National Aeronautics and Space Administration

OPERA

Observational Products for End-Users from Remote Sensing Analysis

Product Specification Document for Dynamic Surface Water Extent from Harmonized Landsat and Sentinel-2

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Observational Products for End-Users from Remote Sensing Analysis (OPERA) Project

OPERA Level-3 Dynamic Surface Water Extent from Harmonized Landsat-8 and Sentinel-2A/B Product Specification

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1 INTRODUCTION

1.1 Document Purpose

The primary purpose of this document is to convey product specifications of the OPERA (Observational Products for End-users from Remote-sensing Analysis) Level-3 Dynamic Surface Water Extent (DSWx) product that uses Harmonized Landsat-8 and Sentinel-2A/B (HLS) as the primary image-based inputs. This product, referred to by the short name DSWx-HLS, will be generated by the OPERA Data System (SDS). It will be openly distributed by NASA's Physical Oceanography Distributed Active Archive Center (PO.DAAC).

1.2 Document Organization

Section 2 provides an overview of the product, including its purpose.

Section 3 provides the structure of the product, including tile definition, file organization, spatial resolution, and temporal and spatial organization of the content, as well as the typical file size and total data volume.

Section 4 provides a detailed description of DSWx-HLS product layers and corresponding metadata.

Appendix A provides a list of the acronyms used in this document.

1.3 Applicable and Reference Documents

The product described in this document responds to requirements imposed by applicable documents indicated below. In case of conflict between the applicable documents and this one, the OPERA Project shall review the conflict to find the most effective resolution.

Applicable Documents

[AD1] NASA SNWG Cycle 2 – OPERA Program Level (Level 1) Requirements Document, Jan. 27, 2022.
[AD2] OPERA Level 2 Requirements, JPL D-107391, Rev B, Sep. 22, 2022.
[AD3] OPERA Product Description, JPL D-107389, Rev A, May 13, 2022.

Reference Documents

[RD1] OPERA Algorithm Theoretical Basis Document for Dynamic Surface Water Extent from Harmonized Landsat-8 and Sentinel-2A/B, JPL D-107397, May 6, 2023.

[RD2] Jones, John W. “Improved Automated Detection of Subpixel-Scale Inundation—Revised Dynamic Surface Water Extent (DSWE) Partial Surface Water Tests.” Remote Sensing, vol. 11, no. 4, 2019 374. doi: 10.3390/rs11040374.

[RD3] Earth Science Data and Information System (ESDIS) Standards Office (ESO). “GeoTIFF File Format, ESDS-RFC-040v1.1." Earthdata, 16 Sept. 2019. earthdata.nasa.gov/esdis/eso/standards-and-references/geotiff. Accessed 14 Oct. 2021.

[RD4] Cloud Optimized GeoTIFF: An imagery format for cloud-native geospatial processing. www.cogeo.org/. Accessed 14 Oct. 2021.

[RD5] “TIFF/IT for Image Technology.” The National Digital Information Infrastructure and Preservation Program at the Library of Congress, 3 Oct. 2006, www.loc.gov/preservation/digital/formats/fdd/fdd000072.shtml. Accessed 21 June 2022.

[RD6] “Coordinate Systems.” National Geospatial-Intelligence Agency (NGA), 1 Mar. 2022, earth-info.nga.mil/index.php?dir=coordsys&action=coordsys#mgrs. Accessed 15 Oct. 2021.

[RD7] European Space Agency (ESA). Sentinel-2 tiling scheme KML, 2016. hls.gsfc.nasa.gov/wp-content/uploads/2016/03/S2A_OPER_GIP_TILPAR_MPC__20151209T095117_V20150622T000000_21000101T000000_B00.kml. Accessed 12 Apr. 2022.

The latest official versions of OPERA documents should be obtained from https://www.jpl.nasa.gov/go/opera/products/dswx-product-suite.

1.4 Applicable Software

This document is being released for Release 4 (R4) of the DSWx-HLS Science Application Software (SAS) at this GitHub repository: nasa/PROTEUS. Version 1.0.1 (v1.0.1) is available at nasa/PROTEUS Releases. Previous versions of the DSWx-HLS SAS are also available at nasa/PROTEUS Releases.

The products generated by this version of the SAS (SOFTWARE_VERSION) v1.0.1 are consistent with this document and are tagged as version (PRODUCT_VERSION) v1.0

2 PRODUCT OVERVIEW

2.1 Product Background

The U.S. Federal Satellite Needs Working Group identified a need for improved understanding of spatial and temporal variations of land inundation by surface water. While providing a multi-decadal record of surface water dynamics, existing datasets based on Landsat alone benefit spatially and temporally from the inclusion of additional satellite-based observations. DSWx products map the extent of surface water features on a near-global basis, i.e., all landmasses excluding Antarctica. Optical DSWx products are derived from HLS data inputs, i.e., Harmonized Landsat-8 and Sentinel-2A/B multispectral data, and radar DSWx products are derived from Synthetic Aperture Radar (SAR) data from Sentinel-1A/B, the NASA-ISRO Synthetic Aperture Radar (NISAR) L-band instrument, and the Surface Water and Ocean Topography (SWOT) Ka-band instrument. This document describes the product specifications of optical DSWx products from HLS datasets, referred to as DSWx-HLS.

The theoretical basis and processing sequence used to generate DSWx-HLS are fully described in the Algorithm Theoretical Basis Document [RD1]. Figure 2-1 conceptually summarizes the DSWx-HLS product workflow.

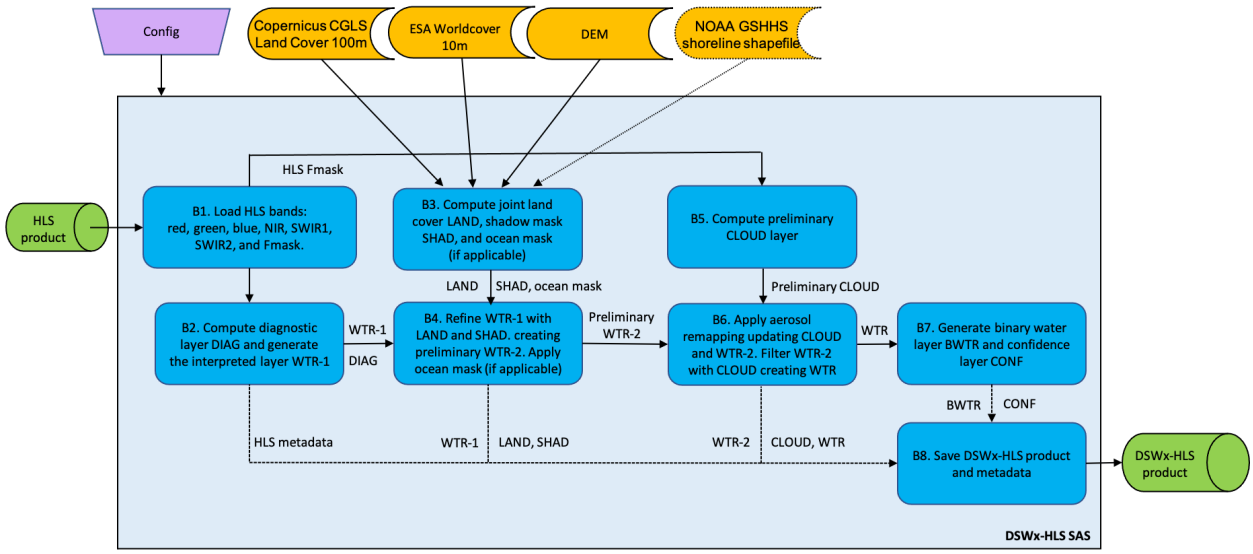

Figure 2-1. OPERA DSWx-HLS workflow diagram.

