Multi-Resolution Land Characteristics 2001 (MRLC2001) Image Processing Procedure
Revised 01/09/2006

(Note: A more readable version of this document is available at http://landcover.usgs.gov/pdf/image_preprocessing.pdf)

The core dataset of the MRLC2001 database consists of Landsat 7 ETM+ images. Image selection is based on vegetation greenness profiles defined by a multi-year normalized difference vegetation index (NDVI) data set derived from the Advanced Very High Resolution Radiometer (Yang, Homer, and others, 2001). Specifically, the conterminous U.S. is divided into 66 mapping zones. For each mapping zone, the temporal NDVI profiles of major land cover types within that mapping zone are used to define ideal time windows for acquiring images in early, peak and late growing seasons, and three images are acquired for each Landsat path/row. When no reasonably clear and cloud free ETM+ image is available within the ideal time windows, the Landsat 5 image archive is searched for a replacement. This document first details the procedures for preprocessing selected Landsat 7 images for the MRLC2001 database, most of which are also applied to Landsat 5 images because the TM sensor and the ETM+ sensor are geometrically and radiometrically compatible. Differences between the procedures for preprocessing Landsat 5 and Landsat 7 are discussed in section 5.

1. Document list

MRLC2001 database images are distributed in TAR format. Two TAR files are produced for each Landsat Path-Row/Date.

NZT or MBZ .tar files contain the National Land Archive Processing System Data Format (NDF) image files and associated processing records. The following is representative of the NDF file structure:

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tar -xvf NZT070350300716200200.tar (scene ID = NZT, Landsat 7, Path 035,
 Row 030, Acq. Date 07/16/2002)

x LE7035030000219750.DD, 122942086 bytes, 240122 blocks - DEM Data file
x LE7035030000219750.DH, 1782 bytes, 4 blocks - DEM Header file
x LE7035030000219750.H1, 2721 bytes, 6 blocks - NDF Header for bands 1-5 and 7
x LE7035030000219750.H2, 2156 bytes, 5 blocks - NDF Header for thermal bands
6&9
x LE7035030000219750.H3, 2016 bytes, 4 blocks - NDF Header for band 8
x LE7035030000219750.HI, 173644 bytes, 340 blocks - NDF Job History file
x LE7035030000219750.I1, 61471043 bytes, 120061 blocks - NDF Image band 1
x LE7035030000219750.I2, 61471043 bytes, 120061 blocks - NDF Image band 2
x LE7035030000219750.I3, 61471043 bytes, 120061 blocks - NDF Image band 3
x LE7035030000219750.I4, 61471043 bytes, 120061 blocks - NDF Image band 4
x LE7035030000219750.I5, 61471043 bytes, 120061 blocks - NDF Image band 5
x LE7035030000219750.I6, 15363840 bytes, 30008 blocks - NDF Image band 6
x LE7035030000219750.I7, 61471043 bytes, 120061 blocks - NDF Image band 7
x LE7035030000219750.I8, 245884172 bytes, 480243 blocks - NDF Image band 8
x LE7035030000219750.I9, 15363840 bytes, 30008 blocks - NDF Image band 9
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x LE7035030000219750.MTL, 7217 bytes, 15 blocks - NDF L1_METADATA_FILE
x LE7035030000219750.WO, 12372 bytes, 25 blocks - NDF Work Order report file
x README.TXT, 15125 bytes, 30 blocks - NDF PRODUCT README

NOTE: scene ID LE7035030000219750 = Landsat 7, Path 035, Row 030, Julian Date 02197 = Acq. Date 07/16/2002

