MRLC 2001 IMAGE PROCESSING PROCEDURE

REVISED MAY 22, 2006

The core dataset of the MRLC 2001 database consists of Landsat 7 (L7) Enhanced Thematic Mapper Plus (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 (AVHRR) [1]. 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 (L5) Thematic Mapper (TM) archive is searched for a replacement.

This document details the procedures for processing selected L7 ETM+ images for the MRLC 2001 database; most of these same procedures are also applied to L5 TM images because the TM sensor and the ETM+ sensor are geometrically and radiometrically compatible. Differences between the procedures for processing Landsat 7 ETM+ and Landsat 5 TM are discussed in section 7.

1. TAR files

MRLC 2001 database images are distributed in TAR format. Two TAR files are produced for each Landsat Path-Row/Date. NZT/NNS or MBZ/MBS designations are used to differentiate the image files and associated records produced to support the National Land Cover Database (NLCD) project - NZT/NNS, vs. the Monitoring Trends in Burn Severity (MTBS) project - MBZ/MBS.

NZT or MBZ .tar files contain the National Land Archive Processing System (NLAPS) Data Format (NDF) image files and associated processing records. MRLC 2001 Landsat 7 ETM+ images and Landsat 5 TM images are initially processed through NLAPS using standard geometric and radiometric correction methods, they are also corrected for possible geo-location errors due to terrain effects using the 1-arc second NED data set, yielding 8-bit images.

The following is representative of the MRLC 2001 NLAPS/NDF precision, terrain corrected NZT/MBZ .tar-file structure:

Syntax for UNIX tar -extract, verbose, file name: tar -xvf NZT070350300716200200.tar

> Scene ID = NZT (NLCD) / MBZ (MTBS), Landsat 7, Path 035, Row 030, Acquisition Date 07/16/2002

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

NOTE: Scene ID LE7035030000219750 = Landsat 7, Path 035, Row 030, Julian Date 02197 = Acquisition Date 07/16/2002

NNS or MBS .tar files contain the derived image files (at-satellite reflectance (REFL), processed thermal band(s), tasseled cap (TC), normalized burn ratio (NBR), and other associated records. 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):

Syntax for UNIX tar -extract, verbose, file name: tar –xvf NNS070350300716200200.tar

> Scene ID = NNS (NLCD) or MBS (MTBS), Landsat 7, Path 035, Row 030, Acquisition Date 07/16/2002

7035030000219750.GMD, 8289 bytes, 17 blocks - ERDAS Imagine Model file
7035030000219750.TXT, 1679 bytes, 4 blocks - ERDAS Imagine Model metadata file
7035030000219750_B9.IMG, 67952726 bytes, 132721 blocks - Band 9 at-satellite temperature image
7035030000219750_REFL.IMG, 407699653 bytes, 796289 blocks - Bands 1-5 and 7, at-satellite reflectance corrected
7035030000219750_TC.IMG, 203851476 bytes, 398148 blocks - Tasseled Cap brightness, greenness, wetness

7035030000219750_NBR.IMG, 134684902 bytes, 263056 blocks - Normalized Burn Ratio image LE7035030000219750.H1, 2721 bytes, 6 blocks - NDF Header for bands 1-5 and 7
LE7035030000219750.H2, 2156 bytes, 5 blocks - NDF Header for thermal bands 6&9
LE7035030000219750.METADATA, 319 bytes, 1 block - TAR METADATA FILE
MRLCIMGPROC.DOC, 13898 bytes, 28 blocks – MRLC 2001 IMAGE PROCESSING PROCEDURE DOCUMENT

NOTE: Scene ID 7035030000219750 = Landsat 7, Path 035, Row 030, Julian Date 02197 = Acquisition Date 07/16/2002

2. Standard geometric and radiometric corrections

All MRLC 2001 images are geometrically and radiometrically corrected using standard methods at the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) using the National Landsat Archive Production System (NLAPS). Possible geo-location errors due to terrain effect are corrected using the 1-arc second National Elevation Dataset (NED). Bands 1 to 5 and 7 are re-sampled to a 30 m spatial resolution using the cubic 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 re-sampled to 30 m to match the pixel size of the reflective 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.

3. Projection parameters

All MRLC 2001 images have the Albers Conical Equal Area projection with projection parameters defined below:

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

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

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

4. Converting DN to at-satellite reflectance

Standard NLAPS/NDF 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:

$$L_\lambda = Gain_\lambda \cdot DN_\lambda + Bias_\lambda \qquad (1)$$

$$\rho_\lambda = \frac{\pi \cdot L_\lambda \cdot d^2}{ESUN_\lambda \cdot \sin(\theta)} \qquad (2)$$

where:

λ = 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

ρ	=	at-satellite reflectance, unitless
d	=	Earth-Sun distance in astronomical unit
ESUN	=	Solar exoatmospheric spectral irradiance from Table 1
θ	=	Sun elevation angle, provided in the header file sceneid.h1

The Earth-Sun distance can be derived from table 2 or calculated according to [2].

TABLE 1. *ESUN*
SOLAR SPECTRAL IRRADIANCES
watts/(meter squared * µm)

Band	L7 ETM+	L5 TM
1	1969.000	1957.000
2	1840.000	1826.000
3	1551.000	1554.000
4	1044.000	1036.000
5	225.700	215.000
7	82.070	80.670
8	1368.000	

TABLE 2. EARTH-SUN DISTANCE IN ASTRONOMICAL UNIT

Julian Day	Distance	Julian Day	Distance	Julian Day	Distance	Julian Day	Distance	Julian Day	Distance
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

NOTE: At-satellite reflectance values range from 0 to 1. Reflectance values higher than 0.6375 are truncated to 0.6375. This should not degrade the data quality significantly for land cover purposes, because most land targets, especially vegetated surfaces, have reflectance values less than 0.6375. To save disk space, the reflectance values are multiplied by 400 to produce 8-bit data.

