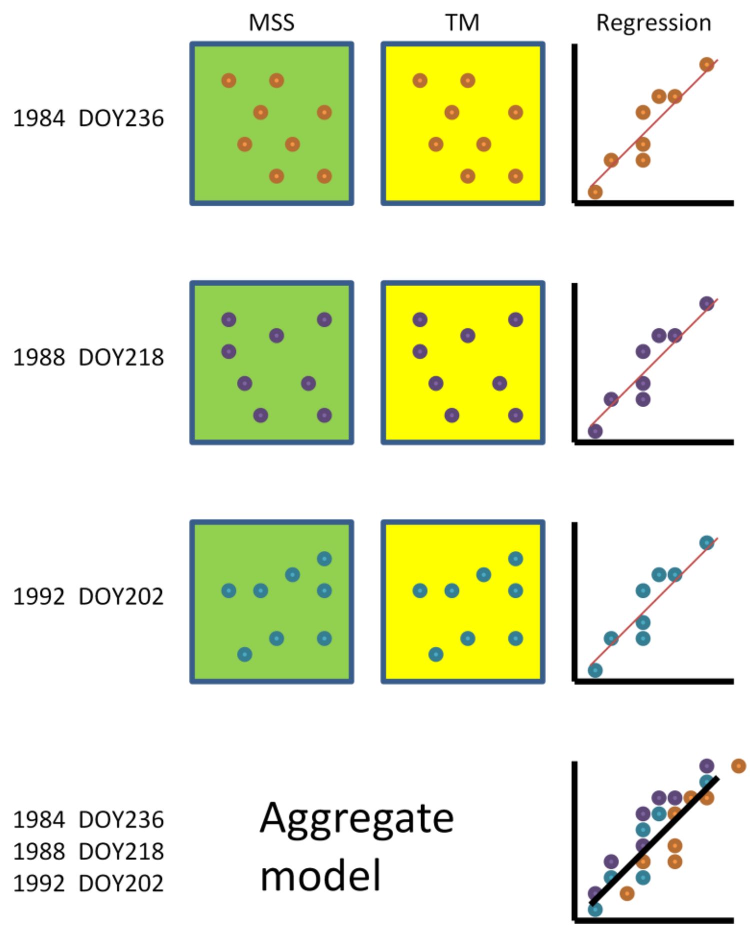


Figure 17. Conceptual depiction of LLR calibration model development. MSS and TM coincident image pairs are used to develop an "aggregated model" to predict TM indices from MSS bands. Each image pair provides a subset of data from which to develop the model. Combining information on the relationship between each image pair provides a mean model with which to apply to all MSS images in LLR project.

