

Department of the Interior
U.S. Geological Survey

LANDSAT ECOSYSTEM DISTURBANCE ADAPTIVE PROCESSING SYSTEM (LEDAPS)

ALGORITHM DESCRIPTION DOCUMENT

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Executive Summary

The U.S. Geological Survey (USGS) is developing science-quality, applications-ready time series of key terrestrial variables and produce them on an operational basis using historical, current, and future Landsat observations. The terrestrial variables will follow the guidelines established through the Global Climate Observing System and include Climate Data Records (CDRs) that represent geophysical transformations of Landsat data, and Essential Climate Variables (ECVs) that represent specific geophysical and biophysical land properties. CDRs and ECVs offer a framework for producing long-term Landsat datasets suited for monitoring, characterizing and understanding land surface change over time.

This document provides a description of the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) algorithm implemented by the USGS to produce a Landsat Surface Reflectance CDR. It will be followed by a USGS Open File Report which will include programming details.

Document History

Document Version	Publication Date	Change Description
1.0	11/15/2012	Baseline LEDAPS 1.0.0
1.1	11/20/2012	Revised after Peer Review
1.2	12/04/2012	Revised to correct ozone input detail
1.3	12/11/2012	Revised to clarify details noted in associated Open File Report

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Section 1 Introduction

The LEDAPS (Landsat Ecosystem Disturbance Adaptive Processing System) software was originally developed in 2006 at National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) and the University of Maryland with funding from the NASA Terrestrial Ecosystems and Applied Sciences Programs (Wolfe, R., et al., 2004, Vermote, E., et al., 2007, Unknown, 2007). A February 2011 version was released through the NASA Advancing Collaborative Connections for Earth System Science (ACCESS) program (Masek, J., et al., 2006, Unknown, 2007), with contribution from the U.S. Geological Survey (USGS) Landsat Program. The U.S. Geological Survey (USGS) Earth Resources Observation and Science Center (EROS) used that version to create a baseline LEDAPS 1.0.0.

LEDAPS 1.0.0 produces top-of-atmosphere (TOA) reflectance from Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) Level 1 digital numbers (DN) and applies atmospheric corrections to generate a surface reflectance product. The corrections are based on the Second Simulation of a Satellite Signal in the Solar Spectrum (6S; Kotchenova, S. et al., 2006, Vermote, E., et al., 1997b) radiative transfer model used by the Moderate Resolution Imaging Spectroradiometer (MODIS) Land Science Team. Examples of the results, compared to TOA reflectance, are displayed in Figure 1.

LEDAPS is written in six modules to execute the following three key steps:

1. Convert DN to TOA reflectance
2. Detect cloud pixels based on the TOA reflectance
3. Correct to surface reflectance from TOA reflectance and auxiliary data sets

The modules provided in the LEDAPS software are described below and the overall processing flow is depicted in Figure 1.

Module 1 Parameter: “Indpm” parses the Landsat metadata file and creates the necessary input files for each of the downstream LEDAPS modules.

Module 2 Calibration: “Indcal” calibrates Landsat data from DN to TOA reflectance (and brightness temperature for the thermal band).