More details on how to convert DN to at-satellite reflectance are provided in the references [3] [4] [5].

5. Processing 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 MRLC 2001 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. 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:

$$T = K2 / \ln (K1/L + 1) \quad (3)$$

where:

T = Effective at-satellite temperature in Kelvin

K2 = Calibration constant 2 from Table 3

ln = log

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:

$$T\_8bit = (T\_float - 240) * 3 \quad (4)$$

6. The panchromatic band

The pan band (ETM+ band 8) is processed using standard geometric and radiometric correction methods described in section 2 to produce a DN image. No further processing is performed.

7. Processing Landsat 5 TM images

Because the Landsat 5 TM sensor and the Landsat 7 ETM+ sensor are geometrically and radiometrically compatible, the standard Landsat 7 processing procedures (including converting DN to at-satellite reflectance, tasseled cap transformation, and normalized burn ratio) also apply to L5 TM images.

As of May 5, 2003, Landsat 5 TM data processed and distributed by the USGS/EROS have been radiometrically calibrated using a new procedure incorporating revised calibration parameters as part of the standard NLAPS/NDF production system. This change has improved absolute calibration accuracy, consistency over time, and consistency with Landsat 7 ETM+ data [6]. With this change revised parameters for gains and offsets listed in the Landsat 5 TM NLAPS/NDF header file are used to convert the calibrated data products to radiance and revised ESUN numbers (Table-1) for L5 TM are used for the at-satellite reflectance calculation.

Prior to May 5, 2003 the pseudo-improvement in radiometric calibration procedure was performed as part of the ancillary product production process. To take advantage of the superior radiometric calibration of the ETM+ sensor, TM DN (DN5) is first converted to ETM+ DN (DN7) using the following equation:

$$DN7 = DN5 * slope + intercept \quad (5)$$

where the slope and intercept values are as follows [7]:

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

After this conversion, the L5 TM DN is treated as L7 ETM+ DN, and the L7 ETM+ gain, offset and ESUN values are used respectively for radiance and at-satellite conversion.

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. Gain and bias values are provided in the sceneid.h1 header file and the constants K1 and K2 are provided in table 3 [6]. The at-satellite temperature image is re-sampled from the original 120 m resolution to 30 m.

8. At-satellite reflectance based tasseled cap transformation

The 8-bit, at-satellite reflectance images (bands 1 to 5 and 7) described in section 4, 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):

$$tc\_8bit = round[(tc\_value + offset) * 255 / range] \quad (6)$$

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. Theoretical background of the tasseled cap transformation is given by [8]. The at-satellite reflectance based coefficients listed above were derived by [5].

9. Normalized Burn Ratio

The Normalized Burn Ratio (NBR) is a 16-bit image product generated from bands 4 and 7 of Landsat 5 TM and Landsat 7 ETM+ imagery. This product is only generated for those Landsat images acquired and processed for the Monitoring Trends in Burn Severity (MTBS) project that began in 2005. For further information about MTBS see contact information below. All scenes processed for the MTBS project are part of the MRLC 2001 database, but previously processed MRLC images will not have this new data product. MRLC 2001 scenes that include the NBR will be prefaced with MBS or MBZ.

The NBR is derived from a ratio of bands 4 and 7 (corrected to at-satellite reflectance). Specifically:

$$NBR = [(4-7) / (4+7)] \times 1000 \qquad (7)$$

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

The 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:

$$dNBR = \text{Prefire NBR} - \text{Postfire NBR} \qquad (8)$$

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:

Customer Services
User Services Department
EROS Data Center
47914 252nd Street
Sioux Falls, SD 57198
Email: custserv@usgs.gov

Phone: (605) 594-6151
Fax: (605) 594-6589

11. References

[1] Yang, L., Homer, C., Hegge, K., Huang, C., and Wylie, B., 2001, A Landsat 7 Scene Selection Strategy for a National Land Cover Database, *in* IEEE International Geoscience and Remote Sensing Symposium, Sydney, Australia, Institute of Electrical and Electronics Engineers, Inc., CD ROM, 1 disk.

[2] Iqbal, M., 1983, An introduction to solar radiation: Toronto, Academic Press, p.390.

[3] Markham, B.L., and Barker, J.L., 1986, Landsat MSS and TM post-calibration dynamic ranges, exoatmospheric reflectances and at-satellite temperatures: EOSAT Landsat Technical Notes, v. 1, p. 3-8.

[4] Irish, R.R., 2000, Landsat 7 science data user's handbook: http://ltpwww.gsfc.nasa.gov/IAS/handbook/handbook_toc.html, National Aeronautics and Space Administration.

[5] Huang, C., Wylie, B., Homer, C., Yang, L., and Zylstra, G., 2002, Derivation of a Tasseled cap transformation based on Landsat 7 at-satellite reflectance: International Journal of Remote Sensing, v. 23, no. 8, p. 1741-1748.

[6] Chander, G., Markham, B.L., “Revised Landsat-5 TM Radiometric Calibration Procedures, and Post-Calibration Dynamic Ranges,” *IEEE Transactions on Geoscience and Remote Sensing,* vol. 41, No. 11, pp. 2674-2677, Nov, 2003.

[7] Vogelmann, J.E., Helder, D., Morfitt, R., Choate, M.J., Merchant, J.W., and Bulley, H., 2001, Effects of Landsat 5 Thematic Mapper and Landsat 7 Enhanced Thematic Mapper Plus Radiometric and Geometric Calibrations and Corrections on Landscape Characterization: Remote Sensing of Environment, v. 78, no. 1-2, p. 55-70.

[8] 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.