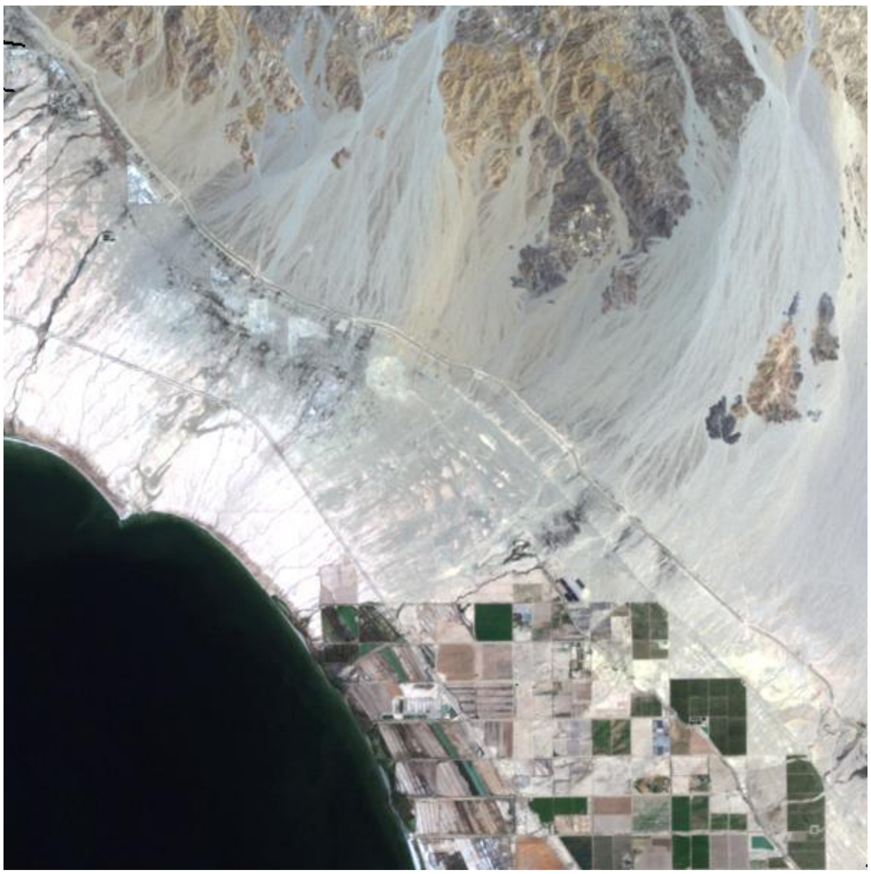
Department of the Interior
U.S. Geological Survey

PRODUCT GUIDE

LANDSAT CLIMATE DATA RECORD (CDR) SURFACE REFLECTANCE



Version 1.6

January 2013

USGS
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Executive Summary

This document describes relevant characteristics of the Landsat Surface Reflectance Climate Data Record to facilitate its use in the land remote sensing community.

Document History

Document Version	Publication Date	Change Description
Version 1.0	10/17/2012	Initial Draft
Version1.1	10/24/2012	Revision after Peer Review
Version1.2	11/07/2012	Revision after Bureau Review
Version 1.3	12/06/2012	Updated for LEDAPS 1.1.1
Version 1.4	12/11/2012	Updated with Fill and B6 details
Version 1.5	01/02/2013	Updated for LEDAPS 1.1.2
Version 1.6	01/16/2013	Corrected typos, added saturation value for Band 6, updated NLAPS processing protocol, revised product package description

Contents

List of Tables

Section 1 Introduction

Landsat satellite data have been produced, archived, and distributed by the U.S. Geological Survey (USGS) since 1972. Users rely on these data for historical study of land surface change, but shoulder the burden of post-production processing to create applications-ready data sets. In compliance with guidelines established through the Global Climate Observing System (GCOS), USGS has embarked on production of higher-level Landsat data products to support land surface change study. Terrestrial variables such as surface reflectance and land surface temperature will be offered as Climate Data Records (CDR). Leaf area index, burned area extent, snow covered area, and surface water extent will represent Essential Climate Variables (ECV). These CDRs and ECVs will offer a framework for producing long-term Landsat data sets suited for monitoring, characterizing and understanding land surface change over time.

