GLOBAL WEB-ENABLED LANDSAT DATA (GWELD)
User Guide

Version 3.x

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1 Introduction

The Global Web-Enabled Landsat Data (GWELD) project builds upon the success of the CONUS and Alaska WELD products by expanding to a global scale, using all contemporaneous Landsat 4, 5, and 7 images to provide monthly and annual Landsat 30 m information for any terrestrial non-Antarctic location for six 3-year epochs spaced every 5 years from 1985 to 2010. GWELD data products are developed specifically to provide consistent data that can be used to derive land cover, as well as geophysical and biophysical products, for assessment of surface dynamics and to study the functions of Earth systems. The GWELD products are processed so that users do not need to apply the equations, spectral calibration coefficients, and solar information to convert the Landsat digital numbers to reflectance and brightness temperature. Successive products are defined in the same coordinate system and align precisely, making them simple to use for multi-temporal applications.

The GWELD project is funded by NASA's Making Earth System Data Records for Use in Research Environments (MEaSUREs) program. Monthly and annual global products for six 3-year epochs (1985, 1990, 1995, 2000, 2005, 2010) are planned. Version 3.0 products are currently available for the 2010 epoch. The epochs are planned to be processed in reverse chronological order (i.e. 2005, 2000, ... 1985). The products may be reprocessed as improved versions of the algorithms are developed.

The GWELD products are freely available for educational, research, or commercial applications. Please cite the GWELD products following the GWELD citation guidelines in Section 6.2.

2 Product Types

2.1 GWELD Version 3.1

Monthly and annual GWELD Hierarchical Data Format (HDF) data products are available. The monthly product period is defined by the days in the calendar month. The annual product period is defined as December 1 from the preceding year through November 30 of the current year. For each product period, the single best Landsat observation at each pixel location is selected using a compositing algorithm.

Table 1: GWELD Product Types

Product Type	Temporal Definition
Annual	The preceding year's December through the current year's November.
Monthly	The days in each calendar month.

2.2 GWELD Version 3.1 Product Digital Object Identifiers

The Digital Object Identifier (DOI) for each dataset is given below to provide users with a persistent link to the product information.

Table 2: List of GWELD Version 3.x Product DOIs

Product Short Name	DOI
GWELDYR	10.5067/MEaSUREs/GWELD/GWELDYR.031 10.5067/MEaSUREs/GWELD/GWELDYR.003
GWELDMO	10.5067/MEaSUREs/GWELD/GWELDMO.031 10.5067/MEaSUREs/GWELD/GWELDMO.003

3 Algorithm Description

3.1 GWELD Version 3.x Products Algorithm Description

For complete details of the theoretical description and algorithms used to generate the GWELD Version 3.x Products, see the Algorithm Theoretical Basis Document (ATBD).

3.1.1 Input Data

The GWELD data products are made from Landsat 4 and 5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper Plus (ETM+) acquisitions. The GWELD products for the 2010 epoch (36 monthly products and annual products for 2009, 2010, and 2011) were made using pre-Collection Landsat input data. Specifically, the pre-Collection Level-1 Precision and Terrain (L1TP) corrected data were used. The Level 1T processing includes radiometric correction, systematic geometric correction, precision correction using ground control points, and the use of a digital elevation model to correct parallax error due to local topographic relief. While most pre-Collection Landsat data were processed as L1T, certain acquisitions did not have sufficient ground control or elevation data necessary for precision or terrain correction, respectively. In these cases, the best level of correction was applied and the data were processed to Level 1G-systematic (L1G) with a geolocation error of less than 250 meters. The GWELD products for the other epochs are made using Collection 1 Landsat input data.

3.1.2 Angular Geometry Computation

The Landsat viewing vector (Ω = view zenith angle, view azimuth angle) and the solar illumination vector (Ω’ = solar zenith angle, solar azimuth angle) are defined for each Landsat 30 meter pixel. For the pre-Collection data, the solar illumination vector is computed using an astronomical model parameterized for geodetic latitude and longitude and time following the approach developed for MODIS geolocation (Wolfe et al. 1998).

The calculations to derive the solar illumination vector and the viewing vector are described in detail in the ATBD.