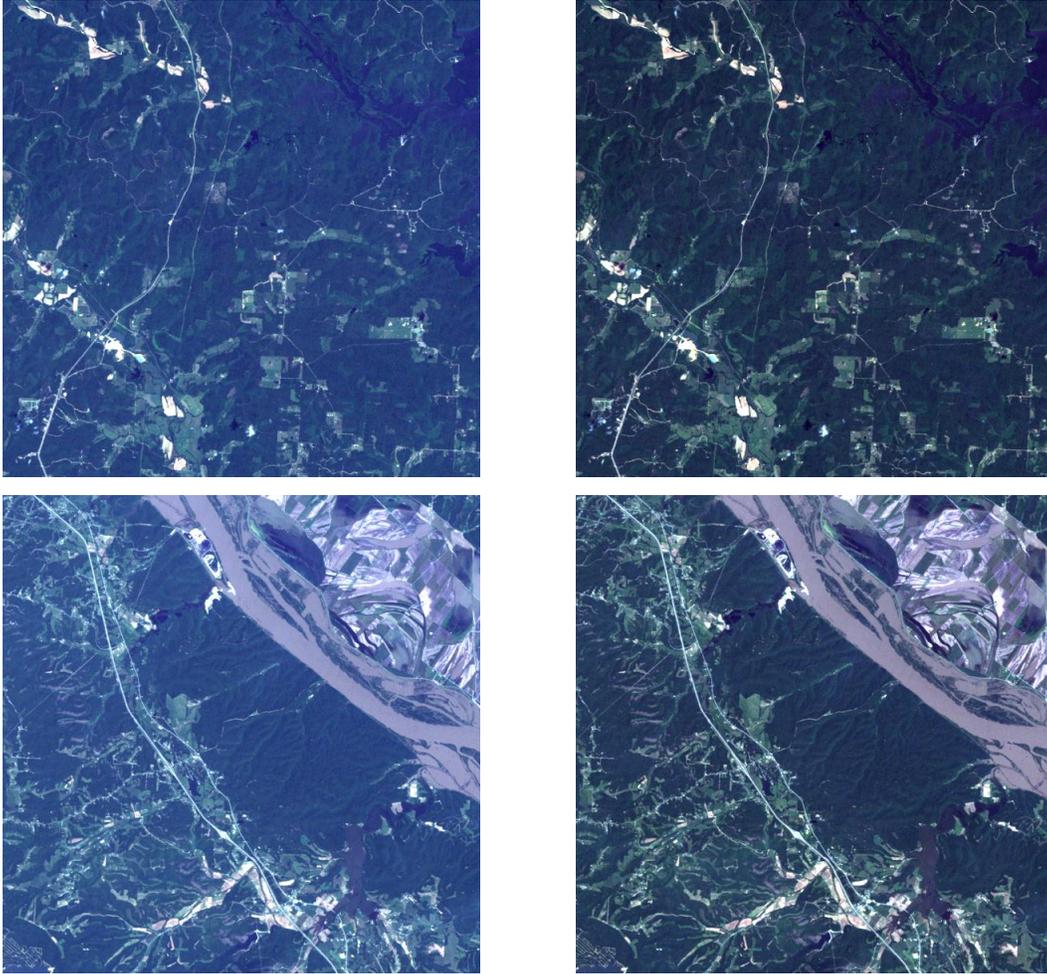


Figure 1 Examples of atmospheric correction results.

All images are Landsat 5 Thematic Mapper acquired May 30, 1995 in Path 23, Row 34 spanning the Mississippi River in Missouri. The images in the right column are surface reflectance data derived from the atmospheric correction of the top of atmosphere reflectance shown in the left column.

Module 3 Cloud Shadow Mask: “Indcsm” produces a cloud mask based on a pre-2004 C translation of an Interactive Data Language (IDL) Automated Cloud Cover Assessment (ACCA) algorithm. Please note that this is an outdated and inaccurate ACCA algorithm intended for use as a preliminary cloud filter and the USGS implementation of LEDAPS 1.0.0 excludes this module.

Module 4 Surface Reflectance: “Indsr” computes the surface reflectance for the TM and ETM+ reflectance bands and produces a quality mask for fill, dark dense

vegetation (DDV), snow, and land/water data. It includes a derivation of select internal cloud mask values used in production, but these are reset in the “Indsrbm” module.

Module 5 Surface Reflectance Based Mask: “Indsrbm” detects and creates masks for cloud, cloud shadow, and adjacent clouds using a surface reflectance based algorithm.

Module 6 Append: “Indapp” appends the thermal brightness temperature band to the surface reflectance output product.