The surface reflectance CDR is generated from specialized software called Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS). LEDAPS was originally developed through a National Aeronautics and Space Administration (NASA) Making Earth System Data Records for Use in Research Environments (MEaSUREs) grant by NASA Goddard Space Flight Center (GSFC) and the University of Maryland (Masek et al., 2006). The software applies Moderate Resolution Imaging Spectroradiometer (MODIS) atmospheric correction routines to Level-1 Landsat Thematic Mapper (TM) or Enhanced Thematic Mapper Plus (ETM+) data. Water vapor, ozone, geopotential height, aerosol optical thickness, and digital elevation are input with Landsat data to the Second Simulation of a Satellite Signal in the Solar Spectrum (6S) radiative transfer models to generate top of atmosphere (TOA) reflectance, surface reflectance, brightness temperature, and masks for clouds, cloud shadows, adjacent clouds, land, and water. The result is delivered as the Landsat surface reflectance CDR.

Section 2 Caveats and Constraints

1. The Landsat surface reflectance CDR products are considered provisional.
2. Landsat 5 TM and Landsat 7 ETM+ scenes acquired from 1984 to within one week of present imaging can be corrected, with the exception of some Landsat 5 TM scenes, which were processed through the National Landsat Archive Processing System (NLAPS).
   - NLAPS scenes are formatted and calibrated differently than those processed through the standard Landsat Product Generation System (LPGS). Previous implementations allowed these scenes into the processing system, where they would cause the entire order to fail. With the current version of LEDAPS, NLAPS-based scenes will be automatically removed from the order and the remaining scenes will continue processing.
3. Efficacy of the correction is likely to be reduced in:
   - hyper-arid or snow-covered regions.
   - low sun angle conditions.
   - coastal regions where land area is small relative to adjacent water.
   - areas with extensive cloud contamination.
4. Users are strongly cautioned against correcting data acquired over high latitudes (> 65 degrees North or South).
5. Refer to the quality assurance (QA) layers for pixel-level condition and validity flags.

Section 3 Product Package

The Landsat surface reflectance CDR is distributed as a compressed file package and includes several data layers in Hierarchical Data Format for Earth Observing System (HDF-EOS). The contents of typical file packages from Landsat 7 and Landsat 5 inputs are described below for reference.

3.1 Landsat 7

Surface reflectance processing can be applied to any Landsat 7 scene in the USGS archive, whether acquired before or after the Scan Line Corrector (SLC) failure (SLC-On and SLC-Off). File details are given below.

3.1.1 Naming Convention

Landsat 7-based surface reflectance files build on the naming convention of the source scenes. An example breaking down the components of a typical file package is:

LE70390372008210MOR00-sr.tar.gz

LE7	Landsat 7 Enhanced Thematic Mapper Plus
039	Path 39
037	Row 37
2008	Year of Acquisition
210	Julian Date of Acquisition (July 28)
MOR	Received at the Moscow, Russia International Ground Station
00	Version Number
-sr	Surface Reflectance
tar	Tar-based file archive
gz	g-zip file compression

3.1.2 Contents

The zipped and tarred file package has to be decompressed in two steps to extract the data files. Following the example given above,

unzip to file: LE70390372008210MOR00-sr.tar

untar to file: LE70390372008210MOR00-sr

open directory: LE70390372008210MOR00

The extracted directory will contain the HDF-EOS data files and text files used in surface reflectance production, as well as information from the source Landsat scene. An example of the final directory content for surface reflectance derived from Landsat 7 is shown below.

```
<DIR>              gap_mask
938                LE7039037_03720080728.metadata.txt
12,431             LE70390372008210MOR00_GCP.txt
639,141            LE70390372008210MOR00_MTL.txt
599,040            LE70390372008210MOR00_VER.jpg
54,272             LE70390372008210MOR00_VER.txt
726,521,758        lndcal.LE70390372008210MOR00.hdf
332                lndcal.LE70390372008210MOR00.hdf.hdr
231                lndcal.LE70390372008210MOR00.txt
1,285,511,609      lndsr.LE70390372008210MOR00.hdf
332                lndsr.LE70390372008210MOR00.hdf.hdr
445                lndsr.LE70390372008210MOR00.txt
```