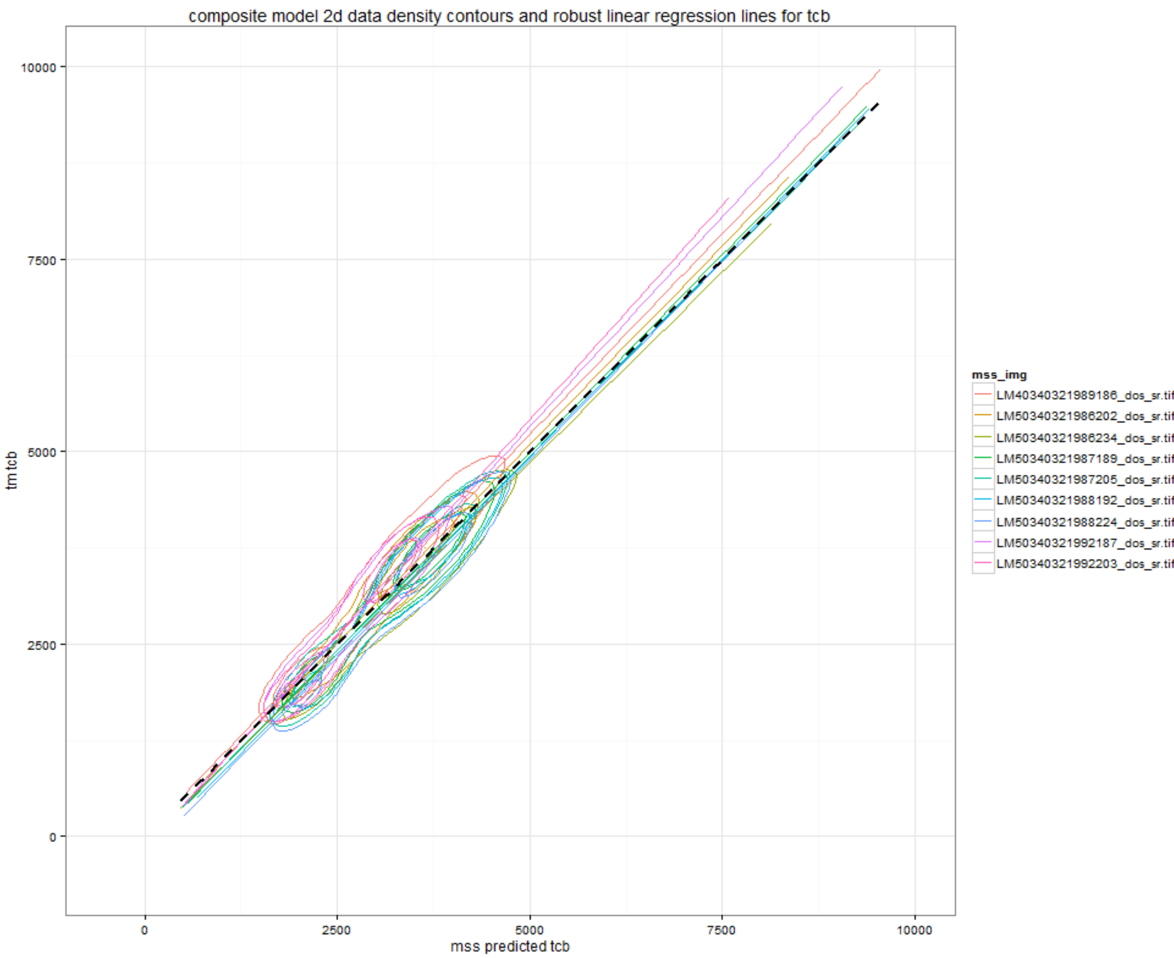


Figure 18. Example of actual models from Nine MSS/TM image pairs showing the data cloud and linear relationship for each individual image pair along with the aggregated model regression line (black dashed line). The aggregated model represents the mean relationship between MSS and TM and is applied to all MSS images.