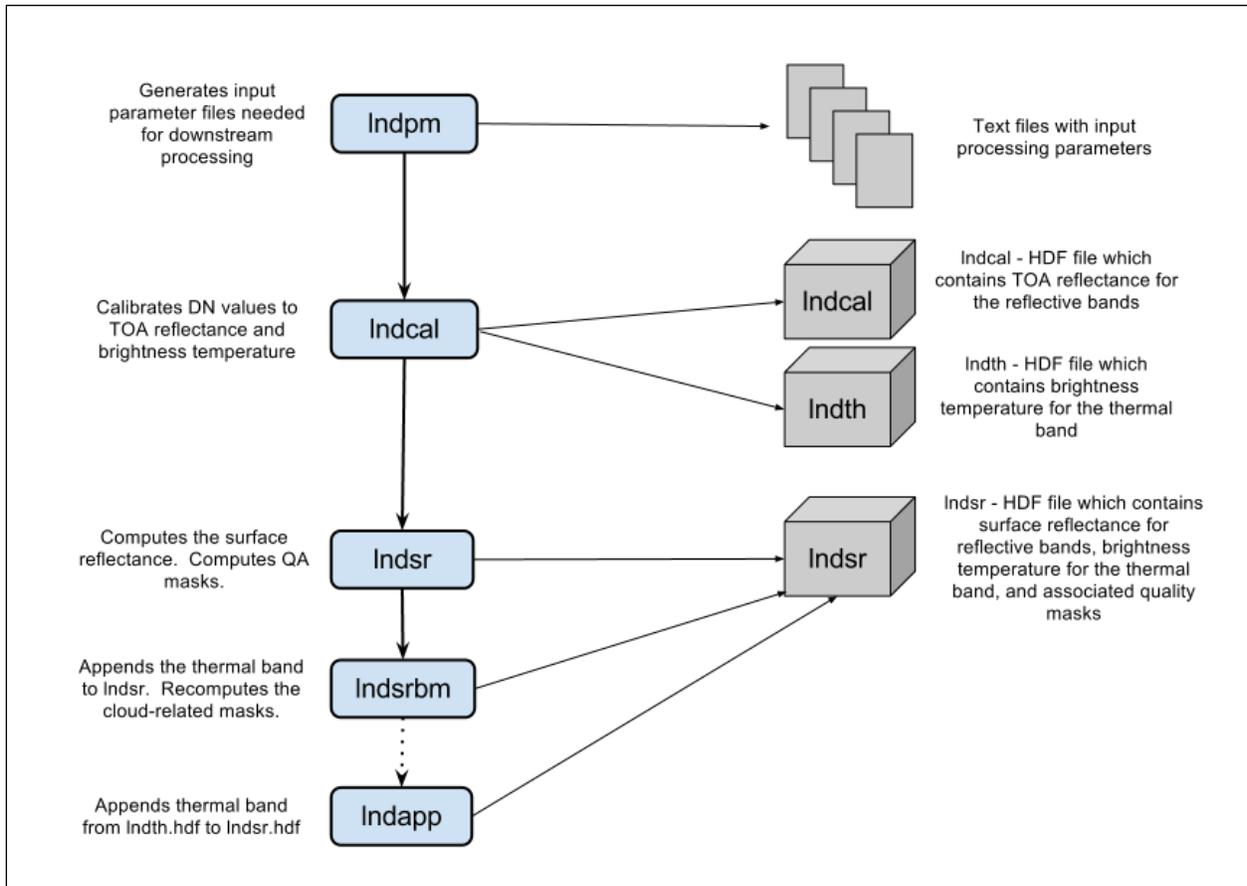


Figure 2 Algorithm Processing Flow

Section 2 Dependencies

The LEDAPS applications are designed to work with formatting specific to the Landsat TM and ETM+ scenes and the auxiliary data sets needed to perform atmospheric corrections. Processing is dependent on:

- Properly-formatted Landsat TM or ETM+ metadata files
- Georeferenced Tagged Image File Format (GeoTIFF) band data
- Air pressure, water vapor, air temperature, ozone, and digital elevation model (DEM) data.

Section 3 Inputs

The inputs required for each of the LEDAPS software modules are listed in Table 1. The modules build on each other, using output from one as input to another, as well as incorporating auxiliary data sets as needed.