The directory is labeled “gap_mask” and holds nine zipped files, each representing SLC gap information for the Landsat 7 bands 1, 2, 3, 4, 5, 6-1, 6-2, 7, and 8. Please note that though gap information is provided for Band 8, neither the SR nor TOA products include Band 8 values. The “metadata.txt” file contains select metadata information from the source scene formatted for use in production.

Original information carried through from the source Landsat scene includes the “GCP.txt” which lists the ground control points used for terrain correction, and the “MTL.txt” containing full metadata. “VER” denotes the verification files that assist users in determining the geometric accuracy of the source scene, i.e., the grid of verification points delivered in graphical and text format.

The files of primary interest have names starting with “lndsr” and deliver Landsat (“lnd”) surface reflectance (“sr”) data. The “lndsr.*.hdf” includes reflectance data layers for Landsat bands 1, 2, 3, 4, 5, and 7, band 6 temperature, atmospheric optical thickness, and quality assurance. The “lndsr.*.hdr” contains Exelis Visual Information Solutions (ENVI) header information, and the “lndsr.*.txt” is a small file with production input information.

All files prepended with “lndcal” are related to TOA reflectance. The “lndcal.*.hdf” contains TOA reflectance and quality information for Landsat bands 1, 2, 3, 4, 5, and 7. The associated “hdr” and “txt” files include the same kind of information as described for surface reflectance, but it is specific to TOA processing.

3.2 Landsat 5

Landsat 5 TM scenes dating back to 1984 can be processed into surface reflectance CDR products as well. File details are similar to those for Landsat 7, as described below.

3.2.1 Naming Convention

Landsat 5-based surface reflectance files build on the naming convention of the source scenes. An example breaking down the components of a typical file package is:

LT50400331995173AAA02-sr.tar.gz

LT5 Landsat 5 Thematic Mapper
040 Path 40
033 Row 33
1995 Year of Acquisition
173 Julian Date of Acquisition (June 22)
AAA Received at North American site unknown International Ground Station
02 Version Number
-sr Surface Reflectance
tar Tar-based file archive
gz g-zip file compression

3.2.2 Contents

The zipped and tarred file package has to be decompressed in two steps to extract the data files. Following the example given above,

unzip to file: LT50400331995173AAA02--sr.tar

untar to file: LT50400331995173AAA02-sr

open directory: LT50400331995173AAA02

The unzipped directory will contain the HDF-EOS data files and text files produced to support surface reflectance, as well as the metadata file from the source Landsat scene. An example of the final directory content (below) for surface reflectance derived from Landsat 5 shows eight files, but no additional directories. All “lndcal” and “lndsr” files share the same characteristics described above for Landsat 7.

```
938             LT5040033_03319990622. metadata.txt
11,225          LT50400331995173AAA02_GCP.txt
591,225         LT50400331995173AAA02_MTL.txt
601,357         LT50400331995173AAA02_VER.jpg
53,112          LT50400331995173AAA02_VER.txt
718,395,456     lndcal.LT50400331995173AAA02.hdf
332             lndcal.LT50400331995173AAA02.hdf.hdr
449             lndcal.LT50400331995173AAA02.txt
1,271,134,304   lndsr.LT50400331995173AAA02.hdf
332             lndsr.LT50400331995173AAA02.hdf.hdr
445             lndsr.LT50400331995173AAA02.txt
```

Section 4 Product Characteristics

4.1 Basic Characteristics

Basic product characteristics are shared by the surface reflectance (lndsr) and TOA reflectance (lndcal) components delivered in the CDR package. File sizes vary according to the scene of interest.