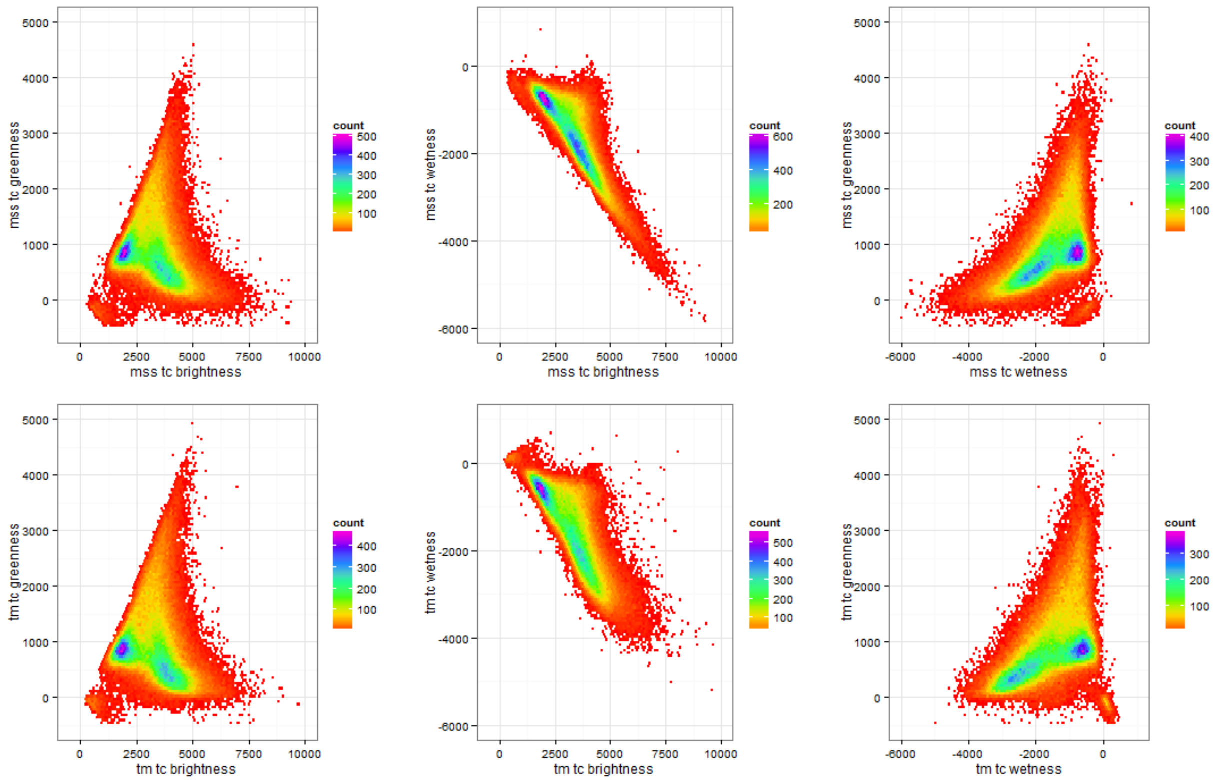


Figure 19. Comparison of the standard Tasseled cap planes for MSS (top row) and TM (bottom row) for coincident images.

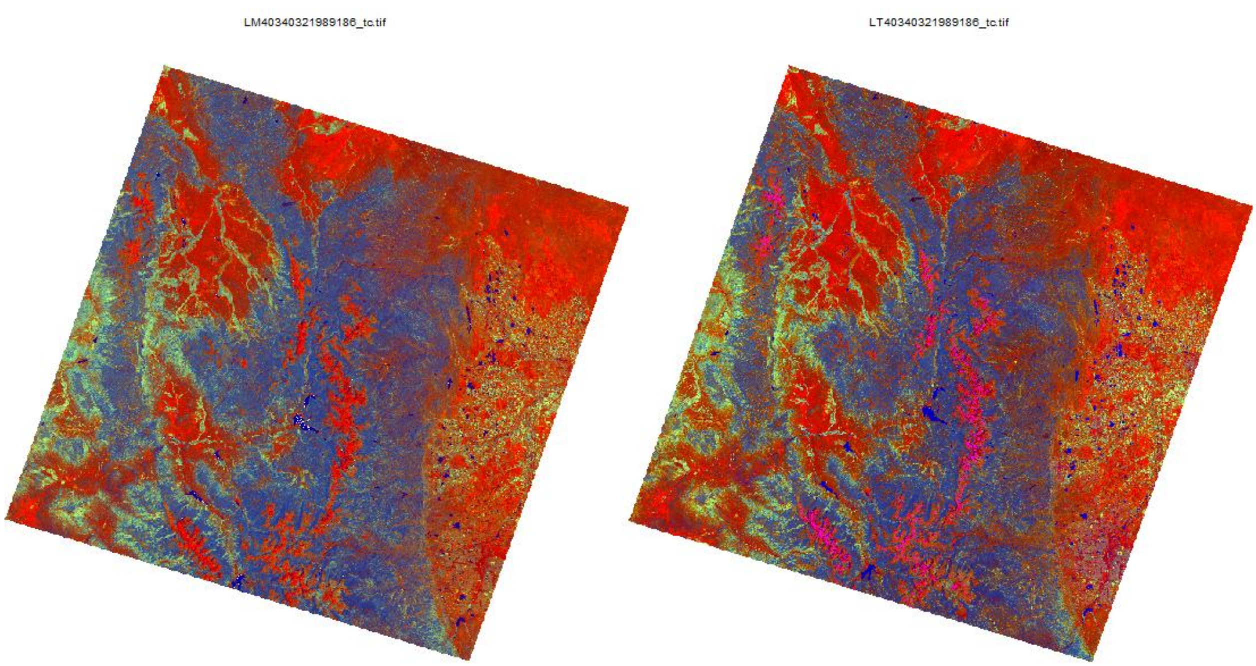


Figure 20. Example of MSS (left) and TM (right) tasseled cap indices brightness, greenness, wetness displayed with red, green, and blue color guns for a standardized scale. Note the close similarity between the two coincident image displays.