LEDAPS atmospheric correction utilizes external inputs from:

- National Centers for Environmental Prediction (NCEP) meteorological reanalysis data
- NASA Goddard Space Flight Center (GSFC) Ozone Monitoring Instrument (OMI)
- NASA Goddard Space Flight Center (GSFC) Meteor-3 and Nimbus-7 Total Ozone Mapping Spectrometer (TOMS)
- National Oceanic and Atmospheric Administration (NOAA) Television and Infrared Observation Satellite (TIROS) Operational Vertical Sounder (TOVS)
- Global Climate Model (GCM) DEM.

The daily atmospheric inputs to LEDAPS 1.0.0 are needed for the acquisition date of the desired Landsat scene. OMI, TOMS and NCEP REANALYSIS from 1980 to present are available for download from their respective data centers. In cases where TOMS data are not available, (e.g., 1994-1996), TOVS data are used. Scripts developed at USGS EROS download the inputs, sort the files by years, save them to subdirectories, and reformat them into Hierarchical Data Format (HDF). USGS EROS also holds the GCMDEM HDF file delivered with the LEDAPS source code.

The table of inputs below includes listings for “GOLD” and “GNEW” auxiliary files. These are gain variables for each spectral band utilized to recalibrate the Landsat 5 Thematic Mapper (TM) products, but because LEDAPS pulls gain and bias values from the input product metadata, the default is to skip this recalibration function. The “old” vs. “new” is used to distinguish between the file applied to remove the original calibration values and the one that recalculates them correctly. The GOLD_2003 file is applied to products acquired after 2003. These files are delivered with the LEDAPS source code and can be obtained from USGS EROS if needed.

LEDAPS is configured to read all standard Landsat metadata, as generated by either Level 1 Product Generation System (LPGS), National Landsat Archive Production System (NLAPS), or the University of Maryland (UMD). Files with extensions “*.MTL.txt” or “*.met” are treated as ETM+ metadata from LPGS. Extensions “*H1,” “*.hdr,” “*_WO”, and “*.prodreport” are treated as TM metadata from NLAPS. UMD metadata file extensions are simply “*.umd” or “*.UMD,” but the USGS implementation of LEDAPS 1.0.0 phased out handling UMD input files.

Table 1: Algorithm Inputs

DEM digital elevation model, DN digital number, ETM+ Enhanced Thematic Mapper Plus, GCM Global Climate Model, GeoTIFF Geostationary Tagged Image File Format, GNEW new time dependent Landsat 5 TM gain, GOLD old time dependent Landsat 5 TM gain, HDF Hierarchical Data Format, HDF4 HDF Version 4, L1 level 1, LPGS Level 1 Product Generation System, NCEP National Centers for Environmental Prediction, NLAPS National Landsat Archive Processing System, QA quality assurance, TM Thematic Mapper, TOA top of atmosphere, TOMS Total Ozone Mapping Spectrometer-Earth Probe, UL upper left, UMD University of Maryland, WO work order

Module	Description	Units	Source	Type
Indpm	Landsat metadata file		LPGS, NLAPS, NLAPS WO, UMD (TM or ETM+)	Text file
	Path to the auxiliary files: GCMDEM, OMI/TOMS, NCEP REANALYSIS data, and GOLD/GNEW calibration files for TM		ANC_PATH	Environment variable
	Read UL corner, number of rows and columns, and resolution from Band 1 (if GeoTIFF from LPGS) or metadata if from NLAPS		LPGS, NLAPS, NLAPS WO, UMD	GeoTIFF or metadata file
Indcal	Calibration input parameter file (Indcal.txt)		Indpm	Text file