3.1.3 Reflective Wavelength Surface Reflectance NBAR and TOA Brightness Temperature Computation

The GWELD processing is applied to the following Landsat TM/ETM+: the 30 meter blue (0.45-0.52µm), green (0.53-0.61µm), red (0.63-0.69µm), near-infrared (0.78-0.90µm), the two mid-infrared (1.55-1.75µm and 2.09-2.35µm) bands, and the 60-meter thermal (10.41-12.50 µm) band. Processing is not applied to the ETM+ 15-meter panchromatic band.

3.1.3.1 Top of Atmosphere Reflectance (TOA) Computation

For the Collection 1 Landsat data, the calibration is derived using various onboard and vicarious calibration techniques (Markham and Helder 2012; Morfitt et al. 2015). A reflectance-based calibration is used as it has higher accuracy than the pre-Collection radiance-based approach (Markham et al. 2014). In the GWELD code, the stored digital numbers are converted to reflectance:

$$\rho_\lambda = \frac{(\, g_\lambda \times DN_\lambda + b_\lambda)}{\cos \theta_s}$$

where ρ_λ is the top of atmosphere (TOA) reflectance (unitless), DN_λ are the reflectance-based sensor calibration gain and bias coefficients stored in the Collection 1 image metadata, b_λ is 8-bit DN values (0-255), and θ_s is the solar zenith angle (radians) derived at 30 m resolution.

For the pre-Collection Landsat data, a radiance-based calibration is used (Thorne et al. 1997). In the GWELD code, the stored digital numbers are first converted to spectral radiance using the sensor calibration gain and bias coefficients stored in the Landsat L1T file metadata. Then, the radiance is converted to top of atmospheric reflectance:

$$\rho_\lambda = \frac{(\, \pi \times L_\lambda \times d^2)}{(ESUN_\lambda \times \cos \theta_s)}$$

where ρ_λ is the top of atmosphere (TOA) reflectance (unitless), L_λ is the TOA spectral radiance (units: W m^{-2} sr^{-1} μm^{-1}), d is the Earth-Sun distance (astronomical units), $ESUN_\lambda$ is mean TOA solar spectral irradiance (units: W m^{-2} μm^{-1}), and θ_s is the solar zenith angle (radians) derived at 30 m resolution.

3.1.3.2 Atmospheric Correction of the TOA Reflectance Bands

The impact of the atmosphere is variable in space and time and requires correction for quantitative remote sensing applications (Ju et al. 2012). Consistent Landsat surface reflectance data are needed in support of high to moderate spatial resolution geophysical and biophysical studies. TOA reflectance is atmospherically corrected to surface reflectance.

The established Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) (Masek et al. 2006) method is used for atmospheric correction. LEDAPS uses the 6SV radiative transfer code, which has an accuracy better than 1% over a range of atmospheric stressing conditions (Kotchenova et al. 2006). The LEDAPS algorithm derives the aerosol optical thickness independently from each Landsat acquisition using the Kaufman et al. (1997) dense dark vegetation approach and assuming a fixed aerosol type. The LEDAPS method also uses the NCEP/NCAR 6-hour Reanalysis water vapor and surface atmospheric pressure data and NASA's EP TOMS ozone data.

3.1.3.3 Reflective Wavelength Reflectance BRDF Normalization

Most terrestrial surfaces are not Lambertian, so directional reflectance effects are present in satellite reflectance retrievals due to solar-surface-sensor geometry structural variability and optical properties of the surface components (soil, grass, trees, etc.), and these effects nominally may vary with the land cover type and condition. Directional reflectance effects, commonly described by the bidirectional reflectance distribution function (BRDF) (units of sr^{-1}), are relatively small in Landsat data due to the narrow 15° sensor field of view and because the acquisition view zenith angle is usually less than the solar zenith angle, so Landsat reflectance hot-spot effects do not occur (Zhang et al. 2016). However, across the Landsat swath, the red and NIR reflectance can vary by 0.02 to 0.06 (reflectance units) due only to view variation effect (Roy et al. 2016a). These differences may constitute a significant source of noise for certain Landsat applications.