Currently, the primary input dataset for generating each DSWx-HLS product is the HLS product version 2.0. HLS products provide surface reflectance (SR) data from the Operational Land Imager (OLI) aboard the Landsat 8 satellite, the Operational Land Imager 2 (OLI-2) aboard the Landsat 9 satellite, and the MultiSpectral Instrument (MSI) aboard the Sentinel-2A/B satellites. While DSWx-HLS does not yet incorporate OLI-2 HLS inputs, the combined OLI and Sentinel-2 system provides observations over landmasses, excluding Antarctica, approximately every two to three days. HLS products are distributed over projected map coordinates aligned with the Military Grid

Reference System (MGRS). Each MGRS tile covers an area of 109.8 km × 109.8 km. This area is divided into 3,660 rows and 3,660 columns at 30-m pixel spacing. Each tile overlaps neighbors by 4,900 m in each direction.

In addition to the HLS product, three other ancillary inputs, listed in Table 2-1, are required for generating the DSWx-HLS product: the Copernicus Global Land Cover (CGLS) discrete classification map provided at 100-m pixel spacing, the ESA WorldCover map provided at 10-m pixel spacing, and a digital elevation model (DEM). The DEM employed in production of the DSWx-HLS product is derived from the Copernicus DEM 30-m (GLO-30) globally with the exception of restricted areas around Armenia and Azerbaijan where the Copernicus DEM GLO-30 is not publicly available and the Copernicus DEM 90-m (GLO-90) was used instead.

The DSWx-HLS SAS also provides an option, disabled in production of the standard DSWx-HLS product v1.0, to perform global ocean masking of the DSWx-HLS layers. When enabled, the ocean masking requires the National Oceanic and Atmospheric Administration (NOAA) Global Self-consistent, Hierarchical, High-resolution Shorelines (GSHHS) shapefile to identify the shoreline.

Table 2-1. Product Dependency Diagram.

Product	Scope	Description
Harmonized Landsat-8 and Sentinel-2A/B	Near-global	The input HLS products to OPERA system
DEM	Global	The reference Digital Elevation Model, referenced to the World Geodetic System (WGS84) ellipsoid.
Copernicus Land Cover	Near-global (lat. range from -60 deg. to 80 deg)	The Copernicus Global Land Service (CGLS) Land Cover Layers with fine thematic resolution and 100-m spatial resolution
ESA WorldCover	Near global (lat. range from -60 deg. to 84 deg.	Broader land-cover classes with higher spatial resolution (10-m) used to downscale 100-m Copernicus Land Cover

2.2 DSWx-HLS Product Overview

Each DSWx-HLS product is distributed as a set of 10 GeoTIFF (Geographic Tagged Image File Format) files corresponding to 10 DSWx-HLS layers. In addition, images for product browsing are provided in GeoTIFF and Portable Network Graphic (PNG) formats (see Section 4.1). The GeoTIFF files are saved as Cloud-Optimized GeoTIFFs (COGs) [RD3] to make retrieval of GeoTIFF data from web storage, including Distributed Active Archive Centers (DAACs), more efficient.

The pixel spacing of the DSWx-HLS product in east and north directions is consistent with the input HLS product (Table 2-2).

Table 2-2. Posting of the DSWx-HLS product.

Product	Posting in Northing (m)	Posting in Easting (m)
DSWx-HLS	30	30

3 PRODUCT ORGANIZATION

In this section, we describe the DSWx-HLS file format and naming convention, as well as tile definition, labeling scheme, and spatial organization.

3.1 File Format – GeoTIFF

Each OPERA DSWx-HLS product is distributed as a set of 10 GeoTIFF [RD3] files containing additional metadata. The GeoTIFF files are COGs providing more efficient data retrieval from Web Object Storages [RD4].

The GeoTIFF is a format to store georeferenced raster images and is widely used by remote-sensing communities. The GeoTIFF format is defined in the public domain as Tagged Image File Format (TIFF) [RD5]. It enables the storage of compressed images with associated metadata that can be easily read by Geographic Information System (GIS) software, including the open Geospatial Data Abstraction Library (GDAL) and Quantum GIS (QGIS).

3.2 File-Naming Convention

OPERA DSWx-HLS granule names are designed to ensure unique and descriptive identification for the OPERA DSWx-HLS products. The following file-naming convention is used:

OPERA_L3_DSWx-HLS_[TileID]_[DateTime]_[ProductGenerationDateTime]_[Satellite]_[PixelSpacing]_[ProductVersion]_[LayerNumber]_[LayerName].[Ext]

- **T**ile**ID**: Specific tile ID of the product, which is also the tile ID of the input HLS product in the MGRS. Field starts with a “T” followed by the tile ID.
- **D**ate**T**ime: The acquisition date and time (Greenwich Mean Time or GMT) derived from the input HLS granule name (format: YYYYMMDDTHHMMSSZ)
- **P**roduct**G**eneration**D**ate**T**ime: The date and time (GMT) at which the product was generated by OPERA (format: YYYYMMDDTHHMMSSZ)
- **Satellite**: The image input satellite “S2A” (Sentinel-2A) “S2B” (Sentinel-2B), or “L8” (Landsat 8)
- **P**ixel**S**pacing: Pixel spacing in meters
- **P**roduct**V**ersion: OPERA DSWx-HLS product version number with four characters, including the letter “v” and two digits indicating the major and minor versions, which are delimited by a period. See Section 4.2.1 for more information on the Product Version. The ProductVersion should match the first two digits of the Product Specification version (this document).
- **L**ayer**N**umber: Three characters corresponding to the letter “B,” followed by a two-digit integer indicating the DSWx-HLS layer number, starting with 01 for the WTR layer
- **L**ayer**N**ame: Name of the DSWx-HLS layer (see Table 4-1)

- **E**xt: File extension (“tif” or png”)

Example:
OPERA_L3_DSWx-HLS_T15SXR_20210205T163901Z_20220101T140222Z_S2A_30_v1.0_B01_WTR.tif

3.3 Tile Definition

OPERA DSWx-HLS products conform to the HLS products’ tiling scheme. Each tile has a ground footprint of 109.8 km × 109.8 km divided into 3,660 rows and 3,660 columns with 30 m pixel spacing in both directions. Both the HLS and DSWx-HLS products include an overlap of 4,900 m in every direction over the MGRS 100,000-m square tiling scheme to facilitate mosaicking of contiguous DSWx-HLS product tiles without gaps. DSWx-HLS tiles are provided over projected map coordinates aligned with the MGRS [RD6].

The MGRS is a geographic grid reference system defined using the Universal Transverse Mercator (UTM) for most latitudes and the Universal Polar Stereographic (UPS) coordinate systems for polar regions (North of 84°N and South of 80°S). The OPERA DSWx-HLS products are defined over the UTM coordinate system with a 100 km-by-100 km tiling scheme (same as original Sentinel-2 tiling system [RD7]). At this precision level, MGRS tiles are labeled using the grid zone designation followed by the 100,000-m square identification.

The grid zone designation is defined by the UTM zone number followed by the latitude band. Each longitude section has a width of 6°, resulting in 60 UTM zones. Each zone is divided into 20 latitude bands of 8° in the latitude direction and each band (tile) is identified by a letter starting from “C” at 80°S to “X” at 80°N, omitting letters “I” and “O” because of their similarity to numerals 1 and 0. Both latitude bands “C” and “X” are extended 4° towards the Poles, i.e., the latitude band “C” comprises the latitude range from −84° to −72° and the latitude band “X” identifies the latitude range from 72° to 84°.