	Input metadata file (metadata.txt)		Indpm	Text file
	L1 Landsat imagery (bands 1-7, includes band 6 for the thermal band, include band 8 if ETM+)	DN, (band 6 is Kelvin), unsigned byte	LPGS, NLAPS (TM or ETM+)	GeoTIFF file, one band per file
	GOLD, GNEW, GOLD_2003 (if processing TM data)	Gains per band, W/(m ² sr micron)	Landsat cal/val team	Text file
Indcsm	Cloud mask input parameter file (Indcsm.txt)		Indpm	Text file
	Landsat calibrated TOA reflectance (bands 1-7)	Reflectance	Indcal	HDF4 file
	Landsat thermal band brightness temperature	°Celsius	Indcal	HDF4 file
Indsr	TOA reflectance for all reflective bands (Indcal.hdf)	Reflectance, signed 16-bit integer, scale factor 0.0001	Indcal	HDF4 file
	QA bits to indicate band saturation (Indcal.hdf)	Flag, unsigned byte	Indcal	HDF4 file
	Brightness temperature for thermal band (Indth.hdf)	°Celsius, signed 16-bit integer, scale factor 0.01	Indcal	HDF4 file
	QA bits to indicate band saturation (Indth.hdf)	Flag, unsigned byte	Indcal	HDF4 file
	OMI/TOMS ozone data	Dobson, signed 16-bit integer, scale factor 1.0	OMI, TOMS data centers	HDF4 file
	NCEP REANALYSIS data (pressure, water vapor, air temperature)	Signed 16-bit integer, pressure in Pascals, scale factor 1.0, water vapor in kg/m ² , scale factor 0.01, air temperature in Kelvin, scale factor 0.01	NCEP REANALYSIS	HDF4 file
	Global GCMDEM	Meters		HDF4 file
Indsrbm	Surface reflectance input parameter file (Indsr.txt)		Indpm	Text file
	Landsat surface reflectance product	Reflectance	Indsr	HDF4 file
	Landsat thermal band brightness temperature	°Celsius	Indcal	HDF4 file
	NCEP REANALYSIS data (pressure, water vapor, air temperature)	Signed 16-bit integer, pressure in Pascals, scale factor 1.0, water vapor in kg/m ² , scale factor	NCEP REANALYSIS	HDF4 file

		0.01, air temperature in Kelvin, scale factor 0.01		
Indapp	Landsat surface reflectance product	Reflectance	Indsr	HDF4 file
	Landsat thermal band brightness temperature	°Celsius	Indcal	HDF4 file

Section 4 Outputs

As mentioned above, the LEDAPS modules build on each other by outputting files or information that are used as input in the subsequent steps. The outputs are listed in Table 2 below.

Table 2: Algorithm Outputs

ACCA Automated Cloud Cover Assessment, ENVI Exelis Visualization Solutions, HDF Hierarchical Data Format, HDF4 HDF Version 4, LEDAPS Landsat Ecosystem Disturbance Adaptive Processing System, QA Quality Assurance, TOA top of atmosphere

Module	Description	Units	Target	Type
Indpm	Input files for each of the downstream LEDAPS modules (metadata.txt, Indcal.txt, Indcsm.txt, Indsr.txt)		Indcal, Indcsm, Indsr	Text file
	ENVI header file for each of the output HDF files (Indcal.hdf, Indcsm.hdf, Indth.hdf, Indsr.hdf)		Indcal, Indcsm, Indsr	Text file
	LogReport file to track the matching metadata parameters		User info	Text file
Indcal	TOA reflectance for all reflective bands (Indcal.hdf)	Reflectance, signed 16-bit integer, scale factor 0.0001	Indcsm, Indsr	HDF4 file
	QA bits to indicate band saturation (Indcal.hdf)	Flag, unsigned byte	Indcsm, Indsr	HDF4 file
	Brightness temperature for thermal band (Indth.hdf)	°Celsius, signed 16-bit integer, scale factor 0.01	Indcsm, Indsr	HDF4 file
	QA bits to indicate band saturation (Indth.hdf)	Flag, unsigned byte	Indcsm, Indsr	HDF4 file
Indcsm	ACCA cloud/snow mask 0=land, 1=cloud, 2=shadow, 4=water, 8=snow, 255=fill	8-bit, unsigned byte	Indsr, optional	HDF4 file
	Intermediate band 6 temp file	8-bit, unsigned byte	User info	Raw binary file
	Intermediate clmaskb temp file	8-bit, unsigned byte	User info	Raw binary file