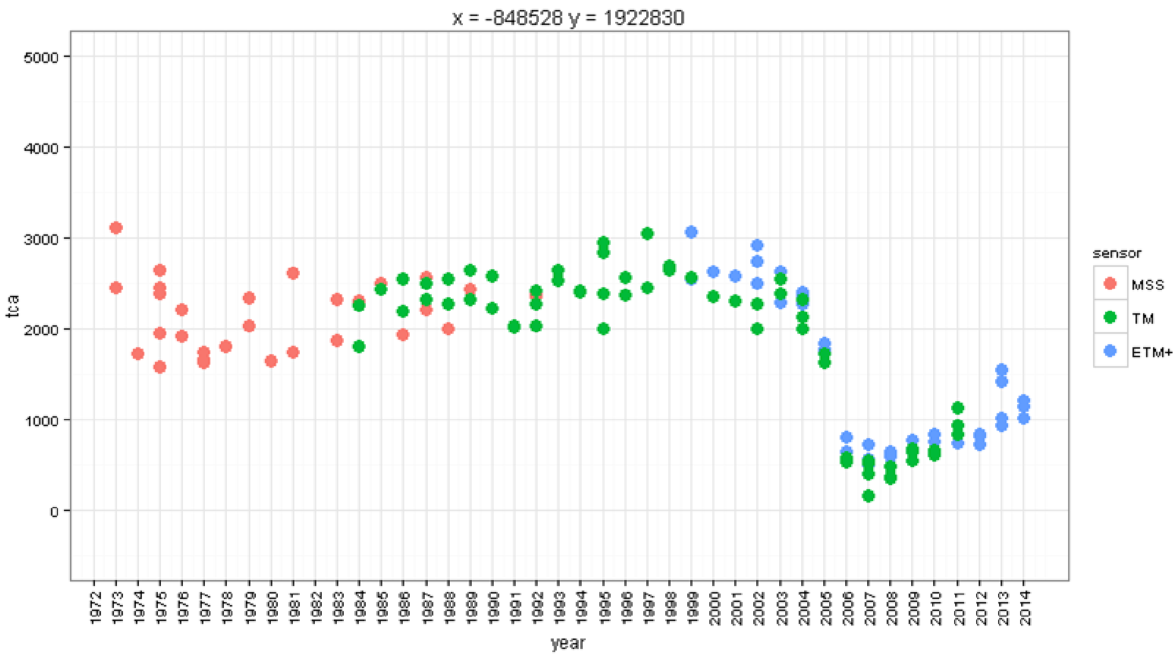


Figure 21. Calibrated pixel values at a given coordinate for all images included in this example LLR project. Note the smooth blended transition between sensors at their overlap.

miXel

miXel is the image composting component of the LLR system. It creates cloud-free annual composite images by blending multiple images from the same year together using the overlapping pixel mean and ignoring pixels identified as cloud or cloud shadow (obscured) in the calculation (Figure 22). In the case where all overlapping pixels are identified as obscured, the composite pixel is assigned a value of NA. Given a series of directory locations and an area of interest raster file, miXel looks through the given directories and finds images (and their corresponding cloud masks) that intersect the area of interest file. It organizes the images by year and for each year creates a composite image for each and then clips the composite image to the extent of area of interest file. It creates separate composites for all indices produced in the MSS-to-TM/ETM+ calibration procedure (MSScal) and writes them to a user-defined directory as both individual year files and as a time series stack with as many bands as there are years. Figure 23 shows a visual example of miXel mean composting for a single-pixel time series and Figure 24 shows an example of temporal fitting based on mean annual compositing.