3.1.3.4 Normalized Difference Vegetation Index Computation

The normalized difference vegetation index (NDVI) is the most commonly used vegetation index, derived as the near-infrared minus the red reflectance divided by their sum (Tucker 1979). The 30 meter NBAR NDVI is computed from the red and near-infrared Landsat surface reflectance NBAR and is stored as signed 16-bit integers after being scaled by 10,000.

3.1.3.5 TOA Brightness Temperature Computation

For both the pre-Collection and Collection-1 data, the digital numbers stored in the Landsat image are first converted to spectral radiance and the radiance senses in the Landsat thermal bands are converted to TOA brightness temperature using a standard formula:

$$T = \frac{K_2}{log(K_1/L_\lambda + 1)}$$

where T is the 10.40-12.50µm TOA brightness temperature (Kelvin), K_1 and K_2 are thermal calibration constants set as values in Table 7 in (Chandler et al 2009), and L_λ is the TOA spectral radiance (units: W m^{-2} sr^{-1} μm^{-1}). The 30 m TOA brightness temperature data are stored as signed 16-bit integers with units of degrees Celsius by subtracting 273.15 from the brightness temperature and then scaling by 100.

3.1.4 Band Saturation Computation

The Landsat TM/ETM+ calibration coefficients are configured in an attempt to globally maximize the range of land surface spectral radiance in each spectral band (Markham et al. 2006). However, highly reflective surfaces, such as snow and clouds, may over-saturate the reflective wavelength bands, with saturation varying spectrally and with the illumination geometry (solar zenith and surface slope) (Cahalan et al. 2001; Bindschadler et al. 2008). Similarly, hot surfaces may over-saturate the thermal bands, and cold surfaces may under-saturate the high-gain thermal band. Over- and under-saturated pixels are designated by digital numbers 255 and 1, respectively, in the L1T data. As the radiance values of saturated pixels are unreliable, a

30 m 8-bit saturation mask is generated, storing bit packed band saturation (1) or unsaturated (0) values for the eight Landsat bands.

3.1.5 Cloud Masking

Both the Landsat automatic cloud cover assessment algorithm (ACCA) and a classification tree-based cloud detection approach are implemented for GWELD Version 3.1 products. More detailed information on the cloud cover assessments used is described in the ATBD.

3.1.6 Reprojection, Resampling, and Tiling

The processed data are reprojected from UTM image coordinates into global sinusoidal tiles nested within the 10° x 10° MODIS land product tiles so it is straightforward to compare the 30 m GWELD products with any of the standard gridded MODIS land products (Wolfe et al. 1998; Justice et al. 2002). The sinusoidal projection is (i) uninterrupted, (ii) equal area, and (iii) has less pixel loss and duplication than other global equal-area projections (Seong et al. 2002; Mulcahy 2000). Additional information on the reprojection, resampling, and tiling of WELD products can be found in Section 2.6 of the ATBD.

3.1.7 Compositing

Compositing procedures are applied independently on a per-pixel basis to gridded satellite time series and provide a practical way to reduce cloud and aerosol contamination, fill missing values, and reduce the data volume of moderate resolution global near-daily coverage satellite data (Chilar 1994). Compositing was developed originally to reduce residual cloud and aerosol contamination in Advanced Very High Resolution Radiometer (AVHRR) time series to produce representative *n*-day datasets (Holben 1986). Compositing criteria have included the maximum NDVI, maximum brightness temperature, maximum apparent surface temperature, maximum difference in red and near-infrared reflectance, minimum scan angle, and combinations of these (Roy 2000). Ideally, the criteria should select from the time series only near-nadir observations that have reduced cloud and atmospheric contamination. Composites generated from wide field of view satellite data, such as AVHRR or MODIS, often contain significant BRDF effects (Chilar 1994, Gao et al. 2002, Roy et al. 2006). Compositing algorithms that model BRDF have been developed to compensate for this problem and combine all valid observations to estimate the NBAR (Schaaf et al. 2002). However, this approach does not provide a solution for compositing thermal wavelength satellite data and is less appropriate for application to Landsat data as the comparatively infrequent 16-day Landsat repeat cycle and the narrow 15° Landsat sensor field of view do not provide a sufficient number of angular samples of the surface to invert bidirectional reflectance models (Danaher et al. 2001, Roy et al. 2008). Additional information on the GWELD compositing logic can be found in the ATBD.