NNS or MBS .tar files contain the image files and associated records produced to support the National Land Cover Database (NLCD) project and the Monitoring Trends in Burn Severity (MTBS) project. These images are produced in either ERDAS Imagine .img format or GeoTIFF .tif format. The following is representative of the ERDAS Imagine .img file structure (GeoTIFF is similar):

tar -xvf NNS070350300716200200.tar (scene ID = NNS (NLCD), Landsat 7, Path 035, Row 030, Acq. Date 07/16/2002)

x 7035030000219750.GMD, 8289 bytes, 17 blocks - ERDAS Imagine Model file
x 7035030000219750.TXT, 1679 bytes, 4 blocks - ERDAS Imagine Model metadata file
x 7035030000219750_B9.IMG, 67952726 bytes, 132721 blocks - Band 9 at-satellite temperature image
x 7035030000219750_REFL.IMG, 407699653 bytes, 796289 blocks - Bands 1-5 and 7, at-satellite reflectance corrected
x 7035030000219750_TC.IMG, 203851476 bytes, 398148 blocks - Tasseled Cap brightness, greenness, wetness, at-satellite reflectance corrected
x 7035030000219750_NBR.IMG, 134684902 bytes, 263056 blocks - Normalized Burn Ratio image, at-satellite reflectance corrected
x LE7035030000219750.H1, 2721 bytes, 6 blocks - NDF Header for bands 1-5 and 7
x LE7035030000219750.H2, 2156 bytes, 5 blocks - NDF Header for thermal bands 6&9
x LE7035030000219750.METADATA, 319 bytes, 1 block - TAR METADATA FILE
x MRLCIMGPROC.DOC, 13898 bytes, 28 blocks - MRLC2001 IMAGE PROCESSING PROCEDURE DOCUMENT

NOTE: scene ID 7035030000219750 = Landsat 7, Path 035, Row 030, Julian Date 02197 = Acq. Date 07/16/2002

2. Converting DN to at-satellite reflectance

The above standard geometric and radiometric correction results in digital number (DN) images. DN is a measure of at-satellite radiance. To further standardize the impact of illumination geometry, the DN images are converted first to at-satellite radiance and then to at-satellite reflectance using the following equations:

$$L(i) = DN(i) * gain(i) + bias(i) \quad (1)$$
$$R(i) = 3.1415926*L(i)*d*d / (Esun * \sin (SE)) \quad (2)$$

where:

i = ETM+/TM band number
L = at-satellite radiance

gain = band specific, provided in the header file sceneid.h1
bias = band specific, provided in the header file sceneid.h1
p = at-satellite reflectance, unitless
d = Earth-Sun distance in astronomical unit
Esun = Mean solar exoatmospheric irradiance from Table 1
SE = Sun elevation angle, provided in the header file sceneid.h1

The Earth-Sun distance can be derived from table 2 or calculated according to Iqbal (1983).

TABLE 1. ETM+ SOLAR SPECTRAL IRRADIANCES

Band	watts/(meter squared * µm)
1	1969.000
2	1840.000
3	1551.000
4	1044.000
5	225.700
7	82.070
8	1368.000

TABLE 2. EARTH-SUN DISTANCE IN ASTRONOMICAL UNIT

JulianDay	D	JuliaDay	D	JuliaDay	D	JuliaDay	D	JuliaDay	D
1	.9832	74	.9945	152	1.0140	227	1.0128	305	.9925
15	.9836	91	.9993	166	1.0158	242	1.0092	319	.9892
32	.9853	106	1.0033	182	1.0167	258	1.0057	335	.9860
46	.9878	121	1.0076	196	1.0165	274	1.0011	349	.9843
60	.9909	135	1.0109	213	1.0149	288	.9972	365	.9833

At-satellite reflectance values range from 0 to 1. To save disk space, the values are multiplied by 400 and then truncated to produce 8-bit data. As a result of truncation, reflectance values higher than 0.6375 are set to 0.6375. This should not degrade the data quality significantly for land cover purpose, because most land targets, especially vegetated surfaces, have reflectance values less than 0.6375.

More details on how to convert DN to at-satellite reflectance are provided by Markham and Barker (1986), Irish (2000, at http://ltpwww.gsfc.nasa.gov/IAS/handbook/handbook_toc.html), and Huang et al. (2002).

3. Preprocessing of the thermal band

Landsat 7 produces two thermal images, one acquired using a low gain setting (often referred to as band 6L, saturating at 347.5K) and the other using a high gain setting (often referred to as band 6H or band 9, saturating at 322K). Band 6H, or band 9, is used in the MRLC2001 database because it is more sensitive to most land targets, especially vegetated targets. While the temperature of some land surfaces like desert, sand beach and impervious surface can be higher than 322K (saturation temperature for band 6H), this problem should not be a major concern for most land cover studies,

as these targets are relatively easy to discern in Landsat images.