The 100,000-m square identification, or 100_SID, consists of a 100_SID column letter “A” to “Z” followed by a 100_SID row letter from “A” to “V.” Similar to latitude bands, 100_SID column and row letters also omit letters “I” and “O.”

The resulting MGRS tiling scheme used by HLS and DSWx-HLS has the following format:

UTM_ZONE_NUMBER**L**ATITUDE_BAND100_SID_**C**OLUMN_LETTER100_SID_**R**OW_LETTER>

For instance, the Japan example that is shown in Section 5 is located at the tile identified as “53SNV ,” where “53” is the UTM zone number, “S” is the latitude band, “N” is the 100_SID column letter, and “V” is the 100_SID row letter.

3.4 Spatial Organization

Salient features of the output grid for the DSWx-HLS product are as follows:

1. The output grid is common to all layers in the product.
2. The DSWx-HLS data are arranged on a uniformly spaced, north-up and west-left grid – i.e., decreasing north or Y coordinate in the row direction and increasing east or X coordinate in the column direction following the row-major order convention of representing 2D raster arrays.

3.5 Grid Alignment

OPERA DSWx-HLS products use a “pixel is area” convention. The “pixel is area” convention uses northing and easting coordinates Y and X, with (0,0) denoting the upper-left corner of the image, and increasing X to the east, increasing Y to the south. The first pixel value fills the grid cell with the top-left position (0,0) and bottom-right position (1,1).

4 PRODUCT SPECIFICATION

In this section, we describe the DSWx-HLS product layers and associated metadata.

4.1 Product Raster Layers

Each DSWx-HLS product bundle contains 10 GeoTIFF files (layers), each with 3,660 rows and 3,660 columns (Section 3.3). Layers are provided as Unsigned Integers of 8 bits (UInt8), Unsigned Integers of 16 bits (UInt16), or floating-point numbers of 32 bits (Float32). The product bundle also includes browse images in GeoTIFF and PNG formats. Specifics regarding DSWx-HLS layer names and content are shown in Table 4-1.

Table 4-1. DSWx-HLS raster layers and browse images.

Product Variables		
Layer: 1	**Water classification (WTR)**	
Format: GeoTIFF	**Type:** UInt8	**Shape (x, y):** (3660 × 3660)
Description: Masked interpreted water classification layer. This represents pixel-wise classification into one of three water classes (not water, open water, and partial surface water), snow/ice, cloud/cloud shadow and adjacent to cloud/cloud shadow, ocean masked, or no data classes as a result of processing the diagnostic (DIAG) layer through all intermediate steps/layers (WTR-1, and WTR-2).		
Layer classes: 0: Not water – an area with valid reflectance data that is not open water (class 1), partial surface water (class 2), snow/ice (class 252), cloud/cloud shadow (class 253), or ocean masked (class 254). Masking can result in "not water" (class 0) where land cover masking is applied. 1: Open water – an area that is entirely water and unobstructed to the sensor, including obstructions by vegetation, terrain, and buildings. 2: Partial surface water – an inundated area that is at least 20% and less than 100% open water. This may be referred to as "subpixel inundation" when referring to a pixel's area. Examples include wetlands, water bodies with emergent vegetation, and pixels bisected by coastlines. 252: Snow/ice – an area identified as snow/ice according to input HLS Fmask quality assurance (QA) data. 253: Cloud/cloud shadow and adjacent to cloud/cloud shadow– an area identified as cloud, cloud shadow, or adjacent to those features according to input HLS Fmask quality assurance (QA) data. 254: Ocean masked – an area identified as ocean using a shoreline database with an added margin 255: Fill value (no data).		
Layer: 2	**Binary water (BWTR)**	
Format: GeoTIFF	**Type:** Uint8	**Shape (x, y):** (3660 × 3660)
Description: The binary water map is derived from the WTR layer as a union of water classes (open water and partial surface water) into a binary map indicating areas with and without water. This layer is meant to provide users with a quick view for water/no-water. Invalid data classes (snow/ice, cloud/cloud shadow along with adjacent to cloud/cloud shadow, ocean masked, and fill value) are also provided to indicate areas in which the binary classification does not provide water/no-water classification.		
Layer classes: 0: Not water – an area with valid reflectance data that is not water (class 1) and not snow/ice (class 252), cloud/cloud shadow (class 253), or ocean masked (class 254). 1: water – an area classified as "open water" or "partial surface water" (see WTR layer). 252: Snow/ice – an area identified as snow/ice according to input HLS Fmask quality assurance (QA) data. 253: Cloud/cloud shadow – an area identified as cloud or cloud shadow or adjacent to cloud/cloud shadow according to input HLS Fmask quality assurance (QA) data. 254: Ocean masked – an area identified as ocean using a shoreline database with an added margin 255: Fill value (no data).		
Layer: 3	**Confidence (CONF)**	
Format: GeoTIFF	**Type:** Uint8	**Shape (x, y):** (3660 × 3660)

Description: A representation of the confidence associated with the WTR classification that is based on a combination of DIAG results and quality assurance information provided with the input HLS data. For example, the Open water class of the WTR layer is split into two classes: High Confidence and Moderate Confidence while WTR Partial surface water Class pixels of WTR are flagged as either Partial surface water Conservative or Partial surface water Aggressive, with the latter exhibiting less certainty. More specifics regarding this representation are documented in [RD1]. As in the WTR and BWTR layers, pixels for which water retrievals are difficult or impossible due to snow/ice, cloud/shadow, or fill values are also noted in the CONF layer.

Layer classes:

Not masked:
0: Not water – an area with valid reflectance data that is not water or ocean masked (class 254) and is not identified as snow/ice, cloud/cloud shadow, adjacent to cloud/cloud shadow, or snow/ice in the input HLS Fmask quality assurance (QA) data. “not water” (class 0) also exists where terrain shadow and/or land cover masking is applied.
1: Open water high-confidence – an area that is entirely water with high-confidence that has not also been ocean masked (class 254) and is not identified as snow/ice, cloud/cloud shadow, adjacent to cloud/cloud shadow, or snow/ice in the input HLS Fmask quality assurance (QA) data.
2: Open water moderate-confidence – an area that is entirely water with moderate-confidence that has not also been ocean masked (class 254) and is not identified as snow/ice, or cloud/cloud shadow, adjacent to cloud/cloud shadow, or snow/ice in the input HLS Fmask quality assurance (QA) data
3: Partial surface water conservative – an inundated area that is at least approximately 50% and less than 100% open water with a conservative classification that has not also been ocean masked (class 254) and is not identified as snow/ice, cloud/cloud shadow, adjacent to cloud/cloud shadow, or snow/ice in the input HLS Fmask quality assurance (QA) data.
4: Partial surface water aggressive – an inundated area that is at least 20% and less than approximately 50% open water, that is a less strict classification that has not also been ocean masked (class 254) and is not identified as snow/ice, cloud/cloud, adjacent to cloud/cloud shadow, or snow/ice in the input HLS Fmask quality assurance (QA) data.