Table 3: GWELD Compositing Logic

Priority	Compositing Criteria
1	If n_{valid}=0: minimum blue over all observations
2	If n_{valid}=1 & (n_{water}==1 OR n_{snow}==1): minimum blue over all observations.
3	If n_{valid}=1 & (n_{water}==0 OR n_{snow}==0): valid observation.
4	If n_{valid} =2 & n_{water}==2: minimum blue over the two valid observations.
5	If n_{valid} =2 & n_{water}==1 & n_{soil}==0: (1) If SAM > 0.7: minimum blue over the two valid observations (2) else: maximum weighted NDVI and ND51
6	If n_{valid} =2 & n_{water}==1 & n_{soil}==1: (1) If SAM ≤ 0.7: minimum blue over the two valid observation (2) else: maximum weighted NDVI and ND51
7	If n_{valid} =2 & n_{water}==0: maximum weighted NDVI and ND51
8	If n_{valid} =2: (1) if n_{water} / n_{valid} ≥ 0.5: minimum blue over the valid observations (2) else: maximum weighted NDVI and ND51

SAM is the spectral angle mapper metric calculated over two Landsat TOA spectra using bands TM/ETM+ 2, 3, 4, 5, and 7.

3.1.8 GWELD Global Imagery Browse Services (GIBS) Generation

The Global Imagery Browse Services (GIBS) is a core NASA EOSDIS component that provides a scalable, responsive, highly available, and community standards-based set of imagery services. Monthly and annual GWELD 30 m Version 3.0 GIBS browse image products, referenced to the World Geodetic System 1984 (WGS84) geographic coordinate system, were generated and are available in NASA worldview. False color GIBS browse images that highlight burned areas and snow/ice surfaces were also generated. Additional information on GWELD GIBS generation can be found in the ATBD.

4 Product Contents

4.1 File Format

The GWELD products are stored in Hierarchical Data Format (HDF), a self-descriptive data file format designed by the National Center for Supercomputing Applications to assist users in the storage and manipulation of scientific data across diverse operating systems and machines.

The version 3.0 GWELD 2010 epoch products (36 monthly products and annual products for 2009, 2010, and 2011) are defined in HDF4. The other version 3.1 GWELD epochs are defined in HDFEOS.

The products are generated in separate 5295 x 5295 30 m pixel tiles. Each GWELD product tile is composed of 24 bands (24 HDF science data sets) stored with appropriate data types to minimize the file size and with band-specific attributes (fill value, scale factor, units, valid range). Each GWELD product tile carries the default HDF metadata and a number of product specific metadata that summarize the pixels in each tile.

4.1.1 GWELD Version 3.x Product File Naming Convention

The file naming convention for GWELD Version 3.x products is provided below.

Table 4: GWELD Product Filename Convention

L<ss>.Globe.<period>.<year>.hh<xx>vv<yy>>.h<x>v<y>.doy<min DOY>to<max DOY>.NBAR.v<version number>.hdf		
	Valid Range	**Notes**
<ss>	04, 05, 07, 45, 57	Combination of Landsat sensors (4, 5, 7) used in the product.
<Period>	Annual month01 through month12	Annual products are generated from a year of Landsat data acquired from December 1 of the previous year to November 30 of the current year. Monthly products generated from the Landsat data acquired in that month.
<Year>	1983 to 2011	Year the data was acquired (monthly products)
<xx>	00, 01, ..., 35	Horizontal MODIS land tile coordinate.
<yy>	00, 01, ..., 17	Vertical MODIS land tile coordinate.
<x>	0, 1, …, 6	Horizontal WELD tile coordinate within the MODIS land tile.
<y>	0, 1, …, 6	Vertical WELD tile coordinate within the MODIS land tile.
<min DOY>	001, 002, …, 366	Minimum non-fill Day_Of_Year pixel value present in the tile.
<max DOY>	001, 002, …, 366	Maximum non-fill Day_Of_Year pixel value present in the tile.
<Version Number>	3.0, …	Major and minor algorithm version changes reflected in the first and second digits, respectively.