The thermal band is first converted from DN to at-satellite radiance using equation (1), and then to effective at-satellite temperature (T) using the following equation:

$$T = K2 / Ln(K1/L + 1) \qquad (4)$$

where:

T= Effective at-satellite temperature in Kelvin
K2= Calibration constant 2 from Table 3
K1= Calibration constant 1 from Table 3
L= Spectral radiance in watts/(meter squared * ster * µm)

Notice the gain and bias values required for equation (1) are provided in the sceneid.h2 file for the thermal band.

Table 3. ETM+ Thermal Band Calibration Constants

	K1 watts/(meter squared*ster*µm)	K2 Kelvin	Source
Landsat 7	666.09	1282.71	Irish (2000)
Landsat 5	607.76	1260.56	Markham and Barker (1986)

The above equations assume unity emissivity and use pre-launch calibration constants.

The temperature image (T_float) is resampled to have a spatial resolution of 30 m, and is rescaled to produce 8-bit data (T_8bit) as follows:

$$T\_8bit = (T\_float - 240) * 3 \qquad (5)$$

4. The panchromatic band

The pan band (band 8) is processed using standard geometric and radiometric correction methods described in section 6 to produce DN image. No further processing is performed.

5. Preprocessing Landsat 5 TM image

As are the ETM+ images, Landsat 5 TM images are processed using standard geometric and radiometric correction methods and are corrected for possible geolocation errors due to terrain effect using the 1-arc second NED data set, yielding TM DN images. With the TM sensor and the ETM+ sensor being geometrically and radiometrically compatible, the above Landsat 7 preprocessing procedures (including converting DN to at-satellite reflectance and tasseled cap transformation) are also applied to Landsat 5 TM images. To take advantage of the superior radiometric calibration of ETM+, however, TM DN (DN5) is first converted

to ETM+ DN (DN7) using the following equation:

$$DN7 = DN5 \ (\ slope + intercept \ ) \qquad (6)$$

where the slope and intercept values are as follows according to Vogelmann et al. (2001):

Band #	Slope	Intercept
1	0.9398	4.2934
2	1.7731	4.7289
3	1.5348	3.9796
4	1.4239	7.032
5	0.9828	7.0185
7	1.3017	7.6568

Using the following set of gain and bias values, the derived image is then treated as an ETM+ DN image in calculating at-satellite reflectance and tasseled cap transformation:

Band#	gain	bias
1	0.7756863	-6.1999969
2	0.7956862	-6.3999939
3	0.6192157	-5.0000000
4	0.6372549	-5.1000061
5	0.1257255	-0.9999981
7	0.0437255	-0.3500004

While the equations for converting the thermal band DN to at-satellite temperature and then rescaling the image to produce 8-bit data are the same as those for ETM+ images, the gain and bias values are provided in the sceneid.h1 header file, and the constants K1 and K2 are provided in table 3. The two constants were derived by Markham and Barker (1986). However, the unit used in Markham and Barker (1986) for K1 is different from that used in processing current Landsat 5 data. As a result, K1's value as listed in table 3 is 10 times of that provided by Markham and Barker (1986). The at-satellite temperature image is resampled from the original 120 m resolution to 30 m.

All Landsat 5 TM image products are rescaled to produce 8-bit data the same ways ETM+ image products are generated.

6. Standard geometric and radiometric corrections

All MRLC2001 images are geometrically and radiometrically corrected using standard methods at the USGS EROS Data Center (EDC) using the National Landsat Archive Production System (NLAPS). Possible geolocation errors due to terrain effect are corrected using the 1-arc second National Elevation Dataset (NED). Bands 1 to 5 and 7 are resampled to a 30 m spatial resolution using the cubical convolution method. The thermal band has a pixel size of 60 m after

being processed using the standard geometric and radiometric correction methods, but is resampled to 30 m to match the pixel size of the spectral bands. The panchromatic band has a pixel size of 15 m. More details on the standard geometric and radiometric correction methods are given at http://edc.usgs.gov/glis/hyper/guide/nlapssys3.html.