Table 4-1 Basic Product Characteristics

UTM Universal Transverse Mercator, HDF-EOS Hierarchical Data Format 4 for Earth Observing Systems, m meter

Characteristic	Definition
Projection	UTM
Format	HDF-EOS
Pixel Size	30-m
Temporal Coverage	March 1984 – within one week of present

Each CDR component has unique specifications pertaining to the geophysical derivation it represents. The following tables detail the Science Data Sets (SDSs) in the surface reflectance, TOA reflectance, and brightness temperature HDF-EOS files. An additional table (*Table 4-4*) is included to provide a legend for the bit mapped quality assurance (QA) SDS in TOA reflectance temperature files. Surface reflectance QA information is now delivered in separate SDSs within “lndsr.”

4.2 Surface Reflectance Specifications

The surface reflectance SDSs are defined very much as MODIS, with the notable exception that the QA is delivered in separate, condition-specific SDSs rather than as a single bit-packed layer as was present in previous versions. Table 2 lists the specifications for the 15 surface reflectance SDSs.

Regarding the the “fill_QA” SDS, the previous implementation (LEDAPS 1.1.1) of setting a pixel to 255 (fill) only if the corresponding Band 1 pixel was a fill value has been modified. A pixel is now marked as fill if any of the reflectance bands holds a fill value for that pixel. Additionally, there is a separate “fill_QA” layer specific to Band 6.

By default, LEDAPS selects the low gain thermal band (Band 6-1) when processing ETM+ data. The specific thermal band used for processing is specified in the “*metadata.txt” for reference.

Table 4-2 Surface Reflectance Specifications

SDS Science Data Set, INT16 16-bit signed integer, UINT8 8-bit unsigned integer, QA quality assurance, DDV dark dense vegetation, NA not applicable

SDS Order	SDS Name	Data Type	Units	Range	Fill Value	Saturate Value	Scale Factor	Calibrated NT
1	Band 1 Reflectance	INT16	Reflectance	-2000 - 16000	-9999	20000	0.0001	5.5
2	Band 2 Reflectance	INT16	Reflectance	-2000 - 16000	-9999	20000	0.0001	5.5
3	Band 3 Reflectance	INT16	Reflectance	-2000 - 16000	-9999	20000	0.0001	5.5
4	Band 4 Reflectance	INT16	Reflectance	-2000 - 16000	-9999	20000	0.0001	5.5
5	Band 5 Reflectance	INT16	Reflectance	-2000 - 16000	-9999	20000	0.0001	5.5
6	Band 7 Reflectance	INT16	Reflectance	-2000 - 16000	-9999	20000	0.0001	5.5
7	Atmospheric Opacity	INT16	Reflectance	-2000 - 16000	-9999	NA	0.0010	NA
8	Fill QA	UINT8	Flag	0 not fill 255 fill	NA	NA	NA	NA
9	DDV QA	UINT8	Flag	0 clear 255 DDV	NA	NA	NA	NA
10	Cloud QA	UINT8	Flag	0 clear 255 cloud	NA	NA	NA	NA
11	Cloud Shadow QA	UINT8	Flag	0 clear 255 cloud shadow	NA	NA	NA	NA
12	Snow QA	UINT8	Flag	0 clear 255 snow	NA	NA	NA	NA
13	Land Water QA	UINT8	Flag	0 land 255 water	NA	NA	NA	NA
14	Adjacent Cloud QA	UINT8	Flag	0 clear 255 adjacent cloud	NA	NA	NA	NA
15	Band 6 Temperature	INT16	Celsius	-7000 – 7000	-9999	20000	0.0100	NA

4.3 Top of Atmosphere Reflectance Specifications

Calibration is applied to Landsat digital numbers to derive the TOA reflectance component of the CDR. Specifications for TOA SDSs are similar to those for surface reflectance, but with a higher minimum value. Table 3 lists the data type, units, value range, fill value, saturation value, scale factor, and calibrated NT for the 7 TOA reflectance SDSs.