	Intermediate clmaskb2 temp file	8-bit, unsigned byte	User info	Raw binary file
	Intermediate clmask temp file (ultimately contains the same values as the HDF4 ACCA cloud/snow mask file)	8-bit, unsigned byte	User info	Raw binary file
	Cloud mask log file		User info	Text file
Indsr	Surface reflectance for all reflective bands (Indsr.hdf)	Reflectance, signed 16-bit integer, scale factor 0.0001	User info	HDF4 file
	QA bands to indicate band features and quality for fill, dark dense vegetation, cloud, cloud shadow, snow, land/water, and adjacent cloud (Indsr.hdf)	Flag, unsigned byte	User info	HDF4 file
Indsrbm	Updated cloud, cloud shadow, and adjacent cloud QA bands in Landsat surface reflectance product (Indsr.hdf)	Flag, unsigned byte	User info	HDF4 file
	Updated Landsat surface reflectance product to contain thermal brightness temperature band (Indsr.hdf)	°Celsius, signed 16-bit integer, scale factor 0.01	User info	HDF4 file
Indapp	Updated Landsat surface reflectance product to contain thermal brightness temperature band (Indsr.hdf)	°Celsius, signed 16-bit integer, scale factor 0.01	Indsrbm	HDF4 file

Section 5 Prototype Code

LEDAPS 1.0.0, as implemented by USGS, was derived from a February 2011 prototype version of LEDAPS adapted by Feng Gao and available from <ftp://hydrolab.arsusda.gov/pub/fgao/Ledaps> (last accessed November 9, 2012).

Section 6 Verification Methods

Given that the LEDAPS software is already in place and validated, the production version of LEDAPS which is used for Landsat Surface Reflectance generation can be validated against the existing software. Any changes made to the baseline LEDAPS 1.0.0 code will need to be independently validated, based on the type of change made.

Section 7 Maturity

The LEDAPS software is stable, and USGS expects only limited and/or minor modifications from the original code developers. Future enhancements are planned to support additional Landsat satellites (such as Landsat 8, 2013).

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 Procedure

LEDAPS 1.0.0 strings six software modules together to step through the processes of creating TOA and surface reflectance with quality information. A general description of each module is given below. “Module 3 Cloud Shadow Mask (Indcsm)” is included for posterity though that software is not used in LEDAPS 1.0.0 (due to its outdated and inaccurate calculations). Programming details are excluded from this document but are described in a USGS Open File Report

9.1 *Module 1 Parameter*

The Indpm application reads the input Landsat TM or ETM+ metadata and LEDAPS-related environment variables, calculates the gain and bias (for LPGS products), and generates the parameter files needed for each of the downstream processing applications.

9.2 *Module 2 Calibrate*

The Indcal application reads the sensor information and scene information from the input parameter and metadata files. Gains, biases, and other reflectance parameters are read from the input parameter and metadata files. In the unlikely event these parameters are not available in the metadata, LEDAPS has functionality to perform recalibration based on the band and sensor using the “GOLD” and “GNEW” files. The brightness temperature is computed and written to Indth.hdf, with saturated and fill values being modified in the output and flagged in the quality assurance (QA) band. TOA reflectance values are calculated for each band and written to Indcal.hdf, with saturated and fill values being modified in the output and flagged in the QA band. Associated metadata is written to both files. The application also outputs statistics, such as the minimum and maximum reflectance per band, to the user. There are three steps to complete processing in this module: calibration, and computation of brightness temperature and TOA reflectance.

9.3 *Module 3 Cloud Shadow Mask*

A description of this module is included here for posterity. It was formerly used as a preliminary cloud filter in production, but was deactivated in LEDAPS 1.0.0 because it uses a C translation of pre-2004 heritage ACCA code and was not particularly successful in its calculations. The Indcsm application opens, reads, and applies a scale factor to the Indcal and Indth values. The brightness temperature values are converted from °Celsius to Kelvin. All fill pixels are marked as such, otherwise the pixels are initialized as land pixels. Various band ratios are then computed for each pixel (such as the normalized difference snow index (NDSI)) and compared to known threshold values for cloud-, snow-, and water-related pixels. The respective QA mask is then written to the Indcal.hdf file, along with associated metadata.