Cloud/cloud shadow and adjacent to cloud/cloud shadow:
10: Not water – an area with valid reflectance data that is not water or ocean masked (class 254) but is potentially obstructed by cloud/cloud shadow according to the input HLS Fmask. “not water” (class 0) also exists where terrain shadow and/or land cover masking is applied.
11: Open water high-confidence – an area that is entirely water with high-confidence that has not also been ocean masked (class 254) but is potentially obstructed by cloud/cloud shadow according to the input HLS Fmask.
12: Open water moderate-confidence – an area that is entirely water with moderate-confidence that has not also been ocean masked (class 254) but is potentially obstructed by cloud/cloud shadow according to the input HLS Fmask.
13: Partial surface water conservative – an inundated area that is at least approximately 50% and less than 100% open water with a conservative classification that has not also been ocean masked (class 254) but is potentially obstructed by cloud/cloud shadow according to the input HLS Fmask.
14: Partial surface water aggressive – an inundated area that is at least 20% and less than approximately 50% open water and less than 100% open water with a less strict classification that has not also been ocean masked (class 254) but is potentially obstructed by cloud/cloud shadow according to the input HLS Fmask.

Snow/ice masked:
20: Not water – an area with valid reflectance data that is not water, that is marked as snow/ice according to the input HLS Fmask, but not obstructed by cloud/cloud shadow according to the input HLS Fmask and is not ocean masked (class 254). “not water” (class 0) also exists where terrain shadow and/or land cover masking is applied.
21: Open water high-confidence – an area that is entirely water with high-confidence and that is marked as snow/ice according to the input HLS Fmask, but not obstructed by cloud/cloud shadow according to the input HLS Fmask and is not ocean masked (class 254).
22: Open water moderate-confidence – an area that is entirely water with moderate-confidence and that is marked as snow/ice according to the input HLS Fmask, but not obstructed by cloud/cloud shadow according to the input HLS Fmask and is not ocean masked (class 254).
23: Partial surface water conservative – an inundated area that is at least 50% and less than 100% open water with a conservative classification and that is marked as snow/ice according to the input HLS Fmask, but not obstructed by cloud/cloud shadow according to the input HLS Fmask and is not ocean masked (class 254).
24: Partial surface water aggressive – an inundated area that is at least 20% and less than approximately 50% open water, that is a less strict classification and that is marked as snow/ice according to the input HLS Fmask, but not obstructed by cloud/cloud shadow according to the input HLS Fmask and is not ocean masked (class 254).

254: Ocean masked - an area identified as ocean using a shoreline database with an added margin
255: Fill value (no data).

Layer: 4	**Diagnostic layer (DIAG)**	
Format: GeoTIFF	**Type:** UInt16	**Shape (x, y):** (3660 × 3660)
Description: A layer coded to indicate which of five initial DSWx-HLS tests were positive for water detection on a per-pixel basis. Values range from 0 (i.e, 00000), indicating that none of the five DSWx-HLS tests returned a positive result, to 11111, denoting that all tests resulted positive. The tests are described in [RD1] [RD2] and are used to derive the confidence layer above. The combination of positive tests for a particular class determines its confidence value. The Fill value (no data) is represented by the number 65535.		
Layer: 5	**Interpretation of diagnostic layer into water classes (WTR-1)**	
Format: GeoTIFF	**Type:** UInt8	**Shape (x, y):** (3660 × 3660)
Description: Classification of the DIAG layer results in open water, partial surface water, and no-water. This layer is further refined through the application of masks resulting in Layers 6 (WTR-2) and 1 (WTR).		
Layer classes: 0: Not water – an area with valid reflectance data that is not open water (class 1) or partial surface water (class 2). 1: Open water – an area that is entirely water and unobstructed to the sensor, including obstructions by vegetation, terrain, and buildings. 2: Partial surface water – an inundated area that is at least 20% and less than 100% open water. This may be referred to as "subpixel inundation" when referring to a pixel's area. Examples include wetlands, water bodies with emergent vegetation, and pixels bisected by coastlines. 254: Ocean masked - an area identified as ocean using a shoreline database with an added margin (not applicable for the standard DSWx-HLS product v1.0) 255: Fill value (no data).		
Layer: 6	**Interpreted layer refined using land cover, terrain shadow testing, and aerosol overcorrection mitigation (WTR-2)**	
Format: GeoTIFF	**Type:** UInt8	**Shape (x, y):** (3660 × 3660)
Description: The WTR-2 layer is derived from the WTR-1 (Layer 5) outcome by applying additional tests based on land cover and terrain shadow information, and aerosol overcorrection mitigation, as described in [RD1][RD2] to mask (eliminate) false-positive water detections.		
Layer classes: 0: Not water – an area with valid reflectance data that is not open water (class 1) or partial surface water (class 2). 1: Open water – an area that is entirely water and unobstructed to the sensor, including obstructions by vegetation, terrain, and buildings. 2: Partial surface water – an inundated area that is at least 20% and less than 100% open water. This may be referred to as "subpixel inundation" when referring to a pixel's area. Examples include wetlands, water bodies with emergent vegetation, and pixels bisected by coastlines. 254: Ocean masked - an area identified as ocean using a shoreline database with an added margin 255: Fill value (no data).		
Layer: 7	**Land cover classification (LAND)**	
Format: GeoTIFF	**Type:** UInt8	**Shape (x, y):** (3660 × 3660)
Description: Land cover thematic layer used to determine where additional testing is performed to potentially mask WTR-1 layer water detections to produce the intermediate WTR-2 layer [RD1].		

Layer classes: 0 - 99: Low intensity developed (number = last two digits of ESA WorldCover dataset year) 100 - 199: High intensity developed (number = 100 + last two digits of ESA WorldCover dataset year) 200: Water, wetland, mangrove forest 201: A variety of forest classes 255: Fill value (no data)		
Layer: 8	**Terrain shadow layer (SHAD)**	
Format: GeoTIFF	**Type:** UInt8	**Shape (x, y):** (3660 × 3660)
Description: Mask used to eliminate likely locations of terrain-induced shadow based on a classification of shadow areas generated for the capture date/time of the input HLS image from Digital Elevation Model (DEM - Layer 10) data. This is used in the creation of the intermediate layer WTR-2 [RD1]. **Layer classes:** 0: Shadow 1: Not shadow		
Layer: 9	**Input HLS Fmask cloud/cloud-shadow/water classification (CLOUD)**	
Format: GeoTIFF	**Type:** UInt8	**Shape (x, y):** (3660 × 3660)
Description: Cloud, cloud-shadow, and snow/ice classification layer from HLS input.		
Layer classes: 0: Not masked 1: Cloud shadow, adjacent to cloud/cloud shadow, or both 2: Snow/ice 3: Snow/ice and class 1 (cloud shadow or adjacent to cloud/cloud shadow) 4: Cloud 5: Cloud and class 1 (cloud shadow or adjacent to cloud/cloud shadow) 6: Cloud and snow/ice 7: Cloud, snow/ice, and class 1 (cloud shadow or adjacent to cloud/cloud shadow) 8. Fmask identified water 9: Fmask identified water, cloud shadow or adjacent to cloud/cloud shadow 10: Fmask identified water, snow/ice 11: Fmask identified water, snow/ice and class 1 (cloud shadow or adjacent to cloud/cloud shadow) 12: Fmask identified water, cloud 13: Fmask identified water, cloud and class 1 (cloud shadow or adjacent to cloud/cloud shadow) 14: Fmask identified water, cloud and snow/ice 15: Fmask identified water, cloud, snow/ice, and class 1 (cloud shadow or adjacent to cloud/cloud shadow) 255: Fill value (no data)		
Layer: 10	**Digital elevation model (DEM)**	
Format: GeoTIFF	**Type:** Float32	**Shape (x, y):** (3660 × 3660)
Description: The reference Digital Elevation Model, referenced to the World Geodetic System (WGS84) ellipsoid, that is used for terrain shadow calculation. The DEM employed in production of the DSWx-HLS product v1.0 is derived from the Copernicus DEM 30-m (GLO-30) globally, and the Copernicus DEM 90-m (GLO-90) in restricted areas around Armenia and Azerbaijan where GLO-30 is not publicly available.		
Browse images (GeoTIFF and PNG)		
Format: GeoTIFF	**Type:** UInt8	**Shape (x, y):** (3660 × 3660)

Format: PNG	**Type:** UInt8	**Shape (x, y):** (1024 × 1024)
Description: The browse images provide a visual representation of the DSWx-HLS product for t browsing. They contain a mix of classes from multiple DSWx-HLS layers including translucent cloud/cloud shadow and adjacent to cloud/cloud shadow areas providing a quick assessment of the interpreted water classes with and without cloud masking, at the same time as areas that may be obscured by cloud-derived artifacts are highlighted by a semi-transparent gray layer.		