4.1.2 GWELD Product Data Volume

The HDF format tiles are stored with HDF internal compression applied and are typically 280 MB and 370 MB for each monthly and annual tile product, respectively. The annual products have larger file sizes since there are fewer fill value pixels. The total number of monthly composited files is around ~80,000/year and the total volume about 20TB/year. The total number of annual composited files is around ~8,000/year and the total volume about 3TB/year.

4.2 Product Contents

The GWELD products are defined in the same coordinate system and align precisely with the MODIS land product tiles. The GWELD products are defined in the equal area sinusoidal projection. The projection parameters for the USGS General Cartographic Transformation Package (GCTP) are summarized in Table 4. The datum is World Geodetic System 84 (WGS84). The most upper left pixel coordinate is defined as

ULX = -20015109.3557974174618721, ULY = 10007554.6778987087309361

Table 5: Sinusoidal Projection Parameters (GCTP format)

Num	Parameter	Value	Description
0	Sphere	6371007.181	Radius of reference (meters) sphere
1-3		0.0	Not used
4	CentMer	0.0	Longitude of the central meridian
5		0.0	Not used
6	FE	0.0	False Easting in the same units as the sphere radius
7	FN	0.0	False Northing in the same units as the sphere radius
8-14		0.0	Not used

4.2.1 GWELD Version 3.x Product Contents

Each Version 3.x GWELD product pixel has 24 bands storing the information described below:

Table 6: GWELD Version 3.x Product Contents

Band Name	Data Type	Valid Range	Scale factor	Units	Fill Value	Notes
Band1_SRF_REF	int16	-2000 to 16000	0.0001	reflectance, unitless	-32768	The conventional Landsat 4/5/7 band numbering scheme is used. Surface reflectance (SRF) derived using the LEDAPS atmospheric correction code and subsequently BRDF adjusted to nadir view (0 degree view zenith) with a modelled solar zenith defined in NBAR_Solar_Zenith. Top of atmosphere (TOA) brightness temperature (BT) is computed using standard formulas and calibration coefficients associated with each acquisition.
Band2_SRF_REF	int16	-2000 to 16000	0.0001	reflectance, unitless	-32768	
Band3_SRF_REF	int16	-2000 to 16000	0.0001	reflectance, unitless	-32768	
Band4_SRF_REF	int16	-2000 to 16000	0.0001	reflectance, unitless	-32768	
Band5_SRF_REF	int16	-2000 to 16000	0.0001	reflectance, unitless	-32768	
Band61_TOA_BT	int16	-32767 to 32767	0.01	Degrees Celsius	-32768	
Band62_TOA_BT	int16	-32767 to 32767	0.01	Degrees Celsius	-32768	
Band7_SRF_REF	int16	-2000 to 16000	0.0001	unitless	-32768	

						Band 6 brightness temperature data are defined at 30 m. The Band62 pixel value is set to FILL if the pixel was from Landsat 4 or 5 as this band does not exist on the Landsat 4 and 5 TM sensors.
NDVI_SRF	int16	-10000 to 10000	0.0001	reflectance, unitless	-32768	Normalized Difference Vegetation Index (NDVI) value generated from Band3_SRF_REF and Band4_SRF_REF.
Day_Of_Year	int16	1 to 366	1	date	0	Day of year the selected ETM+ pixel was acquired. Note (a) days 1-334 (or 1-335) were acquired in January-November of the nonleap (or leap) current year; (b) days 335-365 (or 336-366) were acquired in December of the nonleap (or leap) previous year; (c) in the annual composite of a leap year, day 335 always means November 30.
Saturation_Flag	uint8	0 to 255	1	bit field	None[1]	The least significant bit to the most significant bit corresponds to bands 1, 2, 3, 4, 5, 61, 62, 7, with a bit set to 1 signifying saturation in that band and 0 not saturated.
DT_Cloud_State	uint8	0, 1, 2, 200	1	unitless	255	Decision Tree Cloud Classification, 0 = not cloudy, 1 = cloudy, 2 = not cloudy but adjacent to a cloudy pixel, 200 = could not be classified reliably.
ACCA_State	uint8	0, 1	1	unitless	255	ACCA Cloud Classification, 0 = not cloudy, 1 = cloudy.
Num_Of_Obs	uint16	0 to 65534	1	unitless	None[1]	Number of observations considered over the compositing period.
Composite_Path	uint8	0 to 15	1	unitless	None[1]	Internal compositing algorithm pathway code.
Sensor	uint8	0 to 254	1	unitless	255	Landsat satellite that the pixel was selected from (4 = Landsat 4 TM, 5 = Landsat 5 TM, 7 = Landsat 7 ETM+)