Table 4-3 Top of Atmosphere Reflectance Specifications

SDS Science Data Set, INT16 16-bit signed integer, UINT8 8-bit unsigned integer, lndcal Landsat TOA Reflectance, TOA top of atmosphere, QA quality assurance, NA not applicable

SDS Order	SDS Name	Data Type	Units	Range	Fill Value	Saturate Value	Scale Factor	Calibrated NT
0	Band 1 Reflectance	INT16	Reflectance	-100 - 16000	-9999	20000	0.0001	5.0
1	Band 2 Reflectance	INT16	Reflectance	-100 - 16000	-9999	20000	0.0001	5.0
2	Band 3 Reflectance	INT16	Reflectance	-100 - 16000	-9999	20000	0.0001	5.0
3	Band 4 Reflectance	INT16	Reflectance	-100 - 16000	-9999	20000	0.0001	5.0
4	Band 5 Reflectance	INT16	Reflectance	-100 - 16000	-9999	20000	0.0001	5.0
5	Band 7 Reflectance	INT16	Reflectance	-100 - 16000	-9999	20000	0.0001	5.0
6	lndcal QA	UINT8	Bit Index	0 - 255	1	NA	NA	NA

TOA reflectance uses a generic 8-bit QA derivation to simply express the saturation state of all input bands.

Table 4-4 Top of Atmosphere Reflectance QA Bit Map Index

LSB least significant bit, MSB most significant bit, QA quality assurance

QA Bit	Description
Bits are numbered from right to left (bit 0 = LSB, bit 7 = MSB)	
0	Data Fill Flag (0 valid data, 1 invalid data)
1	Band 1 Data Saturation Flag (0 valid data, 1 saturated data)
2	Band 2 Data Saturation Flag (0 valid data, 1 saturated data)
3	Band 3 Data Saturation Flag (0 valid data, 1 saturated data)
4	Band 4 Data Saturation Flag (0 valid data, 1 saturated data)
5	Band 5 Data Saturation Flag (0 valid data, 1 saturated data)
6	Band 6 Data Saturation Flag (not set)
7	Band 7 Data Saturation Flag (0 valid data, 1 saturated data)

Section 5 Product Manipulation

The format of the surface reflectance CDR (HDF-EOS) facilitates the derivation and delivery of key parameters in the product. However, it may not facilitate ready application of the products. Tools are available to assist users with visualization and basic processing services such as format conversion, data extraction, and reprojection.

5.1 Visualization

Any software packages capable of reading HDF-EOS will be able to open surface reflectance CDRs and display them to users. MODIS users will notice familiar discrepancies between the functionality of one or the others, but all HDF-capable software can be expected to nominally display an SDS and its attributes.

The following image processing software suites are known to provide visualization for surface reflectance CDR products. This list does not include all possible solutions. Although these software programs have been used by USGS, no warranty, expressed or implied, is made by the USGS or the U.S. Government as to the accuracy and functioning of the program and related program material nor shall the fact of distribution constitute any such warranty, and no responsibility is assumed by the USGS in connection therewith.

Table 5-1 Visualization Tools

*Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government. Any usability questions relating to software packages are to be directed to the software vendor.

Software	Domain	Access
HDFView	Public	http://www.hdfgroup.org/hdf-java-html/hdfview/
ENVI ®	Private	http://www.exelisvis.com/language/en-us/productsservices/envi.aspx
ERDAS Imagine ®	Private	http://geospatial.intergraph.com/products/ERDASIMAGINE/ERDASIMAGINE/Details.aspx

5.2 Basic Processing Services

Data manipulation tools that function with MODIS products are likely to work with Landsat surface reflectance CDRs as well. The public domain tools listed below are suggested for format conversion, SDS extraction, QA bit extraction (for TOA saturation values only, Jones, J., et al., 2012), and reprojection. The Landsat-Land Data Operational Product Evaluation (L-LDOPE) Toolbelt is, in fact, a subset of the MODIS LDOPE Toolbox, and is available with other surface reflectance tools at http://landsat.usgs.gov/cdrtools.php.