4.2 GeoTIFF Metadata

All DSWx-HLS product layers (GeoTIFF files) are saved with the same metadata fields, divided into four sections: 1) Product Identification, 2) input datasets, 3) HLS product metadata, and 4) Processing Parameters.

4.2.1 Product Identification

Table 4-2 lists the product identification fields of the GeoTIFF metadata. The attribute PRODUCT_VERSION informs the version of the DSWx-HLS product (structure and metadata), whereas the attribute SOFTWARE_VERSION describes the version of the software that generated the DSWx-HLS product.

Table 4-2. GeoTIFF metadata: product identification.

Attribute	Description
PRODUCT_ID	The DSWx-HLS product identification
PRODUCT_VERSION	The DSWx-HLS product version (same as in the product filename). It increments with changes to the structure and/or metadata contained within the product. This document is consistent with PRODUCT_VERSION 1.0
SOFTWARE_VERSION	The algorithm software version used to generate the DSWx-HLS product. This document is consistent with SOFTWARE_VERSION 1.0.1
PROJECT	The project name: “OPERA”
PRODUCT_LEVEL	The product level: “3”
PRODUCT_TYPE	The product type: “DSWx-HLS”
PRODUCT_SOURCE	The DSWx-HLS product source for reflectance measurements: “HLS”
PROCESSING_DATETIME	DSWx-HLS product processing date. Format: YYYY-MM-DDTHH:MM:SSZ.
SPACECRAFT_NAME	Name of the sensor platform (e.g., “Landsat-8”, “Sentinel-2A”, or “Sentinel-2B”)
SENSOR	Name of the sensor instrument (e.g., “OLI” or “MSI”)

4.2.2 Input Datasets

Table 4-3 describes the metadata fields that list the HLS product and ancillary inputs used to generate the DSWx-HLS product.

Table 4-3. GeoTIFF metadata: input datasets.

Attribute	Description
HLS_DATASET	Name of the input HLS product used to generate the DSWx-HLS product
DEM_SOURCE	Description of the input DEM
DEM_COVERAGE	Input DEM coverage over the DSWx-HLS product: “FULL” for full coverage, “FULL_WITH_ANTIMERIDIAN_CROSSING” for full coverage with antimeridian crossing, or “NOT_TESTED” if coverage checks are disabled
LANDCOVER_SOURCE	Description of the input CGLS discrete classification map file used to provide detailed land cover type
LANDCOVER_COVERAGE	Input CGLS discrete classification map coverage over the DSWx-HLS product: “FULL” for full coverage, “FULL_WITH_ANTIMERIDIAN_CROSSING” for full coverage with antimeridian crossing, “PARTIAL” if DSWx-HLS product coverage exceeds CGLS map limits (i.e., beyond latitudes -60 or +80 degrees), or “NOT_TESTED” if coverage checks are disabled
WORLDCOVER_SOURCE	Description of the input ESA WorldCover file.
WORLDCOVER_COVERAGE	Input ESA WorldCover map coverage over the DSWx-HLS product: “FULL” for full coverage, “FULL_WITH_ANTIMERIDIAN_CROSSING” for full coverage with antimeridian crossing, “PARTIAL” if DSWx-HLS product exceeds the WorldCover map limits (i.e.,beyond latitudes -60 or +84 degrees), or “NOT_TESTED” if coverage checks are disabled
SHORELINE_SOURCE	Description of the National Oceanic and Atmospheric Administration (NOAA) Global Self-consistent, Hierarchical, High-resolution Shorelines (GSHHS) shoreline shapefile. The NOAA GSHHS shoreline shapefile is only used for ocean masking, which is disabled in production of the standard DSWx-HLS product v1.0) by default.

4.2.3 HLS Product Metadata

Table 4-4 lists the metadata copied or derived from the HLS product metadata to the DSWx-HLS GeoTIFF metadata.

Table 4-4. GeoTIFF metadata: HLS product metadata.

Attribute	Description
SENSOR_PRODUCT_ID	Landsat product IDs, copied from the HLS metadata field LANDSAT_PRODUCT_ID, for Landsat-derived HLS products, or Sentinel granule Uniform Resource Identifier (URI), copied from PRODUCT_URI for Sentinel-derived HLS products
SENSING_TIME	Sensing time copied from the HLS metadata. Format: list of YYYY-MM-DDTHH:MM:SS.SSSSSSSZ
INPUT_HLS_PRODUCT_SPATIAL_COVERAGE	The percentage of the tile area with observational data (as opposed to fill value) in the input HLS product
INPUT_HLS_PRODUCT_CLOUD_COVERAGE	The percentage of cloud/cloud shadow over observational data (as opposed to fill value) in the input HLS product derived using the HLS Fmask layer
MEAN_SUN_AZIMUTH_ANGLE	The mean solar azimuth in the tile in degrees
MEAN_SUN_ZENITH_ANGLE	The mean solar zenith in the tile in degrees
MEAN_VIEW_AZIMUTH_ANGLE	The mean view azimuth angle in degrees
MEAN_VIEW_ZENITH_ANGLE	The mean view zenith angle in degrees
NBAR_SOLAR_ZENITH	The solar zenith angle used in Nadir Bidirectional Reflectance Distribution Function Adjusted Reflectance (NBAR) derivation.
ACCODE	The version of Land Surface Reflectance Code (LaSRC) used by HLS for the Landsat-8 30m (L30) product or the Sentinel-2 30m (S30) product for atmospheric correction

4.2.4 Processing Parameters

Table 4-5 lists processing and other product parameters associated with the DSWx-HLS product.

Table 4-5. GeoTIFF metadata: DSWx-HLS processing parameters.

Attribute	Description
AREA_OR_POINT	Indicates that pixel values are assumed to represent an area rather than points: “Area”
SPATIAL_COVERAGE	The percentage of the tile area with observational data (as opposed to fill value and ocean masked)