9.4 *Module 4 Surface Reflectance*

The Indsr algorithm performs the atmospheric correction needed to calculate surface reflectance for Landsat TM and ETM+ data. 6S is run to generate a look up table (LUT) accounting for pressure, water vapor, ozone and geometrical conditions over the whole scene for a range of aerosol optical thicknesses (AOT). A LUT is created for every band and is used both in the aerosol retrieval process as well as in the correction step. Incorporating the DDV method developed by Kaufman et al. (1997), AOT is extracted directly from the imagery based on the physical correlation between chlorophyll absorption and bound water absorption. A linear relationship is created between shortwave infrared (SWIR) and surface reflectance in visible bands so that AOT can be estimated by comparing visible band surface reflectance with TOA reflectance.

AOT is averaged to 1-kilometer (km) resolution and candidate dark targets are selected in the image. The relationship between blue and SWIR reflectance is derived over the dark targets and propagated across the spectrum using a continental aerosol model. 6S is summarized in the figure below, excerpted from Vermote and El Saleous, 2007.

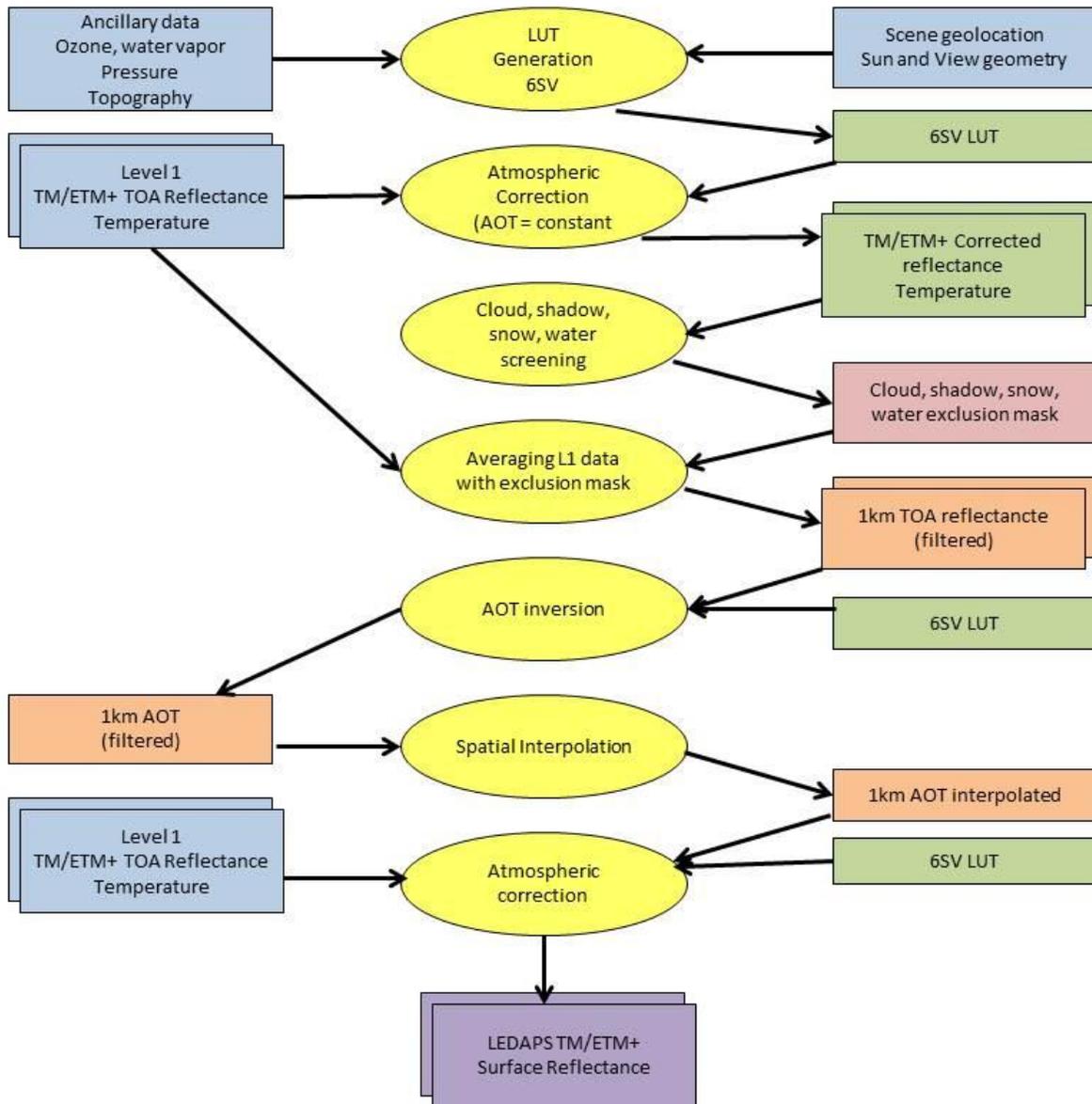


Figure 3 Atmospheric Correction Flow

9.5 Module 5 Surface Reflectance Based Mask

The Indsrbm application includes the process which appends the brightness temperature band to the surface reflectance product. The surface reflectance product is read, along with the metadata, and the scene center computed. The auxiliary data is read for the scene center and acquisition date. The air temperature, solar zenith, solar azimuth, northern adjustment, and pixel size are all used to determine cloud-related properties. The cloud-related QA band values are reset/cleared, ignoring what was

previously set in the Indsr application. Bands 1, 3, 5, and 6 are used to determine cloudy pixels, and the average clear temperature is computed for the non-cloudy pixels. For every cloudy pixel, the 5x5 surrounding window is marked as adjacent cloud, unless the pixel is already marked as a cloud. For every cloudy pixel, the cloud shadows are determined. And, for every cloud shadow, the 3x3 surrounding window is marked as cloud shadow if it is not already cloud or adjacent cloud. The updated cloud-related QA information and associated metadata are written to the surface reflectance product, overwriting the previous cloud-related QA bands.