7. Image resampling and projection

All MRLC2001 images have the Albers Conical Equal Area projection with projection parameters defined below:

For conterminous US,

```
Projection Type:               Albers Conical Equal Area
Spheroid Name:                       GRS 1980
Datum Name:                    NAD83
Latitude of 1st standard parallel:  29:30:00.00000 N
Latitude of 2nd standard parallel:  45:30:00.00000 N
Longitude of Central Meridian:      96:00:00.00000 W
Latitude of origin of projection:   23:00:00.000000 N
False easting at central meridian:  0.0000000 meters
False northing at origin:           0.0000000 meters
```

For Alaska,

```
Projection Type:               Albers Conical Equal Area
Spheroid Name:                       WGS 84
Datum Name:                    WGS 84
Latitude of 1st standard parallel:  55:00:00.00000 N
Latitude of 2nd standard parallel:  65:00:00.00000 N
Longitude of Central Meridian:      154:00:00.00000 W
Latitude of origin of projection:   50:00:00.000000 N
False easting at central meridian:  0.0000000 meters
False northing at origin:           0.0000000 meters
```

For Hawaii,

```
Projection Type:               Albers Conical Equal Area
Spheroid Name:                       WGS 84
Datum Name:                    WGS 84
Latitude of 1st standard parallel:  08:00:00.00000 N
Latitude of 2nd standard parallel:  18:00:00.00000 N
Longitude of Central Meridian:      157:00:00.00000 W
Latitude of origin of projection:   03:00:00.000000 N
False easting at central meridian:  0.0000000 meters
False northing at origin:           0.0000000 meters
```

8. At-satellite reflectance based tasseled cap transformation

The 8-bit, at-satellite reflectance images (bands 1 to 5 and 7) produced in

section 2 are used to calculate tasseled cap brightness, greenness and wetness using the following coefficients:

	band 1	band 2	band 3	band 4	band 5	band 7
brightness:	0.35612057	0.39722874	0.39040367	0.69658643	0.22862755	0.15959082
greenness:	-0.33438846	-0.35444216	-0.45557981	0.69660177	-0.02421353	-0.26298637
wetness:	0.26261884	0.21406704	0.09260517	0.06560172	-0.76286850	-0.53884970

The following equation is used to rescale the tasseled cap values (tc_value) to fit in the 8-bit data range (tc_8bit):

tc_8bit = round[(tc_value + offset) * 255 / range] (3)

Offset and range are defined as follows:

	offset	range
brightness	-20	380
greenness	100	255
wetness	170	320

Most land targets have tasseled cap values between 0 and 255 after being rescaled using (3). Theoretical background of tasseled cap transformation is given by Crist and Cicone (1984). The at-satellite reflectance based coefficients listed above are derived by Huang et al. (2002).

9. Normalized Burn Ratio

The Normalized Burn Ratio (NBR) is a 16-bit image product generated from bands 4 and 7 of Landsat thematic mapper and enhanced thematic mapper imagery. This product is only generated for those Landsat images acquired and processed for the Monitoring Trends in Burn Severity (MTBS) project which began in 2005. For further information about MTBS see contact information below. All scenes processed for the MTBS project are part of the MRLC2001 database, but previously processed MRLC images will not have this new data product. MRLC scenes which include the NBR will be prefaced with MBS or MBZ. Preprocessing of scenes used for the MTBS project is the same as that used for MRLC (i.e. terrain correction and projection, radiometric correction to at-satellite reflectance, tassel cap transformation, etc). The NBR is derived from a ratio of bands 4 and 7 (corrected to at-satellite reflectance). Specifically:

NBR = [(4-7) / (4+7)] x 1000

Thus, NBR values can range from -1000 to +1000.

An NBR image is used as an input for the derivation of the Differenced Normalized Burn Ratio (dNBR) that is used to assess post fire burn severity effects:

dNBR = Prefire NBR - Postfire NBR

More information about the NBR and its use can be found under 'FIREMON' at:

http://fire.org/

10. Contact information

For further information, please contact:

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11. References

Crist, E.P., and Cicone, R.C., 1984, A physically-based transformation of Thematic Mapper data -- the TM Tasseled Cap: IEEE Trans. on Geosciences and Remote Sensing, v. GE-22, no. 3, p. 256-263.

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