SPATIAL_COVERAGE_EXCLUDING_MASKED_OCEAN	The percentage of the tile area with observational data (as opposed to fill value and ocean masked) excluding masked ocean
CLOUD_COVERAGE	The percentage of pixels with observational data (as opposed to fill value and ocean masked) that HLS QA mask marks as cloud, cloud shadow, or adjacent-to-cloud (per MASK_ADJACENT_TO_CLOUD setting)
AEROSOL_CLASS_REMAPPING_ENABLED	Indicate if the aerosol class remapping is enabled (TRUE) or disabled (FALSE)
AEROSOL_NOT_WATER_TO_HIGH_CONF_WATER_FMASK_VALUES	HLS Fmask values to convert not-water to high-confidence water in the presence of high aerosol
AEROSOL_PARTIAL_SURFACE_AGGRESSIVE_TO_HIGH_CONF_WATER_FMASK_VALUES	HLS Fmask values to convert moderate-confidence water to high-confidence water in the presence of high aerosol
AEROSOL_PARTIAL_SURFACE_WATER_CONSERVATIVE_TO_HIGH_CONF_WATER_FMASK_VALUES	HLS Fmask values to convert partial surface water conservative to high-confidence water in the presence of high aerosol
AEROSOL_WATER_MODERATE_CONF_TO_HIGH_CONF_WATER_FMASK_VALUES	HLS Fmask values to convert partial surface water aggressive to high-confidence water in the presence of high aerosol
SHADOW_MASKING_ALGORITHM	Shadow masking algorithm, either “sun_local_inc_angle” (default) or “otsu”
MIN_SLOPE_ANGLE	Minimum slope angle (only applicable for “sun_local_inc_angle” shadow masking algorithm)
MAX_SUN_LOCAL_INC_ANGLE	Maximum sun local-incidence angle (only applicable for “sun_local_inc_angle” shadow masking algorithm)
MASK_ADJACENT_TO_CLOUD_MODE	Define how areas adjacent to cloud/cloud-shadow are handled. Three options are available: “mask” - mask out these areas marking them as cloud shadow (default); “ignore” - ignore the adjacent to cloud/cloud shadow classification; and “cover” - cover these areas with a dilation algorithm.
FOREST_MASK_LANDCOVER_CLASSES	Copernicus CGLS Land Cover 100m forest classes used in additional testing that may mask false water detections from the WTR-2 and WTR layers, due to vegetation-related dark reflectance.
OCEAN_MASKING_ENABLED	Indicate if the ocean masking is enabled (TRUE) or disabled (FALSE)
OCEAN_MASKING_SHORELINE_DISTANCE_KM	Ocean masking distance from shoreline in km (only applicable if the ocean masking is enabled)

5 DSWx-HLS Sample Product

To provide a visual presentation of the product, we selected a Landsat-8 30m (S30) HLS product (v.2.0) processed from a Landsat-8 OLI dataset acquired over the states of Nevada and Arizona in the Southwestern United States on March 30, 2019 (HLS dataset HLS.L30.T11SQA.2019072T181446.v2.0). The south of the scene includes Lake Mead, a reservoir formed by the Hoover Dam on the Colorado River. The dataset north contains clouds and cloud shadows that are used to exemplify the DSWx-HLS CLOUD layer classification as well as the cloud masking of WTR, BWTR, and CONF layers.

Figure 5-1 (left) shows the Landsat-8 30m (S30) HLS Red, Green, and Blue (RGB) false-color-composition representing the reflectance bands Short-Wave Infrared band 1 (SWIR-1), near infrared (NIR), and red, respectively. We select a subset of the dataset, indicated by the yellow rectangle in Fig. 5-1, to show details of the DSWx-HLS product layers.

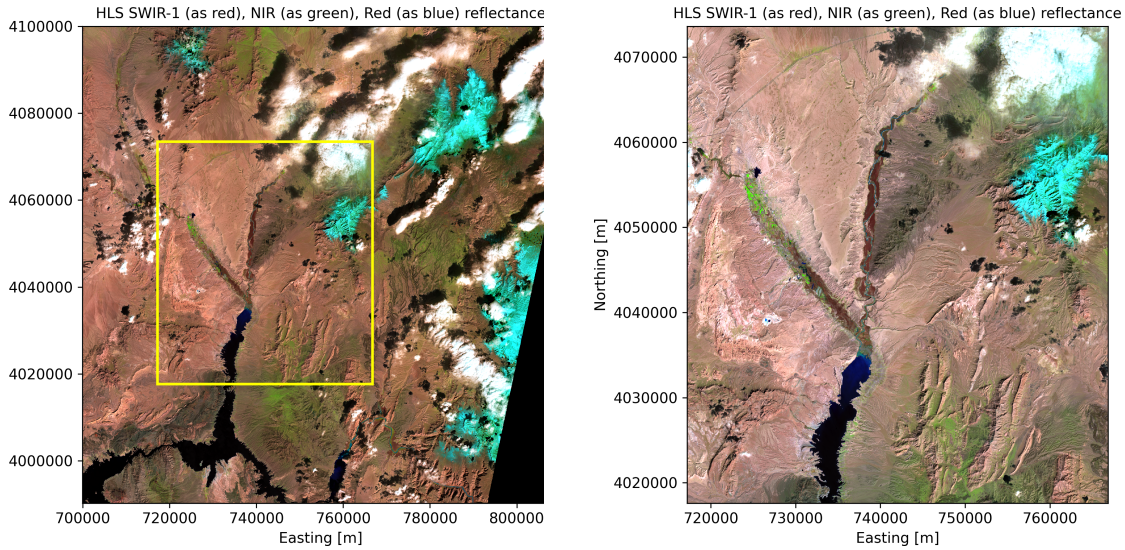

Figure 5-1. Input HLS: entire granule (left) and portion used for all product examples (right) of Red, Green, and Blue (RGB) false-color-composition representing the reflectance bands SWIR-1, NIR, and RED, respectively.

The HLS optical reflectance layers blue, green, red, NIR, SWIR-1, and SWIR-2 are employed in 5 initial tests to detect the presence of water on a per-pixel basis [RD1][RD2]. The test results are encoded into the diagnostic layer DIAG as shown in the Fig. 5-2 (left). DIAG is an integer-valued layer in which each value is composed of five binary digits indicating positive for the presence of water (value 1) or negative (value 0) for each of the 5 tests. The fill value (no data) is represented by the value 65535.

The DIAG layer is interpreted into open and partial surface water classes, and saved as the

WTR-1 layer, Figure 5-2 (right). The WTR-1 layer of the standard DSWx-HLS product contains only 3 values: not water (0, shown in white); water (1, in blue), and fill or no data value (255, shown in black).

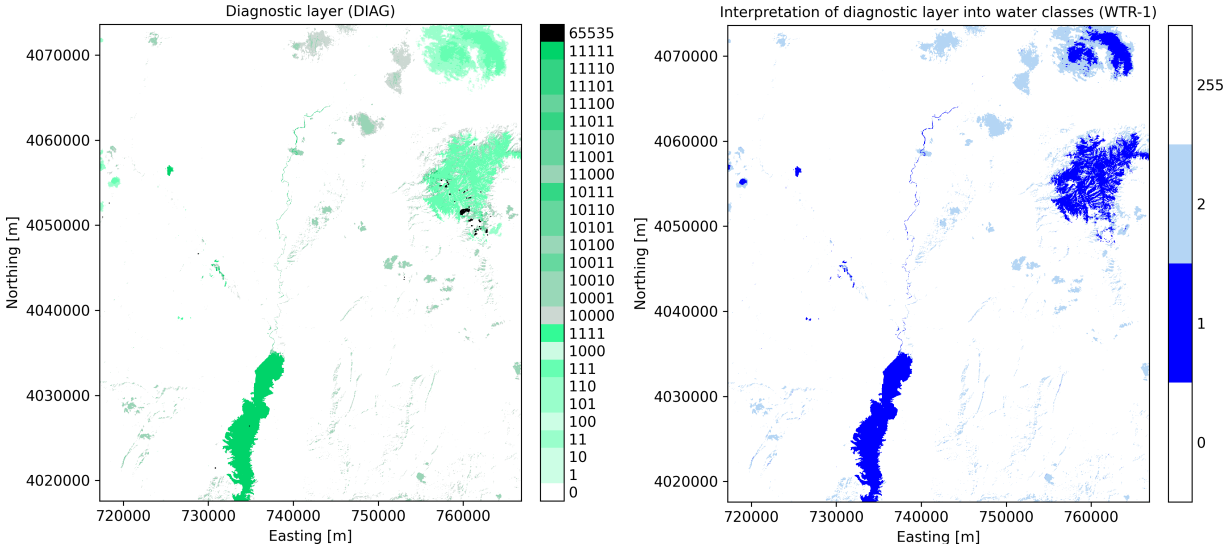

Figure 5-2. Diagnostic layer DIAG (left) and interpretation of diagnostic layer into water classes WTR-1 (right).