Sensor_Zenith	int16	0 to 9000	0.01	Degrees	-32768	Sensor_Zenith (nadir = 0 degrees).
Sensor_Azimuth	int16	-18000 to 18000	0.01	Degrees	-32768	Sensor_Azimuth.
Solar_Zenith	int16	0 to 9000	0.01	Degrees	-32768	Solar_Zenith of pixel observation (directly overhead = 0 degrees).
NBAR_Solar_Zenith	int16	0 to 9000	0.01	Degrees	-32768	Solar_Zenith used for NBAR generation of pixel surface reflectance value.
Solar_Azimuth	int16	-18000 to 18000	0.01	Degrees	-32768	Solar_Azimuth.
L1T_Index	uint16	0 to 65534	1	unitless	65535	Index to the L1T image that the pixel was selected from (reference L1T_Index_Metadata to find the Level 1T filename).
L1T_Column	uint16	0 to 10000	1	unitless	65535	Pixel column number in the input Level 1T image.
L1T_Row	uint16	0 to 10000	1	unitless	65535	Pixel row number in the input Level 1T image.

1 Version 3.0 data has a fill value of “0”.

4.2.2 GWELD Version 3.x Metadata Contents

Table 7: GWELD Version 3.x Metadata Contents

Name	**Data Type**	**Valid Range**	**Units**	**Description**
Mean_B1	Float	-0.1 to 1.0	unitless	Mean band 1 reflectance computed from all non-fill and non-cloudy (ACCA == 0 && DT != 1) pixels in the tile.
Mean_B2	Float	-0.1 to 1.0	unitless	Mean band 2 reflectance computed from all non-fill and non-cloudy (ACCA == 0 && DT != 1) pixels in the tile.
Mean_B3	Float	-0.1 to 1.0	unitless	Mean band 3 reflectance computed from all non-fill and non-cloudy (ACCA == 0 && DT != 1) pixels in the tile.
Mean_B4	Float	-0.1 to 1.0	unitless	Mean band 4 reflectance computed from all non-fill and non-cloudy (ACCA == 0 && DT != 1) pixels in the tile.
Mean_B5	Float	-0.1 to 1.0	unitless	Mean band 5 reflectance computed from all non-fill and non-cloudy (ACCA == 0 && DT != 1) pixels in the tile.
Mean_B6	Float	-200 to 300	Degrees Celsius	Mean band 6 brightness temperature computed from all non-fill and non-cloudy (ACCA == 0 && DT != 1) pixels in the tile
Mean_B7	Float	-0.1 to 1.0	unitless	Mean band 7 reflectance computed from all non-fill and non-cloudy (ACCA == 0 && DT != 1) pixels in the tile.
Mean_NDVI	Float	-0.1 to 1.0	unitless	Mean NDVI computed from all non-fill and non-cloudy (ACCA == 0 && DT != 1) pixels in the tile.
Mean_Solar_Zenith	Float	0 to 90	degrees	Mean solar zenith angle computed from all non-fill pixels in the tile.

Mean_NBAR_Solar_Zenith	Float	0 to 90	degrees	Mean NBAR solar zenith angle computed from all non-fill pixels in the tile.
Percent_Saturated	Float	0.0 to 100.0	Percentage	Percentage of non-fill pixels in the tile that were flagged as saturated in any band (Saturation_Flag != 0).
Percent_ACCA_Cloudy	Float	0.0 to 100.0	Percentage	Percentage of non-fill pixels in the tile that were flagged as ACCA Cloudy (ACCA == 1).
Percent_DT_Cloudy	Float	0.0 to 100.0	Percentage	Percentage of non-fill pixels in the tile that were flagged as DT cloudy (ACCA == 1).
Mean_JDOY	Int	1 to 366	Day	Mean Julian Day of Year of non-fill pixels in the tile.
Min_JDOY	Int	1 to 366	Day	Minimum Julian Day of Year of non-fill pixels in the tile.
Max_JDOY	Int	1 to 366	Day	Maximum Julian Day of Year of non-fill pixels in the tile.
Number_Valid_Obs	Int	0 to 28037025	Count	The number of non-fill pixels in the tile.
Number_Valid_Noncloudy_Obs	Int	0 to 28037025	Count	The number of non-fill and non-cloudy (ACCA == 0 && DT != 1) pixels in the tile.
Count_L1T	Int	0 to 10000	Count	Count of the number of unique L1T images present in the tile.
Sensor_List	String	4/5 or 5/7	Unitless	List of Landsat satellites present in the tile.
Number_Valid_Sensor_Obs	String	0 to 28037025	Count	The number of non-fill pixels in the tile for each satellite indexed by Sensor_List.

