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, Oct. 15, 2021

[AD2] OPERA Level 2 Requirements, JPL D-107391, Rev A, Dec. 16, 2021

[AD3] OPERA Product Description, JPL D-107389, Rev A, Dec. 14, 2021

Reference Documents

[RD1] OPERA Algorithm Theoretical Basis Document for Dynamic Surface Water Extent from Harmonized Landsat-8 and Sentinel-2A/B, JPL D-108272, Rev Preliminary, 31 Jan. 2022.

[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/about-opera. This document is a ‘live’ one with the primary purpose of developing and describing the DSWx-HLS product for the OPERA Algorithm Development Team’s (ADT) Interface delivery to the OPERA SDS.

1.4 Applicable Software

This document is being released for Point Release 3.3 (R3.3) of the Cal/Val delivery of the DSWx-HLS Science Application Software (SAS) at this GitHub repository: nasa/PROTEUS. Version 0.5.2 (v0.5.2) is available at nasa/PROTEUS Releases. This Point Release updates the repository to be the official repository supported by NASA and the OPERA Project. Previous versions of the DSWx-HLS SAS are available at nasa/PROTEUS Releases.

The products generated by this version of the SAS are consistent with this document.

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. Currently, the 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 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.

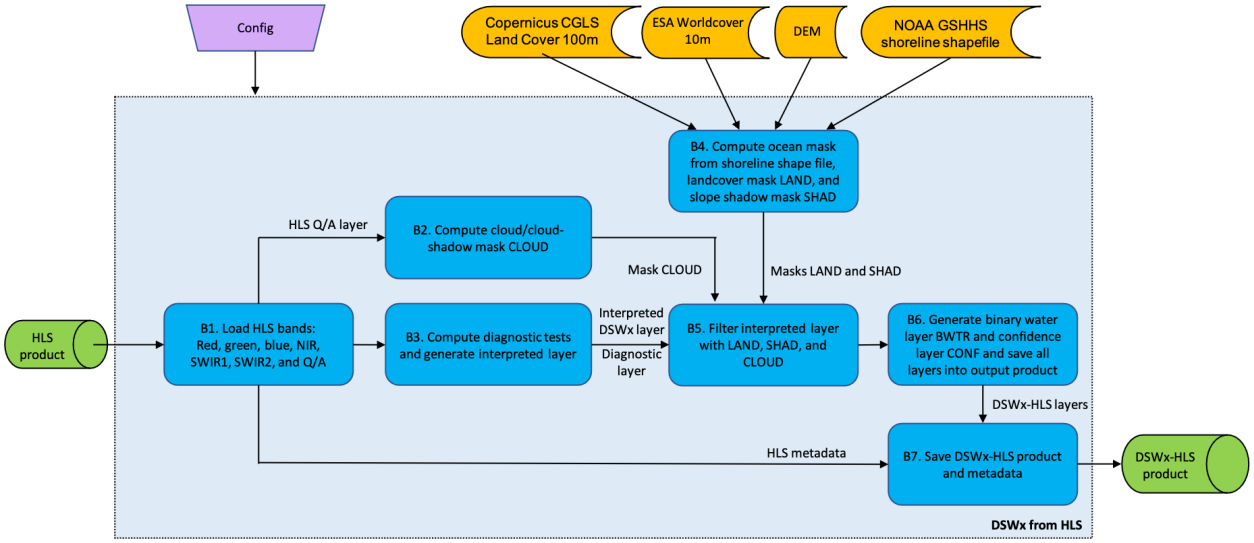

Figure 2-1. OPERA DSWx-HLS workflow diagram.

Table 2-1. Product Dependency Diagram.

Product	Scope	Description	Granule Size
Harmonized Landsat-8 and Sentinel-2A/B	Near-Global	The input HLS products to OPERA system	3660 × 3660 (x, y)
Copernicus DEM	Global	Copernicus Digital Elevation Model (DEM) 30-m GLO-30	Variable from 360 × 3600 to 3600 × 3600 (x, y)
Copernicus Land Cover	Global	The Copernicus Global Land Service (CGLS) Land Cover Layers with fine thematic resolution and 100-m spatial resolution	Variable
ESA Worldcover	Global	Broader land-cover classes with higher spatial resolution (10-m) used to downscale 100-m Copernicus Land Cover	Variable
NOAA GSHHS Shapefile	Global	National Oceanic and Atmospheric Administration (NOAA) Global Self-consistent, Hierarchical, High-resolution Shorelines (GSHHS) shoreline shapefile	Not applicable

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 each DSWx-HLS layer (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 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:

Project_**L**evel_**P**roduct**S**hort**N**ame-**S**ource_**T**ile**ID**_**D**ate**T**ime_**P**roduct**G**eneration**D**ate**T**ime_**Satellite**_**P**ixel**S**pacing_**P**roduct**V**ersion_**L**ayer**N**umber_**L**ayer**N**ame.**E**xt

- **P**roject: “OPERA”
- **L**evel: “L3”
- **P**roduct**S**hort**N**ame: “DSWx”
- **S**ource: The input source of the product (“HLS” in this case)
- **T**ile**ID**: Specific tile ID of the product, which is also the tile ID of the input HLS product in the MGRS
- **D**ate**T**ime: The acquisition date and time (Greenwich Mean Time or GMT) of the input satellite imagery for this product (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.
- **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” in this case)

Example:
OPERA_L2_DSWx-HLS_T15SXR_20210205T163901Z_20220101T140222Z_S2A_30_v0.1_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 84ºN and South of 80ºS). 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 6º, resulting in 60 UTM zones. Each zone is divided into 20 latitude bands of 8º in the latitude direction and each band (tile) is identified by a letter starting from “C” at 80ºS to “X” at 80ºN, omitting letters “I” and “O” because of their similarity to numerals 1 and 0. Both latitude bands “C” and “X” are extended 4º towards the Poles, i.e., the latitude band “C” comprises the latitude range from −84º to −72º and the latitude band “X” identifies the latitude range from 72º to 84º.

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, which is the default, 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 number 32 (Float32). The product bundle also includes a single browse image in Portable Network Graphic format, as noted by its '.png' file name extension. Specifics regarding GeoTiff layer names and content are shown in Table 4-1.

Table 4-1. DSWx-HLS raster layers.

Product Variables	
Layer: 1	**Water classification (WTR)**
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.	
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 area that is at least 50% and less than 100% open water. This may be referred to as "subpixel inundation" when referring to a pixel's area. Examples include inundated sinkholes, floating 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)**
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)**
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 and not 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 and not 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 area that is at least 50% and less than 100% open water with a conservative classification and 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 area that is at least 20% and less than 100% open water with 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) that 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 and not ocean masked (class 254) that 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 and not ocean masked (class 254) that is potentially obstructed by cloud-/cloud-shadow according to the input HLS Fmask.
13: Partial Surface Water Conservative – an area that is at least 50% and less than 100% open water with a conservative classification and ocean masked (class 254) that is potentially obstructed by cloud-/cloud-shadow according to the input HLS Fmask.
14: Partial Surface Water Aggressive – an area that is at least 20% and less than 100% open water with a less strict classification not ocean masked (class 254) that 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 or ocean masked (class 254) 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. “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 not ocean masked (class 254) 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.
22: Open Water Moderate-Confidence – an area that is entirely water with moderate-confidence and not ocean masked (class 254) 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.
23: Partial Surface Water Conservative – an area that is at least 50% and less than 100% open water with a conservative classification and ocean masked (class 254) 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.
24: Partial Surface Water Aggressive – an area that is at least 20% and less than 100% open water with a less strict classification not ocean masked (class 254) 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.

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)**

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)**
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 area that is at least 50% 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 floating 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: 6	**Interpreted layer refined using land cover and terrain shadow testing (WTR-2)**
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 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 area that is at least 50% and less than 100% open water. This may be referred to as “subpixel inundation” when referring to a pixel’s area. Examples include inundated sinkholes, floating 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)**
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 = first year development is present, e.g. ‘0’ = 2000, ‘99’ = 2099) 100 - 199: High Intensity Developed (number = first year development is present, e.g. 100’ = 2000, ‘199’ = 2099) 200: Water, Wetland, Mangrove Forest 201: A variety of Forest Classes 255: Fill value (no data)	

Layer: 8	**Terrain shadow layer (SHAD)**
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: 9	**Input HLS Fmask cloud/cloud-shadow classification (CLOUD)**
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 or adjacent to cloud/cloud shadow 2: Snow/ice 3: Snow/ice and class 1 (cloud shadow or 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) 255: Fill value (no data)	
Layer: 10	**Digital elevation model (DEM)**
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.	

4.2 GeoTIFF Metadata

All DSWx-HLS product layers (GeoTIFF files) are saved with the same metadata. The DSWx-HLS metadata is divided into three sections: 1) Product Identification and Processing Information, 2) input datasets, and 3) HLS product metadata.

4.2.1 Product Identification and Processing Information

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.
SOFTWARE_VERSION	The algorithm software version used to generate the DSWx-HLS product
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 lists the input dataset fields of GeoTIFF metadata.