The WTR-1 layer is then refined using the knowledge of the local topography, obtained from a reference DEM, and through additional testing using a fusion of two land cover maps, i.e, the CGLS land cover map and ESA WorldCover.

Figure 5-3 (left) is the digital elevation model (DEM) described in the Layer 10 section of table 4-1. It is symbolized in grayscale according to elevation value with the lowest elevation in the model colored black and highest colored white. These data are used to generate the terrain shadow mask SHAD shown in Figure 5-4 (right). The algorithm to generate the shadow mask from the DEM is described in [RD1]. The areas identified as shadow (0, black) have a higher chance of presenting dark reflectance similar to water, which may result in false positives in the WTR-1 layer. Therefore, further screening is applied to the WTR-1 layer in shadow areas. Where nonshadow areas are demarcated (1, white), this shadow screening is not applied. This process is fully described in [RD1].

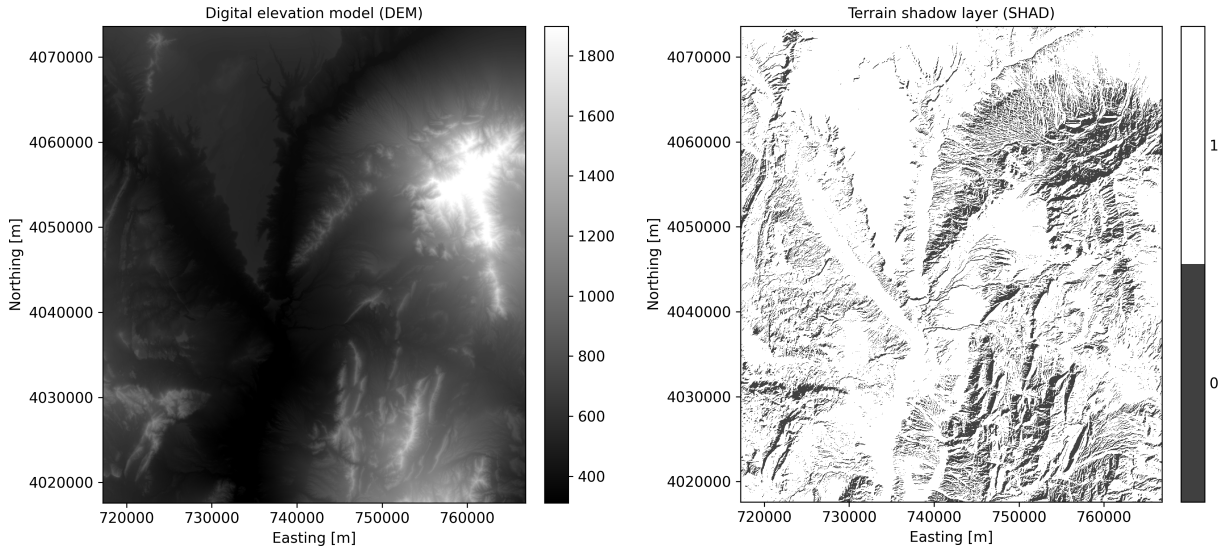

Figure 5-3. Digital elevation model DEM (left) and Terrain shadow layer SHAD (right).

Figure 5-4 (left) shows the land cover classification LAND, derived from the CGLS land cover map and ESA WorldCover [RD1]. The areas identified as low-intensity developed (value 0) are shown in magenta, whereas the areas identified as high-intensity developed (value 100) are shown in red. The land-cover-derived water class (value 200) is shown in blue. Selected forest classes that may affect the water classification (value 201) are shown in green. No data or fill values (value 255) are shown in white (transparent). The complete list of LAND classes is given in Table 4.1.

Figure 5-4 (right) shows the WTR-2 layer of the DSWx-HLS product. The WTR-2 layer is derived from the WTR-1 layer with additional land cover and terrain shadow testing, as described in [RD1] and [RD2]. This layer is a masked version of the WTR-1 layer.

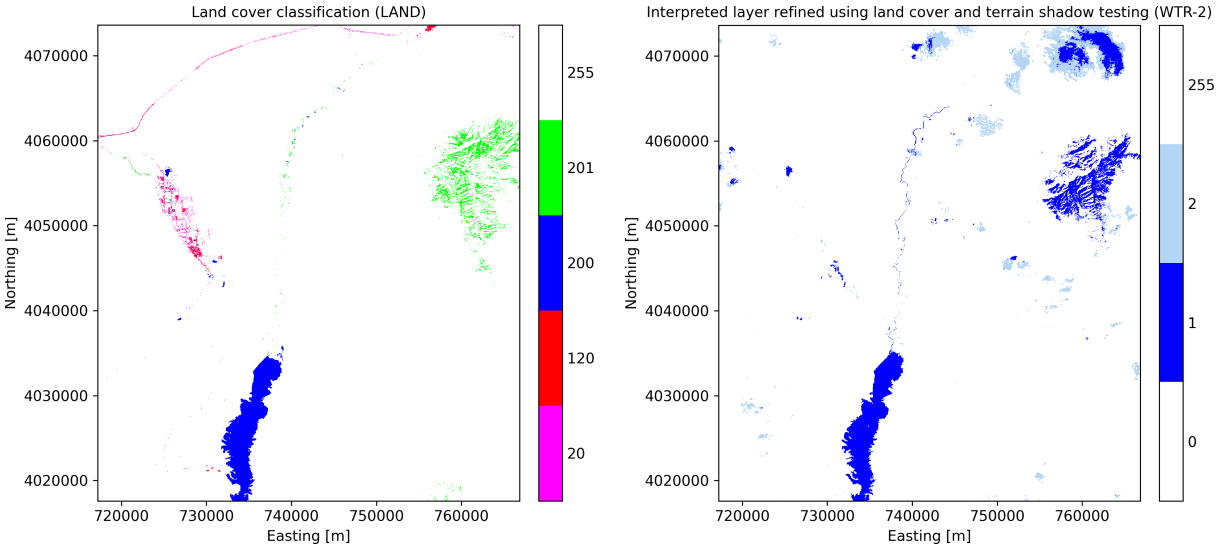

Figure 5-4. Land cover classification LAND (left) and the result of refining the interpreted layer using refined land cover and terrain shadow testing WTR-2 (right).

Figure 5-5 (left) illustrates the CLOUD layer of the DSWx-HLS product. The CLOUD layer shows the cloud, cloud-shadow, and snow-ice masks carried from the input HLS product, including conditions in which multiple masks can apply to individual pixels. Possible class values for this layer are listed in the Layer 9 section of table 4-1. This particular example includes: not masked (0, transparent); clouds shadow or adjacent to cloud shadow (1, black color); snow/ice (2, cyan color); snow/ice and class 1 (3, forest green color); cloud (4, gray); cloud and class 1 (5, olive green color); Fmask identified water (8, tan color); and fill/nodata (255, transparent).

DSWx-HLS water (WTR) layer, which is shown in Figure 5-5 (right). Described in the Layer 1 section of table 4-1, this layer may contain up to seven values: not water (0, shown in white); open water (1, shown as blue), partial surface water (2, shown as light blue); snow/ice (252, shown in cyan); cloud/cloud shadow (253, shown as gray color); ocean masked (254, shown in dark blue); and fill or no data value (255, shown in black).