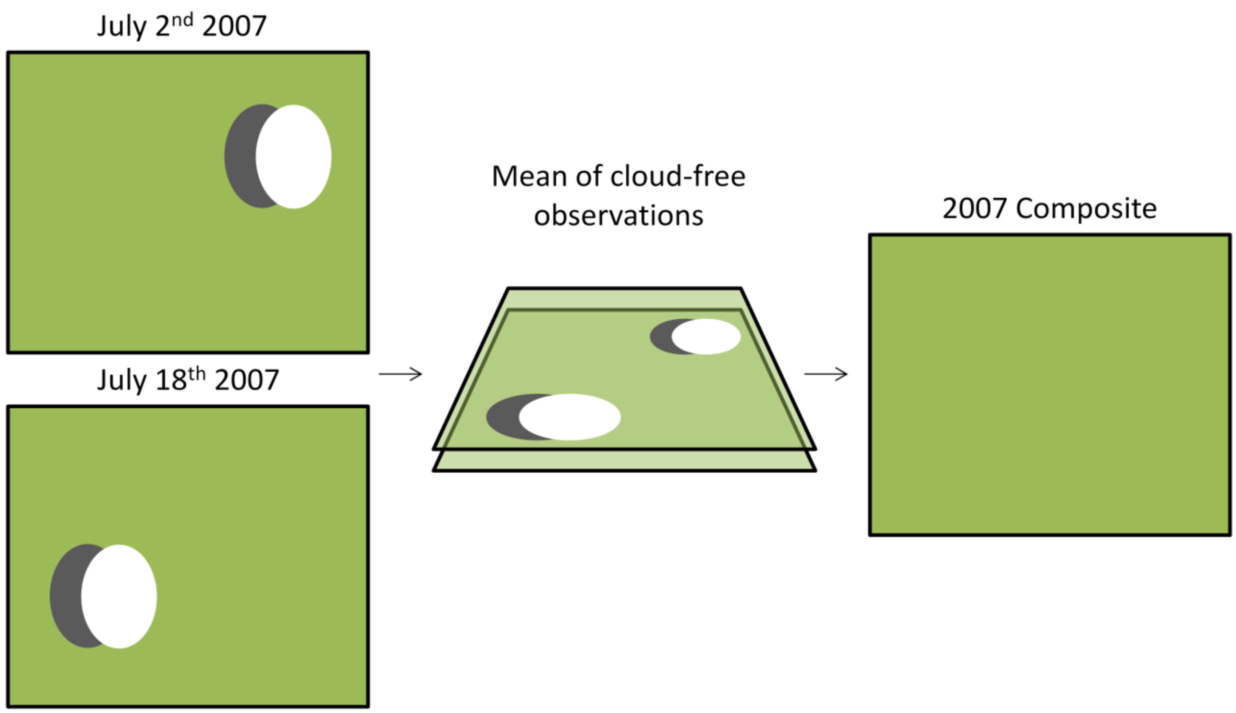


Figure 22. Conceptual example of LLR miXel cloud-free compositing. Given multiple images from the same year and season, miXel creates a composite from the mean of all overlapping cloud-free observations.