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
LANDCOVER_SOURCE	Description of the input CGLS Land Cover Layer file used to provide detailed land cover type
WORLDCOVER_SOURCE	Description of the input ESA WorldCover 10-m file.
SHORELINE_SOURCE	Description of the NOAA GSHHS Level 1 shoreline shapefile

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:SSZ
SPATIAL_COVERAGE	The percentage of the tile area that includes observational data (as opposed to fill)
CLOUD_COVERAGE	The percentage of cloud/cloud shadow
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 DSWx-HLS Processing and Product Parameters

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

Table 4-5. GeoTIFF metadata: HLS product metadata.

Attribute	Description
AREA_OR_POINT	Indicate that pixel values are assumed to represent an area rather than points: “Area”
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 should be handled
FOREST_MASK_LANDCOVER_CLASSES	Copernicus CGLS Land Cover 100m forest classes to mask out from the WTR-2 and WTR layer due to dark reflectance that is usually misinterpreted as water.
OCEAN_MASKING_SHORELINE_DISTANCE_KM	Ocean masking distance from shoreline in km

5 DSWx-HLS Sample Product

To provide a visual presentation of the product, an HLS input was randomly selected to generate the following graphics. Figure 5-1 (left) shows the Landsat-8 30m (S30) HLS product (v.2.0) processed from a Landsat-8 OLI dataset acquired over Japan (U.S.) within tile ID 53SNV on March 22, 2016. This optical satellite data input was processed to yield the DSWx-HLS water (WTR) layer, which is shown in Figure 5-1 (right). Described in the Layer 1 section of table 4-1, this layer contains five values: not water (0, shown in white); open water (1, shown as blue), partial surface water (2, shown as light green); 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).

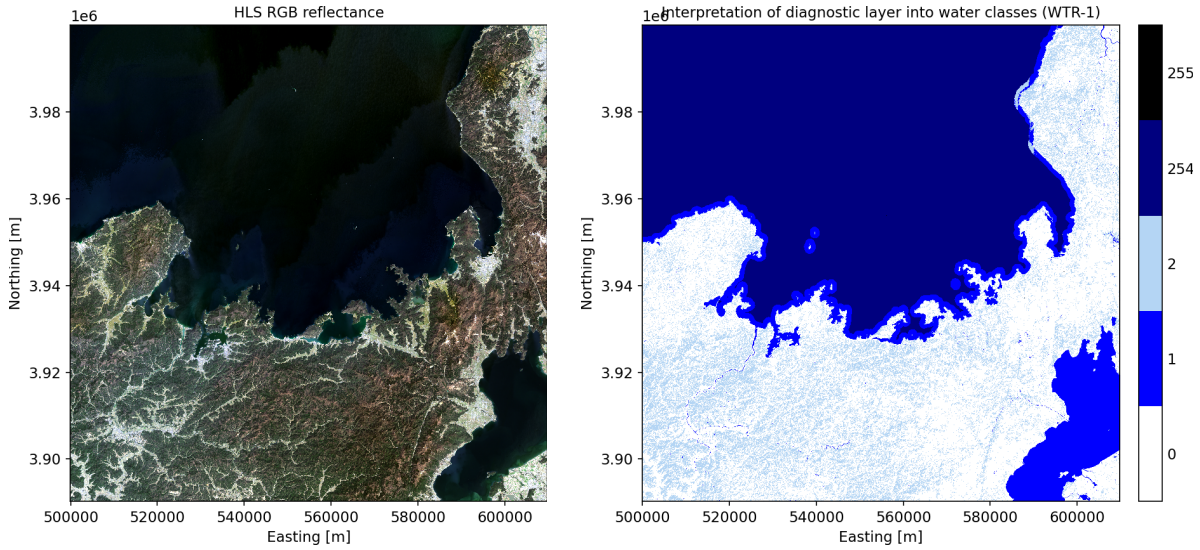

Figure 5-1. Input S30 HLS RGB layers (left) and water classification layer WTR-1 (right).

Figure 5-2 (left) shows the BWTR layer, which is a binary water map (0, not water in white, 1, water in blue, and 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 5-2 (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.

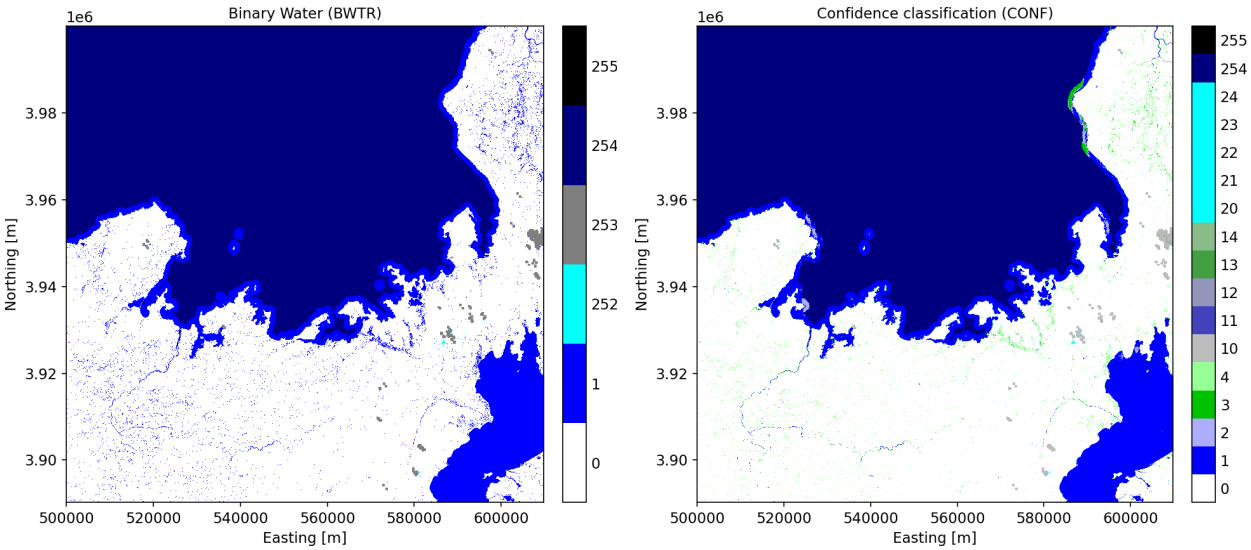

Figure 5-2. Binary water layer BWTR (left) and confidence layer CONF (right).

Figure 5-3 (left) 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. Because the scene is mostly flat, WTR-1 and WTR-2 layers are similar for this area. Figure 5-3 (right) 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.

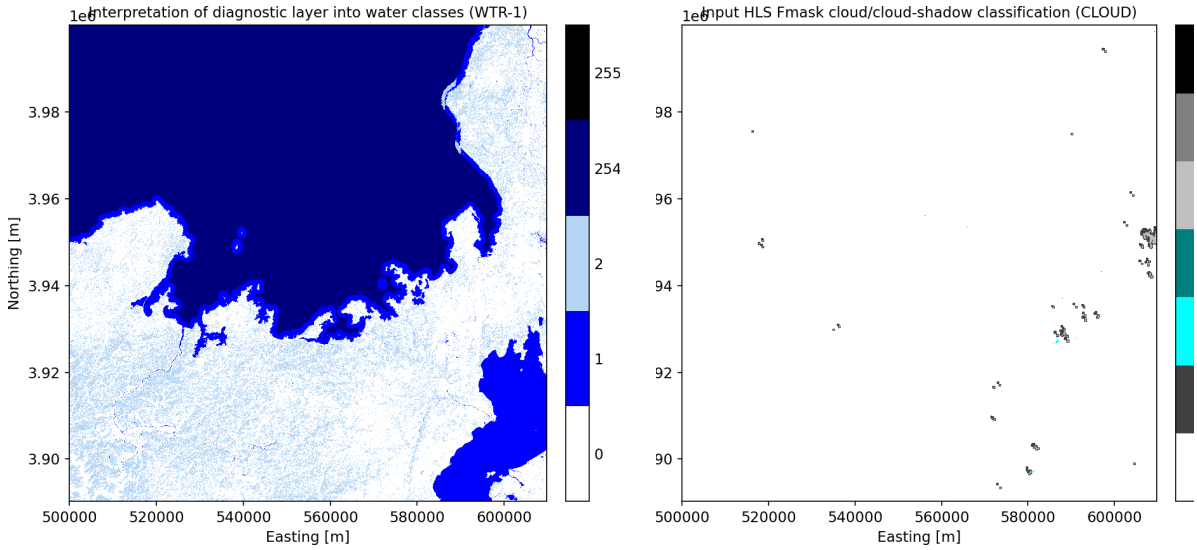

Figure 5-3. Interpretation of diagnostic layer into water classes WTR-1 (left) and cloud/cloud-shadow classification CLOUD (right).

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
GHSL	Copernicus Global Human Settlement Layer
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	Multi-Spectral Instrument
NBAR	Nadir Bidirectional Reflectance Distribution Function Adjusted Reflectance
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
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
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
WRS	World Reference System