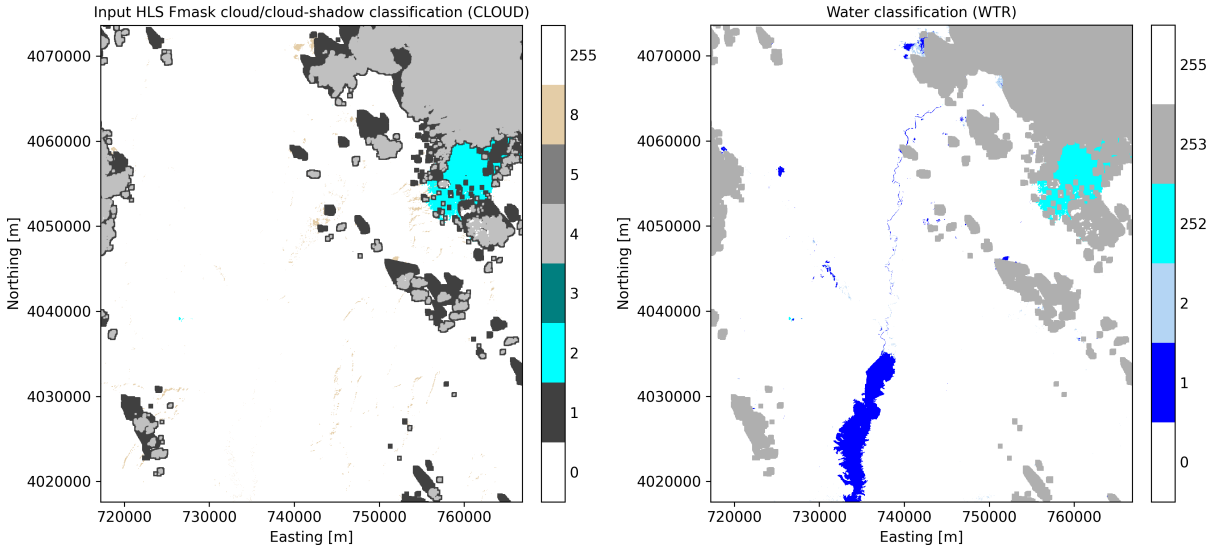

Figure 5-5. Input HLS Fmask cloud/cloud-shadow/water classification CLOUD (left) and the interpreted water classification WTR (right).

Figure 5-6 (left) shows the binary water (BWTR) layer. Described in the Layer 2 section of table 4-1, this layer may contain up to 6 values: not water (0, shown in white); water (1, in blue), and the masked and invalid classes 252-255 following the WTR layer. The single water class is a union of all water classes in the WTR layer.

Figure 5-6 (right) shows the CONF layer, which is a representation of the confidence associated with the WTR classification that is based on a combination of DIAG results and quality assurance information provided with the input HLS data. A complete description of the confidence values can be found in Table 4-1.

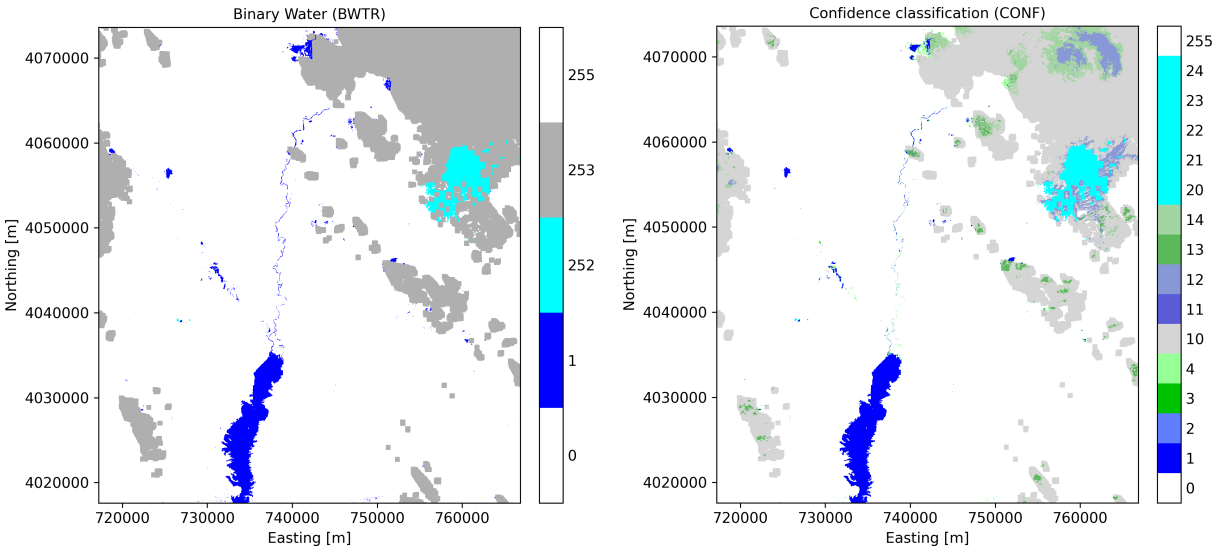

Figure 5-6. Binary water layer BWTR (left) and confidence layer CONF (right).

6 DSWx-HLS Product Version Change Log

This section will identify the changes in the DSWx-HLS product between Product Versions.

6.1 Product Version 1.0

This is the first release of the product.

APPENDIX A: ACRONYMS

ADT	Algorithm Development Team
CGLS	The Copernicus Global Land Service
COG	Cloud-Optimized GeoTIFF
DAAC	Distributed Active Archive Center
DEM	Digital Elevation Model
DOI	Digital Object Identifier
DSWx	Dynamic Surface Water Extent
ESA	European Space Agency
ESDIS	Earth Science Data and Information System
ESO	ESDIS Standards Office
Float32	Floating-point number of 32 bits
GDAL	Geospatial Data Abstraction Library
GeoTIFF	Georeferenced Tagged Image File Format
GIS	Geographic Information System
GSHHS	Global Self-consistent, Hierarchical, High-resolution Shorelines
HLS	Harmonized Landsat and Sentinel-2
IF	Interface (delivery)
L30	HLS generated from Landsat inputs (30 denotes 30 m spatial resolution)
LaSRC	Land Surface Reflectance Code
MGRS	Military Grid Reference System
MSI	MultiSpectral Instrument
NBAR	Nadir Bidirectional Reflectance Distribution Function Adjusted Reflectance
NIR	Near infrared
NGA	National Geospatial-Intelligence Agency
NISAR	NASA-ISRO Synthetic Aperture Radar
NOAA	National Oceanic and Atmospheric Administration
OLI	Operational Land Imager
OPERA	Observational Products for End-users from Remote-sensing Analysis
PNG	Portable Network Graphic
PO.DAAC	NASA's Physical Oceanography Distributed Active Archive Center
QA	Quality Assurance
QGIS	Quantum Geographic Information System
RGB	Red, Green, and Blue
S30	HLS data generated from Sentinel-2 (30 denotes 30 m spatial resolution)
SAR	Synthetic Aperture Radar
SAS	Science Application Software
SDS	Science Data System

SR	Surface Reflectance
SWIR-1	Short-Wave Infrared Band 1
SWOT	Surface Water and Ocean Topography
TIFF	Tagged Image File Format
UInt8	Unsigned Integers of 8 bits
UInt16	Unsigned Integers of 16 bits
UPS	Universal Polar Stereographic
URI	Uniform Resource Identifier
UTM	Universal Transverse Mercator