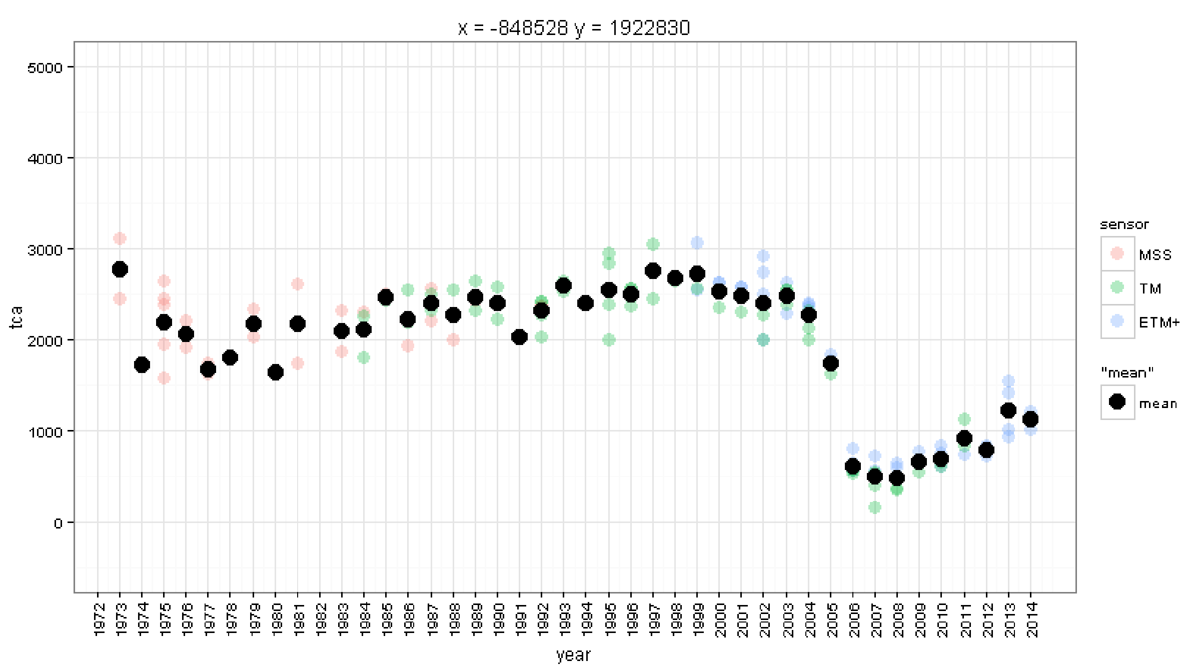


Figure 23. Visual example of miXel mean composting for a single-pixel time series. Transparent colored dots are the original individual image pixel values and the black dots represent the mean value of the pixel values for each year.

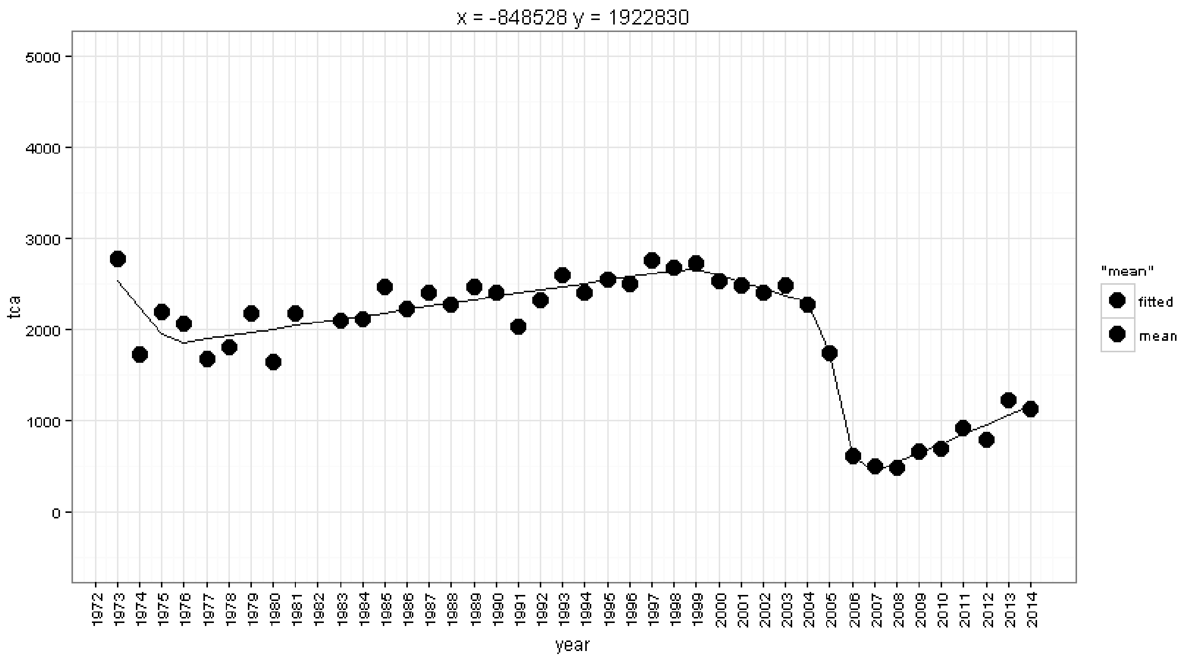


Figure 24. Example of temporal fitting of composite values for a given pixel. Annual compositing along with temporal fitting produces a simplified representation of the pixel's spectral history. In this case the pixel experienced a spectral decline, followed by a recovery, a gradual decline that transitioned to a more rapid high magnitude decline, and finally another recovery.

References

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