9.6 Module 6 Append

The Indapp application reads the thermal band from the thermal brightness temperature file (Band 6) and appends that band to the surface reflectance file. Associated metadata for this band is also written.

Section 10 Selected References

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Section 11 Acronyms

Acronym	Definition
6S	Second Simulation of a Satellite Signal in the Solar Spectrum
ACCA	Automated Cloud Cover Assessment
ACCESS	Advancing Collaborative Connections for Earth System Science
CDR	Climate Data Record
cm	Centimeter
DDV	Dense Dark Vegetation
DEM	Digital Elevation Model
DN	Digital Number
ECV	Essential Climate Variable
ENVI	Exelis Visualization Solutions
EROS	Earth Resources Observation and Science
ETM+	Enhanced Thematic Mapper Plus
ft	Foot
GCM	Global Climate Model
GeoTIFF	Georeferenced Tagged Image File Format
NEW	Gain variable for Landsat 5 TM – new
GOLD	Gain variable for Landsat 5 TM – old
GSFC	Goddard Space Flight Center
HDF	Hierarchical Data Format
IDL	Interactive Data Language
in	Inch
km	Kilometer
L1	Level 1
LEDAPS	Landsat Ecosystem Disturbance Adaptive Processing System
LPGS	Level 1 Product Generation System
m	Meter
MEaSURES	Making Earth System Data Records for Use in Research Environments
mi	Mile
mm	Millimeter
MODIS	Moderate Resolution Imaging Spectroradiometer
MSS	Multispectral Scanner System
NASA	National Aeronautic and Space Administration
NCEP	National Centers for Environmental Prediction
NLAPS	National Landsat Archive Production System
nmi	Nautical Mile
OMI	Ozone Monitoring Instrument
QA	Quality Assurance
SD	South Dakota
SGT	Stinger Ghaffarian Technologies
SI	International System of Units
TIROS	Television and Infrared Observation Satellite
TM	Thematic Mapper
TOA	Top of Atmosphere
TOMS	Total Ozone Mapping Spectrometer
TOVS	TIROS Operational

	Vertical Sounder
UL	Upper Left
UMD	University of Maryland
USGS	U.S. Geological Survey
WGS	World Geodetic System
WO	Work Order
Yd	Yard