5 Product Quality

For complete and updated information regarding product quality, see the GWELD Project Website.

5.1 Known Issues

Known issues can be found in Section 4 of the Algorithm Theoretical Basis Document (ATBD). Please note that the version 3.0 GWELD products for 2009, 2010 and 2011 are defined in HDF4 which cannot be read correctly by GDAL/ArcGIS. This is not an issue for the version 3.1 GWELD products.

5.2 Improvements on Previous Versions

Version 3.0 products introduce several improvements over the decommissioned Version 2.2 products, including the following:

- Atmospheric correction of the wavelength bands to surface reflectance using the LEDAPS code.
- Normalization of the surface reflectance to nadir view (0 degree view zenith) and a modelled solar zenith angle.
- Improved best-pixel compositing.

Version 3.1 products use Landsat Collection 1 products as inputs and have improved per-pixel cloud mask, new quality data, improved calibration information, and improved product metadata that enable view and solar geometry calculations.

5.3 Accuracy/Consistency

No formal assessment of the GWELD product accuracy/consistency has been undertaken but are a function of the accuracy/consistency of the Landsat L1T geolocation, calibration, and the LEDAPS atmospheric correction processes.

6 Data Ordering

The following tools offer options to search the LP DAAC data holdings and provide access to the data:

Bulk download: LP DAAC Data Pool and DAAC2Disk

Search and browse: USGS EarthExplorer, NASA Earthdata Search, and NASA Worldview

Subset and explore: AppEEARS

6.1 Software Tools

A complete list of software tools that can be used to visualize and manipulate GWELD product data can be found on the WELD Project Website under Software Tools.

6.2 Citations

If you wish to cite the GWELD products in a report or publication, please cite using the product's DOI that is listed in Table 2.

In addition to citing the dataset with the product DOI, please include these additional citations:

Roy, D.P., Ju, J., Kline, K., Scaramuzza, P.L., Kovalskyy, V., Hansen, M.C., Loveland, T.R., Vermote, E.F., Zhang, C., 2010, Web-enabled Landsat Data (WELD): Landsat ETM+ Composited Mosaics of the Conterminous United States, *Remote Sensing of Environment*, 114: 35-49.

Hansen, M.C., Egorov, A., Potapov, P.V., Stehman, S.V., Tyukavina, A., Turubanova, S.A., Roy, D.P., Goetz, S.J., Loveland, T.R., Ju, J., Kommareddy, A., Kovalskyy, V., Forsythe, C., Bents, T., 2014, Monitoring conterminous United States (CONUS) land cover change with Web-Enabled Landsat Data (WELD), Remote sensing of Environment, 140, 466-484

If you use a GWELD product generated graphic or browse image, please insert the text "GWELD" somewhere that is clearly visible.

7 References

Arvidson, T., Gasch, J., & Goward, S. N. (2001) Landsat 7's long-term acquisition plan--- an innovative approach to building a global imagery archive. *Remote Sensing of Environment, 78*, 13-26.

Arvidson, T., Goward, S. N., Gasch, J., & Williams, D. (2006). Landsat-7 long-term acquisition plan: development and validation. *Photogrammetric Engineering & Remote Sensing, 72* (10), 1137-1146.

Bindschadler, R., Vornberger, P., Fleming, A., Fox, A., Mullins, J., Binnie, D., Paulsen S. J., Granneman B., & Gorodetzky, D. (2008). The Landsat image mosaic of Antarctica. *Remote Sensing of Environment, 112*(12), 4214-4226.

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