Table 5-2 Manipulation Tools

MRT MODIS Reprojection Tool, MODIS Moderate Resolution Imaging Spectroradiometer, L-LDOPE Landsat LDOPE, LDOPE Land Data Operational Product Evaluation, HEG HDF to GeoTIFF, HDF Hierarchical Data Format, GeoTIFF Geospatial Tagged Image File Format

Software	Domain	Access
MRT	Public	https://lpdaac.usgs.gov/tools/modis_reprojection_tool
L-LDOPE Toolbelt	Public	http://landsat.usgs.gov/L-LDOPE_Toolbelt.php
HEG	Public	http://newsroom.gsfc.nasa.gov/sdptoolkit/HEG/HEGHome.html

Section 6 Citation Information

There are no restrictions on the use of the surface reflectance CDR. It is not a requirement of data use, but please include the following citation in publication or presentation materials based on these products to acknowledge the USGS as a data source, and to credit the original research.

Landsat Surface Reflectance products courtesy of the U.S. Geological Survey Earth Resources Observation and Science Center.

Masek, J.G., Vermote, E.F., Saleous, N., Wolfe, R., Hall, F.G., Huemmrich, F., Gao, F., Kutler, J., and Lim, T.K. (2006). A Landsat surface reflectance data set for North America, 1990-100, IEEE Geoscience and Remote Sensing Letters. 3:68-72.

If possible, reprints or citations of papers or oral presentations based on USGS data are welcome at the User Services addresses included in this guide. Such cooperation will help USGS stay informed of how the data are being used.

Section 7 Acknowledgments

The original LEDAPS software was developed by Eric Vermote, Nazmi Saleous, Jonathan Kutler, and Robert Wolfe with support from the NASA Terrestrial Ecology program (Principal Investigator: Jeff Masek). Subsequent versions were adapted by Dr. Feng Gao (GSFC/ERT Corp.) with support from the NASA Advancing Collaborative Connections for Earth System Science (ACCESS) and the USGS Landsat Programs.

Section 8 User Services

The Landsat CDRs, ECVs, and associated interfaces are supported by User Services staff at USGS EROS. Any questions, comments, or interface problems are welcomed through the Landsat "Contact Us" on-line correspondence form. Please indicate "Surface Reflectance Data/LAI Request" as the topic of regard. Electronic mail can also be sent to the customer service address included below, with the same indication of topic.

USGS User Services
http://landsat.usgs.gov/contactus.php
custserv@usgs.gov

User support is available Monday through Friday from 8:00 a.m. – 4:00 p.m. Central Time. Inquiries received outside of these hours will be addressed during the next business day.

Section 9 References

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Section 10 Acronyms

Acronym	Description
6S	Second Simulation of a Satellite Signal in the Solar Spectrum
ACCESS	Advancing Collaborative Connections for Earth System Science
CDR	Climate Data Record
DDV	Dark Dense Vegetation
DOI	Department of the Interior
ECV	Essential Climate Variable
ENVI	Exelis Visual Information Solutions
EOS	Earth Observing System
EROS	Earth Resources Observation and Science
ETM+	Enhanced Thematic Mapper Plus
GCOS	Global Climate Observing System
GeoTIFF	Geospatial Tagged Image File Format
GSFC	Goddard Space Flight Center
HDF	Hierarchical Data Format
HEG	HDF to GeoTIFF
INT	Signed Integer
LDCM	Landsat Data Continuity Mission
LDOPE	Land Data Operational Product Evaluation
LEDAPS	Landsat Ecosystem Disturbance Adaptive Processing System
LPGS	Landsat Product Generation System
LSB	Least Significant Bit
m	Meter
MEaSUREs	Making Earth System Data Records for Use in Research Environments
MODIS	Moderate Resolution Imaging Spectroradiometer
MRT	MODIS Reprojection Tool
MSB	Most Significant Bit
NA	Not Applicable
NASA	National Aeronautics and Space Administration
NLAPS	National Landsat Archive Processing System
QA	Quality Assurance
SDS	Science Data Set
SLC	Scan Line Corrector
SR	Surface Reflectance
TM	Thematic Mapper
TOA	Top of Atmosphere
UINT	Unsigned Integer
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator